Development of a 4DVAR Data Assimilation System for the JMA Nonhydrostatic Model

- *JNoVA* -

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Motivation

- The JMA nonhydrostatic model (NHM) is planed to be run as a operational forecast model in the near future.
  - 2003- : run as a mesoscale model
    domain: Japan, resolution: 10km40L
  - 2006- : run as a regional model
    domain: Asia, resolution: 5km50L

- A data assimilation system specified for NHM is requested to complete the forecast/analysis system.

- Researchers also require an appropriate method to analyze mesoscale phenomena.

JNoVA Project (since April, 2002)

- *J*MA *No*nhydrostatic model-based *V*ariational data *A*ssimilation system

- Collaboration between two sides:
  - operational side : Numerical Prediction Division
  - research side : Meteorological Research Institute

- *JNoVA* has two analysis models.
  - 3DVAR (*JNoVA*0) - for aviation use / for real-time analysis
  - 4DVAR - for daily operational forecast

General Frame of Current 4DVAR

- Forward Model

  JMANHM(rel-01-02 version) with full physics

  - Version of current JMANHM is rel-01-08.

- Backward Model

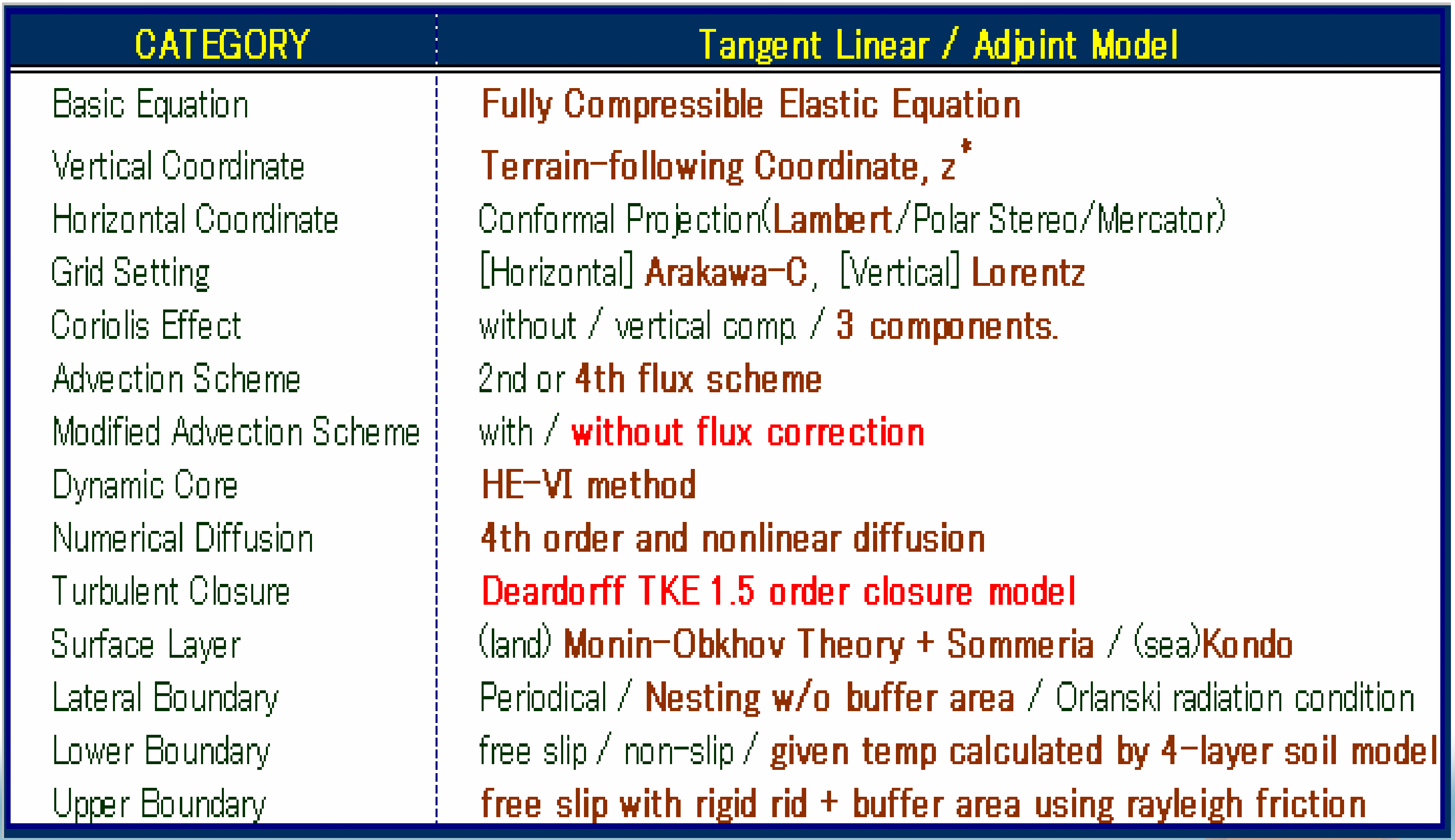
  Adjoint model of simplified JMANHM(rel-01-02)

