# 地形激發對流影響侵台颱風運動之位渦趨勢診斷分析

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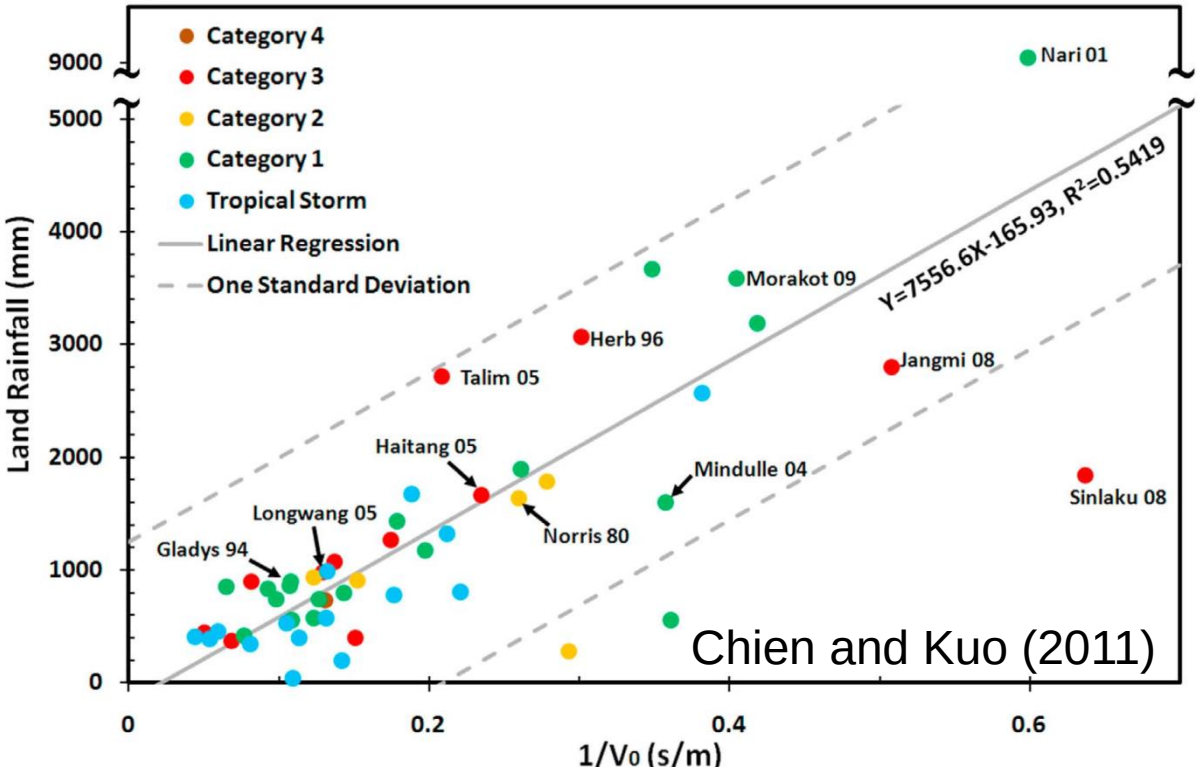
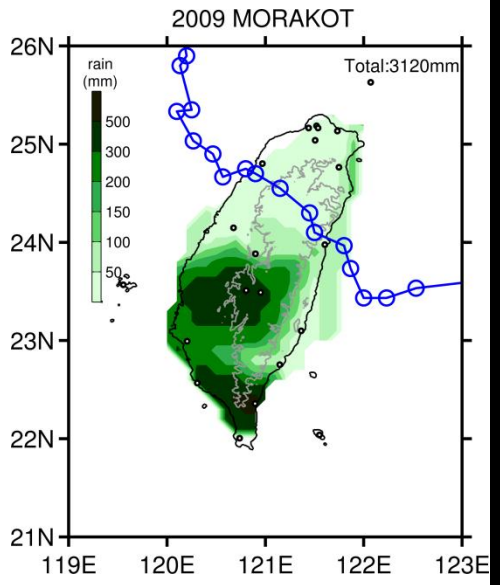
**102**年天氣分析與預報研討會

# MOTIVATION

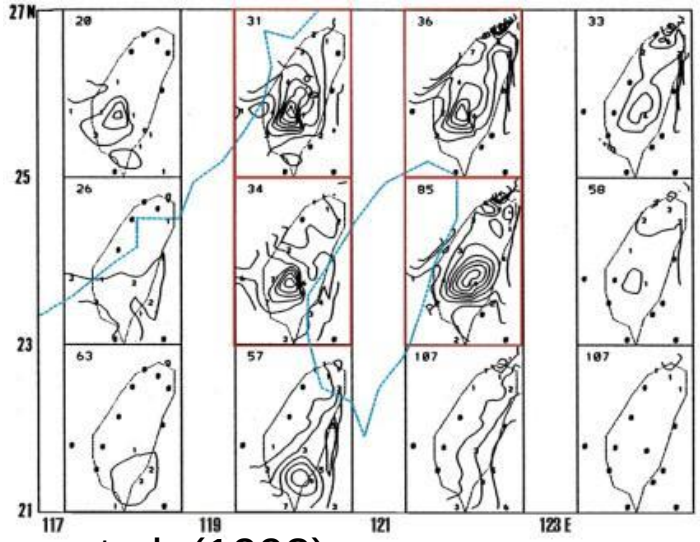
- **Slow moving typhoons with heavy rainfall often cause serious disaster to Taiwan.**
- **Land rainfall amount is roughly proportional to the inverse of TCs' translation speed over land. (Chien and Kuo 2011)**



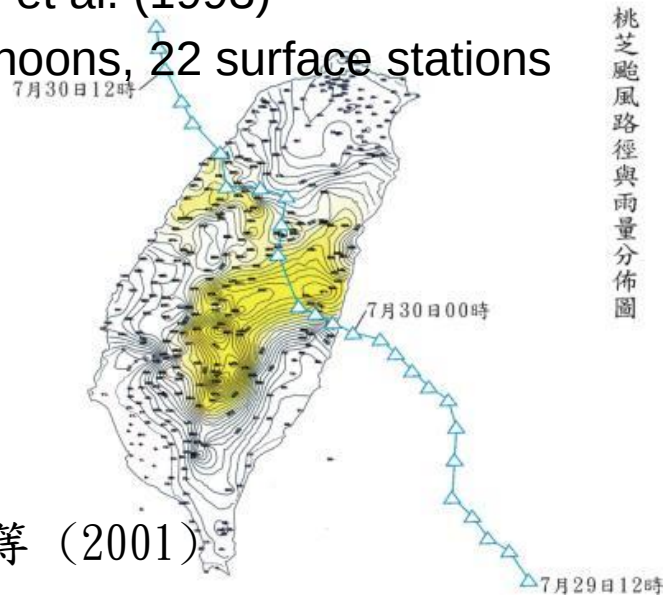
# TC rainfall climatology over Taiwan

## Rainfall phase locked with topography

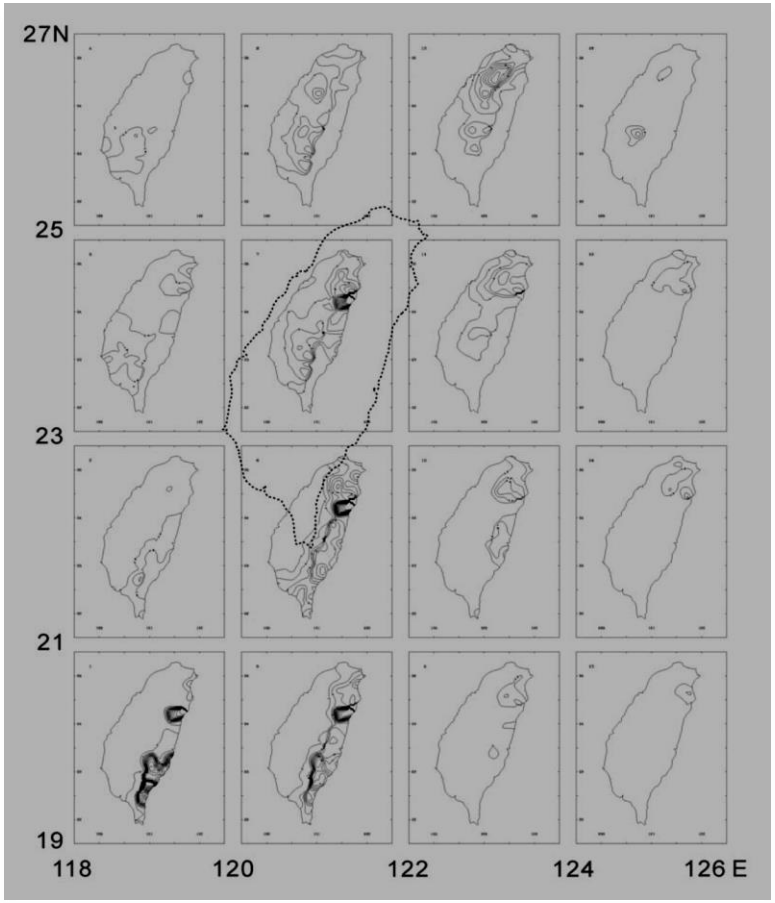



Chang et al. (1993)

82 typhoons, 22 surface stations




郭等（2001）

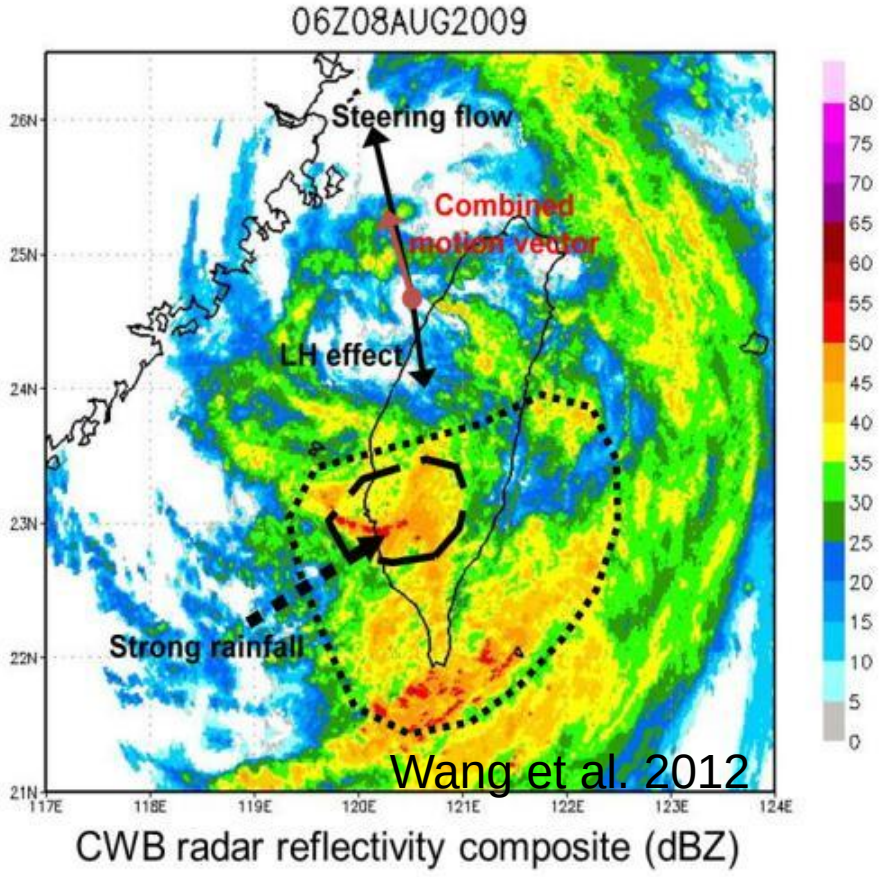



Cheung et al. (2008)

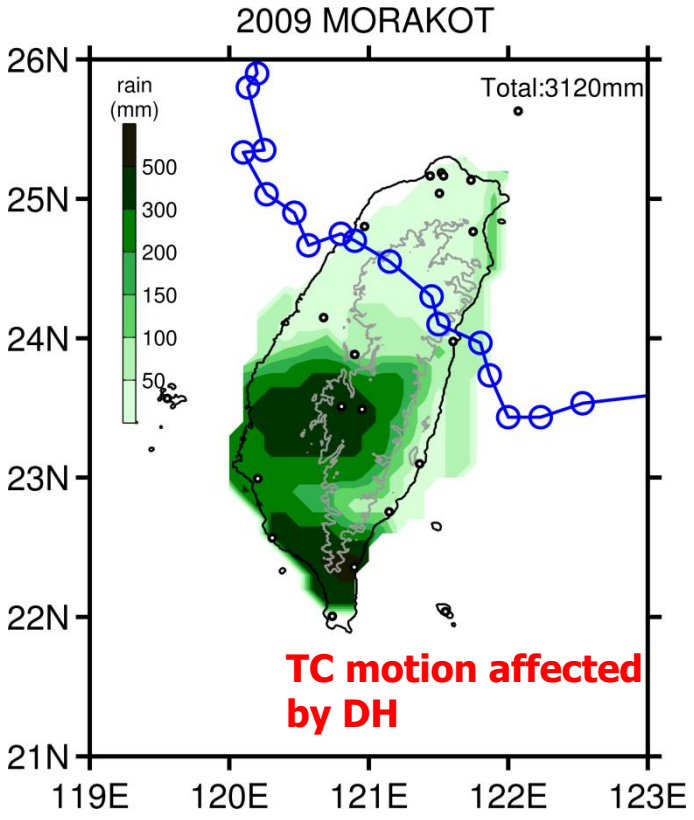
62 typhoons, 371 rain gauges

**Maximum in windward side and central mountain area**

- Topography **phase locked convection** and **diabatic heating** may affect the translation speed and modified typhoon tracks.
- **Slowdown of typhoon motion for northern landfall typhoons.**

