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Refinement and testing of analysis nudging in MPAS-A

Presented by

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WRF User's Workshop
June 15, 2017

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Introduction

- The U. S. Environmental Protection Agency is working with the Model for Prediction Across Scales - Atmosphere (MPAS-A) and the Community Multi-scale Air Quality (CMAQ) model to create an integrated system for global air quality modeling. (as shown on posters by Rob, Jerry and Hosein)
- Last year, we reported on initial efforts to add Four Dimensional Data Assimilation (FDDA) to MPAS v4.0 using analysis nudging and showed results for July 2013. We now have January 2013.
- Why not 3d or 4dVar? Our target fields are generated from 1°×1° NCEP FNL (Final) Operational Global Analysis datasets from the Global Data Assimilation System (similar to 4dVar).
- Also, gradual nudging in a continuous simulation avoids air quality model disruptions.

Analysis Nudging 101

- For a description of analysis nudging, the MPAS v4.0 code changes and new namelist options, please refer to last year's presentation.

http://www2.mmm.ucar.edu/wrf/users/workshops/WS2016/oral_presentations/5b.5.pdf

- Any significant changes from last year will be highlighted in the following slides.

Kain-Fritsch Issue

- In the first application of analysis nudging for January 2013, we encountered a “segmentation fault” abort that was traced to the Kain-Fritsch convective scheme.
- K-F was defining an updraft to just above 5 kPa (~21km / 69kft) and was seeking data outside the bounds of a lookup table.
- Modified *module_cu_kfeta.F* to expand the pressure range in that lookup table and provide a graceful abort for any future excursions
  - Original: 220 values from 110-5 kPa
  - New: 250 values from 110-1 kPa

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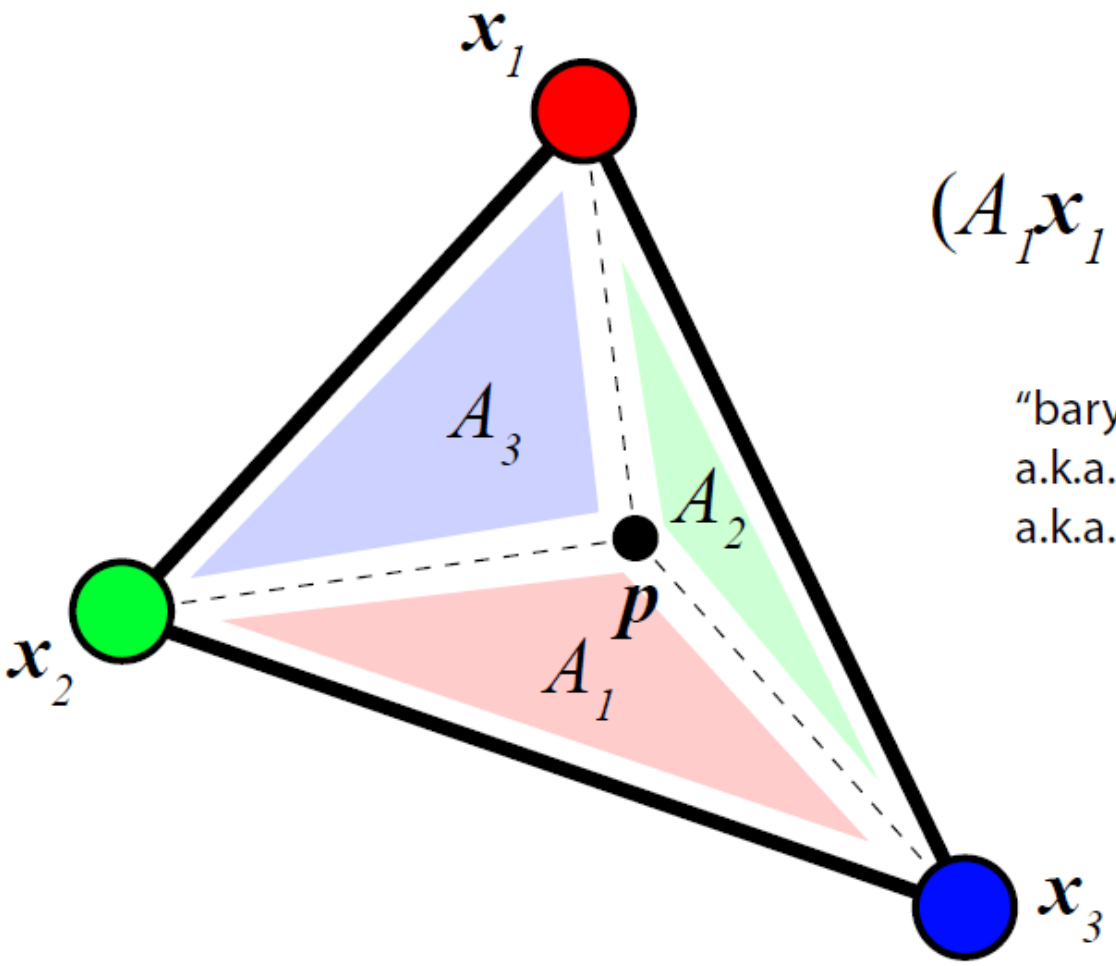
FDDA data recycling

- The previous method for defining reference fields (nudging targets) read in both the “new” and “old” data elements at each update time.
- We now “recycle” these reference fields, reading in only the “new” fields representing the targets at the end of each FDDA interval.
- Monthly FDDA files for 92-25km runs: 64 Gb → 32 Gb.
- In the future, we hope to use more frequent FDDA target updates which would make file size even more important.

Barycentric Interpolation

- To better evaluate MPAS-A results, we started using barycentric interpolation of MPAS-A outputs to the location of observations.
- For WRF, we use bi-linear interpolation. For MPAS-A, we were using nearest neighbor (i.e., value at nearest cell center)
- Each vertex in the MPAS-A mesh is formed from three cells whose centers define a triangle.
- Finding the closest vertex to a particular point identifies the three cell centers forming a triangle containing that point.

Barycentric Interpolation



Value at p:

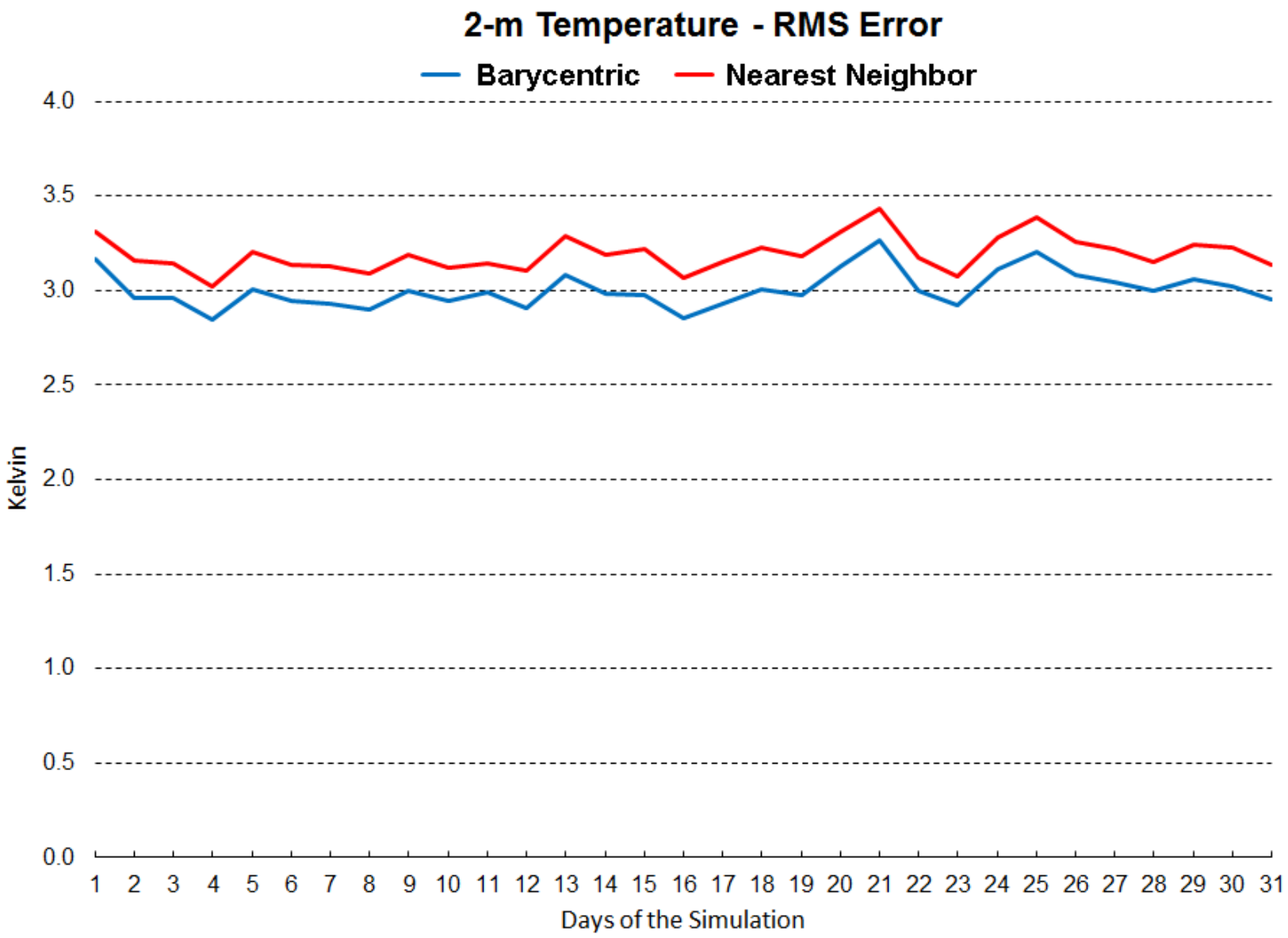
$$(A_1 x_1 + A_2 x_2 + A_3 x_3)/A$$

"barycentric interpolation"
a.k.a."convex combination"
a.k.a."affine linear extension"

