THE CORRELATION BETWEEN SEA SURFACE TEMPERATURE VARIABILITY AND CONVECTIVE CLOUD CHARACTERISTICS OVER AMBON ISLAND COASTAL WATERS

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ABSTRACT

Sea surface temperature (SST) plays a key role in modulating tropical convection, yet its influence on the vertical structure of convective clouds in island-based, anti-monsoonal regions remains poorly quantified. This study examines the relationship between SST variability and convective cloud characteristics over the coastal waters of Ambon Island during 2023. Daily SST data were obtained from ERA5 reanalysis, while convective parameters Convective Condensation Level (CCL) and Equilibrium Level (EL) were derived from twice-daily radiosonde observations. Owing to non-normal distributions and serial autocorrelation, Spearman rank correlation was applied with effective sample size (ESS) correction and bootstrap confidence intervals. Results show that SST exhibits a pronounced seasonal cycle primarily governed by monsoonal forcing. SST displays a moderate positive correlation with CCL (ρ = 0.532-0.580) and a consistently strong correlation with EL across all stations (ρ = 0.770-0.778; $p_{adj} < 0.001$), indicating a stronger SST control on convective depth than on cloud-base height. Although large-scale climate modes (ENSO, IOD, and MJO) contribute to short-term variability, seasonal monsoonal forcing remains the dominant modulator of SST-convection coupling. These findings represent robust statistical associations and highlight the importance of ocean-atmosphere coupling in regulating convective cloud structure in tropical maritime island environments.

Keywords: Sea Surface Temperature (SST), Convective Cloud Characteristics, Radiosonde Observations, Monsoonal Variability, Ambon Coastal Waters

1. Introduction

Tropical deep convection is a key component of the climate system over the Maritime Continent, shaping regional rainfall variability and interacting with large-scale atmospheric circulation in this complex land-sea environment [1]. As a lower boundary forcing, sea surface temperature (SST) modulates surface evaporation and the atmospheric moisture budget, thereby influencing convective precipitation and the associated vertical motion patterns over tropical oceans [2], [3]. Radiative-convective processes linked to SST variability further affect cloud development and atmospheric energetics under radiative-convective equilibrium frameworks [4]. Nevertheless, the SST-convection linkage is not straightforward; it is often nonlinear and sensitive to environmental controls and becomes particularly complex over island-dominated regions where local ocean-atmosphere coupling and monsoonal dynamics strongly modulate convective activity, as documented for the Indonesian Maritime Continent [5].

Within the Maritime Continent, Ambon Island represents a distinctive climatic setting characterized by an anti-monsoonal rainfall regime. Unlike western Indonesia, where convective activity and rainfall generally peak during the westerly monsoon, Ambon experiences enhanced precipitation during the easterly monsoon, with rainfall maxima typically occurring between May and July. This contrasting seasonal behavior has been consistently documented in climatological analyses of Indonesian rainfall regions, which classify the Maluku region as an area with a mid-year (JJA) rainfall maximum, in contrast to the DJF-dominated rainfall regime of western Indonesia [1], [6]. Previous studies further indicate that this rainfall pattern is governed by the combined influence of regional atmospheric circulation associated with monsoonal wind reversal, strong sea-land thermal contrasts, and persistent atmospheric moisture over the surrounding seas [1]. Consequently, Ambon offers a valuable natural laboratory for investigating SST-convection interactions under non-classical monsoonal conditions within an island-dominated tropical environment.

Previous studies in Indonesian waters have documented seasonal SST variability and its association with rainfall and convective activity [7], [8]. Several works have also examined the influence of large-scale climate modes such as the El Niño-Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the Madden-Julian Oscillation (MJO) on SST and convection over the Maritime Continent [9], [10]. Nevertheless, most of these studies rely on precipitation, outgoing longwave radiation (OLR), or cloud fraction as proxies for convection, thereby providing limited insight into the vertical structure of convective clouds.

In tropical regions, the vertical structure of convection can be characterized using radiosonde-derived parameters. The Convective Condensation Level (CCL) represents the altitude at which near-surface air becomes saturated solely due to surface heating and typically occurs at heights of approximately 1-2 km above ground level in tropical environments [11]. The Equilibrium Level (EL), defined as the altitude at which a rising air parcel becomes neutrally buoyant, generally occurs in the upper troposphere and often approaches the climatological height of the tropical tropopause, thereby reflecting the depth of convective cloud development [12]. Despite their fundamental importance for understanding convective initiation and vertical extent, these parameters have rarely been examined quantitatively in relation to SST variability in Indonesian waters.

In particular, quantitative relationships between SST and radiosonde-derived convective parameters, such as the CCL and the EL, remain poorly explored in Indonesia. While several studies have examined SST variability and rainfall or upper-air conditions separately, existing SST-convection correlation studies rarely distinguish between cloud-base processes and convective depth, and few have investigated how these relationships vary seasonally or under unique regional climatic regimes. Moreover, the anti-monsoonal character of the Ambon region where convection frequently persists during the southeast monsoon despite regional SST cooling suggests potential deviations from the commonly observed relationship that reduced SST universally suppresses convective development [11], [13].

