# WRF 4D-Var System

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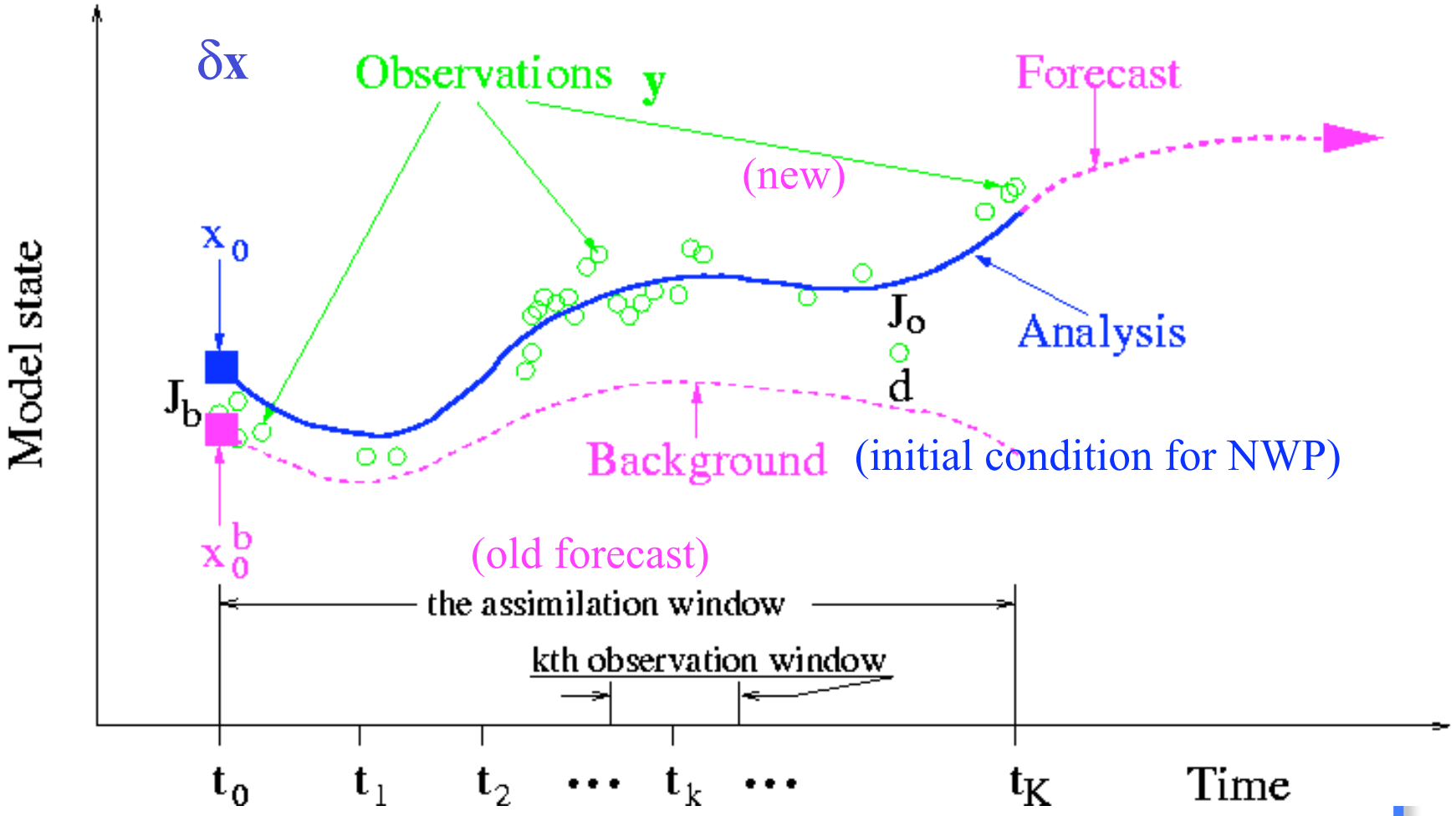
# 4D Variational Data Assimilation



# Current Status of WRF 4D-Var

Black – WRF-3DVar [$\mathbf{B}$, $\mathbf{R}$, $\mathbf{U}=\mathbf{B}^{1/2}$, $\mathbf{v}^n=\mathbf{U}^{-1}(\mathbf{x}^n-\mathbf{x}^{n-1})$]

