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Revising the Bureau's ENSO Alert System: Adapting Indices in a Changing Climate

Chris Lucas, Matthew C Wheeler, Hanh Nguyen, Andrew B Watkins, Zhi-Weng Chua, Catherine Ganter

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Summary

The Bureau of Meteorology currently uses a multivariate approach to monitoring and declaring ENSO events called the ENSO Alert (or Outlook) System. This system has shown its worth through multiple El Niño and La Niña events since its operational adoption in 2014.

However, since the ENSO Alert system was conceived and subsequently implemented two things have changed. The first is the development of highly skilled operational coupled climate models, able to provide skilful predictions of ENSO including developing El Niño and La Niña events months to seasons in advance. This development means that measures such as analogues and static measures of ocean conditions are less useful than they might once have been.

The other change which is the focus of this paper is the continued rapid warming of global sea surface temperatures. Traditional ENSO indices of the ocean are based on absolute temperature values or anomalies (typically from a 30-year base period) in regions which tend to have homogenous variability. Noting that nearly all parts of the planet are currently seeing warming, indices based on sea surface temperatures are tending to drift towards higher values over time. Given that the traditional ocean view of El Niño and La Niña events is for above or below average water temperatures in the central and eastern Pacific this warming can substantially bias traditional measures of ENSO events.

In response to the above, and particularly the second point, this paper argues for the adoption of more recent 30-year sea-surface temperature (SST) climatologies and operational use of the Relative Niño 3.4 index to improve the Bureau's monitoring, detection, and prediction of the El Niño–Southern Oscillation (ENSO) phenomenon. Specifically, the Bureau should:

- Recognize that in a warming climate, any 30-year SST climatology is likely to be too cool relative to the current climate state, leading to errors and uncertainty in the real-time detection and monitoring of ENSO with respect to the current climate state. This will generally result in an overestimation of El Niño events and an underestimation of La Niña in real time when using the Niño 3.4 anomaly index.
- As soon as practical, shift from using the 1961-1990 SST climatology to the 1991-2020 climatology in the calculation and discussion of current SST anomalies. In the future, this climatology should be updated at a minimum of every 10 years, in line with leading international National Meteorological and Hydrological Services, and in accordance with World Meteorological Organization (WMO) recommendations.
- To aid the real-time monitoring and prediction of ENSO, the existing standard Niño 3.4 index should be augmented with the Relative Niño3.4 index, which subtracts the tropical 20°S-20°N area-mean anomaly from the Niño 3.4 index. It is recommended that these anomalies are computed using a baseline from the most recent 30 years, and that the relative index be used for future ENSO definition.

- While noting that Niño3.4 index continues to be used widely, these should continue to be computed, but provide secondary information for the definition and communication around El Nino and La Nina events.

While the above will eliminate many immediate issues with ENSO detection and monitoring, further research is required to accurately identify other flavours of ENSO (i.e., ENSO Modoki) that correspond strongly to Australian impacts, and to incorporate these into future Bureau warnings.

1. Introduction

The El Niño–Southern Oscillation (ENSO) is a coupled ocean-atmosphere climate phenomenon that plays a key role in setting the annual weather patterns and climate anomalies of Australia and the globe (Philander 1990). Its influence is primarily on seasonal to interannual timescales, although sometimes its impacts extend over longer periods of a few years. Its centre of action is in the tropical Pacific where it alternates between its warm SST phase (El Niño) and cool SST phase (La Niña). Over Australia, El Niño brings warmer days and drier conditions, particularly in the east, while La Niña results in cooler and wetter conditions (Risbey et al. 2009). Globally, ENSO causes anomalies that stem from its redistribution of tropical atmospheric moist convection (i.e., storms) which drives teleconnections through the global atmosphere via wave propagation (Sterl et al. 2007).

A high-priority effort for Bureau climate services is to monitor the state of the ocean-atmosphere system and issue forecasts of ENSO state. This is accomplished using a network of observations, including from satellite, and the routine running of complex coupled ocean-atmosphere numerical models to forecast the future state of the system.

Public communication of the ENSO state and its forecasts is of crucial interest for many Bureau customers. This effort is not confined to the Bureau; many countries issue similar products and communication alerts through their weather agencies (e.g., NOAA, NIWA, JMA, Singapore, WMO). One of the key challenges to identifying whether an ENSO event is underway is that similar but non-identical definitions of ENSO exist across these agencies (Nguyen et al. 2022). Furthermore, the analysis techniques and forecast models also vary across agencies. While the differences can create discrepancies and confusion, these different approaches when combined can also create an ensemble of forecasts and techniques to better capture the breadth of uncertainty in both the identification and forecast of ENSO events.

We note that while official forecasts are generally able to skilfully predict seasonal conditions several months in advance, many users find value in understanding why a forecast might be wet or dry. This is a key reason for continuing to focus on climate drivers, noting that for Australia ENSO events account for a large fraction of our variability. Communication around ENSO also provides an opportunity to raise literacy around Bureau services and the climate, allowing increased vigilance when impactful El Niño or La Niña events become established.

In this report, we provide recommendations to revise the definition of ENSO events within the Bureau of Meteorology operational framework, aiming to make it more robust and accurate. There are several issues identified here which complicate the identification of ENSO events. First is the current Bureau use of a single 30-year SST climatology (currently set as 1961-1990) from which the SST anomalies used to define ENSO events are computed. This fixed climatology means that global warming and other long-term temperature trends are not removed from the computation of SST anomalies and thereby affect the identification of ENSO events. This is larger the further away the event from 1990. A second is that even if the 30-year SST climatology is regularly updated, it will always be at least 15 years too 'old' with respect to the current climate state. In other words, regardless of how we define the climatology, the outcome will be that the real-time definition have a leaning towards El Niño events at the expense of La Niña events under global warming.

In this work, we propose updating the current climatology to a 1991-2020 climatology as well as the use of the 'Relative Niño 3.4' index (RN34) described by van Oldenborgh et al. (2021) which attempts to remove the real-time effects of global warming. The report also discusses, but provides no recommendation for, the impact of ENSO Modoki and the need to monitor this variant of ENSO in the future. This should be a topic of future research.

