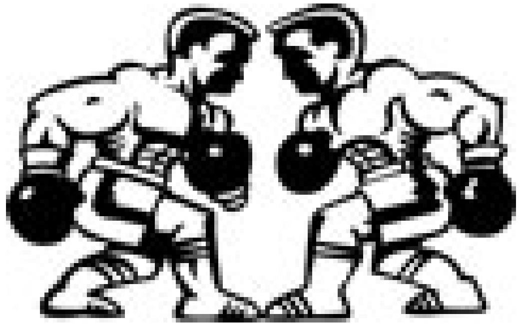
The DTC
Winter Forecast Experiment (DWFE):

Analysis of WRF ARW and NMM

William Skamarock
(*NCAR/MMM*)

Dave Dempsey
(*San Francisco State University; DTC Visitor*)



The DTC
Winter Forecast Experiment (DWFE):

Kinetic Energy Spectra Analysis

William Skamarock
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- Bob Gall (*Director, DTC/NCAR*)

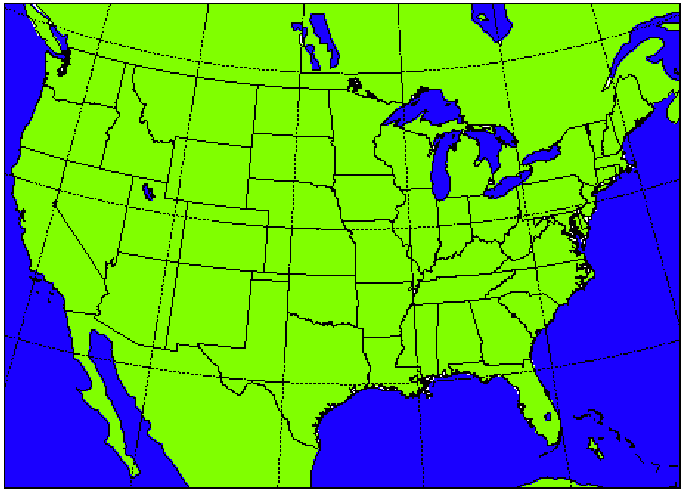
Outline:

- DTC Winter Field Experiment (DWFE)
- Motivating observations
  - mountain waves
- Kinetic energy spectra
  - background
  - ARW and NMM results
  - **sensitivity study: NMM spectra and model configuration**

- Conclusions and Further Work

DTC Winter Forecast Experiment
Jan 15 - March 31, 2005

ConUS Domain

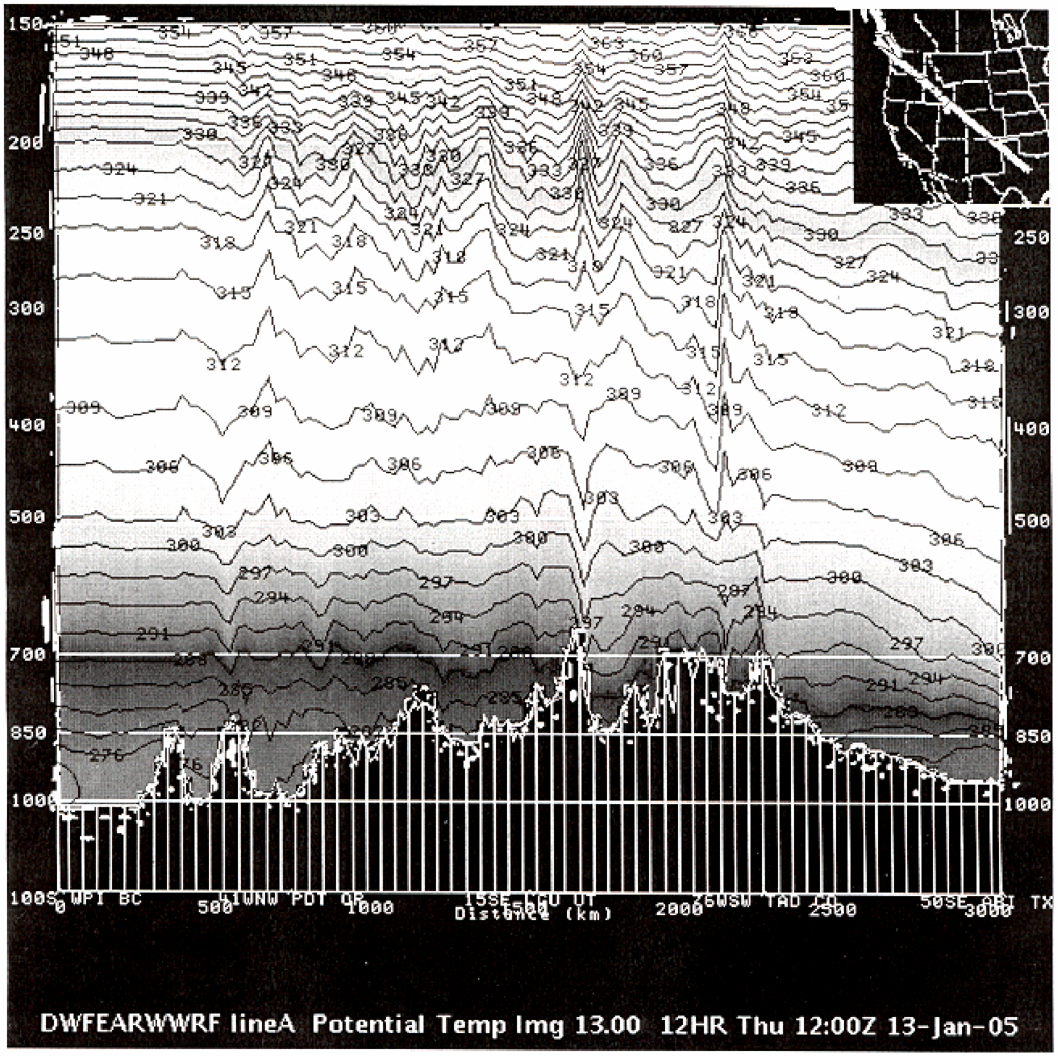


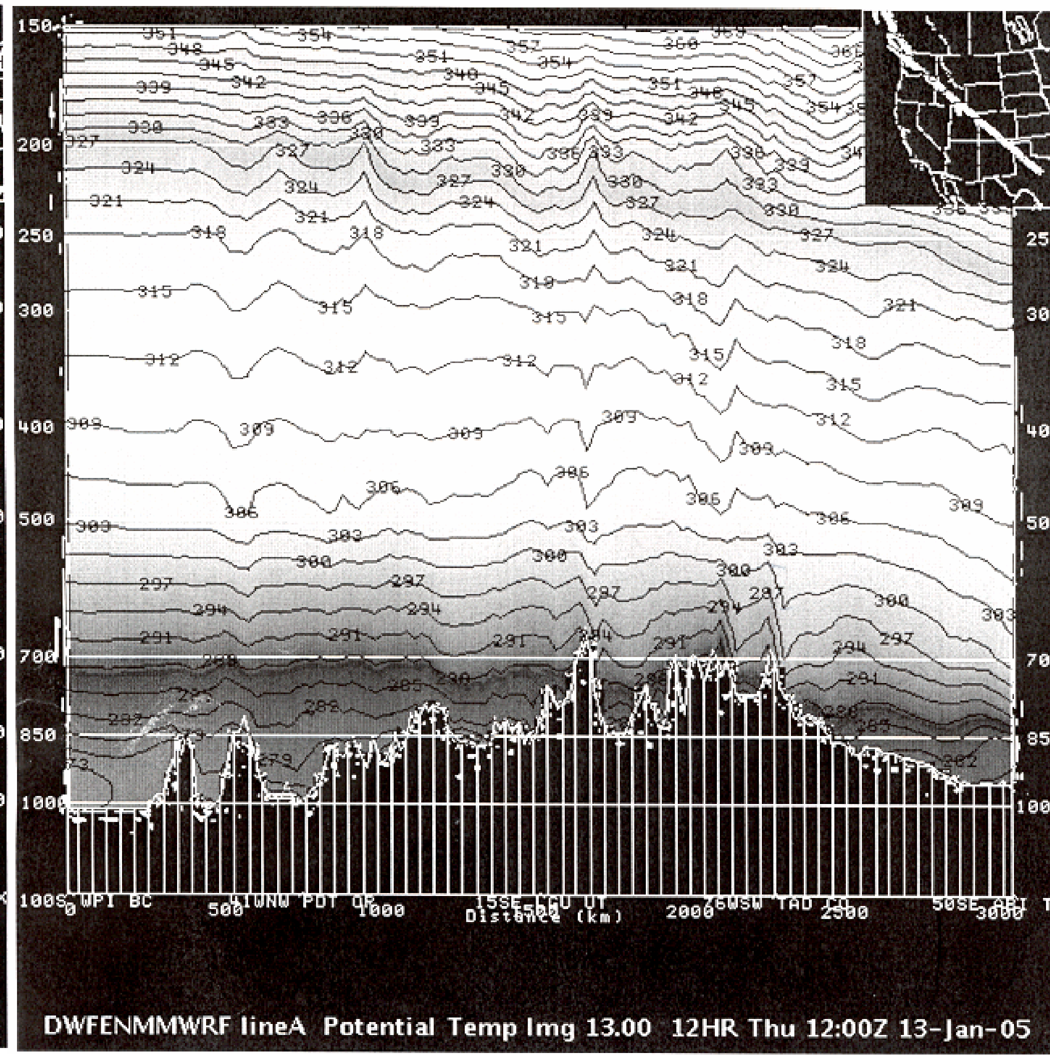
- Two versions of WRF:
  - Two different dynamical cores (NMM & ARW)
  - Two different physics packages (NCEP & NCAR)
- 5 km resolution; 37 levels
- Initial and boundary conditions from Eta212 (40 km)
- 00Z initialization, daily 48-hour forecasts
- Explicit convection (no convective parameterization)

