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CPS/WTK Mini-Workshop on Planetary Atmospheres II

Wind fields in the Martian atmospheric boundary layer obtained by high-resolution large eddy simulations

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Self introduction

- Doctor course student
  - This presentation shows planning of my doctor thesis
- Sorry for be late, because of business trip to Nayoro observatory

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- Dormitory leader of Keiteki-ryo dormitory (2013 – 2014)

It's me!

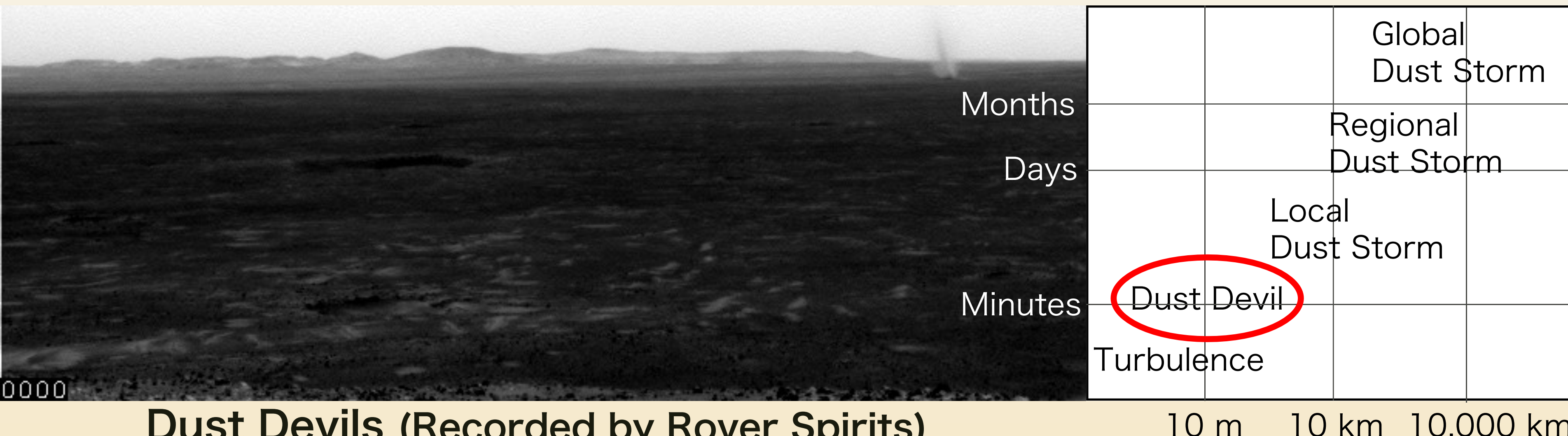
One third of Keiteki-ryo Dormitory residents (2014)

Outline

- Introduction
  - Dust in the Martian atmosphere
  - MGCM calculation including dust processes
  - Problems of dust lifting schemes used in MGCM
  - Purpose of this study
- LES Model / Data
- Results
  - Wind fields of the highest resolution results
  - Surface wind stress of various resolution results
  - Wind structures associated with the strongest wind stress
  - Dust flux distribution
- Summary

Dust in the Martian atmosphere

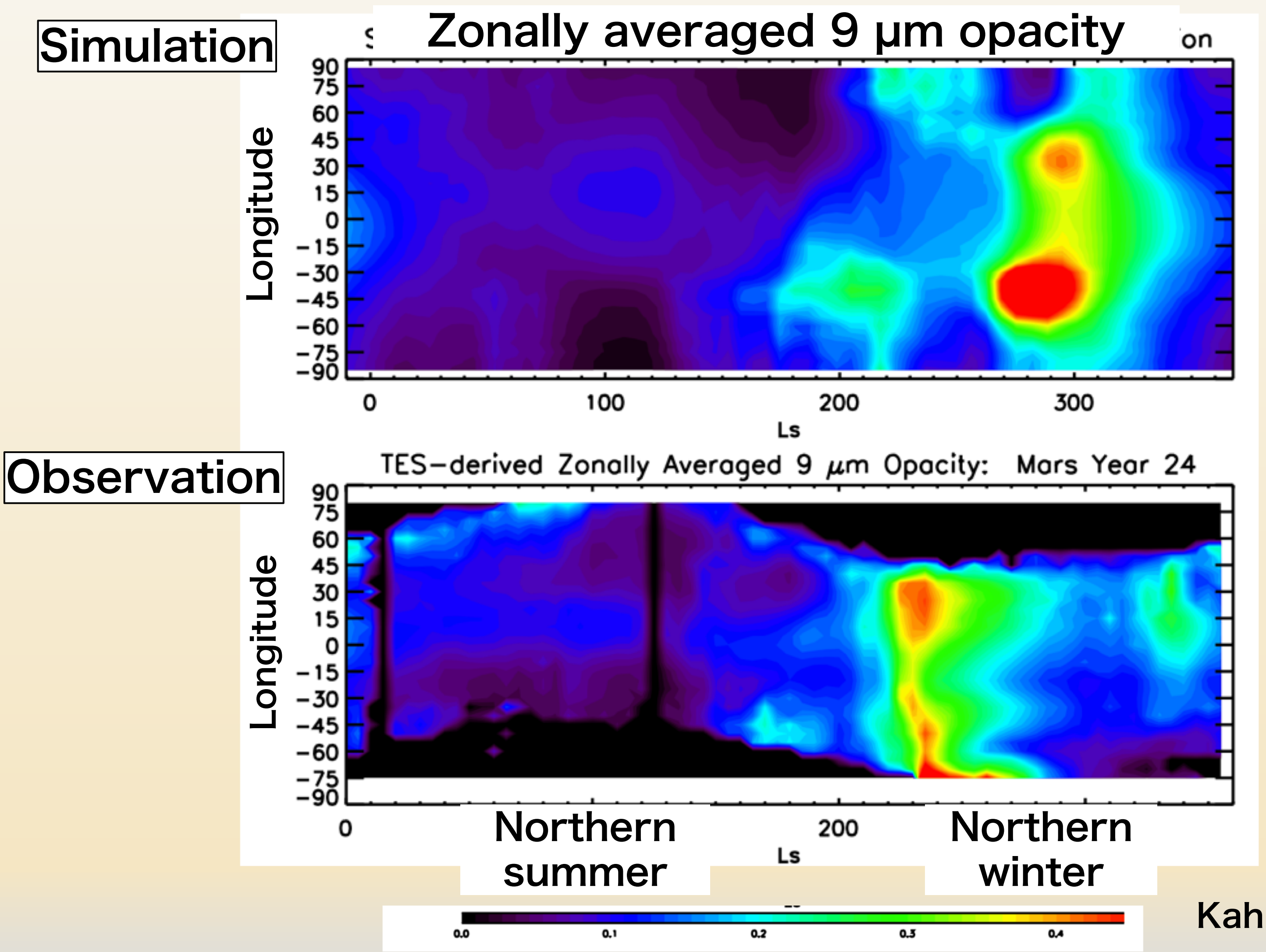
- Dust in the Martian atmosphere greatly influences optical depth and temperature structure. (Smith, 2009, etc.)
- Various space-time scale dust phenomena exist.



