The relationship between the VAD wind and orographic heavy rainfall of southwestern Taiwan induced by typhoon circulation

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Motivation

- More understanding on orographic heavy rainfall that cause damage.
  - 3hr > 200mm
  - 6hr > 400mm
  - 12hr > 800mm
  - Each situation means different disaster scale!

- FAQ: The heavy rain will persist how many hours?
Landslide and debris flow

影像來源:飛虎、元智大學
台東太麻里

mountain torrents

資料來源：屏東科技大學
flood
Heavy rainfall (conceptual)

\[ P = RD \]

\[ D = \frac{L_s}{c_s}, \]

\[ R = E(wq). \]

Water content

vertical velocity

Total rainfall = rain rate \( \times \) duration

\[ P = E(\nabla_H \cdot \nabla h + w_{env})qL_s/c_s. \]

B) BACKBUILDING / QUASI-STATIONARY (BB)

Stationary front (Mei-Yu)

Precipitation Efficiency

Terrain enhanced rainfall

Precipitation efficiency

\[ \text{Efficiency} = \frac{\text{Rainfall}}{\text{Cumulus Clouds}} \]

Stationary front or other boundary

Low-level shear

Cell motion

Stratiform motion

Alps

Slightly unstable air

0°C
Orographic heavy rainfall

\[ P = RD \]

\[ P = E(V_H \cdot \nabla h + w_{env})qL_s/c_s. \]

**Table 1. An estimate of the contributions from some common ingredients.**

<table>
<thead>
<tr>
<th>Event</th>
<th>NLLJ ((U \text{ in m s}^{-1}))</th>
<th>Mountain slope ((\delta h/\delta x))</th>
<th>(q) ((g \text{ kg}^{-1}))</th>
<th>Index ([U (\delta h/\delta x)q])</th>
<th>(w_{env}) (synoptic system)</th>
<th>Max rainfall rate</th>
<th>CAPE ((J \text{ kg}^{-1})) (selected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Thompson, CO</td>
<td>12.5</td>
<td>0.025</td>
<td>16</td>
<td>5.0+</td>
<td>Trough</td>
<td>915 mm day(^{-1})</td>
<td>2526</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>305 mm (4 h(^{-1}))</td>
<td>1143 mm day(^{-1})</td>
<td>(&lt;2180)</td>
</tr>
<tr>
<td>Rapid City, SD</td>
<td>12.5</td>
<td>0.020</td>
<td>13.5</td>
<td>3.4+</td>
<td>Trough</td>
<td>519 mm day(^{-1})</td>
<td>628</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[381 mm (4 h(^{-1}))]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fort Collins, CO</td>
<td>10</td>
<td>0.021</td>
<td>13</td>
<td>2.7+</td>
<td>Trough</td>
<td>600 mm day(^{-1})</td>
<td>286</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>259 mm (6 h(^{-1}))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madison County, VA</td>
<td>12.5</td>
<td>0.025</td>
<td>16</td>
<td>5.0+</td>
<td>Trough</td>
<td>300 mm day(^{-1})</td>
<td>2662</td>
</tr>
<tr>
<td>Vaison-la-Romaine, France</td>
<td>15</td>
<td>0.027</td>
<td>15</td>
<td>6.1+</td>
<td>Trough</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[259 mm (6 h(^{-1}))]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piedmont, Italy</td>
<td>13</td>
<td>0.033</td>
<td>11</td>
<td>4.7+</td>
<td>Trough</td>
<td>250 mm day(^{-1})</td>
<td>212</td>
</tr>
<tr>
<td>South Ticino, Switzerland</td>
<td>10</td>
<td>0.033</td>
<td>9.3</td>
<td>3.1+</td>
<td>Trough</td>
<td>260 mm day(^{-1})</td>
<td>383</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[130 mm (6 h(^{-1}))]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lago Maggiore, Italy</td>
<td>12.5</td>
<td>0.033</td>
<td>11.5</td>
<td>4.74+</td>
<td>Trough</td>
<td>300 mm (36 h(^{-1}))</td>
<td>90</td>
</tr>
</tbody>
</table>

* Plus signs indicate that the index may be higher with the addition of \(w_{env}\) associated with an approaching synoptic system.

Lin Y.-L. (2001)
Morakot typhoon (2009)

8月8日 20:00 LST

LLJ ~ 33 m/s (strong wind)

> 1500 mm/ 24hr
Mei-Yu front (IOP#4)

SoWMEX/TiMREX Nagoya Blue Radar
2008/06/02 06:47:06

LLJ ~ 20 m/s

Japan blue radar

Accumulated 72 hours
06/02 01:00 -- 06/05 00:00 LST (2008)
Mei-Yu front (IOP#4)

The southwest flow seems not working hard!

