Some best practices for WRFDA

Craig Schwartz
NCAR/NESL/MMM

schwartz@ucar.edu

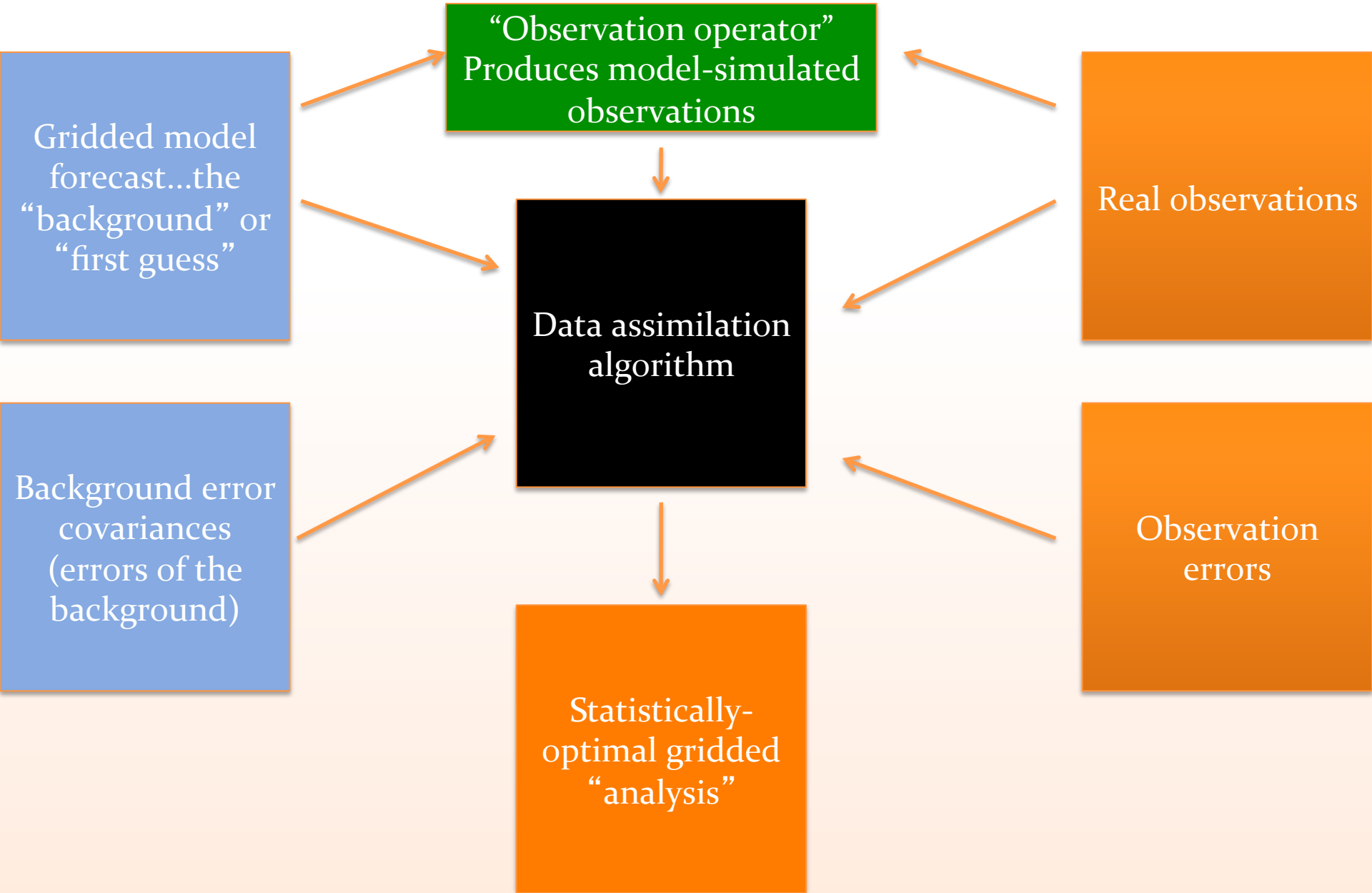
NCAR is sponsored by the National Science Foundation

What is data assimilation?

- Data assimilation (DA) is a statistical method

- In the atmospheric sciences, DA involves combining a model and observations, along with their respective errors, to produce an *analysis* that can initialize a numerical weather prediction model (i.e., WRF)

What is data assimilation?



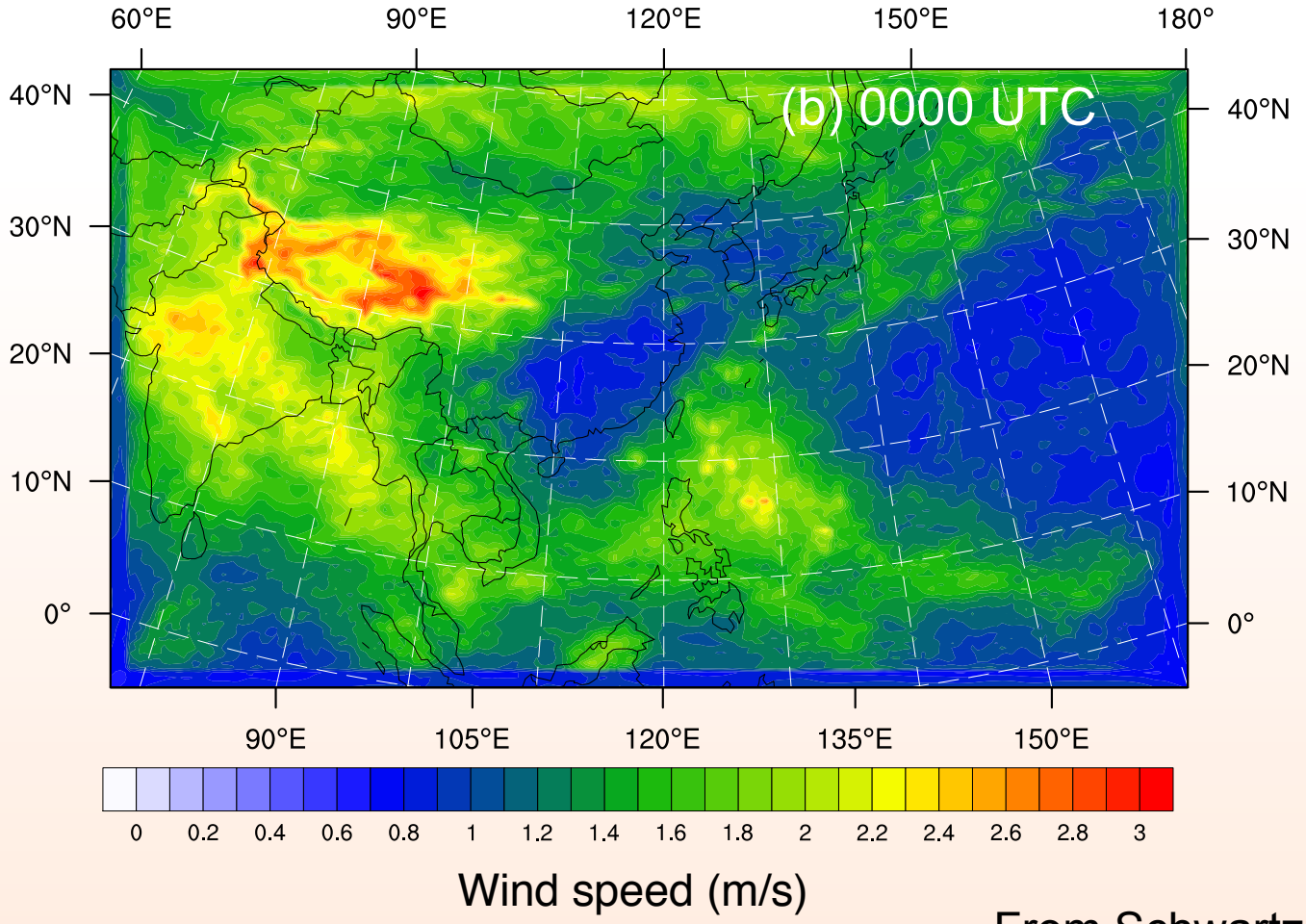
A few data assimilation approaches

- Three-dimensional variational (3DVAR)
  - Background error covariances (BECs) typically fixed/ time-invariant
  - May yield poor results when actual flow differs from that encapsulated within the fixed "climatology"
  - Supported in WRFDA

- Ensemble Kalman filter (EnKF)
  - Time-evolving, "flow-dependent" BECs estimated from a short-term ensemble forecast
  - WRFDA supports an EnKF flavor called the ETKF

Ensemble BECs (i.e., spread)

- Average ensemble spread of wind speed over ~3 weeks at oooo UTC



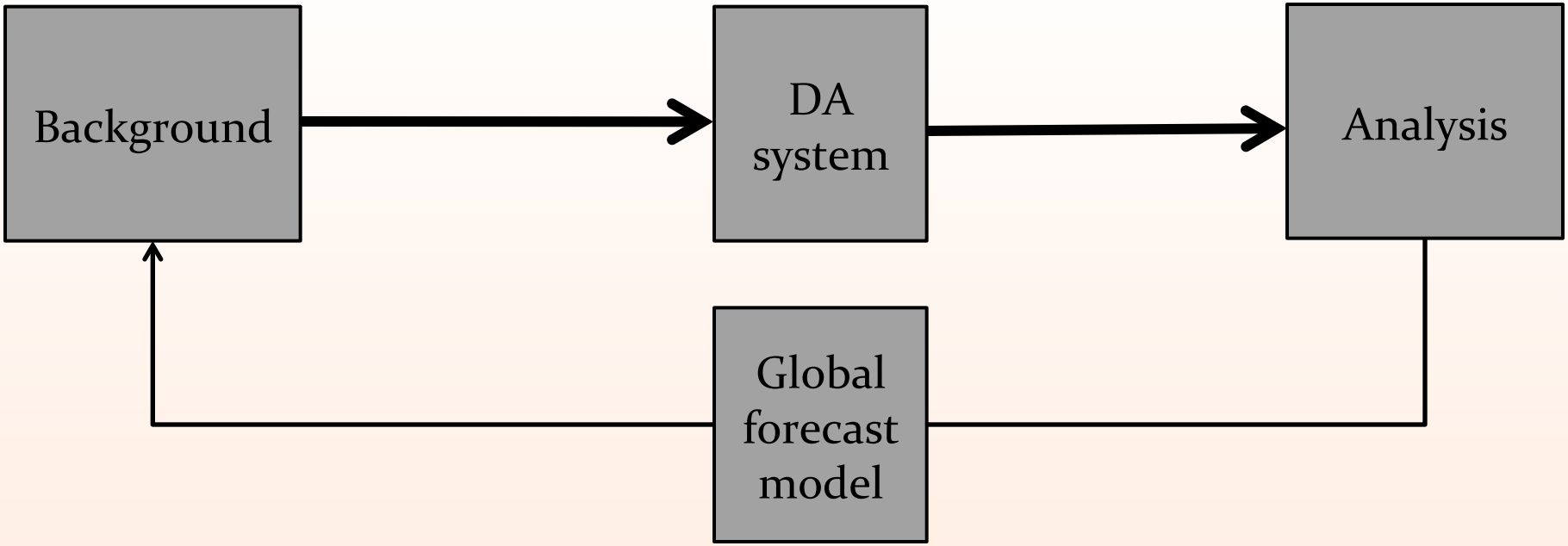
From Schwartz et al. (2013)