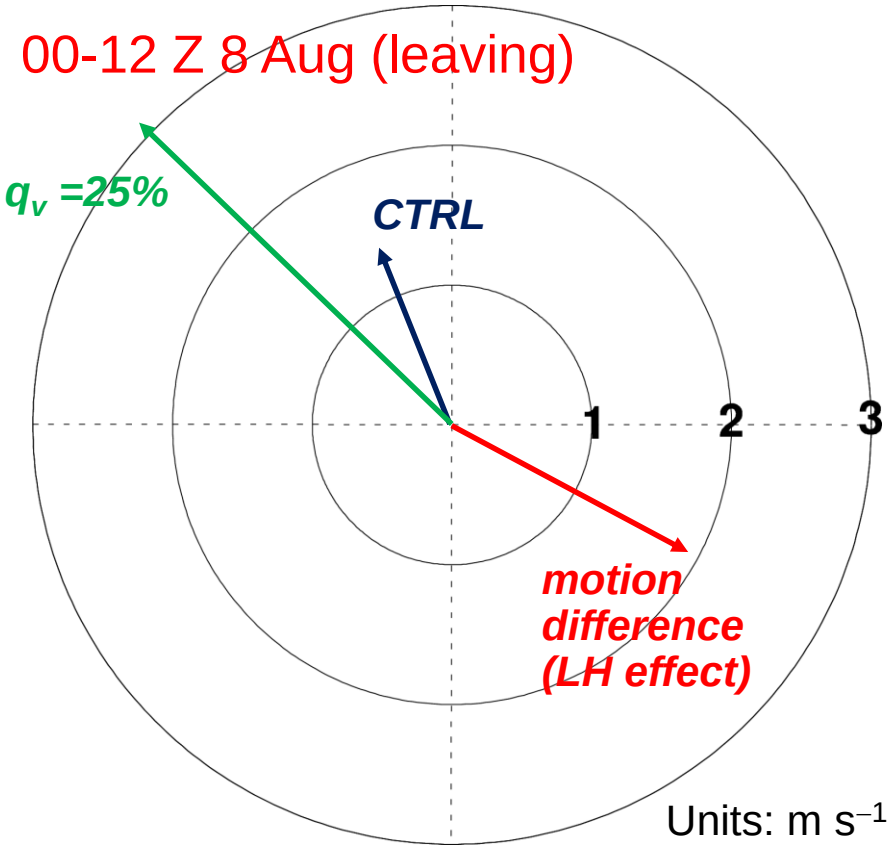



Wang et al. 2012



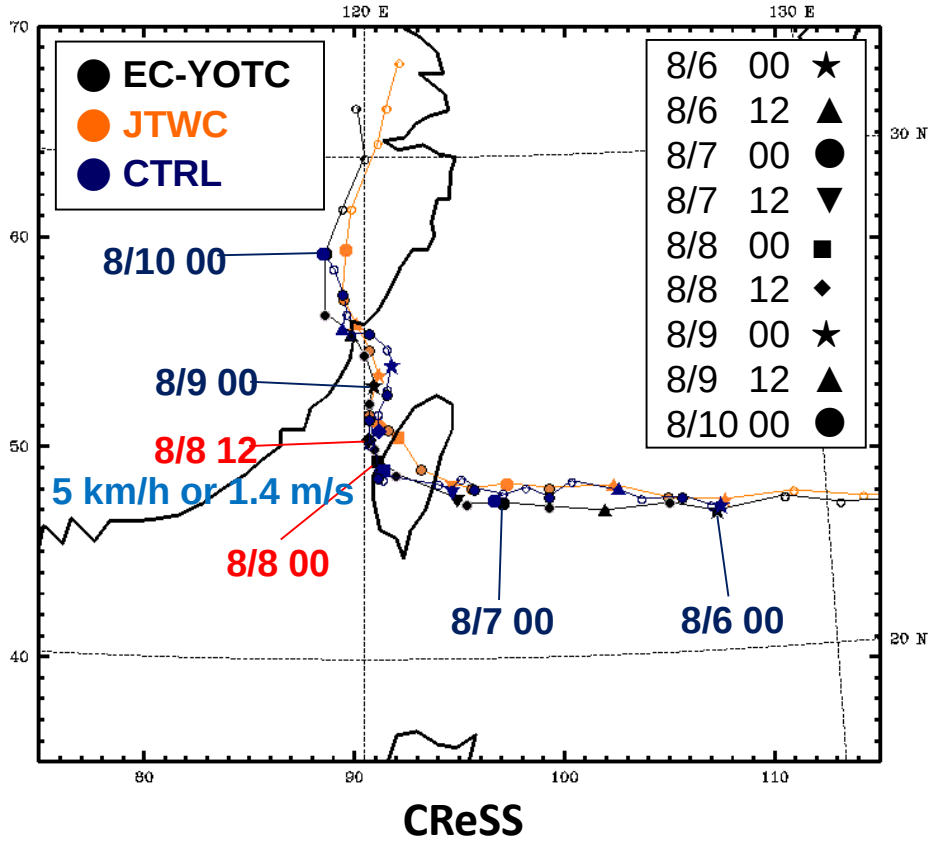
# Influence of Latent heating to storm motion of Morakot (2009)

**Difference in mean motion vectors between CTRL and 25% $q_v$ due to LH effect**




Wang et al. (2012)

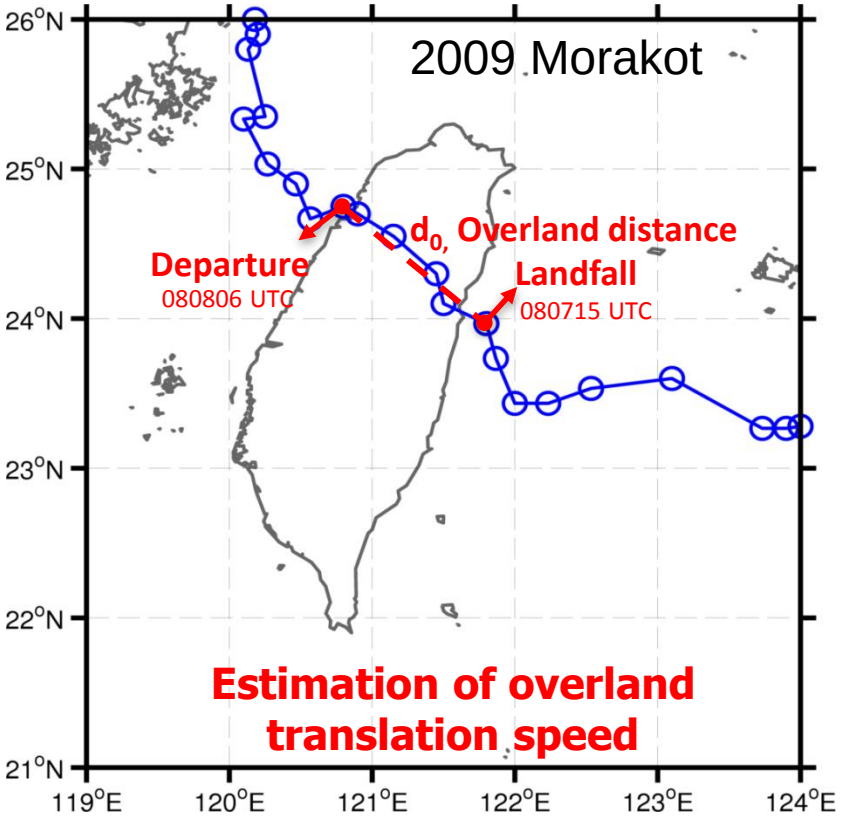
Morakot (2009) simulation

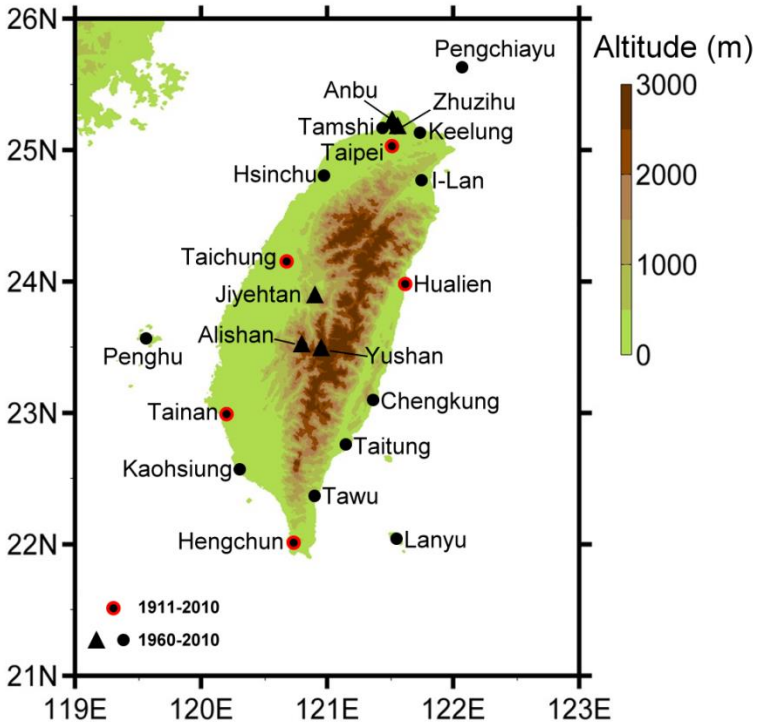



CReSS

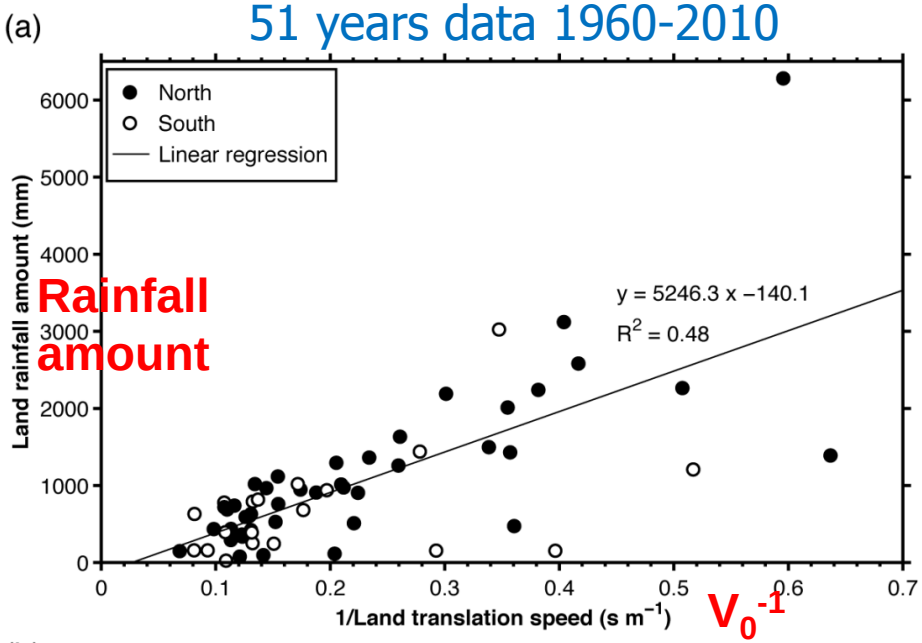
# OBSERVATION RESULTS

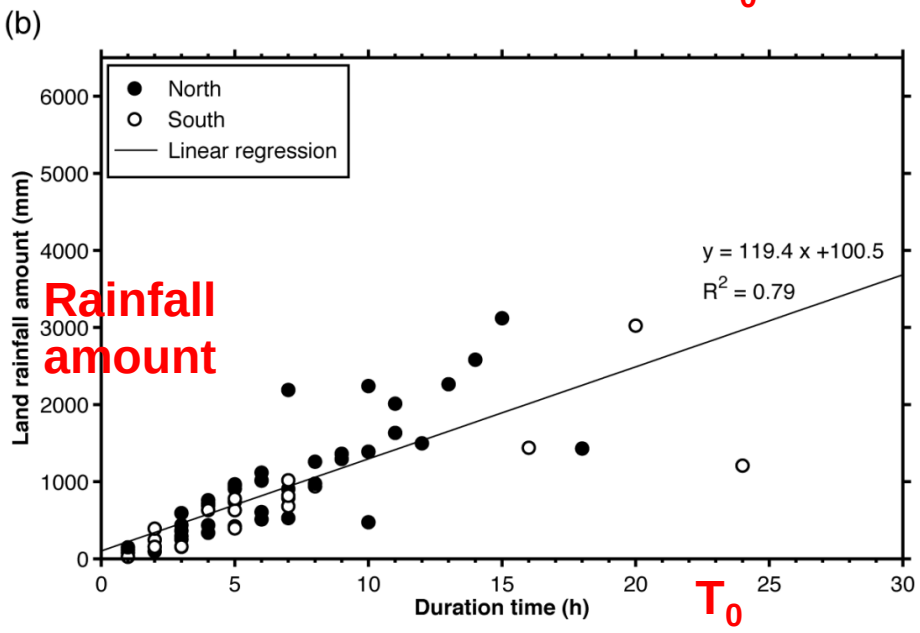
- 1960-2010 westward landfall typhoons (61) with continuous track
- Hourly typhoon position from Typhoon database of CWB
- Rainfall data from 21 CWB surface stations

