Making Forecasts Better

NOAA Research
Earth System Research Laboratory
Boulder, Colorado

Global Systems Division
Science Review

November 3 - 5, 2015
David Skaggs
Research Center
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Overview

Welcome to the NOAA Earth System Research Laboratory (ESRL) Global Systems Division (GSD) Science Review. Laboratory science reviews are conducted every five years to evaluate the quality, relevance, and performance of research conducted in the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR) laboratories. This review is for both internal OAR/NOAA use for planning, programming, and budgeting, and external interests. It helps the Laboratory in its strategic planning of its future science. These reviews are also intended to ensure that OAR laboratory research is linked to the NOAA Strategic Plan, is relevant to NOAA Research mission and priorities, is of high quality as judged by preeminence criteria, and is carried out with a high level of performance.

This review will cover the ESRL/Global Systems Division research since 2010. GSD’s research areas are summarized in this section. Additional information is presented throughout this document and is also available on our website at: http://www.esrl.noaa.gov/gsd/research/review/2015/

Research Areas

RESEARCH AREA 1: NUMERICAL WEATHER PREDICTION

The Global Systems Division is a world leader in developing storm-scale to global weather prediction models and is well aligned with NOAA’s objectives to build a holistic understanding of the Earth system and an integrated environmental modeling system. Through the research and development of the hourly-updating Rapid Refresh (RAP) and the High Resolution Rapid Refresh (HRRR) models, GSD transformed storm-scale modeling technologies to greatly improve localized severe weather forecasts by operational weather services. GSD will continue to evolve these models to better support timely decision-making, particularly for disaster preparedness, air traffic management and energy development. Working with colleagues from other organizations, GSD researchers are performing in-depth Observing System Simulation Experiments (OSSEs) and Observing System Experiments (OSEs) to quantitatively evaluate the benefits of current and future observing systems for improving weather forecasts from numerical models. GSD scientists are also working to develop the next-generation global hydrostatic and non-hydrostatic atmospheric models to help the National Weather Service build a Weather-Ready Nation. Using its own internal supercomputing facility plus external high performance computing resources, GSD is also testing the current generation of global models, running them at unprecedented resolutions in real-time, to evaluate the model output and compare the different data assimilation techniques. These results will inform model developers how to improve the next generation of global models. GSD will be at
the forefront of coupling atmospheric, land surface, ocean and air chemistry models, an effort towards an earth system model which will enhance the scope and accuracy of weather predictions.

RESEARCH AREA 2: DECISION SUPPORT

Supporting NOAA’s goal to improve preparedness, response, and recovery from weather and water events by building a Weather-Ready Nation, GSD continues to develop innovative, leading-edge forecast tools. The tools, usable by human and automated decision-making processes, will improve public safety, transportation safety and efficiency, effective usage of wind and solar energy, and other economic activities strengthening the resiliency of the Nation’s communities. Since the 1980s beginning with the Advanced Weather Interactive Processing System (AWIPS), GSD has developed and transitioned decision-support tools to the National Weather Service (NWS). Over the next 5-10 years, GSD will build and deploy advanced technologies that revolutionize and streamline operations for NWS and other partners by developing tools for: 1) issuing timely and accurate weather hazard information, 2) monitoring forecasts and providing short-term updates as weather changes, 3) two-way communication for collaboration between forecasters and decision-makers, and 4) the effective use of ensemble forecast information to better convey weather uncertainty to decision-makers and the public. GSD will continue to work with its Federal Aviation Administration partner to develop and transition state-of-the-art technologies used by air traffic planners to identify and mitigate the effects of potential weather impacts resulting from convective storms, low ceiling or visibility, icing, strong winds, or turbulence within the National Airspace System (NAS), thus improving traffic flow efficiency and reducing flight delays.

RESEARCH AREA 3: ADVANCED TECHNOLOGIES

GSD is a world leader in advancing technologies that make it possible to: 1) perform numerical weather and climate prediction on the fastest computer technologies available, 2) create next generation weather and environmental forecast and analysis systems to ingest, manage, analyze, understand and forecast, and 3) bring this complex information together in a form viewable, understandable and seen by millions worldwide. GSD efforts are central to both Scientific and Enterprise Goals established by NOAA in its Next Generation Strategic Plan and are foundational for the creation and use of an Earth Modeling System. The advanced computing efforts in GSD have forged the basis of virtually all High Performance Computing methods used in NOAA operations and research. Through their design and management efforts, GSD researchers are leading the world in reinventing this framework for Massively Parallel Fine Grain (MPFG) systems by providing some key benchmarks in MPFG computing that are being used by industry to create the next generation hardware. GSD is reimagining how users will use and interact with global environmental information with its NOAA Earth Information System (NEIS).
NEIS has leveraged the latest in server technology and new gaming paradigms developed in-house to selectively transport vast amounts of information across the Internet to scientific users who will use a visually compelling interface. GSD has been a leader in closing data gaps for NOAA Operations and the meteorological community: GSD’s recent transition of MADIS to Operations has forged a path for rapid expansion of observation density and quality. Tools have emerged from MADIS-related efforts that have led to a better understanding of real-time environmental conditions and are a clear value-added within the NWS and with other decision-making partners. NOAA calls for an educated public with an improved capacity to make scientifically informed environmental decisions. GSD is a clear NOAA leader in pursuit of this goal with its growing worldwide Science On a Sphere® (SOS) program which is actively pursuing the SOS Explorer™ concept to bring this information to educators and the public via the Internet.
ESRL Global Systems Division Science Laboratory Review

3-5 November 2015
David Skaggs Research Center (DSRC) – 325 Broadway, Boulder, CO
http://esrl.noaa.gov/gsd/research/review/2015/

Day 1: Tuesday, 3 November 2015

PRELIMINARIES

7:00  Breakfast (closed) at the Homewood Suites for OAR DAA Steve Fine, and Review Panel
7:30  Transportation to ESRL (Review Panel meet Phyllis in lobby and caravan to DSRC/ESRL; Observers carpool from hotel lobbies)

WELCOME (Room GC402)

7:15  Check-in begins for Observers
8:10  Meeting Overview and Logistics – Jennifer Mahoney (Deputy Director, GSD)
8:15  Welcome and Charge to Reviewers – Craig McLean (Assistant Administrator, OAR)
8:25  Overview of NOAA and OAR Research Planning and Funding; Introduction of Review Panel – Steve Fine (Deputy Assistant Administrator, NOAA OAR)
8:35  ESRL Organization Overview, Research at ESRL – Alexander E. MacDonald (Director, NOAA ESRL)
8:45  Overview of ESRL GSD – Kevin Kelleher (Director, GSD)

9:45 – 10:00  Break – Light Refreshments (Check-in for Reviewers)

THEME 1: NUMERICAL WEATHER PREDICTION: REGIONAL MODELS (Room GC402)

10:00  Opening: Numerical Weather Prediction: Mission and Grand Challenges (Stan Benjamin)
Session 1
10:10  Modeling Challenge #1 - Toward Storm-scale Ensemble Data Assimilation and Prediction (Steve Weygandt)
10:25  HRRR Overview – R2O to NWS and Application to Severe Weather (Curtis Alexander)
10:30  Radar Assimilation for HRRR (David Dowell)
10:35  Land-surface Cycling for Better Hydrometeorology (Tanya Smirnova)
10:40  Energy Applications and Design for RAP/HRRR (Joe Olson)
10:45  HRRR/RAP - Mitigating Aviation Hazards for Safety and Efficiency (Jaymes Kenyon)
10:50  Probabilistic Forecasting at Regional Scales (Isidora Jankov)
10:55  Short Discussion
11:05  Poster Session (30 min)
11:35  Session Discussion (10 min)

11:45  Lunch Provided (All Attendees; Room GB124)
(Working lunch Review Panel and Federal Scientists: Room GB144)
THEME 1: NUMERICAL WEATHER PREDICTION: GLOBAL MODELS (Room GC402)

**Session 2**
1:00  Modeling Challenge #2 – Toward Earth System Modeling  
     FIM Atmospheric Global Model for Medium-range Forecast Applications (Stan Benjamin)
1:20  Impact of Composition and Chemistry on Weather Forecasting (Georg Grell)
1:25  Coupled Atmospheric-Ocean Earth System Modeling for Sub-seasonal Prediction (Shan Sun)
1:30  Development of Non-hydrostatic Global Models – NIM (Jin Lee)
1:35  High-performance Software Engineering (Tom Henderson)
1:40  Physics for Global Non-hydrostatic Applications (John Brown)
1:45  Short Discussion (10 min)
1:55  Poster Session (30 min)
2:25  Session Discussion (10 min)

2:35 – 3:10  Tour of GSD Computing Facility (Reviewers only)
2:35 – 3:10  Science on a Sphere (SOS) Demonstration (All Others)

3:10 - 3:30  Break - Light Refreshments

THEME 1: NUMERICAL WEATHER PREDICTION: CROSS-CUTTING ACTIVITIES (Room GC402)

**Session 3**
3:30  NWP: GSD’s Path Forward (Tim Schneider)
3:45  Global Developmental Testbed Center (DTC) – (Ligia Bernardet)
3:50  Global Observing Systems Analysis – (Lidia Cucurull)
3:55  Improving Winter Storm Forecasts with Dropsonde Data – (Jason English)
4:00  Renewable Energy Program (Melinda Marquis)
4:05  Short discussion (10 min)
4:15  Poster Session (30 min)
4:45  Session Discussion and Wrap-up (15 Min)

5:00  Adjourn (Day 1) Observers finished for the day and dinner on your own

5:00  Review Panel (Closed) (Room GB144)
6:30  Dinner Boulder Dushanbe Tea House (Closed Review Panel, OAR HQ, GSD Senior Leadership, and CI Directors)
Day 2: Wednesday, 4 November 2015

PRELIMINARIES

7:00  Breakfast on your own
7:40  Transportation to DSRC/ESRL (Review Panel meet Phyllis in lobby to caravan to DSRC/ESRL; All others carpool from hotel lobbies)

THEME 2: DECISION SUPPORT (GC402): A BUSY DAY AT FORECAST OFFICES

Session 4
8:15  Opening Talk: A Busy Day at Forecast Offices (Mike Kraus)
8:30  Ensemble Forecasts and Uncertainty (Paul Schultz)
8:35  Forecast Monitoring and Short Term Updates (Kevin Manross)
8:40  Tropical Hazards (Tom LeFebvre)
8:45  Unified and Consistent Hazardous Weather Forecasts (Tracy Hansen)
8:50  Sharing the Wealth: Forecaster Tools for Our Partners (Joe Wakefield)
8:55  Short Discussion (10 min)
9:05  Poster Session (30 min)
9:35  Session Discussion (10 min)

9:45 - 10:15  Break - Light Refreshments

THEME 2: DECISION SUPPORT FOR AVIATION (GC402)

Session 5
10:15  Opening Talk: Decision Support and Evaluation for Aviation (Mike Kraus)
10:30  Aviation Forecasting with AWIPS (Woody Roberts)
10:35  Impact-based Decision Support for Aviation (Brian Etherton)
10:40  Verification Tools for Aviation Weather (Missy Petty)
10:45  Investigation of Truth Sets for Verification (Laura Paulik)
10:50  Assessment of Aviation Algorithms and Forecast Technologies (Matt Wandishin)
10:55  Short Discussion (10 min)
11:05  Poster Session (30 min)
11:35  Session Discussion and Wrap Up (15 Min)

11:50  Lunch Provided (All Attendees; GB124)
       Review Panel and Non-Federal GSD Scientists meeting (GB144)

THEME 3: ADVANCED TECHNOLOGIES (GC402)

Session 6
1:00  Opening Talk: Advanced Technology (John Schneider)
1:15  The NOAA Earth Information System (NEIS) Data Discovery, Collection, and Distribution (Jebb Stewart)
1:20  Advanced Visualization Development using Gaming Technology (Eric Hackathorn)
1:25  Massively Parallel Fine Grain (MPFG) Computing (Mark Govett)
1:30  Specialized Information and Warning Systems (Greg Pratt)
1:35  Science on a Sphere (SOS): Technical Innovation and Network Growth (Keith Searight and Shilpi Gupta)
1:45  Short Discussion (10 min)
1:55  Poster Session (30 min)
2:25  Session Discussion (10 min)

2:35 – 3:10  SOS Demonstration (Reviewers Only)
2:35 – 3:10  Concurrent Sessions: Tour of Computing Facility (All Others)

3:10 – 3:25  Break – Light Refreshments

THEME 3: ADVANCED TECHNOLOGIES (GC402)

Session 7
3:25  Opening Talk: Outreach and Research to Operations (John Schneider)
3:40  MADIS Innovations and the Path to Operations (Gopa Padmanabhan and Leon Benjamin)
3:50  NOAA’s International Collaboration with Taiwan (Fanthune Moeng)
3:55  Global Visualization using NOAA’s TerraViz (Beth Russell and Jeff Smith)
4:05  Short Discussion (10 min)
4:15  Poster Session (30 min)
4:45  Session Discussion and Wrap Up (15 min)

5:00  Adjourn (End of review for Observers, group dinner at 6:30)

5:15 – 6:30  Review Panel Session (Closed: GB144)
5:15 – 6:15  Concurrent Session: OAR Senior Management Meeting with Line Office Reps and GSD Senior Management (GC402)

6:30 – Dinner
(Reviewers – Boulder Cork)
(All Others – The Med – Pay per Person)
Day 3: Thursday, 5 November 2015

PRELIMINARIES

7:00 Breakfast on your own
7:30 Transportation to ESRL (Review Panel meet Phyllis in lobby and caravan to ESRL)

STAKEHOLDER SESSIONS

8:00 Preparation for Concurrent Closed Sessions with Review Panel

Session 1 (Room GB124)
8:15 Steve Abelman (Program Manager, FAA Aviation Weather Program)
8:35 Dave Michaud (Acting Director of Central Processing, NWS)
8:55 Louisa Nance (Deputy Director, Developmental Testbed Center, NCAR)
9:15 Chris Davis (Director, Meso Scale and Microscale Meteorology Laboratory)
9:35 Fred Toepfer (HFIP Program Manager, NCEP)

Concurrent: Session 2 (Room GB124)
8:15 Brian Gross (Acting Deputy Director for High Performance Computing, OCIO)
8:35 Jason Chasse (NextGen Program Manager, NWS)
8:55 Hendrik Tolman (Director, Environmental Modeling Center, NCEP)
9:15 Tom Auligne (Director, Joint Center for Satellite Data Assimilation)

9:35 – 10:00 Break – light refreshments

REVIEW PANEL SUMMARY, WRAP-UP, AND DISCUSSION (GC402)

10:00 Brief Wrap-up and Question and Answer Session (Kevin Kelleher and GSD Chiefs)

REVIEW PANEL (CLOSED SESSION) (GB144)

10:30 Discussion, Report Coordination (begin writing), and preparation for Report-out
(Bring in Lunch)

REVIEW PANEL PRELIMINARY REPORT-OUT (GC402)

12:00 OAR and GSD Senior Management with Review Panel
1:00 Adjourn
A. Presentations and Posters

Session 1: Numerical Weather Prediction – Regional Models

- Numerical Weather Prediction: Mission and Grand Challenges (Stan Benjamin)
- Modeling Challenge #1 - Toward Storm-scale Ensemble Data Assimilation and Prediction (Steve Weygandt)
- HRRR Overview – R2O to NWS and Application to Severe Weather (Curtis Alexander)
- Radar Assimilation for HRRR (David Dowell)
- Land-surface Cycling for Better Hydrometeorology (Tanya Smirnova)
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- HRRR/RAP - Mitigating Aviation Hazards for Safety and Efficiency (Jaymes Kenyon)
- Probabilistic Forecasting at Regional Scales (Isidora Jankov)
**Theme 1 - Introduction**

**NOAA Research and Development Funnel**

- All of atmospheric and oceanic science and technology
- Modernized and enhanced to include operational and information services
- Science and Technology Specific to NOAA Operational and Information Services

Session 2: Global NWP toward earth system 2-10 years ahead

Session 1: Regional NWP (HRRR/RAP + applications) 0.5 to 4 years ahead

**GSD’s 5-year NWP Trajectory**

- **2010**
  - RUC–CONUS domain Internal development
  - HRRR
    - RUC init cond, CONUS just started
    - no pathway to NWS
  - Assimilation - RUC 3dvar
    - FIM could run (starting late 2009)
    - but no evaluation, poor skill (as it turned out)
    - NCEP/ERSL MOA
    - Chem – WRF, not connected to RUC or early FIM
    - LAPS, RTMA

- **2015+**
  - RAP – N. American domain
    - Development with community WRF/GSI
    - HRRRv2 @NCEP. Centennial for NOAA, Physics dev, energy appli
    - GSI - hybrid ens/var DA with radarcloud assimilation
    - FIM skill sufficient to consider multi-model GEFS at NCEP, extensive global experience toward NCGPS
    - Aerosol-aware microphysics (HRRR/RAP), RAP/HRRR-
    - chem/smoke, FIM-chem/CO2
    - GSI-community 3-d RUA
    - HRRR-based RTMA

**GSD Challenge #1 (This morning)**

- Hourly-to-subhourly global storm-scale (<3 km) ensemble data assimilation and ensemble forecasting for global situational awareness
- Start with: Storm-scale CONUS-wide 3 km data assimilation and ensemble forecast modeling
  - More accurate severe weather forecasts
  - Safer aviation
  - More effective use of renewable energy
  - Improved hydrological, flood, water/snow resource guidance

**GSD Challenges (This afternoon)**

- Session 2 - A fully coupled earth system modeling prediction capability – Challenge #2
  - Atmosphere, ocean, chemistry, ice, and land-surface components for research and potential operational applications
  - Improved air quality / health forecasts
  - More useful seasonal outlooks
  - Full environmental prediction
  - Improved global NWP forecasts from Day 1 – Week 4 (including ensembles/ reforecasting)
- Session 3 – Cross-cutting activities including Optimized observing system (Challenge #3)

**Need: Accurate Hazardous Weather Guidance**

- Mayflower Arkansas devastation: Deadly tornado destroys everything in its path
- 10 firefighters killed battling fast-moving Ariz. wildfire

**Toward Storm-scale Ensemble Data Assimilation and Prediction**

Stephen S. Weygandt

NOAA/ESRL/GSD

GSD Science Review
3-5 Nov 2015
**A. Presentations and Posters**

**RAP and HRRR: Fulfilling a prediction need**

GSD develops regional to storm-scale weather prediction systems and transitions them to operations.

- Rapid Refresh model (RAP)
- High-Resolution Rapid Refresh model (HRRR)
- Advanced hourly data assimilation cycle
- Radar data

**Quality: RAP and HRRR Predictions**

Real-time experimental HRRR forecast of April 27, 2014 Mayflower, AR tornadoic storm.

Real-time experimental HRRR forecast of June 29, 2013 thunderstorm gust front associated with Yarnell, AZ wildfire blowup.

**Group and individual awards**

- 2015: Department of Commerce Gold Medal
- 2015: Governor’s Award for High-Impact Research
- 2015: CIRA Research and Service Initiative Award
- 2014: Commendation from NASA
- 2014: CIGRES Outstanding Performance Award
- 2013: NOAA Research Employees of the Year (Team)
- 2012: CIGRES Employees of the Year (Team)
- 2010: Department of Commerce Bronze Medal

**Quality: Publications / Other Recognition**

Branch publications by year:

![Graph showing publication data](image)

**Other Recognition**

- 2014: HRRR NCEP implementation mentioned on national evening news
- 2014: Nomination for Presidential Early Career Award for Scientists and Engineers – Curtis Alexander
- 2014: Co-chair AMS Severe Local Storms Conference – Curtis Alexander
- 2011: CIGRES Fellow – Stan Benjamin

**Performance: Research to operations**

**NCEP Operational RUC Implementations:**

Long record of successful R2O transitions

- 1994 RUC
  - First Rapid Update Cycle
- 1998 RUC
  - 40km, 1-hour update cycle
- 2002 / 2003 RUC
  - 20km, 3DVAR, GOES cloud
- 2005 RUC
  - 13km, GFSPW METAR cloud
- 2008 RUC
  - Radar reflectivity assimilation

**NCEP Operational RAP/HRRR Implementations:**

Improved system, accelerated implementation

- May 2012 RAP v1
  - WRF/GSI-based Rapid Refresh (RAP) replaces RUC
- Feb 2014 RAP v2
  - Global hybrid DA, improved storm environment
- Sept 2014 HRRR
  - Hourly, 3km CONUS storm-scale model with radar reflect DA
- Plan Feb 2016
  - RAP v3/HRRR v2
  - Better assimilation, reduced biases, better storm forecasts.
Performance: Advancing Forecasting Science

Group accomplishments: Innovation, collaboration

- Ongoing contributions to WRF ARW and GSI
- Extensive verifications and observation impact assessment
- Strong interaction with NWS centers and offices

Performance: Extensive collaborations

We work with many groups

Relevance: Use of RAP / HRRR by NWS

Significant increase in number of references to RAP / HRRR in NWS... (Graph showing increase)

"Much love for the HRRR"
-- Dan Niefield, WPS Science and Operations Officer, WFO Omaha at 2015 GOES-R / JPSS PG User Readiness Meeting

"The HRRR is a game-changer"
-- Andy Edman, NWS Western Region SSD Chief at UMAC Strategic Review of NCEP Production Suite

Relevance: Supporting OAR Mission

Develop technology to improve NOAA science, service, and stewardship

Transition the results so they are useful to society

Implement to give improved guidance

R4O Build best techniques into prediction systems

GSD’s core expertise + GSD’s ability to bring together research communities = Improved NOAA model guidance

Relevance: Supporting NOAA Priorities

Supporting NOAA Administrator’s top priorities

- Community Resilience
  - Accurate, detailed guidance with longer lead-time supports preparation, recovery

- Evolve the Weather Service
  - Giving forecasters the tools to support Weather-Ready Nation

- Observation Infrastructure
  - Development of a practical radar reflectivity assimilation technique, first operational use in NOAA

- Organizational Excellence
  - Strong coordination between OAR and NWS to transform experimental HRRR into NOAA operational model

Future plans: Regional / Storm-scale modeling

Storm-scale ensemble data assimilation
- Next major skill jump
- Collaborative effort (EMC, UNBSSL, NCO)
- Ensemble design workshop: July 2015

Storm-scale ensemble post-processing
- USWRF hazard prediction project
- Collaborative effort (EMC, WPC, NCO)
- Strong tie to FACETS, includes social science

Continued improvement of model / assimilation components
- Physics – boundary layer, land surface model, microphysics (reducing model biases)
- Assimilation – improve near-surface structure

Evolution of rapid refresh technology to global models
- Need better boundary layer structure in global models
- Global cloud / precip analysis (sat., LTG data)
Electronic Posters with Science Highlights

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<td>Curtis Alexander</td>
<td>HRRR science, NCEP implementation</td>
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<td>David Dowell</td>
<td>Radar and storm-scale assimilation</td>
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<td>Tanya Smirnova</td>
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<td>Isidora Jankov</td>
<td>Ensembles and probabilistic guidance</td>
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**Development and operational implementation of the first convection-allowing (3-km) hourly-updating numerical weather model**
- Situational awareness for severe, aviation, energy, hydrological communities
- Community resiliency, reduces hazard impacts towards Weather-Ready Nation

*29 June 2012 Obs  HRRR 15 UTC Forecast*

Continue development to make forecasts better...see poster

**Evolve from a deterministic (single-model) to a convection-allowing forecast ensemble to provide forecast uncertainty**

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**Skill from Reflectivity Data Assimilation**

**HRRR Forecast Skill for Reflectivity (30 dBZ)**

- Radar data assimilation in RAP and HRRR
- No radar data assimilation

**Critical Success Index X 100**

- More Skill 60
- Less Skill 0

**Forecast Length (Hours)**

- 0.0
- 4.0
- 8.0
- 12.0

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**Example: With and Without Radar Data Assimilation**

- RAP radar DA improves convective forecast in both RAP and HRRR
- Additional HRRR radar DA improves fine-scale initialization of HRRR

15-minute HRRR forecast

- No radar DA
- Observed reflectivity
- Radar DA in RAP and HRRR
Land-surface cycling for better hydrometeorology

Tanya Smirnova
NOAA/ESRL GDS

Examples: With and Without Radar Data Assimilation

- RAP radar DA improves convective forecast in both RAP and HRRR
- Additional HRRR radar DA improves fine-scale initialization of HRRR

- 3-hour HRRR forecast
- Radar DA in RAP and HRRR

Near Future: HRRR Ensemble Data Assimilation

- Improved probabilistic, high-resolution, 0-6 h forecasts of winds, clouds, and convective storms

- Applications: energy, aviation, fire weather, hydrology, Warn on Forecast

Complicated physics interactions

- Clouds (GFO)
- Precip (GF-conv)
- Turbulent fluxes
- Radiation
- LSM (land-surface model)
- PBL (MYNN)
- Soil/snow conditions
- Hydrology

RUG LSM – Land surface component in RAP, HRRR and WRF

Cycled soil/snow state in RAP and HRRR

- Soil temperature/moisture and snow temperature/depth cycling – unique in RAP and HRRR
- Updating snow and sea ice from 4-km NESDIS Snow and Ice Analysis
- Adjustment of soil temperature and moisture from surface analysis increments in GSI – unique in RAP and HRRR

Data assimilation for improved land state

- Satellite assimilation
- Surface 3D assimilation
- Radar assimilation
- Soil/snow state
- Cycled land-atmos conditions
- Best start for next cycle

Develop fully coupled data assimilation and forecast system across the atmosphere/land-surface interface
Collaborations and future work

- NOHRSC / NWC
  - Snow analysis - uses RAP and HRRR background
  - HRRR precipitation for WRF-Hydro forcing
- NASA Land Information System (LIS) – RUC LSM implementation in LIS 7.2 version – Spring 2016
  - WRF-Hydro, NLDAS and GLDAS applications
- WRF model community
- The World Climate Research Programme (WCRP)
  - GCIP, PILPS, SnowMIP experiments
- Include RUC LSM into RAP/HRRR physics suite for NGGPS models and FIM (GSD challenge #2)
  - work in progress

Renewable Energy Applications and Design for the RAP and HRRR

Joseph Olson
NOAA ESRL/GSD

3-5 Nov 2015

Goals for RAP/HRRR Development

- Improve our understanding of physical processes (e.g., clouds & turbulence) important for wind & solar energy.
- Improve representation of these processes in the RAP/HRRR parameterization schemes.
- Make model physics scale-aware to improve forecasts for all products/applications

Topics Presented in Poster

Improving solar (cloud) forecasts:
- Improved aerosol-aware microphysics and radiation physical parameterizations (in poster)
- Improved representation of unresolved stratus & shallow-cumulus (below)

Improving wind forecasts:
- Improved turbulent length scale (in poster)
- Stably PBL, scale-aware
- Improved representation of non-local mixing with addition of mass-flux scheme (below)

Results from Atmospheric Radiation Measurement (ARM) case (June 2006)

- Better match to Large Eddy Simulation (LES)

Please see poster for more details...
HRRR / RAP – Mitigating Aviation Hazards for Safety and Efficiency

Jaymes Kenyon
CRES
Performing Work for NOAA/ESRL/GSD

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Aviation Benefits from Model Improvements

- 12-h Critical Success Index
- 12-h RMSE

Benefits:
- Proactive traffic management
- Better situational awareness for general aviation

Benefits:
- Turbulence forecasting
- Anticipation of low-level wind shear
- Route optimization, fueling requirements

Benefits:
- Accurate cloud forecasts (horizontal, vertical coverage)
- Icing avoidance

Mitigating Aviation Hazards for Safety and Efficiency

- See poster...
  - Aviation-specific applications of RAP & HRRR
  - Advancements in data assimilation and physical parameterizations with aviation benefits
  - Improved post-processing algorithms

- See also Session 5 (Theme 2):
  "Impact-Based Decision Support Tools for Aviation" (talk & poster)

Probabilistic Forecasts at Regional Scales

Isidora Jankov
CRES
Performing work for ESRL/GSD

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North American Rapid Refresh Ensemble (NARRE)

- ARW and NMMB dynamic cores
- Eight members (4RAP and 44NAM)
- Rapid Refresh
- 13km grid spacing
- Different IC and LBC
- Mixed physics

Stochastic Physics Approach
- Evaluation of stochastic vs. mixed physics approach
- Focus on convective treatment, PBL and LSM
Toward High Resolution Rapid Refresh Ensemble

- 3km grid spacing
- CONUS scales
- Rapid Refresh
- 18 hour forecasts
- Time-lagged Ensemble
- Spatial and temporal filters

More details ... on the poster
Session 2: Numerical Weather Prediction – Global Models

- Modeling Challenge #2 – Toward Earth System Modeling (Stan Benjamin)
- FIM Atmospheric Global Model for Medium-range Forecast Applications (Stan Benjamin)
- Impact of Composition and Chemistry on Weather Forecasting (Georg Grell)
- Coupled Atmospheric-Ocean Earth System Modeling for Sub-seasonal Prediction (Shan Sun)
- Development of Non-hydrostatic Global Models – NIM (Jin Lee)
- High-performance Software Engineering (Tom Henderson)
- Physics for Global Non-hydrostatic Applications (John Brown)
Quality: innovative global model development

- Accurate numerics (FIM, NIM)
- Extension to in-line chemistry – FIM-chem
- Coupling to ocean community model (HYCOM)
  - First-only NOAA global coupled model with HYCOM
- Development of non-hydrostatic icosahedral model (NIM)
- Real-data evaluation
  - Successful performance vs. GFS – deterministic (including hurricane) and mixed-model ens.
- Physical parameterizations
  - GFS physics suite within alternate dynamic core
  - Development of scale-independent and storm-scale physics suites, aerosol-chemistry

ESRL Finite-volume Icosahedral Models

FIM: Hydrostatic

- Model candidate for NOAA global ensemble and subseasonal real-time applications.
- Backbone for ESRL Earth-System Analyzer (ESA – chem-global) research applications.
  - Target resolution ≥ 10 km

NIM: Nonhydrostatic

- Demonstration for actual 3km real-data global forecasting with advanced computing and numerics.
  - Target resolution: Down to 0(1 km)

Innovative numerical approaches for global models

- Icosahedral horizontal coordinate
- Isentropic-adaptive coordinate
- Application of finite-volume approach within icosahedral and isentropic framework

Why global modeling in GSD?

Experience with physical parameterizations

- Alternative scale-aware deep cumulus parameterization, sub-grid-scale cloud effects
- Development and demonstration of HRRR-RAP physics suite (main NOAA development for storm-scale physics suite)
- Aerosol-aware physics, aerosol chemistry (smoke, volcanic ash)
- Collaboration with WRF, WRF-Chem, Climate Processes Team, NGGPS Global Modeling Test Bed

Performance in global modeling

7-day 500 hPa height anomaly correlation

N. Hemisphere

GFS better

FIM better

S. Hemisphere

6-month averaging
95% significance bracket shown

Performance in global modeling

12-h 250 hPa wind forecast errors (vs.

radbs, FIM, FIM minus GFS)

Pressure (hPa) matched

Wind speed (m/s) (boxes show 95% confidence)
Performance - upcoming

Subseasonal National Multi-Model Ensemble (S-NMME) – Week 3-4

Coupled FIM-HYCOM
- atmosphere-ocean model
- testing down to 15km

Component of Earth System Prediction Capability – ESPC
- NOAA, Navy, DoD
- Focus Areas – Blocking, etc

Subseasonal NMME participants

<table>
<thead>
<tr>
<th>Time</th>
<th>Resd.</th>
<th>Enn.</th>
<th>Freq</th>
<th>Hosts</th>
<th>Holth length</th>
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<td>Past 15y</td>
<td>weekly</td>
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<td>weekly</td>
<td>Fix</td>
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<td>Fix</td>
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<td>weekly</td>
<td>Fix</td>
<td>1981-2010</td>
<td>weekly</td>
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<td>30kmL64 OL32</td>
<td>10</td>
<td>weekly</td>
<td>Fix</td>
<td>1999-2014</td>
<td>weekly</td>
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</tbody>
</table>

Relevance in GSD global modeling

- Hurricane Forecast Improvement Project
- HIWPP – 15km FIM out to 14 days, hourly output
- ESPC – blocking
- NMME – subseasonal forecasting – coupled FIM-HYCOM

Relevance to NOAA 5-year Research Plan

What improvements to observing systems, analysis approaches and models will allow us to better analyze and predict the atmosphere, ocean, and hydrological land processes?

ESRL/GSD role:
- Develop new or improved models and assimilation techniques
  - improve prediction and understanding of phenomena
  - support operational forecasting and research
- Apply those “sharpened tools” to --
  - aviation, severe weather, hydrology, energy, others

Relevance to NOAA Administrator’s Priorities

1. Community resilience
   - global model readiness for 15→10→3km, GSD vanguard for NOAA high-res global modeling
2. Evolve NWS
   - exp FIM demo for HFIP, HIWPP – use in NWS
3. Observation infrastructure
   - advanced use of sat data for global
   - situational awareness
4. Organizational excellence
   - FIM/NIM/HPC – cross-ESRL to NGGPS, NMME

Relevance to NOAA 5-year Research Plan

- FIM atmos model
- UM-HR
- ESRL software architecture
- NMIR
- To understand and predict changes in climate, ocean, and atmosphere
- To share that knowledge and information with others
- To conserve and manage coastal and marine ecosystems and resources

NOAA Mission: Science, Service, Stewardship
Earth-System modeling:
The impact of composition and chemistry on weather forecasting

Georg Grell
NOAA/ESRL

Monitoring Atmospheric Composition and Climate (MACC), Now MACC-III

Our method
Use experience gained with the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem)

- WRF-Chem estimated 2000 users worldwide, community effort led by ESRL
- Original WRF-Chem paper (2005) cited 500 times according to ResearchGate
- Perform convection permitting simulations in areas with strong aerosol signals
- Use best and computationally affordable setup for NGGPS

Surface Temperature biases from ECMWF modeling systems, when aerosol impacts are included over Brazil

Using different NGGPS chemistry suites in FIM

Aerosol impacts on NWP: Can this be done with the simple GOCART modules? First evaluation of aerosol predictions compared to AERONET observations: 2 stations near dust and wildfire locations

Future: Use chosen chemistry suites for next generation NGGPS core
Using WRF-Chem with highest degree of complexity in chemistry suites for aerosol direct and indirect effect:

Systematic and random short wave radiation differences, 20 runs, 72hr forecasts)

In areas of strong sources (wildfires, dust) there is a significant impact of aerosol on NWP!

Coupled Atmosphere-Ocean-Earth System Modeling for Subseasonal Forecasting

Shan Sun
GDOE
Performing work for NOAA ESRL/GSD

Subseasonal Prediction: Extreme Events

Goal: Seamless prediction from days to months

- Traditional Numerical Weather Prediction (NWP): Up to 2 weeks; Rossby wave interactions, baroclinic instability;
- Sub-seasonal prediction: Week 3-4; persistent flow anomalies, coherent structures, e.g. Madden-Julian Oscillation and blocking;
- Model skills are limited on sub-seasonal time scales.

Multi Model Ensemble Approach

- Ensemble forecasting improves skill by reducing uncertainty in the initial conditions;
- Multi Model Ensemble forecasting further improves skill by reducing uncertainty in both the initial conditions and model numerics;
- NMME (North American Multi Model Ensemble project has started subseasonal hindcast experiments with FIM-iHYCOM participating.

Coupled FIM-iHYCOM Model

Unstructured horizontal grid

Adaptive Vertical Coordinate

Flow-following Icosahedral Model (FIM)

Icosahedral Ocean Model (i-HYCOM)
Summary

See details in the poster …

- Different from the current NMME models: FIM and iHYCOM would enrich gene pool of the NMME ensemble;
- Individual model improvement is the ultimate goal for better prediction;
- Preliminary studies show FIM-iHYCOM presently has skill similar to CFSv2;
- More model improvements on the way: subgrid-scale param., vert. resolution.

Development of non-hydrostatic global models:
Non-hydrostatic Icosahedral Model (NIM)

Jin Lee
NOAA/ESRL/GSD

Brief Review of Global Modeling

<table>
<thead>
<tr>
<th>Hydrostatic global models</th>
<th>Non-hydrostatic limited area models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse resolution (Cumulus parameterizations)</td>
<td>High resolution (Lateral boundary condition)</td>
</tr>
</tbody>
</table>

Brief review of global modeling

NIM: A 3-D finite-volume Non-hydrostatic Icosahedral Model

Newton’s 3rd Law to approx. pressure gradient force (PGF)
**A. Presentations and Posters**

### NIM meso-scale hurricane Sandy simulation

- **Summary**
  
  • A Non-hydrostaticicosahedral Model (NIM) has been developed and tested with benchmarks and real data runs.
  
  • Use of 3-D finite-volume tracer transport to follow three-dimensional atmospheric flow, and improves PGF over topography with Newton's 3rd Law.
  
  • Fine-grained parallel computing of NIM implemented and tested on CPU and GPU clusters.
  
  • Extend research experience to help NGGPS model development.

### High Performance Software Engineering

**High Performance Software Engineering**

Tom Henderson

CSA

Performing work for NOAA/ESRL/GSD

---

### GSD High Performance Software Research

- Keeps NOAA research competitive
  - A catalyst for science
    - GSD:
      - Exploits new architectures
      - Explores new techniques
      - Develops software automation
      - Drives process improvement

---

### ePoster

- New software techniques for new architectures
- New software automation methods
- Process improvements
- Collaborations
Physics for global non-hydrostatic applications

John M. Brown
NOAA/ESRL/CGD

Physics for Global Models

Cloud-allowing and variable resolution
Grid-refinement or nesting likely

➢ “Scale-aware” physics
➢ Initial development: “HRRR-like” physics suite
➢ Proven at 13 and 3km grid spacing

Physics for Global Models

- Example of scale-aware physics. Grell-Freitas (GF) convection from a single 72-h global run with a stretched grid.
- Parameterization of convection still needed, perhaps even at 3km grid spacing
- Avoid bulls-eyes of excessive precipitation
- GF convection becomes essentially a shallow scheme at 3km

Outlook

- Test global application of HRRR-like physics to stretched grids with MPAS and FV3
- Intrigued? Come see the poster!

HRRR-like Physics:
- RRTMG lw and sw radiation
- RUC (Smirnova) land-surface
- MYNN surface layer
- MYNN boundary layer +GFO shallow convection
- Grell-Freitas convection scheme
- NCAR aerosol-aware microphysics
Session 3: Numerical Weather Prediction – Cross-Cutting Activities

- NWP: GSD’s Path Forward (Tim Schneider)
- Global Developmental Testbed Center (DTC) (Ligia Bernardet)
- Global Observing Systems Analysis (Lidia Cucurull)
- Improving Winter Storm Forecasts with Dropsonde Data (Jason English)
- Renewable Energy Program (Melinda Marquis)

The High Impact Weather Prediction Project (HIWPP):
- GSD-led: “We make forecasts better”
- OAR “Sandy Supplemental” Project
  - $12,000M
  - 3-Year Accelerator
- HIWPP engages:
  - 3 NOAA Labs; 4 Cooperative Institutes; 2 NCEP Centers; Navy; NOAR
- HIWPP is comprised of:
  - 5 Subprojects
  - 19 Tasks

How are we doing it?
- Partnerships & collaboration
  - HIWPP funding has unified and focused the NWP community
- Building on existing effort
- Enhance & accelerating science
  - Drive the science to a higher technical readiness level
- Research to operations:
  - Hand-off to the Next Generation Global Prediction System (NGGPS)
NGGPS

Next Generation Global Prediction System (NGGPS)

- An R2O initiative to
  - Implement a cloud-permitting, fully-coupled NWP system
- Through accelerated development and implementation of
  - Current global weather prediction models and physics
  - Improved data assimilation techniques, and
  - Improved software architecture and system engineering
- Extend forecast skill at two weeks and beyond
- Improve high-impact weather forecasts including hurricane track and intensity
- Built upon HWMWP successes
- Why GSD? This is in our wheel house

GSD’s NWP Core Strengths

Better Models for Better Forecasts

- Next generation global modeling: GSD is at the forefront of model development & transitions
- Our research supports the enterprise and helps NOAA better use infrastructure and more efficiently use our Nation’s resources
- Session 3: A glimpse into three fascinating worlds…key aspects of these challenges

New Paths Forward: Cross-Cutting Themes

- Developmental Testbed Center
- Global Observing Systems Analysis
- Renewable Energy

New Paths Forward: Current Research

- Developmental Testbed Center
  - Community Support, Community Tools
  - GSD partners with NCAR to support NOAA numerical weather prediction
  - Global Model Test Bed recently established to support NGGPS
  - GC1: Continuous global, storm-scale (10km) ensemble data assimilation and ensemble forecasting for global situational awareness
  - GC2: A fully-coupled earth system modeling/prediction capability
- Better use of current observations and plan for future observations
  - Global Observing Systems Analysis (GOSA) Group
    - OCE: Provide the Nation the ability to efficiently determine the best environmental observing systems
    - Tandem: NOAA and DTC working groups on future observing systems
- Using forecasts to help produce and use energy more efficiently
  - GSD-led Renewable Energy Program
  - GCE: Provide the most accurate environmental information, including uncertainty and probabilities, to the right people at the right time and in the right form for optimal understanding and decision making

Global Model Test Bed of the Developmental Testbed Center (DTC)
Leader: Lijia Bernardet

Quality:
- 2014 C/RES Outstanding Performance Award in Science and Engineering – Lijia Bernardet
- Lead: NGGPS Workflow and Launch Subcommittee

Relevance:
- NOAA Administrator priorities
- Achieve organizational excellence

Performance:
- Hurricane Weather Research Forecast (HWRF) code management contributed to DOE Gold Medal Award to V.T. and NOAA-HWRF Team
- R2O for HWRF surface flux improvement, HWRF radiation and partial cloudiness, Short-Range Ensemble Forecast (SREF) downscaling
- Yearly code releases, tutorials and workshops on five NOAA-operational NWP codes
Global Observing Systems Analysis (GOSA) Group
Chief: Lidia Cucurull

Quality:
- Cucurull
- AMS Fellow
- 2011 NOAA David Johnson Award
- NOAA COSMIC-2 Program Scientist
- Chair, Expert Team on New Remote-Sensing Technologies of WMO
- NOAA DAR Technical Liaison for the COSAP
- Quantitative Observing System Assessment Program (COSAP)

QAR Representative
- NOAAP Priorities
  - Develop new NWS, invest in observational infrastructure, achieve organizational excellence

Performance:
- MOU with NESDIS/NWS to lead R&D and R&D to Radio Occultation technology
- Global OSB/OSSEa for NOAA UAS Program and Radio Occultation observations
- GPS/MET

Renewable Energy Program
Program Manager: Melinda Marquis

Quality:
- Utility Variable-Generation Integration Group Annual Achievement Award
  - 2014
- Group award for WIP-1
- 2015 Department of Commerce Gold Medal: "For the success of HRRR, the first storm-scale model to give forecasters and decision-makers fast, local weather guidance"
- 2015 Colorado Governor’s Award for High Impact Research: Sustainability

Relevance: NOAA Priorities
- NOAA Next Generation Strategic Plan (NGSP): "Production of renewable energy through better information"
- Support NGSP goal about climate adaptation and mitigation
- Improve the weather service

Performance:
- Improved wind forecast skill at turbine height
- Leveraged RAP and HRRR (developed for aviation and severe weather)
- WP-1 improvements translated to NCEP early 2016 HRRR and RAP
- WP-1 improvements translated to NCEP Feb 2014

Session Presentations & Posters

Ligia Bernardet
- Developmental Testbed Center (Including Global Model Test Bed)

Lidia Cucurull
- Global Observing Systems Analysis (GOSA) Group

Jason English
- GOSA project: Improving Winter Storm Forecasts with Dropoande Data

Melinda Marquis
- NOAA Renewable Energy Program

The Developmental Testbed Center (DTC)
Ligia Bernardet

DTC improves operational models by transitioning innovations from the research community

By supporting operational codes to the community, development can be implemented and tested directly in the operational model, which reduces transition costs.
**Global Model Test Bed**

A new effort within DTC toward increased transfer of research to operations for NOAA’s next generation global prediction system.

GMTB builds on the experiences of the DTC and High-Impact Weather Prediction Project to evaluate models for operations. Initial focus is on community involvement in the development of atmospheric physics.

**Summary**

- DTC connects operational models and the research community outside of NOAA.
- DTC is a collaboration between GSD and the National Center for Atmospheric Research and has staff at both institutions.

Come see the poster!

- Evaluation of innovations in clouds and radiation for two operational models.
- Details on the Global Test Bed.

**Global Observing Systems Analysis**

Lidia Cucurull

NOAA/ESRL/GSD

**Observing System (Simulation) Experiments**

- Necessary to quantitatively evaluate benefits of current and new obs in weather forecasting.
- Helps NOAA management prioritize mission designs in a cost-effective way.
- Saves taxpayer and NOAA $$

**Radio Occultation (RO)**

One of the top contributors to improve global weather forecast skill.

- Provides very accurate weather observations under all-weather conditions.
- Improve the use of current obs in operational weather models.
- Evaluate the impact of future constellations.

**Summary**

- Increasing demand for tradeoff studies.
- Need to quickly and efficiently assess the value and capabilities of existing and proposed observing systems.
- Strengthen collaboration with AOML, NWS/EMC, JCSDA, NESDIS, UCAR, and the private sector.
- More details at my poster.
- Poster BONUS: GSD’s Global Positioning System (GPS) precipitable water network.
Improving Winter Storm Forecasts with Dropsonde Data

Jason M. English
CDMS
Performing work for ESRL/GSD

GSD Science Review
3-5 Nov 2015

Motivation

GFS model had > 3 day track errors with Hurricane Sandy

Hurricane Sandy (Track error)

Does GFS need improved model resolution, physics, or data assimilation?

Data from NASA/NOAA fleet of Global Hawk Unmanned Aircraft may improve data assimilation:
Observing System Experiments (OSEs)

Instead of flight campaigns, we can simulate dropsonde data from a “perfect” model and determine whether it improves GFS forecast accuracy: Observing System Simulation Experiments (OSSEs)

A Tale of Two Storms

GFSF study: initialize GFS model with perfect observations from the Nature Run and evaluate winter storm accuracy

500 mb Quota Heights (CONUS)

“Jan 30 Storm” (initialized Jan 25 W02) “Feb 25 Storm” (initialized Feb 20 W02)

Summary

• GFS model had > 3 day track errors with Hurricane Sandy; was this due to model resolution, physics, or data assimilation?

• The NASA/NOAA Global Hawk Unmanned Aircraft can provide observations for data assimilation, and forecast improvements can be quantified (OSEs)

• GFS forecasts initialized with perfect observations over the Pacific Ocean from the Nature Run are analyzed for two winter storms (OSSEs)

• Forecasts are improved for 7-day forecast of Jan 30 storm but not Feb 25 storm. Why? Come to the poster to find out!

Research for Weather-Dependent Renewable Energy

Melinda Marquis
NOAA/ESRL/GSD

GSD Science Review
3-5 Nov 2015

NOAA/ESRL/GSD Roles in Renewable Energy

• New NOAA effort.
• ESRL uniquely qualified.
• All four ESRL divisions contribute.
• Partnership with DOE, NCAR, and private sector.
• Utilities, grid operators, and private forecast vendors consider the Rapid Refresh (RAP) and High Resolution Rapid Refresh (HRRR) to be state-of-the-art.

