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A 30-Year Climatological Analysis of Atmospheric Dynamics Anomalies during CENS in Western Indonesia

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ABSTRACT

Cross Equatorial Northerly Surges or CENS are an important atmospheric phenomenon influencing weather variability over the Maritime Continent. These surge events frequently generate hazardous hydrometeorological conditions, including heavy rainfall and surface cooling, posing risks to maritime activities and coastal regions. This study presents a climatological analysis of atmospheric dynamics anomalies associated with CENS over the Western Maritime Continent using a 30 year dataset covering the period from 1991 to 2020. Atmospheric anomalies in precipitation rate, outgoing longwave radiation, relative humidity, and maximum temperature are analyzed using NCEP NCAR Reanalysis data. Active CENS events are identified based on meridional wind speed thresholds during the boreal winter season from November to March, resulting in 170 active CENS days. The results indicate that CENS events are consistently associated with enhanced precipitation, reduced outgoing longwave radiation, increased low level relative humidity, and widespread surface cooling. These anomalies reflect intensified convective activity driven by the transport of cold and moist air masses from the Northern Hemisphere. Maximum temperature decreases by up to 4.5 degrees Celsius due to the combined effects of cold air advection and increased cloud cover that suppresses incoming solar radiation. By adopting a multi decadal climatological framework, this study provides new insights into persistent atmospheric responses to CENS that are not fully captured by shorter term or event based analyses. The climatological baseline established here improves understanding of large scale drivers of extreme rainfall and atmospheric instability over western Indonesia and offers valuable information for enhancing weather forecasting, early warning systems, and maritime risk management.

Keyword: Cross-Equatorial Northerly Surge, Atmospheric Anomalies, Maritime Stability, Western Maritime Continent

INTRODUCTION

Indonesia sits at the heart of the Maritime Continent, where tightly spaced islands, steep terrain, and warm surrounding seas create strong land sea contrasts and multi-scale convection. This setting makes atmospheric processes highly nonlinear: local diurnal cycles interact with regional circulations, while large-scale flows modulate where deep clouds organize and persist. As a result, relatively small shifts in background winds or moisture can translate into substantial rainfall changes, especially along long coastlines and semi-enclosed seas that funnel low-level flow. This article positions Indonesia as a “high-sensitivity” laboratory for studying how synoptic disturbances translate into hydrometeorological extremes (Wijaya et al., 2022; Yamanaka, 2016).

A core driver of Indonesia's seasonal hydroclimate is the Asian–Australian monsoon system, which regulates the timing and intensity of rainfall across the archipelago. The wet-season regime emerges when northerly monsoon flow and tropical moisture supply strengthen, while dry-season conditions develop as cross-equatorial flow and regional subsidence become more dominant. Importantly, monsoon impacts are not spatially uniform: topography and island geometry shape rainfall contrasts between western and eastern sectors, and between coastal waters and inland slopes. Understanding monsoon background states is therefore essential for interpreting any surge-related rainfall anomalies (As-Syakur et al., 2016; Matsuzaki et al., 2023).

The urgency of this topic is practical as well as scientific: Indonesia's rainfall variability frequently escalates into floods, coastal disruptions, and cascading impacts on dense urban maritime corridors. Extreme rainfall is particularly consequential in Greater Jakarta and other western Indonesian hubs where exposure is high and drainage capacity can be rapidly overwhelmed. Recent evidence shows that rainfall extremes in the region depend strongly on seasonally varying large-scale conditions and intraseasonal modulation, meaning "hazardous" rainfall can emerge from specific combinations of background climate and weather-scale triggers. A surge-focused perspective is therefore relevant for risk reduction and operational preparedness (Lestari et al., 2019; Ramadhan et al., 2024).

