能源及環境學院
SCHOOL OF ENERGY AND ENVIRONMENT

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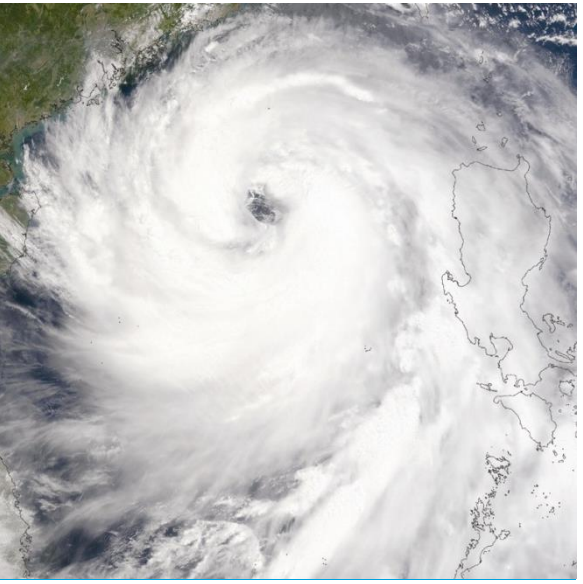


Applications of the TC motion concepts II

Johnny Chan

School of Energy and Environment

City University of Hong Kong

Outline

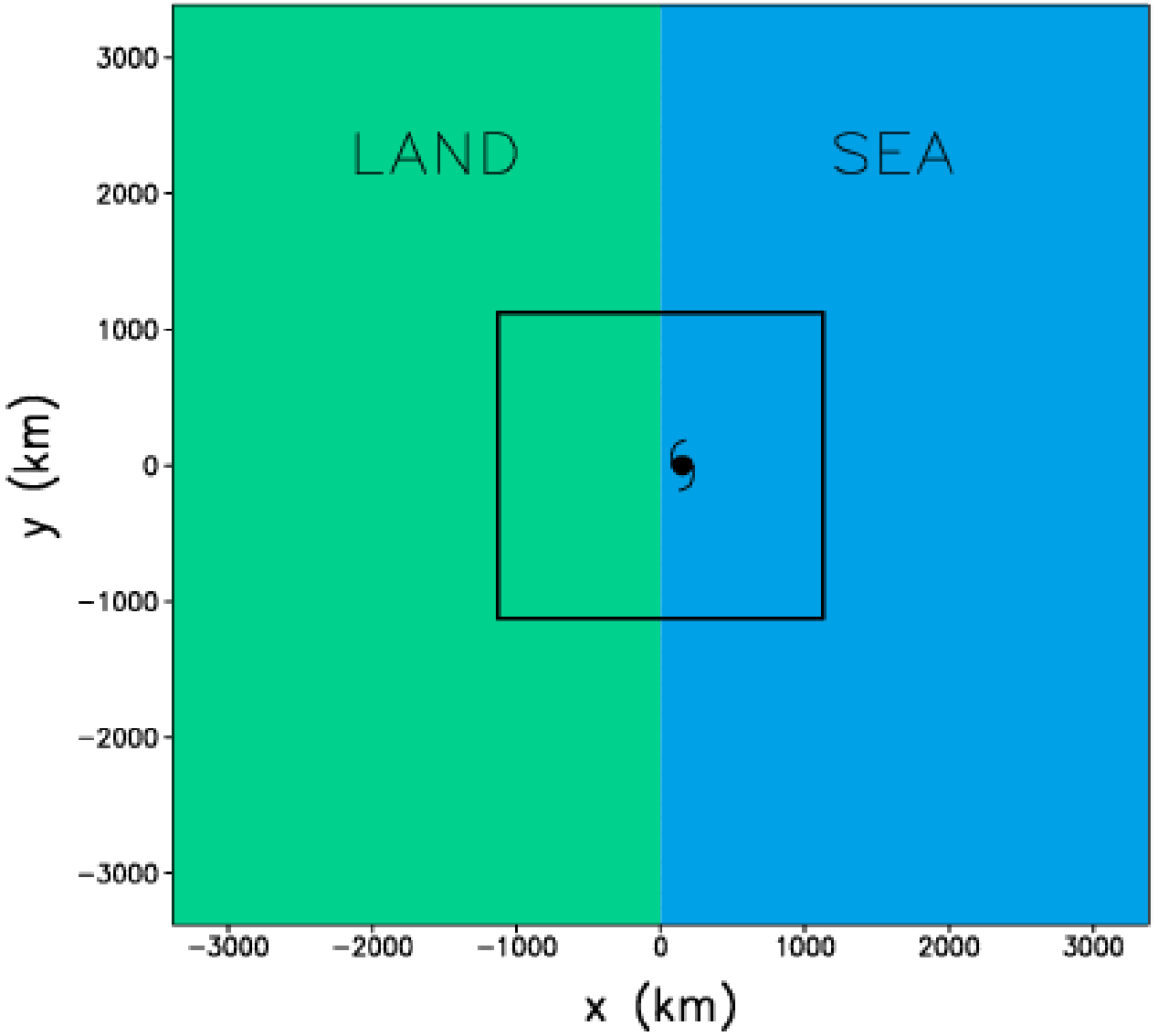
- Effects of differential surface roughness
  - Flat terrain on an *f* plane
  - Flat terrain on a beta plane
  - Flat terrain with varying roughness on an *f* plane
- Effect of topography

Effect of differential surface roughness

Flat Terrain
f plane

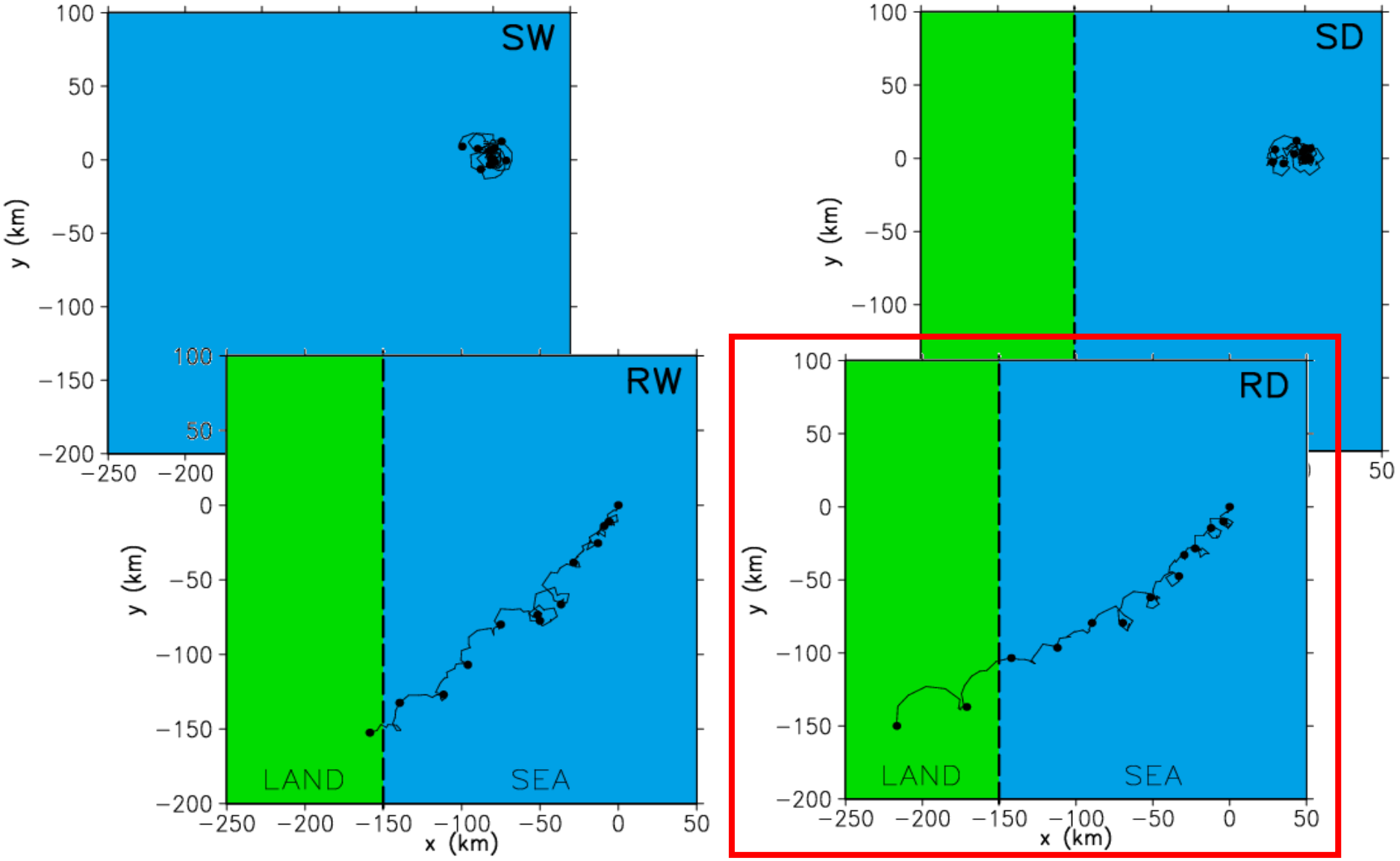
Wong and Chan (2006)

f plane experiments

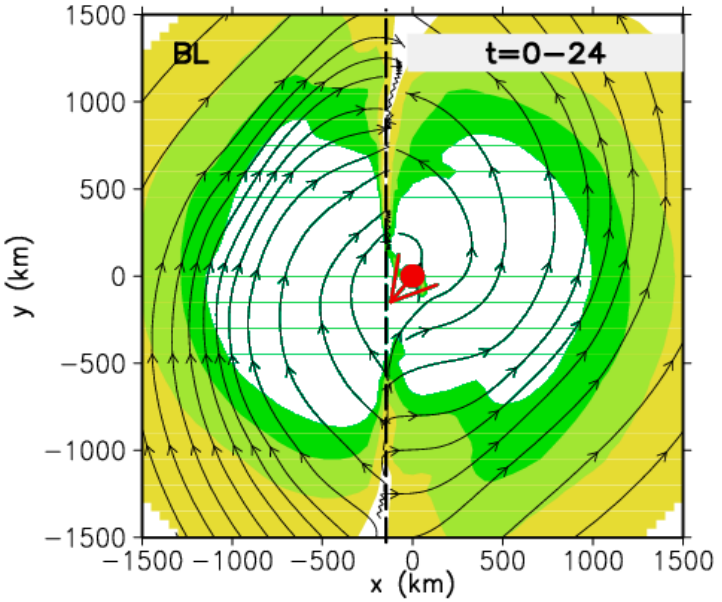


Wong and Chan (2006)

f plane experiments

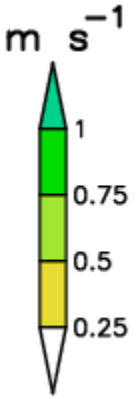


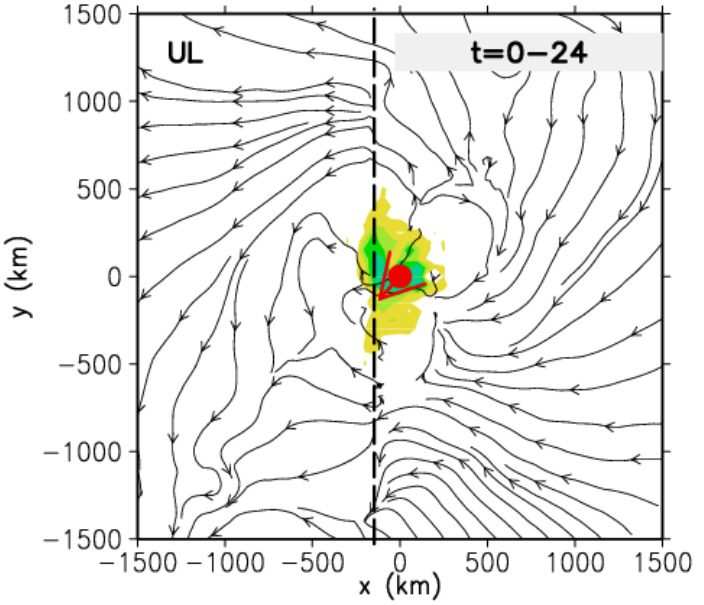
Asymmetric flow (rough-dry land, DAY 1)



boundary layer

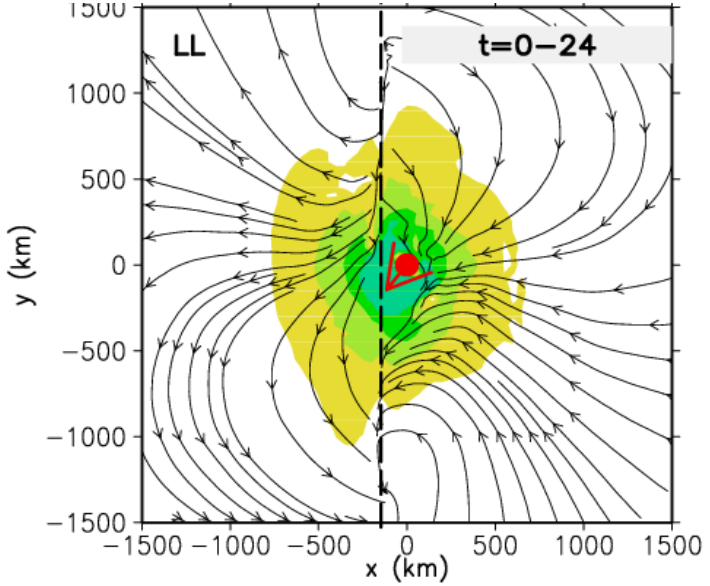
(0.9<σ<1.0)





upper layer (UL)

(0.25<σ<0.55)



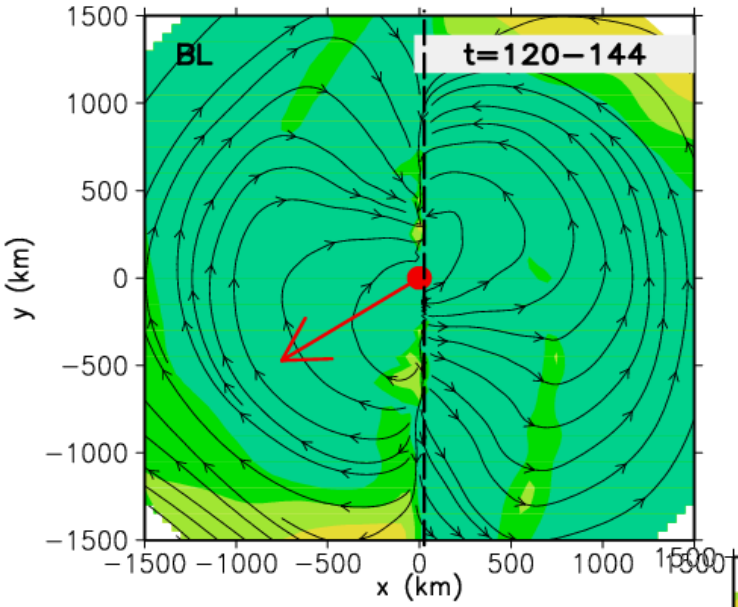
lower layer (LL)

(0.55<σ<0.9)

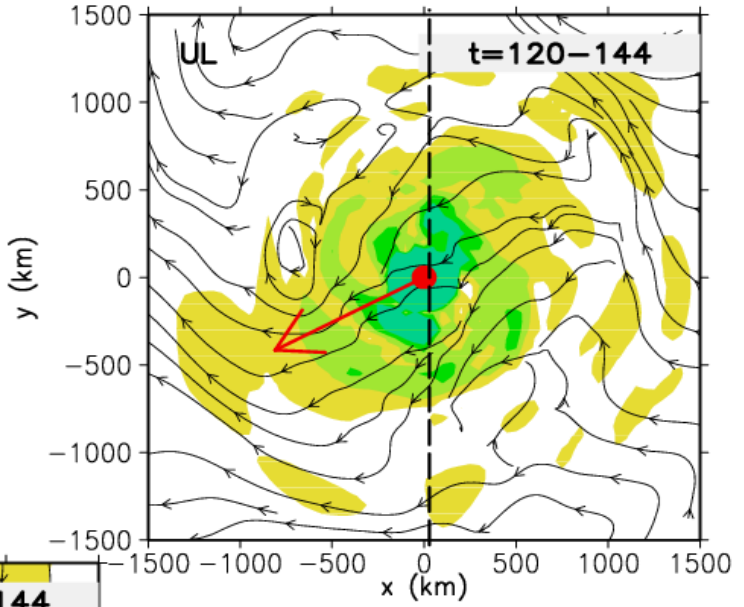
- **Reverse of convergence/divergence in LL along coast**
- **Small magnitude in UL**

Wong and Chan (2006)

Asymmetric flow RD experiment Day 6

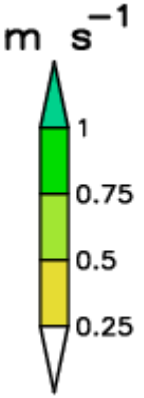


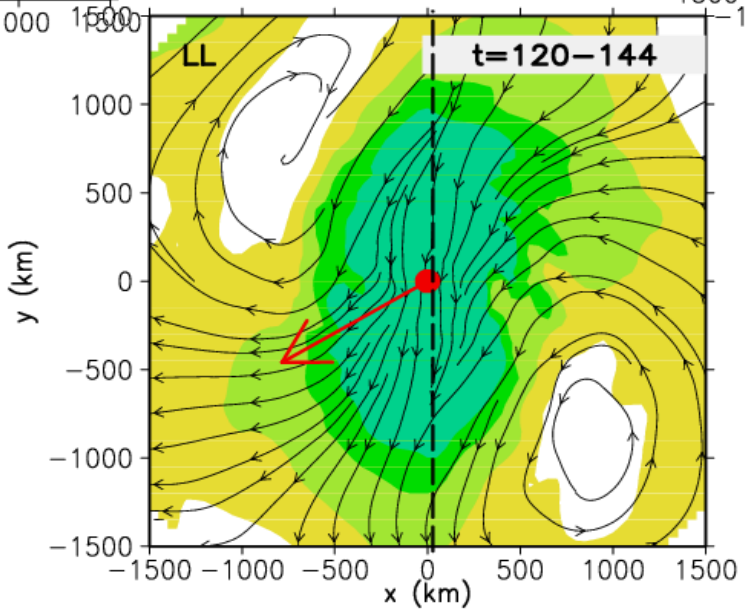
boundary layer (0.9<σ<1.0)



upper layer (0.25<σ<0.55)

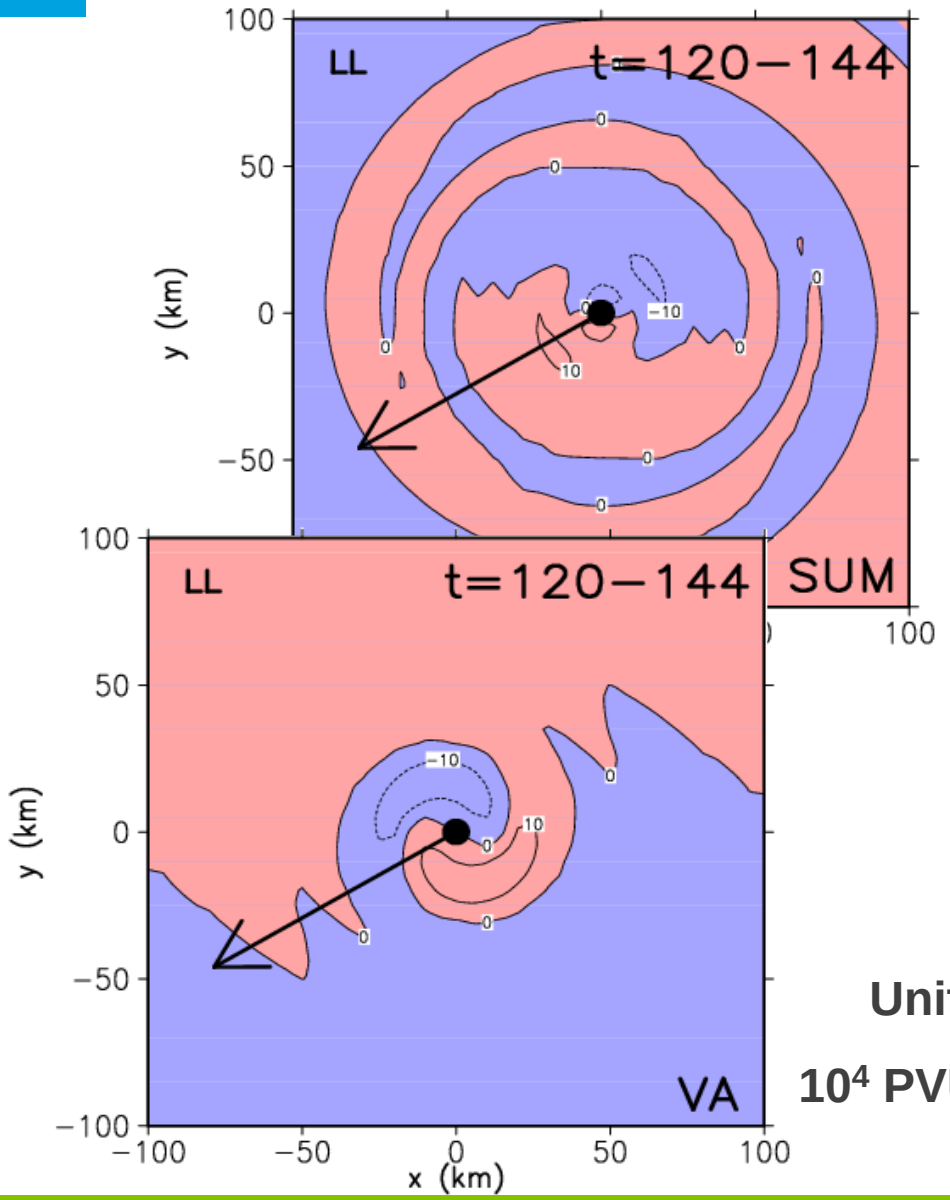
lower layer (0.55<σ<0.9)

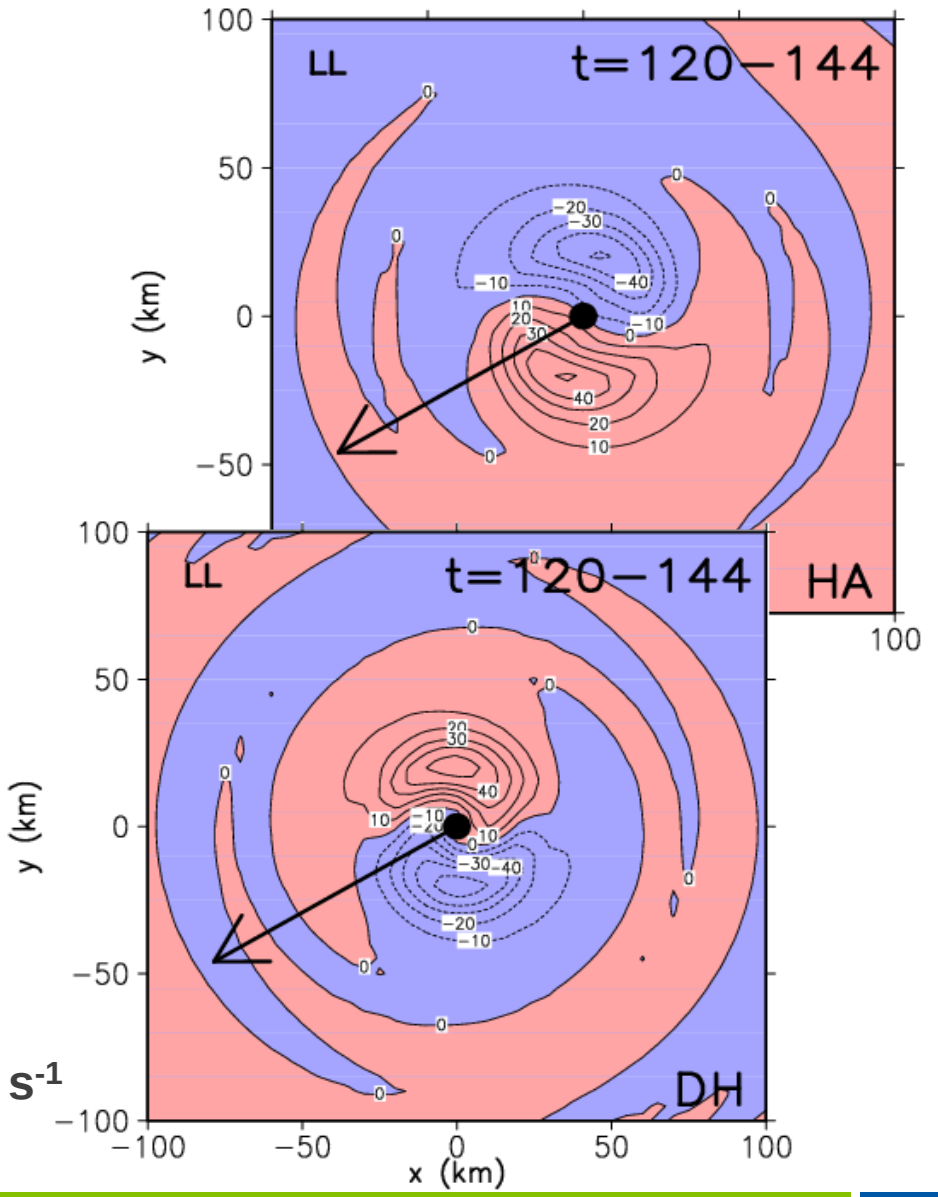




Wong and Chan (2006)

PV budget at LL (RD experiment Day 6)



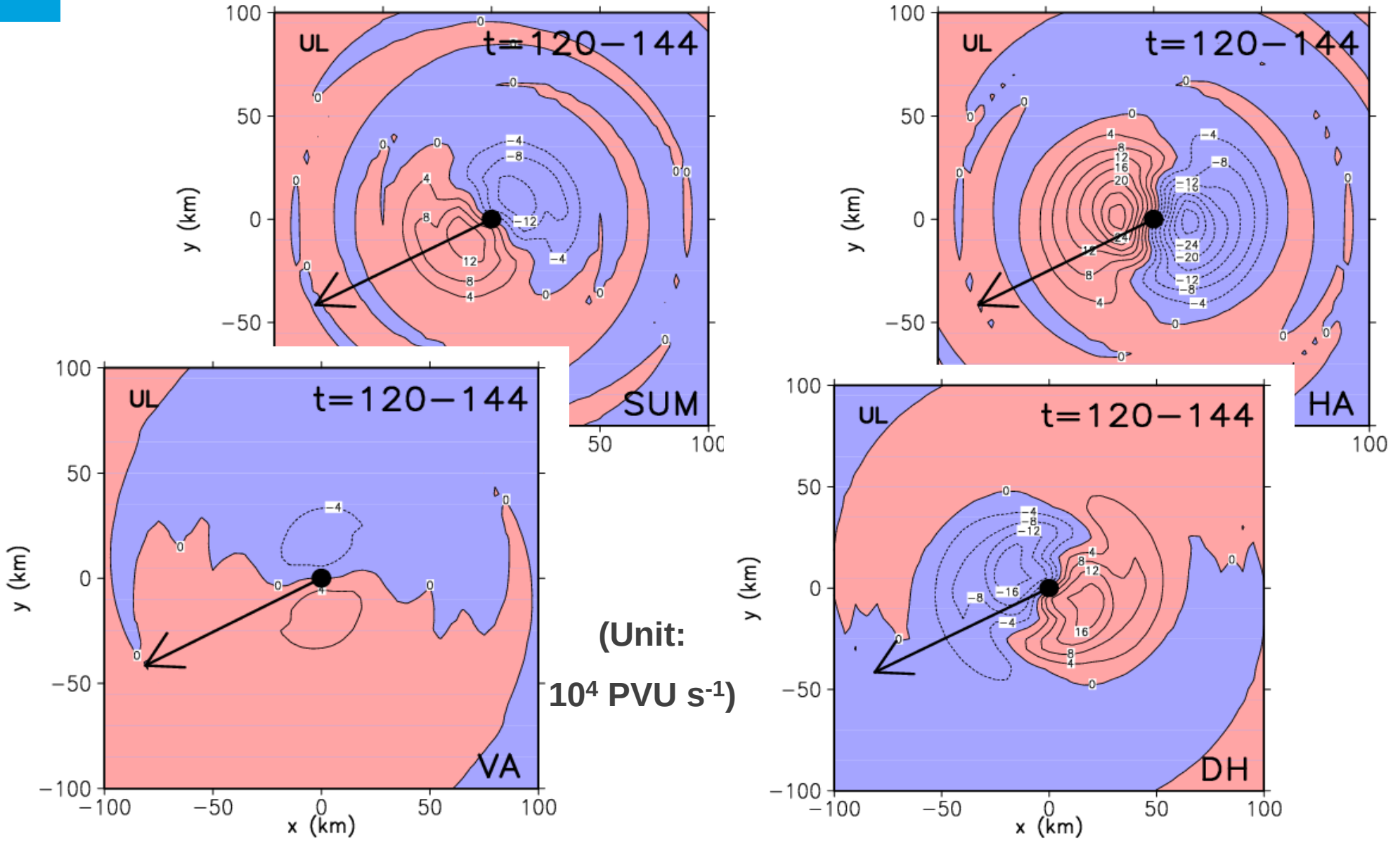


Unit:

