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應用自組織映射圖分類法客觀辨識東亞地區之春夏季節演變

Identifying the East Asia Spring-to-Summer Transition Using Self-Organizing Map

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Outline

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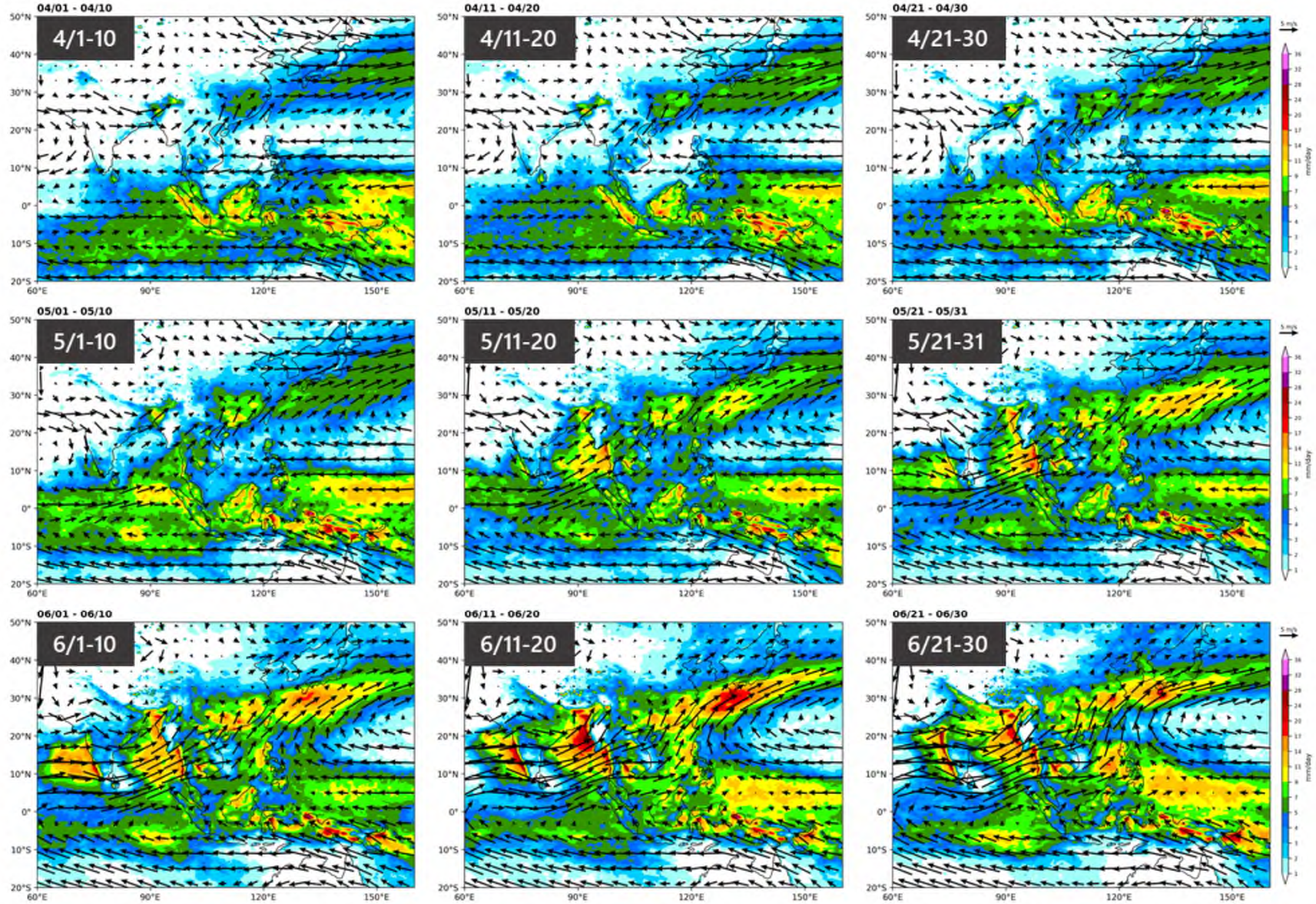
  - **02** - ENSO Modulations on EAM
  - **03** - SOM WTs and Taiwan-Philippine Extreme Weather
- **Conclusions & Future Works**
- **References**

Spring to Summer Transition of Asian Monsoon

- Substantial change of low-level wind and precipitation exhibits during spring-to-summer transition. [Ding and Chan 2005]



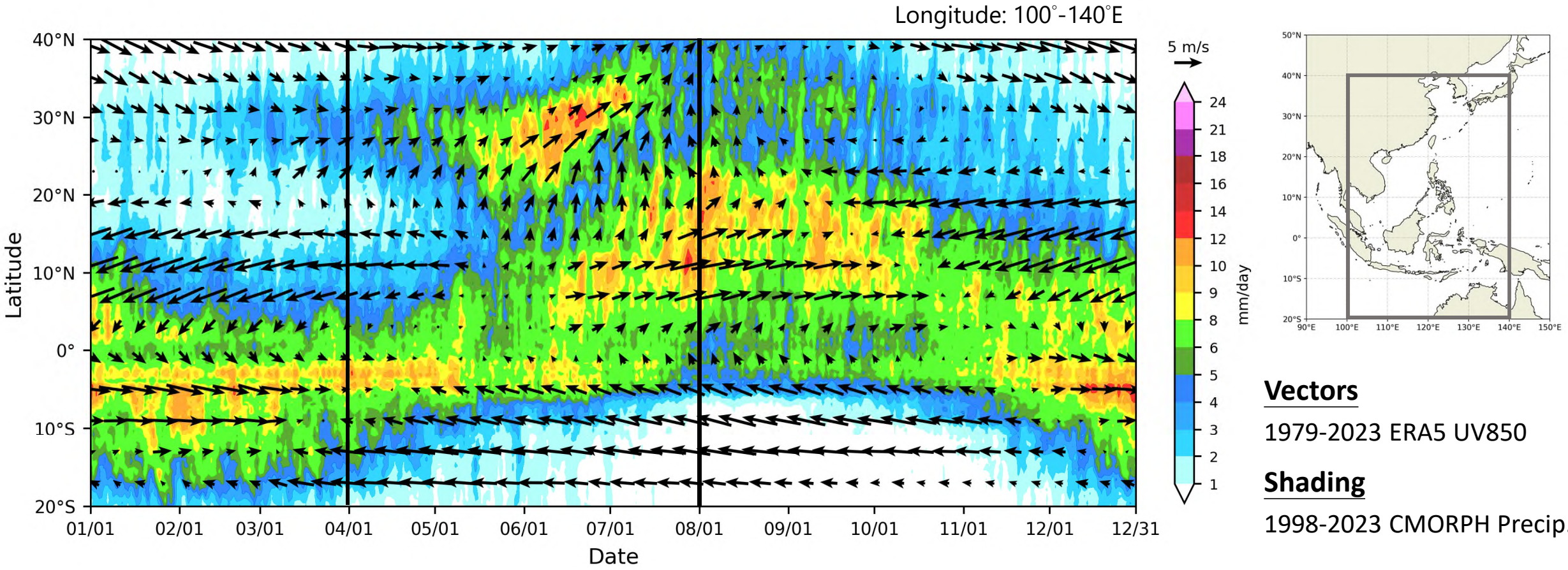
Vectors

1979-2023 ERA5 UV850

Shading

1998-2023 CMORPH Precip.

Annual Cycle of East Asian Monsoon (EAM)



Vectors

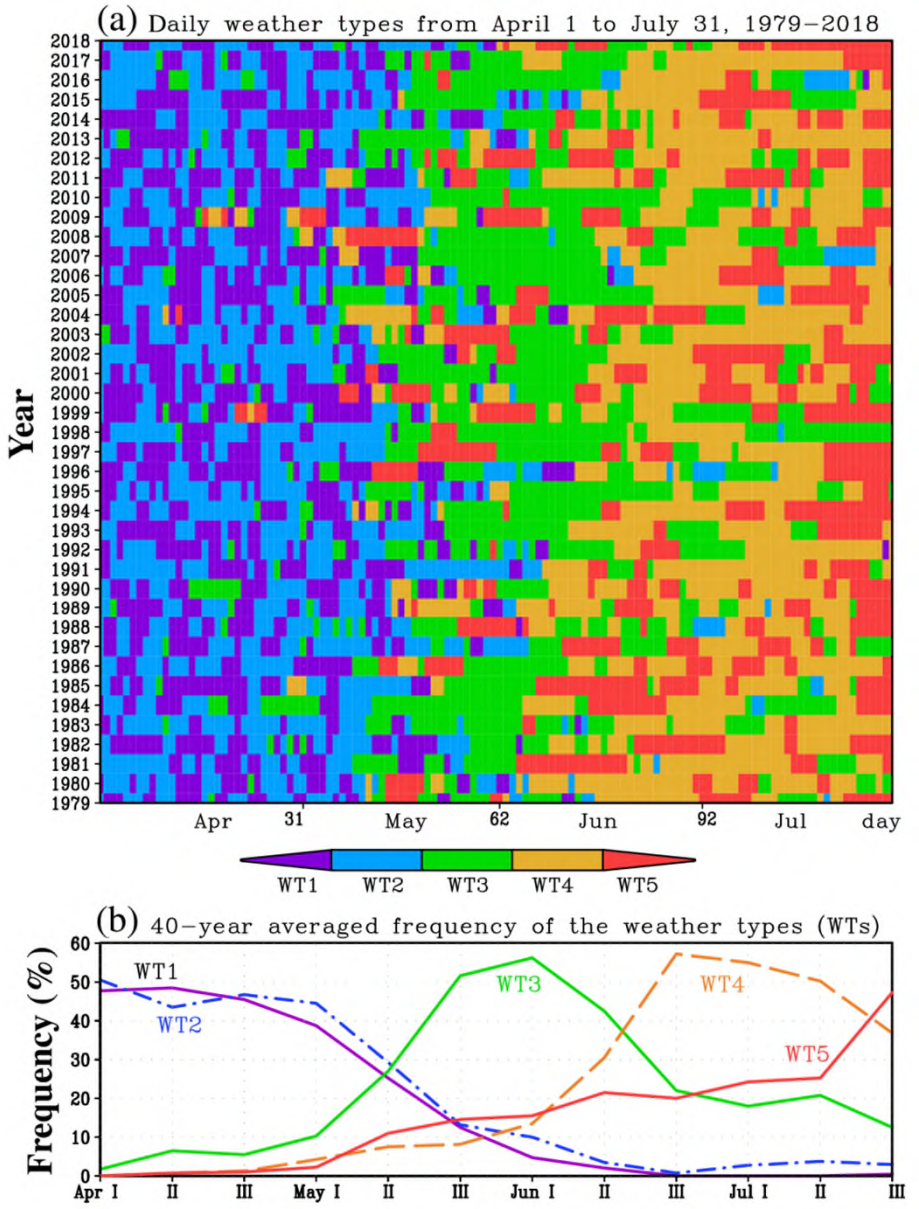
1979-2023 ERA5 UV850

Shading

1998-2023 CMORPH Precip.

- The transition of low-level wind from easterlies to westerlies during May to June coincides well with the precipitation from dry to wet condition.
- The low-level wind serves as an appropriate indicator for the monsoon evolution over East Asia.

Weather Type Clustering Analysis



- Qian et al. (2022) applied K-means clustering to analysis daily weather type over East Asia during April-July.

  ✓ **Discuss climate in weather time scale**

  ✓ **Examine interannual climate variability**

  More detailed wind field patterns?
  and seasonal evolution process?

- From another perspective, self-organizing map (SOM) method is adopted in this study for clustering analysis.

Research Objectives

01 **Three Development Stages of EAM**

To objectively separate the development stages of the EAM based on the AMJJ daily WTs.

02 **ENSO Modulations on EAM**

To present the ENSO modulation on EAM climate variability using the EAM weather calendar.

03 **SOM WTs and Taiwan-Philippine Extreme Weather**

To investigate the extreme weather around Taiwan and Philippine regions through SOM WTs.

Dataset

- **Research Domain:** the East-Asian monsoon region (0-37.5N, 90-140E) [Qian et al. 2022]

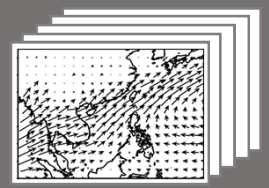
Dataset	Variables	Frequency	Grids	Periods
NOAA **CMORPH**	Precipitation	daily	0.25° × 0.25°	1998-2023 AMJJ
ECMWF **ERA-5**	UV850			1979-2023 AMJJ
	VIWV, VIWVD			
	Total Precipitation			
NOAA **GPCP**	Precipitation	pentad	2.5° × 2.5°	1979-2023 AMJJ
NOAA **ERSST v5.**	SST	monthly	2° × 2°	1951-2023
JMA RSMC **Best Track Data** (Including tropical cyclone of TD and TS intensity or higher)		6-hr	-	1979-2023 AMJJ

Weather Type Analysis – Self-organizing Maps (SOM)

Input Layer

Input dataset

1979-2022 April-July
Daily ERA-5 UV850



Data Preprocessing

Standardization | EOFs Analysis (≥ 75% variances)

Input Vectors $x_i = [x_1, x_2, x_3, \dots x_n]$

● ● ● … ●

t

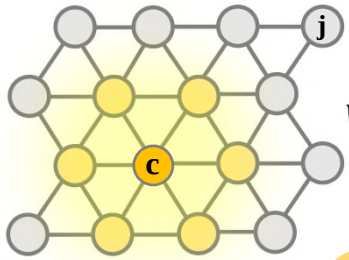
Iteration step t

Competition Layer — 3×3 SOM

Parameters Map size, learning rate, sigma, iteration times, etc.

