Warn-on-Forecast Accomplishments and Plans: NOAA ESRL Global Systems Division

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NCAR: Glen Romine, Chris Snyder

WoF Workshop, Norman, OK, 23 Feb 2011
Hourly Updated NOAA NWP Models

Rapid Refresh (RR) replaces RUC at NCEP in 2011: WRF, GSI + RUC-based enhancements, new 18h fcst every hour

13km Rapid Refresh
rapidrefresh.noaa.gov/RR/

13km RUC

3km HRRR
rapidrefresh.noaa.gov/hrrrconus/

High-Resolution Rapid Refresh
Experimental 3km nest inside RUC or RR, new 15-h fcst every hour
Rapid Refresh: Hourly WRF-ARW 13-km Analyses and Forecasts

Hourly updating using all available observations

Data types used
- Rawinsonde (balloons)
- Wind Profilers (405 MHz, 915 MHz)
- RASS virtual temperatures
- VAD winds (WSR-88D radars)
- Aircraft (ACARS, TAMDAR)
- Surface (METAR, Buoy, Mesonet)
- Precipitable water (GPS, GOES, SSM/I)
- GOES cloud-drift winds
- GOES cloud-top pressure/temp
- Radar reflectivity, lightning
- Ship reports/dropsondes
- Satellite radiances

Time (UTC)
High Resolution Rapid Refresh (HRRR): Hourly 3-km (Analyses and) Forecasts

HRRR Milestones

2007: Inception northeastern US
Late 2009: Domain expanded to CONUS
2010: WRF-ARW v3.2
2010: Forecast period extended to 15 hrs
2010: ~95% reliability
Late 2010: Latency ~2 hrs

HRRR initialization:

- From RUC analysis currently; from RR analysis starting this spring
- No additional DA on 3-km grid currently; radar DA on 3-km grid soon
Year One* Activities and Deliverables

1. Develop code necessary to provide output from the High-Resolution Rapid Refresh (HRRR) model every 15 min during the 0-3 forecast.

   • **Transition to GRIB2** for all output
     much smaller file sizes than for GRIB1

   • GRIB2 **sub-hourly output** generated for a test case
     success with Unipost for 15-min output
     GRIB issues with time conventions for sub-hourly output

   • Approximately 20 fields in **2D output**
     requests for additional fields welcomed from W-o-F partners
     data to be made available by ftp

   • **3D output** available upon request for specific cases
     files too large to be made available regularly on ftp server

* March 2010 - February 2011
Year One Activities and Deliverables

2. Test direct application of the digital filter initialization (DFI) radar DA at the 3-km HRRR resolution.

- **Temperature tendency** based on observed reflectivity, applied during forward model integration
- **Digital filter** applied after model integration, to reduce noise
- Technique used to initialize 13-km models (RUC, RR)
- Method now being tested for HRRR (3-km) initialization
- **Inexpensive** method for initializing small scales

Note: **Doppler velocity** data assimilation, which is needed for W-o-F and desired for the HRRR, will also be tested in the near future.
Diabatic Digital Filter Initialization (DDFI)

Technique for assimilating reflectivity data into the HRRR will be somewhat like that currently used to assimilate reflectivity data into the 13-km models (RR and RUC).

-2Δ min  -Δ min  Init  +Δ min

Δ ~ 10 min

Backward integration, no physics
Forward integration, full physics
Apply latent heating from radar reflectivity, lightning data

Obtain initial fields with improved balance, vertical circulations associated with ongoing convection

RUC/RR/HRRR model forecast

Radar reflectivity assimilation in RUC, RR, and now HRRR
Rapid Refresh reflectivity assim. (DDFI) example

NSSL radar reflectivity (dBZ)

14z 22 Oct 2008
Z = 3 km

Low-level Convergence
(induced by temperature forcing)

K=4 U-comp. diff
(radar - norad)

Upper-level Divergence
(induced by temperature forcing)

K=17 U-comp. diff
(radar - norad)
3-km Reflectivity DA (DDFI) Experiment: Initialization Time

- Without 3-km refl DA
- With 3-km refl DA

Observations
3-km Reflectivity DA (DDFI) Experiment: 1-hr Forecast
3-km Reflectivity DA (DDFI) Experiment: 2-hr Forecast

Without 3-km refl DA

With 3-km refl DA

Observations
3-km Reflectivity DA (DDFI) Experiment: 3-hr Forecast
3. Hire a federal scientist with expertise in data assimilation for convective scales to help lead the warn-on-forecast efforts.

D. Dowell joined the project in late October after recovering from VORTEX2.
Year One Activities and Deliverables

4. Collaborate with other project partners in exploring complex issues related to the frequent updating of convective-scale models, both deterministic and ensemble systems.

June 2009 retrospective study (Glen Romine, David Dowell, Chris Snyder)
- Demonstration of current EnKF (WRF-DART) capabilities
- Mesoscale ($\Delta x=15\text{ km}$) CONUS domain: successful cycling for 18 days (radisonde, surface, aircraft, and satellite wind obs every 3 h)
4. Collaborate with other project partners in exploring complex issues related to the frequent updating of convective-scale models, both deterministic and ensemble systems.

