Numerical simulation of low-level misocyclones associated with winter convective cells over the Japan Sea area

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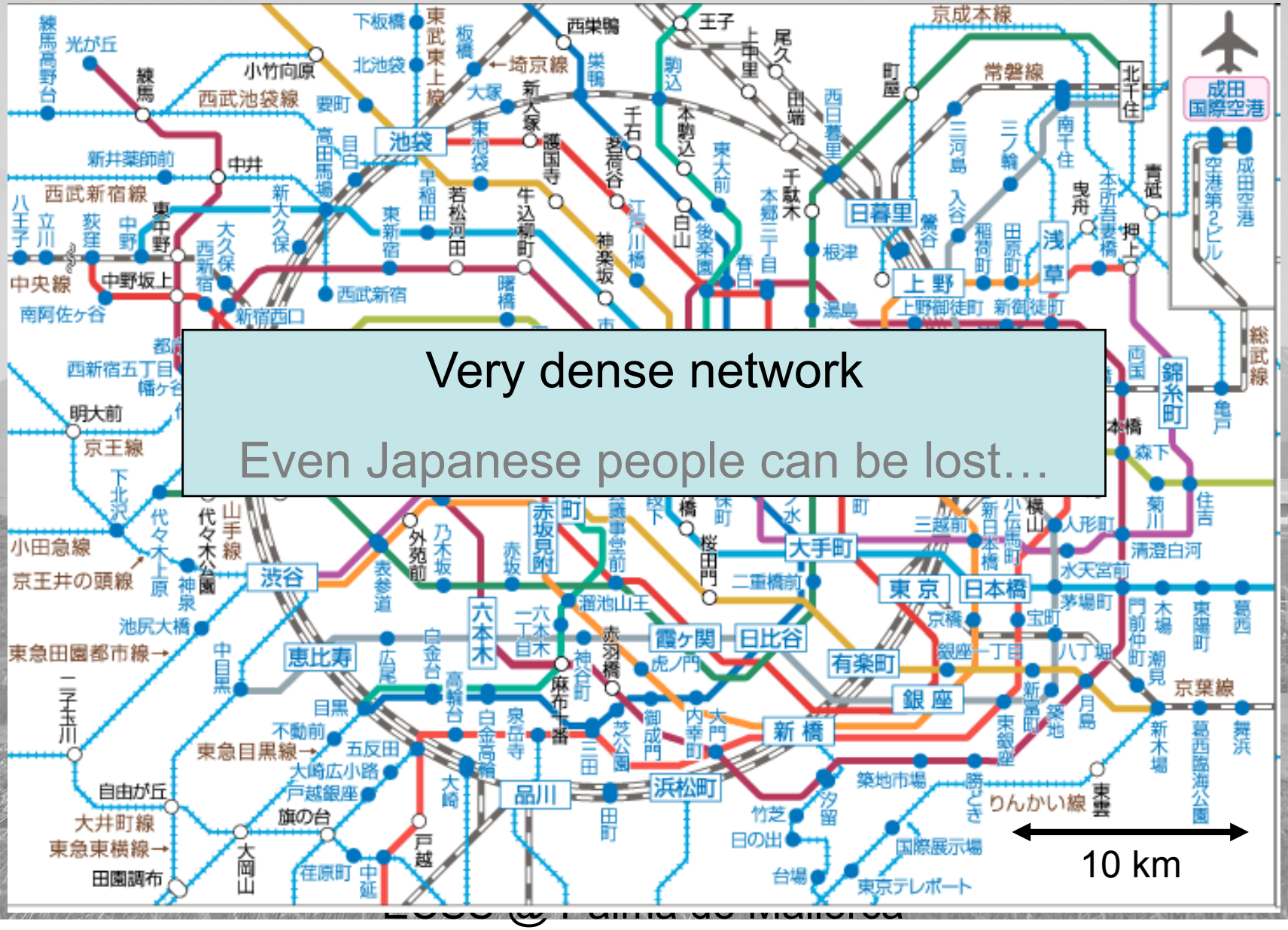
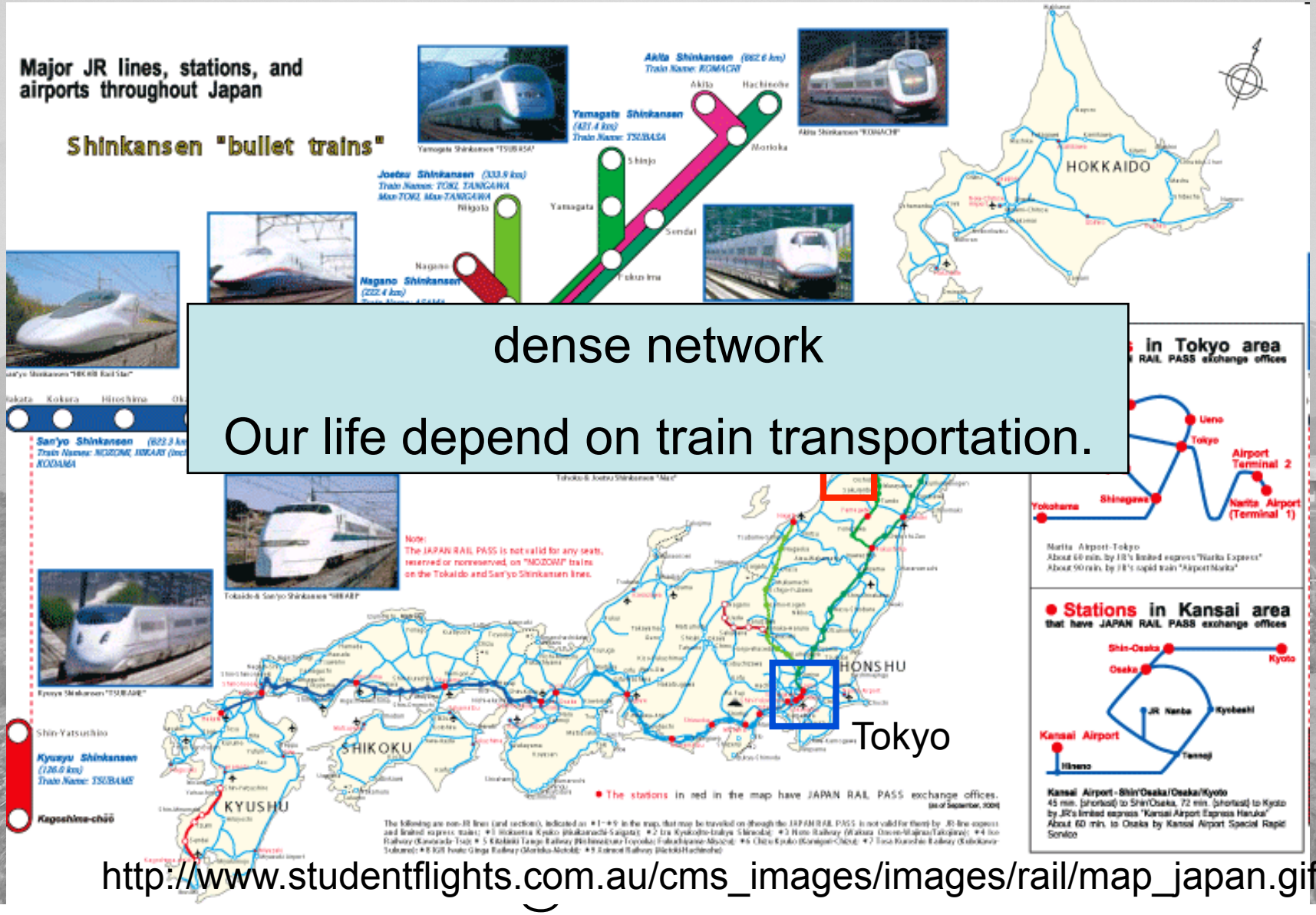
1: Alpha-denshi / MRI, 2: MRI, 3: JMA, 4: Railway Technical Research Institute, 5: East Japan Railway Company

Railroad Network around Tokyo



Railroad Network in Japan

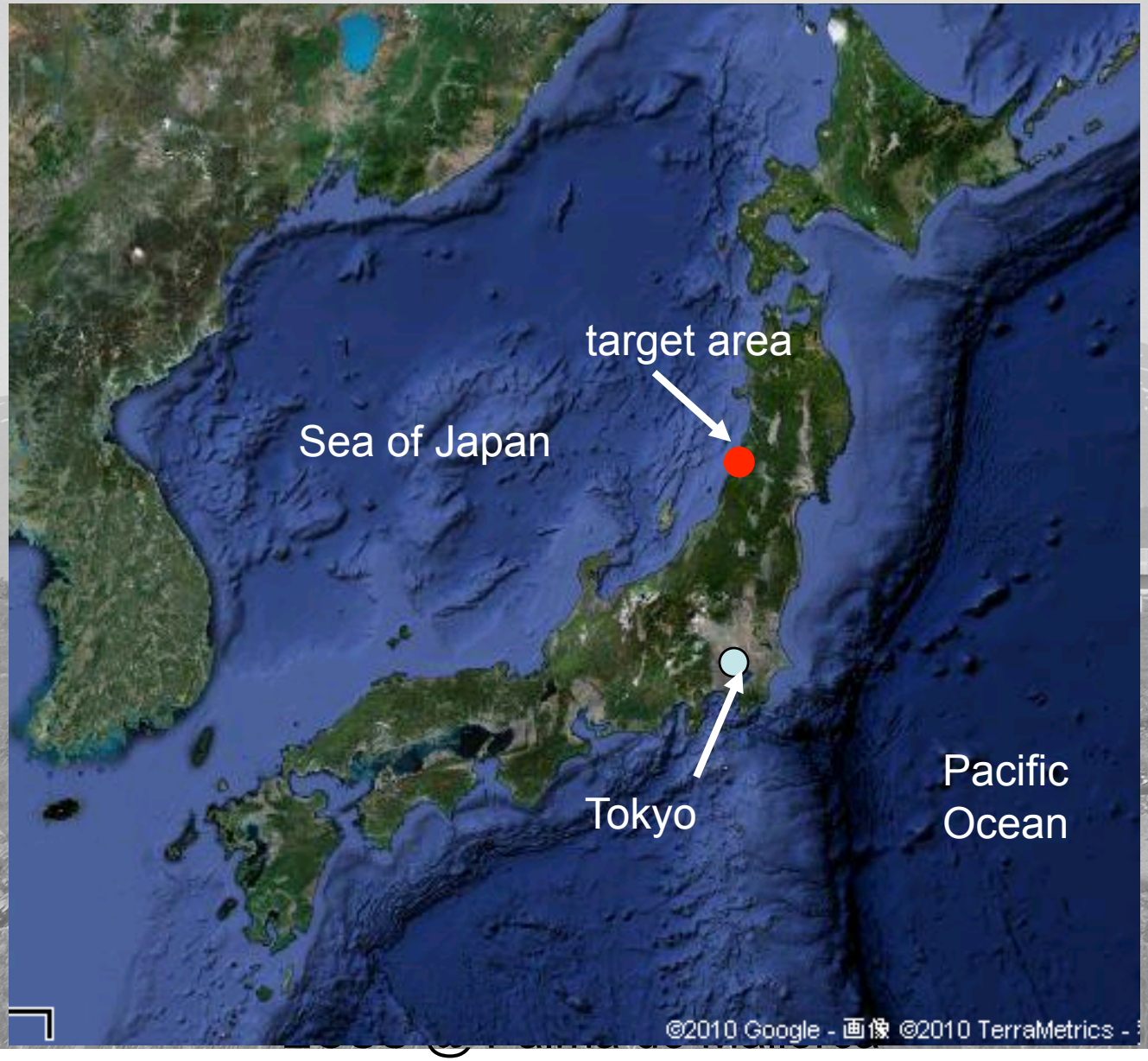


http://www.studentflights.com.au/cms_images/images/rail/map_japan.gif

Background of our project

- Strong and gusty winds sometimes affect the safety operation of trains and cause delay or shutdown of trains.
- Since anemometers discretely cover on the railroads, small-scale but strong gusty winds are difficult to detect with the present system.

