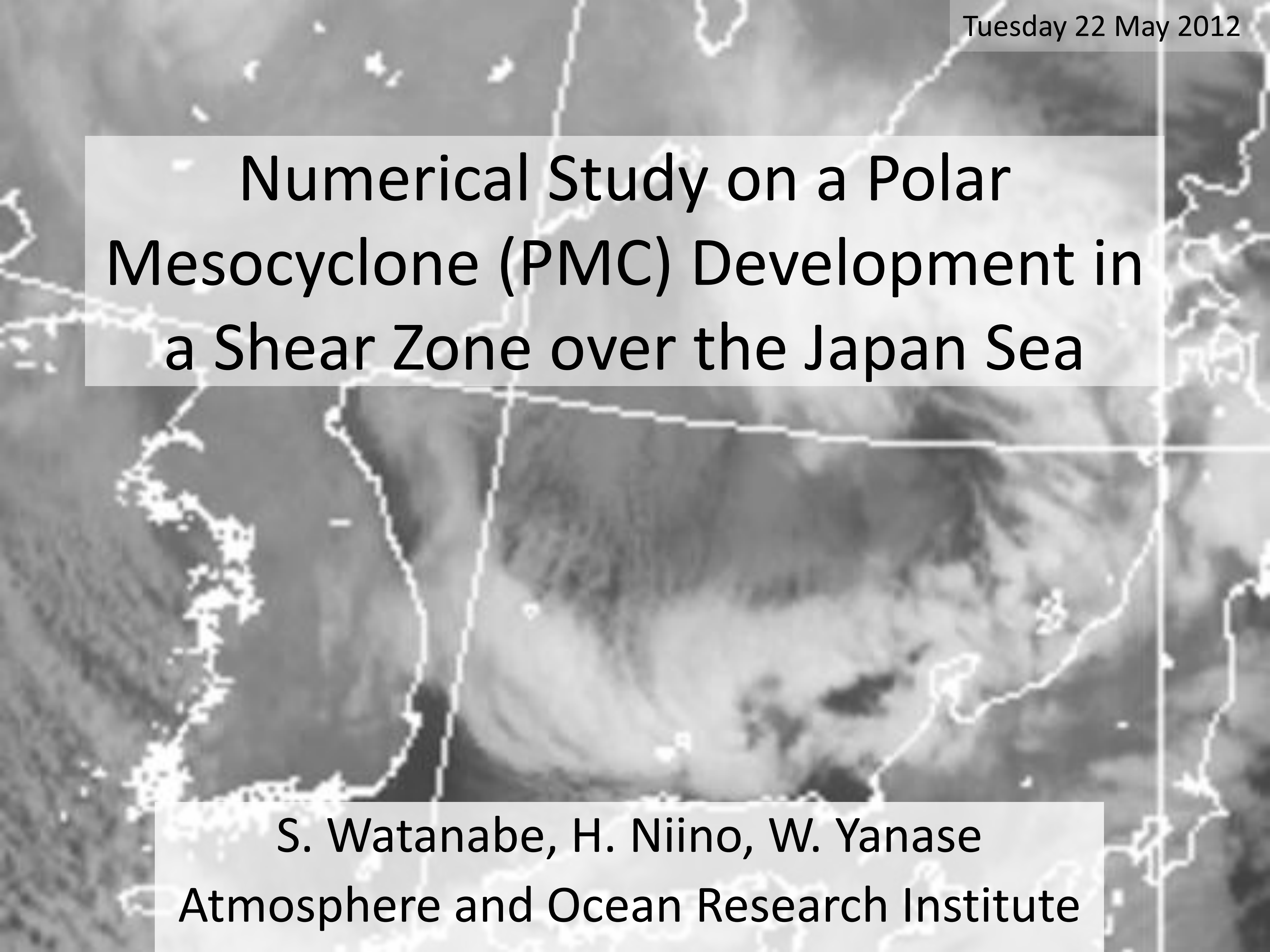
Tuesday 22 May 2012



Numerical Study on a Polar Mesocyclone (PMC) Development in a Shear Zone over the Japan Sea

S. Watanabe, H. Niino, W. Yanase
Atmosphere and Ocean Research Institute

Outline

1. Introduction
2. Overview of the observed PMC
3. Numerical Experiment
    1. Model description
    2. Result of the Simulation
    3. Structure and development of the PMC
4. Discussion
5. Summary and conclusion
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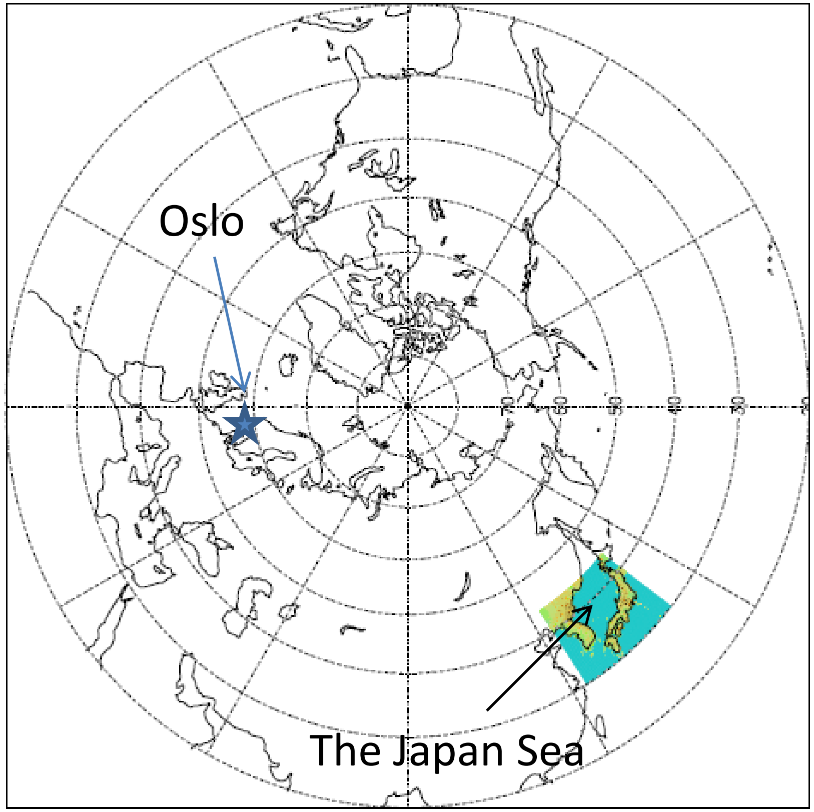
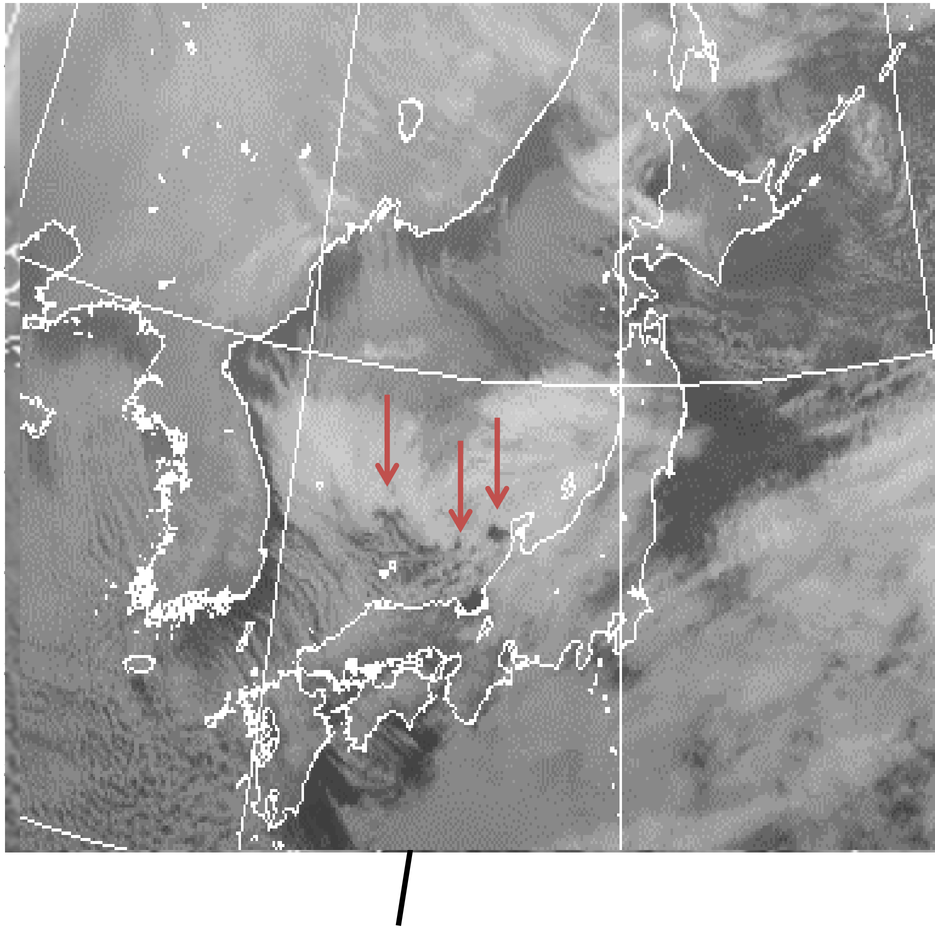
1. Introduction

- The Japan Sea is one of the regions where polar lows and polar mesocyclones are often observed. (Ninomiya 1988, Asai 1988)
- The Japan Sea is located at lower latitudes (35N~50N) compared with other regions of frequent polar low generation. (Ninomiya, 1988)