Earth System Research Lab
Global Systems Division
Global Monitoring Division
Chemical Sciences Division
Physical Sciences Division
AF Resources Lab
NWS/NCEP
Research Topics

- Physical processes that affect irradiance and turbine-height winds
- Model physics and data assimilation
- Optimal suite of sensors to support renewable energy
- Balance of power supply and demand
- Design optimized energy systems using high resolution weather data.

Projects

- Wind Forecast Improvement Projects
- Solar Forecast Improvement Project
- National Energy Weather System
High-Resolution Rapid Refresh: From Research to Operations

Curtis Alexander, Steve Weygandt, Stan Benjamin, David Dowell, Ming Hu, Tanya Smirnova, Joe Olson, Jaymes Kenyon, Georg Grell, Eric James, John Brown, Haidao Lin, Bill Moninger, Jeff Hamilton, Xue Wei, Terra Ladwig and Brian Jamison

Path to Operations
Growth in High Performance Computer Resources
- Moore's Law Growth Rate Doubling Every 18-24 Months
- Progressively Finer Grids Higher Spatial Resolution
- Wet and Dry Scheme
- Effective Initial Conditions
- Accurate Storm Structure Estimate Permeability
- More Effective Flight Planning
- Progressively Larger Domains Boundary Influence Removed
- High-Impact Weather Prediction Success
- Thunderstorm Droughts Winds
- Wildlife Behavior
- Heavy Snowfall Bending

Model Design
- Leverage Higher-Density Frequent Observations
  - Observation Densities Enables Hourly Updating
  - Observation Sensitivities Aircraft Greatest Impact
  - Hybrid EnKF-3DVAR DA Improved Upper-Air Forecasts

Improving Forecast Accuracy
- RAP and HRRR Development History
- Operational Implementations
- RAPv2HRRRv1 Model Bias Feedback
- RAPv3HRRRv2 Bias Mitigation

Verification of Forecast Improvements
- Upper-Air
- Surface
- Reflectivity - Stats
- Reflectivity - Convective
- Reflectivity - Convection

Community Model Physics Development
- Current Operational Configuration
- Next Operational Configuration

Operational Availability at NCEP
- Research and Development Systems 90% Average Availability
- Operational System > 99.9% Average Availability
- Storm System 1
- Storm System 2
- 96 System 3
Radar Data Assimilation for RAP and HRRR

David Dowell, Curtis Alexander, Stan Benjamin, John Brown, Ming Hu, Eric James, Terra Ladwig, Tanya Smirnova, Steve Weygandt

Current Use of Radar Data
Motivation
Accurate convective forecasts needed for severe weather forecasting and aircraft routing

Opportunity provided by national radar network (WSR-88D) and quality-controlled reflectivity composite from Multi-Radar Multi-Sensor (MRMS) system

A Closer Look
Reflectivity Assimilation Method
Temperature tendency from precipitation microphysics scheme replaced by reflectivity-based heating during WRF model integration

\[ \frac{dH}{dt} = \frac{1000}{P} \left( \frac{F_{\text{radar}} - F_{\text{HRRR}}}{\text{Reflectivity Factor}} \right) \] 

Model response to heating: development of updrafts, formation of clouds and precipitation.

Ensemble Data Assimilation
Why Ensembles?
Situation-dependent background-error covariances representative of convective systems, which are localized, non-geostrophic, and non-hydrostatic
Better radar-data quality control (Doppler-velocity unfolding, identification of non-hydrometeor reflectivity observations)

Applications
0-6 hour probabilistic predictions of clouds, storms, and other local phenomena (e.g., wind shifts)

Forecast Improvement from Reflectivity Assimilation

Combined Use of Radar, Satellite, and Surface Data
Cloud and precipitating hydrometeors added (removed) in GSI where radar, satellite, and surface observations indicate hydrometeors (no hydrometeors)

Research and Development
Proof of concept demonstrated through collaboration with NOAA’s Warn-on-Forecast project

Opportunities for Further improvement

Reflectivity analysis and forecast at 2-minute intervals

27 April 2011
Southeast US Tornado Outbreak

HRRR ensemble radar-data assimilation development underway, real-time testing planned in 2016
Land-surface cycling for better hydrometeorology

Tatiana Smirnova, Eric James, Stan Benjamin, John Brown

**GOAL:** Accurate initial land surface state – important for both regional and global predictions
- Sufficient skill of physics parameterizations
- Use of observations to prevent from model drift
  - radar, satellite, surface observations, etc.
- Cycling of soil/snow fields
  - soil temperature/moisture adjustments in GSI
  - NESDIS snow/sea-ice analysis
- Coupling to sub-surface hydrology, water drainage, large-scale river routing

**Precipitation verification in 13-km RAP and storm-scale HRRR:**
- 1-h RAP minus Stage IV (precipitation total)

- **Ratio 1-h HRRR QPF/QPE (Stage IV)**

**Recent improvements to RUC LSM - WRF v3.7 and NASA Land Information System**
- Simple treatment of cropland irrigation during the growing season
- 30° MODIS Land-use
- Leaf Area Index (LAI)
- Mosaic approach to snow-covered and snow-free portions of the grid cell

- Separate treatment of energy and moisture budgets for snow-covered and snow-free portions of the grid cell
- Aggregate solutions at the end of time step

**Cycled RAP snow water equivalent**
1-10 January 2015

**Couple to Hydrology**

**Add RUC LSM to LIS:**
- 1-d testing is finished
- 2-d testing is underway

**Collaborations:**

NOAA RESEARCH • EARTH SYSTEM RESEARCH LABORATORY • GLOBAL SYSTEMS DIVISION
**Improving Solar Forecasts**

Aerosol-Aware Microphysics and Radiation
- Improved cloud cover over land and water
- Improved downward SW in clear-skies

**Improved Subgrid-Scale Clouds**
- Addition of cloud probability distribution functions coupled to radiation scheme
- Improved shallow-cumulus scheme

**Improved Downward Shortwave Radiation Forecasts**
- Daily averaged GHI comparisons show large improvements in warm season due to better shallow-cumulus treatment.
- Improved treatment of stratus is necessary for remaining errors.

**Improving Wind Forecasts**

RAP/HRRR Wind Speed Bias
The current RAP/HRRR has a distinct high wind speed bias in the boundary layer. This bias is robust in all observational platforms.

Reducing the High-Wind Speed Bias: Mixing Length ($l_m$) Revision Important for controlling diffusivity:

$$K_{diff} = l_m S_{2/3} (2 * TKE)^{1/2}$$

- Problems with mixing lengths
- Revised mixing lengths

**Example of Impact on Strong Low-Level Jet**
Mean profiles over Kansas 06-08 UTC 11 June 2015.

**Improved Forecast Skill**
RAP forecasts validated against a variety of platforms during the week of the strong LLJ event (08-15 June 2015) show consistent improvement in wind speed forecast.

**Current/Future Work**

Improved Non-Local Mixing
- Mass-flux scheme
- Momentum transport
- TKE transport
- Scale-aware adapting to grid spacing

**Fully Scale-Aware Turbulence Scheme**
- Blended diffusivity
- Transforms from 1D to 3D

**Summary**

Substantial Improvements for Future RAP/HRRR Major improvements to subgrid-scale clouds, inclusion of aerosols, and turbulent mixing.

**Ongoing collaborations:**
- Wind Forecast Improvement Project II (DOE & Vaisala)
- Solar Forecast Improvement Project (DOE, NCAR, IBM)
- ESRL Renewable Energy Team (GSD, CSD, PSD, GMD)
HRRR / RAP: Mitigating Aviation Hazards for Safety and Efficiency

Jaymes Kenyon, Joe Olson, Curtis Alexander, John Brown, Stan Benjamin, Tanya Smirnova, Steve Weygandt, Eric James, Ming Hu, Terra Ladwig, David Dowell, Georg Grell, Isadora Jankov, Steven Peckham, and Bill Moninger

Providing Hazard Guidance for Routing and Traffic-Management Decisions

Frequently cycled models are adept at leveraging available observations to “keep up” with rapidly evolving weather within U.S. airspace.

Acknowledgment: FAA Aviation Weather Research Program, NOAA

Icing and Turbulence

- RAP drives hourly-updated operational icing turbulence algorithms at AWC

CoSPA

- Blends short-term extrapolation with longer-term HRRR dynamical guidance

HCPF & Gate Forecasts

- Time-tagged HRRR ensemble decision tools

CCFPG

- Incorporates HRRR guidance to facilitate strategic decision making by FAA, industry

Towards Improved Ceiling, Visibility, and Icing Guidance

The GSD Hydrometeor Analysis

- Leverages METAR, radar, and satellite observations for better initial-state cloud field in RAP & HRRR

Aerosol-Aware Microphysics

- Accounts for essential role of aerosols in double-moment representation of ice, liquid clouds

Subgrid-Scale Cloud Parameterizations

- Represent clouds of limited vertical and/or horizontal extent, not depicted by microphysics scheme

Future Directions

Improved Postprocessing Algorithms

- Utilize both resolved-scale and subgrid-scale information for more accurate diagnostics

Model In-Line Chemistry

- Explicitly predict concentrations of operationally important particulates and trace gases

HRRR / RAP Aviation Skill Metrics
Probabilistic Forecasts at Regional Scales
Isidora Jankov, Curtis Alexander, Jeff Beck, Trevor Alcott, Hongli Jiang, Scott Gregory, Joseph Olson, Jaymes Kenyon, Tatiana Smirnova, Georg Grell, John Brown and Stan Benjamin

North American Rapid Refresh Ensemble (NARRE)
- NARRE is planned for implementation into operations in 2017
- Collaborative work between GSD and EMC
  - 13km horizontal grid spacing
  - RAP members include variations in
  - PBL, sfc, layer, and convective treatment
  - NCLBCs
  - NMMB members differ only in NCLBCs

Testing of use of Stochastic Physics approach

High Resolution Rapid Refresh Ensemble – Time Lagged
Time-Lagged Design
- 3km, 18 hour forecasts
- CONUS scales
- Rapid Refresh
- Time-lagged
- Spatial and temporal filters

Probabilistic Hazard Prediction Tool
- The tool will facilitate process of issuing watches and warnings
- The product is planned for operation implementation in 2018
- The tool will be addressing wide spectra of hazards:
  - Intense rainfall
  - Heavy snowfall
  - Severe weather
  - Aviation hazards

Next generation ensemble will consist of multiple ensemble members with stochastically perturbed physics parameterizations.
The FIM global model for medium-range forecast applications

Stan Benjamin, Shan Sun, Rainer Bleck, Haiqin Li, Georg Grell, Jian-Wen Bao, and John Brown

Development of Earth System Models for All Time-Scales
- Atmos-ocean-chem-bio
- NWP to seasonal to nowcasting
- Cloud/precipitation/AQ

Results

Numerical Weather Prediction

7-day 500 hPa height anomaly correlation

Stratospheric vortex breakdown
PV on 800K, slice valid 00 UTC 28 Mar 2014

Current NWP activities and near future:

Next coupled model/seasonal directions:

Key aspects of FIM atm/ocean/chem model:
- Quasi-uniform horizontal unstructured grid – Icosahedral, like NIM
- Quasi-icosahedral vertical coordinate
- Skill slightly exceeding that of GFS, benchmark for NGGPS skill
- Contributes to NOAA coupled model capability including component interoperability with CFSNCEP and GFDL
- Candidate for multi-model ensemble
- Likely use within subseasonal NMME ensemble
- Earth system research tool for NOAA

Advantages of Isentropic Coordinates

Tropical Cyclone Prediction Results

Outlook for FIM

NOAA RESEARCH • EARTH SYSTEM RESEARCH LABORATORY • GLOBAL SYSTEMS DIVISION
Earth-System modeling: The impact of composition and chemistry on weather forecasting

Georg Grell, Steven Peckham, Pallavi Marrapu, Li Zhang, Stuart McKeen

Principal goal of ECMWF for forthcoming decade: physical and chemical weather - One of the four aims: “We will deliver operationally global analysis and forecasts of atmospheric composition.”
Prof. Alan Thorpe, ECMWF Director-General, 2012

Surface Temperature biases from ECMWF modeling system: aerosol impacts are included over Brazil during biomass burning season. September 2012, average over 10 day period.

Aerosol impacts on NWP: can this be done with simple bulk aerosol models?
Our Method: Use chemistry and aerosol packages with different levels of complexity to evaluate interaction of aerosols with radiation and microphysics, five experiments:
1. Only climatology for aerosols, no chemistry
2. A tracer transport package for decadal simulations of CO2, CH4, and SF6 (earth-analyzer experiments)
3. Very light package that uses GOCART modules only – ideal solution for NWP, only 17 additional variables
4. A medium package (similar to ECMWF), that includes gas-phase chemistry (around 80 additional variables)
5. A sophisticated package with even more complexity than what is used for air quality forecasting (190 additional variables)
The three chemistry suites [(3) – (5)] may later be included in any future NGGPS dynamic core

Using WRF-chem chemistry and physics suites:
- Estimated 2000 users worldwide, community effort lead by ESRL, Original WRF-Chem paper (2005) cited 500 times
- Outreach: we teach national and international tutorials (test international ones in Nepal, Brazil, Malaysia, and Cabo Verde, funding from United Nations, World Meteorological Organization, or local Met services)

Near surface temperature differences (Temperature at 2m above surface) during mid-morning hours averaged over twenty 12, 36, 60-hr forecasts, using convection permitting simulations with a regional model and a sophisticated chemistry.

Using complex physics/chemistry, significant differences are found compared to meteorology only runs.

Modeling domains, using WRF-Chem and suites 1, 3, 4, and 5

<table>
<thead>
<tr>
<th>Domain</th>
<th>Temperature</th>
<th>Error Bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (South America)</td>
<td>19°C</td>
<td>±2°C</td>
</tr>
<tr>
<td>2 (North Brazil)</td>
<td>18°C</td>
<td>±1°C</td>
</tr>
<tr>
<td>3 (North Brazil)</td>
<td>18°C</td>
<td>±1°C</td>
</tr>
<tr>
<td>4 (South Brazil)</td>
<td>18°C</td>
<td>±1°C</td>
</tr>
</tbody>
</table>

NOAA RESEARCH • EARTH SYSTEM RESEARCH LABORATORY • GLOBAL SYSTEMS DIVISION
Coupled Atmospheric-Ocean Earth System Modeling for Subseasonal Forecasting

Shan Sun, Rainer Bleck, Haiqin Li, Stan Benjamin, Georg Grell and Ben Green

Introduction

Unstructured Horizontal Grid
Adaptive Vertical Coordinate

Flow-following* finite volume Icosahedral Model (FIM)

Icosahedral Ocean Model (iHYCOM)

- A matched pair of numerical models for simulating the global atmospheric and oceanic circulation is under development at NOAA's Earth System Research Laboratory. Both models use an icosahedral horizontal grid and a hybrid-isentropic adaptive vertical coordinate.
- The atmospheric component FIM has already undergone extensive testing as a medium-range forecast model (http://fim.ncep.noaa.gov) [1,2]. Column physics in FIM is based on GPS & CPS.
- iHYCOM is an icosahedral-grid version of the ocean model HYCOM [3].
- Coupling strategy: Grid nesting is common in weather modeling, but grid discontinuities are usually kept away from the region of interest. To avoid joining disparate grids at the ocean-atmosphere interface, arguably the region of most interest in coupled modeling, the two models share the same horizontal grid.

NMME subseasonal forecast

- Multi-model ensembles improve the skill over that of each individual model.
- North American Multi-Model Ensemble (NMME) project by NOAA/CPC is aimed at improving forecast skill by blending predictions from different models and reducing uncertainties in the initial conditions as well as in the numerical models.

Summary

- Sub-seasonal predictability of extreme weather is of great interest to many sectors of the community. Finding potential sources of predictability is crucial on this time scale, including Madden Julian Oscillation (MJO), blocking, sudden stratospheric warming, etc.
- The innovative FIM-iHYCOM uses unstructured horizontal grid and adaptive vertical grid;
- Preliminary evaluation of FIM-iHYCOM results suggests its monthly and seasonal predictions are credible;
- 16yr hindcast sub-seasonal experiments are under way with FIM-iHYCOM at 30km horizontal resolution (50% done);
- Given that both FIM and iHYCOM are very different from the current NMME models, they would add diversity to the NMME ensemble, and likely improve the overall skills;
- More model results are here: MJO, MJO, blocking.

References


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[0]
Non-hydrostatic Icosahedral Model (NIM)

NIM team: Jin Lee, Man Zhang, Kayee Wong, Gerard Ketefian

Introduction
The Earth System Research Laboratory (ESRL) is developing a new global 3-D finite-volume Non-hydrostatic Icosahedral Model, NIM, for ESRL Earth System Analyzer and weather and climate prediction. NIM is a multi-scale model that can be used to improve tropical convective clouds and to extend weather forecasts into intra-seasonal predictions.

NIM model characteristics
NIM uses innovations in model formulations similar to those of FIM developed by ESRL. These innovations include:
- A finite-volume icosahedral shallow water model on local coordinate (Lee and MacDonald, MWR, 2009).
- A multistep flux-corrected transport scheme (Lee, Black and MacDonald, 2010 JCP).
- Efficient indirect addressing scheme on irregular grids (MacDonald, Middlecoff, Henderson, and Lee, 2010, LHPGC).
- Implementation of NIM for large parallel computing on CPU/GPU clusters.
- Use of the three-dimensional finite-volume for advection and pressure gradient force (PGF) over complex terrains.

Idealized benchmarks
NIM has been tested with many idealized benchmarks as well as real data simulations. These idealized test cases include:

- Warm bubble
- Baroclinic waves
- Supercells
- Mountain waves

NIM 3-km hurricane Sandy (2012)
simulation
- Initial condition: GSI/T1534 at 2012-10-24 1800 UTC
- Topography: GSI/T1534 surface geopotential height

- Physics package: GFS physics
- Model results: Validation of 3-hr accum precip

Remarks and future directions
- A Nonhydrostatic Icosahedral Model (NIM) has been developed and tested with benchmarks and real data retro runs.
- Use of the three-dimensional control volume and the Newton 3rd Law to improve PGF over complex terrain.
- Incorporation of GFS physics into NIM modeling systems.
- Implementation and test of fine-grained parallel computing of NIM on CPU and GPU HPCs.
- NIM 3km simulation at 1% wall-clock time w/ Q(100,000) cores.
- Extend research experience to help NGGPS development.
High Performance Software Engineering: A Catalyst for NWP

Tom Henderson, Mark Govett, Jacques Middlecoff, James Rosinski, Paul Madden, Chris Harrop, Craig Tierney

Software Techniques

Purpose
Enable research NWP models to run on operational schedules on the world’s largest supercomputers

- Improvements in Numerical Weather Prediction skill well correlated with improvements in computational power since 1986
- NOAA research must use all available resources to remain competitive
  - 3km NGGPS forecast tests consumed half of “theia”
- CPU clock speeds have stalled
  - Use traditional and emerging architectures to increase computing power
    - CPU, millions of cores
    - Graphics Processing Units
    - Many Integrated Core
  - Single source code required to avoid slowing NWP development
  - Solution: Directives

Why is Software Engineering So Important?

- NWP models require advanced software techniques to run efficiently on modern supercomputers
- Scientific Method depends upon strong software automation and processes
  - Experimental “apparatus” must be controlled or experiments cannot be repeated
  - Software is the apparatus for NWP
  - Use software engineering “best practices” to control our apparatus

Techniques: WSM6 Microphysics

Purpose
Use directive-based techniques to improve performance of popular microphysics package

- Strong Collaborations
  - NCEP: John Michalakes
  - Intel: Hardware and compiler engineers
- Improvements benefit all architectures
  - CPU: Intel & AMD
  - MIC: Intel
  - GPU: NV/DIA
- Apply Proven Techniques
  - Loop “chunking”
  - Compile-time constants
  - Threading & Vectorization

Software Automation and Processes

Purpose
Reduce risk and increase pace of NWP software development

- Use Best Practices
  - Separate “science” and software engineering
  - Use software repositories (svn, git)
  - Formalize developer communication
  - Automate build, run, test, workflow, CI
  - Prepare for operations (NEMS)
- Target All Resources
  - NOAA Research: theia, “jet”
  - ORNL: Titan (GPU)
  - TACC: Stampede (MIC)
- Collaborate
  - NCEP, SWPC, NASA

Automation: Rocoto

Purpose
Support deadline-driven NWP workflows involving tens of thousands of jobs on modern HPC systems

- NWP workflows are extremely complex
  - Many types of dependencies: [FIM8=2000, x10 if ensemble] Many failure modes Many recovery modes
- Rocoto solutions
  - Serverless
  - Flexible dependencies
  - Automatic fault tolerance
- DDTS Users
  - NOAA
    - NWS NCEP
  - GSD
  - NCAR
  - DTC
Physics for Global Non-Hydrostatic Applications
John M. Brown, Georg Grell, Tanya Smirnova, Joe Olson, Stan Benjamin, Jaymes Kenyon, Ligia Bernardet

Next Generation Global Prediction System (NGGPS)

**Challenge:** Physics schemes, particularly those for deep convection, most work well at a range of resolutions for which the hydrostatic approximation is valid down to where realistic deep convection can be forecast explicitly. i.e., horizontal cell spacings ranging from ~3–20 km.

**Semifinalist in NGGPS “competition”**

- **FV3**
  - Finite Volume dynamical core
  - discretized on a cubed-sphere grid (SDG)
- **MPAS**
  - Model for Prediction Across Scales (NCAR)

**Envisioned physics development process**
- Will concentrate on improvement / development of a few physics suites. Possibilities: Global Model Test Bed (GTM contribution)
- Will require extensive objective and subjective verification
- Will require extensive objective and subjective verification
- Parallel real-time cycles and extensive retrospective testing will require large computational resources (far beyond what is currently available through the NESCC (NOAA Environmental Security Computing Center)

**What does it mean to be “scale-aware”**

Critical for “deep” (cumulonimbus) convection at planned NGGPS horizontal resolutions

- Current mass-flux parameterizations assume (a) below
  - Updrafts occupy small fractional area (c) of grid cell
  - Mass budget of convection is self-contained within a grid volume

**RAPS / HRRR physics suite**

- Processes intensively worked on over past several years by GSD
  - Land-surface – Smirnova
  - Surface layer
  - Boundary layer
  - Shallow boundary-layer-driven clouds (fair-weather cumulus, marine and post-frontal stratus-cumulus, etc.)
  - Deep convection – Grell, Freitas
  - Microphysics – Thompson (NCAR)
  - Coupling between schemes – all

Work is continuing on all these, with particular emphasis on how they contribute to the formation and dissipation of clouds.

**Current components of RAPS / HRRR physics suite**

- RRTMG long and short-wave radiation
  - Includes climatological aerosol, trace gases, dust, clouds
- RUC land-surface model (Sminnov et al [4])
  - Includes snow, snow on sea and lake ice
- MYNNO Surface-layer, boundary-layer and boundary-layer clouds; includes forecast of fractional coverage by low-level clouds
  - Grell-Freitas [3] scale-aware deep convection
  - Includes: cloud water (2-moment)
  - snow (2-moment)
  - graupel

**References**
What is the DTC?

**Purpose**
- Facilitate the interaction and transition of numerical weather prediction (NWP) technology between research and operations
  - **O2R**: Support operational NWP systems to the community
  - **R2O**: With developers, get innovations tested, incorporated into central code, and available for operational implementation
- **Interaction between R & O**: workshops, visitor program

**Activities with operational NWP codes**

- **Data assimilation**
  - 3D/4D Statistical Interpolation (3D/4D SI)
  - Ensemble Kalman Filter (EnKF)
  - Regional ensemble data assimilation
toward the N American Rapid Refresh Ensemble

- **Tropical Cyclone atmos-ocean**
  - Hurricane Weather Research and Forecast (HURWRF)

- **Regional NWP**
  - Non-Hydrostatic Multiscale Model on the B-grid (NMMB)
  - ARW (Advanced Research WRF) for the High-Resolution Rapid Refresh model

Sample of operational codes used at DTC. Activities vary and can include testing and/or community support (e.g., repository maintenance, extension to more computational platforms, tutorials, and documentation). This work complements WRF support provided by NCAR Microscale and Mesoscale Meteorology Laboratory.

Regional Testing and Evaluation

- **Hurricane WRF**
  - A successful collaboration with the NOAA Environmental Modeling Center and community scientists to improve the forcing in the operational HWRF.
  - UCLA scientists acted as subject matter experts to assist in DTC’s testing, evaluation, and improvement of HWRF.

- **Non-Hydrostatic Multiscale Model in B-grid (NMMB)**
  - DTC ran the operational NMMB model using the default Ferrier-Aligo and the Thompson microphysical parameterizations.

Results for a 94-case test over four seasons indicate that the Thompson microphysics alleviates the overprediction of composite reflectivity for light precipitation associated with winter storms.

Global Numerical Weather Prediction

- **Global Model Test Bed (GMBT)**: a new area for DTC
- The Next-Generation Global Prediction System (NGGPS) will replace the current Global Forecast System (GFS) and become operational in 2019.

This is a community system for non-hydrostatic NWP and seasonal prediction with a multi-component forecast application.

DTC is participating by fostering community involvement and creating mechanisms to evaluate innovations in physical parameterizations.

Contributions from DTC

- Research and operational communities closely connected
- Relevant research and development using operational codes
- Mature testing infrastructure
- Transition of several developments to operational models
Global Observing Systems Analysis (GOSA) Group
L. Cucurull (1), K. Holub (1), R. Li (2), G. Ge (2), H. Wang (3), J. English (2), T. Peevey (2), A. Kren (3)

OSSEs and OSEs

• Observing System Experiments (OSEs) allow the evaluation of the impact of current observations in weather forecasting
• Observing System Simulation Experiments (OSSEs) provide a rigorous, cost-effective approach to evaluate the potential impact of new observing systems, alternate configurations and deployments of existing systems, and to optimize observing strategies. They are also used to prepare for the utilization of new types of data and to optimize the utilization of existing data
• Both OSEs and OSSEs are necessary to quantitatively evaluate the benefits of observations in weather forecasting

Radio Occultation Science

• Engaged in ongoing R&D to quantify impacts of additional GNSS Radio Occultation measurements on operational forecast models (e.g., what is the saturation point?)
• Leading GNSS science activities within NOAA
• Fully committed to Radio Occultation and the COSMIC-2 Program – formal agreement with NWS and NESDIS to support Radio Occultation research and associated R2O

GPS-Met Network

• NOAA/GSD GPS-Met network to be transitioned to the private sector
• Observations currently assimilated in NOAA’s operational regional models
• Started work on the assimilation of less retrieved ground-based products with global coverage in NOAA’s operational global models
Improving Winter Storm Forecasts with Dropsonde Data
Jason M. English (CIRES/NOAA), Tanya R. Pevey (CIRES/NOAA), Hongli Wang (CIRA/NOAA), Lidia Cucurull (NOAA)

Motivation
Hurricane Sandy errors in GFS medium-range forecast
- The medium-range forecast track of Hurricane Sandy was accurately predicted by the ECMWF model but not GFS
- Does GFS need better model resolution, model physics, or data assimilation?

Global Hawk Aircraft may improve data assimilation
- Data from NASA/NOAA fleet of Global Hawk Unmanned Aircraft may improve data assimilation: Observing System Experiments (OSEs)

OSSEs: Compare GFS to the “Nature Run”
- Instead of flight campaigns, we can simulate dropsonde data from a “perfect” model and determine whether it improves GFS forecast accuracy: Observing System Simulation Experiments (OSSEs)

OSSE Studies: Two Winter Storms
Jan 30 Storm  Feb 25 Storm
- Initialize GFS with Nature Run “observations”
  - Initialize GFS model with temperature, winds, and relative humidity from the Nature Run and compare forecast accuracy

Improved forecast for Jan 30 storm but not Feb 25!
- Initializing the GFS with perfect observations from the Nature Run improves 7-day forecast accuracy for the Jan 30 Storm but not the Feb 25 Storm. Why?

Exploring Storm Differences
Why the poor forecast for the Feb 25 Storm?
- Important dynamical features outside of sampling region?
  Storm enters sampling region Feb 22; Forecasts initialized after this date are improved
- Other storm features beyond 500 mb Geopotential Heights are improved? Total Energy Error is improved more than 500 mb Geopotential Heights
- Model physics error?

Summary
- GFS had long-range track errors with Hurricane Sandy; due to model resolution, physics, or data assimilation?
- The NASA/NOAA Global Hawk can provide observations for data assimilation, and forecast improvements can be quantified (OSEs)
- GFS forecasts initialized with perfect observations over the Pacific Ocean from the Nature Run are analyzed for two winter storms (OSSEs)
- Adding perfect observations improves some forecast parameters, depending on when important features enter the sampling region.

Next Steps
- Run a series of GFS forecast runs on Theis with lead times 1-7 days for both Jan 30 and Feb 25 storms and evaluate forecast accuracy
- Using targeting techniques, reduce sampling area and quantify forecast accuracy; results can guide whether and where to fly Global Hawk aircraft for OSEs
ESRL Renewable Energy Research Program

Wind Forecast Improvement Project-1
DOE-led Public Private Partnership
WFIP1 had four main goals:
1) To collect new meteorological observations from the public and private sector
2) To incorporate those observations into the RAP model
3) To determine whether using these additional observations led to better wind forecasts
4) To determine whether improved model forecasts also improved the economics of wind power generation.

Solar Forecast Improvement Project
DOE-led Public Private Partnership
This project has three main goals:
1) Determination of a standardized set of metrics for quantifying forecast accuracy
2) Transformational improvements over the state of the art for solar irradiance forecasting
3) Incorporation of the improved solar irradiance and power forecasts into utility and ISO system operations, and their quantification of the resultant economic and reliability benefits.

Results

Validation of NREL/SCR against ground measurements:
Left: dual wind site at WTSU (SBM/ESRL), SUMMIT; June 2014
Right: Power forecasts at SED/NASA Systems, IL (21-23June 2014)

National Energy with Weather System
We have developed a tool that simulates the electric and energy sector to investigate what happens in the system as large amounts of variable generation (wind and solar PV) are integrated as power sources. The aim is to produce a simulator that can be leveraged for decision making on a variety of scales and incorporate a broad range of technologies. The NEWS simulator designs new systems based on the inputs provided, and the system is cost-optimized. NEWS can find additional solutions that produce the least amount of carbon dioxide, waste the smallest percentage of the electric load, build the least amount of new generation, or even create the smallest amount of new transmission.
Session 4: Decision Support – A Busy Day at Forecast Offices

- A Busy Day at Forecast Offices (Mike Kraus)
- Ensemble Forecasts and Uncertainty (Paul Schultz)
- Forecast Monitoring and Short Term Updates (Kevin Manross)
- Tropical Hazards (Tom LeFebvre)
- Unified and Consistent Hazardous Weather Forecasts (Tracy Hansen)
- Sharing the Wealth: Forecaster Tools for Our Partners (Joe Wakefield)
Quality

Tech Transfer – AWIPS Enhancements

- Prototype tools in the field
- Continual feedback
- Acceptance into operational software
- Primary operational tools for forecasters
- 7 Invited talks

Performance

- In line with NWS field office and FAA requirements
- Development driven by sponsor needs
- Effectiveness gauged by:
  - sponsor satisfaction
  - operational implementation
  - continued support

Relevance

- Co-author: Weather-Ready Nation Roadmap “Society is prepared for and responds to weather-related events”
- Objective: Reduced loss of life, property, and disruption from high-impact events
- Relationships

Theme 2 Session 4 Talks

- Unified and Consistent Hazardous Weather Forecasts (Tracy Hansen)
- Sharing the Wealth: Forecaster Tools for Our Partners (Joe Wakefield)
Decision support tools for WFOs

Paul Schultz
GSE
Performing work for NOAA/ESRL/ED

Evolving role of WFOs

- Increasingly sophisticated users are optimizing their weather-impacted decisions by considering:
  - Event probabilities
  - Alternate scenarios
- The Ensemble Tool in AWIPS II was developed to help forecasters communicate this information

Primary source: Ensembles

- 10+ forecasts from computer models
  - Any one of them could be today's best
  - Each represents an alternative scenario
  - Probabilities are estimated from the frequency of an event in the ensemble:
    - If 6 out of 10 of the forecast models indicate precipitation in excess of 1 cm, the probability of precipitation in excess of 1 cm is about 60%

Summary

- Weather Ready Nation calls for better decision support by NWS forecasters
- Decision support = communicating forecasts and their uncertainty
- Uncertainty = probabilities and/or alternative scenarios
- Poster gives examples of how the Ensemble Tool enables this
Forecast Monitoring and Short-term Updates

Kevin Manross
CIRA
Performing work for ESRL/GSD

The first point mentioned in the Weather Ready Nation Roadmap is to "shift from product-focused service to interpretation and consultation."

- Requires maintaining a high-level of forecast accuracy while reducing workload in maintenance of forecast grids.
- GSD continues to develop tools to aid the forecaster quickly assess forecast verification trends and to correct them when necessary.

Even the best forecasters “bust.”
Catch “drift” (from verification) of forecast grids early.
“Grid Monitor” is a tool to quickly assess (qualitatively and quantitatively) which guidance option is verifying best in the short term.

Offer best option (Grid Monitor Choices) for updating a forecast.
“Point Blender”. Use best performing model at each gridpoint to minimize forecast error.
Point Blender Covers 0-24 time period.
“National Blend of Global Models Project” covers days 3-8.

Summary

These tools would minimize tedious workload on the forecaster and allow her or him the freedom to focus on more intensive service-oriented responsibilities (warning operations and communication).

A poster is available and will elaborate on details of each tool.
Tropical Hazards

Tom LeFebvre

GSD Science Review
3-5 Nov 2015

NOAA ESRL/Global Systems Division Science Review
A. Presentations and Posters

Tropical Cyclone Forecast Information

As part of its AWIPS-II work, GSD is assisting with improving the precision and detail of Tropical Cyclone forecast information to the public.

Tropical Cyclone Watch/Warning Product

GSD also implemented the TCV text formatter for NWS

Hurricane Local Statement

GSD led the implementation of the HLS text format:
- Complex collection of cyclone impact info
- Provides critical data
- Decision Support
- Saves forecasters time when resources are

Hurricane Forecast Improvement Program (HFIP)

Product Web Pages

- Compares Operational and Experimental Hurricane forecasts
- Used as an operational briefing tool at NHC, NWHSQ, and FEMA
- Operational forecasters exposed to research models

Feedback has been positive:
- “...website is great and most impressed with the fact that it works on their iPads and smartphones”
Summary

GSD developers continue to provide NWS with techniques to:
- Save forecasters valuable time, reduce effort
- Allow more time for impact-based Decision Support Services
- Complete the transition from Research to Operations

Future Work includes...
- Enhancements to existing techniques
- Extending Hazard collaboration to Wind, Inland Flooding
- New methods for defining tropical cyclone wind fields

Unified and Consistent Hazardous Weather Forecasts

Tracy Hansen
NOAA/ESRL/Geos

Unifying Legacy Applications

Multiple Communication Pathways

Forecast Process

Conduit for transforming leading edge science into actionable information for decision-makers

A better-informed Weather-Ready Nation that is resilient in the face of high impact weather and environmental events
Consistent Continuous Forecasts

- Shared Platform for consistency and accuracy across hazard phenomena on local to national scales
- Leading the way to Forecasting a Continuum of Environmental Threats (FACETs)

Wildfire Operations

Exploratory R&D of services and tools for fire weather decision support

Customers/funders
- National Interagency Fire Center (NIFC)
  Field meteorologists, fire resource managers
- Wildland Fire Management Research, Development, and Application
  Cloud-based software-as-a-service, AWIPS II virtual server

Sharing the Wealth: Forecaster Tools for Our Partners

Joe Wakefield
NOAA/ESRL/GSD

Spacelift Weather Support

Range Standardization and Automation (RSA)
- U.S. Air Force
- Western Range
- Customized AWIPS-I, with national + local data, local model

Taiwan

25+ years of collaboration

Recently...
- Support of AWIPS I-based operations at Central Weather Bureau (CWB)
- Annual CWB visitors, work with Hazard Services, Graphical Forecast Editor
- Familiarization with/developer training for AWIPS II

(More information in Theme 3.)
Canada

Environment Canada - NOAA Agreements
- Participation in Marine Forecast Systems focus
- Goal is improved and seamless forecasts provided to mariners - coastal, Great Lakes
- February 2014 Marine workshop, Halifax

Australia

Bureau of Meteorology
- work with NOAA began 2003
- completed nationwide implementation 2014
- numerous awards in-country, internationally

Spain - State Meteorological Agency (AEMET)
- collaborative work with NOAA since 2011
- initial operations 2014

Looking ahead
- Multi-year agreement being worked with NIFC
- Ongoing RSA support
- New five-year cycle starting with Taiwan CWB
- Expecting continued interaction with Environment Canada under bi-lateral agreement
- Exploring new work with Australia BoM
- Anticipate new agreement with AEMET/Spain for continued development support
Session 5: Decision Support – Aviation

- Decision Support and Evaluation for Aviation (Mike Kraus)
- Aviation Forecasting with AWIPS (Woody Roberts)
- Impact-based Decision Support for Aviation (Brian Etherton)
- Verification Tools for Aviation Weather (Missy Petty)
- Investigation of Truth Sets for Verification (Laura Paulik)
- Assessment of Aviation Algorithms and Forecast Technologies (Matt Wandishin)
Current QA Research

- Evaluation of AIV algorithms requires new methodologies
- Requires new ways to establish “truth”
- 25 years of experience

Quality

- Publications - 9 assessment reports
- Methodology is reviewed by stakeholders and developers
  - Invited presentations
- Assessments inform decisions on transition of algorithms to operations
- Expertise used to develop tools that translate forecasts into impact information

Performance

- Leadership role in conducting assessments - GSD is sought out
- Driven by sponsor needs and requirements
- Success gauged by:
  - Satisfaction
  - Effect on operational implementation
  - Continued support

Relevance

- Weather-Ready Nation:
  Society is prepared for and responds to weather-related events
- Objective: Reduced loss of life, property, and disruption from high-impact events

Decision support and evaluation for aviation

To Be Continued...
Aviation Forecasting with AWIPS

Woody Roberts

Science, Technology, and Operational Challenges

Science Challenges:
- Sparse observational network, especially west of the Mississippi.
- NWP guidance for aviation parameters (e.g., ceiling, visibility, turbulence, icing, etc.) is not particularly good.
- Ceiling and visibility can change rapidly and repeatedly.
- Aircraft emergencies, air rescue, etc. don’t always occur around airports.

Technology Challenges:
- Provide improved forecaster tools for generating information that goes into Aviation products (e.g., TAF’s) generated by NWS – “adding the third dimension.”

Mission Supports:
- General Aviation.
- Commercial Aviation.
- USAF/Vandenberg Launch Facility.

Summary

- Significant scientific, technological, and challenges exist.
- We are working closely with NWS management, and forecasters at national, regional, and local level to streamline the process and improve aviation forecast information.
- Poster will summarize past evaluations, current capabilities, planned enhancements, and future evaluations.
Impact-based Decision Support for Aviation

Brian Etherton
NOAA/ESRL/GSD

GSD Science Review
3-5 Nov 2015

Impact-based Decision Support

- Allow for better planning
  - Strategic, rather than tactical decisions
  - Fewer delays, diversions, and cancellations
  - Maintain safety, improve efficiency
- Operations
  - INSITE in transition to operations at the National Weather Service, expected in 2017
  - Transition via Integrated Dissemination Program (IDP)
- Future plans
  - Add in other weather (fog, snow, winds)
  - Test INSITE
  - Incorporated into the electronic poster session

Aviation Weather

WEATHER FORECAST

TRAFFIC FORECAST

Forecast issued by the NWS Aviation Weather Center – convective (thunderstorm) weather of importance for en-route air traffic

Making forecasts better

Impact-based Decision Support

TIME SERIES OF WHICH ROUTES WILL BE MOST IMPACTED BY WEATHER

Constraint colors:
- Blue: None
- Green-Light
- Yellow-Lime
- Red-High
- Purple-Passable

INSITE

GSD Science Review
3-5 Nov 2015
Verification Tools for Aviation Weather

Missy Petty
ORAU
Performing work for ESRL/NOAA

NOAA ESRL/Global Systems Division Science Review
A. Presentations and Posters

Measuring Product Performance

• Performance in an aviation context
• Monitor product performance
• Support in-depth analysis
• Provide feedback to product developers

Technical Challenges

Summary

• Our verification tools provide capabilities for ongoing monitoring and assessment of product quality in an operational context
• Support management decisions and provide feedback to forecasters/developers
• Future direction
  – Additional weather variables and verification techniques
  – Transition to NWS operations

November 3-5, 2015
Investigation of Truth Sets for Verification

Laura Paulik
CRES
Performing work for ESRL/GSD

GSD Science Review
3-5 Nov 2015
Summary

- We are investigating new truth sets and developing new verification techniques to support assessments and tools.
- Future work:
  - Global observations for turbulence and convection.
  - Investigation of GOES-R for verification.
  - Capturing forecast uncertainty through scenarios.
- Please join me and co-author, Soner Yorgun, at our poster.
Summary Theme 2: Decision Support

- Enhance Forecaster Decision Support Environment capability
  - Determine when and where forecaster can best add value
- Help NWS shift from product-focused service to interpretation
- Further develop impact forecast and evaluation capability
  - Better understanding of customer decision support needs
- Improved communication of forecast uncertainty and probability
- Help decision makers better utilize probabilistic information
Decision support tools for WFOs
Paul Schultz

Expanding role of WFOs

Users need more than the basic forecast
“How confident are you in your forecast?”

Uncertainty qualifiers:
• Event probabilities
• Alternative scenarios

A point forecast, the first basis for DS

Event probabilities

“What is the probability that the temperature will fall below 28F for three consecutive hours tonight?”

“What is the probability that the cross winds at I-25/Co7 will exceed 25 mph this afternoon?”

Alternative scenarios

“What will the conditions be if the inversion doesn’t break?”

“How cold will it get tonight if the clouds go away?”

“How much will the temperature drop if it rains?”

A ‘deterministic’ forecast such as this is incomplete without additional information about the forecaster’s uncertainty.

Distribution viewer example from MATLAB
Forecast Monitoring and Short Term Updates

Kevin L. Manross, Thomas Lefebvre, I-Shan Tsai, Jeremy Kerr and Patrick Sobolewski

Forecast Monitoring

Graphical Forecast Editor Grid Monitor

- General layout of Graphical Forecast Editor "Grid Monitor"
- Highly configurable
- Model guidance selection
- Weather Element selection
- Spatial domain selection

"Gridlet" Overview:
Used for quick assessment
Gridlet display is configurable

Forecaster can set preferred layout
State (models, elements, layout) can be saved and recalled

Short Term Updates

Point Blender Framework

- Create time-series of error grids
- Determine best performing guidance (per MAE, RMSE, etc.) at each gridpoint and weight
- Similar technique to NCEP-based "National Point Blender" project, but run at WFO to address 0-24 hour forecast period

Point Blender performance based on spatial mean MAE as compared to "Obs" verification grids.
Graphical User Interface developed to compare available guidance

Use Case

Combination of Tools Improves Efficiency

- Setup
- Assess
- Update

- Forecasters focus on support during incident/impact weather

Archive:
- Separate, long-term HDF5 storage (time series of grids)
- Easily configurable

Efficient:
- Weights automatically update based on time window
- Bias-corrected grids calculated on the fly

Verification:
- User-selectable "Truth" dataset (RTMA, Obs, etc.)

NOAA RESEARCH • EARTH SYSTEM RESEARCH LABORATORY • GLOBAL SYSTEMS DIVISION
Tropical Hazards
Tom LeFebvre, Tracy Hansen, Paula McCaslin, and Sarah Pontius (CIRA)

NWS improving the quality and precision of tropical forecasts
GSD is contributing to three separate efforts:

- **Hurricane Local Statement (HLS)** – text product formatter that provides detailed information such as watches, warnings, surge and tide,
- **Tropical Cyclone Valid Time Event Code (TCV)** – text product formatter that summarizes all watches and warnings by coastal breakpoint
- **Digital Storm Surge** – translates probabilistic storm surge forecasts into official Storm Surge Watches and Warnings

Hurricane Local Statement

```
HLSMPFL
F27005-016-076-168-172>176-2141600-
HURRICANE WILMA LOCAL STATEMENT ADVISORY NUMBER 35A
NATIONAL WEATHER SERVICE MIAMI FL AL242005
100 AM EDT MON OCT 24 2005

HLS PRODUCT FORMATTER
```

**EXTENSIVE TO DEVASTATING DAMAGE AND LIFE-THREATENING CONDITIONS POSSIBLE AS HURRICANE WILMA MOVES NORTHEAST TOWARDS SOUTH FLORIDA**

* STORM INFORMATION:
  - ABOUT 530 MILES WEST-SOUTHWEST OF MIAMI...
  - 21.4N 87.1W
  - STORM INTENSITY 100 MPH
  - MOVING NORTH OR 360 DEGREES AT 2 MPH
  EXTREMELY DANGEROUS HURRICANE ...

Tropical Cyclone Valid Time Event Code

```
TCV 72-173-2321730-
JO.NEW.KMFL.HU.W.1024.051023T0922Z-000000T0000Z-
JO.UPG.KMFL.HU.A.1024.000006T1000Z-000000T1000Z-
052 AM EDT SUN OCT 22 2005
HURRICANE WARNING IN EFFECT...
```

NOAA RESEARCH • EARTH SYSTEM RESEARCH LABORATORY • GLOBAL SYSTEMS DIVISION
Unified and Consistent Hazardous Weather Forecasts

Tracy Hansen, Chris Golden, Kevin Manross, Jennifer Mahoney, Randy Pierce, Joe Wakefield, Susan Williams

**Unifying Legacy Applications**
- WarnGen (<1 hour)
- Graphical Hazard Generator (Hours, Days)
- RiverPro (Days)

**Forecast Process**
Conduit for Transforming Leading edge science into Actionable Information
A better-informed Weather-Ready Nation that is resilient in the face of high impact weather and environmental events

**Consistent Continuous Forecasts**
- Consistency and accuracy across hazard phenomena on local to national scales
- Partnering to improve communicating probabilities and uncertainty – Forecasting a Continuum of Environmental Threats (FACETs)

**Multiple Communication Pathways**
- “Raw” Hazard Information
- Text
- XML

**Leading Edge Science**

**Hazard Services**

**Move to Higher Ground NOW!**

**Actionable Information**

**Experimental Hazard Services**
- Aviation Weather Center
- Alaska Aviation Weather
- Weather Prediction Center

**FLASH**

**Probabilistic Hazard Information**
Sharing the Wealth: Forecaster Tools for Our Partners
Joe Wakefield, Xiangbao Jing (CRES), Tom LeFebvre, Tracy Hansen, Evan Polster (CIRA)

GFE: The Graphical Forecast Editor
Origins:
AFPS: AWIPS Forecast Preparation System
Early design work 1990-1993.

Development:
GFE
Prototypes 1993-1999
Rapid Prototyping 1999-2003

Operations: 2001-present
Forecasts manage a catalog of grids representing expected sensible weather conditions for the coming week.

Australia Bureau of Meteorology
Under a five-year agreement, NOAA helped BoM adapt the GFE for their use. Rolled out over several years operational nationwide in 2014.
Basic operation similar to NWS, but significantly modernized.

Agencia Estatal de Meteorología (AEMET) Spain
Seeing the success at BoM, AEMET approached GSD to help with a similar application of GFE to their local situation. Initial operations commenced 2014.