Therefore, a clear gap exists in understanding how SST variability quantitatively controls different aspects of convective cloud structure (cloud base versus cloud top) in anti-monsoonal island regions of Indonesia, and how this relationship compares with previously reported SST-convection linkages. The purpose of this study is to investigate the seasonal and spatial variability of SST around Ambon Island and to quantify its relationship with convective cloud characteristics derived from radiosonde observations, focusing on CCL and EL. Specifically, this study addresses the following scientific questions: (1) How does seasonal SST variability influence cloud-base height (CCL) and convective cloud-top height (EL)? (2) Is the SST-EL relationship stronger than the SST-CCL relationship, indicating a dominant control of SST on convective depth rather than convective initiation? (3) How are these relationships modulated by monsoonal forcing and large-scale climate variability (ENSO, IOD, and MJO) in an anti-monsoonal region?

Based on established theories of tropical convection, we hypothesize that higher SST enhances convective depth by increasing moist static energy and buoyancy, leading to a stronger relationship with EL than with CCL [2], [5]. We further hypothesize that, despite modulation by ENSO, IOD, and MJO, seasonal monsoonal forcing remains the primary control on SST-convection coupling over Ambon. By explicitly separating the influence of SST on convective cloud-base height (CCL) and convective cloud-top height (EL) using radiosonde observations, this study provides new quantitative insights into ocean-atmosphere coupling in anti-monsoonal island environments and contributes to improved understanding of tropical convection variability over the Maritime Continent.

2. Method

Data. This study employs a combination of reanalysis SST data and in-situ upper-air observations to investigate ocean-atmosphere interactions over Ambon Island, eastern Indonesia. The research time refers explicitly to the data analysis period, covering a complete annual cycle from January to December 2023, rather than the research implementation schedule. Radiosonde observations were conducted operationally and routinely throughout this period, with launches performed twice daily at 00:00 and 12:00 UTC, following standard meteorological observing practices. Daily SST data were obtained from the Copernicus Climate Data Store (CDS) (https://cds.climate.copernicus.eu) using the ERA5 reanalysis product (single levels). ERA5 is generated by the European Centre for Medium-Range Weather Forecasts (ECMWF) using a state-of-the-art four-dimensional variational (4D-Var) data assimilation system, which combines numerical model forecasts with a wide range of global observations to produce physically consistent atmospheric and oceanic fields [50]. The SST variable represents near-surface ocean temperature. ERA5 SST has a horizontal spatial resolution of approximately 0.25° × 0.25° (≈31 km) and a temporal resolution of one hour, with daily mean values derived through temporal aggregation [14], [15].

SST data for the period 2018-2022 were used to construct a short-term climatological reference, while SST data for 2023 constitute the primary dataset analyzed in this study. SST values were extracted using a nearest-grid-point approach, ensuring consistency with the native ERA5 grid, and subsequently converted from Kelvin to degrees

Celsius. Daily mean SST was used so that sub-daily variability, including the diurnal cycle, was not explicitly resolved.

Upper-air atmospheric data were obtained from radiosonde observations conducted at the Pattimura Ambon Meteorological Station (3.71156° S, 128.09595° E). Radiosonde data were provided in PILOT and TEMP code formats, containing vertical profiles of air temperature, humidity, wind speed, wind direction, and geopotential height at standard pressure levels. Radiosonde launches follow routine operational quality-control procedures applied by the meteorological authority. Missing or incomplete radiosonde profiles occurred very rarely during the study period; when such cases were encountered, simple linear vertical interpolation was applied between adjacent pressure levels to maintain profile continuity prior to the derivation of convective parameters. This procedure was applied conservatively and does not alter the fundamental thermodynamic structure of the sounding.

Given the relatively small size of Ambon Island and the dominant maritime influence on the atmospheric boundary layer, radiosonde observations at Pattimura are considered representative of atmospheric conditions over the surrounding coastal waters. To represent the spatial variability of SST around Ambon Island, four SST sampling points were defined relative to the radiosonde station, located in the northern (Station 1), eastern (Station 2), southern (Station 3), and western (Station 4) sectors. The coordinates of these stations are: Station 1: 3.48698° S, 128.09595° E Station 2: 3.71156° S, 128.32052° E Station 3: 3.93613° S, 128.09595° E Station 4: 3.71156° S, 127.86995° E These SST locations are not identical to the radiosonde launch site but are positioned at a distance of approximately 25 km from the Pattimura station, corresponding to the nearest ERA5 grid points surrounding Ambon Island. This spatial offset is small relative to the ERA5 grid spacing and is therefore considered acceptable for linking SST variability with the atmospheric column sampled by the radiosonde. Large-scale climate variability was characterized using the Niño-3.4 index for the El Niño-Southern Oscillation (ENSO), obtained from the National Oceanic and Atmospheric Administration (NOAA), as well as the Dipole Mode Index (DMI) for the Indian Ocean Dipole (IOD) and the Madden–Julian Oscillation (MJO) phase index, obtained from the Australian Bureau of Meteorology (BoM) (http://www.bom.gov.au/climate/mjo/). These indices cover January-December 2023 and were used for descriptive and interpretative purposes only.

