The GSI-based WRF 4D-Var

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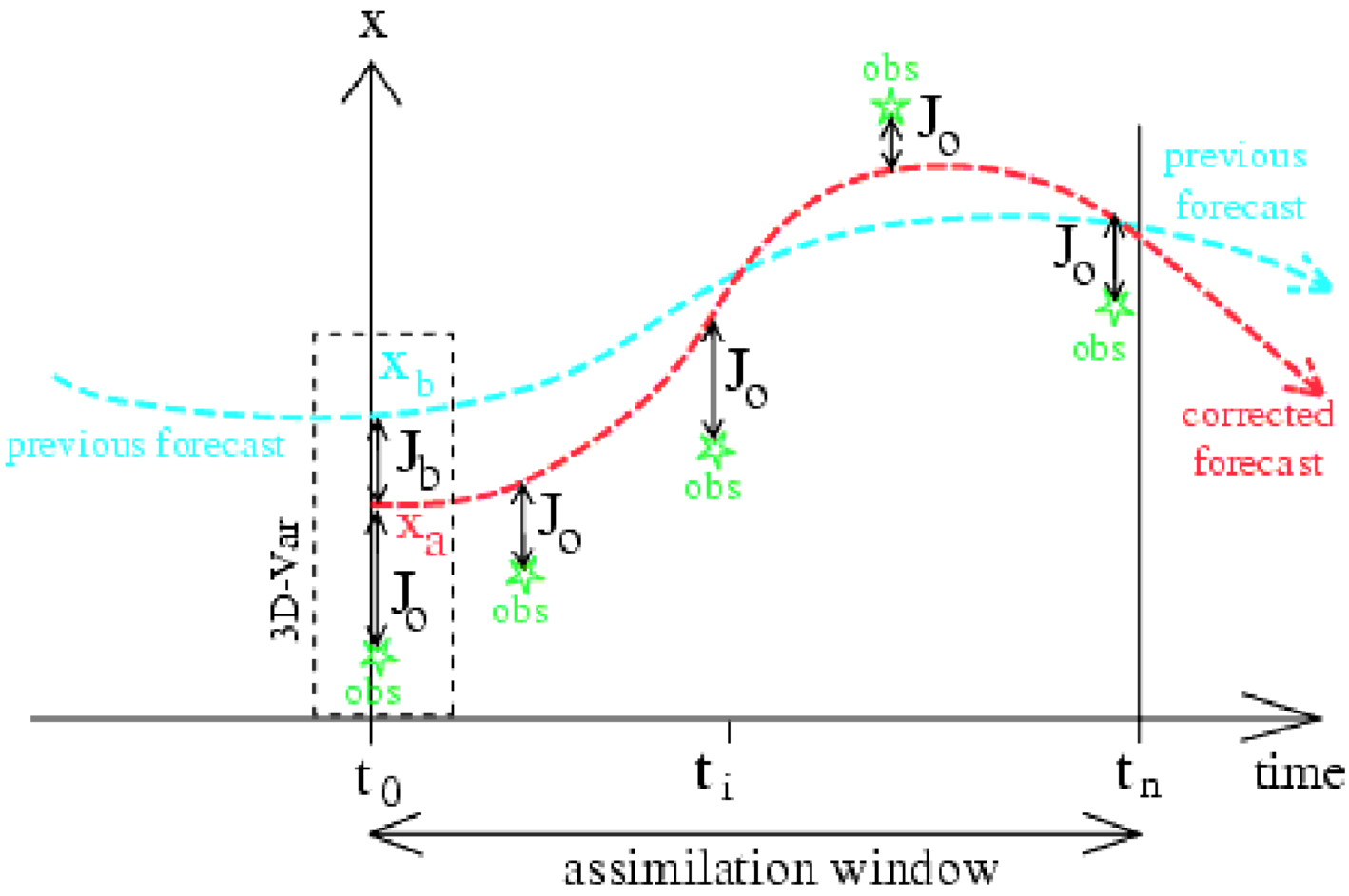
The development has been supported by AFWA.

GSI Workshop
8 August 2013

4D-Var versus 3D-Var

(Adopted from ECMWF training Course)



4D-Var versus 3D-Var

(Adopted from ECMWF training Course)

- 4D-Var is comparing observations with background model fields at the correct time
- 4D-Var can use observations from frequently reporting stations
- The dynamics and physics of the forecast model is an integral part of 4D-Var, so observations are used in a meteorologically more consistent way
- 4D-Var combines observations at different times during the 4D-Var window in a way that reduces analysis error
- 4D-Var propagates information horizontally and vertically in a meteorologically more consistent way

Background

- Re-development of the WRF tangent linear and adjoint model (WRFPLUS).

  Zhang, X., X.-Y. Huang, and N. Pan, 2013: Development of the Upgraded Tangent Linear and Adjoint of the Weather Research and Forecasting (WRF) Model. *J. Atmos. Oceanic Technol.* 30, 1180-1188.

- Experiences gained from upgrading the WRF 4D-Var from MPMD to SPMD.

  Zhang, X., X.-Y. Huang, J. Liu and J. Poterjoy, 2013: Development of an efficient regional four-dimensional variational data assimilation system for WRF. Submitted to *J. Atmos. Oceanic Technol.*

- Existed 4D-Var developments in current GSI framework.

  Thank Dr. R. Todling and others.

The GSI-based WRF 4D-Var: Current Status

- Updates toward the GSI-based WRF 4D-Var have been done.
- All Changes have been synchronized and tested with the revision 1061 of Boulder repository (2nd April, 2013).

- The GSI-based WRF 4D-Var is able to run parallel.
- Multiple outer-loops setup works (with script controlled)
- JcDFI as weak constraint for WRF MASS CORE is added and works. (more investigation needed for regional WRF model.)
- All test cases pass the adjoint test.
- All test cases pass the gradient test.

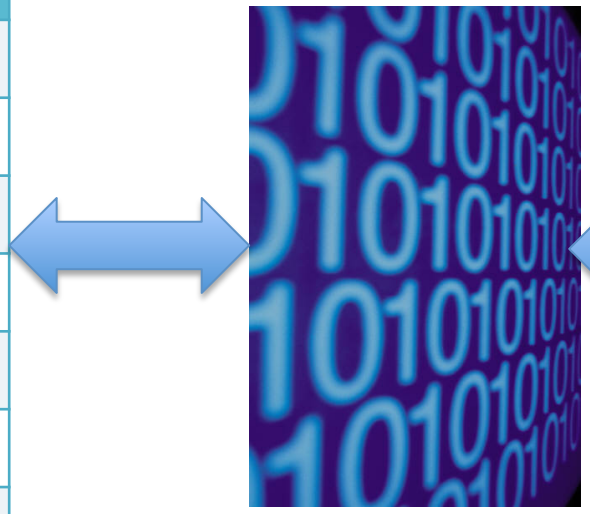
- Most of the changes related to the GSI-based WRF 4D-Var were isolated using *#ifdef*.

Outline

- Linking GSI with WRF TLM and ADM
- GSI-based WRF 4D-Var
- Summary

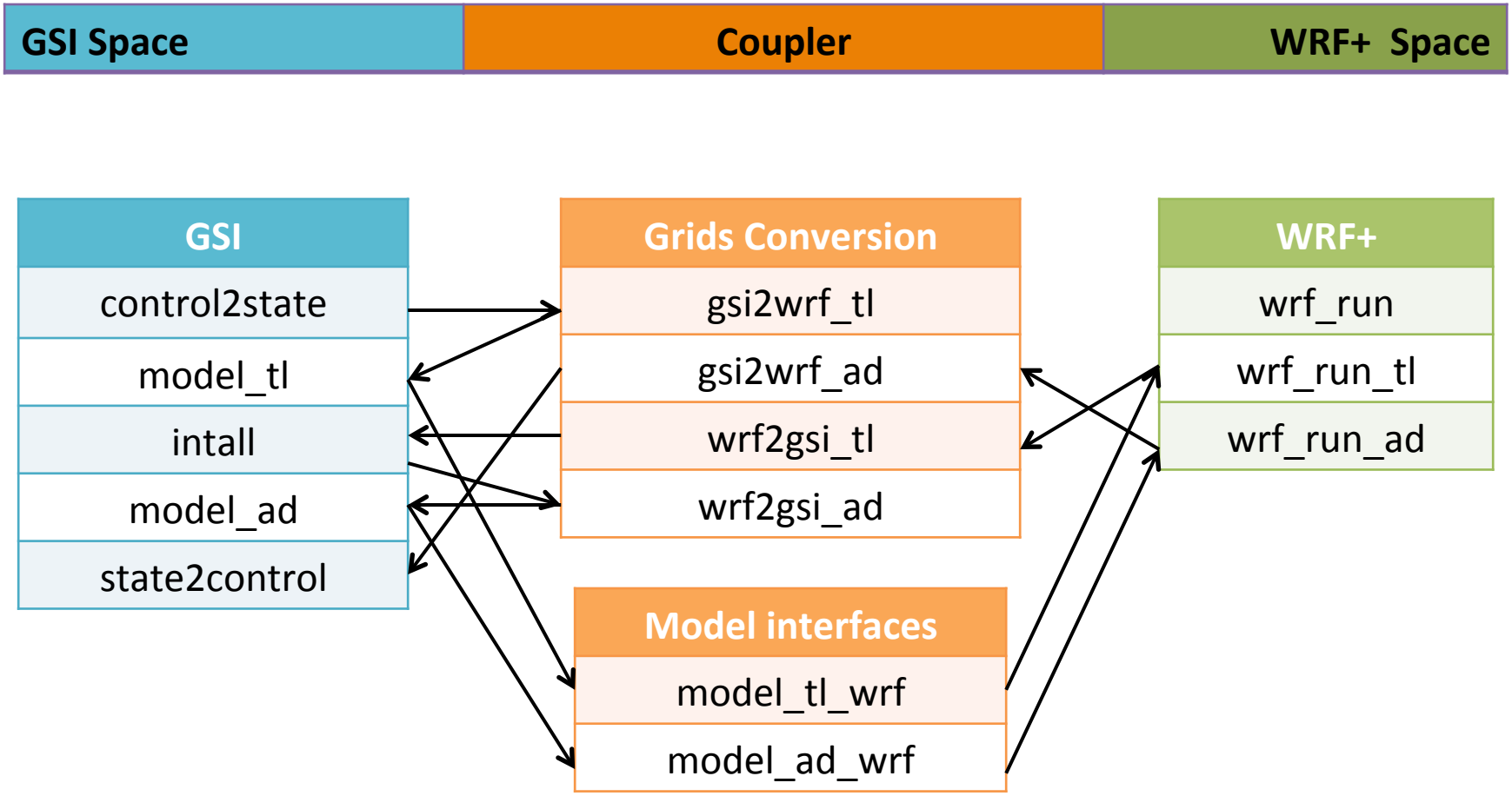
What do we need to link GSI with WRFPLUS?

GSI Space		WRF+ Space

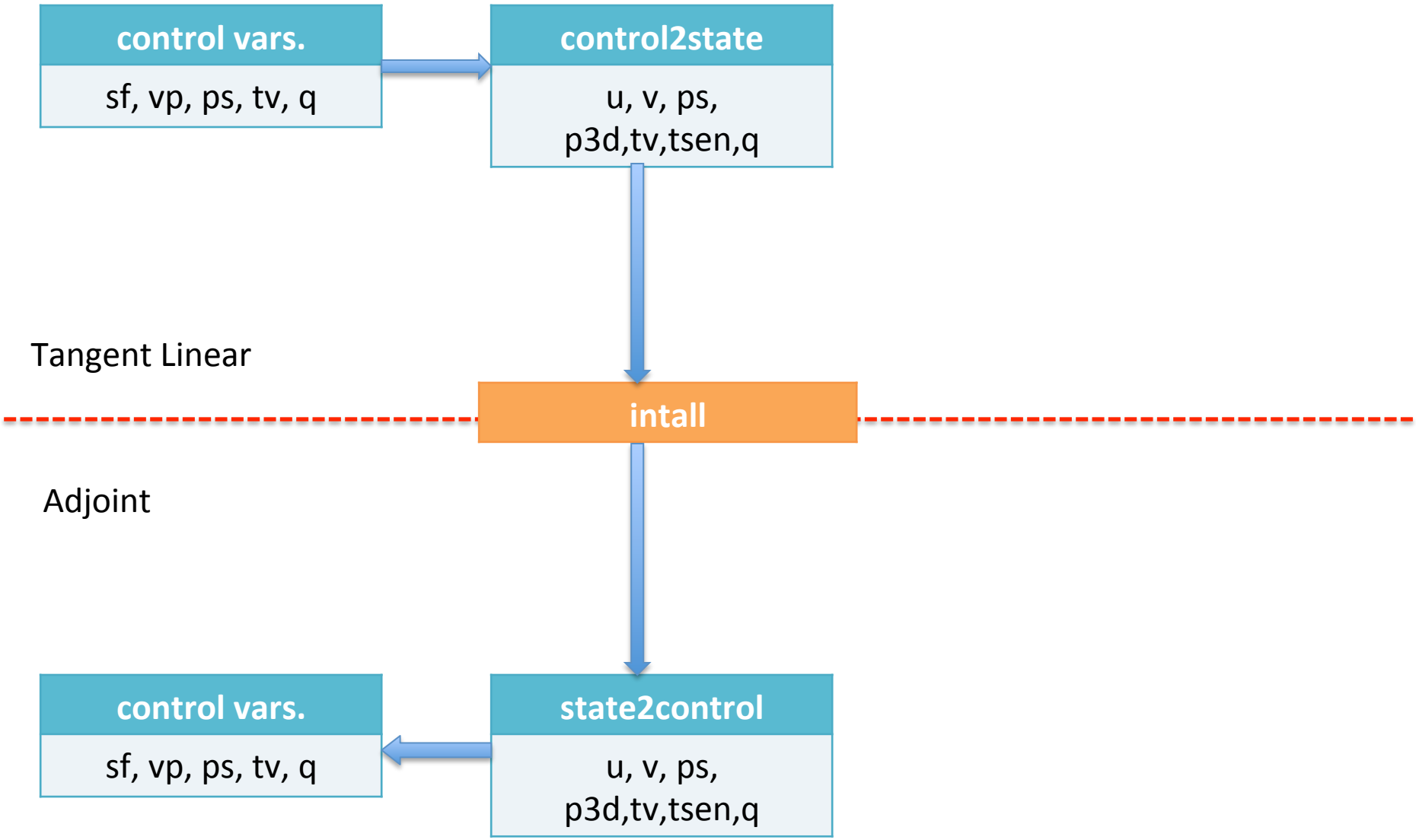


GSI	WRF+
U,V on A-Grid	U, V on C-grid
Virtual Temp.	Potential Temp.
Specific Humidity	Mixing Ratio
Surf. Press.	Dry Surf. Press.
model_tl	wrf_run_tl
model_ad	wrf_run_ad

