6th Asia-Oceania Group on Earth Observations (AOGEO) Workshop

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Monitoring Agricultural Drought and Waterlogging over Mainland Southeast Asia: Surveying Soil from the Sky

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Earth Observations for Asia-Oceania

https://conferences.cis.um.edu.mo/AOGEO-workshop-2023/

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Content

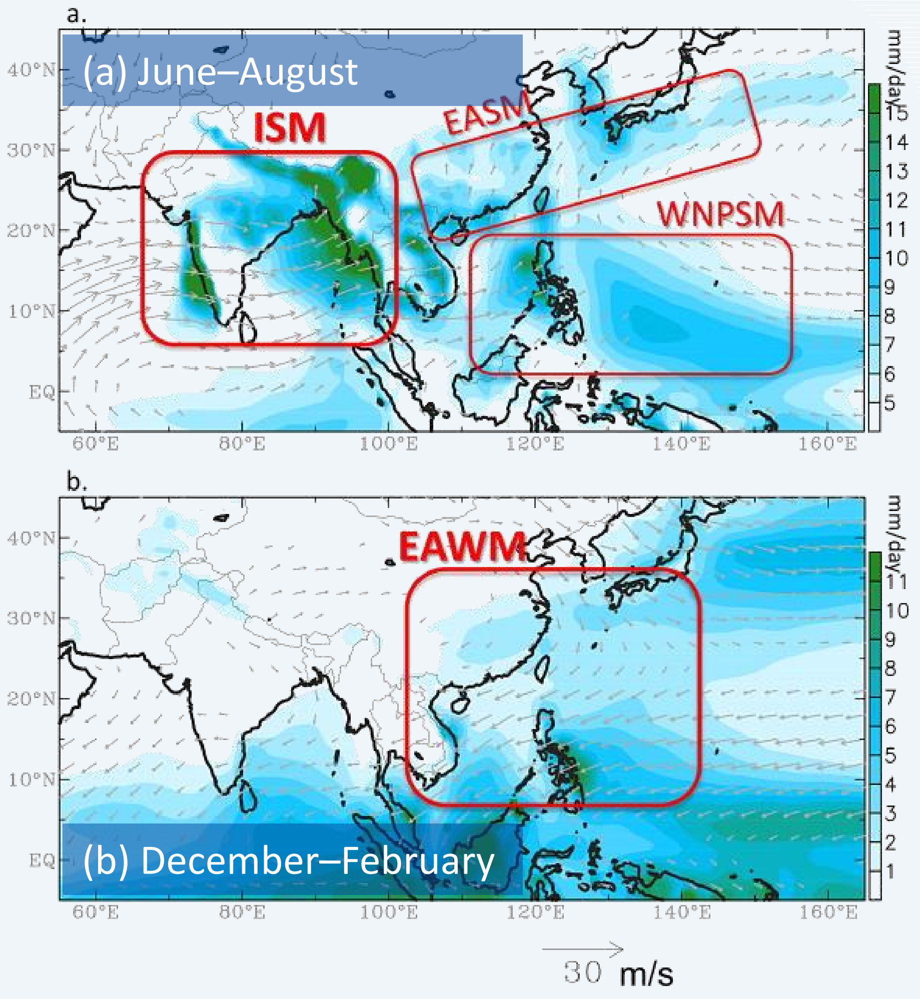
- The Asian monsoon can be conceptualized as several related components:
  - the Indian Summer Monsoon (ISM)
  - the East Asian Summer Monsoon (EASM)
  - the Western North Pacific Summer Monsoon (WNPSM)
  - the East Asian Winter Monsoon (EAWM)

Mainland Southeast Asia is sandwiched between these regional monsoon systems, highlighting its complex climate dynamics.

Drought and flooding *occurred as a direct consequence of Monsoon extremes, thus affects the stability and sustainability of regional societies.*

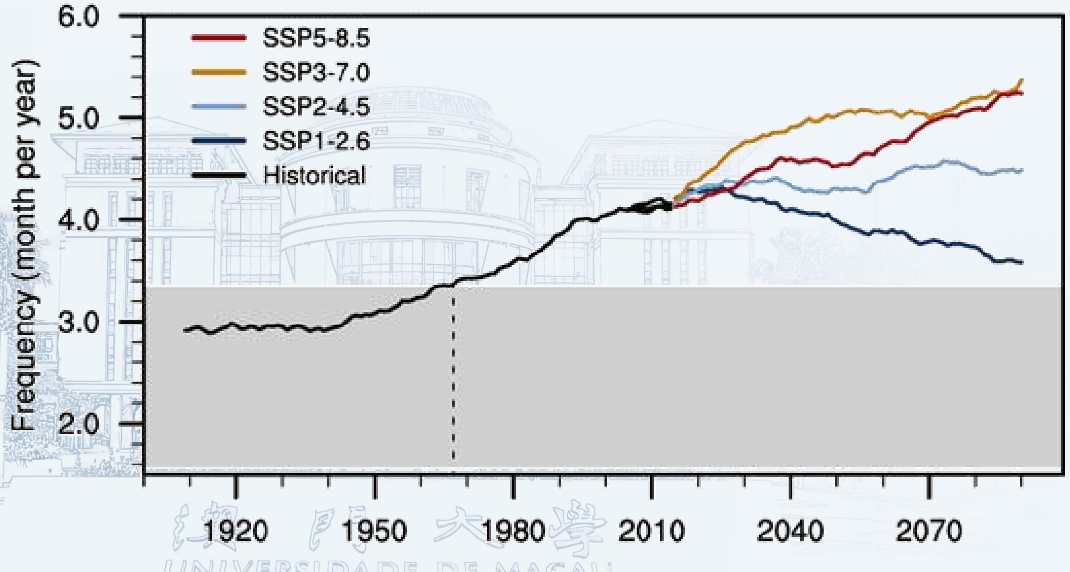
- The late 16th and early 17th century experienced climate instability and the collapse of the Ming Dynasty in China under a period of drought.

