TCCIP 網格化觀測資料於水文氣象研究之應用

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May 09, 2023

Four Applications

- Understanding land-atmosphere interactions
- Assessment of satellite and model precipitation
- Trend analysis of Taiwan's drought
- Water resources availability into the future

Application I:
Understanding Land-Atmosphere Interactions

Motivation and Scope

- Understand the impact of LUCC on hydrometeorology in central Taiwan, where “urbanization” is a dominant type of LUCC.
- Make use of the best available numerical modeling technique (e.g., Weather Research and Forecasting model, WRF) driven by survey-based land use data to conduct a “realistic” modeling experiment.

IOP Publishing Environ. Res. Lett. 15 (2020) 034015 https://doi.org/10.1088/1748-9326/ab68aa

Environmental Research Letters

CrossMark

OPEN ACCESS

RECEIVED
17 September 2019

REVISED
5 January 2020

ACCEPTED FOR PUBLICATION
7 January 2020

PUBLISHED
19 February 2020

LETTER

Central Taiwan’s hydroclimate in response to land use/cover change

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Keywords: land-atmosphere interactions, land-surface model, statistical analysis, climate change

Supplementary material for this article is available online

Abstract

Land use/cover change (LUCC) has taken place since the 1990s in central Taiwan; however, its impacts on the local and regional hydroclimatology are not understood thoroughly. This study is grounded in a numerical experiment using the Weather Research and Forecasting (WRF) model and statistical assessments of continuous land cover and gridded precipitation data derived for central Taiwan. We incorporate survey-based land use data in 1995 and 2007 in driving WRF to simulate selective non-rainy and rainy (dry and wet) cases under weak synoptic forcings in July and August (JA). The two land-use conditions reveal changes in simulation fields on account of increased urban and built-up lands. Results averaged over the dry cases show increased (diminished) sensible heat fluxes and 2 m temperatures (latent heat fluxes and 2 m specific humidity) in 2007 compared to that in 1995. The wet-case simulation further identifies intensified precipitation over the downwind areas of urban and built-up lands, strongly subject to local topography and prevailing winds. Statistical assessments of the Landsat land cover and gridded precipitation data verify significant increasing trends in urbanization and the JA rainfall. Regression-based analysis that scales the effect of the LUCC on the change in precipitation corroborates the WRF simulation: LUCC has induced eastward, downwind association with the JA rainfall.

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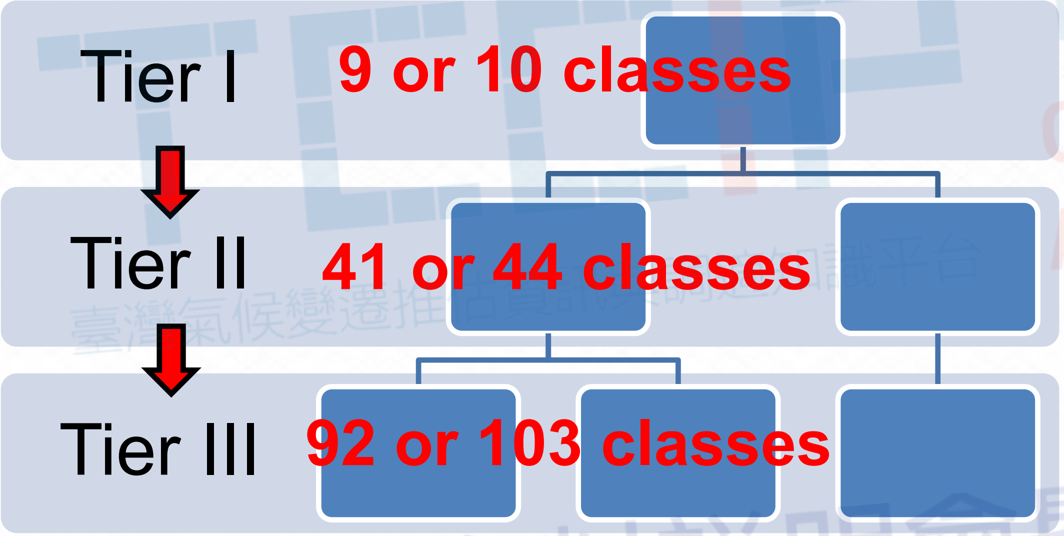
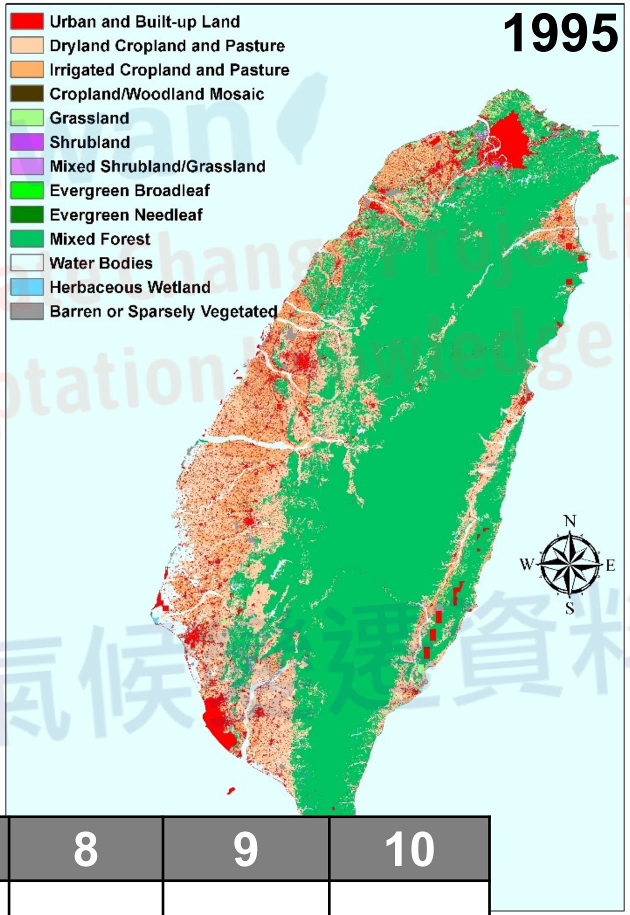
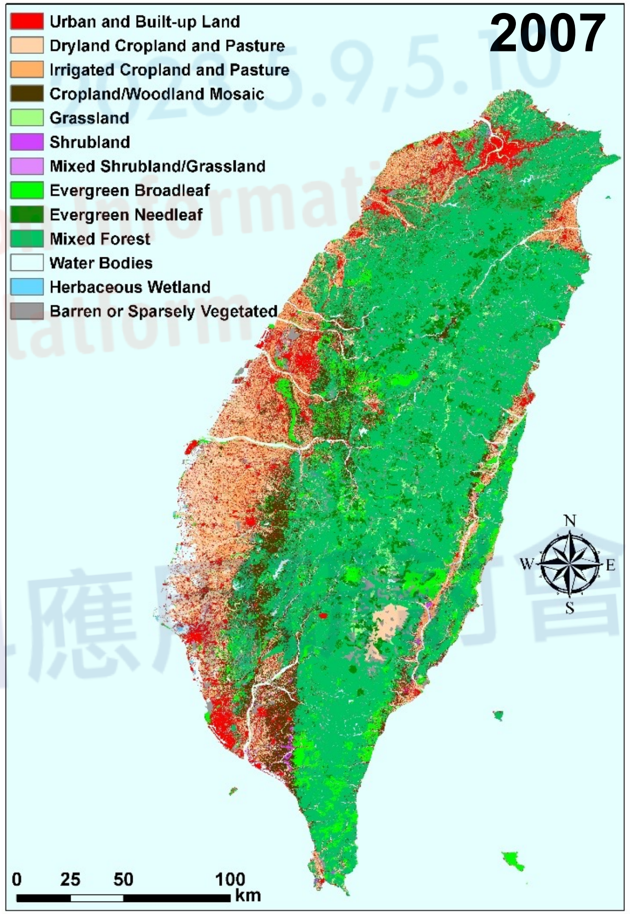
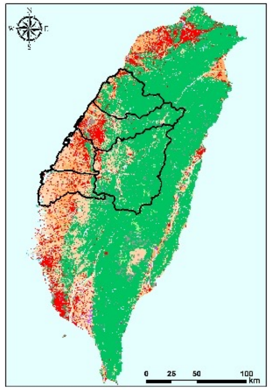
NLSC Land Use Data





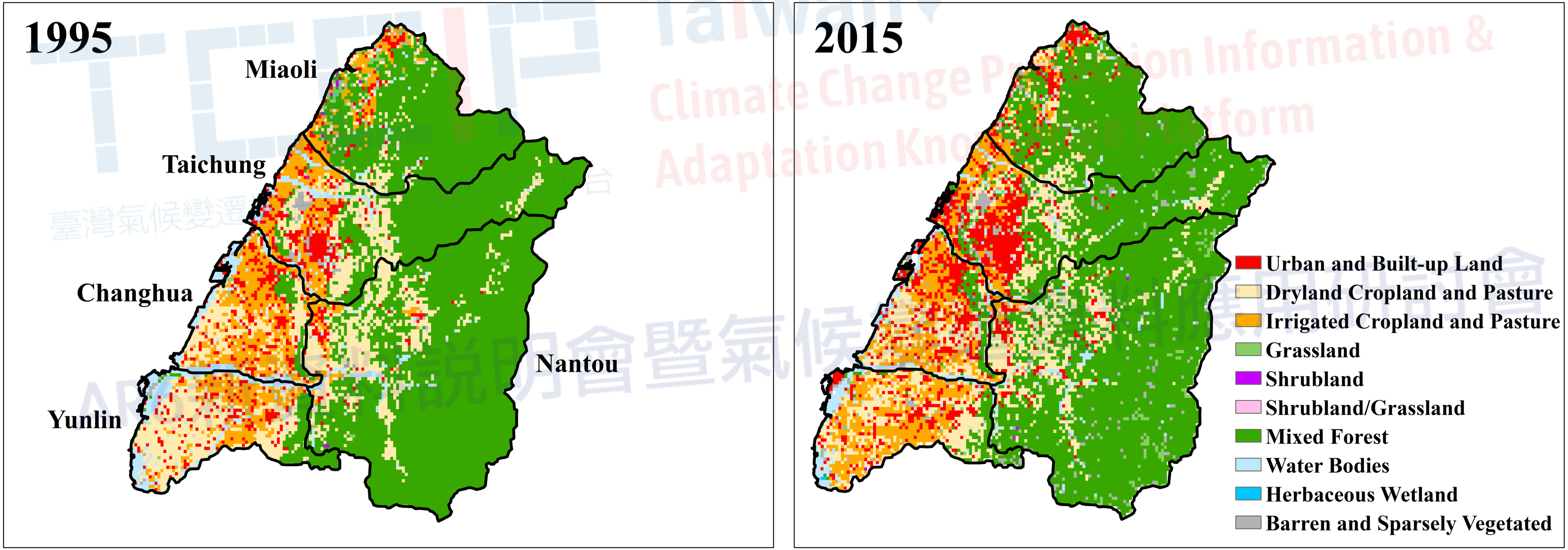


ID	1	2	3	4	5	6	7	8	9	10
1995	Agr	Trans	Hydro	Built	Ind	Recre	Salt	Ore	Milit	Others
2007	Agr	Forest	Trans	Hydro	Built	Public	Recre	Salt	Others	