Within the broader monsoon environment, wintertime cold surges from East Asia represent a key synoptic forcing that can reorganize low-level winds and moisture pathways toward the tropics. These surges are often linked to strengthened continental pressure systems and downstream circulation adjustments that enhance northerly flow over marginal seas. Their intensity and structure can vary with the evolving East Asian winter monsoon background, including changes in the Siberian High and related midlatitude wave patterns. Because cold surges can extend influence far downstream, they provide a plausible physical bridge between extratropical variability and equatorial rainfall anomalies (Dai et al., 2025; Samah et al., 2016).

A distinctive expression of surge dynamics over Indonesia is cross-equatorial penetration that strengthens northerly winds into the southern hemisphere sector of the Maritime Continent. In western Indonesia, such flow can accelerate moisture transport toward the Java Sea and adjacent coasts, changing convergence patterns that favor organized convection. Evidence from Indonesian case-based analyses indicates that cold surge conditions can work together with intraseasonal variability to intensify convective cloud formation and rainfall over Java. This motivates treating cross-equatorial surge behavior not as an isolated curiosity, but as a repeatable mechanism shaping wet-season extremes (Syamsudin et al., 2026; Wicaksono & Hidayat, 2016).

From a process standpoint, rainfall enhancement under surge conditions is expected to depend on where moisture flux converges in the lower troposphere, particularly near ~925 hPa where monsoon inflow interacts with coastal geometry. Moisture transport patterns can either concentrate ascent over specific seas and coastal zones or, conversely, redistribute convection away from neighboring landmasses through compensating subsidence and divergence. Tracking these spatial reorganizations is crucial because the same regional "wet" season can contain localized drying signals adjacent to intensified rain cores. This article therefore treats moisture convergence and source pathway behavior as central explanatory links between circulation forcing and rainfall outcomes (Chen et al., 2024; Coll-Hidalgo et al., 2024).

To diagnose convective organization beyond rainfall totals, outgoing longwave radiation (OLR) is widely used as a radiative proxy: sustained deep convection with high, cold cloud tops tends to reduce OLR, yielding negative anomalies where convection intensifies. OLR therefore complements precipitation by indicating whether enhanced rainfall is accompanied by stronger or more persistent deep convective cloud development. This is particularly helpful over data-sparse oceanic areas where rainfall retrieval uncertainties can be larger. Using OLR alongside rainfall also supports clearer mechanism statements about convective growth, not merely hydrological accumulation (Dai & Fan, 2021; Prabhu & Pandithurai, 2018).

Indonesia's rainfall extremes also reflect multi-driver interactions across timescales, including ENSO, the Indian Ocean Dipole, and intraseasonal oscillations such as the Madden–Julian Oscillation (MJO). Reviews emphasize that coupled ocean–atmosphere modes can reshape monsoon background conditions, altering the likelihood that a synoptic trigger produces extreme convection. Meanwhile, observational studies of MJO–rainfall relationships show that convection proxies such as OLR are tightly linked to intraseasonal rainfall modulation, highlighting why surge impacts should be interpreted within broader variability regimes rather than as a standalone forcing. This article explicitly builds on that multi-driver framing (Li et al., 2024; Morita et al., 2006).

Despite growing interest in surge-related rainfall, a key gap remains: long-baseline climatological work that isolates persistent surge-linked signals from short-lived event noise is still limited relative to the societal importance of wet-season extremes. Multi-decadal perspectives matter because interannual variability can mask or exaggerate apparent relationships in shorter samples, especially in a region as heterogeneous as the Maritime Continent. Long-term rainfall assessments and reconstructions in Indonesia underscore both the feasibility and necessity of extended time windows when characterizing hydroclimate variability. Addressing this gap strengthens the scientific basis for diagnosing repeatable patterns rather than anecdotal episodes (Fazal et al., 2023; Wati et al., 2025).

Accordingly, this study advances a 30-year (1991–2020) climatological approach to examine how Cross-Equatorial Northerly Surge activity is expressed in frequency, variability, and associated atmospheric anomalies over the Western Maritime Continent. The discussion is organized to (i) establish the surge climatology during NDJFM, (ii) quantify composite anomalies in rainfall and key thermodynamic–radiative indicators, and (iii) interpret physical pathways linking low-level flow to convection and surface impacts. By anchoring the analysis in a long baseline, the article aims to provide findings that are more transferable to monitoring and risk-reduction contexts, where anticipating extremes is as important as explaining them.