Methods. Daily SST data for 2023 were organized into continuous time series for each station, and seasonal variability was examined using time-series analysis and monthly summary statistics. Vertical atmospheric profiles from radiosonde observations were processed using the RAOB (RAwinsonde OBservation) software to derive key convective parameters, namely the CCL and the EL, based on thermodynamic analysis of Skew-T log-P diagrams.

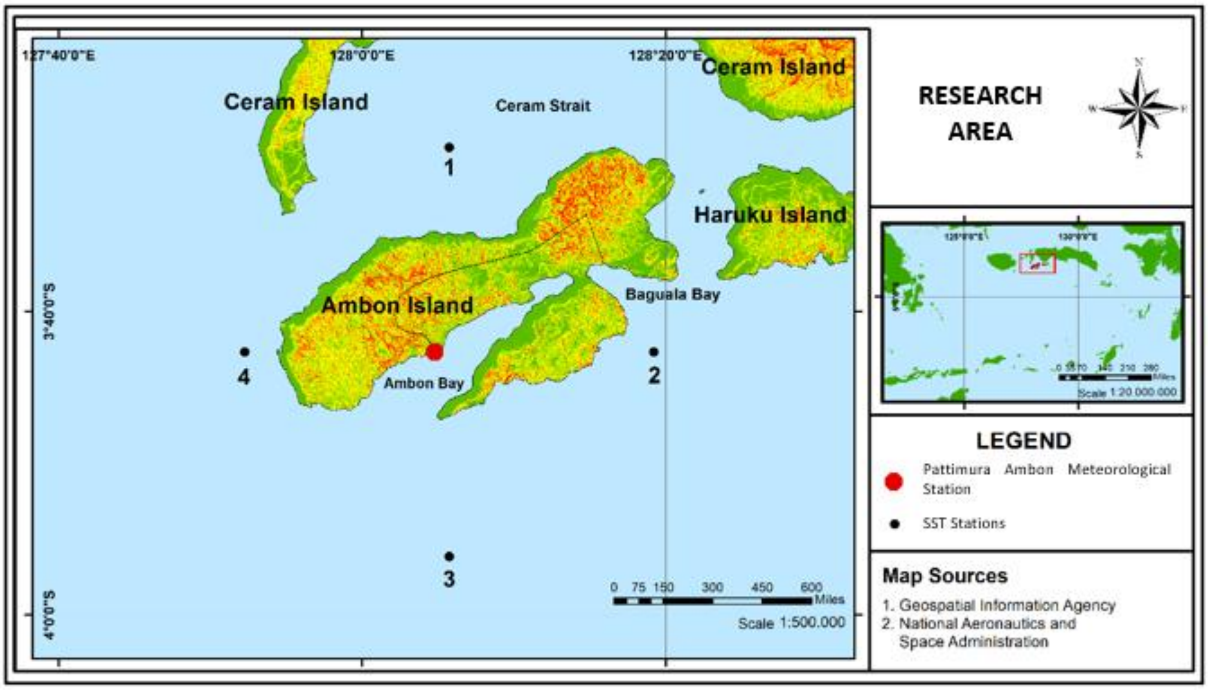

Figure 1. Study area showing Ambon Island, eastern Indonesia

In tropical environments, the CCL represents the altitude at which near-surface air parcels become saturated solely due to surface heating and is widely used as a proxy for convective cloud-base height. Observational studies over tropical maritime regions indicate that CCL typically occurs within the lower troposphere, on the order of 1-2 km above ground level, depending primarily on boundary-layer moisture conditions and thermodynamic structure [16]. The EL corresponds to the level at which a rising air parcel becomes neutrally buoyant relative to the surrounding environment and is generally located in the upper troposphere, often approaching the tropical tropopause under deep convective conditions [16]. Accordingly, EL serves as an indicator of convective cloud depth rather than cloud initiation [17].

Prior to correlation analysis, the statistical distributions of SST, CCL, and EL were evaluated using normality tests (Kolmogorov-Smirnov), which indicated non-normal distributions for all variables. Consequently, the key assumptions required for Pearson correlation were not satisfied. Therefore, Spearman's rank correlation coefficient (ρ) was employed as a non-parametric measure to quantify monotonic relationships between SST and convective parameters, which is appropriate for non-normally distributed environmental and atmospheric data [18].

Spearman correlations were calculated for SST-CCL, SST-EL, and CCL-EL pairs at each SST station, with statistical significance initially assessed at the 95% confidence level ($p < 0.05$). Because the analysis is based on daily time series, serial autocorrelation was explicitly considered. Lag-1 autocorrelation coefficients were estimated for each variable, and an effective sample size (ESS) correction was applied to adjust the degrees of freedom prior to significance testing, following standard practices in atmospheric time-series analysis [18], [19].

Uncertainty in correlation estimates was further quantified using non-parametric bootstrap resampling to obtain 95% confidence intervals. The ESS correction mitigates potential inflation of statistical significance due to temporal dependence, while the bootstrap confidence intervals provide a robust estimate of uncertainty for correlation coefficients derived from autocorrelated data. All statistical results were interpreted within the physical framework of tropical convection to assess the strength and characteristics of ocean-atmosphere coupling over the coastal region of Ambon Island.

