



Role of Westerly Wind Bursts in driving the multi-year negative Indian Ocean Dipole of 2021-2022

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सार – उष्णकटिबंधीय हिंद महासागर में 2021-2022 के दौरान बहु-वर्षीय ऋणात्मक हिंद महासागर द्विध्रुव (Negative Indian Ocean Dipole–NIOD) की अभूतपूर्व स्थिति देखी गई, जो लगातार तीन बार ला-नीना (triple-dip La Niña) के साथ घटित हुआ। इस अवधि के प्रेक्षणों से भूमध्यरेखीय हिंद महासागर के ऊपर असामान्य रूप से बार-बार और प्रबल पश्चिमी पवन झोंकों (Westerly Wind Bursts–WWBs) की उपस्थिति का पता चलता है। इस अध्ययन में वायुमंडलीय पुनर्विश्लेषण आँकड़ों द्वारा संचालित महासागरीय मॉडल का उपयोग करके इस घटना के दौरान महासागरीय परिवर्तनशीलता को नियंत्रित करने में WWBs की भूमिका का परीक्षण किया गया। एक नियंत्रण सिमुलेशन की तुलना एक संवेदनशीलता प्रयोग से की गई, जिसमें हिंद महासागर की भूमध्यरेखीय हवाओं के स्थानीय प्रशमन (Smoothing) द्वारा WWB-संबंधित पवन परिवर्तनशीलता को दबा दिया गया। परिणामों से पता चला कि WWBs ने पूर्वगामी भूमध्यरेखीय धाराओं को उल्लेखनीय रूप से सुदृढ़ किया तथा अधोगामी भूमध्यरेखीय केल्विन तरंगों को उत्पन्न किया, जो पूरे महासागरीय बेसिन में आगे बढ़ीं। इन प्रक्रियाओं के कारण तापसंतुलनमंडल (thermocline) की गहराई बढ़ी तथा पूर्वी उष्णकटिबंधीय हिंद महासागर के ऊपरी महासागरीय भाग में ऊष्मा-सामग्री में वृद्धि हुई। जब WWBs को दबाया गया, तब अनुकरणों में पूर्वगामी परिवहन कमजोर, तापसंतुलनमंडल उथला तथा उपसतही ऊष्मा संचय कम पाया गया। निष्कर्ष भूमध्यरेखीय महासागरीय गतिकी को नियंत्रित करने में अंतःऋतुकालीन पवन झोंकों के महत्व को रेखांकित करते हैं और संकेत देते हैं कि 2021-2022 के दौरान असामान्य रूप से बार-बार आने वाले WWBs ने पूर्वगामी ऊष्मा पुनर्वितरण को बढ़ाकर बहु-वर्षीय NIOD को बनाए रखने में योगदान दिया।

ABSTRACT. The tropical Indian Ocean experienced an unprecedented multi-year negative Indian Ocean Dipole (NIOD) during 2021–2022, coinciding with the triple-dip La Niña. Observations during this period show unusually frequent and strong Westerly Wind Bursts (WWBs) over the equatorial Indian Ocean. Here, we examine the role of WWBs in modulating oceanic variability during this event using an ocean model forced with atmospheric reanalysis. A control simulation is compared with a sensitivity experiment in which WWB-related wind variability is suppressed through localized smoothing of equatorial zonal winds in the Indian Ocean. The results show that WWBs significantly enhance eastward equatorial currents and generate downwelling equatorial Kelvin waves that propagate across the basin. These processes deepen the thermocline and increase upper-ocean heat content in the eastern tropical Indian Ocean. When WWBs are suppressed, the simulations exhibit weaker eastward transport, a shallower thermocline, and reduced subsurface heat accumulation. The results highlight the importance of intraseasonal wind bursts in regulating equatorial ocean dynamics and suggest that the unusually frequent WWBs during 2021–2022 contributed to sustaining the multi-year NIOD through enhanced eastward heat redistribution.

Key words – Indian ocean dipole, Westerly wind burst, Wyrtki jet.

1. Introduction

The Indian Ocean Dipole (IOD) is a dominant mode of coupled ocean–atmosphere variability in the tropical Indian Ocean. It plays an important role in modulating the

climate over surrounding regions such as East Africa, Australia, and South Asia (Ajayamohan *et al.*, 2008, 2009; Ajayamohan & Goswami, 2007; Ajayamohan & Rao, 2008; Bazo *et al.*, 2013; Cai *et al.*, 2009; Chan *et al.*, 2008; Endris *et al.*, 2019; Qiu *et al.*, 2014; Saji *et al.*,

1999; Zubair *et al.*, 2003). The mature phase of the IOD is characterized by an anomalous zonal gradient in the sea surface temperature (SST) between the western and eastern tropical Indian Ocean. IOD events are accompanied by anomalous equatorial wind stress and adjustments to the thermocline. Despite substantial progress in understanding the growth and decay of IOD events, the mechanisms governing their initiation and development are an area of active research.