Initialization of Weight Vectors

SOM Training Process



Weight vectors of **Unit j**

$\boldsymbol{w}_j(t) = [w_j^1, w_j^2, \dots w_j^n]$

Find the **BMU**

Update each unit $\boldsymbol{w}_j$ through the iterations

Determine Daily Weather Types

Repeat Clustering

Random Seed = 1-300

Find the Most **Stable** and **Representative** Cases

Multi-SOM

67-case Clustering Results

Daily WTs

Combined-SOM

Spring-to-summer Asian Monsoon Calendar

Naming WTs: **Units A – I**

Define ENSO Phases During 1979-2023

ONI Calculation → OND | NDJ | DJF | JFM

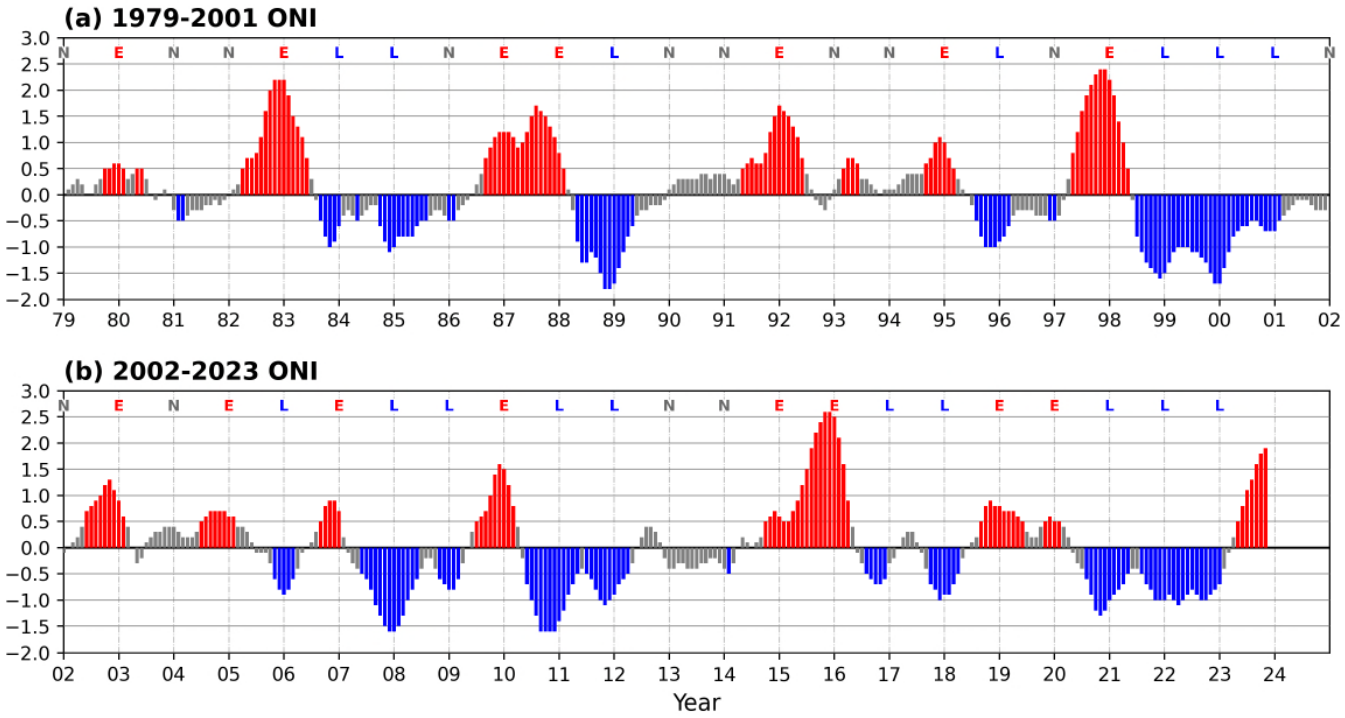
Data: NOAA ERSST v5

Region: Niño 3.4 (5N-5S, 120-170W)

(follow the definition of CPC)

Mean of any three ONI values

> 0.5	El Niño
< -0.5	La Niña



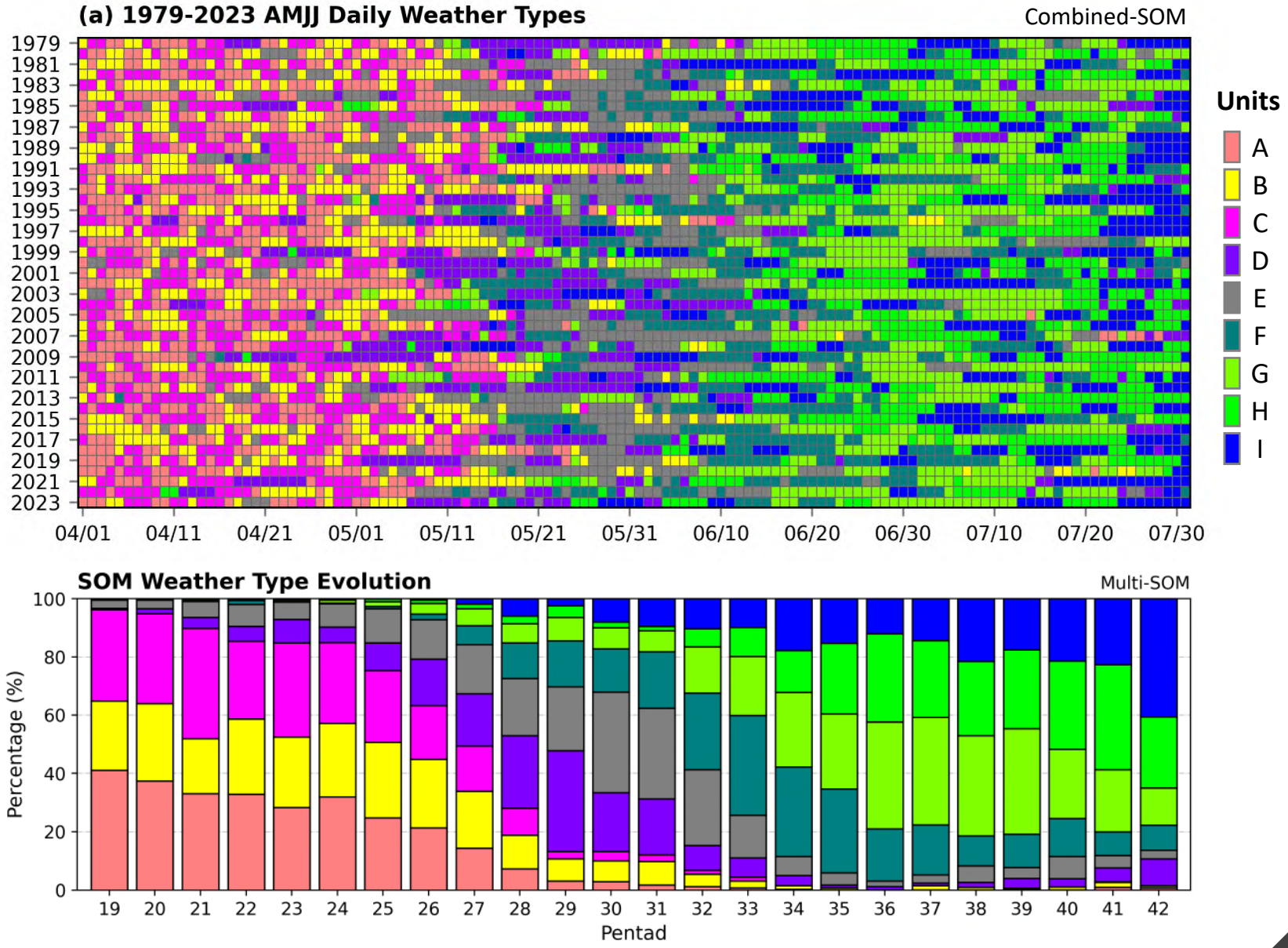
ENSO Phases	Years (1979-2023)
El Niño (15 yrs)	1980, 1983, 1987, 1988, 1992, 1995, 1998, 2003, 2005, 2007, 2010, 2015, 2016, 2019, 2020
Neutral (13 yrs)	1979, 1981, 1982, 1986, 1990, 1991, 1993, 1994, 1997, 2002, 2004, 2013, 2014
La Niña (17 yrs)	1984, 1985, 1989, 1996, 1999, 2000, 2001, 2006, 2008, 2009, 2011, 2012, 2017, 2018, 2021, 2022, 2023

01 Three Development Stages of EAM

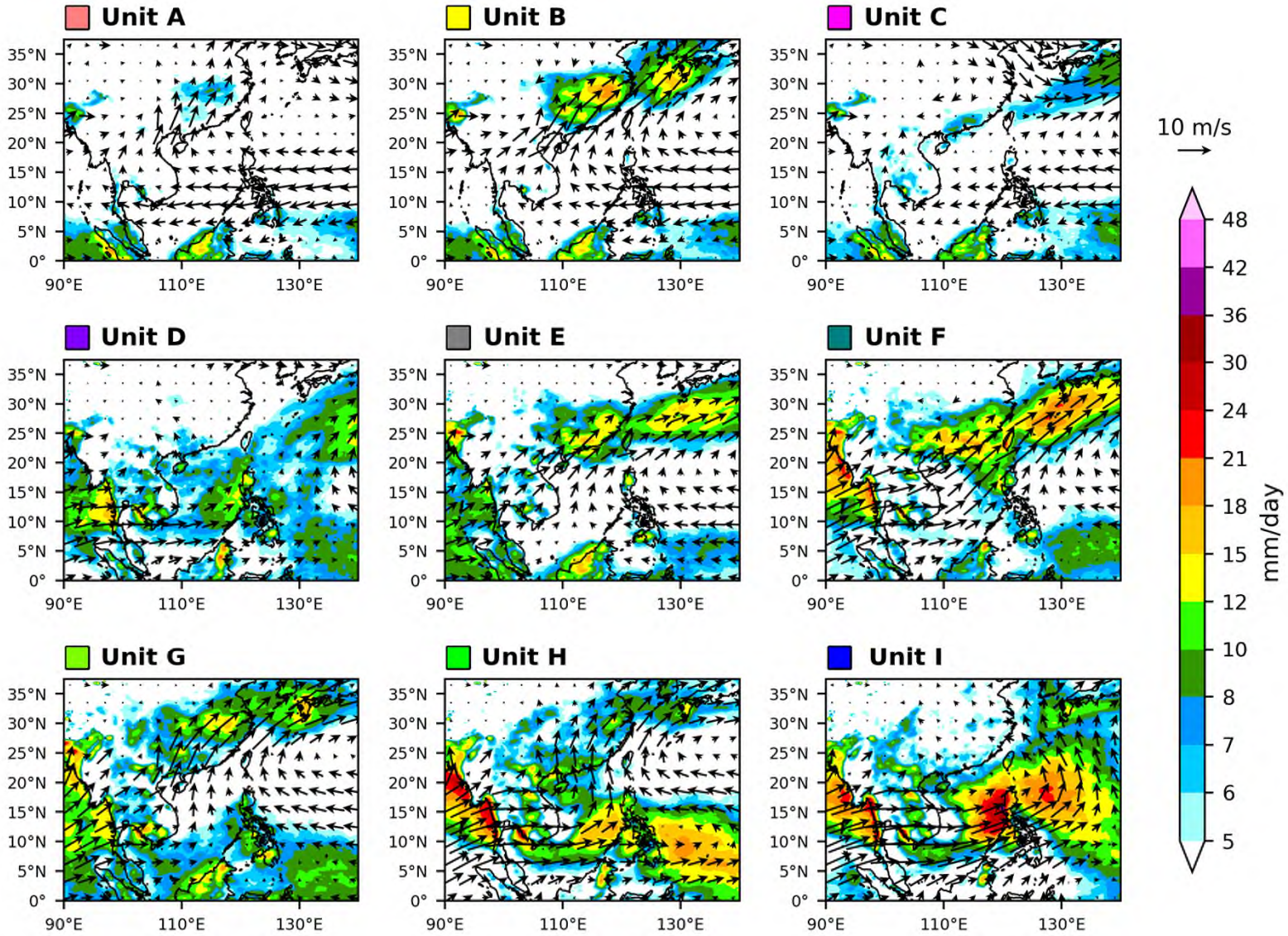
- SOM Weather Types
- EAM Weather Calendar
- Three Monsoonal Stages

Temporal Evolution of WTs During April to July

- Seasonal evolution of EAM from April to July can be presented by the evolution of daily WTs.
- The period from early May to mid-June includes most kinds of WTs, illustrating the seasonal transition process.



Composite of WTs: *ERA5 UV850 & CMORPH Precipitation*



Units A - C

- Strong easterlies over the SCS
- Weak precipitation over East Asia

Units D - F

- Westerlies from the BoB to SCS
- Precipitation contrast between E and F

Units G - I

- Northward movement of Mei-yu rainband
- Circulation of the subtropical high
- Monsoon trough

Construct the EAM Weather Calendar

- **Multi-SOM**

  WTs occurrence **on pentad time scale**

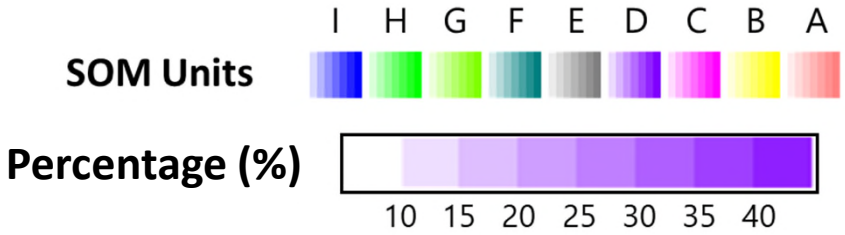
  Arrange the WTs in **chronological order**

