Nonhydrostatic Multi-scale Model (NMMB)

Z. Janjic, T. Black and R. Vasic

- Climate high on the agenda of most meteorological centers
- Two major recent projects at NCEP
  - New version of Climate Forecasting System (CFS) released
    - Based on the spectral Global Forecasting System (GFS)
    - Officially adopted for climate studies in India
  - NOAA Environmental Modeling System (NEMS)
    - Grid point Nonhydrostatic Multi-scale Model (NMMB) fully implemented
    - Implementation of the spectral Global Forecasting System (GFS) nearing completion
    - Implementation of the NOAA/ESRL grid point global model FIM commenced
- NMMB adopted by SEEVCCC, link to NCEP modeling efforts established

Nonhydrostatic Multiscale Model on the B grid (NMMB)

- Further evolution of the WRF NMM
- Intended for wide range of spatial and temporal scales (from meso to global, and from weather to climate)
- Built on NWP and regional climate experience by relaxing hydrostatic approximation (Janjic et al., 2001, MWR; Janjic, 2003, MAP)
  - No over-specification
- The nonhydrostatic option as an add–on nonhydrostatic module
- Pressure based vertical coordinate

Nonhydrostatic Multiscale Model on the B grid (NMMB)

- Conservation of important properties of the continuous system aka “mimetic” approach in Comp. Math. (Arakawa 1966, 1972, …; Jacobson 2001; Janjic 1977, …; Sadourny, 1968, … ; Tripoli, 1992 …)
  - Nonlinear energy cascade controlled through energy and enstrophy conservation
  - “Finite volume”
  - A number of first order and quadratic quantities conserved
  - A number of properties of differential operators preserved
  - Omega-alpha term, transformations between KE and PE
  - Errors associated with representation of orography minimized
  - Mass conserving positive definite monotone Eulerian tracer advection

Nonhydrostatic Multiscale Model on the B grid (NMMB)

- Coordinate system and grid
  - Global lat-lon
  - Regional rotated lat-lon, more uniform grid size
  - Arakawa B grid (instead of the WRF-NMM E grid)

```
h       h       h
    v       v
h       h       h
    v       v
h       h       h
```

  - Pressure-sigma hybrid (Simmons and Burridge 1981)
  - Lorenz vertical grid

Nonhydrostatic Multiscale Model on the B grid (NMMB)

- Regional domain lateral boundaries
  - Narrow zone with upstream advection zone, no computational outflow BC
  - Narrow linear blending zone (5 rows best)
- Conservative global polar boundary conditions
- Polar filter configuration
  - “Decelerator,” tendencies of T, u, v, Eulerian tracers, divergence, dw/dt, deformation
  - Waves in the zonal direction faster than waves with the same wavelength in the latitudinal direction slowed down
  - Physics not filtered

Nonhydrostatic Multiscale Model on the B grid (NMMB)

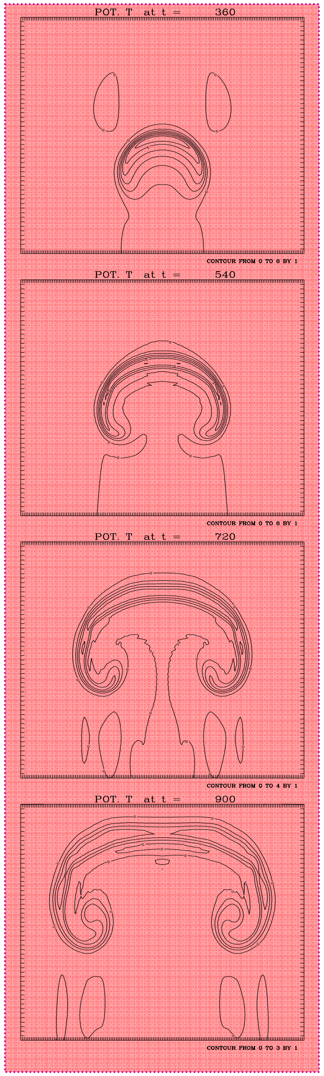
- Time stepping
  - No splitting
  - Adams-Bashforth for horizontal advection of u, v, T and Coriolis force
  - Crank-Nicholson for vertical advection of u, v, T (implicit)
  - Forward-Backward (Ames, 1968; Janjic 1979, Beitrage) fast waves
  - Implicit for vertically propagating sound waves (Janjic et al., 2001, MWR; Janjic, 2003, MAP)

Nonhydrostatic Multiscale Model on the B grid (NMMB)

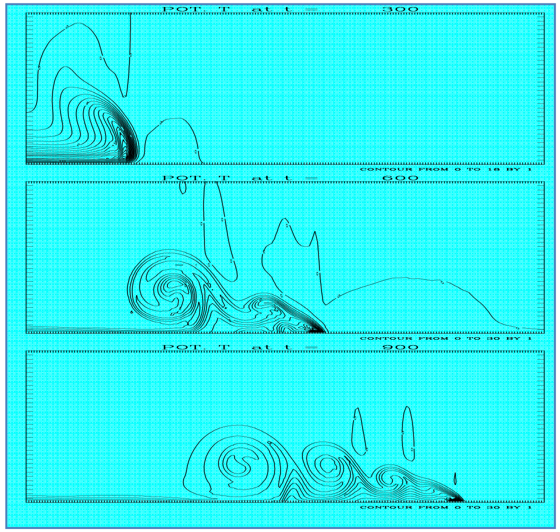
- Upgraded NCEP WRF NMM “standard” physical package
  - RRTM, GFDL radiation
  - NOAH, LISS land surface model
  - Mellor-Yamada-Janjic turbulence
  - Ferrier microphysics
  - Betts-Miller-Janjic convection
- GFS physics recently added