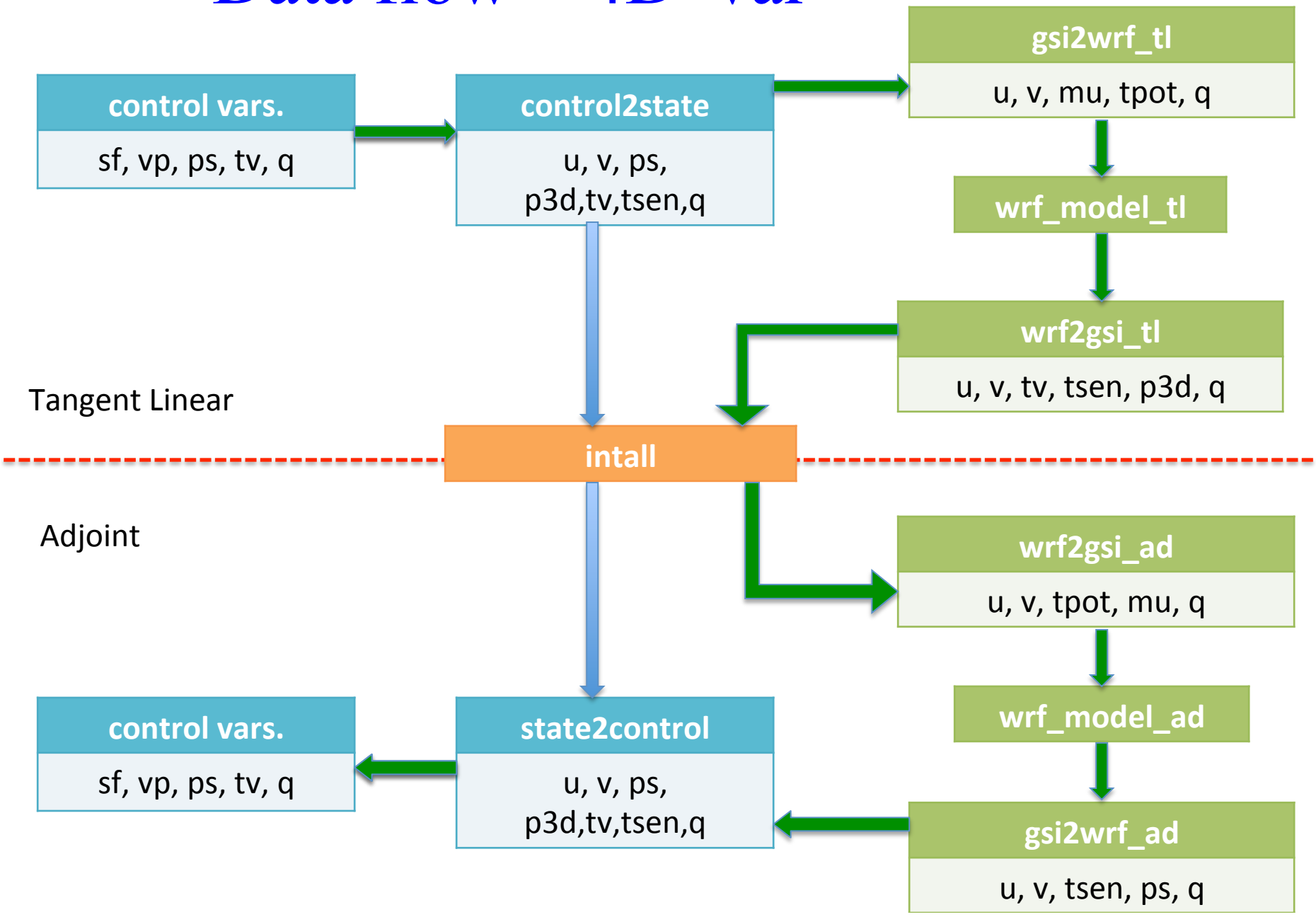
Linking GSI with WRFPLUS



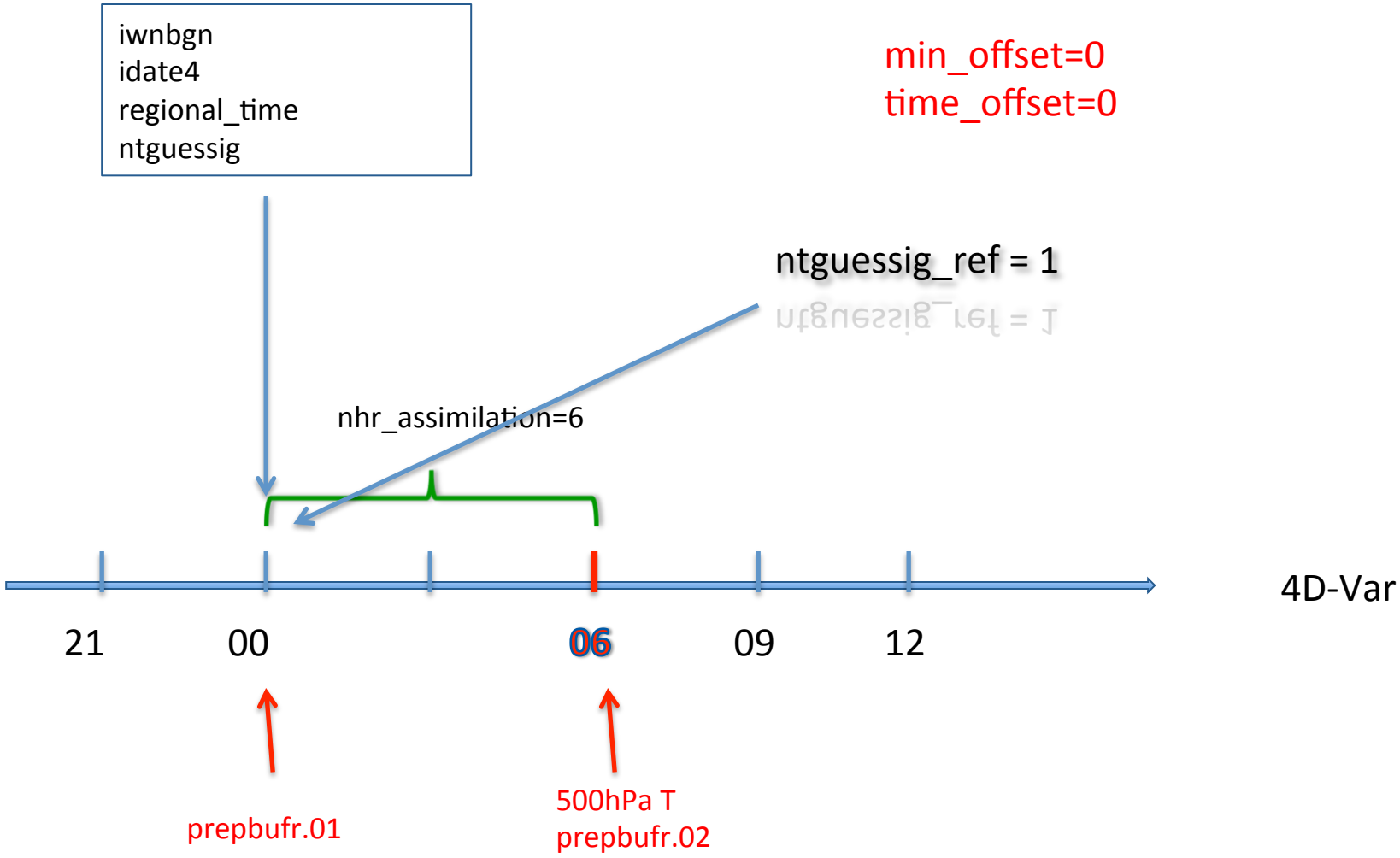
Data flow – 3D-Var



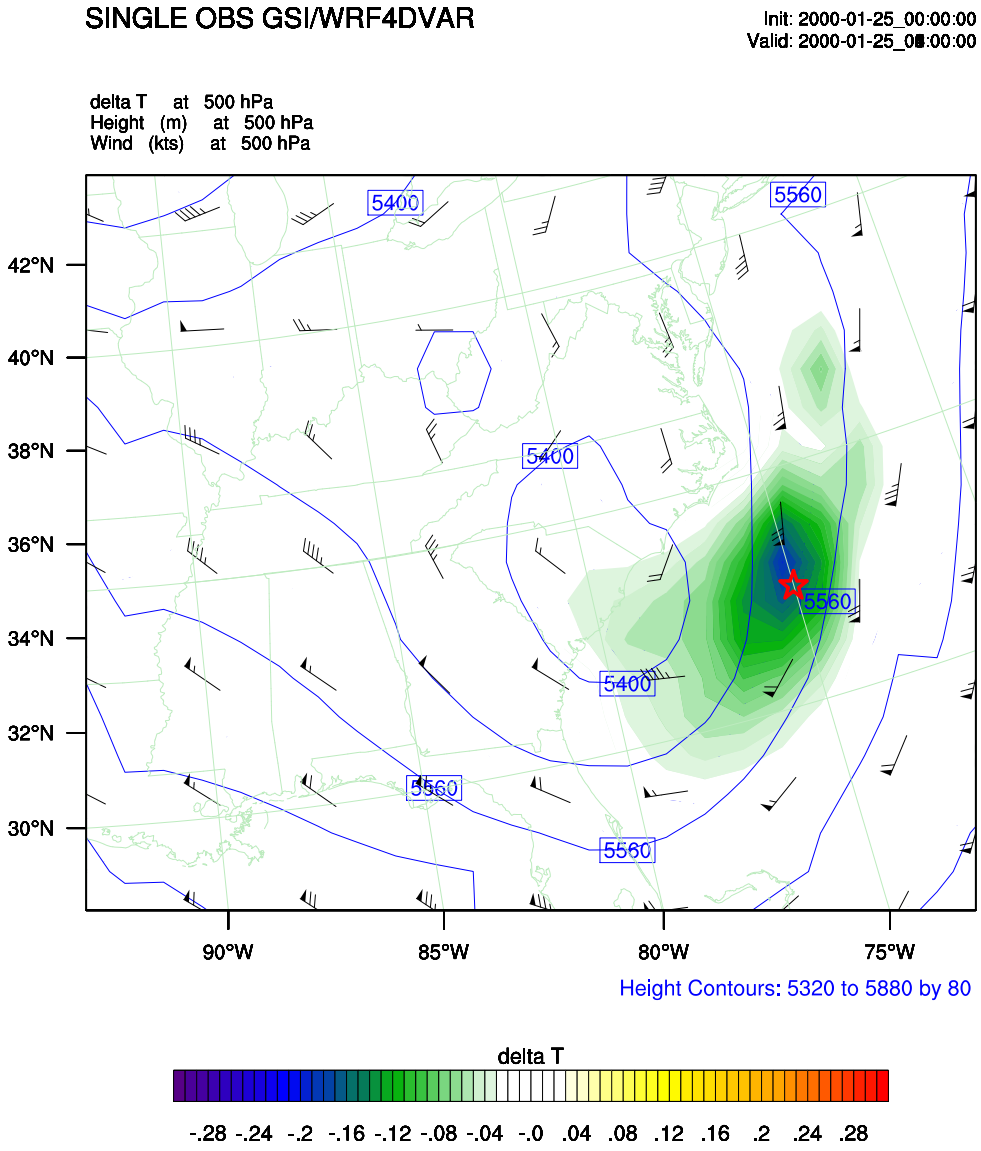
Data flow – 4D-Var



Single observation experiment

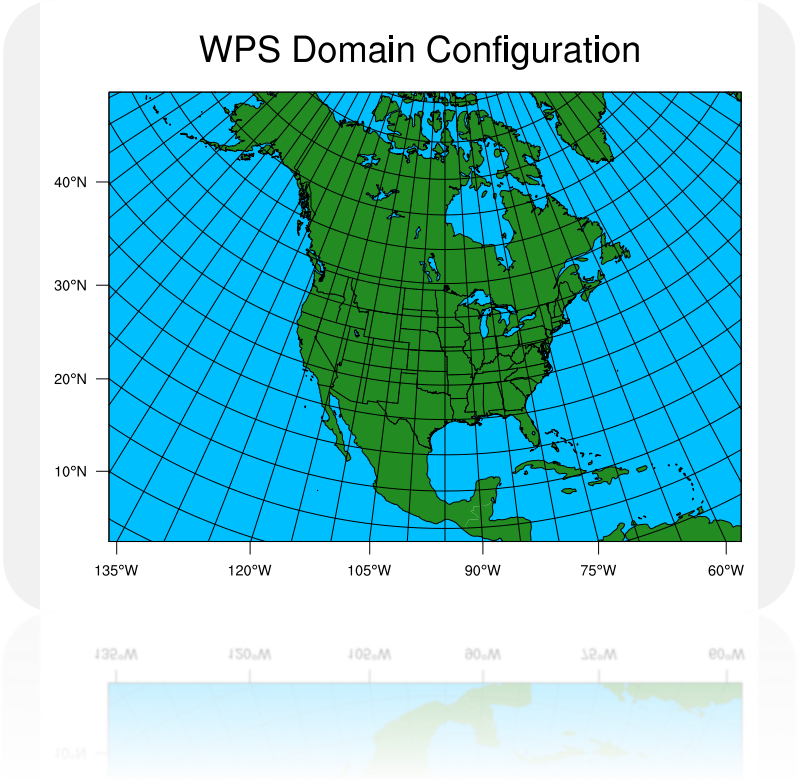


Single observation (at 6h)



The GSI tutorial case (downgraded to a lower resolution)

- Analysis time:
  - 2011•03•22•12
- Domain size:
  - 175×83×L51
- Domain horizontal resolution:
  - 90km
- Assimilation window
  - 6 hours (2209 to 2215) for both 3D-Var and 4D-Var
- Minimization algorithm
  - lsqrtb = .true.
  - lcongrad = .true.
  - ltint = .true.
  - 1 outer loop, 50 inner loops



Observation Usage Statistics

	Surface Pressure	Temp.	Wind	Moisture	GPS	Radiance
3D-Var	13852	9233	25582	4210	8707	131221
4D-Var	13855	9233	25590	4210	8750	145356
Variation	+3	0	+8	0	+43	+14135

Question: We expect that the 4D-Var mode should use more data (especially surface obs.) than 3D-Var mode does. What's wrong ?

Adjoint Test

3D-Var -before	4D-Var-before
ADTEST starting ADTEST use random_cv(xhat) ADTEST 0.123456789012345678 ADTEST <F*F.Y,X>= 1.90534135460727 1496E+06 ADTEST <F.Y,F.Y>= 1.90534135460725 7294E+06 ADTEST 14 digits are identical ADTEST rel. err.= 7.454133732279982765E-16 ADTEST mach.eps = 2.220446049250313081E-16	ADTEST starting ADTEST use random_cv(xhat) ADTEST 0.123456789012345678 ADTEST <F*F.Y,X>= 1.13977404317319 6539E+07 ADTEST <F.Y,F.Y>= 1.13977404317320 3059E+07 ADTEST 14 digits are identical ADTEST rel. err.= 5.719781092889553150E-15 ADTEST mach.eps = 2.220446049250313081E-16

3D-Var-after	4D-Var-after
ADTEST starting ADTEST use random_cv(xhat) ADTEST 0.123456789012345678 ADTEST <F*F.Y,X>= 1.14501750793260 3126E+06 ADTEST <F.Y,F.Y>= 1.14501750793260 9413E+06 ADTEST 14 digits are identical ADTEST rel. err.= 5.490245638256641478E-15 ADTEST mach.eps = 2.220446049250313081E-16	ADTEST starting ADTEST use random_cv(xhat) ADTEST 0.123456789012345678 ADTEST <F*F.Y,X>= 1.03408858477236 8520E+07 ADTEST <F.Y,F.Y>= 1.03408858477237 2805E+07 ADTEST 14 digits are identical ADTEST rel. err.= 4.142859621812996916E-15 ADTEST mach.eps = 2.220446049250313081E-16

Observation Adjoint Test

(By Rizvi Syed)

4D-Var

ADTEST_OBS <F*F.Y,X>= 6.75854342347027 6175E+05
ADTEST_OBS <F.Y,F.Y>= 6.75854342347027 5011E+05
ADTEST_OBS 15 digits are identical

Gradient Test

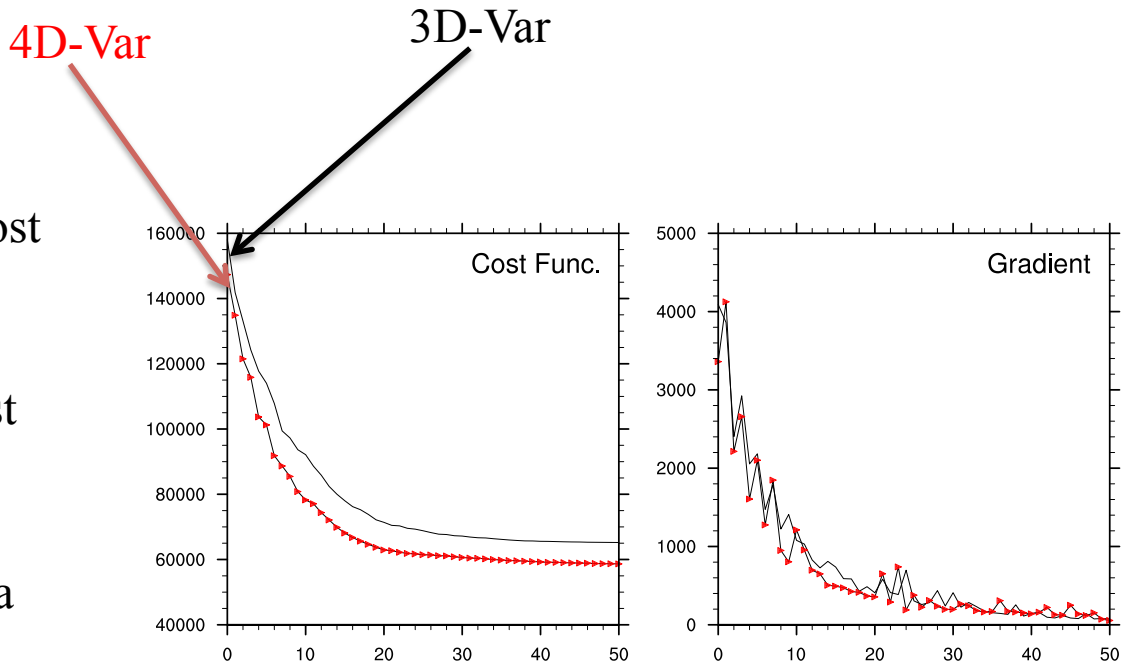
- Parallel problem in gradient test ? (32 PE used)
- One-processor run produces good gradient test results.
- No impact on final analysis.
- Conventional data only works fine.

