remote sensing

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Editorial

Editorial for Special Issue "Remote Sensing of Precipitation"

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Abstract: This Special Issue hosts papers on all aspects of remote sensing of precipitation, including applications that embrace the use of remote-sensing techniques of precipitation in tackling issues, such as precipitation estimations and retrievals, along with their methodologies and corresponding error assessment; precipitation modelling including validation, instrument comparison, and calibration; understanding of cloud and precipitation microphysical properties; precipitation downscaling; precipitation droplet size distribution; assimilation of remotely sensed precipitation into numerical weather prediction models; and measurement of precipitable water vapor.

Keywords: precipitation; TRMM; GPM; IMERG; weather radar; precipitable water vapor; precipitation retrieval; rain rate; QPE

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1. Introduction

Precipitation is a key meteorological variable and one of the most important pillars in the global water and energy balances. In its various forms, precipitation comprises the primary source of freshwater, which is vital for the sustainability of almost all human activities, and the significance of this natural resource is fundamental in effectively managing applications ranging from irrigation to industrial and household usage. Precipitation is often associated with extreme weather events, such as floods, droughts, and landslides, which can have tremendous socio-economic impacts on the local scale but quite frequently on the regional scale. It is well documented that precipitation is one of the elements that is greatly affected by climate change.

The sufficiently accurate observation or estimation of precipitation has important theoretical but also practical significance. Indeed, on the one hand, the accurate and timely understanding of its characteristics at the local, regional, and global scales is vital for an insightful understanding of the mechanisms underlying the Earth's atmosphere–ocean complex system; on the other hand, the timely issuance of flood warnings, drought monitoring, and effective water resource management is crucial in some areas.

Precipitation observations made with rain gauges provide relatively accurate point-based measurements of precipitation. However, due to precipitation heterogeneity across a broad spectrum of spatiotemporal scales, rain gauge observations most often represent only the local conditions and can result in potential errors when interpolated to larger scales, especially in areas characterized by complex terrain.

Additionally, the spatial distribution of rain gauges is extremely uneven, with sparse gauges in remote areas, less developed regions, oceanic surfaces, and areas with complex terrain. Therefore, in situ rain gauge data usually cannot meet the requirements of applications that depend on high spatiotemporal resolution precipitation data, some of which have already mentioned above.

Remotely sensed precipitation data have the advantage of adequate temporal resolution and fine spatial resolution with a wide coverage, enabling accurate precipitation estimates in data-scarce or ungauged regions. Remote sensing of precipitation is pursued through a broad spectrum of continuously enhanced and upgraded instrumentation, embracing sensors which can be satellite-borne, ground-based over land, ship-borne, and aerial. The subsequent processing of the remotely sensed precipitation data provides added value to this vast source of precipitation data, widening the horizons for a more effective usage. Indeed, the advances in the establishment of reliable remotely sensed precipitation datasets has provided an opportunity to reliably retrieve the spatiotemporal pattern of precipitation.

Through the scientific contributions contained in this volume, this Special Issue aims at exposing the scientific community to the current advances in many important areas of the remote sensing of precipitation. By presenting state-of-the-art technologies and methodologies regarding the remote sensing of precipitation, this Special Issue aspires to stimulate further research in this unceasingly expanding scientific discipline.

The following Section delivers a summary of all the thirty-nine articles published in the current special issue. The articles are presented in alphabetical order based on the first author's name.

2. Overview of Contributions

Anagnostou et al. [1] evaluate the advantages of using X-band polarimetric (XPOL) radar as a means to fill the coverage gaps and improve complex terrain precipitation estimation and associated hydrological applications based on a field experiment conducted in an area of Northeast Italian Alps characterized by large elevation differences. The corresponding rainfall estimates from two operational C-band weather radar observations are compared to the XPOL rainfall estimates for a near-range (10–35 km) mountainous basin (64 km^2). In situ rainfall observations from a dense rain gauge network and two disdrometers (one 2D-video and one Parsivel) are used for ground validation of the radar-rainfall estimates. Ten storm events over a period of two years are used to explore the differences between the locally deployed XPOL versus longer range operational radar-rainfall error statistics.