A few data assimilation approaches

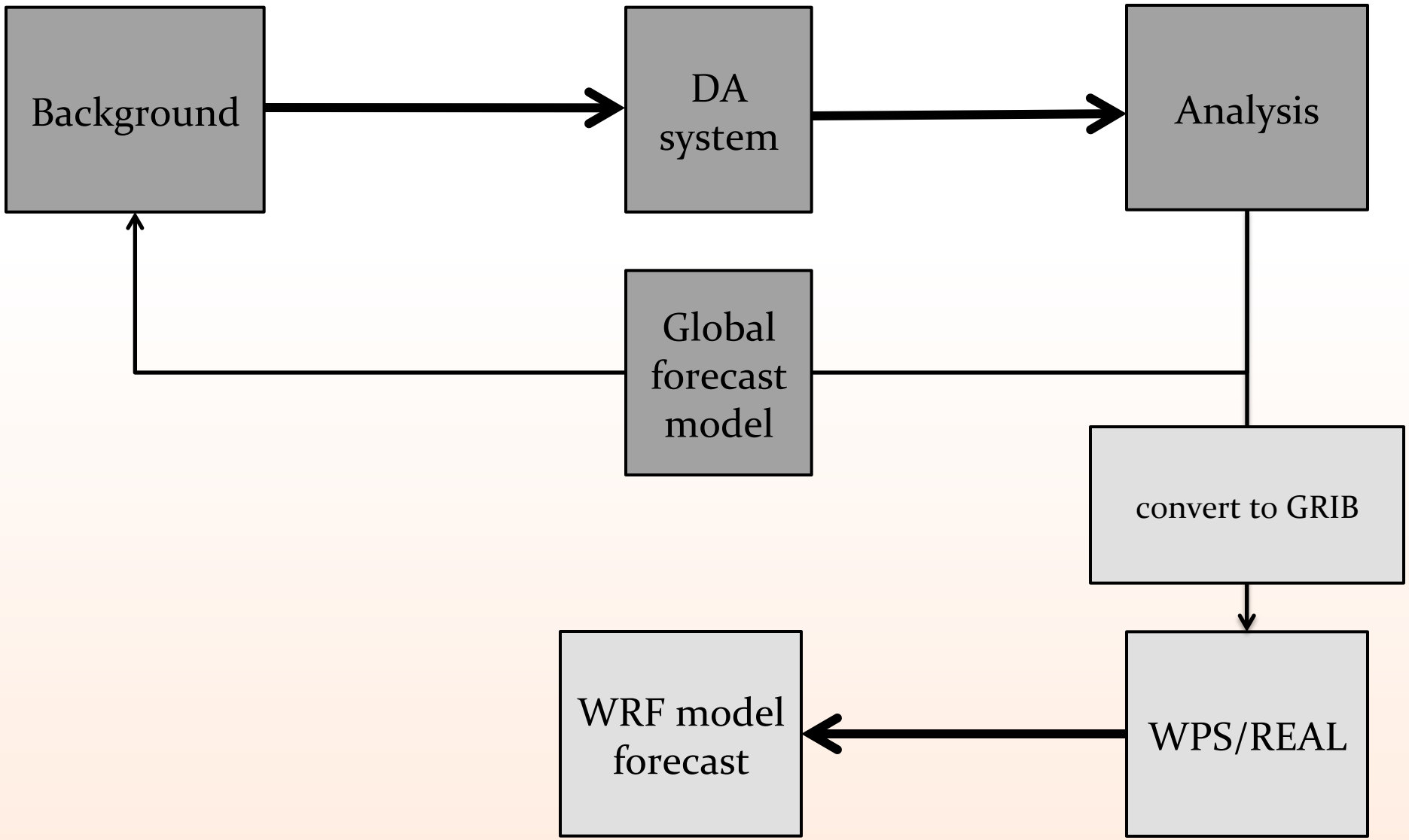
- "Hybrid" variational/ensemble
  - Incorporates ensemble background errors within a variational (e.g., 3DVAR) framework
  - Combination of fixed and time-evolving background errors
  - Supported in WRFDA

Global data assimilation and WRF

- Global modeling systems employ "continuously cycling" data assimilation



Global data assimilation and WRF



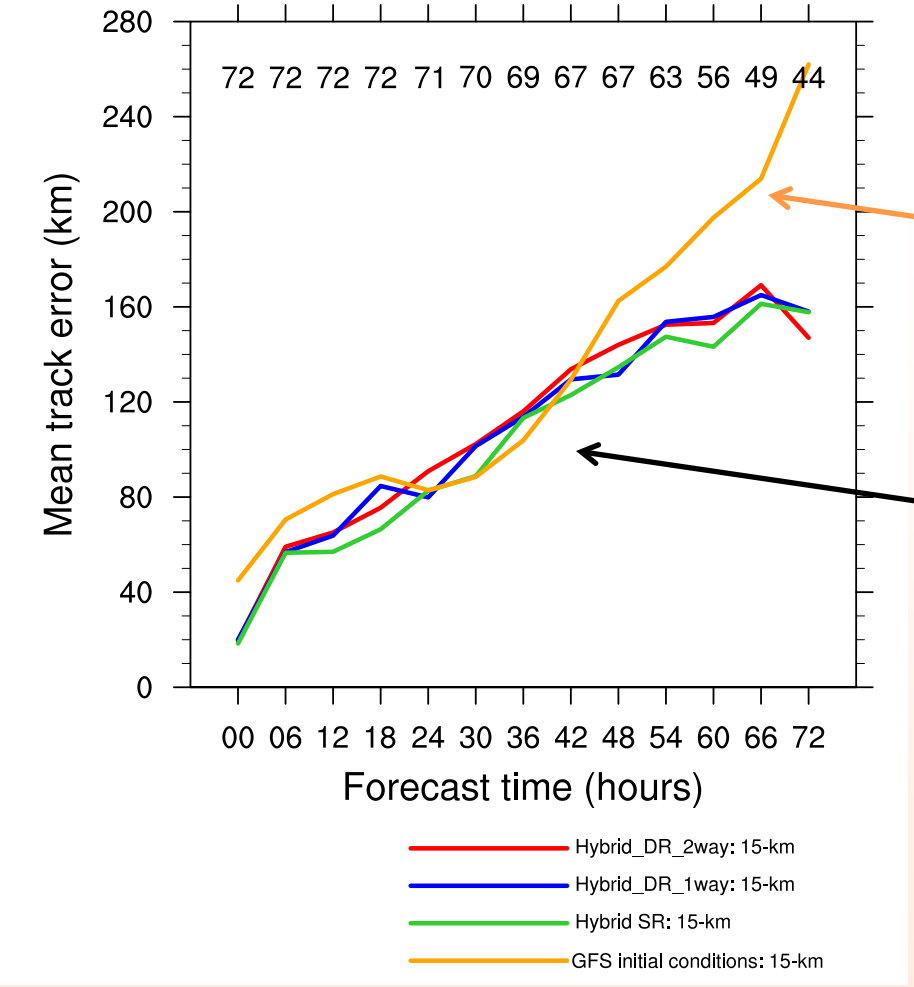
Global data assimilation and WRF

- When you initialize WRF from GFS, ECMWF, NAM, or other *analyses*, you implicitly employ data assimilation

- Can performing *regional* data assimilation with WRF improve forecasts?