LUCC from 1995 to 2015

Administrative areas : **Miaoli, Taichung, Changhua, Nantou, and Yunlin**



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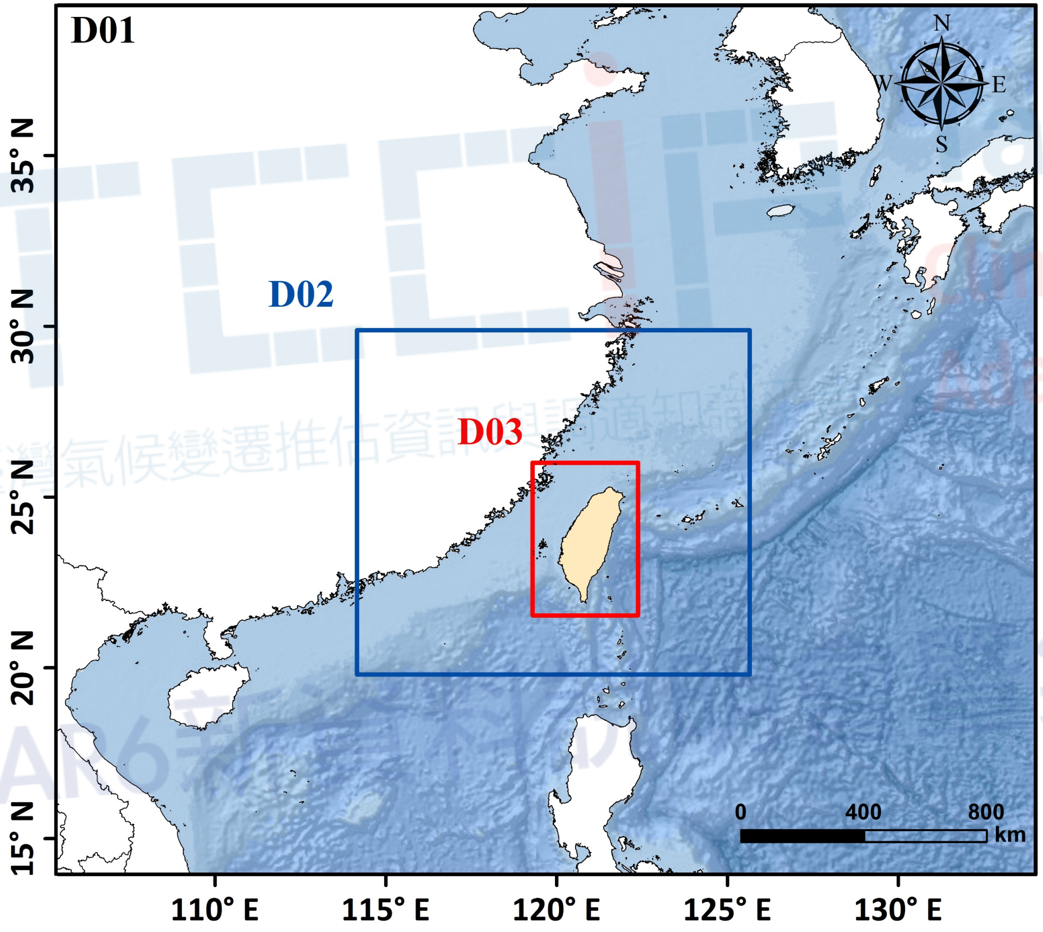
Approximately 20% of cropland has transformed to urban and built-up land.

WRF Configuration and Case Selection

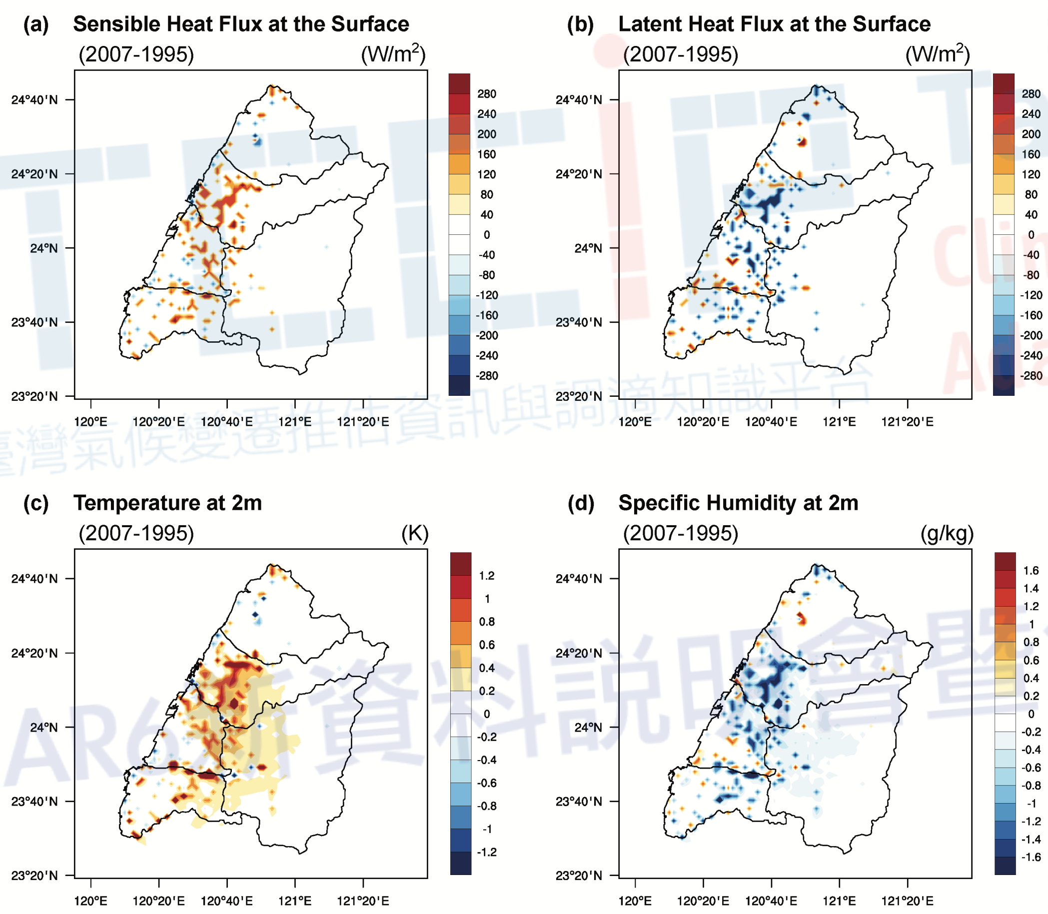


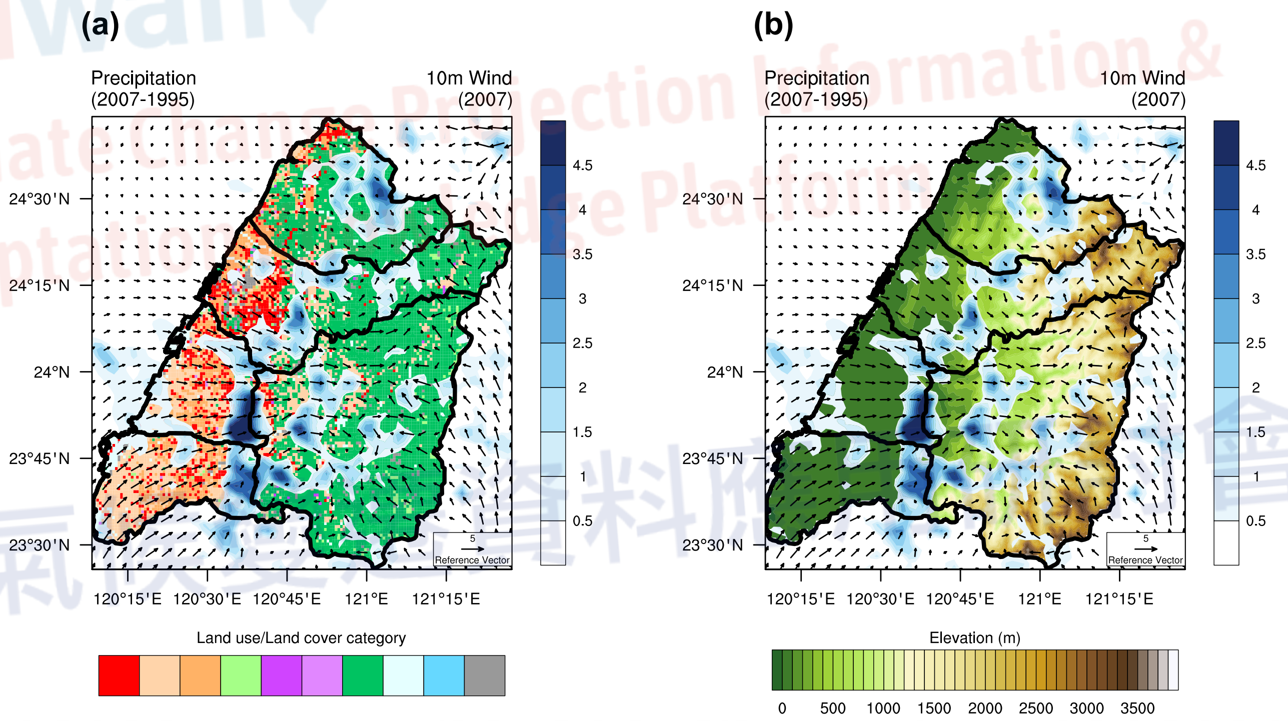
WPS Domain Configuration

10 wet (rainy) cases under weak synoptic forcings (e.g., no typhoons or weather fronts) in July-August are selected.