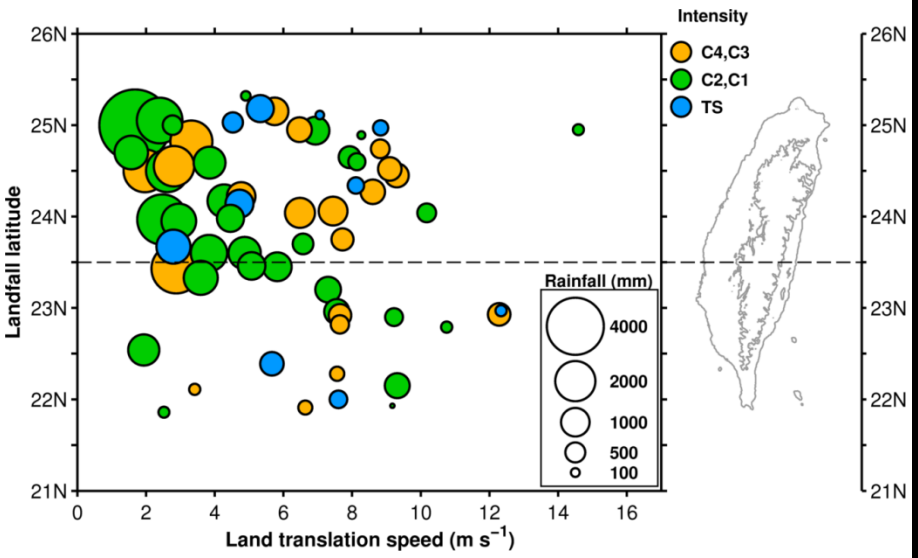


51 years data 1960-2010

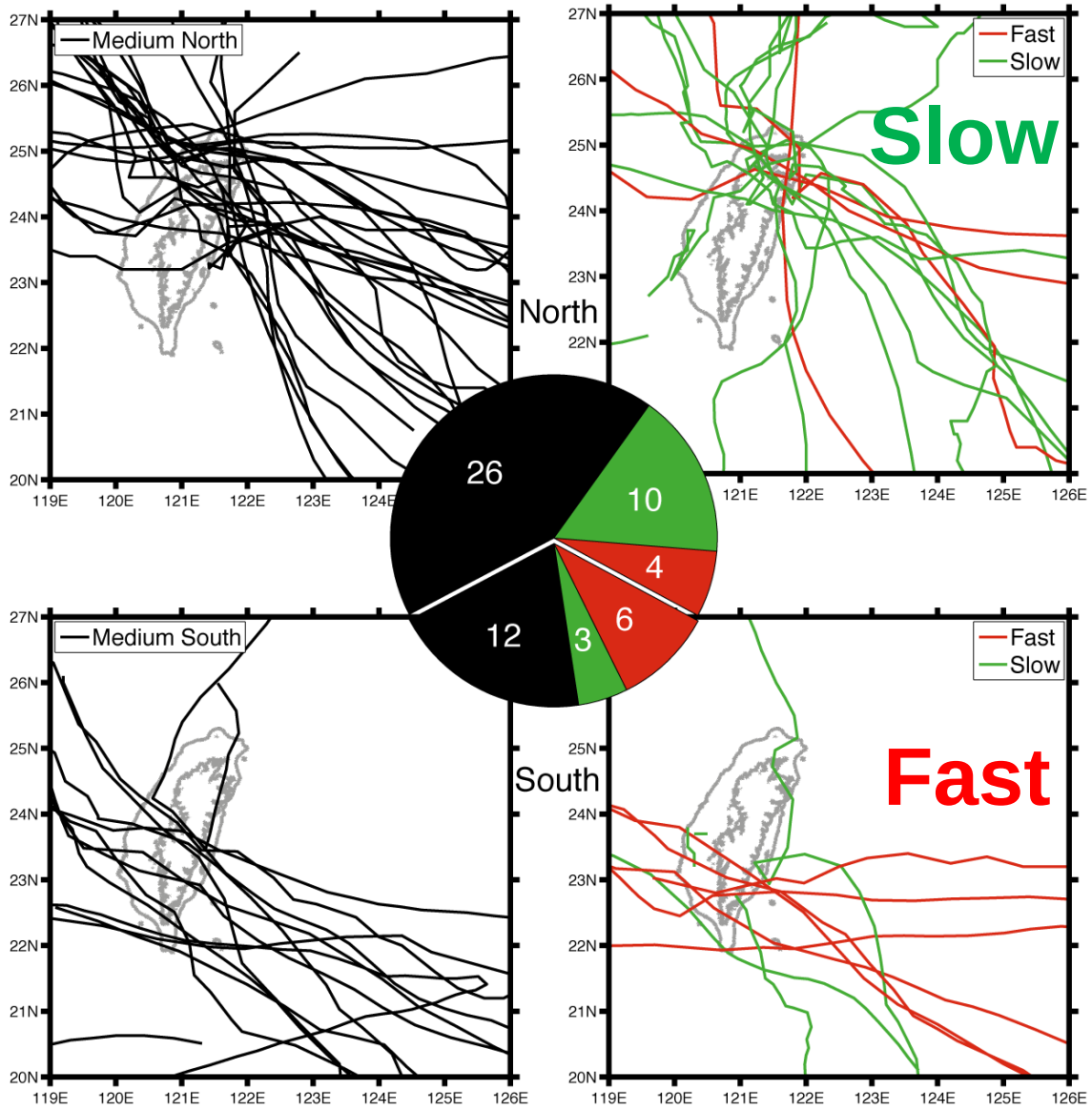



**Slow "northern landfall" typhoons are with heaviest rainfall amount**

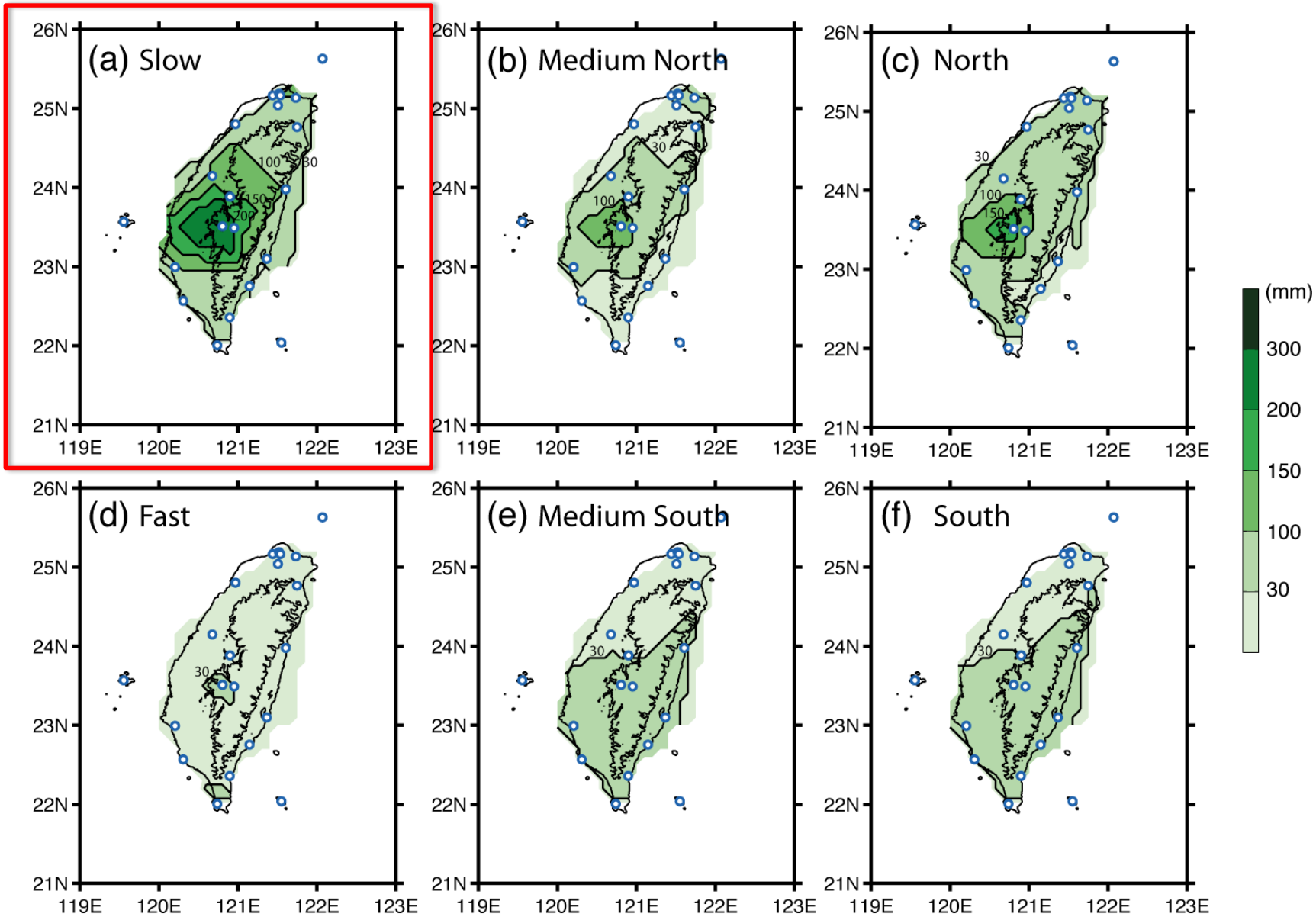
# Asymmetric distribution of typhoon translation speed overland




**Speed criteria :**
**61 continuous track typhoons** mean translation speed (6.2 m/s)± 1 std. (2.9 m/s)

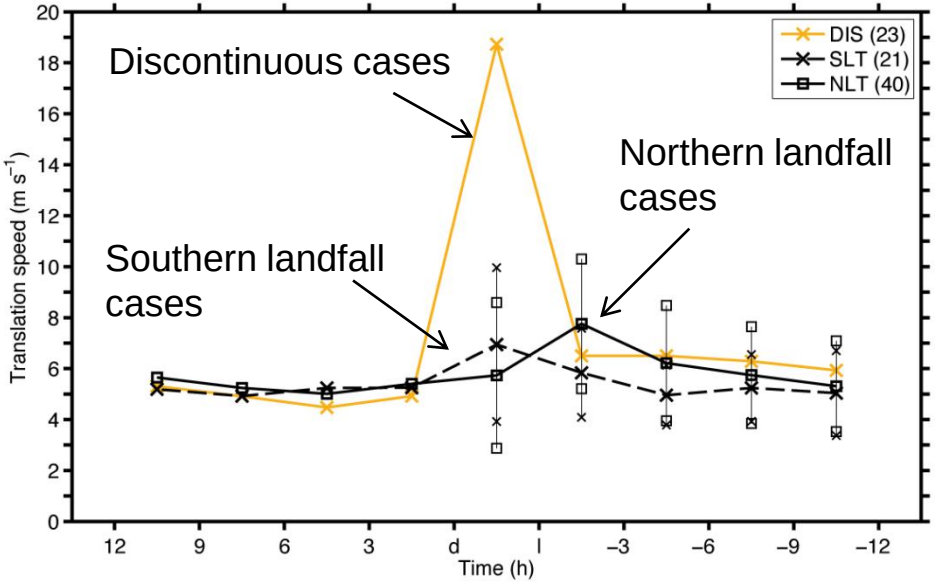
- 77 % of slow moving storms making landfall on northern Taiwan (10/13).
- 60 % of fast cases making landfall on southern Taiwan (6/10).

# Composite Rainfall

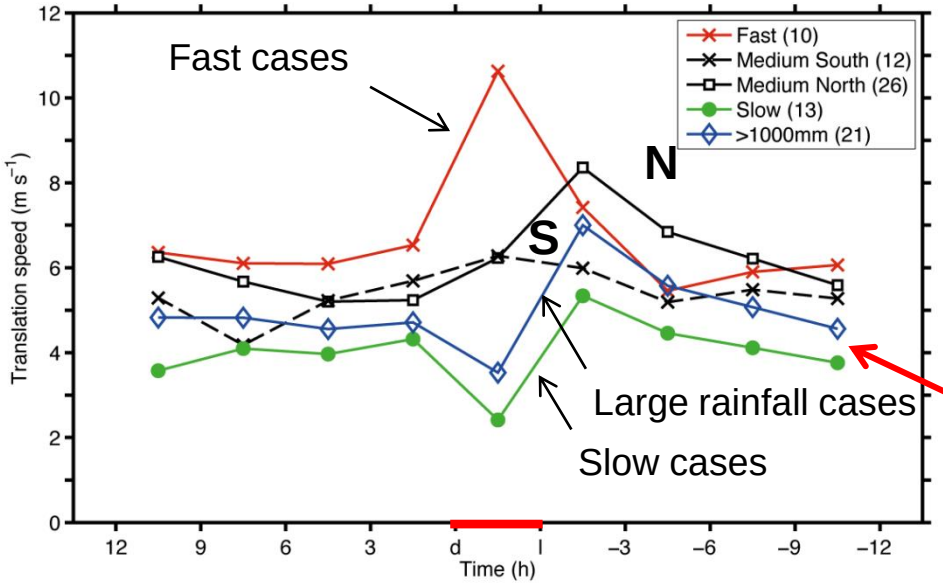


# 3-hourly mean translation speed variations

(a)




(b)



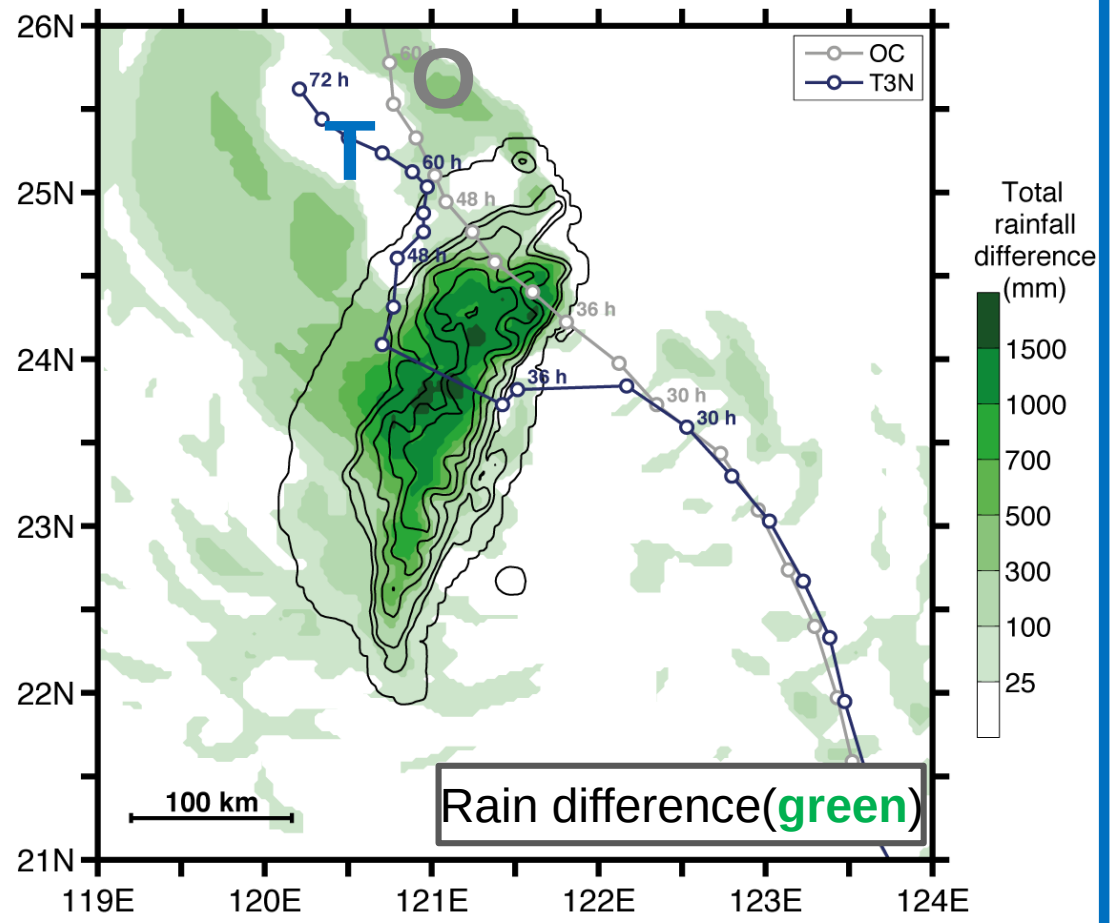

- **All subgroups speed up before landfall**
- **Speed up** after landfall
  - ✓ Discontinuous cases
  - ✓ Southern landfall cases
  - ✓ Fast cases
- **Slow down** after landfall
  - ✓ Northern landfall cases
  - ✓ Slow cases
  - ✓ Large rainfall cases

The large scale mean flow still important

# NUMERICAL EXPERIMENTS

## Modified WRF Ver. 3.1.1 experiment

(Fovell and Su, 2007; Fovell et al., 2009,2010; Cao et al., 2011)




*small part of domain*

### Experiment design :

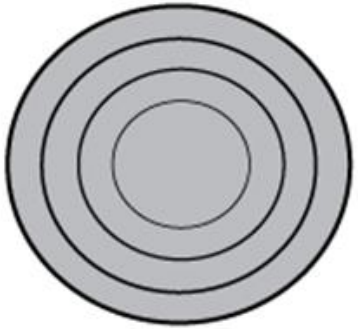
- 1500 km x 1500 km domain
- 5 km horizontal resolution, 35 vertical levels
- Uniform 3 m/s easterly flow
- Lin et al. microphysics scheme
- Jordan's (1958) Caribbean hurricane season sounding with fixed SST=29°C
- Bogused Rankine Vortex Initial vortex Vm=50 m/s Rm=50 km
- Taiwan topography (land free) water-crafted mountain