Green – modification required

Blue – existing (for 4DVar)--WRF

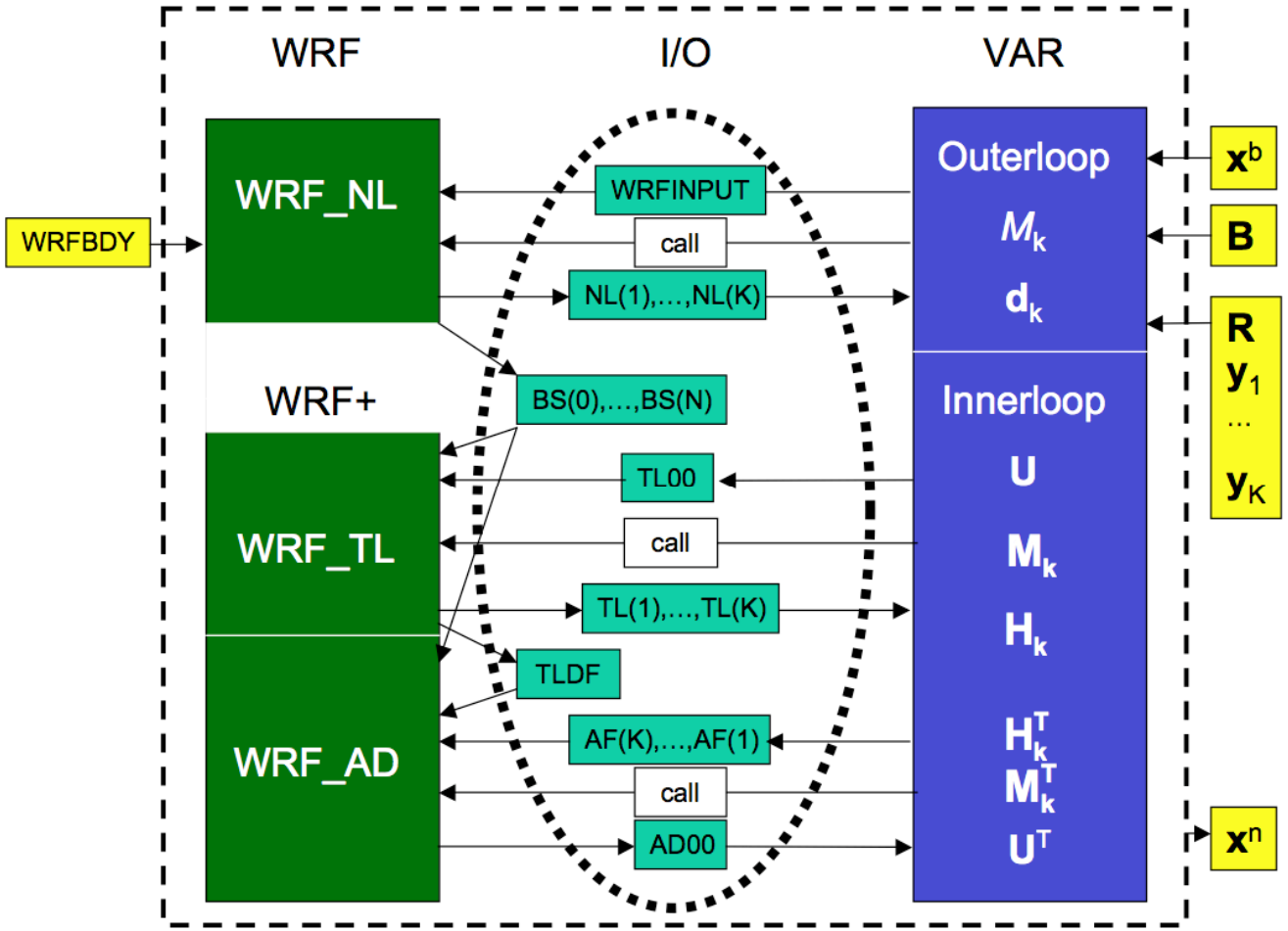
Red – new development

$$J'_{vn} = \mathbf{v}^n + \sum_{i=1}^{n-1} \mathbf{v}^i + \mathbf{U}^T \mathbf{S}_{V\text{-}W}{}^T \sum_{k=1}^{K} \mathbf{M}_k{}^T \mathbf{S}_{W\text{-}V}{}^T \mathbf{H}_k{}^T \mathbf{R}^{-1} [\mathbf{H}_k \mathbf{S}_{W\text{-}V} \mathbf{M}_k \mathbf{S}_{V\text{-}W} \mathbf{U}^{-1} \mathbf{v}^n + H_k(M_k(\mathbf{x}^{n-1})) - \mathbf{y}_k]$$

WRF AD — WRF TL — ARW WRF

*(Huang, et.al. 2006: Preliminary results of WRF 4D-Var. WRF users' workshop, Boulder, Colorado.)*

# Basic system: 3 exes, disk I/O, parallel, full dyn, simple phys, JcDF




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

# Single Observation Experiments

The idea behind single ob tests:

The solution of 3D-Var should be

$$\boldsymbol{x}^a = \boldsymbol{x}^b + \mathbf{B}\mathbf{H}^T\left[\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R}\right]^{-1}\left[\boldsymbol{y} - H\boldsymbol{x}^b\right]$$

Single observation

$$\boldsymbol{x}^a - \boldsymbol{x}^b = \mathbf{B}_i\left[\sigma_b^2 + \sigma_o^2\right]^{-1}\left[\boldsymbol{y}_i - x_i\right]$$

3D-Var $\rightarrow$ 4D-Var: $H \rightarrow HM$; $\mathbf{H} \rightarrow \mathbf{HM}$; $\mathbf{H}^T \rightarrow \mathbf{M}^T\mathbf{H}^T$

