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SST Cooling in the Indonesian Seas

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Abstrak

Menggunakan satelit pemantau suhu permukaan laut (SPL) dan angin permukaan laut telah dikaji karakteristik dari SPL dan angin permukaan laut di perairan Indonesia. Siklus musiman SPL di perairan Indonesia dicirikan dengan "pendinginan" selama musim panas. Pendinginan, yang terjadi dari bulan Mei sampai Agustus, maksimum di perairan Indonesia timur dan minimum di perairan Indonesia barat. Studi ini mengindikasikan bahwa angin monsoon dari arah tenggara berperan penting dalam fenomena pendinginan di perairan Indonesia. Pendinginan pertama kali muncul di bulan Mei dan mencapai maksimum di bulan Agustus. Pendinginan tersebut disebabkan oleh pengaruh angin monsoon yang sangat kuat di bulan Juli. Area dengan SPL di bawah 26°C tampak di Laut Banda, dimana merupakan perairan yang paling dingin di Indonesia. Hasil penelitian menyimpulkan bahwa pendinginan di laut Indonesia disebabkan oleh interaksi angin monsoon tenggara dengan laut.

Kata kunci: *satelit penginderaan jauh, pendinginan suhu permukaan laut, angin monsoon tenggara.*

Abstract

Using advance satellite-derived sea surface temperature (SST) and sea surface wind, the characteristics of SST and wind variations in the internal Indonesian Seas (hereafter INA) were investigated. The seasonal cycle of SST in the INA is marked by a cooling in the dry season. The cooling, which occurs during May–August, is maximum in the eastern INA and decreases towards west. This study indicated that the southeasterly monsoon winds play a significant role in the cooling phenomena in Indonesian Seas. The cooling is first identified in May, while August is its mature phase and it is affected by stronger winds (7-8 m/s) during July. An area with SST lower than 26°C appears in the Banda Sea, representing the coolest region in the INA. The results of the present investigation inferred that SST cooling in the INA is caused by southeast monsoon winds-ocean interaction.

Key words: *satellite remote sensing, SST cooling, southeast monsoon winds.*

Introduction

Lying on the confluence of the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate is the Indonesian Archipelago. The Indonesian region is also known as the "Maritime Continent" (Qu *et al.*, 2005). Because of its unique position, the Indonesian maritime continent experiences seasonal (i.e., monsoons) to inter-annual (i.e., El Nino-Southern Oscillation, ENSO) climate variations. There are two monsoon seasons every year, i.e. southeast (SE) monsoon and northwest (NW) monsoon. The SE monsoon (dry season) is associated with easterlies from Australia that carry warm and dry air over the region (Figure 1, black arrow). On the other hand, the NW monsoon (rainy season) is associated with westerlies from the Eurasian continent that carry warm and moist air to the Indonesian region (Figure 1, gray arrow).

The interest case here is the SE monsoon forcing on the SST in the INA. The seasonal cycle of surface temperature in the INA is marked by a cooling during summer (May-August). The SE monsoon winds cause a large decrease in SST, which is called the sea surface cooling in this paper. SST is one of the essential parameters in studies of the ocean, atmosphere and atmosphere-ocean interactions (Kawamura *et al.*, 2010).

The need for accurate global SST fields has been receiving increasing attention, primarily because of their importance in understanding variability in the global climate. Satellite SST measurements are attractive because of their global repeated coverage compared to any other type of measurements of this quantity (Kilpatrick *et al.*, 2001). Taking advantages of cloud-free and high-resolution satellite observation, the seasonal evolutions of SST cooling in the INA were investigated. This study presents not only comprehensive SST maps that show the detailed spatial structure of the cooling, but also its seasonal variations.

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Material and Method

The Center for Atmospheric and Oceanic Studies (CAOS) has developed the Tohoku OISST (Optimum Interpolation SST). Satellite SST observations from infrared radiometers (NOAA/NASA AVHRR Pathfinder Ver.4.1, Tohoku Univ. TRMM/VIRS SST) and a microwave radiometer (JAXA/EORC TRMM/MI SST, ERS-2/ATSR-2 SST) are objectively merged to generate this SST product, which is quality-controlled, cloud-free, high-spatial resolution (0.1 degree-gridded), global coverage, and daily SST digital map. Detailed explanations of the Tohoku OISST are given by Kawai *et al.* (2006). In this study, the daily data for 1999-2004 were used to perform monthly climatology analysis.

The microwave scatterometer on the QuikSCAT satellite measures surface wind velocity over the world ocean on a daily basis (Liu *et al.*, 2000). A monthly climatology of wind speed was constructed from daily QuikSCAT observations for April 2000 to October 2004 on a 0.25° grid.

