Global Retrievals of Daily Evapotranspiration Under All Sky Using Passive Microwave Measurements From FengYun Satellites of China

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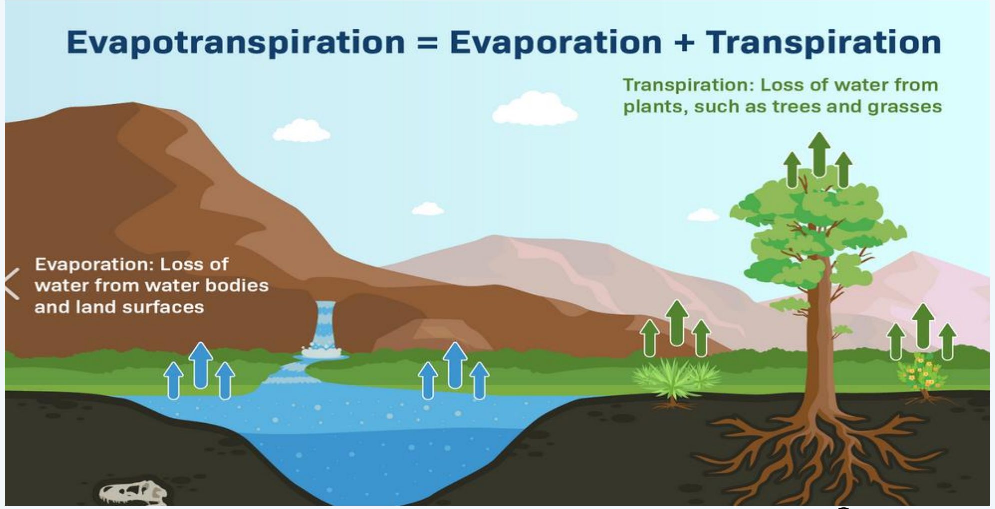
Outline

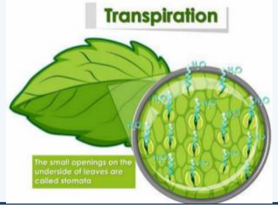
Motivation

A fundamental process of water-energy cycles in land-atmosphere systems

- **Evapotranspiration (ET)**： the water loss from the land surface to the atmosphere via evaporation and transpiration



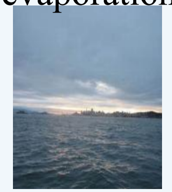
Transpiration

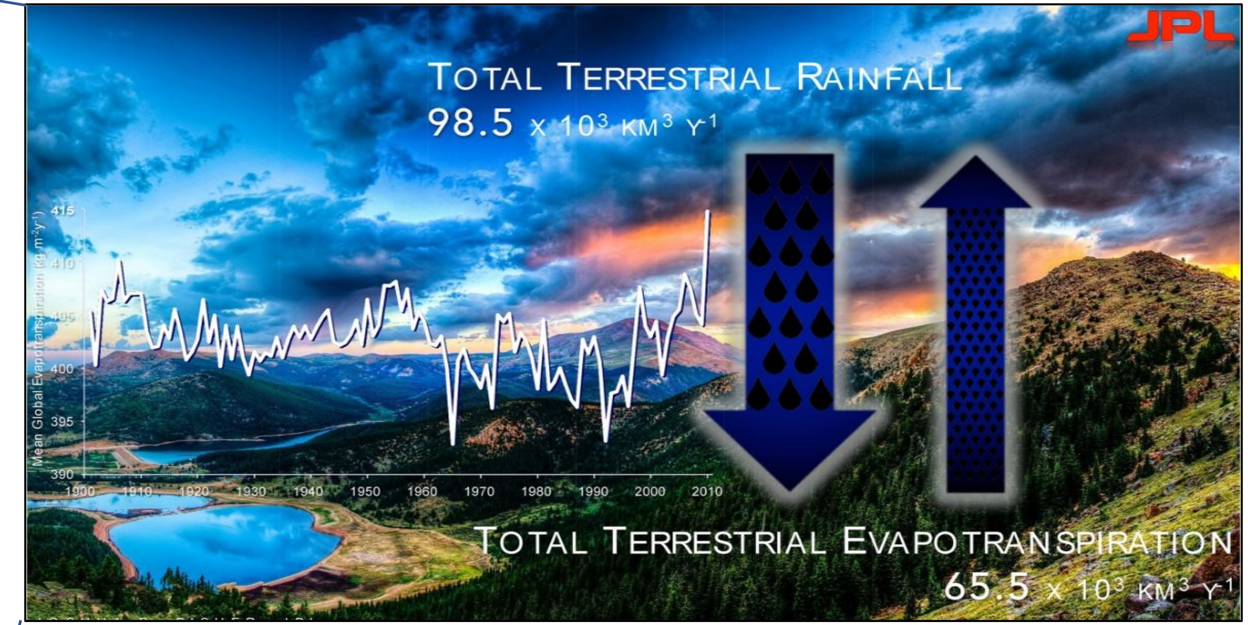


Soil evaporation

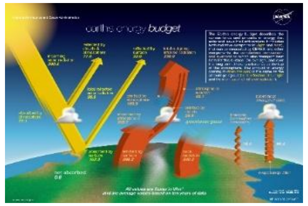
Canopy evaporation

Open water evaporation





Energy balance



Cloud/precipitation formation

Drought evaluation

Ecosystem water use

- **ET returns more than 60% of land surface precipitation and approximately 50% of net radiation energy to the atmosphere.**

Trenberth et al.(2009); Fisher et al.,(2017).,Wang and Dickinson (2012)

Tools for measuring ET between land and atmosphere:

➢ In-situ measurements:

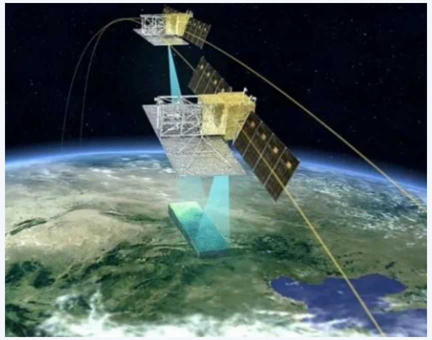
- sap flow (plant scale)

- Lysimeter (field scale)

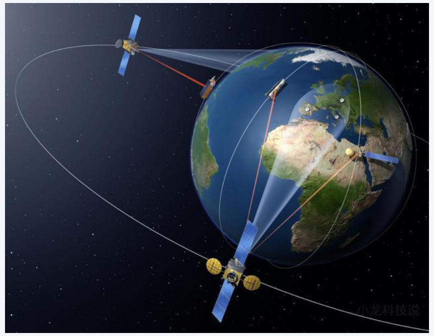
- eddy covariance flux tower (ecosystem scale)

High temporal intervals, accurate, local

➢ Satellite remote sensing:

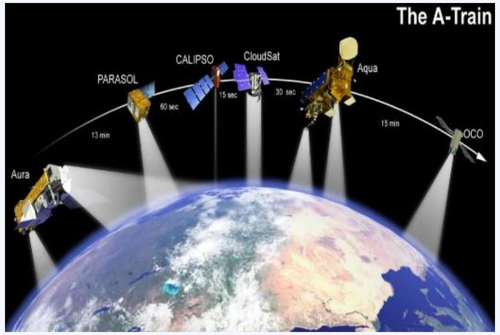


Fengyun-3 polar-orbiting satellites

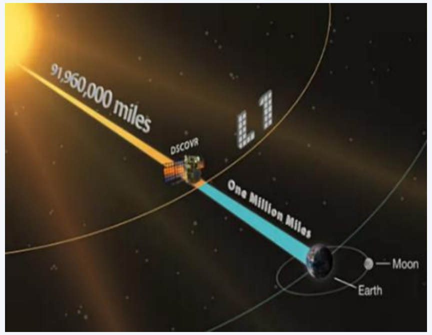


Fengyun-4 geostationary satellites

GOES satellites



A-Train satellites



DSCOVR EPIC

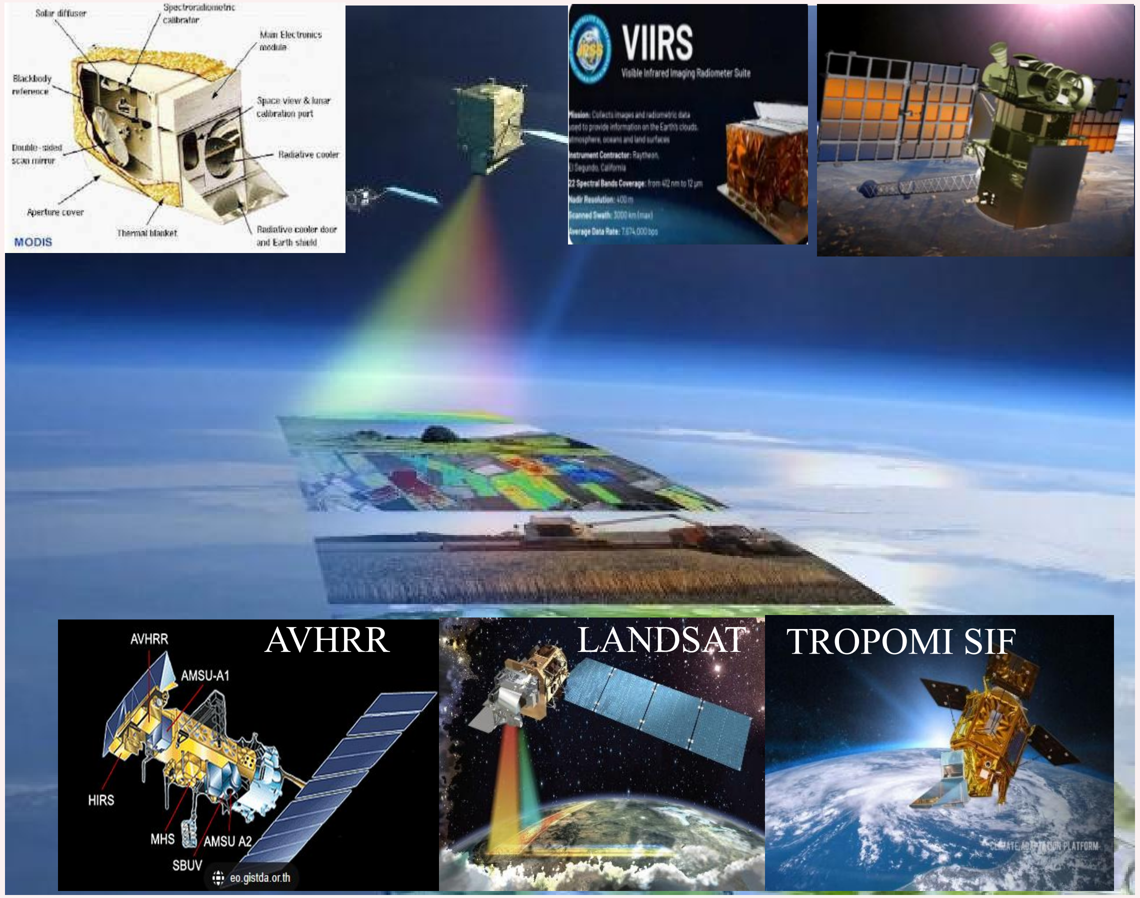
Regional and global scales

Motivation

Satellite passive remote sensing of vegetation for retrieving ET

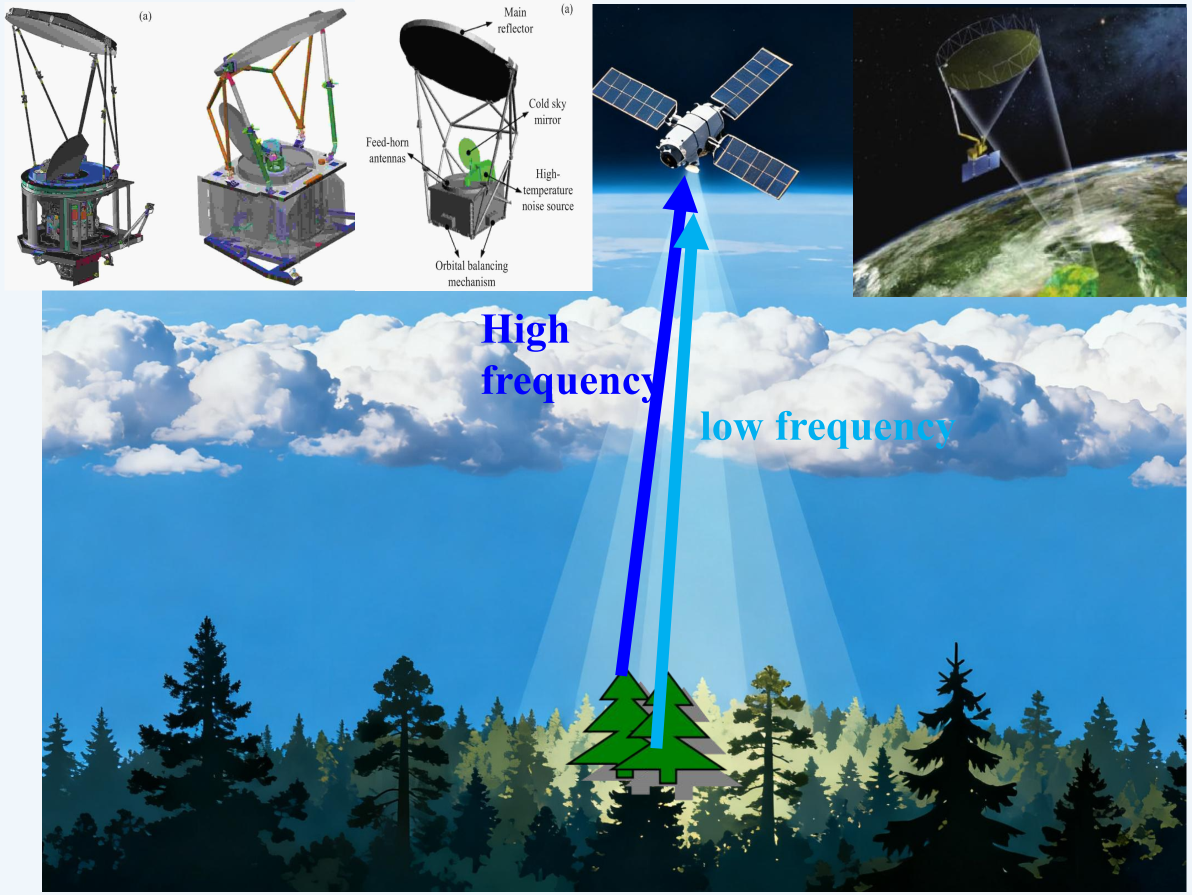
Optical sensors（for clear sky）

Aqua MODIS　　VIIRS　　DSCOVR EPIC



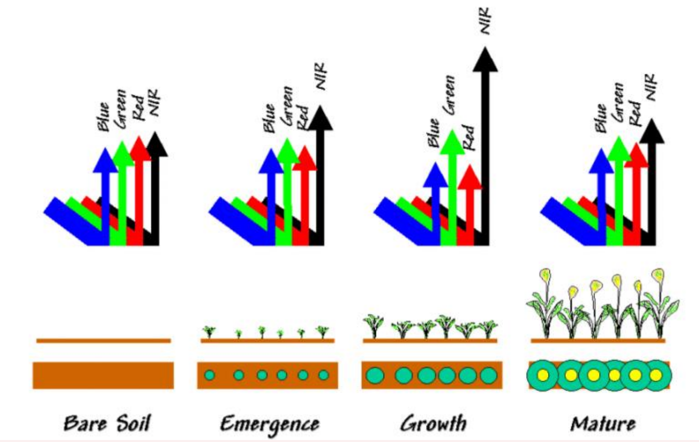
Passive microwave sensors（for clear and cloudy sky）

