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The response to ENSO under global warming

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Abstract: This investigation explores the impact of global warming on the El Niño-Southern Oscillation (ENSO), a pivotal climatic phenomenon with far-reaching consequences for worldwide weather patterns and ecosystems. In the context of ongoing endeavors to mitigate climate change, comprehending ENSO's response assumes a position of utmost significance. Current research suggests that the amplitudes of ENSO events may intensify in response to elevated temperatures, linked to non-linear increments in atmospheric water vapor. Furthermore, careful analysis reveals an augmented variability in sea surface temperature (SST) fluctuations during the 21st century compared to prior periods. The research also sheds light on the concurrent existence and interactions of Eastern Pacific (EP) and Central Pacific (CP) ENSO variations in the context of a warming climate. Ongoing investigations are committed to unraveling the intricacies of these phenomena and their implications for future climatic patterns. Nevertheless, uncertainties persist regarding the drivers of CP-type ENSO and heightened amplitudes, with some attributing these changes to global warming while others associate them with multidecadal rhythms.

Keywords: ENSO, Global Warming, Amplitude, Diversity.

1. Introduction

In recent decades, Earth has undergone rapid and transient climate change, marked by significant global warming that has deeply affected various facets of our environment. These changes have had widespread repercussions on weather patterns, climate dynamics, ecosystems, societal well-being, and economic stability (IPCC, 2019). To mitigate these impacts, a range of strategies has been implemented, from land and ocean-based CO2 drawdown methods to carbon capture and storage. The Paris Agreement of 2016 stands as a landmark policy effort aimed at preserving a reasonable chance of limiting global warming to well below 2 degrees [1].

A common misunderstanding, prevalent in public discourse, is the assumption that stabilizing atmospheric composition would also stabilize global mean temperatures. An illustrative case is provided by the Hadley Centre model, which simulates a decline in Pacific zonal sea surface temperature gradients and leads to a rapid die-back of the Amazon Forest by the mid-21st century. This ecological collapse triggers a nonlinear rise in atmospheric CO2, further accelerating global warming [2].

Among Earth's climate phenomena, the El Niño-Southern Oscillation (ENSO) is of paramount importance [3]. Originating in the Tropical Pacific, ENSO wields a dominant interannual influence on global climate. It exerts profound effects on both the climate and ecology of the Tropical Pacific and beyond. For example, El Niño events often lead to droughts and forest fires due to an eastward shift in

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convection, while La Niña events tend to cause heavy rains and flooding. These broad-reaching effects position ENSO as a key component in the Earth's response to anthropogenic warming.

This essay focuses on the potential changes in ENSO dynamics under greenhouse warming, specifically the eastward shift and intensification of ENSO-related atmospheric teleconnections, such as the Pacific-South American patterns. Over the years, the Coupled Model Intercomparison Project (CMIP) has evolved from its first phase to the current sixth phase (CMIP6). The projections from these models align closely with observed temperature increases over land and present a spatial congruency between projections and observations [4]. This suggests that CMIP models might be slightly conservative in their future warming projections up to the year 2020. However, these models face challenges in accurately capturing long-term trends, particularly due to their sensitivity to internal variability over timescales of 20 years or less.

2. ENSO

2.1. Definition

The El Niño-Southern Oscillation (ENSO) stands as a paramount internal climate fluctuation on an interannual temporal scale [5]. It is imperative to acknowledge that, within the scientific community, there exists no universally ratified characterization for an "El Niño" phenomenon. Nevertheless, a widely embraced criterion posits that an El Niño event may be deemed to have transpired when the 5-month moving average of sea surface temperature anomalies, situated within the Nino 3.4 region (extending from 5°N to 5°S and from 120°W to 170°W), surpasses the threshold of 0.4°C for an uninterrupted duration of at least six consecutive months (Trenberth, National Center for Atmospheric Research, Boulder, Colorado) [6]. In alignment with this established criterion, it can be asserted that El Niño occurrences manifest approximately 31% of the time, while concomitant to this, La Niña events, defined in a comparable fashion, materialize approximately 23% of the time.

