An Evaluation of High-Impact Weathers over Korea Simulated by the Non-Hydrostatic Regional Spectral Model

Eun-Chul Chang and **Song-You Hong**

Numerical Modeling Laboratory, Yonsei University

Introduction

- Most regional models employ the non-hydrostatic dynamics as a dynamical core
- Non-hydrostatic forcing is important at higher resolution when dynamical and thermodynamical forcing are strong

Global and Regional Integrated Model System (GRIMs)

Regional Spectral Model (RSM) in GRIMs

- Widely used for climate researches (>50km)
- For high-resolution (<10km) climate simulation, non-hydrostatic system is highly needed

Non-hydrostatic version of NCEP RSM (Juang 1992, 2000) is implemented to GRIMs

Introduction

Global and Regional Integrated Model System (GRIMs)

Spectral dynamic core : T62 — T426

1. **Spherical harmonics (SPH) system : for Global and Regional**
2. **Double Fourier series (DFS) system : for Global**

Physical processes	
Land surface	Kang and Hong (2008, JGR), Chen and Duhdia (2001, MWR)
PBL	Hong et al. (2006, MWR), Noh et al. (2003, BLM)
Cumulus	Byun and Hong (2007, MWR), Park and Hong (2007)
Cloud and microphysics	Hong et al. (1998, MWR; 2004, MWR)
Radiation	Chou (2006), Ham et al. (2009, ATP)
Gravity wave drag	Chun and Baik (1998, JAS), Kim and Arakawa (1995, JAS), Hong et al. (2008, WAF)

Experimental design

Two regional models are utilized in this study

Regional Spectral Model (RSM)

Weather Research and Forecasting (WRF) model

RSM	Hydrostatic Non-hydrostatic
WRF	Hydrostatic Non-hydrostatic

Regional Model Domains :

Lambert conformal conic map projection

4 domains are used for downscaling

1-way nesting (27km – 9km – 3km – 1km)

time step (Δt) for integration

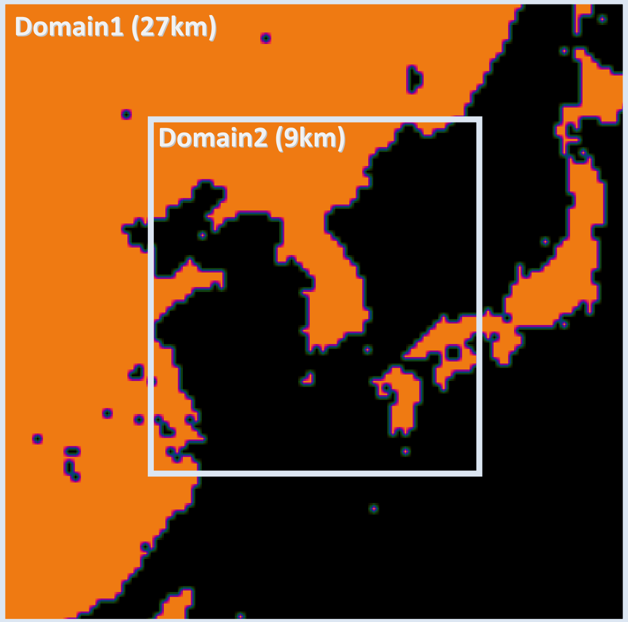
	Dm 1	Dm 2	Dm 3	Dm 4
RSM	60 s	20 s	6 s	
WRF	90 s	30 s	10 s	3 s

NCEP Final Analysis Data (FNL, $1^{o} \times 1^{o}$) is used for I.C. and B.C.

Case 1 : 2005. 4. 4. 12UTC – 4. 6. 00UTC
down slope severe wind storm case (Lee wave)

Case 2 : 2005. 12. 21. 00UTC – 12. 22. 00UTC
Heavy snowfall case

Case 3 : 2006. 7. 15. 00UTC – 7. 16. 00UTC
Heavy rainfall case



Objective

Objective

For the WRF model and RSM,

the non-hydrostatic and hydrostatic versions are available.

Evaluate high-impact weathers simulated by the non-hydrostatic models

Find out advantages of the non-hydrostatic dynamical cores in high resolution

Result 1

Case 1 : downslope windstorm (Lee wave)

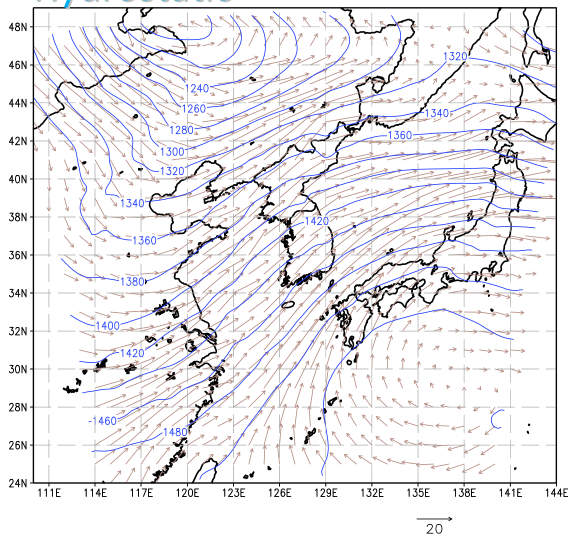
Case 1 : downslope windstorm (Lee wave)