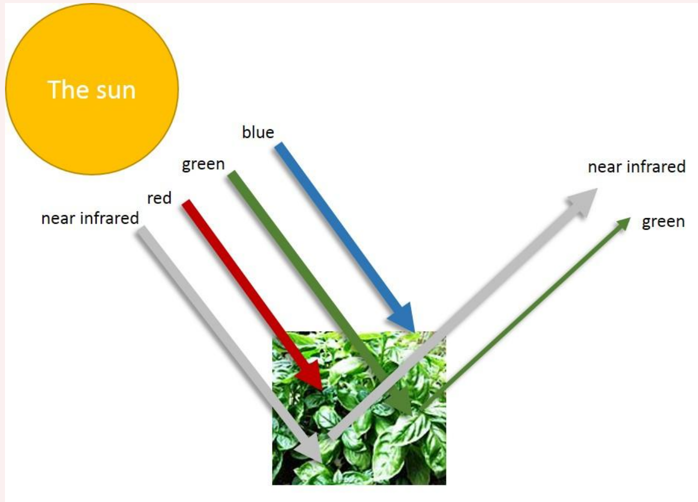
GPM-GMI　　FY-MWRI　　AMSR2　　SMAP



Satellite passive remote sensing of vegetation for retrieving ET

Optical measurements（for clear sky）





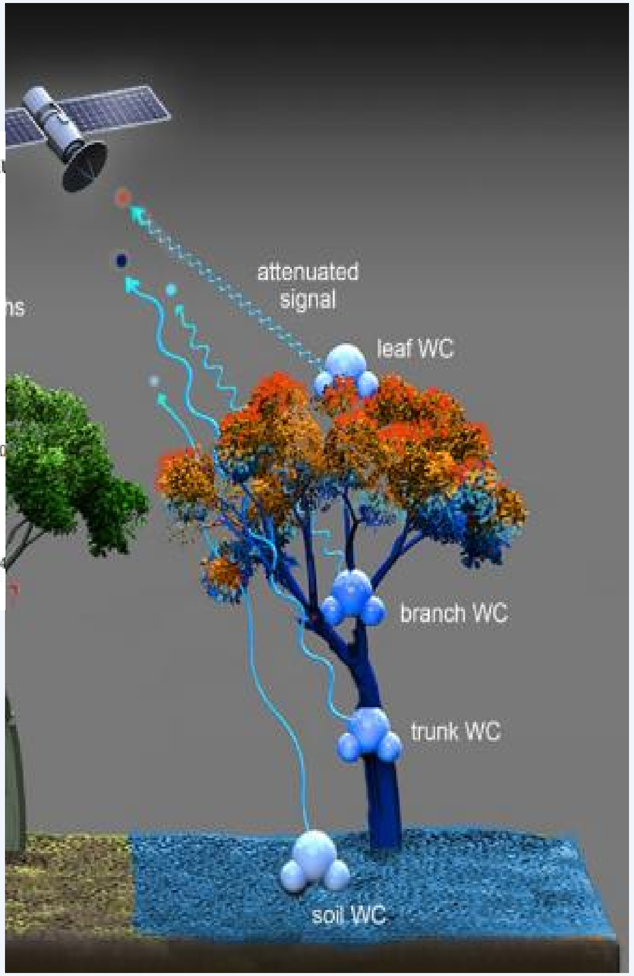
Optical vegetation index

SR	Jordan,(1969)[24]
MSI	Hunt and Rock,(1989) [34]
WI	Penuelas et al.(1993)[10]
SRWI	Zarco-Tejada et al.(2003)[35]
NDVI	Huete et al. (2002)[22]
EVI	Huete et al. (2002)[22]
SAVI	Huete (1988)[23]
NDII	Hardinsky et al.(1983)[36]
NDWI	Gao et al. (1996)[26]

Passive microwave measurements（for clear and cloudy sky）

Microwave vegetation index

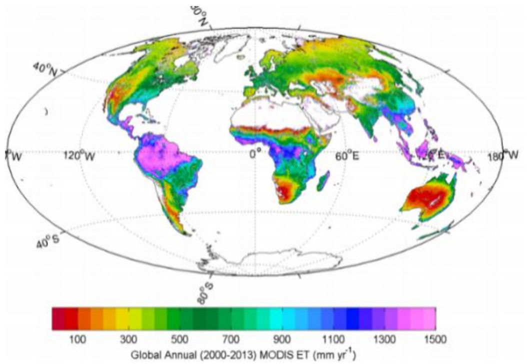
MPDI	Normalized microwave polarization difference index	Becker & Choudhu (1988)[37]
EDVI	Microwave emissivity difference vegetation index	Min & Lin (2006a,b) [38, 39]
MVIs	Microwave vegetation indices	Shi et al. (2008) [40
MVWI	microwave vegetation water index (MVWI)	Wang et al(2008)[4



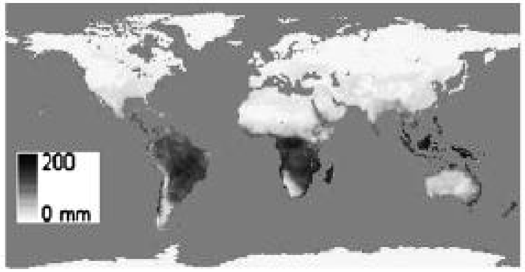
Motivation

Widely-used satellite ET products

MODIS-ET

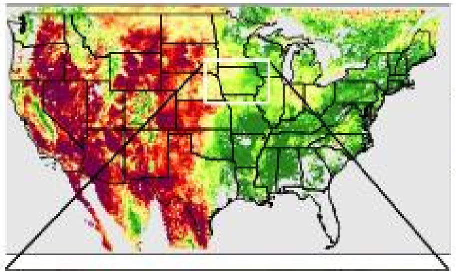


PT-JPL ET



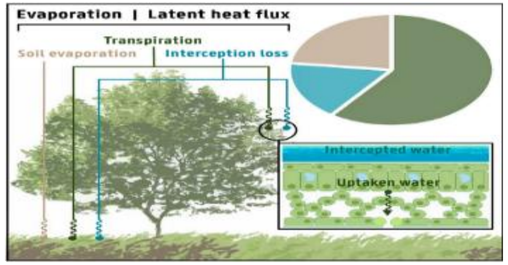
Fisher et al., (2008)

ALEXI ET



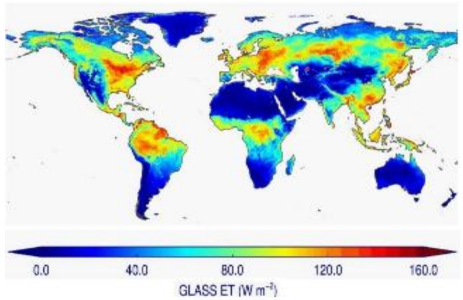
Anderson et al., (2007)

GLEAM-ET



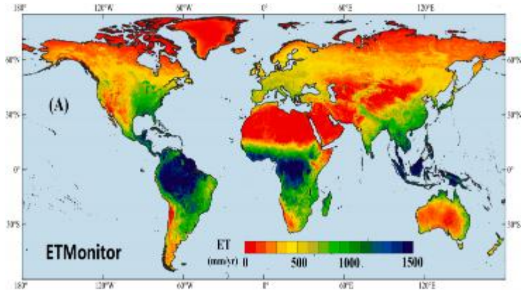
Mirras et al., (2011)

GLASS ET



Yao et al., (2014)

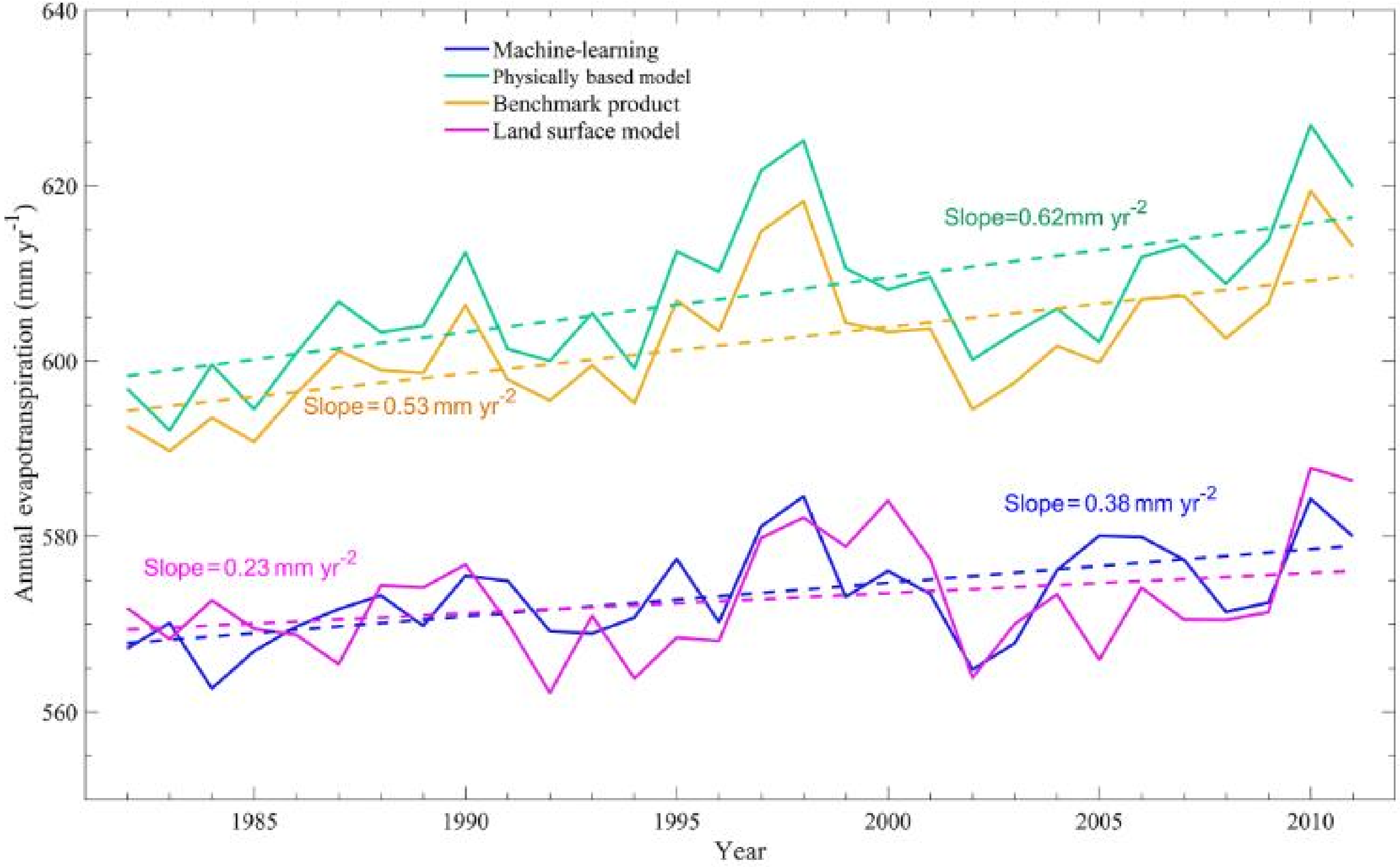
ETMonitor



Zheng et al., (2022)

➢ **Satellite optical products are successful, while microwave-based products are very limited.**

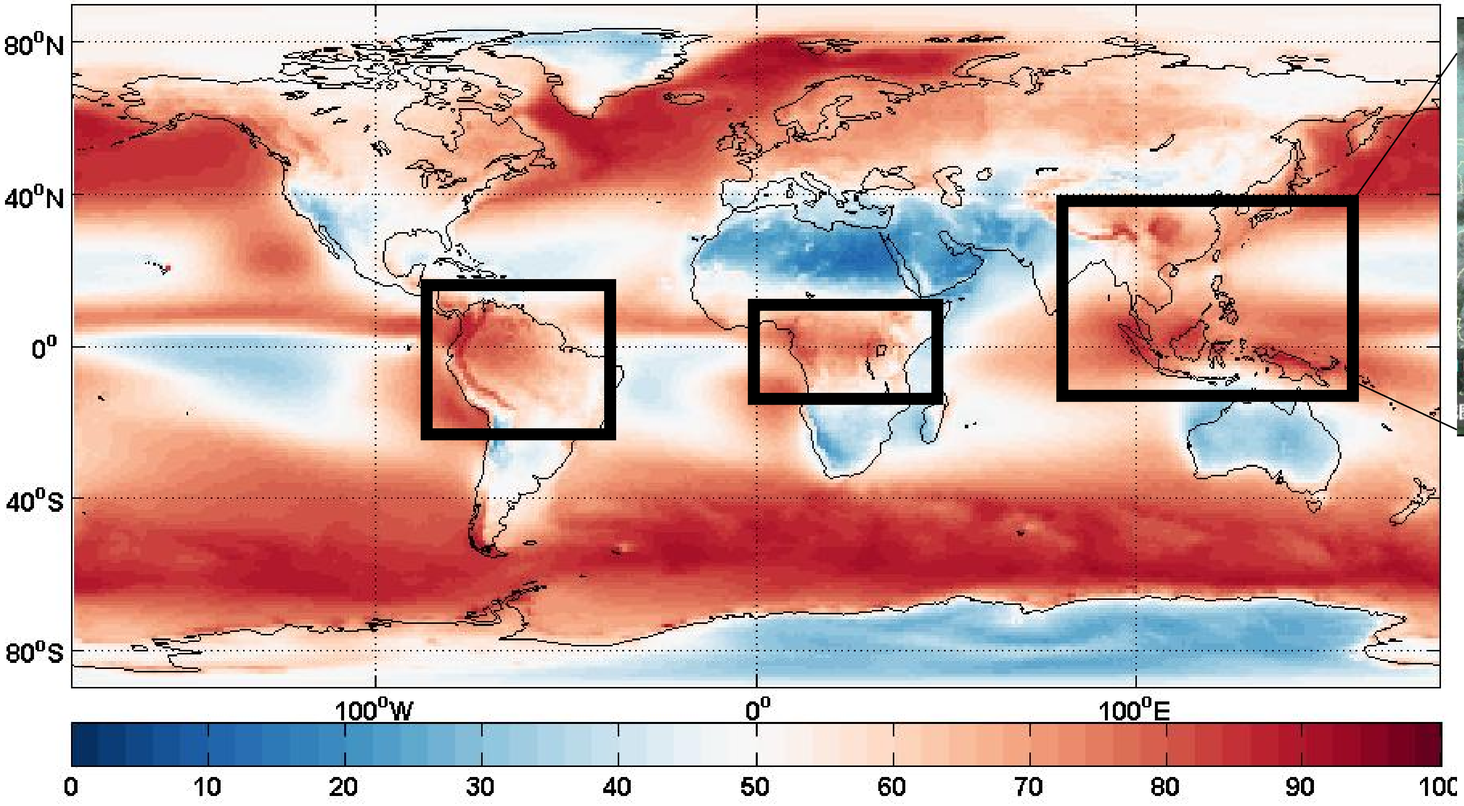
Substantial discrepancies persist in current ET products



