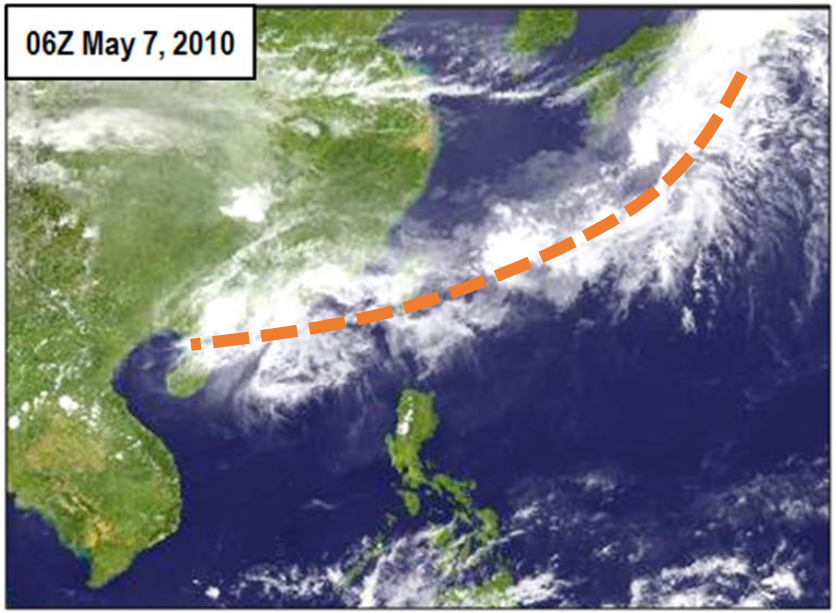
國立臺灣師範大學
NATIONAL TAIWAN NORMAL UNIVERSITY

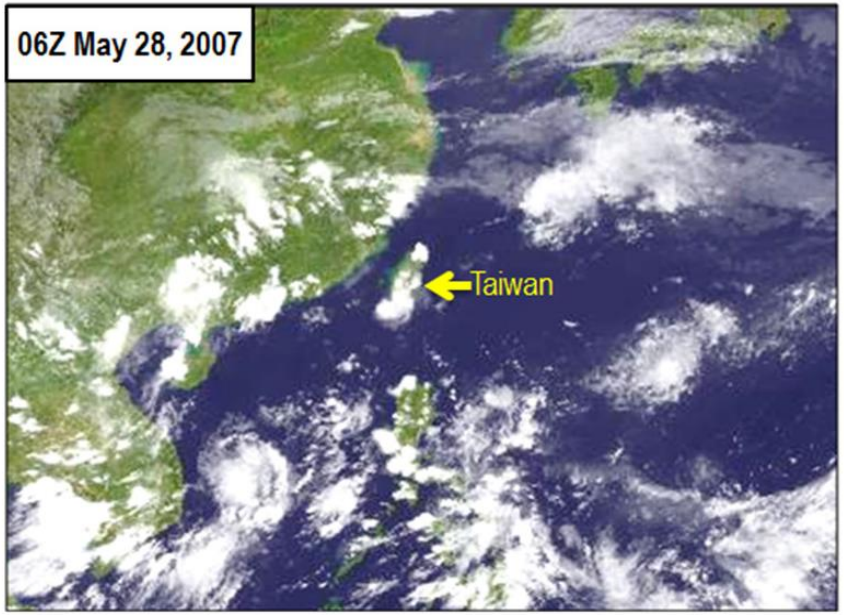
多尺度環流變化對臺灣午後對流降雨現象之影響

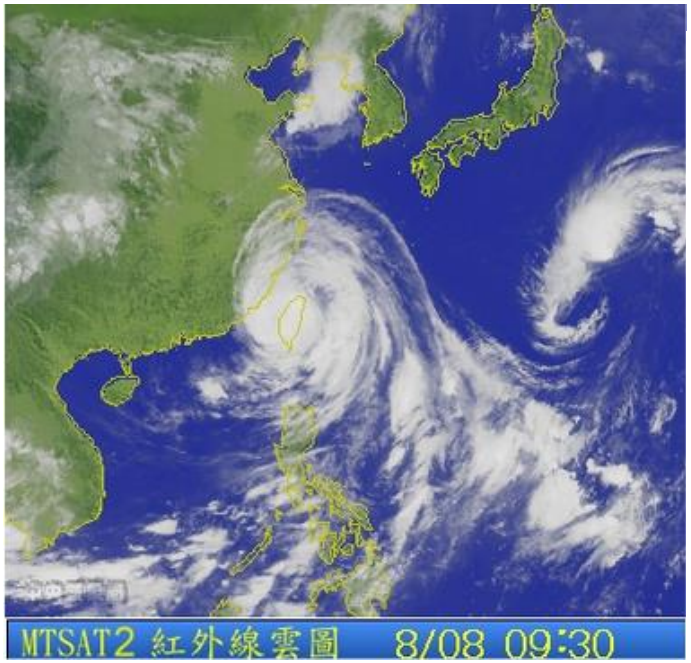
黃婉如

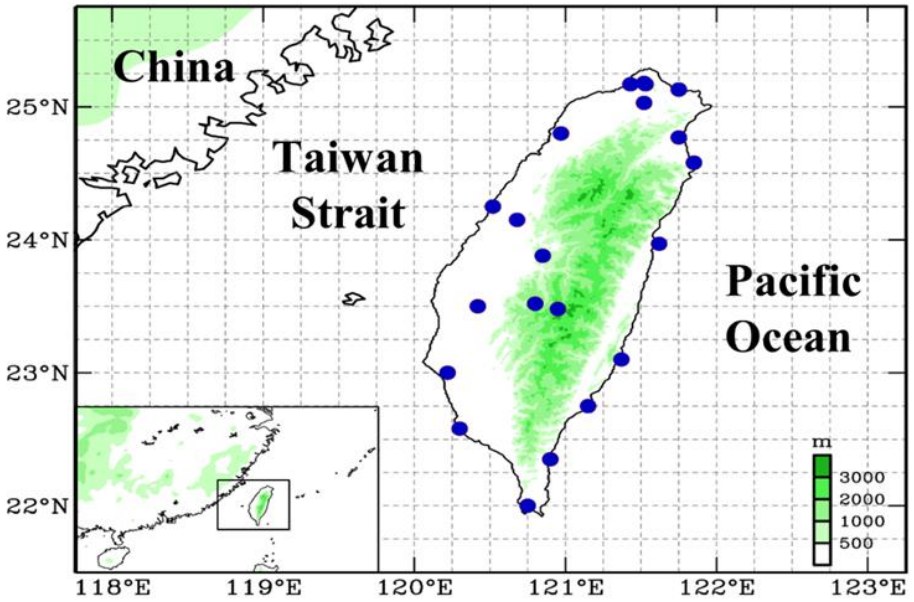
國立臺灣師範大學地球科學系

Motivation

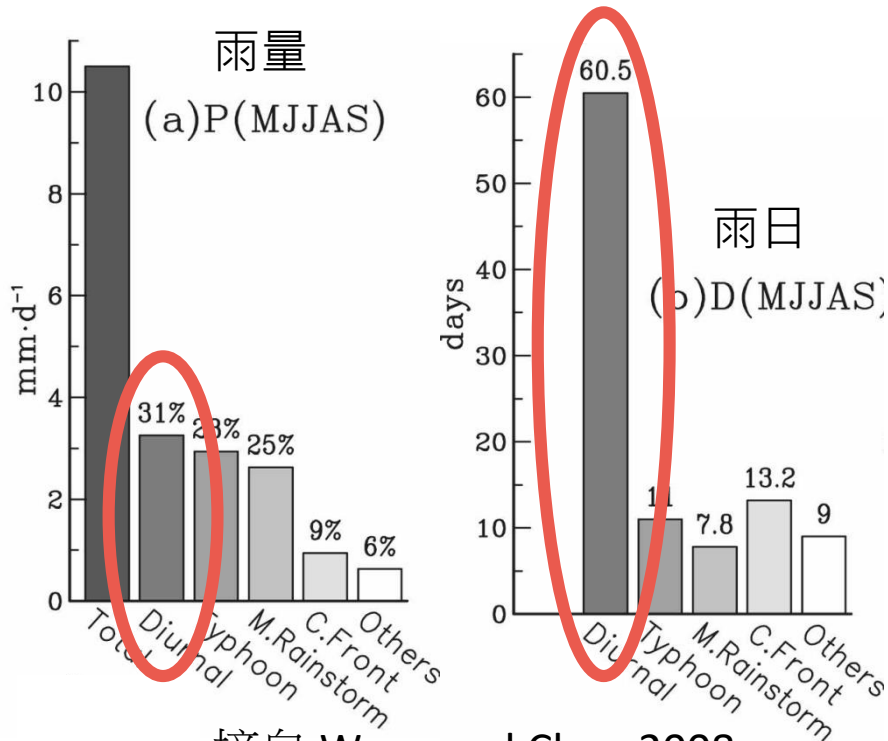

06Z May 7, 2010


06Z May 28, 2007
Taiwan


MTSAT2 紅外線雲圖 8/08 09:30


China
Taiwan
Strait
Pacific
Ocean
25°N
24°N
23°N
22°N
118°E
119°E
120°E
121°E
122°E
123°E
m
3000
2000
1000
500

臺灣暖季的主要降雨系統



摘自 Wang and Chen 2008

根據過去研究臺灣地區之各季節降水氣候值分布結果發現，顯著降水主要發生在暖季(5-9月)(Chen and Chen 2003；Kerns et al. 2010)。

其中，除了梅雨鋒面和颱風所帶來的豐沛雨量之外，午後對流降雨(Convective Afternoon Rainfall，CAR)的貢獻亦相當顯著(Wang and Chen 2008)。

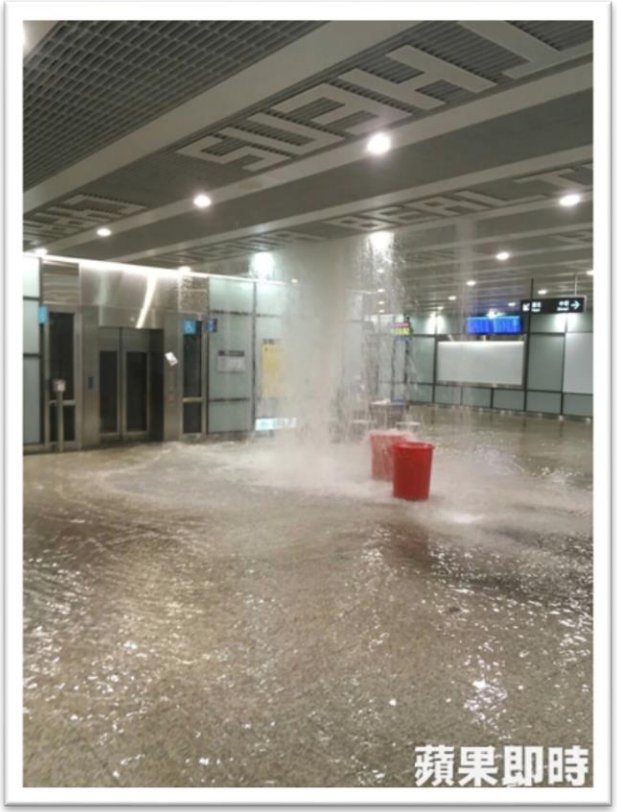
降雨系統帶來的災害：以2016年為例

6/2

桃園機場二航廈B2內淹水過腳踝。

6/28

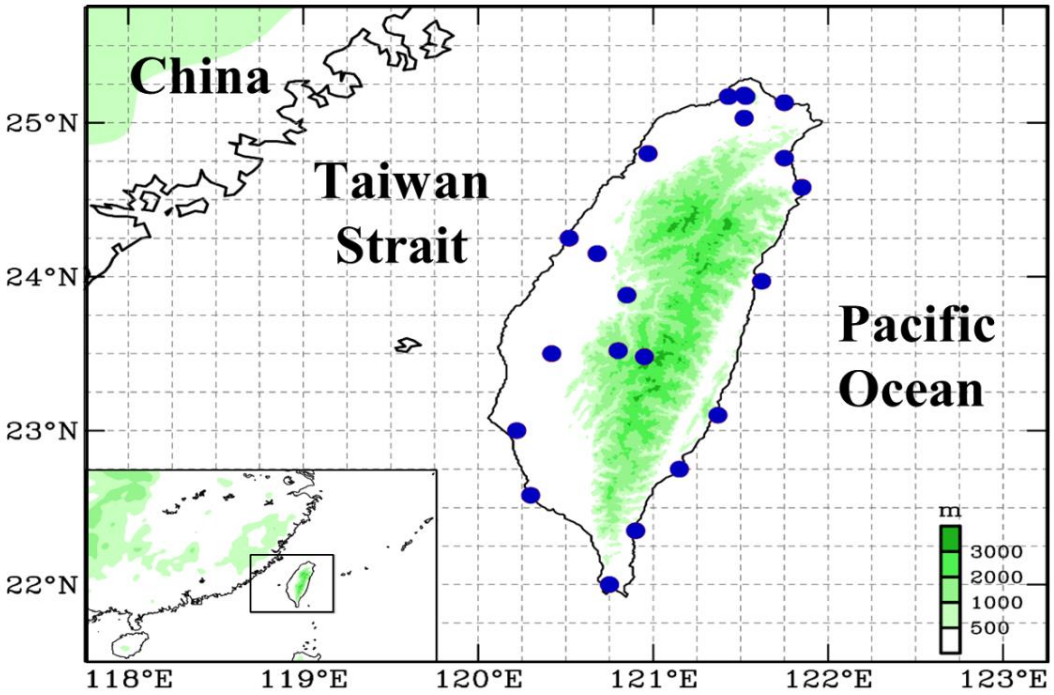
機場捷運A13站水管破裂，大量雨水從天花板傾瀉而下。



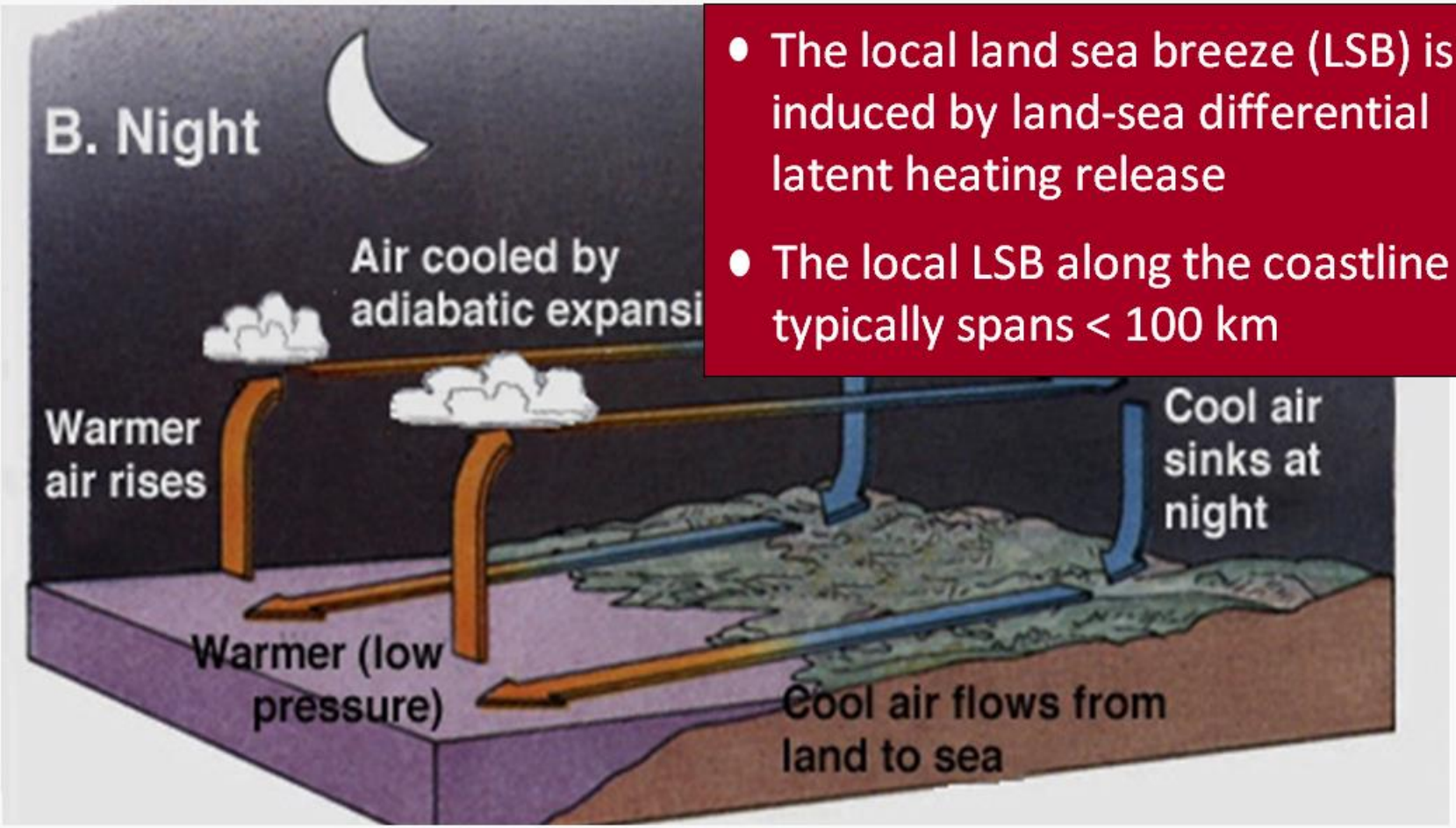
6/14

一般而言，臺灣CAR的時空分布特徵與局部環流變化和地形效應息息相關。

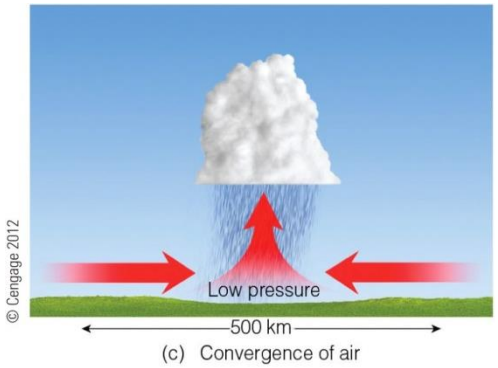
新聞圖



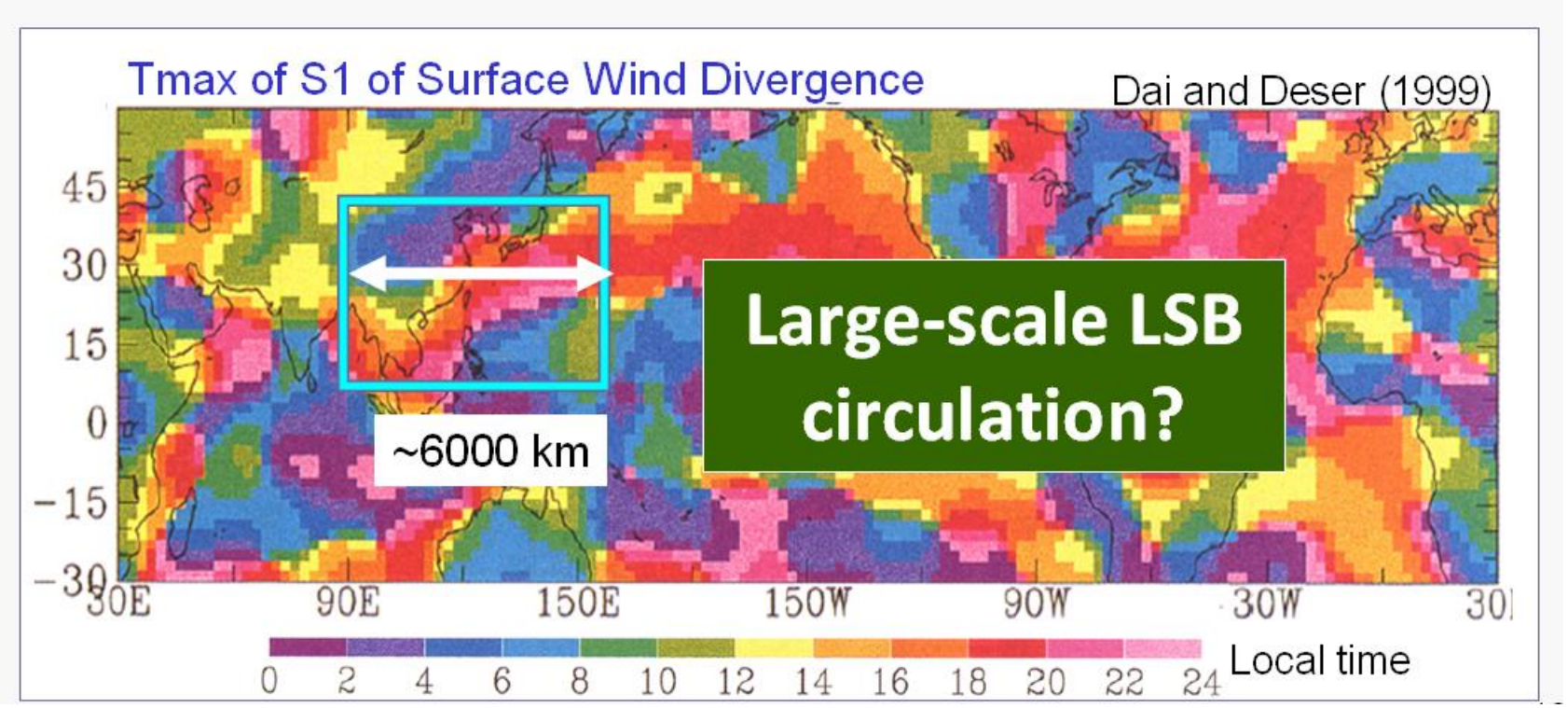
General concept of diurnal rainfall variation



- The local land sea breeze (LSB) is induced by land-sea differential latent heating release
- The local LSB along the coastline typically spans < 100 km

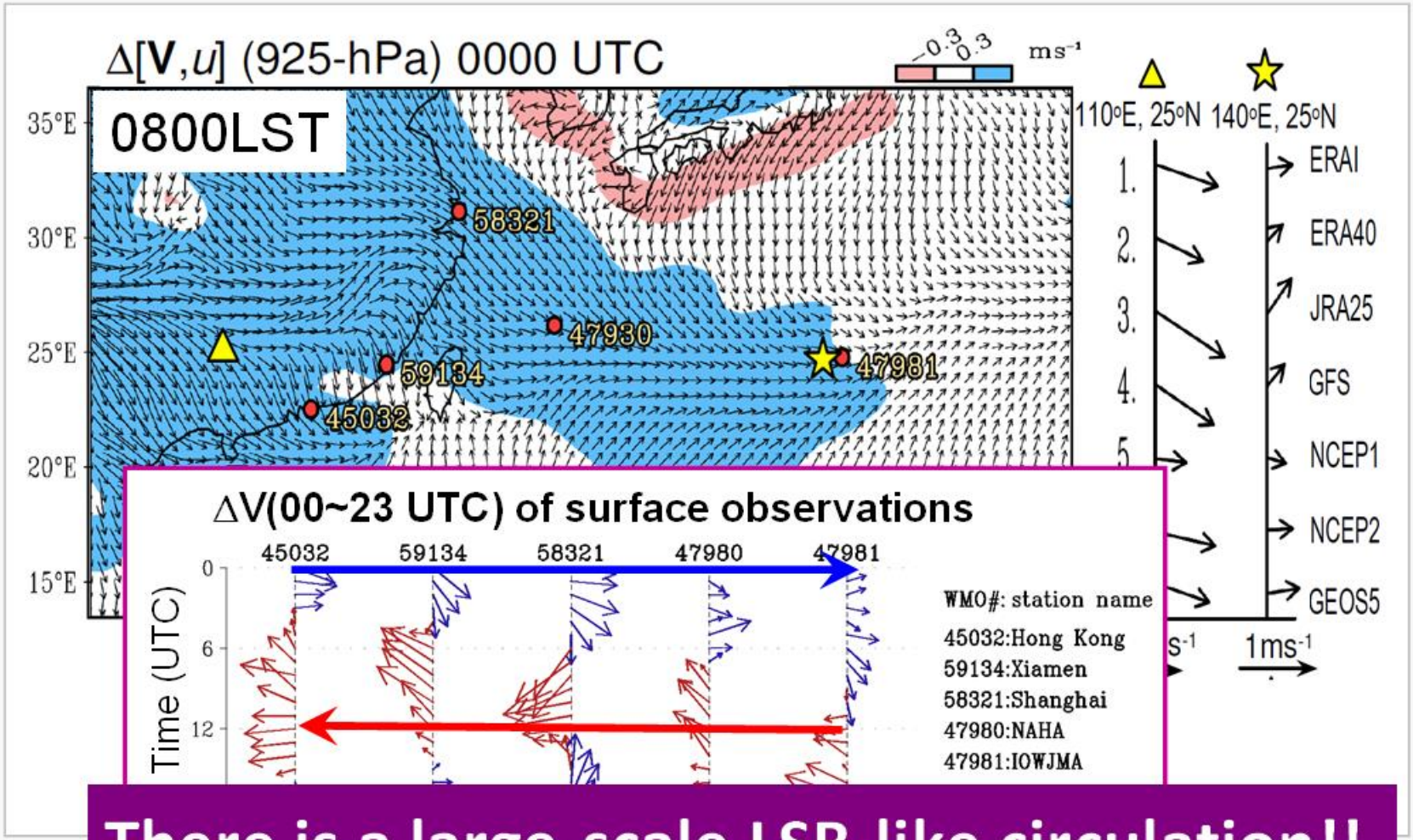


下圖為一日之間近地表風輻合達到最大值的時間點 (Tmax)



S1: Diurnal component

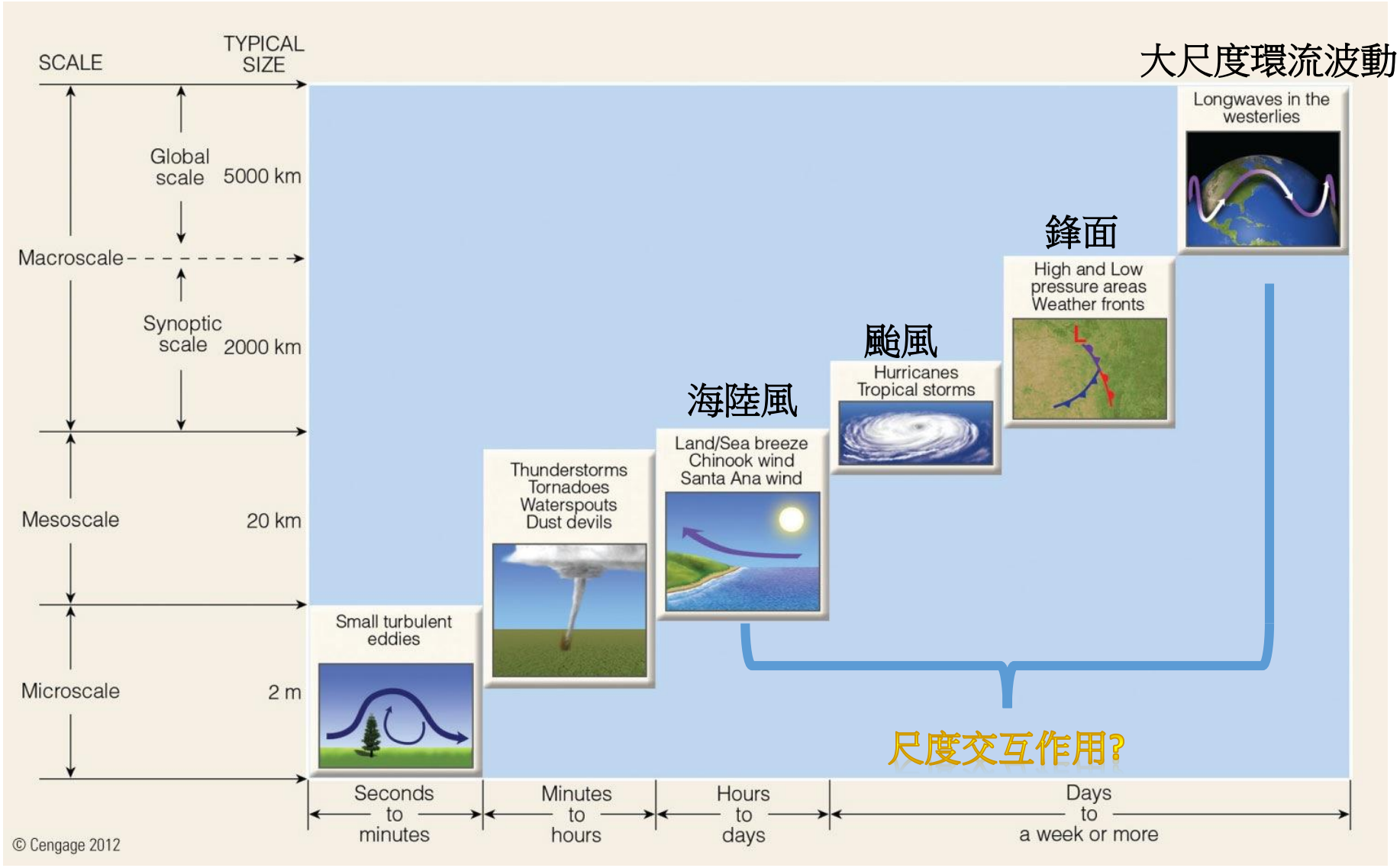
Does the large-scale LSB circulation exist?



