出國報告（出國類別：短期進修）

美國加州大學短期進修
-以衛星資料估算降雨強度

服務機關：空軍航空技術學院
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派赴國家/地區：美國/加州爾灣
出國期間：**108** 年 **7** 月 **20** 日至 **109** 年 **7** 月 **29** 日
報告日期：**109** 年 **8** 月 **19** 日

摘要

本次短期進修訓期自 108 年 7 月 25 日至 109 年 7 月 24 日，共計 1 年。短期進修地點為美國加州大學爾灣分校，短期進修的科系為土木及環境工程系所屬之水文遙測中心(Center for Hydrometeorology and Remote Sensing, CHRS)，短期進修期間工作主要以閱讀最新衛星降雨估算相關文獻、課堂上課以及與 CHRS 所屬教授們共同討論研究，並將研究相關成果在 108 年 12 月 9-13 日於舊金山舉辦之「American Geophysical Union, AGU 國際研討會」上發表，最後將成果發表於「Asia-Pacific Journal of Atmospheric Sciences」國際期刊。本報告內容分別為基本資料、研究計畫背景、研究步驟、目的及過程、研究成果呈現、心得與建議以及附錄。

目錄

壹、基本資料

一、原屬單位：空軍航空技術學院

二、派訓單位：空軍航空技術學院一般學科部軍事氣象系

三、經費來源：科技部

四、出國時間：108 年 7 月 20 日

五、返國時間：109 年 7 月 29 日

六、短期進修地點及校名：美國加州大學爾灣分校 (University of California, Irvine) 土木及環境工程系所屬水文遙測中心(Center for Hydrometeorology and Remote Sensing, CHRS)

七、CHRS 成員：中心主任(Director) Sorooshian 教授、副主任 Kuolin 教授及 Phu 教授，以及幾位博士研究員跟博士班學生。

貳、研究計畫背景

台灣四面環海，一年四季都由不同的天氣系統所造成的降雨現象，不論是颱風本身降雨或是颱風所引進(發)其它天氣天氣系統(例如西南氣流、強對流等)，以及 5-6 月常見的梅雨鋒面，都會對台灣地區降下豪大雨，不僅造成台灣人員傷亡及財產損失，更重創國家基礎建設。因此，本研究希望透過氣象衛星來估算可能的降雨，進而防範天然災害所造成的損失，“豪大雨防災”的預警作業，也是目前迫切需要積極研究的重要課題之一。

利用衛星微波資料估算海上降雨最直接的方法為 Wilheit et al. (1980)以衛星觀測的 TB 與地面觀測站的 RR 建立其關係式，緊接著 80 及 90 年代陸續有學者利用衛星資料估算降雨強度(Wilheit 1986, Petty, 1994, Ferraro et al. 1995)，Ferraro et al. (1996)發表文章來改善自己於 1995 年發表的降雨反演式外，也提出微波資料演算法比紅外線資料演算法可以更精確地估算瞬間降雨量。到了 2000 年代已有許多學者利用星載被動式微波頻道來估算 RR (Adler et al. 2001, Chen and Li 2002, Levizzani et al. 2002, Yeh et al. 2015)。因為不同的微波頻道有不同的物理特性與降雨反演的極限，所以 Liu et al. (2002)及 Joyce et al. (2004)結合多頻道的觀測資料來進行降雨的反演，主要目的是擷取各頻道的

優點以增加降雨反演的動力範圍(Dynamic Range)。

參、研究步驟

本研究步驟為使用地球同步衛星的紅外線資料估算降雨擁有高時間解析度的優點，而利用繞極軌道衛星或低軌道衛星的被動微波資料因可以穿透雲層，有估算之降雨的準確度大於紅外線資料所估算之降雨的優點。類似 Kidd et al. (2003)結合了被動微波資料與 IR 資料來估算降雨，提供每 30 分鐘一筆降雨估算資料，來解決僅使用繞極軌道衛星時間解析度不足的問題。

本研究使用的 GSMaP 也就是結合了紅外線資料及微波資料的降雨產品，基本原理為先使用準確度較高的微波資料估算降水，再利用較高時間解析度的紅外線資料填補(Mapping)空缺的資料，也就是說，此方法結合了紅外線資料高時間解析度及微波資料高準確度之優點。本研究使用近 15 年(2001 年-2015 年)的 5 月份符合世界氣象組織 WMO 大雨的 20 個梅雨鋒面個案分別進行定性及定量的分析比較，藉以了解 GSMaP 與 CWB 間的資料特性。

Yamamoto et al. (2015)採用某演算法來改善 GSMaP 在亞洲地區的降雨估算，顯見使用 GSMaP 降雨產品需要依地區做適當的修正。陳，1994 及陳，2007 指出梅雨期的強降雨與台灣複雜的地形息息相關，而分布於台灣各地的 425 測站分布甚廣(最低為 4 公尺，最高 3402 公尺，故本研究為了找出 GSMaP 降雨在台灣地區最佳的地形分類，特別做了 4 種地勢高度分類，並從 20 個個案中的選擇 18 個個案(表 1 中的個案編號 1 至編號 18)，總共 7650 樣本數分析探討哪一組地勢高度的分類最適合 GSMaP 在台灣地區使用。

