An evaluation of the new hybrid vertical coordinate in the RAP and HRRR

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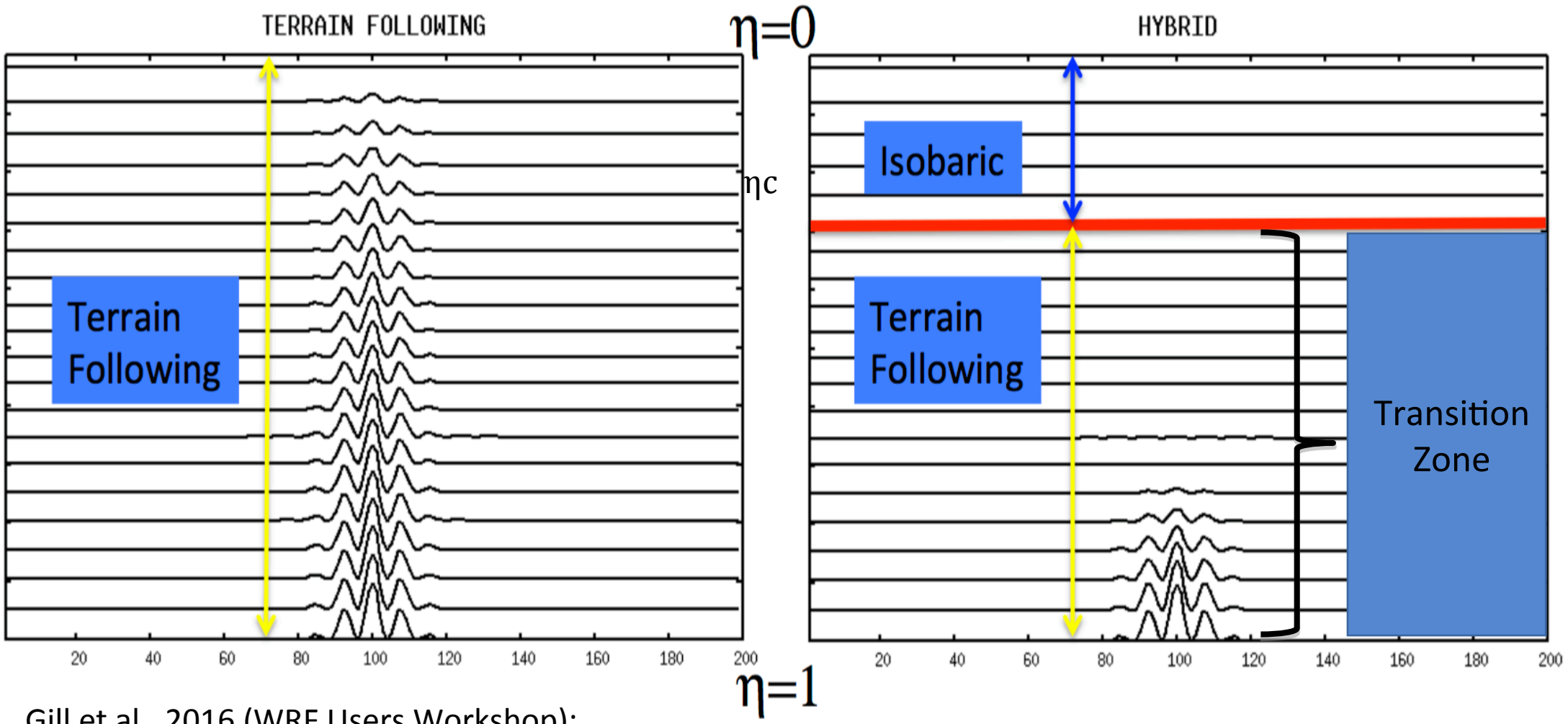
Motivation

- Terrain-following coordinates are known to induce small-scale horizontal and vertical accelerations over areas of steep terrain due to the reflection of topography in model levels
- Introduces error into the model equations and can impact model forecasts, particularly as errors are advected downwind of major mountain ranges
- Operational models such as the RAP and HRRR are impacted by this “noise” and could benefit from an improved vertical coordinate
- Development of a hybrid vertical coordinate to address these issues was undertaken at NCAR (Klemp et al., 2011)

A Collaborative Effort…

- NOAA (OAR) funding provided to DTC for implementation, testing and evaluation within WRF
- NCAR/MMM incorporated hybrid coordinate code into WRF v3.8.1
- GSD and DTC contributed to evaluation in both the RAP and HRRR
- GSD and MMM collaboration was crucial to implementation
- Evaluations of extended retrospective runs and single case studies were conducted