METHODOLOGY

This study adopts a quantitative research design with a descriptive climatological approach to examine atmospheric perturbations associated with Cross Equatorial Northerly Surges (CENS) (Creswell & Creswell, 2018; Neuman, 2014). Rather than focusing on single event case studies, the study applies a multi-decadal climatological framework to identify persistent and recurring atmospheric responses linked to CENS activity. The analysis is conducted over the Western Maritime Continent, a region where monsoon circulation interacts strongly with complex regional topography. The study period spans 30 years (1991–2020), which provides a standard climatological baseline for assessing long-term atmospheric variability and enables robust detection of CENS-related anomalies while reducing the influence of episodic events.

Atmospheric fields are obtained from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) Reanalysis version 1 dataset, which offers globally consistent variables derived through data assimilation that combines observations with numerical weather prediction. The dataset has a spatial resolution of 2.5° × 2.5° and continuous temporal coverage appropriate for climatological analyses.

Although this resolution is relatively coarse for Indonesia's regional complexity, it remains adequate for capturing large-scale circulation features and broad anomaly structures associated with CENS. Higher-resolution products such as ERA5 are not utilized due to considerations of temporal coverage length and potential inhomogeneity when extending across multi-decadal periods.

A dual-domain configuration is implemented to separate the CENS forcing corridor from the broader atmospheric response region. CENS identification is performed within 0°S–5°S and 105°E–115°E, following the criteria of Hattori et al. (2011) as the principal pathway where northerly surges cross the equator. The wider analysis domain covers the Western Maritime Continent (97.77°E–117.11°E; 8.52°N–8.06°S) to capture spatially distributed atmospheric responses beyond the immediate surge corridor. Temporally, the analysis is limited to the boreal winter season (November–March), aligning with the active phase of the Asian Monsoon when cold surges occur frequently. A day is classified as an active CENS event when northerly meridional wind speed exceeds 5 m s^{-1} within the identification domain and continues southward across the equator, yielding 170 active CENS days during 1991–2020.

Meteorological variables used include meridional wind speed, precipitation rate, outgoing longwave radiation (OLR), relative humidity, and maximum temperature, representing key dynamical and thermodynamic processes related to convection and instability during CENS events. Most variables (OLR, relative humidity at 925 mb, and maximum temperature at 2 m) are used directly from the reanalysis. Precipitation, originally expressed in kg m^{-2} s^{-1}, is converted to mm day^{-1} by multiplying by the number of seconds in one day, based on the equivalence that 1 kg m^{-2} of liquid water corresponds to 1 mm rainfall depth. This conversion ensures consistency with standard meteorological conventions and supports clearer interpretation of rainfall intensity.

Table 1. Specifications of Meteorological Parameters Used in The Study

No	Parameter	Unit	Level
1	Precipitation rate	kg/m²/s	Surface
2	Outgoing Longwave Radiation	W/m²	Other
3	Relative Humidity	%	925 mb
4	Maximum Temperature	K	2 m

Source: Author, 2025

Composite anomaly analysis is applied as the primary analytical technique. Composite means are calculated for each variable using all identified active CENS days, then compared against the long-term seasonal climatology (November–March) for 1991–2020. Anomalies are computed by subtracting the climatological mean from the CENS composite mean to isolate signals associated specifically with CENS while suppressing background seasonal variability. Formal statistical significance testing is not conducted; therefore, the findings are interpreted as climatological tendencies rather than deterministic causal relationships. Nevertheless, the sample size of 170 events provides a strong basis for identifying coherent and spatially consistent anomaly patterns, which are subsequently visualized to evaluate the distribution and intensity of atmospheric responses across the Western Maritime Continent.

