Characteristics of the Marine Boundary Layer Jet over the South China Sea during the Early Summer Rainy Season of Taiwan

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Outline

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- Part I: Characteristics of marine boundary layer jet (MBLJ) over South China Sea during the early summer rainy season of Taiwan
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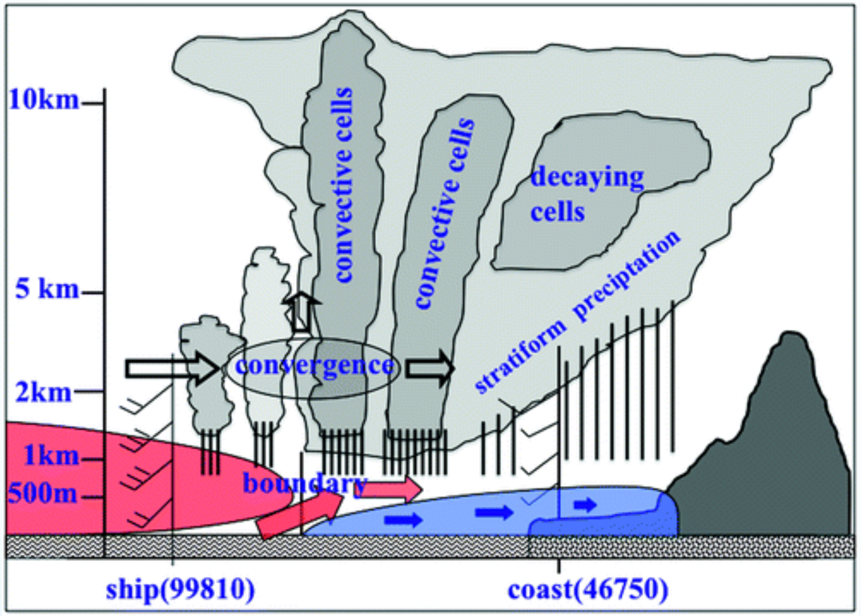
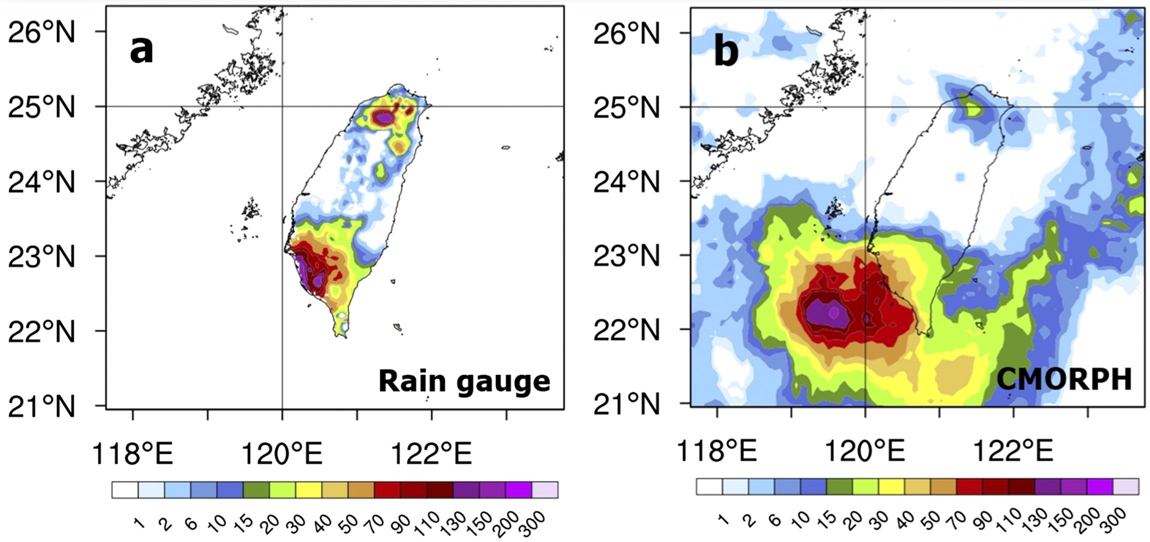
Introduction

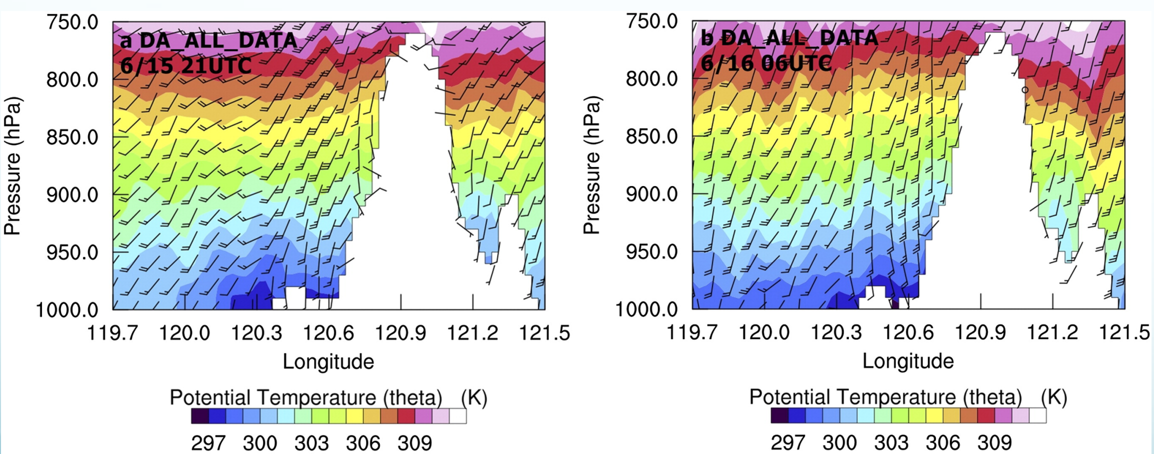


Red: unstable air Blue: cold pool Wind barbs: winds from soundings
boundary: between the cold pool and upstream flows

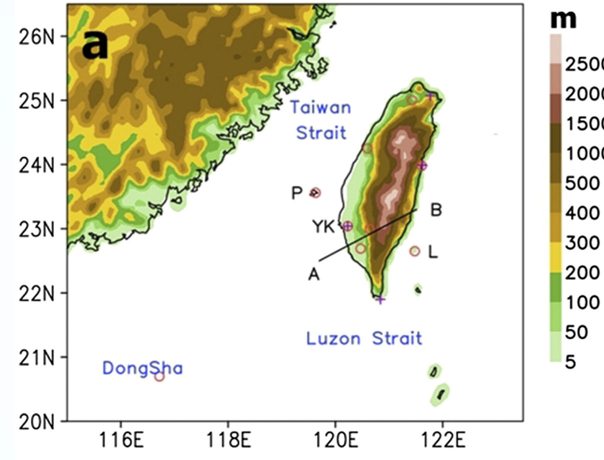
- For 2008 TiMREX IOP8 case, **Xu et al. (2012)** show that the uptream southwesterly LLJ (>15 m s^{-1} , between 950 and 900 hPa) is evident only up to 850–800 hPa using ship soundings and S-POL radar observation.
- Inside the large MCSs, new convection keeps developing upstream offshore at the boundary between a precipitation-formed cold pool and LLJ (**Xu et al. 2012**).

Daytime rainfall during 6/16 00-10UTC





Potential temperature and winds (1 barb= 5 m/s) along the line AB



- **Tu et al. (2014, 2017)** diagnose the interaction between southwesterly LLJ and precipitation-formed cold pool using model sensitivity tests.