- Minimization method: L-BFGS method

- Preconditioning: $\delta \mathbf{v} = \left(\sqrt{\mathbf{B}}\right)^{-1/2} \delta \mathbf{x}$

- No penalty term, so far

Specification of Simplified JMANHM(rel-01-02)



CATEGORY	Tangent Linear / Adjoint Model
Basic Equation	**Fully Compressible Elastic Equation**
Vertical Coordinate	**Terrain-following Coordinate, z^***
Horizontal Coordinate	Conformal Projection(**Lambert**/Polar Stereo/Mercator)
Grid Setting	[Horizontal] **Arakawa-C**, [Vertical] **Lorentz**
Coriolis Effect	without / vertical comp. / **3 components.**
Advection Scheme	2nd or **4th flux scheme**
Modified Advection Scheme	with / **without flux correction**
Dynamic Core	**HE-VI method**
Numerical Diffusion	**4th order and nonlinear diffusion**
Turbulent Closure	**Deardorff TKE 1.5 order closure model**
Surface Layer	(land) **Monin-Obkhov Theory + Sommeria** / (sea)**Kondo**
Lateral Boundary	Periodical / **Nesting w/o buffer area** / Orlanski radiation condition
Lower Boundary	free slip / non-slip / **given temp calculated by 4-layer soil model**
Upper Boundary	**free slip with rigid rid + buffer area using rayleigh friction**

Code Check of TLM/ADM

- Code Check of Tangent Linear Model

$$\frac{\left\| F(x+\alpha\mathbf{d}) - F(x) \right\|}{\left\| \mathbf{F}(\alpha\mathbf{d}) \right\|} - 1 = O(\alpha)$$

$$\frac{\left\langle F(x+\alpha\mathbf{d}) - F(x) \right\rangle, \mathbf{F}(\mathbf{d})}{\left\| F(x+\alpha\mathbf{d}) - F(x) \right\| \left\| \mathbf{F}(\mathbf{d}) \right\|} - 1 = O(\alpha^2)$$

- Code Check of Adjoint Model

$$\left\langle \mathbf{F}(x), \mathbf{F}(x) \right\rangle = \left\langle x, \mathbf{F}^* \mathbf{F}(x) \right\rangle$$

- Code Check of Gradient
  of Cost Function in X-Space and U-Space

$$\frac{J(x+\alpha\mathbf{d}) - J(x)}{\left\langle \alpha\mathbf{d}, \nabla J(x) \right\rangle} - 1 = O(\alpha)$$

Encountered Problems During Code Check

- Deardorff TKE 1.5 Turbulent Closure Model
  - This scheme is highly nonlinear
  - Prevent the code from passing the TLM code check
  - Omit the variance of the following variable:
    - Mixing Length Scale: *l*

$$\begin{cases} l_\infty = \Delta s & for\ N_l \le 0 \\ l_\infty = \min(\Delta s, E^{1/2}, N_l^{-1}) & for\ N_l > 0 \end{cases} \Longrightarrow \frac{1}{l} = \frac{1}{\kappa(z - z_s)} + \frac{1}{l_\infty}$$

    - Eddy Diffusion Coefficients are functions of *l*

$$K_m = C_m l E^{1/2}, K_e = 2K_m, K_h = P_r^{-1} K_m$$

    - Ignore δl => Ignore δK, too
  - The variance of TKE is taken into consideration.
  - But it isn't one of control variables.