3D-Var -before	4D-Var-before
grtest: gradient T1= 1.0007996634370 64	grtest: gradient T1= 0.9990476095484848
grtest: gradient T1= 1.000801257924277	grtest: gradient T1= 0.9990423154564589
grtest: gradient T1= 1.000795318307842	grtest: gradient T1= 0.9990367849678288
grtest: gradient T1= 1.000735631073795	grtest: gradient T1= 0.9989816676095885
grtest: gradient T1= 1.000138699719116	grtest: gradient T1= 0.9984306588591904
grtest: gradient T1= 0.9941693692653023	grtest: gradient T1= 0.9929206249020169
grtest: gradient T1= 0.9344760659344273	grtest: gradient T1= 0.9378202843136800
grtest: gradient T1= 0.3375430327161567	grtest: gradient T1= 0.3868168788307939

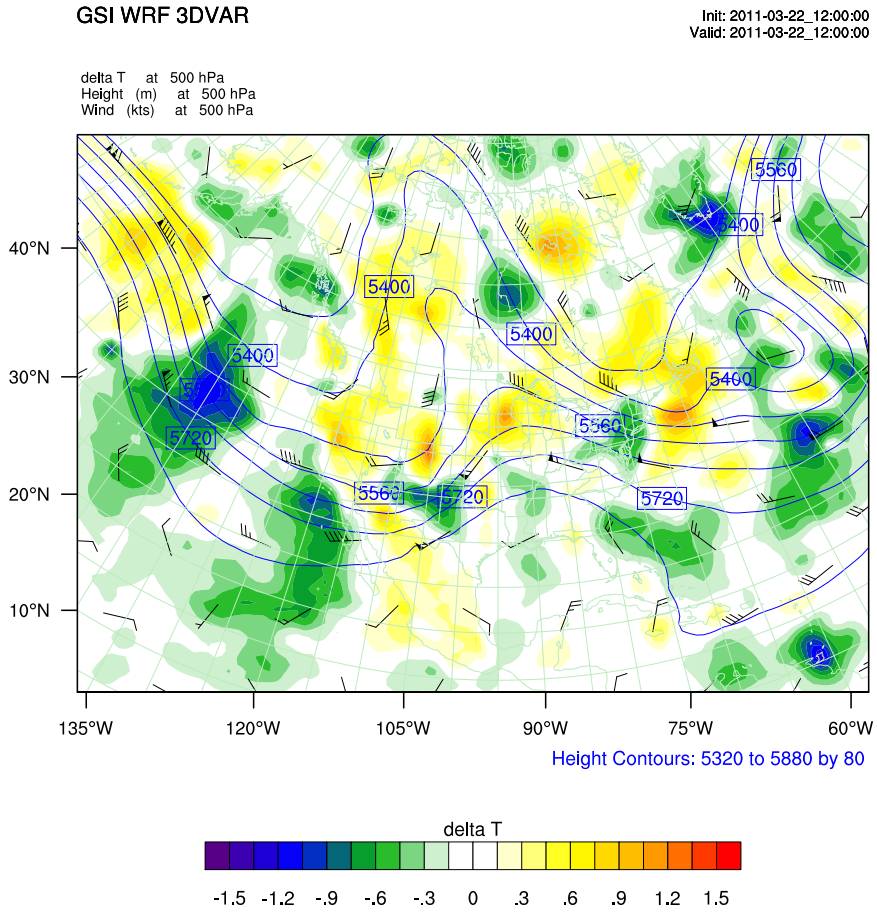
3D-Var-after	4D-Var-after
grtest: gradient T1= 1.000015804044360	grtest: gradient T1= 0.9999606139497992
grtest: gradient T1= 1.000010961587316	grtest: gradient T1= 1.000010809460202
grtest: gradient T1= 1.000000368712534	grtest: gradient T1= 1.000001562918812
grtest: gradient T1= 0.9999990975675600	grtest: gradient T1= 0.9999995022610166
grtest: gradient T1= 0.9999914246943746	grtest: gradient T1= 0.9999934563438821
grtest: gradient T1= 0.9999140072440680	grtest: gradient T1= 0.9999345317021266
grtest: gradient T1= 0.9991400604212262	grtest: gradient T1= 0.9993453113466101
grtest: gradient T1= 0.9914006048800456	grtest: gradient T1= 0.9934531128869484

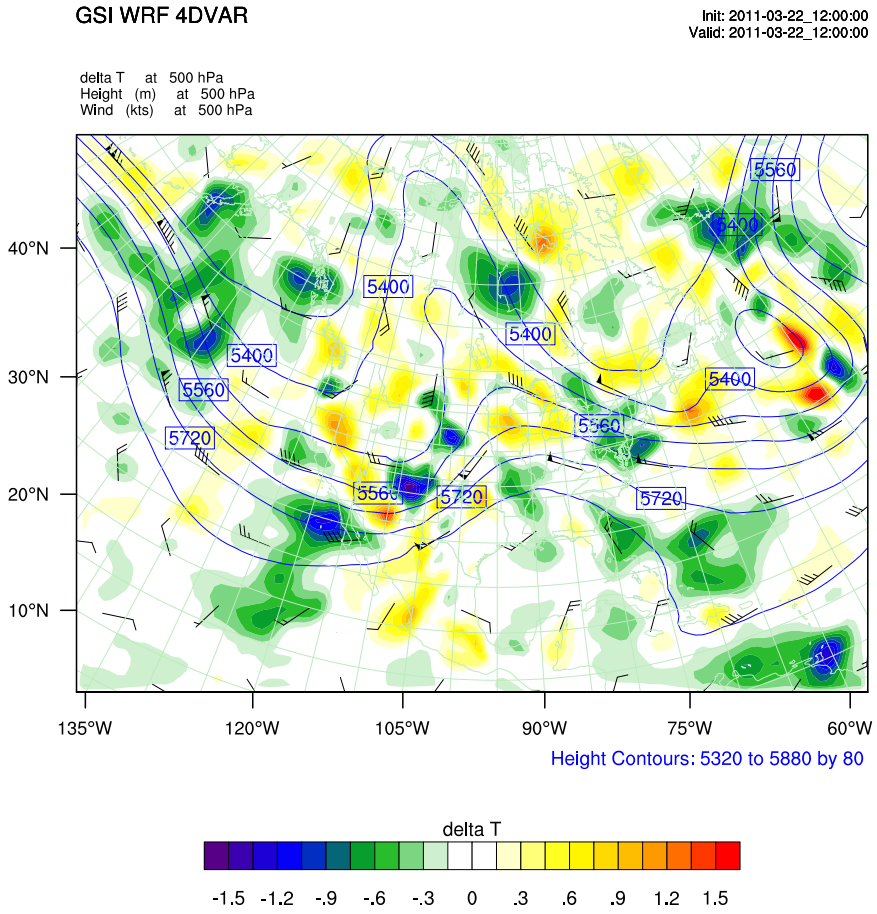
Minimization
(pcgsoi)

- 4D-Var has smaller initial cost function.
- 4D-Var has smaller final cost function.
- Note: 4D-Var uses more data than 3D-Var.