> 20 m/s
Fig. 1. Rainfall statistics of Morakot typhoon in warning stage (95 hours) using surface raingauge network: (a) maximum hourly rainrate; (b) maximum 12 hours accumulation; (c) even total rainfall.
Morakot typhoon U vs. R

面積平均時雨量
(\sim 3,300 \text{ km}^2)
面積約 3,300 km²

莫拉克颱風平均西風與降雨關係

Avergae Wind vs. Rainrate

box = 35 km x 95 km

Average rainrate (mm/hr) vs. Average Wind (m/s)

Time Series (hour)
Does the upstream rainband common occur for other typhoons?

Are all upstream rainband associate with strong and deep westerly wind? (still in working no answer this time)
2009 Morakot

upstream horizontal rainband persistent more than 31 hours
2007 Krosa

upstream horizontal rainband persistent more than 15 hours

about 0700 UTC appear the feature!

about 2200 UTC persist more than 15 hours
2005 Haitang

upstream horizontal rainband persistent more than 15 hours

about 01 UTC appear the feature!
2005 Talim

upstream horizontal rainband persistent more than 12 hours

about 1600 UTC appear the feature!

about 0400 UTC
Use the similarity to build conceptual model
U (0-3 km) vs. Rainrate

- Rain vs Wind
- Slope = 1.521, Correlation = 0.8817
Morakot, Haitang and Talim

Wind speed vs. Rainrate

- **Morakot Typhoon (2009)**
  - Slope = 1.521, Correlation = 0.88

- **Haitang Typhoon (2005)**
  - Slope = 1.233, Correlation = 0.84

- **Talim Typhoon (2005)**
  - Slope = 1.21, Correlation = 0.80
Linear Regression Model

Use the Morokat typhoon data to build a Rainfall Prediction Model

\[ R \text{ (mm/hr)} = 1.756 \times U(1-3\text{km}) - 4.16 \]
Use the Morakot regression model to predict Morakot and Haitang typhoon, it is very good for Morakot but not so good for Haitang.

預報莫拉克很好 (R = 0.879) 預報海棠比較差 (R = 0.545)
Recently, try to build a multiple regression model with U, Div and reflectivity
$R(U, \text{Div})$ and $R(U, Z)$ are not successful, due to the bigger spread of the new variables.
Observation in Planning
Orographic Heavy Rain Obs. (旗山溪)

- 關山村（中興國小）
- 五里埔（小林村）
- 那瑪夏鄉（三民）
- 杉林鄉（大埔山/真福山）
- 可移動式偏極化雷達
- 地面雲物理整合站
Orographic Heavy Rain Obs. (荖濃溪)
車載式偏極化雷達合作觀測

第一次「西南氣流觀測實驗」 (5月27日~ 6月16日)
第二次「萊羅克颱風觀測」 (8月31日~ 9月02日)
第三次「凡那比颱風觀測」 (9月18日~ 9月21日)
凡那比颱風雨量圖（9/18~9/20）

最大累積3小時雨量圖

TEAM-R
雷達觀測位置

Maximum 3 hour rainrate in 72 hours
09/18 08:00 ~ 09/21 07:00 LST (2010)

最大累積12小時雨量圖

TEAM-R
雷達觀測位置

Maximum 12 hour rainrate in 72 hours
09/18 08:00 ~ 09/21 07:00 LST (2010)
凡那比(Fanapi)颱風聯合觀測

參與人員：颱洪中心5員、中央大學3員(含教授1員)及台灣大學3員(研究生)
設備：車載偏極化雷達、日本小型都卜勒雷達、中央大學雨滴譜儀3套及地面氣象站3套
9月19日早上8點的雷達徑向風場顯示低層北風風速超過35m/s，造成雷達車前方50米的樹木及作業室後方的老樹攔腰折斷。強風造成杉林鄉大愛村附近路樹折斷倒塌超過百棵以上，路旁40呎貨櫃屋被吹落大水溝。
凡那比颱風暴風圈尚未接觸陸地(9/19 AM1:00)，中央山脈西側山麓就起括風下雨比預期早許多，至使觀測作業準備時間不足。
summary

1. Heavy orographic rainfall need a strong upslope wind that perpendicular to mountain and need the pre-exist convetion (line or cells) in the upstream side.

2. Typhoons in northern part of Taiwan can form a convergence zone in the southwest part of Taiwan.

3. The Linear regression model that use the U(1-3km) can predict the average rainfall amount not too bad, the Multiple regression model not improve anymore.
Thanks for your attention
a snapshots of upstream rainband
upstream rainband vs. typhoon main rainband

Absolute Vorticity \((10^5 \text{s}^{-1})\)

z-wind component \((\text{m s}^{-1})\)

Didlake and Houze (2009)