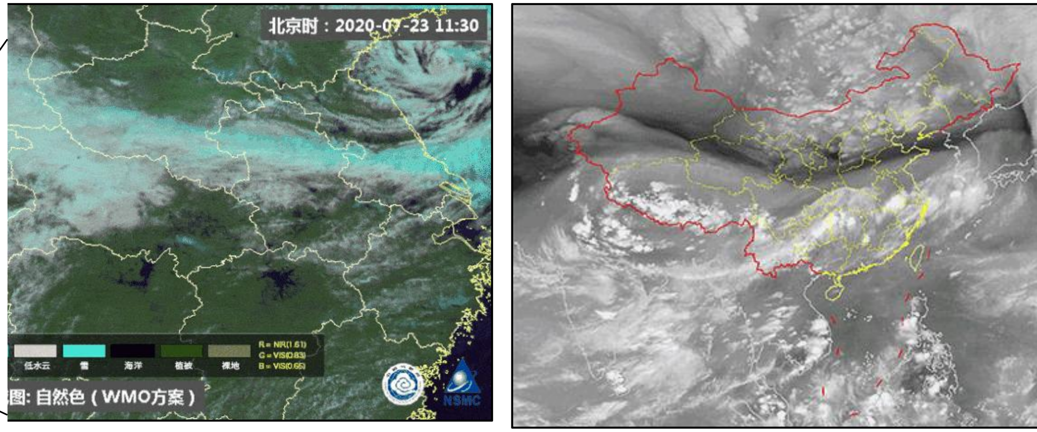
Pan et al., 2022

Cloud cover: A non-negligible uncertainty source in satellite remote sensing of vegetation and water fluxes.

- Clouds cover more than 70% of the Earth's surface
- More than half of all global weather phenomena is related to cloud change on a day.



Fig：Global cloud cover （Karlsson et al., 2018）



Fengyun-4 satellite observations of surface and cloud cover

How to detect the dynamics of vegetation under cloud cover ?

Cloud cover: A non-negligible uncertainty source in satellite remote sensing of vegetation and water fluxes

- Removing cloud contaminations is required for satellite optical measurements.

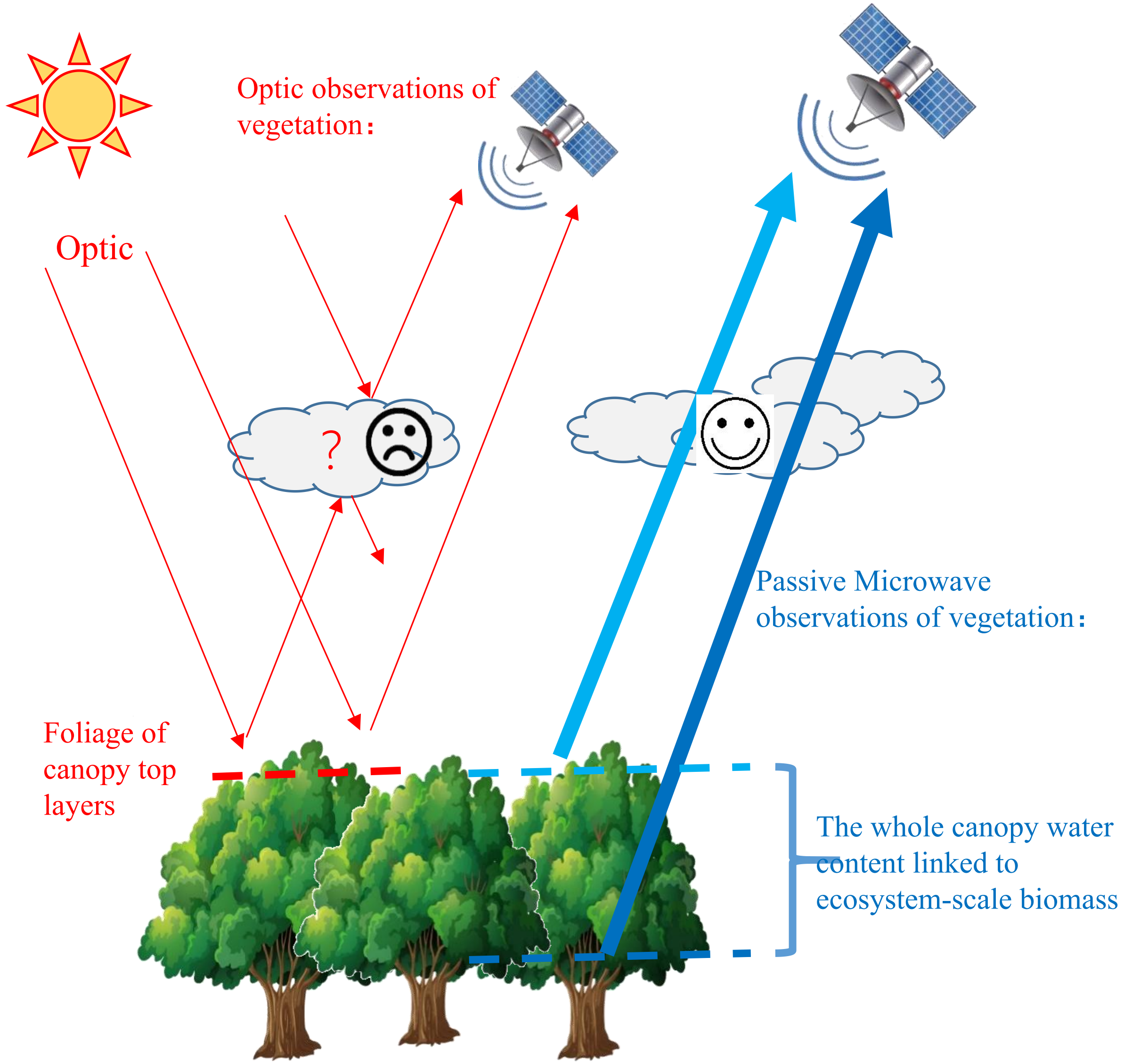
- Optical measurements are suitable for vegetation monitoring under clear and small cloud cover condition，challenging to detect vegetation directly under cloud cover.

- **Roles of temporally and spatially interpolated optical remote sensing in ET and GPP estimation under cloud cover need to be evaluated carefully.**

  - **Extrapolating clear-sky ET retrievals to cloudy-sky conditions may result in overestimation of more than 30%. （Delogu et al., 2012; Shwetha & Kumar, 2020; Jiang et al., 2009）；**

Motivation

Passive microwaves are independent and complementary to optical measurements.



- Directly respond to vegetation water content.
- Hold a potential for being used under cloudy sky.
- Low-frequency microwave observations (e.g., L-band VOD) are primarily employed to study biomass and carbon storage, whereas higher-frequency microwaves (such as X-, C-, Ka-, and Ku-bands) are rarely used for studying vegetation carbon fluxes and lack fundamental parameterization schemes.
- Coarse spatial resolution makes them more suitable for large-scale and global applications.
- Its application in studying land–atmosphere carbon and water fluxes has lagged significantly behind optical remote sensing.

EDVI : a satellite passive microwave vegetation water content index for all-sky

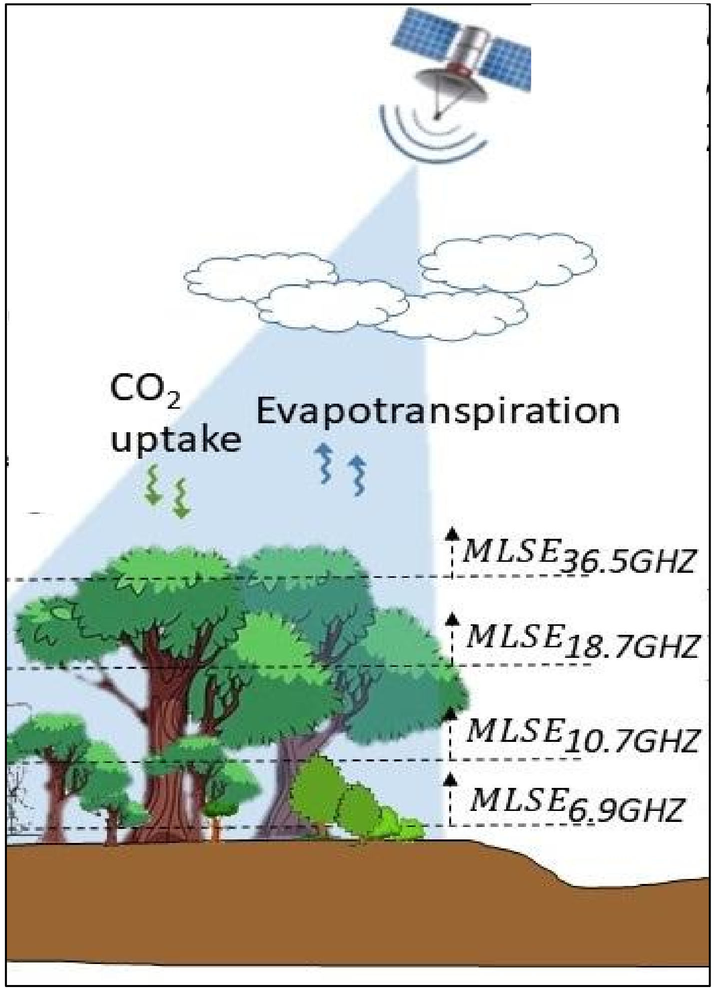
Emissivity Difference Vegetation Index

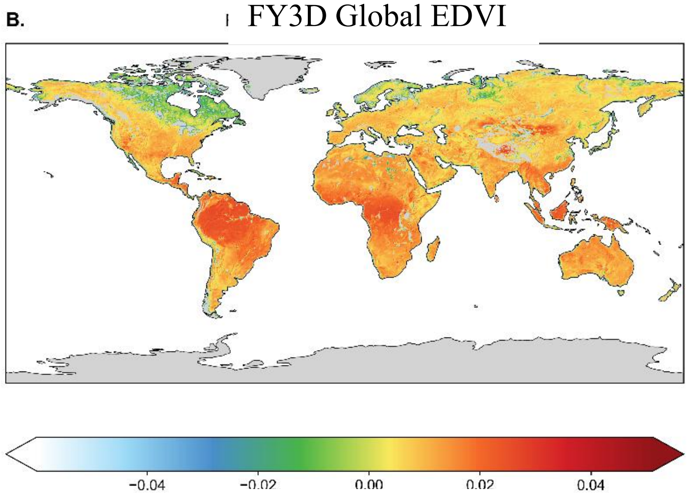
$$EDVI = \frac{MLSE^{low-freq} - MLSE^{high-freq}}{0.5(MLSE^{low-freq} + MLSE^{high-freq})}$$

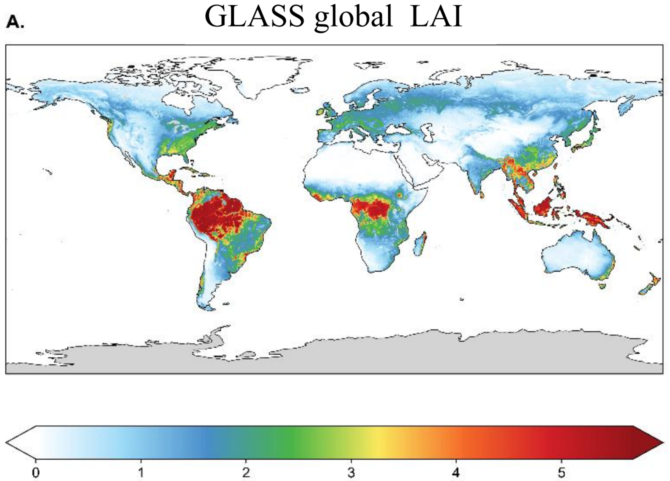
MLSE: passive microwave land surface emissivity

- ✓ Microwave channels: 6.9, 10.7, 18.7, 36.5 GHz
- ✓ Atmospheric effects on surface-upwelling microwaves are corrected via microwave radiative transfer model using atmospheric profiles and cloud parameters。
- ✓ **For all-sky and large-scale monitoring。**
- ✓ **EDVIs defined by MLSEs across different channels have a potential to detect the vertical structure of ecosystem water and carbon fluxes。** $EDVI_{18.7}^{36.5}$ $EDVI_{6.9}^{36.5}$ $EDVI_{10.7}^{36.5}$ $EDVI_{10.7}^{18.7}$
- ✓ EDVI datasets: AMSR-E, GPM-GMI, FY3B and FY3D。

✓ **Chines Fengyun-3B and Fengyun-3D EDVI can monitor global, daily changes in vegetation under both clear and cloudy sky.**







Li et al. AAS, 2022； Hu et al. RS, 2021； Liu et al. JGR-A, 2025； Li et al.. ESS, 2020； Hu et al., JUSTC, 2020