2D very high resolution tests

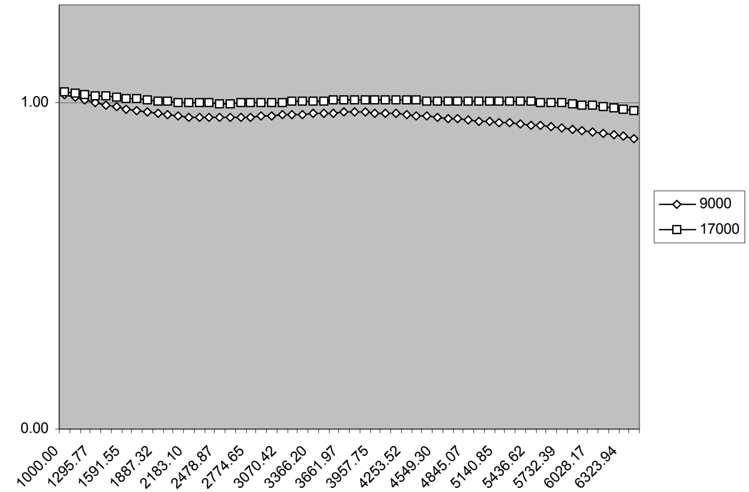
Warm bubble,
100 m resolution



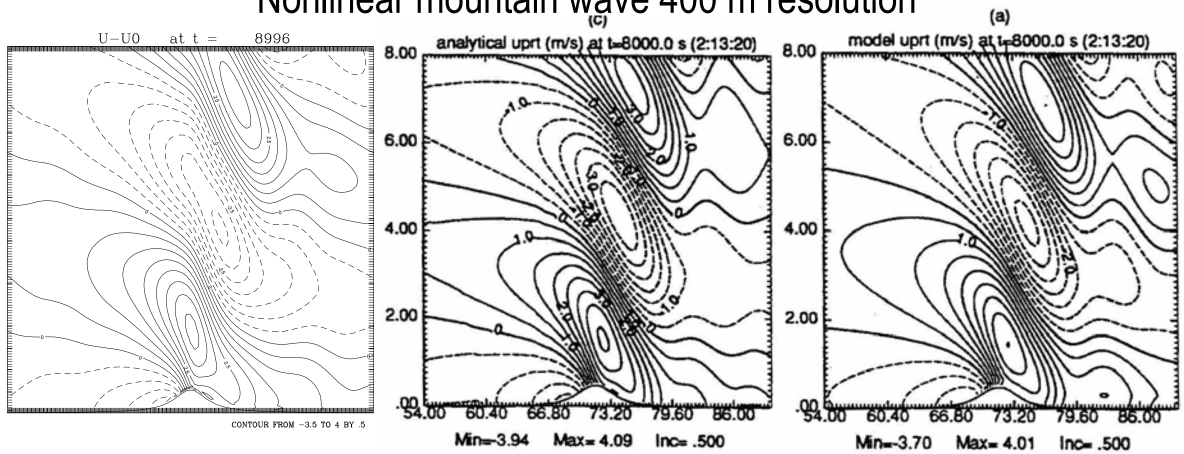
Cold bubble, 100 m resolution



Normalized vertical momentum flux,
400 m resolution



Nonlinear mountain wave 400 m resolution



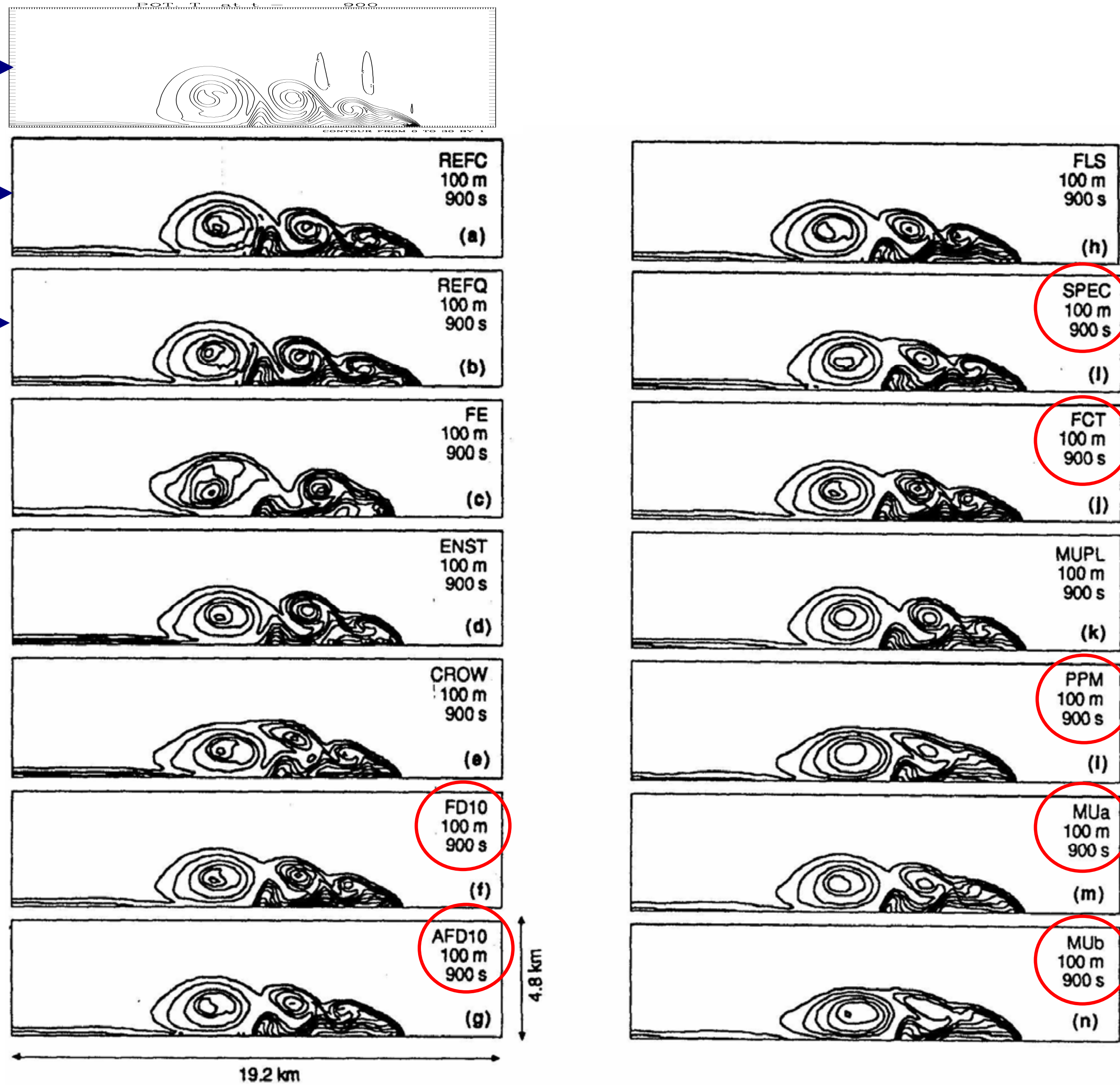
Full compressible NMM Analytical (Boussinesque) ARPS (Boussinesque)

