Rapid-Refresh Core Test: Aspects of WRF-NMM and WRF-ARW forecast performance relevant to the Rapid Refresh application

J. M. Brown¹, S. G. Benjamin¹, T. G. Smirnova¹,², G. A. Grell¹,², L. R. Bernardet¹,³,⁴, L. B. Nance⁵,⁴, R. S. Collander¹,³, and C. W. Harrop¹,²

Motivation
Experimental design
Statistical and subjective results
GSD recommendation

¹NOAA/ESRL/GSD
²In collaboration with Cooperative Institute for Research in the Environmental Sciences
³In collaboration with Cooperative Institute for Research in the Atmosphere
⁴Also with NCAR-NOAA Developmental Testbed Center
⁵NCAR/MMM
<table>
<thead>
<tr>
<th>Contributors (Affiliation)</th>
<th>Contributors (Affiliation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louisa Nance (DTC)</td>
<td>Tanya Smirnova (ESRL/GSD)</td>
</tr>
<tr>
<td>Chris Harrop (GSD-DTC)</td>
<td>John Brown (ESRL/GSD)</td>
</tr>
<tr>
<td>Ligia Bernardet (DTC-GSD)</td>
<td>Stan Benjamin (ESRL/GSD)</td>
</tr>
<tr>
<td>Meral Demirtas (DTC)</td>
<td>Kevin Brundage (ESRL/GSD)</td>
</tr>
<tr>
<td>James Pinto (NCAR-RAL)</td>
<td>Randy Collander (GSD-DTC)</td>
</tr>
<tr>
<td>Marcia Politovich (NCAR-RAL)</td>
<td>Ed Szoke (ESRL-GSD)</td>
</tr>
<tr>
<td>Ben Bernstein (NCAR-RAL)</td>
<td>Jennifer Mahoney (ESRL/GSD)</td>
</tr>
<tr>
<td>Paul Herzegh (NCAR/RAL)</td>
<td>Andy Loughe (GSD-DTC)</td>
</tr>
<tr>
<td>Richard Bateman, Jenny Simard (NCAR/RAL)</td>
<td></td>
</tr>
<tr>
<td>Roy Rasmussen (NCAR/RAL)</td>
<td>Steve Koch (DTC)</td>
</tr>
<tr>
<td>Greg Thompson (NCAR/RAL)</td>
<td>Robert Gall (DTC)</td>
</tr>
<tr>
<td>Bob Sharman (NCAR/RAL)</td>
<td>Nelson Seaman (NWS)</td>
</tr>
<tr>
<td>Rod Frehlich (NCAR/RAL)</td>
<td>Matt Pyle (NCEP/EMC)</td>
</tr>
<tr>
<td>Bruce Carmichael (NCAR/RAL)</td>
<td>Brad Ferrier (NCEP/EMC)</td>
</tr>
<tr>
<td>Jimy Dudhia (NCAR/MMM)</td>
<td>Tom Black (NCEP/EMC)</td>
</tr>
<tr>
<td>Wei Wang (NCAR/MMM)</td>
<td>Hui-ya Chuang (NCEP/EMC)</td>
</tr>
<tr>
<td>Dave Gill (NCAR/MMM)</td>
<td></td>
</tr>
</tbody>
</table>
RUC

Rapid-Refresh (2009)

Continental situational awareness Model w/ WRF

Hourly NWP Update for:
- CONUS
- AK/Can
- Pac/Atl
- Caribbean
Goal in RR-core-test comparison experiments

• Recommendation from GSD to NCEP/EMC on preferred version of WRF core …

Choices
  • ARW
  • NMM

• Focus on ~13km/50-60 levels, short-range (1-12h), aviation/severe-weather application

VIA

• Fully controlled core-test comparisons
  - Requires use of same physics suite in each core
• Use of RUC initial conditions (clouds, assim of sfc obs, etc.)
Verification design in RR-core-test comparison experiments

• Match domains, topography as well as possible

• Use of WRF-NCEP verification package and RTVS-designed interface for observation-based verification.

• Use of East and West split verification sub-domains as well as National domain

• Graphics available for key fields for all experiments
Goal for RR core test

-- two sets of physical parameterizations
(GFDL radiation used for both)

• Phase 1 - Default NMM physics (thought to be “easiest”)
• Phase 2 - RUC-like physics

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explicit clouds</td>
<td>Ferrier</td>
<td>Thompson-NCAR</td>
</tr>
<tr>
<td>Sub-grid convection</td>
<td>Betts-Miller-Janjic</td>
<td>Grell-Devenyi</td>
</tr>
<tr>
<td>Land-surface</td>
<td>F77 version of Noah (“99” LSM)</td>
<td>RUC-Smirnova</td>
</tr>
<tr>
<td>Turbulent mixing</td>
<td>Mellor-Yamada-Janjic</td>
<td>Mellor-Yamada-Janjic</td>
</tr>
</tbody>
</table>
ARW and NMM Forecast Domains