Japan Sea area



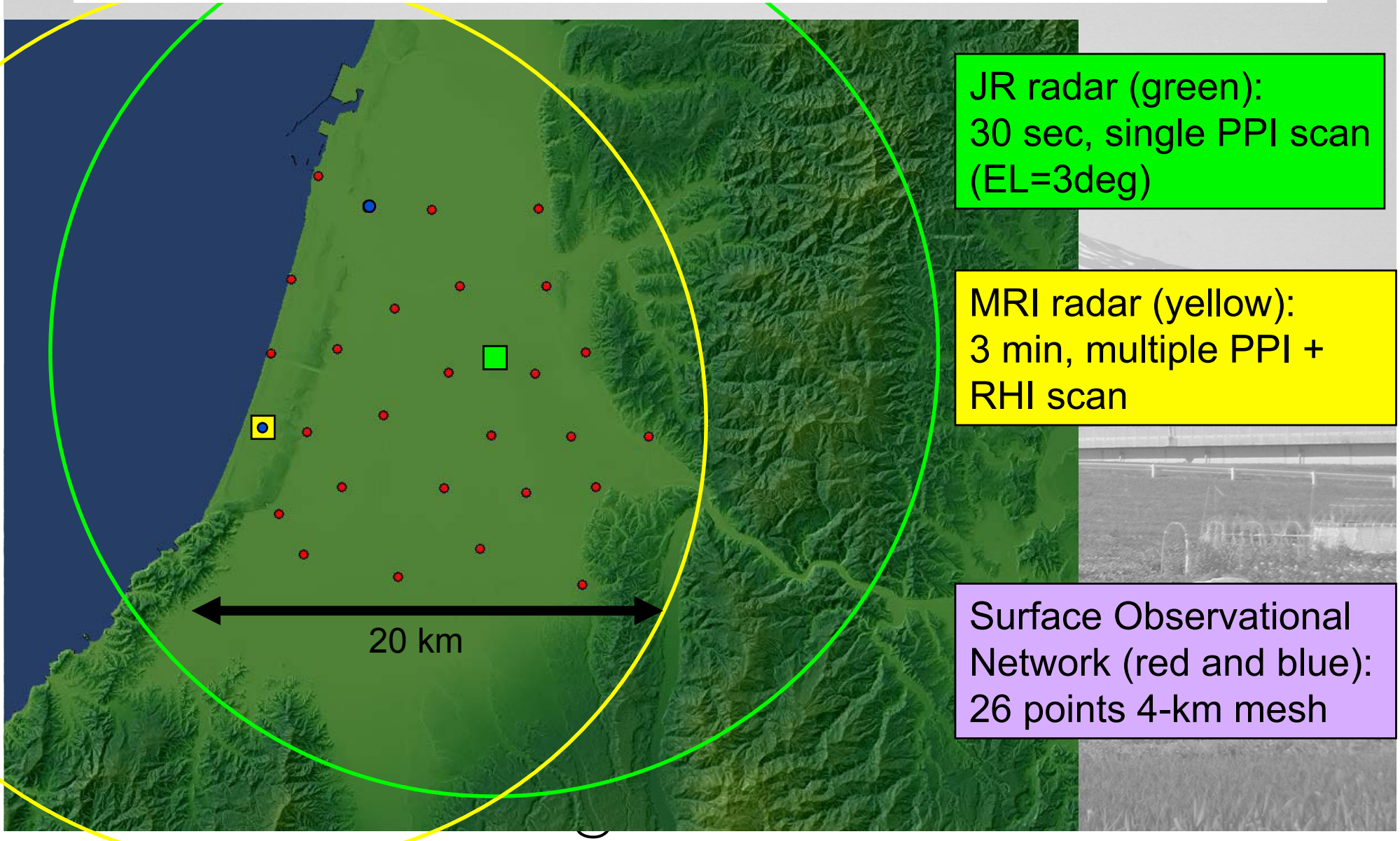
Background of the Japan Sea area

- On the coast of the Sea of Japan, significantly strong winds associated with the winter monsoon cold serge.
- Because of the cold serge from the continent (~ -5 - 10℃) and relatively warm SST (~ 15℃), the low-level atmosphere is unstable over the Sea of Japan.
- This situation can help to develop convective cells accompanied by gusts.

Shonai area railroad weather project

- Final Goal
  - Development of an automatic strong gust detection system for railroad
    - Decision to warn is generally based upon information from a single-Doppler radar
- Ongoing
  - Investigation of the fine-scale structure of winter wind gust dynamics and kinetics around the Shonai area

Overview of the field experiment



JR radar (green):
30 sec, single PPI scan
(EL=3deg)

MRI radar (yellow):
3 min, multiple PPI +
RHI scan

Surface Observational
Network (red and blue):
26 points 4-km mesh

Findings so far

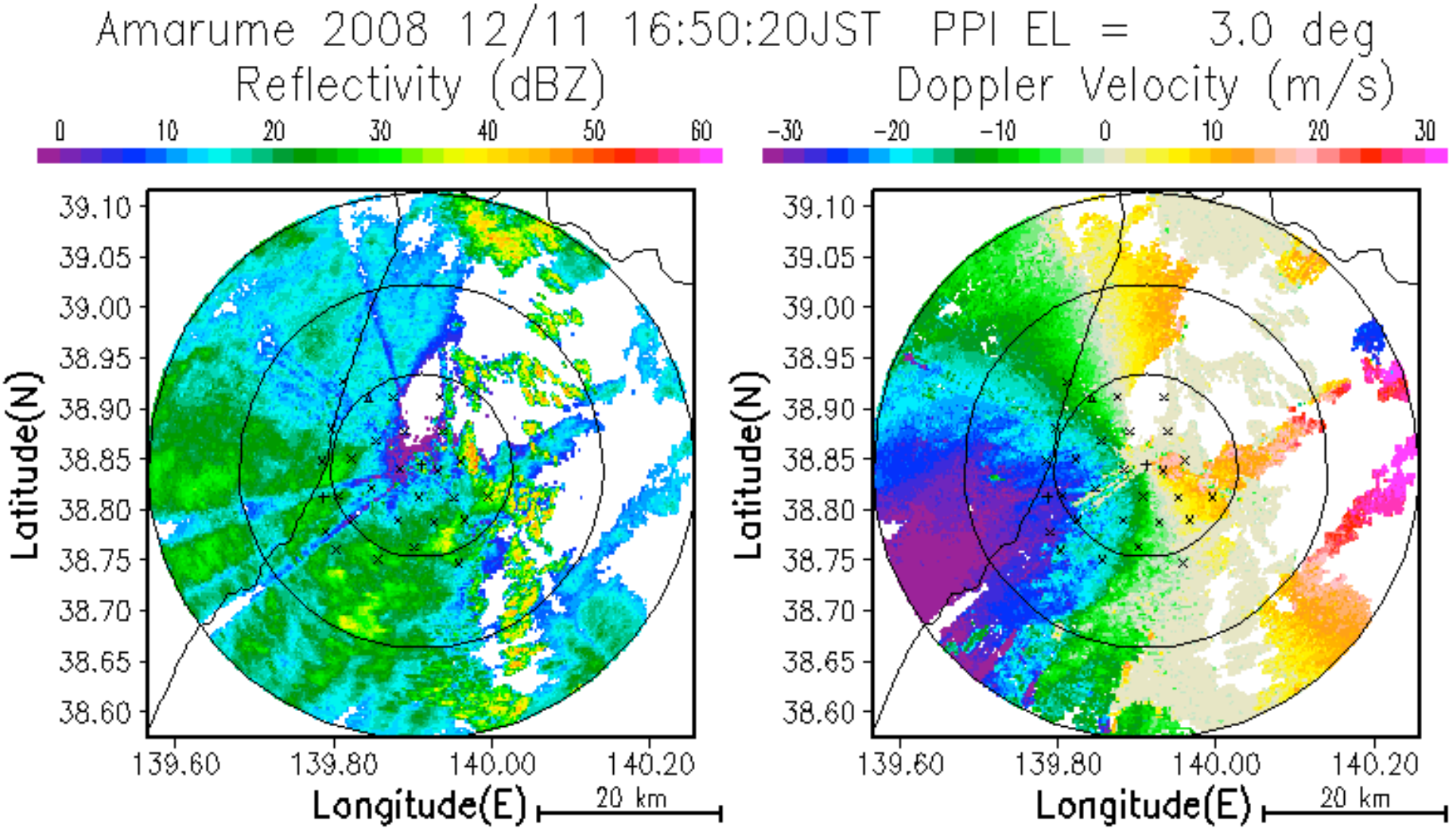
- Observed gusts are mainly associated with low-level misocyclones.
- Misocyclones are generated over the sea and some of them land.
- Observations capture aspects of gusts and their parent storms. → It is difficult to catch 3D structure of the storm.

Solution

- Numerical approach can compensate the weak point of observation (e.g. near-surface information).
  - Results can be used to the effective improvement of the gust detection system.
- On this talk, one case study is introduced.