Zavisa Janjic

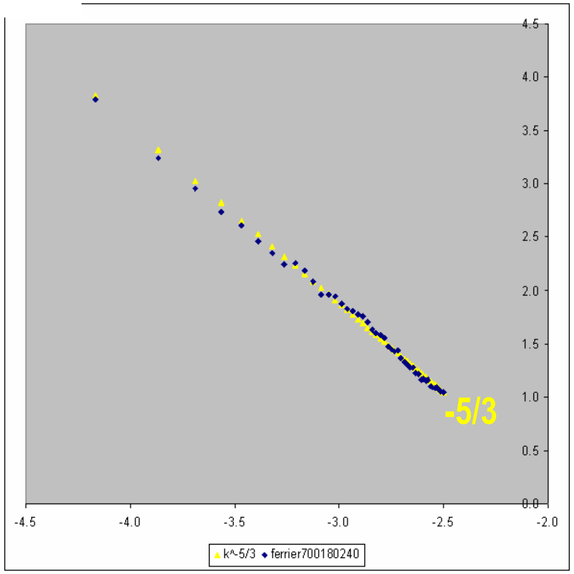
Janjic et al. 2001

Reference

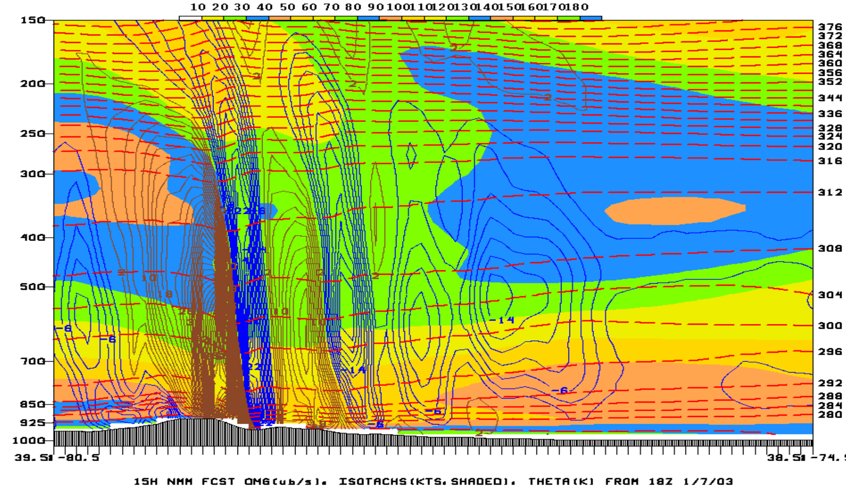
Reference



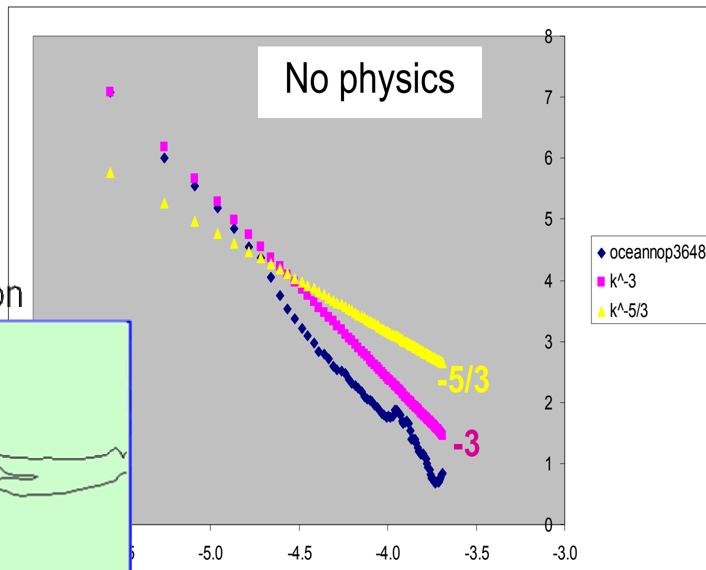
Decaying 3D turbulence, 1 km resolution

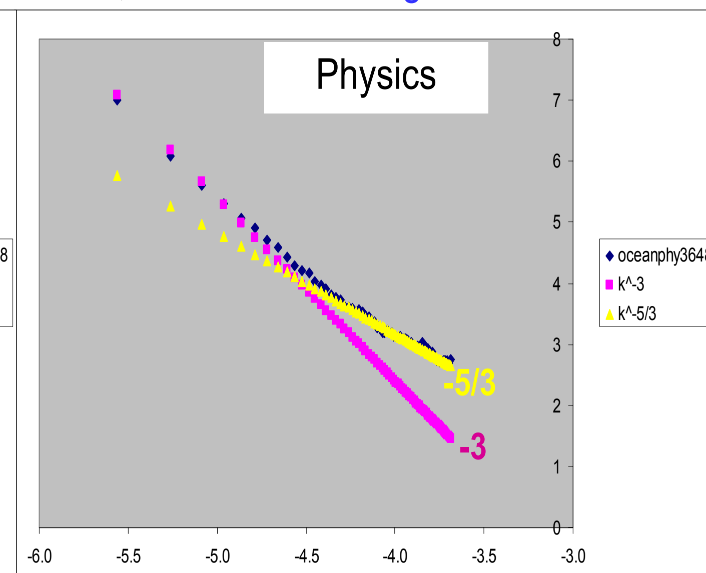


Mountain waves, 8 km resolution

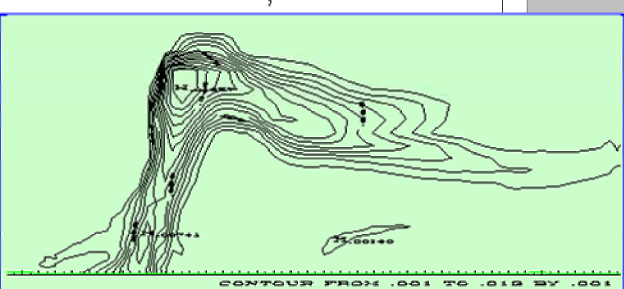


Atlantic case, NMMB, 15 km, 32 Levels, 36-48 hour average





Convection, 1 km resolution



4km resolution, no parameterized convection

2004

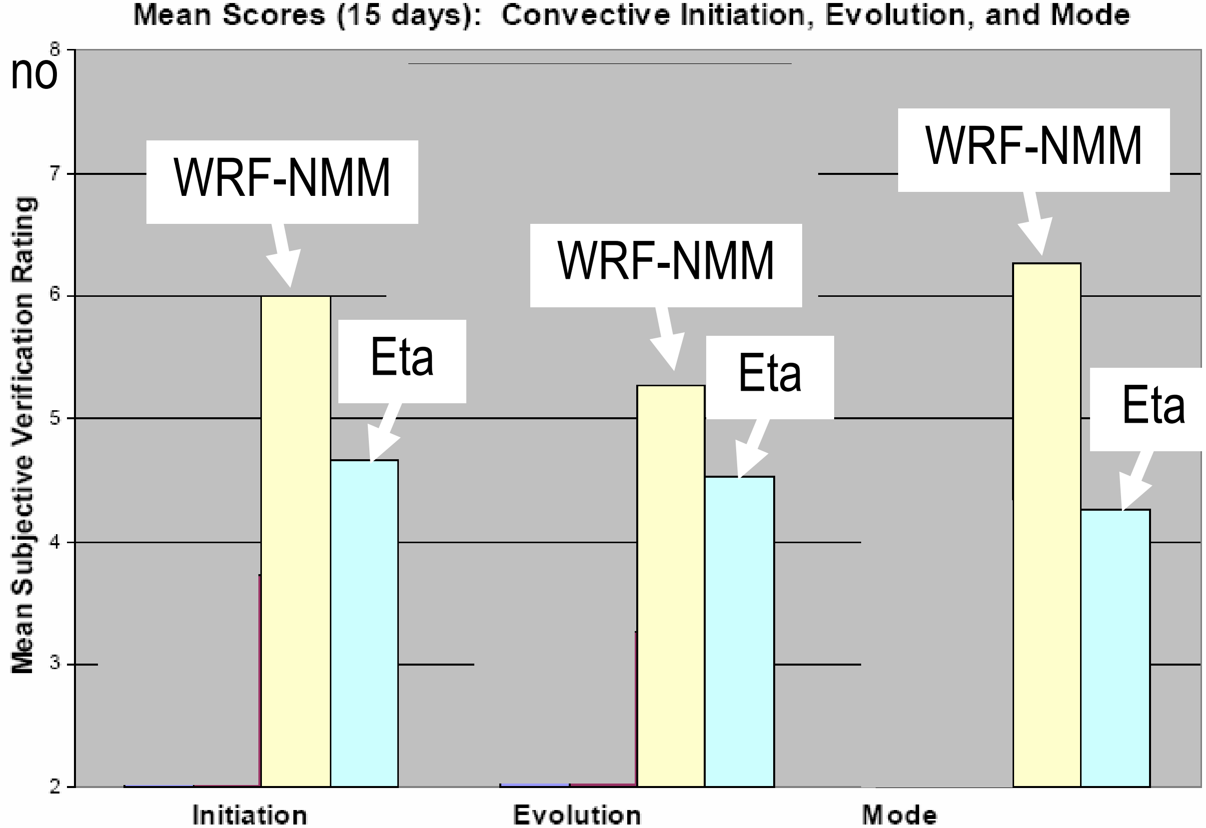


Fig. 5. Mean subjective verification ratings for the operational Eta model and the 3 high-resolution configurations of the WRF model, for categories of convective initiation, evolution, and mode, for the 15 days when all 4 models were available

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. Weiss[*,1], J. S. Kain[2], J. J. Levit[1], M. E. Baldwin[2], and D. R. Bright[1]

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

22nd Conference on Severe Local Storms, October 3-8, 2004, Hyannis, MA.

Global Scales

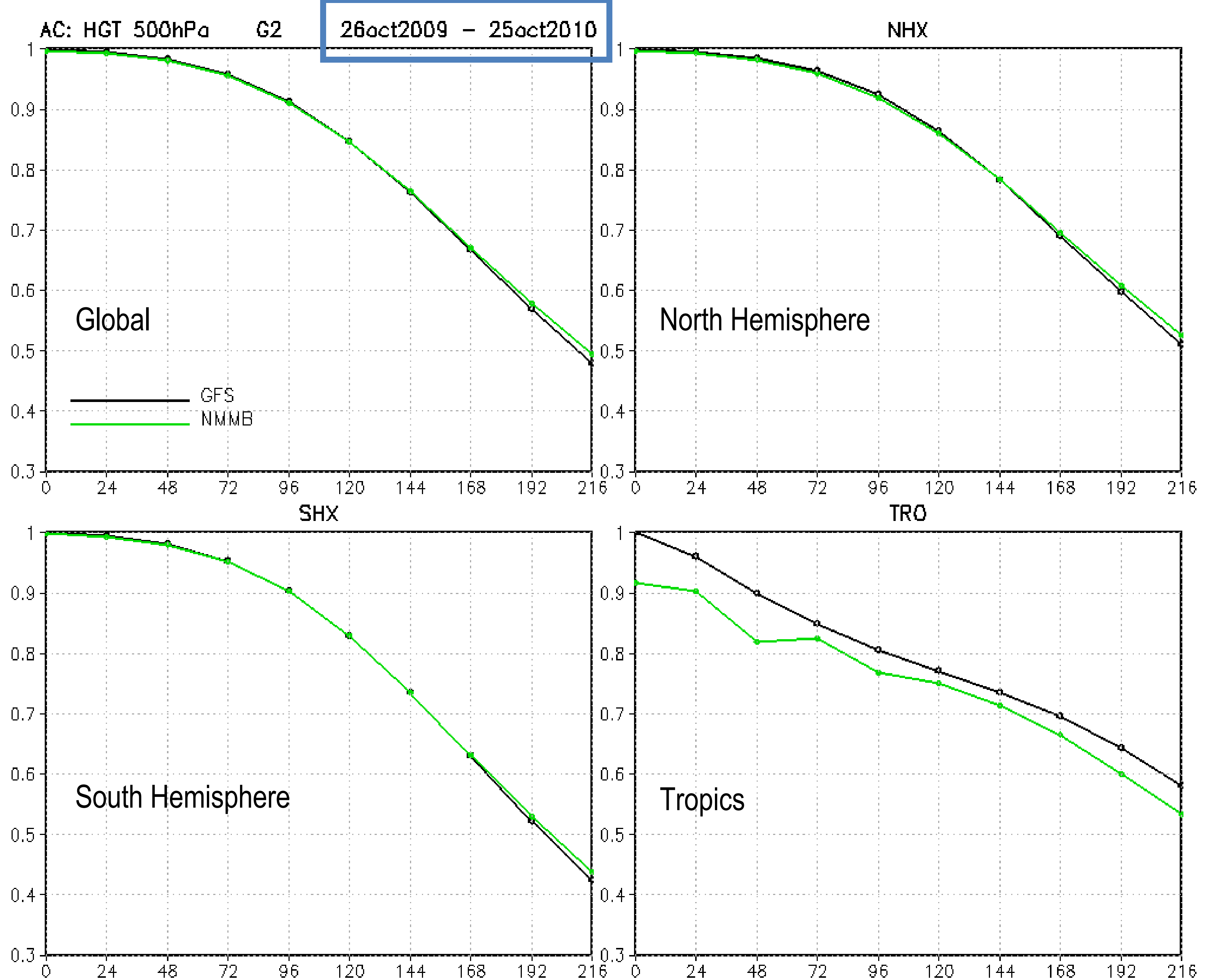
- One year of parallel global forecasts, October 26, 2009-October, 25 2010
  - Initialized from spectral GFS analyses
    - Compatibility issues between grid-point and spectral data (Gibbs phenomenon)
  - Verified against GFS analyses and climatology
  - 500 hPa Height Anomaly Correlation Coefficients
  - Although starting from “same” initial conditions, skill of NMMB and GFS forecasts often disparate
  - Potential advantage, global NMMB considered for global ensemble forecasting

