THE NCEP WRF NMM CORE


National Centers for Environmental Prediction
Camp Springs, Maryland
The NCEP WRF-NMM

Janjic, 2003, *Meteorology and Atmospheric Physics*
Black, Tucillo, Parallelization, Optimization, WRF standards

- Review of model features
- Some general results
- Severe weather applications: examples, results
- Ongoing research beyond WRF-NMM
Basic discretization principles (Janjic, 1977, Beitrage) following Arakawa, (1966,1972, ...), aka “mimetic” approach, currently hot topic in Applied Math, conservation of important properties of the continuous system.

- Controlled nonlinear energy cascade through energy and enstrophy conservation
- Omega-alpha term, consistent transformations between KE and PE.
- Minimization of errors associated with representation of orography.

Fundamental principles deeply embedded into the dynamics of the system, no unique answers, variety of schemes possible!

- Conservation of a number first order and additional quadratic quantities.
- Isotropic divergence operator, interchangability between advective and flux forms (Janjic, 1984; Ming, 2002).
- Pressure-sigma hybrid (Arakawa and Lamb, 1977).
- Arakawa E grid in the initial NCEP formulation, B grid formulation (NMM-B) also exists (Janjic, 2003, MAP).
Wind component developing due to the spurious pressure gradient force in the sigma coordinate (left panel), and in the hybrid coordinate with the boundary between the pressure and sigma domains at about 400 hPa (right panel). Dashed lines represent negative values.
● Time stepping
  - Adams-Bashforth for horizontal advection of $u$, $v$, $T$ and Coriolis force.
  - Crank-Nicholson for vertical advection of $u$, $v$, $T$ (60 levels).
  - Implicit for vertically propagating sound waves \cite{Janjicetal2001, MWR}.
  - Split forward, long time steps for physics \cite{Janjic1990, MWR}.

● No redundant computations, high computational efficiency despite the complexity!
Formulation successfully reproduces classical 2D nonhydrostatic solutions

The cold bubble test. Potential temperatures after 300 s, 600 s and 900 s in the right hand part of the integration domain extending from the center to 19200 m, and from the surface to 4600 m. The contour interval is $1^0$ K.

Potential temperature after 360 s, 540 s, 720 s and 900 s. The area shown extends 16 km along the x axis, and from 0 m to 13200 m along the z axis. The contour interval is $1^0$ K.
Atmospheric spectrum.

- Accumulation of energy at small scales due to computational problems (false nonlinear energy cascade from large to small scales), a difficulty early discovered in the history of numerical modeling of atmosphere (Phillips, 1954; Arakawa, 1966; Sadourny 1975; ...).

- Historically, the problem controlled by:
  - Removing spurious energy at small scales by filtering, dissipation.
  - Preventing excessive nonlinear energy transport to small scales by enstrophy and energy conservation (Arakawa, 1966).

- But, ...
Sadourny, 1975, JAS:

the “inertial” range; however, a correct energy spectrum for a numerical solution is not by itself a proof of the accuracy of the simulated energy transfers. In fact, it is always possible to force the energy distribution of any numerical solution to conform to a known spectral shape in the inertial range through ad-hoc assumptions, regarding, for instance, addition of artificial viscosity. However, if we are to trust numerical modelling as a method for providing better understanding of the real processes, we must then admit that a realistic energy spectrum should not be forced by artificial techniques, but should come instead as a by-product of the
first principles only, via correct treatment of the non-linear interactions. More precisely, accurate long-term statistical distributions of kinetic energy should result from:

1) An accurate distribution of sources and sinks (outside the inertial range).

2) Accurate representation of the statistical transfers of energy within the resolved scales ("internal" transfers) in spite of the truncation error of the finite-difference scheme in the smaller scales.

3) An accurate parameterization of the statistical effects of nonlinear interactions with the subgrid-scale motions.

The WRF-NMM and the NMM-B well qualified for investigating numerical spectra by design.
- No time (and space) for downscale nonlinear energy cascade, physical or spurious energy source needed on small scales.