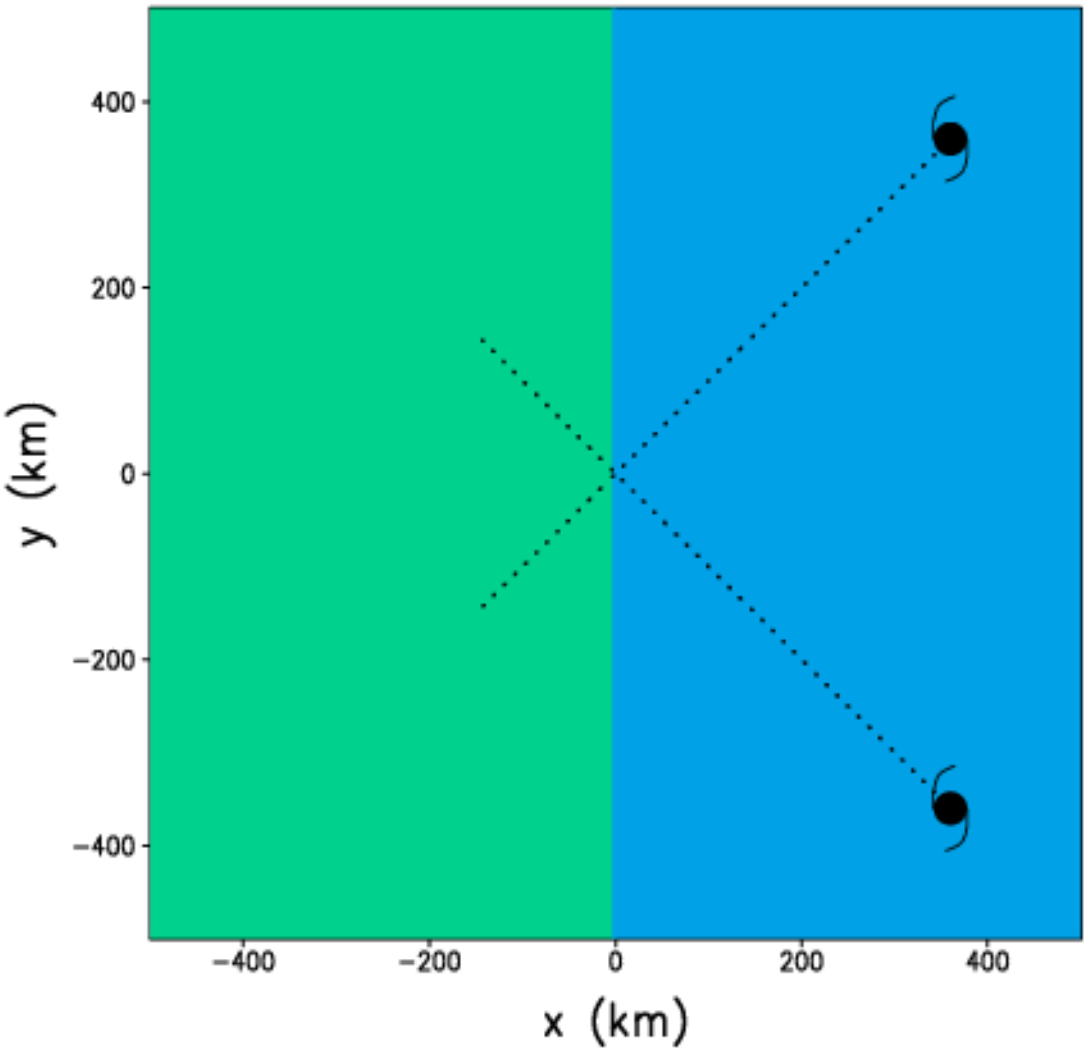
10^4 PVU s^{-1}

Wong and Chan (2006)

PV budget at UL (RD experiment Day 6)

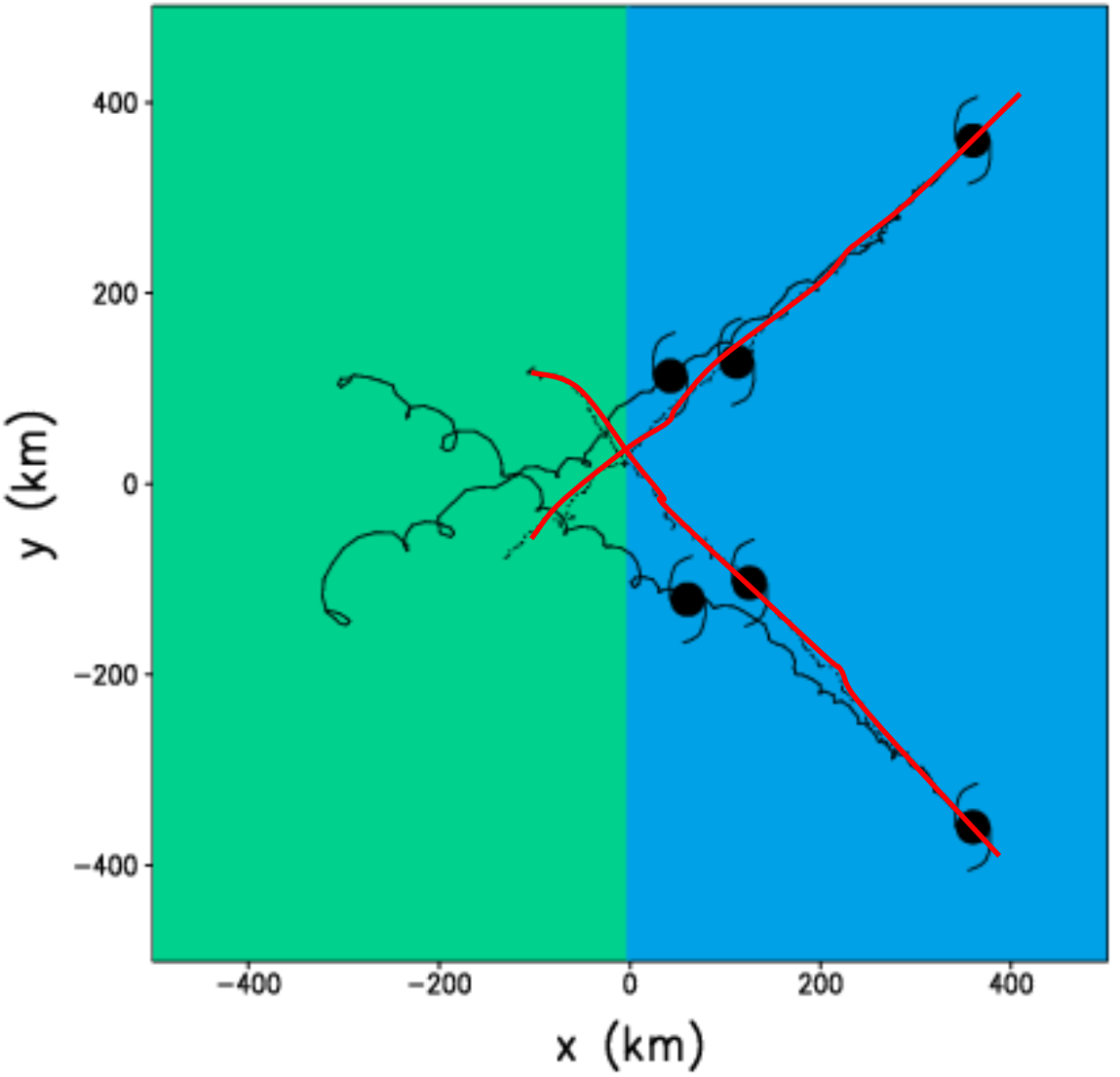


Additional Experiments



- TCs in 5 km/h NE or SE background flow
- 360 km from coast
- Landfall near origin at t=102 h if no land.

Additional Experiments

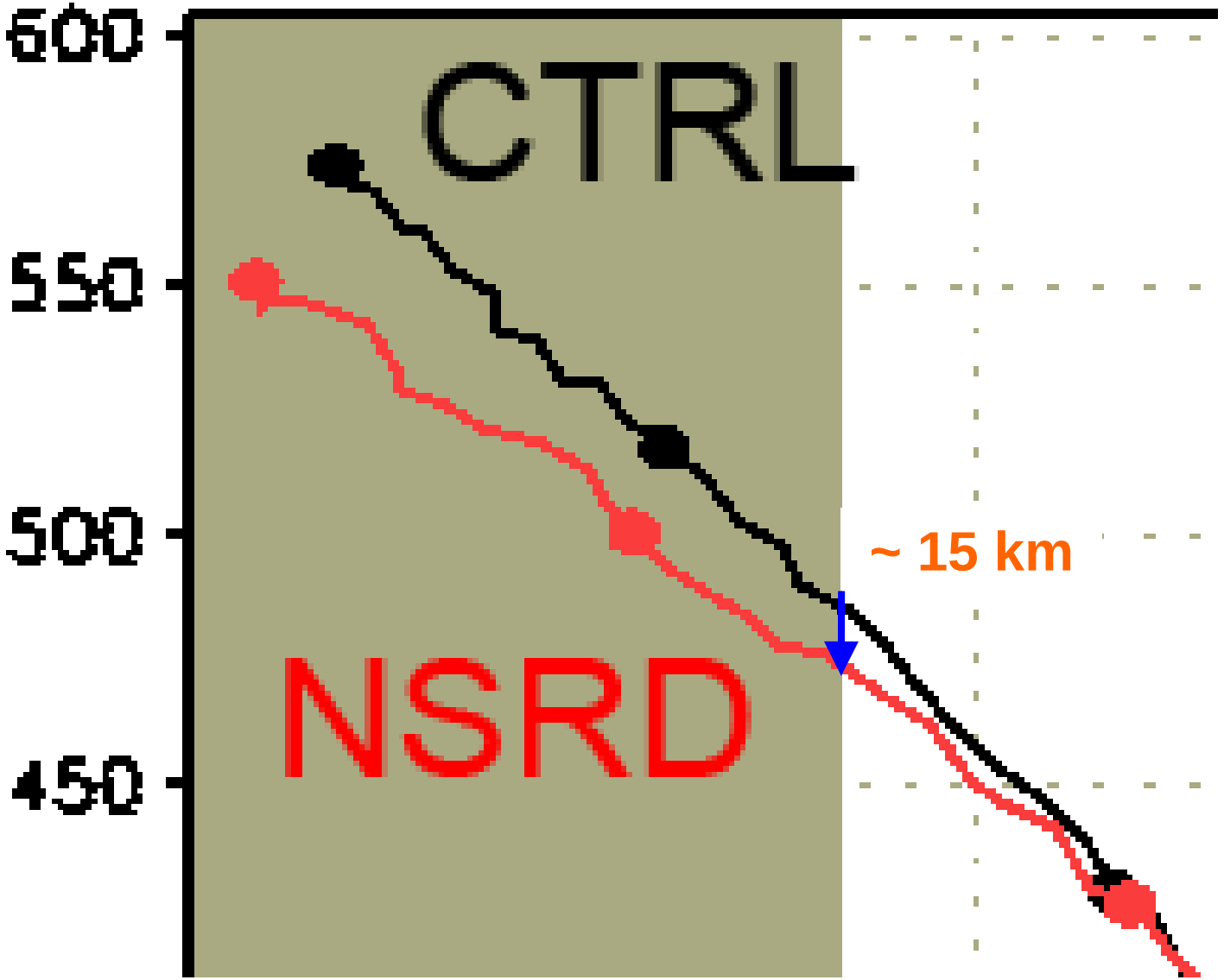


control (no land)

Flat Terrain β plane

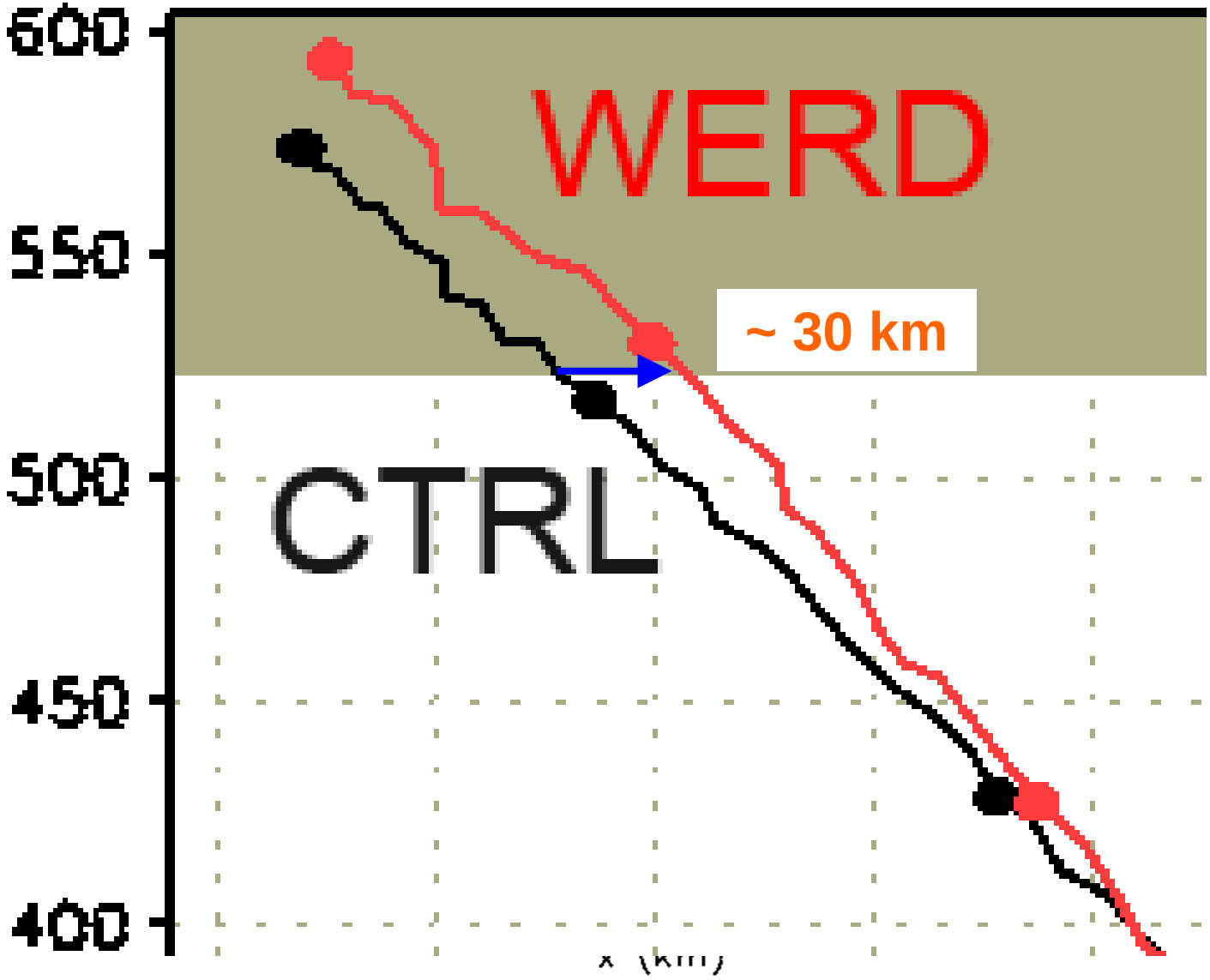
Szeto and Chan (2010)

β plane experiments NS-oriented coastline



Szeto and Chan (2010)

β plane experiments EW-oriented coastline



Land-induced flow

Hypothesis :

TC circulation = Symmetric flow + Asymmetric flow

Asymmetric flow = Beta gyres + Land-Induced Flow

Not present in the CTRL

Land-induced Flow = Asymmetric flow – Beta gyres

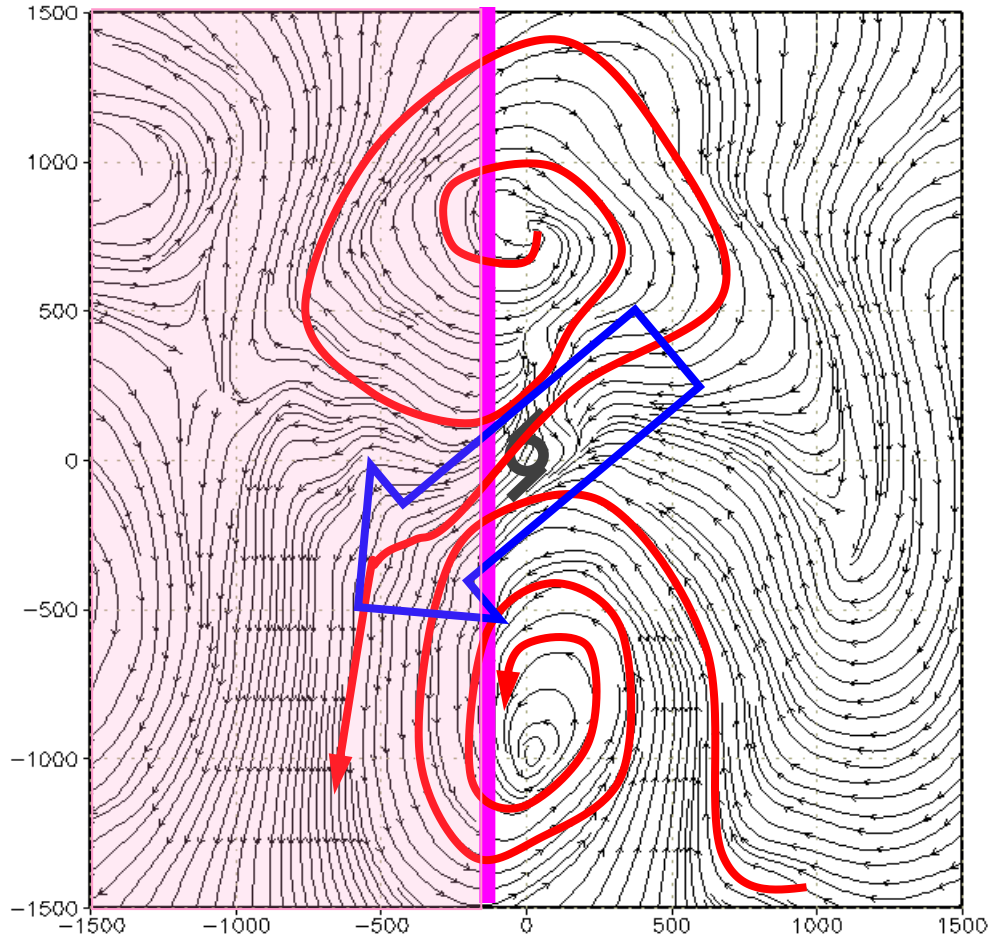
= (Asymmetric flow) $_{Landfall}$ –

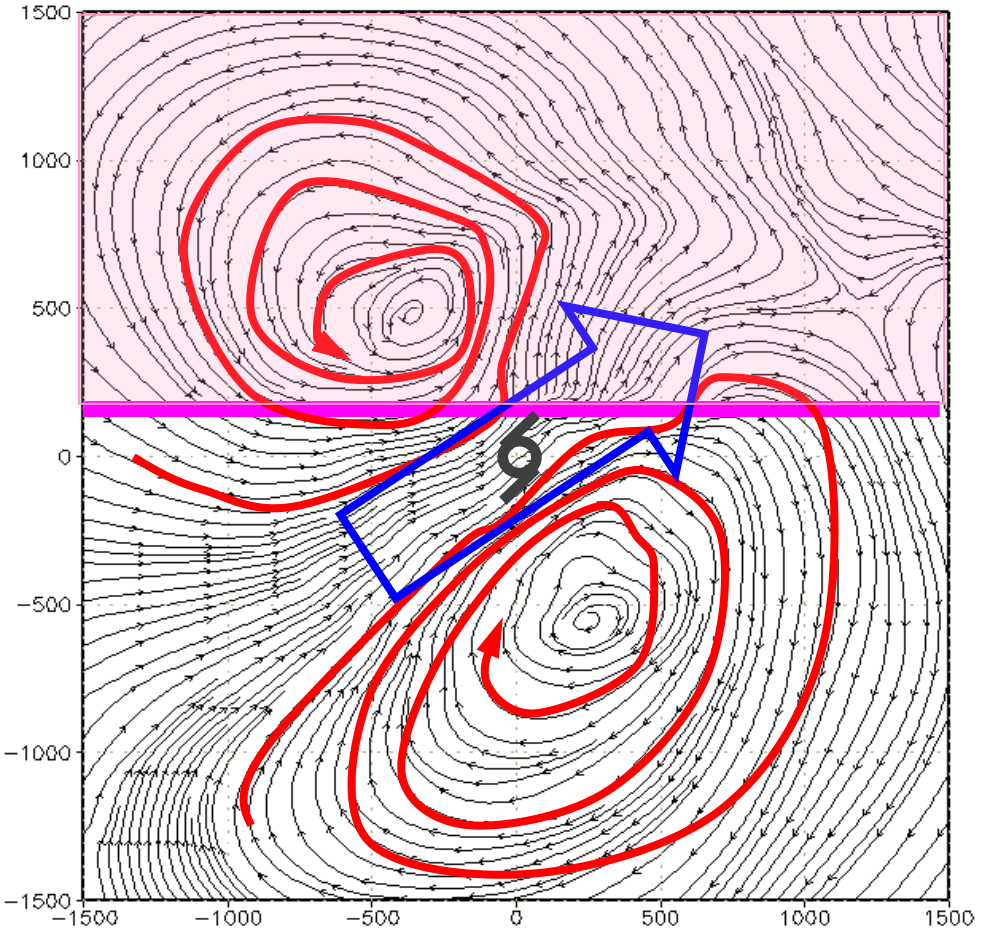
(Asymmetric flow) $_{CTRL}$

Szeto and Chan (2010)

LL Asymmetric flow ($0.9 \geq \eta \geq 0.55$) t = 36 – 48 h

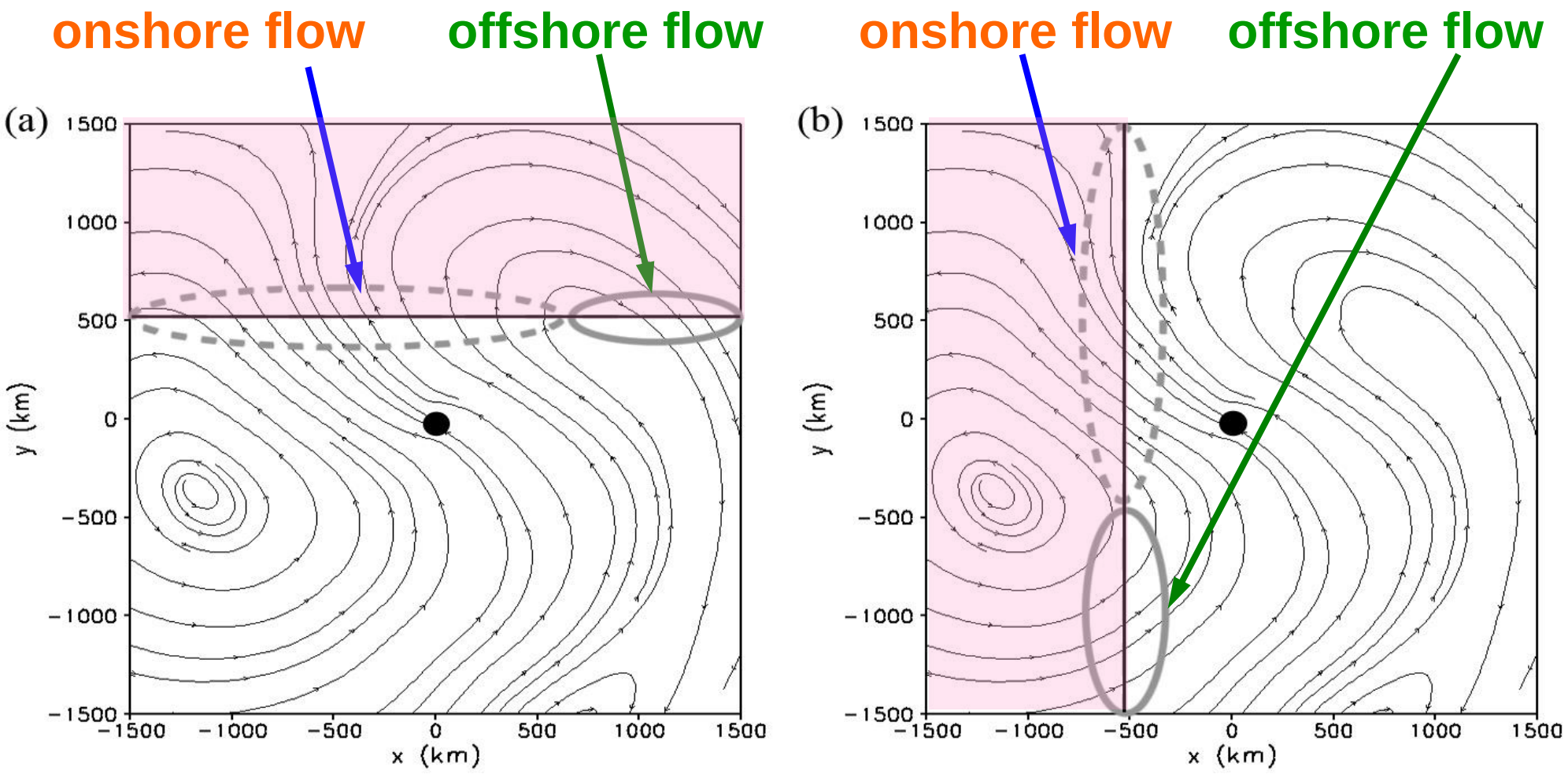
Rough and dry land





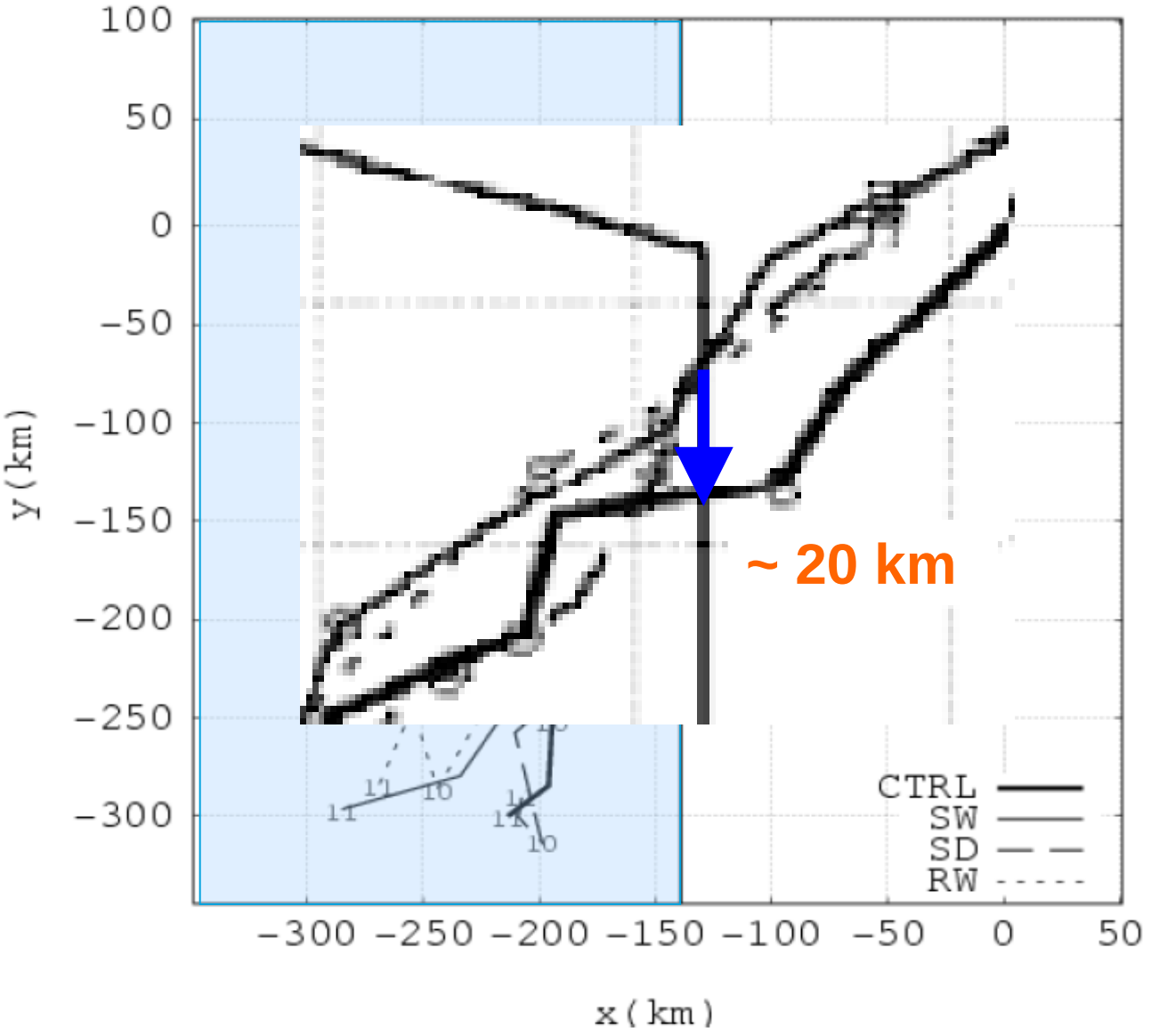
Szeto and Chan (2010)

