WRF 4D-Var System
(Will be released soon)

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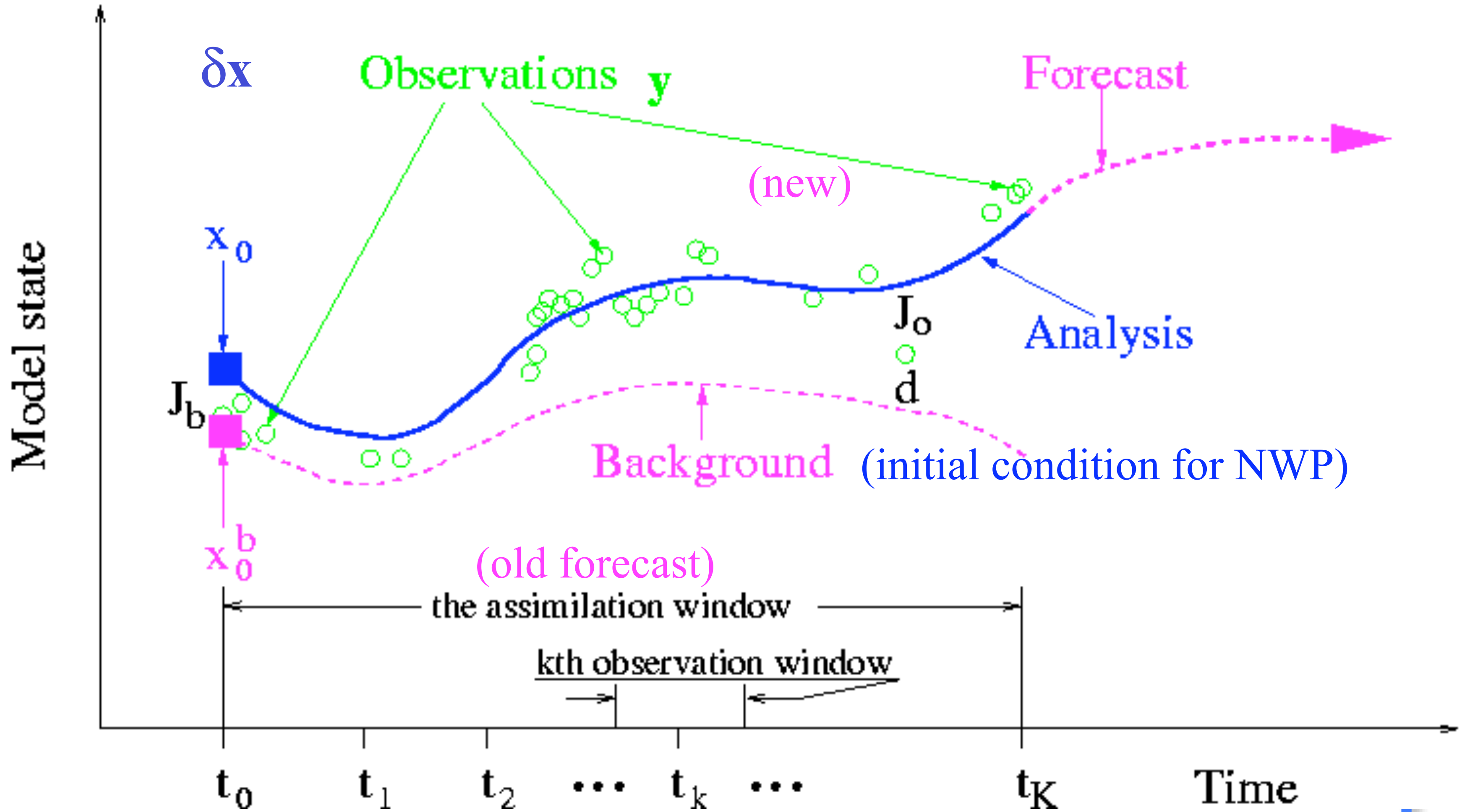
4D Variational Data Assimilation



From 3D-Var to 4D-Var

$$J = \frac{1}{2}\left(\mathbf{X}-\mathbf{X}^b\right)^T \mathbf{B}^{-1}\left(\mathbf{X}-\mathbf{X}^b\right) + \frac{1}{2}\left(\mathbf{y}^o - \mathbf{HX}\right)^T \mathbf{O}^{-1}\left(\mathbf{y}^o - \mathbf{HX}\right)$$

$$J = \frac{1}{2}\left(\mathbf{X}-\mathbf{X}^b\right)^T \mathbf{B}^{-1}\left(\mathbf{X}-\mathbf{X}^b\right) + \frac{1}{2}\sum_{t=1}^{k}\left(\mathbf{y}_t^o - \mathbf{H}_t\mathbf{M}_t(\mathbf{X})\right)^T \mathbf{O}^{-1}\left(\mathbf{y}_t^o - \mathbf{H}_t\mathbf{M}_t(\mathbf{X})\right)$$

$$\nabla J = \mathbf{B}^{-1}\left(\mathbf{X}-\mathbf{X}^b\right) + \sum_{t=1}^{k} M_t^T H_t^T \mathbf{O}^{-1}\left(\mathbf{y}_t^o - \mathbf{H}_t\mathbf{M}_t(\mathbf{X})\right)$$

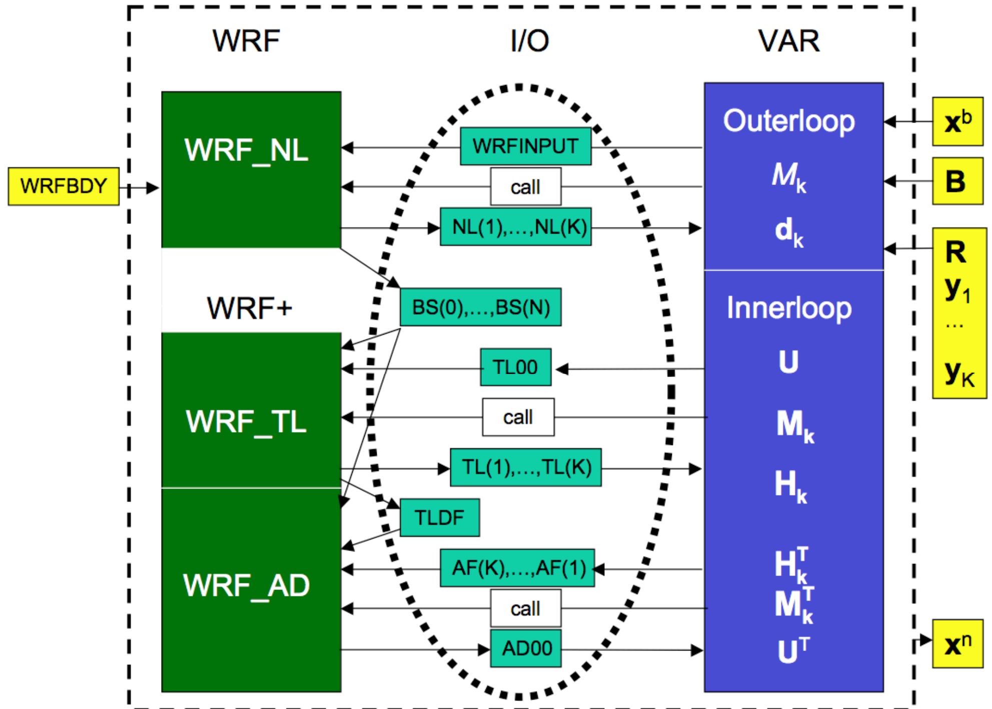
$$= \mathbf{B}^{-1}\partial\mathbf{X} + \sum_{t=1}^{k} M_t^T H_t^T \mathbf{O}^{-1}\left(\mathbf{y}_t^o - \mathbf{H}_t\mathbf{M}_t\left(\mathbf{X}^b\right) - H_t M_t(\partial\mathbf{X})\right)$$