- **EAM Weather Calendar**

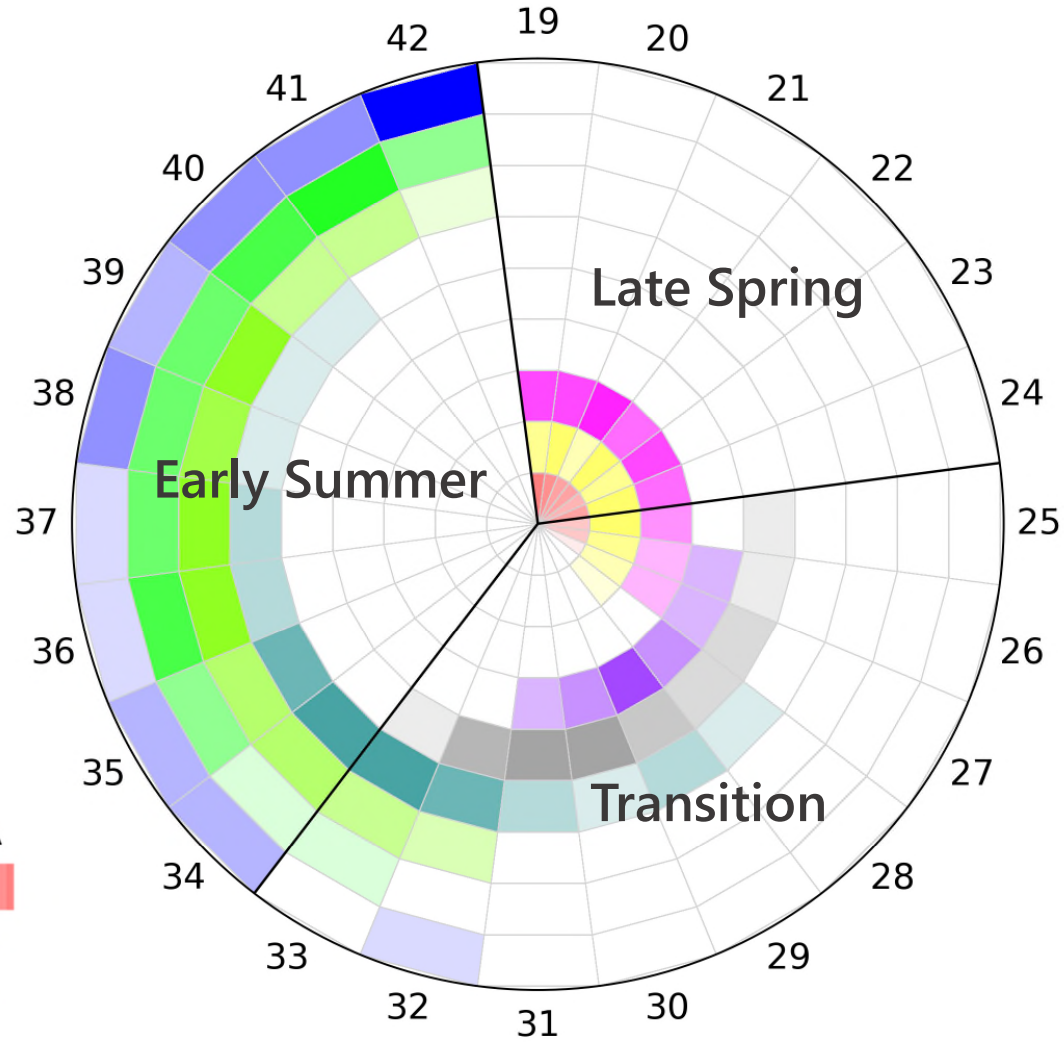
  Dominant period of **Unit E** (the centered WT)

  Persisting occurrence of **Unit I**

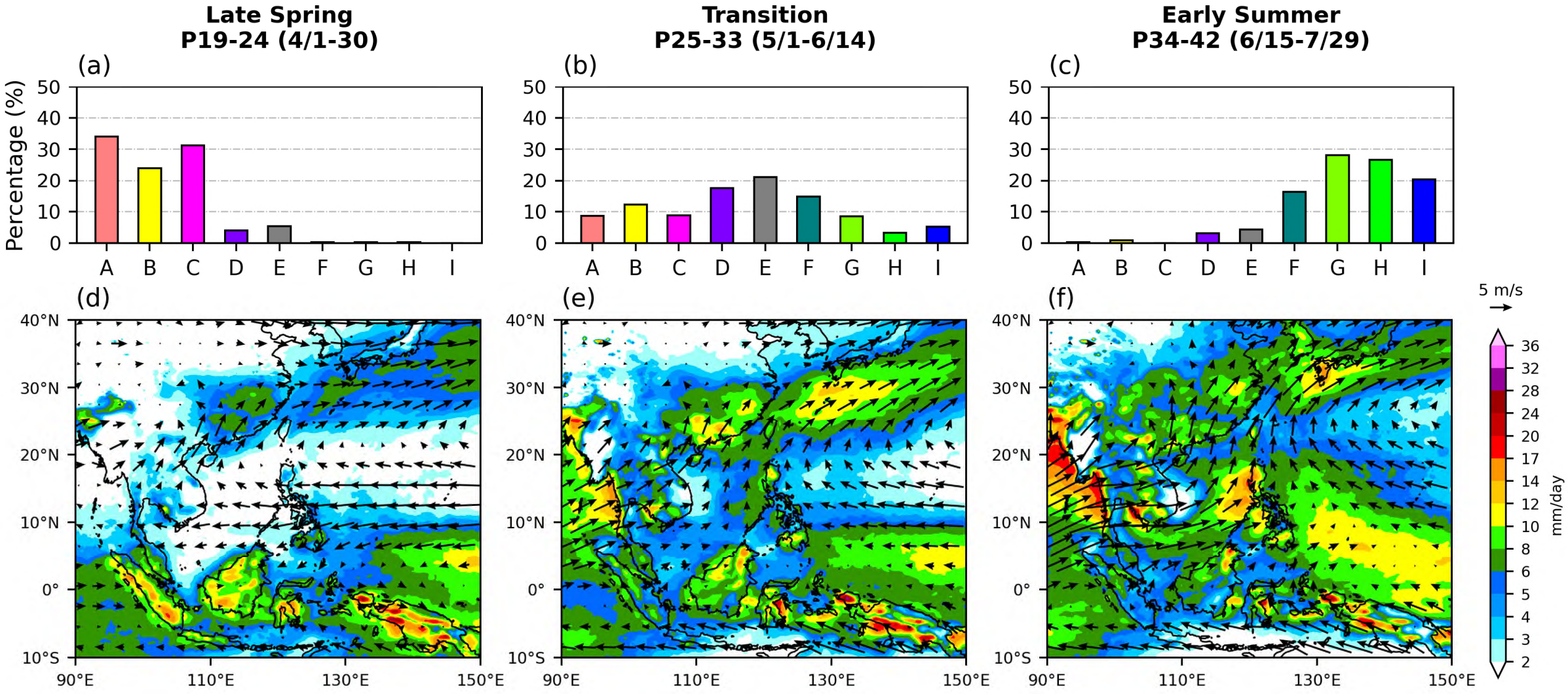
- **Three Development Stages of EAM**



Pentad 19 (4/1-5) – Pentad 42 (7/25-29)



Three Development Stages of EAM during AMJJ



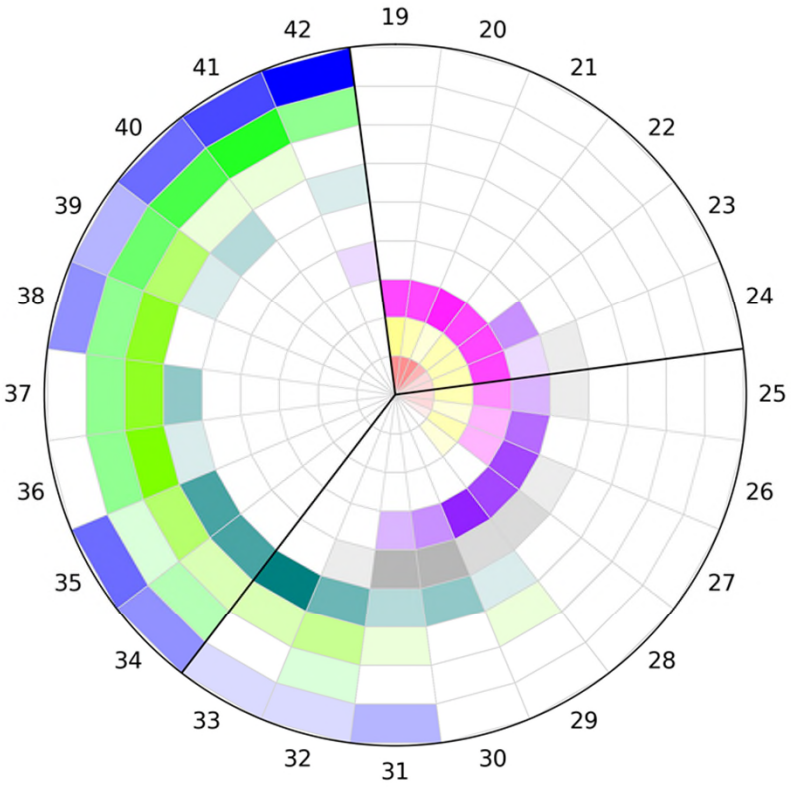
- The dominant WTs in three stages present the transition of climate regime from late spring to early summer.