RESULTS AND DISCUSSION

1. Climatological Overview of CENS Activity (1991–2020)

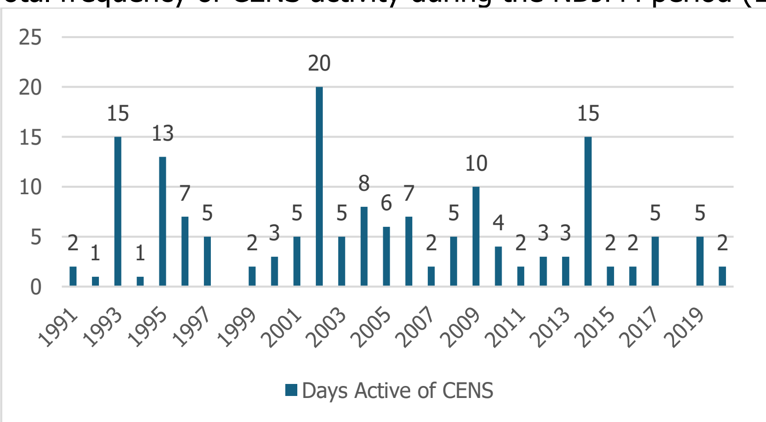
The foundation of this research is a climatological overview of Cross Equatorial Northerly Surges (CENS) based on a 30-year analysis period from 1991 to 2020. The assessment is focused on the boreal winter season, specifically November, December, January, February, and March (NDJFM), when northerly surge activity is most prominent within the broader Asian monsoon system. This seasonal framing provides a consistent temporal window to evaluate the typical behavior of CENS under comparable large-scale monsoon conditions. By constraining the analysis to NDJFM, the study avoids mixing surge signals with transitional-season dynamics that may obscure the CENS climatological signature.

To capture the long-term atmospheric state, the study utilizes the NCEP–NCAR Reanalysis dataset, which provides continuous and internally consistent meteorological fields suitable for multi-decadal evaluation. Using this dataset, the research extracts the temporal frequency and spatial distribution of CENS-related circulation features across the relevant equatorial corridor and surrounding regions. The reanalysis-based approach supports systematic detection of CENS characteristics across three decades, enabling the study to move beyond short observational records or isolated case events. In this way, the dataset serves as the primary basis for describing how CENS occurrences are expressed in a consistent atmospheric framework over time.

This long-term climatological perspective strengthens the identification of recurring CENS patterns while minimizing the influence of short-lived atmospheric disturbances or event-specific anomalies. With multi-decadal coverage, the analysis can distinguish persistent tendencies from interannual noise and better represent the natural variability of CENS activity across different years. The approach therefore provides a stable foundation for interpreting CENS persistence, seasonal regularity, and variability over the Western Maritime Continent. Ultimately, the climatological overview functions as the baseline for subsequent analyses of atmospheric responses, ensuring that later findings are anchored to a reliable depiction of CENS behavior across the 1991–20

Temporal Variability and Event Frequency; Important to note that CENS activity during the boreal winter season (NDJFM) is not expected to occur at a constant rate from year to year. Instead, surge events typically emerge in response to variations in large-scale monsoon dynamics and background circulation conditions that can amplify or suppress cross-equatorial northerly flow in different years. For that reason, examining temporal variability and event frequency provides a critical baseline for interpreting whether CENS behavior over 1991–2020 reflects stable climatological tendencies or strong interannual modulation. Figure 1 therefore serves as a descriptive summary of how often CENS events occurred each year during NDJFM across the 30-year analysis period.