June 2009 retrospective study (Glen Romine, David Dowell, Chris Snyder)

- Storm-scale (\(\Delta x=3\) km) high plains domain: assimilation of WSR-88D Doppler velocity and reflectivity obs every 3 min for 1 hour, followed by 6-hour, 50-member ensemble forecast
Year One Activities and Deliverables

4. Collaborate with other project partners in exploring complex issues related to the frequent updating of convective-scale models, both deterministic and ensemble systems.
June 2009 retrospective study (Glen Romine, David Dowell, Chris Snyder)

Probability of Rotating Updrafts, 6-Hour Ensemble Forecast

Control (no radar DA)

With radar DA

Severe Weather Reports

1000 km
Year One Activities and Deliverables

5. Compute model-to-observation statistics for the Rapid Refresh / HRRR models using observations provided by the Meteorological Assimilation Data Information System (MADIS) and incorporate the statistics into the National Mesonet database along with the station and instrumentation information.

http://madis.noaa.gov/

- “National Mesonet” data are now being ingested into the MADIS.
- New observations and metadata from other stationary and mobile observing platforms will also be ingested.
- A “use list”, which includes the Alaska mesonet, is being developed for the Rapid Refresh (RR) model.
Year One Activities

Observation Processing and Wind Synthesis (OPAWS) software http://code.google.com/p/opaws/

• Tools for radar-data quality control, objective analysis, preparation for data assimilation
• Recent code upgrade (multiple radar-data formats, Fortran namelist input, modular design) by D. Dowell and L. Wicker
• Code now available online

raw velocity data

objective analysis
Year One Activities

HRRR Convective Probability Forecast (HCPF)
http://ruc.noaa.gov/hcpf/hcpf.cgi
• Probability provided by HRRR “ensemble of opportunity”: forecasts initialized at different times but valid at the same time
  • 15-h forecasts produced every 1 h
• Not a Warn-on-Forecast activity, but relevant to our project
  • ensemble post-processing, display concepts, etc.

Identification of moist convection from model forecast fields:
• Stability – Surface lifted index < +2°C (neutral to unstable)
• Intensity – Max vertical velocity in model column > ~1 m s⁻¹
• Time – 2 hr search window centered on valid times
• Location – Stability and intensity criteria searched within 30 points (radius of ~90 km) of each point for each member

HCPF = \[
\frac{\# \text{ grid points matching criteria over all members}}{\text{total } \# \text{ grid points searched over all members}}
\]
Year One Activities

HCPF example:  2300 UTC 15 May 2009

10-h time-lagged ensemble fcst

8-h time-lagged ensemble fcst

6-h time-lagged ensemble fcst

4-h time-lagged ensemble fcst

Forecast Consistency
Year One Activities

HRRR Convective Probability Forecast: display concepts

10-h fcst. prob. of convection, composite reflectivity from a deterministic forecast

observed composite reflectivity

Valid 23z 16 July 2010
Year One Activities

HRRR Convective Probability Forecast: display concepts

10-h fcst. prob. of convection, storm (high refl.) locations in 3 deterministic forecasts

observed composite reflectivity

Valid 23z 16 July 2010
Storm-scale reflectivity data-assimilation study


Pros and cons of reflectivity DA:

- **more rapid storm development** in model (cloud water, vertical velocity) than when only Doppler velocity data are assimilated
- **bias errors** (model microphysics, observations, observation operators) projected onto all state variables
- **cold-pool sensitivity** to details of DA, ensemble design
Proposed Year Two* Activities

RR and HRRR model enhancement
These models are a proposed “backbone” (providing initial and/or boundary conditions) for nested Warn-on-Forecast systems.

• Transition from Rapid Update Cycle (RUC) to Rapid Refresh (RR) as parent model for HRRR (spring 2011)
• Real-time implementation of 3-km reflectivity DA (spring 2011)

• “Development HRRR”
  • Runs every 3 h, opportunity to test new ideas for DA and model config.
  • Assimilation of SatCast and Doppler velocity data
  • Model and DA changes targeting known HRRR issues (low bias Southeast US ordinary storms, difficulty maintaining MCSs, lag in CI in early runs, false alarms)

* March 2011 - February 2012
Future plans for advanced hourly NWP/DA

2011 – Rapid Refresh operational at NCEP
2011-14 – HRRR demo @ESRL improves
2014 – Ensemble Rapid Refresh – NARRE
2014 – High-Resolution Rapid Refresh operational at NCEP for CONUS
2016 – CONUS Ensemble HRRR - HRRRE

- North American Rapid Refresh Ensemble
  - NEMS-based NMM, ARW cores
  - Hourly updating with GSI (hybrid-EnKF-GSI?)
  - Initially 6 members, 3 each core
  - Forecasts to 24-h
  - NMM to 84-h 4x per day

Other improvements
• Add inline chem, chem DA
• Storm-scale radar assimilation
• Sub-hourly DA
Proposed Year Two Activities

Continued collaboration with OU-CAPS on CONUS mesoscale (40-km) EnKF / hybrid system

