Idealized High-Resolution Simulations of a Back-Building Convective System that Causes Torrential Rain

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Speaker: Jo-Yu Wu

OUTLINE

1. Introduction
2. Numerical Setup
3. Simulation Results
4. Discussion
5. Conclusions

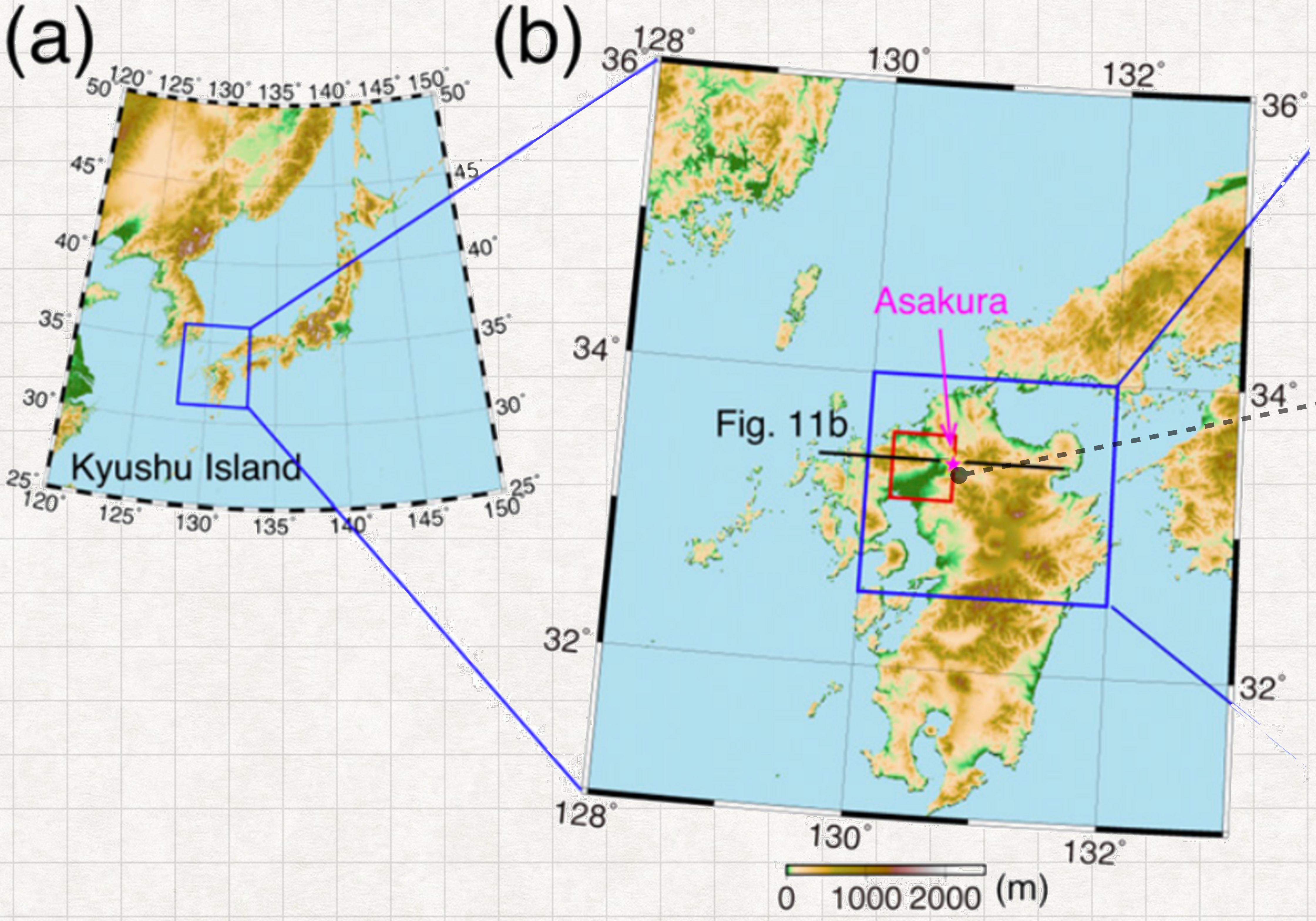
INTRODUCTION

BACKGROUND

- Torrential rainfall is often caused by a long-lived slow-moving quasi-linear convective system (QLCS).
- In a back-building QLCS, new cumulus clouds repeatedly develop up-stream of the preceding clouds.
- A back-building QLCS may persist for several hours.
- It is difficult for current operational models to precisely predict time and location of their occurrence and amount of precipitation. (Kato 2020)
- A large fraction of the quasi-stationary QLCSs occurred over Kyushu (九州) Island in the southwestern part of Japan. (Unuma and Takemi 2016)

INTRODUCTION

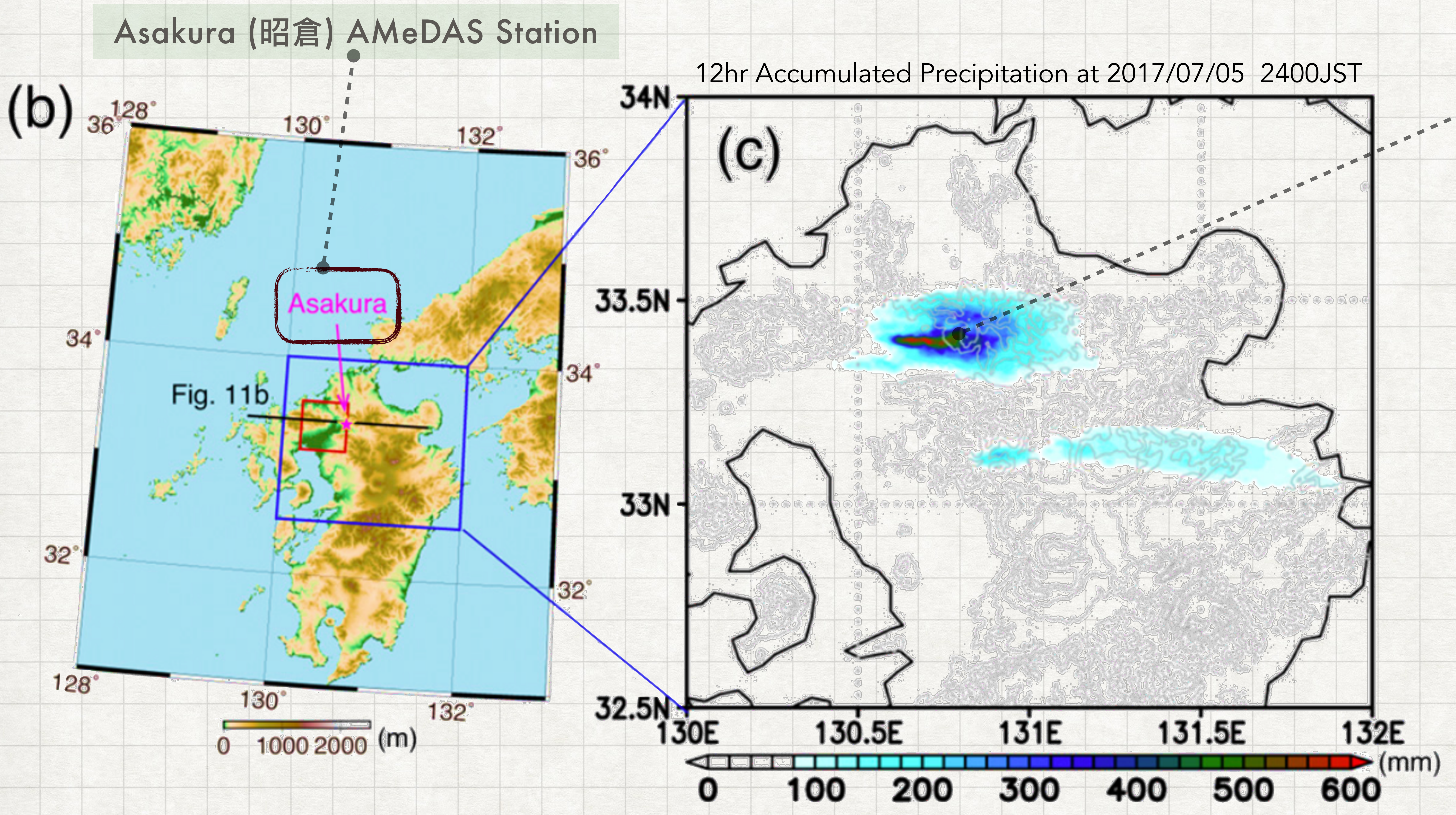
REGION DESCRIPTION



Kyushu Island is exposed to warm moist westerly or southwesterly flow from the East China Sea during the summer.

INTRODUCTION

CASE DESCRIPTION: 2017/07/05(KH2017)



The torrential precipitation over **K**yushu-**H**okubu（北部九州）on 5 July **2017(KH2017)** was record-breaking.

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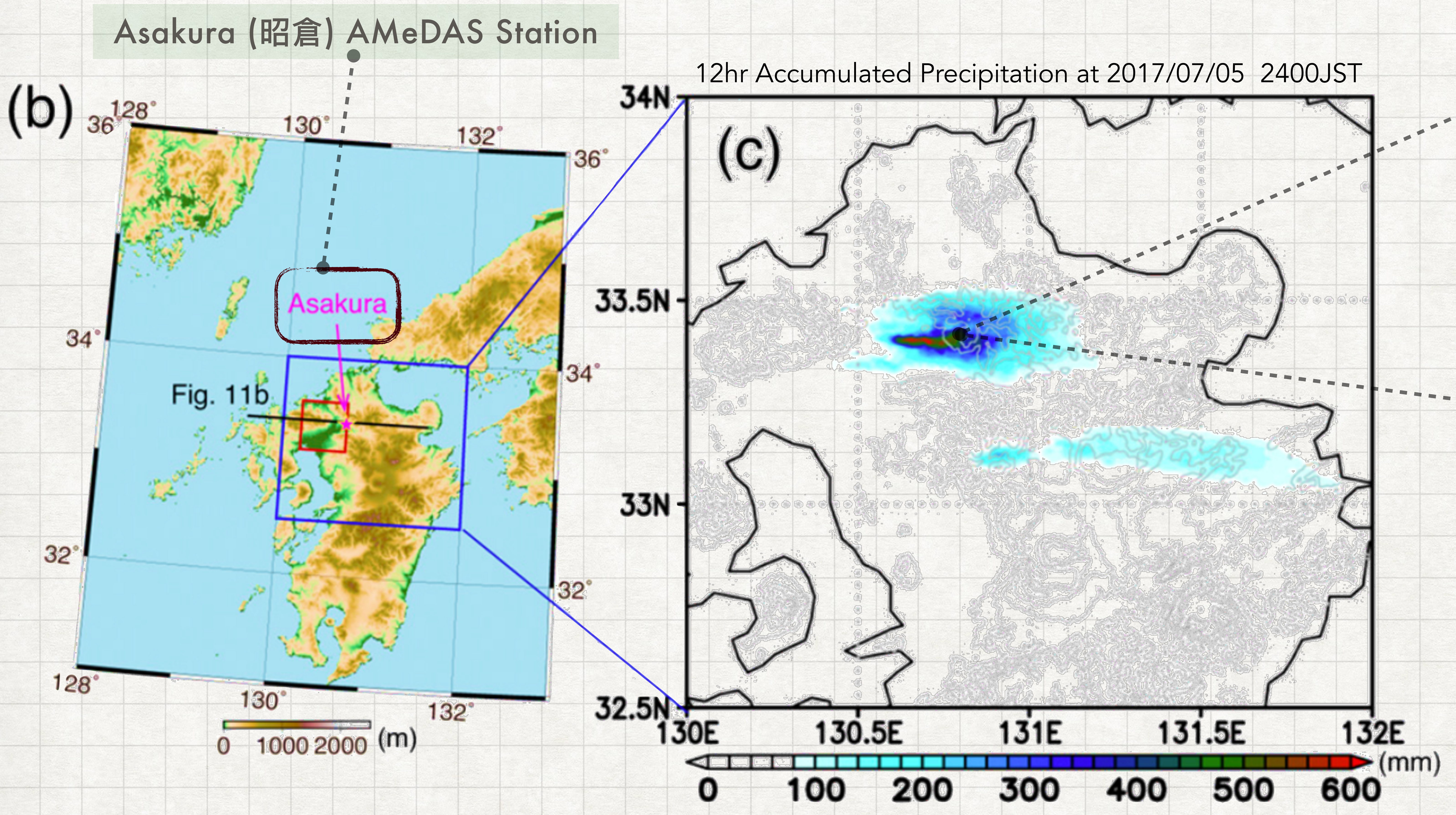

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It was **not** forecasted that the record-breaking rainfall would occur in Kyushu.

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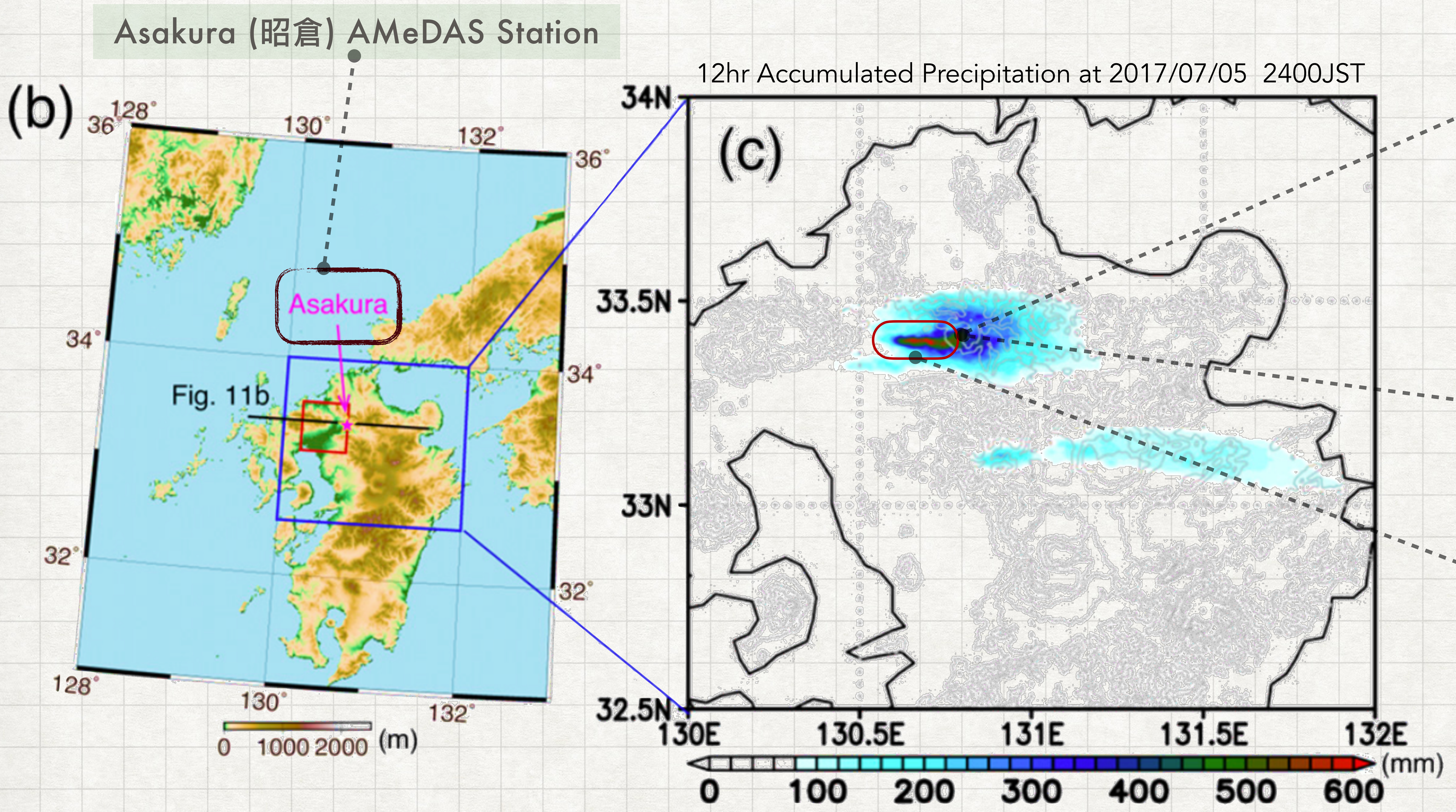

The torrential precipitation over **K**yushu-**H**okubu（北部九州）on 5 July **2017(KH2017)** was record-breaking.

It was **not** forecasted that the record-breaking rainfall would occur in Kyushu.

The heavy rainfall was localized in a small area:

~20km in west-east

~5km in south-north

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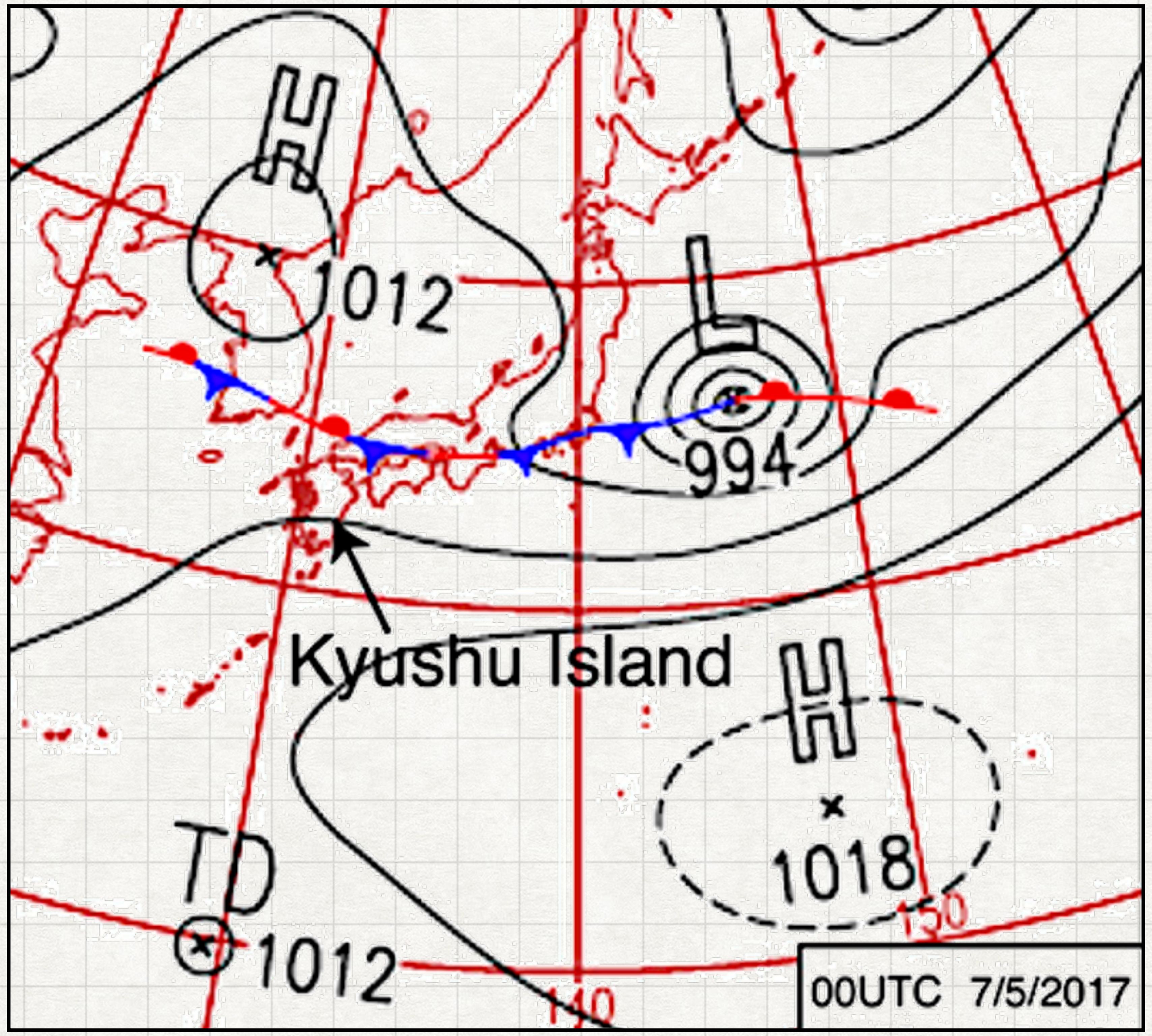
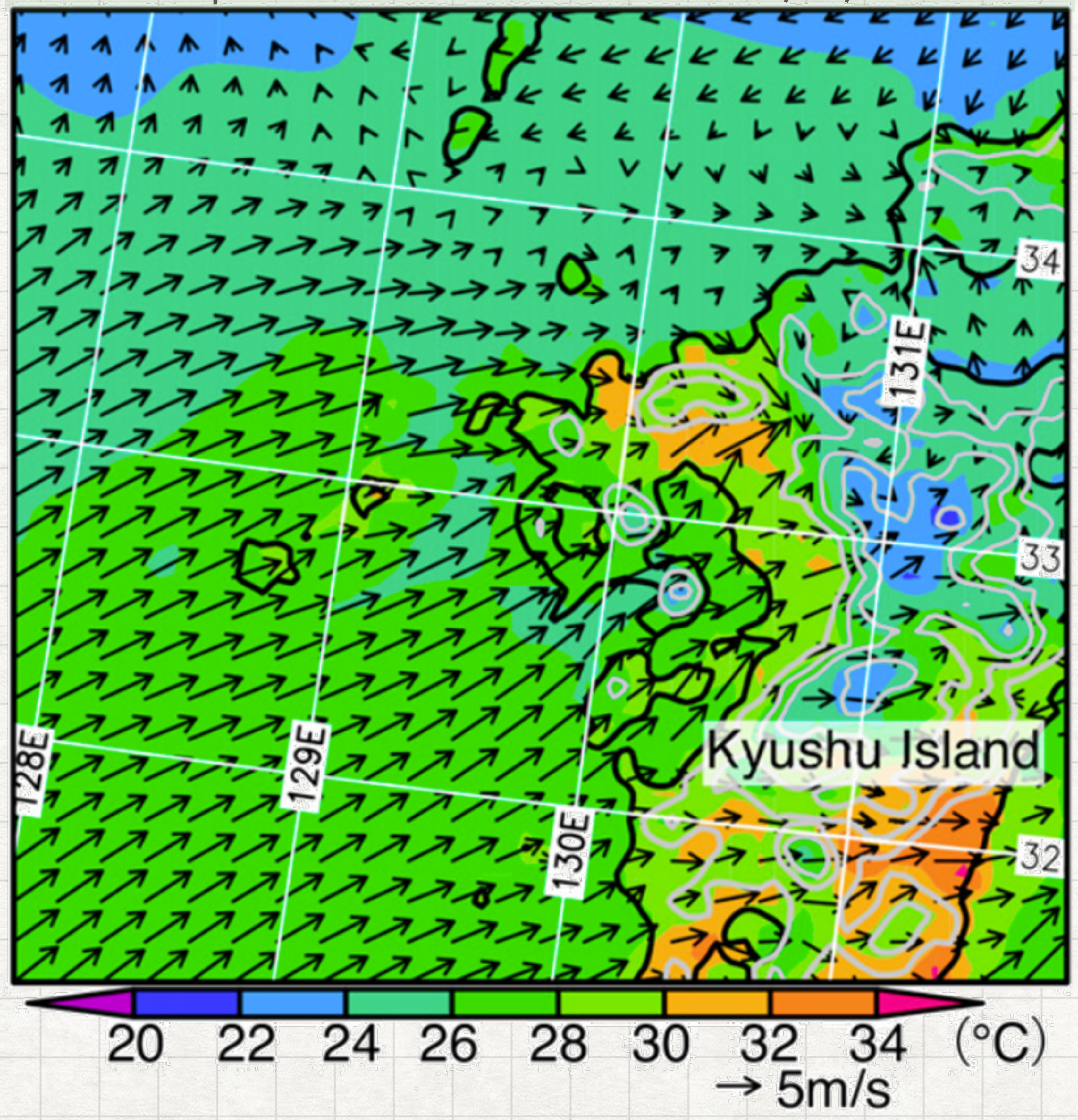


Surface Temperature and Wind Vectors at 2017/07/05 1500 JST



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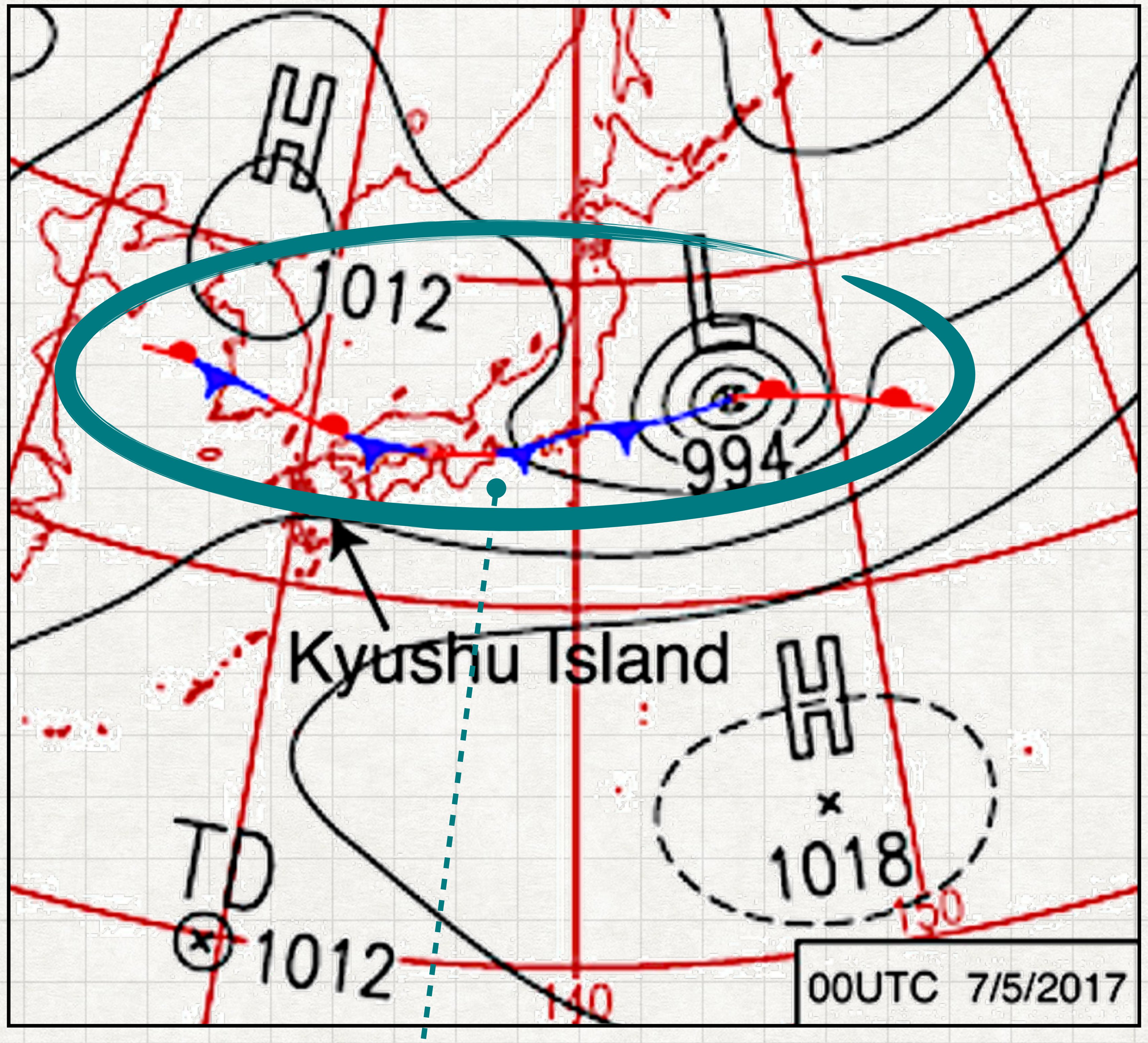
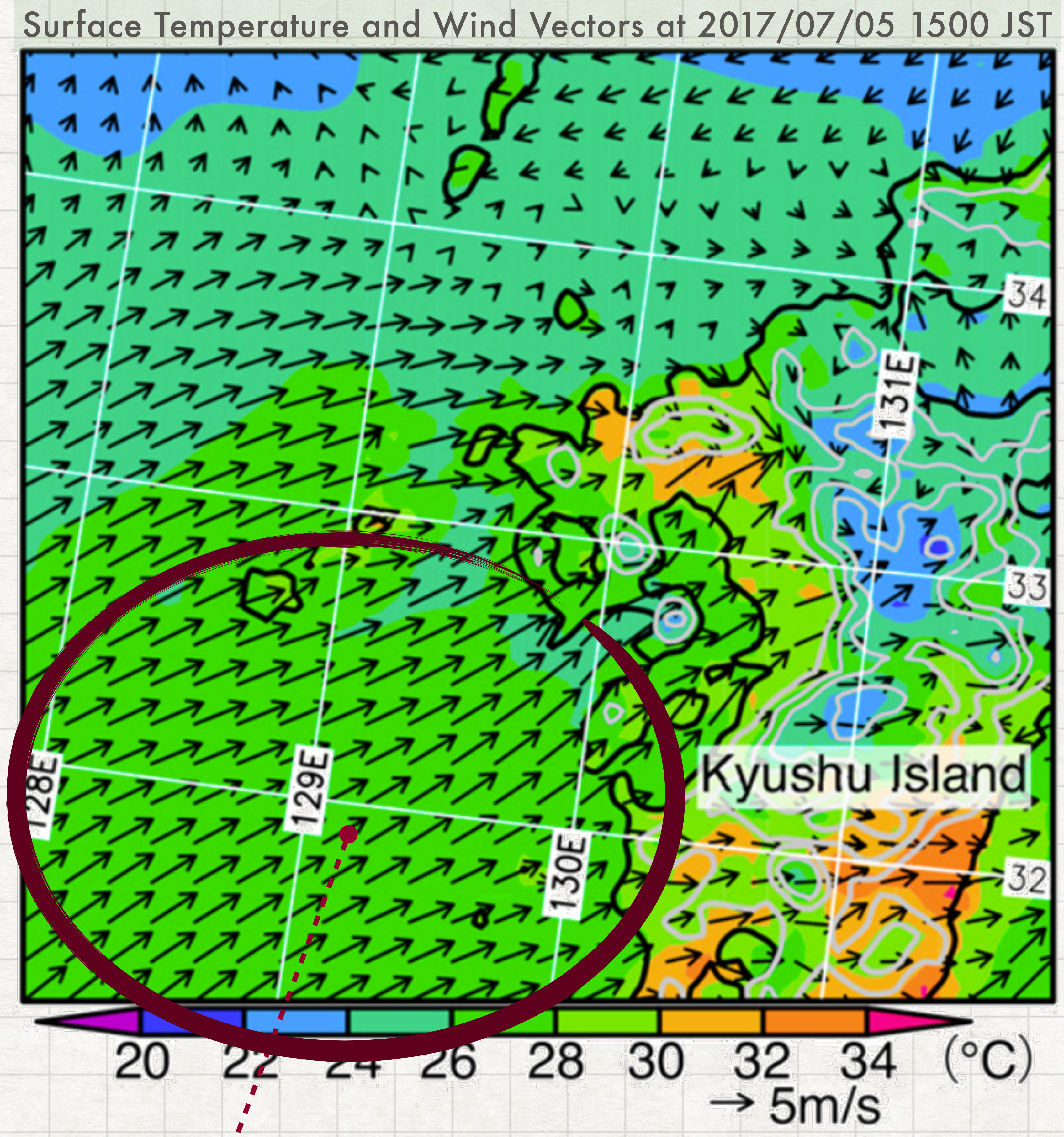