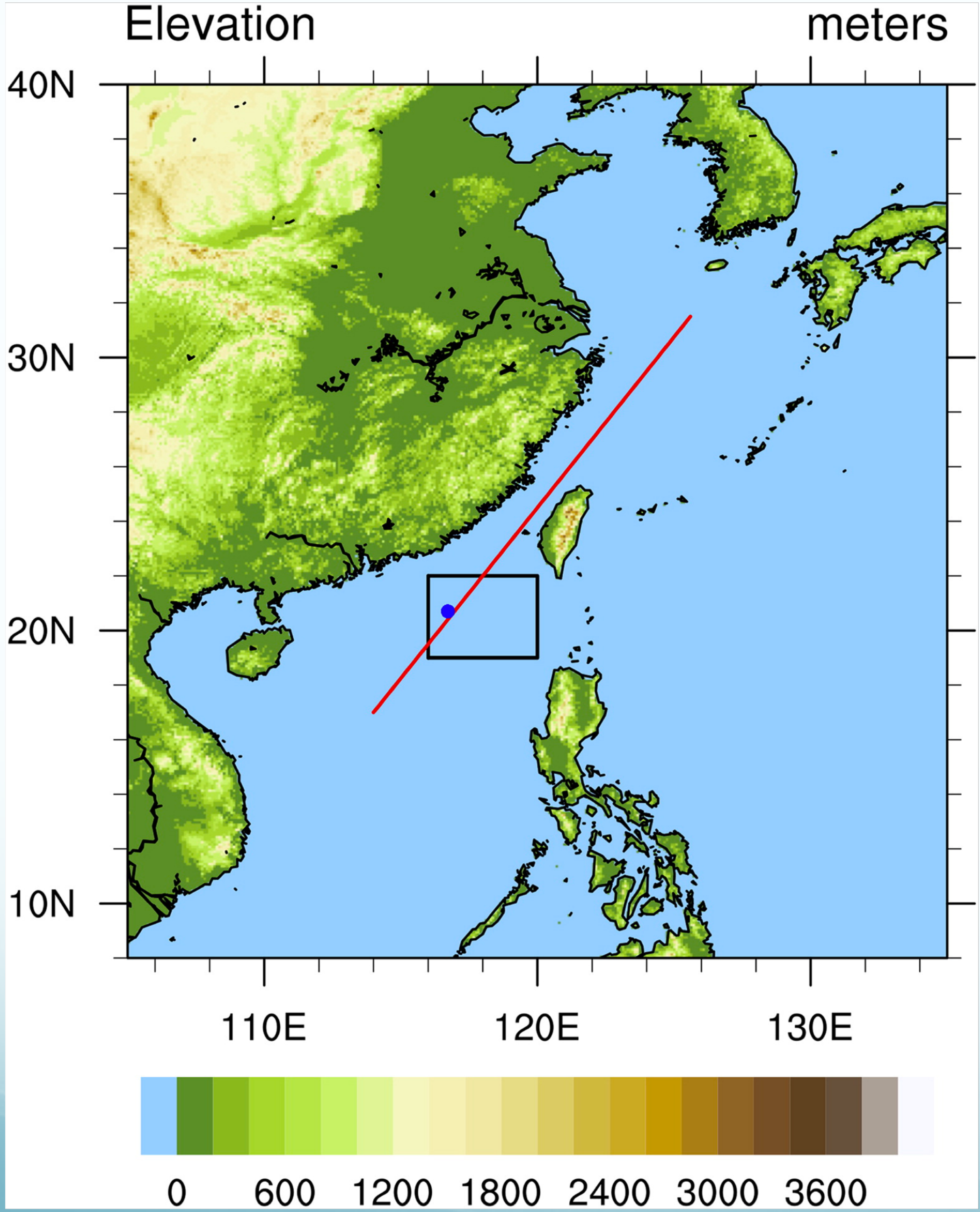
- This type of LLJ (or the marine boundary layer jet) event is apparently different from the LLJs associated with the subsynoptic Mei-Yu frontal systems with the maximum wind speed within the 700-850 hPa level (e.g., Chen and Yu 1988; Chen et al. 1994; and others).

MBLJ (marine boundary layer jet) criteria

- In this study, the NCEP Climate Forecast System Reanalysis (CFSR) data with $0.5^{o} \times 0.5^{o}$ grids are used to analyze climatological characteristics of MBLJs over the South China Sea during the early summer rainy season of Taiwan (June) from 2008-2012.

- The following criteria are used to allow us to identify MBLJ by considering the maximum wind speed and the vertical shear of horizontal wind **(Du et al. 2012, 2014)** : (1) the maximum wind speed below 900hPa level >10 m s^{-1}; and (2) in the lowest 4km (~600hPa) layer, the wind speed must decrease by at least 3 m s^{-1} from the height of the wind maximum within the PBL to the wind minimum above that.

MBLJ day definition



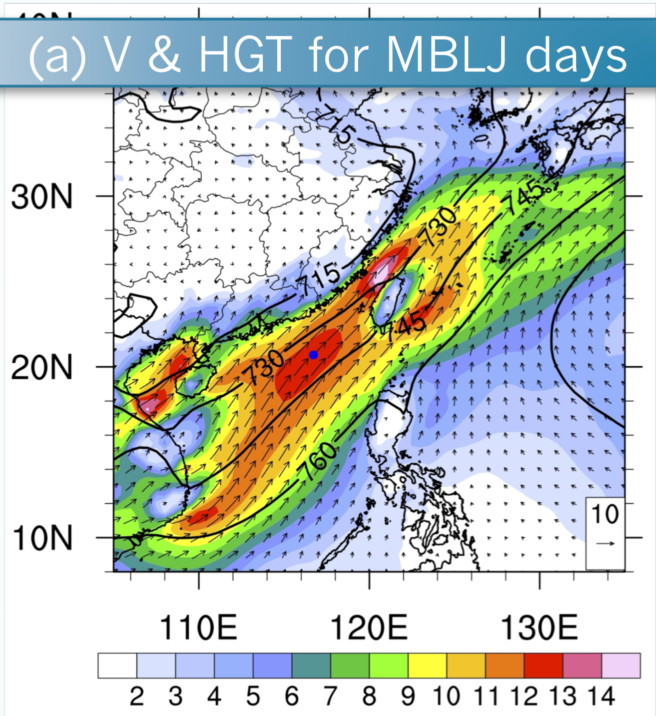
- Terrain Height (m).
- If more than 60% grids in the black box satisfy the MBLJ criteria and the MBLJ event persists over 6 hours, that entire day is defined as a MBLJ day.

Method- composite of MBLJ days

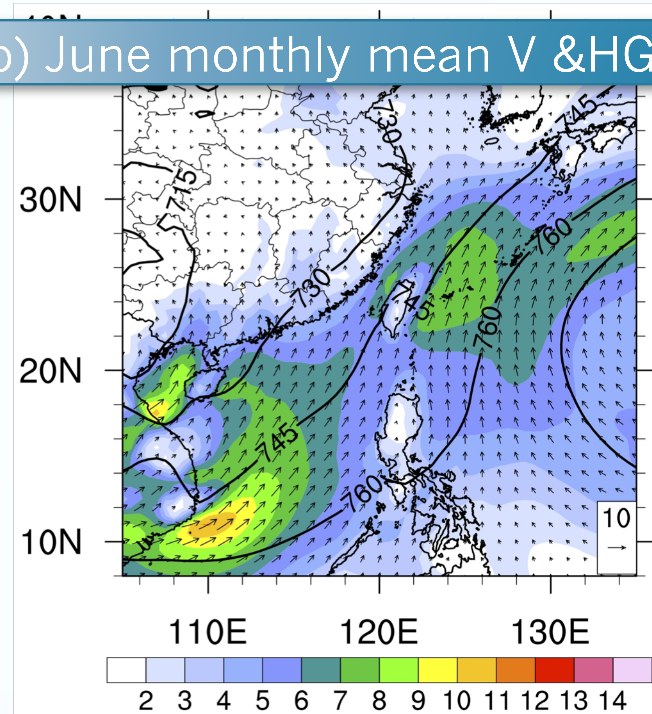
- MBLJ days without the presence of tropical cyclone (TC) or tropical depression (TD) within 105-150^{o}E, 8-35^{o}N over the Western Pacific in June during 2008-2012. (9-events; 21 days)

Year	MBLJ days without TC in June
2008	15-17, 27-28
2009	2-3, 12
2010	14-15, 24-26
2011	27-28
2012	8-10, 23-25