Figure 1. Total frequency of CENS activity during the NDJFM period (1991–2020)



Source: Author, 2025

Figure 1 to summarizes the climatological assessment of Cross Equatorial Northerly Surges spanning the thirty year period from 1991 to 2020. Within this timeframe, the study identifies a total of 170 days of active surge events. The identification of these events is based on the application of strict meridional wind speed criteria within the geographic domain defined by 105°E to 115°E and 0° to 5°S. A comprehensive examination of the temporal distribution of CENS events, as illustrated in figure, demonstrates that surge activity is characterized by pronounced interannual heterogeneity rather than a consistent seasonal baseline. Throughout the 30 year climatological study period, a total of 170 distinct CENS events are identified during the boreal winter months. However, the frequency of these events exhibits substantial year to year variability, indicating that CENS activity is not temporally uniform. This pronounced interannual variability suggests that CENS occurrence is dynamically driven and influenced by large scale atmospheric circulation rather than operating as a fixed seasonal feature. The data reveal specific years of anomalous intensity and suppressed activity.

Periods of intensified activity are observed in several years, with 2002 recording the highest frequency of CENS events at 20 active days, followed by elevated activity in 1993 and 2014 with 15 active days each. In contrast, suppressed CENS activity is identified in 1992 and 1994, during which only a single active event is recorded in each year. From a methodological perspective, it is acknowledged that the total count of 170 identified events may differ from frequencies reported in other climatological studies. As discussed in previous work, including Dewi et al. (2023), such discrepancies are commonly associated with differences in reference datasets or variations in the threshold criteria used to define CENS events. Despite these potential differences, the sample of 170 CENS days constitutes a statistically robust dataset for composite analysis and provides a reliable foundation for examining atmospheric anomalies associated with CENS activity over the Western Maritime Continent.

2. Rainfall Anomalies

The primary impact of CENS propagation is the alteration of precipitation patterns across the tropical maritime region. As the surge advances southward, it carries relatively colder and moisture-laden air masses from the Northern Hemisphere into equatorial environments, modifying the background monsoon flow and the near-surface thermodynamic structure. This intrusion can shift where and when rainfall is most likely to occur, particularly over ocean–land transition zones and coastal areas that are sensitive to changes in low-level winds and moisture supply. These atmospheric changes mainly express themselves through strengthened low-level convergence and enhanced convective instability along the CENS pathway. Increased convergence promotes upward motion that supports cloud growth, while the added moisture and destabilization intensify convective development and rainfall potential. Consequently, CENS events are commonly associated with positive rainfall anomalies in regions aligned with the surge corridor, although the magnitude and spatial footprint of these anomalies can vary depending on concurrent large-scale circulation conditions.

Spatial Distribution of Precipitation; An important feature revealed by Figure 1 is the pronounced asymmetry in rainfall distribution during active CENS events. While rainfall increases significantly over the waters west of Java and within the CENS identification area, other regions exhibit weak negative anomalies. This asymmetry reflects the spatially focused nature of moisture convergence induced by CENS. Specifically, Sumatra and Kalimantan experience slightly reduced rainfall, as indicated by cooler color shading in Figure 2. The trajectory of CENS is not spatially linear across the Indonesian archipelago. As a result, strong moisture convergence and ascending motion are concentrated over the Java Sea region, while adjacent landmasses may experience subsidence or divergent divergent low level flow. This shadowing effect limits convective development outside the primary surge corridor. Overall, Figure 2 confirms that the rainfall response to CENS is highly localized and dynamically controlled by where low-level moisture convergence is maximized along the surge corridor

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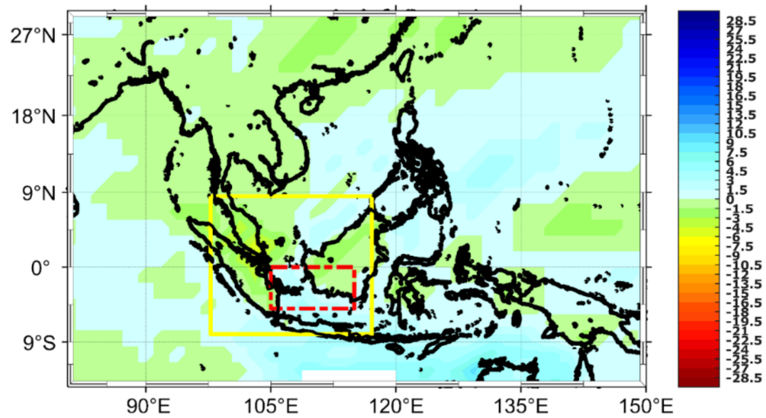