Case ID	Date
1	2000-07-16
2	2005-08-25
3	2008-07-06
4	2010-07-26
5	2010-08-25
6	2013-07-02
7	2014-08-18
8	2015-07-19
9	2016-08-12
10	2016-08-19

Urban Heat Island Effect and Downwind Intensification of JA Rainfall





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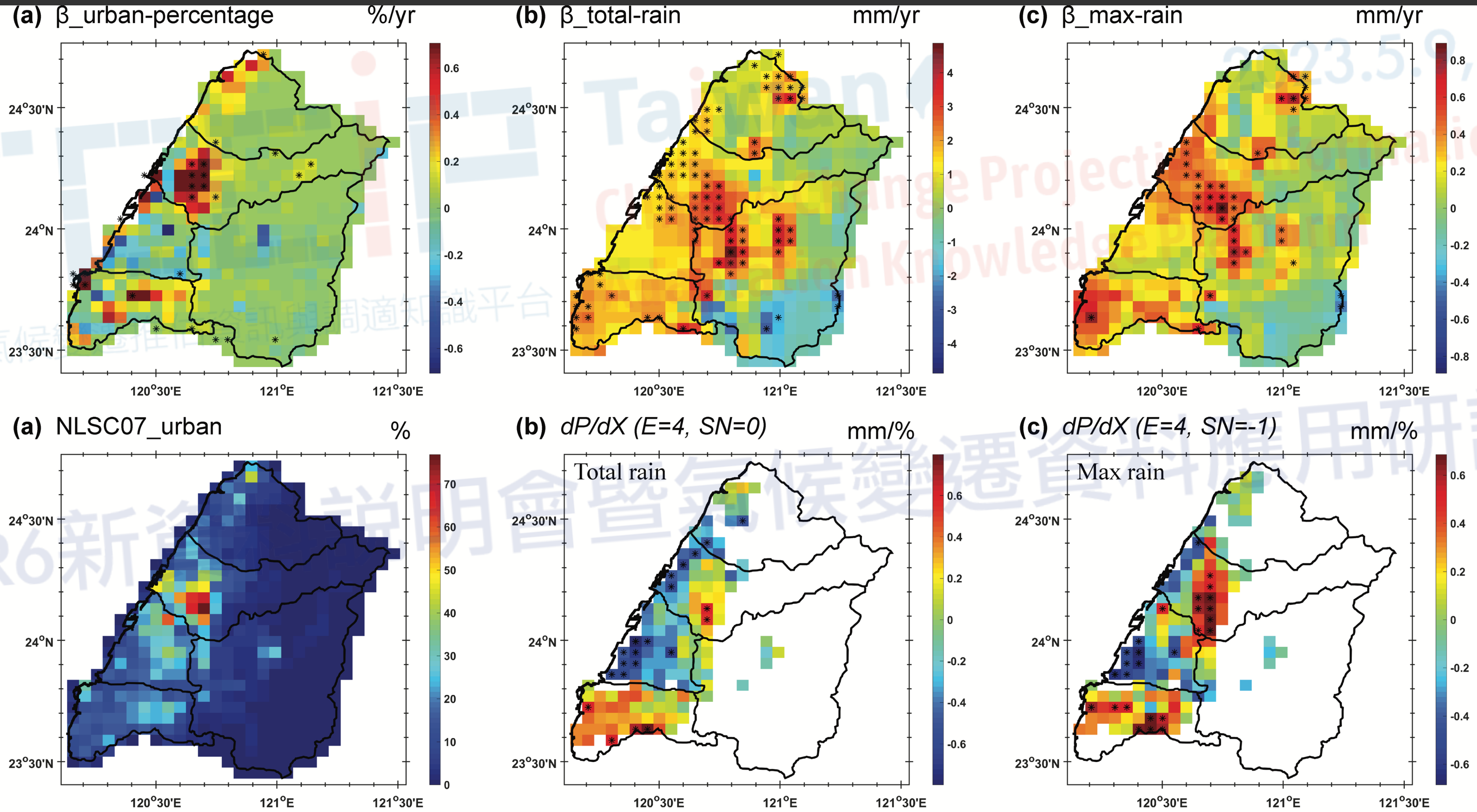
Observed Trends in Rainfall and Relationship with Urban Expansion



App. I Takeaway

- We found that LUCC can induce prominent changes in energy fluxes, temperature, precipitation patterns, etc.

- Enhanced precipitation can take place over the downwind of heavy urbanized areas.

Application II:
Assessment of Satellite and Model Precipitation

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Motivation and Scope

- Satellites of the Global Precipitation Measurement (GPM) mission have played an important role in the information transmission of Earth's water and energy cycles.
- In Taiwan, precipitation patterns, as well as hydrological responses, show sharp variations in different seasons, suggesting a need for a seasonal assessment of various precipitation products and their usefulness for hydrological modeling.

SPECIAL
Global Precipitation Measurement (GPM)
COLLECTION

Hydrometeorological Assessment of Satellite and Model Precipitation Products over Taiwan

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(Manuscript received 30 June 2021, in final form 31 August 2021)

ABSTRACT: Satellite and model precipitation such as the Global Precipitation Measurement (GPM) data are valuable in hydrometeorological applications. This study investigates the performance of various satellite and model precipitation products in Taiwan from 2015 to 2017, including data derived from the Integrated Multisatellite Retrievals for GPM Early and Final Runs (IMERG_E and IMERG_F), Global Satellite Mapping of Precipitation in near-real time (GSMaP_NRT), and the Weather Research and Forecasting (WRF) Model. We assess these products by comparing them against data collected from 304 surface stations and gauge-based gridded data. Our assessment emphasizes factors influential in precipitation estimation, such as season, temperature, elevation, and extreme event. Further, we assess the hydrological response to each precipitation product via continuous flow simulation in two selected watersheds. The results indicate that the performance of these precipitation products is subject to seasonal and regional variations. The satellite products (i.e., IMERG and GSMaP) perform better than the model (i.e., WRF) in the warm season and vice versa in the cold season, most apparently in northern Taiwan. For selected extreme events, WRF can simulate better rainfall amount and distribution. The seasonal and regional variations in precipitation estimation are also reflected in flow simulations: IMERG in general produces the most rational flow simulation, GSMaP tends to overestimate and be least useful for hydrological applications, while WRF simulates high flows that show accurate time to the peak flows and are better in the southern watershed.

SIGNIFICANCE STATEMENT: Precipitation data derived from satellites or numerical weather prediction models are valuable resources since they can provide comprehensive information regarding areal precipitation over a specific region. However, such precipitation products of varying degrees of accuracy may hinder their usefulness for hydrological and other applications. Understanding which precipitation products to use under various circumstances requires knowledge accrued from scrutinizing the relative performance of these products. This study shows that over Taiwan, the performance of satellite and model precipitation is contingent upon season, region, and event. The best-performing precipitation products can thus generate most rational flow simulations, suggesting possibilities for more emerging applications.

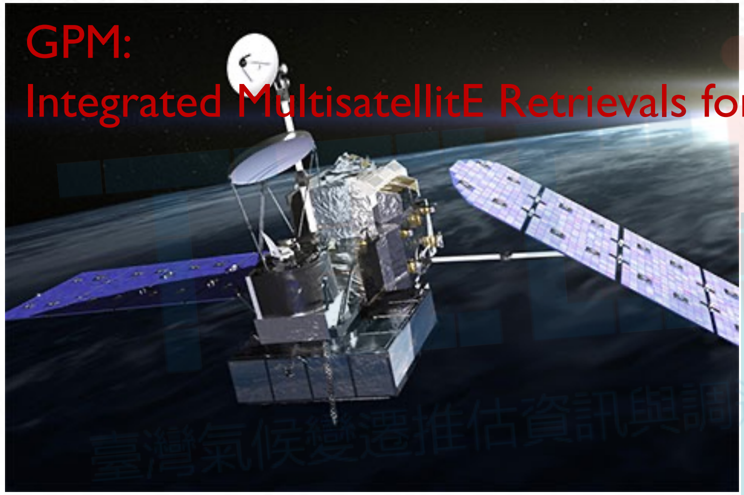
KEYWORDS: Precipitation; Hydrology; Satellite observations; Hydrologic models; Numerical weather prediction/forecasting

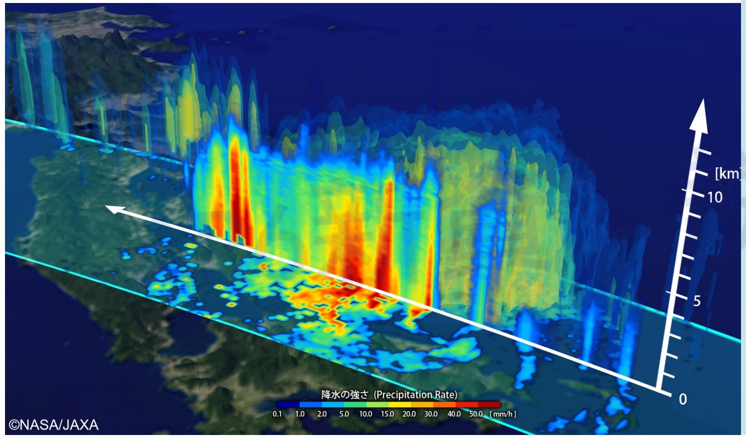
1. Introduction

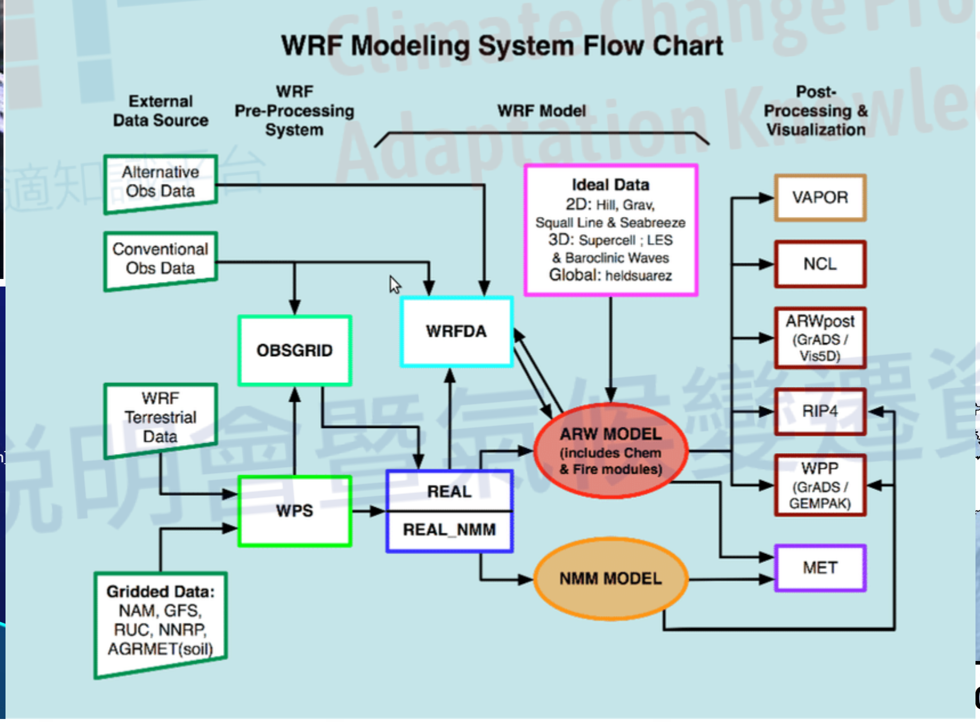
Precipitation is an essential variable in the hydrological cycle. Obtaining accurate precipitation data can crucially aid climate and hydrological research and applications, such as effective allocation of water resources and reducing the risk of flooding disasters. Currently, the most accurate precipitation data still rely on surface observation; however, establishing surface stations is often confined by geographical locations and topographical considerations, resulting in gaps in spatial precipitation information (Qin et al. 2014). Moreover, surface regions (Zhang et al. 2013). Owing to modern-day scientific progress, precipitation products have become increasingly diverse, and the aforementioned information gaps can be filled using remote sensing technologies, such as rainfall radars and satellites. Among the mentioned products, radar precipitation products boast superior performance in precipitation estimation, but their installation is still constrained by topographical complexity and funding limitations (Behrangi et al. 2011; Zhang et al. 2018). By contrast, satellite precipitation products are capable of monitoring all areas across the globe, thereby compensating the

