BAMS
Essay

Westward Displacement of Atmospheric East–West Circulation Ameliorated Drought-Induced Conditions in Australia and India during the Major 2023–24 and 1997–98 El Niño Events

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KEYWORDS:
Climate variability;
El Nino;
ENSO;
La Nina

ABSTRACT: Based on a compilation of widely available climate analysis products, we show evidence for a significant variation in the spatial pattern of the large-scale vertical zonal atmospheric circulation patterns across the equatorial Indo-Australasian domain of the Eastern Hemisphere during the major 2023–24 El Niño event. The region of large-scale subsidence and its associated teleconnection patterns that are usually centered across Indonesia (the "Maritime Continent") were displaced to the west over the equatorial Indian Ocean. In the record of El Niño events with readily available online dynamical tropospheric fields (one source from 1947 and the other from 1979), this has only been seen two other times, during the strong 1997–98 El Niño and the weaker 1977–78 event. These three events may well be consistent with internal variability, but at present, the reason for such occurrences has not been established.

DOI: 10.1175/BAMS-D-24-0049.1
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Manuscript received 17 February 2024, in final form 17 July 2024, accepted 2 August 2024

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1. Introduction

There has been considerable media concern and public consternation that seasonal forecasts of a strong El Niño in 2023–24 failed to result in the suppression of rainfall and expected wider climate impacts in two major regions often influenced strongly by the phenomenon—Australia and India (e.g., Ray 2023; King and Dowdy 2024; Jakob 2024). The reason for this has begun to be explored in scientific papers such as Tozer et al. (2023), while Wittenberg (2009) showed that the intrinsic variability of ENSO can change substantially from decade to decade, and that internal variability can play a strong role in how events and episodes are manifest.

It is well known that La Niña and El Niño events, that usually last around 12–18 months, are the two faces of the El Niño–Southern Oscillation (ENSO) phenomenon (Philander 1990; Allan et al. 1996; Neelin et al. 1998; Allan 2000). Centered in the Indo-Pacific basin, ENSO is a large-scale ocean–atmosphere interaction that varies in its onset, duration, magnitude, decay, and spatial structure (Philander 1990; Neelin et al. 1998; Allan 2000; Newman et al. 2011; Capotondi et al. 2015).

The "canonical" picture of El Niño events is one of the large-scale tropical convection displaced into the central-eastern equatorial Pacific Ocean, where warmer than normal sea surface temperature anomalies (SSTAs) occur (Fig. 1 top panel). Tropical convection is suppressed over Indonesia and equatorial South America and enhanced over eastern central African regions, in response to the atmospheric east–west zonal overturning cells characteristic of El Niño events (Fig. 1 top panel). The Pacific atmospheric east–west zonal overturning cell is often referred to as the "Walker circulation."

During canonical La Niña events, large-scale tropical atmospheric convection is centered on the wider Indonesian region where warmer than normal SSTA occur (Fig. 1 bottom panel). This is juxtaposed to cooler SSTA and subsidence across the central-eastern equatorial Pacific Ocean. Tropical convection is suppressed over the eastern central African region and enhanced over equatorial South America, in response to the atmospheric east–west zonal overturning cells characteristic of La Niña events (Fig. 1 bottom panel).

Although El Niño and La Niña events produce more or less opposite impacts across and around the Indo-Pacific basin, no two events are exactly the same. This is also true of "protracted" El Niño and La Niña episodes, which can last for several years (e.g., most recently with the 2014–16 and 2018–20 protracted El Niños and the 2020–23 protracted La Niña; Allan et al. 2020, 2023). Thus, the phenomenon embraces a family of events and longer episodes, whose atmospheric perturbations and resulting teleconnections carry its influences and physical impacts across the Indo-Pacific domain and to higher latitudes in both hemispheres (Philander 1990; Neelin et al. 1998; Allan 2000; Newman et al. 2011; Capotondi et al. 2015).