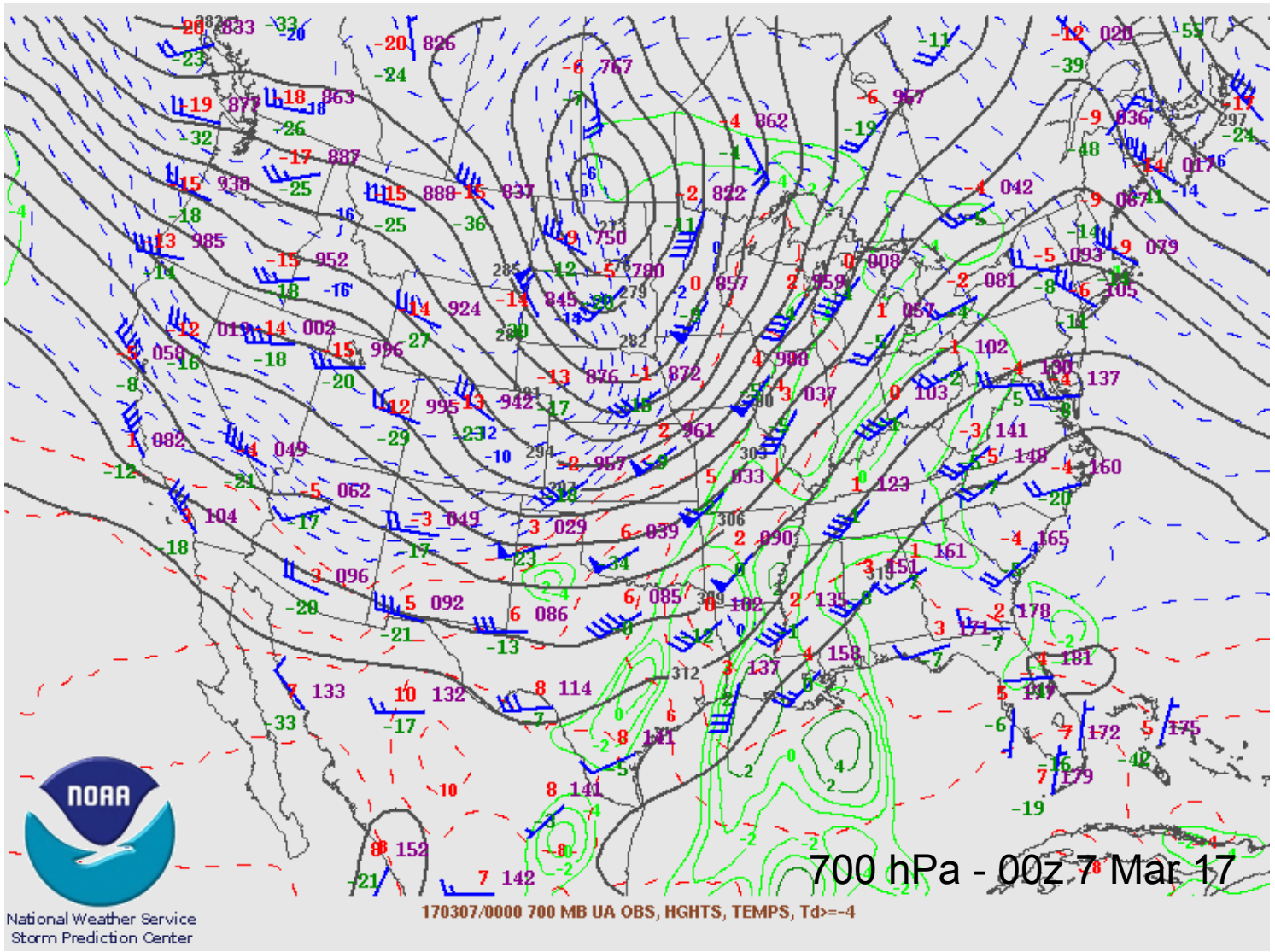
Terrain Following vs. Hybrid Coordinate



Gill et al., 2016 (WRF Users Workshop):
http://www2.mmm.ucar.edu/wrf/users/workshops/WS2016/oral_presentations/1.4.pdf

Testing and Evaluation

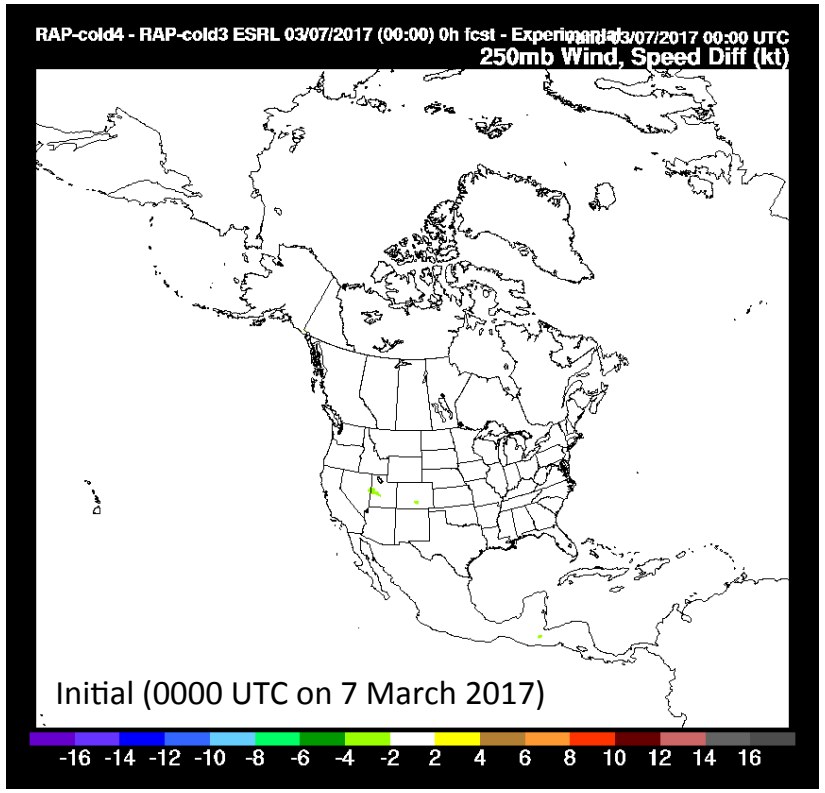
- Several controlled cold-starts and one cycled, winter experiment with 13-km RAP, initialized from GFS
- One cycled, summer 3-km HRRR experiment, initialized from non-hybrid coordinate RAP
- Only difference for these retrospective runs is the hybrid coordinate change
- For cold-season cases, focus was on strong westerly flow across western CONUS favoring vertically propagating mountain wave activity



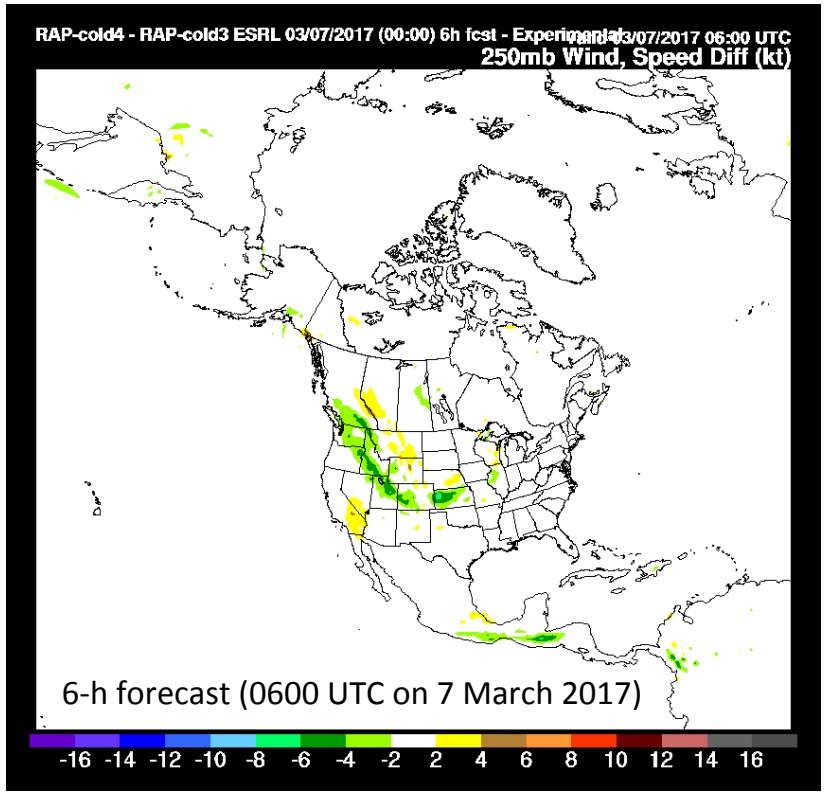
7 March 2017 cold start RAP simulation (250 hPa wind speeds)