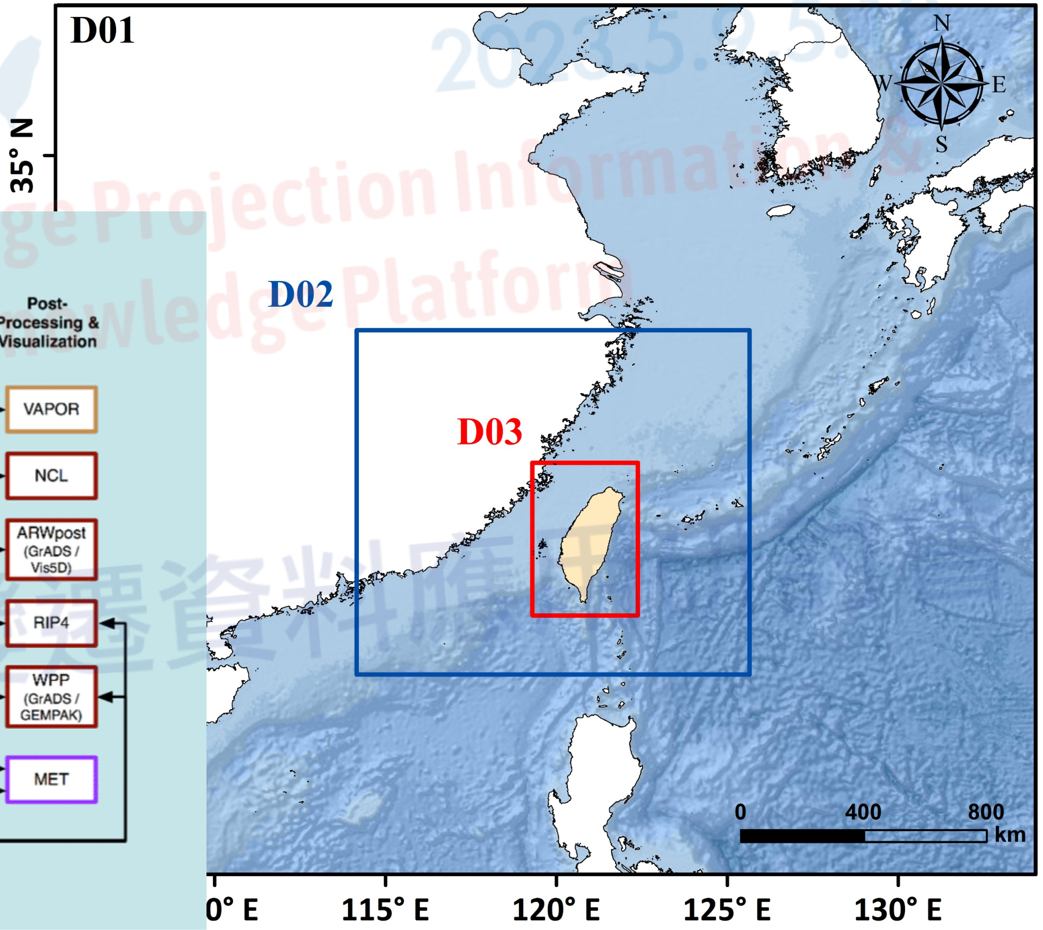
Satellite and Model Precipitation

GPM:
Integrated MultisatellitE Retrievals for GPM (**IMERG**)





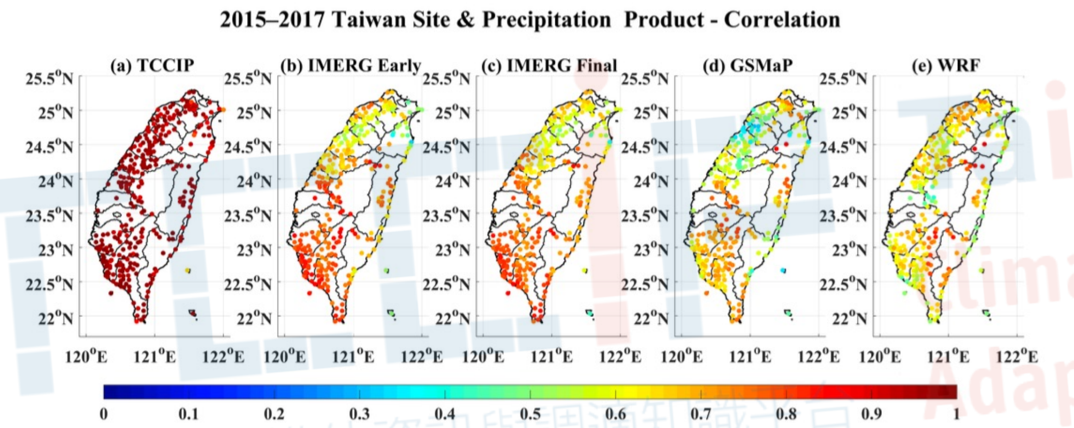


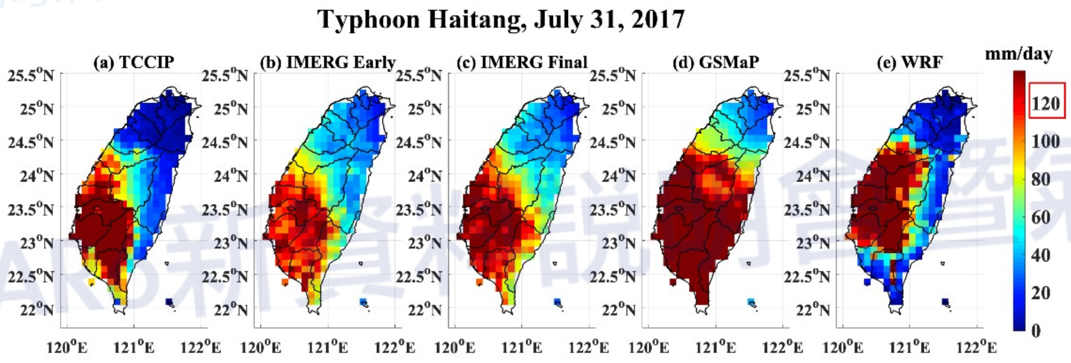


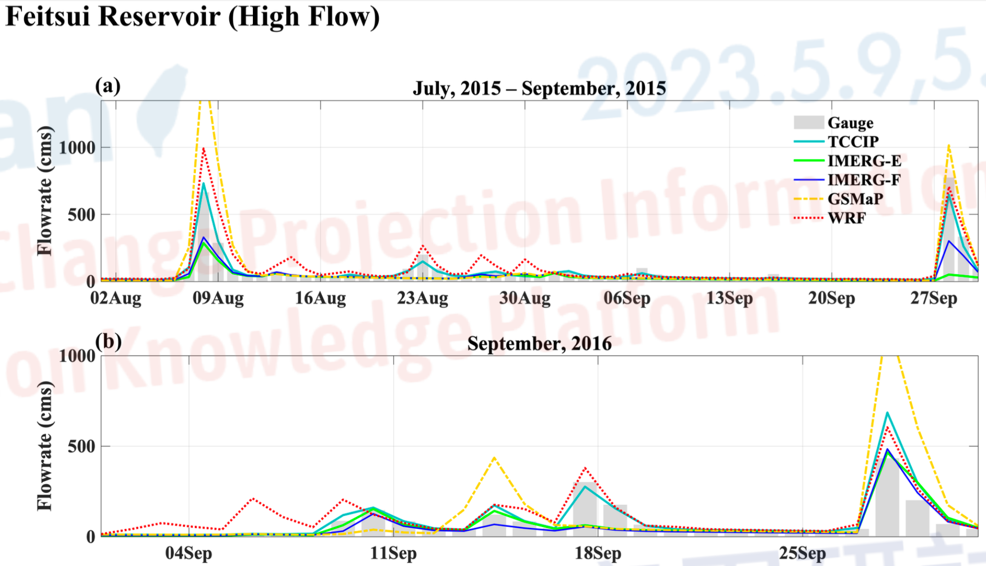
WPS Domain Configuration

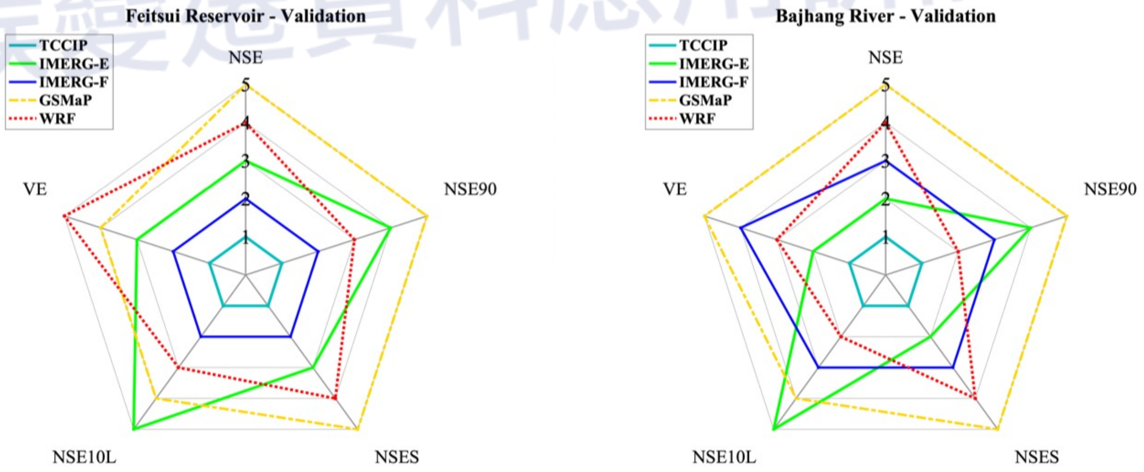
Weather Research and Forecasting (**WRF**) model