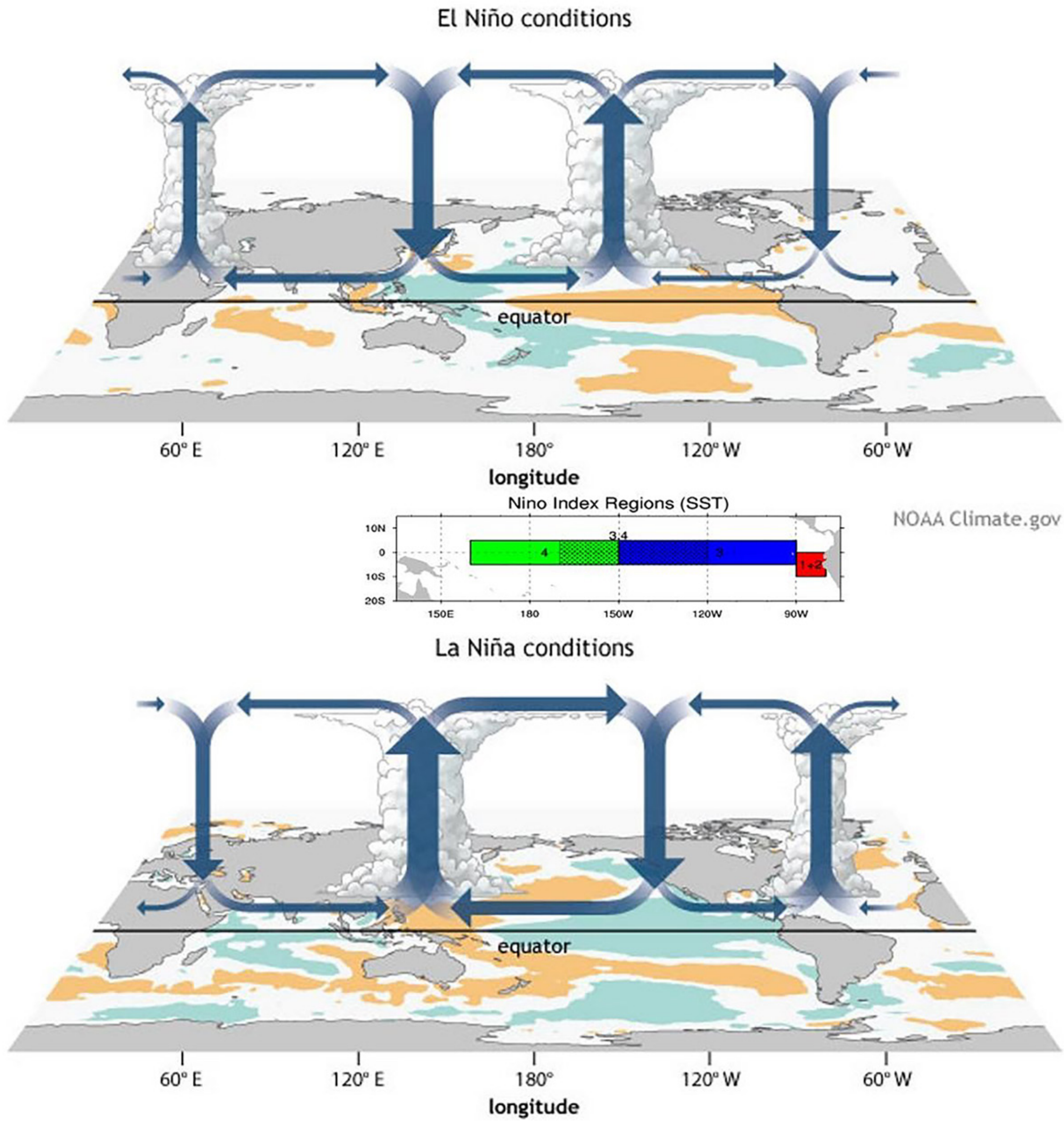

Fig. 1. **Schematic of regions of enhanced and suppressed equatorial convection, set up by the atmospheric east–west zonal overturning cell characteristic of El Niño and La Niña events and SSTA warming (orange) and cooling (blue/green) regions across the Indo-Pacific region. The Pacific atmospheric east–west zonal overturning cell is often referred to as the "Walker circulation." The important oceanic equatorial Pacific SSTAs are usually measured as indices in the various, so-called, Niño regions: Niño-1+2 (0°–10°S, 90°–80°W), Niño-3 (5°N–5°S, 150°–90°W), Niño-3.4 (5°N–5°S, 170°–120°W), and Niño-4 (5°N–5°S, 160°E–150°W) regions shown in the middle inset on the panel. Source: https://www.climate.gov/news-features/blogs/enso/walker-circulation-ensos-atmospheric-buddy.**

