Ensemble Kalman filter data assimilation for the MPAS system

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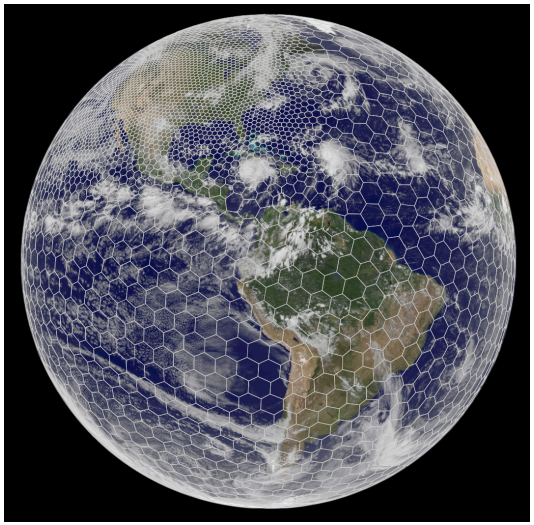
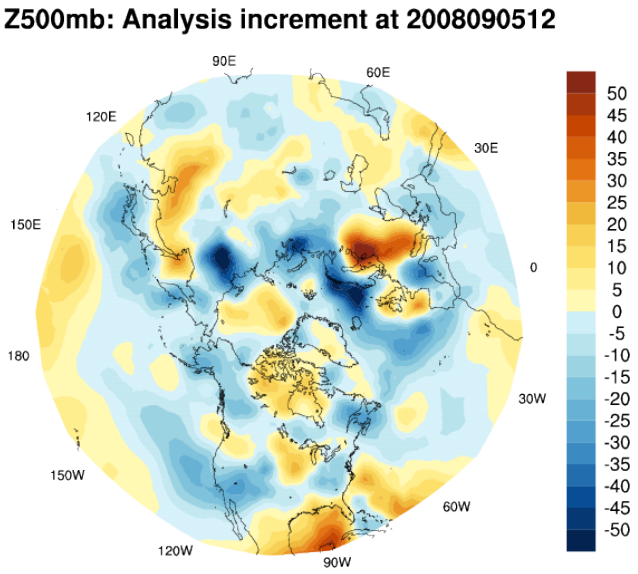
Nancy Collins, Michael Duda, Laura Fowler and Tim Hoar

National Center for Atmospheric Research





MPAS
Model for Prediction Across Scales

Based on unstructured centroidal Voronoi (hexagonal) meshes using C-grid staggering and selective grid refinement.

Jointly developed, primarily by NCAR and LANL/DOE

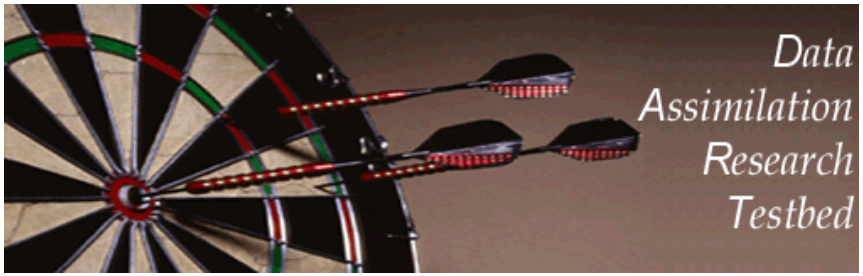
Current version: 2.0

http://mpas-dev.github.io/

MPAS Version 3.0 will be released soon (for both MPAS-Atmosphere and MPAS-Ocean core)

MPAS-A development team in MMM:

Bill Skamarock, Joe Klemp, Michael Duda, Laura Fowler, Sang-Hun Park



A community facility for ensemble data assimilation developed and maintained by the Data Assimilation Research Section (DAReS) at NCAR

The latest release (e.g., the "Lanai" version) of DART includes the MPAS-A and MPAS-O interfaces.

http://www.image.ucar.edu/DAReS/DART/Lanai_release.html

DART development team:

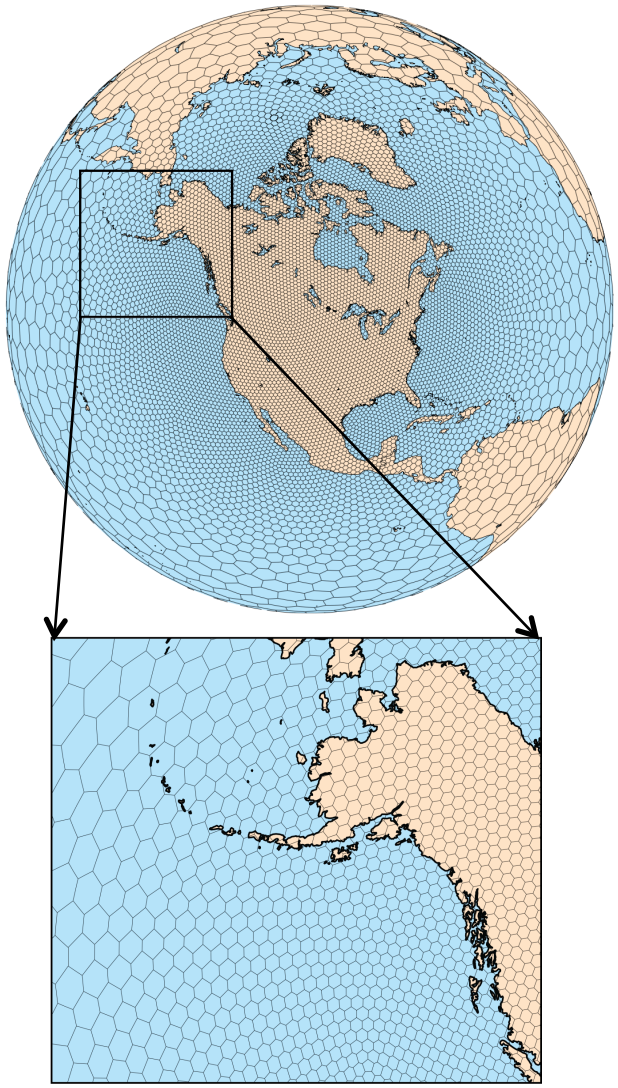
Jeff Anderson, Nancy Collins, Tim Hoar (IMAGe/UCAR)

MPAS-DART interface:

So-Young Ha and Chris Snyder (MMM/NCAR)

MPAS
Model for Prediction Across Scales

MPAS-Atmosphere

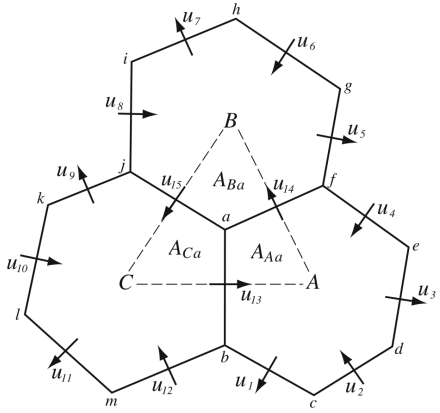


Unstructured spherical Centroidal Voronoi meshes

- Mostly *hexagons*, some pentagons and 7-sided cells.
- Cell centers are at cell center-of-mass.
- Lines connecting cell centers intersect cell edges at right angles.
- Lines connecting cell centers are bisected by cell edge.
- Mesh generation uses a density function.
- Uniform resolution – traditional icosahedral mesh.