2. The current Bureau ENSO Outlook system

2.1. Overview

The Bureau of Meteorology (and other global centres) undertakes regular monitoring of SST in certain regions to understand oceanic changes of importance for global climate variability (Figure 1). Particularly relevant for ENSO is the Niño 3.4 region (Bamston et al. 1997) just to the east of the international dateline, and the SST anomaly area-averaged for the region is referred to as the Niño 3.4 index (hereafter N34). This region has historically been used because it sits on the eastern edge of the western Pacific warm pool, and tropical convection in this region is very sensitive to warming or cooling associated with ENSO events.

In the Bureau, the anomalies reported for these regions are *currently calculated as differences from the 1961-1990 climatological mean,* which has been standard practice for many years. The SSTs are usually estimated with a combination of satellite and *in situ* measurements to produce daily to monthly values that are key inputs to the Bureau's Climate Driver Update (http://www.bom.gov.au/climate/enso/), including the ENSO Alert/Outlook System.

The Bureau's current ENSO Outlook (an 'early warning system') system uses 7 categories to indicate the status and future expectation of ENSO. The system was launched in May 2014, following extensive validation and user co-design. One key criterion of the system is the use of a +0.8 (-0.8)°C N34 threshold for identifying El Niño (La Niña) events. A full description and real-time monitor can be found at http://www.bom.gov.au/climate/enso/outlook/.

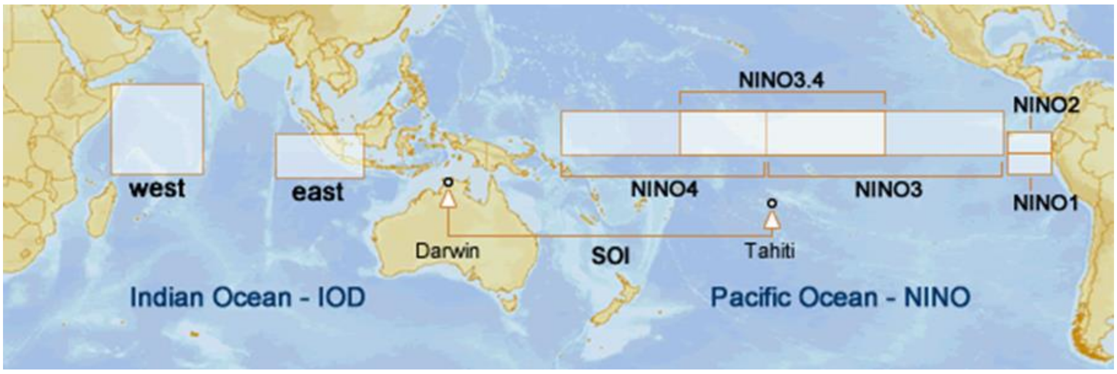

Figure 1. Map of El Nino-Southern Oscillation and Indian Ocean Dipole SST regions in common use.

The 7 categories are composed of an 'Inactive' category, along with a 'WATCH', an 'ALERT' and a 'Declaration' for both El Niño and La Niña. The atmospheric and oceanic criteria used for defining WATCH, ALERT and Declarations are summarized in Table 1, with the observations and forecasts of the SST anomaly in the Niño 3.4 region being a key ingredient. Gamble et al. (2017) perform a retrospective verification of the initial system (from 1980 to 2015) and note that a WATCH status represents a ~50% probability of reaching the ENSO phenomenon later in the calendar year, while an ALERT represents a ~70% chance of the ENSO phenomenon occurring. The resulting outlook is communicated to the public, summarized by the use of 'The Dial' (Figure 2) that indicates the current status.

For 2015 and beyond, the official historical real-time status issued by the system is summarized in Figure 3. Starting from an INACTIVE status in January 2015, a progression through the WATCH and ALERT categories followed by entering the El Niño event category for much of 2015 and early 2016. Much of the remainder of 2016 saw a La Niña WATCH. Early 2017 briefly saw an El Niño WATCH, before moving through La Niña WATCH and ALERT, reaching the La Niña event levels in late 2017 and early-2018. In mid-2018 through early-2019 a series of El Niño WATCH and ALERT categories were declared, although an El Niño event status did not eventuate. ENSO activity was INACTIVE from late-2019 through mid-2020. Since that time, the system has progressed through La Niña WATCH and ALERT and into La Niña Declaration three times. In early 2023, the extended period of La Niña ended, and the system was set to an El Niño WATCH.

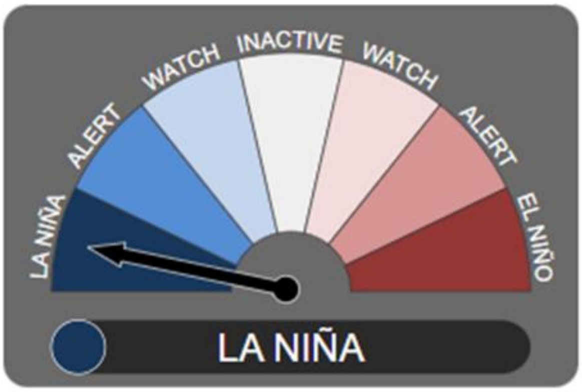

Figure 2. Example of ENSO watch dial, valid in February 2023.

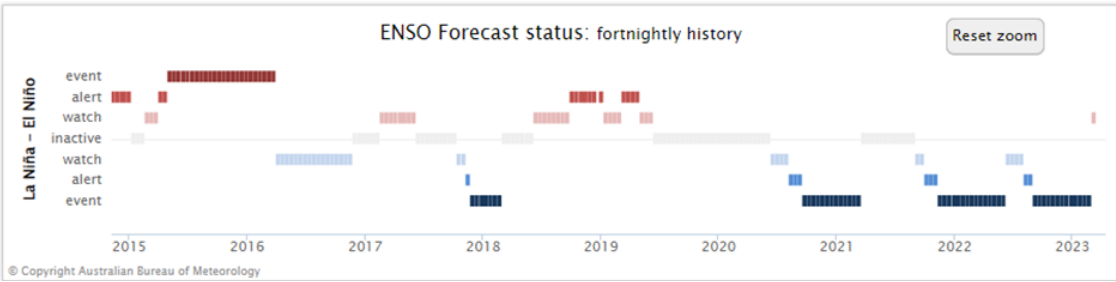

Figure 3. Operational fortnightly ENSO alert status at the Bureau from 2015 through early 2023. From http://www.bom.gov.au/climate/enso/outlook/#tabs=ENSO-Outlook-history.

