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Characteristics of annual, seasonal, and diurnal precipitation in the Southeastern United States derived from long-term remotely sensed data

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ABSTRACT

The objective of this paper is to investigate long-term inter-annual, seasonal, and diurnal rainfall characteristics in the Southeastern United States. In order to capture precipitation features at high resolution, we use precipitation estimates from the Tropical Rainfall Measuring Mission (TRMM); the TRMM Precipitation Radar (TPR 2A25: 0.05° × 0.05°/daily) and the TRMM Multi-satellite Precipitation Analysis (TMPA 3B42: 0.25° × 0.25°/3-h) datasets to create a 13-year rainfall climatology. The higher resolution climatology (2A25) displays a greater ability to capture more localized landform precipitation features when compared with 3B42. On an annual basis, the Southeastern US is characterized by a succession of cold and warm precipitation regimes. The cold season is characterized by higher rain intensity West of 82°W (roughly Atlanta, GA) and the warm season is characterized by higher rain intensity over the coastal areas. The cold/warm rainfall regime duality is modulated by local topographic characteristics that prevail along a W–E direction. During the cold season, the diurnal cycle of precipitation is characterized by a quasi-constant repartition of rain events throughout the day and an absence of land/ocean contrast. On the contrary for summertime there is a strong land/ocean signature with a predominance of late morning/early afternoon (12:00–15:00LST) rainfall over ocean and afternoon/early evening (15:00–18:00LST) precipitation events over land that account for more than 25% of the daily events along the coasts. Differences are observed for the Florida peninsula, where the diurnal cycle displays an afternoon maximum of variable intensity due to sea breeze effects regardless of the season.

1. Introduction

During the past decades, numerous studies have been conducted that focused on the description of seasonal and diurnal precipitation dynamics and their linkage to transport mechanisms such as synoptic, orographic, and solar forcings for the Continental United States and selected domains such as the Southeastern United States (Balling, 1985; Easterling and Robinson, 1985; Dai, 1999; Carbone et al., 2002; Carbone and Tuttle, 2008). The understanding of the diurnal cycle of precipitation is important for improving Regional Climate Models and Global Circulation Models (GCM) that do not capture with satisfying accuracy the diurnal oscillation of precipitation. Using a Regional Climate Model (RegCM), Dai et al. (1999) pointed the challenges in achieving realistic diurnal cycles, especially for summertime over the Southeastern United States where local effects drive precipitation processes. Over the past ten years, other studies have similarly shown the influence of cumulus scheme selection on the modeled annual and diurnal cycles and their relative skills for different areas of

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the Continental United States (Liang et al., 2004a,b; Lee et al., 2007, 2008).

The validation of RegCM outputs requires the availability of long-term precipitation datasets. Over the last 30 years, numerous long-term rainfall datasets were developed using rain gauge (RG) precipitation measurements, remotely sensed (ground based radars, satellites) quantitative precipitation estimates (QPE), or combining optimally different sensors each of which having specific characteristics and limitations. Extensive information on precipitation measurement methodologies and available precipitation products can be found in Michaelides et al. (2009), Kidd et al. (2010), and Tapiador et al. (2012) among others. One of the limitations in using rain gauge based precipitation datasets lies in the fact that the geographical coverage is not spatially homogeneous. By contrast, multi-sensor satellite-based products: PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks: Sorooshian et al., 2000), CMORPH (CPC MORPHing technique: Joyce et al., 2004), and TRMM (Tropical Rainfall Measuring Mission) TMPA (TRMM Multisatellite Precipitation Analysis: Huffman et al., 2007) or ground-based radar rainfall estimates: NCEP (National Centers for Environmental Prediction) Stage IV (Lin and Mitchell, 2005) or more recently the National Mosaic and Multi-sensor QPE (NMQ/Q2) (Zhang et al., 2011), provide an opportunity to broach the problem of sparse observations over land and/or ocean. The available precipitation datasets at high-resolution, both temporal (typically 1 h to 6 h) and spatial (4 km to 25 km), allow for assessing yearly, seasonal, and diurnal signatures of precipitation at local, regional, and continental scales (Sorooshian et al., 2002; Nesbitt and Zipser, 2003; Liu and Zipser, 2008; Sapiano and Arkin, 2009; Sahany et al., 2010; Kidd et al., 2012 among others) and provide a necessary basis for RegCM performance and skill assessment (Surcel et al., 2010). Furthermore, this wealth of continuously growing satellite precipitation datasets makes them a suitable candidate for longer term high-resolution hydrological studies (Tian et al., 2007; Adler et al., 2009; Nesbitt and Anders, 2009; Kidd et al., 2012; Yuan et al., 2012).