Typhoon application with regional DA

- Typhoon track errors averaged over 3 typhoons

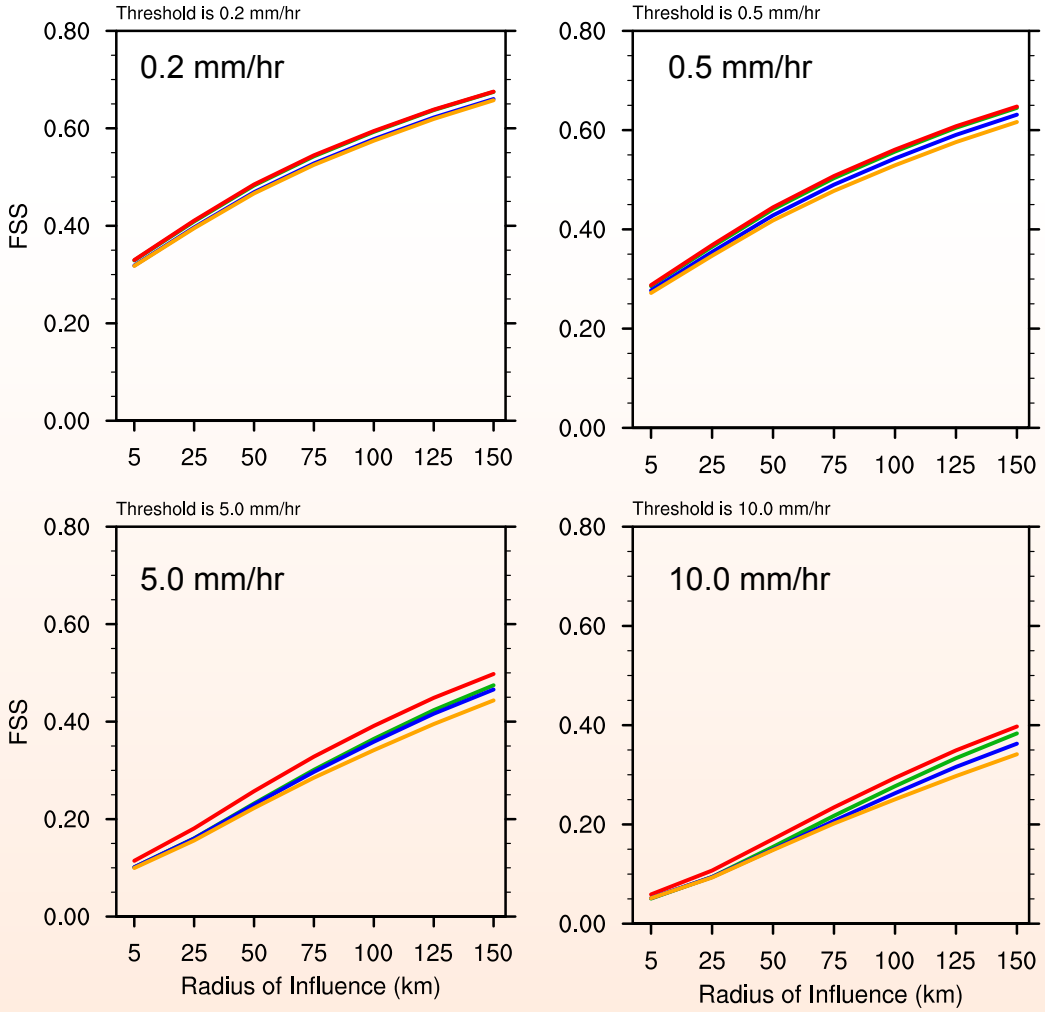


GFS initial conditions: no regional DA

These three experiments performed regional DA

Rainfall application with regional DA

- Fractions skill scores for rainfall (higher is better)



Aggregated over hourly 18-36-hr forecasts of precipitation

EnKF

Hybrid

3DVAR

GFS

Modified from Schwartz and Liu (2014)

But…

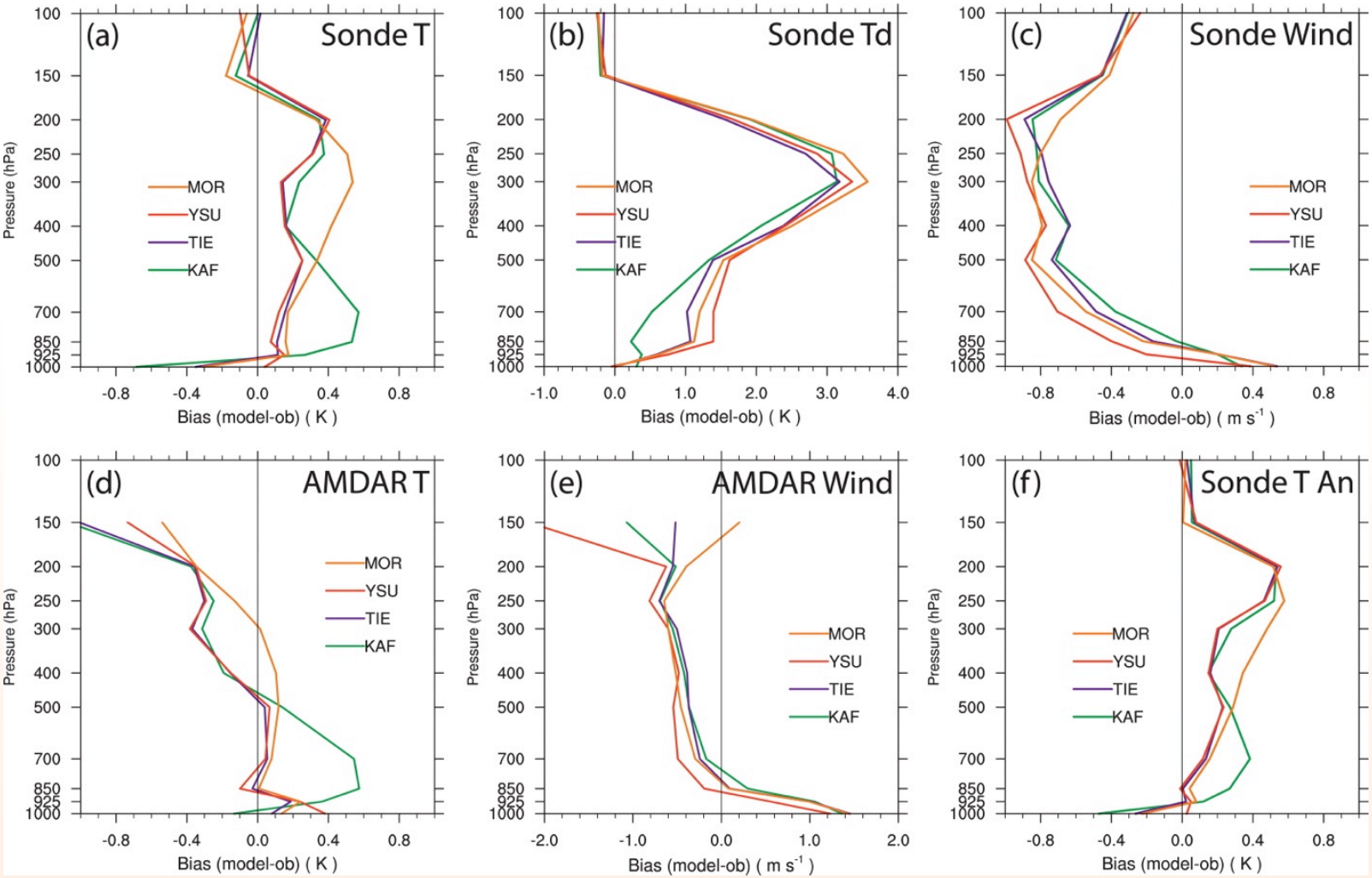
- Global analyses are improving and have increasingly high resolution

- To obtain benefits from regional DA, you must carefully consider your configurations and employ some “best practices”

Background source for regional analyses

- Continuous cycling
  - Will teach much about WRF's performance but may yield poor results due to "build-up" of model bias
- Very important to choose less-biased physics if attempting continuous cycling
- So, one of the "best practices" for WRFDA is choosing a proper *model* configuration

Model bias during continuous cycling



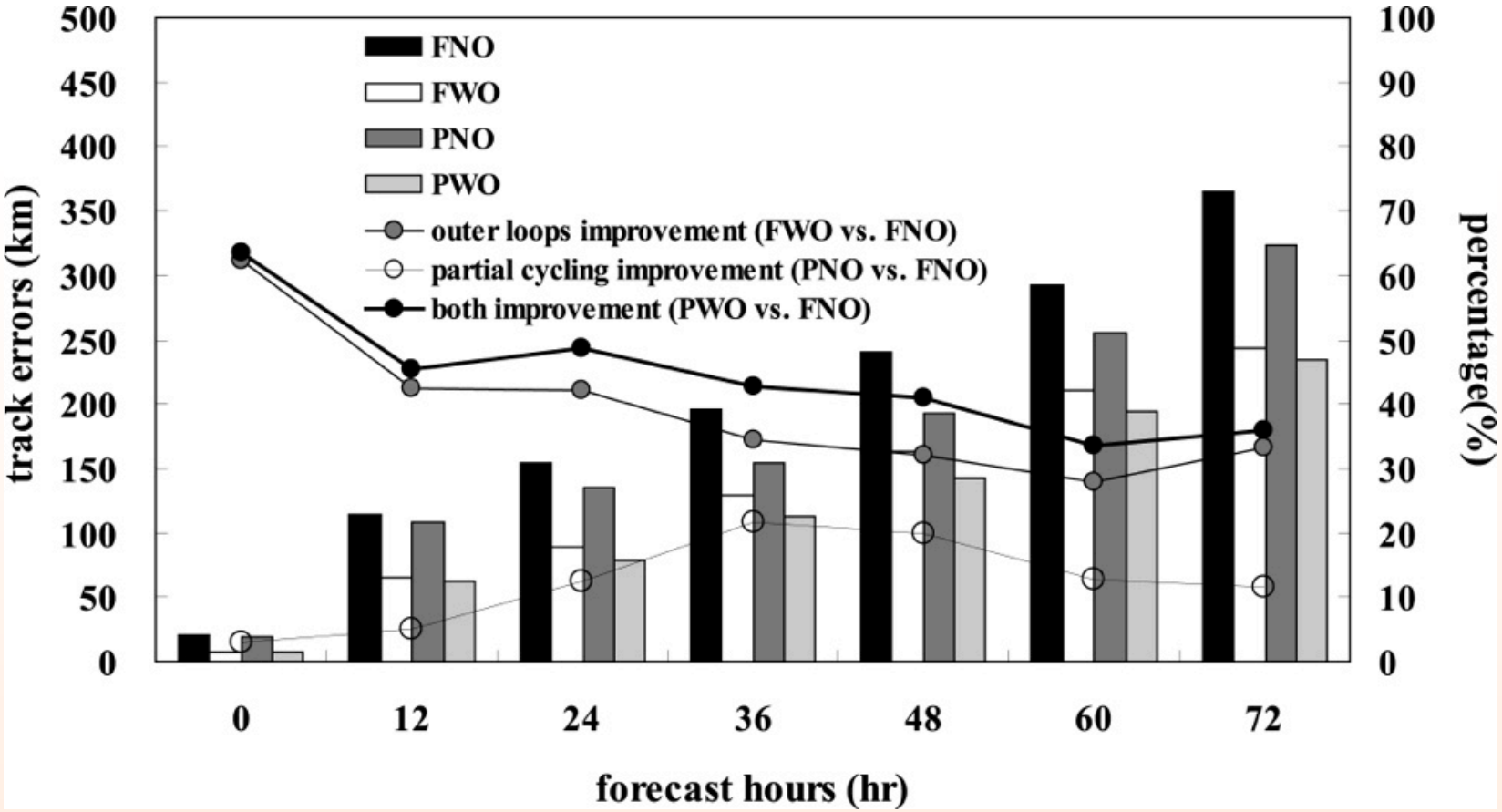
From Romine et al. (2013)

Background source for regional analyses

- "Partial cycling"
  - Continuously cycle for a few cycles, but occasionally "start over" with an external (i.e., GFS) analysis as the background
- Used by NAM and RAP

Partial versus full cycling

- Typhoon application



From Hsiao et al. (2012)