Domain 1 (27km) : 850 hPa geopotential height (m), wind vector

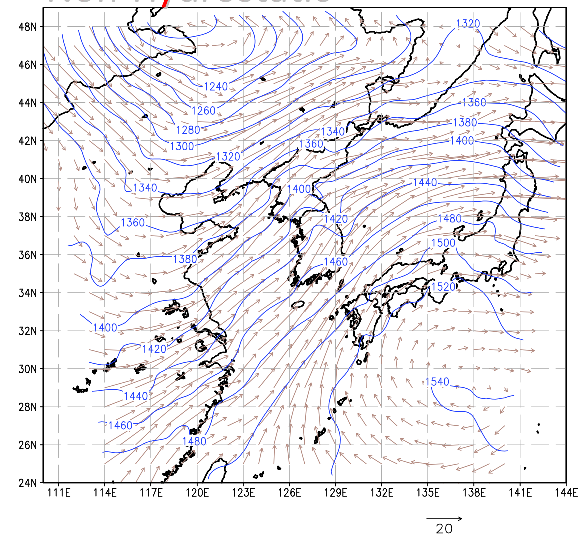
36hr fcst

RSM

Hydrostatic

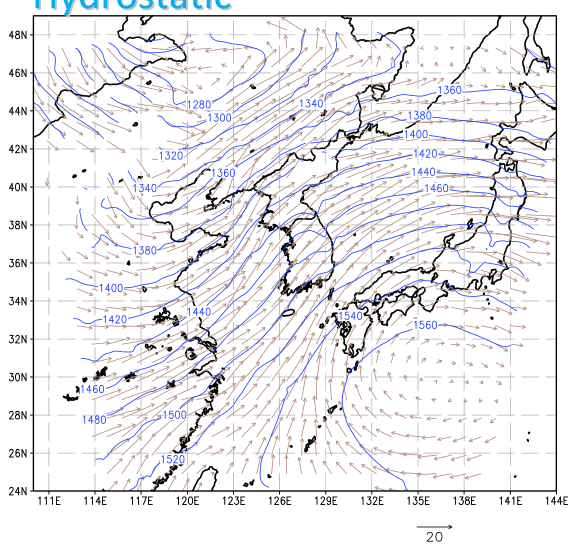


Non-Hydrostatic

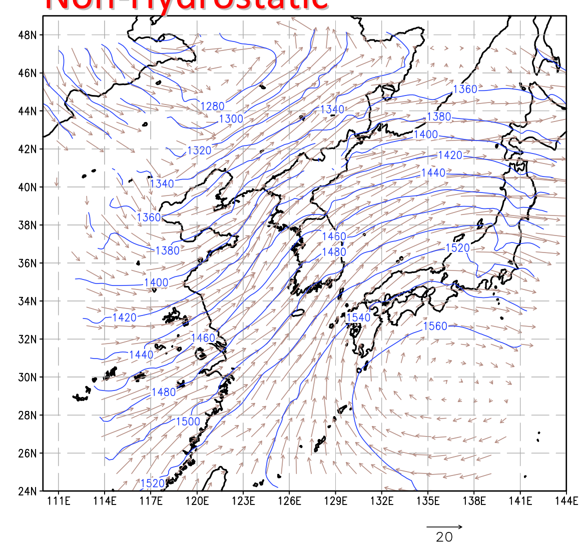


WRF

Hydrostatic



Non-Hydrostatic

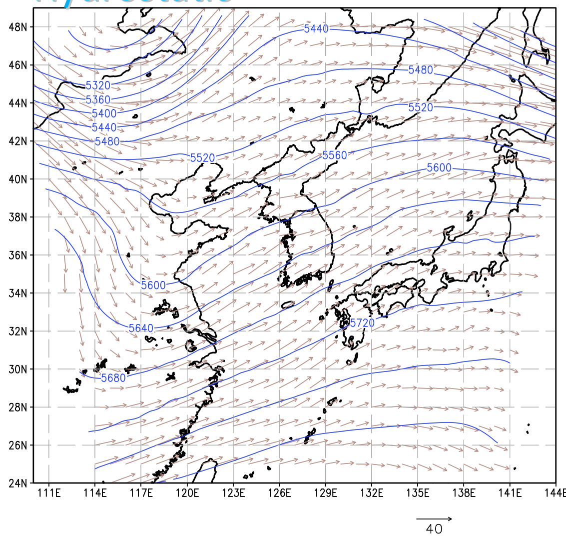


Domain 1 (27km) : 500 hPa geopotential height (m), wind vector

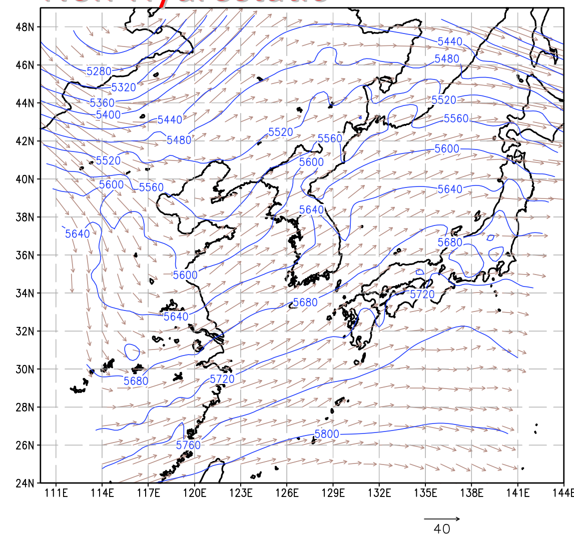
36hr fcst

RSM

Hydrostatic

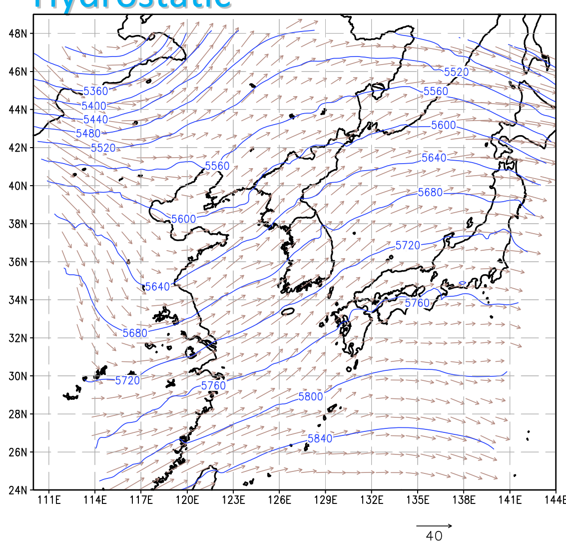


Non-Hydrostatic

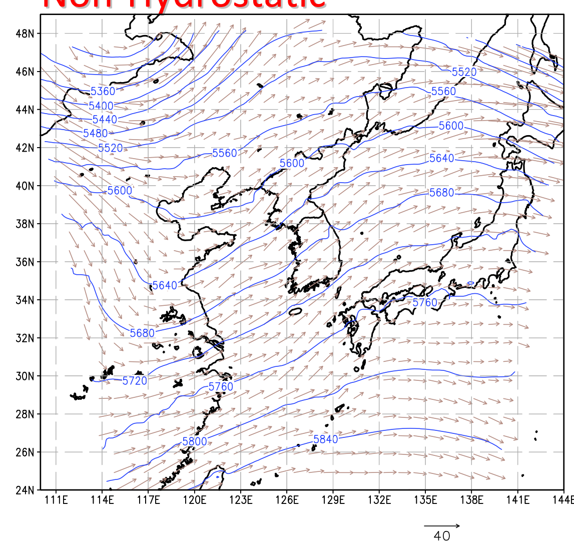


WRF

Hydrostatic



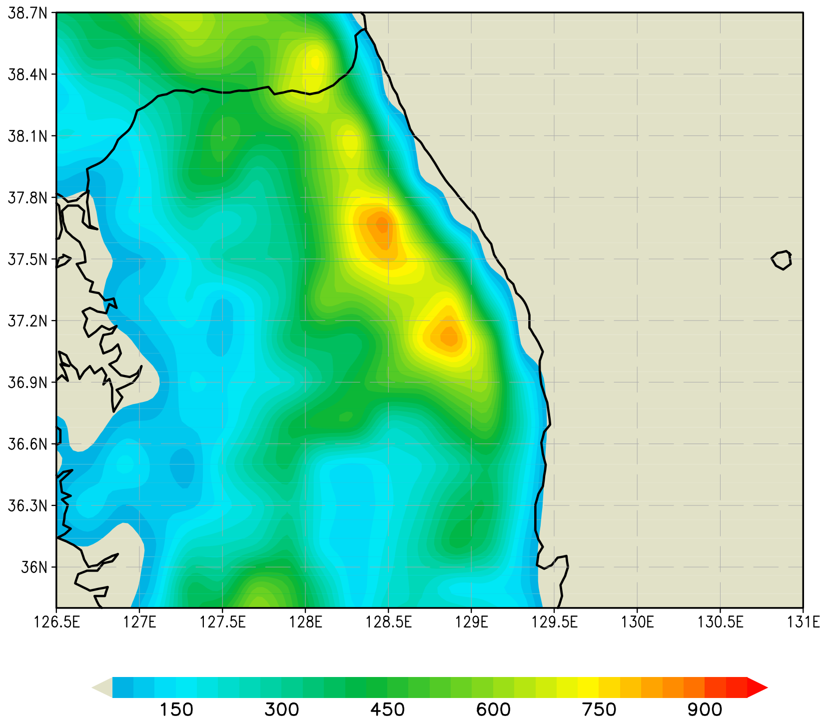
Non-Hydrostatic



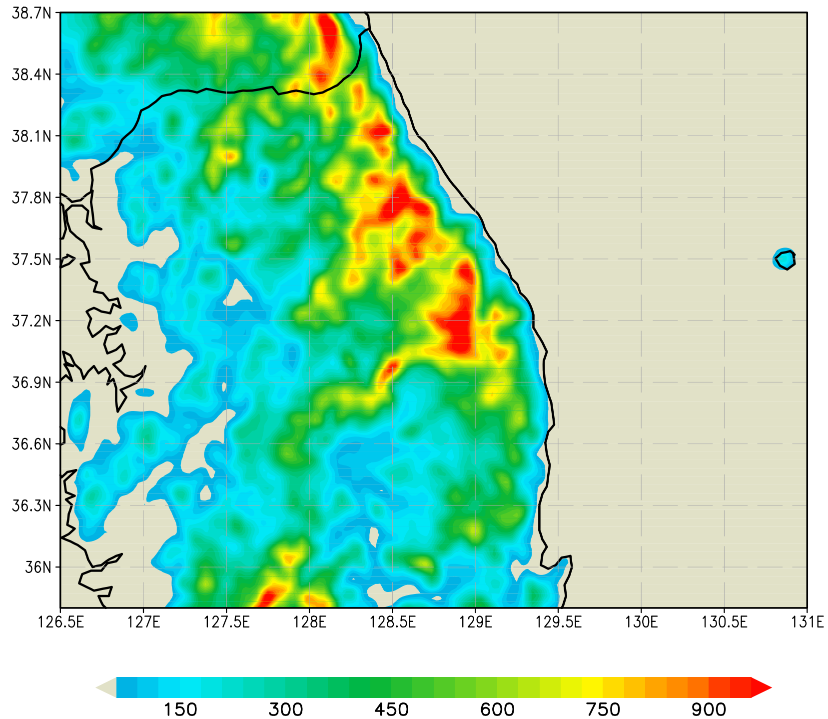
Case 1 : downslope windstorm (Lee wave)