WRF AD

ARW WRF

WRF TL

Basic system: 3 exes, disk I/O, parallel, full dynamics, simple phys



Hans Huang: WRF 4D-Var MMM Seminar, 13 December 2007

mpirun -np 4 da_wrfvar.exe -np 4 wrf.exe -np 8 wrfplus.exe

Scientific Performance of WRF 4D-Var

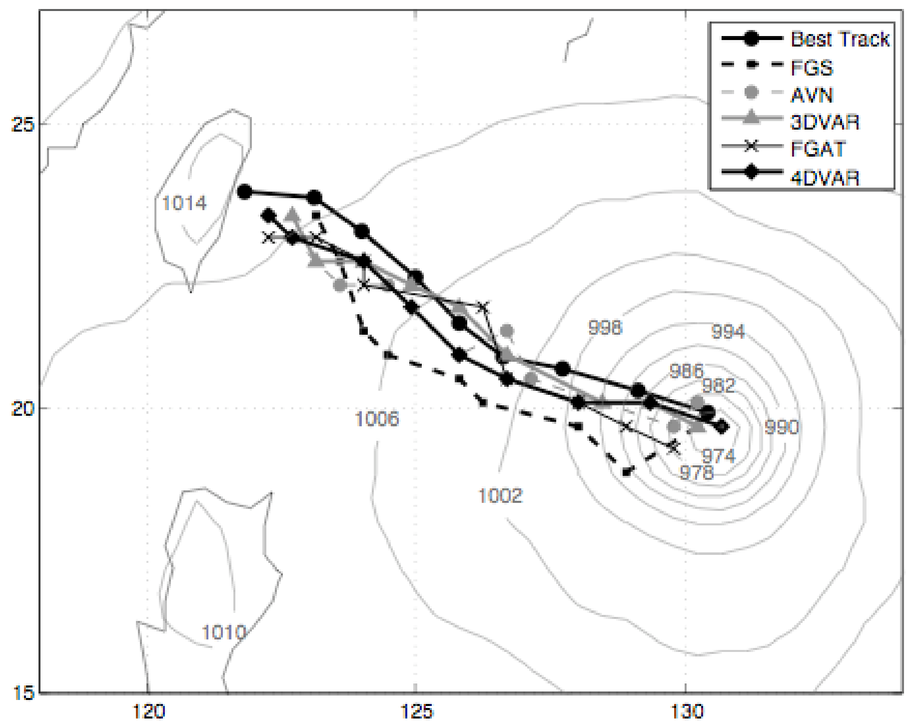
Typhoon Haitang experiments:

5 experiments, every 6 h, 00Z 16 July - 00 Z 18 July, 2005.
Typhoon Haitang hit Taiwan 00Z 18 July 2005

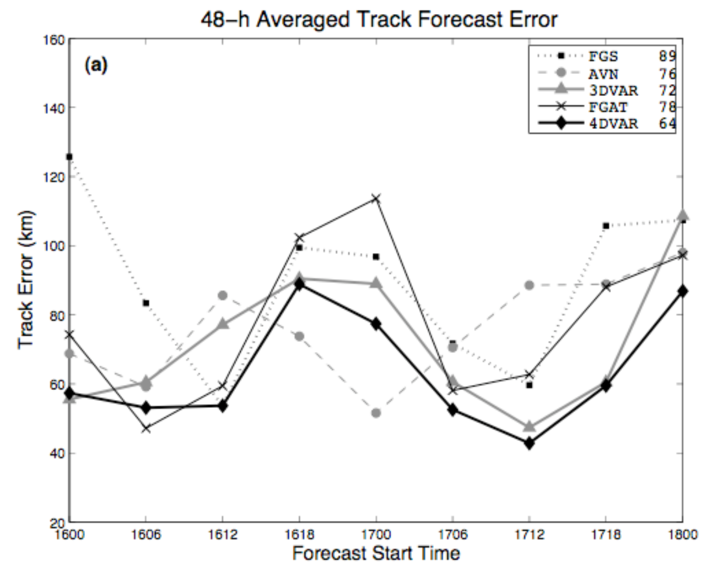
1. FGS – forecast from the background [The background fields are 6-h WRF forecasts from NCEP GFS analysis.]
2. AVN – forecast from the NCEP GFS analysis
3. 3DVAR – forecast from WRF 3D-Var
4. FGAT – first guess at appropriate time (A option of WRF-3DVAR)
5. 4DVAR – forecast from WRF 4D-Var

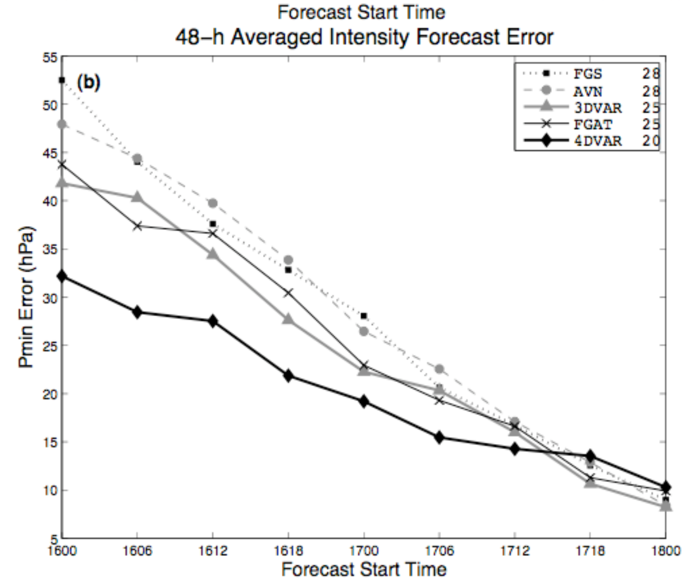
Domain size: 91x73x17
Resolution: 45 km
Time Window: 6 Hours,
Observations: GTS conventional observations, bogus data from CWB