Preliminary Experiment

Accuracy of Basic Fields

- Why? Because ADM needs the basic fields.
- Problem : Requirement of huge size of memory / storage!!!
  - Current System :

    almost (nx * ny * nz * 28) x (time steps)
  - Example: nx = ny = 150, nz = 40, time steps = 360

    Memory size is about 71G Bytes!!!

- How can we reduce this size of memory?
  - Reduction of the precision : Double => Single
  - No update of the basic fields for the small time step
  - Save the fields every several time steps

Preliminary Experiment

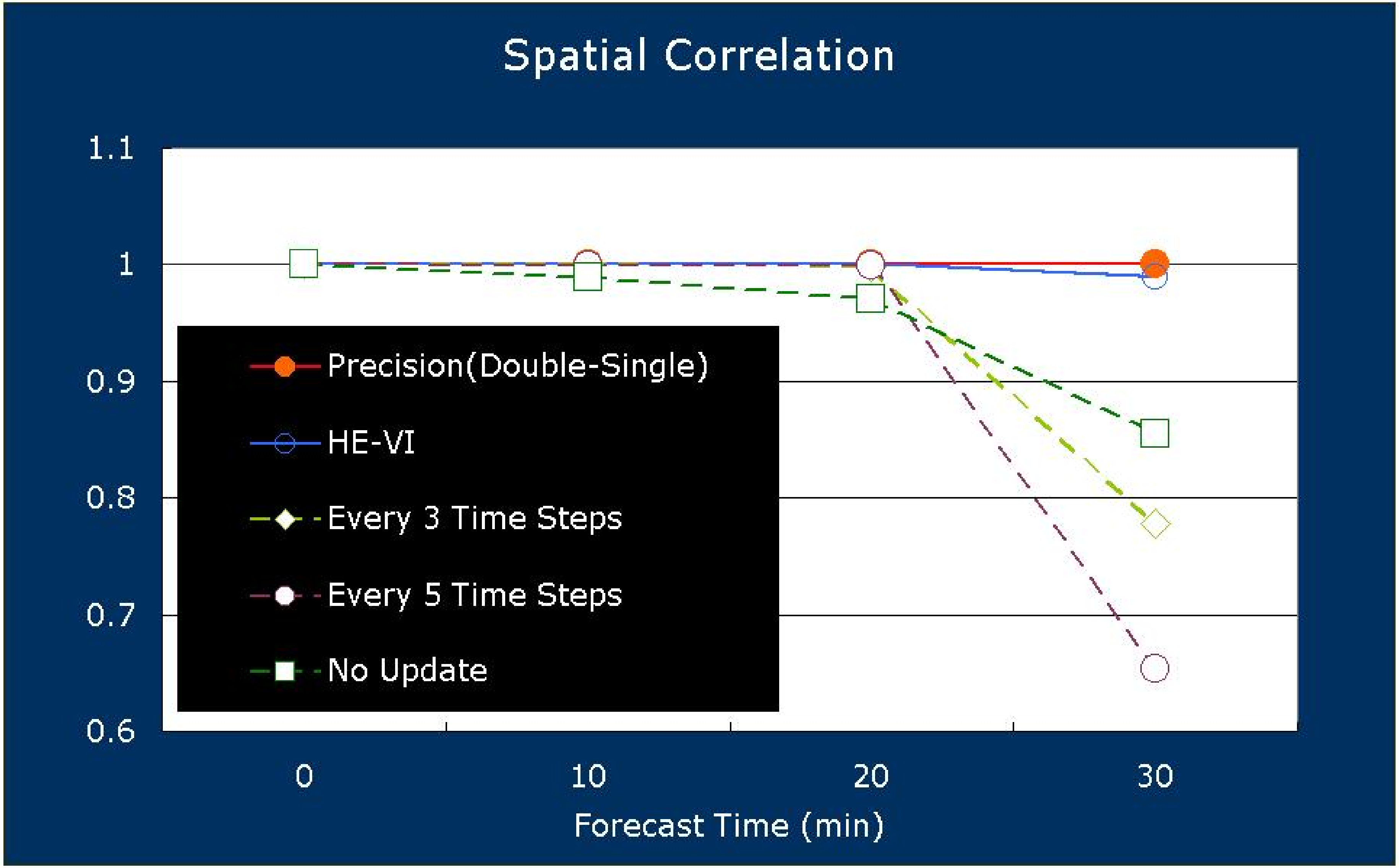
Accuracy of Basic Fields

- Test Case: Mar. 01, 2003. 06UTC
- Model Resolution: (H) 10km, (V) 300-1180m
- Grid Size: 32x32x32
- Initial field: Mesoscale analysis by 4DVAR based on hydrostatic model