2.2. Global Warming and the ENSO Outlook System

From the discussion of active ENSO events since 2015 and a look at the Bureau's current ENSO forecasting procedures, an immediate shortcoming of the current ENSO Outlook system can be identified.

This shortcoming is the current use of the 1961-1990 climatology as the baseline for determining SST anomalies. Tropical-wide SSTs have increased in the >30 years since this period has ended, with anthropogenic climate warming playing a central role (Figure 4). The 1961-1990 climatology is, *in the tropical average*, 0.37°C cooler than the most recently completed 30-year period (1991-2020), and SSTs have generally continued to rise above the 1991-2020 mean as would be expected with global warming.

Table 1. Summary of BoM current ENSO alert system criteria for El Nino and La Nina. Compiled from http://www.bom.gov.au/climate/enso/outlook/#tabs=Criteria.

	El Nino	La Nina
WATCH	All of the following criteria need to be satisfied: 1. Current climate state: ENSO phase is currently neutral or declining La Niña. 2. Either: SOI analogues: Of the 10 years that most closely resemble the current SOI pattern, 4 or more have shown El Niño characteristics. Or: Sub-surface: Significant sub-surface warming has been observed in the western or central equatorial Pacific Ocean. 3. Models: One-third or more of surveyed climate models show sustained warming to at least 0.8 °C above average in the NINO3 or NINO3.4 regions of the Pacific Ocean by late winter or spring.	All the following criteria need to be satisfied: 1. Current climate state: ENSO phase is currently neutral or declining El Niño. Either: 2. SOI analogues: Of the 10 years that most closely resemble the current SOI pattern, 4 or more have shown La Niña characteristics. Or: Sub-surface: Significant sub-surface cooling has been observed in the western or central equatorial Pacific Ocean. 3. Models: One-third or more of surveyed climate models show sustained cooling to at least 0.8 °C below average in the NINO3 or NINO3.4 regions of the Pacific Ocean by late winter or spring.
ALERT	Any three of the following criteria need to be satisfied: 1. Sea surface temperature: A clear warming trend has been observed in the NINO3 or NINO3.4 regions of the Pacific Ocean during the past three to six months. 2. Winds: Trade winds have been weaker than average in the western or central equatorial Pacific Ocean during any two of the last three months. 3. SOI: The two-month average SOI is –7 or lower. 4. Models: A majority of surveyed climate models show sustained warming to at least 0.8 °C above average in the NINO3 or NINO3.4 regions of the Pacific Ocean by the late winter or spring.	Any three of the following criteria need to be satisfied: 1. Sea surface temperature: A clear cooling trend has been observed in the NINO3 or NINO3.4 regions of the Pacific Ocean during the past three to six months. 2. Winds: Trade winds have been stronger than average in the western or central equatorial Pacific Ocean during any two of the last three months. 3. SOI: The two-month average SOI is +7 or higher. 4. Models: A majority of surveyed climate models show sustained cooling to at least 0.8 °C below average in the NINO3 or NINO3.4 regions of the Pacific Ocean by the late winter or spring.
DECLARATION	Any three of the following criteria need to be satisfied: 1. Sea surface temperature: Temperatures in the NINO3 or NINO3.4 regions of the Pacific Ocean are 0.8 °C warmer than average. 2. Winds: Trade winds have been weaker than average in the western or central equatorial Pacific Ocean during any three of the last four months. 3. SOI: The three-month average SOI is –7 or lower. 4. Models: A majority of surveyed climate models show sustained warming to at least 0.8 °C above average in the NINO3 or NINO3.4 regions of the Pacific until the end of the year.	Any three of the following criteria need to be satisfied: 1. Sea surface temperature: Temperatures in the NINO3 or NINO3.4 regions of the Pacific Ocean are 0.8 °C cooler than average. 2. Winds: Trade winds have been stronger than average in the western or central equatorial Pacific Ocean during any three of the last four months. 3. SOI: The three-month average SOI is +7 or higher. 4. Models: A majority of surveyed climate models show sustained cooling to at least 0.8 °C below average in the NINO3 or NINO3.4 regions of the Pacific Ocean until the end of the year.

Similar (but not identical) increases apply to the N34 index as well. The implication here is that the warming trend has spuriously made it easier to reach the warm SST anomaly threshold for El Niño, while La Niña thresholds have become spuriously harder to reach. We note that the warming of the Nino region by around 0.4°C since 1961-1990 means that the historical threshold associated with El Niño has effectively halved to 0.4°C, while the threshold for La Niña has increased to 1.2°C.

With no update to the climatology, the ongoing warming would mean that average conditions in the Niño 3.4 region SST will likely pass +0.8°C in the future, meaning an almost permanent El Niño state; reaching La Niña thresholds may not be possible in this scenario. Of course, this is an extreme example, but it highlights that a failure to directly address climate change in definitions will lead to an unworkable outcome. Clearly, a future state where El Niño events are perpetually identified goes against the understanding of ENSO as an oscillating phenomenon of approximately equal magnitude in both positive and negative directions.