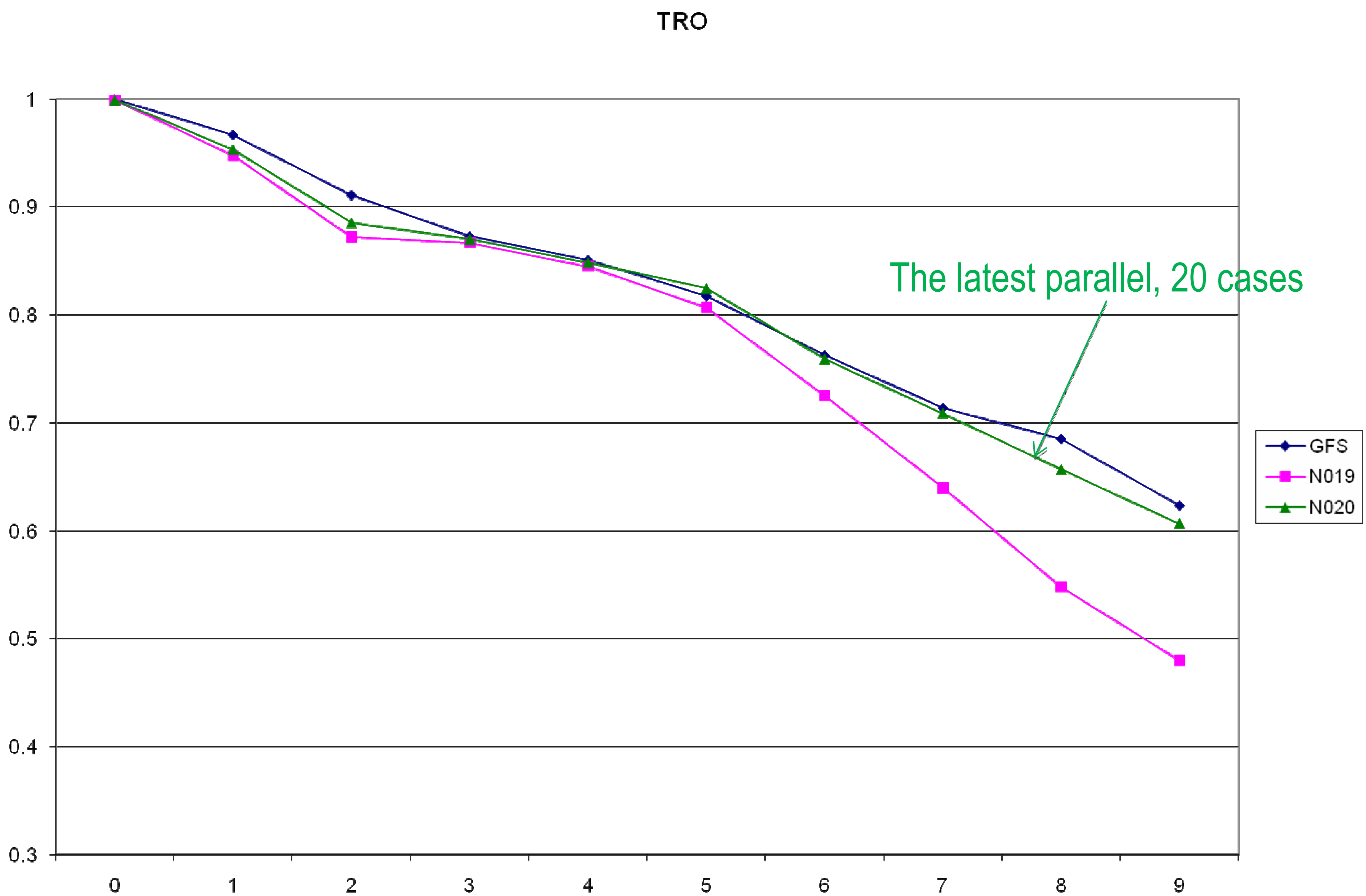
Global NMMB vs. GFS

1 year 500 hPa Height Anomaly Correlation Coefficient vs forecast time

NMMB initialized and verified using GFS analyses and climatology

NMMB comparable or lower resolution, from July 28 GFS has 2.5 times more points



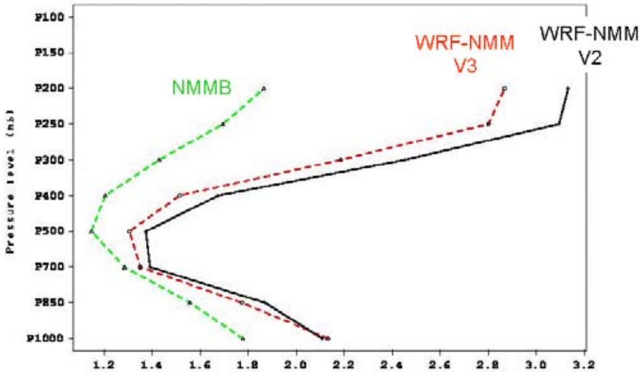

TRO
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
1
2
3
4
5
6
7
8
9
The latest parallel, 20 cases
GFS
N019
N020

Meso Scales

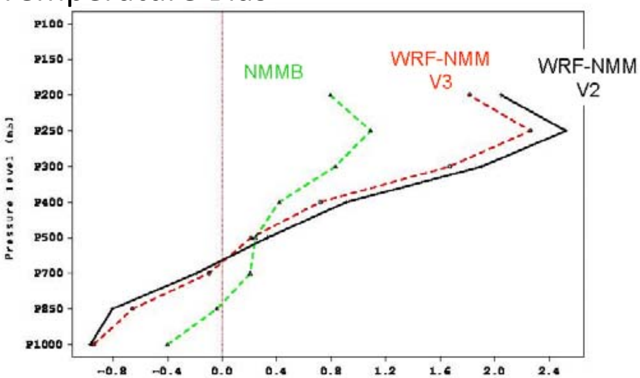
- Regional NMMB to replace WRF NMM in the NAM slot in 2011
- Hierarchy of nests running simultaneously, 12 km, 6 km, 4 km, 1.33 km (fire weather on the fly) resolutions