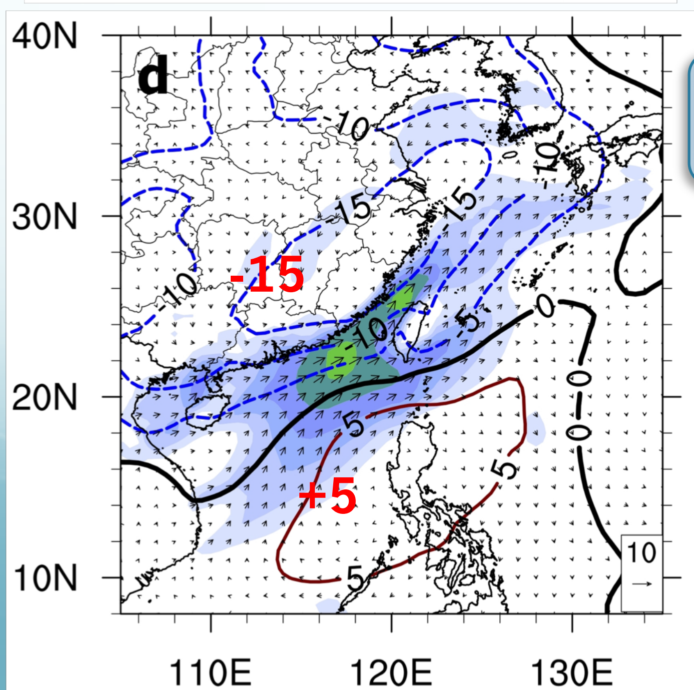
(a) V & HGT for MBLJ days



(b) June monthly mean V &HGT



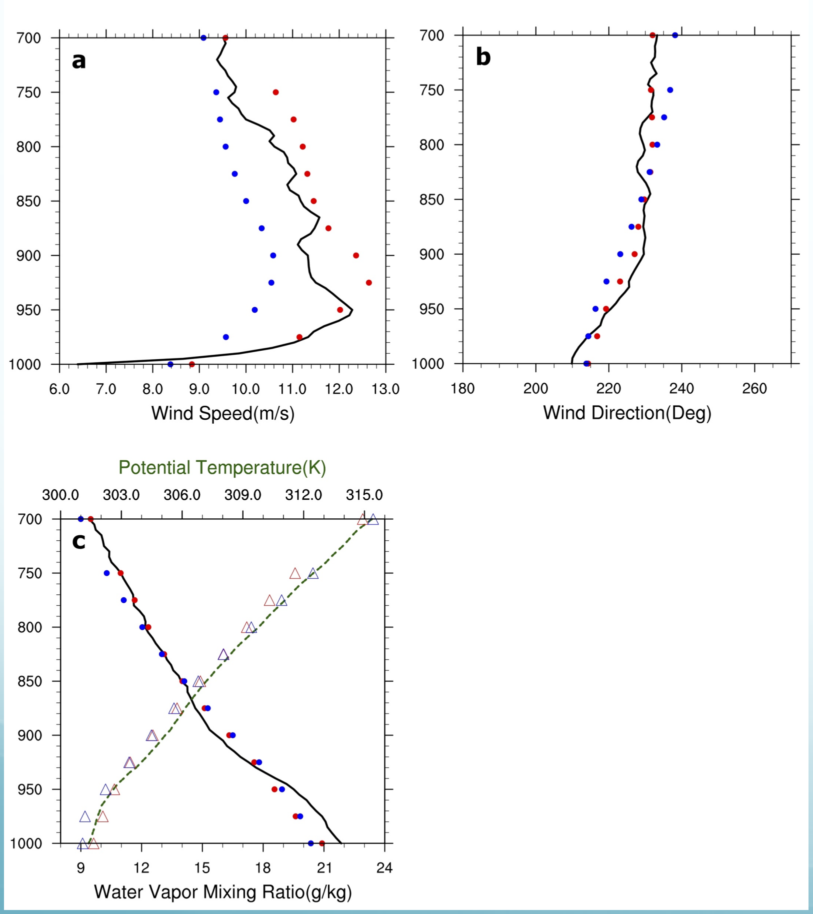
2008-2012 June
CFSR 925 hPa
composite



(c) V(m/s) & HGT (gpm) difference
(MBLJ days-mean)

During MBLJ days, the Mei-Yu trough is deeper and WPSH extends further westward and is stronger with larger pressure gradients over the northern South China Sea as compared with monthly mean chart.

(a) The composite wind speed (m s^{-1}) from Dongsha soundings during the MBLJ days from 2010 to 2012 June (solid black line) (Dongsha sounding system is upgraded to new system — Vaisala DigiCORA® Sounding System MW41 since September 2009). The red and blue dots represent composite wind speed profiles near Dongsha Island (116.7°E, 20.7°N) from the CFSR (116.5°E, 20.5°N) and ERA-Interim (116.7°E, 20.7°N) reanalysis, respectively. (b) Same as (a) but for the composite wind direction (deg). (c) The composite water vapor mixing ratio (g kg^{-1}, solid black line) and potential temperature (K, dashed green line) from Dongsha soundings during the MBLJ days from 2010 to 2012 June. The red and blue dots (triangles) represent composite water vapor mixing ratio (potential temperature) profiles from the CFSR and ERA-Interim reanalysis, respectively.

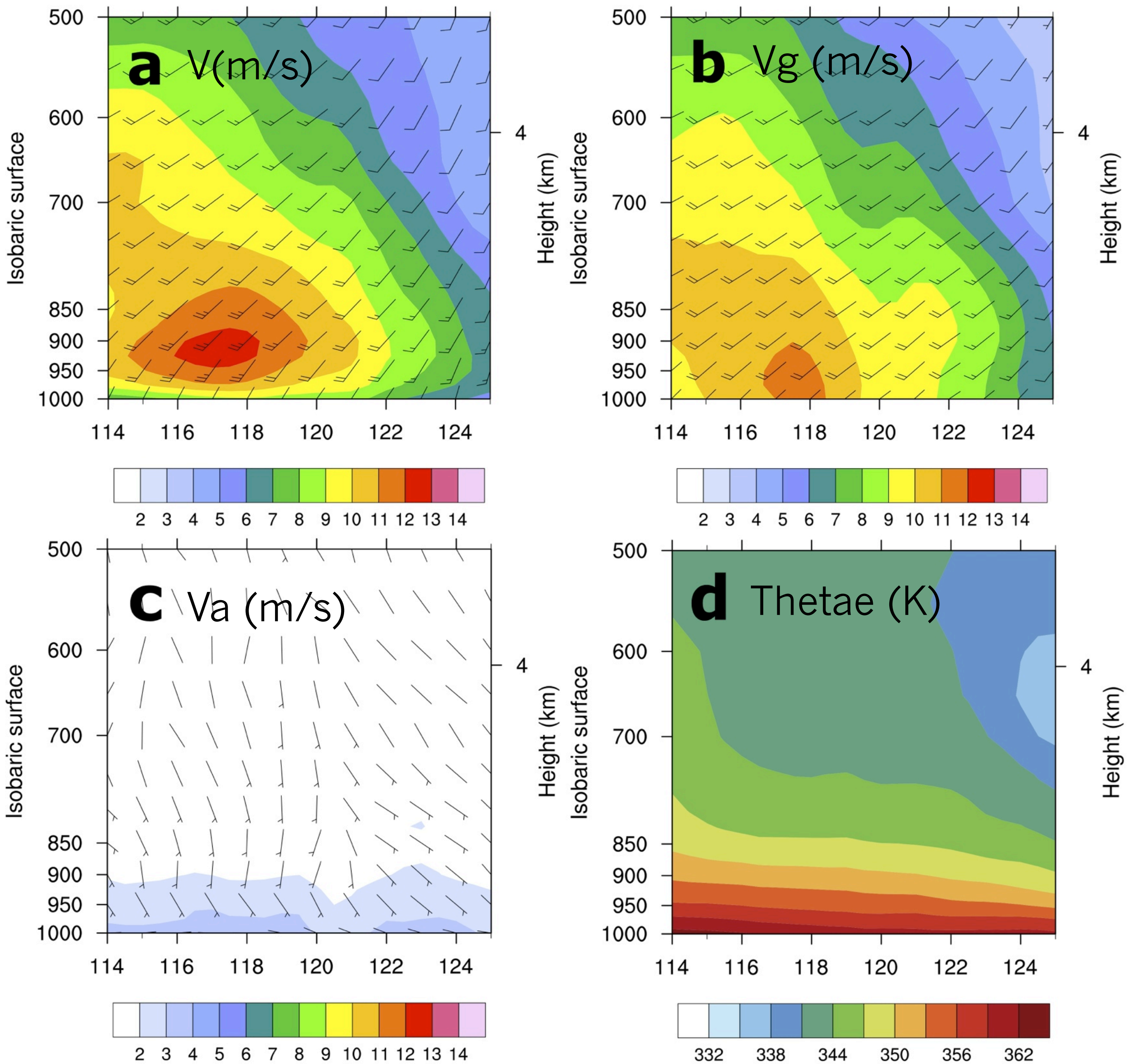


Sounding Observation
CFSR
ERA-Interim

-The composite CFSR wind profile agrees reasonable well with the Dongsha soundings except the jet level is slightly lower in observations (~ 950 hPa) as compared with the CFSR analysis (~ 925 hPa)

-Both CFSR and ERA-Interim data underestimate the moisture in the lowest layer

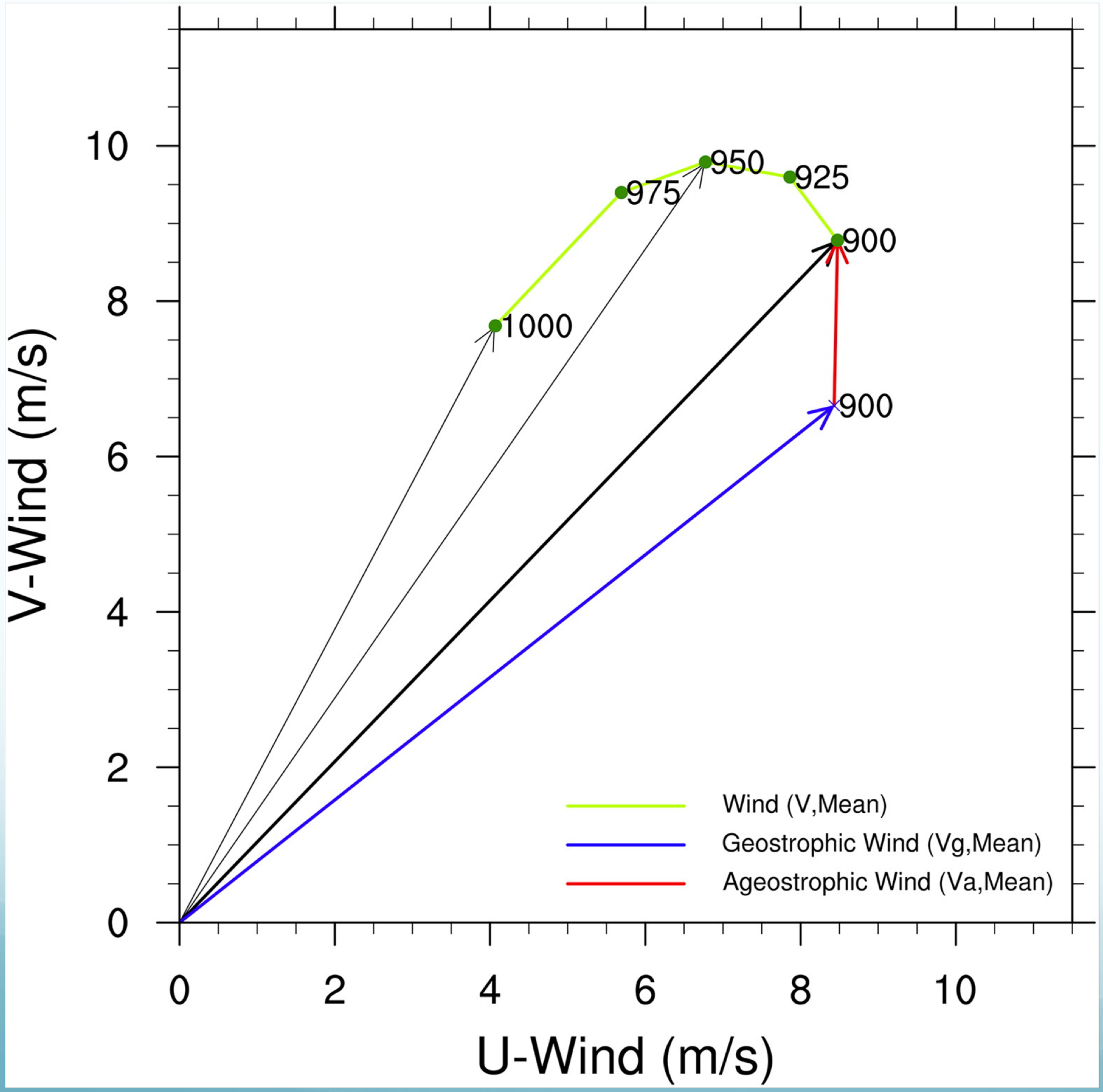
CFSR composite of vertical cross section along 21°N for MBLJ days.



