

Seasonal Pulsation Connections in Southern Oceanic Oscillations

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How to cite this paper: Hagen, M. and Azevedo, A. (2026) Seasonal Pulsation Connections in Southern Oceanic Oscillations. *Open Journal of Marine Science*, 16, 111-128.

<https://doi.org/10.4236/ojms.2026.163007>

Received: May 8, 2026

Accepted: July 10, 2026

Published: July 13, 2026

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Abstract

The focus of this study is on significant, interconnected climate patterns that shape worldwide weather, sea temperatures, and atmospheric circulation. Here, the Sun-Earth interaction is the variation in Earth's position as the seasons change. A seesaw pattern in the sea surface temperatures of the Indian Ocean characterizes the Indian Ocean Dipole (IOD). The system cycles through positive and negative phases, characterized by distinct temperature distributions in the west and east. The El Niño-Southern Oscillation (ENSO), a significant recurring climate cycle in the tropical Pacific, influences global weather patterns and impacts Brazil's temperature and rainfall. The Antarctic Oscillation describes the north-south shift of the powerful westerly winds surrounding Antarctica. The tightening winds that move closer to Antarctica during the positive phase help maintain storms at more southerly latitudes. The equatorward shift of winds in a negative phase leads to an increase in cold fronts and storms reaching mid-latitudes.

Keywords

Ocean Oscillations, Earth's Environment, Climate Changes

1. Introduction

The scientific community has downplayed the oceans' crucial role. Despite this, our knowledge of the oceans remains limited, as many factors are prone to change due to solar cycles, seasonal variations, and other external phenomena. This introductory conversation is designed to meticulously outline and describe a diverse range of considerations, including aspects specific to oceanic environments and related to them, to scrutinize their consequential effects on Earth's climate.

New research indicates that the shape of the ocean floor can account for up to

half of the variation in long-term carbon storage. With its influence on climate, erosion, rainfall, and weather, the Ocean blankets 71% of our planet's surface. The Coriolis effect governs current directions, creating spirals such as the Ekman spiral that influence vertical mixing and nutrient distribution. Gyres also distribute global heat, influencing climate, weather, and landforms. These processes alter seabed topography and influence marine life and ecosystems.

As a fundamental and indispensable part of the planet's intricate system, the Ocean actively absorbs excess heat, thereby significantly mitigating the accelerated warming driven by rising global temperatures. Since 2020, a new record was set for the highest combined global and Ocean surface temperatures ever recorded, surpassing all previous data collected since systematic global temperature tracking began in 1880, according to the annual Global Climate Report compiled by the National Centers for Environmental Information (NCEI).

The most reliable way to quantify the amount of heat the Ocean contains is to use *in situ* ocean temperature profiles, meaning collecting data right where the phenomenon occurs. From the 1950s to the present, increased geographic coverage of temperature measurements has enabled scientists to estimate upper-ocean heat content on annual and seasonal timescales.

Changes in ocean heat content are determined by comparing current *in situ* ocean temperatures with long-term averages from the surface to a depth of 2000 meters. The geographic distribution and density of temperature measurements largely determine the uncertainty associated with the ocean heat content calculation. The uncertainty in the calculated ocean heat content will be larger for monthly time periods than for longer periods, given the distribution of data. The actual monitoring of several parts of the Ocean that are attributable to climate change. They are: North Atlantic Oscillation (NAO), Pacific-North American Pattern (PNA), in the Northern Hemisphere. El Niño Southern Oscillation (ENSO), Antarctic Oscillation (AAO), and Indian Ocean Dipole (IOD) in the Southern Hemisphere. Those variables disrupted the weather and climate across different regions of the planet. They mostly depend on the seasons and solar variations [1]-[3]. This report is part of a project involving all the events in the Oceans, given the complex system of currents and their implications worldwide. We divide the data into two parts: the Southern and the Northern Hemisphere [4]. We first studied the Southern Hemisphere, since the phenomenon known as the El Niño Southern Oscillation occurs there.

Given the profound complexity of Earth's oceans, it is conceivable that a strategic approach would involve delineating distinct regions and conducting separate detailed studies of their unique characteristics.

- Associated with the northwest Pacific—ENSO.
- Associated with the Indian Ocean—IOD.
- Antarctica Ocean Oscillation—AAO.

These three oceanic zones each boast distinct features, with their conditions notably influenced by various external factors, chief among them the predictable

rhythm of the seasons. Ocean variables such as temperature, circulation, salinity, and chemical composition play a critical role in regulating the global climate by storing and distributing heat, carbon, and water.

Ocean currents, functioning as a vast conveyor belt, transport warmer waters from the equatorial regions toward the polar regions while simultaneously facilitating the return flow of frigid water back to the tropics. This regulation of regional climates results in areas such as Western Europe experiencing warmer temperatures than other locations at equivalent latitudes.

The Ocean absorbs significant amounts of CO₂, but this has increased acidity, harming marine ecosystems such as corals and potentially reducing the Ocean's future capacity to absorb carbon. Arctic and Antarctic sea ice regulates heat exchange between the Ocean and the atmosphere, and its high reflectivity (albedo) helps keep the polar regions cool. Its decline allows more sunlight to be absorbed by the dark Ocean, accelerating warming. In this paper, we are going to consider the three Southern Oscillations, as ENSO, IOD, and AAO, and the entire data system to analyze the possible evolution of each oscillation in different temporal cycles and compare them to investigate how they are possibly changing the world-wide climate.

2. El Niño Southern Oscillation (ENSO)

ENSO (El Niño-Southern Oscillation) is located in the equatorial Pacific Ocean, stretching from the coast of South America (near Peru and Ecuador) westward to Indonesia and Australia. It operates through a dynamic “seesaw” interaction between ocean temperatures and atmospheric pressure. The system operates in three distinct phases, powered by the strength of the trade winds (winds blowing east to west across the Equator):

Neutral Phase: Trade winds push warm surface water toward the western Pacific (Indonesia), allowing cold, nutrient-rich water to well up from the deep Ocean off the coast of Peru.

