Understanding the physical mechanisms of winter extreme precipitation over northern Taiwan

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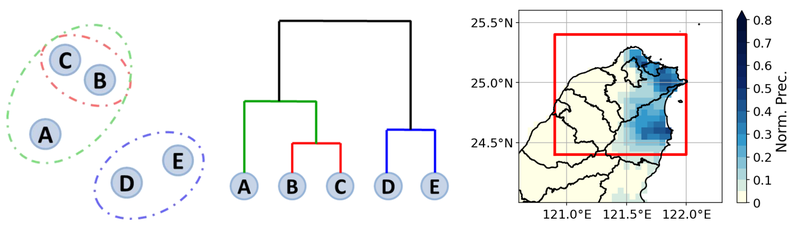
Abstract In this study, we applied hierarchical agglomerate clustering to classify winter precipitation patterns in northern Taiwan and designed a preliminary idealized TaiwanVVM experiment based on the cluster results. The results show that the two precipitation hotspots in Yilan and the north coast constitute four precipitation patterns, with different occurrences of extreme precipitation, and corresponding to different upstream vapor transport and boundary layer structures. In the preliminary idealized TaiwanVVM experiment, it is shown that the regional flow regime and turbulent structure would cause different rain patterns when the upstream environment interacts with the complex topography.

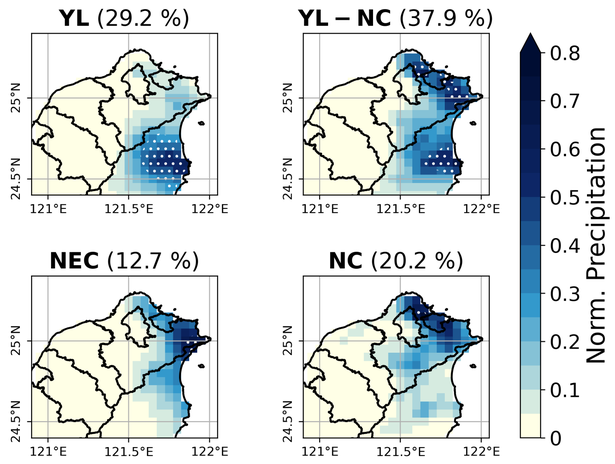
The rain patterns in northern Taiwan

Data and Methodology

Data	TCCIP Gridded Historical Daily Data (Weng and Yang, 2012)
Time	Sep.-Feb., 1996-2020
Cases	Penjiayu WD $0^\circ - 90^\circ$, WS $\geq 4\ m \cdot s^{-1}$ No SW/FT/TC1000 events (TAD; Su et al., 2022) Mean Prec. < 0.5 mm for plain and hill (<1500 m) in Hsinchu and Miaoli Max. precipitation of grid $\geq 15\ mm \cdot day^{-1}$
Normalize	Maximum absolute scaling
Total 848 cases out of 3020 NE monsoon days	