(1 barb = 5m/s)

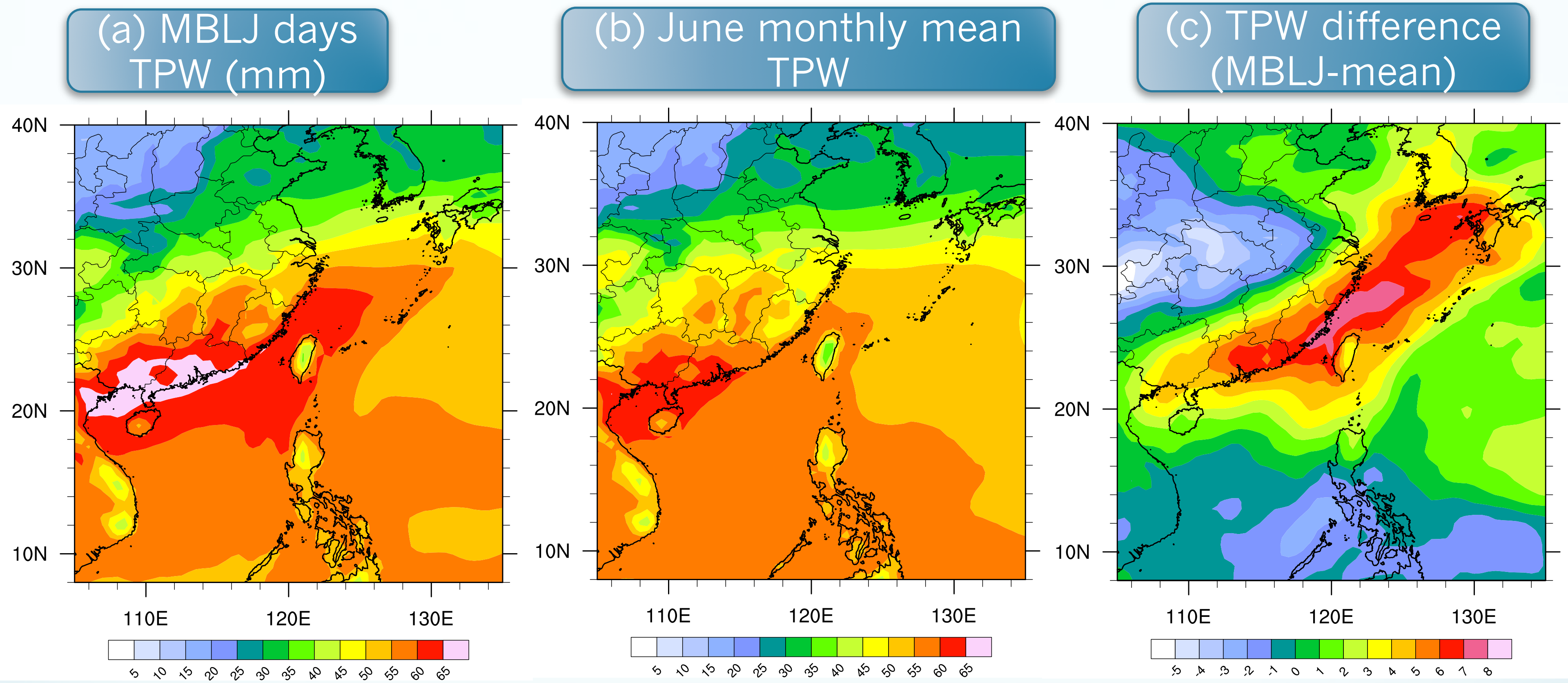
- The supper-geostrophic wind is near the top of the marine boundary layer
- The dry and stable air is above the MBLJ core, near the top of marine boundary layer.

The hodograph at the jet core of the MBLJs (20.5°N, 116.5°E)



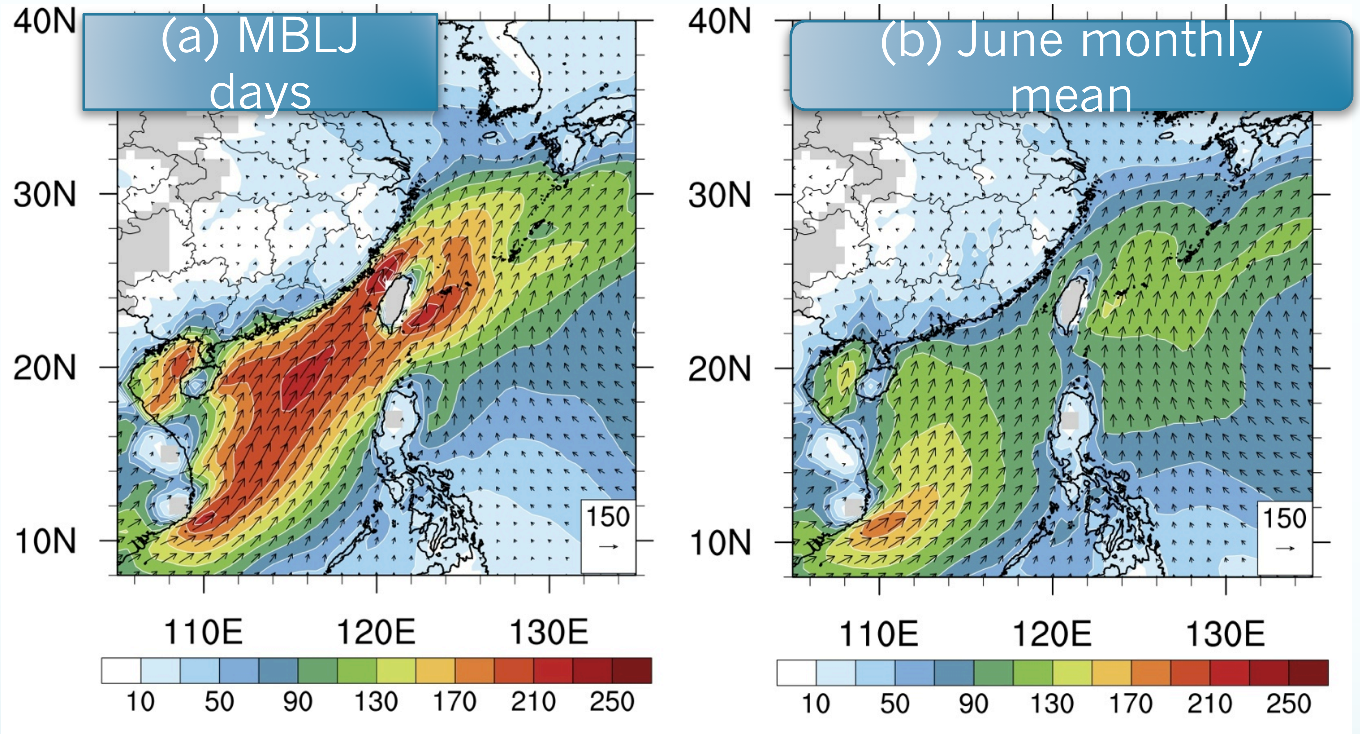
- The vertical wind profile at the jet core resembles an Ekman spiral (*Holton*, 2004; *Mellor*, 1996)

2008-2012 CFSR composite TPW (mm)
MBLJ days; June monthly mean; differences (MBLJ days-mean)



- A moisture tongue extends from the South China Sea to Taiwan when a MBLJ occurs.

