Impact Study of the Vertical Coordinate on a High-Resolution Meso-scale Model

Li Xingliang and Chen Dehui

Center for Numerical Prediction Research,
CAMS/CMA

(For WRF-GRAPES joint-workshop on 18~19 Jan. 2005)

Outline

- Introduction
- Analysis of coordinate
- Ideal test
- Numerical simulation
- Conclusions and remarks

Introduction

1. Geometry Height (Z) Coordinate (Richardson, 1922) : Bottom b. c. ?

2. Pressure (P) Coordinate (Eliassen, 1949): Bottom b. c. ?

3. Sigma Coordinate (sigma＝P/Ps) (Phillips, 1957): PGF in upper

4. Hybrid Coordinate (Sangster, 1960): PGF

5. θ-Coordinate in 1970s: conservative, but Bottom b. c. ?

6. Terrain-following Height Coordinate (Gal-Chen and Sommerville, 1975)

7. ETA Coordinate (“step mountain coordinate”) (Mesinger, 1984)

8. SLEVE (Smooth LEvel VErtical) Coordinate recently (Christoph Schär et al., 2002).

   It is a scale-dependent vertical decay of topographic (small scale-faster).

Questions: V.C. suitable to H. R. NWP model ?

- With rapid development of H.P.C., it is possible to run a higher and higher resolution NWP with N-H dynamic core.
- **It needs to properly depict the vertical motion with a vertical momentum equation.**
- **What's the impact of a vertical coordinate to a H. R. NWP model with N-H dynamic core**
- Investigating two widely used coordinates:

Height T. F. C. : Height coordinate, EH(Gal-Chen and Sommerville,1975)

Pressure T. F. C.: Mass coordinate, EM(Phillips,1957; Laprise,1992)

Features of two Coordinates EH, EM

- Two vertical coordinates:

Height coordinate (EH):

$$\sigma_z = Z_t \frac{Z - Z_s}{Z_t - Z_s}$$

Mass coordinate (EM):

$$\sigma_p = \frac{p_h - p_{ht}}{p_{hs} - p_{ht}}$$

Features of two Coordinates EH, EM

Metric terms

- **General terrain-following coordinate expression**

$$\nabla_z p = \nabla_s p - (\frac{\partial s}{\partial z})_z \cdot \nabla_s z \cdot \frac{\partial p}{\partial s}$$

1.independent on time
2.Smoother in higher levels

- **Formulations in h-coordinate and m-coordinate:**

$$-\alpha \nabla_z p = -\alpha \nabla_{\sigma_z} p - \frac{z_t - \sigma_z}{z_t} \cdot \nabla_{\sigma_z} \phi_s$$

$$-\alpha \nabla_z p = -\nabla \phi = -\nabla_{\sigma_p} \phi - (\frac{p - p_t}{p}) \cdot RT \cdot \nabla_{\sigma_p} \ln(p_s - p_t)$$

1.dependent on time
2.Less smooth in higher levels

Reference atmosphere for EM test

- **Design of reference atmosphere for EM test :**

$$\begin{cases} \dfrac{\partial \overline{\phi}}{\partial \ln p} = -R\overline{T} \\ \left(\dfrac{g}{C_p} + \dfrac{d\overline{T}}{dz}\right)\dfrac{R\overline{T}}{g} = C_0^2 \equiv const \end{cases}$$

Where $\overline{T}$ is p function, $\overline{\phi}$ is p function, $p_t = 10$ hPa

PGF of the reference atmosphere satisfies:

$$\left(\frac{\partial \overline{\phi}}{\partial x(y)} + R\overline{T}\frac{\partial \ln p}{\partial x(y)}\right)_\sigma = 0 = \nabla_p \overline{\phi}$$

Notes: In the test, the central-finite-difference scheme is used for discretization

Reference atmosphere for EH test

- **Design of reference atmosphere for EH test**：

$$\begin{cases} \overline{\pi}(z) = \exp(-\dfrac{gz}{c_p T_0}) \\ \overline{\theta}(z) = T_0 \exp(-\dfrac{gz}{c_p T_0}) \\ z = \dfrac{z_t - z_s}{z_t}\sigma_z + z_s \end{cases}$$