Changes in the location of onshore vs. offshore flow



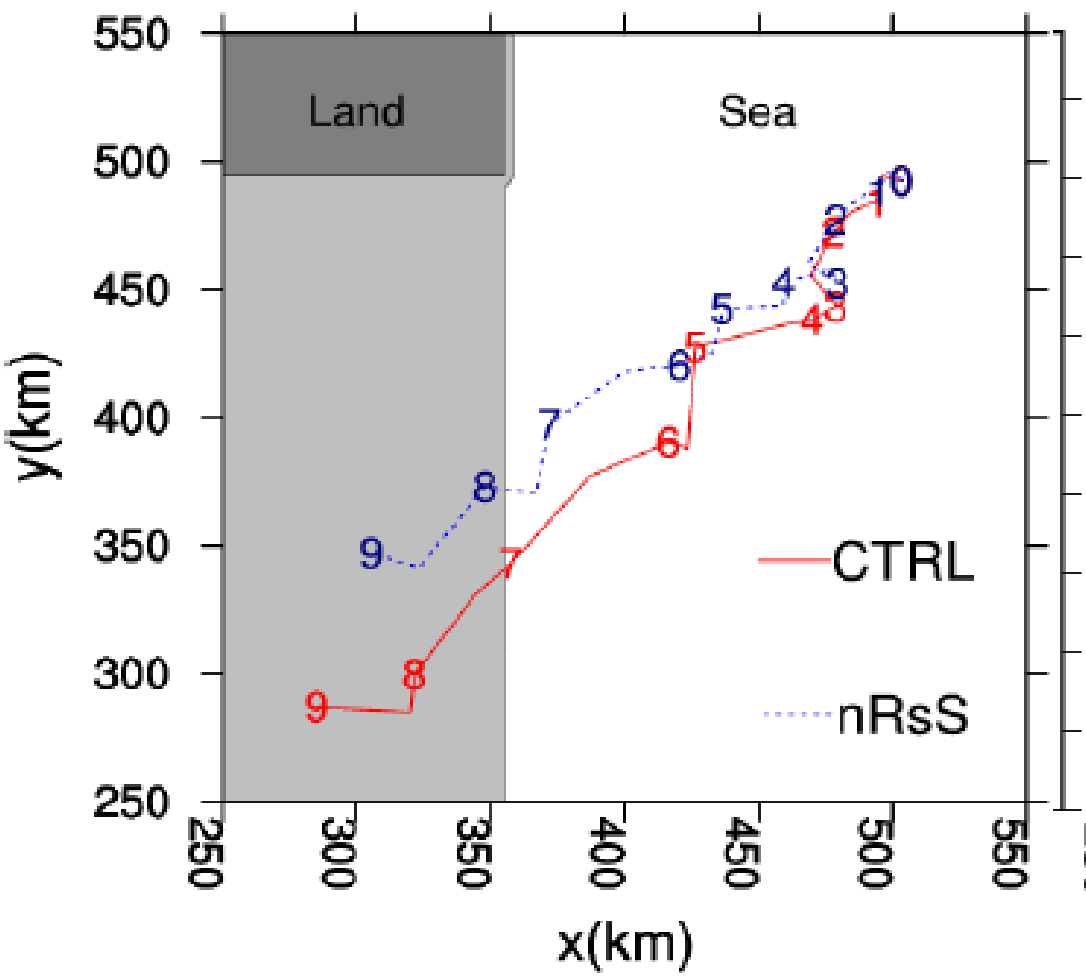
Flat Terrain
f plane
Varying Friction

Track – *f* plane experiments River Delta

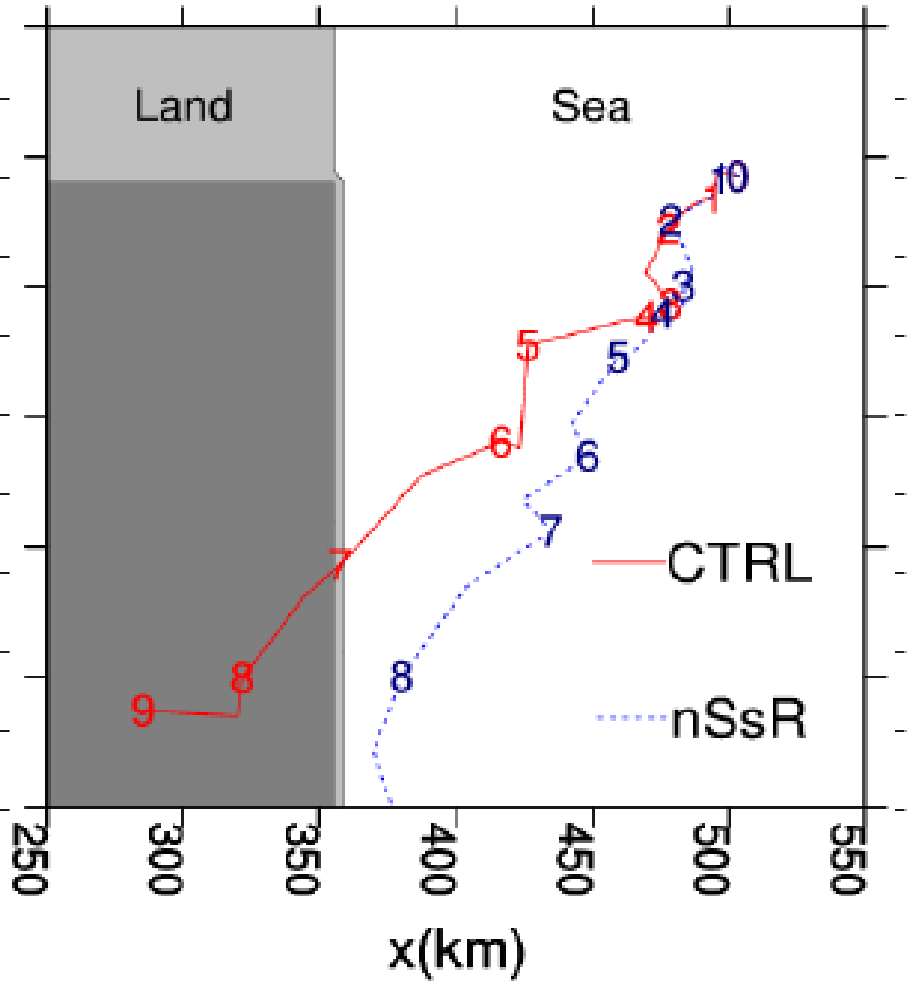


Au-Yeung and Chan (2010)

f plane experiments Differential roughness



north Rough south Smooth



north Smooth south Rough

Summary on track changes due to friction

- An inherent vortex motion in the presence of a discontinuity in surface friction.
- Such motion is caused by two main processes:
  - the development of a “ventilation flow” associated with a vortex pair through the generation of relative vorticity from the divergent term in the vorticity equation
  - diabatic heating due to differential convergence

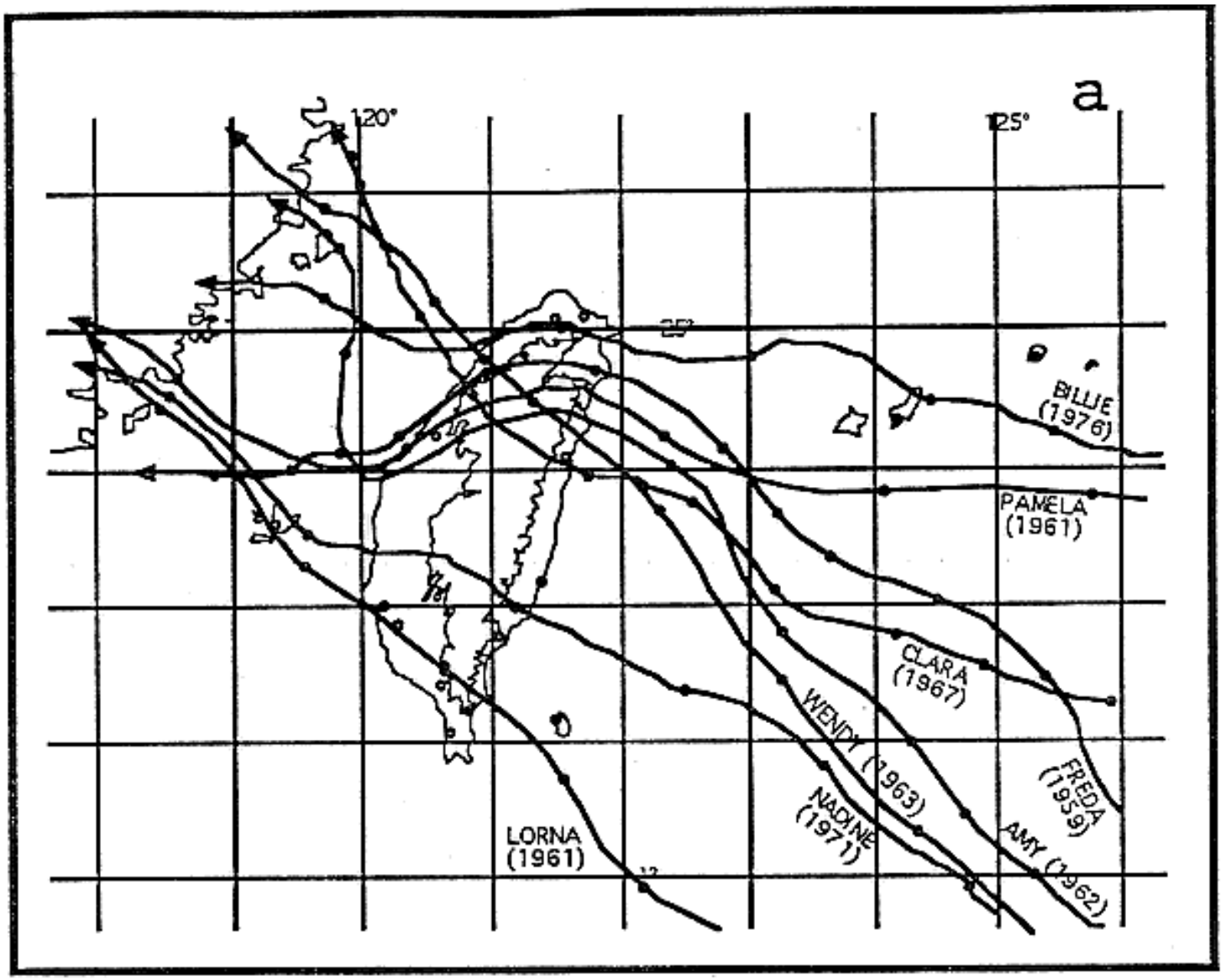
Summary on track changes due to friction

- Such an inherent motion modifies the beta effect so that different coastline orientation will cause the TC track to deviate differently.
- Differential friction over land will also cause track deviations towards rougher land

Effect of Topography - Observations

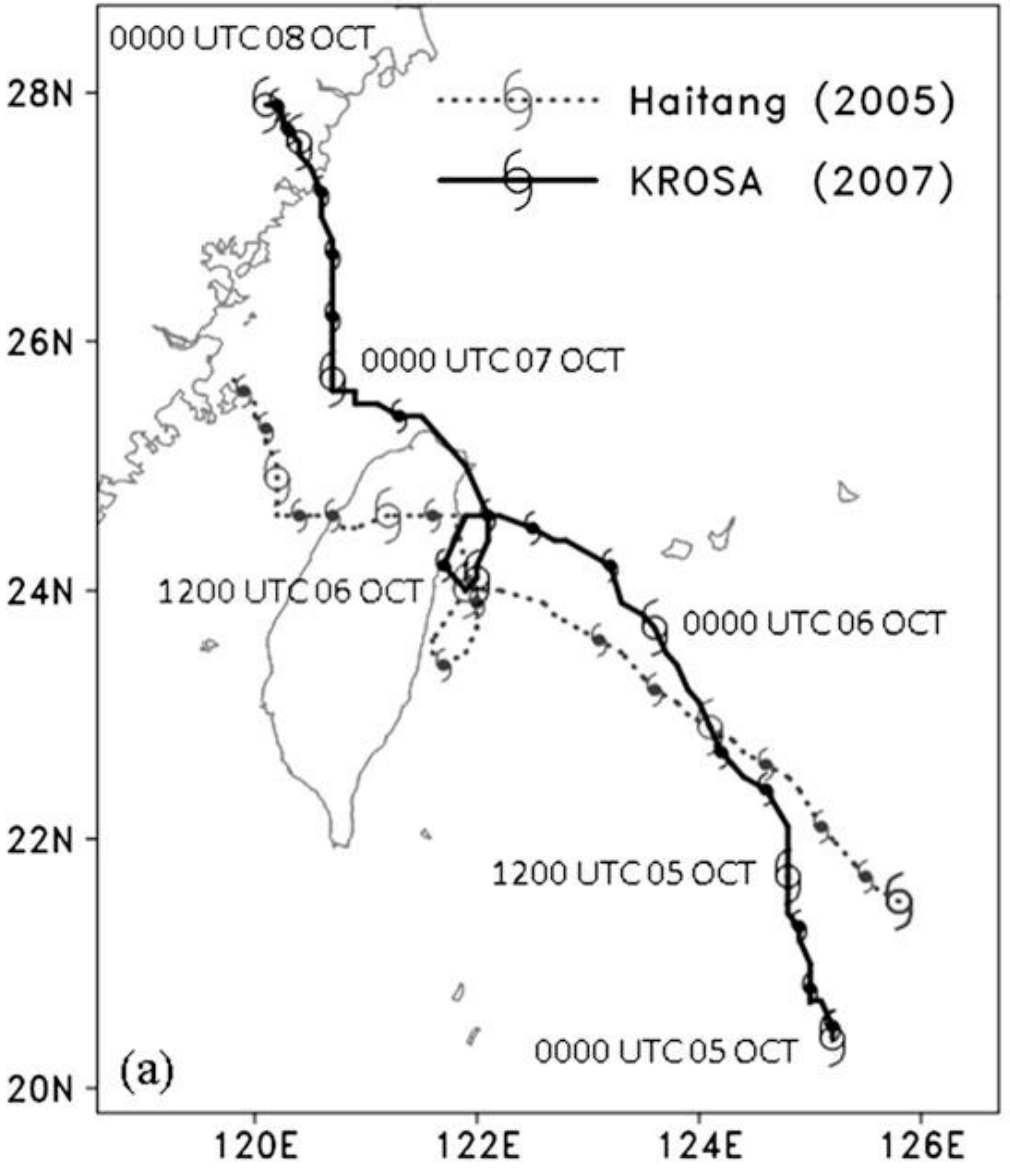
Lin et al. (1999)

Effect of topography – Taiwan



Effect of topography – Taiwan

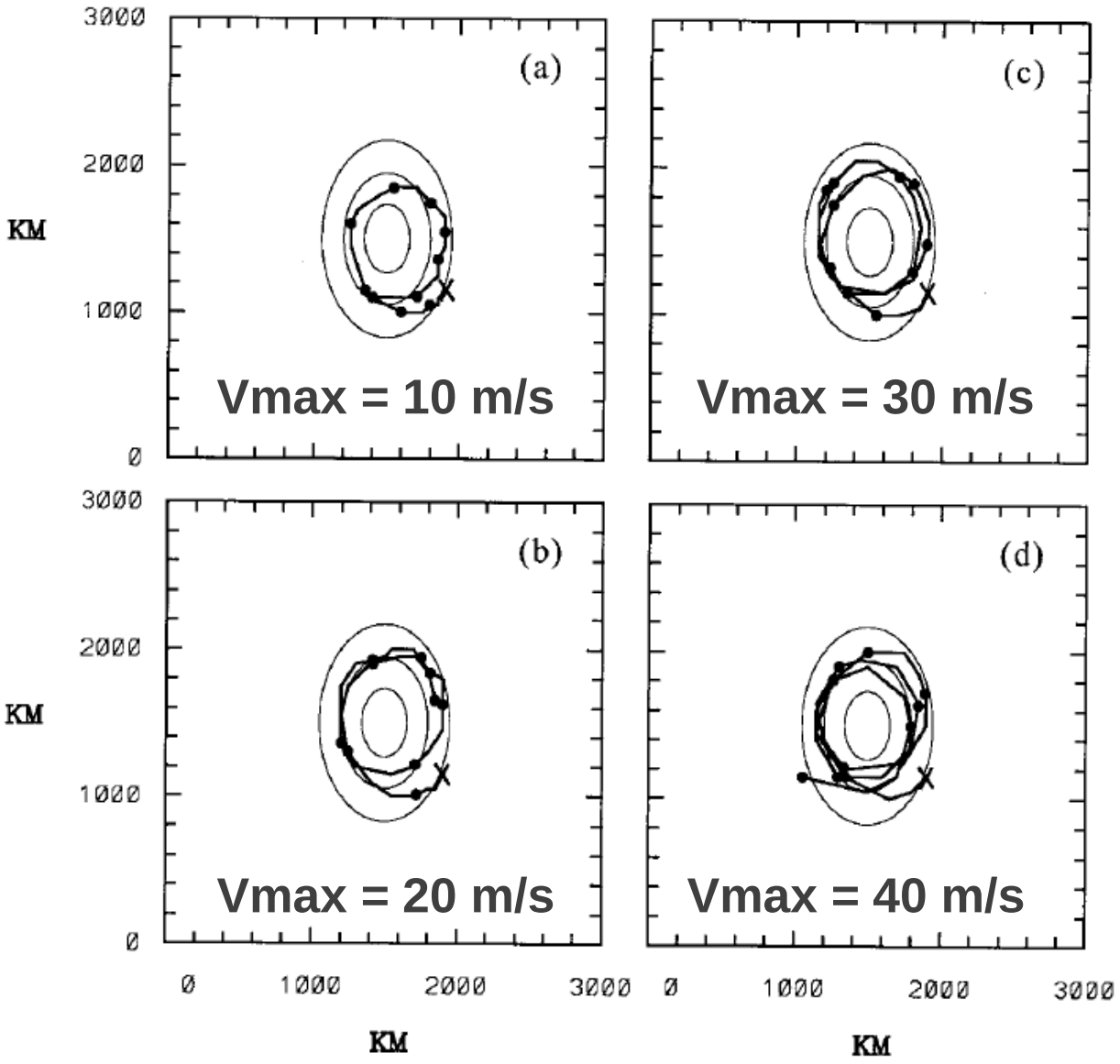
Huang et al. (2011)



Effect of Topography – Modeling Studies

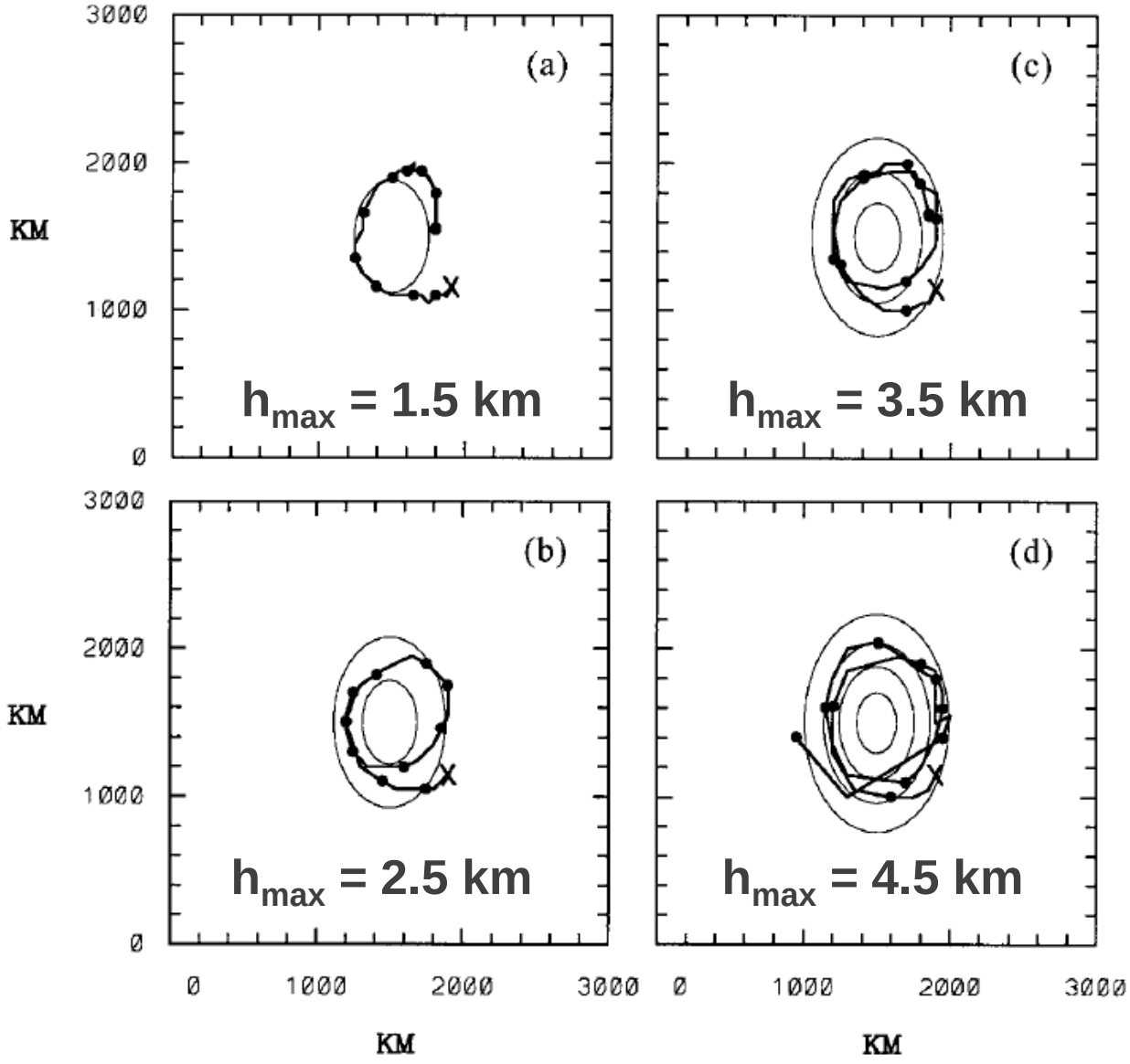
Kuo et al. (2001)

Effect of topography – barotropic vortex



Kuo et al. (2001)

Effect of topography – barotropic vortex



Effect of topography – barotropic vortex

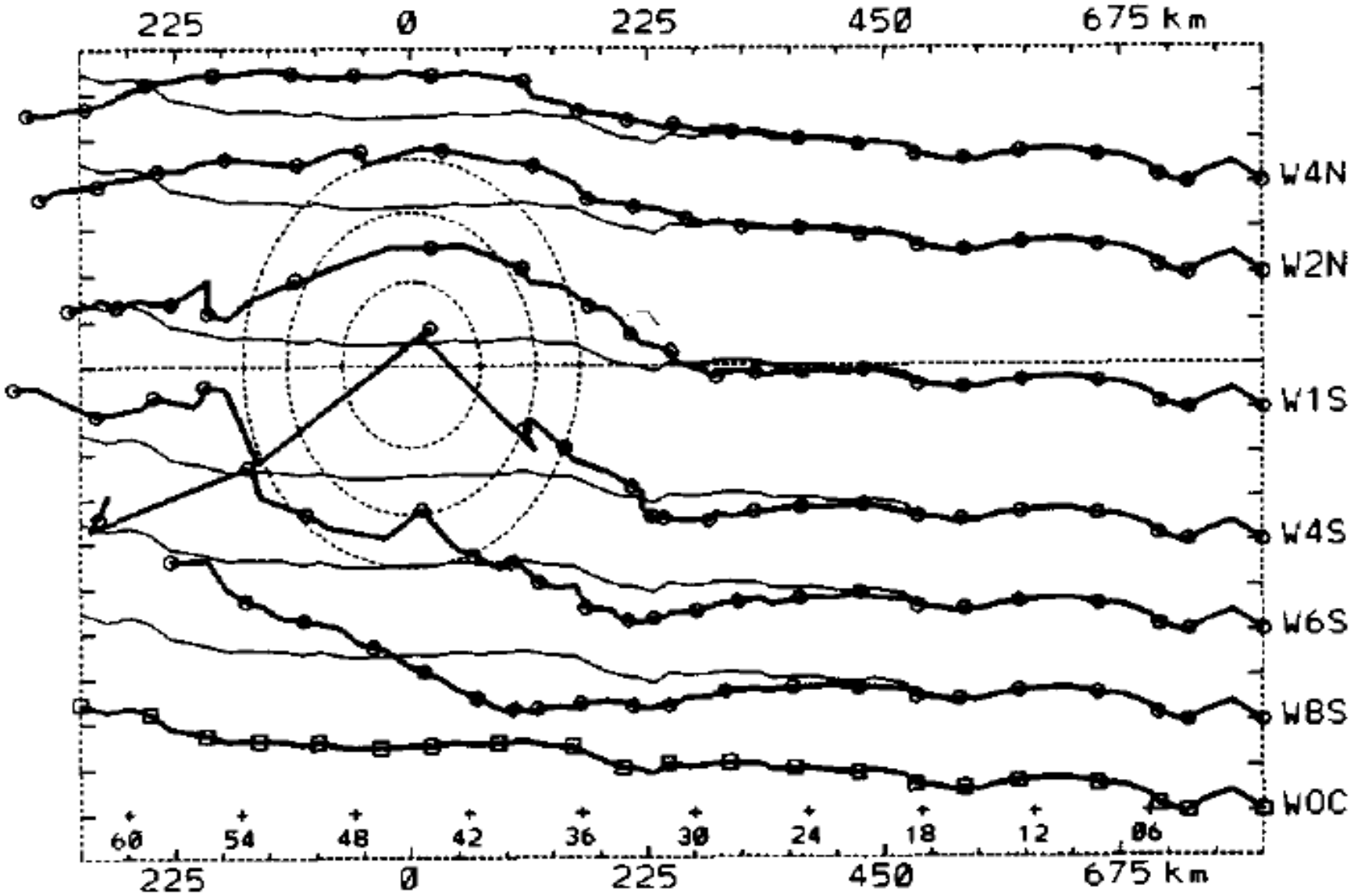
The reason for this clockwise rotation is because the mountain changes the equivalent depth of the fluid *H* and hence changes the equivalent rotation of the earth *f*, causing the fluid to behave like on a beta plane. This is therefore known as the topographic beta effect. The motion of the vortex is to conserve potential vorticity.

$$\beta_e = \frac{f}{H}\frac{h_{\max}}{a_0}$$

where h_{max} is the maximum height and a_0 a scale parameter of the width of the mountain

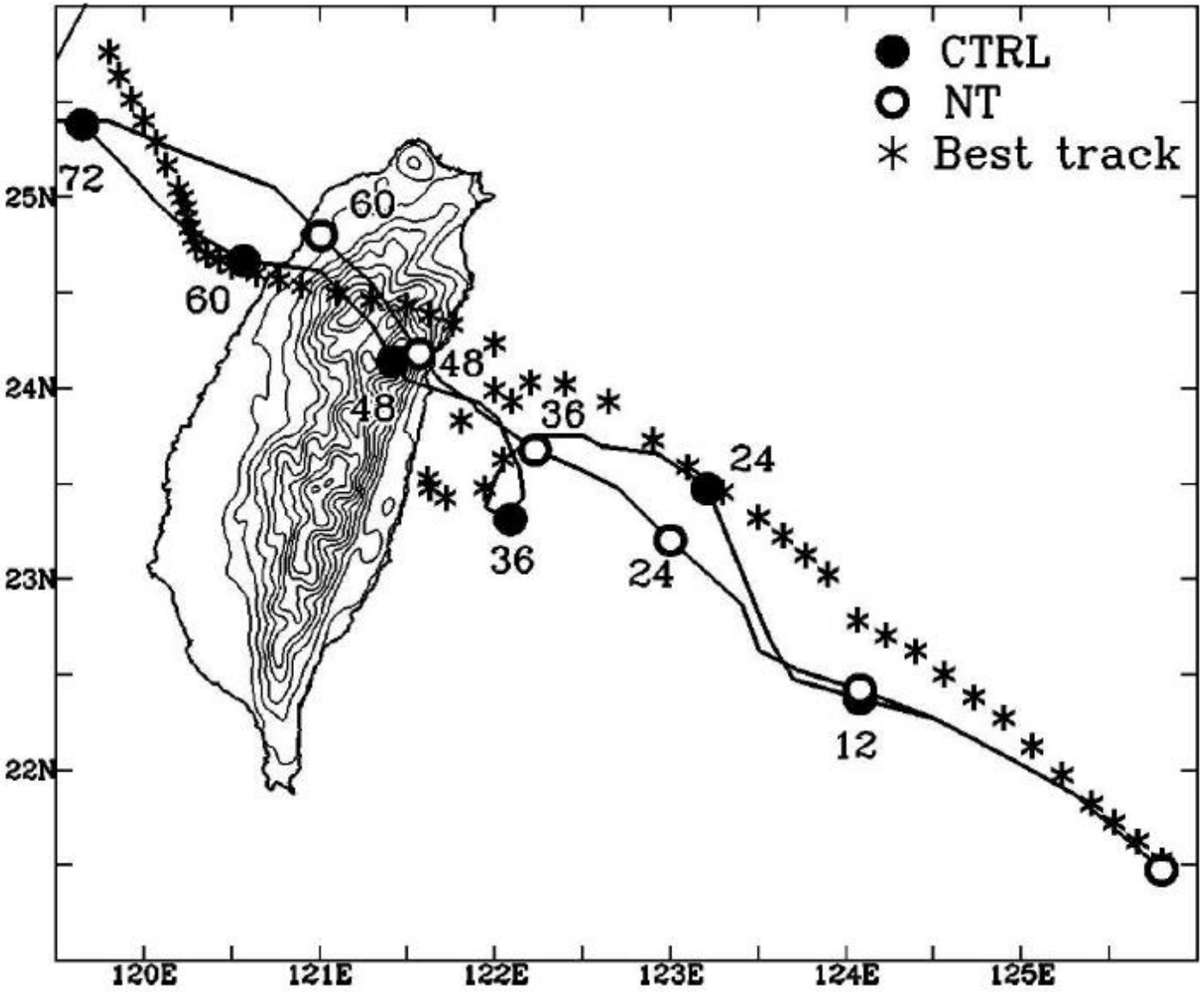
Yeh and Elsberry (1993)