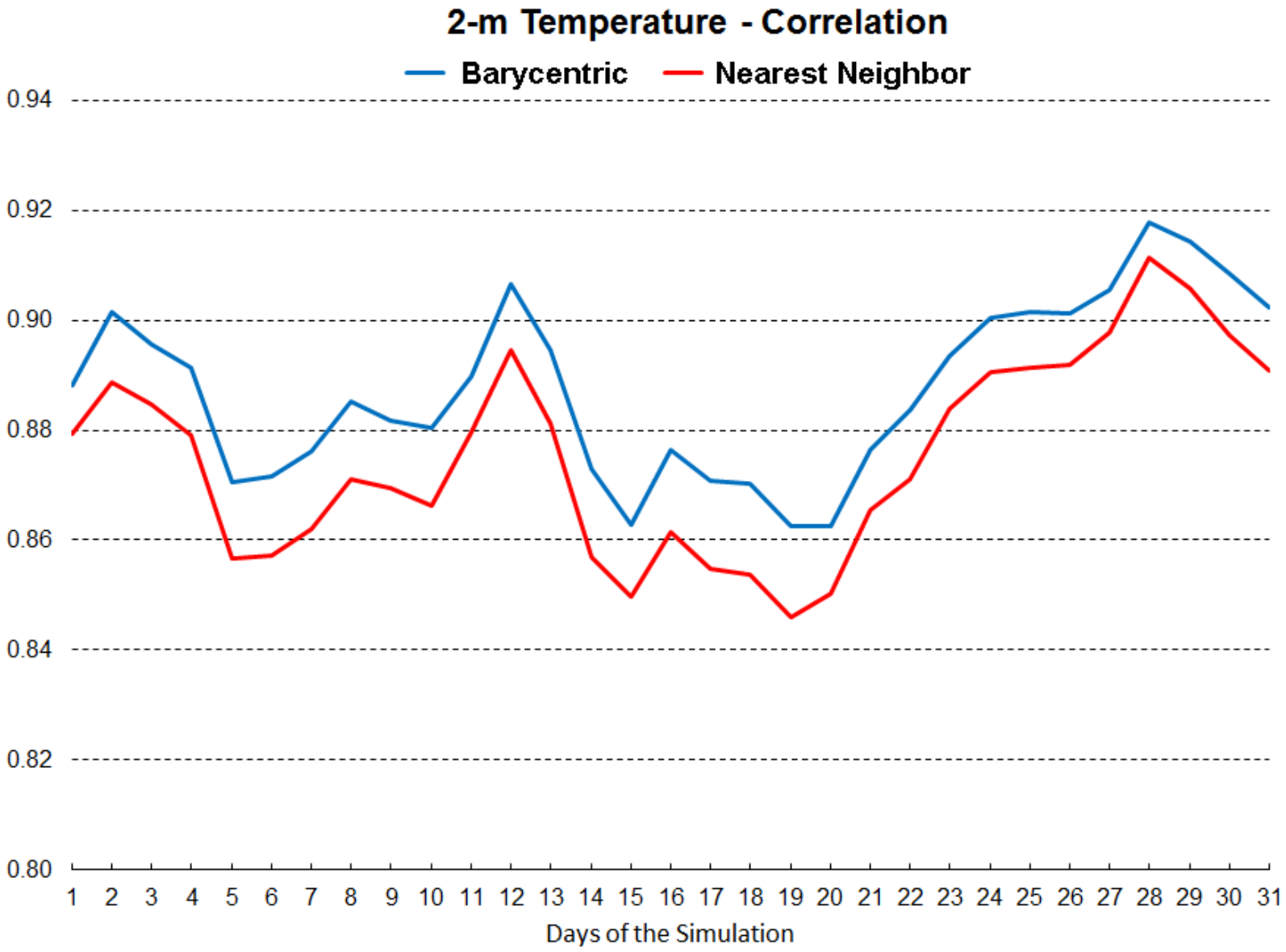
Barycentric Interpolation

- Once we started using barycentric interpolation to match MPAS-A results with observations in our Atmospheric Model Evaluation Tool, evaluation statistics improved considerably in most cases.

July 2013 – Normal FDDA



July 2013 – Normal FDDA



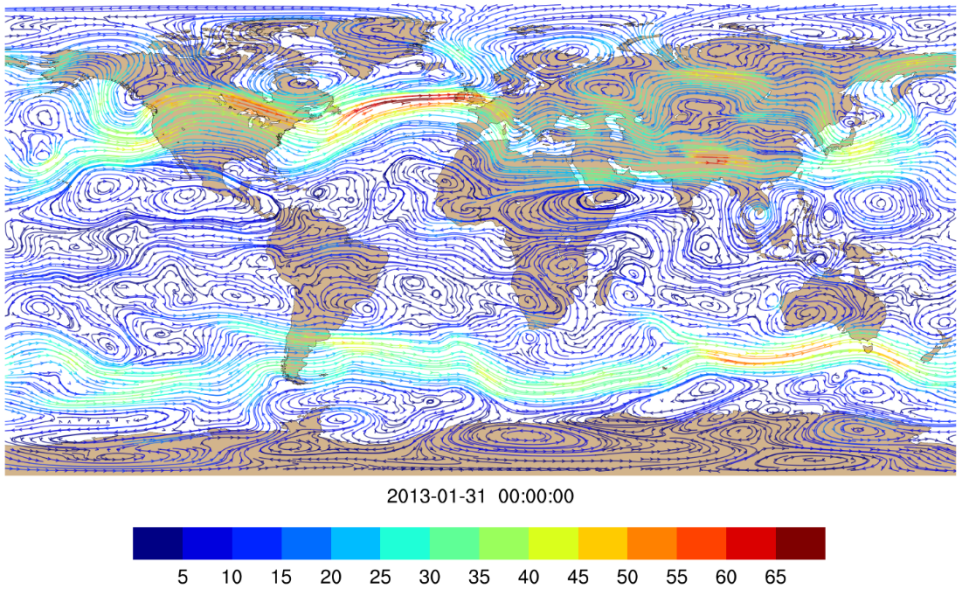
Barycentric Interpolation

- Once we started using barycentric interpolation to match MPAS-A results with observations in our Atmospheric Model Evaluation Tool, evaluation statistics improved considerably for most test cases.
- However, we started seeing different sensitivities to nudging strength and “scaled” nudging.
- Investigation continues…….

Another Use for B.I.

- No NCL graphics functions available to generate wind streamline analyses from MPAS-A mesh (only rectangular arrays)
- Modified existing NCL scripts to generate latitude-longitude arrays using barycentric interpolation

Voila!



New FDDA Test Applications

- MPAS-A was applied on the 92-25km mesh (x4.163842.grid.nc) with the origin repositioned to 40N, 95W
- Model initialization and FDDA reference fields were produced from 1 x 1° NCEP FNL Operational Model Global Tropospheric Analyses (ds083.2)
- USGS land use data
- Model top: 30 km W-damping height: 27 km
- Model layers: 50 (custom vertical distribution)
- Simulation periods: January 2013 and July 2013
- Time step length: 150 s
- RK steps per transport step: 3 Acoustic sub-steps: 2
- Horizontal diffusion length: 25 km

New FDDA Test Applications

- Physics options for FDDA

  config_fdda_scheme = 'off', 'analysis' (still working on 'scaled')

  config_fdda_t = .true.
  config_fdda_t_in_pbl =.false.
  config_fdda_t_min_layer = 0
  config_fdda_t_coef = 3.0E-4.