- Give the white noise and forecast for 30mins.
- Compare the structure of the perturbation
  - Spatial Correlation

Preliminary Experiment

Accuracy of Basic Fields



Control Variables

- Two sets: Treatment of horizontal wind is different
  - Set A: JMA's MSM4DVAR-like – U, V
  - Set B: MM5-4DVAR-like – ψ , χ
- Considered balance
  - Hydrostatic balance

$$\frac{\partial \pi}{\partial z} = -\frac{g}{c_p}\theta^{-1} \Longrightarrow \boxed{(\Delta\Theta, \Delta P_S) \Rightarrow \Delta P_B}$$

  - Geostrophic balance

$$f\vec{k} \times \vec{v} = -\nabla p \Longrightarrow \boxed{\Delta P_B \Rightarrow (\Delta U_B, \Delta V_B)}$$

  - Balance by mass continuity

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \Longrightarrow \boxed{(\Delta U, \Delta V) \Rightarrow \Delta W_B}$$

Control Variables

- Set A
  - Unbalanced Wind

$$\begin{pmatrix}\Delta U_U\\ \Delta V_U\end{pmatrix} = \begin{pmatrix}\Delta U\\ \Delta V\end{pmatrix} + \begin{pmatrix} C_{UU} & C_{VU}\\ C_{UV} & C_{VV}\end{pmatrix}\begin{pmatrix}\Delta U_B\\ \Delta V_B\end{pmatrix}$$

$$\Delta W_U = \Delta W - C_W \Delta W_B$$

  - Potential Temperature & Surface Pressure

$$\left(\Delta\Theta, \Delta P_S\right)$$

  - Unbalanced Pressure

$$\Delta P_U = \Delta P - C_P \Delta P_B$$

- Set B
  - Unbalanced Potential Velocity & Stream Function

$$\Delta\Psi_U = \Delta\Psi + C_\Psi \Delta P_B \qquad \Delta X_U = \Delta X + C_X \Delta P_B$$