C-grid staggering

Solve for normal velocities on cell edges.



Solvers

Fully compressible nonhydrostatic equations

Current Physics

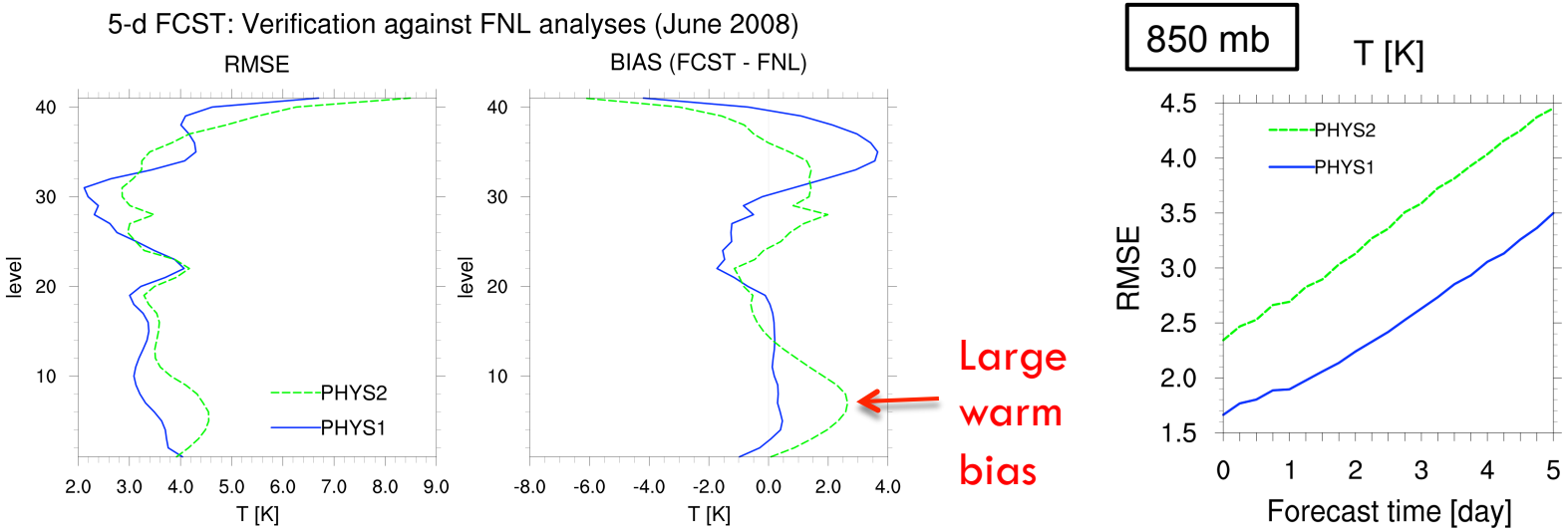
- Noah LSM, Monin-Obukhov surface layer
- YSU PBL
- WSM6, Thompson microphysics
- Kain-Fritsch and Tiedtke cumulus parameterization
- RRTMG and CAM longwave and shortwave radiation

Model diagnostics thru MPAS/DART cycling

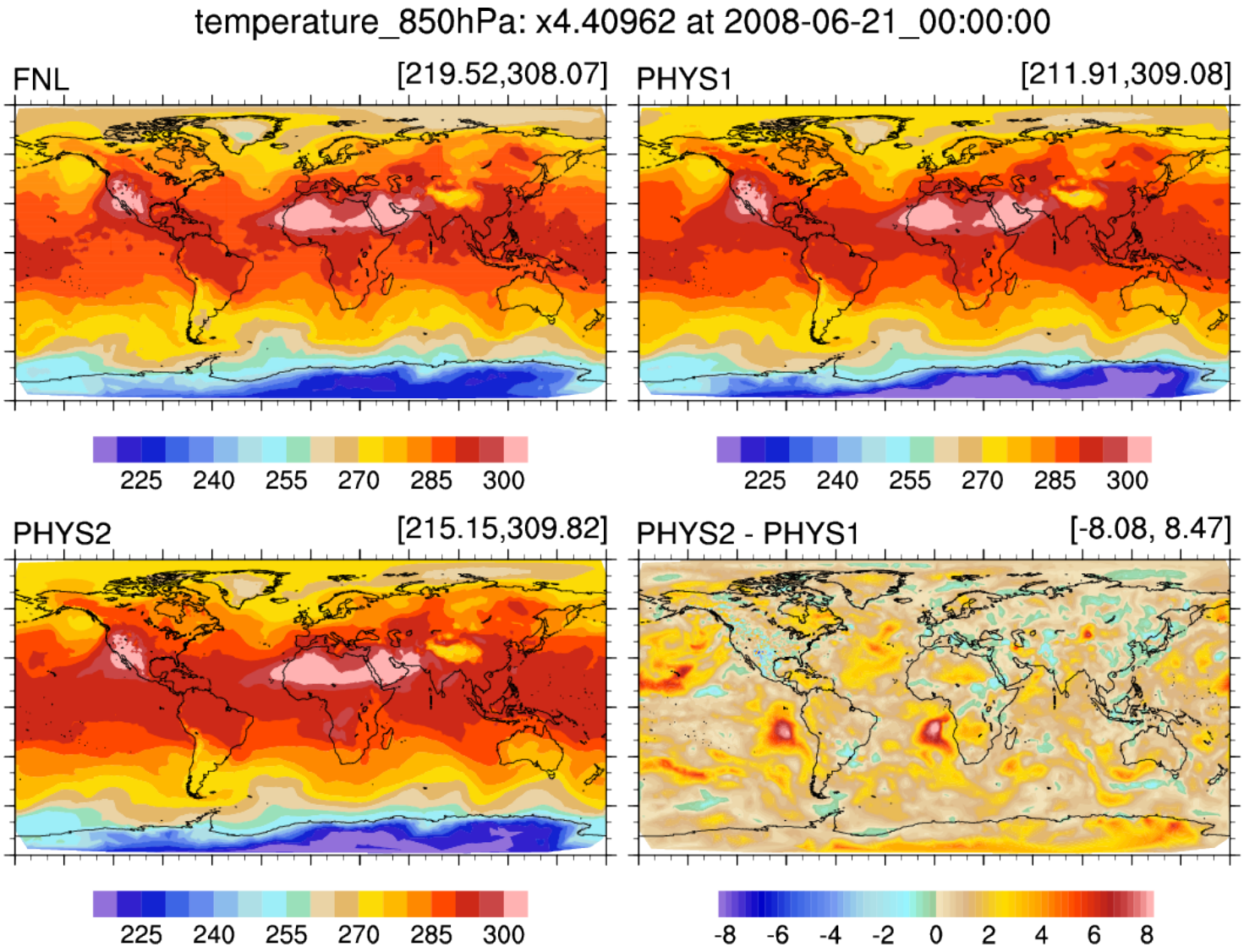
- Different model bias from different physics