Background source for regional analyses

- Use GFS/NAM/ECMWF/etc. analysis as the background
- NCAR's Antarctic Mesoscale Prediction System (AMPS) uses this approach
- *Either this approach or partial cycling will likely yield best results but will not teach you as much about WRF*

Background error covariances

- Background error covariances are very important for successful analyses

- WRFDA provides a "default" background error covariance file
  - Works with any domain
  - Good for code testing
  - May provide poor results for your region

Background error covariances

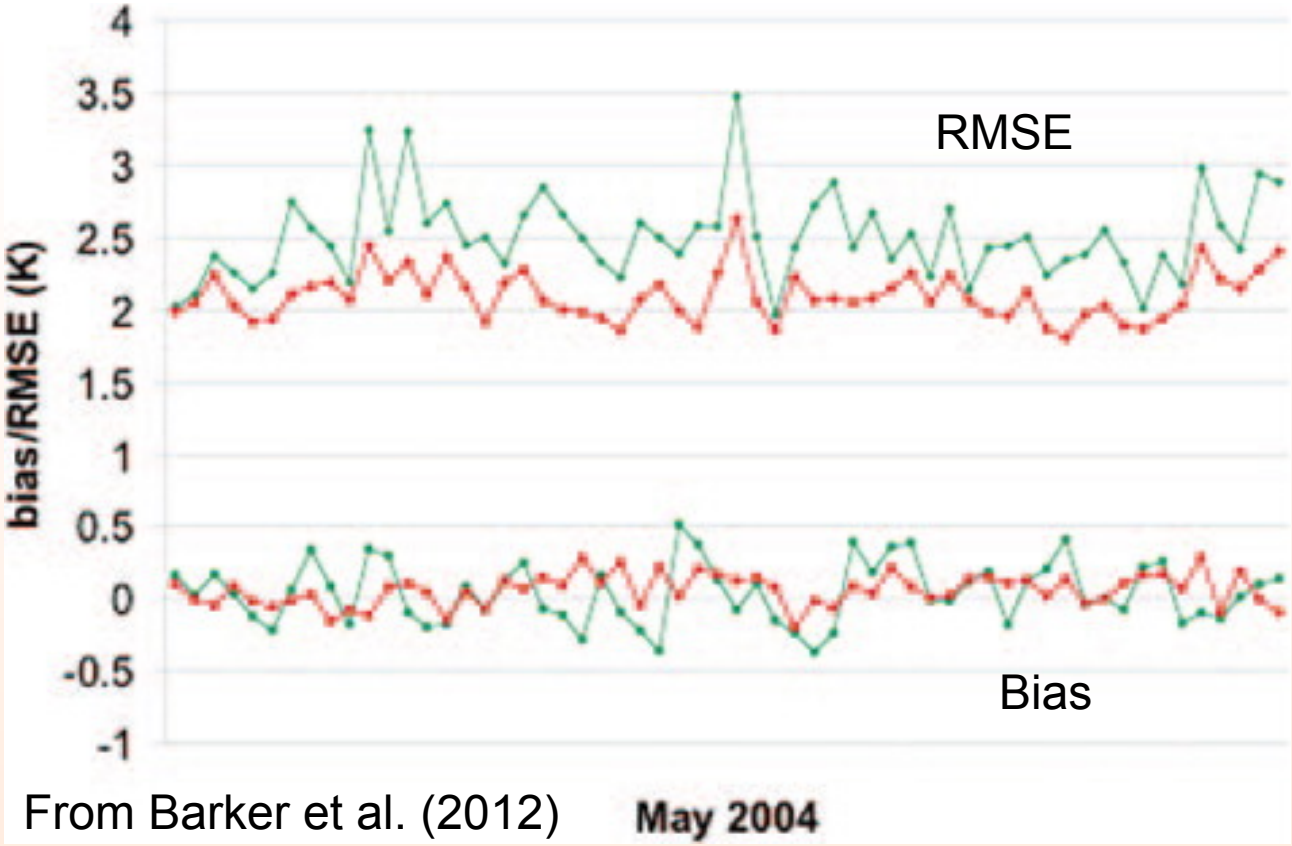
- WRFDA "gen_be" tool allows creation of background errors specifically for your domain
  - Usually done by taking differences between 24- and 12-hr forecasts valid at common times

- Producing region-specific background error covariances can greatly improve WRF analyses and forecasts

Example

- Green: default background errors
- Red: region-specific background errors
- Antarctic application—24-hr forecasts

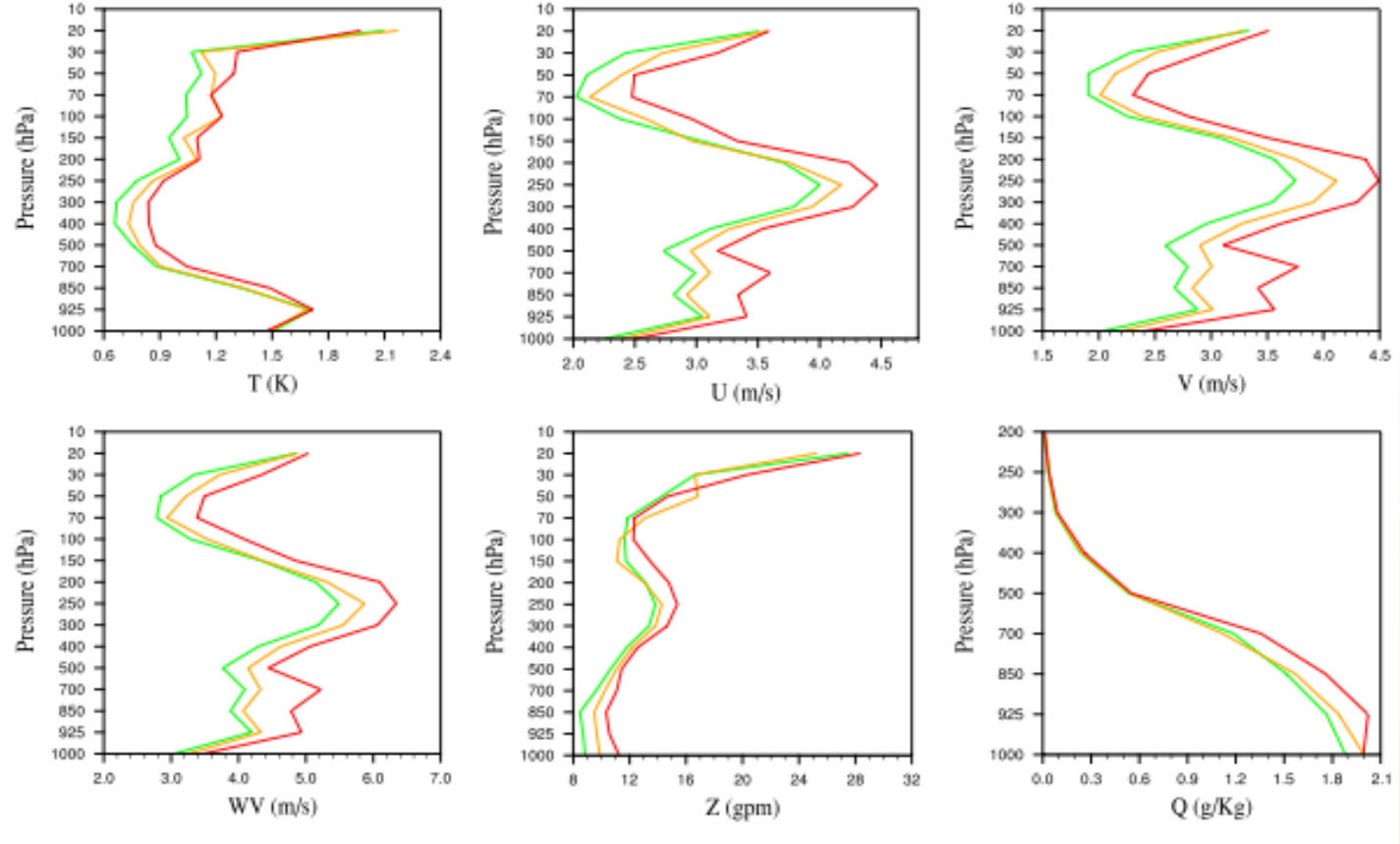
Temperature



From Barker et al. (2012)

Example

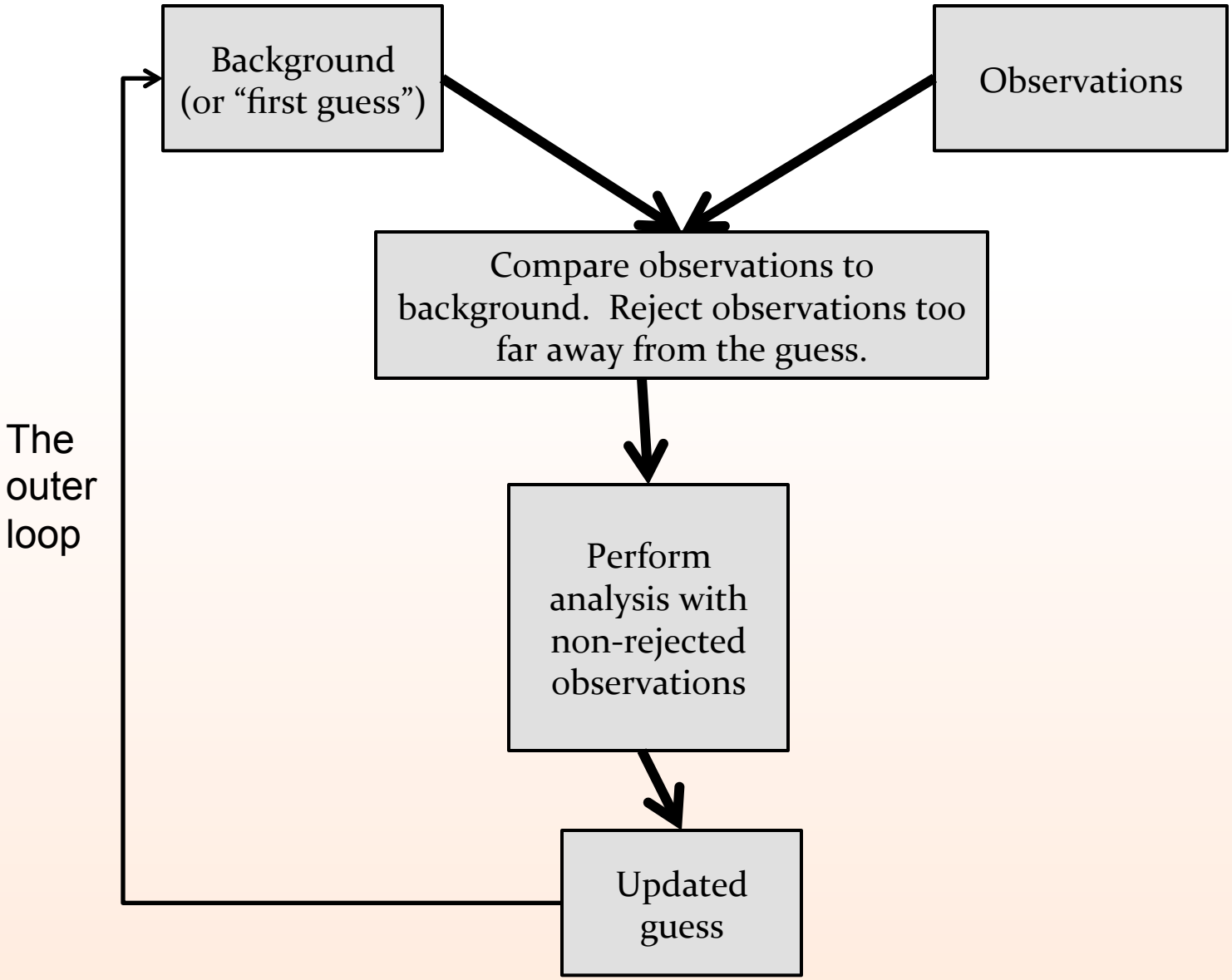
- Application over the Middle East
- RMSEs for 24-hr forecasts