Dust Devils (Recorded by Rover Spirits)
http://mars.nasa.gov/mer/gallery/press/spirit/20050819a.html

MGCM calculation including dust processes

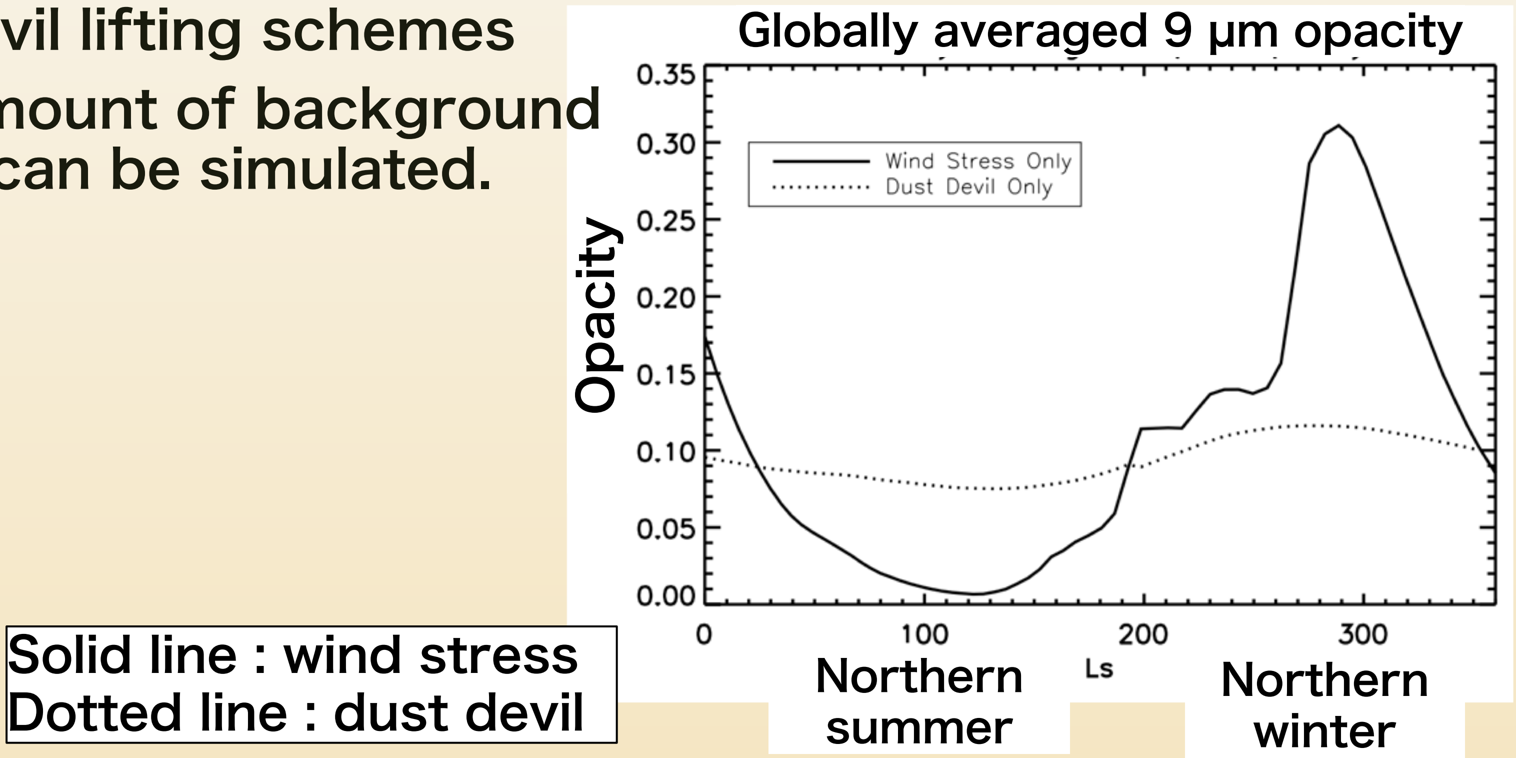
- Kahre et al. (2006) simulates seasonal variability of dust distribution.



Kahre et al. (2006)

Dust lifting schemes used in MGCM

- Kahre et al. (2006) uses 2 types of dust lifting parameterization schemes.
  - Wind stress lifting schemes
    - The seasonal variability of dust amount can be simulated.
  - Dust devil lifting schemes
    - An amount of background dust can be simulated.



Kahre et al. (2006)

Wind stress lifting schemes

- KMH scheme (Kahre et al., 2006)

$$F_W = \alpha_W \times 2.3 \times 10^{-3} \tau^2 \left(\frac{\tau - \tau^*}{\tau^*} \right)$$

F_W : Dust flux [kg/(m² s)]

α_W : Efficiency factor

τ : Surface wind stress [N/m²]

τ^* : Threshold value [N/m²]

Parameters in Kahre et al. (2006)

τ^*	α_W
10×10^{-3}	0.02
22.5×10^{-3}	0.1
35×10^{-3}	0.45

- Based on observational results on the Earth (Sahara desert). (Westphal et al., 1987)
- Adjusting to the Martian conditions. (Kahre et al., 2006)
  - Atmospheric density, gravitational acceleration.