Wildfire Operations
Exploratory R&D of services and tools for fire weather decision support
- National Interagency Fire Center (NIFC) - Field meteorologists, fire resource managers
- Wildland Fire Management: Research, Development, and Application
- Cloud-based software-as-a-service, AWIPS II virtual server

Taiwan Central Weather Bureau
Recent work with CWB has focused on transition from AWIPS I to AWIPS II; visitors learning about how to ingest and display local datasets.

CWB staff engaged in our development – GFE tools, Hazard Services, Decision Support tools – while supporting forecast operations.

Spacelift Weather Support
Range Standardization and Automation (RSA)
- U.S. Air Force program, applied at the Western Range (Vandenberg)
- Customized AWIPS-I, with national + local data, local model

Canada
GSD participates in bi-lateral planning to support collaboration between Environment Canada and NWS on common concerns such as Great Lakes shipping forecasts.
Aviation Forecasting with AWIPS

Woody Roberts, Tom LeFebvre, Tracy Hansen, Joe Wakefield, Kevin Manross, Sarah Pontius

Aviation in AWIPS – A brief history

- Air Force Range Standardization and Automation (RSA)
  - Began in mid-1990s with transition to AWIPS system at Vandenberg
  - Became operational in mid-2000s
  - Includes specialized and customized features for enhanced range observations and LAPS analysis

- Interactive Calibration in 4-Dimensions (IC4D)
  - Initially prototyped by NWS/MDL (starting with AWIPS/GFE) for evaluation by the Alaska Aviation Weather Unit (AAWU) in 2005
  - Capability evaluated by GSO (Roberts, 2012)
  - Recommended capability transition to AWIPS 4 baseline now underway

- Terminal Aerodrome Forecasts (TAFs) using the AWIPS GFE for Ceiling and Visibility (CV)
  - Capabilities initially developed by Eastern Region (ER) WFOs using AWIPS/GFE
  - Capabilities evaluated by GSO (Roberts, 2013) at 4 ER WFOs
  - Recommended capability transition to AWIPS 4 baseline now underway

- In-flight Aviation product generation at the Aviation Weather Center (AWC) using GFE and Hazard Services
  - Initial demonstration/evaluation conducted at the Aviation Weather Testbed (AWT) in 2015
  - Prototype tools under development at GSO

Common technical challenges:

- Content requirements
- Formatting
- Filtering out unnecessary information
- Customization for specific ranges, areas, airports, and runway configurations

Scientific challenges:

- Aviation impact variables (cloud, visibility, icing, turbulence, etc.) not well represented in NWS guidance
- Rapidly-changing conditions difficult to represent in analyses and NWP in a timely fashion

Near Surface

Guidance

WFO/AWIPS Forecasters

In Flight

Guidance

AWC/HFO/AAWU - AWIPS Forecasters

GFE Grids

Hazard Services

Products & NDFD
Impact-based Decision Support for Aviation

Brian Etherton, Forecast Impact and Quality Assessment Section

FCI
Flow Constraint Index
The Flow Constraint Index highlights potential constraints by combining raw weather information with air-traffic density, emphasizing constraint in areas of denser traffic.

The area of interest (the CONUS) is broken into a set of hexagons. Traffic can flow in three different directions through each hexagon. Information for the individual hexagons is combined to produce the geographical map.

FCI for each hexagon is computed as a normalized weighted sum:

\[
FCI = 0.75 \times (SW/NE) + 0.5 \times (S/W/E) + 0.25 \times (N/W/SE)
\]

The resulting summary is a ‘heat map’ representing constraint using a color spectrum from yellow (low constraint) to red (severe constraint).

INSITE
Integrated Support for Impacted air-Traffic Environments
INSITE is a web-based tool designed to provide forecaster guidance by highlighting areas of potential impact and providing detailed information on the effects of convective weather on aviation operations. It supports a shift from product focus to product interpretation and consultation. Communicating on-demand forecast confidence information. Delivering information in a way that conveys potential impacts and supports good decision-making and planning.

Transition/Expansion
Transition of INSITE to operations
The establishment of the Collaborative Aviation Weather Statement (CAWS) as a product produced by the NWS Aviation Weather Center (AWC) has proven the utility of the INSITE tool.

INSITE shall transition to operations via close collaboration with our partners. The platform for this transition if the Integrated Dissemination Program (IDP).

Expansion of INSITE
At present, INSITE is only configured to calculate the constraint to air traffic resulting from convection. There are a number of other weather types that can constrain air traffic, including: Winds, Ceiling and Visibility, and Winter Weather.

As INSITE is transitioned to operations, work will continue at GSD to incorporate these other types of weather into INSITE.

http://esrl.noaa.gov/fgas/tech/impact/insite/
**Verification Tools for Aviation Weather**

**Missy Petty, Forecast Impact and Quality Assessment Section**

### Automated Tools
GSD has years of experience in the development of automated web-based verification tools for aviation weather that provide:
- Operationally relevant metrics – where weather matters
- Ongoing performance monitoring
- Feedback to Forecasters and Developers
- Support for in-depth analysis for assessments

### CBVT
**CWSU Briefing and Verification Tool**
Capture CWSU briefings of wind shifts impacting current runway configuration

**Challenge:** Automated identification of wind events in ASOS observations

### EVENT
**Event-based Verification and Evaluation of NWS Gridded Products Tool**
- Measure performance of NWS products in the context of thunderstorms at the terminal
- Requirements defined by TRWG
- Lead time to onset and cessation of events

**Challenge:** Defining event-based verification techniques

- Thunderstorm events within 75 nmi radius around terminal
- ¾ coverage defines event
- Construct time series and merge into events with duration
- Matches occur within a certain time window
- Metrics for Onset and Cessation

### VRMC
**Verification Requirements and Monitoring Capability**
Supports assessment and monitoring of FAA AWXP products

**Challenge:** Flexibility for in-depth analysis

**Technical Challenges**
- Efficient storage and processing of raw data
- Timely computation
- Responsive user interface

**Future Work**
- CBVT: Extension to Ceiling & Visibility
- EVENT: Extension to other weather variables (winds, icing)
- VRMC: Capabilities for convection
Core Research: Datasets Investigation and Technique Development

Laura Paulik, Soner Yorgun, and Forecast Impact and Quality Assessment Section

Verifying Offshore Precipitation with Satellite Data and Surface Reports

Filling the Data Gaps

Global Precipitation Mission (GPM) satellite data and surface reports (METARs) were investigated prior to the Offshore Precipitation Capability (OPC) Assessment. A product that provides radar-like variables over the Caribbean and western Atlantic.

Examining Aircraft and Satellite Data for Icing Verification

PIREP Location Errors

Eddy Dissipation Rate (EDR)

- Aircraft-independent measure of atmospheric turbulence.
- EDR measurements from Delta and United Airlines are compared to PIREPs.
- Jan 2013 – Jun 2015 period is analyzed.

Matching PIREPs to EDRs

- PIREPs are matched to their corresponding set of EDRs from the same aircraft.
- Different time windows (around a PIREP) are used to match the maximum peak EDR value to the PIREP.

Summary of Results

- PIREP location errors show sensitivity to the choice of time window for matching.
- Location error statistics for ±7.5 minutes window agree with previous studies.
- There is a strong relationship between the PIREP report lag and the location errors.
- Further work is required to incorporate this new information into verification techniques.
Assessment of Aviation Algorithms and Forecast Technologies
Matthew Wandishin, Forecast Impact and Quality Assessment Section

Introduction
Assessments are often just one step of a verification process in which core research informs assessments which then undergird ongoing monitoring efforts.

Core Research
Investigation of new data, new methods, new scores

Assessments
Findings are presented along with a formal document of the results. This is used by FAA management for R2O decisions.

Monitoring
If the product moves into operations, the assessment infrastructure is leveraged to provide ongoing analysis via the Verification Requirements and Monitoring Capability (VRMC).

Examples:

Graphical Turbulence Guidance
- The distribution of forecast values in GTG3 displayed a marked shift compared to the GTG2.5
- Product just recently moved to operations with a new approach to displaying the forecast information

EVENT Thunderstorm and Winds
- Thunderstorm: The remarkable gap between product skill and MOC requirements questions the practicality of those requirements
- Winds: Led to a consideration of the need for post-processing even for variables explicitly forecast by the models

Current (Forecast) Icing Product
- Highlighted the differences between the prototype version developed at NCAR and the implemented version at AWC
- Also identified “holes” in the CIP field that led to lower performance of the CIP than for the 1-h FIP forecast

Radar Mosaic Comparison
- The two radar mosaics present sharply dissimilar views of the intensity and coverage of the convection
- Led to the producer of the new product to create a new, aviation-targeted version of the VIL and ET fields

Auto-CCFP
- The auto-generated product has similar skill to the human-generated product, though with different forecast characteristics
- This helped alleviate concerns over the move away from the human-generated product

TRACON Gate Forecasts
- Found substantially different results at CLT compared to ATL, where the forecast rules were developed
- This highlighted the fact that implementation of the forecast for other airports will likely not follow a simple plug-and-play model
Session 6: Advanced Technologies

- Opening Talk: Advanced Technology (John Schneider)
- The NOAA Earth Information System (NEIS) Data Discovery, Collection, and Distribution (Jebb Stewart)
- Advanced Visualization Development using Gaming Technology (Eric Hackathorn)
- Massively Parallel Fine Grain (MPFG) Computing (Mark Govett)
- Specialized Information and Warning Systems (Greg Pratt)
- Science on a Sphere (SOS): Technical Innovation and Network Growth (Keith Searight and Shilpi Gupta)
A. Presentations and Posters

Relevance – *Inspiring GSD to Explore*

Opportunities for Advancement
- Deep Water Horizon
- Hurricane Sandy
- Leveling - Moore’s Law
- IT advances
- 4K Imagery

Technical Curiosity

Expectations of Quality

Worldwide Sponsorships

Relevance – *Inspiring GSD to Explore*

Opportunities for Advancement
- Deep Water Horizon
- Hurricane Sandy
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- IT advances
- 4K Imagery

Technical Curiosity

Expectations of Quality

Worldwide Sponsorships

Reality

*Our Focus – the Hard Technology Problems*
- Enough compute at low enough cost
- Right info, right place, right time
- Blending disparate information
- Building science understanding

3 of 5 GSD’s Grand Challenges

**3 of 5 GSD’s Grand Challenges**

**Foundational Effort**

- Fully Coupled Earth System Modeling & Prediction
- Advanced Computer Engineering
- Massively Parallel Fine Grain (MIPPS)

**Central Solutions**

- NEIS Viz
- SOS Explorer
- GTAS
- TerraViz
- VACT

2 of 5 GSD Grand Challenges

- Science on a Sphere
- MADIS+
The 5 year Trajectory

2010

Google Earth

CPU

Segregated, Specialized, Limited

Specialized and Regional

2015

NOAA TerraViz

MPFG

Anytime, anywhere, any platform

Global - NEIS

SOS Explorer - desktop based

SOS - venue based

GSD is First in NOAA

Data Management & IT Systems Firsts:
- 4D data cube with single authoritative source
- Consolidation of thousands of global obs into operational usage
- NOAA use of Amazon cloud computing

Computing Firsts:
- Only weather model running on CPU, GPU and MIC (2013)
- Weather model run on GPUs (2009)
- Weather model to run on Linux clusters in (2003)
- Weather model to run on massively parallel processors (1999)

GSD is First in NOAA

Specialized Warning Tool Firsts:
- Rapid internet delivery of global forecast models
- Impact based weather mapping/forecaster tools
- Plume dispersion and satellite differencing
- Bi-directional data sharing
- Moving weather elements with rapid updates

Global Visualization and Outreach Firsts:
- Automated alignment for spherical displays
- Patented global visualization methods
- NOAA use of a twitter account
- First WAO App in COAR

Extraordinary people with extraordinary skill

Session 6: Advanced Technology Investigations

John P. Schneider
NOAA/ESRL/GSD

The NOAA Earth Information System (NEIS)
data discovery, collection, and distribution
– Jeff Stewart

Real Performance

Advanced Visualization Development
using Gaming Technology
– Eric Hackathorn
Real Performance

Massively Parallel Fine Grain (MPFG) Computing
- Mark Govett

Specialized Information and Warning Systems
- Greg Pratt

Science On a Sphere New Technology Innovations
Network Growth and Outreach
- Keith Searight & Shilpi Gupta

The NOAA Earth Information System (NEIS)

Jebb Q Stewart
CIRA
Performing work for ESRL/SSU

Discovery and Interoperability

- Improve access, interaction, and integration of NOAA data

Data Ingest and Distribution

- Event Driven, Asynchronous, Stream based data processing
- Server Side GPU processing
Summary

Next

- Continue evaluation of new emerging technologies
- Larger and Larger data
- Modular Distributed services

Advanced Visualization using Gaming Technology

Eric Hackathorn
NOAA/ESRL/GSD

Gaming Technology

- What is your research
  - Using game engines to drive the next generation of interactive data visualization and analysis
- Why is it important
  - Gaming drives new technology as a research organization we need to keep up with industry trends
  - Leveraging a multi-billion dollar industry in something with more value than pure entertainment
Fine-Grain Computing

Mark Govett
NOAA/ESRL/OSD
GSD Science Review 3-5 Nov 2015

Evolution of HPC
- Increasing number of cores
- Increasing cost: system, facilities, power

CPU
Intel Haswell
24 cores / chip
270 Watts, 53.5K

Key Chip Technologies in 2015

Fine-Grain: GPU & MIC
NVIDIA/Kepler GPU
4992 cores / chip
300 Watts, 5.5K

NOAA Research Systems

Theta CPU: 25K cores, $17M

Fine-Grain Computing Research
- Goal: run 3 km global at NWS by 2020
  - 5 billion grid cells (50M horizontal, 100 vertical)
  - 1000 GPUs = 5 million compute cores
  - Models must exploit parallelism
- NIM used to demonstrate and drive requirements
  - Good design
    - Portability, Performance
    - CPU, GPU, MIC
  - Compilers, directives
    - P2C-ACC drives industry

Research and Operations
- Leadership on HPC for NOAA
  - Explore new technologies
  - Collaborations with industry
- Apply NIM lessons to FV-3, MPAS

Specialized Information and Warning Systems

Greg Pratt
NOAA/ESRL/OSD
GSD Science Review 3-5 Nov 2015

Overview of Projects
- Traffic Management Unit (TMU) 2000 – 2013
- Volcanic Ash Coordination Tool (VACT) 2009 – 2011
- Geo-Targeted Alert System (GTAS)

The systems provided the users the ability to:
- Communicate
- Collaborate
- and Exchange Information
to improve the understanding of the impact of the event and deliver details of the event in a more useful form to the decision maker. (Forecaster, Traffic Manager, Emergency Manager, First Responder, …)
Science On a Sphere® (SOS)
Technical Innovation and Network Growth

Keith Searight, GFS
Performing work for ESRL/GSD

Shilpi Gupta, CRES
Performing work for ESRL/GSD

Each of the projects dealt with the delivery of the right information, in the right form to the user of the system. Users were both NWS forecasters and operational decision makers.

NOAA's most influential outreach tool for public science education

- 2.6K Web Visits/Day
- 68° Sphere, 4 Projectors, 1 Linux Server, 1 iPad
- 128 Sites Installed
- 0.5 TB Data Distributed/Day
- NOAA's #1 Award
- $1.20 Stamp
- 30K Facebook Likes
- 100 Most Influential

Unique Patented Technology

Hardware:

Software:

Content:
**SOS Growth And Reach**
- 128 Science On a Sphere® (SOS) installations worldwide:
  - Museums
  - Visitor Centers
  - Aquariums
  - Labs
  - Schools/Univ.
  - Zoos
  - 71 Domestic in 29 States
  - 57 International in 22 Countries
- 33 million viewers per year
- Technology transferred by 12 distributors worldwide
- SOS Data Catalog contains 500+ freely available datasets:

**The SOS Network**
- **SOS Network**: institutions with SOS and partners creating and sharing content and educational programming for SOS
  - Build capacity of presenters
  - Provide guidelines for good SOS content
  - Evaluate the effectiveness of SOS
- **SOS Education Webinars** held quarterly
- **SOS Users Collaborative Network Workshops**

**The Value of SOS**
- Support NOAA’s goal to enhance environmental literacy
  - Engage audiences of all ages
  - Build public understanding of diverse topics
  - Foster appreciation for the interconnectedness of the planet
- Excellent collaboration and outreach opportunities
- Discovering innovative ways to use SOS
- **Network surveys**: 82% of visitors stated that seeing information on the sphere is more realistic and changed how they understood the information.
  - 87% of visitors who had a facilitated sphere experience reported learning something new.
Session 7: Advanced Technologies

- Opening Talk: Outreach and Research to Operations (John Schneider)
- MADIS Innovations and the Path to Operations (Gopa Padmanabhan and Leon Benjamin)
- NOAA’s International Collaboration with Taiwan (Fanthune Moeng)
- Global Visualization using NOAA’s TerraViz (Beth Russell and Jeff Smith)
Relevance: Customers, Partners & Users

- IBM
- CRAY
- NVIDIA
- INTEL
- Unity
- Adobe
- Airline
- America
- Netherlands
- Environment
- USDA
- ORNL
- NASA
- GSFC
- USGS
- NOAA

Quality: Recognition and Leadership

Leadership Positions
- Co-Organizer NOGSS Multi-Core workshops 2011-2013
- NOAA Representative - Federal Games Guild

Journal Editorships
- OpenACC

Awards
- NOAA Administers Award – 2015 – MADIS
- NOAA Bronze Medal – 2015 – SOS
- NOAA Research Employment of the Year – David Hines – 2013
- AMS Editors Award – 2015 – Mark Guert
- Multiple awards – CRES and CIRA

Invited presentations
- Advanced Computing
- Educational
- Global visualization
- Data management concepts

Real Performance

Meteorological Assimilation Data Ingest System (MADIS) Innovations and Path to Operations
- Gopa Padmanabhan – Leon Benjamin

NOAA’s International Collaboration with Taiwan
- Fanthune Moeng

Global Visualization with NOAA’s Terraviz
- Beth Russell
- Jeff Smith

MADIS Innovations and Path to Operations
Gopa Padmanabhan and Leon Benjamin

Provides a finer resolution higher quality NOAA observational database and distribution system through partnerships with non-NOAA providers.
**A. Presentations and Posters**

**MADIS 2010-2015**

- Collect/Integrate
  - Continue to handle disparate data sets.
  - Improve Observational Knowledge.
  - Adopt data standards where possible.
  - Continue to fill holes.

**MADIS 2010-2015**

- Quality Control/Distribution
  - MADIS data handling time cut from 15 minutes down to 5 minutes.
  - Worked with NWS and the FAA on data delivery and discovery standards.
  - Google maps and ESRI displays.

**MADIS Innovations Summary**

- Surface
- Aircraft
- Radiosonde
- Profiler
- GOES Satellite
- POES Satellite
- Radiometer

- In order for MADIS to stay relevant, MADIS most continually be making improvements to:
  - Gap filling data from the ground up
  - Quality
  - Data throughput
  - Distribution services.

**Path to MADIS Operations**

- Pre 2005
  - General I&O on ingest, integration, quality control, and data delivery techniques.

- 2005 – 2008
  - Develop transition strategy: I&O between NWS and OAR signed.

- Sept 2008
  - MADIS accomplish initial operating capability (IOC) at NWS.

- May 2012
  - Revised transition strategy from lessons learned with IOC systems. New I&O between NWS, NESS, and OAR.

- Sept 2013
  - Funding and operational location for MADIS transition identified and agreed to.

- Oct 2013
  - MADIS Implementation Project charter signed.

- Dec 2014
  - MADIS enters final development and testing at NCEP and NESDIS.

- Jan 2015
  - Operational MADIS achieved.

**Getting There W asn’t Easy!**

- Must be sustainable.
- Must have a common vision.
- The last mile is hardest, but most rewarding.

**Path to Operations Summary**

- It was a hard process to go through.
- MADIS now bridges the gap between research and operations.
NOAA’s International Collaboration with Taiwan

Fanthune Moeng
NOAA/ESRL/GSD

What is CWB Project
- GSD leads and CWB funded collaborative project (1995-now)
- 5 NOAA agencies (GSD, NSDL, NESDIS, AVIRIS, NCOE)
- Visitor exchange program

Why is it relevant to NOAA
- Shared knowledge of GSD’s AVIPS information system
- Provided NSDL unique precipitation data for Precipitation Estimation (PFE)

CWB Forecast Office Modernization

Summary
- NOAA’s unique and successful international collaboration (Dr. Sandy MacDonald since 1990)
- Future plan (3 GSD Core Competences)
  - Observation systems (Himawari-8)
  - Modeling and data assimilation
  - Information System (AVIPS II transition)

Global Visualizations with NOAA’s TerraViz

Jeff Smith
CDA
Performing work for ESRL/GSD

Beth Russell
CRES
Performing work for ESRL/GSD

Visualization for Everyone

TerraViz is a NOAA-developed environmental data visualization tool built on top of a 3D game engine
• Has been formatted for different users to view global data
• Pulls data from many sources and visualizes the world in motion

NOAA Earth Information System

SOS Explorer
**TerraViz**

- NOAA Earth Information System
- Forecasters
- Researchers

**SOS Explorer**

- Teachers
- Public
- Students
- Museums

**SOSx Preview**

*Welcome to SOS Explorer™!*

Pressing the "X" will close this overview.

**NEIS Preview**

**Why Visualization?**

- Enables scientists to visualize both forecasts and observations in novel ways
- Provides new insights into the phenomena and guides research into productive directions
- Brings the SOS experience into the classroom and home
- Allows teachers and informal educators to incorporate easily accessible data visualizations into their lessons
- A majority of people are visual learners

**Next Steps**

**SOS Explorer:**
- Touchscreen version
- More SOS datasets
- Custom content

**NEIS:**
- Global Hawk flights
- Very high resolution satellite and weather model data
**Advanced Technology:**

*The Way Forward*

John P. Schneider  
NOAA/ESRL/GSD

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**2020 Vision - Visualization**

- **NOAA Terraviz**
- SOS Explorer - desktop based
- Global - NES
- SOS - venue based

- Terraviz: Tablet, phones, immersive - 3 and 4D - beyond mouse interactivity
- SOS Explorer: 100s of classrooms - 100s of public venues - real-time and high-res data - easy user content builder
- NES: Big data from many clouds - in use across NOAA - in use by fed and private sector

---

**2020 Vision - HPC and IT Systems**

- CPU & MPFG

- Global to local data from the ground up NOAA tech is central in NOAA Operations
- Data delivery - seconds vs minutes
- Operational data today – the light switch serves selected data defined by and tuned to user needs

- NES Data Services:
  - Cross cloud directed access and find
  - On the fly data processing and analysis
The NOAA Earth Information System (NEIS)

Jebb Q. Stewart², Jeff Smith², Jonathan Joyce³, MarySue Schultz², Eric Hackathorn¹, Randy Pierce², Chris MacDermaid², Chris Golden³

Interoperability
What does it mean?
The ability to discover, access, view, interact, and integrate data regardless of format or physical location.

Components of an Interoperability System
- Format Agnostic
- Owner/Physical Location Agnostic
- Platform Agnostic
- Preview Capabilities
- Semantics/Ontology/Vocabulary
- Machine to Machine Communication

Benefits of Interoperability
- Improve accessibility
- Foster data exploration and use
- Decrease complexity
- Provide framework for new tools and applications
- Possibilities are endless

Support of Research: Physical, chemical, and biological data are all interrelated. The NEIS framework provides capabilities to quickly integrate and interact with data from all diverse sources through all time.

Interoperability through Standards
- Community developed allowing common language for interacting with services and exchanging information.
- Services allow user to get only the data they need (subset, format, time, station, etc.)
- Standards, like Open Geospatial Consortium (OGC), are widely adopted by vast user communities. Many applications already use these standards.
- Modular - Upgrade components without taking down entire framework.

High Performance Data Dissemination
New Data Require New Tools

- New real-time observation platforms
- Unmanned Aerial Systems (UAS), Micro Satellites

Our diverse and complex world requires new capabilities to understand complex relationships.

Understanding needs
- Terabytes to Petabytes of new data daily.
- Already have Petabytes of existing data.
- Tools needed to evaluate and compare data from different sources and different formats – remotely!
- Near real-time data access

What NEIS Provides
- High Performance Data Visualization through TerraViz
- High performance stream based data processing system.
- Ability to integrate data from a variety of sources
- Remote processing capability

Impacts
Framework is built towards standards, not data.
- NOAA data ready for action. Services model facilitates agile response to events. Services can be combined or reused quickly, upgraded or modified independently.
- Any data available through framework can be operated on or combined with other data. Integrated standardized formats and access.
- New and existing systems have access to wide variety of NOAA data. Any new data added is easy incorporated with minimal to no changes required.

Benefits: A common picture in space and time for ecological, physical, and oceanic information, from the bottom of the ocean through the top of the atmosphere.

Ongoing Research
- Continue evaluation and development of new emerging technologies
- Modular Distributed services
- Larger and Larger data
- Better remote processing

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Advanced Visualization using Gaming Technology
Eric Hackathorn¹, Jonathan Joyce², Jeff Smith³

Why Gaming Technology?
Cutting Edge Performance with Off-the-Shelf Pricing
While a game engine may seem a strange choice, it takes advantage of existing off-the-shelf technologies. Additionally, it can run on many platforms: desktops, browsers, consoles, and mobile devices. Video games are a multi-billion dollar industry, and represent an ideal choice for providing a wealth of data to a user in real-time. The industry harnesses the power of graphical processing units (GPUs) available in commodity PCs to render and display information in efficient ways.

Virtual Reality
Physical Presence in an Imaginary World
The Oculus Rift will be released in the first quarter of 2016, making it one of the first consumer-targeted virtual reality headsets. It has a resolution of 1080x1200 per eye, a 90 Hz refresh rate, and a 110 degree field of view. The final version have integrated headphones providing spatialised audio. The positional tracking is performed by a separate IR sensor, that is included with each Rift and normally sits on the user’s desk. This system allows for using the Rift while sitting, standing, or walking around the same room.

Collaboration
Augmented Reality for Visualization and Analysis
8] The first speaker is recorded by a web camera. Behind her is the second speaker as seen through viewpoint “A.” 9] A virtual world created from data that is added as a layer in front of the speakers. 10] The second speaker is recorded by a web camera. Behind him is the first speaker as seen through viewpoint “B.”

Our Mission
Our project leverages game mechanics and technology for a variety of projects and has unique expertise straddling science, education, and entertainment.

The goal is to ingest "big data" and prepare it for real-time analysis. Designed for a world where everything is in motion, game technologies allow fluid data integration and interaction across four dimensions and provide a tool for exploring vast collections of information. This demonstration is running on a standard desktop computer with an NVIDIA GPU.

Volumetric Visualization
Visualizing Information in its True Form
The ability to look at weather and other Earth data in three dimensions gives researchers new insight into the nature of storm development, and that information can result in better forecasts. Historically it has been difficult to allow interactivity due to the amount of information being processed and the time it takes to render, but gaming technology can help.
Background & Motivation
- GSD has been exploring new and emerging HPC technologies for NOAA since the early 1990s.
- With CPU clock speeds stalling manufacturers are increasing the number of CPUs or "cores" on a chip. CPU now have 24 or more cores / chip.
- In 2015, it is common for HPC systems to have more than 10,000 cores, with some systems containing over 100,000 cores. These systems often require specialized facilities to house them, with power bills exceeding $1M / year.
- There are two types of fine-grain computer chips: Graphics Processing Units (GPUs) from NVIDIA and AMD, and the Many Integrated Core (MIC) from Intel. These accelerator chips are currently attached to the CPU via the PCIe bus.
- By the end of the decade, CPU based systems could have more than 300,000 compute cores. Fine-grain systems will be sold containing millions of compute cores.

Fine-Grain Computing Chips
- Up to two accelerators can be directly attached to a CPU, with systems such as Cray Storm, that support 8 or more per compute node.

Vendor Collaborations
- Collaborations with technical teams at Intel, Cray, PGI, IBM, and NVIDIA on the NIM model have led to significant hardware and software improvements.
- F2C-ACC is a GPU compiler developed at GSD in 2009 before commercial GPU compilers were available. It has been used to run the NIM, and evaluate performance of the commercial Fortran GPU compilers since 2011. In 2014, we showed the Cray and PGI compilers ran NIM 1.7 and 2.1 times slower than the F2C-ACC.
- GSD worked with PGI to improve their compiler, such that it’s performance is now within 5% of F2C-ACC.

NIM Performance: CPU, GPU & MIC
Comparison between chips is essential. There are three general ways to compare performance.

- Device Performance is the best way to compare chip technologies. We show performance of the NIM model through generations of CPUs, three generations of GPU, and one generation of the MIC.

- Node Performance considers both the host and attached GPU or MIC chips. Comparisons are also made when both the CPU and host are used (symmetric mode). We also make comparisons with nodes containing up to 8 GPUs.

Vendors are telling us the NIM:
- "has the best thread scaling on the MIC of any weather or climate application" (IBM)
- "is the only weather or climate model where we can make comparisons between CPU, GPU and MIC architectures" (PGI)
- "is the best weather model we’ve seen on the GPU" (HPE)
Specialized Information and Warning Systems
Greg Pratt¹, Jim Frimel², Herb Grote³, Chris Golden³, Leigh Cheatwood², Jim Ramer², and Xiangbao Jing³

Project Objectives
Traffic Management Unit (TMU)
• Improve and standardize the weather briefings given to FAA traffic managers.

Volcanic Ash Coordination Tool (VACT)
• Ensure warnings for ash are timely, accurate, and are fully consistent across domains of responsibility.

Geo-Targeted Alert System (GTAS)
• Ensure warnings for chemical spills and toxic plumes are timely, accurate, and share this information with state and local emergency managers.

Initial State of Forecaster Systems and Delivery Process:
• Weather products may need interpretation.
• Weather products may be conflicting across areas of responsibility.
• NWS Center Weather Service Units (CWSU) not providing standardized weather briefings to FAA traffic managers.
• FAA traffic managers not supported 24/7.
• Inability to share products with other agencies and collaborators.
• Tools and products used to detect and forecast ash and chemical dispersion not available on NWS operational systems.

Accomplishments
Interpreted Data
Integrated Data
Information Sharing
Briefings
Tailored Delivery

Concepts to Further Explore
Real-Time Information Sharing
GotoMeeting on Steroids
Tailored Delivery
Single Authoritative Source

Operational Achievements
• Aviation product ingest and display software implemented in AWIPS.
• The ability for the Hybrid Single Particle Lagrangian Integrated Dispersion (HySPLIT) model to handle chemicals.
• Interface requirements for NWS operations and collaborators to run HySPLIT.
• AWIPS collaboration capability.
• AWIPS drawing tool capability.

Testimonials
‘OPF friendly Tom strategizes supports the TMU/AVDA convective weather forecast tool used at ZFR. The CWSU/WFO team both have access to the weather displays externally. TMU/AVDA was a significant factor in making good tactical and strategic decisions during the significant thunderstorms that the airspace experienced during the Winter to Summer period of 2007. Of the nearly 90 days that the airspace experienced significant thunderstorm activity, TMU/AVDA was able to provide clear two-hour thunderstorm predictions nearly 80 percent of the time, greatly increasing our effectiveness as an operational team.’

Tom Amos, ERC, Ft Worth CWSU

‘VACT enables more timely and accurate forecasts from a coordinated multi-agency response, allowing operational scientists in USGS and NWS to collaborate in real-time with shared situational awareness. VACT was operationally tested during the 2006 eruptions of Augustine Volcano that caused ash to fall in several communities, many airline flights to be canceled, and military aircraft to be redeployed. All Volcano Observatory (USGS) scientists repeatedly expressed gratitude for VACT because it facilitated coordination.’

Laura Purgione, Director, NWS Alaska Region
### Science On a Sphere® – Technical Innovation

*Keith Searight*¹, Shilpi Gupta², Vincent Keller², Ian McGinnis², Beth Russell², Steve Albers¹, Stephen Kasica², Vivian LeFebvre³, and Tony Liao⁴

#### Hardware
- **The Sphere**
  - Carbon fiber composition
  - Custom manufactured for SOS in 68" and other sizes

- **Computer Systems**
  - Dell servers with Linux (5→1)
  - Nvidia graphics cards (4→1)

- **Projectors**
  - SD → HD → 4K
  - Networked with server

- **Graphics Resolution**
  - SD → HD → 4K
  - Limited by hardware specs

- **Controllers**
  - Wi gaming remote
  - Apple iPad and iPhone

- **Alignment**
  - Manually set by controllers
  - Automated using cameras

#### Software
- **Visualization**
  - On-the-fly Rendering
  - Global “splitter”

- **Delivering Presentations**
  - Feature-rich iPad App
  - Wi-Fi and Bluetooth support

- **Interactive Display Tools**
  - Annotations and Icons
  - Animated pictures-in-pictures (PIPs)
  - Adjustable zooming

- **Creating Presentations**
  - Playlist Builder on iPad
  - Playlist Editor on Desktop

- **Public Kiosk**
  - Touch screen interface
  - Trackball-style sphere control

- **SphereCasting**
  - Remote SOS control
  - Live video streaming

#### Content
- **Real-time Data**
  - Satellites & NOAA models
  - 0.5 TB distributed daily

- **High Resolution Data**
  - 6K+ images and movies
  - Crisp text and lines

- **Data Catalog**
  - Metadata management
  - Powerful browse & search

- **SOS Website**
  - Extensive SOS information
  - Interactive sphere
  - Responsive design

- **Language Localization**
  - Multi-language interfaces
  - Leverage dataset translations

- **Data Standards**
  - Google Earth KML
  - Web Mapping Service

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Science On a Sphere® (SOS) Network Growth and Reach
Shilpi Gupta¹, John Schneider², Beth Russell¹, Hilary Peddicord¹, Fanhune Moeng² (¹Cires, ²Noaa)

### SOS Reach and Growth

128 Installations worldwide
- Museums, Science Centers, Visitor Centers, Aquariums, Labs, Schools, Universities, Zoos

**Installation distribution**
- 71 Domestic in 29 States, 57 International in 22 Countries

33 Million visitors per year
- K-12, Families, University Students, Scientists, General Public, Policy Makers, Special Interest Groups, etc.

Technology transferred by 12 distributors worldwide
- BWC Visual Technology, Climate Institute, Global Imagination, Huafeng Group, Korean Broadcast, System, Sigong Tech, Our Planet, Globocess, etc.

SOS Data Catalog of 500+ freely available datasets

### The SOS Network

**SOS Network**
Institutions with SOS and partners creating content and educational programming for SOS

- Brings together people with different skills: technical, education, science, exhibits, film production, etc.
- Build capacity of presenters to interpret complex data visualizations and discuss Earth system science with public audiences
- Provide guidelines for creating easily understood, scientifically accurate content for spherical display systems
- Evaluate the effectiveness of SOS as a learning tool

**SOS Users Collaborative Network Workshop**
- Held every 18 months at an SOS site

**SOS Education Forum**
- Educators, docents, and content creators who meet quarterly via online webinar to discuss how to use SOS to effectively educate K-12 and beyond.

### The Value of SOS

Support NOAA's goal to enhance environmental literacy and display Earth science data in a way that:

- Engages audiences of all ages
- Builds public understanding of scientific, technological, and environmental topics
- Fosters appreciation for the interconnectedness of the planet and its changing landscape

**Collaboration opportunities amongst:**
- Scientists, Visualization Developers, Education/Outreach Specialists, Artists, Programmers, Film Producers, etc.

**Outreach**
- SOS engages in many outreach activities with diverse audiences

**Network Surveys and Feedback**
- Many evaluations have been conducted at SOS sites to evaluate its efficacy

**Going beyond...**
- SOS is used in many innovative ways to engage the public
MADIS

NOAA Mission
"To understand and predict changes in climate, weather, oceans, and coasts; To share that information with others" increasingly demands advanced data management processes, including data integration, to achieve interoperable, accessible, and readily usable observational data.

MADIS Goal
A more usable, complete, accurate, timely, and higher density observational infrastructure for use in local weather warnings and products, numerical weather prediction, and use by the greater meteorological community.

MADIS Provides
- Access to real-time and archived data sets
- Uniform data formats, observation units, and time stamps
- Observational Quality Control (QC)
- Network-enabled distribution with server-site sub-setting
- Authorization and authentication for proprietary data
- User documentation and help desk support

MADIS Data Scope
- 66,127 stations from over 160 surface networks producing nearly 13 million observations per day
- 113 Profiler sites (>200,000 observations per day)
- >700,000 aircraft observations per day
- Plus global radiosonde and satellite observations

Future Plans
1. Gap filling data from the ground up.
   - National Mesonet program.
   - NWS Office of Observations.
   - 1 Minute ASOS data.
   - Non-Federal AWOS data.

2. Light Switch
   - Data and Metadata standards.
   - Standardized MADIS ingest interface.

3. Improved Quality Control
   - Extended metadata
   - Quality Control Sandbox
   - Faster throughput of data.

4. Distribution Services
   - Graphics – One display all data and metadata
   - Data queries – One dump utility for all data and metadata
   - Open Geospatial Consortium compliant
     - Formats - WXXM
     - Delivery – Web Feature Service
     - Data Discovery
Meteorological Assimilation Data Ingest System (MADIS) Path to Operations

Leon Benjamin, Greg Pratt, Tom Kent, Gopa Padmanabhan, Leigh Cheatwood-Harris, Michael Leon, Michael Vrecur, and Randy Collander

MADIS Time Line
2001 – Birth of MADIS.
2005 – NWS sees value.
2010 - MADIS Initial Operating Capability.
2012 – NWS, OAR, and NESDIS sign new LOA.
2012 – Centralized System at WOC.
2013 – Centralized System at NCO.
2013 – Centralized System at NCO/IPID.
2015 – Operational MADIS Realized at NCO/IPID.

NCO/IPID MADIS

Data Capabilities

Systems and Data in Transition

Clarus
1 Minute FAA ASOS

AMDAR.NOAA.GOV

SNOTEL

VOS

EDIS

NOAA RESEARCH • EARTH SYSTEM RESEARCH LABORATORY • GLOBAL SYSTEMS DIVISION
NOAA’s International Collaboration with Taiwan
Fanthune Moeng¹, John Schneider¹, Joe Wakefield¹, Kenneth Howard², Jian Zhang³, Fuzhong Weng³, Ninghai Sun³, Stephen Smith⁵, Lingyan Xin⁵, Shi-Keng Yang⁵
1. ESRL/GSD, 2. NSSL, 3. NESDIS, 4. NWS/MDL, 5. NWS/NCEP/CPC

**Background**
- Dr. Sandy MacDonald established the collaboration project with Taiwan Central Weather Bureau (CWB) in 1990
- Annual reimbursable budget ~ $1.2 M to $1.8 M (2010-2015)
- Five NOAA agencies involved currently

**Taiwan complex terrain and heavy precipitation (and over 700 rain gauges)**

**CWB AWIPS (GSD)**
- CWB AWIPS (a.k.a. WINES: Weather Integration and Nowcasting System) is the essential component for their forecast operation

**TPW data (NESDIS)**
- Real-time blended and anomaly TPW (Total Precipitable Water) products to analysis heavy rain

**FFMP (MDL)**
- FFMP (Flash Flood Monitoring and Prediction) localization, processing and display all data sources

**QPE (NSSSL)**
- QPE (Quantitative Precipitation Estimation) from 7 radars, over 700 rain gauges and lightning system

**Taiwan-West Pacific Climate Forecast System (TWPCFC) Workshop (CPC)**
- Annual TWPCFC Workshop since 2013 to plan for CWB Global Forecast System
- Training at NCEP’s Monsoon Training Desk program

**Research papers (GSD, NSSL, NESDIS since 2013)**

**Future Plan**
- New Japanese Himawari-8 Satellite
- New radars (4 new precipitation radars, and one wind profiler)
- Local-to-global models
- AWIPS II transition
SOS Explorer for Education and the Public
Beth Russell\textsuperscript{1}, Eric Hackathorn\textsuperscript{1}, Jonathan Joyce\textsuperscript{1}, Hilary Peddicord\textsuperscript{1}, Jeff Smith\textsuperscript{2}
\textsuperscript{1}NOAA, \textsuperscript{2}Cooperative Institute for Research in the Atmosphere, \textsuperscript{3}Cooperative Institute for Research in Environmental Science

**What is SOS Explorer?**
A flat screen version of Science On a Sphere®
- Provides teachers, students, and public their own personal Science On a Sphere (SOS)
- Uses the NOAA-developed TerraViz\textsuperscript{TM} visualization engine to create an Interactive Earth for a flat screen display

**Motivation for creating SOS Explorer**
- High demand for the SOS experience in the classroom and home where SOS is not feasible
- Need from teachers and informal educators to incorporate data visualizations into their lessons

**Connection to TerraViz and NEIS**
- TerraViz is a visualization engine developed by NOAA that uses gaming technology to generate high resolution displays
- SOSx is a simplified version of NEIS for teachers and the public

**Why use SOS Explorer?**
Visualization for the classroom and home
- Data visualization allows analysis and understanding of complex data relationships
- Data visualization helps bridge understanding of observations versus computer modeling
- Data visualization lets you see things that would otherwise go unnoticed - trends, behavior patterns.

**Tours**
Tours are scripted presentations with pop-up windows that walk a user through the datasets using a storyline and a learning goal.

**School Materials**
- Student worksheets and additional learning activities for each tour
- Direct hands-on learning activities provided for selected datasets as an example of what is possible
- Inquiry and scientific literacy lessons for selected datasets to give teachers an idea of how to encourage students to interact with the datasets

**Where is SOS Explorer going?**
One application, many venues
In its current release, SOSx is designed for classrooms and homes, but future versions will allow for use in a broad range of settings
- Version 1.0* (pre-packaged, 14 datasets and freely available)
- Interactive Exhibit (pre-packaged with specialized content)
- Tailored (access to all features and SOS datasets)
- Premium

**Interactive Exhibit**
A touchscreen compatible version of SOSx on a kiosk in a public setting that will control a larger view projected on a wall or monitor. Museums will be able to choose which datasets and topics to use in their exhibit space.

**Tailored**
A prepackaged collection of datasets where a sponsoring group chooses which datasets and tours to include to tell their own story and support their own learning goals.

**Premium**
A version of SOSx that includes access to all the SOSx features and all the SOS datasets that are compatible with SOSx.
NEIS Visualization for Professional Users

Jeff S Smith, Eric Hackathorn, Jonathan Joyce, Jebb Stewart, Chris Golden

Flight Tracks / Dropsondes
Visualizes the flight paths of UAVs such as Global Hawk aircraft, including charting the data captured from the 50-80 dropsondes typically dropped during a 24 hour mission.

Supports Latest Hi-Res Global Models
Global 3 Km Models produce an enormous amount of data. For example, 72 time steps of the Hurricane Sandy animation depicted below consumes 8 GB on disk. TerraViz can not only display these 1440x720 pixel images, it can animate them at 10 frames per second.

Environmental Visualizations
TerraViz can mash up multiple datasets at once, visualize clouds, wind as barbs, vectors, or trails of particles that flow over the globe, as well as KML (Google Earth) data.

Users can also animate data over time and graph transects.

Built With Gaming Technology
Games are basically data visualizations where the data might be soldiers on a "Call Of Duty" virtual battlefield. Billions of dollars have been invested by the gaming industry to optimize the rapid display of millions of polygons on modern graphics cards with graphical processing units (GPUs).

TerraViz leverages the advances in this industry to visualize environmental data such as storms moving across the ocean or the annual ebb and flow of sea ice in the Arctic. NOAA has filed a patent for TerraViz.

The development process is a combination of designing within the Unity 3D editor (similar to working in a CAD environment) and writing C# code (a language very similar to Java).

Compare Models To Observations
TerraViz can visualize up to 4 globes of data, enabling the comparison global models (each on its own globe) to the actual observations (e.g. satellite IR).

