Effect of Low-level Jets on the Movement of the Mei-yu Front

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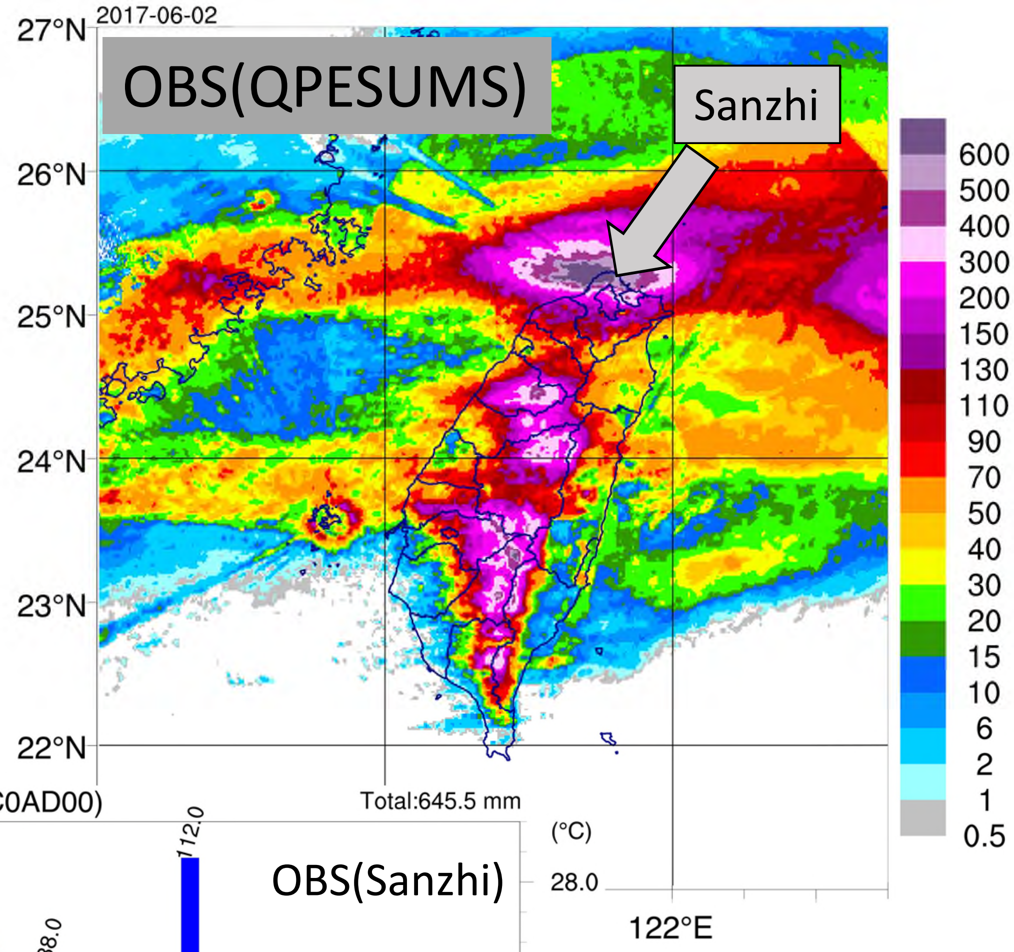
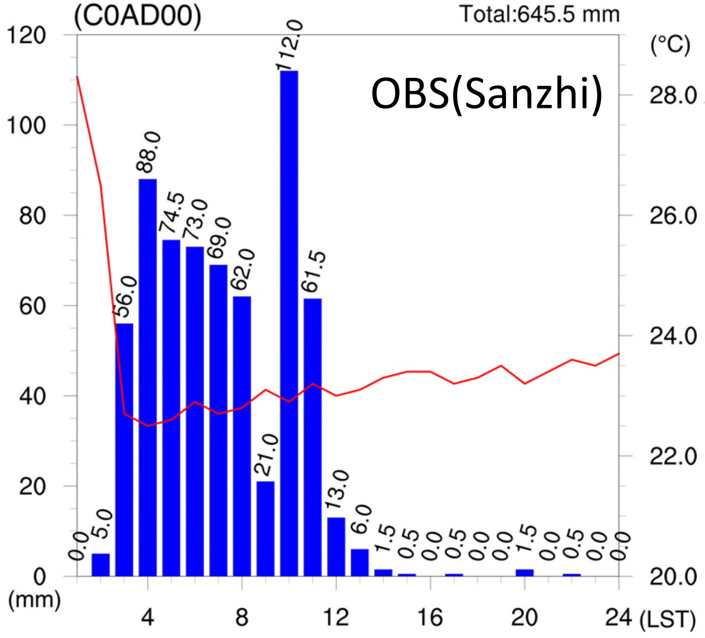
Introduction

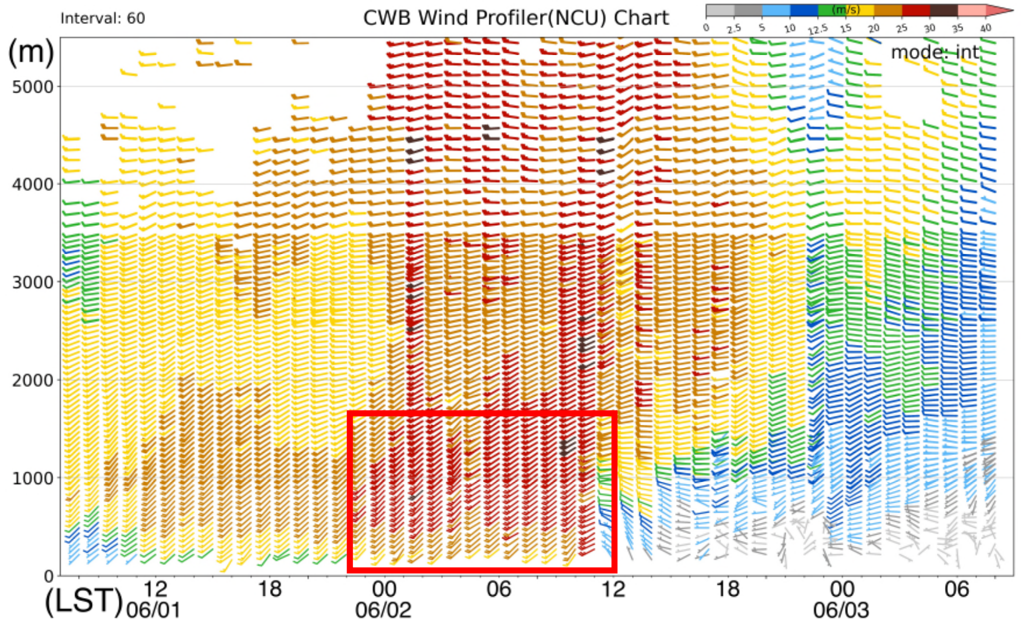
- A Mei-Yu frontal system affected northern Taiwan on 2 June 2017.
- The event resulted in a maximum accumulated rainfall of 645.5 mm over northern Taiwan.
- The front remained quasi-stationary over northern Taiwan.
- More than 600 mm of rainfall was accumulated within a 10-hour period.
- Observations revealed the presence of a barrier jet.