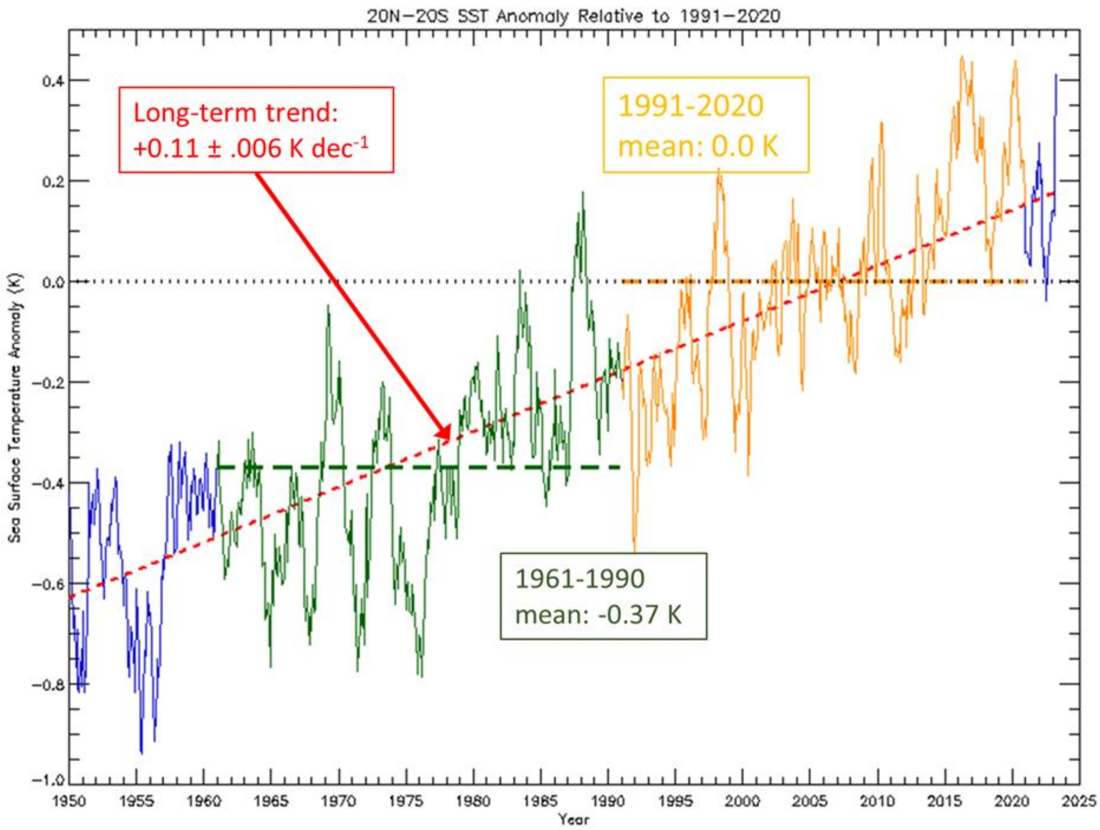

Figure 4. The ERSST 20°N-20°S SST anomaly from 1950 to 2023, relative to the 1991-2020 (orange) period. The 1961-1990 period average is also highlighted (green). 1991-2020 relative means during each period are shown (1961-1990: -0.37 K, 1991-2020: 0 K, dashed lines), as is the long-term trend over the entire period (red dash).

One means to alleviate the above issue is the use of a constantly updated climatology. The US's National Oceanic and Atmospheric Administration (NOAA), for example, has a policy to update its 30-year climatology every 5 years (Lindsey et al. 2013). However, despite adjustments of the climatology to the latest 30 years, the ongoing, generally upward broader SST trend implies that the latest SST anomalies will likely be warmer than what they would be once a centred climatology is available and used. For instance, since 2015 the average tropical SST in the ERSST data has been 0.22°C above the 1991-2020 mean, with values as high as +0.45°C in a given month (April 2016). Put simply, an updating climatology is better, but it goes only part way to addressing the issue that global warming is being aliased as ENSO variability when traditional indices are used.

Furthermore, the NOAA system determines *historical* events based on a centred climatology of the N34 index, while *real-time* events are determined using the past 30 years. For example, this means that an event may be declared in real-time in 2023 based on the 1991-2020 climatology, but that declaration may be revoked in future years as it is refactored every 5-years until its final value is determined using the 2006-2035 climatology. The best methodology for accomplishing this will need to be identified in the future.

3. The Relative Niño 3.4 Index

3.1. Overview

The N34 index has been shown to well capture the remote effects of ENSO with a simple index (Bamston et al. 1997). Anomalies of SST in this region are a key influence on the global circulation, in part through changes in the location of tropical convective activity. These changes in convection subsequently drive broader teleconnection patterns, contributing to the global impact of ENSO. However, studies of the circulation response to rising SST indicate that convective activity responds better to *relative* SST at a location -- i.e. how warm or cool it is compared to the rest of the tropics -- rather than the absolute value of temperature (e.g. Izumo et al. 2020). Understanding changes in the Niño 3.4 region in both a global warming context and compared to the rest of the tropical SST through the Relative Niño 3.4 index is a key to better understanding the impacts of ENSO in a warming climate.

3.2. Calculation

The intent of the Relative Niño 3.4 index (RN34) is to remove the effects of larger-scale features of the global SST structure (like climate change) from the more localized process associated with ENSO. In this work, we will follow the procedure of van Oldenborgh *et al.* (2021) to compute the RN34 index, estimated as follows:

$$RN34 = S \times [(N34o - N34c) - (TMo - TMc)]$$

where N34o and TMo are the observed monthly values over the Niño 3.4 region and the 20°N-20°S tropical mean (TM) SST, respectively while N34c and TMc are the contemporary (1991-2020 at this writing) climatological values for the appropriate day/month depending on dataset; the difference terms are the Nino3.4 Index and

Tropical Mean Index, referred to as N34 and TM. *S* is a scaling factor that provides a small correction to the magnitude of RN34 to make its variance equivalent to that of N34 using the method of L'Heureux et al. (2023). The use of S means that thresholds currently used for N34 can also be applied to RN34. Datasets chosen here include the monthly ERSST v5 and daily OISST v2, routinely available online from NOAA. As indicated in Figure 1, N34 is computed over the box 5°N to 5°S and 170°W to 120°W.

Figure 5 presents this calculation since 1950 to June 2023 for ERSST, showing both N34 and RN34. As one moves further back in time, the difference between the two indices increases, with N34 dropping below the relative (RN34) values. This is due to warming tropical SSTs since at least 1950 (Figure 4) and earlier (not shown). This historical spatial warming pattern is not uniform and impacts the eastern and central Pacific differently. This difference between the two indices means that N34 has more difficultly in detecting La Niña in the present climate, as well as El Niño being more difficult to detect during earlier periods. However, the trend in N34 remains far less than the full trend in TM (correlations of S range from 0.05 - 0.2). Table 2 highlights calculated trends since 1950. Overall, the background trend in TM is positive as is the trend in N34. However, the trend in RN34 shows the opposite with a negative trend, suggesting a tendency towards more frequent La Niña conditions. A shift to a more La Niña-like pattern, once the effects of global warming are removed, is consistent with other observational studies (Lee et al. 2022). In other words, when the global warming signal is removed from global SST patterns, we see that the Pacific has tended to increasingly favour La Niña conditions in recent decades

.

Table 2. Trends in computed indices from 1950 to Feb 2023 based on monthly data.