Figure 2. Spatial distribution of rainfall anomalies in the Western Maritime Continent during active CENS events.
Source: Author, 2025

The marked enhancement over the waters west of Java and the Java Sea, contrasted with weak negative anomalies over parts of Sumatra and Kalimantan, indicates that CENS does not uniformly increase precipitation across the archipelago. Instead, it reorganizes regional convection by concentrating ascent within the primary pathway while promoting subsidence or divergence in adjacent areas. This spatially asymmetric anomaly structure provides a clear baseline for interpreting subsequent thermodynamic and convective indicators (e.g., humidity, OLR, and temperature) as coupled responses to the same surge-driven circulation adjustments.

3. Atmospheric Thermodynamics and Radiation Analysis

To clarify the physical mechanisms behind enhanced rainfall during Cross Equatorial Northerly Surge (CENS) events, this study examines anomalies in outgoing longwave radiation (OLR) and relative humidity (RH). Rainfall anomalies alone describe the hydrological outcome, but they do not directly reveal whether precipitation increases are primarily driven by stronger convective cloud growth, greater moisture supply, or a combination of both. By incorporating thermodynamic and radiative indicators, the analysis links observed precipitation changes to underlying atmospheric processes that regulate convection.

OLR is used as a proxy for deep convective activity and cloud-top characteristics. During active convection, high and cold cloud tops reduce the amount of longwave radiation emitted to space, resulting in negative OLR anomalies. Therefore, areas with decreased OLR during CENS conditions can be interpreted as regions where deep convective clouds are more frequent, more intense, or more persistent. This radiative signal helps identify where the atmospheric column is experiencing stronger ascent and enhanced convective organization along the surge pathway.

Relative humidity, particularly in the lower troposphere, represents the availability of moisture that supports cloud formation and sustains convection. Positive RH anomalies indicate a moister environment that reduces evaporative inhibition and favors continuous convective development, whereas negative anomalies suggest drier conditions that can suppress cloud growth. When interpreted together, OLR and RH provide complementary evidence: OLR describes the convective cloud response, while RH describes the moisture environment that enables or limits that response. This combined thermodynamic–radiative perspective strengthens the interpretation of how CENS modulates convection and rainfall across the Western Maritime Continent. Outgoing Longwave Radiation (OLR) Anomalies; Outgoing Longwave Radiation anomalies represent the amount of thermal radiation emitted

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from the Earth surface and atmosphere into space and serve as a key proxy for convective activity. Higher OLR values indicate reduced cloud cover, while lower OLR values correspond to deep convective clouds with cold cloud tops.

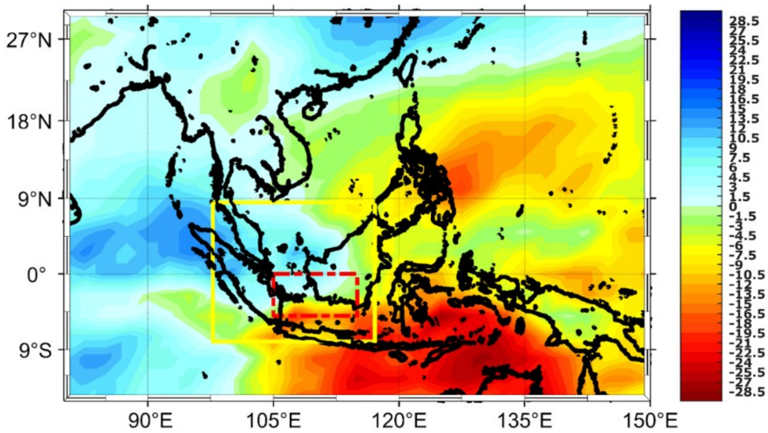

Figure 3. Spatial distribution of Outgoing Longwave Radiation (OLR) anomalies in the Western Maritime Continent during active CENS events.
Source: Author, 2025