Buckley et al. (2014). Quaternary Science Reviews

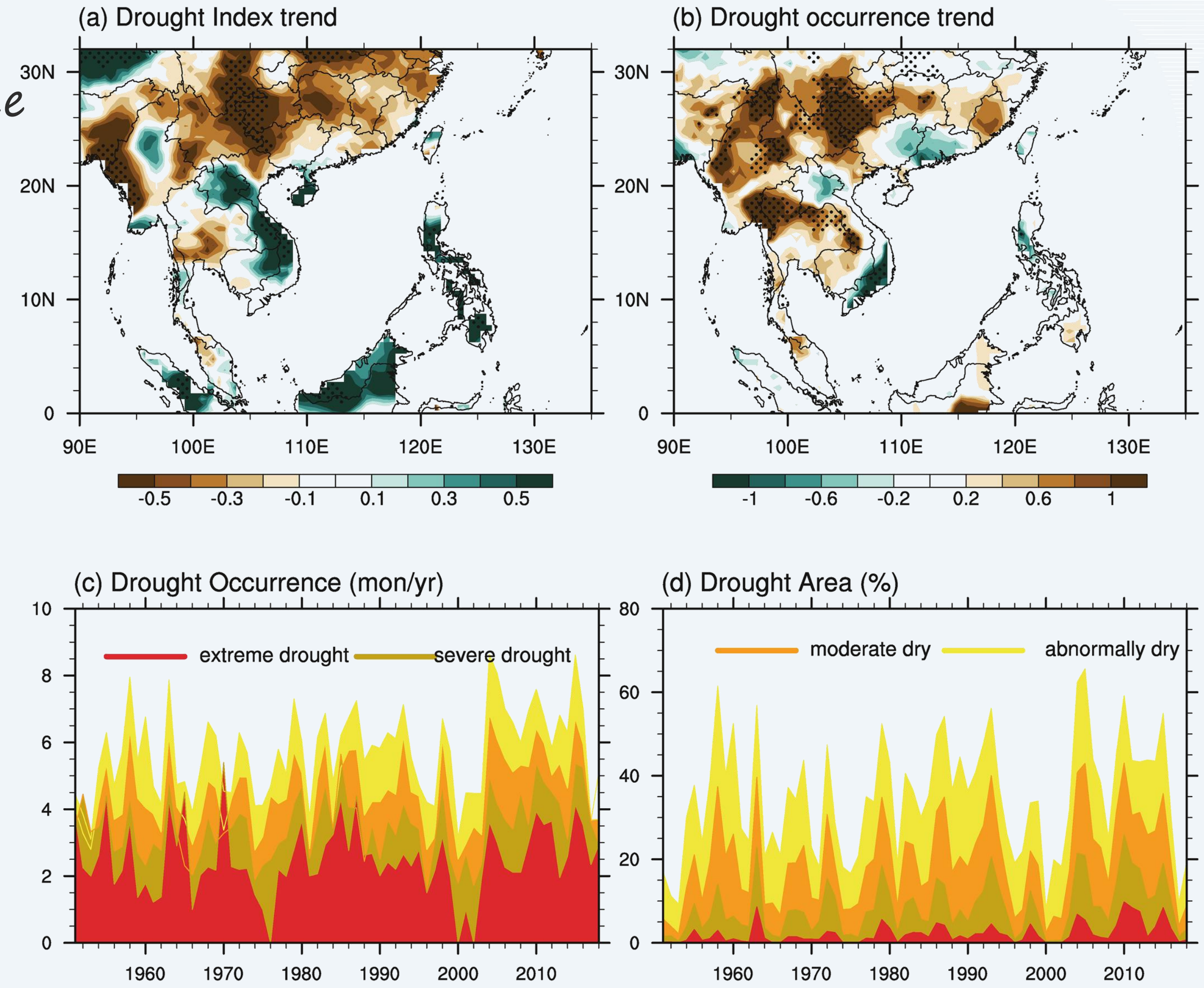


Wind climatology (vectors) at ~ 1500 m altitude

- *Drought occurrence and affected area over Southeast Asian region has been increasing since 1951 in the observation, centered:*
  - Southwest China
  - Northern Thailand
  - Myanmar



Zhang, L., et al. (2021). *Geophysical Research Letters*.



Background

Water balance over land

Precipitation **Evapotranspiration** **Runoff** **Storage**

$$P - ET = R + \Delta S$$

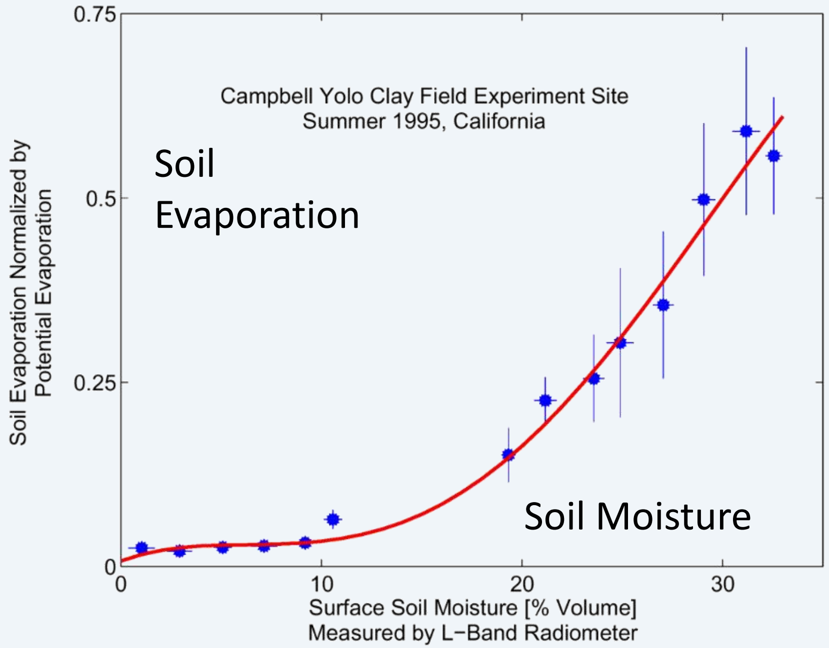
Infiltration

Land-Atmosphere Boundary Condition： Soil moisture

Drought

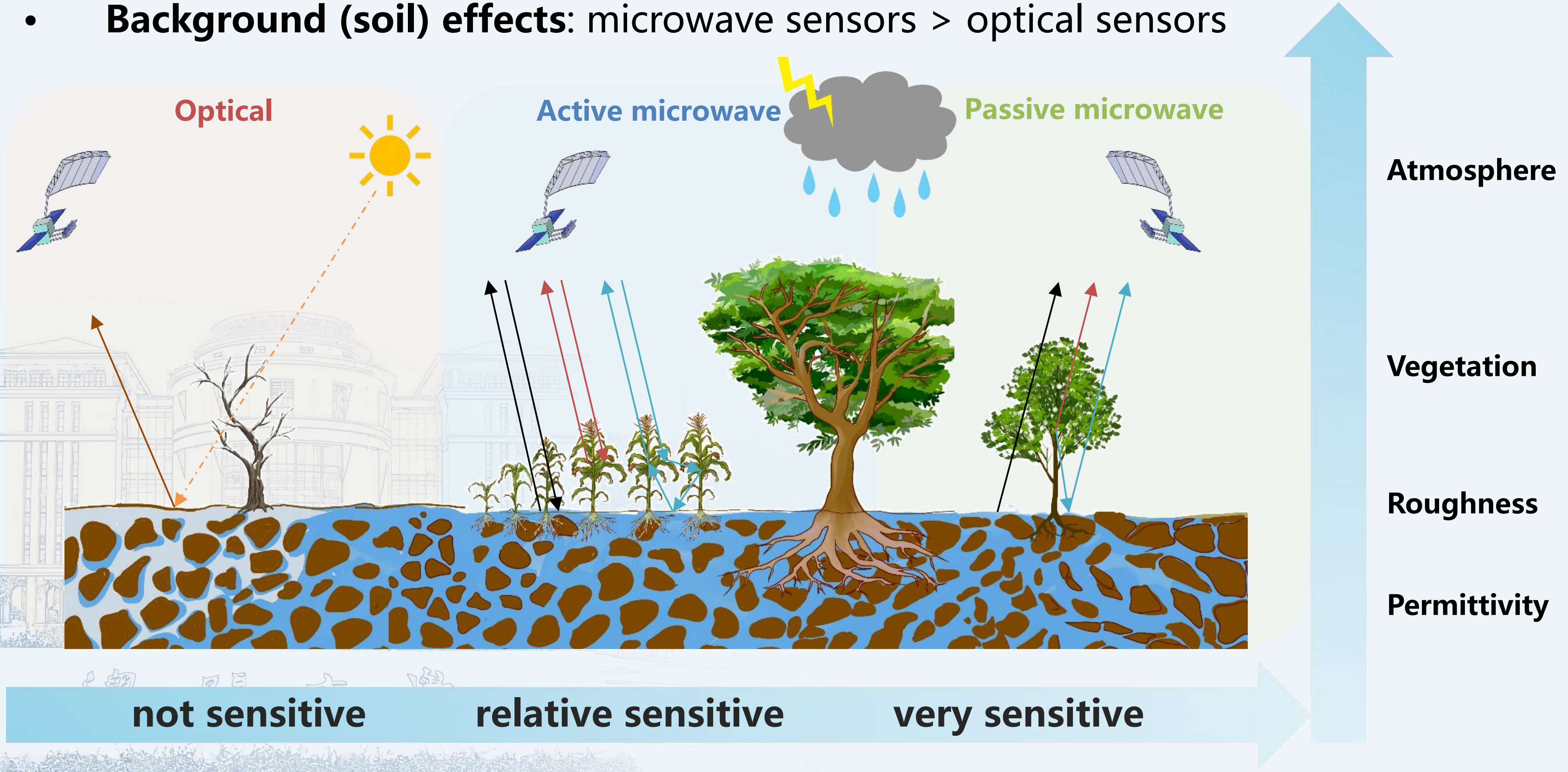
Waterlogging

Soil moisture controls transformation of incident radiation into sensible heat flux and latent heat flux, which directly affects evapotranspiration intensity.