Effect of topography – Taiwan



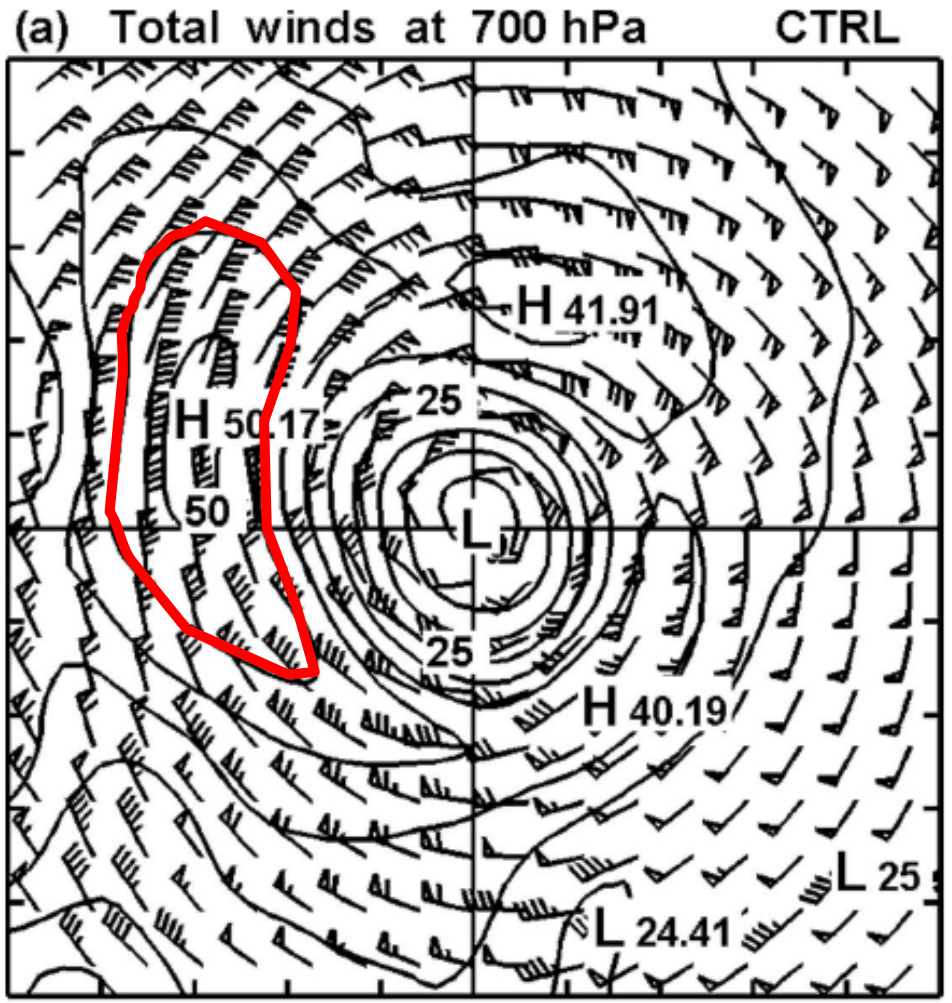
Jian and Wu (2008)

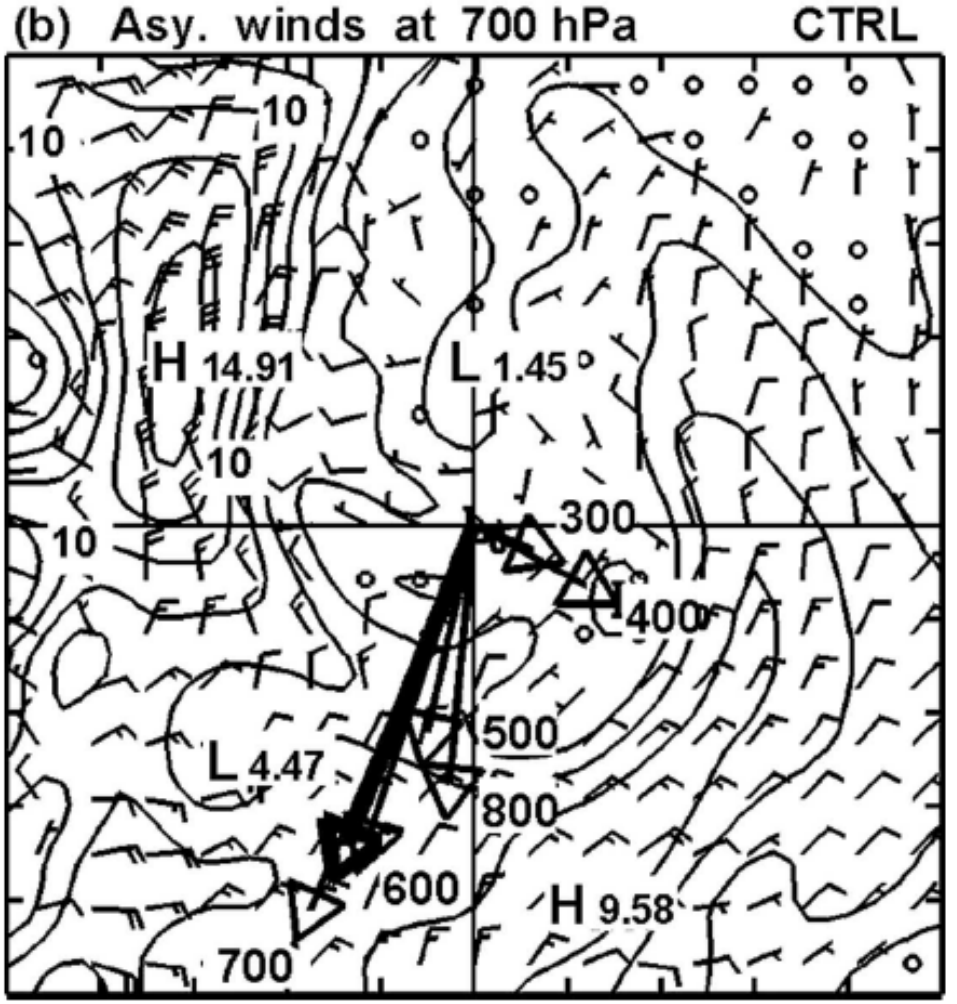
Effect of topography – Taiwan



Jian and Wu (2008)

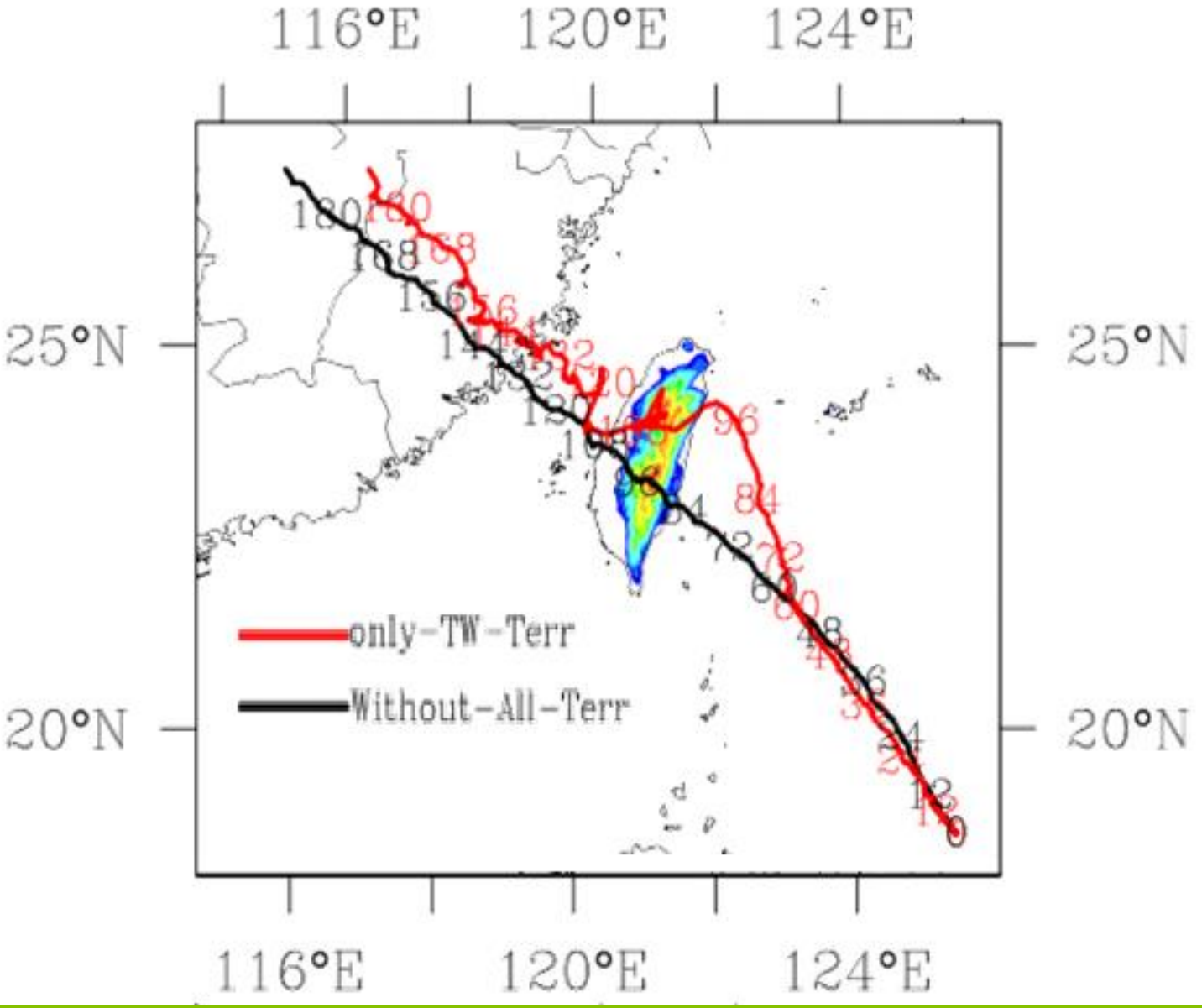
Effect of topography – Taiwan





Tang and Chan (2014a)

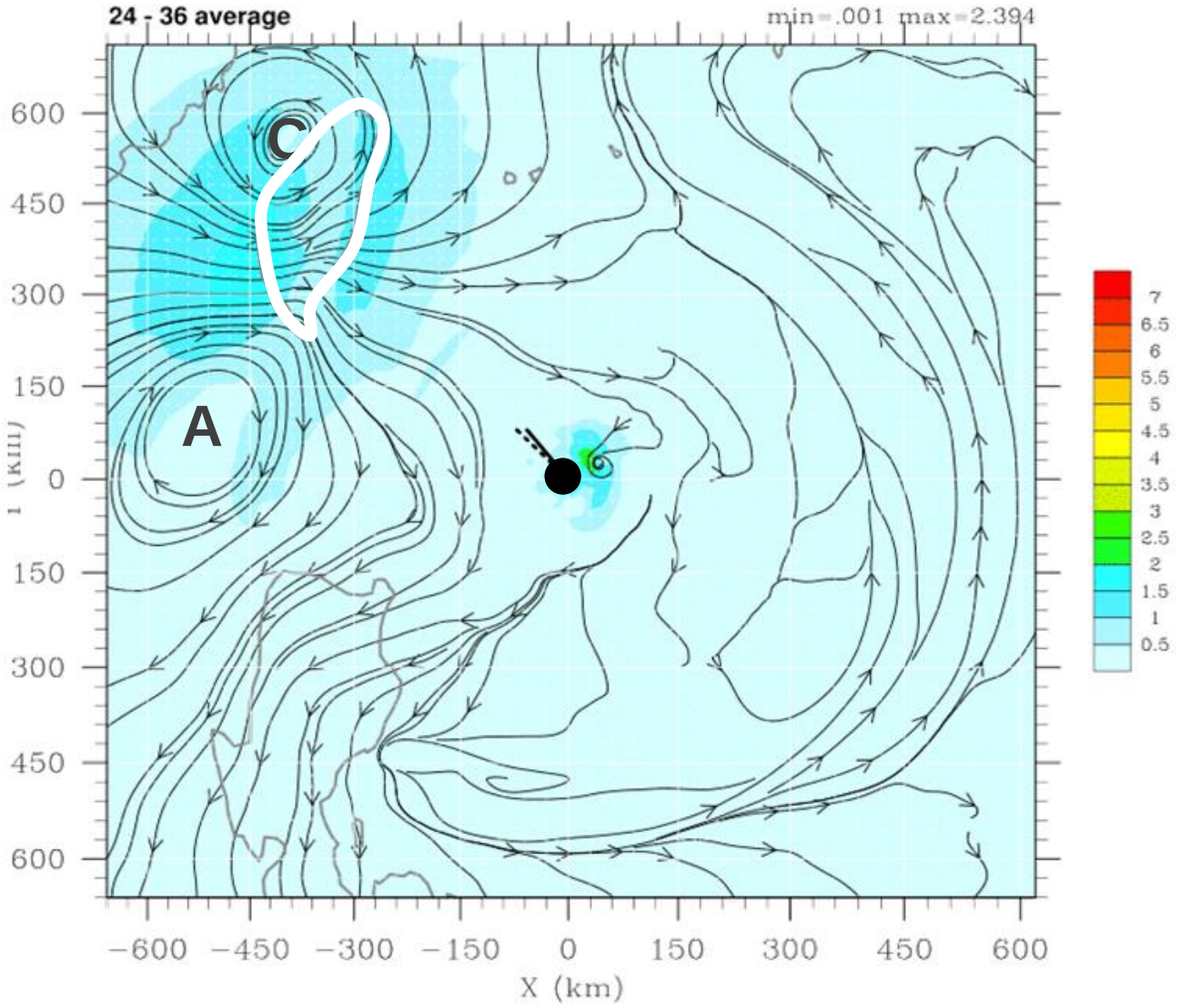
Effect of topography – Taiwan



Tang and Chan (2014a)

Effect of topography – Taiwan

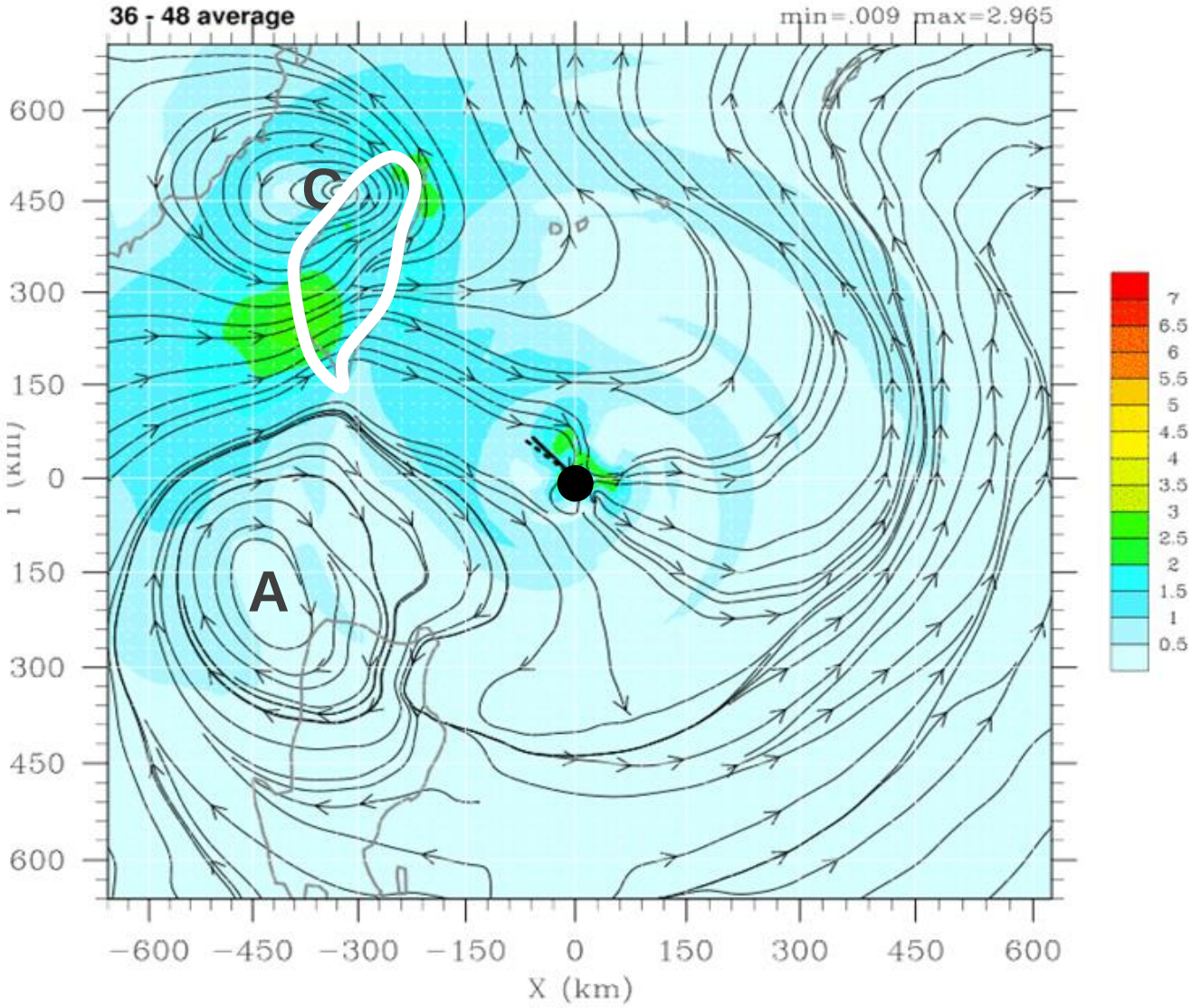
Asymmetric flow: with Taiwan topography minus without



24-36 h

Effect of topography – Taiwan

Asymmetric flow: with Taiwan topography minus without

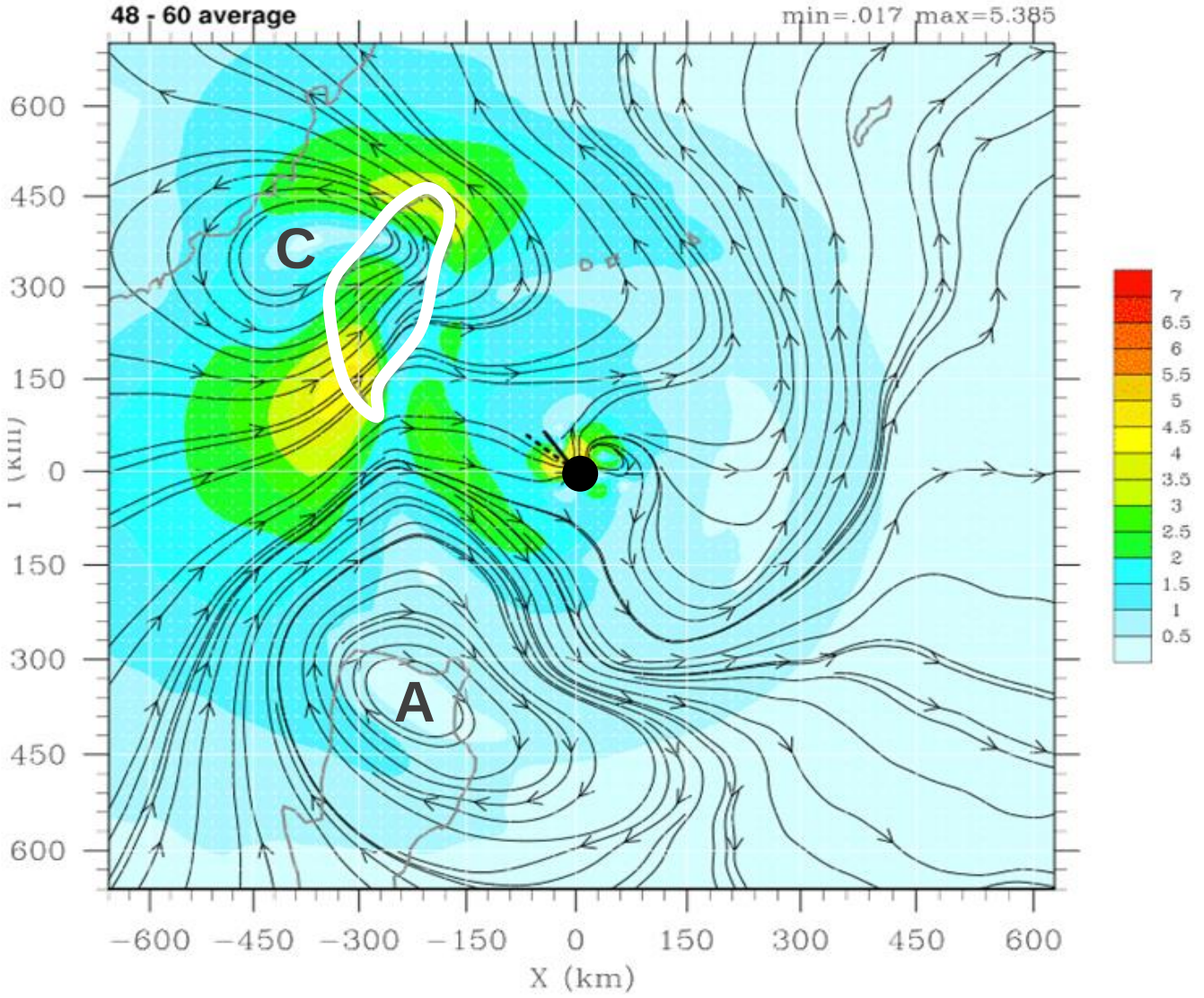


36-48 h

Tang and Chan (2014a)

Effect of topography – Taiwan

Asymmetric flow: with Taiwan topography minus without

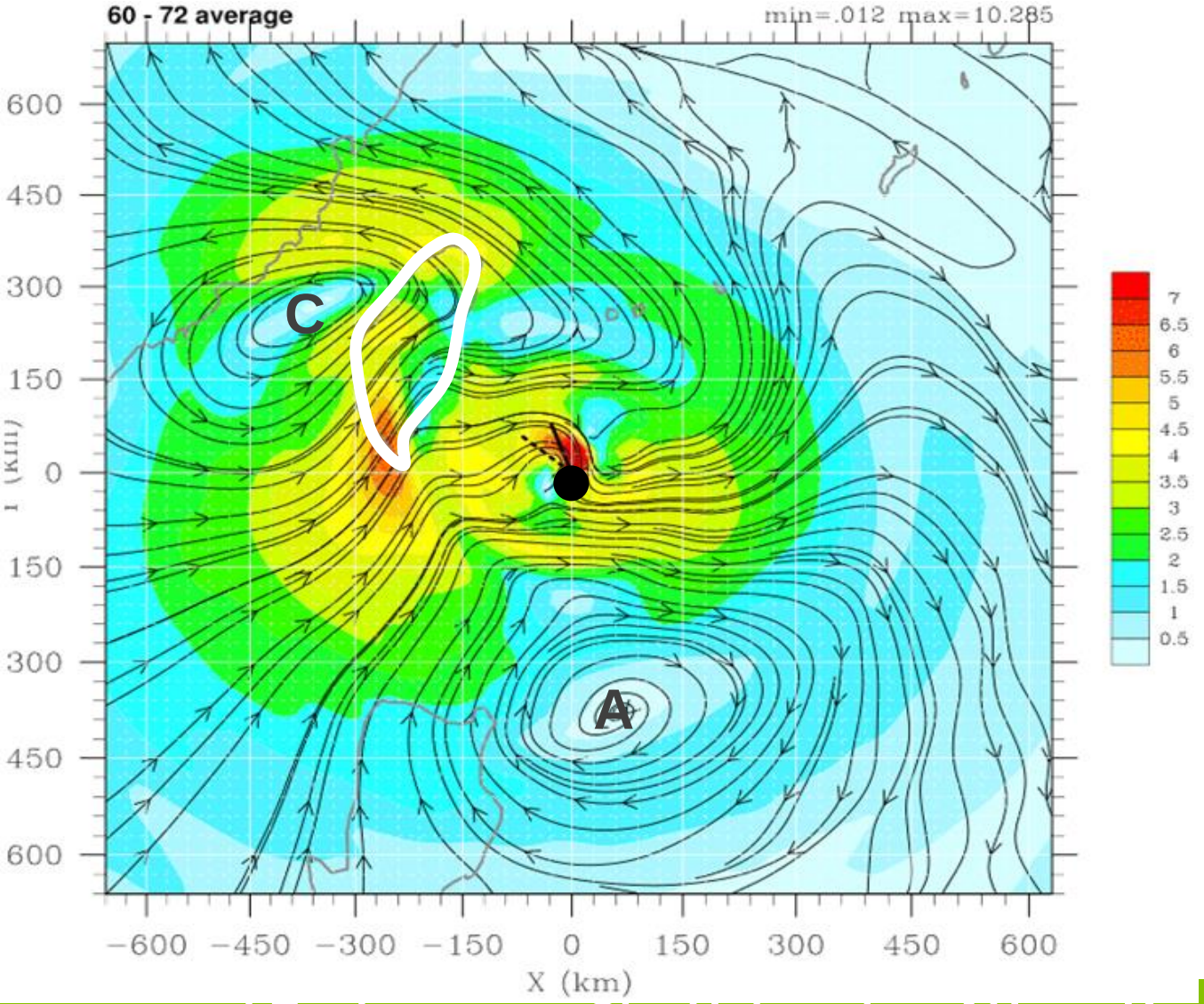


48-60 h

Tang and Chan (2014a)

Effect of topography – Taiwan

Asymmetric flow: with Taiwan topography minus without

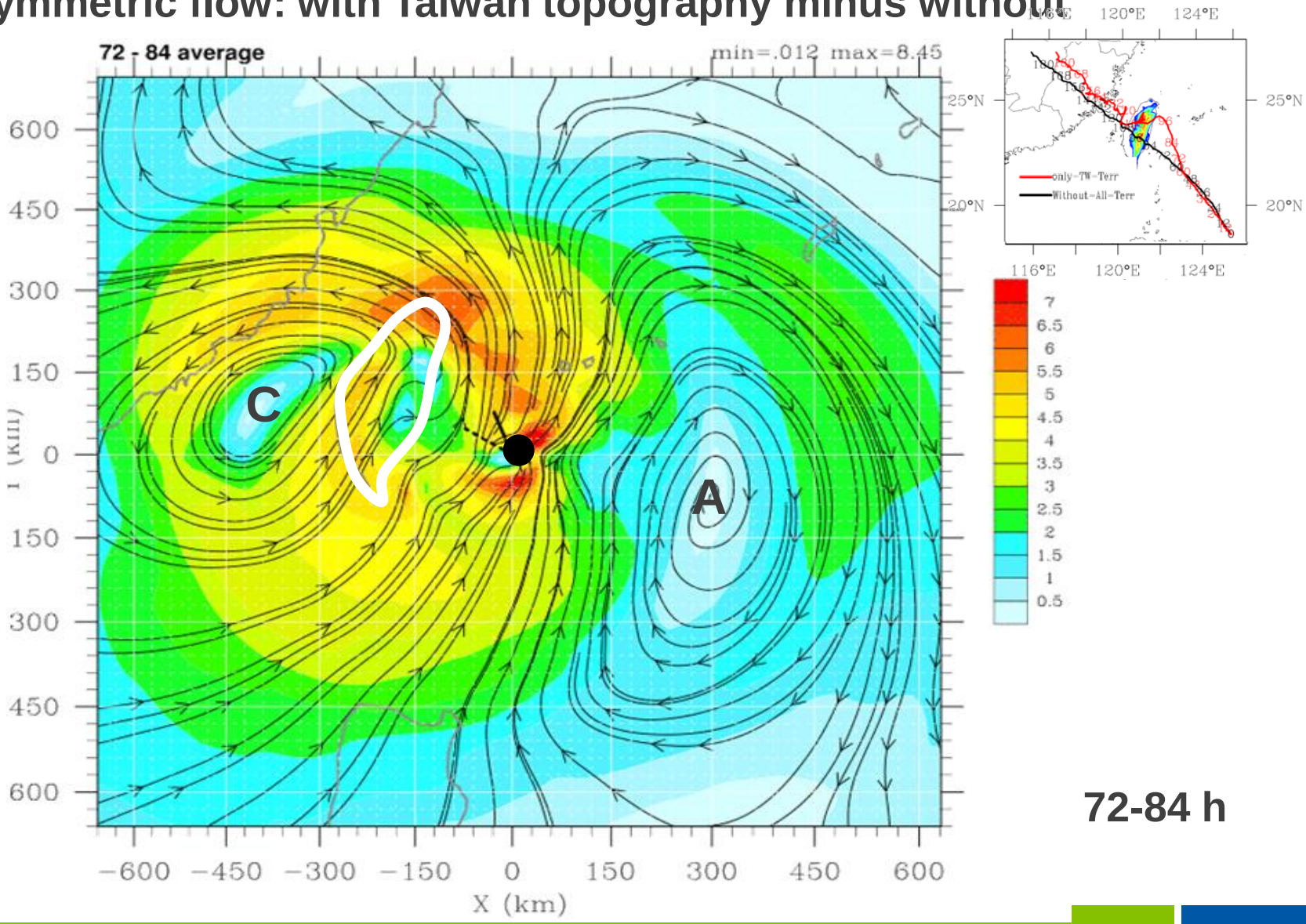


60-72 h

Tang and Chan (2014a)