Solid: RUC13 domain
Dashed: ARW domain
Dotted: NMM domain

Range in grid spacing:
NMM  13.07 – 13.41 km
ARW  12.68 – 13.47 km

Number of vertical levels: 50 for both cores – similar distribution
Difference between NMM and ARW Terrain

NMM terrain: 5-point smoother
ARW terrain: TOPTWVL_PARM_WRF = 4.
Retrospective Testing

Model configuration –
  Initial conditions: RUC13
  Lateral boundary conditions: NAM
  Upper boundary condition:
    NMM – default
    ARW – upper level damping layer
      - zdamp = 5km
      - damp_coef = 0.02

Forecast length: 24 h
  Initial times: 00Z and 12 Z
  Time steps: ARW - 72 s, NMM – 30 s
  Physics frequency:
    Radiation: 30 min for both cores
    Other: ARW 72 s, NMM – 60 s
Retrospective Testing (cont)

Dates -
  Summer: 15 July to 15 August 2005
  Fall: 1 to 30 November 2005
  Winter: 15 January to 15 February 2006
  Spring: 25 March to 25 April 2006

Post-Processing –
  Interpolate output from both cores from their native grid to RUC13 grid – data available for native vertical levels, constant pressure surfaces, and surface
Verification Domains

Full Domain

West & East Sub Domains

Boundary of full verification domain - 12 points in from the boundary of ARW domain

Strongest differences on 24-h forecasts verified over Eastern domain
Upper-Air verification
Level of concern for month-long ARW-NMM differences

**Winds** – any level (850-150 hPa) – RMS vector error
- < 0.10 m/s
- 0.10-0.25 m/s
- > 0.25 m/s

Empirically defined “levels of concern”
- Found to be nearly equivalent to formal statistical significance
  (DTC/Weatherhead et al.)

**RH** – 850-500 hPa – RMS error (raobs)
- < 0.5 %
- 0.5-1.0 %
- > 1.0 %

**Temperature** – any level (850-150 hPa) – RMS error (raobs)
- < 0.1 K
- 0.1-0.2 K
- > 0.2 K

Used aircraft as primary wind verification—more accurate than raobs, particularly for high winds
Wind rmse Diff. 24h (ARW-NMM) Aircraft: CONUS East

Example of Stat sig for RR core test

-SSDs - statistical seasonal differences
- For aircraft winds – 5-2 (ARW-NMM)
(out of 56 possible SSDs)
Temperatures - For aircraft temps – 3-1 (ARW-NMM) (out of 56 possible SSDs)

- Wind speed bias - no SSDs established
- NMM generally better

- Temperatures
- For aircraft temps – 3-1 (ARW-NMM)
NMM advantages

Major advantages
- Wind speed bias, particularly at upper levels.
- Precipitation bias
- Lower clock run time by 5-20% 
  (with same physics time step) – more with new, faster ijk version

Secondary advantages
- Code already developed for calling microphysics less often than every dynamic time step.
- NCEP/EMC will continue to develop NMM in the context of the NAM application.
ARW advantages

Major advantages
• Upper-level wind. This is apparent in aircraft verification. Rawinsonde verification (where ARW advantage was even stronger) is considered flawed.
• Lower-troposphere temperature
• Lower-troposphere relative humidity, primarily at 850 hPa, considered to be potentially important for icing and ceiling forecasts.
• Turbulence (see objective verification results)

Secondary advantages
• Community involvement – Currently more significant with ARW testing and applications than with NMM. This may be different after additional NMM community exposure via DTC, workshops, etc.
NOAA/ESRL/GSD recommendation to NCEP– 1 Sept 2006:

By a slight margin, the ARW core over the NMM core for the initial operational Rapid Refresh implementation.

- Some significant advantages evident for one core or the other, dependent on variable or vertical level, with a slight edge for ARW overall, but …
- No strong overall advantage for either.
- GSD will fully support NCEP decision, regardless of which core chosen. We urge your careful consideration of the comparison results in the report.

(http://ruc.noaa.gov/coretest2/GSD-report.pdf)

- RUC physics (Grell-Devenyi convection, NCAR-Thompson microphysics) ready to go for either NMM or ARW cores
- Jun07 status – Still no decision for RR-WRF core. Rapid Refresh testing w/ GSI assimilation and WRF-ARW/RUC physics (swappable to NMM, if needed)
June 06 - Physics availability due to WRF-RR Core-Test Project
-- all now in WRF v2.2

<table>
<thead>
<tr>
<th></th>
<th>NMM</th>
<th>ARW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrier microphysics</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>NCAR-Thompson microphysics</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MYJ PBL</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>BMJ conv</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Grell/Dev conv</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Option 99 LSM</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Noah LSM</td>
<td>--</td>
<td>✓</td>
</tr>
<tr>
<td>RUC LSM</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RUC initconds</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>