Typhoon Haitang Verification

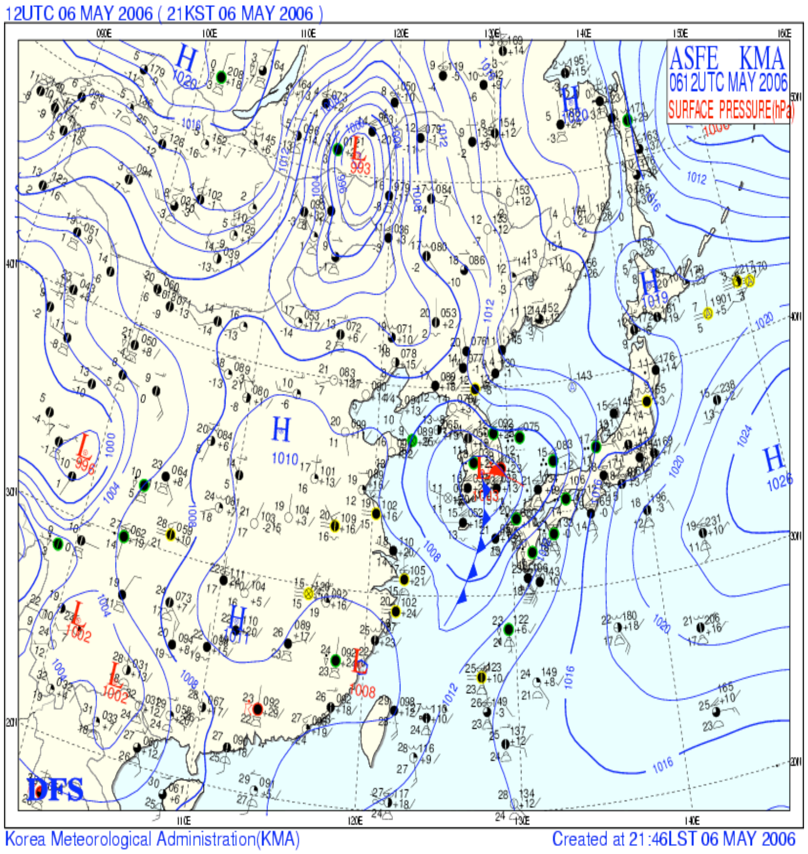


48-h forecast typhoon tracks from FGS, AVN, 3DVAR, FGAT, 4DVAR, together with the observed best track. Forecasts are all started from 0000 UTC 16 July 2005.



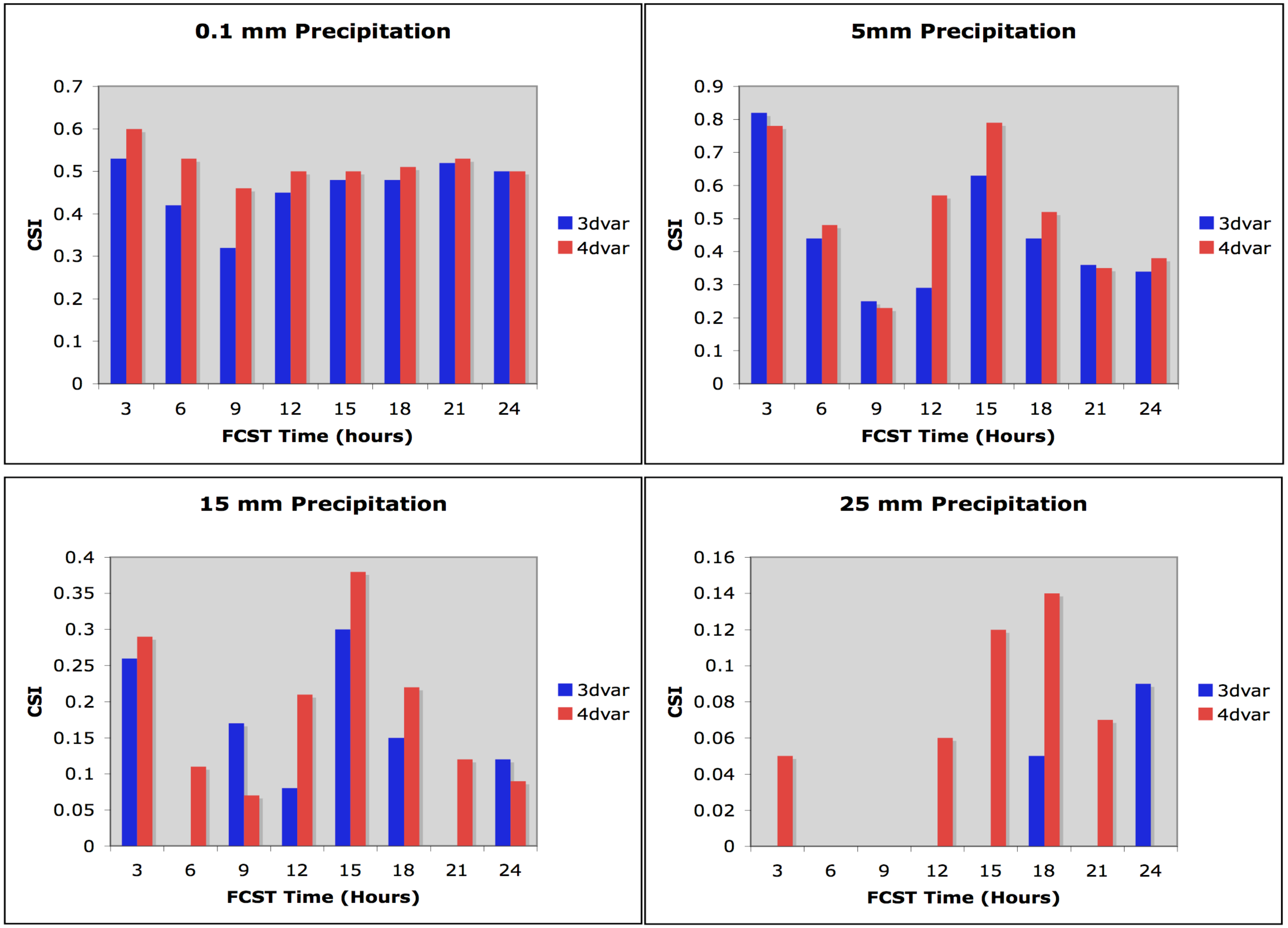


KMA Heavy Rain Case



- **Period**: 12 UTC 4 May - 00 UTC 9 May, 2006
- **Grid** : (60,54,31)
- **Resolution** : 30km
- **Domain size**: the same as the operational 10km do-main.
- **Assimilation window**: 6 hours
- Warm started cycling run