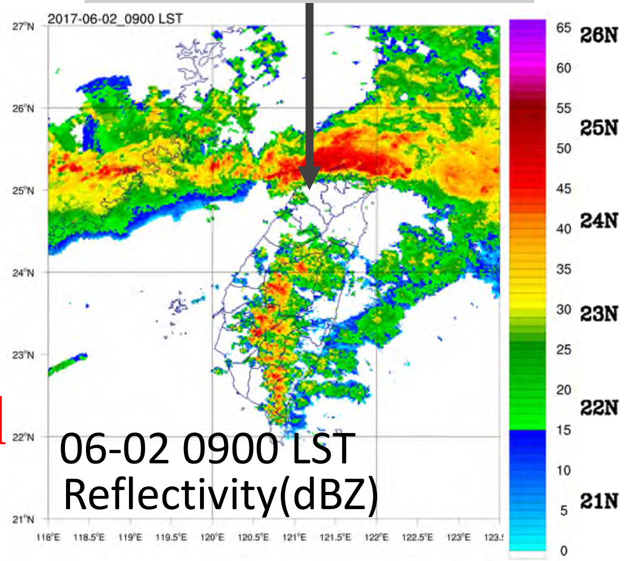


Introduction

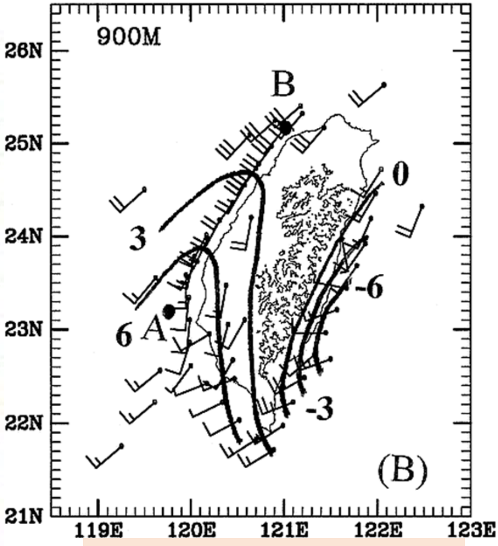
- The blocking effect of the terrain induces a relative high-pressure ridge on the windward side.
- The approach of the Mei-Yu front from the north enhances the meridional pressure gradient.
- The strengthened pressure gradient leads to the formation of a barrier jet along the northwestern coast of Taiwan.
- What is the specific role of barrier jets in modulating frontal movement and associated precipitation?



Wind Profiler at NCU



06-02 0900 LST
Reflectivity(dBZ)

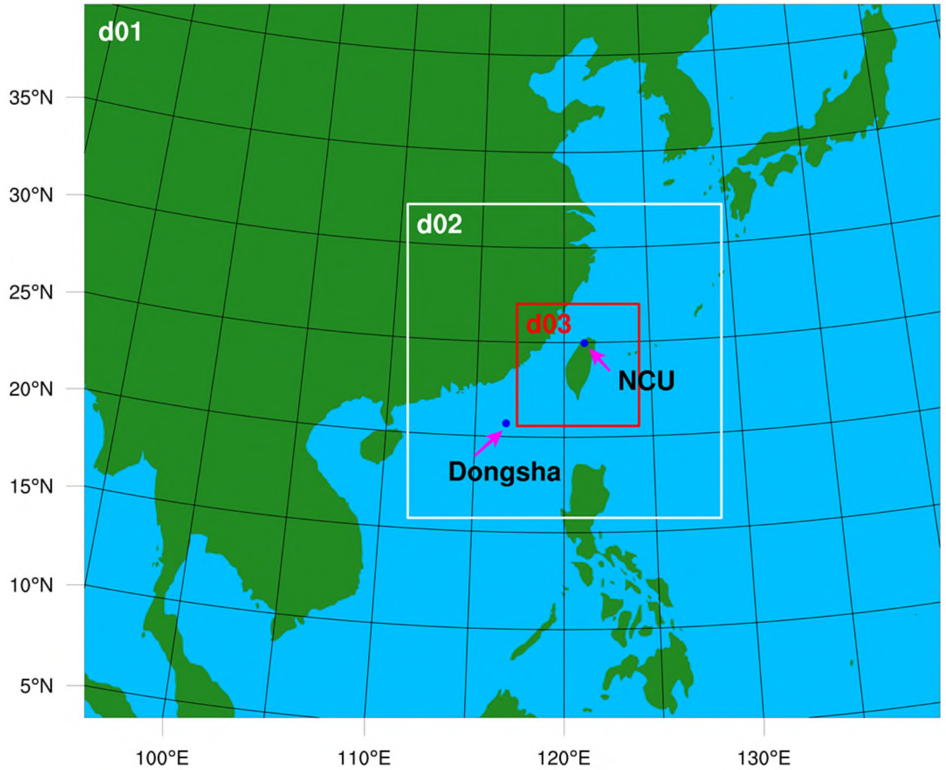


Chen and Li 1995

Chen, Y.-L., and J. Li, 1995: Large-Scale Conditions Favorable for the Development of Heavy Rainfall during TAMEX IOP 3. *Monthly Weather Review*, **123**, 2978–3002, https://doi.org/10.1175/1520-0493(1995)123<2978:Lscfft>2.0.Co;2.

Model

- To investigate the impact of the barrier jet on frontal movement and rainfall, sensitivity experiments were conducted using the WRF model.



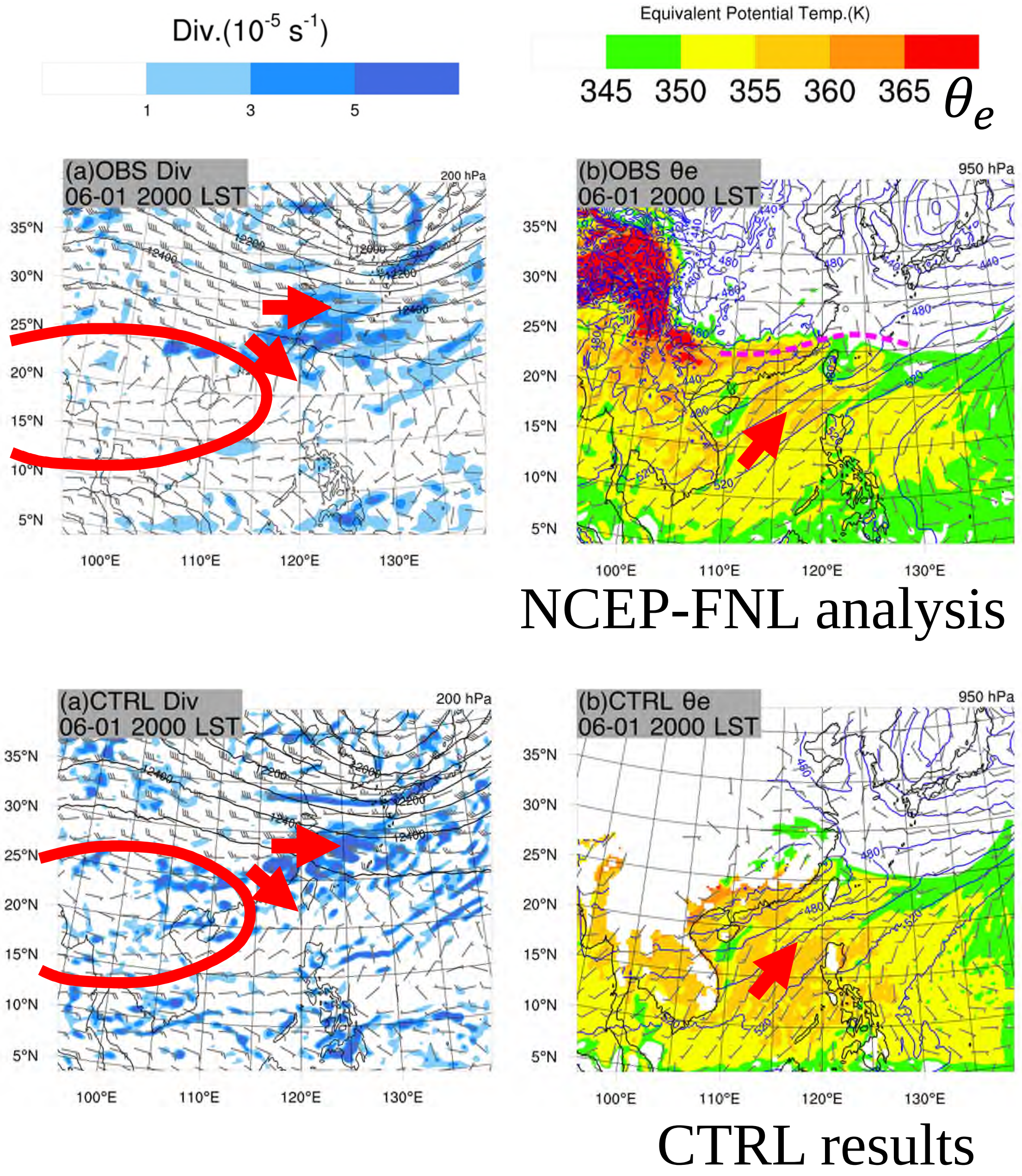
Version	WRF 3.9.1.1		
Grid Size	D01(27km)	D02(9km)	D03(3km)
Initial condition	NCEP-FNL 0.25°×0.25°		
Period	48hr (from 2017/6/1 0800 LST)		
Microphysics	Goddard GCE scheme		
Longwave	RRTM scheme		
Shortwave	Goddard short wave		
Surface-layer	Revised MM5 Monin-Obukhov scheme		
Land-surface	Unified Noah land-surface model		
PBL	YSU scheme		
Cumulus	Kain-Fritsch (new Eta) scheme		X

