

Dynamical Downscaling Simulation and Future Projection of Extreme Precipitation Activities in Taiwan during the Mei-Yu Seasons

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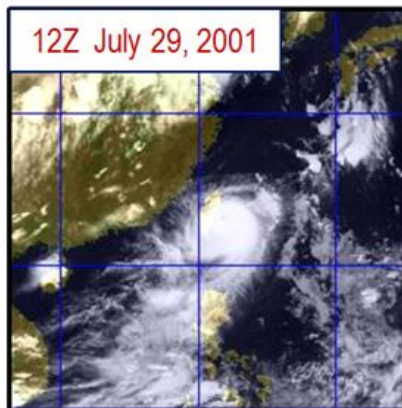
Outline

- **Introduction**
- **Data and Methods**
- **Results – Present & Projected changes**
- **Discussion – Possible Mechanism**
- **Summary**

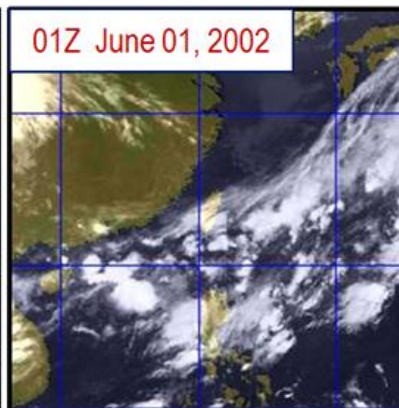
Introduction

- Summer rainfall in Taiwan is composed of four types of rain events: **tropical cyclone (TC)**, **frontal convection (FC)**, **diurnal convection (DC)**, and **other southerly convection (SC)** that propagates from the nearby ocean.

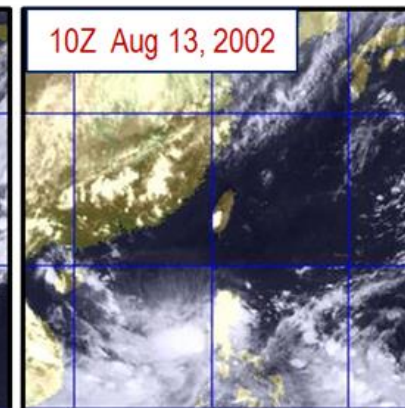
(a) Tropical Cyclone



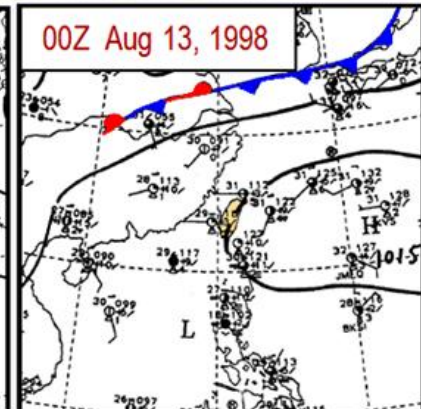
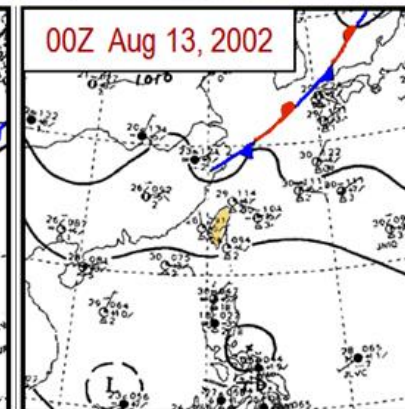
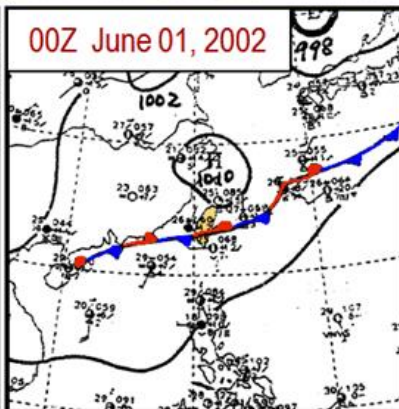
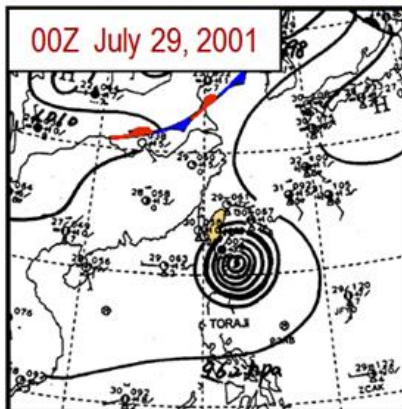
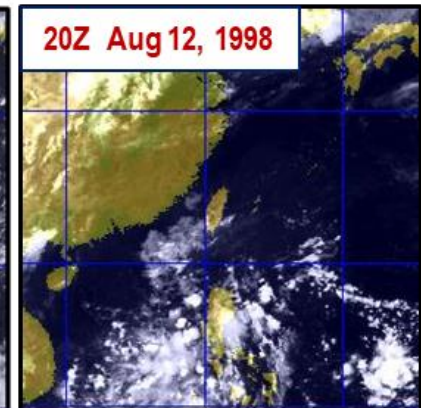
(b) Frontal Convection



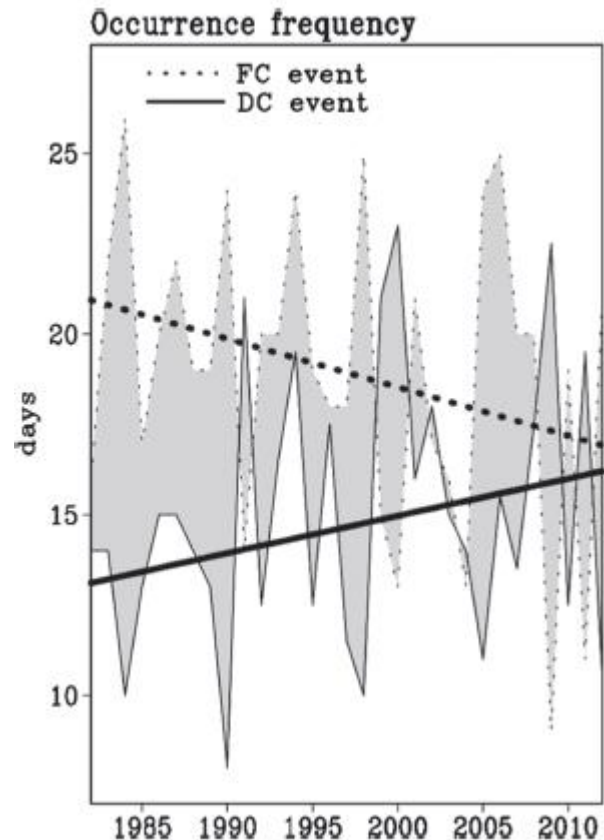
(c) Diurnal Convection



(d) Southerly Convection



Introduction

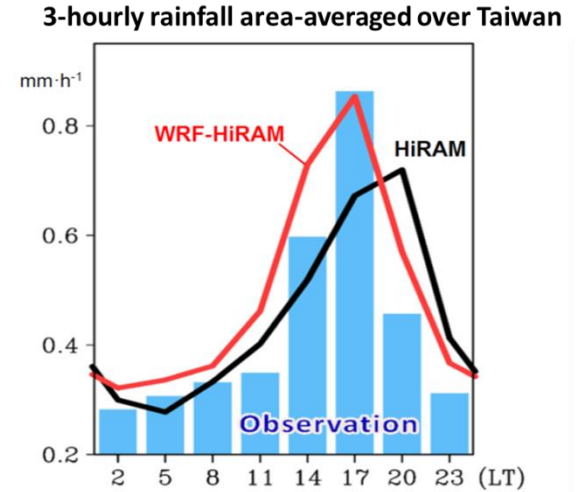


Huang and Chen (2015)

- Huang and Chen (2015) noted that the occurrence frequency of **frontal precipitation in Taiwan declined** (a negative trend) during the Mei-Yu seasons of 1982–2012, which was due to **the changes in the East-Asian monsoonal circulation** over the past several decades.
- It is likely that **future changes in the East-Asian monsoonal circulation** might also play an important role in affecting the **Mei-Yu season extreme precipitation activities** in Taiwan.