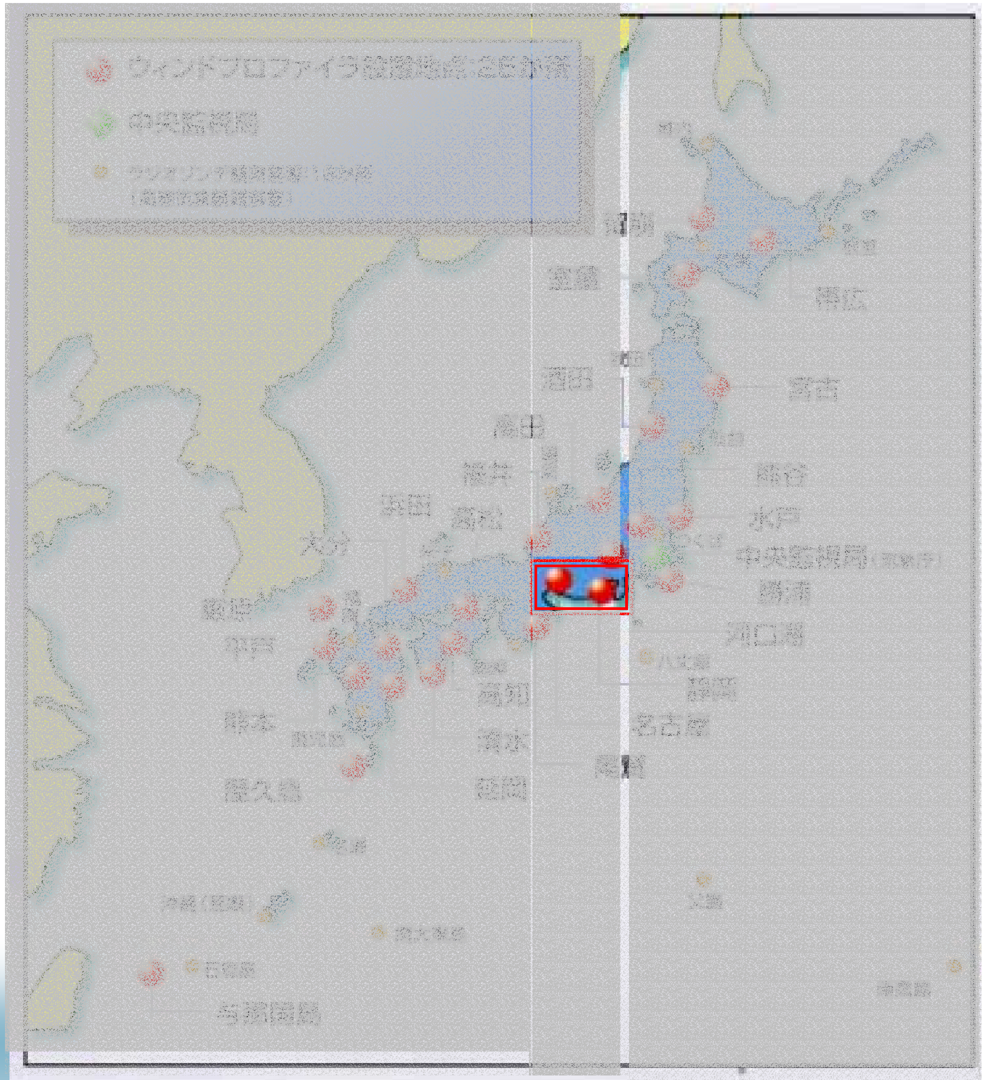
Same to Control Variables for 3DVAR

Control Variables: Cons & Pros

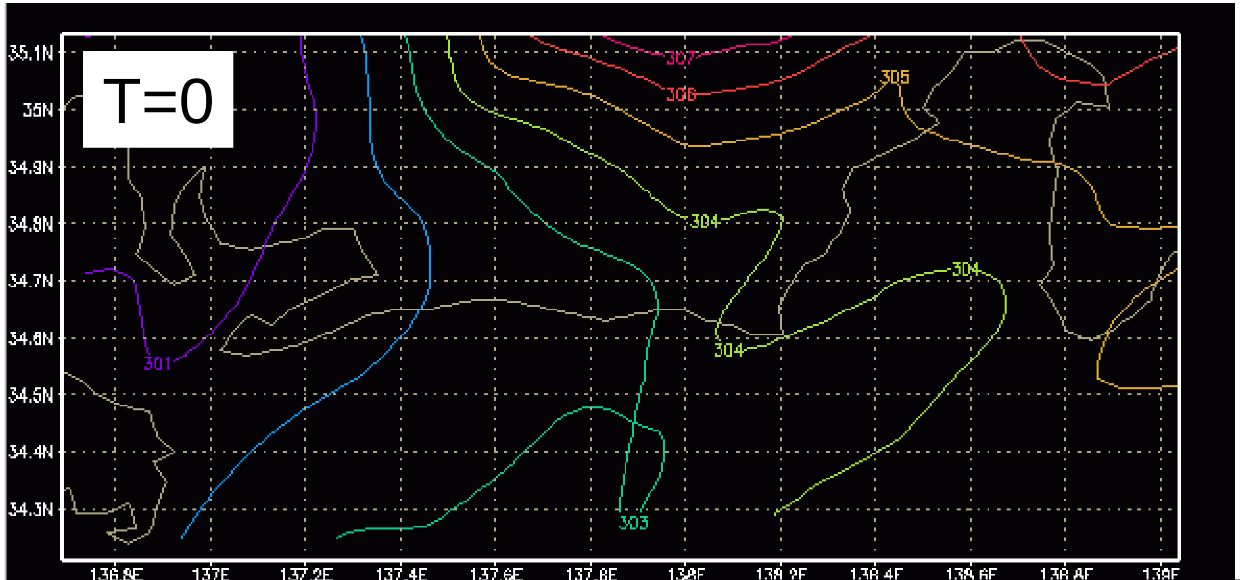
- Set A (Miyoshi, 2003)
  - Pro
    - Same to control variables for hydrostatic 4DVAR
    - Might be useful in the case of very fine analysis
  - Con
    - VERY WEAK to the noise in pressure
- Set B
  - Pro
    - Simple Design
    - Computationally Efficient
  - Con ?
    - Don’t Know the Performance over Steep Terrain