Utilizing reanalysis and high sensitivity W-band radar observations from CloudSat, Behrangi and Richardson [2] assess simulated high-latitude precipitation and its future changes under the RCP8.5 global warming scenario. A subset of models was selected based on the smallest discrepancy relative to CloudSat and ERA-I reanalysis using a combined ranking for bias and Root Mean Squared Error (RMSE). After accounting for uncertainties introduced by internal variability due to CloudSat's limited four-year day-night observation period, RMSE provides greater discrimination between the models than a typical mean state bias criterion. Over 1976–2005 to 2071–2100, colder months experience larger fractional modeled precipitation increases than warmer months, and the observation-constrained models generally report a larger response than the full ensemble.

The Global Precipitation Measurement (GPM) mission Core Observatory is equipped with a dual-frequency precipitation radar (DPR) with the capability of measuring precipitation simultaneously at frequencies of 13.6 GHz (Ku-band) and 35.5 GHz (Ka-band). Since the GPM-DPR cannot use information from polarization diversity, radar reflectivity factor is the most important parameter used in all retrievals. Biswas and Chandrasekar [3] quantitatively compare GPM's observations of reflectivity at dual-frequency and instantaneous rainfall products against dual-polarization ground-based Next-Generation Radars (NEXRAD) from the GPM Validation Network (VN), adopting a 3-D volume matching technique. The ground radars are located in the southeastern plains of the Unites States of America.

In their paper, Cánovas-García et al. [4] study the accuracy of three Quantitative Precipitation Estimates (QPEs) obtained from remote sensing or ground-based radars and the extent to which they could complement or even be an alternative to rain gauge readings in the Iberian Peninsula. The first QPE is the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) Cloud Classification System, a satellite-based QPE. The second and the third are QPEs from a meteorological radar with Doppler capabilities that work in the C-band. Pixel-to-point comparisons are made between the values yielded by the QPEs and those obtained by two networks of rain gauges. The results obtained indicate that all the QPEs were well below the rain gauge values in extreme rainfall time slots.

The paper by Cersosimo et al. [5] presents a geostatistical downscaling procedure to improve the spatial resolution of precipitation data. The kriging method with external drift is applied to surface rain intensity (SRI) data obtained through the Operative Precipitation Estimation at Microwave Frequencies (OPEMW), which is an algorithm for rain rate retrieval based on Advanced Microwave Sounding Units (AMSU) and Microwave Humidity Sounder (MHS) observations. SRI data have been downscaled from the coarse initial resolution of AMSU-B/MHS radiometers to the fine resolution of Spinning Enhanced Visible and InfraRed Imager (SEVIRI) flying on board the Meteosat Second Generation (MSG) satellite. Orographic variables, such as slope, aspect, and elevation, are used as auxiliary data in kriging with external drift together with observations from the Meteosat Second Generation-Spinning Enhanced Visible and InfraRed Imager (MSG-SEVIRI) in the water vapor band and in thermal-infrared.

The performances of the latest released Integrated Multi-satellite Retrievals for GPM mission (IMERG) version 5 (IMERG v5) and the TRMM Multi-satellite Precipitation Analysis 3B42 version 7 (3B42 v7) are evaluated and compared by Chen et al. [6] at multiple temporal scales over a semi-humid to humid climate transition area (Huaihe River basin) from 2015 to 2017. The impacts of rainfall rate, latitude, and elevation on precipitation detection skills are also investigated. Results indicate that both satellite estimates show a high Pearson correlation coefficient (above 0.89)—with gauge observations—and an overestimation of precipitation at monthly and annual scales. The mean daily precipitation of IMERG v5 and 3B42 v7 displays a consistent spatial pattern, and both characterize the observed precipitation distribution well, but 3B42 v7 tends to markedly overestimate precipitation over water bodies.