Effect of topography – Taiwan

Asymmetric flow: with Taiwan topography minus without

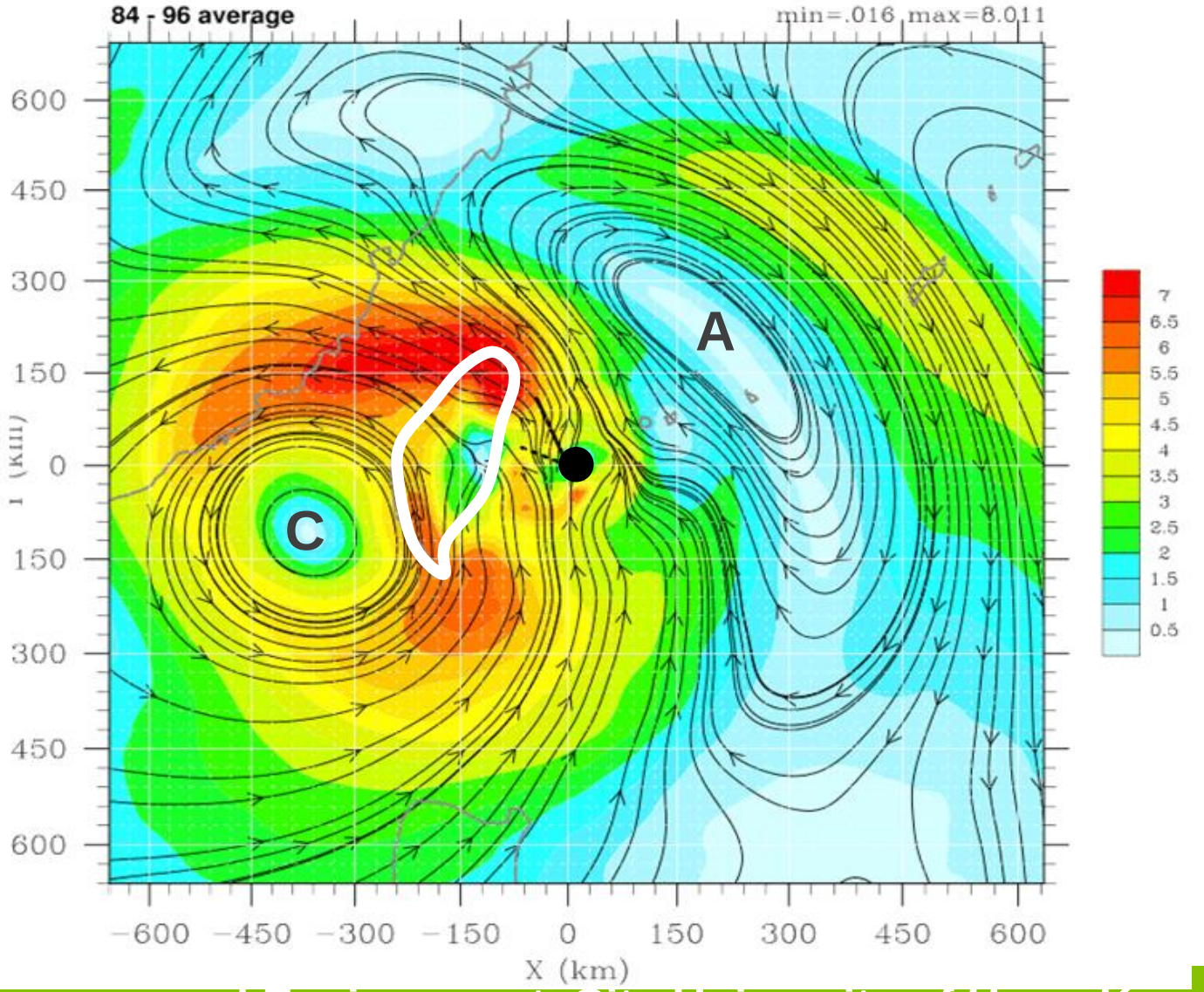


72-84 h

Tang and Chan (2014a)

Effect of topography – Taiwan

Asymmetric flow: with Taiwan topography minus without

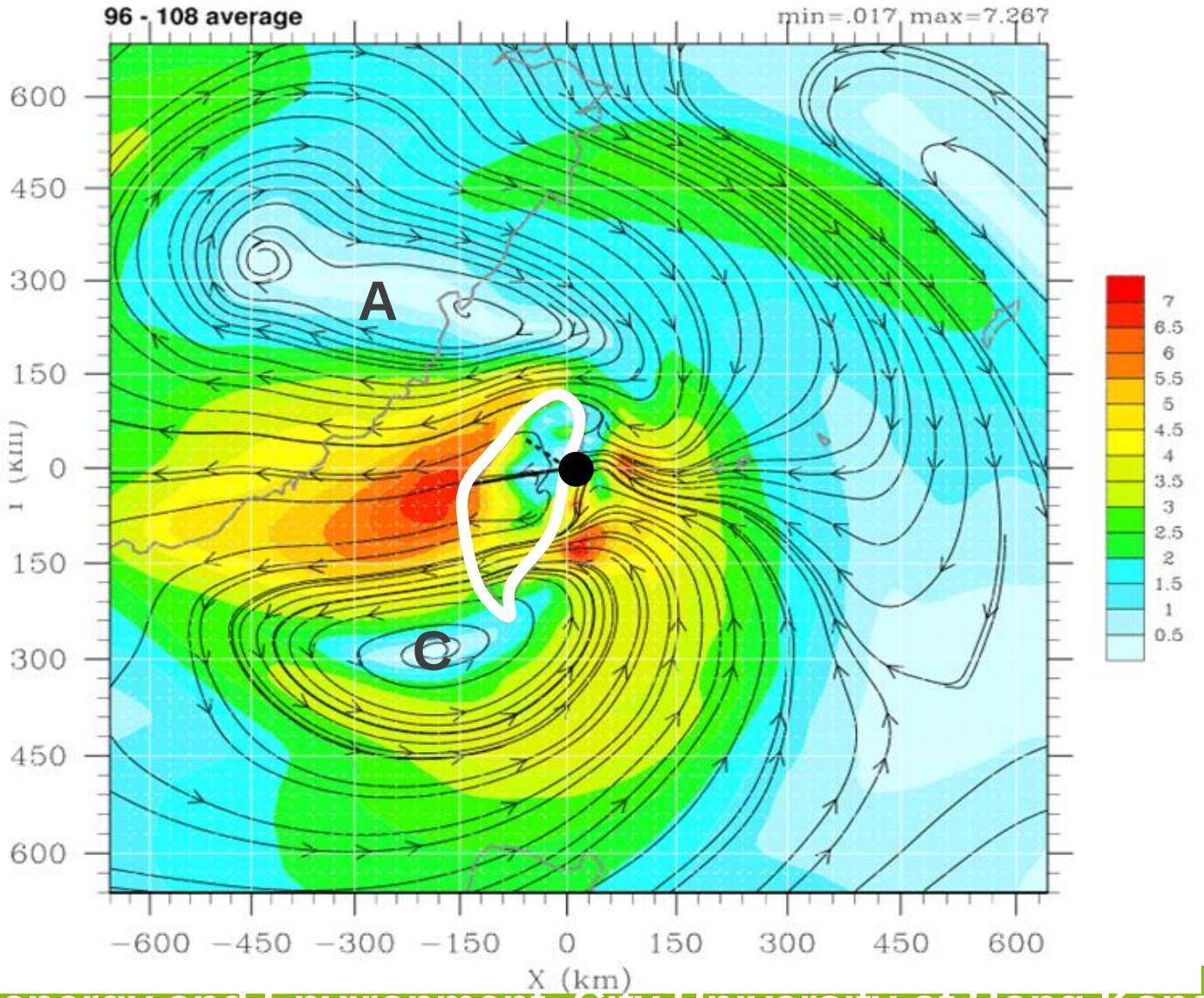


84-96 h

Tang and Chan (2014a)

Effect of topography – Taiwan

Asymmetric flow: with Taiwan topography minus without

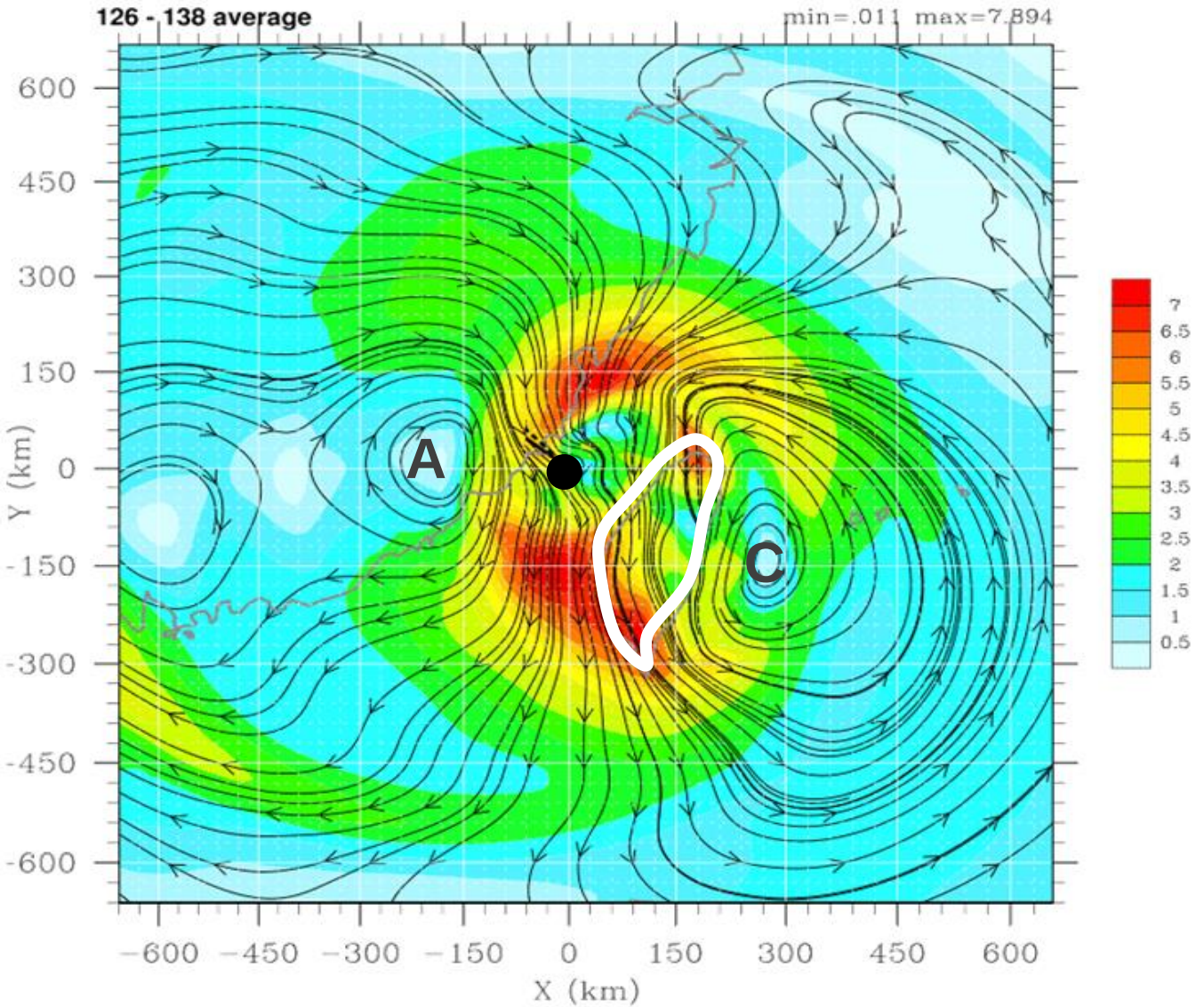


96-108 h

Tang and Chan (2014a)

Effect of topography – Taiwan

Asymmetric flow: with Taiwan topography minus without

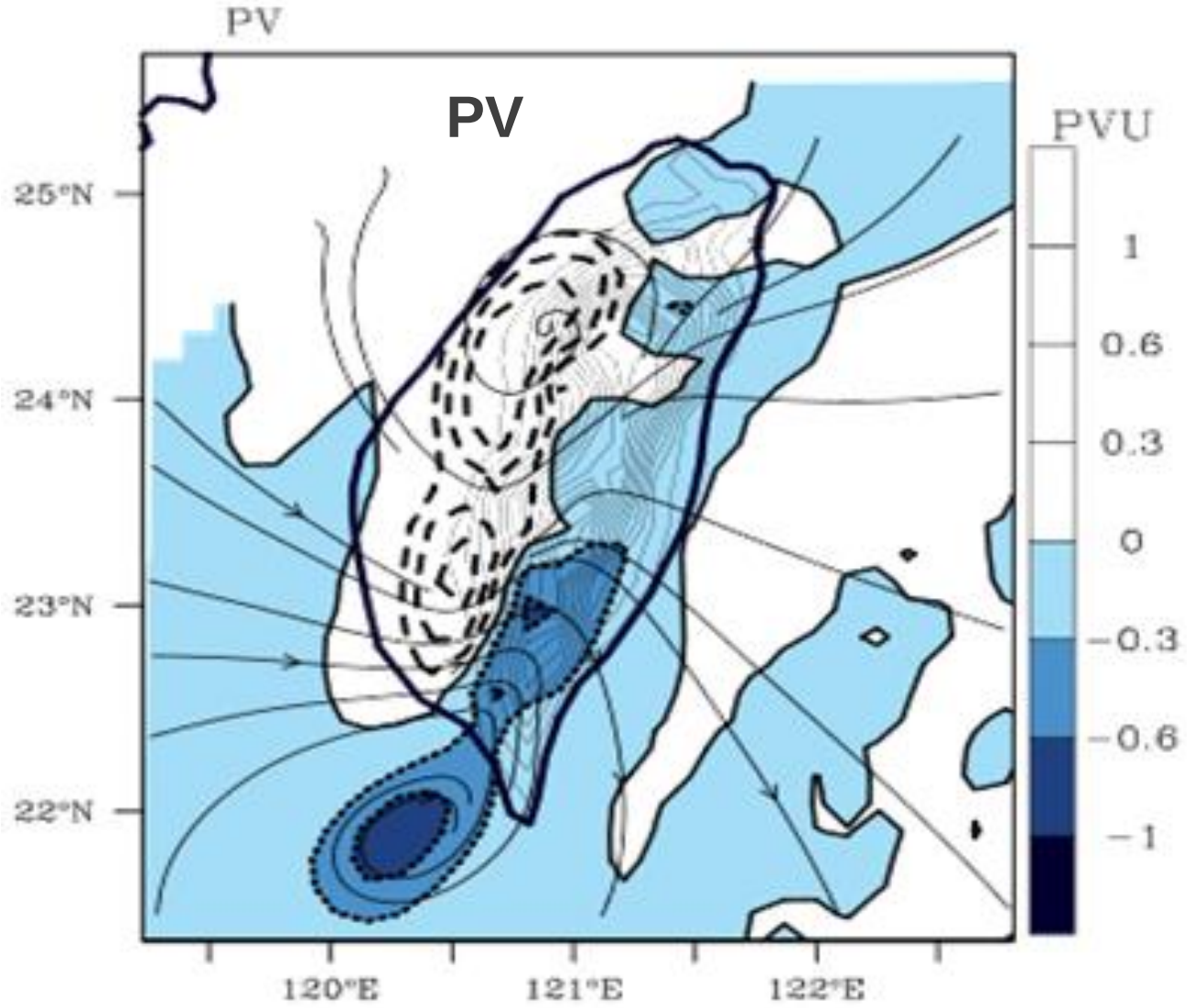


126-138 h

Tang and Chan (2014a)

Mechanism for the formation of gyres

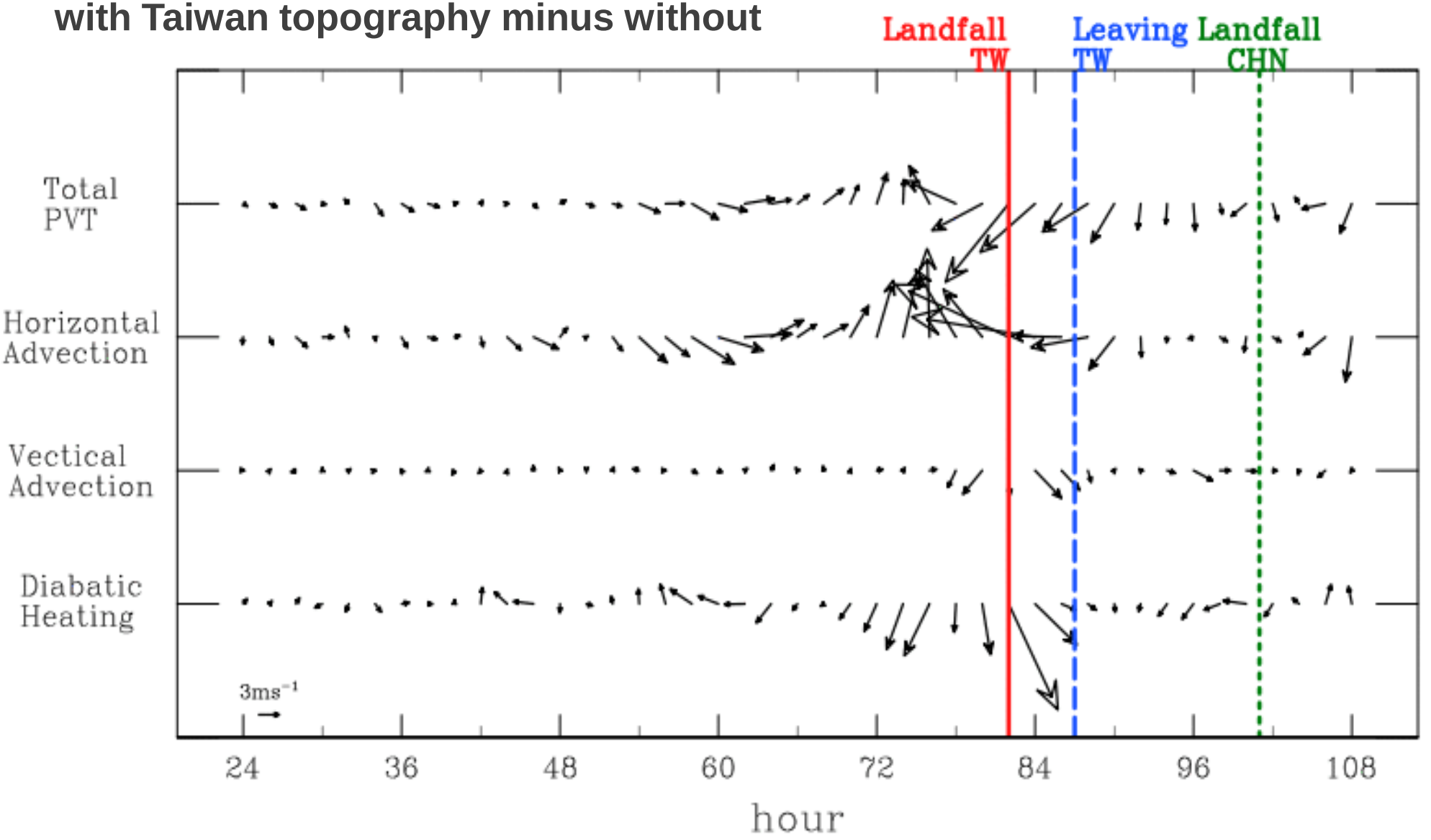
with Taiwan topography minus without



Tang and Chan (2014a)

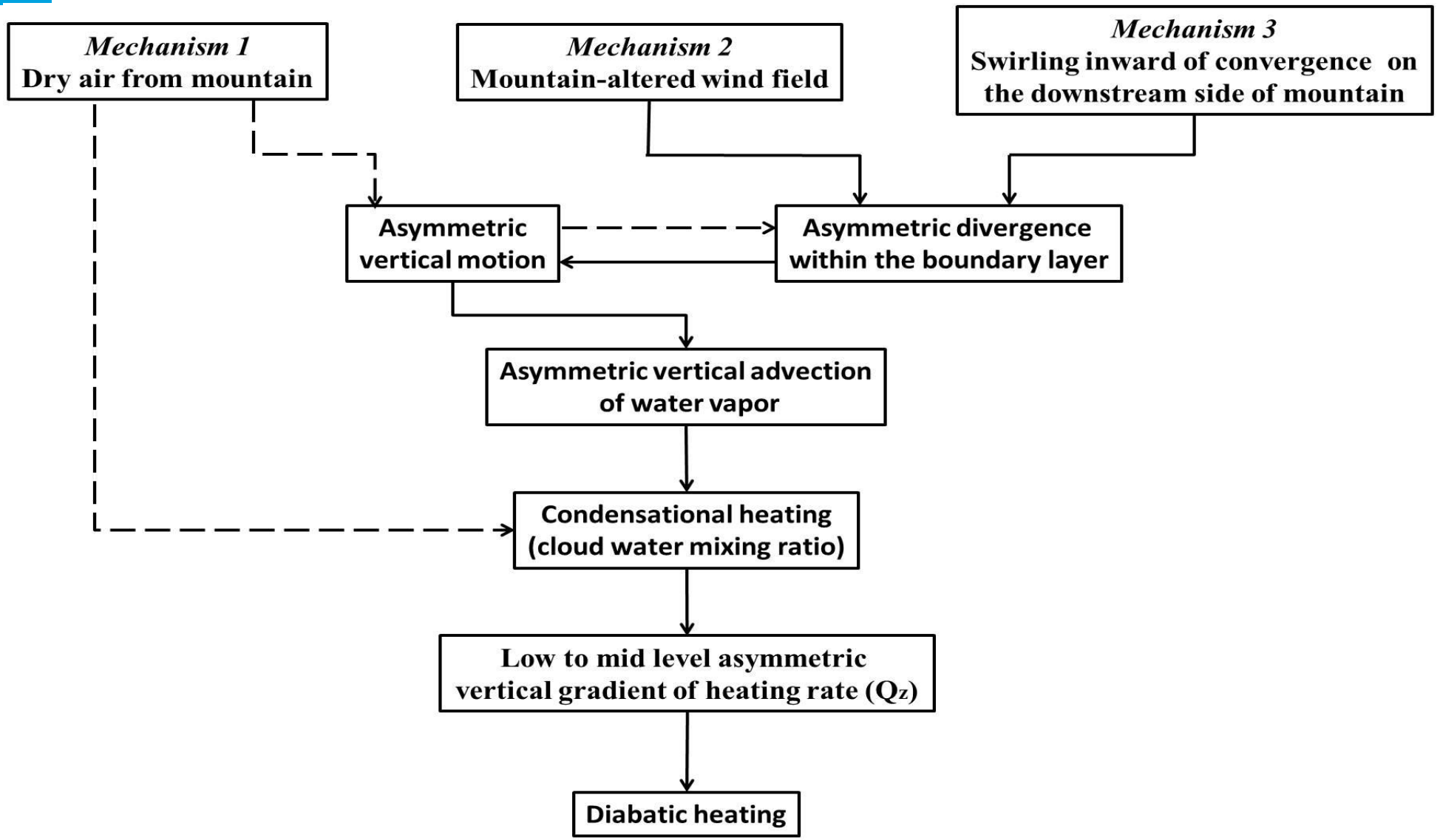
Terms in the PV tendency equation

with Taiwan topography minus without



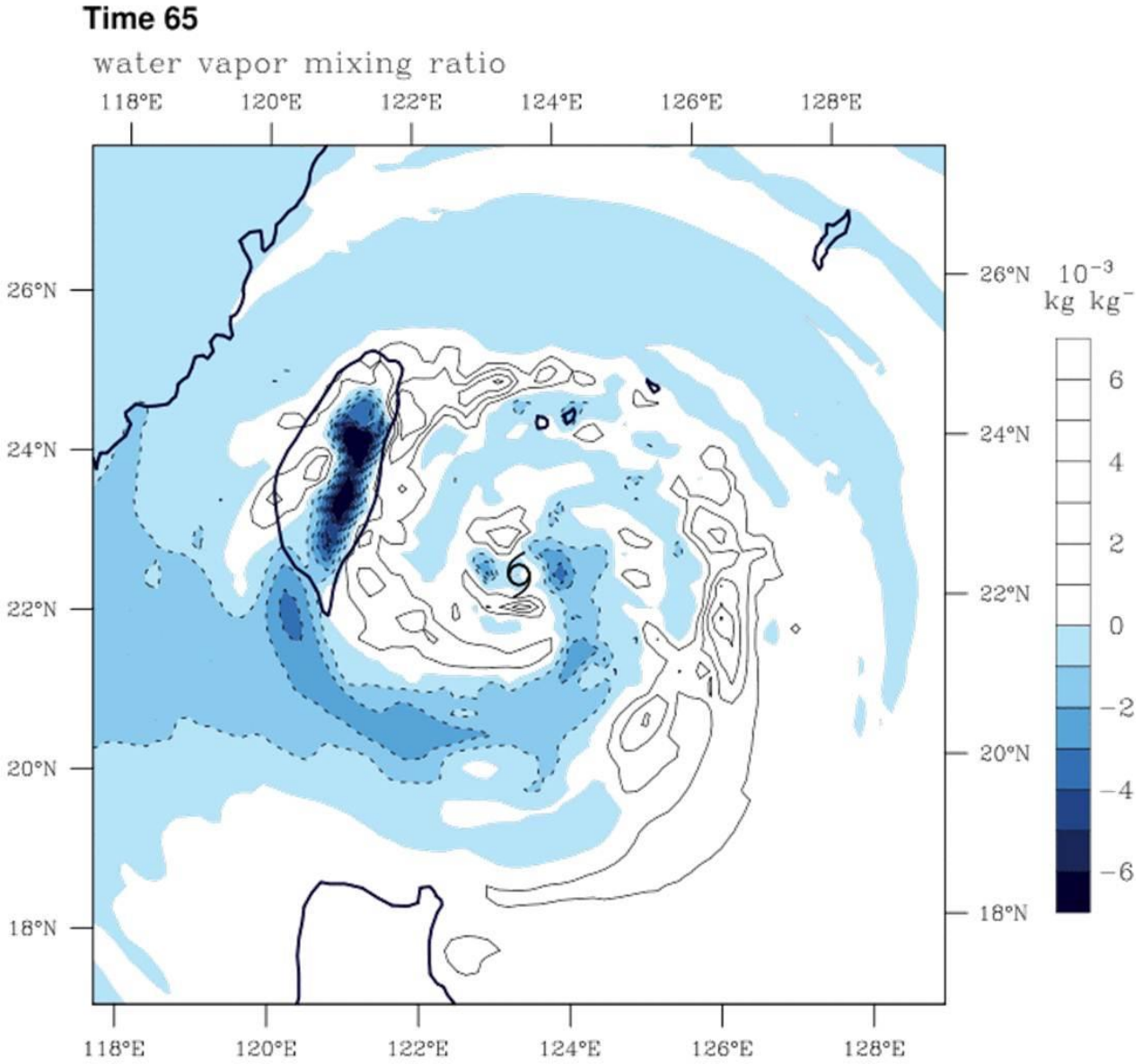
Tang and Chan (2014a)

Mechanisms for the establishment of diabatic heating



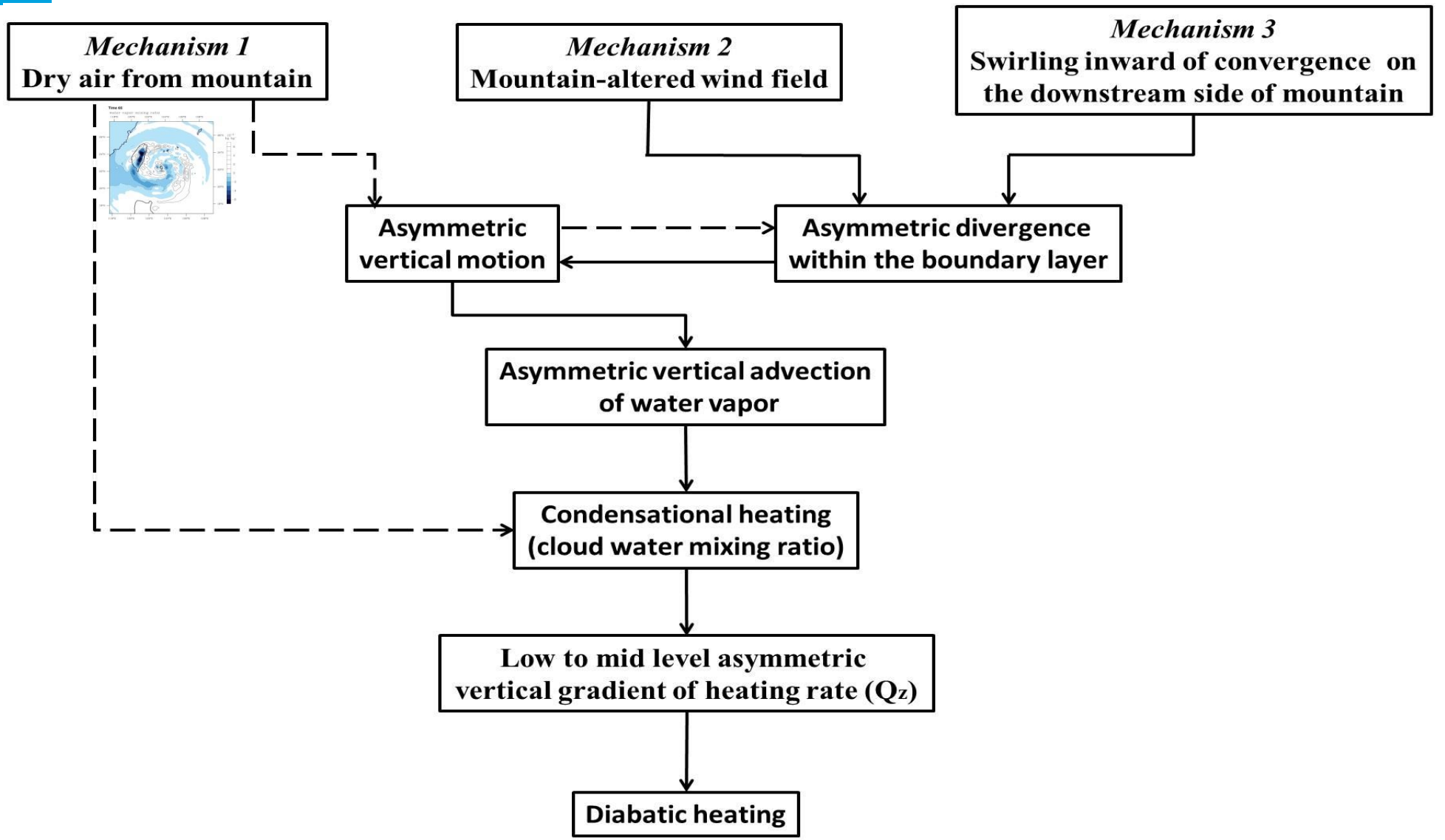
Tang and Chan (2014a)