- Analysis/forecast cycling for June 2008 with the assimilation of real observations on the variable mesh
  - PHYS1: Tiedtke cumulus and CAM LW/SW radiation
  - PHYS2: Kain-Fritsch cumulus and RRTMG LW/SW radiation

=> Verification of 5-day forecasts from the EnKF mean analysis against FNL analyses



Model diagnostics thru MPAS/DART cycling (cont'd)



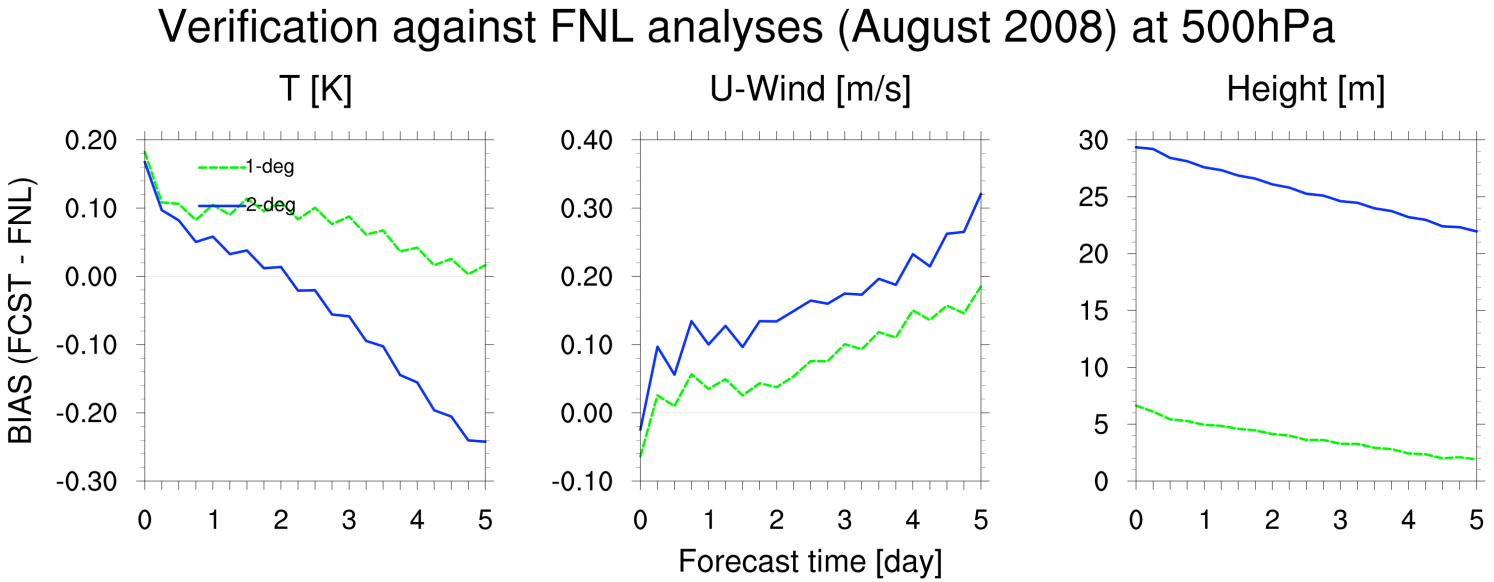
Model diagnostics thru MPAS/DART cycling (cont'd)

- Effect of the model grid resolution

: Analysis/forecast cycling for Aug 2008 with the assimilation of real observations on the quasi-uniform mesh (details coming later)

  - 1-degree vs. 2-degree resolution

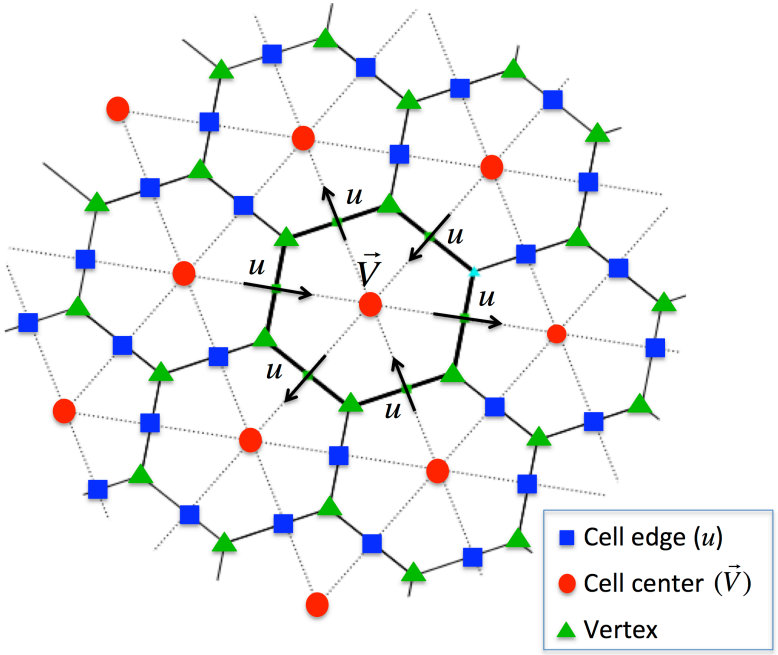
=> Verification of 5-day forecasts from the EnKF mean analysis against FNL analyses

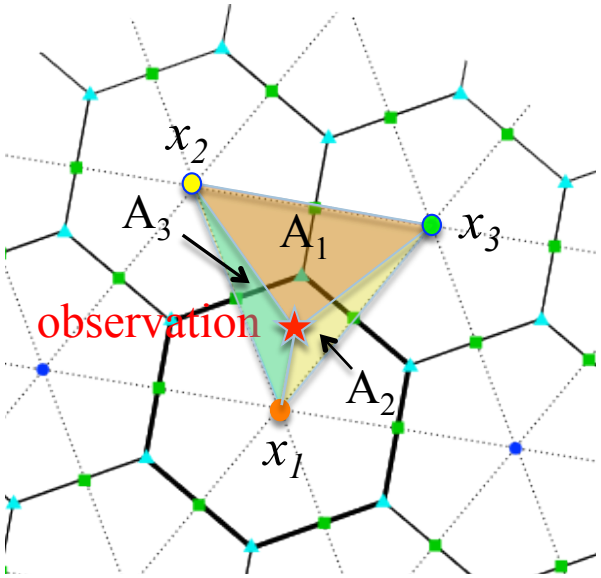


=> High resolution is beneficial. In particular, bias grows quickly in the 2-degree run.