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B. GSD Staffing, Budget, and Annual Operating Plan

10-Year Workforce Profile

Workforce Distribution

2005

- Contractors 28%
- Federal 40%
- CIRA & CIRES 32%

2015

- Contractors 17%
- Federal 26%
- CIRA & CIRES 57%
Workforce Demographics

**Function**
- Management/Admin: 70%
- IT Support: 16%
- Scientists: 14%

**Education Level**
- PhD: 30%
- Masters: 26%
- Bachelors: 32%
- Other: 12%

Total GSD Staff and Affiliates: 174
Currently representing OAR, CIRES, CIRA, NWS

FY15 Age of Federal Workforce

- 5 in <30 age group
- 3 in 31-40 age group
- 2 in 41-50 age group
- 20 in 51-60 age group
- 5 in >60 age group
Workforce Diversity

Federal Retirement Eligibility

2015
Average age of Federal Employees = 59.98
Eligible to retire = 43%

2019
Average age of Federal Employees = 65
Eligible to retire = 70%
Budget

GSD 10-Year Funding Profile

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<td>$10,091</td>
<td>$6,216</td>
<td>$8,244</td>
<td>$6,006</td>
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<td>Yearly Totals</td>
<td>$23,294</td>
<td>$22,213</td>
<td>$22,040</td>
<td>$33,162</td>
<td>$35,040</td>
<td>$32,876</td>
<td>$31,772</td>
<td>$26,062</td>
<td>$41,567</td>
<td>$32,003</td>
</tr>
</tbody>
</table>

Distribution of GSD Incoming Funds Allocated to R&D Time Horizon (2015)
GSD Funding by Project

**FY 2015 Total $32M**

GSD Expenditures

**FY 2010 Total $28M**

- **Joint Institutes**, 31.8%
- **OAR/ESRL Over Heads**, 5.3%
- **Training**, 0.1%
- **Other Recurring**, 0.1%
- **Supplies**, 3.3%
- **Equipment**, 1.5%
- **Contract Services**, 18.4%
- **Publications**, 0.1%
- **Communications & Utilities**, 2.6%
- **Rent**, 5.0%
- **Travel**, 1.7%
- **Federal Labor**, 30.2%

**FY2015 $32M**

- **Joint Institutes**, 43.0%
- **OAR/ESRL Over Heads**, 7.3%
- **Training**, 0.5%
- **Other Recurring**, 0.0%
- **Supplies**, 1.6%
- **Equipment**, 1.2%
- **Contract Services**, 13.8%
- **Communications & Utilities**, 3.0%
- **Rent**, 5.0%
- **Travel**, 1.0%
### GSD Annual Operating Plan 2010-2015

**Summary**

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Milestone</th>
<th>Objective</th>
<th>Actuals</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number of ESRL-GSD journal articles published in peer-reviewed literature</td>
<td>33</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual number of technologies transferred to NWS, other government organizations or the private sector</td>
<td>33</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cumulative percentage improvement in accuracy (total skill score of ceiling &lt;1000 ft) of the 3-hour cloud ceiling for aviation forecasts</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td></td>
<td></td>
<td>Cumulative percentage improvement in accuracy in forecasts of radar reflectivity as measured against observed radar reflectivity. Accuracy metric is equitable threat score for 3-hour forecasts of reflectivity exceeding 25 dBZ averaged to a 40km grid.</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cumulative percentage improvement in Probability of Detection (POD-y) from HRRR model forecasts of change in 10m wind speed of &gt;5m/s in one hour over CONUS land areas.</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td></td>
<td></td>
<td>Cumulative number of assessments conducted on aviation weather products to evaluate potential for transition to NWS operations supporting FAA activities</td>
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<tr>
<td>Performance Measure</td>
<td>Objective</td>
<td>Actuals</td>
<td>Target</td>
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<tr>
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<tr>
<td></td>
<td></td>
<td>10</td>
<td>11</td>
<td>12</td>
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<tr>
<td>Complete assessment of MRMS/CIWS forecasts for NWS sponsor by 12/31/2014.</td>
<td>NOAA FY2015 Goal: Evolve the National Weather Service</td>
<td>2</td>
<td>5</td>
<td>10</td>
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<tr>
<td>Cumulative number of major tests and evaluations of numerical weather prediction forecast system components to inform decisions for NWS operational systems</td>
<td>NOAA Science and Technology Enterprise: An integrated environmental modeling system</td>
<td>0</td>
<td>10</td>
<td>20</td>
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<tr>
<td>Complete coupled atmospheric-ocean-chem FIM-HYCOM-chem model with some retrospective runs completed to be considered a candidate member for the National Multi-Model Ensemble (NMME)</td>
<td>NOAA Science and Technology Enterprise: An integrated environmental modeling system</td>
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<tr>
<td>Annual number of retrospective year-long experiments of FIM (Flow-following, finite-volume, Icosahedral Model) to support the development of the High-Impact Weather Prediction Project (HIWPP) ensemble.</td>
<td>NOAA Science and Technology Enterprise: An integrated environmental modeling system</td>
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<tr>
<td>Cumulative number of NOAA Environmental Information System (NEIS) to demonstrate new visualization capabilities for High Impact Weather Prediction Project (HIWPP) global data</td>
<td>NOAA Engagement Enterprise: Integrated services meeting the evolving demands of regional stakeholders</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Annual number of 7-day parallel tests of experimental High Resolution Rapid Refresh (HRRR) model upgrades at 3-km for future incorporation into NWS/NCEP suite of operational models</td>
<td>NOAA Science and Technology Enterprise: An integrated environmental modeling system</td>
<td>5</td>
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<td>Number of 1-week retrospective tests of the GSD North American Rapid Refresh ensemble (NARRE)</td>
<td>NOAA Science and Technology Enterprise: An integrated environmental modeling system</td>
<td>n/a</td>
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### SUMMARY OF GSD ANNUAL OPERATING PLANS FY2010-2015

<table>
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<tr>
<th>Performance Measure</th>
<th>Objective</th>
<th>Actuals</th>
<th>Target</th>
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<tr>
<td>Cumulative number of models or components (eg. dynamics, physics) coded to run on fine-grain Computing systems including GPUs (Graphics Processing Units) and MIC (Many Integrated Core)</td>
<td>NOAA Science and Technology Enterprise: An integrated environmental modeling system</td>
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<td>FY15 Global Forecast System Physics coded for fine grain.</td>
<td>NOAA Science and Technology Enterprise: An integrated environmental modeling system</td>
<td>X</td>
<td></td>
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<tr>
<td>Annual number of Forcaster Decision Support Environment (FDSE) prototype applications developed for AWIPS II in the forecast office of the future</td>
<td>NOAA Engagement Enterprise: Integrated services meeting the evolving demands of regional stakeholders</td>
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<td>Develop a Gridded Forecast Monitor prototype</td>
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<td>Annual number of tasks performed to transition MADIS components and functions to NWS operations towards achieving Final Operational Capability</td>
<td>NOAA Engagement Enterprise: Integrated services meeting the evolving demands of regional stakeholders</td>
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<tr>
<td>Transition MADIS realtime system to NCEP/NCO/IDP</td>
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<td>X</td>
<td></td>
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<tr>
<td>Transition MADIS data recovery system to NCEP/NCO/IDP</td>
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<td>X</td>
<td></td>
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<tr>
<td>Transition MADIS data archive functionality to NESDIS/NCDC</td>
<td></td>
<td>X</td>
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<tr>
<td>Annual number of MADIS updates submitted to NWS operational MADIS</td>
<td>NOAA FY2015 Goal: Investing in Observational Infrastructure</td>
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<tr>
<td>Annual number of stations added to feed observations data to MADIS</td>
<td>NOAA FY2015 Goal: Investing in Observational Infrastructure</td>
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<td>Cumulative number of domestic and international Science On a Sphere exhibits permanent and temporary installations in science museums and other venues</td>
<td>NOAA Engagement Enterprise: An engaged and educated public with an improved capacity to make scientifically informed environmental decisions.</td>
<td>52 74 87 103 118 130 178</td>
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### SUMMARY OF GSD ANNUAL OPERATING PLANS FY2010-2015

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<th>Performance Measure</th>
<th>Milestone</th>
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<th>Actuals</th>
<th>Target</th>
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<tr>
<td>Cummulative number of datasets visualizations available for use within the Science On a Sphere network as made available by NOAA.</td>
<td></td>
<td>NOAA Engagement Enterprise: An engaged and educated public with an improved capacity to make scientifically informed environmental decisions.</td>
<td>100</td>
<td>536</td>
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<tr>
<td>Annual number of visitors to Informal Education Institutions displaying Science On a Sphere®</td>
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<td>NOAA Engagement Enterprise: An engaged and educated public with an improved capacity to make scientifically informed environmental decisions.</td>
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<td>39M</td>
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C. Publications and Citations

The journal publications and citations for GSD authors on staff between 2010 and 2015 are summarized in the table below. The totals in each column represent the lifetime counts for each GSD author. The values were gathered using the Web of Science and Google Scholar Harzing, A.W. Publish or Perish (2007; available from [http://www.harzing.com/pop.htm](http://www.harzing.com/pop.htm)) search functions. Web of Science reports citations from refereed journal articles, scholarly book chapters, and published conference proceedings while Google Scholar also captures citations from technical reports, technical memoranda, science and technology magazine articles, conference papers, book chapters, and other science-related documents. The range provided by both sources should give an optimal sense of a researcher’s impact in his/her field. GSD has 68 researchers who have published articles with 16 researchers having an H-Index of 10 or higher.

<table>
<thead>
<tr>
<th>Researcher</th>
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<td>Benjamin, Stan</td>
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<td>Bleck, Rainer</td>
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<td>Brown, John</td>
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<td>Cucurull, Lidia</td>
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<td>Dowell, David</td>
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<td>Fiorino, Michael</td>
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<td>Grell, Georg</td>
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<td>Jiang, Hongli</td>
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<td>Moninger, William</td>
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<td>Pagowski, Mariusz</td>
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<td>Peckham, Steven</td>
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<td>Schlatter, Thomas</td>
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<td>Smirnova, Tatiana</td>
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<td>Sun, Shan</td>
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<td>Toth, Zoltan</td>
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<td>Weatherhead, Betsy</td>
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<td>TOTALS</td>
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<td>1,239</td>
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List of GSD Peer-Reviewed Publications 2010-2015

http://www.esrl.noaa.gov/gsd/publications/

1 = Federal Staff, 2 = CIRA, 3 = CIRES, 4 = Contractor, 5 = Other. GSD staff authors in bold.

2015

Ahmadov³, R., S. McKee³, M. Trainer¹, R. Banta¹, A. Brewer¹, S. Brown¹, P. M. Edwards³, J. A. De
gouw³, J. B. Olson³, et al., 2015: Understanding high wintertime ozone pollution events in an oil-

Balzarini⁵, A., G. pirovano⁵, L. Honzak⁵, R. Žabkar⁵, G. Curci⁵, R. Forkel ⁵, M. Hirtl ⁵, R. San José ⁵, P.
Tuccella ⁵, G. Grell¹, 2015: WRF-Chem model sensitivity to chemical mechanisms choice in

Baró⁵, R., P. Jiménez-guerrero⁵, A. Balzarini⁵, G. Curci⁵, R. Forkel⁵, G. Grell¹, et al., 2015: Sensitivity
analysis of the microphysics scheme in WRF-Chem contributions to AQMEII phase 2. Atmospheric
Environment, 115, 620–629.

Bleck³, R., S. Benjamin¹, J. M. Brown¹, M. Fiorino¹, T. B. Henderson², J. L. Lee¹, A. E. Macdonald¹,
P. Madden³, J. Middlecoff², J. Rosinski², et al., 2015: A vertically flow-following icosahedral grid
model for medium-range and seasonal prediction. Part I: Model description. A Vertically Flow-
Following Icosahedral Grid Model for Medium-range and Seasonal Prediction. Part I, 143(6), 2386–
2403.

Bocquet⁵, M., H. Elbern⁵, H. Eskes⁵, M. Pagowski², G. Grell¹, et al., 2015: Data assimilation in
atmospheric chemistry models: current status and future prospects for coupled chemistry

Cardellach⁵, E., L. Cucurull³, et al., 2015: Sensitivity of PAZ LEO Polarimetric GNSS Radio-
Occultation Experiment to Precipitation Events. IEEE Transactions on Geoscience and Remote
Sensing, 53(1), 190-206.

Chen³, Y., H. Wang², J. Min³, X. Huang³, P. Minnus³, R. Zhang³, J. Haggerty⁵, R. Palikonda³, 2015:
Climatol.

Clack³, C., Y. Xie¹, A. E. MacDonald¹, 2015: Linear programming techniques for developing an
optimal electrical system including high-voltage direct-current transmission and storage.

Cucurull³, L., 2015: Implementation of a quality control for radio occultation observations in the
presence of large gradients of atmospheric refractivity. Atmospheric Measurement Techniques, 8(3),
1275-2015.

Gao⁵, F., X. Huang⁵, N. A. Jabobs⁵, H. Wang², 2015: Assimilation of wind speed and direction observations: results from real observation experiments. Tellus, 67, 27132.


Hsiao⁵, L. F., X. Y. Huang⁵, Y. H. Kuo⁵, D. S. Chen⁵, H. Wang², and et al., 2015: Blending of global and regional analyses with a spatial filter: Application to typhoon prediction over the western North Pacific Ocean. Wea. Forecasting, 30(3), 754–770.

Longmore², S., S. Miller², D. Bikos², D. Lindsey⁵, E. Szoke², D. Molenar⁵, D. Hillger⁵, R. Brummer², J. John knaff⁵, 2015: An Automated Mobile Phone Photo Relay and Display Concept Applicable to Operational Severe Weather Monitoring. J. Atmos. Oceanic Techno., 32(7), 1356–1363.


2014


2013


Grell\textsuperscript{1}, G. A., S. R. Freitas\textsuperscript{5}, 2013: A scale and aerosol aware stochastic convective parameterization for weather and air quality modeling. \textit{Atmos. chem. Phys. Discuss.}, \textbf{14}(9).


Hamill\textsuperscript{1}, T. M., G. T. Bates\textsuperscript{3}, J. S. Whitaker\textsuperscript{1}, D. R. Murray\textsuperscript{3}, \textbf{M. Fiorino}\textsuperscript{1}, T. J. Galarneau\textsuperscript{5}, Y. Zhu\textsuperscript{1}, W. Lapenta\textsuperscript{1}, 2013: NOAA's second-generation global medium-range ensemble reforecast dataset. \textit{Bull. Amer. Meteor. Soc.}, \textbf{94}(10), 1553-1565.

Hewson\textsuperscript{5}, M., S. Phinn\textsuperscript{3}, \textbf{S. Peckham}\textsuperscript{3}, \textbf{G. Grell}\textsuperscript{1}, H. Mcgowan\textsuperscript{5}, 2013: Exploring anthropogenic aerosol effects on rainfall for Brisbane, Australia. \textit{Climate}, \textbf{1}(3), 120-147.

Hong\textsuperscript{5}, S., \textbf{M. Koo}\textsuperscript{5}, J. Jang\textsuperscript{5}, \textbf{J. E. Kim}\textsuperscript{2}, H. Park\textsuperscript{5}, M. Joh\textsuperscript{5}, J. Kang\textsuperscript{5}, T. Oh\textsuperscript{5}, 2013: An evaluation of the software system dependency of a global atmospheric model. \textit{Mon. Wea. Rev.}, \textbf{141}(11), 4165-4172.

Hong\textsuperscript{5}, S. Y., H. Park\textsuperscript{5}, H. B. Cheong\textsuperscript{5}, \textbf{J. E. Kim}\textsuperscript{2}, \textbf{M. S. Koo}\textsuperscript{5}, J. Jang\textsuperscript{5}, S. Ham\textsuperscript{5}, S. O. Hwang\textsuperscript{5}, B. K. Park\textsuperscript{5}, E. C. Chang\textsuperscript{5}, et al., 2013: The Global/Regional Integrated Model system (GRIMs). \textit{Asia-Pacific J. Atmos. Sci.}, \textbf{49}(2), 219-243.


Kim\textsuperscript{5}, O. Y., C. G. Lu\textsuperscript{3}, \textbf{J. A. McGinley}\textsuperscript{1}, \textbf{S. C. Albers}\textsuperscript{2}, J. H. Oh\textsuperscript{5}, 2013: Experiments of LAPS wind and temperature analysis with background error statistics obtained using ensemble methods. \textit{Atmospheric Research}, \textbf{122}, 250-269.


Li\textsuperscript{5}, W., \textbf{Y. F. Xie}\textsuperscript{1}, G. J. Han\textsuperscript{5}, 2013: A theoretical study of the multigrid three-dimensional variational data assimilation scheme using a simple bilinear interpolation algorithm. \textit{Acta Oceanologica Sinica}, \textbf{32}(3), 80-87.


2012


Hou1, D., M. Charles1, Y. Luo5, Z. Toth1, Y. Zhu1, R. Krzysztofowicz5, Y. Lin1, P. Xie1, D. Seo5, M. Pena5, et al., 2012: Climatology-calibrated precipitation analysis at fine scales: Statistical adjustment of Stage IV towards CPC gauge based analysis. *J. Hydrometeor, 15*(6), 2542–2557.


Leelasakultum⁵, K., N. Molders⁵, H. N. Tran⁵, G. A. Grell¹, 2012: Potential impacts of the introduction of low-sulfur fuel on PM2.5 concentrations at breathing level in a subarctic city. *Advances in Meteorology, 2012*(Article ID 427078), 16 pages.


Solazzo⁵, E., R. Bianconi⁵, G. Pirovano⁵, V. Matthias⁵, R. Vautard⁵, M. D. Moran⁵, K. W. Appel⁵, B. Bessagnet⁵, J. Brandt⁵, G. Grell¹, et al., 2012: Operational model evaluation for particulate matter in Europe and North America in the context of AQMEII. *Atmospheric Environment, 53*(Special Issue), 75-92.

Solazzo⁵, E., R. Bianconi⁵, R. Vautard⁵, K. W. Appel⁵, M. D. Moran⁵, C. Hogrefe⁵, B. Bessagnet⁵, J. Brandt⁵, J. H. Christensen⁵, G. Grell¹, et al., 2012: Model evaluation and ensemble modeling of surface-level ozone in Europe and North America in the context of AQMEII. *Atmospheric Environment, 53*, 60-74.


2011


2010


Wei⁵, M., Z. Toth¹, Y. Zhu⁵, 2010: Analysis differences and error variance estimates from multi-centre analysis data. *Australian Meteorological and Oceanographic Journal (AMO)*, 59(Special Issue), 25-34.


### Technical Assessments and Reports

At the request of NWS and FAA, GSD conducts technical assessments of new aviation weather forecasting products as part of the transition to operations process. The assessments evaluate the functionality and capability of the new products: does the product or technology do what it was designed to do? GSD has also designed verification technologies as a result of these assessments. The assessment findings are reviewed by experts in the field for their input prior to final release of the report and the findings. The findings are presented either in a technical report or conference poster as listed below.

#### 2015


#### 2014

**Etherton¹, B.J., Wandishin³, M.S., Paulik³, L.A., Layne³, G.J., Petty², M.A.,** 2014: *Assessment of the Multi-Radar/Multi-Sensor System (MRMS) and the Corridor Integrated Weather System (CIWS)*, submitted to the NWS NextGen Program.


#### 2013

**Hamer², P., M. A. Petty² and J. L. Mahoney¹,** 2013: *A Framework for Automated Forecast Verification and Dissemination of Performance Information*. 29th Conference on Environmental Information Processing Technologies, 6-10 January, Austin, TX.

**Layne³, G.J., A.F. Loughe³, J.E. Hart³, M.S. Wandishin³, M.A. Petty², and J.L. Mahoney¹,** 2013: *A comparison of RUC-derived and RAP-derived CIP and FIP icing products*. Poster: 16th Conference on Aviation, Range, and Aerospace Meteorology, 6-10 January, Austin, TX.
Layne³, G.J., P. Hamer², M.P. Kay⁵, M.S. Wandishin³, M.A. Petty², S.A. Lack³, J.E. Hart³, and J.L. Mahoney¹, 2013: VERIFIED: A web based tool to assess potential airspace constrain from operationally-relevant forecast products. Poster: 16th Conference on Aviation, Range, and Aerospace Meteorology, 6-10 January, Austin, TX.

Wandishin³, M.S., Layne³, G.J., Etherton¹, B.J., Petty², M.A., Mahoney¹, J.L. 2013: Lead Time and Displacement Error for Thunderstorm Forecasts in Terminal and Jetway Domains, submitted to the NWS Aviation Services Branch.


2012


2011

Loughe, A.F.³, B.P. Pettegrew², J.K. Henderson¹, J.E. Hart³, S. Madine², and J. Mahoney¹, 2011: A Performance Assessment of the National Ceiling and Visibility Analysis Product. 15th Conference on Aviation, Range, and Aerospace Meteorology, 1-4 August, Los Angeles, CA, Amer. Met. Soc.

Lack³, S.A., M.S. Wandishin³, and J.L. Mahoney¹, 2011: An object-based approach for identifying and evaluating convective initiation. 15th Conference on Aviation, Range, and Aerospace Meteorology, Los Angeles, CA, USA.


Loughe³, A.F., J.E. Hart³, G.J. Layne³, M.A. Petty², and J.L. Mahoney¹, 2011: Icing Algorithm Assessment: RUC-derived and WRR-derived CIP and FIP. Submitted to the FAA Aviation Weather Research Program.


2010

The Developmental Testbed Center with staff from GSD and NCAR produced the following peer-reviewed science documentation:


Gall⁵, R., F. Toepfer¹, F. Marks¹, E. Rappaport¹, A. Aksoy⁵, S. Aberson¹, J. W. Bao¹, M. Bender¹, S. Benjamin¹, L. Bernardet³, et al., 2014: HFIP Technical Report: HFIP2014-2, 2013 HFIP R&D Activities Summary: Recent Results and Operational Implementation, 2013 HFIP R&D Activities Summary: Recent Results and Operational Implementation, 50.


D. Research to Operations and Applications

GSD’s research and development supports the NOAA goal of a Weather-Ready Nation as well as the NOAA objectives for an integrated environmental modeling system, accurate and reliable data from sustained and integrated earth observing systems, and a holistic understanding of the Earth system through research. GSD complies with NOAA’s Annual Guidance Memorandum to accelerate the transition of research advances to applications. The recipients of our R&D products, services, and information include public, private and academic organizations who apply our research to make better operational decisions supporting various societal and economic sectors. GSD’s applications research is utilized by its operational recipients to improve the following:

- life, property, and natural resources protection during severe weather
- emergency management and disaster preparedness such as evacuations
- disaster response and resiliency of communities
- efficiency of renewable energy generation and use
- air traffic efficiency and passenger safety
- safety and efficiency of surface transportation
- atmospheric aerosols prediction such as wildfire smoke, dust, and volcanic ash which can affect weather,
- physical science education and outreach at all age levels, particularly K-12

Numerical Weather Prediction (NWP)

Research to Operations/Applications – Transition Readiness Level

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<tr>
<th>Project</th>
<th>IM-1 Basic Science</th>
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Key:
- RAP – Rapid Refresh Model
- HRRR – High Resolution Rapid Refresh
- NARRRE – North American Rapid Refresh Ensemble
- HRRRE – High Resolution Rapid Refresh Ensemble
- FIM – Flow-following finite-volume Icosahedral Model
- iHYCOM – Icosahedral Hybrid Coordinate Ocean Model
A summary of the numerical modeling technologies and an assessment of their significance/impact on operations is provided here.

**Regional Modeling**

Our nation increasingly needs detailed, reliable, quickly-updated weather guidance to enable the commerce and transportation that drive US economic activity and the warnings that save citizens’ lives and increase public safety. GSD has developed weather models covering North America that provide frequently updated short-range weather forecasts primarily for the severe weather forecasting and U.S. aviation communities, but increasingly critical for the renewable energy generation industry as well.

1. **Rapid Refresh (RAP) Model**

*Research Description:* The Federal Aviation Administration (FAA) needed faster updates to weather forecasts at higher resolutions to support both the commercial and civil aviation communities, particularly at airports for takeoff and landings. Through the FAA’s Aviation Weather Research Program (AWRP), resources were provided to GSD to develop an hourly-updated regional model at 13-km resolution which would cover North America and replace the Rapid Update Cycle model running at 13-km resolution over CONUS. The RAP uses a community numerical forecast model (WRF-ARW) and analysis/assimilation system (GSI; Gridpoint Statistical Interpolation) components to initialize the model. In the RAP model, GSD implemented innovations for radar reflectivity, cloud, and surface data assimilation options to GSI that are also available for other models. GSD has also developed improved parameterizations of boundary-layer mixing, convective clouds, and land-surface (soil, snow, vegetation) processes with the Weather Research and Forecasting (WRF) community model to improve RAP forecasts but also has made them available to all WRF users. For further information, visit [http://rapidrefresh.noaa.gov/](http://rapidrefresh.noaa.gov/).

*Research to Applications:* On May 1, 2012, the 13-km Rapid Refresh Model (RAP) became operational at NWS/NCEP. The RAP replaced the previous RUC (Rapid Update Cycle) model and expanded coverage from CONUS to North America, including Alaska. RAPv2 was implemented at NCEP in February 2014, and RAPv3, with further improvements to storm environment, cloud, and winter-storm fields, is planned for NCEP in February 2016. The RAP is the parent model for the 3-km High-Resolution Rapid Refresh (HRRR) model providing boundary layer conditions for HRRR initialization.

2. **High-Resolution Rapid Refresh (HRRR) Model**

*Research Description:* With support again from the FAA for even higher resolutions for airport terminal weather forecasts, GSD developed the High-Resolution Rapid Refresh (HRRR) model. The HRRR provides a significant new capability in severe weather prediction for NWS. With the HRRR, GSD scientists merged advances in weather prediction science and high performance computing technology with a new breakthrough technique for using radar data to achieve a new standard process for up-to-the-minute weather forecasting at a 3-km scale. For further information, visit [http://rapidrefresh.noaa.gov/hrrr/](http://rapidrefresh.noaa.gov/hrrr/).
**Research to Applications:** The HRRR model went operational at NWS in September, 2014. Its impact was immediate, delivering forecasts, in high detail, of critical weather events such as severe thunderstorms, flash flooding, and localized bands of heavy winter precipitation. Since the HRRR is run hourly and assimilates many data sources including radar reflectivity data, the HRRR helps provide critical details to forecasters in rapidly-changing and evolving weather events. For more information, visit http://www.noaanews.noaa.gov/stories2014/20140930_hrrr.html. HRRRv2 is planned for operational implementation also in February 2016.

The RAP and the HRRR produce hourly weather forecast updates that support decision making. Air traffic controllers depend on the forecasts to direct air traffic around rapidly developing hazardous weather and emergency managers use them to prepare for potential national disasters that threaten property and lives. The U.S. energy sector relies on the RAP/HRRR to help them improve the efficiency and effectiveness of wind and solar energy production. Wildfire managers use the forecasts to help tactical firefighting decisions.

3. **WRF-Chem Model**

**Research Description:** GSD leads the global community development of WRF-Chem, a next-generation coupled weather/air quality numerical prediction system based on the WRF model. Gas-phase chemistry and aerosol processes are tightly coupled to meteorology within the WRF model structure. WRF-Chem has a large international user base. GSD currently runs experimental online chemistry versions for many of its models, including RAP-Chem, HRRR-Smoke, and FIM-Chem. These higher-resolution experimental models are used to predict weather, dispersion, and air quality, including predictions of dust, smoke and volcanic ash dispersion and also support other weather, climate, and air chemistry research experiments, e.g. SENEX 2013 (Studying the Interactions between Natural and Anthropogenic Emissions at the Nexus of Climate Change and Air Quality) and FRAPPE (Front Range Air Pollution and Photochemistry Experiment). For further information about WRF-Chem, visit http://ruc.noaa.gov/wrf/WG11/.

**Research to Applications:** The WRF-Chem model was used operationally by the U.S. Air Force until recently but continues to be used operationally by many forecasting centers in other countries. For a list of some of the countries using WRF-Chem, visit http://ruc.noaa.gov/wrf/WG11/Real_time_forecasts.htm.

4. **Ensembles at Regional Scales**

**Research Description:** Current ensemble guidance provided by NWS comes from the Short Range Ensemble Forecast (SREF), updated every 6 hours at a 16-km resolution. But transportation providers (particularly air traffic managers), emergency managers, and the renewable energy providers want enhanced, higher-resolution (both temporal and spatial) regional ensemble guidance that provides more forecast uncertainty or probabilistic information, especially about severe weather. The idea is to have SREF continuing to run on 6-hourly cycles out to 84 forecast hours with GSD’s and NCEP’s North American Rapid Refresh Ensemble (NARRE) members as a subset updating hourly at 12-km grid spacing and running out to 18-24 forecast hours. Having these members as a subset of SREF means that the model uncertainty, at least at the beginning, will be addressed by use of two dynamic cores ARW (RAP) and NAM (NMMB) and variations in physics.
Next will be to transition the NARRE to the High Resolution Rapid Refresh Ensemble (HRRRE) to provide 3-km, hourly forecast guidance.

The HRRRE system will build upon a prototype time-lagged ensemble package that has been running since June 2009 producing a real-time, experimental probabilistic thunderstorm guidance product. The existing HRRR Convective Probability Forecast (HCPF) algorithms will serve as a starting point for the creation of the new Automated High-Resolution Ensemble-Based Hazard Detection Guidance Tools. The development will also leverage the previous ensemble generation work of the NCEP/EMC group and NCAR and to collaborate on best methods for creating these hazard guidance tools using time-lagged ensembles from the 3-km, hourly-updated HRRR model. A direct outcome of the project will be improved ensemble hazard guidance tools for operational forecasters that will reduce the ensemble information overload problem and enable a more efficient and accurate characterization of forecast uncertainty.

**Research to Applications:** GSD is working with the NWS/EMC and the Developmental Testbed Center (DTC) to develop the NARRE as an hourly-updated ensemble related to the current 6 member SREF now running at NCEP. According to the EMC roadmap, the new 6-member NARRE is scheduled for operational implementation in 2017. Currently, a preliminary time-lagged version of NARRE using multiple RAP members initialized at different times is running at NCEP. After 2017, the next implementation will be for the HRRRE to provide 3-km, hourly-updated probabilistic forecast guidance. An experimental HRRRE has been running in real time, producing thunderstorm probability grids which have been delivered to the Aviation Weather Center (AWC) and Storm Prediction Center (SPC) for the last 3 years. Over the next three years the work will advance to enable a transition of HRRRE (or High-Resolution Ensemble Forecast –HREF) to operations in 2019. The Automated High-Resolution Ensemble-Based Hazard Detection Guidance tools being developed by GSD using the HRRRE will then be available to operational forecasters.

5. **Hazardous Weather System for U.S. Space Centers**

**Research Description:** Operations at U.S space centers are heavily impacted by severe weather conditions and windstorm forecasts. Safety regulations restrict work on tall gantries, shuttle transport, refueling, and other operations during high wind events. Winds may also impact safety following rocket blasts, fuel spills, and other accidents by carrying toxins from an accident zone farther afield. Beginning in FY2003, NOAA ESRL/GSD developed and implemented a state-of-the-art analysis, forecast, product generation, and display system as part of the U.S. Air Force’s Range Standardization and Automation (RSA) program.

**Research to Applications:** Since FY2003, GSD continues to maintain and update the RSA weather forecasting system. The data management, processing, and display modules are based on the National Weather Service’s Advanced Weather Interactive Processing System (AWIPS-I) and eventually will be transitioned to AWIPS-II. The Local Analysis and Prediction System (LAPS), also developed at GSD, is used to analyze the current weather and then initialize a local model running in three nested domains with horizontal grid resolutions of 10, 3.3, and 1.1 km. In FY2015, the local model was replaced with the Weather Research and Forecasting Model (WRF)/Advanced Research WRF (WRF-ARW). This modeling system is widely used around the world to provide weather
guidance to supplement NOAA models including HRRR, RAP, and GFS. In addition, GSD provides system upgrades to improve Launch Weather Officers’ effectiveness and efficiency.

6. Local Analysis and Prediction System (LAPS)

Research Description: GSD provides the Local Analysis and Prediction System (LAPS) to more than 150 group and individual users in support of data assimilation, nowcasting, and mesoscale model initialization and post-processing. The LAPS user base has historically included federal agencies, state agencies, private entities, academic institutions, and international agencies. LAPS is a highly portable system with adjustable horizontal, vertical, and temporal resolution that runs on inexpensive hardware (including desktops and laptops), providing the capability to blend a wide variety of global, national, and local datasets into analyzed grids. LAPS benefits forecasters, decision makers, and researchers with high-resolution frequently updated weather information for a wide variety of settings.

Research to Applications: In FY2014, LAPS was implemented into the AWIPS II basic suite of forecasting tools because NWS Weather Forecasting Offices continue to need it for very high resolution nowcasting, particularly in complex terrain. GSD is now collaborating with NWS in an effort to use GSI data assimilation and HRRR forecast model to provide nowcasting 3-D cloud/wind/temperature grids (Rapidly Updating Analysis - RUA) to replace LAPS for NWS and other agencies.

7. Modeling Support for R&D Testbeds

Research Description: GSD supports a number of NOAA research-to-applications testbed activities with high-resolution experimental model guidance and advanced data assimilation to meet the needs of the testbed experiments and product transition to operations. Over the past five years, GSD researchers participated in and contributed to the following testbeds and experiments:

- Hydrometeorological Testbed (HMT) in collaboration with ESRL/PSD using the Experimental Regional Ensemble Forecast System (ExREF) up to winter 2013-14 and then switching to NARRE for winter 2014-15

- Hazardous Weather Testbed (HWT) in collaboration with NSSL, NCEP/SPC and the NWS forecast office in Norman, OK: Spring Experiment/Warning and Forecasting Programs using the RAP and HRRR with 3 to 6 GSD participants for a week every spring for the past 15 years; Participation in Forecasting a Continuum of Environmental Threats (FACETs) planned for 2016.

- Aviation Weather Testbed (AWT) in collaboration with NCEP/AWC using experimental RAP and HRRR; one or two GSD participants for a week in Kansas City every summer since inception.

- Climate Testbed (CTB) to design possible ensemble guidance for improved sub-seasonal forecasting including use of GSD’s FIM-iHYCOM coupled model.
• GOES-R Testbed to improve use of GOES-R products in the RAP and HRRR models.

• Flash Flood and Intense Rainfall (FFaIR) in collaboration with the NCEP/WPC and NSSL using the HRRR (NCEP and experimental); one or two GSD participants for a week every summer at the WPC since inception.

• Winter Weather Experiment (WWE) in collaboration with HMT and NCEP/WPC using the RAP, HRRR, and prototype NARRE; one or two participants for a week at the WPC every winter since inception.

Research to Applications: In these testbed activities NWS operational units are given the opportunity to use advanced experimental products in their operations and developers have opportunity to gain familiarity with operational challenges. This interaction between developers and operational forecasters and the feedback to developers regarding product performance has proven very valuable over the years. Products tested during these exercises are given a rigorous evaluation and increases the likelihood that they will be incorporated into NWS operations.

Next Generation Global Modeling

NOAA seeks to accelerate improvements in the skill of U.S. operational global numerical weather prediction systems which can provide more accurate, longer lead-time forecasts. Having a reliable and skillful forecast, especially in the case of high-impact weather events such as hurricanes, would enable better decision-making to save lives and property. In addition to improving the current generation of hydrostatic global models and ensemble products from them, NOAA is accelerating the development of the next generation of non-hydrostatic, cloud-resolving global models for medium range forecasts for the Next Generation Global Prediction System (NGGPS). These models are expected to provide a quantum-leap forward in the Nation’s forecast skill by the end of this decade.

1. High Impact Weather Prediction Project (HIWPP)

Research Description: Funded by the Disaster Relief Act of 2013 in the aftermath of Superstorm Sandy, HIWPP was a cross-NOAA effort with several goals. GSD participated to 1) Test next-generation global weather models in a real-time running mode; 2) Evaluate the North American Multi-Model Ensembles’ ability to improve forecasts out to months and use cutting-edge visualization technology; and 3) Partner with the broader weather community to assess research models in realtime. For the first goal, GSD used its expert researchers and high performance computing resources to conduct a comparison of the dynamical cores from four experimental global models provided by NWS/EMC, OAR/GSD, OAR/GFDL, and NSF/NCAR. For the second goal, GSD provided results from the Flow-following Finite Volume Icosahedral Model (FIM) using the NOAA Earth Information System (NEIS) visualizations to evaluate the model data. The third goal was addressed through the HIWPP Open Data Initiative where members of the modeling community could access model results and provide input. http://hiwpp.noaa.gov/

Research to Applications: In July 2015, GSD provided the report the NWS used to down-select two of the model cores to consider for operational development for the NGGPS. Although the GSD
global model dynamical core was not selected, GSD will continue to play a central role in transitioning an experimental global weather model to operations due to its past successes transitioning models to NWS operations. HIWPP also implemented an Open Data Initiative providing experimental real-time global forecast data to the community or anyone who wants the model codes and data.

2. Flow-following Finite-volume Icosahedral Model (FIM)

Research Description: With the advent of distributed-memory computing late in the last century, it was recognized that, because of poor scaling with the spectral approach, alternative architectures for global models were going to become necessary. Both Louis Uccellini (now head of the National Weather Service) and Professor Don Johnson of the University of Wisconsin encouraged GSD to develop a global version of a model with an isentropic coordinate, following GSD's successful use of the Rapid Update Cycle (RUC) hybrid-isentropic model for regional forecasting. As a result, ESRL Director Sandy MacDonald, Dr. Jin Lee and others in GSD designed and coded a shallow-water model on an icosahedral grid in the early 2000s, and in 2005 handed this code to GSD to use as the foundation for building a hybrid isentropic coordinate global model.

Over the next few years, such a model, called FIM, was built, and based on the original design of the horizontal (Arakawa “A” grid and differencing by MacDonald and Lee, but using an “Arbitrary Lagrangian-Eulerian” (ALE) framework for the vertical coordinate developed by Dr. Rainer Bleck for the well-regarded Hybrid Coordinate Ocean Model (HYCOM). The ALE framework for the hybrid-isentropic vertical coordinate is FIM's most distinctive feature, having the advantage of accuracy by reducing transport to a quasi-two-dimensional problem over most of the domain, excepting areas where diabatic effects are dominant. By adapting the physics then being used in NCEP's Global Forecast System (GFS), the FIM began producing real-time forecasts based on initial conditions from the GFS in 2009. Since then, the FIM has been substantially upgraded both in its numerical procedures and in its use of the latest operational version of the GFS physics suite. Moreover, an icosahedral version of the ocean model HYCOM (called i-HYCOM) has been constructed and coupled to FIM.

Research to Applications: The FIM’s anomaly correlation scores for 500mb height have rivaled and slightly exceeded those of the GFS since 2012, demonstrating the viability of both the hybrid isentropic coordinate and the numerical procedures used on the icosahedral grid. FIM has participated in the Hurricane Forecast Improvement Project since 2011, producing tropical cyclone track forecasts competitive with the GFS and even the ECMWF. It also participates as one of the high-resolution global hydrostatic models producing twice daily 15km-grid-spacing forecasts for the Sandy-Supplemental-funded High Impact Weather Prediction Project (HIWPP). At a yet-to-be-determined date, the coupled FIM-iHYCOM is a candidate member of the sub-seasonal North American Multi-Model Ensemble (NMME). The NMME aims to improve operational forecast skill on intraseasonal to interannual time scales and to provide real-time forecasts to user communities.

3. Non-hydrostatic Icosahedral Model (NIM)
**Research Description:** ESRL/GSD began development of a 3-km, non-hydrostatic, cloud-resolving icosahedral model, related to FIM, in 2010. The goal is to improve numerical accuracy for weather and climate simulations at ultra-high resolutions, as well as to utilize leading edge high performance computing architecture such as Massively Parallel Fine-Grain (MPFG) to optimize model runs for timely forecasts.

**Research to Applications:** In July 2015, based on the results from HIWPP testing and evaluation of model dynamical cores, NIM was not selected by NWS as one of its next-generation, non-hydrostatic models primarily because it wasn’t as mature as the two selected models. Given that decision, GSD has significantly reduced its investment in NIM development, but will continue to use it as an experimental model with which new science and techniques can be tested first before being nominated for infusion into NOAA’s current operational global model.

4. **Developmental Testbed Center (DTC)**

**Research Description:** Sponsored by NOAA, the U.S. Air Force, NCAR, and National Science Foundation, the multi-agency Developmental Testbed Center facilitates and conducts major tests and evaluations of improvements to NWP forecast system components provided by the NWP research community. It should be noted that the scope of the DTC has recently been expanded to involve global, as well as regional, NWP. These tests and evaluations are critical for selecting proposed changes that need to be transitioned to operational centers. For example, DTC evaluations will be critical for selection of the optimal physics packages, data assimilation strategies, and ensemble configurations used in the Hurricane Weather Research and Forecast (HWRF) model, the Rapid Refresh (RAP) model, and by the Next-Generation Global Prediction System (NGGPS). GSD DTC staff also conduct tutorials for the modeling community on the HWRF model, GSI/EnKF data assimilation system, and other operational codes.

**Research to Applications:** Over the past five years, the DTC has put in place several mechanisms to facilitate the use of operational models by the general NWP community, mostly by supporting operational codes and organizing workshops and tutorials. Some of those are: the GSI Workshops in 2013, 2014, and 2015; the 2014 HWRF tutorials in College Park, MD and Taiwan; and the 2015 tutorial on the Non-Hydrostatic Multiscale Mesoscale model in the B-grid (NMMB). This year the DTC completed a project, NWP Information Technology Environment (NITE), which focuses on infrastructure design elements that can be used to facilitate a closer collaboration between the research and operational groups and improve transition of research products to operations. Finally, over the last few years DTC has conducted several tests that led to the transition of innovations to NCEP. Some examples for HWRF are improvement of surface fluxes and of cloud-radiation interactions for the 2014 and 2015 operational versions of HWRF, respectively.

**Observing System Experiments (OSE) and Simulations (OSSE)**

OSSEs are needed for an objective evaluation and to optimize the utilization of existing data. They are an extension of OSEs, which use data denial experiments to determine the impact of existing observing systems. Atmospheric OSSEs determine the impact of new systems by performing data denial experiments that assimilate “synthetic” observations simulated from a realistic nature run stipulated to represent the “true” atmosphere. For the OSSEs to produce accurate quantitative
results, all of the components of the OSSE system must be realistic. This includes (1) a nature run that represents the main characteristics of the real atmosphere, (2) realistic differences between the nature run model and the model used for assimilation and forecasting should exist, (3) existing and new proposed observations should be simulated with realistic coverage and accuracy, and (4) the entire OSSE system must be validated to ensure that the accuracy of analyses and forecasts, and the impact of existing observing systems in the OSSE environment are comparable to the accuracies and impacts of the same observing systems in the real world.

Designing optimal configurations for observing systems is a new growth area within GSD, and it complements GSD’s long history in designing instrumentation. This is one of the main reasons why GSD’s Global Observing Systems Analysis (GOSA) Group was established. Furthermore, GSD is an active member of NOAA’s Quantitative Observing System Assessment Program (QOSAP), which coordinates and prioritizes OSEs and OSSEs within NOAA’s Line Offices, and participates in NOAA OSSE Testbed activities.

1. **Unmanned Aircraft System OSEs/OSSEs**

   **Research Description:** GSD collaborated with many different institutions to develop an OSSE framework and implement it at ESRL in support of the NOAA Unmanned Aircraft Systems (UAS) Program. GSD is a key participant of the Sensing Hazards with Operational Unmanned Technology (SHOUT) project by performing OSEs and OSSEs to evaluate the impact of current and future instruments on the Global Hawk in terms of global forecast skill, to help select instruments for future flight campaigns, and to design optimal flight patterns. Within this project, GSD’s focus is on high-impact weather events in mid-latitudes. GSD has also supported flight campaigns by providing input on potential developing storms and finding areas of larger sensitivity to error growth with the use of targeted observation techniques.

   **Research to Applications:** Observations from the Global Hawk’s FY15 flight campaign were operationally assimilated into the NWS National Hurricane Center. GSD has developed a methodology to support real flight campaigns and to evaluate the impact of future observations. Results of this work will be published in a peer-reviewed journal and presented at different conferences.


   **Research Description:** NWS/NCEP has successfully assimilated RO observations into its Global Data Assimilation System since May 2007. Since then, GSD has continued to develop new algorithms to improve the utilization of these observations in NOAA’s operational models. GSD has a large expertise on the GNSS-RO technology and GOSA’s Chief is the Program Scientist for the COSMIC-2 mission (a US-Taiwan GNSS-RO mission). GSD has established a 5-year 3-way MOU with NESDIS and NWS to maintain R2O work and to support the COSMIC-2 mission. Finally, and in collaboration with JCSDA and AOML, GSD is conducting studies to quantify the impacts of additional GNSS-RO data on operational forecast models.

   **Research to Applications:** Improved GNSS-RO assimilation algorithms were transferred to NCEP and became part of their upgraded operational forecast system. Initial results with a preliminary OSSE
configuration demonstrated that overall increasing the number of RO satellites for data assimilation from 6 to 18 improves weather forecast skill: 18 satellites is better than 12 satellites and 12 satellites is better than 6 satellites. Experiments are now being repeated with a more state-of-the-art OSSE configuration and results will be reported to U.S. Congress by the end of 2015. Results will also be published in a peer-reviewed journal.

3. Observation Sensitivity Experiments

Research Description: Observation sensitivity experiments are designed to assess the relative contribution to forecast accuracy of various observation systems. This may be for the purpose of evaluating well-established observation types, such as rawinsondes and surface observations, relative to newer observations such as satellite radiances or satellite-derived atmospheric-motion vectors. It may also be for purposes of evaluating a new observation type, such as GPS-Meteorology, to see if its use contributes to forecast improvement, given the mix of existing observations. To conduct these experiments requires access to a complete set of data that is being used at the operational centers as well as access to any experimental data that are to be assessed. In addition, a state-of-the-art data-assimilation/forecast system, including the forward models needed to effectively use experimental data, must be used. Preferably, this will be an operational system in order for results to be more directly relevant to operations.

Typically, such experiments are first conducted by running the assimilation / forecast system for a certain retrospective period with the total suite of observations. Normally this control run would give the most accurate forecasts. Next, successive experiments are conducted by removing one observation type at a time (keeping all the others) and measuring the extent of degradation relative to the control. These runs indicate the contribution of each omitted observation type. Results from well-conceived and -designed observation sensitivity experiments, together with the relative costs associated with each data platform, can in principle form a rational basis for prioritizing the importance of each platform in relation to its cost.

With its own data-assimilation/forecast system, GSD has always been aggressive in obtaining and using new observation types in order to evaluate their actual or potential contribution to operational forecasting. Motivated by its leadership in rapidly updating, short range NWP, GSD has performed a number of studies of new instrumentation types, including radar wind profilers, GPS-Met and aircraft, in conjunction with development of, first, the RUC model, then the RAP and HRRR models.

Research to Applications: The observation sensitivity experiments have been directed toward application to short-range forecasts over the CONUS, such as: an exhaustive study using the Rapid Update Cycle; an early assessment of observation impacts in the RAP model presented at the WMO Observation Impact Workshop in 2012 at Sedona, AZ; an assessment of aircraft observations using RAP for the NOAA Aircraft Data Workshop in 2014; and a more comprehensive experiment including satellite radiance assimilation earlier in 2015, for which a manuscript is in preparation. The latter showed that aircraft observations were the most important observation type, the first time that radiosondes were relegated to second place in the regional experiments that GSD has conducted. An observation sensitivity experiment is currently underway to examine the impact on
forecasts of convection in the HRRR from assimilation of GOES super-rapid-scan atmospheric motion vectors.

4. Satellite Product Assessments: Global Precipitation Measurement (GPM) and Atmospheric Motion Vectors (AMV) Cloud Drift Wind Data for GOES-R Preparation

Research Description: Beginning in October 2013, GSD started collaborating with the Joint Center for Satellite Data Assimilation (JCSDA) and NASA to evaluate the utility of PMM (GPM + TRMM) space-based radar data for initializing a weather forecasting model. Case studies running with and without TRMM radar data along with ground based radar are being performed. The GPM satellite system consists of a core satellite and a constellation of additional satellites. The use of space-based radar in combination with microwave sensors will also be considered in design recommendations for operational assimilation systems. The space-based radar can be used to help calibrate and leverage the more abundant microwave sensors to provide the most complete picture of global hydrometeors for use in models.

Beginning in January 2014, GSD started collaborating with the National Severe Storms Laboratory (NSSL), NESDIS and CIRA to evaluate the utility of satellite AMV cloud drift wind data, merged with other commonly available observations for initializing a weather forecast model. GOES (SRSOR) Rapid Scan satellite data are being used to help prepare for GOES-R. A number of modeling case studies are being performed to compare analysis and forecast results both with and without the AMV data. Comparison of cloud analysis hydrometeor fields with rapid scan satellite imagery data is an ancillary benefit of this collaboration with NSSL.

Research to Applications: The GPM assessment results and report will be presented in December 2015 at the American Geophysical Union meeting, and in a document provided to NESDIS. The assessment results for GOES-R preparation will be reported via NSSL on a regular basis through September 2016.

GSD. For more information on MADIS, refer to https://madis.noaa.gov/.

5. GPS-Meteorology (Ground-based)

Research Description: Global Positioning System meteorology (GPS-Met) system was developed by GSD to offer high temporal resolution, all-weather observations of precipitable water (PW) with accuracies comparable to radiosondes and surface microwave radiometers. These observations are assimilated into operational models and are used to validate in situ, satellite and model PW estimates. Since 2010, GSD has worked with private companies, other government agencies, other NOAA organizations, and universities to 1) use GPS-Met data to validate offshore weather predictions and investigate the accuracy of polar orbiting satellite vapor estimates; 2) demonstrate that "blackbox" zenith tropospheric delay (ZTD) estimates from commercial GPS data vendors should be verified to insure their accuracy is suitable for meteorological applications; 3) assisted with GPS-derived water vapor estimates to study deep convective time scales in the Amazon, and 4) assisted in verification of a new GOES precipitable water vapor retrieval algorithm which improved the accuracy and utility of GOES PW observations. GPS-Met data is assimilated in both NWS...
operational and OAR experimental weather forecast models and is used by forecasters to improve situational awareness. For more information, please visit http://www.gpsmet.noaa.gov/.

**Research to Applications:** In FY2014, a CRADA was awarded to Trimble, Ltd. The CRADA with Trimble demonstrated that commercial vendors can meet NWS requirements for atmospheric water vapor data used in operational models and for nowcasting. NWS was able to obtain the GPS-Met data through the one-year Mesonet Data Buy contract and will perform an initial assessment of the quality of the data in Q1 of FY16. At the same time, NWS will begin a more robust, fully competed, multi-year procurement process in first quarter of FY16 to purchase only the GPS-Meteorology data that will have more detailed requirements and quality thresholds. GSD will work closely with NWS during this process to ensure data quality and continued data delivery to NWS operational MADIS.