Warm Phase: Trade winds weaken or reverse. Warm surface water sloshes back toward the central and eastern Pacific, suppressing upwelling off South America. Rainstorms follow the warm water, causing droughts in Indonesia/Australia and heavy rainfall in the eastern Pacific.

The Cool Phase: Trade winds become unusually strong. This blows more warm water into the western Pacific and causes severe upwelling of cold water in the eastern Pacific. Because of the Pacific's vast size, these temperature and wind shifts trigger a ripple effect on global weather patterns. The data used in this study come from the NOAA catalog, covering the period from 1950 to 2025.

The Southern Oscillation describes changes in air pressure patterns in the Southern Pacific Ocean between Tahiti, in the middle of the Southern Pacific, and Darwin, Australia, to the west. Normally, lower pressure over Darwin and higher pressure over Tahiti encourage east-to-west airflow. This, in turn, drives the westward movement of warm surface water, creating an ocean circulation that also

brings cold, deep, nutrient-rich water to the surface in the eastern Pacific along the northwest coast of South America.

During El Niño conditions, however, the average air pressure over Darwin is higher than over Tahiti, slowing these circulations. This change in circulation affects the movement and temperature of air and water across the entire Pacific. As a result, El Niño is associated not only with heavy rain and warmer ocean currents in equatorial South America to the east, but also with severe drought in parts of the western Pacific, such as Australia. The occurrence of warmer-than-normal temperatures in the Eastern Pacific suggests that periods of cooler-than-normal water temperatures can also occur. These cooler periods are called La Niña. By convention, when we hear the name El Niño, it refers to the warm episode of ENSO, while the cool episode of ENSO is called La Niña. ENSO is monitored by looking at pressure differences between Tahiti and Darwin, Australia, using the Southern Oscillation Index (SOI), as well as sea surface temperatures (SST). Sea surface temperatures are monitored in four regions along the Equator:

Niño 1 (80°-90°W - 5°-10°S)

Niño 2 (80°-90°W - 0°-5°S)

Niño 3 (90°-150°W - 5°N-5°S)

Niño 4 (150°-160°E - 5°N-5°S)

These regions were defined in the early 1980s, but subsequent research has led to changes to the original regions. The original Niño 1 and Niño 2 are now combined into a region called Niño 1 + 2. A new region, Niño 3.4 (120° - 150°W and 5°N - 5°S), is also now used. It correlates more closely with the Southern Oscillation Index and is the preferred region for monitoring sea surface temperature.

ENSO causes extreme weather by disrupting atmospheric circulation. El Niño (Warm Phase): Dries Australia, Indonesia, and parts of the Amazon; floods southern US and coastal Peru. Global temperatures often reach their peak at these times. La Niña's cold phase typically brings dry weather to the southern US and wet weather to Australia, Indonesia, and parts of the Amazon. Atlantic hurricane activity decreases with El Niño due to wind shear; Pacific cyclone activity increases. La Niña typically fosters the development of Atlantic hurricanes. ENSO impacts worsen with climate change, leading to severe coral bleaching, heatwaves, and disrupted fisheries [5].

3. Indian Ocean Dipole (IOD)

The Indian Ocean Dipole (IOD) is an irregular oscillation of sea surface temperatures in which the western Indian Ocean becomes alternately warmer (positive phase) and then colder (negative phase) than the eastern part of the Ocean (**Figure 1**).

The IOD involves periodic oscillations in sea-surface temperatures (SST) between “positive”, “neutral”, and “negative” phases. A positive phase is characterized by above-average sea-surface temperatures and increased precipitation in the western Indian Ocean, with a corresponding cooling of waters in the eastern In-

dian Ocean, which tends to cause droughts in adjacent land areas of Indonesia and Australia. The negative phase of the IOD brings about opposite conditions: warmer water and greater precipitation in the eastern Indian Ocean, and cooler, drier conditions in the west. The IOD also affects the strength of the monsoon over the Indian subcontinent. A significant positive IOD occurred in 1997-98 and again in 2006. The IOD is one aspect of the general cycle of global climate, interacting with similar phenomena like the El Niño-Southern Oscillation (ENSO) in the Pacific Ocean. The IOD phenomenon was first identified by Indian climate researchers at the Indian Institute of Science in 1999 [6].

The Indian Ocean Dipole

The IOD phenomenon is the difference in sea-surface temperatures in opposite parts of the Indian Ocean. It can shift moisture away from Australia (positive phase) or towards it (negative phase)

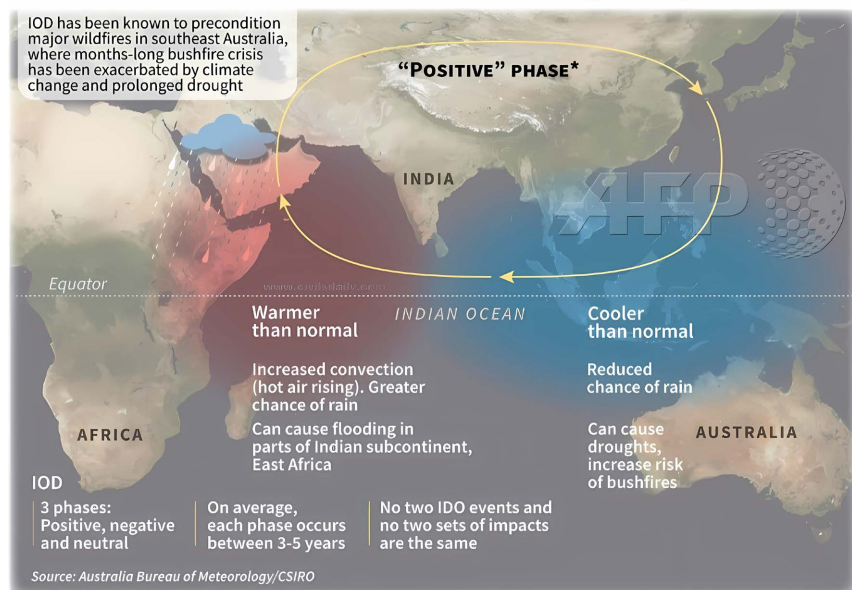


Figure 1. The location and phases of the Indian Ocean Dipole.