1. Introduction

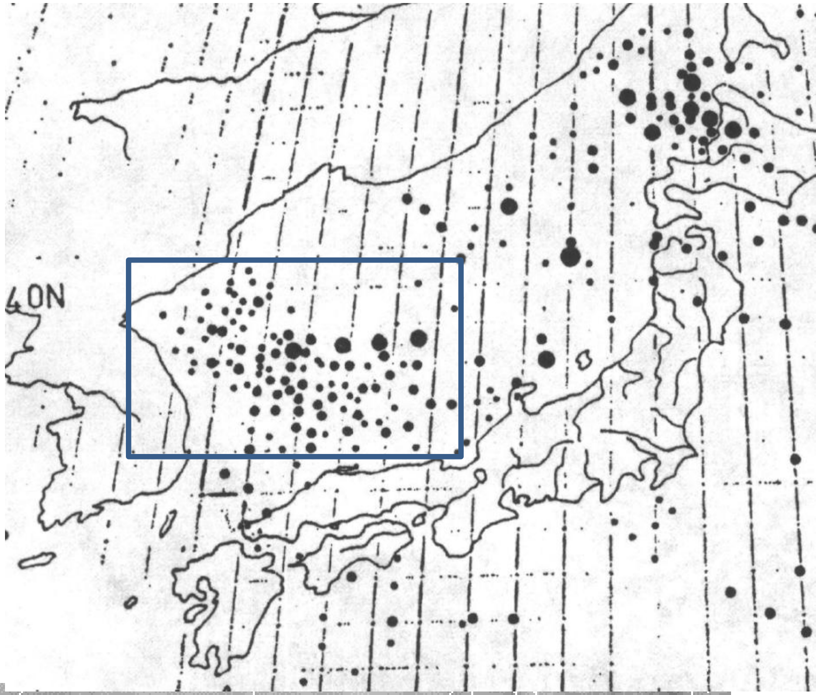
- Japan Sea Polar Airmass Convergence Zone (JPCZ)
- Convergence at lower layer
- Active cumulus convection
- Large horizontal shear
- Mechanisms of JPCZ (Nagata 1991)
  1. Mountains north of the Korea Peninsula
  2. The land-sea thermal contrast
  3. Large north-south SST gradient

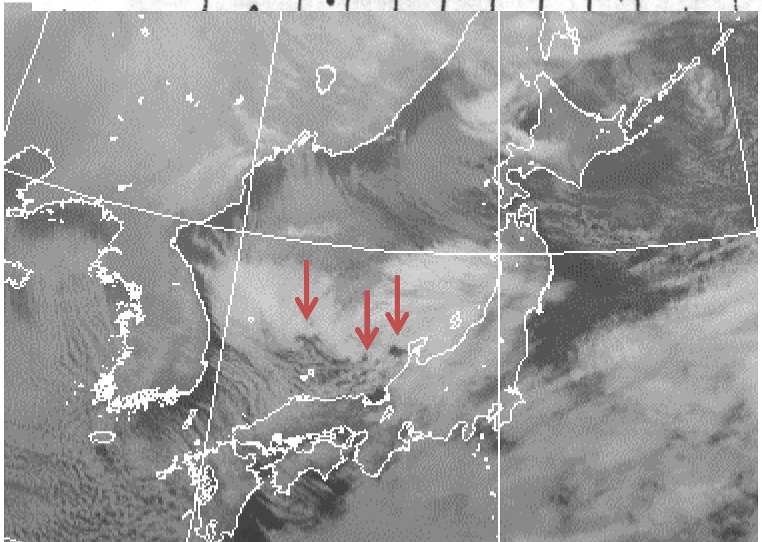


1.Introduction

- Many polar mesocyclones (PMCs) are observed in the vicinity of Japan Sea Polar Airmass Convergence Zone (JPCZ). (Asai 1988)
- Small scale (Meso-β-scale)
- Disaster to coastal region of the Japan Sea
  - Heavy snow fall
  - Gust

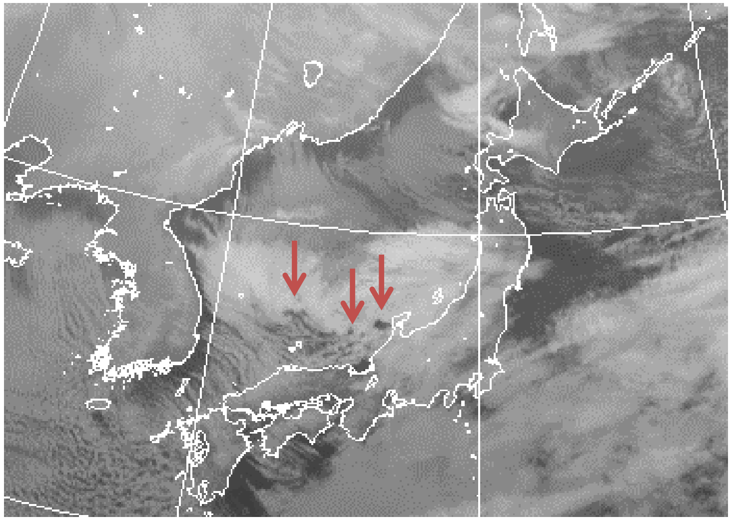
The location of PMC (from Asai 1988)





1. Introduction

- Mechanisms for development of PMCs
  - Barotropic instability
    （e.g. Nagata 1993）
  - Baroclinic instability
    （e.g.　Ninomiya et al　1990）
  - Latent heat release
    (e.g. Yanase et al 2004)



The early stage of development of PMCs during the formation stage of JPCZ has not studied in detail yet.
There are few researches on these vortices with non-hydrostatic model.

Purpose: To clarify the mechanisms of the development of PMCs

Method: The simulation using non-hydrostatic cloud-resolving model

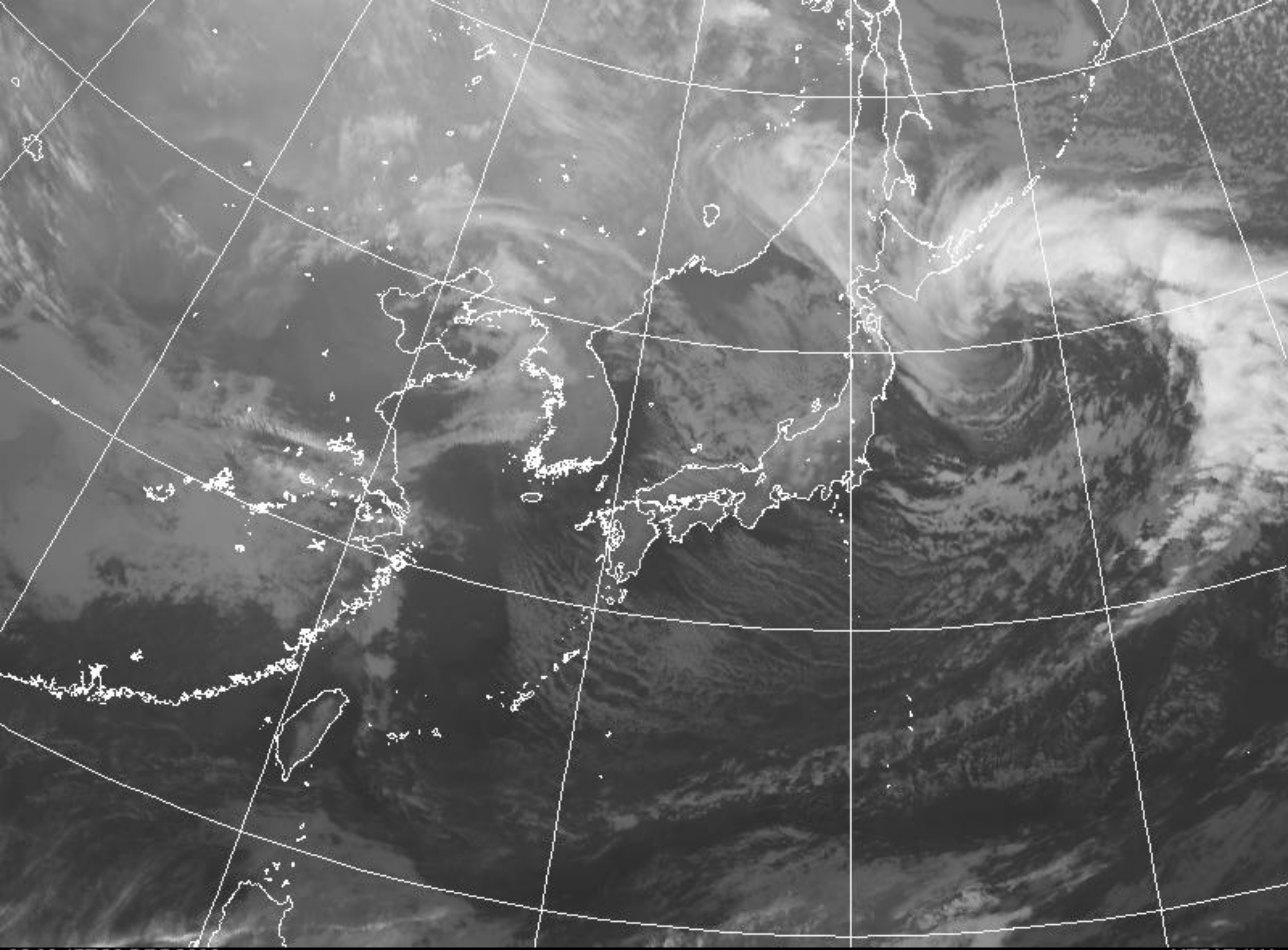
2. Overview of the observed PMC

On 30 Dec. 2010, a PMC observed over the Japan Sea

Daily snowfall Yonago: 79cm Daisen: 120cm record high!

Cars were stacked due to heavy snow.