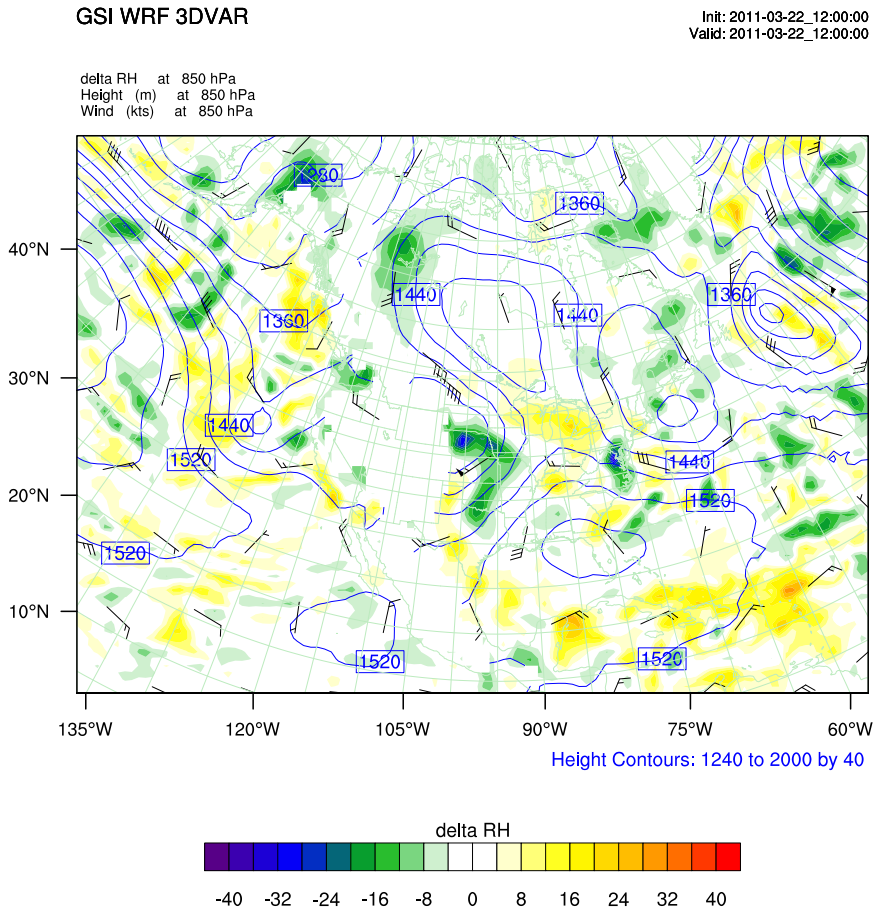


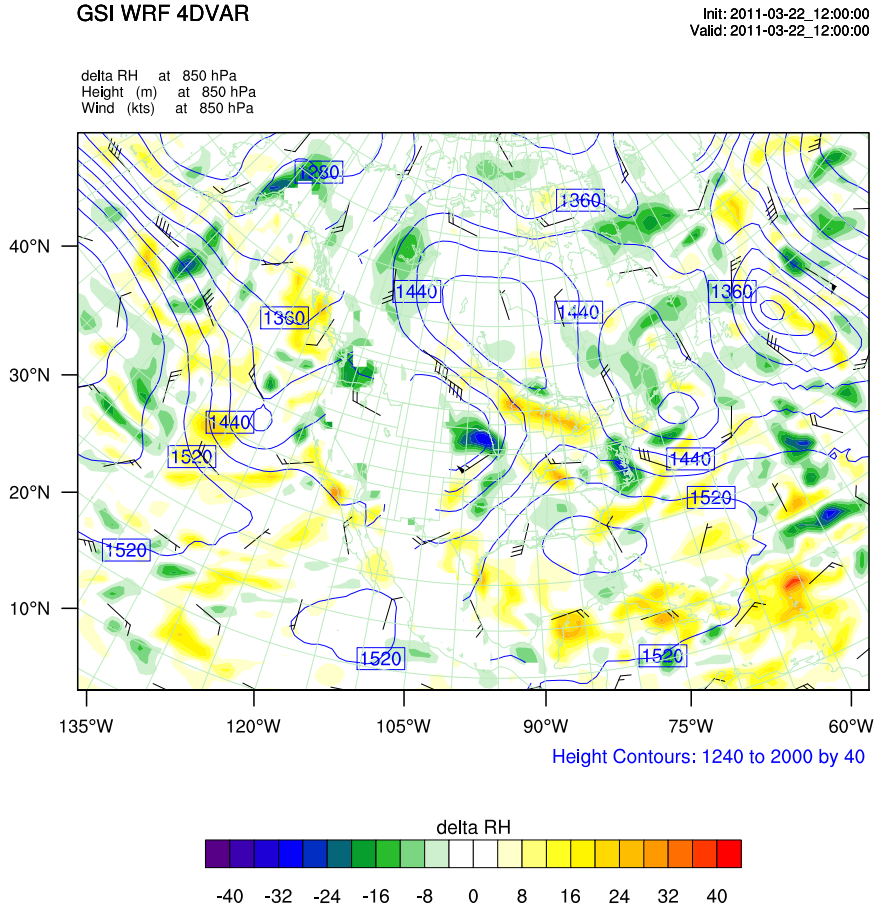
Increments: Temperature at 500hPa





Increments: RH at 850hPa



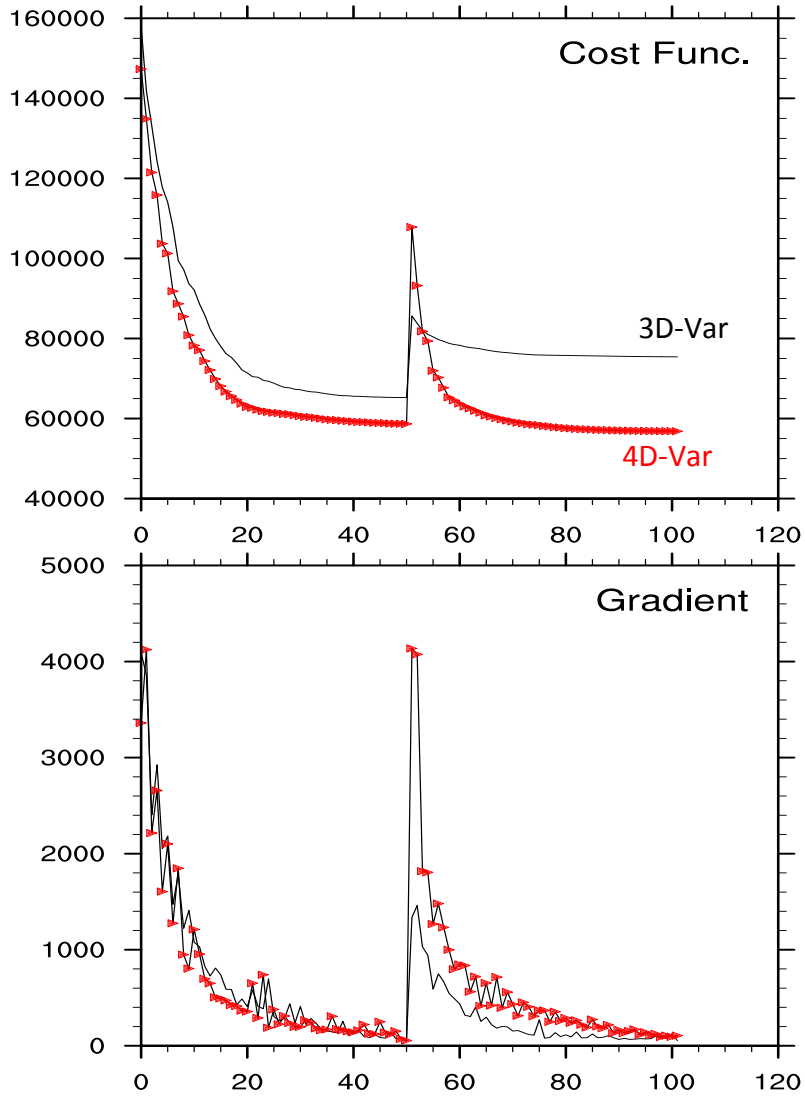


2 outer-loops minimization

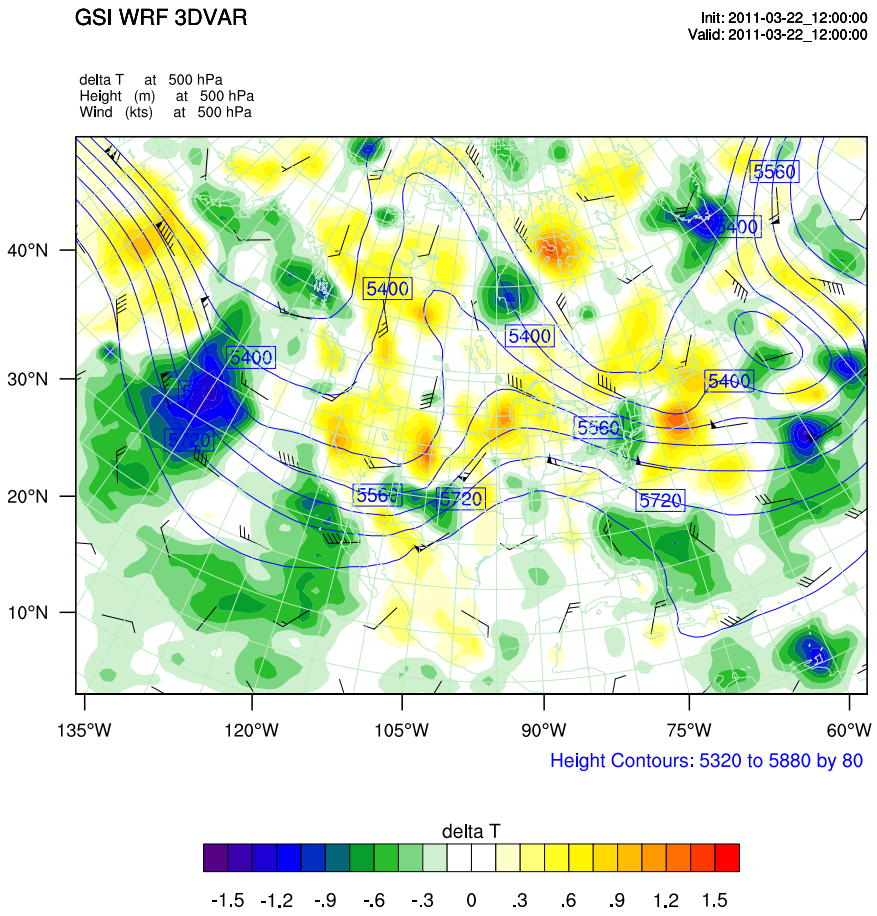
(pcgsoi, inner loops: 50/50)

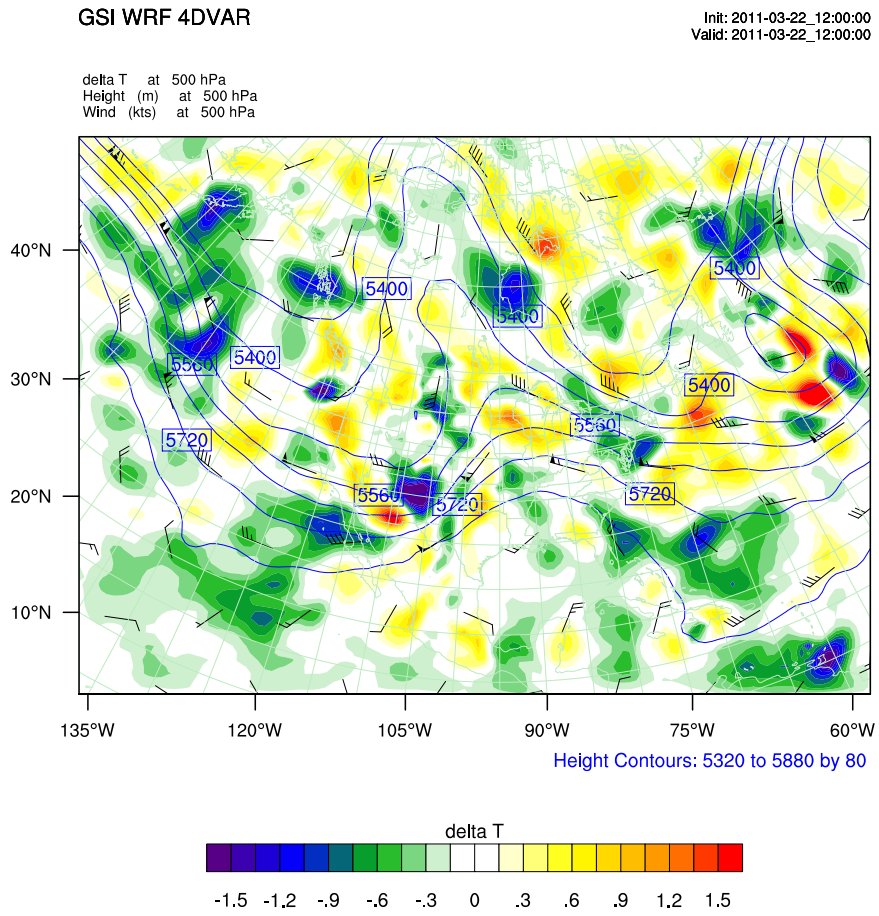
Obs. Number Statistics

Obs.	3D-Var		4D-Var	
	1st outer	2nd outer	1st outer	2nd outer
Surf. Press.	13852	13859	13855	13861
Temp.	9233	9233	9233	9233
Wind	25582	25636	25590	25636
Moist.	4210	4210	4210	4210
GPS	8707	8837	8750	8864
Radiance	131221	154758	145356	160179
Total	**192805**	**216533**	**206994**	**221983**

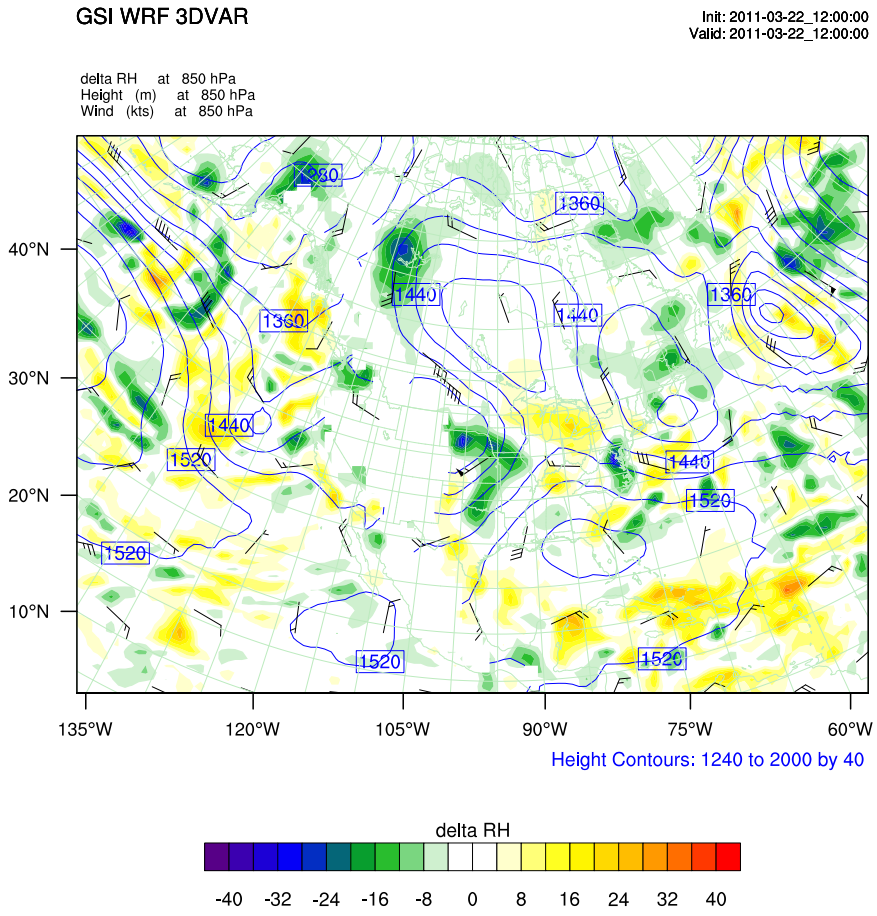


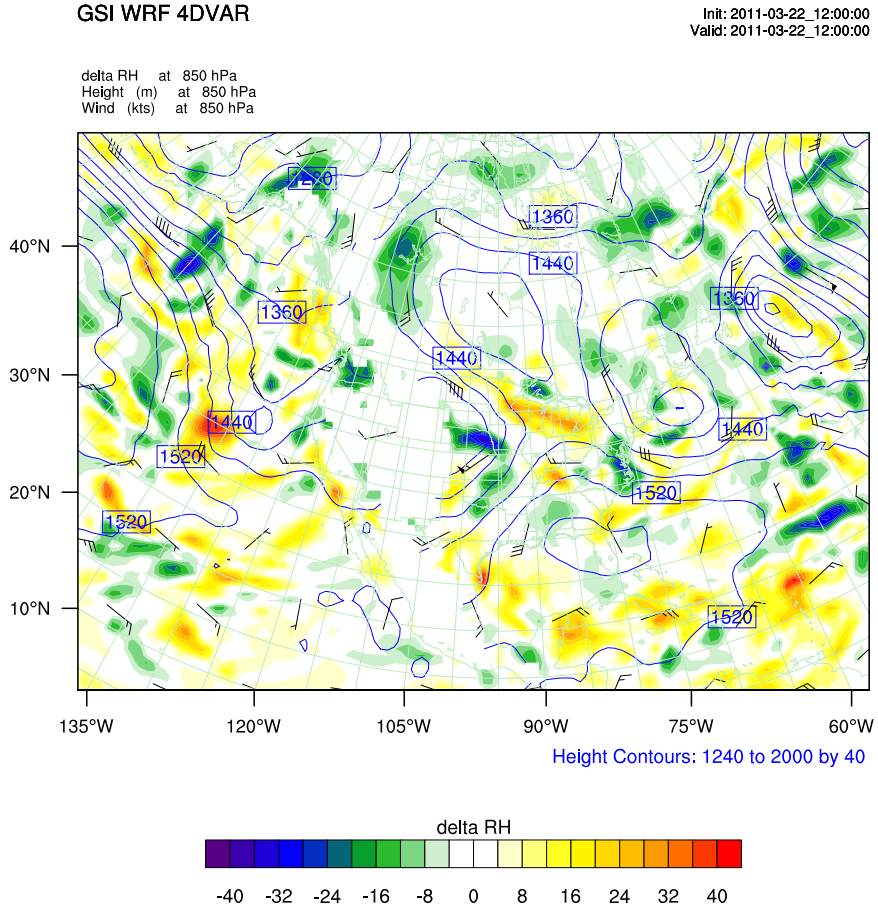
Increments after 2 outer loops: Temperature at 500hPa





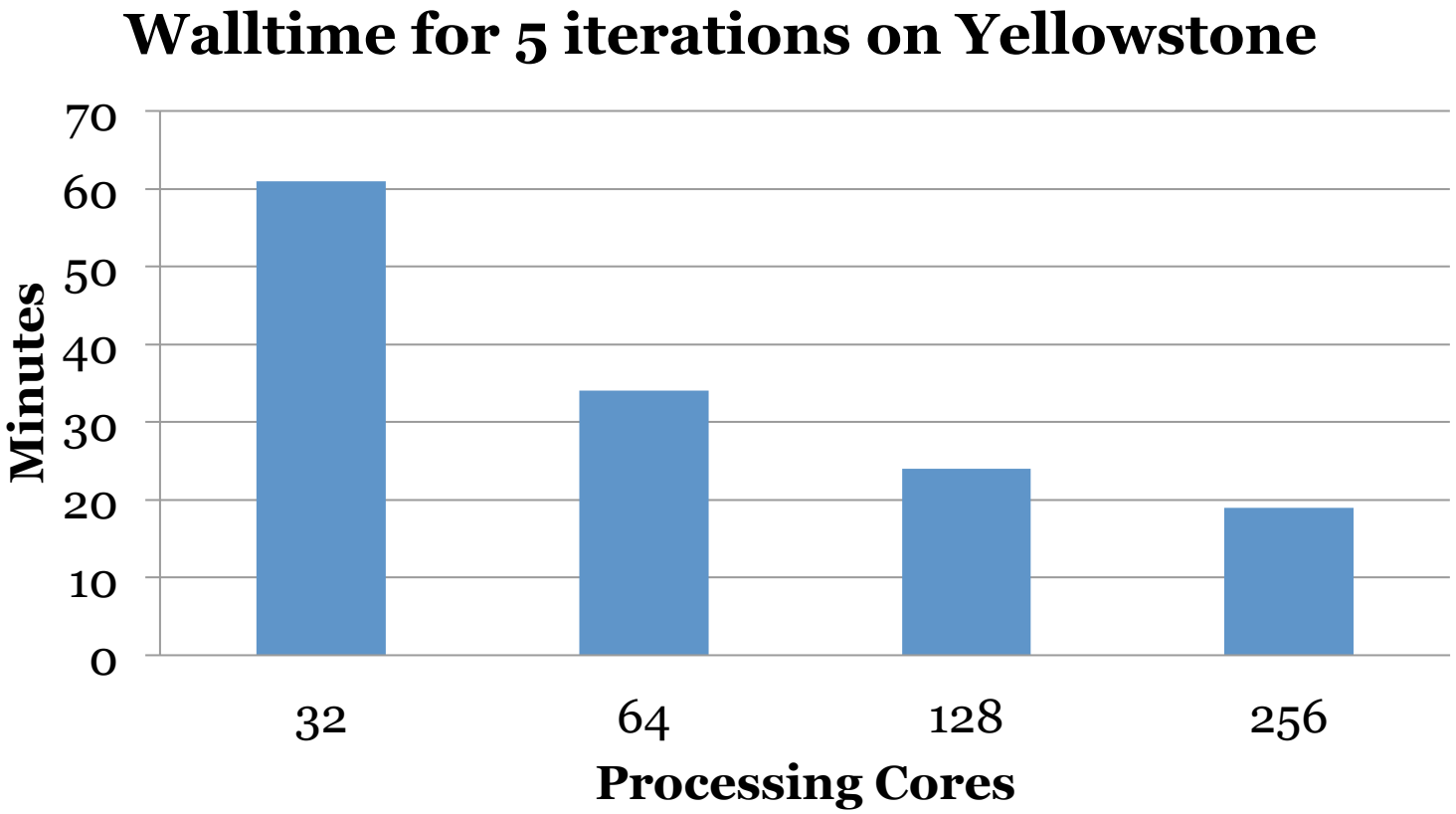
Increments after 2 outer loops: RH at 850hPa





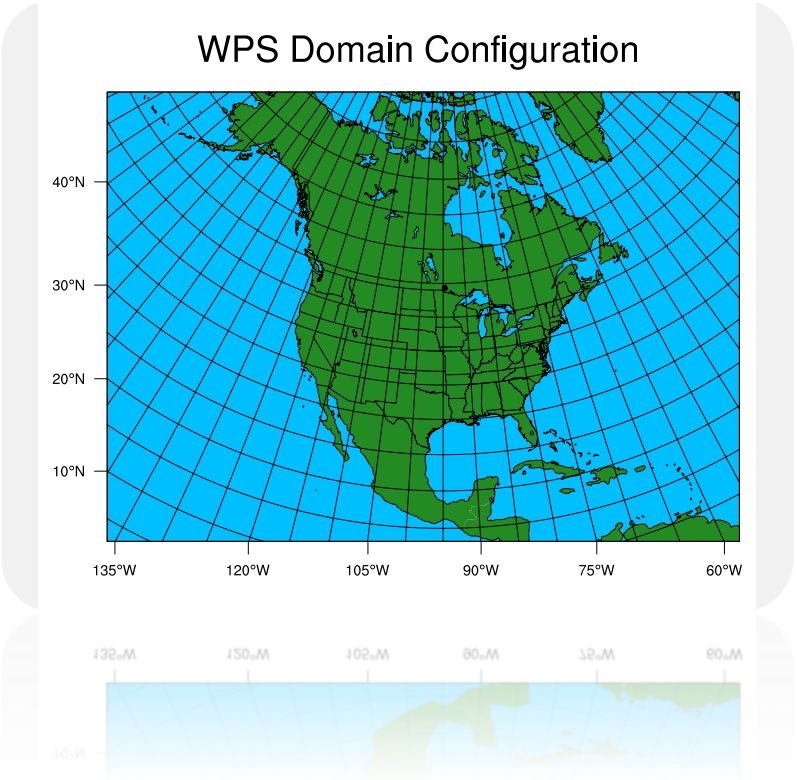
Parallel Performance

- Domain size:
  - 349×247×L51
- Domain horizontal resolution:
  - 30km
- Assimilation window
  - 6 hours (2209 to 2215)