Model Validation

- **Divergence**:
  At 200 hPa, diffluent upper-level flow over Taiwan is induced by the South Asian High and the midlatitude westerlies.

- **Equivalent Potential Temperature** (θ_e):
  At 950 hPa, southwesterly flow of 15–20 $m\ s^{-1}$ prevails over the South China Sea, accompanied by high θ_e (>350K).

- These features indicate that the CTRL run successfully reproduces the large-scale environment associated with the Mei-Yu front.



Model Validation

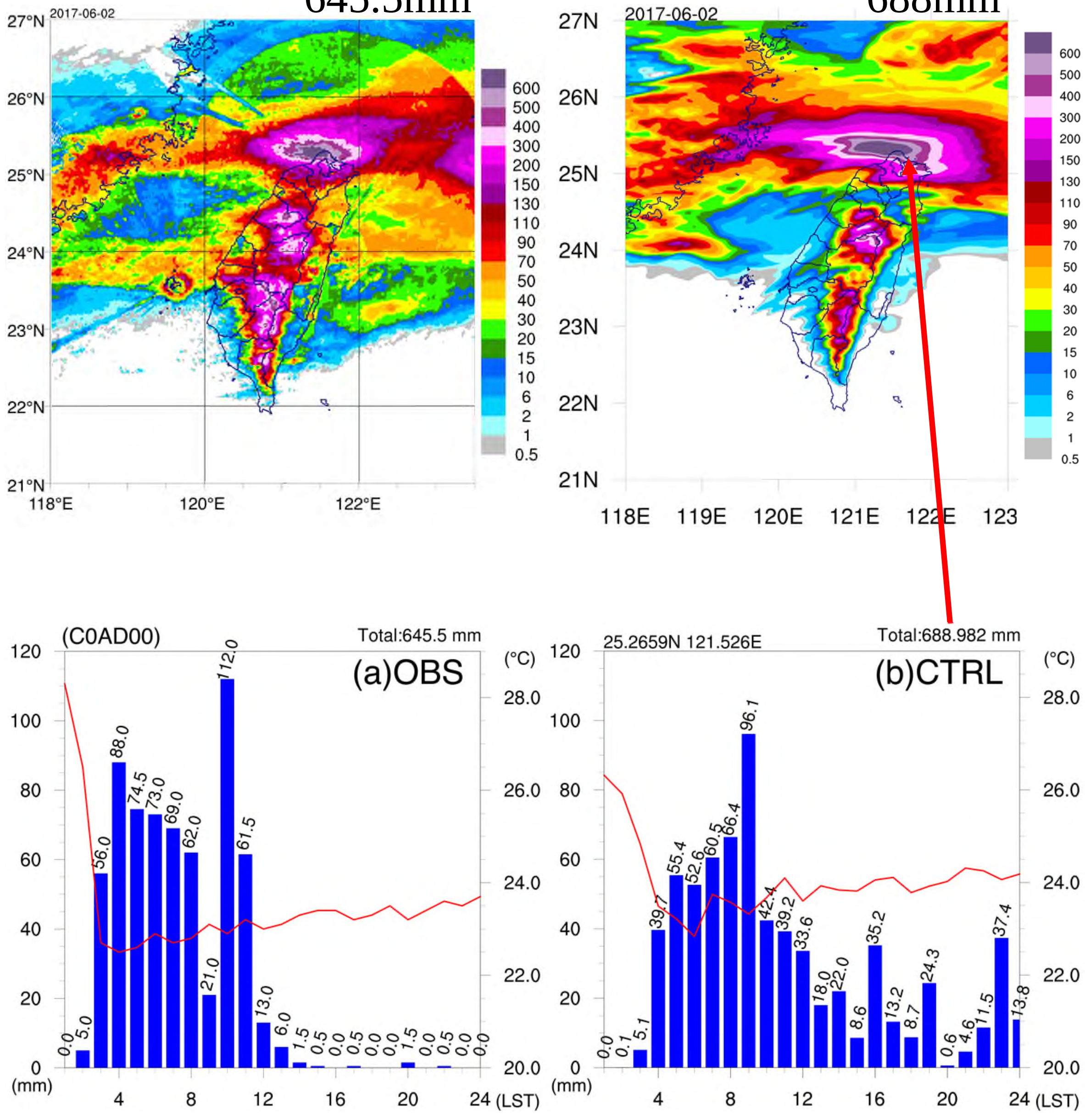
- **Rainfall Distribution:**
  The WRF simulation successfully reproduces the spatial and temporal characteristics of rainfall, with a maximum accumulated amount of 688 mm over northern Taiwan.

- **Hourly Rainfall:**
  Over 620 mm of rainfall was observed within a 10-hour period, while the CTRL simulation produced about 500 mm. The model effectively captures the intense rainfall associated with the stationary front, including a peak hourly rate of 96.1 mm.

- The model effectively reproduces the key features of this case. Sensitivity experiments will be conducted to further investigate the impact of barrier jet intensity on Mei-Yu front.