肆、目的及過程

該研究的成果可應用於台灣地區的梅雨降雨強度的估算，藉由修正方程式的修正衛星估算降雨強度，讓使用者可以得到更接近實際的降雨強度，對於豪大雨的預警及防災策略可有正面助益，而其研究成果將可提供(或移轉)台灣各氣象預報作業單位參考。另外，課堂上課可吸收 UCI 多元上課方式及技巧以及多元評分，提供返國(校)教學時應用。

此次短期進修的起迄日為 108 年 7 月 25 日至 109 年 7 月 24 日，為了能夠準時於短期進修首日進入狀況，提早至 108 年 7 月 20 日啟程前往美國加州大學爾灣分校(UCI)，經過數日的時差調整、住宿、交通等生活起居安置，於 108 年 7 月 25 日至 UCI 國際中心報到，開始為期一年的短期進修，期間除了定期與 CHRS 教授們進行討論及意見交流外，也與該中心研究生進行交流，學期中也前往課堂上課，學習不同國家的上課方式、評量方式等。短修期間適逢「American Geophysical Union, AGU 國際研討會」在舊金山舉辦，該研討會為地球科學領域年度規模最大的研討會，CHRS 所有教授、研究員及博士班學生皆會前往參與並發表研究成果，我也將部分研究成果投稿 AGU，並前往舊金山參加其研討會。除此之外，也趁 UCI 上課、研究之餘，前往揚克斯航空博物館參觀各式各樣的飛機，其中包含台灣自製的經國號，亦有當時馬英九總統的簽名紀念；至聖地牙哥參觀已退役的航空母艦，以及前往德州休士頓參觀太空中心，增廣見聞。

但因為 109 年 3 月因為冠狀肺炎爆發，學校全面禁止面對面上課、交談等，故從 3 月開始到 7 月返國，所有的教學、研究活動皆改為遠端線上進行，藉由利用線上授課，線上討論開會等方式繼續未完成的課程及研究進度，直至 109 年 7 月底返國，返國航班也因為新冠肺炎更改，並較預期返國日期延後數天。

伍、研究成果呈現

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ORIGINAL ARTICLE

Bias Adjustment of Satellite Precipitation Estimation Using Ground-Based Observation: Mei-Yu Front Case Studies in Taiwan

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Abstract

The Global Satellite Mapping of Precipitation (GSMaP) was used to estimate the accumulated rainfall in May from the Mei-Yu front in Taiwan. Rainfall estimation from GSMaP during 2002–2017 were evaluated using more than 400 local gauge observations, collected from the Taiwan Central Weather Bureau (CWB). Studies have demonstrated that the GSMaP rainfall estimation estimates can be biased, depending on the target region, elevation, and season. In this experiment, we have evaluated GSMaP over three elevation ranges. The GSMaP systemic errors for each elevation range were identified and corrected using regression analysis. The results indicated that GSMaP estimation can be improved significantly through adjustment over three elevation ranges (elevation less than 50 m, elevation of 50–100 m, and elevation higher than 100 m). For these three elevation ranges, the correlation coefficient between the GSMaP estimations and CWB rainfall data was 0.76, 0.78, and 0.59, respectively. This indicated that the GSMaP estimation was more accurate for low-elevation regions than high-elevation regions. After the proposed approaches were employed to correct the errors, the bias errors were respectively improved by 5.64(13.7%), 7.33(38.4%) and 10.52(31.2%) mm for low-, mid- and high-elevation regions. This study demonstrated that the local correction approaches can be used to improve GSMaP estimation of Mei-Yu rainfall in Taiwan.

Keywords Mei-Yu front · Global satellite mapping of precipitation (GSMaP) · Accumulated rainfall · Regression equation

1 Introduction

The Mei-Yu front is the main source of rainfall in Taiwan in May. Because of continuous rainfall during the Mei-Yu season, the soil water content is high, which causes natural disasters such as rockfalls, landslides, mudflows, and floods in several low-lying areas. Moreover, when the rain is heavy, traffic accidents, including car, shipping, and aviation accidents, are more frequent because of low visibility. Nonetheless, Mei-Yu rain is a major source of water in Taiwan and is essential for water resources management, especially for agriculture and the domestic water supply.