Precipitation Verification



The first radar data assimilation experiment using WRF 4D-Var

Yong-Run Guo

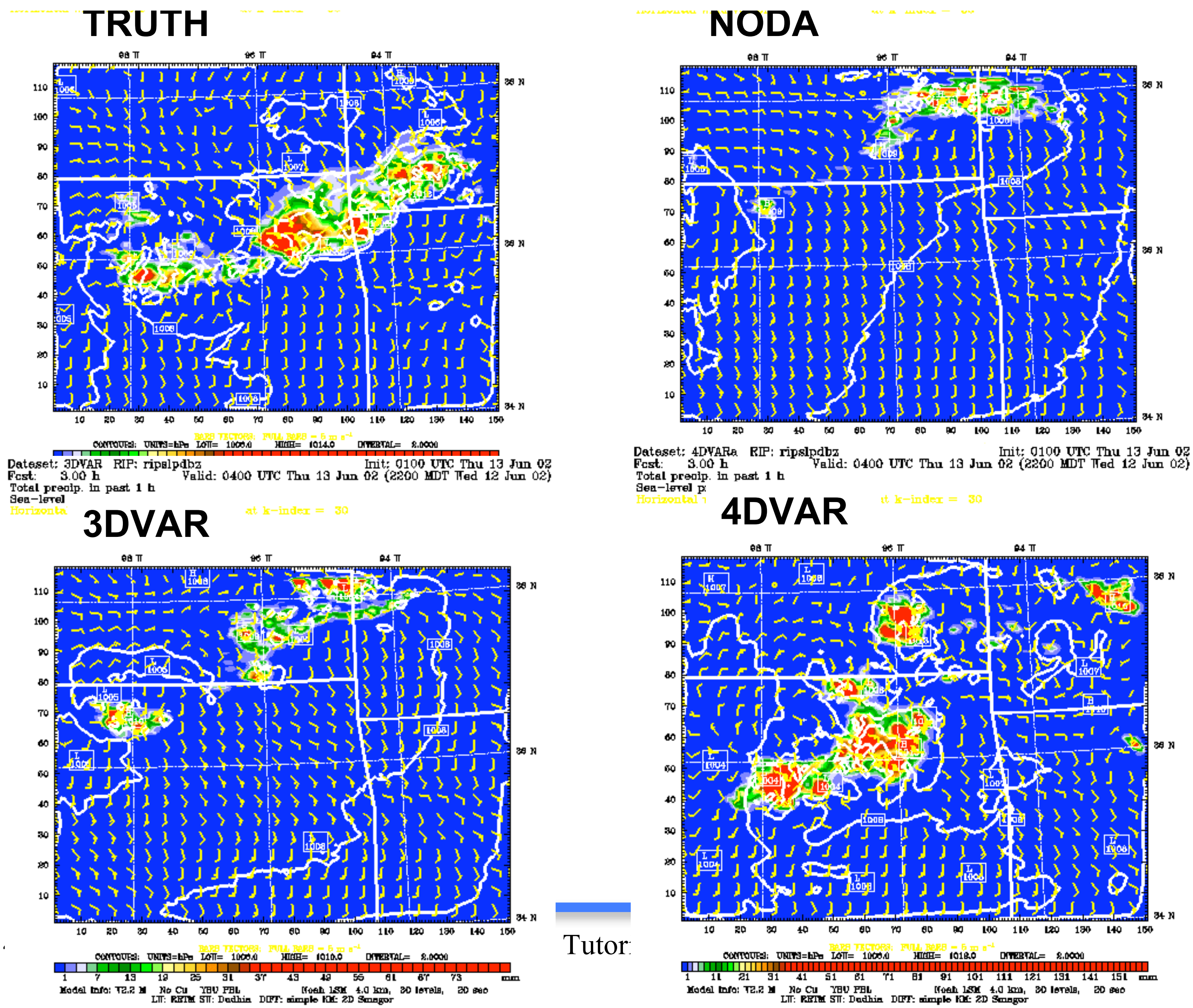
TRUTH ----- Initial condition from TRUTH (13-h forecast initialized at 2002061212Z from AWIPS 3-h analysis) run cutted by ndown**,** boundary condition from NCEP GFS data.

NODA ----- Both initial condition and boundary condition from NCEP GFS data.

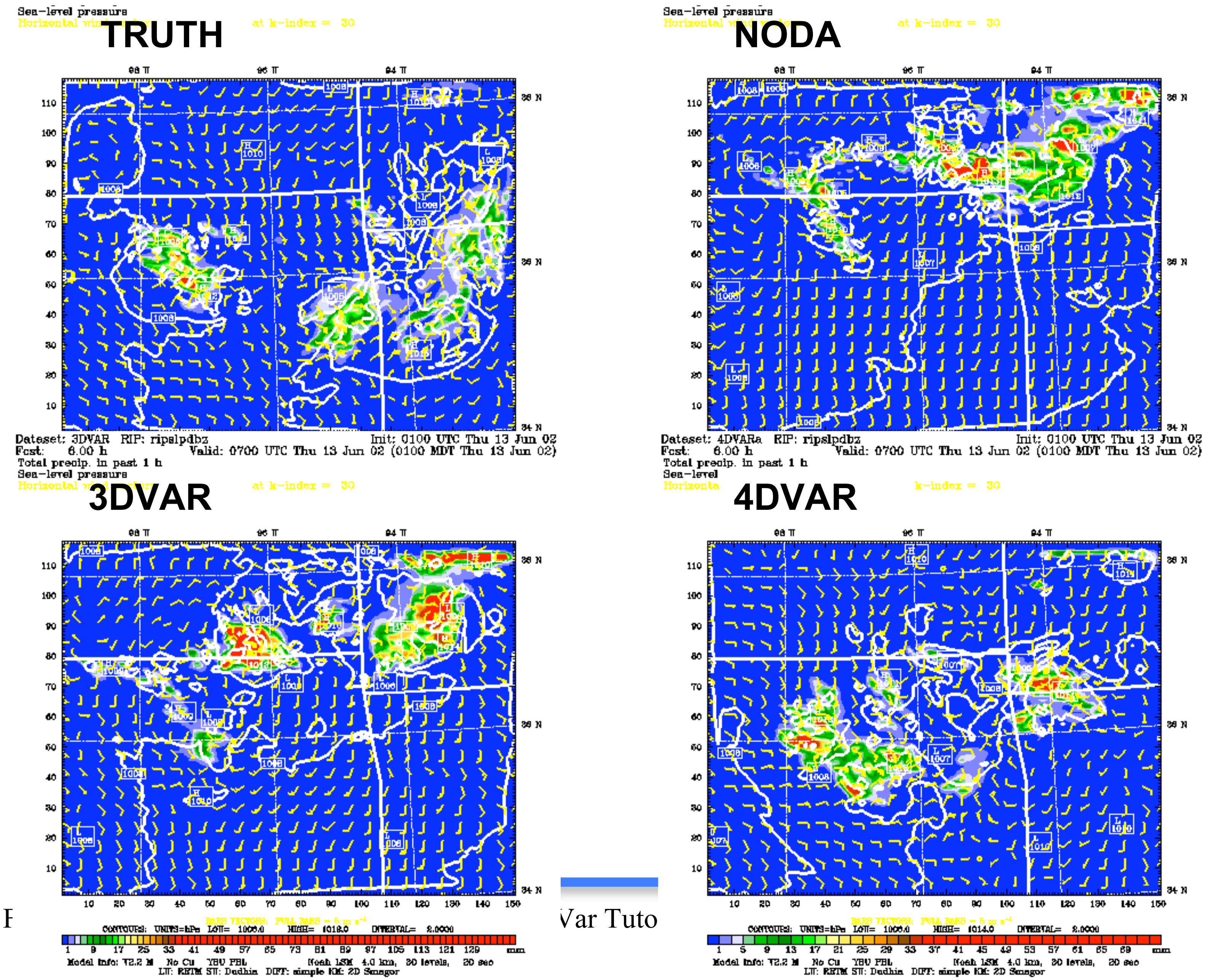
3DVAR ----- 3DVAR analysis at 2002061301Z used as the initial condition, and boundary condition from NCEP GFS. Only Radar radial velocity at 2002061301Z assimilated (total # of data points = 65,195).