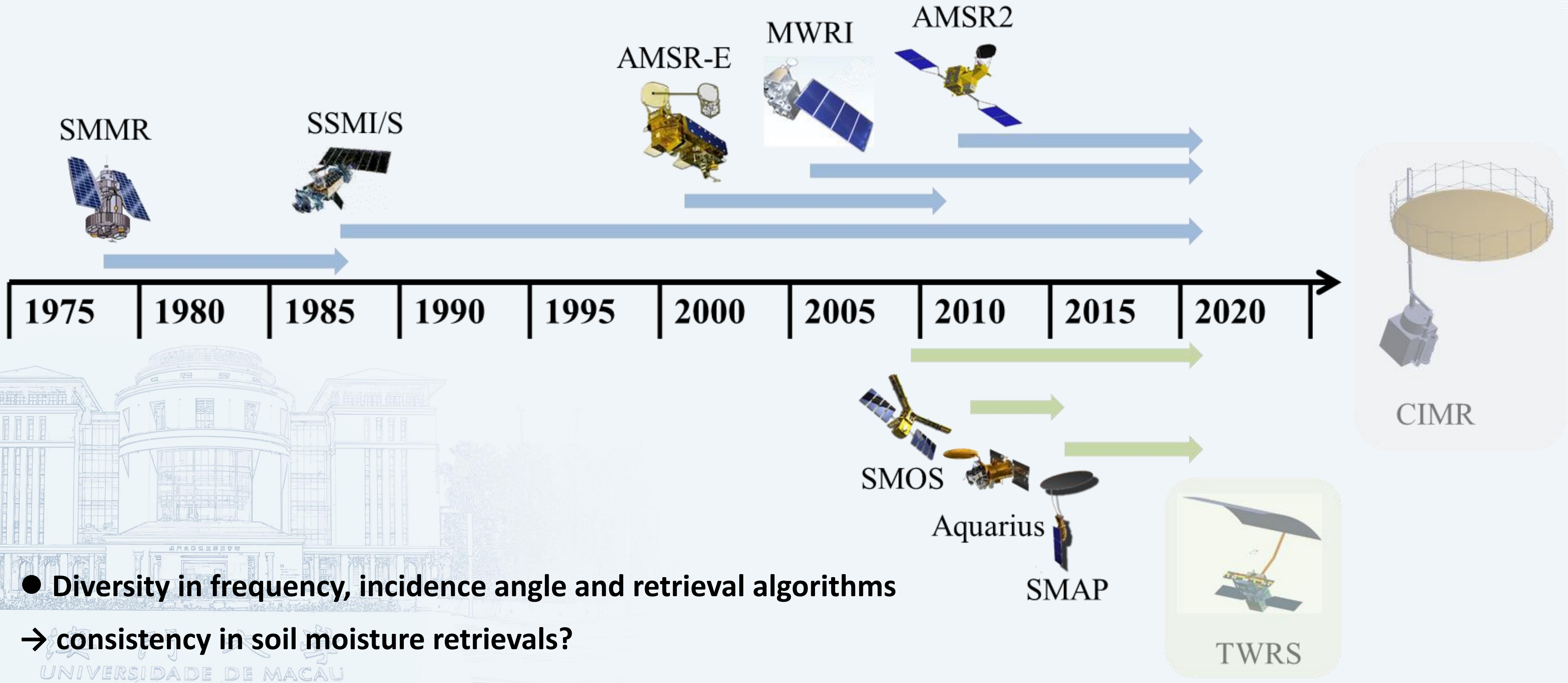


Challenges:

- **Atmospheric effects**: optical sensors > microwave sensors
- **Background (soil) effects**: microwave sensors > optical sensors



- **(Microwave) Remote sensing is a key tool for monitoring large-scale water content in soil and vegetation from space.**



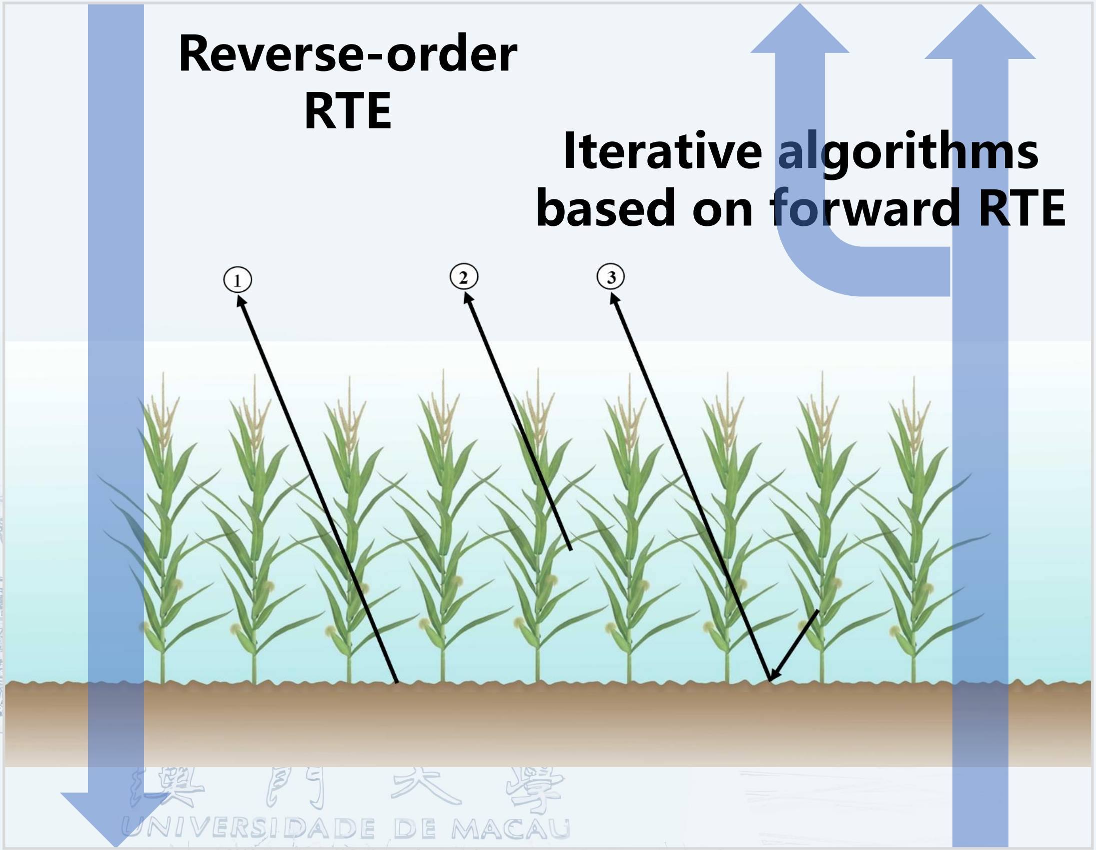
- Diversity in frequency, incidence angle and retrieval algorithms

→ consistency in soil moisture retrievals?

Background

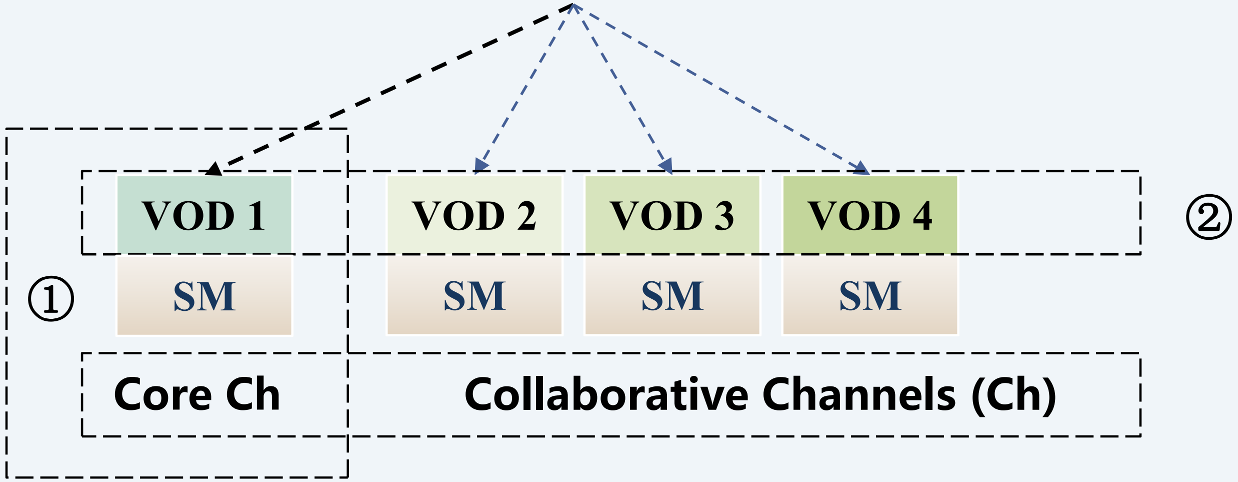
$$TB_p(\theta) = T_s\left(1 - r_p(\theta, \epsilon_r)\right) \cdot e^{-\tau} + T_c\,(1-\omega)(1 - e^{-\tau})\left(1 + r_p(\theta, \epsilon_r) \cdot e^{-\tau}\right)$$

Microwave Remote Sensing of Soil Moisture



- **Contributions from**
  a) Surface emission
  b) Vegetation emission
  c) Surface-vegetation emission

Multi-channel Collaborative Algorithm (MCCA)



Multi-solution issue:

- Current algorithms rely on the use of priori information
    - **SMOS** (Kerr et al., 2012; Wigneron et al., 2021)

$$\min \Phi : \frac{\sum_{i=1}^{N} \left(Tb_{ch(i)}^{estimated} - Tb_{ch(i)}^{total}\right)^2}{\sigma(Tb)^2} + \sum_{i=1}^{2} \frac{\left(P_i^{ini} - P_i^{*}\right)^2}{\sigma(P_i)^2}$$

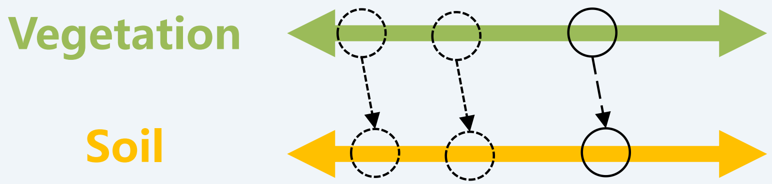
-
    - **SMAP** (Konings et al., 2016; Chaubell et al., 2021)

$$\min \Phi : \left(Tb_V^{estimated} - Tb_V^{total}\right)^2 + \left(Tb_H^{estimated} - Tb_H^{total}\right)^2 + \lambda^2(\tau - \tau^*)^2$$

- **Self-constraint relationship between soil and vegetation parameters is used as constraints**

The reverted omega-tau model at the core channel

$$F_{\omega-\tau}^{-1}: \tau_{ch} = -\log\left(\frac{-b' - \sqrt{b'^2 - 4 \cdot a' \cdot c'}}{2 \cdot a'}\right) \cdot \cos\theta$$

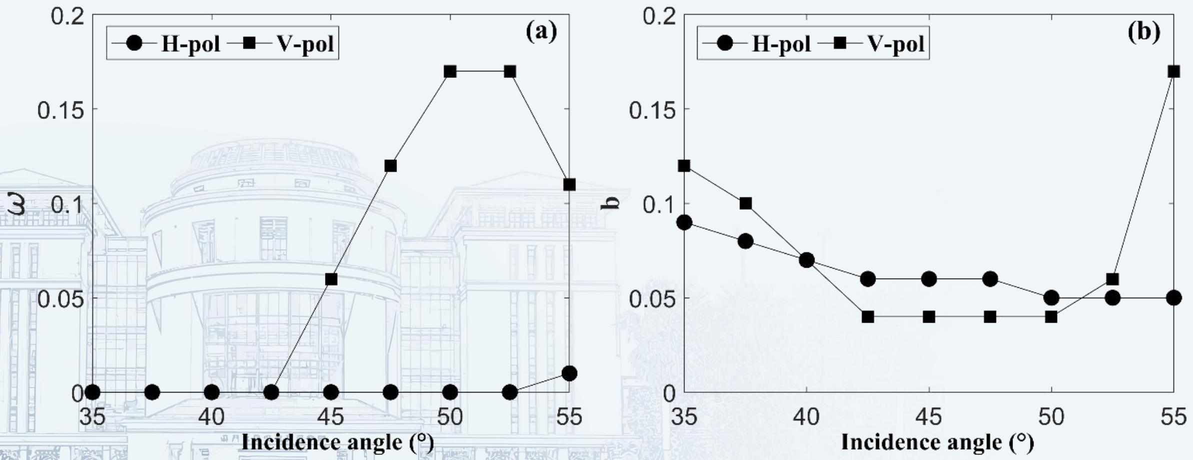


VOD at different channels are retrieved in MCCA

- Vegetation tau (VOD) is function of vegetation water content (VWC), and it is dependent on frequency, polarization and incidence angle

$$\tau^0 = \int_0^h \kappa_e dx = A \cdot f \cdot VWC \cdot \varepsilon'' \Rightarrow \tau_{ch} = \tau_{P,\theta,f} = b \cdot VWC$$

Corn Field



- **Frequency:**

$$b = b' \cdot (\lambda)^x$$

Jackson et al., 1991

- **Polarization and incidence angle**

$$\tau_{P,\theta} = \tau^0 \cdot (\cos^2\theta + C_P \cdot \sin^2\theta)$$

Wigneron et al., 1995

- VOD at any two channels (ch: polarization, incidence angle and frequency):

$$F_{asm}: \frac{\tau_{ch(1)}}{\tau_{ch(2)}} = \left(\frac{f_1}{f_2}\right)^{C_f} \cdot \frac{\sin^2\theta_1 \cdot C_{P_1} + \cos^2\theta_1}{\sin^2\theta_2 \cdot C_{P_2} + \cos^2\theta_2}$$

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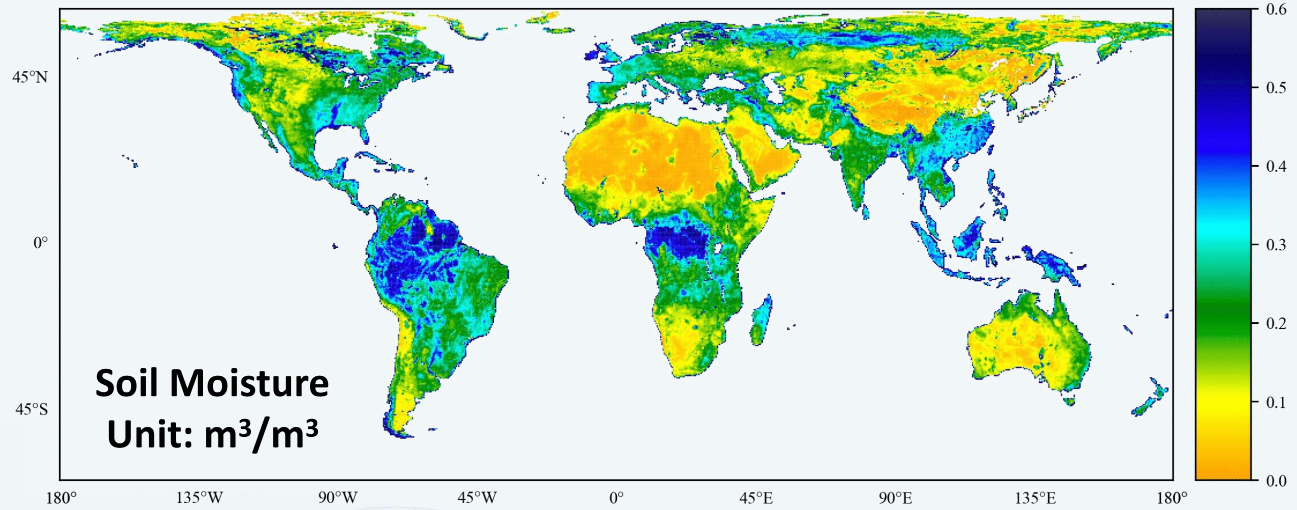
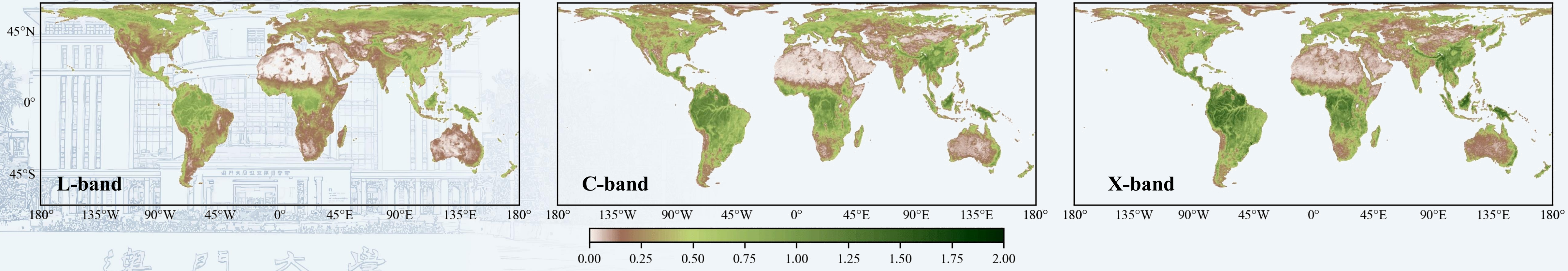


TPDC国家青藏高原科学数据中心

多通道协同反演算法

Multi-channel collaborative algorithm (MCCA)