Satellite observation is not affected by obstacles (e.g. a mountain) and is clearly useful for estimating rainfall in regions with various landforms. Satellite-derived precipitation is classified into two categories by data resource. One is infrared/visible observation form geosynchronous satellites (D'Souza et al. 1990 ; Vicente et al. 1998; Porcu et al. 1999; Delgado et al. 2008), the other one is the passive microwave observation from low Earth orbiting satellites or from Polar orbiting satellites (Petty 1994; Ferraro and Marks 1995; Ferraro et al. 1996; Yeh et al. 2015). Different sensors have different characteristics and advantages. For instance, the infrared data collected by geosynchronous satellites have high temporal resolution, but the passive microwave data obtained by polar- or low-orbiting satellites enable more accurate rainfall estimation than do infrared data. The introduction and comparison of different channels precipitation products can be found from Adler et al. (2001) and Levizzani et al. (2002).

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Some studies represented retrieval algorithms of rainfall data by analyzing the data obtained from both infrared and passive microwave channels (Todd et al. 2001; Chen and Li 2002; Liu et al. 2002; Kidd et al. 2003; Joyce et al. 2004; Huffman et al. 2007). The Global Satellite Mapping of Precipitation (GSMaP) rainfall estimation used in this study is the combination of infrared and passive microwave data. Hence, the GSMaP product was able to utilize the advantages of these distinct channels, increasing the feasibility of rainfall retrieval (Kubota et al. 2007; Seto et al. 2009; Ushio et al. 2009; Aonashi et al. 2009; Yamamoto and Shige 2015, 2017).

Numerous papers report that heavy rainfall during Mei-Yu seasons is closely related to the topographic complexity of Taiwan (Chen 1994; Chen 2007), with studies having employed numerical analysis to determine topographic influences on rainfall (Chu and Lin 2000; Chen and Lin 2005; Chen et al. 2008). Accordingly, the topographic complexity in Taiwan is likely to affect the rainfall estimation of the Global Satellite Mapping of Precipitation (GSMaP). This is exactly indicated that certain adjustments were necessary when using the GSMaP product.

The biases and random errors of satellites-retrieval rainfall product have significant differences in terms of location, season, terrain and atmospheric conditions (Dinku et al. 2011; Sorooshian et al. 2011). Therefore, many studies have been conducted to validate satellite-derived rainfall estimations at different scales and regimes. Such as Africa (Dinku et al. 2007; Hughes 2006; Thiemig et al. 2012; Zhou et al. 2014), Indonesia (Vernimmen et al. 2012), U.S. (AghaKouchak et al. 2011; Zhou et al. 2014), Australia (Zhou et al. 2014), Bangladesh (Rahman et al. 2012; Islam 2018). There is very limited reference related to the validation and correction of satellite-derived precipitation products over Taiwan, which is the main focus of this study.

There are many methods to reduce the bias of satellite-derived rainfall estimation by the additive or multiplicative bias against reference data (i.e., rain gauge observations). For example, using the differences between gauges and the satellite-derived rainfall, and consider the inverse distance weighting to reduce the bias (Boushaki et al. 2009). A method of reducing bias by blending gauge data with multiple satellite-derived rainfall (Lin and Wang 2011). Remove rainfall estimation bias by using satellite-derived, radar, and gauge rainfall products (Tesfagiorgis et al. 2011). A probability-based bias adjustment approach for satellite-derived rainfall using a qxuantile mapping technique.(Yang et al. 2016).

This study estimated the intensity of rainfall from the Mei-Yu front in Taiwan by using satellite data. The aforementioned studies have indicated that researchers should use different GSMaP retrieval algorithms according to the target season, region, and elevation when making rainfall estimates. Such considerations enable more accurate estimation of rainfall intensity, which was the aim of the present study. Such estimates would enable the authorities to inform people of the possible rainfall intensity during Mei-Yu seasons. Furthermore, governmental units (e.g. disaster prevention and response teams and reservoir administrations) would be able to prepare for heavy rains in advance and thus prevent disasters.

2 Data Collection and Analysis

Data were obtained from two sources, namely (1) the GSMaP and (2) Taiwan Central Weather Bureau (CWB) rain gauge observations. We collected 16 years (2002–2017) data on the Mei-Yu front in May–June each year. The rainfall for each year met the standard for heavy rain (Greater than or equal to 50 mm in the past 24 h) specified by the World Meteorological Organization (WMO). A total of 22 front data were collected, the dates of which are presented in Table 1.

2.1 GSMaP

The GSMaP was developed by the Japan Science and Technology Agency. This product combines microwave and infrared techniques and covers the area between the latitudes of 60° North and 60° South. The temporal resolution is one recording per hour, with a spatial resolution of latitude of 0.1°. Currently, GSMaP data are provided by the Japan Aerospace Exploration Agency. The GSMaP product version we analyzed from 2002 to 2014 and from 2015 to 2017 is RNL (Reanalysis Ver.) and NRT. (Near-Real-Time Ver.) respectively.

The GSMaP RR data were retrieved from the microwave imager and sounder. The retrieval algorithm for the imager was based on the method proposed by Aonashi and Liu (2000); that for the sounder was based on the method of Shige et al. (2009), who incorporated features of the emission-based estimate from T_B at 23 GHz and a scattering-based estimate from T_B at 89 GHz. The algorithm is suitable for estimating the rainfall intensity at the sea surface.