3. Results and Discussion

Sea Surface Temperature Variability. The average SST during the 2018-2022 period across the four observation stations is illustrated in Figure 2. From January to April, SST values at all stations remain relatively high, ranging between 28.9 °C and 29.7 °C. A gradual decline in SST begins in May and continues through June, with the lowest average temperatures occurring during July-August, reaching a minimum of approximately 26.3 °C. SST values start to increase again in September and reach their maximum in December. The highest average SST is recorded at Station 3 and Station 2, each attaining about 29.8 °C in December, followed by Station 1 with a maximum of 29.5 °C in the same month.

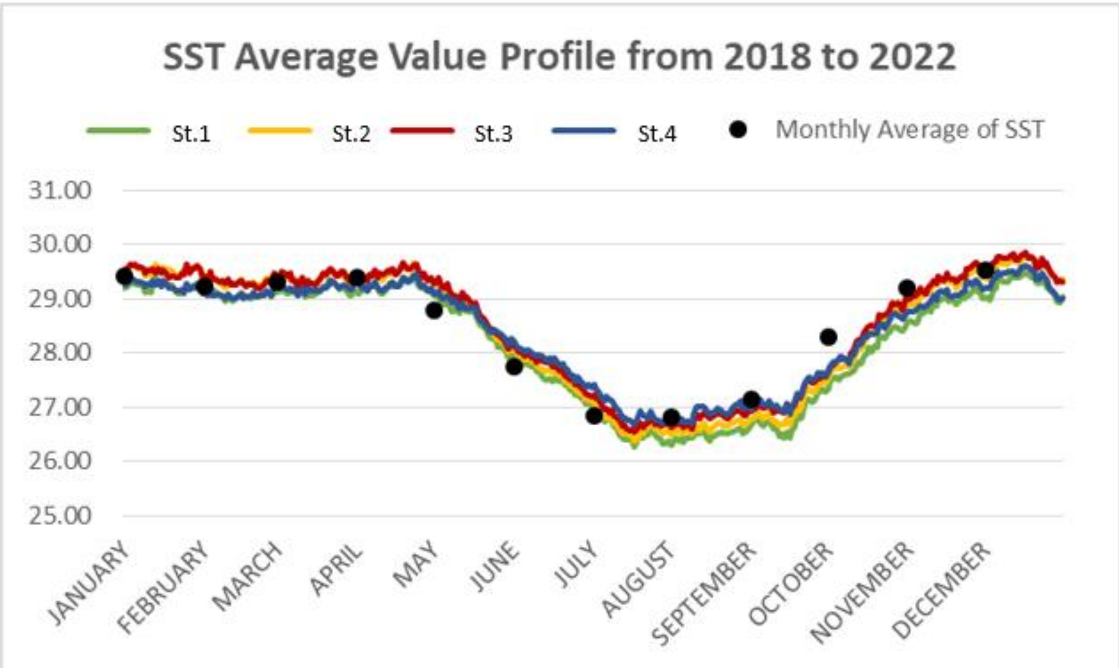

Figure 2. Monthly mean SST (°C) averaged over the 2018-2022 period at four observation stations surrounding Ambon Island, derived from ERA5 reanalysis data. Stations are labeled numerically (Stations 1-4) to ensure consistency with subsequent figures and analysis.

The averaged SST time series further indicates a persistent spatial hierarchy among the stations, with the coolest location. This spatial pattern is broadly consistent with previous studies reporting by Dzikiro et al. (2018) [20], who analyzed SST distribution in the waters surrounding Ambon using a combination of in-situ observations, satellite data, and numerical modeling for the period 2006-2016. Their spatial analysis showed that open Banda Sea waters tend to maintain higher SSTs compared to semi-enclosed regions around Ambon Island. The seasonal decline in SST observed between June and August is closely associated with monsoonal circulation over the Banda Sea. According to Tristianto et al. [8], during the southeast monsoon (June-August), southward transport of surface waters occurs, leading to the depletion of warm surface layers. This process is accompanied by intrusion and mixing of cooler subsurface waters, which substantially lowers SST. Because the waters surrounding Ambon Island form part of the Banda Sea system, this mechanism explains the pronounced SST reduction during June, July, and August, and in some years extending into September, corresponding to the second transitional season.

Spatial differences in SST among the four stations (Figure 2) can be attributed to contrasting oceanographic settings. Station 1 is located in a semi-enclosed environment comprising Piru Bay and part of the Seram Strait, making it the most hydrologically restricted station. Station 2 lies within the Haruku Strait, which is also semi-enclosed but hydrologically connected to both the Banda Sea to the south and the Seram Strait to the north. Circulation in this strait is primarily governed by tidal exchange and seasonal monsoonal winds [21]. Station 3 is situated in the open waters of the Banda Sea, rendering it highly exposed to regional wind forcing and large-scale ocean circulation. Station 4, although still part of the Banda Sea, lies between Ambon and Buru Islands and is partially shielded while remaining influenced by open-ocean dynamics. Consequently, Stations 1 and 2 generally exhibit lower SSTs than Stations 3 and 4, reflecting reduced ocean-atmosphere interaction and

Station 3 consistently exhibiting the warmest SST, followed by Stations 2 and 4, while Station 1 remains limited influence of large-scale processes in semi-enclosed waters. In contrast, the more exposed stations allow stronger coupling with the surrounding marine environment, including the Indonesian Throughflow (Arus Lintas Indonesia, ARLINDO) [22].