Mountain Waves

Potential Temperature Cross Sections
(12 hr forecasts valid 12Z Jan 13, 2005)

ARW **NMM**





Coming Up Next:

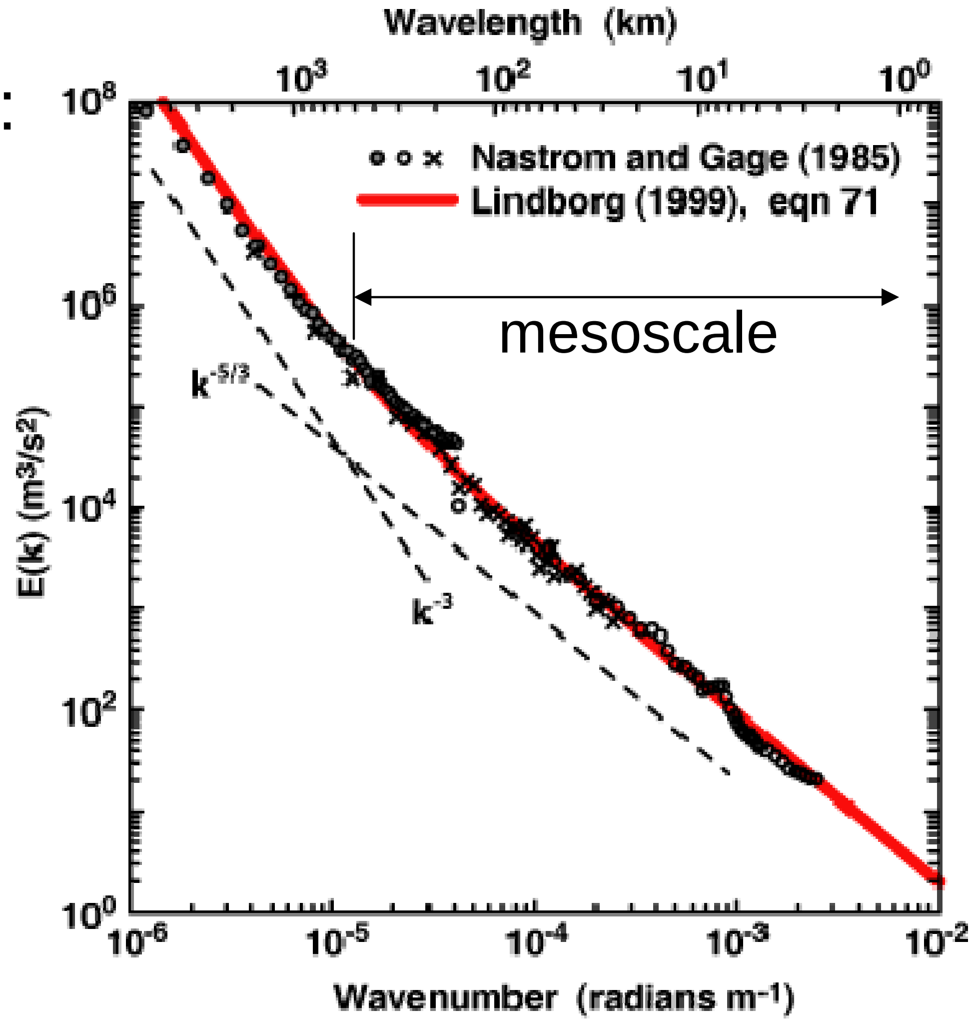
- DTC Winter Field Experiment (DWFE)
- Motivating observations
  - mountain waves
- Kinetic energy spectra
  - background
  - ARW and NMM results
  - **sensitivity study: NMM spectra and model configuration**

- Conclusions and Further Work

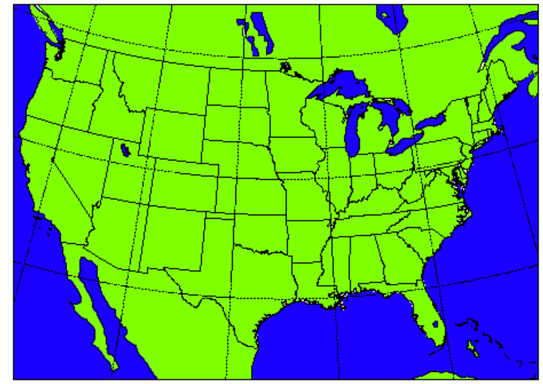
Kinetic Energy Spectra

- Nastrom and Gage (1985): Spectrum computed from GASP observations (commercial aircraft)

- Lindborg (1999): Functional fit to MOZAIC observations (aircraft)



Computing model spectra



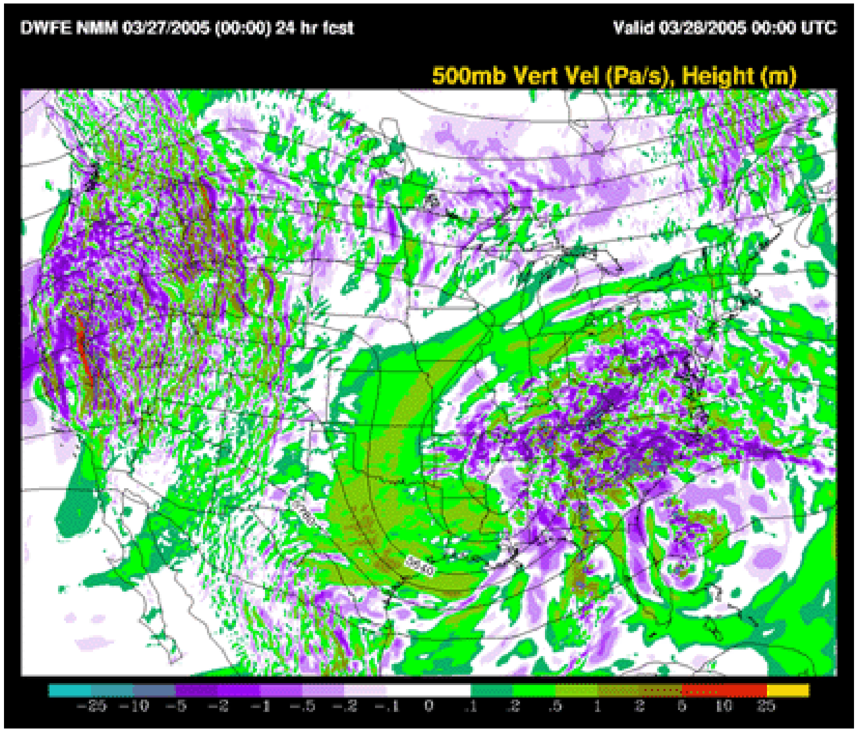
- Interpolate u, v to pressure levels
- Detrend u, v along each east/west row of grid points
- Compute discrete Fourier transform of kinetic energy along each E/W row
- Average the spectra over rows and pressure layer

Questions

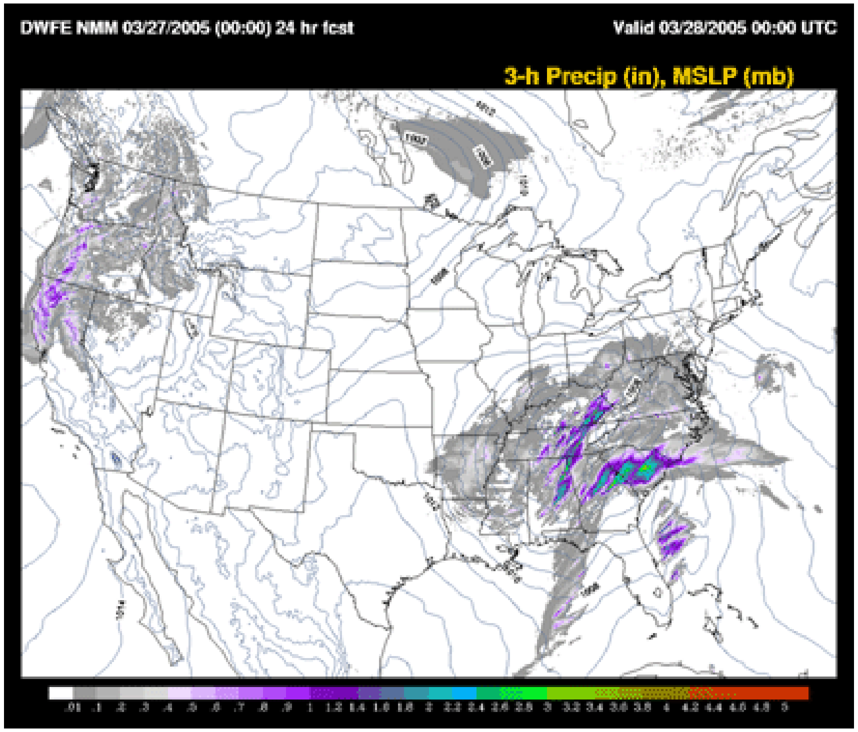
- Do DWFE model spectra resemble the Nastrom & Gage (1985) observed spectrum?
- Should they?
- If they should, and if they do, do they for the right (physical) reasons? And how can we tell?