Domain 3 (3km) : topography

RSM domain3



WRF domain3

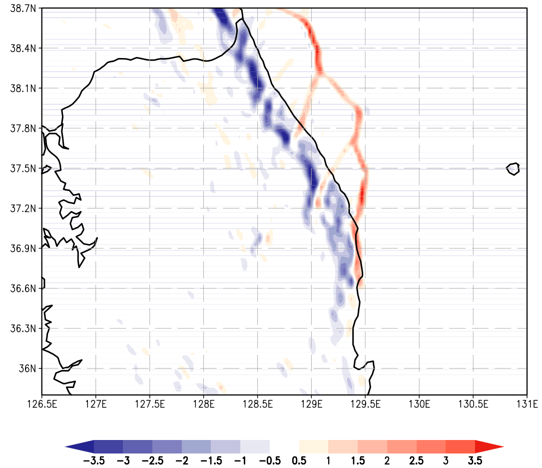


Case 1 : downslope windstorm (Lee wave)

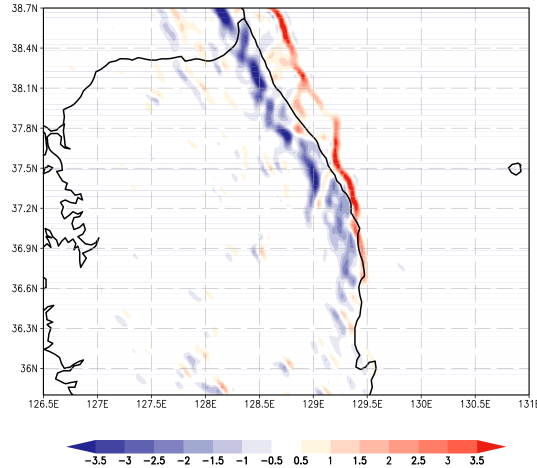
WRF – Domain 3 (3km) : 850 hPa vertical velocity (m/s)

Hydrostatic WRF

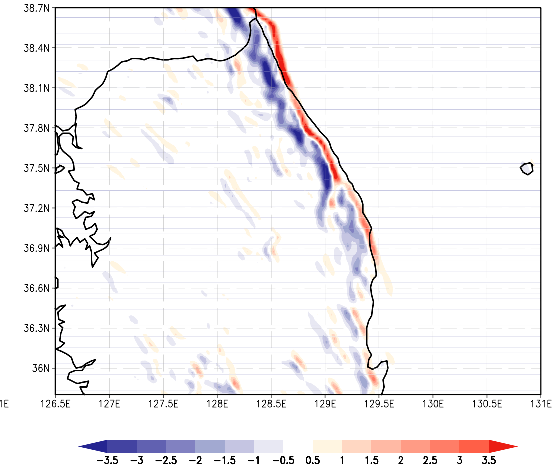
2005. 4. 5. 12 UTC



2005. 4. 5. 15 UTC

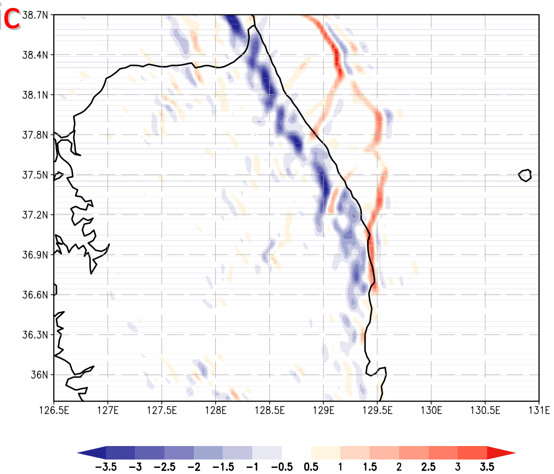


2005. 4. 5. 18 UTC

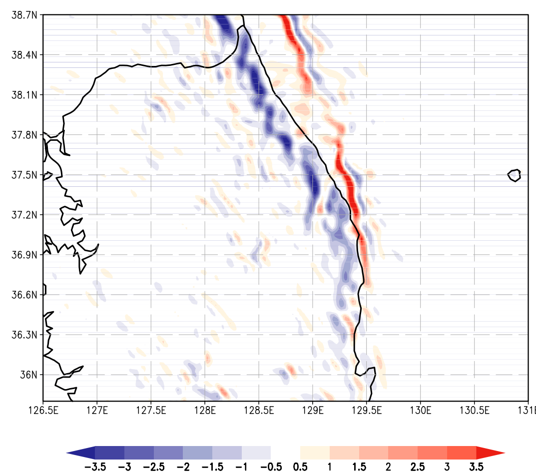


Non-Hydrostatic WRF

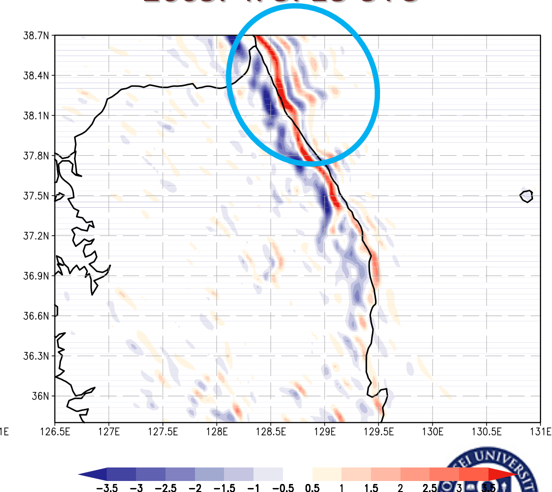
2005. 4. 5. 12 UTC



2005. 4. 5. 15 UTC



2005. 4. 5. 18 UTC



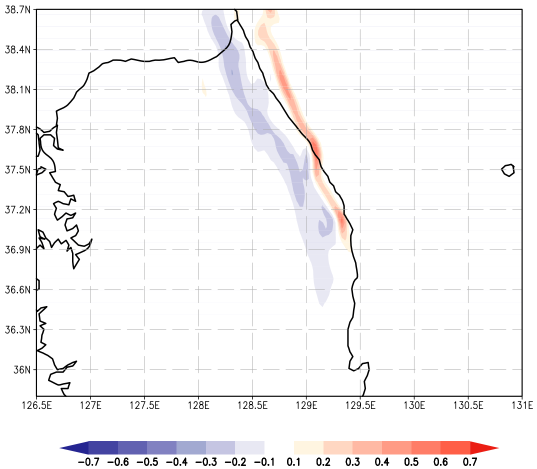
Case 1 : downslope windstorm (Lee wave)

RSM – Domain 3 (3km) : 850 hPa vertical velocity (m/s)