Based on rain drop size distribution (DSD) measurements from 16 disdrometers located in Lausanne, Switzerland, Ghada et al. [7] present evidence that rain DSD differs among general weather patterns (GWLs). GWLs were successfully linked to significant variations in the rain microstructure characterized by the most important rain properties: rain intensity, mass weighted rain drop diameter, and rain drop concentration as well as parameters of the Z–R relation. The results highlight the potential to improve radar-based estimations of rain intensity, which is crucial for several hydrological and environmental applications.

Huang et al. [8] assess the performance of the latest version V5B of IMERG Early and Final Runs over southern China during six extremely heavy precipitation events. Observations from a dense network composed of 2449 rain gauges are used as a reference to quantify the performance in terms of spatiotemporal variability, probability distribution of precipitation rates, contingency scores, and bias analysis. The results show that both IMERG with gauge calibration and without gauge correction generally capture the spatial patterns of storm-accumulated precipitation with moderate to high correlation coefficients. Moreover, IMERG with gauge calibration and without gauge correction captured the area-average hourly series of precipitation over rainfall centers with a high correlation coefficient. Lastly, IMERG with gauge calibration tends to underestimate precipitation, especially the rainfall over the rainfall centers, when compared to IMERG without gauge correction.

Ivanov et al. [9] present a pre-processing approach adopted for the radar reflectivity data assimilation and results of simulations with the Harmonie numerical weather prediction model. The proposed method creates a 3-D regular grid in which a horizontal size of meshes coincides with the horizontal model resolution. This minimizes the representative error associated with the discrepancy between resolutions of informational sources. After such pre-processing, horizontal structure functions and their gradients for radar reflectivity maintain the sizes and shapes of precipitation patterns similar to those of the original data. The method shows an improvement of precipitation prediction within the radar location area in both the rain rates and spatial pattern presentation. It redistributes precipitable water with smoothed values over the common domain since the control runs show, among several sub-domains with increased and decreased values, correspondingly. It also reproduces the mesoscale belts and cell patterns of sizes from a few to ten kilometers in precipitation fields.

In the paper by Khan et al. [10], the performance of Level-3 gridded GPM-based precipitation products (IMERG) is assessed against two references over oceans: the OceanRAIN dataset, derived from oceanic shipboard disdrometers, and a satellite-based radar product (the Level-3 Dual-frequency Precipitation Radar, 3DPRD). Daily IMERG products (early, late, final) and microwave-only (MW) and Infrared-only (IR) precipitation components are evaluated at four different spatial resolutions (0.5○, 1○, 2○, and 3○) during a 3-year study period (March 2014–February 2017). Their performance is assessed based on both categorical and continuous performance metrics, including correlation coefficient, probability of detection, success ratio, bias, and RMSE. A triple collocation analysis (TCA) is also presented to further investigate the performance of these satellite-based products. Overall, the IMERG products show an underestimation with respect to OceanRAIN. Rain events in OceanRAIN are correctly detected by all IMERG products ~80% of the time. IR estimates show relatively large errors and low correlations with OceanRAIN compared to the other products. The MW component performs better than other products in terms of both categorical and continuous statistics. TCA reveals that 3DPRD performs consistently better than OceanRAIN in terms of RMSE and coefficient of determination at all spatial resolutions.

Dual-frequency Global Navigation Satellite Systems (GNSSs) enable the estimation of Zenith Tropospheric Delay (ZTD) which can be converted to Precipitable Water Vapor (PWV). The density of existing GNSS monitoring networks is insufficient to capture small-scale water vapor variations that are especially important for extreme weather forecasting. A densification with geodetic-grade dual-frequency receivers is not economically feasible. Cost-efficient single-frequency receivers offer a possible alternative. Krietemeyer et al. [11] study the feasibility of using low-cost receivers to increase the density of GNSS networks for retrieval of PWV. The authors process one year of GNSS data from an International GNSS Service station and two co-located single-frequency stations. Additionally, in another experiment, the Radio Frequency signal from a geodetic-grade dual-frequency antenna was split to a geodetic receiver and two low-cost receivers.