Fish boats were overturned by heavy snow

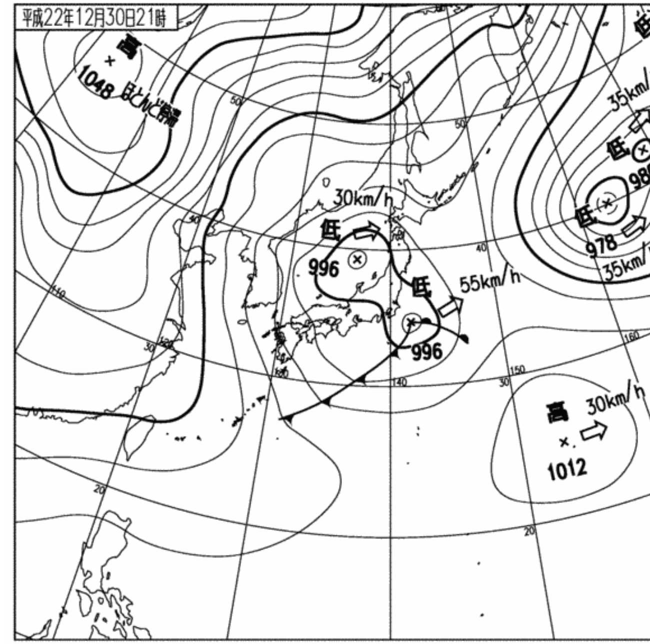


18:00 JST 29 DEC 2010 MTSAT JMA

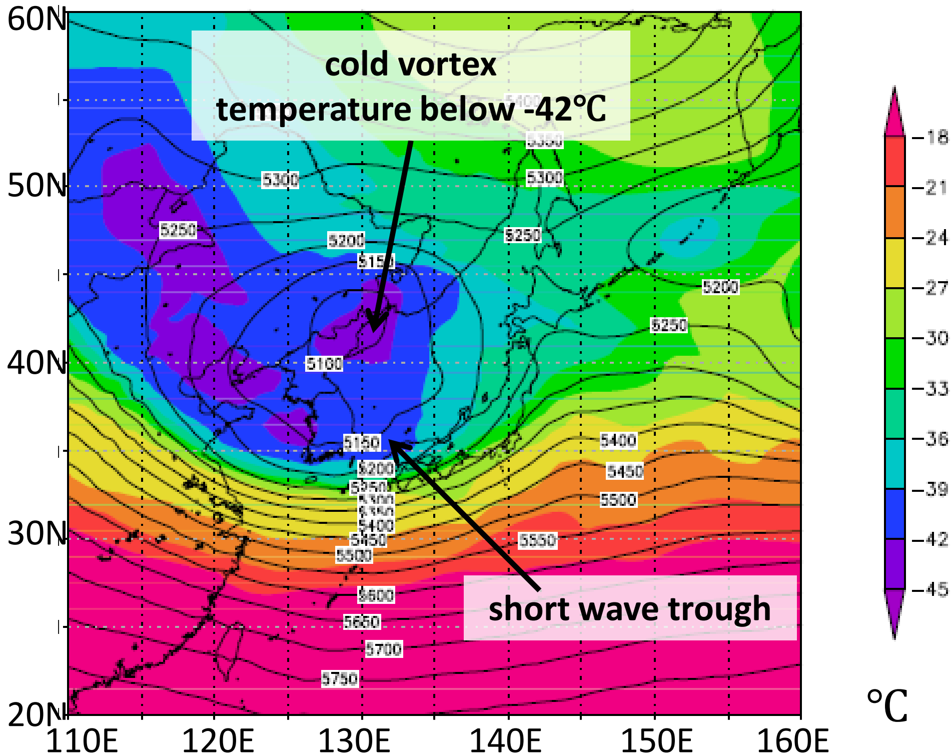
Synoptic situation（30/12UTC）

Surface・・・large scale low at the Pacific coast
500hPa・・・cold vortex and short wave trough
850hPa・・・cold advection behind the low

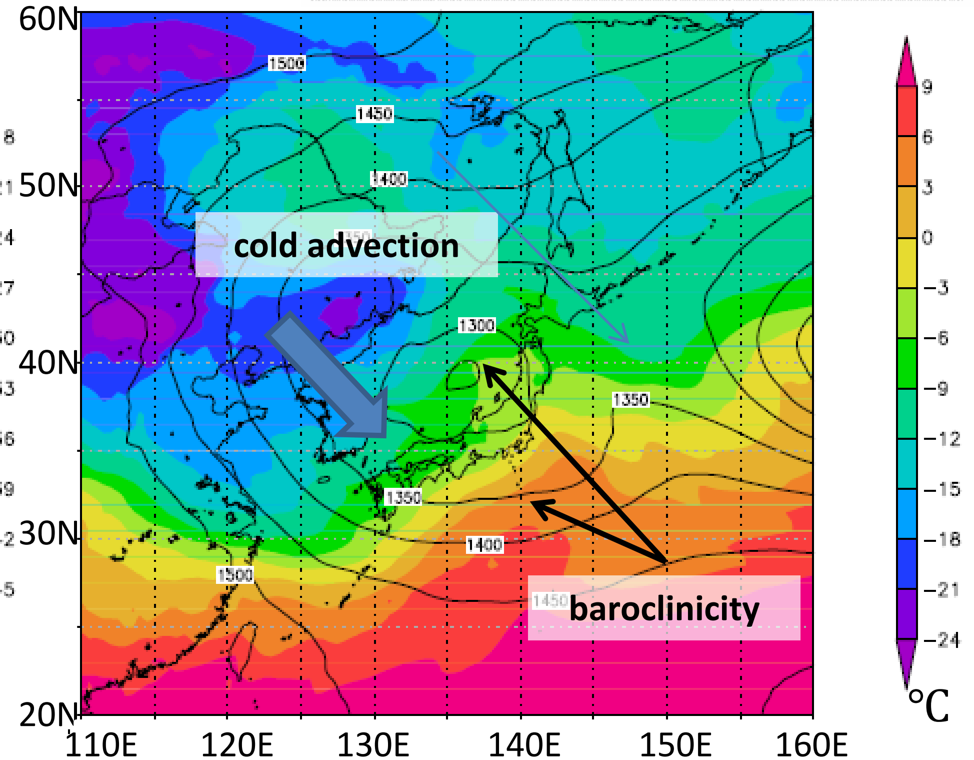
surface



500hPa 12Z30DEC2010



850hPa

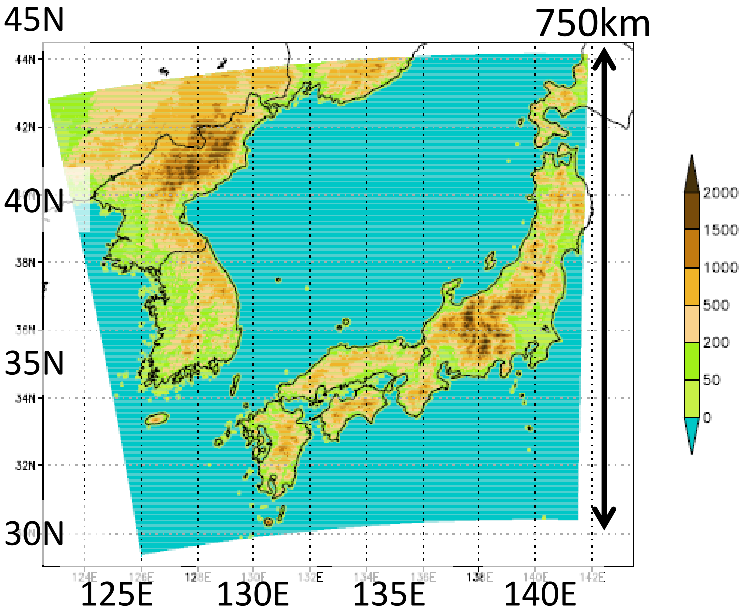


by JMA GSM

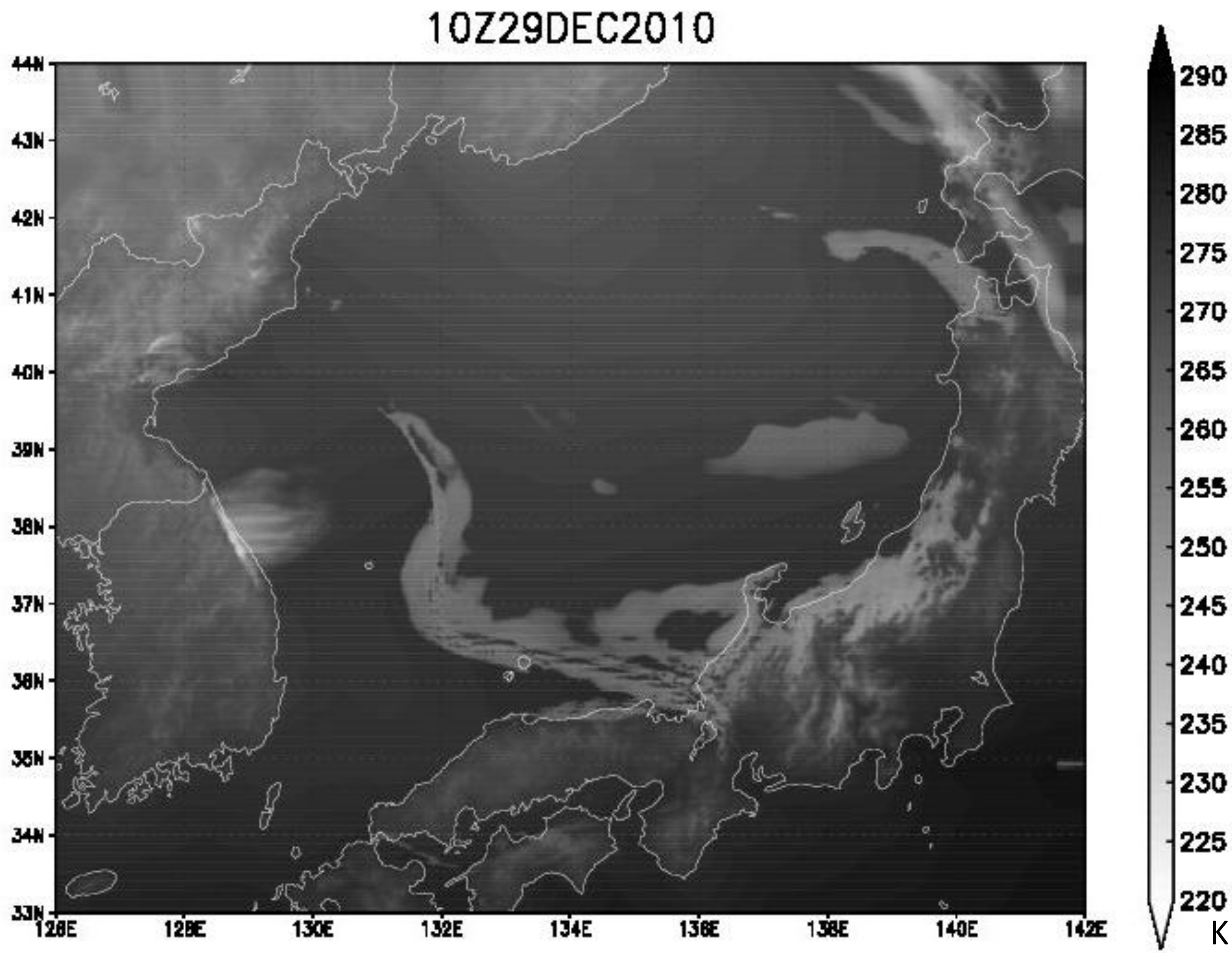
3. Numerical Experiment

3. 1. Model description

Model	JMA-NHM
Initial data Boundary data	Meso-scale Model of JMA
Horizontal domain Vertical domain	Map on the right (1500km × 1500km) 20m~15.64km
Horizontal resolution Vertical resolution	2km 40m~823m（stretched)
Initial time	09UTC 29 December 2010
Forecast time	48hours
Precipitation scheme	1-moment bulk scheme (qc,qr,qci,qs,qg)
Cumulus parameterization	No use
Turbulent closure	MYNN（Level3）