Multiple outer loops

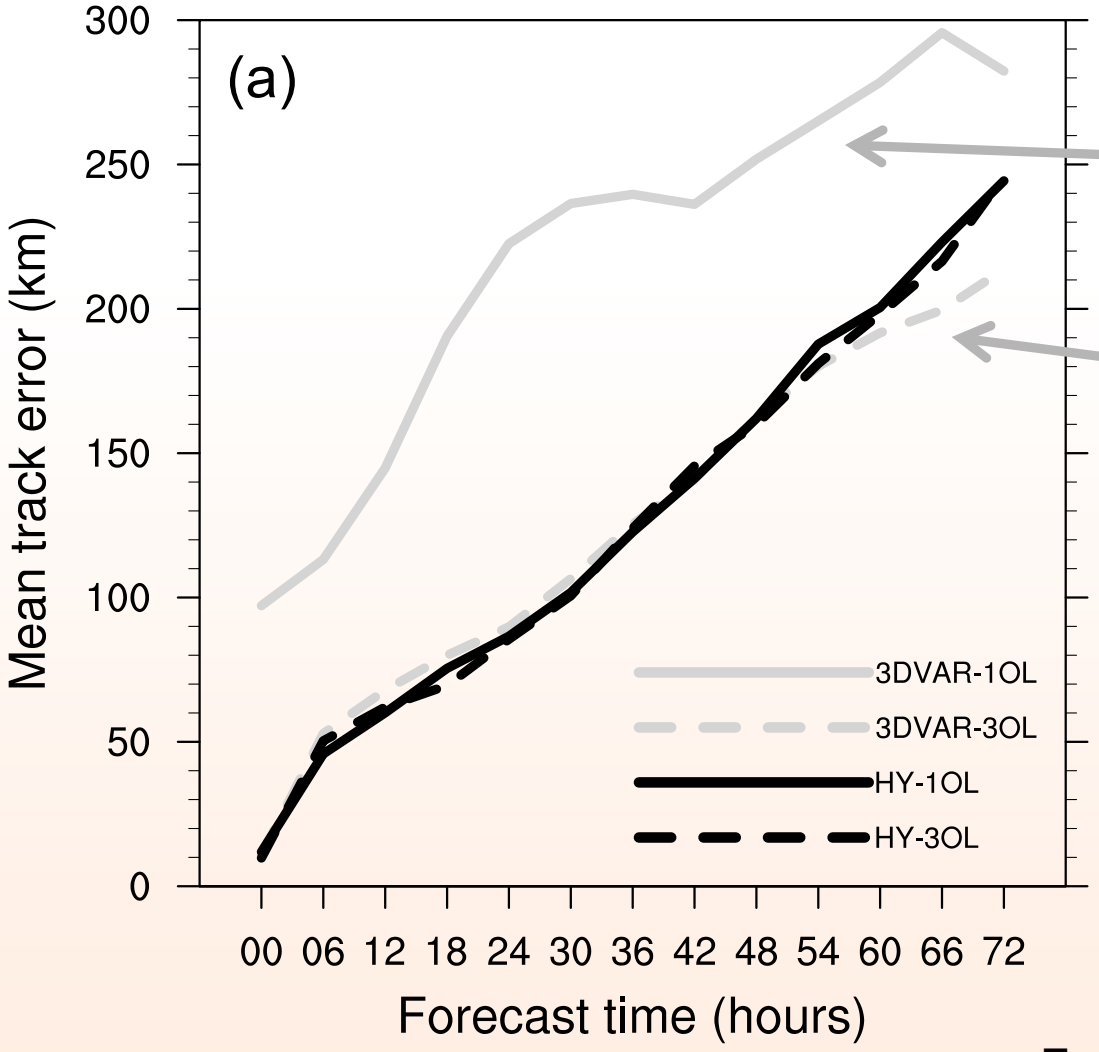
- Running WRFDA with multiple *outer loops* can improve forecasts
  - Each outer loop, observations are rejected based on their proximity to the model guess
  - Therefore, an observation rejected in an early outer loop may be assimilated in a later one
- Outer loops may have more of impact in 3DVAR analyses (as compared to hybrid analyses)

Simplistic outer loop schematic



Multiple outer loops

- Typhoon application



1 outer loop 3DVAR

3 outer loops 3DVAR

From Schwartz et al. (2013)

How to use multiple outer loops

- WRFDA namelist:

```
&wrfvar6
max_ext_its=3,
ntmax=100,100,100
/
```

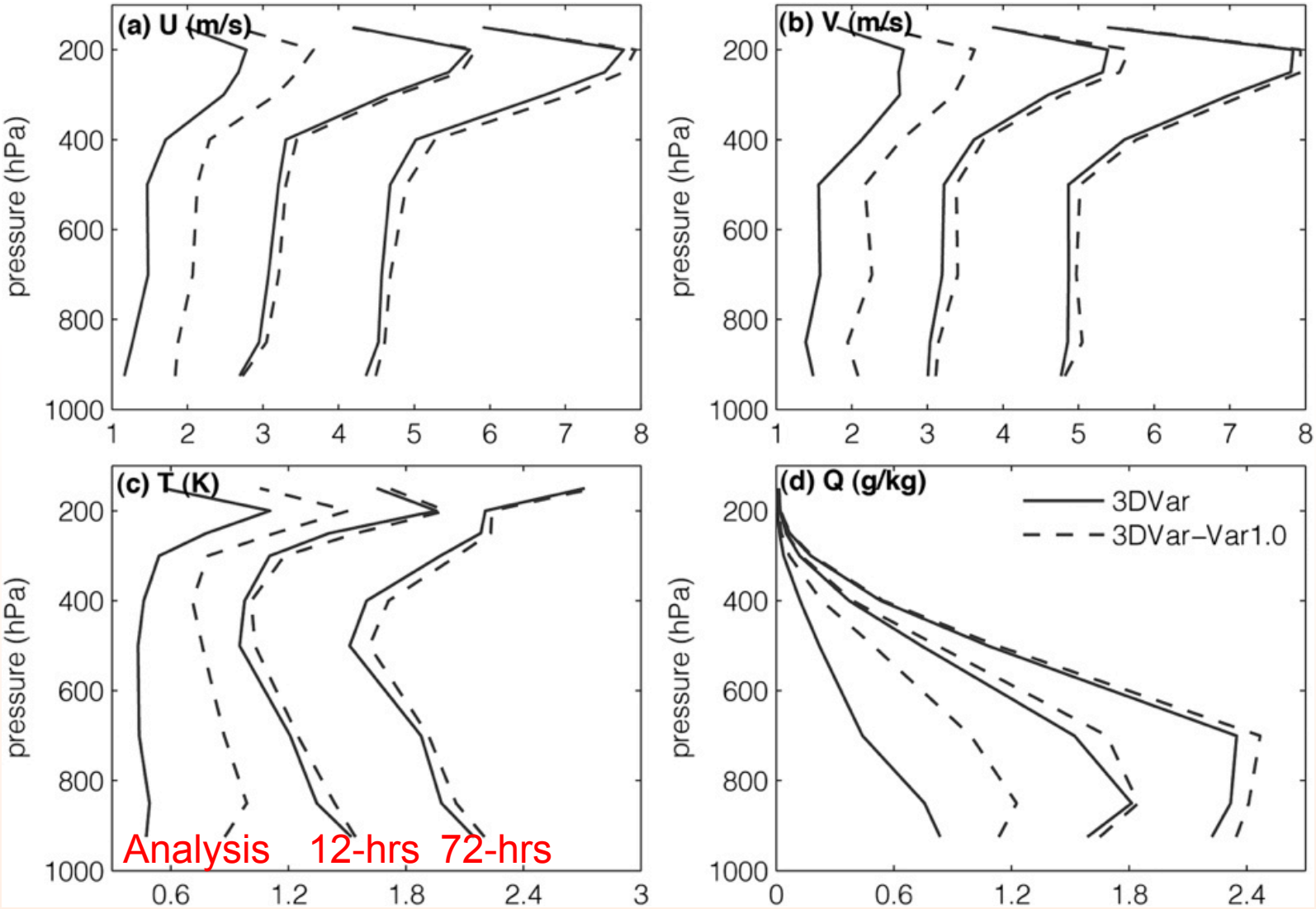
- max_ext_its is the number of outer loops
- ntmax is the number of iterations per outer loop and can differ for each outer loop

Background error tuning

- The background errors contain variances and length-scales that can be tuned and varied each outer loop

- Some studies have found that increasing the error variances (and fitting the observations closer) have improved forecasts (e.g., Zhang et al. 2013)