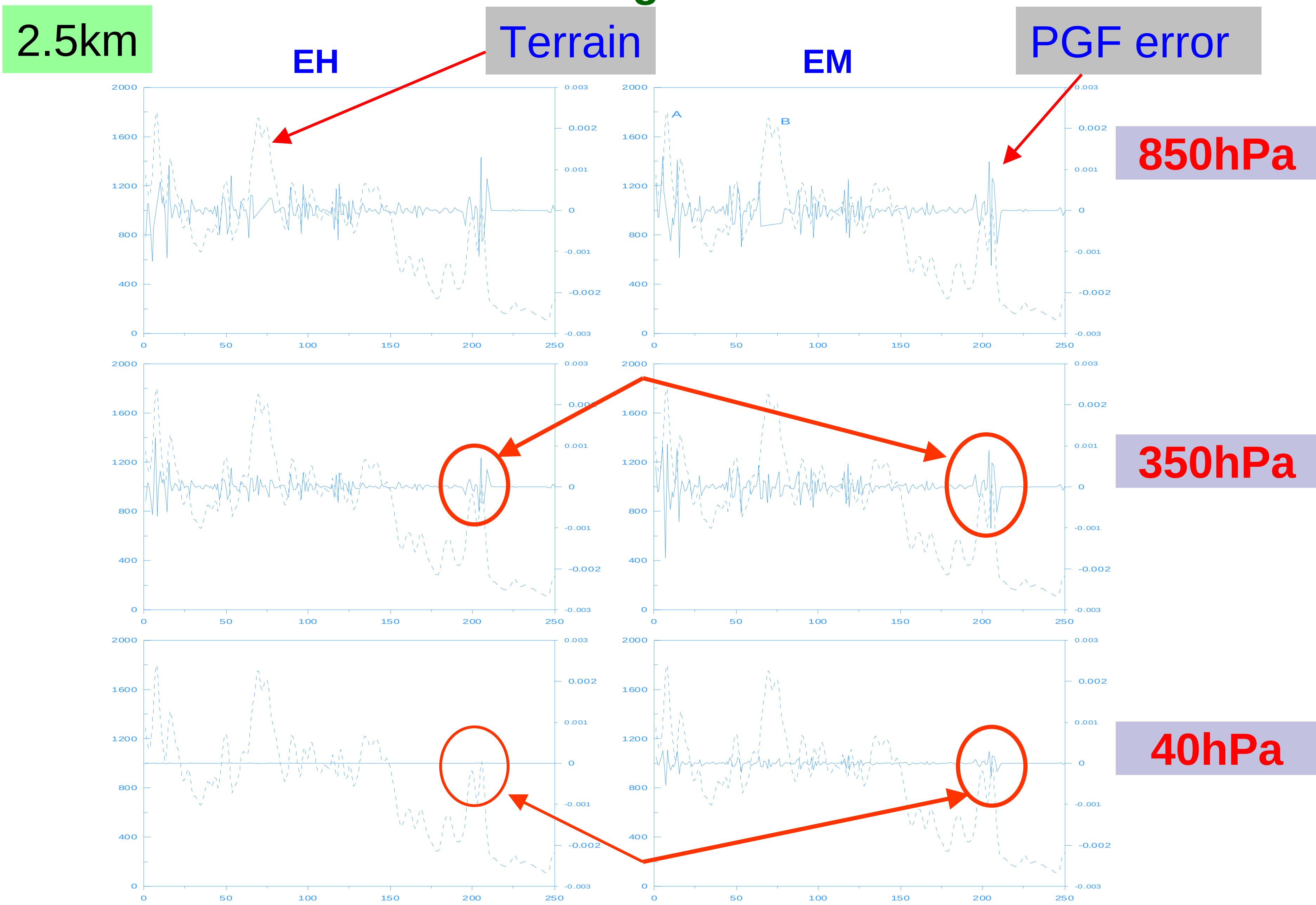
$\overline{\pi}$ is z function, $\overline{\theta}$ is z function, Z_t =3100m (10hPa)

PGF of reference atmosphere satisfies:

$$-\alpha\nabla p = -(c_p\theta\bullet\nabla\pi + \frac{z_t - \sigma_z}{z_t}\nabla\phi_s)_{\sigma_z} = 0$$

Notes: In the test, the central-finite-difference scheme is used for discretization