02 ENSO Modulations on EAM

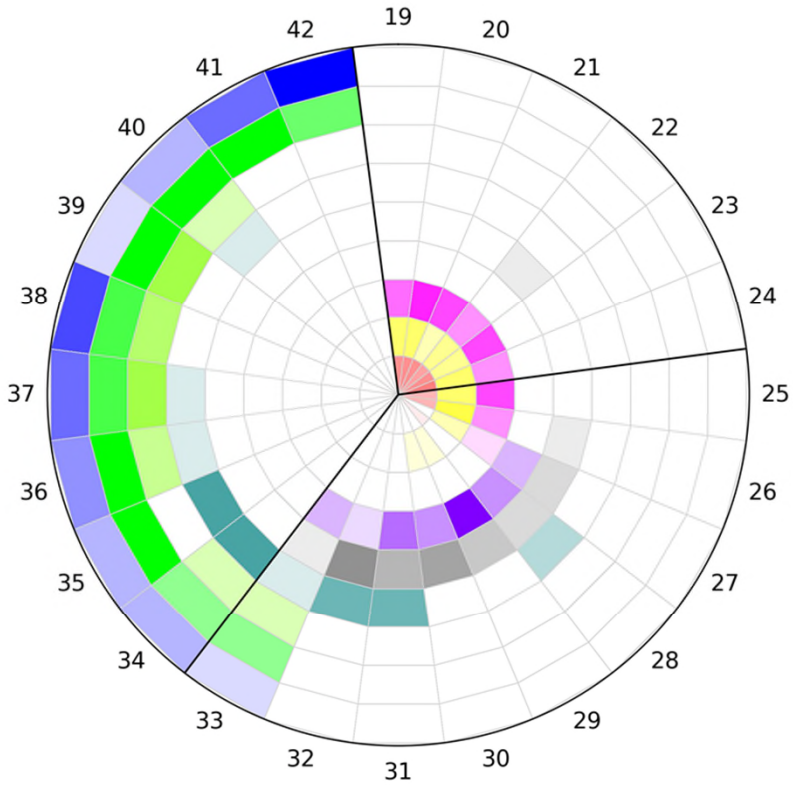
- ENSO vs. SOM WTs
- ENSO Modulation

EAM Weather Calendars of Three ENSO Phases

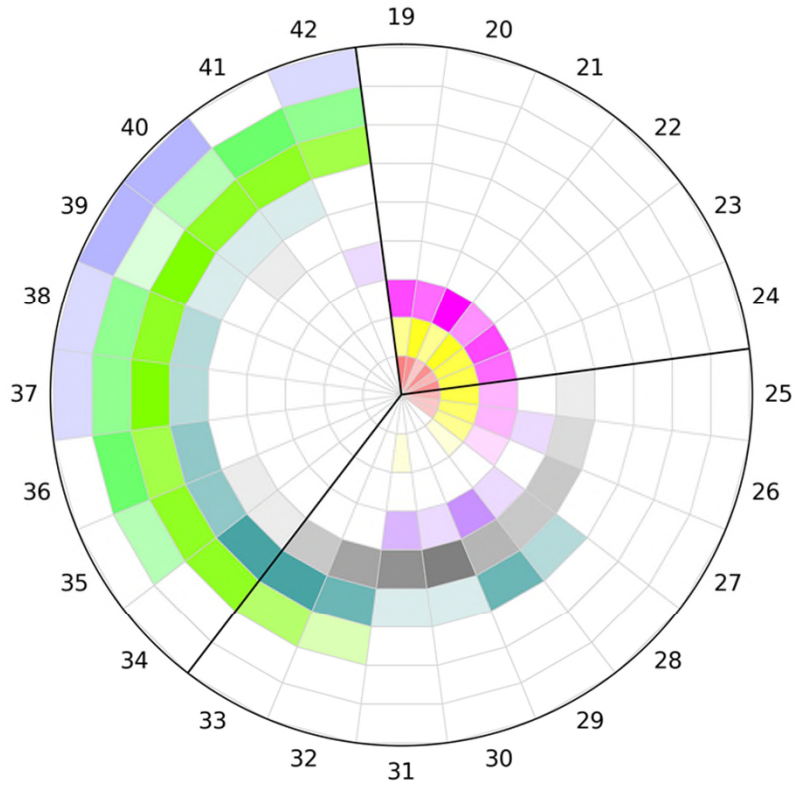
La Niña

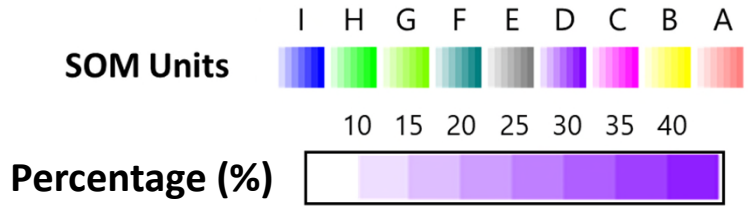


Neutral



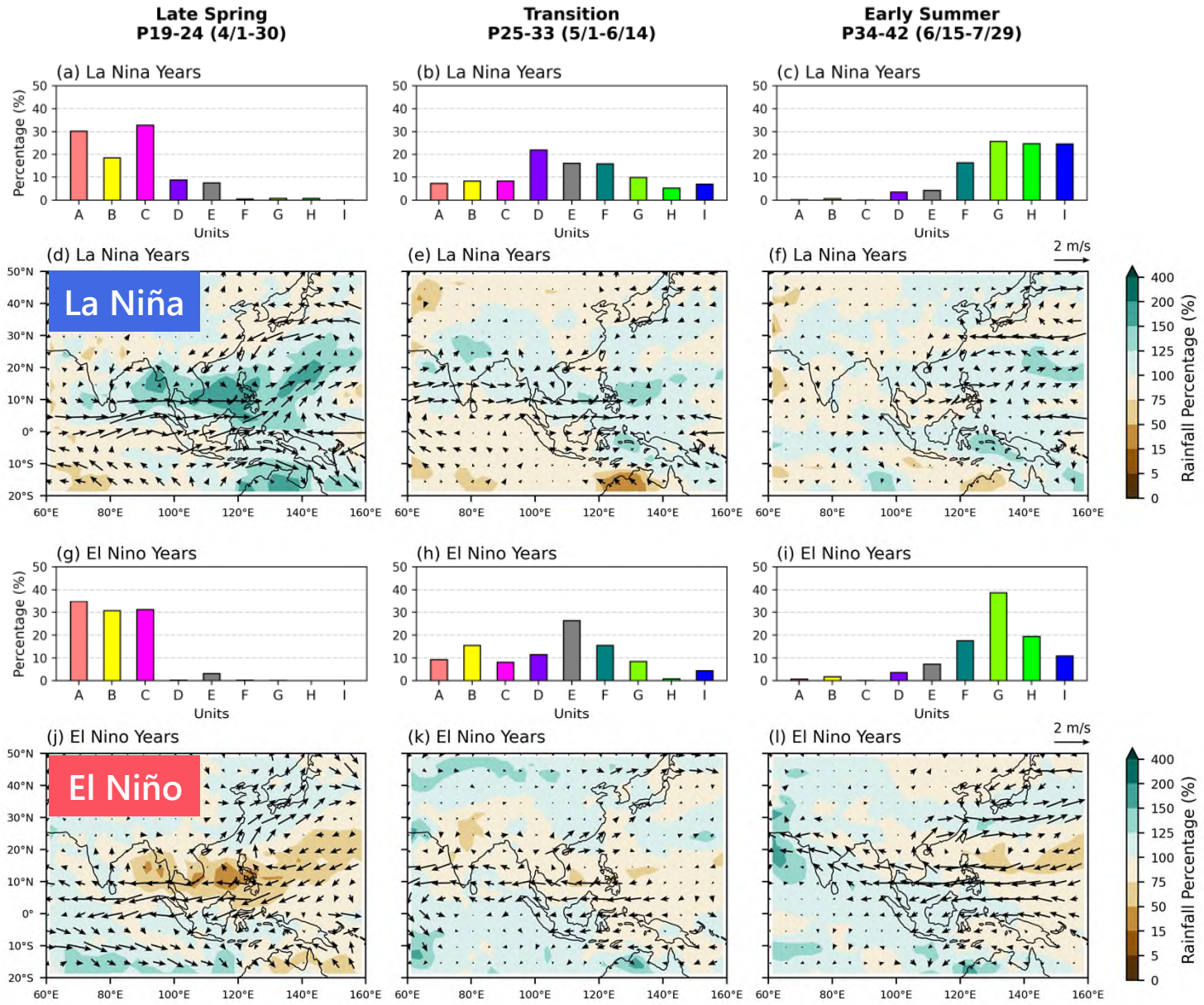
El Niño





- EAM weather calendars constructed by different ENSO years show different occurrence of WTs and their evolution processes.

Composite Anomalies vs. SOM WT Occurrence



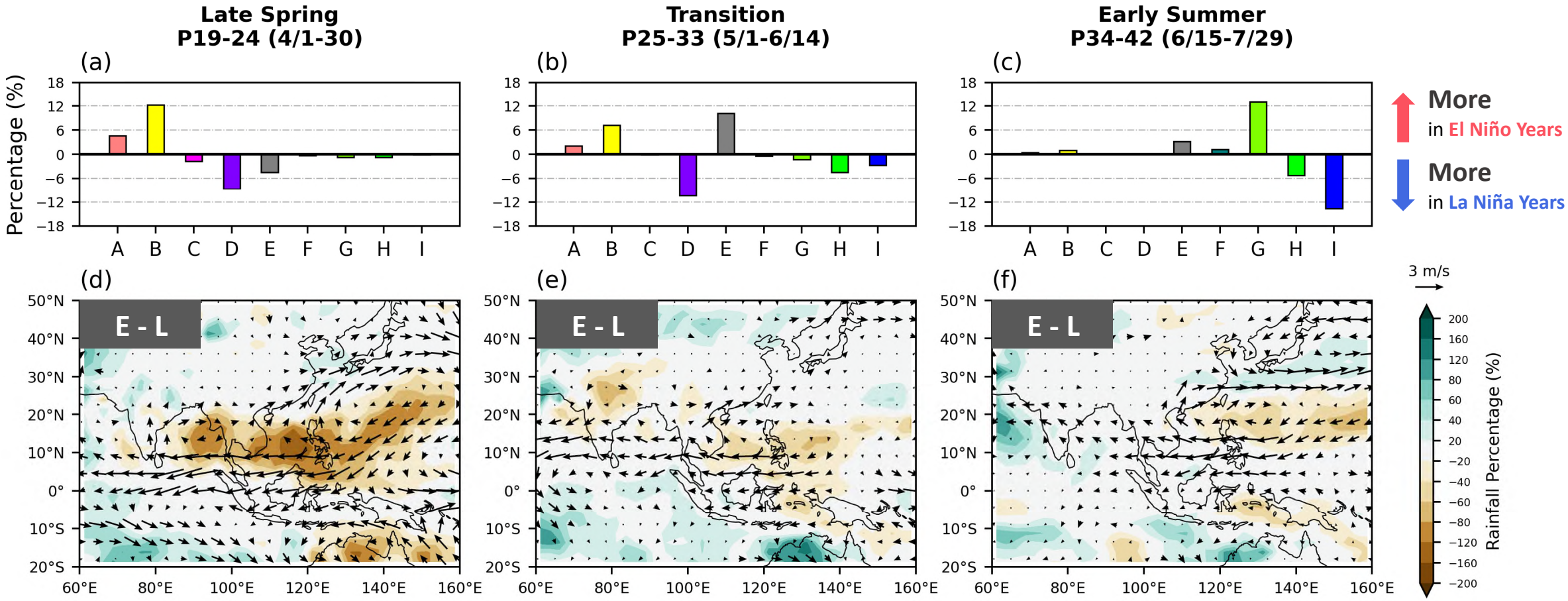
- The anticyclonic (cyclonic) anomalies and suppressed (enhanced) precipitation in El Niño (La Niña) years are shown in the composite maps.
- Different distribution of WTs reflect the anomalies of ENSO modulation in three monsoonal stages.

Vectors 1979-2023 ERA5 UV850

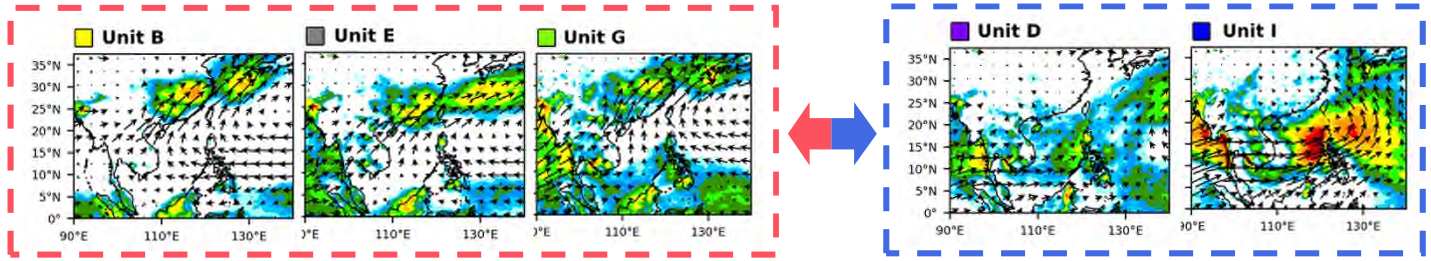
Shading 1979-2022 GPCP Rainfall pct.

Differences of Composite Anomalies vs. SOM WT Occurrence

ENSO Modulation



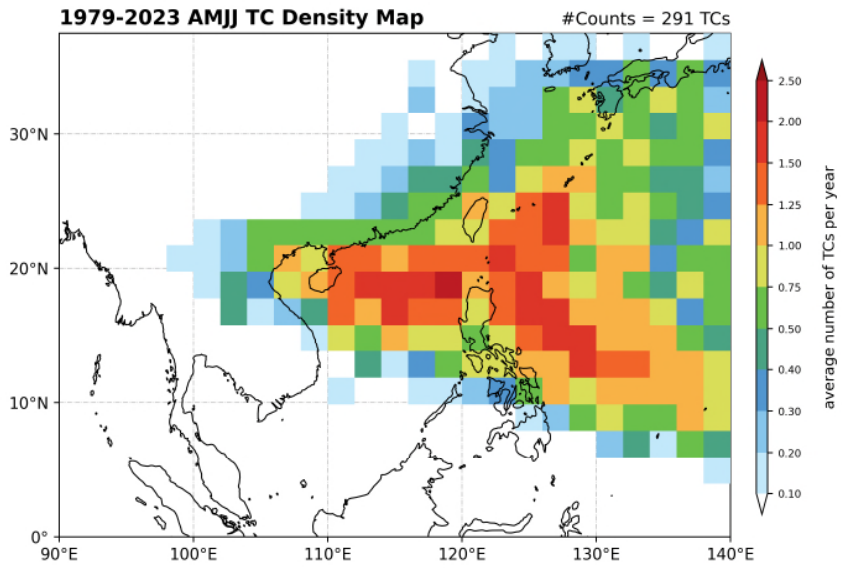
- Anticyclonic circulation over the WNP
- Easterlies from SCS to BoB
- Dry condition over the WNP

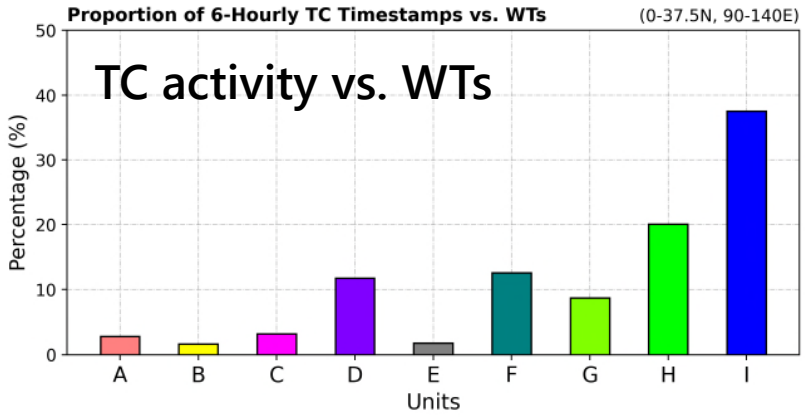


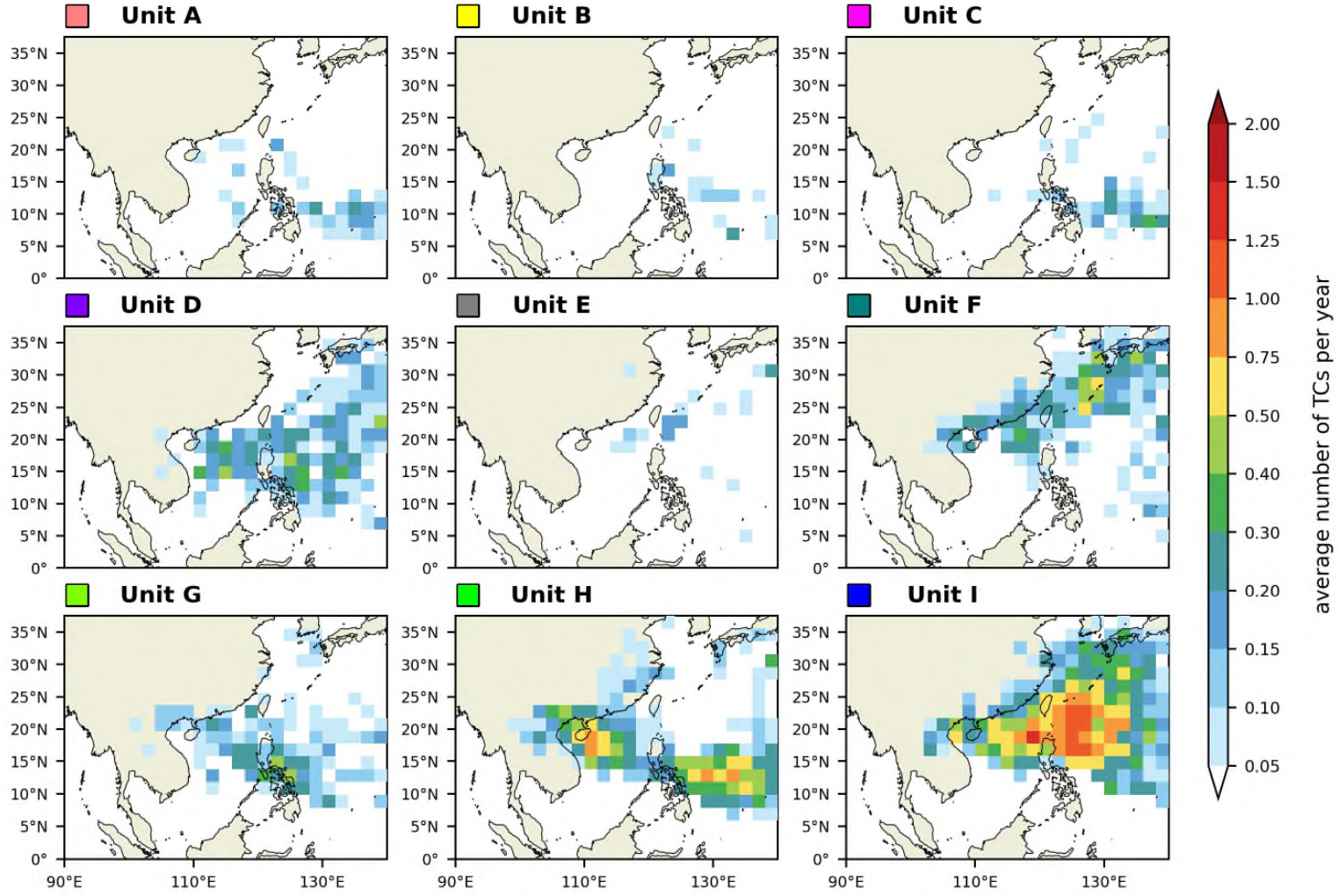
03 SOM WTs and Taiwan-Philippine Extreme Weather