- Initial fields *as interpolated to 250 hPa* are slightly different (see UT and CO)
- Differences appear by 1 h and grow, but are mainly over or downstream of mountainous terrain
- Smoothed coordinate surfaces result in less spurious accelerations, therefore less vertical mixing of horizontal momentum
- No major differences over the Pacific Ocean except near land

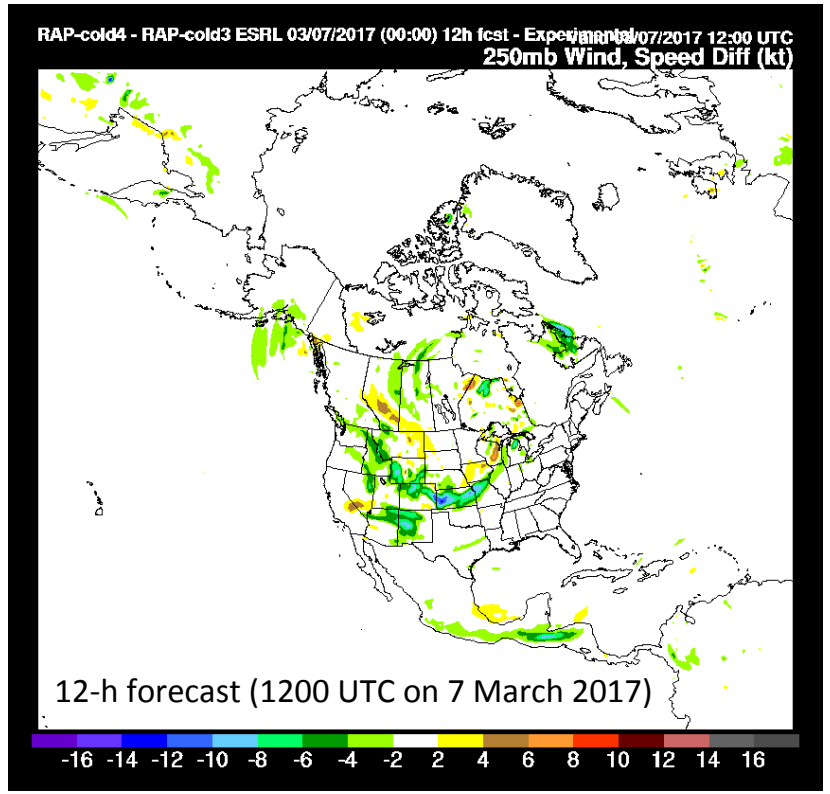
Cool colors: Hybrid coordinate winds faster
Warm colors: Hybrid coordinate winds slower



Initial (0000 UTC on 7 March 2017)



6-h forecast (0600 UTC on 7 March 2017)

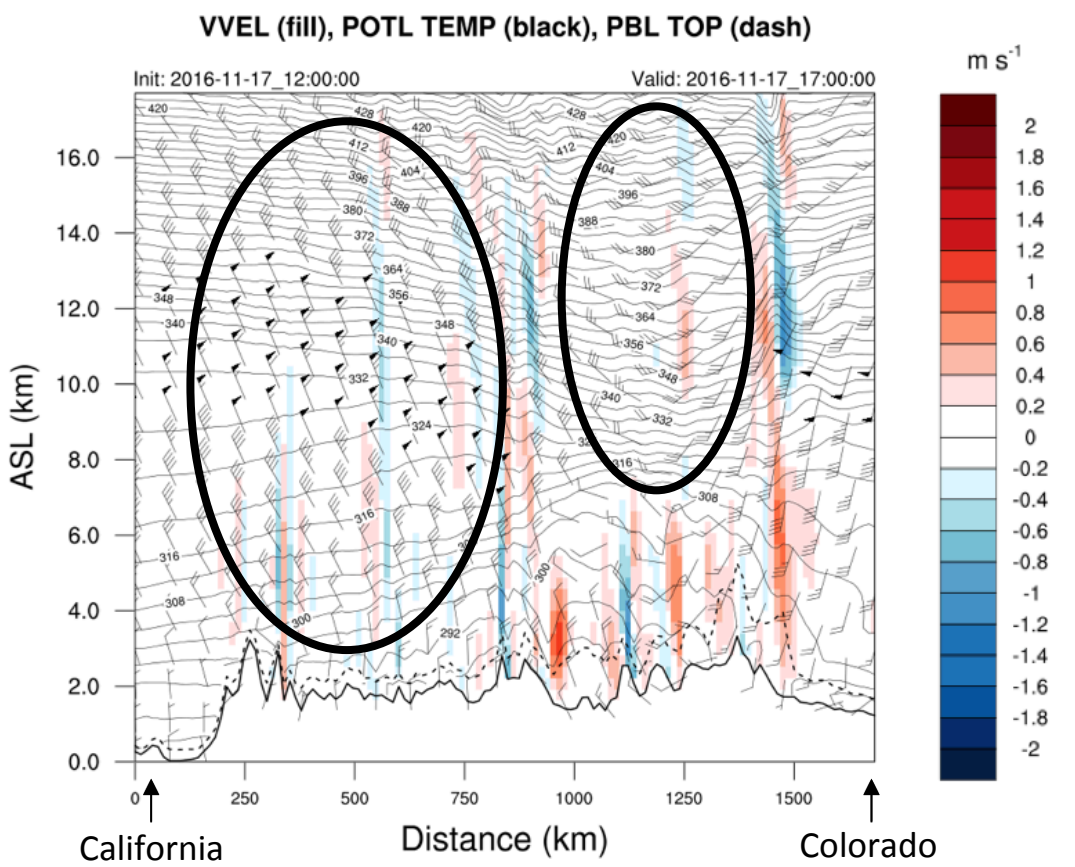


12-h forecast (1200 UTC on 7 March 2017)