Outline

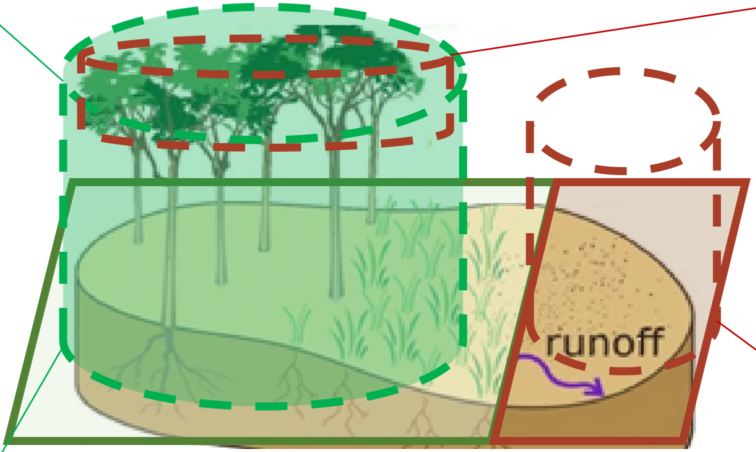
A Multi-source Satellite Microwave–Optical Model for Retrieving Evapotranspiration

Schemes of EDVI-ET model

EDVI-based Penman-Monteith transpiration over vegetated surface

- Canopy Conductance correlated with day-to-day variations in EDVI
- Normolized EDVI for upscaling stomatal-canopy conductance
  - ✓ $ET_{veg} = EF_{veg} \times (Rn - G)_{veg} \times (1 - f_{wet})$
  - ✓ $EF_{veg} = \frac{\alpha\Delta}{\Delta+\gamma(1+r_c/2r_a)}$
  - ✓ $r_c = \left[\frac{1}{r_{cuticle}} + \frac{f_1(Ta)f_2(PAR)f_3(VPD)f_4(\Psi)f_5(CO_2)}{r_{cmin}}\right]^{-1}$
  - ✓ $r_{cmin} = r_{cmin0}/N_{EDVI}$
  - ✓ $F(VPD, \psi, CO_2) = [b - a \times dEDVI)\,]^{-1}$
  - ✓ $dEDVI = EDVI_i - EDVI_{i-1}$

Li et al.,2009RSE



Vegetated surface: f(NDVI)

Non-vegetated surface: 1-f(NDVI)

Evaporation Schemes

- Modified Priestley -Taylor method
  - ✓ $[f_{wet} + (1 - f_{wet}) \times f_{SM}] \times \alpha \frac{\Delta}{\Delta+\gamma} \times A_{soil}$
  - ✓ $f_{wet} = \begin{cases} 0.0 & RH < 70\% \\ RH^4 & RH \geq 70\% \end{cases}$
  - ✓ $f_{sm} = RH^{VPD/\beta}$

$$ET_{int} = \begin{cases} f_{wet} \times \alpha \frac{\Delta}{\Delta+\gamma} \times A_{veg} & fwet > 0,\ \text{forest types} \\ 0.0 & fwet = 0,\ \text{other types} \end{cases}$$

。。。

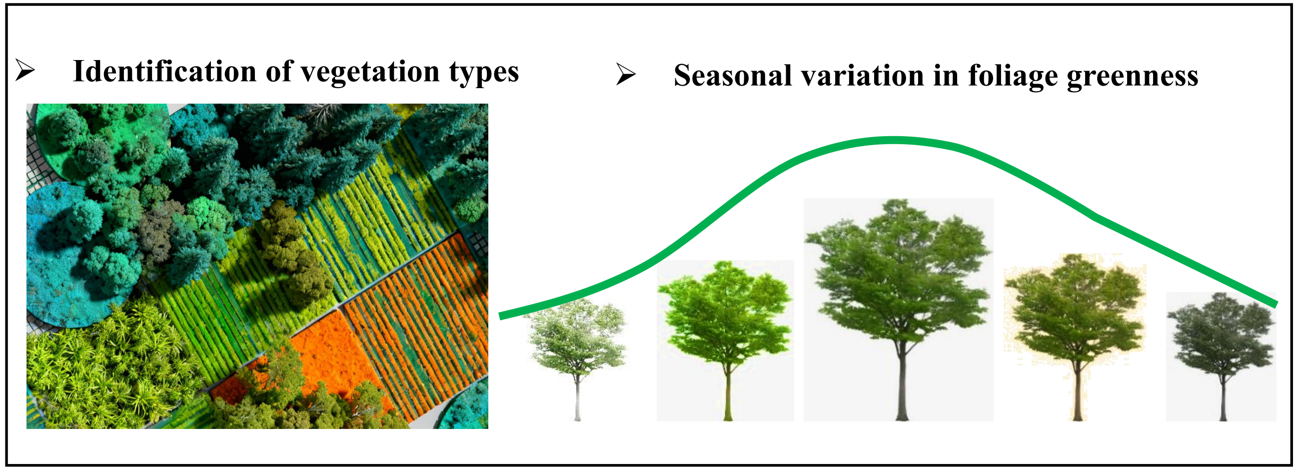
（*Wang et al.,2019RSE, 2023AFM, 2025JGR-A,2019RS; Liu et al.2025*）

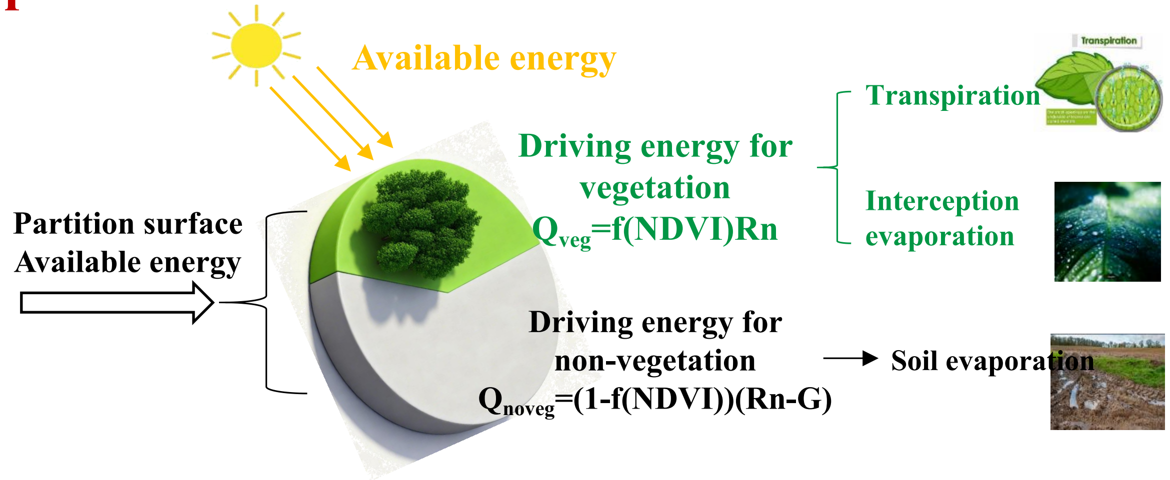
- ☐ Comprising synoptic-scale microwave derived water content information and seasonal-scale optical vegetation cover change。
- ☐ Directly retrieving ET under cloudy conditions
- ☐ Separating different ET components— canopy transpiration and evaporation, bare-soil evaporation.

Physical Integration of satellite optical and microwave measurements in EDVI-ET

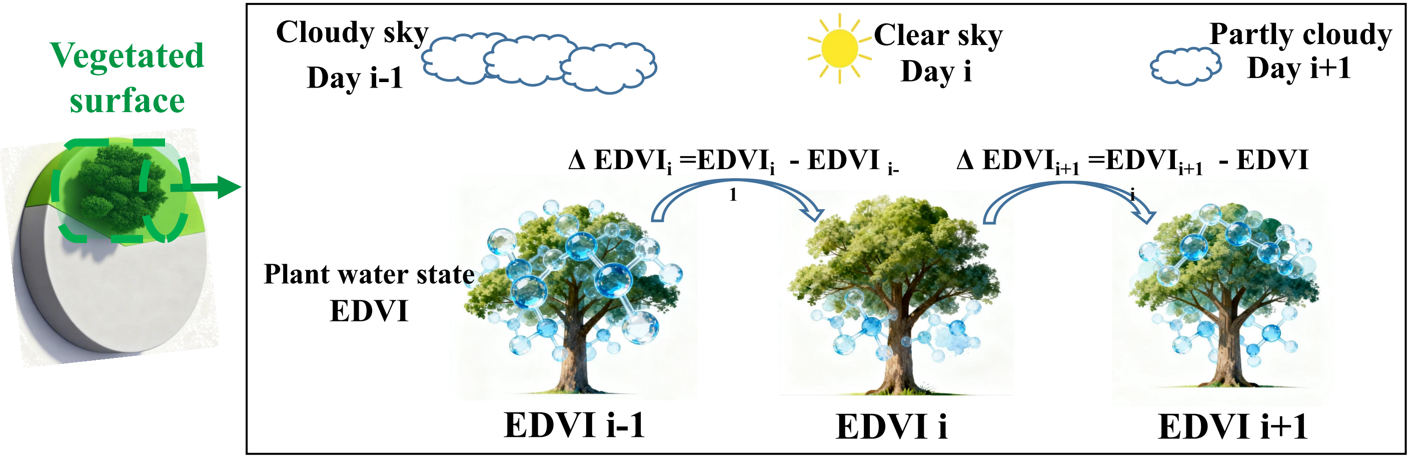
Wang YP, Li R et al., RSE，2019; Liu et al. 2025JGR-A

Seasonal variation of optical greenness (NDVI) over sub-pixels

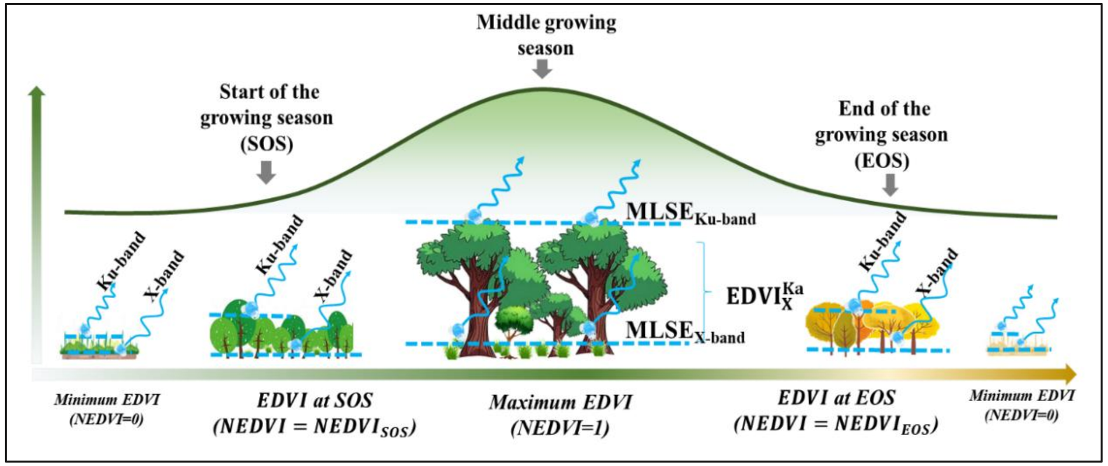




Day-to-day variation of water content under clouds



Seasonal variation of water content

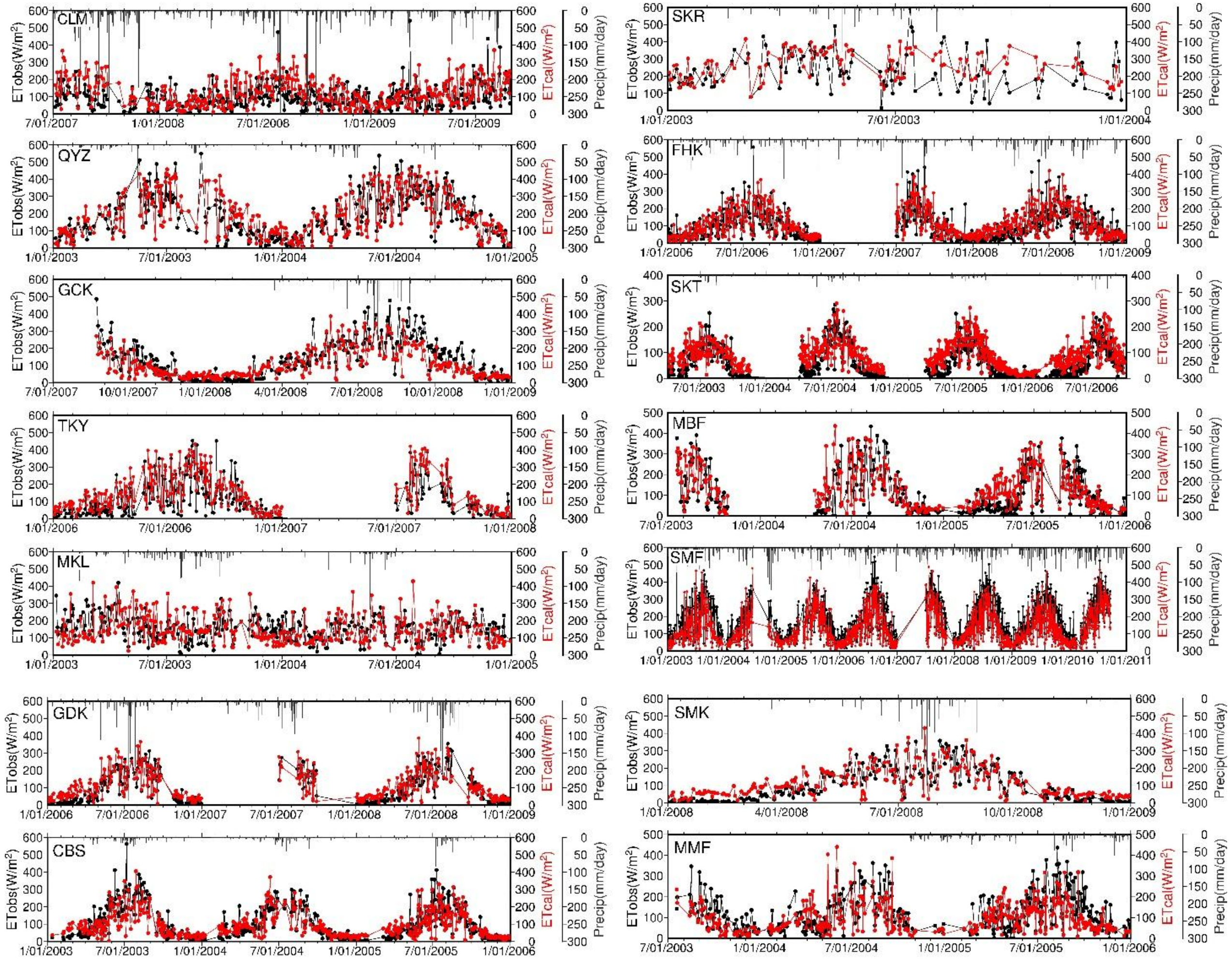


Validations of All-sky EDVI-ET at twenty flux sites in East Asia

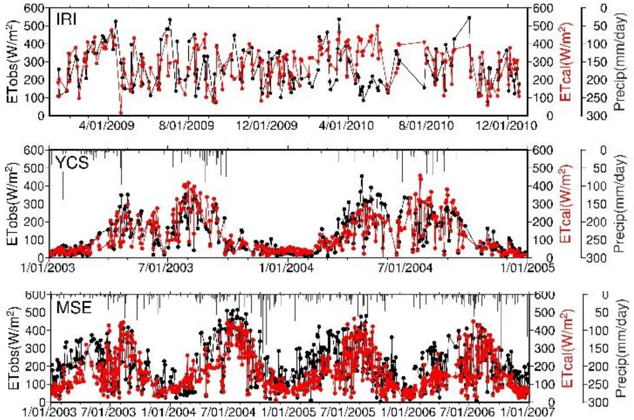
Wang YP, Li R et al., RSE，2019

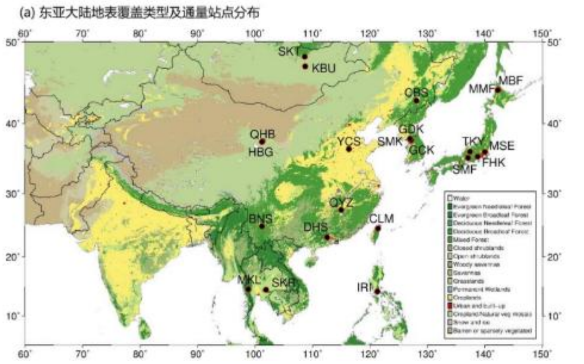
✓ **EDVI-ET model performs better over dense, cloudy forests in humid southern regions than other types and regions.**