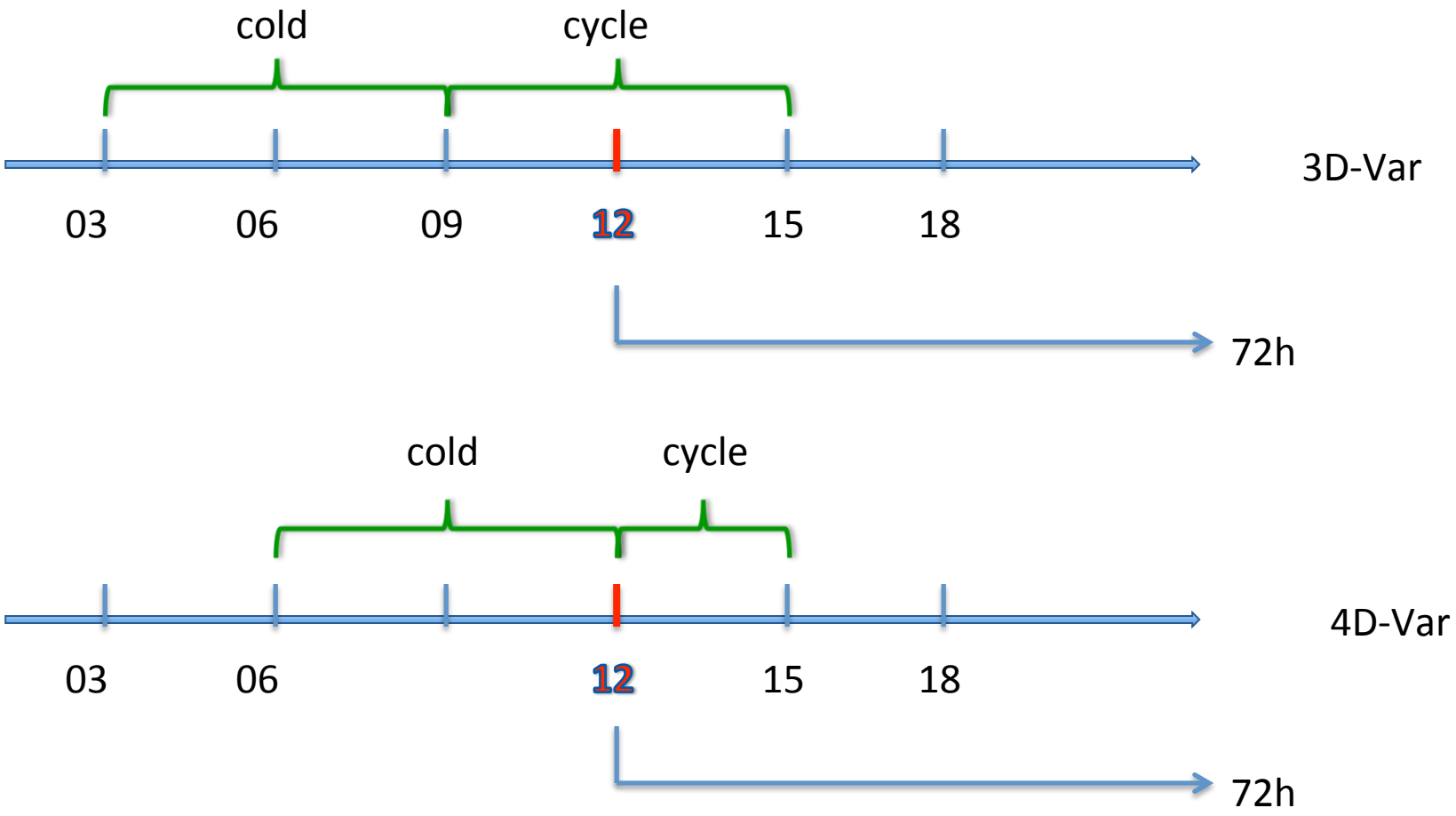


One-month regression test

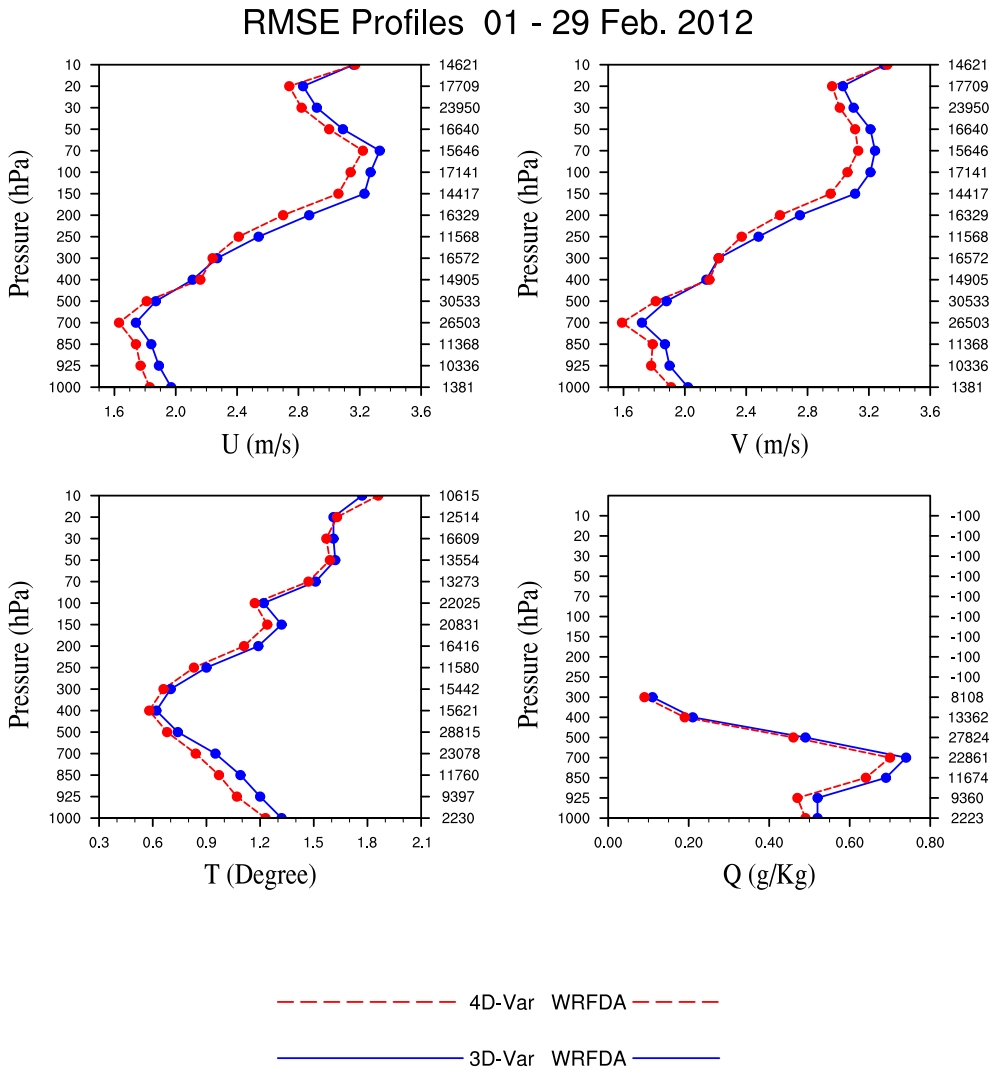
- Analysis time:
  - 2012•02　12Z
- Domain size:
  - 175×124×L51
- Domain horizontal resolution:
  - 60km
- Conventional data only



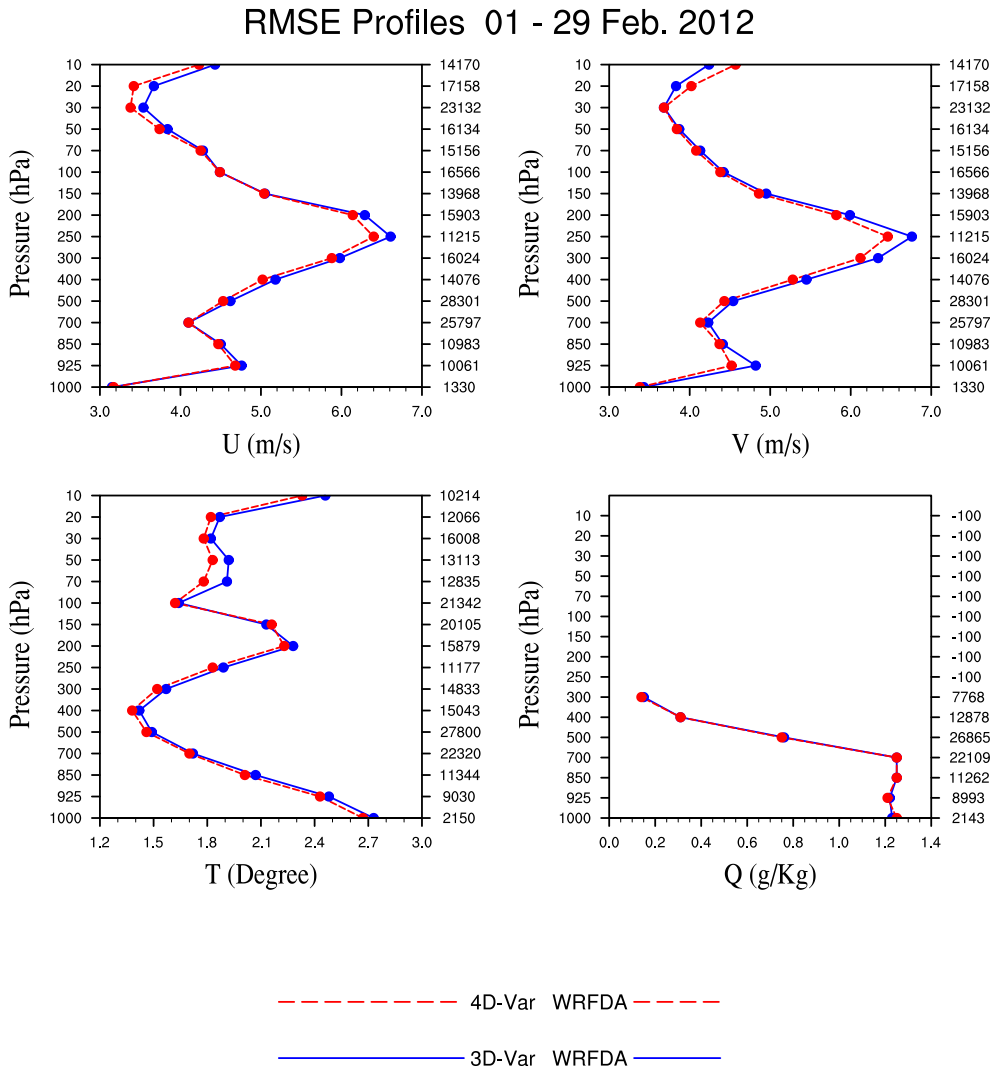
Experiments design:



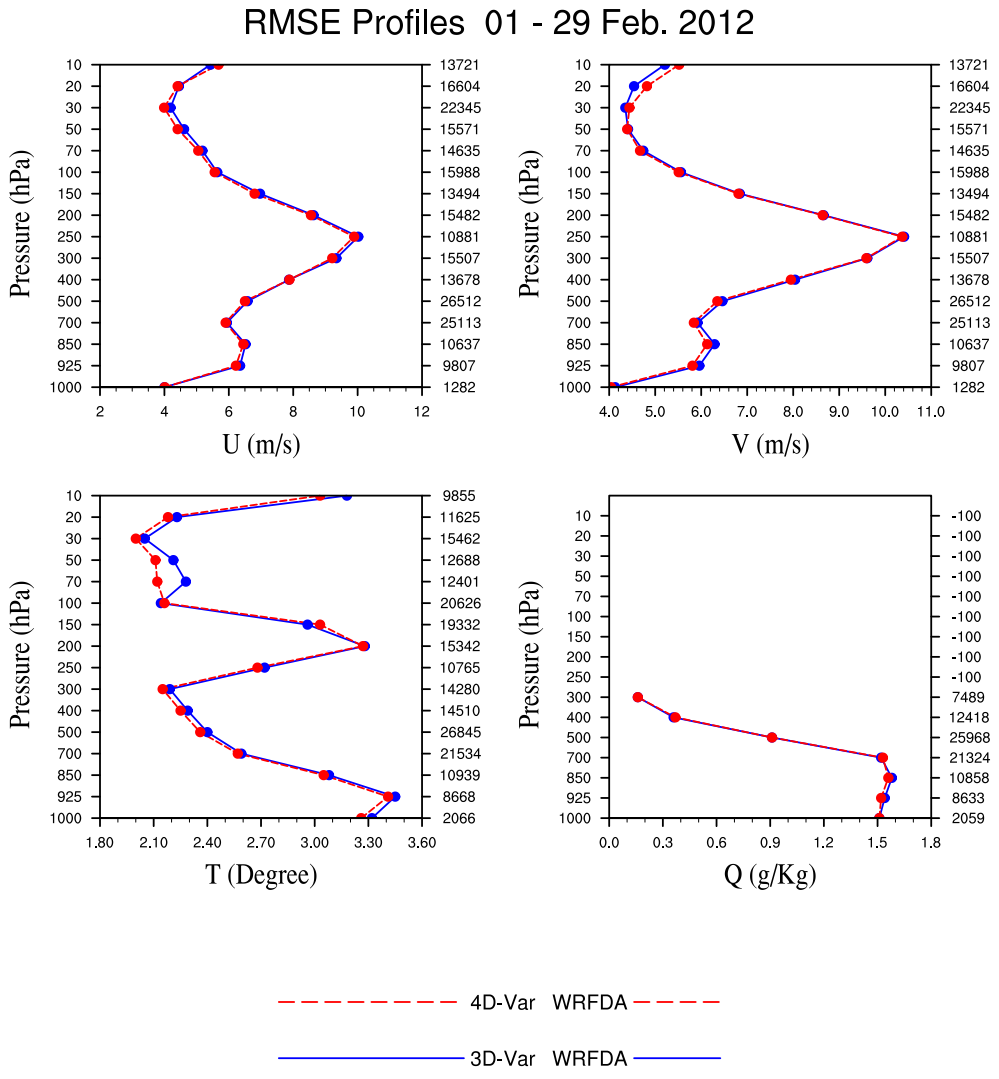
Aggregated RMSE Profiles: 0H



Aggregated RMSE Profiles: 24H



Aggregated RMSE Profiles: 48H



Summary

- The basic development of the GSI-based WRF 4D-Var is done. Good for research purpose use.
- The preliminary results shows the promising results compared to 3D-Var.

Planned:

- Multiple incremental 4D-Var has been planned.

GSI related work at NCAR/MMM

- Coupled GSI with WRFPLUS: 4D-Var.
- Coupled GSI with WRFPLUS: FSO.
- Applied GSI to assess the impact of ATMS and CrIS.
- Developed the WRFDA gen_be code for GSI background error calculations.
- Developed a user-friendly community tool for BE
  (re-engineered software, unified WRFDA and GSI)
- Developed GSI for WRF-Chem.
- Applied GSI hybrid to study the impact of MODIS cloudy radiance.
- Implemented the observation adjoint test in GSI.

All supported by AFWA!