4DVAR ----- 4DVAR analysis at 2002061301Z used as initial condition, and boundary condition from NCEP GFS. The radar radial velocity at 4 times: 200206130100, 05, 10, and 15, are assimilated (total # of data points = 262,445).

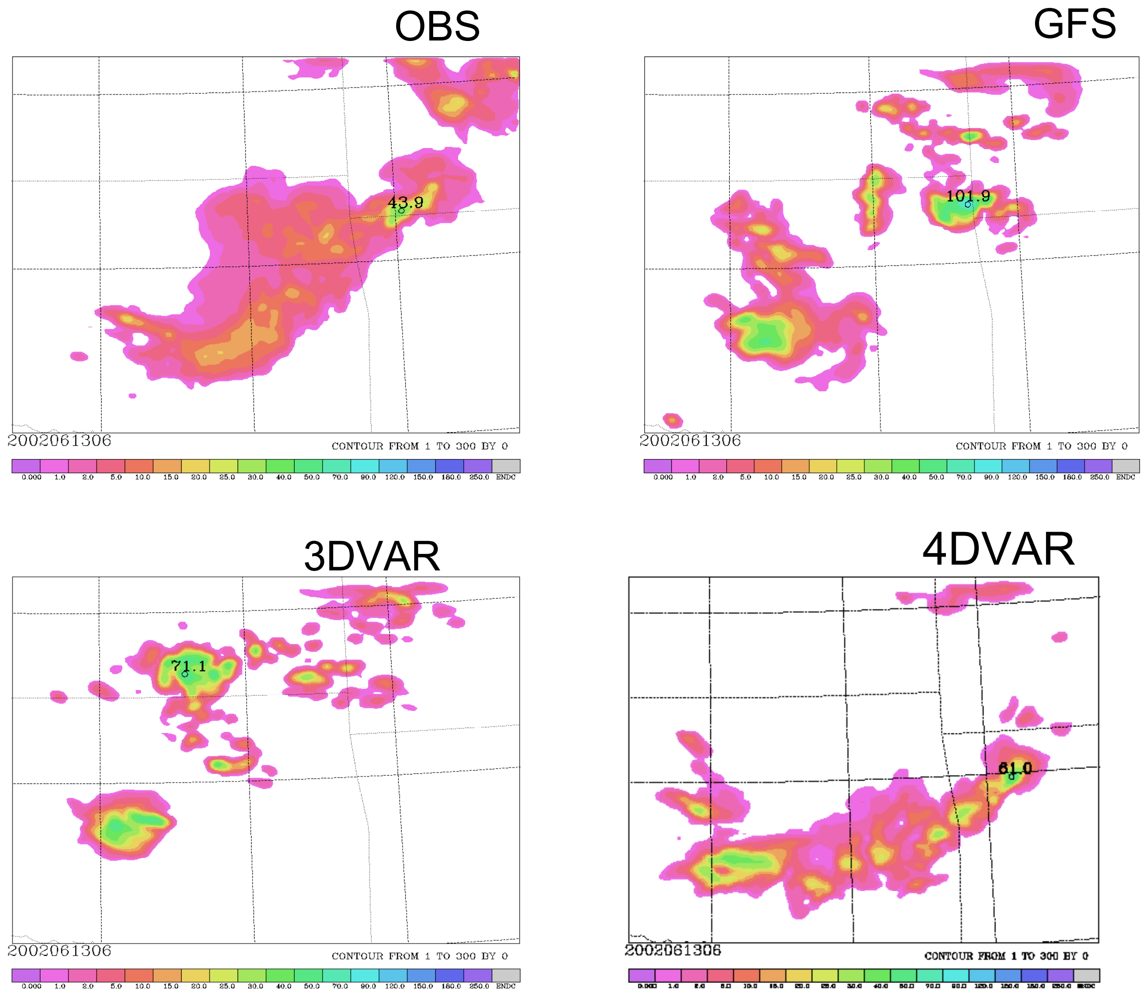
Hourly precipitation ending at 03-h forecast



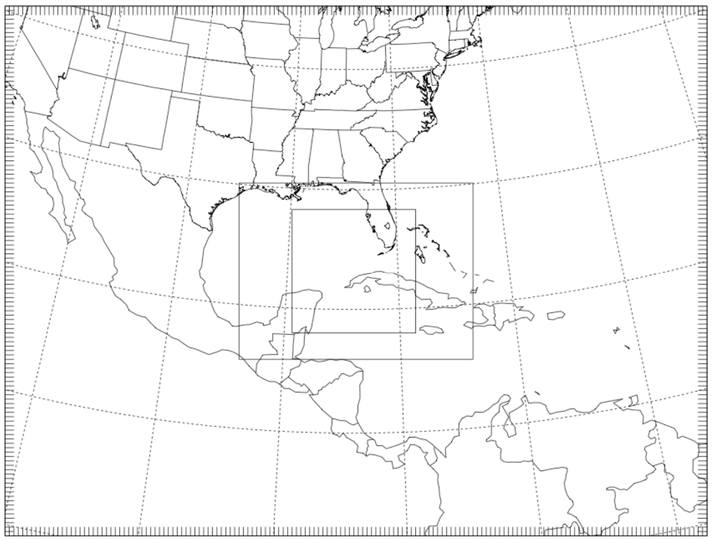
Hourly precipitation ending at 06-h forecast



Real data experiments



IKE----Domain Configuration (From Fuqing Zhang, real time setup)



Period: 2008091000-2008091500

IC is from 6h forecast.