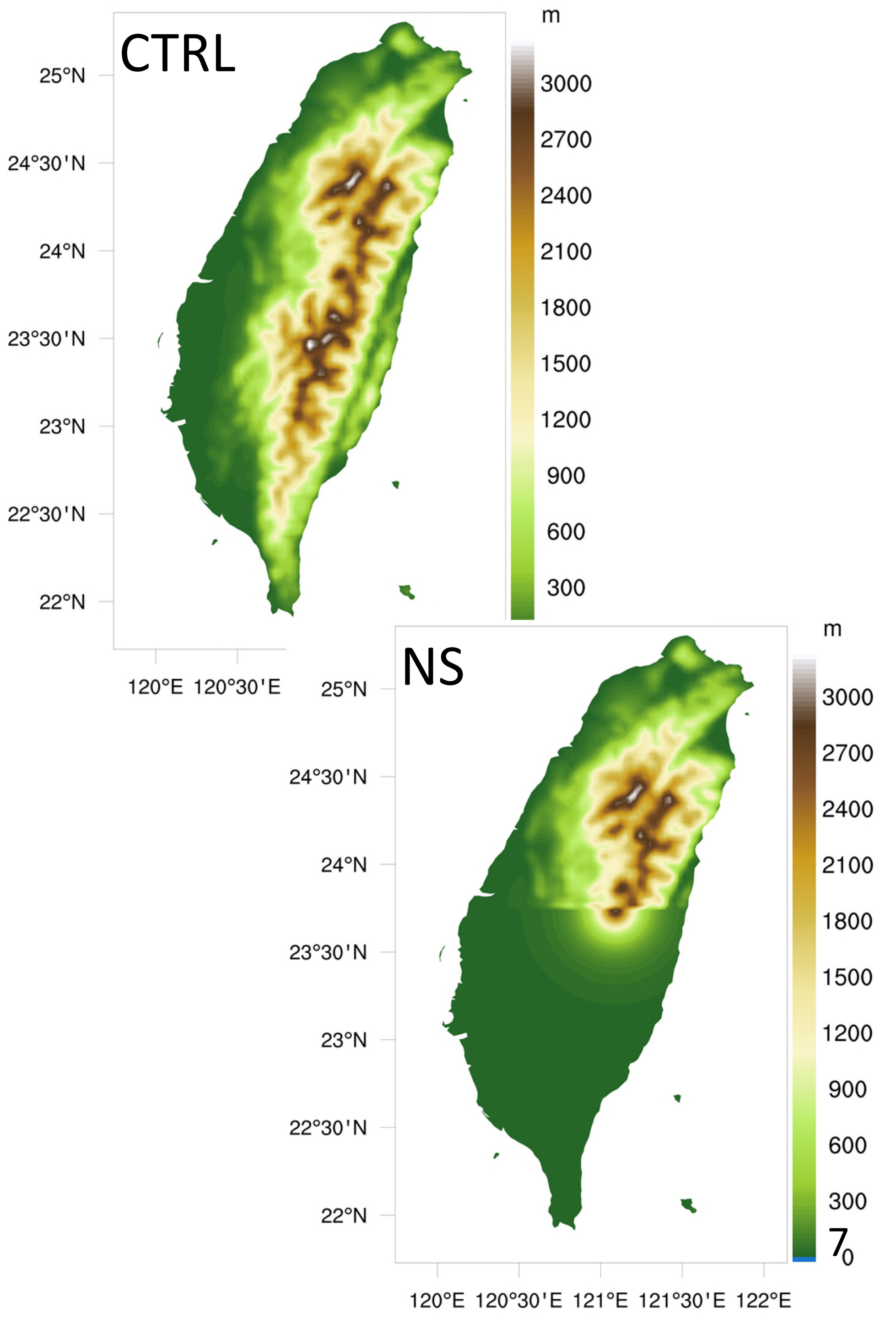
maximum accumulated 645.5mm

maximum accumulated 688mm



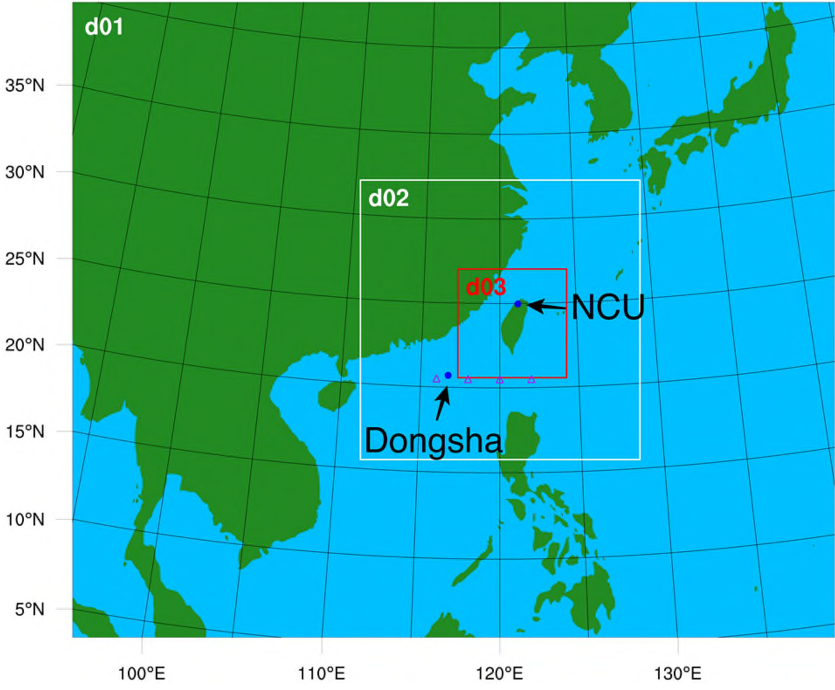
Sensitivity Experiments

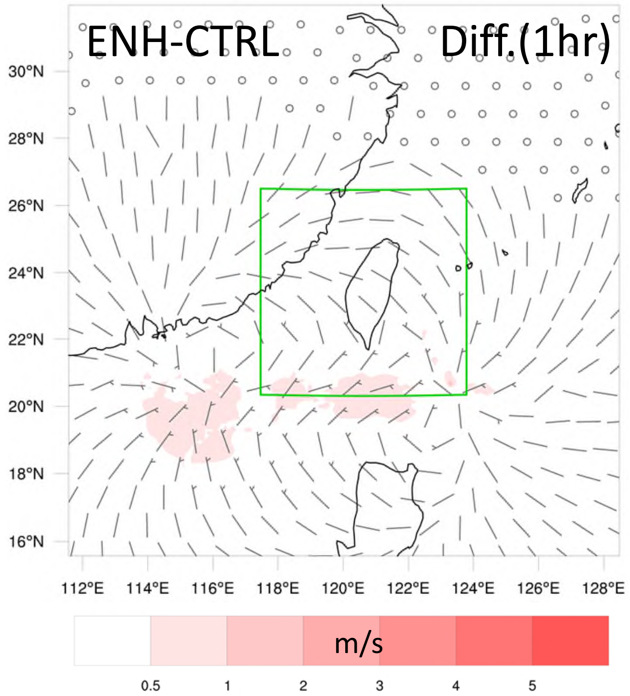
- **Weakened Barrier Jet** (NS Run):
- The northern terrain is retained, while the southern terrain is removed.
- An idealized bell-shaped mountain is added near the southern boundary to ensure a smooth topographic transition.
- This setup weakens the intensity of the barrier jet to varying degrees without altering the frontal influence of the northern terrain.
- Will weakening the barrier jet diminish its blocking effect and consequently alter the evolution of the Mei-Yu front?