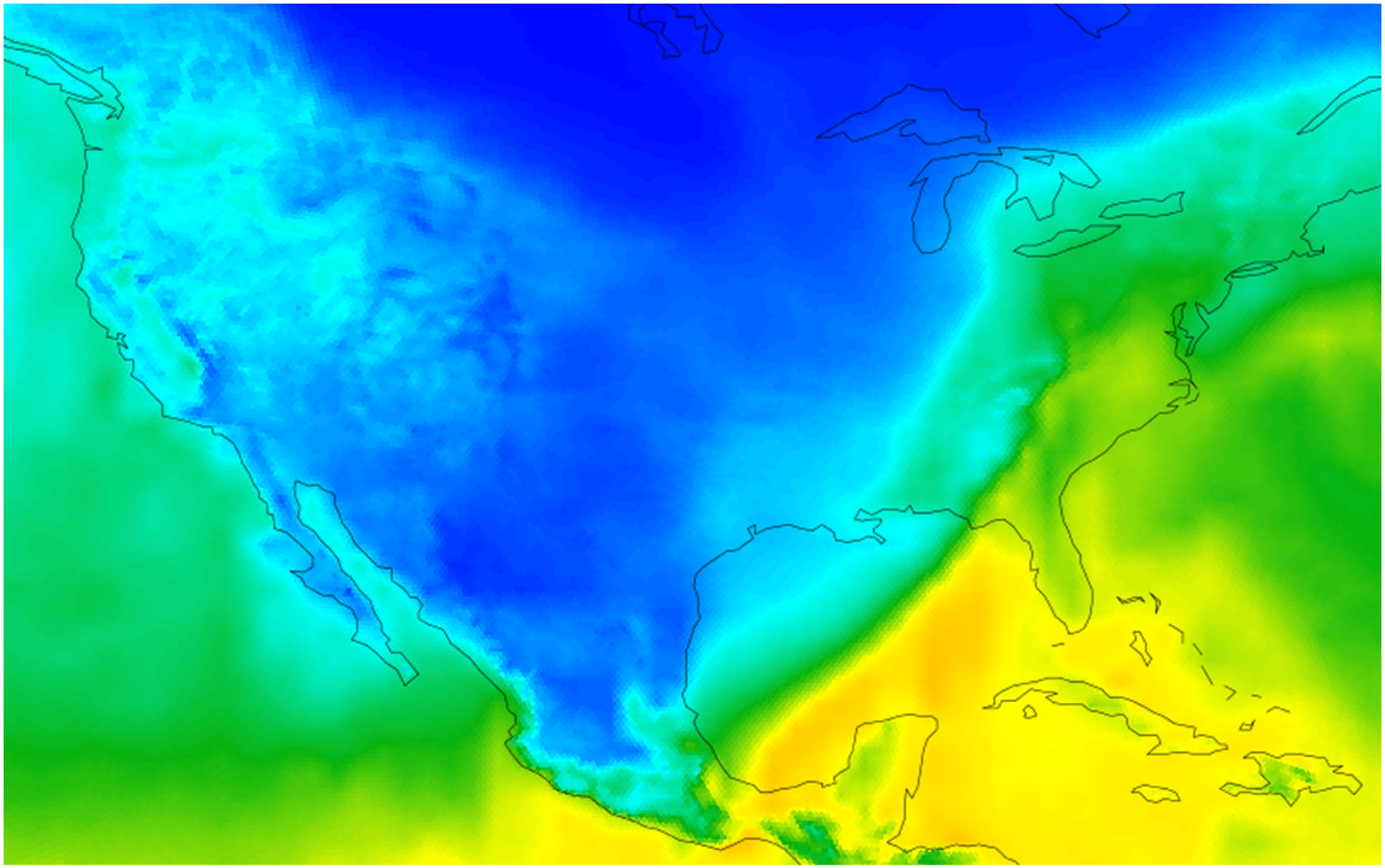
  config_fdda_q = .true.
  config_fdda_q_in_pbl =.false.
  config_fdda_q_min_layer = 0
  config_fdda_q_coef = 3.0E-5 (3.0E-4 for "Equal" case)

  config_fdda_uv = .true.
  config_fdda_uv_in_pbl =.false.
  config_fdda_uv_min_layer = 0
  config_fdda_uv_coef = 3.0E-4

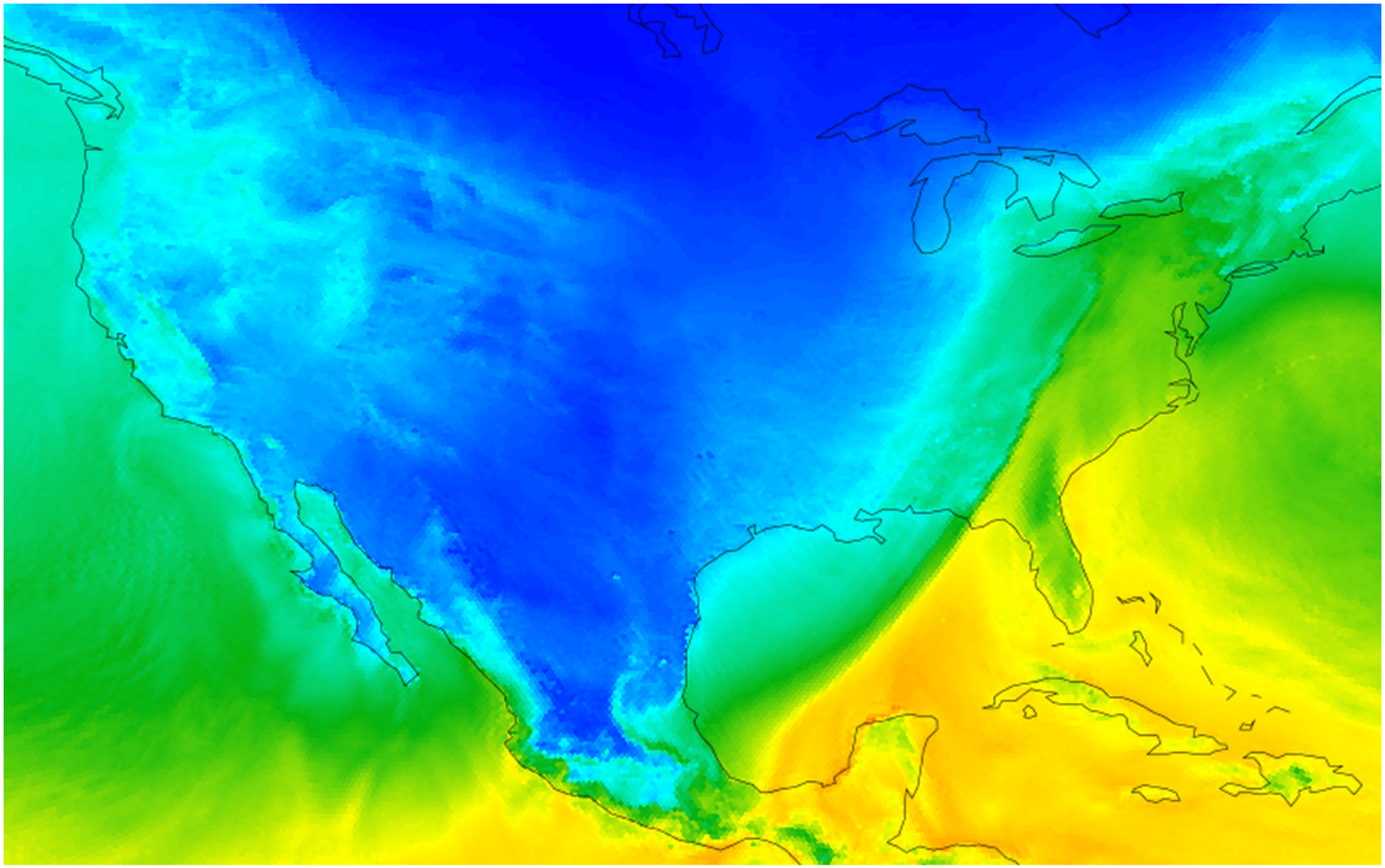
Comparisons to Target Fields

- ***Yes, we know that strong analysis nudging guarantees good agreement.***
- ***But if you nudge "just right" you can actually get fields that look more realistic than the target fields.***