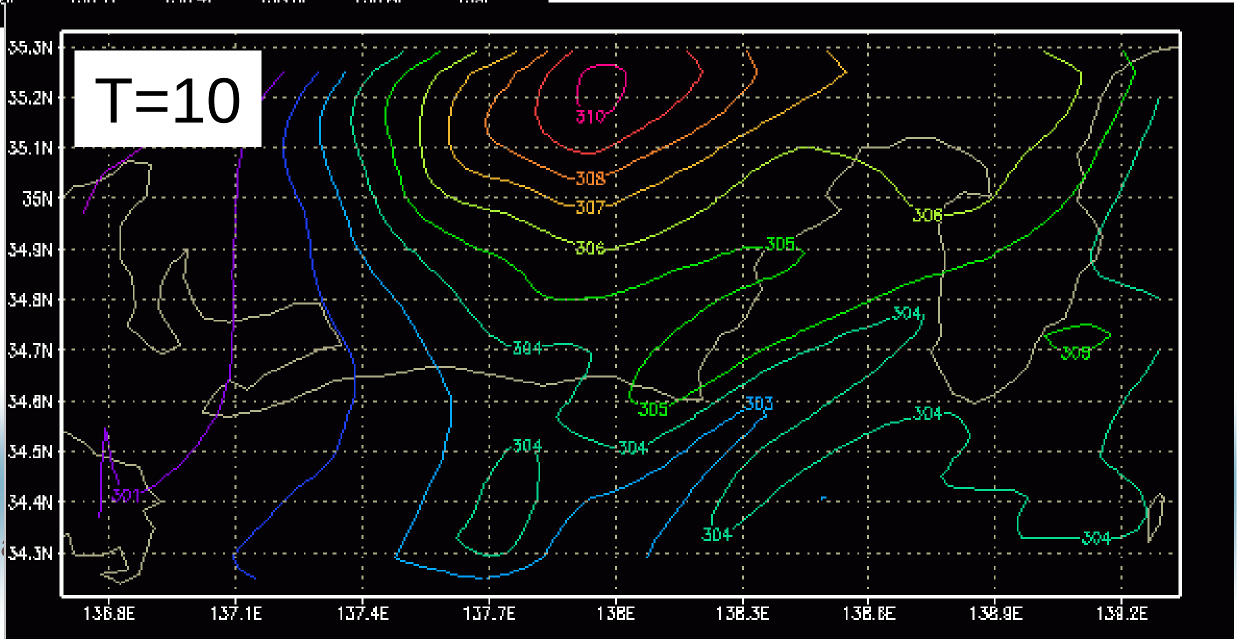
Real Case Experiment

- Sep. 29, 2003. 00UTC
- Resolution and Grid
  - (H) 5km, 48x 24
  - (V) 40-900m, 45L
- Data Assimilation Window: 10mins
- Observation Data:
  - Wind profiler at 2 Points
  - Injected at the end of data assimilation window