The SST time series for 2023 (Figure 3) reveals pronounced intra-annual variability. SST remains relatively high during January-April, decreases steadily from May through September, and increases again from October to December. Station 3 consistently records the highest SST during most months, particularly in January, early February, late March, April, May, and from August through December. Station 1 generally exhibits the lowest SST throughout the year, except in January when minimum SST values are observed at Station 4. Station 2 shows relatively higher SSTs during January-February, while Station 4 reaches peak SST mainly during June-July.

These results differ somewhat from those of Pamungkas et al. [23], who analyzed SST in the Seram Sea region using 2016 data and found lower SSTs at the location corresponding to Station 4 compared to other stations. Differences between the present study and Pamungkas et al. [23] likely arise from interannual variability and differing background climate conditions. Nevertheless, the seasonal SST evolution observed in 2023 closely follows the pattern reported by Saputra et al. [24], who showed that SST in Ambon Bay typically decreases during the first transitional season (March-May), reaches a minimum during the southeast monsoon (June-August), and increases again during the second transitional season (September-November), peaking during the northwest monsoon (December-February). This seasonal cycle plausibly explains the SST minimum observed between June and September 2023. Large-scale climate modes also contribute to SST variability in the region.

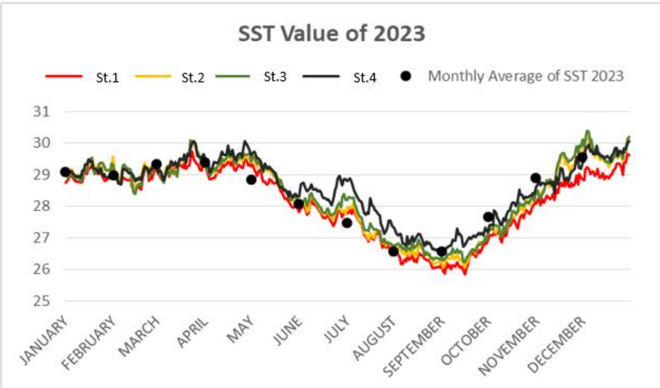

Figure 3. Daily SST (°C) time series at four observation stations surrounding Ambon Island during 2023, derived from ERA5 reanalysis data. The figure highlights intra-annual SST variability and spatial contrasts among stations.

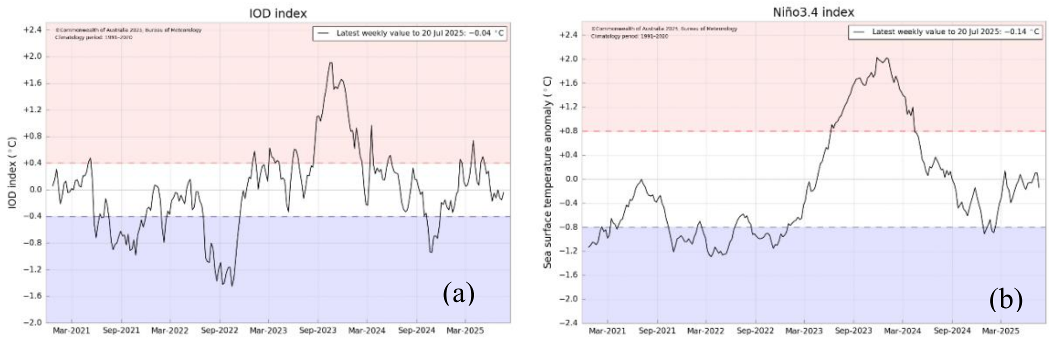

Figure 4. (a) Indian Ocean Dipole (IOD) index during 2023, representing variability of the Indian Ocean Dipole. Positive (negative) values indicate positive (negative) IOD phases**.** (b) Niño-3.4 index during 2023, representing El Niño–Southern Oscillation (ENSO) variability. Positive values indicate El Niño conditions, while negative values indicate La Niña conditions.*Source: Australian Bureau of Meteorology (BoM),* http://www.bom.gov.au/climate/enso/indices.shtml