The years 2021 and 2022 witnessed consecutive negative IOD (NIOD) events, with the 2022 event being the strongest on record since the 1960s. The dipole mode index (DMI) became negative in the summer of 2021 and remained negative till early winter 2022, making it the first such occurrence of a multi-year NIOD since systemic Indian Ocean observations became available in 1960 (Srivastava *et al.*, 2026; referred to as AS26 henceforth). This multi-year event co-occurred with the triple-dip La Niña of 2020-22. NIOD events are usually characterised by anomalous westerlies over the tropical Indian Ocean (TIO), which warm SSTs in the southeastern TIO and deepen the thermocline (Lu *et al.*, 2018). AS26 showed that persistent zonal westerly wind anomalies dominated the TIO, along with record-breaking occurrences of Westerly Wind Bursts (WWBs) during 2021-22 (5 events in 2021 and 3 in 2022; against a climatological average of ~1.6 events per year, See AS26 Fig. 3). Westerly wind bursts are synoptic-scale episodes of intense anomalous westerly winds that occur close to the equator and are predominantly observed in the equatorial Indian and Pacific Oceans (Seiki & Takayabu, 2007). WWBs trigger strong eastward currents in the equatorial Indian Ocean, which are referred to as the Wyrtki Jets (Wyrtki, 1973). The redistribution of heat and mass transport associated with these jets plays an important role in the initiation and sustenance of IOD events (Cai *et al.*, 2014; Murtugudde *et al.*, 2000; Srivastava *et al.*, 2026; Vinayachandran *et al.*, 1999, 2007). A detailed analysis of the possible drivers of the enhanced WWBs during 2021–2022 was reported in AS26. The study suggested that persistent La Niña conditions helped maintain a large-scale background state favorable for WWB occurrence, with 5 of the 8 identified WWB events occurring during strong La Niña conditions. In addition, intraseasonal variability also played an important role, as six of the eight WWB events co-occurred with MJO phase 4, while several boreal summer events coincided with BSISO phases favorable for westerly wind anomalies over the tropical Indian Ocean.

Using ocean model experiments, Menkes *et al.* (2014) have shown that the lack of strong WWB sequences can strongly inhibit the growth of oceanic heat content in the eastern tropical Pacific, thereby preventing the occurrence of "super" El Niños. WWBs are also

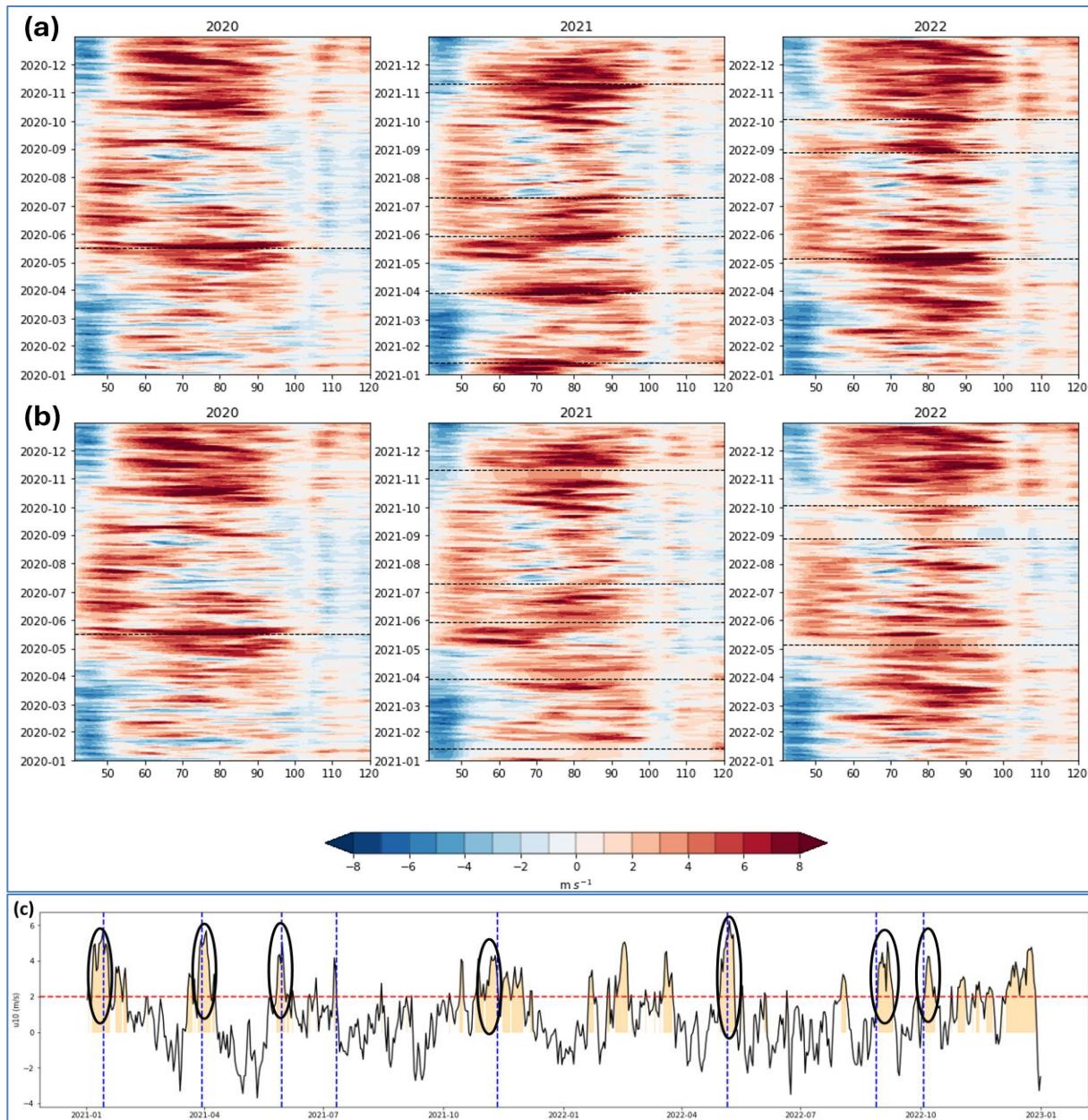
known to modulate the strength and irregularity of ENSO (Gebbie *et al.*, 2007; Lian *et al.*, 2014; Lopez *et al.*, 2013). AS26 argues that unusually large and long-lived WWBs played an important role in sustaining the multi-year NIOD by modulating the timing and intensity of Wyrtki jets in the equatorial Indian Ocean. Further, Lu *et al.*, (2018) have shown that anomalous intraseasonal westerly wind events early in the summer can lead to earlier initiation of NIOD events. Such anomalous events can warm ocean temperatures in the southeastern TIO by reducing local evaporation and wind-induced deepening of the thermocline. It is plausible that a mechanism similar to that associated with WWB and ENSO, as reported by Menkes *et al.* (2014), is also significant in the Indian Ocean. In addition, recent studies have shown that intraseasonal easterly wind anomalies over the equatorial Indian Ocean can trigger positive IOD events by generating anomalous upwelling Kelvin waves, which shoal the thermocline in the eastern TIO (Moum *et al.*, 2014; Xiao *et al.*, 2024; Zhang *et al.*, 2021)). The resulting cooling off the Sumatra–Java coast subsequently activates the Bjerknes feedback, favoring the growth of the positive IOD event. By analogy, it is therefore important to investigate whether the opposite mechanism also exists — namely, whether WWBs contribute to the initiation or maintenance of NIOD events.