Real Case Experiment: First Guess



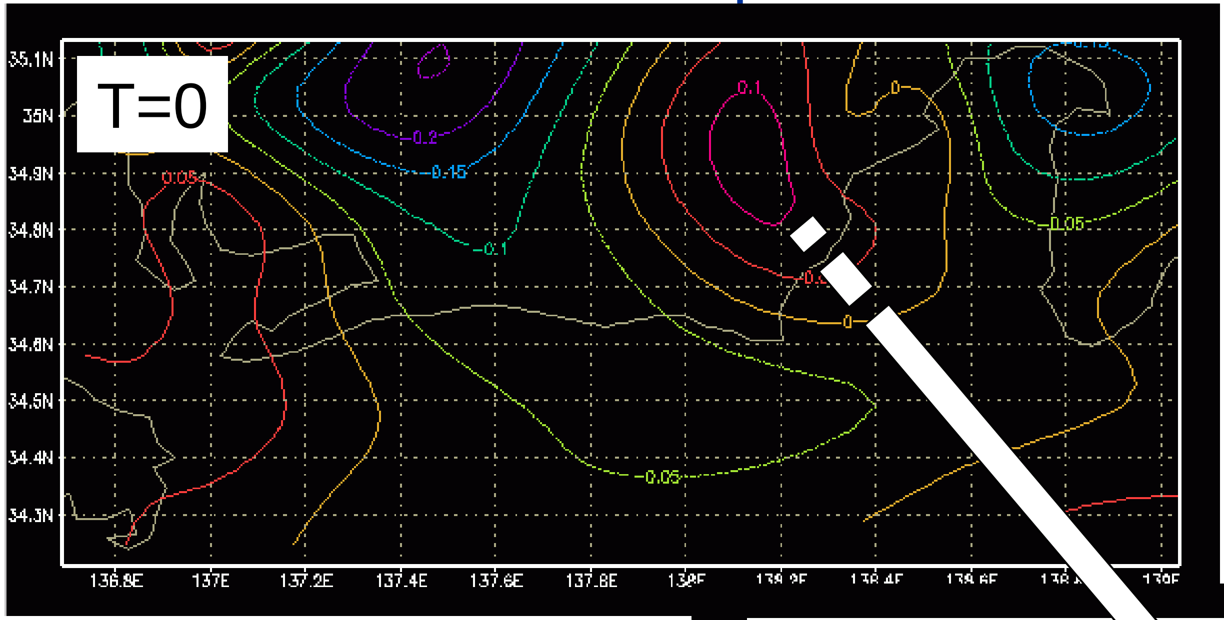


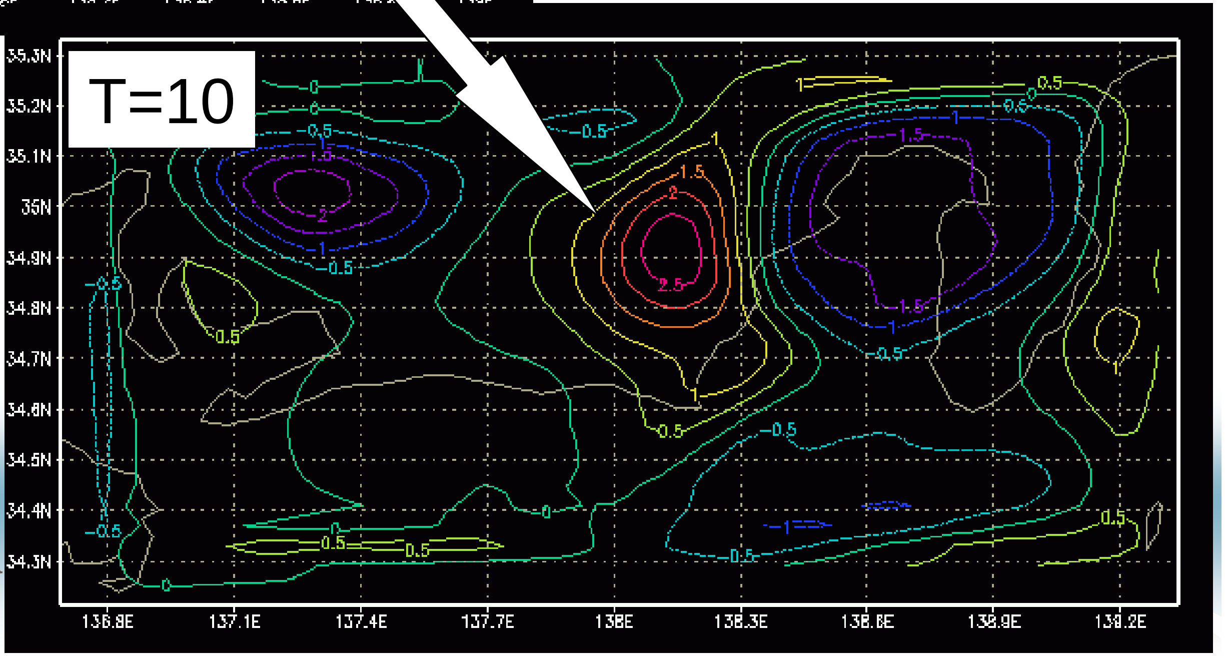
Model 10th Level

Contour:

Potential Temp.