**Renewable Energy**

**Research Description:** ESRL’s efforts to assist with renewable energy sector began in 2008 and accelerated with a Department of Energy/National Renewable Energy Laboratory collaboration that began in 2010. In FY2013, Congress provided funding to ESRL for continued development of model physics and data assimilation to improve wind and solar prediction. The main focus of the ERSL Renewable Energy Program is to improve the skill of the 13-km Rapid Refresh (RAP) and 3-km High Resolution Rapid Refresh (HRRR) weather models, which the renewable industry considers state-of-the-art. Our efforts focus on improvements in skill of forecasting wind-turbine-height-winds and surface solar irradiance, which greatly impact the amount of wind and solar power, respectively, which can be produced. In the Wind Forecast Improvement Project-1 (WFIP1), GSD improved boundary-layer parameterizations in the RAP and HRRR using the modified Mellor-Yamada-Nakanishi-Nino (MYNN) scheme, such that the diffusion of momentum and heat more accurately simulate the low-level jet. These modifications to the surface-layer mixing length formulation have reduced the (high) bias in the forecasts of 10-m and 60-m wind speeds during the daytime. Also from WFIP1, GSD improved the surface-layer parameterization using the modified MYNN scheme, such that we reduced the (high) bias in the sensible heat fluxes in the previous version of the scheme. This reduction in sensible heat flux bias allows us to make more accurate forecasts of temperatures at 2m above ground. Lastly, in the WFIP1, GSD improved the RUC Land Surface Model (RUC LSM), utilized in the RAP and HRRR, by increasing the aerodynamic roughness lengths, further reducing the high 10-m wind speed bias. Additional layers were added to the RUC LSM soil model, allowing for a more accurate characterization of the heat conduction within the soil and an improved diurnal variation of the surface temperature. Together, these modifications allow the RUC LSM to more realistically represent the exchanges of heat, moisture, and momentum with the overlying atmosphere, which is crucial for low-level wind forecasting.

For the upcoming Wind Forecast Improvement Project-2 (WFIP2), the 13-km RAP, 3-km HRRR, and a 750-m HRRR Nest over the Pacific Northwest will be improved to better model turbine-height winds in regions of complex terrain. Specifically, in the PBL scheme, GSD will work to make parameterizations fully “scale aware”, including the development of 3D turbulence parameterization. Additional research will pursue z-less mixing-length formulations, the development of an eddy-diffusivity / mass-flux capability within the MYNN, and improved subgrid-scale cloud parameterizations. For improved surface-layer modeling, GSD will pursue sub 3-km
grid spacing within complex terrain. For the forest canopy model GSD will strive for very high vertical resolution \((dz < 10 \text{ m})\), and not resort to surface-roughness modifications to parameterize tall canopies. For the land-surface model, GSD will focus on heat and moisture fluxes with an aim to improve the lower-boundary condition for PBL. To improve subgrid-scale cloud representation (especially unresolved stratiform clouds), GSD will aim to develop a prognostic statistical cloud scheme with full radiative coupling. And for shallow cumulus parameterization, GSD will seek development of a scale-aware prognostic scheme with appropriate closures and stochastic capability.

Early 2015 in the Solar Forecast Improvement Project (SFIP), values for Global Horizontal Irradiance (GHI) were provided for the first time ever in the RAPvX model. In September 2015, GSD provided output for Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI) in the ESRL HRRR-X model. For further information, visit http://www.esrl.noaa.gov/research/renewable_energy/

**Research to Applications:** The WFIP1 improvements were in RAPv2 that went to NCEP in 2014. The SFIP improvements including the first-ever GHI output in ESRL RAP-X and the DNI and DHI in the ESRL HRRR-X will be implemented in the operational RAPv3 and HRRRv2 with the next NCEP implementation (scheduled for February 2016). Improvements from WFIP2 will be incorporated into RAP and HRRR and transitioned to NCEP in 2018 and 2019.
Decision Support

Research to Operations/Applications – Transition Readiness Level

Decision Support Systems

A Weather-Ready Nation requires system and software tools to help decision-makers issue and communicate timely and accurate weather information, including potential impacts from weather events. GSD works with decision-makers to understand their needs and develop decision support tools responsive to those needs.

1. Advanced Weather Interactive Processing System (AWIPS) Enterprise

Research Description: AWIPS, the information system used nationwide by the National Weather Service (NWS) for forecast operations, is the result of exploratory development and technology transfer conducted by GSD and its predecessor, the Forecast Systems Laboratory, since 1979. The first deployment of AWIPS to NWS Weather Forecast Offices (WFOs) was in 1998 followed by multiple enhanced operational builds by GSD through January 2010.

AWIPS has undergone a significant transition over the past ten years to a contractor-built (Raytheon), Java-based, service-oriented architecture now called AWIPS-II. However, by design, the look-and-feel of AWIPS-II is nearly identical to AWIPS-I and runs on the same hardware platform in the WFO’s. This transition was completed by the end of FY15 and NWS will award a new 10-year contract for its maintenance and evolution in 2016.
In the past five years, GSD has continued to be involved in the original AWIPS maintenance and enhancements which transitioned to NWS AWIPS during the AWIPS-II development and installation period. GSD also helped with the development and evaluation of AWIPS-II during its field evaluation and deployment phase. Specific AWIPS-II developments such as Forecaster Decision Support Environment (FDSE) and Hazard Services are discussed in the following sections.

2. **Graphical Forecast Editor (GFE)**

*Research Description:* The Graphical Forecast Editor (GFE) further NWS forecasting operations using AWIPS. Developed by GSD beginning in the early 1990s, the GFE is used by field staff (initially at Weather Forecast Offices and now moving into River Forecast Centers and the NWS/NCEP National Centers) to prepare a gridded database of weather elements extending out to seven days. This database is used to automatically generate routine forecast products (e.g., zone forecasts, point-and-click Web forecasts) and is also the basis for issuing and tracking long-term hazard statements and warnings (e.g., winter storms, wind storms).

Much of the development work over the past five years has focused on the standardization of commonly-used smart tools and procedures for NWS operations. This allows for easier maintenance and upgrades of these tools, as needed. GSD leads this activity through the NWS GFE Migration Strategy Group (GMSG). Development has also been done for improved aviation impact variables (e.g. ceiling and visibility, turbulence, and icing), and automated text generation for Terminal Aerodrome Forecasts (TAFs) and Tropical Storm text products. For additional information, visit [http://www.nwstc.noaa.gov/GFE/GFEBasicUser/](http://www.nwstc.noaa.gov/GFE/GFEBasicUser/).

*Research to Applications:* The GFE suite of software has been adopted by private industry and the meteorological services of other nations, such as The Central Weather Bureau (CWB) of Taiwan, and by the Bureau of Meteorology in Australia in 2006-2011 and the Spanish Meteorological Agency in 2010-2014. Beginning mid-2012, an additional focus has been on the expanded use of GFE at the NWS/NCEP National Centers and collaboration on forecast grids between the Tropical Prediction Center and coastal WFOs.

3. **Hazard Services**

*Research Description:* NWS hazard operations needed to be simplified and streamlined to provide forecasters better tools to perform their mission-critical job of providing lifesaving watches, warnings, and advisories. GSD collaborated with NWS and Raytheon Technical Services to combine functionality from three AWIPS-I legacy warning applications into an application for AWIPS-II. For more information, please visit: [http://integratedhazards.noaa.gov/](http://integratedhazards.noaa.gov/).

*Research to Applications:* The December 2015 field release of AWIPS-II will include a version of Hazard Services that will allow forecasters across the nation to experiment with the new functionality for hydrological hazards in a “Practice mode” setting. Input from the forecasters will be incorporated into the software to produce an operational system. The new functionality also supports disseminating hazard information through social media and mobile devices, and two-way...
exchanges between NWS forecasters and external partners such as emergency managers and law enforcement agents.

4. Forecaster Decision Support Environment (FDSE)

**Research Description:** The FDSE project (led by NWS) is a collection of risk reduction activities designed to test ideas and operational concepts for the forecast office of the future. FDSE will identify, develop, and test Environmental Intelligence Management Capabilities designed to enable the Weather Forecast Office forecasters to exploit the full range of data, tools, and knowledge available in the 2018 timeframe. The FDSE will not replace existing data processing and distribution mechanisms (e.g., AWIPS II and broadcast by the SBN) but rather will use these mechanisms as a strong foundation that will then be refined and augmented to deliver the enhanced capabilities as defined in the NWS Roadmap. A primary goal is to allow forecasters more time to devote to Impact-based Decision Support (IDS) within their areas of responsibility. Capabilities developed within the FDSE context will be implemented whenever they are determined to be operationally viable and can be transitioned to operations.

Four specific areas of development have been identified for initial GSD-lead development:

- **Hydrometeorological Grid Monitoring** - Provide real-time grid monitoring tools to identify deviations between forecast and observed sensible weather elements to prompt forecaster intervention in the process. Additional monitoring of significant impact weather events and climatological anomalies will be added this year for evaluation.

- **Short-term Forecast Update Tools** - Develop a new generation of smart initializations and model consensus approaches to streamline the forecast database population process and automate current labor-intensive processes.

- **Short-term Forecast Point Blend Method** – Develop a model weighting scheme that is based on a comparison between an objective analysis and the recent performance of each model for any given forecast point in the office’s area of responsibility.

- **Model Ensembles** - Provide intelligent verification-based statistics and the capability to select different model ensemble options rather than direct grid editing. The software will be available for WFO testing and evaluation via an AWIPS Test Authorization Note (ATAN).

**Research to Applications:** Over the past two years (2013-2014), initial prototypes for these four capabilities were developed and refined, based on user feedback. The focus for 2015-2018 is “operationalizing” these initial capabilities, hosting a workshop, and testing in NWS Operational Proving Ground to determine the best methods and operational procedures for these FDSE components. For example, work is near completion on the initial ensemble tool integration into the December 2015 field release of AWIPS-II to allow testing by and feedback from forecasters.
5. **AWIPS-Based System Support for Fire Weather: FX-Net System**

*Research Description:* FX-Net began as a prototype meteorological PC workstation providing access to the basic display capability of an AWIPS I workstation via the Internet. The FX-Net system provides full AWIPS visualization and data analysis capability with a Graphical User Interface (GUI) that closely emulates the standard AWIPS I workstation, allowing the NWS Incident Meteorologists (IMETs) to move seamlessly between their Weather Forecast to FX-Net in the field. In 2001, FX-Net was integrated into NWS operations through its regional offices with continued support from GSD.

As FX-Net has evolved, new products have emerged such as Gridded FX-Net which is also used by field-offices for retrieving and manipulating model data. Gridded FX-Net is an AWIPS I workstation architected by GSD to work from a network-remote location. For further information, visit http://fx-net.noaa.gov/.

FX-Net and Gridded FX-Net are actively being used by the National Interagency Fire Center (U.S. Forest Service, Bureau of Land Management, and others) in support of their Geographic Area Coordination Centers (GACCs) during fire weather season. This operational use allows GSD to develop and evaluate next generation system designs such as client and server virtualizations (referred to as FX-CAVE) which can feed back into the NWS AWIPS-II evolution.

*Research to Applications:* The FX-Net support for IMETs and aviation was fully transitioned over to NWS ownership in FY2013.

6. **AWIPS-II-Based System Support for Fire Weather: FX-CAVE System**

*Research Description:* The FX-CAVE workstation is the next generation of meteorological workstation based on the AWIPS II CAVE workstation. It will eventually make the FX-Net System obsolete. The National Interagency Fire Center (NIFC), and its eleven field offices, are transitioning to FX-CAVE starting in 2015. Agreements are in place to proceed indefinitely with this interagency cooperation. Like FX-Net, FX-CAVE is another successful experimental application of the GSD blueprint which remains unchanged for 30 years: work with users to determine requirements, build solution systems, and iterate.

*Research to Application:* In addition to the FX-Net workstation, the GACC forecasters are beginning to use FX-CAVE: Two remote Virtual Machine users (Boise and Albuquerque) and two desktop application users (Redding and Boise) will provide feedback to GSD developers. The GACC forecaster in Albuquerque used (and continues to use) a virtual FX-CAVE application served entirely from GSD for almost the entire 2015 fire weather season. Not only was the forecaster provided with excellent performance and reliability from FX-CAVE, but a working model of a future enhancement to AWIPS-II was demonstrated convincingly.

7. **Hurricane Forecast Improvement Program (HFIP): Consolidated Display of Products**

*Research Description:* After Hurricane Katrina, Congress provided significant research funding to several organizations for better hurricane prediction. NOAA’s HFIP program provided funds to GSD to develop a website which consolidates and centralizes the products from different experimental
and operational weather and hurricane models and effectively displays them in uniform formats for comparison. For more information, see http://www.hfip.org/products/.

**Research to Applications:** Starting in 2012, the website displaying the various HFIP products was used by National Hurricane Center (NHC) forecasters, NWS managers, and FEMA managers who continue to use the information provided as a quasi-operational forecasting tool for tropical weather events. NHC said that the “website is great and most impressed with the fact that it works on their iPads and smartphones”.

8. **INtegrated Support for Impacted air-Traffic Environments (INSITE)**

**Research Description:** INSITE is a web-based prototype that extends the typical use of forecast weather information by combining it with air traffic data to determine potential impacts to aviation operations. INSITE incorporates weather information from observations as well as from five convective weather forecast products. In addition to displaying the original weather products, a constraint field derived from each forecast product using a combination of weather and traffic density information is provided, highlighting potential impacts to air traffic based upon the forecast weather. INSITE also provides a weighted average of the five constraint forecasts, considered a ‘synthesis’ of the products. Each constraint forecast includes a measure of confidence of that forecast, or in the case of the synthesis, a measure of the consistency between the five member forecasts. Another key feature of INSITE is that the user can interact with the application to outline a region of interest to determine the severity of constraint within that region. More detailed constraint information can be viewed specific to this region with respect to airways or Air Route Traffic Control Centers (ARTCCs) that intersect it.

Users of INSITE include AWC forecasters, the National Aviation Meteorologist at the FAA Air Traffic Control Systems Command Center, and local WFO and Center Weather Service Unit (CWSU) offices. For further information, visit http://esrl.noaa.gov/fiqas/tech/impact/insite/

**Research to Applications:** Work is ongoing to transition INSITE to NWS operations in the May-June 2017 timeframe.

**Assessment and Verification**

GSD performs in depth assessments of forecast quality to verify that the most accurate weather information is provided to planners and decision makers, including assessments of new software products’ readiness for NWS operations. This work is supported by both the FAA and NWS.

1. **Technical Reports for NWS and FAA/AWRP**

**Research Description:** To provide targeted weather information to aviation weather consumers, the Federal Aviation Administration Aviation Weather Research Program (AWRP) is developing automated aviation weather forecast products for icing, turbulence, ceiling and visibility, and convective weather. Prior to the transition of these products to NWS operations, these forecast products are extensively evaluated for quality and accuracy. GSD provides this independent assessment as the Quality Assessment Product Development Team and is responsible for delivering
scientific evidence of product quality in the context of aviation operations. The customers of AWRP weather products include the aviation industry, FAA operations, and NWS Aviation Weather Forecasters. The customers of the GSD evaluations include: the FAA AWRP as part of their research transition process, aviation weather product developers, and FAA Project Managers and decision makers.

Research to Applications: Over the past 10 years, GSD has evaluated 19 weather products for transition to NWS operations. Of those products, eight have completed a full transition to operations. The related GSD publications can be found at the following web site: http://esrl.noaa.gov/fiqas/publications.html

2. TRACON Gate Forecast and Verification Tool

Research Description: Certain CWSU offices produce a TRACON (Terminal Radar Approach Control) Approach and Departure Gate Forecast product communicating potential convection-based impacts to sectors within the TRACON using a traffic light format. The NWS Aviation Weather Center has developed an automated tool to centralize production of these forecasts, and in the future will allow forecaster-over-the-loop edits to the automated product. The NWS Aviation and Space Weather Services Branch has tasked GSD to develop a peer automated verification tool that will produce performance metrics of the automated and forecaster-modified products, with statistics made available via a web user interface.

Research to Applications: GSD has developed a prototype tool that provides performance metrics for the automated output, including both traditional techniques and event-based techniques that measure skill with respect to the onset and cessation of impactful convective events. Activities in 2015-16 include expansion of the tool to incorporate forecaster-modified output, and preparatory activities for transition of the tool to NWS operations in 2018. This tool will be used to track performance for the automated forecast product as well as the value added by the human forecaster.

3. CWSU Briefing and Verification Tool (CBVT)

Research Description: NWS meteorologists at the 21 Center Weather Service Units (CWSUs) provide decision support services at FAA Air Route Traffic Controller Centers (ARTCCs). The CWSU meteorologists provide routine and on-demand briefings containing weather forecast information critical to FAA Traffic Flow Management (TFM) decisions (e.g., winds that could affect runway configuration changes, ceiling and visibility). Each CWSU is required to track and verify their forecast information for specific variables, which is currently done manually, with approaches that vary by CWSU. As part of the NWS initiative to centralize and standardize verification processes that are currently performed manually by individual CWSUs, the Aviation and Space Weather Services Branch has funded GSD to develop the CBVT. This tool is a prototype web application allowing CWSU forecasters to enter forecast information they have provided to TFM for wind events impactful to current terminal configurations. The tool will also provide automated verification capabilities for these forecasts and the results will be used by the NWS to track and report performance metrics to the FAA as part of their quality assurance activities.
Research to Applications: The tool is currently being tested and evaluated by a subset of CWSUs established as a focus group, and will be expanded in 2015/16 to provide automated verification capabilities for these forecasts. The tool incorporates event-based verification techniques that measure forecast performance with respect to onset of impactful wind events.

4. Verification Requirements Monitoring Capability (VRMC)

Research Description: VRMC is an automated, web-based application developed by GSD that supports the product assessment and monitoring activities sponsored by the FAA Aviation Weather Research Program. The VRMC serves as a supporting tool for formal, in-depth forecast quality assessments; provides an ongoing historical performance record of forecast quality to serve as a baseline for evaluating future developments in aviation weather products; and provides a platform for assessment and methodology configuration management and statistical baseline control. The tool incorporates verification techniques that measure product quality relative to operational decision criteria, for both Turbulence and Icing products. Verification statistics are computed via backend processing, stored in a relational database, and made available via a web interface in the form of graphical plots and tables.

Research to Applications: The VRMC has Icing and Turbulence components that correspond to formal quality assessments performed by GSD as part of the FAA AWRP-sponsored Quality Assessment Product Development Team. The verification results have been utilized in quality assessment reports as part of the AWRP formal transition process of aviation weather products into operations.

5. Real-Time Verification System (RTVS)

Research Description: The National Weather Service has a need for a comprehensive and adaptive verification/performance management system to collect, report, and interpret key measures and indicators related to the quality, timeliness, accuracy, and usefulness of its products and services. As part of this comprehensive NWS verification system, the NWS has stated the need for an aviation verification capability. The Real-Time Verification System (RTVS) was developed to provide automated verification of aviation weather products and was a technological opportunity for the NWS. RTVS provides automated real-time verification tools for four aviation weather service areas: convection, ceiling and visibility, icing, and turbulence. RTVS is currently the most comprehensive system of ongoing performance metrics for NWS Aviation Weather products, and provides a historical performance record for aviation products that is used to track and improve the quality of aviation forecasts, as well as a feedback mechanism to managers, forecasters, and operational planners. RTVS users include the NWS Aviation and Space Weather Services Branch, NWS Aviation Weather Center, Alaska Aviation Weather Unit, Center Weather Service Units, and others.

Research to Applications: RTVS has been operated by GSD staff since 1999 in a quasi-operational mode to support the historical record of NWS aviation forecast performance, feedback to NWS and Federal Aviation Administration (FAA) aviation forecasters, managers, and decision makers, and the transition of experimental forecast products into NWS operations. Monthly reports of verification statistics from RTVS are provided to the NWS for product performance tracking.
6. Event-Based Verification and Evaluation of NWS Gridded Products Tool (EVENT)

Research Description: The EVENT Tool, sponsored by NWS Aviation and Space Weather Services Branch, supports NWS efforts to measure forecast accuracy relative to aviation traffic flow management decisions. The tool provides ongoing, automated computation of verification statistics that are made available via an interactive web user interface, for users to query results for specific date ranges, issues, leads, or locations. The performance metrics included in the tool are framed by requirements established by the Traffic Flow Management Weather Requirements Working Group, a joint FAA/NWS working group formed to baseline current weather support to Traffic Flow Management and determine requirements for weather services. The underlying verification techniques in the tool are event-based verification techniques that measure product performance with respect to prediction of the onset and cessation of weather events impactful to aviation operations. Current capabilities provide performance metrics for products in the context of thunderstorm events relevant to both terminal and en-route operations, and provide multiple views within the web application to evaluate product performance for several NWS products, including National Digital Forecast Database (NDFD), RAP, Localized Aviation MOS Program (LAMP) product, and HRRR.

Research to Applications: The EVENT tool is an actualization of the NWS and FAA initiative to evaluate product performance in the context of the product’s operational use. Beginning in 2011 the tool is used by the NWS to monitor product performance with respect to these new, operationally-relevant performance requirements. It is currently being expanded to incorporate verification capabilities for products with respect to wind events at the terminal and should transition to operations in 2018.
Advanced Technologies

Research to Operations/Applications – Transition Readiness Level

Fine Grained Computing Technologies

GSD’s High Performance Computing Section supports the development of new models and conducts research and development in next-generation high-end computing. Tools are developed to improve the ability to port, test and run models in diverse computing environments including shared memory clusters, distributed memory Linux clusters, Graphics Processing Units (GPUs), and Many Integrated Core (MIC) fine-grain parallel computers. Modeling support activities include parallelization and optimization of regional and global atmospheric weather models, with occasional focus on upper atmosphere, chemistry and ocean models.

1. **Dependency Driven Test System (DDTS)**

   **Research Description:** GSD has designed and developed a tool called the Dependency Driven Test System (DDTS) to rigorously compose and test models being modified by scientists, parallelization experts and support staff. A series of regression tests can be composed by scientists, software engineers, or parallel programmers to ensure changes made to source code do not result in unexpected or erroneous results being generated. In addition, computational tests can test the model’s ability to run on CPU, GPU, and MIC chips using Message Passing Interface (MPI), OpenMP
and OpenACC compilers to insure correct results and track performance. New tests can be easily composed and added when needed to cover a new model capability or computing requirement. As a result, DDTS is now an essential part of the model development and test cycle at GSD.

**Research to Application:** Past research and development activities for fine-grain computing includes porting and running a new weather model, called the Non-hydrostatic Icosahedral Model (NIM), on GPUs in 2009, and Intel MIC in 2012 when it became available. NIM code is written in Fortran, with industry standard OpenACC and OpenMP directives used for parallelization that target CPU, GPU, and MIC architectures. The Scalable Modeling System (SMS) is used to support MPI-based parallelization via a support library and directives that are inserted into the code. Collectively, the directives and library allow a single NIM source code to be maintained that has demonstrated good performance and scaling to thousands of CPU, GPU, or MIC devices.

2. **Massively Parallel Fine Grain (MPFG) Computing/Compiler**

**Research Description:** In support of Graphical Processor Unit (GPU) research, GSD has developed a compiler to convert our scientific codes, originally written in Fortran, into CUDA, the language supported on GPUs. The Fortran-to-CUDA compiler, called F2C-ACC, was developed to reduce the time required to run on the GPU. CUDA is based on C programming language with some additional extensions to call GPU routines (kernel codes), move data between the host Central Processing Unit (CPU) and GPU and to manage computations and memory on the GPU. The F2C-ACC compiler was developed from 2009-2012 to support the parallelization of the NIM for NVIDIA GPUs. It has also been used for parallelization of its predecessor model called the Flow-following Finite-volume Icosahedral Model (FIM), and portions of the Weather Research and Forecast Model (WRF).

Development of F2C-ACC began before commercial Fortran GPU compilers were available. It has since become the standard by which commercial compilers are judged, and an effective vehicle to gain important and substantial improvements in the openACC compilers. GSD conducted four evaluations of commercial compilers in 2011, 2012, 2014, and 2015. A comprehensive performance evaluation in 2014 showed the Cray and PGI compilers were running the NIM 1.7 and 2.1 times slower than F2C-ACC. GSD worked with vendors to identify and address performance issues by sharing F2C-ACC, code and expertise. As a result, recent results show PGI (Cray evaluation pending) has closed the substantial performance gap and now offers equivalent performance to F2C-ACC.

**Research to Applications:** The compiler was released to the community in 2009, and has been used by researchers worldwide. GSD worked with vendors to identify and address their compiler performance issues by sharing F2C-ACC, code and expertise. This development has been noted in many web pages and technical documents released by NVIDIA, Inc., the leading manufacturer of GPUs.

**Environmental Information Systems**

GSD develops technologies that allow users to visualize and answer questions requiring data from different data sources regardless of format or location. In particular, GSD is exploring better
methodologies to help users exploit “big data” resulting from high resolution global models and the latest environmental satellites and sensors.

1. **NOAA Earth Information System (NEIS)**

*Research Description:* NOAA’s data dissemination, data management and decision support systems are challenged to adequately handle a new wave of data volume and data requests. In addition to increased volume, there is an increase in the velocity of throughput required for structured, semi-structured, and unstructured data flowing into and out of NOAA. NEIS will make the data discovery, access, analysis, and processing agnostic to the visualization environment and interoperable between systems. This will allow legacy systems to utilize the underlying NEIS information management infrastructure to immediately access a suite of real time information needed for the environmental ‘problem of the day’ allowing NOAA and its partners to do their mission. Sometimes it’s a matter of finding, sometimes processing, sometimes accessing, sometimes visualizing diverse information in the context of today’s problem. NEIS works to address all of those needs. A patent is pending for the NEIS technology and capability. For further information, visit [http://www.esrl.noaa.gov/neis/](http://www.esrl.noaa.gov/neis/)

*Research to Applications:* Through the High Impact Weather Prediction Project (HIWPP), NEIS is providing interested parties (researchers, private companies, and public) research grade near real-time data delivery and visualization allowing them to compare and analyze research models. Through this program, participants for the first time have access to new weather forecast models under development and can provide feedback to the model developers on model performance from many different perspectives around the world. Additionally, the NEIS team has worked with the National Weather Service Integrated Dissemination Program (IDP) team to discuss how NEIS is using new technologies and data delivery concepts and how they could be used for future services within the IDP infrastructure to deliver data in a timelier fashion.

2. **TerraViz: Using Gaming Technology**

*Research Description:* GSD is using technology created by the video game industry to drive the next generation of interactive data visualization and analysis. While video game technology may seem a strange choice, it takes advantage of existing off-the-shelf technologies. Additionally, it can run on many platforms: desktops, browsers, and mobile devices. A patent is pending for GSD’s invention of TerraViz. Video games are a multi-billion-dollar industry, and represent an ideal choice for providing a wealth of data to a user in realtime. The industry harnesses the power of graphics card technology (GPUs) available in commodity PCs to render and display information in efficient ways. For further information, visit [http://www.esrl.noaa.gov/neis/library/terraviz-video.html](http://www.esrl.noaa.gov/neis/library/terraviz-video.html)

*Research to Applications:* As research progressed it became clear that TerraViz could be used for both scientists and educators. Two different products emerged - the NOAA Earth Information System was developed for scientific use and SOS Explorer™ was developed for educational and public use. SOS Explorer™ creates an interactive Earth for flat screen displays including those projected on walls, computers, and large displays, providing teachers, students, and the public their own personal SOS. In addition, tools included in the application allow users to zoom into, probe,
and graph the data, as well as add supplementary material including websites, videos, pictures, and place marks.

3. **Specialized Information and Warning Systems**

*Research Description:* GSD develops prototype systems and tools that explore ways to better communicate the impact of weather events, weather related hazards, and other natural disasters to non-scientist and operational decision makers. The Specialized Information and Warning Systems include the following three different systems:

- **The Traffic Management Unit (TMU) project** started in 2001 and was an effort to take all the convective hazard products and combine them in a graphic that could be easily understood by FAA Air Route Traffic Controllers to help with their air traffic routing decision making process. TMU efforts experimented with displays tailored for FAA traffic manager's use, improved briefing capabilities, improved methods for integrating data, and tools for forecasters to facilitate the creation, delivery, and accuracy of forecasted impacts to airspace.

- **The Volcanic Ash Coordination Tool (VACT)** started in 2004 with a goal of improving the ability to coordinate and communicate the impacts of a volcanic ash event. The project explored tools for collaborating, briefing, forecasting, and sharing of data to improve the warnings and watches that were issued for volcanic events.

- **The Geo-Targeted Alerting System (GTAS)** started in 2009 to improve the understanding of impacts to society of a toxic chemical release. The GTAS system incorporated the latest advancements in chemical plume modeling, high resolution weather models, and network-enabled operations to build upon NWS operational meteorological information and warning infrastructure and the Federal Emergency Management Agency's (FEMA) Integrated Public Alert and Warning System (IPAWS) to enable emergency managers and first responders from their desktops to collaborate with their local Weather Forecast Office to provide more accurate and timely warnings for toxic plume events.

*Research to Applications:* TMU: AWIPS-II aviation product display capabilities came directly from TMU efforts. TMU and VACT: Provided requirements for AWIPS-II collaboration, thin client, and drawing tools. GTAS: By 2011, GTAS had been implemented in seven cities as well as FEMA headquarters in Washington, D.C. and although GTAS met all the FEMA requirements, FEMA discontinued funding after FY2011 and the project was discontinued.

4. **Meteorological Assimilation Data Ingest System (MADIS)**

*Research Description:* MADIS is a global database and delivery system developed at ESRL/GSD beginning in July 2001 that serves the greater meteorological community by supporting the collection, integration, quality control, and distribution of many thousands of NOAA and non-NOAA observations. This includes observations from over 60,000 surface mesonet stations from local, state, and federal agencies, plus private networks. MADIS also collects upper-air data sets, including multiagency wind profilers, and ground-based radiometer observations.
The purpose of MADIS was to leverage the many public and private observations available by integrating them into a single database in a form that could easily be used by data assimilation, numerical weather prediction models, and forecasters. MADIS receives these observations with different formats, units, and time stamps, and integrates them into a single uniform database. The wealth of observations available through MADIS improves the lead-time of forecasts and severe weather warnings. In addition to providing the assimilated data in near real time, MADIS also supplies data providers with quality control and station monitoring information to assist in their maintenance activities and to enhance and promote the mutual benefits of public/private data sharing.

**Research to Applications:** MADIS achieved quasi-operational status at NWS on September 30, 2010. The transition to full operations at NWS was completed January 21, 2015. Three systems were transitioned into operations: a real-time system for ingest, processing and distribution; a data recovery system; and an archival system. Operational MADIS is administered and supported by NCEP Central Operations (NCO) with the MADIS archive being housed at the NESDIS National Centers for Environmental Information (NCEI) and improvements to the system being provided by Science On a Sphere® (SOS) Program

1. **SOS Technology, Data, and Installations**

**Research Description:** Technical innovation and development of the SOS system’s capabilities has rapidly progressed since 2010, with regular software releases and new technology deployment made at SOS sites worldwide. Below are examples from three main research areas with status of five years ago versus the current status.

SOS has leveraged available technology improvements in computer systems, projectors, graphics cards, networked cameras, and controller devices.

<table>
<thead>
<tr>
<th>Hardware for SOS</th>
<th>2010 Status</th>
<th>2015 Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon fiber sphere</td>
<td>68” diameter only</td>
<td>68” + smaller/larger sizes</td>
</tr>
<tr>
<td>Computer Systems</td>
<td>5 PCs/graphics cards</td>
<td>1 PC/graphics card</td>
</tr>
<tr>
<td>Projectors</td>
<td>Standard definition</td>
<td>High Definition &amp; 4K/Ultra HD</td>
</tr>
<tr>
<td>Controllers</td>
<td>Wii game controller</td>
<td>iPad/iPhone App (Wi-Fi &amp; Bluetooth)</td>
</tr>
<tr>
<td>Alignment</td>
<td>Manual via Wii remote</td>
<td>Visual iPad/iPhone App controls; Automated using computer vision</td>
</tr>
</tbody>
</table>

SOS custom software has steadily improved to provide better preparation and delivery of SOS shows, including SphereCasting to conduct remote broadcasting to other SOS sites, and new widely requested public kiosk software.
Software for SOS

<table>
<thead>
<tr>
<th></th>
<th>2010 Status</th>
<th>2015 Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visualization</td>
<td>Basic 3D rendering</td>
<td>Added sphere section replication</td>
</tr>
<tr>
<td>Giving Presentations</td>
<td>Desktop interface or Wii controller</td>
<td>Full iPad App with data descriptions &amp; customizable presenter notes</td>
</tr>
<tr>
<td>Display Tools</td>
<td>Minimal</td>
<td>Annotations, custom cursors, drawing, &amp; regional magnification</td>
</tr>
<tr>
<td>Creating Presentations</td>
<td>Text editor for playlists</td>
<td>Graphical playlist editor; Playlist builders on iPad and website</td>
</tr>
<tr>
<td>Public Kiosk</td>
<td>Unsupported, 3rd party</td>
<td>NOAA kiosk with easy configuration</td>
</tr>
<tr>
<td>SphereCasting</td>
<td>Basic functionality</td>
<td>Full SOS support with streaming video</td>
</tr>
</tbody>
</table>

Innovation in hardware and software has enabled greater volumes and resolutions of datasets for SOS. As the data collection has grown, more data management capabilities have been added to the software and website, including localization to support a rapidly growing non-English speaking audience.

Content for SOS

<table>
<thead>
<tr>
<th></th>
<th>2010 Status</th>
<th>2015 Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-Time Data</td>
<td>Initial capabilities</td>
<td>0.5 TB of satellite and NOAA model data distributed daily worldwide</td>
</tr>
<tr>
<td>Dataset Resolution</td>
<td>Limited to 4K</td>
<td>Datasets with resolutions up to 16K</td>
</tr>
<tr>
<td>Data Catalog</td>
<td>File system navigation for a few hundred datasets</td>
<td>Added metadata query and browse for 500+ datasets on website and iPad</td>
</tr>
<tr>
<td>SOS Website</td>
<td>Static pages viewed on desktop browsers</td>
<td>Extensive information and dataset access, adaptive to many screen sizes</td>
</tr>
<tr>
<td>Language Localization</td>
<td>English only</td>
<td>Chinese website content; Translation support in user interfaces</td>
</tr>
<tr>
<td>Use of Data Standards</td>
<td>Common image and movie formats</td>
<td>Display Google Earth KML/KMZ files; Direct web mapping (WMS) support</td>
</tr>
</tbody>
</table>

Research to Applications: In June of 2010 the 50th Science On a Sphere was installed. In September of 2015, the 128th Science On a Sphere was installed. The growth seen by the Science On a Sphere (SOS) project is evidence of the educational value of the exhibit. This popular outreach tool for NOAA continues to be installed in museums, universities, labs, and visitor centers around the world. SOS serves as a way to help NOAA inspire the next generation of scientists by engaging students in a wide variety of Earth system topics ranging from climate change to tsunamis to hurricanes. It also extends NOAA goals of an environmentally literate society that is able to make informed decisions.
It is estimated that SOS is seen by over 33 million people every year. For further information, visit http://sos.noaa.gov/What_is_SOS/

2. **Science On a Sphere Explorer™ (SOSX)**

*Research Description:* While Science On a Sphere has seen great growth in the last five years, there is still room for further expansion. In order to meet the needs of teachers and schools that aren’t able to install a full Science On a Sphere exhibit in their schools, NOAA has developed SOS Explorer™ (SOSx), a desktop based version of SOS that can be used in classrooms and on personal computers. SOSx builds on the success of SOS and adds even more interactive capabilities. SOS Explorer™ uses the NOAA-developed TerraViz™ visualization engine to create an interactive Earth for a flat screen display including those projected on walls, computers, and large displays, providing teachers, students, and the public access to a library of selected Science On a Sphere® datasets and movies. The visualizations show information provided by satellites, ground observations and computer models and rapidly animate through real-time global data. In addition, tools included in the application allow users to zoom into, probe, and graph the data, as well as add supplementary material including websites, videos, pictures, and placemarks. In order to make the product more accessible for teachers, lesson plans and pre-programmed tours through standards-relevant topics are provided. For further information, visit http://sos.noaa.gov/SOS_Explorer/

*Research to Applications:* The first public version of SOSx was released on September 1, 2015. This version comes with 15 datasets, three educational tours and supplementary lesson plans. It was featured on the NOAA and OAR homepages after its release, in addition to appearing in news articles, blogs, and social media. Within two weeks of its release, SOSx had been downloaded and used by over 750 people in 44 countries.
Daily number of new users of SOSx within the first two weeks.

Locations of SOSx usage within the first two weeks of release.
Summary of GSD’s Technology Transfer Projects

<table>
<thead>
<tr>
<th>GSD Tech Transfer Project Name</th>
<th>TRL</th>
<th>Date Transfer Started</th>
<th>Date Transfer Completed</th>
<th>Expected Transfer Date</th>
<th>Transfer to What</th>
<th>Description of what is being transferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid Refresh (RAP) Model v1</td>
<td>TRL 9</td>
<td></td>
<td>5.01.2012</td>
<td></td>
<td>NWS/NCEP/EMC</td>
<td>RAPv1 replaced the Rapid Update Cycle (RUC) operational model, expanding the domain from CONUS to all of North America but maintaining resolution at 13-km. RAP uses the WRF-ARW and GSI community code. The RAP benefits users needing frequently updated short-range weather forecasts, including those in the US aviation community and US severe weather forecasting community.</td>
</tr>
<tr>
<td>Rapid Refresh (RAP) Model v2</td>
<td>TRL 9</td>
<td></td>
<td>2.25.2014</td>
<td></td>
<td>NWS/NCEP/EMC</td>
<td>RAPv2 provides significant improvement over RAPv1, a 13-km resolution, hourly-updated, North American weather model. RAPv2 improves winds/upper-air forecasts, mid-level moisture, near-surface fields, and convective environments. The enhancements will benefit users needing frequently updated short-range weather forecasts, including, those in the US aviation community and US severe weather forecasting community. Also used prominently for energy-related (especially renewable) forecast guidance.</td>
</tr>
<tr>
<td>Rapid Refresh (RAP) Model v3</td>
<td>TRL 8</td>
<td>1.01.2015</td>
<td>2.15.16</td>
<td></td>
<td>NWS/NCEP/EMC</td>
<td>RAPv3 provides significant improvement over RAPv2 for summer/winter storm environment, advanced physics with WRFv3.6, assimilation, and improved initiation conditions for HRRR.</td>
</tr>
<tr>
<td>High Resolution Rapid Refresh (HRRR) Model v1</td>
<td>TRL 9</td>
<td></td>
<td>9.30.2014</td>
<td></td>
<td>NWS/NCEP/EMC</td>
<td>The HRRR is a NOAA real-time 3-km resolution, hourly updated, cloud-resolving, convection-allowing atmospheric model, initialized by 3km grids with 3km radar assimilation over a 1-h period, adding further detail to the HRRR initial conditions otherwise determined by the hourly data assimilation from the 13km radar-enhanced RAP model. It will provide significant improvement in convective forecasts.</td>
</tr>
</tbody>
</table>

Research Area: NUMERICAL WEATHER PREDICTION
<table>
<thead>
<tr>
<th>Project Name</th>
<th>Started</th>
<th>Completed</th>
<th>Date</th>
<th>Entity</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Resolution Rapid Refresh (HRRR) Model v2</td>
<td>TRL 8</td>
<td>1.01.2015</td>
<td>2.15.16</td>
<td>NWS/NCEP/EMC</td>
</tr>
<tr>
<td>WRF-Chem Model</td>
<td>TRL 7</td>
<td>1.01.2000</td>
<td></td>
<td>U.S. Air Force, Other Countries Weather Agencies</td>
</tr>
<tr>
<td>North American Rapid Refresh Ensemble (NARRE) and the High-Resolution Rapid Refresh Ensemble (HRRRE)</td>
<td>TRL 7</td>
<td>2010</td>
<td>2017 - 2019</td>
<td>NWS/NCEP/EMC</td>
</tr>
</tbody>
</table>

HRRRv2 provides significant improvement for summer/winter storm environment, in surface forecasts, and advanced physics.

WRF-Chem is the Weather Research and Forecasting (WRF) model coupled in-line with atmospheric chemistry. This international community-developed model simulates the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. The model is used for investigation of regional-scale air quality, field program analysis, and cloud-scale interactions between clouds and chemistry. Coupled with the HRRR model, the experimental HRRR-Chem provides real-time predictions for smoke transport from wildfires that are used by the National Interagency Fire Center.

GSD is working with the NWS/EMC and DTC to develop the North American Rapid Refresh Ensemble (NARRE) as an hourly-updated ensemble related to the current 6-8-member SREF (Short Range Ensemble Forecast) now running at NWS. According to the EMC roadmap, the new 6-member NARRE is scheduled for operational implementation in 2017. (Currently, a preliminary time-lagged version of NARRE using multiple RAP members initialized at different times is running at NCEP). After 2017, the next implementation will be for the HRRRE to provide 3-km, hourly updated probabilistic forecast guidance. An experimental time-lagged HRRRE has been running in real time, producing thunderstorm probability grids which have been delivered to the Aviation Weather Center (AWC) and Storm Prediction Center (SPC) for the last 3 years. Over the next three years the work will advance to enable a transition of HRRRE (or High-Resolution Ensemble Forecast - HREF) to operations in 2019.

GSD Tech Transfer | TRL | Date Transfer | Date Transfer | Expected Transfer to What |
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Description of what is being transferred</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Name</td>
<td>Started</td>
<td>Completed</td>
<td>Date</td>
<td>Entity</td>
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</tr>
<tr>
<td>High Impact Weather Prediction Project: Knowledge/reports</td>
<td>TRL 6</td>
<td>4.01.2013</td>
<td>2.28.2016</td>
<td>NWS/OD</td>
</tr>
<tr>
<td>Hazardous Weather System for U.S. Space Centers--Air Force Range Standardization and Automation(RSA)/AWIPS and LAPS</td>
<td>TRL 8</td>
<td>2001</td>
<td>Ongoing</td>
<td>USAF Vandenberg Air Force Base</td>
</tr>
<tr>
<td>Global Precipitation Measurement (GPM) Product Assessment</td>
<td>TRL 5</td>
<td>10.01.2013</td>
<td>9.30.2015</td>
<td>JCSDA/NASA</td>
</tr>
<tr>
<td>Global Positioning System Meteorology (GPS-Met Data)</td>
<td>TRL 8</td>
<td>2016</td>
<td>Commercial contractor</td>
<td>Commercial contractor</td>
</tr>
</tbody>
</table>
Completed in June 2015, the GSD CRADA demonstrated that commercial vendors can meet NWS requirements for atmospheric water vapor data used in operational models and for nowcasting. NWS was able to obtain the GPS-Met (ground-based GPS-meteorology) data through the one-year Mesonet Data Buy contract and will perform an initial assessment of the quality of the data in Q1 of FY16. At the same time, NWS will begin a more robust, fully completed, multi-year procurement process in first quarter of FY16 to only purchase the GPS-Meteorology data that will have more detailed requirements and quality thresholds. GSD will play a role in the transition after a contract is awarded.