Assessment Results









TCCIP: 臺灣氣候變遷推估資訊與調適知識平台計畫

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App. II Takeaway

- IMERG和GSMaP (即衛星降雨)於溫暖季節之表現優於WRF (即模式降雨)，於寒冷季節則反之，尤以臺灣北部特別明顯。

- 對於選定之極端事件，WRF可以合理地模擬降雨量和分佈。

- 降雨推估準確度之季節性和區域變化也反映在流量模擬中，如IMERG通常能產生最合理之流量模擬，GSMaP因其對於雨量之高估因而造成流量模擬之參考性最差。

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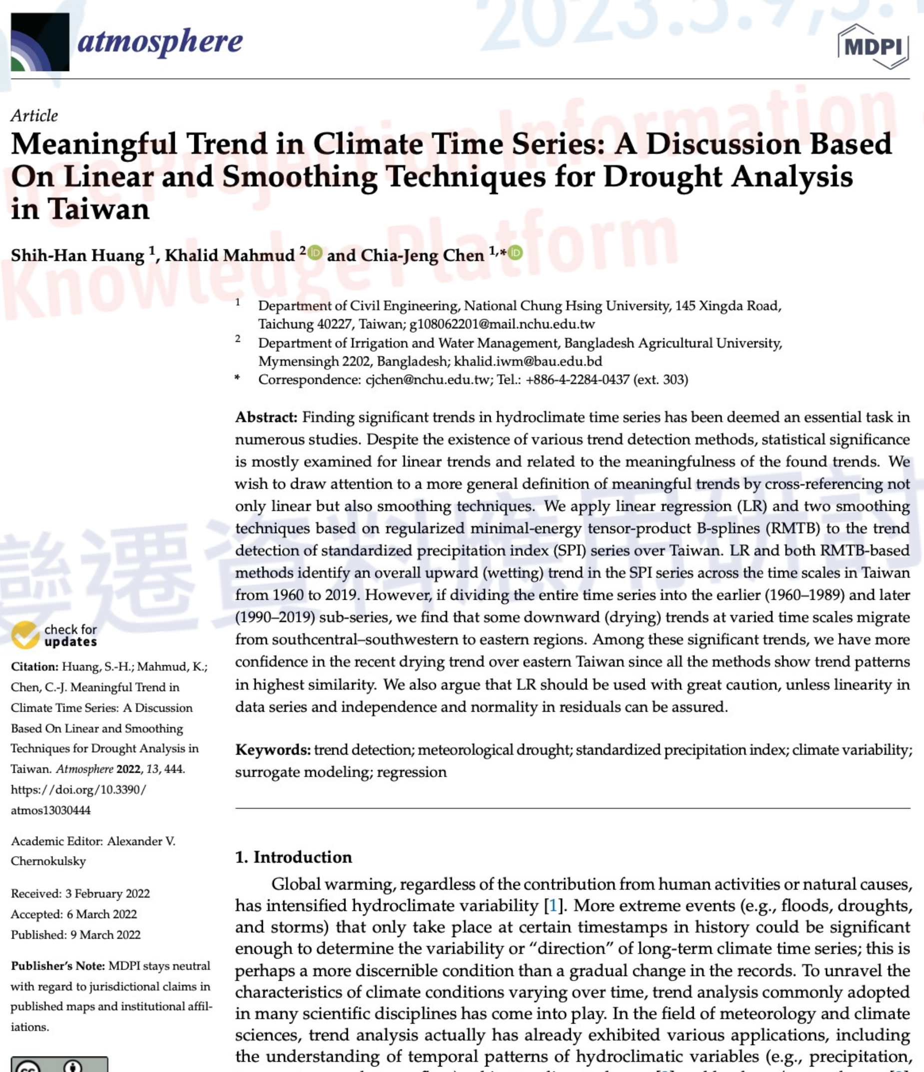
Application III:
Trend Analysis of Taiwan's Drought

Motivation and Scope

- Classic trend detection methods (e.g., linear regression, Mann-Kendall, Theil-Sen slope) have been used for a long time, yet some new methods have been (or will be) developed.
- We wish to argue that the discrepancy or similarity between trend detection results should be a useful indicator of the existence of real or "meaningful" trend.



atmosphere MDPI

Article

Meaningful Trend in Climate Time Series: A Discussion Based On Linear and Smoothing Techniques for Drought Analysis in Taiwan

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Abstract: Finding significant trends in hydroclimate time series has been deemed an essential task in numerous studies. Despite the existence of various trend detection methods, statistical significance is mostly examined for linear trends and related to the meaningfulness of the found trends. We wish to draw attention to a more general definition of meaningful trends by cross-referencing not only linear but also smoothing techniques. We apply linear regression (LR) and two smoothing techniques based on regularized minimal-energy tensor-product B-splines (RMTB) to the trend detection of standardized precipitation index (SPI) series over Taiwan. LR and both RMTB-based methods identify an overall upward (wetting) trend in the SPI series across the time scales in Taiwan from 1960 to 2019. However, if dividing the entire time series into the earlier (1960–1989) and later (1990–2019) sub-series, we find that some downward (drying) trends at varied time scales migrate from southcentral–southwestern to eastern regions. Among these significant trends, we have more confidence in the recent drying trend over eastern Taiwan since all the methods show trend patterns in highest similarity. We also argue that LR should be used with great caution, unless linearity in data series and independence and normality in residuals can be assured.

Keywords: trend detection; meteorological drought; standardized precipitation index; climate variability; surrogate modeling; regression

check for updates

Citation: Huang, S.-H.; Mahmud, K.; Chen, C.-J. Meaningful Trend in Climate Time Series: A Discussion Based On Linear and Smoothing Techniques for Drought Analysis in Taiwan. *Atmosphere* **2022**, *13*, 444. https://doi.org/10.3390/atmos13030444

Academic Editor: Alexander V. Chernokulsky

Received: 3 February 2022
Accepted: 6 March 2022
Published: 9 March 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Global warming, regardless of the contribution from human activities or natural causes, has intensified hydroclimate variability [1]. More extreme events (e.g., floods, droughts, and storms) that only take place at certain timestamps in history could be significant enough to determine the variability or "direction" of long-term climate time series; this is perhaps a more discernible condition than a gradual change in the records. To unravel the characteristics of climate conditions varying over time, trend analysis commonly adopted in many scientific disciplines has come into play. In the field of meteorology and climate sciences, trend analysis actually has already exhibited various applications, including the understanding of temporal patterns of hydroclimatic variables (e.g., precipitation,

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Standardized Precipitation Index (SPI) and Regularized Minimal-Energy Tensor-Product Spline (RMTS)

- SPI at 3-, 6-, 9-, and 12-month periods were derived for trend analysis.
- Two types of splines are available: RMTB (B-spline) and RMTC (cubic Hermite spline).
- Two trend detection methods based on RMTC were used: (1) Locally Weighted Least Squares Regression or LOcally Estimated Scatterplot Smoothing (LOESS) and (2) using first derivatives.

$$SPI_q = \frac{P_q - \overline{P_q}}{S_{P_q}}$$

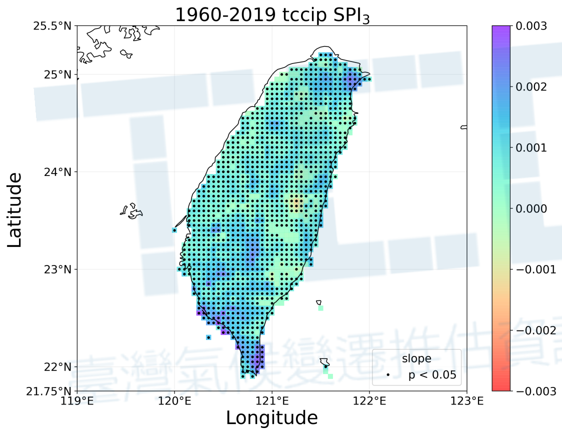
$$y = F(x)w$$

$$F(x) = \sum_{i_1,\ldots,i_{n_x}} b_{1,i_1}(x_1)\cdots b_{n_x,i_{n_x}}(x_{n_x})$$

$$\min_w \frac{1}{2} w^T H w + \frac{1}{2}\beta w^T w + \frac{1}{2}\frac{1}{\alpha}\sum_i^{n_t}\left[F\left(x_t^{(i)}\right)w - y_t^{(i)}\right]^2$$

Trend Analysis Results

(a)



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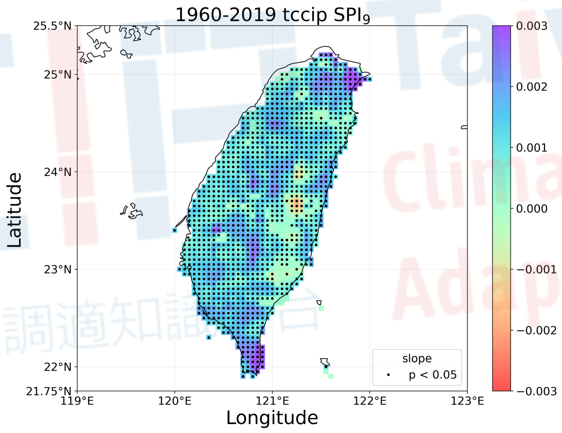

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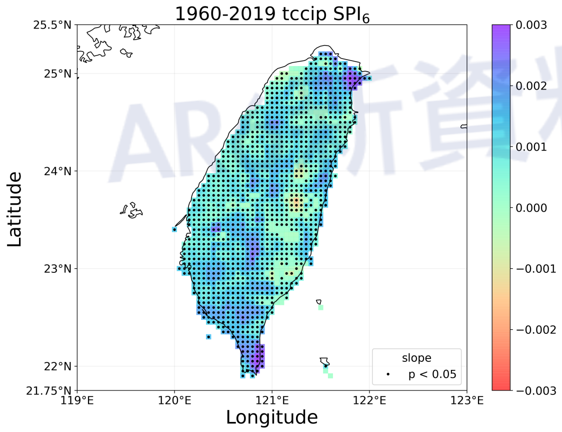

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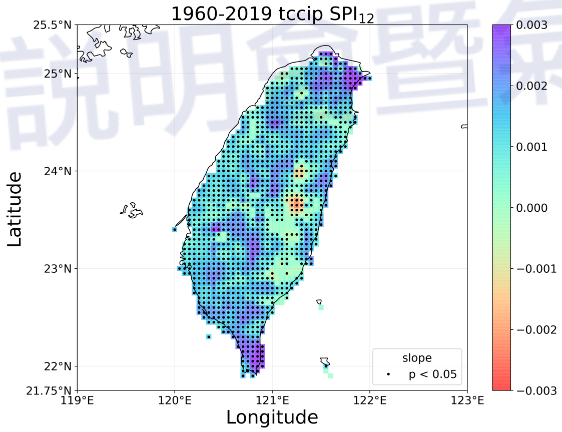
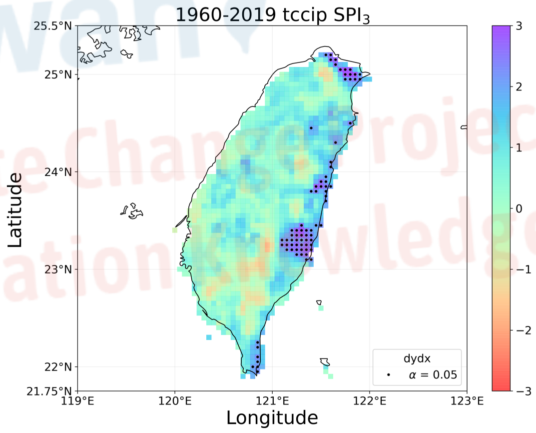


Linear Regression

(a)