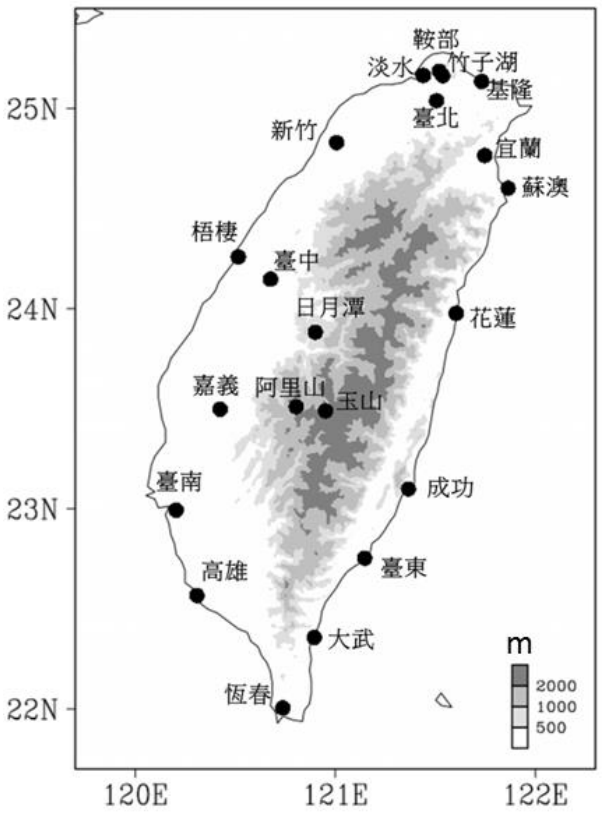
There is a large-scale LSB-like circulation!!

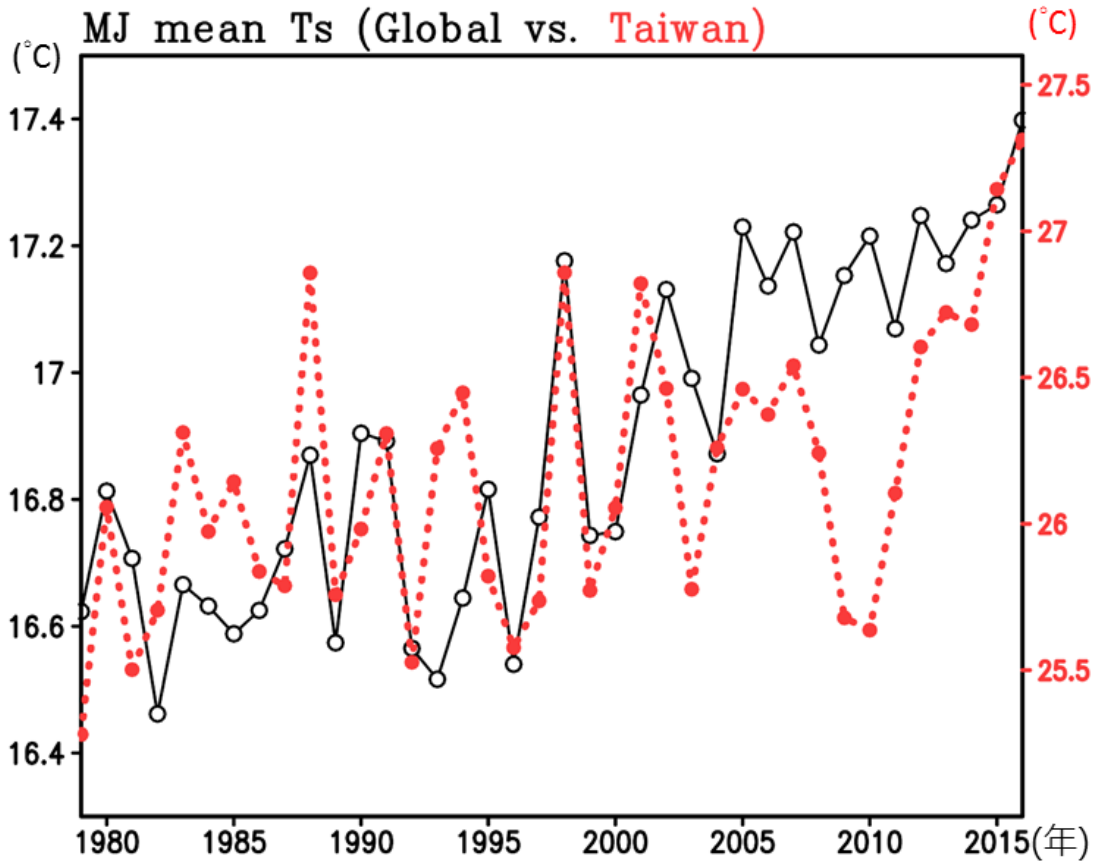
Huang et al. (2010, QJRMS)

大氣現象的尺度分類



Source: Meteorology Today





由於溫度的變化又意味著大氣熱力穩定度的變化，且大氣熱力穩定度的變化可進而影響對流性降雨的發生頻率（Huang and Chen 2015）

➔降雨型態與往年應有所差異，且午後對流之發生頻率應明顯增加

本演講的內容主要著重在介紹「**多重時間尺度大氣環流變化，對臺灣午後對流降雨特性變化造成的影響**」。

報告的內容將涵蓋

(1) 觀測資料顯示過去及現在的午後對流降雨特性變化特徵

(2) 氣候模式資料推估午後對流降雨在未來的可能變化

SCIENTIFIC QUESTIONS :

- **What is the impact of land-sea breezes at different scales on the diurnal rainfall in Taiwan?** (Huang and Wang, 2014)

- **Modulated by the large-scale circulation changes, does the diurnal rainfall in Taiwan consist of trend signal?** (Huang and Chen, 2015)

- **Does the long-term variation of diurnal rainfall in Taiwan consist of regional differences?** (Huang et al., 2015)

SCIENTIFIC QUESTIONS :

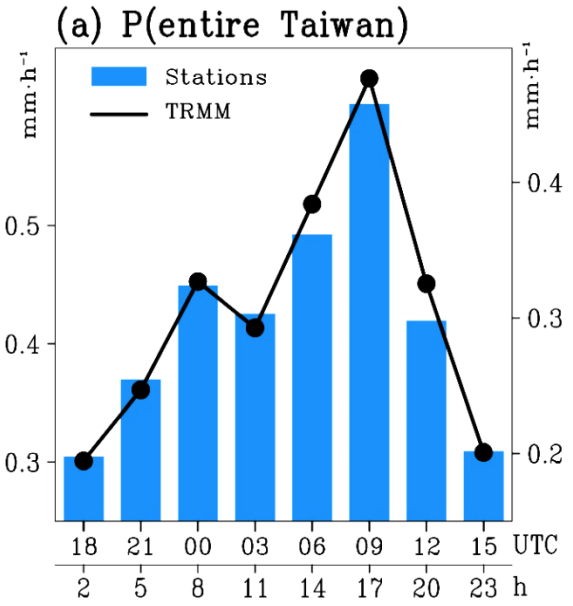
- **Has the relationship between the diurnal rainfall in Taiwan and the sea surface temperature over the Nino3.4 region changed over past sixty years?** (Huang et al., 2018; Huang et al., 2019)

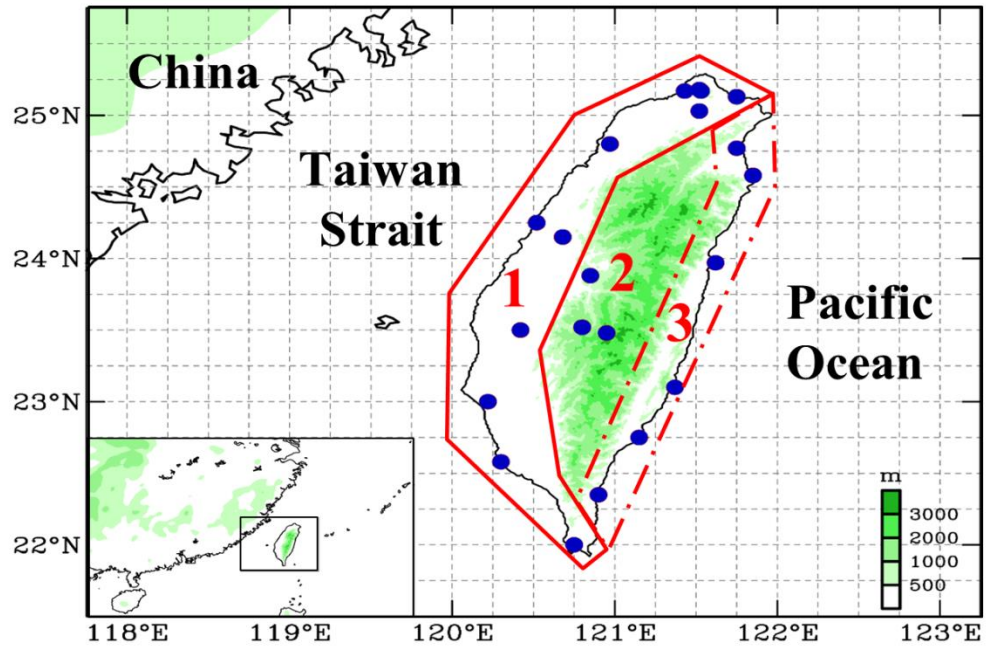
- **How the characteristics of diurnal rainfall events in Taiwan to be modulated by the BSISO features?** (Huang and Chang, 2018)

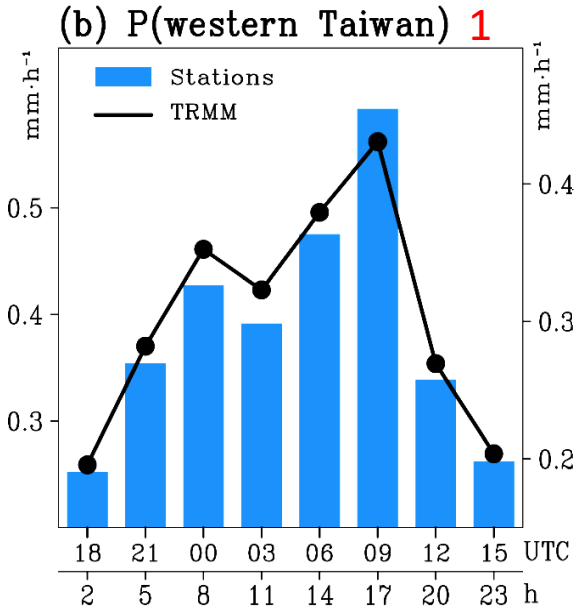
- **What is the projected change of diurnal rainfall convection and other types of rainfall in Taiwan in the future?** (Huang et al., 2016; Huang and Wang, 2017)

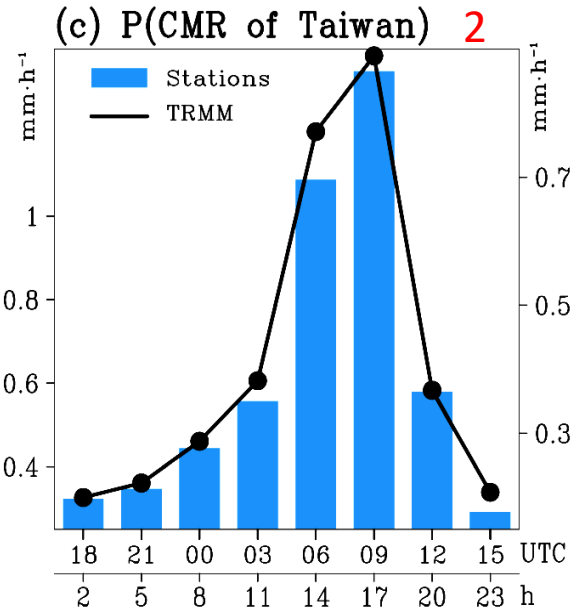
What is the impact of land-sea breezes at different scales on the diurnal rainfall in Taiwan?

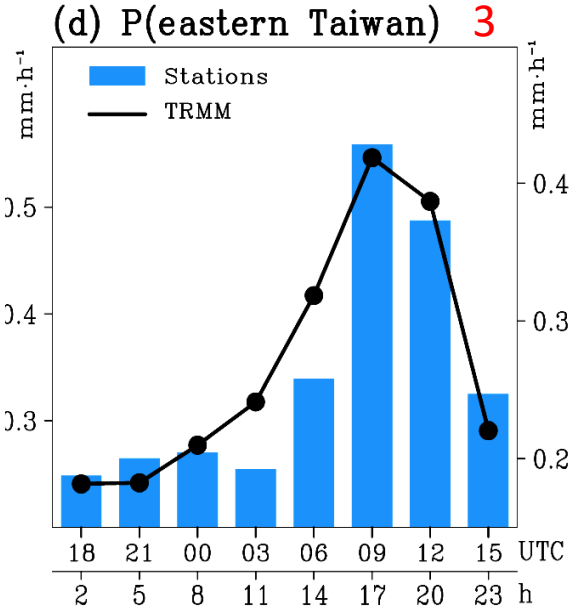
Characteristics of diurnal rainfall in Taiwan









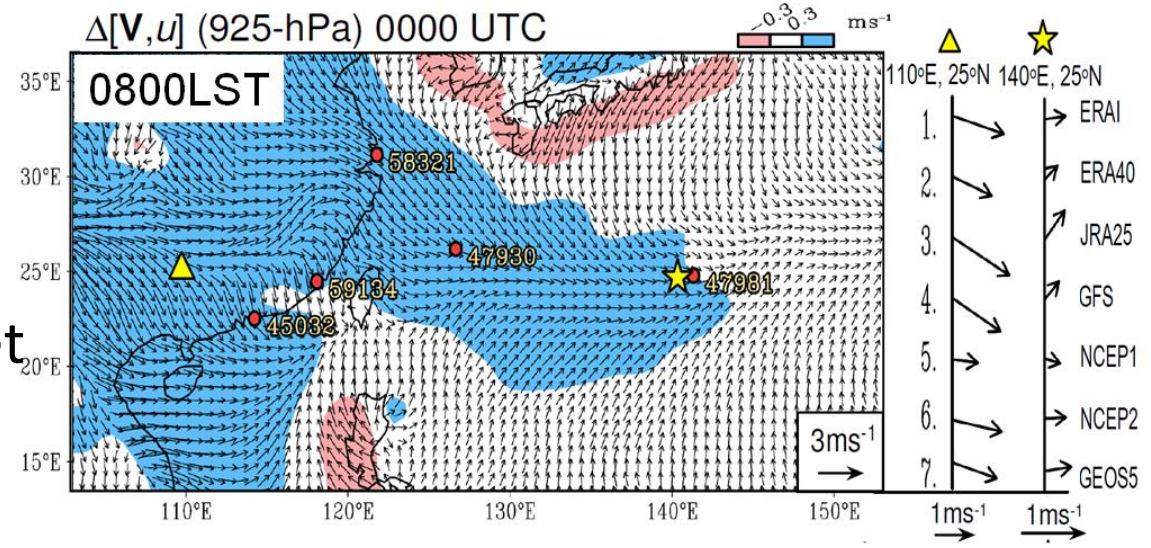


Literature review

- The formation mechanism of diurnal rainfall in Taiwan is commonly recognized as a result of local forcing involving solar thermal heating and island-scale land-sea breeze (LSB) interacting with orography.

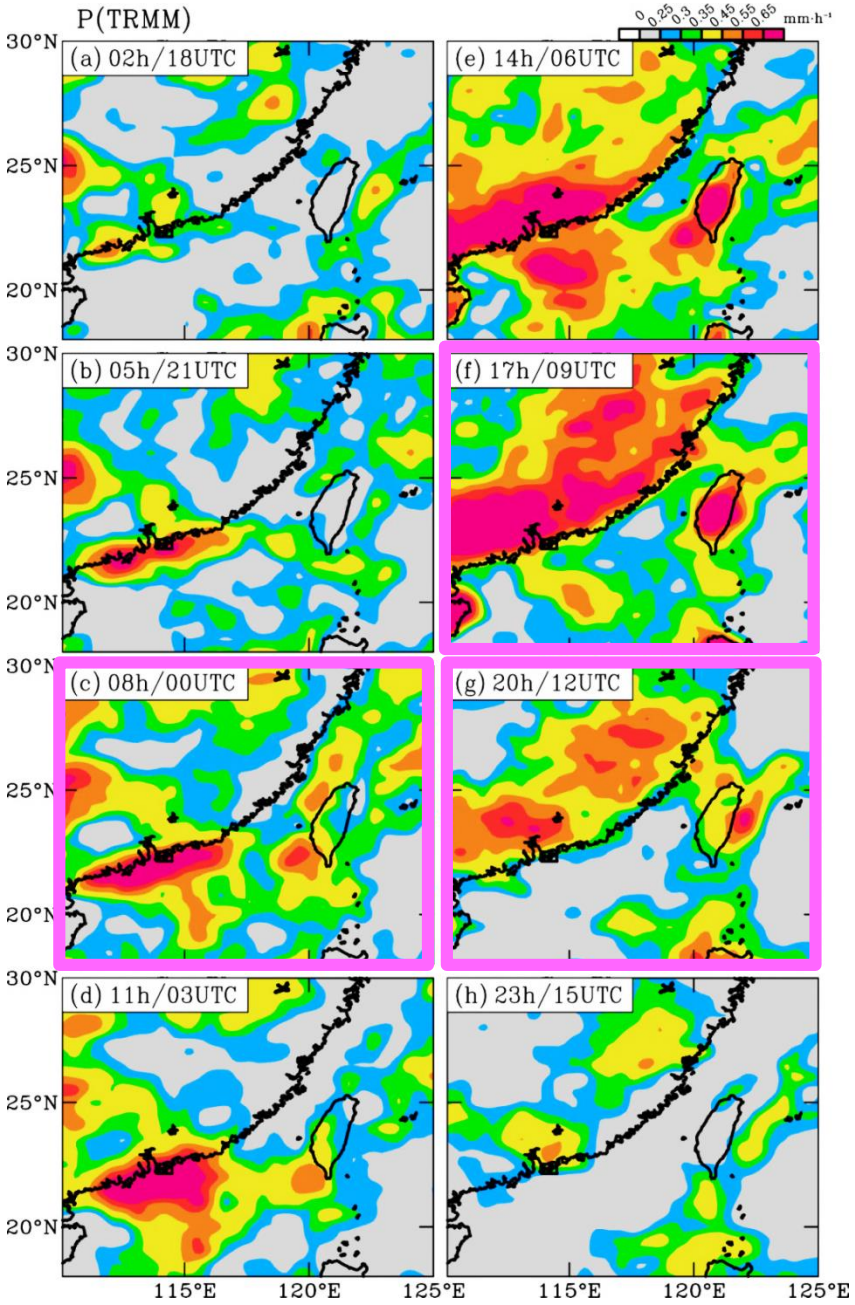
Problem: This mechanism alone cannot explain the observed regional differences of diurnal rainfall in Taiwan

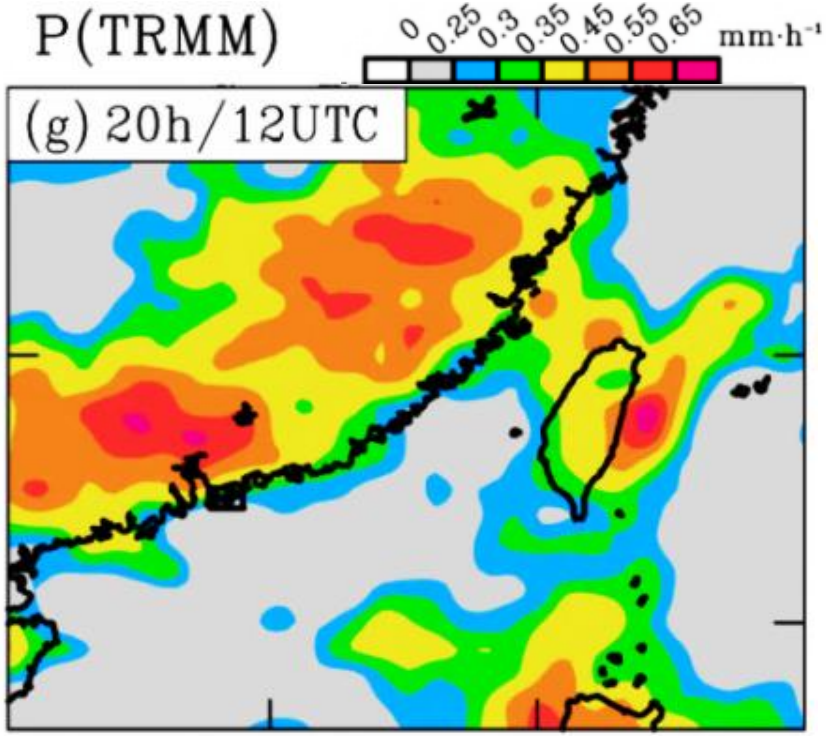
- The existence of large-scale land-sea breeze like circulation (Huang et al. 2010)



△: anomalies, i.e. daily mean has been removed
Blue color: zonal wind (u) > 0

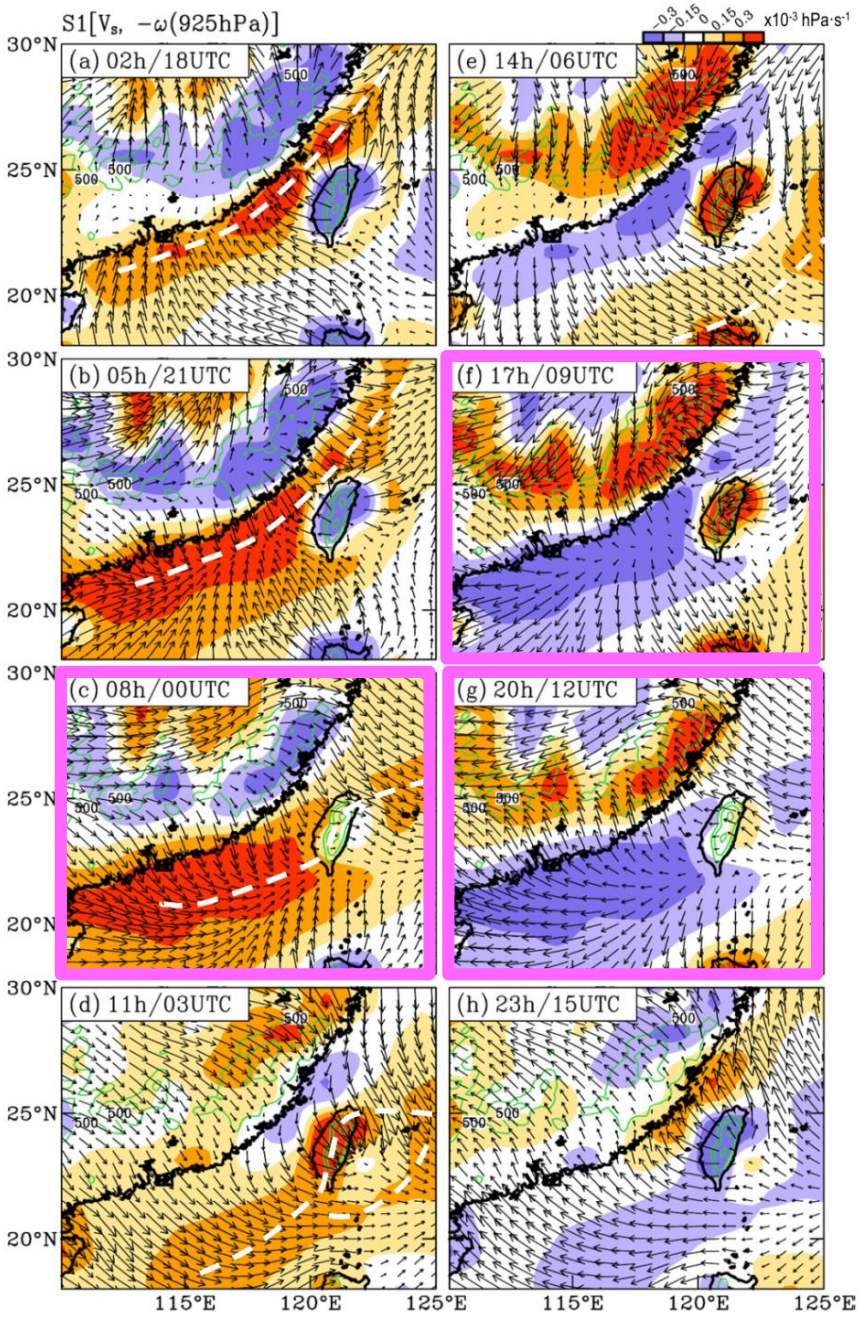
Spatial - temporal variation of P(TRMM)





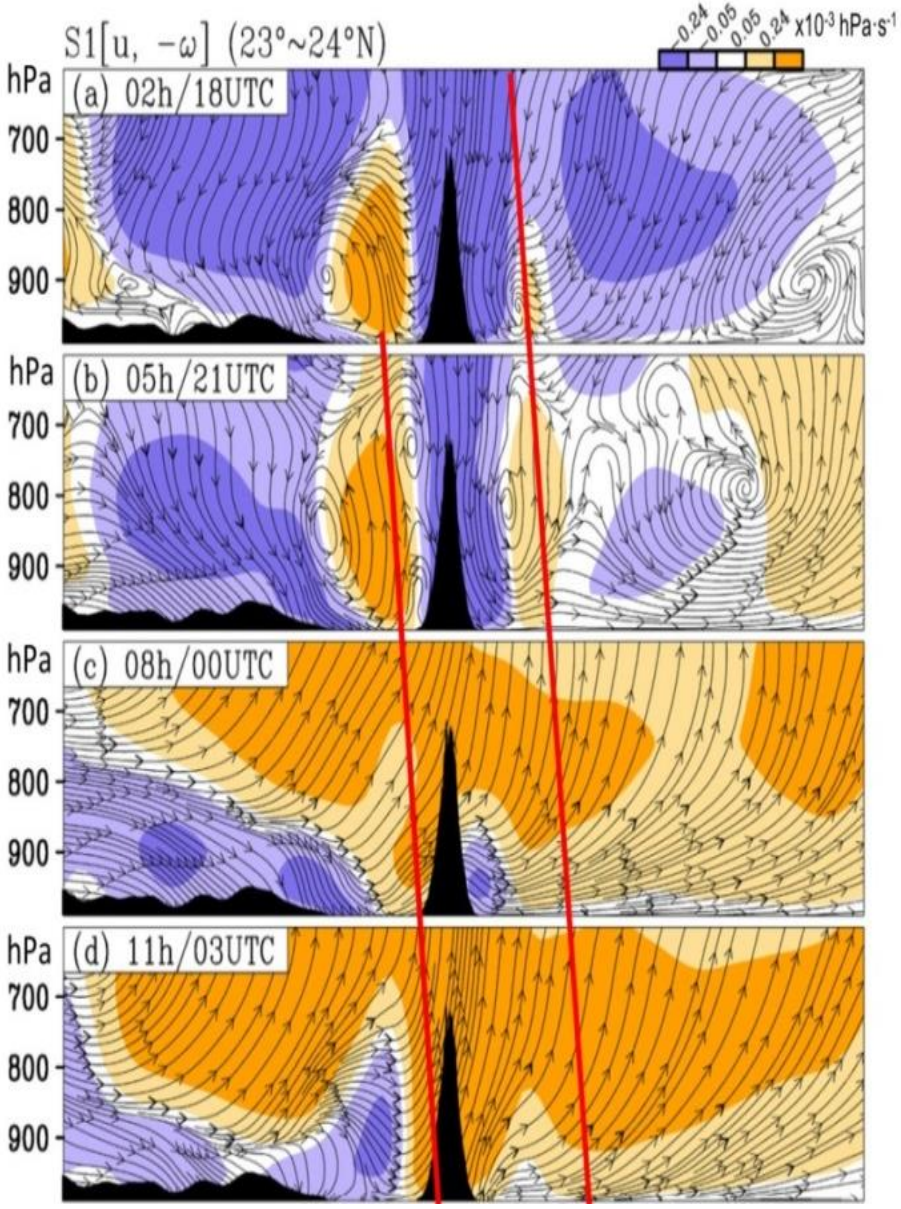
Climatology: averaged during 1998-2012 MJ
Local time in Taiwan is universal time + 8 h