### Research Area: DECISION SUPPORT

<table>
<thead>
<tr>
<th>GSD Tech Transfer Project Name</th>
<th>TRL</th>
<th>Date Transfer Started</th>
<th>Date Transfer Completed</th>
<th>Expected Transfer Date</th>
<th>Transfer to What Entity</th>
<th>Description of what is being transferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard Services Tool</td>
<td>TRL 7</td>
<td>2009</td>
<td>Ongoing</td>
<td>2017</td>
<td>NWS/WFOs</td>
<td>The Hazard Services Tool integrates several software tools into a common interface for issuing timely and accurate hazard information and building a two-way communication platform for collaboration among all decision-makers. It was made available in the AWIPS II September 2015 release in a &quot;practice mode&quot; setting for NWS forecasters and test sites to use and provide feedback to GSD developers.</td>
</tr>
<tr>
<td>GFE Tools for NCEP National Centers</td>
<td>TRL 7</td>
<td>2012</td>
<td>Ongoing</td>
<td>2020</td>
<td>NWS/NCEP</td>
<td>Streamlining the forecast process at the NCEP National Centers to produce gridded forecasts replacing outdated methodologies.</td>
</tr>
<tr>
<td>FDSE Decision Support Tools</td>
<td>TRL 6</td>
<td>2012</td>
<td>Ongoing</td>
<td>2017</td>
<td>NWS/WFOs</td>
<td>For the NWS Forecast Decision Support Environment (FDSE) project, develop three decision support components: Gridded Forecast Monitor, Short-Term Update Techniques, and an Ensemble Tool</td>
</tr>
<tr>
<td>GSD Integrated Support for Impact Air Traffic Environments (INSITE)</td>
<td>TRL 6</td>
<td>2011</td>
<td>Ongoing</td>
<td>2017</td>
<td>NWS/NEXTG EN/IDP</td>
<td>The Integrated Support for Impacted air-traffic Environments (INSITE) prototype provides guidance to NWS forecasters by combining weather and traffic data to produce detailed information on the potential impacts of forecast convective weather to en-route aviation operations.</td>
</tr>
<tr>
<td>Transfer Project Name</td>
<td>Transfer Started</td>
<td>Transfer Completed</td>
<td>Transfer Date</td>
<td>to What Entity</td>
<td>transferred</td>
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<td>-----------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Aviation Weather Forecast Product Assessments</td>
<td>None</td>
<td>2000</td>
<td>Ongoing</td>
<td>FAA and NWS</td>
<td>As part of the evaluation process for transitioning new aviation weather products into operations, GSD is often tasked by NWS and/or FAA to conduct new product assessments to help determine their operational viability. Technical reports are developed and issued or presentations of the findings are given to NWS and/or FAA.</td>
<td></td>
</tr>
<tr>
<td>Real-Time Verification System (RTVS)</td>
<td>TRL 8</td>
<td>1996</td>
<td>Ongoing</td>
<td>None</td>
<td>Used for NWS operations. The Real-time Verification System (RTVS) is an outdated tool for assessing the quality and effectiveness of weather observations, warnings, and forecasts, and is maintained by GSD. Although there are no plans by NWS to transition RTVS to operations, the NWS/Aviation and Space Weather Services Branch continues to fund its operation and maintenance at GSD. GSD provides monthly reports of verification statistics from RTVS for product performance tracking.</td>
<td></td>
</tr>
<tr>
<td>Event-Based Verification and Evaluation of NWS Gridded Products Tool (EVENT)</td>
<td>TRL 6</td>
<td>2011</td>
<td>Ongoing</td>
<td>2018 NWS/NEXTG EN/IPD</td>
<td>EVENT is an automated web-based tool that provides ongoing performance measures of NWS gridded products with respect to their ability to forecast events impactful to aviation operations.</td>
<td></td>
</tr>
<tr>
<td>TRACON Gate Forecast Verification Tool</td>
<td>TRL 5</td>
<td>2015</td>
<td>Ongoing</td>
<td>2018 NWS/NEXTG EN/IPD</td>
<td>The automated production of TRACON Approach and Departure gate forecasts has been centralized for a subset of CWSUs. The automated tool, produced and operated by AWC, also allows for forecaster-over-the-loop updates to the automated output. Work in 2015/16 included extension of the tool to include verification of the forecast output as modified by the CWSU forecaster, as well as preparatory activities for the transition of the GSD verification tool to NWS operations.</td>
<td></td>
</tr>
<tr>
<td>CWSU Briefing Tool</td>
<td>TRL 7</td>
<td>2015</td>
<td>Ongoing</td>
<td>2019 NWS/NEXTG EN/IPD</td>
<td>NWS meteorologists at 21 Center Weather Service Units (CWSUs) provide decision support services at FAA Air Route Traffic Controller Centers (ARTCCs). The CWSU meteorologists provide routine and on-demand briefings containing weather forecast information critical to FAA Traffic Flow Management (TFM) decisions. In 2015/16, GSD completed the development of an automated tool for all 21 CWSUs for terminal winds. Work for 2016/17 will include developing ceiling and visibility capabilities for a CWSU focus group.</td>
<td></td>
</tr>
<tr>
<td>Transfer Project Name</td>
<td>Transfer Started</td>
<td>Transfer Completed</td>
<td>Transfer to What Entity</td>
<td>transferred</td>
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<tr>
<td>GFE to Australian Bureau of Meteorology</td>
<td>TRL 9</td>
<td>2006</td>
<td>2012</td>
<td>Australian Bureau of Meteorology</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td>Graphical Forecast Editor (GFE) tool was redesigned to meet the requirements of the Bureau of Meteorology (BOM) in Australia. After several years of development, they have deployed their version of GFE across their entire country and are using it for weather forecast operations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FX-Net System</td>
<td>TRL 9</td>
<td>2001</td>
<td>2013</td>
<td>NWS Regional Offices</td>
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<td></td>
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<td></td>
<td>The FX-Net system uses the Internet to provide full AWIPS visualization and data analysis capability with a Graphical User Interface (GUI) that closely emulates the standard AWIPS I workstation, allowing the National Weather Service (NWS) Incident Meteorologists (IMETs) to move seamlessly between their Weather Forecast Offices (WFO) equipped with the AWIPS system to FX-Net in the field. This system was fully transitioned to NWS Regional Office ownership in 2013.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gridded FX-Net Tool</td>
<td>TRL 8</td>
<td>2007</td>
<td>Ongoing</td>
<td>BLM/USFS/ NIFC</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Used regularly in operations</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td>Gridded FX-Net Tool is being used by the Bureau of Land Management to develop and execute fire potential algorithms used to rate fire danger indexes. Gridded FX-Net allows the National Interagency Fire Center (NIFC) Predictive Services forecasters to retrieve model grids which are applied to specialized fire prediction and fire danger models. Products from these models provide the USFS, BLM and other land management agencies with long-range resource planning and fire management decision support information.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FX-CAVE Workstation</td>
<td>TRL 6</td>
<td>2015</td>
<td>Ongoing</td>
<td>BLM/USFS/ NIFC</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Limited use in operations</td>
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<td>The FX-CAVE workstation is the next generation of meteorological workstation based on the NWS AWIPS II CAVE workstation. It will eventually make the FX-Net System obsolete. The National Interagency Fire Center (NIFC), and its eleven field offices, are transitioning to FX-CAVE System starting in 2015. Agreements are in place to proceed indefinitely with this interagency cooperation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation of Earth Networks Total Lightning Products</td>
<td>TRL 7</td>
<td>2014</td>
<td>Ongoing</td>
<td>NSSL</td>
<td>2017</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td>GSD is doing the programming to provide the ability to display the Earth Networks total lightning data set on AWIPS-II so it can be evaluated for its utility for initializing weather forecast models.</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GSD Tech</th>
<th>TRL</th>
<th>Date</th>
<th>Date</th>
<th>Expected</th>
<th>Transfer</th>
<th>Description of what is being transferred</th>
</tr>
</thead>
</table>

**November 3-5, 2015**
<table>
<thead>
<tr>
<th>Transfer Project Name</th>
<th>Transfer Started</th>
<th>Transfer Completed</th>
<th>Transfer Date</th>
<th>to What Entity</th>
<th>transferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFIP Consolidated Display of Products</td>
<td>TRL9</td>
<td>2012</td>
<td>2016</td>
<td>NWS</td>
<td>After Hurricane Katrina, Congress provided significant research funding too many organizations for better hurricane prediction. NOAA’s HFIP program provided funds to GSD to develop a website which consolidates and centralizes the products from different experimental and operational weather and hurricane models and effectively displays them in uniform formats for comparison. The website displaying the various HFIP products is used by National Hurricane Center (NHC) forecasters, NWS managers, and FEMA managers as a quasi-operational forecasting tool for tropical weather events. GSD continues to maintain the website but anticipates that it will transition to NWS O&amp;M.</td>
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| MADIS Real-Time system; Data Recovery system; Data Archive system | TRL 9 | 2010 | 1.21.2015 | NWS/NCEP/NCO | MADIS Initial Operating Capability (IOC) at NWS/NCEP/NCO was completed 9/30/2010. ESRL/GSD’s responsibility for the MADIS real-time system, the MADIS Data Recovery System, and MADIS Data Archive system was completed 12/31/2014. After NWS testing, Final Operating Capability (FOC) was achieved 1/21/15. |
| MADIS Improvement Process for Operations | TRL 4 | 2015 | Ongoing | Ongoing | NWS/NCEP/NCO | NOAA has the ability to better use non-NOAA provided weather data to improve the understanding of current conditions and improve hazardous weather forecasts. Non-NOAA provided mesonet data fills gaps and supplements NOAA’s investment in the National Mesonet (NM) program. Improvements to these data sets will provide a backup and supplement NOAA’s NM investment. The improvement process would analyze and develop improved pathways for acquiring and disseminating non-NOAA data for use by NWS operations. Standard, unified, internet-based tools for capturing and maintaining metadata would be built into MADIS. Through these improvements new data in MADIS would be of higher quality and more quickly assimilated into NWS operations. Acquiring new observations that are useable by NOAA, which sometimes takes years, would be near instantaneous. |

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<tr>
<th>GSD Tech</th>
<th>TRL</th>
<th>Date</th>
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<th>Expected</th>
<th>Transfer</th>
<th>Description of what is being</th>
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<tr>
<td>Transfer Project Name</td>
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<tr>
<td>Transition of Clarus to MADIS</td>
<td>TRL 6</td>
<td>2015</td>
<td>09.30.2016</td>
<td>NWS/NCEP/NCO</td>
<td>Clarus is a research and development system run by the Federal Highway Administration to demonstrate and evaluate the value of “Anytime, Anywhere Road Weather Information” provided by both public agencies and the private weather enterprise to transportation users and operators. The Federal Highway Administration (FHWA), NWS, and the Office of Oceanic and Atmospheric Research (OAR) agreed that MADIS should become the operational home for Clarus. The objective is to incorporate Clarus system functionality into the MADIS system so that transportation users and operators don’t lose the Clarus capabilities they have grown to rely on to help with transportation decision support issues.</td>
<td></td>
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<tr>
<td>Transition of HADS/AFWS to MADIS</td>
<td>TRL 6</td>
<td>2015</td>
<td>9.30.2016</td>
<td>NWS/NCEP/NCO</td>
<td>Data from HADS and AFWS will be transitioned into MADIS. The Hydrometeorological Automated Data System (HADS) is a real-time and near real-time data acquisition, processing, and distribution system operated by the National Weather Service to support the Flood and Flash Flood Warning programs administered by the Weather Service Forecast Offices and the operations performed at River Forecast Centers. HADS created data products bolster several other NWS program areas including fire weather support services, local and national analysis of precipitation events, hydrologic modeling, and the verification of NEXRAD precipitation estimates. The Automated Flood Warning Systems (AFWS) network connects numerous local flood−warning systems, and integrates and shares information from 1700 sensors in 12 states.</td>
<td></td>
</tr>
<tr>
<td>Science On a Sphere Installations and Development</td>
<td>TRL 9</td>
<td>Ongoing</td>
<td>Ongoing</td>
<td>Various commercial, non-profit, and government entities</td>
<td>Considered R2U for public education and outreach, Science On a Sphere (SOS) is a room-sized global display system that uses computers and video projectors to display planetary data on a six-foot diameter sphere to help illustrate earth system science to people of all ages. The captivating display is in demand by science centers, museums, universities, schools, science conferences, and other venues and can display over 475 scientific datasets. As of August 14, 2015, over 119 permanent installations of Science On a Sphere are operating in 22 countries around the world. GSD continues to infuse SOS with new technologies to enhance its educational impact.</td>
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<tr>
<td>GSD Tech Transfer Project Name</td>
<td>TRL</td>
<td>Date Transfer Started</td>
<td>Date Transfer Completed</td>
<td>Expected Transfer Date</td>
<td>Transfer to What Entity</td>
<td>Description of what is being transferred</td>
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<tr>
<td>Science On a Sphere Explorer</td>
<td>TRL 8</td>
<td>9.07.2015</td>
<td>Ongoing</td>
<td>Ongoing</td>
<td>Educational Institutions and the Public</td>
<td>NOAA has the ability to build a more resilient public by bringing its SOS experience to classrooms throughout the Nation via Internet. NOAA’s vast collection of data is often difficult for teachers and students to find, understand, and incorporate into classroom lessons. SOS Explorer (SOSx) provides a single access point to a large collection of Earth system visualizations and provides analysis tools to better understand them. This increased understanding helps to engage students, encourage them to pursue careers in science, and foster better stewardship and decision making.</td>
</tr>
<tr>
<td>Central Weather Bureau (CWB) in Taiwan Tech Transfers</td>
<td>TRL 8</td>
<td>2000</td>
<td>Ongoing</td>
<td>Ongoing</td>
<td>CWB</td>
<td>GSD coordinates a collaborative program between the NOAA weather community and the Central Weather Bureau in Taiwan, sponsoring its guest weather researchers and forecasters engaged in developing CWB’s Weather Information and Nowcasting System (WINS) and working collaboratively on weather applications to benefit both NOAA and CWB weather communities. GSD tech transfers examples: 2011--Prototype of GFE/Hazard Services software for AWIPS; 2012--evaluation of the performance of NOAA’s HWRF model over the Western Pacific area; 2013--GPS-Met data assimilation and real-time evaluation; 2014--AWIPS II Development Environment training 2015--GFE smart tools for CWB’s text formatter development</td>
</tr>
<tr>
<td>CWB AWIPS-II Conversion</td>
<td>TRL 4</td>
<td>10.01.2014</td>
<td>9.30.2016</td>
<td>Central Weather Bureau, Taiwan</td>
<td>Assist CWB with conversion from AWIPS I to AWIPS-II and the development of high-resolution product generation assistance tools.</td>
<td></td>
</tr>
<tr>
<td>Fortran GPU Compiler</td>
<td>TRL 7</td>
<td>2009</td>
<td></td>
<td>2016</td>
<td>Commercial vendors</td>
<td>The F2C-ACC compiler was developed by GSD from 2009-2012 to support the parallelization of the NIM for NVIDIA GPUs. GSD works with vendors (such as Cray, PGI, Intel) to identify and address their compiler performance issues by sharing F2C-ACC, code and expertise. It has since become the standard by which commercial compilers are judged, and an effective vehicle to gain important and substantial improvements in the openACC compilers. NWS operations will ultimately benefit from GSD’s work to ensure procurement of fast and efficient commercial GPU compilers.</td>
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NOAA/ESRL Global Systems Division Science Review  
D. Research to Operations and Applications  
170  
November 3-5, 2015
Transfer Project Name | Transfer Started | Transfer Completed | Transfer Date | to What Entity | transferred
--- | --- | --- | --- | --- | ---
NEIS and TerraViz | TRL 6 | 2012 | To Be Determined | Other NOAA Line Offices; Private Sector | Through the High Impact Weather Prediction Project (HIWPP), NEIS is providing interested parties (i.e. NOAA researchers, private companies, and the public) research grade near real-time data delivery and visualization using TerraViz allowing them to compare and analyze research models results. A patent application was filed for this technology.

**Key**

**Technical Readiness Levels (TRL) Definitions**

**TRL 1** Basic principles observed and reported

**TRL 2** Technology concept and/or application formulated

  - Analytical and experimental critical function and/or characteristic proof-of-concept

**TRL 4** Component/subsystem validation in laboratory experiment

**TRL 5** System/subsystem/component validation in relevant environment

  - System/subsystem model or prototyping demonstration in a relevant end-to-end environment

**TRL 7** System prototyping demonstration in an operational environment

  - Actual system completed and "mission qualified" through test and demonstration in an operational environment.

**TRL 9** Actual system "mission proven" through successful mission operations
E. Patents, Trademarks, and CRADAs

Trademarks

**Planet Theater™**
Registered Trademark Serial Number: 78512934
Registration Date: 2006-09-26
Trademark Holder: NOAA

Patents

**Science On a Sphere®**
Patent Number: US 6,937,210
Date of Patent: August 30, 2005
Inventor: Dr. Alexander E. MacDonald

Science On a Sphere® (SOS) is a room sized global display system that uses computers and video projectors to display planetary data onto a six foot diameter sphere, analogous to a giant animated globe. Dr. Alexander MacDonald invented Science On a Sphere® and researchers at NOAA developed Science On a Sphere® as an educational tool to help illustrate Earth system science to people of all ages. Animated images of atmospheric storms, climate change, and ocean temperature can be shown on the sphere to explain complex environmental processes in a way that is simultaneously intuitive and captivating.

**High Performance Real-Time Interactive Exploration and Visualization of Discrete Geospatial Data in Time and Space**
Patent Application Number: 14866716

This invention includes tools that brings massive amounts of 4-D data, including output from multiple environmental forecast models as well as different data from different observations (surface observation, upper air, maritime observation) into one user friendly interactive display tool. This also includes a server side architecture provides a real-time stream processing system, which utilizes server-based Graphical Processing Units (GPU’s) for data processing, wavelet based compression, and other preparation techniques for visualization, to minimize the bandwidth and latency for data delivery to end-users. Through these technologies, the inventors have improved accessibility to ‘Big Data’ along with providing tools allowing novel visualization and seamless integration of data across time and space, regardless of data size, physical location, or data format. Invention components are also known as NOAA Earth Information System™ and TerraViz™
CRADA (Cooperative Research and Development Agreement)

**GPS-Meteorology (GPS-Met)**  
Established: April 24, 2014  
Duration: Two years  
Collaborator: Trimble Navigation

This agreement provides collaborative work toward GSD’s intention to transfer the GSD GPS-Met Data Acquisition and Processing System and/or to verify that equivalent capabilities, held by Trimble Navigation, to meet or exceed NOAA’s specifications for GPS-Met products. Completion of this CRADA will provide NOAA some assurance that the private sector can provide the desired observations. The CRADA also provides opportunities to conduct joint research and development to refine, improve, or evaluate commercial extensions of the GPS-Met technology.

Trimble Navigation has demonstrated that it can meet NOAA’s specifications for GPS-Met products. NWS will conduct a competitive acquisition in early FY2016 to procure the GPS-Met products for NOAA use from a commercial vendor.

**Air Quality Applications**  
Established: June 15, 2015  
Duration: Five years  
Collaborator: AURAIA, LLC

Description of Collaboration: GSD and AURAIA, LLC intend to conduct collaborative research and development on the integration of NASA MODIS Earth Observation into the High-Resolution Rapid Refresh model from NOAA to demonstrate the feasibility of achieving the highest spatial, 3x3km2, and temporal, hourly, resolution of PM2.5 concentrations over the United States to date. If successful, AURAIA, LLC will attempt to integrate these data into AirBreath Get American Breathing Clean Air™, a revolutionary proprietary mobile application to allow individuals exposed to outdoor air pollution to find clean air and prevent health effects. In addition, GSD will produce climatological statistics of PM2.5 concentrations over the U.S. over time periods such as months, season, and years at 3x3km2. AURAIA, LLC will develop proprietary Application Programming Interfaces and online platforms using climatological data to identify populations at risk and to enable healthcare providers to enhance prevention.

**Integrated Weather Solution for Civil Aviation Stakeholders: Air Traffic Management, Airlines, and Airports**  
Established: Expected 1st week of November 2015  
Duration: Five years  
Collaborator: I.M. Systems Group (IMSG)
Description: Over the past two years, IMSG has designed the Integrated Aviation Weather System (IAWS) with the following basic Service Functions: 1) IAWS-R for En-Route Aviation Weather; 2) IAWS-T for Terminal Area Aviation Weather and 3) IAWS-C for Collaborative Decision Making (CDM) Support. These service functions are to provide highly accurate nowcast and forecasts to support operational Aviation Weather Stakeholders including Air Traffic Management, Airlines, and Airports both within the U.S. and overseas. INtegrated Support for Impacted air-Traffic Environments (INSITE), developed at NOAA/ESRL/GSD, is a web-based prototype application designed to be used in the convective weather forecast process. One goal is to incorporate INSITE into the IAWS-C system and another is to help stand up convection permitting numerical weather prediction as a component of IAWS-R. GSD is also expected to consult on radar based nowcasting techniques which are the primary component of IAWS-R and IAWS-T.

Nondisclosure Agreements

- Iberdrola Renewables, Inc.
- XCEL Energy
- GIE EUMETNET (Network of European National Meteorological Services)
- Federal Aviation Administration
- Raytheon Company, Integrated Defense Systems
F. Awards, Honors, and Other Recognition

Department of Commerce

2015 Gold Medal – Scientific and Engineering Achievement
GSD's Assimilation and Modeling Branch/High Resolution Rapid Refresh (HRRR) Model Team (along with NWS colleagues in NCEP Central Operations and the Environmental Modeling Center) for achieving success for the High-Resolution Rapid Refresh, the first storm-scale model to give forecasters and decision-makers fast, local weather guidance.

NOAA

2015 Bronze Medal
William B. Bendel, Fanthune Moeng, Wilfred G. Von Dauster, Vivian A. LeFebvre, Alexander E. MacDonald, Phyllis Gunn, and Rhonda Lange for achieving the 100th worldwide Science On a Sphere® installation and continuing to grow its global engagement of the public in NOAA science.

2014 Bronze Medal
Scott Nahman, Kathryn Gilbert, Rusty Benson, Mark Iredell, Geoff Dimego, Shraddha Upadhyaya, Luis Cano, Michael Blumenfeld, Michael Young, and David Michaud for dedication in acquiring supercomputing services to sustain production of the Nation’s operational numerical weather and climate forecast systems.

2010 Bronze Medal
Steve Weygandt, Stan Benjamin and John Brown for developing the first NCEP operational radar reflectivity assimilation technique and improving convective storm forecasting.
Seth Gutman for innovative contributions to the development of the Coastal Atmospheric River Monitoring and Early Warning System

2015 NOAA Administrator's Award
Kevin Kelleher, John Schneider, and Greg Pratt (as part of an NWS/NESDIS/OAR Team) for successfully transitioning MADIS (the Meteorological Assimilation Data Ingest System) to operations within the NWS and archiving in NESDIS.

2014 NOAA Administrator's Award
Kevin Kelleher with other NOAA colleagues for helping to establish the first systematic approach and consistent voice for advancing the testing capabilities at NOAA testbeds and proving grounds.

2011 NOAA Administrator's Award
Seth Gutman for long-term leadership in establishing a national ground-based GPS observing network for measuring and monitoring atmospheric water vapor.
2014 Distinguished Career Award for Professional Achievement
Darien Davis - for an enduring commitment to NOAA's mission, a tenacity to succeed, and an optimistic vision of the future that drew experts from across the agency to advance NOAA IT systems.

2012 NOAA Research Employees of the Year
Individual - David K. Himes – ESRL/GSD – posthumously awarded the NOAA Research Employee of the Year (Individual) for Personal and Professional Excellence for his innovative software engineering critical to the development of Science on a Sphere®.

Group - ESRL/GSD/Assimilation and Modeling Branch – for the development, integration, and transition of the next generation of NOAA’s hourly North American prediction, a foundation for realizing NOAA’s ‘Weather Ready Nation’ strategies as well as position NOAA for emerging service areas.

2011 August Employee of the Month Award from NOAA Research EEO/Diversity
Dr. Hongli Jiang for her current research on the development of methods for fine scale and frequent updated numerical analysis.

Cooperative Institute Awards

2015 CIRA Research and Service Initiative Award was presented to Steve Albers. The award is for outstanding contributions to science and technology research and his noteworthy, sustained, accomplishments leading and contributing to numerous research projects over the past four years. These accomplishments include team leadership and mentoring, the implementation of innovative and creative technology, and successful research proposals resulting in significant funding to the laboratory. Steve has applied his considerable scientific and technological expertise to many projects acknowledged by ESRL/GSD awards including the all-sky camera vs. LAPS cloud analysis, cutting edge NWP-based cloud analysis, NWP visualization software and complex Science on a Sphere® data sets.

2015 CIRES Outstanding Performance Award - Service presented to Chris Golden - GSD/Evaluation and Decision Support Branch for his work developing a user interface for the National Weather Service’s “Hazard Services.” The Hazard Services application on AWIPS II (the National Weather Service Advanced Weather Interactive Processing System), is designed to streamline forecaster workflow by combining functions of three legacy applications.

2015 CIRES Bronze Medal for Superior Performance was presented to Shilpi Gupta, Hilary Peddicord, and Beth Russell, CIRES staff in GSD/Advanced Technology and Outreach Branch, were part of a NOAA team honored with a DOC Bronze Medal for achieving the 100th worldwide installation of Science On a Sphere®.

2014 CIRES Outstanding Performance Award in Science and Engineering was presented to Ligia Bernardet, CIRES staff in GSD/Assimilation and Modeling Branch, for her excellence in scientific research, collaborative and multi-disciplinary approach, and uncommon initiatives, specifically for, her leadership in working to unify differing versions of the Hurricane Weather Research and Forecasting (HWRF) Model.
2013 CIRES Innovative Research Program Grant was presented to Shilpi Gupta (and non-GSD colleague), CIRES staff in GSD/Advanced Technology and Outreach Branch, for their project entitled “SOS: Cognition + Affect = Effect” that studied how collaboration between the arts and sciences may be more effective for inspiring social engagement and behavior change than science alone.

2013 CIRES Outstanding Performance Award was presented to Christopher Clack, CIRES staff in GSD/Renewable Energy Program, for his work in renewable energy and atmospheric science.

2013 CIRA Research and Service Initiative Award was presented to Sher Schranz, CIRA staff in GSD/Advanced Technology and Outreach Branch, for her outstanding service in administrative oversight, project management, and outreach. From the notification letter by CIRA Director Christian Kummerow, "Your superb accomplishments across a myriad of high-visibility programs and projects (fire weather research, NextGen aviation weather, unmanned aircraft systems, NEIS, FX-Net) are highly valued. Your wealth of technical knowledge, coupled with excellent project management and leadership skills, are especially noteworthy."

2013 CIRES Outstanding Performance Award for Science and Engineering was presented to Julien Lynge, CIRES staff in GSD/Advanced Technology and Outreach Branch. Julien works with scientists to make data easy to find, access, visualize, and understand, and is the lead developer on TerraViz, a highly creative and innovative graphical interface that may revolutionize the way scientists and others visualize massive physical data sets in real time. TerraViz is the visualization component of GSD’s NOAA Earth Information System (NEIS).

2012 CIRES Employees of the Year (Team) was presented to Curtis Alexander, Eric James, Steven Peckham, Patrick Hofmann, Bill Moninger, Tanya Smirnova, Ming Hu, Joe Olson, and Xue Wei for the development, integration, and transition of the next generation of NOAA's hourly North American prediction, a foundation for realizing NOAA’s 'Weather Ready Nation' strategies as well as position NOAA for emerging service areas.

2012 CIRA Research Initiative (Team) Award was presented to Jebb Stewart, Jeff Smith, Chris MacDermaid, and Randy Pierce for their work on the NOAA Environmental Information System (NEIS).

2012 CIRA Research Initiative Award was presented to Haidao Lin for his work on satellite temperature and moisture bias corrections in the High Resolution Rapid Refresh (HRRR) Model.

2012 CIRA Service Initiative Award was presented to Chris MacDermaid for his efforts as GSD’s representative on a number of NOAA and OAR working groups and committees.

2011 CIRES 2011 Performance Award - Service Category was presented to Dr. Steven Peckham for helping to develop and provide support for a complex modeling system known as WRF-Chem.

2011 CIRES 2011 Performance Award - Service Category was presented to Dr. Craig Tierney for promoting and inspiring excellence and dedication to the science and research performed at CIRES as a cornerstone of the NOAA High Performance Computing (HPC) team in Boulder, and took
on the demanding role of acting High Performance Computing (HPC) Lead, responsible for managing all aspects of NOAA Boulder's HPC resources and representing NOAA Boulder's HPC interests in the midst of a NOAA-wide HPC realignment.”

2010 CIRA Research and Service Initiative Award was presented to Isidora Jankov and Steve Albers. The award is in recognition for their contributions to numerical weather prediction (NWP) forecasting – and more specifically, research that focuses on the initialization of fine-scale numerical models in GSD's Local Analysis and Prediction System (LAPS) and research efforts aimed at improved physical parameterization schemes and ensemble forecast techniques in NWP.

2010 CIRES Bronze Medal Awards to Curtis Alexander, Ming Hu, and Tanya Smirnova, received the awards for their contributions to the operational assimilation of radar reflectivity that won 2010 NOAA Bronze Medal awards for Stan Benjamin, Steve Weygandt, and John Brown. GSD CIRA colleagues Kevin Brundage and Bob Lipschutz were also a part of this cooperative effort.

Other External Awards and Commendations


2015 State of Colorado Governor's Award for High Impact Research – Presented to GSD's High Resolution Rapid Refresh (HRRR) Model Development Team from the Earth Modeling Branch for the development and implementation of the HRRR Weather Model. The prestigious award was presented in a ceremony at the Denver Museum of Nature and Science on Thursday, October 8, 2015. The Governor's Award for High-Impact Research was launched in 2009 by CO-LABS to celebrate the achievements of Colorado scientists. CO-LABS is a non-profit consortium of federal laboratories, research institutions, businesses and economic development organizations that provide financial and in-kind support for programs that promote the retention and expansion of Colorado's scientific resources. For more information visit http://cires.colorado.edu/news/press/2015governorsawards/.

2015 Certificate of Recognition – Presented to GSD Senior Scientist Zoltan Toth by the U.S. THORPEX Executive Committee for his international leadership and multifaceted research contributions to US participation in the World Meteorological Organization’s THORPEX Weather Research Program.

2015 UVIG Achievement Award - The Utility Variable-Generation Integration Group (UVIG), previously known as the Utility Wind Integration Group (UWIG), is giving a UVIG 2015 Achievement Award to the DOE/NOAA Wind Forecast Improvement Project (WFIP) staff for contributions to improve wind energy forecasts. The NOAA Team includes Stan Benjamin and Joseph Olson from GSD's Earth Modeling Branch and Melinda Marquis from GSD's Office of the Director. The UVIG was established in 1989 to provide a forum for the critical analysis of wind and solar technology for utility applications and to serve as a source of credible information on the status of wind and solar technology and deployment. The group's mission is to accelerate the development and application of good engineering and operational practices supporting the appropriate integration and reliable operation of variable generation on the electric power system.
2015 The Combined Federal Campaign (CFC) Gold Award for the calendar year 2014 was presented to ESRL’s Global Systems Division.

2015 Combined Federal Campaign (CFC) Silver Star Awards for the calendar year 2014 were presented to two members of the GSD’s Office of the Director, Cherie Adams for her administering and running of the CFC Silent Auction, and Penny Granville for processing almost all of the on-line CFC contributions from an overwhelming majority of the David Skaggs Research Center’s on-site organizations.

2015 American Meteorological Society’s Outstanding Leadership Award presented to CU/CIRES Senior Scientist and GSD/Evaluation and Decision Support Branch Scientist Betsy Weatherhead, who received the award at the 2015 annual AMS conference in Phoenix, Arizona. Betsy received the award for her work with the public, private, and academic sectors in improving weather forecasts.

2014 UVIG Achievement Award - The Utility Variable-Generation Integration Group (UVIG), previously known as the Utility Wind Integration Group (UWIG), is giving a UVIG 2015 Achievement Award to GSD’s Melinda Marquis for her work in leading research to improve weather forecasts in support of wind power.

2014 Commendation From NASA to GSD - A team from the Global Systems Division/Assimilation and Modeling Branch, Stan Benjamin, John Brown, Bill Moninger, Eric James, Curtis Alexander, and Steve Weygandt, was commended by the National Aeronautics and Space Administration’s (NASA) Aviation Safety Program for support and performance in providing numerical weather model data and modeling support to the program for their development and evaluation of new Integrated Alerting and Notification (IAN) concepts for the Vehicle Systems Safety Technologies (VSST) Project. The team provided NASA with numerical data from the High-Resolution Rapid Refresh (HRRR) Model to represent the weather conditions for the NASA/IAN/VSST studies. They also provided support and expertise in aiding NASA’s use of special software for accessing the formatted model data and in properly interpreting the data.


2013 Thomas Day, National Weather Service NextGen IT Project Manager, commended GSD’s MADIS Team, Greg Pratt, Leon Benjamin, Tom Kent, Gopa Padmanabhan, and Leigh Cheatwood-Harris, in a formal letter to then Acting GSD Director, Dr. Scott Hausman for their work on connecting MADIS to the NextGen Web Service Environment.

2013 National Science Foundation’s International Research Fellowship Award to GSD/Office of the Director/Global Observing Systems Analysis Group’s Tanya Peevey.

2012 Australia’s Bureau of Meteorology Awards - Australia’s Bureau of Meteorology received Highly Commended Award in the Comcover Awards for Excellence 2012 – Risk Initiative for their Next Generation Forecast and Warning System Project, a major component of which was installing...
the Graphical Forecast Editor (GFE), designed, developed, and transferred by GSD/Information Systems Branch, in their forecasting offices. In addition, just recently the Next Generation Forecast and Warning System Project featured prominently in the Excellence in eGovernment Awards that recognize the most outstanding initiatives in Government Information and Communication Technologies (ICT) at the local, state, and federal level. These are very prestigious awards for Australia’s Bureau of Meteorology. Congratulations to GSD/ISB’s Graphical Forecast Editor Team.

**2011 OAR EEO Newsletter Recognition** - In the September 2011 quarterly issue of OAR EEO, "CONNECTIONS", the EEO/diversity newsletter for NOAA Research, Vivian LeFebvre is recognized in the "Many Backgrounds, Many Stories: One American Spirit” article, and Jeff Van Buskirk is recognized in the "EEO/Diversity Across OAR” article.

**2011 Federally Employed Women** - Penny Granville was named the Vice President of the Rocky Mountain Chapter of Federally Employed Women (FEW). She helped get GSD mentioned in a document from FEW on how federal government employees affect everyone’s everyday life. A subset of this document, including a GSD reference, was a major part of an article in the Wednesday, December 2, 2011 edition of the Washington Post titled, "Employee group shows impact of proposed cuts on government services."

**2011 Space Shuttle Program Commendation for GSD** – The Global Systems Division recently received a commendation from the Space Shuttle Program and the National Weather Service/Spaceflight Meteorology Group (SMG) for our assistance in customizing AWIPS for unique data sets and displays needed for every space shuttle launch and landing.
G. GSD Science, Service, and Leadership

a. Service on NOAA Boards, Committees, and Projects

Stan Benjamin
- Associate Director, Executive Committee/OAR Representative, for the Joint Center for Satellite Data Assimilation (JCSDA)
- Serves as Lead, Global Modeling Team, NOAA Hurricane Forecast Improvement Project
- Serves as Lead, HIWPP Hydrostatic Global Model Subproject

Ligia Bernardet
- Serves as the Lead of the Global Model Test Bed of the interagency project GSD/NCAR Developmental Testbed Center
- Serves as a member of the NOAA Hurricane Forecast Improvement Project (HFIP) Model Physics and Strategy Team and the Ocean Model Impact Tiger Team
- Serves as a member of the NOAA Next Generation Global Prediction System Software Architecture and Engineering Team, the Overarching System Team, and the Nesting Team

Lidia Cucurull
- Served as NOAA GNSS RO Chief Scientist for the COSMIC-2 Radio Occultation satellite mission and Jason-CS satellite mission
- OAR Technical Liaison to the Joint Center for Satellite Data Assimilation (JCSDA)

Mark Govett
- Serves as a Voting Member of the OpenACC committee representing NOAA on the development of parallelization standards for accelerated computing

Tracy Hansen
- Core team member, Science and Strategic Implementation (SSIP) Development Team for Forecasting a Continuum of Environmental Threats (FACETs)

Craig Hartsough
- Co-editor, The Developmental Testbed Center Newsletter

Paula McCaslin
- Co-editor, The Developmental Testbed Center Newsletter

Greg Pratt
- Served as Technical Lead for the Geo-Targeted Alerting System (GTAS) project, a prototype implementation of the latest developments in plume modeling, high-resolution weather models, and network enabled operations for NOAA’s National Weather Service Program Manager for Meteorological Assimilation Data Ingest System (MADIS) and its implementation at NWS/NCEP, NESDIS/NCEI, and NOAA Integrated Dissemination Program (IDP)
Tom Schlatter
- Served as Chair, Test and Evaluation Working Group, North American Observing System (NAOS) Program, NOAA
- Served as Lead, Data Assimilation Development Team for the Weather Research and Forecasting (WRF) model
- Served on Observations Integrated Planning Team for the National Weather Services’ Science and Technology Infusion Plan
- Served as Program Scientist for New England Pilot Project for Improving Air Quality and Surface Temperature Predictions
- Served on Advisory Board of the Developmental Test Center, Boulder, Colorado

Timothy Schneider
- Serves as Project Manager for NOAA’s High Impact Weather Prediction Project (HIWPP)

Bonny Strong
- Serves as Lead, HIWPP Test Program Subproject

Sher Schranz
- Served as Subject Matter Expert - NOAA External Fire Weather Research Science Advisory Board

Susan Williams
- Serves on Boulder Outreach and Coordinating Council
- Serves on Boulder Labs Diversity Council as Secretary

Zoltan Toth
- Served as NOAA U.S. The Observing Research and Predictability Experiment (THORPEX) Program Manager
- Served as Co-Chair, Ensemble Prediction and Post-Processing Team for NOAA Forecast Uncertainty program (NFUSE)

Hongli Wang
- Served on the 2015 Review Panel for the National Oceanic and Atmospheric Administration (NOAA) Ernest F. Hollings and Educational Partnership Program (EPP) with Minority Serving Institutions Undergraduate Scholarship Programs

b. Service on International Research Organizations

Lidia Cucurull
- Chair, Expert Team on New Remote-Sensing Technologies, World Meteorological Organization (WMO) Commission for Instruments and Methods of Observation
Melinda Marquis
• Served as Editor, IPCC Working Group 1 – Physical Science Basis – for the Fourth Assessment Report

Jennifer Mahoney
• Served on the International Civil Aviation Organization (ICAO) World Area Forecast Center committee

William Moninger
• Served as Technical Expert for the World Meteorological Organization (WMO) Aircraft Meteorological Data Relay (AM DAR) Panel

Tom Schlatter
• Served on Scientific Steering Committee, International H2O Project (IHOP)
• Served as Member, Expert Team on Observational Data Requirements and Redesign of the Global Observing System, under the Commission on Basic Systems, World Meteorological Organization (WMO)

Zoltan Toth
• Serves as U.S. Representative, International Core Steering Committee (ICSC) for The Observing Research and Predictability Experiment (THORPEX)
• Served as Co-chair, THORPEX Global Interactive Forecasting System (GIFS) – THORPEX Interactive Grand Global Ensemble (TIGGE) Working Group
• Serves as Secretary for Predictability Section in the Nonlinear Processes in Geosciences Division of the European Geophysical Union
• Served as invited expert – International Aviation Working Group, Boulder, Colorado
• Served three times as invited lecturer – Hungarian Meteorological Service and Hungarian Meteorological Society, Budapest, Hungary
• Served twice as invited lecturer – Korea Meteorological Administration, Seoul, South Korea
• Served as invited lecturer – European Center for Medium Range Forecast, Reading, England
• Served as invited lecturer – Central Weather Bureau, Taipei, Taiwan
• Served as invited lecturer – ETH Zurich University, Zurich, Switzerland
• Served as Deutsche Forschungsgemeinschaft (DFG) Collaborative Research Center Proposal review panel member, Munich, Germany
• Served as JSC/CAS/WMO alternate member

Betsy Weatherhead
• Served as Lead Author – Arctic Climate Impact Assessment
• Served as a member of the World Meteorological Organization – Global Atmospheric Watch Program – Scientific Advisory Group

c. Service on Federal/Interagency/State Committees

Stan Benjamin
• Served as Lead, Product Development Team for Model Development and Enhancement
• Serves on Federal Aviation Administration (FAA) Aviation Weather Research Program (AWRP)
• Served as Lecturer, Utility Variable-Generation Integration Group (UVIG), previously known as the Utility Wind Integration Group (UWIG)
• Serves as Associate Director, Executive Committee/OAR Representative - Joint Center for Satellite Data Assimilation

Mark Govett
• Serves as a Co-organizer of multiple NCAR Multi-Core Workshops

Eric Hackathorn
• Served on NASA and National Science Foundation Grants Advisory Boards

Steve Koch
• Served as National Research Council Advisor; Lead, Federal Aviation Administration (FAA) Model Development and Enhancement Project Development Team (PDT)
• Served as Co-lead, FAA Turbulence Product Development Team
• Served on NSF's Linked Environments for Atmospheric Discovery (LEAD) External Advisory Panel

Chris MacDermaid
• Served as a member of the National Science Foundation Review Panel

Jennifer Mahoney
• Serves on the AMS Board on Environmental Information Processing Technologies
• Serves on the OAR Evaluations of Community of Practice
• Served on the OAR Weather Ready Nation Committee
• Served on the Joint FAA-NWS Traffic Flow Management Weather Requirements Working Group
• Served on the FAA Weather Evaluation Team
• Served on the Joint Planning and Development Office of Environmental Information Integrated Project Team (IPT)
• Served on the Aviation Weather Integration IPTs for Icing, Turbulence, Convection, Verification (FAA)

Melinda Marquis
• Serves as the OAR Representative to the Resource Assessment and Design Conditions Interagency Working Group

Patricia Miller
• Served on Federal Committee for Integrated Observing Systems (CIOS)
• Served on Federal Highway Administration (FHWA) Clarus Initiative Coordinating Committee
• Served on FHWA Clarus Initiative Coordinating Committee Observation, Quality Control (QC), and Metadata Task Forces
• Served on NOAA Meteorological Assimilation Data Ingest System (MADIS) Transition Team

Thomas Schlatter
• Served on Science Steering Committee, U.S. Weather Research Program
• Served as Lead, Product Development Team for Model Development and Enhancement - Federal Aviation Administration (FAA) Aviation Weather Research Program (AWRP)
• Served as Member, Scientific Steering Committee, Joint Center for Satellite Data Assimilation, operated by NOAA and National Aeronautics and Space Administration (NASA)
• Served as one of the principal authors of Cost and Operational Effectiveness Analysis for the NOAA Profiler Network, a report mandated by the U.S. Senate Appropriations Committee, 2003-2004. This report was instrumental in preserving a network of wind-profiling radars in the central U.S. that contribute toward more accurate weather forecasts, severe weather watches, and warnings. It also laid the groundwork for an upgrade of the network, currently in progress
• Served as member of the National Academy of Sciences Committee on Developing Mesoscale Meteorological Observations to Meet Multiple National Needs

Keith Searight
• Served as a staff mentor for the UCAR Leadership Academy Program

Lynn Sherretz
• Served on NextGen Joint Planning and Development Office
• Served on Weather Working Group Info Tech and Environmental Services Team, Environmental Information Team, and Demonstration Team

Zoltan Toth
• Served as Chair, U.S. The Observing Research and Predictability Experiment (THORPEX) Executive Committee
• Served as Member, U.S. Weather Research Program (USWRP) Prospectus Team
• Served as Review Panel member for NASA ROSES-2014 A.25 research proposal solicitation, entitled Severe Storm Research
• Serves as a NOAA Next Generation Global Prediction System (NGGPS) Statistical Post-Processing Team member
• Served as Invited Expert, International Aviation Working Group, Boulder, CO
• MAPP Proposal Review Panel member, NOAA Climate Program Office
• Served as a member of various NUOPC (National Unified Operational Prediction Capability) panels and working groups
• Serves as Chair, Interim Interagency Weather Research Coordination Committee

Betsy Weatherhead
• Served as a member of the Department of Energy – External Program Review Panel
• Served as a member of the National Science Foundation External Review Panel
• Served as a member of the Department of Energy – Proposal Review Panel

d. Service on Professional Societies and Journals

Curtis Alexander
• Served as program co-chair for American Meteorological Society (AMS) 2014 Severe Local Storms Conference
• Served on AMS Severe Local Storms Scientific and Technological Activities Commission (STAC) Committee

Dan Birkenheuer
• Served on American Meteorological Society Satellite Meteorology and Oceanography Committee
John Brown
• Served on American Meteorological Society Committee of Mesoscale Processes
• Served on American Meteorological Society Program Committee for Severe Local Storms

Lidia Cucurull
• Serves a reviewer for *AMS Journal of Atmospheric and Oceanic Technology*.

Brian Etherton
• Serves as an Editor for the *Bulletin of the American Meteorological Society*
• Serves as an Associate Editor for *Weather and Forecasting* (American Meteorological Society)
• Served as Founder of the AMS Symposium on High Performance Computing, under the umbrella of the Environmental Integrated Product Team

Mark Govett
• Serves as a Reviewer for the *Bulletin of the American Meteorological Society*
• Serves as a Reviewer for the *Journal on Parallel Computing*
• Serves as a Reviewer for *Copernicus Publications*

Steven Koch
• Served as Editor, *Weather and Forecasting* (American Meteorological Society)
• Served on American Meteorological Society Committee on Mesoscale Processes
• Served on American Meteorological Society Committee of Judges for Undergraduate Awards
• Served as Co-Chair, 12th American Meteorological Society Conference on Mesoscale Processes
• Served as Co-convener of American Meteorological Society short course “A Primer on Radar Analysis Techniques used in Mesoscale Meteorology”

Terra Ladwig
• Serves as an editor for the American Meteorological Society’s *Monthly Weather Review* publication

Scott Mackaro
• Served on Board of Higher Education, American Meteorological Society

Jennifer Mahoney
• Serves on the AMS Committee on Environmental Information Processing Technologies

Melinda Marquis
• Served as a member and founding chair of the American Meteorological Society Renewable Energy Committee
• Serves as a member and chair of the American Meteorological Society Board on Enterprise Economic Development
• Serves as a member and founding chair of the American Meteorological Society Board on Global Strategies
Joseph Olson
- Serves as a Reviewer for the *Journal Applied Meteorology and Climatology*
- Serves as a Reviewer for the *Quarterly Journal of the Royal Meteorological Society*
- Serves as a Reviewer for *Monthly Weather Review*
- Serves as a Reviewer for *Weather and Forecasting*

Woody Roberts
- Serves as Chair of the American Meteorological Society Board on Environmental Information Processing Technologies

Thomas Schlatter
- Served as a Councilor for the American Meteorological Society
- Served as Chair, Interim Editorial Board for the *Bulletin of the American Meteorological Society* (BAMS)
- Served on and was Chair of American Meteorological Society Nominating Committee (for President and Council members)
- Served on European Geosciences Union (EGU) Expert Team on Observational Data Requirements and Redesign of the Global Observing System, under the Commission on Basic Systems
- Served as Co-Chair of the 8th, 9th, and 10th Symposia on Integrated Observing and Assimilation Systems for Atmosphere, Ocean and Land Surface in conjunction with AMS Annual Meetings

Lynn Sherretz
- Served on Team Chaired American Meteorological Society Committee on Aviation, Range and Aerospace Meteorology (ARAM)

Ed Szoke
- Serves on American Meteorological Society Committee on Weather Analysis and Forecasting
- Serves as Associate Editor of *Weather and Forecasting* (American Meteorological Society)

Zoltan Toth
- Serves as Editor, *Nonlinear Processes in Geophysics*
- Serves as Editorial Board Member, *Idojaras*
- Served as Vice-President and Secretary for Predictability for the European Geophysical Union

Betsy Weatherhead
- Served on American Geophysical Union Scientific Advisory Group for Ultraviolet (UV) Radiation

e. Service to Cooperative Institutes and Universities

Curtis Alexander
- Served as an academic tutor for undergraduate students at Penn State University
- Served as Graduate Student Senate Chair, External Affairs Committee, University of Oklahoma
- Served as Chair, Student Affairs Committee, University of Oklahoma, Oklahoma School of Meteorology
Rainer Bleck
• Serves as University of Miami, Florida Adjunct Professor

John Brown
• Serves as an Affiliate Faculty Member on various PhD. Committees: Department of Atmospheric Science, Colorado State University, Ft. Collins, Colorado
• Served with the Department of Aerospace Engineering, University of Colorado, Boulder, Colorado
• Served with the School of Meteorology, University of Oklahoma, Oklahoma
• Served with the Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Florida

Brian Etherton
• Served as an Adjunct Faculty Member, North Carolina State University
• Served as an Adjunct Faculty Member, University of North Carolina-Charlotte

Mike Fiorino
• Served on dissertation committee, University of Hawaii
• Served on dissertation committee, Colorado State University

Tracy Hansen
• Served in Interdisciplinary Scientific Environmental Technology (ISET) Educational Partnership program
• Served as mentor for four undergraduate and graduate students, and helped find mentors for two more students, all from North Carolina A&T State University
• Served on Master’s Degree Thesis Committee for Masters Candidate from North Carolina A&T State University
• Serves as a mentor for University of Colorado Environmental Economics Research Methods course

Chris Harrop
• Served as an Interdisciplinary Scientific Environmental Technology (ISET) mentor to undergraduate student working at GSD for a summer

Craig Hartsough
• Serves as Adjunct Instructor in Astronomy, Front Range Community College, Larimer Campus, Fort Collins, CO
• Serves as WxChallenge Forecasting Contest Team Manager, University of Colorado – Boulder/CIRES

Christina Holt
• Serves as GSD Representative to University of Colorado – Boulder/CIRES Members’ Council
Steven Koch
• Serves as Adjunct Professor, North Carolina State University
• Serves as Technical Monitor, NOAA Educational Partnership Program (EPP) Minority Serving Institution Interdisciplinary Scientific Environmental Technology (ISET) Cooperative Science Center at North Carolina A&T University
• Serves as Associate Faculty Member, Iowa State University

Andrew Loughe
• Served on faculty at University of Colorado – Boulder

Adam Mabrouk
     Served as Lecturer, Murray State University, Murray, Kentucky

Paul Madden
• Served as supervisor of University of Colorado – Boulder summer students doing software development at GSD
• Served with University of Colorado – Boulder Faculty/Student Mentor Program

Kevin Manross
• Served as an adjunct faculty member at American Public University Systems teaching meteorology to undergraduate non-majors
• Served as a guest speaker on radar at Metropolitan State University, Denver, CO

Steven Peckham
• Served as Adjunct Professor, Florida State University, Florida
• Served as mentor/advisor for college student’s dissertation work

Tom Schlatter
• Served as Lecturer, Colorado School of Mines National Science Academy, Golden, Colorado, for middle school and high school science teachers

John Schneider
• Serves as Adjunct Faculty member in the University of Colorado – Boulder’s Department of Mechanical Engineering

Zoltan Toth
• Served as Guest Lecturer, Department of Meteorology - University of Maryland
• Served as Guest Lecturer, Columbia University, New York
• Served as Guest Lecturer, Howard University, Washington DC

Jeff VanBuskirk
• Serves as Project Management instructor for the Colorado State University – Continuing Education Program
f. Memberships to Professional Societies

Curtis Alexander - Member, American Meteorological Society

Stan Benjamin - Fellow, American Meteorological Society

Ligia Bernardet - Member, American Meteorological Society

Carl Bullock - Fellow, American Meteorological Society

Lidia Cucurull - Fellow, American Meteorological Society

Jason English - Member, American Meteorological Society
- Member, American Geophysical Union

Brian Etherton - Member, AMS Board on Environmental Information Processing Technologies
- Member, AMS Committee on Probability and Statistics

Mike Fiorino - Centennial Fellow, College of Earth and Mineral Sciences, Penn State University

Mark Govett - Member, Association for Computing Machinery

Ben Green - Member, American Meteorological Society

Christopher Harrop - Member, Association for Computing Machinery
- Member, IEEE Computer Society

Thomas Henderson - Member, American Meteorological Society

Ming Hu - Member, American Meteorological Society

Eric James – Member, American Meteorological Society

Isidora Jankov – Member, American Meteorological Society

Hongli Jiang – Member, American Meteorological Society
- Member, American Geophysical Union

Jaymes Kenyon – Member, American Meteorological Society

Mike Kraus - Member, American Meteorological Society

Steve Koch – Fellow, American Meteorological Society

Andrew Kren – Member, American Meteorological Society
Terra Ladwig  – Member, American Meteorological Society
Jennifer Mahoney  – Member, American Meteorological Society
Kevin Manross  – Member, American Meteorological Society
                – Member, American Geophysical Union
Joseph Olson  – Member, American Meteorological Society
John Osborn  – Senior Member, Society for Technical Communication – Rocky Mountain Chapter
                – Member, Society for Technical Communication Special Interest Group on Science Writing
Steven Peckham  – Member, European Geophysical Union
Tanya Peevey  – Member, American Geophysical Union
                – Member, American Meteorological Society
                – Member, American Physical Society
                – Member, Earth Science Women’s Network
William Roberts  – Member, American Meteorological Society
Thomas Schlatter  – Fellow, American Meteorological Society
                – Member, AMS Committee on Weather Forecasting and Analysis
Sher Schranz  – Member, American Association for the Advancement of Science (AAAS)
                – Member, American Institute of Aeronautics and Astronautics
Paul Schultz  – Member, American Meteorological Society
Tracy Lorraine Smith  – Member, American Meteorological Society
Jebb Stewart  – Member, American Geophysical Union
Bonny Strong  – Member, American Meteorological Society
                – Member, Project Management Institute
                – Member, Institute of Electrical and Electronics Engineers (IEEE)
Ed Szoke  – Member, American Meteorological Society
            – Member, AMS Committee on Weather Analysis and Forecasting
Craig Tierney  – Member, American Geophysical Union
Edward Tollerud  – Member, American Meteorological Society
                – Member, American Geophysical Union
Zoltan Toth
- Alternate Member, World Meteorological Organization/Commission for Atmospheric Sciences/Joint Science Committee
- Member, American Meteorological Society
- Member, European Geophysical Union

Joe Wakefield
- Member, American Meteorological Society

Yuanfu Xie
- Member, American Meteorological Society

g. Memberships to Cooperative Institute and Universities

Stan Benjamin
- Fellow, Cooperative Institute for Research in Environmental Sciences

Dan Birkenheuer
- Fellow, Cooperative Institute for Research in the Atmosphere

Thomas Schlatter
- Fellow, Cooperative Institute for Research in Environmental Sciences

John Schneider
- Fellow, Cooperative Institute for Research in the Atmosphere

h. Memberships to Other Technical and Scientific Organizations

Steve Albers
- Member, Longmont, Colorado Astronomical Society

Dan Birkenheuer
- Member, AMS Satellite and Oceanography Committee

Thomas Henderson
- Member, Message Passing Interface Forum

Scott Nahman
- Member, AFCOM (Association for Data Center Management Professionals)
- Member/Vice President, 7x24 Exchange/Rocky Mountain Chapter (education forum bringing together organizations to promote a better understanding of design, execution, and management issues involved in achieving reliability within all facets of mission critical systems and operations)

Hilary Peddicord
- Member, National Science Teachers Association
- Member, National Earth Science Teachers Association
- Member, 2014 Review Committee for CLEAN Materials (climate change education compilation for teachers)

Thomas Schlatter
- Member, National Academy of Sciences Committee on Developing Mesoscale Meteorological Observations to Meet Multiple National Needs

Jeff VanBuskirk
- Member, Project Management Institute (Project Management Professional [PMP])
i. Invited Talks

**Listing is for 2010 to 2015, Current GSD Staff Only**


Ligia Bernardet, Invited Talk, “The role of testbeds in NOAA for transitioning NWP research to operations”, European Centre for Medium-Range Weather Prediction (ECMWF), Reading, UK, November 18, 2013.