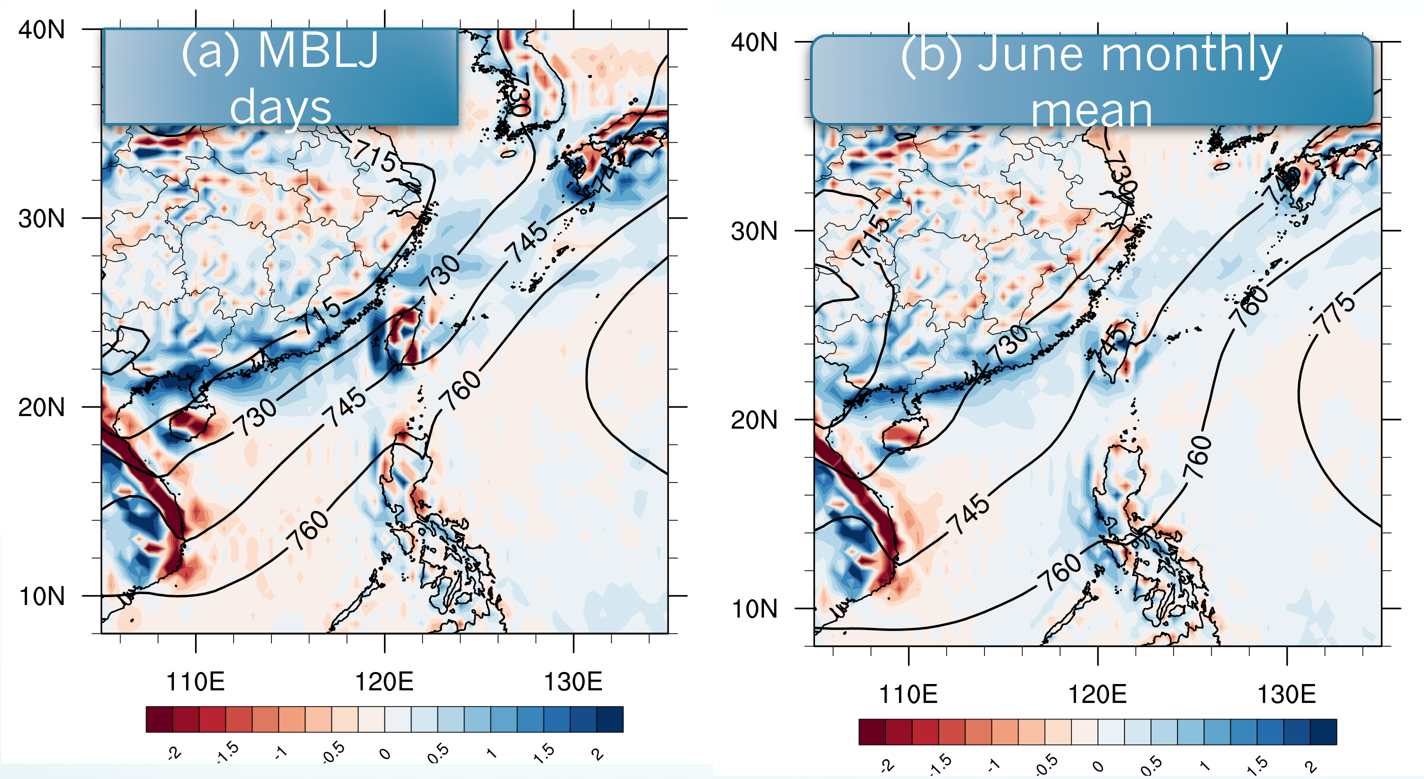
2008-2012 June CFSR composite of vertically integrated water vapor transport (hereafter, integrated vapor transport, IVT, kg m^{-1} s^{-1}) in the boundary layer (below 900hPa)



The vectors in (a), and (b) show the direction of IVT.

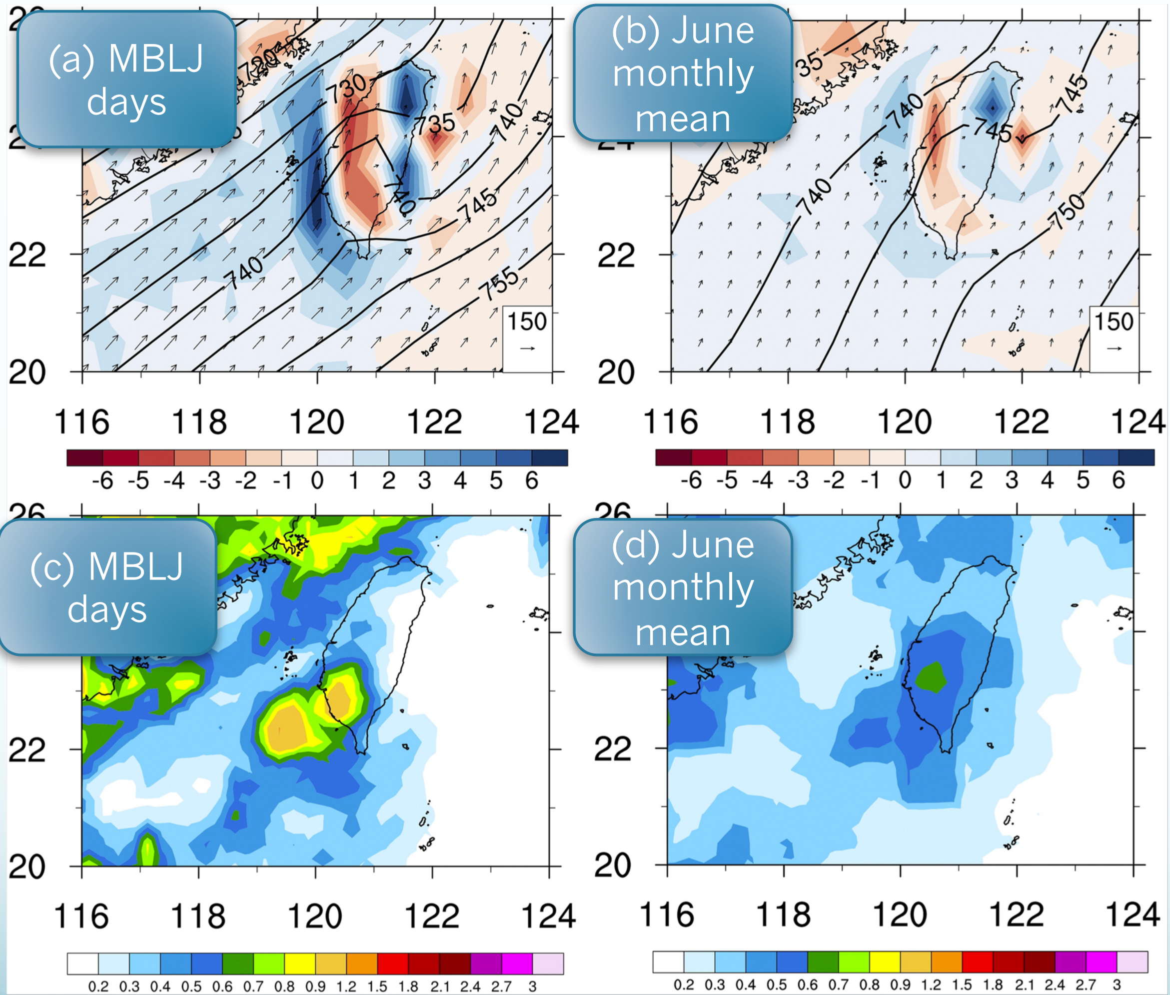
- The IVT pattern has a maximum at the jet core over the northern South China Sea and the IVT axis covers almost entire South China Sea.

2008-2012 June composite CFSR 925 hPa w (cm/s) & HGT



- Due to the orographic blocking of MBLJ, there is significant upward motion off the the southwestern Taiwan coastal area at the 925-hPa level.
- For the monthly mean flow, with a weaker southwesterly monsoon flow upstream of Taiwan, the orographic blocking is less significant.