2. The 2023–24 El Niño event

During the recent ongoing El Niño event, that began around the middle of 2023 and has continued into 2024 (Climate Prediction Center/NCEP/News 2023) and is among the fifth strongest on record [El Niño is forecast to swing to La Niña later this year (wmo.int)], the pattern of widespread suppressed rainfall over eastern Australia, usually experienced in such events around austral winter to spring (McBride and Nicholls 1983; Allan et al. 1996; Risbey et al. 2009), was absent. Areas of dry conditions that were experienced in eastern Australia during July–September (JAS) and October–December (OND) seasons in 2023 (see Figs. 2c,d) were probably due to the periodic northward displacement of the subtropical ridge of high pressure rather than the impact of the suppressed El Niño conditions over Australia (Pittock 1975; Thresher 2002; Williams and Stone 2009). Instead, bouts of higher than average rainfall and flooding were observed across much of the states of the Northern Territory, Queensland, and New South Wales (http://www.bom.gov.au/climate/maps/rainfall/?variable=rainfall&map=anomaly&period=3month&region=nat&year=2024&month=01&day=31). Similarly, the 2023 Indian summer monsoon season only experienced a 6% deficit in rainfall (Ray 2023). Other regions around the Indo-Pacific basin suffered their typical hydroclimatic impacts during the 2023–24 event.