The solution of 4D-Var should be

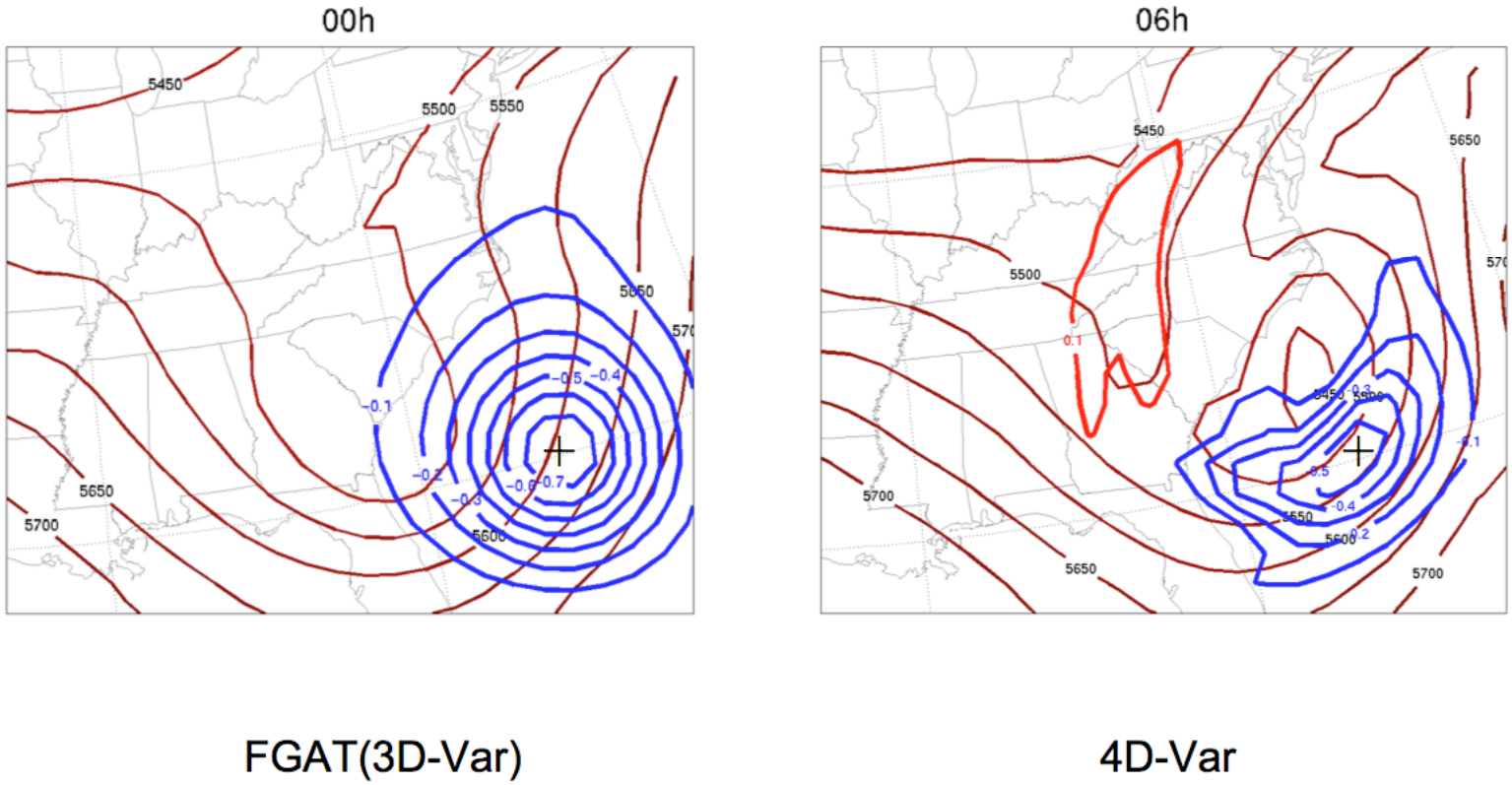
$$\boldsymbol{x}^a = \boldsymbol{x}^b + \mathbf{B}\mathbf{M}^T\mathbf{H}^T\left[\mathbf{H}\left(\mathbf{M}\mathbf{B}\mathbf{M}^T\right)\mathbf{H}^T + \mathbf{R}\right]^{-1}\left[\boldsymbol{y} - HM\boldsymbol{x}^b\right]$$

Single observation, solution at observation time

$$\mathbf{M}\left(\boldsymbol{x}^a - \boldsymbol{x}^b\right) = \left(\mathbf{M}\mathbf{B}\mathbf{M}^T\right)_i\left[\sigma_b^2 + \sigma_o^2\right]^{-1}\left[\boldsymbol{y}_i - x_i\right]$$