The current study aims to isolate the impact of WWBs on the TIO variability and their role in the multi-year NIOD event of 2021-22. The article is organized as follows: Section 2 presents the data, model, and methods; Section 3 presents the results; and Section 4 summarizes the study's findings.

2. Data and methodology

2.1. Data

We use the 10m winds, 2m temperature and specific humidity, sea-level pressure, precipitation, and the surface heat fluxes from the National Centers for Environmental Prediction (NCEP)/Department of Energy (DOE) Atmospheric Model Intercomparison Project (AMIP-II) reanalysis (R-2) (Kanamitsu *et al.*, 2002) available freely from their website at <https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html>. The ocean temperature profiles (pentad) are obtained from the NCEP-Global Ocean Data Assimilation System (GODAS, Behringer *et al.*, 1998), and the depth of the 20 °C isotherm is computed from it. The OSCAR (Ocean Surface Current Analysis Real-time, <https://doi.org/10.5067/OSCAR-03D01>, ESR, 2009) dataset provides near-surface ocean current estimates at 5-day resolution. WWBs are identified according to the definition used in AS26. WWB events over the Indian



Figs. 1(a-c). Longitude–time Hovmöller diagrams of equatorial (5°S–5°N averaged) NCEP 10m zonal wind (U10) winds for (a) the control (CTL) run & (b) the experiment where the westerly wind bursts (WWBs) were suppressed (EXP) run. Vertical dashed lines denote the occurrences of WWB events. (c) The time series of 60°E–90°E averaged U10 from (a). The dates when $U10 > 2 \text{ m s}^{-1}$ were smoothed to the climatological mean annual cycle and highlighted with black ellipses, and the shading denotes values greater than 2 m s^{-1} .

Ocean are identified using ERA5 10 m zonal wind data, following the framework of Seiki and Takayabu (2007), with a stricter criterion on event duration. Daily anomalies are calculated from zonal winds averaged over 2.5° S–2.5° N, relative to a 91-day running mean climatology. A WWB is defined when the anomaly exceeds 5 m s^{-1} , spans at least 10° of longitude ($\sim 1100 \text{ km}$), and persists for more than 4 days (compared to 2 days in the original method). To ensure independence, consecutive events must be separated by at least 7 days, preventing a single prolonged westerly episode from

being classified as multiple WWBs. We utilize a global configuration of the Modular Ocean Model version 4p0 (MOM4p0; Griffies *et al.*, 2004) for ocean experiments. It has a varying meridional resolution, with a quarter-degree resolution near the equator and decreasing polewards. The zonal resolution is 0.5° . The vertical resolution is 10m in the upper 200m of the ocean column and decreases progressively with depth. The ocean model time-step is 30 minutes and is forced with daily surface fluxes from the NCEP/DOE AMIP2 reanalysis.