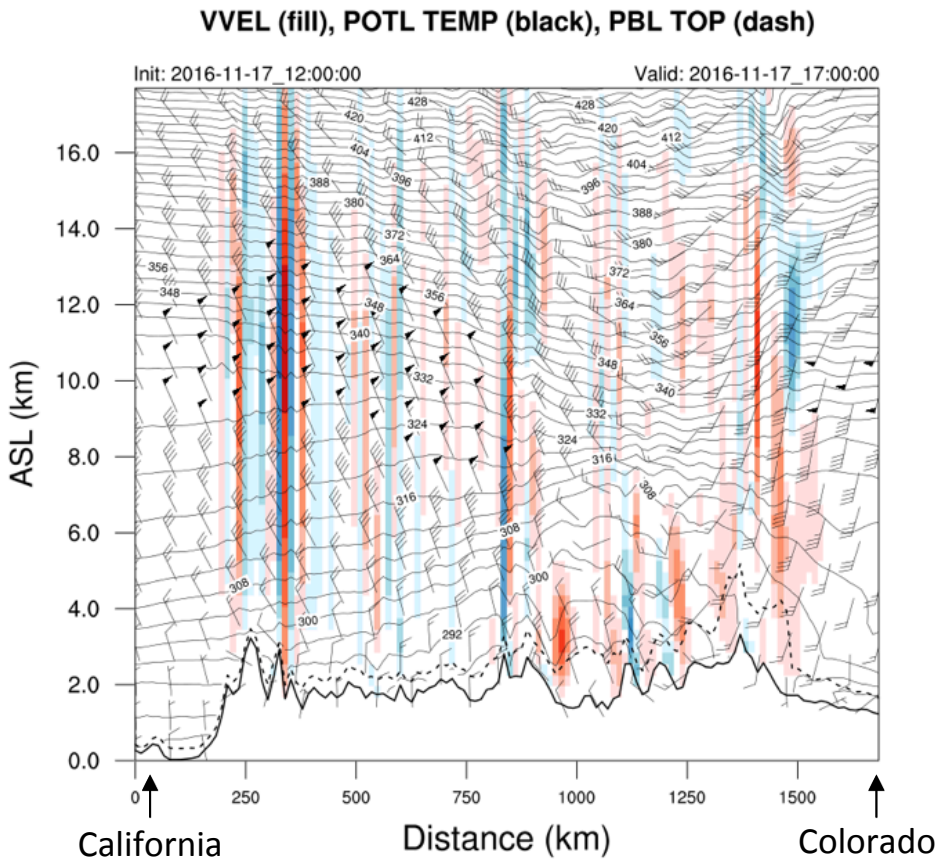
17 November 2016 cold start RAP simulation
(5-h forecast of vertical motion)