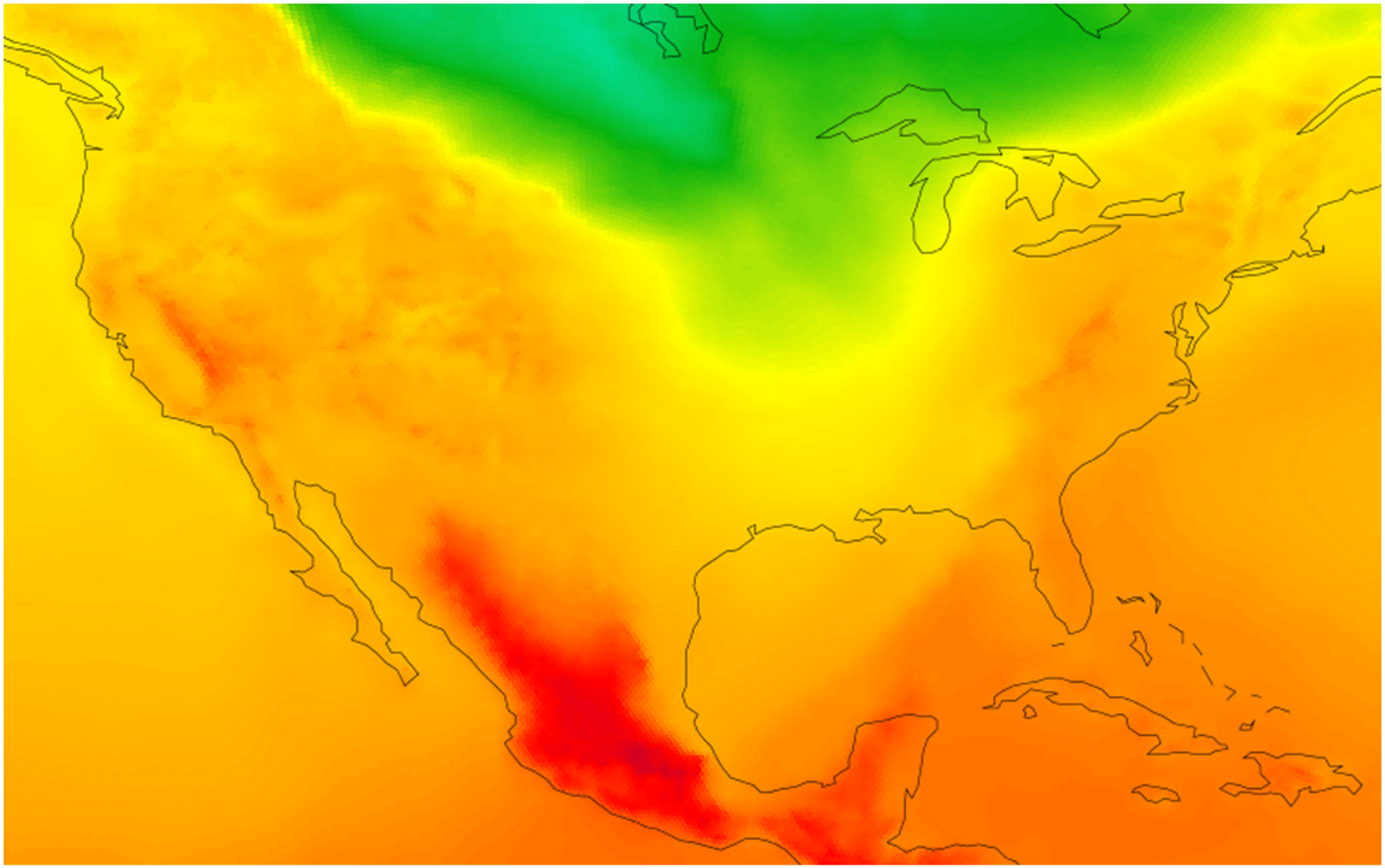
q_v – Layer 1 - FDDA target



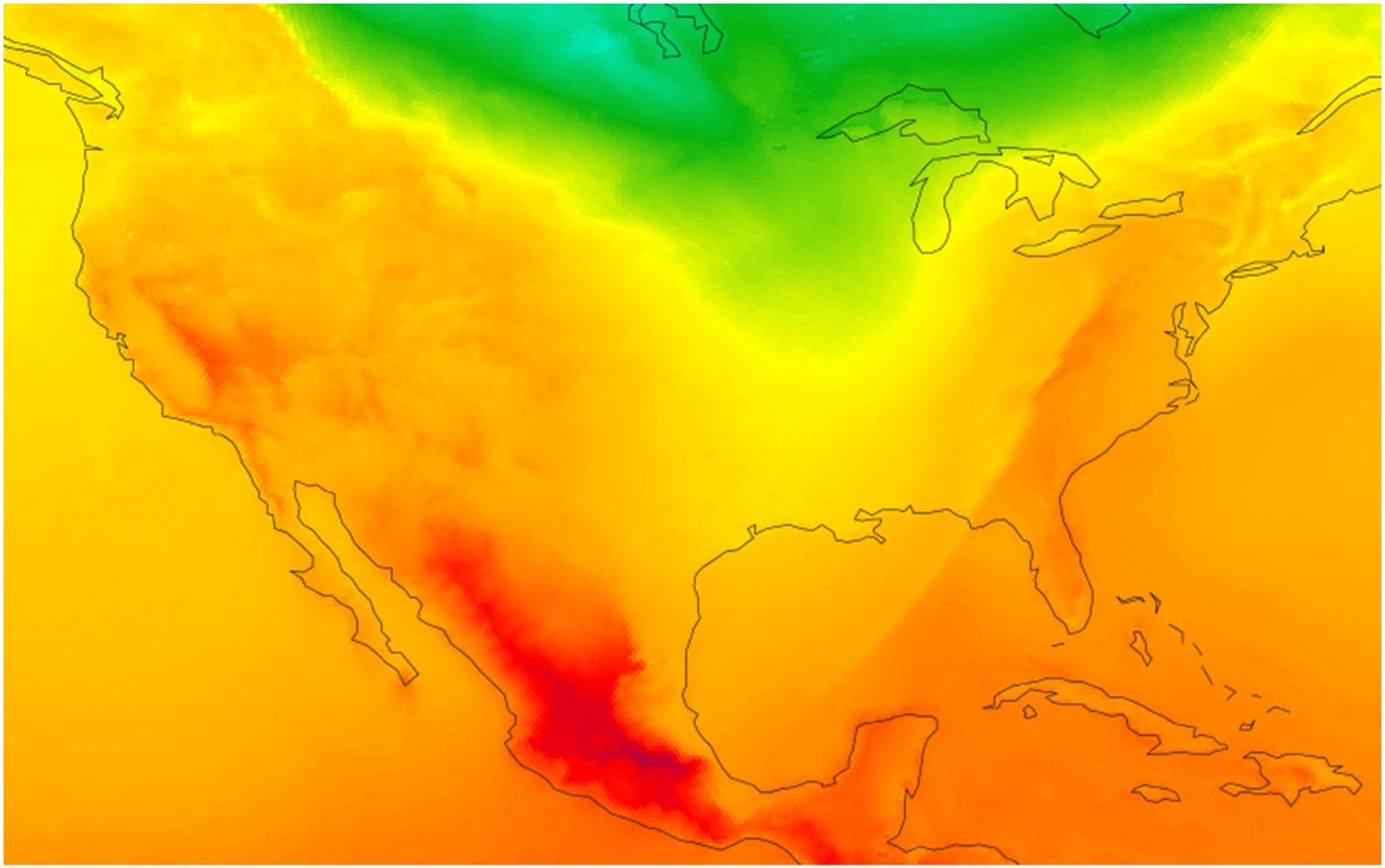
q_v – Layer 1 – MPAS with FDDA



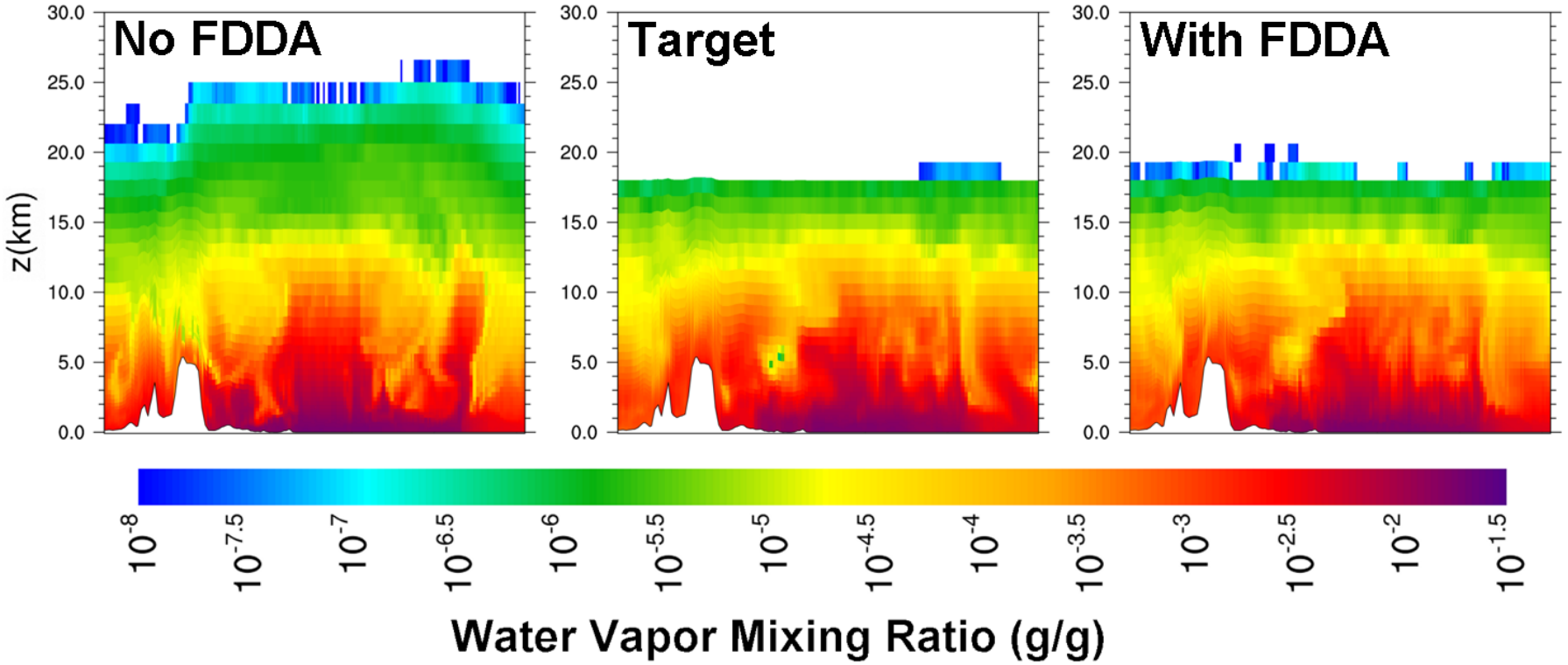
θ – Layer 1 - FDDA target



θ – Layer 1 – MPAS with FDDA



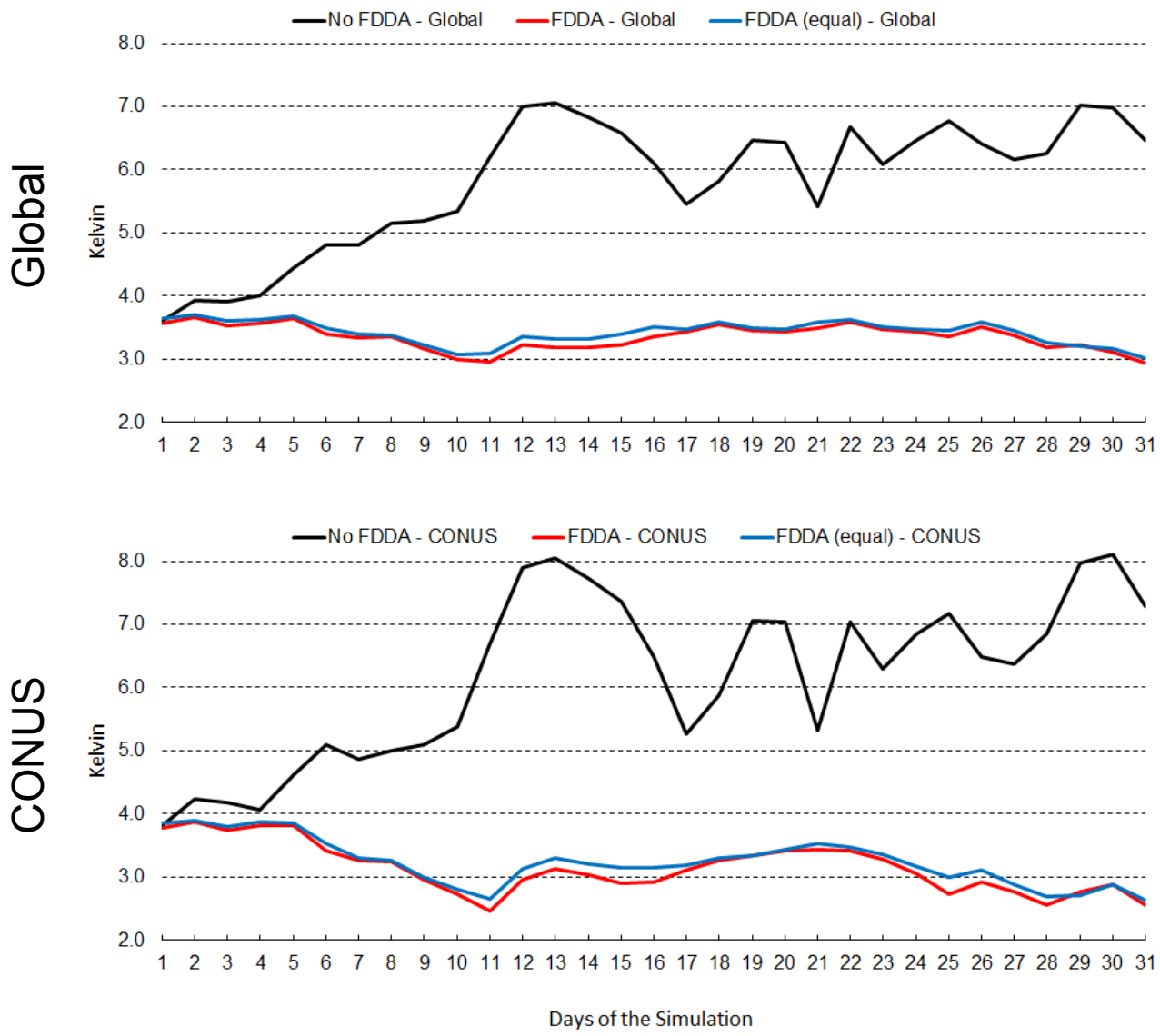
FDDA Corrects "Tropopause Leakage"

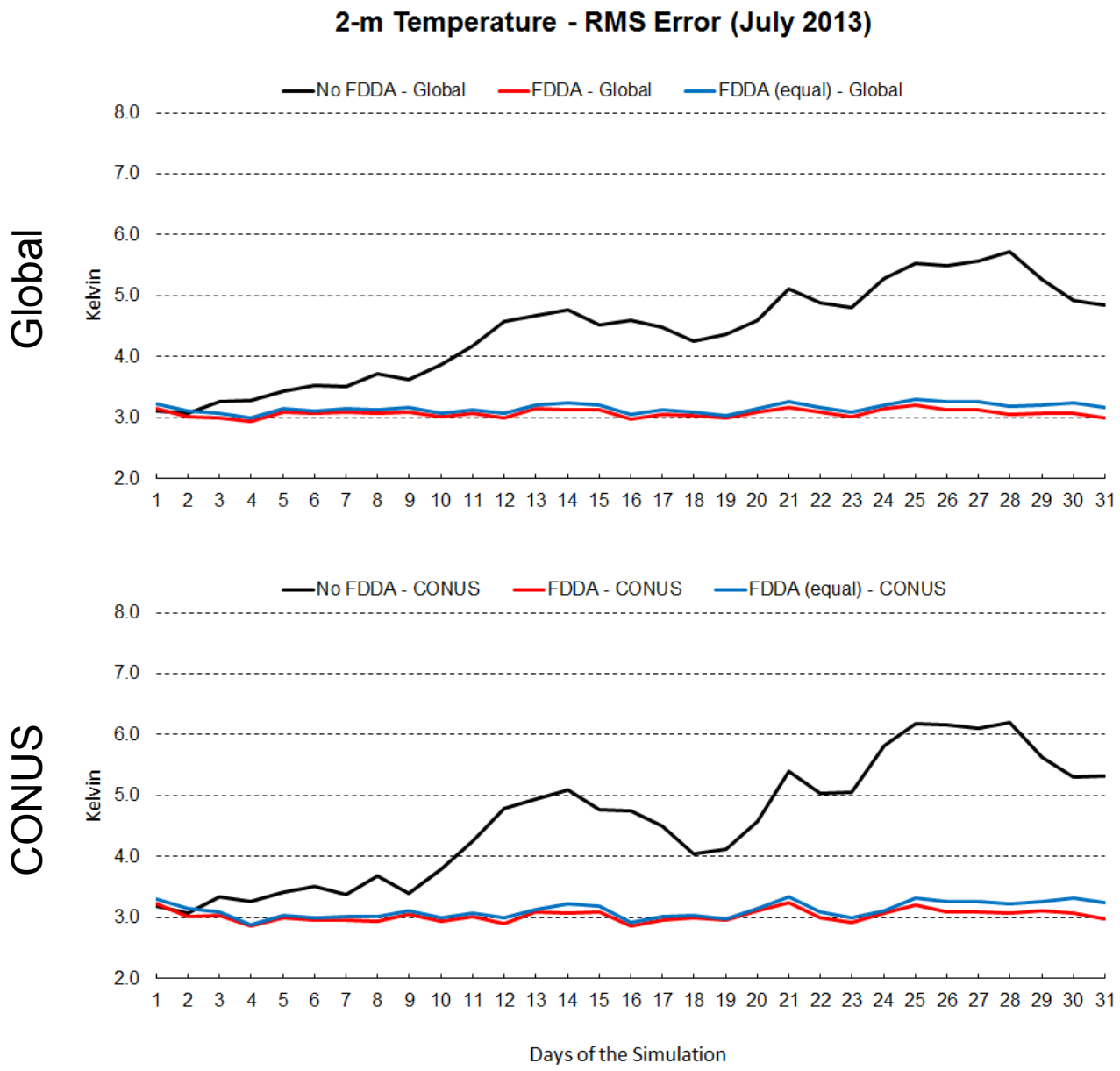