Truncation errors in height and mass coordinate



Truncation errors in EM and EH

Remarks：

- For the higher resolution model, the PGF errors are almost the same in lower levels for both EM and EH, but the PGF error in EM are larger in higher levels than those in EH
- However, for the coarser resolution model (Δx=10~30km), the truncation errors are the same in both EM and EH, not only in lower as well as in upper levels

Case study on sensitivity of vertical coordinates

00 UTC 8 June 2002 —00 UTC 9 June 2002

A heavy rain case in Xi'an of Shanxi province

Model : WRF with EH and EM, respectively

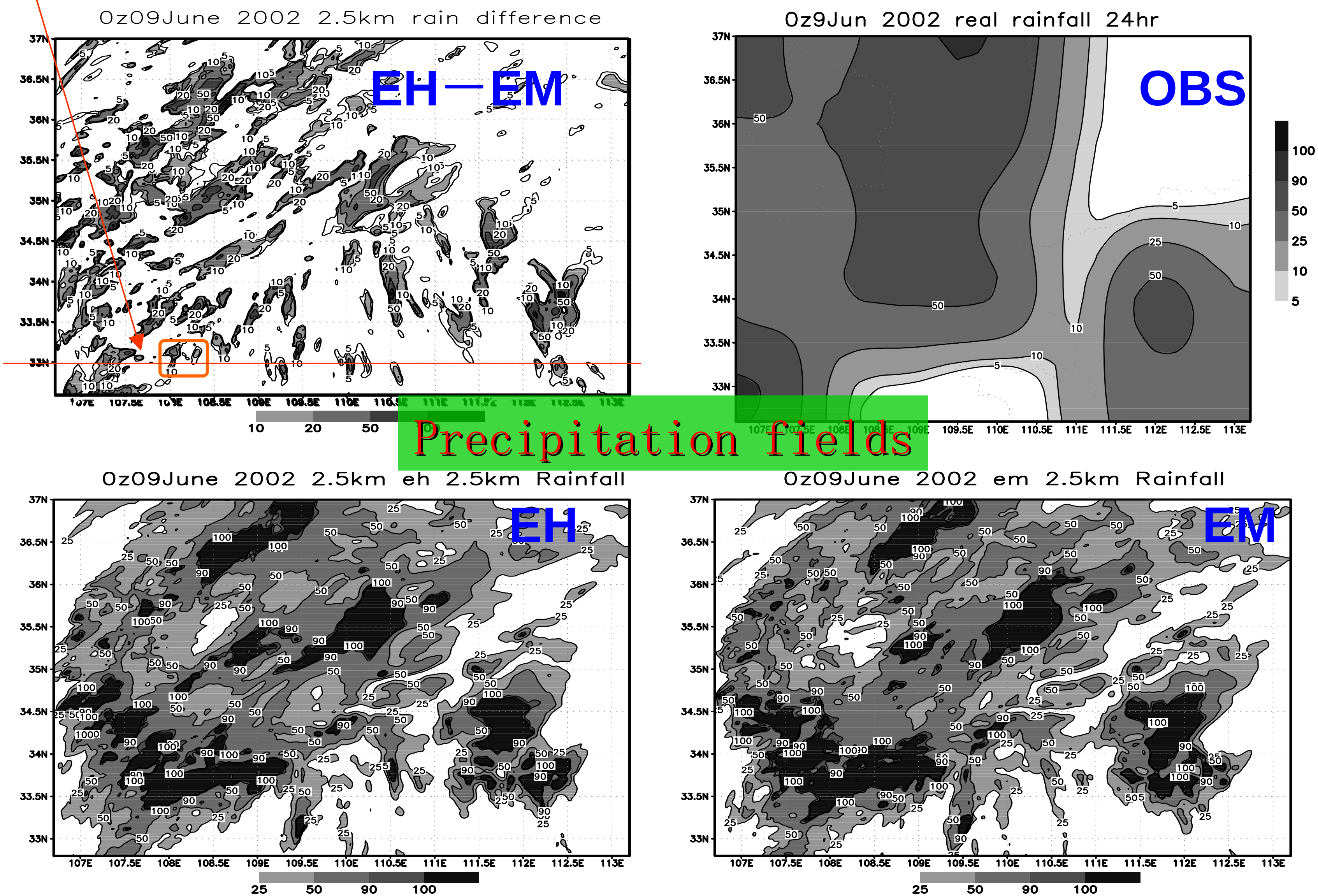
Grid size: 2.5km

F.T. : 24 hours

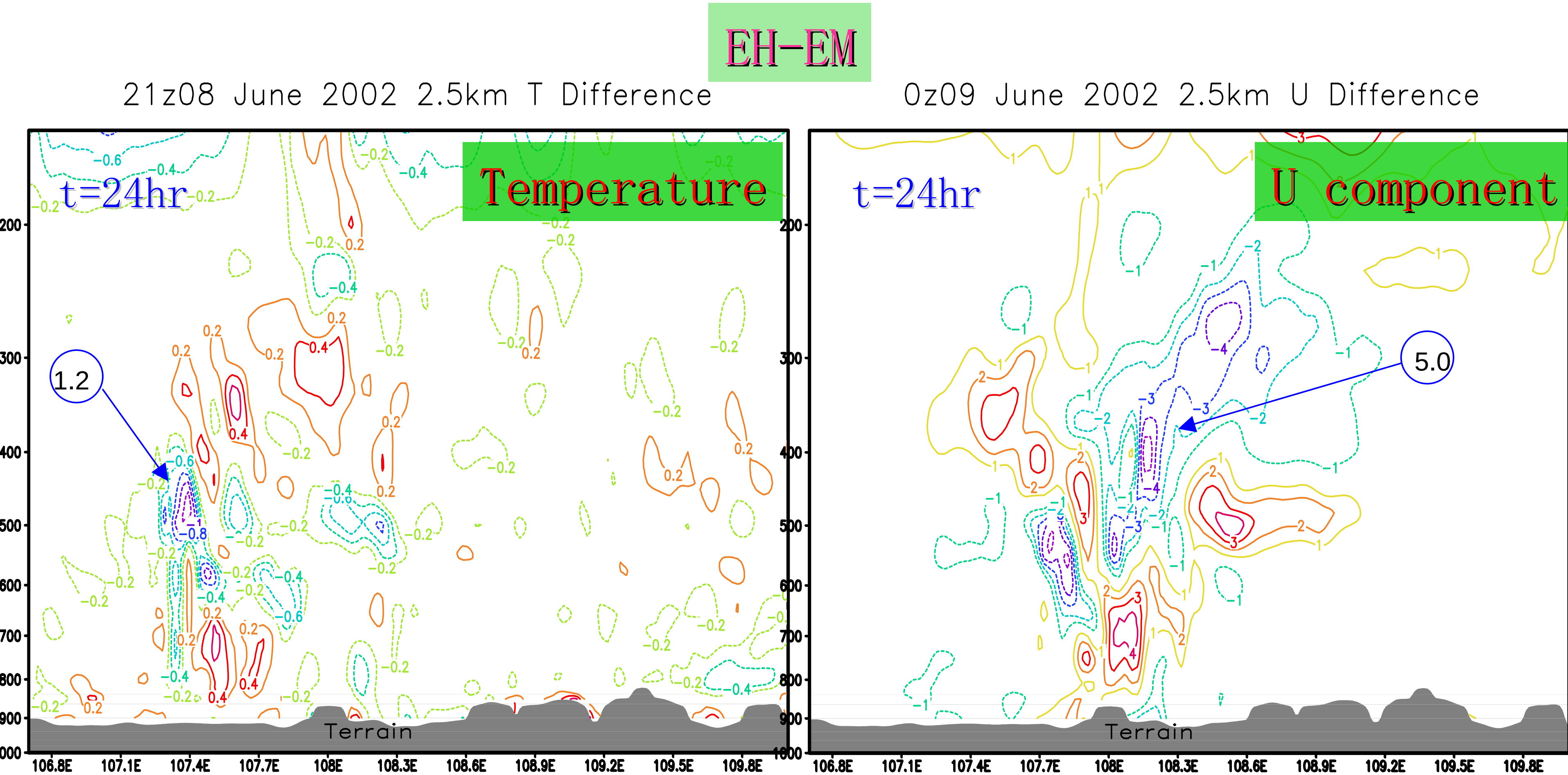
Initial conditions: same initial fields, same L.B.C., same topography and same top of the model