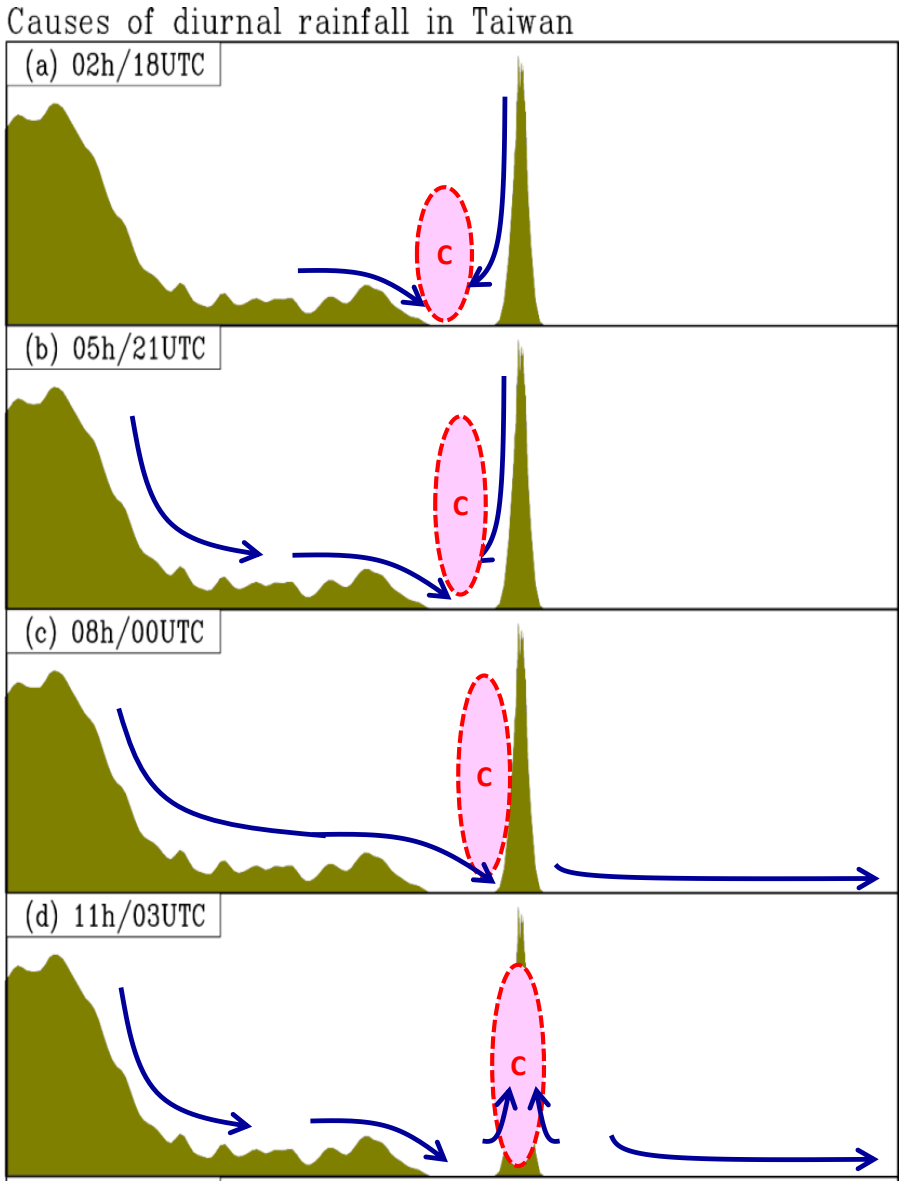
Diurnal variation (S1) of wind and vertical motion



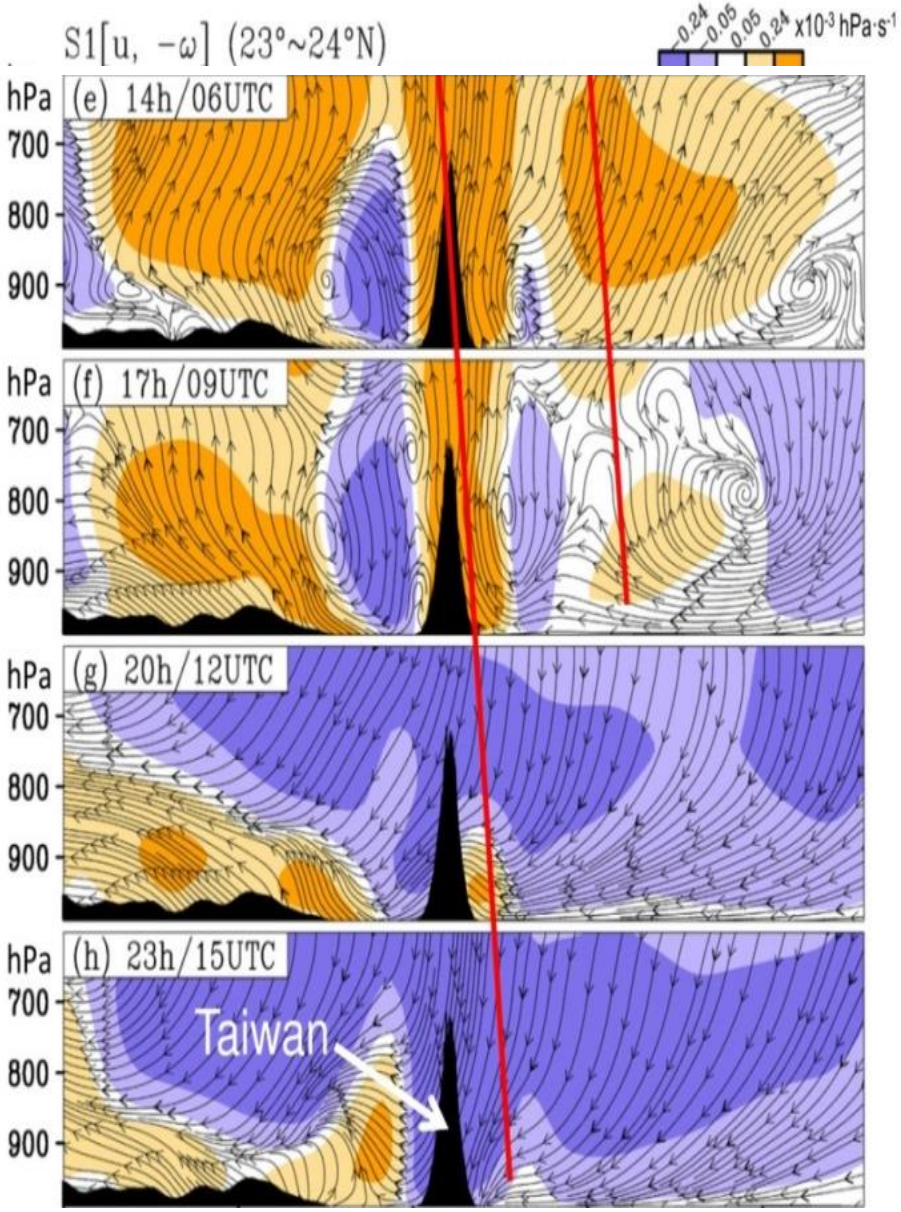
Orange color: upward motion
Green color: mountains

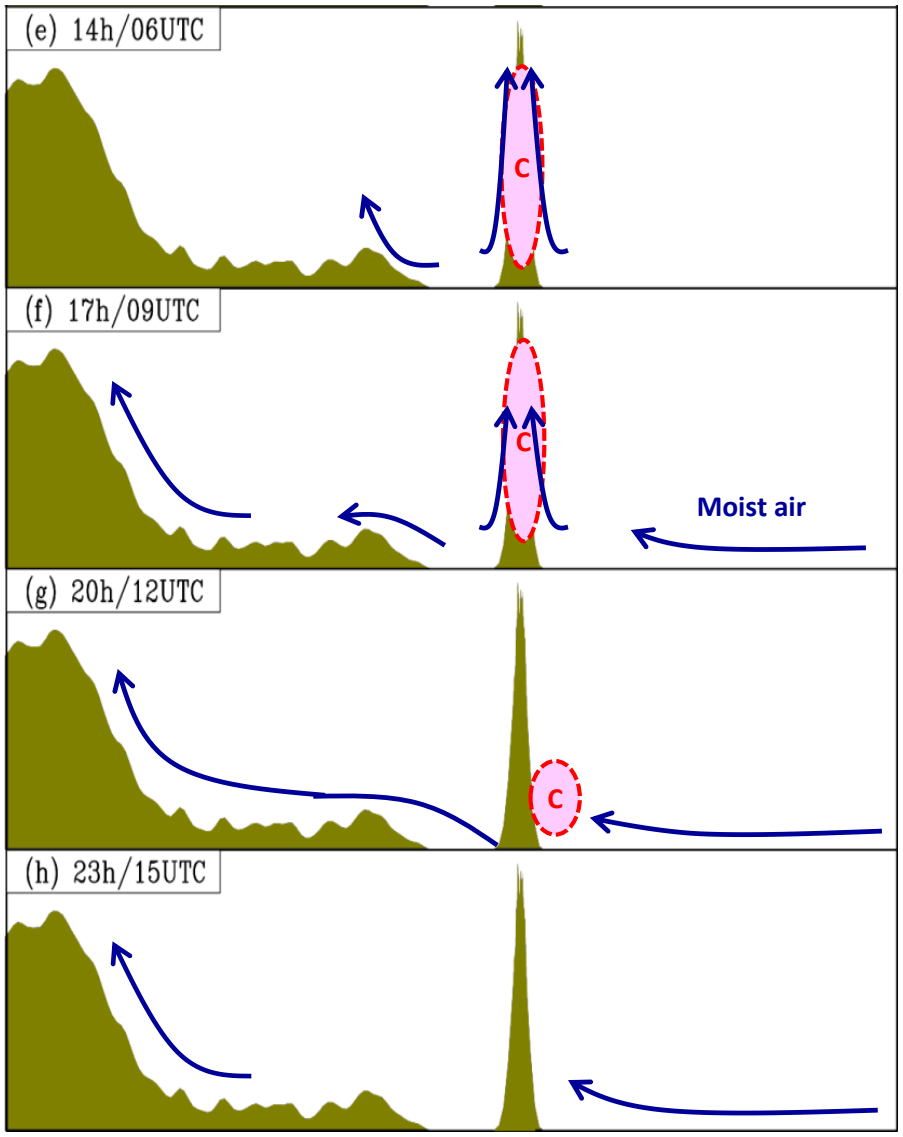
Diurnal (S1) of east-west circulation; 02-11 h





Diurnal (S1) of east-west circulation; 14-23 h

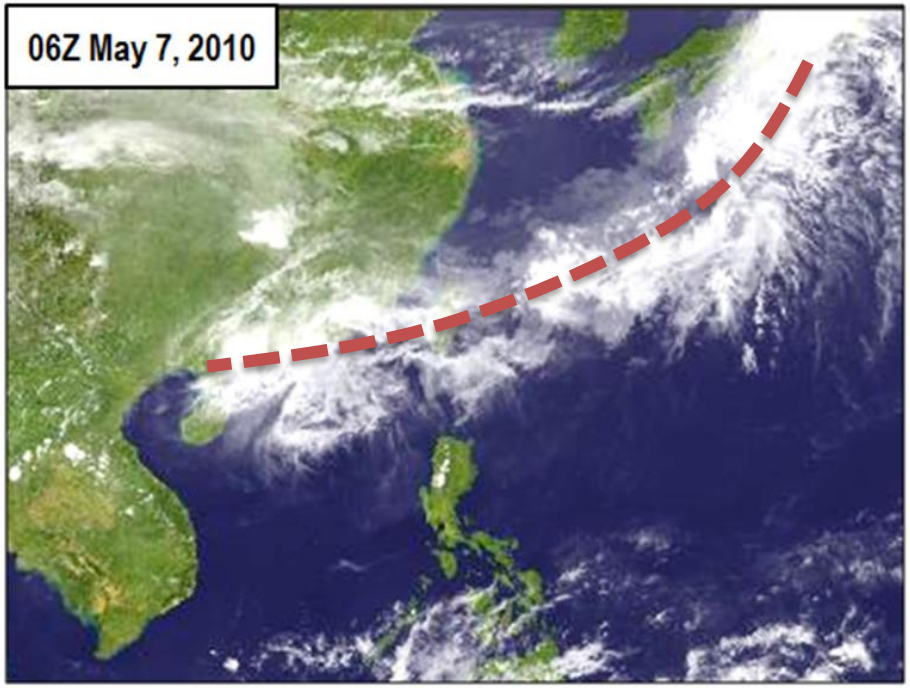




Does the diurnal rainfall in Taiwan consist of trend signal?

Diurnal rainfall vs. Frontal rainfall

(a) Frontal convection event

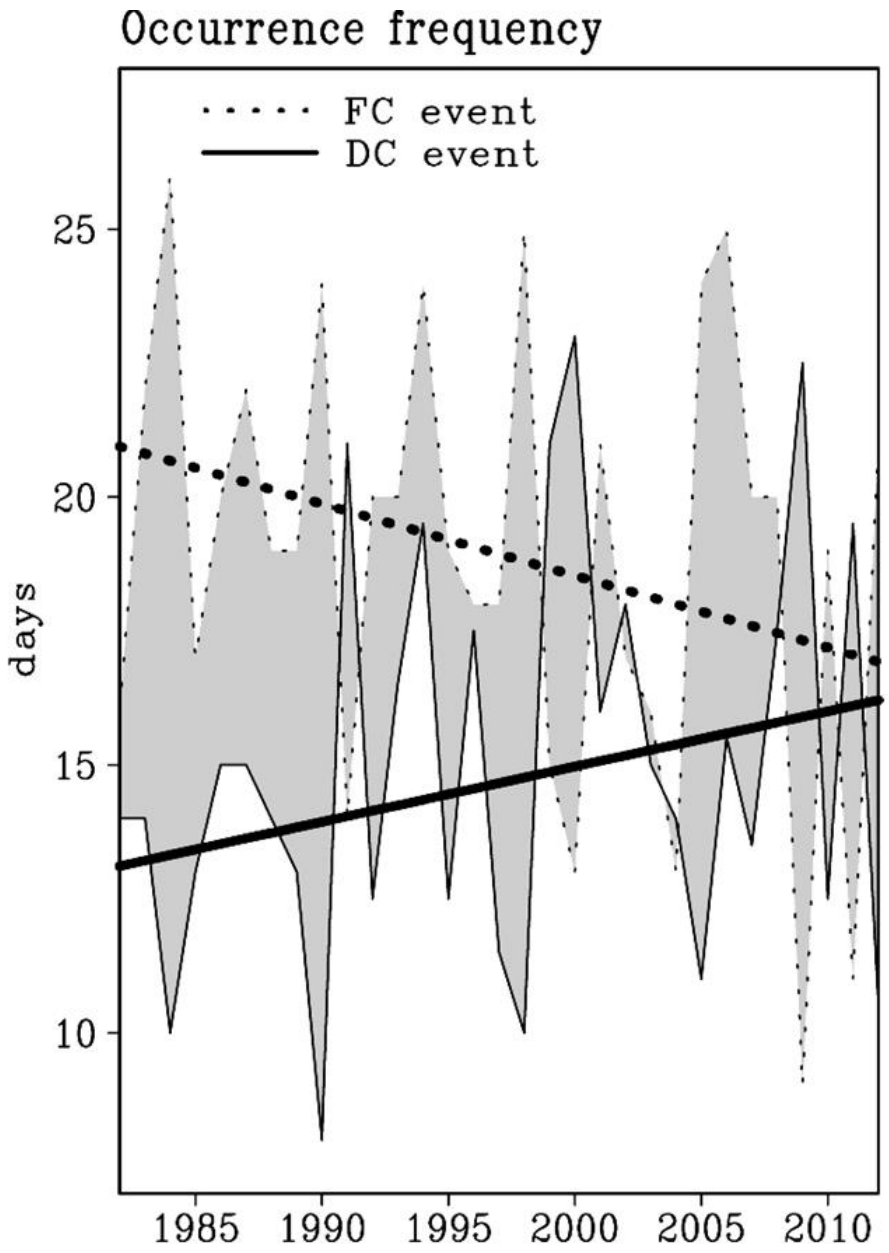


(b) Diurnal convection event

Quantifying weather systems

- JMA weather maps, station observation, TRMM 3B42 and **Gridded Satellite infrared brightness temperature (GSBT); 1982-2012 May and June**

Trend in DC and FC

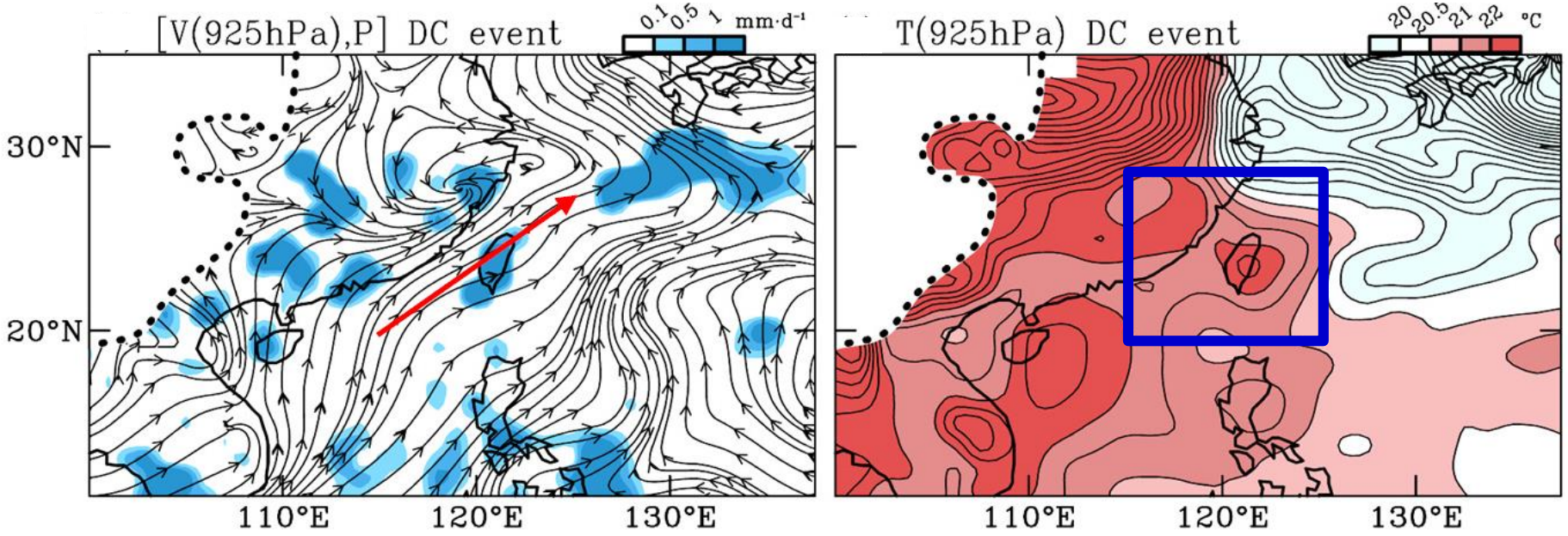


	Occurrence frequency Taiwan (Southeast China)	Rainfall Intensity Taiwan (Southeast China)
FC event	-20.3%* (-16.3%)*	-12.1% (-11.5%)
DC event	+19.6%* (+15.6%)*	+48.2%** (+40.8%)**
Other event	+3.1% (+4.7%)	+10.3% (+11.2%)

* significant at 90% confidence intervals

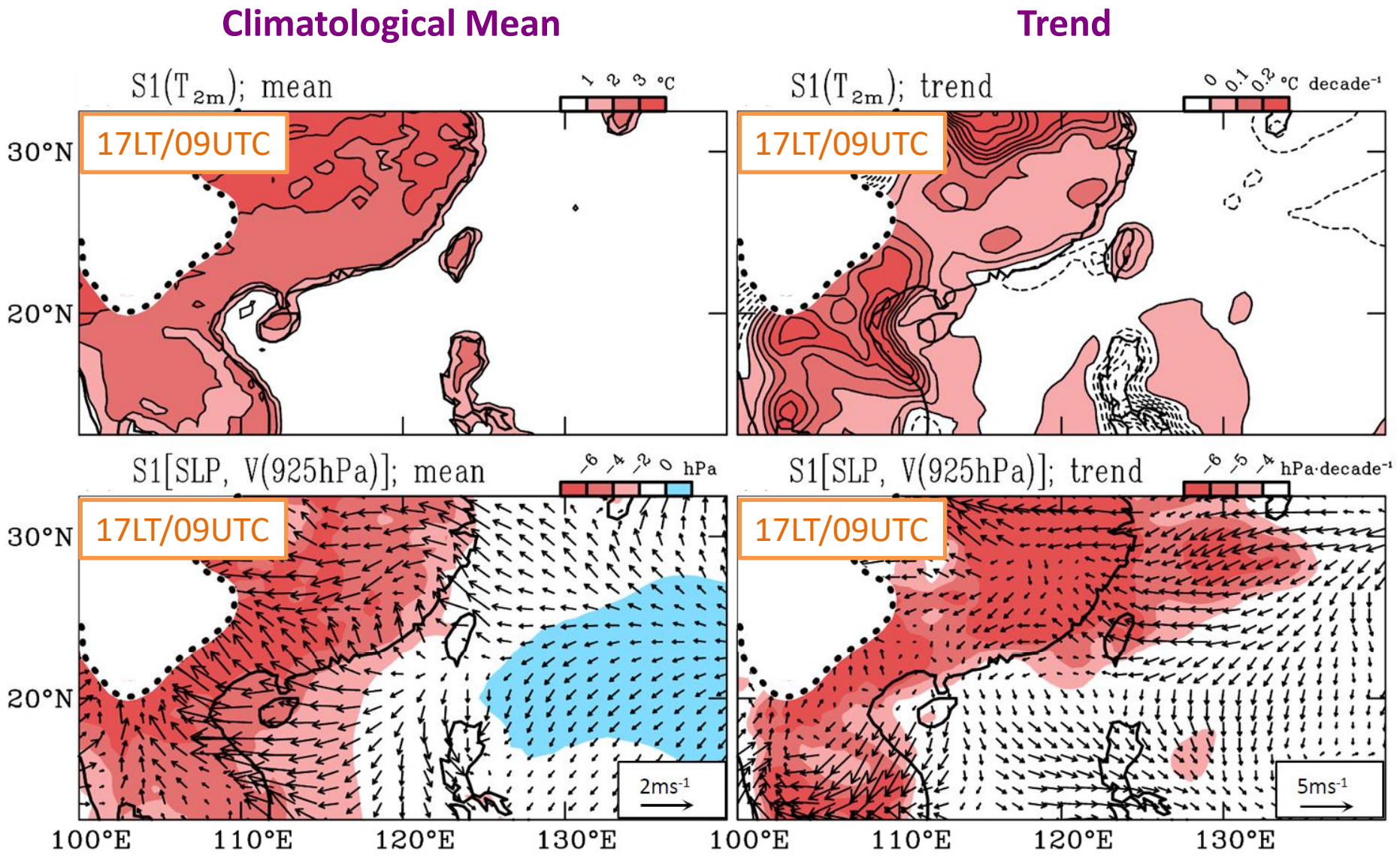
** significant at 99% confidence intervals

Cause of increase in DC days



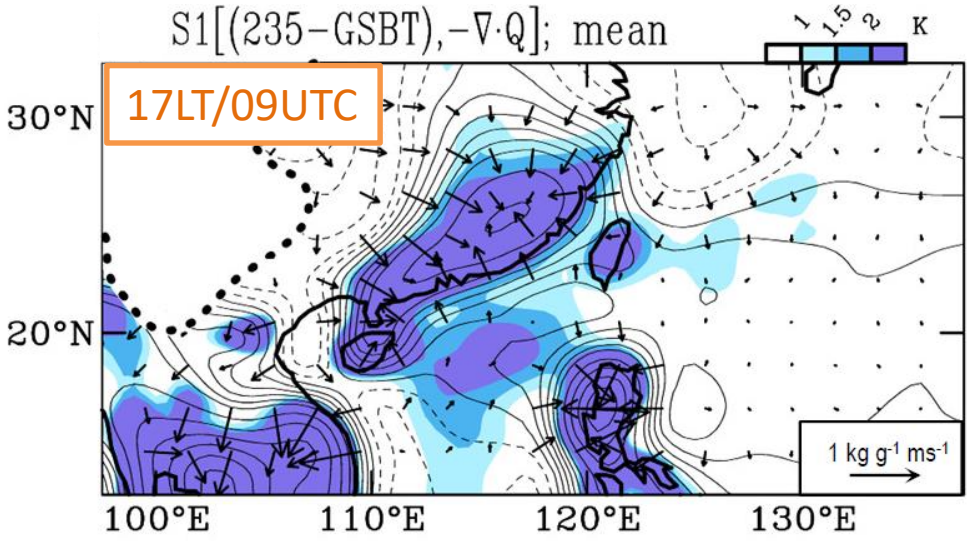
- Land-sea thermal contrast change?
- Land-sea breeze change?