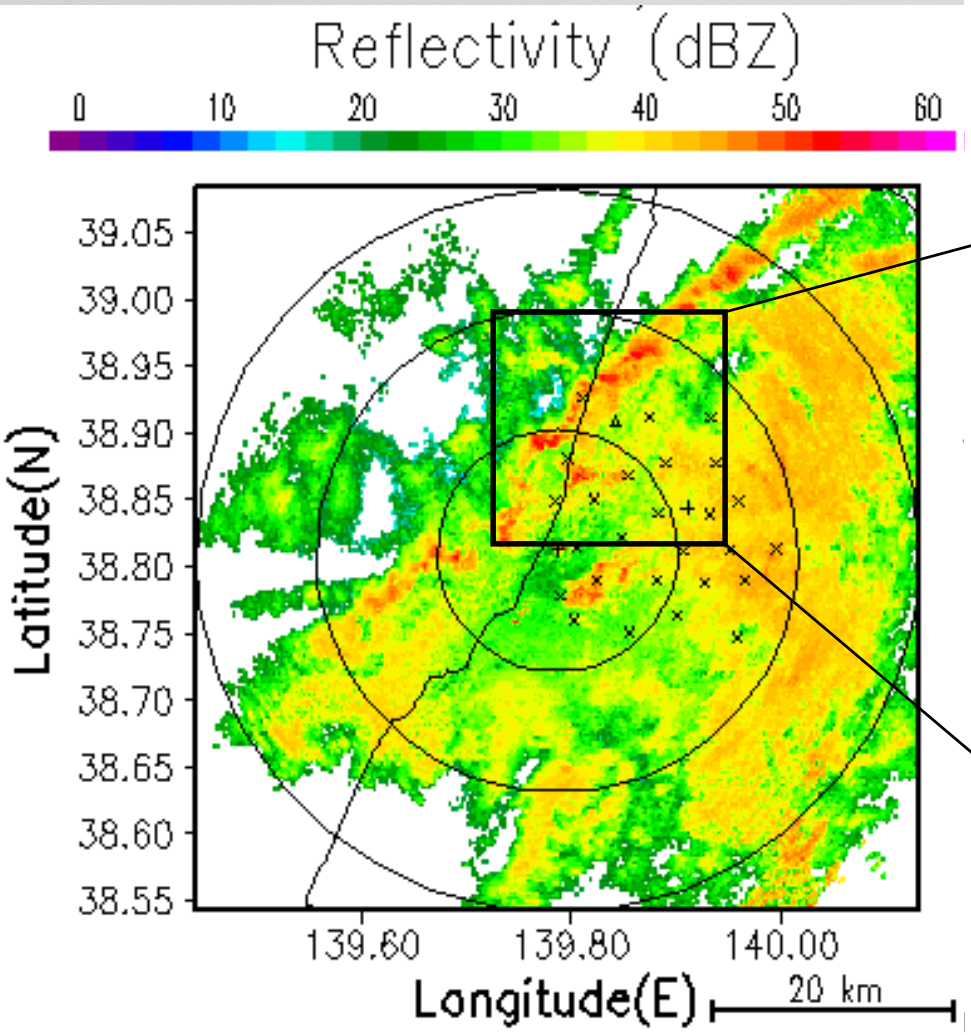
Case Overview

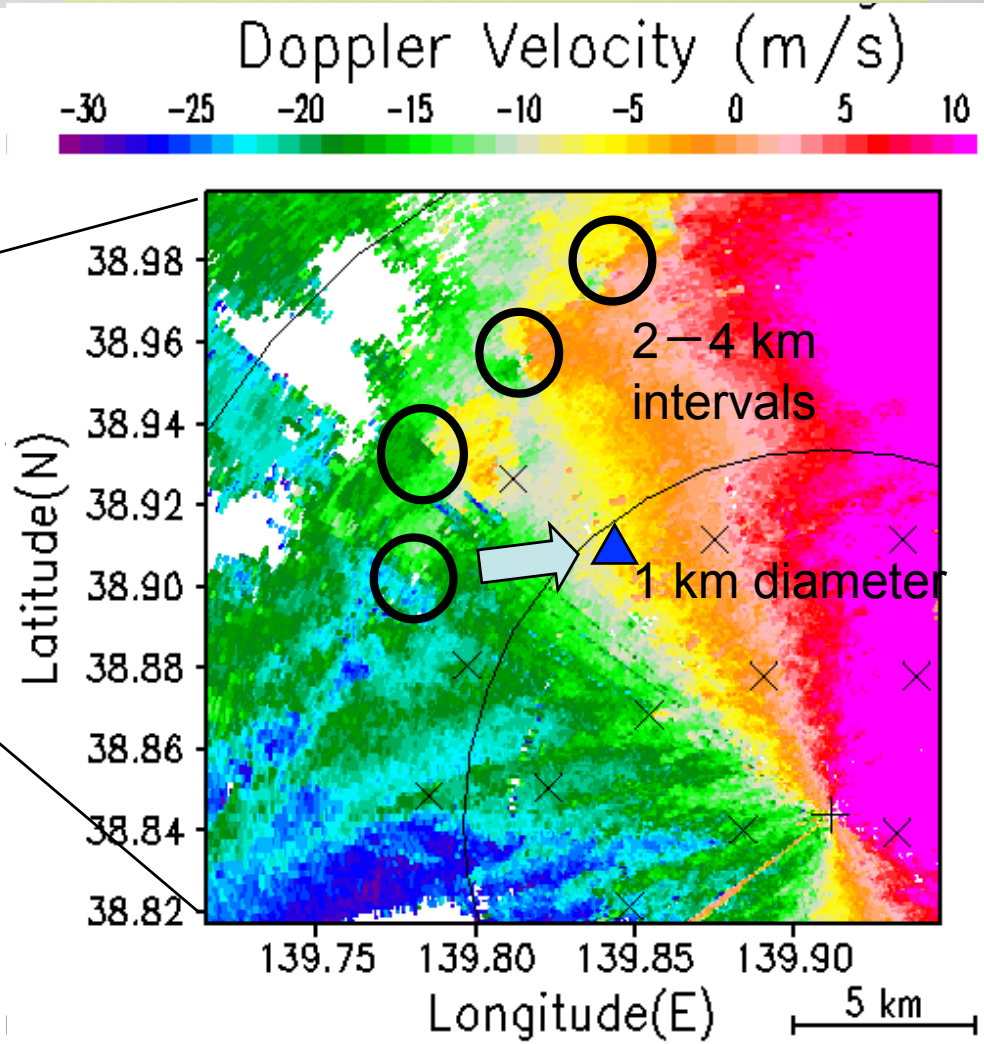
- 1711JST, 11 December 2008
  - JST: Japan Standard Time (UTC + 9 hours)
- Max. wind speed: 26.8 m s^{-1}
- Associated with the cold front
- No damage


Amarume 2008 12/11 16:50:20JST PPI EL = 3.0 deg
Reflectivity (dBZ)
0 10 20 30 40 50 60
Doppler Velocity (m/s)
-30 -20 -10 0 10 20 30
Latitude(N)
39.10
39.05
39.00
38.95
38.90
38.85
38.80
38.75
38.70
38.65
38.60
139.60 139.80 140.00 140.20
Longitude(E)
20 km

MRI radar (1710 JST, EL = 3 deg)

JR radar (1706 JST, EL = 3 deg)





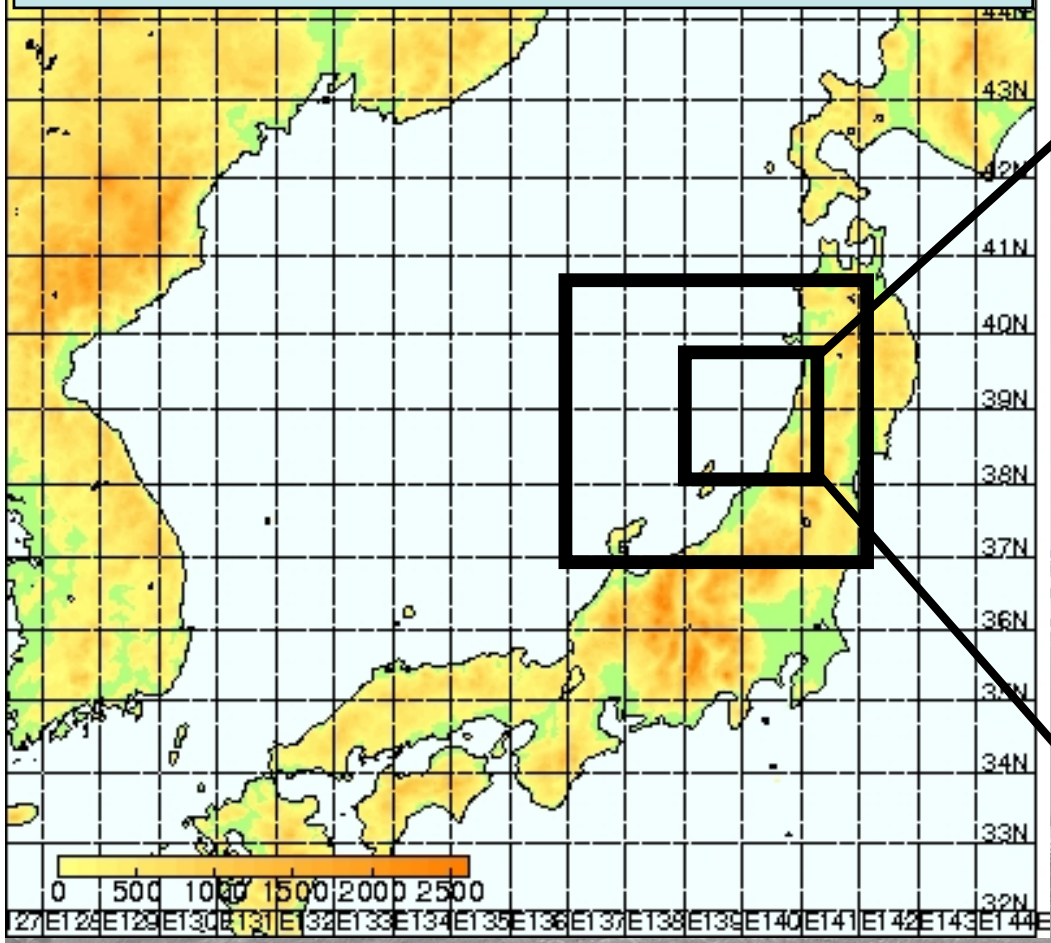
Case Overview of 11 Dec 2008

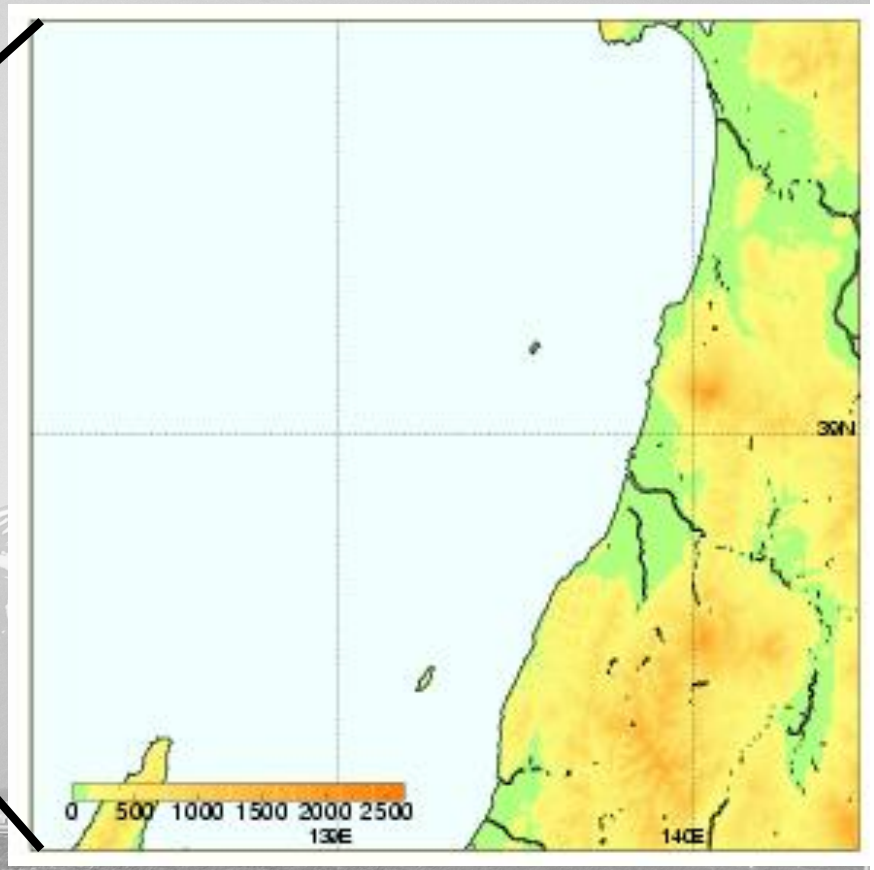
- Convective cells were initiated along the convergence line over the sea.
- Misocyclones were embedded in the surface convergence line associated with the cold front.
- Misocyclones were distributed at the intervals of 2-4 km and some of them landed.