Sensitivity Experiments

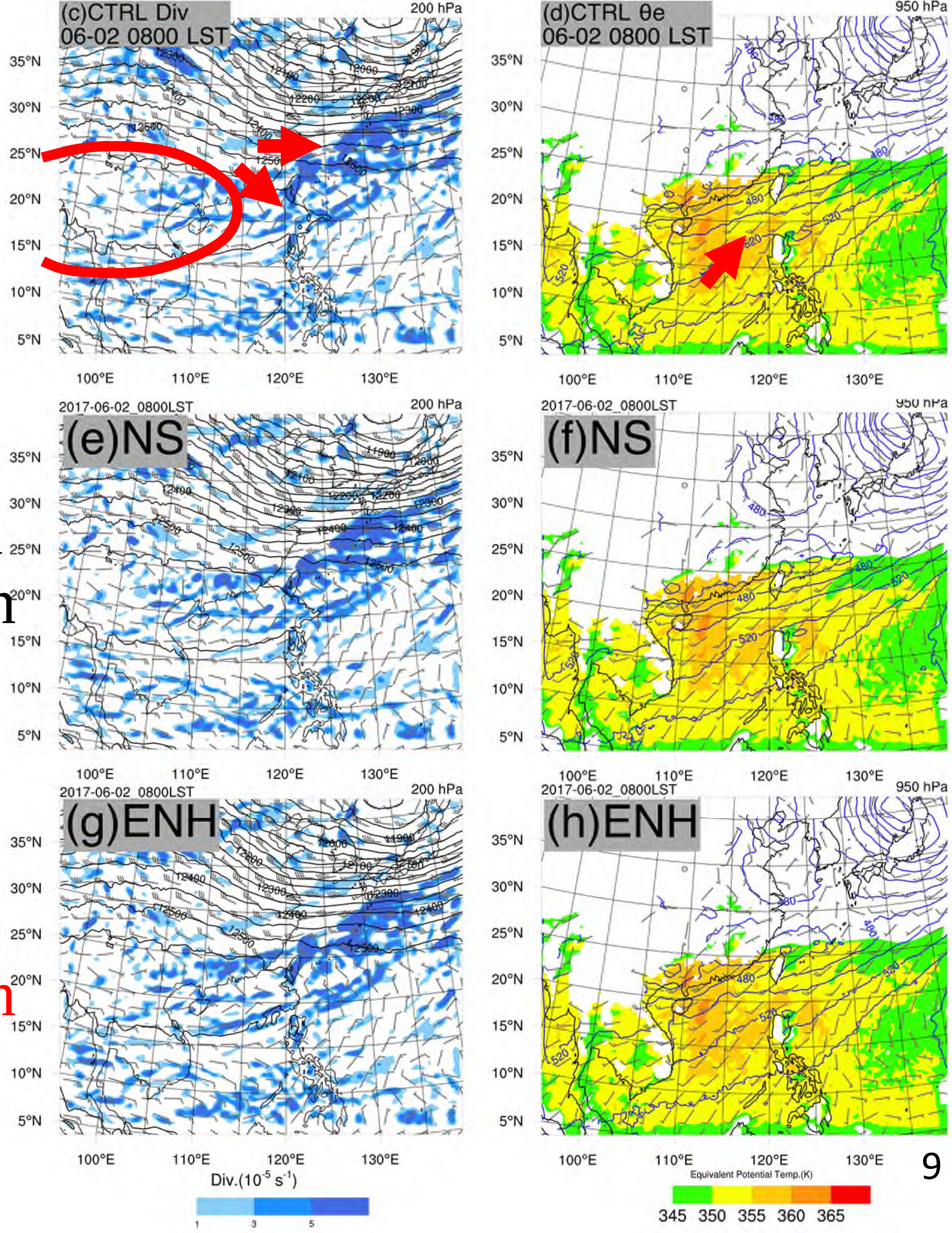
- **Enhanced Barrier Jet** (ENH Run):
- To enhance the intensity of the barrier jet, observation nudging is applied to control the upstream wind field.
- The nudging configuration is based on the WRF-FDDA tutorial. Horizontal radius of influence is set to 180 km.
- NCEP-FNL data with 31 vertical levels and a temporal resolution of 6 hours are used for nudging via OBS_DOMAIN(u, v, T, Q) at selected longitudes (116°, 118°, 120°, and 122°E) along 20.5°N.
- In accordance with the nudging guideline — *“FDDA has fake sources and sinks and so should not be used on the domain of interest and in the time period of interest for scientific studies and simulations”* — **nudging is applied only to the two outer nested domains, thereby preserving the physical consistency of the innermost domain.**
- What are the effects of a stronger barrier jet on frontal evolution and precipitation distribution?





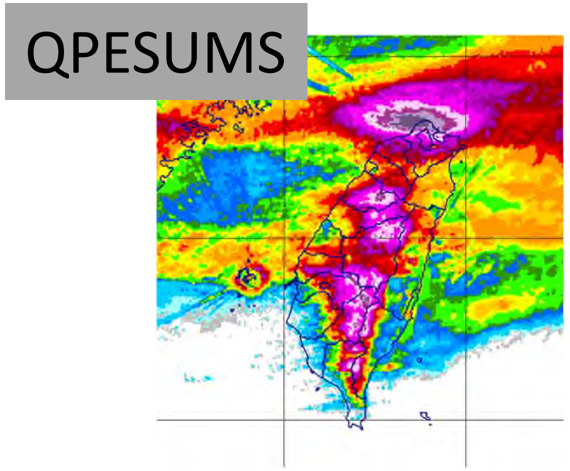
Synoptic Comparison

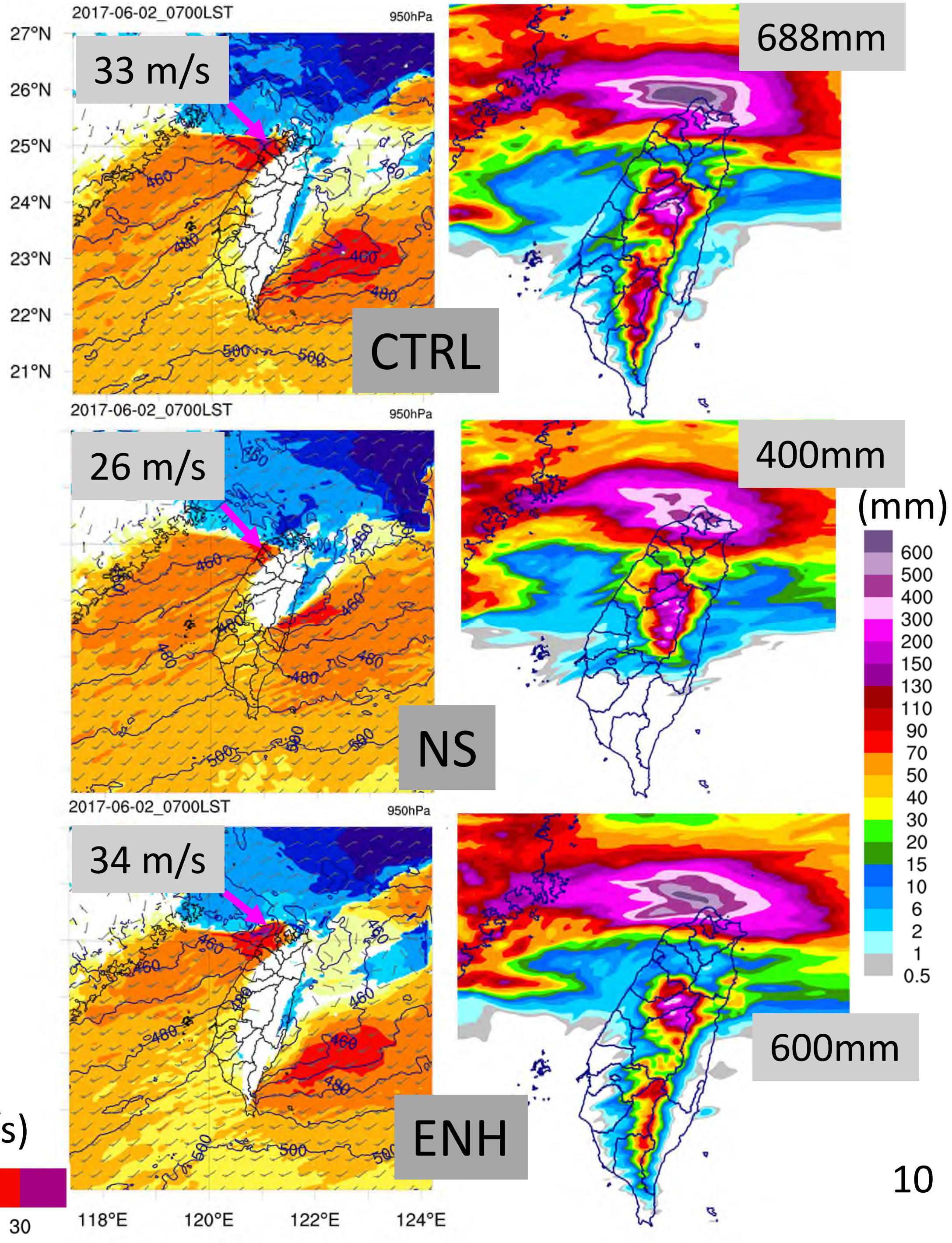
- **Synoptic Environment in Each Experiment:**
- The upper-level divergence pattern and the location of the flow splitting remain similar across experiments.
- The low-level southwesterly flow and the distribution of high θ_e are also comparable.
- Overall, the synoptic conditions in each experiment are similar to those in the CTRL run.