Trend in diurnal temperature and circulation

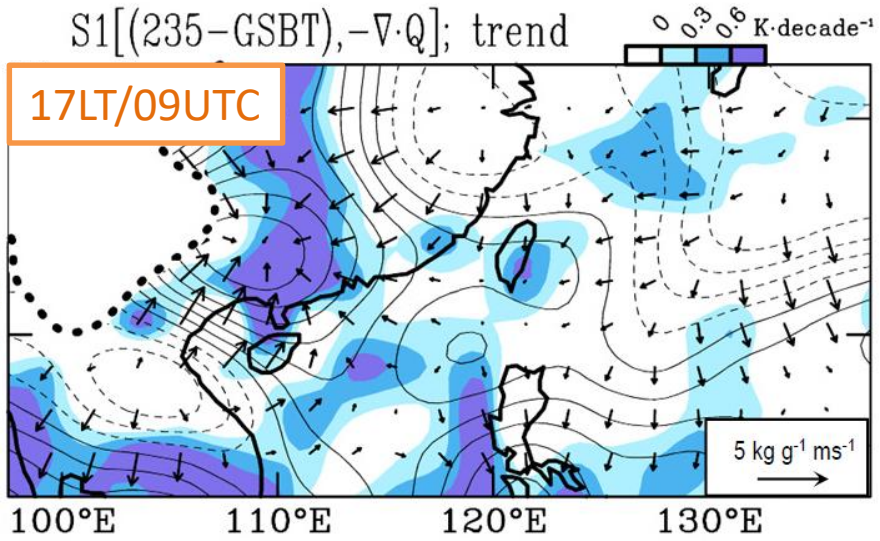


Cause of increase in DC intensity

Climatological Mean

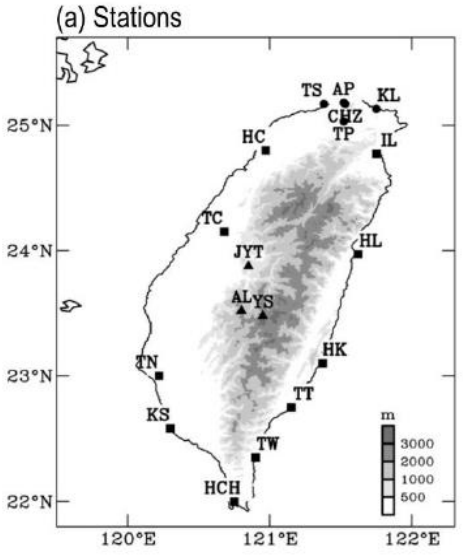


Trend



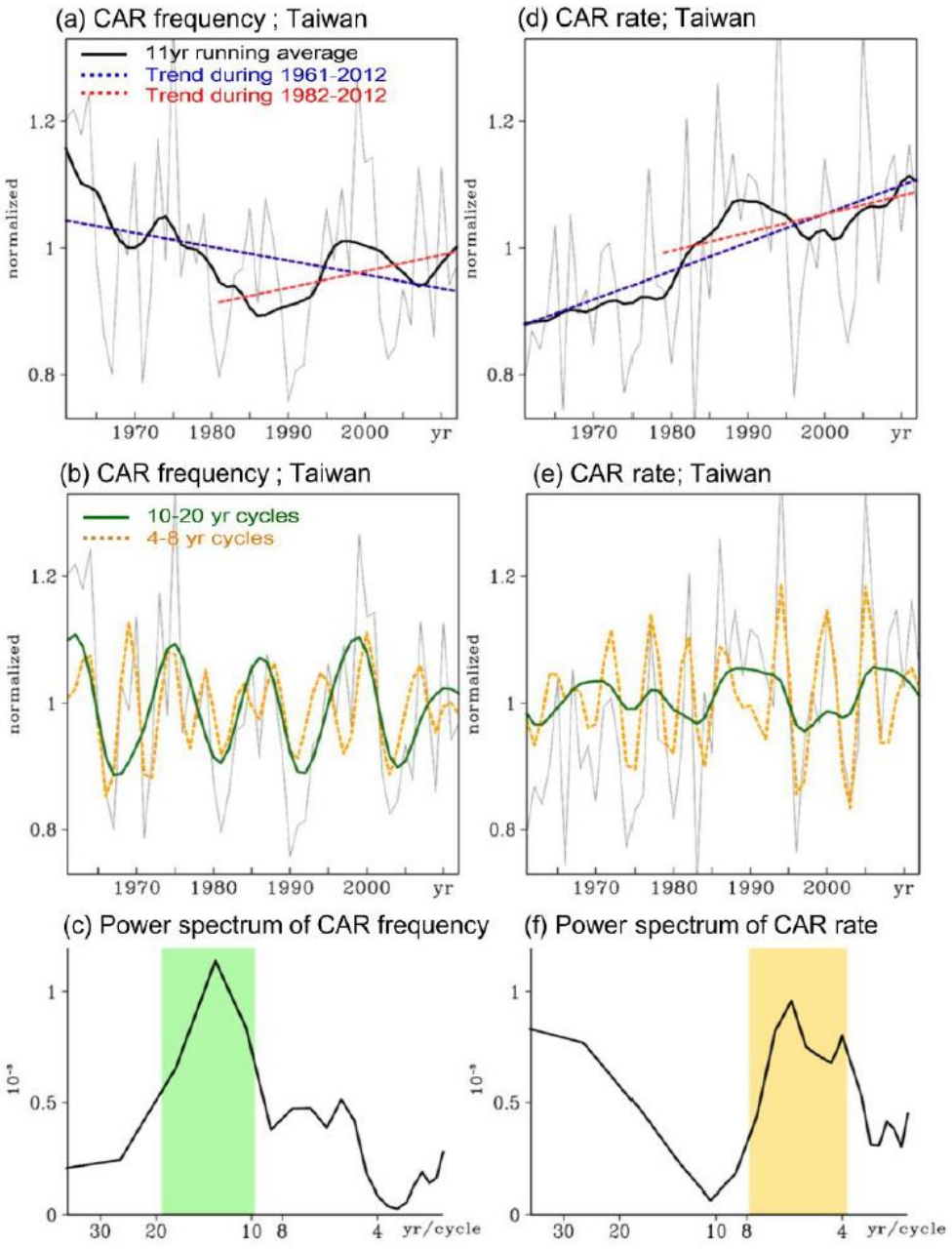
Does the long-term variation of diurnal rainfall in Taiwan consist of regional differences?

Low-frequency variations of diurnal rainfall



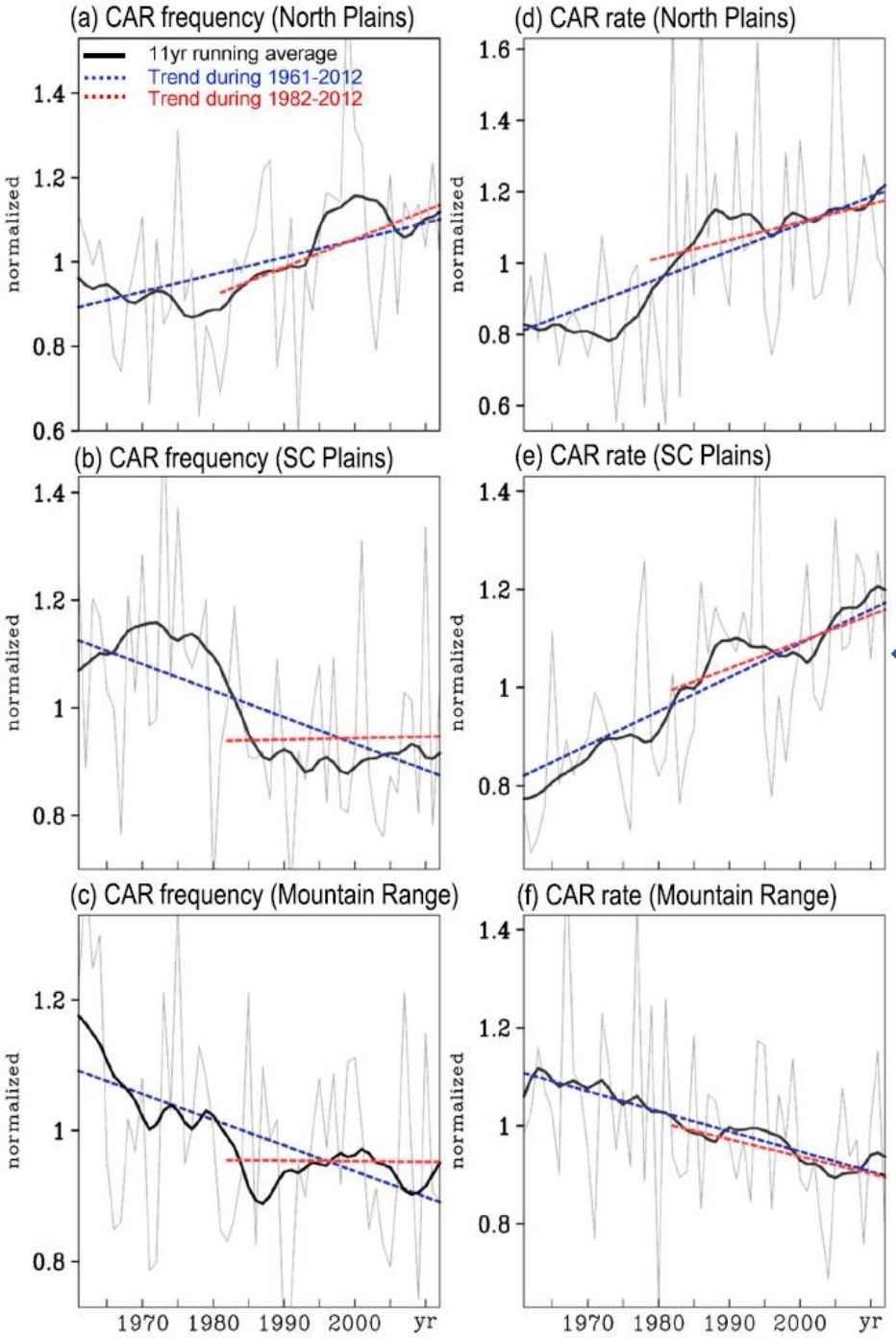
CAR: Convective Afternoon Rainfall

➔Low-frequency variations of CAR activity over Taiwan are modulated by long-term trend & 10-20 year variations



Regional differences

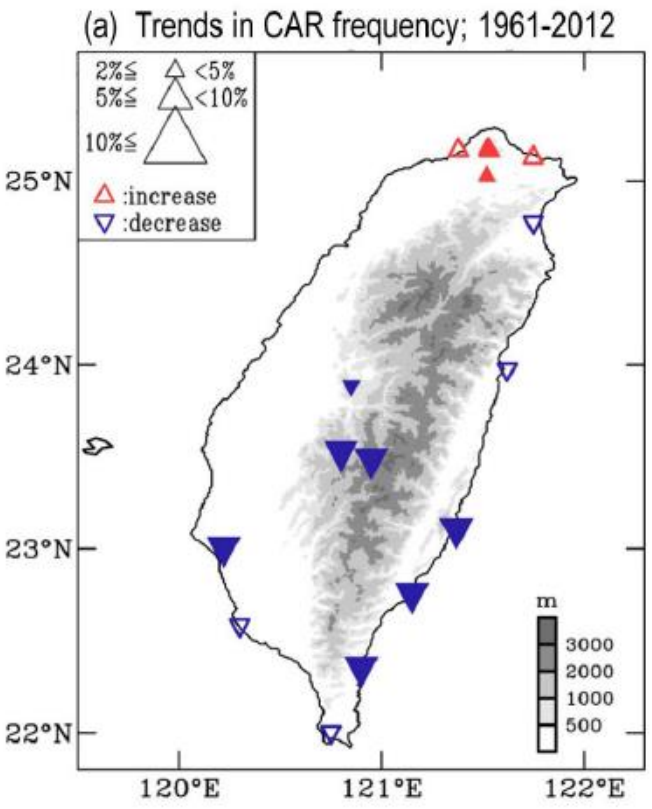
For frequency, the change is more like **interdecadal change** (i.e. differences between two periods: 1992~2012 and 1961~1981)

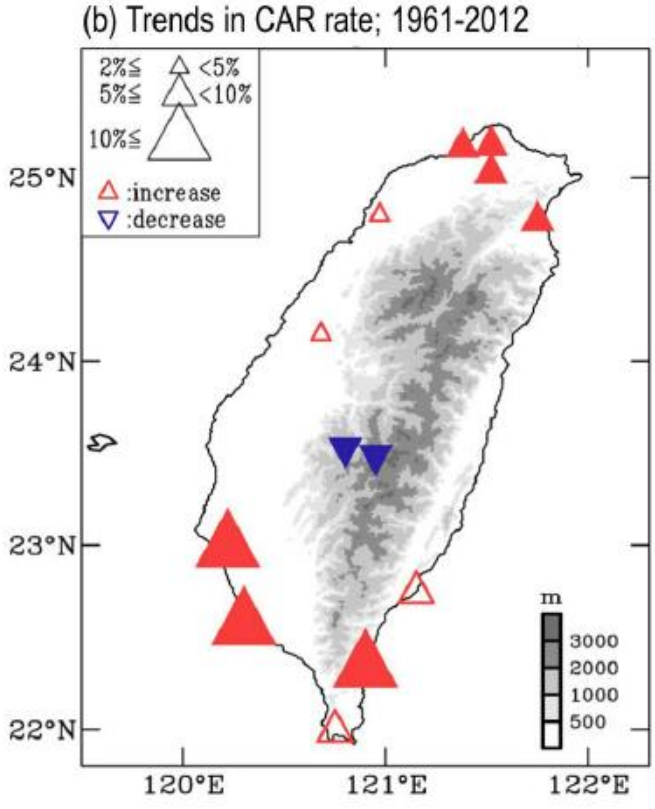


For intensity, the change is more like a **linear trend**

Regional differences in trend of diurnal rainfall

CAR: Convective Afternoon Rainfall



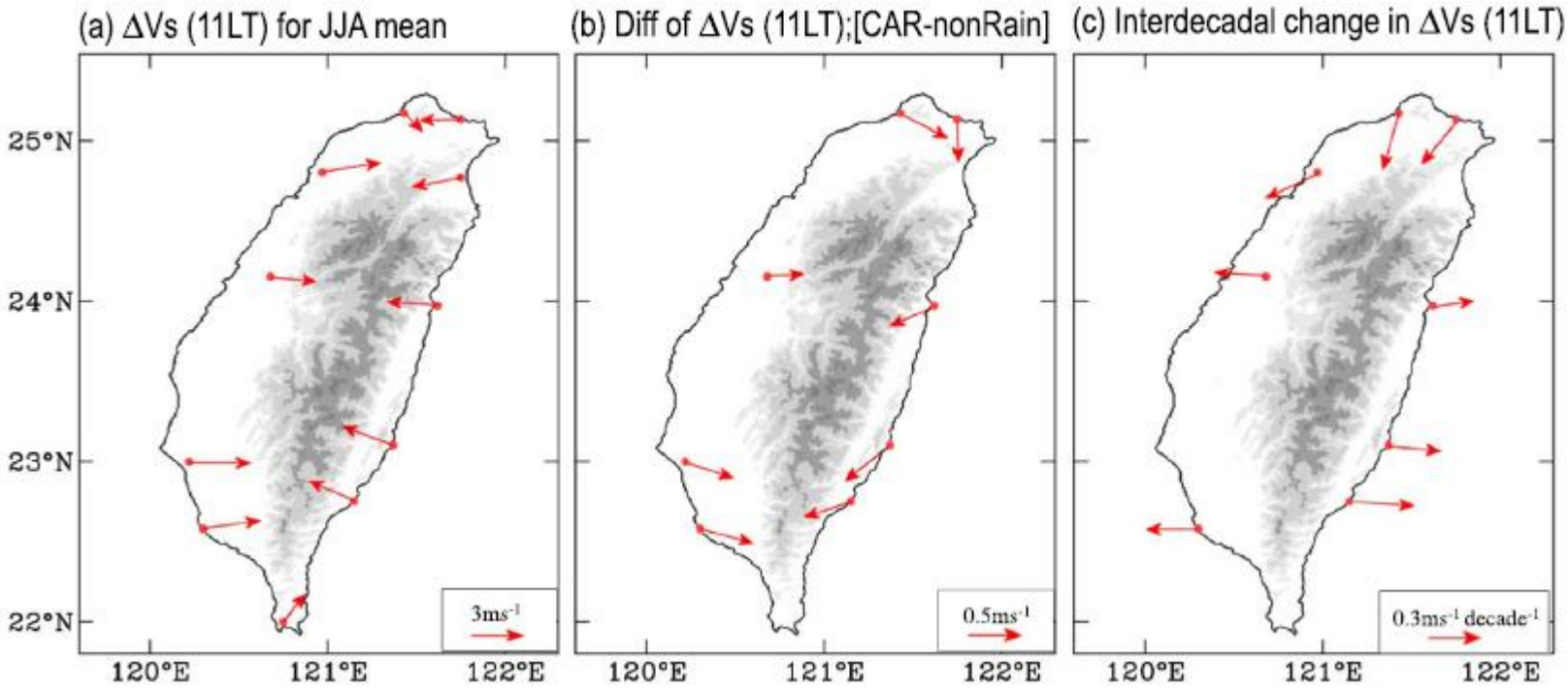


南、北差異

山區和平地差異

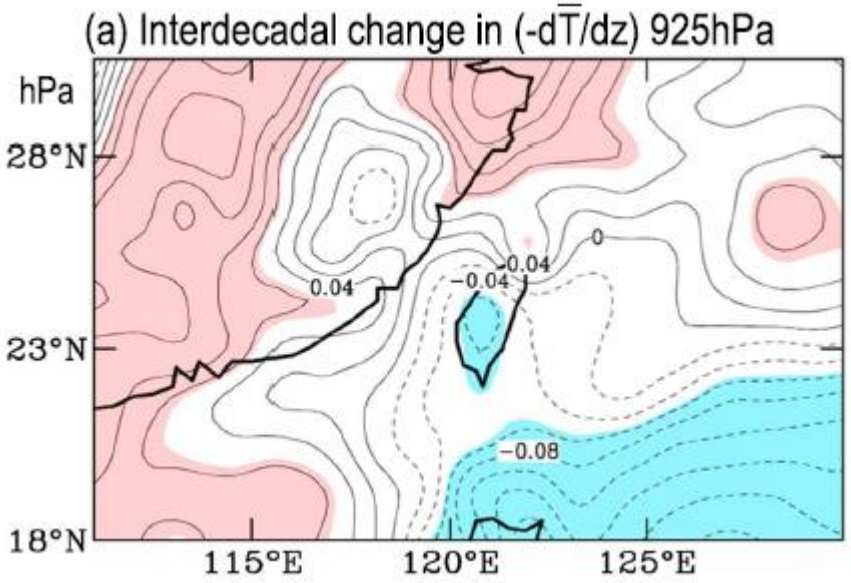
➔The trend in CAR activity consists of regional differences

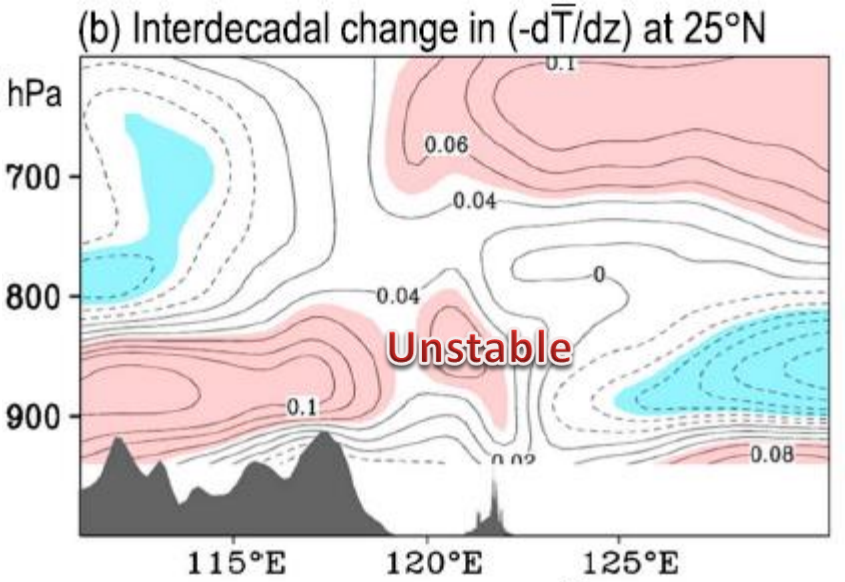
Cause of interdecadal change in diurnal frequency

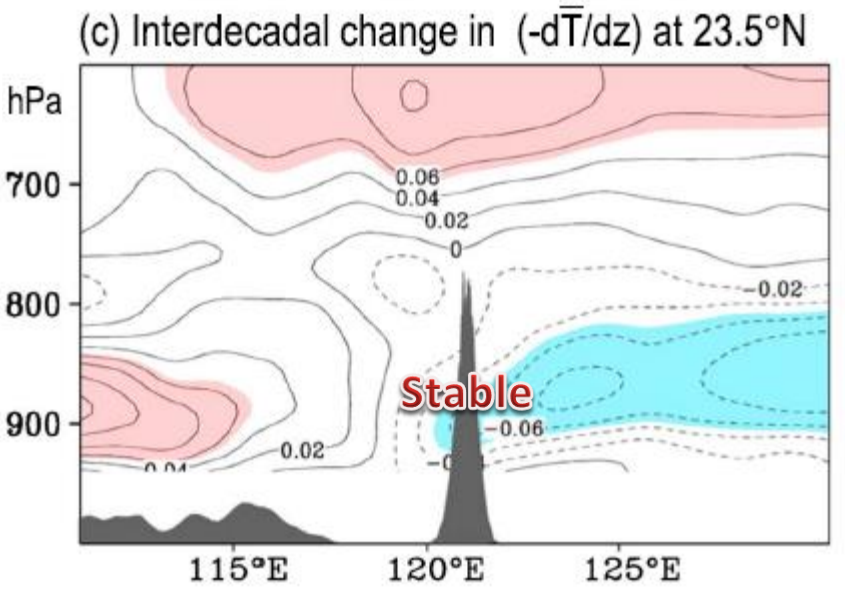


- Dynamical change explains the regional differences in diurnal frequency (i.e. 南、北差異)

Cause of interdecadal change in diurnal frequency

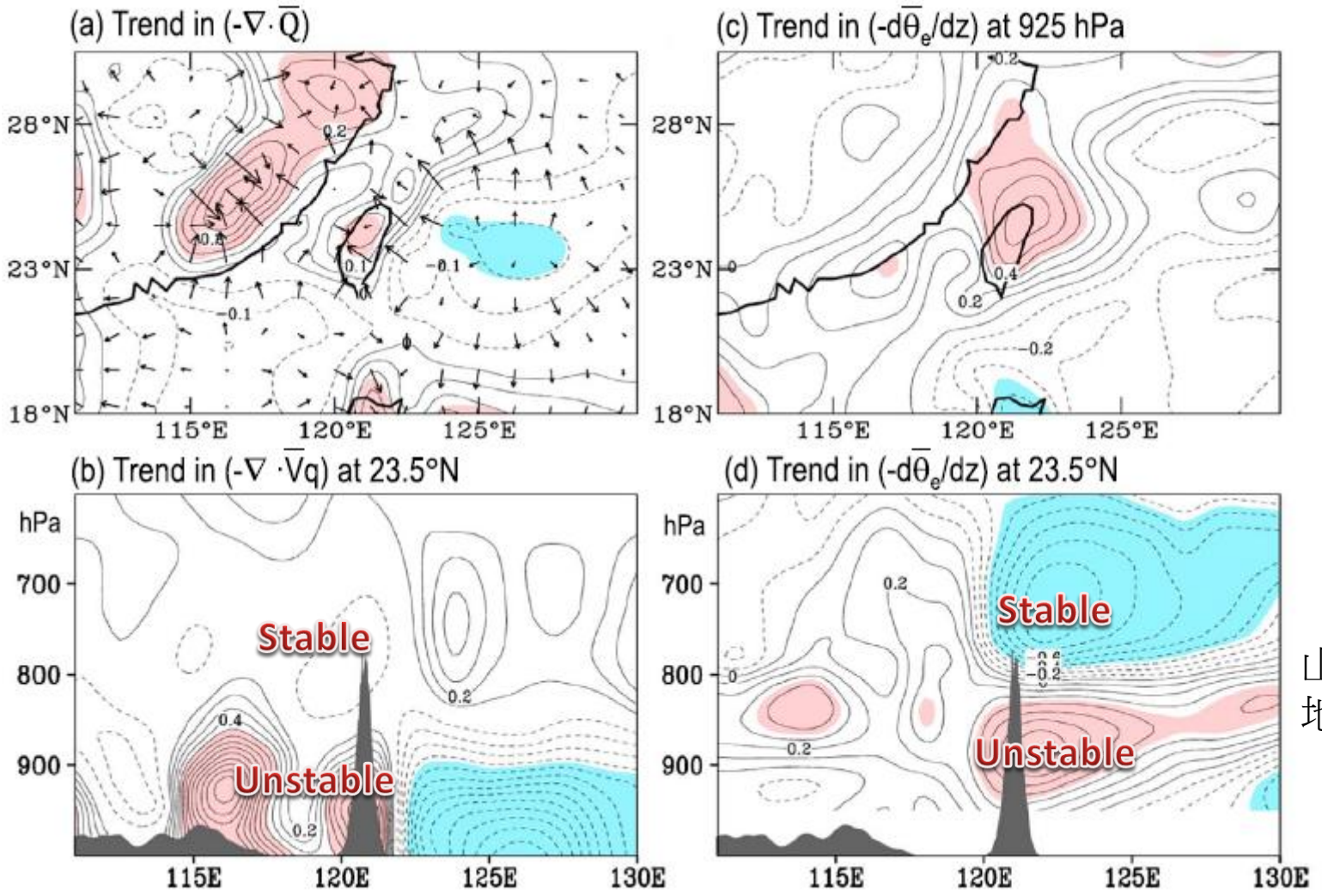






- Thermal instability change explains the regional differences in diurnal frequency (i.e.南、北差異)

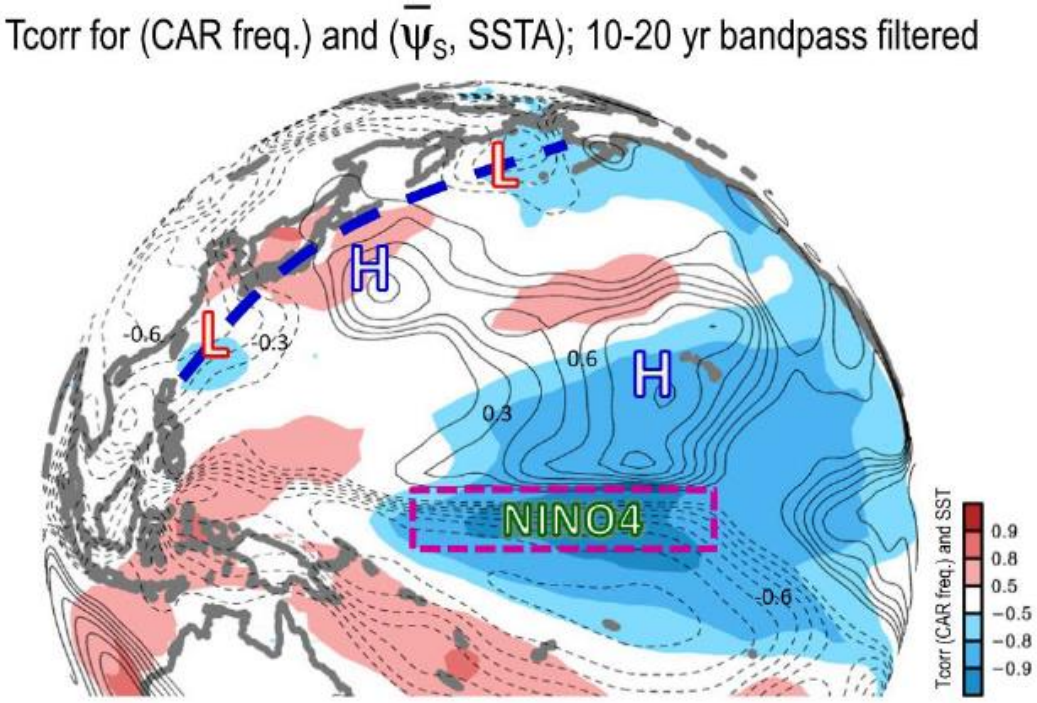
Cause of trend in diurnal rain rate



山區和平地差異

- Changes in moisture flux and moist instability explain the change in diurnal intensity

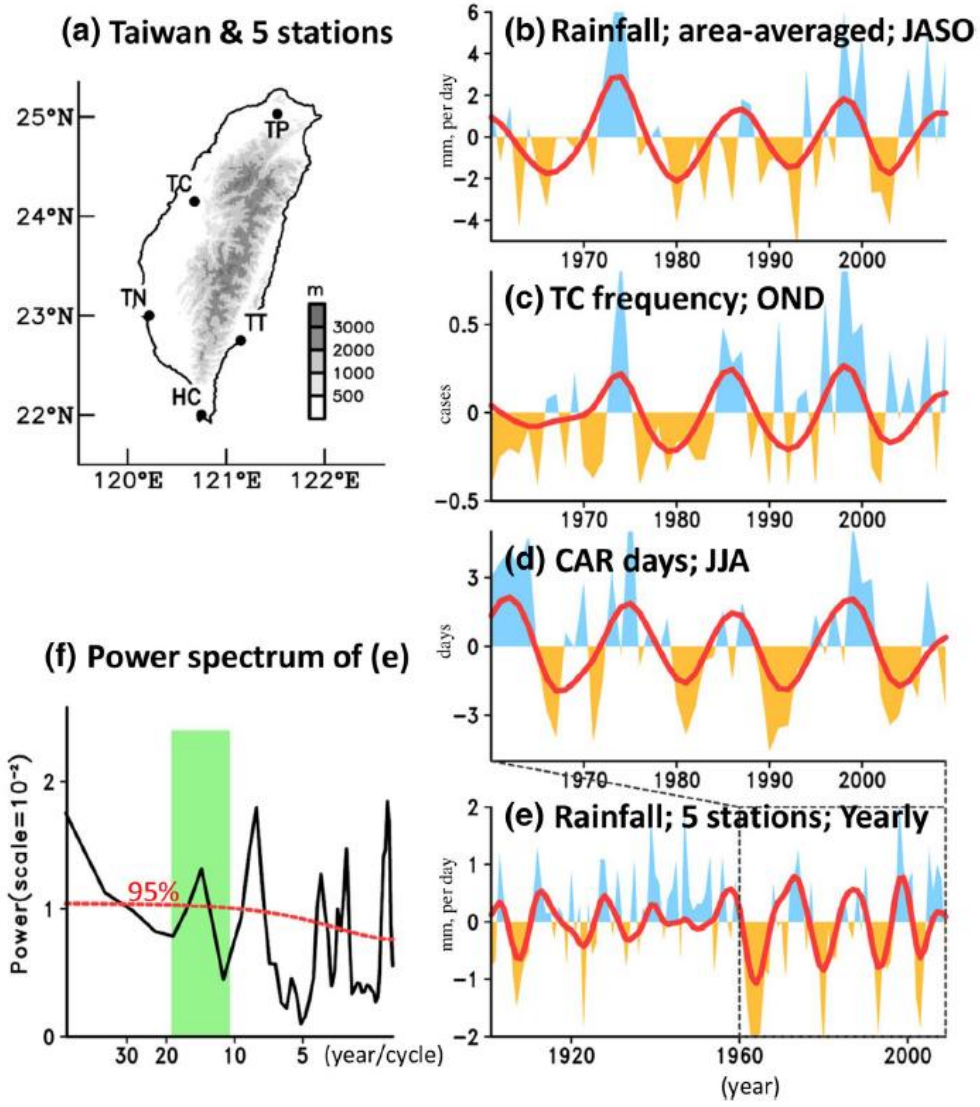
Cause of 10-20 yr variations of diurnal frequency

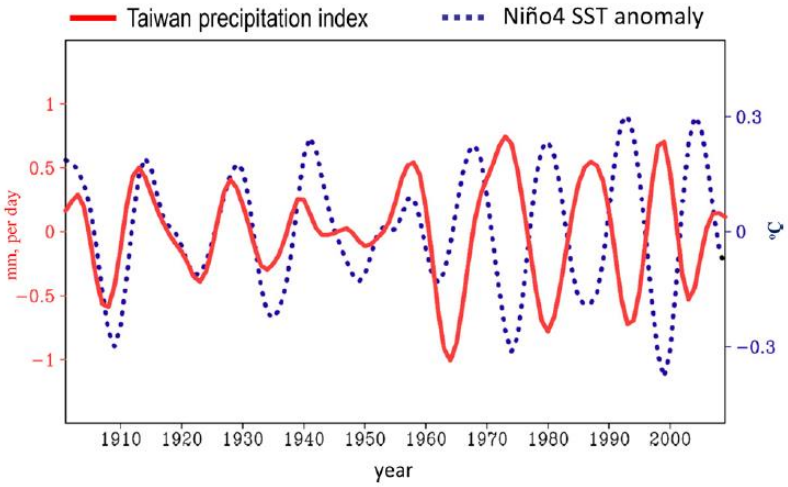


➔Cause of 10-20 year variations of CAR frequency is related to the quasi-decadal oscillation of sea surface temperature over NINO4 region

Has the relationship between the diurnal rainfall in Taiwan and the sea surface temperature over the Nino3.4 region changed over past sixty years?