3.2 Result



10Z29DEC2010
44N
43N
42N
41N
40N
39N
38N
37N
36N
35N
34N
33N
126E
128E
130E
132E
134E
136E
138E
140E
142E
290
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275
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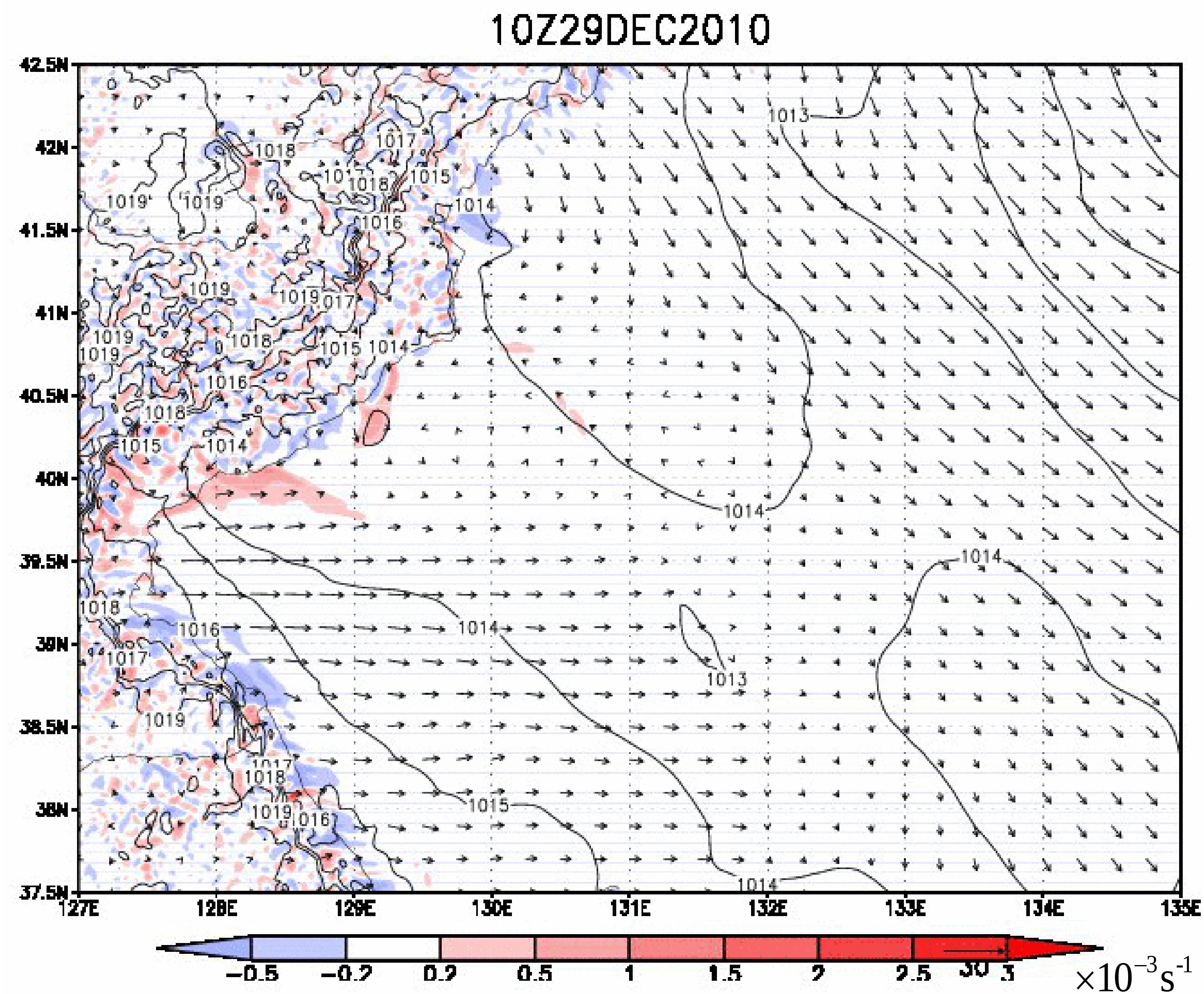
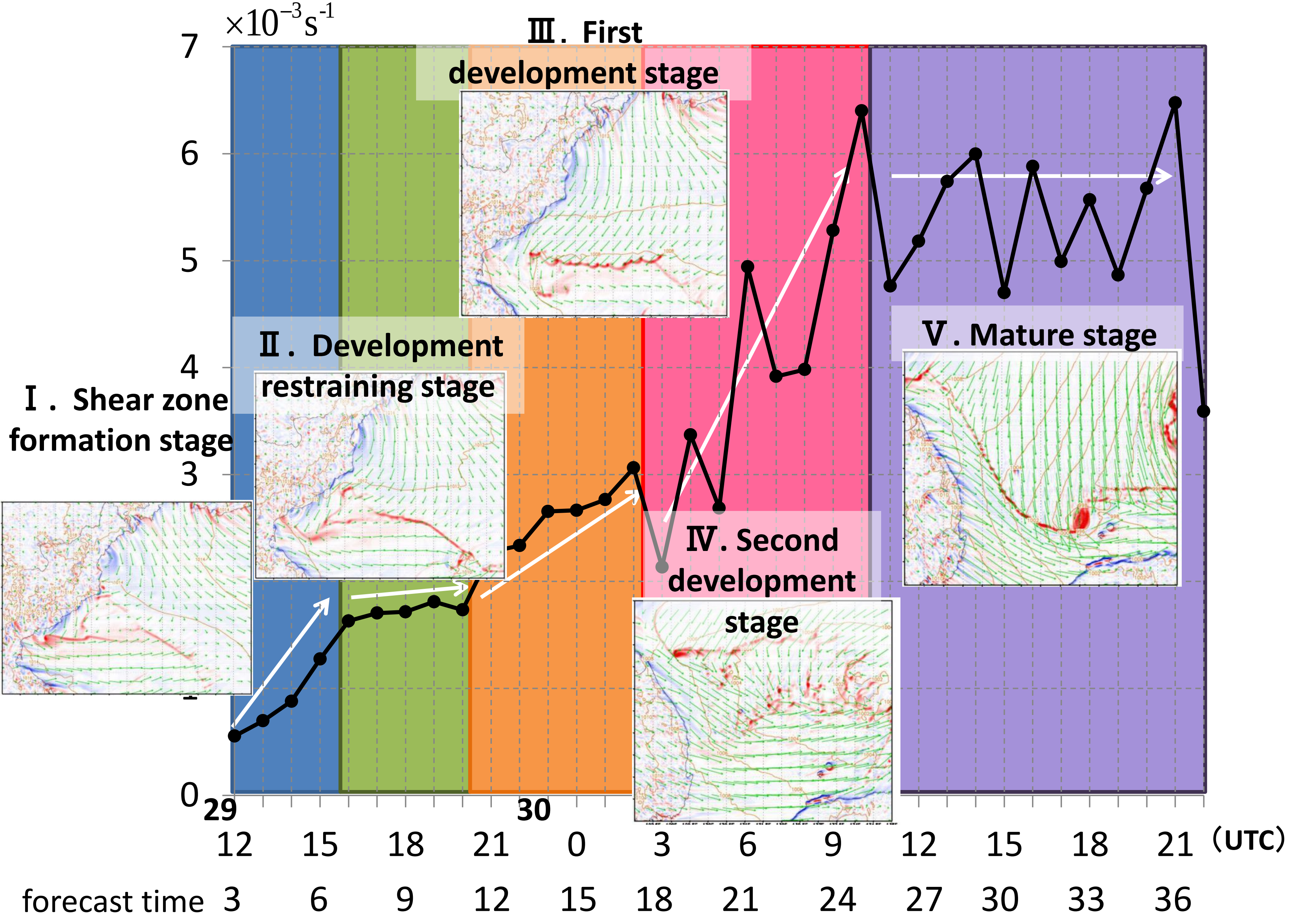
220
K