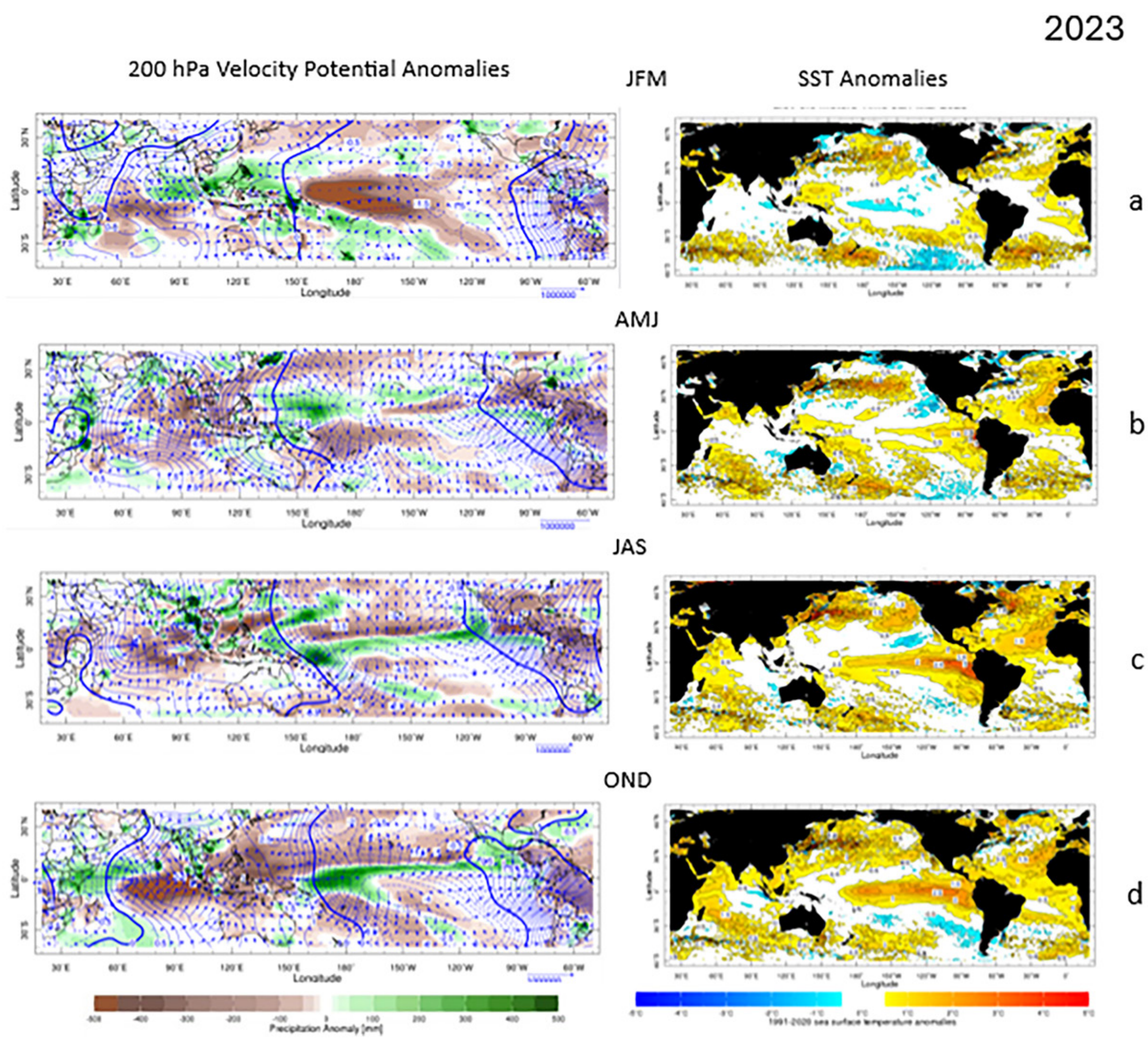

Fig. 2. **(left) Global seasonal 200-hPa standardized VP and precipitation *P* anomalies during (a) January–March (JFM), (b) April–June (AMJ), (c) JAS, and (d) OND 2023. The *P* anomaly shading values (mm) are shown, respectively, below the panels. Areas shaded in brown (green) represent negative (positive) precipitation anomalies from the 1991 to 2020 mean. Blue contours on the RH panel represent the seasonal standardized VP anomalies; solid lines are positive anomalies from the 1991 to 2020 mean, and dashed lines are negative anomalies. The standardized VP anomalies are contoured at an interval of 0.5 standard deviations, and the scale is shown below the panels. The blue vectors indicate the gradient of the seasonal VP anomalies, representing the divergent part of the wind. The magnitude of the gradient is indicated by the vector length. Source: http://iridl.ldeo.columbia.edu/maproom/ENSO/Tropical_Atm_Circulation/PRCP_Std_Vpot.html. (right) Global SSTAs (°C) during (a) JFM, (b) AMJ, (c) JAS, and (d) OND 2023, with positive in yellow to red and negative in light to dark blue. Anomalies are from the 1991 to 2020 mean. Source: https://iridl.ldeo.columbia.edu/maproom/Global/Ocean_Temp/Seasonal.html?T=Nov%202023%20-%20Jan%202024.**

An examination of the Indo-Pacific atmospheric east–west zonal overturning cells using spatial patterns of lower-level 925-hPa and upper-level 200-hPa velocity potential (VP) anomalies during each season of 2023 (Figs. 2a–d) (http://iridl.ldeo.columbia.edu/maproom/ENSO/Tropical_Atm_Circulation/PRCP_Std_Vpot.html) shows that the region of suppressed equatorial convection, usually located over the Indonesian region (Fig. 1), was expanded westward and centered more into the equatorial Indian Ocean (see Figs. 2a–d below). This resulted in an enhanced positive phase of the IOD that suppressed northwest cloud bands (seen at 925 hPa in JAS–OND velocity potential anomalies not shown), with even a distinct subsidence anomaly over Western Australia. Across eastern Australia, mixed conditions occurred, with an area of enhanced convection centered in the Coral Sea (in 925-hPa velocity potential anomalies not shown) and warmer SSTA off eastern-northeastern Australia. The latter have persisted since around the onset of the El Niño event in June 2023 (https://www.weather.gov/news/230706-ElNino) and probably influenced the very enhanced rainfall experienced in this region. This effect of enhanced SST in the Coral Sea region has been reported by van Rensch et al. (2019) during the years 1982, 1997, and 2015 of El Niño events and in the more recent studies of Holgate et al. (2020; Holgate et al. 2022).