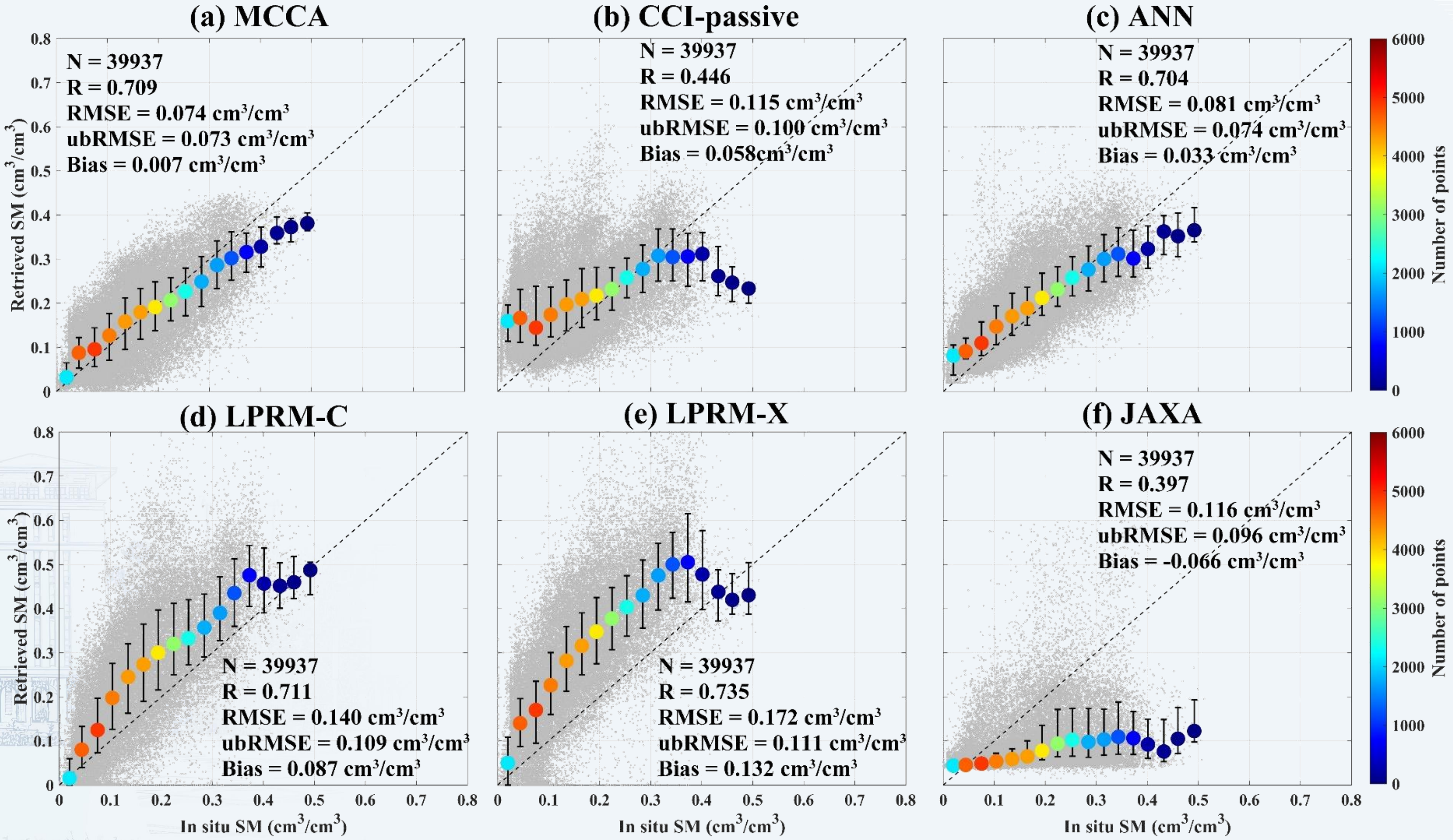
DOI:
10.11888/Terre.tpdc.272088



Vegetation optical depth (VOD)

Surveying Soil from the Sky

- In comparison with other SM products over 25 dense SM networks, MCCA achieved the best scores in terms of unbiased root mean square error and bias.



Surveying Soil from the Sky

Earth observation provides a unique tool for surveying soil moisture from the sky and offers a basis for drought and waterlogging monitoring.

SPI is a drought index based on the probability distribution of precipitation :

transform accumulated **precipitation** to a standard normal distribution, with a standard deviation of 1 and mean of 0 .

- ☐ **Twelve-month are used to assess decadal variability;**
- ☐ **3/6-month are used for multiyear drought assessment;**
- ☐ **1-month are used for short dry-wet condition monitoring**

The soil moisture was used to fit the Beta distribution in a 180-day window:

$$f(SM;\alpha,\beta)=\frac{(SM-a)^{(\alpha-1)}(b-SM)^{\beta-1}}{B(\alpha,\beta)(b-a)^{\alpha+\beta-1}}$$

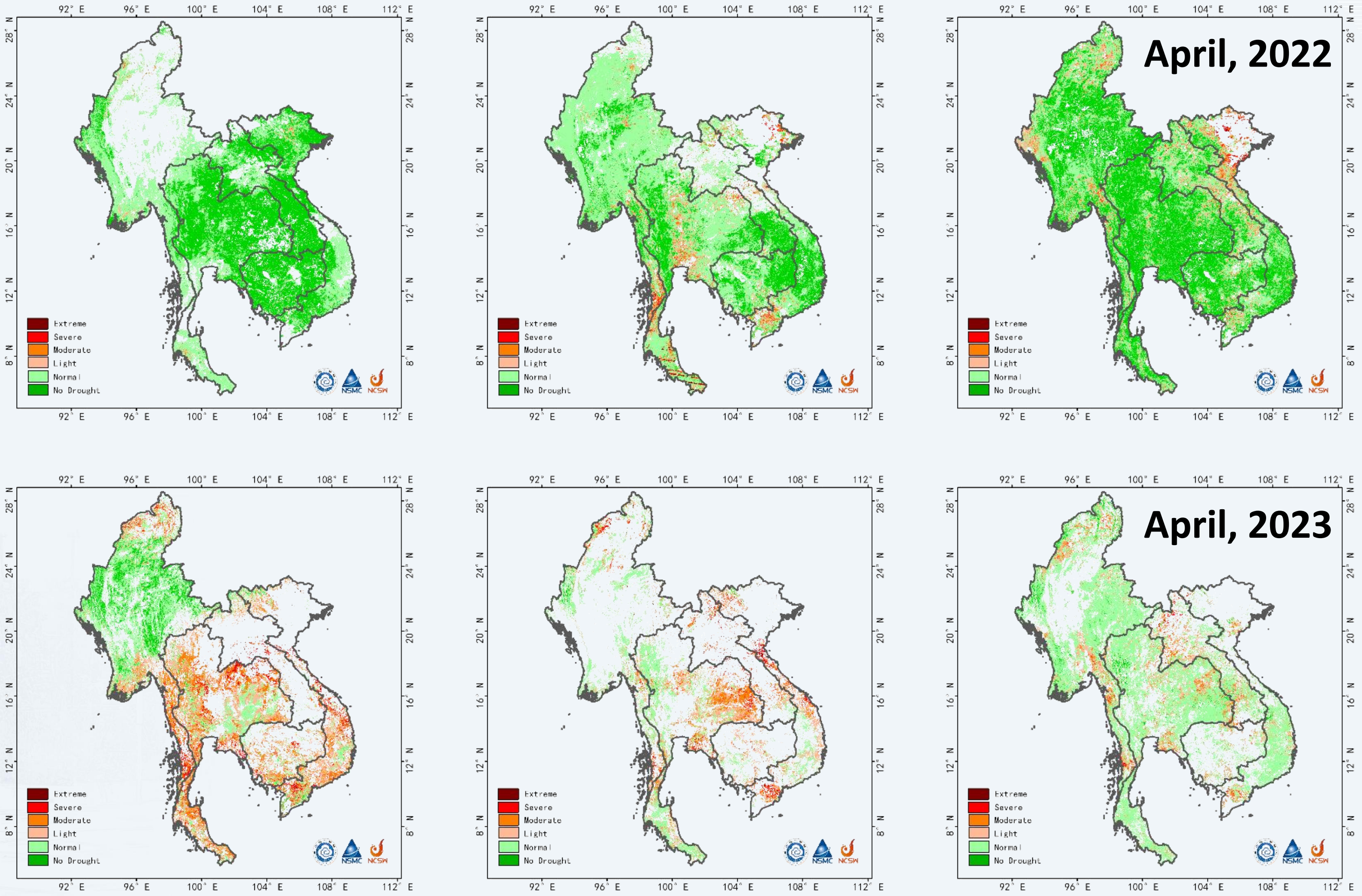
- ☐ **The 180-day window can capture seasonality;**
- ☐ **The shape parameters varying with seasons and soil moisture;**
- ☐ **Sensitively monitor short-term changes in soil moisture**