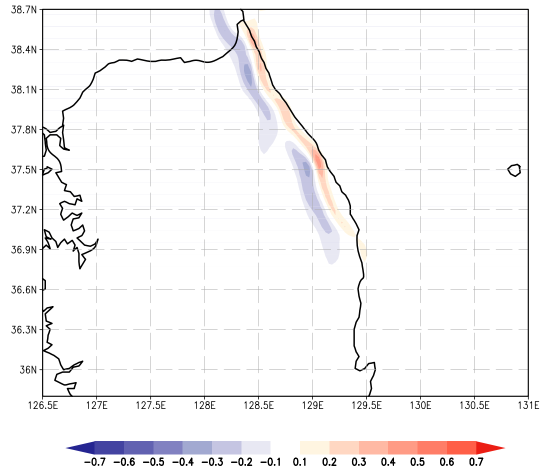
Hydrostatic

RSM

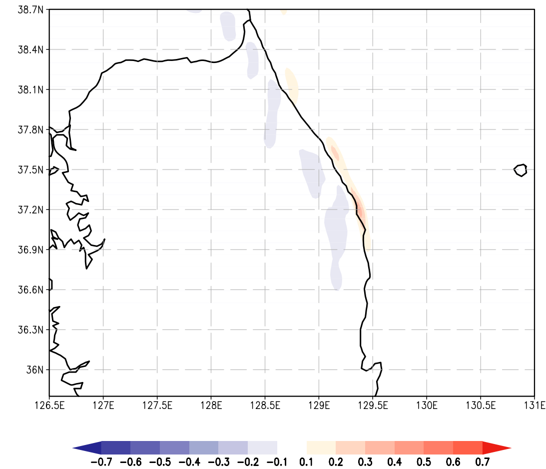
2005. 4. 5. 12 UTC



2005. 4. 5. 15 UTC



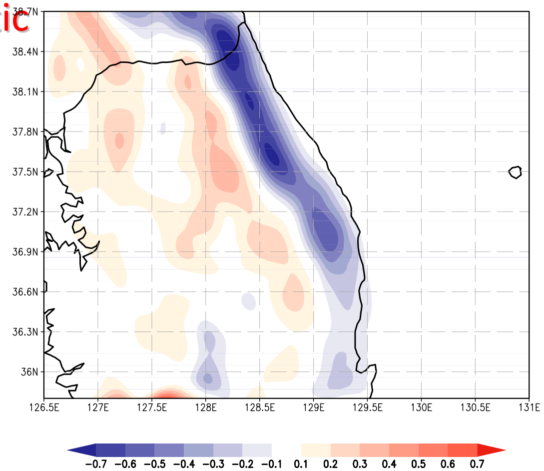
2005. 4. 5. 18 UTC



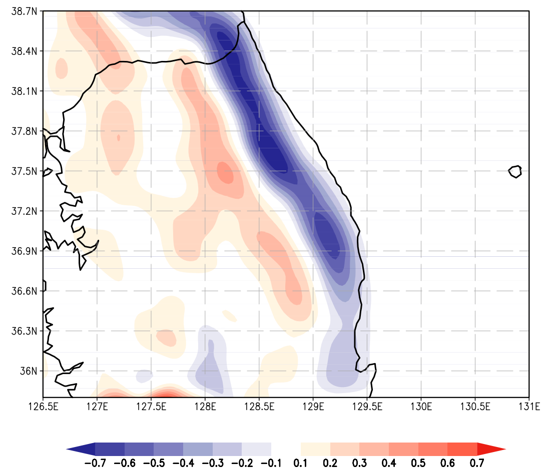
Non-Hydrostatic

RSM

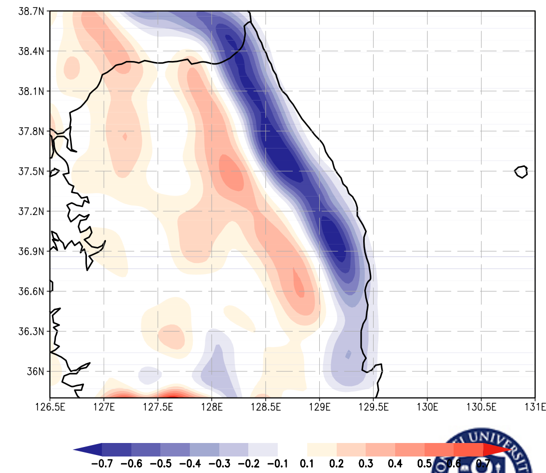
2005. 4. 5. 12 UTC



2005. 4. 5. 15 UTC

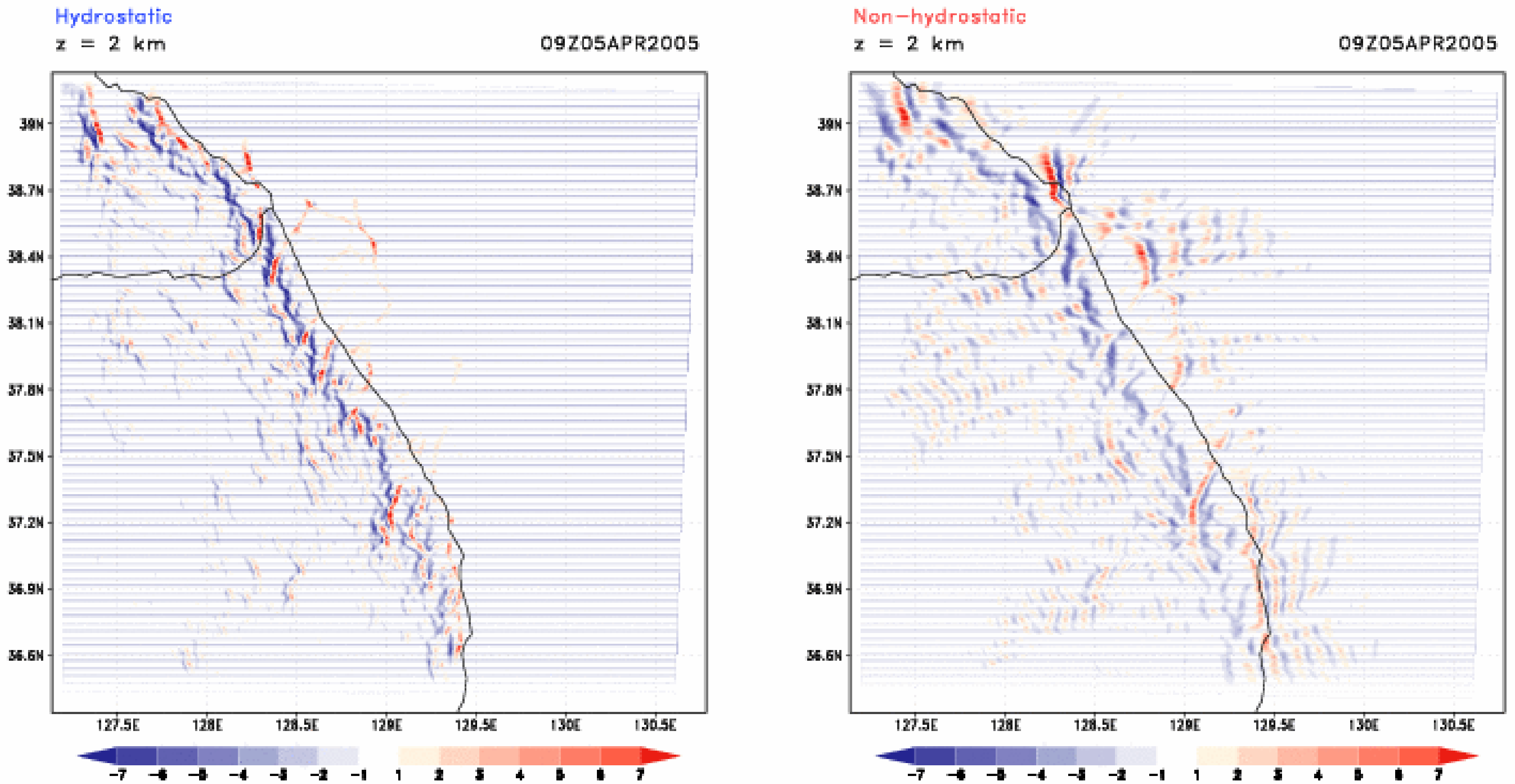


2005. 4. 5. 18 UTC



Case 1 : downslope windstorm (Lee wave)

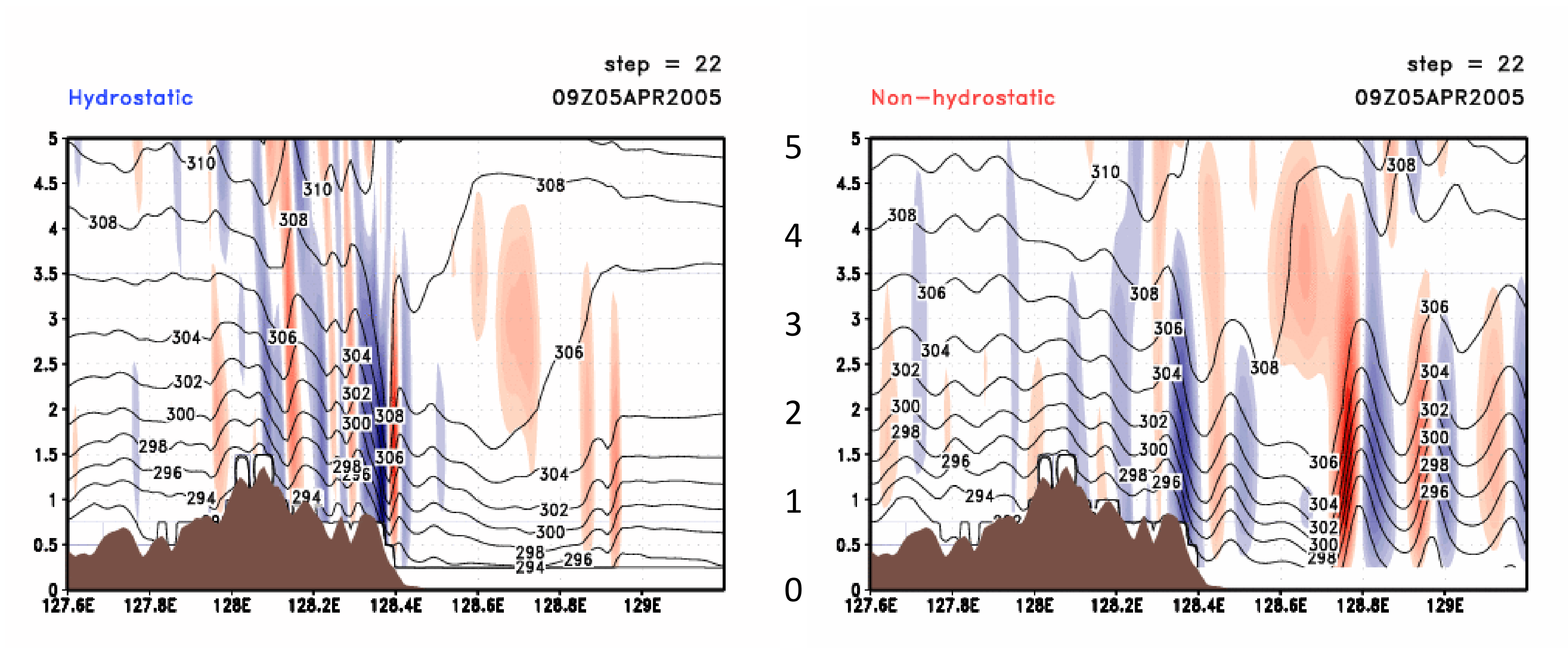
WRF – Domain4 (1km) : Vertical velocity (m/s) at z = 2 km