Votex following moving nest domains:

D1: 160x121x35, 40.5 km

D2: 160x121x35, 13.5 km (moving domain from beginning, interpolated from mother domain)

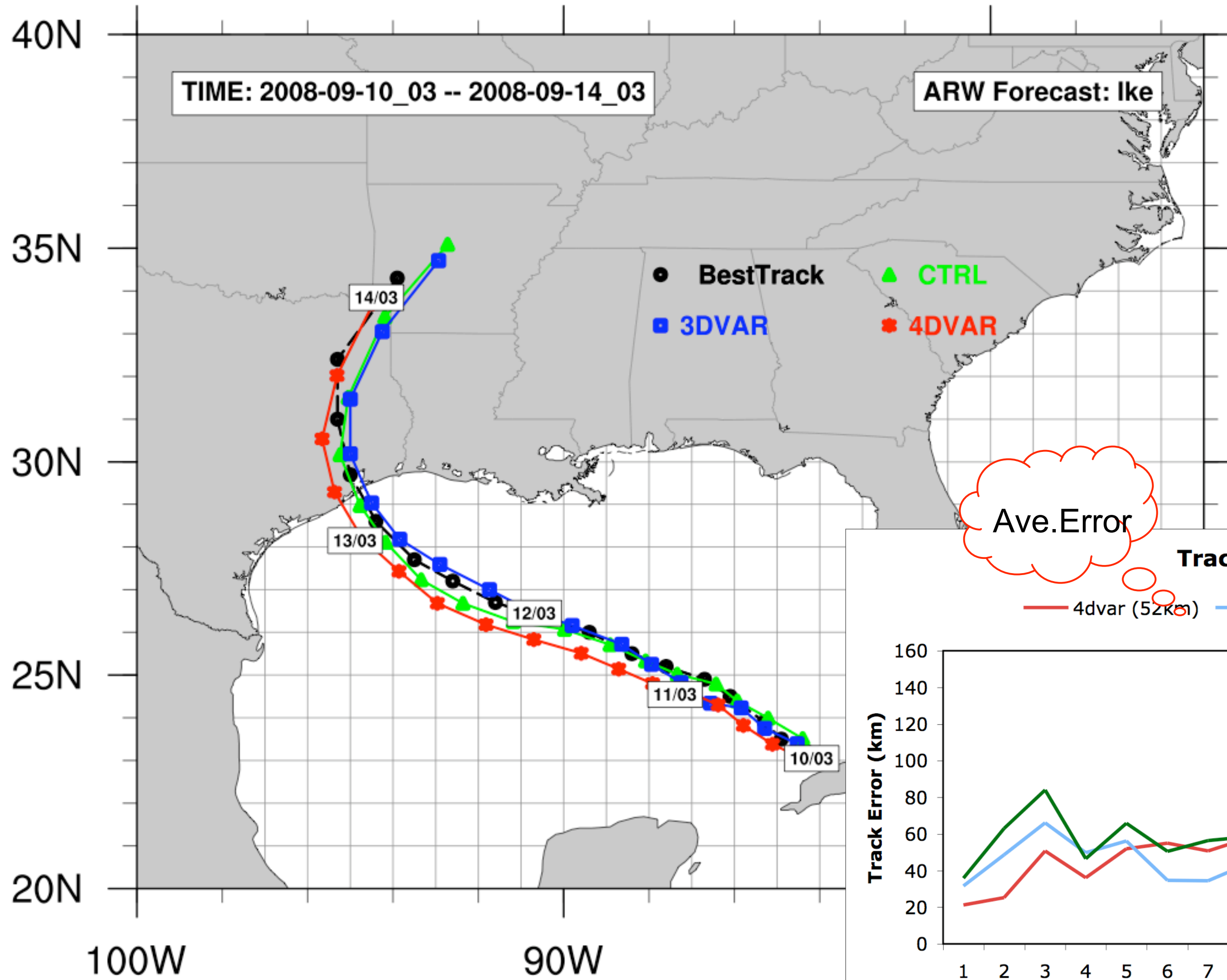
D3: 253x253x35, 4.5 km (moving domain from beginning, interpolated from mother domain)

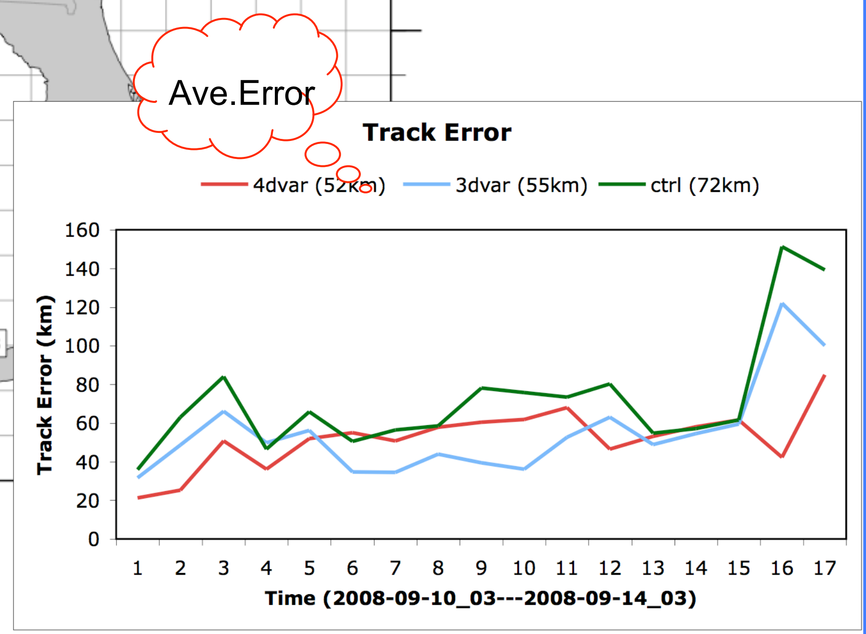
```
 &physics
mp_physics                  = 6,    6,    6,    6,
ra_lw_physics               = 1,    1,    1,    1,
ra_sw_physics               = 1,    1,    1,    1,
radt                        = 30,   30,   30,   30,
sf_sfclay_physics           = 1,    1,    1,    1,
sf_surface_physics          = 1,    1,    1,    1,
bl_pbl_physics              = 1,    1,    1,    1,
bldt                        = 0,    0,    0,    0,
cu_physics                  = 3,    0,    0,    0,
cudt                        = 5,    5,    5,    5,
isfflx                      = 1,
ifsnow                      = 0,
icloud                      = 1,
surface_input_source        = 1,
num_soil_layers             = 5,
maxiens                     = 1,
maxens                      = 3,
maxens2                     = 3,
maxens3                     = 16,
ensdim                      = 144,
/
```

Conventional Obs.