Dust devil lifting schemes

- DDA scheme (Newman et al., 2002)

$$F_D = \alpha_D F_s (1 - b) \qquad b = \frac{p_s^{\chi+1} - p_{con}^{\chi+1}}{(p_s - p_{con})(\chi + 1) p_s^{\chi}} \qquad \chi \equiv \frac{R}{c_p}$$

F_D : Dust flux [kg/(m² s)]

F_s : Sensible heat flux [W/m²]

α_D : Efficiency factor [kg/J]

p_s : Surface Pressure [Pa]

p_{con} : Pressure at the top of PBL [Pa]

R : Specific gas constant

c_p : Specific heat capacity

- Based on the thermodynamics of dust devils as a heat engine.
  (Rennò et al., 1998)
- Thermal efficiency is used for expressing dust flux.
  - With the higher sensible heat flux, kinetic energy of convection becomes larger.
  - With the higher PBL altitude, the conversion rate of kinetic energy from sensible heat flux becomes larger.
  - Therefore the amount of dust flux increases.

Problems of parameterization

- Adjusting parameters are necessary in order to simulate observational results.
  - Wind stress threshold value should be decreased compared to experimental value. (Greeley and Iversen, 1985)
- Schemes have been developed without considering details of wind structures.
- Wind stress schemes are suspected to include effects of dust devil schemes.

Purpose of this study

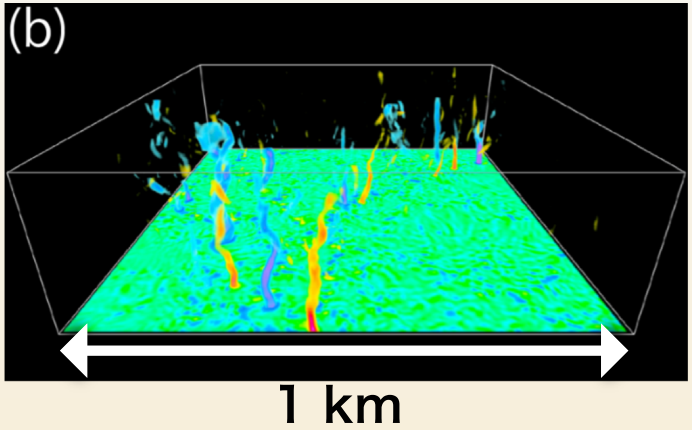
- Our purpose is to reconsider the schemes with examining relationship between wind microstructures such as dust devils and large scale convective structures.
  - What are characteristics of the wind field?
  - How much is the strength of the wind stress?

- In this study, we examine LES with several km domain.
  - Our results can be applied to MGCM.
  - The most high-resolution MGCM can resolved up to several km. (~ 11 km; Takahashi et al., 2011)

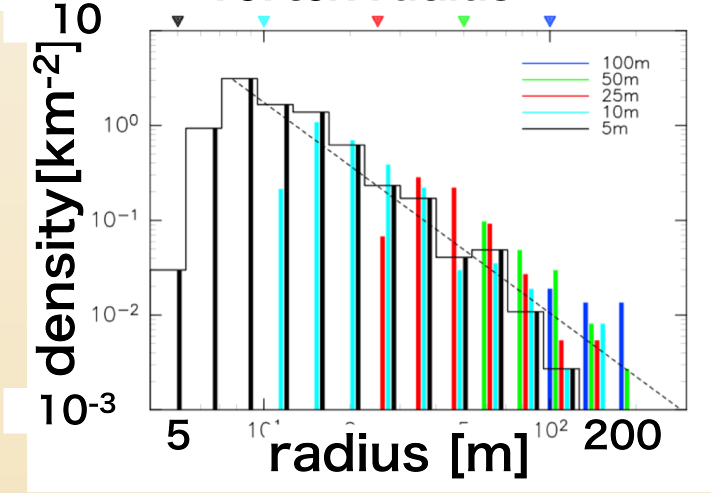
The highest resolution LES for the Mars

- Nishizawa et al. (2016)
  - Domain :
    Horizontal 19.2 km, Vertical 21 km
  - Horizontally periodic boundary conditions.
  - Resolution 5, 10, 25, 50, 100 m
    - About 4.8 x 10^{10} grid points in 5 m resolution.
      (1 time snapshot has 1.2 TB !)
- Statistics on vortices are investigated.
  - e.g. vortex radius distribution of 62.5 m height at LT = 14:30

Vorticity distribution



Frequency distribution of vortex radius



Nishizawa et al. (2016)

Model

- **SCALE-LES** (Nishizawa et al., 2015; Sato et al., 2015)
  - https://scale.aics.riken.jp/index.html
  - 3D fully compressible non-hydrostatic equations model.
  - Developed by RIKEN/AICS.
- **Turbulence process**
  - Smagorinsky-type eddy viscosity model (Brown et al., 1994; Scotti et al., 1993).
- **Surface model**
  - Louis-type bulk method (Louis 1979, Uno et al., 1995).