Model Descriptions

- Model: JMA-NHM (Saito et al., 2006)
- I.C., B.C.: MANAL (an objective analysis made by JMA and horizontal resolution is 10 km)
- Microphysics: 2-moment 4-ice scheme

Model Domains

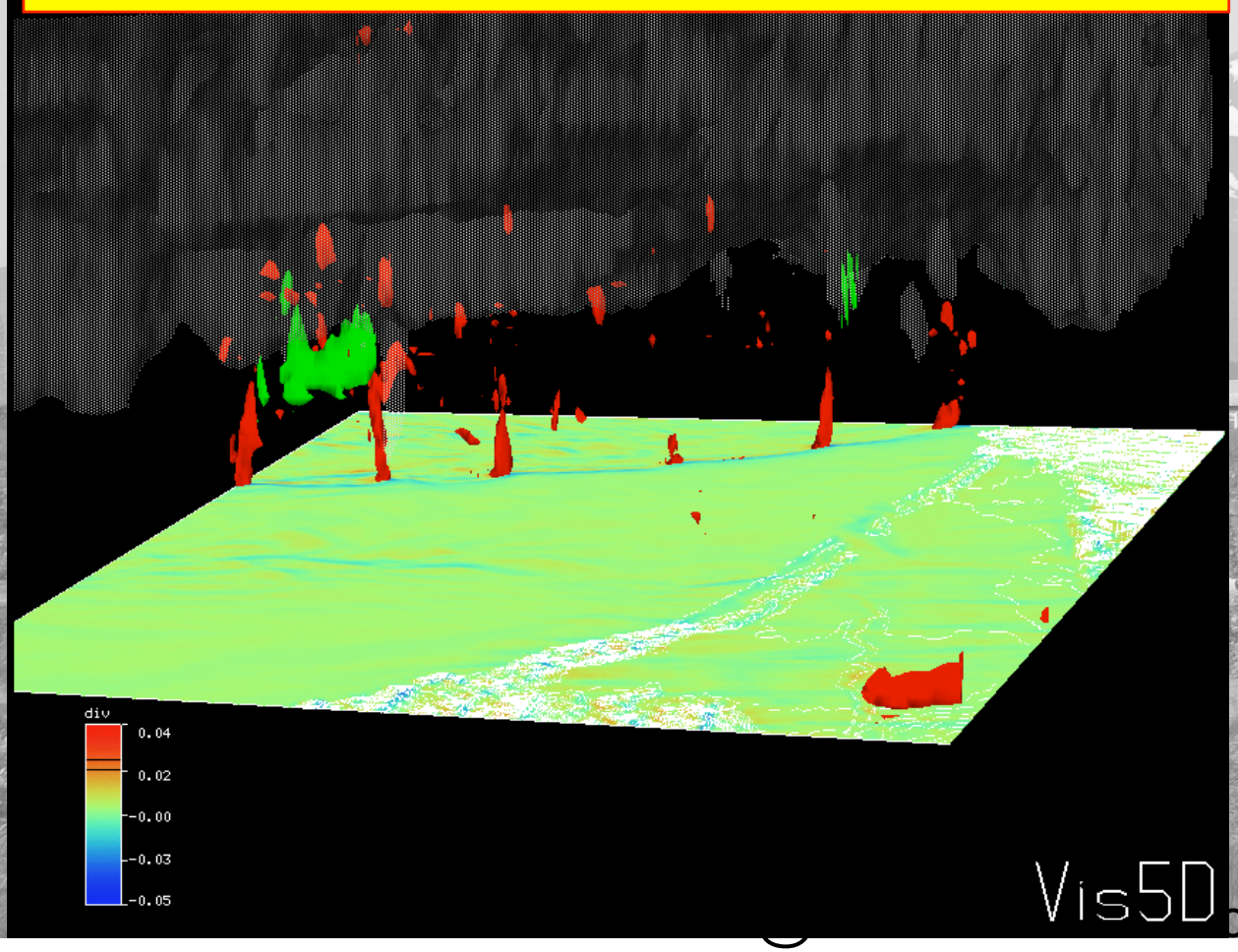




	NHM5km	NHM1km	NHM250m
Grid Points	301x301	551x451	951x701
Levels	50	50	60
⊿x	5 km	1 km	250 m

Numerical Results (NHM250 m)

several strong vertical vorticity region are developed from surface to upward.



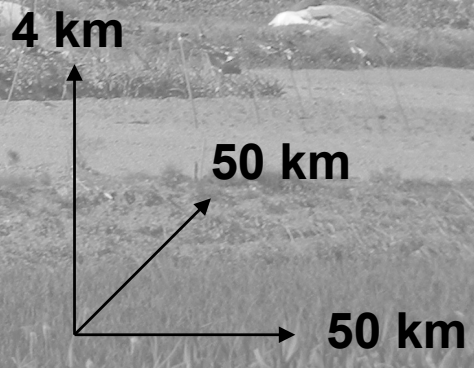
Red: Vertical Vorticity (>0.02 /s)

Green: Updraft (>5 m/s)

Gray: Condensate (>0.2 g/kg)

Surface Color: Divergence

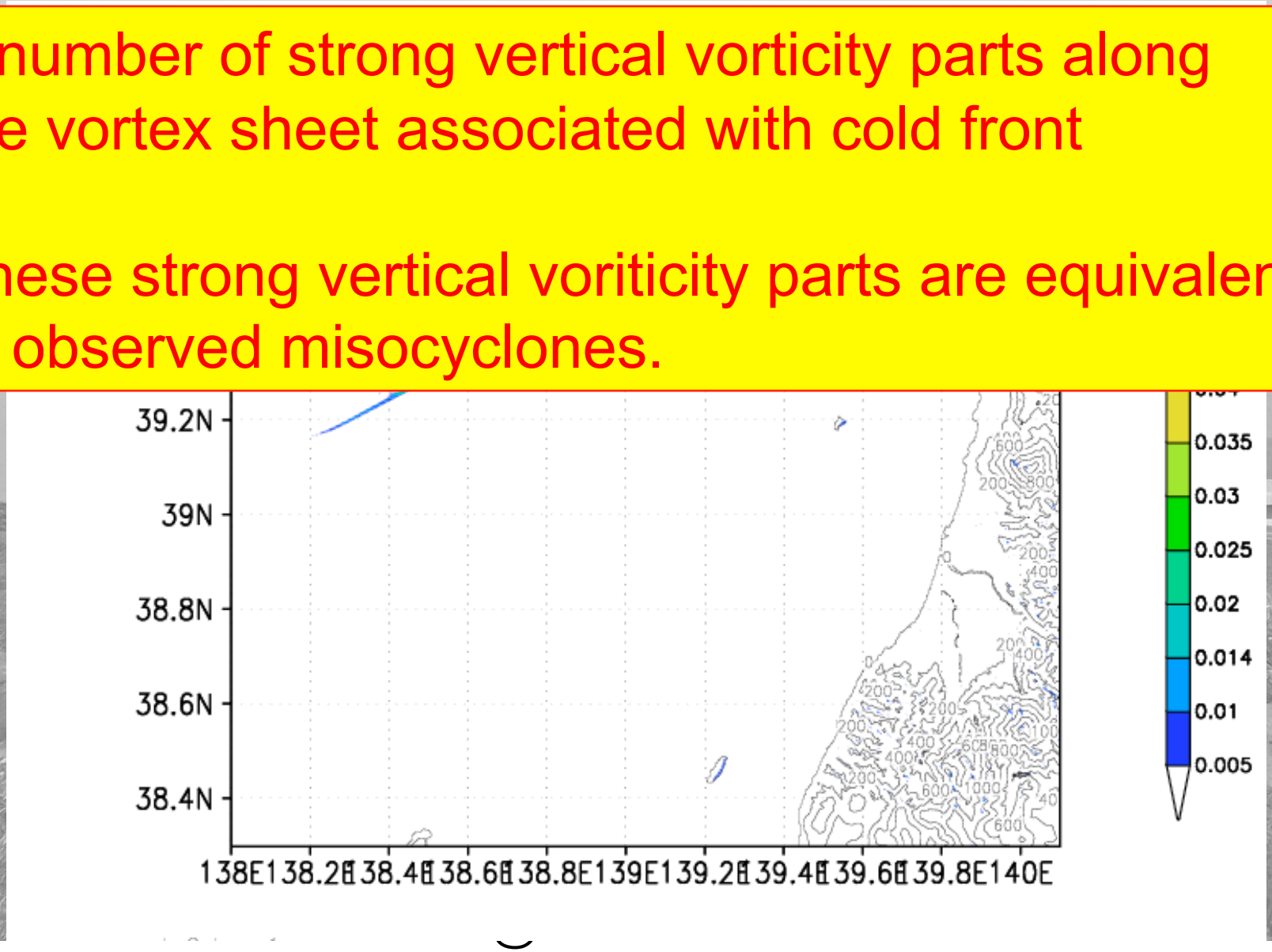
Surface Contour: Terrain



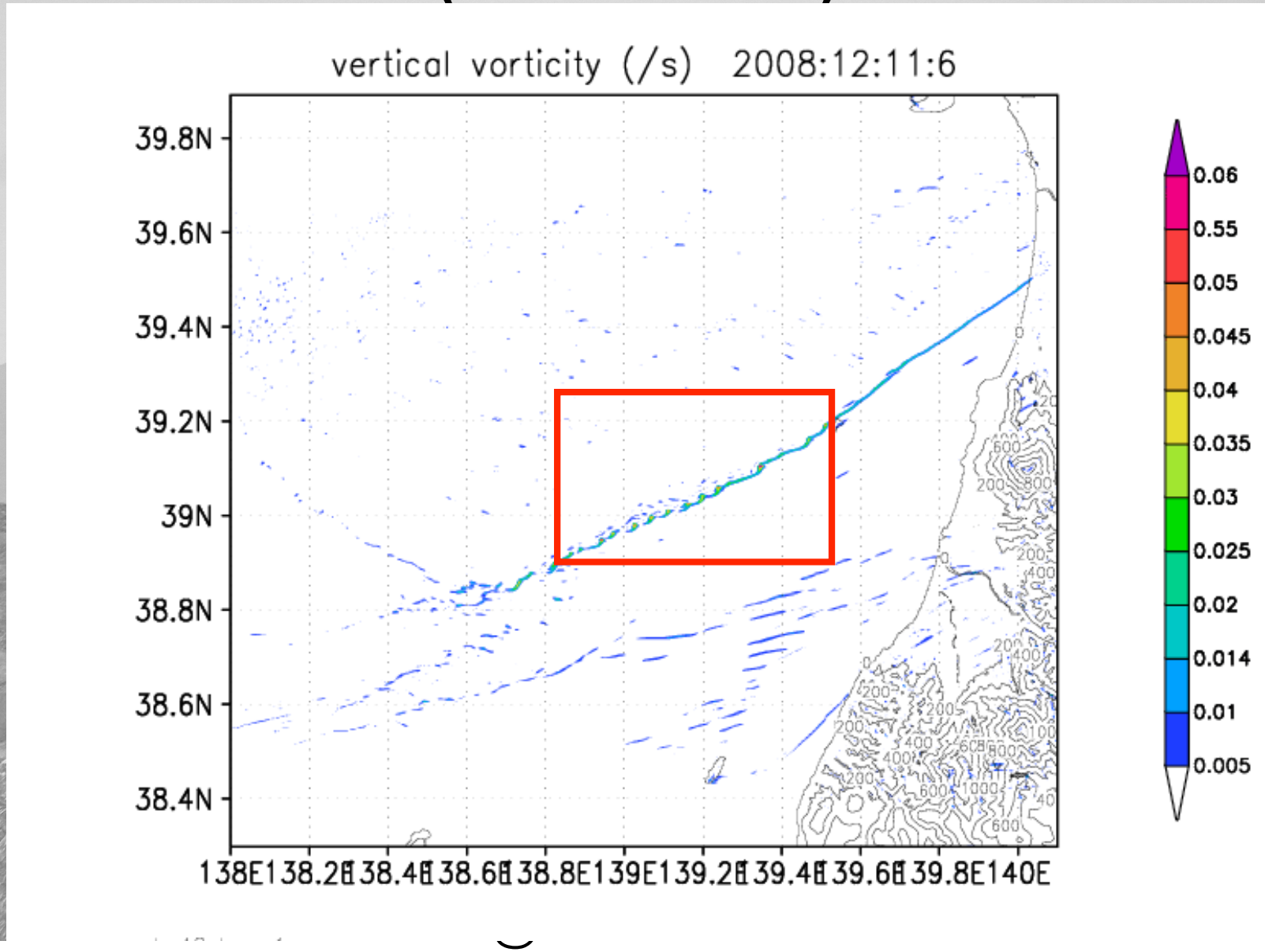
Evolution of vertical vorticity field @ near surface

a number of strong vertical vorticity parts along the vortex sheet associated with cold front