- Where is the small scale energy in the observed spectrum coming from?

The Atlantic case, NMM-B, 15 km, 32 Levels
Decaying 3D turbulence, Fort Sill storm, 05/20/77.

NMM-B, Ferrier microphysics, 1km, 32 levels, 112km by 112km by 16.4km, double periodic.

Spectrum of \( w^2 \) at 700 hPa, hours 3-4 average.
● Excellent agreement with observed spectra.

● **Sufficiently strong physical or spurious energy sources needed on small scales:**

  - Physical sources (like in the NMM Atlantic example).
  
  - Spurious sources.
  Numerical errors (computational nonlinear cascade, sigma errors…)
  Numerical instabilities
  Parameterization errors …

☞ **Problem:** Keep physical, eliminate spurious energy sources.
“Isabel”

NMM
8 km, 60 lev.

GFS data

Sea level Pressure

951.72 mb
Obs. 953 mb

NMM
8 km, 60 lev.
GFS data
3 hour
Accumulation

NCAR
geometrical progression
color code
"Hurricane WRF"

WRF-NMM to replace the current operational hurricane model at NCEP in 2007.

NCEP/GFDL/U. of Rhode Island

Surgi, Tuleya, Gopalakrishnan, ...

Courtesy Naomi Surgi
National Severe Storm Laboratory (NSSL)/Storm Prediction Center (SPC) Spring Program 2004 (Weiss et al., 2004; Kain et al., 2005, WAF).

- Independent, respectable, carefully controlled assessment of experimental technologies for severe weather forecasting.

- WRF-NMM, first time participation.

- 4.5 km, 35 levels, about Central domain, Ferrier microphysics, Janjic turbulence, no parameterized convection, Eta initial and boundary conditions, 00Z, up to 30 hours, available in the morning.

- Emphasis on prediction of newly developed mesoscale convective systems, not present in initial conditions.

- NMM starting from the Eta data needs several hours to spin up convective systems.
24 hour 4.5 km forecast of 1 hour accumulated precipitation valid at 00Z April 21, 2004 (better than 12 hour forecasts by operational models).

Verifying 2 km radar reflectivity. Courtesy Jack Kain.
NCEP NMM, 4.5 km, 35 lev., Ferrier

NCAR EMC, 4 km, 35 lev., Lin

Radar, 2 km

NSSL/SPC 2004 Spring Program

04/04/28, 00Z ~ +24 hours

Courtesy: Jack Kain, Steve Weiss
NCEP NMM, 4.5 km, 35 lev., Ferrier

NCAR EMC, 4 km, 35 lev., Lin

Radar, 2 km

NSSL/SPC
2004 Spring Program
04/05/28, 00Z ~ +24 hours

Courtesy: Jack Kain, Steve Weiss
Zavisa Janjic
WRF Boulder, June 2005

NCEP NMM, 4.5 km, 35 lev., Ferrier
NCAR EMC, 4 km, 35 lev., Lin
NSSL/SPC 2004 Spring Program
04/06/01, 00Z ~ +24 hours

Courtesy: Jack Kain, Steve Weiss
Mean Scores (15 days): Convective Initiation, Evolution, and Mode

Fig. 5. Mean subjective verification ratings for the operational Eta model and the 3 high-resolution configurations of the WRF model, for categories of convective initiation, evolution, and mode, for the 15 days when all 4 models were available.

17.1 EXAMINATION OF SEVERAL DIFFERENT VERSIONS OF THE WRF MODEL FOR THE PREDICTION OF SEVERE CONVECTIVE WEATHER: THE SPC/NSSL SPRING PROGRAM 2004

Steven J. Weiss¹, J. S. Kain², J. J. Levit¹, M. E. Baldwin², and D. R. Bright¹

¹NOAA/NWS/Storm Prediction Center
²University of Oklahoma/CIMMS/National Severe Storms Laboratory

22nd Conference on Severe Local Storms, October 3-8, 2004, Hyannis, MA.
NWP on near-cloud scales successful more frequently and with stronger signal than if only by chance.