4 km NMM-B CONUS Nest – 36 h Fcst

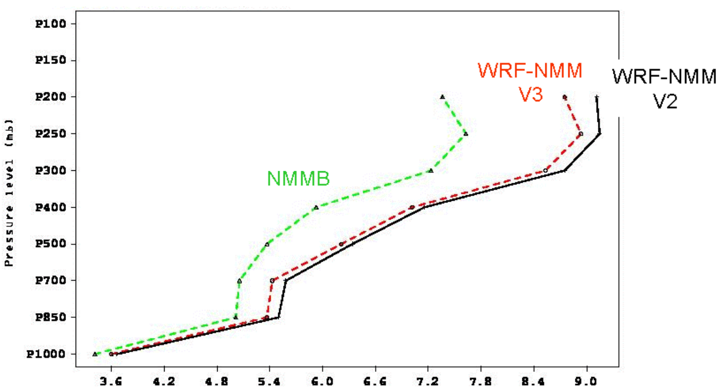
RMS Temperature Error



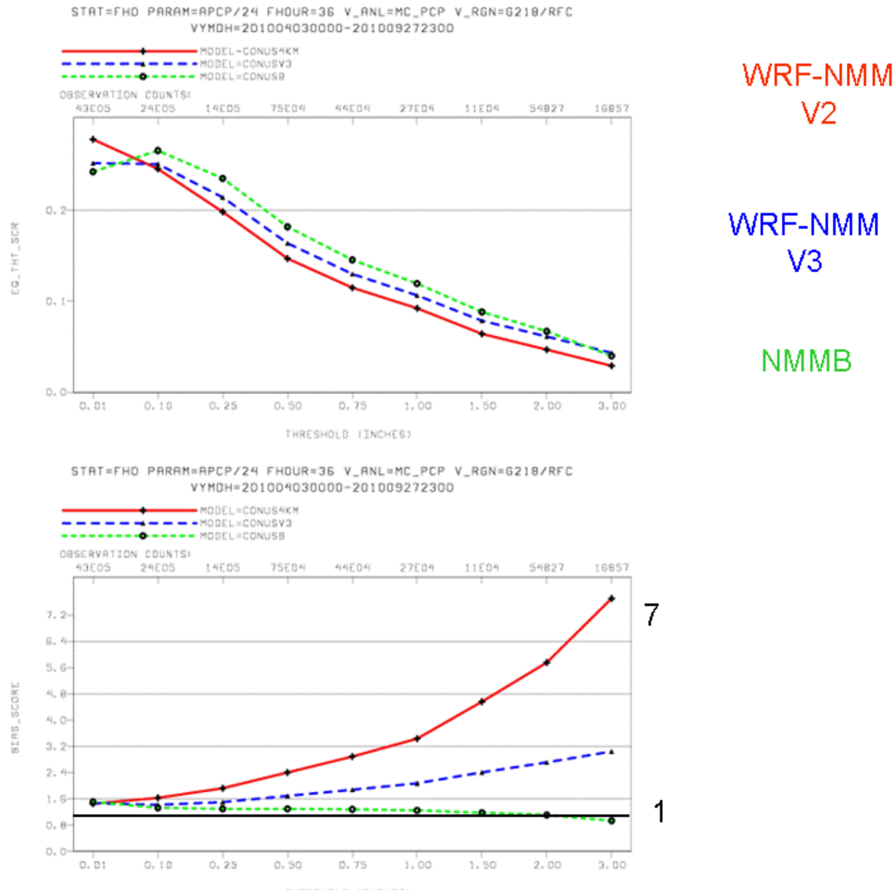
Temperature Bias



RMS Vector Wind Error



April 3 – Sept. 27 2010

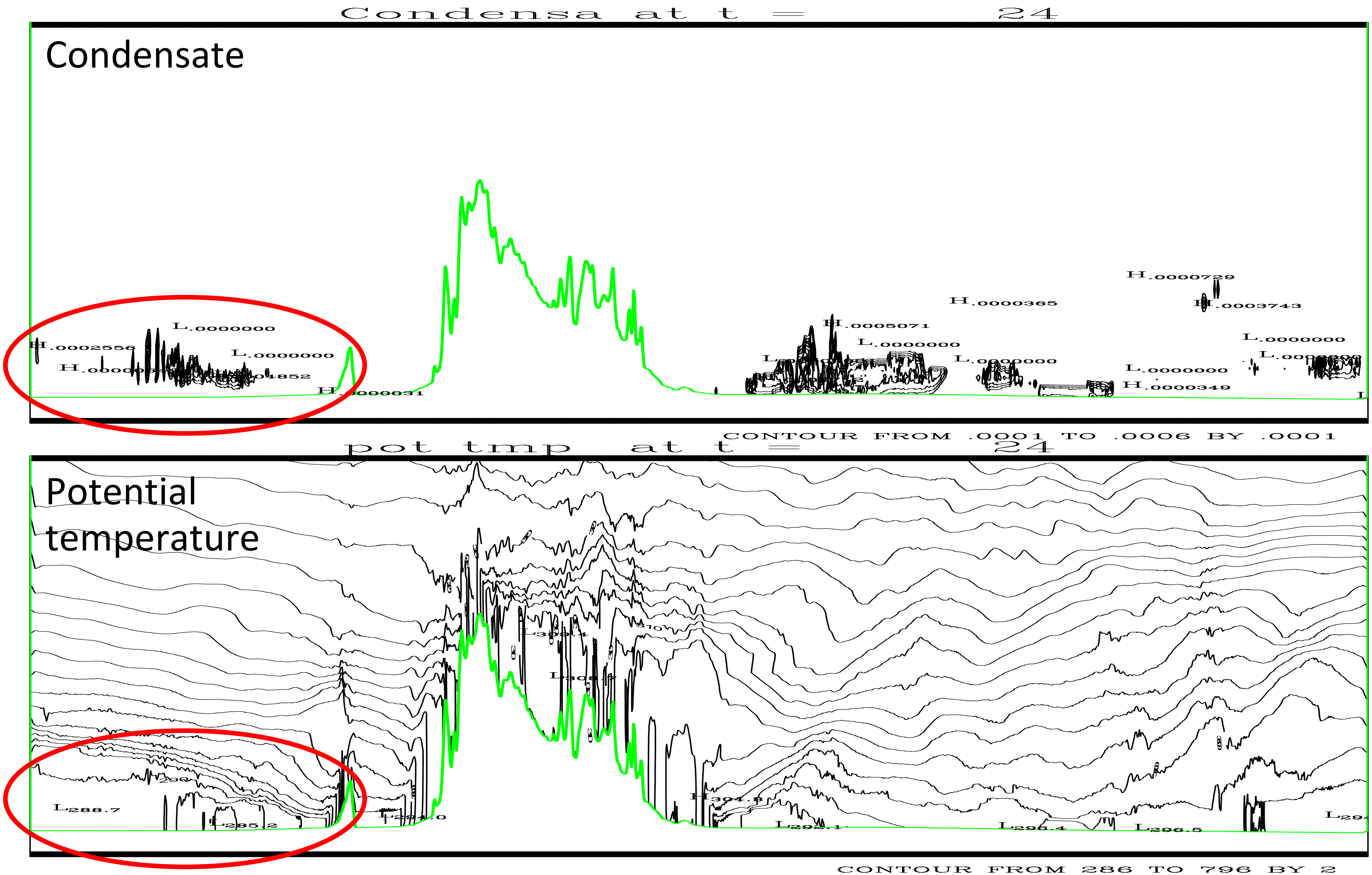


SREF Upgrades

- SREF
  - Eliminate 6 Eta and 5 RSM members
  - Add 7 NMMB, 2 WRF-ARW and 2 WRF-NMM members
  - Update WRF code versions
  - Increase horizontal resolution to 22 km
  - Bias correct precipitation

Outstanding Issues

- Shallow cloud topped marine PBL common problem in numerical models
  - Shallow convection parameterization unable to break low level cloudiness
  - Example from nested NMMB model:

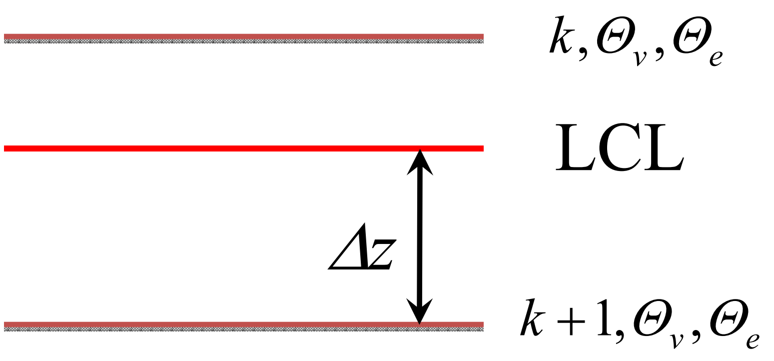

Condensa at t = 24
Condensate
CONTOUR FROM .0001 TO .0006 BY .0001
pot tmp at t = 24
Potential temperature
CONTOUR FROM 286 TO 796 BY 2
Pacific
CA
Mexico
Gulf

Outstanding Issues

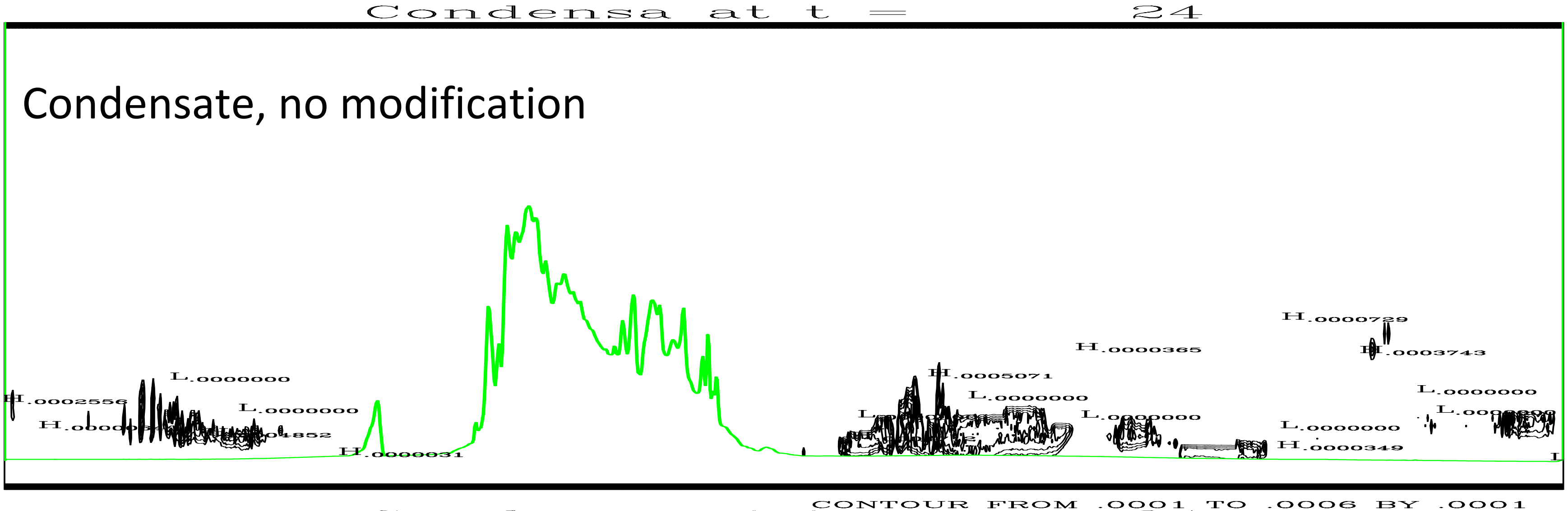
- Modify the PBL scheme to take into account potential instability?
- Mellor-Yamada-Janjic (MYJ)
  - Heisenberg & Kolmogorov
    - Exchange coefficients, dissipation
  - Mellor and Yamada (1982) Level 2.5 model
    - Proportionality factors
    - Empirical "constants"
    - Does not work in case of growing convective turbulence (Helfand and Labraga, 1988; Janjic, 1996, 2001)
  - Janjic (1996, 2001):
    - Realizability condition for growing convective turbulence
    - Constraints on diagnostically computed master length scale
    - New empirical "constants"
    - Numerical algorithm for solving TKE equation