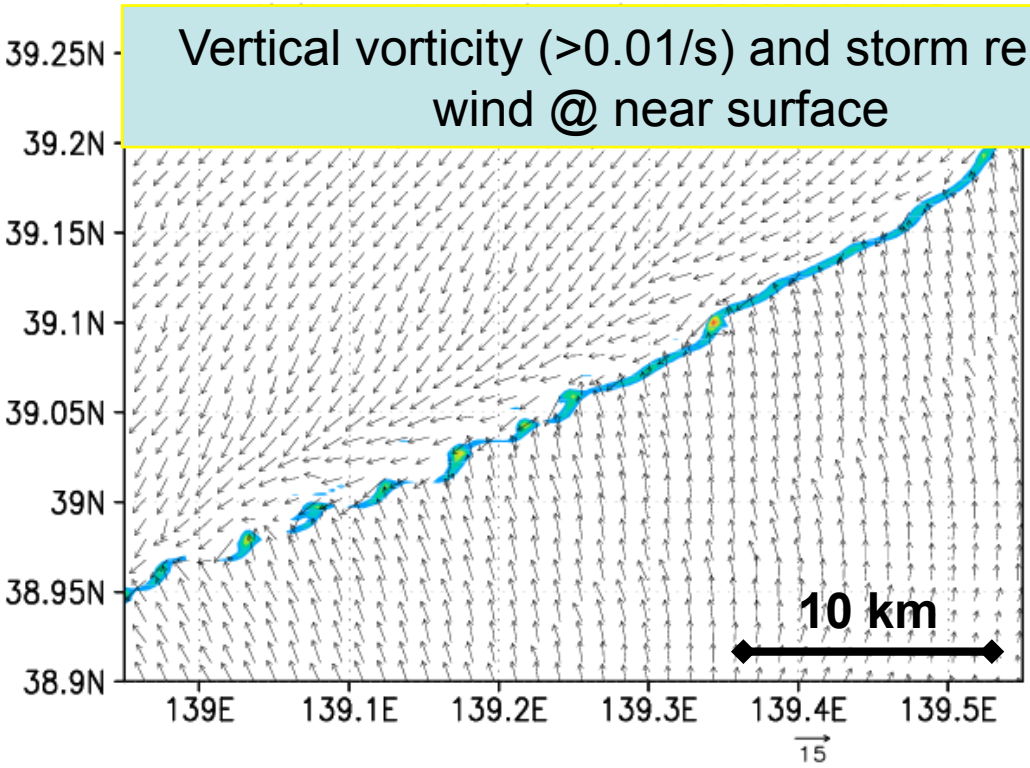
These strong vertical voriticity parts are equivalent to observed misocyclones.



Vertical vorticity @ near surface (1534JST)



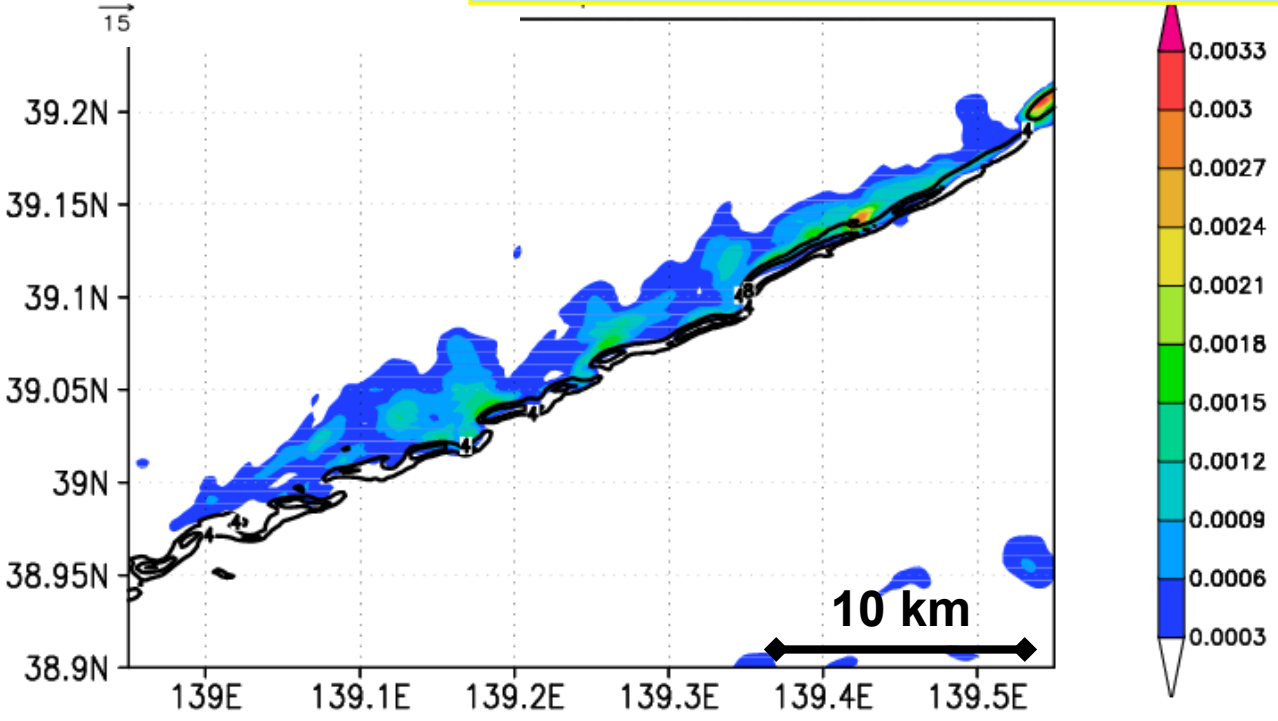
Vertical vorticity (>0.01/s) and storm relative wind @ near surface

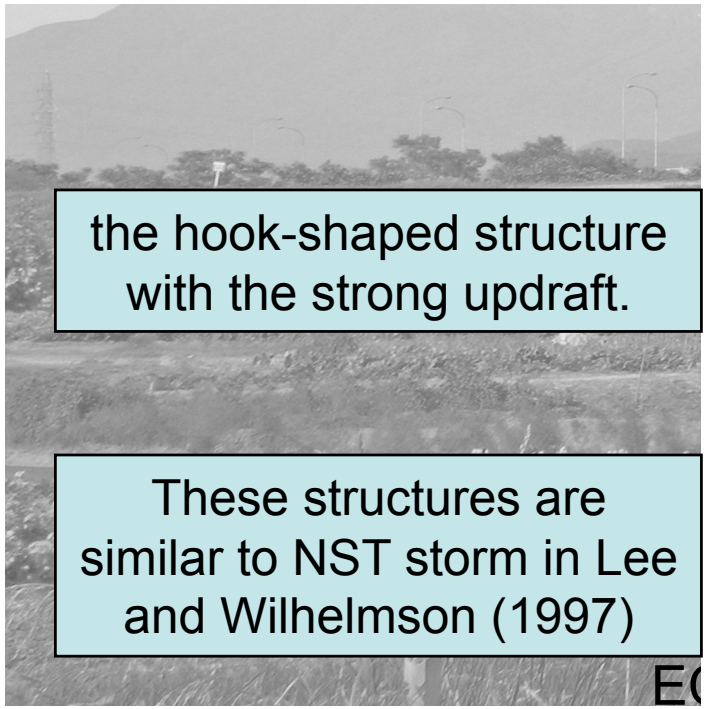


distributed at 2-5 km intervals

color: condensate（>0.2g/kg）

contour: vertical velocity @ z=1km





the hook-shaped structure with the strong updraft.

These structures are similar to NST storm in Lee and Wilhelmson (1997)

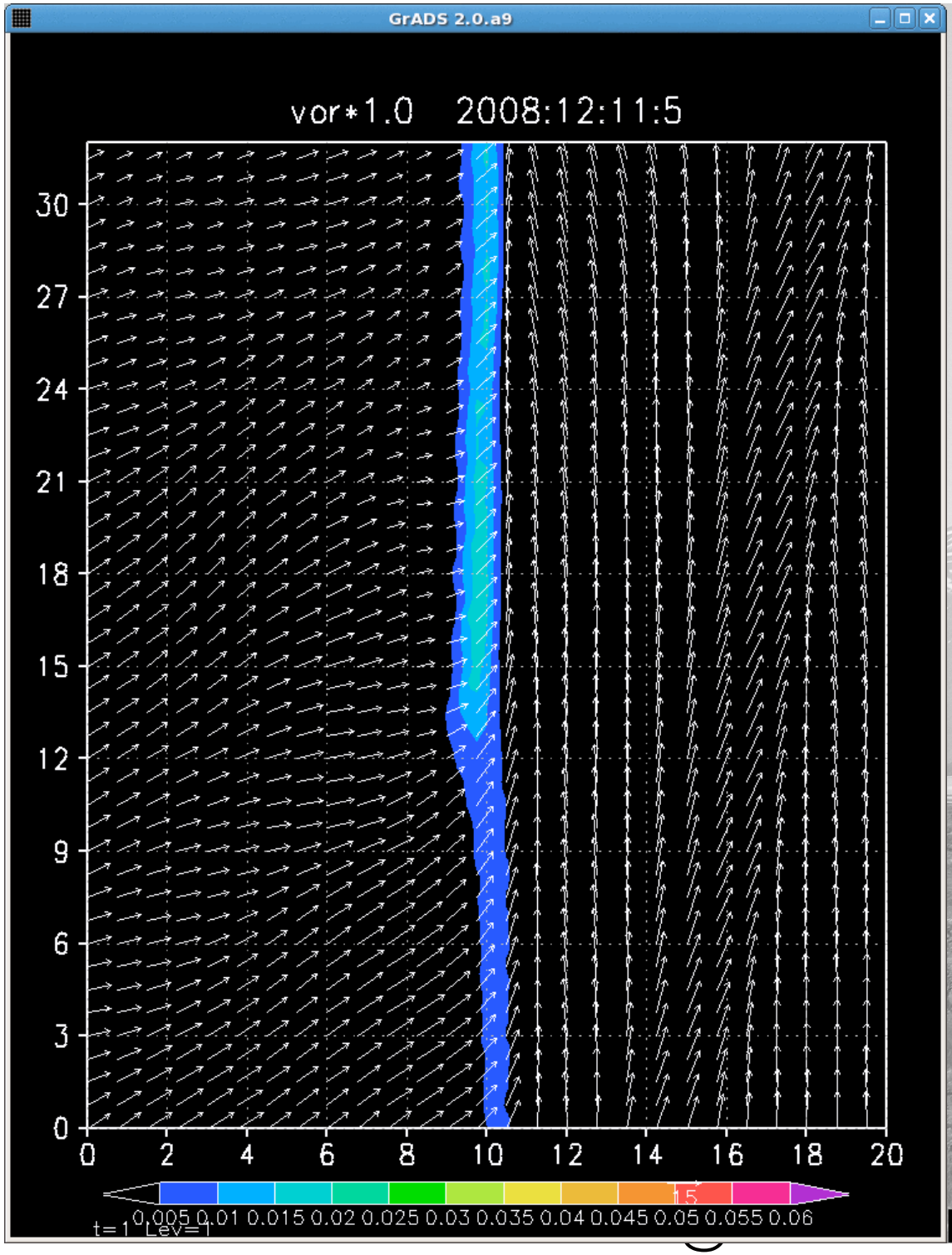
Energy analysis

- To understand the generation of these misocyclones, the energetics along the front are investigated.