Comparison to Observations

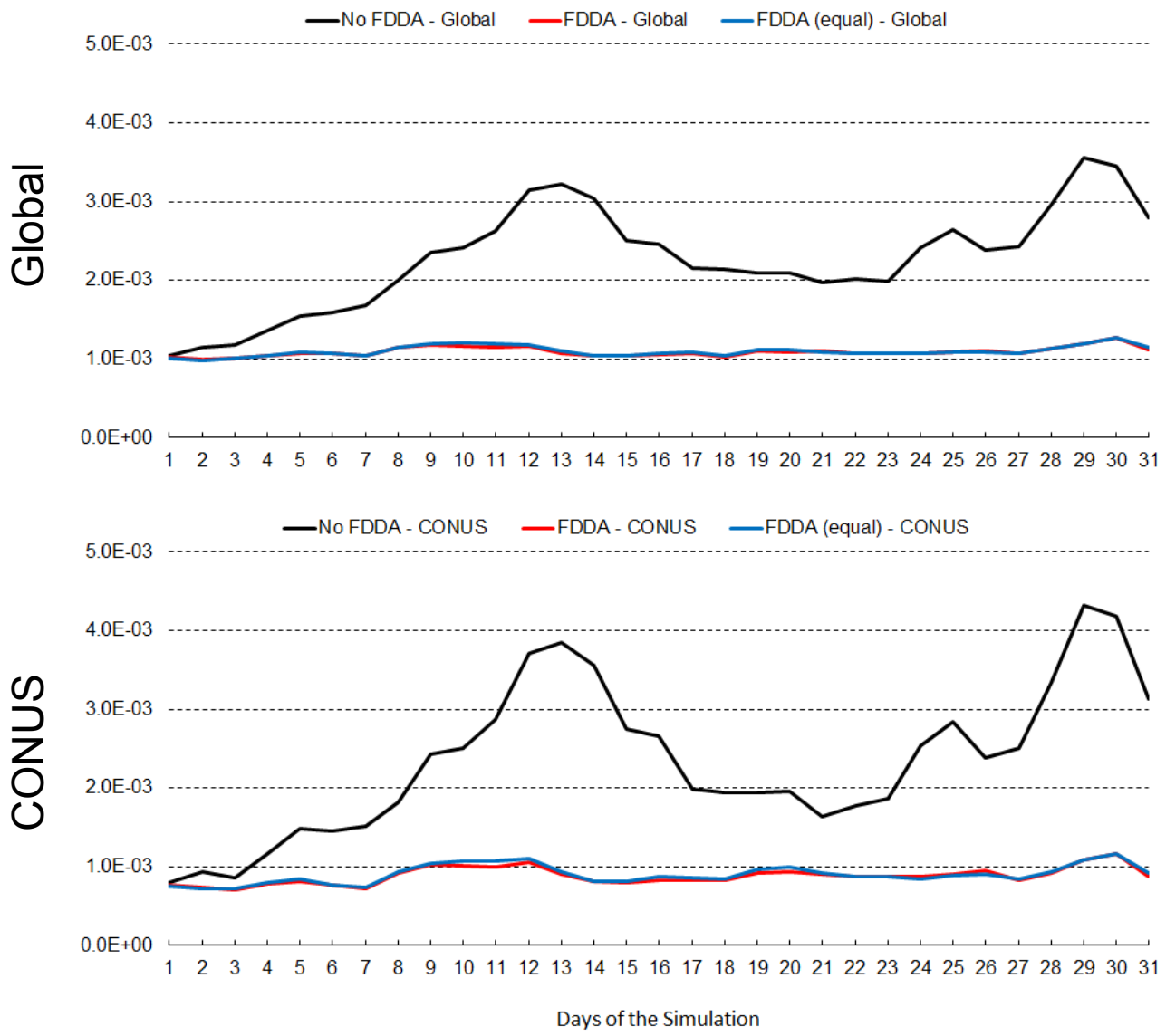
- *Atmospheric Model Evaluation Tool (AMET)*
- *Surface observations from Meteorological Assimilation Data Ingest System (MADIS)*
- *Global data, but more concentrated in North America and Europe*
- *4000+ observations at the top of each hour (+/- 15 minute window applied)*
- *Daily averaged statistics*