DC 與西太平洋年代際變化之間的關係





(Huang* et al., 2018; climate dynamics)

Decadal fluctuations in the western Pacific recorded by long precipitation records in Taiwan

Wan-Ru Huang[1] · S.-Y. Simon Wang[2,3] · Biing T. Guan[4]

Interannual variation

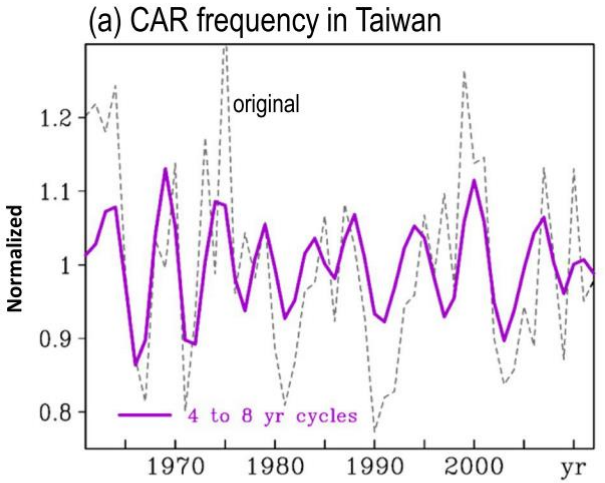
SCIENTIFIC REPORTS

OPEN

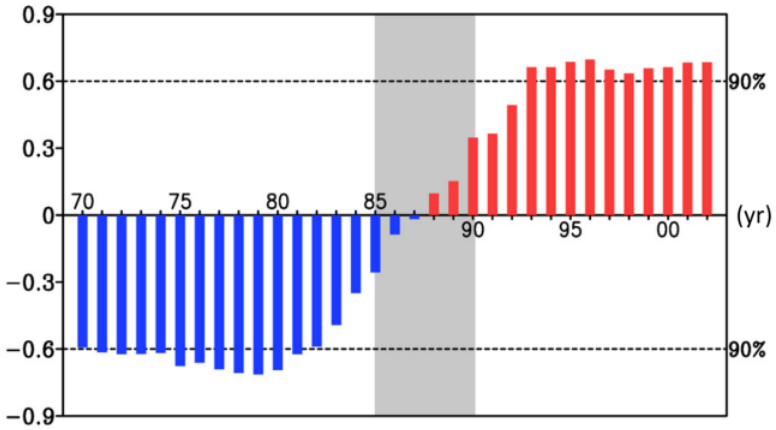
Relationship between the Interannual Variations of Summer Convective Afternoon Rainfall Activity in Taiwan and SSTA(Niño3.4) during 1961–2012: Characteristics and Mechanisms

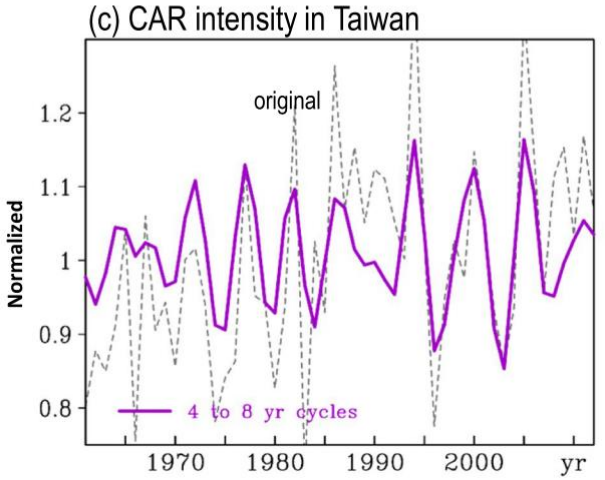
Received: 19 February 2019
Accepted: 17 June 2019
Published online: 28 June 2019

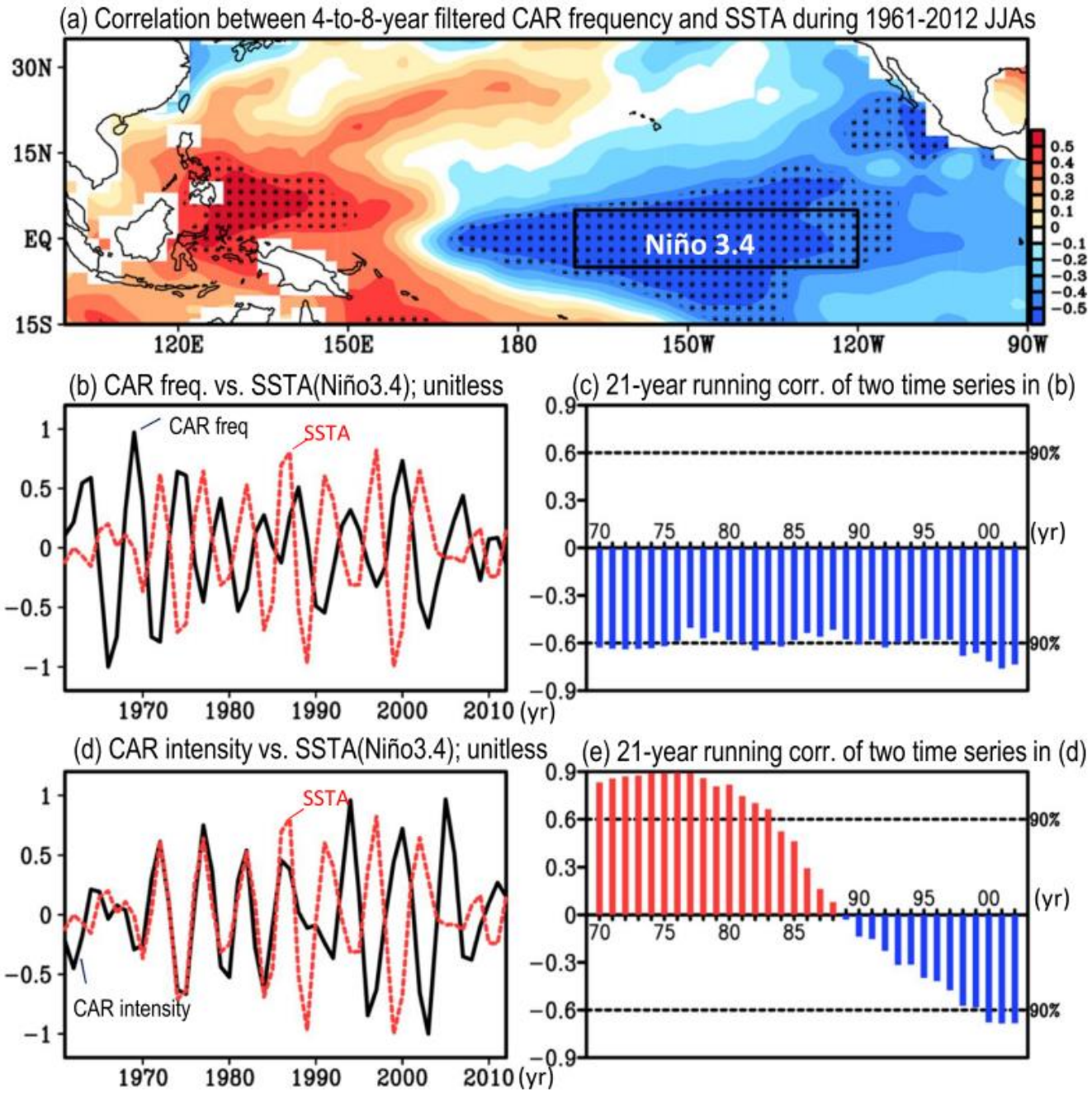
Wan-Ru Huang, Ya-Hui Chang & Po-Han Huang

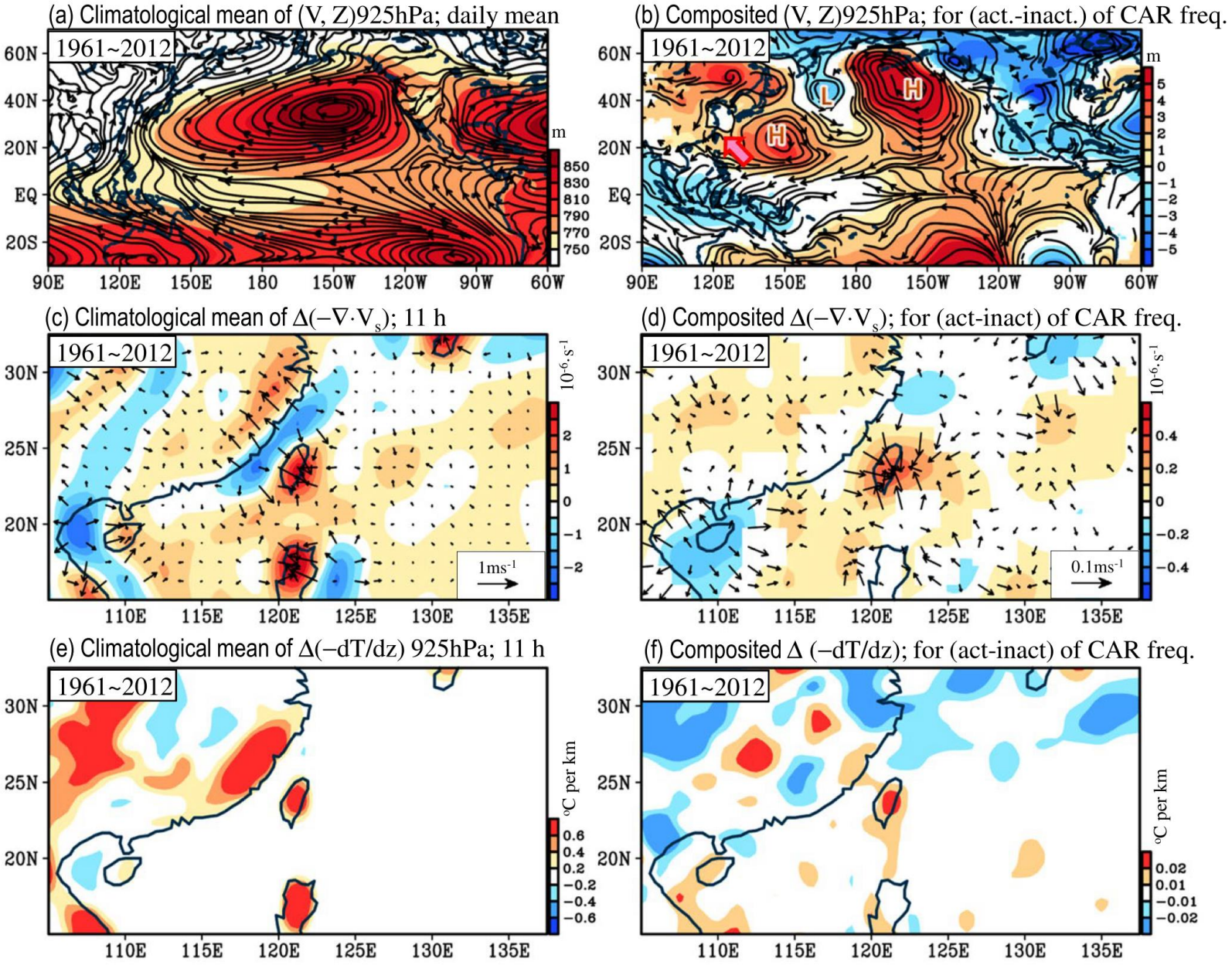


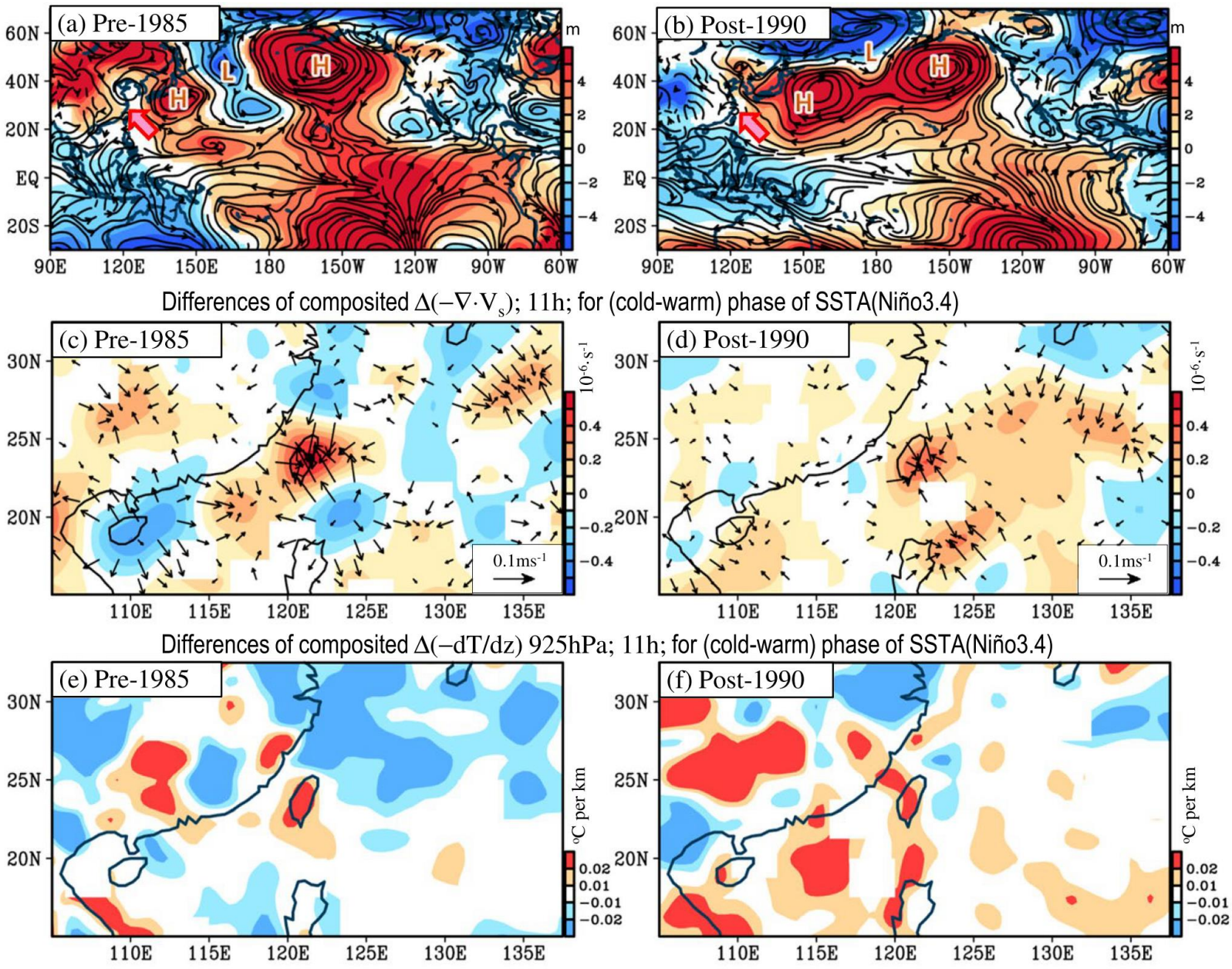
Running correlation between filtered CAR frequency and filtered CAR intensity

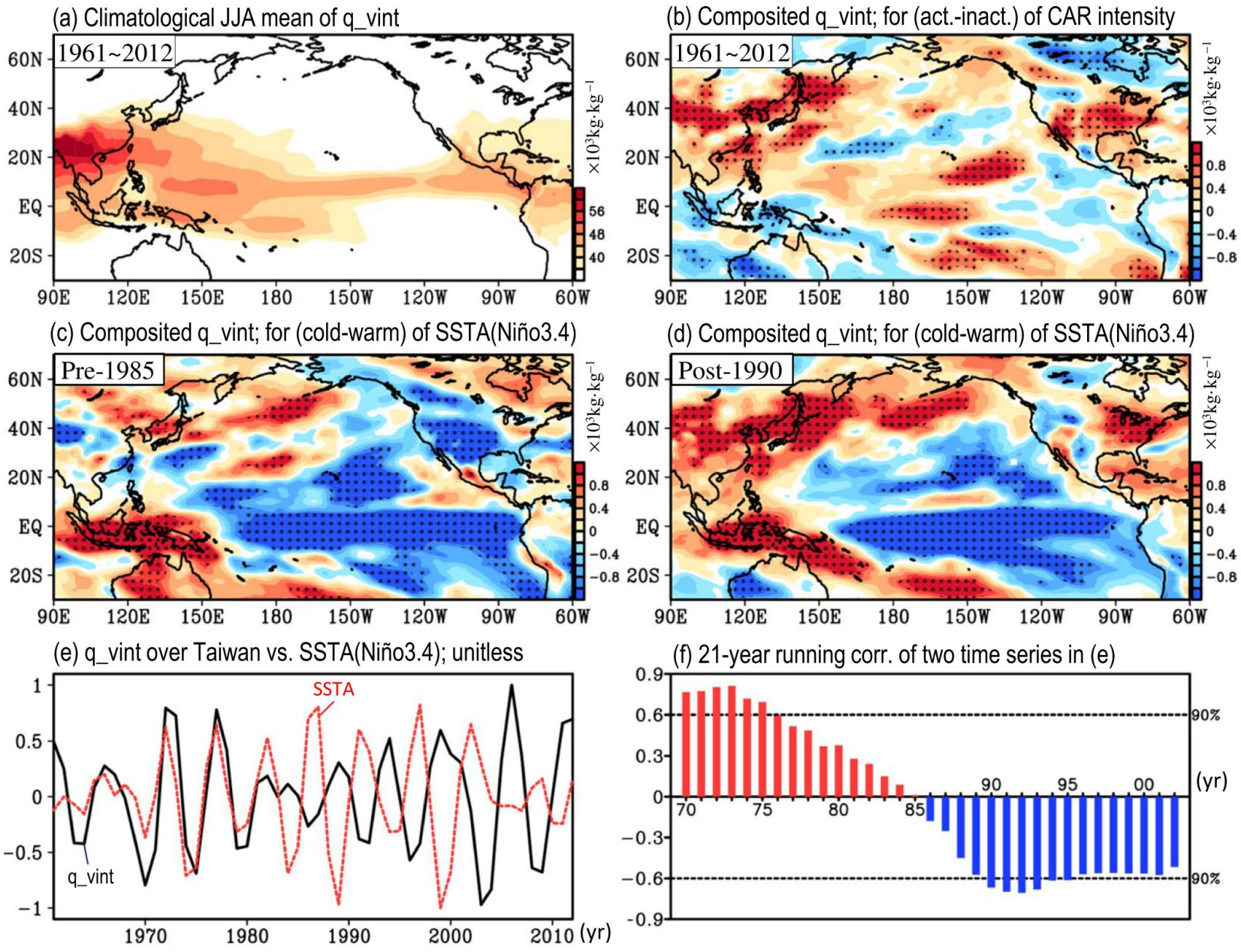


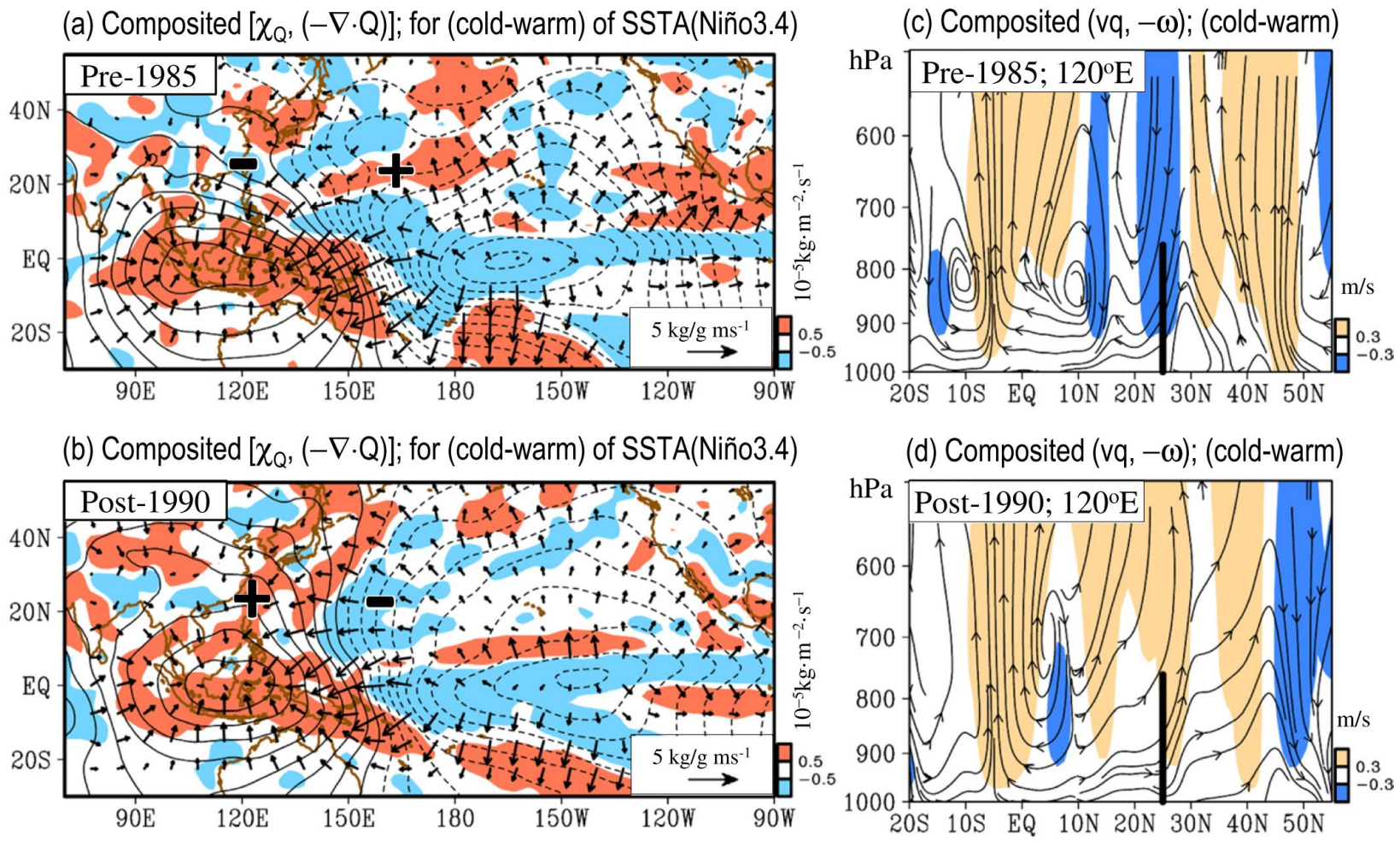



(a) Correlation between 4-to-8-year filtered CAR frequency and SSTA during 1961-2012 JJAs
30N
15N
EQ
15S
120E
150E
180
150W
120W
90W
Niño 3.4
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
(b) CAR freq. vs. SSTA(Niño3.4); unitless
CAR freq
SSTA
1
0.5
0
−0.5
−1
1970
1980
1990
2000
2010 (yr)
(c) 21-year running corr. of two time series in (b)
0.9
0.6
0.3
0
−0.3
−0.6
−0.9
90%
70
75
80
85
90
95
00
(yr)
(d) CAR intensity vs. SSTA(Niño3.4); unitless
SSTA
CAR intensity
(e) 21-year running corr. of two time series in (d)


(a) Climatological mean of (V, Z)925hPa; daily mean
1961~2012
m
850
830
810
790
770
750
60N
40N
20N
EQ
20S
90E
120E
150E
180
150W
120W
90W
60W
(b) Composited (V, Z)925hPa; for (act.-inact.) of CAR freq.
1961~2012
m
5
4
3
2
1
0
−1
−2
−3
−4
−5
L
H
H
(c) Climatological mean of Δ(−∇·V$_s$); 11 h
1961~2012
10^{-6}·s^{-1}
2
1
0
−1
−2
1ms^{-1}
30N
25N
20N
110E
115E
120E
125E
130E
135E
(d) Composited Δ(−∇·V$_s$); for (act-inact) of CAR freq.
1961~2012
10^{-6}·s^{-1}
0.4
0.2
0
−0.2
−0.4
0.1ms^{-1}
(e) Climatological mean of Δ(−dT/dz) 925hPa; 11 h
1961~2012
°C per km
0.6
0.4
0.2
−0.2
−0.4
−0.6
(f) Composited Δ (−dT/dz); for (act-inact) of CAR freq.
1961~2012
°C per km
0.02
0.01
−0.01
−0.02


Differences of composited (V, Z) 925hPa; for (cold-warm) phase of SSTA(Niño3.4)
(a) Pre-1985
(b) Post-1990
m
60N
40N
20N
EQ
20S
90E
120E
150E
180
150W
120W
90W
60W
H
L
Differences of composited Δ(−∇·V_s); 11h; for (cold-warm) phase of SSTA(Niño3.4)
(c) Pre-1985
(d) Post-1990
10⁻⁶·s⁻¹
0.1ms⁻¹
30N
25N
20N
110E
115E
120E
125E
130E
135E
Differences of composited Δ(−dT/dz) 925hPa; 11h; for (cold-warm) phase of SSTA(Niño3.4)
(e) Pre-1985
(f) Post-1990
°C per km


(a) Climatological JJA mean of q_vint
1961~2012
60N
40N
20N
EQ
20S
90E
120E
150E
180
150W
120W
90W
60W
×10³kg·kg⁻¹
56
48
40
(b) Composited q_vint; for (act.-inact.) of CAR intensity
1961~2012
0.8
0.4
0
−0.4
−0.8
(c) Composited q_vint; for (cold-warm) of SSTA(Niño3.4)
Pre-1985
(d) Composited q_vint; for (cold-warm) of SSTA(Niño3.4)
Post-1990
(e) q_vint over Taiwan vs. SSTA(Niño3.4); unitless
SSTA
q_vint
1
0.5
0
−0.5
−1
1970
1980
1990
2000
2010
(yr)
(f) 21-year running corr. of two time series in (e)
0.9
0.6
0.3
0
−0.3
−0.6
-0.9
90%
70
75
80
85
90
95
00
(yr)