Category	SPI Input	SPI Ranges	SED Input	SED Percentile
Abnormally Dry	Precipitation	-0.5 ~ -0.7	Soil Moisture	30%
Moderate Drought	SPI Distribution	-0.8 ~ -1.2	SED Distribution	21%
Severe Drought	Gamma	-1.3 ~ -1.5	Beta	11%
Extreme Drought	SPI Temporal Resolution	-1.6 ~ -1.9	SED Temporal Resolution	6%
Exceptional Drought	Monthly	~ -0.2	8-day	3%

Li, Y., Lu, H., et al. (2022). IEEE J-STARS

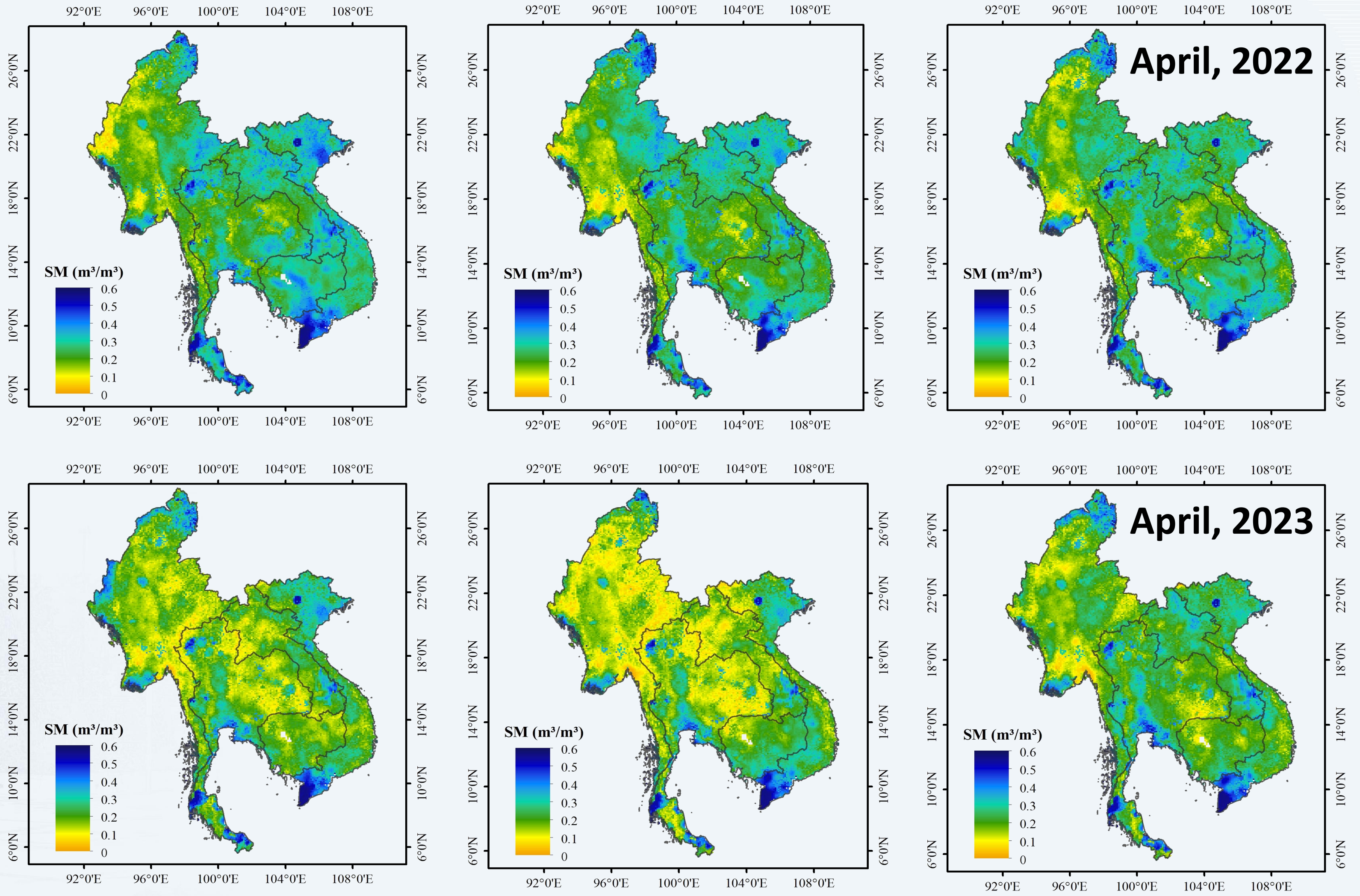
Drought Category from SPI

- There are no obvious droughts in the year of 2022.
- In 2023, the drought has detected, with a **wide-spread area**, **higher levels of drought severity**, and **longer duration.**
- The most severe drought in April 2023 took place during **the first ten days**, impacting all five countries in the region. Subsequently, **the situation gradually improved and stabilized.**



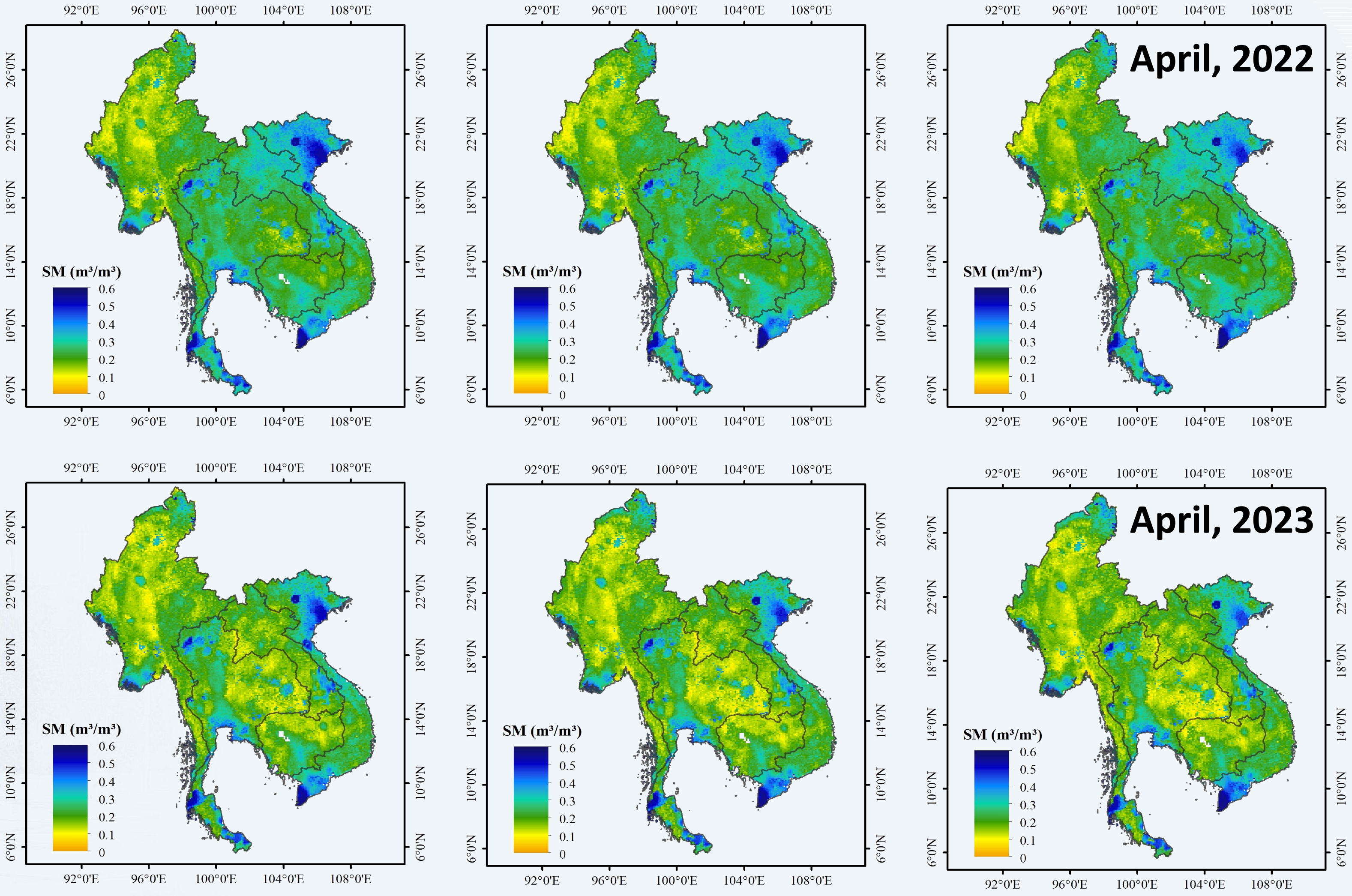
Surface soil moisture

- In 2022, the **temporal variation** of surface soil moisture was **minimal**.
- Soil moisture in 2023 exhibited a pronounced **overall decreased values compared to 2022**.
- The most severe decline in surface soil moisture occurred in **mid-April** 2023, with nearly all of **Myanmar**, **Thailand**, and **Laos** experiencing levels as low as 0.1.