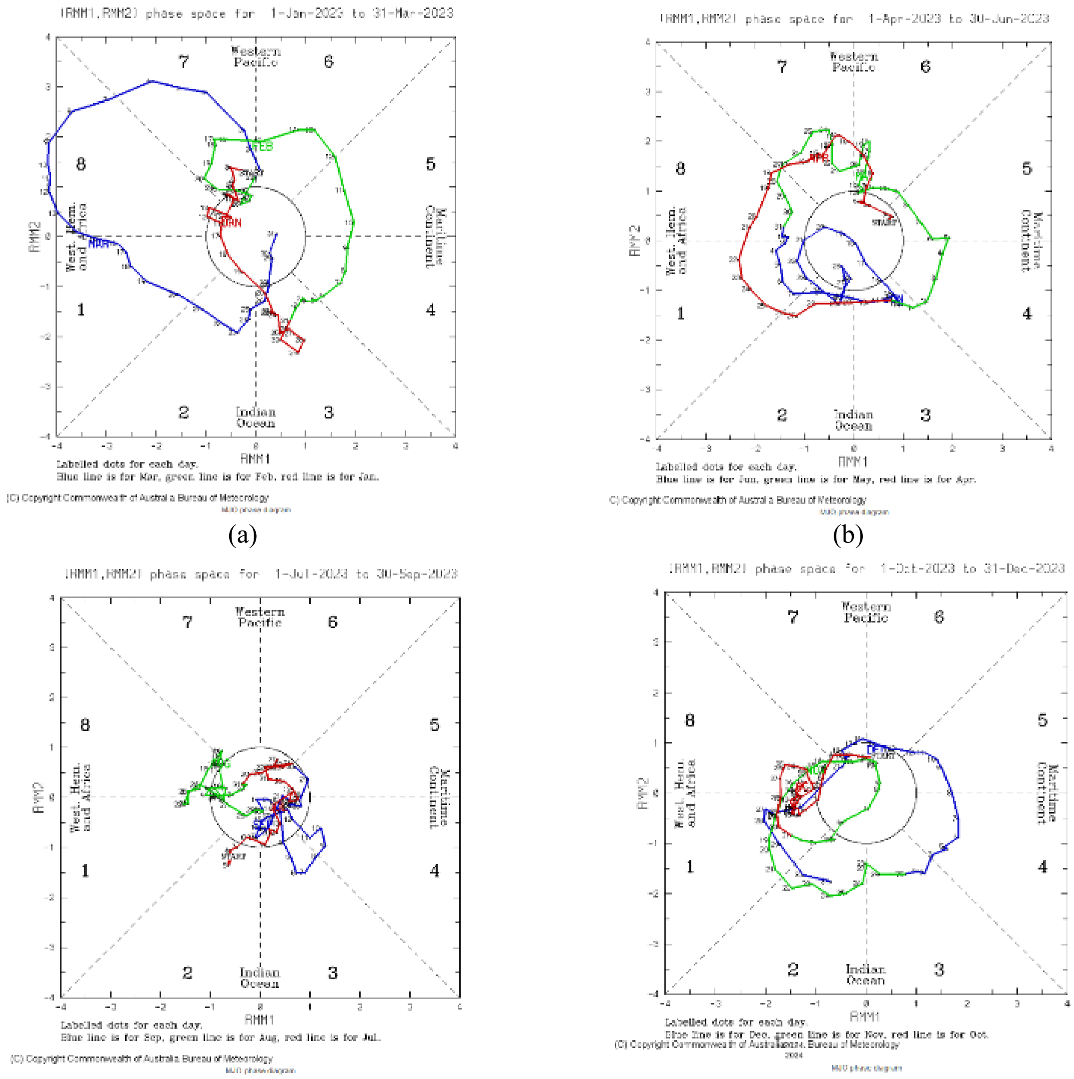

Figure 5. Madden-Julian Oscillation (MJO) phase diagrams during 2023: (a) Quarter I, (b) Quarter II, (c) Quarter III, and (d) Quarter IV. Shaded regions indicate periods when MJO activity propagates through phases 4-5 over the Maritime Continent. *Source: Australian Bureau of Meteorology (BoM),* http://www.bom.gov.au/climate/mjo/#tabs=Monitoring

As shown in Figure 4a, a predominantly positive Indian Ocean Dipole (IOD) phase persisted during most of 2023, with peak values reaching +1.91 in October. Figure 4b indicates that the Niño-3.4 index remained positive from April to December 2023, exceeding +0.8 from June onward and peaking in

November-December. Nurafifah et al. [10] demonstrated that during El Niño conditions, particularly when combined with IOD anomalies, SST in the Banda Sea tends to decrease due to intensified upwelling. Accordingly, the SST decline observed mainly between May and September 2023 is consistent with the combined effect of positive ENSO and IOD conditions, superimposed on the dominant monsoonal cycle. The SST recovery observed from October to December suggests that local and regional ocean-atmosphere interactions also play an important role beyond ENSO and IOD forcing. These associations are interpreted qualitatively and do not imply direct causality. The Madden-Julian Oscillation (MJO) further modulates short-term SST variability.

Figure 5 shows that active MJO phases (phases 4-5) occurred during several periods in 2023, including early February, early May, early September, and early December, temporally coinciding with short-term SST reductions. SST cooling during active MJO phases has been reported previously and is commonly attributed to enhanced cloud cover, reduced shortwave radiation, and increased latent heat fluxes [9]. However, despite these episodic influences, the overall SST variability in the Ambon region appears to be more strongly governed by seasonal monsoonal circulation, consistent with the conclusions of Corvianawatie et al. [7].

Convective Cloud Parameters and Their Relation to SST. To examine the atmospheric response to SST variability, changes in convective cloud parameters are first assessed using the CCL. The CCL provides an estimate of cloud-base height. Figure 6 presents the time series of CCL during 2023 derived from morning (00 UTC) and evening (12 UTC) radiosonde observations. Morning CCL heights range from approximately 79 to 3.110 m, while evening CCL heights vary between about 499 and 2.493 m. Occasional occurrences of very low CCL (<500 m) are observed, particularly during May, August, and October, reflecting periods of enhanced low-level moisture. The highest CCL values occur predominantly in February, corresponding to relatively drier boundary-layer conditions.

