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Investigating sea surface temperature diurnal variation over the Tropical Warm Pool using MTSAT-1R data

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ABSTRACT

Diurnal variation (DV) of sea surface temperature (SST) plays an important role in air–sea interaction. We have validated four months (January to April 2010) of the version 3 Australian Bureau of Meteorology reprocessed Multifunction Transport SATellite-1R (v3 MTSAT-1R) SST data over the Tropical Warm Pool (TWP) region (90°E to 170°E, 25°S to 15°N) against both drifting buoy and Advanced Along-Track Scanning Radiometer (AATSR) SST data. Validation against collocated point measurements from drifting buoys, under conditions where the surface ocean is well-mixed, shows that overall the v3 MTSAT-1R SSTs perform well with an average bias of 0.00 °C and a 0.73 °C standard deviation (STD). The average daytime and night-time mean bias is −0.06 °C and 0.08 °C, respectively. For all hours of the diurnal cycle, the mean biases are within ±0.25 °C, indicating the consistency between day and night v3 MTSAT-1R data. However, on average, the v3 MTSAT-1R SSTs are overestimated at cold SSTs and underestimated at warm SSTs. Similar results are obtained from validation against the AATSR satellite SSTs but with smaller STD (0.48 °C) and smaller average daytime and night-time mean biases (−0.04 °C and 0.06 °C, respectively). These results indicate that the v3 MTSAT-1R data set is suitable for SST DV investigations and validation of DV models. Using the validated v3 MSTAT-1R data, together with surface wind speed and solar shortwave insolation (SSI) outputs from the Australian Community Climate and Earth-System Simulator – Regional (ACCESS-R) numerical prediction model, we investigate SST DV events over the TWP region. Good correlation is found between DV events and low wind and high SSI conditions. The dominant role of wind speed in SST DV events over the SSI is also revealed.

1. Introduction

Sea surface temperature (SST) is recognized as one of the most important variables in climate and weather studies. It plays a key role in constraining the exchange of moisture and heat in air–sea interaction and is able to exert influences on both short and long term climate dynamics. SSTs are also controlled by atmospheric conditions. For example, the sea surface wind causes turbulent mixing in the upper ocean, thus changing the ocean's near surface temperature profile. Warm SST also increases near-surface air temperature and reduces the stability of the atmospheric boundary layer. The role of SST is of particular significance in the Tropical Warm Pool (TWP) region, defined as the western equatorial Pacific Ocean and eastern Indian Ocean, which exhibits some of the highest average SSTs over a large expanse of the earth's surface (Fig. 1). Previous investigations have shown that the seasonal, inter-annual and long-term natural climate fluctuations in the equatorial and mid-latitude regions are particularly sensitive to the SST distribution in the warm tropical oceans (e.g. An, Kim, Im, Kim & Park, 2012; Park, Yeh & Kug, 2012; Vecchi, Clement & Soden, 2008).

Diurnal variation (DV) of SST, or diurnal warming, normally refers to the daily temperature fluctuation in the upper few meters of the ocean. The thermal stratification of the ocean surface layer is the result of the interaction of several factors, including the heat exchange between the atmosphere and the ocean, turbulent mixing, and the absorption of solar insolation. Under most conditions, there is net loss of heat from the ocean with the skin, or interfacial, layer being cooler than the water below (Fairall et al., 1996). However, during the day, especially under calm winds and clear skies, a warm layer can develop in the uppermost 5–10 m of the ocean (Gentemann, Minnett, Le Borgne & Merchant, 2008). Diurnal warm layers have typical temperature differences relative to the body of water below on the order of 0.5–3 °C, but in some cases can reach values up to 5–8 °C (e.g. Gentemann et al., 2008; Karagali, Høyer & Hasager, 2012; Merchant et al., 2008). Previous studies have shown that a better understanding of DV events

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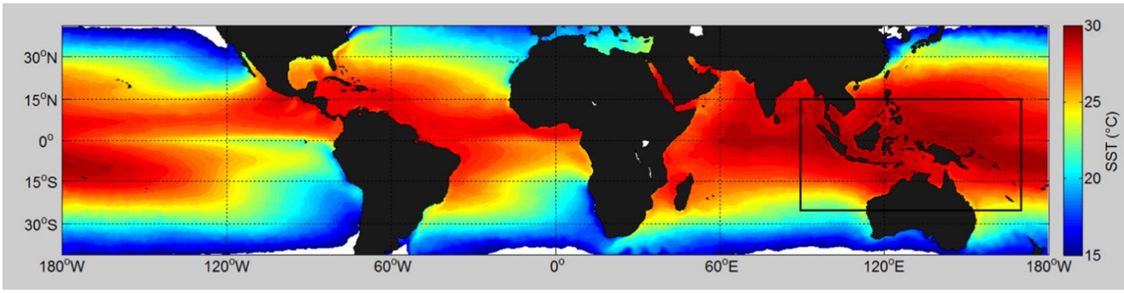

Fig. 1. Annual average SST in 2010, obtained from Global Australian Multi-Sensor SST Analysis data (Zhong & Beggs, 2008). The box shows the TWP study domain.

is essential to better represent the air–sea interaction in weather and climate models (e.g. Clayson & Bogdanoff, 2013; Fairall et al., 1996). Ignorance of the SST DV could lead to errors in the surface flux estimates. For instance, Clayson and Bogdanoff (2013) have found that significant portions of the tropical oceans experience total heat flux differences as high as 10 Wm^{-2} on a yearly average when the SST DV effects are taken into consideration.