2-m Temperature - RMS Error (January 2013)

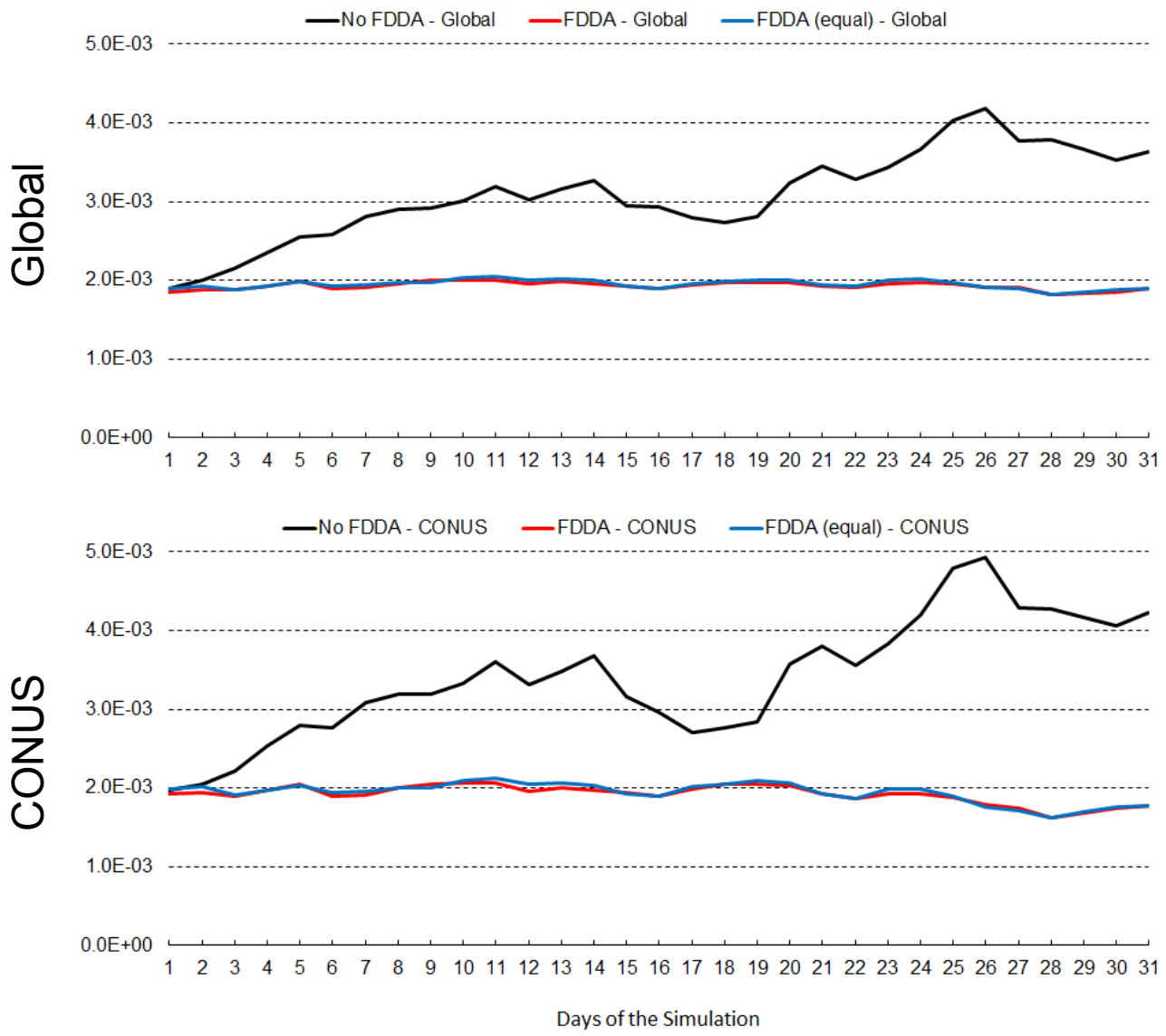


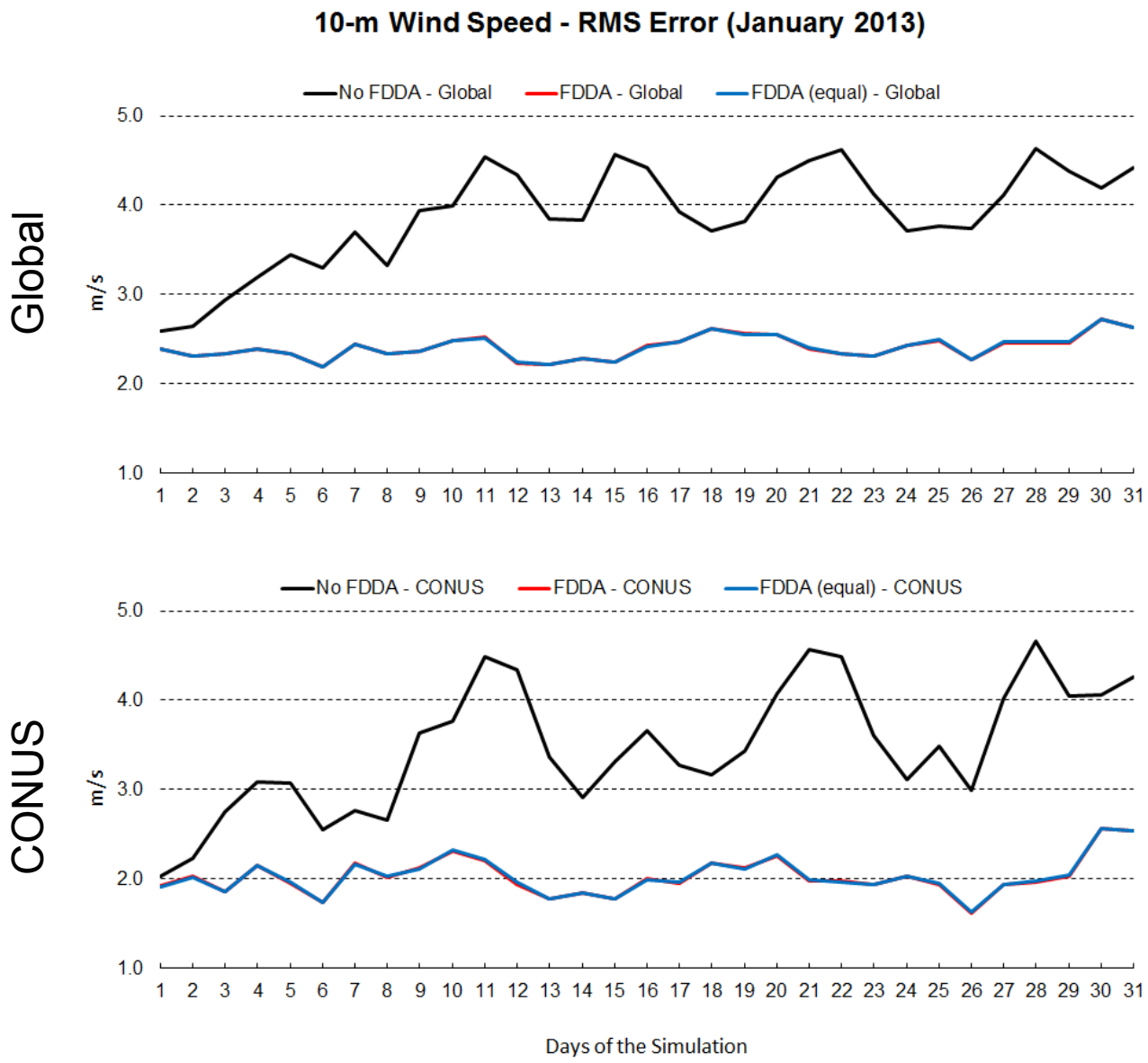

2-m Temperature - RMS Error (July 2013)
Global
No FDDA - Global
FDDA - Global
FDDA (equal) - Global
Kelvin
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
CONUS
No FDDA - CONUS
FDDA - CONUS
FDDA (equal) - CONUS
Kelvin
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days of the Simulation