The terminology and understanding of what constitutes an El Niño event have evolved over time, making it a challenging phenomenon to define precisely. Numerous researchers, from Quinn et al. (1978) and Glantz and Thomson (1981) to Glantz (1996), have highlighted the varying historical interpretations of the term. Glantz (1996) eventually proposed a definition for El Niño that aimed for clarity and consistency suitable for dictionary inclusion.

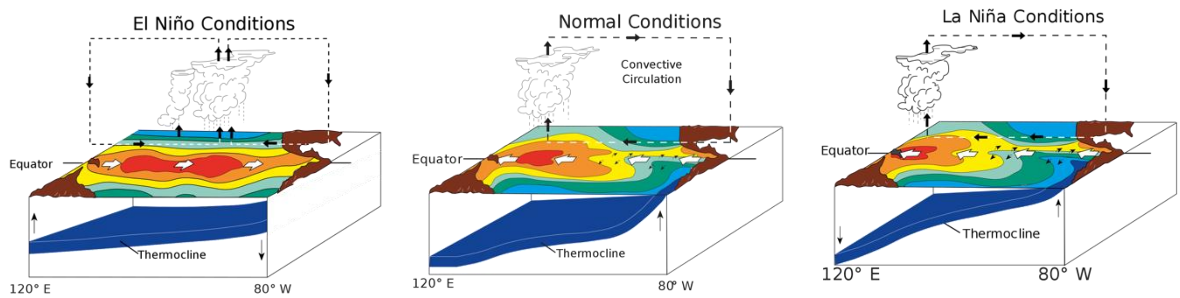

Figure 1. The Walker Circulation is a tropical Pacific atmospheric pattern moving warm, moist air westward, causing rainfall in the western Pacific and dryness in the east. El Niño, a warming of the Pacific, disrupts global climate. La Niña, its counterpart, features cooler waters and distinct climate impacts [7].

2.2. El Nino and La Niña

ENSO exhibits irregular fluctuations between cold (La Niña) and warm (El Niño) conditions in the eastern and central equatorial Pacific, occurring on a timescale of 2 to 7 years. Initially, the term "El Niño" referred to an annual, relatively weak warm ocean current that flowed southward along the coasts of Peru and Ecuador around Christmastime. However, in contemporary understanding, this term has come to signify a much broader anomalous warming of the ocean that extends to the international date

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line, accompanied by global climatic disruptions. The atmospheric element associated with El Niño is called the “Southern Oscillation.”

Conversely, “La Niña,” which translates to “the girl” in Spanish, is defined as an event characterized by the cooling of the tropical Pacific and represents the cold phase of the ENSO cycle. For public understanding and scientific discourse, the overarching term for this complex interplay of oceanic and atmospheric conditions is “ENSO.”

2.3. EP- and CP-type

Two distinct categories of ENSO occurrences, specifically Eastern Pacific El Niño and Central Pacific El Niño, are subjected to scrutiny through an examination of their Pattern Correlation Coefficients (PCCs) concerning monthly sea surface temperature (SST) anomalies within the tropical expanse of the Pacific Ocean [8].In the context of two distinct Shared Socioeconomic Pathway (SSP) scenarios, SSP2-4.5 and SSP5-8.5, ensemble models present projections that indicate a potential decrease in the overall frequency of El Niño events by approximately 26% and 16%, respectively, in relation to historical occurrences and future predictions [9].

Furthermore, this analysis posits that the recent upswing in the incidence of Central Pacific El Niño events may find its origins in multidecadal fluctuations rather than being ascribed solely to anthropogenic global warming.

El differentiations of El Niño phenomena are commonly classified into three categories: (EP (Eastern Pacific type), CP (Central Pacific type), or Mix (mixed type), with undiagnosed cases indicated by a dash [10]. Diverse methodologies are employed to facilitate this categorization, encompassing the Pattern Correlation approach (referred to as the PTN method) and the El Niño Modoki Index (known as EMI). Additionally, certain investigations make use of indices such as the cold tongue and warm pool (CP/EP) for classification purposes.

According to Table 1, there has been a notable increase in the number of Central Pacific El Niño events over the last two decades, with six Central Pacific events diagnosed compared to just three Eastern Pacific events. This trend aligns with the findings of previous research, which also indicates that Central Pacific El Niño events have become more frequent in recent years.