Case 1 : downslope windstorm (Lee wave)

WRF – Domain 4 (1km)

Cross section : vertical velocity & potential temperature



Result 2

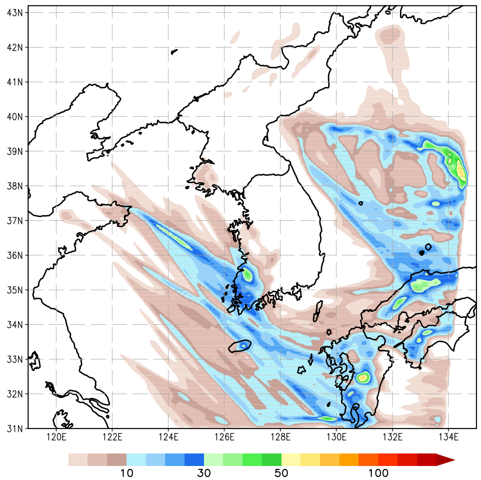
Case 2 : Heavy snowfall

Case 2 : Heavy snowfall (2005. 12. 21. 00UTC ~ 12. 22. 00UTC)

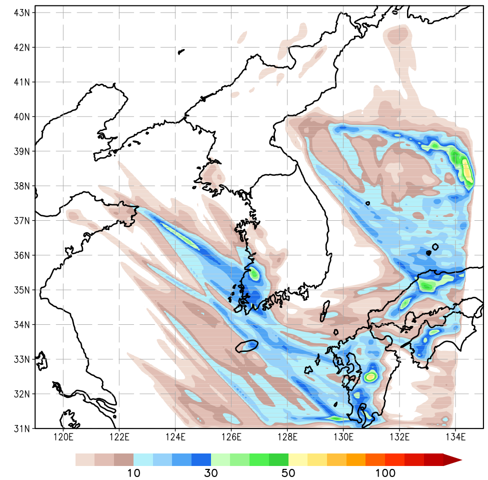
Domain 2 (9 km): total precipitation (mm) for 24 hours

WRF (WSM6)

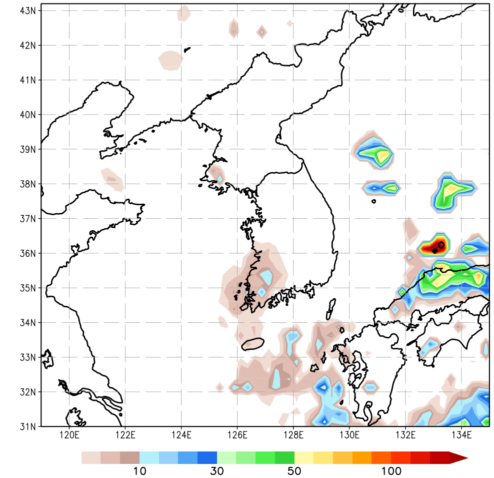
Hydrostatic



Non-Hydrostatic

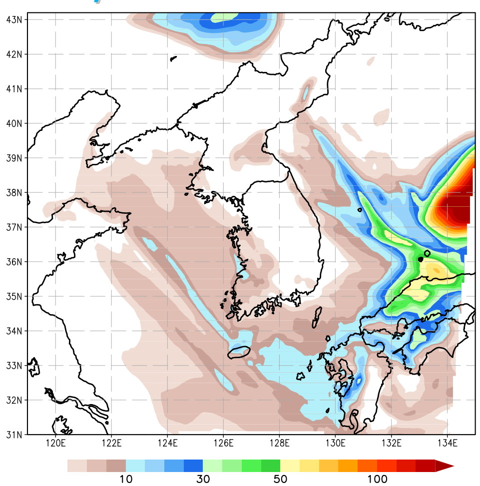


TMPA

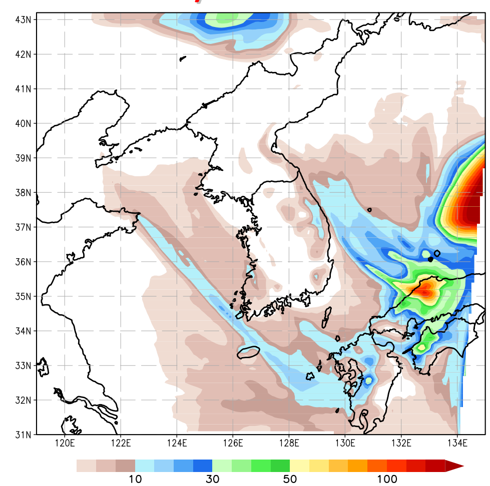


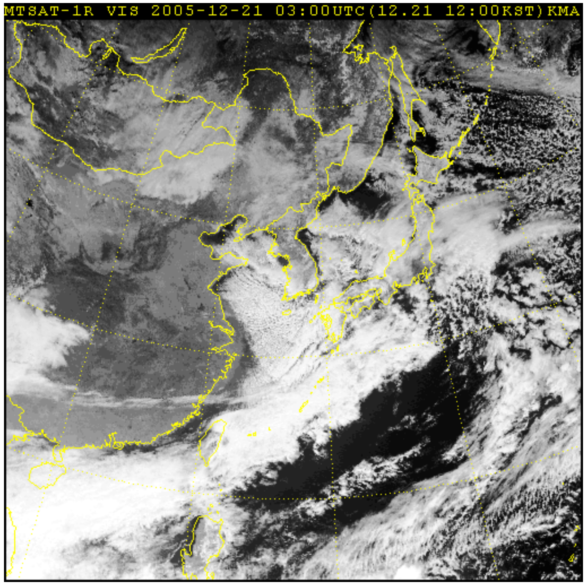
RSM (WSM1)

Hydrostatic



Non-Hydrostatic





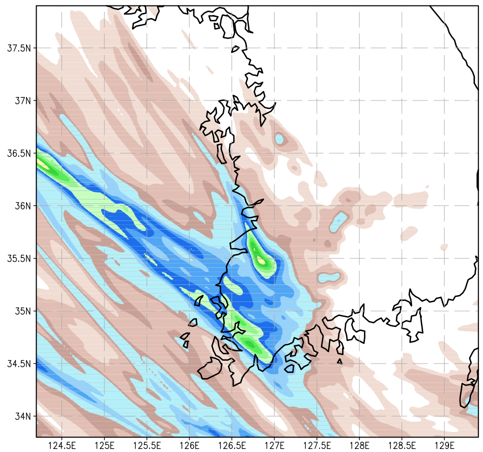
Numerical Modeling Laboratory, Department of Atmospheric Sciences, Yonsei University

Case 2 : Heavy snowfall

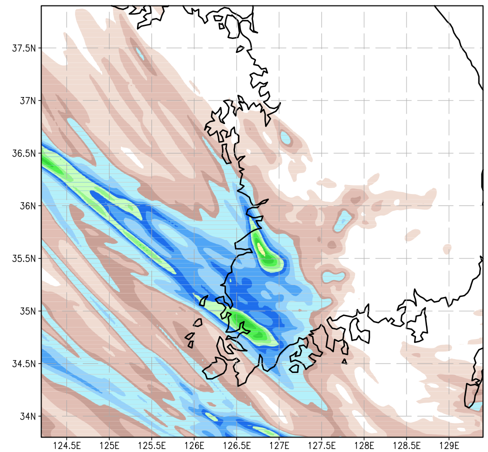
Domain 3 (3 km): total precipitation (mm) for 24 hours