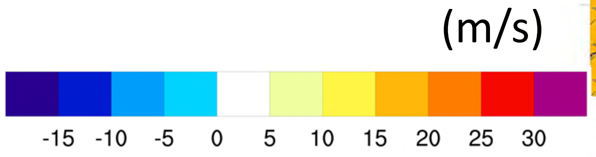


Result

- **Barrier Jet Intensity:**
- CTRL 33m/s; NS run 26m/s; ENH rum 34m/s
- **Accumulated Rainfall:**
- CTRL 680mm; NS run 400mm; ENH rum 600mm
- In the NS run, weakening of the barrier jet led to more dispersed rainfall and a notable reduction in total accumulation.
- In the ENH run, a stronger barrier jet shifted the rainfall northward and caused more concentrated precipitation in a localized area, resulting in higher accumulated rainfall.



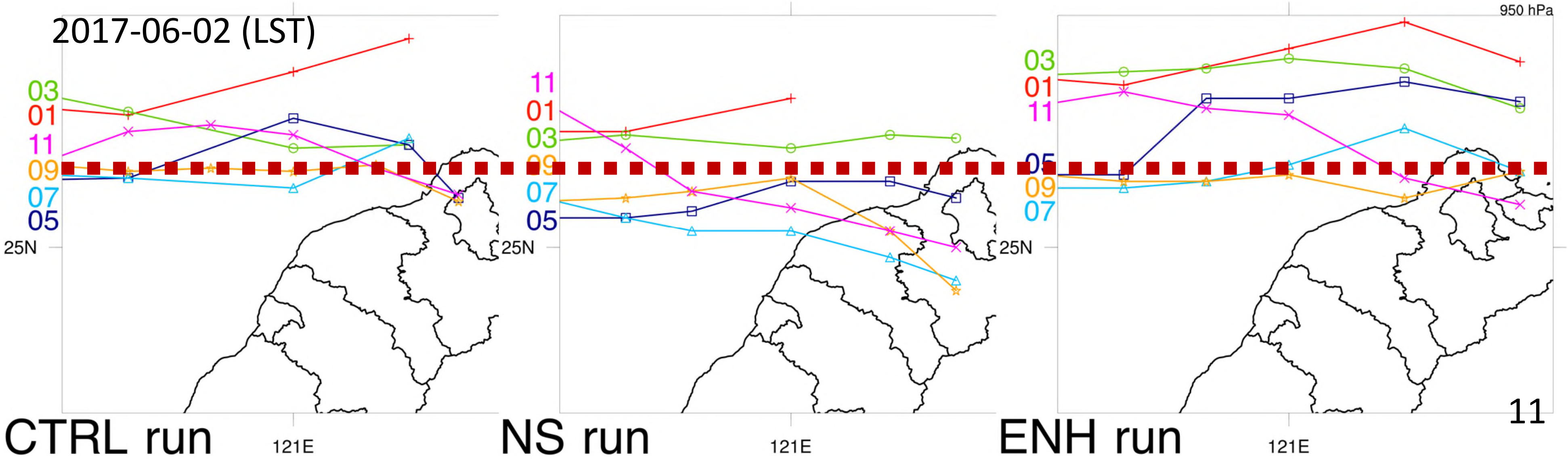




Frontal identification is performed using a combination of low-level wind shear line and θ_e gradients. (Thomas and Schultz 2019; Wang et al. 2021)

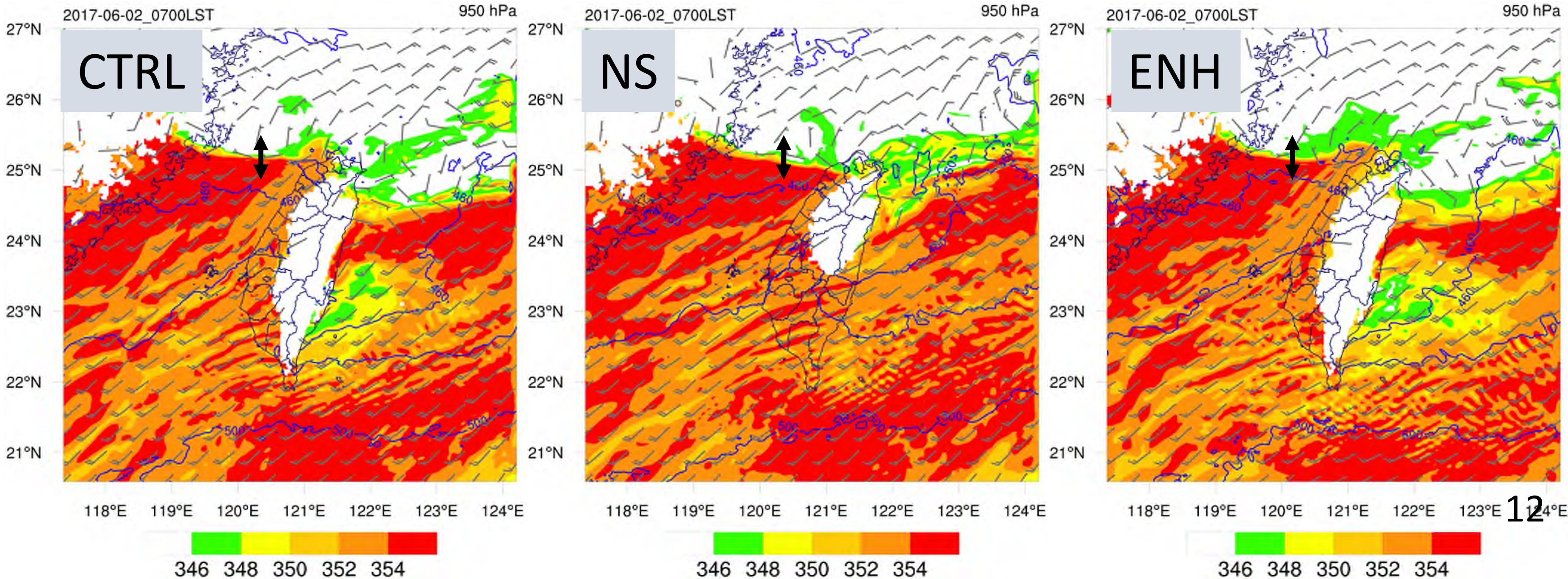
Frontal Positions

- Along the northwestern coastal region, a stronger barrier jet leads to a more pronounced frontal stagnation and concentrated rainfall. In the ENH run, the front remains farther north compared to other experiments.
- In contrast, the weaker barrier jet in the NS run exhibits a reduced blocking effect, allowing the front to advance southward more rapidly. As a result, the rainfall becomes more dispersed, and total accumulation is reduced.