Settings

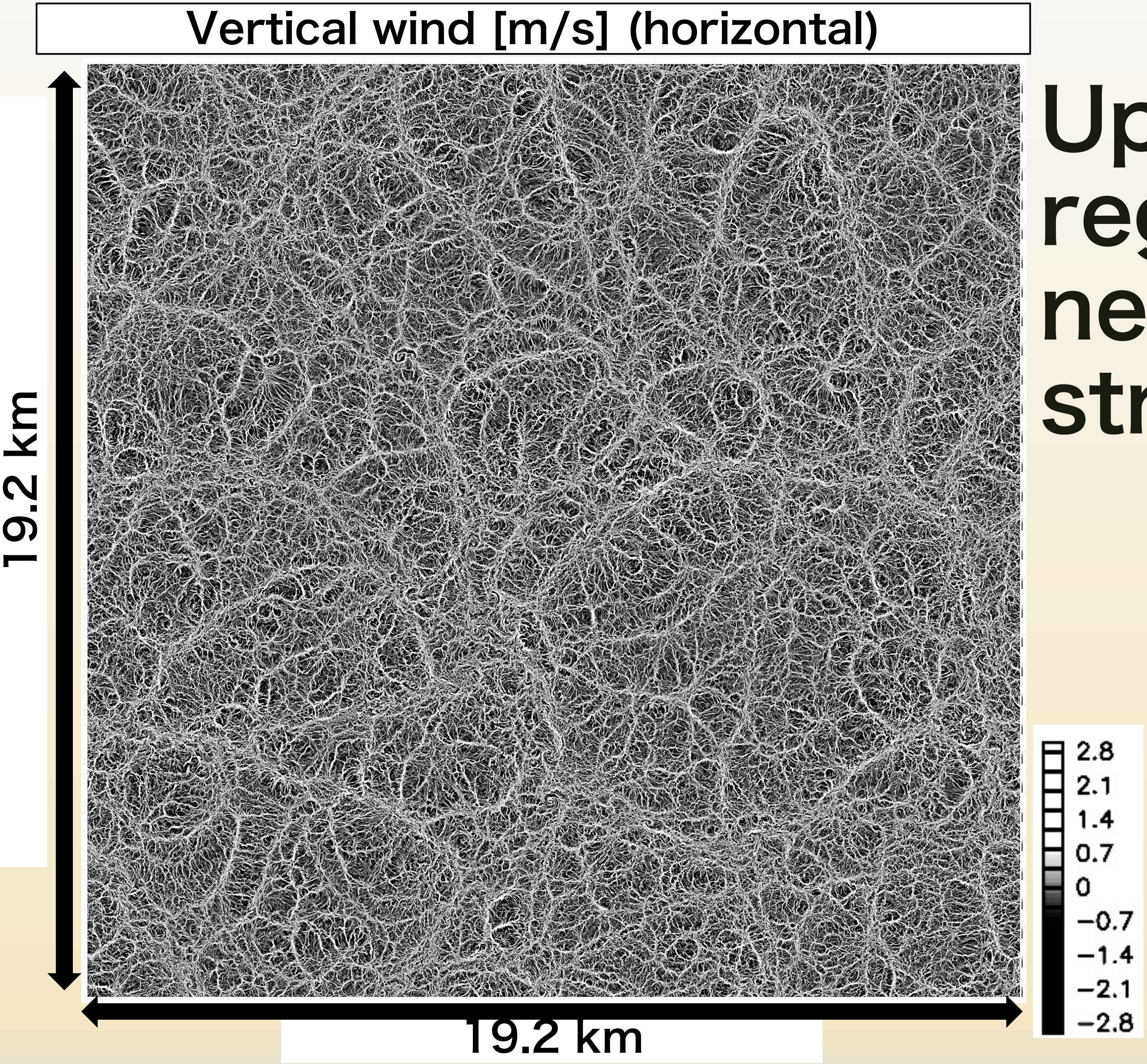
- **Thermal forcing**
  - The heating rate and surface temperature are given by one-dimensional simulation by Odaka et al. (2001)
- **Initial State**
  - 10 - 100 m resolution :
    Stable stratified stationary atmosphere
    with tiny random temperature perturbations.
  - 5 m resolution :
    interpolated 10 m result on LT = 14:00
- **Integration period**
  - 10 – 100 m resolution : from LT = 0:00 - 24:00
    (LT : Local Time)
  - 5 m resolution : from LT = 14:00 - 15:00

Analysis in this study

- In this analysis, using LT = 14 : 30 data.
  - The same as Nishizawa et al. (2016) analysis.

- Analysis procedure
  - Merging original data sets.
    - 5 m resolution original data files consist 7,200 files.
    - It takes a few hour.
    - Each data are about 240 MB.
    - Script language Ruby is used.
  - Making
    - Horizontal distribution
    - Vertical distribution
    - Histogram ...etc.

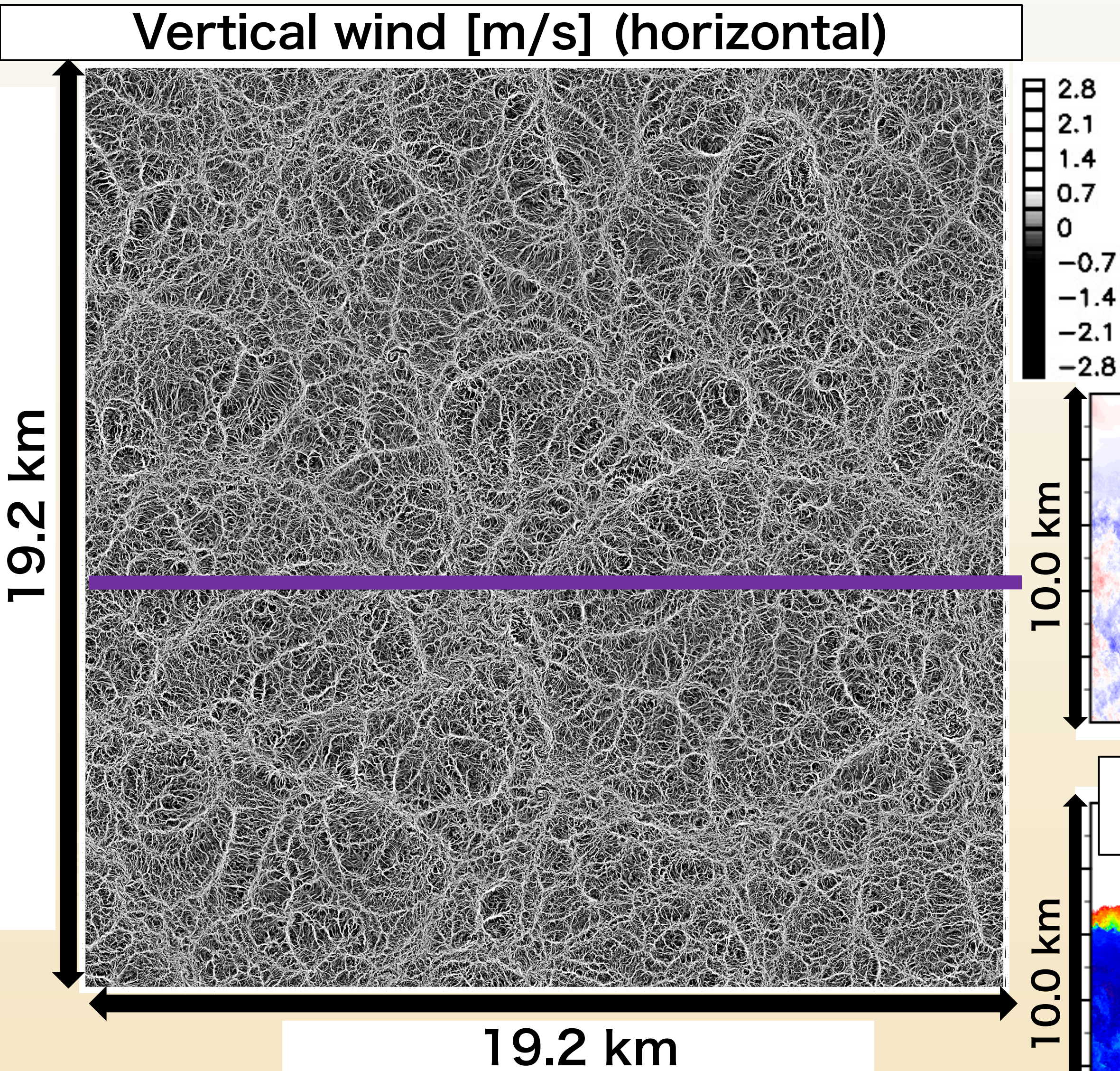
Vertical wind (bottom level z = 2.5 m)