- WNP TC Activity

TC Activity over the WNP during AMJJ vs. SOM WTs

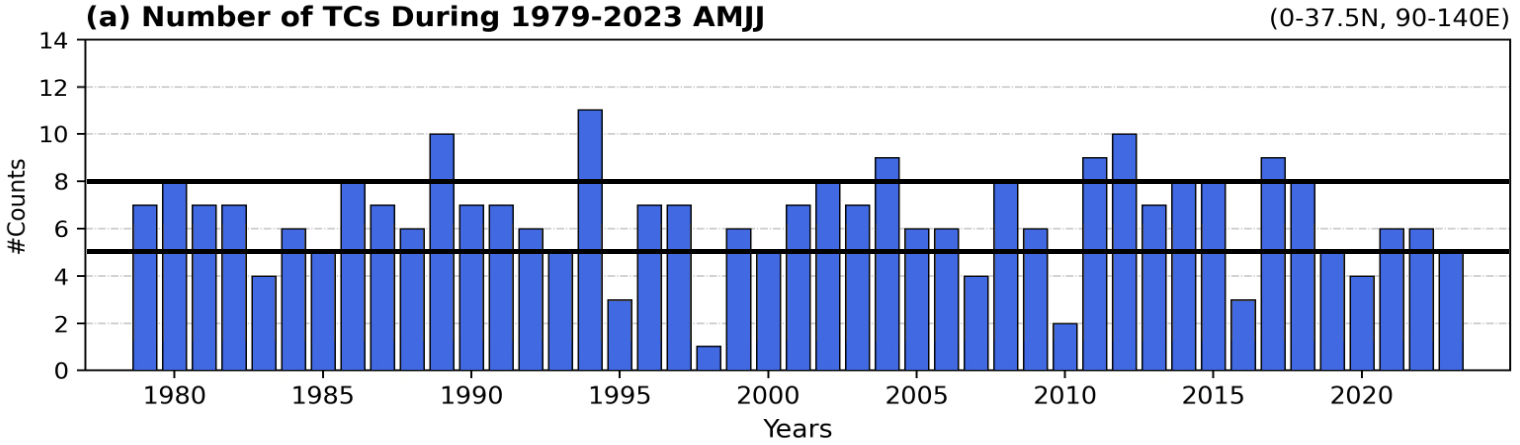


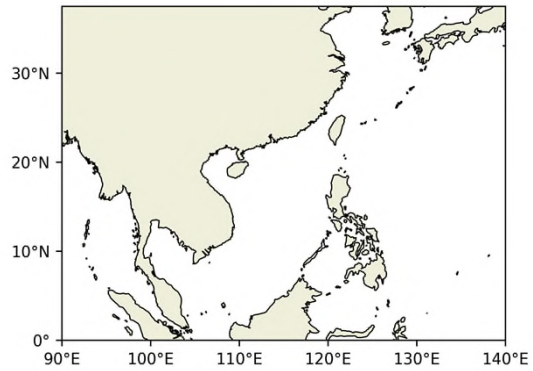




- Nine WTs show distinct spatial distribution and occurrence of TCs over the WNP.
- TC activity during April to July is primarily over the PhS and northern SCS, strongly related to Units H and I.

TC Activity during April to July vs. ENSO Phase



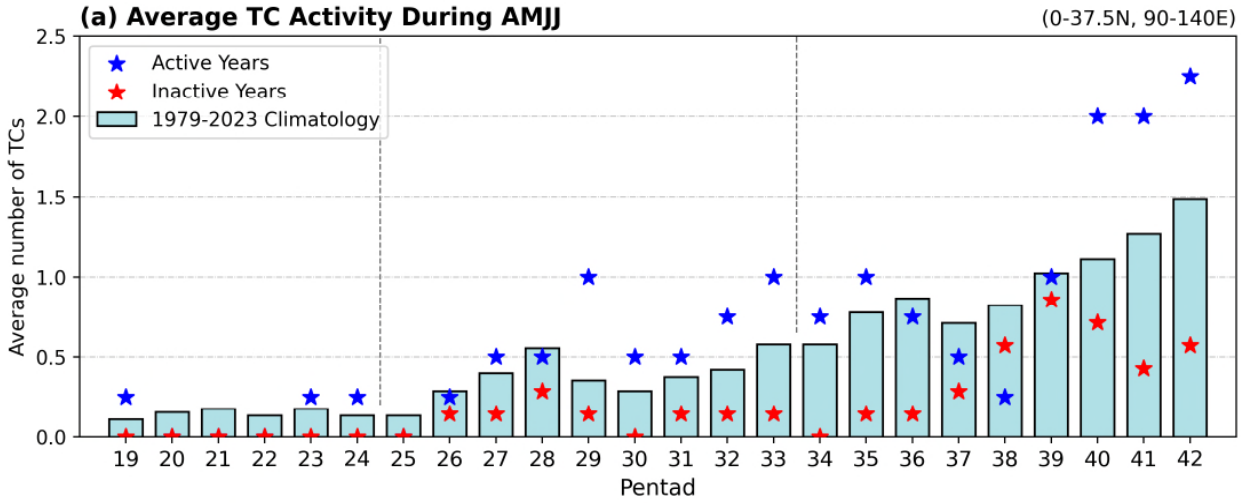


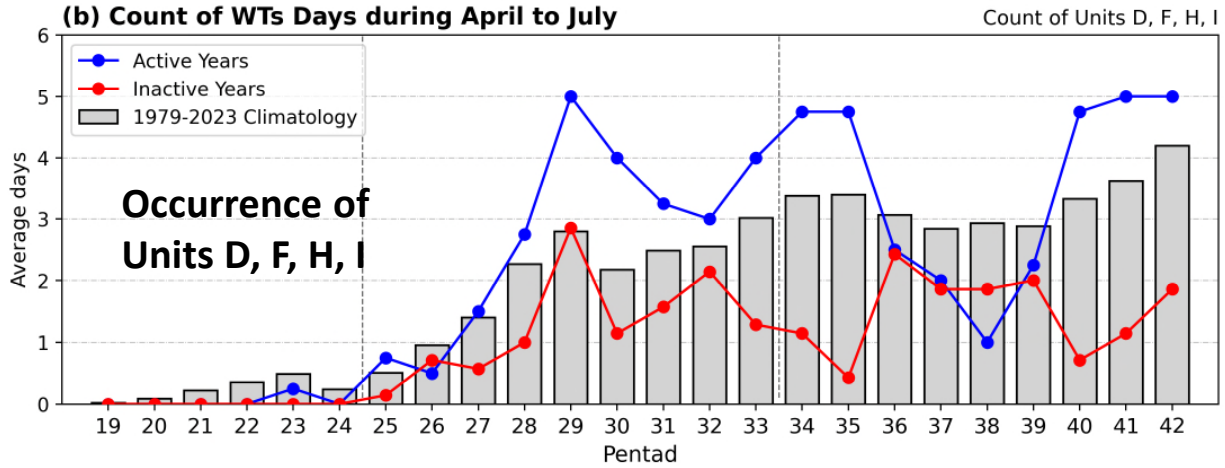
ENSO Phases	Number of TCs ≤ 4	5 ≤ Number of TCs ≤ 8	Number of TCs ≥ 9
El Niño	1983, 1995, 1998, 2007, 2010, 2016, 2020	1980, 1987, 1988, 1992, 2003, 2005, 2015, 2019	-
Neutral	-	1979, 1981, 1982, 1986, 1990, 1991, 1993, 1997, 2002, 2013, 2014	1994, 2004
La Niña	-	1984, 1985, 1996, 1999, 2000, 2001, 2006, 2008, 2009, 2018, 2021, 2022, 2023	1989, 2011, 2012, 2017

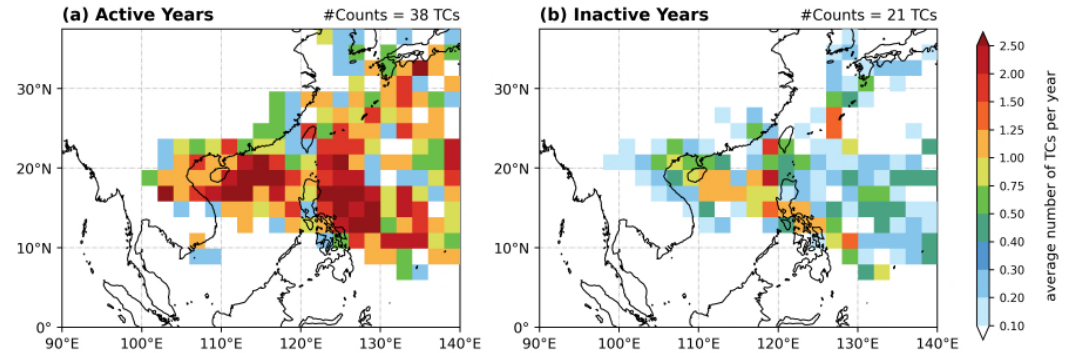
El Niño-inactive Years

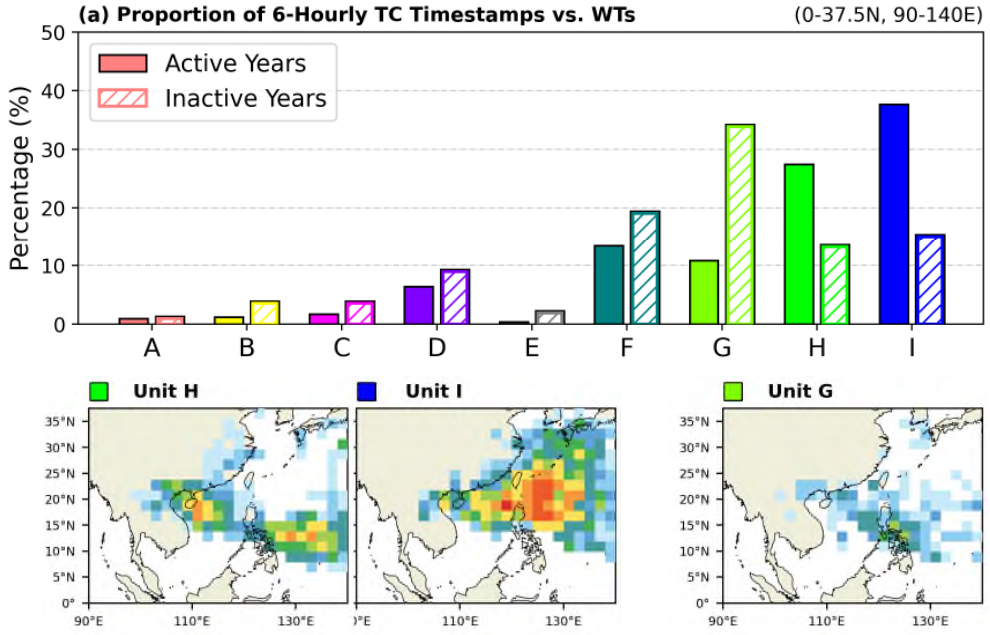
La Niña-active Years

TC Activity and WTs of Active and Inactive Years









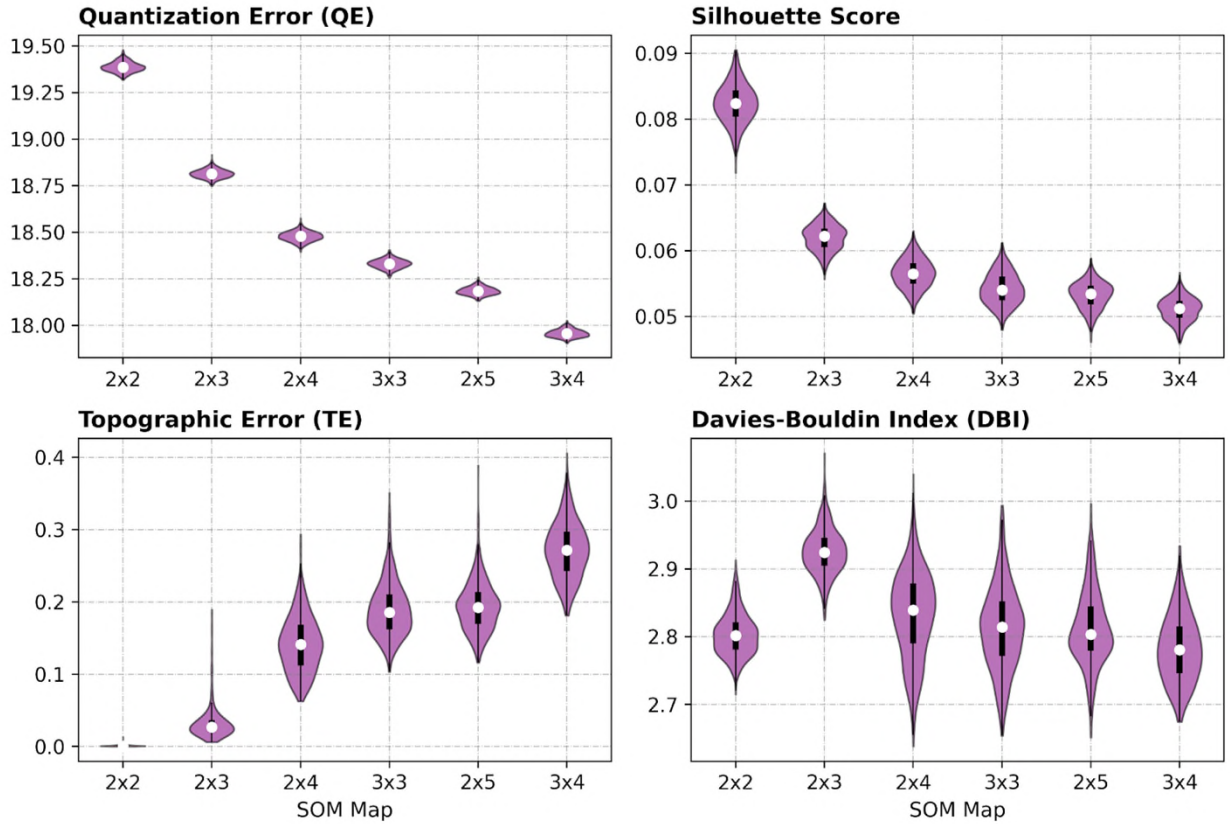
- The occurrence of WTs can properly reflect the TC activity over the WNP during April to July between La Nina-active and El Nino-inactive years.

Conclusions

- Three development stages of EAM during April to July are identified based on nine WTs of daily low-level wind data from 1979 to 2023 using SOM method, presenting on the EAM weather calendar.
- The ENSO modulation over East Asia on interannual time scale can be presented by different occurrence of WTs and the corresponding anomalous fields in three monsoonal stages.
- In the applications, the WTs and EAM weather calendar show that they can be used as a framework for monitoring or explaining the relationship between ENSO, EAM and TC activity over the WNP.