Water Vapour Mixing Ratio



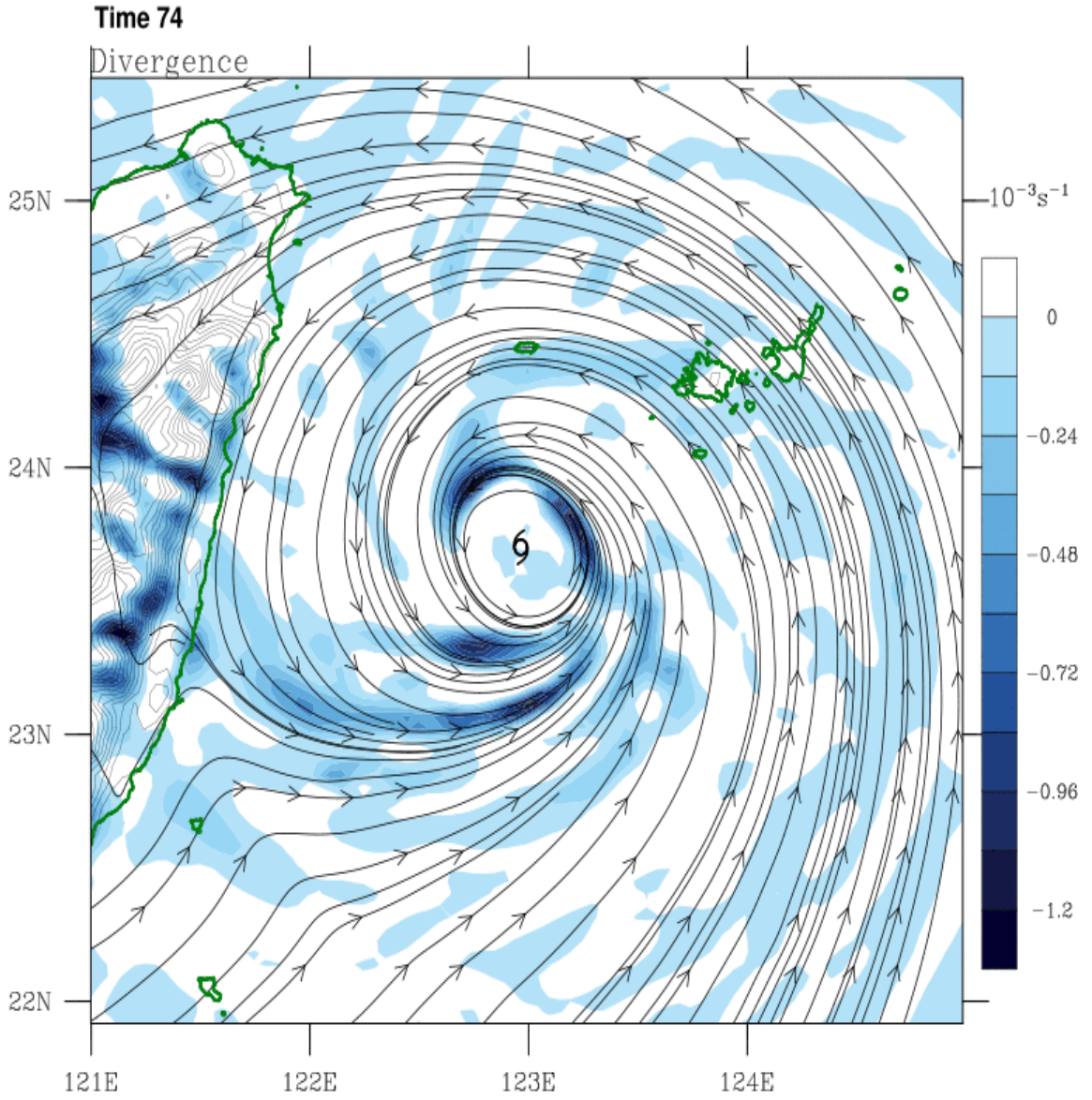
Tang and Chan (2014a)

Mechanisms for the establishment of diabatic heating



Tang and Chan (2014a)

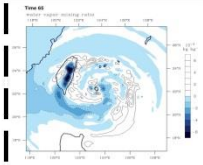
Asymmetric divergence



Tang and Chan (2014a)

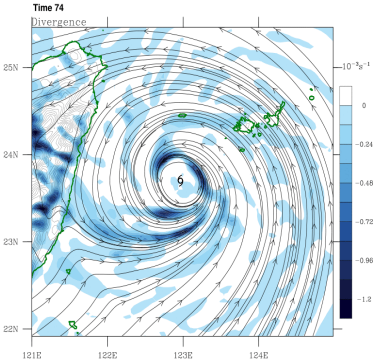
Mechanisms for the establishment of diabatic heating

Mechanism 1
Dry air from mountain



Mechanism 2
Mountain-altered wind field

Mechanism 3
Swirling inward of convergence on the downstream side of mountain



Asymmetric vertical motion

Asymmetric divergence within the boundary layer

Asymmetric vertical advection of water vapor

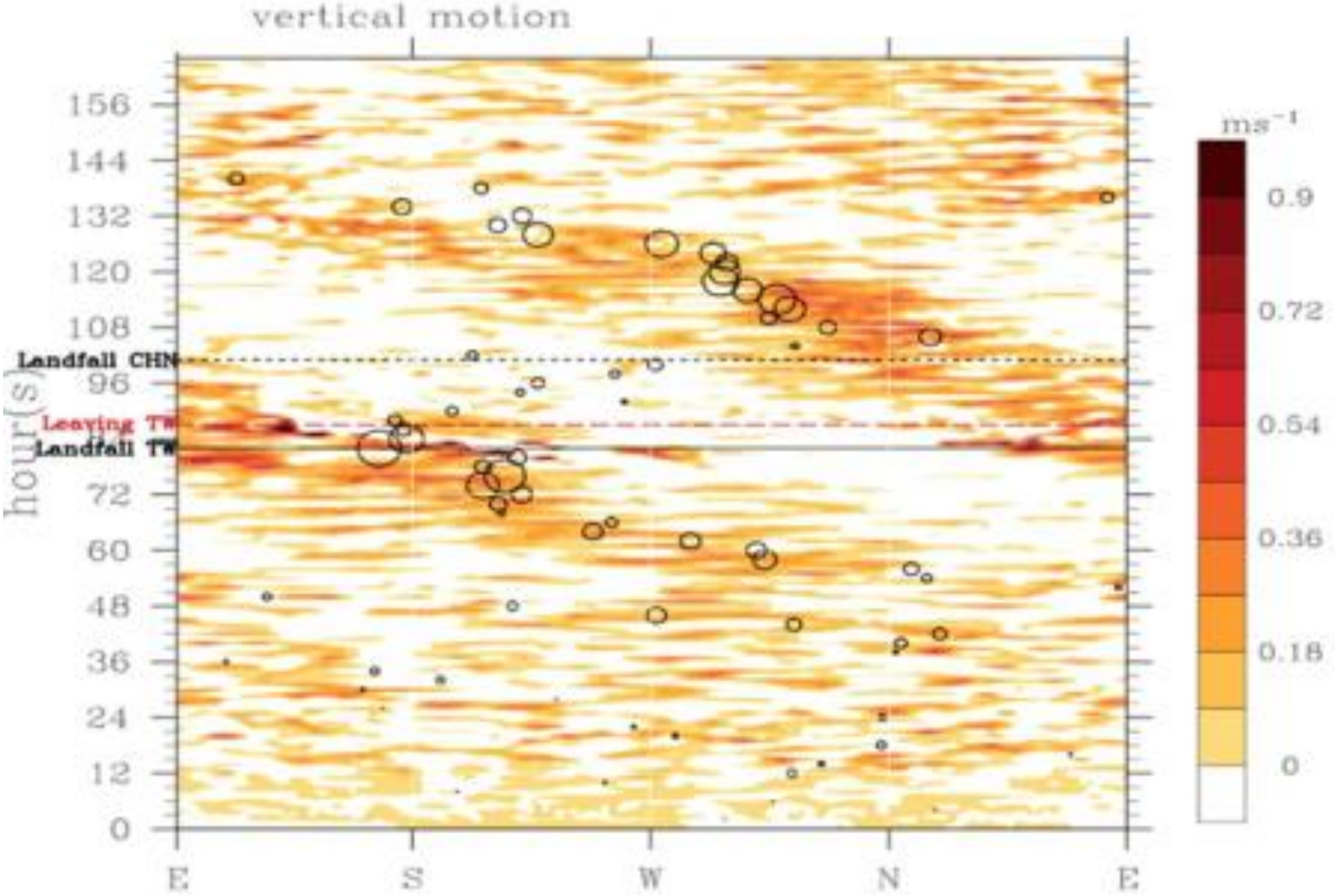
Condensational heating (cloud water mixing ratio)

Low to mid level asymmetric vertical gradient of heating rate (Q_z)

Diabatic heating

Tang and Chan (2014a)

Vertical motion



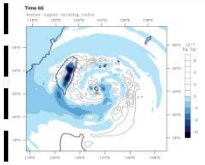
Tang and Chan (2014a)

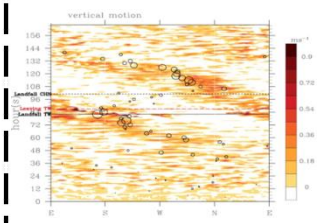
Mechanisms for the establishment of diabatic heating

Mechanism 1
Dry air from mountain

Mechanism 2
Mountain-altered wind field

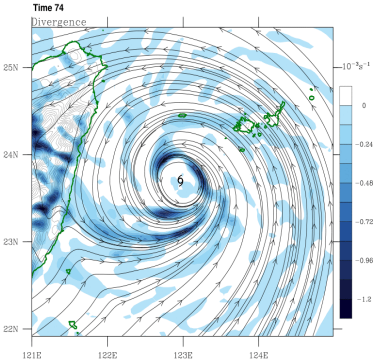
Mechanism 3
Swirling inward of convergence on the downstream side of mountain





Asymmetric vertical motion

Asymmetric divergence within the boundary layer



Asymmetric vertical advection of water vapor

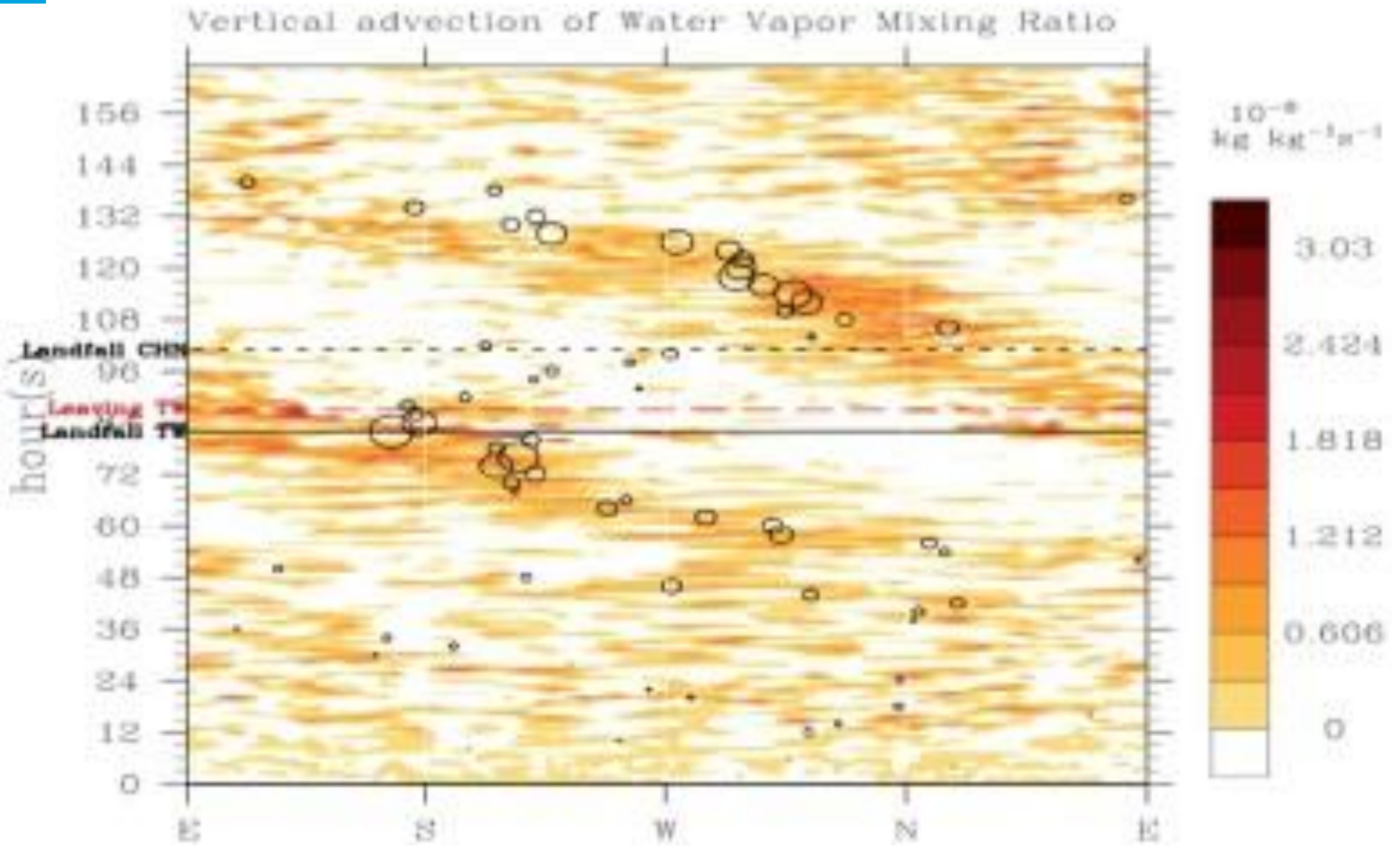
Condensational heating (cloud water mixing ratio)

Low to mid level asymmetric vertical gradient of heating rate (Q_z)

Diabatic heating

Tang and Chan (2014a)

Vertical advection of water vapour



Tang and Chan (2014a)

Mechanisms for the establishment of diabatic heating

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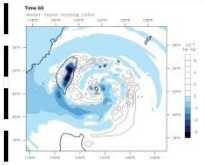
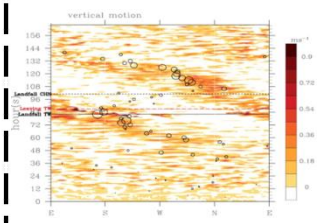
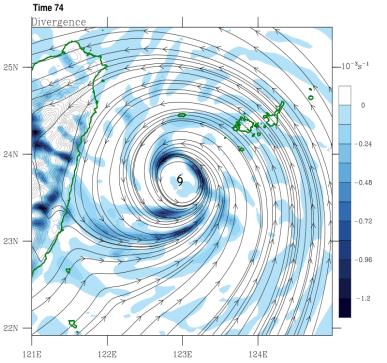
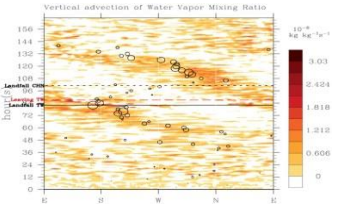




Asymmetric vertical motion

Asymmetric divergence within the boundary layer





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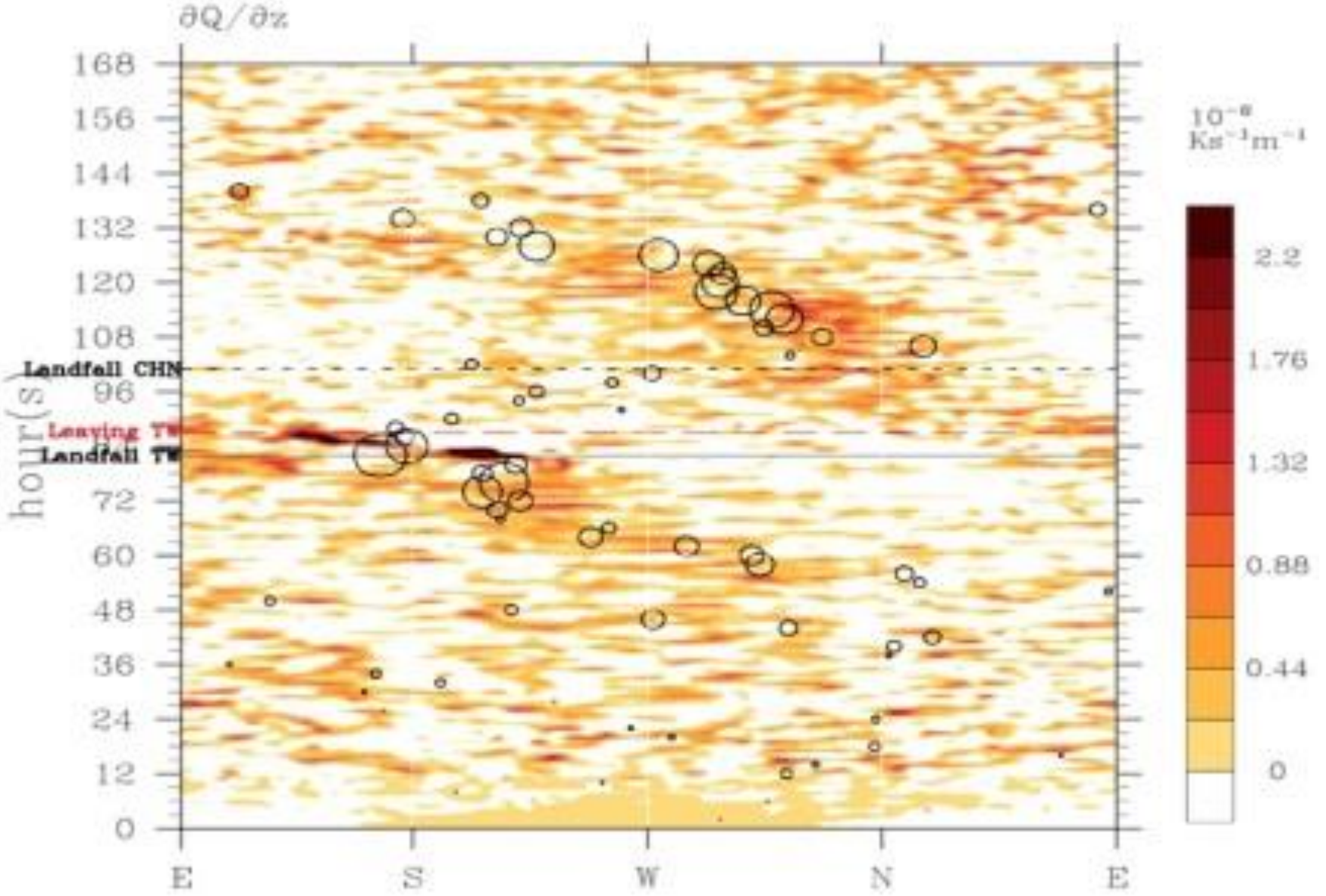
Tang and Chan (2014a)

Vertical gradient of heating rate



Tang and Chan (2014a)

Mechanisms for the establishment of diabatic heating

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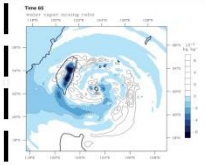

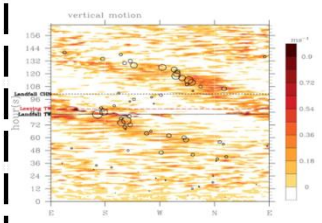

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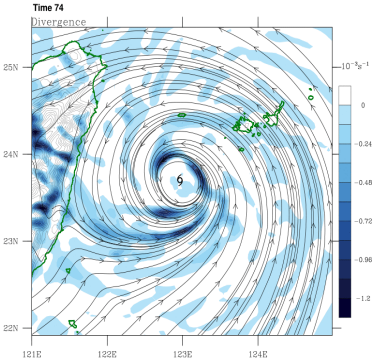
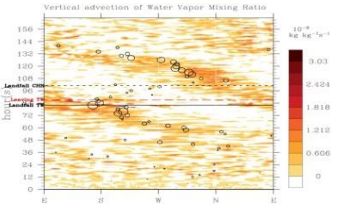


Asymmetric vertical advection of water vapor



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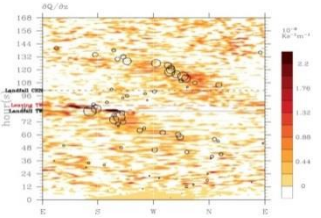
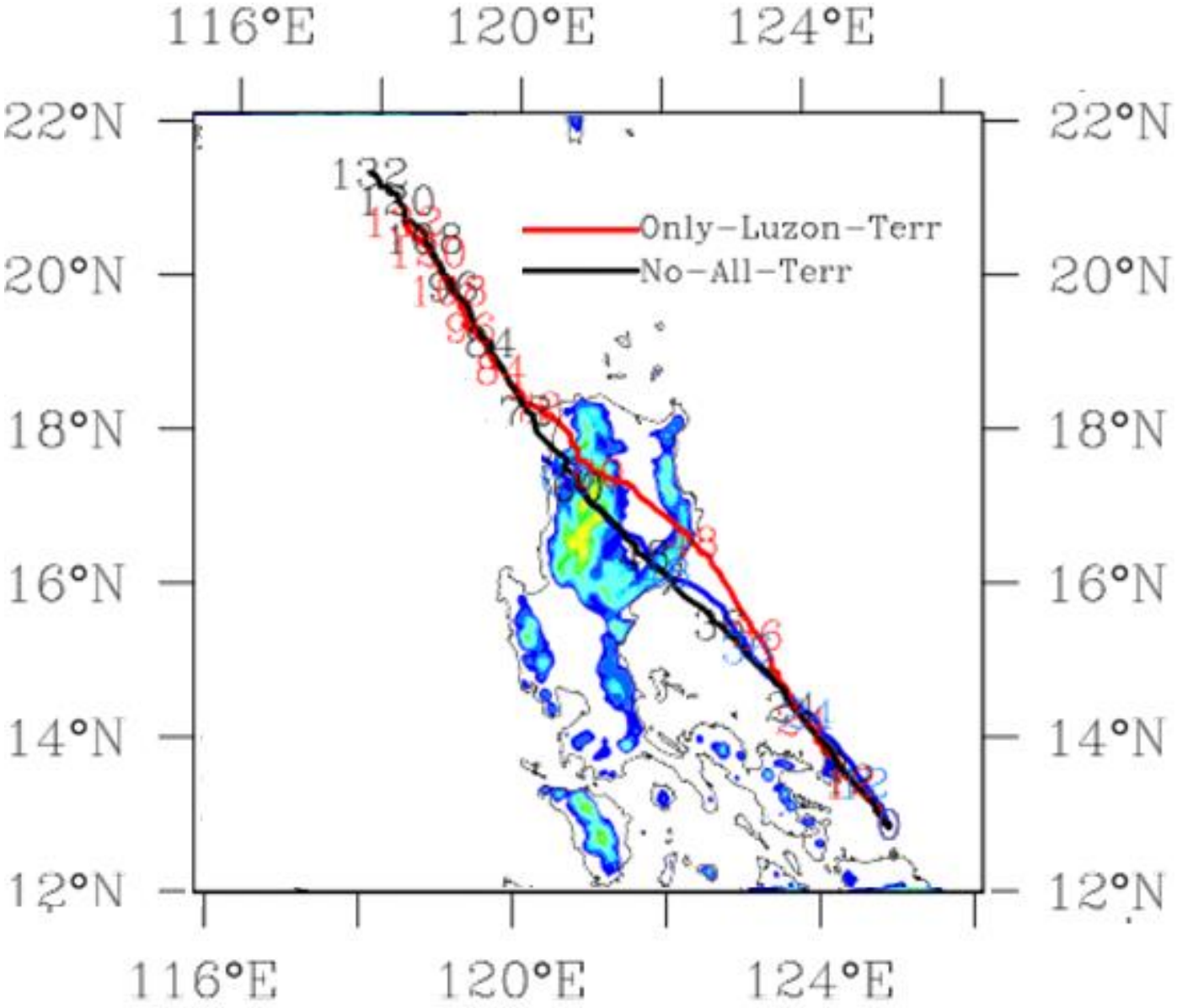


Diabatic heating

Tang and Chan (2014a)

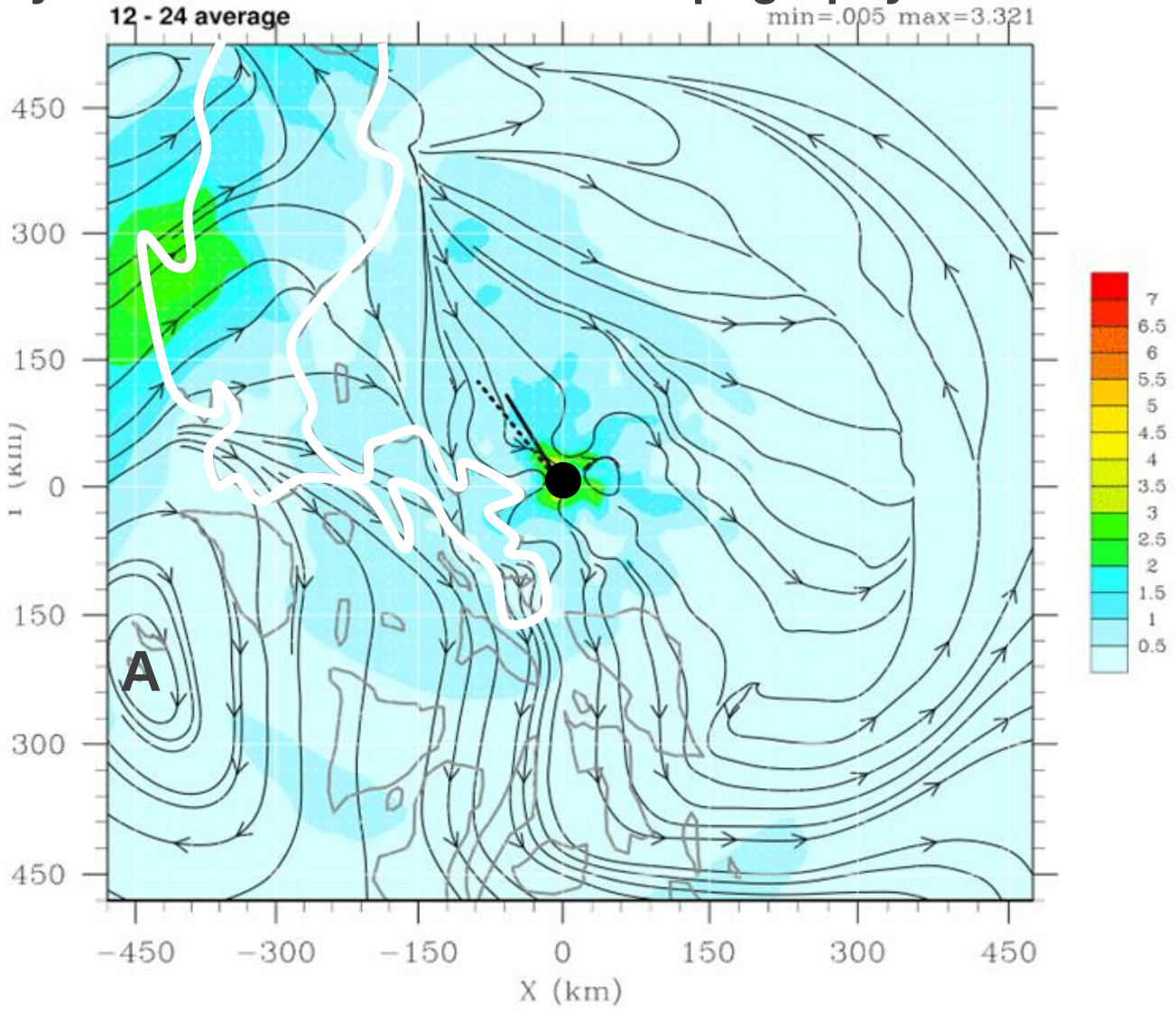
Effect of topography – Luzon



Tang and Chan (2014a)