# PV tendency equation of baroclinic and diabatic TC motion

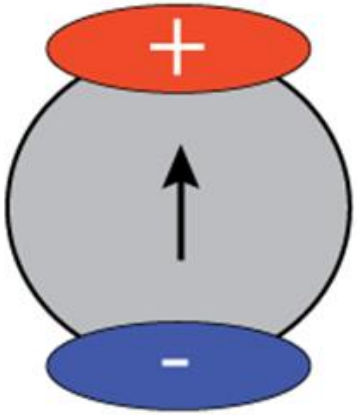
HA VA DH

PV tendency $\frac{\partial P}{\partial t} = -\mathbf{V} \cdot \nabla_h P - w\frac{\partial P}{\partial z} + \rho^{-1}\nabla_3 \cdot (Q\mathbf{q})$

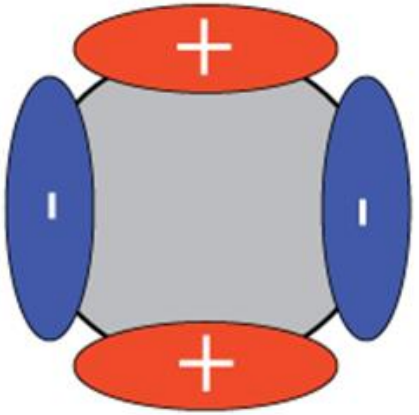
Symmetric



Wavenumber 1




Wavenumber 2




Obtained by the least squares method

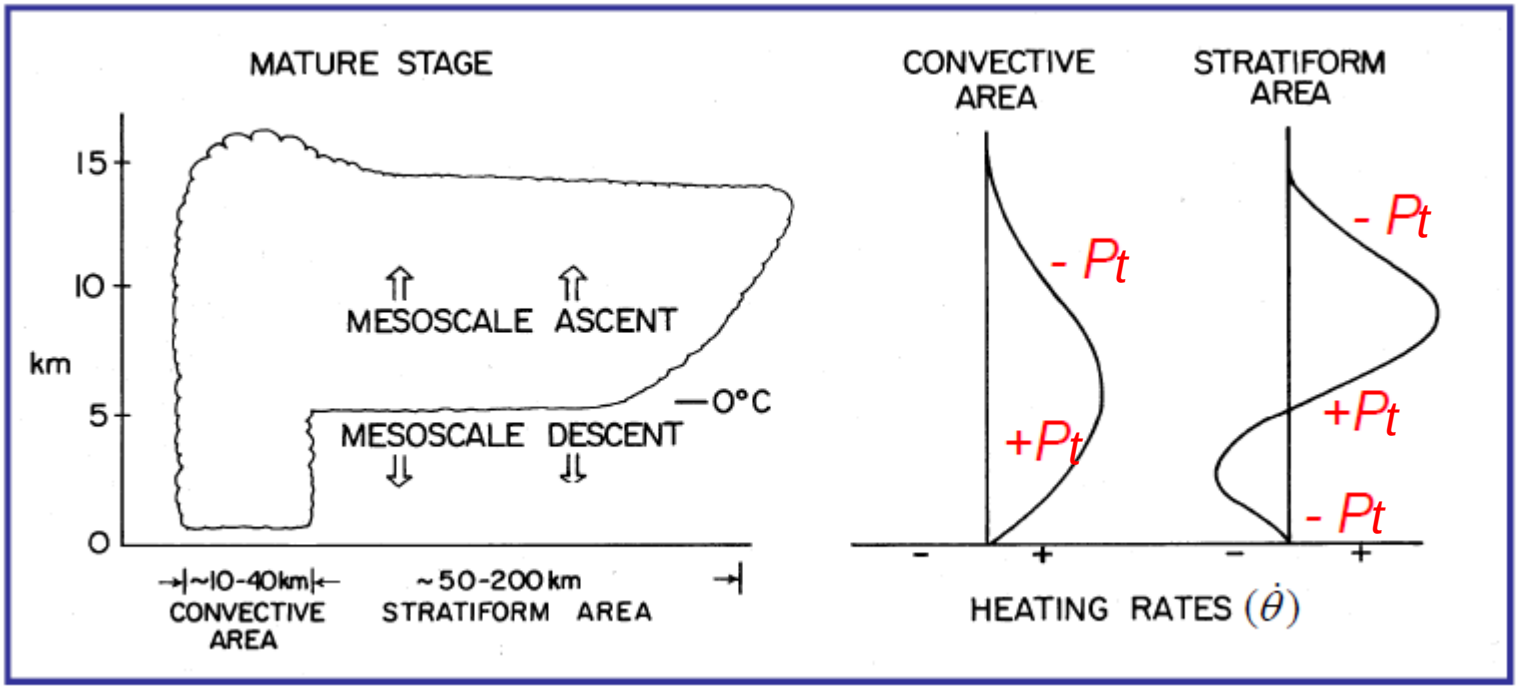
Symmetric PV advected by WN1 PV tendency

$$\left(\frac{\partial P}{\partial t}\right)_1 = -C_x\frac{\partial P_s}{\partial x} - C_y\frac{\partial P_s}{\partial y}$$

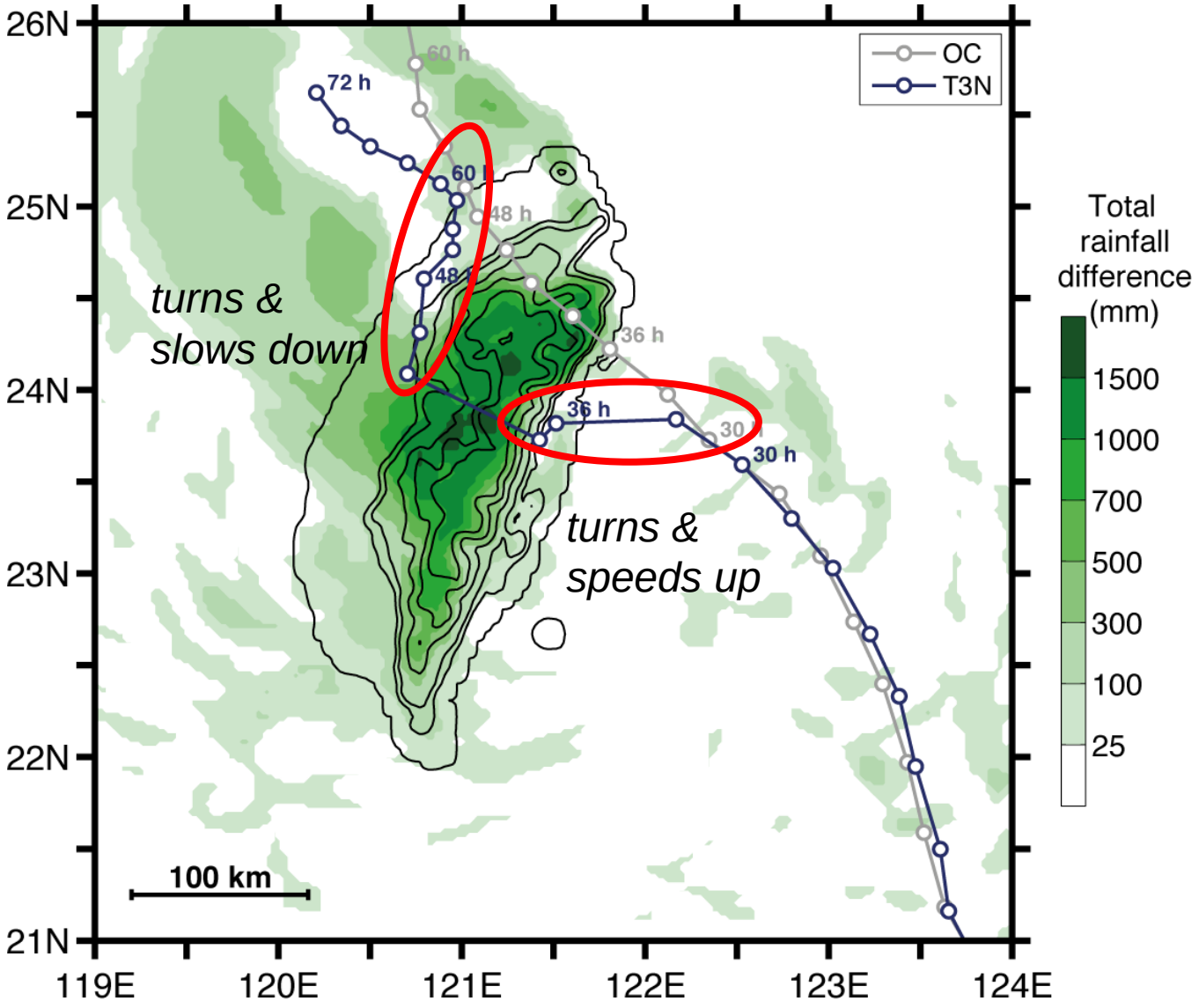
Wavenumber 1

Wu and Wang (2000), etc

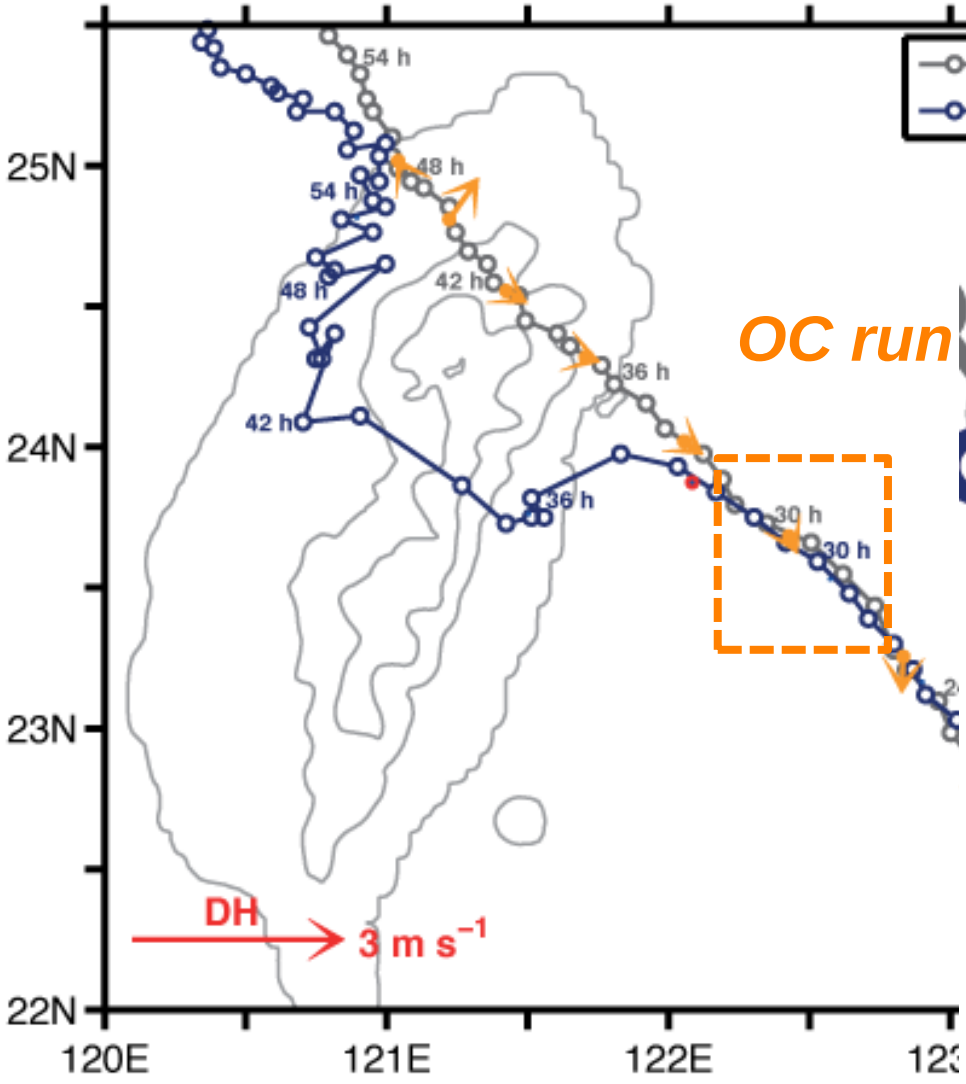
$$\mathrm{DH} = \frac{1}{\rho}\left[(\zeta + f)\frac{\partial Q}{\partial z} + (\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x})\frac{\partial Q}{\partial y} + (\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z})\frac{\partial Q}{\partial x}\right]$$




- **DH ($\propto \partial Q/\partial z$) is not necessarily positive where $Q$ is positive, because we consider the WN1 component.**
- **The level or vertical averaging depth makes a big difference.**

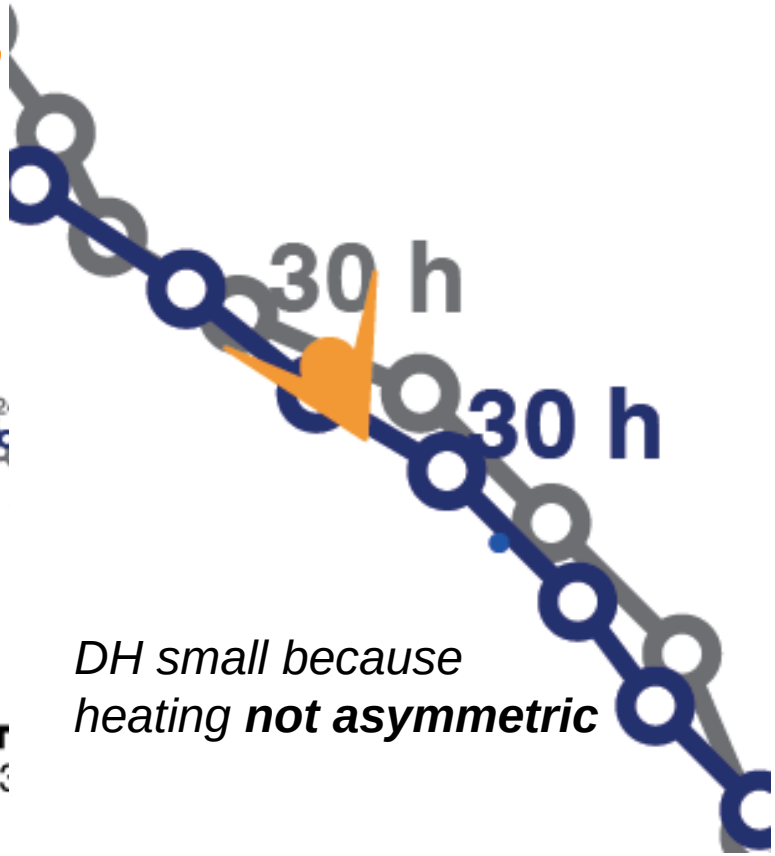

26N
25N
24N
23N
22N
21N
119E
120E
121E
122E
123E
124E
OC
T3N
72 h
60 h
48 h
36 h
30 h
turns &
slows down
turns &
speeds up
100 km
Total
rainfall
difference
(mm)
1500
1000
700
500
300
100
25