An average of four positive-negative IOD events occurs every 30 years, with each event lasting around six months. However, there were 12 positive IODs between 1980 and 2009, and no negative events between 1980 and 1992. The occurrence of consecutive positive IOD events is extremely rare, with only two recorded: 1913-1914 and the three consecutive events from 2006 to 2008, which preceded the Black Saturday bushfires. Modeling suggests that consecutive positive events could be expected to occur twice over the years. The positive IOD in 2007 coincided with La Niña, a very rare phenomenon that has occurred only once in the available historical records (in 1967). A strong negative IOD developed in October 2010, which, coupled with a concurrent strong La Niña, caused the 2010-2011 Queensland floods and the 2011 Victorian floods.

Abram (2008) created a 1846 AD-extending coral Dipole Mode Index using Indian Ocean coral records. This extended perspective on IOD behavior suggested that positive IOD events became stronger and more frequent during the 20th cen-

ture. A positive IOD is associated with droughts in Southeast Asia and Australia. A 2009 study by Ummenhofer *et al.* [7] at the University of New South Wales (UNSW) Climate Change Research Center demonstrated a significant correlation between the IOD and drought in the southern half of Australia, particularly in the southeast. Every major southern drought since 1889 has coincided with positive-neutral IOD fluctuations, including the 1895-1902, 1937-1945, and the 1995-2009 droughts.

The research shows that when the IOD is in its negative phase, with cool waters in the western Indian Ocean and warm waters off northwest Australia (Timor Sea), winds form that pick up moisture from the Ocean and sweep down toward southern Australia, delivering higher rainfall. In the IOD-positive phase, the pattern of ocean temperatures is reversed, weakening the winds and reducing the amount of moisture picked up and transported across Australia. As a result, rainfall in the southeast is well below average during positive IOD events. The study also shows that the IOD has a much more significant effect on rainfall patterns in southeast Australia than the El Niño-Southern Oscillation (ENSO) in the Pacific Ocean, as several recent studies have already shown. A positive IOD is associated with higher-than-average rainfall during the East African Short Rains (EASR) season between October and December. Higher rainfall during the EASR is associated with warm Sea Surface temperatures (SST) in the western Indian Ocean, and low-level westerlies across the equatorial region of the Ocean bring moisture over East Africa. The increased rainfall associated with a positive IOD has been found to lead to increased flooding across East Africa during the EASR period. During a particularly strong positive IOD at the end of 2019, average rainfall across East Africa was 300% above normal. This higher-than-average rainfall has led to widespread flooding in Djibouti, Ethiopia, Kenya, Uganda, Tanzania, Somalia, and South Sudan. Torrential rainfall and an increased risk of landslides across the region during this period often result in widespread destruction and loss of life. It is expected that the Western Indian Ocean will warm rapidly due to climate change, leading to a higher frequency of positive IOD events. This is likely to increase rainfall intensity during the short rain period over East Africa.

A 2018 study by Hameed *et al.* at the University of Aizu [8] simulated the impact of a positive IOD event on Pacific surface winds and SST variations. They showed that IOD-induced surface wind anomalies can produce El Niño-like SST anomalies, with the IOD's impact on SST strongest in the far eastern Pacific. They further demonstrated that the IOD-ENSO interaction is key to the generation of Super El Niños. A positive IOD cycle was linked to multiple cyclones that ravaged East Africa in 2019, killing thousands. The unusually active 2018-2019 Southwest Indian Ocean cyclone season was aided by warmer-than-normal waters offshore (starting with Cyclone Idai and continuing into the subsequent cyclone season). The positive IOD dipole also caused the Australian drought/bushfires, the 2020 Jakarta floods, and the 2019-21 East Africa locust infestation.

Oceanic tides regulate regional climates by mixing cold, deep water with warmer

surface waters, acting as a crucial heat sink that moderates atmospheric temperatures and influences coastal weather patterns. Tides generally exert a stronger cooling effect in Summer, reducing air temperatures over the sea and nearby land. Tides play a significant role in Summer by enhancing the mixing of cold water, which cools the air temperature over the sea and coastal land, potentially reducing summer precipitation by up to 6%. During low tide, the sea surface area contracts, while at high tide, more cool, moist air is exposed, which can create a localized sea breeze that mitigates heat on land. In regions such as the Maritime Continent, tidal mixing is a major driver of colder sea surface temperatures, influencing regional short-term climate patterns. While tides are active year-round, studies indicate that atmospheric sensitivity to tidal influence is higher in Summer than in Winter. Beyond seasonal changes, tidal mixing contributes to the overall stability of the climate by enhancing the Ocean's ability to absorb excess heat from greenhouse gases. Regional mixing (e.g., Maritime Continent): In regions such as the Maritime Continent, tidal mixing is a major driver of colder sea surface temperatures, influencing regional short-term climate patterns.

Tides, driven by the gravitational forces of the Moon and Sun, play a significant, often underappreciated role in regulating global climate and weather systems by driving ocean circulation, facilitating deep-water mixing, and mediating heat distribution. They also amplify the effects of climate change, particularly through increased coastal flooding, accelerated erosion, and impacts on sea ice. Tidal movements generate strong tidal currents and internal waves, which are crucial for driving ocean circulation, including the deep-ocean overturning circulation that transports heat from the Equator to the poles. Tidal energy mixing is essential for maintaining the global Meridional Overturning Circulation (MOC), which transports heat across the globe, thereby reducing climate extremes and regulating temperatures. By strengthening the overturning circulation, enhanced tidal mixing can increase poleward oceanic heat transport, specifically in the Atlantic, Indian, and Pacific Oceans, while weakening it in the Southern Ocean. Research shows that tidal mixing can create cold-water patches in the Ocean (e.g., in the Maritime Continent), which can cool air temperatures over the sea by up to 4°C and over nearby land by up to 4°C during Summer. High tides increase the coastal surface area, exposing more cool, moist air to the land, often enhancing sea breezes and causing a localized cooling effect that influences convection and can initiate or intensify thunderstorms. Extremes in tidal forces (roughly every 9 or 18.6 years) can cause episodic cooling of sea surface temperatures, reflecting a near-decadal, even centennial, tidal cycle that influences global temperature records. Tidal forcing and the resulting mixing in polar regions, such as the Arctic and Southern Ocean, can open leads and enhance upward heat flux from deeper, warmer ocean layers. This enhances summer sea-ice melt and can reduce overall sea-ice concentration. In the Antarctic, tides increase ice-shelf basal melt by influencing the turbulent exchange of heat and salt across the ice-ocean boundary, thereby contributing to sea-level rise. As climate change fuels sea-level rise, the baseline water level for