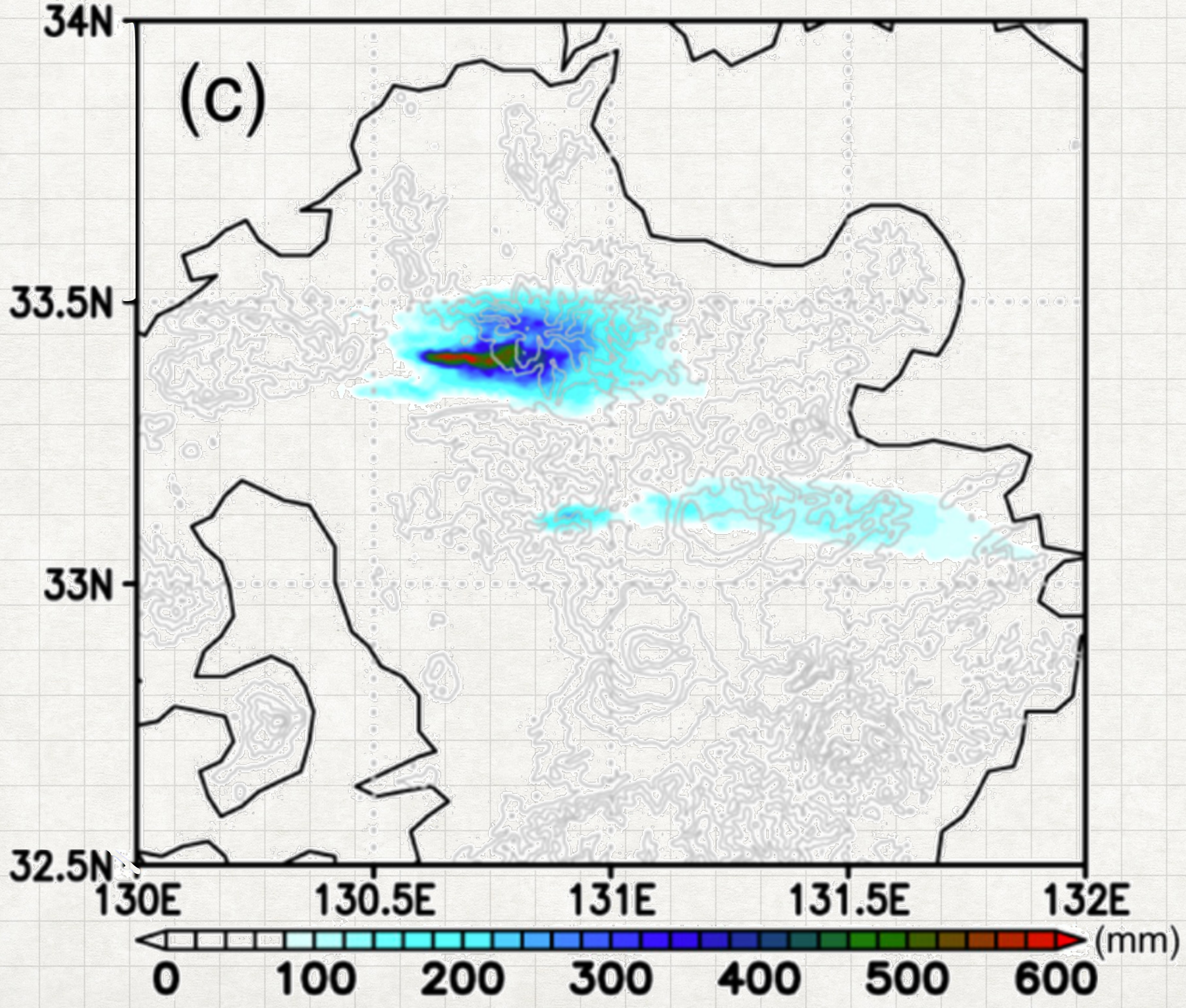


A stationary front to the north of Kyushu Island

A humid southwesterly flow toward the front

INTRODUCTION

ARGUMENTS



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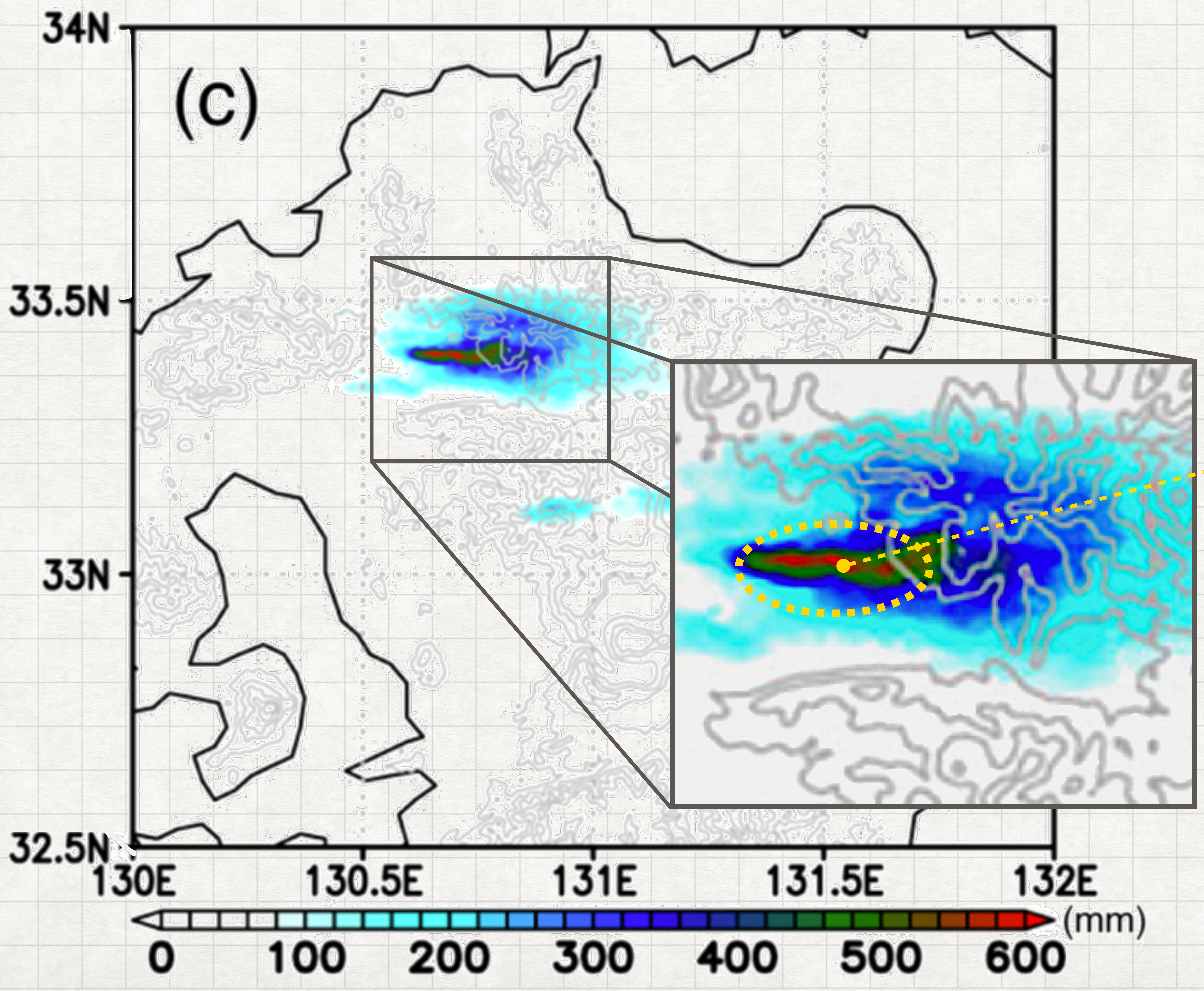
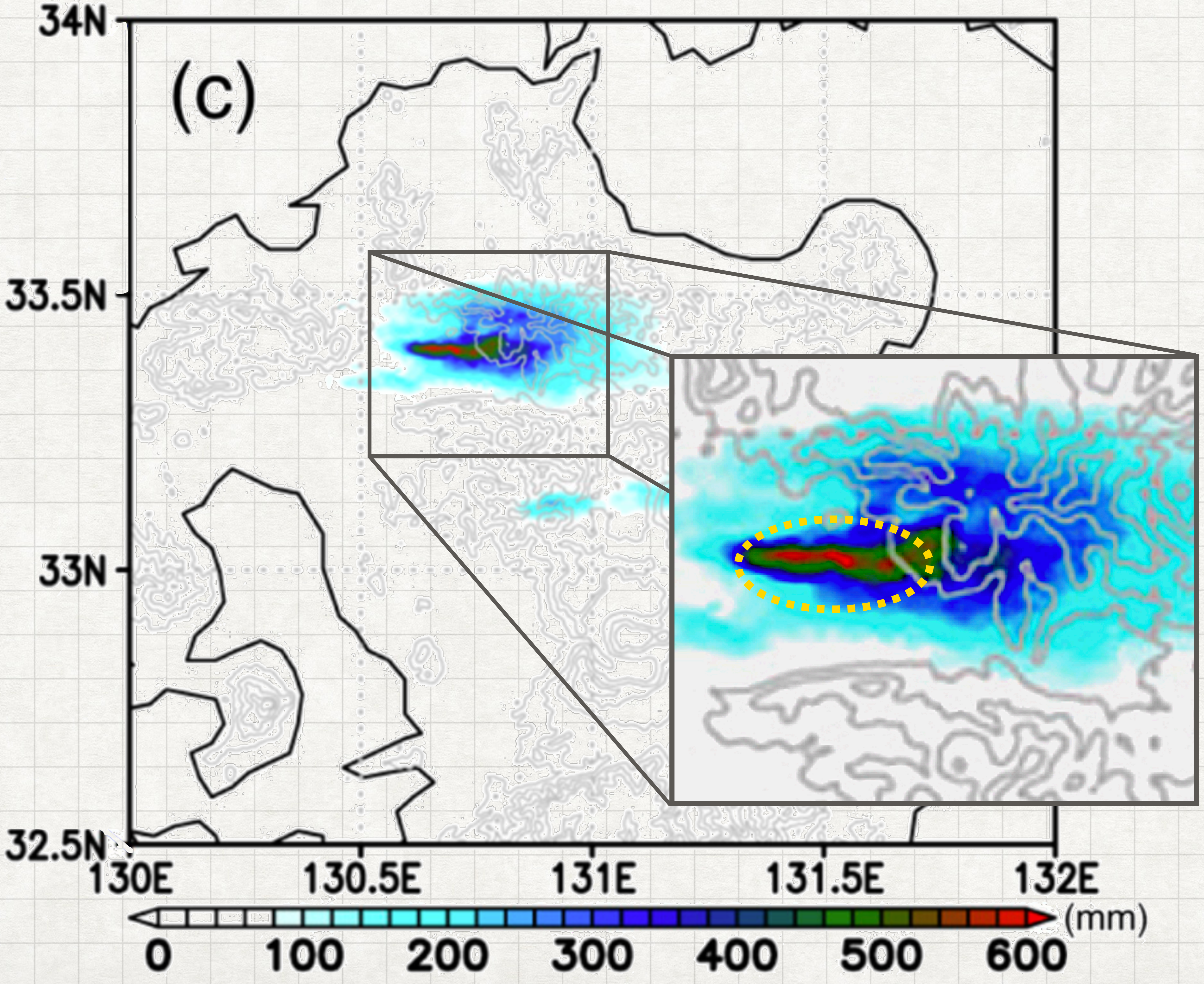


The maximum precipitation in the KH2017 event occurred at the valley bottom.

INTRODUCTION

ARGUMENTS



Including detailed topography in a numerical model may be a key to accurate prediction of the location and precipitation of the QLCS in the KH2017 event. (Takemi 2018)

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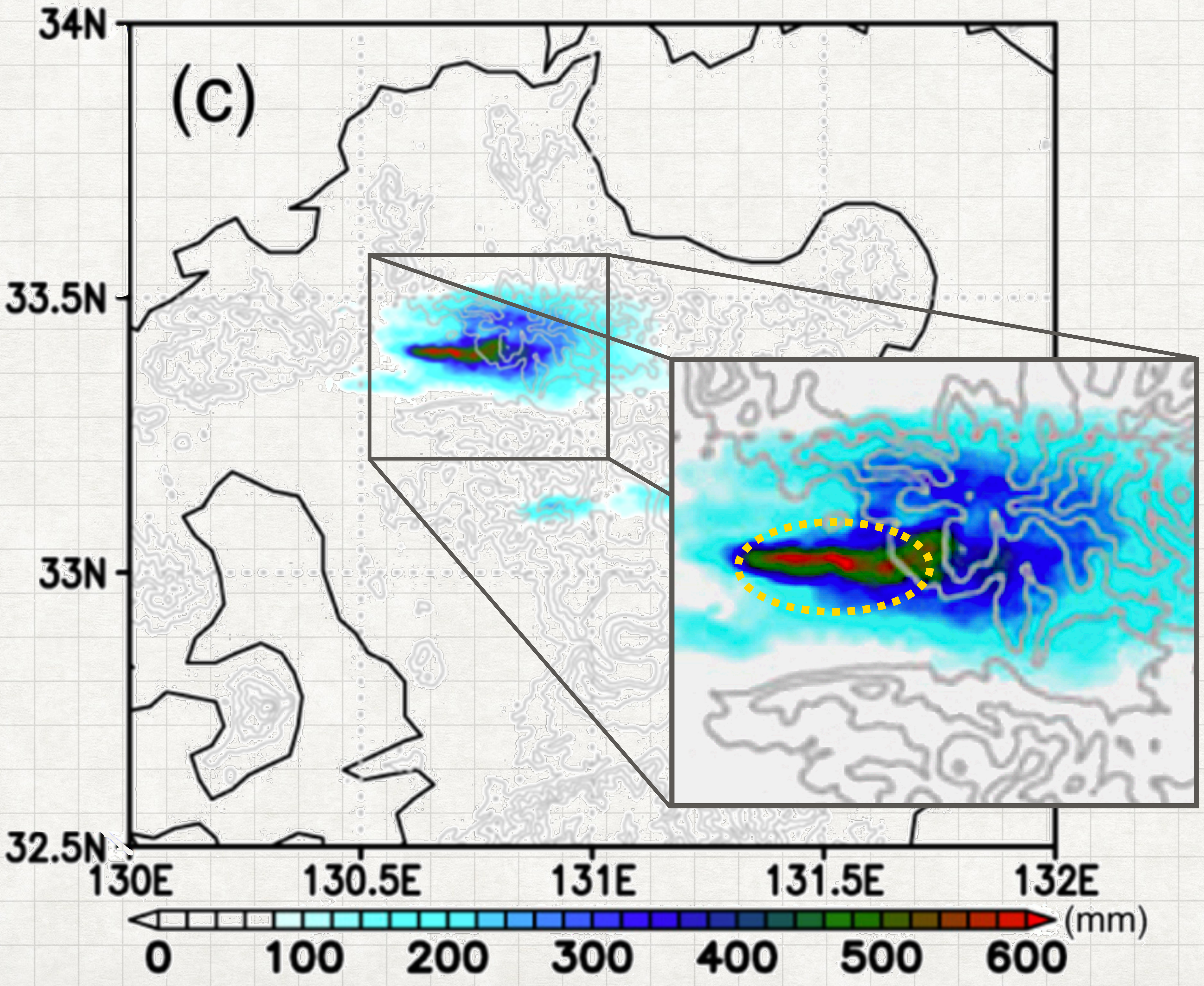
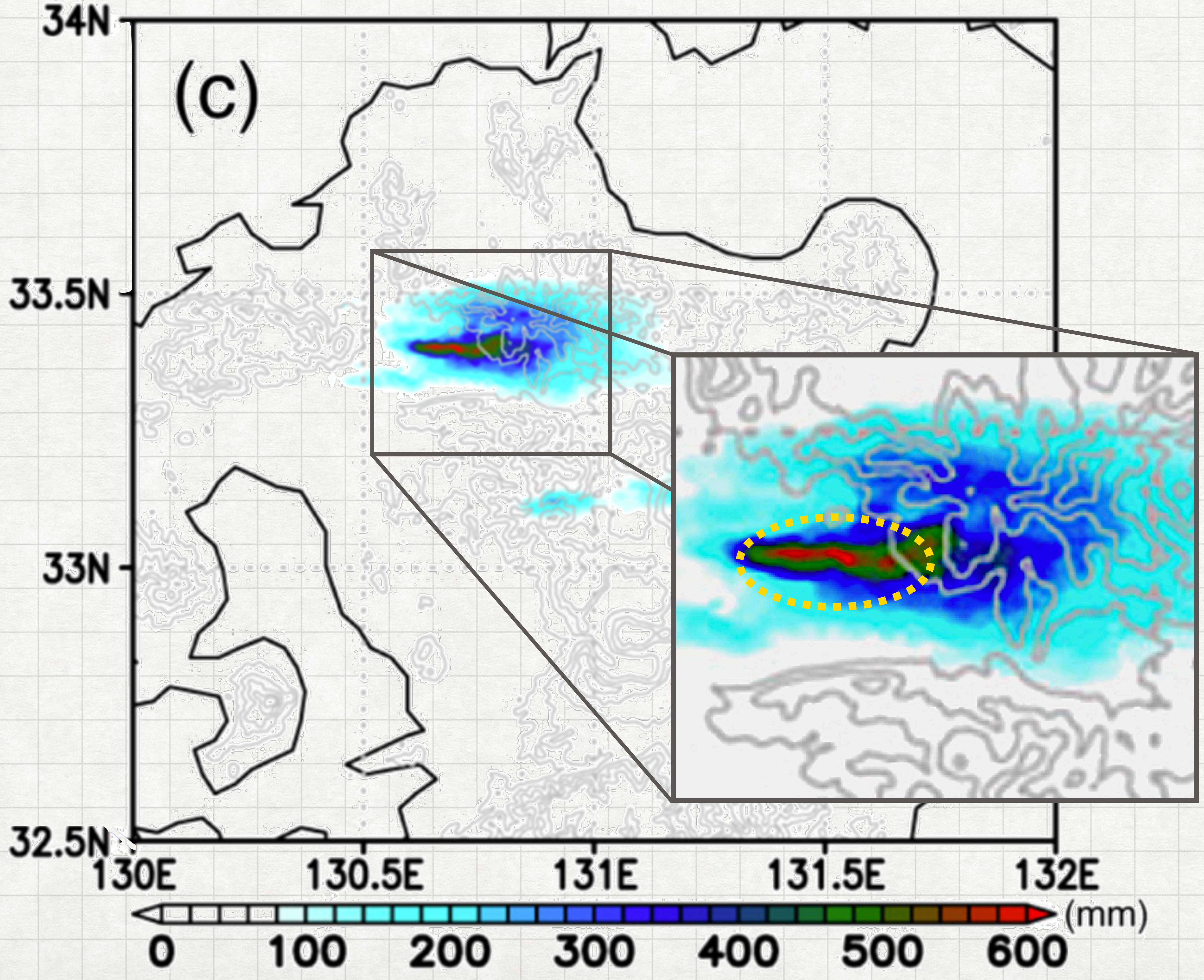


Including detailed topography in a numerical model may be a key to accurate prediction of the location and precipitation of the QLCS in the KH2017 event. (Takemi 2018)

The quasi-stationary QLCS formed even in the absence of the topography of northern Kyushu Island, so that the topography does not seem to be a critical factor for the present QLCS. (Tsuguti 2019; Kawano and Kawamura 2020)

INTRODUCTION

ARGUMENTS



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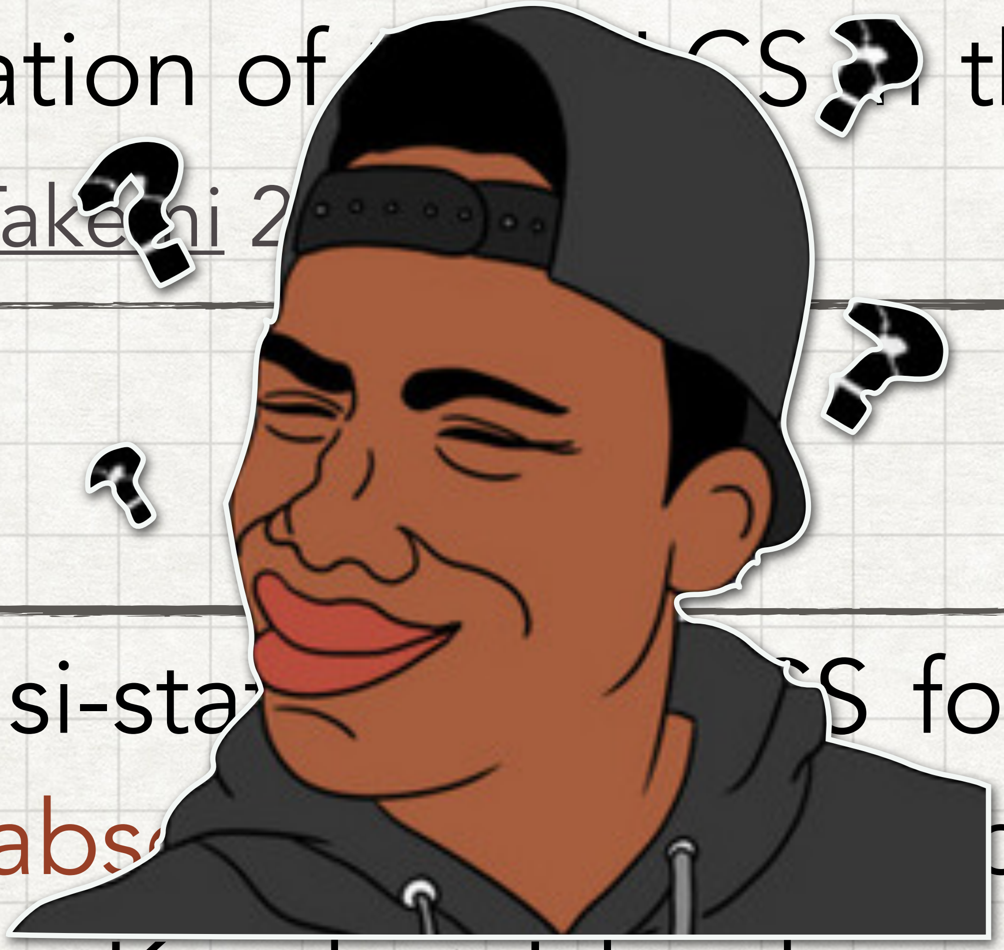

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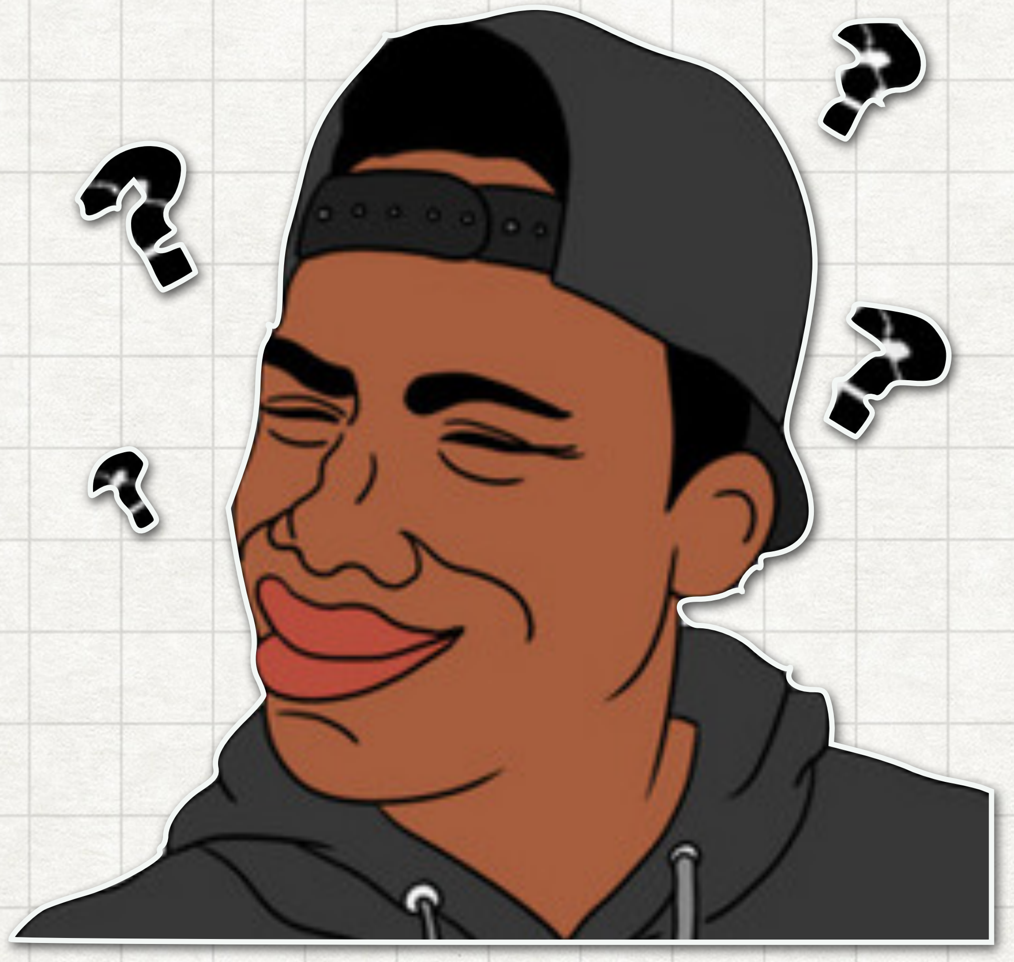
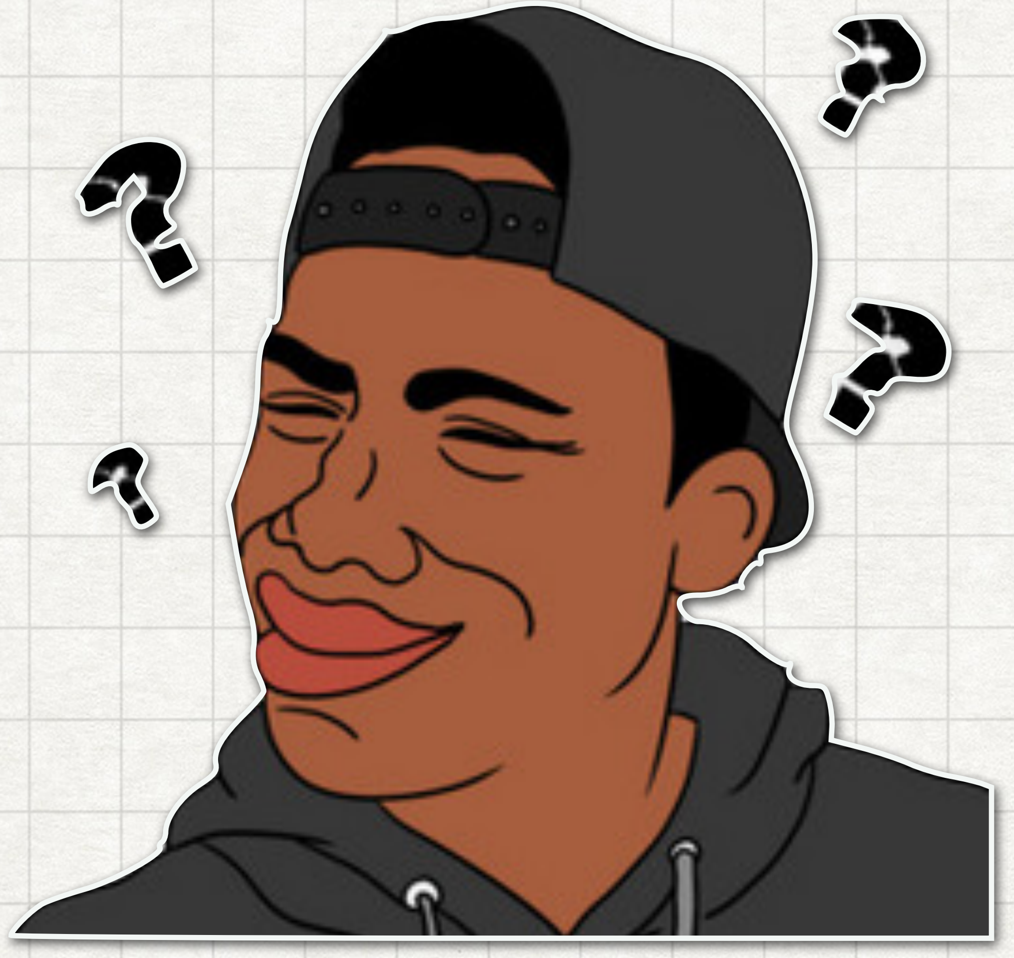


INTRODUCTION

ARGUMENTS

A cold pool was not essential to maintain the quasi-stationary QLCS.

(Tsuguti 2019; Kawano and Kawamura 2020)



INTRODUCTION

ARGUMENTS

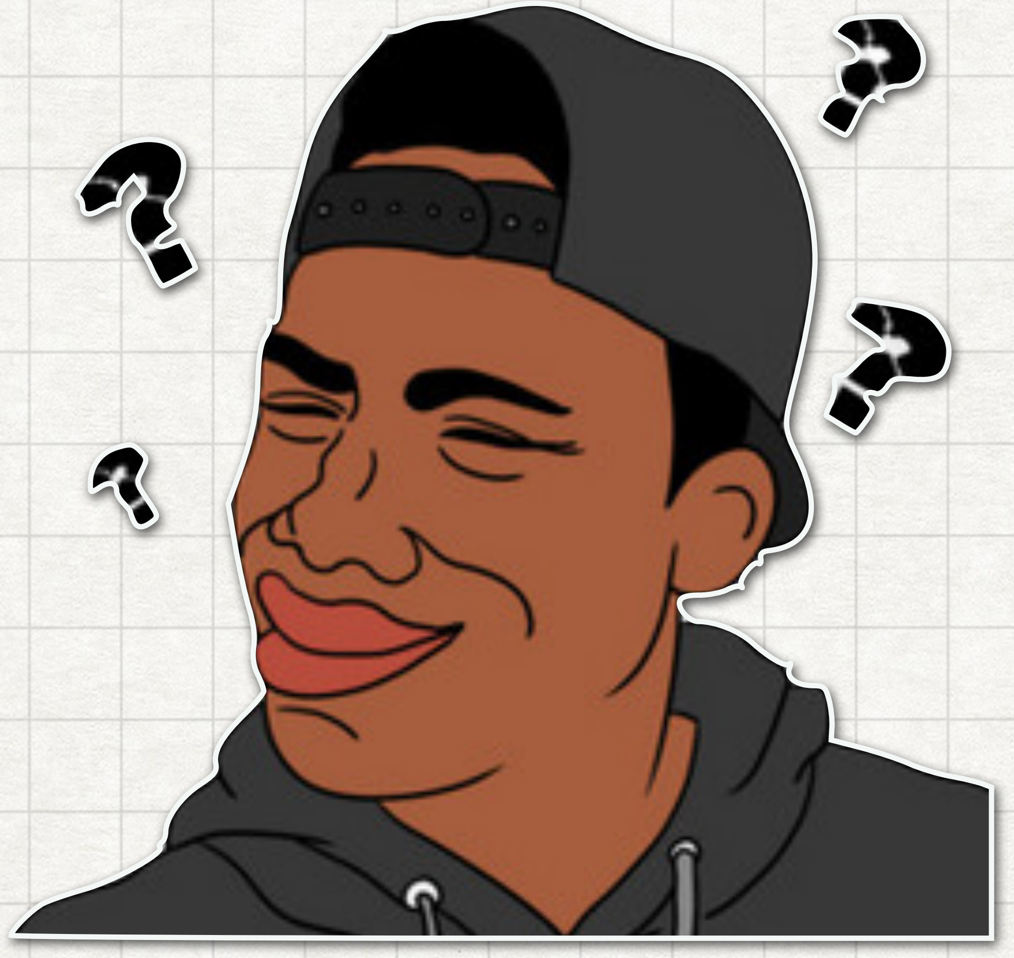
A cold pool was not essential to maintain the quasi-stationary QLCS.

(Tsuguti 2019; Kawano and Kawamura 2020)

It is generally considered that quasi-stationary QLCSs may be caused by larger-scale forcing such as a mesoscale convective vortex.

(Unuma and Takemi 2016)

⇢ Such forcing was absent in the KH2017 case.



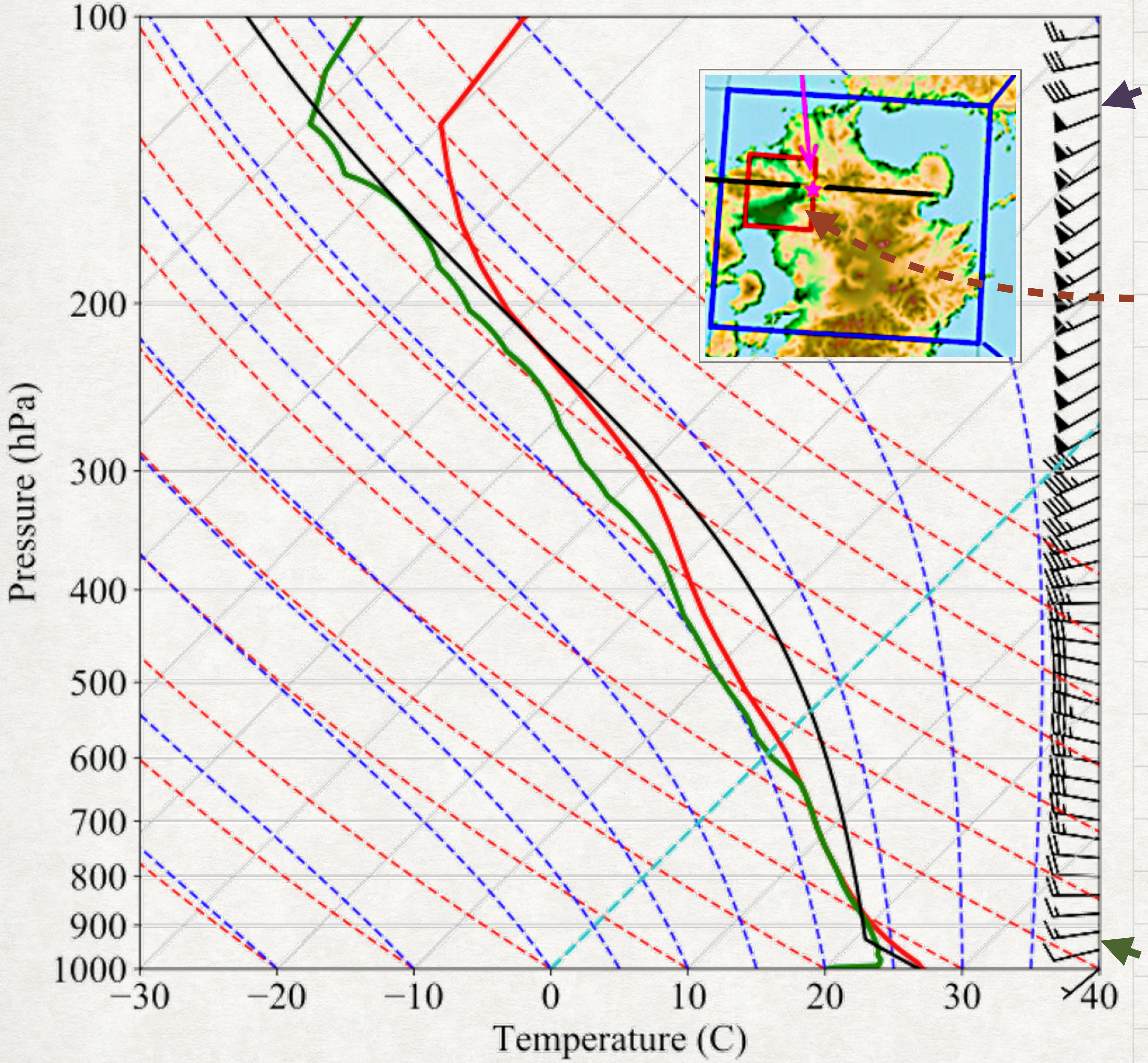
NUMERICAL SETUP

MODEL SETTING

Model	JMA Non-Hydrostatic Model (JMA-NHM) (Saito et al. 2006, 2007)
Settings	Horizontally Explicit and Vertically Implicit (HE-VI) Scheme
	Three-Ice Single-Moment Bulk Scheme (Lin et al. 1983; modified by Ikawa and Saito, 1991)
	Simple Local Closure for the Turbulence Parameterization (Deardorff 1971)
	Bulk Method for the Surface Flux of Momentum, Sensible Heat, and Moisture (Beljaars And Holtslag 1991)
	Coriolis Force (Not Considered)

NUMERICAL SETUP

SOUNDING

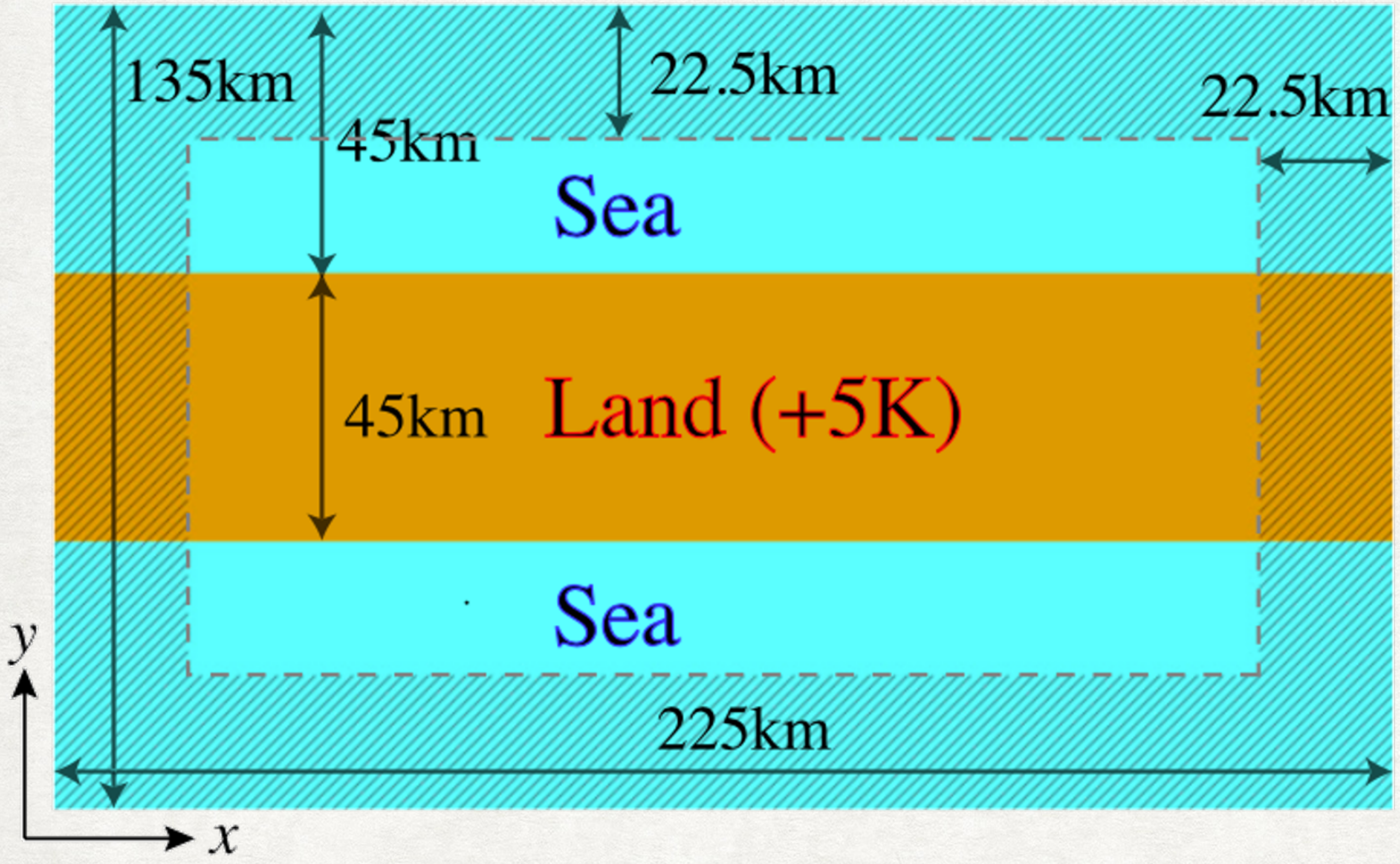


The sounding is obtained by averaging the JMA 5-km-mesh mesoscale analysis at the time of peak torrential rain (2017/07/05 1500 JST) over the red box.