Future Works

- 擴大輸入資料的空間範圍，並嘗試延長分析時段（將以4-10月為主，涵蓋北半球主要降雨時期）。
- 嘗試應用此分析方法在即時氣候監測，以了解短期氣候的天氣類型演變特徵。
- 搭配其他客觀的分群評估指標，共同檢視 SOM 分群數量選擇的合理性。



重新使用500組 (seed=1-500) 不同群數的 SOM 對東亞4~7月逐日低層風場的分群結果評估

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Quantization Error (QE) Lower is better

QE is the average distance between data points and their corresponding best-matching units (BMUs) on the map.

$$QE = \frac{1}{N}\sum_{i=1}^{N}\|\boldsymbol{w}_c - \boldsymbol{x}_i\|$$

N: number of input samples
$\boldsymbol{x}_i$: input vector of sample i
c : Best matching unit of sample i
$\boldsymbol{w}_c$: weight vector of Unit c

Topographic Error (TE) Lower is better

TE measures the degree of topology preservation, which indicate whether similar clusters are positioned closely on the map.

$$TE = \frac{1}{N}\sum_{i=1}^{N} u_{\boldsymbol{x}_i}$$

$$u_{x_i} = \begin{cases} 0, & if\ 1^{\text{st}} \text{ and } 2^{\text{nd}} \text{ BMU of } \boldsymbol{x}_i \text{ are neighbors} \\ 1, & if\ 1^{\text{st}} \text{ and } 2^{\text{nd}} \text{ BMU of } \boldsymbol{x}_i \text{ are not neighbors} \end{cases}$$

Silhouette Score 輪廓係數 Higher is better

The silhouette score is to measure each data point's similarity to the cluster it belongs to and how different it is from other clusters.

$$s(i) = \frac{b(i) - a(i)}{max\{a(i), b(i)\}}$$

$$\begin{cases} s(i) \approx 1 : \text{Well-clustered.} \\ s(i) \approx 0 : \text{Between two clusters.} \\ s(i) < 0 : \text{Likely misclassified.} \end{cases}$$

$s(i)$: silhouette score of sample i
$a(i)$: Avg. distance to points in the same cluster
$b(i)$: Avg. distance to points in the nearest different cluster

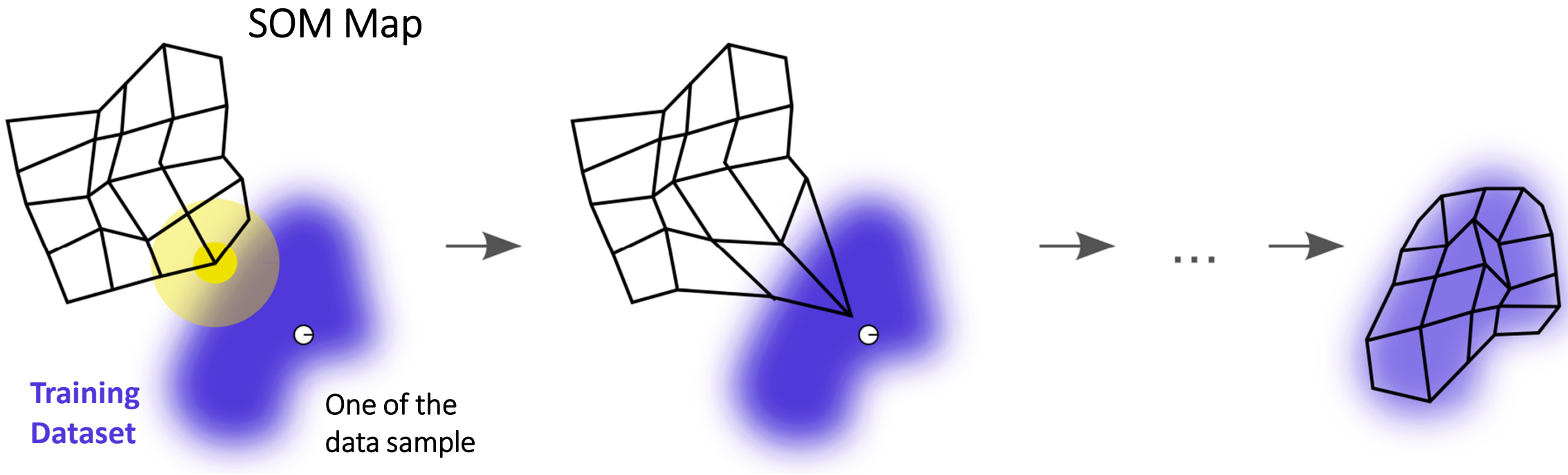
Davies-Bouldin Index (DBI) Lower is better

DBI measures how good clusters are by checking if the points in each cluster are close together (compactness) and if the clusters are far apart from each other (separation).

$$DBI = \frac{1}{k}\sum_{i=1}^{k}\max_{j\neq i}\left(\frac{S_i + S_j}{M_{ij}}\right)$$

k : Number of clusters
S_i : Avg. distance of points in cluster i to its center
M_{ij} : Distance between centers of clusters i and j

Schematic Diagram of Self-organizing Maps (SOM)



https://en.wikipedia.org/wiki/Self-organizing_map

ENSO modulation on East Asian Monsoon

- The ENSO modulation on the interannual variability of EAM are well documented in previous studies. [Wang and Zhang 2002; Wang et al. 2000; Wang et al. 2003; Xie et al. 2009]
- The delayed impact of ENSO on the SCS and Philippine Sea region is related to anomalous Philippine Sea anticyclone, persisting from mature El Nino to ensuing summer. [Wang and Zhang 2002; Wang et al. 2000]

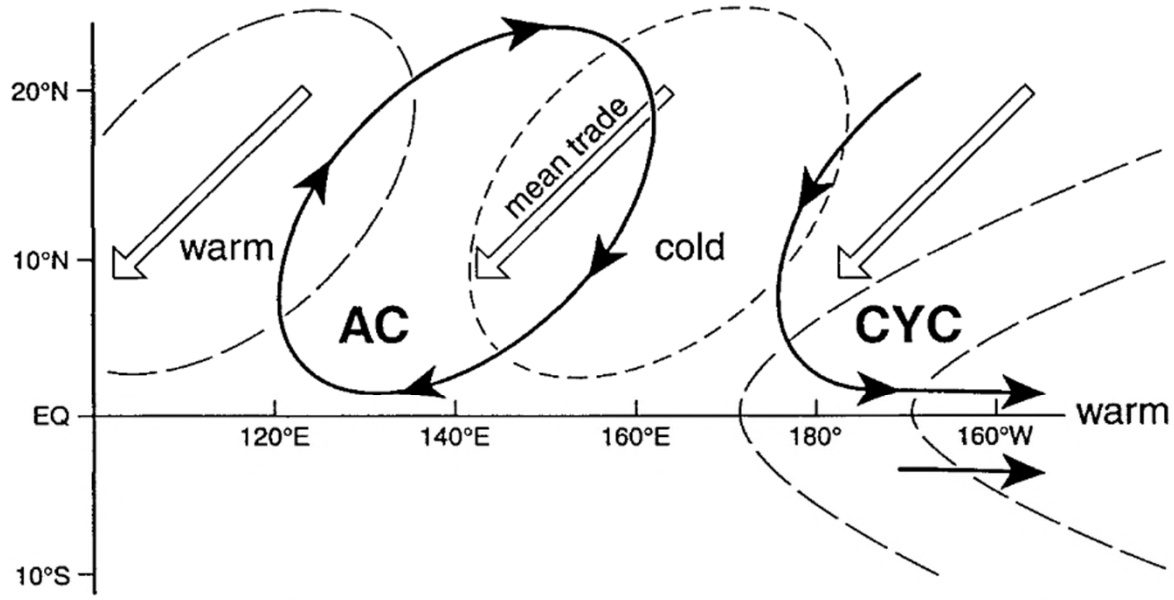
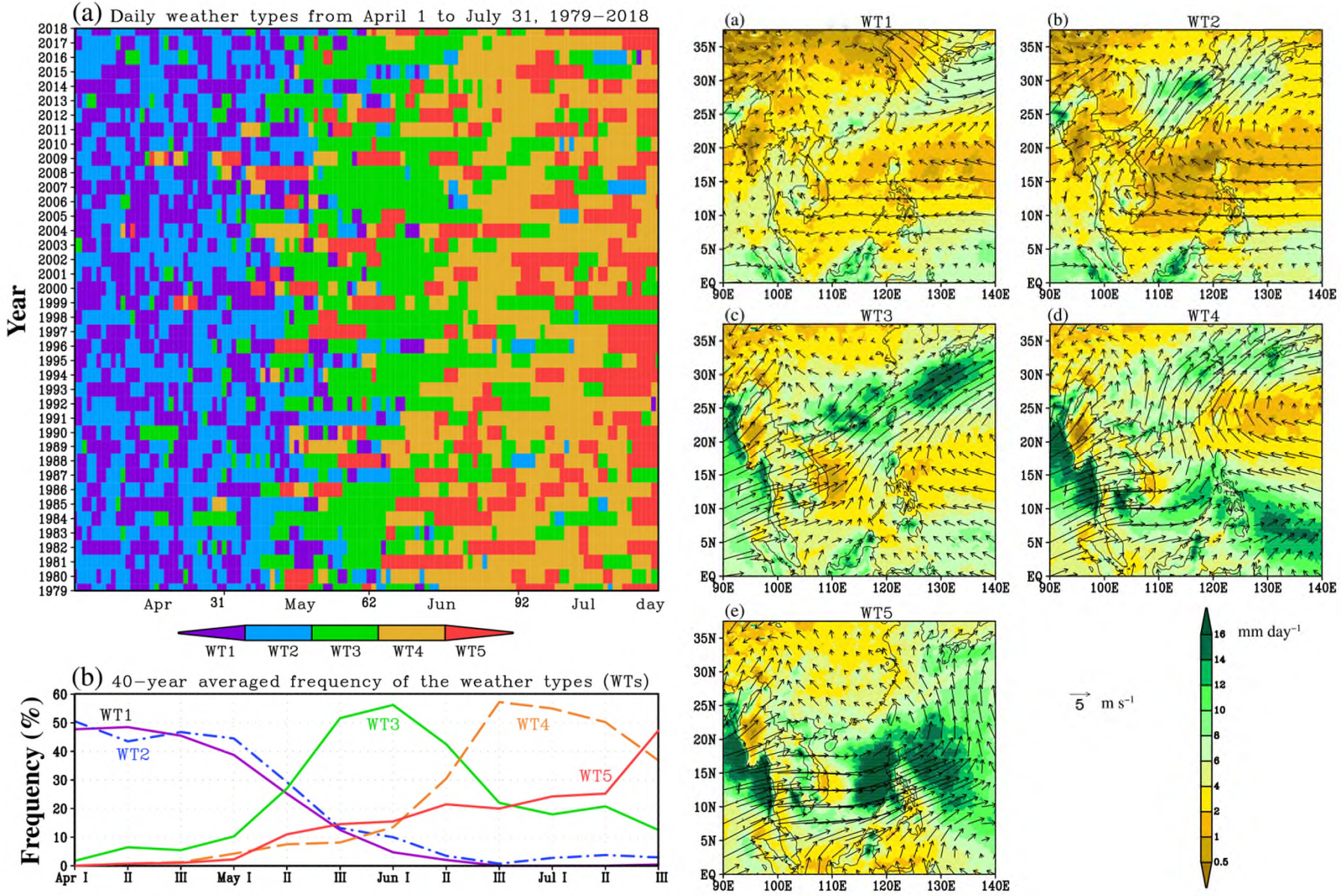


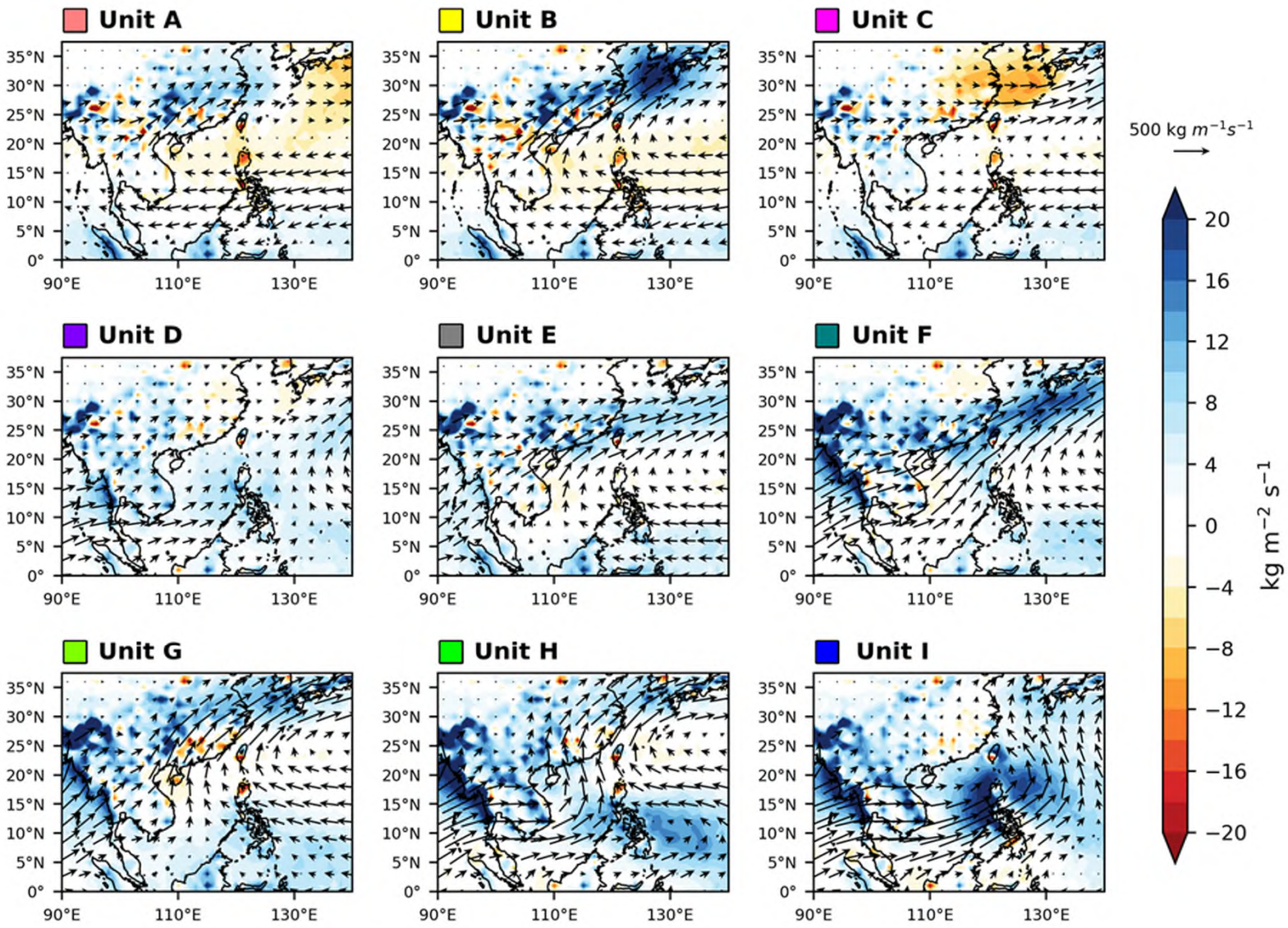
FIG. 16. Schematic diagram showing the air–sea interaction in the western North Pacific that maintains the Philippine Sea anticyclonic anomalies and associated negative SST anomalies in the western North Pacific. The double arrows denote the mean trade winds. The heavy lines with black arrows represent the anomalous winds. The long (short) dashed lines indicate contours of positive (negative) SST anomalies.