# Analysis increments of 500mb θ

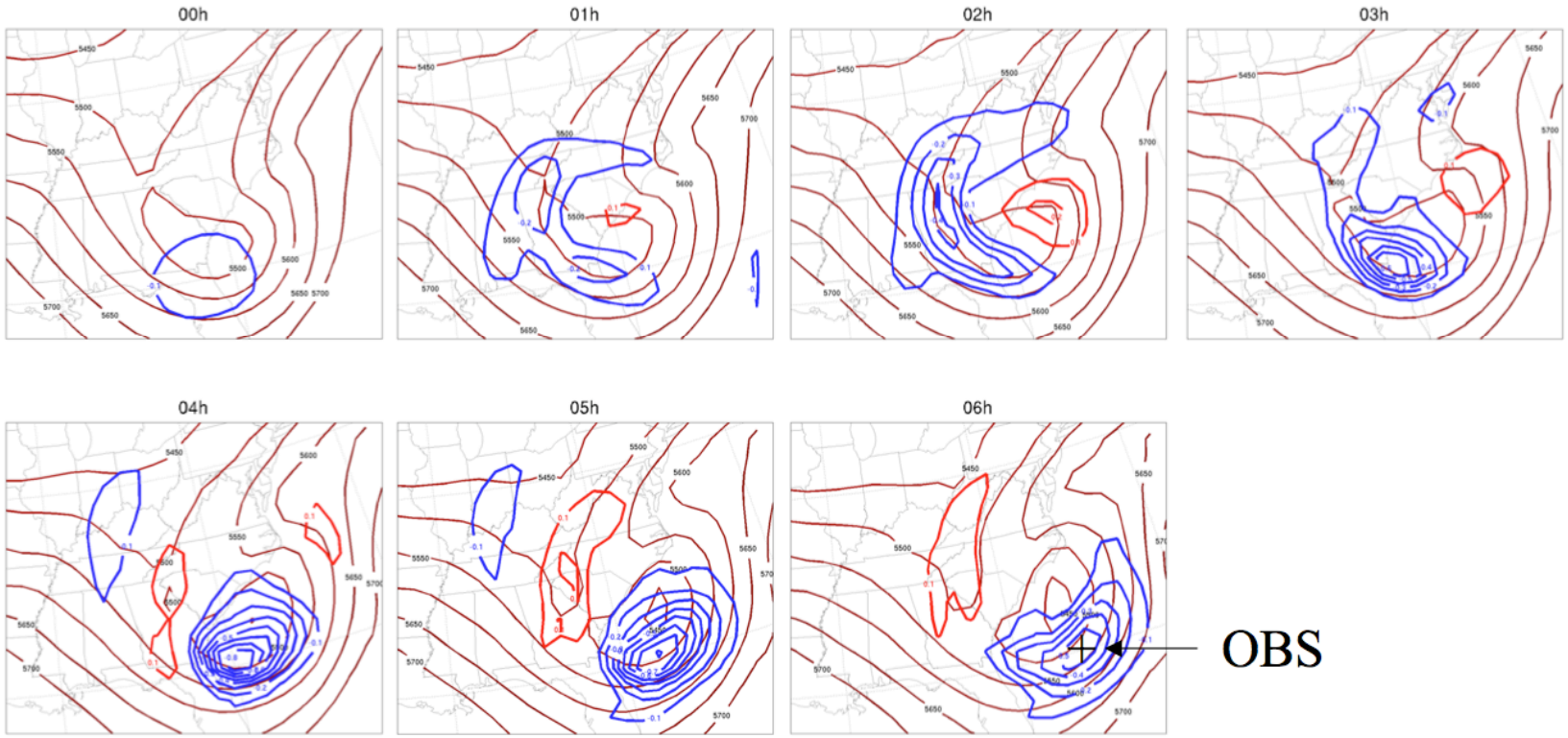
## from 3D-Var at 00h and from 4D-Var at 06h due to a 500mb T observation at 06h



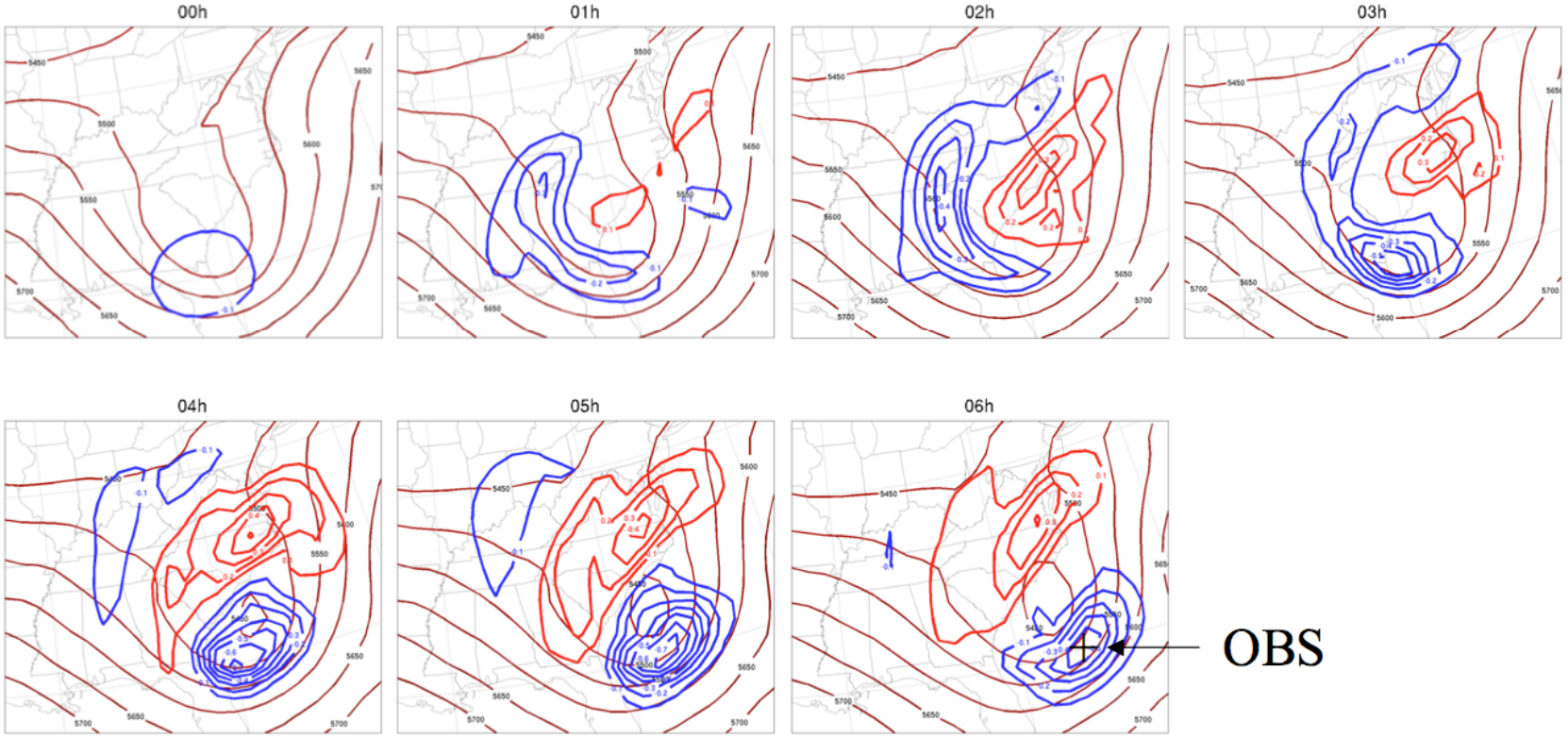

FGAT(3D-Var)

