Theme 2: Modeling, Data Assimilation, and Advanced Computing

Stan Benjamin

Introduction, Global Modeling Development
From NOAA Research 5-Year Plan

From “overarching research questions”

“4. What improvements to observing systems, analysis approaches, and models will allow us to better analyze and predict the atmosphere, ocean, and hydrological land processes? “
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ESRL 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, other
Themes on ESRL Efforts in Modeling/Assimilation

• ESRL activities have been *diverse*
  • from 1 to 12-h-forecast to interseasonal NWP applications
  • strongly focused around interaction with NCEP but with other applications

• ESRL’s modeling/assimilation activities toward operations
  • *primarily regional* (RUC, WRF, LAPS) but with...
  • *rapidly increasing global component* in last three years (FIM/NIM, EnKF assimilation)

• ESRL’s advanced computing facility and related software development have been essential for Theme 2 achievements.
Themes on ESRL efforts in modeling/assimilation

- **Collaboration with partner labs** in development of modeling, data assimilation, post-processing, advanced computing
  - already generally strong (NCEP, NCAR, NASA, OAR (NSSL, GFDL, AOML, ARL), universities), poised to grow stronger

- A strong growth toward development of **coupled models**
  - WRF-chem, related FIM-chem
  - FIM-atmosphere-ocean coupled model on common icosahedral grid (extendable to nonhydrostatic NIM also)
  - Improvements in land-surface (soil, snow, vegetation) models
Successes at ESRL

- **Operational impacts**
  - RUC since 1994, hourly updating niche in NCEP’s suite
    - First effective hourly assimilation to reduce forecast errors
    - First radar reflectivity assimilation at NCEP, implemented November 2008
  - Rapid Refresh – RUC replacement in 2010, 3-km HRRR nest, both using ESRL-enhanced WRF
  - LAPS – data assimilation component of AWIPS
    - Commonly used in NWS Forecast Offices, supports local modeling
  - FIM global model development (upcoming)
  - Ensemble Kalman Filter assimilation (upcoming)
Successes at ESRL

- Contributions to community
  - Key role in development of WRF
    - Parameterizations – convection, land-surface model, cloud physics, WRF-chem. PBL schemes
    - Digital filter initialization (key for 1-h cycle)
  - Development of GSI for cloud assimilation, application to WRF-ARW
  - Demonstration of uncertainty forecasts, especially for QPF via NOAA Hydrometeorology Testbed (HMT)

Snow water equiv – 1Feb10
RR-WRF cycled using RUC LSM
NOAA’s NWS Model Production Suite

Global Data Assimilation

- Climate CFS
  - MOM3

- North American Ensemble Forecast System
  - GFS, Canadian Global Model

- North American Mesoscale Forecast System
  - WRF NMM

- Short-Range Ensemble Forecast
  - WRF: NMM+ARW
  - ETA, RSM

- Hurricane Forecast System
  - GFDL
  - HWRF

Coupled

- Dispersion
  - ARL’s HYSPLIT

- Severe Weather
  - WRF NMM
  - WRF ARW

- Air Quality
  - NAM+CMAQ

- Rapid Update for Aviation, Severe Weather, Energy

- Oceans
  - HYCOM
  - WaveWatch III

- Global Forecast System
  - ~2B Obs/Day
  - Mostly Satellite + Radar

NCEP overview
Contributions from ESRL toward NOAA’s Future Model Production Suite

High-performance computing

- CFS
- MOM3
- Hurricane
- FIM
- Coupled

North American Mesoscale
WRF NMM

Short-Range Ensemble Forecast
WRF: NMM+ARW
ETA, RSM

Oceans
- HYCOM
- WaveWatch III

Dispersion
- ARL’s HYSPLIT

Severe Weather
- HRRR, HRRRens

Forecast Uncertainty

- EnKF, hybrid DA
- FIM, NIM

Inline chemistry

RR/HRRR
for Aviation, Severe Weather, Energy

End of Theme 2 Introduction
..... And now on to Global Modeling
Flow-following-finite-volume Icosahedral Model (FIM)
NOAA/ESRL

Flow-following- finite-volume
Icosahedral
Model FIM

240-km icosahedral grid
– 10,242 polygons
Real-time FIM forecasts-
10-km – 8.8M polygons

Lat-lon grid

2-m temp
18 Feb 2010 – 00z
240-km icosahedral grid
- 10,242 polygons
Real-time FIM forecasts-
15-km  - ~4M polygons
FIM hybrid-isentropic vertical coordinate
FIM Configurations

Resolution

- Real-time testing at 30-km, 15-km, and 10-km resolution
- 64 vertical levels – hybrid θ-σ
- $P_{\text{top}} = 0.5 \text{ hPa}$, $\theta_{\text{top}} = 2200\text{K}$, $\sim 60 \text{ km}$

Physics

- Current real-time FIM uses GFS physics suite
- Testing with WRF physics options, WRF-chem

Initial conditions for real-time runs

1. Interpolation from GFS spectral data to FIM icosahedral hybrid θ-σ vertical coordinate
2. Ensemble Kalman using GFS T190 – FIMY parallel
FIM simulations on 60-km mesh using 2 vertical coordinate options

Hybrid isentropic-sigma

Hybrid isentropic coordinate (including PV conservation) provides sharper vortex roll-up than sigma coordinate.
Vertical coordinate comparison - parallel
- FIM-hybrid θ-σ (FIM) vs. FIM-σ (FIMX)