Fourteen forest sites

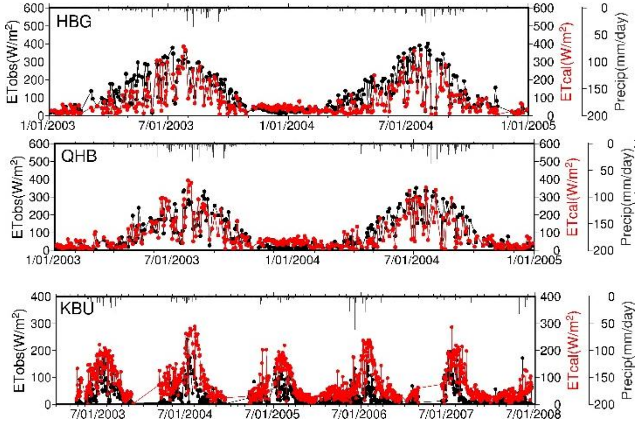


Three cropland sites





Three grassland sites



Metrics under all sky：
R^2 = 0.61 ;
Bias = 13.6% ;
RMSE = 52.5%；

Fig: Time series of daily **EDVI-ET and in-situ ET** across forest, grass and cropland sites

Comparison of satellite microwave EDVI-ET with optical MODIS-ET

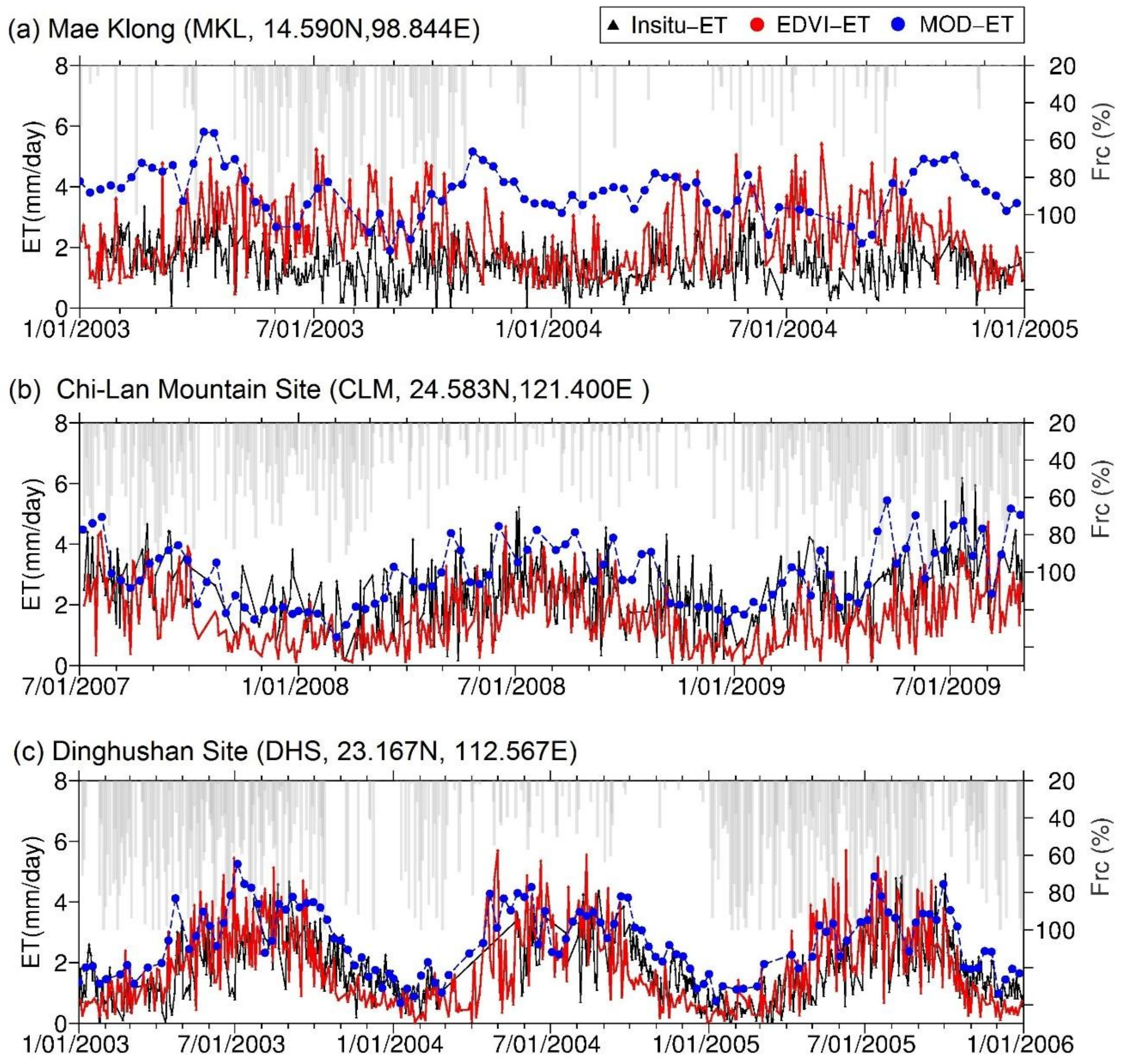
Wang YP, Li R et al., RSE，2021a

At three tropical forests:

(a) MKL: tropical mixed forest in Thailand
(b) CLM: cloudy evergreen needleleaf forest in Taiwan
(c) DHS: evergreen broadleaf forests in south China

- **Seasonal variation (long-term):**
  - ✓ **EDVI–ET better reflects the weak seasonal variability of ET in tropical rainforests.**

- **Synoptic variation (short-term):**
  - ✓ **EDVI–ET captures daily and day-to-day ET changes in time caused by the rapid changes of weather and environment conditions.**



Cloud effects on ET estimation in East Asia

中国科学技术大学地球和空间科学学院
University of Science and Technology of China, School of Earth and Space Sciences

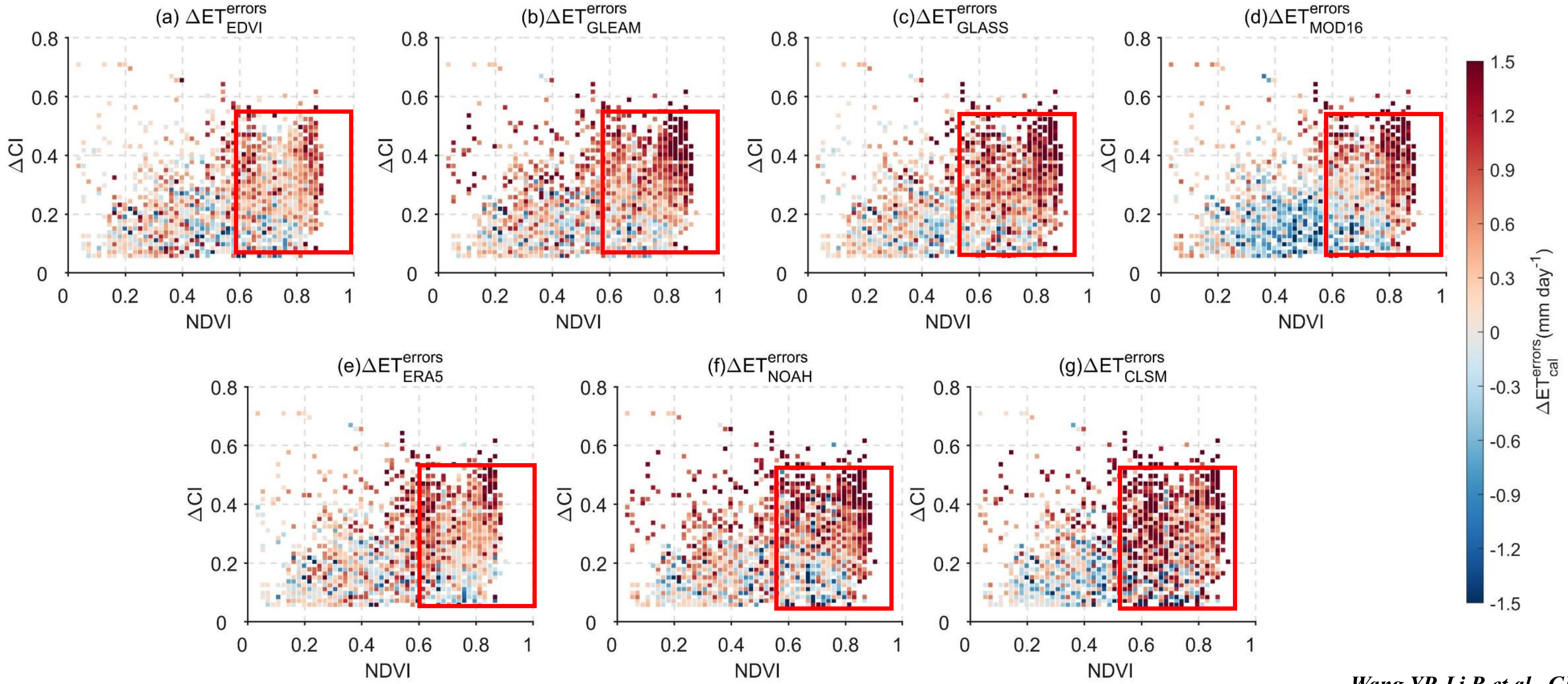
Systematical overestimation of ET typically present in densely vegetated areas (NDVI > 0.6) and under more cloudy conditions (shown in the red box).

$$\Delta ET = ET_{cloudy} - \overline{ET_{clear}}$$

$$\Delta ETerrors = \Delta ETcal - \Delta ETobs$$

$$\Delta CI = CloudIndex_{cloudy} - CloudIndex_{clear}$$

- **4 satellite ET：EDVI-ET，GLEAM, GLASS,MOD16**
- **3 reanalysis and LSM ET：ERA5-ET,NOAH-ET，CLSM-ET**



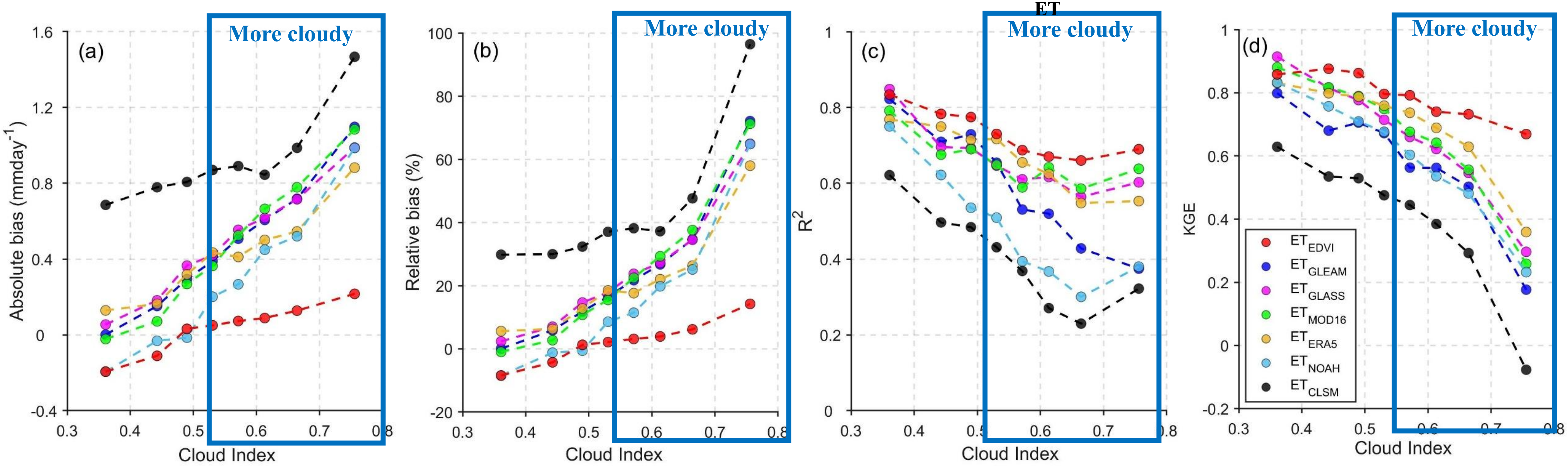
Wang YP, Li R et al., GRL2023

Cloud effects on ET estimation in East Asia

Wang et al., GRL，2023

- **Comparison of EDVI-ET with six global ET under cloud change over forest sites (8-day average)**

> - **4 satellite ET：EDVI-ET，GLEAM, GLASS,MOD16**
> - **3 reanalysis and LSM ET：ERA5-ET,NOAH-ET，CLSM-ET**