Table 1. Type of EI Nion events determined in the present study and previous studies [12].

	Type							
		Yu and Kim (2013) (1951--2010)						
El Niho years	Present study (1951-2020)	PTN	Nion	EMI	CT/WP	Jeong and Ahn (2017) (1982-2014)	Paek et al. (2017) (1961-2016)	Shi et al. (2020) (1965-2016)
1951-1952	EP	Mix	EP	EP	EP			
1953-1954	Mix	Mix	EP	CP	CP			
1957-1958	EP	CP	EP	CP	EP			
1963-1964	EP	CP	EP	CP	EP		-	
1965-1966	EP	CP	EP	CP	EP		CP	EP
1966-1967	CP	-	-	-	-		-	CP

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Table 1. (continued).

1967-1968	CP	-	-	-	-		-	CP
1968-1969	-	CP	CP	CP	CP		CP	-
1969-1970	-	CP	EP	EP	EP		Mix	EP
1972-1973	EP	Mix	EP	EP	EP		EP	EP
1976-1977	EP	Mix	EP	EP	EP		EP	EP
1977-1978	-	CP	CP	CP	CP		CP	CP
1982-1983	EP	EP	EP	EP	EP	Mix	EP	EP
1986-1987	Mix	Mix	EP	EP	EP	-	Mix	CP
1987-1988	-	CP	EP	EP	CP	-	-	-
1990-1991	CP	-	-	-	-	CP	-	CP
1991-1992	EP	CP	EP	EP	EP	EP	CP	CP
1993-1994	Mix	-	-	-	-	-	-	-
1994-1995	CP	CP	CP	CP	CP	CP	CP	CP
1997-1998	EP	EP	EP	EP	EP	EP	EP	EP
2001-2002	CP	-	-	-	-	-	-	-
2002-2003	CP	CP	EP	CP	CP		CP	CP
2004-2005	CP	CP	CP	CP	CP	CP	CP	CP
2006-2007	EP	Mix	EP	EP	EP	EP	Mix	-
2009-2010	EP	CP	CP	CP	EP	CP	EP	-
2014-2015	CP						-	-
2015-2016	EP						Mix	EP
2017-2018	CP							
2019-2020	CP							

3. Response

3.1. Amplitude

In the context of global warming, the potential impact on ENSO is a subject of significant concern, particularly the possibility of an amplified ENSO amplitude. This amplification is theoretically rooted in the planet's warming conditions, which can lead to more pronounced climate fluctuations. One key mechanism behind this involves the nonlinear increase in atmospheric water vapor content as global temperatures rise, thereby enhancing feedback loops that are crucial to ENSO dynamics. Observations in recent years have indeed pointed to changes in ENSO amplitude that align with these expectations. This relationship highlights the complex interaction between various climate drivers and ENSO behavior in a warming world, marking it as a critical area of research for understanding future climate changes.