θ_e Distribution

- The θ_e differences within 25 km to the north and south of the frontal position are examined for each experiment.
- All experiments exhibit a similar frontal θ_e gradient of approximately 10K/50km over the Taiwan Strait.
- This indicates that the overall frontal structure is comparable among the experiments.
- Therefore, the changes in frontal movement and rainfall distribution are primarily attributed to variations in the intensity of the barrier jet.

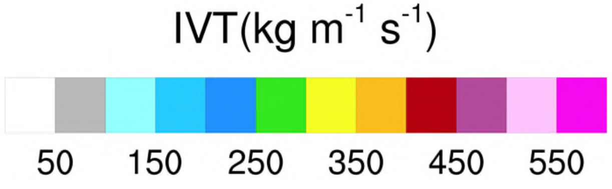


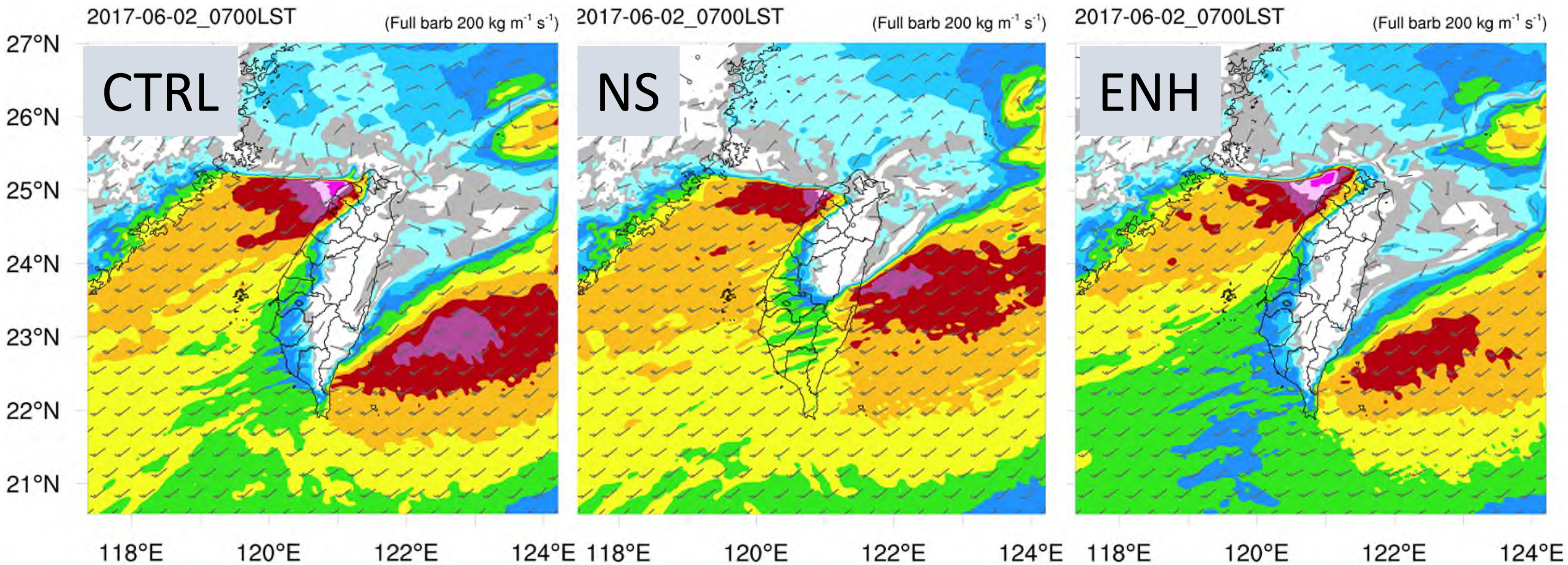
Integrated Vapor Transport (IVT)

- Heavy rainfall events require a continuous supply of moisture.
- IVT is computed by vertically integrating low-level moisture flux between 1000 and 900 hPa.
- The upstream moisture transport is similar across all experiments.
- However, in the downstream region over northwestern Taiwan, differences in barrier jet intensity lead to significant variations in moisture flux.