2.2 Data from the CWB Observation Stations

The CWB observation stations situated over Taiwan (temporal resolution = 1 h; spatial resolution = station-dependent). A total of 425 stations were involved in data collection. The station data contained weather variables of all types. We selected the following variables: longitude–latitude, hourly rainfall, and elevation. The lowest-lying station had an elevation of 4 m, whereas the highest-lying station had an elevation of 3402 m. The longitude–latitude and elevation of each station are depicted in Fig. 1. All rainfall data were subject to CWB quality control to ensure that rainfall observations are correct.

Table 1 Twenty two cases for the Mei-Yu front from 2002 to 2017

Case no.	Date (accumulated rainfall)	Case no.	Date (accumulated rainfall)
1	May 16, 2002	12	May 5, 2008
2	May 22, 2002	13	May 31, 2008
3	May 15, 2003	14	May 7, 2010
4	May 4, 2004	15	May 13, 2011
5	May 31, 2004	16	May 17, 2012
6	May 3, 2005	17	May 28, 2012
7	May 24, 2005	18	May 11, 2013
8	May 23, 2006	19	May 17, 2013
9	May 27, 2006	20	May 22, 2015
10	May 6, 2007	21	June 6, 2016
11	May 19, 2007	22	June 16, 2017

Before conducting analysis on the GSMaP products and CWB-data accumulated rainfall, we had to identify the differences between the time at which GSMaP estimates were calculated and CWB rainfall data were collected. The GSMaP defines the rainfall that accumulates during a certain hour to be the rain that accumulates from minute 00 to minute 59. The CWB defines the rainfall accumulates during a certain hour as the rain that accumulates from minute 00 to minute 59 in the hour before the hour in question.

Therefore, comparing GSMaP and CWB rainfall data must ensure that the data from the two sources were obtained from the same time intervals. Specifically, when the CWB rainfall was selected for hour N, the GSMaP rainfall for hour N + 1 was compared. The GSMaP presented data on a grid map based on 0.1° units of latitude and longitude. The CWB data, however, were in-situ data. Accordingly, we compared the two rainfall data by interpolating the grid point data of GSMaP to the position of CWB stations. In this study, we evaluated daily totals of rainfall by accumulating hourly estimates from GSMaP rainfall.

3 Methods

Previous studies have shown that complex terrain does affect the amount of satellite-derived rainfall. Because two-thirds of the land is mountains and hills in Taiwan, and the overall slope is more than 30 degrees on average. This study has tested different correction methods. In addition to classification of elevation, the satellite-derived rainfall estimation was corrected by using the weighted nearest neighbor, average within a certain domain, inverse distance weighting and so on. The method to get the best results is as follows. We divided the actual data obtained by the Central Weather Bureau (CWB) of Taiwan and the estimation data obtained using the GSMaP into groups on the basis of elevation. Next, the data were compared and analyzed to identify systemic errors in the GSMaP estimations. We then conducted statistics and regression analysis to correct the errors, ensuring that the GSMaP estimates approximated the actual rain rates (RRs).

3.1 Classification of Elevation

The GSMaP and CWB rainfall data during the Mei-Yu season were displayed on diagrams to explore the relationship between the GSMaP and CWB data. For example, on case 2, the rainfall estimated by the GSMaP (Fig. 2b) was lower than that observed by CWB observation stations (Fig. 2a). This difference was possibly attributed to the topographic complexity of Taiwan. The result of underestimation of rainfall estimation by satellites is similar to the findings of Aonashi et al.