(a) Composited [χ_Q, $(-\nabla\cdot Q)$]; for (cold-warm) of SSTA(Niño3.4)
Pre-1985
40N
20N
EQ
20S
90E
120E
150E
180
150W
120W
90W
5 kg/g ms^{-1}
0.5
−0.5
10^{-5}kg·m^{-2}·s^{-1}
(b) Composited [χ_Q, $(-\nabla\cdot Q)$]; for (cold-warm) of SSTA(Niño3.4)
Post-1990
(c) Composited (vq, −ω); (cold-warm)
Pre-1985; 120°E
hPa
600
700
800
900
1000
20S 10S EQ 10N 20N 30N 40N 50N
m/s
0.3
−0.3
(d) Composited (vq, −ω); (cold-warm)
Post-1990; 120°E

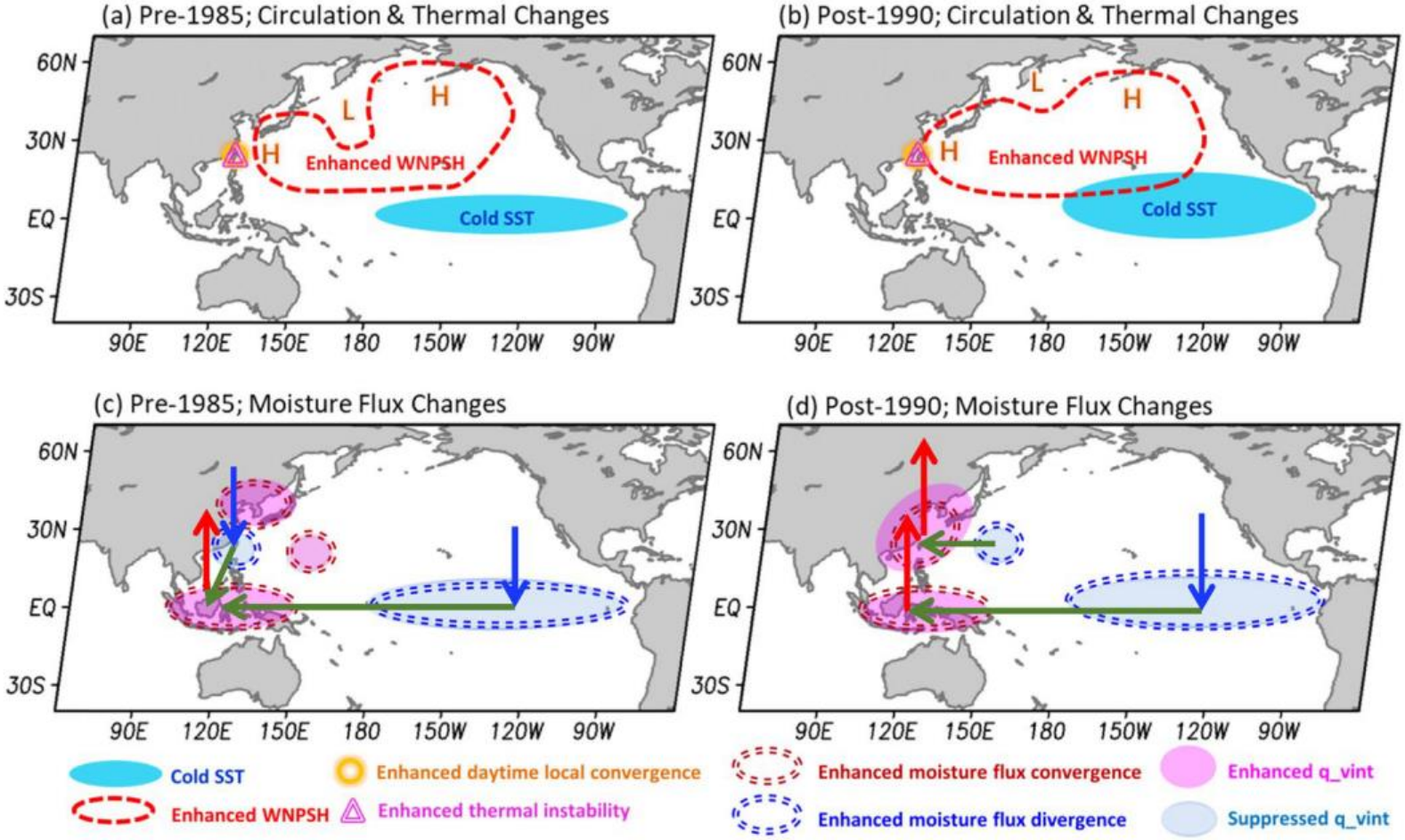


Figure 8. Schematic diagrams of the maintenance mechanisms of the interannual variation of CAR frequency in Taiwan during two periods: (**a**) pre-1985 and (**b**) post-1990. (**c**,**d**) correspond to (**a**,**b**) but for the interannual variation of CAR intensity in Taiwan. In (**c**,**d**), the green, red and blue arrows denote the directions of the horizontal moisture transport, upward motion and downward motion, respectively. The meanings of the other symbols are given below (**c**,**d**).

How the characteristics of diurnal rainfall events in Taiwan to be modulated by the BSISO features?

Intraseasonal variation

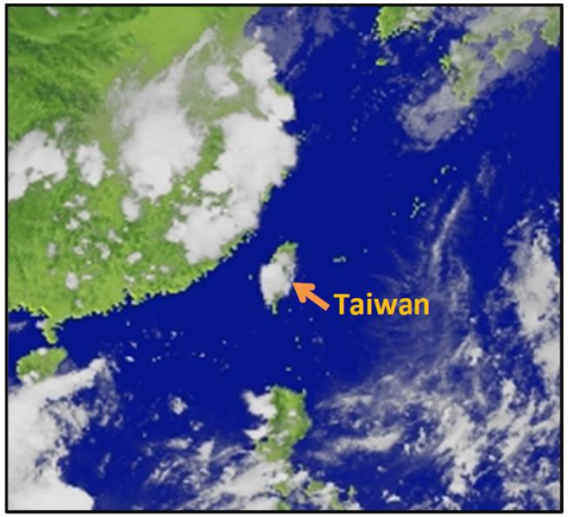
INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **38**: 2187–2200 (2018)
Published online 3 November 2017 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.5326

RMetS
Royal Meteorological Society

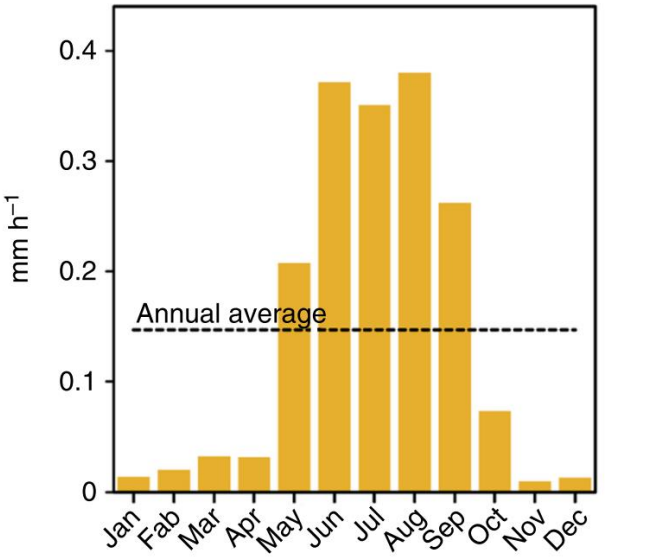
Impact of boreal summer intra-seasonal oscillations on warm season diurnal convection activity in Taiwan

Wan-Ru Huang* and Ya-Hui Chang
Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan

(a) IR cloud image (3 Aug 2007, 17 h)



(b) Monthly mean of diurnal rainfall variability



1982-2012, MJJAS

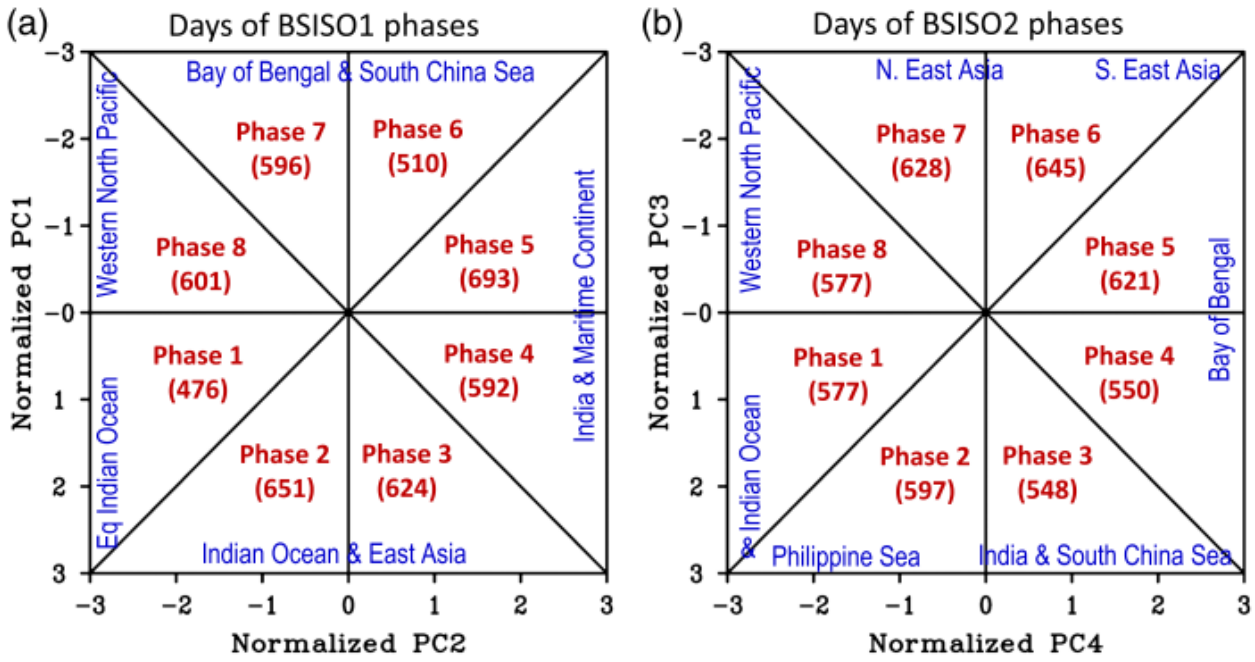
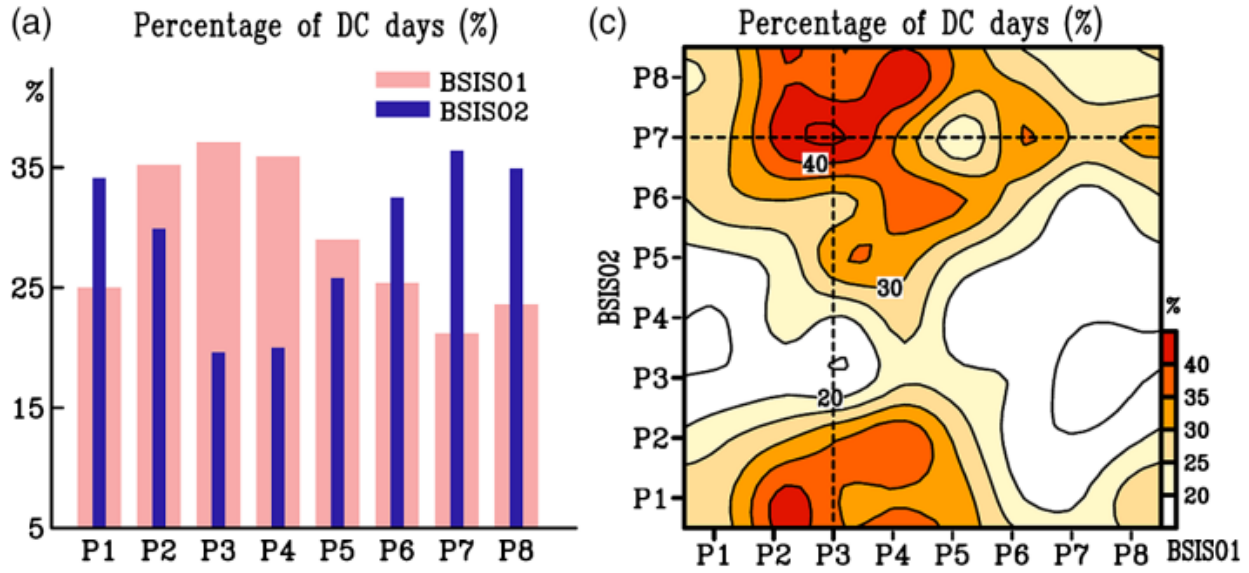
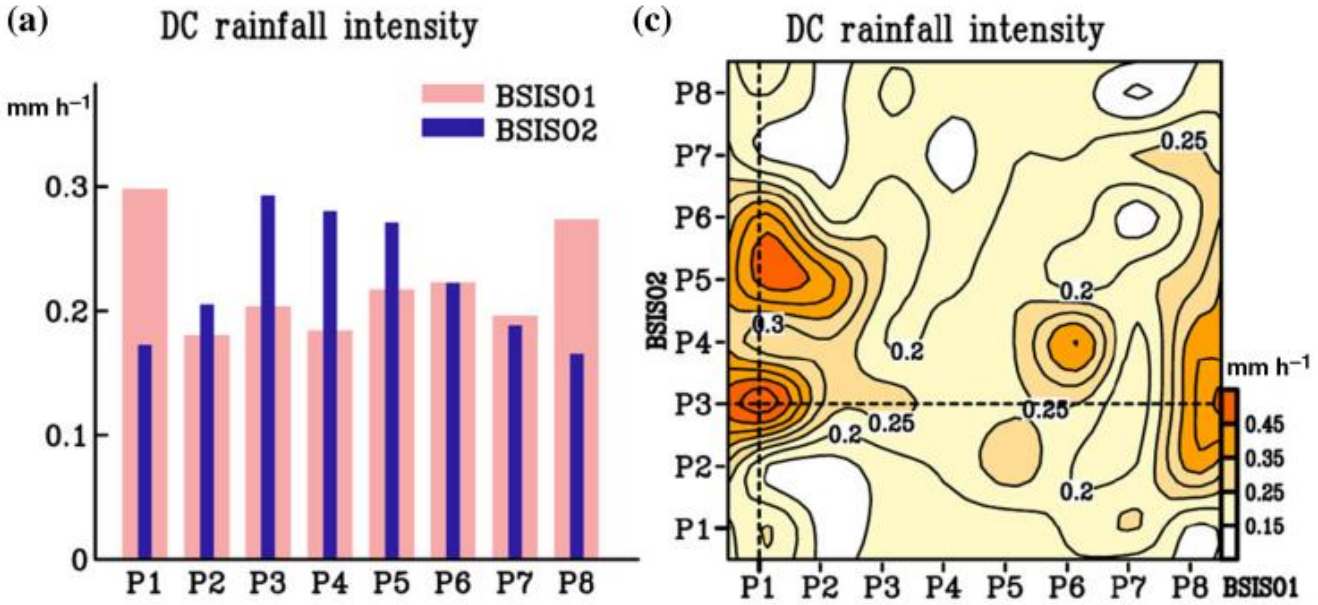
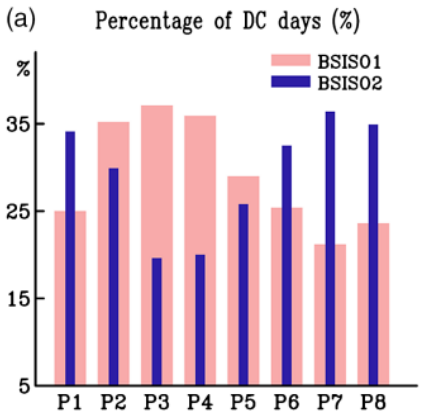
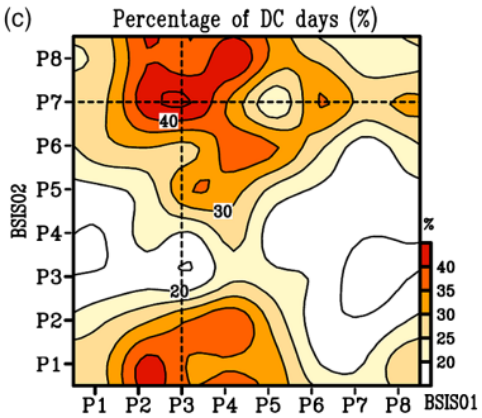


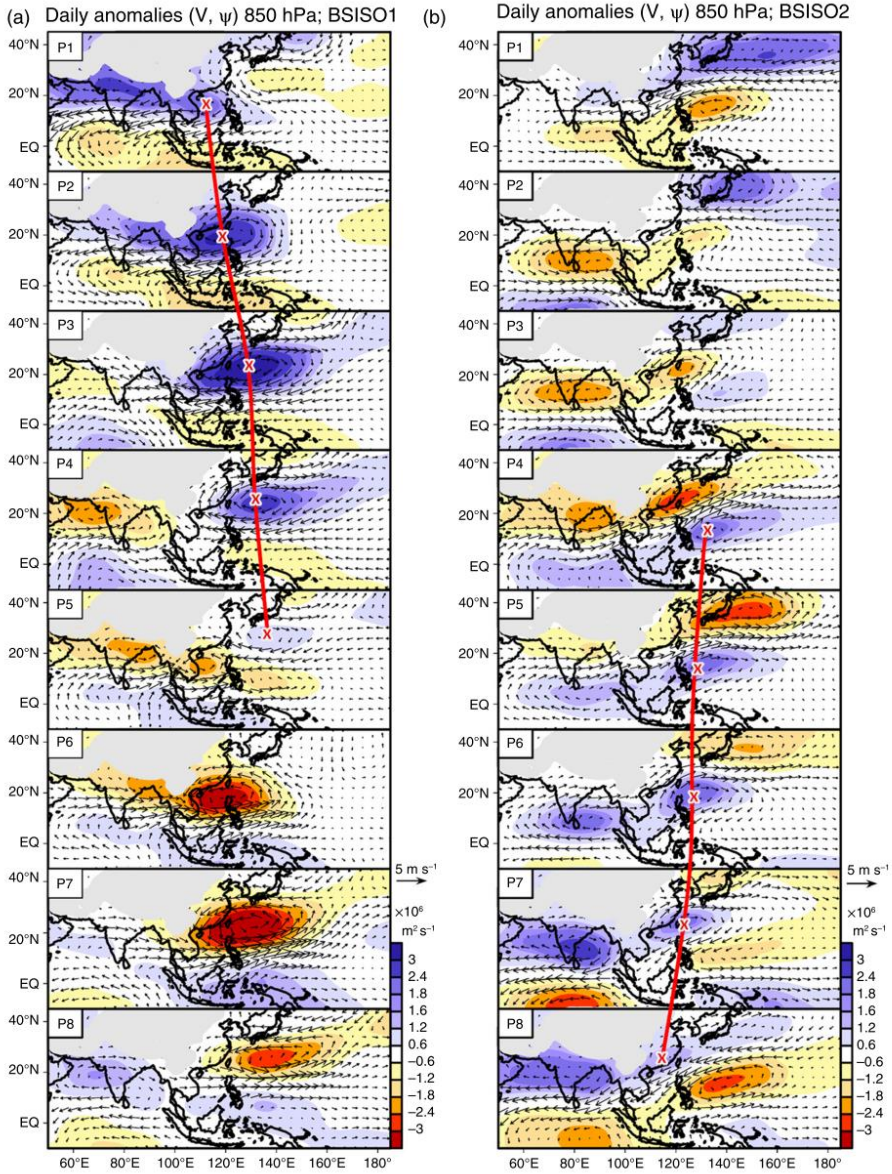
Figure 2. Phase diagram of (a) BSISO1 and (b) BSISO2, following Lee *et al.* (2013, figure 6). The value inside the parentheses represents the number of days counted for each phase of (a) BSISO1 and (b) BSISO2 over the time period from May to September (hereafter MJJAS), 1982–2012. Details for how to identify the phase and the propagation of BSISO1 and BSISO2 are referred to in Lee *et al.* (2013). [Colour figure can be viewed at wileyonlinelibrary.com].

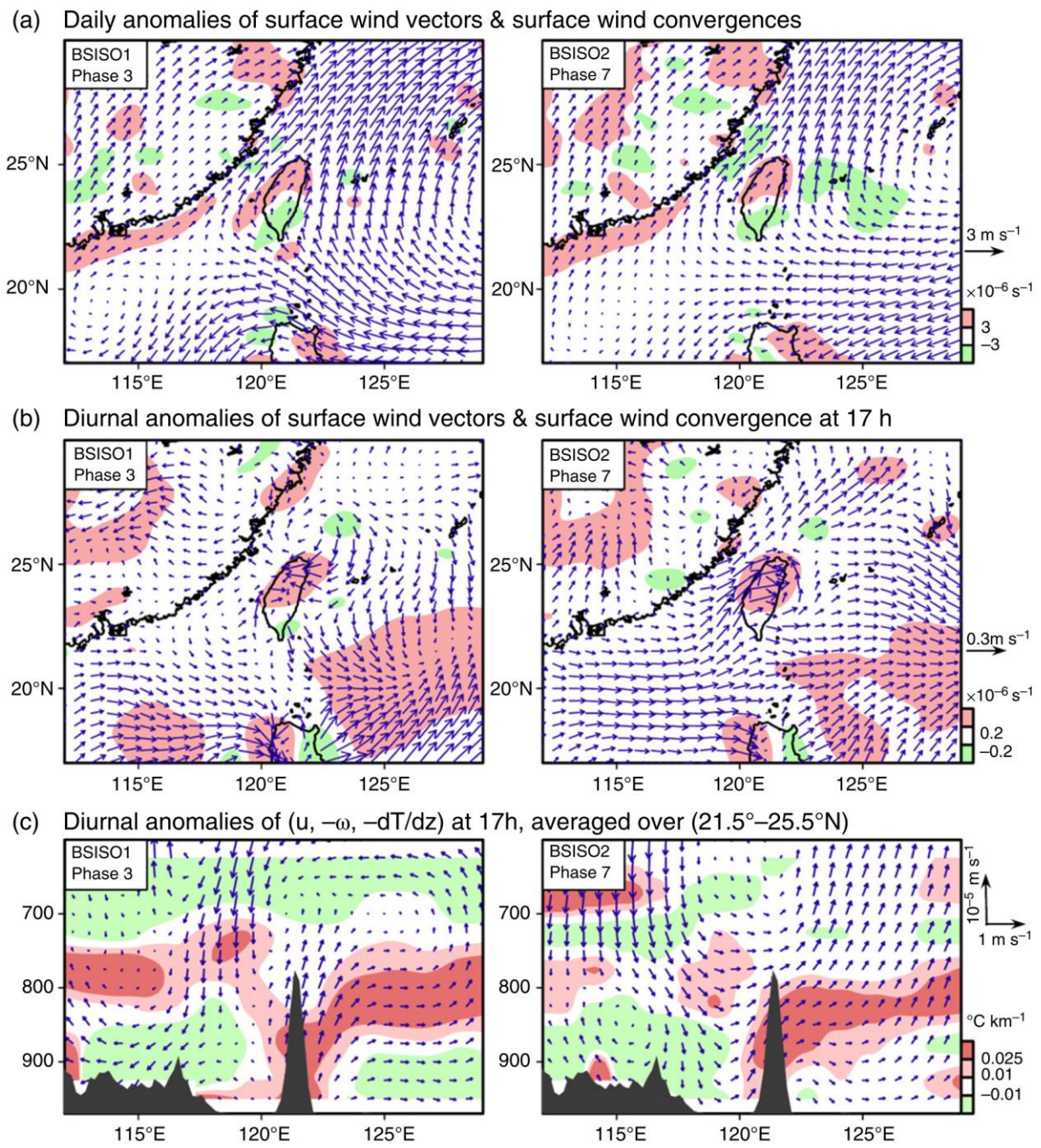

(a)
Percentage of DC days (%)
%
BSISO1
BSISO2
35
25
15
5
P1 P2 P3 P4 P5 P6 P7 P8
(c)
Percentage of DC days (%)
P8
P7
P6
P5
P4
P3
P2
P1
BSISO2
40
30
20
%
40
35
30
25
20
P1 P2 P3 P4 P5 P6 P7 P8 BSISO1

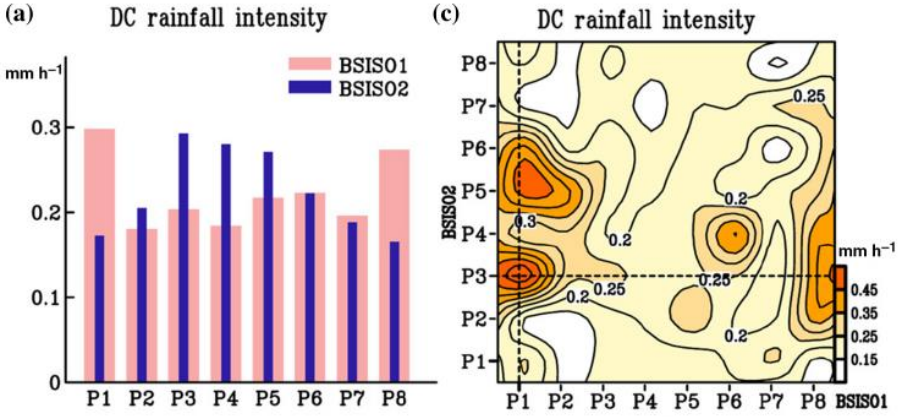

(a)
DC rainfall intensity
mm h⁻¹
BSISO1
BSISO2
0.3
0.2
0.1
0
P1 P2 P3 P4 P5 P6 P7 P8
(c)
DC rainfall intensity
P8
P7
P6
P5
P4
P3
P2
P1
BSISO2
0.25
0.2
0.3
0.2
0.25
0.25
0.2
0.2
mm h⁻¹
0.45
0.35
0.25
0.15
P1 P2 P3 P4 P5 P6 P7 P8 BSISO1