# PV tendency analysis on TC motion - DH component along track



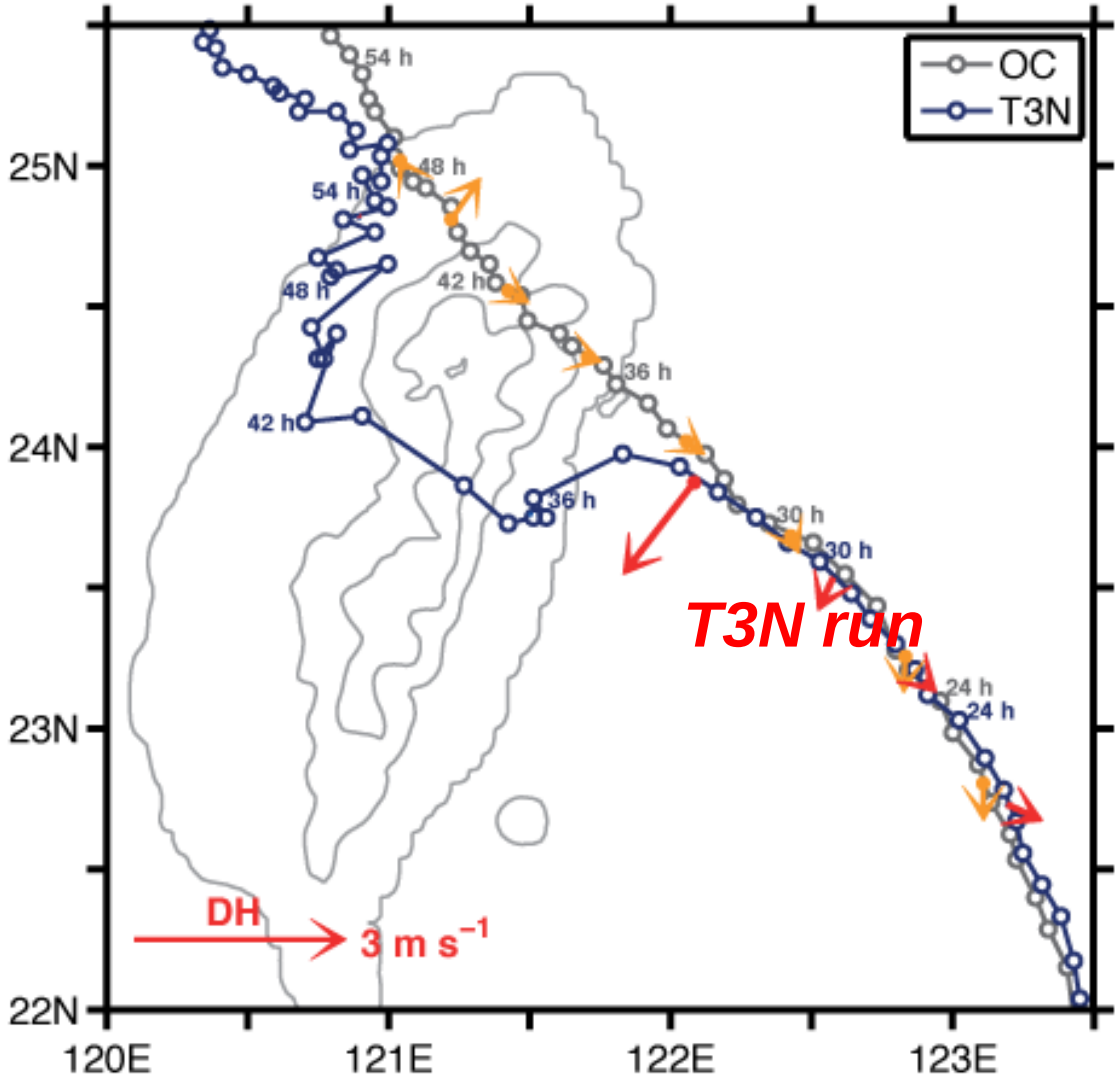

**PV DH term averaged over 3 h and z=1-11 km**

***OC run***



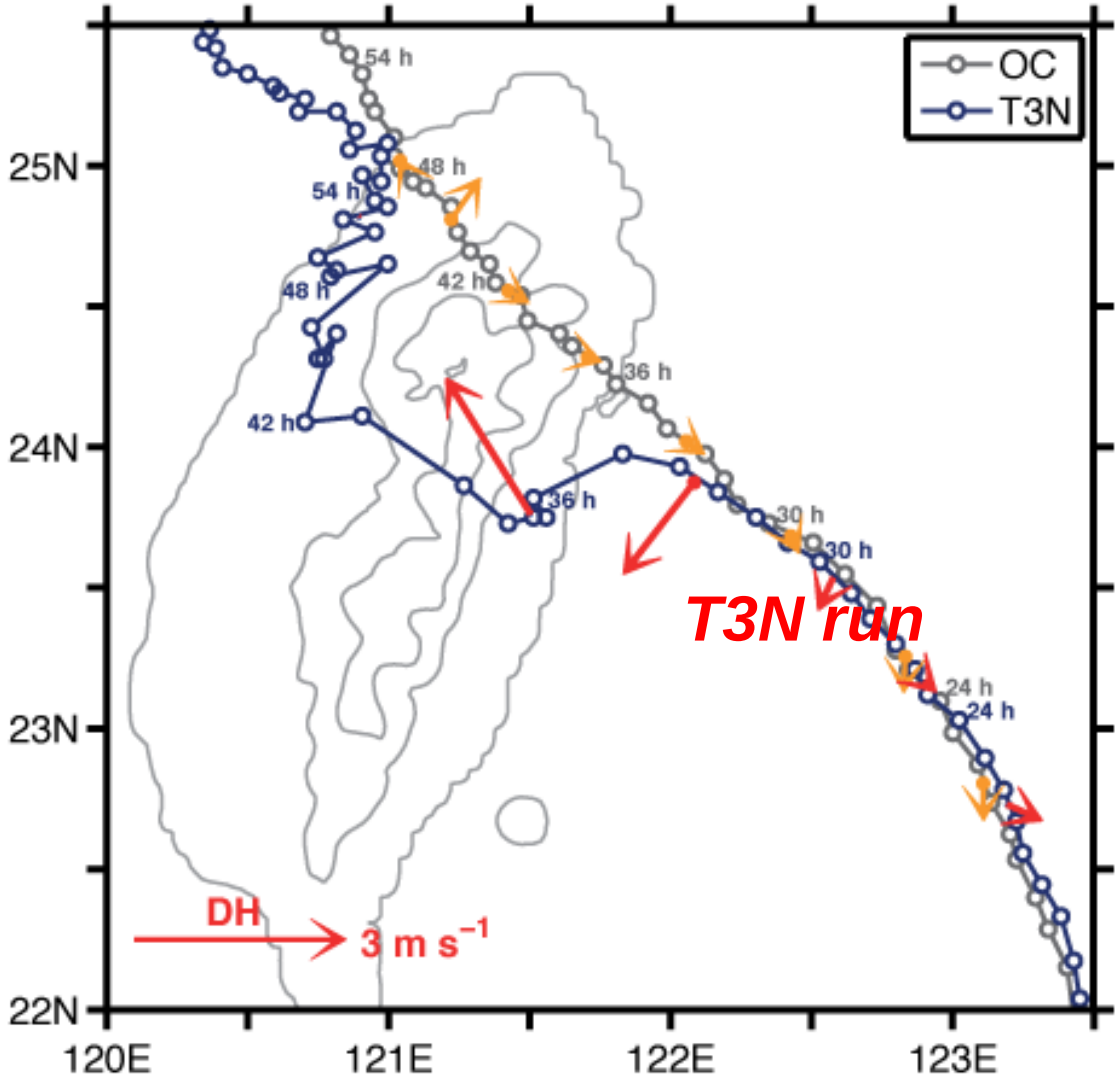

*DH small because heating **not asymmetric***

# PV tendency analysis on TC motion - DH component along track



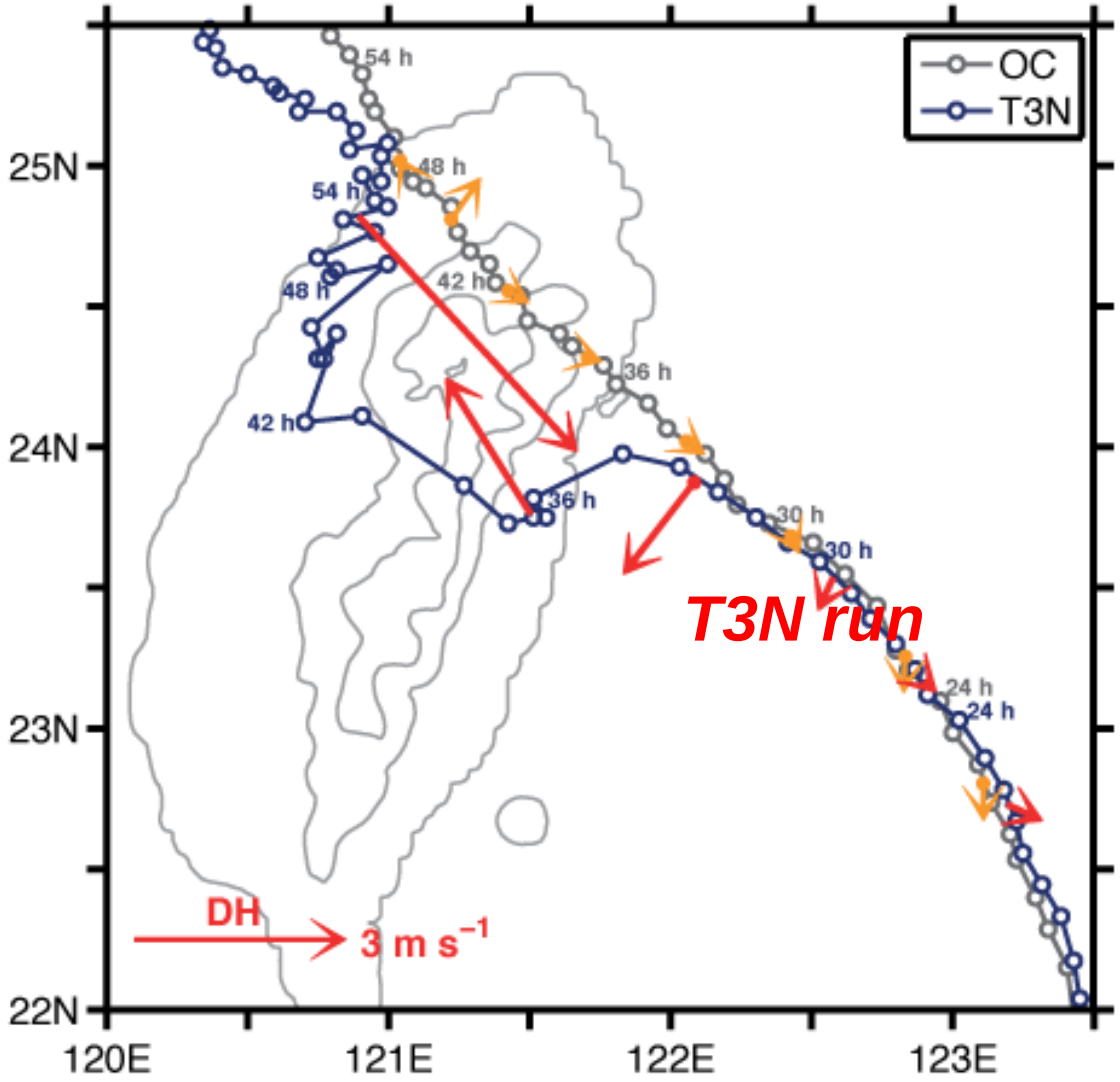

**PV DH term averaged over z=1-11 km**

# PV tendency analysis on TC motion - DH component along track



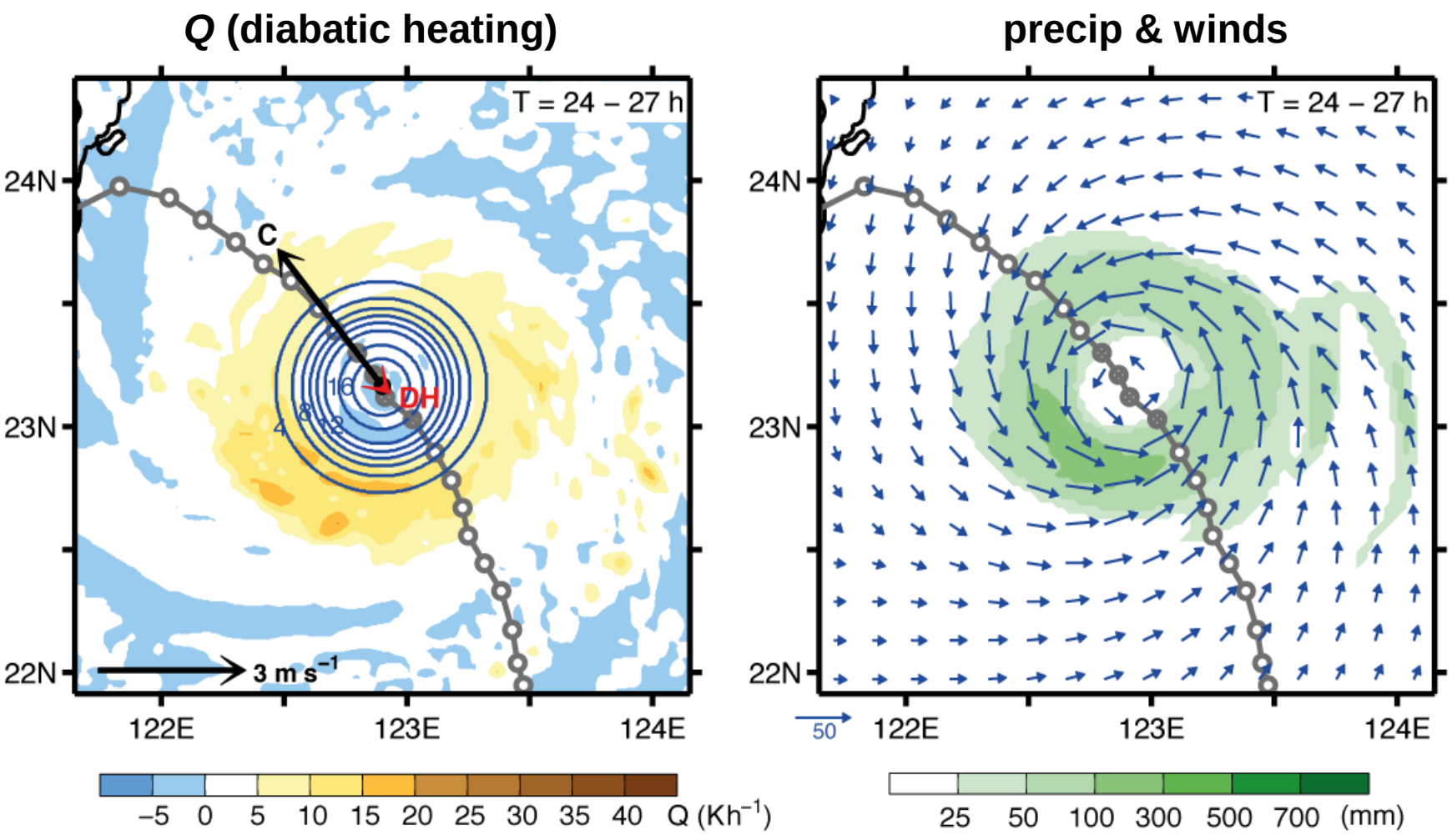

**PV DH term averaged over z=1-11 km**

# PV tendency analysis on TC motion - DH component along track



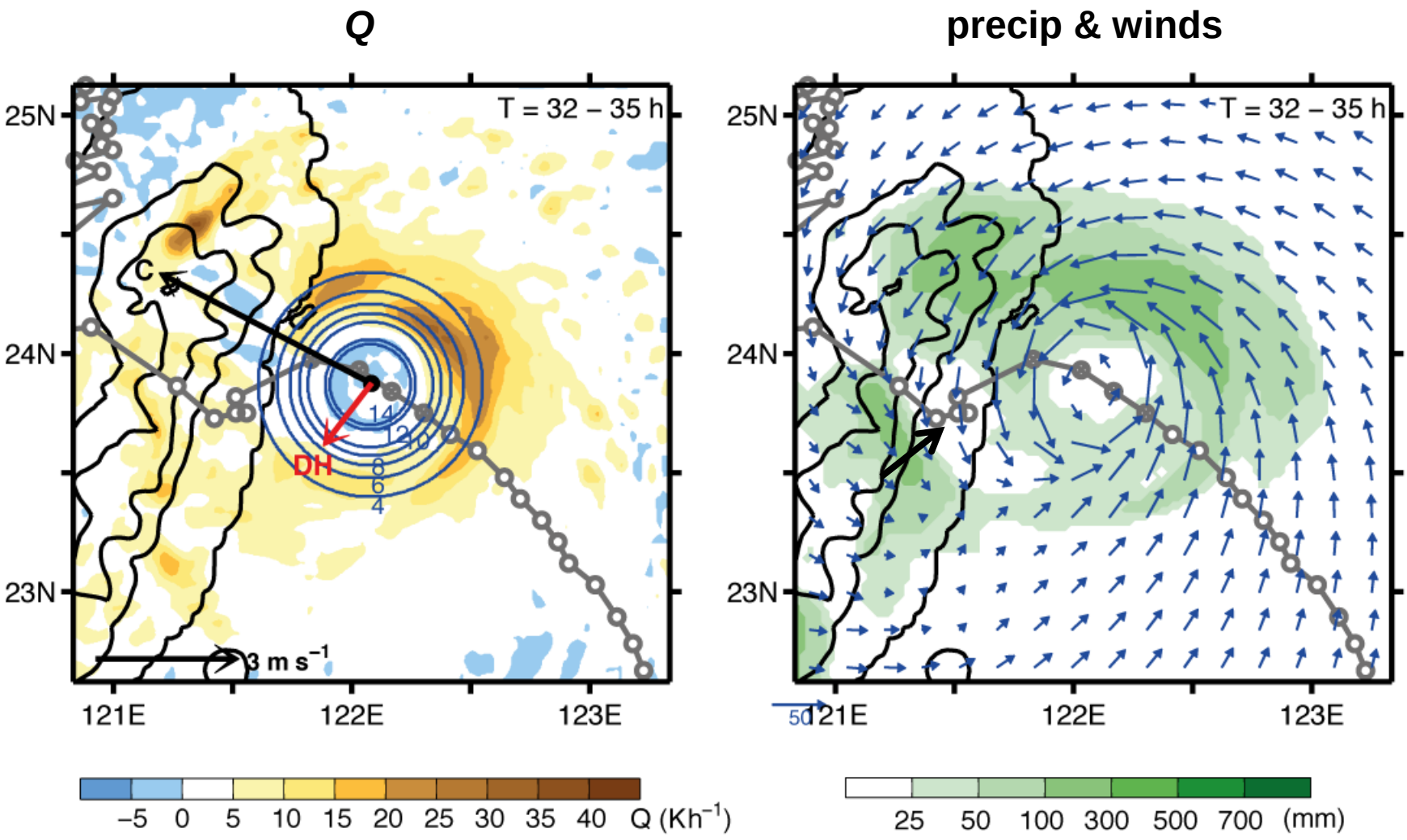