Introduction

- Most global models have problems capturing the right timing of the appearance of the diurnal precipitation maximum in Taiwan.
- Such a bias can be reduced using the **WRF dynamical downscaling simulation** (Huang et al. 2016a, b; Huang and Wang 2017).



Huang et al. (2016a)

- Likely, the use of a **WRF dynamical downscaling approach** might be a good method to reduce the bias of global models in simulating the Mei-Yu season extreme precipitation activities over Taiwan; this issue is examined in this study.

Objective

The main objectives of this study are as follows:

- (1) To clarify whether the **WRF dynamical downscaling** approach can add valuable information when simulating the Mei-Yu season extreme precipitation activities (including intensity and frequency) in Taiwan.
 - (2) To clarify whether the **projected changes** in the Mei-Yu season extreme precipitation activities in Taiwan are location dependent.
 - (3) To clarify whether the findings of issues (1) and (2) are dependent on the models.
- We assessed the **present-day simulation (1979–2003) and future projection (2075–2099, the RCP 8.5 scenario)** of rainfall in Taiwan by **using the regional WRF model driven by the High Resolution Atmospheric Model (HiRAM) and Meteorological Research Institute Atmospheric General Circulation Model (MRI).**

Data and Method

Identification of Extreme precipitation Events

- Two frequently used core indices, **Prec90p** and **R90N**, from the Statistical and Regional dynamical Downscaling of Extremes (STARDEX) indices suggested by the European Union are adopted in this study.
- **Prec90p** : the 90th percentile rainfall intensity of daily precipitation area-averaged over whole Taiwan (P_{TW}) – **criteria of extreme rainfall events**.
- **R90N** : the number of days with daily precipitation intensity $>$ prec90p; this was counted for each grid over the domain of Taiwan – **extreme rainfall frequency**.
- **PR90** : the precipitation intensity for extreme events, which is the average intensity for cases with $P_{TW} > \text{Prec90p}$ – **extreme rainfall intensity**.
- **Pav** : climatological mean of Mei-Yu season precipitation; averaged for all days of May and June – **MJ mean**.

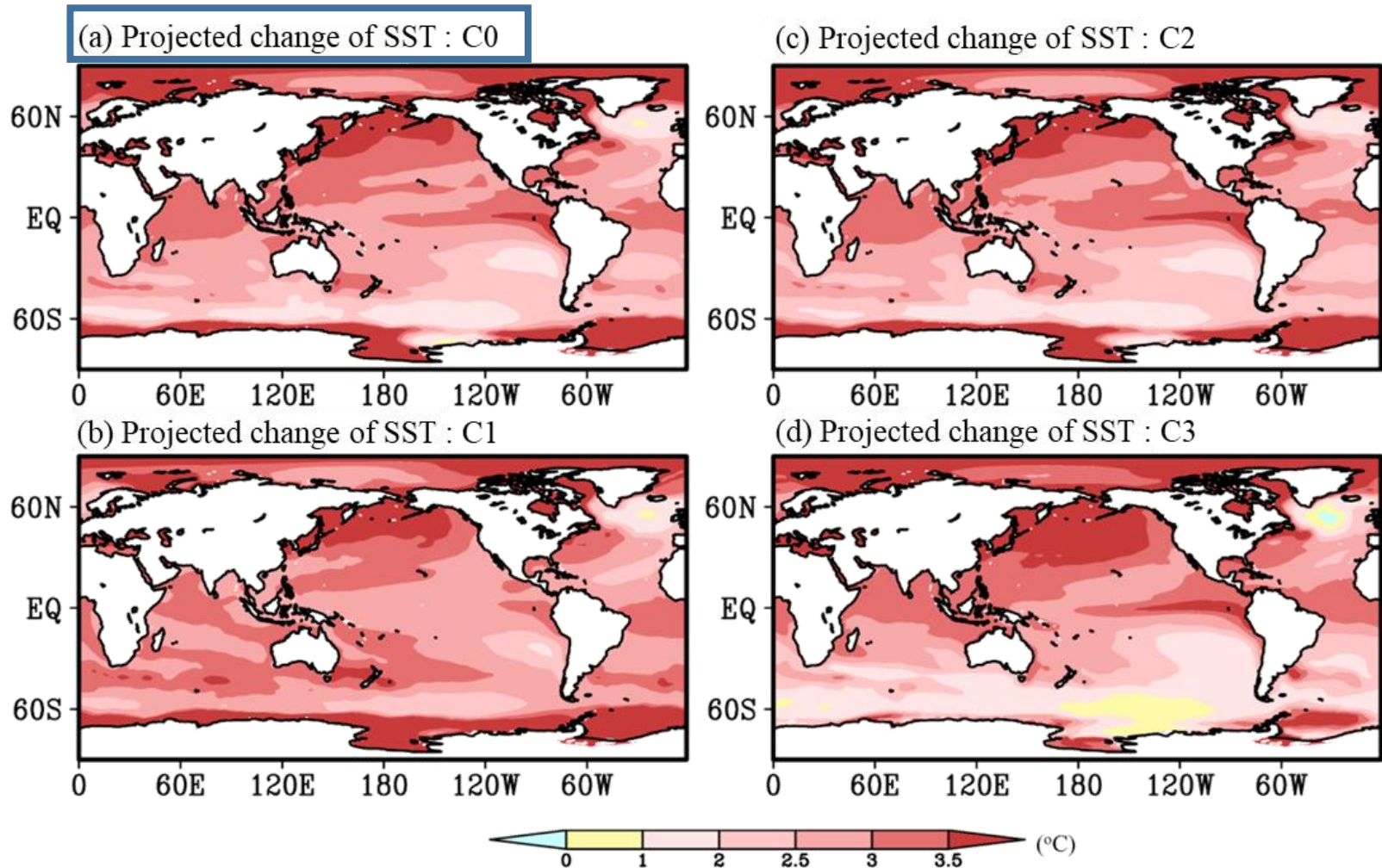
Data and Method

Observation	Description	Resolution
Precipitation	uniform grid remapping data from the rain gauge-observations in Taiwan	5km
Circulation	MERRA (Modern-Era Retrospective Analysis for Research and Applications) reanalysis	1.25°x1.25°
Models	Description	Resolution
HiRAM	High Resolution Atmospheric Model (Zhao et al. 2009)	25km 32 vertical layers and model top at 1 hPa
MRI	Meteorological Research Institute Atmospheric General Circulation Model (Mizuta et al. 2012)	20km 64 vertical layers and model top at 0.01 hPa
WRF	Weather Research and Forecasting (Skamarock et al. 2008)	5km 36 vertical layers from surface to 50 hPa