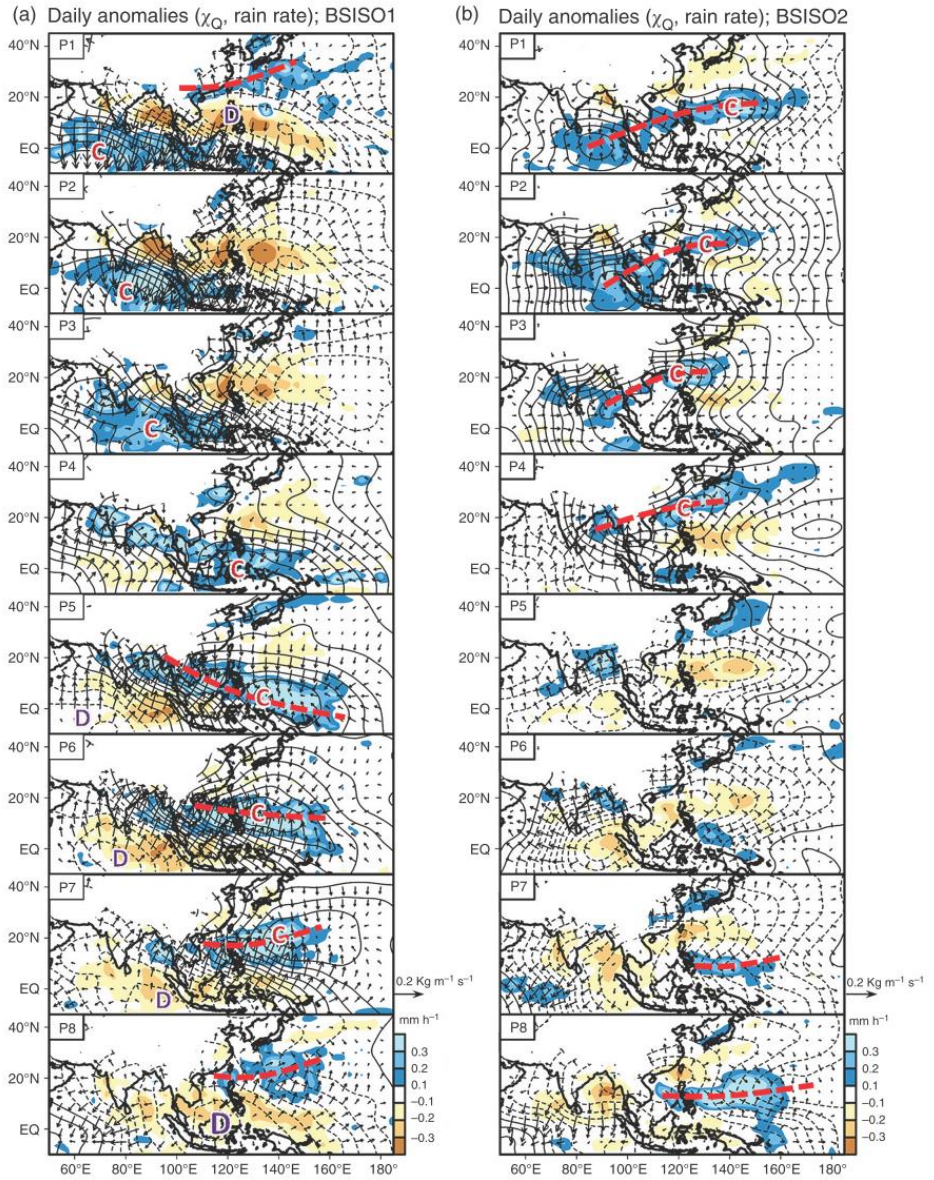

(a)
Percentage of DC days (%)
%
BSISO1
BSISO2
35
25
15
5
P1 P2 P3 P4 P5 P6 P7 P8

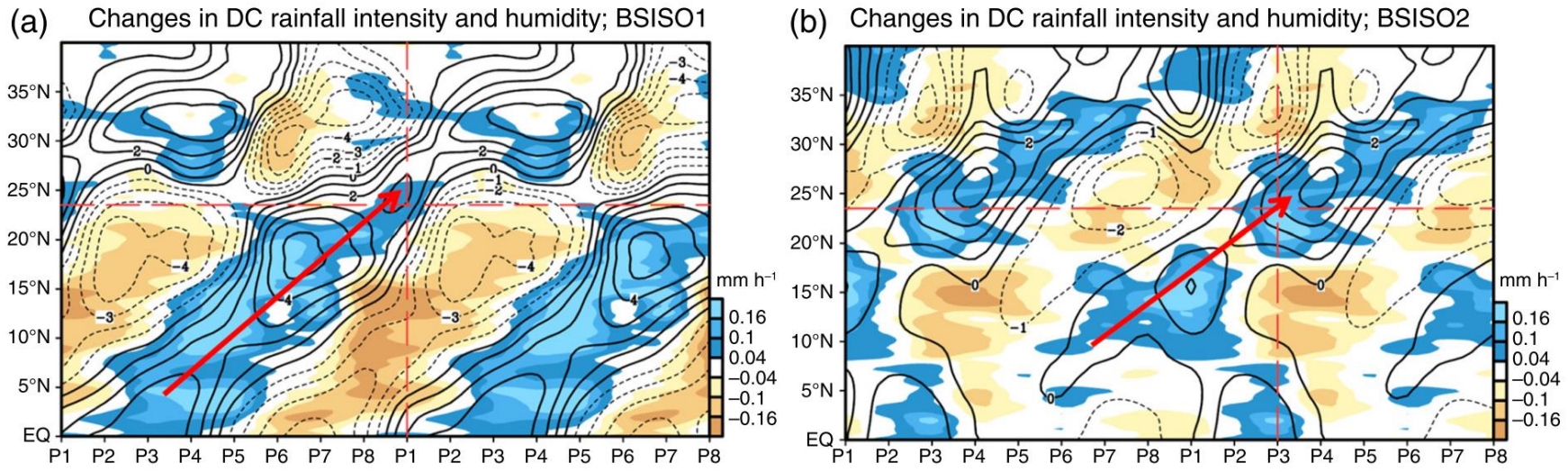

(c)
Percentage of DC days (%)
BSISO2
P8
P7
P6
P5
P4
P3
P2
P1
40
30
20
%
40
35
30
25
20
P1 P2 P3 P4 P5 P6 P7 P8 BSISO1


(a) Daily anomalies (V, ψ) 850 hPa; BSISO1
(b) Daily anomalies (V, ψ) 850 hPa; BSISO2
P1
P2
P3
P4
P5
P6
P7
P8
40°N
20°N
EQ
60°E 80°E 100°E 120°E 140°E 160°E 180°
5 m s⁻¹
×10⁶ m² s⁻¹
3
2.4
1.8
1.6
1.2
0.6
−0.6
−1.2
−1.8
−2.4
−3


(a) Daily anomalies of surface wind vectors & surface wind convergences
BSISO1
Phase 3
BSISO2
Phase 7
25°N
20°N
115°E
120°E
125°E
3 m s−1
×10−6 s−1
3
−3
(b) Diurnal anomalies of surface wind vectors & surface wind convergence at 17 h
0.3m s−1
0.2
−0.2
(c) Diurnal anomalies of (u, −ω, −dT/dz) at 17h, averaged over (21.5°–25.5°N)
700
800
900
10−5 m s−1
1 m s−1
°C km−1
0.025
0.01
−0.01


(a)
DC rainfall intensity
mm h⁻¹
BSISO1
BSISO2
0.3
0.2
0.1
0
P1 P2 P3 P4 P5 P6 P7 P8
(c)
DC rainfall intensity
P8 P7 P6 P5 P4 P3 P2 P1
BSISO2
0.25
0.2
0.3
0.2
0.2
0.25
0.25
0.2
mm h⁻¹
0.45
0.35
0.25
0.15
P1 P2 P3 P4 P5 P6 P7 P8 BSISO1


(a) Daily anomalies (χ_Q, rain rate); BSISO1
(b) Daily anomalies (χ_Q, rain rate); BSISO2
P1
P2
P3
P4
P5
P6
P7
P8
40°N
20°N
EQ
C
D
60°E 80°E 100°E 120°E 140°E 160°E 180°
0.2 Kg m⁻¹ s⁻¹
mm h⁻¹
0.3
0.2
0.1
−0.1
−0.2
−0.3


(a)
Changes in DC rainfall intensity and humidity; BSISO1
35°N
30°N
25°N
20°N
15°N
10°N
5°N
EQ
P1 P2 P3 P4 P5 P6 P7 P8 P1 P2 P3 P4 P5 P6 P7 P8
mm h⁻¹
0.16
0.1
0.04
−0.04
−0.1
−0.16
(b)
Changes in DC rainfall intensity and humidity; BSISO2
35°N
30°N
25°N
20°N
15°N
10°N
5°N
EQ
P1 P2 P3 P4 P5 P6 P7 P8 P1 P2 P3 P4 P5 P6 P7 P8
mm h⁻¹
0.16
0.1
0.04
−0.04
−0.1
−0.16

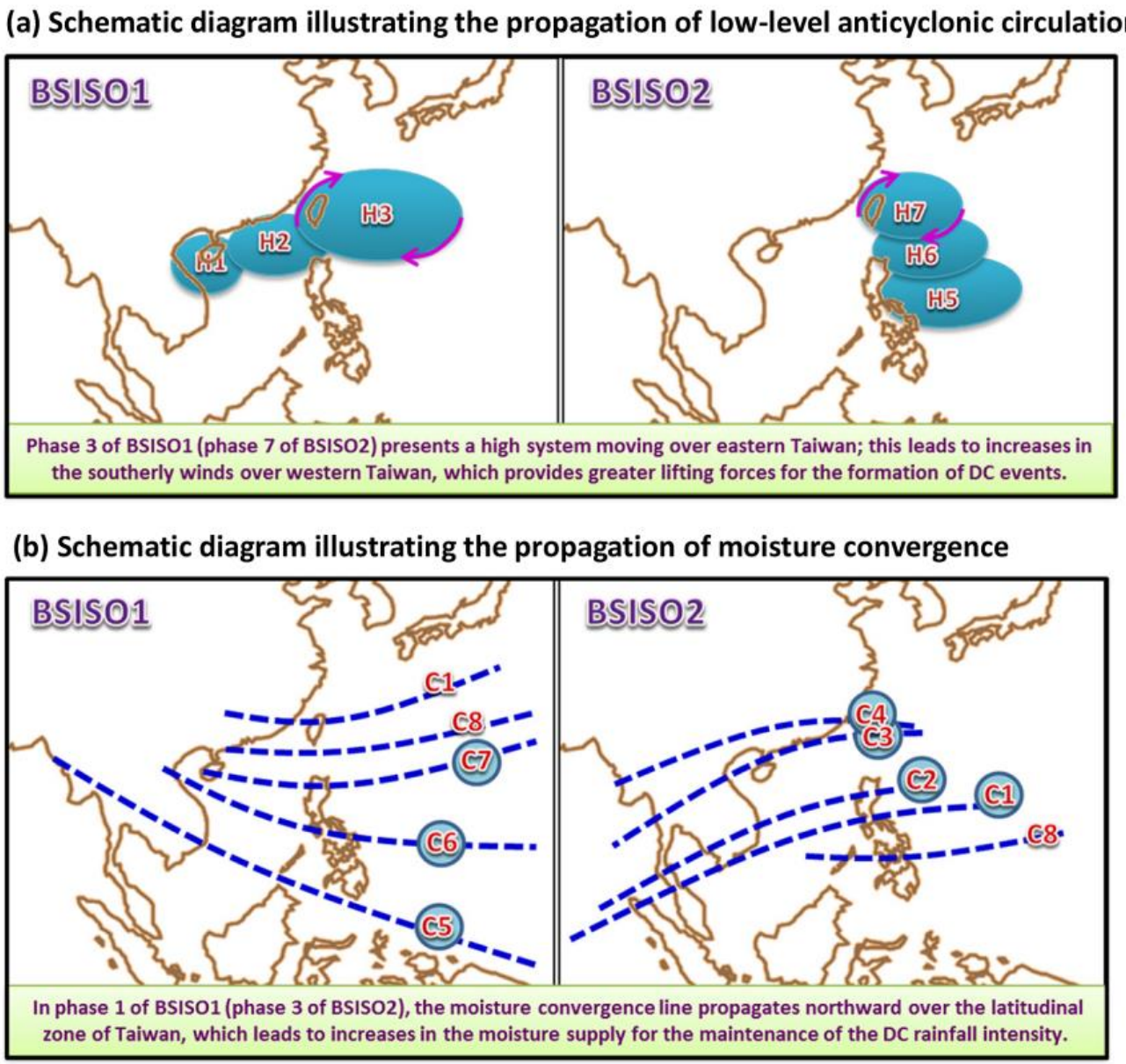


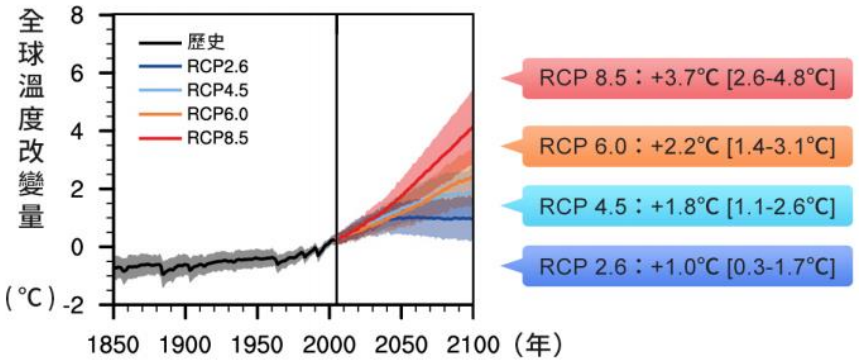
Figure 11. (a) Schematic diagram illustrating the propagation of the anticyclonic circulation ('H' denotes the high system, number denotes the phase of related BSISOs) that is important to the modulation of DC occurrence frequency. (b) Schematic diagram illustrating the propagation of the moisture convergence line ('C' denotes the convergence, number denotes the phase of related BSISOs, circle denotes the convergence centre of χ_Q in Figure 9) that is important to the modulation of DC rainfall intensity. [Colour figure can be viewed at wileyonlinelibrary.com].

What is the projected change of diurnal rainfall convection and other types of rainfall in Taiwan in the future?

對未來氣候模擬的分析方式

- 政府間氣候變遷委員會(Intergovernmental Panel on Climate Change, IPCC)針對氣候變遷發布的第5次評估報告(AR5)裡以「代表濃度路徑(Representative Concentration Pathways, RCP)」作為未來人為溫室氣體排放量的情境假設。共有4種情境，分別為RCP2.6、RCP4.5、RCP6.0、RCP8.5。各情境代表意義如下：

RCP2.6	相對較低的溫室氣體增加的情境，大氣輻射力先在二十一世紀中葉達到最大值3Wm^{-2}，大約和二氧化碳濃度490ppn相似， 然後再緩慢下降到二十一世紀末。
RCP4.5	大氣輻射力會在二十一世紀末達到一個穩定狀態的情境，約為4.5Wm^{-2}，和二氧化碳濃度650ppm相似，代表世界各國會想盡辦法做到溫室氣體減量的目標。
RCP6.0	和RCP4.5相似，但大氣輻射力為6Wm^{-2}，約為二氧化碳濃度850ppm，代表世界各國並沒有盡全力積極做到溫室氣體減量的目標。
RCP8.5	大氣輻射力持續的增加到大於8.5Wm^{-2}，即二氧化碳濃度會大於1370ppm，代表世界各國並無任何減量的動作。



(TCCIP, 2017)

Future changes

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2016JD025643

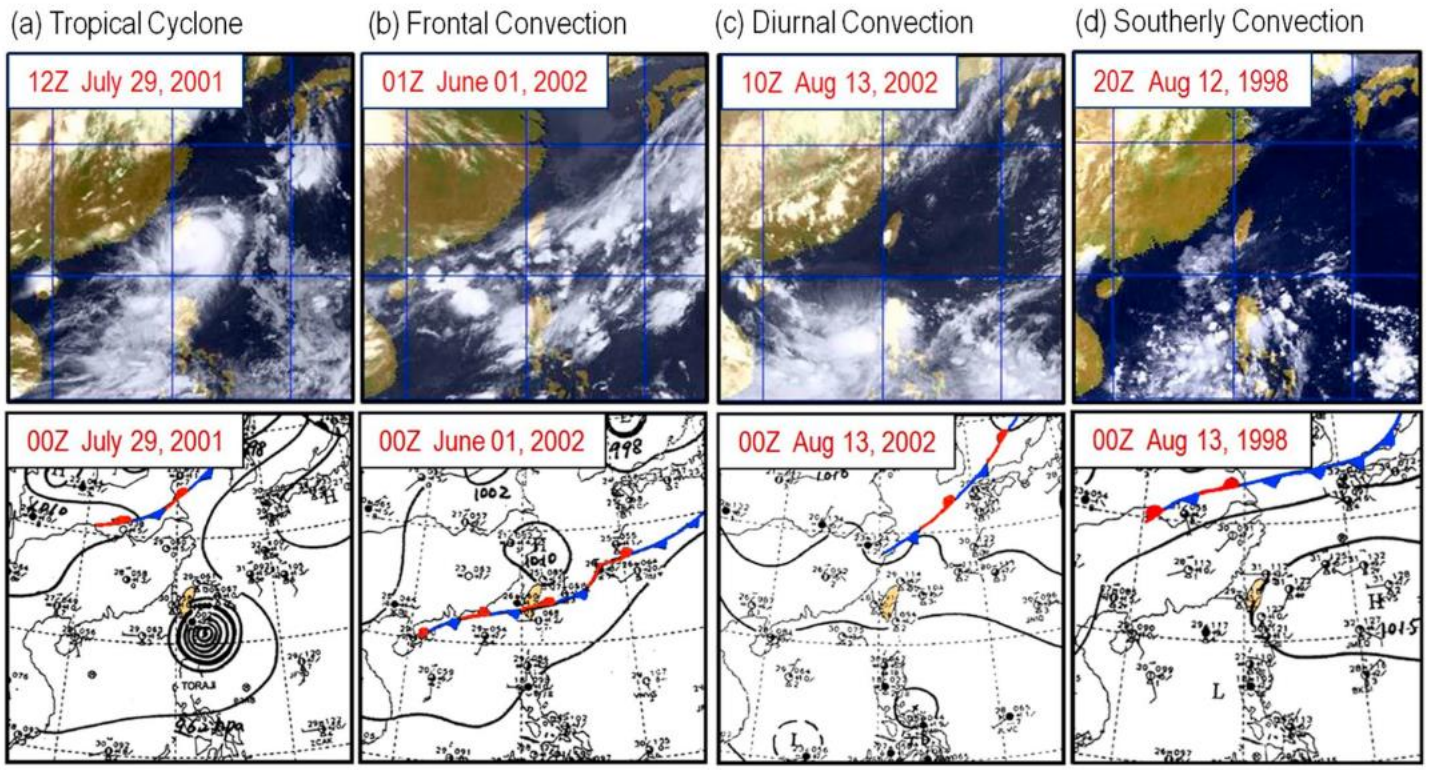
Key Points:

- The dynamical downscaling simulation using WRF improves the simulation of different types of rain events over Taiwan
- The change in total summer rainfall in Taiwan under a warmer climate is mainly dominated by the change in light rainfall events
- Heavy rainfall events will become fewer, but more intense, in Taiwan as

Dynamical downscaling simulation and future projection of summer rainfall in Taiwan: Contributions from different types of rain events

Wan-Ru Huang[1], Ya-Hui Chang[1], Huang-Hsiung Hsu[2], Chao-Tzuen Cheng[3], and Chia-Ying Tu[2]

[1]Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan, [2]Research Center for Environmental Changes, Academia Sinica, Taipei, Taiwan, [3]National Science and Technology Center for Disaster Reduction, New Taipei City, Taiwan



Introduction

- In this study, we accessed 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).

- This investigation focuses on the contribution of the four types of rain events to the total summer rainfall in Taiwan during a warmer future.

Data and Method-Models

HiRAM

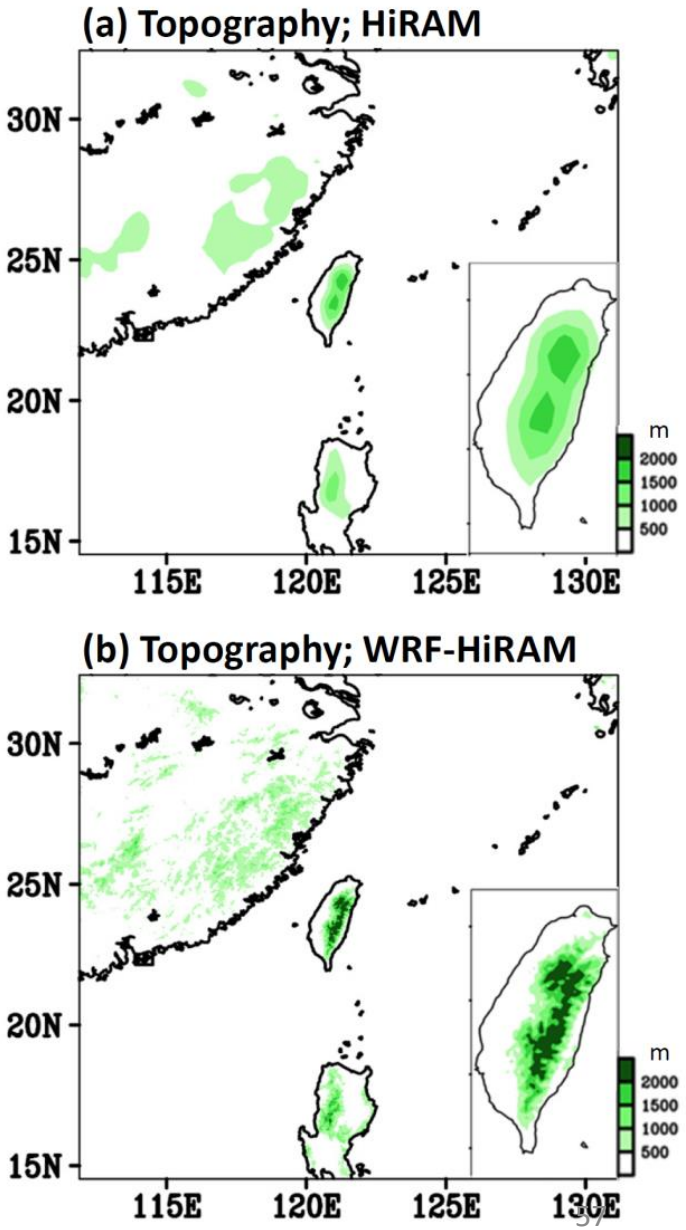
- Horizontal resolution ~25km
- 32 vertical layers and model top at 1 hPa
- [Zhao et al. 2009]

WRF-HiRAM

- Horizontal resolution ~ 5 km
- 36 vertical layers from surface to 50 hPa
- WRF version 3.5.1 [Skamarock et al., 2008]

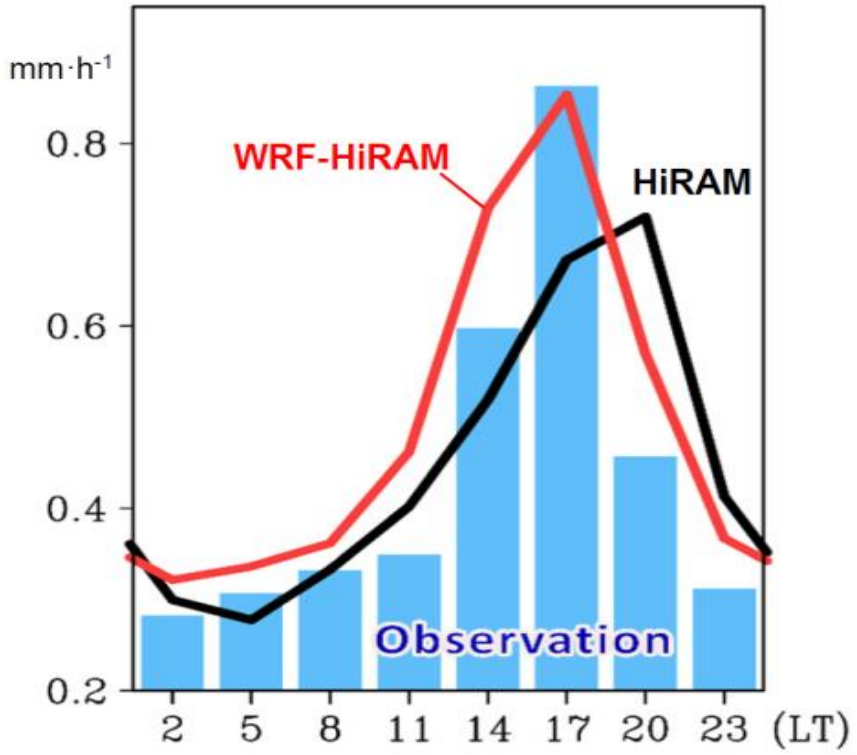
Time Periods

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



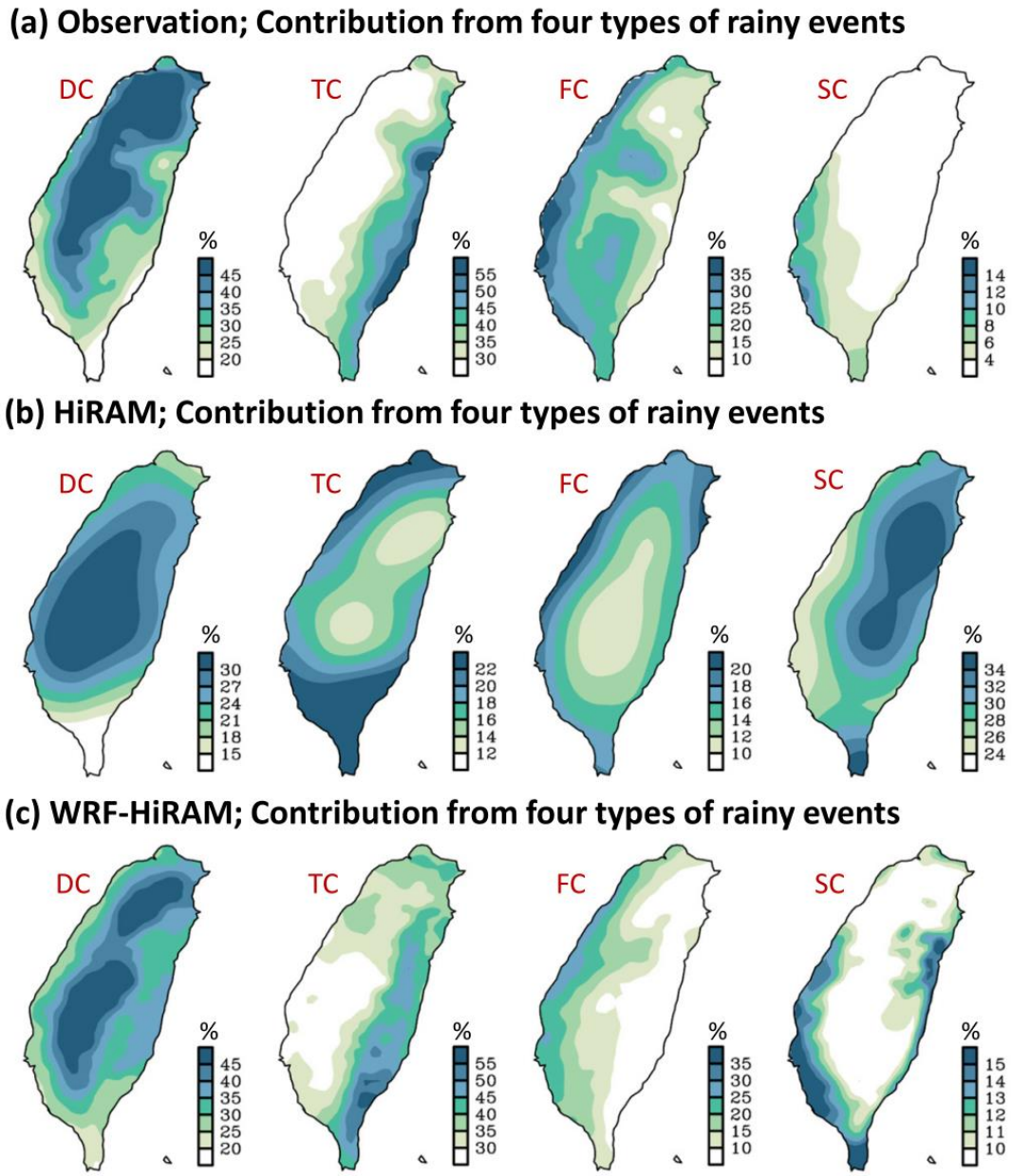
Results-Present Day- 3 hourly rainfall evolutions

3-hourly rainfall area-averaged over Taiwan



- WRF-HiRAM can successfully depict the appearance of maximum diurnal rainfall at 17 h local time, while HiRAM cannot.