MPAS/DART: Observation operators

- Built on the unstructured grid mesh (using a dual mesh of a Voronoi tessellation)
- Barycentric interpolation in the triangle for scalar variables
- As a prognostic wind variable is normal velocity on the edge, there are various options to assimilate wind observations.





MPAS/DART-Atmosphere: Observation operators (cont'd)

https://subversion.ucar.edu/DAReS/DART/trunk/models/mpas_atm/model_mod.html

Wind_DA options

use_u_for_wind: .false. / .true.

State vector

- .false.: $\vec{V}$ — Zonal and meridional winds at cell center
- .true.: u — Normal component of velocity on the edge

Horizontal interpolation

- .false.: Barycentric
- .true.: Radial Basis Function : RBF → use_rbf_option (= 1, 2, or 3)

Analysis update for *u*

update_u_from_reconstruct

- .true. → use_increments_for_u_update
  - Cell_wind .true.:

$$u_{13}^a = u_{13}^b + 0.5*(\Delta\vec{V}_A + \Delta\vec{V}_C)$$
$$u_{14}^a = u_{14}^b + 0.5*(\Delta\vec{V}_A + \Delta\vec{V}_B)$$
$$u_{15}^a = u_{15}^b + 0.5*(\Delta\vec{V}_B + \Delta\vec{V}_c)$$
$$where\ \Delta\vec{V} = \vec{V}^a - \vec{V}^b$$

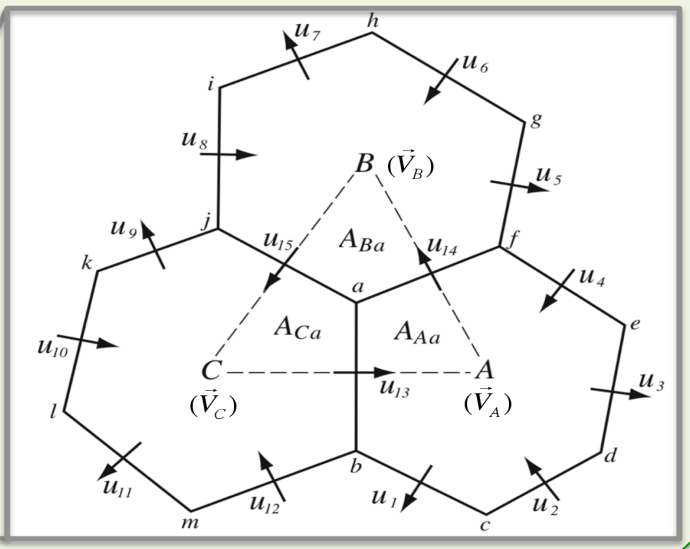
  - Cell_wind .false.:

$$u_{13}^a = 0.5*(\vec{V}_A^a + \vec{V}_C^a)$$
$$u_{14}^a = 0.5*(\vec{V}_A^a + \vec{V}_B^a)$$
$$u_{15}^a = 0.5*(\vec{V}_B^a + \vec{V}_C^a)$$

  - use_increments_for_u_update .false.: u updated by filter

- .false. → u updated by filter

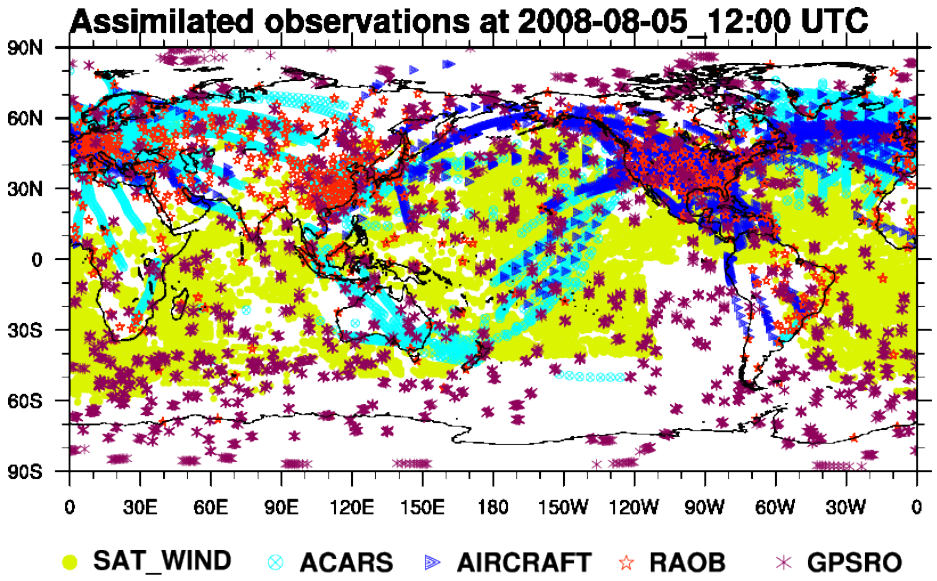
u updated by filter → Edge_wind

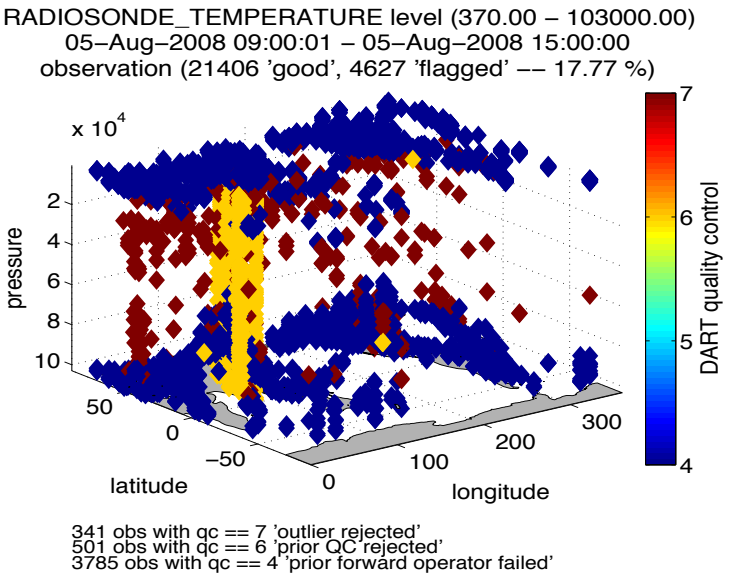


*Superscript **a** stands for "analysis" and **b** "background".*

Assimilation of real observations in MPAS/DART

- Model configuration: 80-member ensemble at ~2-degree uniform mesh, 41 vertical levels w/ the model top at 30-km
- Conventional observations (NCEP PrepBUFR) + GPS RO
- Ensemble filter data assimilation design: localization (1200H/4V), adaptive inflation in prior state, 6-hrly cycling for one month of August 2008.
- WRF-Physics: WSM6 microphysics, YSU PBL, NOAH LSM, Tiedtke cumulus parameterization, CAM SW/LW radiation schemes