SST DV events have been studied for decades. Before the 1980s, in-situ SST measurements served as the primary data source (e.g. Halpern & Reed, 1976; Stommel, Saunders, Simmons & Cooper, 1969). Since remotely sensed data from Advanced Very High Resolution Radiometer (AVHRR) sensors on-board the National Oceanic and Atmospheric Administration (NOAA) series satellites became widely available in the 1980s, satellite data soon greatly facilitated the research in terms of temporal and spatial data coverage (e.g. Böhm, Marullo & Santoleri, 1991; Hawkins, Clancy & Price, 1993; Stuart-Menteth, Robinson & Challenor, 2003). Remotely sensed observations of SST may be obtained from infrared or microwave sensors on-board either geostationary or low earth orbit satellites. In order to take advantage of the high quality in-situ data, most studies have been conducted on regional scales, such as over the Mediterranean Sea (Böhm et al., 1991; Castro, Wick & Buck, 2014), the Mutsu Bay (Kawai, Otsuka & Kawamura, 2006), the North and Baltic Seas (Karagali & Høyer, 2013; Karagali et al., 2012), the western Pacific Ocean (Kawai & Kawamura, 2005), and even the Arctic Ocean (Eastwood, Le Borgne, Péré & Poulter, 2011). Global studies are fewer mostly due to the requirement of continuous high quality data coverage both spatially and temporally (e.g. Clayson & Bogdanoff, 2013; Stuart-Menteth et al., 2003). The TWP region is an ideal area for DV studies due to the frequent occurrence of large DV events associated with the region's relatively calm winds, strong insolation, and sensitivity to changes in air–sea fluxes. Webster, Clayson, and Curry (1996) addressed the relationship between clouds, radiation, and the diurnal cycle of SST in the TWP region. They concluded that the amplitude of the diurnal cycle is largest for the greatest insolation and lowest wind speed, and that the influence of surface wind speed on the diurnal cycle amplitude of SST is nonlinear. In Soloviev and Lukas (1997), large diurnal warming events were observed from very high resolution measurements of near-surface thermohaline and turbulence structures made using bow-mounted probes and a free-rising profiler. In Kawamura, Qin, and Ando (2008), the amplitude and temporal characteristics of SST DV were examined as well using a combination of in-situ and AVHRR data. Tanahashi, Kawamura, Takahashi, and Yusa (2003) also studied the SST DV events using the Geostationary Meteorological Satellite (GMS) data over the open ocean.

In 2005, the Multi-functional Transport SATellite-1R (MTSAT-1R) was launched by the Japan Aerospace Exploration Agency (JAXA) on behalf of the Japan Civil Aviation Bureau and the Japan Meteorological Agency as a successor to the GMS series satellites. MTSAT-1R was in a geostationary orbit above 140°E and carried the Japanese Advanced Meteorological Imager (JAMI) on board that captured full-disc imagery on an hourly basis during the period 2005–2010 using five spectral channels (wavelengths of 0.6–12.0 μm). MTSAT-1R provided a further step forward in observing technology for SST DV. So far, published works focus more on SST retrieval algorithms and algorithm validation than on the application in analysing the SST DV events (e.g. Kawamura, Qin, Sakaida & Qiu, 2010a; Kawamura, Qin, Sakaida & Setiawan, 2010b). With the version 3 (v3) MTSAT-1R data specially processed for the Tropical Warm Pool Diurnal Variability project (TWP+ project, see details in Section 2) by the Australian Bureau of Meteorology (Bureau), we are offered a valuable opportunity to investigate SST DV events in detail within the TWP region.

The focus of this paper is to validate the v3 MTSAT-1R data set and to characterise the derived SST DV events. Section 2 introduces the data sets and the methods used in this work, followed by Section 3 which illustrates the validation results. The SST DV events are investigated in Section 4. Discussion and conclusions regarding the results are presented in Section 5.

2. Data and methods

2.1. Data

2.1.1. MTSAT-1R data

The v3 MTSAT-1R data set provides SST at approximately 10 μm depth (SST_{skin}), calculated from radiance observations of spectral channels centred at 3.7, 10.8 and 12.0 μm. These full-disc radiances measured at approximately 10 μm depth were regressed against drifting buoy SST observations at 20 to 30 cm depth during the period June 2006 to June 2010 to produce a sub-skin SST (for detailed SST definition please refer to Donlon et al., 2007). The sub-skin is converted to a skin SST by subtracting a constant 0.17 °C (Beggs et al., 2013) to account for the average cool-skin effect, following the method of Beggs, Kippo, and Underwood (2012b). In order to reduce temporal and spatial biases relative to the version 2 (v2) MTSAT-1R SSTs which were originally reprocessed by the Bureau for the Integrated Marine Observing System (IMOS) (Beggs et al., 2012a), the v3 processing system applied correction factors to account for a number of geometric and temporal properties, including pixel and line position, observation hour, solar declination and earth-sun distance (Beggs et al., 2013; Majewski, Griffin & Beggs, 2013). The v3 MTSAT-1R SST data used in this study were produced to fulfil the requirements of the TWP+ project and are available on request (h.beggs@bom.gov.au).

The TWP+ project is conducted as a collaboration between the Bureau, Group for High Resolution SST (GHRSST), IMOS, Météo-France, University of Edinburgh (UoE) and REMote Sensing Systems (REMSS) for the study of DV over the TWP region (https://www.ghrsst.org/ghrsst/tags-and-wgs/dv-wg/twp/). The TWP+ dataset is a comprehensive data collection compiled by assembling different data sources (in-situ data, satellite data, and models) that provide a variety of parameters, including SST, wind speed, and solar insolation, over the TWP study region (90°E–170°E, 25°S–15°N) and time period (1 January to 30 April 2010). The v3 MTSAT-1R data, produced in December 2012, are the key component of the TWP+ data set for validation of DV