4D-Var

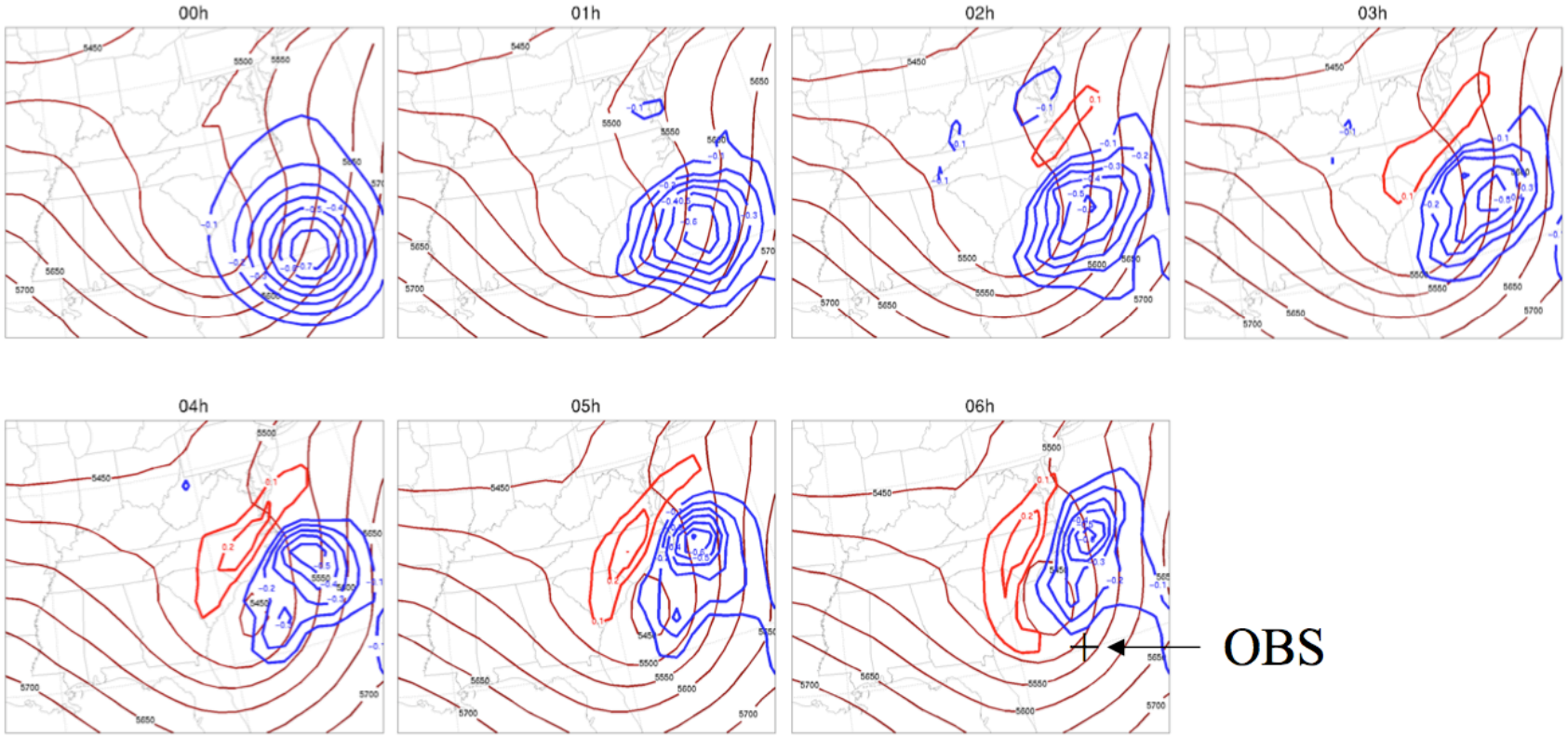
# 500mb θ increments at 00,01,02,03,04,05,06h to a 500mb T ob at 06h