tides is higher, making “nuisance” or “sunny day” flooding twice as common in the US as it was 20 years ago, and projections indicate this will continue to worsen. Higher tides and sea levels allow tidal forces to reach further inland and higher up the shore, increasing erosion rates and causing greater damage to coastal infrastructure. Tides affect ecosystems by regulating habitat expansion during high tides and exposing areas to drier conditions during low tides. As seas rise, tidal wetlands and marshes may be permanently submerged if they cannot migrate inland. Tidal patterns are acting as a “natural, recurring model of future climate conditions”. By studying the impacts of today’s “King Tides”—the highest tides of the year—scientists can identify future flood-prone locations and predict the consequences of sea-level rise for coastal communities and environments.

4. The Antarctic Oscillation

The Antarctic oscillation (AAO, to distinguish it from the Arctic oscillation or AO), also known as the Southern Annular Mode (SAM), is a low-frequency mode of atmospheric variability of the Southern Hemisphere that is defined as a belt of strong westerly winds or low pressure surrounding Antarctica, which moves north or south as its mode of variability. It is a climate driver in Australia, influencing the country’s weather. It is associated with storms and cold fronts that move from west to east, bringing precipitation to southern Australia. During its negative phase, the westerly wind belt expands towards southeastern Australia. Both positive and negative SAM events typically last for approximately 10 days to 2 weeks, though the interval between a positive and a negative event is random. It usually lasts from a week to a few months, with a negative SAM more common in the cool months and a positive SAM more prolonged in the warmer months. Winds associated with the Southern Annular Mode drive oceanic upwelling of warm circumpolar deep water along the Antarctic continental shelf; a process linked to ice-shelf basal melt and a possible wind-driven mechanism that could stabilize large portions of the Antarctic ice sheet (**Figure 2**).

Positive—In its positive phase, the westerly wind belt that drives the Antarctic Circumpolar Current intensifies and contracts towards Antarctica.[9] In Winter, a positive phase increases rainfall (including East Coast Lows) in southeastern Australia (above Victoria) due to stronger onshore flows from the Pacific Ocean, decreases rainfall in the southwest, and reduces snow in alpine areas. In Spring and Summer, a positive phase reduces the chance of extreme heat and increases onshore humid flows, thereby making Spring and Summer wetter than normal. A positive phase usually occurs more frequently during a La Niña event.

Negative—Its negative phase involves the belt moving towards the Equator, thereby decreasing summer rainfall in southeastern Australia and increasing the likelihood of spring heatwaves. Moreover, winters will usually be wetter than normal in the South and southwest, with more snowfall in the alpine areas, but drier along the eastern coast due to less moisture in onshore flows from the east and the blocking of cold fronts by the Great Dividing Range, which acts as a rain

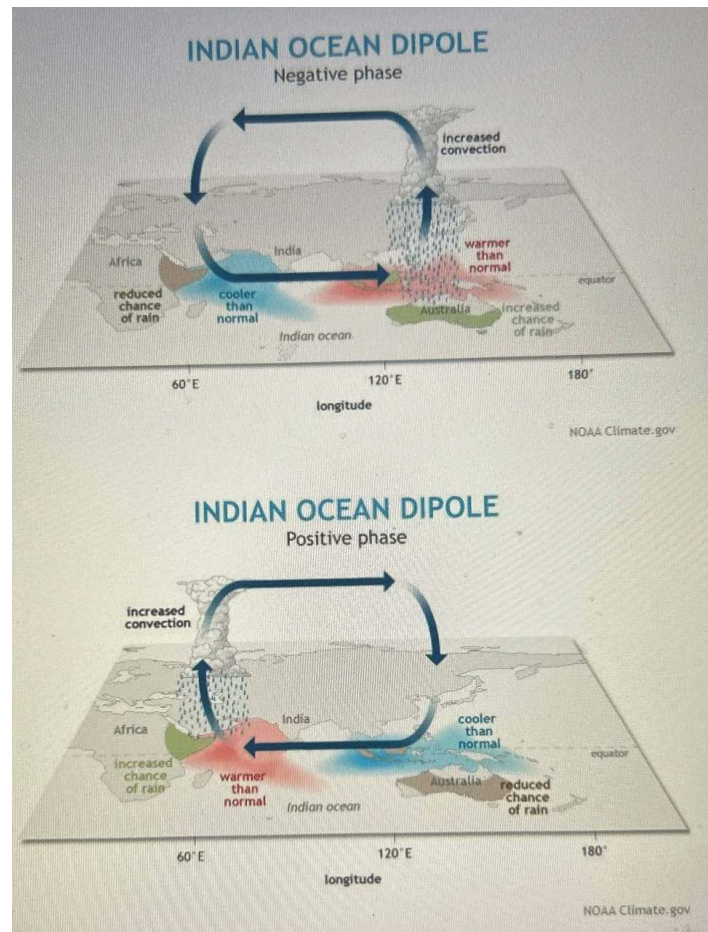


Figure 2. The location and phases of the Indian Dipole Ocean.

shadow. This phase is more frequent during El Niño events. Deep beneath the surface of the Ocean surrounding Antarctica, a channel of cold, dense water known as Antarctic Bottom Water flows northward, playing a crucial role in the global climate system by transporting heat and carbon across the oceans. This water forms one of the key components of the “global ocean conveyor belt,” known to scientists as the Atlantic Meridional Overturning Circulation, which influences weather patterns, sea levels, and heat distribution across the globe. Scientists discovered significant warming and a slowdown in the Antarctic Bottom Water during a comprehensive investigation of ocean observations. The next paragraphs present statistical results from studies using data in three Southern Hemisphere regions: ENSO, IOD, and Antarctica. The global data for the three oscillations are divided by month, and we created tables for each month and for each season. Therefore, as a first step, the influence of Month and Season on the Oscillations is determined, whether it is constant or varies. In this study, we used the NOAA events catalog (see each of them at the end of this paper). For each oscillation, the difference lies in the periods: ENSO has records since 1877; we started the analysis after 1950; the other two events do not have such a timeline; IOD since 1950; and Antarctica’s records began in the early 70’s.