For the first time a model with near-cloud-scales resolution outperformed the NCEP meso guidance with coarser resolution and with parameterized convection.

Convective systems direct circulations spun-up by the model, predictable on 24 hour scale?

Further improvement in mesoscale forecasts possible with increased resolution?

Reemphasized importance of forcing and (micro)physics on meso scales.

Full potential of mesoscale NWP not yet developed.

- Computationally robust, reliable in operations.
- Little noise, no Rayleigh damping and associated extra computational boundary condition at the top with real data with resolutions down to 100 m.
- Several times faster than most established NH models.
- NWP, convective cloud runs, PBL LES, with resolutions from 50 km to 100 m.
- Operational at NCEP HiRes Windows, Fire Weather, On Call (no filtering of mountains, small domains, initialized and driven by the Eta).
- Scheduled to replace the Eta in 2006, Hurricane WRF scheduled for 2007.
- Quasi-Operationally run elsewhere.
Next: Unified MOdel (UMO) dynamical core being developed for a wide range of spatial scales

- Extension of the Nonhydrostatic Mesoscale Model (NMM).
- Built on experiences of NWP (Janjic et al., 2001; Janjic, 2003).
  - Relaxing the hydrostatic approximation, while,
- The nonhydrostatic option as an add–on nonhydrostatic module.
  - Reduced computational effort at lower resolutions
  - Easy comparison of hydrostatic and nonhydrostatic solutions
Grid

- Gravity-inertia wave frequencies on rectangular grids with 2nd order finite differencing (Winninghoff 1968, UCLA PhD; Arakawa and Lamb 1977, MCP; Janjic 1984, MWR; Randall, 1994, MWR; Gavrilov, 2004, MWR).

\[
\begin{array}{ccc}
  h & h & h \\
  v & v \\
  h & h & h \\
  v & v \\
  h & h & h \\
  B \\
\end{array}
\quad
\begin{array}{ccc}
  h & u & h & u & h \\
  v & v & v \\
  h & u & h & u & h \\
  v & v & v \\
  h & u & h & u & h \\
  C \\
\end{array}
\]

- B grid: problems with shortest waves with erroneous low frequency due to averaging of the divergence term in continuity equation.

- C grid: in case of very coarse resolution or weak static stability problems on all scales due to averaging of Coriolis force terms.
Spherical geometry?

- Many possibilities considered.
- No decisive advantages found over lat-lon with filtering.
- Another approach pursued with NMM dynamics yin-yang (baseball ball) – Purser.
Polar filtering

- Chopping of waves shorter than a threshold wavelength, works but Gibbs ripples.

- Arakawa 1977, works but for a different problem (linear external gravity waves), may be too damping near the poles.

- “Pseudo-2-point”:
  \[ \cos\left(\frac{k\Delta x}{2}\right)^n \]
  - Applied to waves shorter than a threshold in Fourier space and faster than waves propagating in meridional direction;
  - \( n \) increases toward poles.

- Mass variables tendencies, \( u,v \) filtered.
Major requirements:

- **Accuracy**
  - Good,
  - Indirect evidence (regional forecasts).

- **Efficiency**
  - Very good on regional scales;
  - Competitive with most efficient methods on global scales, estimate on the basis of the existing serial F90 code.
  - Parallel code nears completion.
Global domain, 256 x 181 points, 31 level
45 min per day on 1.5 GHz Pentium M laptop
The 500 hPa map obtained in a 20 day simulation initialized with real data. The contour interval is 60m.
Sanity check
Conclusions

- Unified model for a wide range of spatial scales being developed as an extension of the NMM.
- Grid point, explicit.
- Promising accuracy on regional and global scales.
- Promising efficiency, competitive with most efficient other methods.
- Work in progress.