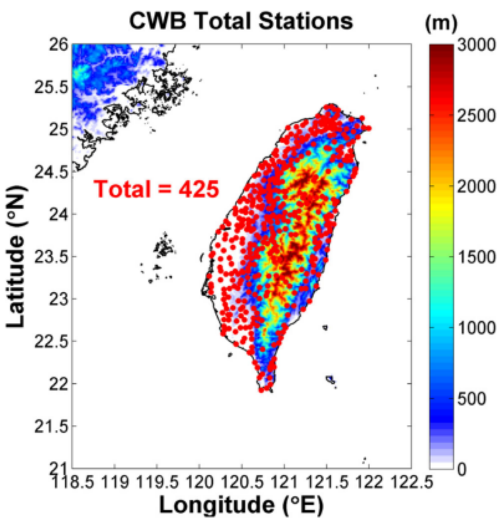

Fig. 1 Location and elevation of the 425 CWB observation stations

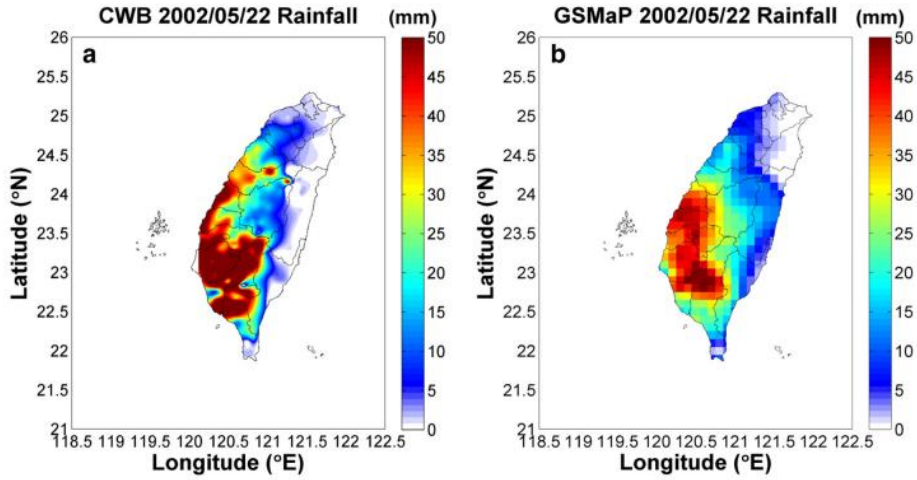

Fig. 2 **a** CWB and **b** GSMaP accumulated rainfall on May 22, 2002

(2009) and Takido et al. (2016). Subsequently, using the elevation categorizations (Table 2), we investigated the relationship between topography and rainfall for the 22 selected datasets. It was found that GSMaP products are compared with observation of stations below 100 m, and the correlation coefficient exceeds 0.75. As the height of the observation station increases, the correlation coefficient begins to decrease. The correlation coefficient is less than 0.6 when the height of observation station is exceeding 100 m. In other words, the accuracy of rainfall estimation by satellites is inversely proportional to the terrain height. The result of relationship between accuracy and terrain height is consistent with Takido et al. (2016).

In order to find the rainfall estimations in Taiwan during Spring, qualitative and quantitative analyses were conducted on the 22 sets of data for the Mei-Yu front in May–June each year from 2002 to 2017 (16 years in total). The definition of heavy rain according to the CWB was met for each set of data. Our objective was to examine and compare the characteristics of the GSMaP and CWB data.

Therefore, to provide the most suitable elevation categorization for GSMaP estimation in Taiwan, we divided the data into elevation categories using four types of categorization. We selected 22 sets of data (cases in Table 1) comprising 9350 samples to determine which of the four categorizations was most suitable for describing Taiwan's landmass. The details of the elevation categorizations are listed in Table 2.

3.2 Confirmation and Correction of Systemic Errors

The four categorization types were then separately used to calculate the coefficients of correlation between the CWB and GSMaP accumulated rainfall data. According to the most adequate categorization of elevation levels determined above, we compared the rainfall data estimated by the GSMaP with the actual rainfall data collected by the CWB stations. Accordingly, the systemic errors in the four types of elevation categorization were identified, and a regression equation was determined by fitting the curve in the GSMaP–CWB scatter plot.

Compare the average correlation coefficients between four categorization types. The average correlation coefficient of Categorization B is greater than 0.7, which is better than the other three categorization types. In addition, the rainfall distribution of higher than 100 m is similar, and the number of stations higher than 100 m is limited. For the above two reasons, we have included elevation of more than 100 m in the same group. Therefore, the Categorization B is considered to be the most suitable categorization for GSMaP application in Taiwan. In this paper, we only discuss the data with what was

Table 2 Elevation categorization of 425 CWB observation stations

Categorization Elevation level	A	B	C	D
Low elevation	<100 m	<50 m	<500 m	<30 m
Middle elevation	100–500 m	50–100 m	500–1000 m	30–150 m
High elevation	>500 m	>100 m	>1000 m	>150 m

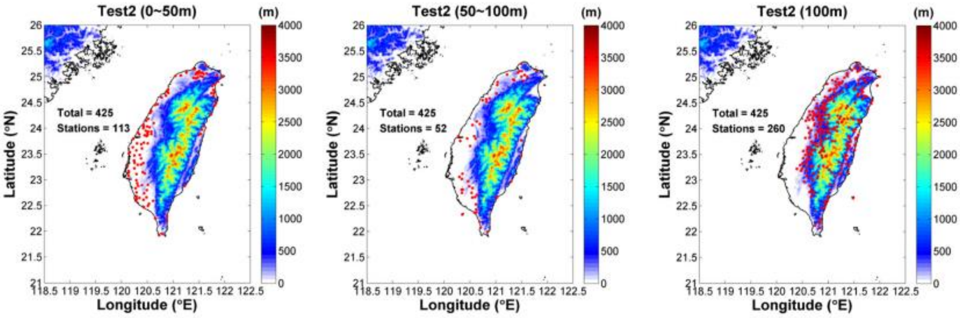

Fig. 3 Rainfall at stations categorized into three elevation groups according to Categorization B

discovered to be the most suitable categorization (i.e. Categorization B).

Finally, the cross-validation for all cases was categorized according to the most suitable categorization scheme to correct the errors in the GSMaP data. Furthermore, regression analysis was performed on these two datasets to revise the GSMaP algorithm. In this way, the accuracy of the RR distribution obtained using the GSMaP was improved.