**PV DH term averaged over z=1-11 km**

# T3N FAR OFFSHORE



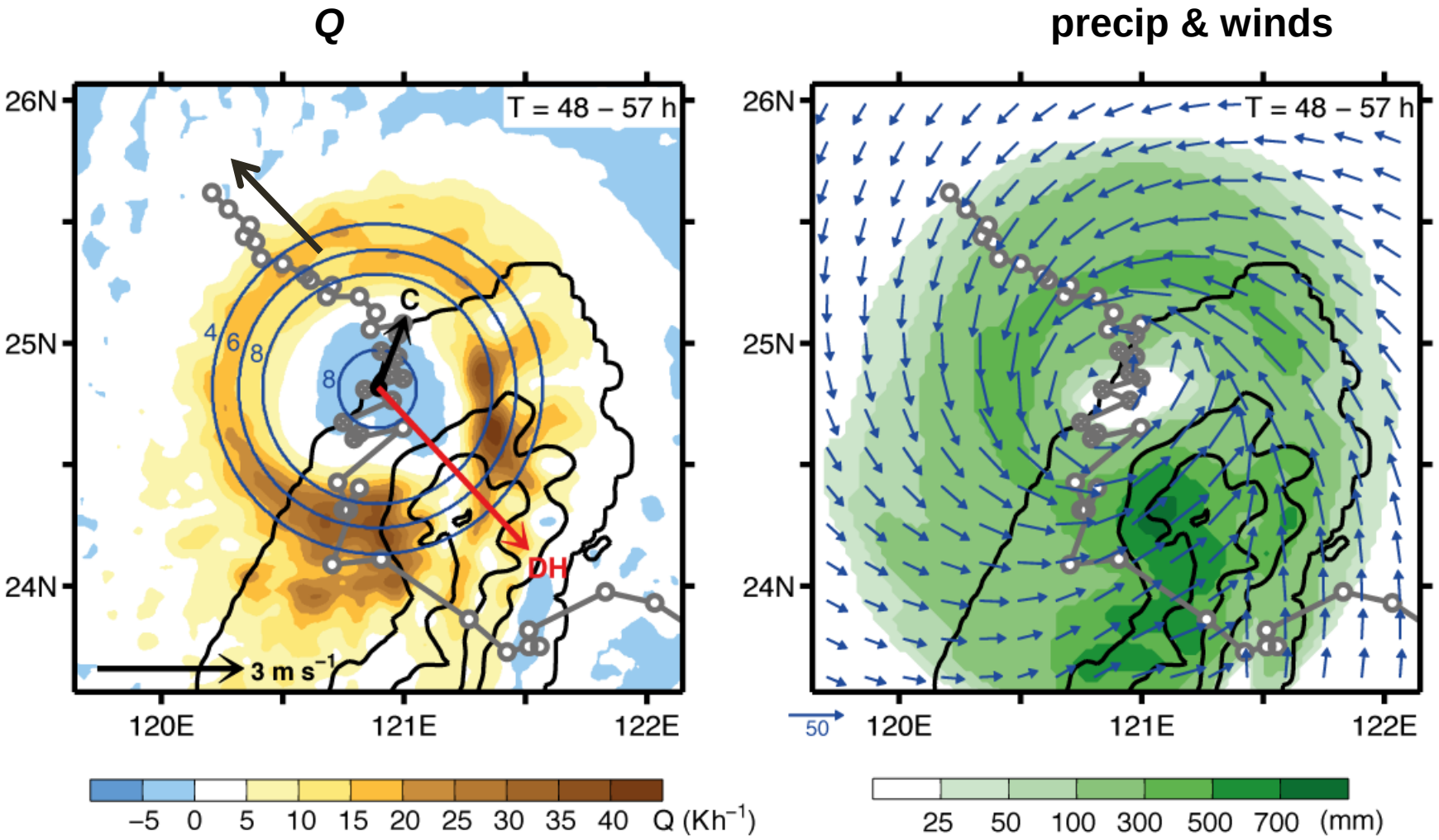

*Q* is quite symmetric, therefore DH is small.
Similar with OC

# T3N APPROACH TO LANDFALL



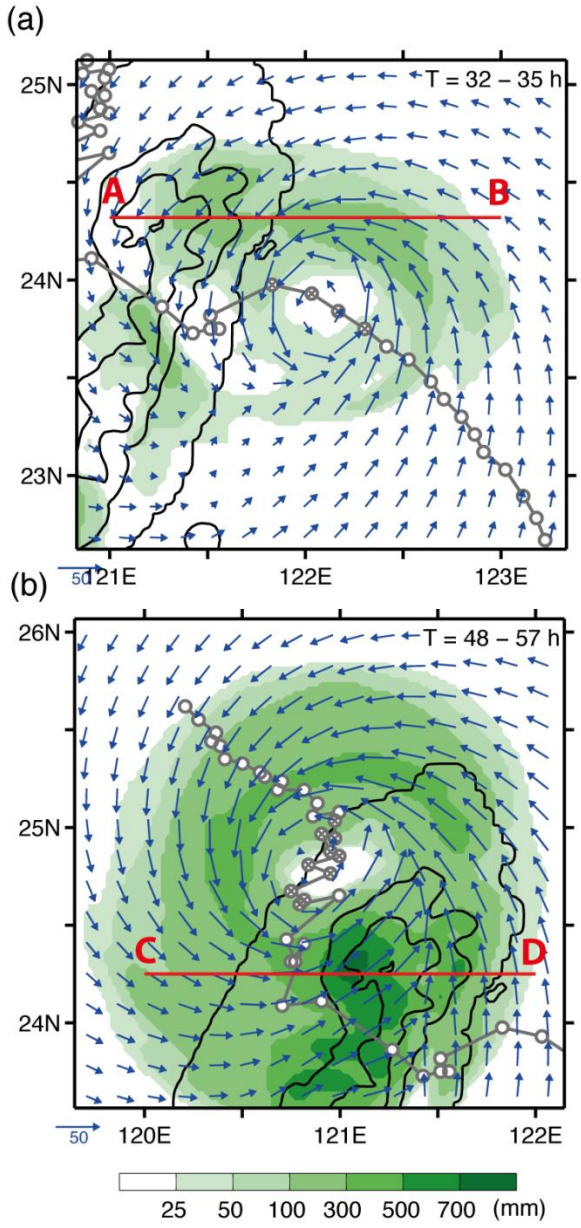

Note DH points *away* from *Q* and subsidence in SW quadrant

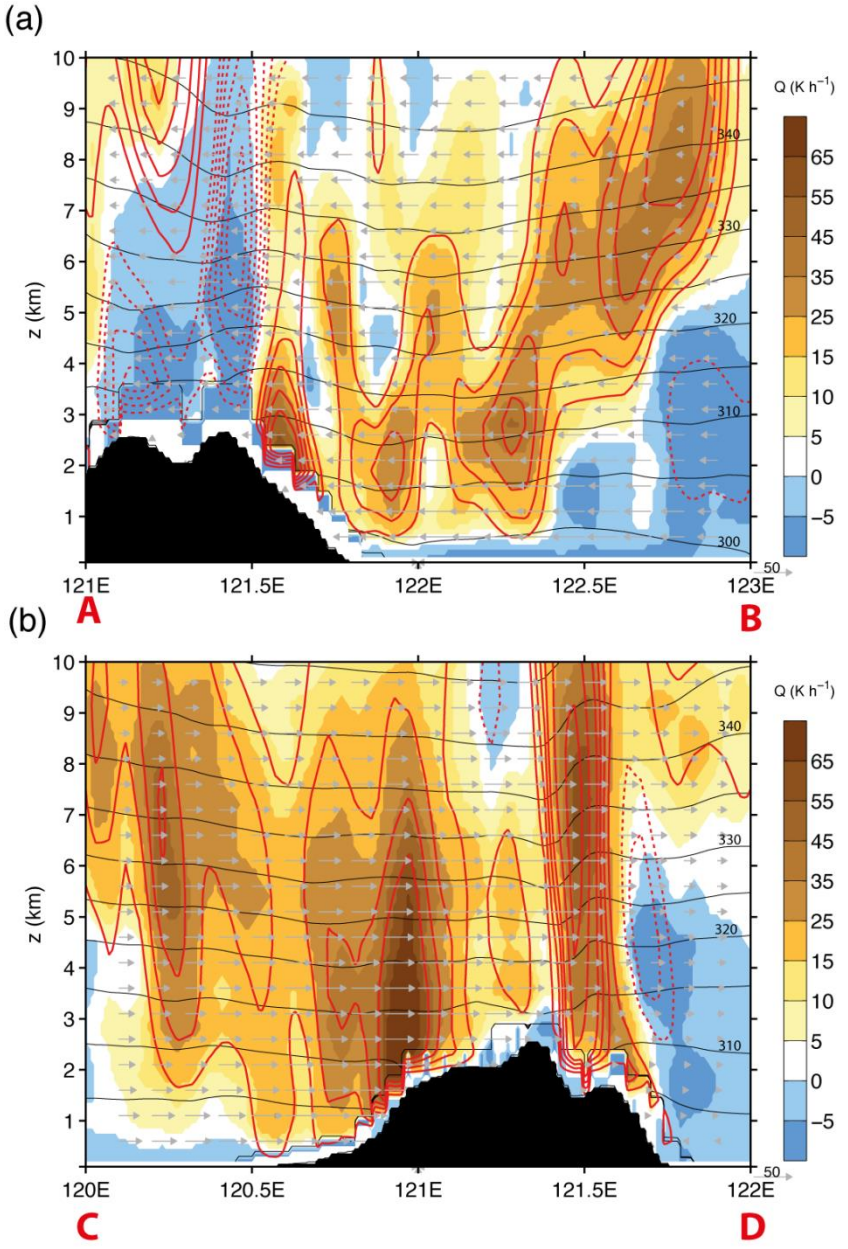
# T3N AFTER MOUNTAIN CROSSING



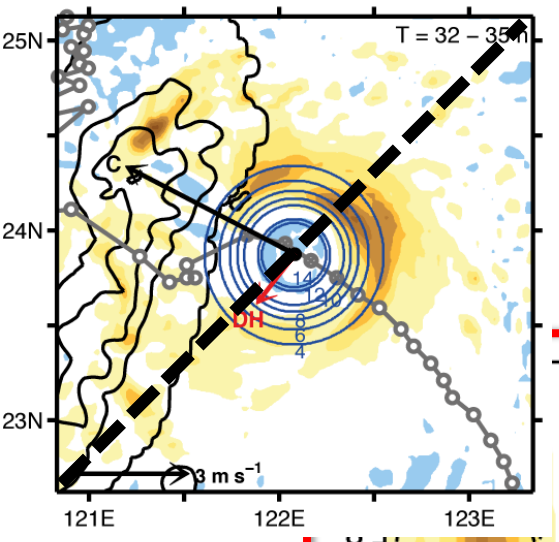

Very slow progress along W coast when DH strongly *opposes* motion;
Storm weakened but also expanded significantly