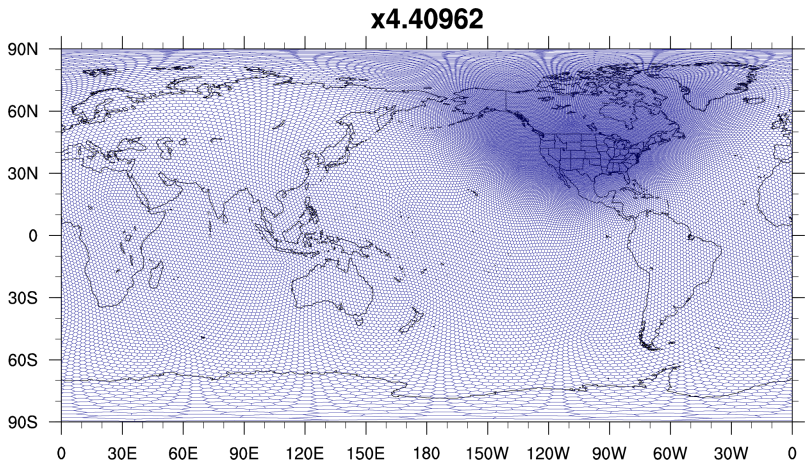




Sensitivity test

- Filter design
  - Adaptive inflation: on and off
  - Localization radius: horizontal and vertical
  - Ensemble size
- Model design
  - Grid resolutions: {1- vs. 2-degree} and {uniform vs. variable} mesh
  - Different physics parameterizations

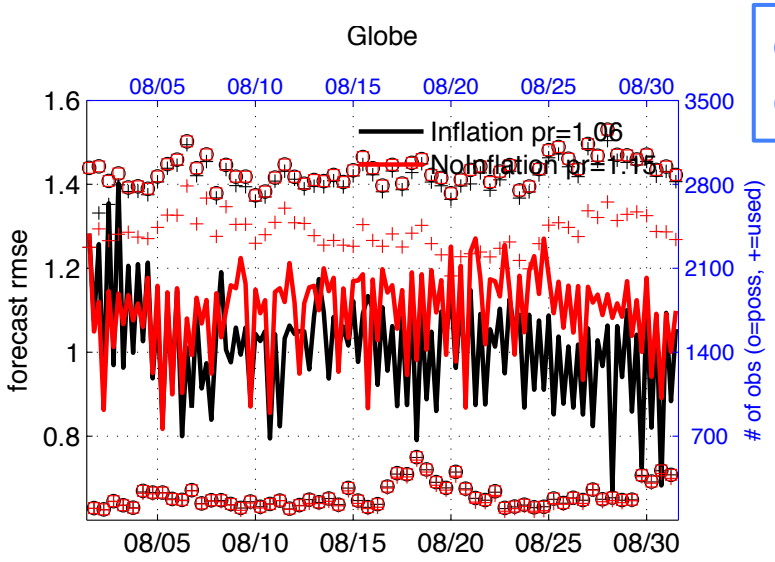
	Uniform		Variable
240km	X1.10242	240-60km	X4.40962
120km	X1.40962		
60km	X1.163842	60-15km	x4.535554
15km	X1.2621442		



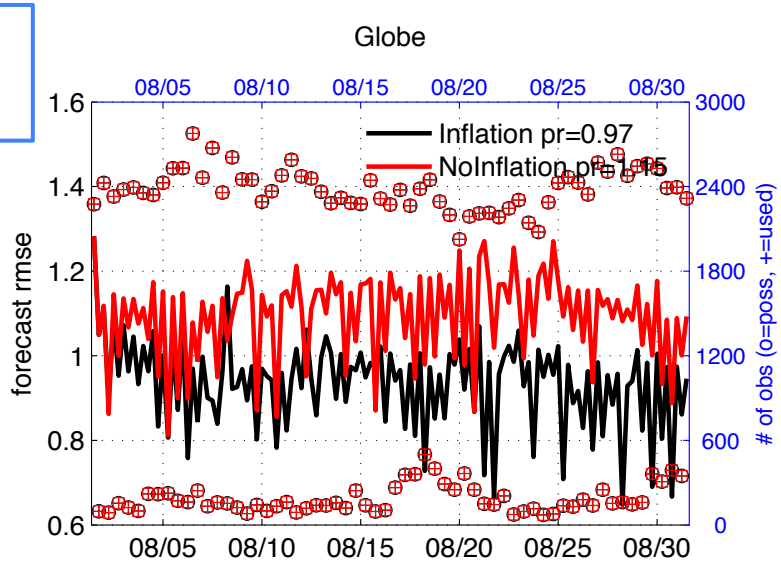
Sensitivity test: Adaptive inflation (on and off)