DWFE Case: 3/27/05

500 mb Height & ω (24 hr fcst)

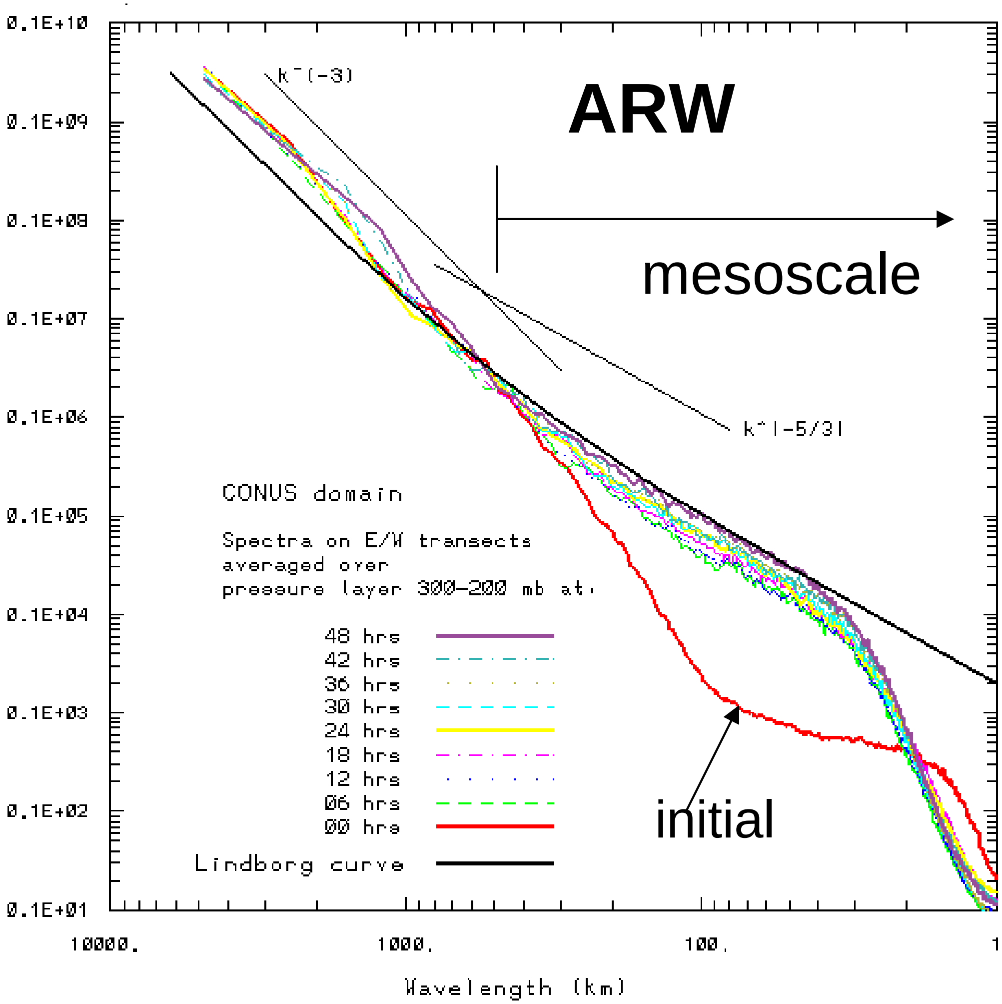


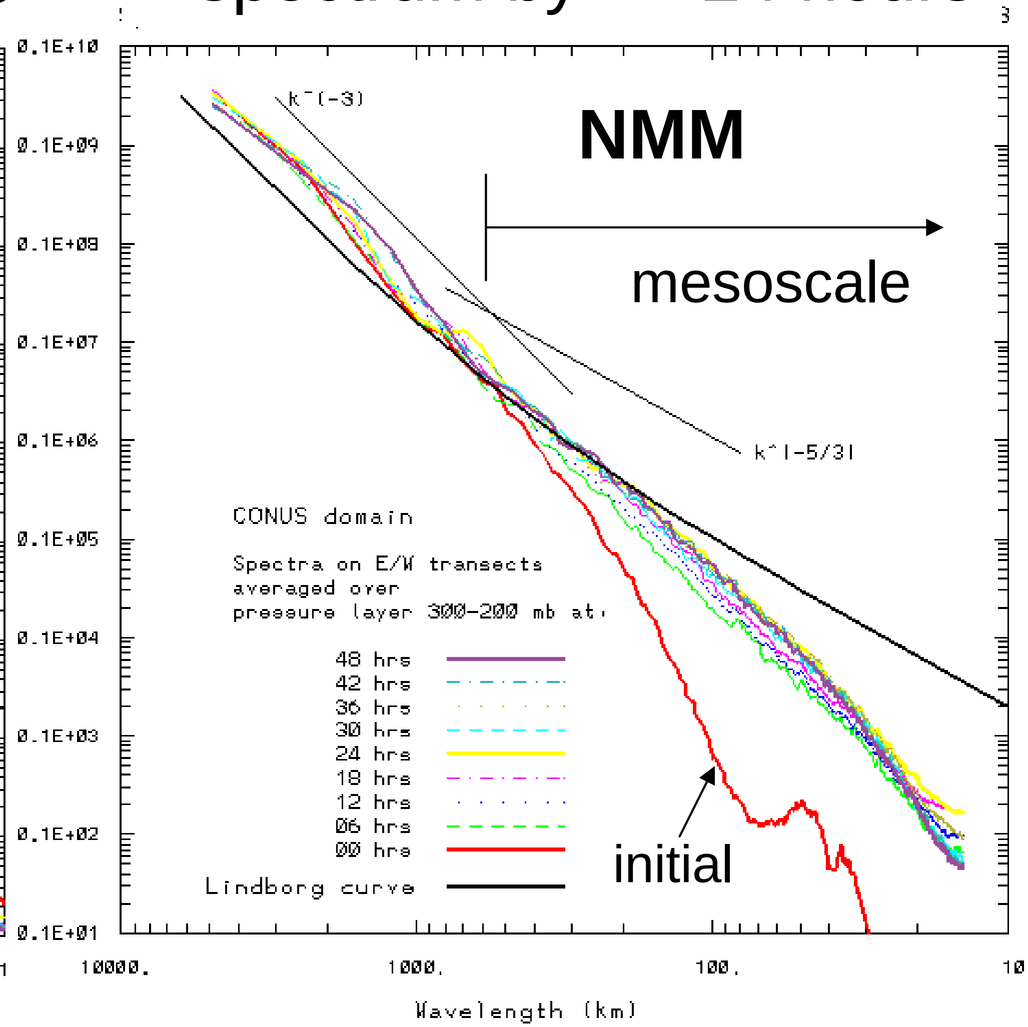
MSL Pressure & 3-hr Precip (24 hr fcst)



Spin-up of Kinetic Energy Spectra

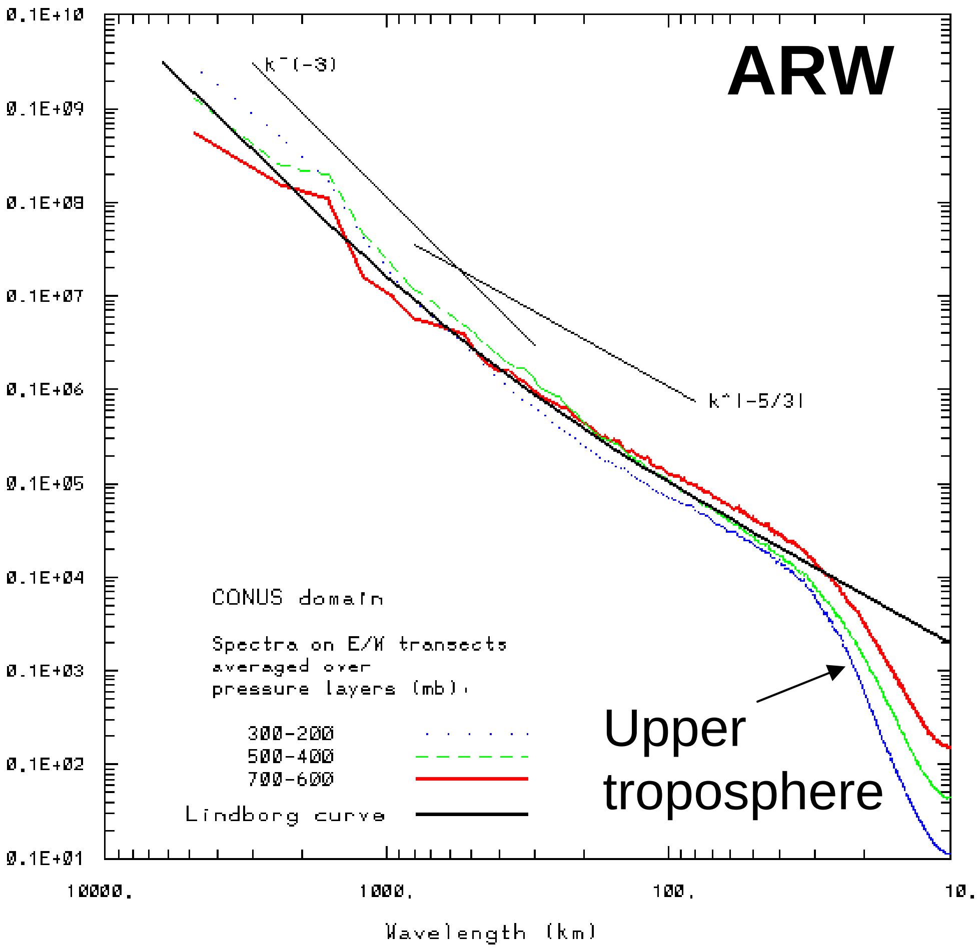
- Spectra in 300-200 mb layer
- 6 hour intervals, 00 to 48 hrs
- Note: get mature spectrum by ~< 24 hours

