The Cascade of Determining Precipitation Hotspots of Summertime Afternoon Thunderstorms in Northern Taiwan: from Synoptic Scale to Local Scale

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Abstract

This study investigates the determination of precipitation hotspots (PH) during summertime afternoon thunderstorms (ATS) in northern Taiwan, tracing a cascade across multiple scales. Hierarchical clustering analysis identifies six clusters of PH that capture the historical event variability. Synoptic-scale weather composites reveal a correlation between cluster occurrence and the extent of the western subtropical high-pressure system (WPSH) and the 700hPa moisture transport pattern. To explore finer-scale mechanism, we classified 90 cases from the TaiwanVVM output by [Chang et al., 2021] into the aforementioned six clusters, focusing on four of them. Local circulation induced by orography and sea breezes determines convection triggering locations, while wind shear between surface and mid-levels influences convection propagation. The variability among these factors results in varying PH patterns. Further analysis could provide a methodology bridging synoptic and local characteristics from different approaches.

Introduction

- **Environmental factors across multiple scales** may influence the formation, enhancement, and precipitation of ATS in northern Taiwan.
  - The weak synoptic environment, conducive to ATS occurrence, is associated with the extension of the ridge of the **west Pacific subtropical high pressure (WPSH)** [e.g. Miao and Yang, 2020].
  - **Local circulation** has been recognized as crucial one that determine the intensity and the PH of ATS [e.g., Kuo and Wu, 2019].
- Objective: To investigate the **potential mechanisms determining the PH during ATS events**. We examined the several associated factors across various scales, and present the environmental characteristics associated with different PH patterns.

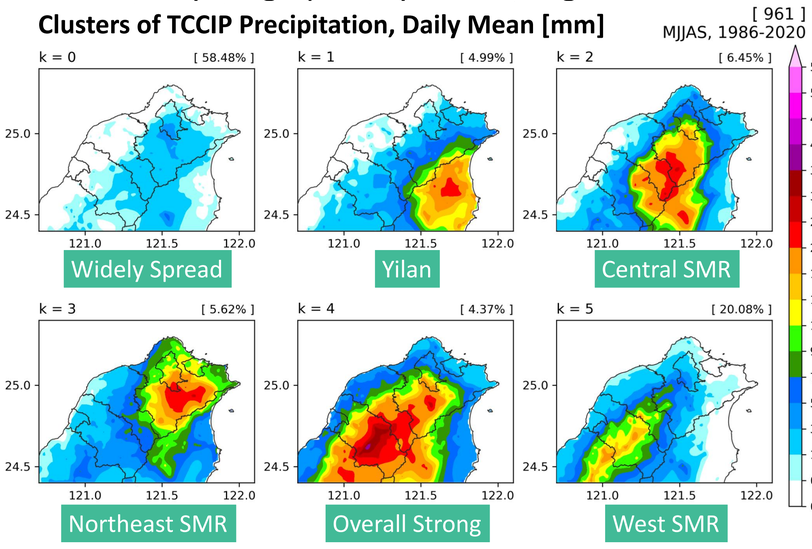
Data & Methodology

- **Study Area:** Northern Taiwan (120.7°E-122.1°E, 24.4°N-25.4°N)
- **Case Selection:** 961 ATS Events in 35-yr period
  - Weak-synoptic weather days in TAD [Su et al., 2018] in MJJAS, 1986-2020
  - Higher rainfall in 13-24LT than in 01-12LT in CWB rain gauge observations
  - Exclude Days with average accumulated rainfall > 1mm in 01-12LT
- **Identify Precipitation Hotspot: Clustering Analysis**
  - TCCIP 1-km Gridded Historical Daily Precipitation Dataset v2
  - Normalized by dividing values by the maximum of the day (focus on spatial pattern)
  - Hierarchical cluster analysis: Ward's linkage, prescribed cluster # = 6
- **Identify the Favorable Synoptic Environment for Hotspots: Weather Composites**
  - Utilize daily mean of ERA5 Reanalysis Dataset
  - Make composites in the dates of respective clusters
- **Analyze the Local Circulation for the Hotspots: TaiwanVVM Simulations**
  - Utilize the 90 cases of TaiwanVVM output in [Chang et al., 2021]
  - Classify them as the type of which the least RMSE to the clusters aforementioned
  - Present the subdaily evolution of local circulation in each classification type