RADIOSONDE_TEMPERATURE @ 500 hPa

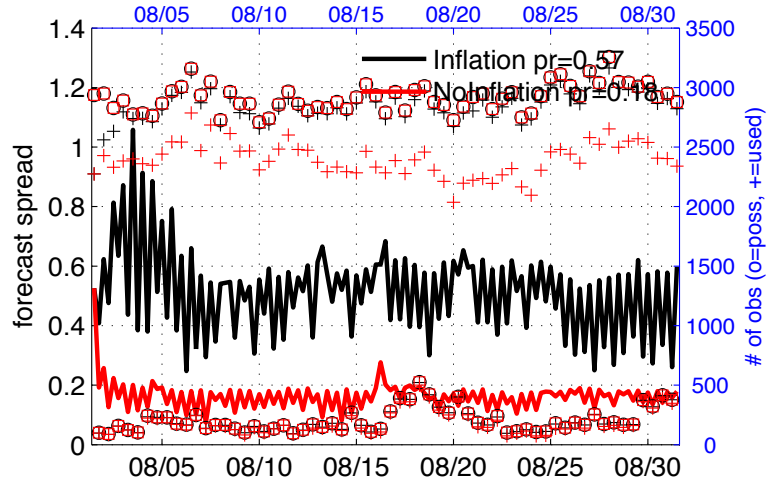
RMSE



Common OBS



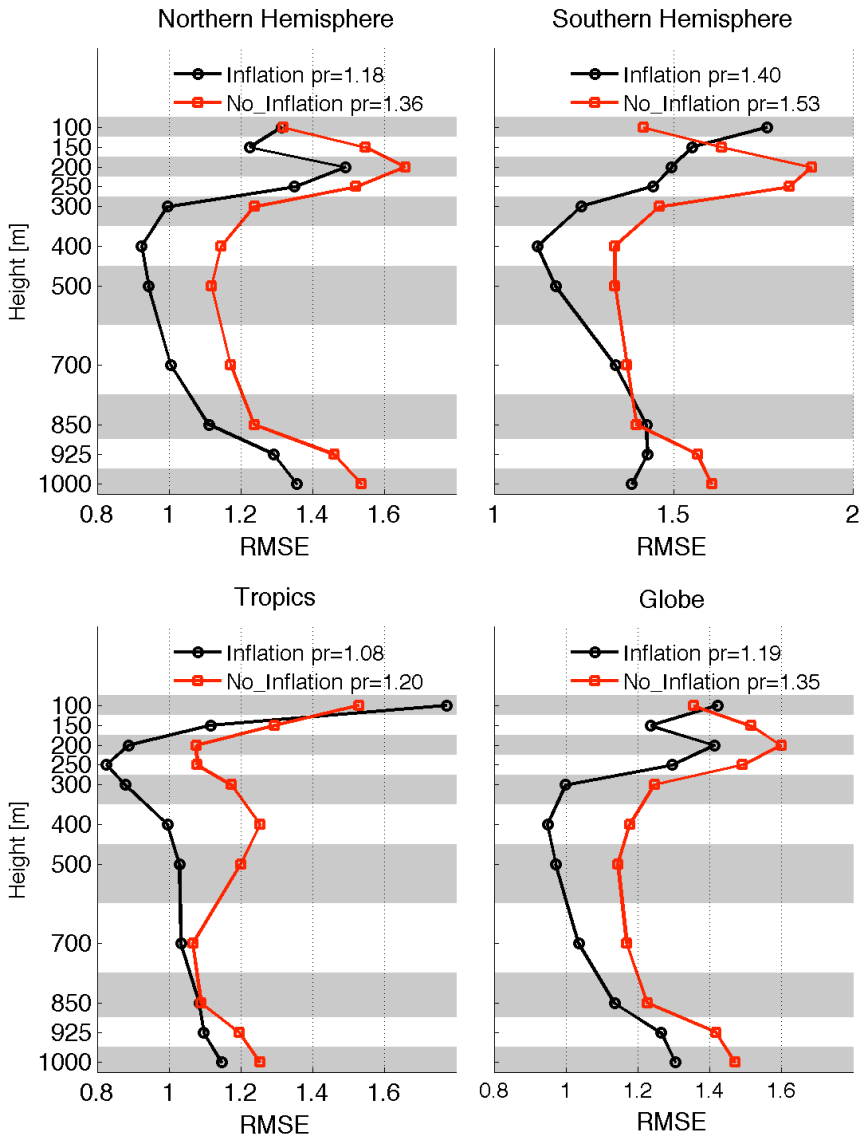
SPRD



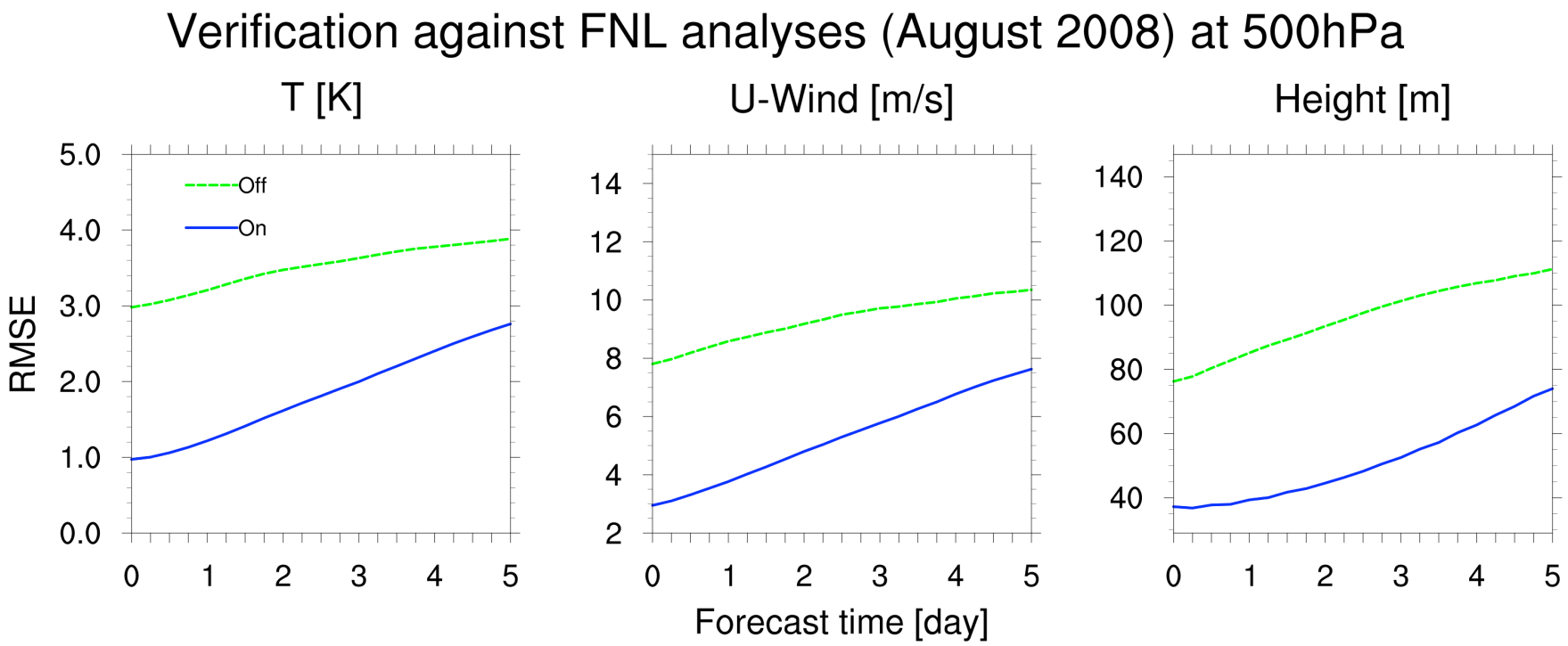
- Adaptive covariance inflation (Anderson 2009) improved the 6-h forecast skills by up to 15% throughout the period.
- Without inflation, ensemble spread was quickly reduced and remained small rejecting more observations, which led to a bad performance.

Adaptive inflation (cont'd)