Over much of northwestern India, the 925-hPa level velocity potential field (http://iridl.ldeo.columbia.edu/maproom/ENSO/Tropical_Atm_Circulation/PRCP_Std_Vpot.html) (not shown) is strongly convergent, also supporting enhanced rainfall. Figure 2 shows both the evolution of strong, warmer equatorial Pacific SSTA indicative of the 2023–24 El Niño event and persistent warm SSTA in the Indian seas. In the Indian Ocean, there continues to be a positive IOD pattern linked to ENSO through the displaced atmospheric east–west zonal overturning cell.

The evolution of the westward displacement of the east–west zonal overturning cells during 2023–early 2024 can be clearly seen when the Hovmöller diagram of 200-hPa pentad velocity potential anomalies is juxtaposed with the position of their canonical convection and subsidence patterns (Fig. 3). This displacement, centered around 60°–120°E, persisted over the equatorial Indian to western Pacific sector during the entirety of 2023 and would have resulted in anomalous teleconnections to higher latitudes in

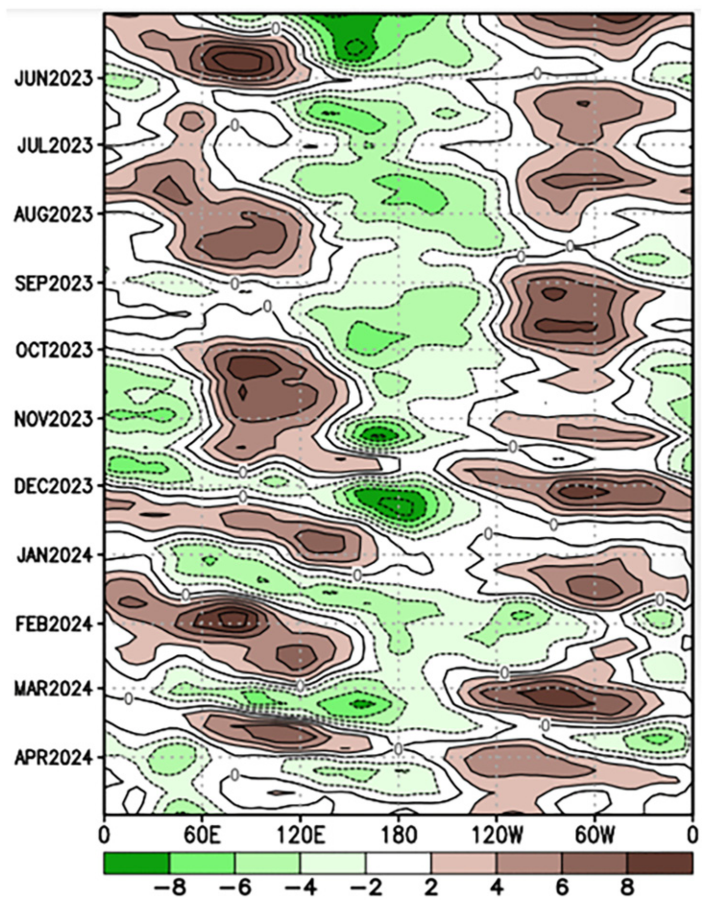

Fig. 3. (top) Time–longitude Hovmöller section of anomalous pentad 200-hPa velocity potential averaged between 5°N and 5°S (CDAS/Reanalysis) during 2023–early 2024. Dashed contours indicate negative anomalies. Anomalies are departures from the 1991 to 2020 base period pentad means. The data are smoothed temporally using a 3-point running average. Source: Climate Diagnostics Bulletin, April 2024 (https://www.cpc.ncep.noaa.gov/products/CDB/Tropics/figt12.shtml).

both hemispheres. It returned to a more "normal" position for a short time until early January 2024, after which it was replaced by a short duration of enhanced convection, and then showed a period of more westward displacement in mid-January to mid-February until being closer to the "Maritime Continent" by mid-March 2024. However, over the eastern equatorial Pacific and South American sector from 120° to 30°W in Fig. 3, atmospheric subsidence and its interlinked teleconnection pattern appear to be more or less in its canonical position.