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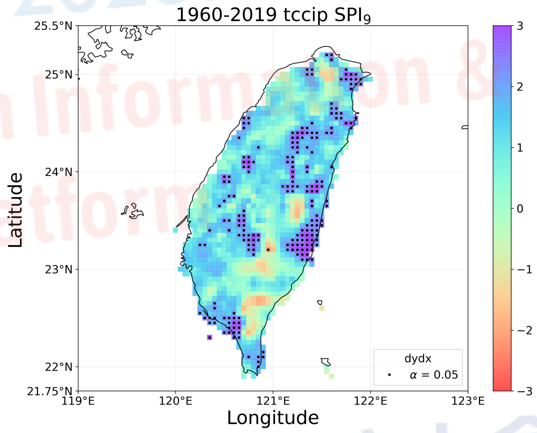

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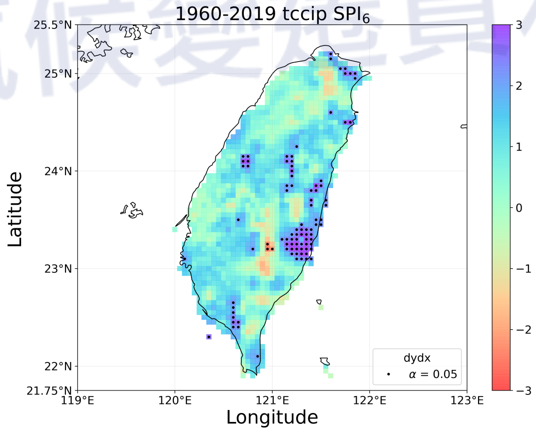

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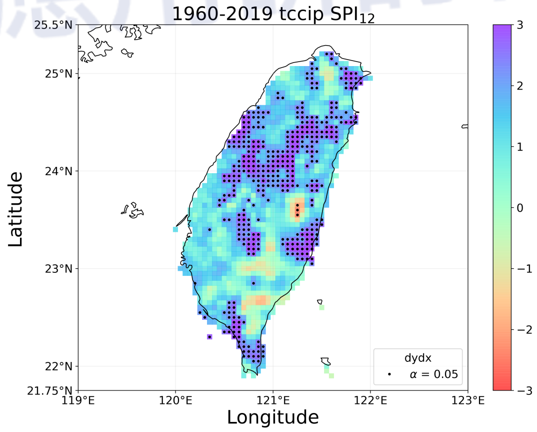
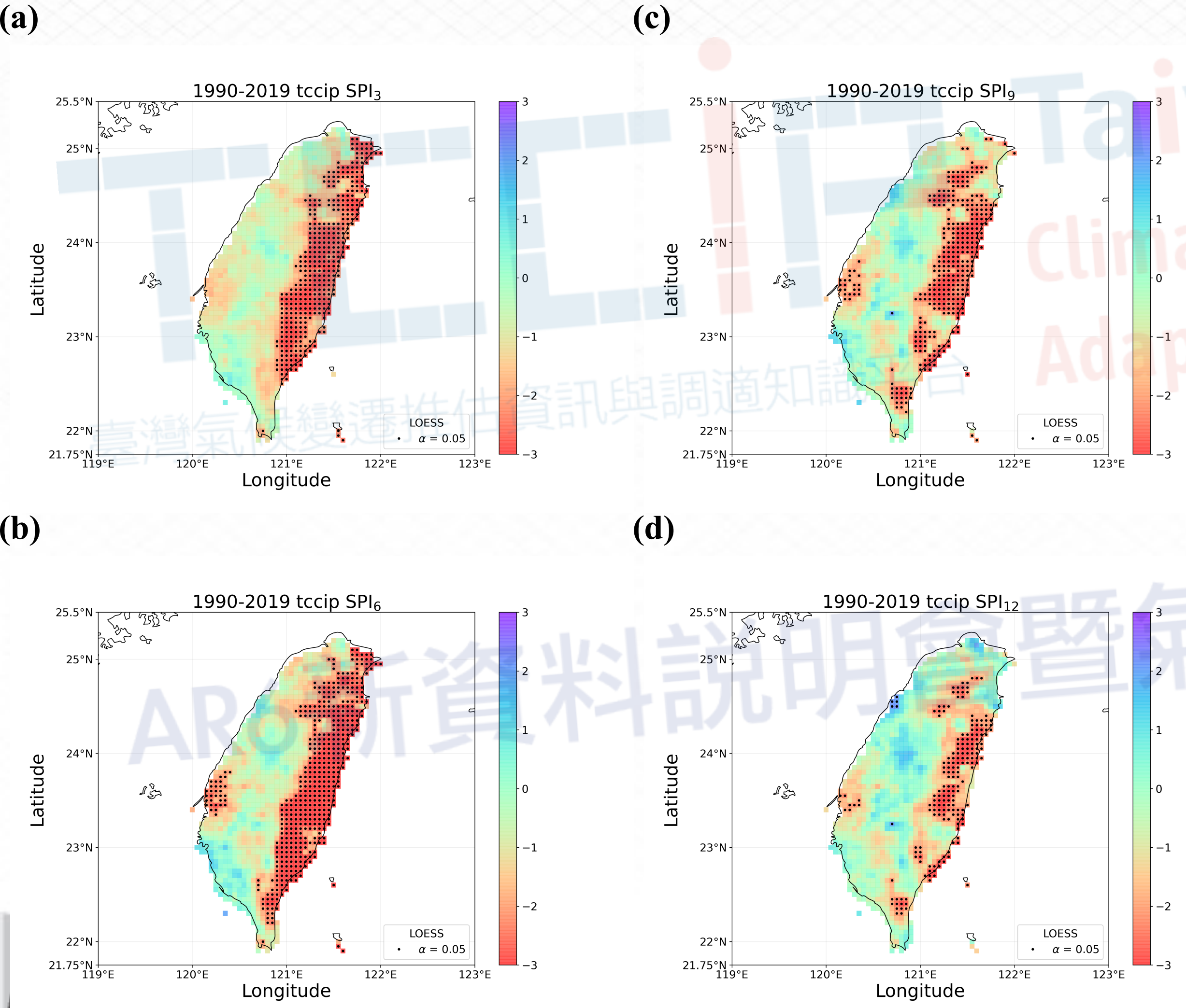
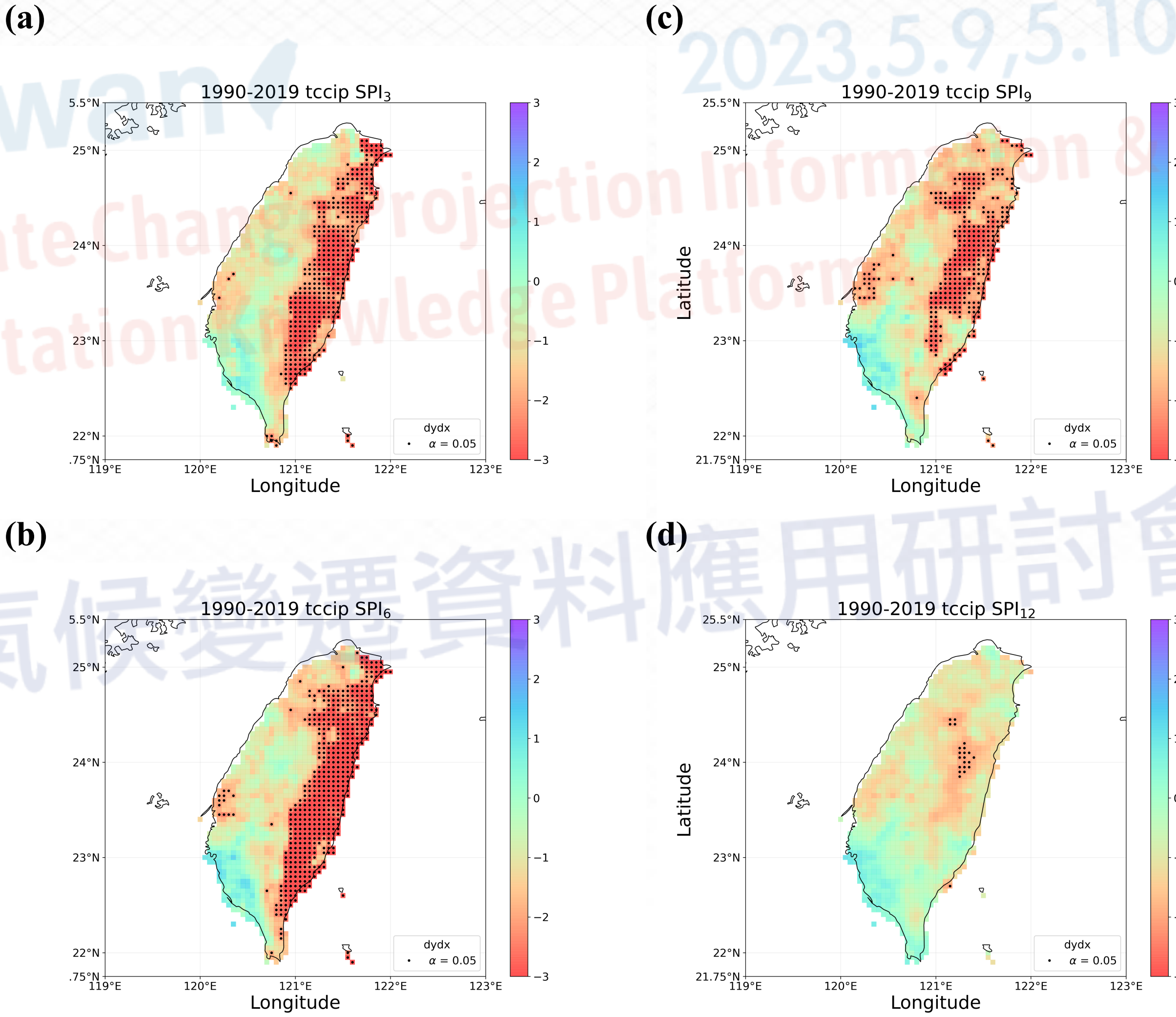


First derivatives of RMTB

Trend Analysis Results (cont’d)



LOESS of RMTB, 1990~2019



First derivatives of RMTB, 1990~2019

App. III Takeaway

Table 1. Pattern correlations between detected trend in the SPI using one of the three methods and that using another method over three different time periods. The first, second, and third values in each parenthesis indicate correlations derived from the paired methods: linear regression (LR) vs. first derivative; LR vs. locally estimated scatterplot smoothing (LOESS), and first derivative vs. LOESS, respectively. Correlation values greater than 0.35 are in bold.

Time Period	SPI3	SPI6	SPI9	SPI12
1960–2019	(0.03, 0.02, **0.67**)	(0.04, 0.05, **0.74**)	(0.09, 0.10, **0.66**)	(0.19, 0.22, **0.68**)
1960–1989	(0.04, 0.06, **0.79**)	(0.03, 0.22, **0.44**)	(0.26, 0.23, **0.37**)	(0.01, 0.19, 0.08)
1990–2019	(0.32, **0.36**, **0.91**)	(**0.40**, **0.38**, **0.86**)	(**0.49**, **0.52**, **0.71**)	(0.28, **0.40**, 0.13)

- When all the methods reached a consensus in the patterns of detected trends with significance, intuitively we could have more confidence in such detected trends.
- While the general wetting trend was identified over a great portion of Taiwan’s territory in the past 60 years, some migrations of drying or wetting trends actually took place in different time intervals.

