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Multi time-scale evaluation of high-resolution satellite-based precipitation products over northeast of Austria

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ABSTRACT

Over the years, combinations of different methods that use multi-satellites and multi-sensors have been developed for estimating global precipitation. Recently, studies that have evaluated Integrated Multi-satellite Retrievals for GPM (IMERG) Final-Run (FR) version V-03D and other precipitation products have indicated better performance for IMERG-FR compared to other similar products in different climate regimes. This study comprehensively evaluates the two GPM-IMERG products, specifically IMERG-FR and IMERG-Real-Time (RT) late-run, against a dense station network (62 stations) in northeast Austria from mid-March 2015 to the end of January 2016 using different time-scales. Both products are examined against station data in capturing the occurrence and statistical characteristics of precipitation intensity. With regard to probability density functions (PDFs), the satellite precipitation estimate (SPE) products have detected more heavy and extreme precipitation events than the ground measurements. Both precipitation products at all time-scales, except for IMERG-RT 12-hourly and daily precipitation, capture less occurrence of precipitation than the station dataset for light precipitation. This partially explains the under-detection of precipitation events. For all time-scales, both IMERG products' CDFs (Cumulative Distribution Function) are well above that of the stations' precipitation. For lower precipitation levels, IMERG-RT is slightly below the IMERG-FR whereas IMERG-RT is above IMERG-FR at higher precipitation levels. Furthermore, for entire spectrum precipitation rates ($P \geq 0.1$ mm), 1, 3, 6-hourly, IMERG-FR did not show a clear improvement of the Bias over IMERG-RT, while for 12-hourly and daily precipitation estimates, the bias in IMERG-FR has improved compared to IMERG-RT. In addition, IMERG-FR shows a considerable improvement in RMSE as compared to IMERG-RT. IMERG-FR, however, systematically underestimates moderate to extreme precipitation and overestimates light precipitation for all time scales against rain-gauges in northeast Austria. When comparing the bias, RMSE, and correlation coefficients, IMERG-FR has outperformed IMERG-RT particularly for 6-hourly, 12-hourly, and daily precipitation. Despite the general low probability of detection (POD) and threat score (TS) and the high false alarm ratio (FAR) within specified precipitation thresholds, the contingency table shows relatively acceptable values of the POD, TS and FAR for precipitation without classification.

1. Introduction

Accurate precipitation estimation on fine spatio-temporal resolutions is important for water resources-related applications such as hazards forecast and management, agricultural water use, water resource management for human and industrial use, and understanding the ecosystems (Joyce et al., 2004; Yong et al., 2010). In-situ observations are often limited; however, currently available SPE products can potentially provide the precipitation estimation needed for meteorological and hydrological applications. Moreover, accurate monitoring and prediction of rainfall would help to reduce property damages and potential loss of life that may occur due to flooding (Wong and Chiu, 2008). Hence, for a better understanding of the impact of rainfall on the environment, it is crucial that one has good spatial and high temporal resolution rainfall observations available. This is specifically the case over complex mountainous regions where there is insufficient rain-gauge available and rainfall is distinguished by complex patterns (Gebere et al., 2015; Krakauer et al., 2013).

Over the ocean, microwave emissivity is low and highly polarized, allowing passive microwave (PMW) sensors to (largely) separate the surface radiation signal and the (warm) emission signal arising from liquid hydrometeors. However, over land, the microwave emissivity is

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higher and more variable because of its complex relationship with a number of highly variable surface characteristics such as soil moisture, roughness, vegetation properties, canopy, and snow cover (Aires et al., 2011). Moreover, the spatial distribution of precipitation within the footprint and the precipitation's microphysical characteristics can significantly impact the quality of PMW rainfall estimates (Carr et al., 2015).

In mountainous regions, rainfall is extremely variable and changes in rainfall distribution can occur over short distances and within short periods of time. The hydrological regime in these areas is extremely variable, characterized by a short duration and high-intensity rainfall events. Since mountain areas are known for their undulating topography, the number of ground-based rain-gauge stations is usually very limited. Therefore, rainfall observation with high spatial and temporal resolution is extremely important to understand the hydrologic processes in these areas (Collier, 2009; Germann et al., 2009; Villarini et al., 2009). However, the interaction between different scales to resolve atmospheric dynamics and land surface hydrology still needs progress. Well-balanced high-resolution precipitation datasets play an essential role in such land-atmosphere interactions (Vila et al., 2009). One of the motivations for this study is the potential use of high-resolution atmospheric datasets for diagnostic and prognostic atmospheric numerical modeling and land surface hydrology studies over the northeast of Austria by combining surface observations with remotely sensed information.

The main requirement in precipitation assessment is to know where and how much precipitation is falling at any given time. Such precipitation attributes may be determined through traditional ground-based rain-gauges and/or advanced SPE products. Ground-based radar is of limited value in areas with large elevation variations due to topographic shading effects (Germann et al., 2006). Another important aspect deals with the duration of precipitation (Sharifi et al., 2016).