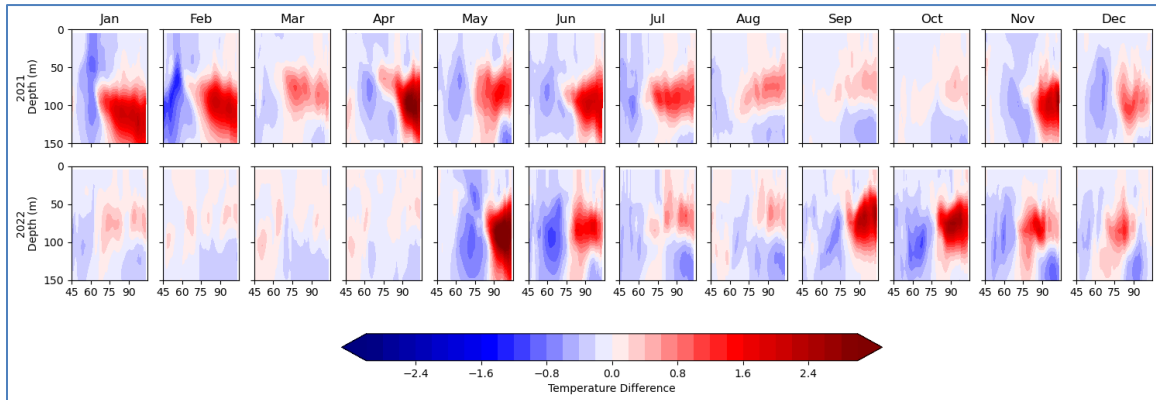


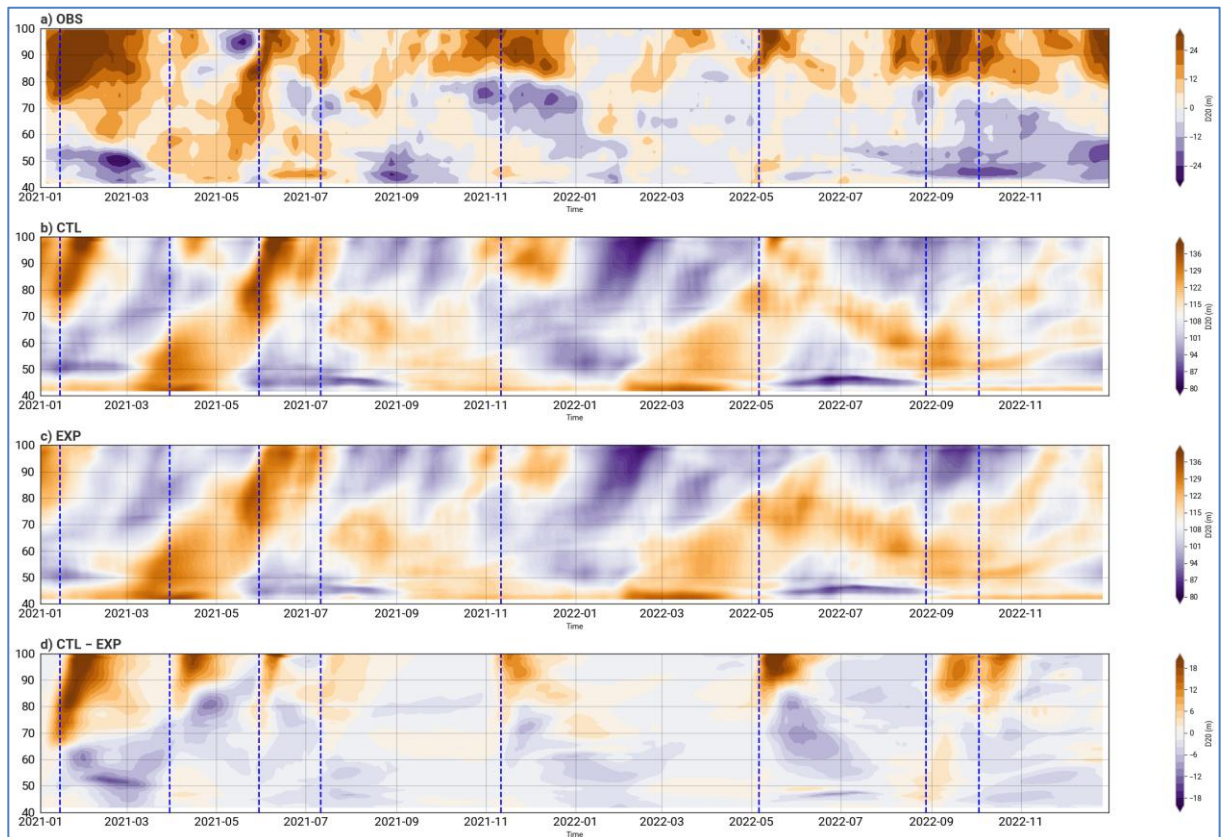
Fig. 2. Monthly longitude–depth sections of temperature differences (CTL – EXP, °C) averaged along the equatorial band for 2021 (top row) and 2022 (bottom row).

The control experiment (CTL) is performed using the surface forcings from the atmospheric reanalysis. For the sensitivity experiment (EXP), the 10m zonal wind values greater than 2 m s^{-1} in the equatorial band (5°S – 5°N , 50°E – 105°E) are smoothed to the daily climatological annual cycle around WWB occurrences during 2021 and 2022. Composite analysis of equatorial zonal wind anomalies around identified WWB events (Fig. not shown) shows that anomalous westerly winds rapidly intensify beyond 2 m s^{-1} ~15 days before the event peak, and settle to similar values 15 days after the event peak. Thus, the 2 m s^{-1} criterion effectively captures the core WWB activity. The selected threshold is also broadly consistent with magnitudes associated with the WWB events, as shown in Fig. 1(c). The smoothed daily climatological annual cycle of zonal winds was constructed using a Fast Fourier Transform (FFT) by retaining only the first two harmonics. This approach preserves the low-frequency seasonal variability and the mean annual cycle of the circulation while filtering out high-frequency transient variability. The resulting smoothed climatology was substituted during identified WWB periods, specifically within ± 5 days of each WWB event, over the equatorial Indian Ocean region (5°S – 5°N , 50°E – 105°E). Since the WWB identification employed strict filtering criteria, the modified periods primarily correspond to strong episodic intraseasonal westerly wind events. Therefore, the procedure effectively suppresses WWB activity while largely retaining the broader seasonal background circulation and minimizing impacts on unrelated low-frequency variability. The forcing for 2020 is the same in both runs, as there was a single WWB event in 2020, which is potentially unrelated to the sequence of WWBs during 2021–22. A smooth transition is applied in space and time (centered on the WWB event date and spanning ± 5 days) to prevent spurious jumps in the forcing field. Fig. 1(a) shows the original 10m zonal winds from the NCEP forcing (5°S – 5°N averaged). Horizontal dotted lines mark the identified occurrences of

Westerly Wind Bursts (WWBs) during each year. Fig. 1(b) shows the same fields after applying temporal and spatial smoothing around the WWB occurrences, which are used to force the EXP run. The smoothing is applied locally near the WWB periods (indicated by the same dotted lines) to reduce high-frequency variability while preserving the large-scale structure. This processed wind field is subsequently used as surface wind forcing for ocean model experiments, ensuring that the WWB signal driving the ocean response is coherent and dynamically consistent. The dates where such smoothing was applied are shown in Fig. 1(c).