The paper by Le et al. [12] aims at exploring the capacity of the satellite-based rainfall product Tropical Rainfall Measurement Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA), including 3B42V7 research data and its real-time 3B42RT data, by comparing them against data from 29 ground observation stations over the lower part of the Red-Thai Binh River Basin from March 2000 to December 2016. Various statistical metrics were applied to evaluate the TMPA products. The results show that both 3B42V7 and 3B42RT had weak relationships with daily observations, but 3B42V7 data had strong agreement on the monthly scale compared to 3B42RT. Seasonal analysis shows that 3B42V7 and 3B42RT underestimate rainfall during the dry season and overestimate rainfall during the wet season, with high bias observed for 3B42RT. In addition, detection metrics demonstrate that TMPA products could detect rainfall events in the wet season much better than in the dry season. When rainfall intensity is analyzed, both 3B42V7 and 3B42RT overestimate the no rainfall event during the dry season but underestimate these events during the wet season.

The study by Lu et al. [13] assesses the performance of the latest GPM Integrated Multi-satellite Retrievals (IMERG V5) and Global Satellite Mapping of Precipitation version 7 (GSMaP V7) products and their hydrological application over the Tibetan Plateau. Two IMERG Final Run products (uncalibrated IMERG [IMERG-UC]) and gauge-calibrated IMERG [IMEEG-C]) and two GSMaP products (GSMaP Moving Vector with Kalman Filter [GSMaP-MVK] and gauge-adjusted GSMaP [GSMaP-Gauge]) were evaluated from April 2014 to March 2017. Results show that all four satellite precipitation products could generally capture the spatial patterns of precipitation over the Tibetan Plateau.

Martins Costa do Amaral et al. [14] apply the Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF) consolidated radar data processing to the X-band radar used in the CHUVA (Cloud Processes of the Main Precipitation Systems in Brazil: A Contribution to Cloud-Resolving Modeling and to the Global Precipitation Measurement) campaigns in Brazil. They apply the well-established H-SAF validation procedure to these data and verify the quality of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) H-SAF operational passive microwave precipitation products in two regions of Brazil, namely, Vale do Paraíba and Manaus. These products are based on two rainfall retrieval algorithms: the physically based Bayesian Cloud Dynamics and Radiation Database (CDRD algorithm) for SSMI/S sensors and the Passive microwave Neural network Precipitation Retrieval algorithm (PNPR) for cross-track scanning radiometers (AMSU-A/AMSU-B/MHS sensors) and for the Advanced Technology Microwave Sounder (ATMS) sensor.

Remote sensing techniques provide extensive spatial coverage compared to ground-based rainfall data, but it is imperative to assess the quality of the estimates. Previous studies underline, at regional scale in the Amazon Basin in Brazil, and for some years, the efficiency of the Tropical Rainfall Measurement Mission (TRMM) 3B42 Version 7 (V7) (denoted by 3B42) daily product data to provide a good view of the rainfall time variability, which is important to understand the impacts of El Nino Southern Oscillation. The study by Michot et al. [15] aims at enhancing the knowledge about the quality of this product on the entire Amazon Basin and to provide a useful understanding about its capacity to reproduce the annual rainfall regimes. For that purpose, the authors compare 3B42 against 205 quality-controlled rain gauge measurements, for the period from March 1998 to July 2013, with the aim to reveal whether 3B42 is reliable for climate studies.

