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The Interaction of Australian Winter Monsoon and East Asian Summer Monsoon and Its Impacts on Convergence Around Kalimantan

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Abstract — The Australian Winter Monsoon (AWM) and East Asian Summer Monsoon (EASM) play a crucial factor in altering the global climate. The two monsoons are closely linked to each other through cross-equatorial flow. As the Australian High anomaly increases, the Western Pacific Subtropical High (WPSH) also increases, resulting in an anticyclone anomaly in Australia and the Western Pacific region that intensifies the AWM and EASM. This study examines the effect of variations between the two monsoons by removing ENSO and IOD signals on meteorological parameters in the Kalimantan region. European Center for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 data with a resolution of 0.25° × 0.25° is used to examine the effect at the local scale and rainfall data from local observations for 35 years in the June-July-August (JJA) or boreal summer. Composite and correlation analyses were conducted by calculating the regression coefficients between the composite variables and the target variables. The EASM and AWM were also analyzed using Singular Value Decomposition (SVD) to identify the most relevant spatial patterns. This research reveals that when the AWM and EASM increase at once, two connected anticyclone anomalies over the maritime continent trigger easterly wind anomalies, leading to convergence in Kalimantan, which increases the rainfall intensity in the Kalimantan region.

Keywords— Australian Winter Monsoon, East Asian Summer Monsoon, Kalimantan, Boreal summer, Rainfall

I. INTRODUCTION

The Asia-Australia monsoon system plays a crucial role in global climate patterns [1]. Climate and weather changes in this area are influenced by the South Asian monsoon, East Asian monsoon, and Australian monsoon. The Australian Winter Monsoon (AWM) and East Asian Summer Monsoon (EASM) are integral components of this circulation system, closely linked by cross-equatorial airflow. Concurrent fluctuations in both monsoons (EAAM) can occur [1-3].

Anomalies of zonal winds in the equatorial region associated with the East Asian and Australian monsoons indicate a connection between variations in the East Asian monsoon and the El Niño Southern Oscillation (ENSO) [4]. During ENSO periods, cold sea surface temperature (SST) anomalies emerge in the western Pacific, leading to the genesis of circulation anomalies in the western Pacific subtropics and Australia, thereby affecting East Asian monsoon anomalies. The activity of both monsoons is not solely influenced by SST in the western Pacific and in the Indian Ocean. Positive Indian Ocean Dipole (IOD) events cause a cold SST anomalies and anticyclonic circulation anomalies in the eastern Indian Ocean, enhancing the transfer of water vapor from the Indian Ocean and Bay of Bengal to eastern China. Consequently, above-normal rainfall may occur in eastern China [5].

As previously mentioned, ENSO and IOD are two significant factors that influence the variations of both EASM and AWM. However, upon removing the signals of ENSO and IOD, climate anomalies emerge in East Asia and Australia, leading to convergence in the Kalimantan region due to variations in the interaction between the two monsoons [1, 3]. The objective of this study is to examine anomalies resulting from variations in both monsoons, particularly in the Kalimantan region.

II. METHODOLOGY

A. Data

This study uses data including sea level pressure (SLP), sea surface temperature (SST), precipitation, and 2-meter temperature obtained from the ERA-5 reanalysis dataset offered by the European Center for Medium-Range Weather Forecasts (ECMWF) with 0.25° × 0.25° spatial resolution and a monthly temporal resolution, along with rainfall observation data from meteorological stations in Kalimantan. These datasets were gathered over the period from 1979 to 2013 (35 years) and subsequently averaged. The months of June, July, and August (JJA) were chosen as the reference period, aligning with the ongoing summer season in the northern hemisphere.

B. The EAAM Index with ENSO and IOD Removed

The Australian Winter Monsoon (AWM) is characterized by the eastward equatorial wind at 850 hPa and the westward equatorial wind at 200 hPa. An index to describe AWM variability can be calculated by the zonal wind at 850 hPa averaged over Australia. On the other hand, the East Asian Summer Monsoon (EASM) is characterized by the changing of south and north winds at 850 hPa in summer and winter seasons. Hence, the meridional wind at 850 hPa can be used as an index to describe EASM [1 - 3].

C. Singular Value Decomposition

The SVD analysis performed by taking zonal wind anomalies over 110-160°E, 40-10°S in Australia and meridional wind over 110-140°E, 20-45°N in East Asia [1 - 3]. Key areas of high correlation between the EASM and AWM are identified based on the spatial pattern of SVD1. These areas span from 130° to 157.5°E and from 25° to 10°S (with variations in the AWM phase), as well as from 115° to 122.5°E and from 20° to 27.5°N (with variations in the EASM phase) [2]. Applying the SVD helps to identify the primary spatial pattern of EASM circulation that exhibits the strongest connection with the AWM [4]. After filtering out the signals of Nino 3.4 and IOD using regression methods, the SVD results show a close relationship between AWM and EASM. SVD analysis indicates that during the strong winter in northern Australia (evidenced by eastward wind anomalies), positive anomalies of meridional wind in East Asia south of 30°N located in the South China Sea at the southern Taiwan Strait. Meanwhile, negative anomalies appear in the north of 30°N. Conversely, when AWM is weak, the condition will be reversed.