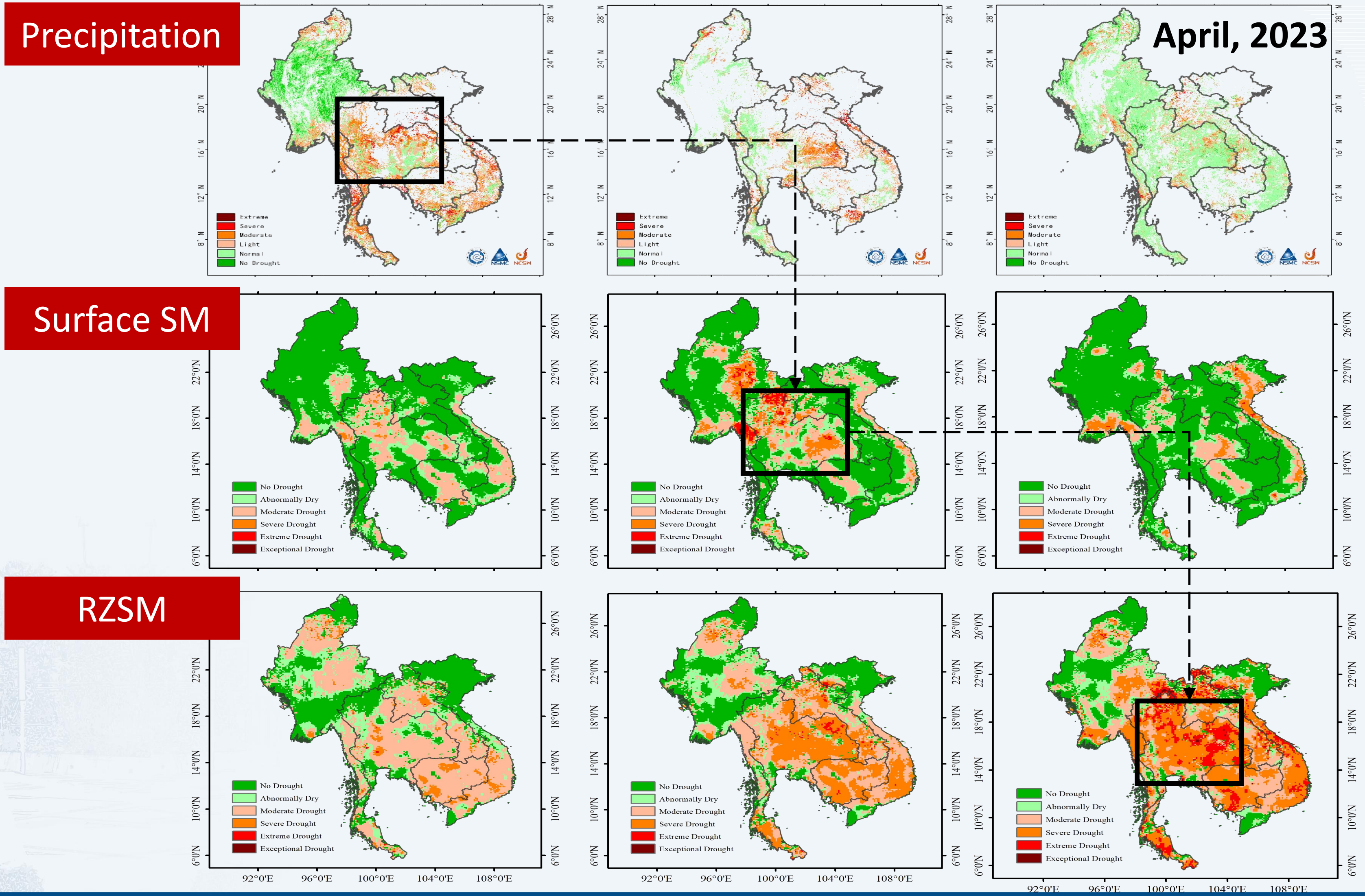
Root-Zone soil moisture

- The spatial distribution of **RZSM** closely **resembles** that of the **surface layer**, with even **weaker temporal** variation.
- While the changes in **RZSM** are relatively **slow during April**, notable differences are **observed between years**.
- In 2023, the **RZSM** is **significantly drier** compared to 2022, particularly in **Thailand**, **Cambodia**, and **Laos**.



Drought category

- Different drought categories exhibit a time lag.
- SPI detects early signs of drought, followed by surface drought caused by insufficient precipitation.
- he root zone then supplies moisture to the surface, with its drought condition experiencing a larger lag relative to precipitation.



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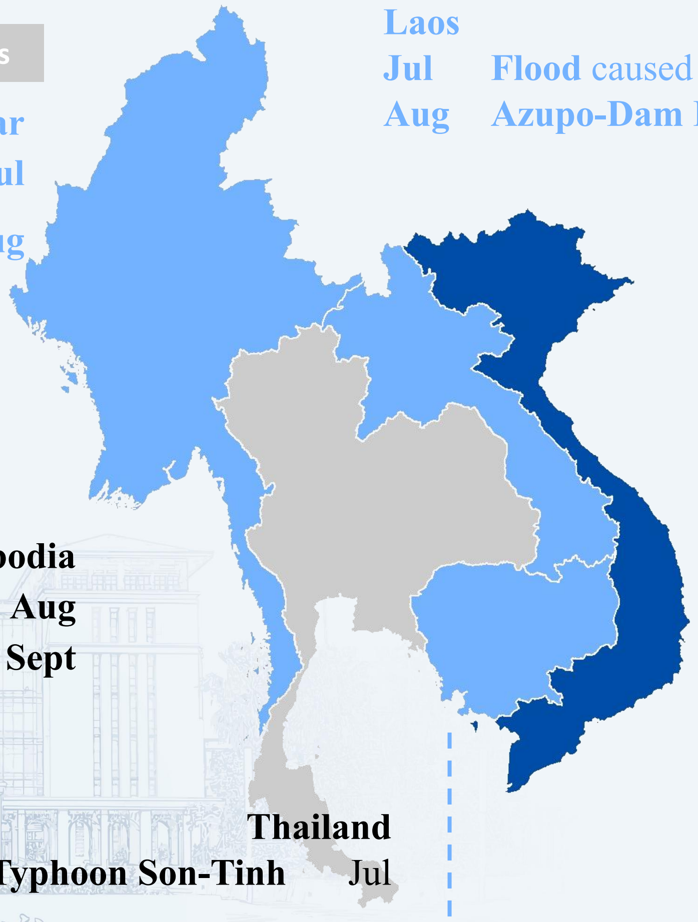
Application in Agricultural Drought

Application in Soil Waterlogging

Disasters

More			Less



Laos

Jul	**Flood** caused by **Rainstorm**
Aug	**Azupo-Dam Break**

Myanmar

Rainstorm	**Jul**
Dam Break and **Flood** caused by **Rainstorm**	**Aug**

Cambodia

Flood caused by **Rainstorm**	**Aug**
Flood caused by **Rainstorm**	**Sept**

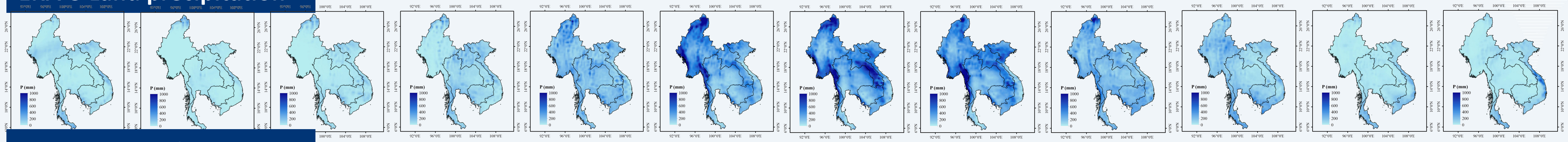
Thailand

Typhoon Son-Tinh	Jul

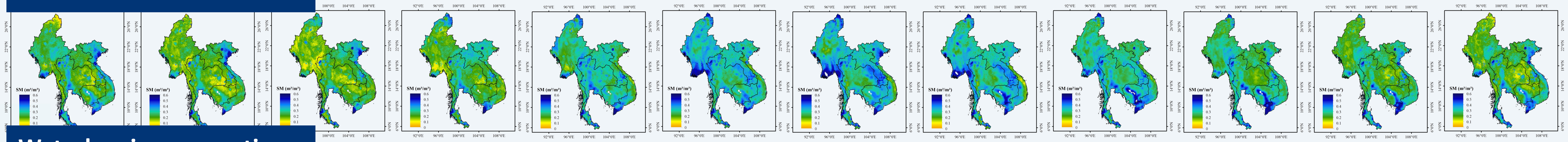
Vietnam

Jun	**Flood** and **Debris Flow** in the **North** caused by **Rainstorm**
Jul	**Typhoon Son-Tinh**
Aug	**Flood** and **Debris Flow** in the **North Center** caused by **Rainstorm**
Sept	**Flood** and **Debris Flow** in the **North Center** caused by **Rainstorm**
Nov	**Debris Flow** in **Nha Trang** caused by **Rainstorm**