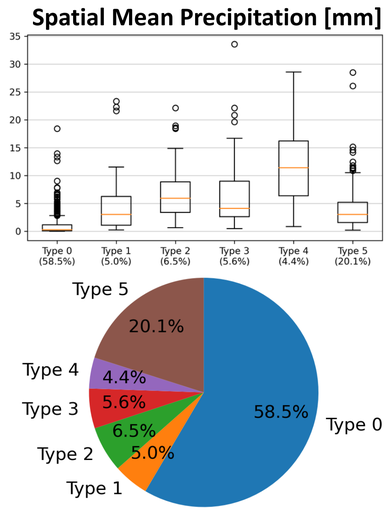
Precipitation Hotspot Clusters

- **Typical Precipitation Hotspots**
  - Primarily orographically locked; aligned with different terrain features

Clusters of TCCIP Precipitation, Daily Mean [mm] [961] MJJAS, 1986-2020



Spatial Mean Precipitation [mm]

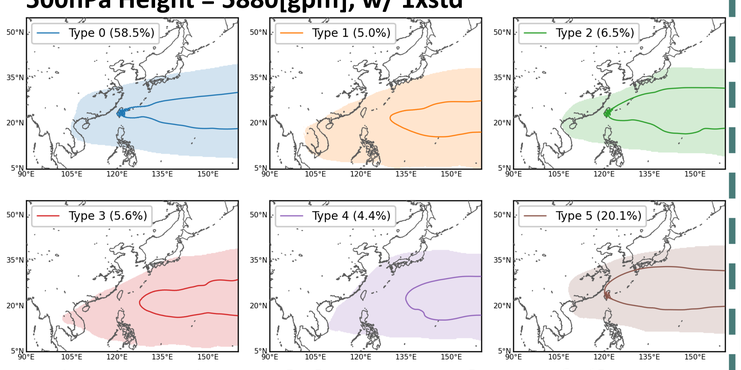


- **Intensity and Frequency**
  - Daily rainfall varies apparently both within and between clusters
  - 961 ATS events accounted for 17.9% of summertime, while PH Type 0 (widely spread) and Type 5 (west SMR) occurred the most often.

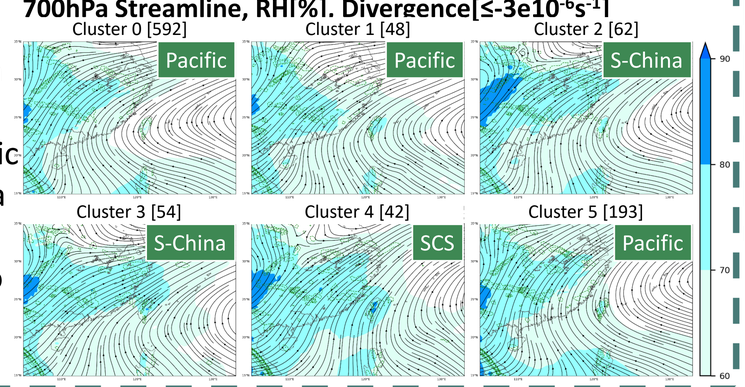
Synoptic Weather Composites

- **WPSH Extent at 500hPa**
  - Inhibit other synoptic systems
  - Affect variability of dynamics
  - 0, 2, 5: westward & northward 1, 3, 4: farther from Taiwan
- **Streamline at 700hPa**
  - Correlated to WPSH extent
  - Determine the direction of the upstream
- **Moisture Transport**
  - Sensitive to the upstream with various humidity
  - 0,1,5: limited vapor from Pacific
  - 2,3: more from southern China
  - 4: most vapor from SCS
  - The magnitude is correlated to the precipitation intensity

500hPa Height = 5880[gpm], w/ 1xstd



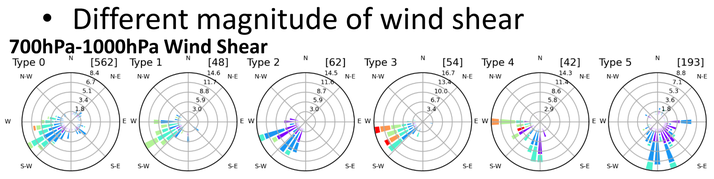
700hPa Streamline, RH[%], Divergence[≤-3e10^{-6}s^{-1}]



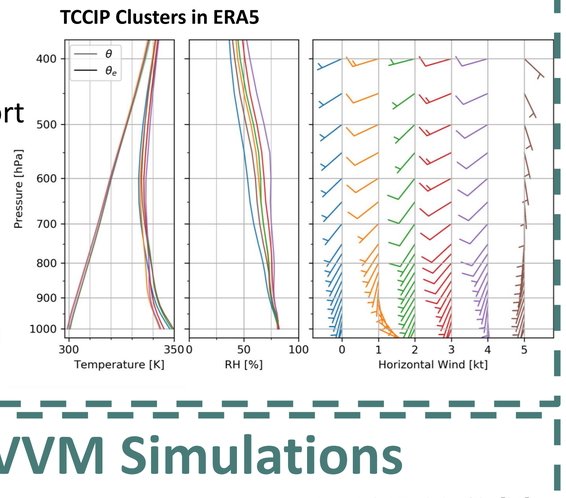
Variability of Vertical Profiles

- **Similar Thermodynamic Characteristics**
  - Convective instability allow in all clusters
  - RH exhibits variation correlated to vapor transport
- **Variant Dynamic Structure**
  - Different wind direction at low-level
  - Different magnitude of wind shear

