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An assessment of satellite-based high resolution precipitation datasets for atmospheric composition studies in the maritime continent☆

F. Joseph Turk [a,*], Peng Xian [b]

[a] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, United States
[b] ASEE Fellow, Naval Research Laboratory, Marine Meteorology Division, Monterey, CA 93940, United States

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ABSTRACT

The Maritime Continent (MC) region of Southeast Asia is known for land use practices that are modulated by precipitation occurrence and fire activity. The polluted environment may modify cloud/precipitation formation mechanisms, but meteorological or weather patterns may disrupt or otherwise influence these same processes. Since the simultaneous retrieval of precipitation and aerosol properties is not possible from current satellite observations, the choice of the precipitation dataset used for applications such as model assimilation and scavenging in aerosol transport models could provide very different results. In this article, a seven-year (2003–2009) time period was analyzed with five satellite-based high-resolution precipitation products (HRPP), the MERRA model reanalysis, and MODIS-derived aerosol observations within nine Southeast Asia domains. Substantially different trends between the aerosol concentration and precipitation time series were noted for different MC island regions, as well as HRPP differences in the precipitation diurnal variability and their capability to track precipitation extremes. For all regions, the most noticeable change to the diurnal cycle was noted during the genesis phase (Phase 1 in the MC) of the intraseasonal Madden Julian Oscillation (MJO). Since these studies do not take any aerosol transport or precipitation dynamics into account, the use of Lagrangian models is proposed to study non-localized aerosol/precipitation interactions and better establish their veracity in current model simulations.

1. Introduction

Within the past decade there has been a marked increase in the number of studies undertaken to better understand the collective nature of cloud, precipitation and aerosol processes. The current Seven SouthEast Asian Studies (7-SEAS) experiment (http://7-seas.gsfc.nasa.gov) has been established to characterize aerosol-meteorological interactions in the Southeast (SE) Asia area (the region roughly bounded between 10 S–10 N latitude and 90E–150E longitude), which includes a number of important surface sources for natural and anthropogenic aerosols. Common amongst these studies is the availability of aerosol satellite data records from the Moderate Resolution Spectroradiometer (MODIS) (Kaufman et al., 2000) onboard the Terra and Aqua satellites and the Multiangle Imaging Spectroradiometer (MISR) (Kahn et al., 2009) onboard Terra, and precipitation records created from the Advanced Microwave Scanning Radiometer (AMSR-E) onboard Aqua and the Tropical Rainfall Measuring Mission (TRMM) satellite. TRMM has been gathering combined Ku-band (14 GHz) precipitation radar (PR) and passive microwave (PMW) radiometer observations since early 1998.

The complex interaction between clouds and aerosols, onset and growth of precipitation, how clouds and precipitation evolve in relation to (or are modified by) their environment (dust, pollution, etc.) and meteorological background,

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* Tel.: +1 818 354 0315.
E-mail address: jturk@jpl.nasa.gov (F.J. Turk).

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all occur over a range of space and time scales. Yet the sensors onboard these and similar satellites capture only intermittent snapshots of these processes once or twice per day on average. Aerosol particles perturb cloud properties and boundary layer dynamics, subsequently feeding back into pollution emissions, concentrations, and cloud lifetime. As discussed by Stevens and Feingold (2009), it is difficult to establish cause and effect on changes or modifications to precipitation by the presence of various aerosol types, and they argue that any such relations are likely to be regime dependent. Studies have found that air pollution in and near urban growth centers may be changing localized precipitation patterns downwind of major cities (Van den Heever and Cotton, 2007). Fires and human-activated biomass burning release various amounts of smoke aerosols, which have been shown to be associated with suppressed particle aggregation and precipitation processes (Rosenfeld, 1999; Fromm et al., 2006). Since the simultaneous satellite retrieval of constituent properties is not possible (or severely degraded) from satellite data for cloud and precipitation-affected scenes, the choice of the precipitation dataset used for applications such as model assimilation, comparison with in-situ observations or aerosol removal in transport models could provide very different results.