Ligia Bernardet, Tutorials, "Hurricane Weather Research and Forecasting (HWRF) Model". Boulder Colorado, 2010 and 2011; College Park, Maryland, 2014; and Taiwan, 2014.


Christopher Clack, Invited Talk, “Cost-competitive reduction of carbon emissions of up to 80% from the US electric sector by 2030”, Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, 2015.


Christopher Clack, Invited Talk, “Does the continental United States have the weather to support large-scale wind and solar deployment?” AMS Annual Meeting, San Diego, CA, 2013.


Lidia Cucurull, Invited Talk, “Use of GNSS Radio Occultation data at NOAA”, Coordination Group for Meteorological Satellites (CGMS)--Joint Occultations for Probing Atmosphere and Climate (OPAC) and International Radio Occultation Working Group (IROWG), near Graz, Austria, September 2013.


Tracy Hansen, Plenary Talk, "Hazard Services", Central Region MIC/HIC meeting, Kansas City, MO, May 2014.


Hiliary Peddicord, Invited Talk, “NOAA's SOS Explorer and Data Visualization Resources”, Climate Science Workshop, NOAA Climate Stewards Education Project, UCAR, Boulder, Colorado, June 2015

Tanya Peevey, Invited Talk, “A case study analysis of the double tropopause and the tropopause inversion layer related to the warm conveyor belt and other midlatitude systems”, Swiss Federal Institute of Technology (ETH), Institute for Atmospheric and Climate Science, Zurich, Switzerland, March 2014
Tanya Peevey, Invited Talk, "The relationship between the double tropopause (DT) and the tropopause inversion layer (TIL) in mid-latitudes", Johannes Gutenberg University of Mainz, Institute for Atmospheric Physics, Mainz, German, December 2013.


Jeff S. Smith, Invited Talk, “Introduction to the NOAA Earth Information System (NEIS)”, Gulf of Maine Research Institute Workshop on Data Visualization to Support Ecosystem Based Management, Portland, Maine, February 5-6, 2013.


Jebb Q. Stewart, Invited Talk, "Exploring interoperability: The advancements and challenges of improving data discovery, access, and visualization of scientific data through the NOAA Earth Information System (NEIS)". Search and Discovery of Scientific Data (IN031), San Francisco, CA, American Geophysical Union, Dec. 9 – 13 2013.

Jebb Q. Stewart, Invited Talk, "Real-time Data Interaction and Visualization using the NOAA Earth Information System (NEIS)", Meteorology Technology World Expo, Brussels, Belgium, October 22nd, 2014.


Zoltan Toth, Invited Talk, “THORPEX: Accomplishments and work ahead”, 5th THORPEX Asia Science Workshop, Jeju, South Korea, November 4-6, 2013.


Betsy Weatherhead, Invited Panelist, 2014-11-18: US India Technical Summit. US Department of State, Delhi, India


Betsy Weatherhead, Invited Talk, 2014-11-25: Telangana State Planning - the role of weather forecasts, Hyderabad

Betsy Weatherhead, Invited Talk, 2014-11-20: Detecting Trends in Environmental Data. Presidency University, Kolkata, India


Betsy Weatherhead, Invited Talk, 2014-11-19: 'Techniques for Identifying Small Advances in Forecasting'. National Centre for Medium Range Weather Forecasting, Delhi, India

Betsy Weatherhead, EGU, 2014-5-2: Improvements in approaches to forecasting and evaluation techniques, Vienna, Austria

Betsy Weatherhead, Invited Talk, American Association for the Advancement of Science Annual Meeting, 1/2012 Indigenous Knowledge


Betsy Weatherhead, Invited Talk, Germany, 2011, Max Planck Institute, Use of Unmanned Aircraft in Support of Environmental Science.


Betsy Weatherhead, 2011-3-28: Advances in techniques to understand linkages between ice quality and seal populations: Arctic Science Summit Week, Seoul, and Republic of Korea


Betsy Weatherhead, 2011-12-5: Analysis of detailed, sub-cloud field images of Arctic sea ice. AGU Annual Meeting: In Situ and Field-Based Measurements of the Cryosphere I, San Francisco, CA, USA


Betsy Weatherhead, Invited Talk, 2012-2-16: Indigenous Insights on Climate Change. Annual Meeting of the American Association for the Advancement of Science, Vancouver, Canada

Betsy Weatherhead, 2012-9-1: Designing Monitoring Systems to Detect Changes in Water Vapor. WMO: Global Climate Observing System Reference Upper Air Network, Lindenberg, Germany

H. Education and Outreach

Science On a Sphere® (SOS) Program

After amazing viewers in museums and conferences for almost a decade, Science On a Sphere® is now a central component of the White House initiative's Back-to-School Climate Education Event.

White House Office of Science and Technology Policy

For Immediate Release  August 20, 2015

FACT SHEET: Obama Administration Engages Students, Educators, and Leaders on Climate Education and Literacy

Washington, DC

Administration Commitments

Expanding Science On a Sphere® to Include Renewable Energy Data and ClimateBits Videos. Science On a Sphere® (SOS) is a global display system, developed by National Oceanic and Atmospheric Administration (NOAA) researchers, that uses computers and video projectors to display planetary data onto a six-foot-diameter sphere, analogous to a giant, animated globe. The Department of Energy (DOE) is announcing the release of new energy-related SOS datasets—representing wind, solar, and geothermal energy—to help people learn about renewable energy resources around the world via visualizations. Today, the following members of the Association of Science Technology Centers will begin presenting these new resources to their visitors:

- Boonshoft Museum of Discovery, Dayton, OH
- Children's City, Dubai, United Arab Emirates
- Danville Science Center, Danville, VA
- Denver Museum of Nature and Science, Denver, CO
- Imagination Station Science and History Museum, Wilson, NC
- 'Imiloa, the Astronomy Center of Hawai‘i, Hilo, HI
- International Museum of Art and Science, McAllen, TX
- Maryland Science Center, Baltimore, MD
- McWane Science Center, Birmingham, AL
- Nurture Nature Center, Easton, PA
- Oregon Museum of Science and Industry, Portland, OR
- Orlando Science Center, Orlando, FL
- Science Central, Fort Wayne, IN
- South Florida Science Center and Aquarium, West Palm Beach, FL
- Techmania Science Center, Pilsen, Czech Republic
- The Wild Center: Natural History Museum of the Adirondacks, Tupper Lake, NY
Additionally, NOAA, the University of Maryland, and NASA’s Goddard Space Flight Center have collaborated to produce a series entitled *ClimateBits*, minute-long videos that explain and visualize key concepts in climate science. These resources are available around the globe through NOAA’s [SOS network](#), which has more than 120 member institutions worldwide, including many of the world’s largest science museums, visitor centers, zoos, aquariums, laboratories, and schools.

GSD developed this “power-hitter” in the world of NOAA education and outreach and continues to infuse leading-edge technologies into the SOS system to enhance its visual impact and increase access to earth science information by audiences around the world. Science On a Sphere® is a gleaming 6-foot-diameter, carbon-fiber globe invented by Dr. Alexander E. MacDonald to educate, inspire, and wow any onlooker with the science it presents. This spherical movie screen was patented (2005) for its extraordinary multiyear design and software development accomplished initially by the late David Himes. It is a visualization tool that provides very high impact for every educational exhibit it enhances.

Now in 125 locations worldwide and still growing, SOS informs millions of people daily about the fragility of our planet with the most current science available. NOAA Boulder is the home of SOS, housed in the “David Himes Planet Theater.” SOS is used extensively in our organized outreach efforts and provides a spectacular finale for nearly every visitor to the David Skaggs Research Center (DSRC) in Boulder, Colorado.

On September 7, 2015, GSD released a desktop version of SOS called SOS Explorer. SOS Explorer creates a 3-D interactive Earth on a flat screen display including projection on walls, computers, and other large displays. This provides teachers, students, and the public access to a library of selected Science On a Sphere® datasets and movies. The visualizations show information provided by satellites, ground observations and computer models and rapidly animate through real-time global data. In addition, tools included in the application allow users to zoom into, probe, and graph the data, as well as add supplementary material including websites, videos, pictures, and place marks. In order to make the product more accessible for teachers, lesson plans and pre-programmed tours through standards-relevant topics are provided.

**Education and Public Outreach**

NOAA-Boulder reaches out to the public and schools in the area in an organized effort through the Boulder Outreach and Coordinating Council and the ESRL Outreach Team. Global Systems Division has strong representation in these groups that coordinate informal and formal educational activities on and off site with the goal of enhancing public awareness and understanding of the broad research conducted at our labs in Boulder. Since occupying the DSRC, these outreach groups have successfully attracted a rapidly growing number of visitors ranging from 2nd graders to senior citizens.
Accredited Classes for Teachers

Over the last three years, Science On a Sphere® education has trained 70 teachers in accredited classes. “Integrating SOS Data Visualization into your Teaching” and “The Colorado Flood: A Lasting Teaching Moment” are a couple of the programs offered between a half day to three days in length. Credits for the professional development workshops and in-service days were provided by University of Colorado Continuing Education and Boulder Valley School district as graduate and continuing education units.

On-site Visits

The general public has been on site in mass during several of the larger science open house events hosted over the years. In addition to the weekly lab tours open to the public, there is an organized effort to arrange customized local school tours. Every tour includes a stop at GSD’s David Himes Planet Theater, which houses Science On a Sphere.

The following chart displays SOS’s popularity as reflected in the numbers of nearly every announced visitor to NOAA Boulder.

![Yearly Visitors to Science On a Sphere at the David Himes Planet Theater](image)

*Note: Attendance figures not available before 2011*

Visitors to the David Himes Planet Theater in the past five years have included a large range of groups from second graders to senior citizens to government officials. Below is a sampling of groups that have visited to give an idea of the breadth and diversity of visitors:

- 8th Grade Science Day
- Academy Summer Camp
- Air Force Research Laboratory
- Angevine Middle School
Army Command and General Staff College
Bear Creek YMCA Summer Camp
Boulder High School
Boy Scout Pack 673
Boy Scout Troop 1057
Bring Your Child to Work Day Attendees
Carbon Valley Senior Center
Children's Commerce Center
Chilson Senior Center
CISM Summer School Grad Students
Civil Air Patrol High School Students
Colorado Academy Summer Space Camp
Colorado International School
Colorado State University Atmospheric Science Students
Congressman Jim Bridenstine
CU Summer Science Program
Department of Transportation
Emerald Elementary School
Fairmount Elementary
Fairview High School
Finland Young Ambassadors
Flagstaff Academy
Foothills Elementary School
Fort Collins Classical School
Global Monitoring Annual Meeting
History Book Club
Kyffin Elementary School
McLain High School
Mesa Elementary
Metivier
Montessori School of Denver
NASA's Living with a Star Program
National Weather Center Undergrad Interns
Nederland Elementary School
NIST Summer Students
NOAA Headquarters Central Region Annual Meeting Attendees
NWS Agricultural Observations Budget Office Visitors
Roads Scholar Program
Rochester Community and Technical College
Rock Canyon High School
Rocky Mountain School for Expeditionary Learning
Ryan Elementary School
Strategic Environmental Research and Development Program
SWPC Space Weather Week
Trail Blazer Elementary School
UCAR/CSEP Climate Teacher Workshop
Starting in 2013, the Science On a Sphere® group in GSD has hosted yearly SOS Teacher Workshops for local school teachers. These workshops are designed to help teachers bring SOS content into their classrooms for regular use and to design field trips to NOAA that build upon what they learn in the classroom. [http://sos.noaa.gov/workshop/](http://sos.noaa.gov/workshop/)

**Off-site Outreach and Service**

Staff from the Global Systems Division support off-site outreach and service, helping to spread the word about the science and the activities conducted by NOAA and GSD in order to educate and inspire the public. Examples include:

- Shilpi Gupta, Beth Russell, and Hilary Peddicord volunteered for Girls in Science Day at the Denver Museum of Nature and Science on February 7th, 2015. This involved creating interactive activities centered around Science On a Sphere (SOS). The activities included basic programming tasks for SOS and drawing maps and displaying them on SOS.

- Hilary Peddicord conducted a series of workshops in September 2014 for the one year anniversary of the Boulder floods. She gave the talks to middle school earth science students at Casey Middle School and Centennial Middle School in Boulder Valley School District. They consisted of three full day presentations for 150 students each day answering the most pressing questions about the 2013 Historic Floods by using NOAA data.

- In 2014 and 2015 Hilary Peddicord worked with Casey Middle School over a period of four weeks to lead a Math on a Sphere workshop where students learned programming basics through a NSF project.

- Beth Russell served as a judge at the Ryan Elementary School Learning from 2011 through 2015 and served as a symposium presenter for the afterschool STEAM Symposiums 2011 through 2015. Each symposium was an hour long session that included a lesson and hands on activities.

- Hilary Peddicord participated in Women In Science at the University of Wyoming to give 3 one-hour Workshop for girls aged 14-18 from all over Wyoming getting them excited about careers in science in May of 2013, 2014, 2015.

- Hilary Peddicord participated in October 2014 in the Broomfield Heights career day, giving three one-hour talks with 7-8th grade students about her experience and careers in science education.
• In February 2013 Hilary Peddicord gave a Climate Change talk for local policy makers and politicians in Sheridan, WY at the Over the Moon coffee shop.

• In March 2011 Hilary Peddicord gave presentation at Ryan Elementary that included weather activities.

• Bill Moninger has judged the Colorado State Science Fair for 35 years, often leading the physics judging team, and participating on the best-of-fair team, occasionally serving as the captain.

• Joe Wakefield has volunteered as a judge at the Regional Science Fair at CU each February, including 2010 – 2015.

• John Brown, Meteorologist, is in charge of the Boulder Cooperative Weather Station. He provides information to the Daily Camera on an ongoing basis.

• Tracy Hansen serves as a mentor on the graduate advisory committees of several minority students as part of ISET.

• Tom LeFebvre serves as a mentor for a Boulder High School science student and is helping with his science fair project.

• Scott Nahman serves as Vice President for the 7x24 Exchange Rocky Mountain Chapter—Providing educational forums for those who support mission critical facilities.

• Kevin Manross spoke to Metro State University students about radar meteorology and the recent polarimetric (“dual-pol”) upgrade to the NWS NEXRAD network. He also gave a talk to Rock Ridge Elementary (Castle Rock, CO) 5th grade in November 2014 on the atmosphere and where storms come from. It included several hands on exercises.

• Dan Birkenheuer was a judge for the NASA First Robotics Colorado Regional Competitions in 2010. FIRST stands for Inspiration and Recognition of Science and Technology. The organization’s mission is to inspire young people to be science and technology leaders, by engaging them in exciting mentor-based programs that build science, engineering and tech

• Lee Cohen volunteers as a judge for the Roche Colorado Regional Science Fair.

• Jeff Smith has been a science and engineering fair judge and helped run the fairs at both Lukas Elementary School 2010-15 and Jefferson Academy in Westminster 2014-15.

• Steve Weygandt taught a Math Olympiads class every Monday morning at a Longmont elementary school in 2010.

• Curtis Alexander served as a student mentor for both high school and Hollings scholarship undergraduate college students.

• Ligia Bernardet served on a Ph.D. committee at the University of Colorado.
• Keith Searight serves as a web development instructor at Monarch High School, Louisville, CO.

• Joe Olson is a volunteer for the Ocean Science Bowl.

• Jason English
  o Served as climate modeling and climate change classes teacher, Chinook West High School
  o Served as Earth Explorer volunteer for sixth grade class, Trail Ridge Middle School
  o Served as high school teacher training instructor on Clouds Aerosols, and the Arctic

• Christina Holt serves as member of the Hurricane Weather Research and Forecasting (HWRF) Model Developers Committee.

• Jennifer Mahoney served as a presenter of science programs to students at Boulder-area schools.

• Kevin Manross served as mentor/advisor for Significant Opportunities in Atmospheric Research and Science (SOARS) undergraduate student and Hollings Scholarship undergraduate student.

• Pallavi Marrapu served as mentor/advisor, homework grader, and provider of laboratory/project guidance for 75 undergraduate and graduate students in classes on Introduction to Thermodynamics and Green Chemical and Energy Technologies.

• Tanya Peevey
  o Serves as a writing mentor for a SOARS Program summer student
  o Served as coordinator for a Girl Scouts at NCAR event in Boulder
  o Served as a volunteer/organizer/coordinator a Physics Camp at the University of Texas - Dallas held by the Women in Physics campus group

• Bernadette Pfau serves as a CoCoRaHS (Community Collaborative Rain, Hail, and Snow Network) observer.

• Jim Ramer serves as an elementary school homework helper - Boulder, Colorado Family Learning Center.

• Ed Szoke served as presenter on Colorado Front Range weather for the Boulder County Search and Rescue Group and Colorado Mountain Rescue Dog Group.

• Zoltan Toth served as Expert for BARC on Numerical Weather Prediction (NWP) forecasting issues; as Advisor for Ph.D. student's dissertation research; served as Section Editor for Overview of weather and climate systems. In: *Handbook of Hydrometeorological Ensemble Forecasting*, Ed. Qingyun Duan, Springer, in preparation.

• Will von Dauster serves on, and served as Chair of, Boulder Labs Diversity Council.

• Betsy Weatherhead served as an advisor/mentor for a PostDoc scientist from Denmark, sponsored by the International Fulbright Foundation and served as a coach for NASA's Odyssey of the Mind for K-12 Education.
• Yuanfu Xie served as a guest editor for a special issue of “Data Assimilation in Numerical Weather and Climate Models” and served as an advisor/mentor for 20 different undergraduate and graduate students, visiting scientists, and PostDoc researchers

GSD Educational Outreach at Conferences

GSD has always had a strong presence at the annual American Meteorological Society and American Geophysical Union conferences. There we may help staff the NOAA booth, organize “Meet the Scientist” talks, and hand out materials about our science. We participate regularly in the following conferences/events distributing educational materials, conducting presentations, workshops, demos, etc. and informing a broad range of the public about NOAA and how the agency affects their lives:

National Science Teachers Association
National Broadcasters Association
National Middle School Teachers
National Get Outdoors Day
Colorado Science Convention
Women in Science
The SC (Super Computing) Conference Series
Internet2
Science On a Sphere Users Collaborative Network Workshop
Meteorological Technology World Expo

Web Presence and Social Networking

In the past 5 years, GSD has created the following new web sites:

1. Flow-following finite-volume Icosahedral Model-- http://fim.noaa.gov/
2. NOAA Earth Information System-- http://esrl.noaa.gov/neis/
4. Integrated Hazard Information Service-- http://integratedhazards.noaa.gov/

Science On a Sphere®

Website Analytics--sos.noaa.gov:
2012 - 208,350 page views (analytics installed in July)
2013 - 469,204 page views
2014 - 522,085 page views
2015 - 258,787 page views (through beginning of July) (projected would be 517,574)

Science On a Sphere® Facebook--https://www.facebook.com/scienceonasphere
Likes on Dec 31, 2013 - 4522
Likes on Dec 31, 2014 - 9225
Likes on June 30, 2015 - 27,947
MOST POPULAR POST - video of 2014 sea ice concentration - 3,915,449 views

Science On a Sphere® YouTube Channel- https://www.youtube.com/user/scienceonasphere
437,458 views: 90 videos

April 22, 2014 USPS Postage Stamp Featuring SOS

A NOAA Science On a Sphere dataset showing global sea surface temperatures was featured on a United States Postal Service international forever stamp: http://uspsstamps.com/stamps/global-sea-surface-temperatures

Science Community Education by the Developmental Testbed Center collaboration between NCAR and GSD

In addition to annual tutorials on the HWRF and NMMB models and GSI/EnKF data assimilation, the DTC also holds science community events. Since 2012, the following events have been held in Boulder, Colorado:

Mesoscale Modeling:
- Annual WRF Users Workshop (June 2012-2015)
- MMET instructional session at WRF Users Workshop (June 2015)

Hurricanes:
- Workshop on Numerical Prediction of Tropical Cyclones (May 2014)
- HWRF instructional session at WRF Users Workshop (June 2015)

Data Assimilation:
- Joint DTC-EMC-JCSDA GSI Workshop (August 2013)

Ensembles:
- Mini-workshop w/ GIFS-TIGGE working group (June 2012)
- DTC-NUOPC Ensemble Design Workshop (September 2012)
- 6th NCEP Ensemble User Workshop (March 2014)

Verification:
- Instructional Lectures at WRF Users Workshop
- Introduction to Verification Methods (June 2012)
- Topics in Advanced Verification Methods (June 2013)

Global:
MPAS Workshop (September 2014)
I. Contributions of Data

ESRL/GSD routinely collects, builds and archives Global Earth Observing System of Systems (GEOSS) and national data sets through its development and support of the Meteorological Assimilation Data Ingest System (MADIS). Additionally, GSD collects, quality controls, and archives specialized data sets for research purposes. Contributions to national and international-related databases and programs, and involvement in international quality-control activities to ensure accuracy, precision, inter-comparability, and accessibility of global data sets are described below.

MADIS

The U.S. contribution to GEOSS is the Integrated Earth Observation System (IEOS). The Architecture and Data Management Working Group for the IEOS has listed GSD’s Meteorological Assimilation Data Ingest System (MADIS), which was transitioned to operations at the National Weather Service’s (NWS) National Centers for Environmental Prediction (NCEP) Central Operations (NCO) on January 21, 2015. Research and development of MADIS continues at GSD, and the MADIS archive is now hosted by NOAA’s National Centers for Environmental Information (NCEI). MADIS is designed to collect, integrate, quality control (QC), and distribute observations from NOAA and non-NOAA organizations, leverage partnerships with international, federal, state, and local agencies; universities; volunteer networks; and the private sector (e.g. airlines, railroads). Observations from these NOAA and non-NOAA stations are integrated to a finer-density, higher-frequency global observational database for use by the greater meteorological community. MADIS is now a national asset for improving meteorological observations, improving the delivery of those observations, as well as improving the on-going archive of the data and metadata at NCEI.

MADIS improves observations by Quality Controlling the observations on receipt of the data. MADIS QC is being improved in three ways:

1. Improving the understanding of the data through the collection of more complete metadata by working with programs such as:
   a. The National MESONET (NM) program on metadata standards such as Open Geospatial Consortium’s (OGC) SensorML and Starfish Fungus Language.
   b. Sensing Hazards with Operational Unmanned Technology (SHOUT) program on ISO metadata standards.
2. Using the improved metadata to improve the QC algorithms based on a better understanding of the data.
3. Providing an open source framework and a process for the meteorological community to help improve the QC algorithms used by MADIS.

MADIS improves the delivery of the observational data to the meteorological community by acquiring and decoding data from a wide array of platform types and providers, encoding all of the observational data into a common format with standard units and time stamps, and delivering the data via a set of standard services. MADIS is working with several programs to improve the delivery and discovery of MADIS data:
1. The Next Generation IT Web Services (NGITWS) program on OGC delivery and discovery services such as Web Feature and Web Coverage.
2. The NWS Data Delivery (DD) program on OGC WFS discovery and delivery services.
3. The SHOUT program on ISO discovery and delivery services.

Distribution of MADIS to the greater meteorological community encompasses delivery to 19 national meteorological centers, including NCEP, the European Center for Medium-Range Weather Forecasts (ECMWF), the United Kingdom’s National Weather Service (UK Met Office), the Korean Meteorological Administration (KMA), Taiwan’s Central Weather Bureau (CWB), EUROCONTROL (European Organization for the Safety of Air Navigation), and the Chinese and Finnish Meteorological Centers. For more information about MADIS, go to https://madis.ncep.noaa.gov/.

**GPS-Met**

ESRL/GSD’s GPS-Met project has developed a system to collect, quality control, archive, and distributed total precipitable water (TPW) estimates in near-real-time to support NOAA’s research and operational activities. TPW estimates have been used in studies of atmospheric rivers, deep convection events, and the characteristics of satellite microwave water vapor observations over the ocean. TPW estimates are assimilated by NWS’ operational North American Mesoscale (NAM) and Rapid Refresh (RAP) numerical weather models and are incorporated into the the NOAA’s Environmental Satellite Data and Information Services (NESDIS) Blended TPW product to help fill gaps in precipitable water (PW) estimates where satellites cannot make these estimates.

ESRL/GSD collaborated with the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin affiliate and with NESDIS to test and select an improved algorithm for GOES TPW retrieval. ESRL/GSD scientists believe the requirement for this improved algorithm resulted from previous work that demonstrated calibration/validation problems with GOES TPW retrievals.

ESRL/GSD has participated in the free and open exchange of global atmospheric observations by providing its observations in a standard WMO BUFR format.

ESRL/GSD is currently involved in an on-going experiment to assess the long-term characteristics of offshore satellite observations and their impact on weather forecast accuracy (primarily precipitation).

ESRL/GSD initiated a Cooperative Research and Development Agreement (CRADA) process with a number of private companies to access the interest and capacity to provide total precipitable water (TPW) estimates to NOAA. The CRADA achieved its goal and ESRL/GSD is working with NWS personnel to create the statement of work needed to initiate a data purchase agreement.

For more information about GPS-Met, go to http://gpsmet.noaa.gov/
Science On a Sphere®

Science On a Sphere® (SOS) has established a substantial catalog of data sets that is distributed to each site that installs the system. The catalog was reorganized in 2014 into the categories of Air, Water, Land, Snow and Ice, Space, People, and Extras. The catalog now comprises over 500 datasets, including 41 real-time datasets and 74 narrated movies. The collection continues to grow as new contributions come in from a wide variety of sources including NOAA, NASA, universities, and sites that have SOS. The catalog can be found here: http://sos.noaa.gov/Datasets/.

HIWPP Open Data Initiative

ESRL/GSD has led the Sandy Supplemental project entitled "High Impact Weather Prediction Project" (HIWPP). GSD scientists and engineers have developed and implemented the HIWPP Open Data Initiative, a task within HIWPP designed to share research data with the broader weather community. Within HIWPP, high-resolution global models in late stages of testing and development have been contributed from the NCEP/Environmental Modeling Center (EMC), the Naval Research Laboratory (NRL), and from ESRL/GSD and have been running in a quasi-operational, real-time research mode. Output from these models has been collected in real-time within a central space in GSD. As part of NOAA’s efforts to make environmental data more openly accessible to the public and to interact with the broader weather community, HIWPP has implemented a process that allows members of the public to access these global model output data, and to provide feedback to model developers. This is an innovative effort to make research data publicly available before they have moved into an operational setting. Infrastructure and issues related to the transfer, storage, and access of very large data sets generated by high-resolution global models have been a focus of the HIWPP project, and will inform NWS efforts to move to the next-generation of high-resolution models operationally. For further information, go to http://hiwpp.noaa.gov/open-data/.

NextGen IT Web Services (NGITWS)

ESRL/GSD scientists contributed weather data subject matter expertise to the NGITWS Project. The NOAA Integrated Dissemination Program (IDP) is fielding NGITWS, a web-based data dissemination service that will revolutionize the accessibility, discoverability, and machine-to-machine communication and processing of National Weather Service (NWS) data sets. Focused on OGC standard services and data formats for maximum interoperability, initial operational capabilities will be available from two geographically-diverse state-of-the-art data centers in College Park, Maryland and Boulder, Colorado. While the initial deployment will focus on aviation-centric data sets to support the FAA Next Generation Air Transportation (NextGen) system, the NWS Advanced Weather Interactive Processing System (AWIPS) and Aviation Weather Center (AWC) Web Services are preparing to take advantage of this new service.

FAA Common Support Services - Weather (CSS-Wx)

ESRL/GSD scientists contributed weather data subject matter expertise to the CSS-Wx Program. CSS-Wx is the single provider of weather data, products, and imagery within the National Airspace
System (NAS) using standards-based weather dissemination via System Wide Information Management (SWIM). CSS-Wx makes available both NOAA and FAA observations and forecast model products for integration into air traffic decision support tools improving the quality of traffic management decisions and reducing controller workload during severe weather. Products are provided via a set of common Web Services for weather using internationally recognized data access and data format standards.

EarthCube

The National Science Foundation’s EarthCube is a community-led cyberinfrastructure program that will allow for unprecedented data sharing across the geosciences. EarthCube began in 2011 as a joint initiative between the NSF Directorate for Geosciences (GEO) and the Division of Advanced Cyberinfrastructure (ACI). EarthCube is broadly interdisciplinary, serving the Earth and Environmental Sciences, developing technologies that serve the scientific community EarthCube envisions a dynamic, community-driven cyberinfrastructure that supports standards for interoperability, infuses advanced technologies to facilitate interdisciplinary research, and helps educate scientists in the emerging practices of digital scholarship, data and software stewardship, and open science. ESRL/GSD researcher, Chris MacDermaid, was a member of the Governance Steering Committee which produced the initial EarthCube Governance Roadmap (https://www.nsf.gov/geo/earthcube/docs/EarthCubeGovernanceRoadmap.pdf). Chris MacDermaid is currently an executive committee member of the EarthCube Council of Data Facilities, a member of the EarthCube Technology and Architecture Committee, and a member of the EarthCube Liaison Team.

Pre/Potential Tropical Cyclones (pTC)

All tropical cyclones (TCs) originate from an organized convective disturbance. Studies of TC genesis therefore require a data set of pre-TC disturbance or ‘pTCs.’ ESRL/GSD has developed a global pTC data set derived from the operations of the Joint Typhoon Warning Center (JTWC) and the National Hurricane Center (NHC) for the period 2007-2015. These operational data are not managed in the same way as the post-season ‘best track’ so special processing and quality controlled are needed to make the data useful for research.

Initial results demonstrate, however, that every observed TC was preceded by an operational pTC – a property unique compared to satellite-based pTCs data sets. The pTCs were validated by running a TC diagnostics routine that measures the large-scale meteorological properties of the pTCs based on the analyses of the European Centre for Medium-range Weather Forecast (ECMWF) – the global leader in Numerical Weather Prediction (NWP). Clear differences in the evolution of developing vs. non-developing pTCs were found. This implies the ECMWF data correctly analyze the meteorology of TC genesis.
Forecast Impact and Quality Assessment

Through cutting edge and innovative research, the Forecast Impact and Quality Assessment Section of ESRL/GSD provides operational agencies with technology and tools for improving the accuracy and quality of weather information at critical decision points, thus improving services to the public.

An interdisciplinary team of meteorologists, physicists, mathematicians, and engineers provide quality assessment measures with meaning, network-enabled verification services for automated decision support and verification system unification, and independent comprehensive analyses to interpret and communicate the accuracy of weather.

WMO-Aircraft Based Observations

In the last several years, ESRL/GSD scientist, Bill Moninger, has served as an invited participant as a “U.S. Technical Expert” for the World Meteorological Organization’s (WMO) Automated Meteorological Data and Reporting (AMDAR) panel. AMDAR is the set of automated upper-air weather reports from commercial aircraft. AMDAR provides about 750,000 measurements of wind, temperature, and some turbulence and vapor information, per day. These data are critical inputs to numerical weather prediction (NWP) models. Dr. Moninger was one of a select group of scientists invited to the AMDAR data management workshop in Geneva. Subsequent to that, ESRL/GSD hosted a session with the AMDAR panel when they met in Boulder for an annual meeting.

NOAA Geographic Information System (GIS) Committee

ESRL/GSD researcher, Chris MacDermaid, is the OAR representative to the NOAA GIS Committee. The NOAA GIS Committee provides guidance and oversight for the NOAA GIS community. The Committee establishes policies, priorities, and provides direction for the establishment of a comprehensive NOAA-wide GIS architecture. The Committee additionally provides ongoing examination and monitoring of enterprise-wide standards.

NOAA Web Committee

ESRL/GSD researcher, Jennifer Valdez, is the OAR representative to the NOAA Web Committee. The NOAA Web Committee provides coordination and guidance for communicating NOAA information and data using online tools for the overall NOAA Web enterprise. The Committee formulates policy recommendations to the NOAA CIO and Director of Communications and acts as an advisory body to the NOAA CIO Council. The Committee provides support for the development and execution of NOAA Web-related enterprise-wide projects as well as those Web-related policies passed by the DOC/NOAA CIO and Director of Communications. The Committee may also serve as an advisory body to other NOAA committees and group.
J. Collaborations

Evidence of collaboration with other national and international research groups both inside and outside of NOAA as well as reimbursable support from non-NOAA sponsors

Primary Collaborations

National Weather Service

Since 1990, the National Weather Service has been GSD’s primary collaborator and customer. In the early days, the National Weather Service relied on GSD to develop the first AWIPS system for its forecasting offices nationwide. GSD continues to develop forecaster tools for the AWIPS enterprise, requiring close interaction with NWS forecasters at all levels, including the NCEP centers, for input and feedback during development, testing and implementation. For many years, GSD supported the NWS Incident Meteorologists in the field with a mobile AWIPS system primarily with on-the-scene fire weather forecasts. In the past 10 years, GSD has collaborated with NCEP's Environmental Modeling Center to implement three GSD regional, short-range weather models with new versions to be implemented early next year. Through the High Impact Weather Prediction Project and other programs, GSD will continue to collaborate with NWS in the pursuit of the best next generation global model prediction system and both regional and global ensembles. For many years GSD has specialized in developing and improving aviation weather tools used by NWS aviation forecasters and air traffic managers and conducting assessments of new aviation tools to verify they work as designed as part of the Aviation Weather Research Program (AWRP). GSD highly values this collaboration with NWS and looks forward to a continuing productive synergy with NWS in the future.

Federal Aviation Administration

Twenty-five years ago, GSD’s predecessor, the Forecast Systems Laboratory, and the Federal Aviation Administration (FAA) began a partnership that is still going strong. The Aviation Weather Research Program began with the goal of producing an aviation gridded forecast system. This system was envisioned to consist of a high resolution and frequently updated numerical prediction model, and algorithms to translate the model output into aviation impact variables (AIVs), such as icing, turbulence, ceiling and visibility, and winds (which are a direct model output). AWRP also funded the development of experimental tools to enable better coordination of volcanic ash advisories and to help traffic managers better visualize the effect of convection on aircraft arrivals and departures. AWRP supported the development of the High Resolution Rapid Refresh (HRRR) model, which became operational at NCEP in September of 2014. AWRP continues to support a robust quality assessment project which provides independent assessments of AIV algorithms. These assessments depend on the development and application of new verification methodologies
which take verification science beyond the norm of point forecast and observation comparisons. AIV algorithms developed and assessed have become operational via the Aviation Digital Data Service, which is produced at NWS’ Aviation Weather Center. GSD looks forward to a continuing collaboration with the FAA, improving products for accurate aviation weather information that is so critical to aviation safety and efficiency.

**NOAA and Cooperative Institute Partnerships**

Cooperative Institute for Research in the Atmosphere (CIRA)
Cooperative Institute for Research in Environmental Sciences (CIRES)

Global Systems Division is fortunate to have productive and enduring research partnerships with the venerable University of Colorado’s *Cooperative Institute for Research in Environmental Sciences (CIRES)* and the versatile Colorado State University’s *Cooperative Institute for Research in the Atmosphere (CIRA)*. Both cooperative institutes actively support GSD’s mission, providing expert scientists and technologists to pursue GSD’s grand challenges. A majority of GSD staff are employees of the cooperative institutes and provide new perspectives, energy and innovation to GSD’s research areas.

**NOAA**
- National Weather Service (All Offices, Centers, and Forecasting Offices)
- NOAA Environmental Satellite, Data, and Information Service
- National Ocean Service
- Office of the Chief Information Officer
- Office of the Chief Scientist

**Office of Oceanic and Atmospheric Research (OAR) Laboratories**
- Air Resources Laboratory
- Atlantic Oceanographic and Meteorological Laboratory
- Earth System Research Laboratory (Global Monitoring Division, Physical Sciences Division, and Chemical Sciences Division)
- Geophysical Fluid Dynamics Laboratory
- Great Lakes Environmental Research Laboratory
- National Severe Storms Laboratory
- Pacific Marine Environmental Laboratory

**OAR Programs**
- Office of Weather and Air Quality
- NOAA Climate Program Office
- NOAA Unmanned Aircraft Systems
International Government Agencies

Australia Bureau of Meteorology (BOM)
Central Weather Bureau, Taiwan (CWB)
German Aerospace Center (DLR)
Korea Meteorological Administration, Republic of Korea
Meteorological Service of Canada
Network of European National Meteorological Services (EUMETNET)
Shanghai Meteorological Bureau, Shanghai, People’s Republic of China
Soil and Water Conservation Bureau, Taipai, Taiwan, Republic of China
Spain’s State Meteorological Agency (AEMET), Madrid, Spain
State Oceanic Administration, National Marine Data and Information Service, Tianjin, People’s Republic of China
United Kingdom Meteorological Office
University of Chile, Santiago de Chile
Water Resources Agency, Taipai, Taiwan Republic of China

International Private Companies

China National Huayun Technology Development Corporation, People’s Republic of China
Højbygaard Paper Factory, Denmark
Korea Water Resources Corporation, Republic of Korea
Korean Broadcasting System, Republic of Korea
NAV Canada
Trimble, Ltd.
Vaisala Corporation, Helsinki, Finland

International Non-Profit Organizations

American Institute in Taiwan (AIT)
Max Planck Institut, Mainz Germany

U.S. Government Organizations

National Center for Atmospheric Research (NCAR)
NASA Langley Research Center
National Interagency Fire Center (NIFC)
National Institute of Standards and Technology (NIST)
National Science Foundation (NSF)
U.S. Air Force Base Vandenberg
U.S. Air Force Research Laboratory
U.S. Air Force Space and Missile Command
U.S. Air Force Weather Agency
U.S. Army Research Laboratory
U.S. Department of Agriculture – Office of the Chief Information Officer
U.S. Department of Agriculture – Forest Service
U.S. Department of Energy - Virtual Worlds Strategic Outreach
U.S. Department of Homeland Security – Science and Technology Directorate
U.S. Department of the Interior – Bureau of Land Management
U.S. Department of Transportation/Federal Aviation Administration
U.S. Department of Transportation/Federal Highways Administration
U.S. National Geodetic Survey
U.S. Geological Survey
U.S. Weather Research Program

State Government Organizations
California Department of Water Resources
Colorado Department of Transportation
Colorado State University/Cooperative Institute for Research in the Atmosphere (CIRA)
Iowa State University
Florida State University
Louisiana Spatial Reference Center, Louisiana State University
State of Colorado
New Mexico Institute of Mining and Technology
North Carolina State University
North Carolina A&T University
The Pennsylvania State University
University of Alaska Southeast
University of California, Berkeley
University of Colorado, Boulder/Cooperative Institute for Research in the Environmental Sciences
University of Hawaii
University of Oklahoma
University of Wisconsin/Cooperative Institute for Meteorological Satellite Studies
University of Wyoming

U.S. Private Companies
Ace Info Solutions, Inc.
Atmospheric and Environmental Research, Inc.
AvMet Corp
nCentral Valley Holdings LLC
Cherokee Services Group
Cherokee Nation Technologies
Cirrascale
Cray
Devon Energy Production Company, LP
ENSCO, Inc.
Iberdrola Renewables, Inc.
IBM
ImagiCorps
ITT, Corp.
Intel Corp.
Lockheed Martin Corporation
NVIDIA
Pathscale
PGI
Planning Systems, Inc.
Tim Gard and Comic Visions
Toyota Racing Development USA, Inc.
Trimble Navigation
Weather Decision Technologies, Inc. (WDT)
Xcel Energy

U.S Non-Profit Organizations
University Corporation for Atmospheric Research (UCAR)

Science On a Sphere® Installations

Listed chronologically in order of installation

NOAA Earth System Research Lab, Boulder, CO
Nauticus - The National Maritime Center, Norfolk, VA
The Science Museum of Minnesota, St. Paul, MN
Bishop Museum, Honolulu, HI
The Tech Museum of Innovation, San Jose, CA
The Maryland Science Center, Baltimore, MD
NASA Goddard Space Flight Center, Visitors Center, Greenbelt, MD
Great Lakes Maritime Heritage Center, Alpena, MI
Imiloa, Astronomy Center of Hawaii, Hilo, HI
James Madison University, Harrisonburg, VA
McWane Science Center, Birmingham, AL
Fiske Planetarium and Science Center of Colorado University, Boulder, CO
Orlando Science Center, Orlando, Florida
The Museum of Science and Industry, Chicago, IL
NOAA's National Severe Storms Laboratory, Norman, OK
Clark Planetarium, Salt Lake City, UT
Lawrence Hall of Science, Berkeley, CA
National Museum Of Natural Science, Taichung, Taiwan, R.O.C
Gwacheon National Science Museum, Gwacheon, Republic of Korea
Smithsonian National Museum of Natural History, Washington, D.C.
International Museum of Art & Science, McAllen, TX
Microsoft Visitor Center, Redmond, WA
Ted Stevens Marine Research Institute (NMFS), Juneau, AK
NASA Visitor Center, Wallops Island, VA
Boonshoft Museum of Discovery, Dayton, OH
Harsco Science Center, Harrisburg, PA
North Carolina Aquarium, Manteo, NC
Smithsonian’s National Zoo, Washington, D.C.
Alaska State Museum, Juneau, AK
Infinity Science Center, Stennis Space Center, MS
The Wildlife Experience, Parker, CO
Cite des Sciences et de l'Industrie, Paris, France
Oregon Museum of Science and Industry, Portland, OR
Heureka, The Finnish Science Centere, Vantaa, Finland
Houston Museum of Natural Science, Sugarland, TX
Discovery Cube Orange County, Santa Ana, CA
NASA Ames Exploration Center, Moffett Field, CA
Climate Institute, Mexico City, Mexico
US Astronaut Hall of Fame, Titusville, FL
Beijiko Meteorological Museum, Nanjing, PRC
Cite de l'espace, Toulouse, France
Denver Museum of Nature and Science, Denver, CO
Point Reyes National Seashore, CA
Central Weather Bureau, Taipei, Taiwan
Bay Education Center, Rockport, TX
Climate Institute, Cuernavaca, Mexico
Pacific Science Center, Seattle, WA
Danville Science Center, Danville, VA
Science Museum, London, UK
Climate Institute, Chilpancingo, Mexico
Climate Institute, Atlamoculco, Mexico
Climate Institute, Metepec, Mexico
Climate Institute, Casa de la Tierra, Veracruz, Mexico
Climate Institute, Planetario de Morelia, Morelia, Mexico
Science Museum of Virginia, Richmond, VA
Climate Institute, Acapulco, Mexico
Aquarium of the Pacific, Long Beach, CA
Detroit Zoological Society, Royal Oak, MI
Beijing Huaxinchuanzi Technology Co., Ltd., Beijing, PRC
KIGAM Geological Museum, Daejeon, Republic of Korea
Nurture Nature Center, Easton, PA
Visual Climate Center, Holeby, Denmark
Climate Institute, Texcoco, Mexico
Climate Institute, Valle de Bravo, Mexico
Climate Institute, Villahermosa, Mexico
Museum of Natural History, Halifax, Canada
Aldo Leopold Nature Center, Monona, WI
China Weather Channel, Huafeng Building, Beijing, PRC
Grand Canyon Visitors Center, AZ
China Maritime Museum, Shanghai, PRC
St. Paul's School, Concord, NH
Science Centre Singapore, Singapore
Science City at Union Station, Kansas City, MO
Daegu National Science Museum, Daegu, Republic of Korea
Climate Institute, Oaxaca, MX
Instituto Oceanográfico da Universidade de São Paulo, São Paulo, Brazil
The Wild Center, Tupper Lake, NY
Tausee P.F. Sunia Ocean Center, Pago Pago, American Samoa
Space Foundation Visitors Center, Colorado Springs, CO
The Climate Corporation, San Francisco, CA
Telus World of Science, Edmonton, Canada
Universidad Autónoma de Coahuila, Saltillo, MX
Gwangju National Science Museum, Gwangju, Republic of Korea
National Youth Space Center, Goheung, Republic of Korea
Great Valley Museum - Modesto Junior College, Modesto, CA
China Science and Technology Museum, Beijing, PRC
South Florida Science Museum, West Palm Beach, FL
Fuzhou Science and Technology Museum
E. O. Wilson Biophilia Center, Freeport, Florida
Indiana University, Bloomington, IN
Museo delle Scienze, Trento, Italy
Techmania, Pilsen, Czech Republic
NOAA Headquarters, Silver Spring, MD
Science Central, Fort Wayne, IN
National Museum of Marine Science & Technology, Keelung City, Taiwan
Galaxy Elementary School, Delray Beach, FL
NOAA Inouye Regional Center, Honolulu, HI
Climate Institute, Ciudad Victoria, MX
Dongguan Meteorology and Astronomy Museum, Dongguan, PRC
Discovery Center, Higashimatsushima, Japan
Imagination Station Science Museum, Wilson, NC
St. Charles High School, Waldorf, MD
Climate Institute, Monterrey, MX
Visvesvaraya Industrial & Technological Museum, Bangalore, India
Exploreum, Pasay City, Philippines
Precision Planting, Tremont, IL
Discovery Cube Los Angeles, Sylmar, CA
MTA Natural History Museum, Ankara, Turkey
Children’s City, Dubai, U.A.E.
Climate Institute, Reynosa, Mexico
Hong Kong Maritime Museum, Hong Kong, Hong Kong SAR
GulfQuest Maritime Museum of the Gulf of Mexico, Mobile, AL
Earth Day Texas, Dallas, TX
EcoParque Los Yarumos, Manizales, Colombia
Alternator Science Center, Trebic, Czech Republic
Wings of Eagles Discovery Center, Horseheads, NY
Chongqing Museum of Natural History, Chongqing, PRC
Museum of Arts and Sciences, Macon, GA
Rochester Museum and Science Center, Rochester, NY
K. GSD News Headlines

GSD News Releases

For links to these GSD news releases published on the GSD public website: http://esrl.noaa.gov/gsd/media/headlines.html.