Wang et al. 2000

Five WTs in Qian et al. (2022)

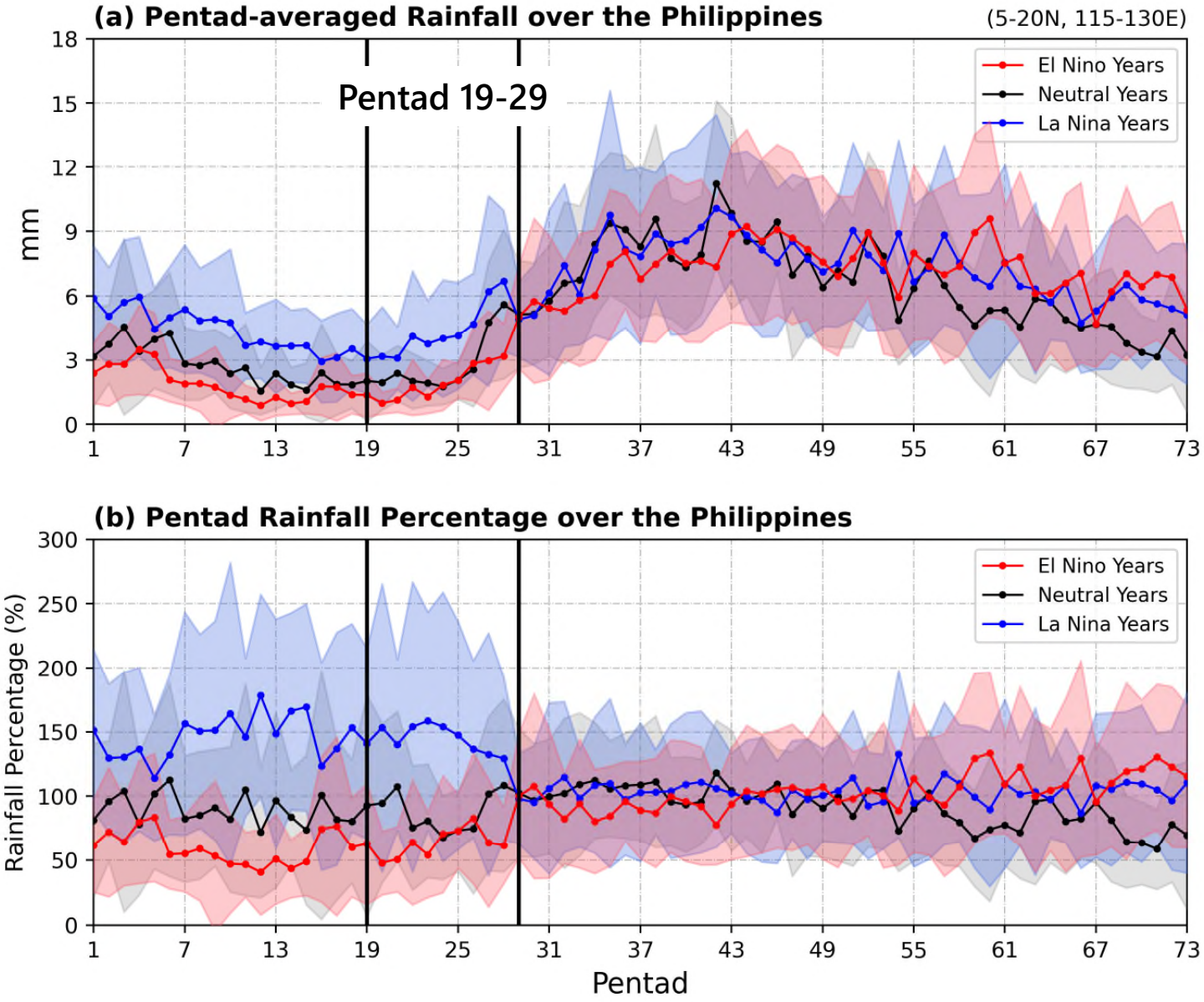


Composite of WTs: *ERA5 VIWV & VIWVD*(-1)*

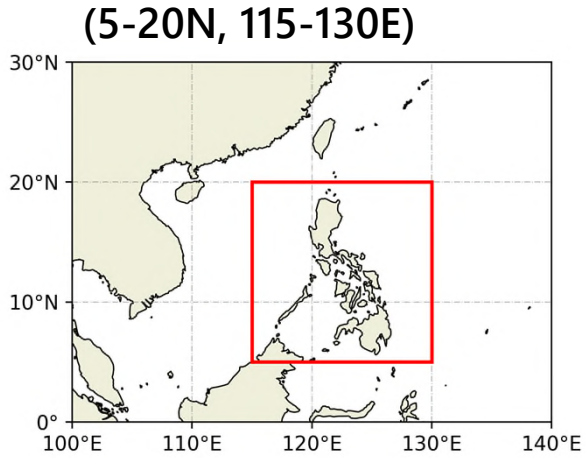


- The vertically-integrated water vapor transport and flux convergence shows the consistent features with low-level wind and precipitation fields.

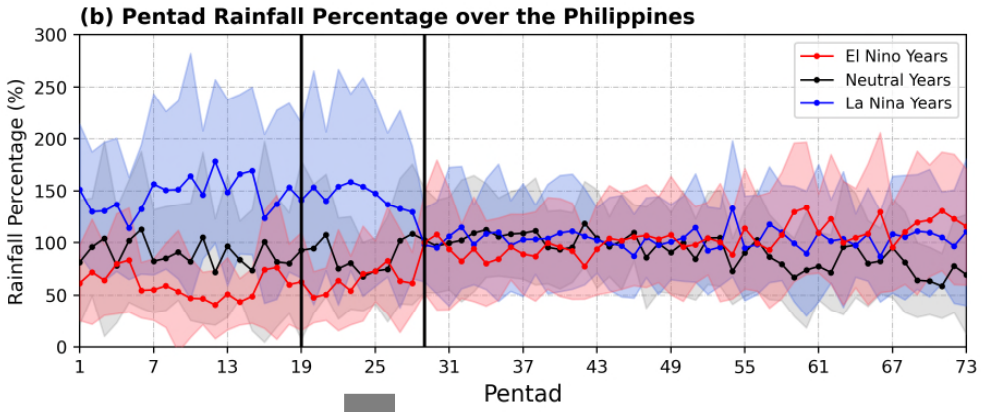
Annual GPCP Rainfall Time Series over the Philippines

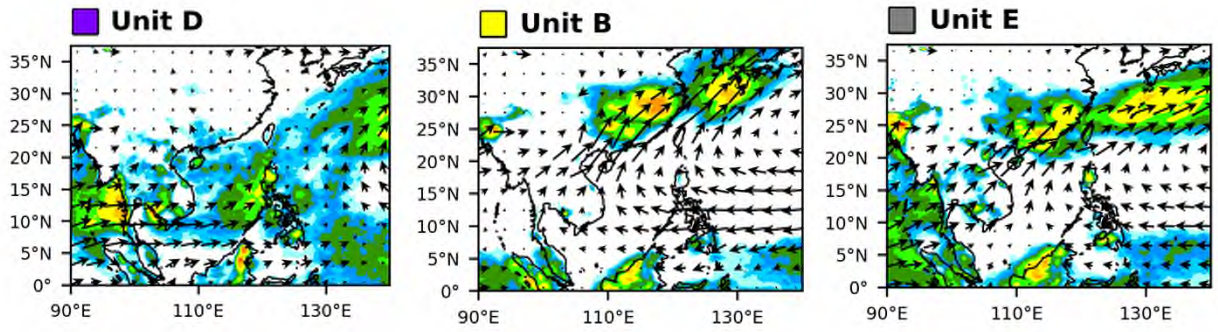


- More rainfall in La Niña years.
- Less rainfall in El Niño years.
- ENSO modulation on rainfall over the Philippines is from winter time to pre-rainy season, while no clear differences after Pentad 29 (5/21-25).



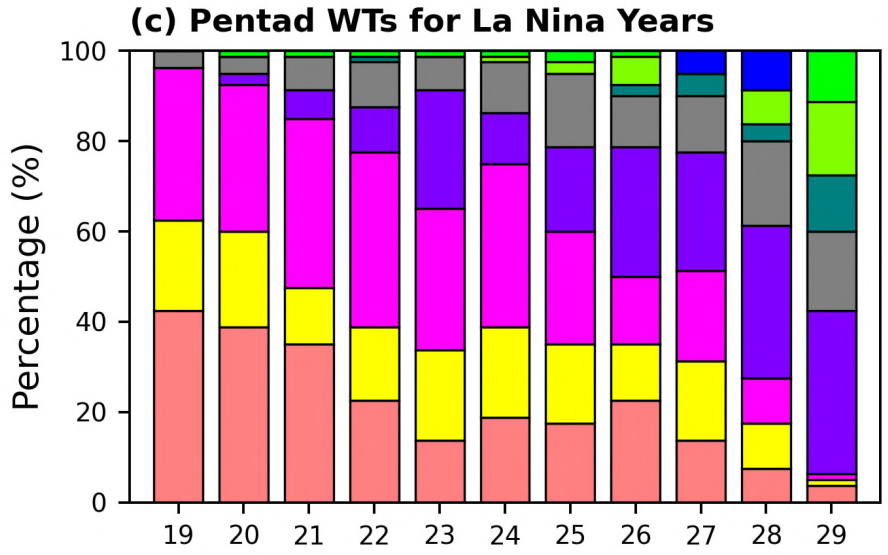
WT Occurrence during Philippine Pre-rainy Season

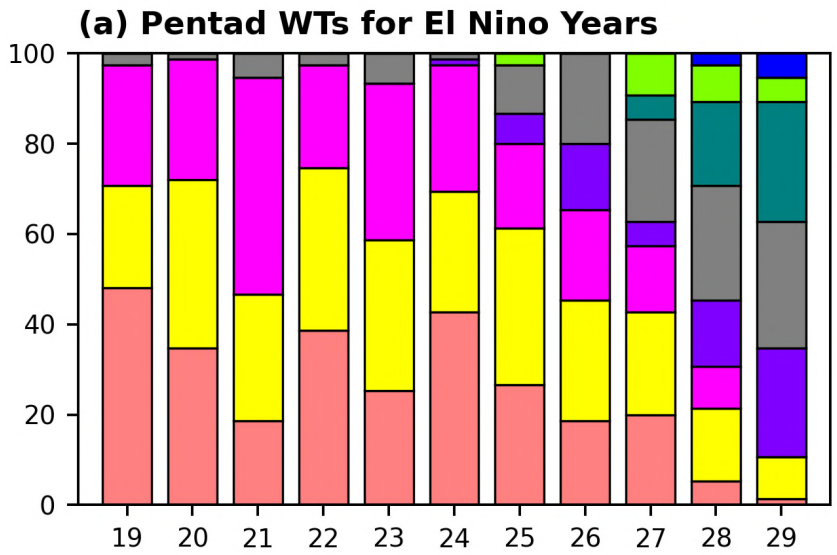




SOM WTs

During P19-29





- The contrast of pre-rainy season over the Philippines between La Nina and El Nino years can be reflected by the different occurrence of Units B, E, D.

Extreme Dry/Wet Events During Taiwan Meiyu Season (4/26-7/4)

Extreme Dry/Wet Cases

Extreme Rainfall Analysis

ERA-5 Total Precipitation

- **Grids:** 2.5°×2.5°
- **Time:** 1979-2023 4/26-7/4

Calculate Rainfall Thresholds

- **Dry day:** Below **PR10**
- **Wet day:** Exceed **PR90**

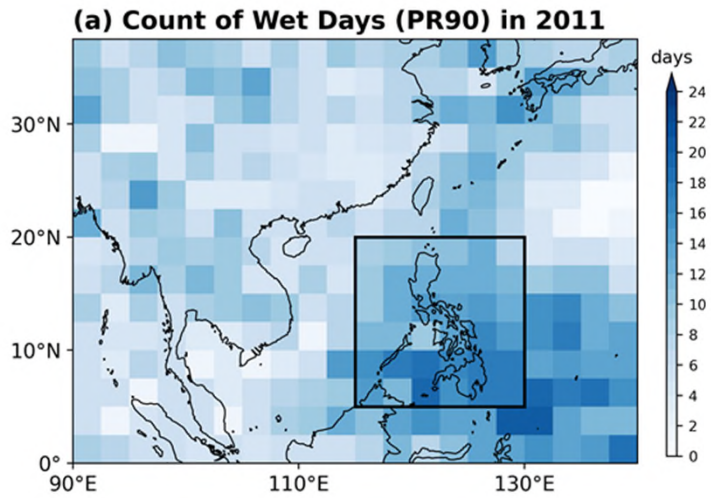
Dry/Wet Days for Selected Regions

Count the dry/wet days for **each grid**, averaged over **Taiwan** and **the Philippines**.