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Application IV:

Water Resources Availability into the Future

Motivation and Scope

- Using the Budyko framework (instead of hydrological modeling) for assessing future water resources in Taiwan.
- It would be better to conduct a transboundary assessment accounting for the entire set of basins, rather than isolated ones, within a domain.

Ecological Indicators 146 (2023) 109808

Contents lists available at ScienceDirect

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Original Articles

Assessing future availability of water resources in Taiwan based on the Budyko framework

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ARTICLE INFO

Keywords:
Climate change
RCP
Drought
Hydroclimate
Sustainable development

ABSTRACT

Assessing water resources availability in a changing climate is a determinant of promoting sustainable development in a region. Such assessment should better be inter-basin in order to unveil a region's overall risk, so a time-varying Budyko framework is developed and adopted in this study. Gauge-based gridded precipitation and temperature, in company with runoff data, were used to derive the Budyko curves for 75 catchments over Taiwan. Downscaled precipitation and temperature data from selected global climate models and Representative Concentration Pathways (RCPs) were then used to calculate the shifts in the Budyko space of each catchment. It was found that the Budyko-related variables (e.g., evaporative and aridity indices, and catchment-specific parameter) exhibited considerable variability island-wide, with a few outliers in certain catchments being modulated by distinct landscape features and/or human activities. Under all RCPs analyzed, the majority of catchments showed the magnified movement vectors pointing at the 1st quadrant in the Budyko space in the late-21st century, suggesting a predominant and aggravating drying trend over Taiwan. Cluster analysis of the movement vectors under RCP8.5, which entailed the least inter-model differences, identified three major clusters, two of which (64 catchments included) indicated a drying trend of varied significance. According to our findings, without effective mitigation of climate change, an increased likelihood of the worst-case scenario will substantialize the reduced availability of Taiwan's water resources.

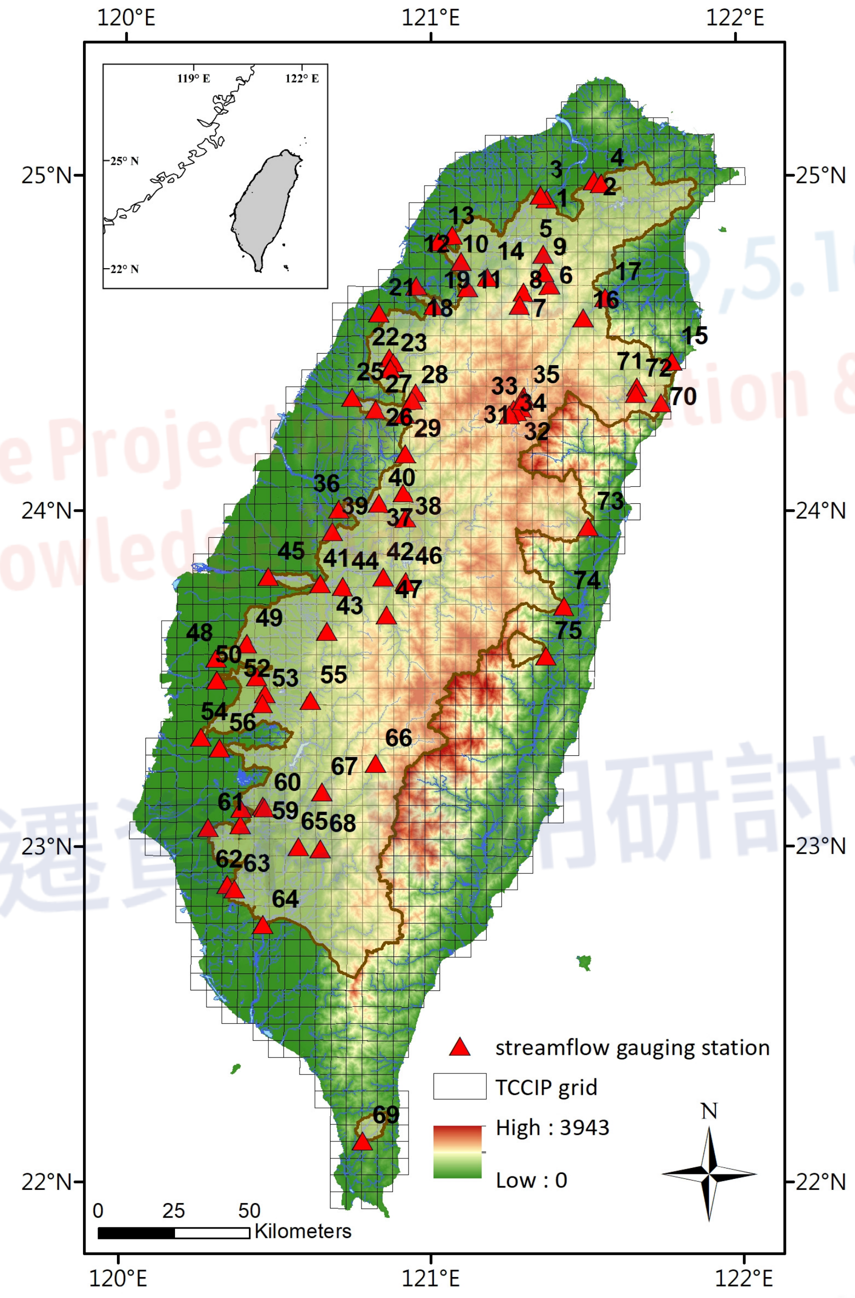
1. Introduction

Along with the increasing trend of the world population and water demand, climate change has heightened enormous tension between users and available water resources over many regions (Gosling and Arnell, 2016; Qin et al., 2019; Vörösmarty et al., 2000). Mekonnen and Hoekstra (2016) pointed out approximately 4 billion people are subject to extreme water shortage for at least one month of a year, and 1.8 billion people even have to deal with water shortage lasting for six months or longer. If employing the Shared Socioeconomic Pathways (SSPs) to make projections for the future, Munia et al. (2020) disclosed a 50 % increase in population under water stress in a path of sustainability (SSP1) by the mid-21st century; such percentage might even double in a path of high population growth (SSP3)

geological properties. However, hydrological modeling-based assessments filled with parameter and/or model uncertainties can sometimes be disputed. In contrast, a simplified analysis framework has been proposed by Budyko (1974), who made use of only precipitation (P), potential evapotranspiration (PET), and actual evapotranspiration (AET) to dissect regional water balance contingent upon hydroclimatic and catchment characteristics. With a less transient temporal scale (e.g., monthly or longer), the expensive measurement of AET can be replaced with the estimate from the water balance equation in the Budyko framework (Ning et al., 2018). Such advantage has demonstrated the usefulness of the Budyko framework in plentiful water resources assessments, leading to a resurgence of Budyko-related studies in recent years (e.g., Zhang et al., 2012; Xu et al., 2013; Greve et al., 2015; Wang et al., 2016; Wang et al., 2021).

Data

- 5-km TCCIP precipitation and temperature from 1960 to 2017
- TCCIP's statistically downscaled data in future scenarios (AR5)
- Potential evapotranspiration (PET) is derived from the Thornthwaite equation.
- Actual evapotranspiration (AET) is derived from the long-term mean of water balance.



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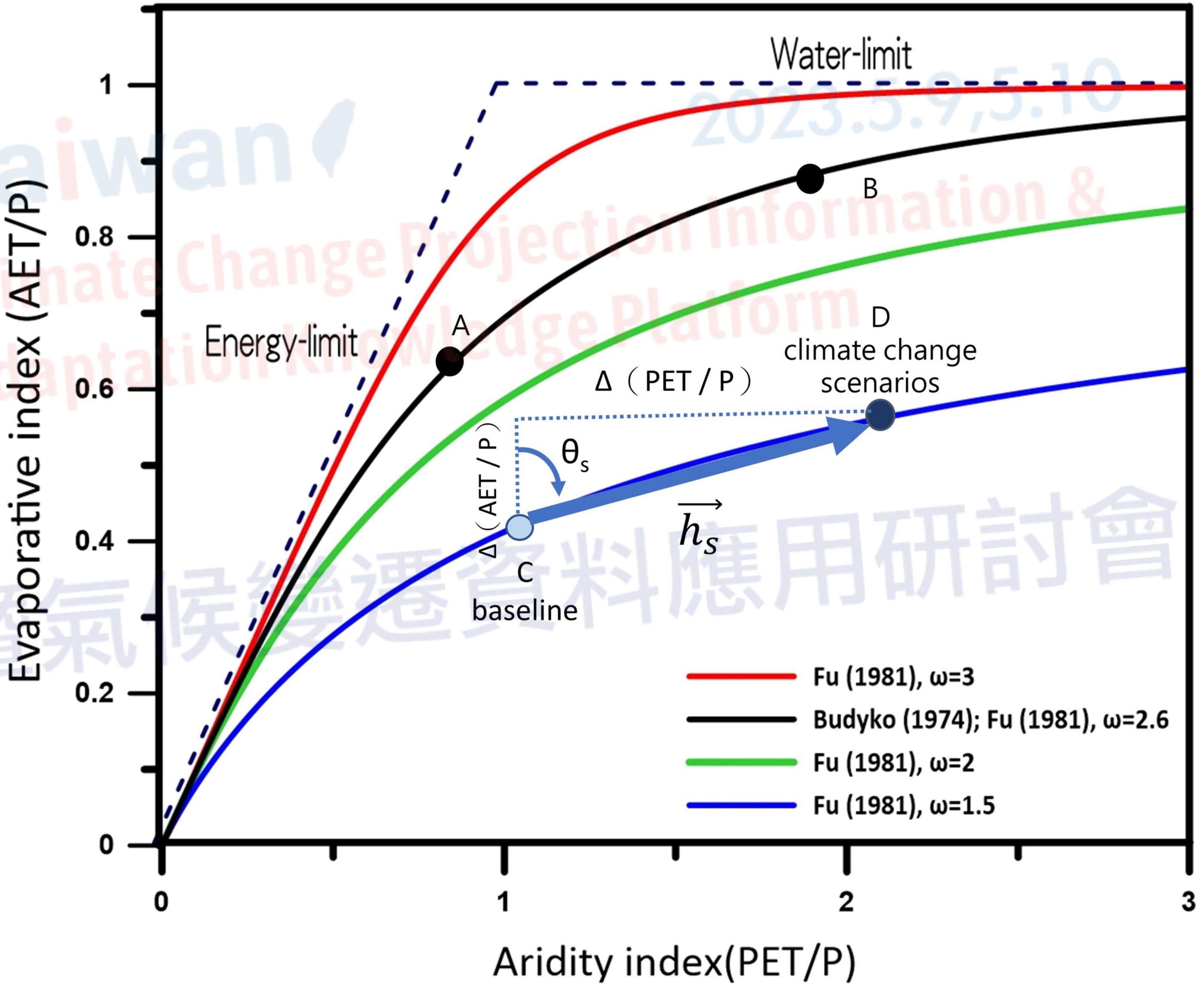
Parametric Budyko Equation