FSO implementation with GSI+WRFPLUS

(Hui-Chuan Lin, Xin Zhang and Zhiquan Liu)

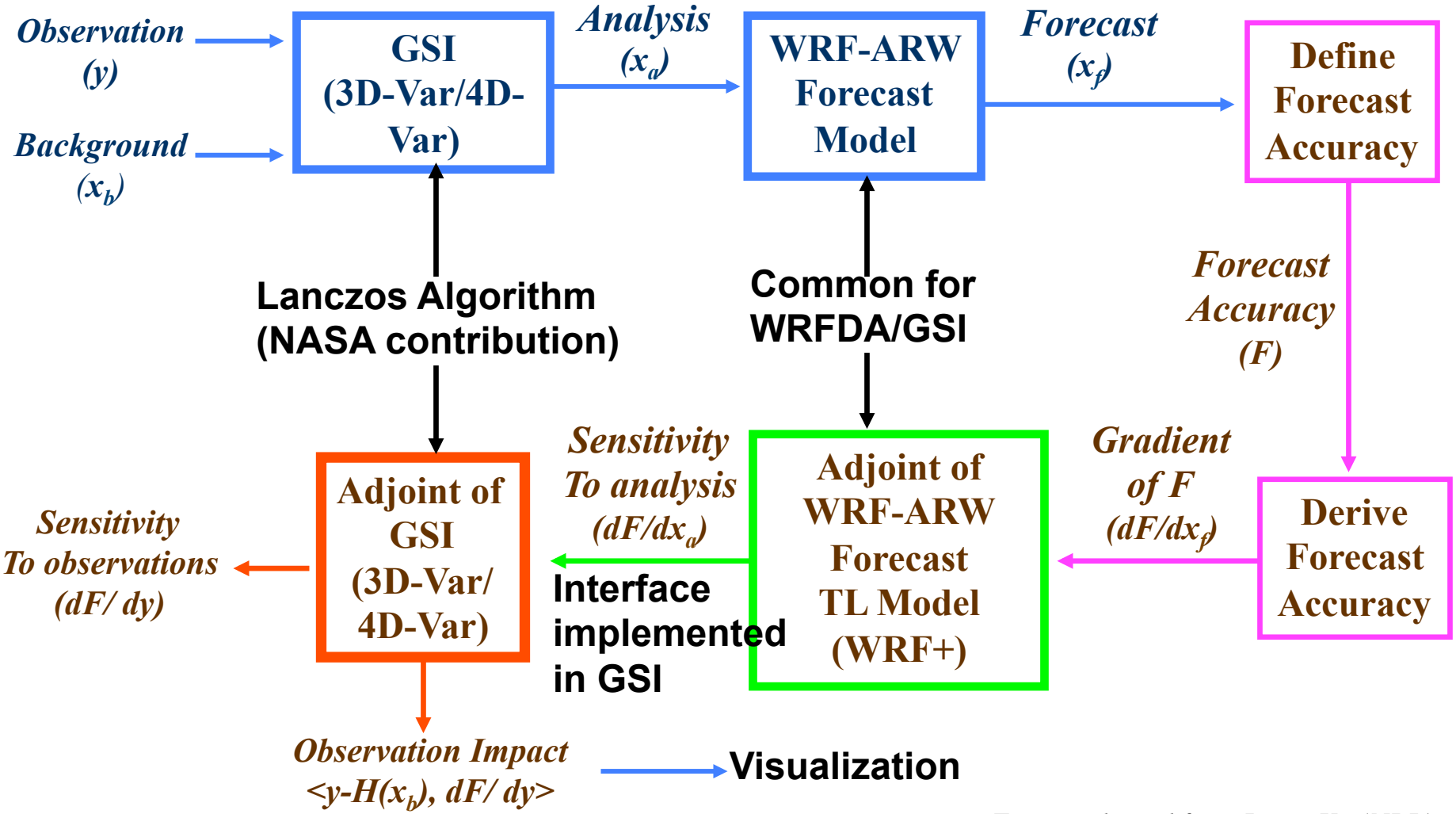


Figure adapted from Liang Xu (NRL)

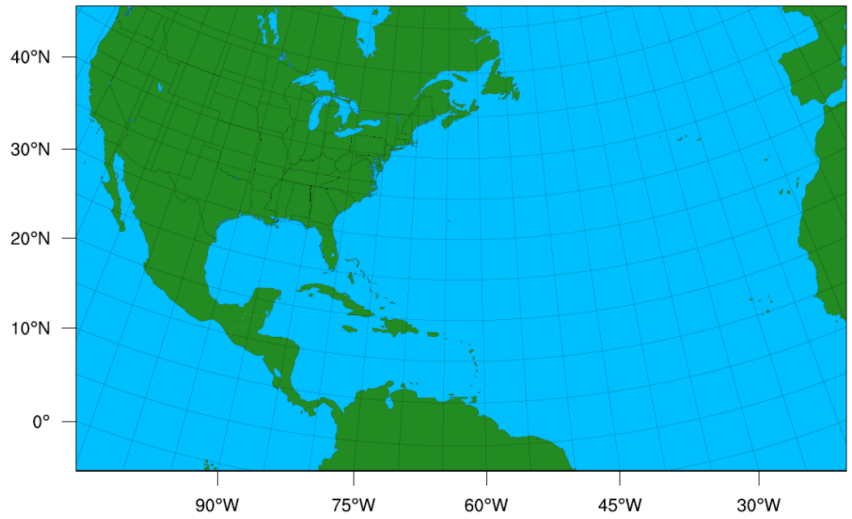
FSO implementation with GSI+WRFPLUS

- Latest (parallelized) WRFPLUS to derive the forecast sensitivity to analysis (FSA)
- **Merged FSA interface with GSI 4D-Var (parallelized) developments**
- Scripts developed to integrate the whole GSI-ARW FSO procedures
- Visualization tools developed

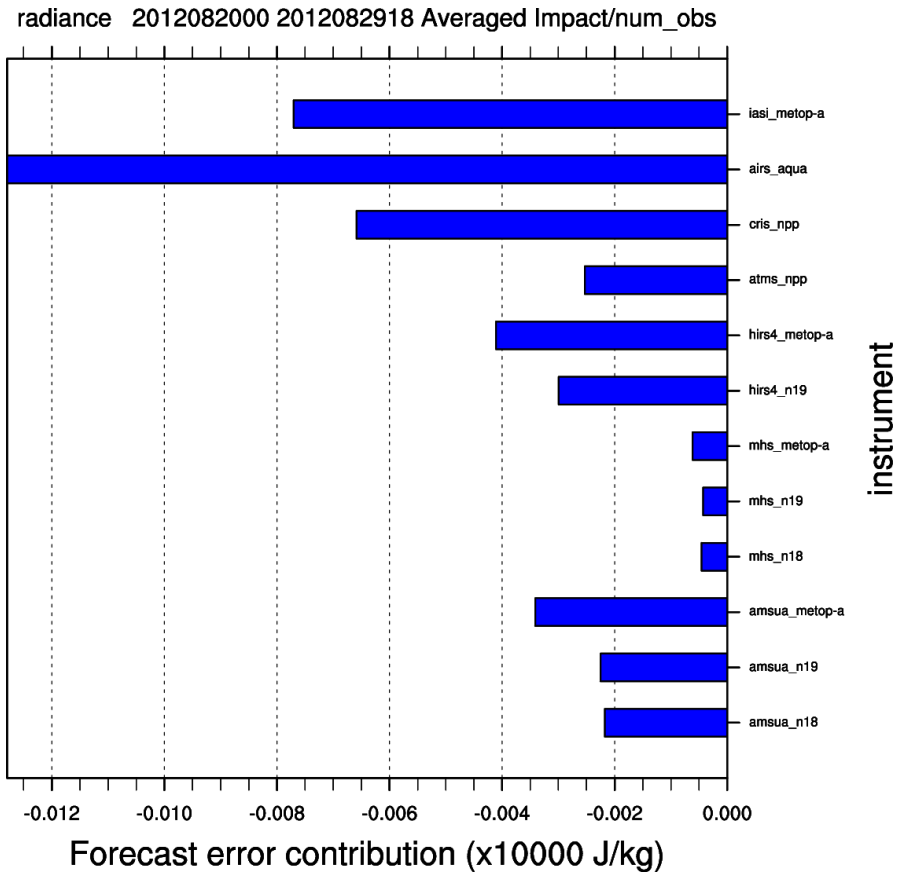
Impact of ATMS and CrIS:
Preliminary FSO Results

Hongli Wang, Zhiquan Liu, Hui-Chuan Lin and Xin Zhang

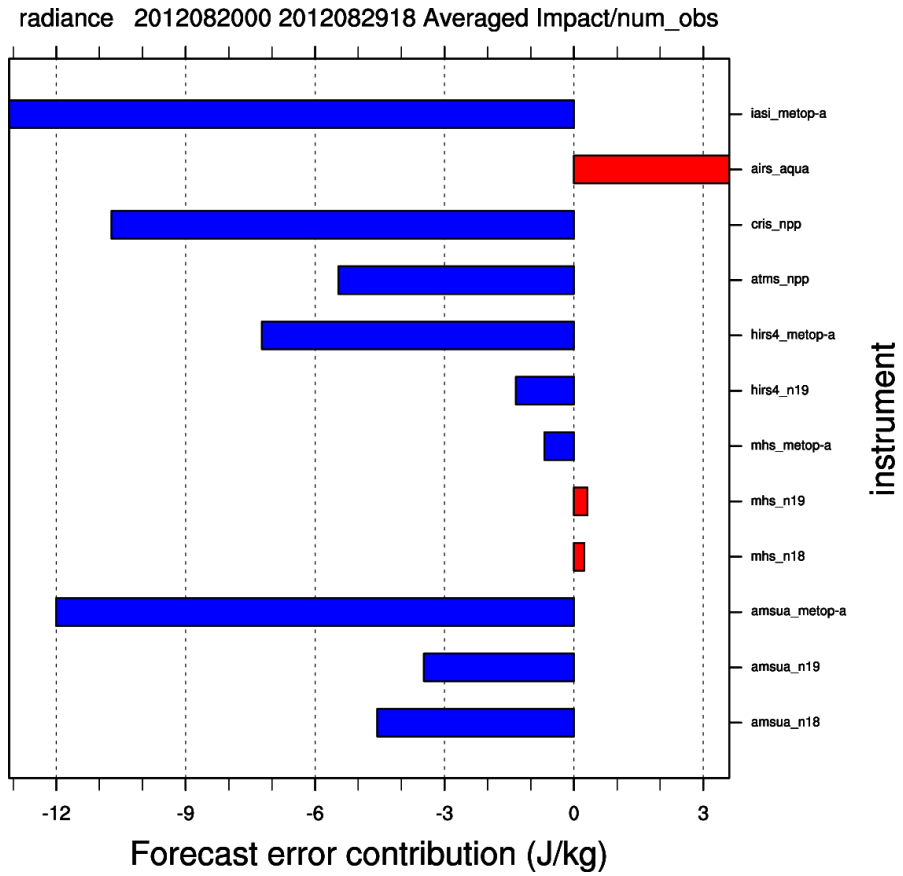
TC 36km domain
6-hour forecasts
10-day period



Impact of different instruments

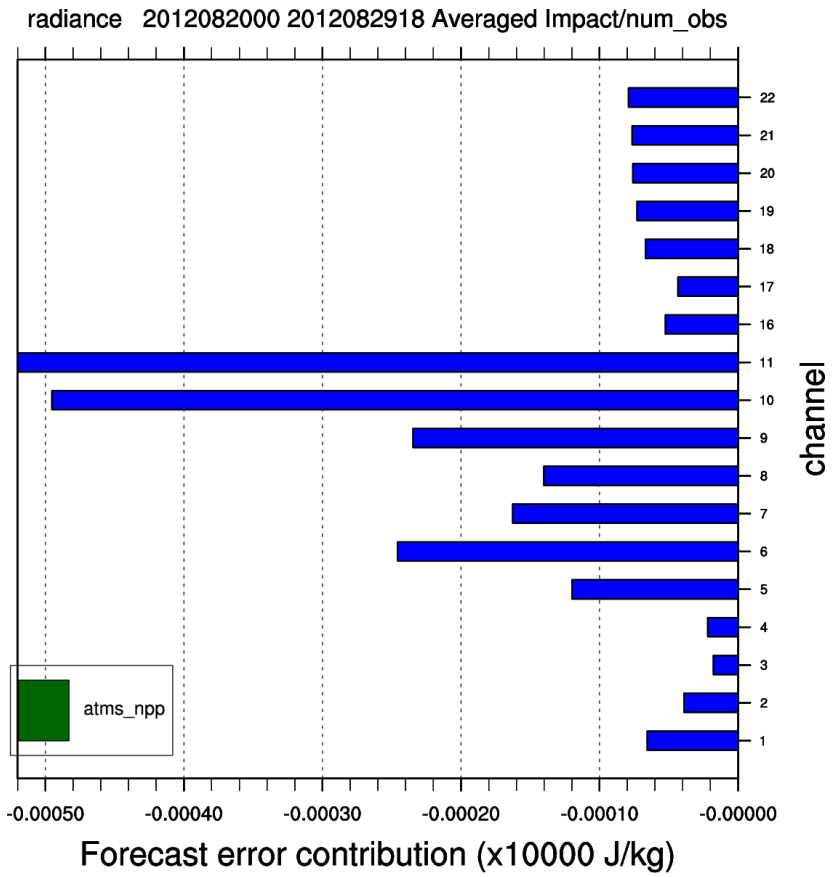


Own analysis as reference (ref1)

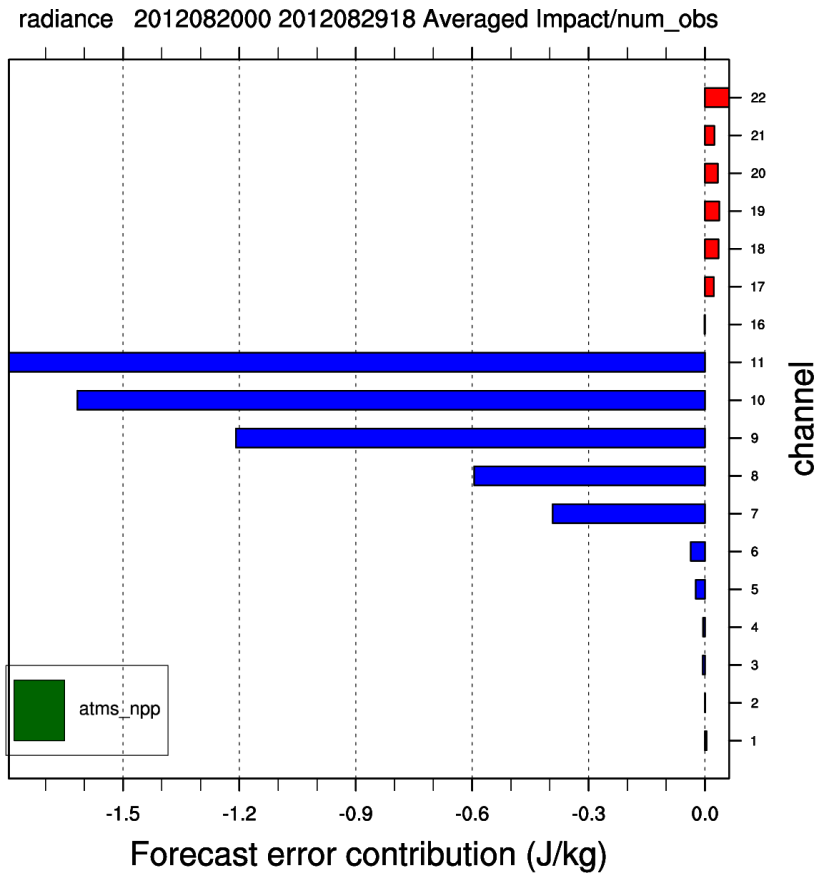


Global analysis as reference (ref2)