$$\frac{\partial \overline{K}_e}{\partial t} = -\overline{v_i' u'}\frac{\partial \overline{v}_i}{\partial x} - \overline{v_i' w'}\frac{\partial \overline{v}_i}{\partial z} + \overline{B' w'} - \left(\overline{u}\frac{\partial}{\partial x} + \overline{w}\frac{\partial}{\partial z}\right)\overline{K}_e$$

$$- C_p\theta_{v0}\frac{\partial}{\partial x}\left(\overline{\pi_1' u'}\right) - C_p\theta_{v0}\frac{\partial}{\partial z}\left(\overline{\pi_1' w'}\right) - C_p\theta_{v0}\overline{\pi_1'\nabla\cdot v'}$$

$$- \overline{v'\cdot\nabla K_e} + \overline{M_F' v'} \quad - \text{dissipation terms}$$



Evolution of vertical vorticity field (after the transformation of coordinate system)

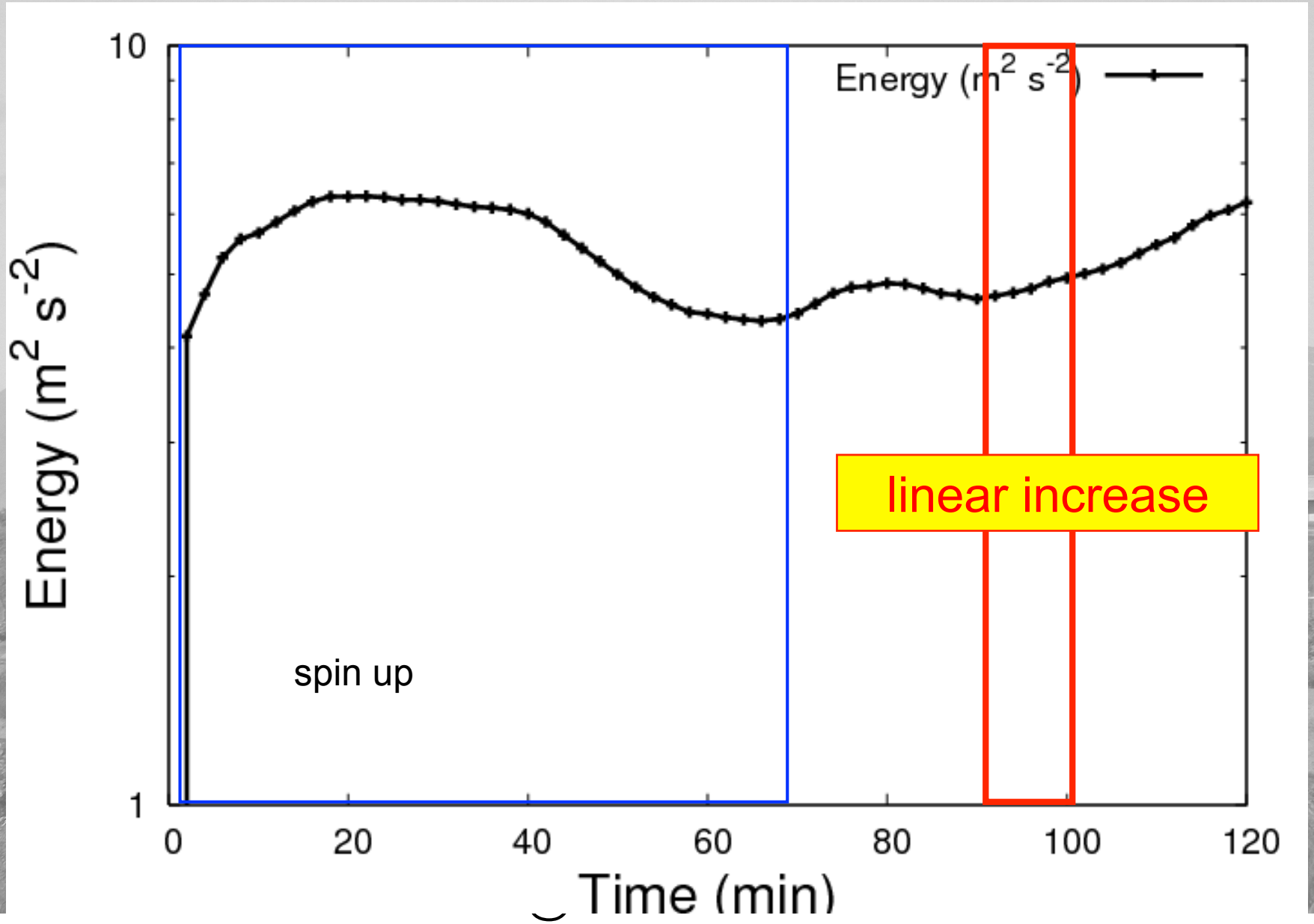
wavelength becomes longer as passage of time.

along front

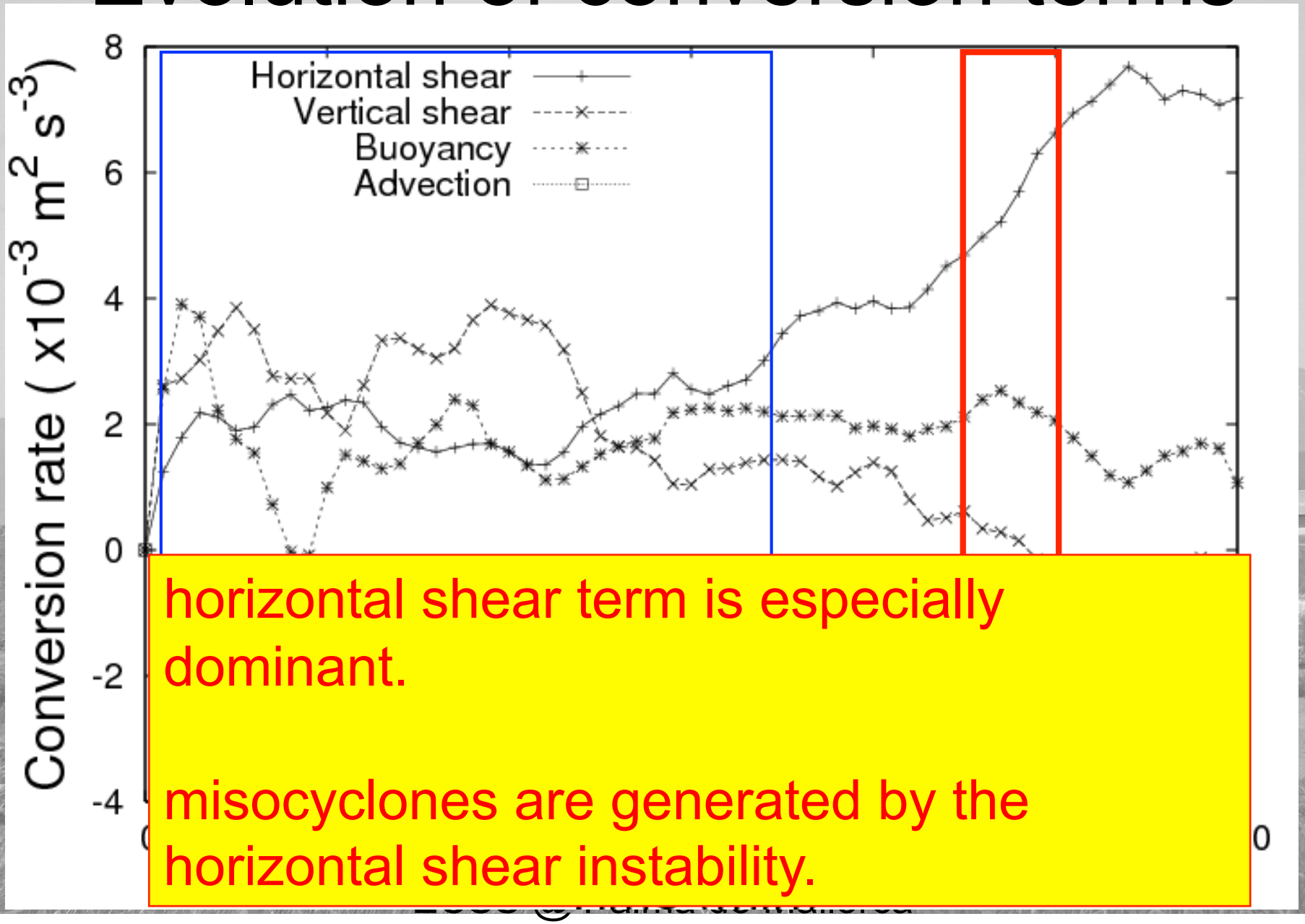
cross front

Mallorca

Eddy kinetic energy



Evolution of conversion terms



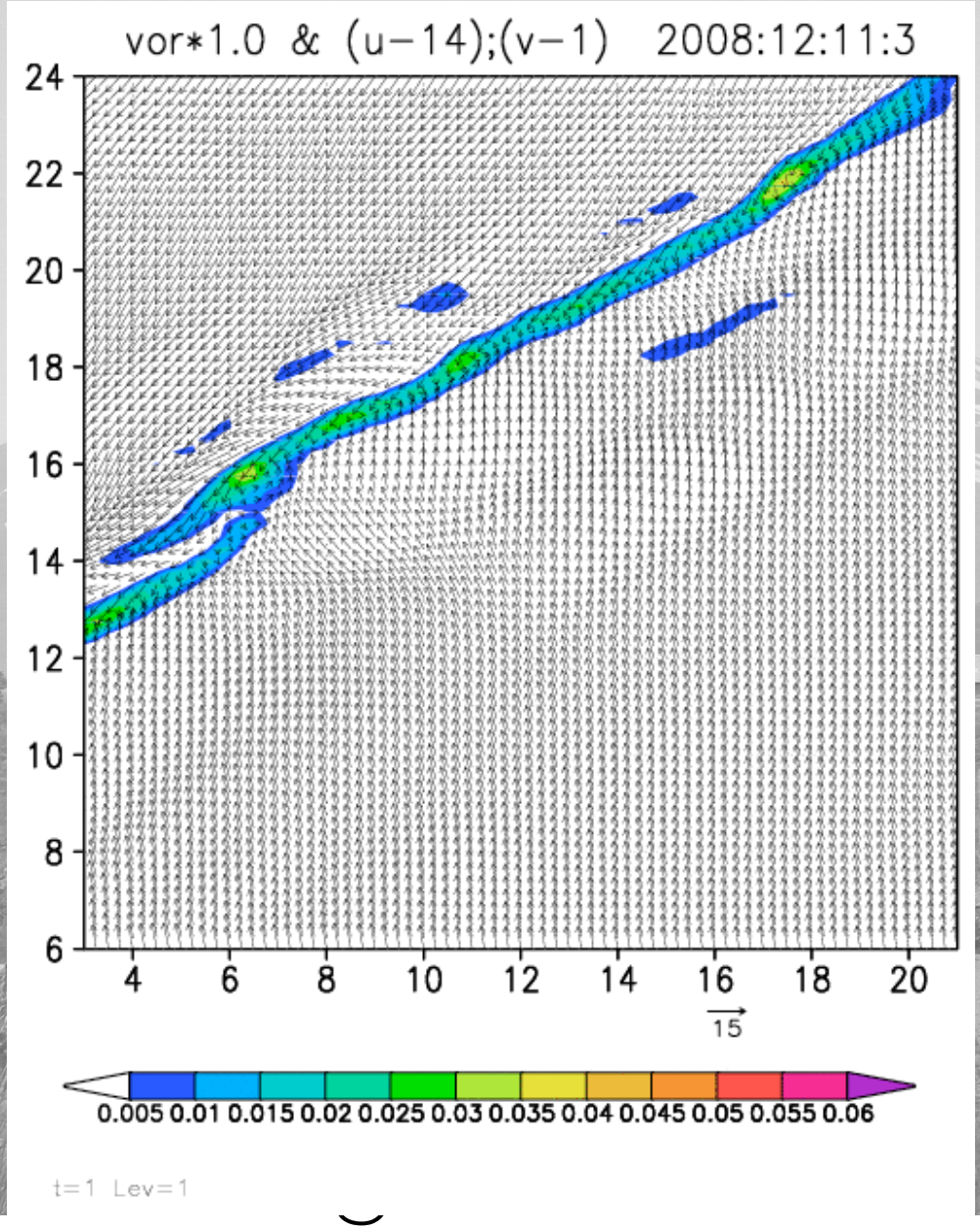
horizontal shear term is especially dominant.

misocyclones are generated by the horizontal shear instability.