3. Results and discussion

The temperature differences between the two experiments primarily emerge in the subsurface layer (~ 80 – 140 m) of the central–eastern basin ($\sim 70^{\circ}\text{E}$ – 100°E) as shown in Fig. 2. In 2021, strong positive anomalies occur in January–February, April–June, and November, indicating that the presence of WWBs in the control simulation enhanced subsurface warming relative to the experiment in which WWBs were suppressed. These warming signals reflect the accumulation of warmer water in the eastern TIO, associated with WWB-driven oceanic adjustment, likely through enhanced eastward zonal advection and downwelling/or through reduced westward zonal advection. In 2022, the differences are weaker during the early months but intensify from May to October, with pronounced warming centered near 80 – 100°E and ~ 80 – 120 m depth. This timing corresponds to the period when WWBs were active in the control simulation but absent in the experiment, suggesting that the suppression of WWBs reduces subsurface heat accumulation and weakens thermocline deepening in the eastern basin. Intermittent negative anomalies in the upper western region indicate a relatively shallower thermocline in the CTL experiment. Overall, experiments demonstrate that removing WWB forcing leads to a systematic



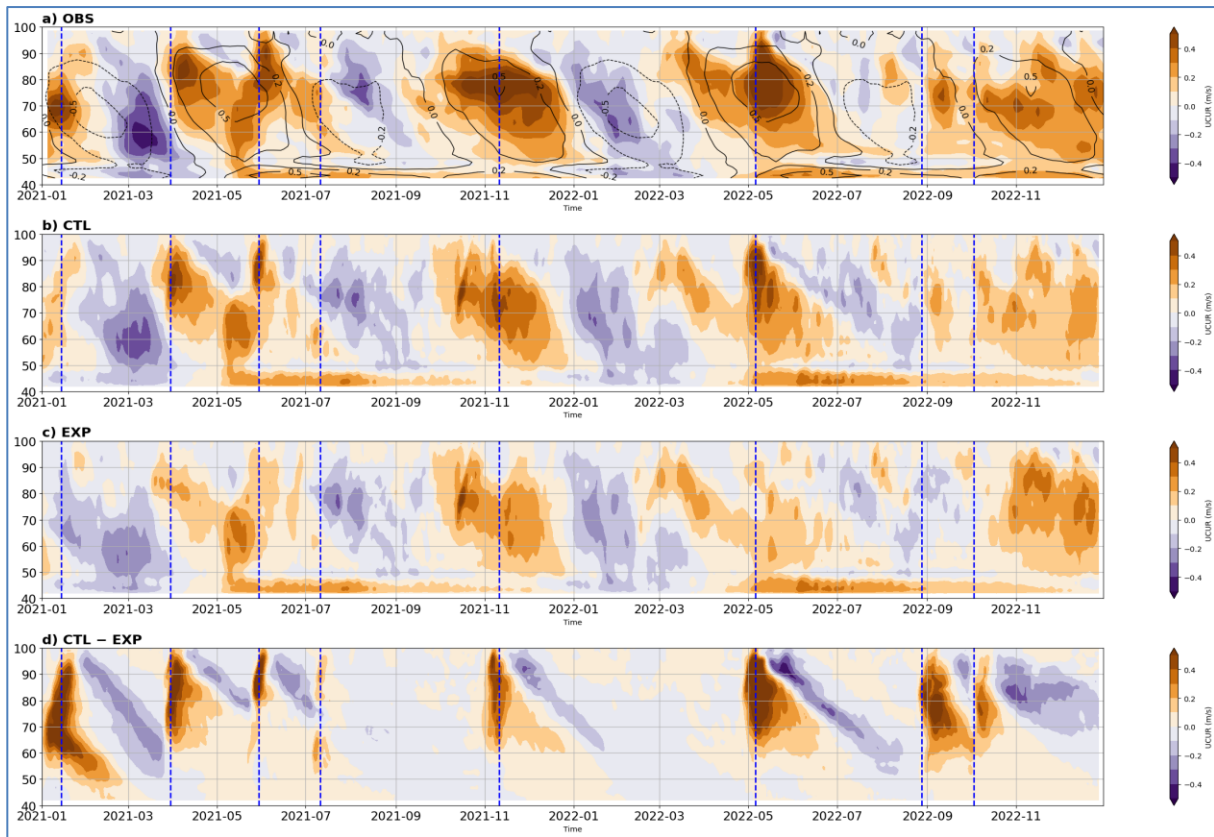
Figs. 3(a-c). Time-longitude evolution of the 20°C isotherm depth anomalies (D20, m) averaged over 2°S–2°N for 2021–2022 for (a) observations (OBS). (b, c) same as (a) but for the mean 20°C isotherm depth in control simulation (CTL) and experiment (EXP), respectively, and (d) the difference (CTL – EXP). The dates of WWB occurrences are marked as vertical dashed lines

reduction of subsurface warming, particularly in the central–eastern equatorial basin, highlighting the role of WWBs in modulating subsurface heat content and thermocline structure.

Fig. 3 shows the zonal evolution of thermocline depth (depth of 20 degree isotherm; D20) in the equatorial Indian Ocean and highlights the role of WWBs in modulating subsurface structure. In the reanalysis, episodic deepening of the thermocline is evident following several WWB events, with signals that appear to propagate eastward across the basin. These features are consistent with the generation of downwelling equatorial Kelvin waves, which are triggered by WWB-induced westerly wind forcing along the equator. The control simulation captures several of these variability patterns, showing thermocline deepening in the central and eastern basin following WWB occurrences. These deepening signals propagate eastward, reflecting the downwelling Kelvin wave response and deepening the thermocline in the eastern equatorial Indian Ocean. In contrast, the experiment with suppressed WWBs shows a weaker, less coherent thermocline response. This indicates that removing WWB forcing weakens the generation of downwelling Kelvin waves and consequently reduces the

associated subsurface adjustment. Fig. 3(d) clearly shows positive anomalies (a deeper thermocline in CTL) that develop following WWB events and extend eastward across the basin. In the absence of WWBs, the experiment maintains a relatively shallower thermocline and weaker basin-scale adjustment. The results demonstrate that WWBs play a key role in exciting downwelling equatorial Kelvin waves that propagate eastward, deepen the thermocline, and redistribute heat in the TIO basin.

