Use of radiation / cloud observations to reduce cloud-radiation model errors from 4-h to 4-week forecasts

Stan Benjamin

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RAP/HRRR: Hourly-Updating Weather Forecast Suite - June 2018 NOAA/NCEP upgrade

13-km Rapid Refresh (RAPv4) – to 39h (Jun 2018)

- More accurate
- Runs longer (out to 36h)
- Alaska domain added

3-km High-Resolution Rapid Refresh Alaska (HRRR-AK) 36 hr (Jun 2018)

3-km High-Resolution Rapid Refresh (HRRRv3) – to 36h (Jun 2018)
Unified model development in NOAA/ESRL
(ESRL divisions: GSD with PSD/GMD/CSD), NCEP, NCAR, etc.)

<table>
<thead>
<tr>
<th>Spatial resolution</th>
<th>Forecast range</th>
<th>Domain</th>
<th>3km 1-36h Regional</th>
<th>13km 1-39h Regional</th>
<th>10-15km 1-10 day Global</th>
<th>15-30km Week 2 – 9 month Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model development area</td>
<td>HRRR (High-Resolution Rapid Refresh model) –</td>
<td>RAP (Rapid Refresh)</td>
<td>NGGPS – FV3 (current physics testing with FIM and FV3)</td>
<td>FIM-HYCOM coupled seasonal (for NOAA SubX experiment, switch to FV3)</td>
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</tr>
<tr>
<td>Data assimilation</td>
<td>Radar/cloud/surface/land, 3km ensemble DA</td>
<td>4D Ensemble DA (Whitaker-PSD, EMC)</td>
<td>FV3 – cubed sphere, FIM - icosahedral</td>
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<tr>
<td>Dynamic core numerics</td>
<td>Use/refinement of WRF-ARW, hybrid vert coordinate</td>
<td>Same as HRRR but with Grell-Freitas scale-aware cumulus</td>
<td>GFS physics + Grell-Freitas cu. Testing of HRRR/RAP suite-2017</td>
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<td>Application of inline chemistry</td>
<td>2-aerosol – NCEP, testing of 18-aerosol</td>
<td>“ + gas-phase chemistry</td>
<td>18-aerosol and gas-phase chem</td>
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<td>Systematic error investigations</td>
<td>Clouds, precipitation</td>
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Example: National Weather Service including Storm and Weather Prediction Centers (SPC and WPC)  
Aviation Weather Center (AWC) and FAA Command Center  
National Severe Storms Laboratory (NSSL) and Air Resources Laboratory (ARL)  
National Centers for Atmospheric Research (NCAR) and Lincoln Laboratory (LL)
Atmospheric process representation necessary for weather prediction (incl. HRRR/RAP)

There is a fundamental connection between solar radiation forecasts (both diffuse and direct) and low-level wind forecasts.

Surface Net Radiation

Energy available for SH, LH, and ground heat flux

Drives turbulent mixing, PBL formation, low-level winds, clouds
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<td>GSD, NCO</td>
<td>North America</td>
<td>953 x 834</td>
<td>13 km</td>
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<td>10 mb</td>
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<th>Model</th>
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<td>Yes</td>
<td>0.12</td>
<td>20 min</td>
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<td>0.01 K/s</td>
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**RAPv4/ HRRRv3 Summary of Changes**

23 May 2018 - GMAC
GSD model verification vs. observations

- Surface METARs
  - Including Ceiling/cloud obs
- RAOBs
- SURFRAD
- SOLRAD
- Precipitation StageIV
- Radar reflectivity NSSL MRMS
- CERES cloud radiation observations

03-Jan-2018 19:04:28 (132552 obs loaded, 88221 in range, 24445 shown)
- Aircraft
- NOAA / ESRL / CERES
  - Altitude: 1000 ft to 45000 ft
  - Aircraft: 3414 regular, 5-g, 200 mph, 118 in. 46V0, 35 in.
  - Min spacing: 0 pixels
July 2016 / Jan 2017 – Downward SW error – models minus from CERES (W/m², day 1)

General problem – excessive downward short-wave radiation, too little resolved and subgrid clouds

- RAP – 13km
- HRRR – 3km
- Global FIM/HYCOM – borrows from cumulus physics for RAP (Grell-Freitas conv)
  - Part of NOAA SubX subseasonal experiment
Goal: More accurate weather guidance (via improved process understanding, modeling, assimilation)

Progress toward lower biases
## Candidates for warm bias / too-little cloud

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Physics Development Emphasis: Sub-Grid Clouds

Explicit (Resolved) Clouds/Precipitation

RAP and HRRR use the Thompson microphysics scheme with 5 hydrometeor types

Sub-Grid (Unresolved) Clouds

Parameterize:
assume subgrid PDFs for thermodynamic variables
Chaboureau and Bechtold (2002)

Retrieve Cloud Fraction, Cloud Condensate

Var(s) \propto Var(q) + Var(T) - Cov(q, T)