Examined time Periods

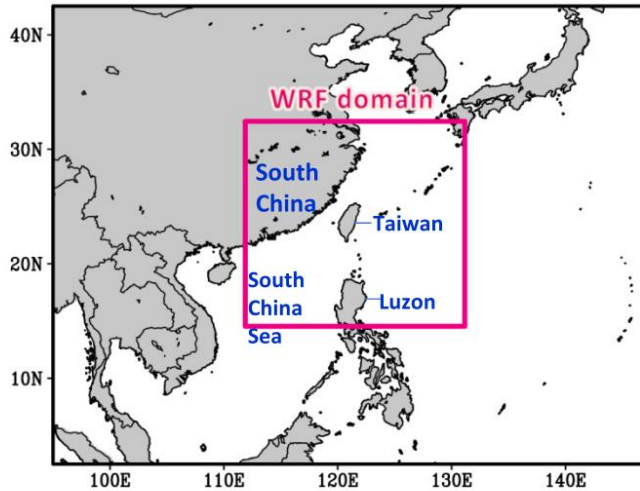
- Historical run : 1979–2003
- Future run: 2075–2099 (under RCP 8.5 scenario)

Data and Method

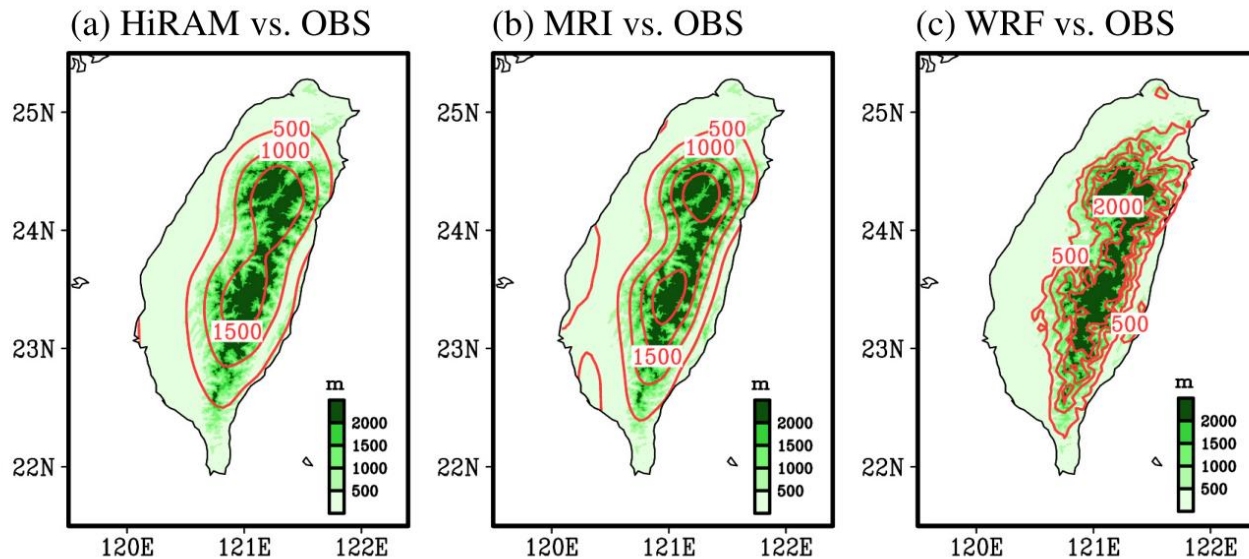


➤ Four clusters of future SST changes classified by Mizuta et al. (2014).

Data and Method



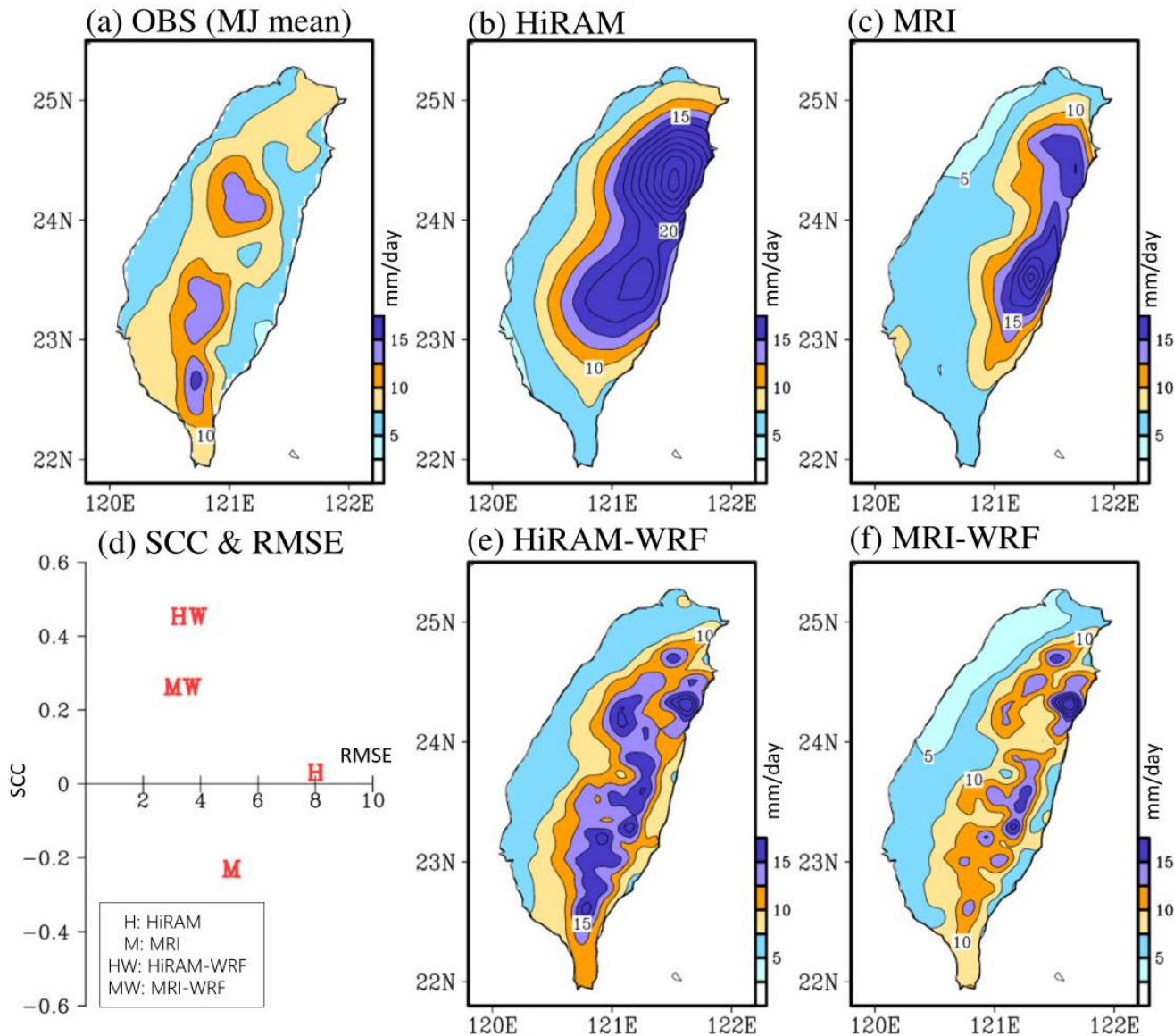
- The domain used for the dynamical downscaling simulations.
- The detailed WRF settings (planetary boundary layer 、 microphysics parameterizations...etc.) , *Please see J. Geophys. Res. Atmos.*, 121, 13973–13988, doi: 10.1002/2016JD025643.