WWBs can drive eastward-flowing surface currents that are responsible for heat and momentum transport in the TIO. Eastward currents are observed during the spring and fall season (the Wyrtki jets; Seiki and Takayabu 2007), or even during summer monsoon months (Senan *et al.*, 2003). The modulation of the timing and intensity of such jets can impact the sub-surface heat storage in the TIO (Srivastava *et al.* 2026). Therefore, we explore the evolution of these currents (Fig. 4). Pronounced eastward currents develop in observations during April–May and October–November, consistent with the well-known spring and fall Wyrtki Jets. These jets extend across much of the equatorial basin and are characterized by strong eastward velocities exceeding $0.3\text{--}0.4\text{ m s}^{-1}$. The timing of these jets coincides with several WWB events (blue

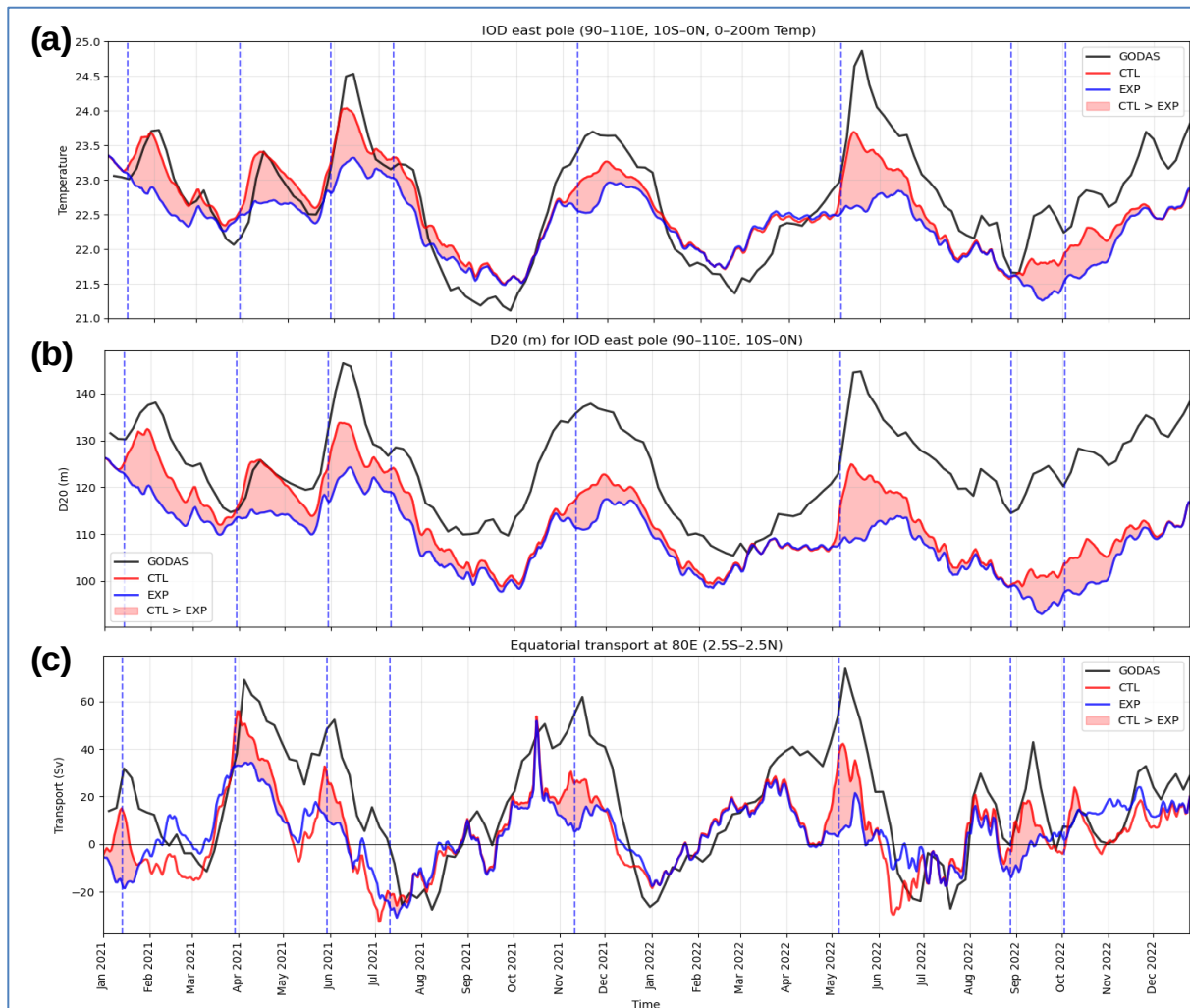


Figs. 4(a-d). Time-longitude evolution of zonal currents (UCUR, m s^{-1}) averaged over 2°S – 2°N and the upper 0–50 m during 2021–2022 (a) observations (OBS; contours depict the climatological currents), (b) control simulation (CTL), (c) experiment with suppressed westerly wind bursts (EXP), and (d) the difference (CTL – EXP).

dashed lines). In addition to these seasonal jets, the observations also show unseasonal eastward current events, notably during January 2021 and mid-2021 (boreal summer). These events occur outside the typical Wyrtki jet seasons and coincide with WWB occurrences marked by the dashed lines. The control simulation (Fig. 4b) captures the seasonal occurrence of the Wyrtki Jets and the unseasonal eastward currents. The jets appear as coherent eastward-flow bands extending from the central to the eastern equatorial Indian Ocean, reflecting the basin-wide response to equatorial wind forcing. In contrast, the experiment with suppressed WWBs (Fig. 4c) shows a weaker and less coherent eastward jet structure. Although the westerlies associated with the seasonal reversal of winds still drives some eastward flow, the amplitude and spatial extent of the jets are reduced compared to the control simulation. Overall, the results indicate that the WWBs acted to significantly strengthen the Wyrtki Jets, enhance eastward surface currents, and facilitate the eastward transport of warm water toward the eastern TIO, thereby influencing thermocline depth and upper-ocean heat distribution across the basin.