Vorticity analysis

- To investigate the development of the misocyclone, vorticity analysis are executed.
- Each term of the vorticity equation is calculated in a moving domain with the volume of 3 km × 3 km in the horizontal and 600 m in the vertical surrounding the center of the misocyclone.
- Calculation is executed each 10 seconds

Evolution of traced misocyclone



Vertical vorticity equation

$$\frac{\partial(\rho_0\zeta)}{\partial t} = -\frac{\partial(\rho_0 u\zeta)}{\partial x} - \frac{\partial(\rho_0 v\zeta)}{\partial y} - \frac{\partial(\rho_0 w\zeta)}{\partial z}$$

Total

Advection

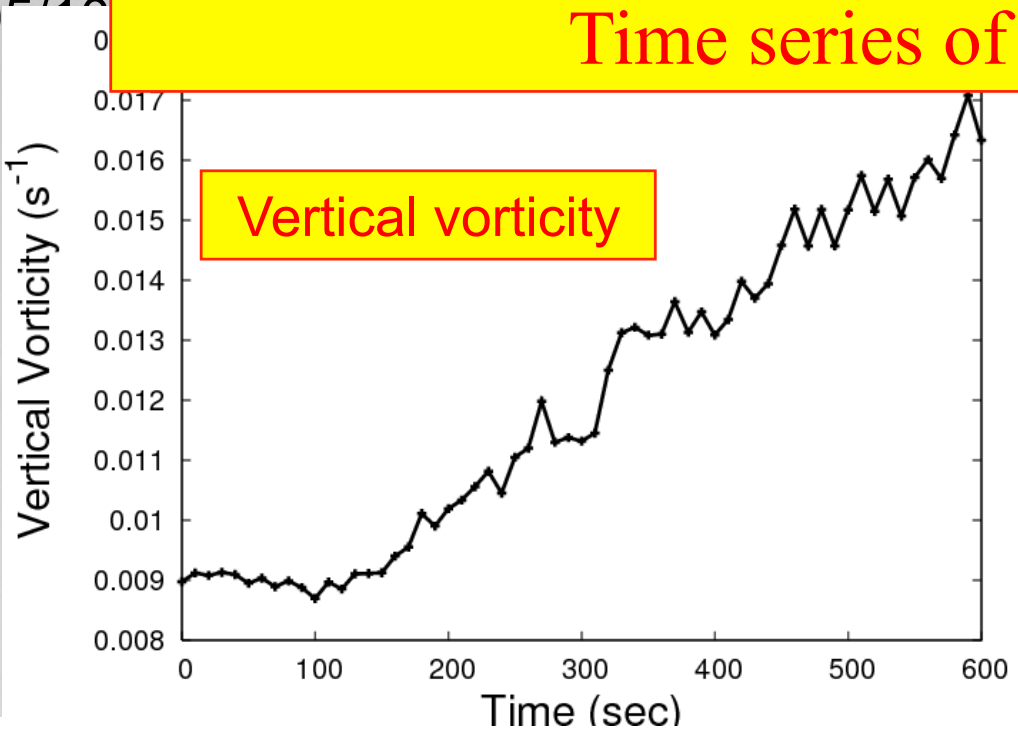
$$+\zeta\frac{\partial(\rho_0 w)}{\partial z} + \rho_0\left[\frac{\partial w}{\partial y}\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\frac{\partial v}{\partial z}\right]$$