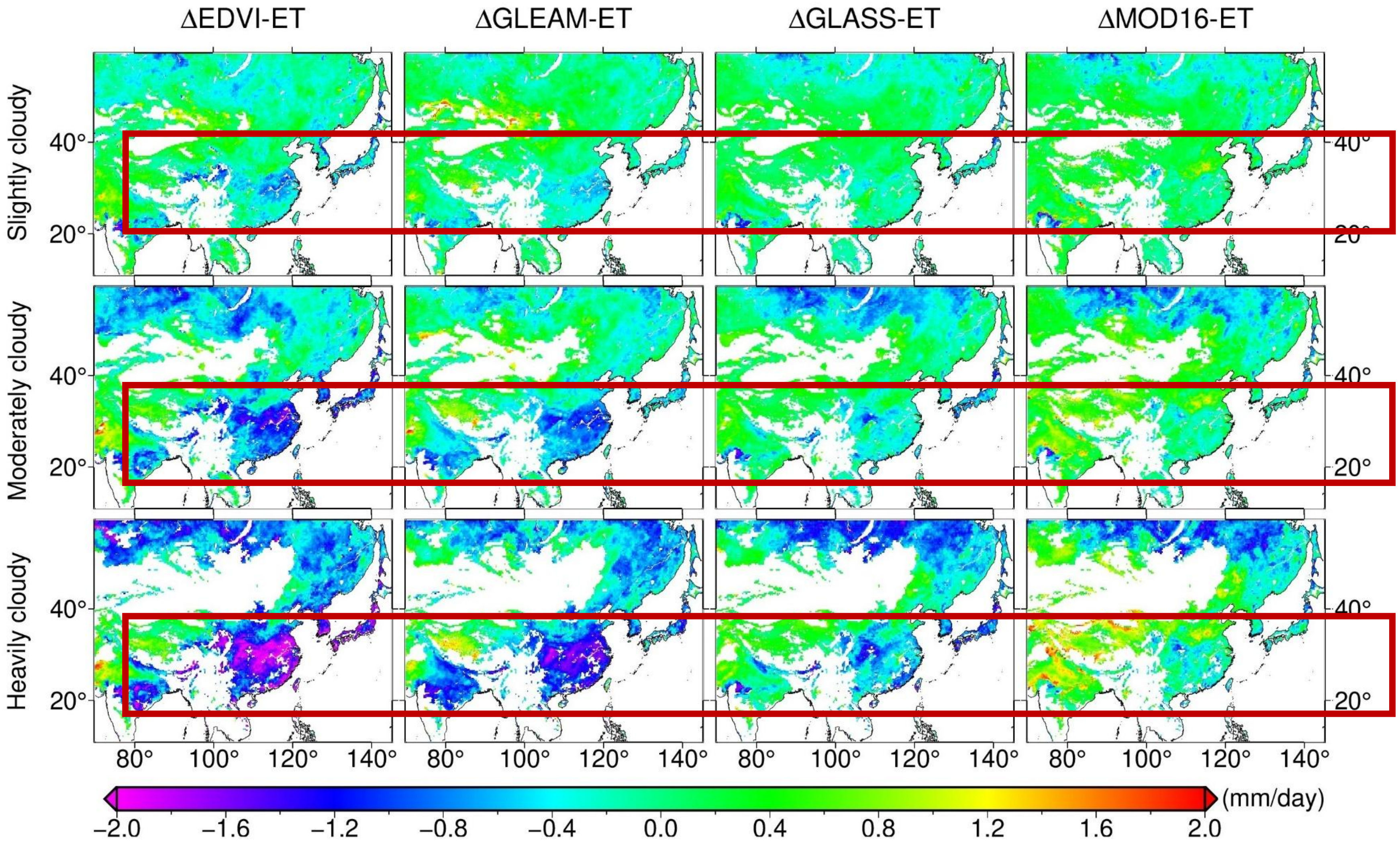


- ☐ **All satellite and LSM derived ET shows an evident overestimation under MORE CLOUDY conditions**
- ☐ Under clear-sky conditions, EDVI–ET is slightly underestimated, but this underestimation is offset in lightly cloudy conditions
- ☐ Under more cloudy conditions, the errors in EDVI–ET are relatively smaller and the variability is more stable.

Cloud effects on ET patterns in East Asia

➢ **Relative changes of ET under clouds relative to clear sky during summer (8-day average)**

$$\Delta ET = ET_{cloudy} - \overline{ET_{clear}}$$



- ☐ **Microwave-based EDVI-ET and GLEAM-ET is more sensitive to cloud increase than optical MOD16-ET and GLASS-ET**

Outline

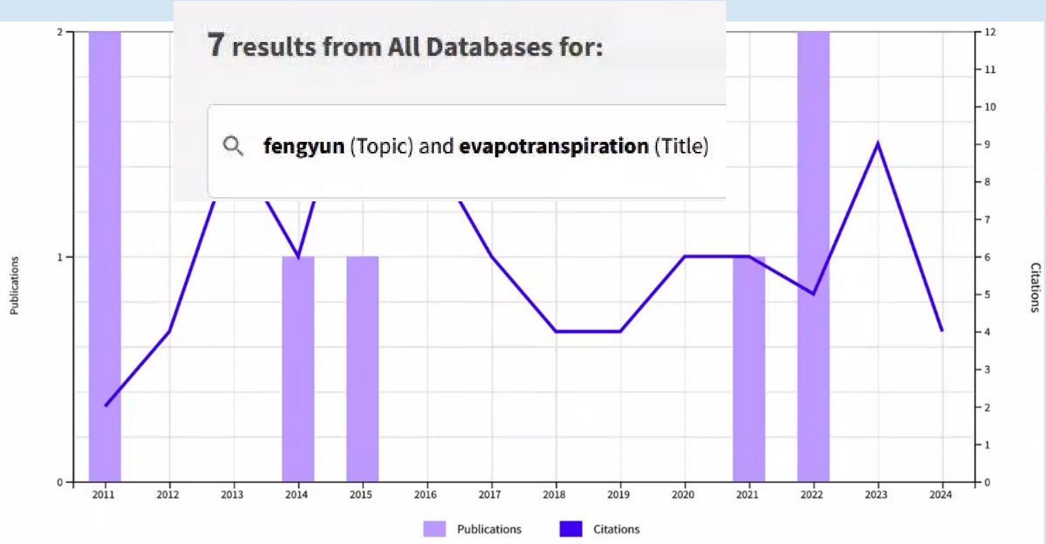
Challenges for Fengyun satellite applications

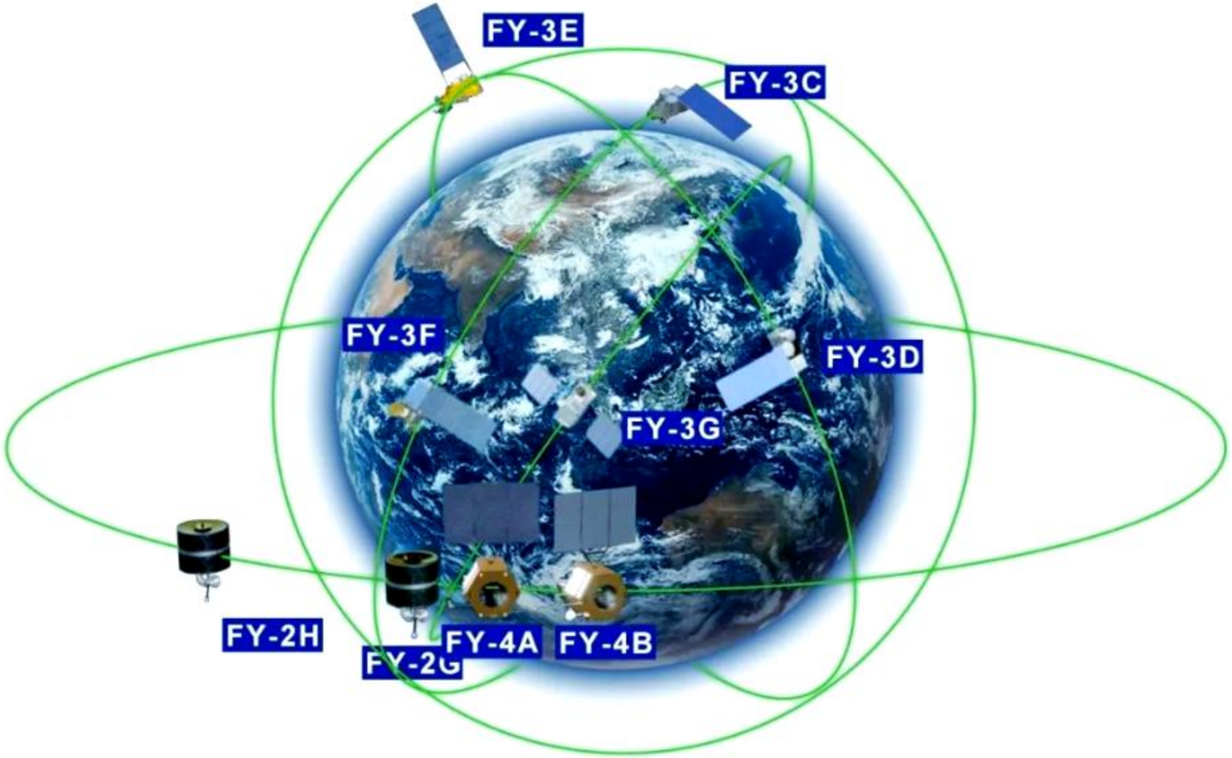
Very few studies have used Fengyun satellites to remotely sense ET

Search Key words on Web of Science：

"Fengyun" & "evapotranspiration "

7 SCI papers（before 2023）

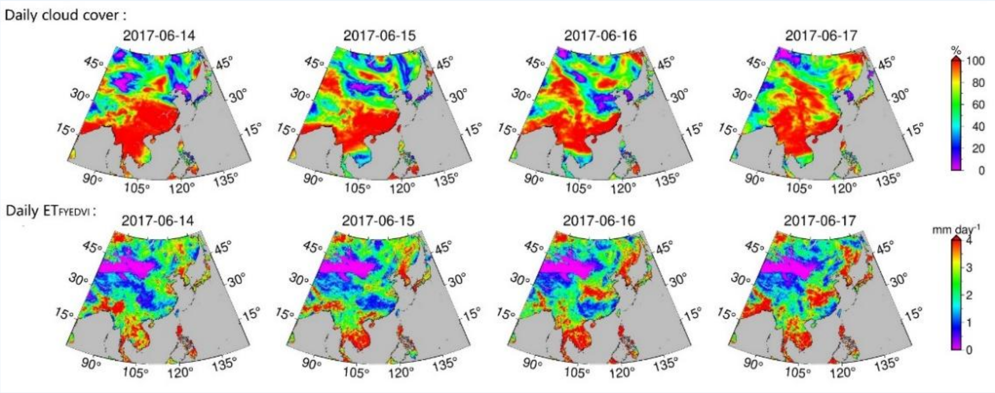




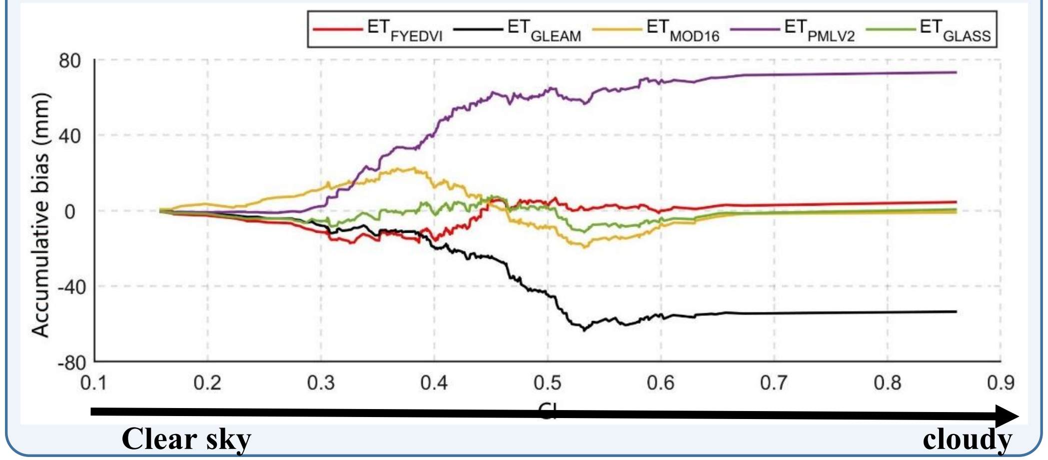
Fengyun-3B passive microwave EDVI-ET over East Asia (2016-2018)

Wang et al. (2025, JGR-A)

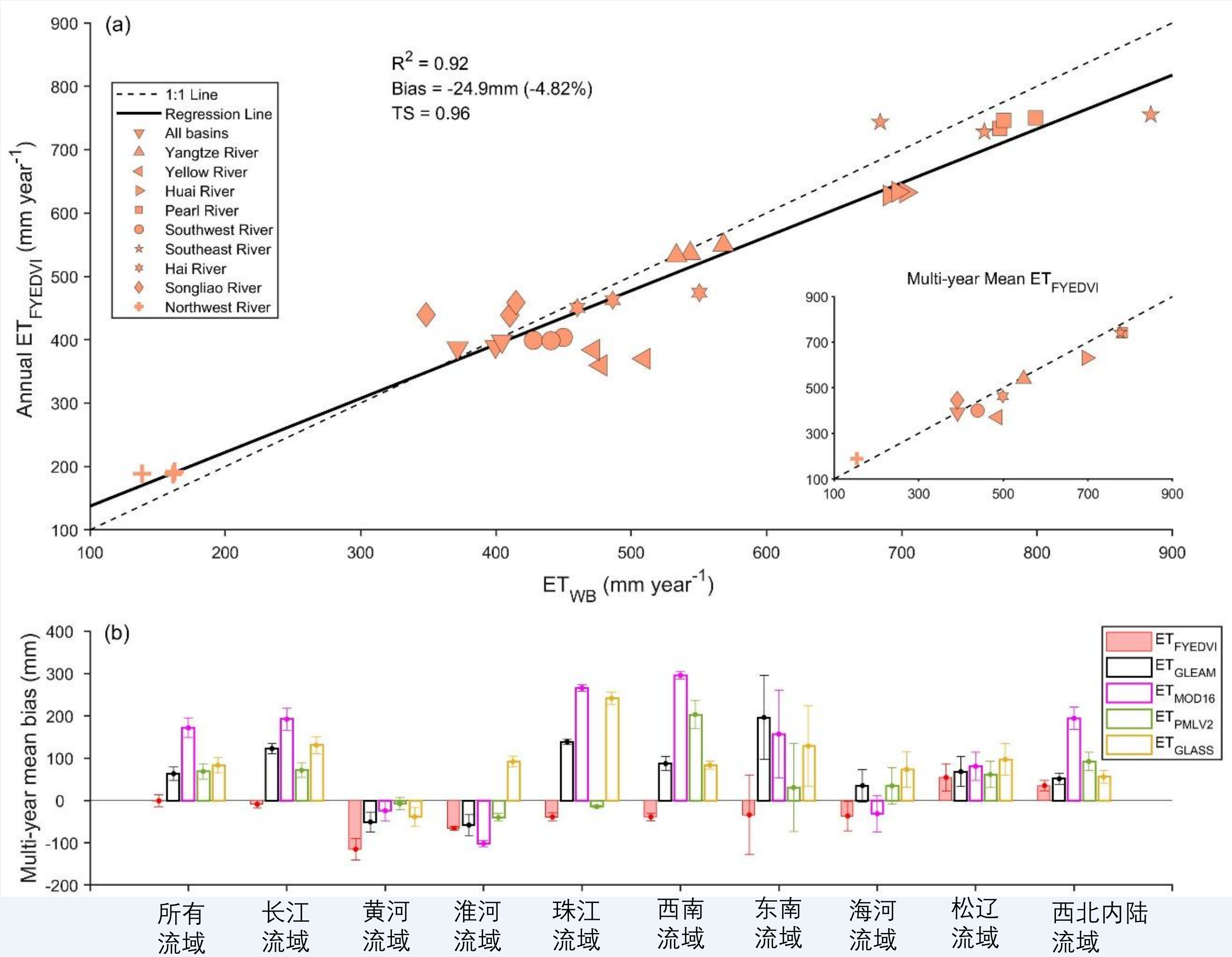
• FY-3B EDVI-ET captures daily ET patterns associated with cloud changes



• FY-3B EDVI-ET presents stable and small accumulated bias as cloud increase



• Water balance based evaluation of FY-3B EDVI-ET.