5. Methodology Used to Work with the Data

The data in this paper are based on the NOAA catalogs. A different time range determines each event, season, or month. Some of those events have a longer time range than others, so for ENSO and IOD, the time range is 1950-2025. The results are considered over the twelve months and for the seasons. The seasons in the Southern Hemisphere are opposite to those in the Northern Hemisphere; thus, Dec-Jan-Feb is the Summer, March-April-May is Fall, Jun-Jul-Aug is the Winter, and finally Sep-Oct-Nov is the Spring. The global Ocean is physically a single, interconnected body of water, but it is divided into the North and South Hemispheres primarily by the Equator (0° latitude), and it is mapped based on surrounding continents and specific oceanographic features. The division between the hemispheres is defined by the oceans that span them: the Pacific Ocean, the largest Ocean on Earth, crosses both hemispheres and is officially divided into the North Pacific and South Pacific, split directly by the Equator. The Atlantic Ocean: Similarly, this S-shaped basin is divided into the North and South Atlantic by the equatorial countercurrents and the Equator. The Indian Ocean: Unlike the Pacific and Atlantic Oceans, it is primarily located in the Southern Hemisphere. The Arctic Ocean: Located entirely within the Northern Hemisphere, it covers the polar region and connects to the North Pacific (via the Bering Strait) and the North Atlantic. The Southern (Antarctic) Ocean: Located entirely in the Southern Hemisphere, it encircles Antarctica and is bounded to the north by an arbitrary invisible line established at 60° S latitude. In this paper, oscillations occurring in the Southern Hemisphere are considered; Northern oscillations will be considered in another paper.

6. ENSO Oscillations

The El Niño-Southern Oscillation (ENSO) is an equatorial phenomenon rather than exclusively a Southern Hemisphere event. It is driven by interactions in the tropical Pacific Ocean, stretching across both the Northern and Southern Hemispheres. **Table 1** shows the years when El Niño and La Niña were strong, moderate, or weak since 1950. Fishermen refer to this event as El Niño due to its peak during the Christmas season. The graphical representations of those occurrences suggest that their duration can extend beyond a single year. This pattern is also evident when examining situations involving La Niña and neutral oceanic conditions.

The first ENSO results indicated that positive ENSO variation is higher during the Summer. The lowest occurs in early Spring, in September, as shown in **Figure 3**.

Figure 3 clearly illustrates that the developmental trajectory of events throughout April and May is identical, and this mirrored pattern also corresponds to the events that took place in October. The data gathered here aligns with the Autumn and Spring seasons, with each descriptor referring to the former and latter period, respectively. The highest point for March follows two consecutive months of in-

creases, specifically in January and February, as well as the preceding month, December (**Figure 4**). The highest observed frequency of this phenomenon exceeds that documented in several other months. See **Table 1** for the intensity of El Niño and La Niña in the records.

Table 1. Delineates the occurrences of weak, moderate, and strong El Niño and La Niña events, along with their temporal durations.

El Niño				La Niña		
Weak-12	Moderate-7	Strong-5	Very Strong-3	Weak-10	Moderate-4	Strong-7
1952-53	1951-52	1957-58	1982-83	1945-55	1955-56	1973-74
1953-54	1963-64	1965-66	1997-98	1964-65	1970-71	1975-76
1958-59	1968-69	1972-73	2015-16	1971-72	1995-96	1988-89
1969-70	1986-87	1987-88		1974-75	2011-12	1998-99
1976-77	1994-95	1991-92		1983-84		1999-00
1977-78	2002-03			1984-85		2007-09
1979-80	2009-10			2000-01		2010-11
2004-05				2005-06		
2006-07				2008-09		
2014-15				2016-17		
2018-19				2017-18		
2019-20						

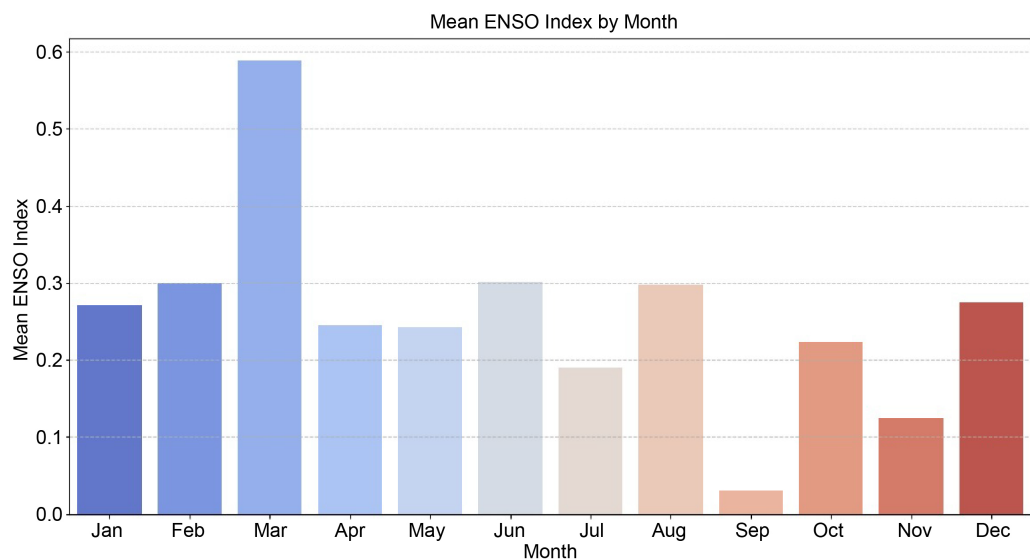


Figure 3. The monthly variation in ENSO events.