- Shading : Real Taiwan topography.
- Red contour line : Taiwan topography simulated by each model.

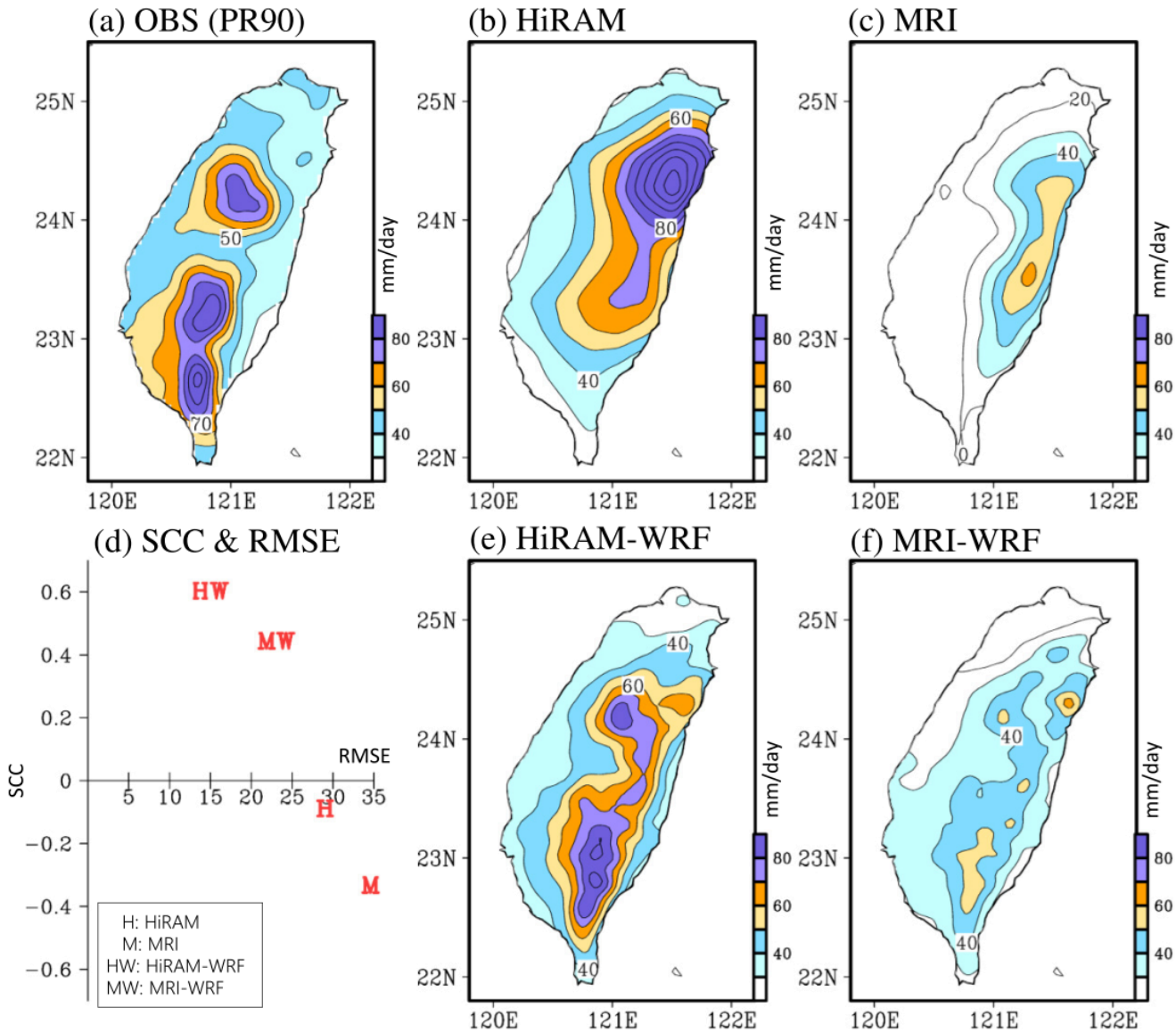
- The topography used in WRF depicts a more delicate Taiwan terrain structure.

Results-Present Day- MJ mean precipitation (Pav)



➤ WRF downscaling simulations are more capable than HiRAM and MRI in depicting the distribution of Pav in Taiwan.

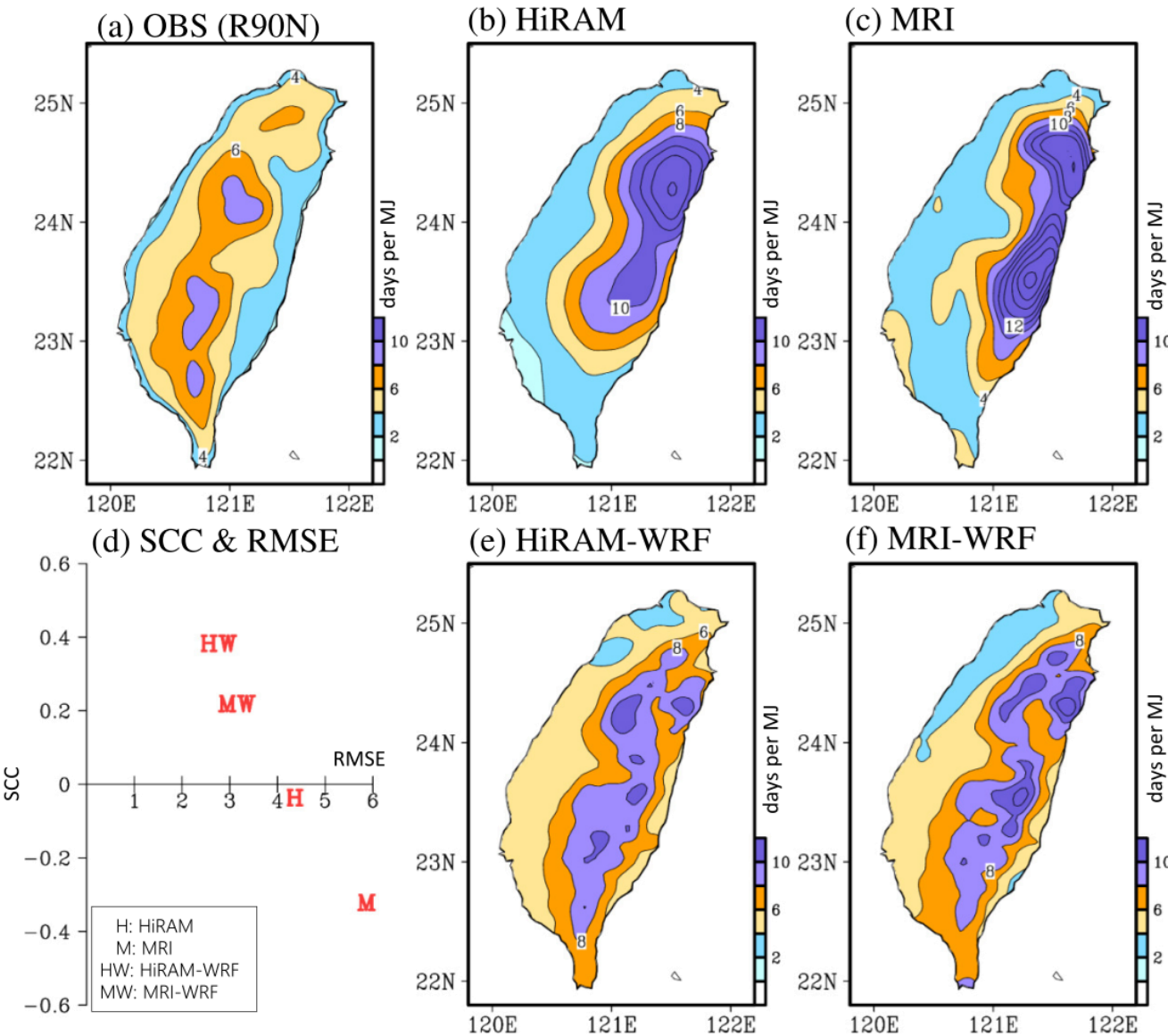
Results-Present Day- extreme precipitation intensity (PR90)