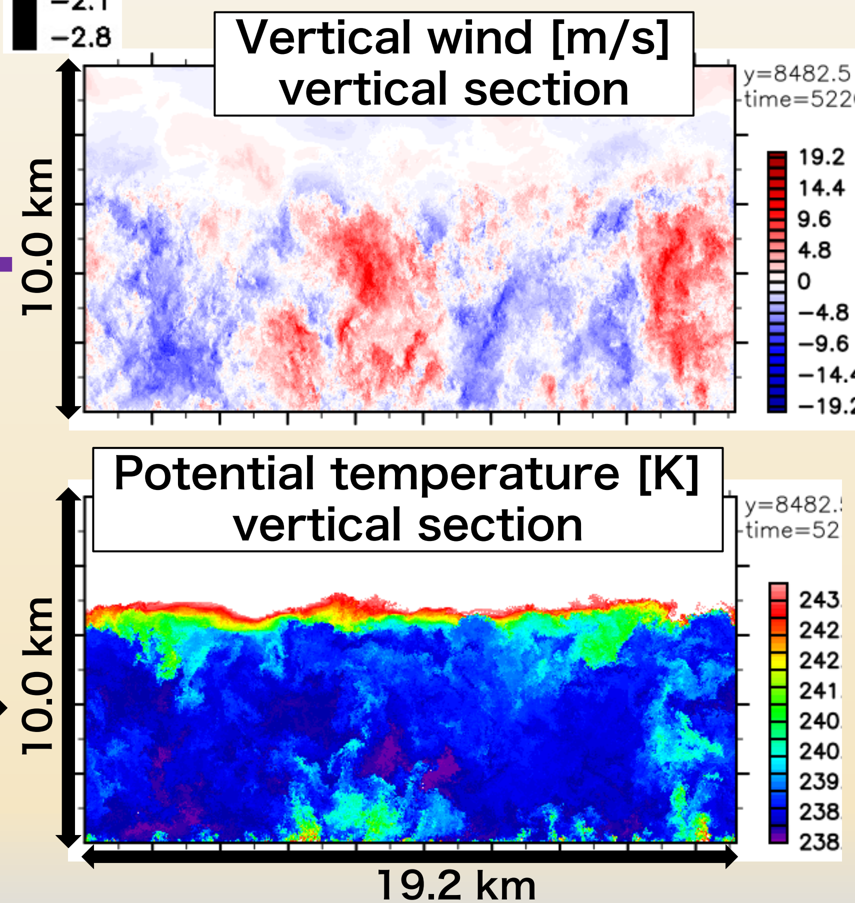


Upward wind region forms network-like structures.

Convective cellular structures

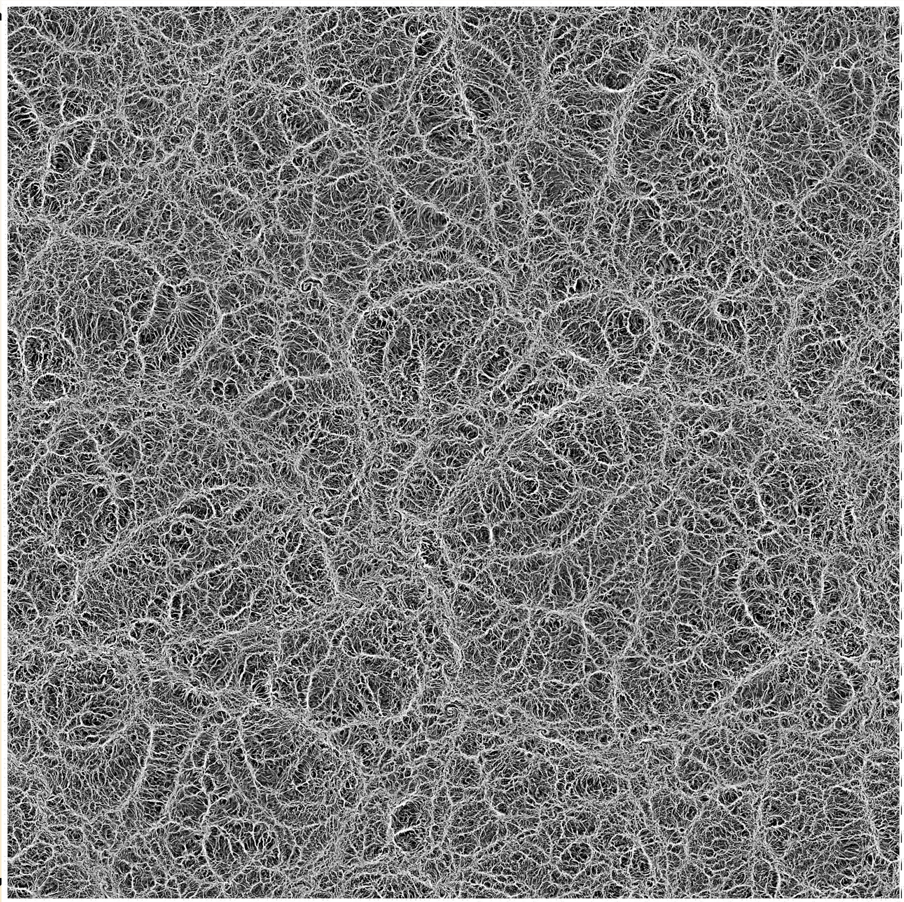
- Convective cell
  - Horizontal scale : Several kilometers
  - Vertical scale : about 6 km