4 Results and Discussion

4.1 Identifying the most Suitable Categorization of Elevation

In Categorization B, the data were divided into categories of elevation of 50 m and lower, 50–100 m, and 100 m and higher. Among the 425 stations, 113 stations had elevations of 50 m

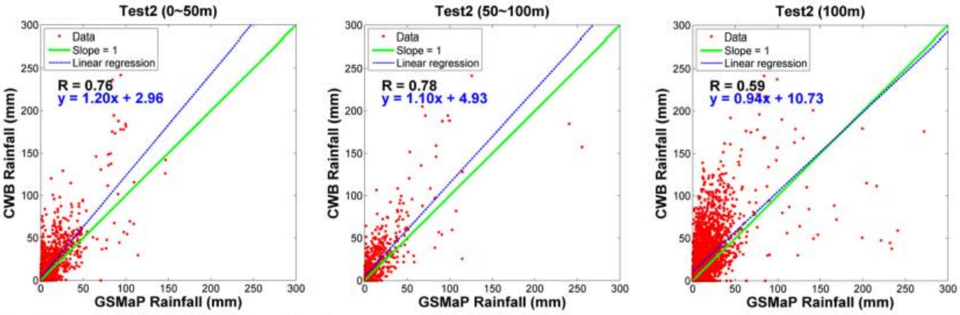

Fig. 4 Linear regression curves of the three elevation groups

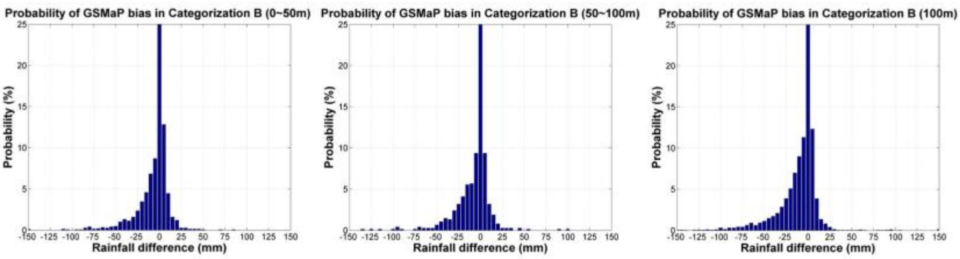

Fig. 5 Probability distribution of the three elevation groups

Table 3 Average rainfall errors of the three elevation groups according to Categorization B

Group	Low elevation	Middle elevation	High elevation
Rainfall error	−5.78 (mm)	−7.51 (mm)	−10.71 (mm)

or lower; 52 stations of 50–100 m; and 260 stations of 100 m and higher (Fig. 3).

We compared the GSMaP and CWB accumulated rainfall scatter plots for the stations in the three elevation groups according to Categorization B. Linear regression analysis was then performed to plot the trend lines, which are presented in Fig. 4. The x-axis and y-axis represent the CWB and GSMaP accumulated rainfall (mm). Each red dot corresponds to an individual rainfall datum; the green lines depict the line corresponding to x = y (i.e. perfect correlation); and the blue lines denote the linear regression trend lines obtained. The equation for each elevation group was the corrected regression equation for the GSMaP accumulated rainfall.

Most of the red dots in Fig. 4 are distributed to the left of green line, that is, GSMaP rainfall estimation is mostly underestimated, and the underestimation of GSMaP rainfall is similar to the result of Taniguchi et al. (2013). This is because the moist air of the front runs toward the mountains and the humid air rises causing rainfall (topographic effect). The GSMaP is a satellite-derived rainfall product, and satellite observations cannot take into account topographic effect. However, topographic effect does have a significant impact on satellite-derived rainfall product, and about two-thirds of Taiwan's land is mountains and hills. Therefore, when using GSMaP to estimate rainfall intensity in Taiwan, it is important to consider the topographic effect, which is one of the contributions of this study.

4.2 Probability Distribution of the Difference between the GSMaP and CWB Accumulated Rainfall and Error Analysis of the Average Rainfall

We linearly interpolated the GSMaP data (of daily accumulated rainfall) into the data obtained from 425 CWB stations according to Categorization B. The CWB accumulated rainfall was then subtracted from the GSMaP accumulated rainfall, resulting in the probability distribution displayed in Fig. 5 regarding estimation differences. The y-axis represents the probability (%), and the x-axis denotes the difference in rainfall (mm). The figure indicates that the GSMaP rainfall values were generally lower than the CWB values after the data were divided into the three elevation groups. The average rainfall error for each elevation group is displayed in Table 3.

4.3 Average Error before and after the Correction

To test the feasibility of the proposed correction to rainfall estimation, this study referred to cross-validation, adopted Categorization B, and employed two approaches to correct the GSMaP accumulated rainfall: the linear regression correction, and the error correction of the average rainfall. The bias before the correction were compared with those after the correction. When the post-correction accumulated rainfall was closer to the actual rainfall than the pre-correction rainfall, the correction approach employed was considered effective.