WRF

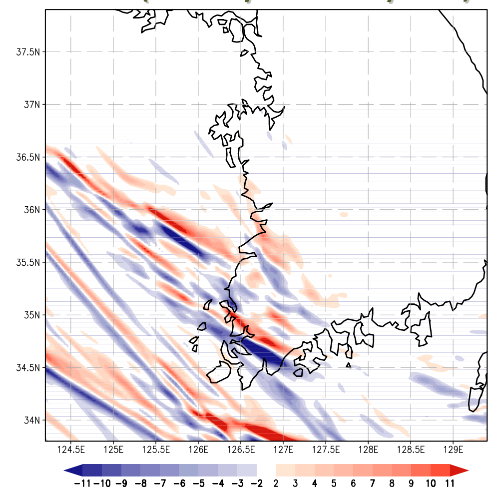
Hydrostatic



Non-Hydrostatic

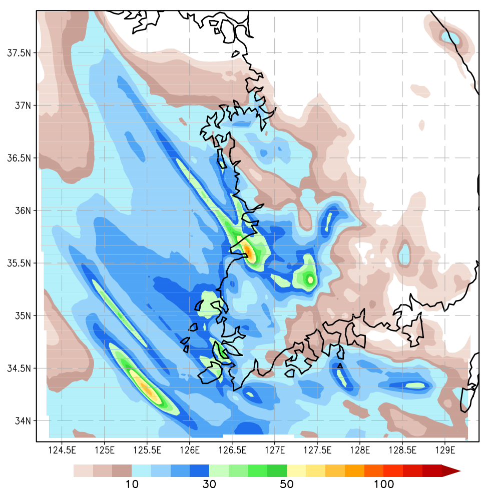


diff (nonhydro – hydro)

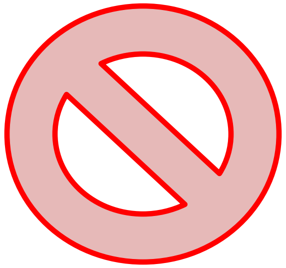


RSM

Hydrostatic



Non-Hydrostatic



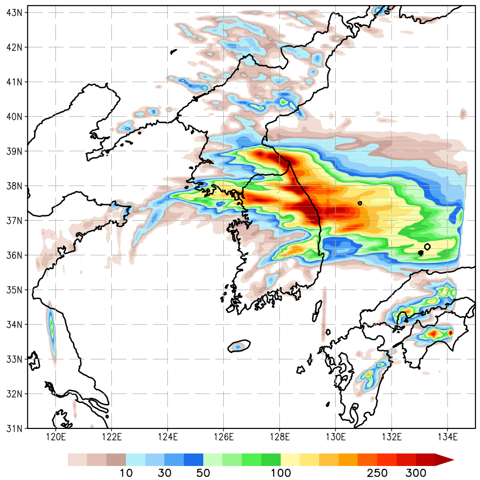
Result 3

Case 3 : Heavy rainfall

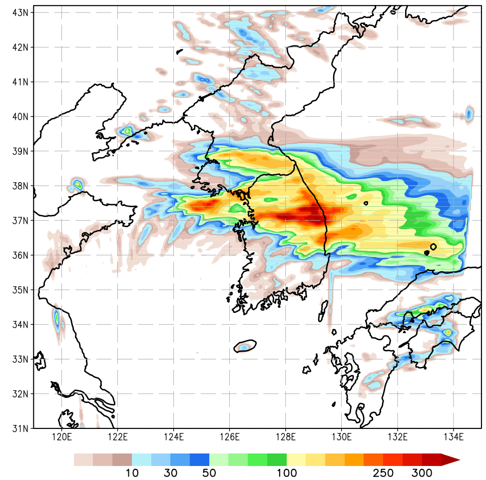
Domain 2 (9 km): total precipitation (mm) for 24 hours

WRF (WSM6)

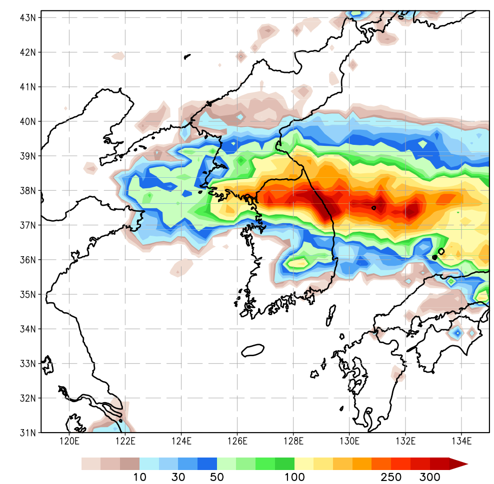
Hydrostatic



Non-Hydrostatic

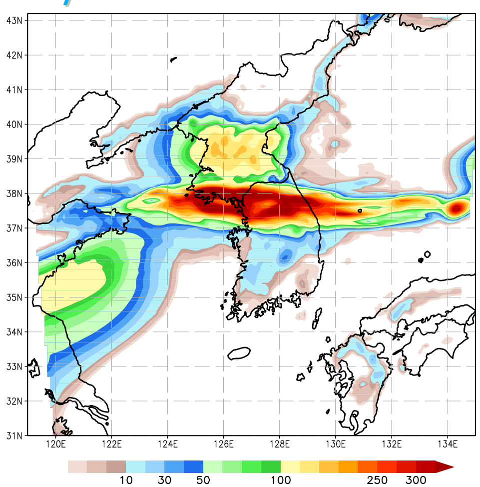


TMPA

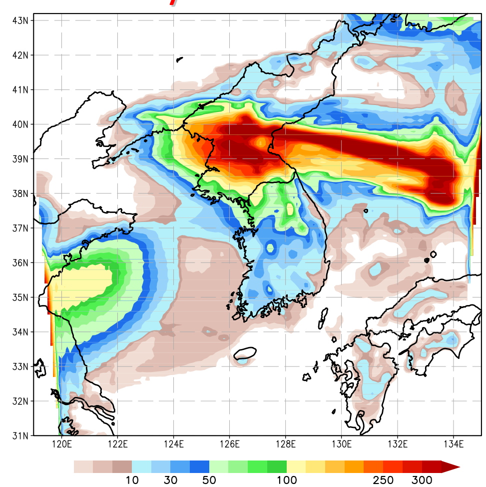


RSM (WSM1)

Hydrostatic



Non-Hydrostatic

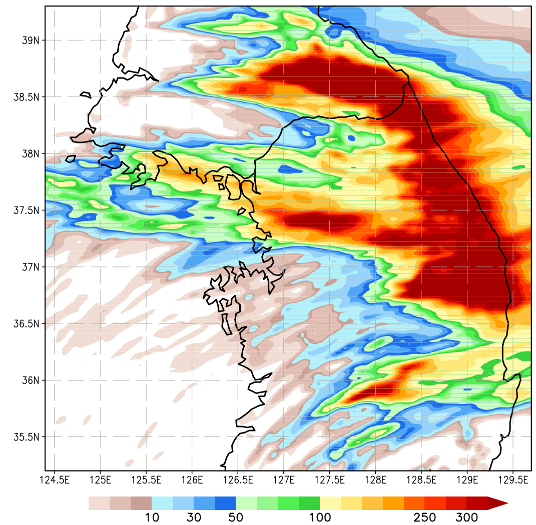


Case 3 : Heavy rainfall

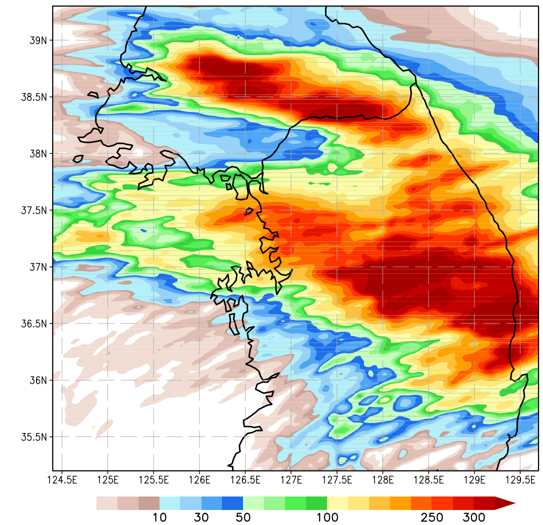
Domain 3 (3 km): total precipitation (mm) for 24 hours

WRF

Hydrostatic

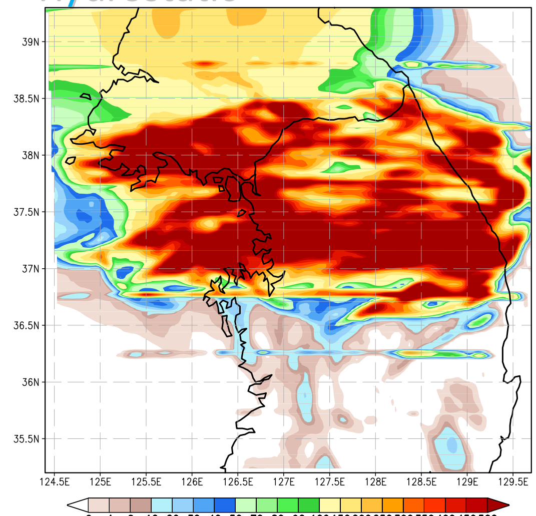


Non-Hydrostatic

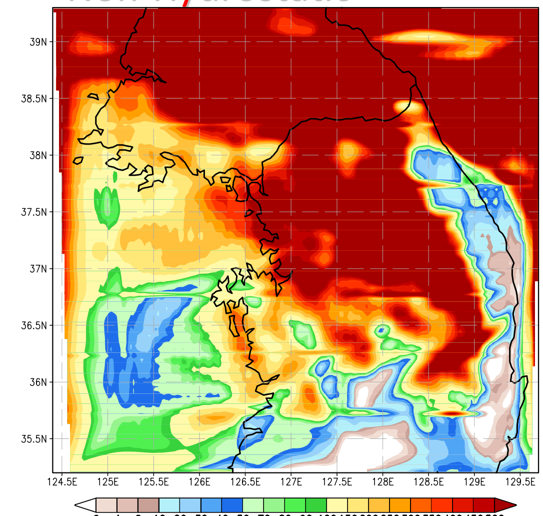


RSM

Hydrostatic



Non-Hydrostatic



Summary

Summary

- For short range forecast, there are no significant differences of results between the hydrostatic and non-hydrostatic dynamics cores in coarse resolution domains (< 9 km).