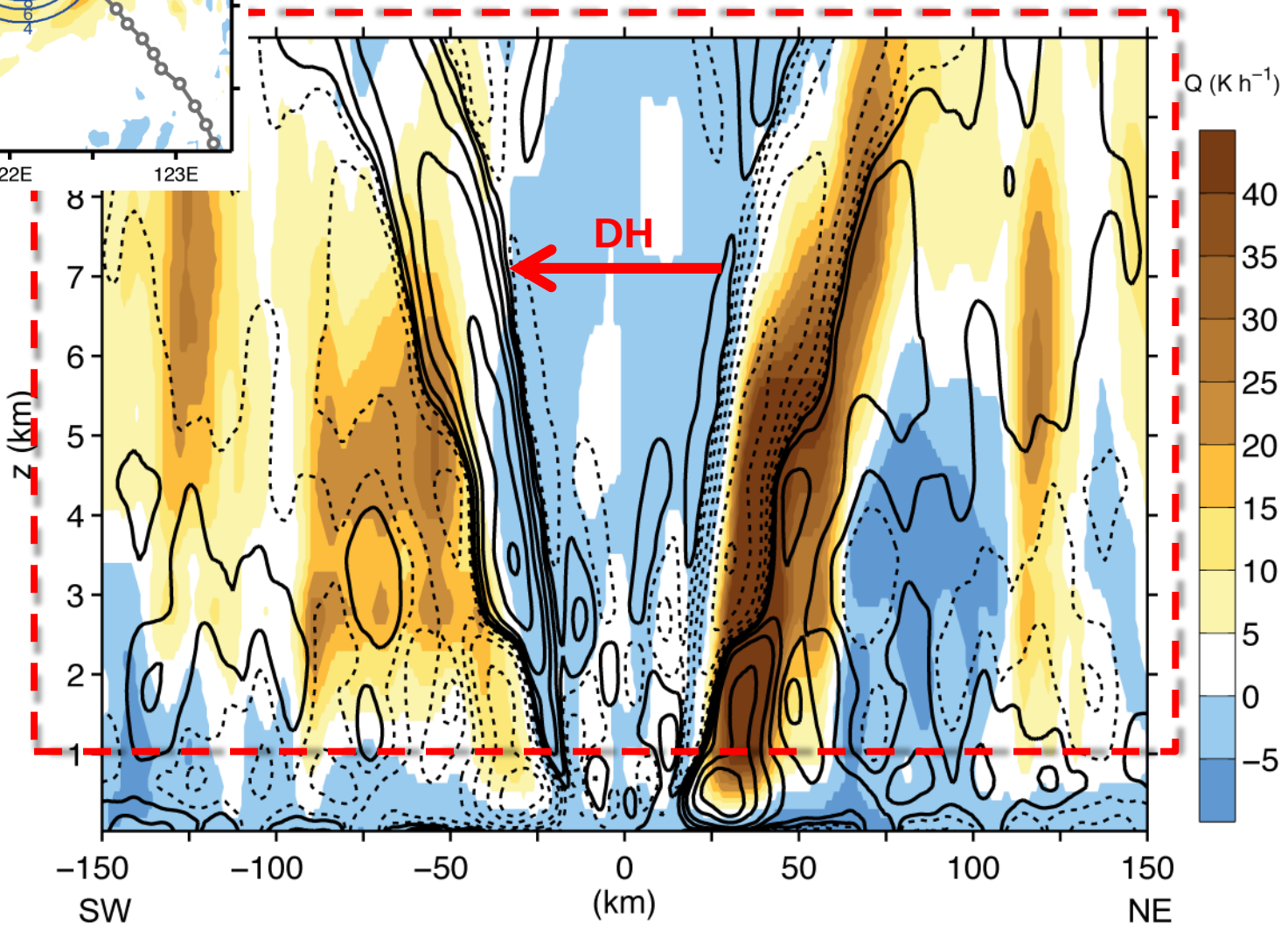
# Vertical cross-section of *Q* and vertical velocity



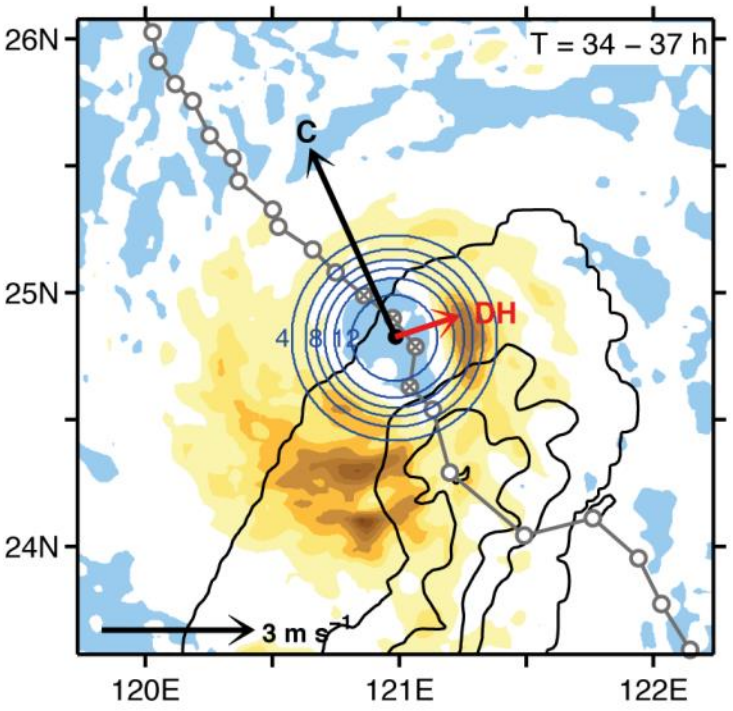
# Vertical cross-section of *Q* …and DH

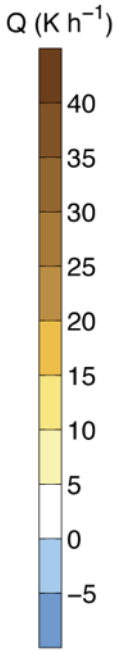


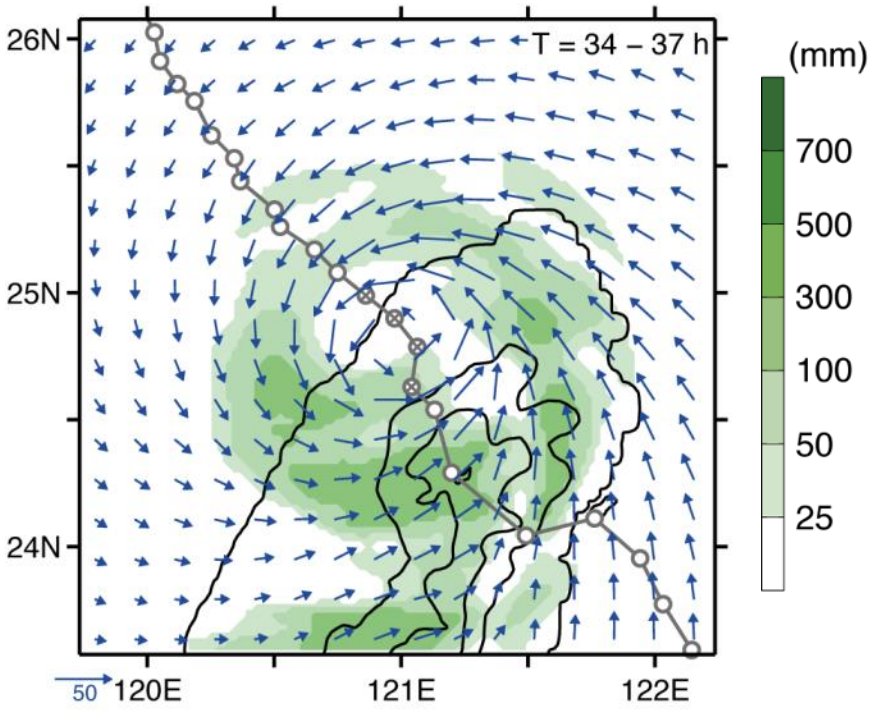
# Fast Northern landfall Experiment (-5 m/s)