Impact of ATMS

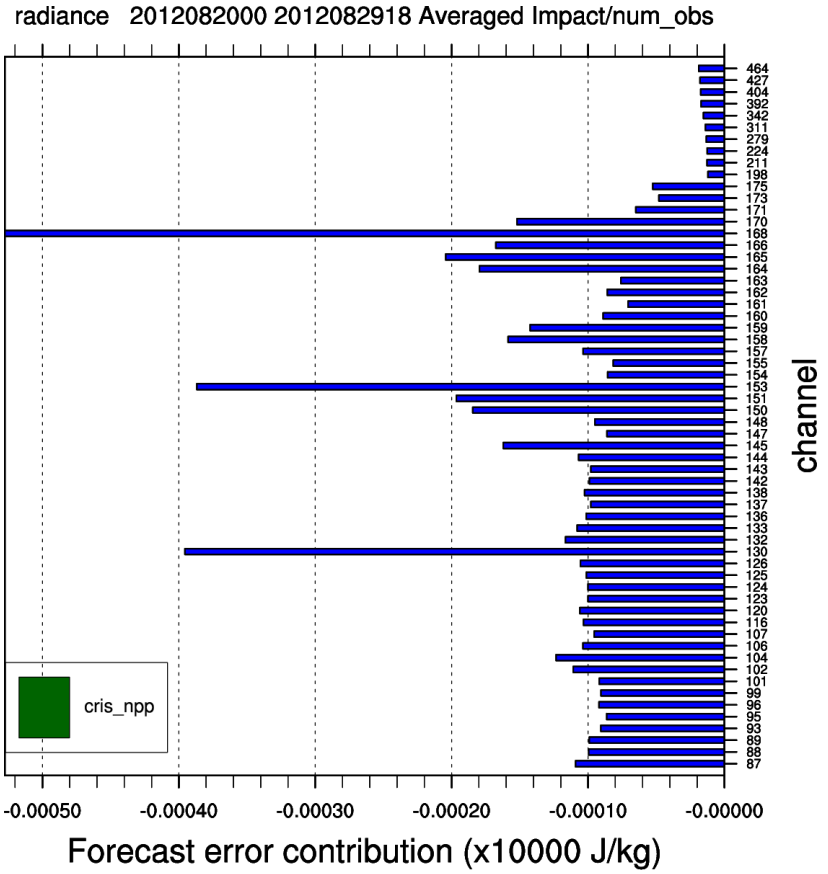


Own analysis as reference (ref1)

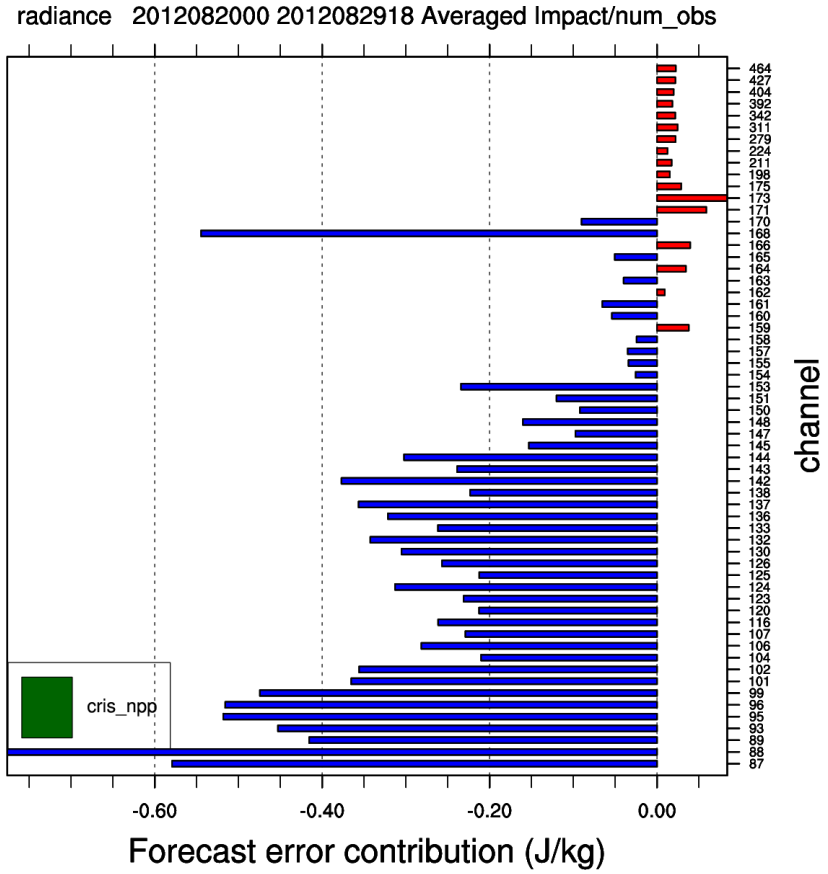


Global analysis as reference (ref2)

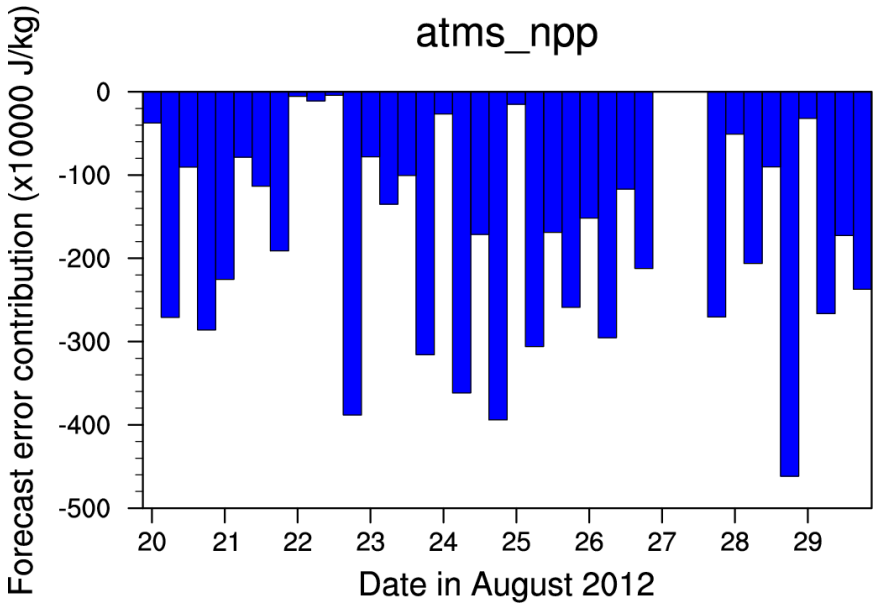
Impact of CrIS

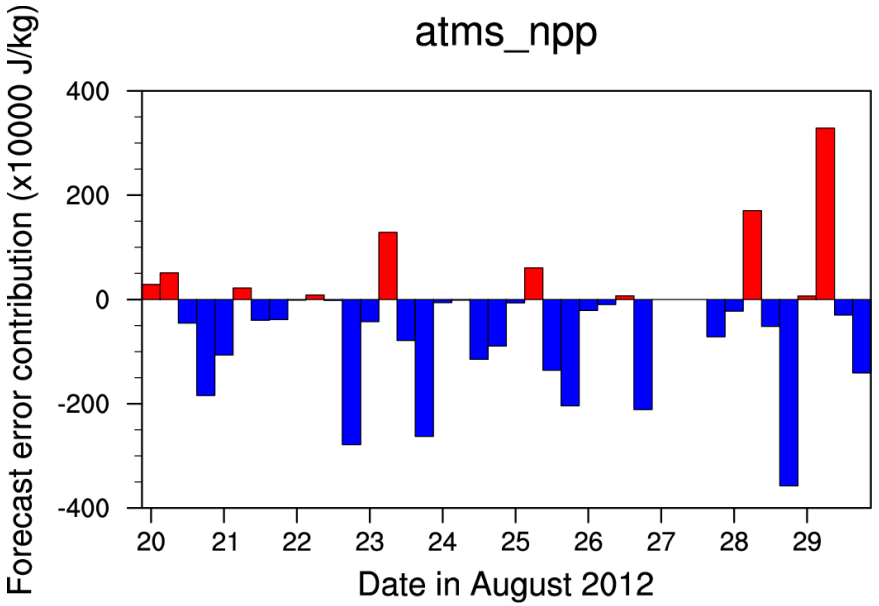


Own analysis as reference (ref1)

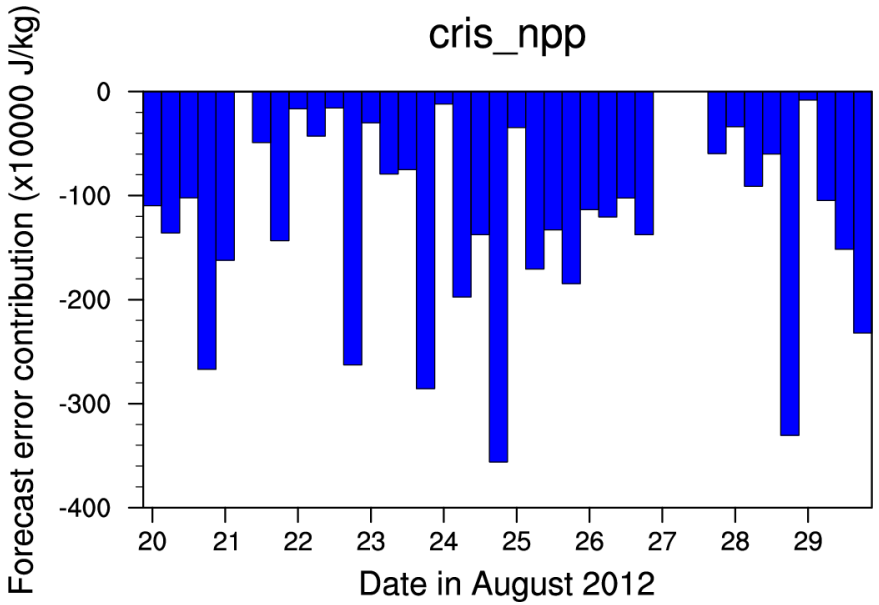


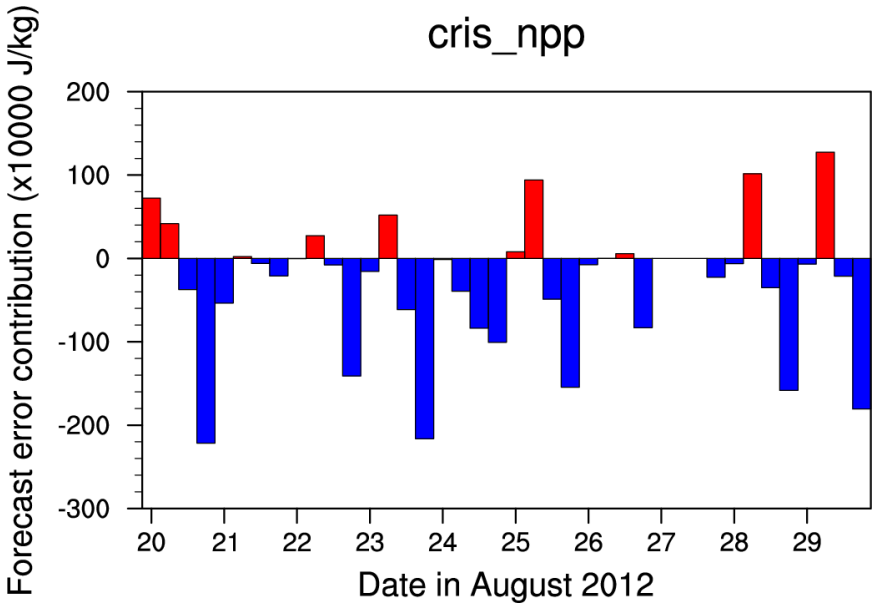
Global analysis as reference (ref2)





larger negative impact at 0600 UTC





Own analysis as reference (ref1)

Global analysis as reference (ref2)

Background Error Covariances

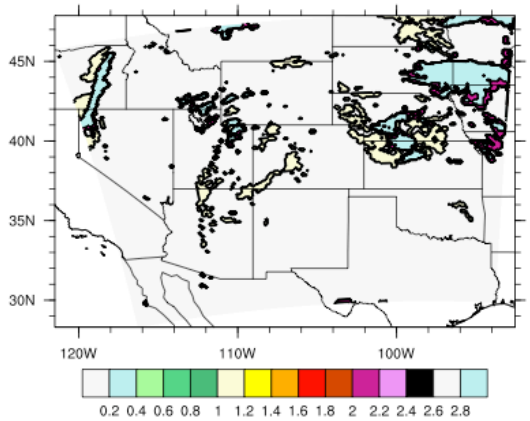
Tom Auligné, Gael Descombes

- GEN_BE 2.0: re-engineered software, unify WRFDA and GSI
- Goal: user-friendly community tool to compute the BE matrix.

- Multi-Models (stage0): WRF, UM, …
- Multi-Regression coefficients (stage2): inverse of the variance, Cholesky decomposition
- Multi-Vertical autocorrelations (stage3): EOFs, Recursive Filters
- Multi-Horizontal autocorrelations (stage4): Gaussian fit or Laplacian
- Multi-Binning option:
  - latitude bands
  - dynamical cloud mask