The next plot shows the seasonal variation in the Mean ENSO Index to understand how it would be affected by the frequency of the phenomenon in the Southern Pacific region.

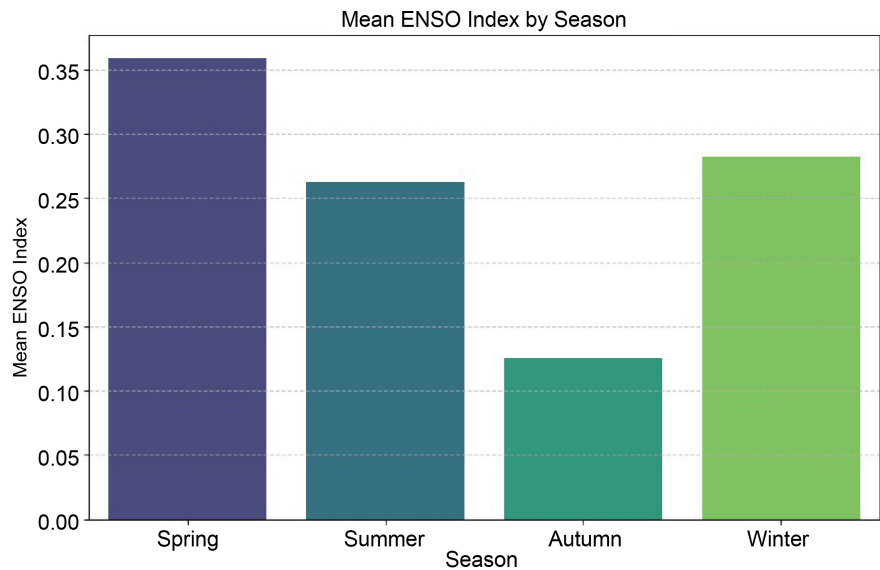


Figure 4. ENSO index by seasons, observing Spring as a maximum and Autumn as a minimum.

The ENSO variations have undergone the most rigorous scientific scrutiny and are considered the principal oscillations that explain prevailing global weather patterns. The same method will be used to calculate temporal variations in the Indian Ocean Dipole and Antarctica.

7. The Indian Ocean Dipole

The Indian Ocean Dipole (IOD) is a naturally occurring, irregular climate pattern characterized by differences in sea-surface temperatures between the western and eastern tropical Indian Ocean. It alternates between three phases—Positive, Negative, and Neutral—which significantly alter rainfall and weather patterns worldwide. The IOD operates in one of three distinct modes, each impacting global weather, such as the Positive IOD (the “Indian Niño”). The westerly winds along the Equator weaken, allowing warmer-than-average water to shift toward the African coast. Off the coast of Sumatra (Indonesia), deep, cool waters rise to the surface. It causes higher rainfall and potential flooding in East Africa, while bringing drought, heat, and severe bushfire conditions to Australia and Southeast Asia.

The equatorial westerly winds intensify, trapping warmer waters near Australia and Indonesia. Meanwhile, cooler-than-average waters emerge near the African coast. Global Impact: It fuels increased moisture and heavier-than-average winter-spring rainfall for southern Australia—neutral IOD. Sea-surface temperatures and winds remain near their long-term averages. Climate patterns remain stable, with minimal abnormal weather directly caused by the IOD. The data presented far more negative events than positive or neutral; therefore, **Figure 5** shows that, on average, the season yielded all negative values, most in Winter, with a maximum in Spring.

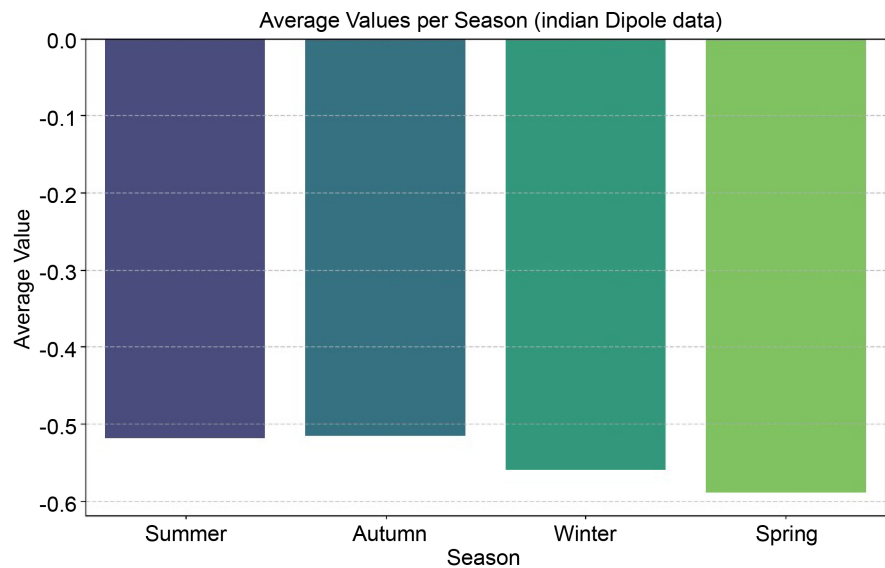


Figure 5. Predominantly negative values across all seasons in the ocean waters of the Indian Dipole region.

The graphical representation in **Figure 6** shows a discernible equilibrium between positive and negative values across the specified regions, particularly during Spring, when positive occurrences are more prevalent than in any other season. During the Autumn and Winter months, there is a notable balance between positive and negative events.