➤ The close relationship between PR90 and Pav over Taiwan is revealed.

➤ WRF downscaling simulations have a better skill in depicting the spatial distribution of PR90.

Results-Present Day- extreme precipitation frequency (R90N)

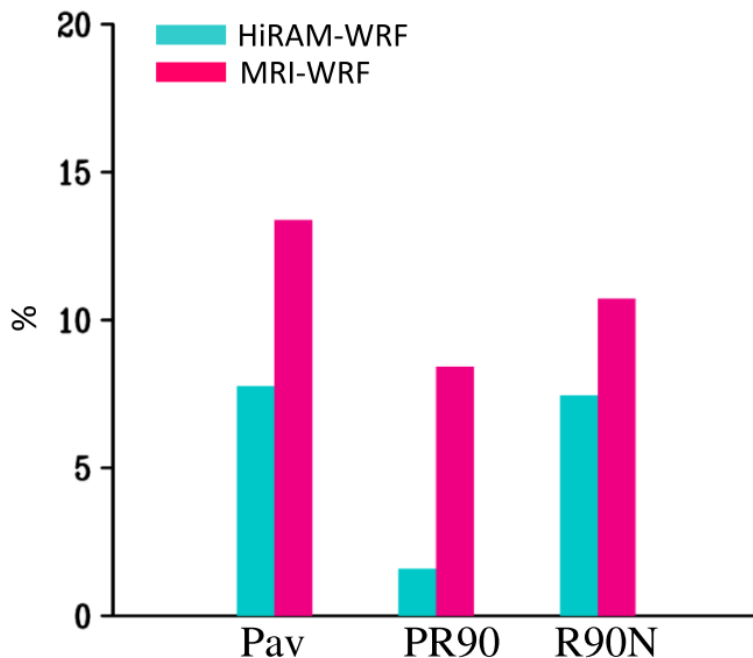


➤ Areas with larger R90N values are also the areas with larger PR90 values, for both the observation and the model simulations.

➤ WRF simulations add values in reproducing the extreme precipitation activities (including intensity and frequency) during the Mei-Yu seasons.

Results-Projected Changes- Pav, PR90 and R90N

- Because **WRF has better simulation skills**, we then adopted only **HiRAM-WRF** and **MRI-WRF** for the discussions of future projections.



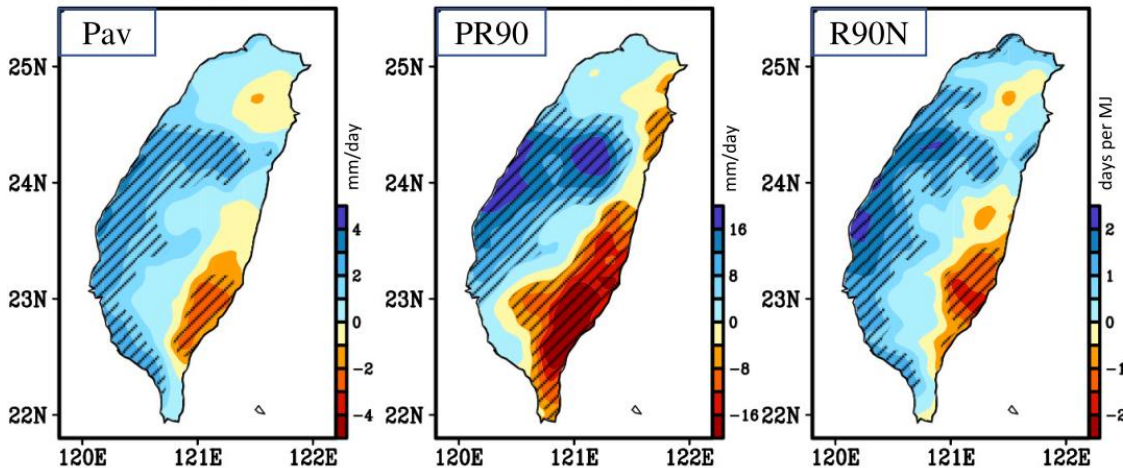
- The percentage of projected changes in Pav, PR90, and R90N area-averaged over Taiwan all showed increase.
- $\text{Percentage (\%)} = \frac{(\text{future minus present})}{\text{present}} \times 100\%$
- None of the changes passed the significance test with 90% confidence intervals.

Two questions:

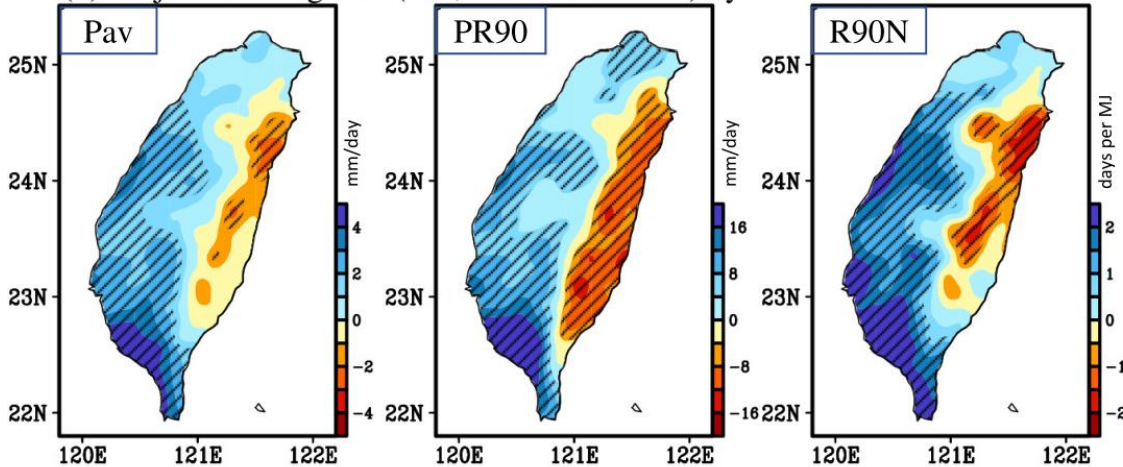
- Is there a **regional difference** in the projected changes of Mei-Yu season extreme precipitation in Taiwan?
- How the **agricultural regions** over Taiwan will likely be affected by the Mei-Yu season extreme precipitation changes in the future?