PROPERTIES	
CAPE	2717 J/kg
CIN	~3 J/kg
LCL	459 m
LFC	689 m

NUMERICAL SETUP

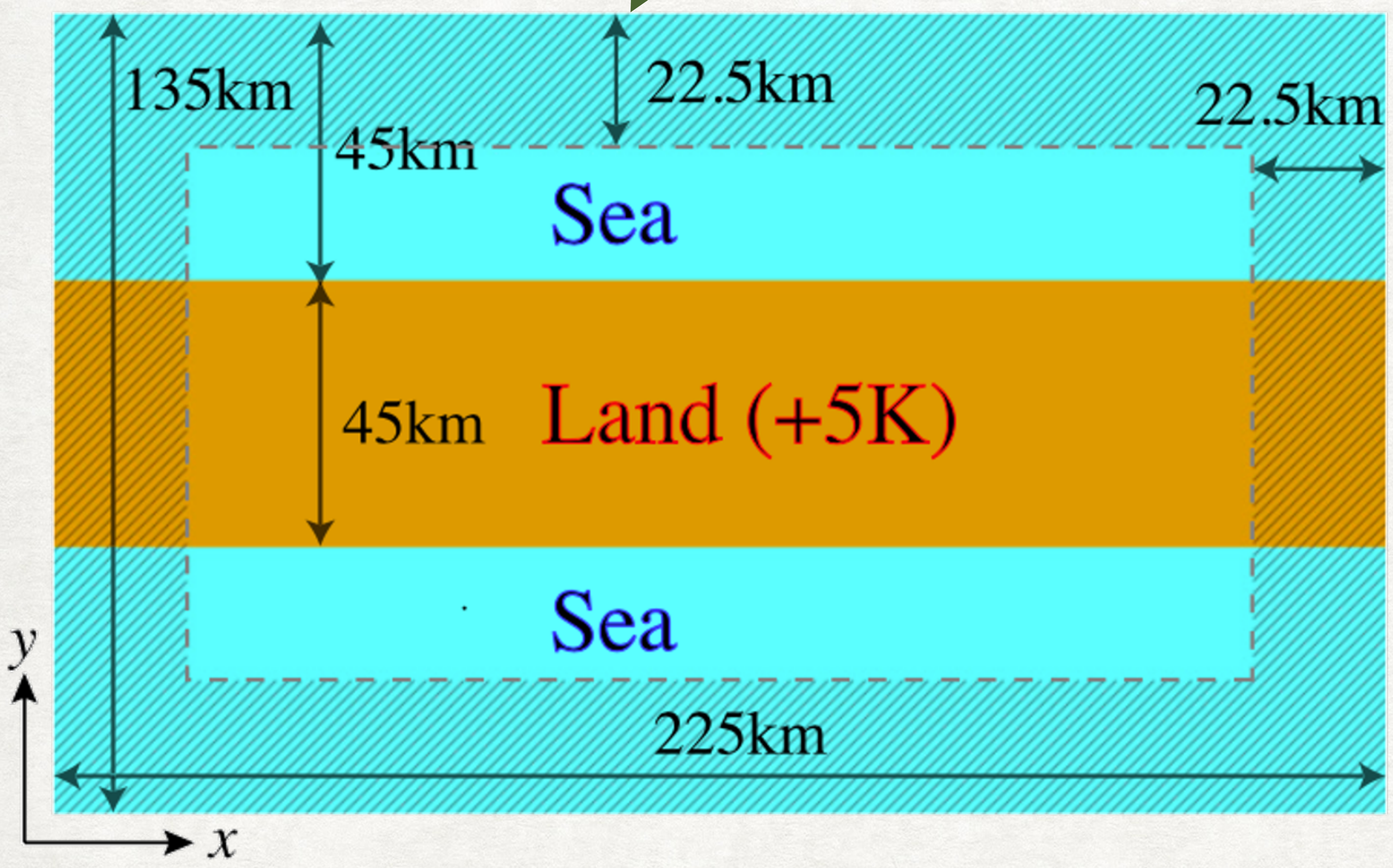
DOMAIN



NUMERICAL SETUP

DOMAIN

X	225 km	Opened BC Sponge layer: hatched area
Y	135 km	
Z	19.3 km	Sponge layer: top 10 layers



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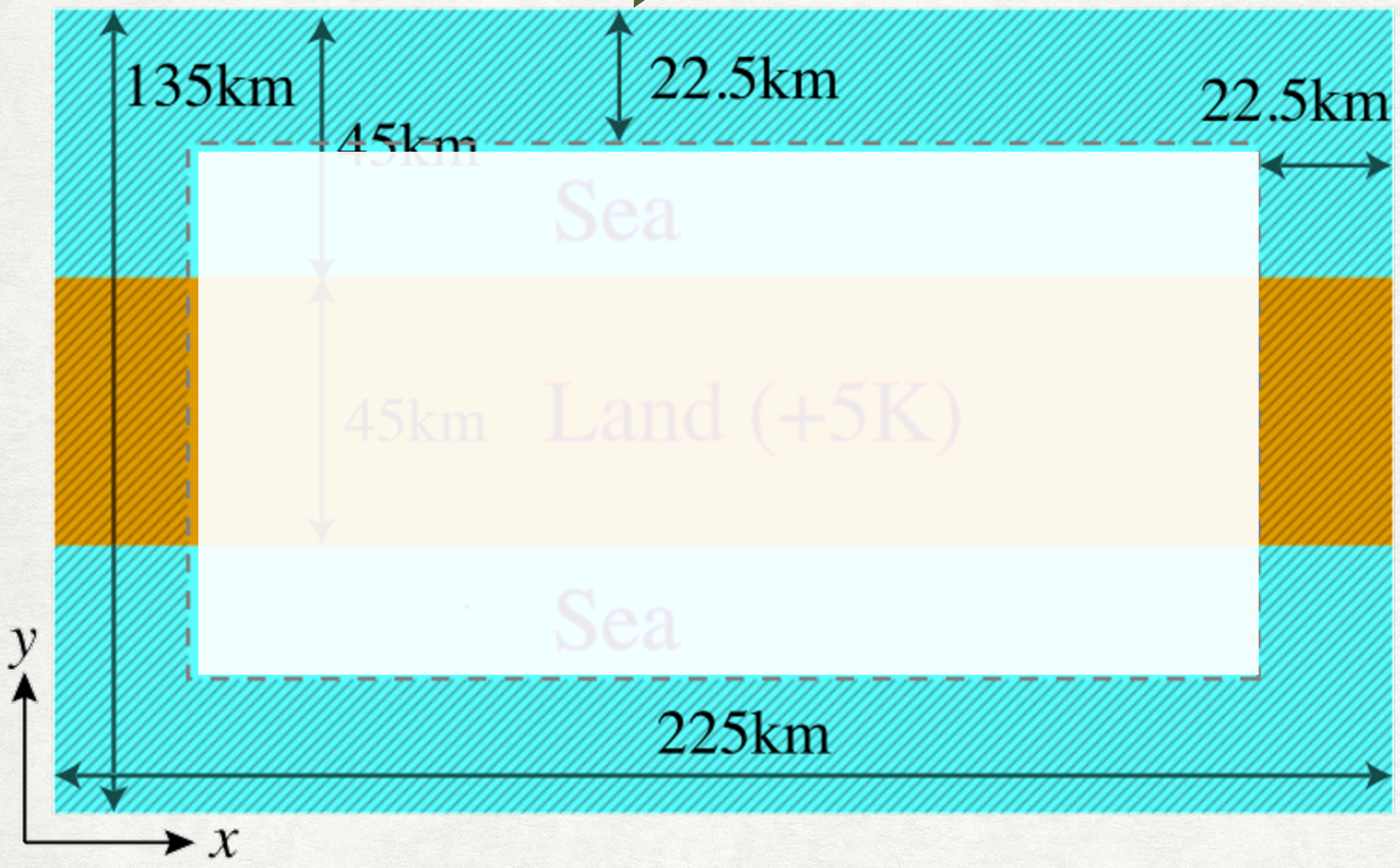

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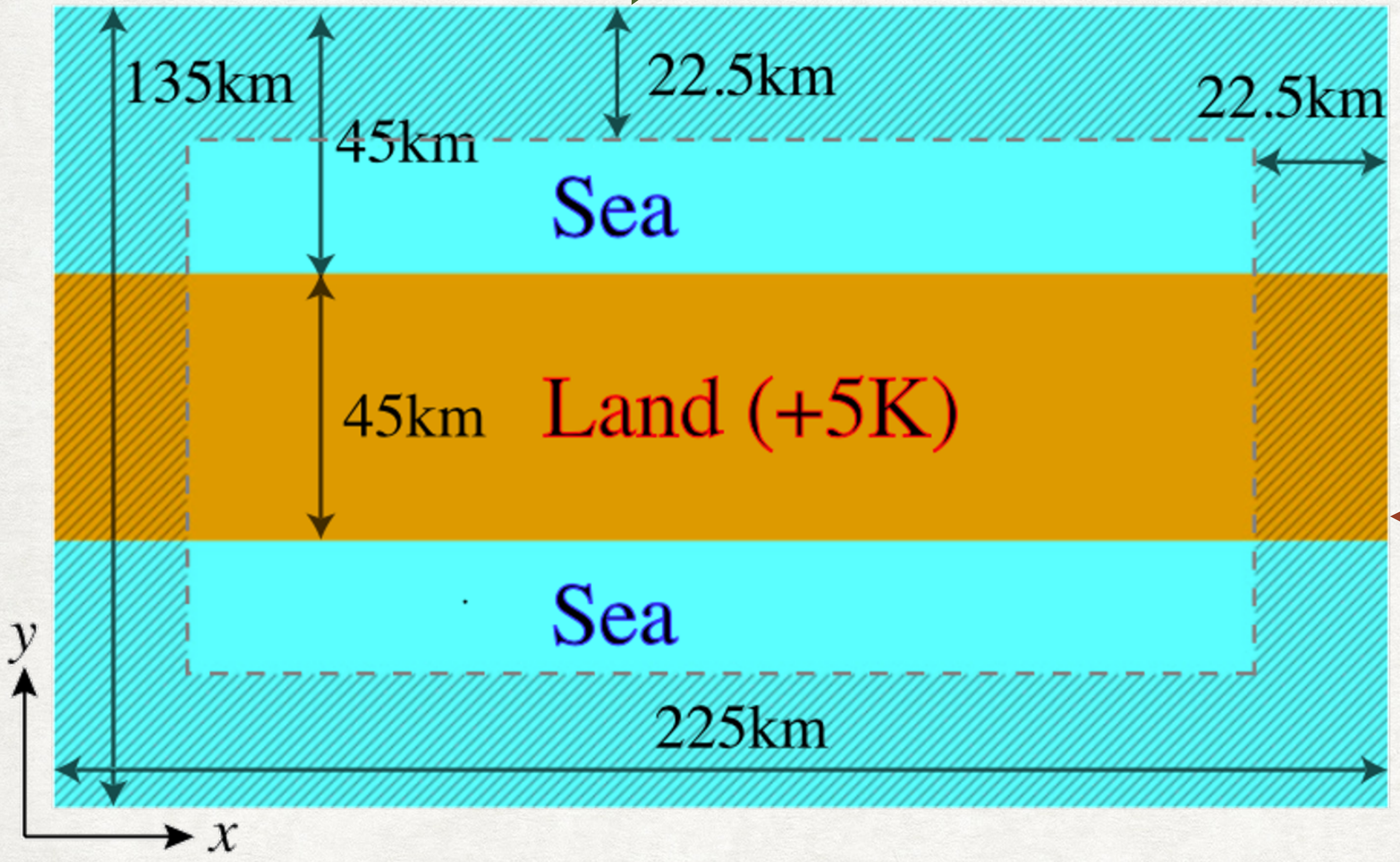

DAYTIME SITUATION	
SEA	T (the lowest layer of the sounding)
LAND	T **+5K**

NUMERICAL SETUP

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X	225 km	Opened BC Sponge layer: hatched area
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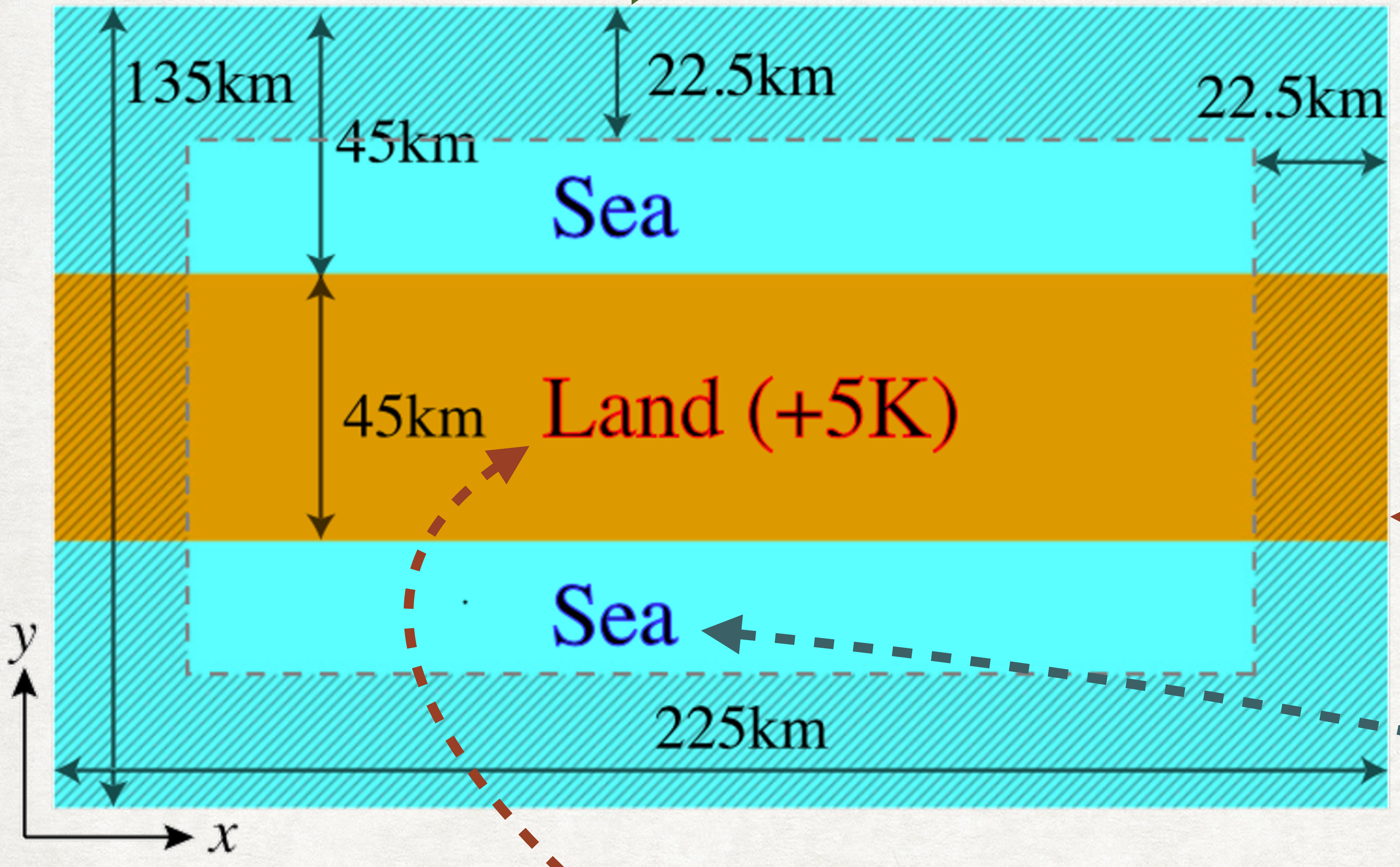


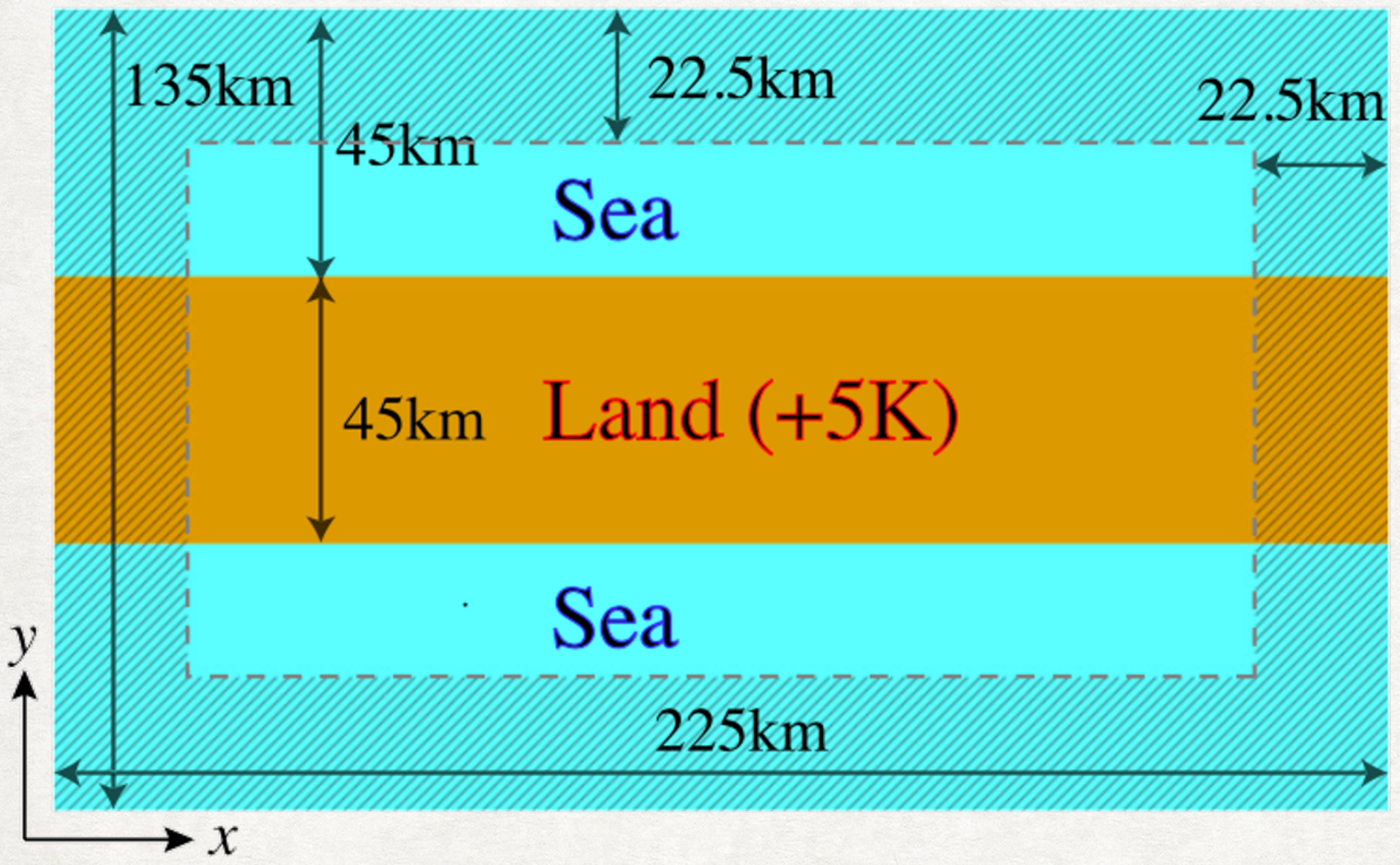
DAYTIME SITUATION	
SEA	T (the lowest layer of the sounding)
LAND	T **+5K**

A flat land surface (no topography)
Roughness length = 0.1 m

Roughness length of the ocean surface depends on wind speeds.
(Beljaars 1995)

NUMERICAL SETUP

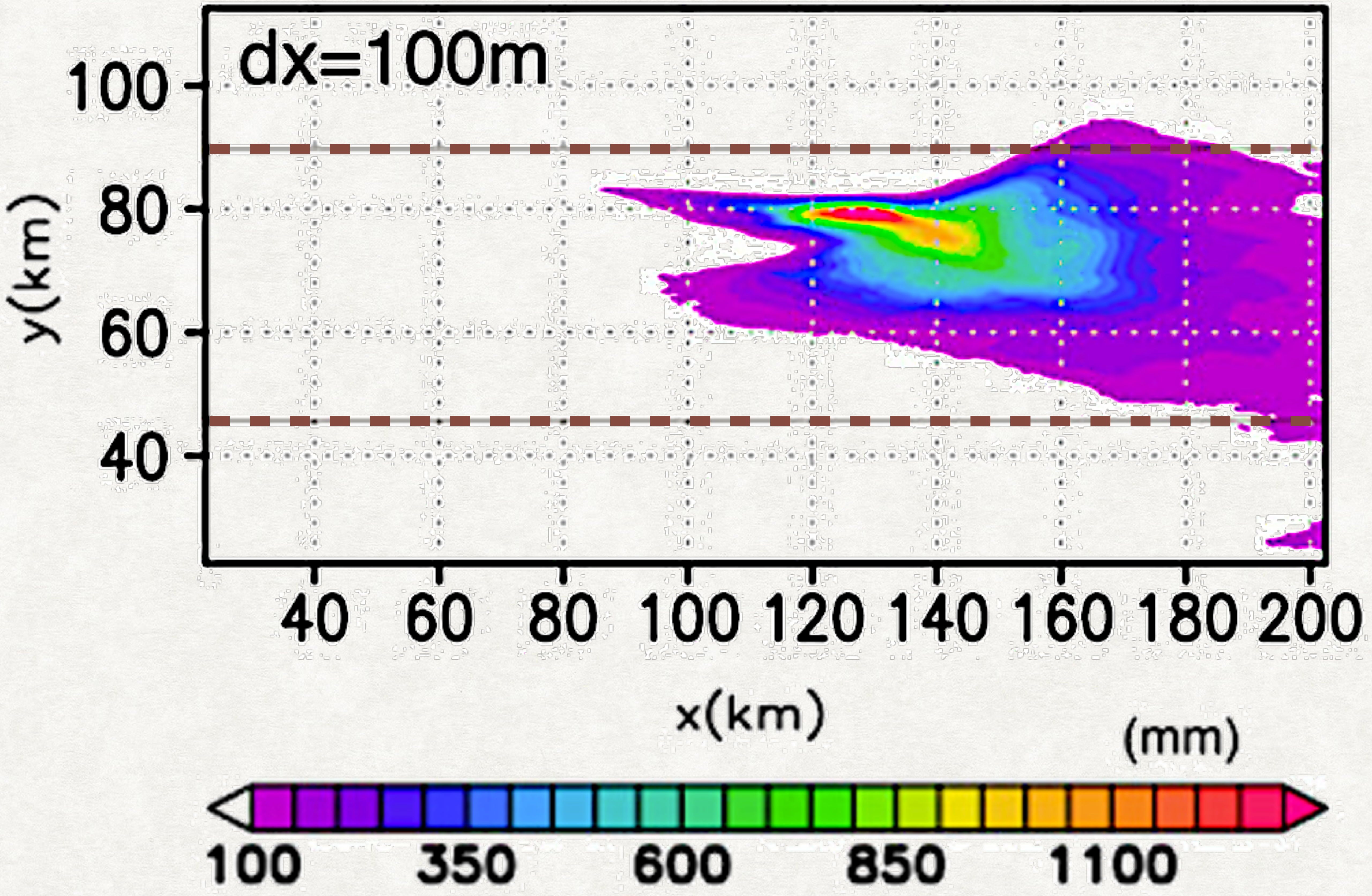
DOMAIN



Experiment	dx, dy [m]	dz [m]	dt [s]
Control	100	100	0.5
Sensitivity	150, 300, 500, 1000, 1500, 2000		

SIMULATION RESULTS

CONTROL EXPERIMENT



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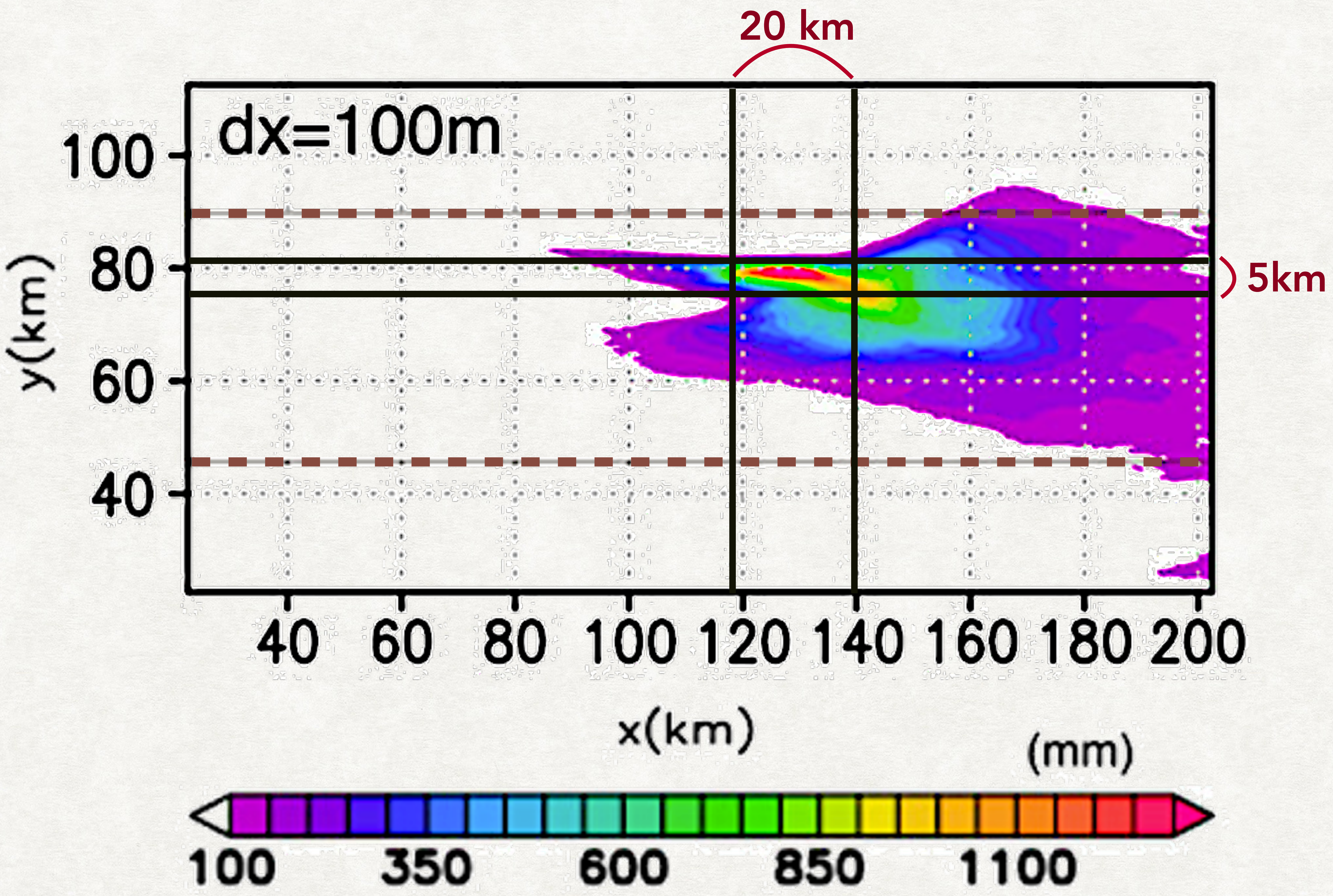

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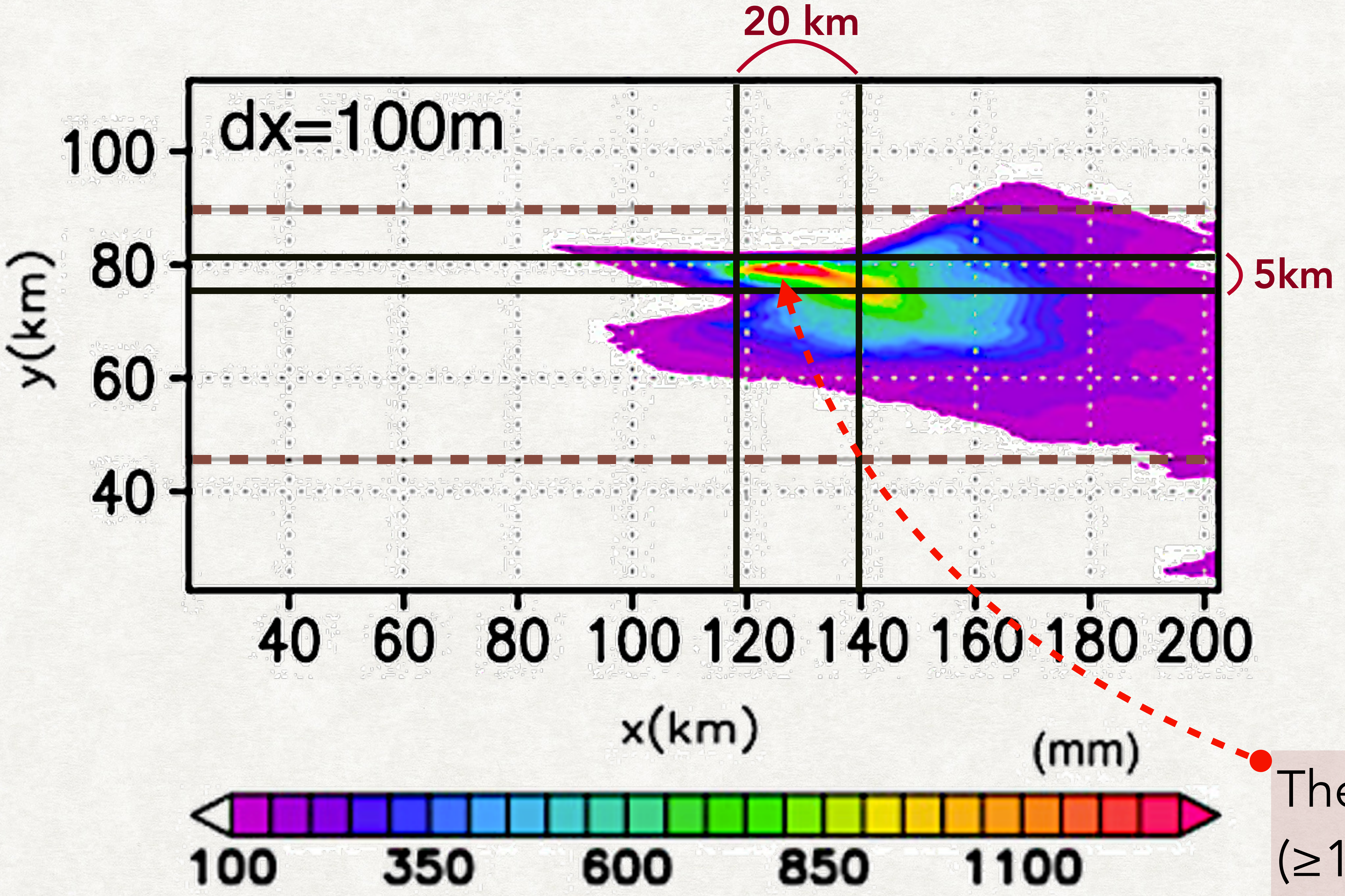
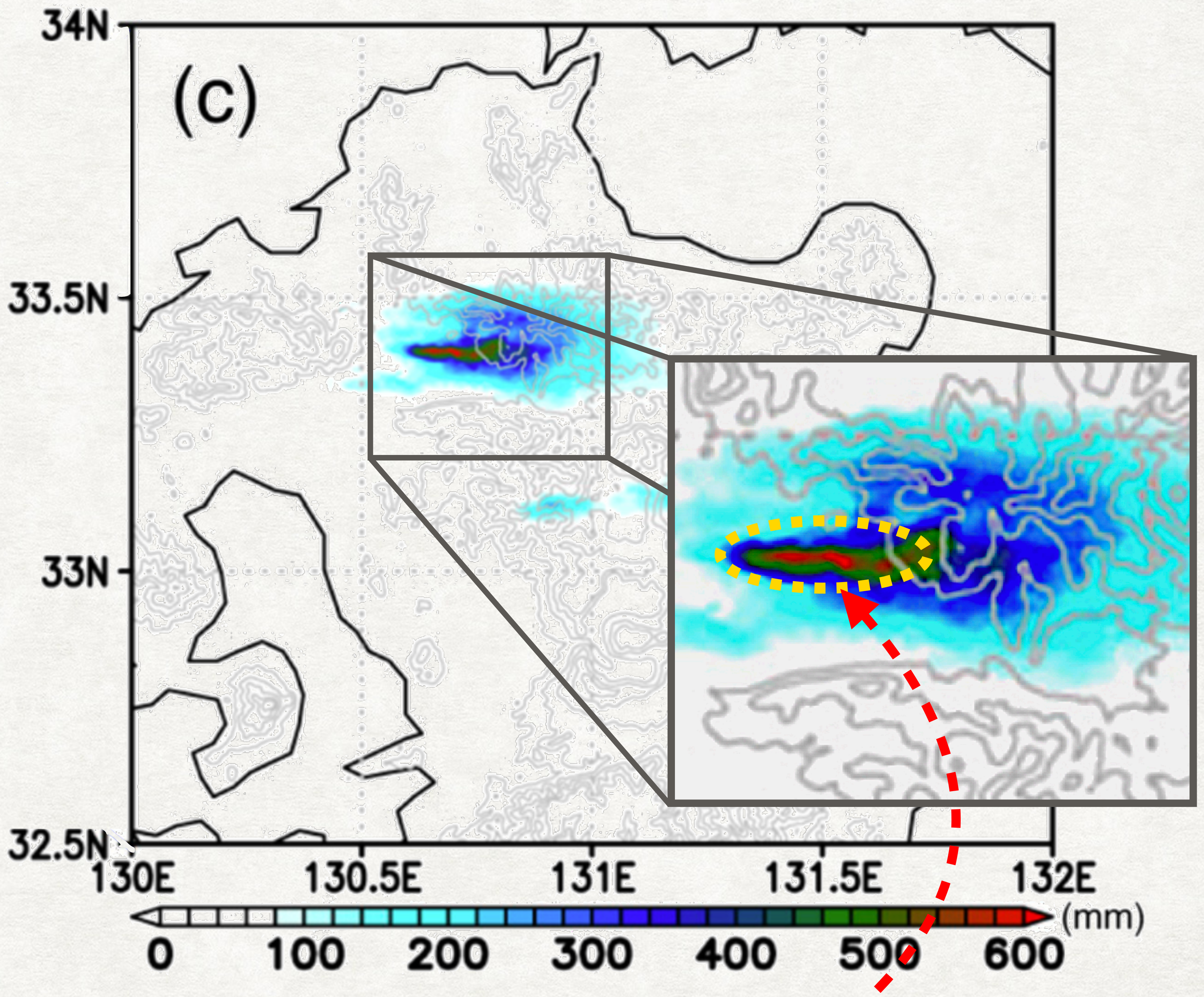




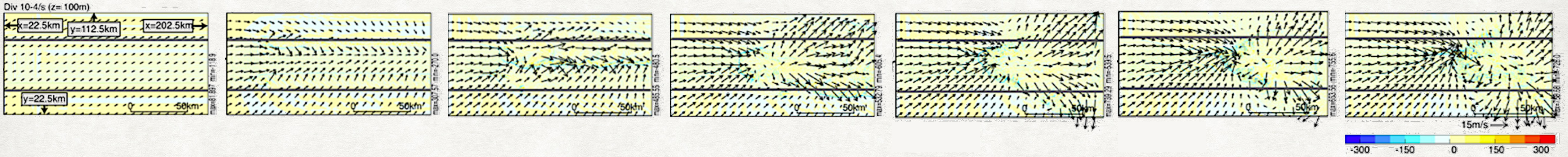
The large accumulated precipitation (≥1000mm) is localized in a small area.