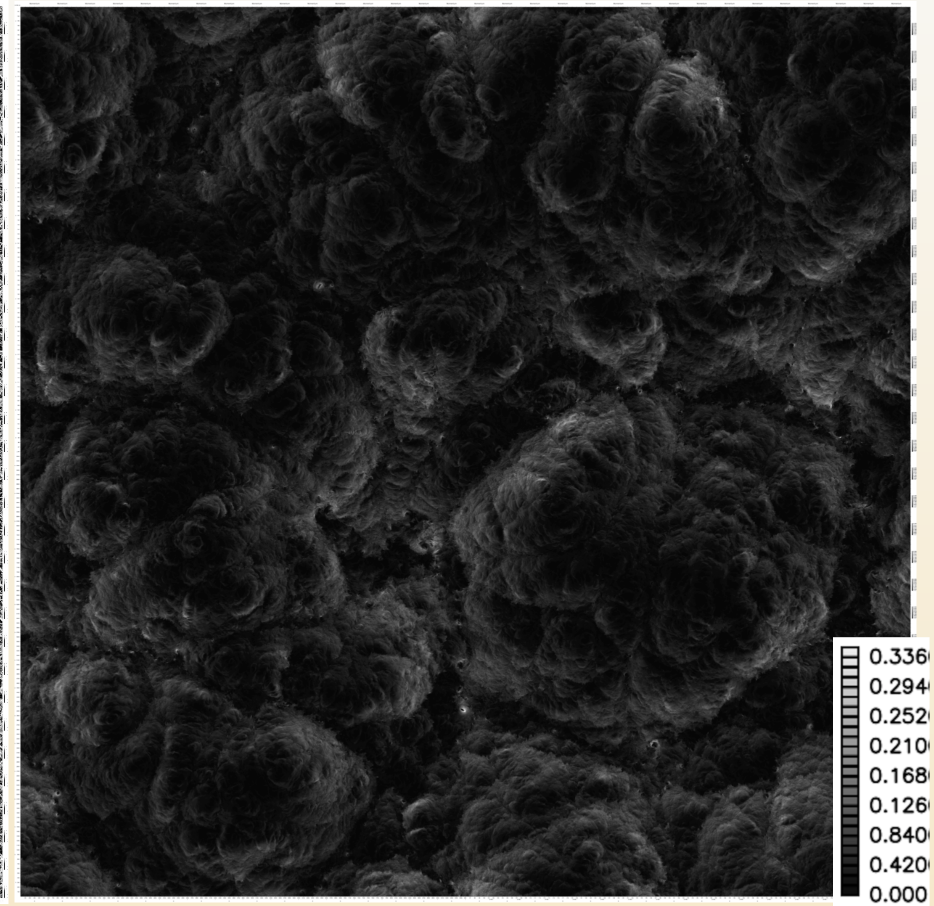


Surface wind stress

Vertical wind [m/s] (horizontal)



Surface wind stress [Pa] (horizontal)