Hybrid θ-σ coordinate provides improvement over σ (hybrid σ–p)

500 hPa ACC
N. Hemisphere
5-day forecasts
- vs. GFS analysis

FIM (θ-σ) – 86.5
FIM-σ – 84.6
FIM vs. GFS, 500-hPa anom corr – 120h
S. Hemisphere – (GSI initial conditions for both)
FIM vs. GFS, 500-hPa anomaly correlation (GSI initial conditions for both)

**N. Hemisphere**
- FIM: 87.4
- GFS: 87.7

**S. Hemisphere**
- FIM: 84.1
- GFS: 83.2
FIM better than GFS in NH/SH at 250 hPa, (not quite as good at 850 hPa)
Tropics

FIM – GFS -

FIM much better than GFS, EnKF IC adds further accuracy

Tropics- m/s
FIM 6.36
GFS 7.44

72-h 250-hPa Wind
RMS vector error (vs. analyses) smaller is better Aug 09

FIM – GFS -
NOAA Hurricane Forecast Improvement Project (HFIP)

- Goal – improve track and intensity forecasts
- NOAA, universities, Navy, NCAR, etc.
- Global component (primarily FIM, some GFS)
  - NSF-funded TACC supercomputer
  - FIM-15km, FIM-10km, FIM-ensemble-30km
  - Ensemble Kalman Filter data assimilation
  - Experiments for resolution and initial condition sensitivity

*Improved intensity with 30km → 15km → 10km resolution, better track forecast with EnKF initial conditions (than 3Dvar)*
FIM/NIM Commonality

- Built on same software structure to allow following common features (some in development):
  - Icosahedral horizontal structure
  - I/O, ESMF structure
  - Grid structure, code design for parallel performance (multi-CPU and GPU)
  - Physical parameterization options
  - Ocean component
- Common regression testing environment
  - More failsafe development
- Initial discussions with NCAR on using similar framework for MPAS (NCAR’s new global icosahedral model)
Recent ESRL effort: Develop mirror FIM-HYCOM Atmosphere-Ocean on same icosahedral grid

*Initial atmos/ocean coupled FIM:
Sea surface height*

- After 5-yr spinup of a 4-layer isopycnic ocean forced by time-invariant zonally averaged zonal wind stress extracted from FIM initial conditions.
- Horizontal resolution ~120 km (G6)
NCEP Architecture using ESMF/NEMS

- Chemistry
  - WRFchem
  - aerosols

- Atmosphere
  - unified atmosphere including digital filter

- Dynamics
  - ARW
  - FVCORE
  - NOGAPS
  - COAMPS
  - spectral
  - FIM
  - FISL

- Dyn-Phy Coupler
  - Simple
  - Regrid, Redist, Chgvar, Avg, etc

- Physics
  - NMM-B
  - NAM Phy
  - GFS Phy
  - WRF Phy
  - Navy Phys

- Ocean
  - HYCOM
  - HYCOM-icos

Color Key
- Component class
- Coupler class
- Completed Instance
- Under Development
- Future Development

ESRL contributions
ESRL models/assimilation transfers to operations at NCEP (past and likely in future)

- 1990: 3h, 60km
- 1995: 1h cycle, 40km, New θ-hybrid, cloud microphysics
- 2000: 13km
- 2005: Radar assimilation
- 2010: Rapid Refresh (WRF, GSI)
- 2015: HRRR

- Global EnKF
- 20th Cent Reanalysis
- HFIP FIM demo
- WRF-chem inline-chem
- FIM
From NOAA Research 5-Year Plan

• From the “Commerce and Transportation mission goal”
  • “Provide accurate, timely, and integrated weather information to meet air and surface transportation needs”

  *RUC, Rapid Refresh, HRRR, assimilation of radar, clouds*

• From “Framing NOAA’s Future Research”
  • “NOAA will foster a research organization with an appropriate rate of radical innovation that can transform our science, emphasizing areas of greatest scientific and technological opportunities and potential benefits to the nation.”

  *Increasing integration within ESRL of modeling/assimilation efforts (Theme 2) with other Themes (physics, weather/climate applications)*
  *Increasing integration with ESRL chemical science efforts*
Contributions from ESRL toward NOAA’s Future Model Production Suite

- High-performance computing
  - CFS
  - MOM3

- Hurricane
  - FIM

- North American Mesoscale
  - WRF NMM

- Short-Range Ensemble Forecast
  - WRF: NMM+ARW
  - ETA, RSM

- Oceans
  - HYCOM
  - WaveWatch III

- Dispersion
  - ARL’s HYSPLIT

- Severe Weather
  - HRRR, HRRRens

- Forecast Uncertainty
  - EnKF, hybrid DA

- Inline chemistry
  - RR/HRRR

- Forecast
  - North American Ensemble Forecast System
    - HWRF
  - FIM, NIM

- Contributions from ESRL toward tomorrow’s
  - NOAA’s Model Production Suite
    - MOM3
    - Coupled
    - Global Data Assimilation
      - HYCOM
      - WaveWatch III
    - EnKF, hybrid DA
Additional oral presentations on ESRL efforts in modeling, assimilation, advanced computing

- Data assimilation, rapid cycling NWP
  Steve Weygandt
- Inline chemistry – model, assimilation
  Georg Grell
- Forecast uncertainty
  Paul Schultz
- Advanced computing
  Mark Govett
- The path forward
  Zoltan Toth