⇢ **Similar to KH2017 event.**

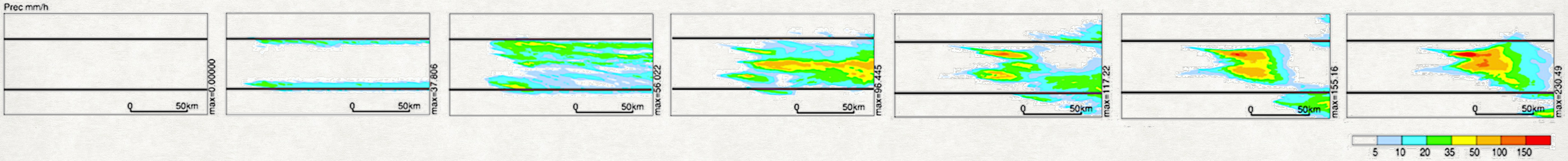
SIMULATION RESULTS

CONTROL EXPERIMENT

Vector: Horizontal Wind [m/s; z=100m] / Shading : Div. [10^-4/s; z=100m]



Precip. [mm/hr]



t = 1hr   t = 2hr   t = 3hr   t = 4hr   t = 5hr   t = 6hr   t = 7hr

SIMULATION RESULTS

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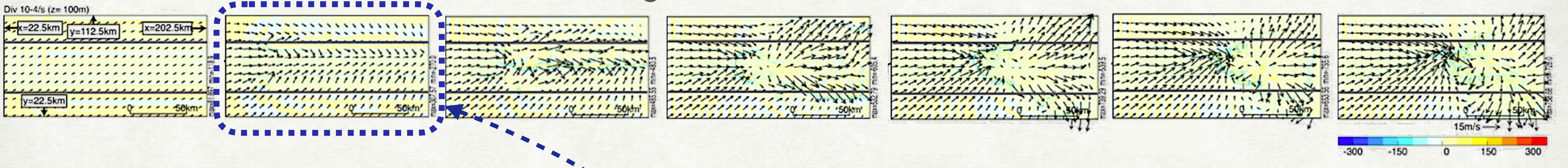

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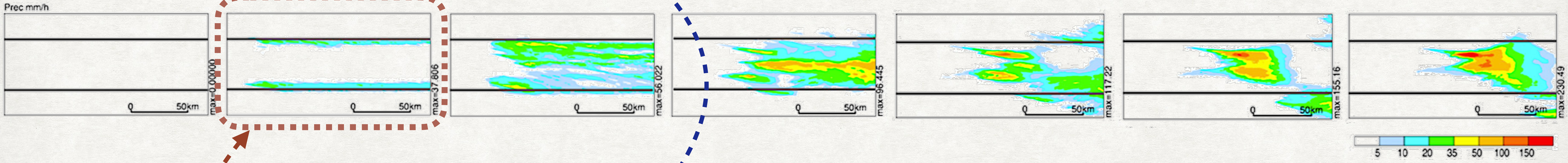


t = 1hr   t = 2hr   t = 3hr   t = 4hr   t = 5hr   t = 6hr   t = 7hr

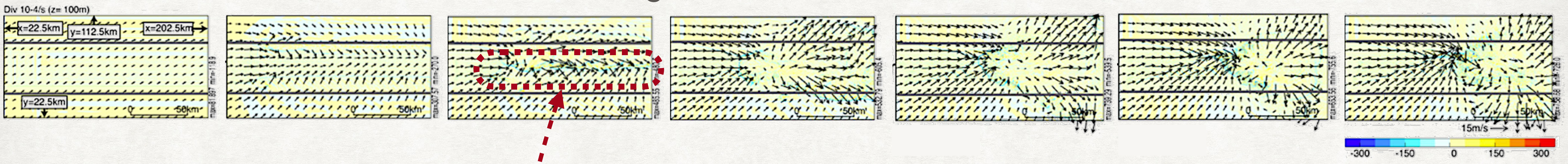
Weak precipitation occurs both along north and south coastlines.

The intrusion of sea breeze from south is stronger.

SIMULATION RESULTS

CONTROL EXPERIMENT

Vector: Horizontal Wind [m/s; z=100m] / Shading : Div. [10^-4/s; z=100m]



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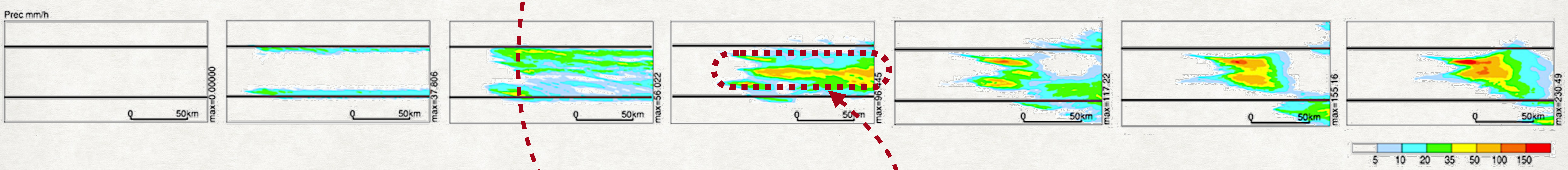

t = 1hr　t = 2hr　t = 3hr　t = 4hr　t = 5hr　t = 6hr　t = 7hr

Convergence at y~75km, triggers the convective clouds and then causes precipitation.

SIMULATION RESULTS

CONTROL EXPERIMENT

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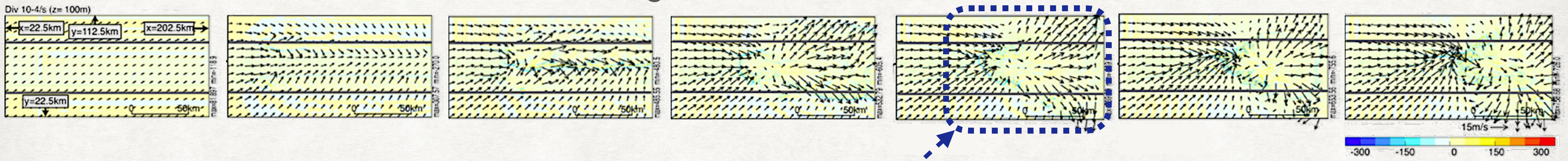
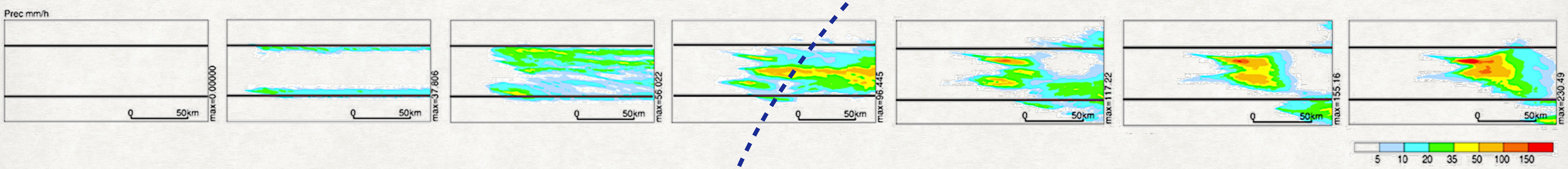


Precip. [mm/hr]

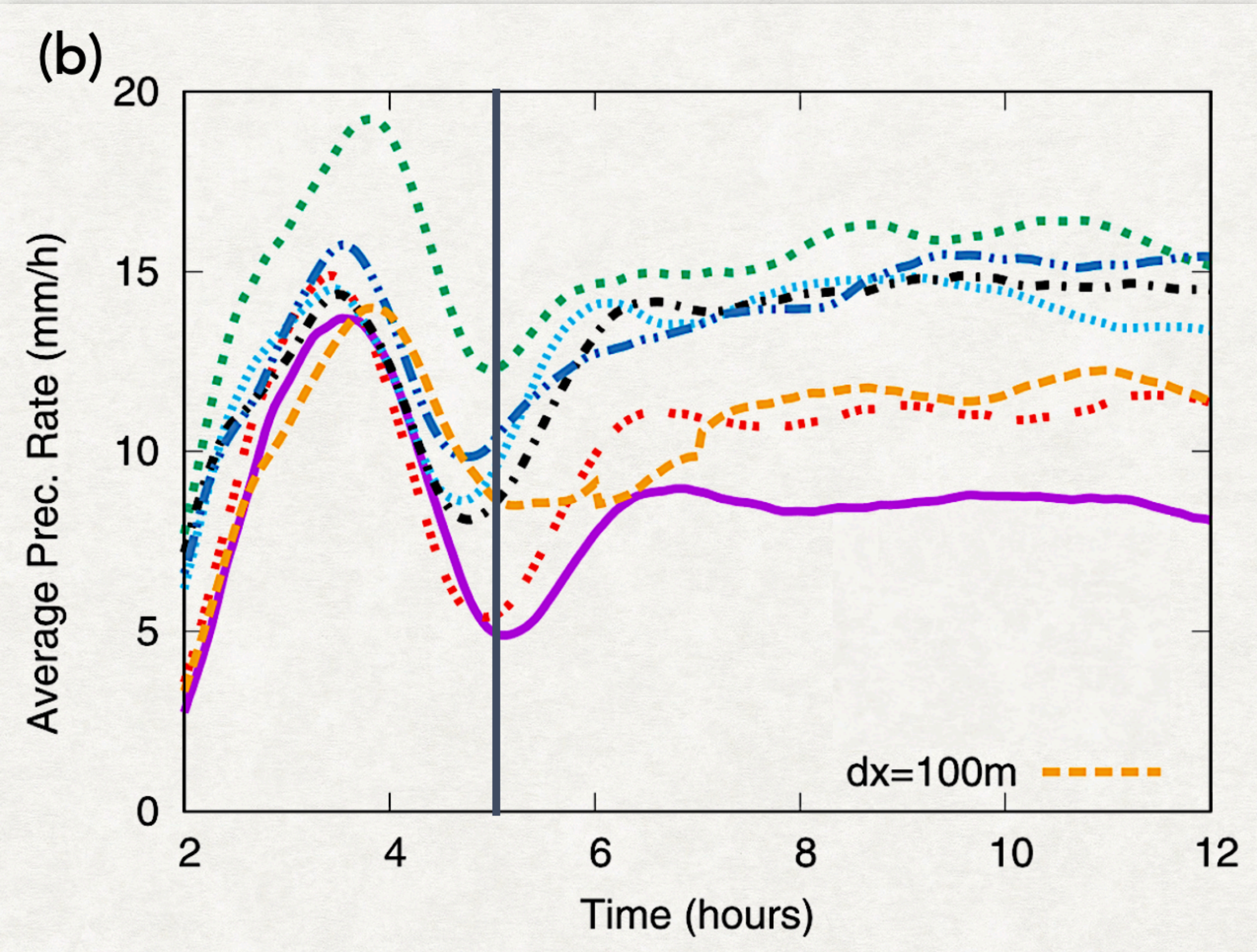


t = 1hr t = 2hr t = 3hr t = 4hr t = 5hr t = 6hr t = 7hr

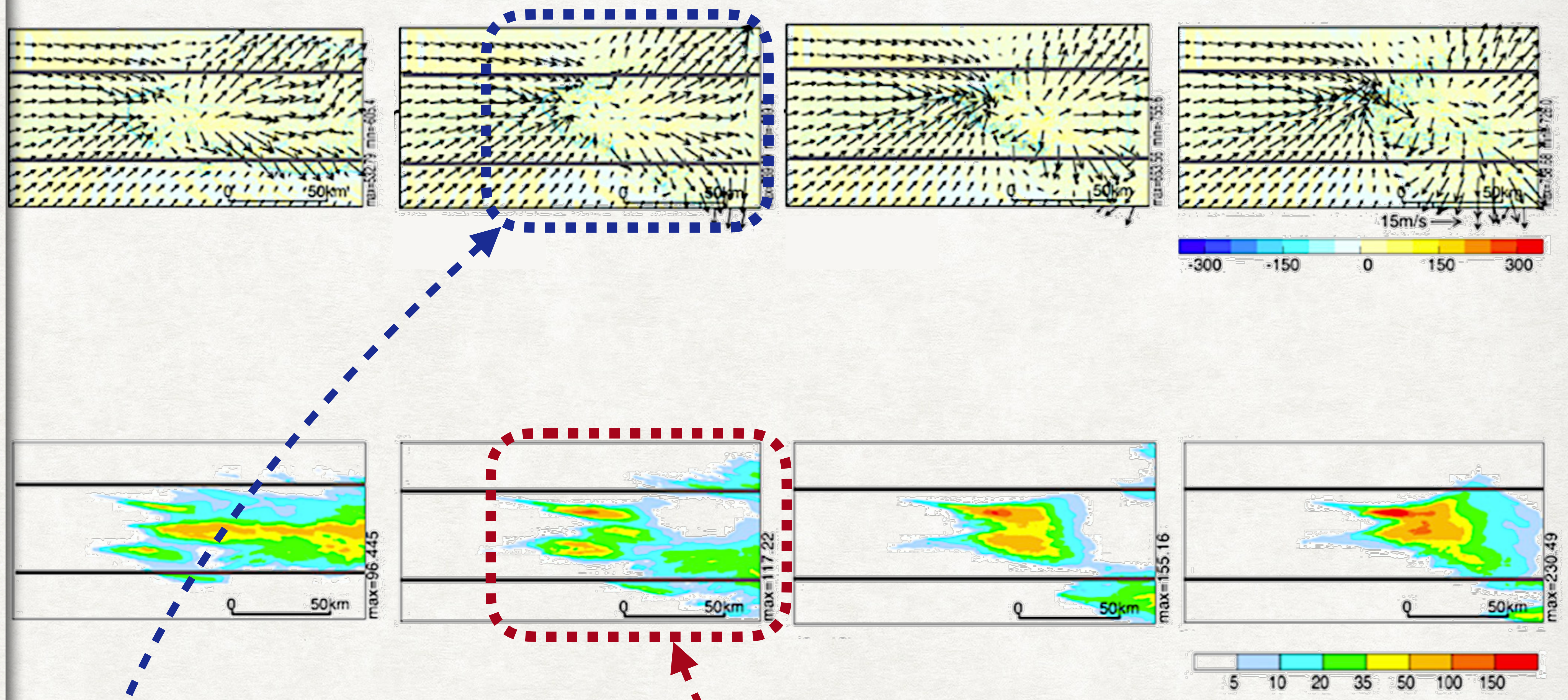
Downdraft and the accompanied cold pool formed, results divergences in lower height.

SIMULATION RESULTS

CONTROL EXPERIMENT



: Div. [10^-4/s; z=100m]



t = 4hr t = 5hr t = 6hr t = 7hr

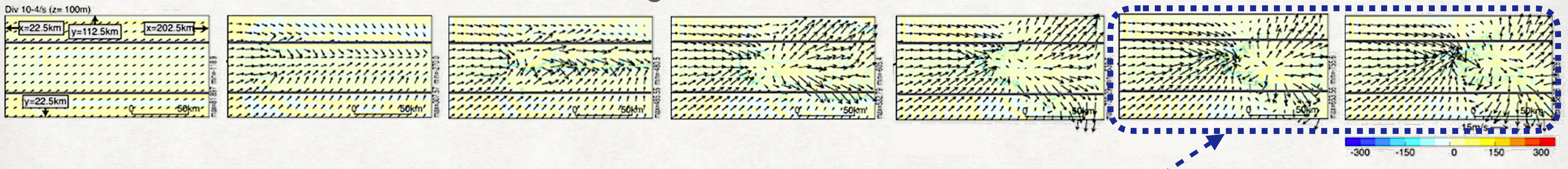
Downdraft and the accompanied cold pool formed, results divergences in lower height.

The original convective clouds dissipates, and the new cells start to develop upstream.

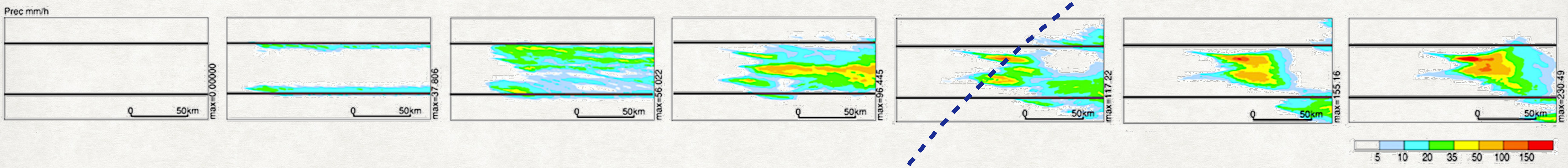
SIMULATION RESULTS

CONTROL EXPERIMENT

Vector: Horizontal Wind [m/s; z=100m] / Shading : Div. [10^-4/s; z=100m]



Precip. [mm/hr]



t = 1hr   t = 2hr   t = 3hr   t = 4hr   t = 5hr   t = 6hr   t = 7hr

The intrusion of sea breeze from the south is stronger than north.

SIMULATION RESULTS

CONTROL EXPERIMENT

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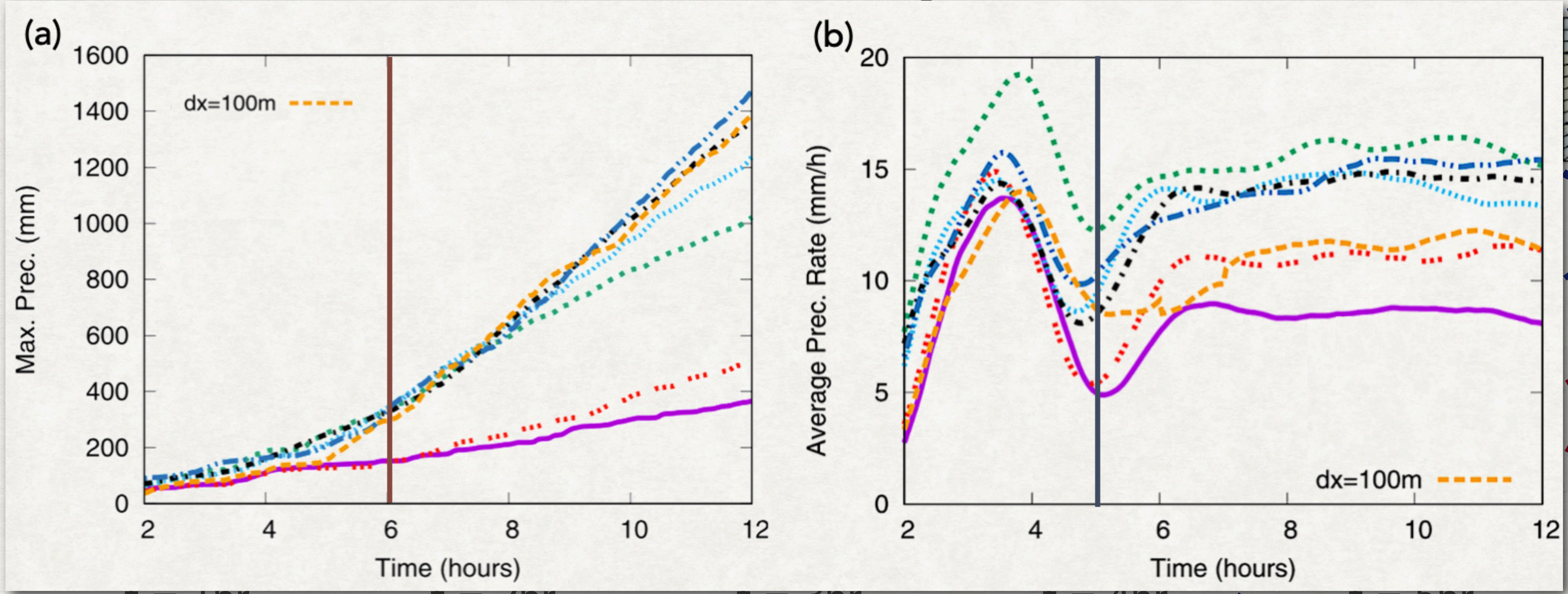
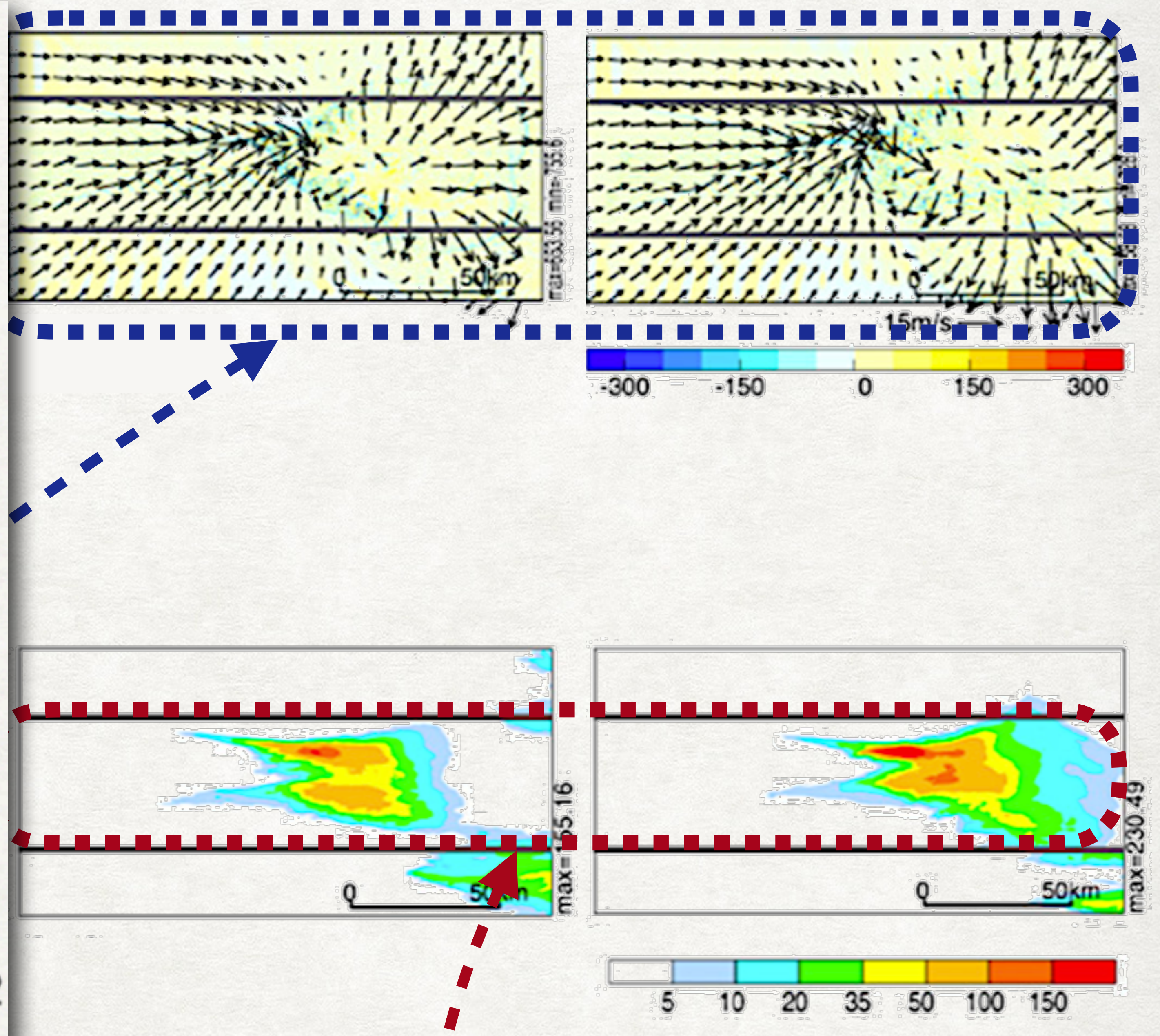




t = 1hr t = 2hr t = 3hr t = 4hr t = 5hr t = 6hr t = 7hr

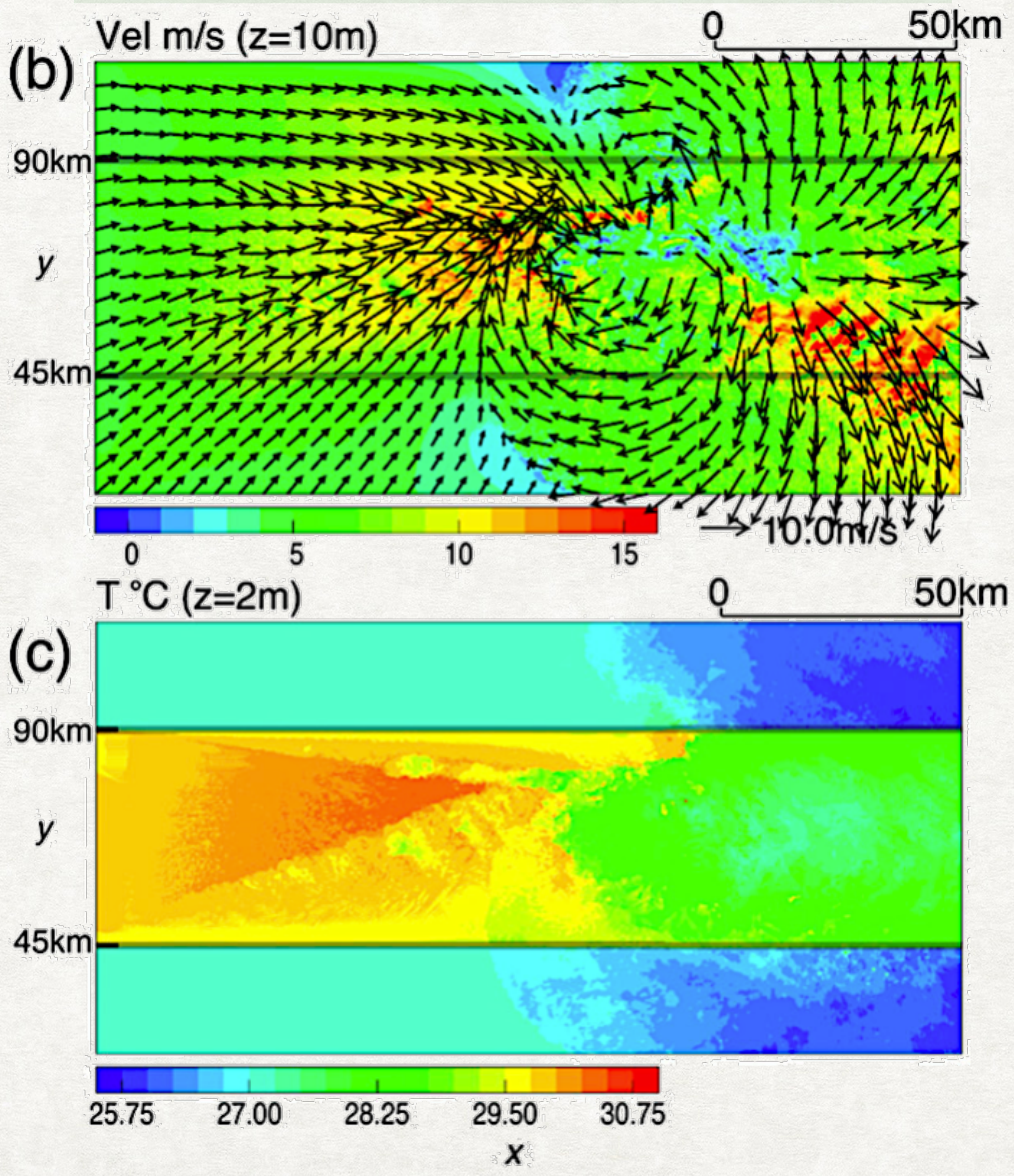
The intrusion of sea breeze from the south is stronger than north.

⇢The northern cell is stronger. And, the quasi-stationary QLCS is formed.