3. Comparisons with the 1997–98 El Niño event

During the 1997–98 event, described by Slingo and Annamalai (2000) as the "El Niño of the Century," this displacement in Indo-Pacific east–west zonal overturning cells is again most evident in the spatial patterns of seasonal 200-hPa velocity potential anomalies (Figs. 3a–d). Wang and Hendon (2007) also refer to this feature of the circulation pattern in 1997 when they contrast it to the weaker 2002 El Niño event. In 1997, Australian rainfall was only severely reduced over southern and eastern Victoria (http://www.bom.gov.au/climate/history/enso/), while the 1997 Indian summer monsoon rainfall was around normal to slightly above average (Slingo and Annamalai 2000). The 1997 pattern is also reported in Chaudhuri and Pal (2014), who compared and contrasted the circulation structure of the strong 1982–83 and 1997–98 El Niño events. Using time–longitude Hovmöller diagrams of anomalies of OLR and mean sea level pressure (MSLP) between 60°E and 80°W,

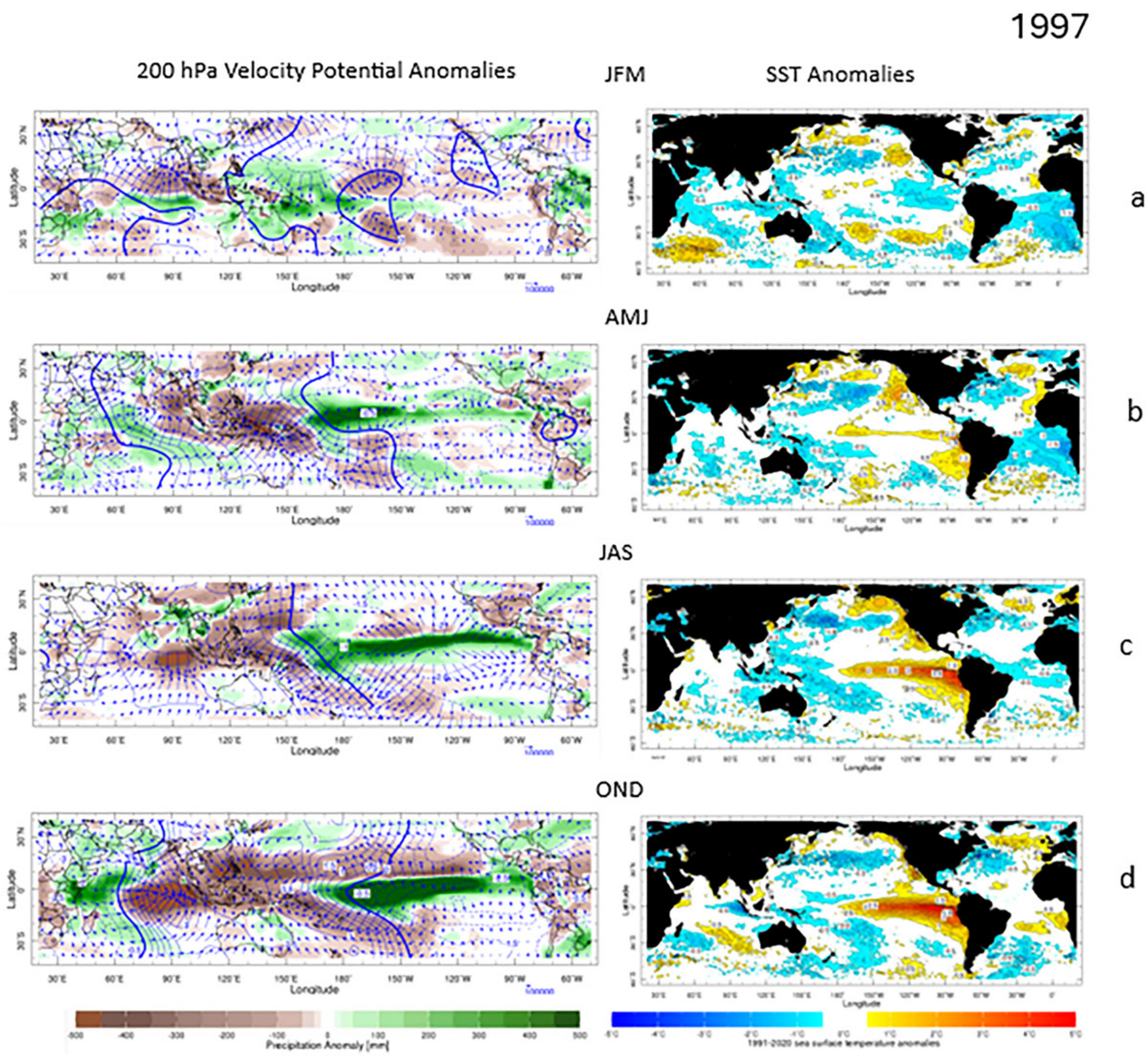

Fig. 4. As Fig. 2, but for 1997.

they highlight that the westward displacement of these features in the Indo-Australian sector is only observed in 1997. However, in contrast with the 2023–24 El Niño event (Figs. 2a–d), the 1997–98 off-equatorial SST anomalies in both hemispheres are dominated by cold anomalies (Figs. 4a–d).

Interestingly, long series of global, seasonal 200-hPa velocity potential anomalies (though calculated from different baselines than are used in this essay) are available on the International Research Institute for Climate and Society (IRI) World Wide Web (WWW) site (since 1979) (http://iridl.ldeo.columbia.edu/maproom/ENSO/Tropical_Atm_Circulation/PRCP_Std_Vpot.html) and on the Tokyo Climate Center, Climate Prediction Division of the Japan Meteorological Agency WWW site (since 1947) (https://ds.data.jma.go.jp/tcc/tcc/products/clisys/anim/anim_tp.html). When they are interrogated, they both indicate that only the major 2023–24 and 1997–98 El Niño events show a distinct westerly displacement of Indo-Pacific atmospheric east–west zonal overturning cells. The longer Tokyo Climate Center analysis also shows a similar displacement during the weaker 1977–78 event.

4. Conclusions