# 500mb θ difference at 00,01,02,03,04,05,06h from two nonlinear runs (one from background; one from 4D-Var)



# 500mb θ difference at 00,01,02,03,04,05,06h from two nonlinear runs (one from background; one from FGAT)



# Scientific Performance of WRF 4D-Var

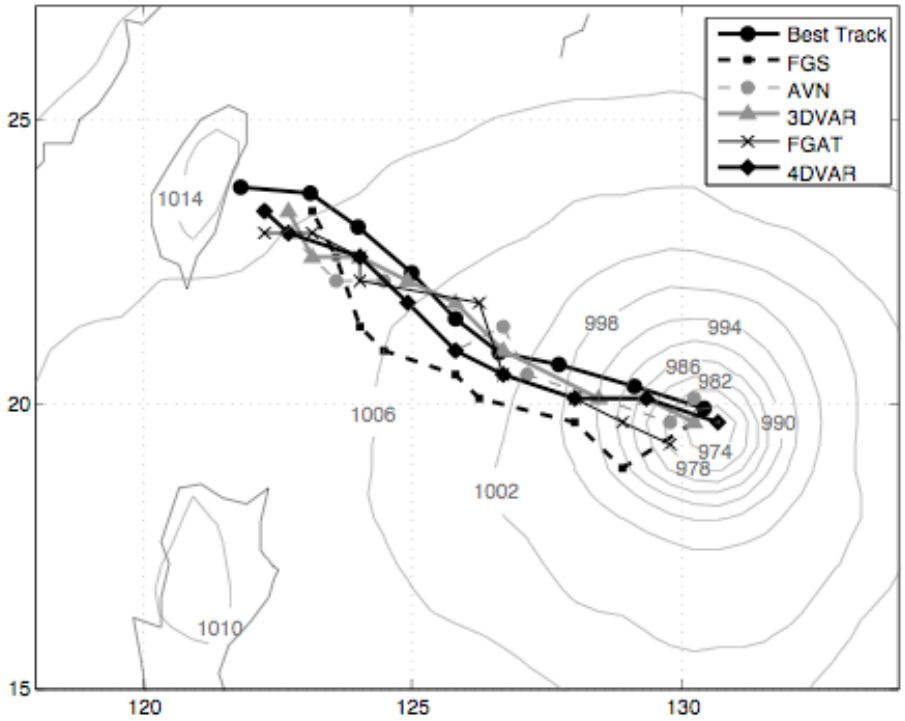
Typhoon Haitang experiments:

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

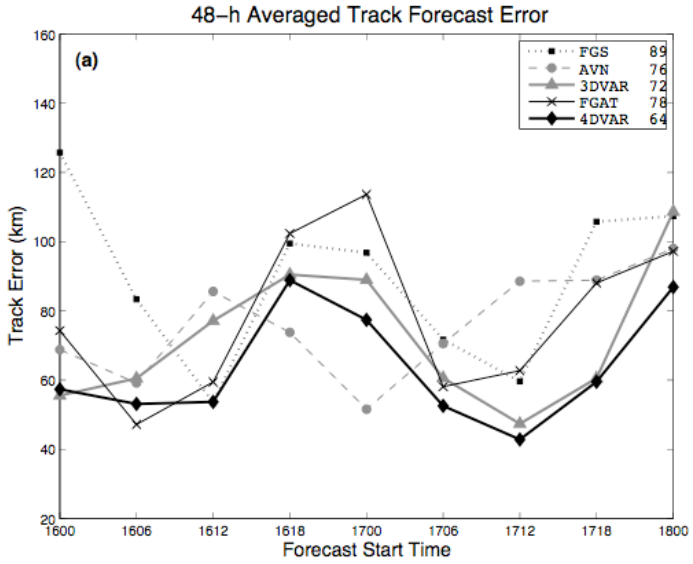
1. FGS – forecast from the background [The background fields are 6-h WRF forecasts from NCEP GFS analysis.]
2. AVN – forecast from the NCEP GFS analysis
3. 3DVAR – forecast from WRF 3D-Var
4. FGAT – first guess at appropriate time ( A option of WRF-3DVAR)
5. 4DVAR – forecast from WRF 4D-Var

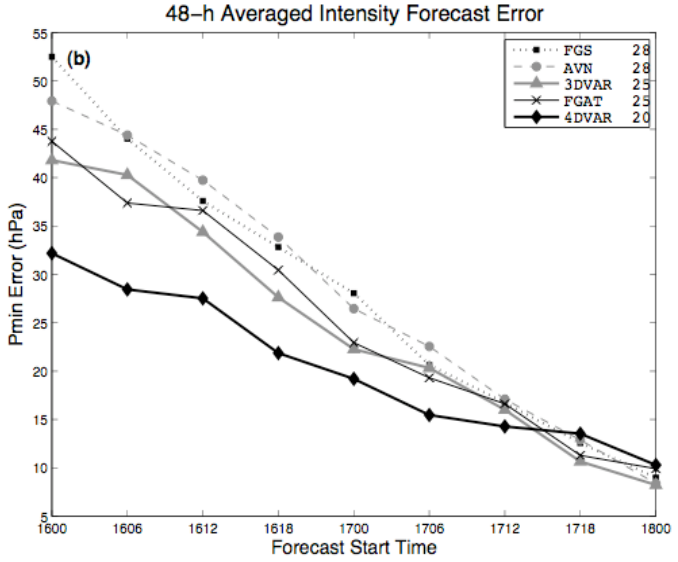
Domain size: 91x73x17
Resolution: 45 km
Time Window: 6 Hours,
Observations: GTS conventional observations, bogus data from CWB