Hybrid coordinate

$\eta_c = 0.2$



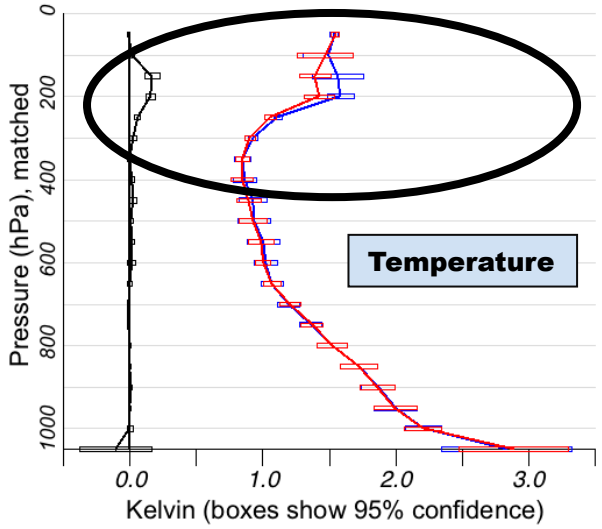
Terrain-following coordinate

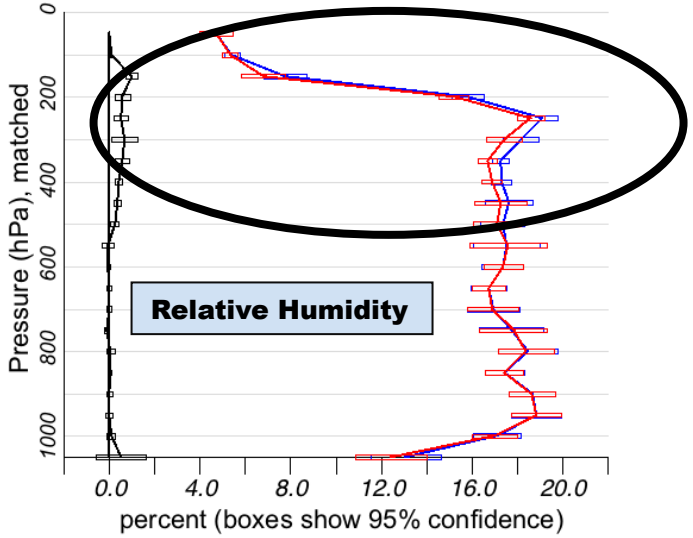


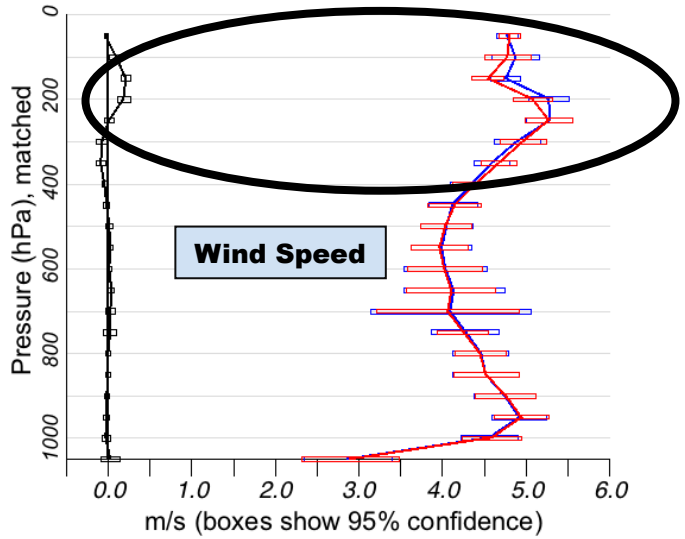
- Reduced spurious vertical motion over mountainous terrain
- More coherent upwind-tilted vertical velocity features (mountain waves)

Late Winter Cycled RAP retro (7-13 March 2017)

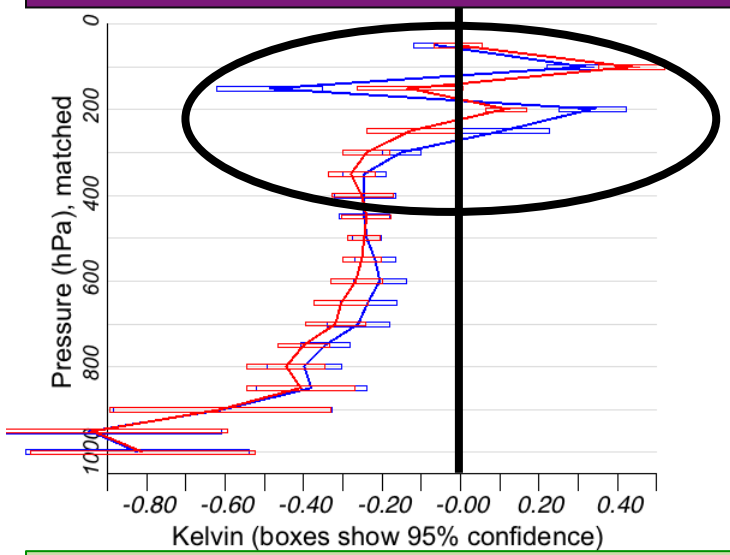
Vertical Profiles of Upper Air RMS for 12-hour forecasts

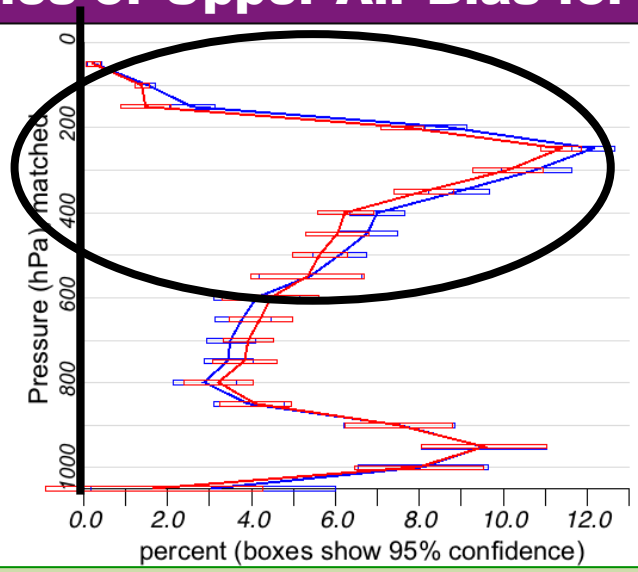


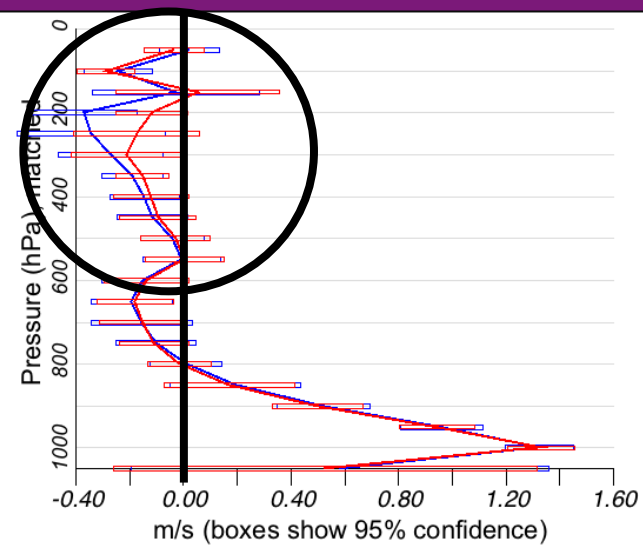




Vertical Profiles of Upper Air Bias for 12-hour forecasts



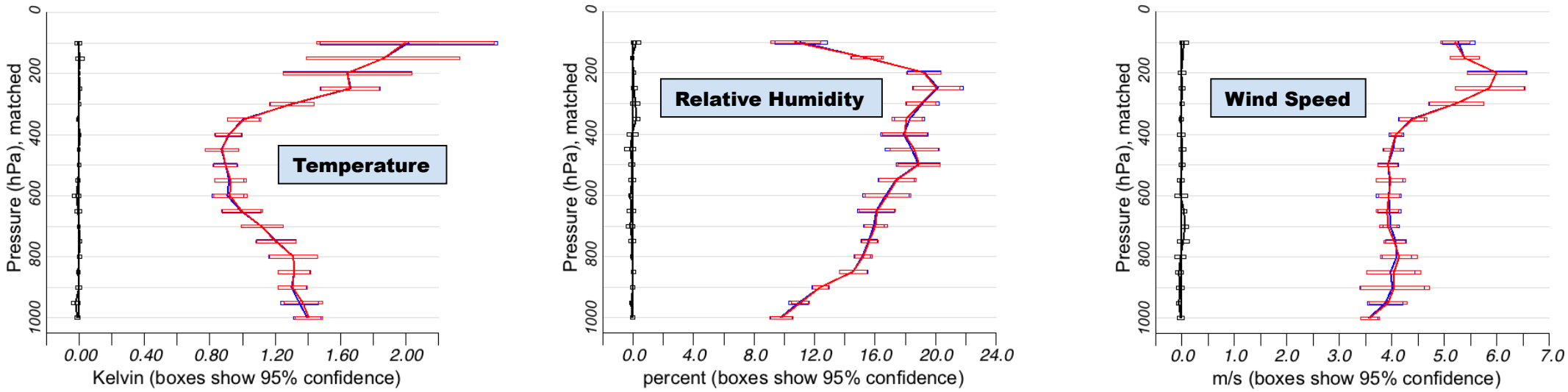




Red: Hybrid Coordinate; Blue: Terrain-Following Coordinate; Black: Terrain Following – Hybrid (Difference)