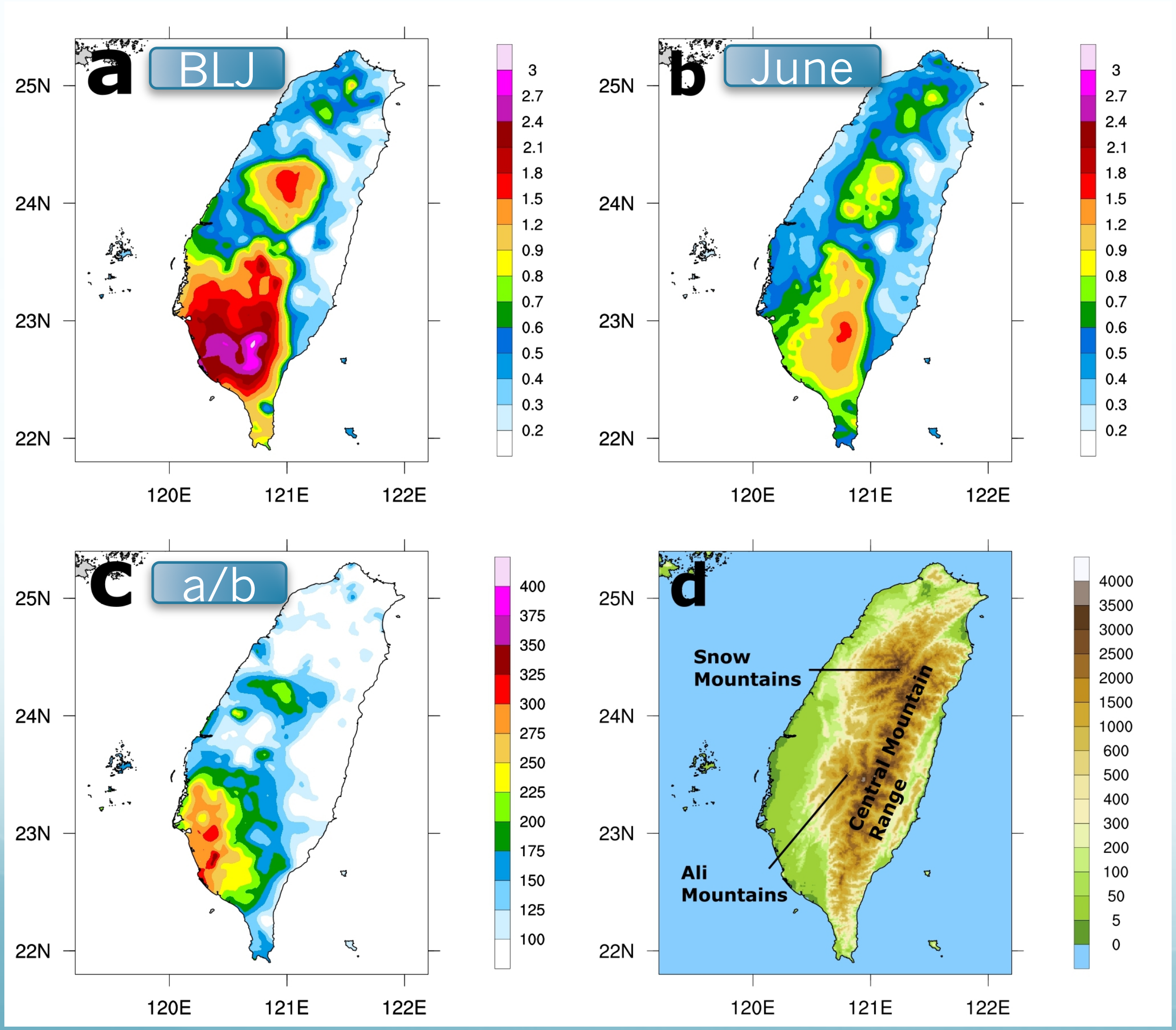
2008-2012 CFSR composite of 925-hPa moisture flux convergence (10^{-4} g kg^{-1} s^{-1}, shaded), geopotential height (gpm, contoured), and moisture flux (g kg^{-1} m s^{-1}, vectors)



2008-2012 0.25° TRMM (c) composite of rain rate (mm hr^{-1}, shaded) (from 3B42 data set)

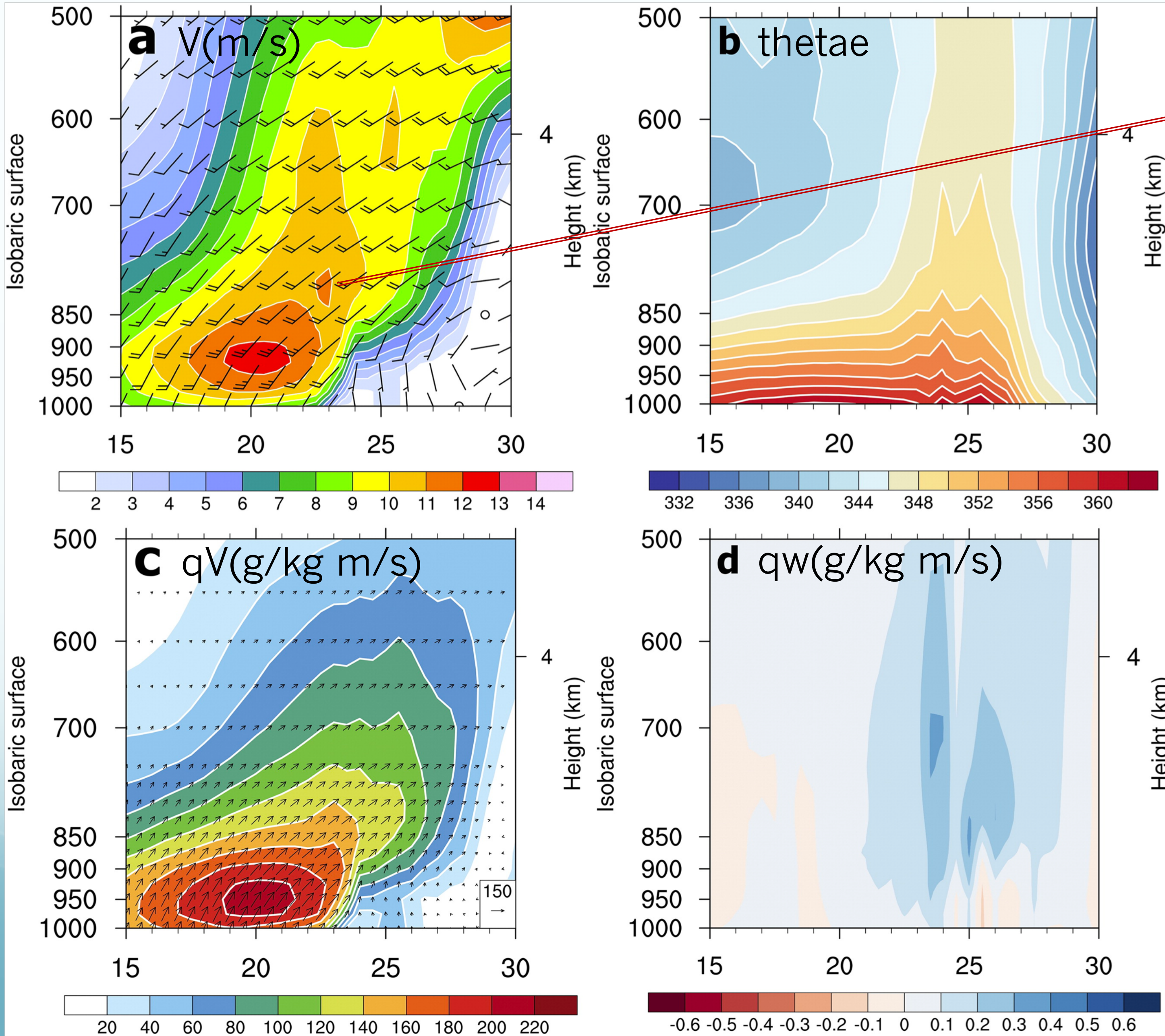
- During the MBLJ days, the large low-level moisture transport and moisture convergence are favorable for the development of heavy rainfall over southwestern Taiwan and offshore.

The 2008-2012 (a) composite of rain rates (mm hr^{-1}, shaded) for the MBLJ days and (b) June monthly mean from rain gauge observations. (c) The ratio of composite rain rates for the MBLJ days to June monthly mean rain rates (%) [(a)/(b)]. (d) Terrain height (m) over Taiwan.



- For the June monthly mean, the moist southwesterly monsoon flow interacts with the Taiwan terrain (e.g., orographic lifting and blocking), which produces a rainfall maximum along the southwestern slope of the CMR and a considerable amount of rain over southwestern Taiwan, the southwestern slope flank of the Snow Mountains, and the Ali Mountains.

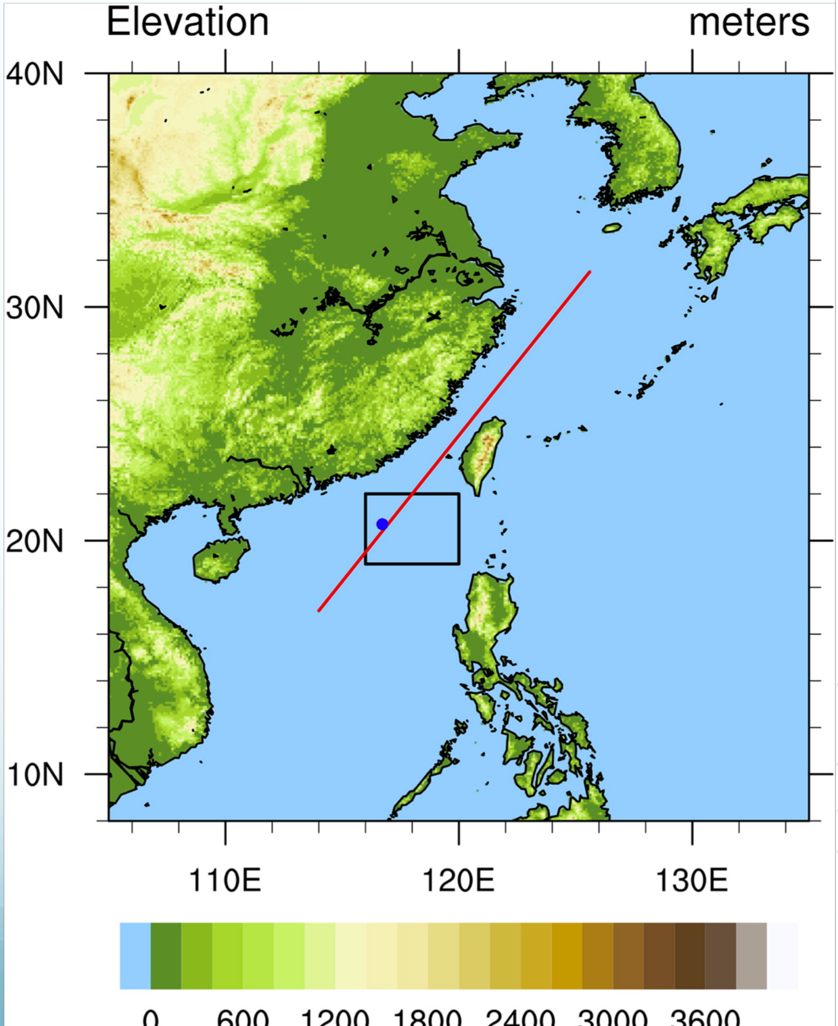
N-S vertical cross section along 116.5°E