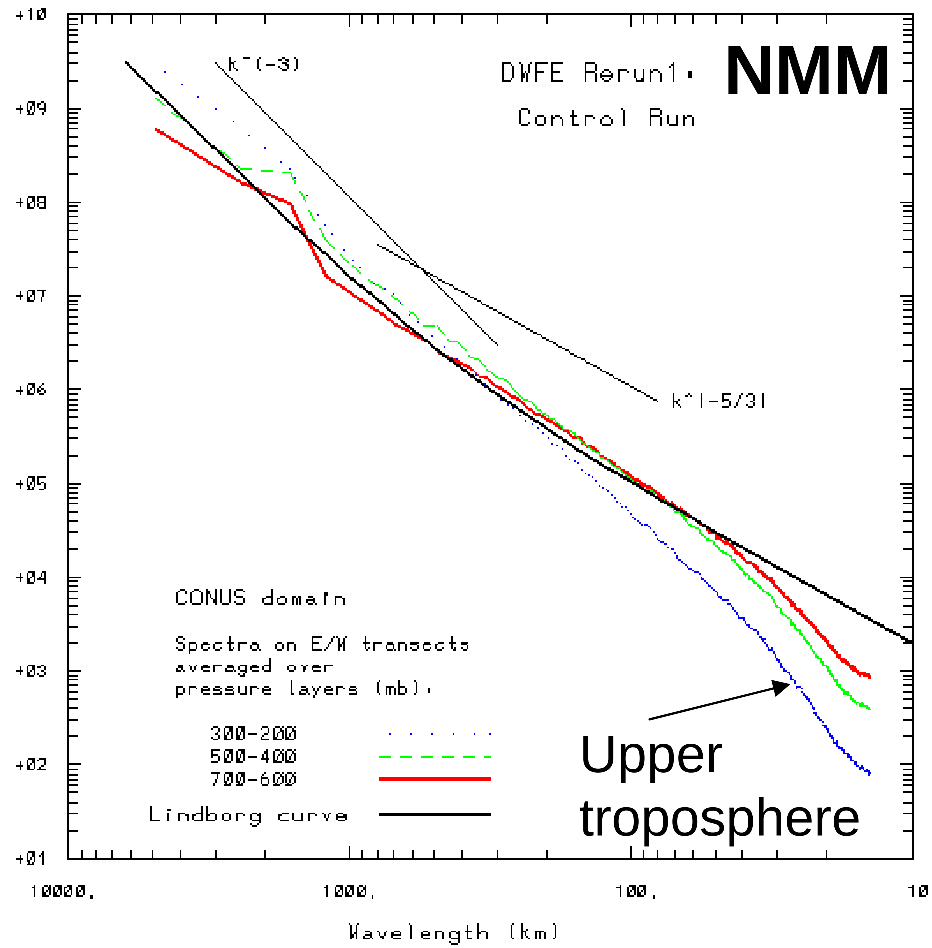




“Mature” Kinetic Energy Spectra

- Average over 24-48 hours; 3 tropospheric layers shown
- Note:
  - NMM: less mesoscale energy aloft
  - NMM: more energy on smallest scales, esp. at lower levels





Questions:

1. Why did NMM spectrum have less energy at mesoscales aloft than observations and ARW, hence lacking transition to $k^{-5/3}$ slope?
2. Why did NMM spectrum have more energy than ARW at smallest scales at low altitudes?

Hypotheses:

- NMM has unsmoothed topography, very low horizontal diffusion, and horizontal-divergence damping

Initial Testing Strategy:

1. Rerun NMM with various bug fixes
2. Rerun with smoothed topography
3. Rerun without horizontal-divergence damping
4. Rerun with more horizontal diffusion (2nd order, 4th order)

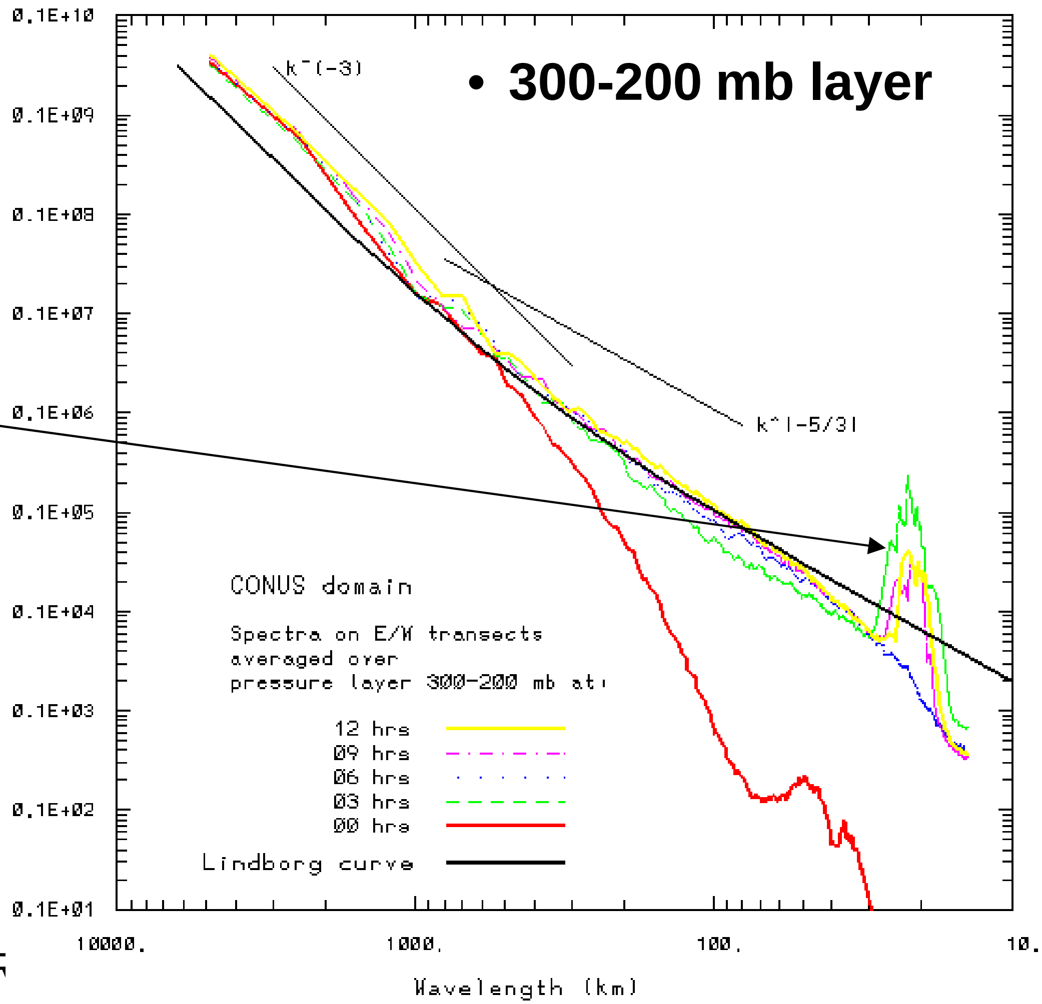
Some results of NMM reruns:

1. Fixing bugs: *little effect on spectra*

2. Smoother terrain: *modest (x 0.5) decrease in energy at small scales*

3. No divergence damping: *Oops! (Results same at all pressure levels.)*

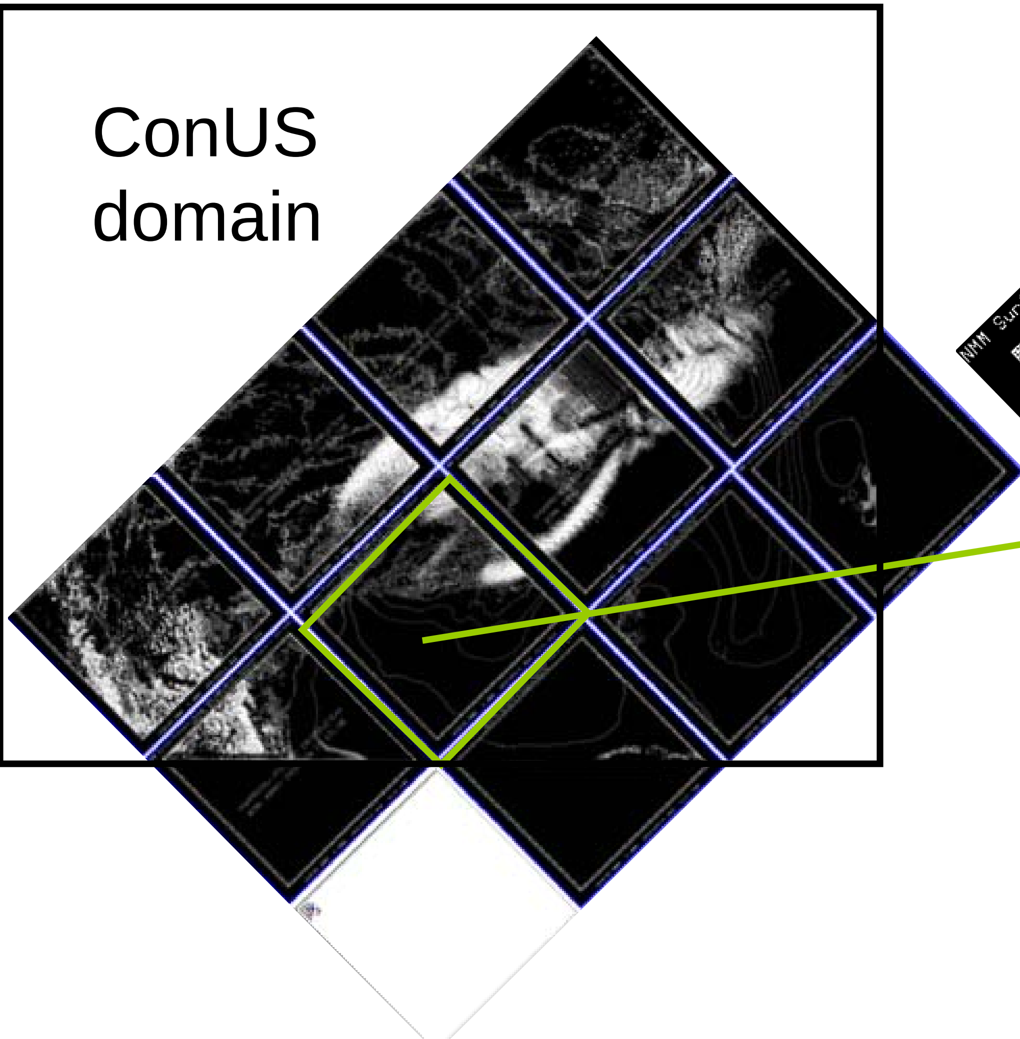
- **Rerun #3: No divergence damping**
- **Forecasts: 00, 03, 06, 09, 12 hrs**

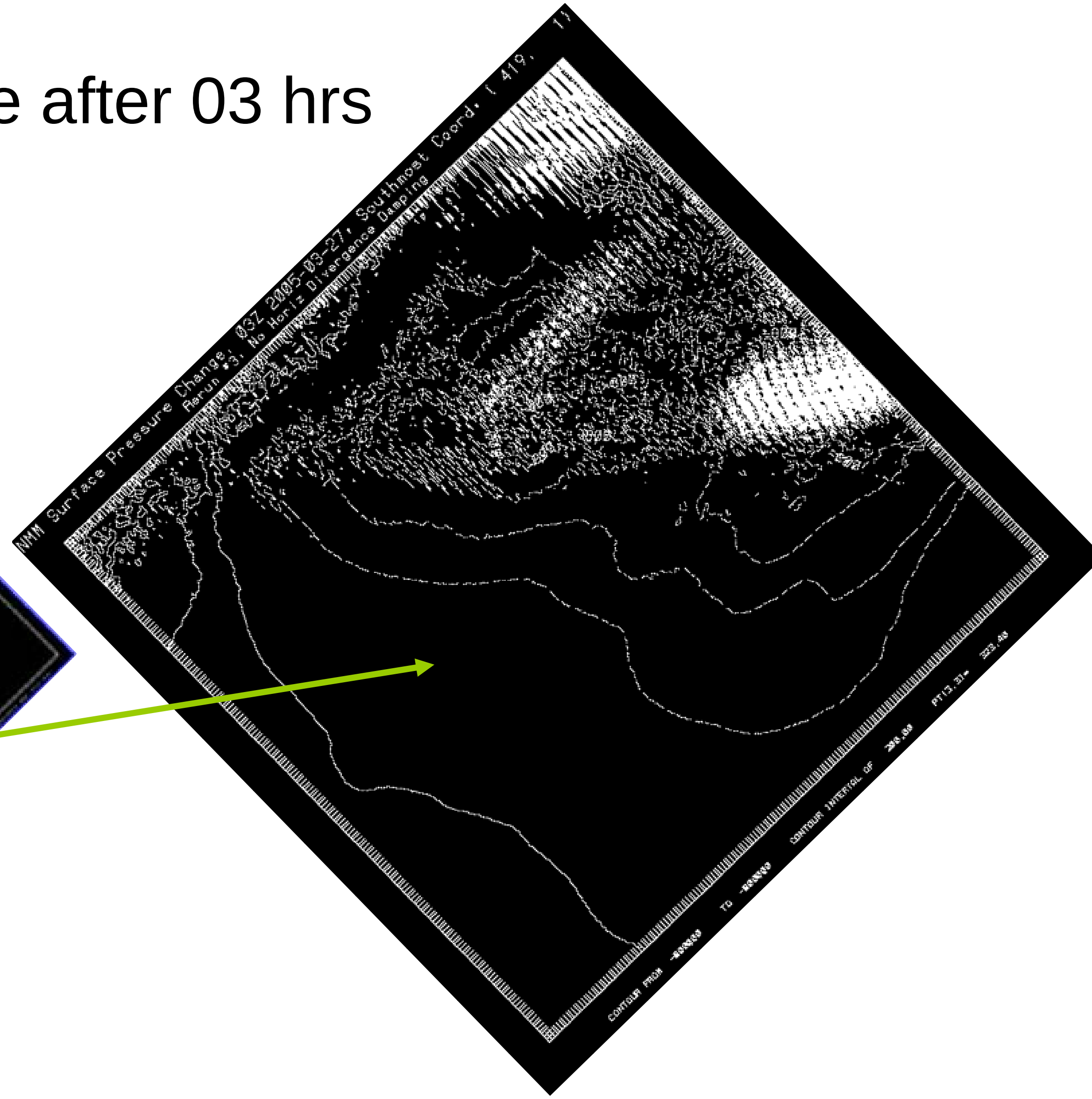


External modes!

Surface pressure change after 03 hrs

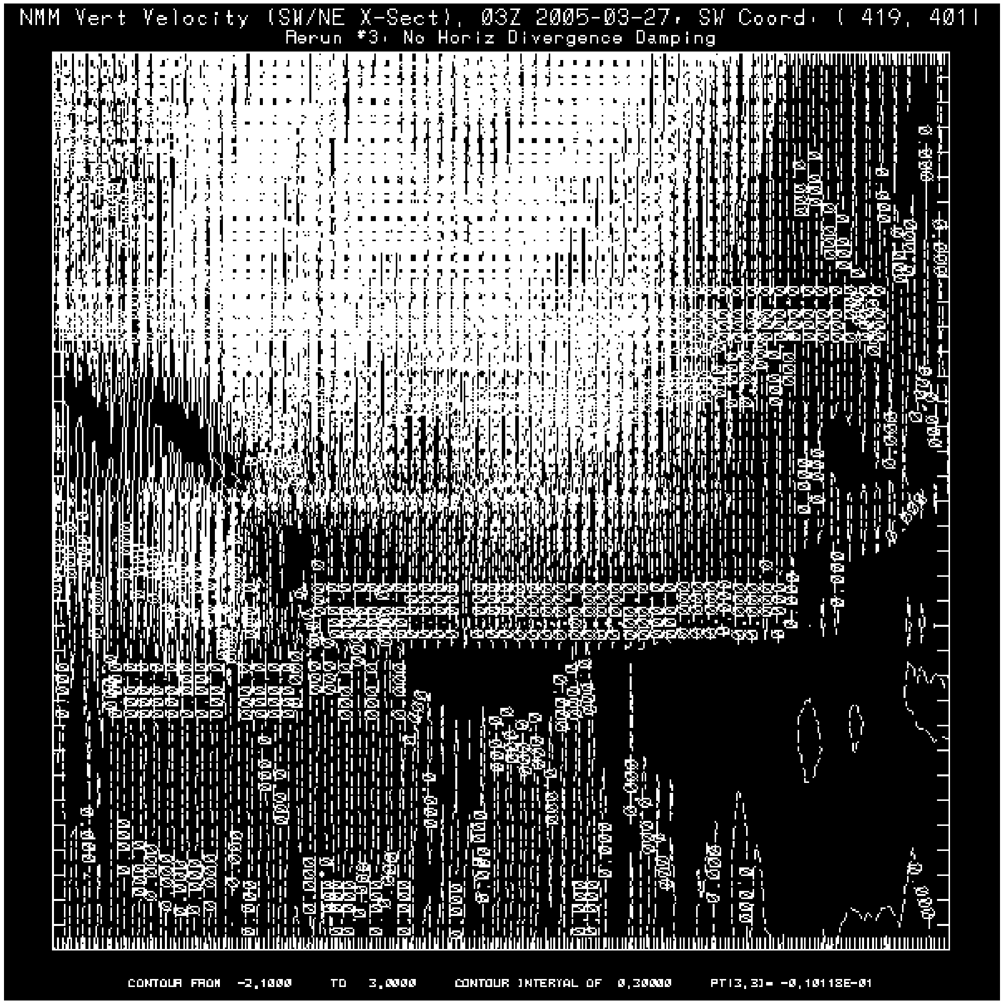
(contour interval = 2 mb)