- For high resolution (> 3 km), non-hydrostatic dynamics frames can generate lee wave propagation, and more strong vertical motions which increase precipitation.

- Advantages of the Non-hydrostatic dynamic core for high resolution (<10 km) climate run.

Plan

- Blow up problems
- Advantages of the Non-hydrostatic dynamic core for high resolution (<10 km) climate run.

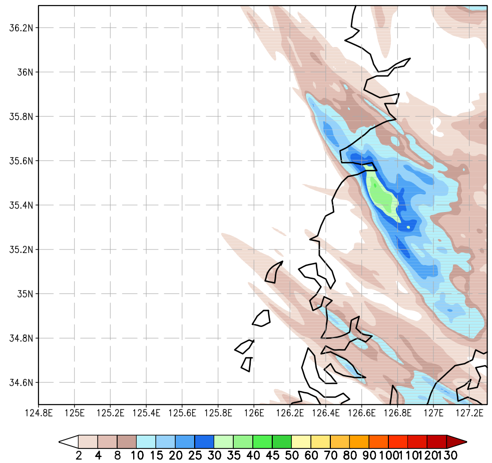
Thank you

Case 2 : Heavy snowfall

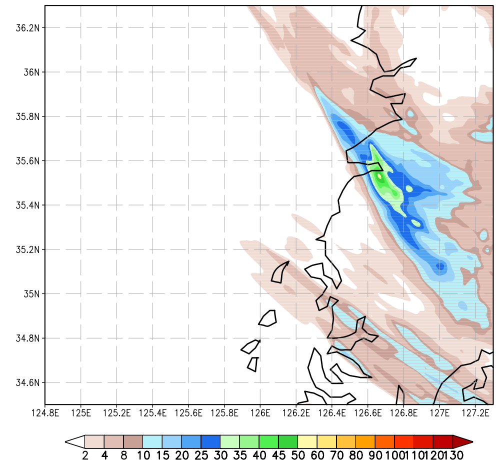
Domain 4 (1 km) : total precipitation (mm) for 24 hours

WRF

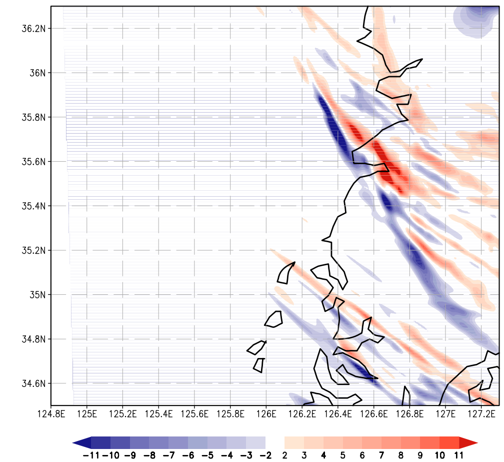
Hydrostatic



Non-Hydrostatic



diff (nonhydro – hydro)



Nonhydrostatic Primitive Equations

Fully compressible nonhydrostatic RSM (Juang 2000)

$$\frac{\partial u'}{\partial t}=-m^2\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)-\dot{\sigma}\frac{\partial u}{\partial \sigma}-E\frac{\partial m^2}{\partial x}+fv-R\left(\overline{T}+T'\right)\frac{\partial \overline{Q_s}+Q'}{\partial x}-\left(1+\frac{T'}{\overline{T}}\right)\left(1+\frac{\partial Q'}{\partial \ln\sigma}\right)\frac{\partial \overline{\phi}}{\partial x}+F_u-\frac{\partial u_b}{\partial t}$$

$$\frac{\partial v'}{\partial t}=-m^2\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)-\dot{\sigma}\frac{\partial v}{\partial \sigma}-E\frac{\partial m^2}{\partial y}-fu-R\left(\overline{T}+T'\right)\frac{\partial \overline{Q_s}+Q'}{\partial y}-\left(1+\frac{T'}{\overline{T}}\right)\left(1+\frac{\partial Q'}{\partial \ln\sigma}\right)\frac{\partial \overline{\phi}}{\partial y}+F_v-\frac{\partial v_b}{\partial t}$$

$$\frac{\partial w'}{\partial t}=-m^2\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}\right)-\dot{\sigma}\frac{\partial w}{\partial \sigma}-g\left[1-\left(1+\frac{T'}{\overline{T}}\right)\left(1+\frac{\partial Q'}{\partial \ln\sigma}\right)\right]+F_w-\frac{\partial w_b}{\partial t}$$

$$Q'(=\ln p),\quad T',\quad w$$

$$\varepsilon_Q\left\{\frac{\partial \overline{Q_s}'}{\partial t}=-m^2\int_0^1\left[u\frac{\partial \overline{Q_s}}{\partial x}+v\frac{\partial \overline{Q_s}}{\partial y}+\left(\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}\right)\right]d\sigma-\frac{\partial Q_{sb}}{\partial t}\right\}$$

$$\varepsilon_T\left[\frac{\partial \overline{T}'}{\partial t}=-m^2\left(u\frac{\partial \overline{T}}{\partial x}+v\frac{\partial \overline{T}}{\partial y}\right)-\dot{\sigma}\sigma^k\frac{\partial \overline{T}\sigma^{-k}}{\partial \sigma}+\kappa\overline{T}\left(\frac{\partial \overline{Q_s}'}{\partial t}+m^2u\frac{\partial \overline{Q_s}}{\partial x}+m^2v\frac{\partial \overline{Q_s}}{\partial y}\right)+F_T-\frac{\partial T_b}{\partial t}\right]$$

$$\frac{\partial Q'}{\partial t}=-m^2u\frac{\partial \overline{Q_s}+Q'}{\partial x}-m^2v\frac{\partial \overline{Q_s}+Q'}{\partial y}-\dot{\sigma}\frac{\partial Q'}{\partial \sigma}-\frac{\dot{\sigma}}{\sigma}-\gamma\nabla_3\cdot\mathrm{V}+\gamma\frac{F_T}{T}-\frac{\partial \overline{Q_s}}{\partial t}$$

$$\frac{\partial T'}{\partial t}=-m^2u\frac{\partial \overline{T}+T'}{\partial x}-m^2v\frac{\partial \overline{T}+T'}{\partial y}-\dot{\sigma}\sigma^k\frac{\partial\left(\overline{T}+T'\right)\sigma^{-k}}{\partial \sigma}+\kappa\left(\overline{T}+T'\right)\left[\frac{\partial\left(\overline{Q_s}+Q'\right)}{\partial t}+m^2u\frac{\partial \overline{Q_s}+Q'}{\partial x}+m^2v\frac{\partial \overline{Q_s}+Q'}{\partial y}+\dot{\sigma}\frac{\partial Q'}{\partial \sigma}\right]+F_T-\frac{\partial T_b}{\partial t}$$

$$\frac{\partial q'}{\partial t}=-m^2u\frac{\partial q}{\partial x}-m^2v\frac{\partial q}{\partial y}-\dot{\sigma}\frac{\partial q}{\partial \sigma}+F_q-\frac{\partial q_b}{\partial t}$$

Nonhydrostatic Primitive Equations

Fully compressible nonhydrostatic equations
: calculation of sigma dot ($\dot{\sigma}$)