Cycled HRRR retro (3-10 September 2016)

Vertical Profiles of Upper Air RMS for 12-hour forecasts



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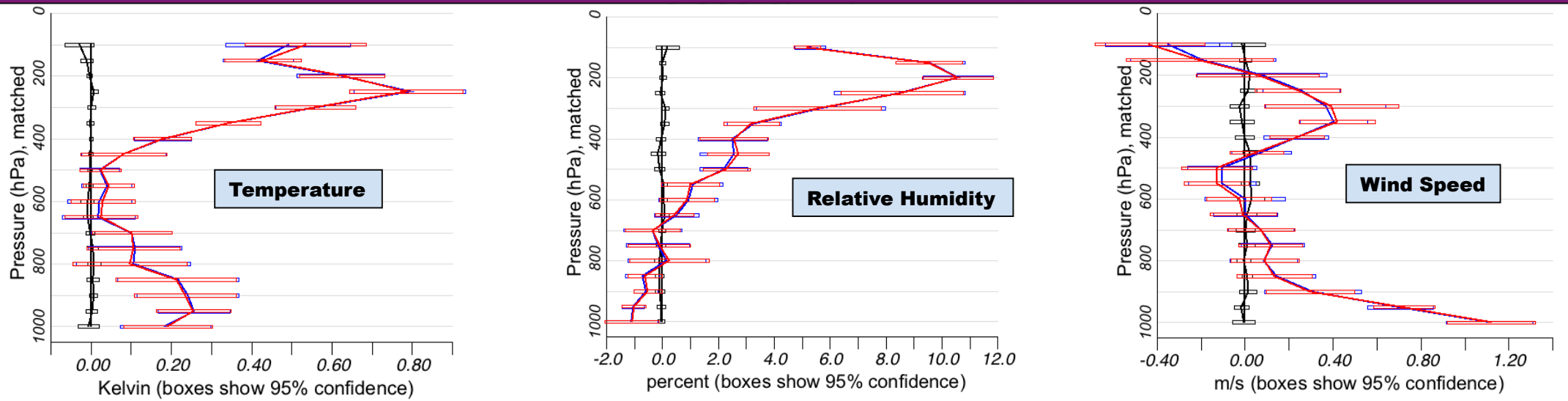

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Why is there no impact in the HRRR?

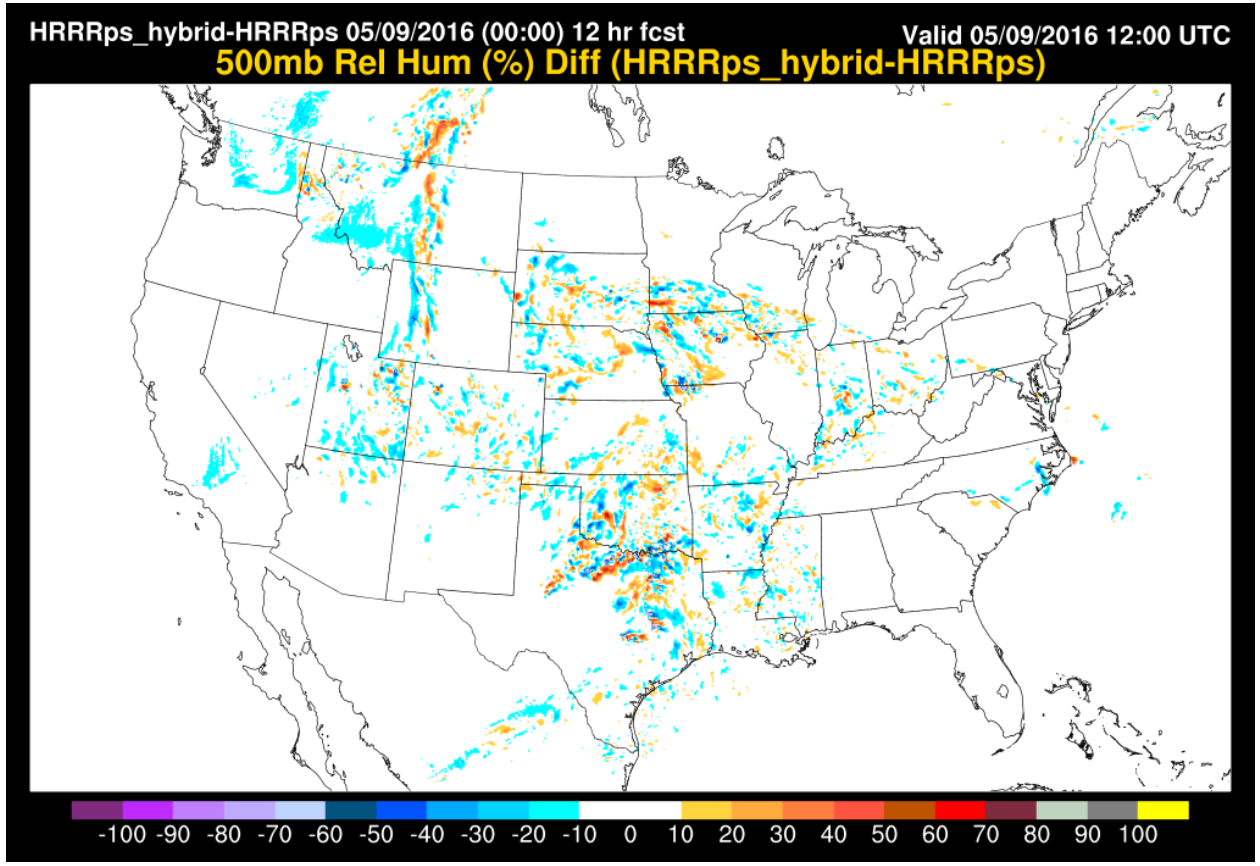
- Relatively weak synoptic flow aloft (3-10 September 2016) minimized impact in the HRRR
- Lack of cycling of atmospheric state (only soil state), so potentially no retention of hybrid coordinate benefits from hourly cycling, such as in the RAP retro