Comparisons of annual ET amount from different ET products over ten river basins

Fengyun-3D global microwave-based EDVI-ET model

Using a new genetic algorithm for parameter optimization to overcome the uncertainty in empirical parameters for global applications.

Liu et al.(JGR-A, 2025)

➢ Step 1: Data Preprocessing

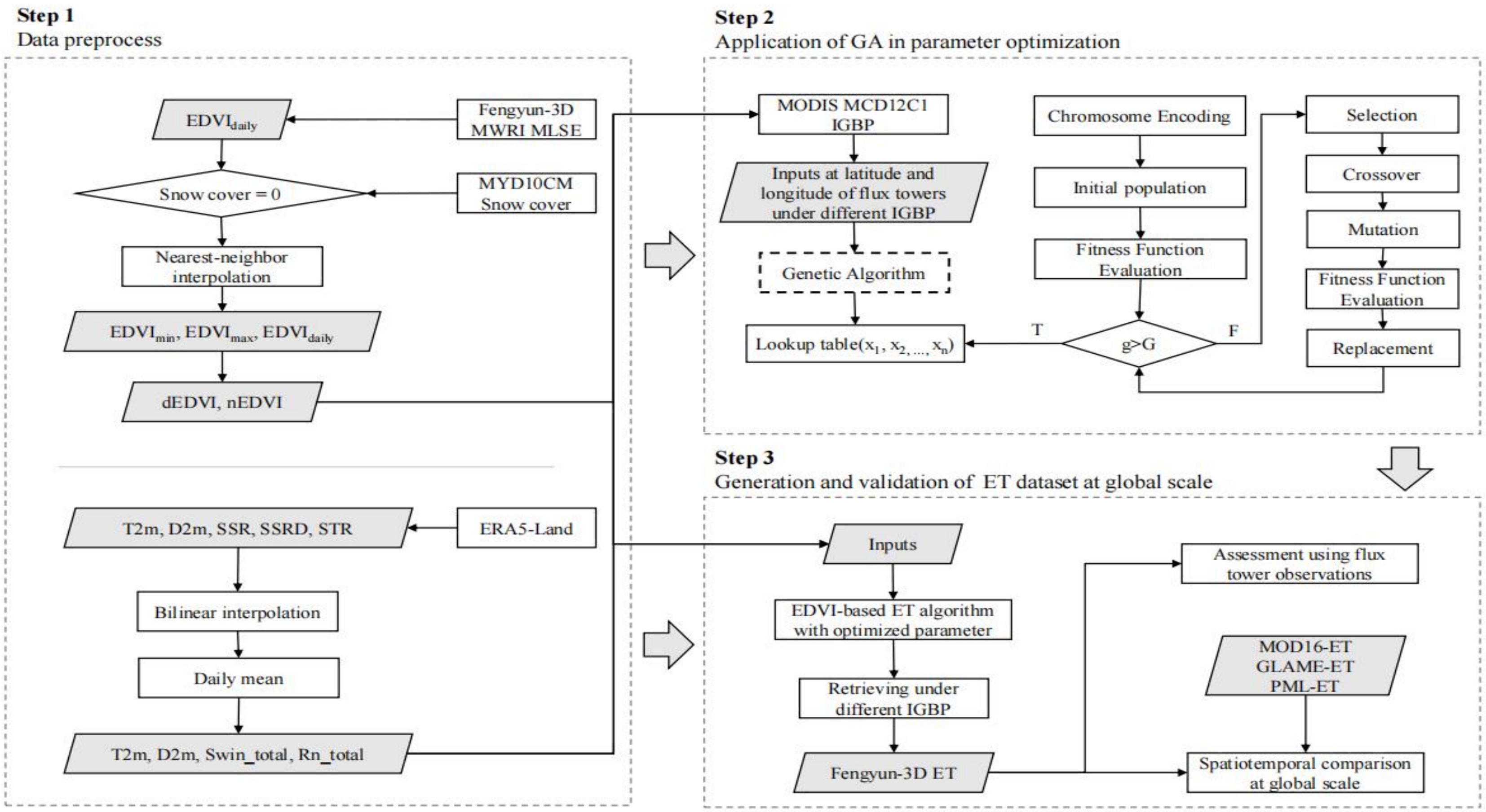
Obtain temperature and radiation data from reanalysis datasets, along with the optical vegetation index NDVI and microwave vegetation index EDVI from satellite observations.

➢ Step 2: Parameter Optimization Using Genetic Algorithm

Input the grid point data corresponding to station observations into the EDVI-ET retrieving algorithm. The retrieval, combined with station observation data, are used to optimize key parameters for different land cover types through a genetic algorithm.

➢ Step 3: Global ET Product Generation and Validation

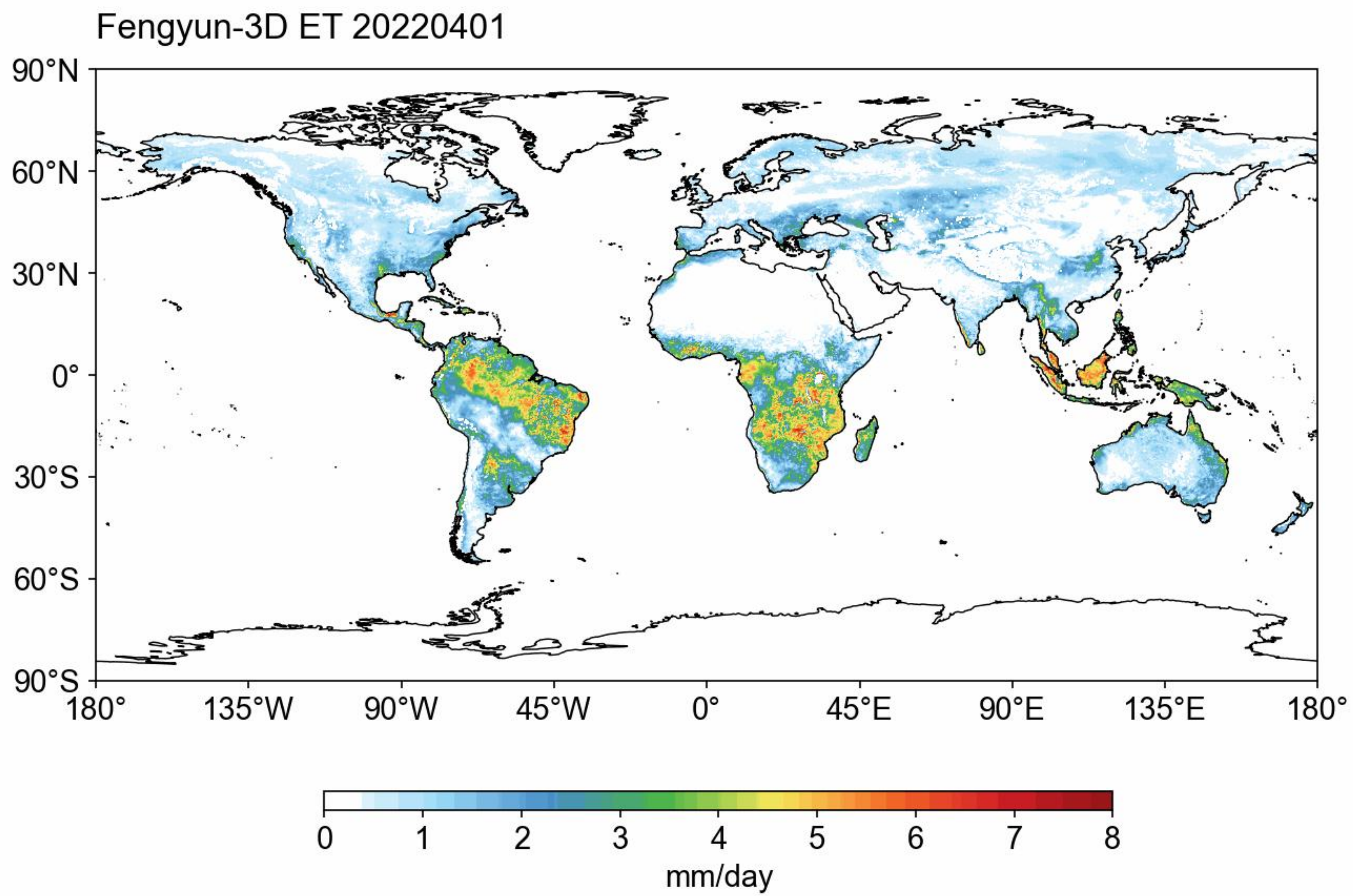
Using the parameter lookup table obtained from the genetic algorithm and integrating global IGBP data, input the global 0.25° gridded data to generate daily all-weather global ET retrieval.

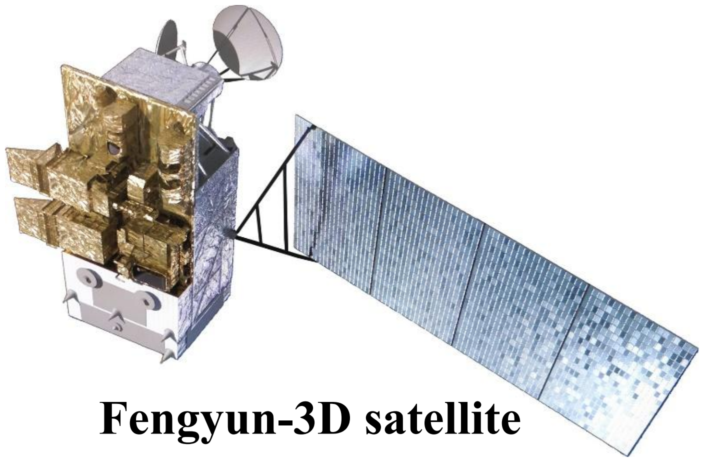


Fig： parameter optimization based Fengyun-3D EDVI-ET for global retrivals

Fengyun-3D global microwave-based EDVI-ET (Daily, 0.25°， All-sky)

Liu et al.(JGR-A, 2025)





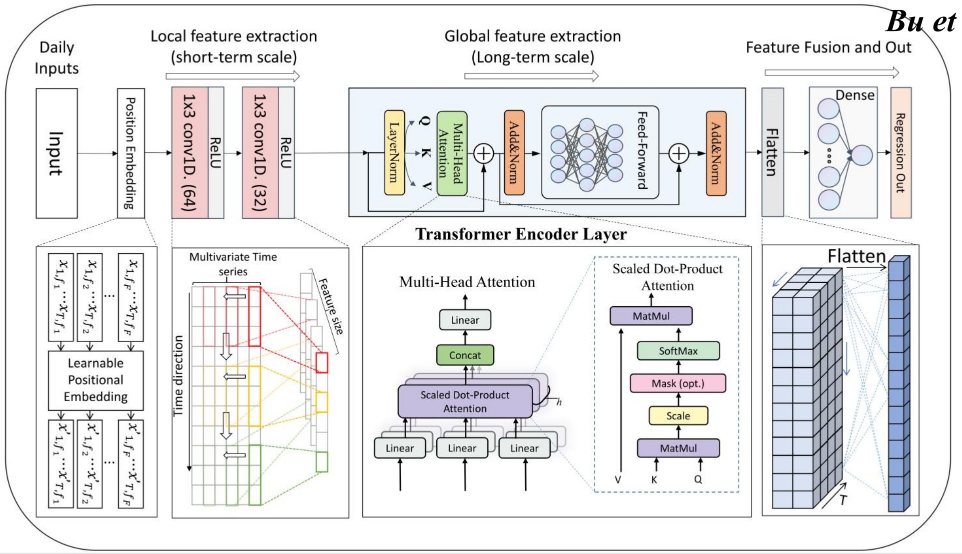
Fengyun-3D satellite

➢ **Provide a key Fengyun satellite data to support research on the water and energy processes globally**

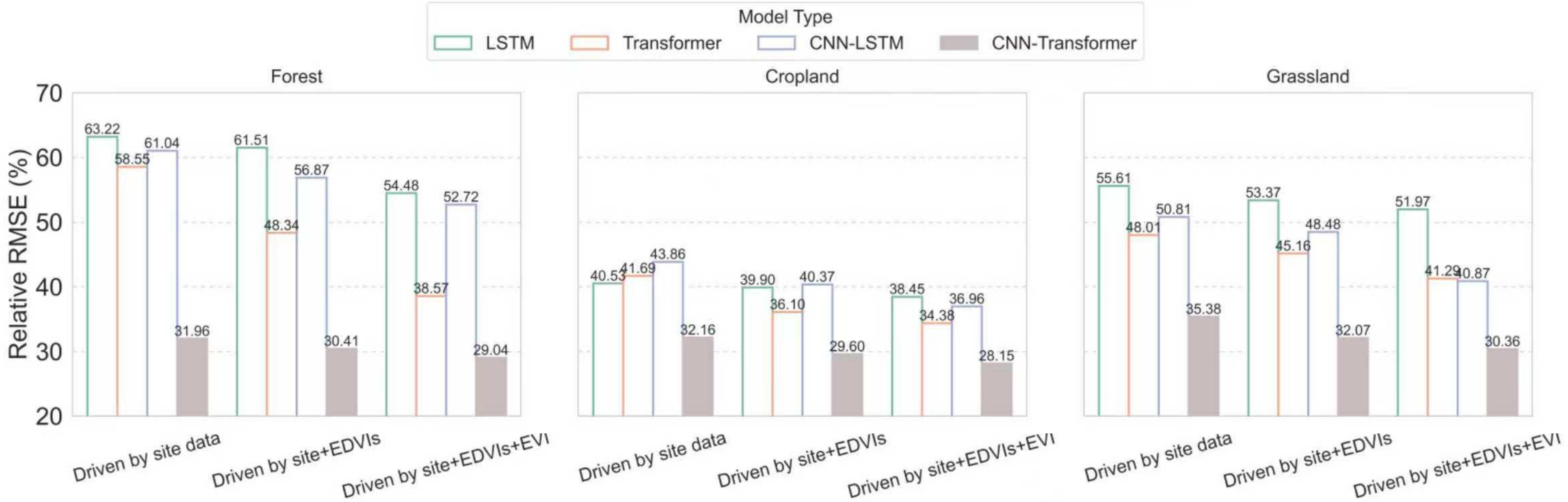
A hybrid CNN–Transformer model for global Fengyun-3D ET retrievals

Bu et al. under review, 2025

- ➢ **Avoid complex physical parameterizations and empirical parameter settings.**
- ➢ **Adaptively learn nonlinear and multi-temporal scale features among variables.**
- ➢ **A lightweight deep-learning model that integrates local (CNN) and global (Transformer) temporal receptive fields.**



☐ Combined use of FY microwave EDVI and MODIS optical EVI can substantially enhance model performance.