Effect of topography – Luzon

Asymmetric flow: with Luzon topography minus without

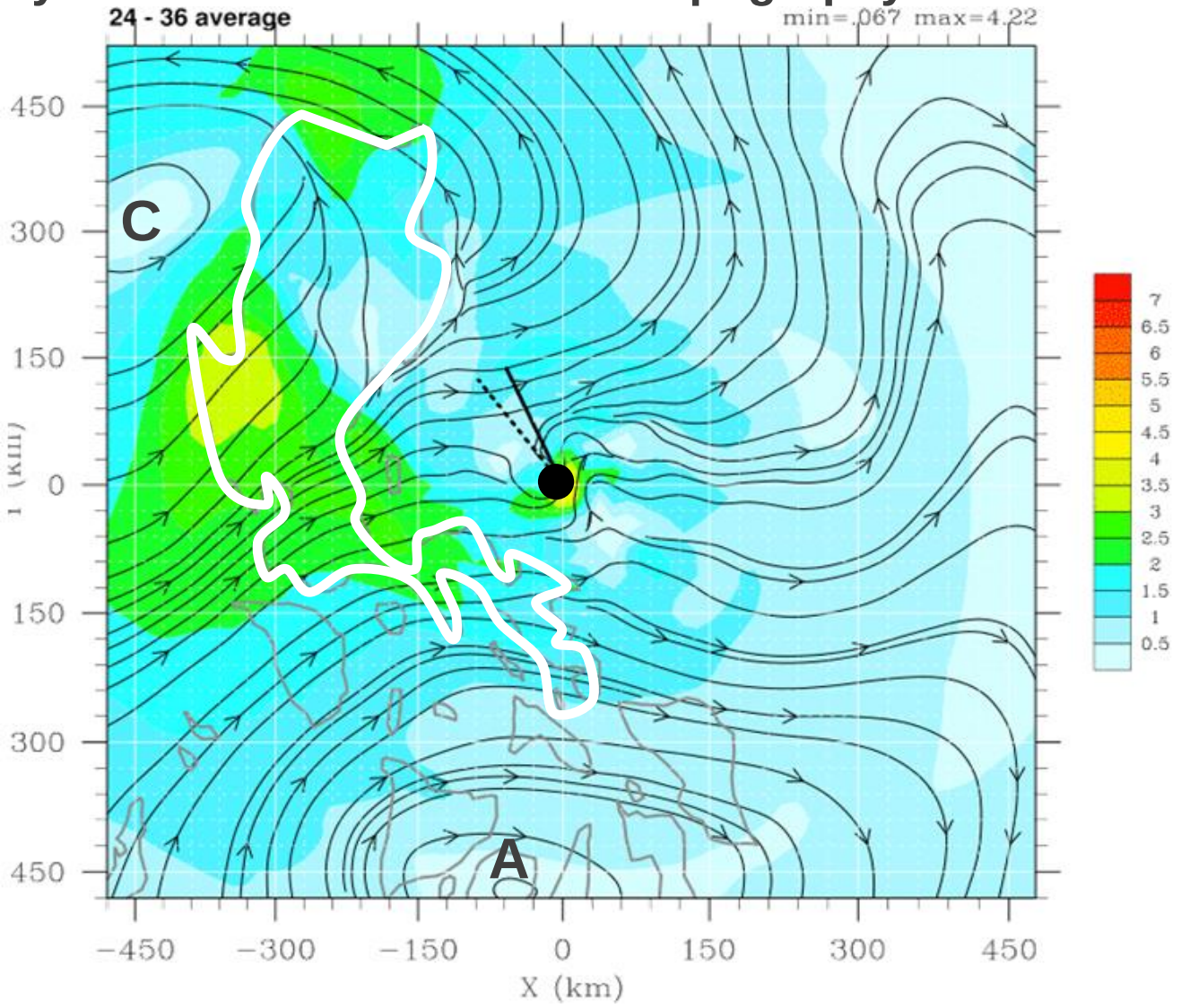


12-24 h

Tang and Chan (2014a)

Effect of topography – Luzon

Asymmetric flow: with Luzon topography minus without

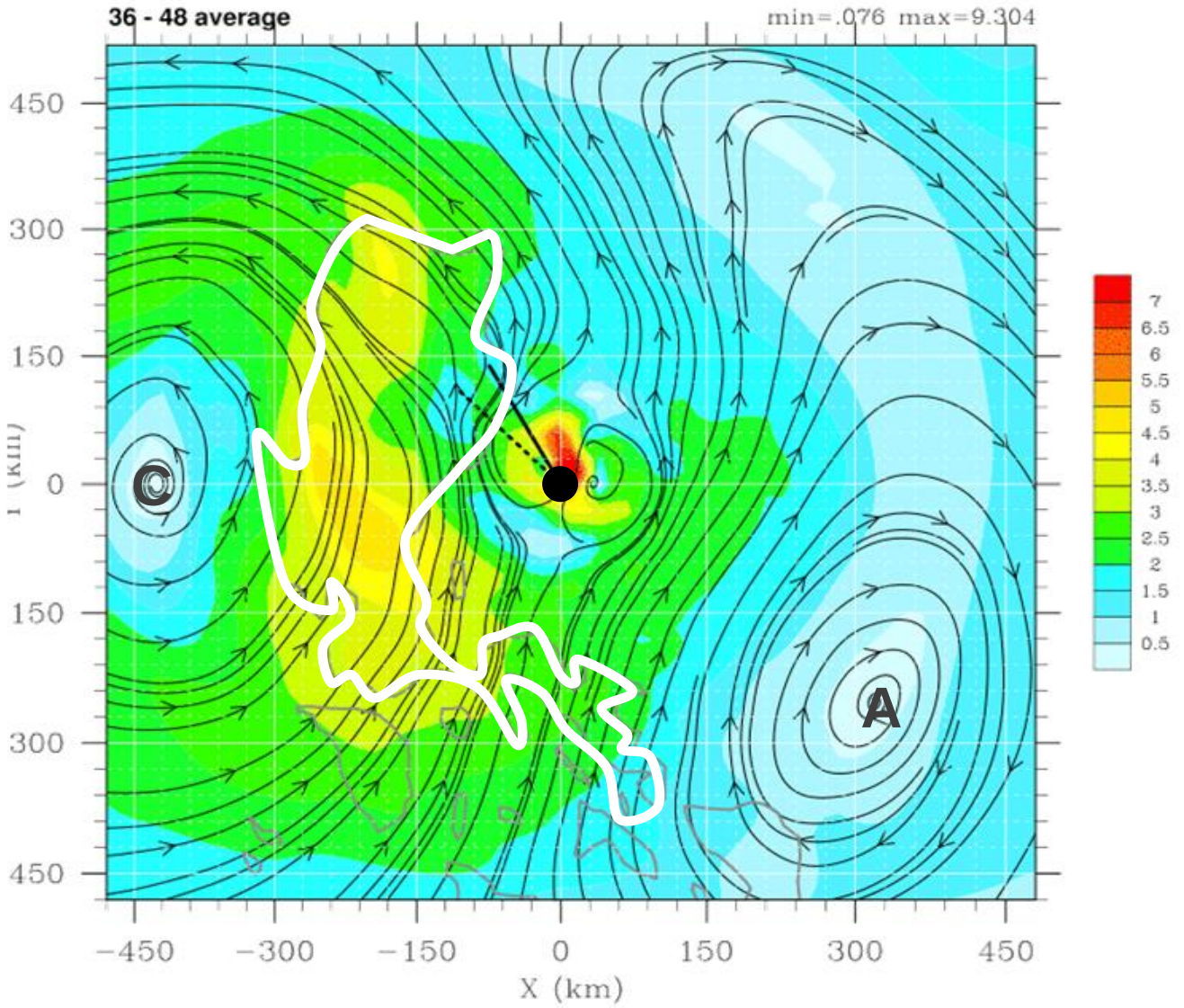


24-36 h

Tang and Chan (2014a)

Effect of topography – Luzon

Asymmetric flow: with Luzon topography minus without

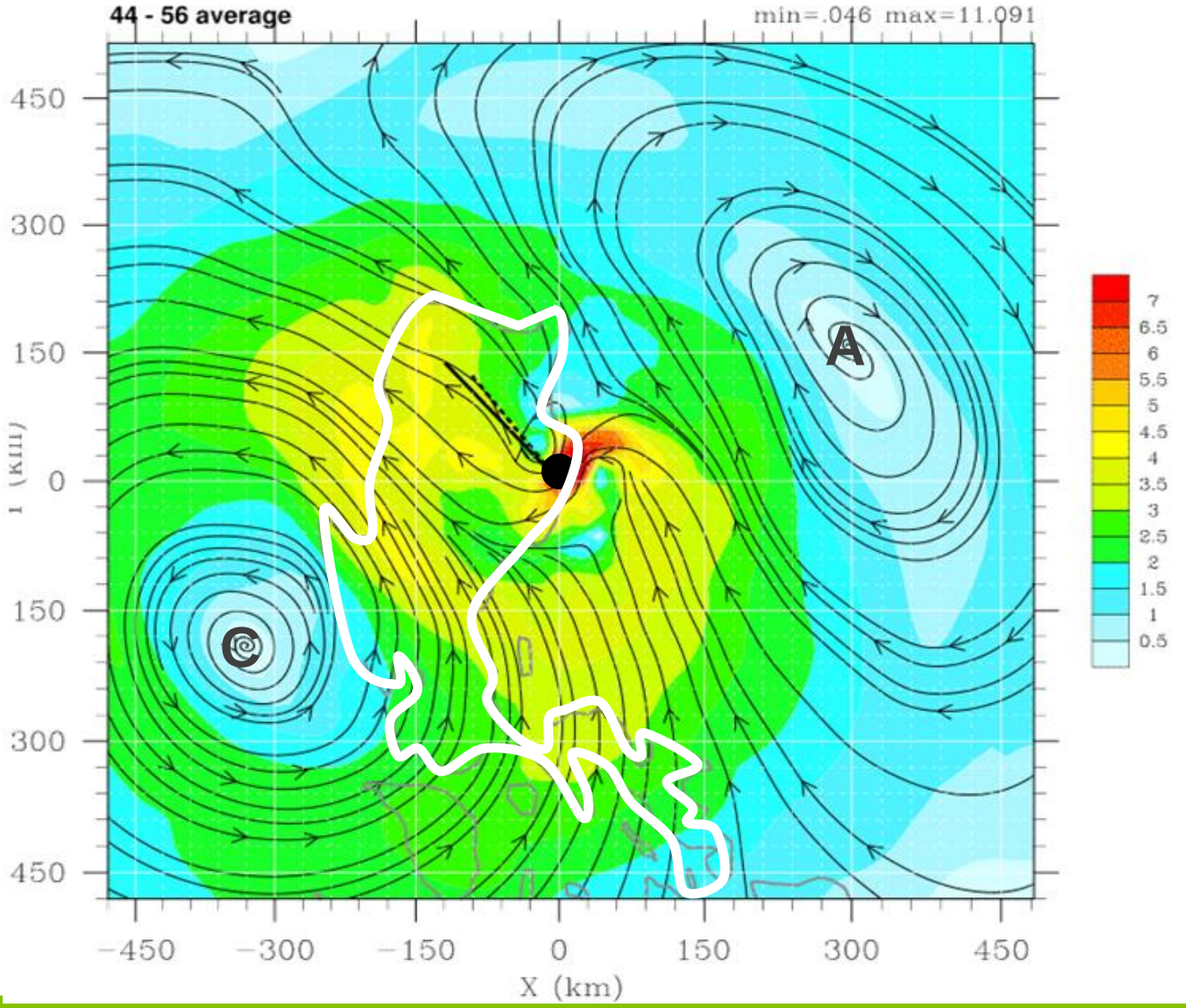


36-48 h

Tang and Chan (2014a)

Effect of topography – Luzon

Asymmetric flow: with Luzon topography minus without

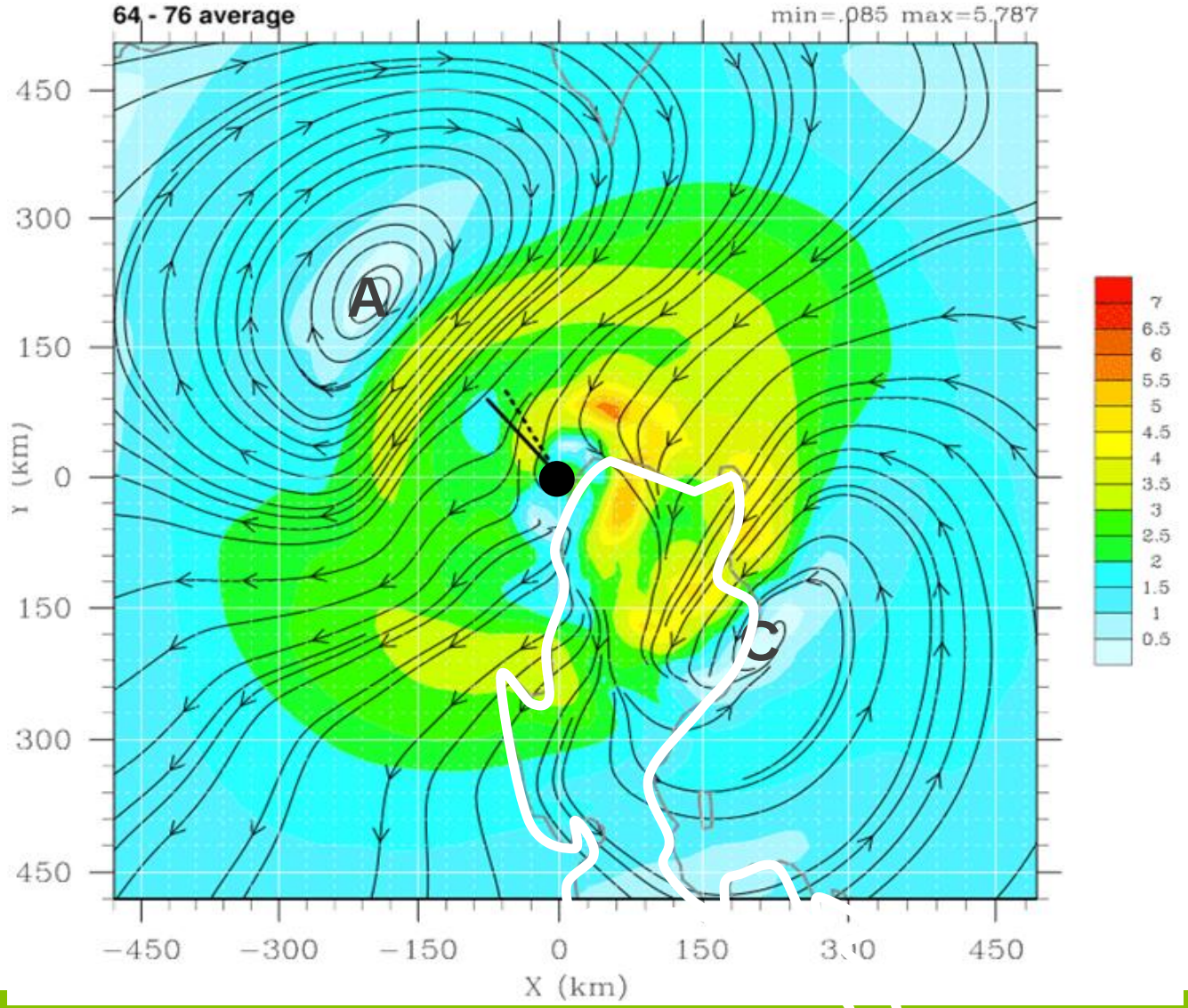


44-56 h

Tang and Chan (2014a)

Effect of topography – Luzon

Asymmetric flow: with Luzon topography minus without

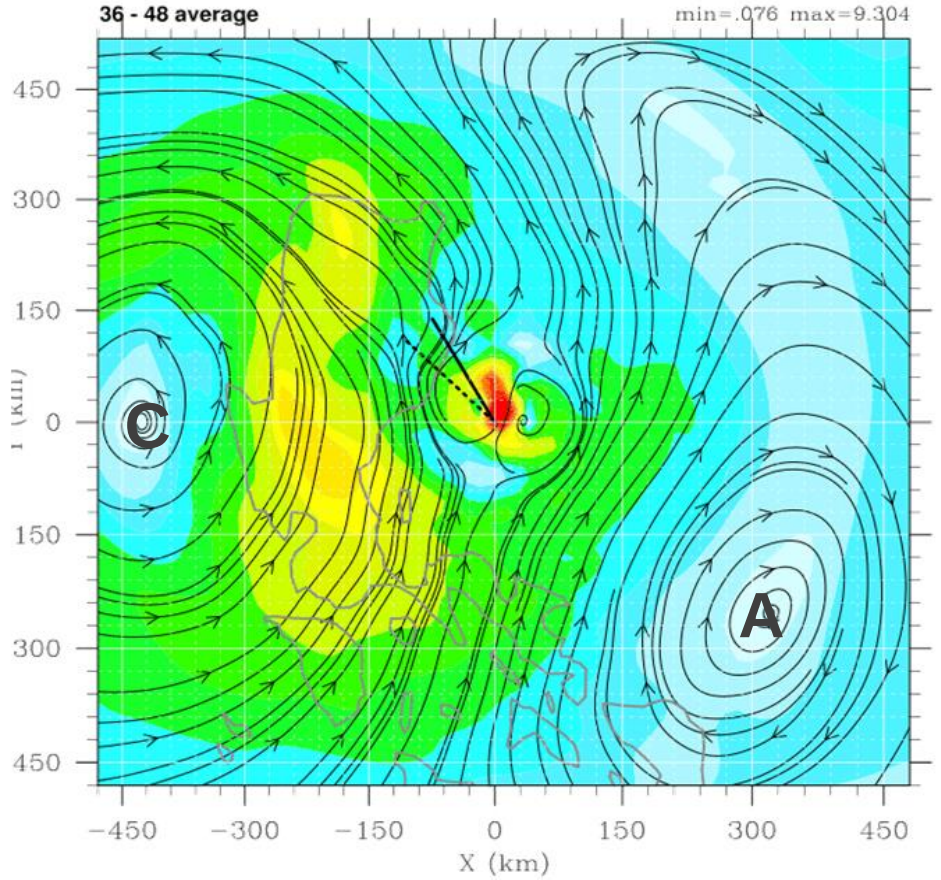


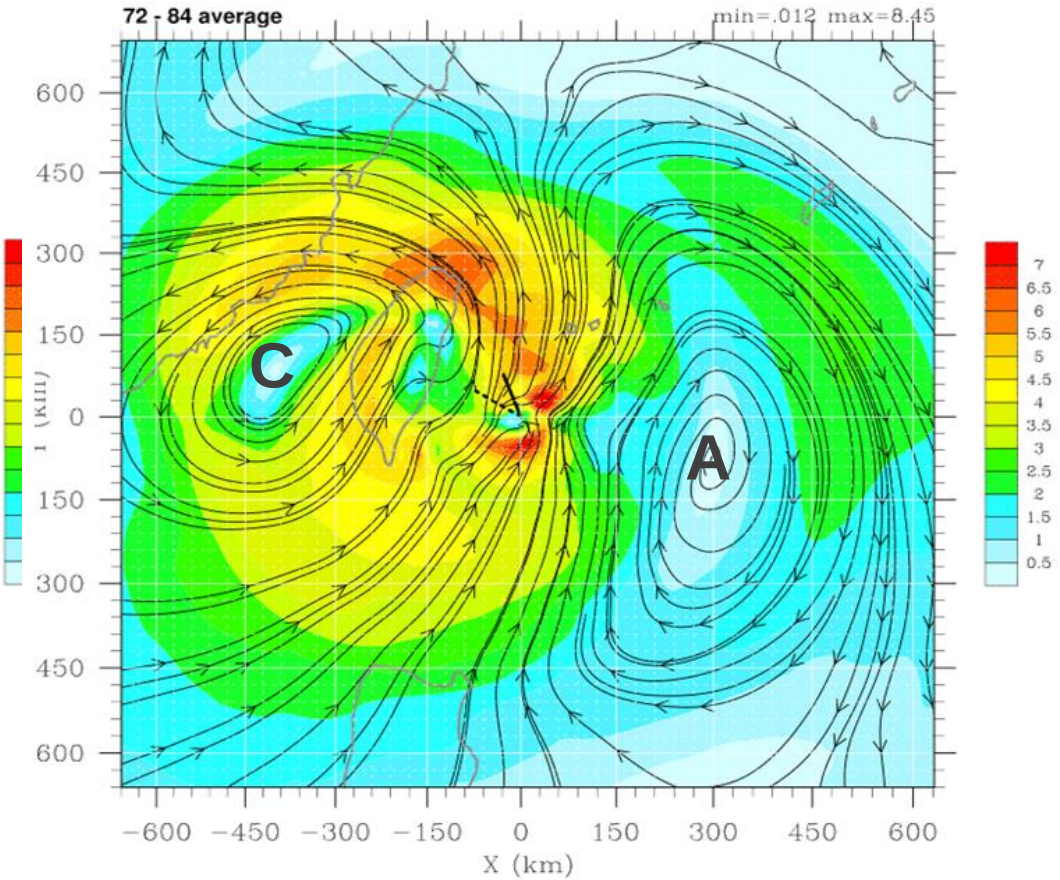
64-76 h

Tang and Chan (2014a)

Effect of topography – Generation of gyres

Asymmetric flow: with topography minus without

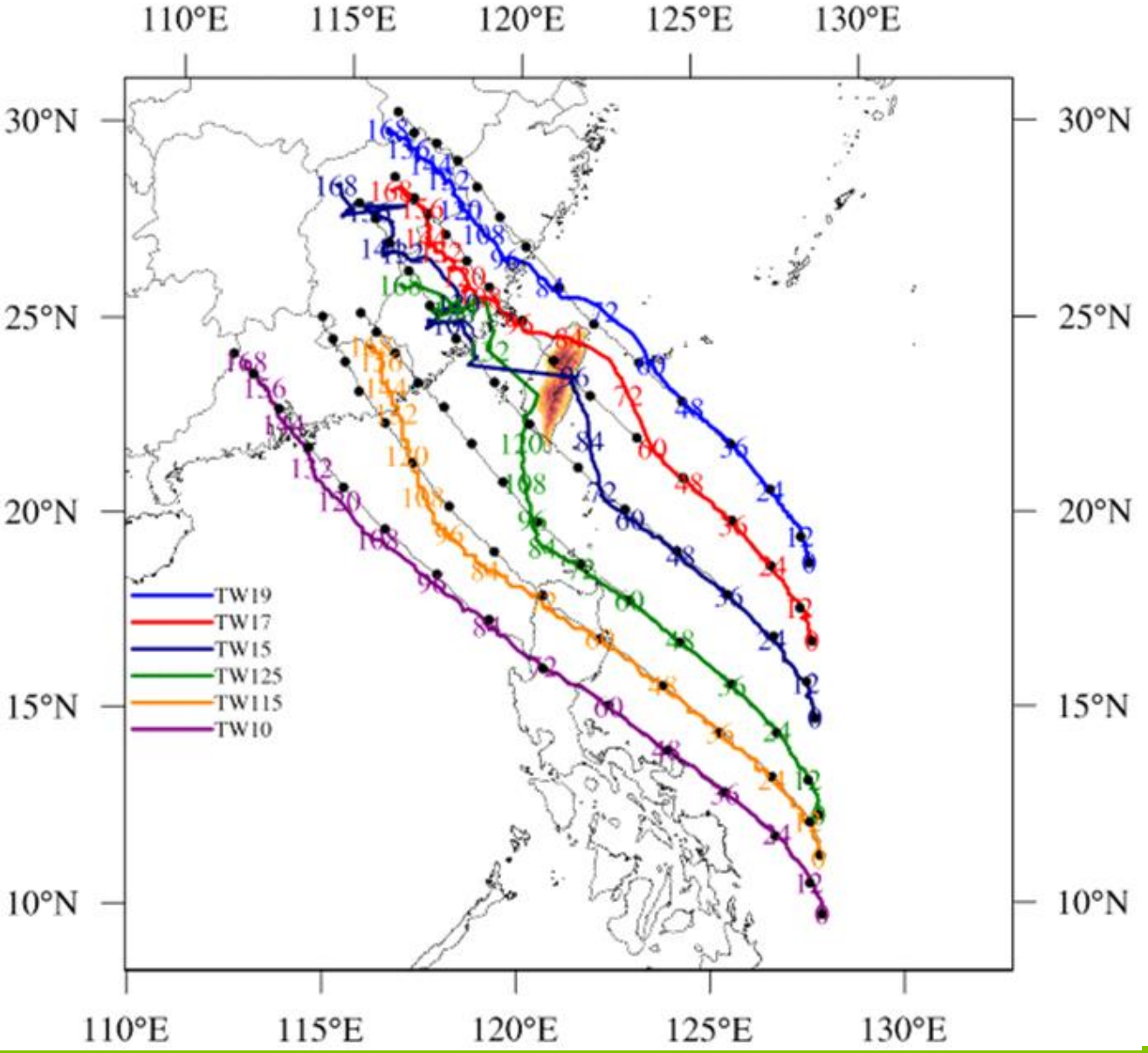




Luzon **Taiwan**

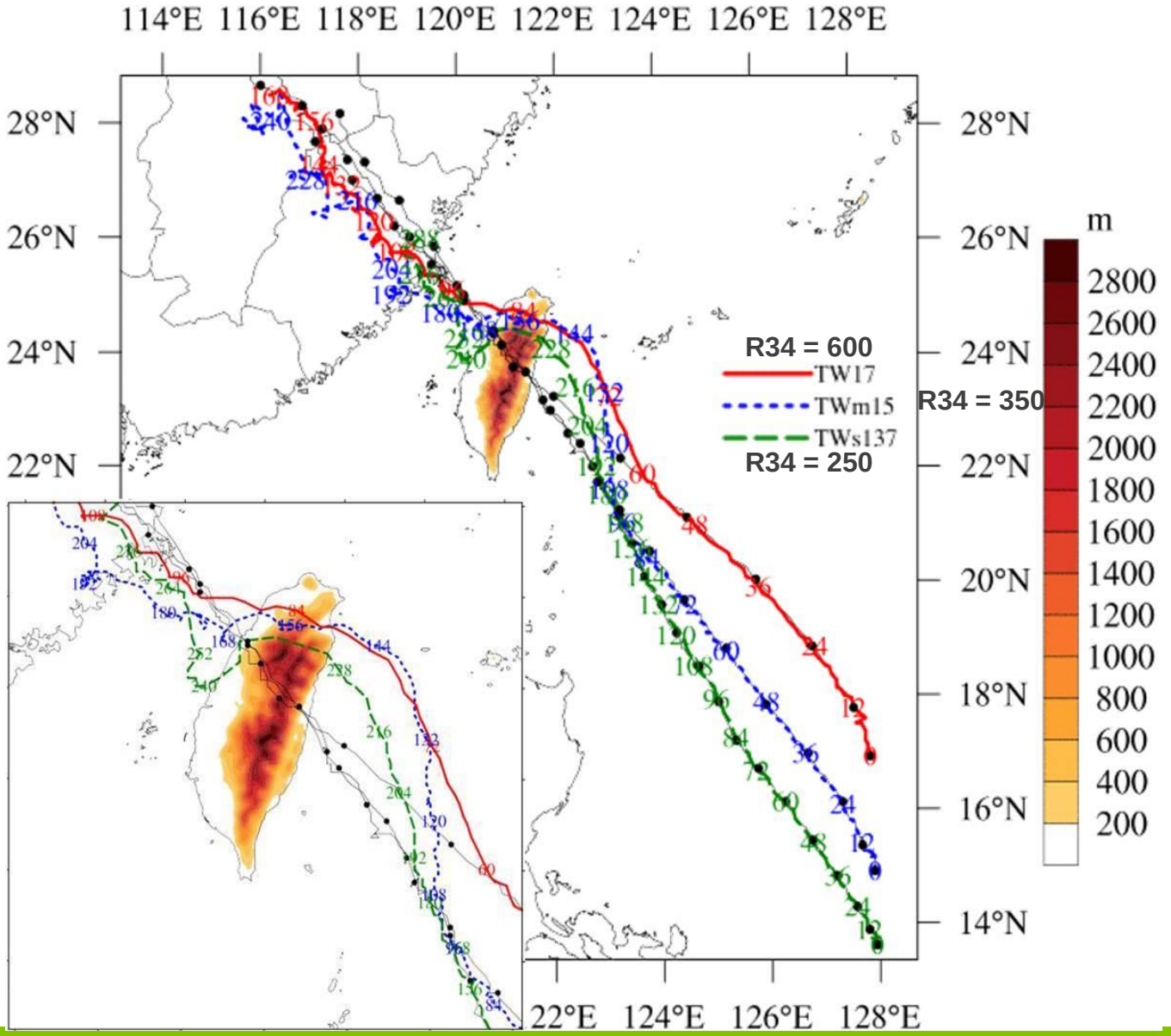
Tang and Chan (2014a)