Real Case Experiment: Increment



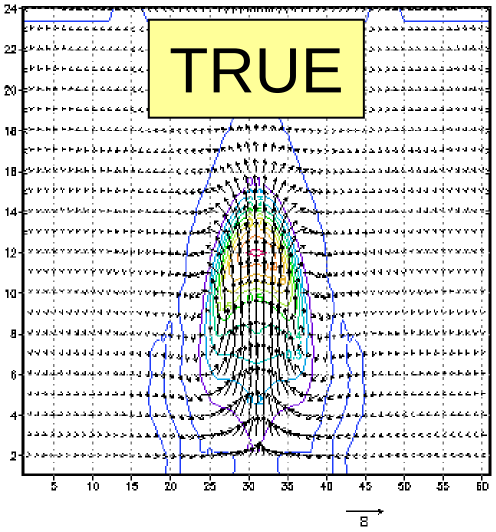


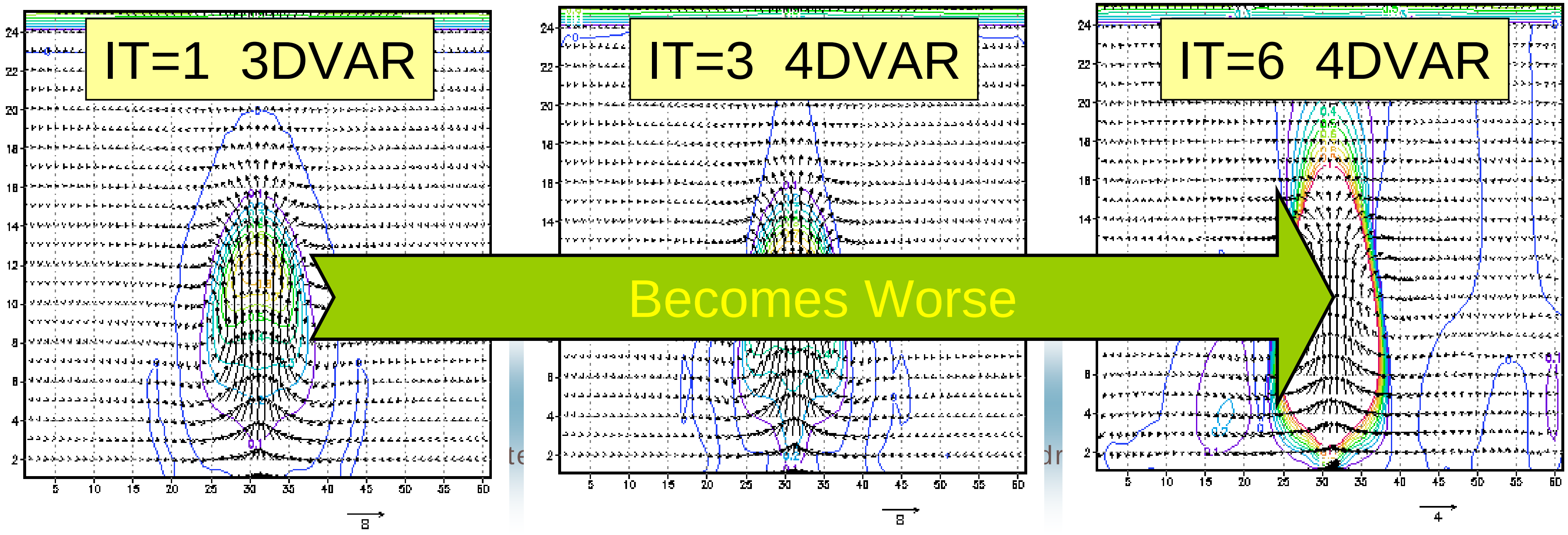
Real Case Experiment: What We Know

- This System works fine as 3DVAR!(Not Shown)
- In this experiment, the cost didn’t decrease after several iterations of minimization…
- The System works odd as 4DVAR…
- Are there still any bugs in our code ?
- Or is this the character of this system ?
- Needs more investigations…

Ideal Experiment
Thermal Bubble

- Predicted Variables as Control Variables
- Give Complete Wind Data at Every Time Step
- Try to Recover Temperature





Summary and Future Plan

- Construct Basic Frame of 4DVAR System
- Need to Do More Experiments and Refine the System
- Understand the Behavior of the System

- Modify and Test the Code to Run the System on the Parallel Computer
- Include the Moist Process
  - Cloud Microphysics
  - Cumulus Convective Parameterization

THANK YOU FOR YOUR ATTENTION!!!