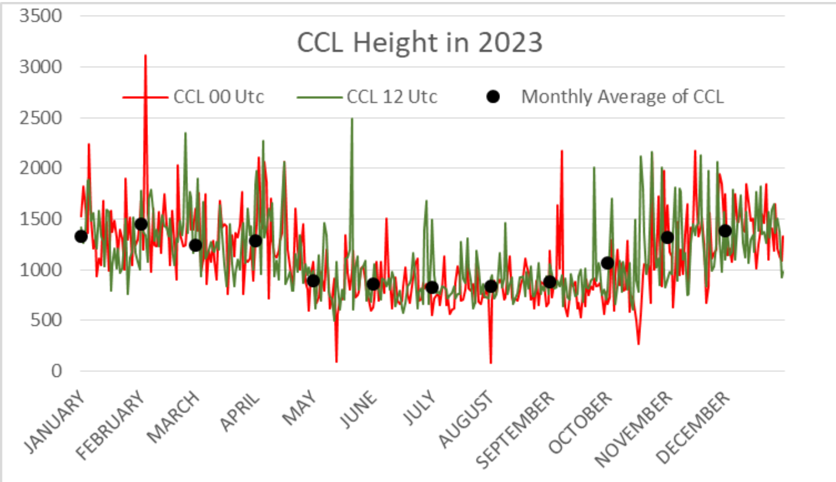

Figure 6. Time series of CCL (m) over Ambon Island during 2023, derived from radiosonde observations at 00 UTC (morning) and 12 UTC (evening). CCL is used as a projection for convective cloud-base height.

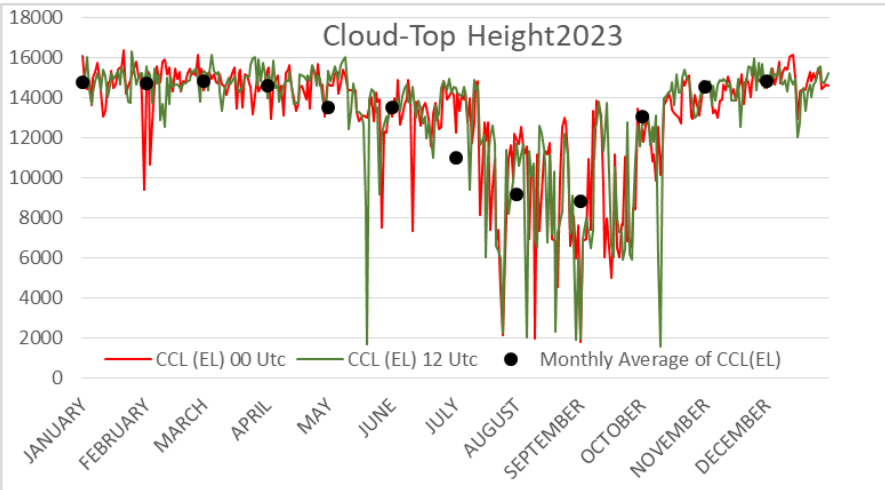

Figure 7. Time series of EL (m), representing convective cloud-top height, derived from radiosonde observations over Ambon Island during 2023 at 00 UTC and 12 UTC.

Table 1. Spearman rank correlation coefficients (ρ) between SST and convective cloud parameters (CCL and EL) at four observation stations surrounding Ambon Island.

Pair	Station	ρ	Neff	p_adj (ESS)	95% BCa CI
CCL - SST	St.1	0.556	80.2	8.27×10^{-8}	0.487 - 0.614
	St.2	0.580	80.2	8.27×10^{-8}	0.512 - 0.636
	St.3	0.568	80.7	3.39×10^{-8}	0.498 - 0.626
	St.4	0.532	81.3	3.04×10^{-7}	0.459 - 0.594
EL - SST	St.1	0.773	29.8	6.09×10^{-7}	0.725 - 0.812
	St.2	0.778	29.8	4.62×10^{-7}	0.728 - 0.817
	St.3	0.770	30.3	6.52×10^{-7}	0.719 - 0.812
	St.4	0.774	30.3	4.55×10^{-7}	0.723 - 0.816
CCL - EL (for reference)	-	0.529	~105	<0.001	0.465 - 0.583

Statistical significance is assessed using an effective sample size (Neff) correction to account for lag-1 autocorrelation in daily time series. Reported values include adjusted p-values (p_adj) and 95% bias-corrected and accelerated (BCa) bootstrap confidence intervals.