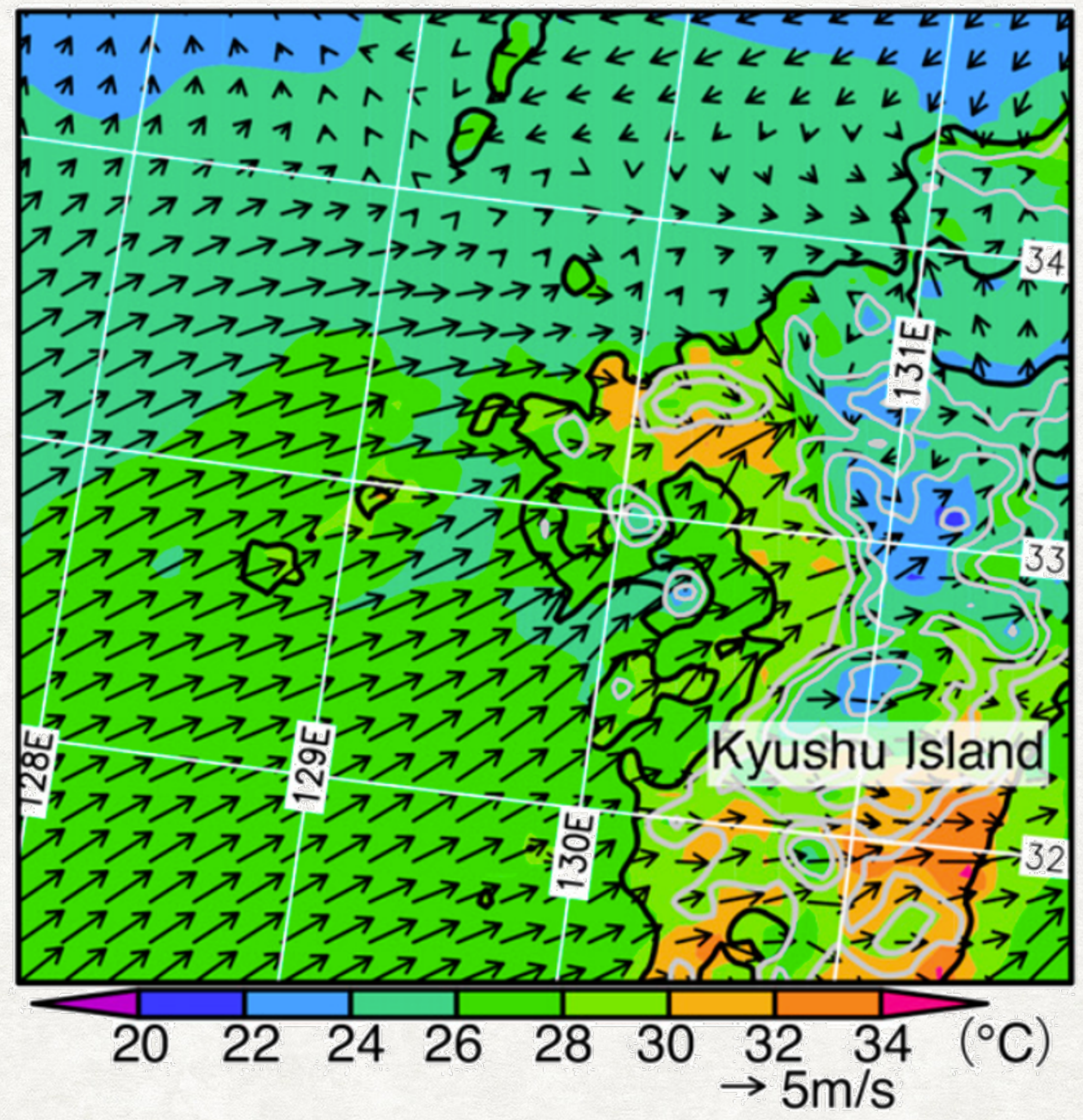
SIMULATION RESULTS

COMPARE WITH OBS.

SIMULATION [z=10m; t=7.5hr]



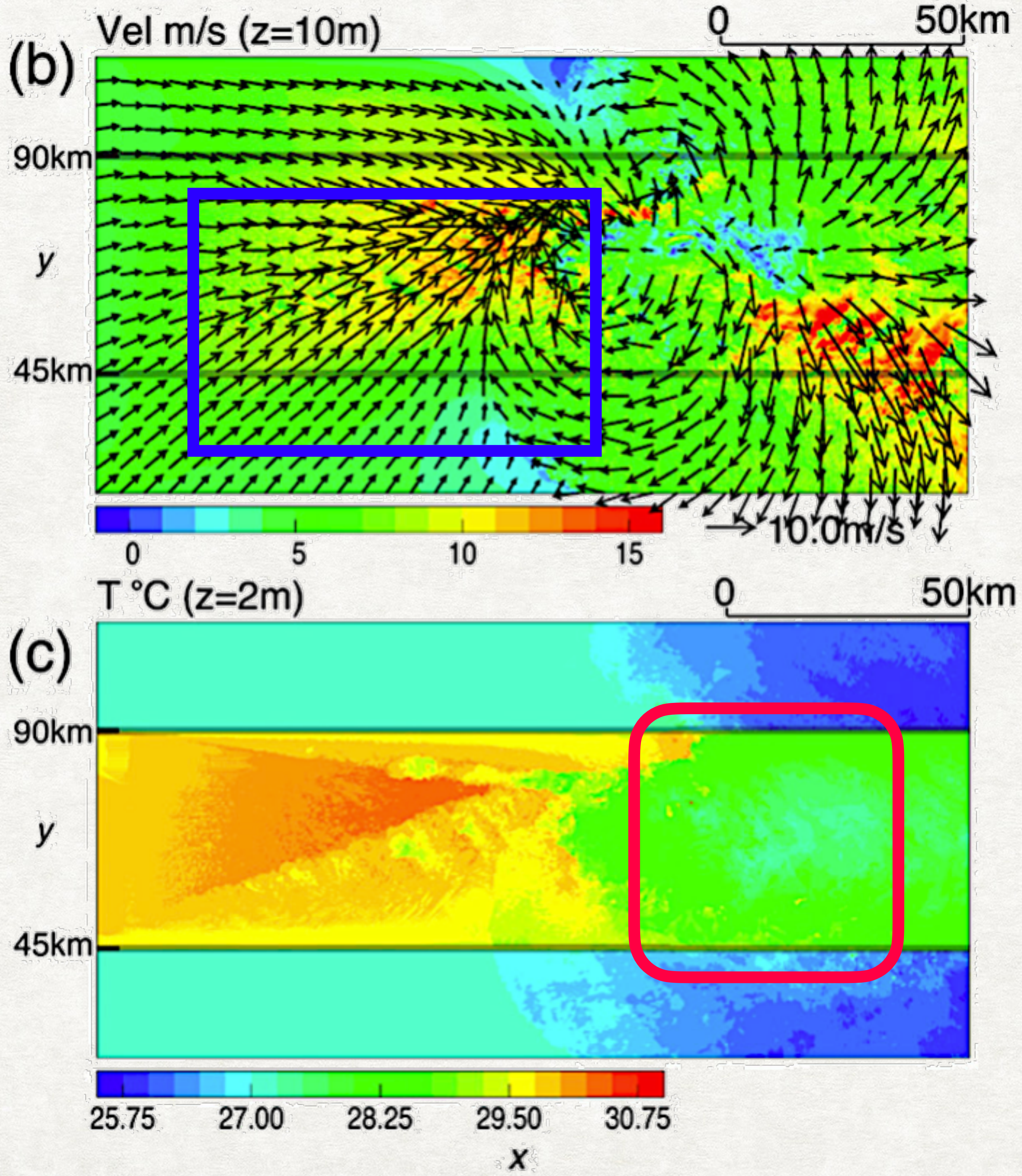
KH2017 [2017/07/05 1500 JST]



SIMULATION RESULTS

COMPARE WITH OBS.

SIMULATION [z=10m; t=7.5hr]



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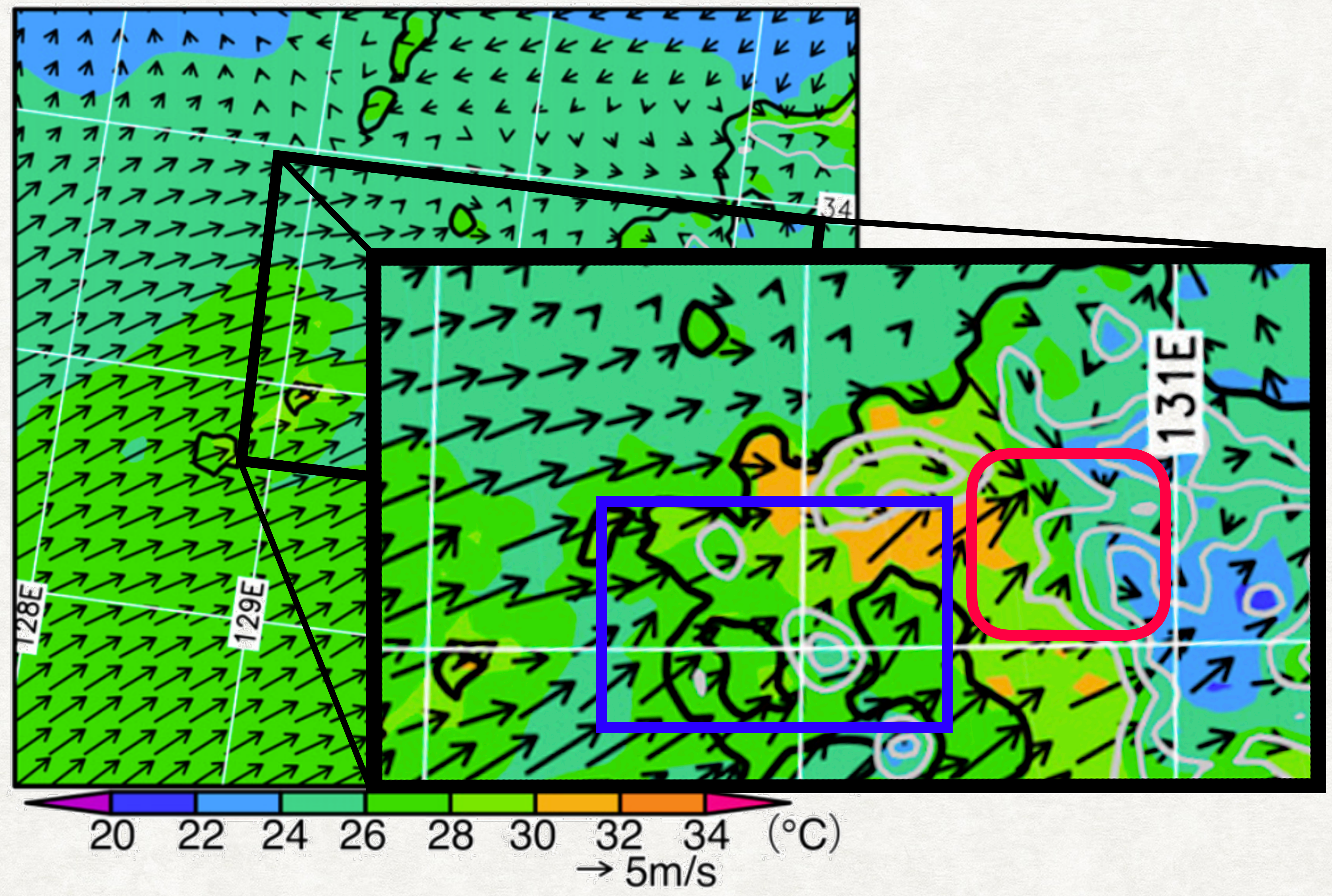

SIMULATION RESULTS

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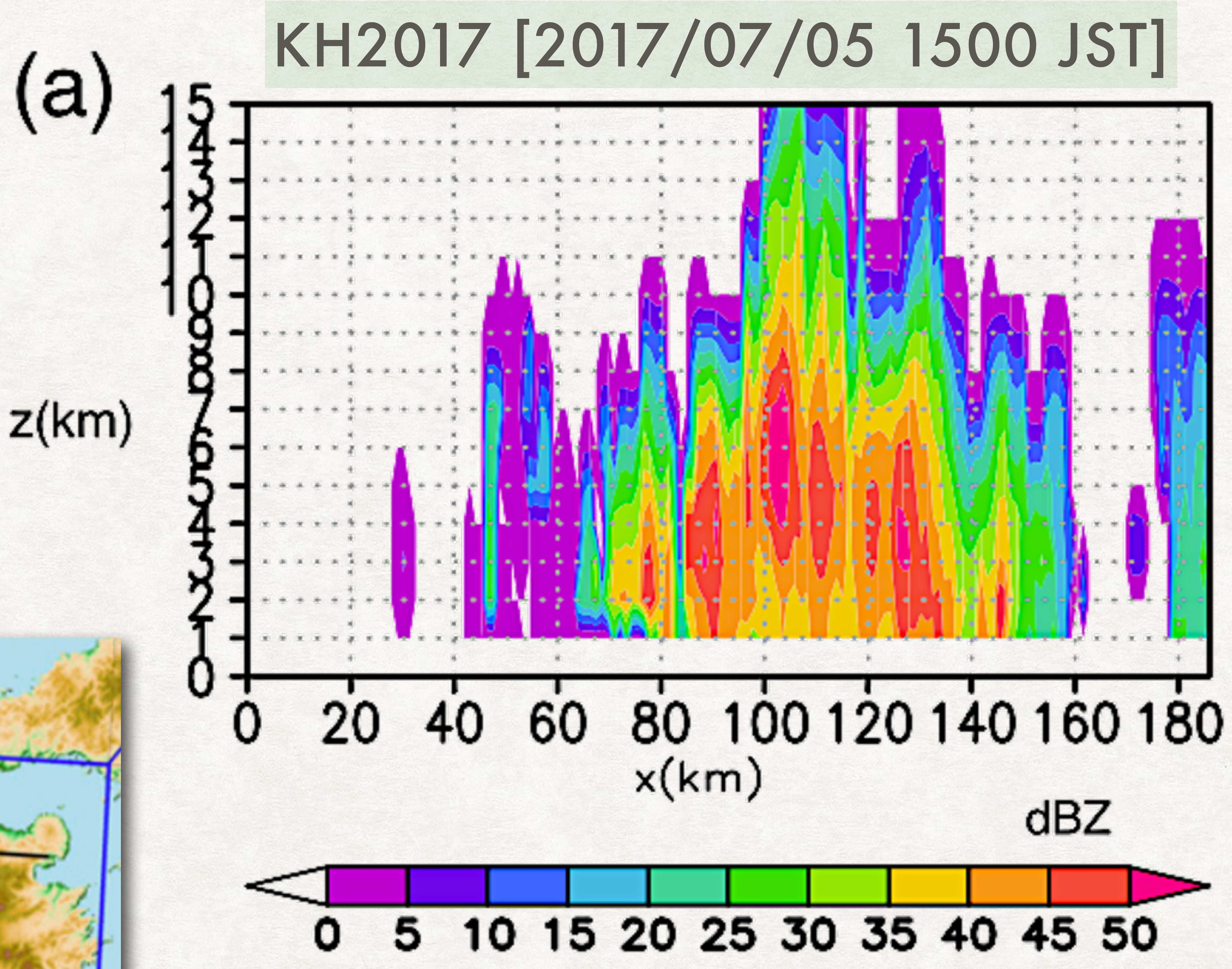

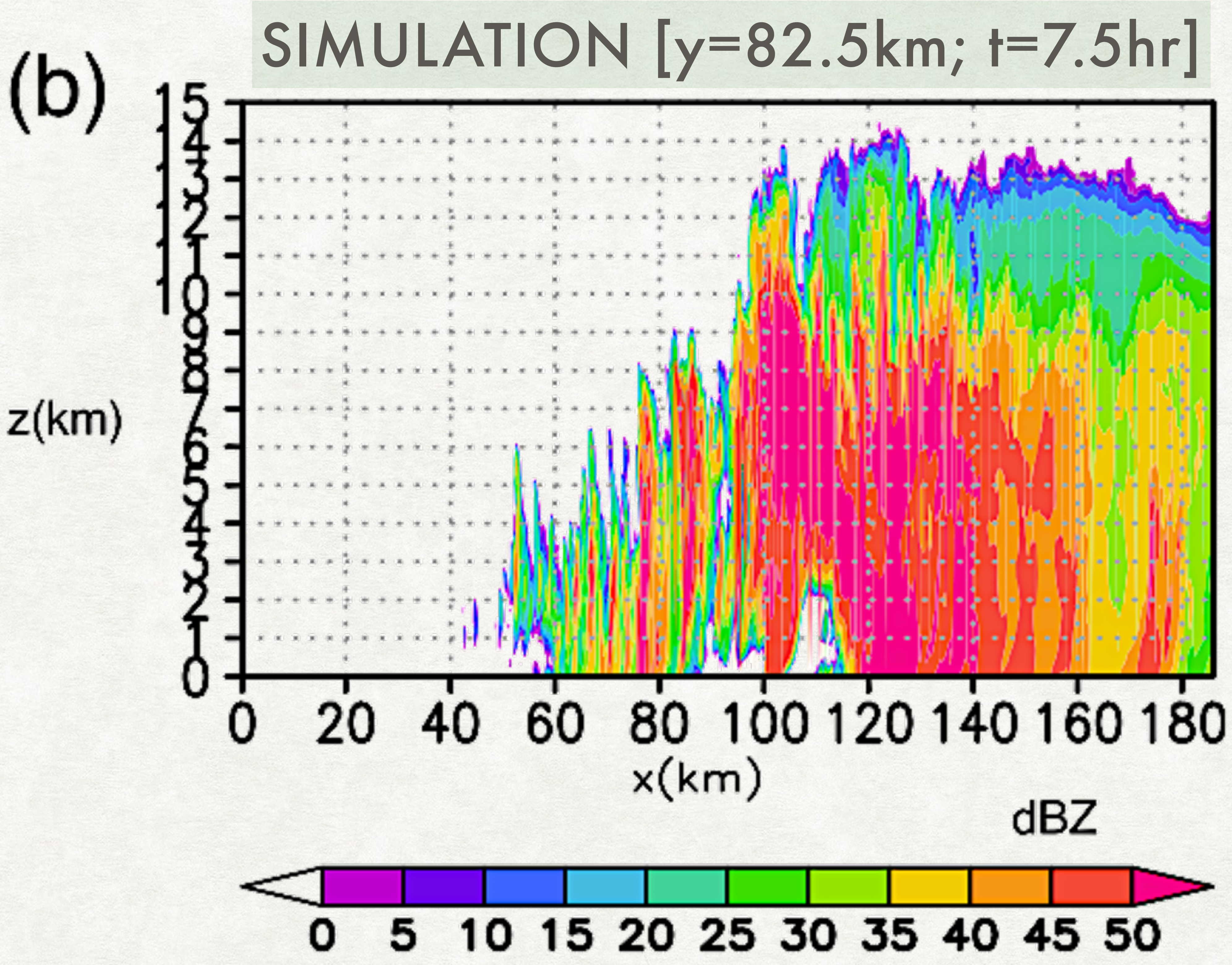

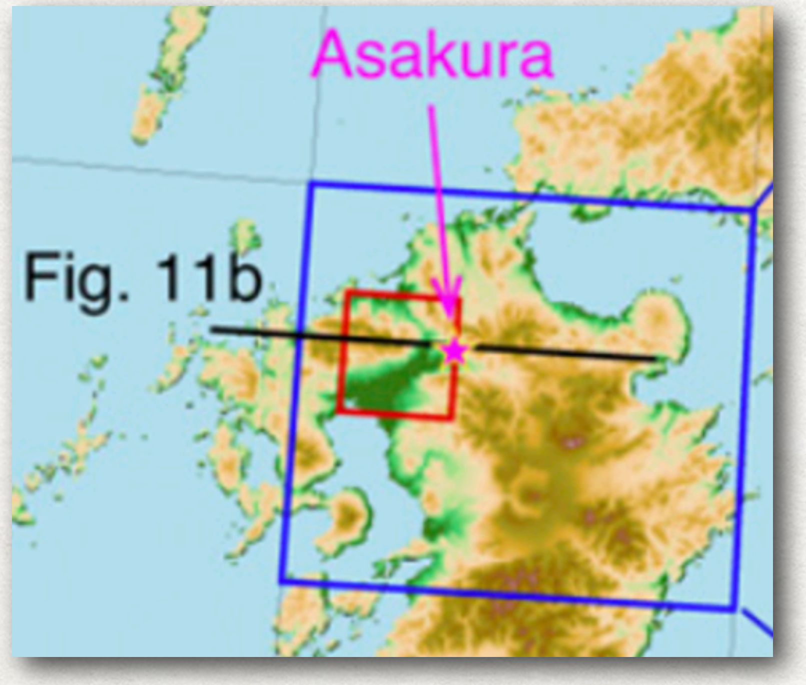

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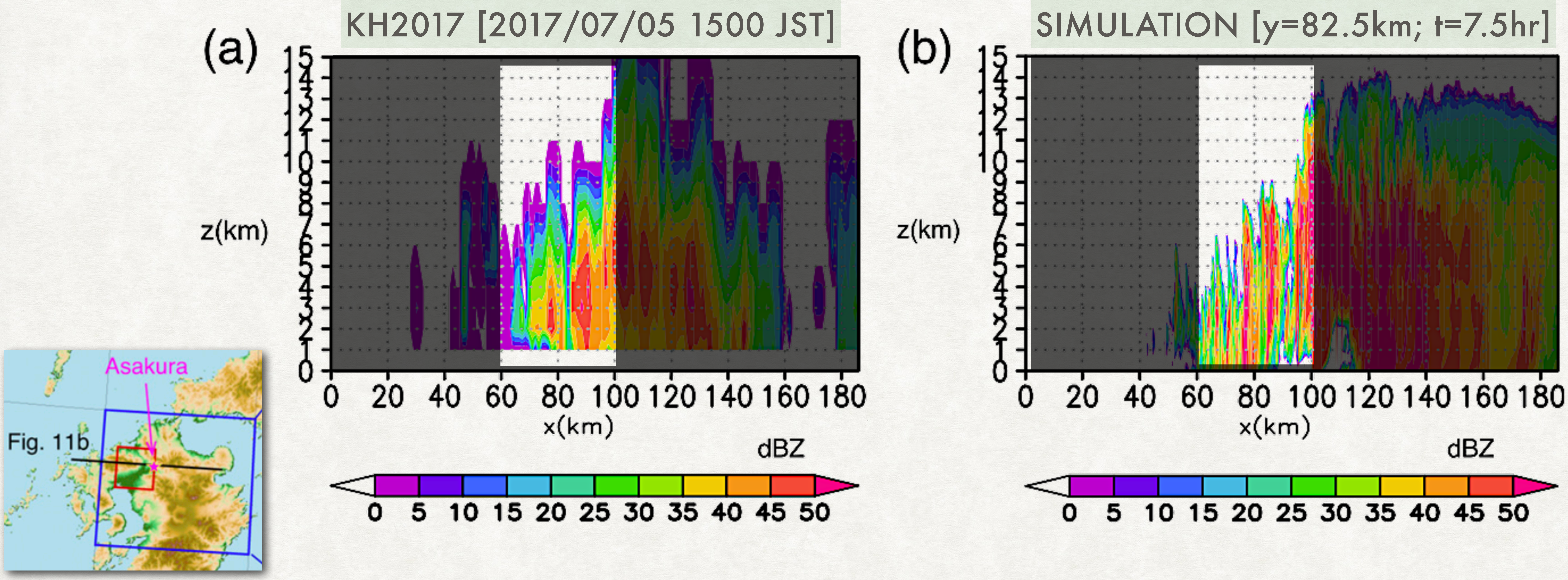
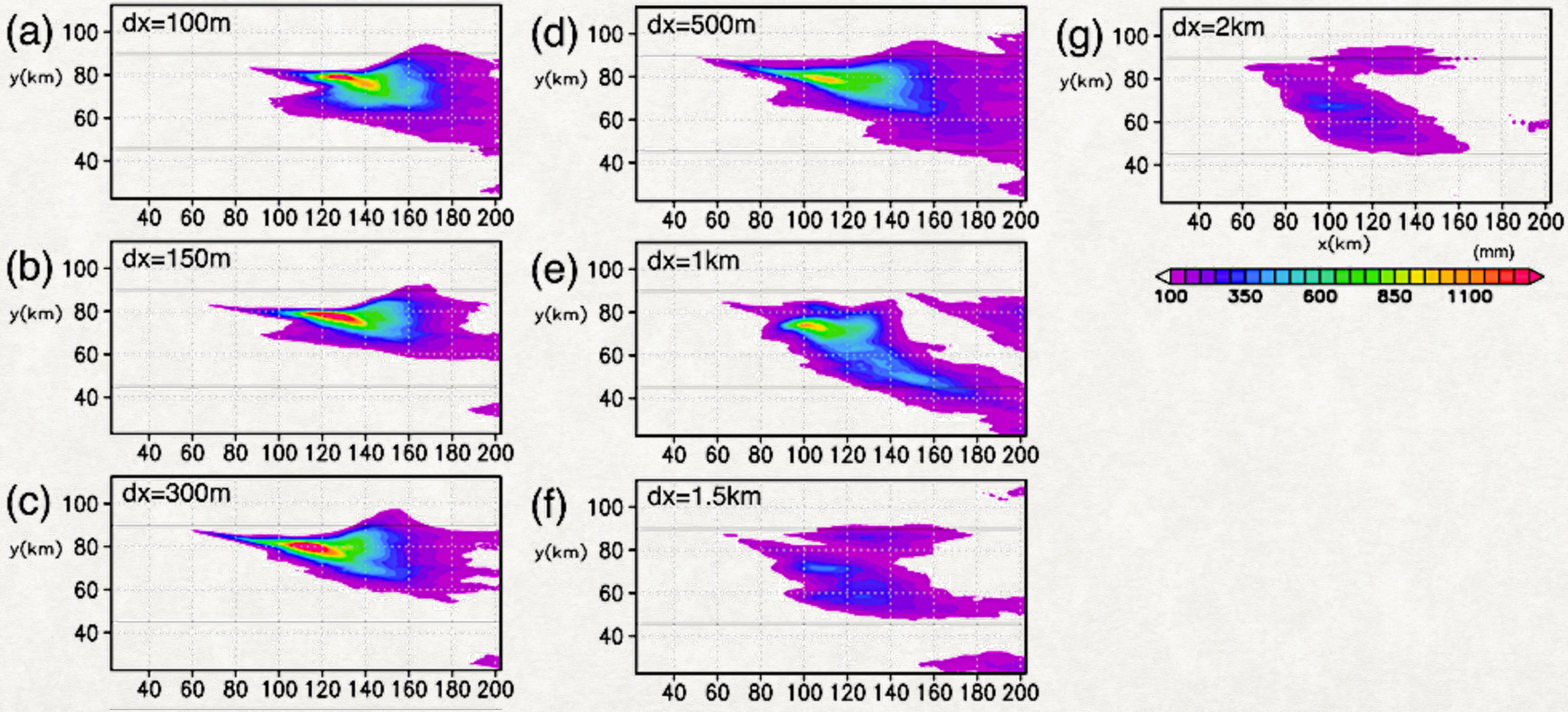


DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE



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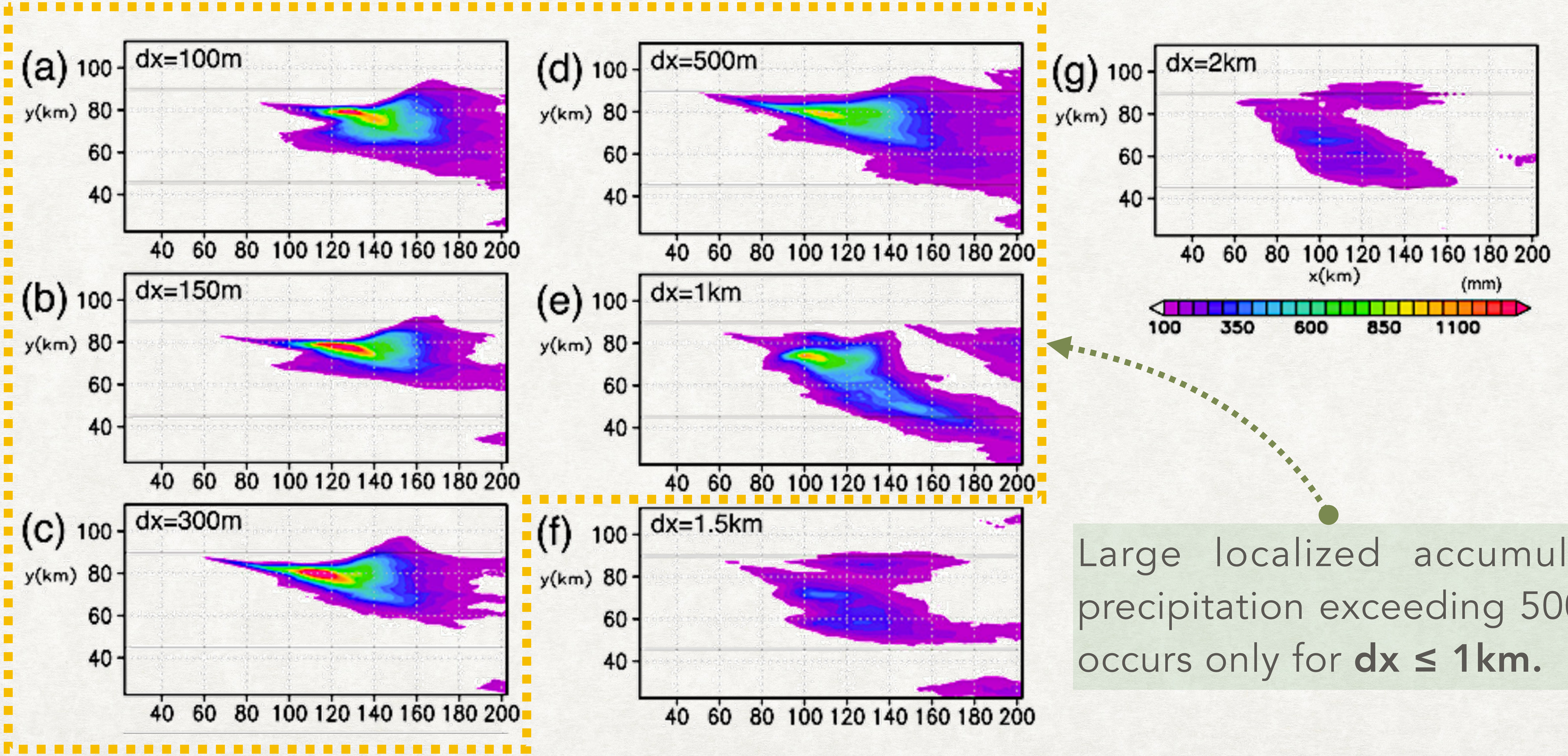
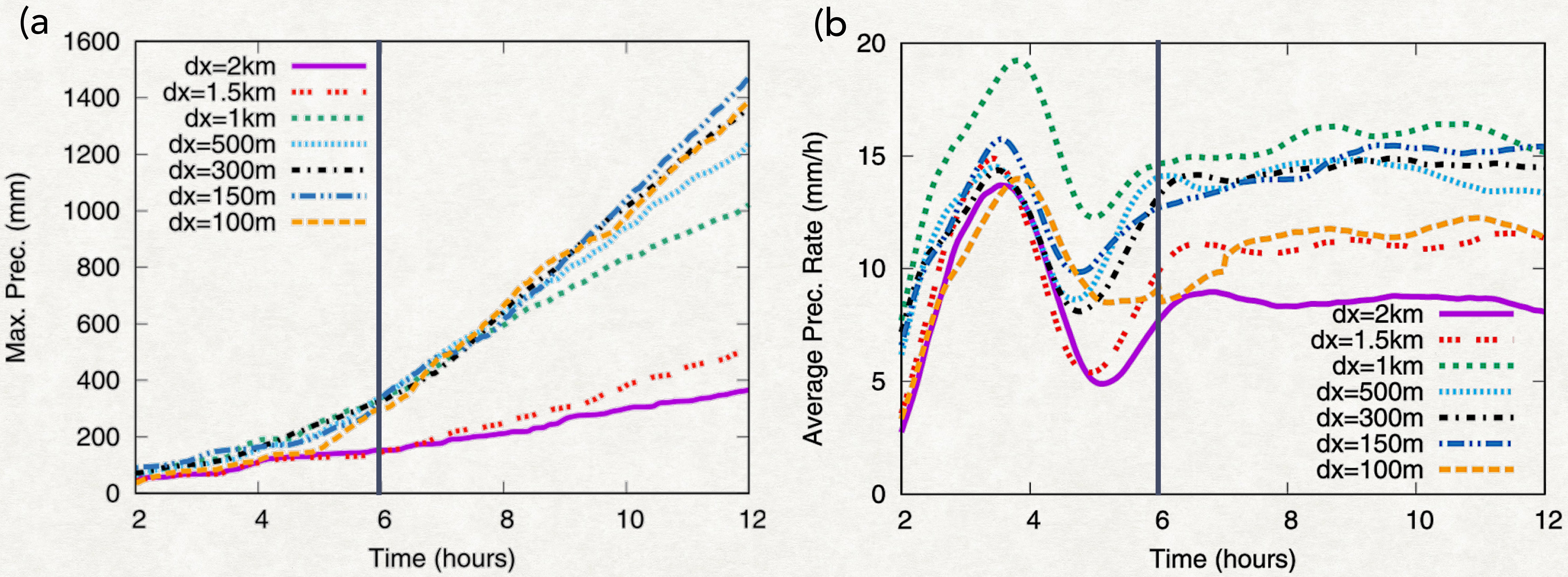
HORIZONTAL RESOLUTION DEPENDENCE



Large localized accumulated precipitation exceeding 500mm occurs only for **dx ≤ 1km.**

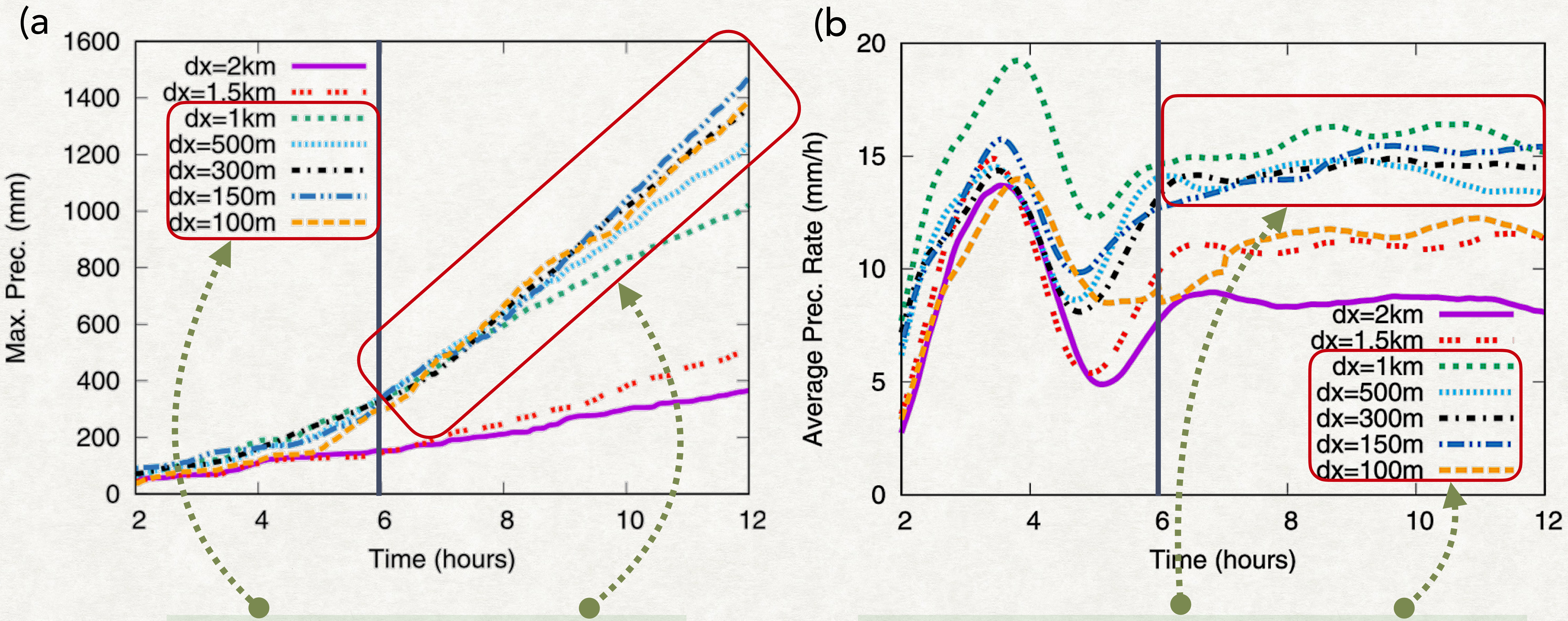
DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE



DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE



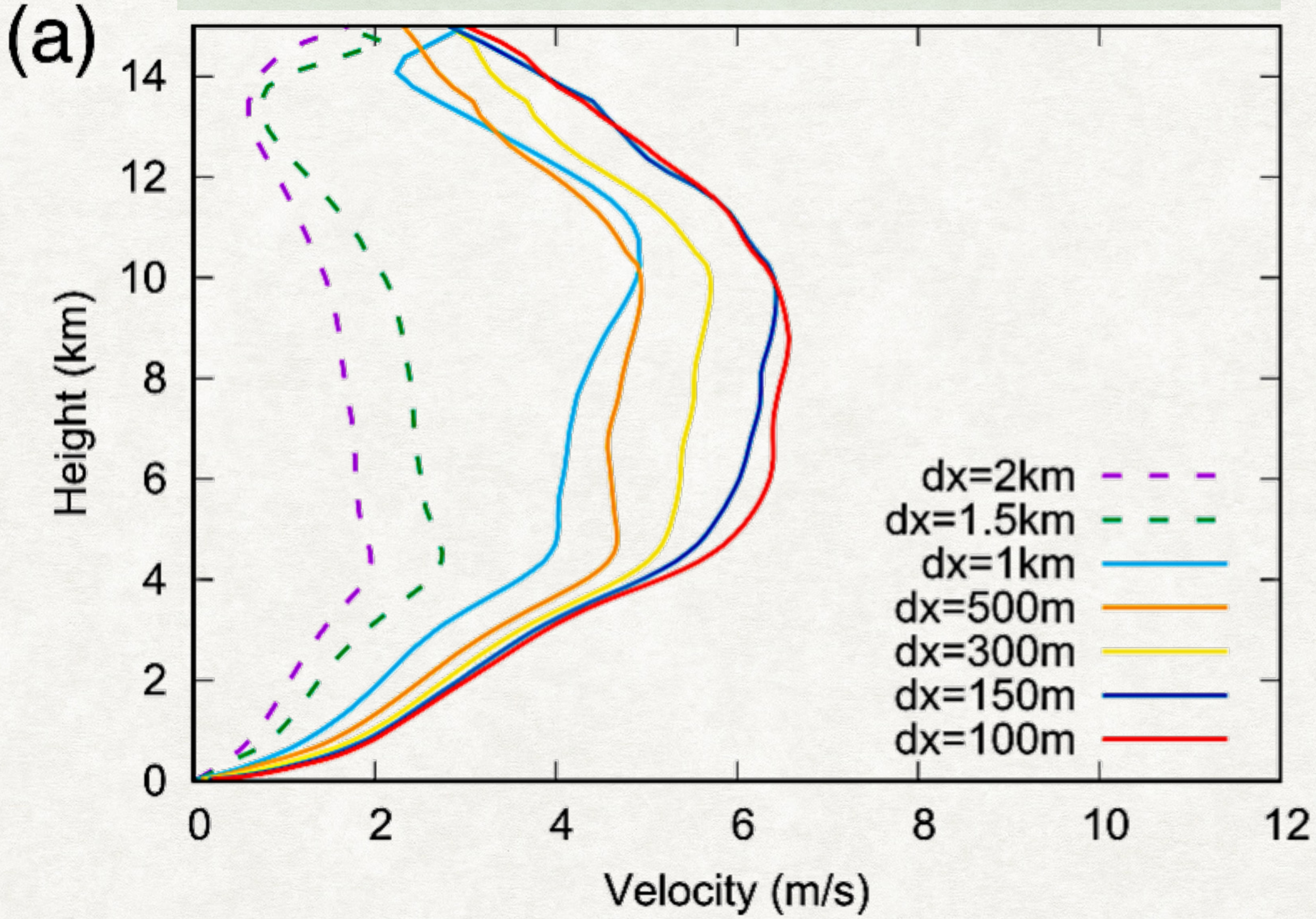
Similar signal can be found in the time series of Maximum Precipitation.