As shown in Figure 3, negative OLR anomalies dominate the CENS affected region and are depicted by cooler color shades. These negative anomalies indicate suppressed outgoing radiation due to the presence of thick and vertically developed convective cloud systems. The reduction in OLR values corresponds closely with the regions of enhanced rainfall shown in Figure. This spatial coherence confirms a strong physical linkage between increased precipitation and intensified deep convection during CENS events. Conversely, higher OLR values over parts of Sumatra are represented by warmer color shades in Figure 3. These positive anomalies indicate reduced cloud cover and are consistent with the lower rainfall observed in the same region.

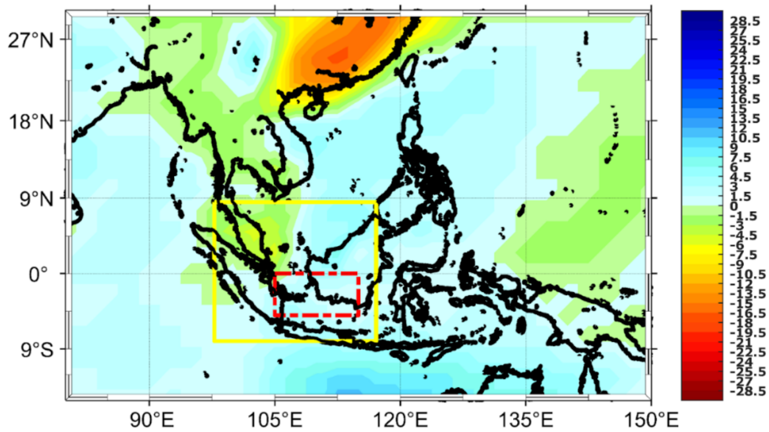

Figure 3. RH Spatial distribution of Relative Humidity (RH) anomalies at the 925 mb level during active CENS events.
Source: Author, 2025

Relative Humidity (RH) and Moisture Convergence; Relative Humidity reflects the proportion of water vapor present in the atmosphere relative to saturation. Figure 4 presents the spatial distribution of Relative Humidity anomalies at the 925 mb level during active CENS events. As illustrated in Figure 3, elevated Relative Humidity anomalies are evident within the

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CENS domain and adjacent coastal regions. Positive Relative Humidity anomalies are indicated by warmer color shades and reflect enhanced moisture accumulation within the lower troposphere. This increase in atmospheric moisture pushes the environment closer to saturation and increases the likelihood of condensation. The strong moisture convergence observed along the northern coast of Java provides favorable conditions for sustained convective development. This process plays a central role in amplifying rainfall intensity during active CENS periods.

In summary, the RH anomaly pattern in Figure 3 reinforces the interpretation that CENS enhances rainfall primarily by increasing low-level moisture availability and sustaining moisture convergence along the surge corridor. The concentration of positive RH anomalies over the CENS domain and the northern coast of Java indicates a lower-tropospheric environment that is closer to saturation, reducing convective inhibition and facilitating persistent cloud development. This moisture-rich boundary layer supports more efficient condensation and latent heat release, strengthening upward motion and maintaining convective systems. Consequently, the RH response provides a consistent thermodynamic explanation for why rainfall intensifies most strongly in the surge-affected regions during active CENS events.

4. Maximum Temperature Anomaly

The spatial distribution of maximum temperature anomalies during CENS events is presented in Figure 5, which reveals a widespread cooling pattern across the Western Maritime Continent, with maximum temperature reductions reaching up to 4.5 degrees Celsius, particularly within the CENS influenced region. Negative temperature anomalies are represented by cooler color shades and indicate suppressed daytime heating. This cooling effect is mechanistically driven by the interplay between atmospheric moisture and radiative transfer, elevated relative humidity levels actively suppress the rise in daily maximum temperatures. Furthermore, the dense cloud distribution serves as a critical physical barrier that intercepts incoming solar energy, thereby preventing direct insolation from reaching the surface and significantly limiting diurnal heating.