# Typhoon Haitang Verification

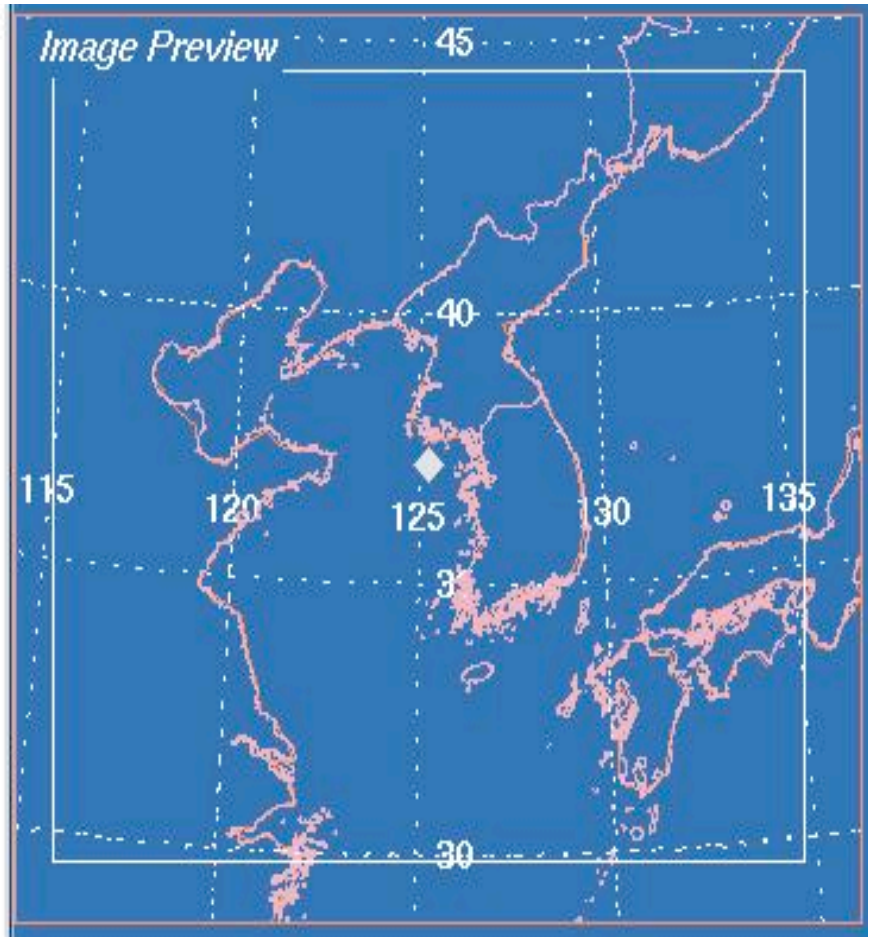



*48-h forecast typhoon tracks from FGS, AVN, 3DVAR, FGAT, 4DVAR, together with the observed best track. Forecasts are all started from 0000 UTC 16 July 2005.*



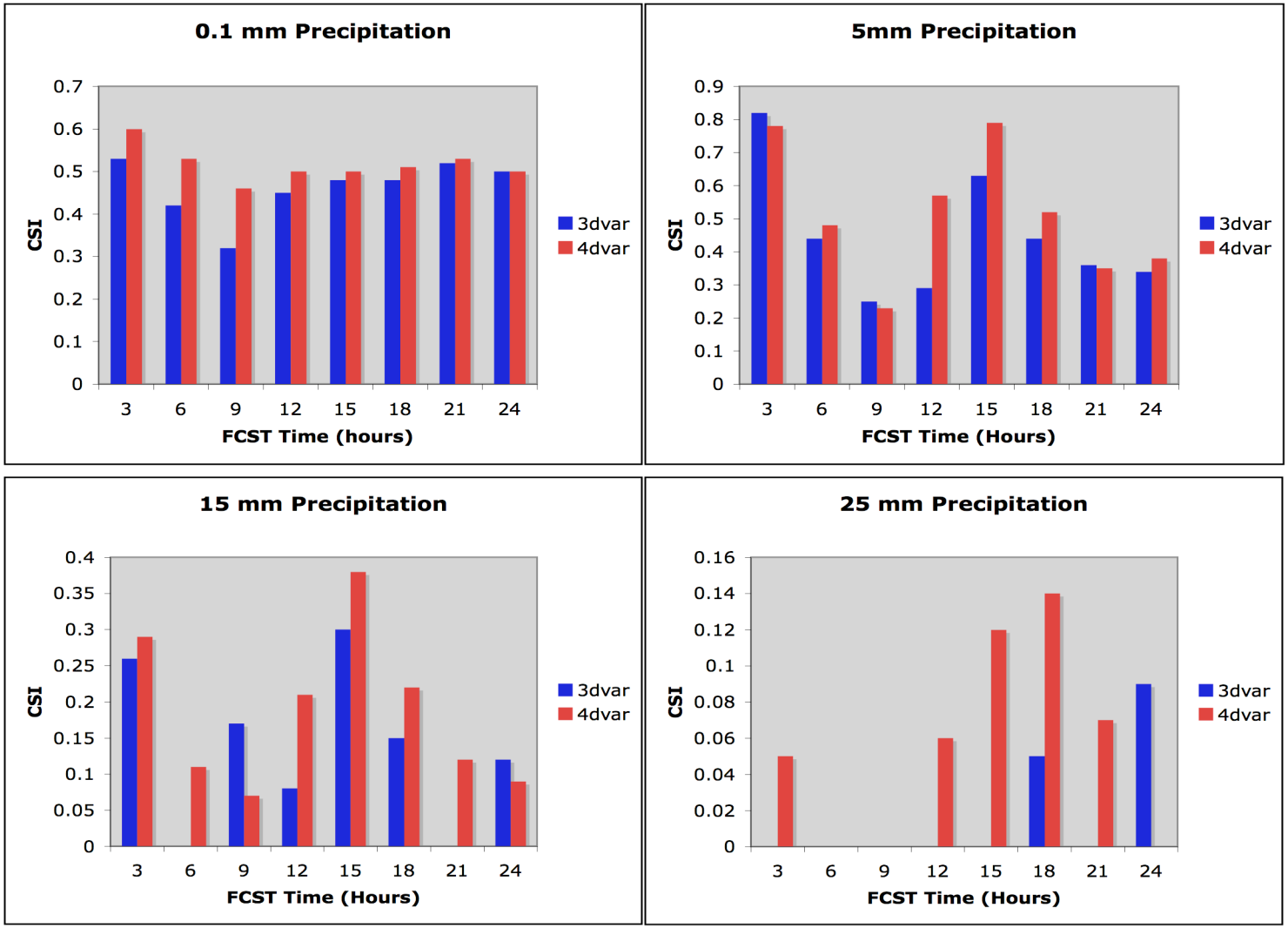



# KMA Heavy Rain Case




- **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



- 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 (Radiance and Radar).
- Both serial and parallel runs are supported.
- Tested Platforms: IBM with XLF, Linux with PGI & G95, Mac G5 with G95 & XLF.
- Multi-incremental 4D-Var.
- Flexible assimilation time window (for example, 15 minutes ~ 6 hours)