$$F_u = \frac{1}{g}\int_{P_0}^{P_1} qu\, dp$$

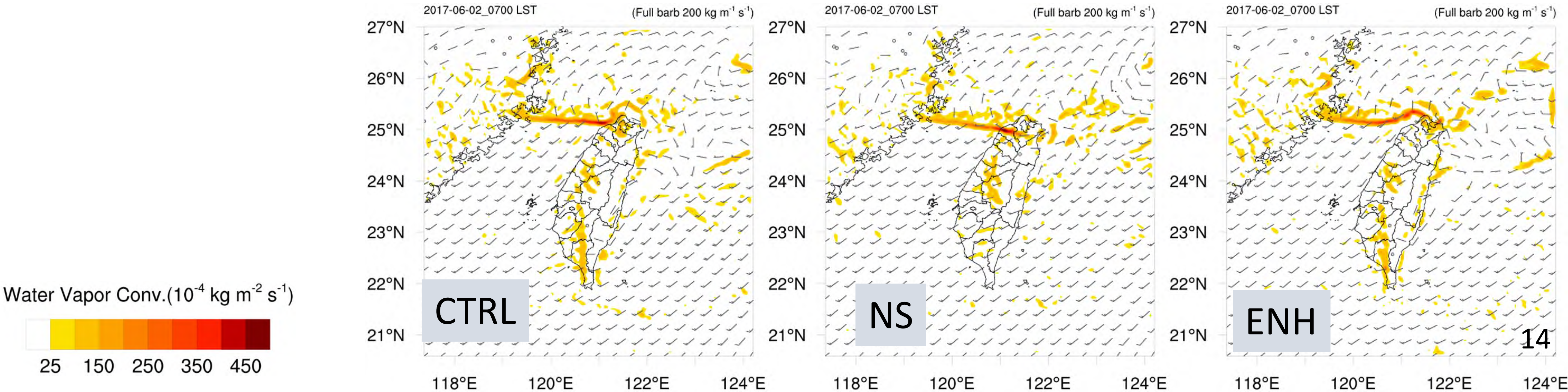
$$IVT = \sqrt{{F_u}^2 + {F_v}^2}$$





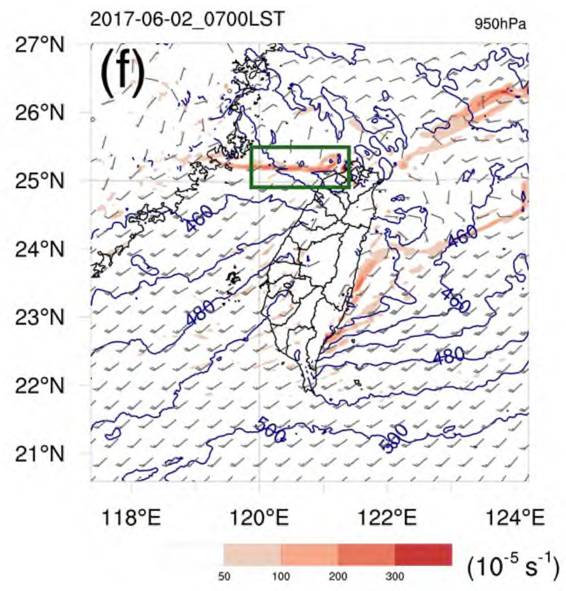
Low-Level Moisture Flux Convergence

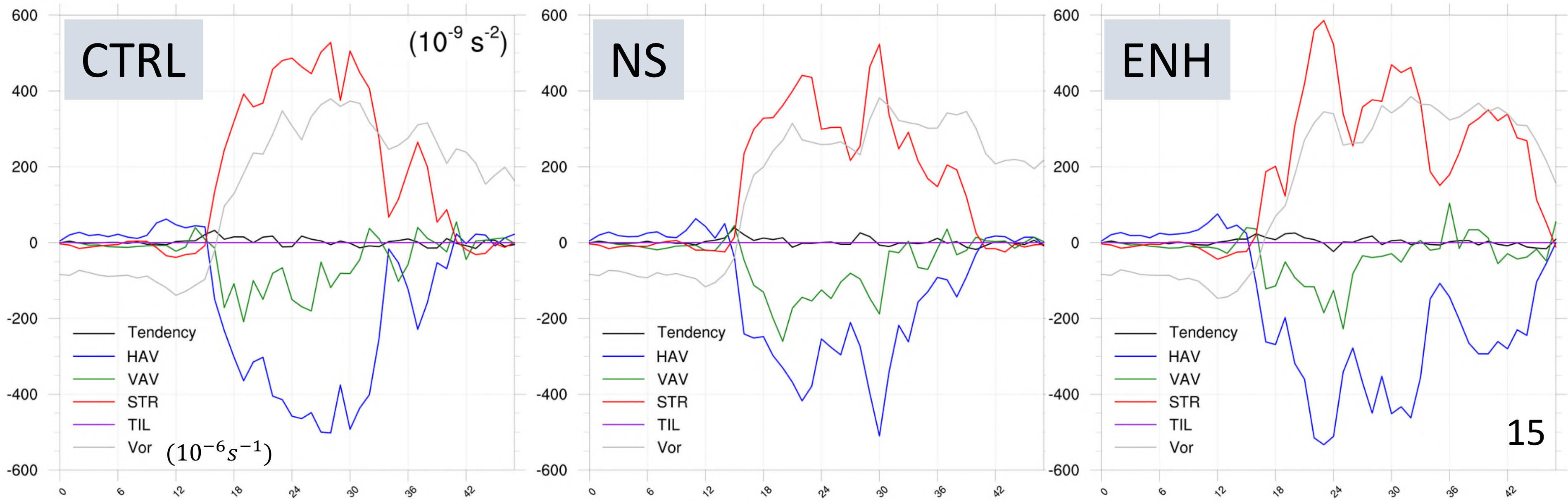
- In addition to sufficient moisture transport, rainfall also requires mechanisms that retain and concentrate moisture locally.
- The low-level moisture flux convergence between 1000 and 900 hPa highlights prominent convergence zones along the frontal zone and on the windward side of the terrain.
- The intensity of convergence along the frontal zone is similar across all experiments.



Vorticity Budget Analysis

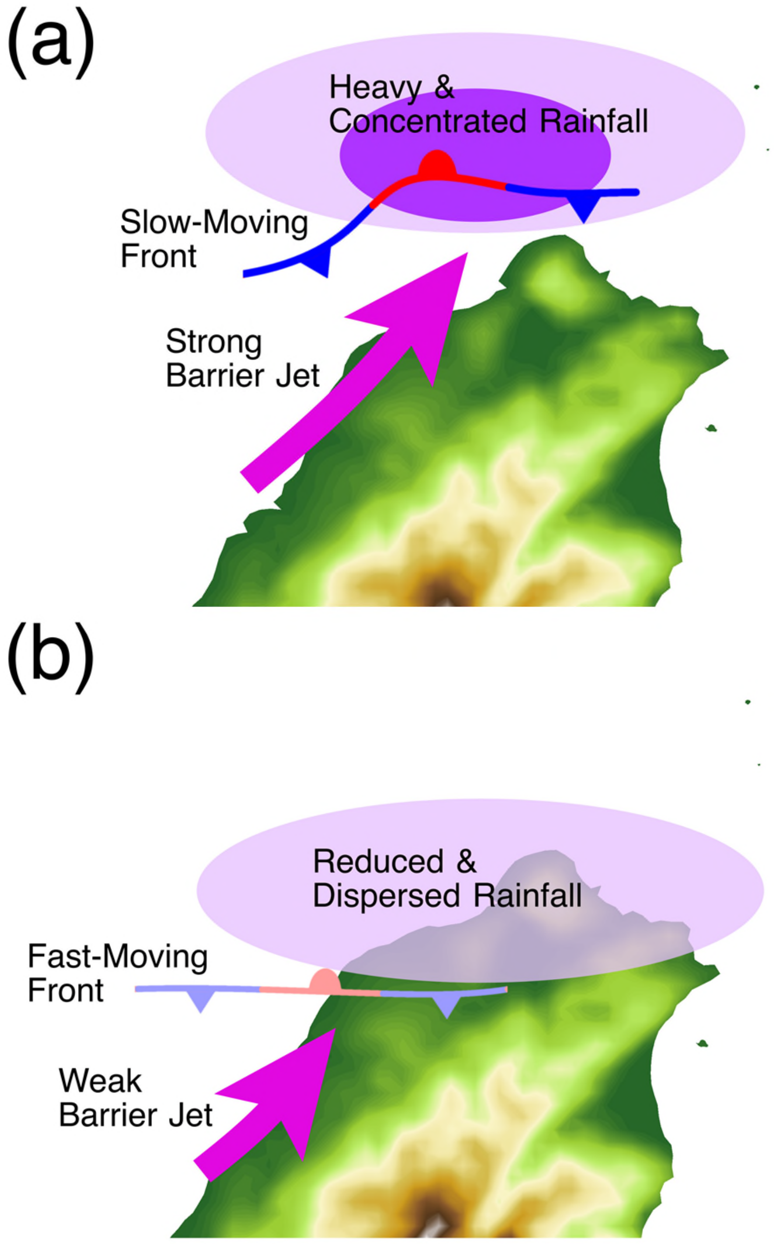
- To examine the dynamical impacts of the barrier jet, a vorticity budget analysis is conducted.
- The frontal zone corresponds to a region of vorticity maxima, meaning horizontal advection typically contributes negatively to local vorticity tendency.
- Strong low-level convergence is the primary positive contribution that sustains frontal development near the surface. While the peak convergence values are similar among experiments, the duration over which large values are maintained varies.
- In the experiment with a stronger barrier jet, enhanced and more persistent low-level moisture flux and convergence were maintained over a longer period, ultimately resulting in greater accumulated rainfall.





Conclusion

- The extreme rainfall event on 2 June 2017 occurred under favorable synoptic conditions, with abundant moisture supply supporting the development of heavy precipitation.
- The similar θ_e gradients and synoptic conditions across all experiments suggest that differences in rainfall and frontal movement result from variations in barrier jet intensity.
- An enhanced barrier jet was found to slow the southward progression of the front and result in a more localized rainfall distribution.
- The barrier jet also strengthened convergence along the frontal zone and provided additional low-level moisture transport into northwestern Taiwan.
- In the ENH experiment, the barrier jet wind speed increased by only 1 m s^{-1}, yet the front remained farther north for a longer period, highlighting the model's sensitivity to changes in barrier jet intensity.



Thank you for your attention!