Results-Projected Changes- Pav, PR90 and R90N

(a) Projected changes in (Pav, PR90 and R90N) by HiRAM-WRF



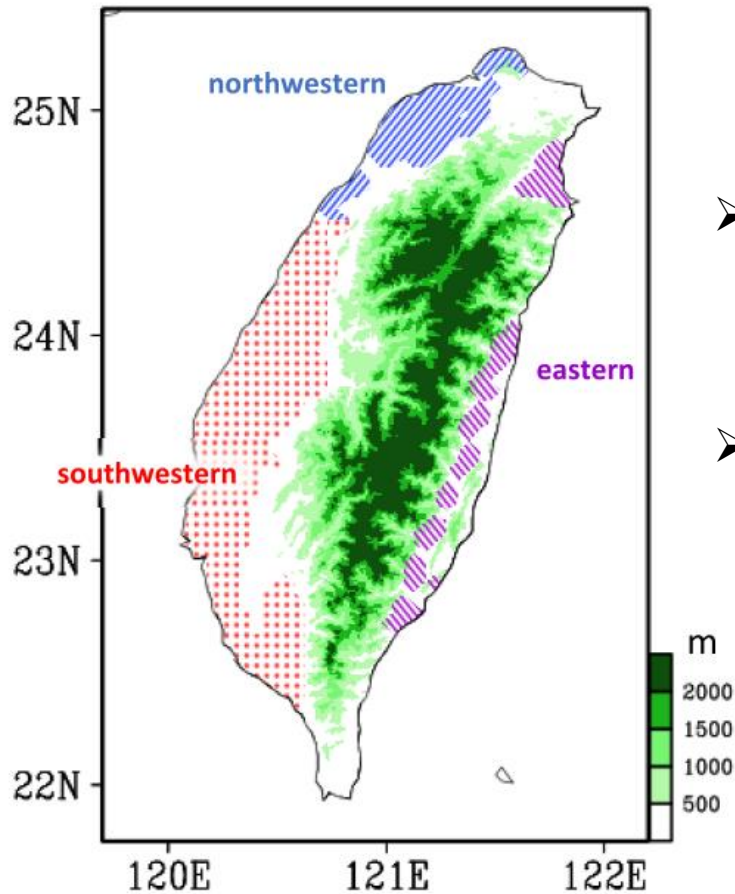
(b) Projected changes in (Pav, PR90 and R90N) by MRI-WRF



➤ The distribution of the projected changes in Pav, PR90, and R90N is characterized by a clear east-west contrast, with positive (negative) values in the west (east) side of the mountain range.

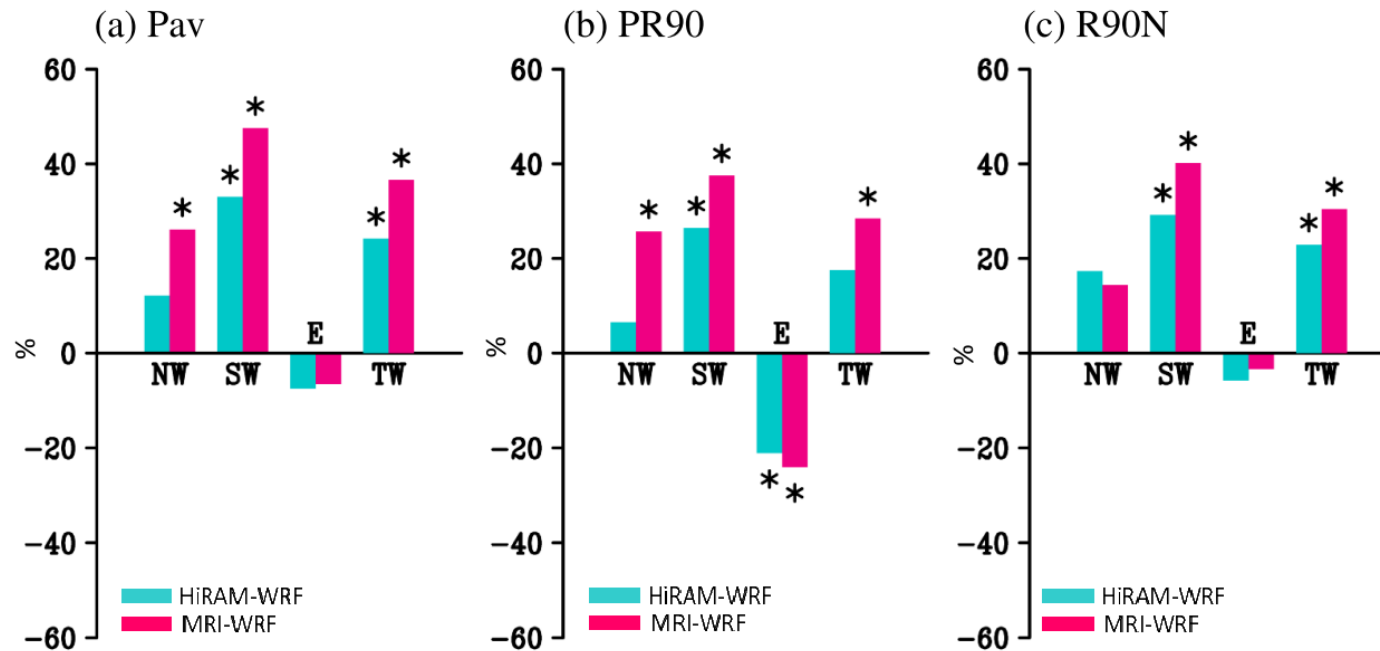
* The areas with significant changes at the 90% confidence interval over Taiwan are marked by a slash.

Results-Topography & agricultural region of Taiwan



- Northwestern agricultural region (blue slash)
- Southwestern agricultural region (red dot)
- Eastern agricultural region (purple backslash)
- The information for agricultural regions are provided by the Council of Agriculture, Executive Yuan in Taiwan.
(<http://aldoc.coa.gov.tw/aldoc/>)