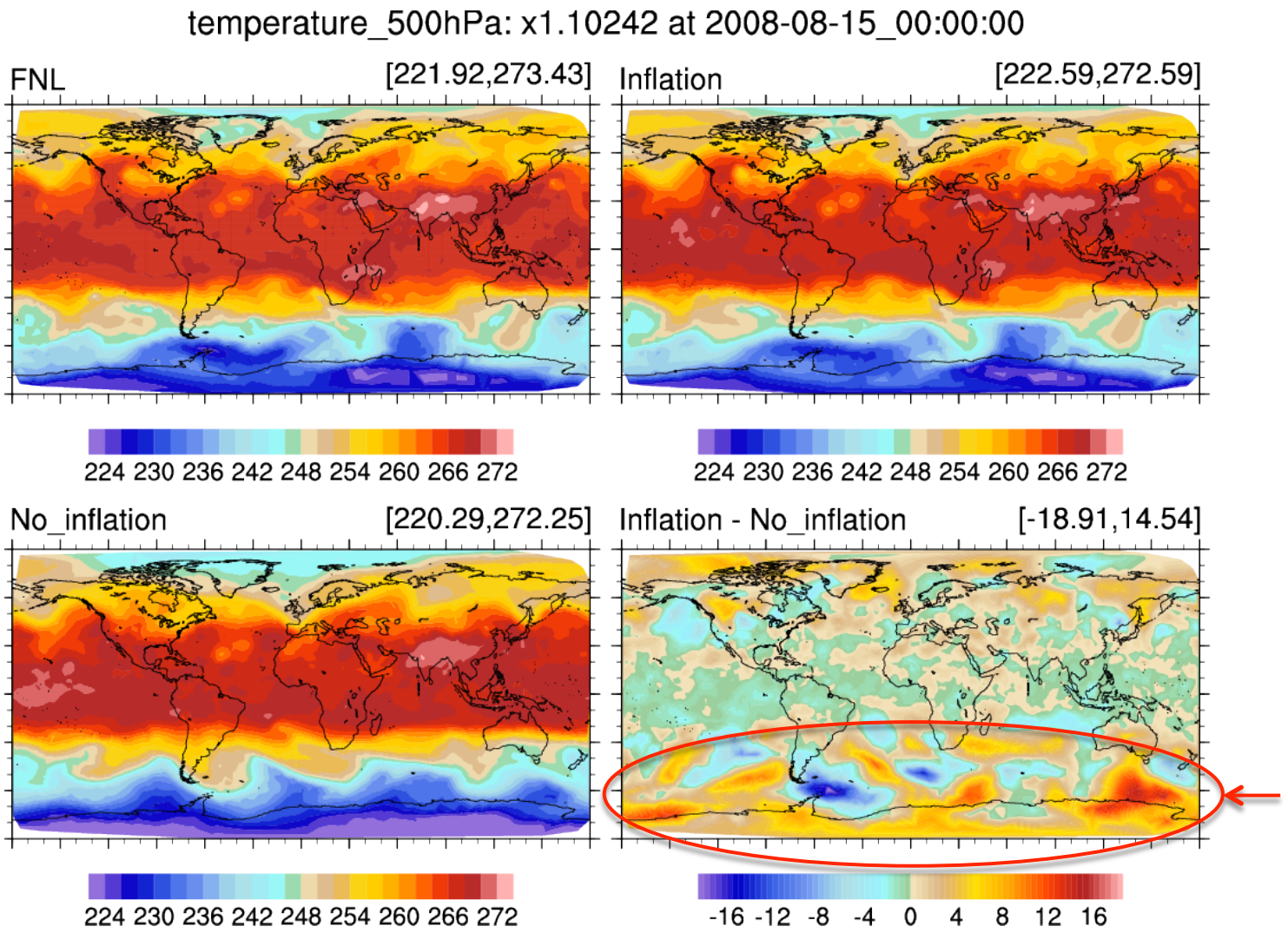
RADIOSONDE_TEMPERATURE



Adaptive inflation (cont'd)



Adaptive inflation (cont'd)