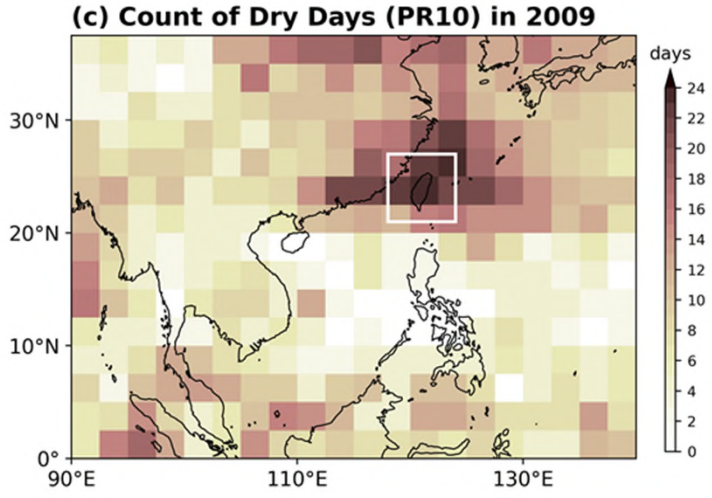
Compare with ENSO

Corr.	PHL	TW
Dry days vs. DJF ONI	**0.56*** **	-0.13
Wet days vs. DJF ONI	**-0.44****	-0.16

Wet Case – Philippines, 2011

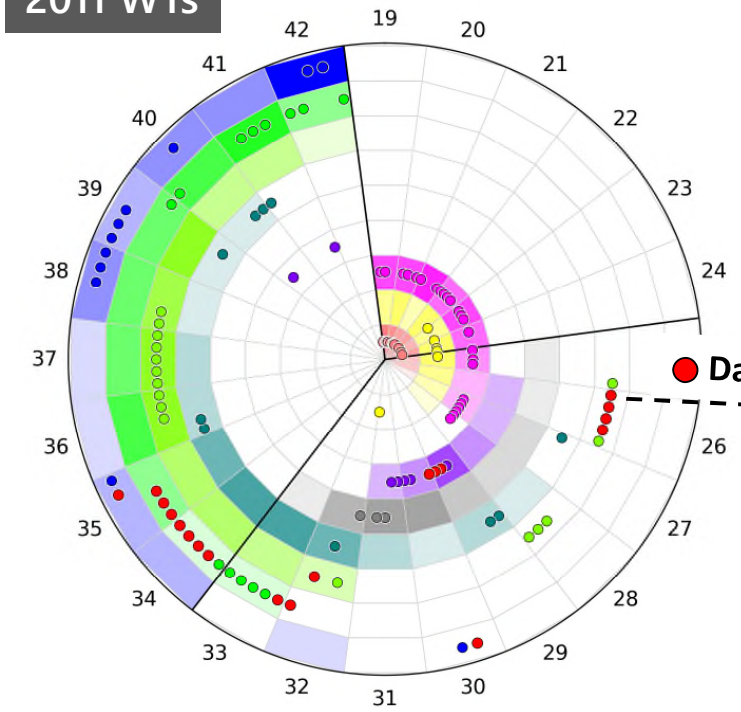


Dry Case – Taiwan, 2009

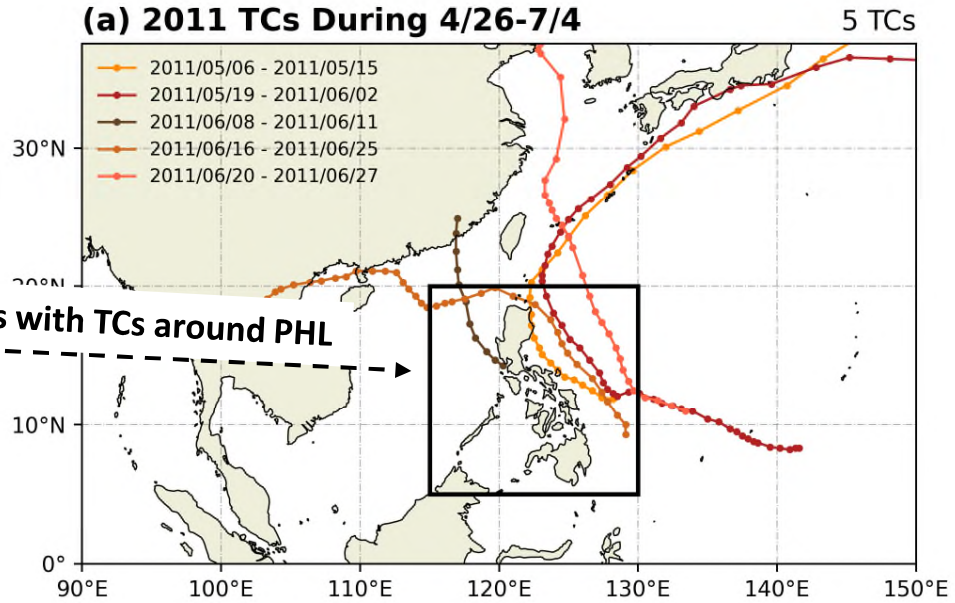


Extremely Wet Case: Philippines, 2011

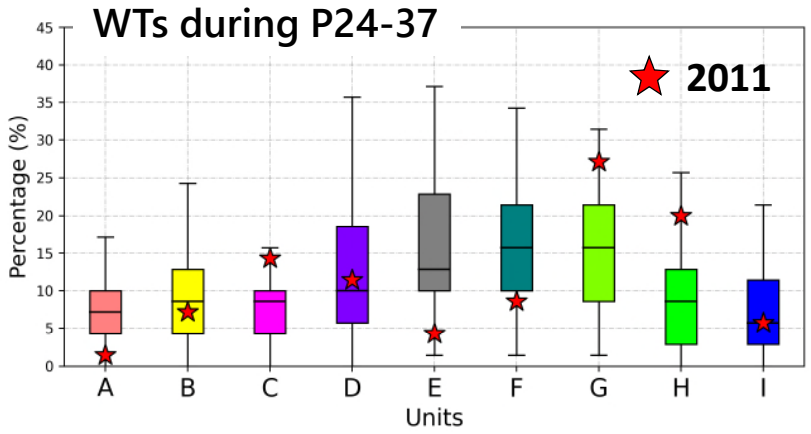
2011 WTs

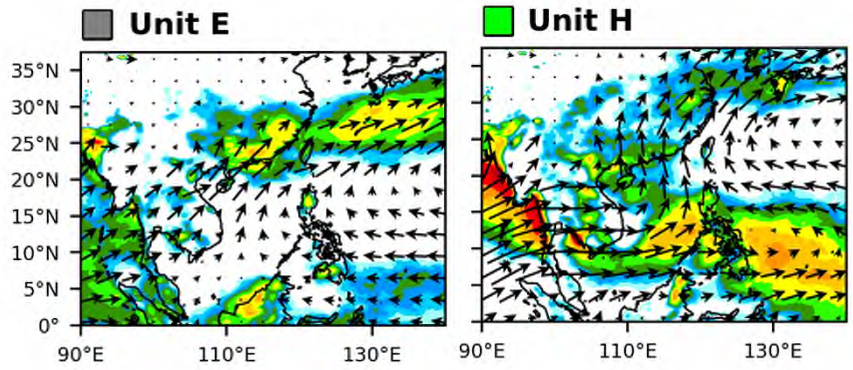


Dates with TCs around PHL



- Extreme wet event over the Philippines in 2011 can be reflected by active TCs around the Philippines, accompanied by less Unit E and more Unit H during 4/26-7/4.



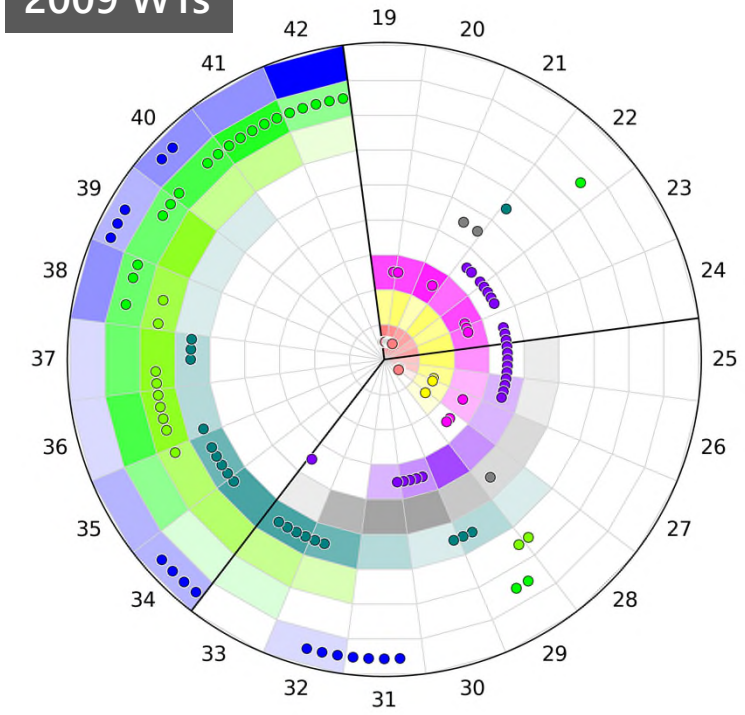


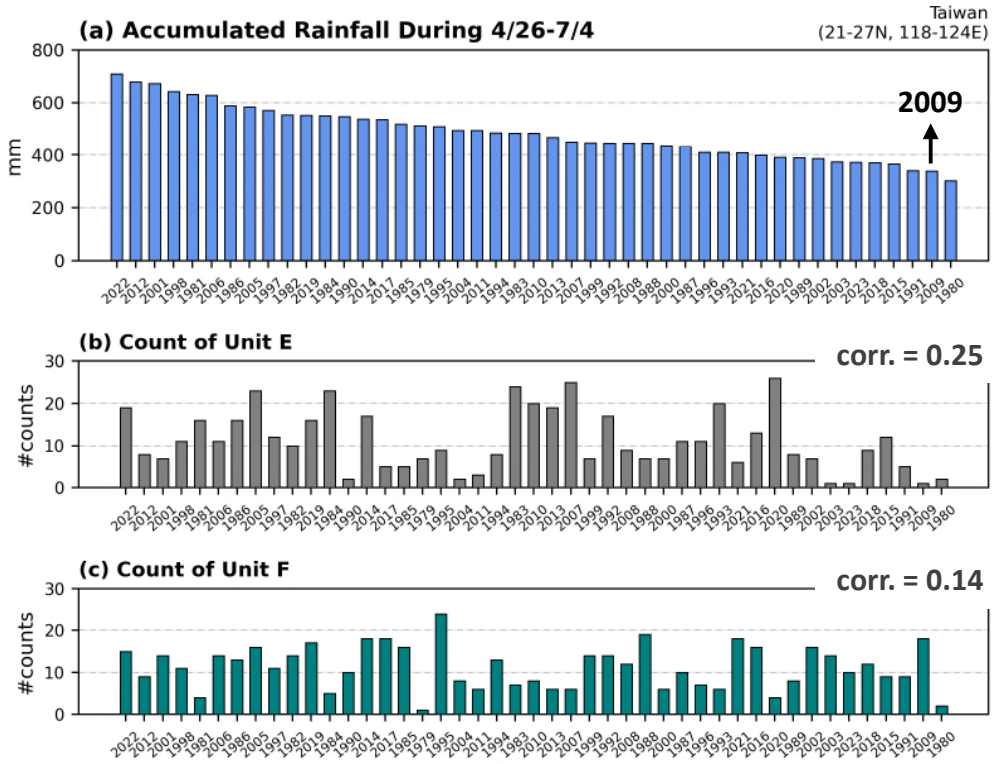
Corr. with accu. rainfall over PHL during 4/26-7/4

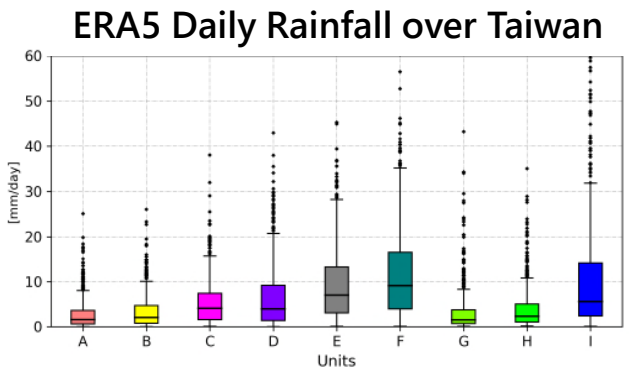
- **Unit E = -0.46****
- **Unit H = 0.4****

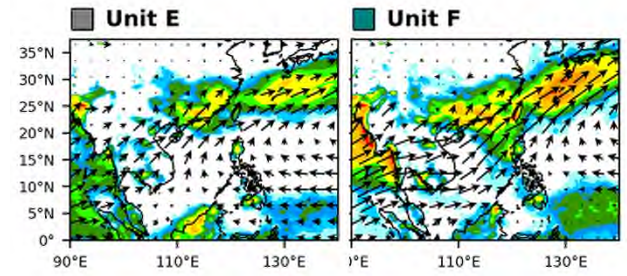
Extremely Dry Case: Taiwan, 2009

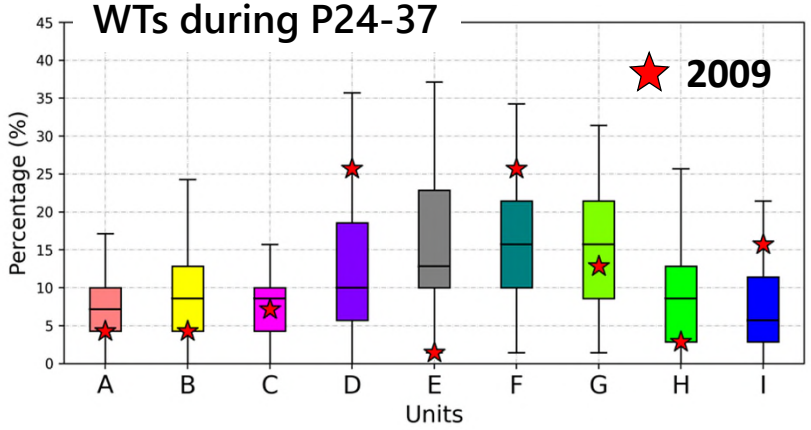
2009 WTs











- The dry case in 2009 may be related to the absence of Unit E.
- The occurrence of Units E and F cannot reflect the dry or wet condition over Taiwan during Mei-yu season in general.