Index	Trend (1950-2023) (°C/decade)
RN34	-0.063 ± 0.026
N34	0.056 ± 0.027
TM	0.11 ± 0.0065

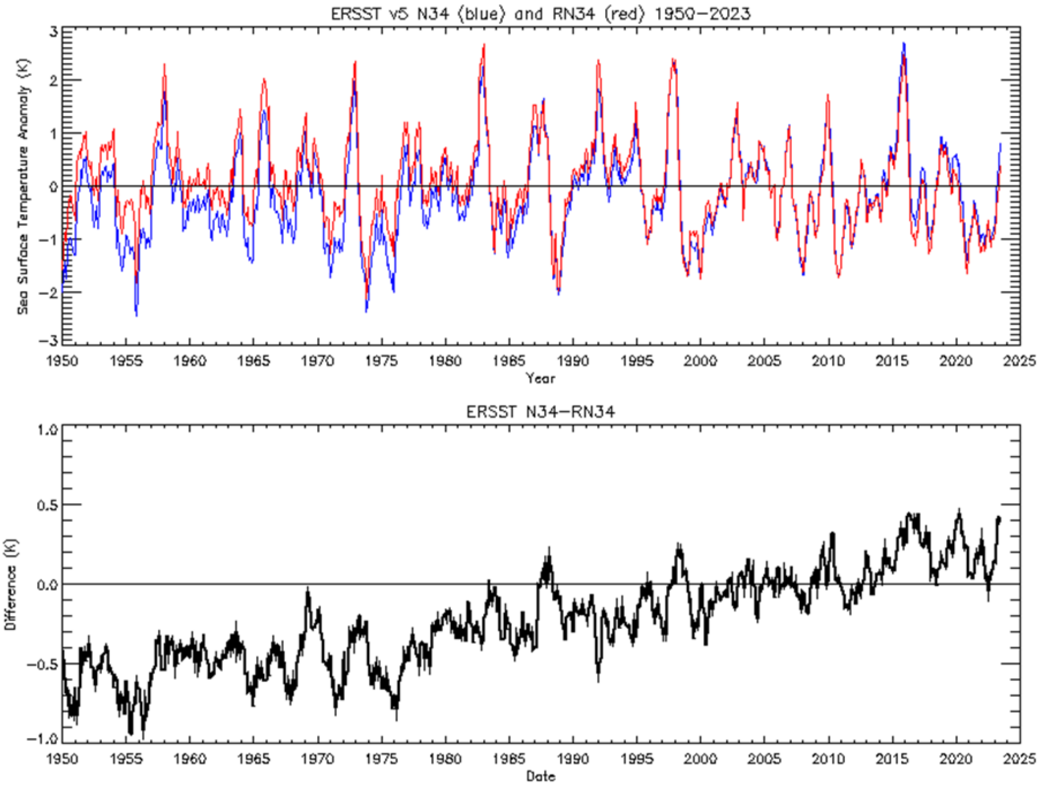

Figure 5. (top)1950-2023 monthly values of Niño3.4 (blue) and Relative Niño3.4 (red) from the NOAA ERSST v5 dataset. Background lines show thresholds for ENSO events for BoM (dashed, ±0.8 °C) and NOAA (dotted, ±0.5 °C). Anomalies are computed relative to 1991-2020 average. (bottom) Difference between Niño3.4 and Relative Niño3.4 for the same period.

L'Heureux et al. (2023) also describes the impacts of RN34 on tropical circulation characteristics and precipitation impacts. RN34 appears to effectively separate effects from increasing carbon dioxide and tropical mean SST from the atmospheric response to ENSO, creating a clearer ENSO-related signal. Similarly, the convective response in the central Pacific and in other regions of the globe is also clearer with RN34. Both features indicate a better discernment of the impacts of ENSO compared to N34.

3.3. Understanding Pacific Variability with RN34 since 2015

For the remainder of this section, we will focus on the period since the strong El Niño of 2015. This also broadly corresponds to the time from when the ENSO Alert System was operationalized. We consider both the response of the Bureau, with its more difficult to meet ENSO definition (> 0.8°C anomalies) and that of NOAA with the more relaxed definition of ENSO (> 0.5°C in three-month averages). Figure 6 shows a close up of N34 and RN34 time series since 2015 from the OISSTv2 dataset, while Figure 7 highlights formal declarations on ENSO events as determined by following archived discussions from the NOAA ENSO Blog (https://www.climate.gov/news-features/blogs/enso) and archived updates of the Bureau's ENSO climate update (http://www.bom.gov.au/climate/enso/wrap-up/archive.shtml). Figure 7 also highlights potential declarations based solely on the RN34 anomalies, using the Bureau's standard 0.8°C definition.

Over this recent period, Figure 6 highlights that the mean difference between the N34 and RN34 indices is 0.30 °C, varying from just below 0 to over +0.55°C., 0.08°C warmer than in the ERSST dataset noted earlier. While generally increasing over the long-term, it is not monotonically increasing over shorter timeframes; several periods of locally-higher and -lower SSTs covering the entire range are noted in the recent record as might be expected.

From Table 2, the trend in the RN34 and N34 indices are of similar magnitude, but with different sign. This indicates that the Pacific over the period has shifted towards an average state which is closer to La Niña, or equivalently La Niña events have tended to be favour over El Niño. Noting that the relative index effectively removes the broad global warming pattern in the tropics, the trend in the RN34 is real and important to capture in any operational system. In contrast, using the N34 suggests that the mean state has shifted to something more like El Niño. This shift is largely spurious as it simply reflects the tropics wide warming trend.

For much of the period, the different thresholds and approaches to identifying ENSO events yield largely the same answers, with perhaps slight differences of a month or two between start and end times. This difference is largely related to the choice of starting threshold (i.e., ±0.5 °C vs ±0.8 °C). Examples of this are noted with the strong El Niño of 2015, the brief La Niña of 2017 and the more extended periods of La Niña from 2020 to 2022. It is encouraging that the definitions between different agencies did not make too much of a difference in terms of declaration of moderate-strong ENSO events since 2015. However, the periods of 2016 and 2018-19 are more ambiguous.