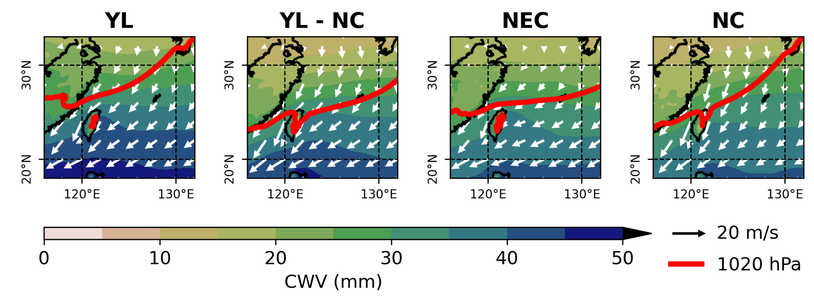


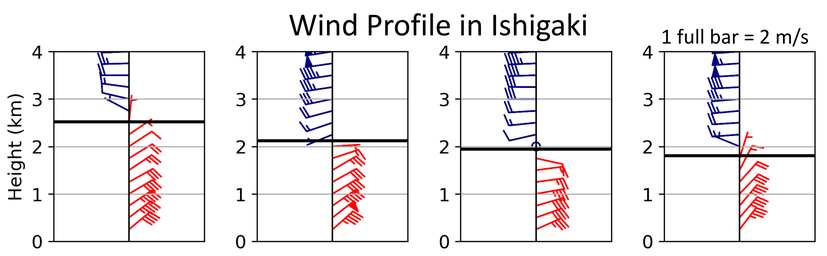
Cluster Results

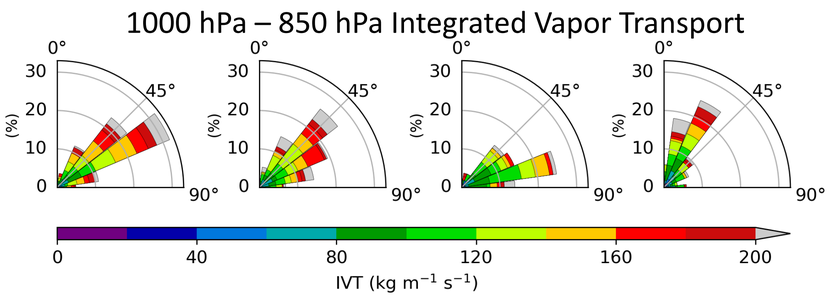


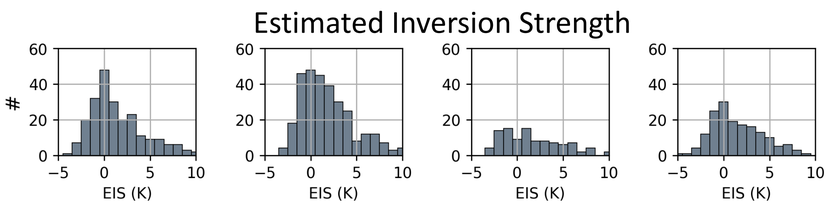
- Cluster analysis suggests the four clusters.
- The white dot region had extreme events (>50 mm day^{-1}) frequency higher than 10%.
- Higher extreme frequency in YL and YL-NC.

Synoptic and upstream properties









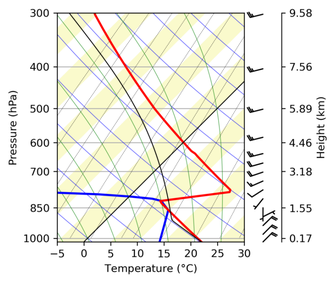
- The reanalysis composite showed the different states of high-pressure movements.
- The rain patterns are sensitive to the upstream wind direction and northeasterly thickness; the extreme events are related to the vapor transport in the boundary layer.
- The higher frequency of high EIS events is found in YL-NC and NC types, indicating the inversion structure influences rain patterns.

The TaiwanVVM simulation

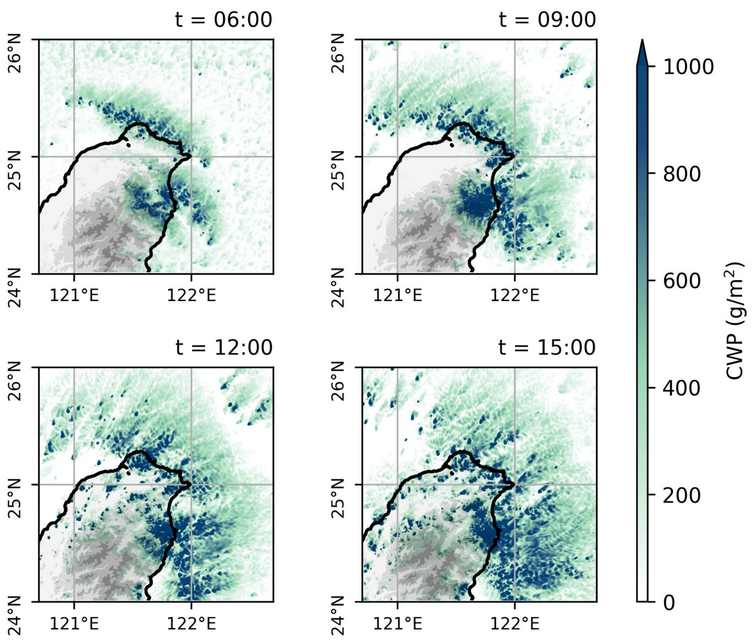
Model Description and Experiment Design

Vector Vorticity equation cloud-resolving Model (VVM)
(Jung and Arakawa, 2008; Wu and Arakawa, 2011)