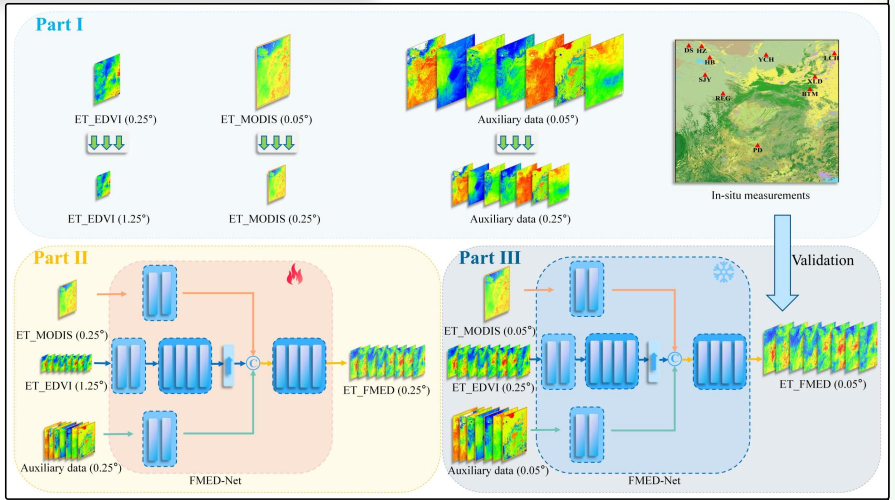


A deep-learning model for downscaling Fengyun-3 satellite EDVI-ET

Li et al. under review, 2025

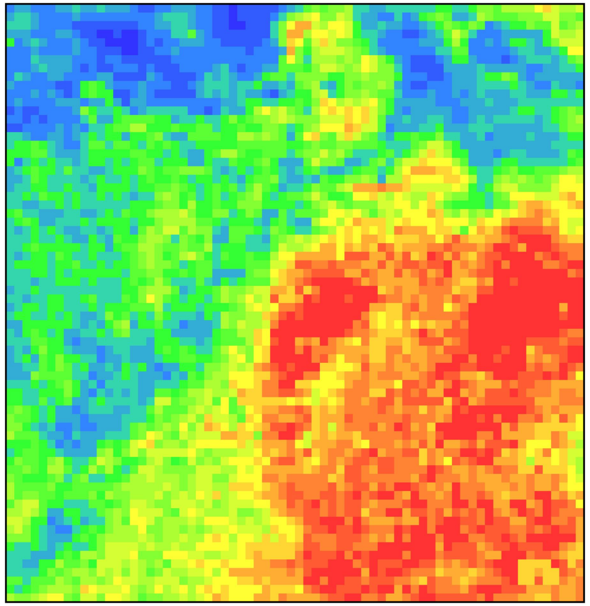
- ➢ **Original EDVI-ET (all-sky, daily, 0.25°, global) is limited at a fine spatial scale.**
- ➢ **A deep learning model for downscaling research is developed by fusing satellite microwave and optical information as well as other multi-source data： (0.25° ->0.05° (finished) ->0.01° (ongoing) ->500m (ongoing))**

Downscaled scheme

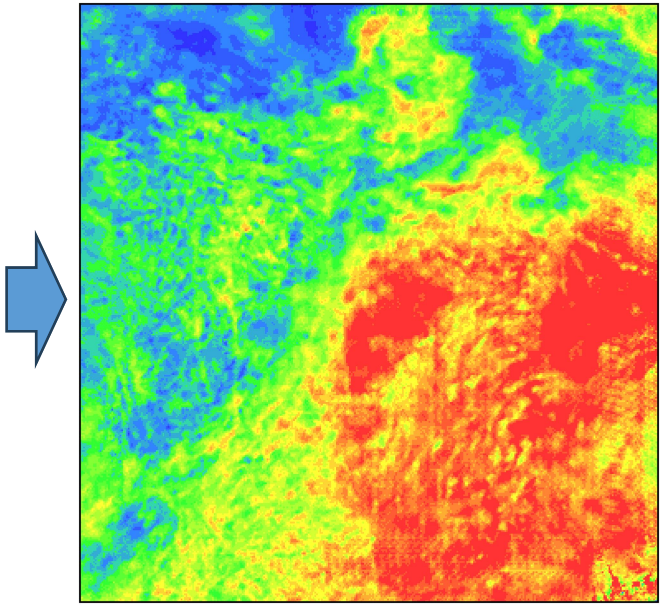


- ☐ Fusing multi-source information:
  - ✓ optical MODIS-ET and vegetation data
  - ✓ surface and meteorological data
- ☐ Extracting cross-scale spatiotemporal features to guide the downscaling process.

EDVI-ET(daily, 0.25°)



FMED-ET(daily, 0.05°)



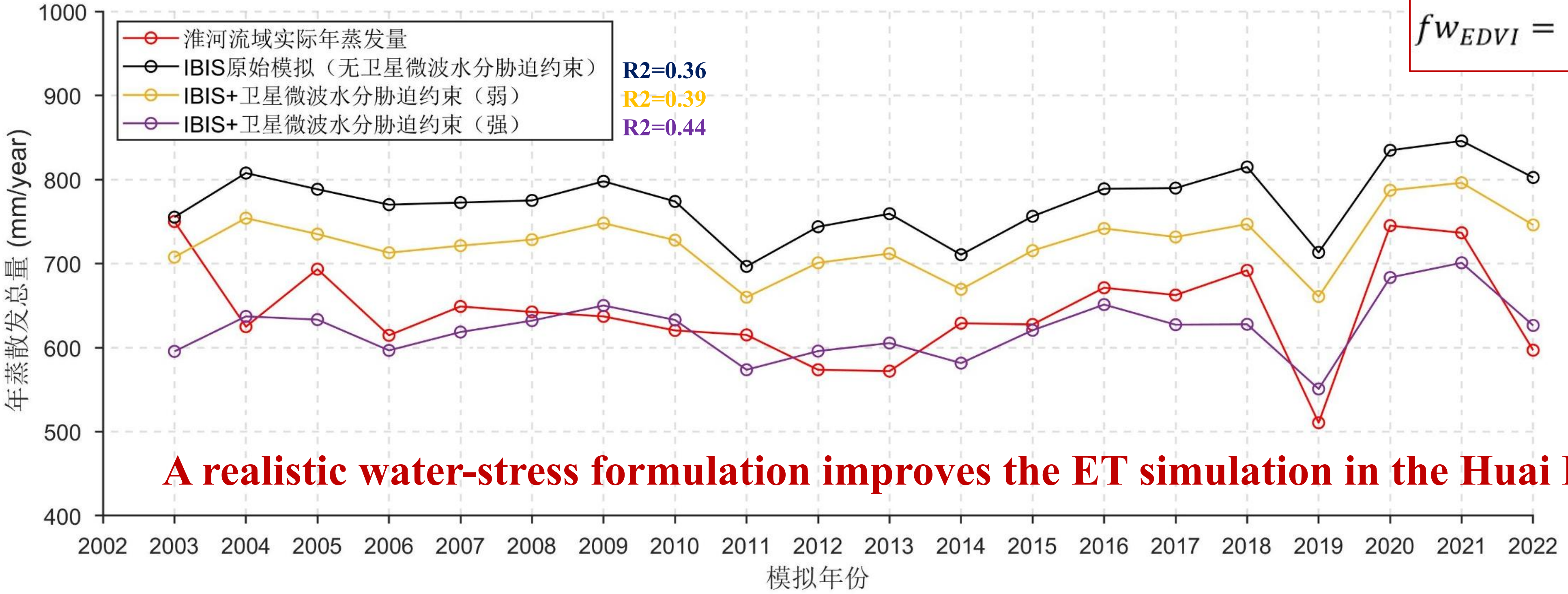
Dynamic vegetation modeling constrained by Fengyun satellite microwave observations.

Wang et al. In preparation

- **In dynamic vegetation models, Vcmax commonly lack an explicit vegetation water-stress scheme.**
- **Using passive microwave index as a stress factor can substantially reduce systematic biases in carbon–water simulations of dynamic vegetation models.**

Vcmax = Vcmax0 * Tastress* SoilWaterstress ⟹ **Vcmax = Vcmax0 * Tastress* SoilWaterstress * plantwaterstre**

$$fw_{EDVI} = \frac{1}{1 + e^{-a \cdot nEDVI^{K} + b}}$$



A realistic water-stress formulation improves the ET simulation in the Huai River Basin.

国家卫星气象中心
(国家空间天气监测预警中心)
NSMC NCSW

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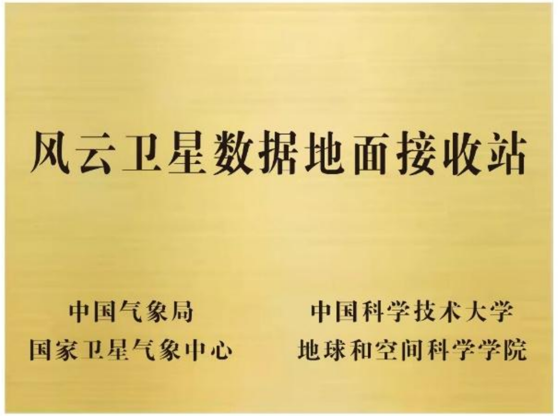
University of Science and Technology of China
地球和空间科学学院
School of Earth and Space Sciences

Joint Laboratory of Fengyun Remote sensing



The founding conference of the laboratory (May-6-2024)

Scientific Application Steering Committee of Fengyun-3G satellite

Ground receiving station of Fengyun satellites in USTC

Publications of satellite passive microwave ET in recent five years

1. **Wang, Y.**, Liu, Q., **Li, R*.**, Hu, J., Zhang, P., Song, B. (2025). Remote sensing of vegetation phenology in the northern hemisphere from multi-channe Chinese FengYun-3D satellite. **Remote Sensing of Environment, 330, 114997.**
2. **Wang, Y.**, **Li, R*.**, Min, Q., Fu, Y., et al. (2019). A three-source satellite algorithm for retrieving all-sky evapotranspiration rate using combined optical and AsiaFlux sites. **Remote sensing of environment**, 235, 111463.
3. **Wang, Y.**, **Li, R***., Hu, J., Fu, Y., Duan, J., & Cheng, Y. (2021). Daily estimation of gross primary production under all sky using a light use efficiency microwave measurements. **Remote Sensing of Environment**, 267, 112721.
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5. **Wang, Y**., Hu, J., **Li, R***., Song, B., et al. (2023). Increasing cloud coverage deteriorates evapotranspiration estimating accuracy from satellite, reanalysis a **Geophysical Research Letters**, 50(8), e2022GL102706.
6. Liu, Q., Zhang, P., **Wang, Y**., Hu, J., & **Li, R.*** (2025). Global evapotranspiration retrieval using Fengyun-3D passive microwave measurements with gene **Geophysical Research: Atmospheres**, 130, e2025JD043823.
7. Song, B., Hu, J., **Wang, Y**., Li, D., Zhang, P., Wang, Y., et al. (2025). Regional gross primary productivity estimation using passive microwave observations from China's Fengyun-3B satellite. **Journal of Geophysical Research: Atmospheres**, 130, e2024JD041425.
8. **Wang, Y.**, **Li, R***., Hu, J., Fu, Y., Duan, J., et al. (2023). Understanding the non-linear response of summer evapotranspiration to clouds in a temperate forest under the impact of vegetation water content. **Journal of Geophysical Research: Atmospheres**, 126(23), e2021JD035239.
9. **Wang, Y.**, **Li, R***., Song B, Hu J. (2023).Divergent Responses of Summer Terrestrial Evapotranspiration to Cloud Increase in East Asia. **Journal of Geophysical Research: Atmospheres.**
10. **Wang, Y.**, Hu J, Li, R., Zhang P, et al. (2025). Monitoring Daily All-sky Evapotranspiration over the East Asian Continent Using Multi-channel Passive Microwave Measurements from Fengyun-3B Satellite of China. **Journal of Geophysical Research: Atmospheres.**
11. **Wang, Y**., Hu, J., **Li, R.**, Song, B., & Hailemariam, M. (2023b). Remote sensing of daily evapotranspiration and gross primary productivity of four forest ecosystems in East Asia using satellite multi-channel passive microwave measurements. **Agricultural and Forest Meteorology**, 339, 109595.
12. **Wang, Y.**, **Li, R***., Hu, J., Fu, Y., Duan, J., Cheng, Y., & Song, B. (2022). Evaluation of evapotranspiration estimation under cloud impacts over China using ground observations and multiple satellite optical and microwave measurements. **Agricultural and Forest Meteorology**, 314, 108806.
13. **Wang, Y.**, **Li, R*.**, Min, Q., Zhang, L., Yu, G., & Bergeron, Y. (2019b). Estimation of vegetation latent heat flux over three forest sites in ChinaFLUX using satellite microwave vegetation water content index. **Remote Sensing**, 11(11), 1359.
14. **Li, R. ***, **Wang, Y.**, Hu, J., Wang, Y., Min, Q., Bergeron, Y., ... & Fu, Y. (2020). Spatiotemporal variations of satellite microwave emissivity difference vegetation index in China under clear and cloudy skies. **Earth and Space Science,** 7(5), e2020EA001145.

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Thanks for your attention !