Adapted from Fig. 2 of Tompkins (2009)
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<th>Process</th>
<th>Model Component</th>
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<td>Turbulent Diffusion</td>
<td>MYNN PBL/3d-Blended TKE</td>
<td>• Mixing length</td>
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<tr>
<td></td>
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<td>o Scale-aware</td>
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<td>o Z-less</td>
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<td>1D → 3D as f(Δx)→0</td>
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<td></td>
<td></td>
<td>• Multi-plume</td>
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<td></td>
<td></td>
<td>• TKE transport</td>
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<td></td>
<td></td>
<td>• Momentum transport</td>
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<td></td>
<td>• Scale-aware</td>
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<td>Non-local Turbulent Transport</td>
<td>MYNN Mass-flux</td>
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<tr>
<td>Surface Fluxes</td>
<td>RUC LSM/MYNN Sfc Layer</td>
<td>• Scalar roughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• M-O alternatives</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 3D surface stress</td>
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<tr>
<td>Clouds</td>
<td>Thompson Aerosol/Chaboureau-Bechtold</td>
<td>• Subgrid scale clouds</td>
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<tr>
<td></td>
<td></td>
<td>• Coupled to radiation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• prognostic</td>
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<tr>
<td>Numerics/Dynamics</td>
<td>Vertical Coordinate, Advection</td>
<td>• Hybrid WRF-ARW Vertical Coordinate</td>
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<tr>
<td>Turbine Drag</td>
<td>Wind Farm Parameterization</td>
<td>• Wind direction effects</td>
</tr>
<tr>
<td></td>
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<td>• Power calculation</td>
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Improvements to mass-flux scheme: not enough coverage

5-h GHI forecasts valid 1800 UTC 19 August 2015

Visible Imagery

Previous version (v3.9)
Improvements to mass-flux scheme: better

5-h GHI forecasts valid 1800 UTC 19 August 2015

Visible Imagery

Updated Version

W m⁻²
12h HRRR v2/v3 downward SW vs. SURFRAD – Mean 15-21z

HRRR-ops
HRRR-opr

Mean abs err

New HRRR Better / worse

SURFRAD geographical diversity critical for model evaluation
12h HRRR  Downward SW bias vs. SURF/SolRAD – Mean 15-21z

Similar excessive downward SW (HRRR) for SURFRAD vs. SOLRAD obs.

Similar excessive downward SW (HRRR) for different SURFRAD stations

SURFRAD geographical diversity critical for model evaluation
FIM-HYCOM uses Grell-Freitas deep/shallow convection (same as RAP).

- Similar downward SW bias for all 4 weeks.
- Warm season: model too high SW over land, cold ocean stratocu zones, high-latitude ocean.
HRRR Improved Convective Forecasts

Experimental HRRRv3 13 hr fcst
Valid 00 UTC 17 May 2017

Composite Reflectivity Observations
00 UTC 17 May 2017

Operational HRRRv2 13 hr fcst
Valid 00 UTC 17 May 2017

More Accurate
Convection Along
Weakly Forced Dryline

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Reflectivity Verification
### Model
- WRF-ARW v3.9+ incl. phys changes
  - **Physics changes:**
    - MYNN PBL update – yet better sub-grid clouds, improved EDMF mixing length, goal: retaining stable layers
    - Aerosols sources/sinks – fire/smoke, dust - Add smoke with VIIRS fire radiative power
  - Improved land-surface/snow model including better 2m T/Td diagnostics
    - no snow mosaic for T<271K
  - Latest Grell-Freitas conv (RAP only)
  - Lake model for small lakes
  - Enhanced gravity-wave drag

### Data Assimilation
- Merge with GSI trunk – 2018
  - **New Observations for assimilation:**
    - GOES-16 radiances, GLM lightning
    - MRMS dual-polarization radar mosaics
    - Extra mesonet data incl. anemometer hgt
    - TC vitals for trop cyclone location/ strength
    - Satellite-based AOD (aerosol optical depth)
    - Aircraft/raob moisture obs for p<300 hPa
  - **Assimilation Methods:**
    - HRRR - 3km ensemble DA (40 members out to 1h) – effective in 2017/18 tests.
      - Reduced LH for radar assim in HRRR
    - Cloud/hydrometeor assim within ens DA
      - DA for subgrid cloud fraction/cloud water w/ METAR, satellite cloud fraction
  - Revised hydrometeor assim (project to resolvable scale) to improve 1h precip

### Land-surface / post
- Switch to MODIS albedo (higher), replace 1-deg albedo.
  - Add zenith-ang albedo adj
  - Fractional sea/lake ice concentration
    - FVCOM SST/ice
  - VIIRS/MODIS/GOES fire radiative power
  - HRRRE prob products
  - Full cycle RAP land-sfc

### Larger impact for wind/solar forecast accuracy
- Enabled by GMD radiation obs

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# Data Assimilation

**New Observations for assimilation:**
- Add satellite cloud-drift winds over land
- Add TAMDAR aircraft observations
- Add new polar-orbiter satellite data (IASI, CrIS, SEVIRI radiances)

**Assimilation Methods:**
- Revised PBL pseudo-observations from sfc – better winds/RH
- Cloud building (satellite, surface) - more cloud droplets now specified
- Radar reflectivity assimilation
  - Latent heating reduced by 50% - RAP only
  - In HRRR – reduces too much convection

# Model

**WRF-ARW v3.8.1+ incl. physics changes**

**Physics changes:**
- Thompson cloud microphysics – improved ice clouds (not excessive)
- MYNN PBL update – better sub-grid clouds, EDMF (local/deep) mixing
- Land-sfc model update – mosaic snow, 2m temp diagnostic
- Revised Grell-Freitas cumulus (RAP)

# Land-surface/post

**MODIS higher-res 15” land-use data**

**VIIRS real-time greenness veg fraction**

**Revised roughness length**

**10m wind (not ~8m)**

**Wind gust diag fix (stronger at night)**

- **GMD network radiation obs critical for model improvement for NOAA RAP/HRRR/global models.**