Results and Discussion

Employing the TOHOKU OISST and the QSCAT vector surface winds (SW), the monthly climatology is generated for the southeast (SE) monsoon season (April to October). The climatological mean SST patterns over the Indonesian region clearly demonstrate the effect of the SE monsoon SW. The east Indonesian seas (hereafter EINA) experience conspicuous decreases of SST during the SE monsoon. On the other hand, SST is relatively high in the west Indonesian seas (WINA). A mechanism controlling the spatial and temporal scales of SST in the EINA has been studied by Susanto *et al.*, (2006), which followed the Wyrtki's role using the Ekman theory. Southeasterly winds that are blowing from the Australian continent have been proposed as a trigger of the SST variability, in which the Ekman pumping and upwelling have dominant roles.

In April, all of the INA are covered by SST~30°C (Figure 2a). Figure 2h shows that the lowest overall wind speeds appear in April, which represents the month of transition between the northwest (NW) and SE monsoons (e.g., Wyrtki, 1961; Gordon, 2005). Because of weak winds and large sea surface heating due to solar radiation, water stratification is well developed in this month, which results in a uniform SST field in the entire INA. An area with wind speeds of 6.5-7 m/s from the Australian continent appears on the Arafura Sea. Slight changes in wind speed also appear in the western Banda Sea and eastern Java Sea.

In May, SST in the WINA is high (Figure 2b). The Natuna Sea is covered by very high SST (~30.5°C). Meanwhile, small changes in SST start in the EINA, particularly in the Arafura Sea with intensification of the southeasterly winds (Figure 2i). This month is the beginning of sea-surface cooling event in the EINA during SE monsoon.

Effects of the strong SWs (8-9 m/s) on the SST fields are pronounced in June (Figure 2j). The strong SWs are spreading and intensifying in the EINA region. SST cooling areas are expanding toward the wind direction from the Arafura Sea. Cold SST areas (greenish in Figure 2c) penetrate deep into the Banda Sea. The western coast of Papua experience significant cooling below 27°C. Gordon & Susanto (2001) have reported that, in the Banda Sea, the Ekman upwelling reaches a maximum in May and June of approximately 2.5 Sv (1 Sv = 106 m^3 s^{-1}). The Ekman pumping is strongest over the eastern Banda and the Arafura Seas. Moreover, Gordon *et al.*, (2003) have revealed that `more-saline surface waters of the Flores and Banda Seas are drawn into the Java Sea by the SE monsoonal winds.

The strong easterly SWs (Figure 2j) blow into the Java Sea, which separate into two streams passing through the Makassar and Karimata Straits. Due to the presence of high mountains in the south of Sulawesi Island, the flows toward the Makassar Strait are intensified around the corner of the Sulawesi Island (Setiawan & Kawamura, 2010). An area with SSTs lower than the surrounding SSTs can be seen in the sea southwest of the Sulawesi Island (Figure 2c). The intensified easterly SWs in the central and eastern Java Sea may bring a slightly decrease of SST. SST cooling appears in the Maluku and Halmahera Seas as well. Compared with the April SST fields, SSTs of these two seas drop of about 0.5°C.

In July, SSTs of about 25°C are found in the Arafura Sea and the western coast of Papua (Figure 2d), which are the lowest SSTs cooled by the SE monsoon winds in the INA. These areas of the lowest SSTs expand in August (Figure 2e), which may be attributed to the Wyrtki's role (e.g., Wyrtky, 1961; Sprintal & Liu, 2005; Susanto *et al.*, 2006). The SST cooling in the Seram, the Maluku, and the Halmahera Seas enhance as well. In this month, very strong winds (7-8 m/s) occupy the EINA particularly in the Banda, the Arafura, and the eastern Seram Seas (Figure 2k), marking the peak of SE monsoon (Gordon & Susanto, 2001; Susanto *et al.*, 2006). In the Java Sea, the strong SWs occupy and intensify, which cools SST in the whole area.

August is the mature of SST cooling in the INA. Gordon & Susanto (2001) mentioned that SST in the Banda Sea ranges from a low of 26.5°C in August to a high of 29.5°C in December and May. However, areas with SSTs lower than 26°C appear in the Banda Sea (Figure 2e). SST cooling further developed in the EINA (the Seram, the Maluku, and the Halmahera) and in the whole Java Sea. A patch with cooled SST is seen in the southern Makassar Strait. In contrast, the SWs retreat in August (Figure 2l) after the SE monsoon peak of July (Figure 2k). The August peak of SST cooling in the INA is most likely a result of stronger winds during July.

SST cooling in the INA is weakened in September (Figure 2f) as well as the SWs (Figure 2m). In October, increased SSTs (> 28°C) start to cause a uniform SST field in the INA except for coastal seas in the EINA (Figure 2g).