The Global Precipitation Measurement (GPM) constellation satellites are an international mission to provide next-generation observations of rain and snow. GPM was particularly designed to bring together advanced precipitation measurements from research and operational sensors from the partner satellites for providing the next-generation global precipitation data products. As more nations contribute to earth observations from space in the coming years, the long-term vision is that GPM sampling will further benefit from additional microwave sensors. Although a suite of sensors flying on a variety of satellites has been used to estimate precipitation on a global basis, generally speaking, the performance of SPEs over land areas is highly dependent on the rainfall regime and the temporal and spatial scale of the retrievals (Ebert et al., 2007). On the other hand, gauge observations continue to play a critical role in observation systems over global land areas. In addition, when precipitation data from rain-gauges are used as reference data, the main concern is related to uncertainties in the accuracy of areal estimates, which stem from the limited spatial representativeness of the gauges (Dezfuli et al., 2017; Sungmin et al., 2018; Villarini et al., 2008). Satellite-derived data deviations from ground-based observations may partly be due to the possible lack of spatial representativeness of the observation sites (Hakuba et al., 2014). The spatial representativeness of a surface site greatly depends on the time-scale considered - hours, days, months - as temporal averaging strongly reduces the mismatch between point observation and surrounding area mean (Wang et al., 2012; Zhang et al., 2010). Despite this fact, gauge observations are the only sources obtained from direct measurements. Both radar and satellite estimates are indirect in nature and need to be calibrated or verified using the gauge observations (Xie and Arkin, 1995). Although it is possible to create rainfall estimates using a combination of different satellite data i.e., IMERG (Huffman et al., 2015a), climate prediction center (CPC) morphing technique (CMORPH: Joyce et al., 2004) and Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN: Sorooshian et al., 2000). Researchers have increasingly moved to using "the best of both worlds" to improve accuracy, coverage, and resolution (Vila et al., 2009).

Table 1
Characteristics of SPE products.

Products	Temporal resolution	Spatial resolution	Regions	Availability period
IMERG-FR	30 min	0.1°	60°N - 60°S	March 2014–January 2016
IMERG-RT	30 min	0.1°	60°N - 60°S	March 2015–present

The GPM Core Observatory satellite flies at an altitude of 407 km in a non-sunsynchronous orbit and continues the Tropical Rainfall Measuring Mission (TRMM) sampling strategy and extended the observations to wider latitudes (65°N-S), while TRMM covered roughly latitudes 35°N-S (Huffman et al., 2015a). However, as can be seen in Table 1, GPM constellation satellite product, IMERG-V03, covers 60°N-S latitude. It has a spatial resolution of 0.1° and is updated every 30 min. IMERG consists of three products: IMERG-FR (currently aimed for research), IMERG-RT Early-Run, and IMERG-RT Late-Run. The IMERG products are built upon the widely used TRMM Multi-satellite Precipitation Analysis (TMPA) products and continue to enhance spatial and temporal resolutions and snowfall estimates. The increased sensitivity of the Dual-frequency Precipitation Radar (DPR) and the high frequency channels on the GPM Microwave Imager (GMI) provide a unique capability for GPM to improve the estimate of light rain and snowfall, even in the winter seasons, which other satellites are unable to measure (Hou et al., 2014; Huffman et al., 2015a; Huffman et al., 2015b).

Since GPM-IMERG is a rather new satellite product, up to now only a few preliminary comparisons between the GPM-IMERG products and other precipitation products have been carried out in Austria (Sungmin et al., 2017). Therefore, more comprehensive comparisons are still needed to better understand their differences, such as in spatial and temporal domains, at different precipitation rates, over surface types, etc. In this study, the Day-1 IMERG-FR which is the post real-time research product and IMERG near real-time late-run product of GPM-IMERG have been evaluated hourly, 3-hourly, 6-hourly, 12-hourly and daily, derived from the accumulation of half-hourly basis for IMERG V-03D for March 2015–January 2016.

Despite the limited data in the initial release of IMERG, results presented here show that systematic differences between the two products do exist and vary with precipitation rates (Liu, 2016). On the aggregate, it should be mentioned, we expect the direct inclusion of gauge analyses product (IMERG-FR) outperform the climatological adjustment product (IMERG-RT) while both use the same input satellite estimates. In addition, there will be differences in the statistics at the various time resolutions and precipitation classes since the monthly gauge adjustments are essentially being "decomposed" to higher temporal resolutions.

2. Study area

To examine the accuracy of satellite-derived precipitation data in the center of Europe, we selected the northeast of Austria, because there is a rather high-density gauge network; moreover, in this area, both stratiform and convective precipitation can occur, and the precipitation pattern is not directly affected by altitude and the topography is moderate.

Austria is located in a temperate climatic zone, and due to the topographical diversity and the relatively large west-east extent there are three quite different climatic regions: the Alpine Region with alpine climate, the eastern part of the country has Pannonian climate with a continental influence and low precipitation, and the remainder of the country, referred to as transient climate is influenced by the Atlantic (in