Hurricane Harvey, one of the most extreme events in recent history, advanced as a category IV storm and brought devastating rainfall to the region of Houston, Texas, the United States of America, during 25–29 August 2017. Omranian et al. [16] study the ability of the recent IMERG final-run product to capture the magnitudes and spatiotemporal patterns of rainfall resulting from hurricane Harvey. The results indicate that the performance of the IMERG product is satisfactory in detecting the spatial variability of the storm and it reconstructs precipitation with nearly 62% accuracy, although it systematically under-represents rainfall in coastal areas and over-represents rainfall over the high-intensity regions.

Rahman et al. [17] evaluate the performance of satellite-based precipitation products (SPPs), including GPM-based Integrated Multi-Satellite Retrievals for GPM (IMERG), TMPA (3B43-v7), PERSIANN and PERSIANN-CDR (Climate Data Record), over Pakistan based on Surface Precipitation Gauges (SPGs) at spatial and temporal scales. A novel ensemble precipitation (EP) algorithm is developed by selecting the two best SPPs using the paired sample t-test and principal component analysis (PCA). The SPPs and EP algorithm are evaluated over five climate zones (ranging from glacial Zone-A to hyper-arid Zone-E) based on six statistical metrics.

Ramsauer et al. [18] examine the performance of NASA's IMERG satellite precipitation dataset in capturing the spatio-temporal variability of weather events compared to the gauge-adjusted quality-controlled RADOLAN (Radar Online Adjustment) RW dataset from the German Weather Service. The results indicate significant differences between the datasets. Overall, GPM IMERG overestimates the quantity of precipitation compared to RADOLAN, especially in the winter season. Moreover, shortcomings in performance arise in this season with significant erroneous detections, yet precipitation events are also missed compared to the weather radar data. Additionally, along secondary mountain ranges and the Alps, topographically-induced precipitation is not represented in GPM data, which generally shows a lack of spatial variability in rainfall and snowfall estimates due to lower resolutions.

Rehman et al. [19] present an assessment on the validation and performance of both TMPA 3-hourly rainfall products, i.e., 3B42 near-real-time and 3B42 research version hourly rain rates, at various time scales for the period of 2007 to 2010 in Pakistan. The major objective of the study is to evaluate TMPA's rainfall rates at 3-h time intervals by using 10-min temporal resolution telemetric rain gauge (TRG) observations. The results show that the performance of TMPA research version in the detection of rain/no-rain events is quite good and has the best scores in a post-monsoon season. The performance of the TMPA near-real time product is inferior compared to the research version. Both TMPA products perform least in the winter season and have the lowest scores for performance indices. Furthermore, the performance of TMPA products is questionable at light rain rates, but it improves at higher rain intensities.

Retalis et al. [20] assess the accuracy of the new IMERG satellite precipitation product over Cyprus on a monthly basis and during extreme events during the first years of GPM. This study is a first attempt to validate a specific GPM precipitation product by using in situ surface observations over the island of Cyprus. The satellite product was validated against the gauge data by simply comparing the former with the latter within each satellite cell. It is concluded that a very good agreement on monthly level was established, although IMERG tends to be underestimated as elevation goes higher, especially for areas higher than 1000 m elevation. Regarding daily evaluation, in terms of extreme recorded events, it seems that there exists a case dependency, while no specific correlation with elevation was established.

Ricciardelli et al. [21] investigate the value of satellite-based observational algorithms in supporting numerical weather prediction (NWP) for improving the alert and monitoring of extreme rainfall events. To this aim, the analysis of the very intense precipitation that affected the city of Livorno, Italy, on 9 and 10 September 2017 is performed by applying three remote-sensing techniques based on satellite observations at infrared/visible and microwave frequencies and by using maps of accumulated rainfall from the weather research and forecasting (WRF) model: The satellite-based observational algorithms are the precipitation evolving technique (PET); the rain class evaluation is from the infrared and visible observations (RainCEIV) technique; and the cloud classification mask is the coupling of statistical and physics methods (C-MACSP).