For all cases, the rainfall estimated by the GSMaP was lower than that of observed by the CWB stations. We then divided the GSMaP data into three elevation levels according to Categorization B. The GSMaP errors were corrected by substituting the rainfall value into the corresponding regression equation and by subtracting the average rainfall errors (Table 3) to get the new rainfall value. The post-correction GSMaP data in the three elevation levels were considerably

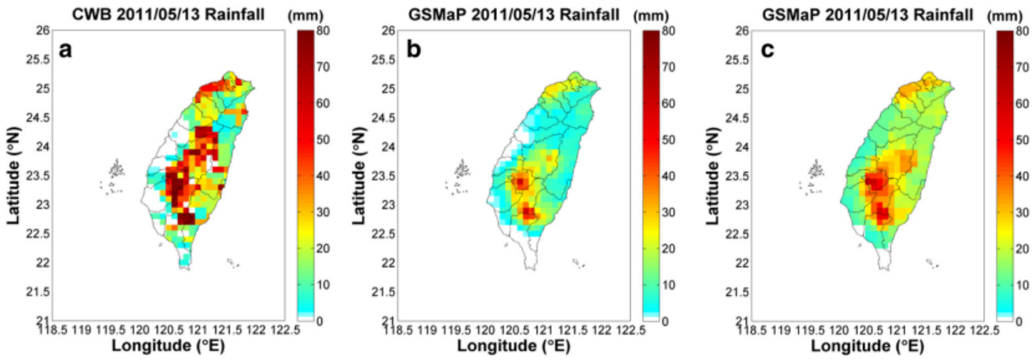

Fig. 6 **a** Ground-Based Observation, **b** post-correction, **c** bias correction GSMaP rainfall distribution on May 13, 2011

improved, and the example as Fig. 6. For the bias correction, the GSMaP data of the high-elevation group were the most improved, followed by the data of the mid-elevation and then the low-elevation group. The estimation error of the GSMaP regarding rainfall intensity increased as the elevation increased, which confirms that topography is highly related to rainfall intensity in Taiwan. We assumed that the GSMaP could not detect the elevation of the target region during estimation; hence, the methods proposed in this study demonstrated greater improvement in the rainfall estimation of the high-elevation group. After corrections were made using the regression equations and by employing the values in Table 3, the bias was reduced by 5.64 (13.7%), 7.33 (38.4%) and 10.52(31.2%) mm for low-, mid- and high-elevation regions, respectively. The bias was both greatly reduced after correction was performed using the two approaches. Therefore, the correction methods proposed in this study effectively reduce errors in GSMaP estimations of accumulated rainfall in Taiwan.

5 Conclusion

This study estimated the rainfall intensity in Taiwan during the Mei-Yu season by using the GSMaP product. The results demonstrated that the elevation of target regions strongly affected the GSMaP rainfall estimations for Taiwan. Regarding elevation level, the most effective categorization of the rainfall data was dividing them into the following three groups: rainfall in regions with an elevation of less than 50 m; that in regions with an elevation of 50–100 m; and that in regions with an elevation of more than 100 m. We then compared the GSMaP rainfall and the CWB rainfall within those three groups. The correlation coefficient between the data for the low-elevation group (elevation <100 m) was 0.77, and that for the high-elevation group (elevation >100 m) was 0.59. The results indicated that the GSMaP makes more accurate estimations for low-elevation regions than for high-elevation regions. The correlation coefficient between the GSMaP and CWB data decreased as the elevation increased.

Subsequently, we conducted error analyses on the data categorized by elevation. The GSMaP underestimated rainfall in regions with low, middle, and high elevation by 5.78, 7.51, and 10.71 mm, respectively. As the elevation increased, the errors also increased. Moreover, by using 8925 rainfall samples (21 Mei-Yu cases), we constructed a regression equation for correcting GSMaP estimations (1 Mei-Yu case) for regions with different elevations in Taiwan.

To verify that the proposed error correction methods (i.e., the average rainfall error and regression equation correction approaches) can effectively improve GSMaP rainfall estimation in Taiwan during the Mei-Yu season, this study analyzed cross-validation and examined the corrected errors. The correction using the regression equation slightly outperformed that using the average rainfall errors. Specifically, the regression approach reduced bias by 7.8 mm (27.7%) on average. The results verified that the proposed correction approaches were effective in improving GSMaP rainfall estimation during the Mei-Yu season in Taiwan.