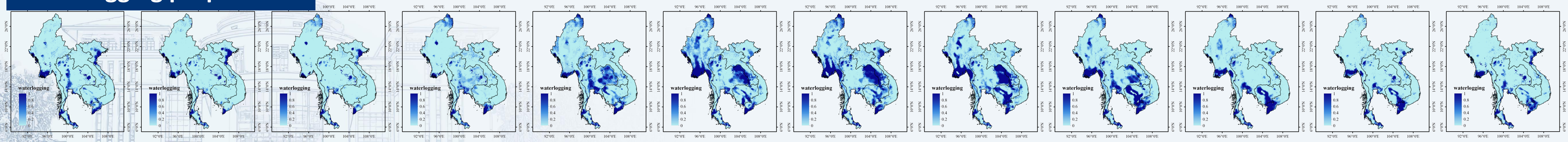
ERA-5 Land precipitation



MCCA-SMAP 9km SM



Waterlogging proportions



- May to September marks the rainy season, during which the MCCA SMAP soil moisture product effectively captures the fluctuations in soil moisture. Consequently, the proportion of waterlogging derived from these calculations becomes more prominent during this period.
- The southern regions of Vietnam, particularly Cà Mau province, and Myanmar's Ayeyarwady Region are known for rice cultivation. As a result, these areas experience high levels of soil moisture and waterlogging proportions.

Application in Soil Waterlogging

Laos

Jul **Flood** caused by **Rainstorm**

Aug **Azupo-Dam Break**

Myanmar

Jul **Flood caused by Rainstorm**

Aug **Dam Break** and **Flood** caused by **Rainstorm**

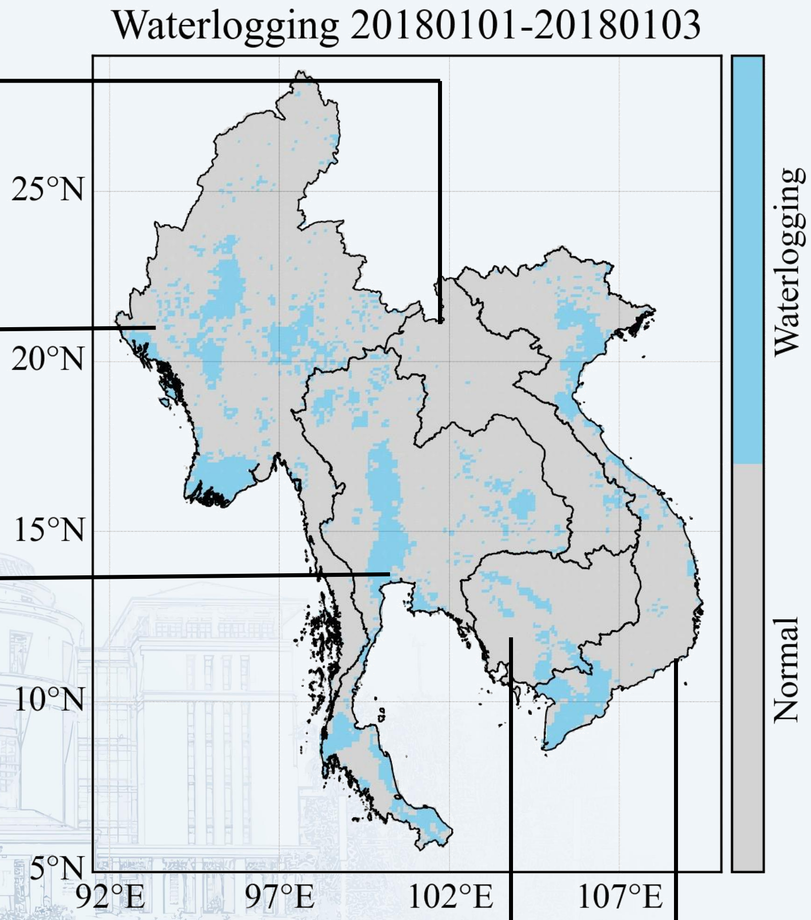
Thailand

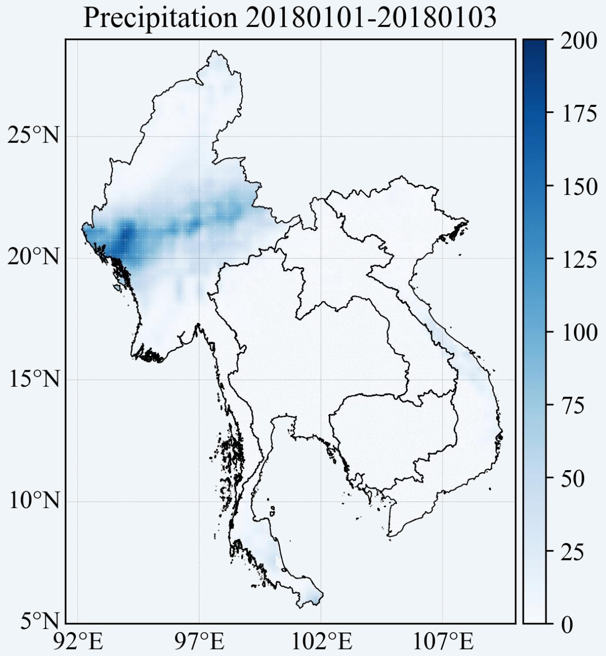
Jul **Typhoon Son-Tinh**

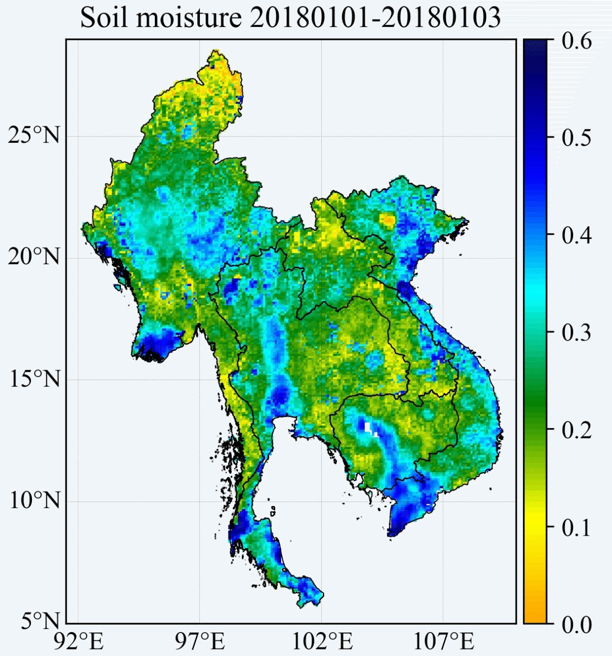
Cambodia

Aug **Flood caused by Rainstorm**

Sept **Flood caused by Rainstorm**







Vietnam

Jun **Flood** and **Debris Flow** in the **North** caused by **Rainstorm**

Jul **Typhoon Son-Tinh**

Aug **Flood** and **Debris Flow** in the **North Center** caused by **Rainstorm**

Sept **Flood** and **Debris Flow** in the **North Center** caused by **Rainstorm**

Nov **Debris Flow** in **Nha Trang** caused by **Rainstorm**

Application in Soil Waterlogging

- A new algorithm, named multi-channel collaborative algorithm is developed for generating long-term soil moisture datasets.
- The MCCA enables simultaneous retrieval of soil moisture and vegetation optical depth across microwave frequencies.
- The soil moisture-based index, named SED, can capture flash drought events in the Mainland Southeast Asia.
- By integration use of soil water holding capacity, the soil waterlogging events can be reflected by using soil moisture from Earth observation.

Summary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6th Asia- Oceania Group on Earth Observations (AOGEO) Workshop
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