In view of the need to evaluate the accuracy of the new suite of GPM products in different regions of the globe, the study by Rozante et al. [22] aims at assessing the IMERG-Final and GSMaP-Gauge retrievals in order to replace the TMPA research version in several regions with different precipitation regimes in Brazil. In this respect, the performance of three satellite-based rainfall estimation products are evaluated in five Brazilian regions with different precipitation regimes, and the whole Brazilian territory, during the period from April 2014 to February 2017. This study shows that GSMaP-G and IMERG-F precipitation products exhibit better performance compared to the current TMPA-V7.

The paper by Rysman et al. [23] describes a new algorithm that is able to detect snowfall and retrieve the associated snow water path (SWP), for any surface type, using the GPM Microwave Imager (GMI). The algorithm is tuned and evaluated against coincident observations of the Cloud Profiling Radar (CPR) onboard CloudSat. It is composed of three modules for (i) snowfall detection, (ii) supercooled droplet detection, and (iii) SWP retrieval. This algorithm takes into account environmental conditions to retrieve SWP and does not rely on any surface classification scheme. Three case studies of snowfall events are investigated, and a 2-year high resolution snowfall occurrence distribution is presented.

Sanò et al. [24] describe a new rainfall rate retrieval algorithm, developed within the EUMETSAT H SAF program, based on the Passive microwave Neural Network Precipitation Retrieval approach (PNPR v3), designed to work with the conically scanning GMI. A new rain/no-rain classification scheme, also based on the Neural Network approach, which provides different rainfall masks for different minimum thresholds and degree of reliability, is also described. The algorithm is trained on an extremely large observational database built from GPM global observations between 2014 and 2016 where the NASA 2B-CMB (V04) rainfall rate product is used as a reference.

Satgé et al. [25] present an assessment of the potential benefits of the successive GPM-based SPEs product versions that include the Integrated Multi–Satellite Retrievals for GPM (IMERG) version 3 to 5 (–v03, –v04, –v05) and the Global Satellite Mapping of Precipitation (GSMaP) version 6 to 7 (–v06, –v07). The analysis is conducted over different geomorphic and meteorological regions of Pakistan while using 88 precipitation gauges as a reference. The results show a clear enhancement in precipitation estimates that were derived from the IMERG–v05 in comparison to its two previous versions IMERG–v03 and –v04; GSMaP–v07 precipitation estimates are more accurate than the previous GSMaP–v06.

In the study by Senent-Aparicio et al. [26], four widely used global precipitation datasets (GPDs) are evaluated: The Tropical Rainfall Measuring Mission (TRMM) 3B43, the Climate Forecast System Reanalysis (CFSR), PERSIANN, and the Multi-Source Weighted-Ensemble Precipitation (MSWEP) against point gauge and gridded dataset observations. Multiple monthly water balance models (MWBMs) are used in four different mesoscale basins that cover the main climatic zones of Peninsular Spain. Results underscore the superiority of the national gridded dataset, although TRMM provides satisfactory results in simulating streamflow.

The aim of the article by Sokol et al. [27] is to describe two new functionalities that they added to the radar data processing to study the cloud structures, which is their research purpose. Specifically, these authors deal with (i) the estimation of vertical air velocity and terminal velocity of hydrometeors and (ii) the classification of hydrometeors for which the vertical velocity and terminal velocity are the input parameters. Hydrometeors are considered to be any kind of liquid or solid water particles in the atmosphere that can result in precipitation which may or may not reach the ground in the form of graupel, rain, snow, or hail. The computational methods are illustrated with a thunderstorm event that occurred over Milešovka observatory, Czech Republic, on 1 June 2018.