Cross-section line

24 hrs Numerical Simulation



Height-Longitude cross-section at 33ºN of numerical simulation

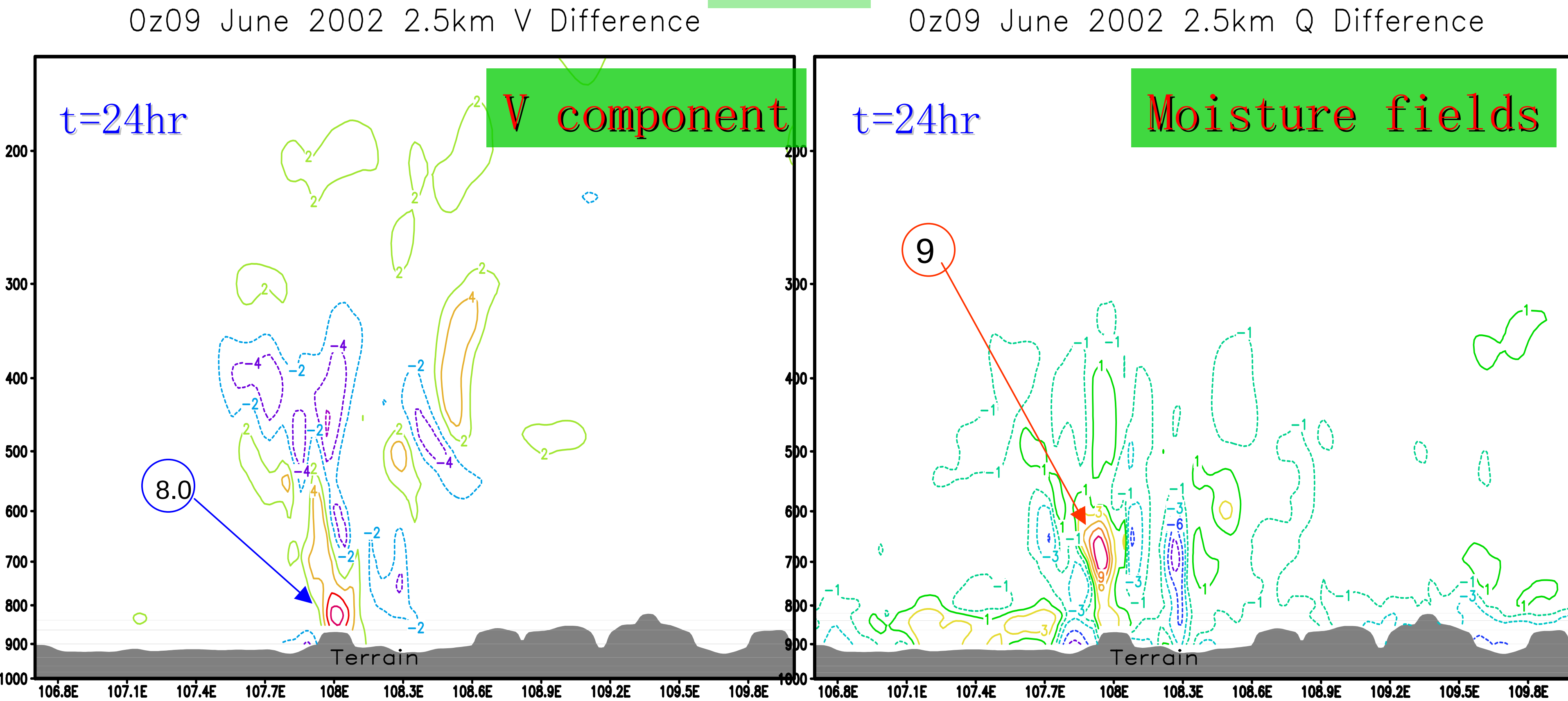


2.5 km

Large differences found at middle and lower levels (earlier 12hrs, few differences)