• Kefeng Zhu, Xuguang Wang, Ming Xue, Jeff Whitaker
• Development and testing for May 2010 retrospective period
  • EnKF and GSI (3DVar) cycling
  • Innovation calculation with GSI
  • Tuning: inflation, localization

• Real-time implementation?
• Boundary conditions for a storm-scale system?
Proposed Year Two Activities

Feasibility study: 2012 storm-scale EnKF demo?
(postponed from year 1 to year 2)

• Advantages and disadvantages of an advanced method for storm-scale radar data assimilation
  • Small domain covered by one or a few radars
  • Side-by-side comparison of analyses and 0-2 h forecasts produced with EnKF and a simpler method (e.g., DDFI and/or 3DVar)
• Good opportunity for multi-institution collaboration (ESRL, NSSL, OU, NCAR)
  • Shared ideas for improving efficiency
  • RR, HRRR, mesoscale EnKF (NCAR, NSSL), and/or CAPS ensembles for initial conditions, boundary conditions, and ensemble perturbations?
  • Computing resources?
• Reducing the computational requirements of an EnKF system
  • Speculation: <10% of the computation does >90% of the “work”
  • Ideas from recent literature
Proposed Year Two Activities

(also postponed from year 1 to year 2)

**Prototype a framework sufficient to perform an initial displaced real-time evaluation of warn-on-forecast techniques and capabilities.**
deliverable: prototype system that can be used to assess techniques and capabilities

**Document the operational procedures and uses of current AWIPS and N-AWIPS capabilities and functionality that support operational severe weather watch and warning programs.**
deliverable: report documenting current WFO and SPC practices for determining and generating severe weather watches and warnings
deliverable: collection of warning and verification information from selected WFOs
Proposed Year Two Activities

Storm-scale ensemble sensitivity analysis (ESA)

- Correlations between initial conditions (or model parameters) and forecast metrics
  - New method (Hakim and Torn 2008, Torn and Hakim 2008), applied so far only to larger scales
- What really affects 0-2 hour forecasts of convective storm strength / location / existence?
- To improve forecasts, where and what should we observe?

composite sensitivity for analysis field and 24-hr forecast SLP in western WA (Torn and Hakim 2008)
Proposed Year Two Activities

Collaboration with partners on VORTEX2 (2009-2010) retrospective modeling and NWP

- Continued collaboration with Glen Romine and Chris Snyder at NCAR on June 2009 multi-case EnKF retrospective study (more cases; journal paper)
- More discussion of VORTEX2 this afternoon
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Comments and Questions?
From analysis to forecast

KPUX Radar Reflectivity

00:00 UTC

00:30 UTC

01:00 UTC

01:30 UTC

Ens mem max updraft

• Smooth transition from analysis to forecast
• Storm merger not well handled (resolved?)
- Hourly cycling of land surface model fields
- 6 hour spin-up cycle for hydrometeors, surface fields
## NOAA/ESRL/GSD/AMB Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Domain</th>
<th>Grid Points</th>
<th>Grid Spacing</th>
<th>Vertical Levels</th>
<th>Vertical Coordinate</th>
<th>Height Lowest Level</th>
<th>Pressure Top</th>
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<tbody>
<tr>
<td>RUC</td>
<td>CONUS</td>
<td>451 x 337</td>
<td>13 km</td>
<td>50</td>
<td>Sigma/Isentropic</td>
<td>5 m</td>
<td>~50 mb</td>
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<tr>
<td>RR</td>
<td>North America</td>
<td>758 x 567</td>
<td>13 km</td>
<td>50</td>
<td>Sigma</td>
<td>8 m</td>
<td>10 mb</td>
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<tr>
<td>HRRR</td>
<td>CONUS</td>
<td>1799 x 1059</td>
<td>3 km</td>
<td>50</td>
<td>Sigma</td>
<td>8 m</td>
<td>85 mb</td>
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<table>
<thead>
<tr>
<th>Model</th>
<th>Run at:</th>
<th>Time-Step</th>
<th>Forecast Length</th>
<th>Initialized</th>
<th>Boundary Conditions</th>
<th>Run Time</th>
<th># of CPUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUC</td>
<td>NCEP oper</td>
<td>18 s</td>
<td>18 hrs</td>
<td>Hourly (cycled)</td>
<td>NAM</td>
<td>~25 min</td>
<td>32</td>
</tr>
<tr>
<td>RR</td>
<td>GSD, EMC</td>
<td>60 s</td>
<td>18 hrs</td>
<td>Hourly (cycled)</td>
<td>GFS</td>
<td>~25 min</td>
<td>160</td>
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<tr>
<td>HRRR</td>
<td>GSD</td>
<td>15-20s</td>
<td>15 hrs</td>
<td>Hourly (no-cycle)</td>
<td>RUC (RR planned)</td>
<td>~50 min</td>
<td>1000</td>
</tr>
</tbody>
</table>
Rapid Refresh vs. RUC (NCEP-oper) upper-air verification +6h forecast RMS Error

27 Dec 2010 - 7 Jan 2011