- **Potentially need:**
  - **A winter HRRR retro**
  - **A fully-cycled HRRR test**
  - **A hybrid RAP -> hybrid HRRR vs. non-hybrid RAP -> non-hybrid HRRR retrospective test**

- However…

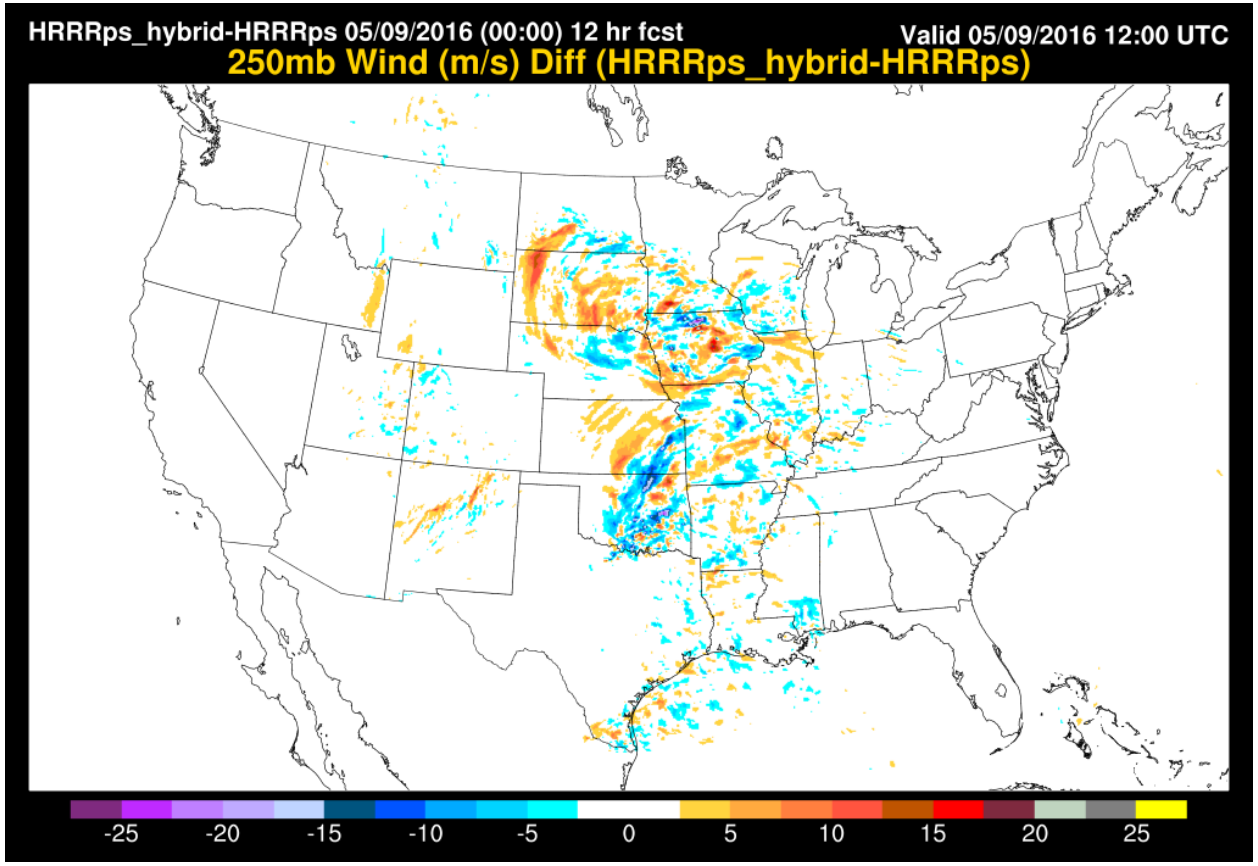
HRRR Spatial Difference Plots
12-hr forecasts from 1200 UTC on 9 May 2016

500 hPa Relative Humidity Differences (Hyb – Non-hyb)



Cool colors: Hybrid coordinate relative humidity is drier
Warm colors: Hybrid coordinate relative humidity is moister

250 hPa Wind Speed Differences (Hyb – Non-hyb)



Cool colors: Hybrid coordinate winds are weaker
Warm colors: Hybrid coordinate winds are stronger

Conclusions

- The hybrid vertical coordinate was successfully implemented in WRF, and tested within the RAP and HRRR models for extended periods
- Smoothed vertical coordinate generally results in improved temperature, relative humidity, and winds aloft in the RAP
- No real differences were found in the extended HRRR retro, but weak flow aloft likely to blame
- Spatial difference plots of select HRRR cases showed an impact of the new hybrid vertical coordinate, especially downwind of high terrain
- Operational implementation of the hybrid vertical coordinate in the RAP and HRRR to take place in 2018 (RAPv4, HRRRv3, and HRRR-AK)

Thank you!