Height-Longitude cross-section at 33ºN of numerical simulation

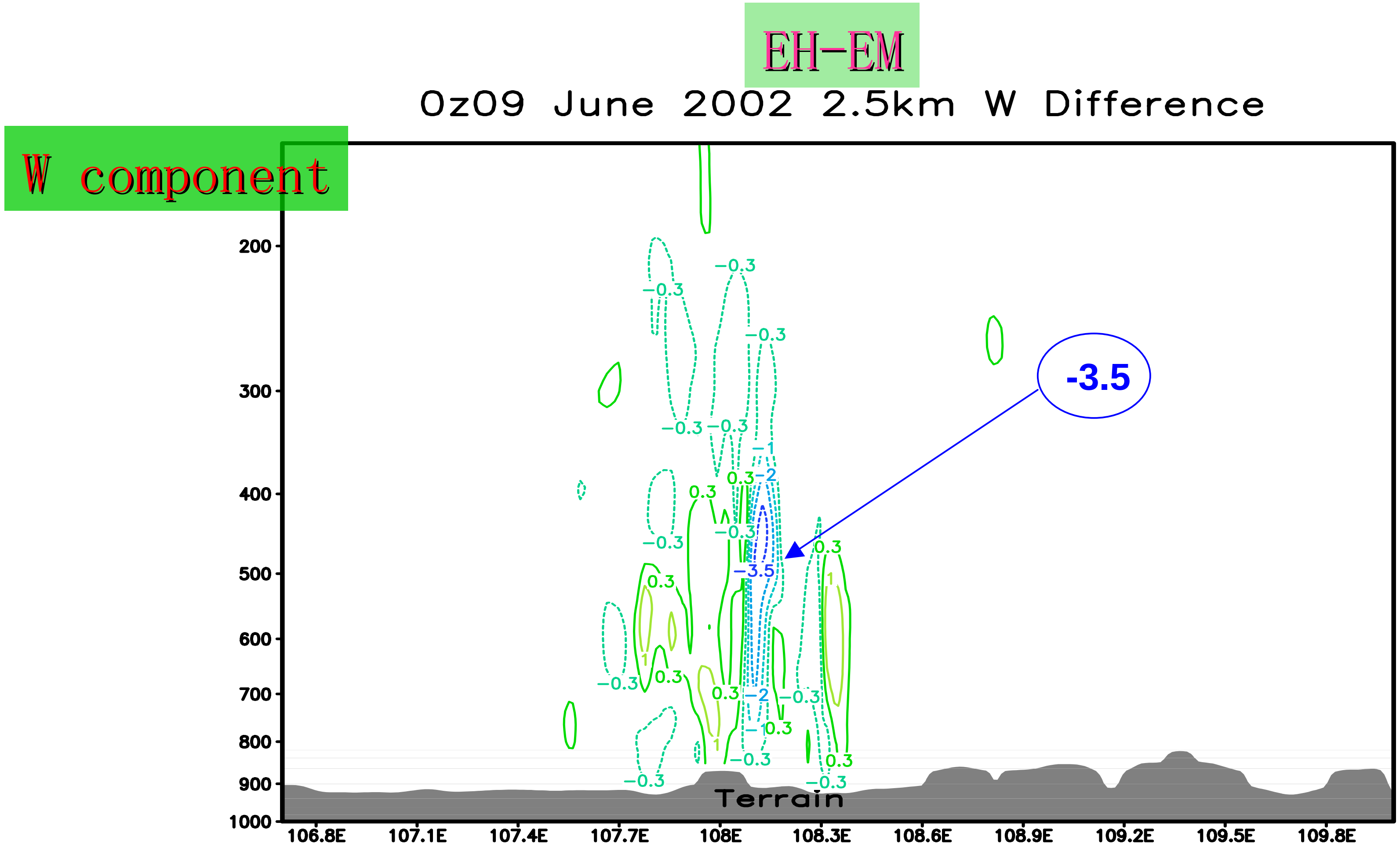
EH−EM



2.5 km

Large differences found at middle and lower levels (earlier 12hrs, few differences)

Height-Longitude cross-section at 33ºN of numerical simulation



2.5 km

Large differences found at middle and lower levels (earlier 12hrs, few differences)

Conclusions and Remarks

- Two vertical coordinates (EH and EM) were investigated
- The metric terms of PGF in EH doesn't change with time; more smoothed with altitude in EH than in EM.
- The truncation errors of PGF calculation are closed in low levels for both EH and EM;
- The simulations are sensitive to the vertical coordinates,more sensitive at low and middle levels.
- For the coarser resolution, few sensitivities

Thanks !