# Timing of a Radar Assimilation Case on IBM blueice

**Domain size**:151x118x31

**Resolution**:4km

**Time-step**: 25s

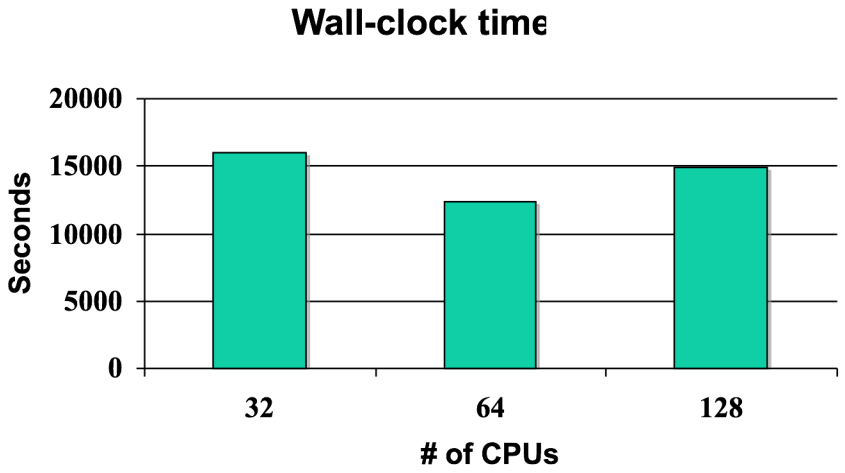
**Time window**:15m

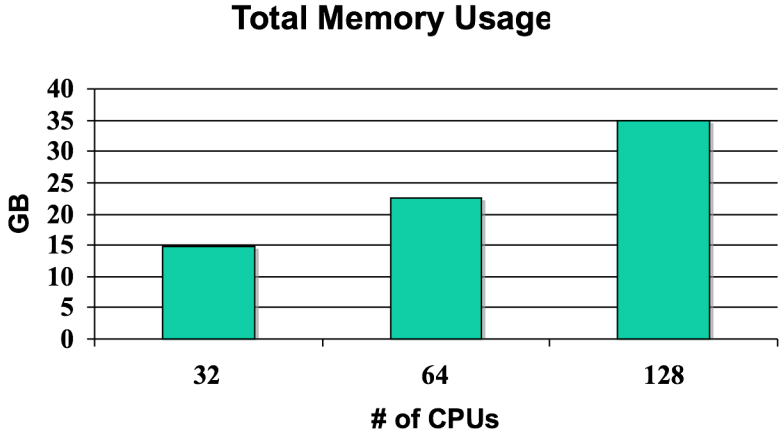
**# of iterations**: 60

**Obs.**: OSSE radar wind

**# of obs.**: 262517

**Obs Freq**: 5m

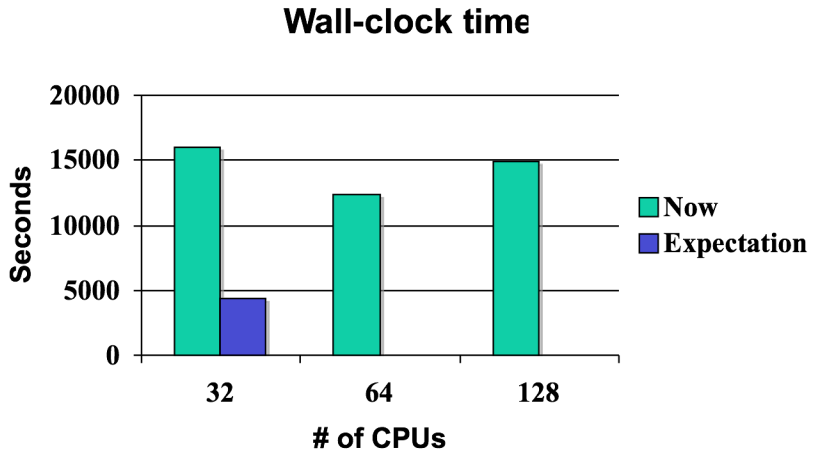



*( P5.6 ASSIMILATION OF DOPPLER RADAR DATA WITH WRF 4DVAR FOR A CONVECT IVE CASE. Yong-Run Guo et al. 9th Annual WRF Users' Workshop)*

# 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)
- Cleanup solve_em_ad (~90% cost), trade re-computation with memory (another ~50% wall-clock time reduction).



# Welcome Collaboration

- Don’t have enough resource to provide support to WRF-4DVAR
- Welcome collaboration!
  - Research Intention
  - Opportunity to write joint proposal
- People of Contact:
  - Hans Huang: huangx@ucar.edu
  - Xin Zhang: xinzhang@ucar.edu