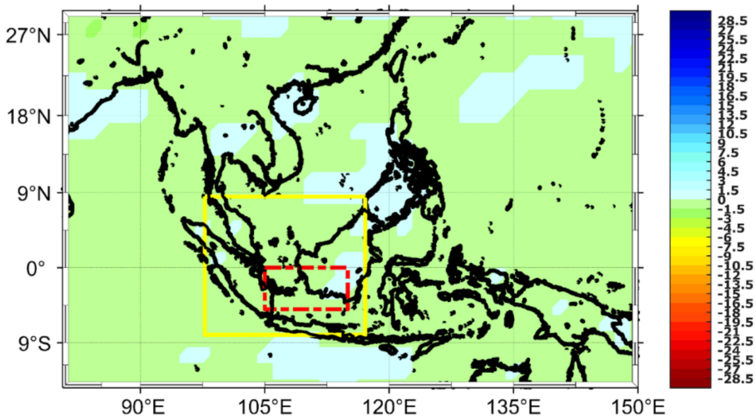

Figure 4. Spatial distribution of Maximum Temperature anomalies in the Western Maritime Continent during active CENS events.

It is important to note that the total number of identified CENS events differs from those reported in previous climatological studies. As noted by Dewi et al. (2023), such discrepancies are commonly attributed to differences in the reference datasets used, such as the choice of reanalysis products, as well as variations in the methodological criteria applied to define surge thresholds. Despite these differences, the identification of 170 active CENS days provides a statistically robust sample for analyzing atmospheric anomalies over the Western Maritime Continent. The observed decrease in maximum temperature during CENS events is driven by a combination of physical mechanisms. First, cold air advection plays a dominant role, as strong northerly winds originating from the Siberian High transport cooler air masses across the equator, directly lowering near surface temperatures. Second, enhanced cloud cover and elevated relative humidity further suppress maximum temperatures by limiting incoming solar radiation. Dense convective cloud systems, as indicated by low outgoing longwave radiation values, act as an effective barrier to surface heating and contribute to widespread cooling during active CENS conditions.

CONCLUSION

This study presents a comprehensive climatological assessment of atmospheric dynamics anomalies associated with Cross Equatorial Northerly Surges over the Western Maritime Continent using a 30 year dataset covering the period from 1991 to 2020. A total of 170 active CENS days are identified during the boreal winter season, confirming that CENS is a recurrent and significant component of regional atmospheric variability. The results demonstrate that CENS events produce coherent and physically consistent atmospheric responses. Enhanced precipitation and reduced outgoing longwave radiation indicate intensified deep convective activity along the primary surge corridor, particularly over the Java Sea region. These conditions are supported by elevated low level relative humidity, which promotes atmospheric saturation and sustained moisture convergence.

A pronounced cooling of surface maximum temperature is observed during active CENS events, with temperature reductions reaching up to 4.5 degrees Celsius. This cooling response is driven by the combined influence of cold air advection associated with northerly surge flow and increased cloud cover that suppresses incoming solar radiation. Together, these processes highlight the coupled dynamical and thermodynamic impacts of CENS on the tropical atmosphere. The use of a long term climatological framework allows this study to distinguish persistent CENS related atmospheric signals from short term variability and individual extreme events. These findings extend previous CENS studies by providing a spatially coherent and statistically robust depiction of atmospheric anomalies over multiple decades. From an applied perspective, the results underscore the importance of monitoring CENS activity as a precursor to extreme rainfall and cooling events over western Indonesia.

The climatological patterns identified in this study can support improvements in operational weather prediction, enhance early warning capabilities, and inform maritime and coastal risk management strategies. Future studies may further investigate the interaction between CENS and large scale climate modes such as the El Nino Southern Oscillation and the Madden Julian Oscillation to refine understanding of interannual variability and improve predictive skill.

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