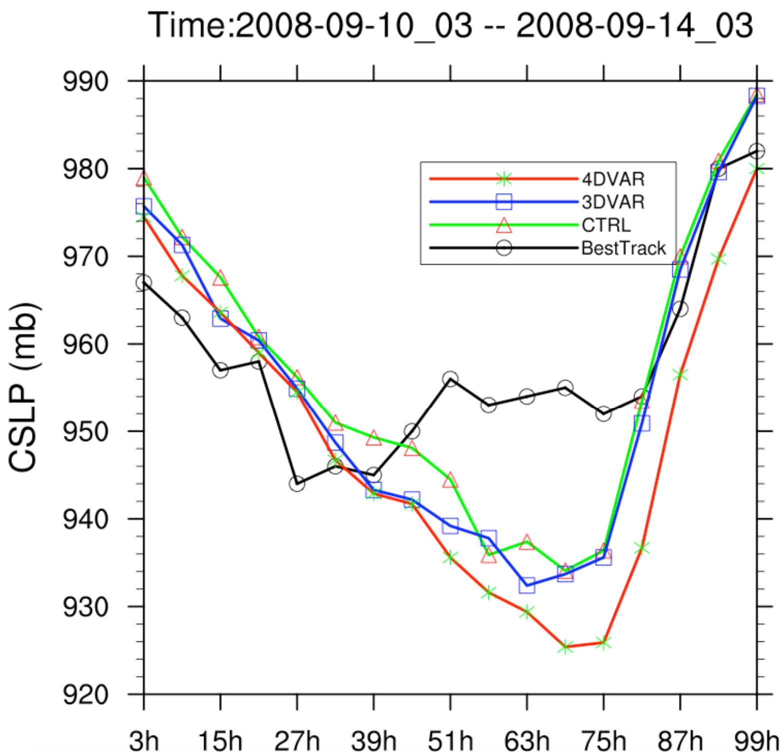
Time	1	2	3	4	5	6	7
Sound	62						
Synop	126						214
Pilot	60						
Satem	62	25					
Geoamv				4175	2168	1452	
Airep	488	16	5			23	81
Gpspw	203	404	200			196	193
Gpsrf		2				2	4
Ships	97	115				106	
Metar	903	643					1178
Qscat							
Profiler	54	6760					
Buoy	642	1277	141		19	1126	634
Sond_sfc	62						