Subsequently, the time coefficients of the SVD were computed, averaged, and standardized to define the combined EAAM index (IEAAM). During the summer season in the northern hemisphere, positive values of IEAAM indicate a stronger than usual EAAM, while negative values indicate a weaker EAAM. Through this index, we can define the relationship between a strong (weak) AWM and strong (weak) EASM [1]. Strong years occur when IEAAM > 0.75, occurring in 1995, 1998, 2006, 2008, 2010, 2012, 2016, and 2017, while weak years are defined when IEAAM < –0.75, occurring in 1982, 1986, 1991, 1997, 1999, 2003, 2004, and 2011 [2].

III. RESULTS AND DISCUSSION

A. Sea Level Pressure (SLP), Sea Surface Temperature (SST), and Surface Temperature Anomalies

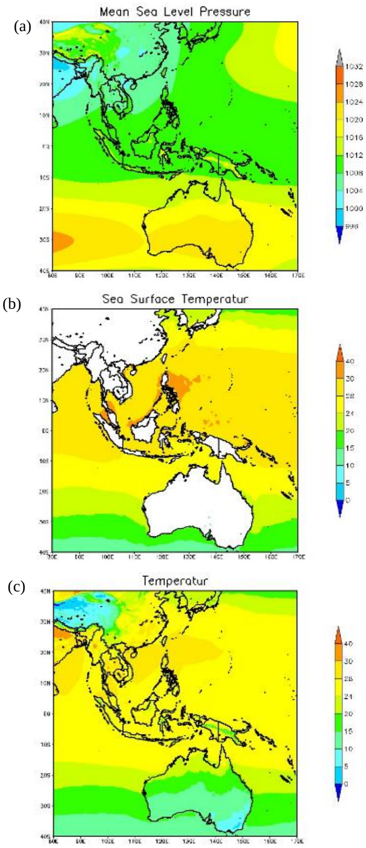

Fig. 1. Composite difference in (a) sea level pressure, (b) sea surface temperature, and (c) 2m-Temperature between strong and weak EAAM index years.

When the EAAM is strong, high-pressure areas form around the western Pacific Ocean and Australia, indicating the presence of the Australian High and Western Pacific Subtropical High (Fig. 1(a)). SST data from the ERA5 model shows temperatures ranging from 24 - 30°C around the Maritime Continent area. Warm SST are observed in the western region of Kalimantan, northeastern North Sumatra, and the Philippines, with values ranging from 30 to 40°C (Fig. 1(b)).

B. Circulation Anomalies

1. Horizontal Circulation Anomalies

When EAAM is strong, in Fig. 2 [3], there is the presence of an anticyclonic circulation in the Australian region at the 850 hPa level. These anomalies are intensified by divergent flows from the South Pacific Convergence Zone (SPCZ) [1]. The anticyclonic anomalies extend towards the equator in the northern part. Anticyclonic circulation is also found in the western Pacific of the northern hemisphere. The anticyclonic anomalies in both regions converge in the Maritime Continent (MC), causing the eastward anomalies in this area. The pattern of circulation anomalies at 200 hPa differs from that at 850 hPa. Overall, strong cyclonic circulation occurs in the upper troposphere from Australia to the southern Pacific. Circulation anomalies oppose the divergent anomalies occurring over the island of Kalimantan. Anticyclonic anomalies over Australia and the northwest Pacific are intensified by divergent flows from the equatorial west Pacific and SPCZ. The anomalies and divergent flows triggers the formation of equatorial eastward anomalies and leads to the formation of convergence over the island of Kalimantan [3].

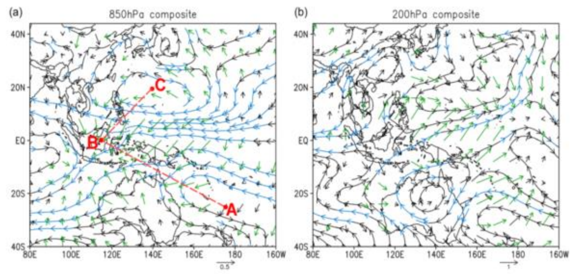

Fig. 2. Composite difference of horizontal circulation at 850 hPa (a) and 200 hPa (b) between strong and weak EAAM [3].