09/28/2015 – Field project to help improve wind forecasts for wind farms – OD
09/23/2015 – NOAA SOS Education Specialist to share NOAA science with local community - ATOB
09/14/2015 – ESRL/GSD Wins Prestigious Governor’s Award for High-Impact Research - EMB
09/09/2015 – Real-Time Data from Global Hawk Provided for Erika and Fred – EMB
08/27/2015 – Global Hawk Data Successfully Assimilated into HWRF for TS Erika – EMB
08/05/2015 – New Science On a Sphere “Explorer” to be released at the end of August – ATOB
07/16/2015 – GSD’s Experimental “Hazard Services” System Tested in Flash Flood Forecasting Environment – EDSB
07/07/2015 – Stratosphere an Accomplice for Santa Ana Winds in California Wildfires – EDSB
06/23/2015 – Teachers Visit Boulder to Learn Climate Research and Education Initiatives – ATOB
04/07/2015 – SOS at the Annual Space Weather Workshop – ATOB
03/25/2015 – NOAA’s SOS at National Science Teacher’s Association (NSTA) National Conference – ATOB
02/23/2015 – GSD Hazard Services Team Meets Major Milestone – EDSB
02/06/2015 – NOAA Engages Broader Weather Community with Open Data Initiative – EMB
01/26/2015 – First SOS System in Middle East – ATOB
01/21/2015 – MADIS Successfully Transitioned from Research to Operations – ATOB
12/03/2014 – Completion of NOAA Work Efforts Under IA#26 for Taiwan’s CWB – ATOB
10/16/2014 – New NOAA Supercomputer Goes into Action – ITS
09/30/2014 – High-Resolution Rapid Refresh Model Implemented Operationally at NWS – AMB
09/25/2014 – NOAA Hurricane Forecast Model Made Available to the Academic Community – FAB
09/12/2014 – GPSMet CRADA Update – FAB
08/18/2014 – SOS Teacher Workshops: Hands-On Data-Driven Activities on Flash Floods – TOB
07/29/2014 - GSD Hosts Hazard Services Focal Point Focus Group Workshop in Boulder, CO – ISB
07/09/2014 – SOS Holds Workshop in Boulder for Elementary School Teachers – TOB
06/30/2014 – WRF-Chem in Nepal – AMB
06/17/2014 – GSD’s SOS Team at Users Collaborative Network Workshop – TOB
05/29/2014 – NOAA’s Science On a Sphere® Takes Center Stage at World Science Festival – TOB
05/02/2014 – NOAA’s Science On a Sphere® Has a USPS Stamp – TOB
02/27/2014 – NOAA’s Science On a Sphere® Dazzled Students at Boulder, CO Middle School – TOB
02/26/2014 – Improved Short-Range Weather Forecasts from RAP Model Upgrade to Ver. 2 – AMB
02/12/2014 – Science On a Sphere® – Now With a Mandarin Chinese Website – TOB
01/30/2014 – GSD Demonstrates Latest Hazard Services Tool to Six NWS Forecast Offices – ISB
11/26/2013 – The Experimental Regional Ensemble Forecast System (ExREF) – FAB
09/15/2013 – OAR Data Sharing and Research Collaborations with EIG EUMETNET – FAB
09/15/2013 – OAR Contributes to Improved Understanding of Precipitation in the Amazon – FAB
08/12/2013 – GSD's Contributions to summer 2013 Intensive Field Studies – AMB
08/06/2013 – Science On a Sphere® – The 100th System Installation Worldwide – TOB
08/05/2013 – GSD's INSITE Tool Completed – ACE
07/23/2013 – SOS® Holds Workshop in Boulder for Science and Social Studies Teachers – TOB
05/09/2013 – Glider Soaring Distance Record with the Aid of GSD’s HRRR Forecast System – AMB
05/07/2013 – NOAA-NIST Collaboration on IT Infrastructure in Boulder, Colorado – ITS
03/26/2013 – NOAA Earth Information System (NEIS) Development Work at GSD – TOB
02/13/2013 – ESRL Contributes to Transition of Improved GOES Sounder Products into Ops. – FAB
01/25/2013 – Weather Evaluation Team Meets at ESRL in Boulder – ACE
11/20/2012 – GSD at the 5th Science On a Sphere® Users Collaborative Network Workshop – TOB
11/15/2012 – The Second LAPS User Workshop – FAB
08/16/2012 – ESRL/GSD Provides HRRR Numerical Weather Model Data To NASA – AMB
07/24/2012 – SOS® Installed in American Samoa – TOB
07/09/2012 – Brand New SOS® Website Now Live – TOB
06/22/2012 – Australia’s Bureau of Meteorology Awards Featuring GSD’s GFE – ISB
06/01/2012 – Smoke Particles/Chemical Data Assimilated in High Res. Real-Time Forecasts – AMB
05/07/2012 – New ESRL Weather Forecast Computer Model Goes On-Line at NWS/NCEP – AMB
04/23/2012 – New NOAA Supercomputer Goes Operational – ITS
11/14/2011 – NOAA SOS® Releases Their First App to Apple’s App Store – TOB
10/07/2011 – Toxic Plume Dispersion Model Proves Successful in Chemical Fire – ISB/AMB
05/18/2011 – ESRL Scientists in National Geographic Show “X-Ray Earth” – A&R
04/13/2011 – ESRL Researchers Hold Training in Korea – AMB
03/28/2011 – Japan Earthquake Impacts NOAA GPS Water Vapor Measurements – FAB
12/14/2010 – Renewable Energy; Hot Topic for NOAA at AGU – OD
12/13/2010 – NOAA Games and Simulation Summit – TOB
11/22/2010 – First SOS® Installation in the U.K. – TOB/OD
10/18/2010 – ESRL’s Global Systems Division Hosts LAPS User’s Workshop – FAB
10/08/2010 – NOAA’s MADIS Reaches Major Milestone – ISB
10/08/2010 – ESRL Scientist Presents at State Department GPS Talks with Australia – FAB
09/08/2010 – ESRL’s Graphical Forecast Editor Extended to New South Wales, Australia – ISB
08/09/2010 – TJET – Making Hurricane Predictions Faster – ITS
05/26/2010 – ESRL Research Backs Australian Innovation Award – ISB
05/07/2010 – New FIM-CHEM-Ash Produces Real-Time Volcanic Ash Forecasts – AMB
05/04/2010 – ESRL Collaboration on Volcanic Ash Dispersion Model – AMB
04/20/2010 – GSD’s Role in NSA Workshop – TOB
04/09/2010 – ESRL Researchers Demo at National Association of Broadcasters Conference – ISB

Key:
ATOB – Advanced Technology and Outreach Branch
EMB – Earth Modeling Branch
EDSB – Evaluation and Decision Support Branch
ISB – Information Systems Branch (from previous GSD organizational structure)
ITS – Information and Technology Services
FAB – Forecast Applications Branch (from previous GSD organizational structure)
TOB – Technology Outreach Branch
A&R – Administration and Research (OD)
ACE – Aviation, Computing, and Evaluation Branch
AMB – Assimilation and Modeling Branch (from previous GSD organizational structure)
OD – Office of the Director

MEDIA RECOGNITION

NOAA Communications Referencing GSD Research Products and Services

Online NOAA.gov homepage stories

May 1, 2012 (RAP)
“NOAA near-term weather forecasts get powerful boost from new computer model – Research yields new tool to achieve a Weather-Ready Nation”
http://www.noaanews.noaa.gov/stories2012/20120501_rapmodel.html

November 14, 2012 (Weather models at ESRL)
“Weather data from nation’s largest wind farms could improve U.S. models, forecasts”

September 30, 2014 (HRRR)
“NOAA’s weather forecasts go hyper local with next-generation weather model”

January 5, 2015 (HRRR)
“NOAA announces significant investment in next generation of supercomputers”
http://research.noaa.gov/News/NewsArchive/LatestNews/TabId/684/ArtMID/1768/ArticleID/1
1015/NOAA%E2%80%99s-investments-in-weather-models-and-partnerships-paying-off-.aspx

Online OAR Research homepage stories

September 1, 2015 (SOS Explorer)
“NOAA's Science On a Sphere® animations coming to your desktop”
http://research.noaa.gov/News/NewsArchive/LatestNews/TabId/684/ArtMID/1768/ArticleID/1
1339/NOAAs-Science-On-a-Sphere174-animations-coming-to-your-desktop.aspx

January 30, 2015 (HIWPP)
“NOAA’s investments in weather models and partnerships paying off: Early improvements effective in forecasting recent Nor-easter; future forecast model upgrades planned”
http://research.noaa.gov/News/NewsArchive/LatestNews/TabId/684/ArtMID/1768/ArticleID/1
1015/NOAA%E2%80%99s-investments-in-weather-models-and-partnerships-paying-off-.aspx
February 19, 2015 (MADIS)
“NOAA’s growing weather observations database goes into full operations”
http://research.noaa.gov/News/NewsArchive/LatestNews/TabId/684/ArtMID/1768/ArticleID/1037/NOAA%E2%80%99s-growing-weather-observations-database-goes-into-full-operations.aspx

Jan 8, 2015 (WRF model and other NWP for short-term wind forecasts)
“Energy Department Announces $2.5 Million to Improve Wind Forecasting”
http://research.noaa.gov/News/NewsArchive/LatestNews/TabId/684/ArtMID/1768/ArticleID/10988/Energy-Department-Announces-25-Million-to-Improve-Wind-Forecasting.aspx

March 3, 2014 (HRRR)
“NOAA’s Upcoming Weather Forecast Model Zeros in Earlier on Severe Weather”

July 2, 2014 (HRRR)
“NOAA teams up with Department of Energy & industry to improve wind forecasts”

Jan 31, 2014 (HIWPP/ESPC/NOPP/GPU)
“NOAA launches research on next generation of high performance weather, climate models”

September 30, 2014 (HRRR)
“NOAA’s Latest High Resolution Weather Model is Released” – NOAA’s Environmental Visualization Lab web site – Description of, and display from, GSD’s High Resolution Rapid Refresh (HRRR) Model
http://www.nnvl.noaa.gov/MediaDetail2.php?MediaID=1620&MediaTypeID=1

OAR EEO Newsletter ‘CONNECTIONS’

September 2011
Vivian LeFebvre is recognized in the ”Many Backgrounds, Many Stories: One American Spirit” article, while Jeff Van Buskirk is recognized in the ”EEO/Diversity Across OAR” article.

June 2014
“Wyoming Women in Science”– Picture and caption on page 2 of GSD's Education Specialist Hilary Peddicord giving a presentation to girls attending the Wyoming Women in Science Conference
**ESRL Quarterly Newsletter**

Summer 2010
“Pseudo Storms, Key Decisions – OSSEs mimic reality to help NOAA prioritize resources”

“Forecasting Ash – ESRL’s FIM-Chem-Ash forecasts volcanic ash cloud in real time”

Fall 2010
“Testing the Wind – NOAA and Industry Partner to Improve Wind Energy Production”

“tJet Roars to Life – “New ESRL supercomputer supports hurricane research, including experimental FIM forecasts”

Winter 2011
“Now Boarding...Weather! ESRL scientists seek to improve aviation efficiency by developing highly accurate and timely weather information for integration into air traffic management operations”

**NWS**

October 31, 2014
*NWS Insider/Director’s Corner* - Louis Uccellini
“My firsthand experience of how the HRRR model is helping build a Weather-Ready Nation”
[https://sites.google.com/a/noaa.gov/nws-insider/directors-corner/myfirsthandexperienceofhowthehrrrmodelishelpingbuildaweather-readynation?pli=1](https://sites.google.com/a/noaa.gov/nws-insider/directors-corner/myfirsthandexperienceofhowthehrrrmodelishelpingbuildaweather-readynation?pli=1)

**External Media Referencing GSD Research Products and Services**

**Online News Stories**

November 5, 2012
CIRES News and Events: CIRES/NOAA models on track toward prediction of storms

September 30, 2014
BloombergBusiness: New U.S. weather tool promises more warning of disasters

October 1, 2014
USA Today: New weather model will improve storm forecasts
October 2, 2014
Boulder Daily Camera: Boulder researchers key in developing sharper weather model

October 6, 2014
HPCwire: NOAA Refines Forecasting Ability
http://www.hpcwire.com/2014/10/06/noaa-refines-forecasting-ability/

September 30, 2014

August 20, 2014
Washington Post – The Capital Weather Gang: “Warning for ‘dangerous’ heat in St. Louis and Ferguson for the next 5 days” – The article leads off with a 3km resolution figure of an 8 hour 2 m maximum temperature forecast from GSD’s High Resolution Rapid Refresh (HRRR)

July 8, 2015
Smoke from Canadian Wildfires Lingers over Colorado (Science On a Sphere®)
9NEWS
http://www.9news.com/story/weather/2015/07/07/smoke-advisory-for-parts-colorado/29804939/

June 20, 2015
Colorado Scientists See Ways to Reduce Carbon Dioxide Emissions
http://denver.cbslocal.com/2015/06/20/colorado-scientists-see-ways-to-reduce-carbon-dioxide-emissions/

October 8, 2015
CIRES-NOAA Teams receive 2015 Governor’s Award for High-Impact Research

Interviews for Multi-Media Stories

October 2, 2014
Weather Nation TV (Recorded interview with Stan Benjamin): http://blog.weathernationtv.com/2014/10/01/video-new-weather-model-could-help-protect-you
Boulder Daily Camera: Boulder researchers key in developing sharper weather model

October 1, 2014
NBC NEWS: Weather goes hyper local with new forecasting model

April 16, 2010
10:00pm edition of Denver, Colorado’s Channel 9 News (NBC)
“Damage of volcanic ash could be felt deep in economy”

**YouTube videos featuring GSD Staff**

GSD Website [9 videos]
http://esrl.noaa.gov/gsd/learn/video.html

UAS -- NOAA ESRL channel video (August 2011),
Dr. Betsy Weatherhead
https://www.youtube.com/watch?v=un4A5XmZSMo

**Newspaper Articles**


July 28, 2015: “Katrina storm season sparked major improvements in hurricane forecasting, NOAA officials say”, New Orleans Times-Picayune – Mention and information on program with substantial GSD contribution, the Hurricane Forecast Improvement Program (HFIP)
http://www.nola.com/katrina/index.ssf/2015/07/katrina_storm_season_sparked_m.html

July 2015: Special Emphasis Events – Wyoming Women in Science/“Galaxy Pancakes, Dragon Genetics, and Wild Wonders Taught here!” - NOAA Research EEO Connections Newsletter – Quotes from, and photograph of, GSD’s Hilary Peddicord as she presents to girls attending the event

May 29, 2015: “Hurricane Season 2015: Better track forecast since Katrina, but intensity a puzzle” – New Orleans Times-Picayune – Mention and information on two programs with substantial GSD contributions, the Hurricane Weather Research and Forecast Model (HWRF) and the Hurricane Forecast Improvement Program (HFIP)  
http://www.nola.com/hurricane/index.ssf/2015/05/major_improvements_in_hurrican.html

February 9, 2015: “As Extreme Weather Increases, A Push for Advanced Forecasts” – Published on Environment360 – Section of article covers NOAA’s High-Impact Weather Prediction Project (HIWPP), with quotes from Project Manager Tim Schneider of GSD  
http://e360.yale.edu/feature/as_extreme_weather_increases_a_push_for_advanced_forecasts/2845

November 24, 2014: “NOAA Brings Big Climate Data Into Your House With Coherent UI” – Coherent Labs – Displays and video from GSD’s NOAA Earth Information System (NEIS™) and its visualization component TerraViz™ (developed at GSD), plus quotes from GSD’s Eric Hackathorn  
http://coherent-labs.com/blog/noaa-brings-big-climate-data-into-your-house/

November 5, 2014: “The ‘glass half full’ National Weather Service” – the Washington Post – Article mentions two GSD efforts, the High Resolution Rapid Refresh (HRRR) Model and Hurricane Weather Research and Forecasting (HWRF) Model  

October 30, 2014: “Weather Model to help Monitor Devastating Ozone Pollution Levels in India” – AccuWeather.com – Article on how a U.S.-designed weather model with a strong GSD research and development contribution, the Weather Research and Forecasting Model – Chemistry (WRF-Chem) is being used to determine the impact of ozone pollution in countries such as India, as well as the United States  

October 3, 2014: “The most accurate weather map of America ever produced: NWS reveals system that can tell exactly where tornadoes and storms will hit 15 hours in advance”, the Daily Mail (British daily middle-market newspaper) – Data display from, and description of, GSD’s High Resolution Rapid Refresh (HRRR) Model, plus video on the HRRR featuring GSD’s Stan Benjamin  
http://www.dailymail.co.uk/sciencetech/article-2775367/Weather-service-storm-forecasts-localized.html


October, 1, 2014: “Specific weather warnings may be in forecast” – the Portland, Maine Press Herald – Description of, and displays from, GSD’s High Resolution Rapid Refresh Model  
http://www.pressherald.com/2014/10/01/specific-weather-warnings-may-be-in-forecast/
September 30, 2014: “Rapid refresh weather model to aid severe storm tracking” - the Washington Post – Description on, and displays from, GSD's High Resolution Rapid Refresh (HRRR) Model

September 30, 2014: “New Weather Forecast Model Can Pinpoint Severe Storms Up to 15 Hours in Advance” – Mashable (a digital media website founded in 2005) – Description of, and displays from, GSD’s High Resolution Rapid Refresh (HRRR) Model

September 30, 2014: “New weather model will improve storm forecasts” - USA Today – Description of GSD’s High Resolution Rapid Refresh (HRRR) Model and quote from GSD’s Stan Benjamin

September 23, 2014: “High-End Weather Modeling, Hour by Hour” – NCAR/UCAR AtmosNews – Description and evolution of GSD's High Resolution Rapid Refresh (HRRR) Model with quotes from GSD’s Stan Benjamin
http://www2.ucar.edu/atmosnews/in-brief/12411/high-end-weather-modeling-hour-hour?utm_source=AtmosNews&utm_campaign=d995c8ebd3-AtmosNews_Oct12014&utm_medium=email&utm_term=0_80502e816e-d995c8ebd3-62439673

May 28, 2014: “SOS Live on The Weather Channel at the World Science Festival” – on The Weather Channel and NBC Today Show – Video interviews on both shows with GSD's Science On a Sphere® in the background.

May 1, 2014: “CU-Boulder hosting science fair for researchers at top of their game” – the Boulder Daily Camera – Quotes on their research efforts from GSD’s Ligia Bernardet and Curtis Alexander

March 20, 2014: “Science On a Sphere® at Southern Hills Middle School” in Boulder, Colorado – the Boulder Daily Camera – Photos of students viewing SOS displays and being given a very animated presentation by GSD’s Beth Russell
http://mediacenter.dailycamera.com/2014/03/20/photos-noaa-science-on-a-sphere-exhibit-at-southern-hills-middle-school/#1

February 24, 2014: “Fighting Aviation Turbulence With High-End GPS” – Forbes/Tech – Quotes on using the existing Global Positioning System (GPS) as a real time probe for atmospheric turbulence from GSD’s Seth Gutman


September 6, 2013: “Summer storm: National Weather Service forecasters nail difficult forecast with high resolution modeling program” – The Oregonian, Portland, Oregon – The model referred to in the article is GSD’s High Resolution Rapid Refresh (HRRR) Model – Quotes in article praising the HRRR's capabilities.
#incart_river_default

August 22, 2013: “National Weather Service Upgrades Could Improve Aviation Forecasts within the Year” – On-Line Journal National Business Aviation Association – Specifically mentions GSD's High Resolution Rapid Refresh (HRRR) model as an integral put of the upgrades

July 25, 2013: “NOAA goes “live” with new weather supercomputers” – ComputerWorld – refers to the article to a project extensively contributed to by GSD staff, the Hurricane Weather Research and Forecasting (HWRF) Model
http://www.computerworld.com/article/2484337/computer-hardware/noaa-goes--live--with-new-weather-supercomputers.html

April 9, 2013: “High score: Gaming moves to the forefront in government” – Government Computing News – Quotes on using gaming tools for educational purposes from GSD’s Eric Hackathorn

February 26, 2013: “Second rate U.S. numerical weather prediction: Why you should care” – the Washington Post – Article graphics showing GSD's High Resolution Rapid Refresh (HRRR) model capturing the 2012 Washington, DC-area derecho hours before it struck

February 3, 2013: “National Weather Center tours offer look at the tools and techniques researchers use to study weather” – News Oklahoma – mentions and describes GSD’s Science On a Sphere®
October 30, 2012: “NOAA gives Boulder Valley eighth graders close-up view of scientist jobs” – the Boulder Daily Camera – Quotes on scientists and their jobs from GSD’s Eric Hackathorn and Julien Lynge

June 29, 2012: “IBM helps U.S. regain world's top supercomputer spot” – USA Today – GSD's Jet supercomputer in the list of Top 500 in the world (#138)
http://www.top500.org/list/2012/06/

June 18, 2012: “Storm Intensity Forecasts Lag: Communities More at Risk” – Climate Central – Discusses Hurricane Forecast Improvement Project using the Hurricane Weather Research and Forecast Model – Work on these spearheaded in GSD by Ligia Bernardet and Christina Holt

June 16, 2012: “Colorado scientists: wildfires make their own weather” – the Denver Post – Quotes from GSD’s Sher Schranz

June 14, 2012: “Cloudy with a chance of hell: Wildfires change the weather” – the Denver Post – Quotes from GSD's Sher Schranz

April 15, 2012: “$5 million addition to Aldo Leopold Nature Center promotes science of climate change” – the Wisconsin State Journal – mention and display photograph of GSD’s Science On a Sphere®

January 27, 2012: “CU-Boulder scientists work to unravel mechanism of sea ice melt” - Boulder Daily Camera - Quotes from GSD’s Senior CIRES scientist, Dr. Betsy Weatherhead
http://www.dailycamera.com/cu-news/ci_19839673

July 20, 2011: “Project to expand wind energy launched” – USA Today – Quotes from GSD’s Melinda Marquis (Renewable Energy Project Manager)
http://content.usatoday.com/communities/sciencefair/post/2011/07/project-to-expand-wind-energy-launched/1#VcEa6PmE1dU

February 2, 2011: “Employee group shows impact of proposed cuts on government services” – the Washington Post – GSD mentioned in article on if funding cuts come to NOAA
http://www.washingtonpost.com/wp-dyn/content/article/2011/02/02/AR2011020200068.html?wpisrc=nl_headline


April 21, 2010: “Scientists find it difficult to predict volcano behavior” – the Washington Post – Quote from GSD’s Dr. Stan Benjamin http://www.washingtonpost.com/wp-dyn/content/article/2010/04/21/AR2010042102100.html

April 19, 2010: “University of Colorado scientists confirm Inuit weather observations” – the Boulder Daily Camera – Quotes from GSD’s Senior CIRES scientist, Dr. Betsy Weatherhead http://www.dailycamera.com/science-environment/ci_14915301#axzz0leLbjY
## L. Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>3DVAR</td>
<td>3-Dimensional Variational Assimilation</td>
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<tr>
<td>4DVAR</td>
<td>4-Dimensional Variational Assimilation</td>
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<tr>
<td>ADE</td>
<td>AWIPS II Development Environment</td>
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<tr>
<td>AERONET</td>
<td>Aerosol Robotic Network</td>
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<tr>
<td>AFB</td>
<td>Air Force Base</td>
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<td>AFWA</td>
<td>Air Force Weather Agency</td>
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<tr>
<td>AFWS</td>
<td>Automated Flood Warning Systems</td>
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<tr>
<td>AGL</td>
<td>Above Ground Level (height above ground)</td>
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<td>AGU</td>
<td>American Geophysical Union</td>
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<tr>
<td>ALPS</td>
<td>Advanced Linux Prototype System</td>
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<tr>
<td>AMB</td>
<td>Assimilation and Modeling Branch (effective 10/1/2014, Earth Modeling Branch)</td>
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<tr>
<td>AMDAR</td>
<td>Aircraft Meteorological Data Report(s)</td>
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<tr>
<td>AMS</td>
<td>American Meteorological Society</td>
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<tr>
<td>AMSU</td>
<td>Advanced Microwave Sounding Unit</td>
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<tr>
<td>AMV</td>
<td>Atmospheric Motion Vectors</td>
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<tr>
<td>AOD</td>
<td>Aerosol Optical Depth</td>
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<tr>
<td>AOML</td>
<td>Atlantic Oceanographic and Meteorological Laboratory</td>
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<tr>
<td>AQ</td>
<td>Air Quality</td>
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<tr>
<td>AR</td>
<td>Atmospheric River</td>
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<tr>
<td>ARL</td>
<td>Air Resources Laboratory</td>
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<td>ARM</td>
<td>Atmospheric Radiation Measurement - Dept. of Energy research program</td>
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<tr>
<td>ARW</td>
<td>Advanced Research WRF (dynamic core option in WRF)</td>
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<tr>
<td>ARTCC</td>
<td>Air Route Traffic Control Center</td>
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<tr>
<td>ASDI</td>
<td>Aircraft Situation Display to Industry (source of air traffic information, for INSITE)</td>
</tr>
<tr>
<td>ASTC</td>
<td>Association of Science-Technology Centers (collaborators with Science on a Sphere)</td>
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<tr>
<td>ATO</td>
<td>Advanced Technology and Outreach (Branch)</td>
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<tr>
<td>AWC</td>
<td>Aviation Weather Center (an NCEP center)</td>
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<tr>
<td>AWIPS</td>
<td>Advanced Weather Interactive Processing System</td>
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<tr>
<td>AWIPS-II</td>
<td>Advanced Weather Interactive Processing System (next generation deployed 2015)</td>
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<tr>
<td>AWT</td>
<td>Aviation Weather Testbed</td>
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<tr>
<td>BL</td>
<td>Boundary Layer</td>
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<tr>
<td>CAVE</td>
<td>Common AWIPS Visualization Environment</td>
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<tr>
<td>CBVT</td>
<td>CWSU Briefing and Verification Tool</td>
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<tr>
<td>CCFP</td>
<td>Collaborative Decision Making (CDM) Convective Forecast Planning</td>
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<tr>
<td>CCP</td>
<td>Collaborative Convective Probabilistic Prediction</td>
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<tr>
<td>CFS</td>
<td>Climate Forecast System (NCEP model)</td>
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<tr>
<td>CICE</td>
<td>Community ICE model (developed largely at Los Alamos Natl. Laboratory)</td>
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<tr>
<td>CIRA</td>
<td>Cooperative Institute for Research in the Atmosphere (CIRA at Colorado State Univ.)</td>
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<tr>
<td>CIRES</td>
<td>Cooperative Institute for Research in Environmental Sciences (CIRES at Univ. of CO)</td>
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<tr>
<td>CIWS</td>
<td>Corridor Integrated Weather System</td>
</tr>
<tr>
<td>CLARUS</td>
<td>Road weather observations database at the Federal Highways Administration</td>
</tr>
<tr>
<td>CONUS</td>
<td>Contiguous United States</td>
</tr>
<tr>
<td>COSMIC</td>
<td>Constellation Observing System for Meteorology, Ionosphere, and Climate</td>
</tr>
</tbody>
</table>
CoSPA  Consolidated Storm Prediction for Aviation
CPC  Climate Prediction Center (an NCEP center)
CPU  Central Processing Unit
CRADA  Cooperative Research and Development Agreement
CSD  Chemical Sciences Division (ESRL)
CSU  Colorado State University
CTB  Climate Testbed
CU  University of Colorado
CWB  Central Weather Bureau of Taiwan
CWSU  Center Weather Service Unit (NWS forecaster units at ARTCCs)
DA  Data assimilation
DMIT  NOAA Data Management Integration Team
DOC  Department of Commerce
DOE  Department of Energy
DOH  Development and Operations Hydrologist (in NWS)
DOT  Department of Transportation
DSS  Decision Support System
DTC  Developmental Testbed Center
Dycore  Dynamic core (for atmospheric model)
EC  Environment Canada
ECMWF  European Centre for Medium-Range Weather Forecasts
EDEX  Environmental Data Exchange
EDM  NOAA Environmental Data Management Committee
EDS  Evaluation and Decision Support Branch
EGU  European Geosciences Union
EMB  Earth Modeling Branch (formerly AMB)
EnKF  Ensemble Kalman filter
EnKF/4DVAR  Ensemble Kalman filter / four-dimensional variational
ENSO  El Niño Southern Oscillation
ESM  Earth System Model
ESMF  Earth System Modeling Framework
ESPC  Earth System Prediction Capability
ESRL  Earth System Research Laboratory (GSD is a division in ESRL)
EVENT  Event-Based Verification and Evaluation of NWS Gridded Products Tool
FAA  Federal Aviation Administration/U.S. Department of Transportation
FAB  Forecast Applications Branch (Effective 10/1/2014, merged into EMB)
FACETs  Forecasting a Continuum of Environmental Threats
FAR  False Alarm Ratio
FDSE  Forecaster Decision Support Environment
FFaIR  Flash Flood and Intense Rainfall (testbed)
FFMP  Flash Flood Monitoring and Prediction
FHWA  Federal Highways Administration/U.S. Department of Transportation
FIM  Flow-following finite-volume Icosahedral Model (experimental global model)
FL  Flight Level (e.g., FL350 for level at 35,000 feet)
FPGA  Field-Programmable Gate Array
FV  Finite Volume (numerical method)
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FV3</td>
<td>GFDL global model (cubed-sphere grid)</td>
</tr>
<tr>
<td>FX-Net</td>
<td>Forecasting in an X-Windows environment using the Internet (AWIPS-I based)</td>
</tr>
<tr>
<td>GCM</td>
<td>Global Climate Model</td>
</tr>
<tr>
<td>GEFS</td>
<td>Global Ensemble Forecast System</td>
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<tr>
<td>GE OSS</td>
<td>Global Earth Observation System of Systems</td>
</tr>
<tr>
<td>GF/GFO</td>
<td>Grell-Freitas (convective scheme, or Grell-Freitas-Olson version)</td>
</tr>
<tr>
<td>GFDL</td>
<td>Geophysical Fluid Dynamics Laboratory</td>
</tr>
<tr>
<td>GFE</td>
<td>Graphical Forecast Editor</td>
</tr>
<tr>
<td>GFS</td>
<td>NCEP Global Forecast System model (currently the Global Spectral Model)</td>
</tr>
<tr>
<td>GHG</td>
<td>Graphical Hazard Generator</td>
</tr>
<tr>
<td>GHI</td>
<td>Global Horizontal Irradiance</td>
</tr>
<tr>
<td>GMAO</td>
<td>NASA Goddard Modeling and Assimilation Office</td>
</tr>
<tr>
<td>GMD</td>
<td>Global Monitoring Division (within ESRL)</td>
</tr>
<tr>
<td>GMTB</td>
<td>Global Modeling Test Bed (program within DTC associated with NGGPS)</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite Systems</td>
</tr>
<tr>
<td>GOCART</td>
<td>Goddard Chemistry Aerosol Radiation and Transport model</td>
</tr>
<tr>
<td>GOES</td>
<td>Geostationary Operational Environmental Satellite</td>
</tr>
<tr>
<td>GOSA</td>
<td>Global Observing Systems Analysis (GSD/Office of the Director)</td>
</tr>
<tr>
<td>GPM</td>
<td>Global Precipitation Measurement</td>
</tr>
<tr>
<td>GPRA</td>
<td>Government Performance and Results Act</td>
</tr>
<tr>
<td>GPS-IPW</td>
<td>Global Positioning System-Integrated Precipitable Water</td>
</tr>
<tr>
<td>GPS-Met</td>
<td>Global Positioning System Meteorology system</td>
</tr>
<tr>
<td>GPU</td>
<td>Graphics Processing Unit</td>
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<tr>
<td>GSD</td>
<td>Global Systems Division (NOAA/OAR/ESRL/GSD)</td>
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<tr>
<td>GSI</td>
<td>Gridpoint Statistical Interpolation data assimilation system</td>
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<tr>
<td>GSM</td>
<td>Global Spectral Model (to be replaced by NGGPS model in future)</td>
</tr>
<tr>
<td>GTAS</td>
<td>Geo-Targeted Alerting System</td>
</tr>
<tr>
<td>GTG</td>
<td>Graphical Turbulence Guidance</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>HADS</td>
<td>Hydrometeorological Automated Data System</td>
</tr>
<tr>
<td>HCST</td>
<td>Hindcast</td>
</tr>
<tr>
<td>HCPF</td>
<td>HRRR Convective Probability Forecast</td>
</tr>
<tr>
<td>HFIP</td>
<td>Hurricane Forecast Improvement Program</td>
</tr>
<tr>
<td>HIWPP</td>
<td>High-Impact Weather Prediction Project (Sandy Supplemental funded project)</td>
</tr>
<tr>
<td>HLS</td>
<td>Hurricane Local Statement</td>
</tr>
<tr>
<td>HMT</td>
<td>Hydrometeorological Testbed</td>
</tr>
<tr>
<td>HPC</td>
<td>Hydrometeorological Prediction Center (within NCEP)</td>
</tr>
<tr>
<td>HPCS</td>
<td>High-Performance Computing System</td>
</tr>
<tr>
<td>HRRR</td>
<td>High-Resolution Rapid Refresh model</td>
</tr>
<tr>
<td>HRRRE</td>
<td>High-Resolution Rapid Refresh Ensemble</td>
</tr>
<tr>
<td>HWRF</td>
<td>Hurricane Weather Research and Forecasting model</td>
</tr>
<tr>
<td>HWT</td>
<td>Hazardous Weather Testbed</td>
</tr>
<tr>
<td>HYCOM</td>
<td>HYbrid Coordinate Ocean Model (community ocean model)</td>
</tr>
<tr>
<td>IDSS</td>
<td>Impact-based Decision Support Services</td>
</tr>
<tr>
<td>iHYCOM</td>
<td>Icosahedral-horizontal-coordinate version of HYCOM ocean model</td>
</tr>
<tr>
<td>IMET</td>
<td>Incident Meteorologist (NWS)</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
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<tr>
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</tr>
<tr>
<td>INSITE</td>
<td>Integrated Support for Impacted Air-Traffic Environments</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>JCSDA</td>
<td>Joint Center for Satellite Data Assimilation</td>
</tr>
<tr>
<td>JPSS</td>
<td>Joint Polar Satellite System Proving Ground</td>
</tr>
<tr>
<td>JTWC</td>
<td>Joint Typhoon Warning Center</td>
</tr>
<tr>
<td>LAMP</td>
<td>Localized Aviation MOS Program</td>
</tr>
<tr>
<td>LAPS</td>
<td>Local Analysis and Prediction System</td>
</tr>
<tr>
<td>LES</td>
<td>Large-Eddy Simulation</td>
</tr>
<tr>
<td>LLWS</td>
<td>Low-Level Wind Shear</td>
</tr>
<tr>
<td>LSM</td>
<td>Land-Surface Model (parameterization)</td>
</tr>
<tr>
<td>LTG</td>
<td>Lightning</td>
</tr>
<tr>
<td>MADIS</td>
<td>Meteorological Assimilation Data Ingest System</td>
</tr>
<tr>
<td>METAR</td>
<td>Aviation Routine Weather Report (translation from French)</td>
</tr>
<tr>
<td>MDL</td>
<td>Meteorological Development Laboratory (within NWS)</td>
</tr>
<tr>
<td>MIC</td>
<td>Intel® Many Integrated Core (HPCS architecture)</td>
</tr>
<tr>
<td>MOA</td>
<td>Memorandum of Agreement</td>
</tr>
<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
</tr>
<tr>
<td>MPAS</td>
<td>Model for Prediction across Scales (NCAR global model)</td>
</tr>
<tr>
<td>MPFG</td>
<td>Massively Parallel Fine Grain (computing)</td>
</tr>
<tr>
<td>MPI</td>
<td>Message Passing Interface -- HPC standard for distributed memory programming</td>
</tr>
<tr>
<td>MPP</td>
<td>Massively Parallel Processor</td>
</tr>
<tr>
<td>MRMS</td>
<td>Multi-Radar/Multi-Sensor (national radar data merger system)</td>
</tr>
<tr>
<td>MYNN</td>
<td>Mellor–Yamada–Nakanishi–Nino (boundary-layer parameterization)</td>
</tr>
<tr>
<td>NARRE</td>
<td>North American Rapid Refresh Ensemble (with RAP and NAM members)</td>
</tr>
<tr>
<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
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<tr>
<td>NCEI</td>
<td>NOAA National Centers for Environmental Information (part of NESDIS)</td>
</tr>
<tr>
<td>NEIS</td>
<td>NOAA Earth Information System™</td>
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<tr>
<td>NCEP</td>
<td>National Centers for Environmental Prediction</td>
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<tr>
<td>NDFD</td>
<td>National Digital Forecast Database</td>
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<td>NEMS</td>
<td>NOAA Environmental Modeling System</td>
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<tr>
<td>NESDIS</td>
<td>National Environmental Satellite, Data &amp; Information Services</td>
</tr>
<tr>
<td>NEXRAD</td>
<td>NEXT generation RADar</td>
</tr>
<tr>
<td>NextGen</td>
<td>Next-Generation Air Transportation System</td>
</tr>
<tr>
<td>NGGPS</td>
<td>Next-Generation Global Prediction System</td>
</tr>
<tr>
<td>NHC</td>
<td>National Hurricane Center (an NCEP center)</td>
</tr>
<tr>
<td>NIM</td>
<td>Non-hydrostatic Icosahedral Model (global model developed in GSD)</td>
</tr>
<tr>
<td>NITE</td>
<td>NWP Information Technology Environment</td>
</tr>
<tr>
<td>NMM</td>
<td>Non-hydrostatic Mesoscale Model</td>
</tr>
<tr>
<td>NMMB</td>
<td>Non-hydrostatic Multiscale Model on the B-grid</td>
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<tr>
<td>NMME</td>
<td>North-American Multi-Model Ensemble (intraseasonal to interannual coupled models, eg FIM-iHYCOM)</td>
</tr>
<tr>
<td>Noah LSM</td>
<td>Noah land-surface model (used widely in WRF and many NCEP models)</td>
</tr>
<tr>
<td>Noah-MP LSM</td>
<td>Noah multi-parameterization land surface model</td>
</tr>
<tr>
<td>NPOESS</td>
<td>NOAA Polar-Orbiting Environmental Satellite System</td>
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<tr>
<td>NPP</td>
<td>NPOESS Preparatory Project</td>
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<tr>
<td>NRL</td>
<td>Naval Research Laboratory</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>---------</td>
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<tr>
<td>NSSL</td>
<td>National Severe Storm Laboratory</td>
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<tr>
<td>NTSB</td>
<td>National Transportation Safety Board</td>
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<tr>
<td>NUOPC</td>
<td>National Unified Operational Prediction Capability (NOAA / DOD)</td>
</tr>
<tr>
<td>NWC</td>
<td>National Water Center (NWS)</td>
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<tr>
<td>NWP</td>
<td>Numerical Weather Prediction</td>
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<tr>
<td>NWS</td>
<td>National Weather Service (NOAA)</td>
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<tr>
<td>O2R</td>
<td>Operations to Research</td>
</tr>
<tr>
<td>OAR</td>
<td>Oceanic and Atmospheric Research (NOAA’s research organization)</td>
</tr>
<tr>
<td>OGC</td>
<td>Open Geospatial Consortium</td>
</tr>
<tr>
<td>OpenACC</td>
<td>Emerging standard for directive-based programming of multicore, many-core, and GPU architectures</td>
</tr>
<tr>
<td>OpenMP</td>
<td>Industry standard for shared-memory directive-based programming</td>
</tr>
<tr>
<td>OSSE</td>
<td>Observing System Simulation Experiment</td>
</tr>
<tr>
<td>OSE</td>
<td>Observing System Experiment or Observation Sensitivity Experiment</td>
</tr>
<tr>
<td>PBL</td>
<td>Planetary Boundary Layer</td>
</tr>
<tr>
<td>PHDT</td>
<td>Probabilistic Hazard Detection Tool (uses time-lagged HRRR)</td>
</tr>
<tr>
<td>PHPT</td>
<td>Probabilistic Hazard Prediction Tool</td>
</tr>
<tr>
<td>PM2.5</td>
<td>Particulate Matter – &lt;2.5 microns</td>
</tr>
<tr>
<td>PMM</td>
<td>Precipitation Measurement Mission</td>
</tr>
<tr>
<td>PSD</td>
<td>Physical Sciences Division (within ESRL)</td>
</tr>
<tr>
<td>PW</td>
<td>Precipitable Water</td>
</tr>
<tr>
<td>QOSAP</td>
<td>Quantitative Observing System Assessment Program</td>
</tr>
<tr>
<td>QPE</td>
<td>Quantitative Precipitation Estimation</td>
</tr>
<tr>
<td>R2A</td>
<td>Research to Applications</td>
</tr>
<tr>
<td>R2O</td>
<td>Research to Operations</td>
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<tr>
<td>RAP</td>
<td>Rapid Refresh model</td>
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<tr>
<td>RMSE</td>
<td>Root-Mean-Square Error</td>
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<tr>
<td>RTVS</td>
<td>Real-time Verification System</td>
</tr>
<tr>
<td>RO</td>
<td>Radio Occultation</td>
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<tr>
<td>RSA</td>
<td>Range Standardization and Automation program at U.S. Space Centers</td>
</tr>
<tr>
<td>RUA</td>
<td>Rapid Updating Analysis</td>
</tr>
<tr>
<td>RUC</td>
<td>Rapid Update Cycle model</td>
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<tr>
<td>RUC LSM</td>
<td>RUC Land-Surface Model</td>
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<tr>
<td>SBN</td>
<td>Satellite Broadcast Network (AWIPS)</td>
</tr>
<tr>
<td>SSD</td>
<td>Science and Technology Services Divisions (NWS)</td>
</tr>
<tr>
<td>SHOUT</td>
<td>Sensing Hazards with Operational Unmanned Technology</td>
</tr>
<tr>
<td>SFIP</td>
<td>Solar Forecast Improvement Project</td>
</tr>
<tr>
<td>SM</td>
<td>Statue Mile</td>
</tr>
<tr>
<td>SMS</td>
<td>Scalable Modeling System</td>
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<tr>
<td>SOO</td>
<td>Science and Operations Officer (in NWS)</td>
</tr>
<tr>
<td>SOS</td>
<td>Science On a Sphere®</td>
</tr>
<tr>
<td>SOSX</td>
<td>SOS Explorer™</td>
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<tr>
<td>SPC</td>
<td>Storm Prediction Center (within NCEP)</td>
</tr>
<tr>
<td>SST</td>
<td>Sea-Surface temperature</td>
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<tr>
<td>SVN</td>
<td>Subversion, a version control system</td>
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<tr>
<td>S2S</td>
<td>Subseasonal to seasonal (global model applications, usually atmos-ocean coupled)</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
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</tr>
<tr>
<td>TCV</td>
<td>Tropical Cyclone Valid Time Event Code product</td>
</tr>
<tr>
<td>TMU</td>
<td>Traffic Management Unit (Aviation)</td>
</tr>
<tr>
<td>TPW</td>
<td>Total Precipitable Water</td>
</tr>
<tr>
<td>TRACON</td>
<td>Terminal Radar Approach CONtrol</td>
</tr>
<tr>
<td>TRMM</td>
<td>Tropical Rainfall Measuring Mission</td>
</tr>
<tr>
<td>TWPCFC</td>
<td>Taiwan-West Pacific Climate Forecast System</td>
</tr>
<tr>
<td>UAS</td>
<td>Unmanned Aircraft System</td>
</tr>
<tr>
<td>UH</td>
<td>Updraft Helicity</td>
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<tr>
<td>USAF</td>
<td>U.S. Air Force</td>
</tr>
<tr>
<td>VACT</td>
<td>Volcanic Ash Coordination Tool</td>
</tr>
<tr>
<td>VRMC</td>
<td>Verification Requirements Monitoring Capability</td>
</tr>
<tr>
<td>VIIRS</td>
<td>Visible Infrared Imaging Radiometer Suite</td>
</tr>
<tr>
<td>WAM</td>
<td>Whole Atmosphere Model</td>
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<tr>
<td>WCRP</td>
<td>World Climate Research Program</td>
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<tr>
<td>WCS</td>
<td>OGC Web Coverage Service</td>
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<tr>
<td>WFIP</td>
<td>Wind Forecast Improvement Project (1 and 2)</td>
</tr>
<tr>
<td>WINS</td>
<td>Weather Integration and Nowcasting System (CWB's version of AWIPS)</td>
</tr>
<tr>
<td>WMS</td>
<td>OGC Web Map Service</td>
</tr>
<tr>
<td>WMTS</td>
<td>OGC Web Map Tile Service</td>
</tr>
<tr>
<td>WoF</td>
<td>Warn-On Forecast – OAR research project</td>
</tr>
<tr>
<td>WPC</td>
<td>Weather Prediction Center (an NCEP center)</td>
</tr>
<tr>
<td>WRF</td>
<td>Weather Research and Forecasting model (community model system)</td>
</tr>
<tr>
<td>WRF-Chem</td>
<td>Extended version of WRF model including inline chemistry (two-way interaction)</td>
</tr>
<tr>
<td>WWE</td>
<td>Winter Weather Experiment</td>
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</tbody>
</table>