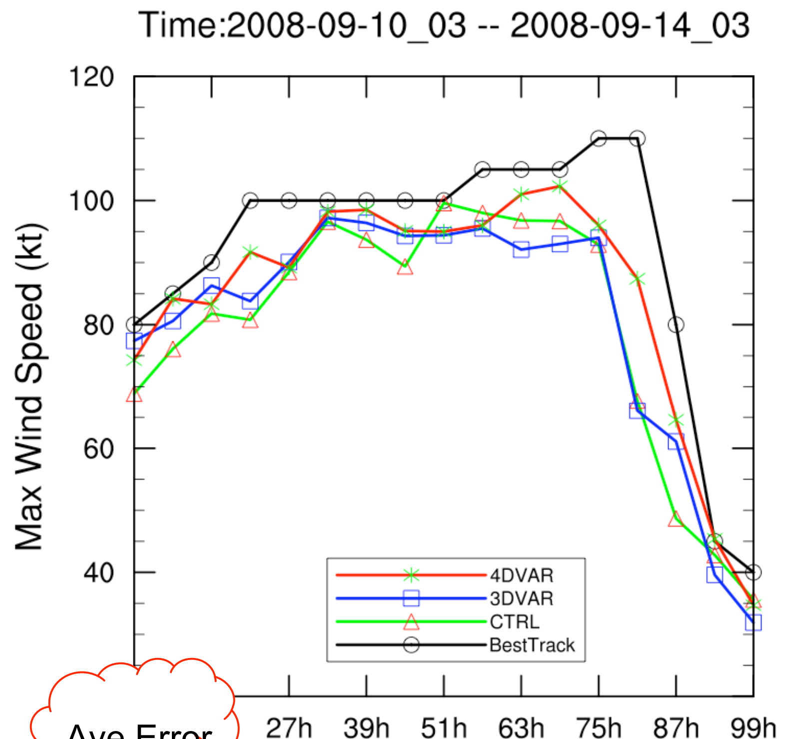
Hurrican Track

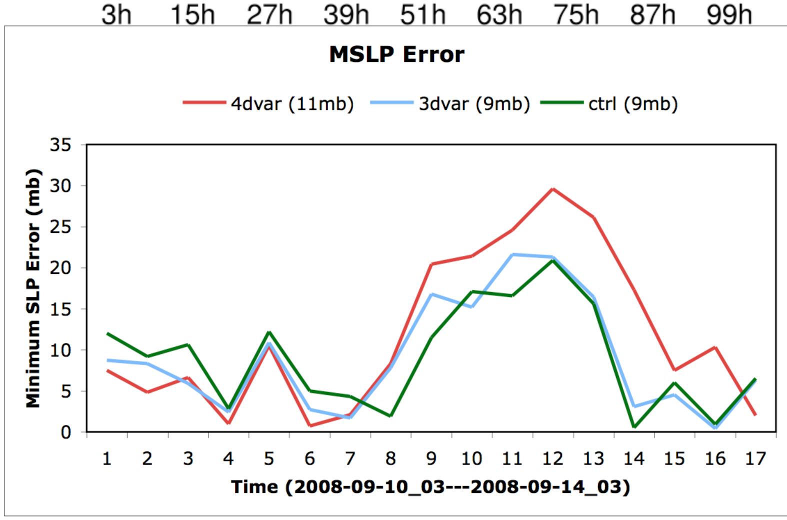


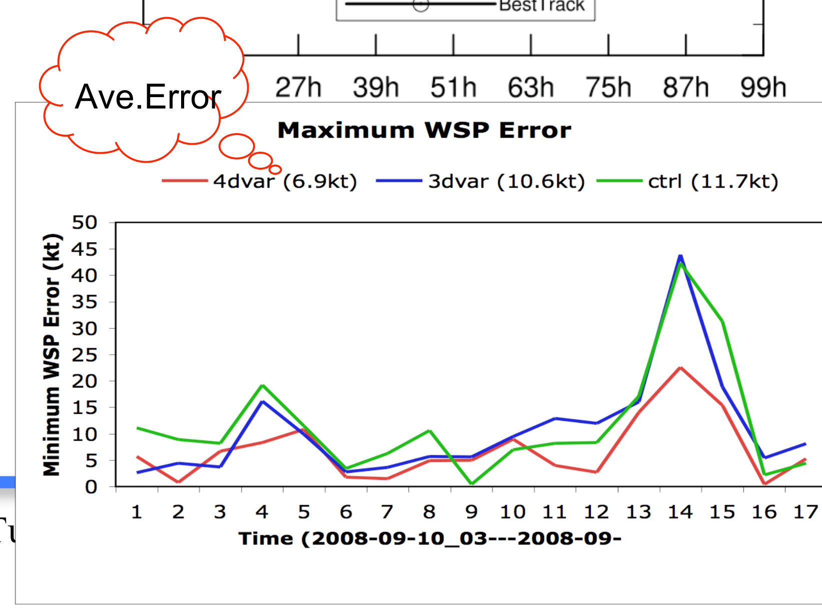


Hurricane Intensity









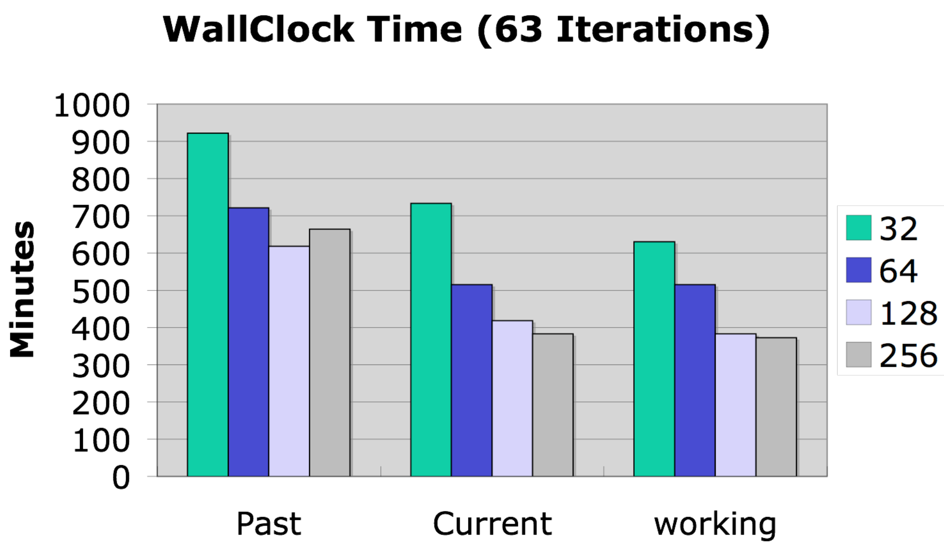
- For general cases, the performance of WRF 4D-Var is comparable with WRF 3D-Var.

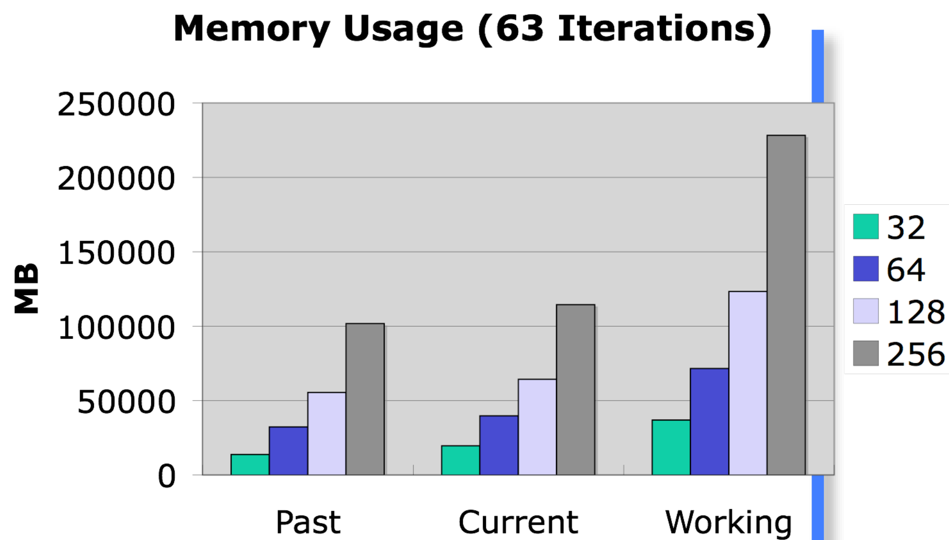
- For some fast developing, fine scale cases such as squall line, tropical cyclone, heavy rainfall case , WRF 4D-Var does a much better job than 3D-Var.

Software Engineering Performance of WRF 4D-Var

- Ability to assimilation all kinds of observation as 3D-Var (include Radiance and Radar).
- Both serial and parallel runs are supported.
- Tested Platforms: IBM with XLF, Linux with PGI & G95, Mac Intel with G95 & GFORTRAN.

Computational Efficiency of IKE case on NCAR Bluefire





Past: Before optimization

Current: Eliminate the disk IO for basic states

Working: Reorganizing adjoint codes,reduce re-computation.

Timing of a Radar Assimilation Case on IBM bluefire

Domain size:151x118x31

Resolution:4km

Time-step: 20s

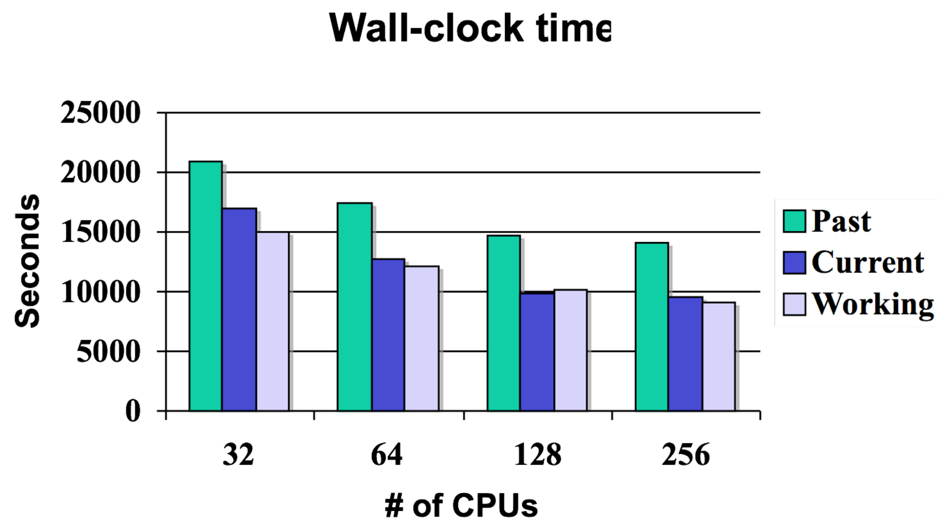
Time window:30m

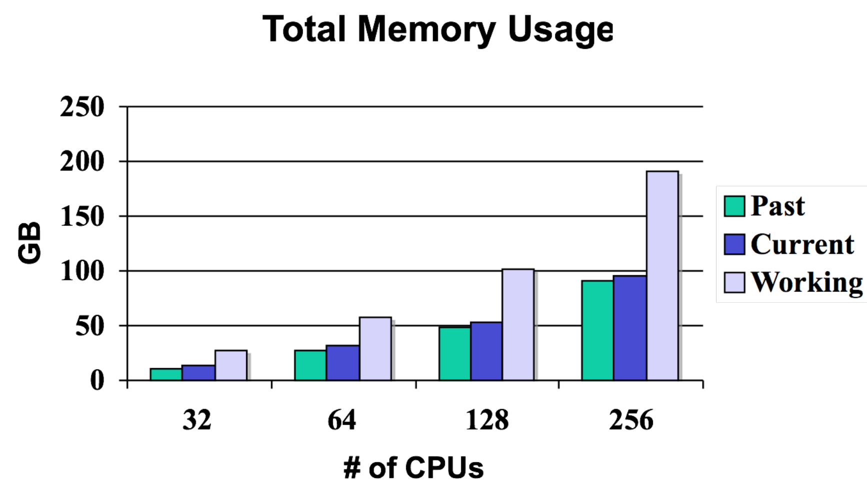
# of iterations: 60

Obs.: OSSE radar wind

# of obs.: 262517

Obs Freq: 5m





On-going Works

- Remove Disk IO which is used as communication among WRF 4D-Var components, ESMF is a candidate.(~50% wall-clock time reduction, improve parallel scalability)
- Improve the portability.
- Prepare the WRF 4D-Var release with WRF 3.1 in Spring.