In order to gain better understanding about the relationship between SST cooling and wind velocity, simple time-series analysis for selected regions (box A and B in Figure 1e) were generated, as shown in Figure 3. On climatological mean, monthly averaged wind speed based on QSCAT shows a good match to the SST. The high wind speed coincides with the low SST for both regions although there is a time lag in the region A (Banda Sea). Nevertheless, it implies that the summertime monsoon winds play a dominant role in determining SST cooling in the INA.

Conclusion

For the past decade, satellite remote sensing technology has been revolutionizing ocean observation, enabling us to make routine and high-resolution measurements of SST and surface winds over the world ocean. In this work, the strength of using a combination of the Tohoku OISST and scatterometer-based sea-surface winds has been demonstrated to investigate the relationship between monsoon wind and sea surface cooling. The regions of high wind coincide with the cooling areas. A particularly noticeable feature is the sharp decline in SST in the Banda Sea in August (below 26°C). From the results of our present work, it is inferred that the SE monsoon winds play a primary role in determining the cooling, and the summertime SST cooling in the INA is a case of monsoon-ocean interaction.

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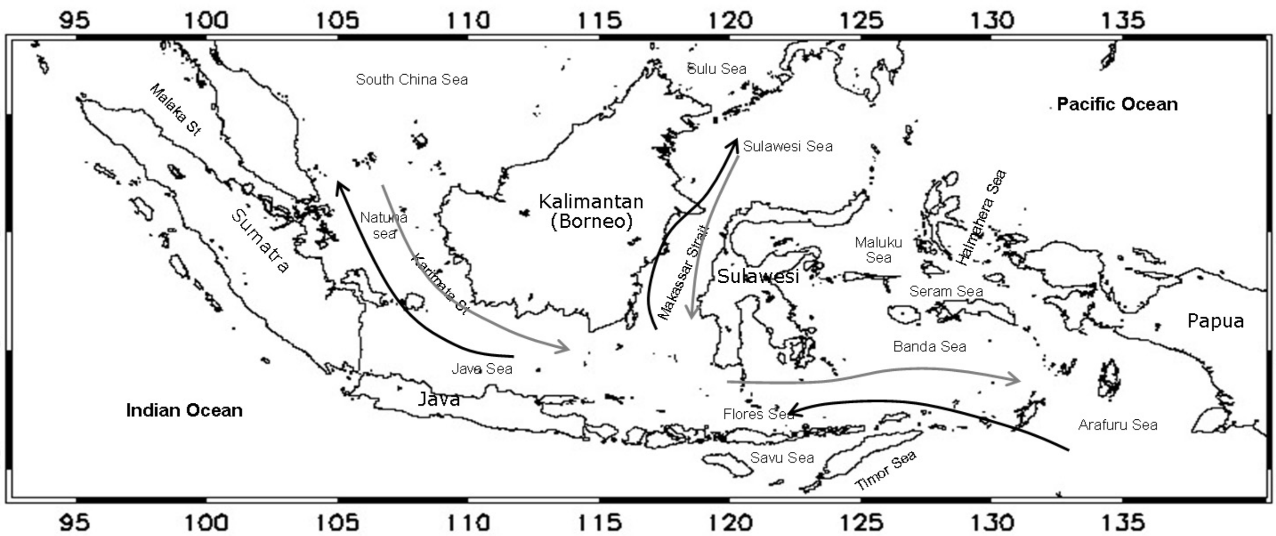

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Rainy season				Transition phase		Dry season				Transition phase	

Figure 1. Map of the Indonesian Maritime Continent. The black and gray arrows denote the general pattern of SE and NW monsoon wind directions.