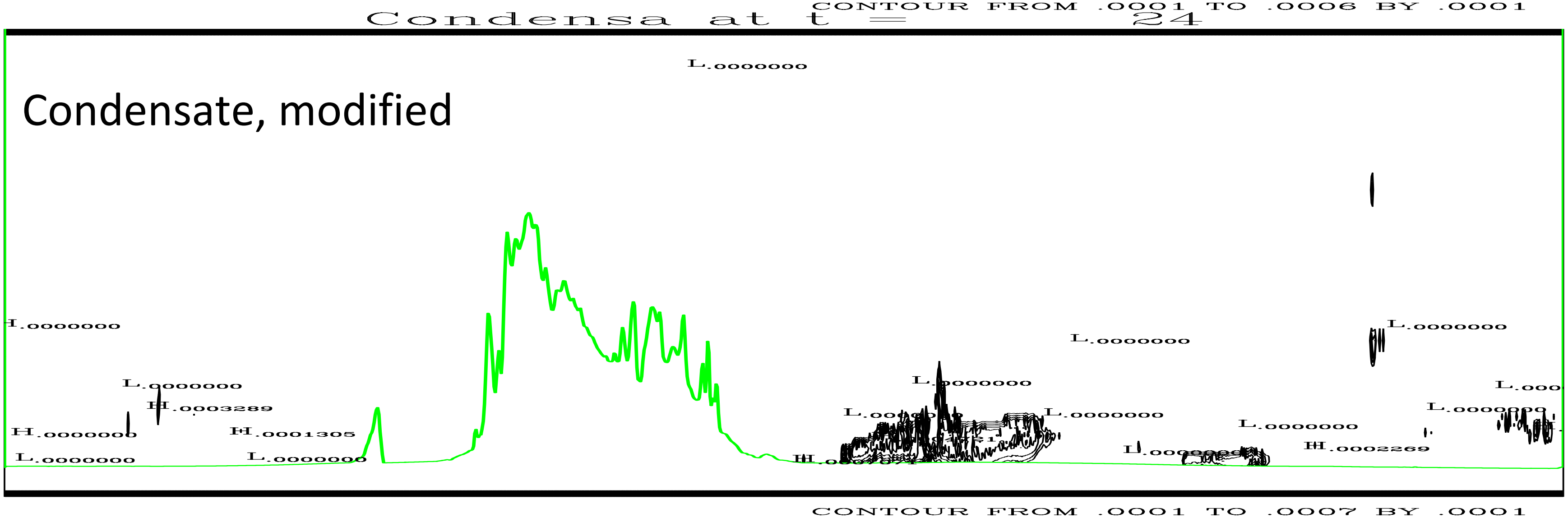
Outstanding Issues

- Modify buoyancy production term in TKE Eq.
- If:
  - LCL within the layer
  - Stable stratification
  - Potential instability
  - Enough TKE

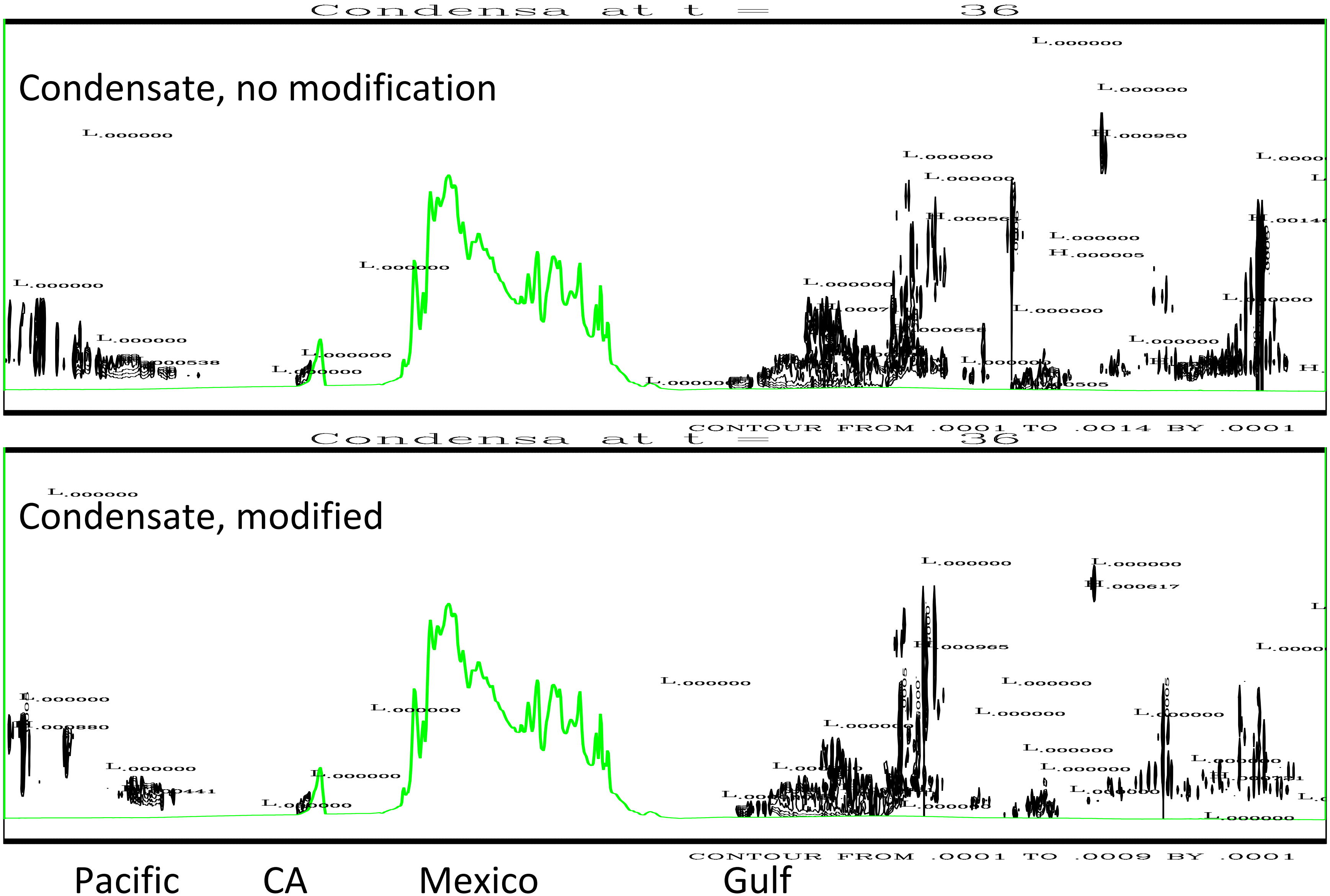


$$P_b = -\beta g K_H \left(\frac{\partial \Theta_v}{\partial z} + \frac{\partial \Theta_e}{\partial z} \right)$$





Pacific CA Mexico Gulf

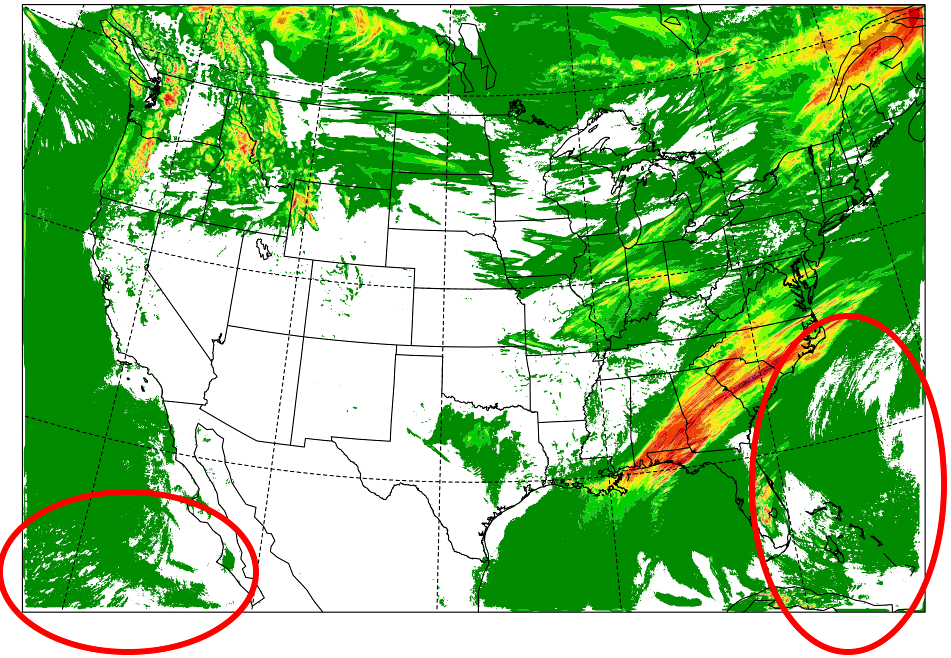

Condensa at t = 36
Condensate, no modification
CONTOUR FROM .0001 TO .0014 BY .0001
Condensa at t = 36
Condensate, modified
CONTOUR FROM .0001 TO .0009 BY .0001
Pacific
CA
Mexico
Gulf