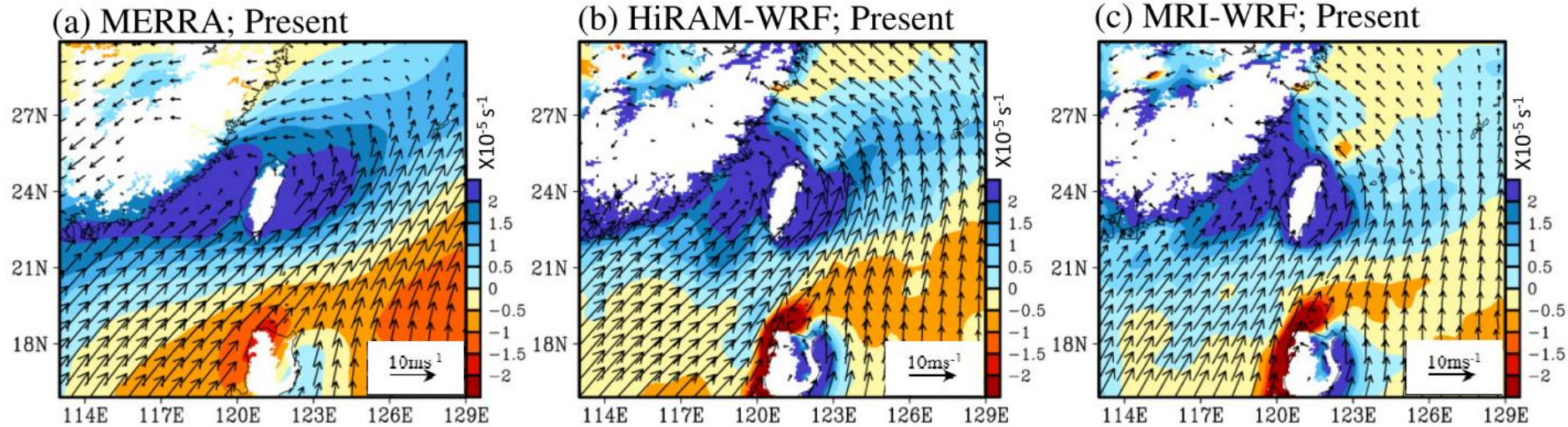
Results-Projected Changes- Pav, PR90 and R90N



The areas with significant changes at the 90% confidence interval over Taiwan are marked by *

- The southwestern (SW) agricultural region shows a significant increase (more than 25%) in Pav, PR90, and R90N.
- For the eastern (E) agricultural region, decreases in Pav, PR90 and R90N.
- Most of Pav, PR90, and R90N (except PR90 in HIRAM-WRF) are projected to significantly increase in the future, when considering the agricultural regions of Taiwan as a whole (TW).

Discussion-Circulation Verification (Present)

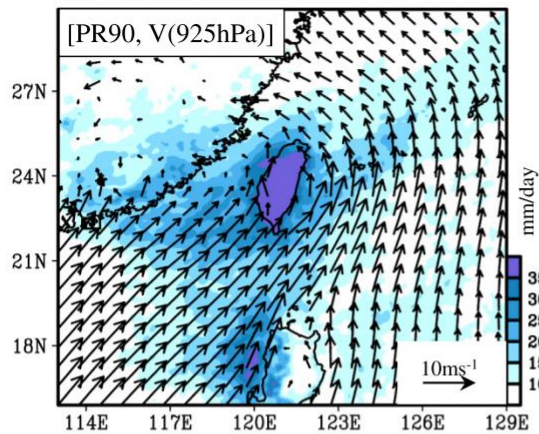


- Shading: MJ mean 925-hPa vorticity
- Vectors: 925-hPa wind circulation

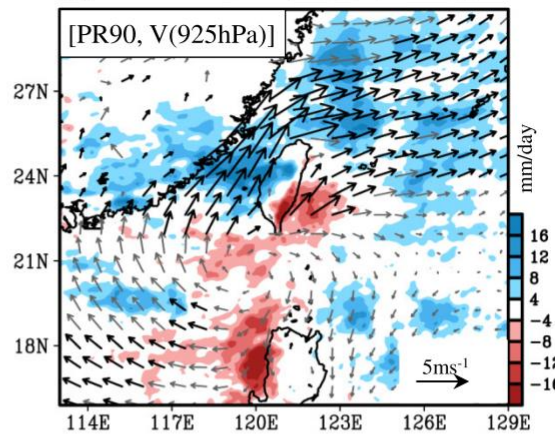
- Both present-day simulations of HiRAM-WRF and MRI-WRF are capable of reproducing the MERRA reanalysis data that Taiwan is under the influence of southwesterly monsoonal flow at the low level.
- To quantitatively evaluate the wind fields, we calculated the spatial correlation of vorticity between (b) 、(c) and (a), and the value is larger than 0.73 、0.68, respectively.

Discussion-Circulation (Present vs. Projected Changes)