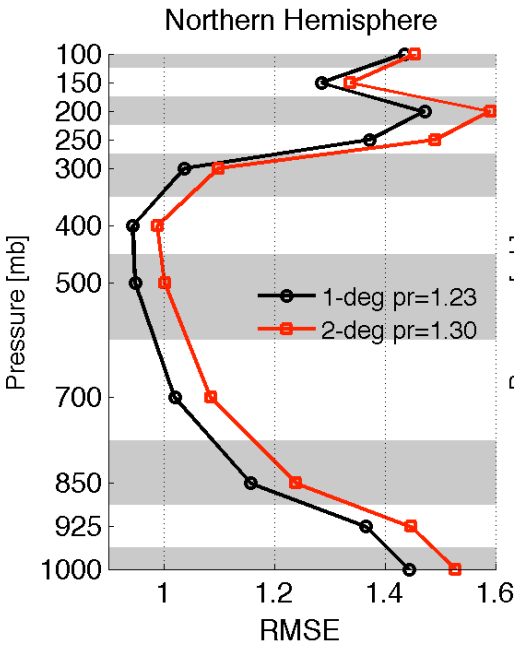


Large errors in SH w/o inflation

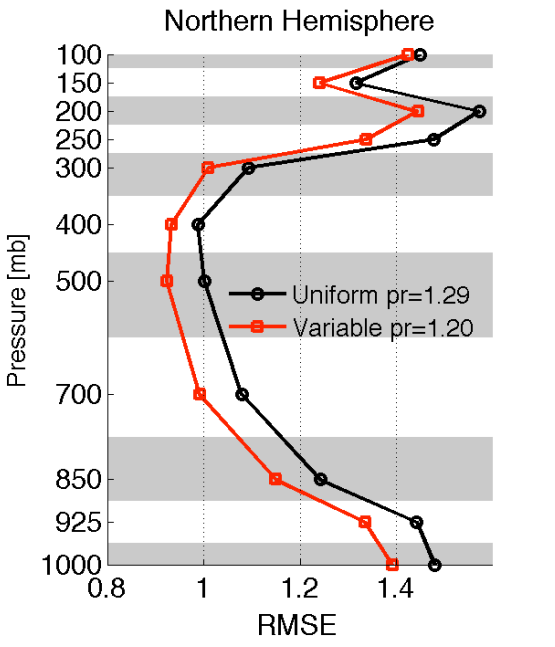
Sensitivity test: Grid resolutions

RADIOSONDE_TEMPERATURE

1-deg vs. 2-deg



Uniform vs. variable mesh



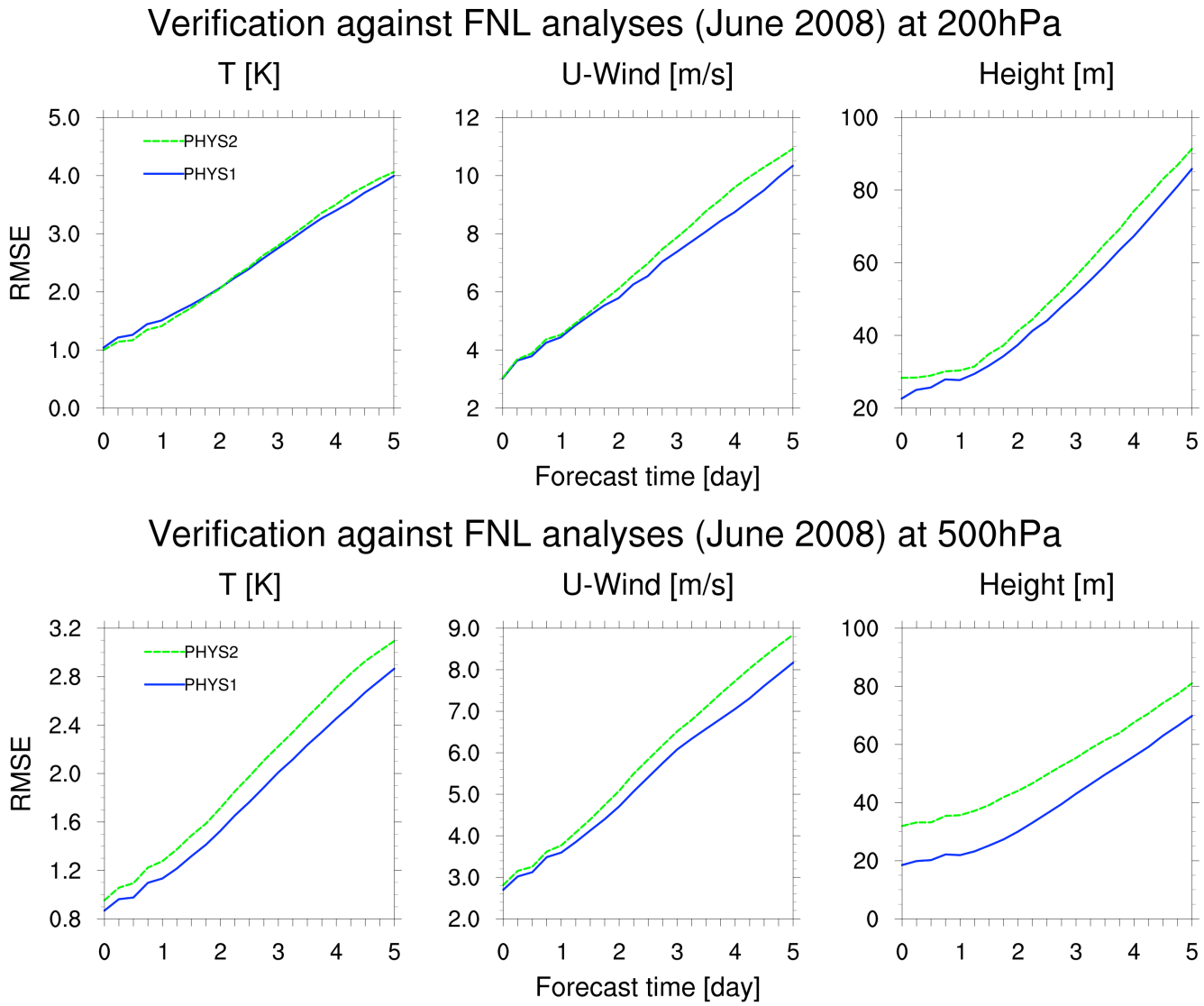
- In quasi-uniform meshes, double the resolution increased the 6-h forecast skill by ~5% (in a verification against common observations).
- A variable mesh with a 1:4 ratio reduces the grid resolution from 240-km in the globe down to 60-km resolution over the CONUS.
- In the variable mesh, the fine-mesh area showed the better fits to the observations.

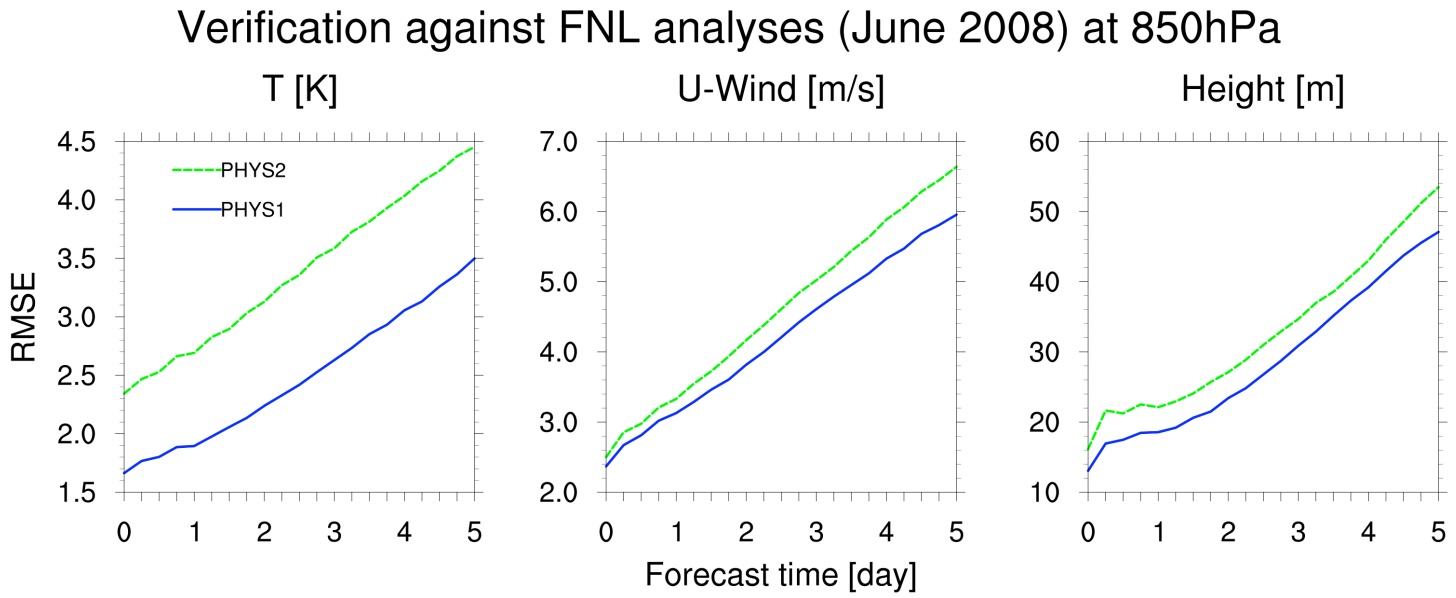
Summary and future plans for MPAS/DART

- The MPAS/DART interface is available with the full capability, officially released in the latest version of DART.
- The analysis/forecast cycling was successfully tested assimilating real observations for summer months of 2008, contributing to the MPAS model development by identifying the systematic issues in the model.
- The performance skill of MPAS can be further improved by more physics options such as GFS or CAM physics – ongoing research.
- More tests will be done for a longer period on the higher resolution meshes focusing on the direct comparison of quasi-uniform and variable meshes on the simulation of regional-scale features.
- Plans for the MPAS data assimilation system:

  - Hybrid GSI/EnKF: Jeff Whitaker (ESRL/NOAA), Tom Auligné (MMM/NCAR)

  - Satellite radiance and aerosol data assimilation


Verification against FNL analyses (June 2008) at 200hPa
T [K]
U-Wind [m/s]
Height [m]
RMSE
PHYS2
PHYS1
Forecast time [day]
Verification against FNL analyses (June 2008) at 500hPa
T [K]
U-Wind [m/s]
Height [m]
RMSE
PHYS2
PHYS1
Forecast time [day]


Verification against FNL analyses (June 2008) at 850hPa
T [K]
U-Wind [m/s]
Height [m]
RMSE
PHYS2
PHYS1
4.5
4.0
3.5
3.0
2.5
2.0
1.5
7.0
6.0
5.0
4.0
3.0
2.0
60
50
40
30
20
10
0
1
2
3
4
5
Forecast time [day]