Cloud-top height, represented by the Equilibrium Level (EL), serves as an indicator of convective depth. Figure 7 shows that cloud-top heights at 00 UTC and 12 UTC exhibit broadly similar seasonal patterns. During January-April, EL remains relatively high, ranging from approximately 9.441 to 16.410 m. A marked reduction occurs between May and September, with EL occasionally dropping below 10 km, before increasing again from October through December. The reduction in average EL during the southeast monsoon raises the question of which physical mechanisms suppress deep convection during this period. Previous studies indicate that vertical wind shear associated with monsoonal circulation plays a key role. Kholiviana et al. [25] showed that changes in wind direction throughout the life cycle of cumulonimbus clouds can significantly affect their vertical development. Strong vertical wind shear can suppress deep convective development, leading to shallower convection and a downward shift in the effective convective heating profile [26]. Climatologically, the region experiences a west monsoon during December-February, transitional periods during March-May and September-November, and an east monsoon during June-August [27]. Ambon is known for its anti-monsoonal rainfall regime [13], in which convection remains frequent during the east monsoon but is dynamically constrained by enhanced wind shear, limiting cloud-top heights despite favorable thermodynamic conditions.

Quantitative Relationships between SST, CCL, and EL. Given the pronounced seasonal variability in SST, CCL, and EL, quantitative relationships among these variables were examined using Spearman rank correlation with correction for serial autocorrelation via the effective sample size (ESS) method. The results are summarized in Table 1. SST exhibits a moderate positive correlation with CCL at all stations (ρ = 0.532-0.580). After applying ESS correction (Neff ≈ 80-81), all SST-CCL relationships remain statistically significant ($p\_adj \leq 3.04 \times 10^{-7}$). The moderate magnitude of these correlations indicates that although higher SST tends to be associated with higher cloud-base heights, CCL is strongly influenced by low-level moisture conditions rather than SST alone. Because CCL corresponds to the level at which a rising air parcel first becomes saturated, it is highly sensitive to near-surface humidity and mixing ratio [28], [29]. In maritime environments such as Ambon, boundary-layer humidity remains relatively high year-round, limiting the sensitivity of CCL to SST variations. Similar behavior has been reported over other tropical oceanic regions [3], [30].

The SST-EL correlations obtained in this study indicate enhanced convective buoyancy, allowing air parcels to reach greater altitudes and resulting in deeper convective clouds and higher equilibrium levels [3], [5], [31]. As an internal reference, the correlation between CCL and EL is also positive and significant (ρ = 0.529), reflecting the vertically coupled structure of convective clouds. However, its weaker magnitude relative to SST-EL further underscores the dominant role of SST in regulating convective depth rather than cloud initiation alone. The SST-EL correlations obtained in this study (ρ ≈ 0.77) lie at the upper end of the range reported in previous tropical convection studies, which typically report values around 0.6-0.7 [3], [31]. This suggests particularly efficient ocean-atmosphere coupling in the Ambon region, likely due to its strongly maritime character and proximity to warm Banda Sea waters. Although SST decreases during the southeast monsoon, convective activity over Ambon remains frequent, albeit with reduced cloud-top heights. This behavior reflects the combined influence of thermodynamic forcing by SST and dynamic suppression by monsoonal wind shear in this anti-monsoonal region [1], [25], [26]. Seasonal analysis indicates that the observed reduction in EL by approximately 3-5 km during this period is associated with concurrent SST cooling and less favorable conditions for deep convection. These results suggest that SST variability plays an important role in modulating convective depth over the Ambon coastal region, consistent with established theoretical understanding of tropical convection linking surface thermal forcing to convective buoyancy and cloud-top height [3].

4. Conclusion

This study demonstrates that SST exhibits a statistically significant and consistent relationship with convective cloud parameters over the coastal region of Ambon during 2023. Spearman rank correlation analysis reveals that SST is moderately correlated with the CCL and strongly correlated with the EL across all observation stations, with these relationships remaining statistically significant after accounting for serial autocorrelation. These findings indicate that ocean surface warming is more strongly associated with the vertical development of convection than with cloud-base initiation processes. The spatial consistency of the SST-EL relationship across all stations suggests that SST-related modulation of convective depth operates coherently over the surrounding waters of Ambon Island. From a physical perspective, this behavior is consistent with the role of enhanced moist static energy associated with warmer SSTs in enabling convective air parcels to reach higher equilibrium levels. Overall, the results highlight the importance of ocean–atmosphere coupling in shaping convective cloud structure in the maritime tropical environment, particularly in regulating convective cloud-top height, while acknowledging that these relationships represent robust statistical associations rather than direct causality. Although large-scale climate modes such as ENSO, IOD, and the MJO contribute to short-term and interseasonal variability, the results indicate that seasonal monsoonal forcing remains the primary modulator of SST-convection coupling in this anti-monsoonal region.

Suggestion

This study is based on observations collected exclusively during 2023, which limits the ability to fully capture interannual variability and longer-term climate influences. Future studies incorporating multi-year datasets would provide a more robust framework for assessing the stability of the observed relationships and for identifying long-term trends in SST and convective cloud characteristics. To further strengthen the quantitative understanding of SST influences on convective cloud structure, particularly cloud-base height (CCL) and convective cloud-top height (EL), subsequent research could apply regression-based or predictive modeling approaches to evaluate the sensitivity and potential predictability of convective cloud development. In addition, a more detailed assessment of the roles of large-scale climate variability, including ENSO, IOD, and MJO, as well as local oceanographic and atmospheric processes, would help clarify their relative contributions to SST variability and its coupling with atmospheric convection in anti-monsoonal island regions.

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