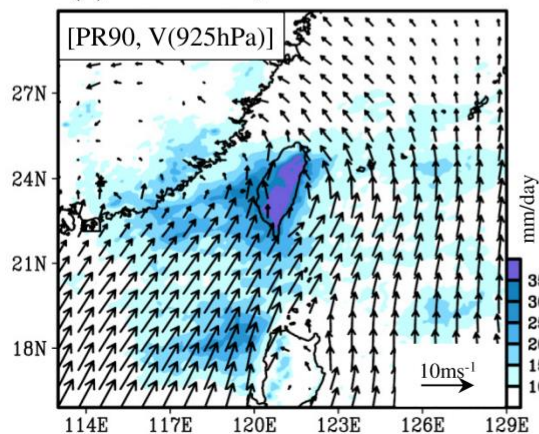
(a) HiRAM-WRF; Present



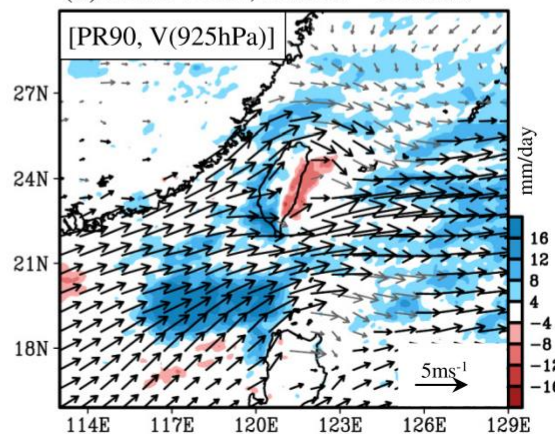
(c) HiRAM-WRF; Future - Present



(b) MRI-WRF; Present



(d) MRI-WRF; Future - Present

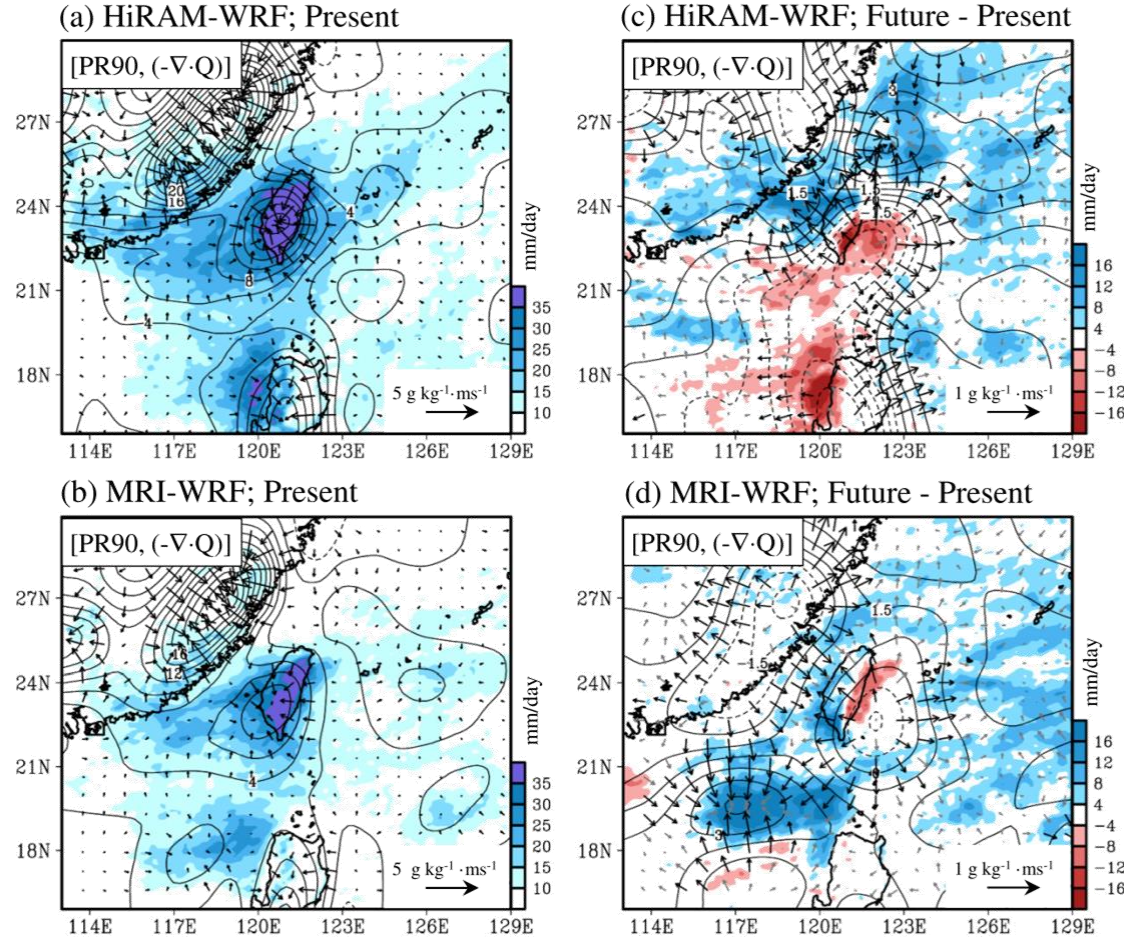


➤ The low-level southwesterly monsoonal flow along the coastal regions of South China will be stronger in the future than in the present-day.

➤ Western (eastern) Taiwan is on the windward (leeward) side of the intensification of low-level southwesterly monsoonal winds.

- Shading: PR90 in (a) and (b) ;
PR90 changes in (c) and (d)
- Vectors: 925-hPa wind circulation in (a) and (b) ;
925-hPa wind circulation changes in (c) and (d)

Discussion-moisture convergence (Present vs. Projected Changes)

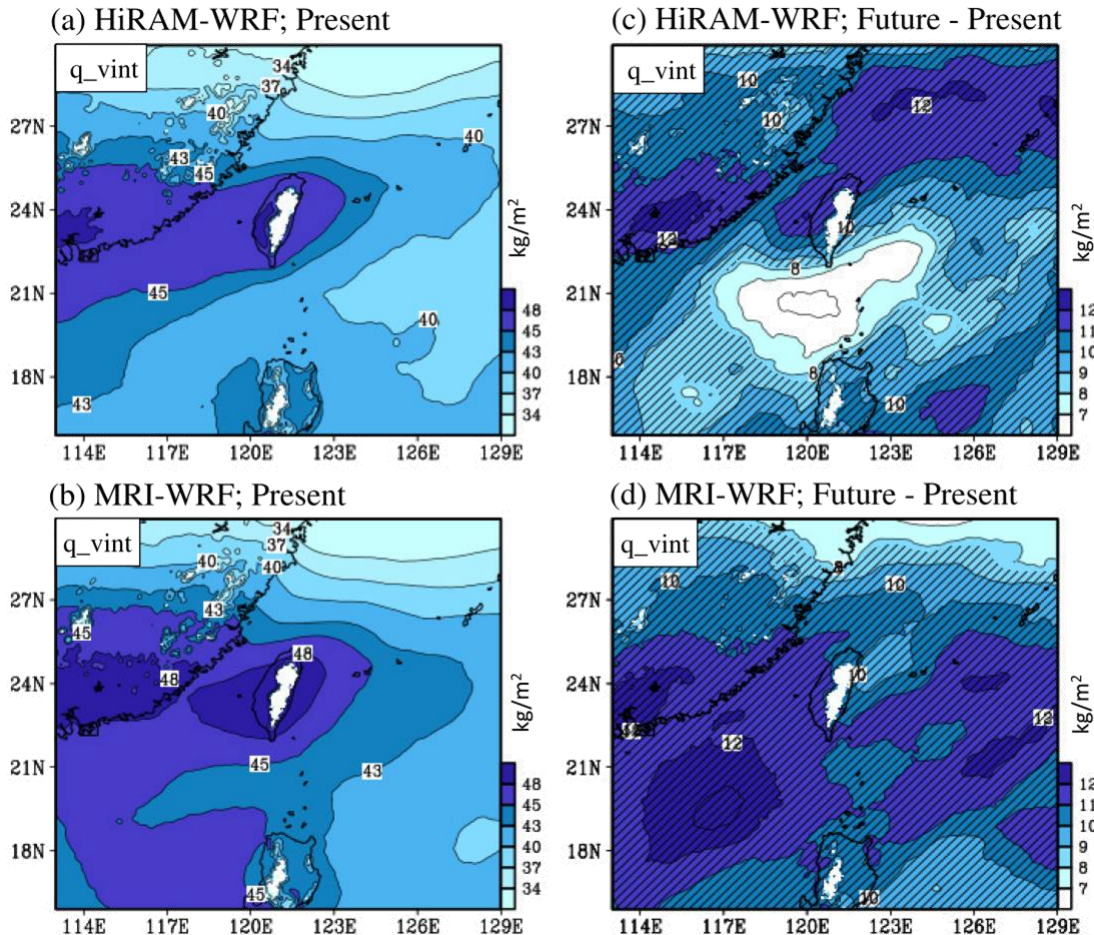


➤ Water vapor flux is convergent from nearby regions to Taiwan, and it provides the moisture supply for the formation of extreme precipitation over Taiwan.

➤ more (less) water vapor flux will converge into western (eastern) Taiwan
➔ extreme precipitation will be more (less) intense over western (eastern) Taiwan.

- Shading: PR90 in (a) and (b) ;
PR90 changes in (c) and (d)
- Contours: 925-hPa moisture convergence in (a) and (b) ;
925-hPa moisture convergence changes in (c) and (d)

Discussion-moisture (Present vs. Projected Changes)



- Shading: q_{vint} in (a) and (b) ;
 q_{vint} changes in (c) and (d)

$$-\nabla \cdot \mathbf{V}q = -\mathbf{V} \cdot \nabla q - q \nabla \cdot \mathbf{V}.$$

- The future change of vertically integrated specific humidity ($q_{vint} = \frac{1}{g} \left(\int_{300}^{p_s} q \, dp \right)$) is positive for all of eastern and western Taiwan.
- The east-west difference in $(-\nabla \cdot \mathbf{Q})$ is not mainly caused by the spatial changes in moisture but rather by the spatial changes in wind circulation.

Summary

- The **dynamical downscaling process** adds value to the present-day simulation of Mei-yu extreme rainfall in Taiwan.
- The future projections show that **Meiyu extreme rainfall** will have a great impact to the **southwestern agriculture** region of Taiwan.
- Extreme precipitation over western Taiwan are projected to become **more intense and more frequent** in the future due to the **enhanced westerly wind** and **the increased moisture supply** in a warmer climate.
- More information please see
J. Meteor. Soc. Japan, **97**, <https://doi.org/10.2151/jmsj.2019-028>.

Thanks for your attention