Outstanding Issues

No modification

3. 5.2010.   0 UTC + 00036

Acummulated Precipitation

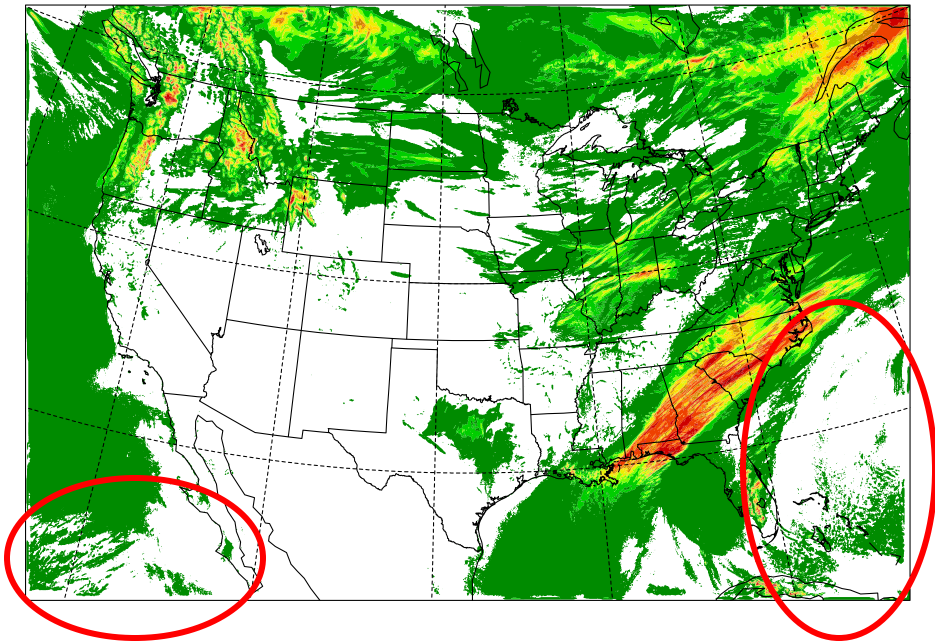


minimum= .9800E+03 maximum= .1032E+04 interval= .4000E+01

Modified

3. 5.2010.   0 UTC + 00036

Acummulated Precipitation



minimum= .9800E+03 maximum= .1032E+04 interval= .4000E+01

24-hour accumulated precipitation

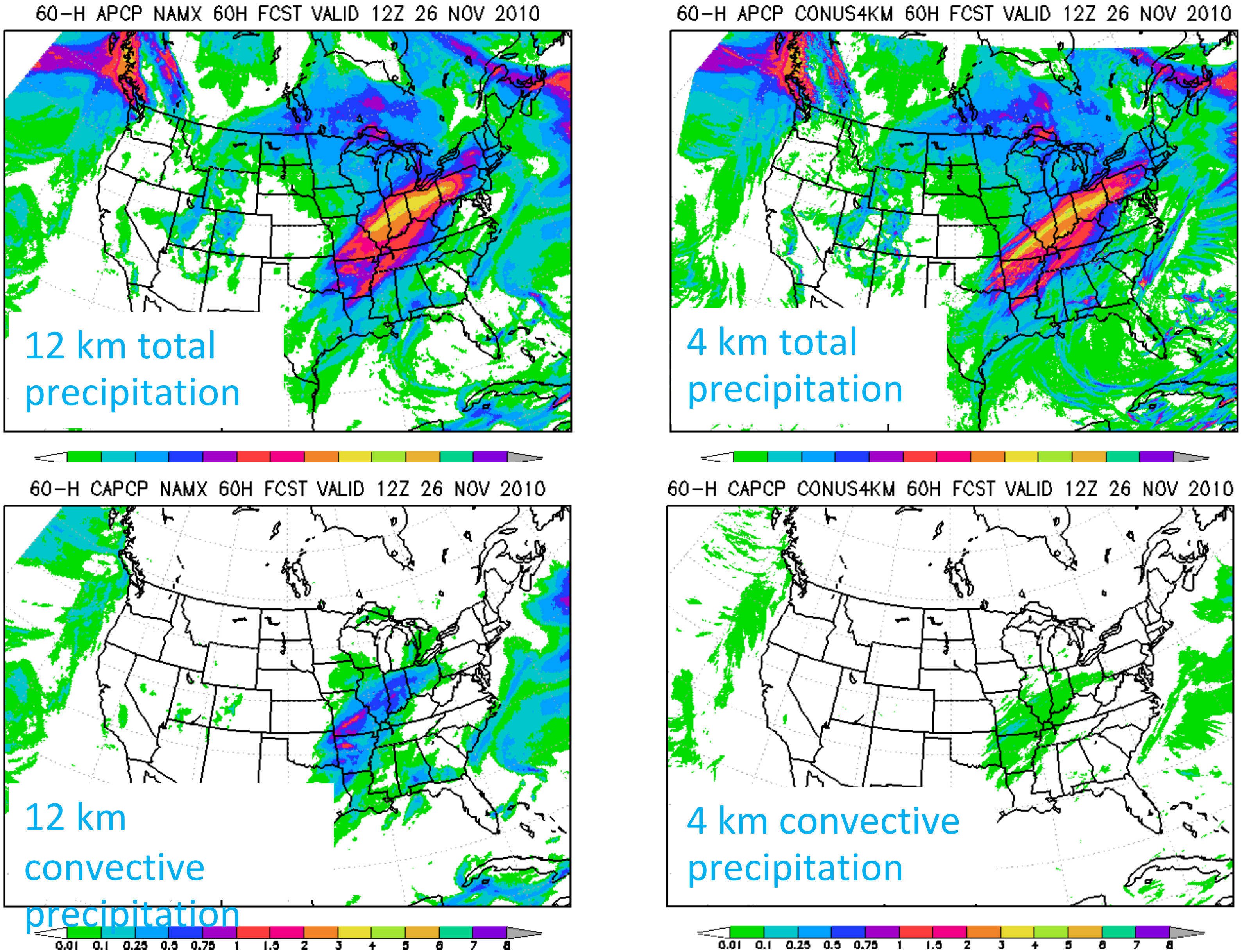
Acts in right direction

Outstanding Issues

- No convergence of parameterization schemes with resolution (e.g. Arakawa et al. 2011)
- Conceptual problem with mass flux convection schemes, fractional convective cloud coverage tends to unity as resolution increases, no “environment"
- Betts-Miller-Janjic (BMJ) deep convection
  - Betts (1986), Betts & Miller (1986) temperature profiles
  - Janjic (1994)
    - Regime dependent moisture profiles and relaxation time
    - With assumed “minimum microphysics”, moist adiabat asymptote
    - No convergence issues

Outstanding Issues

- Tests with “convection allowing” 4km resolution
  - Much better QPF bias
  - Preserved precipitation timing
  - Preserved fine structure
  - Improved surface and upper-air scores


60-H APCP NAMX 60H FCST VALID 12Z 26 NOV 2010
12 km total precipitation
60-H APCP CONUS4KM 60H FCST VALID 12Z 26 NOV 2010
4 km total precipitation
60-H CAPCP NAMX 60H FCST VALID 12Z 26 NOV 2010
12 km convective precipitation
0.01 0.1 0.25 0.5 0.75 1 1.5 2 3 4 5 6 7 8
60-H CAPCP CONUS4KM 60H FCST VALID 12Z 26 NOV 2010
4 km convective precipitation
0.01 0.1 0.25 0.5 0.75 1 1.5 2 3 4 5 6 7 8