We have shown that both the major 1997–98 and 2023–24 El Niño events were characterized by a similar westward displacement of the center of large-scale equatorial subsidence, from across the Indonesian ("Maritime Continent") region out toward the equatorial Indian Ocean. This profoundly changed the teleconnection patterns associated with these two events, such that the usual suppression of rainfall with extensive drought in Australia and India during strong El Niño events was not experienced. Beyond those regions, the climate impacts were much as expected during a strong El Niño event.

The major 1997–98 and 2023–24 and weaker 1977–78 El Niño events were the only instances of westward displacements of the Indo-Pacific atmospheric east–west zonal overturning cells in the period of available online velocity potential fields dating back to 1947 and 1979, respectively. A dynamical explanation for these occurrences is still to be identified. Nevertheless, it should be noted that several papers have speculated about the role that anthropogenically driven factors may have played, and will play in future, in shaping the nature and characteristics of ENSO events and their relationship to various climatic features, such as monsoon systems (e.g., Cai et al. 2014, 2021; McPhaden 2015; Cash et al. 2017; Santoso et al. 2017; Goswami and An 2023).

The future availability of velocity potential fields in historical reanalyses, such as the Twentieth Century Reanalysis (Slivinski et al. 2021), that extends back to 1806, should present a long record with which to investigate these atmospheric east–west zonal overturning cells for any other occurrences of westward displacement during strong El Niño (or La Niña) events.

Acknowledgments. Rob Allan acknowledges his new affiliation as an Associate Researcher at the Institute for Environmental Research and Sustainable Development (IERSD), National Observatory of Athens, Greece. Roger Stone identified the initial concepts and extent of concerns about the veracity of media outputs of seasonal forecasts for the 2023–24 El Niño in Australia. We thank Dr. Dietmar Dommenget, ARC Centre of Excellence for Climate Extremes, School of Earth, Atmosphere and Environment, Monash University, Victoria, Australia, for his comments on the draft manuscript. We also acknowledge the three reviewers whose comments considerably improved the final manuscript.

Data availability statement. This study does not generate any new data.

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