Example

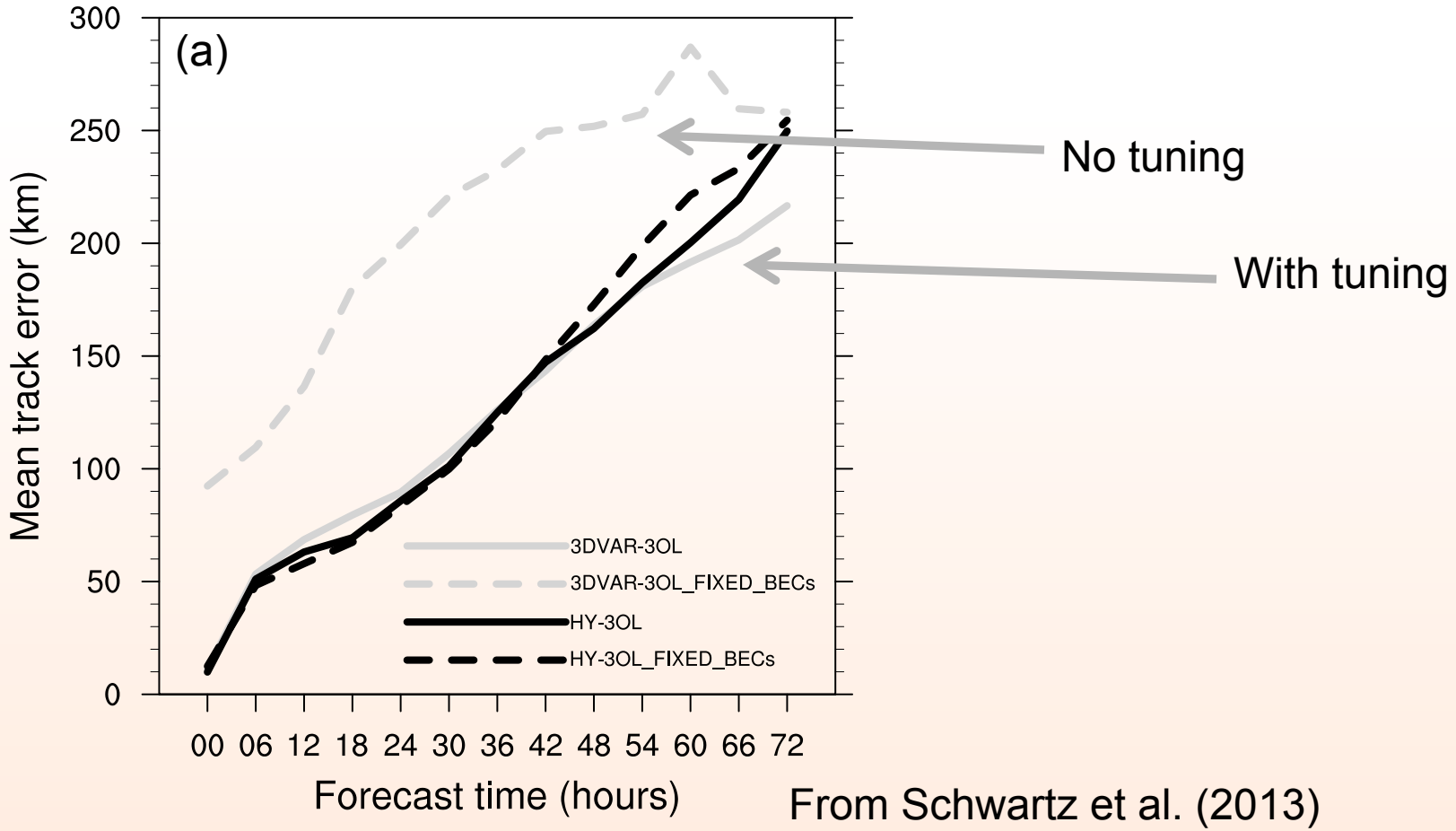


RMSEs

From Zhang et al. (2013)

Example

- Typhoon application
- Try to ignore the black lines



From Schwartz et al. (2013)

How to tune the static background errors

- WRFDA namelist:

```
&wrfvar7
cv_options=5,     ….cv_options=5 means user-generated file specific for your region
VAR_SCALING1=1.50,1.00,0.50,
VAR_SCALING2=1.50,1.00,0.50,
VAR_SCALING3=1.50,1.00,0.50,
VAR_SCALING4=1.00,1.00,0.50,
VAR_SCALING5=1.50,1.00,0.50,
LEN_SCALING1=1.00,0.50,0.25,
LEN_SCALING2=1.00,0.50,0.25,
LEN_SCALING3=1.00,0.50,0.25,
LEN_SCALING4=1.00,0.50,0.50,
LEN_SCALING5=1.00,0.50,0.20,
/
```

Standard deviations: > 1 means to make the background error standard deviation bigger (and fit observations more closely)

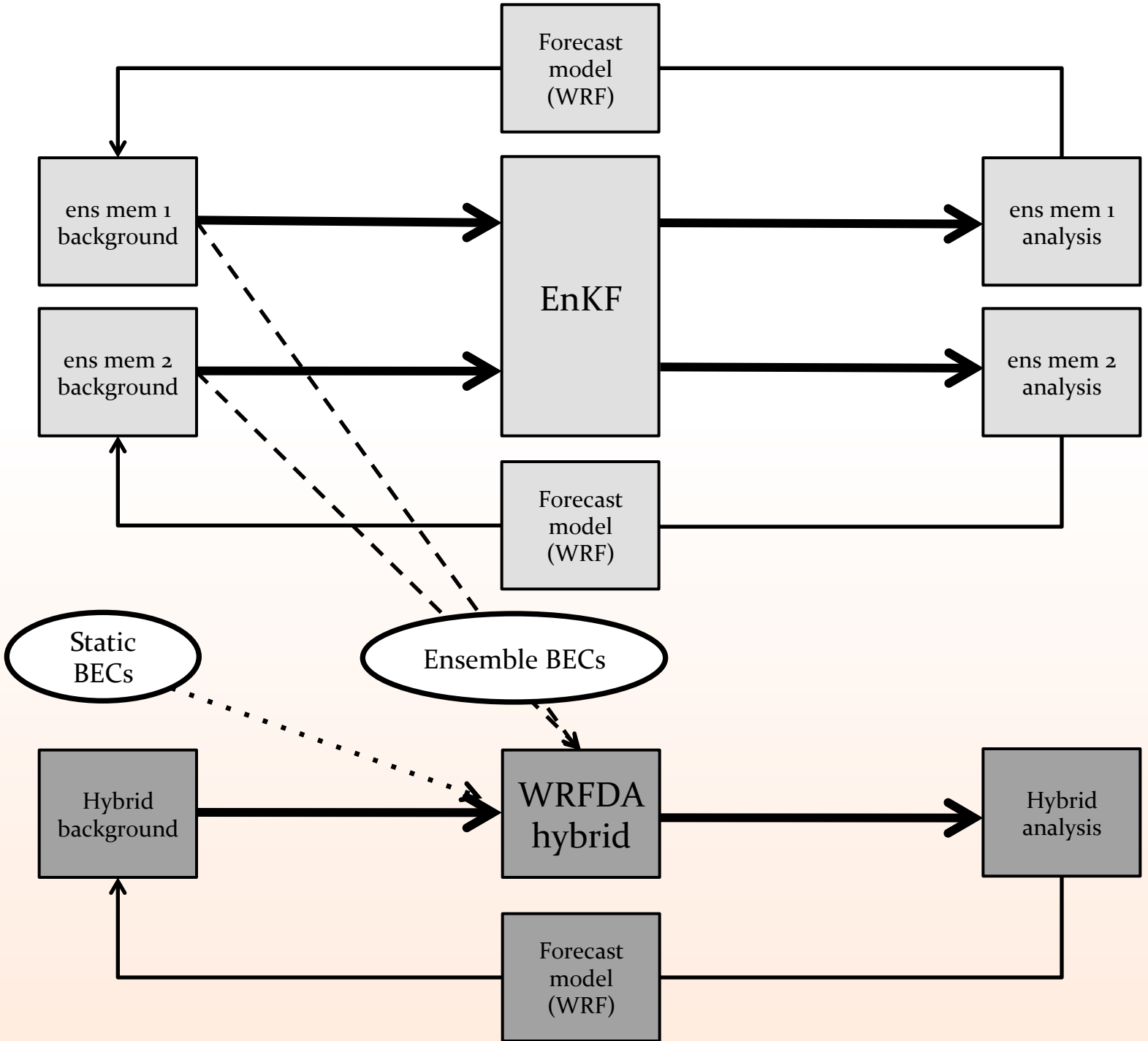
Length scales of control variables

- Each variable is a vector—one entry per outer loop
- Values are multiplicative factors that operate on the values in the static background error file

Use the hybrid

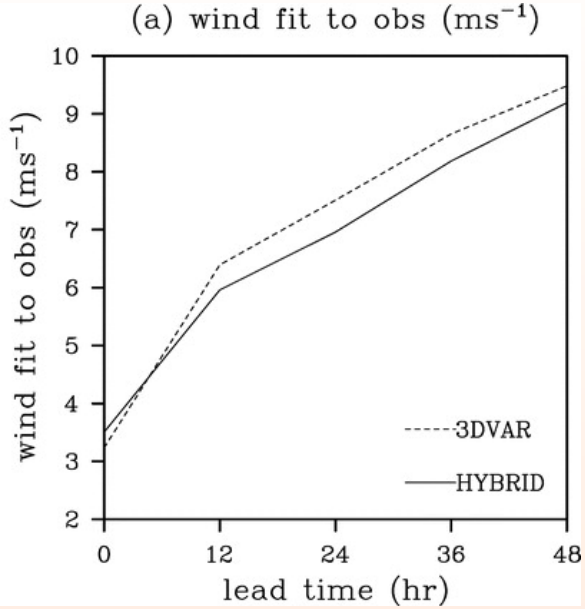
- The hybrid incorporates ensemble background error covariances into WRFDA

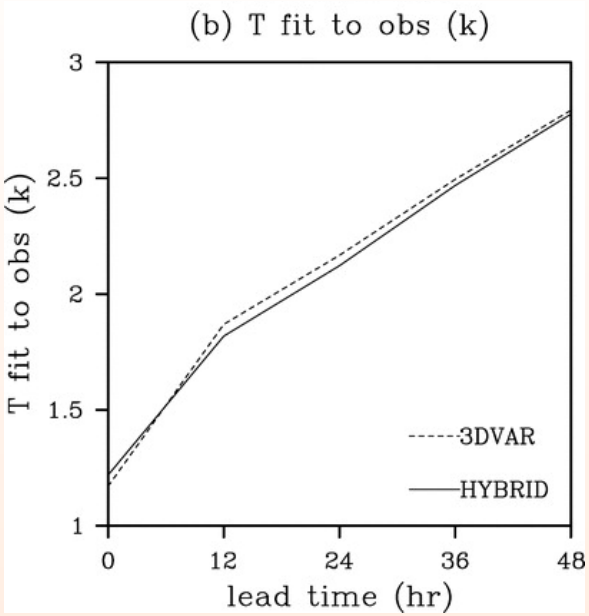
- Main additional expense is running the ensemble of forecasts