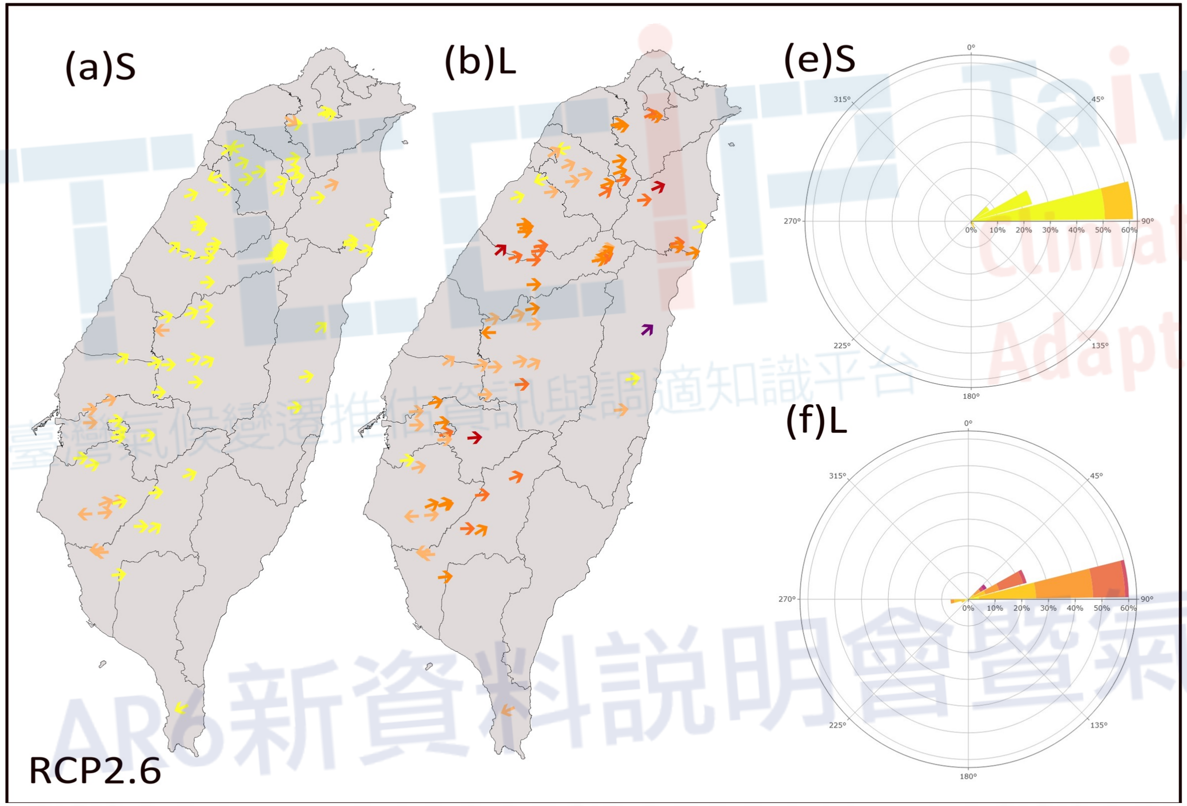
$$\frac{AET}{P} = 1 + \frac{PET}{P} - \left[1 + \left(\frac{PET}{P}\right)^{\omega}\right]^{1/\omega}$$

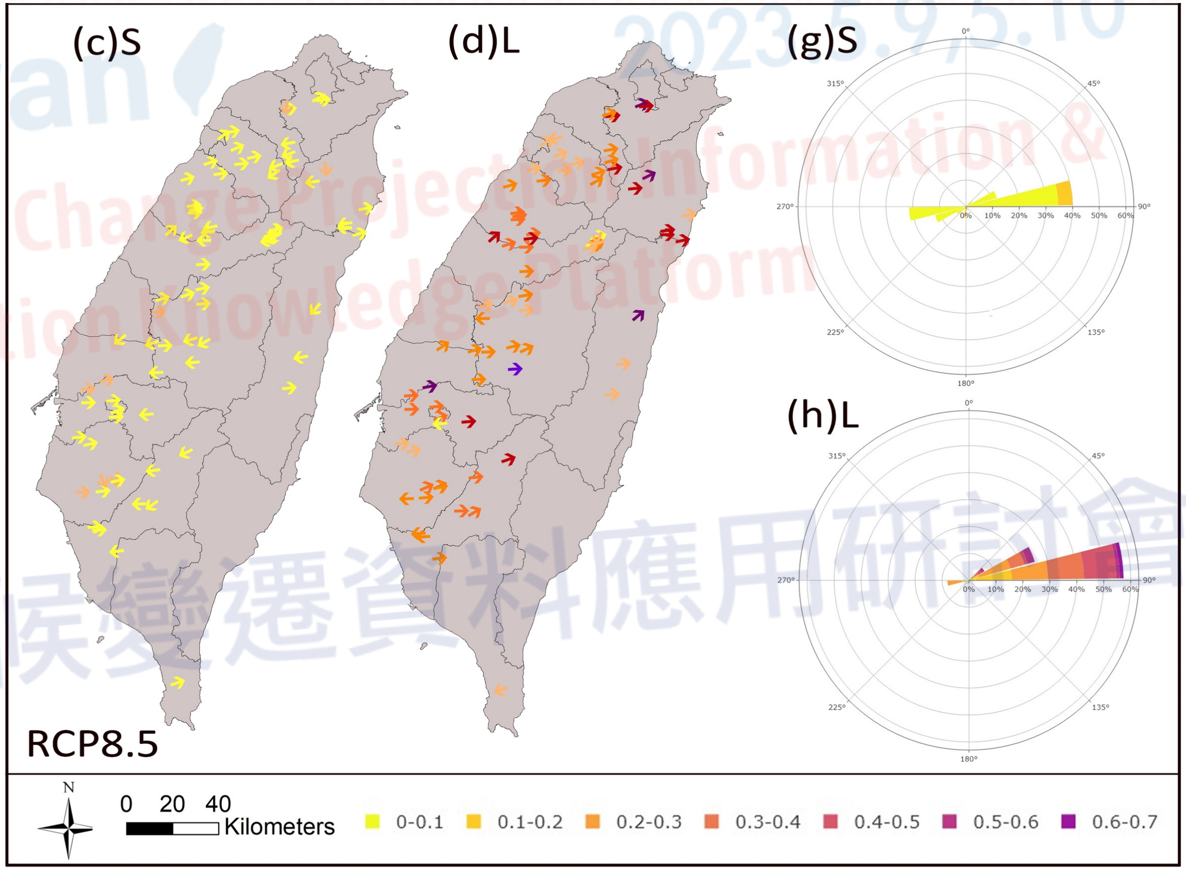
$$I_s = \left|\overrightarrow{h_s}\right| = \sqrt{\left(\Delta\frac{PET}{P}\right)^2 + \left(\Delta\frac{AET}{P}\right)^2}$$

$$\theta_s = b - \left(\left(\arctan\frac{\Delta\frac{AET}{P}}{\Delta\frac{PET}{P}}\right) \times 180/\pi\right)$$



Assessment Results





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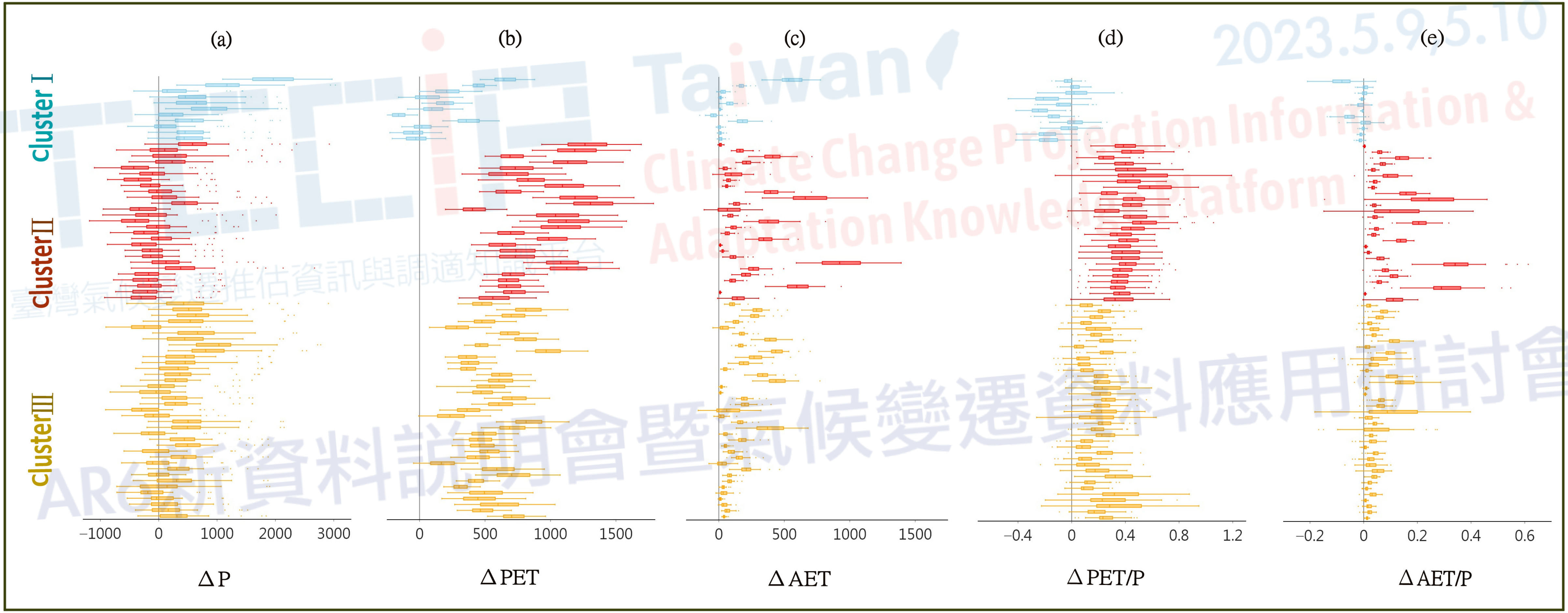
Assessment Results (cont'd)



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App. IV Takeaway

- Nearly 90 % of catchments exhibited the shift towards the 1st quadrant in the Budyko space, with a narrow range of direction from 70 to 80° and the magnified movement vectors in the late-21st century, suggesting a predominant and aggravating drying trend over Taiwan.

- Both Clusters II and III showed a drying trend of varied significancy, implying 64 out of the 75 catchments in Taiwan analyzed will be forced to deal with a shortfall in water resources availability into the future.

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Conclusions

Concluding Remarks

- TCCIP datasets/products are tremendously useful for various and many hydrometeorological applications.

- We look forward to seeing and using more and updated versions of TCCIP datasets/products.

Thank you!

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