The intent of this paper is to provide a regional assessment of several current and widely-used precipitation datasets (five satellite-based and one model) within the Maritime Continent (MC) area (the region of SE Asia encompassing many islands). In the MC, persistent cloud cover and deep convection are common throughout the year, with the principal rainy season centered on December–February and a less wet season around June–August (Aldrian and Susanto, 2003; Chang et al., 2005). A major source of anthropogenic aerosols in the MC originates from fires on oil plantation lands. As discussed by Reid et al. (2012), the warm tropical environment of the MC presents uncertainties regarding how the radiative and thermodynamic properties of aerosol particles influence clouds and precipitation. Even under clear sky conditions, the aerosol particles influence on the surface heat budget and the temperature profile may have resulting feedbacks in cloud cover, which in turn may amplify the aerosol particle effects. A warm phase El Niño Southern Oscillation (ENSO) condition (i.e., El Niño) leads to negative summertime precipitation anomalies in SE Asia, and a corresponding increase in fire activity. The Madden Julian Oscillation (MJO) is a large-scale repeating pattern of deep convection that forms in the Indian Ocean and propagates eastward through the MC and into the Pacific Ocean. MJO phase 1 is associated with MJO genesis. By phase 4, convection approaches the MC and by phase 5, convection is entering the Pacific Ocean and significant drying begins over the MC throughout phases 6 and 7 (Reid et al., 2012). The limited swath of the AMSR-E or TRMM sensor captures only intermittent glimpses of the precipitation, and multiple days may lapse between revisits during the peak phases of an intraseasonal progression.

To overcome this observational gap, Section 2 of this study examines several multi-satellite high resolution precipitation products (HRPP). HRPPs combine TRMM, AMSR-E and other PMW-based precipitation data together with fast-refresh geostationary imaging data to generate a precipitation product that is of a finer spatial and/or temporal resolution than the PMW data (Turk et al., 2008). While verification of HRPP techniques is a central activity of the International Precipitation Working Group (Ebert et al., 2007; Kidd et al., 2010), to date there has not been a detailed examination and comparison of multiple HRPPs within the MC, to examine their performance (relative to gauges), and the variability of the diurnal cycle, including any response to intraseasonal changes such as the MJO. The Modern Era Retrospective Analysis for Research and Applications (MERRA) dataset (Bosilovich, 2008), a NASA model reanalysis using the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5), was used to define the dynamical and meteorological environment within and surrounding the MC and as an additional source of model-derived precipitation data. Although raingauge data has sparse coverage in the MC, in Section 3 these HRPP data were compared against the daily, one-half degree raingauge analysis produced by the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC) (Shen et al., 2009) to examine relative performance when the HRPPs were separated by the MJO phase.

MODIS AOT data are collectively analyzed to separate regional precipitation variability from several sources, but this study does not attempt to dissect quantitative aerosol–precipitation effects resulting from the use of any precipitation dataset or another. To properly perform the latter studies, one would have to take aerosol transport or larger scale precipitation dynamics into account. The study concludes with an example whereby Lagrangian models are proposed to study temporally displaced aerosol/precipitation interactions, to better establish the veracity of current general circulation model simulations.

2. Observations and methodology

The approach follows the recent recommendations of several authors (Stevens and Feingold, 2009; Levin and Cotton, 2009), who emphasize the necessity of observational datasets capable of documenting the time/space evolution of clouds, precipitation and aerosols over different regimes. Five HRPPs, the MERRA reanalysis, and MODIS AOT data products were regionally subsetted at specific island and land areas within the MC for a multi-year period, providing the context for investigation of diurnal precipitation variability. In order to break down the localized meteorology within the MC region, the multi-year data analysis was separated into nine separate domains, as illustrated in Fig. 1. These include portions of Sumatra, Borneo, Java, and Sulawesi, peninsular Malaysia, and the southern Philippine island of Mindanao. Each of these domains has unique topographical and meteorological factors that affect its localized precipitation. For example, the Barisan mountain range shelters the drier, eastern side of Sumatra from its much wetter western side. The main rainy season happens after the southwesterly monsoon, which occurs from May to September. Even though these island areas are closely spaced, interannual and intraseasonal oscillations can affect each area differently. There is much less fire thus less smoke aerosol during the MC wet season (with southward moving air) than during the dry season. And considering that the average smoke aerosol lifetime is less than one week, this wet season effect is different relative to the same aerosol released during the dry season.