３．３．Structure and development of the PMC

Vorticity@z=20m



Max Vorticity@z=20m



3. 3. Structure and development of the Polar mesocyclone

Ⅰ. Shear Zone formation stage（29/12UTC~16UTC）

Ⅱ. Development restraining stage（29/16UTC~20UTC）

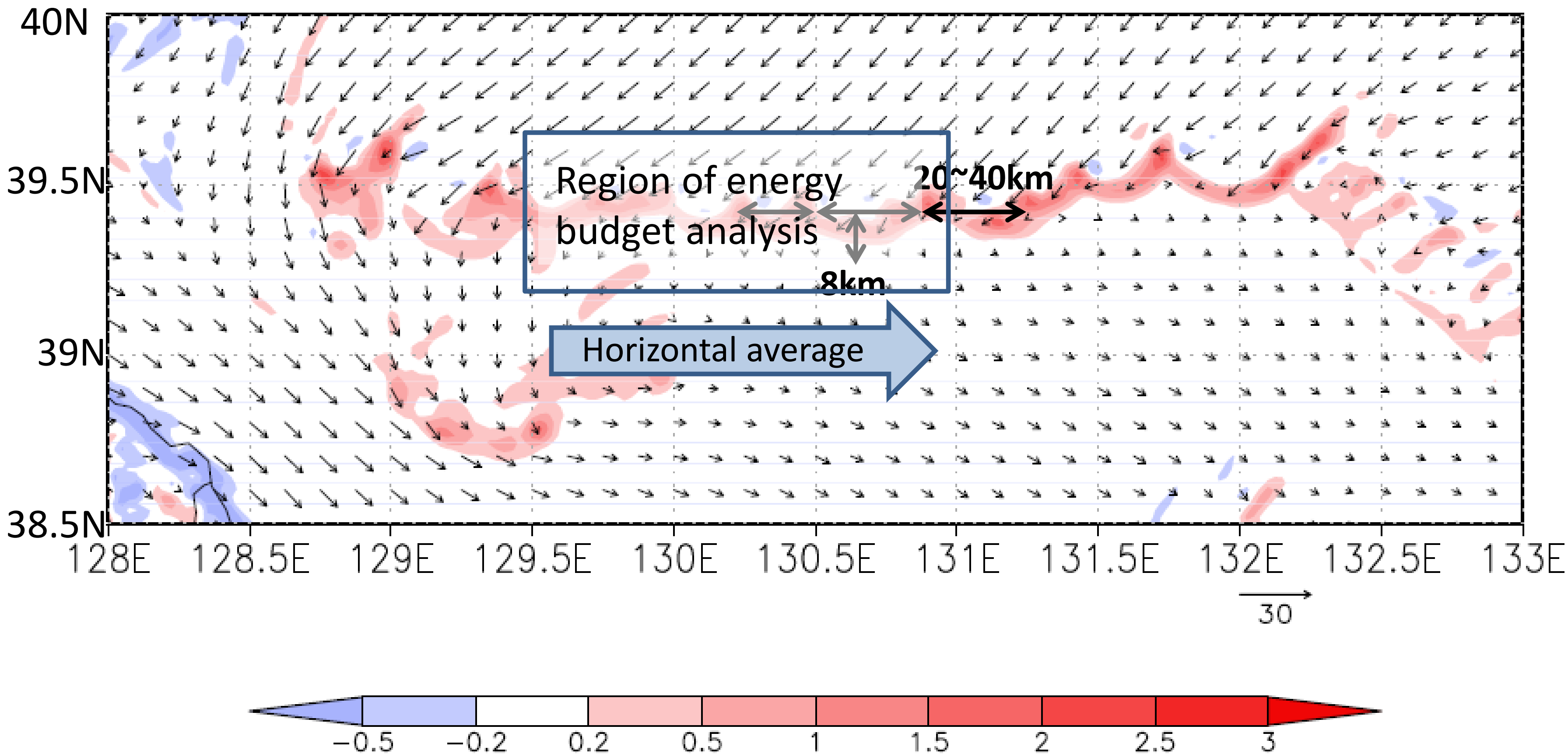
Ⅲ. First development stage（29/20UTC~30/02UTC）

Ⅳ. Second development stage（30/02UTC~10UTC）

Ⅴ. Mature stage（30/10UTC~21UTC）

Ⅲ. First development stage（30/00UTC）

Vorticity @z=20m



The width of shear zone is about 8km. → Expected wavelength is 64km

Barotropic instability theory

The spacing between vortices is 20~40km

Ⅲ. First development stage（30/00UTC）

Energetics of vortices

$$\frac{\partial \overline{K_e}}{\partial t} = -\left(\overline{v}\frac{\partial \overline{K_e}}{\partial y} + \overline{w}\frac{\partial \overline{K_e}}{\partial z} \right)$$ advection $\quad \overline{K_e} = \frac{\overline{u'^2 + v'^2 + w'^2}}{2}$

$$-\left(\overline{u'v'}\frac{\partial \overline{u}}{\partial y} + \overline{v'v'}\frac{\partial \overline{v}}{\partial y} + \overline{w'v'}\frac{\partial \overline{w}}{\partial y} \right)$$ horizontal shear production (HSP)

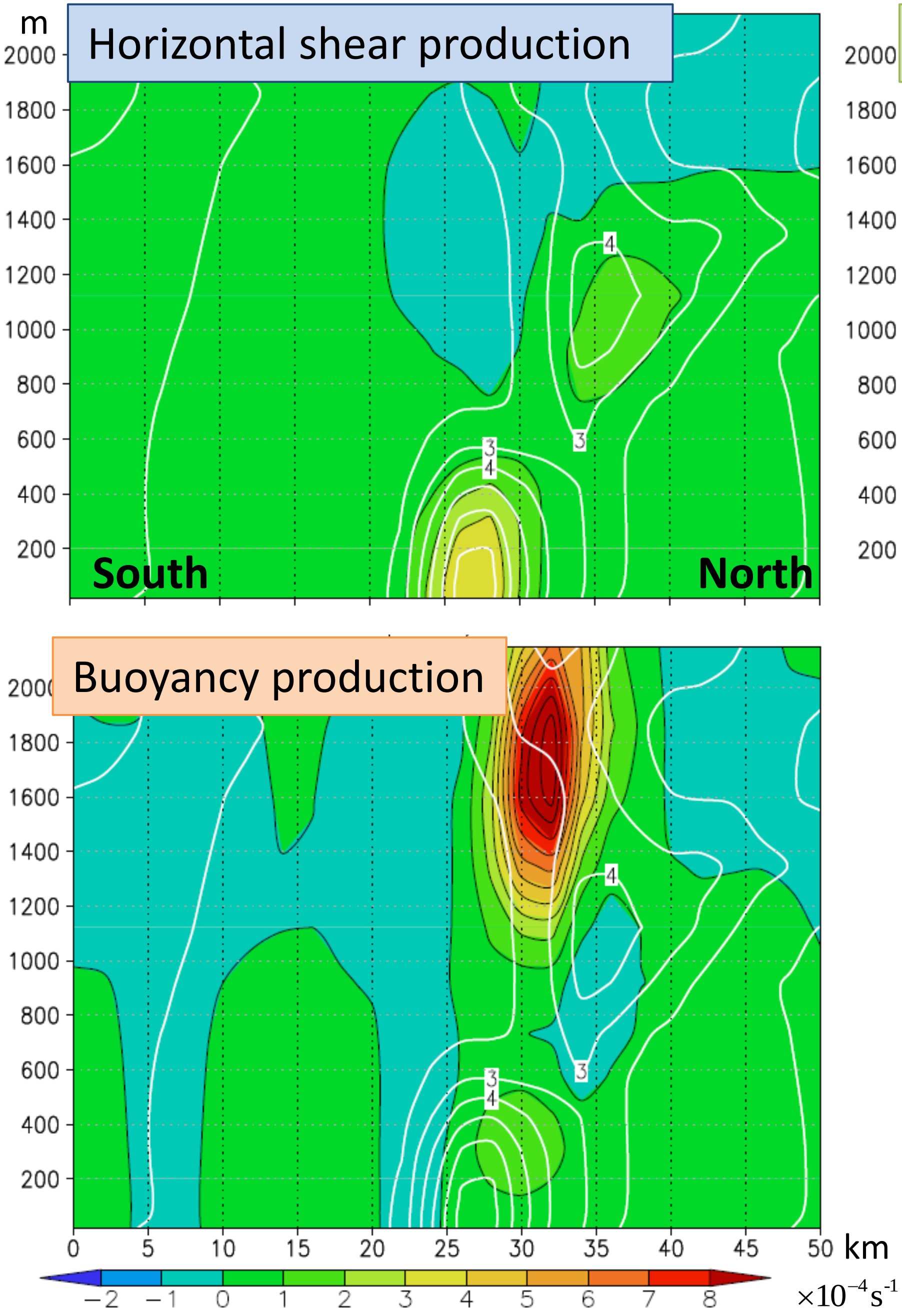
$$-\left(\overline{u'w'}\frac{\partial \overline{u}}{\partial z} + \overline{v'w'}\frac{\partial \overline{v}}{\partial z} + \overline{w'w'}\frac{\partial \overline{w}}{\partial z} \right)$$ vertical shear production (VSP)

$$-\left(\overline{u'\frac{\partial K_e}{\partial x}} + \overline{v'\frac{\partial K_e}{\partial y}} + \overline{w'\frac{\partial K_e}{\partial z}} \right)$$ eddy transport

$$-C_p\Theta\left(\frac{\partial \overline{(u'\pi')}}{\partial x} + \frac{\partial \overline{(v'\pi')}}{\partial y} + \frac{\partial \overline{(w'\pi')}}{\partial z} \right)$$ pressure transport

$$+\overline{B'w'}$$ buoyancy production (BP)

Energetics of vortices



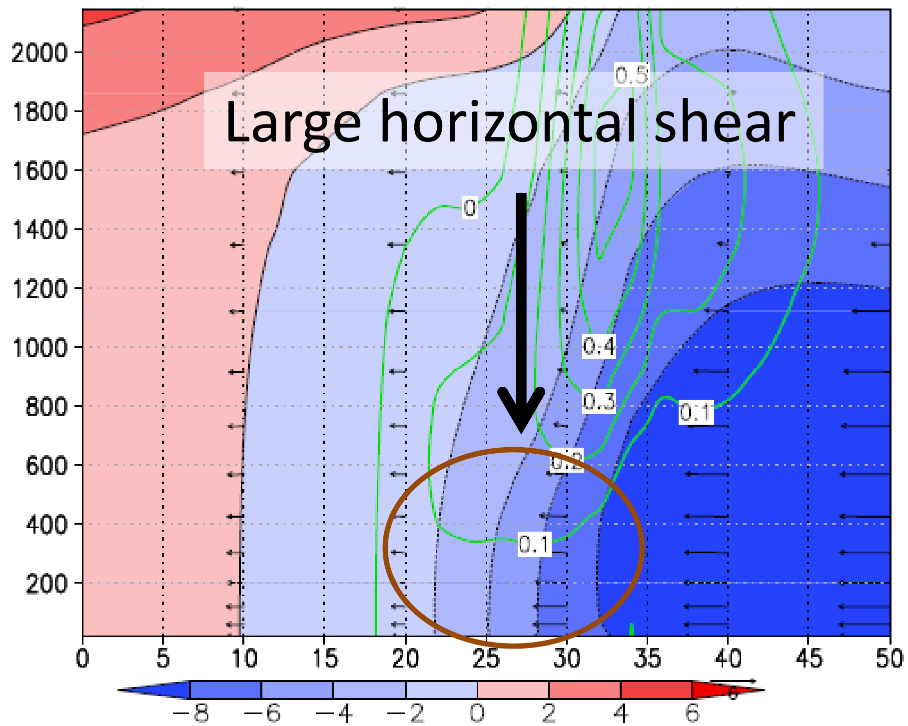
color: production terms normalized by Ke
contour: Ke($m^2 s^{-2}$)

- Eddy kinetic energy is large below 600m
- HSP term is also large below 600m
- VSP term is small and negative around 500m
- BP term is extremely large around 1700m.