The average precipitation over the land is similar in the experiments with **dx ≤ 1km** after t = 6hr.

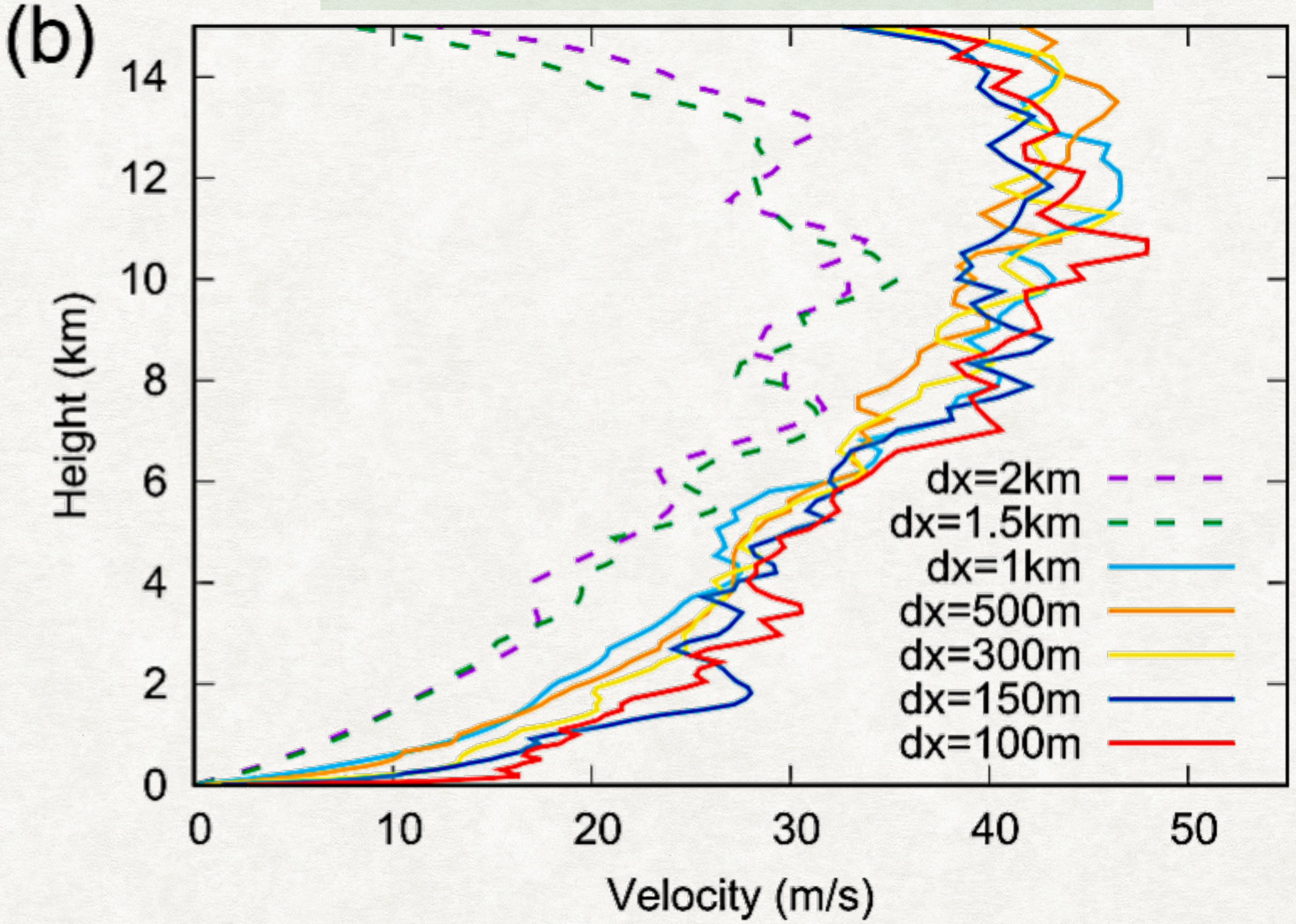
DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE

SPATIOTEMPORALLY AVERAGED UPDRAFT VELOCITY



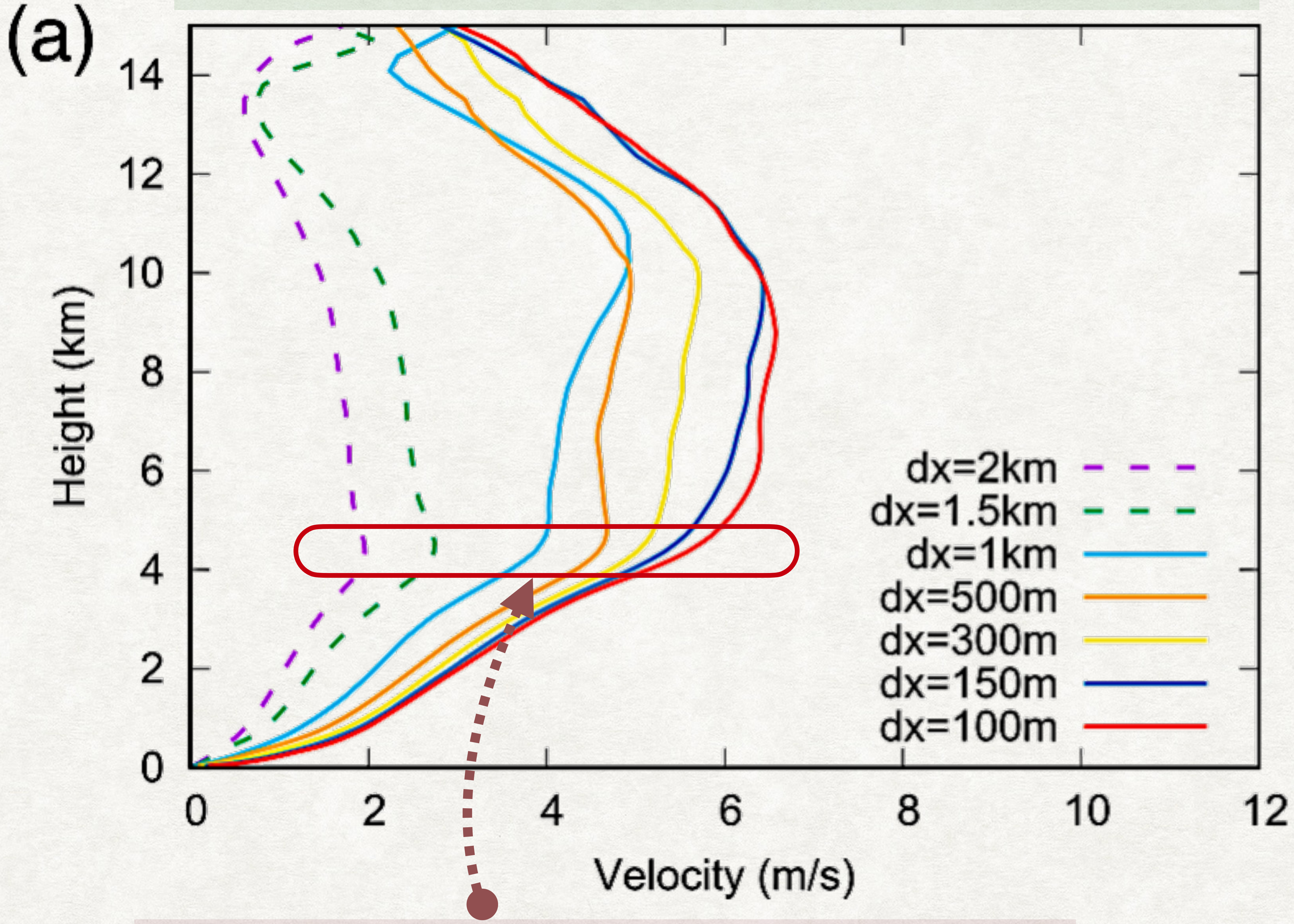
MAXIMUM UPDRAFT VELOCITY



DISCUSSION

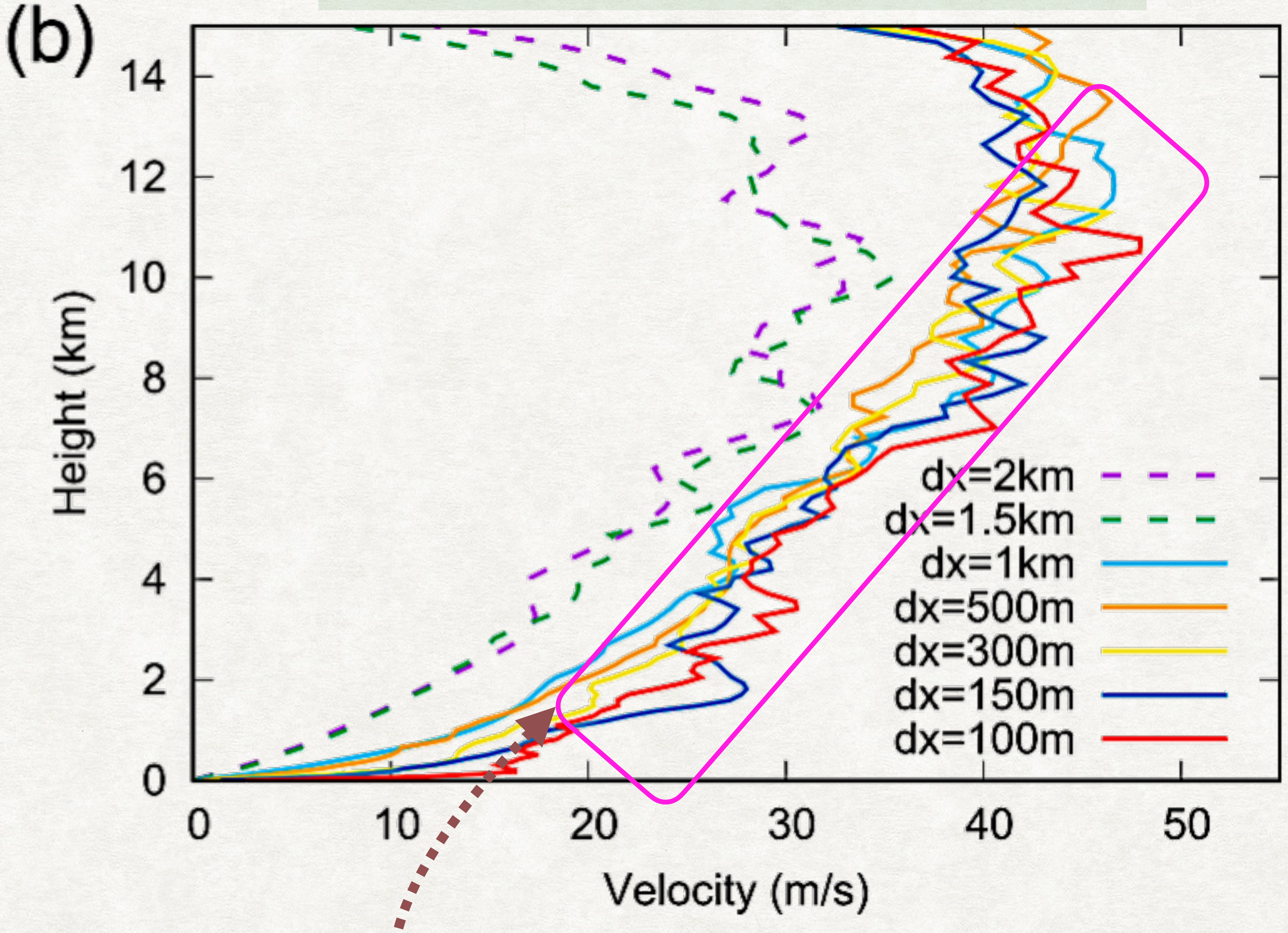
HORIZONTAL RESOLUTION DEPENDENCE

SPATIOTEMPORALLY AVERAGED UPDRAFT VELOCITY



The averaged updraft velocity for grid points with w>0 tends to increase with decreasing dx.

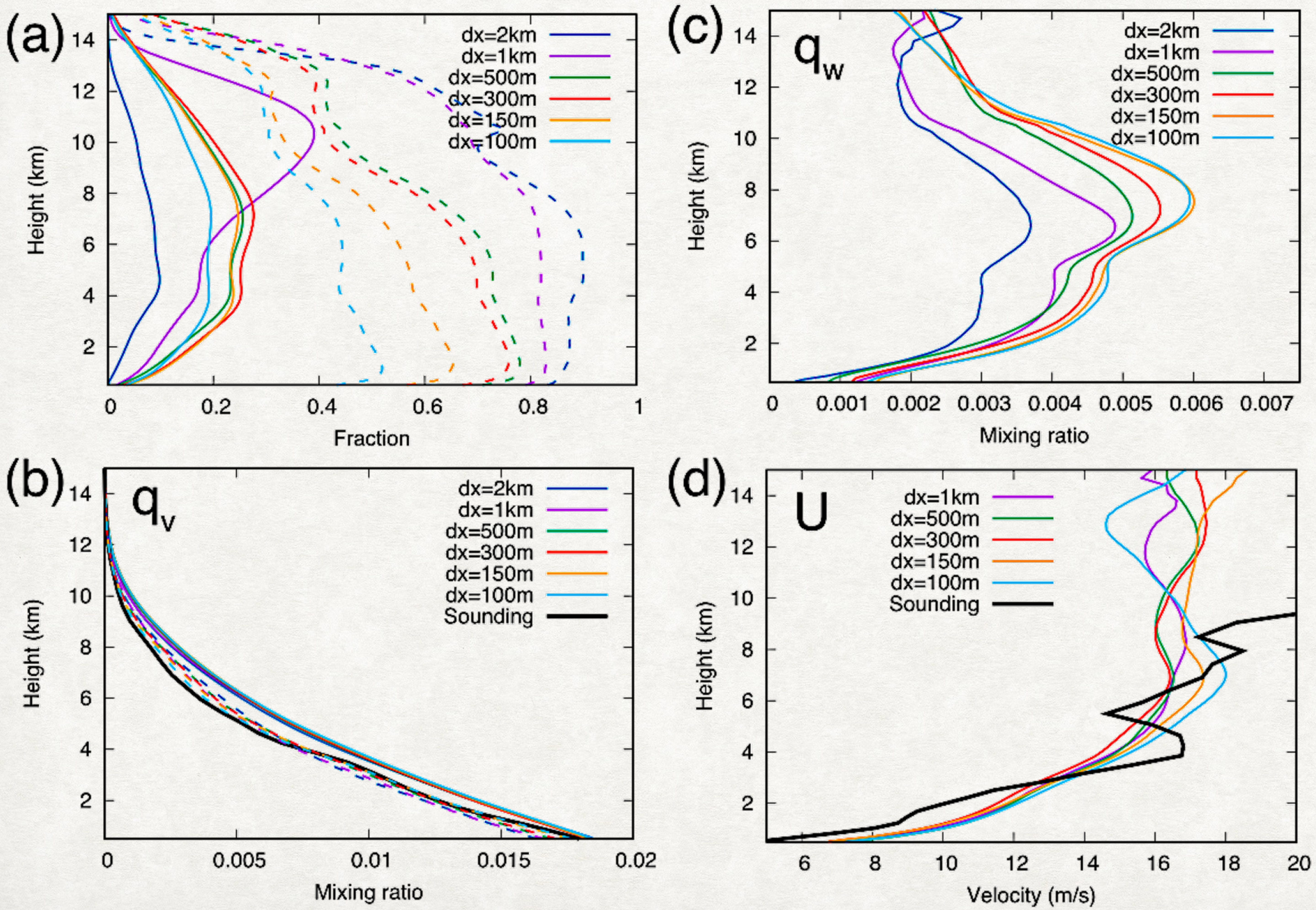
MAXIMUM UPDRAFT VELOCITY



The maximum updraft varies little for dx ≤ 1km.

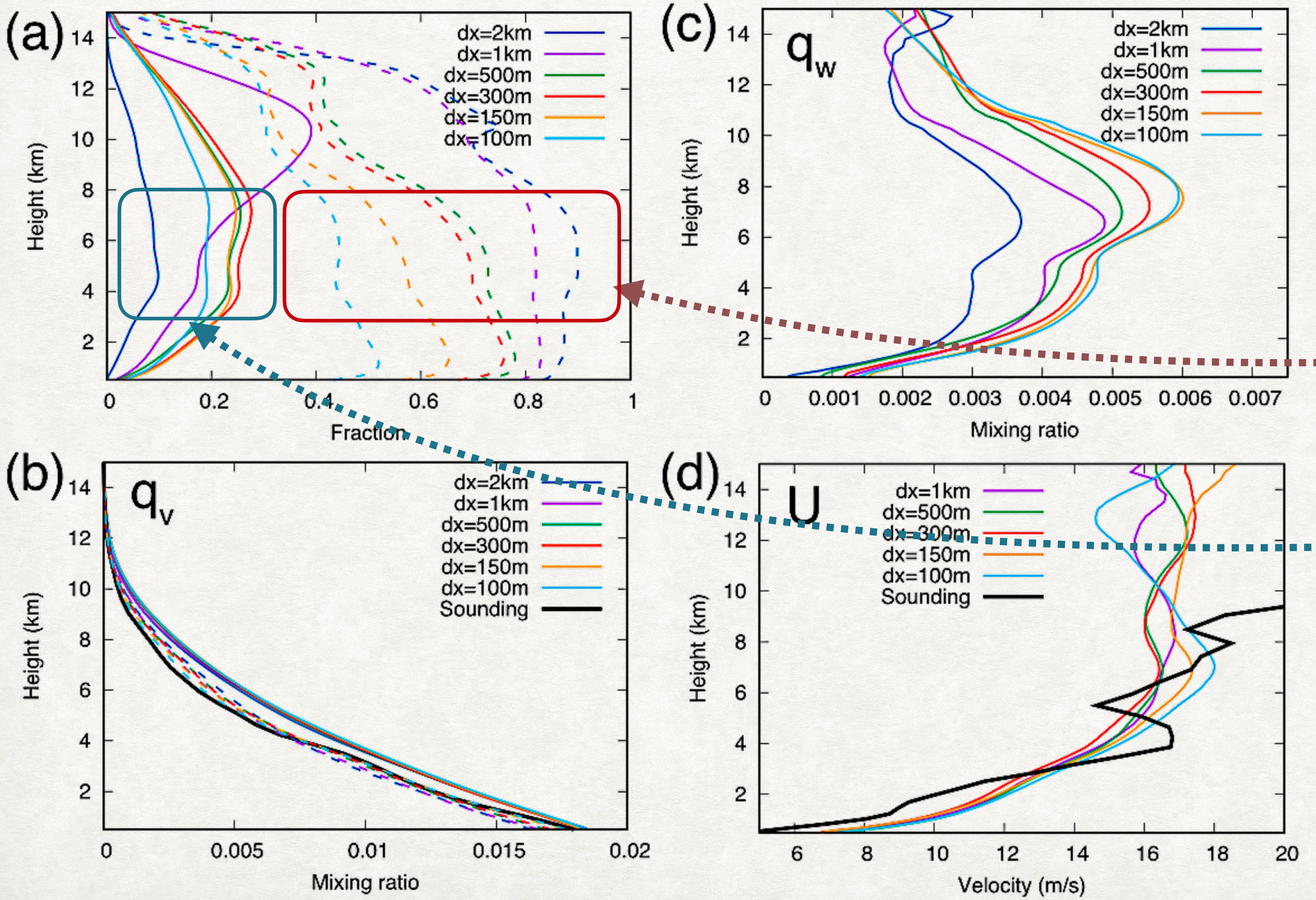
DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE



DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE

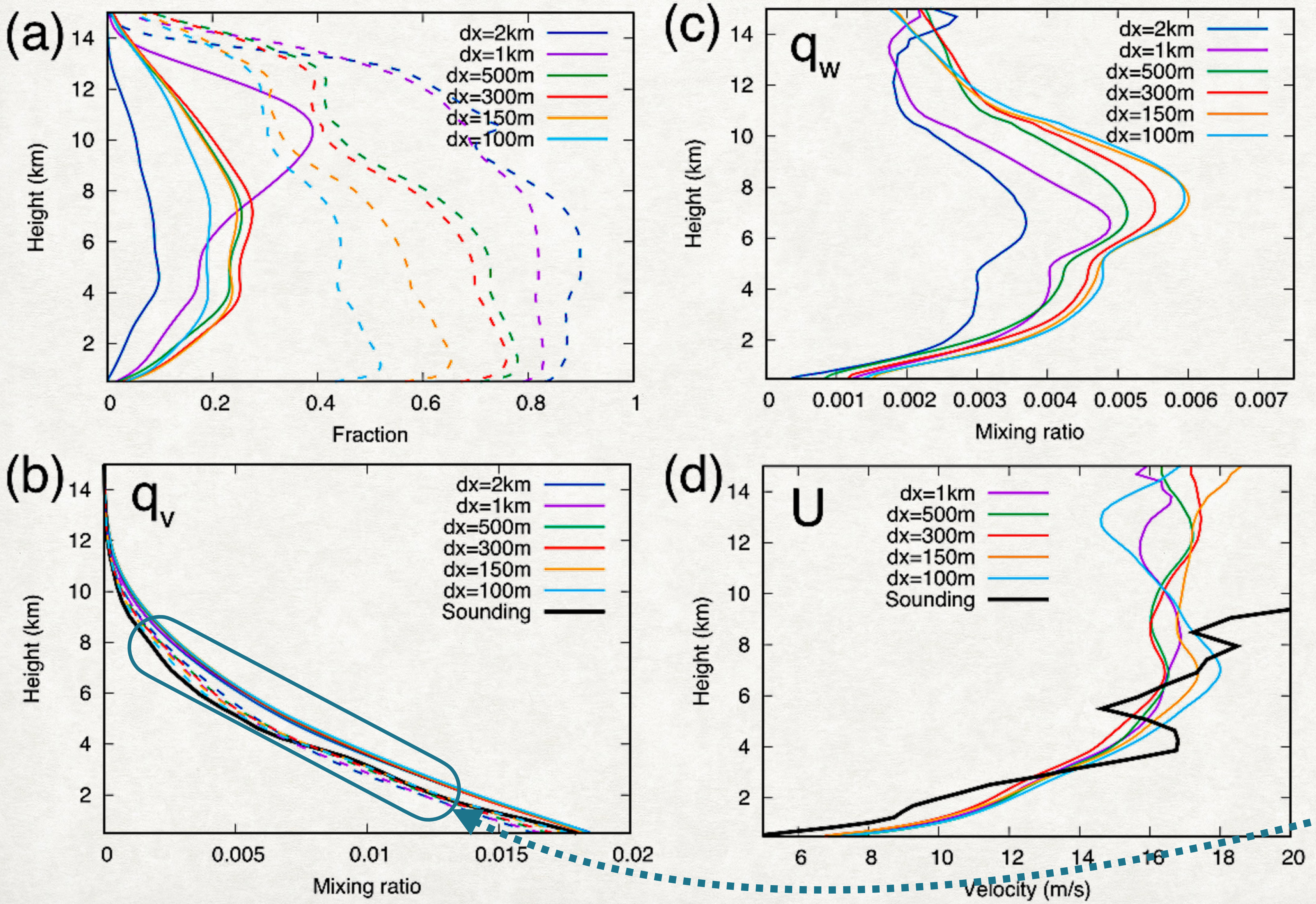


The fraction of cloud area decreases with decreasing dx.

The fraction of cores changes little with dx for dx ≤ 300 m.

DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE

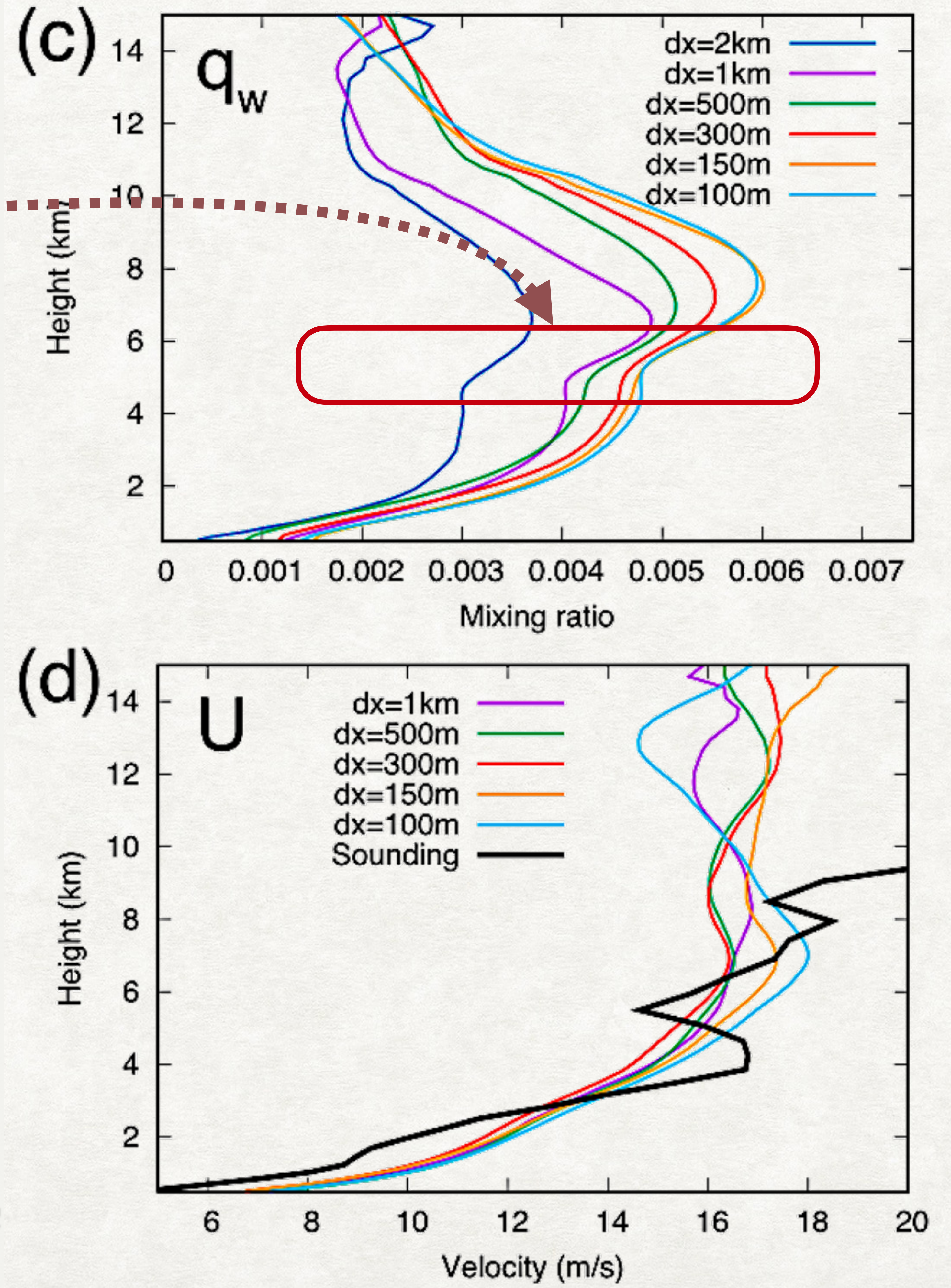


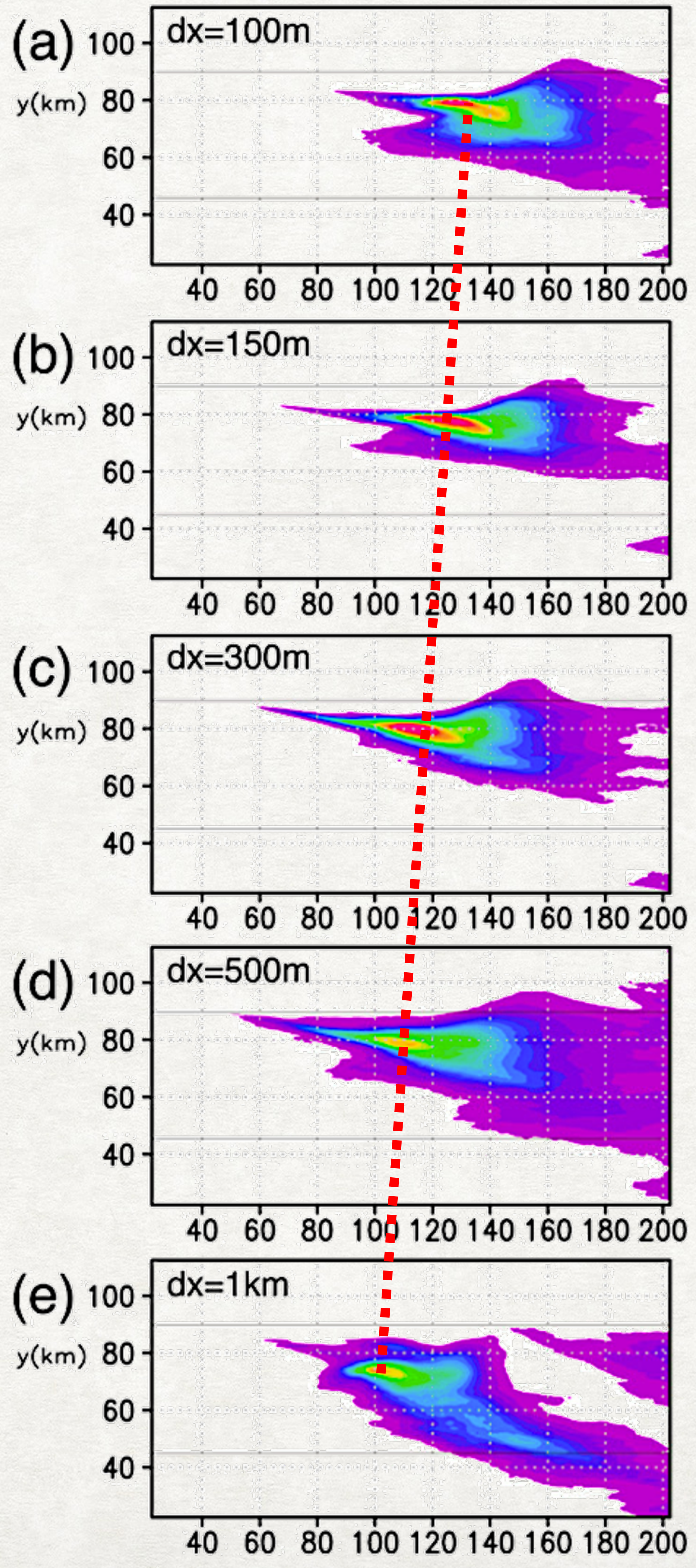
The water vapor mixing ratio (qv) changes little with dx.

DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE

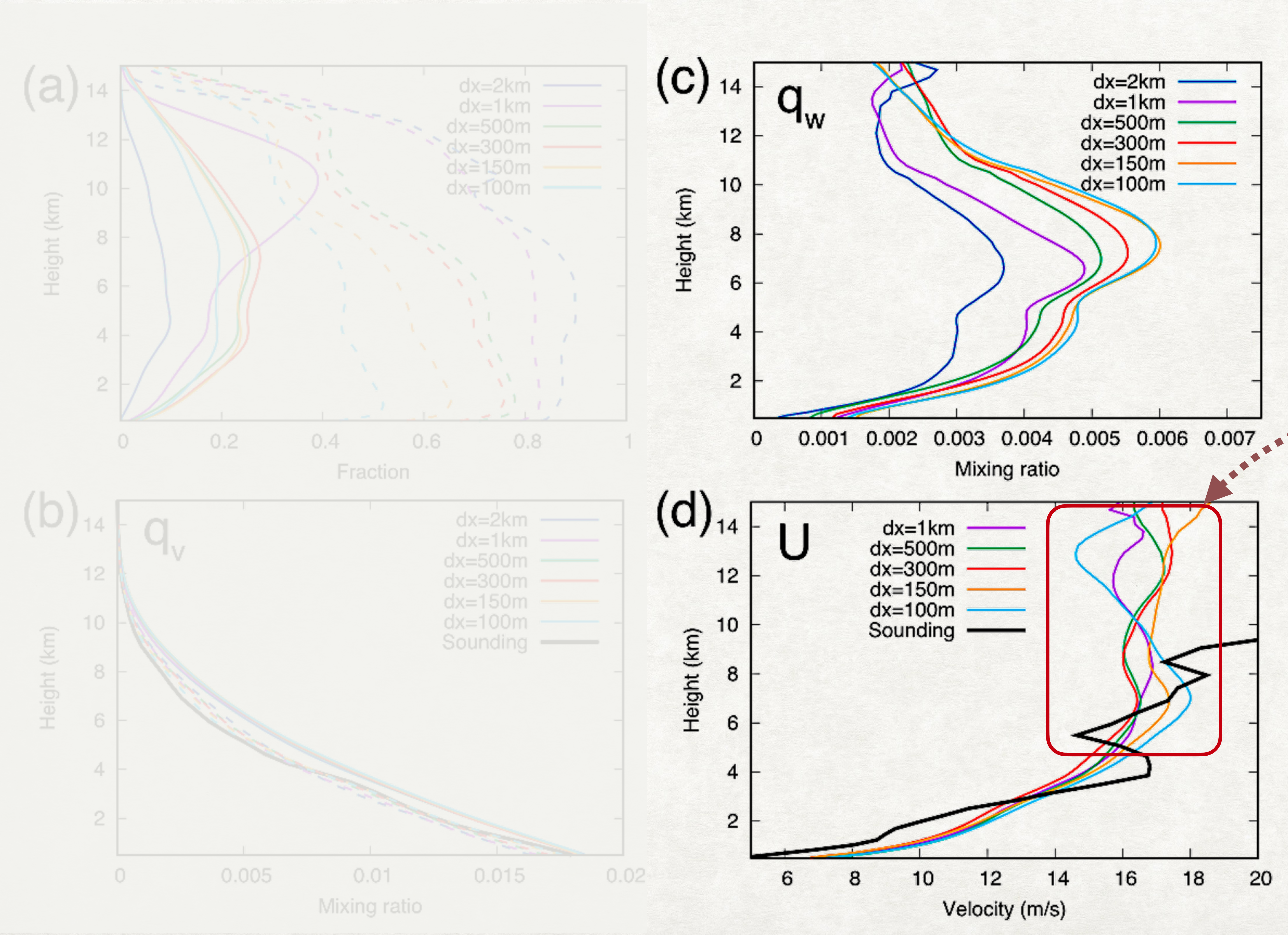
The larger mixing ratio of hydrometeors appears to be associated with stronger w for finer dx above z~4.5 km.





DISCUSSION

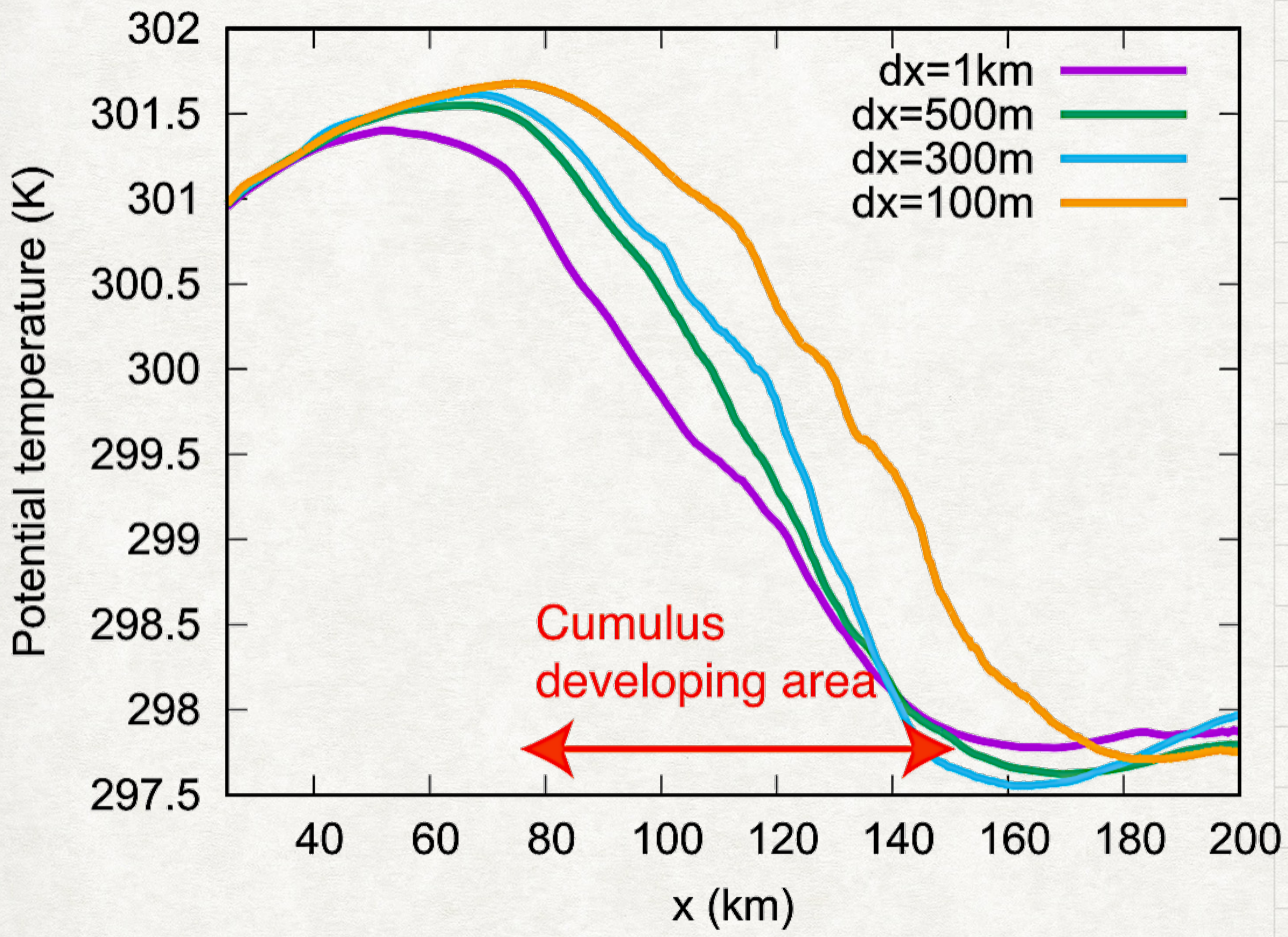
HORIZONTAL RESOLUTION DEPENDENCE



Uc with coarser dx is slightly slower above z ~ 5 km than that for experiments with finer dx.

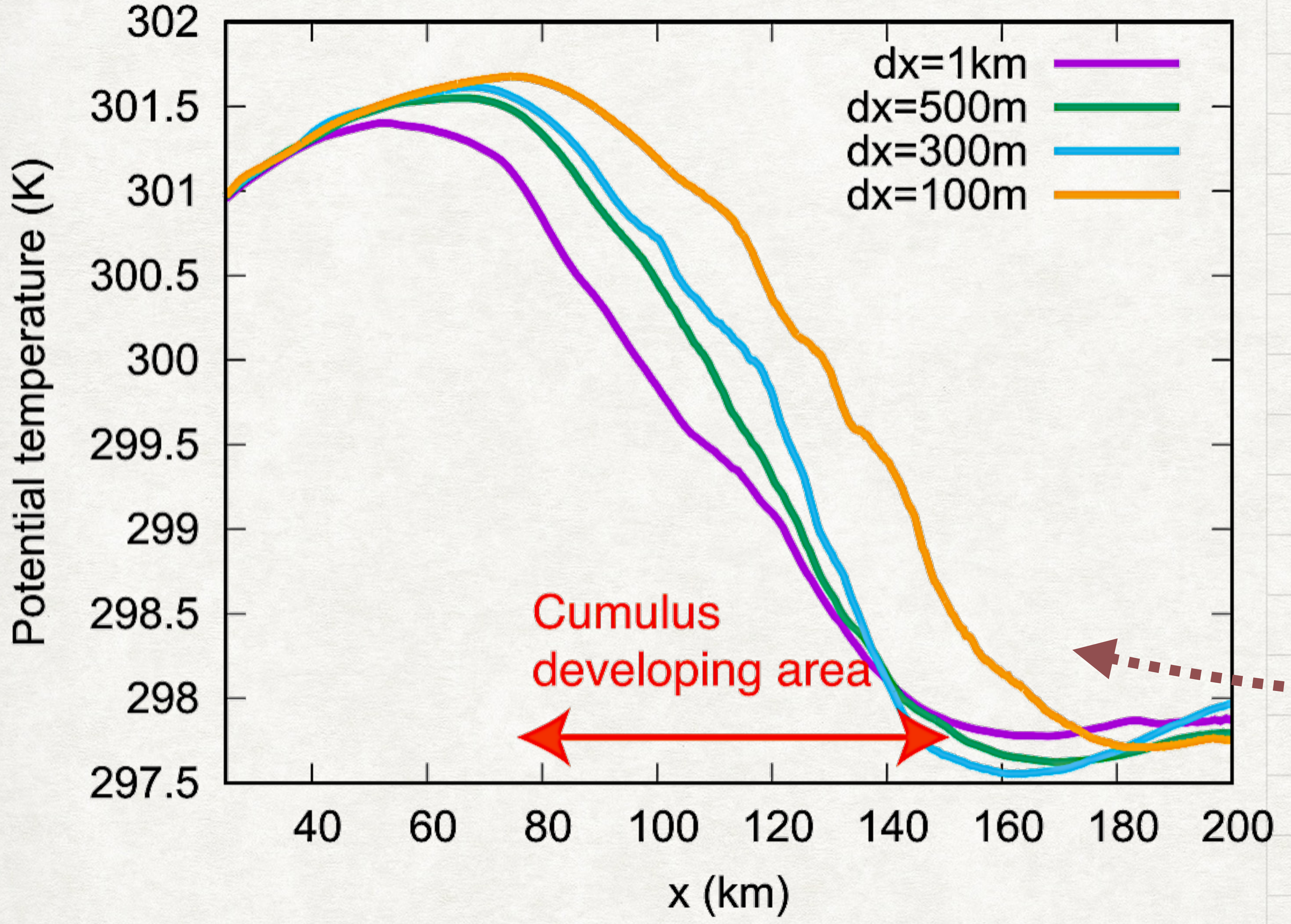
DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE



DISCUSSION

HORIZONTAL RESOLUTION DEPENDENCE

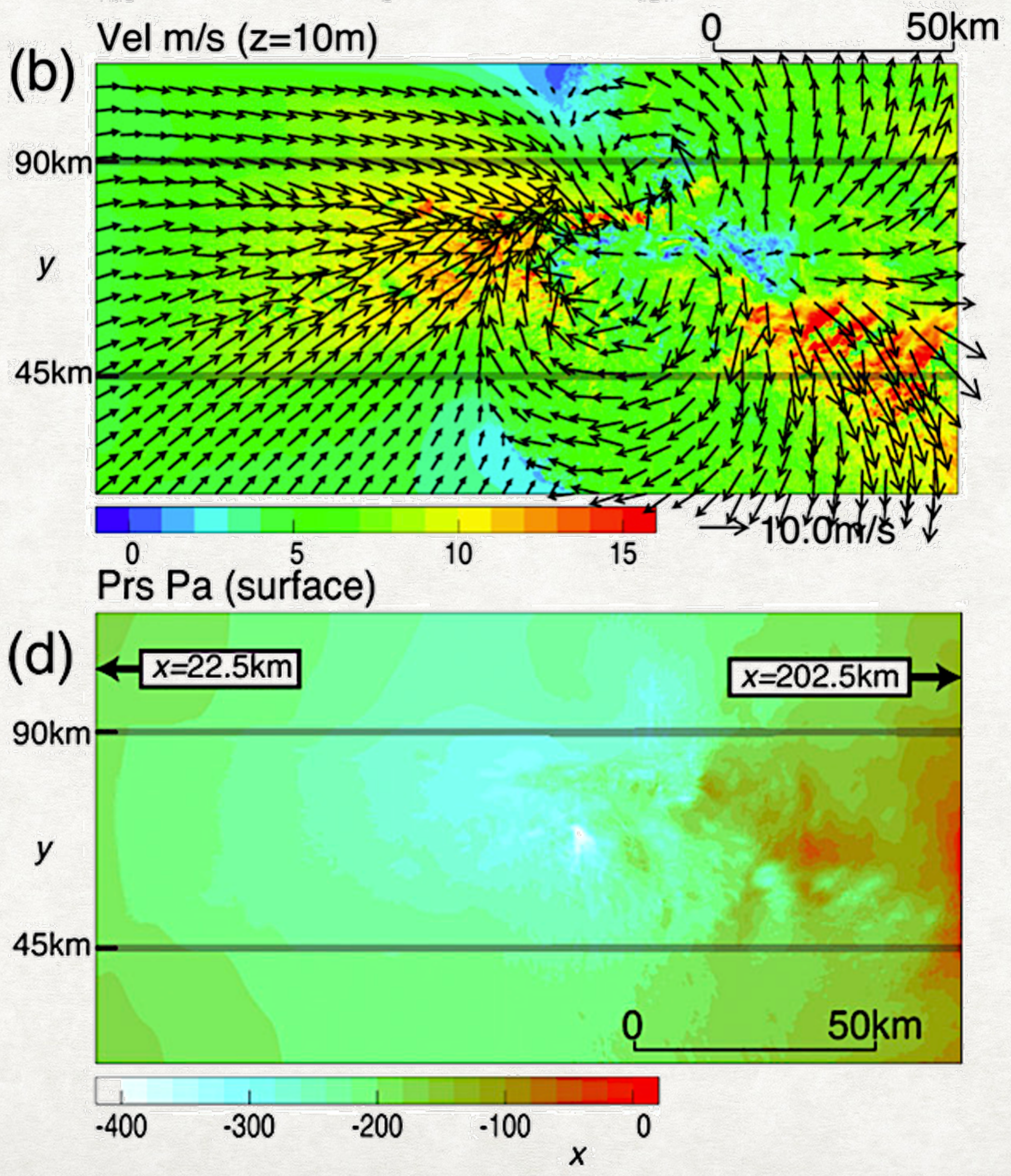


The location of the cold pool moves downstream as dx is decreased.

DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

SURFACE PRESSURE DEPRESSION



$$L = \int_0^T \left(u_0 - \frac{\Delta P}{\rho L} t \right) dt, \quad (1)$$

T: the time when the parcel reaches the convective system

ΔP/ρL: the instantaneous acceleration

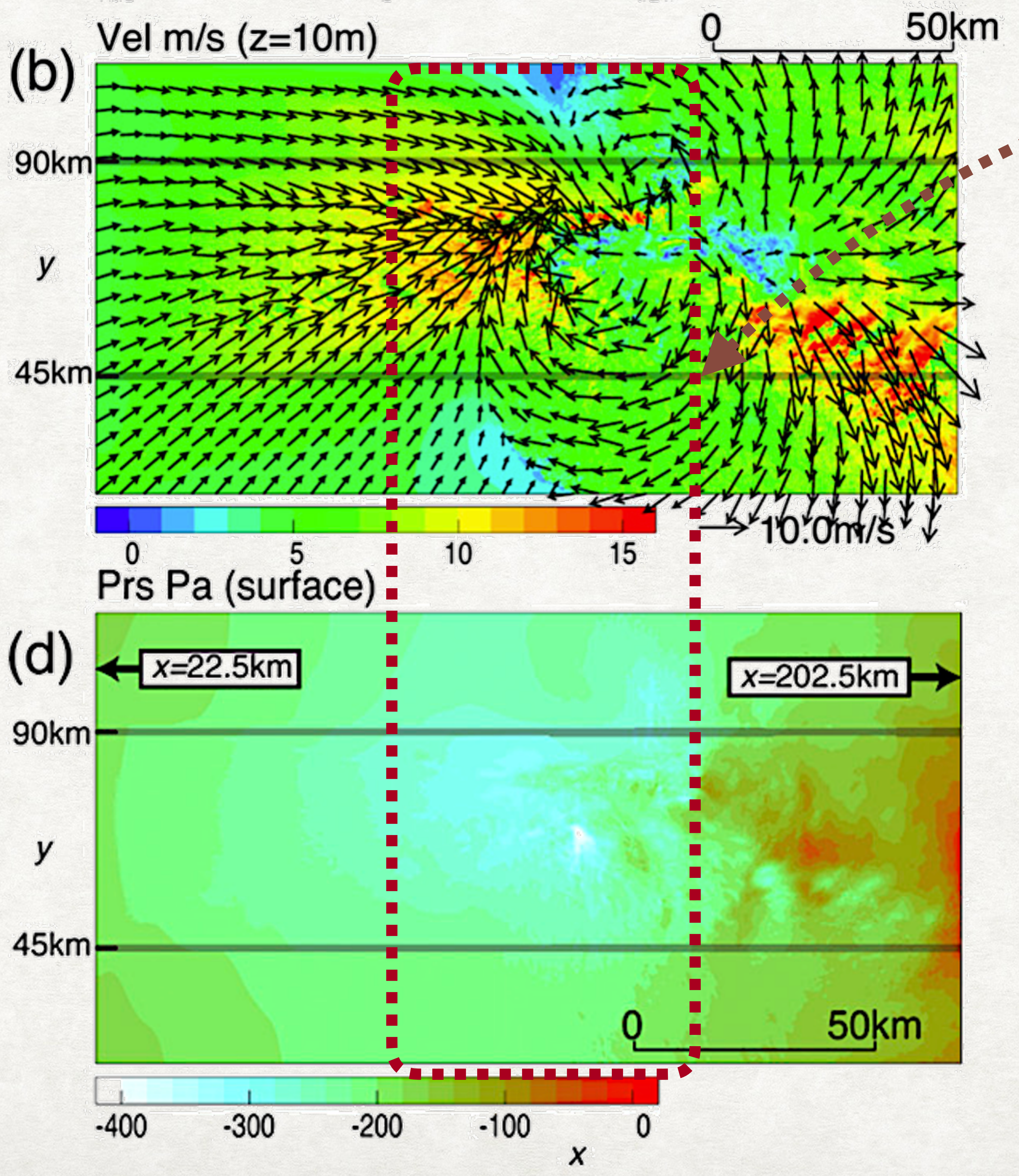
u0: the upstream wind speed

ρ: the air density

DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

SURFACE PRESSURE DEPRESSION



The surface pressure can be lowered beneath the convective system where latent heating is active.

$$L = \int_0^T \left(u_0 - \frac{\Delta P}{\rho L} t \right) dt, \qquad (1)$$

T: the time when the parcel reaches the convective system

ΔP/ρL: the instantaneous acceleration

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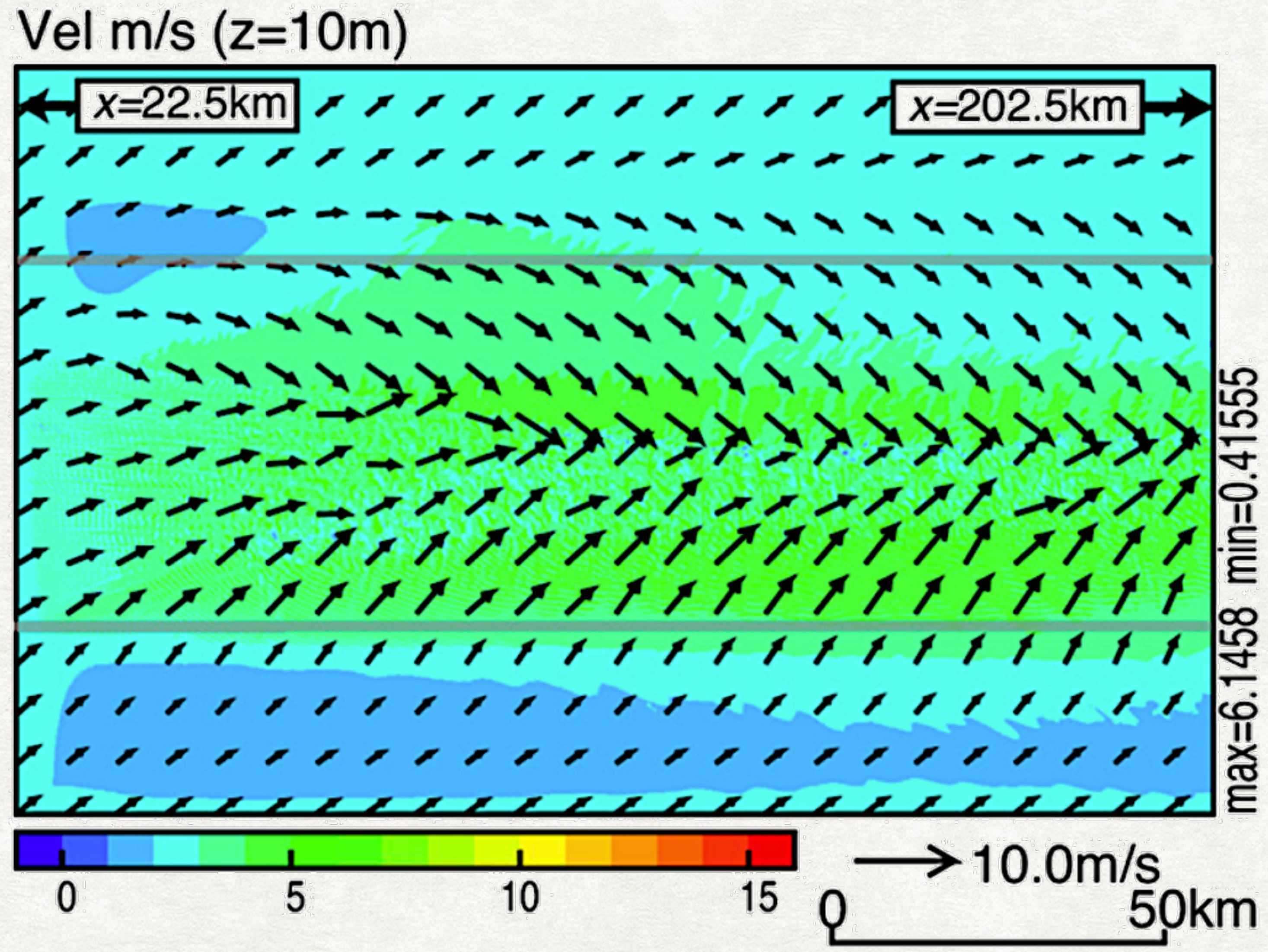
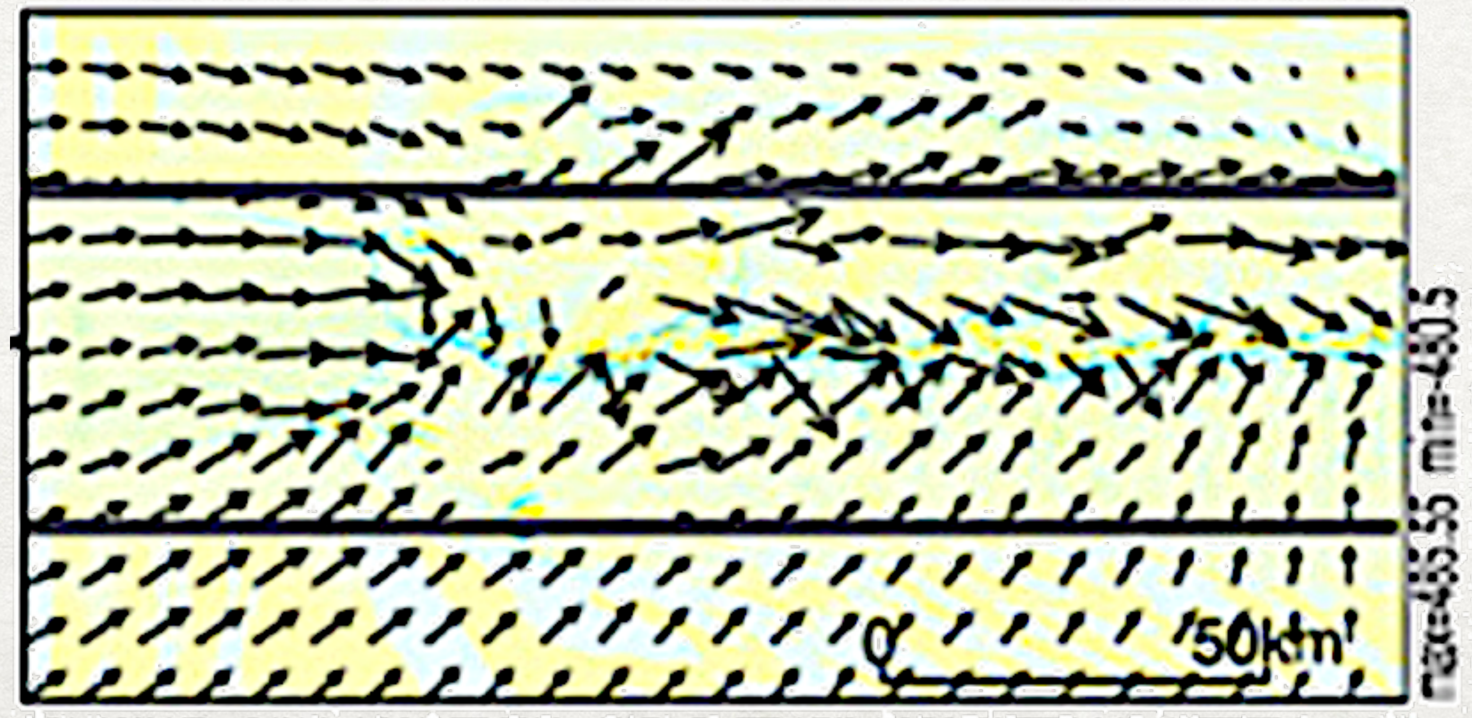
DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

SURFACE PRESSURE DEPRESSION

HORIZONTAL WIND IN THE DRY EXPERIMENT



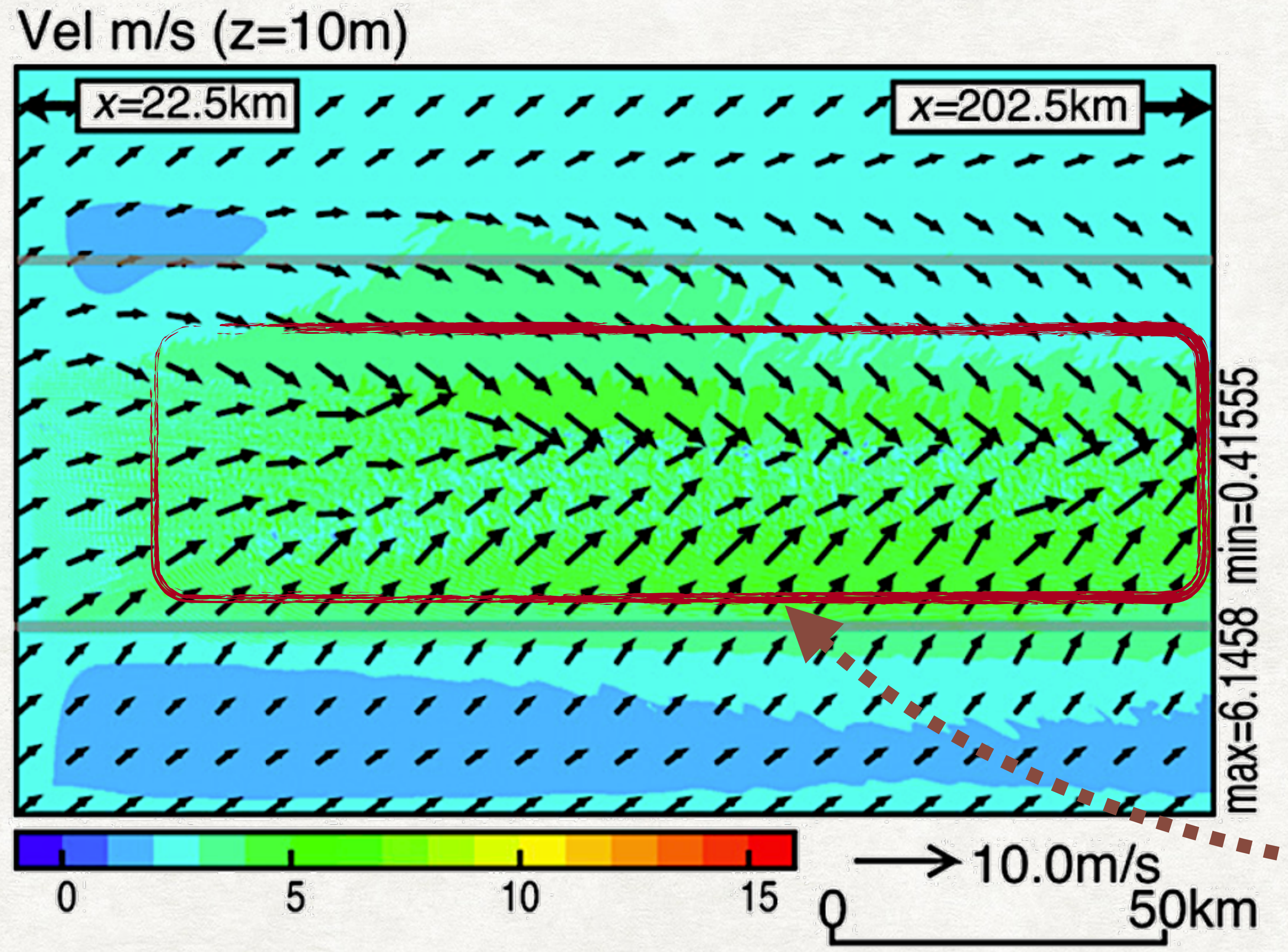


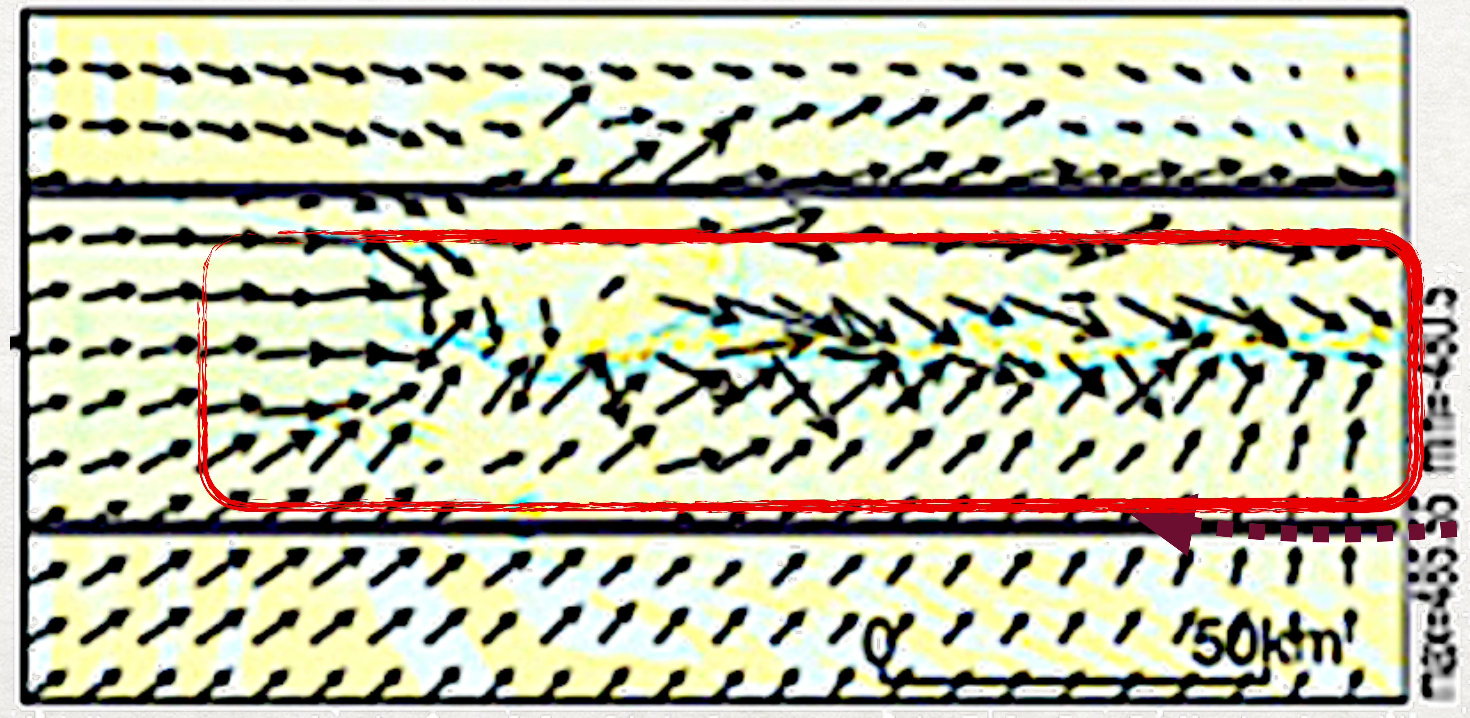
DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

SURFACE PRESSURE DEPRESSION

HORIZONTAL WIND IN THE DRY EXPERIMENT





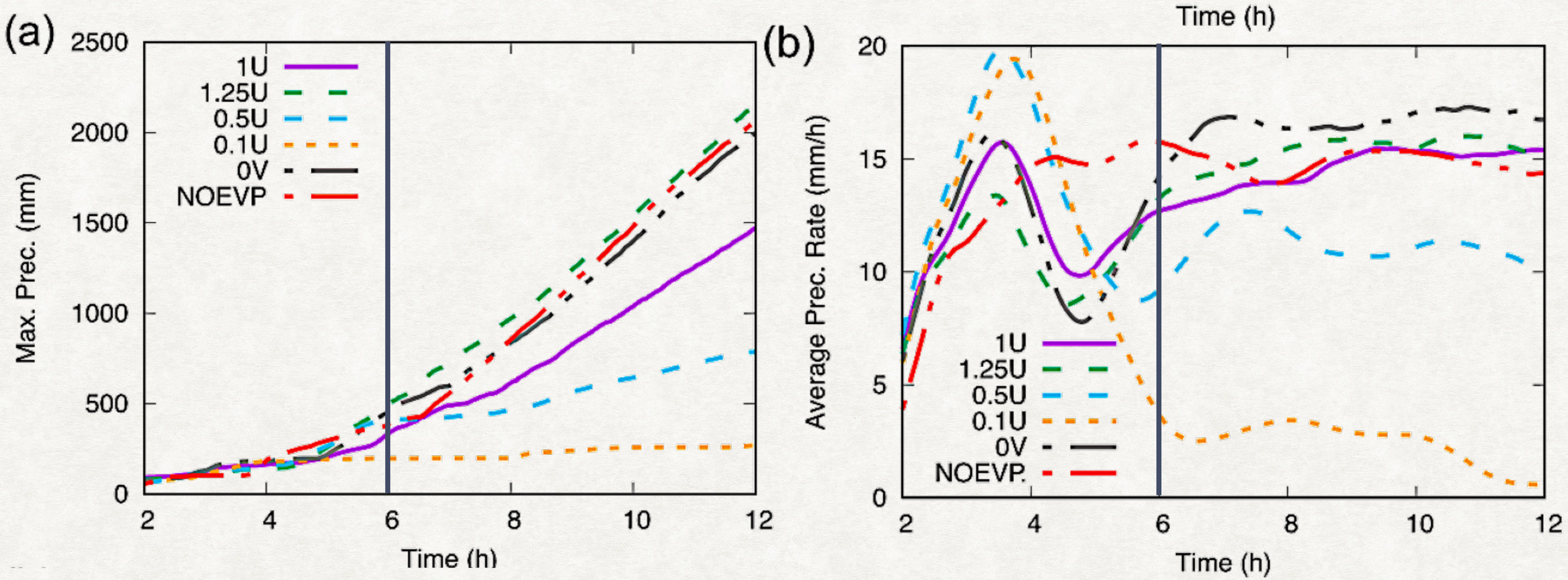
The dry experiment does produce a line-shaped region of convergence over the land, similar to that in the spin-up stage of the control experiment.