External modes:
Vertical Velocity Cross Section

- 03 hr forecast



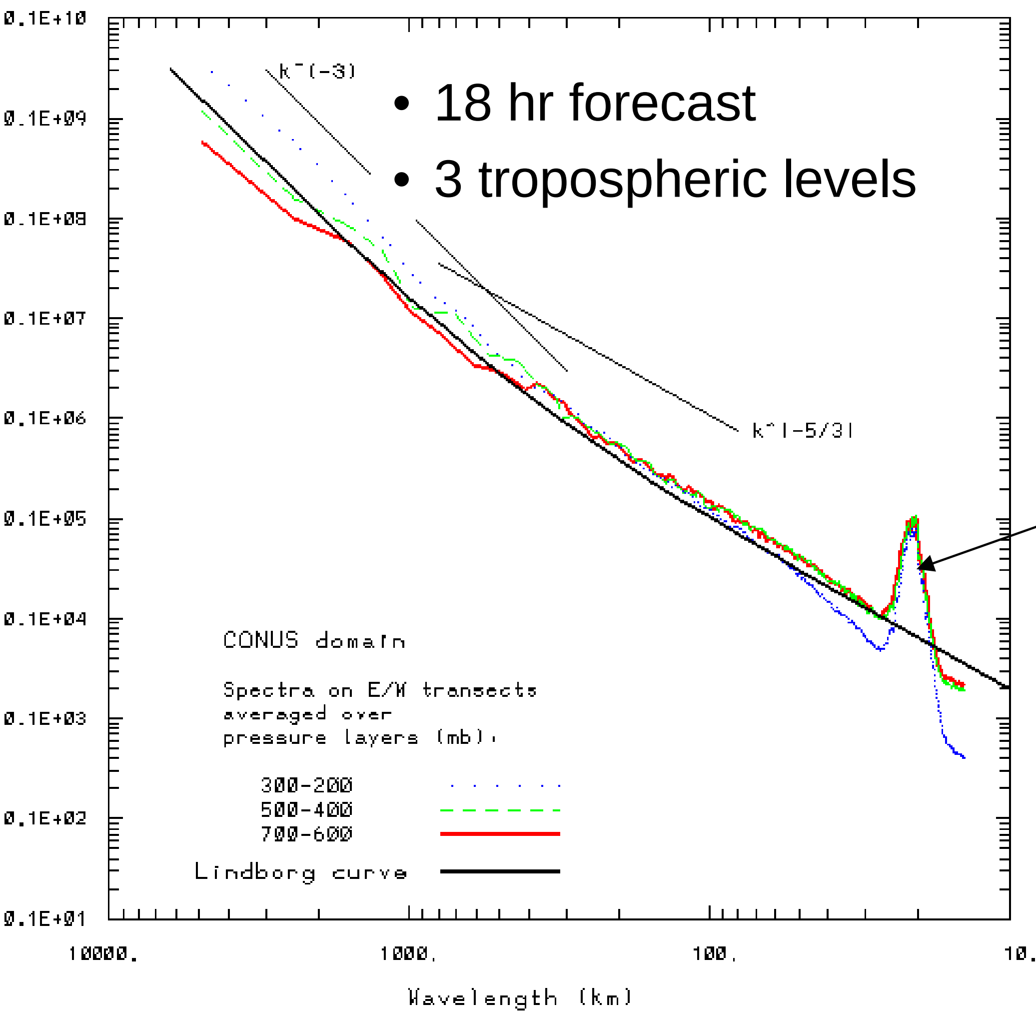
Revised Testing Strategy:

4. Rerun with no horizontal-divergence damping *but add a* ***vertically-integrated horizontal-divergence damper*** *(to damp external modes)*

5. Rerun with more horizontal diffusion (2nd order, then 4th order)

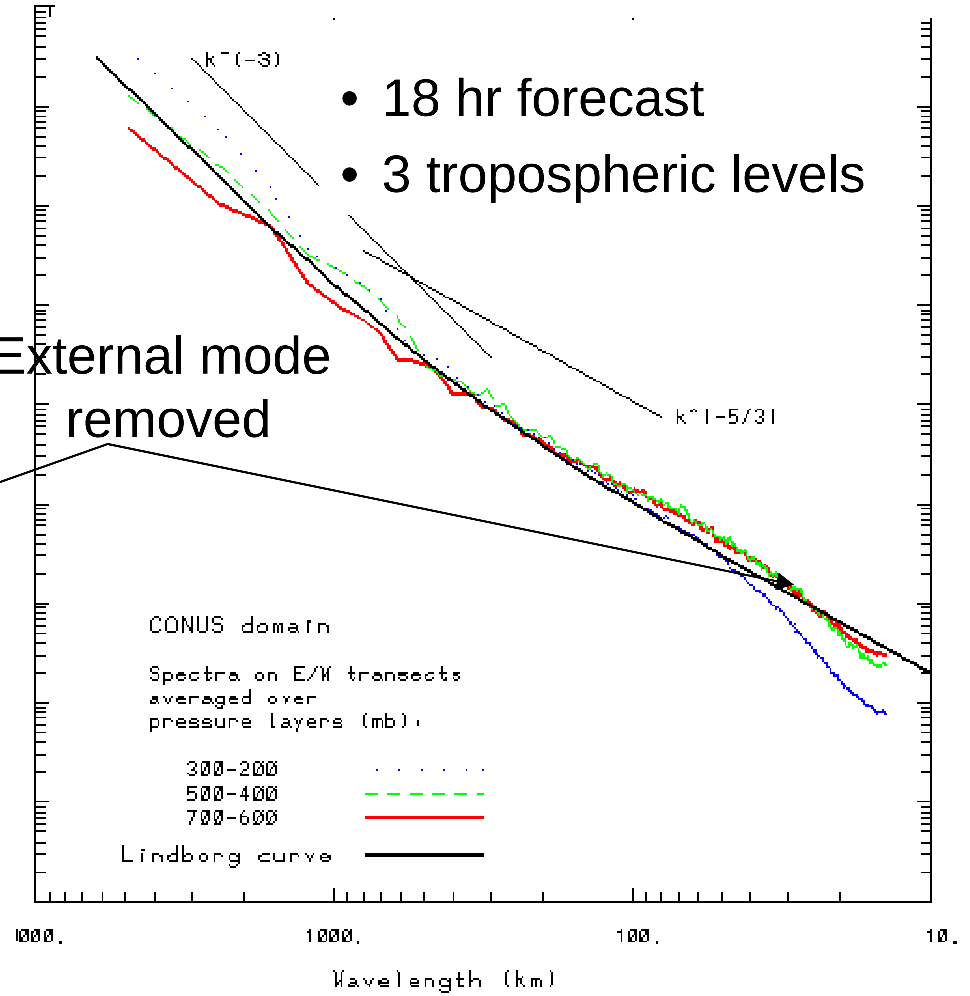
Results:

- **Rerun #3: No divergence damping**
  - 18 hr forecast
  - 3 tropospheric levels



- **Rerun #4: No divergence damping; external-mode damping added**
  - 18 hr forecast
  - 3 tropospheric levels