Precise estimates of precipitation are required for many environmental tasks, including water resources management, improvement of numerical model outputs, nowcasting, and evaluation of anthropogenic impacts on global climate. Nonetheless, the availability of such estimates is hindered by technical limitations. Rain gauge and ground radar measurements are limited to land, and the retrieval of quantitative precipitation estimates from satellite has several problems including the indirectness of infrared-based geostationary estimates and the low orbit of those microwave instruments capable of providing a more precise measurement but suffering from poor temporal sampling. To overcome such problems, data fusion methods have been devised to take advantage of synergisms between available data, but these methods also present issues and limitations. Future improvements in satellite technology are likely to follow two strategies. One is to develop geostationary millimeter-submillimeter wave soundings, and the other is to deploy a constellation of improved polar microwave sensors. Tapiador et al. [28] compare both strategies using a simulated precipitation field. The results show that spatial correlation and RMSE would be little affected at the monthly scale in the constellation, but the precise location of the maximum of precipitation could be compromised.

Multiple scattering in the microwave frequencies has to be accounted for in precipitation retrieval algorithms. Tapiador et al. [29] study the effects of random arrangements of particles in space. In their study, such effects are described on the basis of modeled microwave scattering properties using the T-matrix formalism on the simplified case of spherical, non-intersecting raindrops. The results of measured rain drop size distributions (RDSDs) reveal that the random distribution of particles in space have a measurable but small effect on the scattering because of changes in the relative phases among the particles.

In the paper by Tapiador et al. [30], the oceanic precipitation projections of eight Regional Climate Models (RCMs) for the present-climate and the A2 SRES (Special Report on Emissions Scenarios) future-climate scenario have been compared with satellite and offshore gauge estimates. Notwithstanding observational errors and several other uncertainties, the results show that the RCMs consistently reproduce the observed oceanic precipitation of Europe, thus increasing the confidence in such models being capable of estimating changes in the future oceanic precipitation patterns. By integrating the uncertainties in both the observational and the modeled oceanic precipitation, a consensus estimate is made.

The principal objective of the study by Tsarpalis et al. [31] is to present and evaluate an advanced dust wet deposition scheme in the WRF model coupled with Chemistry (WRF-Chem). The integration of a dust wet deposition scheme into the WRF-Chem model is assessed through a case study of large-scale Saharan dust transport over the Eastern Mediterranean that is characterized by severe wet deposition over Greece. An acceptable agreement was found between the calculated and measured near-surface PM_{10} concentrations as well as when model-estimated atmospheric optical depth (AOD) is validated against the AErosol RObotic NETwork (AERONET) measurements.

Varlas et al. [32] conducted a hydrometeorological analysis of a flash flood event that took place in the sub-urban area of Mandra, western Attica, Greece, using remote-sensing observations and the Chemical Hydrological Atmospheric Ocean Wave System (CHAOS) modeling system that includes the Advanced WRF (WRF-ARW) model and the hydrological model (WRF-Hydro). The flash flood was caused by a severe storm during the morning of 15 November 2017 around the Mandra area resulting in extensive damages and 24 fatalities. The X-band dual-polarization (XPOL) weather radar of the National Observatory of Athens (NOA), which was also used in this analysis, recorded precipitation rates reaching 140 mm/h in the core of the storm. The findings of this study demonstrate the potential benefit of using high-resolution observations from a locally deployed X-band dual-polarization radar as an additional forcing component in model precipitation simulations.

The near-real-time legacy product of Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis (3B42RT) and the equivalent products of Integrated Multi-satellite Retrievals for GPM (IMERG-E and IMERG-L) were evaluated and compared over mainland China from 1 January 2015 to 31 December 2016 at the daily timescale against rain gauge measurements by Wu et al. [33]. Results show that: (i) Both 3B42RT and IMERG products overestimate light rain, while underestimating moderate rain to heavy rainstorm; (ii) higher rainfall intensity associates with better detection; and (iii) both 3B42RT and IMERG products perform better in wet areas with relatively heavy rainfall intensity and/or during wet season than in dry areas with relatively light rainfall intensity and/or during dry season.

Wu et al. [34] assess the performance and hydrological utility of merged precipitation products at the current technical level of integration. A newly developed merged precipitation product, namely, the Multi-Source Weighted-Ensemble Precipitation (MSWEP) Version 2.1, is evaluated in this study based on rain gauge observations and the Variable Infiltration Capacity (VIC) model for the upper Huaihe River Basin, China. For comparison, three SPPs, including Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) Version 2.0, Climate Prediction Center MORPHing technique (CMORPH) bias-corrected product Version 1.0, and TMPA 3B42 Version 7, are appraised.