Ⅲ. First development stage（30/00UTC）

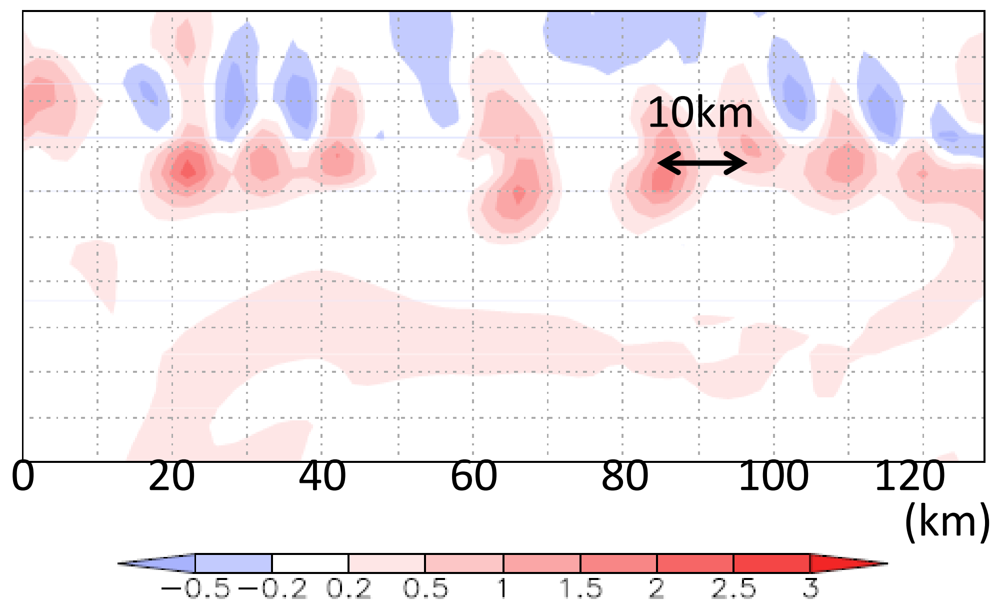
Energetics of vortices

zonal averaged wind



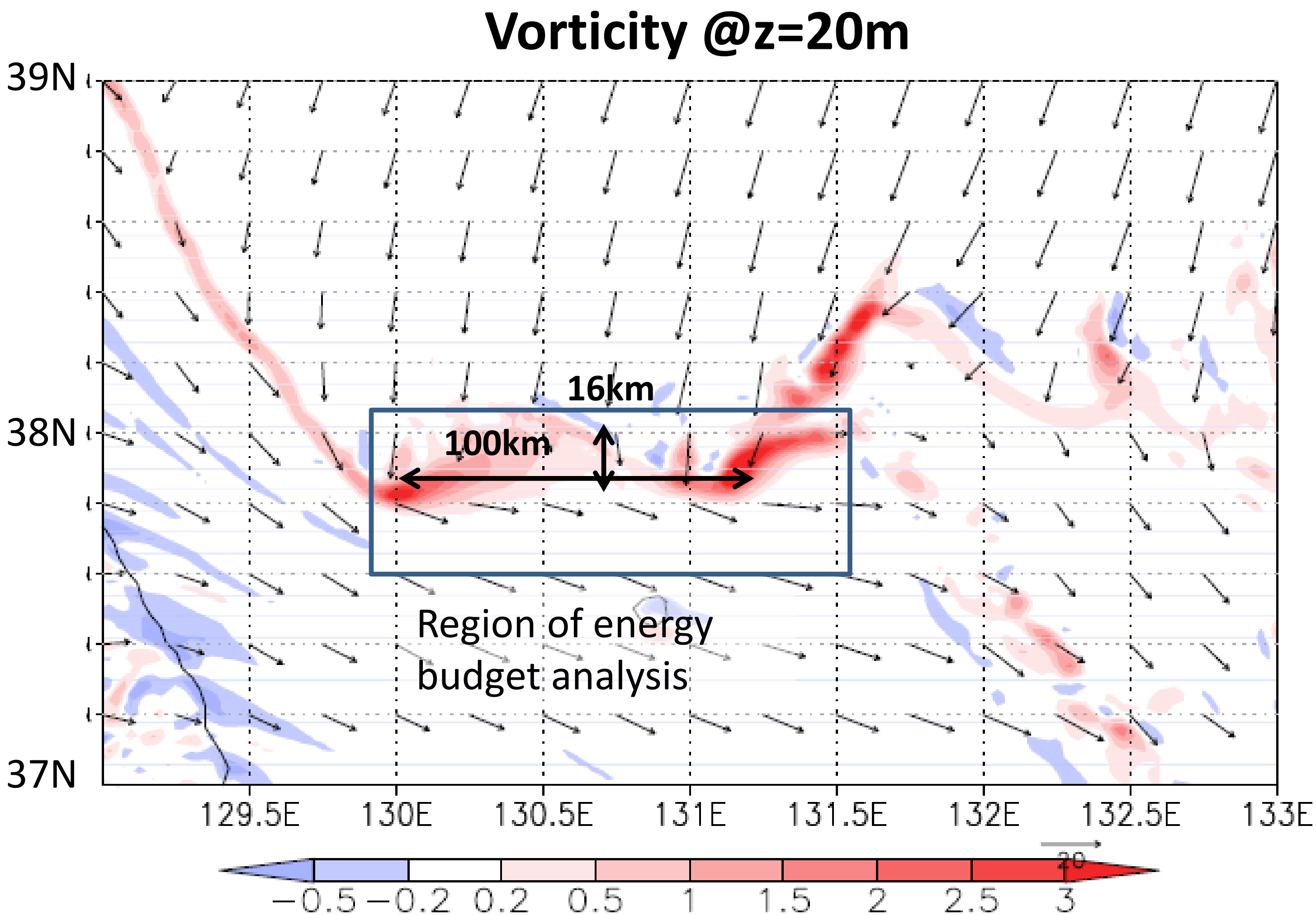
color: wind perpendicular to panel
contour: vertical wind

Vorticity @z=1593m



- Below 600m the vortices are acquiring energy through barotropic instability
- Above 1000m convective scale vortices are dominant

Ⅳ. Second development stage（30/02UTC~10UTC）

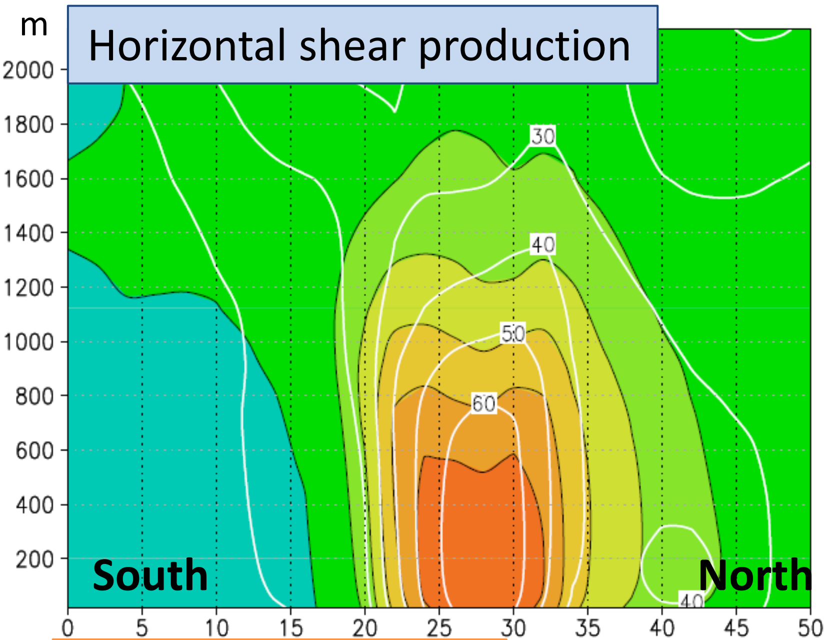


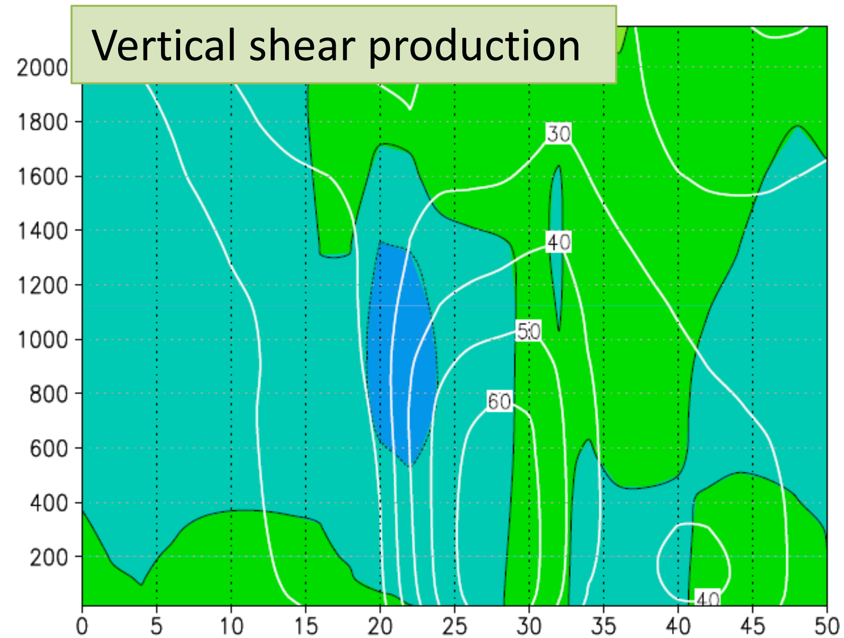
The width of shear zone is about 16km → Expected wavelength is 128km