Stretching

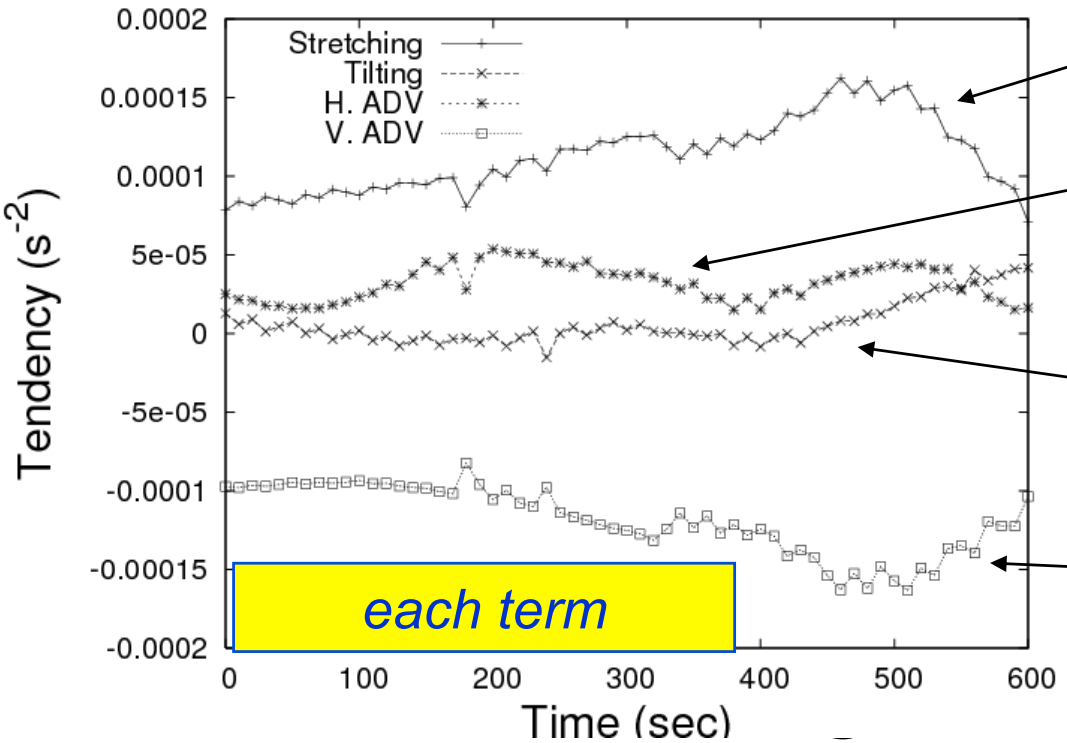
Tilting

wind: $\vec{V} = (u, v, w)$; vorticity: ζ' ; density: ρ_0

Time series of each term



positive contributions from horizontal advection and stretching terms



Stretching

Horizontal Advection

Tilting

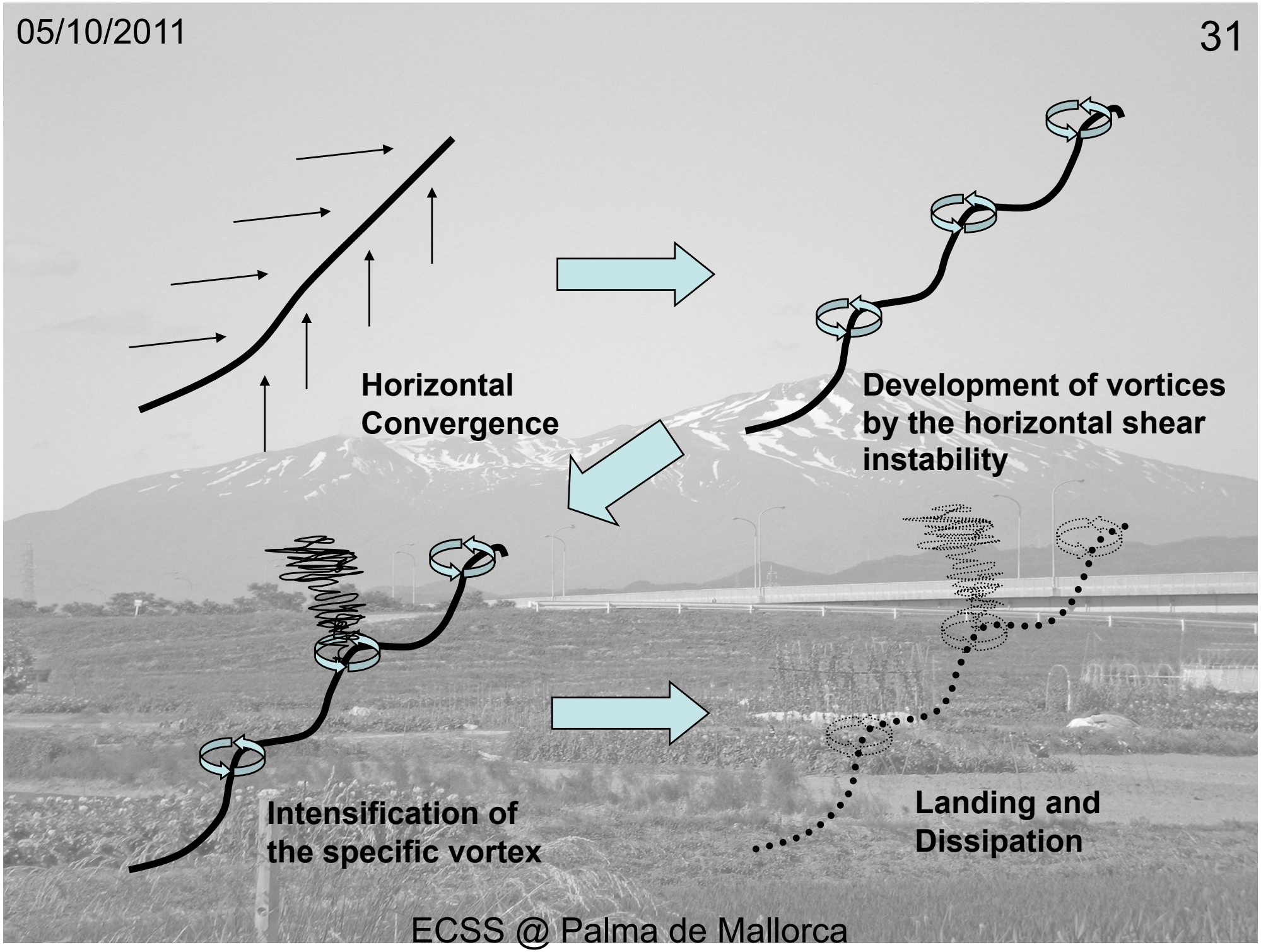
Vertical Advection

Summary

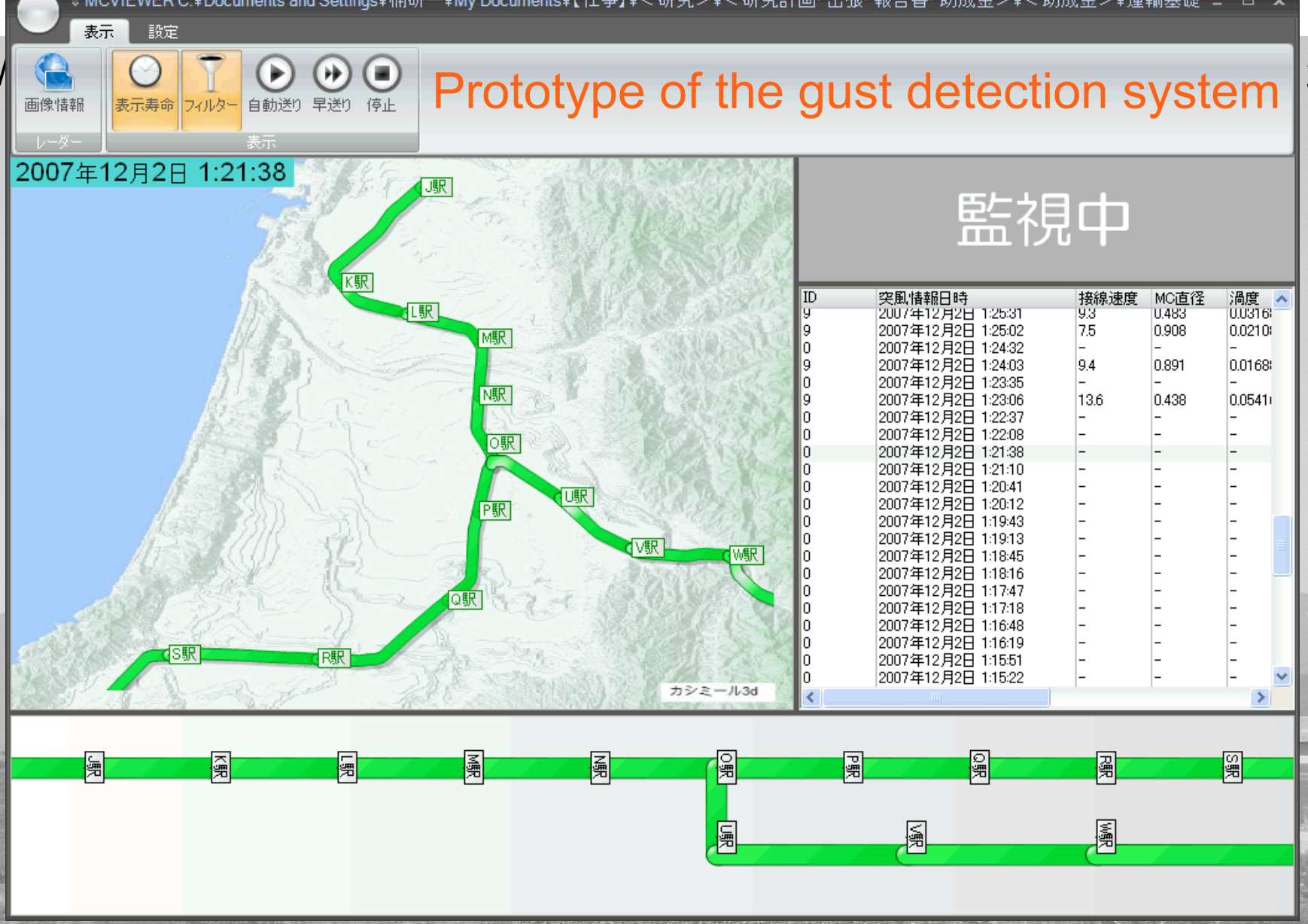
- The simulated misocyclone is initiated near surface, where the horizontal convergence is significantly strong.
- Generation of low-level misocyclone is associated with horizontal shear instability along the cold front.
- Development of low-level misocyclone is associated with strong stretching and horizontal advection of vertical vorticity.

For gust detection system

- It is necessary for the radar scan to monitor the lower layer (below 1 km height) frequently.


Horizontal
Convergence
Development of vortices
by the horizontal shear
instability
Intensification of
the specific vortex
Landing and
Dissipation

Prototype of the gust detection system



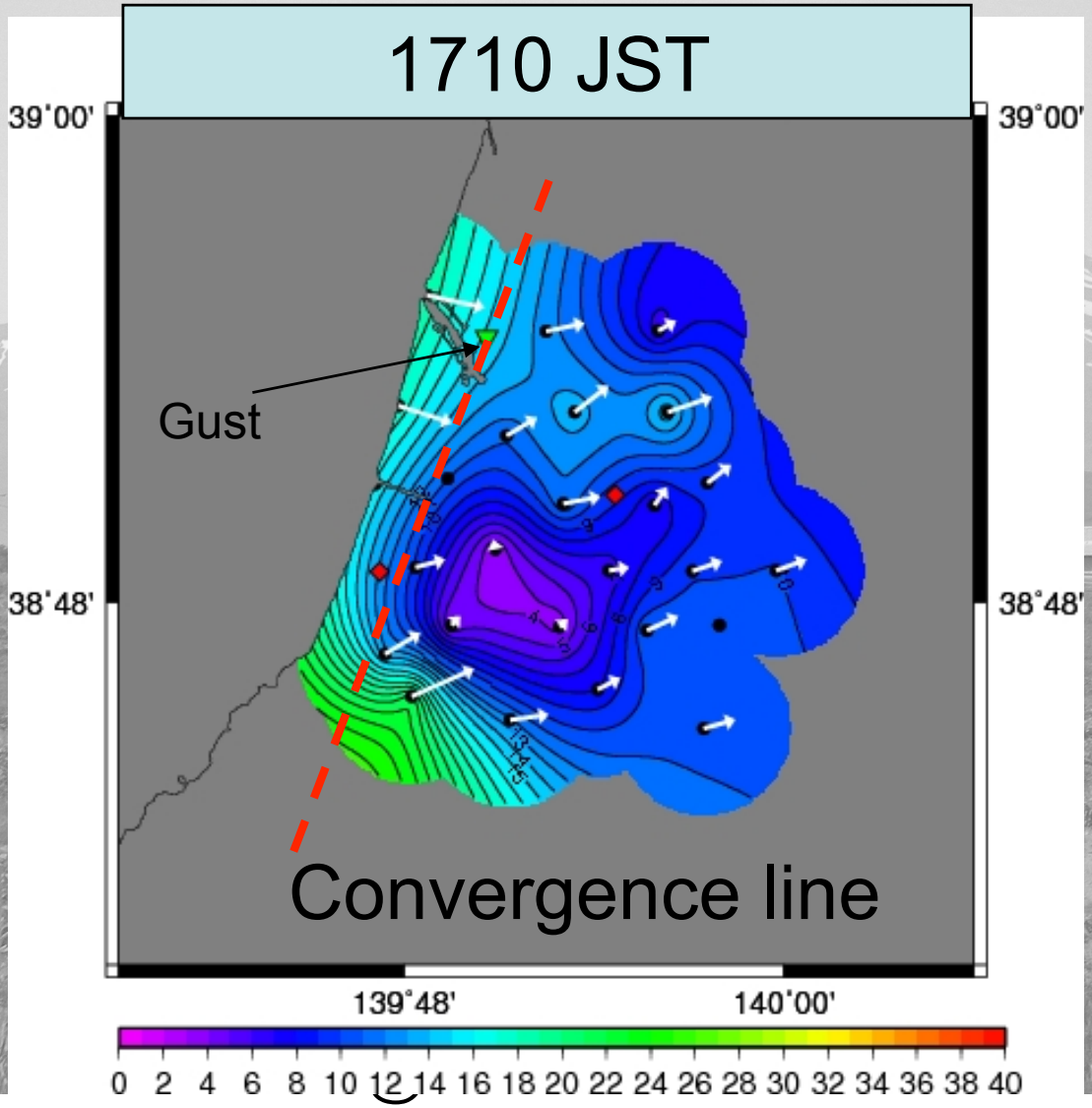
Thank you !

ECSS @ Palma de Mallorca

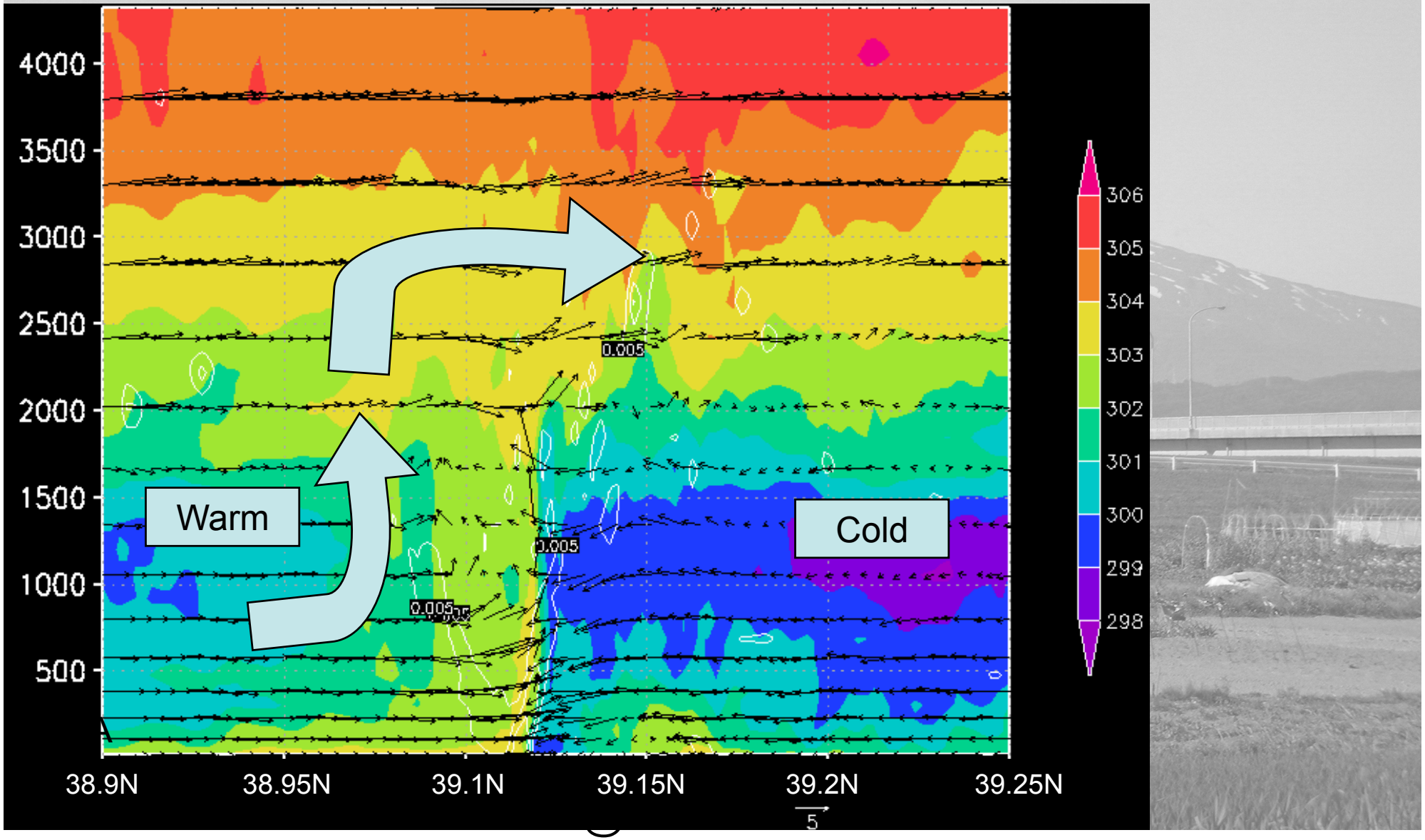
Trigger

- Fatal Railroad Accident @ Shonai area
  - 25th Dec 2005 (winter)
  - 5 killed and 32 injured
  - caused by the strong gust (~50 m s^{-1}) assoc. w/ the convective cell

2-D wind field from surface observation network



Vertical cross section along A-B (color: EPT, contour: horizontal divergence)



Vorticity equation

$$\frac{\partial(\rho_0\zeta)}{\partial t} = -\frac{\partial(\rho_0 u\zeta)}{\partial x} - \frac{\partial(\rho_0 v\zeta)}{\partial y} - \frac{\partial(\rho_0 w\zeta)}{\partial z}$$

Total

Advection

$$+\zeta\frac{\partial(\rho_0 w)}{\partial z} + \rho_0\left[\frac{\partial w}{\partial y}\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\frac{\partial v}{\partial z}\right]$$

Stretching

Tilting

wind: $\vec{V} = (u, v, w)$ *vorticity:* ζ' *density:* ρ_0