Domain	2048 × 2048 × 60 grids (1024 × 1024 × 11.4 km)
Vertical Resolution	100 m under 4000 m Stretch up to 638 m at the top
Grid size	500 m
Time integration	10 s time step Integrate for 15 hours
Boundary	Doubly periodic
Subsidence	$1.8 \times 10^{-6}\ s^{-1}$
Wind nudge	10800 s

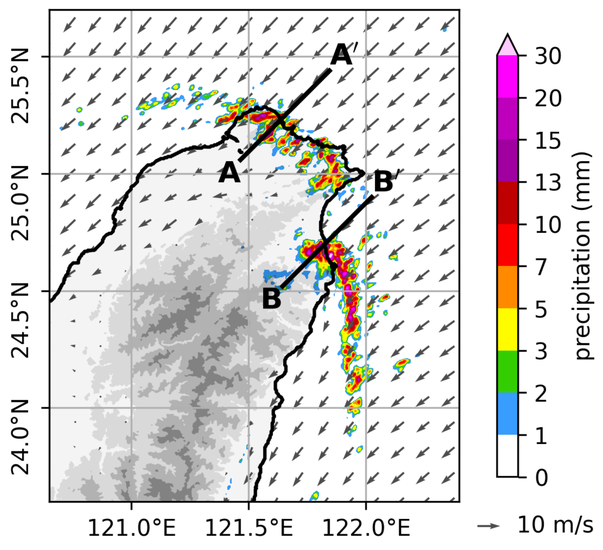


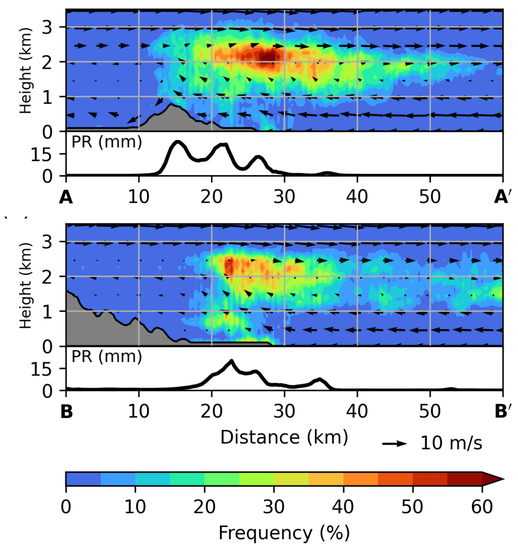
Stratocumulus over Northern Taiwan



- The cloud liquid water path indicated the high water content stratocumulus located in the near coastal region upstream.

Precipitation Mechanisms and Local Circulation





- The precipitation pattern captured the two precipitation hotspots in the TaiwanVVM simulation.
- The turbulent frequency of turbulent kinetic energy over 5 J·kg^{-1} indicates the activity degree of turbulence.
- The stable stratocumulus boundary layer experiences increased vertical mixing, leading to the active stratocumulus turbulence and higher cloud liquid water content in A-A’ profile.
- A convergence zone forms between the orographic return flow and the northeast monsoon, resulting in intense precipitation in the convergent region within the plain area in B-B’ profile.

References

- Jung, J.-H., & Arakawa, A. (2008). A three-dimensional anelastic model based on the vorticity equation. Monthly weather review, 136(1), 276-294
- Su, S.-H., Chang, C.-W., Tsai, I.-C., Chu, J.-L., Chen, Y.-L., & Yo, T.-S. (2022). Taiwan Atmospheric Event Database.
- Weng, S.-P., & Yang, C.-T. (2012). The Construction of Monthly Rainfall and Temperature Datasets with 1km Gridded Resolution over Taiwan Area (1960-2009) and Its Application to Climate Projection in the Near Future (2015-2039), Atmospheric Sciences, 40(4), 349-369 (in Chinese)
- Wu, C.-M., & Arakawa, A. (2011). Inclusion of surface topography into the vector vorticity equation model (VVM). Journal of Advances in Modeling Earth Systems, 3(2).

Acknowledgement

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