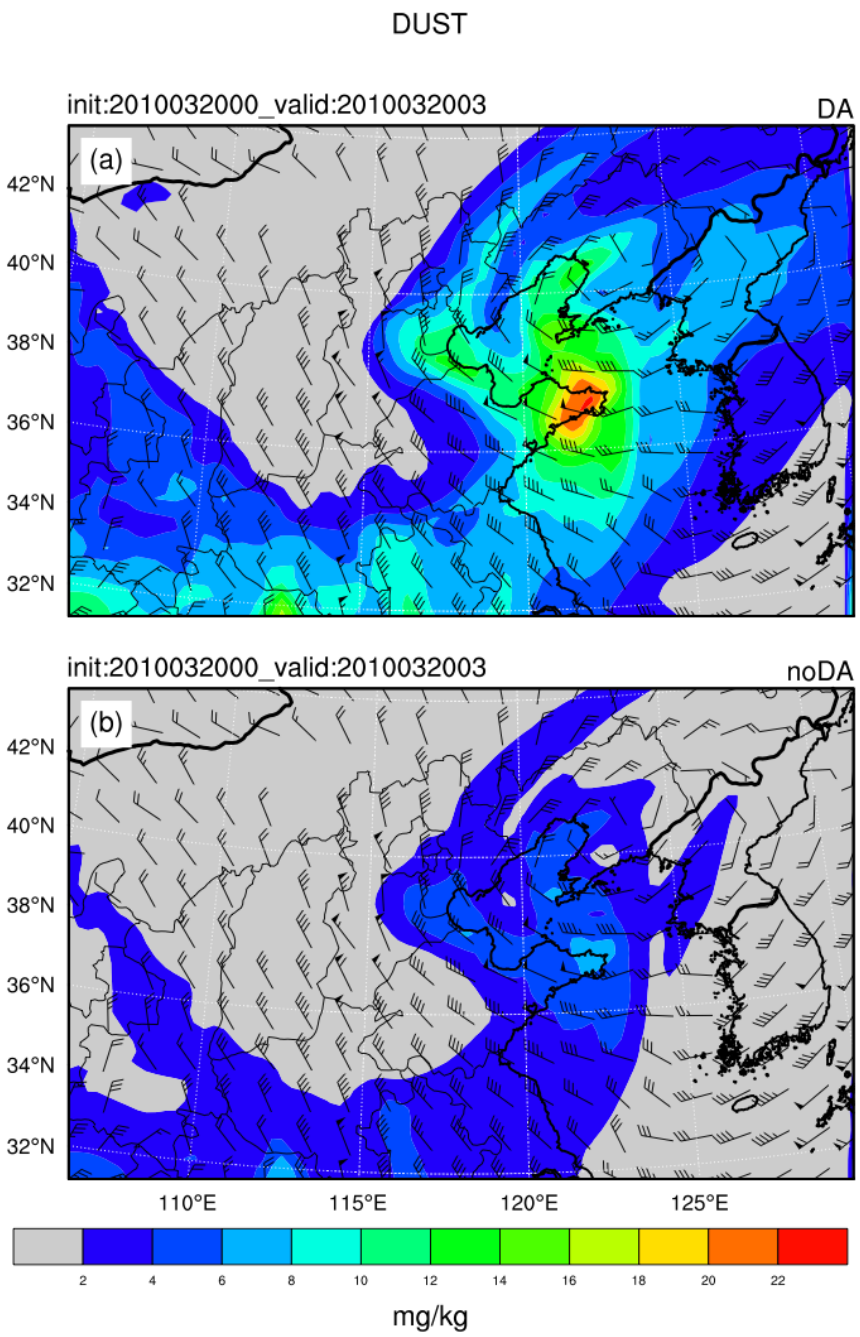
Definition

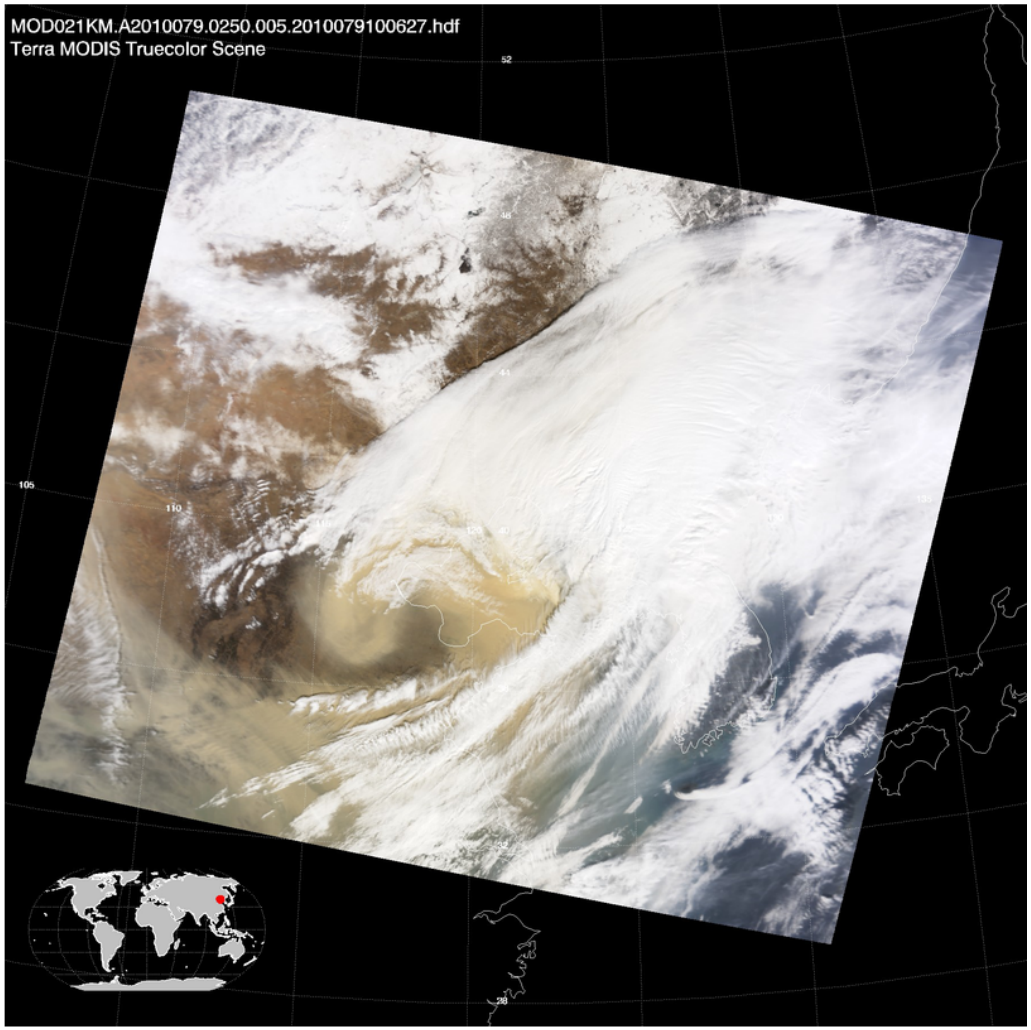
- Clear $q_{\text{rain}}^{1,2} \leq 10^{-3}$ g/kg
- Mixed
- Light Rain $q_{\text{rain}}^{1,2} \geq 10^{-3}$ g/kg and $q_{\text{rain}}^{1,2} \leq 10^{-1}$ g/kg
- Heavy Rain $q_{\text{rain}}^{1,2} \geq 10^{-1}$ g/kg



Michel et al. (MWR, 2011)

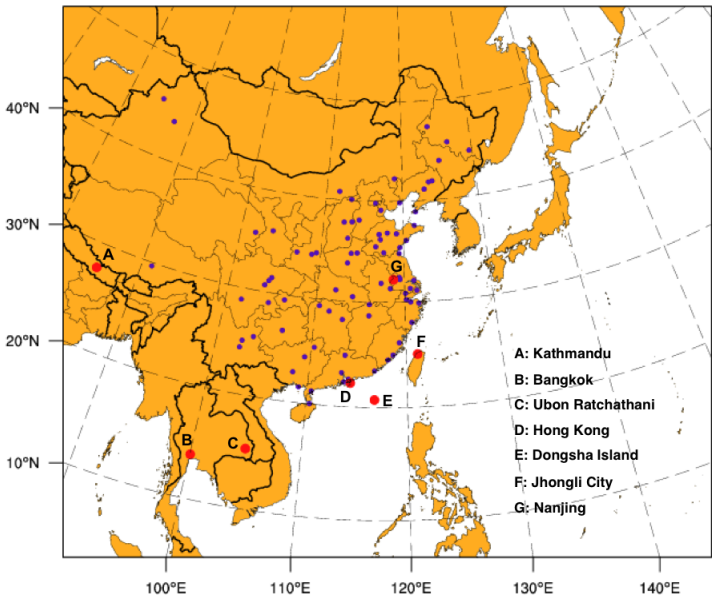
WRF/Chem and GSI AOD DA for a East Asia dust storm (Liu and Lin)

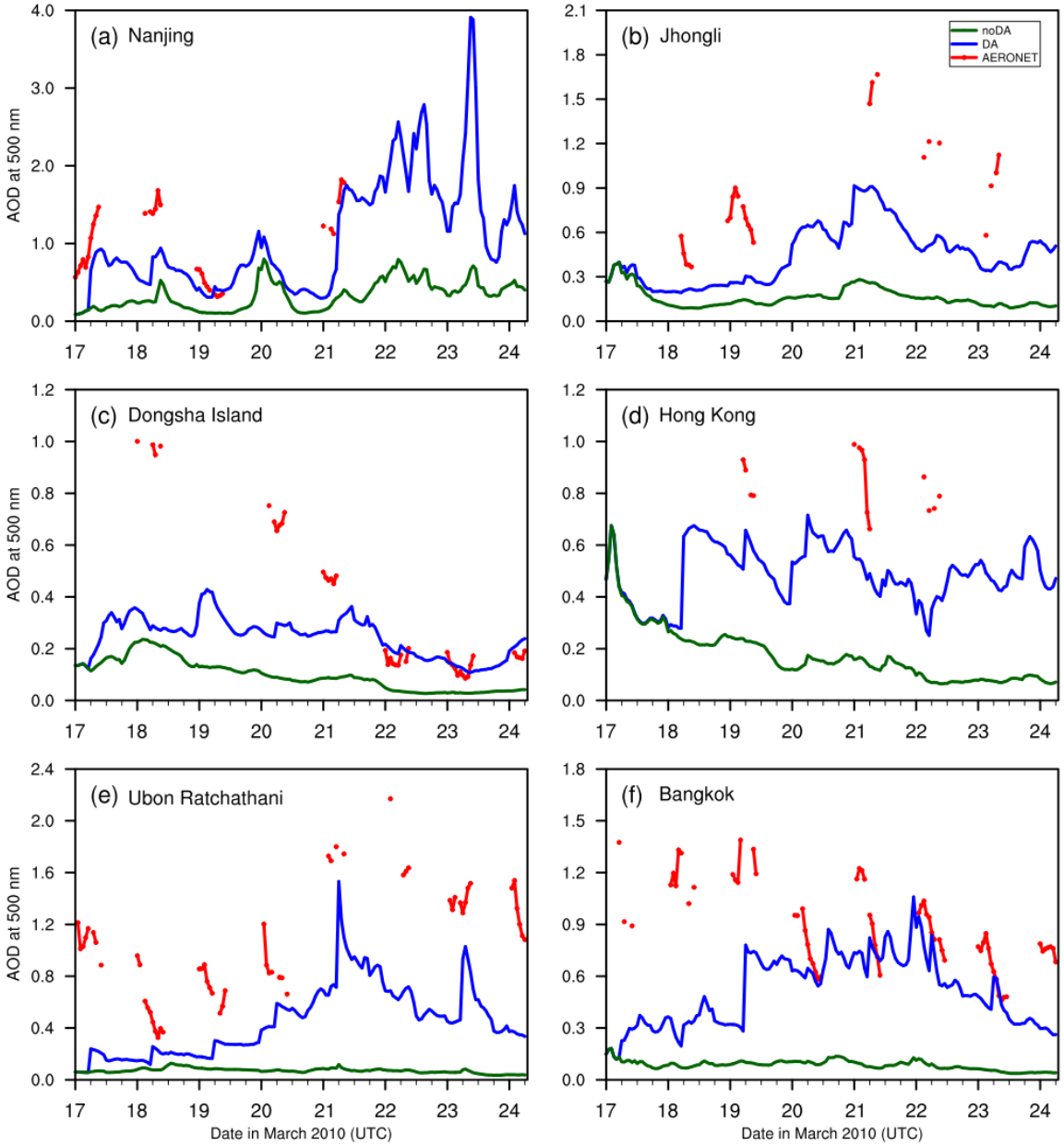




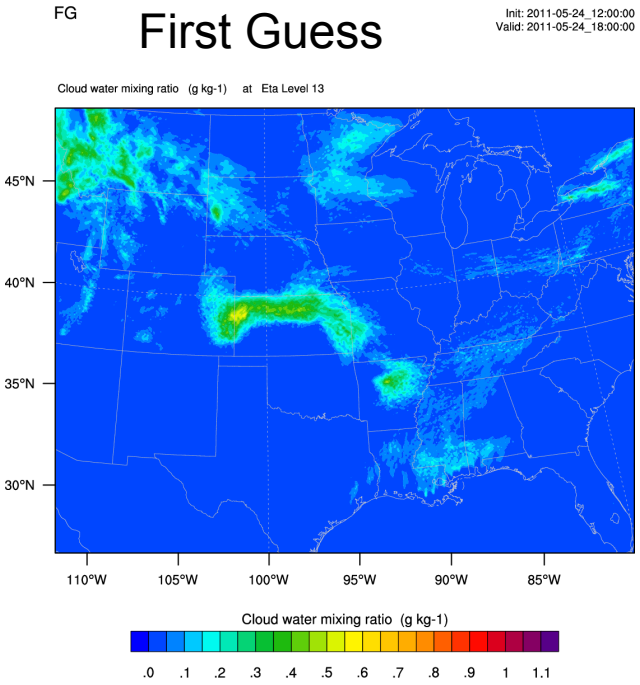
2010032003

Verify @500nm at 6 AERONET sites

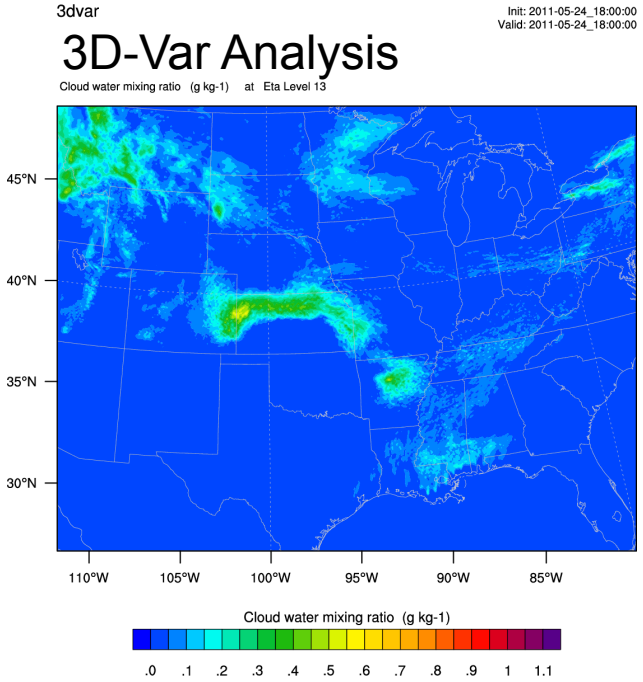


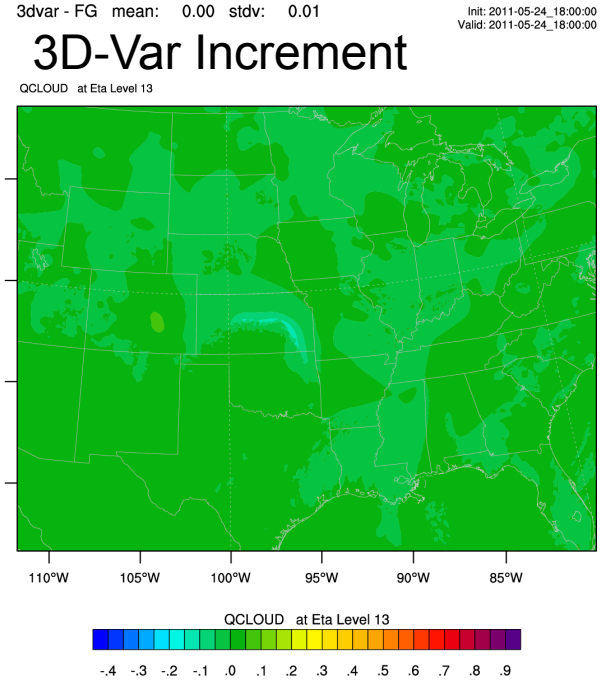


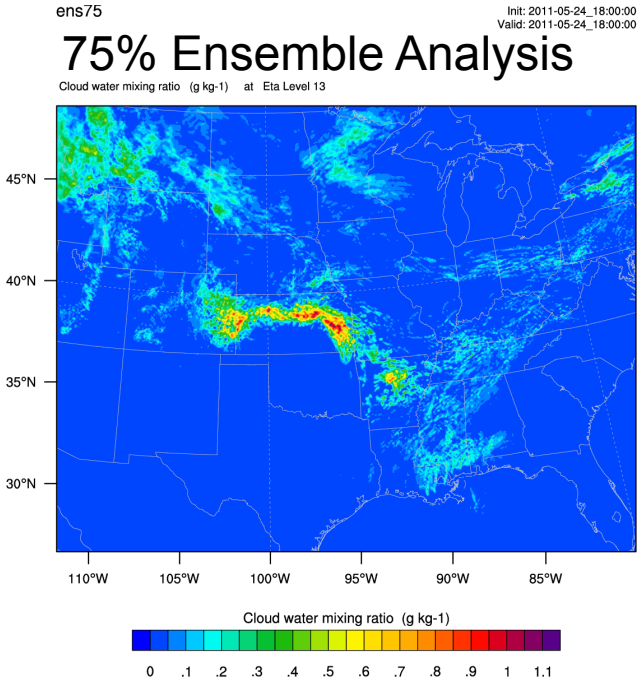
GSI-hybrid applied to MODIS cloudy radiance DA at 4km resolution (Liu and Lin)

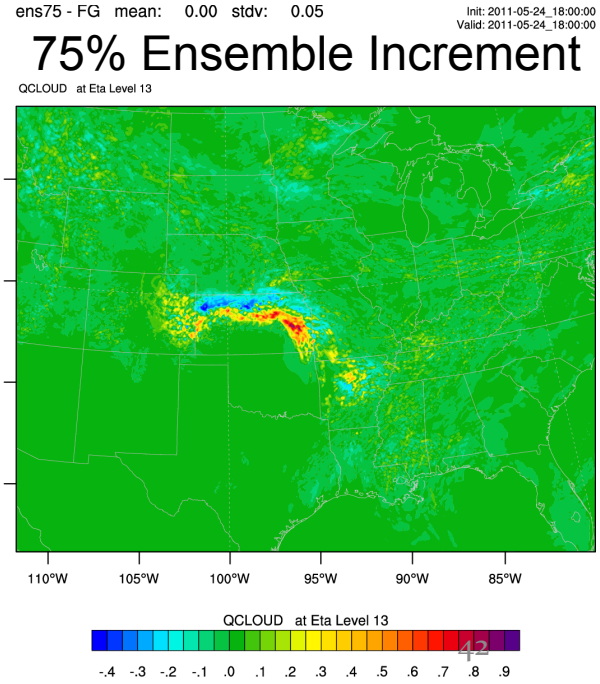


QCLOUD
eta=0.87 (~850 hPa)









Thank You

The NESL Mission is:
To advance understanding of weather, climate, atmospheric composition and processes; To provide facility support to the wider community; and, To apply the results to benefit society.

NCAR is sponsored by the National Science Foundation