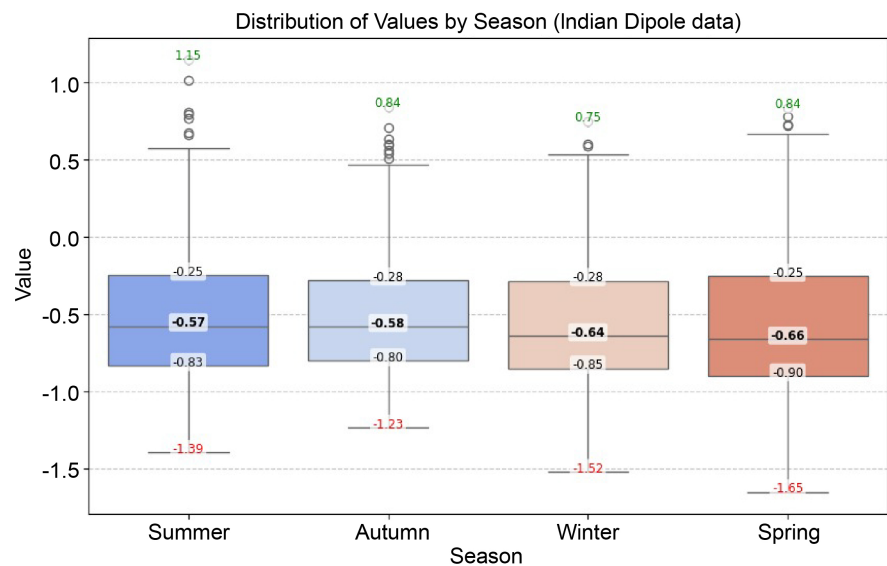


Figure 6. Shows that the largest negative variations occur during Spring, specifically in the interval September-November.

When examining the data, it is evident that the seasons associated with the most significant positive values are Spring and Summer. Analysis of the IOD data revealed that most findings were negative, with these values highest in Winter and

Autumn.

Our last region, Antarctica, yielded seasonal average values that differed from those of the other two regions.

8. The Antarctica Oscillation

The Antarctic Oscillation (AAO)—also known as the Southern Annular Mode (SAM)—is the primary driver of climate in the Southern Hemisphere. It describes the north-south movement of a massive belt of strong westerly winds that circles Antarctica and the corresponding “seesaw” of atmospheric pressure between the mid-latitudes and the polar regions.

The AAO alternates between three distinct phases, which typically last anywhere from a couple of weeks to a few months:

a) **Positive Phase:** The belt of westerly winds contracts and intensifies toward Antarctica. In the mid-latitudes, this results in higher-than-average atmospheric pressure, while lower pressure prevails in the polar zones.

b) **Negative Phase:** The westerly wind belt expands northward. Lower pressure builds over the midlatitudes, while higher pressure builds over Antarctica.

c) **Neutral Phase:** The wind belt stays in its average, middle-ground position.

Because these winds pull weather systems (such as cold fronts and storms) along, the AAO has a massive impact on weather and climate across the Southern Hemisphere. In Australia, a positive phase during Summer increases rainfall in eastern Australia but decreases rainfall in the South and southwest. South America & New Zealand: It drastically alters precipitation patterns and temperatures, guiding storm tracks toward or away from populated coastlines. Antarctica: During a positive phase, strong winds drive upwelling along the continental shelf, bringing warmer deep water to the surface, which affects sea-ice concentration and can cause ice shelves to melt. The AAO has shown a long-term trend toward its positive phase (Figure 7).

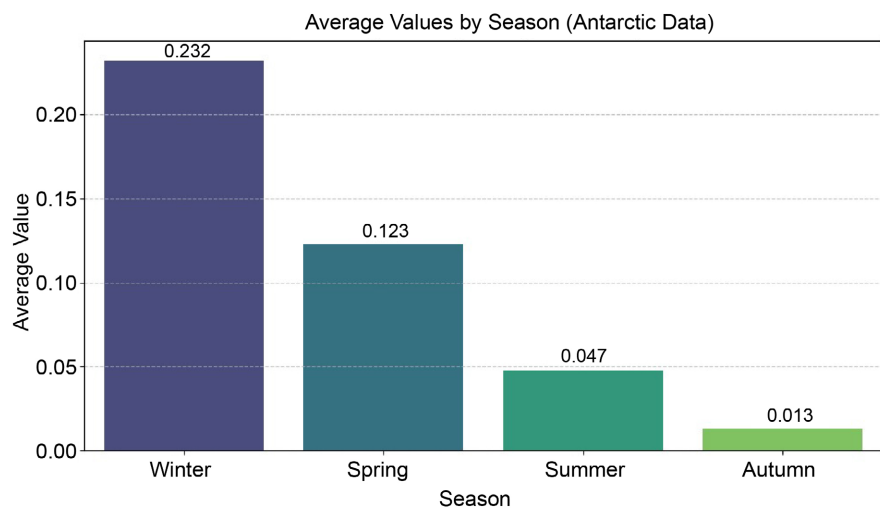


Figure 7. Average numbers by season for the Antarctic Ocean.

The Antarctic oscillation shows a maximum in Winter and a minimum in Autumn. Since the records in the region are shorter than those in the other two regions, it was necessary to keep the analysis brief. Now, it is necessary to compare the three Southern Oscillations and their effects on the seasons. Comparing the results by season, the mean ENSO index showed a maximum in Spring (0.36), followed by Winter (0.26), both positive, and a minimum in Autumn (0.13). The Indian Dipole data showed negative values, with Spring averaging around -0.6 and Winter following. Finally, the Antarctic showed positive values, with a Winter maximum of 0.23, followed by Spring at 0.123, and a minimum in Autumn at 0.013. The Antarctic and ENSO indices showed the same minimum and season, Autumn. The Indian Dipole data never had positive values, and the negative numbers were almost the same on average. These results point to a similar source of oscillation for ENSO and the Antarctic. So, we can create an interregional seasonal correlation among the three oscillations, as displayed in **Figure 8**.