External mode removed



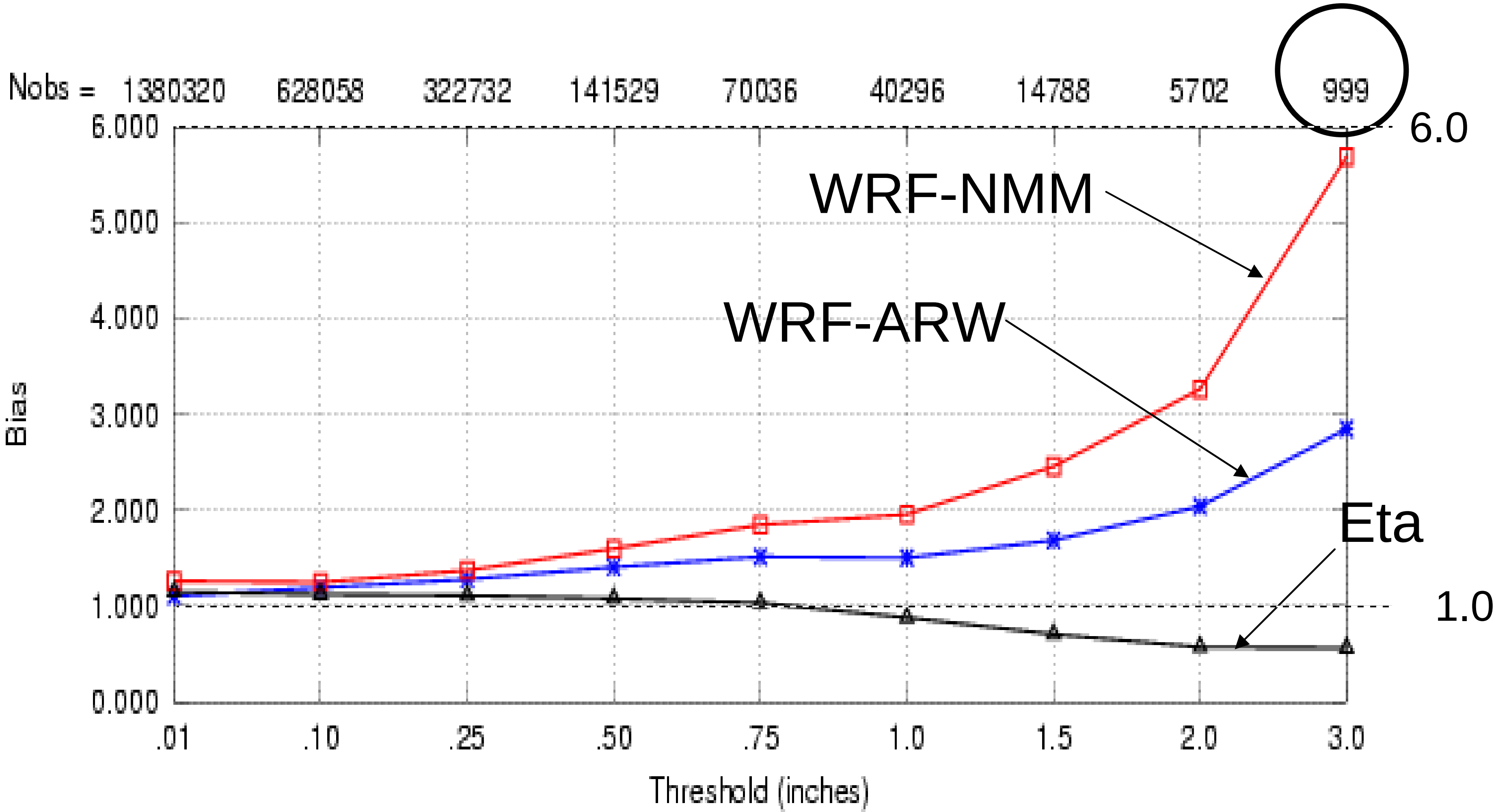
Conclusions

- ARW in DWFE:
  - Kinetic energy spectra similar to Nastrom & Gage (1985) observations at mid-mesoscales (~7Dx) and larger
  - Implicit damping and weak explicit diffusion, plus smoothed topography, reduce small scale energy
  - Arguably desirable (Skamarock and others); or maybe not (Janjic)
- NMM in DWFE:
  - NMM spectra showed less energy at mesoscales than Nastrom & Gage (1985) observations, especially aloft
    - **Can apparently change this by replacing horizontal-divergence damping with sufficient external-mode damping**
  - Spectra show more energy at smallest scales than ARW (but less than observed)
    - smoothing topography reduces small-scale energy somewhat
    - can debate whether need more small-scale damping

Further Work (NMM)

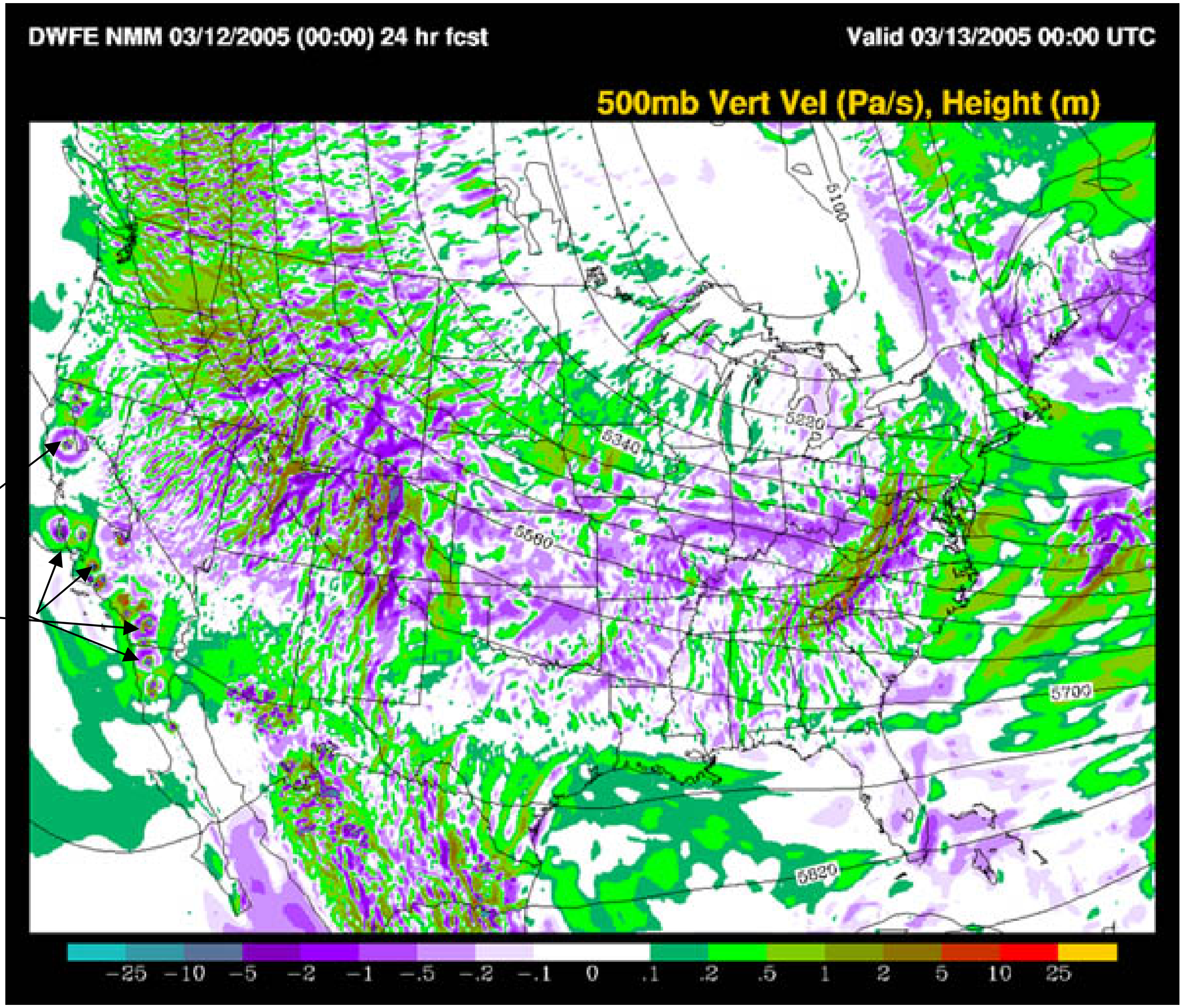
- Fine-tune external-mode damping
- Try 4th-order diffusion to reduce energy selectively on smallest scales
- Evaluate effect of these alternative filters on meteorological fields and traditional verification statistics

24-Hour Precipitation Biases
DWFE: Jan 15-Mar 31 2005

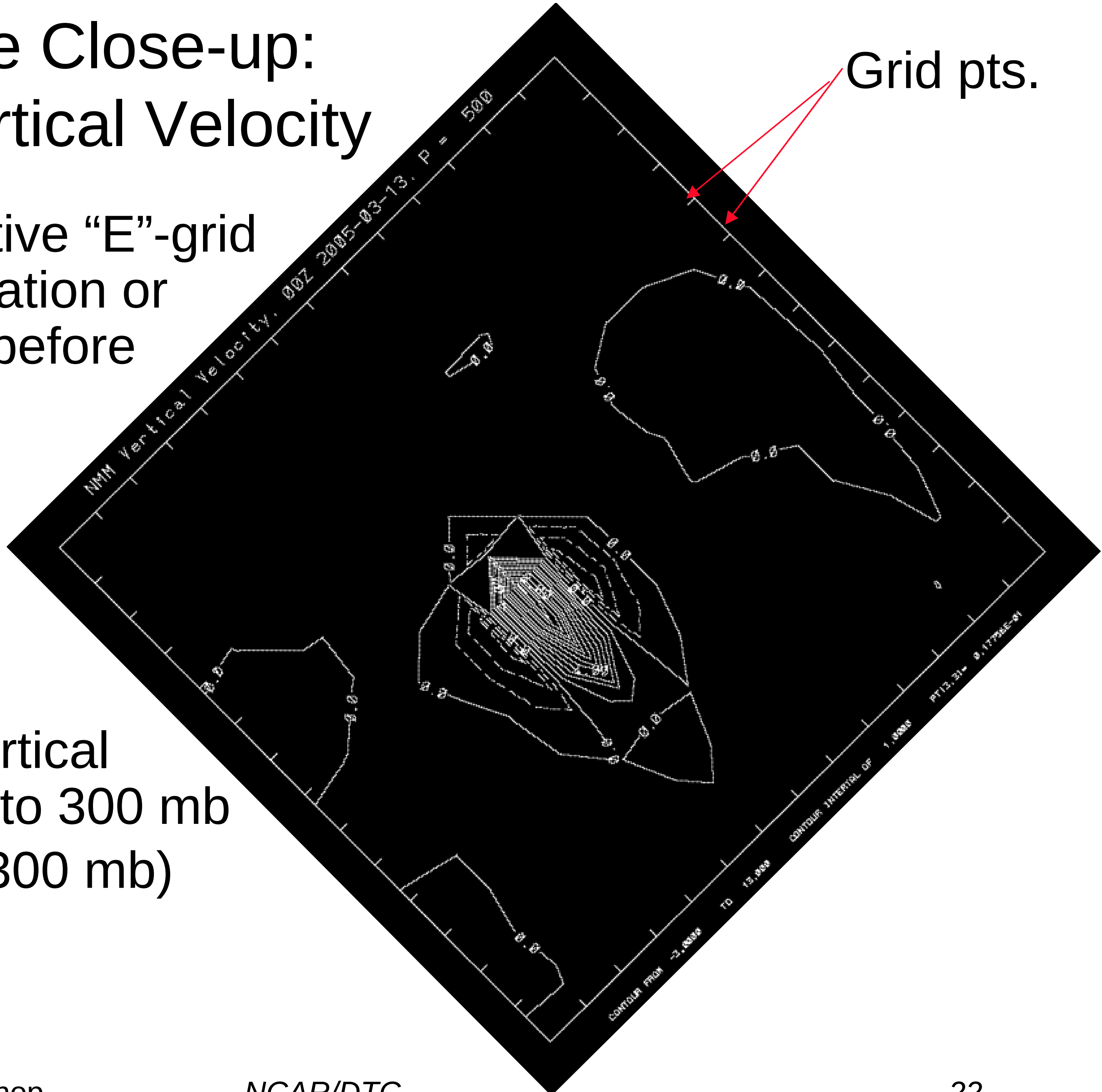


Grid-Point Storms? (NMM)