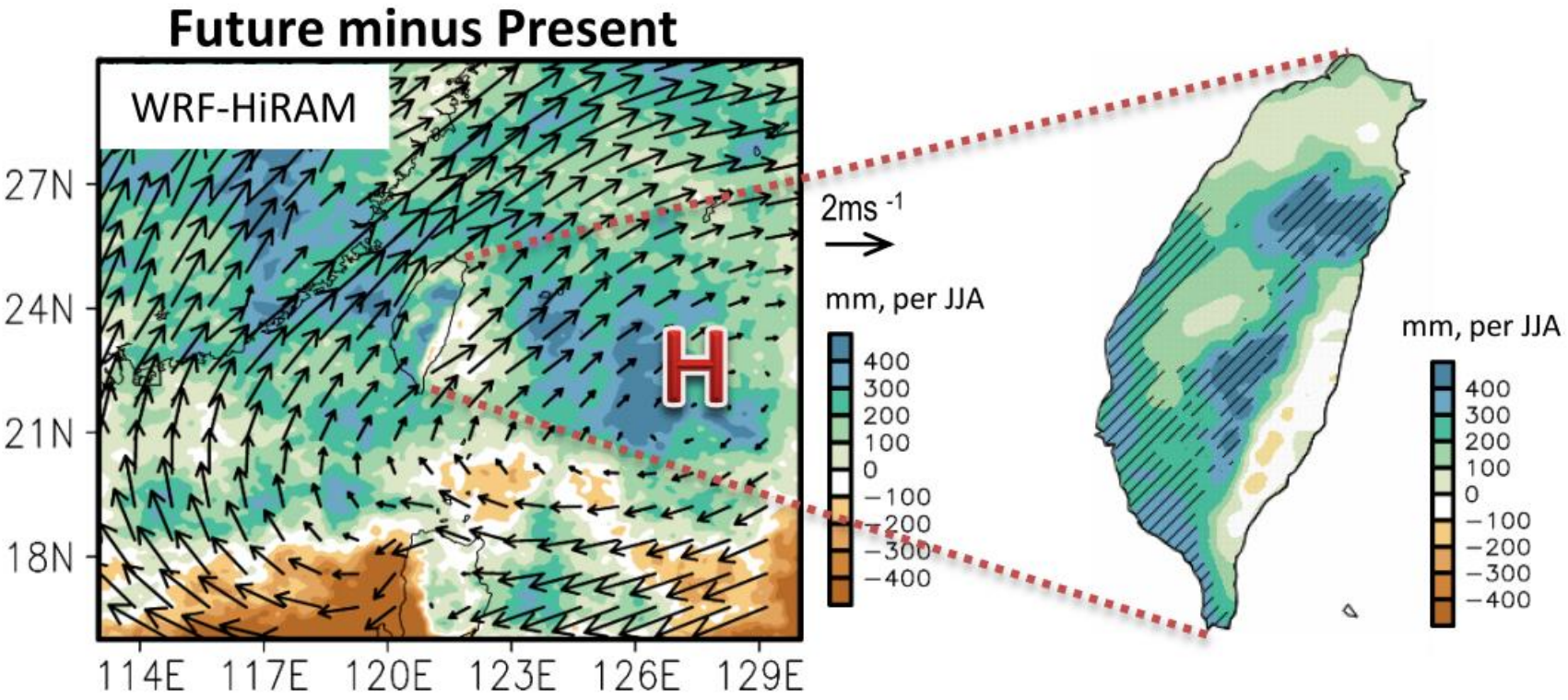
Results-Present Day- Contributions to total rainfall



- WRF-HiRAM also has better ability than HiRAM in capturing the contribution of each type of rain events to the total rain events.

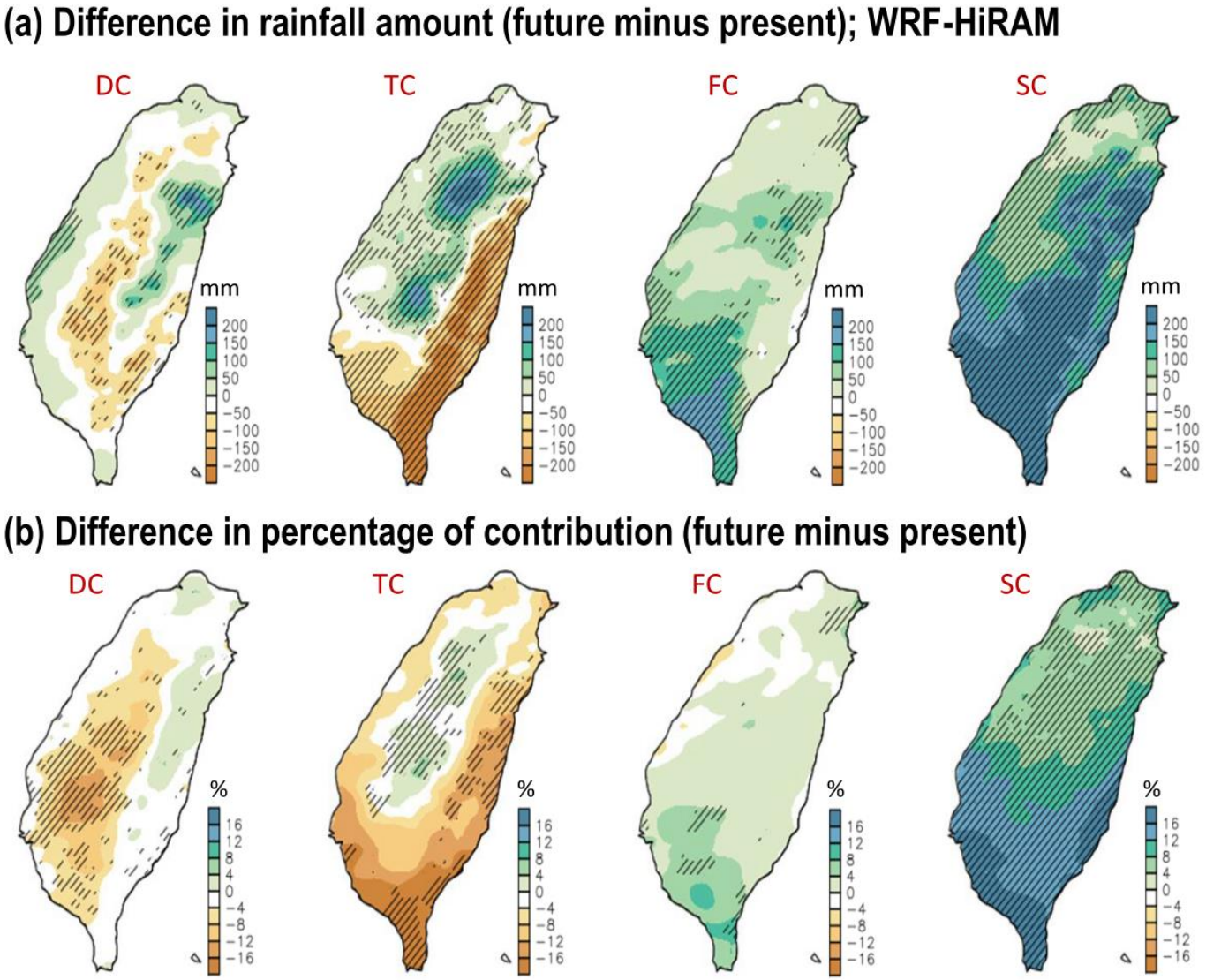
Because WRF-HiRAM is more capable than HiRAM in simulating the contributions of different types of rainfall to total summer rainfall in Taiwan, we only focus on the future changes projected by WRF-HiRAM

Results-Projected Changes- Summer mean precipitation



Shaded: Summer mean precipitation
Vectors: 850 hPa wind circulation changes

Results-Projected Changes- Four types of rainfall amount

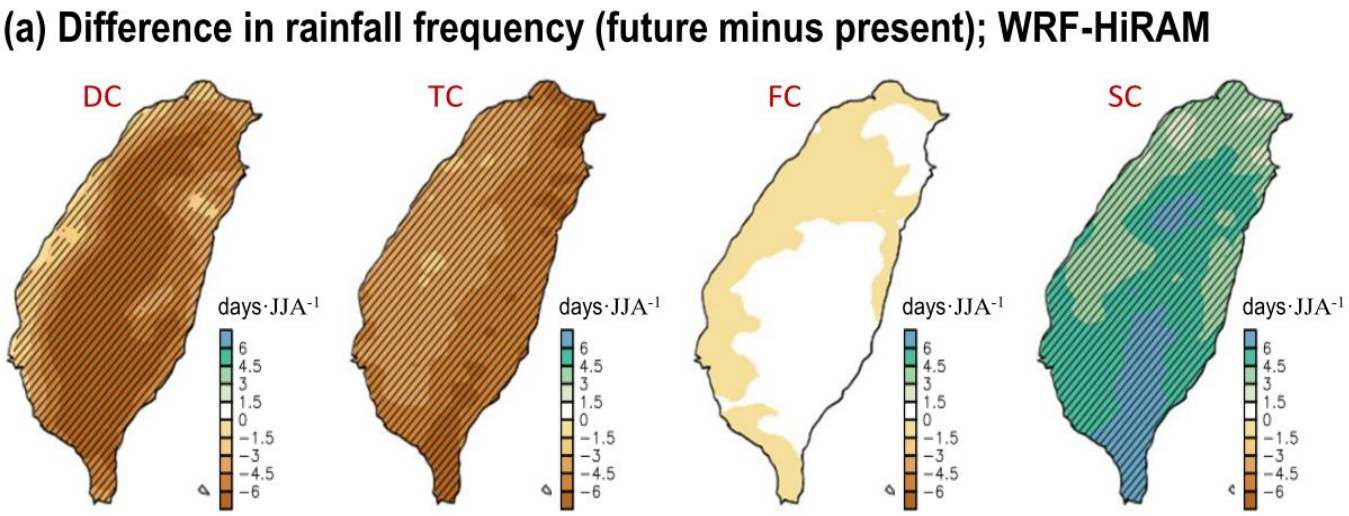


➔Results show that SC events contribute the most to the projected change in summer rainfall in most of Taiwan.

Results-Projected Changes- Frequency vs. Intensity

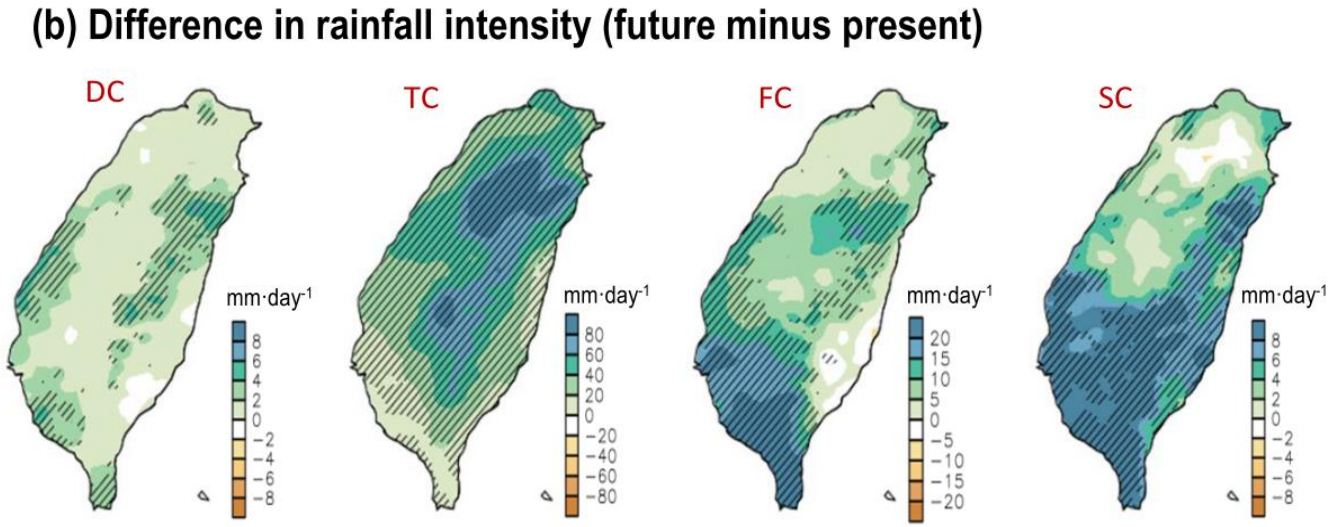
Frequency

- Decrease: DC & FC
- Increase: SC
- No significant changes: FC



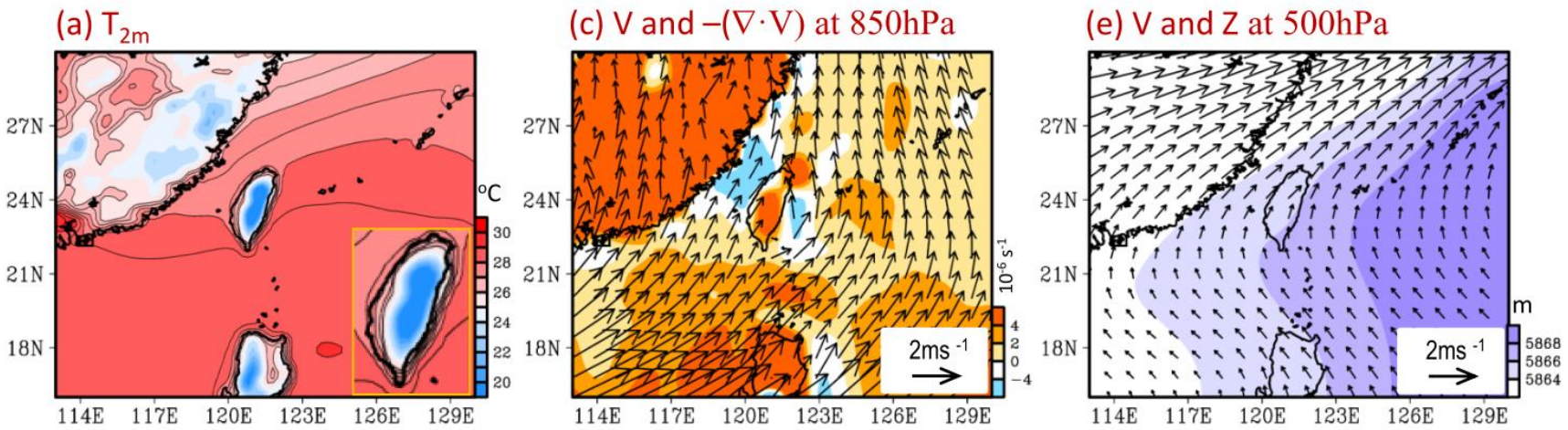
Intensity

- All increases

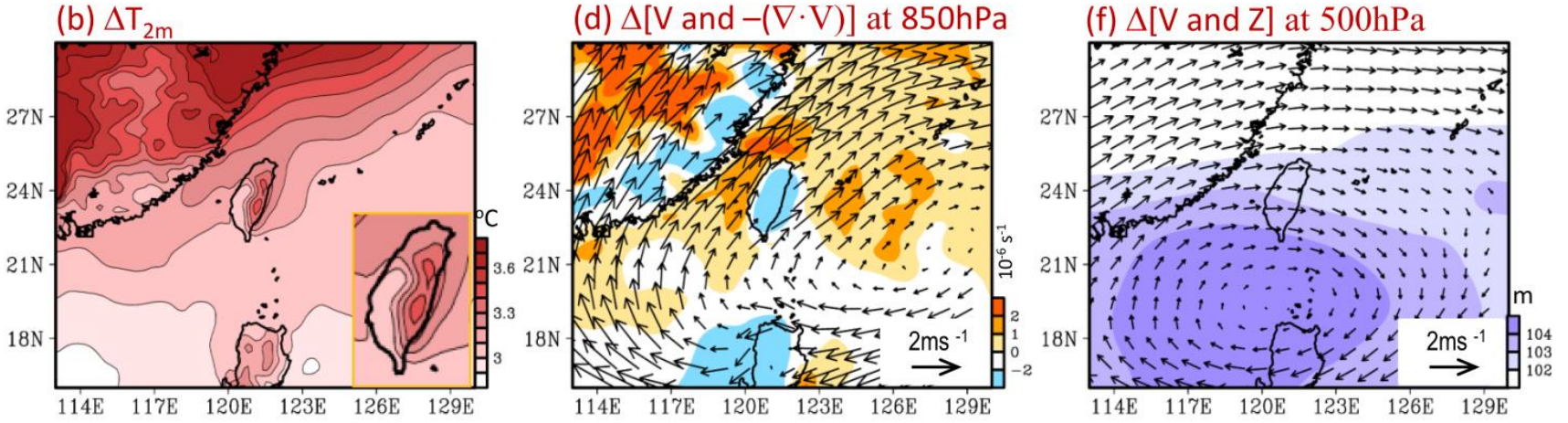


Results-Explanation for projected changes in Frequency

WRF-HiRAM's present-day simulation of selected fields



WRF-HiRAM's projected changes (Δ: future minus present) in selected fields

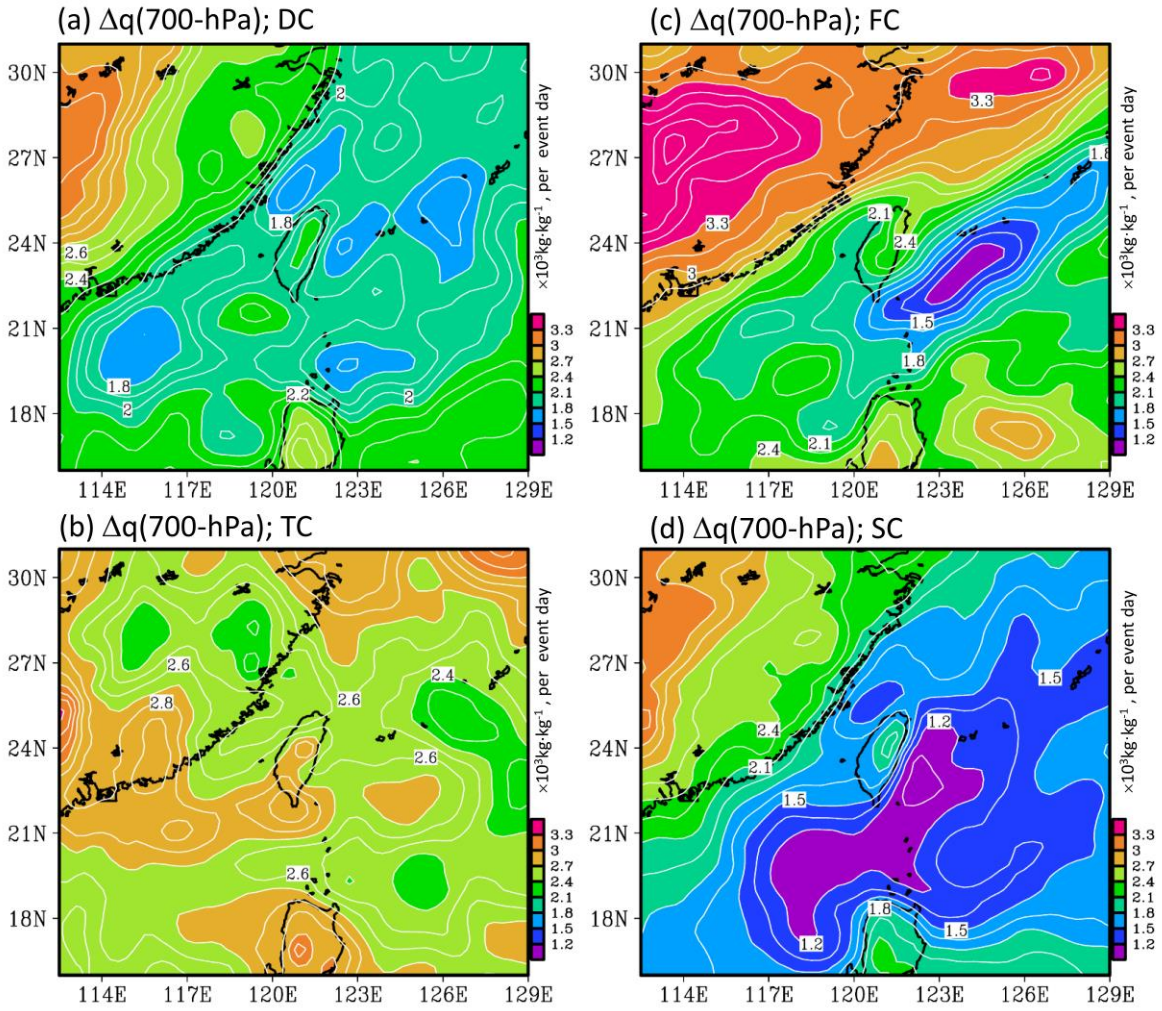


- Decrease in local thermal instability **(fewer DC)**

- Decrease in $(-\nabla \cdot V)$ over Taiwan **(fewer DC)**
- Increase in $(-\nabla \cdot V)$ over ocean **(more SC)**
- Southwesterly wind enhanced **(favorable for SC moving into Taiwan)**

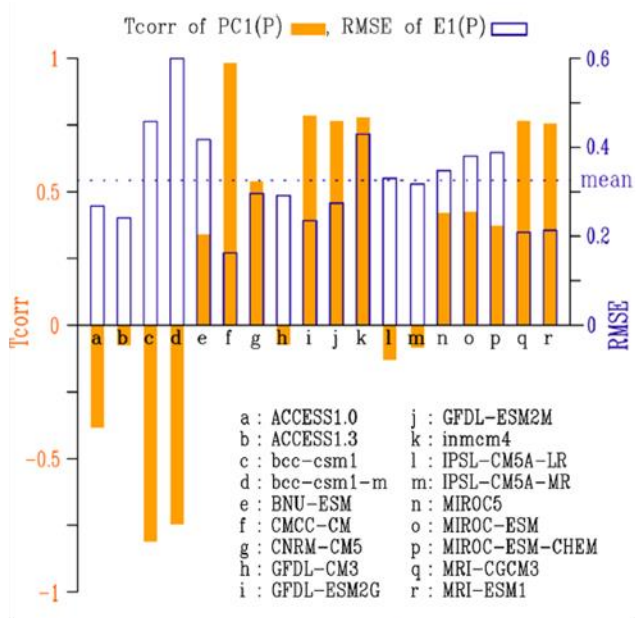
- Southwest extension of subtropical high **(unfavorable for TCs moving toward Taiwan)**

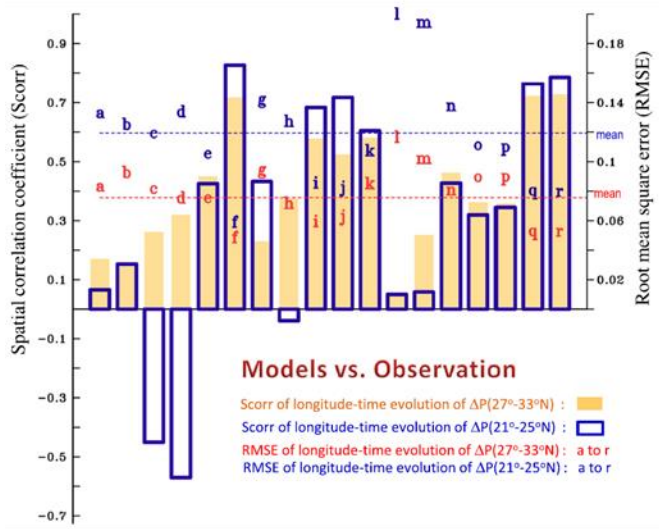
Results-Explanation for projected changes in Intensity

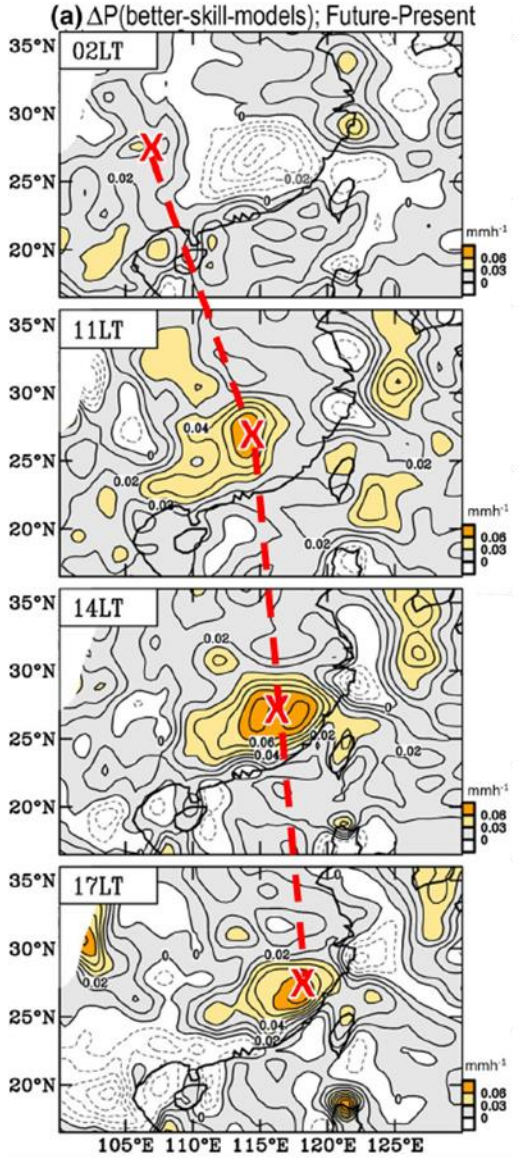


- Increase in atmospheric moisture is found for all types of rain events.
- Among the four types, TC events have the largest increase in atmospheric moisture near Taiwan, while DC events have the smallest increase.

CMIP5全球氣候模式對東亞日夜降雨的模擬、推估







(Huang* and Wang, 2017; climate dynamics)

Summary

多尺度環流變化對臺灣午後對流降雨現象之影響

觀測資料分析

氣候平均

Huang* and Wang (2014)發現台灣的日降雨變化受到東亞 - 西北太平洋大尺度海陸風影響。

長期趨勢

Huang* and Chen (2015)分析臺灣梅雨季日夜降雨，發現近年來FC的發生頻率下降，而DC的發生頻率則明顯增加。

Huang* et al. (2015) 發現台灣日對流降雨特色之長期變化存在區域差異，且找出此差異與大環境場變化的關聯性。

年代際變化

Huang* et al. (2015) 發現台灣日對流降雨特色之長期變化除了有長期趨勢外，亦存在10-20 年振盪周期變化。

Huang* et al. (2018) 以台灣午後對流的年代際變化為出發利用 20CR、ERA20C 再分析資料及CMIP5模式資料，找出台灣降水與西太平洋年代際變化之間的關係。

年際變化

Huang*et al. (2019) 找出台灣日對流降雨特色變化與ENSO指數之關聯性。

季內振盪變化

Huang * and Chang (2018) 找出台灣日對流降雨特色變化與 BSISO 季內振盪指數之關聯性。

模式資料分析

未來的氣候變遷

Huang* et al. (2016) 利用WRF區域模式搭配HiRAM、MRI全球氣候模式，推估出台灣西南部未來受到日對流變化降雨的影響次數將變少，且此與大氣條件變遷有關。

Huang* and Wang (2017) 利用CMIP5全球氣候模式，推估出東亞地區(含台灣)在未來暖化情境下，受到移動性日對流降水的影響將加劇，此和大氣條件變遷有關。

氣候變遷下，多尺度環流特性的變化，對臺灣午後對流降雨特色變化，具有明顯的影響。

Thank you for your listening

References:

- **Huang, W.-R.***, Johnny C. L. Chan, and S.-Y. Wang, 2010: A Planetary-scale Land-sea Breeze Circulation in East Asia and the Western North Pacific. *Quarterly Journal of the Royal Meteorological Society*, 136: 1543–1553.
- **Huang, W.-R.***, and S.-Y. Wang, 2014: Impact of Land-Sea Breezes at Different Scales on the Diurnal Rainfall in Taiwan. *Climate Dynamics,* 43, 1951–1963.
- **Huang, W.-R.***, and K.-C. Chen, 2015: Trends in Pre-Summer Frontal and Diurnal Rainfall Activities during 1982-2012 over Taiwan and Southeast China: Characteristics and Possible Causes. *International Journal of Climatology,* 35: 2608–2619.
- **Huang, W.-R.***, H.-H. Hsu, S.-Y. Wang, and J.-P. Chen, 2015, Impact of atmospheric changes on the low-frequency variations of convective afternoon rainfall activity over Taiwan, *J. Geophys. Res. Atmos.,* 120, 8743–8758.
- **Huang, W.-R.***, Y.-H. Chang, H.-H. Hsu, C.-T. Cheng, and C.-Y. Tu, 2016 : Dynamical Downscaling Simulation and Future Projection of Summer Rainfall in Taiwan: Contributions from Different Types of Rain Events. *J. Geophys. Res. Atmos.,* 121, 13973-13988.
- **Huang, W.-R.*** and S.-Y. Wang, 2017 : Future Changes in Propagating and Non-propagating Diurnal Rainfall over East Asia, *Climate Dynamics*, 49, 375–389.
- **Huang, W.-R.***, S.-Y. Wang and B.-T. Guan, 2018 : Decadal fluctuations in the western Pacific recorded by long precipitation records in Taiwan, *Climate Dynamics*, 50, 1597–1608.
- **Huang, W.-R.*** and Y.-H. Chang, 2018: Impact of Boreal Summer Intraseasonal Oscillations on Warm Season Diurnal Convection Activity in Taiwan. *International Journal of Climatology*, 38, 2187-2200.
- **Huang, W.-R.***, Y.-H. Chang and P.-H. Huang, 2019 : Relationship between the Interannual Variations of Summer Convective Afternoon Rainfall Activity in Taiwan and SSTA(Niño3.4) during 1961-2012: Characteristics and Mechanisms. *Scientific Reports,* **9**, 9378.