Fig. 5(a) shows the variability of the 0–200 m averaged temperature, which serves as a proxy for upper-

ocean heat content to assess heat accumulation in the IOD east pole region in response to zonal currents in the central equatorial Indian Ocean. Periods following WWB events (blue dashed lines) are often associated with enhanced warming in the control simulation (CTL) compared to the experiment (EXP) in which WWBs are suppressed. This difference is particularly evident during early 2021, mid-2021, and mid-2022, when the CTL simulation shows stronger heat accumulation in the eastern equatorial Indian Ocean. The thermocline deepens noticeably following WWB events (Fig. 5b), consistent with the arrival of downwelling equatorial Kelvin waves propagating eastward across the basin. The CTL simulation shows greater thermocline deepening than the EXP run, whereas the experiment maintains a relatively shallower thermocline due to the absence of WWB forcing. Fig. 5c shows the equatorial zonal transport at 80°E , representing the strength of eastward equatorial currents associated with Wyrtki jets and episodic WWB-driven jets. Strong eastward transport events appear during the spring and fall transition seasons, as well as during several unseasonal WWB-driven events. The CTL simulation generally exhibits stronger eastward transport than the EXP simulation, indicating that WWBs enhance eastward



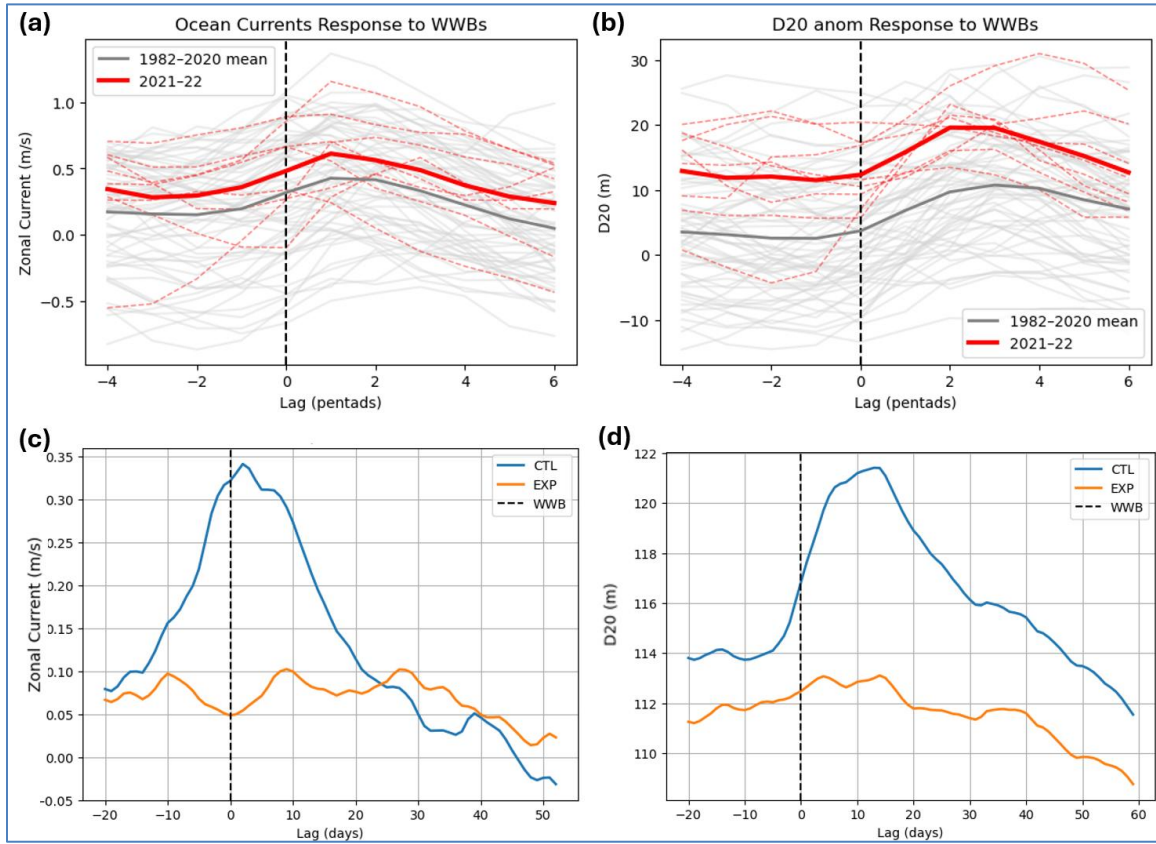
Figs. 5(a-c). Time series of oceanic variability in the eastern pole of the Indian Ocean Dipole (IOD) region (90° – 110° E, 10° S– 0° N) during 2021–2022. The top panel shows upper-ocean temperature averaged over 0–200 m, the middle panel shows the depth of the 20° C isotherm (D20, m), and the bottom panel shows equatorial zonal volume transport at 80° E (2.5° S– 2.5° N). Blue dashed vertical lines mark the timing of WWB events

momentum input and mass transport along the equator. These results also indicate that the volume transport in the model is weaker than in GODAS, and that the associated deepening of the thermocline and the accumulation of upper-ocean heat content are correspondingly lower. This is particularly true for stronger episodes such as those during November 2021 and May 2022. These highlight systematic biases in the ocean model. Nevertheless, the model simulates the timing of the response to WWB forcing reasonably well.

These results demonstrate a consistent chain of processes linking WWB forcing, enhanced eastward equatorial transport, thermocline deepening via downwelling Kelvin waves, and increased upper-ocean heat content in the eastern IOD region. Suppressing WWBs in the experiment weakens each step of this

sequence, resulting in reduced eastward transport, a shallower thermocline, and lower heat content in the eastern TIO.