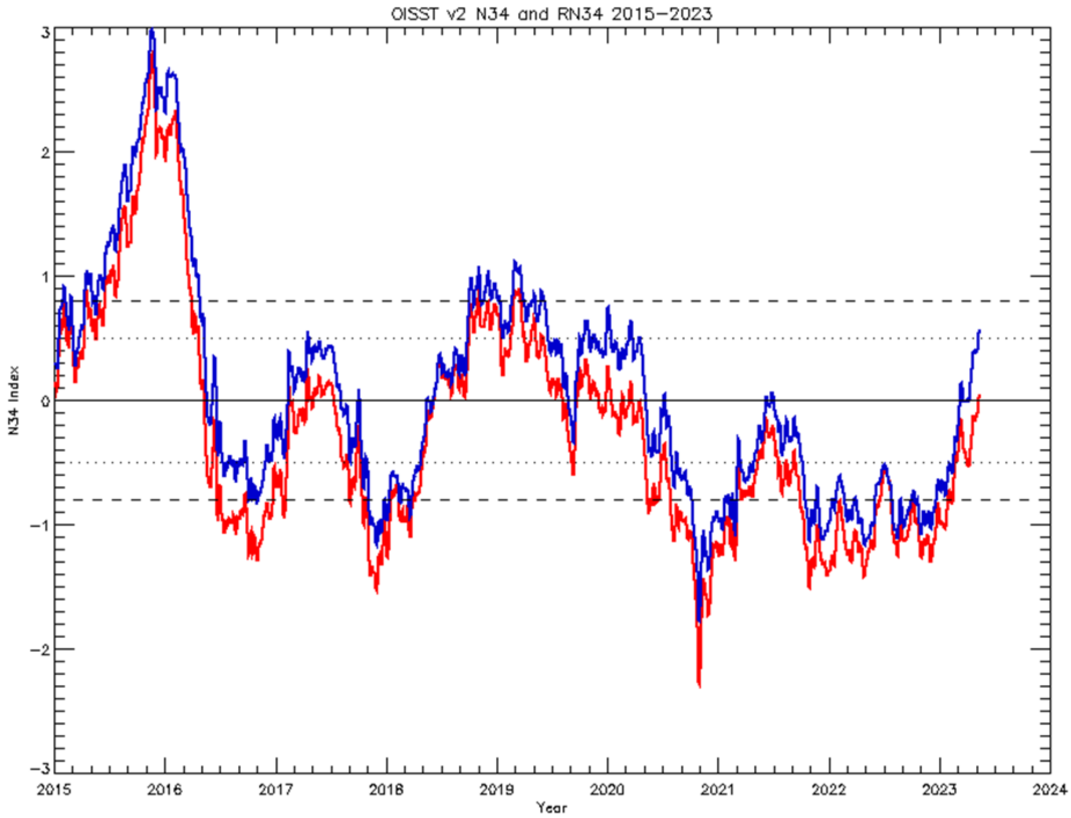

Figure 6. 2015-2023 Niño3.4 (blue) and Relative Niño3.4 (red) from the NOAA OISST v2 dataset. Data are daily but have been smoothed over 7-days for presentation. Data run through mid-May 2023. Background lines show thresholds for ENSO declaration for BoM (dashed, ±0.8 °C) and NOAA (dotted, ±0.5 °C)

During mid-2016, a strong return to La Niña was anticipated by both agencies and indicated by the presence of a La Niña WATCH at the Bureau during much of 2016 (Figure 3). NOAA declared a La Niña in December 2016, while BoM did not; NOAA ended the La Niña early in 2017. However, RN34 suggests that a La Niña should have been declared during July 2016, when RN34 reached below -0.8 °C and remained so until January 2017 (Figure 6). During 2016, the TM anomaly reached very high values, above +0.35 °C for most of the year, and above +0.4 °C for 5 of the 12 months. The RN34 index clearly shows the cooling of the central Pacific to below La Niña thresholds, although it only barely reached the traditional temperature anomaly threshold (and then only for the lower NOAA value). The interpretation here is that the TM temperature climbed to an unusually high level during 2016 and so masked the La Niña response.