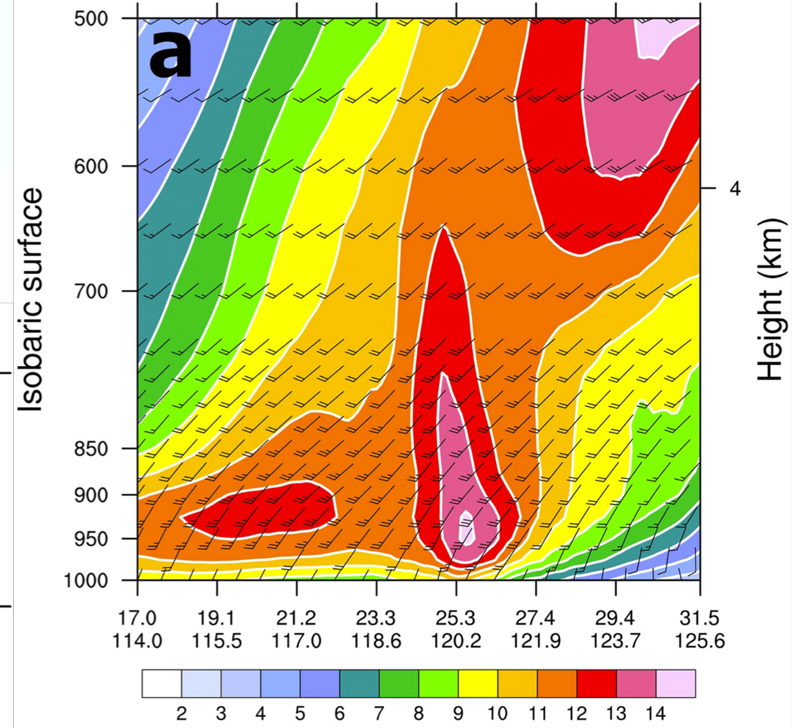


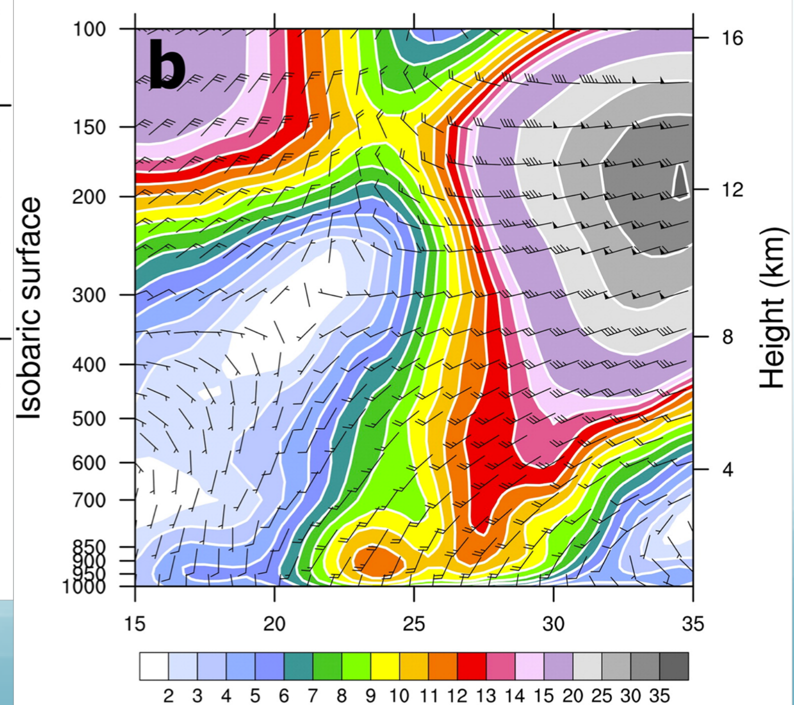
LLJs associated with the subsynoptic Mei-Yu frontal systems with the maximum wind speed within the 700-850 hPa level (e.g., Chen and Yu 1988; Chen et al. 1994; and others). (synoptic-system-related low-level jet/SLLJ)

a) NE-SW vertical cross section line (red)

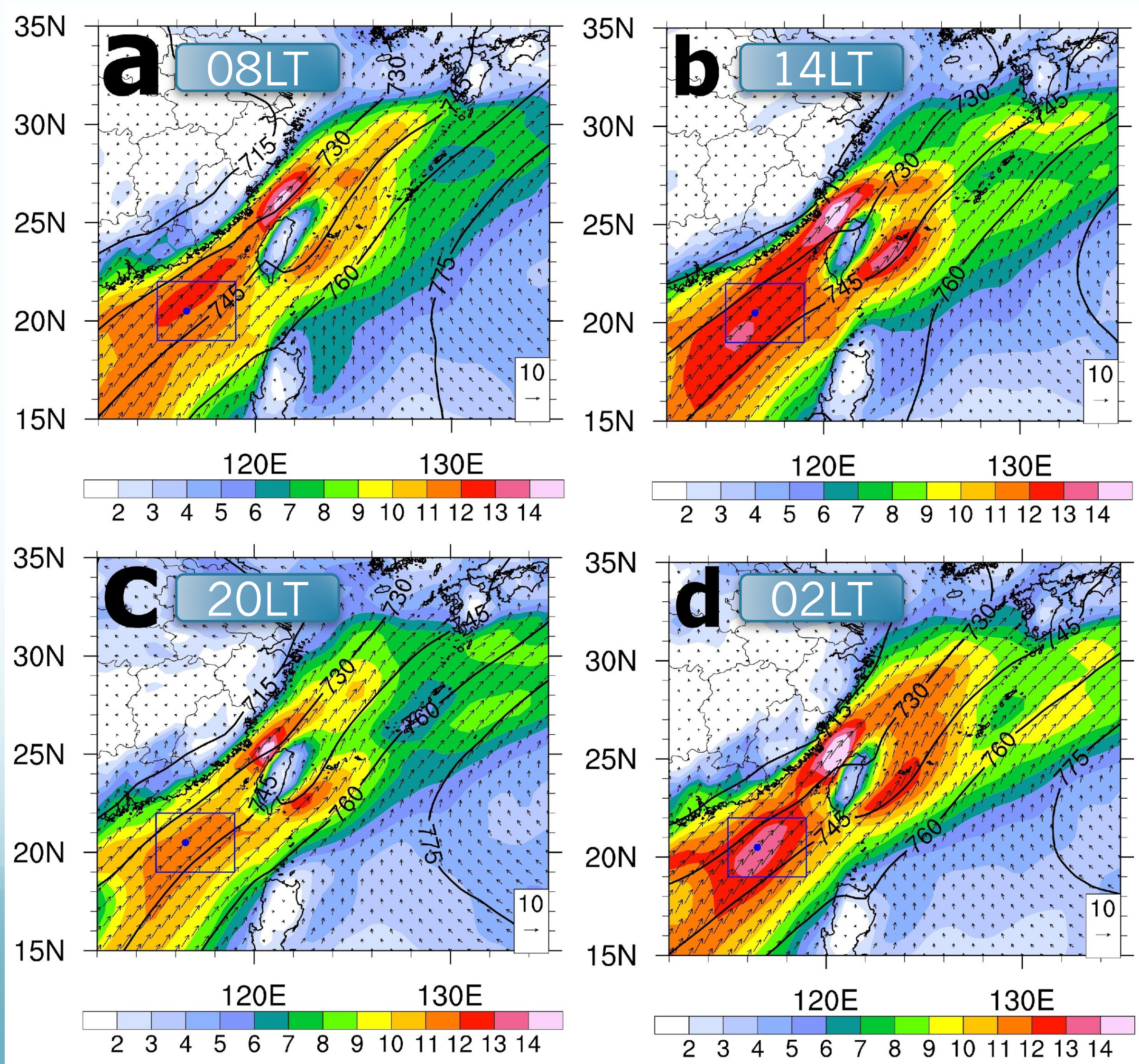
b) N-S vertical cross section along 124°E