As a first step toward developing a precipitation climatology at high-resolution, this paper has two objectives. First, we aim to characterize the diurnal, seasonal, and yearly trends for the temporal frequency and spatial distribution of rainfall over the Southeastern United States. To do so, we use long-term precipitation estimates from TMPA 3B42 that, unlike other comparable remotely sensed products cited above (CMORPH, PERSIANN), provide rain gauge corrected 3-hourly/0.25° × 0.25° rainfall accumulation. The second objective is to generate a precipitation climatology at a finer scale, which takes advantage of the native resolution (0.05° × 0.05°) of the Precipitation Radar (PR) on board the TRMM satellite for the period 1998–2010. Our goal is to investigate the impact of the spatial resolution (0.05° for PR versus 0.25° for TMPA) on the characterization of precipitation features and to verify the statistical robustness of the long-term precipitation climatology derived from sun-asynchronous satellite products such as TRMM.

This paper is organized as follows: In Section 2, we present the precipitation datasets as well as the methodology used to derive the precipitation climatology at fine resolution from the TRMM family of products. In Section 3, we present the seasonal characteristic of rainfall and discuss the influence of landform on the seasonal precipitation dynamics. In Section 4, we will describe the diurnal cycle of rainfall and discuss the robustness of the precipitation climatology retrieved from TRMM PR 2A25. Finally, a summary of the main results is presented in conclusion.

2. Input datasets and derived precipitation climatologies

2.1. TRMM precipitation products

In this work, we use TMPA 3B42 (version 6: hereafter 3B42) and TPR 2A25 (hereafter 2A25) datasets from 1998 to 2010. A detailed description of both precipitation algorithms can be found in Huffman et al. (2007) for 3B42 and in Iguchi et al. (2000) and Meneghini et al. (2000) for 2A25. Briefly, 3B42 is a combination of different remotely sensed microwave (TMI, SSM/I, AMSR, AMSU) and calibrated IR estimates with rain gauge corrected monthly accumulation. The dataset 3B42 provides 3-hourly precipitation estimates at 0.25° × 0.25° resolution, which allows for deriving yearly, seasonal, daily, and sub-daily precipitation trends. In order to capture precipitation features at a higher resolution than allowed by 3B42, we also consider precipitation estimates from 2A25 that provide a picture of the three-dimensional (3-D) structure of rainfall for each satellite overpass. The PR onboard of the TRMM satellite is a scanning radar operating at 13.8 GHz with a horizontal and vertical resolutions of 5 km and 250 m respectively. Specifically intended for the measurement of precipitation, the algorithm 2A25 uses a hybrid of the surface method and the Hitschfeld–Bordan method to correct the attenuation of the measured reflectivity (Iguchi et al., 2000). We use the 2A25 near surface rain rate (see Iguchi et al., 2000 for a description of available rain rate estimates for 2A25) to derive yearly and seasonal rainfall accumulation at 0.05° × 0.05° resolution. For obvious reasons, sun-asynchronous satellites such as TRMM only provide an instantaneous image of a rainfall event but do not allow the characterization of precipitation processes for the duration of the storm system. Despite the lack of continuous temporal coverage, the length of the observation period (1998–2010) allows for the representativeness of the high-resolution precipitation climatology to be derived from 2A25. We will quantify the differences in terms of accumulation between the precipitation climatologies derived from both precipitation products that will be compared with surface observations. We will also discuss the robustness of the diurnal cycle (DC) computed from 2A25. Fig. 1 displays the geographical area (72°W–104°W, 24°N–40°N) considered in the present study. Note that both datasets cover a slightly different geographic area centered on the equator. The product 3B42 provides precipitation estimates for 50°N–50°S (40°N–40°S for 1998–1999) while 2A25 covers approximately 36°N–36°S due to the smaller footprint of the swath of the precipitation radar onboard the TRMM satellite.

2.2. Yearly characteristics of precipitation: differences between TRMM products derived from rainfall climatology

Fig. 2 displays the annual mean precipitation retrieved from 3B42 (Fig. 2a) and 2A25 (Fig. 2b) computed for the period 1998–2010 in addition to a representation of the relative geographical coverage of each satellite product. The accumulation from 3B42 shows that the highest rainfall (>6 mm/day) is found over the ocean along the East Coast and corresponds to the important precipitation activity along