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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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

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.**
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

$00-12 \text{ Z 8 Aug (leaving)}$

$q_v = 25\%$

Wang et al. (2012)
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

Estimation of overland translation speed
51 years data 1960-2010

(a) Rainfall amount

\[ y = 5246.3 \times -140.1 \]
\[ R^2 = 0.48 \]

(b) Rainfall amount

\[ y = 119.4 \times +100.5 \]
\[ R^2 = 0.79 \]

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

(a) Slow

(b) Medium North

(c) North

(d) Fast

(e) Medium South

(f) South

(mm)
3-hourly mean translation speed variations

- All subgroups speed up before landfall
  - Discontinuous cases
  - Southern landfall cases
  - Fast cases

- 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)

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 \( V_m = 50 \text{ m/s} \)
  \( R_m = 50 \text{ km} \)
- Taiwan topography (land free) water-crafted mountain

Rain difference (green)
**PV tendency equation of baroclinic and diabatic TC motion**

\[
\frac{\partial P}{\partial t} = -\nabla \cdot \nabla_h P - w \frac{\partial P}{\partial z} + \rho^{-1} \nabla_3 \cdot (Qq)
\]

Symmetric PV advected by WN1

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

Wavenumber 1

Wavenumber 2

Obtained by the least squares method

Wu and Wang (2000), etc
\[
DH = \frac{1}{\rho} \left[ (\zeta + f) \frac{\partial Q}{\partial z} + \left( \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \right) \frac{\partial Q}{\partial y} + \left( \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} \right) \frac{\partial Q}{\partial x} \right]
\]

- DH (\(\propto \frac{\partial Q}{\partial z}\)) is not necessarily positive where \(Q\) is positive, because we consider the WN1 component.
- The level or vertical averaging depth makes a big difference.
turns & speeds up
turns & slows down
PV tendency analysis on TC motion - DH component along track

OC run

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

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

T3N run
PV tendency analysis on TC motion - DH component along track

PV DH term averaged over z=1-11 km

T3N run
PV tendency analysis on TC motion
- DH component along track

PV DH term averaged over z=1-11 km

T3N run

DH $3 \text{ m s}^{-1}$
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

(a) Vertical cross-section of $Q$ and vertical velocity at $T = 32 - 35 \text{ h}$

(b) Vertical cross-section of $Q$ and vertical velocity at $T = 48 - 57 \text{ h}$
Vertical cross-section of $Q$

...and DH

$Q$ (K h$^{-1}$)
Fast Northern landfall Experiment (-5 m/s)

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 heating $Q = 0$

DH test start
DIABATIC VS. PHYSICAL FORCING

with DH (control)

without DH

L = landfall

DH test start

981 mb

970 mb

965 mb

U3M

NDH

OC

OCNDH
DIABATIC VS. PHYSICAL FORCING

with DH (control)

without DH

L = landfall

DH test start

1.5 m s⁻¹
DIABATIC VS. PHYSICAL FORCING

with DH (control)

without DH

DH test start

L = landfall

24N

23.5N

122E

122.5E

1.5 m s⁻¹

L = landfall
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
~END~
THANKS FOR YOUR ATTENTION!