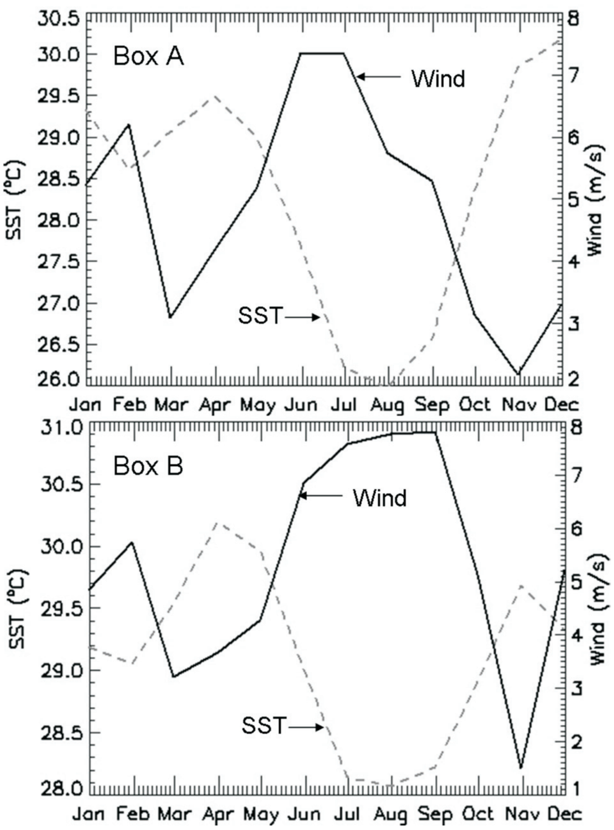

Figure 3. Temporal variability of SST and sea surface wind based on monthly climatology mean. Solid and dashed lines denote wind speed and SST.

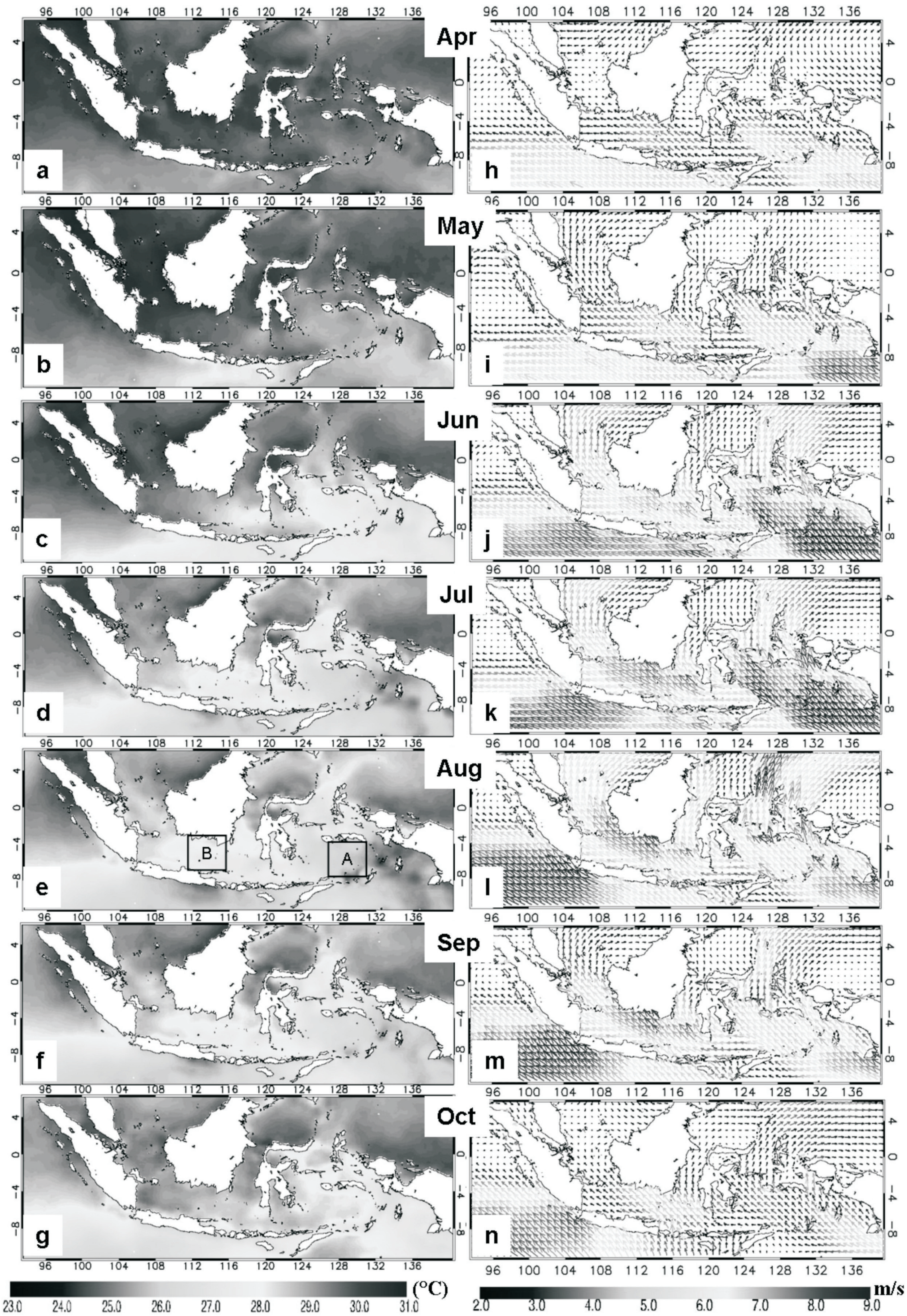

Figure 2. Monthly climatological mean of SST and wind in the Indonesian Seas.