- 500 mb vertical velocity
- 24 hr forecast
- bull's eye patterns



A Bull's Eye Close-up: 500 mb Vertical Velocity

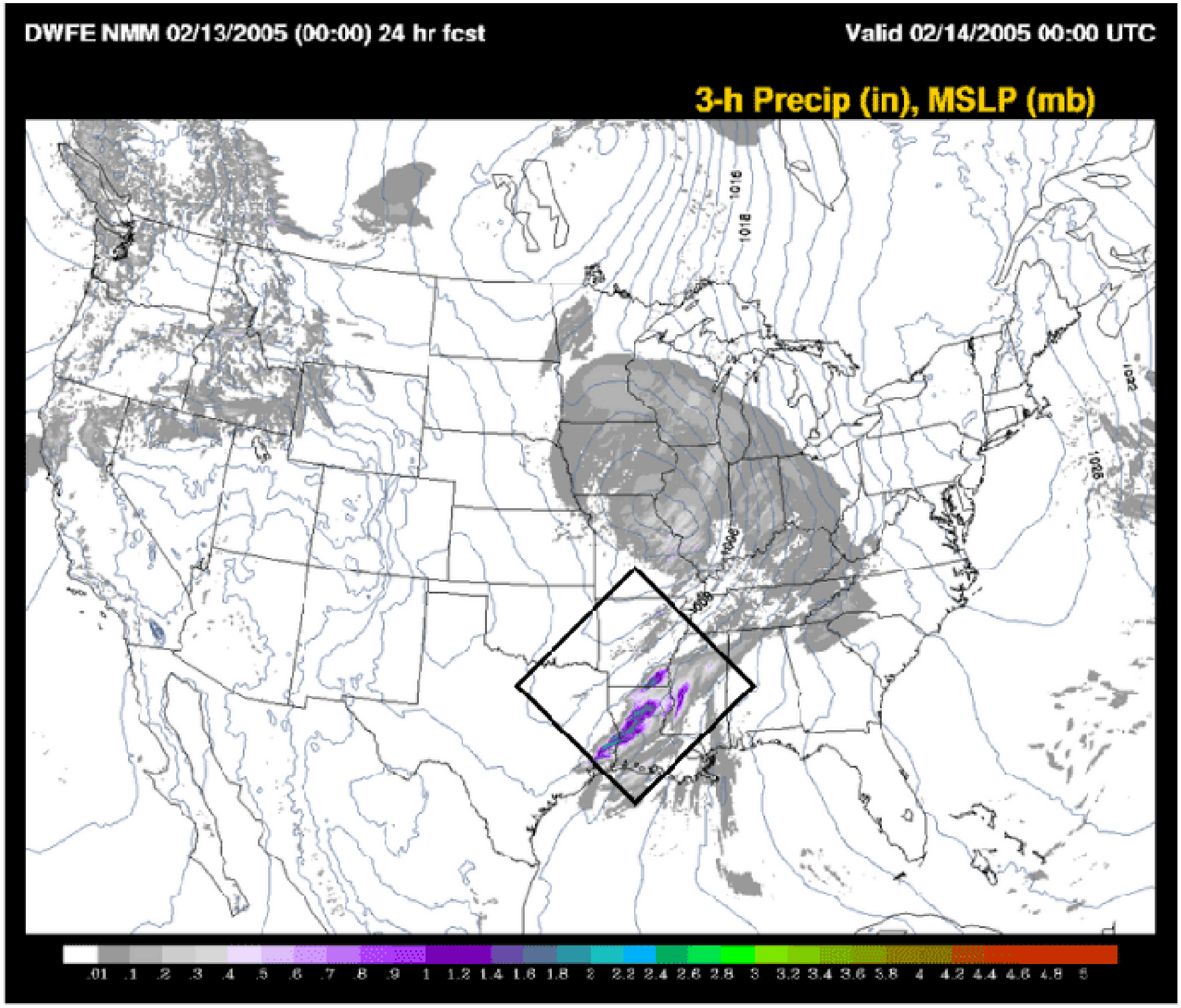


Grid pts.

- Data on native "E"-grid (no interpolation or smoothing before contouring)

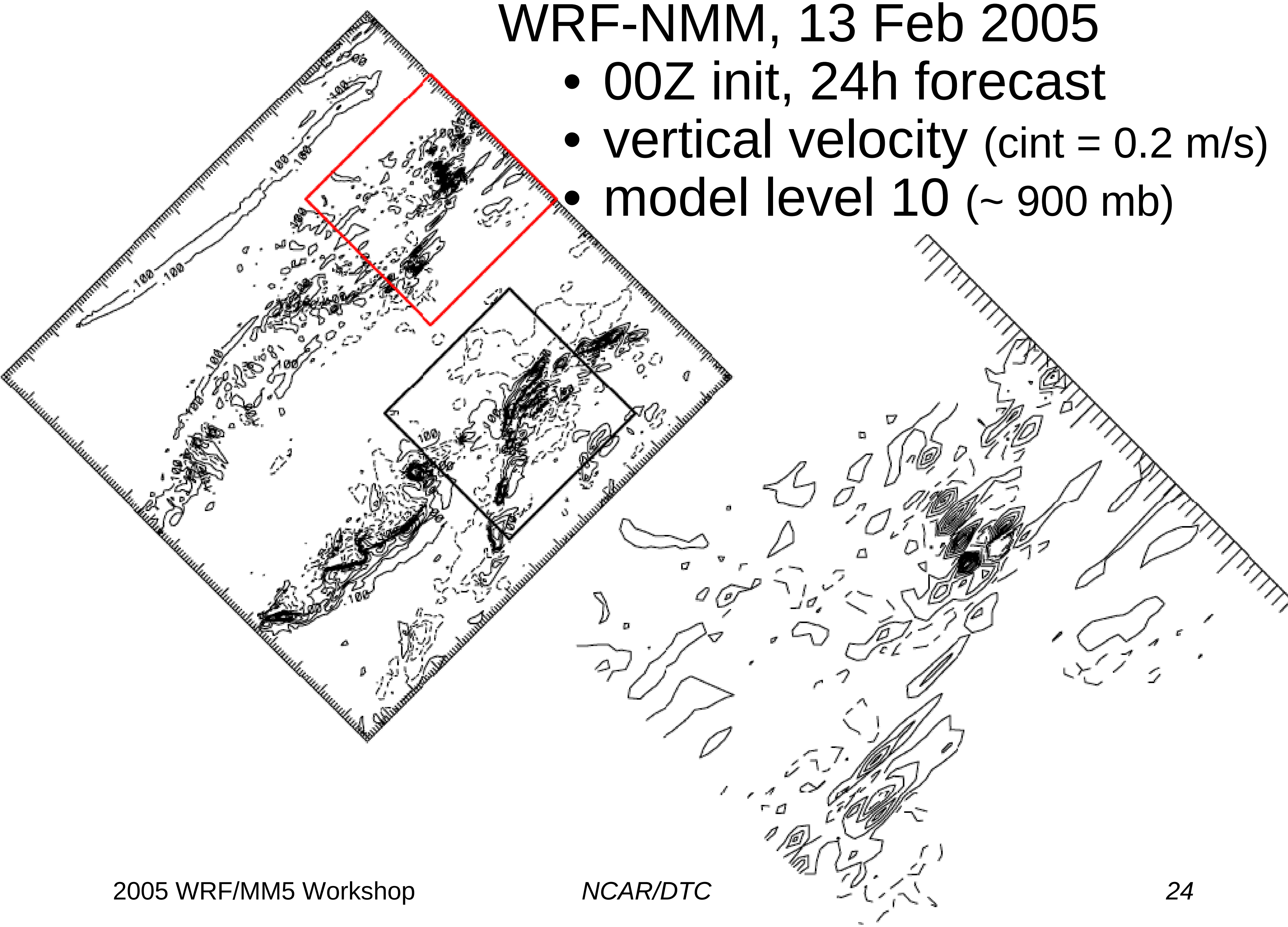
- Depth of vertical motion: sfc to 300 mb (max near 300 mb)

WRF-NMM 24h Forecast (for 00Z 2/15/05)



WRF-NMM, 13 Feb 2005

- 00Z init, 24h forecast
- vertical velocity (cint = 0.2 m/s)
- model level 10 (~ 900 mb)



Further Work (NMM)

- Fine-tune external-mode damping (need a bit more)
- Try 4th-order diffusion to reduce energy selectively on small scales
- Evaluate effect of alternative filtering on meteorological fields and traditional verification statistics