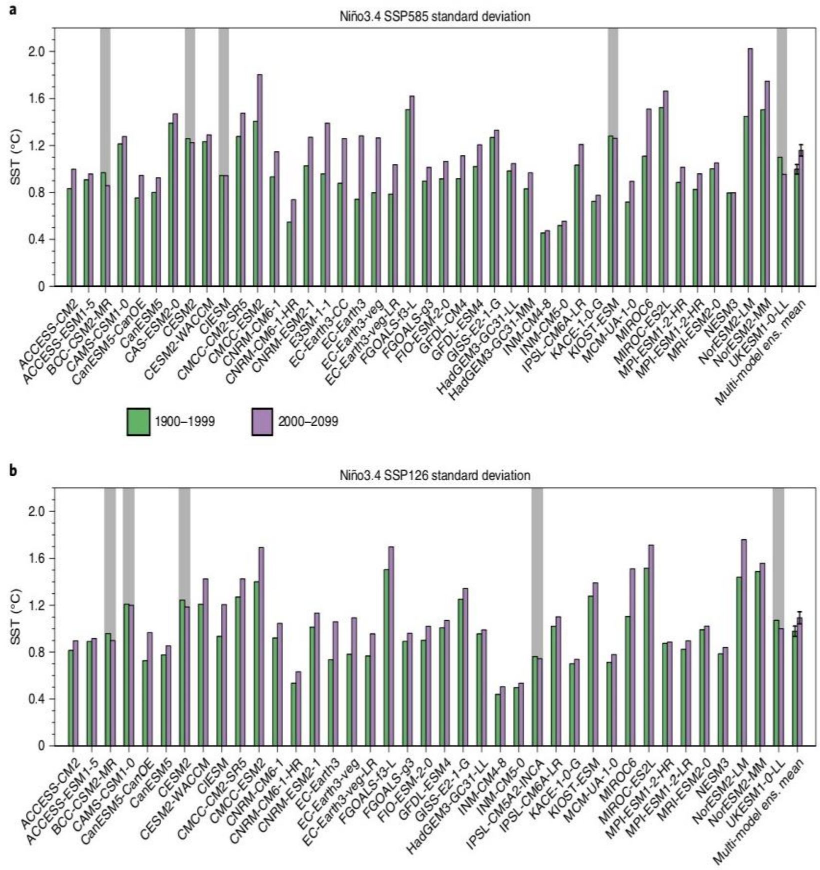

Figure 2. An inter-model consensus on increased ENSO SST variability [11].

A broad consensus among climate models highlights an increase in the variability of sea surface temperatures (SST) associated with ENSO. Specifically, for the SSP585 and SSP126 scenarios, 43 CMIP6 models for SSP585 and 39 for SSP126 provide insights into the standard deviation of ENSO Niño3.4 SST. A significant majority of these models—88.4% under the SSP585 scenario and 87.2% under the SSP126 scenario—predict an escalation in ENSO variability throughout the 21st century (2000–2099) when compared to the 20th century (1900–1999). It's worth noting that models shaded in gray do not corroborate this upward trend. Additionally, the multi-model ensemble mean substantiates this projected increase, backed by statistically significant differences as confirmed through Bootstrap test-derived error bars [11].

3.2. *Diversity*

The inherent variability of sea surface temperatures (SST) in the El Niño-Southern Oscillation ENSO plays a crucial role in its global impacts. However, predicting its future behavior continues to be a complex scientific challenge. While the Intergovernmental Panel on Climate Change (IPCC) suggests that ENSO SST variability may remain consistent across different emission scenarios, a noticeable increase is evident when comparing the 20th and 21st centuries [11].

This upward trend is particularly pronounced in the four reputable emission scenarios outlined by the IPCC.

A consensus among CMIP6 models further supports the notion of increased ENSO SST variability in the 21st century across all four Shared Socioeconomic Pathway (SSP) scenarios [11]. This agreement is based on analyses that contrast century-long periods of SST variability between the two eras [12]. Examining these extended timescales helps to minimize the effects of internal variability, thereby enhancing the detection of signals induced by greenhouse gases. The improved representation of ENSO processes in CMIP6 models, including nonlinear feedback mechanisms, reinforces this consensus. It underscores the importance of ongoing model refinement to generate more reliable future forecasts [13]. Notably, the consensus also highlights an anticipated increase in ENSO SST variability and associated rainfall fluctuations, especially in scenarios that involve aggressive climate mitigation strategies.

4. Conclusions and Discussion

In summary, ENSO is a pivotal climate phenomenon whose reactions to global warming have significant implications. Characterized by its alternating El Niño and La Niña phases, ENSO is at the core of interannual climate variability. The oscillation between these warm and cold phases, reminiscent of the ocean's ebb and flow, has far-reaching effects on global weather patterns, ecosystems, and societies. Advanced climate models have further revealed two distinct types of ENSO: the Eastern Pacific (EP) and the Central Pacific (CP) types [2].

In the final analysis, data from the last two decades indicate that ENSO's amplitude has intensified [11]. Additionally, sea surface temperature (SST) variability and the frequency of Central Pacific-type El Niño events may increase in response to climate warming. However, there is some uncertainty surrounding the underlying reasons for the uptick in Central Pacific-type ENSO events and the strengthened amplitude of the phenomenon. Some theories suggest that this could be attributed to the multidecadal variability of ENSO rather than solely to climate change. As a result, ongoing research is essential to fully understand the implications of these changes for future climate patterns.

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