The spacing between vortices is about 100km

Ⅳ. Second development stage（30/02UTC~10UTC）

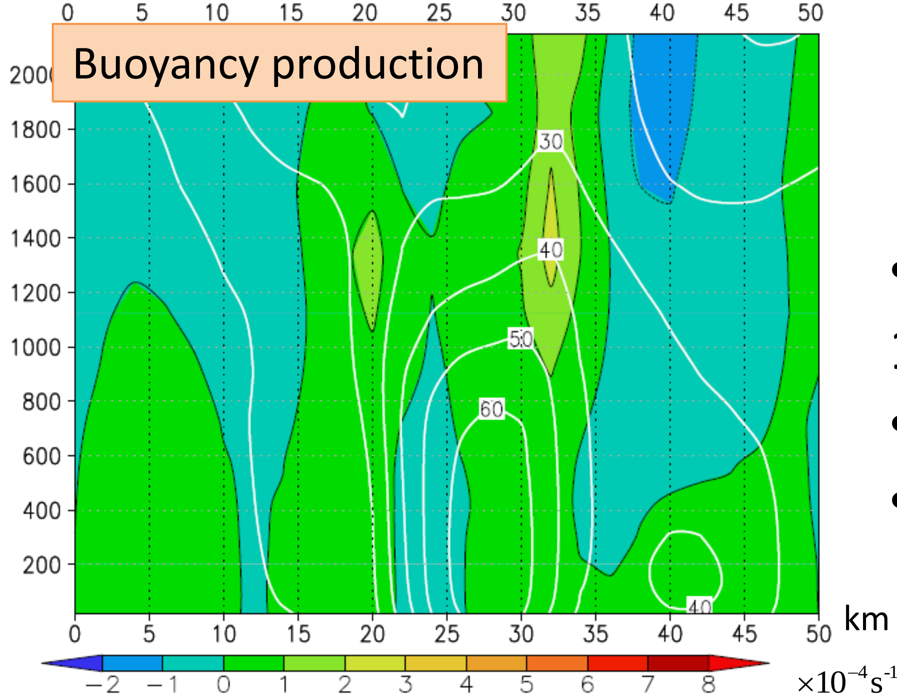
Energetics of vortices





color: production terms normalized by Ke

contour: Ke (m^2s^{-2})

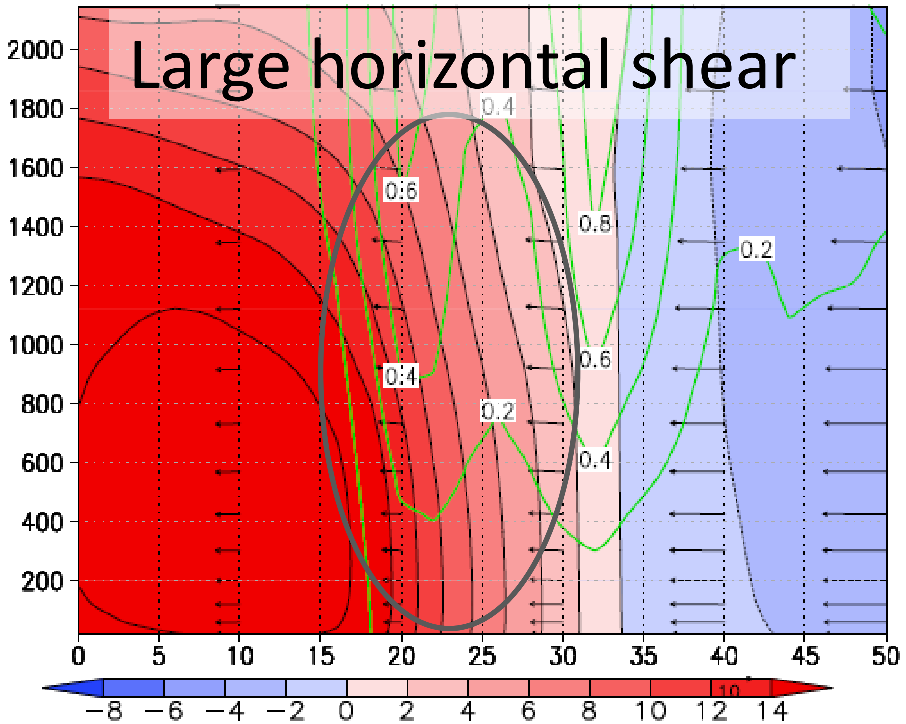


- Eddy kinetic energy is large below 1600m
- HSP term is also large below 1600m
- VSP and BP is relatively small

Ⅳ. Second development stage（30/02UTC~10UTC）

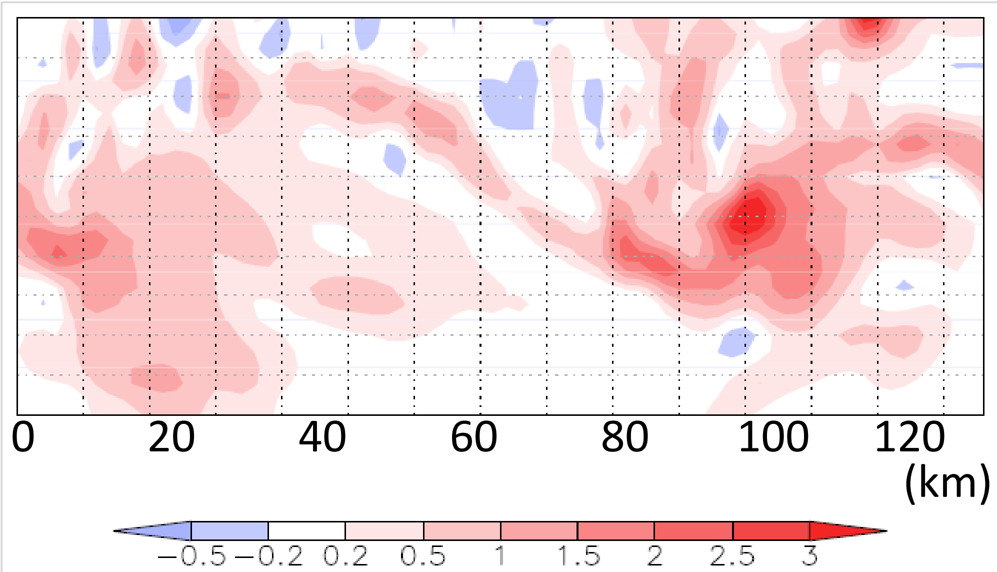
Energetics of vortices

zonal averaged wind



color: zonal wind
contour: vertical wind

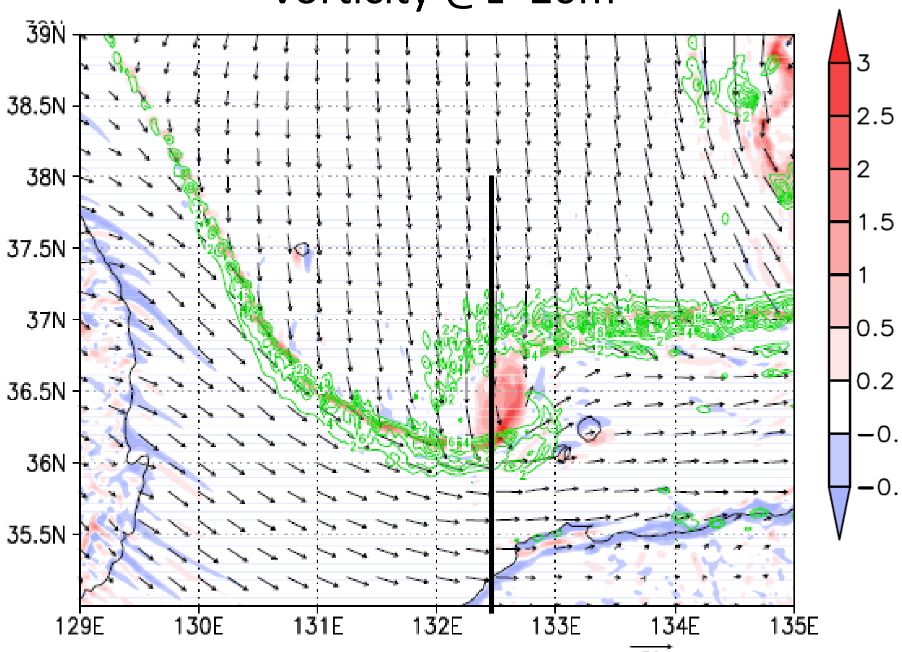
Vorticity @z=1593m



- Large horizontal shear exists below 1600m
- Airmass-transformation
- The vortices are acquiring energy through barotropic instability