However, the horizontal wind speed remains less than ~5 m/s at largest.

DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

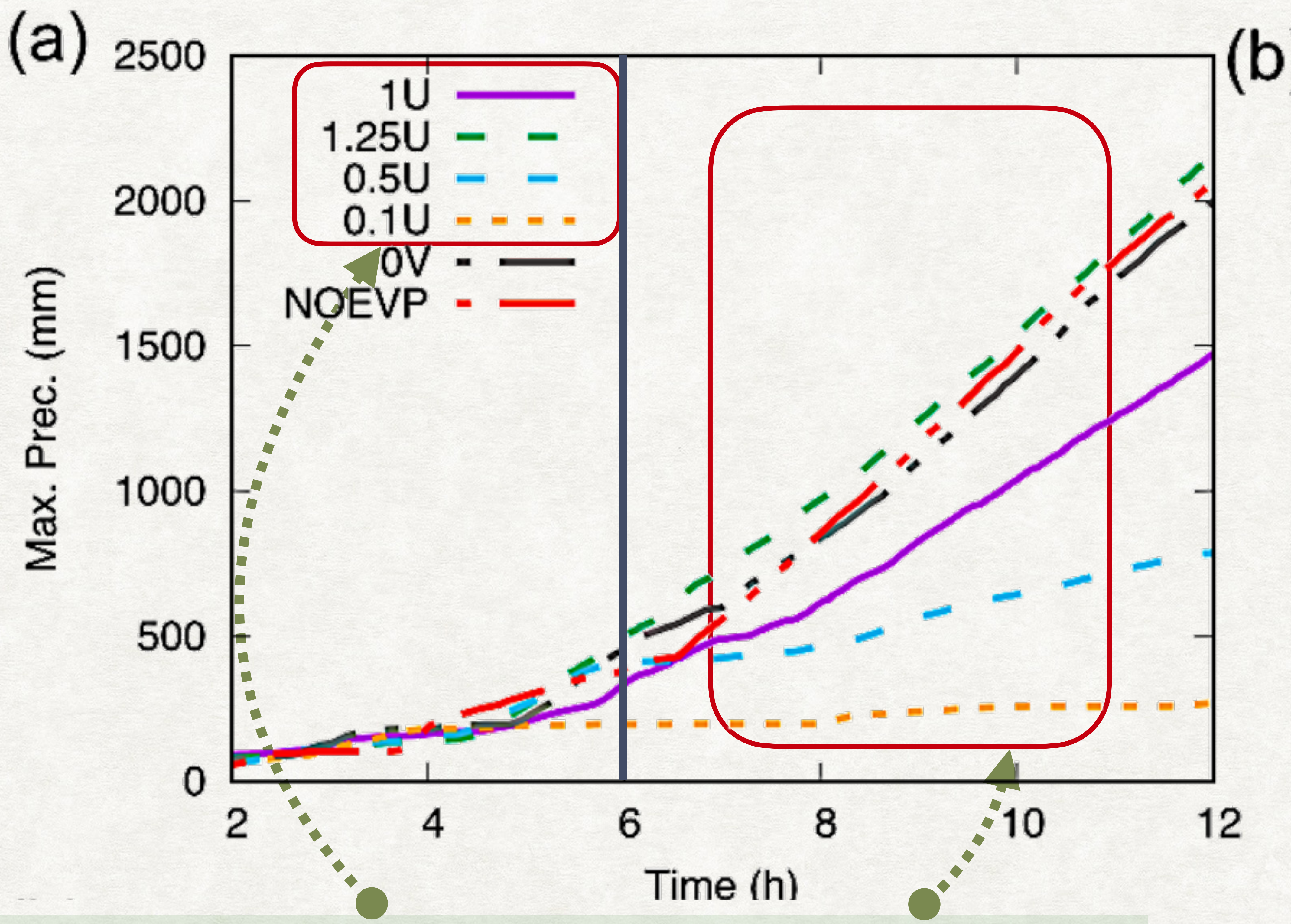
EFFECTS OF VERTICAL SHEAR AND COLD POOL

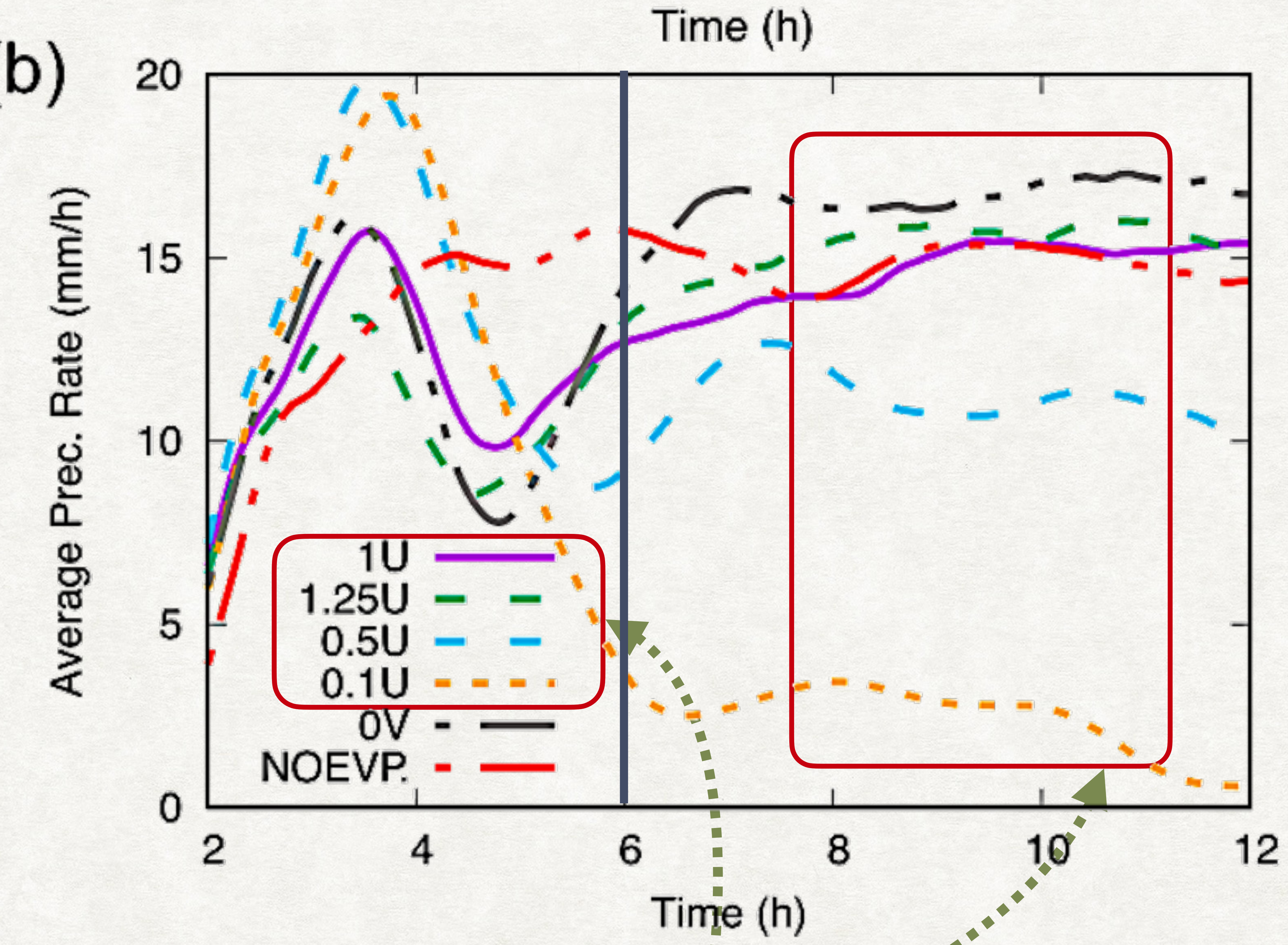


DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

EFFECTS OF VERTICAL SHEAR AND COLD POOL





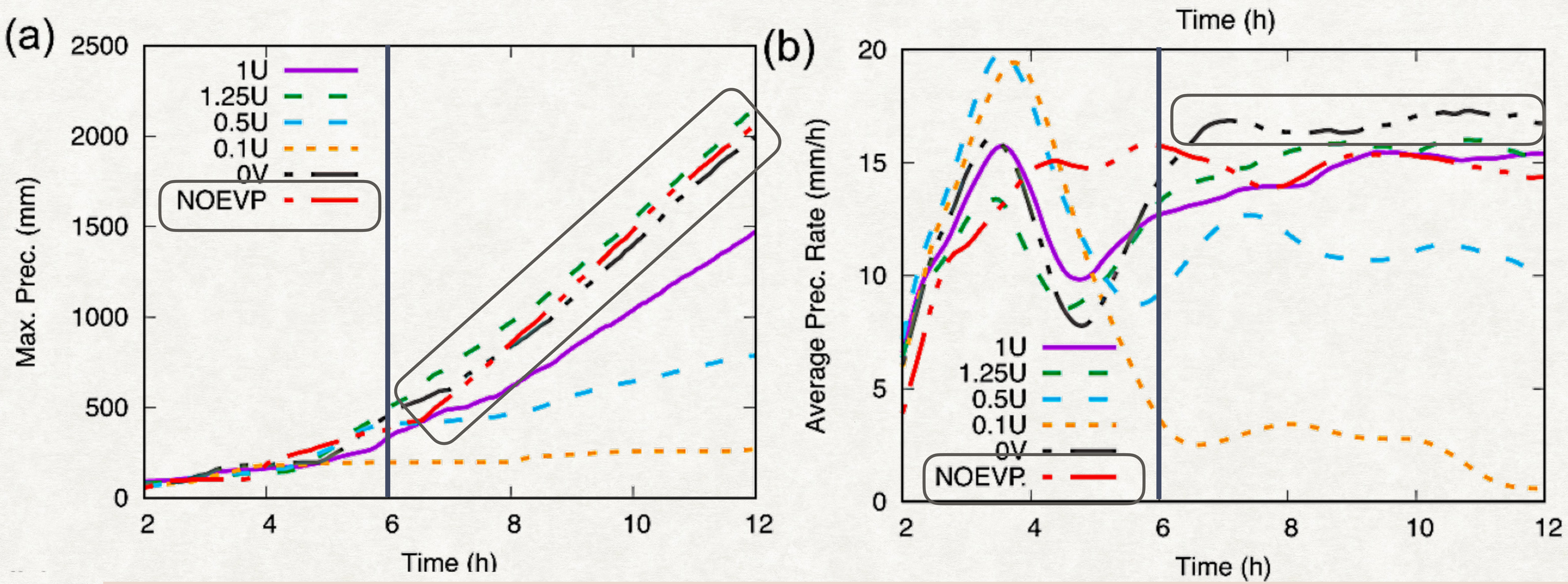
The maximum accumulated rainfall after t=6h increase with increase vertical wind shear.

Same signal in the average precipitation

DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

EFFECTS OF VERTICAL SHEAR AND COLD POOL

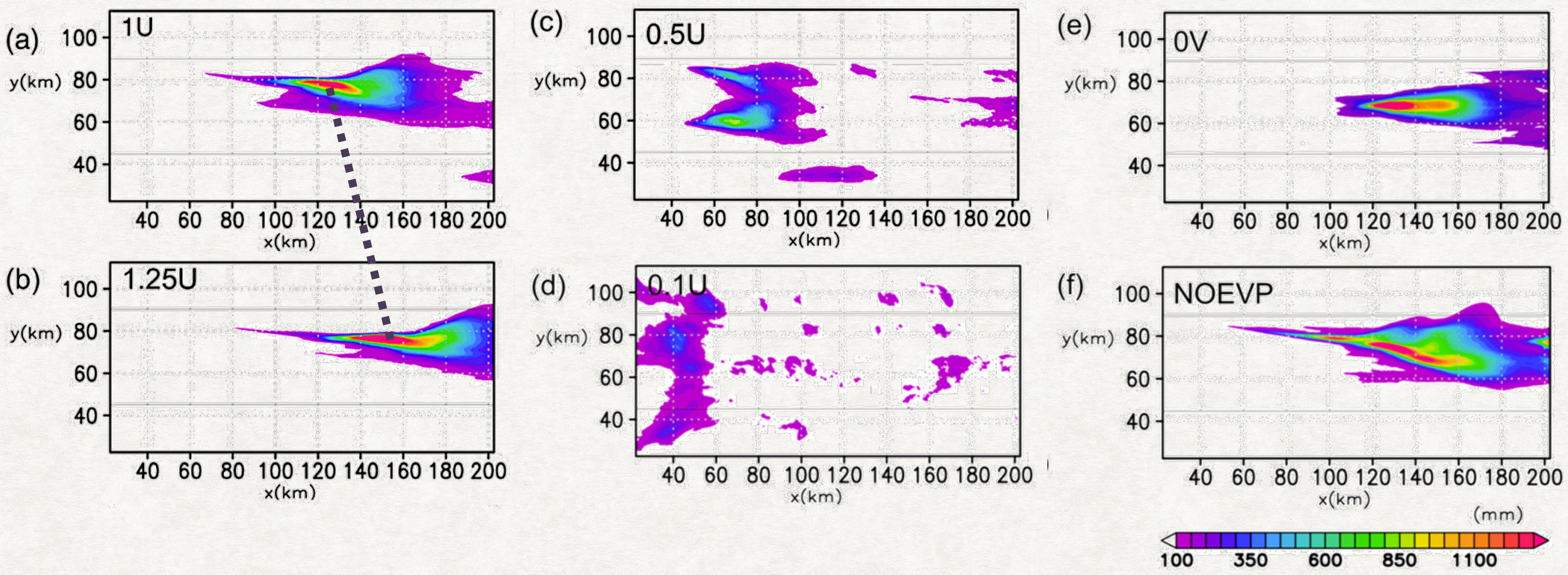


- A stationary QLCS is formed even in the absence of evaporative cooling and hence without a cold pool.
- The total amount of precipitation is larger than that of experiment 1U

DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

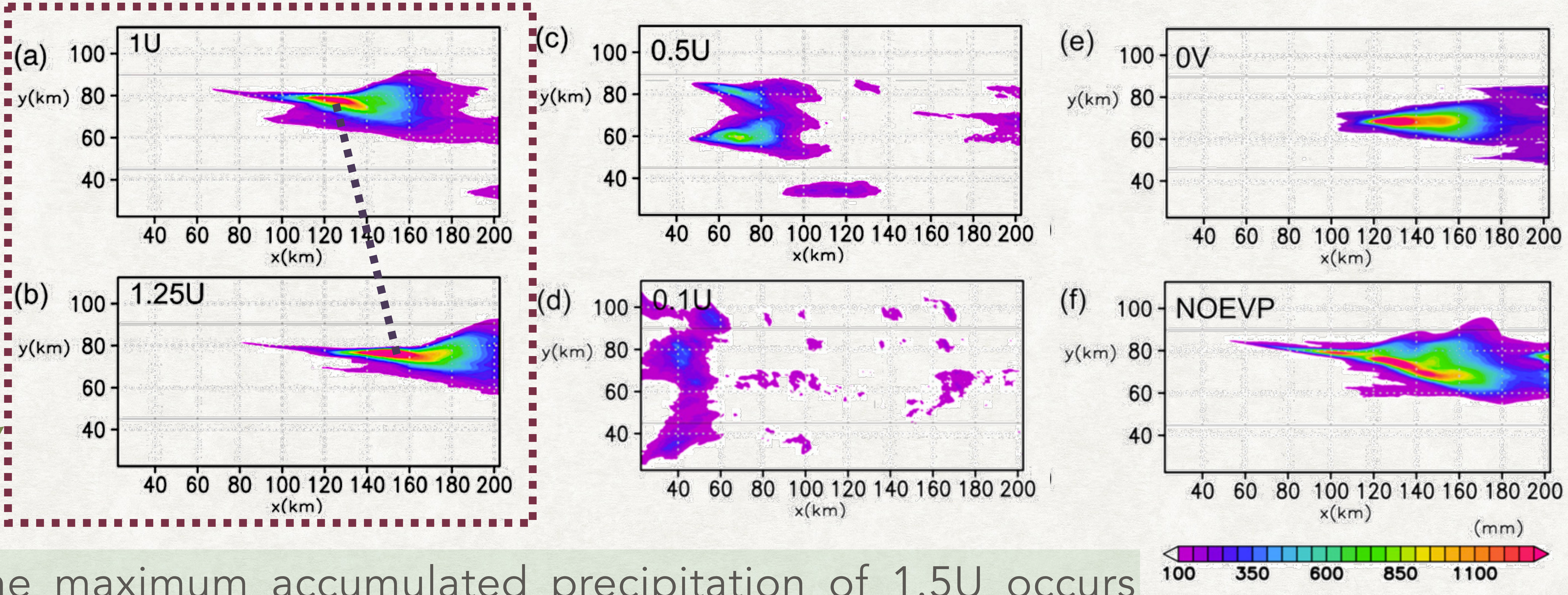
EFFECTS OF VERTICAL SHEAR AND COLD POOL



DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

EFFECTS OF VERTICAL SHEAR AND COLD POOL

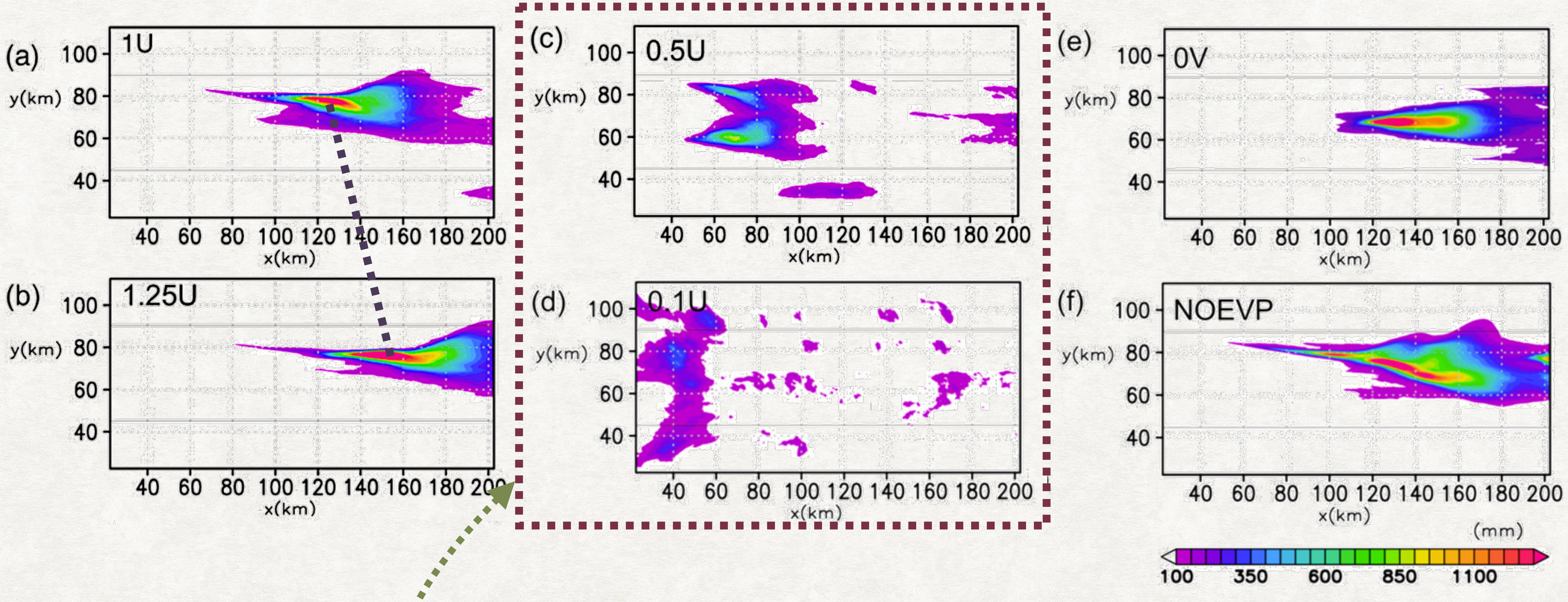


- The maximum accumulated precipitation of 1.5U occurs about 20 km downstream of that for experiment 1U.
- The area with large precipitation is more elongated in the x direction.

DISCUSSION

MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

EFFECTS OF VERTICAL SHEAR AND COLD POOL

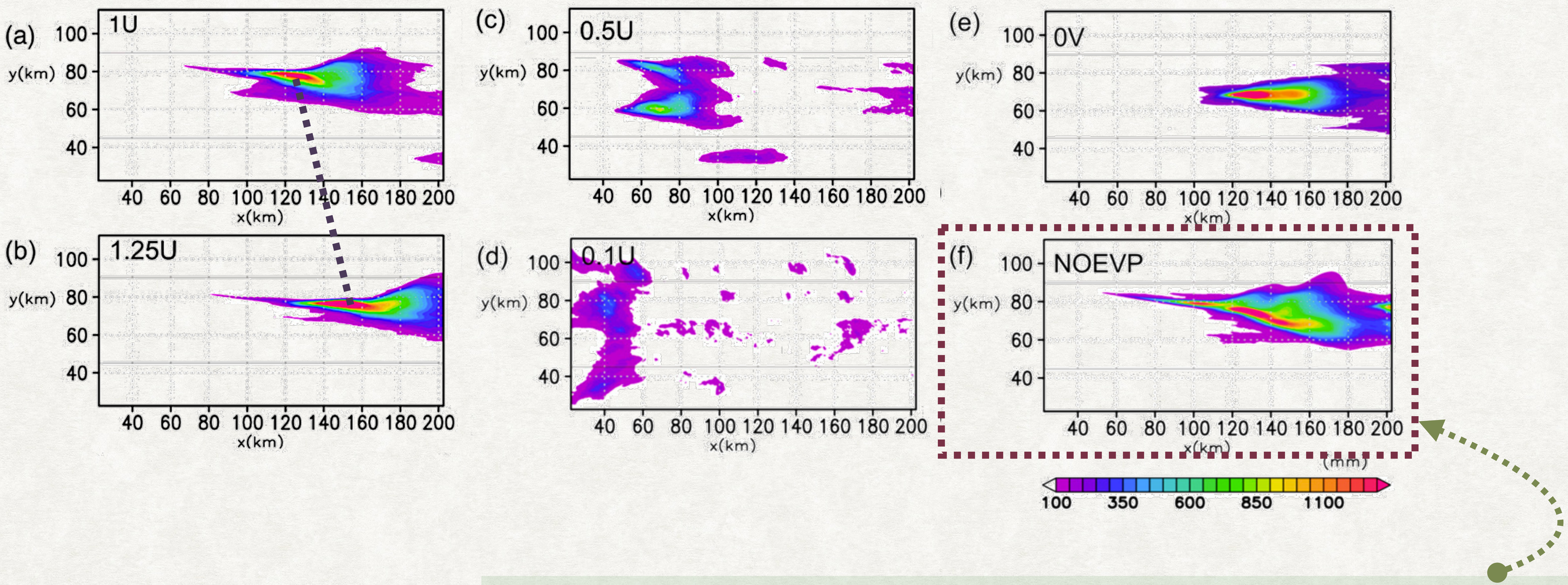


- The organized QLCS is not generated for experiment 0.5U nor for experiment 0.1U.

DISCUSSION

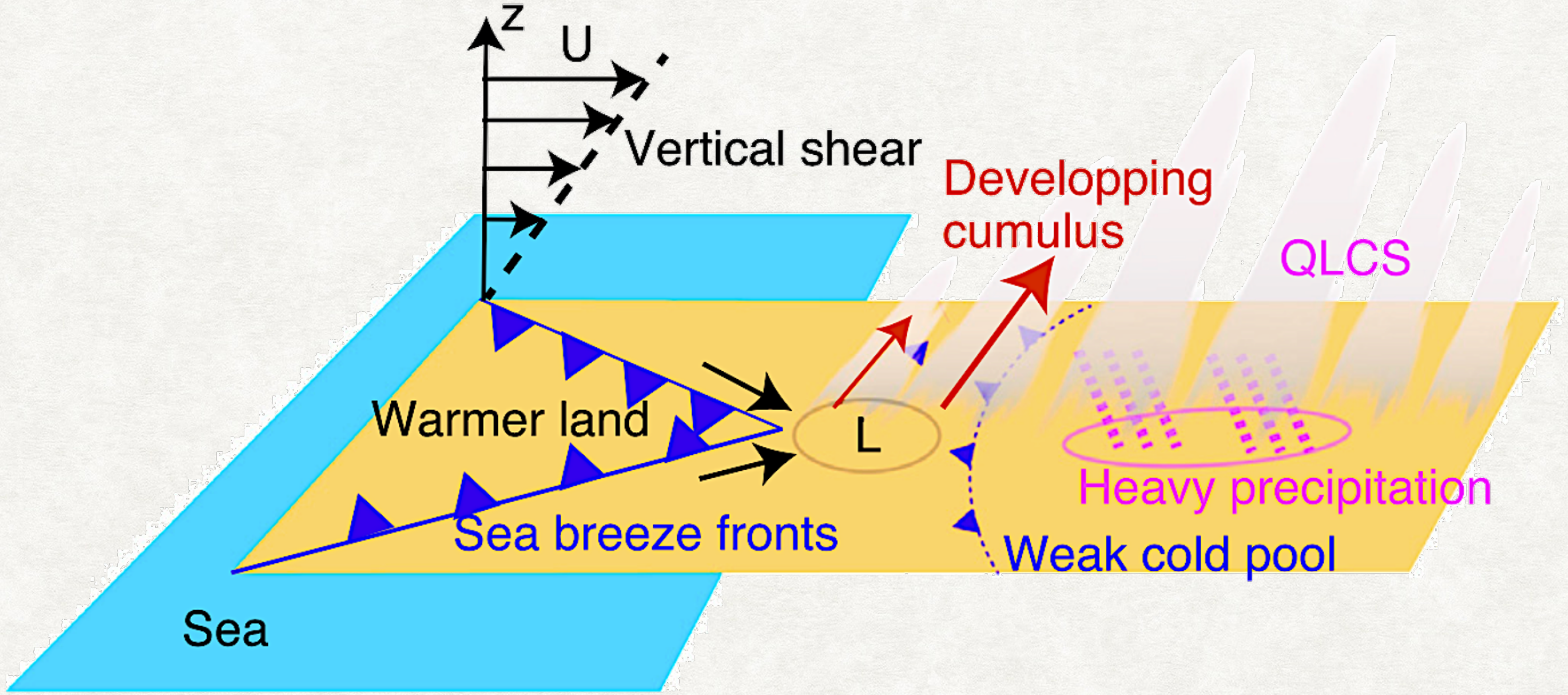
MECHANISM FOR MAINTENANCE OF THE CONVECTIVE SYSTEM

EFFECTS OF VERTICAL SHEAR AND COLD POOL



- A stationary QLCS is formed even in the absence of evaporative cooling and hence without a cold pool.

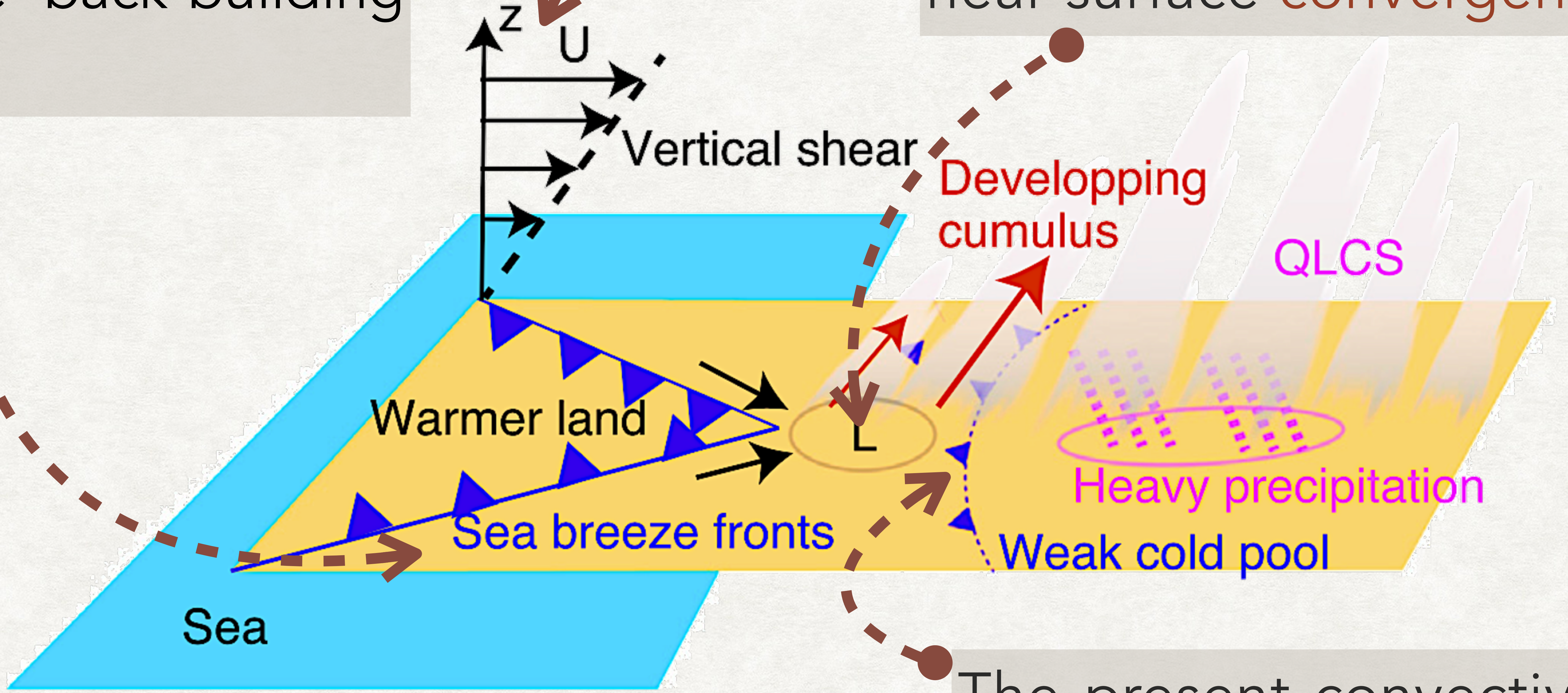
CONCLUSIONS



CONCLUSIONS

The present situation that the sea-breeze fronts and vertical shear nearly parallel to the fronts play important roles in the formation of the back-building QLCS.

A feedback from preceding cumulus clouds generate a mesoscale pressure depression near the surface, which strengthens the near-surface convergence to the system.



The present convective system can develop even in the absence of a cold pool.

Thanks for listening!