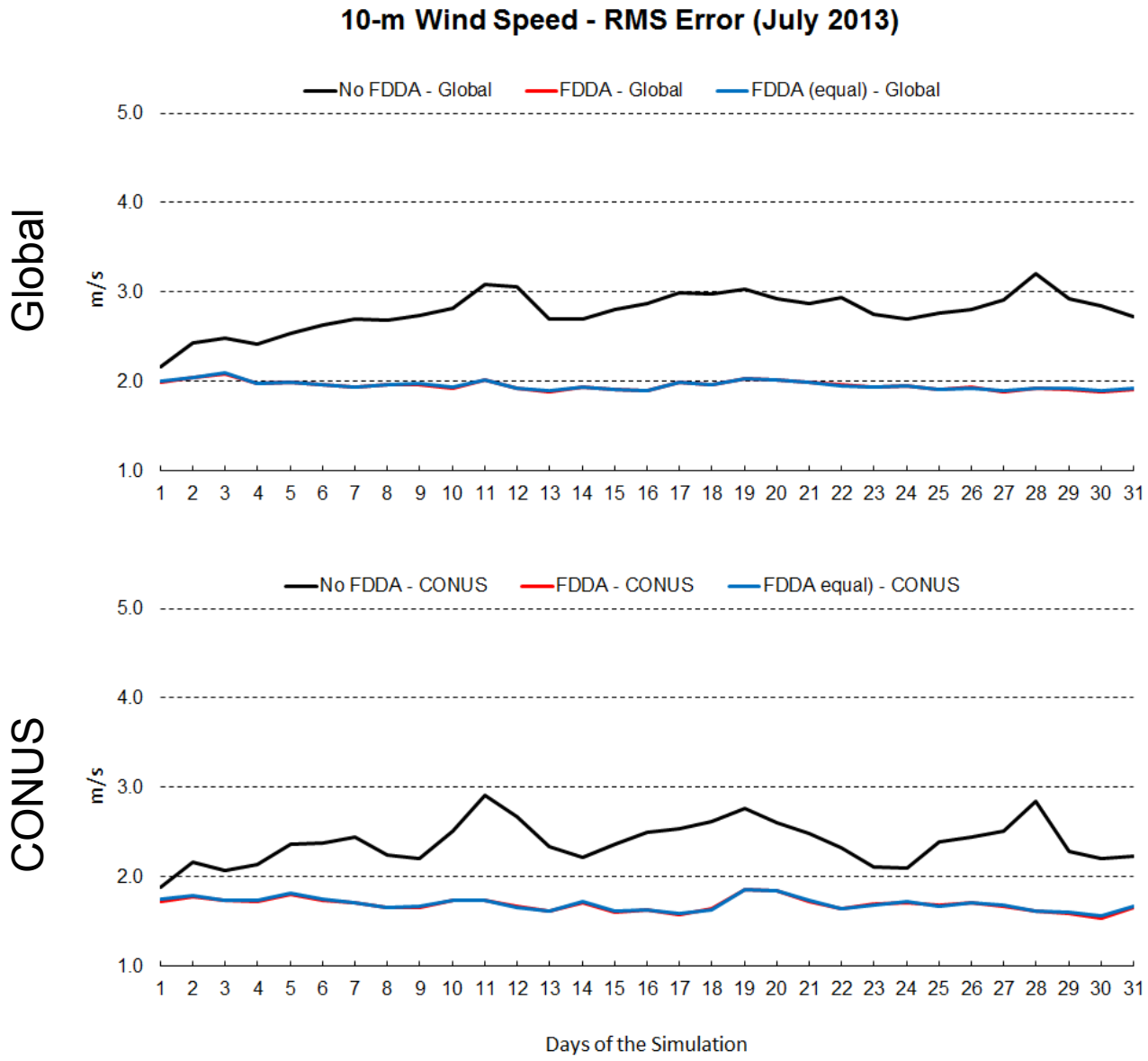
2-m Water Vapor Mixing Ratio - RMS Error (January 2013)



2-m Water Vapor Mixing Ratio - RMS Error (July 2013)



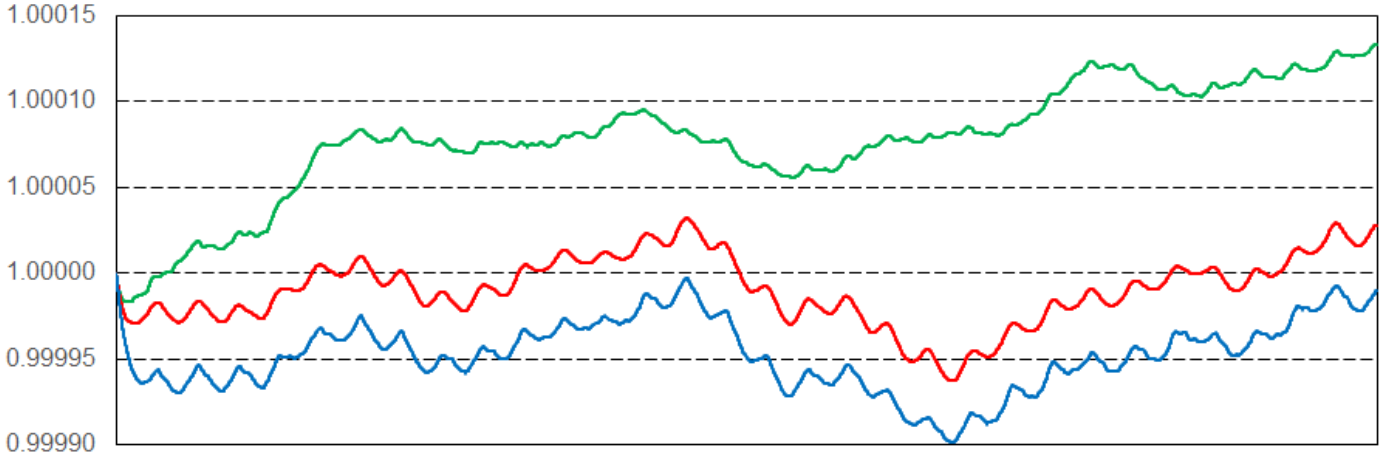

10-m Wind Speed - RMS Error (January 2013)
Global
No FDDA - Global
FDDA - Global
FDDA (equal) - Global
m/s
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
CONUS
No FDDA - CONUS
FDDA - CONUS
FDDA (equal) - CONUS
m/s
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days of the Simulation


10-m Wind Speed - RMS Error (July 2013)
Global
No FDDA - Global
FDDA - Global
FDDA (equal) - Global
m/s
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
CONUS
No FDDA - CONUS
FDDA - CONUS
FDDA equal) - CONUS
m/s
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Days of the Simulation

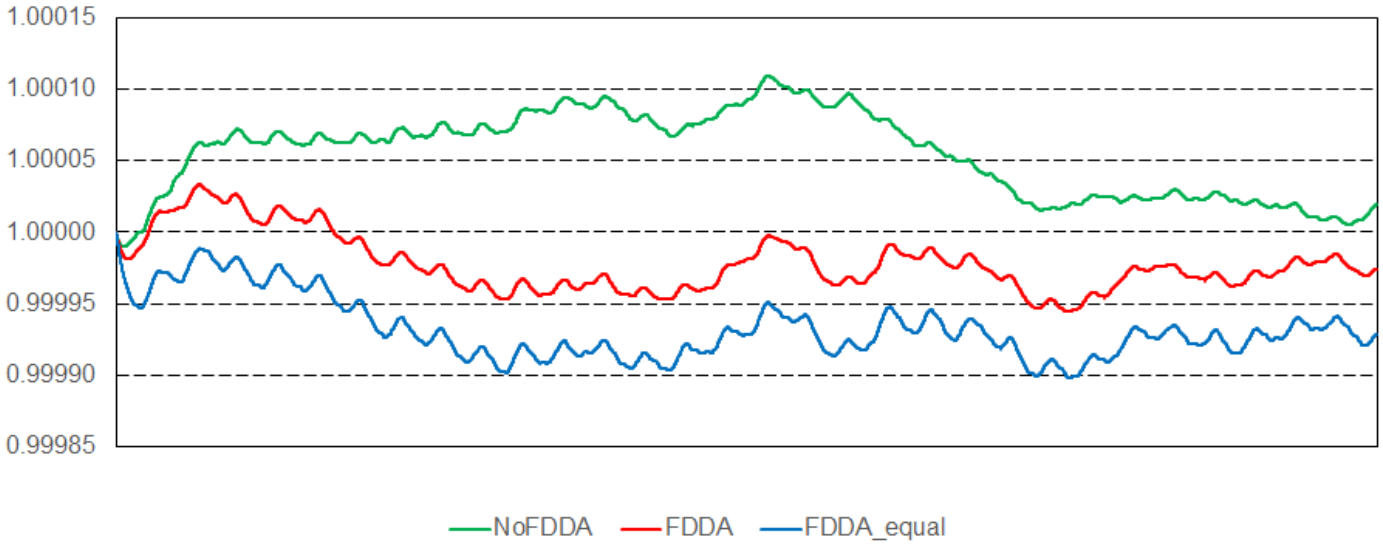
Mass Conservation

- *mpas_atm_time_integration.F* modified to calculate and output total dry air mass and total water vapor mass every time step. (thanks to Hosein Foroutan)
- Results imported into Excel to calculate total air mass (moist air) and scale all mass totals to their initial values.