***Q***



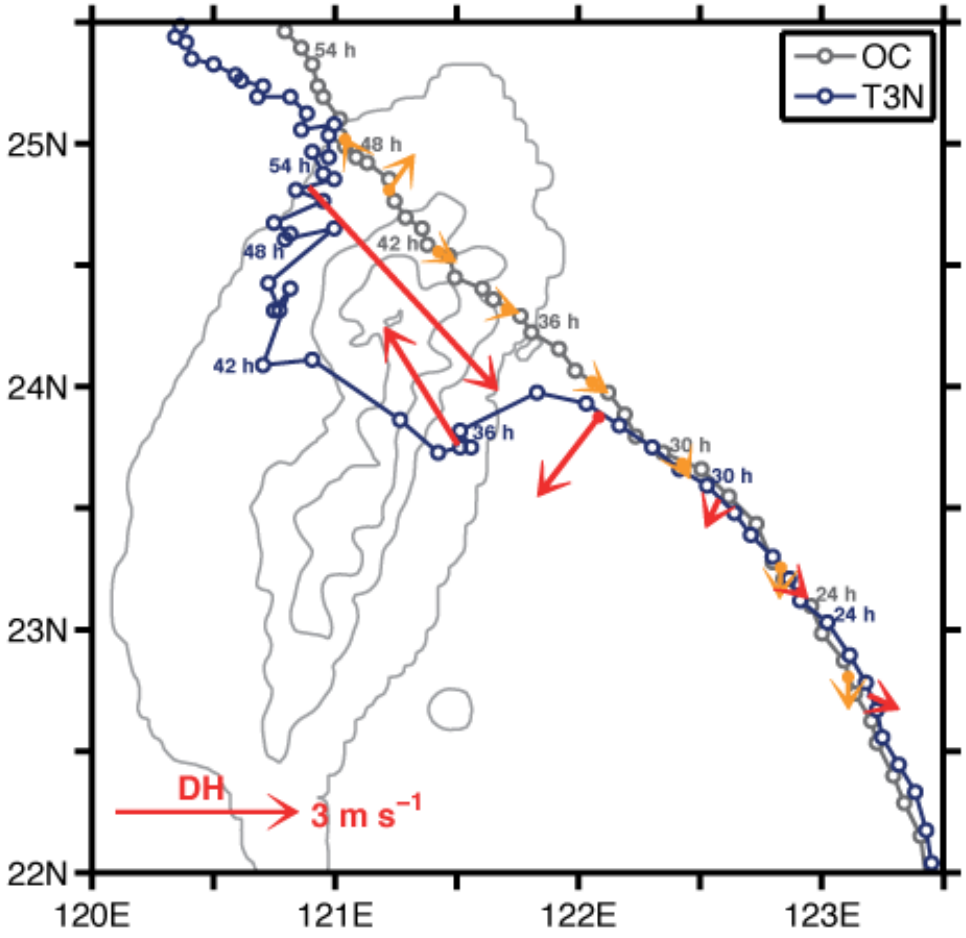

**precip & winds**



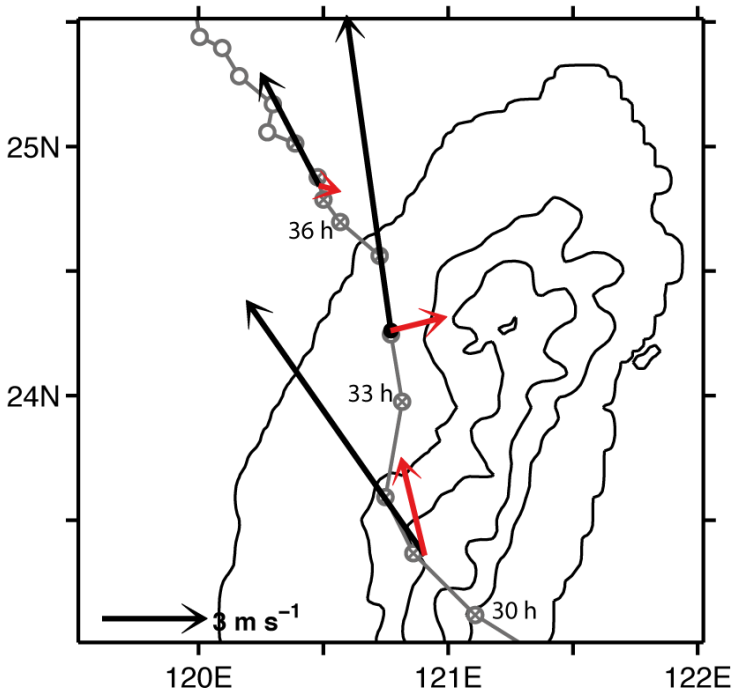

**C= 4.0 m/s**

**DH=1.4 m/s**

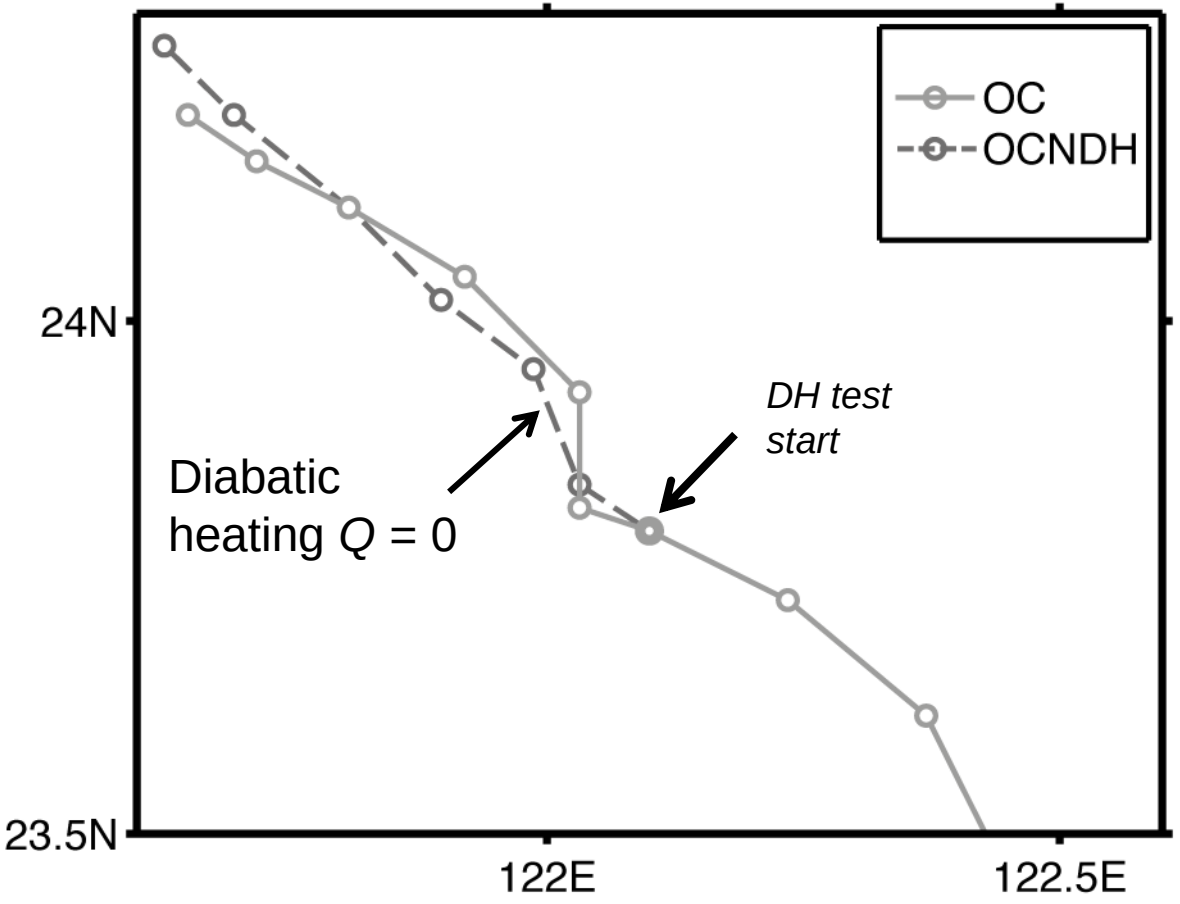
# NORTHERN VS. SOUTHERN LANDFALL



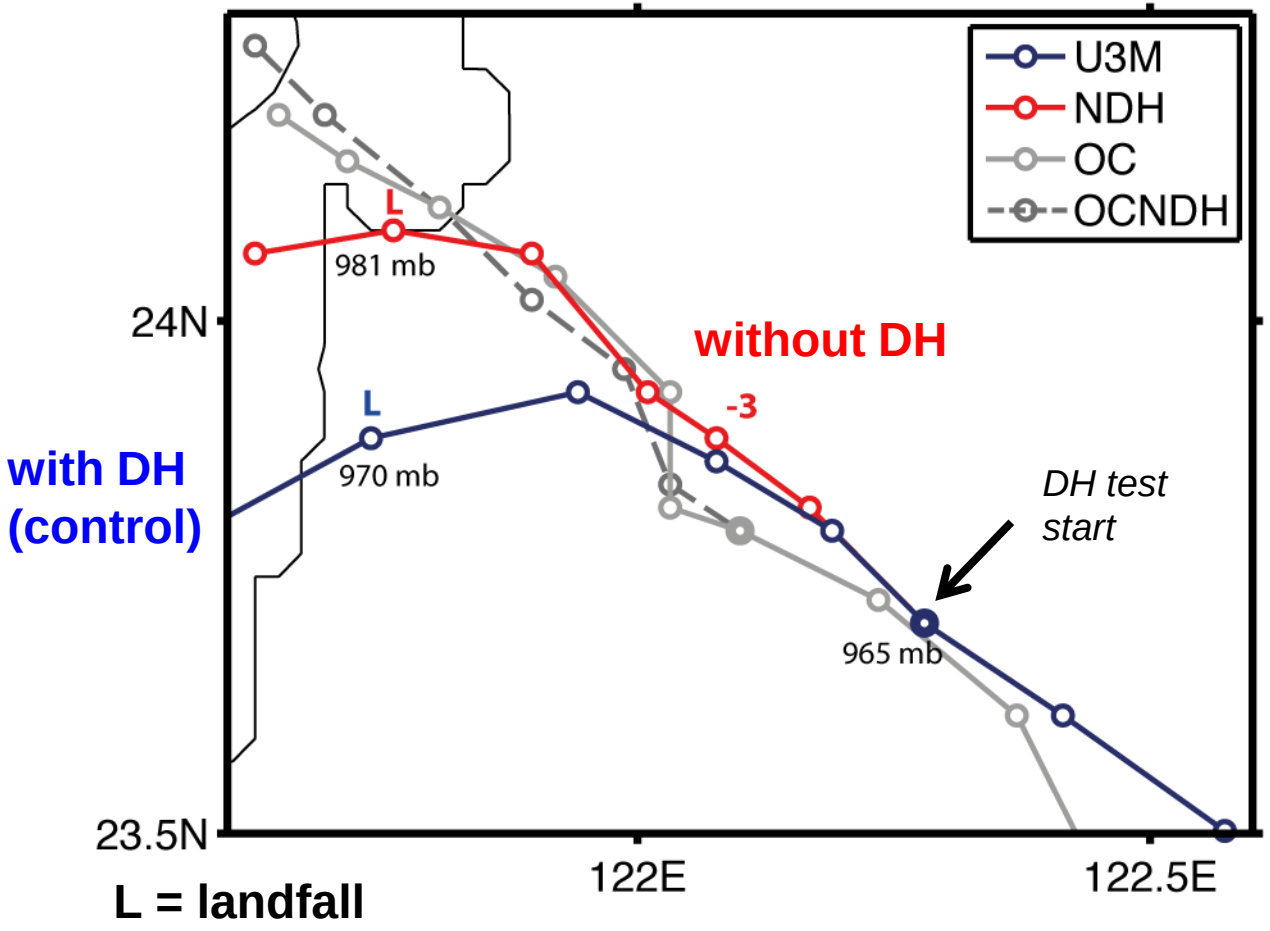

***DH speeds up southern landfall typhoon… while over land***



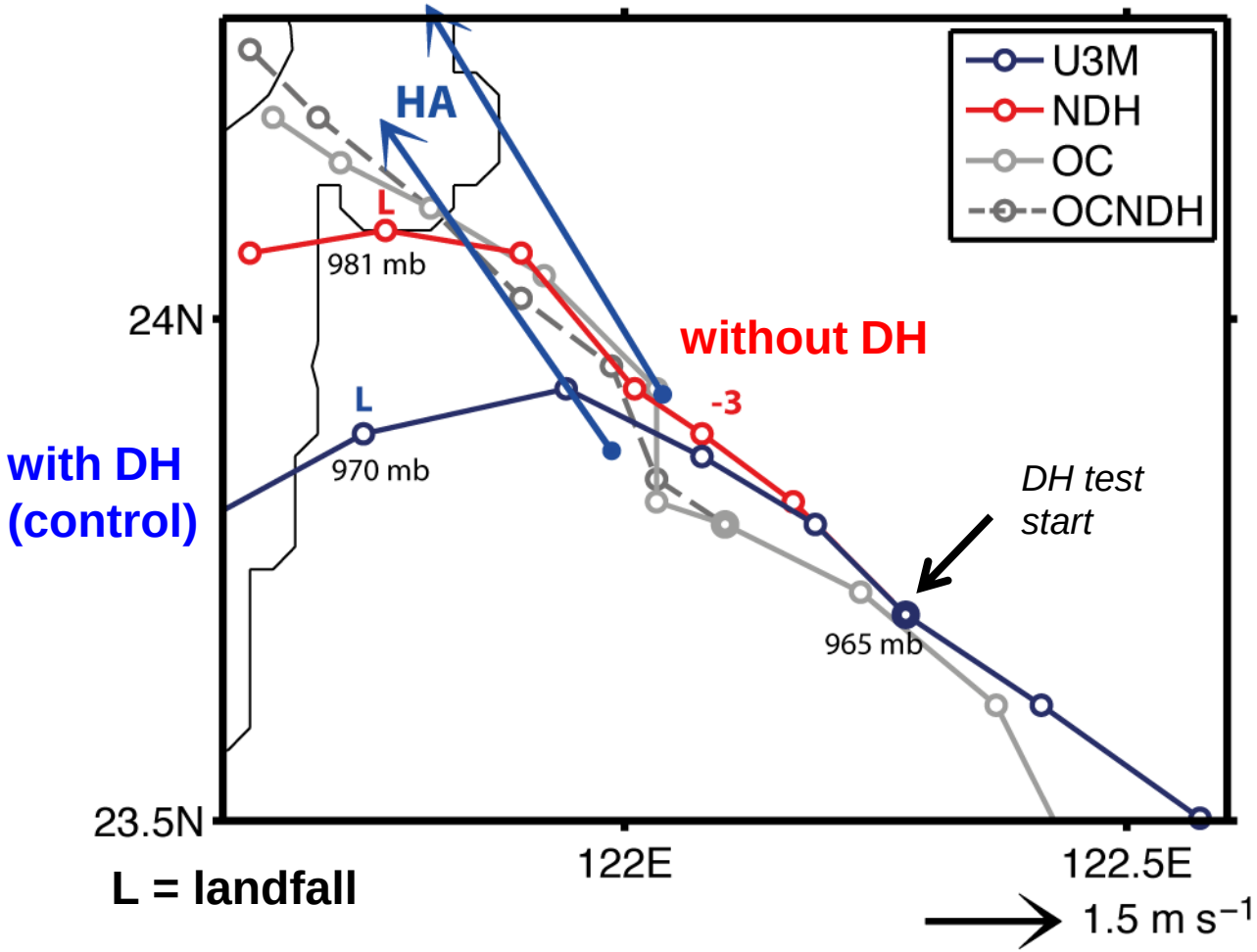
# DIABATIC VS. PHYSICAL FORCING



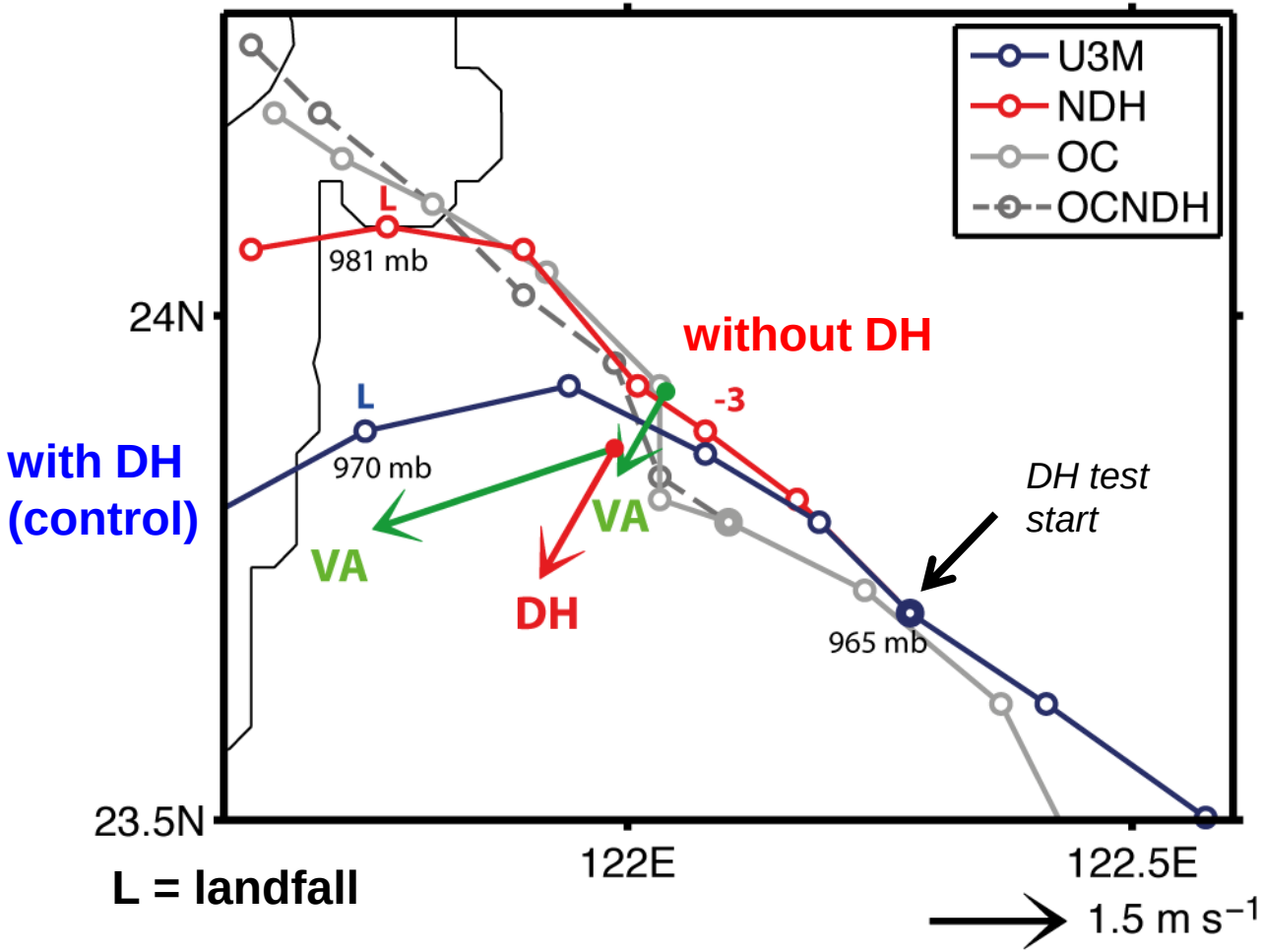
# DIABATIC VS. PHYSICAL FORCING



# DIABATIC VS. PHYSICAL FORCING



# DIABATIC VS. PHYSICAL FORCING



# Summary

- **Rainfall is phase-locked with topography in Taiwan. Slow storms with very large rainfall.**

- **77% (60%) of slow (fast) typhoons making landfall at northern (southern) Taiwan. The slow (fast) cases often with a slower (faster) pre-landfall speed and decelerate (accelerate) further during the landfall period.**

- **A positive feedback of rainfall and typhoon overland translation speed.**

- **Topography induced asymmetric diabatic forcing influences TC motion significantly when the mean flow is weak.**
  - ✧Slow down northwestward TC motion after mountain crossing
  - ✧Speed up and turns the TC to south when approach to landfall

REFERENCE
Hsu, L.-H., H.-C. Kuo, and R. G. Fovell, 2013: On the geographic asymmetry of typhoon translation speed across the mountainous island of Taiwan. *J. Atmos. Sci.*, **70**,1006-1022.

# ~END~
# THANKS FOR YOUR ATTENTION !