Forecast model (WRF)
ens mem 1 background
EnKF
ens mem 1 analysis
ens mem 2 background
ens mem 2 analysis
Forecast model (WRF)
Static BECs
Ensemble BECs
Hybrid background
WRFDA hybrid
Hybrid analysis
Forecast model (WRF)

Hybrid example

- Example over North America at coarse grid spacing
- Similar results have been obtained by many studies worldwide

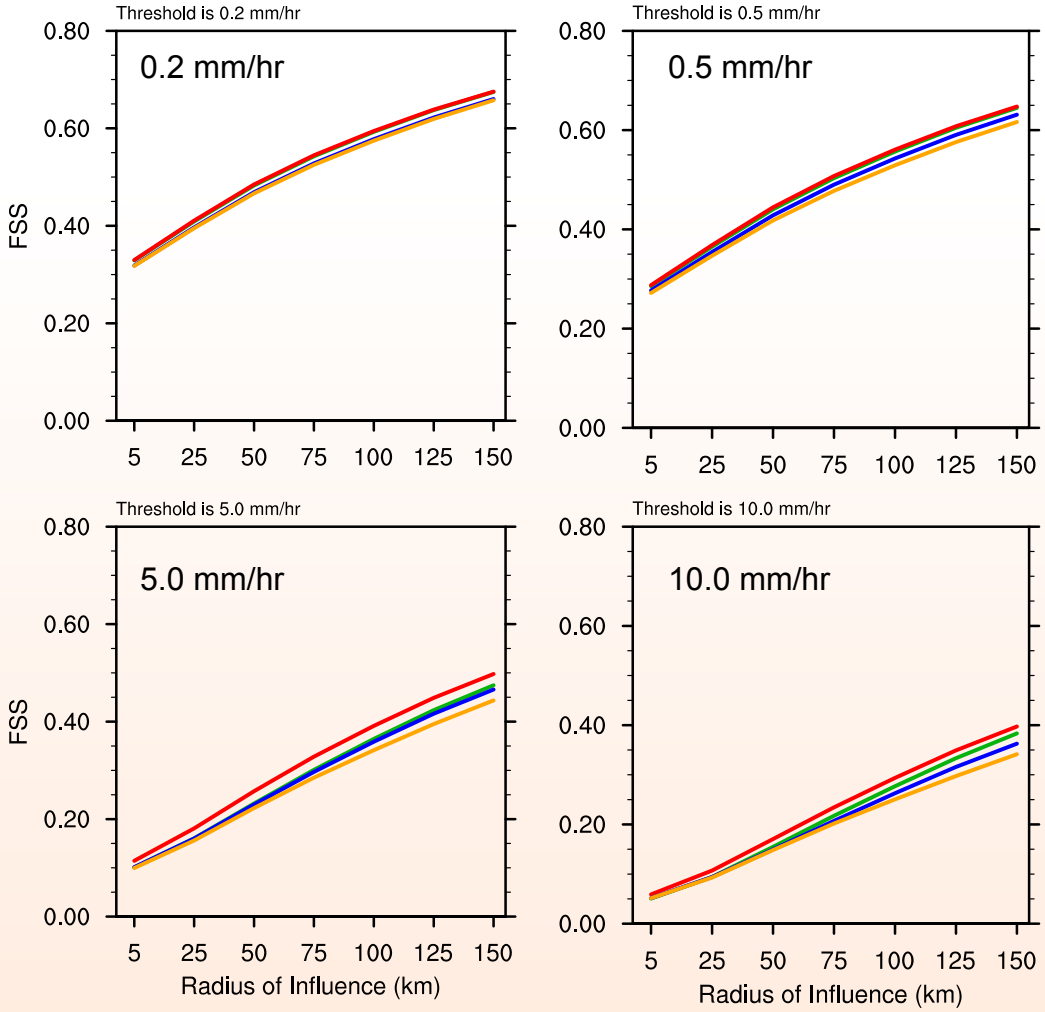




From Wang et al. (2008)

Hybrid vs. 3DVAR and EnKF

- Fractions skill scores for rainfall (higher is better)



Aggregated over hourly 18-36-hr forecasts of precipitation

EnKF

Hybrid

3DVAR

GFS

Modified from Schwartz and Liu (2014)

Radiance assimilation

- WRFDA can assimilate radiance observations from many satellites and sensors

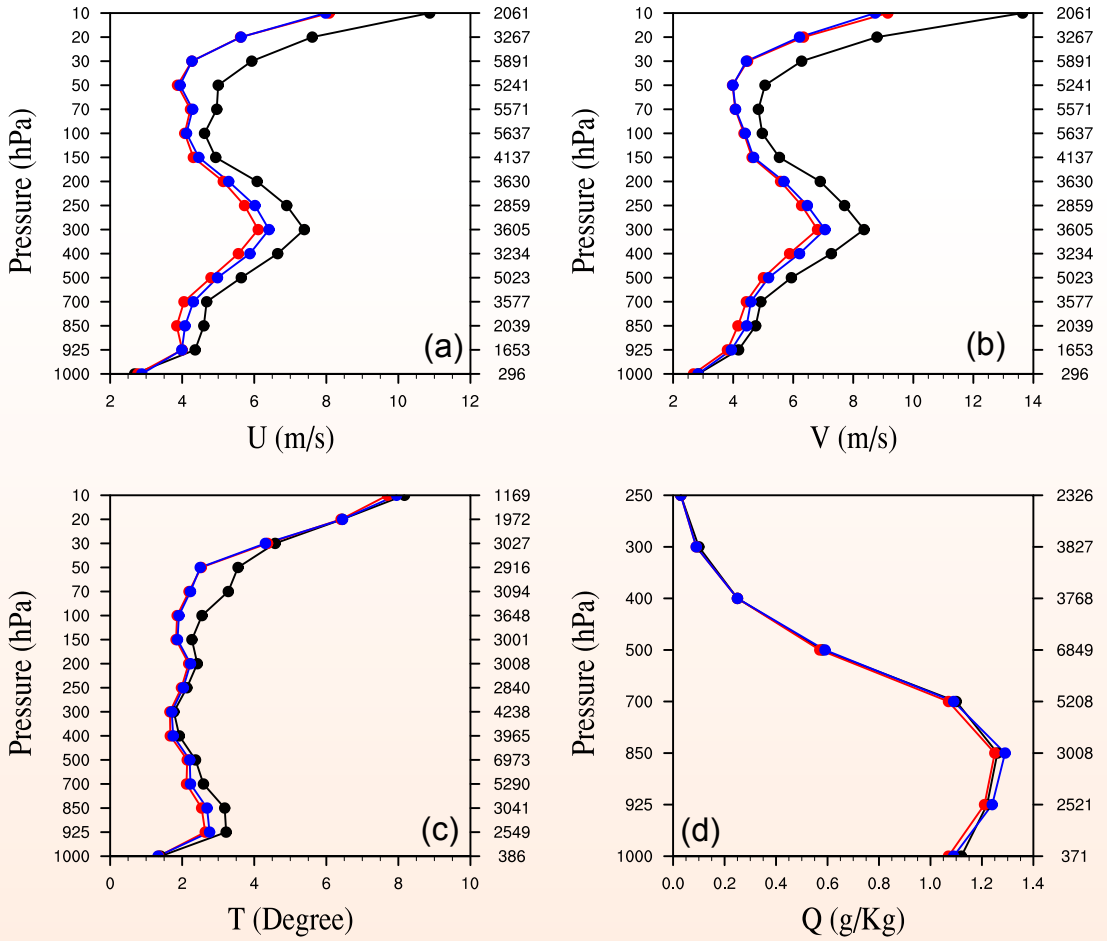
- The impact of assimilating radiances is largest over the ocean and southern hemisphere
  - If your domain is ocean-centric, it may be worth assimilating radiances

Radiances

- Antarctic application
- 48-hr forecasts verified against radiosondes

Black curve: no radiances were assimilated

Other curves: radiances were assimilated



From Schwartz and Liu (2012)

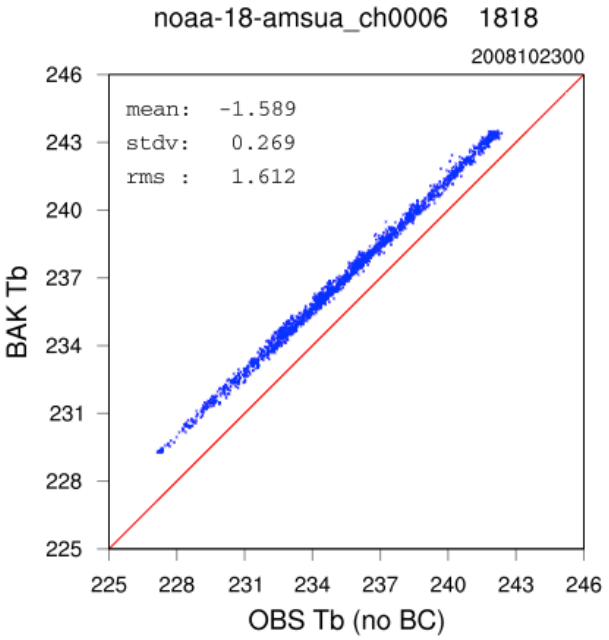
Radiances

- Radiance bias correction is very important and difficult within a regional domain