700hPa-1000hPa Wind Shear

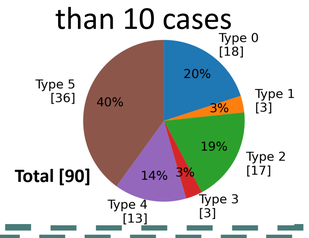


TCCIP Clusters in ERA5

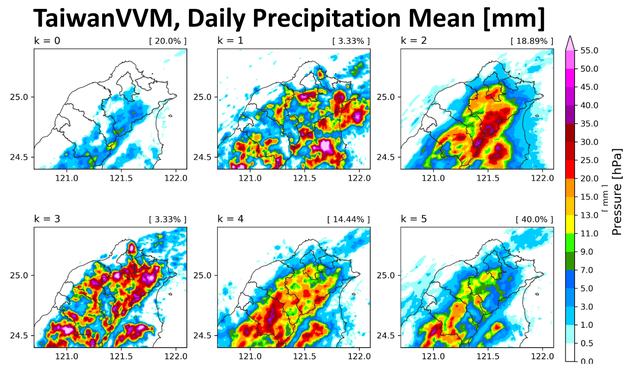


Classification of TaiwanVVM Simulations

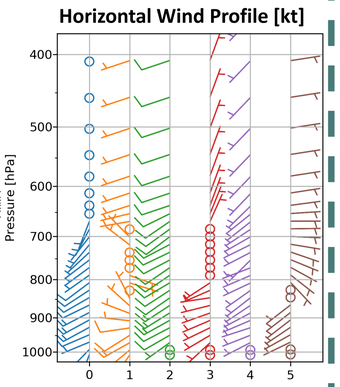
- **Composite of Each Classification Type**
  - We then focus on types with more than 10 cases



TaiwanVVM, Daily Precipitation Mean [mm]



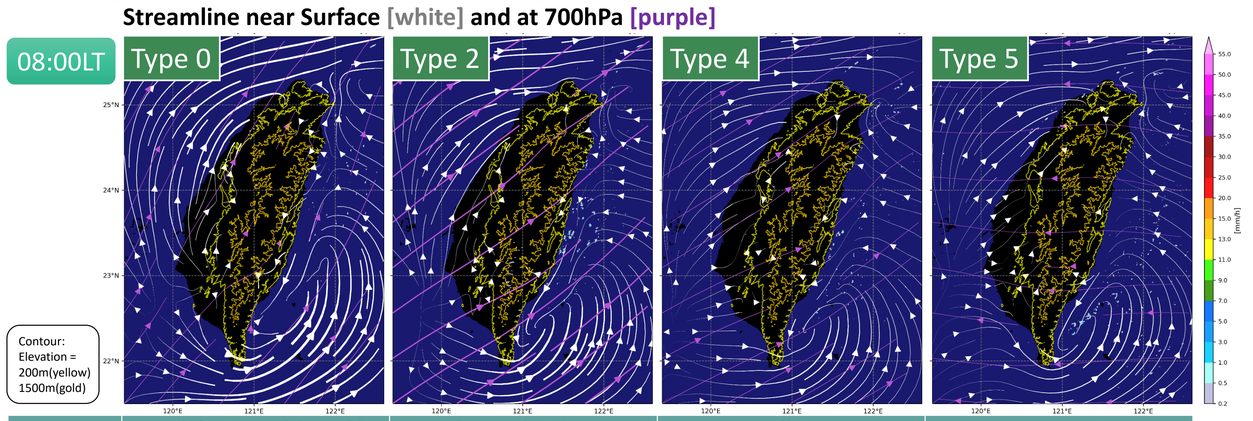
Horizontal Wind Profile [kt]