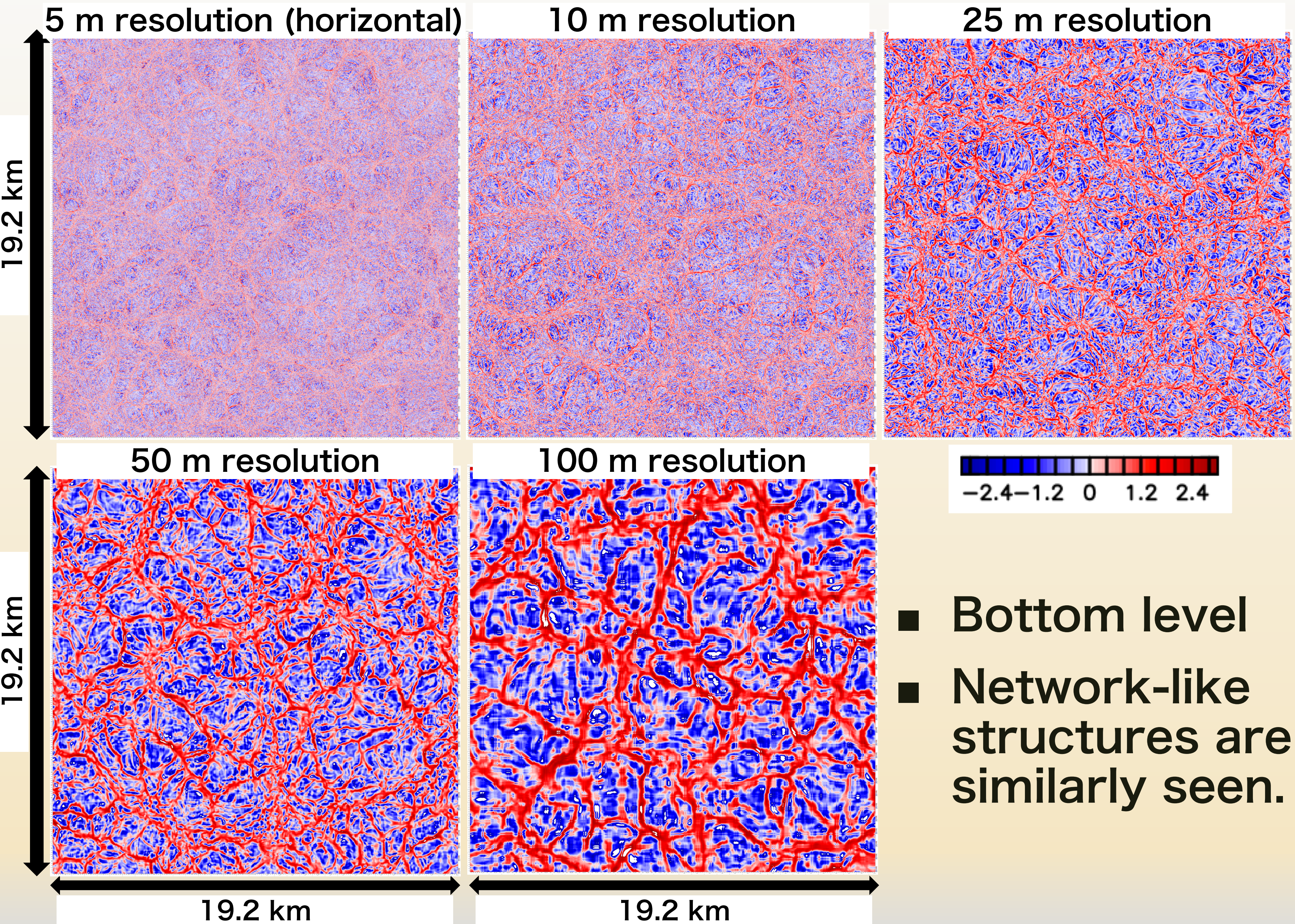
19.2 km

19.2 km

19.2 km

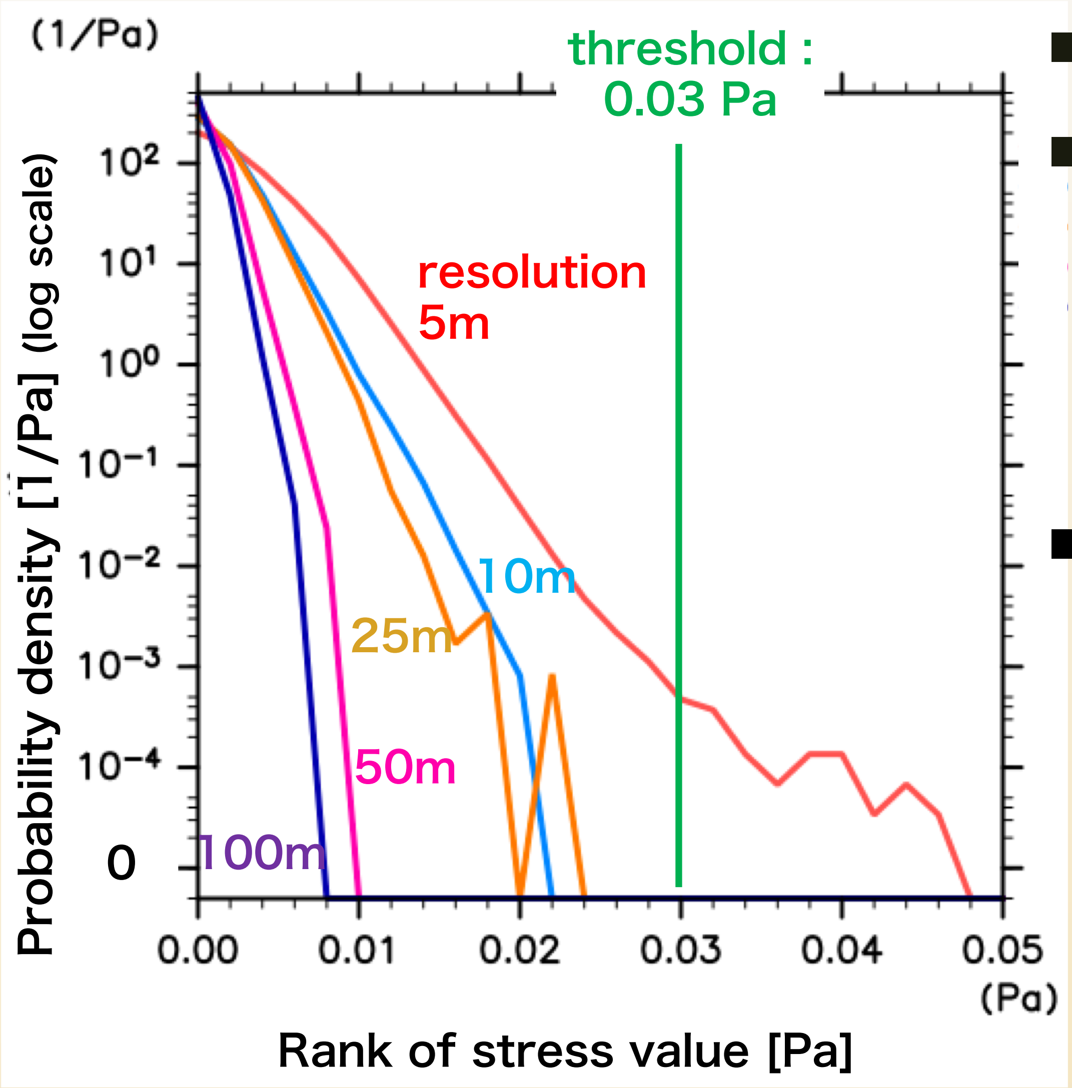
Wind stress tends to be strong near the convective cell boundary

Vertical wind fields of each simulation



- Bottom level
- Network-like structures are similarly seen.

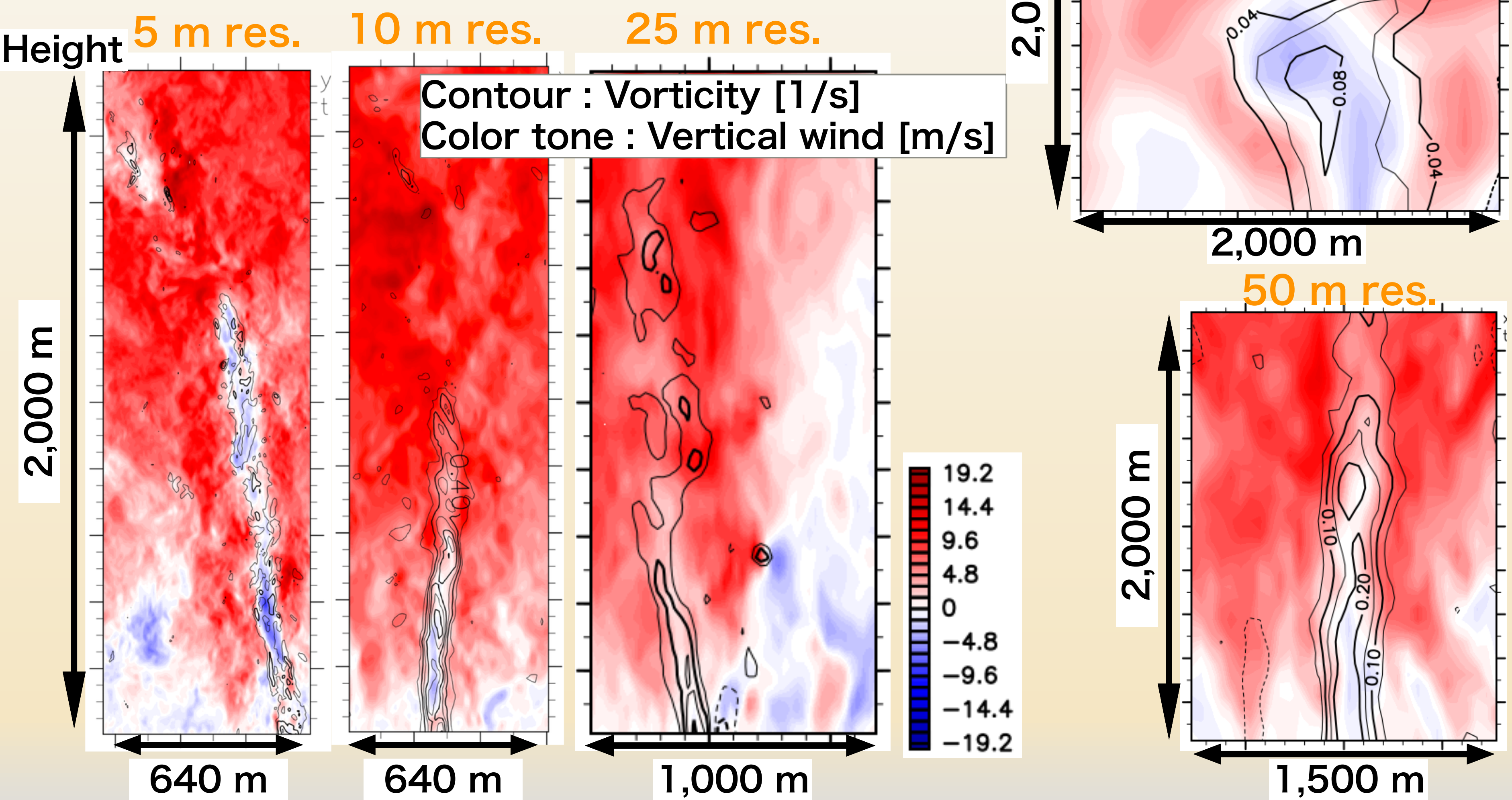
Surface stress probability density distribution