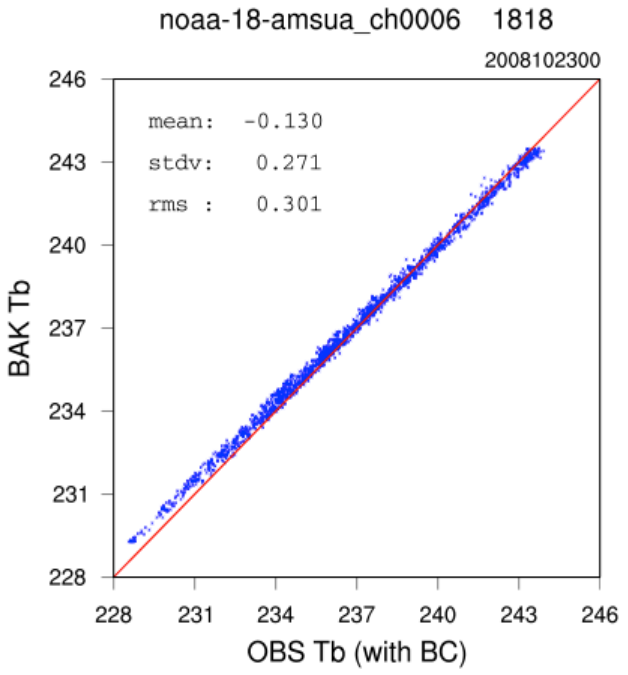
- See Liu et al. (2012) details about “spinning-up” bias correction coefficients

Radiance bias correction

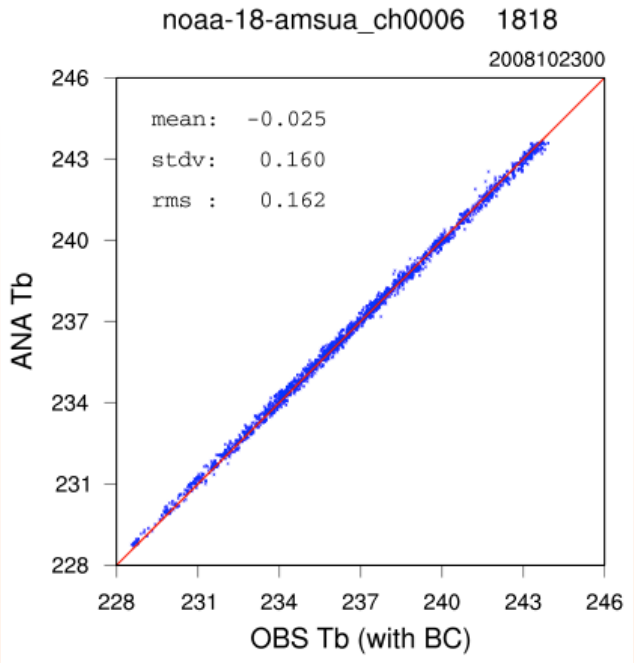
- For an analysis over the Middle East
- NOAA-18 AMSU-A Channel 6



Background vs. obs *before* bias correction



Background vs. obs *after* bias correction



Analysis vs. obs

Conclusion

- There are many possible configurations for WRFDA
- Test out several configurations for your domain to see what works best
- See http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3/users_guide_chap6.htm for more information and guidance

References (1)

Barker, D., and Coauthors, 2012: The Weather Research and Forecasting Model's Community Variational/Ensemble Data Assimilation System: WRFDA. *Bull. Amer. Meteor. Soc.*, **93**, 831–843.

Hsiao, L.-F., D.-S. Chen, Y.-H. Kuo, Y.-R. Guo, T.-C. Yeh, J.-S. Hong, C.-T. Fong, and C.-S. Lee, 2012: Application of WRF 3DVAR to operational typhoon prediction in Taiwan: Impact of outer loop and partial cycling approaches. *Wea. Forecasting*, **27**, 1249–1263.

Liu, Z., C. S. Schwartz, C. Snyder, and S.-Y. Ha, 2012: Impact of assimilating AMSU-A radiances on forecasts of 2008 Atlantic tropical cyclones initialized with a limited-area ensemble Kalman filter. *Mon. Wea. Rev.*, **140**, 4017–4034.

Romine, G., C. Schwartz, C. Snyder, J. Anderson, and M. Weisman, 2013: Model bias in a continuously cycled assimilation system and its influence on convection-permitting forecasts. *Mon. Wea. Rev.*, **141**, 1263–1284.

Schwartz, C. S., and Z. Liu, 2012: Bias correction and assimilation of microwave radiance measurements over the Antarctic. Preprints, *16th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans and Land Surface*, New Orleans, LA, Amer. Meteor. Soc., 10.1.

References (2)

Schwartz, C. S., Z. Liu, X.-Y. Huang, Y.-H. Kuo, and C.-T. Fong, 2013: Comparing limited-area 3DVAR and hybrid variational-ensemble data assimilation methods for typhoon track forecasts: Sensitivity to outer loops and vortex relocation. *Mon. Wea. Rev.*, **141**, 4350–4372.

Schwartz, C. S., and Z. Liu, 2014: Convection-Permitting Forecasts Initialized with Continuously Cycling Limited-Area 3DVAR, Ensemble Kalman Filter, and "Hybrid" Variational–Ensemble Data Assimilation Systems. *Mon. Wea. Rev.*, **142**, 716–738.

Wang, X., D. M. Barker, C. Snyder, and T. M. Hamill, 2008: A hybrid ETKF- 3DVAR data assimilation scheme for the WRF model. Part II: Real observation experiments. *Mon. Wea. Rev.*, **136**, 5132–5147.

Zhang, F., M. Zhang, and J. Poterjoy, 2013: E3DVar: Coupling an ensemble Kalman filter with three-dimensional variational data assimilation in a limited-area weather prediction model and comparison to E4DVar. *Mon. Wea. Rev.*, **141**, 900–917.

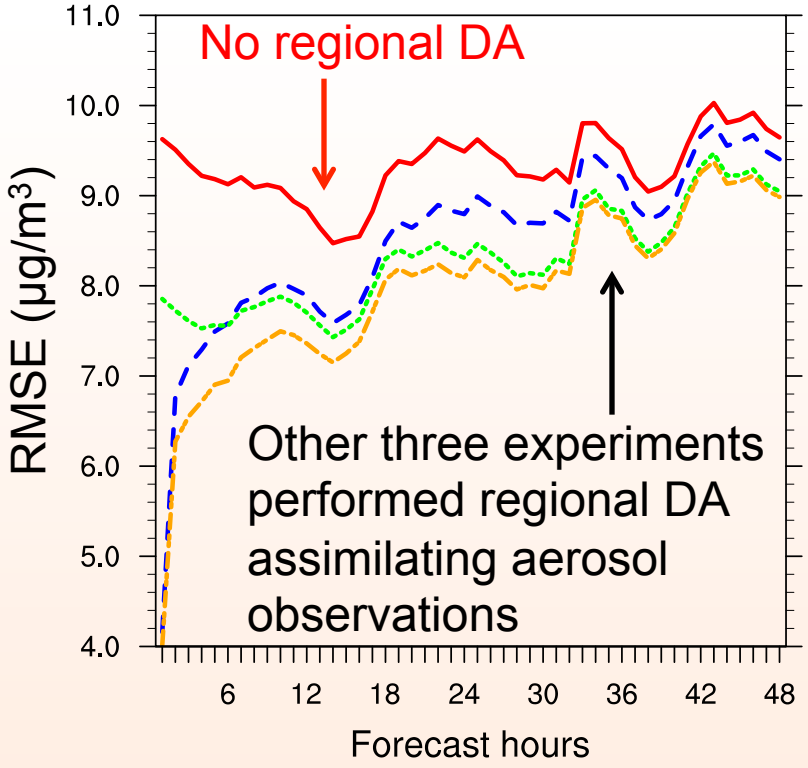

NESL

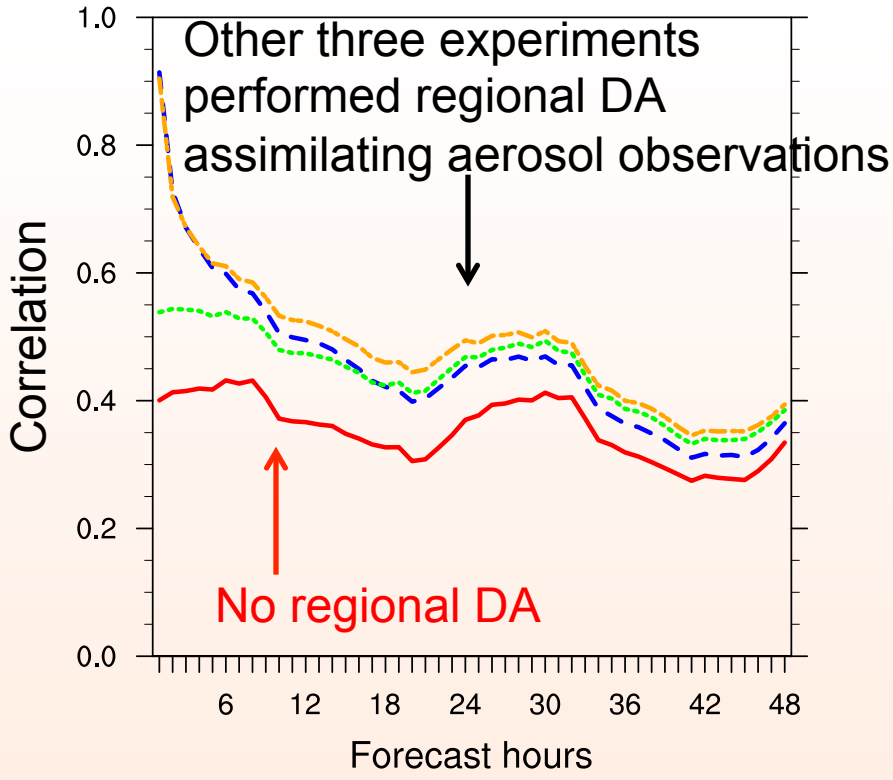

NESL


NESL

Aerosol application

- Data assimilation with WRF-Chem can improve aerosol forecasts
- Forecast errors of surface fine particulate matter





From Schwartz et al. (2012)

How to use the hybrid

- WRFDA namelist:

```
 &wrfvar16
 alphacv_method=2,          don't change
 ensdim_alpha=32,           ensemble size
 alpha_corr_type=3,         don't change
 alpha_corr_scale=200,      recursive filter length-scale, TUNE THIS
 alpha_std_dev=1.0,         probably don't change
 alpha_vertloc = .true.,    true for vertical localization of ensemble increments
/
```

For alpha_vertloc= .true., in your working directory, run …./WRFDA/var/build/ gen_be_vertloc.exe with the number of vertical levels ("e_vert" in WRF namelist) as input:

```
set e_vert = 45
./gen_be_vertloc.exe $e_vert
```