Variation with initial latitude



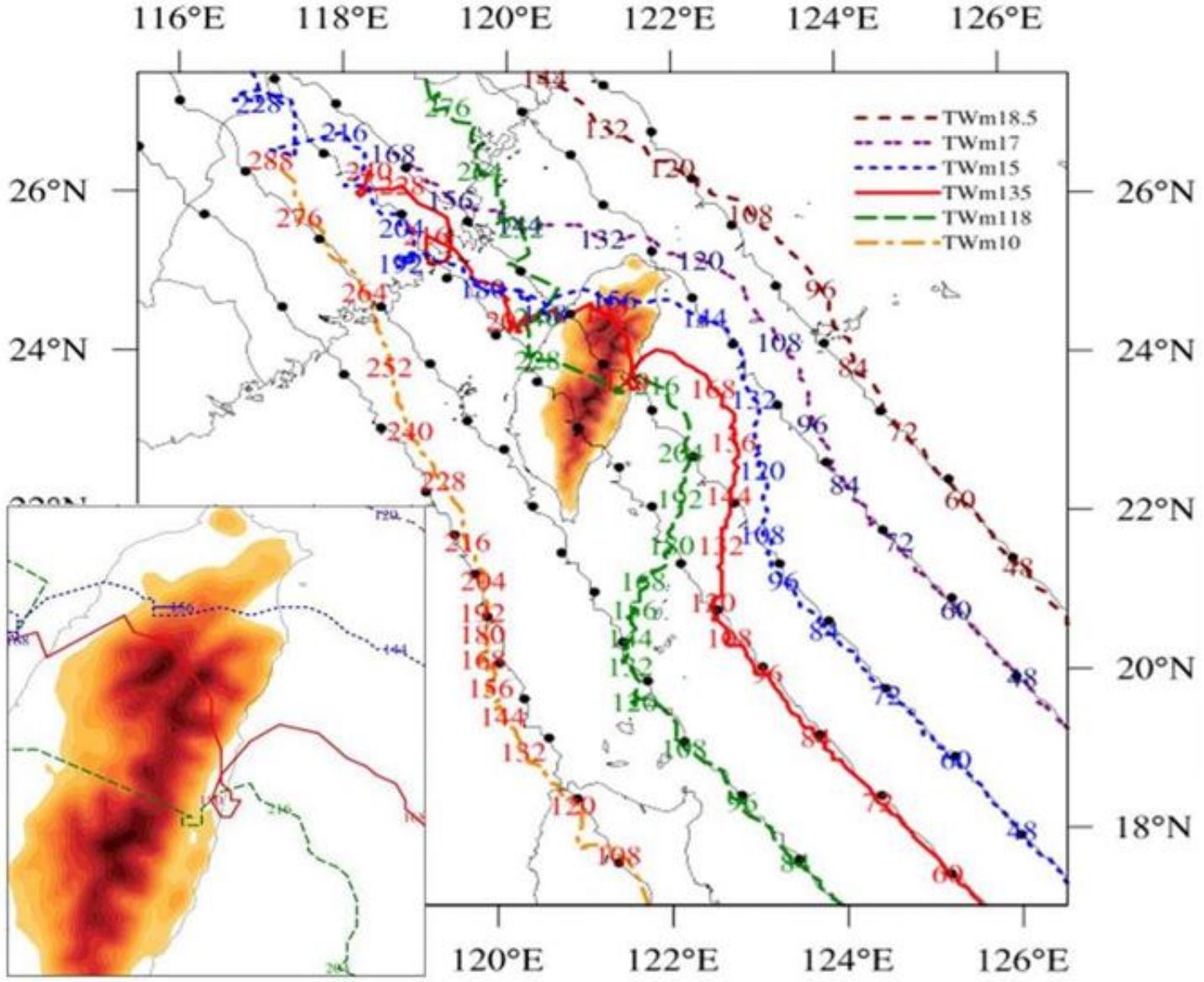
Tang and Chan (2016a)

Effect of size



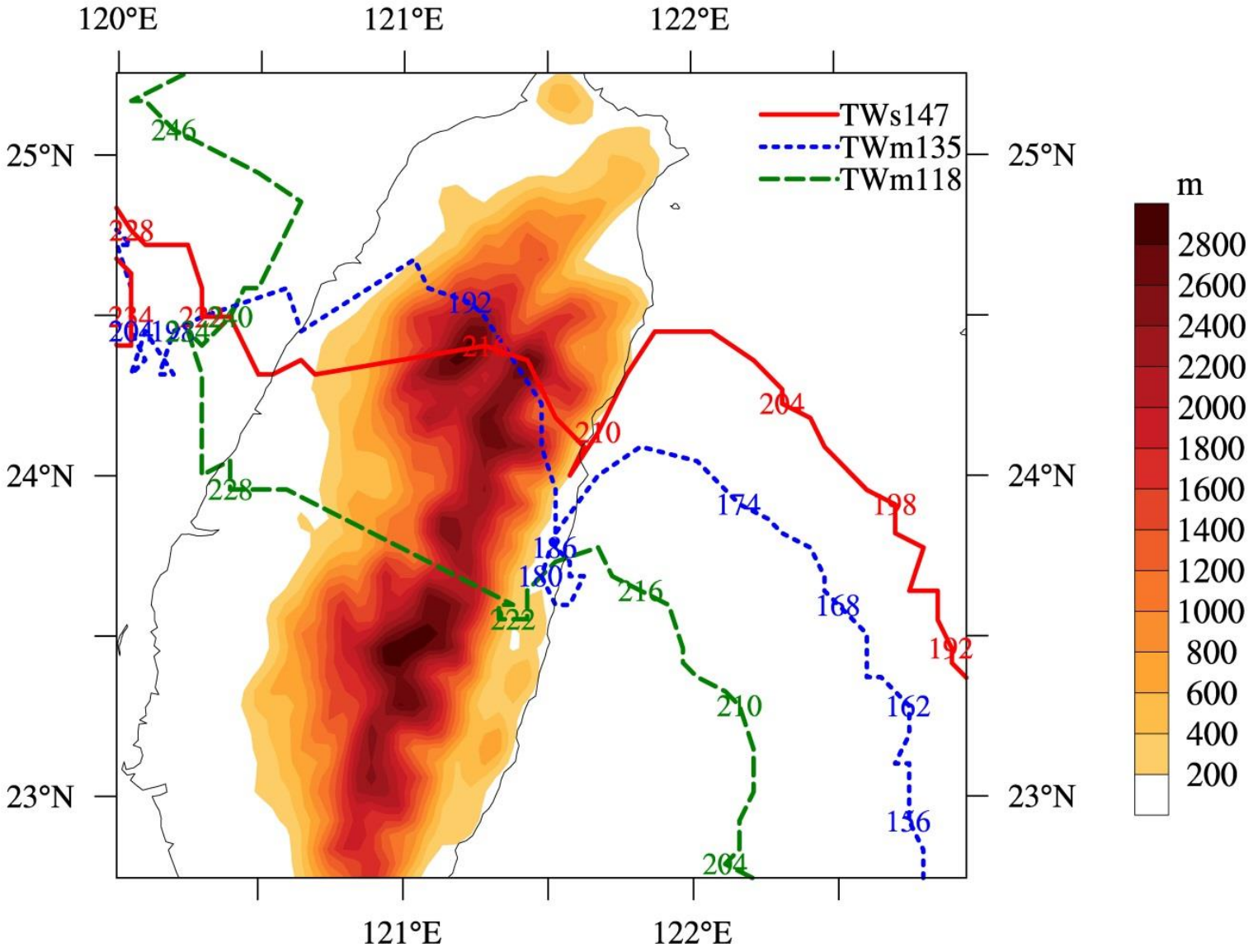
Tang and Chan (2016a)

Effect of size/lat – medium TCs



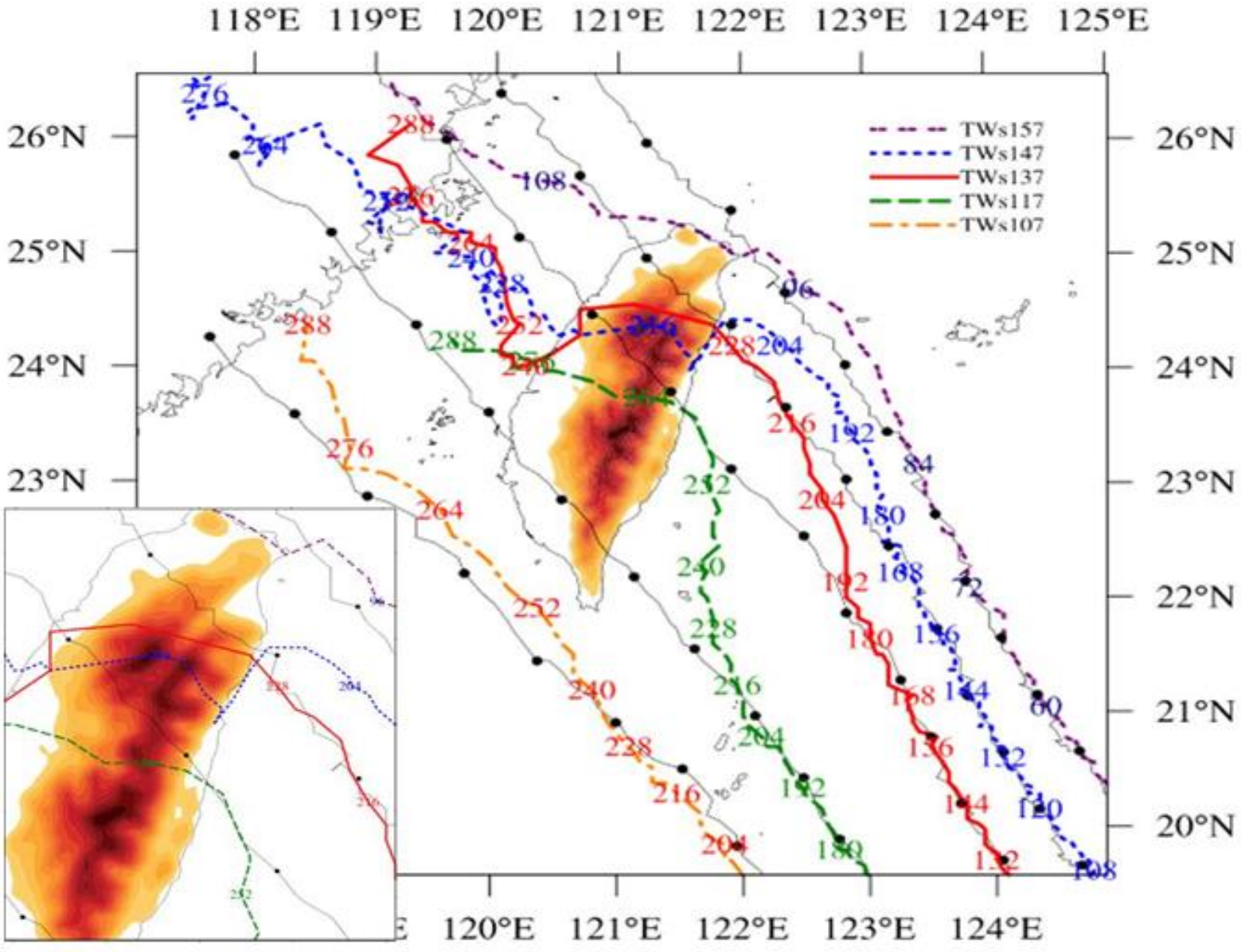
Tang and Chan (2016a)

Effect of size/lat – medium TCs



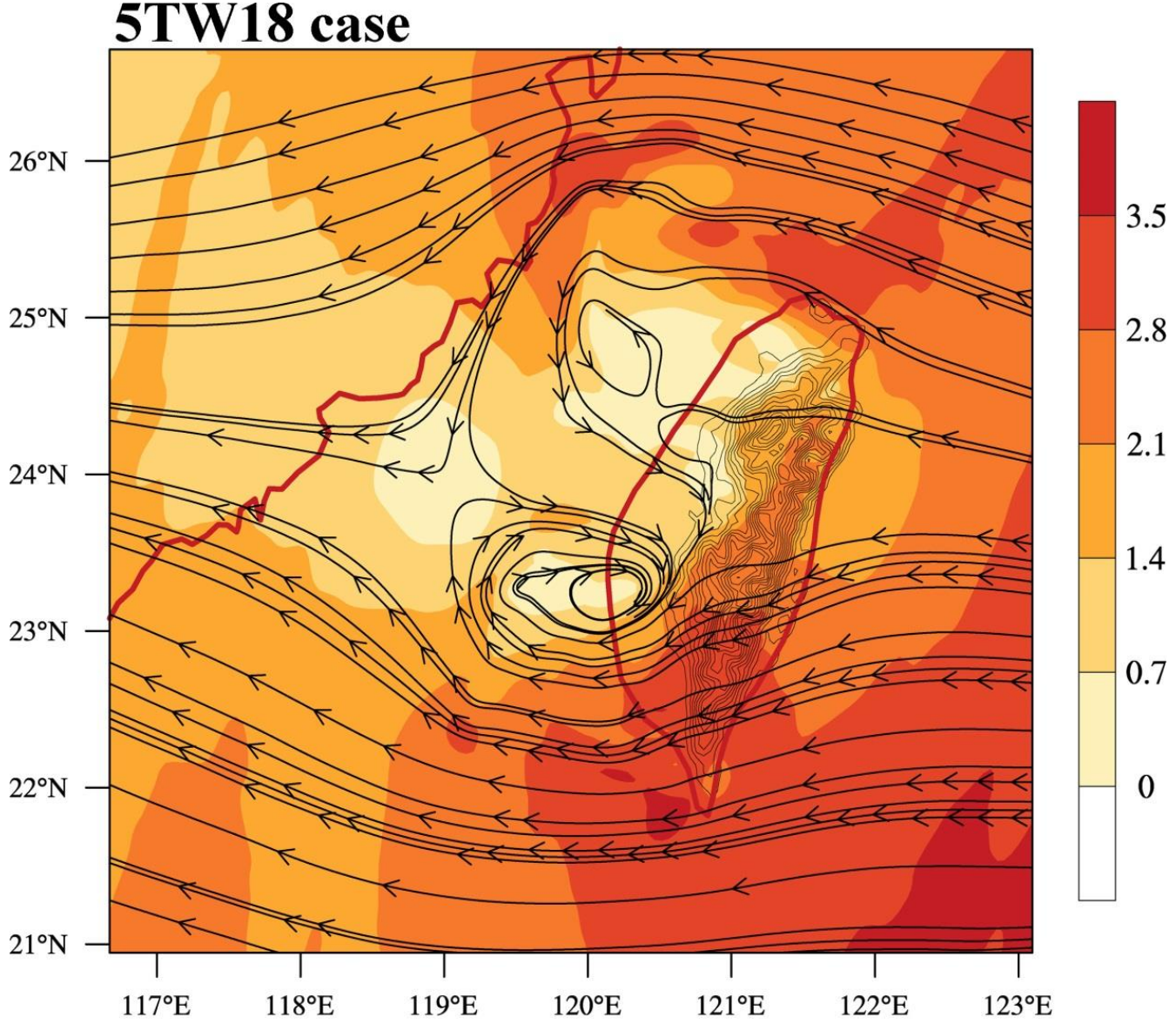
Tang and Chan (2016a)

Effect of size/lat – small TCs

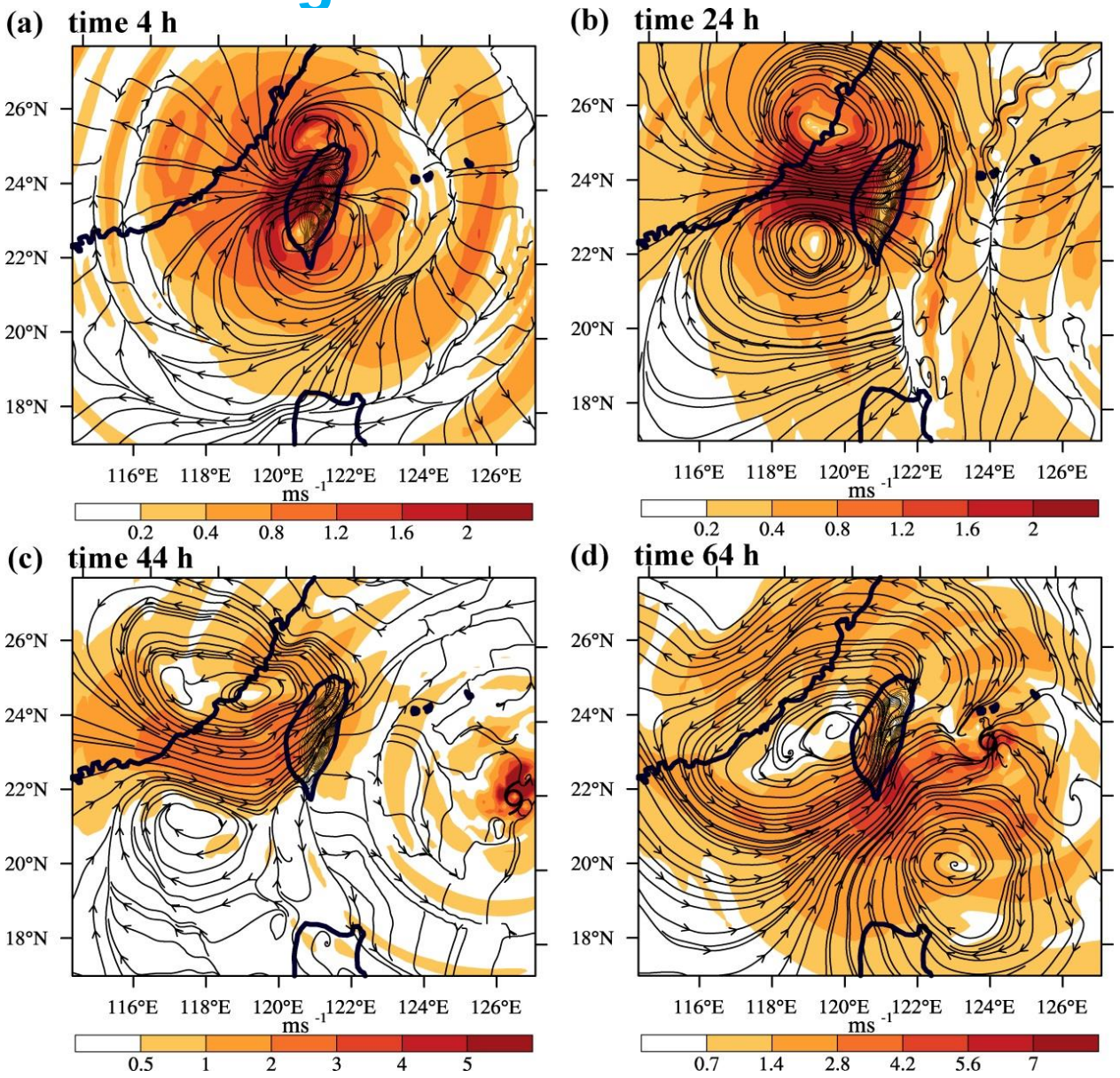


Tang and Chan (2016b)

Effect of steering flow

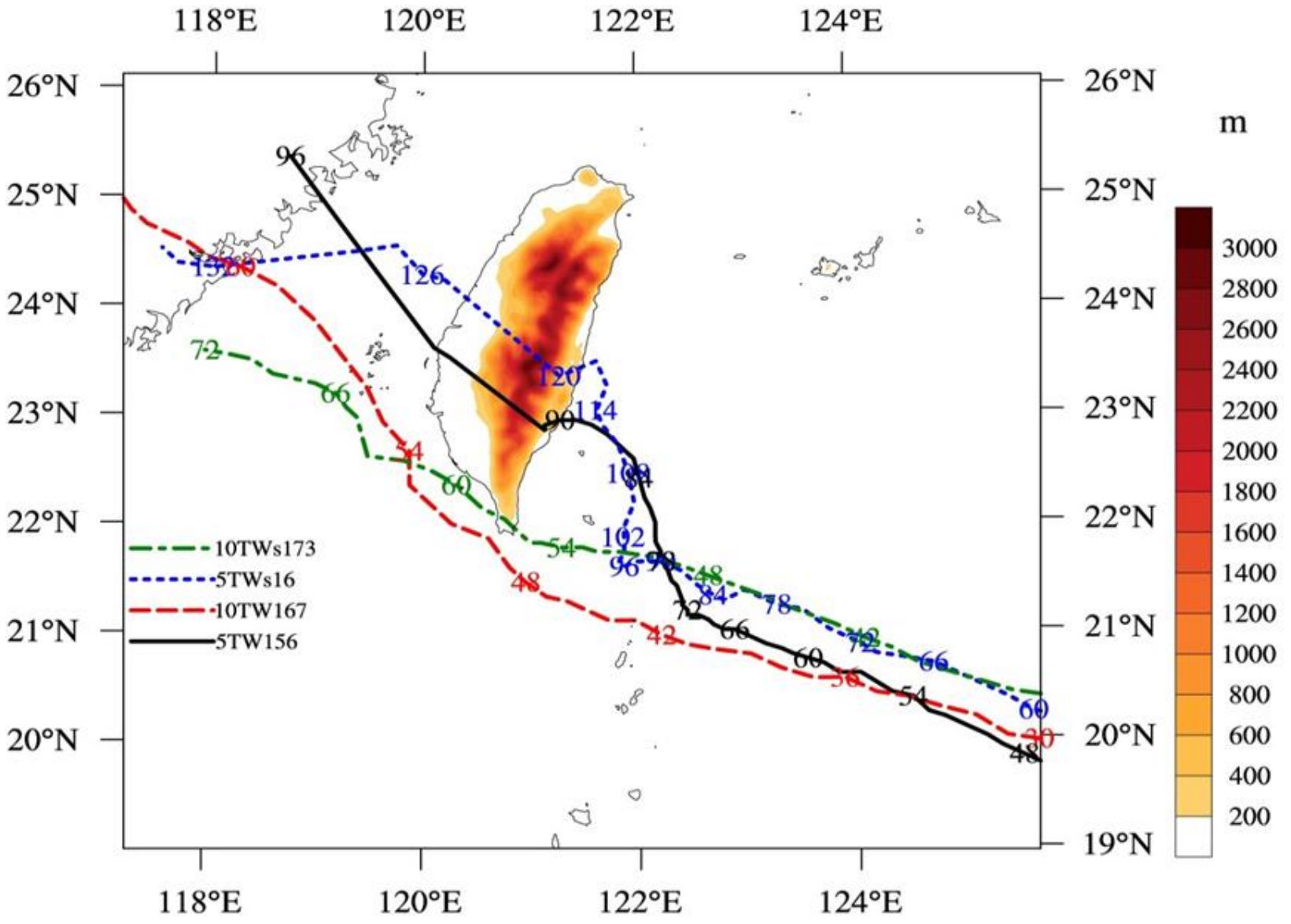


Effect of steering flow



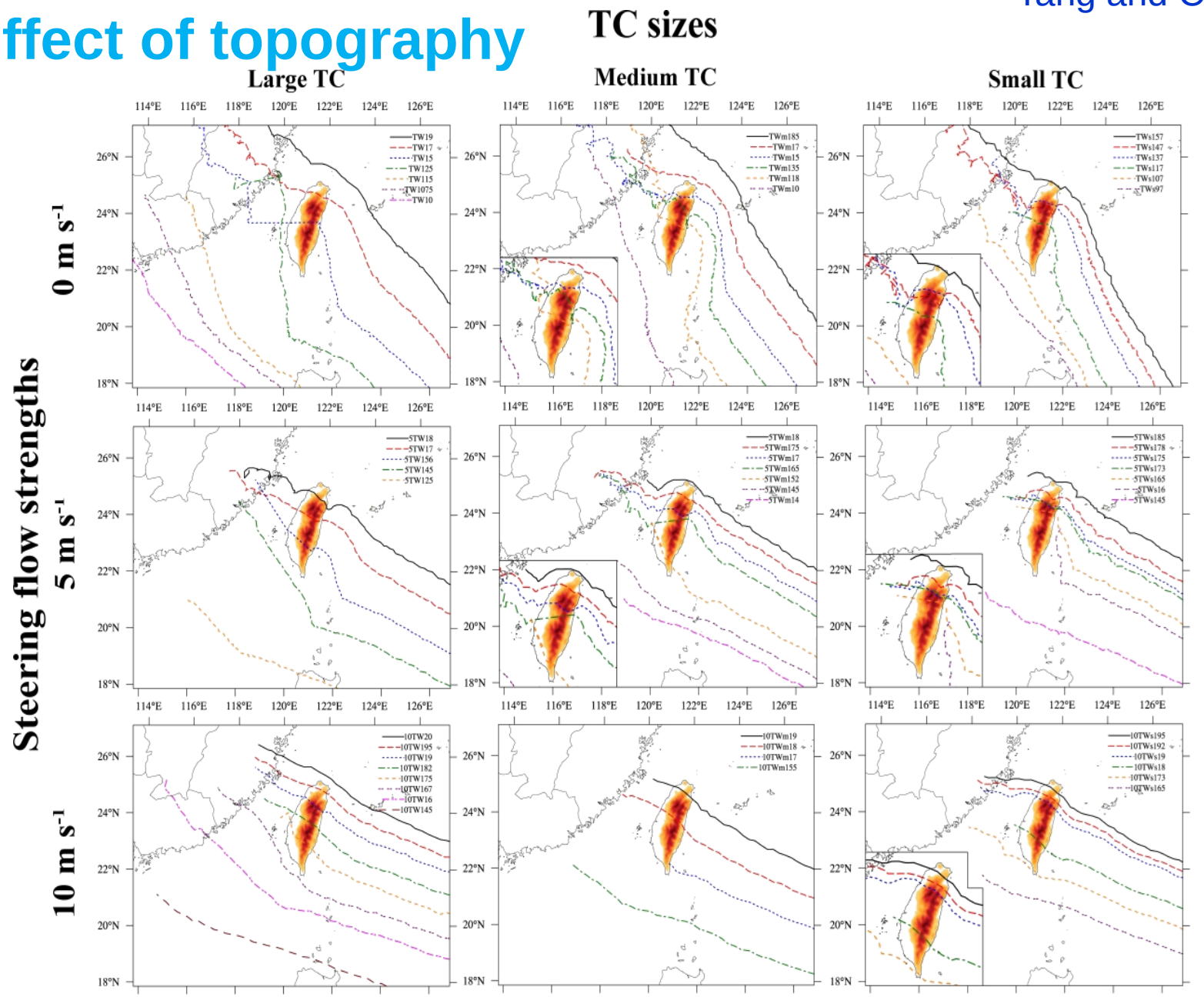
Tang and Chan (2016b)

Effect of steering flow



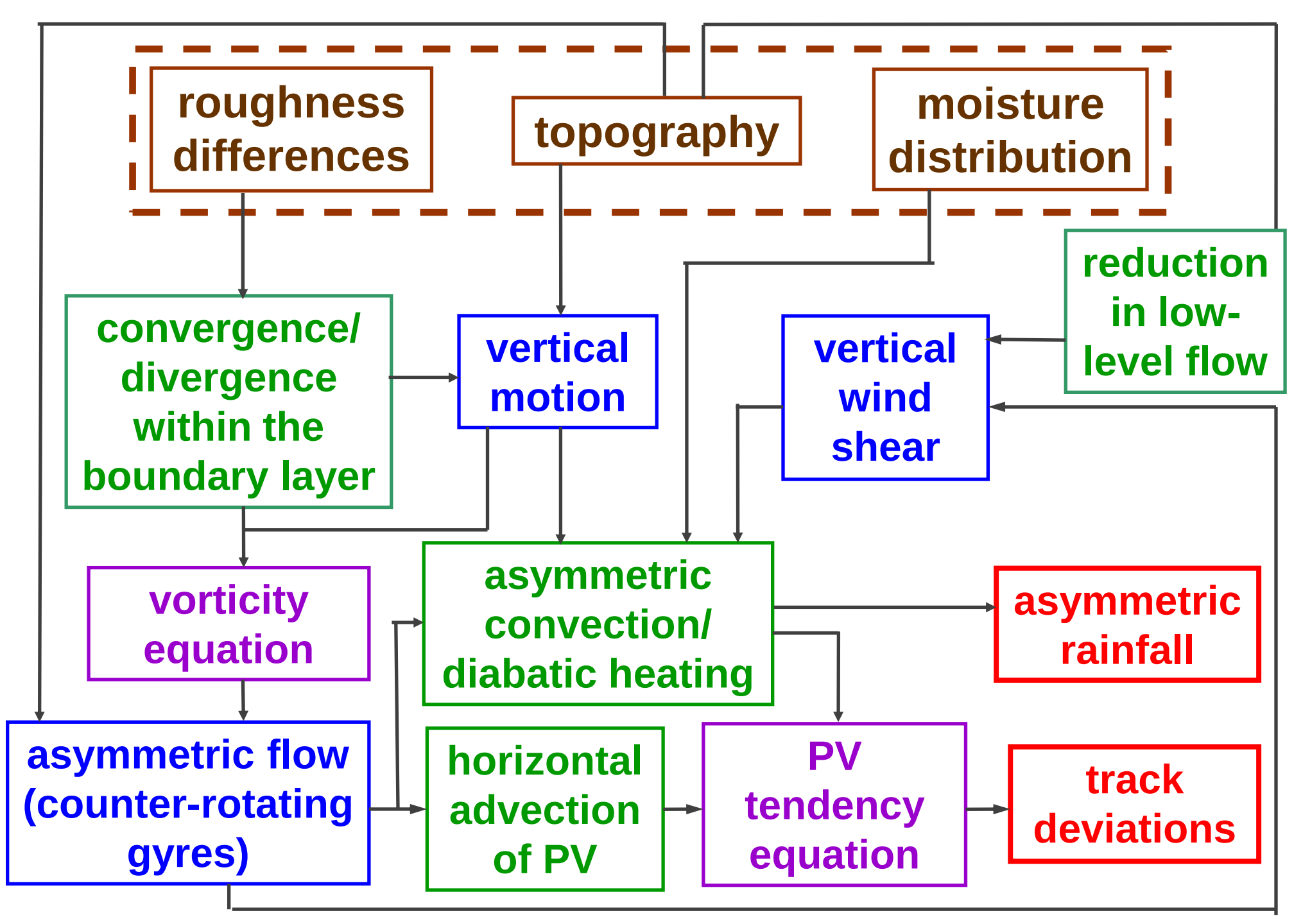
Tang and Chan (2016b)

Effect of topography



Summary

- An inherent vortex motion in the presence of a discontinuity in surface friction.
- The movement of a tropical cyclone would therefore be modified by such an inherent motion, which depends on the strength of the discontinuity.
- Modification of the flow of the tropical cyclone over topography can cause the cyclone to change its direction, the extent of which depends on the height of the topography, the relative location of the cyclone to the topography, cyclone size and background flow.


roughness differences
topography
moisture distribution
reduction in low-level flow
convergence/ divergence within the boundary layer
vertical motion
vertical wind shear
vorticity equation
asymmetric convection/ diabatic heating
asymmetric rainfall
asymmetric flow (counter-rotating gyres)
horizontal advection of PV
PV tendency equation
track deviations