- Bin width : 0.002 Pa
- Result of 5 m resolution is greatly differs from those of more than 10 m resolution results.
- Only 5 m resolution result has the points exceeding threshold value.
  - Threshold value 0.03 Pa obtained by experimental results.
    (Greeley and Iversen, 1985)

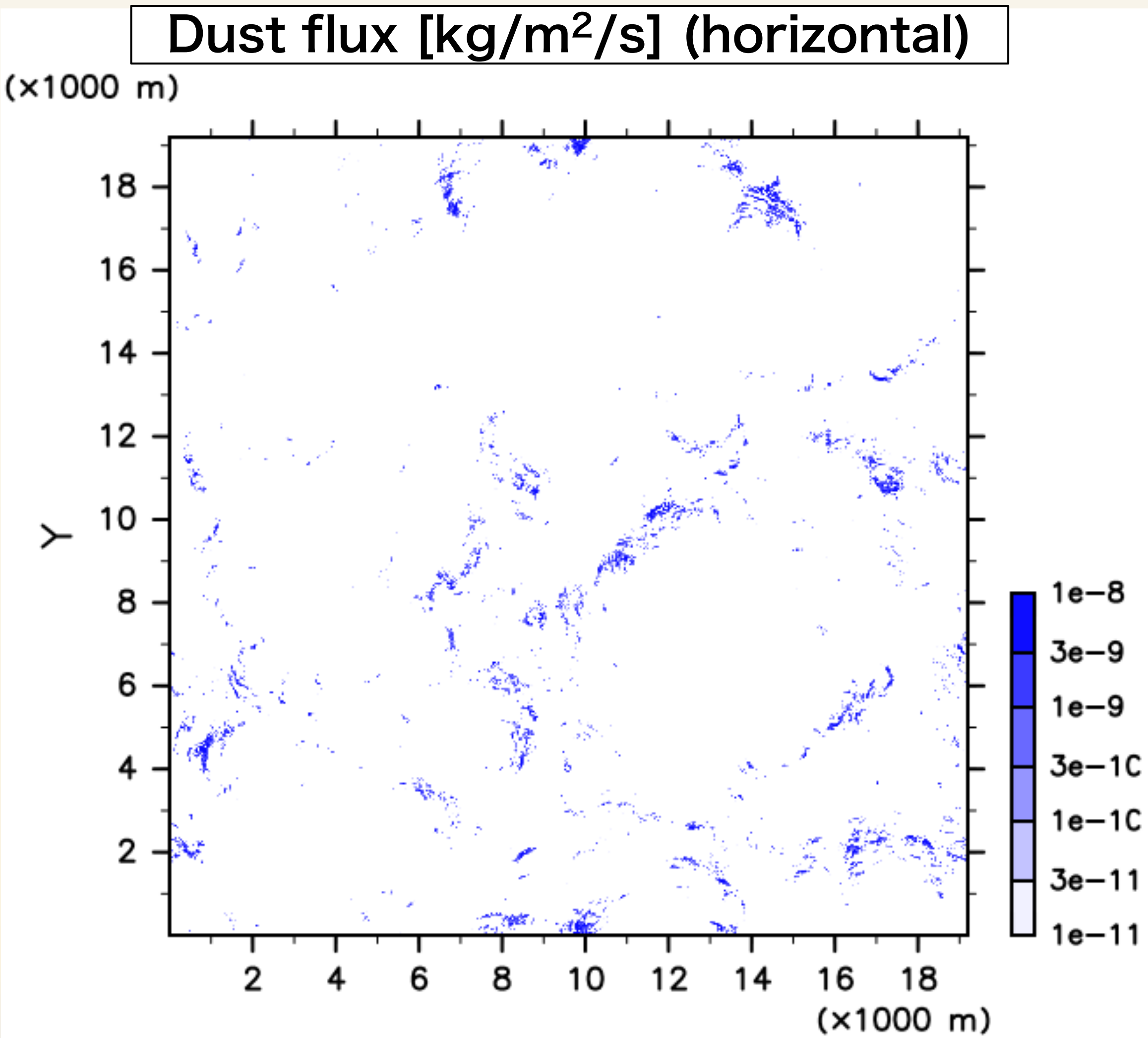
Wind structure associated with the strongest wind stress : vertical sections

- Isolated vortex taller than 1,000 m exists in each resolution.



Horizontal distribution of dust flux

- Dust flux is calculated using wind stress scheme (KMH scheme) of Kahre et al. (2006)



Horizontal averaged dust flux $[10^{-13}\ kg/(m^2\ s)]$

Resolution	5 m	10 m	25 m
Dust flux	391	2.89	3.64

- Adopted parameters
  - τ^* : 0.001 Pa
  - α_W : 0.02
- 5 m result has extraordinaly large dust flux

Summary

- Dust lifting parameterization schemes in MGCM have problems.
  - Schemes have been developed without considering details of wind structures.

- Our purpose is to reconsider schemes with examining wind structures.
- We are investigating high-resolution LES for considering validity of parameterization.
  - An isolated vortex taller than 1,000 m exists at the point with the strongest wind stress in each resolution result.
  - Only 5 m resolution result has the points exceeding threshold value of surface wind stress.

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