Local Circulation

- **Background Flow Induced by Orography**

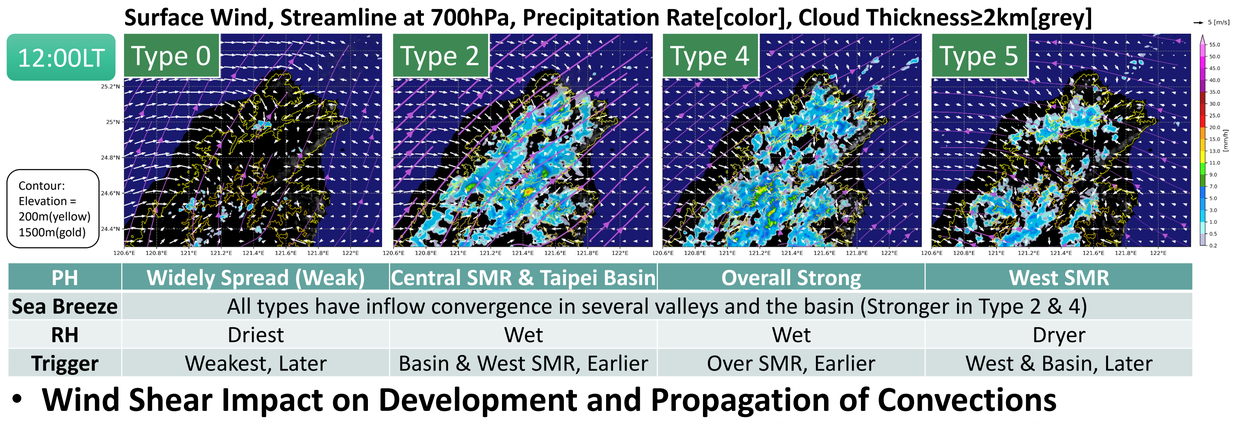
Streamline near Surface [white] and at 700hPa [purple]



PH	Widely Spread (Weak)	Central SMR & Taipei Basin	Overall Strong	West SMR
700hPa	Weak South-Southwesterly	Stronger Southwesterly	Weak Southwesterly	Weak Easterly
Surface	Southwesterly	Southwesterly	Weak Southwesterly	Weak Southwesterly

- **Sea Breeze Convergence and Orography Lifting Triggers the Convections**

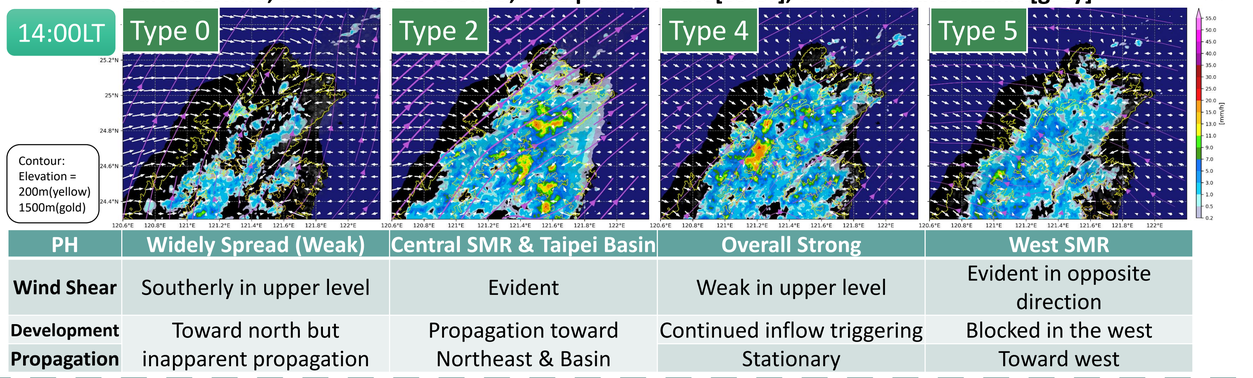
Surface Wind, Streamline at 700hPa, Precipitation Rate[color], Cloud Thickness≥2km[grey]



PH	Widely Spread (Weak)	Central SMR & Taipei Basin	Overall Strong	West SMR
Sea Breeze	All types have inflow convergence in several valleys and the basin (Stronger in Type 2 & 4)			
RH	Driest	Wet	Wet	Dryer
Trigger	Weakest, Later	Basin & West SMR, Earlier	Over SMR, Earlier	West & Basin, Later

- **Wind Shear Impact on Development and Propagation of Convections**

Surface Wind, Streamline at 700hPa, Precipitation Rate[color], Cloud Thickness≥2km[grey]



PH	Widely Spread (Weak)	Central SMR & Taipei Basin	Overall Strong	West SMR
Wind Shear	Southerly in upper level	Evident	Weak in upper level	Evident in opposite direction
Development	Toward north but inapparent propagation	Propagation toward Northeast & Basin	Continued inflow triggering	Blocked in the west
Propagation			Stationary	Toward west

Ongoing Work

- Cross-section analysis to demonstrate the variability in vertical structure of convections and their propagation among the PH clusters
- Investigating the special clusters: Type 1 (Yilan) and Type 4 (Northeast SMR)
- Quantitative estimation of the criteria of determining PH across multiple scales
- Provide the methodology connecting the synoptic clusters in historical data and the local circulations in future semi-idealized simulations

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