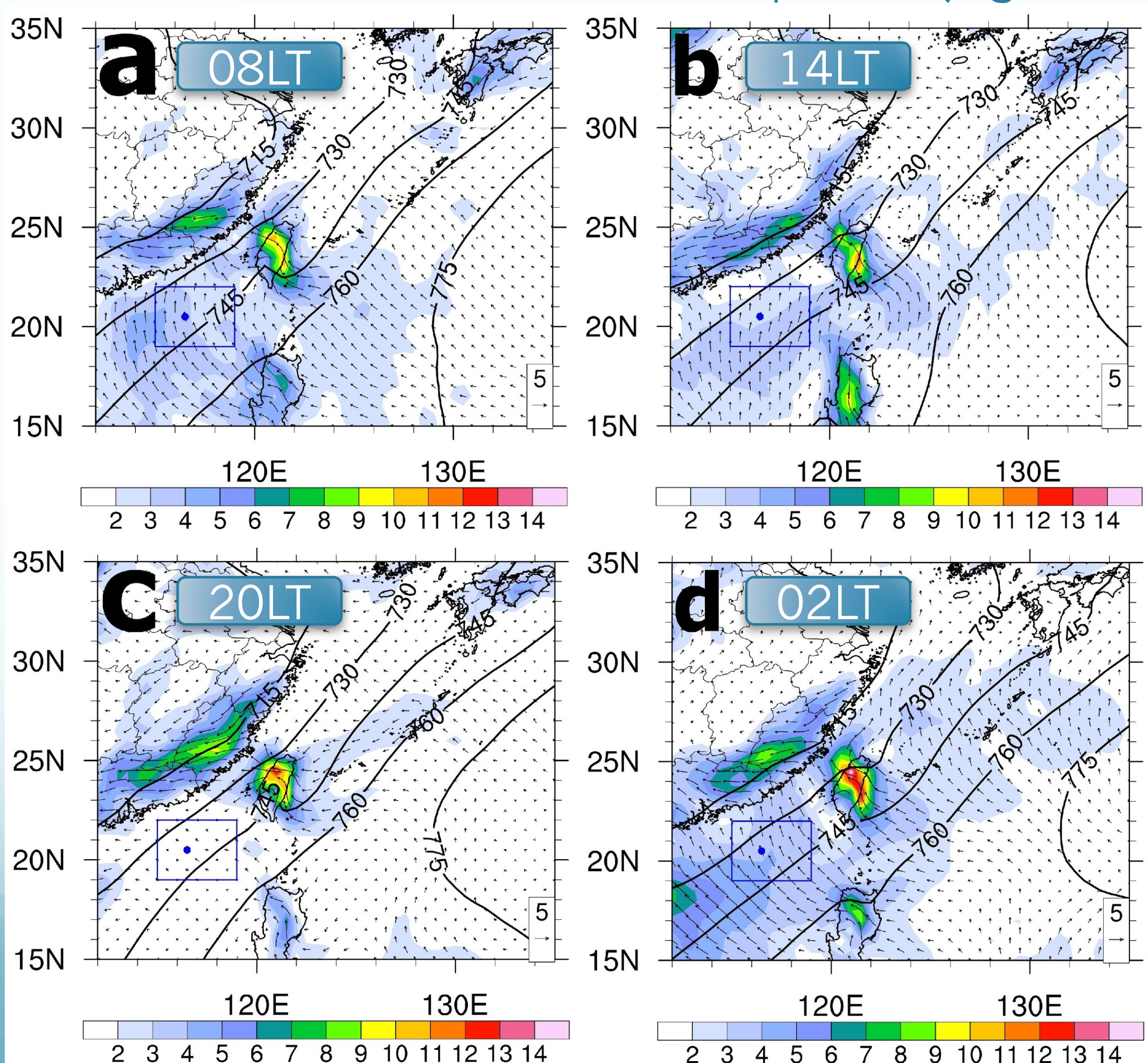


The MBLJ is the weakest in the later afternoon/early evening at 2000 LST and the strongest at 0200 LST.



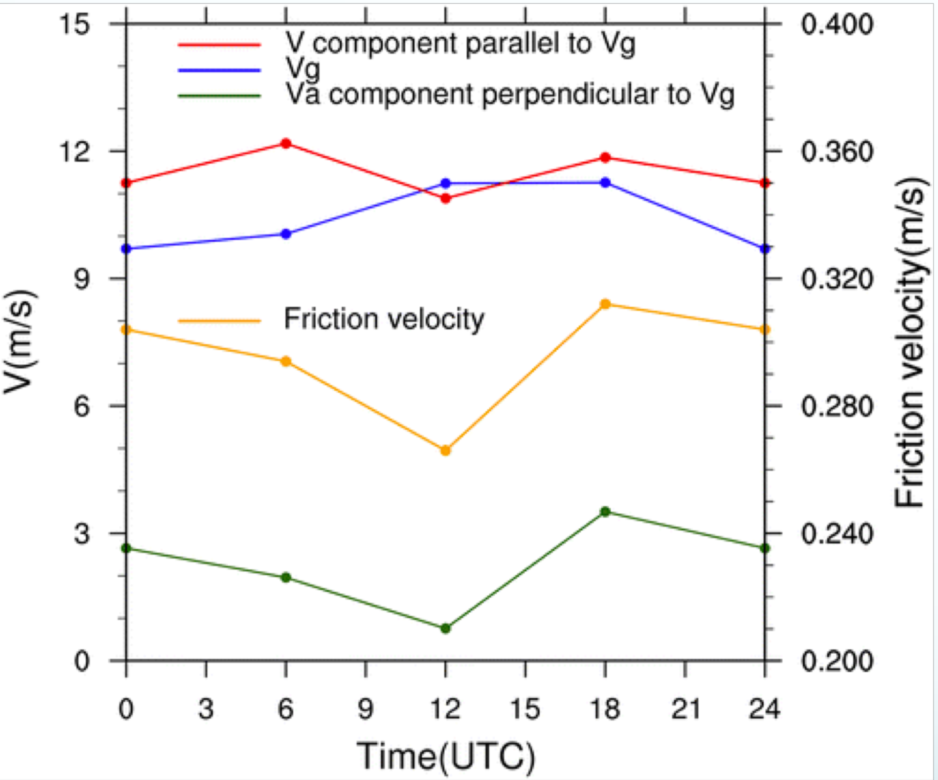
- Diurnal cycle of 925-hPa winds (m s^{-1}) for the MBLJ days: (a) 0000 UTC (0800 LST), (b) 06UTC (1400 LST), (c) 1200 UTC (2000 LST), and (d) 1800 UTC (0200 LST).

At 0200 LST, at the jet core the ageostrophic winds are > 3 m s^{-1} and cross the geopotential height contours with a large angle (Fig. d). At 2000 LST, the ageostrophic winds are rather weak (~ 1 m s^{-1}) (Fig. c).
At both 0800 LST and 1400 LST, the ageostrophic winds also have a cross contour wind component (Figs. a and b).



- Diurnal cycle of 925-hPa ageostrophic winds (m s^{-1}) for the MBLJ days: (a) 0000 UTC (0800 LST), (b) 06UTC (1400 LST), (c) 1200 UTC (2000 LST), and (d) 1800 UTC (0200 LST).

FIG. 15. Diurnal variations of the CFSR wind component parallel to the geostrophic flow (m s^{-1}; red line), the speed of the geostrophic flow (m s^{-1}; blue line), the ageostrophic wind component perpendicular to the geostrophic flow (m s^{-1}; green line), and friction velocity (m s^{-1}) for the MBLJ days over the boxed area (19°–22°N, 115°–119°E; blue box in Fig. 13).



- Around early evening (2000 LST), the airflow near the top of the boundary layer is close to the geostrophic flow and is supergeostrophic during the rest of the day (Figs. 15 and B1) due to diurnal variations in the surface friction velocity.
- During the nighttime, the cross-contour ageostrophic winds increase as the surface friction velocity increases (Figs. 14 and 15).
- The ageostrophic winds that point to lower pressure are most significant during nighttime (0200 LST; Figs. 15 and B1).
- It appears that the slight late afternoon minimum in the MBLJ is related to a reduction in surface friction velocity due to mixing at the lowest levels.

Summary and Conclusion

- The MBLJ found in this study is distinctly different from the low level jets (LLJs) associated with the subsynoptic frontal systems during the early summer rainy season with maximum wind speed at the 700–850-hPa level (e.g., Chen and Yu 1988; Chen et al. 1994; and others).
- The MBLJ events over the northern South China Sea mainly occur during the second half of the monsoon rainy season over Taiwan (after 1 June) and have a wind speed maximum around the 925-hPa level.
- During MBLJ days, the Mei-Yu trough over southeastern China is deeper and the Western Pacific Subtropical High (WPSH) is stronger and extends more westward than climatological mean.

- The MBLJs are mainly caused by the subsyoptic-scale pressure gradients. At the jet core, the vertical wind profile resembles an **Ekman spiral** with a wind speed maximum near the top of the marine boundary layer.
- The horizontal moisture transports by the MBLJs from the northern South China Sea to the Taiwan area is a pre-cursor for the occurrences of heavy rainfall events over southwestern Taiwan.
- Orographic blocking of the MBLJs provides the localized lifting needed for the develop of heavy rainfall over southwestern Taiwan and offshore.
- The MBLJs are strongest at night and close to geostrophic flow in the late afternoon/early evening. This is because the friction velocity and ageostrophic wind decrease during daytime in response to mixing in the lowest levels.

Thank you