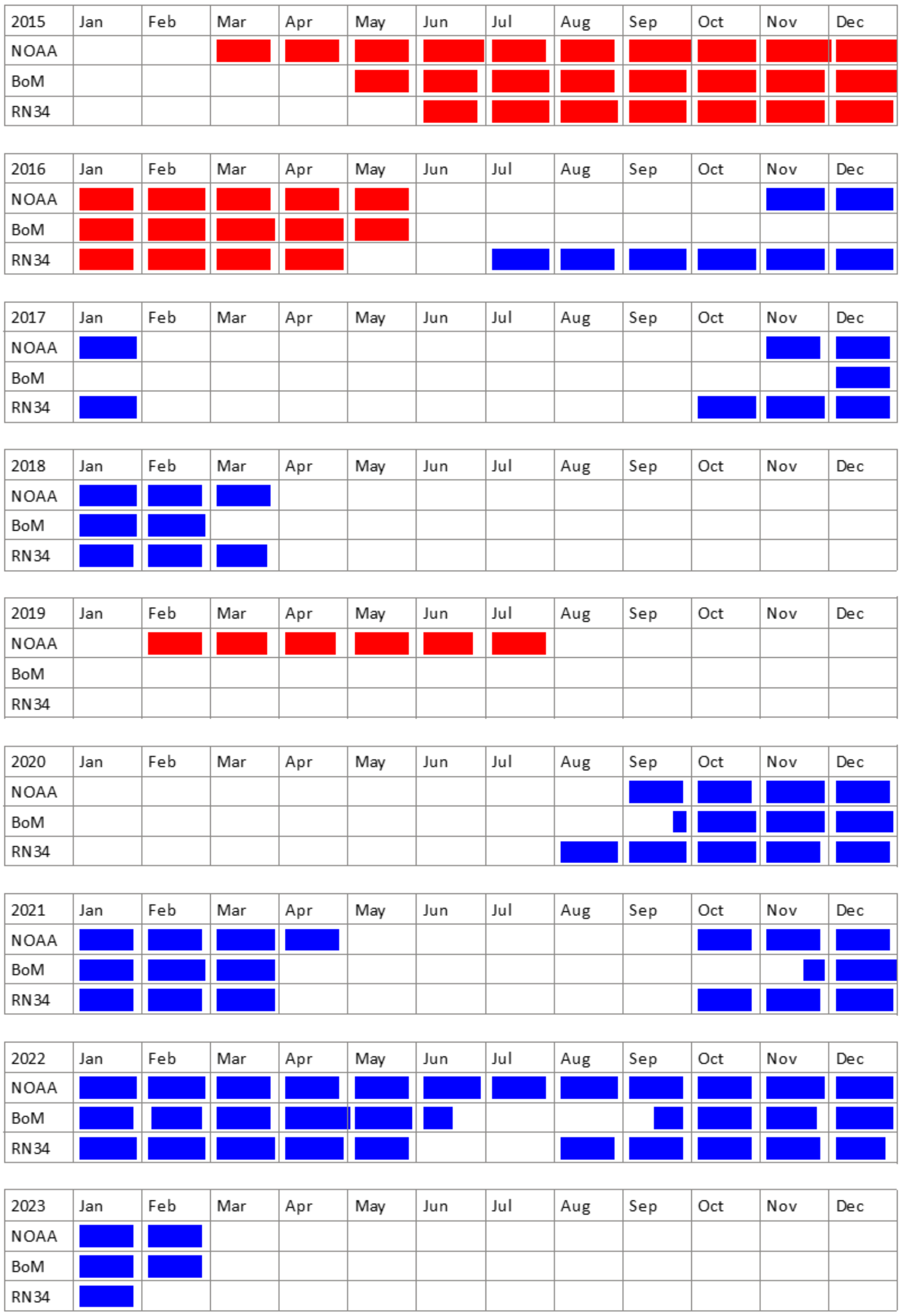

Figure 7. Status of ENSO declaration based on discussion from the NOAA ENSO Blog (https://www.climate.gov/news-features/blogs/enso), the BoM archive of bi-weekly ENSO/IOD updates (http://www.bom.gov.au/climate/model-summary/index.shtml#region=NINO34) and the definition of ENSO strictly based on the RN34 temperature thresholds (i.e. magnitude of RN34 > 0.8 K). Coloured blocks indicate ENSO declaration (red= El Niño, blue= La Niña)

The period of 2018 and 2019 is also interesting. The Bureau was anticipating a return to El Niño conditions, moving to an El Niño ALERT in June 2018 and a El Niño WATCH in October 2018. However, a fully-fledged El Niño did not manifest. In early-December 2018, the Bureau output suggested that the SSTs had exceeded the El Niño threshold, as is apparent in Figure 6, but that the atmosphere had not responded; NOAA noted the same in their November 2018 briefing. The Bureau lowered their status back to El Niño ALERT in late-January. Unlike the raw Nino34 index, the RN34 never crossed the +0.8 °C threshold during 2018 and would have enabled a clearer set of messages to be conveyed about the ENSO status at the time.

Similarly, during February 2019, NOAA declared that El Niño had begun (Figure 6), although it was weak. The Bureau moved to an El Niño ALERT status in mid-March, as the N34 SST returned to being just above +0.8 °C, although no atmospheric response was noted in the April BoM updates. The BoM decreased to El Niño WATCH in mid-March and discontinued the El Niño WATCH in late June; NOAA maintained its El Niño status until August 2019. Later, there was a resurgence of warm SST from October 2019 into early 2020, as N34 values approached and even exceeded the NOAA threshold. However, there were no further declarations for the year. RN34 is clearer in its distinction, again falling just shy of BoM's +0.8 °C threshold in March 2019, but decreasing quickly so that by April 2019, it was below NOAA's threshold of +0.5 °C. There is no significant resurgence of RN34 later in the year. Maps of SST indicate that while there were warm anomalies in the central Pacific during this period, they were often shifted to the west of the Niño 3.4 region, and removed from the Eastern Pacific region that was often neutral or cooler than normal. Furthermore, there were significant warm anomalies often displaced from the equator in the tropical Pacific and Indian oceans. The canonical El Niño pattern was not observed.

In all these operational comparisons since 2015, the RN34 would have performed better for indicating the true state of ENSO than the N34 index.

3.4. Other factors: ENSO Modoki

Complexity is added to the issue of 2018-20 ENSO status by the occurrence of ENSO Modoki, a central Pacific variant of ENSO with different teleconnections and impacts (Ashok et al. 2007). Neither the Bureau nor NOAA officially monitor the status of ENSO Modoki. The standard index (i.e., EMI, or ENSO Modoki Index) used to identify it is presented in Figure 8; note that this index does not require temperature adjustment as it is the difference between several areas. The index clearly shows an extended positive peak in 2018 and 2019, well above the thresholds of 0.5 °C required for the declaration of ENSO Modoki and considerably stronger than the N34 based indices. Wang and Cai (2020) discuss the evolution of this event in more detail. Nguyen et al. (2021) describes the role of EMI and other climate drivers in producing the significant high-impact climate events in late-2019/early-2020. While the values of N34 (and RN34) typically used to monitor these events are weak, the EMI suggests that a significant event occurred across 2018-2020, coinciding with the severe drought and fire activity in eastern Australia. This is more consistent with the unusual SST patterns noted in the previous section.