The blue streamlines indicate anomalies in the rotational wind component, black arrows denote anomalies in the divergent wind component in units of m/s, red arrows represent the U or V components of the divergent wind, and the red dashed lines indicate the path where vertical circulation is plotted as in Fig. 3.

2. Vertical Circulation Anomalies

The relationship between EASM and AWM can also be observed through vertical circulation anomalies. A center of anticyclonic circulation anomalies is evident over Australia and the Western Pacific (Fig. 2(a)), as the result, there are two tilted vertical circulations plotted on the diagonal line from these areas to the center of convergence anomalies above Kalimantan Island. Tilted meridional-vertical circulation anomalies from 175°E, 25°S to 115°E, 0° and further to 140°E, 20°N (Fig. 3) indicate circulation from the SPCZ to northern Australia and Kalimantan Island, as well as from Kalimantan Island to the northwest Pacific in tropical area. Both cells cause upward air motion (updraft) over Kalimantan Island. This suggests that convergence anomalies over Kalimantan Island are truly related to anticyclonic anomalies over Australia and the northwest Pacific [3].

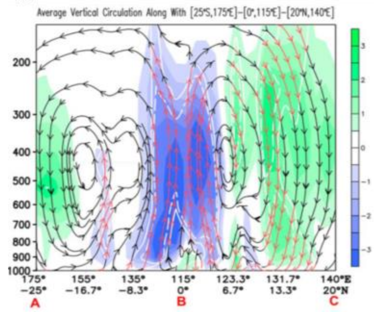

Fig. 3. Composite difference of vertical circulation between strong and weak EAAM years along the red dashed lines in Fig. 2 [3]. Shaded in the figure represents the values of vertical velocity.

C. Composite Precipitation

When EAAM is strong, the anticyclonic circulation anomaly over Australia and the Western Pacific, connected above the MC, induces eastward anomalies and triggers convergence over Kalimantan Island. This convergence is indicated by upward air motion (updraft), leading to the accumulation of air in the upper layers. This air accumulation results in high rainfall over most parts of Kalimantan. This indicates that a strong EAAM is closely related to convergence anomalies in Kalimantan that increase rainfall over most of the region. When the EAAM is strong, the daily rainfall increases to 4 - 11 mm/day, whereas when the EAAM is weak, the daily rainfall decreases to 2 - 8 mm/day (Fig. 4).

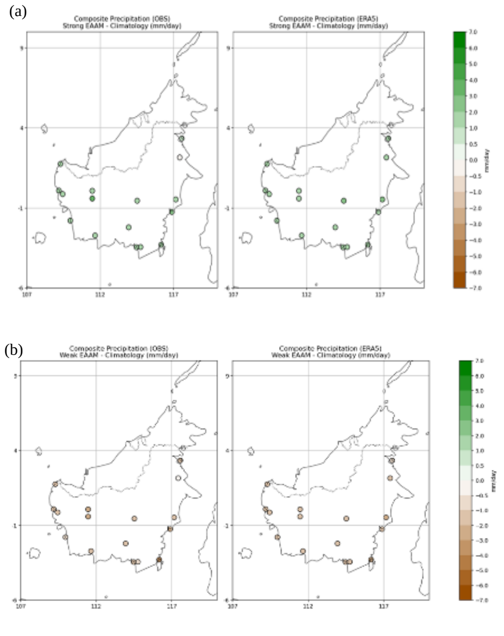

Fig. 4. Composite difference of (a) observed rainfall and ERA5 when EAAM is strong minus the normal, and (b) observed rainfall and ERA5 when EAAM is weak minus the normal.

Based on the observational data and ERA5 model output, the composite precipitation during Strong EAAM exhibits quite similar amounts, typically ranging from 0.0 - 4.0 mm/day. This similarity is also evident in the disparity between strong EAAM and weak EAAM (Fig. 5).

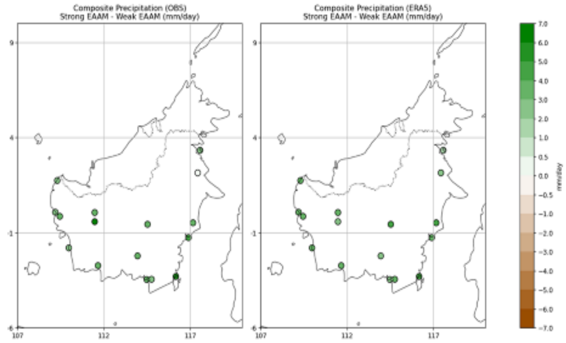

Fig. 5. Composite difference of observed rainfall and ERA5 when EAAM is strong minus when EAAM is weak.