A case study on the impact of assimilating satellite radiance observation data into the rapid-refresh multi-scale analysis and prediction system (RMAPS) is presented by Xie et al. [35]. This case study targets the 48 h period from 19–20 July 2016 which was characterized by the passage of a low pressure system that produced heavy rainfall over North China. Two experiments were performed, and 24 h forecasts were produced every 3 h. The results indicate that the forecast prior to the satellite radiance data assimilation could not accurately predict heavy rainfall events over Beijing and the surrounding area. The assimilation of satellite radiance data from the advanced microwave sounding unit-A (AMSU-A) and microwave humidity sounding (MHS) improves the skills of the quantitative precipitation forecast to a certain extent.

Zhang et al. [36] investigate the accuracies of the estimated precipitation in the Tianshan Mountains, China, from three satellite products, namely, IMERG, TRMM 3B42, and CMORPH. These products are evaluated through comparisons with observations from 46 stations. The study period is from April 2014 to March 2015, which was the overlapping time period of the three respective satellite missions. The findings of this study suggest that GPM may outperform its predecessors in the mid- or high-latitude dryland areas but not in the tropical mountainous areas.

A rainfall retrieval algorithm for tropical cyclones (TCs) using 18.7 and 36.5 GHz of vertically and horizontally polarized brightness temperatures (Tbs) from the Microwave Radiation Imager (MWRI) is presented by Zhang et al. [37]. The beamfilling effect is corrected based on ratios of the retrieved liquid water absorption and theoretical Mie absorption coefficients. To assess the performance of this algorithm, MWRI measurements are matched with the National Snow and Ice Data Center (NSIDC) precipitation for six TCs. The comparison between MWRI and NSIDC rain rates is relatively encouraging. A comparison of pixel-to-pixel retrievals shows that MWRI retrievals are constrained to reasonable levels for most rain categories.

Zhang et al. [38] evaluate the use of precipitation forecasts from a numerical weather prediction (NWP) model for near-real-time satellite precipitation adjustment based on 81 flood-inducing heavy precipitation events in seven mountainous regions over the conterminous United States of America. The study is facilitated by the National Center for Atmospheric Research (NCAR) real-time ensemble forecasts ("model"), the IMERG near-real-time precipitation product ("raw IMERG"), and the Stage IV multi-radar/multi-sensor precipitation product ("Stage IV") used as a reference. The authors evaluate four precipitation datasets (the model forecasts, raw IMERG, gauge-adjusted IMERG, and model-adjusted IMERG) through comparisons against Stage IV at six-hourly and event-length scales. The raw IMERG product consistently underestimates heavy precipitation in all study regions while the domain average rainfall magnitudes exhibited by the model are fairly accurate.

The performance of three SPPs over the upper catchment of the Red River Basin in China, for the time period of 1998–2010, is assessed by Zhang et al. [39]. The SPPs include TRMM 3B42 V7, CMORPH_CRT (CMORPH Bias-corrected product), and PERSIANN_CDR (Climate Data Record). The main objectives of this study are to (i) statistically evaluate the quality of the three SPPs through comparison with rain gauge observations and (ii) comprehensively explore and compare the capability of these three SPPs in streamflow simulations using GR (Génie Rural) hydrological models at daily and monthly scales.

3. Conclusions

The broad worldwide authorship in this Special Issue is a postulation that remote sensing of precipitation is a hot issue. Indeed, the scientific community invests much effort in revealing the power of tools available for remote sensing of this variable. In many cases, the supremacy of remote sensing over other traditional methodologies is demonstrated. However, many studies in this volume stress the significance of conventional measurements in validating remotely sensed estimations of precipitation.

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