Late Summer Cycled RAP retro (4-9 September 2016)

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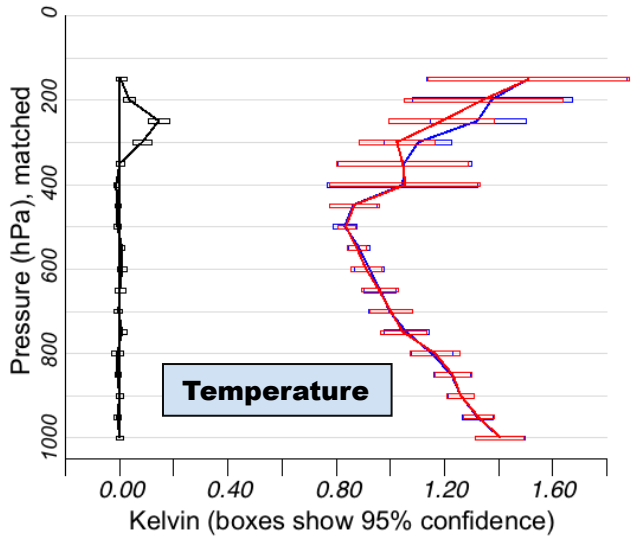

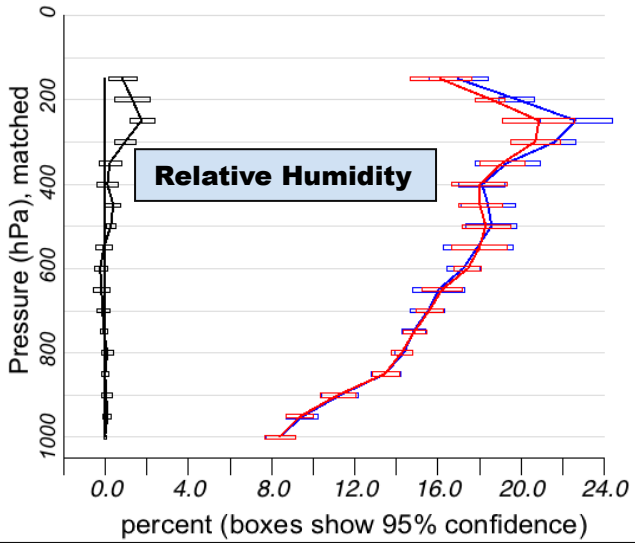

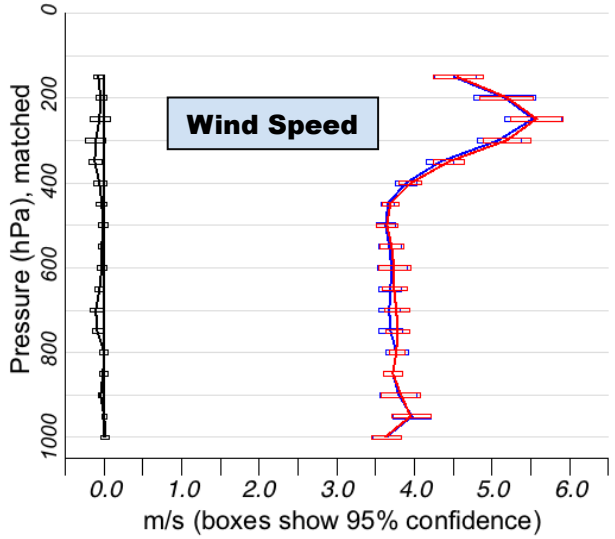

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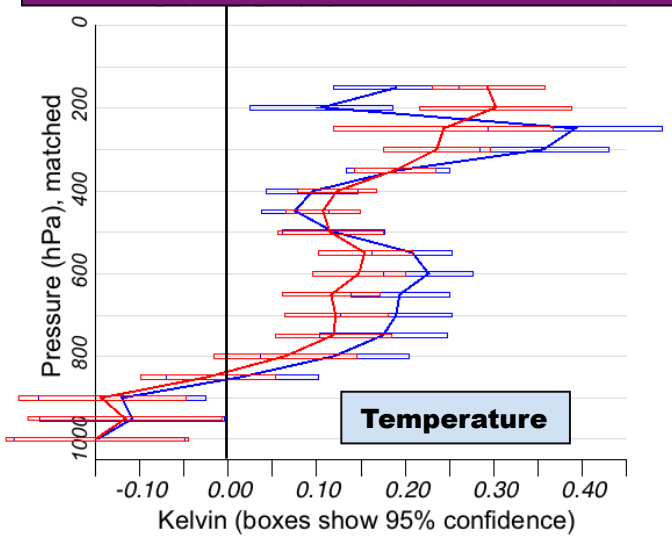

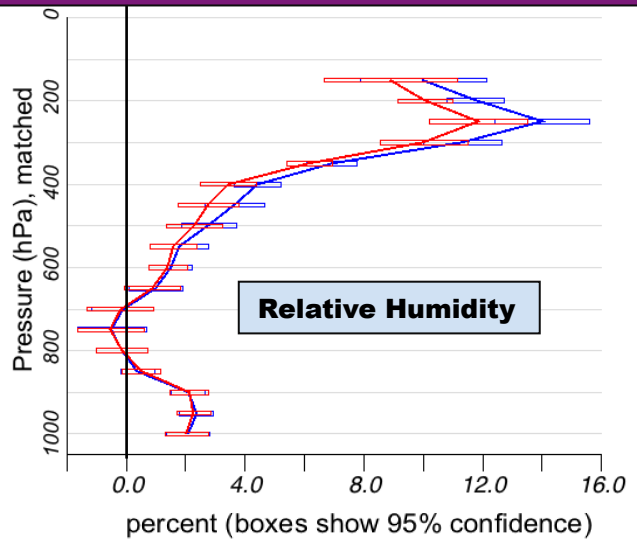

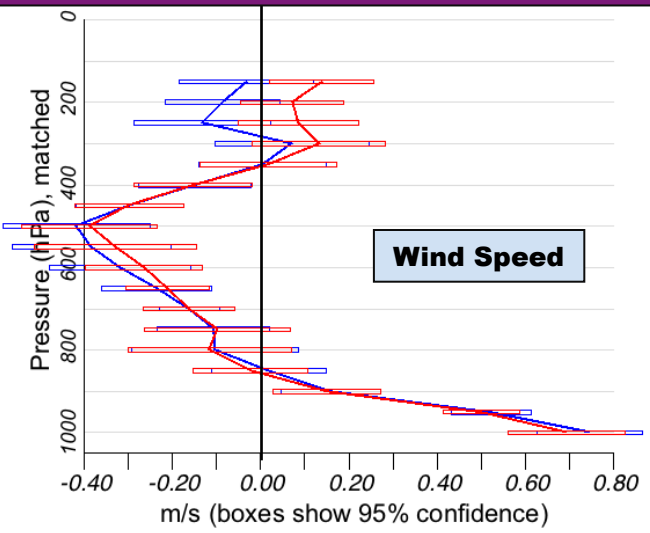

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