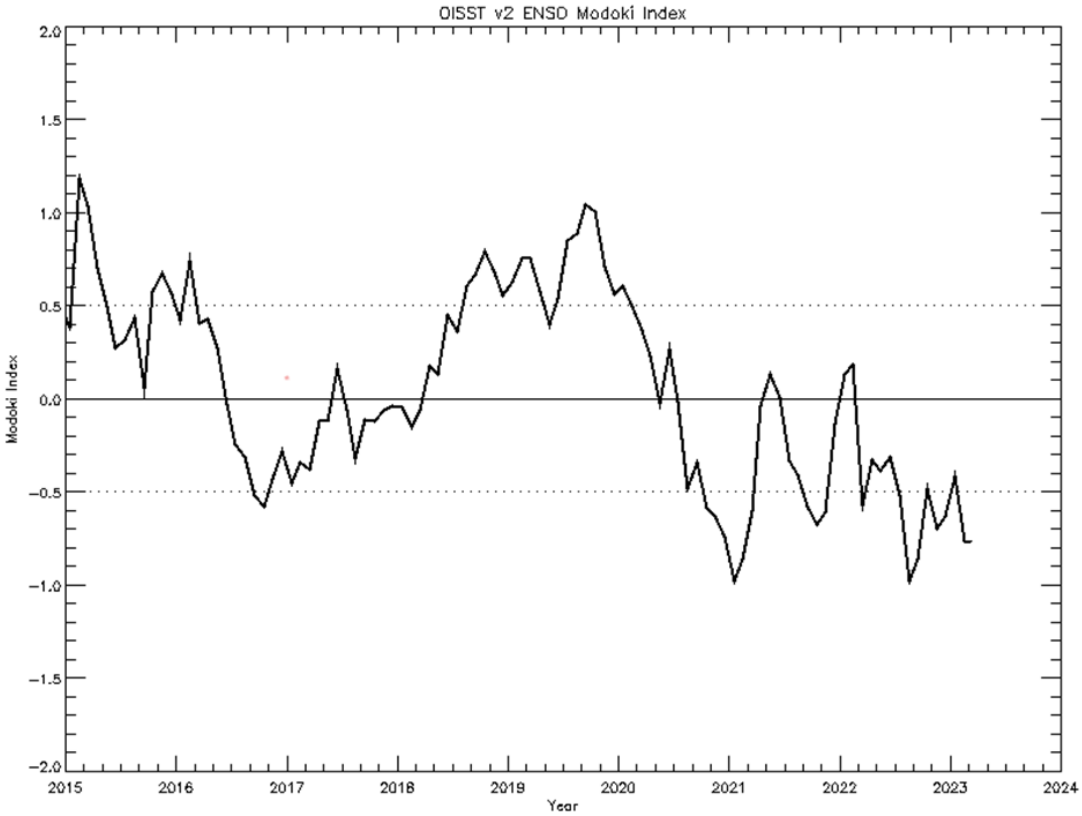

Figure 8. Monthly ENSO Modoki Index (EMI) from 2015 to 2023 from the OISST. Thresholds for EN/LN Modoki at ±0.5 are shown.

4. Summary and Conclusions

This document proposes changes to the Bureau's ENSO Alert/Outlook System that helps to better detect ENSO events as they occur in real time. The first is to update the baseline climatology period for computing SST anomalies to the years 1991-2020, a change from the current 1961-1990, across both observations and where practical all forecast products. This climatology should be updated *at least* every 10 years into the future to reflect changing climate conditions in the global oceans; this step will ameliorate the effects of any long-term trends. While this a necessary step, it will still always be 'out of date' as the climatological SST will be behind the changing climate because of the continuous and ongoing warming.

In addition the Bureau should adopt the use of the Relative Niño3.4 index (RN34), as described by van Oldenborgh et al. (2021). This approach removes tropical mean SST anomalies, broadly eliminating the global warming signal and focussing on the purely ENSO-related component. As shown in van Oldenborgh et al. (2021) and also in the results here, it provides a better discrimination of ENSO-related activity.

With RN34 replacing N34 in routine monitoring and the ENSO Alert System there is the opportunity to further review the components that are inputs into this system. These aspects are not considered here, though we note a preference for simpler methods to be used.

While RN34 improves the situation, the index really only captures one aspect of ENSO phenomena, namely the so-called canonical response. Over the last 15-20 years, a distinct Central Pacific flavour of ENSO has been identified, the so-called Modoki variant. Different indices have been developed to measure the Modoki variant, as well as comprehensive Empirical Orthogonal Function (EOF) approaches. In the future, the Bureau (and other agencies) responsible for issuing ENSO advice might consider also adopting these more complete methodologies to fully warn of the potential impacts of ENSO events.

5. References

Ashok K, Behera SK, Rao SA, et al (2007) El Niño Modoki and its possible teleconnection. J Geophys Res Ocean 112:1–27. https://doi.org/10.1029/2006JC003798

Bamston AG, Chelliah M, Goldenberg SB (1997) Documentation of a highly enso-related sst region in the equatorial pacific: Research note. Atmos - Ocean 35:367–383. https://doi.org/10.1080/07055900.1997.9649597

Gamble F, Beard G, Watkins A, et al (2017) Tracking the El Niño-Southern Oscillation in real-time: a staged communication approach to event onset. J South Hemisph Earth Syst Sci 67:64–78. https://doi.org/10.22499/3.6702.001

Izumo T, Vialard J, Lengaigne M, Suresh I (2020) Relevance of Relative Sea Surface Temperature for Tropical Rainfall Interannual Variability. Geophys Res Lett 47:. https://doi.org/10.1029/2019GL086182

L'Heureux ML, Tippett MK, Wheeler MC, et al (2023) A Relative SST Index for Classifying ENSO Events In a Changing Climate. j Clim

Lee S, L'Heureux M, Wittenberg AT, et al (2022) On the future zonal contrasts of equatorial Pacific climate: Perspectives from Observations, Simulations, and Theories. npj Clim Atmos Sci 5:. https://doi.org/10.1038/s41612-022-00301-2

Lindsey R, L'Heureux ML, Halper M, Blunden J (2013) In Watching for El Niño and La Niña, NOAA Adapts to Global Warming. In: climate.gov. https://www.climate.gov/news-features/understanding-climate/watching-el-niño-and-la-niña-noaa-adapts-global-warming. Accessed 2 Jun 2023

Nguyen H, Lucas C, Wheeler M, Watkins A (2022) Summary of a workshop on ENSO / IOD alert systems for a warming world held 16-17 August 2022. Bur Res Rep No 072

Nguyen H, Wheeler MC, Hendon HH, et al (2021) The 2019 flash droughts in subtropical eastern Australia and their association with large-scale climate drivers. Weather Clim Extrem 32:100321. https://doi.org/10.1016/j.wace.2021.100321

Philander SGH (1990) El Nino, La Nina, and the southern oscillation. Academic Press, San Diego, CA

Risbey JS, Pook MJ, McIntosh PC, et al (2009) On the Remote Drivers of Rainfall Variability in Australia. Mon Weather Rev 137:3233–3253. https://doi.org/10.1175/2009MWR2861.1

Sterl A, van Oldenborgh GJ, Hazeleger W, Burgers G (2007) On the robustness of ENSO teleconnections. Clim Dyn 29:469–485. https://doi.org/10.1007/s00382-007-0251-z

van Oldenborgh GJ, Hendon H, Stockdale T, et al (2021) Defining El Niño indices in a warming climate. Environ Res Lett 16:044003. https://doi.org/10.1088/1748-9326/abe9ed

Wang G, Cai W (2020) Two-year consecutive concurrences of positive Indian Ocean Dipole and Central Pacific El Niño preconditioned the 2019/2020 Australian “black summer” bushfires. Geosci Lett 7:. https://doi.org/10.1186/s40562-020-00168-2