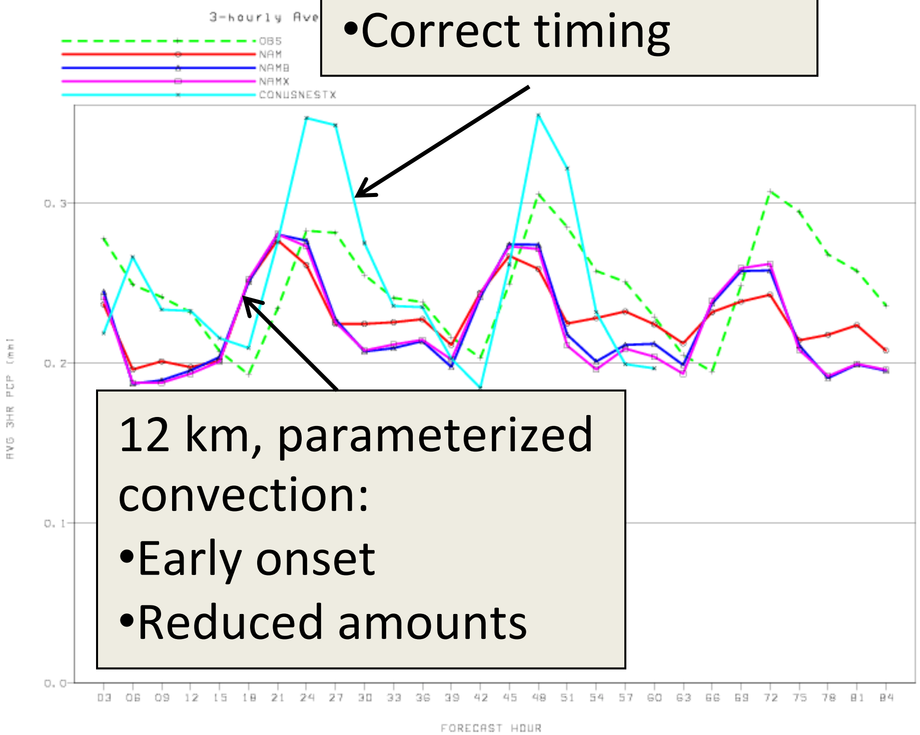
Courtesy Ying Lin

NAM NAMB NAMX, CONUSNESTX 3hr Precipitation

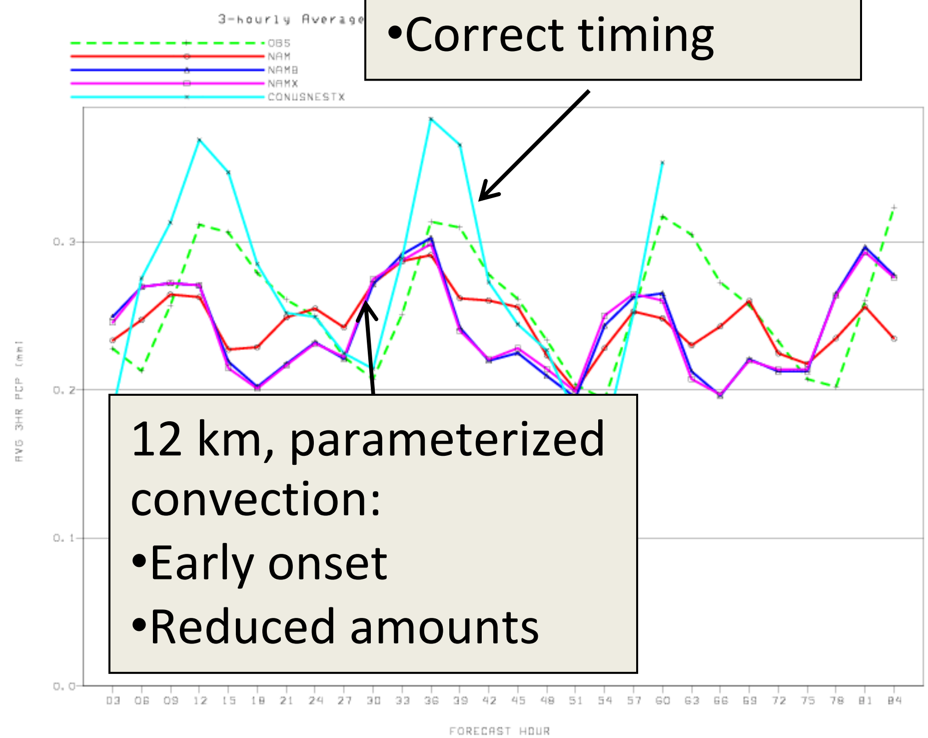
Stage II

4 km, parameterized convection:
- Correct timing

12 km, parameterized convection:
- Early onset
- Reduced amounts



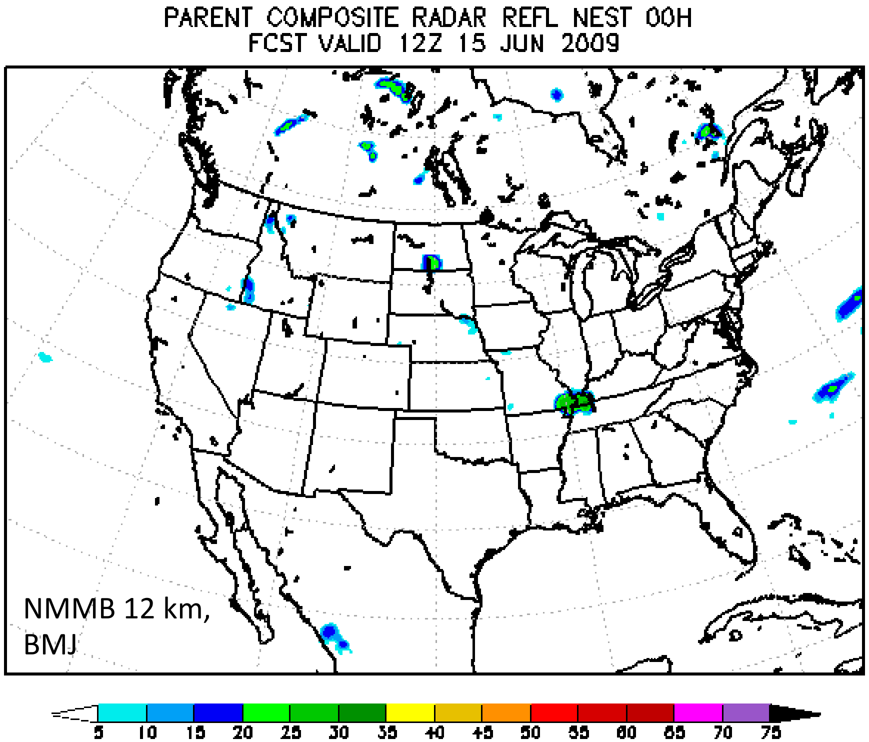
00Z cycles

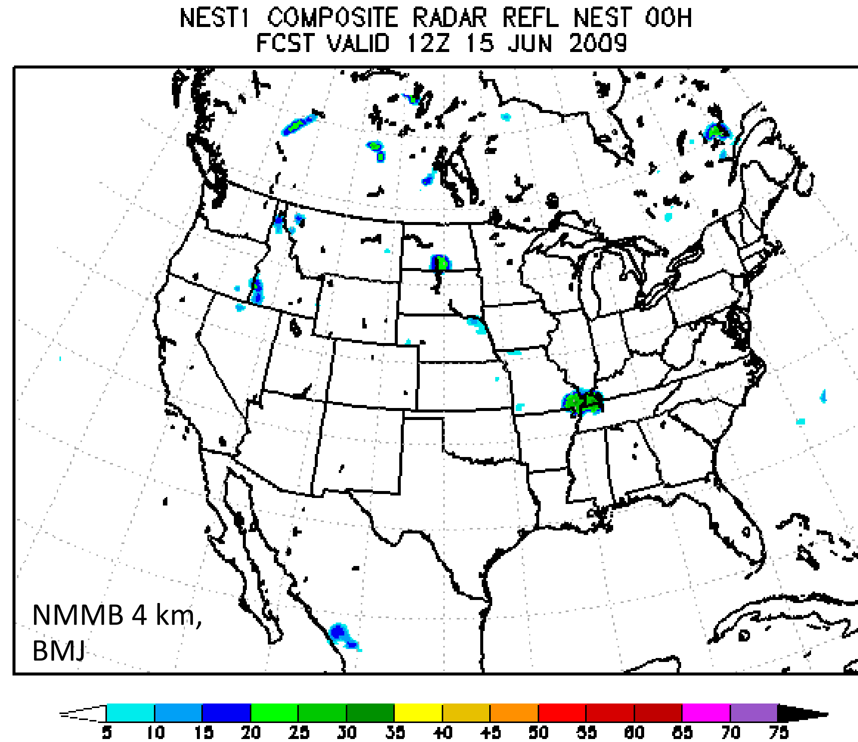


12Z cycles

(CONUSNESTX forecast goes to 60h; the other models go to 84h)

Tests and graphics courtesy of Ferrier





Granular Structure Preserved (loop)

Summary and Conclusions

- Global NMMB shows good results in medium range forecasting
- Global NMMB promising as a global ensemble member
- Operational implementation of the regional NMMB at NCEP in the NAM slot and for nested runs planned for later this year
- Extended MYJ turbulence scheme promising in handling shallow cloud topped marine BLs
- BMJ promising at single digit, “convection allowing” resolutions
- NMMB satisfies requirements for regional climate research set up by SEEVCCC