In Fig. 6, it generally shows that ERA5 values and observations demonstrate similar patterns, although certain areas, such as Tarakan and Muara Teweh, display varied values. Furthermore, an increase in rainfall from its normal conditions is observed in both ERA5 and observational data. There are differences in the values observed in Tanjung Redeb, Paloh, Muara Teweh, and Samarinda, where the climatological rainfall values from ERA5 are higher compared to the climatological values from observational data. Furthermore, during the strong EAAM, the rainfall in the ERA5 data is observed to be higher than that in the observational data. This condition is due to the strong influence of local conditions in those areas. The ERA5 data is a global model dataset, therefore, it can only represent global conditions generally, while weather conditions in Kalimantan are not only related to global-scale phenomena but also to regional and local scales. This causes ERA5 data to be less capable of representing overall weather conditions in Kalimantan.

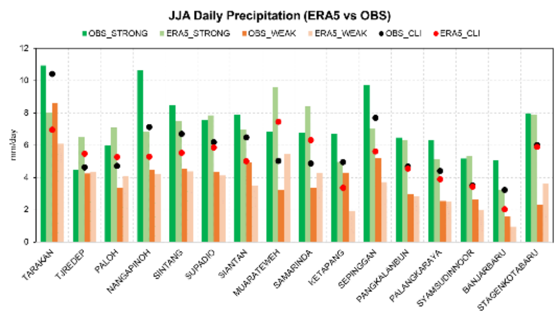

Fig. 6. Daily observed rainfall and ERA5.

Tanjung Redeb, located in East Kalimantan, has relatively flat topography but is close to the coast, leading to increased temperatures due to deforestation and land conversion to plantations or mining [6]. Samarinda, a major city in the region, also experiences the influence of local conditions due to the urban heat island effect and increased air pollution. Furthermore, the increase in hotspot areas and deforestation events in most areas of West and Central Kalimantan has influenced changes in rainfall intensity in these areas [7, 8].

IV. CONCLUSION

Based on rainfall data from the ERA5 model, similarities with observed rainfall values from various meteorological stations in Kalimantan are evident. During strong EAAM years in the JJA season, precipitation amounts increase to 4.0 mm/day. The pattern of ERA5 values and observations indicates comparable values at most meteorological stations in Kalimantan, although disparities are observed in certain areas. A high-pressure area forms in the western Pacific and Australia when EAAM is strong, developing the warm sea surface temperatures (SST) in western Kalimantan, northeastern North Sumatra, and Philippine waters. The warm 2-meter air temperature ranges from 30 to 40°C in the northern Philippines.

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REFERENCES

[1] W. Chen, Z. Guan, H. Yang and Q. Xu, "East Asian-Australian Monsoon Variations and Their Impacts on Regional Climate during Boreal Summer," *J. Meteor. Soc. Japan, Ser. II*, vol. 98, no. 2, pp. 283-297, 2020.

[2] W. Chen and Z. Guan, "A Joint Monsoon Index for East Asian–Australian Monsoons During Boreal Summer," *Atmosph. Sci. Lett.*, vol. 18, pp. 403-408, 2017.

[3] W. Chen, Z. Guan, Q. Xu and H. Yang, "Variation of Anomalous Convergence Around Kalimantan Island in Lower Troposphere and Its Role in Connecting The East Asian Summer Monsoon and Australian Winter Monsoon," *J. Geophys. Res.: Atmosph.*, vol. 124, no. 13, pp. 6892-6903, 2019.

[4] L. Chen and R. Wu, "The Role of The Asian/Australian Monsoons and The Southern/Northern Oscillation in The ENSO Cycle," *Theor. Appl. Climatol.*, vol. 65, pp. 37–47, 2000.

[5] Z. Guan, K. Ashok and T. Yamagata, "Summertime Response of The Tropical Atmosphere to The Indian Ocean Dipole Sea Surface Temperature Anomalies," *J. Meteor. Soc. Japan*, vol. 81, pp. 533–561, 2003.

[6] F. Noor, M. Fadli, R. Rustam and D. Catur, "Master Plan Perubahan Iklim Kalimantan Timur," *Buku Dewan Daerah Perubahan Iklim Kalimantan Timur*, 2016.

[7] N. Anggraini and B. Trisakti, "Kajian Dampak Perubahan Iklim Terhadap Kebakaran Hutan dan Deforestasi di Provinsi Kalimantan Barat," *J. Penginderaan Jauh*, vol. 8, pp. 11-20, 2011.

[8] A. V. Wulandari, N. K. T. Dewi and W. A Swastiko, "Pemanfaatan Data Satelit Himawari 8 Untuk Mendeteksi Sebaran Asap: Studi Kasus Di Kalimantan Dan Sumatera Tanggal 8 Dan 9 September 2015," *Spektra: J. Fisika Dan Aplikasinya*, vol. 2, no. 2, pp. 157-164, 2017.