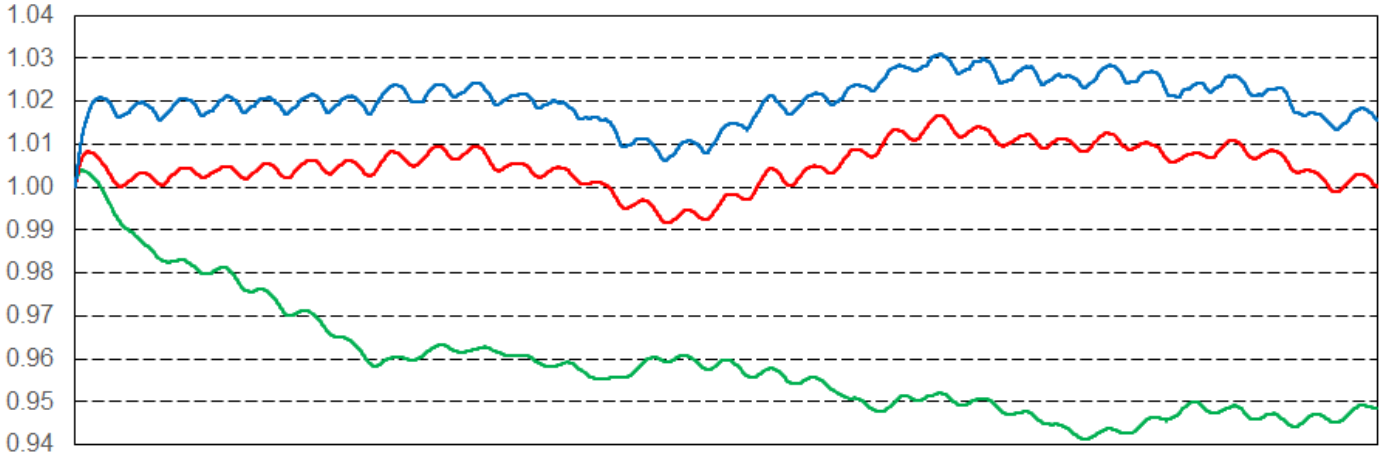
Scaled Dry Air Mass - January 2013



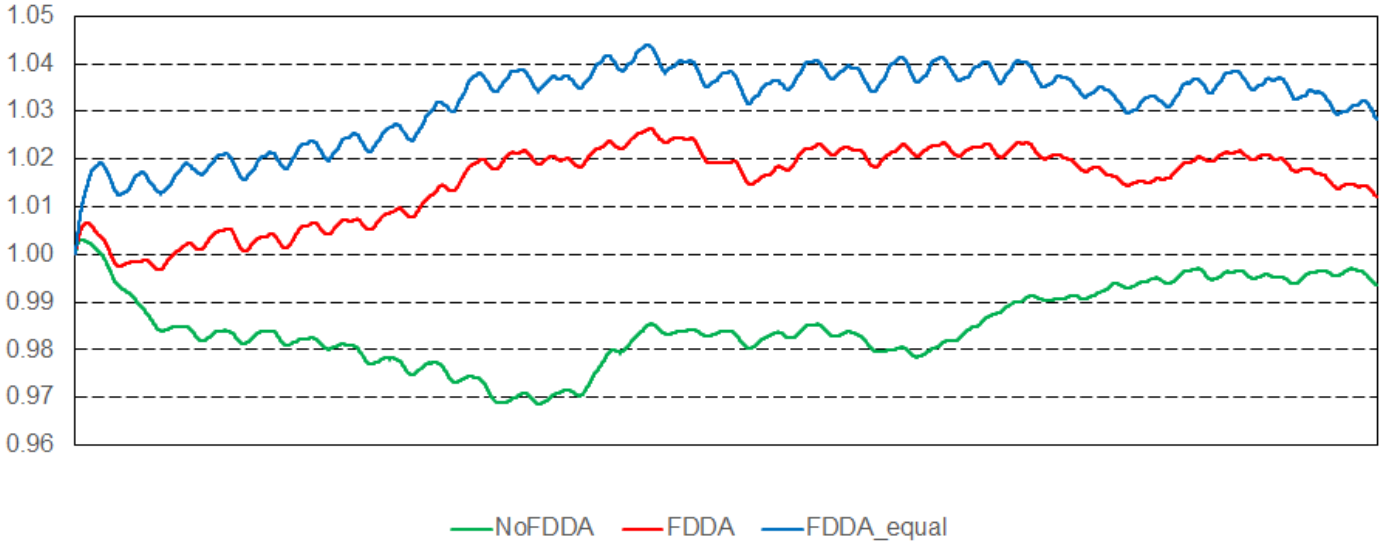
Scaled Dry Air Mass - July 2013



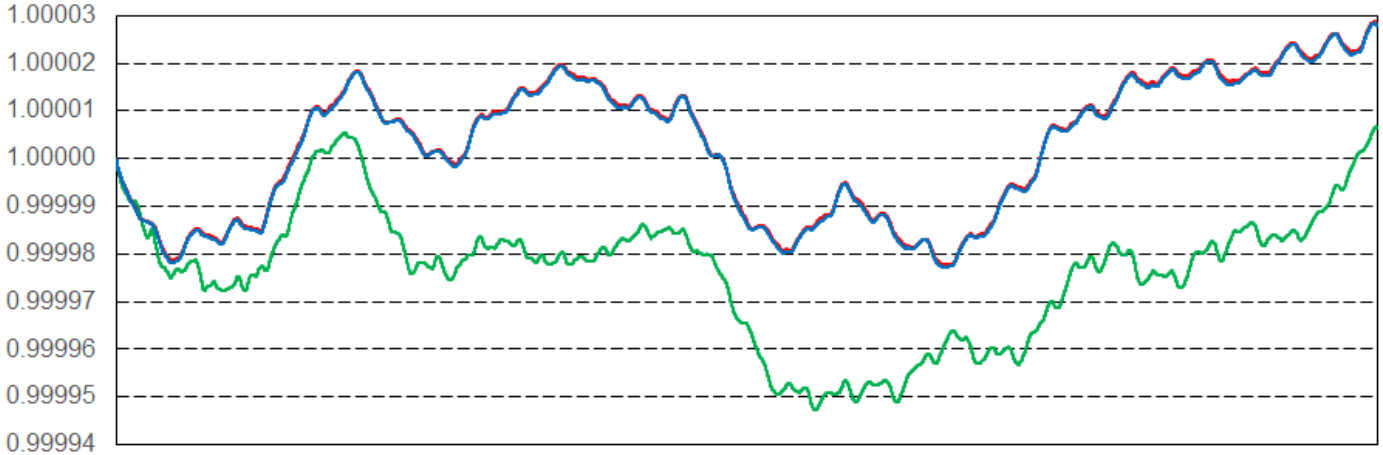
Scaled Water Vapor Mass - January 2013



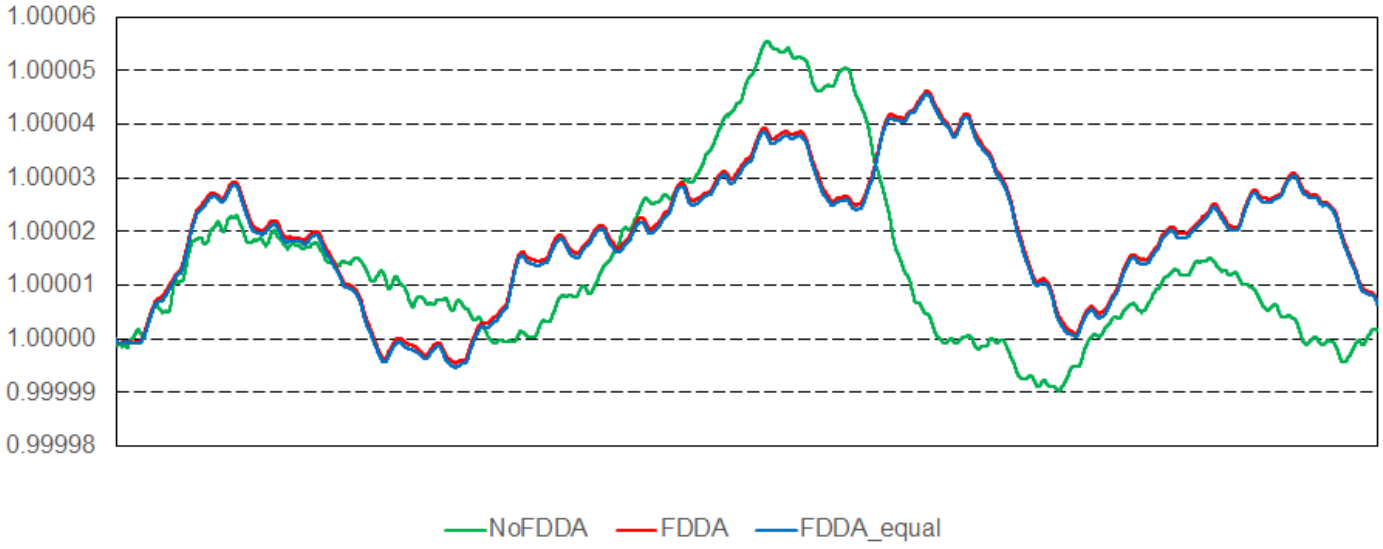
Scaled Water Vapor Mass - July 2013



Scaled Moist Air Mass - January 2013



Scaled Moist Air Mass - July 2013



Continuing Work

- Why did analysis nudging cause the KF scheme to create such a tall updraft? (We've seen warnings written to fort.98 in WRF)
- Why does "scaled" nudging no longer show improvements now that AMET uses barycentric interpolation?
- Still trying to provide something like "spectral" nudging for MPAS
- More frequent updates to reference fields (3-hour, 1-hour?)
- Thanks to Jerry Herwehe and Rob Gilliam, analysis nudging, advanced KF (sub-grid radiation, dynamic tau), and other physics options (ACM2, P-X) are now working in MPAS v5.1
- Design is underway for coupling MPAS to CMAQ. (Hosein Foroutan and others at U.S. EPA)

Questions?