We also contrast the WWB events of 2021–22 with past such events to highlight their uniqueness. Fig. 6(a) shows that WWB events are followed by enhanced eastward equatorial currents, indicating the acceleration of the oceanic jets. The historical mean response shows eastward intensification of the current in the central equatorial Indian Ocean, peaking approximately one pentad after WWB onset. During 2021–2022, the composite jet response (red line) is consistently stronger than the historical mean, and several individual events exhibit particularly strong eastward current anomalies. These enhanced currents indicate stronger eastward momentum input into the equatorial Indian Ocean during



Figs. 6(a–d). Composite responses of equatorial ocean currents and thermocline depth to WWB events. (a) Event-lag composite of equatorial zonal currents (m/s) averaged over 2°S–2°N, 60°–90°E from GODAS. Thin gray curves show individual historical WWB events (1982–2020), the thick gray line indicates their mean response, and dashed red curves show individual events during 2021–2022. The thick red line shows the composite response for the 2021–2022 events. (b) Same as (a) but for thermocline depth anomalies (D20, m) averaged over the eastern equatorial Indian Ocean. (c, d) same as (a, b) but the mean zonal current (m/s) and D20 (m), respectively from the ocean model experiments

this period. Following WWB events, positive D20 anomalies develop in the eastern equatorial basin indicating deepening of the thermocline (Fig. 6(b)). The peak deepening typically occurs about two to four pentads after WWB onset, consistent with the arrival of downwelling equatorial Kelvin waves generated by WWB-driven wind forcing. The 2021–2022 composite shows greater deepening of the thermocline than the historical mean, suggesting stronger subsurface heat accumulation in the eastern TIO during the multi-year NIOD period. Model experiments (shown in Fig. 6 c, d) suggest that in the control simulation (CTL), WWB forcing produces a rapid deepening of the thermocline over the IOD east pole region by initiating eastward zonal currents shortly after WWB onset, followed by a gradual decay over several weeks. In contrast, the EXP simulation shows a much weaker thermocline response. The difference between CTL and EXP indicates that WWBs play a key role in driving downwelling Kelvin waves and enhancing subsurface heat accumulation in the eastern equatorial Indian Ocean.

Together, these results demonstrate that WWBs during 2021–22 generated stronger oceanic currents in response to WWBs and a corresponding thermocline deeper than climatology by ~10m, and sustained subsurface heat anomalies, processes that contributed to maintaining the multi-year negative Indian Ocean Dipole during 2021–2022. CTL simulation produces a thermocline deepening similar to GODAS, with a peak deepening occurring after ~15 days.

4. Conclusions

This study investigates the role of Westerly Wind Bursts (WWBs) in modulating tropical Indian Ocean variability during the multi-year negative Indian Ocean Dipole (NIOD) event of 2021–2022. Using ocean model sensitivity experiments in which WWB-related wind variability is suppressed, we isolate the oceanic response to episodic westerly wind forcing and assess its contribution to subsurface heat redistribution and equatorial circulation.

The results demonstrate that WWBs play a critical role in shaping the subsurface thermal structure of the equatorial Indian Ocean. In the control simulation, WWB occurrences generate strong oceanic adjustments characterized by enhanced subsurface warming in the central–eastern equatorial basin. When WWBs are suppressed, this warming signal is significantly reduced, indicating that episodic westerly wind forcing is an important driver of heat accumulation in the eastern TIO. WWBs also strongly influence thermocline variability by exciting downwelling equatorial Kelvin waves. Observations and the control simulation both show clear eastward-propagating signals of deepening thermocline following WWB events. In contrast, the experiment without WWBs shows a weaker, less coherent thermocline response. The simulations further show that WWBs intensify eastward equatorial surface currents and strengthen Wyrtki jets. The suppression experiment produces weaker and less organized eastward currents, demonstrating that WWBs enhance both the magnitude and spatial extent of equatorial jets and the associated eastward mass transport. Together, these processes form a consistent dynamical pathway linking WWBs to upper-ocean heat redistribution: WWB forcing accelerates eastward equatorial currents, strengthens Wyrtki jets, and excites downwelling Kelvin waves that deepen the thermocline and increase upper-ocean heat content in the eastern TIO. When WWBs are suppressed, each component of this sequence weakens, resulting in reduced eastward transport, a shallower thermocline, and diminished subsurface heat accumulation. The model experiments suggest that WWBs primarily function as amplifying and sustaining mechanisms for the NIOD, while they themselves are sustained by the background La-Niña state and the tropical intra-seasonal oscillations (Srivastava *et al.*, 2026).

It should be noted that the ocean-only model experiments forced with prescribed atmospheric fields cannot simulate the atmospheric response to SST anomalies. In particular, coupled feedback processes associated with NIOD evolution, including the Bjerknes-type feedback involving SST gradients, atmospheric convection, and surface wind anomalies, cannot be represented in the current framework. Consequently, while the experiments effectively isolate the oceanic response to WWB forcing and its impact on equatorial currents, Kelvin wave activity, and subsurface heat redistribution, they do not capture the potential amplification or damping of these signals through interactive atmospheric feedbacks. Fully coupled ocean–atmosphere model experiments would therefore be necessary to comprehensively assess the role of WWBs within the broader coupled dynamics governing NIOD initiation, amplification, and persistence.

Overall, the results suggest that the unusually frequent and intense WWBs during 2021–2022 likely played an important role in sustaining the multi-year NIOD event by enhancing eastward heat transport and maintaining a deep thermocline in the eastern basin. These findings highlight the importance of intraseasonal wind variability in modulating the oceanic processes that influence IOD evolution and persistence.

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Competing interests

The authors declare that there are no competing interests and there is no conflict of interest in this research.

Authors' contributions

Ankur Srivastava performed the analysis, prepared the Figures, conducted the model experiments, and wrote the initial draft of the manuscript. Maheswar Pradhan helped with the model experiments and analysis (*email id*: maheswar@tropmet.res.in). Suryachandra A. Rao conceived the original motivation for the study (*email id*: surya@tropmet.res.in). Gill M. Martin and Sarah Ineson contributed to the study's design and analyses (*email ids*: gill.martin@metoffice.gov.uk, sarah.ineson@metoffice.gov.uk).

All authors contributed to the understanding and interpretation of the analyses and to the final draft of the manuscript.

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