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陸、心得與建議

此次有機會前往美國加州大學爾灣分校短期進修，有機會與國外的專家學者共同合作研究議題，並將研究成果發表於國際期刊，除此之外，也因為該中心屬於水文遙測中心，研究議題包含地面以上的大氣部分，以及地面的水文，甚至水下等研究議題，也因為前往該中心短期進修，除了與我自身專長相關的大氣部分，也有機會與類似領域的教授、研究員等專家學者交流、討論，除了在自身的研究領域上有所收穫外，也對於水文領域的水文氣象及水文循環有多一分地了解。

此次的研究成果可應用於台灣地區的梅雨降雨強度的估算，藉由修正方程式的修正衛星估算降雨強度，讓使用者可以得到更接近實際的降雨強度，對於豪大雨的預警及防災策略可有正面助益，而其研究成果將可提供(或移轉)台灣各氣象預報作業單位參考。

不論是用什麼樣的衛星感測器、不同的演算法進行降雨估算，或是使用不同的數值模式來研究水文氣象及其循環，大方向的研究方法、流程以及邏輯等其實皆相通且類似，而降雨只是水文循環中的一小部分，所以除了目前所進行的降雨估算、預報等降雨議題，或許可以思考後續的研究方向，要如何結合現有的降雨研究成果，並進一步導入水文相關領域，是未來可以嘗試的一個研究方向。另外，課堂上課可吸收加州大學爾灣分校多元上課方式及技巧以及多元評分，以及不同的文化的研究討論方式、不同的上課方式等，提供返國(校)教學時應用。

此次至美國短期進修一年時間，深深體會語言的重要性，生活中的食、衣、住、行、育、樂都是需要外語能力，更能深刻體會英文不應該只是考試會寫會讀就可以，能夠溝通才是最重要的，尤其是聽跟說的能力更是即時性，與人溝通的過程，不可能去查個字典或是使用翻譯 APP，所以在準備出國的同時，基本的外語聽說能力是不可或缺的。

此次短期進修經費是由科技部提供，在 3 月新冠肺炎爆發時，不論是司令部、航空技術學院以及科技部駐洛杉磯科技組都透過通訊軟體關心在美學員的健康狀況，以及是否需要進一步協助，使得在異地遇到疫情爆發的大家，都可以得到最新的訊息以及即時的幫忙，再次感謝各單位的關心及協助。最後建議科技部及國防部，若在經費充足的情況下，多補助國內學者出國短期進修，增加國內的學術研究風氣，也增強國內研究能量。

附錄

圖 1 加州大學爾灣分校校園 (自研究室窗外攝影)

圖 2 CHRS 主任 Sorooshian 教授合影

圖 3 參訪揚克斯航空博物館(Yanks Air Museum)

圖 4 參訪退役航空母艦

圖 5 與 CHRS 博士班學生 Muhammad 合影

圖 6 參加 AGU 國際會議並與 CHRS Sorooshian 教授、Phu Nguyen 教授以及 Matin 博士合影

圖 7 AGU 國際會議之台灣之夜，與中央大學學務長林沛練教授等國內學者合影

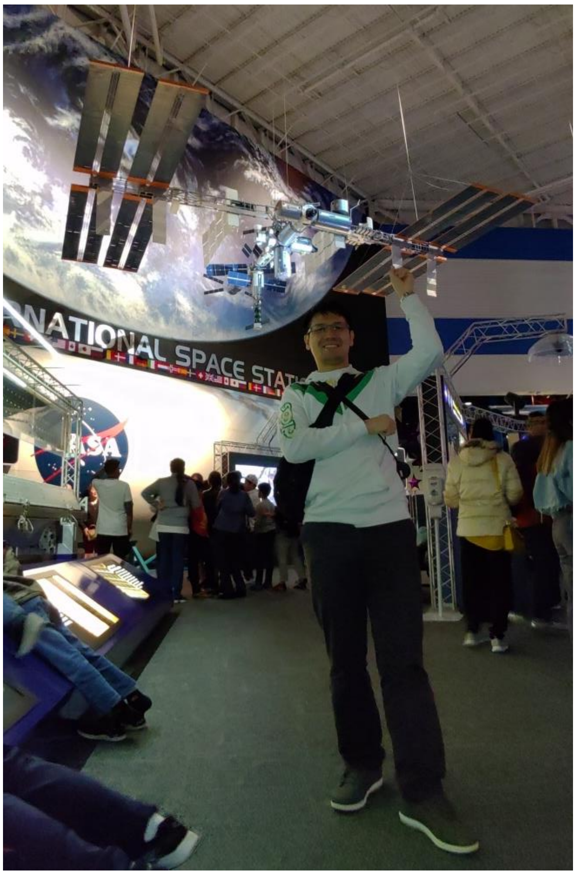

圖 8 參訪德州休士頓太空中心

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To Whom It May Concern

I would like to inform you that Dr. Nan-Ching Yeh, employee ID number# 098631483, had participated in the research team and activities at the Center for Hydrometeorology and Remote Sensing (CHRS) during the period of July 20, 2019 and July 27 2020. Dr. Yeh had completed his research at CHRS and published an international journal during his visit.

Sincerely yours,

Kuolin Hsu, Ph.D.
Professor, Department of Civil & Environmental Engineering

圖 9 結業證書