Hydrostatic $\dot{\sigma}$
: use pressure and wind

$$\frac{\partial \dot{\sigma}}{\partial \sigma} = +\int_0^1 m^2 \left(u\frac{\partial Q}{\partial x} + v\frac{\partial Q}{\partial y} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) d\sigma - m^2 \left(u\frac{\partial Q}{\partial x} + v\frac{\partial Q}{\partial y} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right)$$

$$Q = \ln(p)$$

$$Q_s = \ln(p_s)$$

Nonhydrostatic $\dot{\sigma}$
: use vertical velocity (directly)

$$\dot{\sigma} = -\frac{g\sigma}{R\overline{T}} w + \frac{\sigma}{R\overline{T}} \left[\frac{\partial \overline{\phi}}{\partial t} + m^2 \left(u\frac{\partial \overline{\phi}}{\partial x} + v\frac{\partial \overline{\phi}}{\partial y} \right) \right]$$

Primitive Equations

Nonhydrostatic

$$\frac{\partial u'}{\partial t} = -m^2\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) - \dot{\sigma}\frac{\partial u}{\partial \sigma} - E\frac{\partial m^2}{\partial x} + fv - R\left(\overline{T} + T'\right)\frac{\partial \overline{Q_s} + Q'}{\partial x} - \left(1 + \frac{T'}{\overline{T}}\right)\left(1 + \frac{\partial Q'}{\partial \ln\sigma}\right)\frac{\partial \overline{\phi}}{\partial x} + F_u - \frac{\partial u_b}{\partial t}$$

$$\frac{\partial u}{\partial t} = -m^2\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) - \dot{\sigma}\frac{\partial u}{\partial \sigma} - E\frac{\partial m^2}{\partial x} + fv - R\left(\overline{T} + T'\right)\frac{\partial \overline{Q_s} + Q'}{\partial x} - \left(1 + \frac{T'}{\overline{T}}\right)\left(1 + \frac{\partial Q'}{\partial \ln\sigma}\right)\frac{\partial \overline{\phi}}{\partial x} - 2\Omega\cos^2\varphi\cdot w - \frac{uw}{a}$$

Hydrostatic

$$\frac{\partial u'}{\partial t} = -m^2\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) - \dot{\sigma}\frac{\partial u}{\partial \sigma} - E\frac{\partial m^2}{\partial x} + fv - \left(\frac{\partial \phi}{\partial x} + R\overline{T}\frac{\partial \overline{Q_s}}{\partial x}\right) + F_u - \frac{\partial u_b}{\partial t}$$

$$E = \frac{1}{2}\left(u^2 + v^2\right)$$

$$Q = \ln(p)$$

$$Q_s = \ln(p_s)$$

$$T = \overline{T} + T'$$

$$Q = \overline{Q} + Q'$$

Hydrostatic part — perturbation part

$$Q' = Q - \overline{Q}$$

$$= Q - \overline{Q_s} - \ln\sigma$$

Current status

$$\frac{\partial Q'}{\partial t} = -m^2 u \frac{\partial \overline{Q_s} + Q'}{\partial x} - m^2 v \frac{\partial \overline{Q_s} + Q'}{\partial y} - \dot{\sigma}\frac{\partial Q'}{\partial \sigma} - \frac{\dot{\sigma}}{\sigma} - \gamma \nabla_3 \cdot \mathrm{V} + \gamma \frac{F_T}{T} - \frac{\partial \overline{Q_s}}{\partial t}$$

Nonhydrostatic Pressure

$$Q'(=\ln p), \quad T', \quad w$$

$$\varepsilon_Q \left\{ \frac{\partial \overline{Q_s}'}{\partial t} = -m^2 \int_0^1 \left[u \frac{\partial \overline{Q_s}}{\partial x} + v \frac{\partial \overline{Q_s}}{\partial y} + \left(\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} \right) \right] d\sigma - \frac{\partial Q_{sb}}{\partial t} \right\}$$

Hydrostatic Pressure

Nonhyd Q – hydro Q : Get pressure perturbation

$$\frac{\partial T'}{\partial t} = -m^2 u \frac{\partial \overline{T} + T'}{\partial x} - m^2 v \frac{\partial \overline{T} + T'}{\partial y} - \dot{\sigma}\sigma^k \frac{\partial \left(\overline{T} + T'\right)\sigma^{-k}}{\partial \sigma} + \kappa \left(\overline{T} + T'\right) \left[\frac{\partial \left(\overline{Q_s} + Q'\right)}{\partial t} + m^2 u \frac{\partial \overline{Q_s} + Q'}{\partial x} + m^2 v \frac{\partial \overline{Q_s} + Q'}{\partial y} + \dot{\sigma}\frac{\partial Q'}{\partial \sigma} \right] + F_T - \frac{\partial T_b}{\partial t}$$

Nonhyd T – hydro T : Get temperature perturbation

$$\frac{\partial u'}{\partial t} = -m^2 \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) - \dot{\sigma}\frac{\partial u}{\partial \sigma} - E \frac{\partial m^2}{\partial x} + fv - R\left(\overline{T} + T'\right) \frac{\partial \overline{Q_s} + Q'}{\partial x} - \left(1 + \frac{T'}{\overline{\overline{T}}}\right)\left(1 + \frac{\partial Q'}{\partial \ln \sigma}\right) \frac{\partial \overline{\phi}}{\partial x} + F_u - \frac{\partial u_b}{\partial t}$$

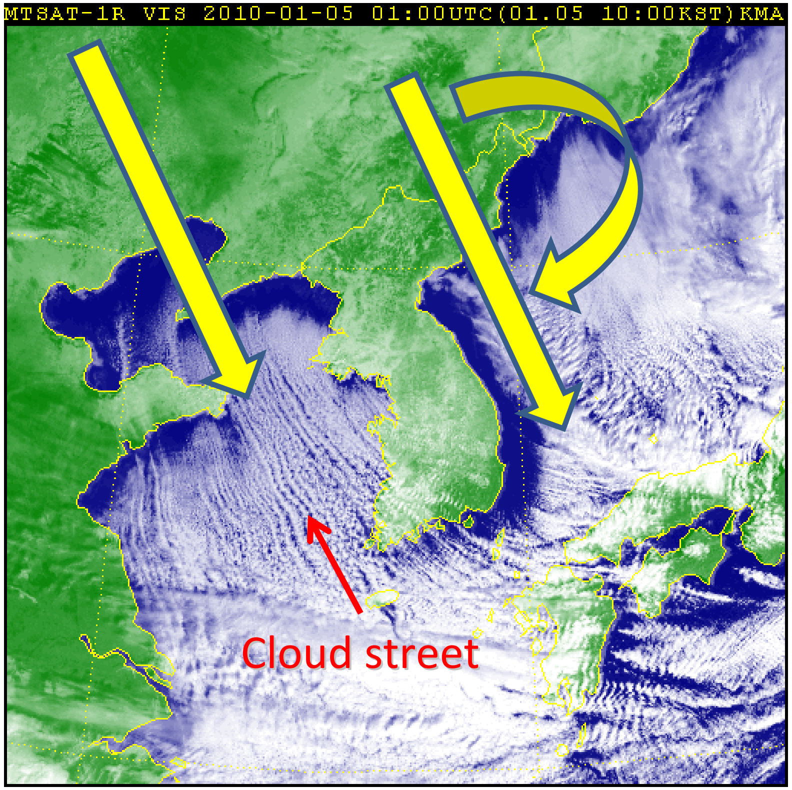
$$\frac{\partial w'}{\partial t} = -m^2 \left(u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} \right) - \dot{\sigma}\frac{\partial w}{\partial \sigma} - g \left[1 - \left(1 + \frac{T'}{\overline{\overline{T}}}\right)\left(1 + \frac{\partial Q'}{\partial \ln \sigma}\right) \right] + F_w - \frac{\partial w_b}{\partial t}$$

$$\dot{\sigma} = -\frac{g\sigma}{R\overline{\overline{T}}} w + \frac{\sigma}{R\overline{\overline{T}}} \left[\frac{\partial \overline{\phi}}{\partial t} + m^2 \left(u \frac{\partial \overline{\phi}}{\partial x} + v \frac{\partial \overline{\phi}}{\partial y} \right) \right]$$

$$\nabla_3 \cdot \mathrm{V} = m^2 \left[\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\sigma}{R\overline{\overline{T}}} \left(\frac{\partial u}{\partial \sigma}\frac{\partial \overline{\phi}}{\partial x} + \frac{\partial v}{\partial \sigma}\frac{\partial \overline{\phi}}{\partial y} \right) \right] - \frac{g\sigma}{R\overline{\overline{T}}} \frac{\partial w}{\partial \sigma}$$

Future plan

Lee wave is a “pure dynamics” phenomena
→ tested when the dynamic core is developed
→ check for RSM non-hydrostatic frame



Suggested cases

Test dynamical core + phenomena

1. development of the convection cell
   Lake effect snow storm over the East (West) sea of Korea

2. dynamically strong cyclogenesis
   cyclogenesis and it’s development in front of the Siberian High