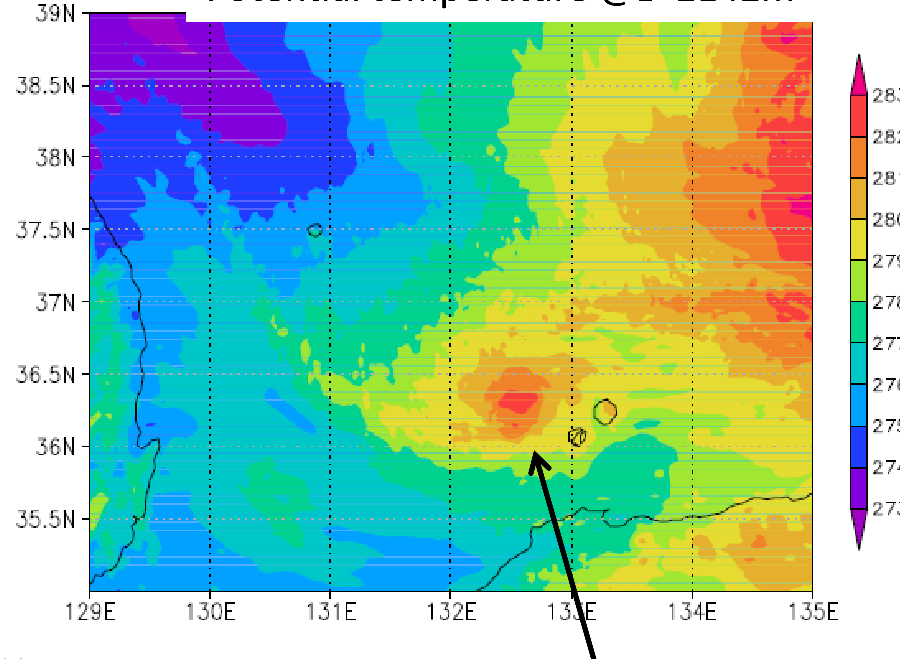
Ⅴ. Mature stage（30/10UTC~21UTC）

Vorticity @z=20m



Color: Vorticity, Contour: Vertical integrated water substance

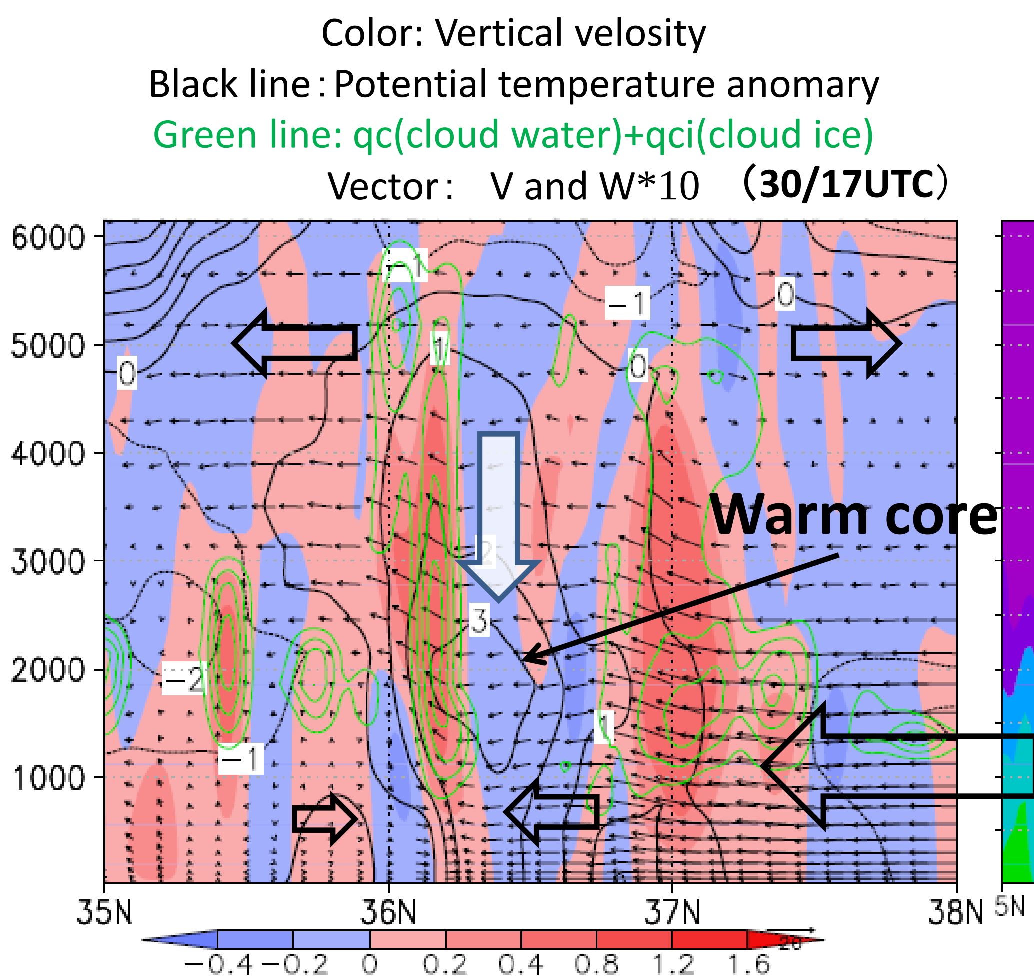
Potential temperature @z=2142m

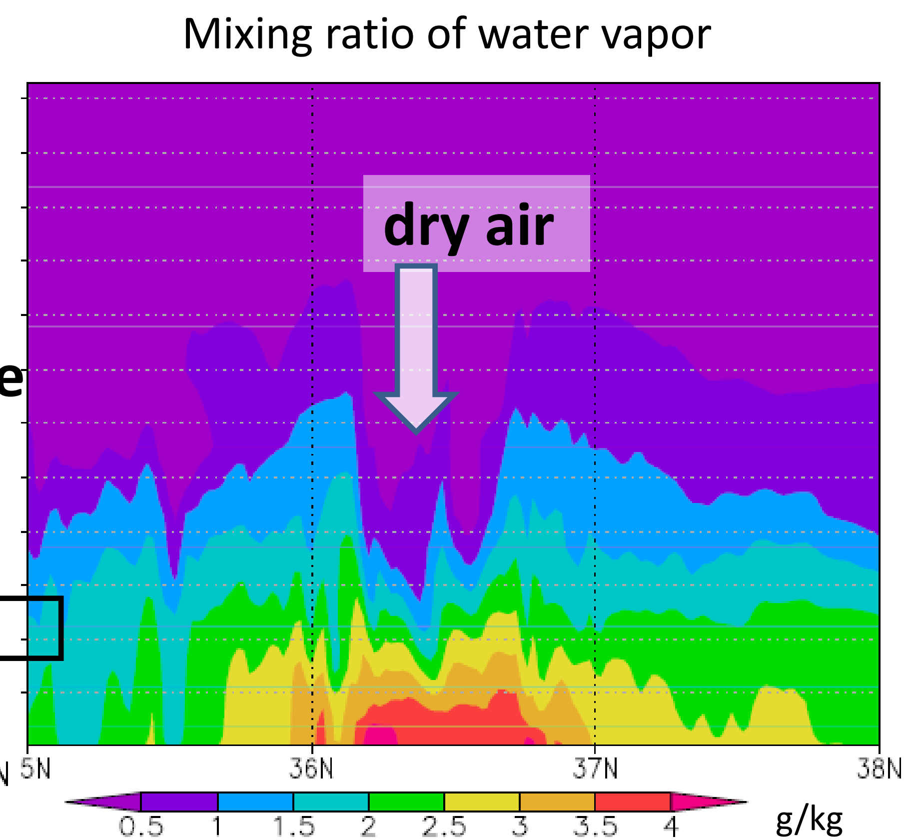


Warm core（3K）

- •Horizontal scale: 100km
- •Nealy axisymmetric
- •Cloud-free eye
- •Warm core (about 3K)

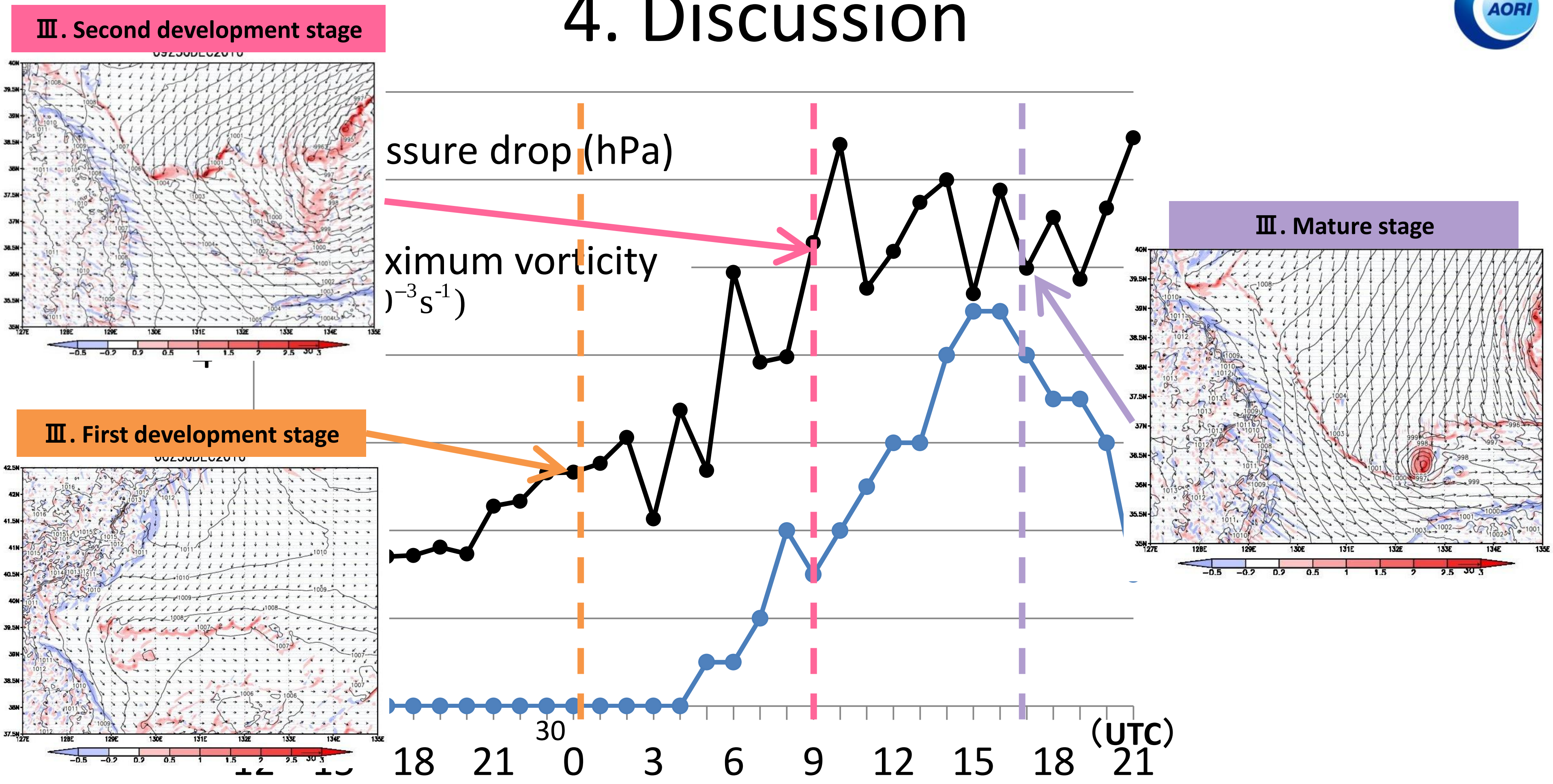
Ⅴ. Mature stage（30/10UTC~21UTC）





- Down draft in the center of the cyclone
- Cloud-free eye is caused by descending dry air
- Warm core is formed by adiabatic heating

4. Discussion



• Surface pressure drop is related to the warm core.

Barotropic instability wave
→ Hurricane like PMC

5. Summary and Conclusion

- A polar mesocyclone(PMC) observed over the Japan Sea was studied by a numerical simulation using a non-hydrostatic model.
- The simulation reproduces quite well the movement and development of the PMC.
- Energy budget analysis indicates that the PMC developed through barotropic instability in its early stage.
- Warm core and cloud-free eye structure is formed at the mature stage of PMC.
- Large amount of latent heat release exist in the eyewall of PMC at mature stage.

6. Future subjects

- What are the triggers of structural change of PMC?
- The effect of latent and sensitive heat flux from sea surface and heat of condensation.
  - When and how do they influence the development of PMCs ?
- Relation between PMCs and the formation of JPCZ
- The impact of cold vortex aloft
- This case is special or universal?