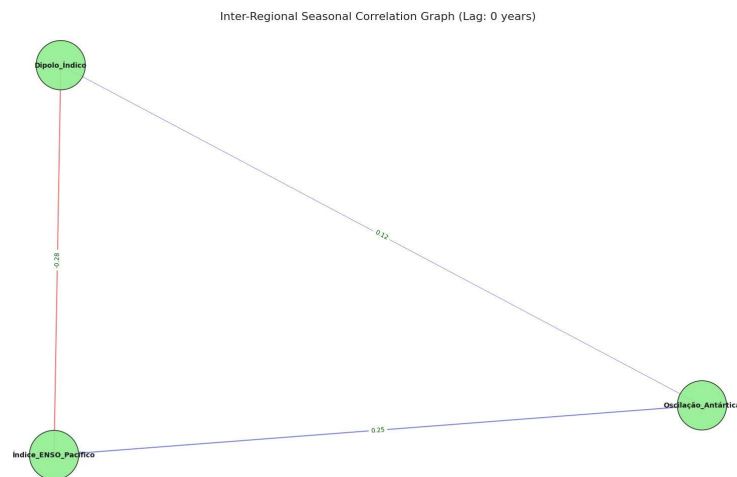


Figure 8. Shows the triangulation among the oscillations in the Southern Hemisphere. It displays a triangulation among the three observed oscillations.

Each of those oscillations shows a similar behavior across seasons; however, the Indian Ocean Dipole shows only negative values, indicating colder waters.

In **Figure 9**, the ENSO temporal behavior is almost cyclical; however, it indicates a slight increase in positive anomalies since 2010. In the Pacific Southern Oscillation (ENSO), the average moving shows the rise of anomalies in two different years: the mid-1970s and around 2008, with minimum values between the maxima. In recent years, there has been a clear decrease in ENSO anomalies, unexpected after years of continued increase since 2010. We are comparing ENSO with the Antarctic oscillation because the anomaly evolution is similar, and there are some positive values for this event.

The Antarctic Ocean shows anomalies in the average rise in 2000. Fell until 2010; since then, it has been enhanced. Therefore, the only one showing a cyclical behavior is ENSO; the other two show an increase, as seen in **Figure 10**.

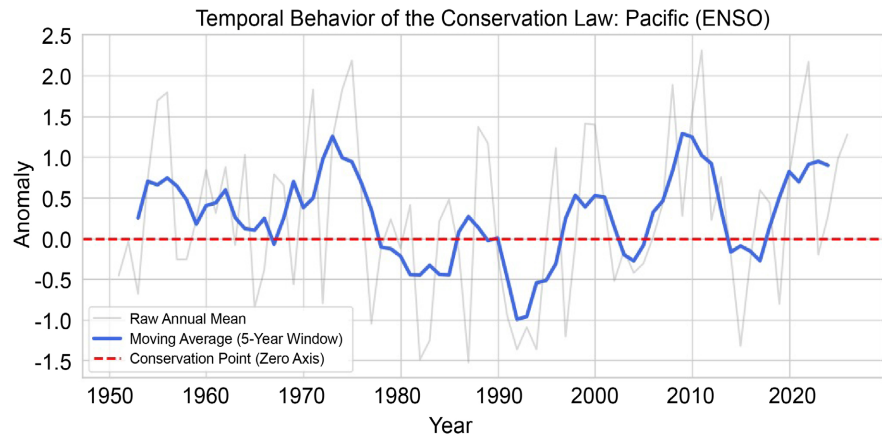


Figure 9. The moving average of ENSO from 1950 to 2025.

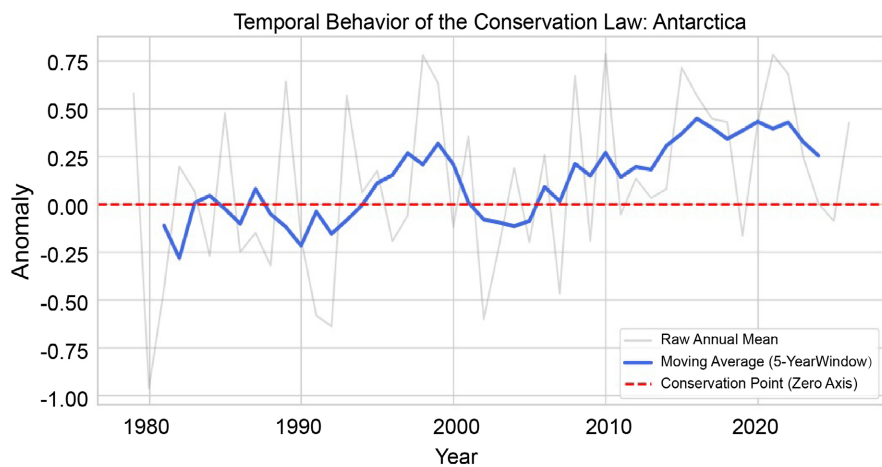


Figure 10. Temporal behavior of Antarctica oscillations.

Finally, **Figure 11** shows the temporal behavior of the Indian Ocean dipole between 1950 and 2025. Although most values are negative, oscillations are also increasing over the period analyzed.

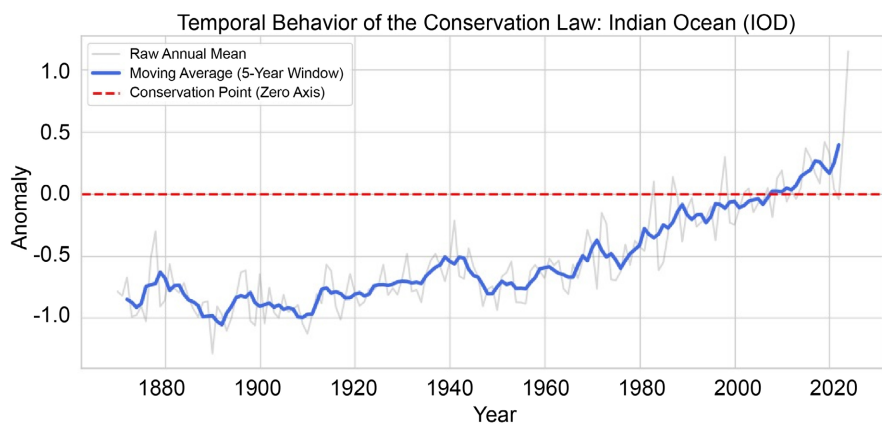


Figure 11. Temporal behavior of the Indian Dipole Oscillation.

Figure 11 shows the most negative values until 2010; the positive anomalies are smoother if compared with the two other ocean oscillations.

In **Figure 11**, the anomalies rise only to positive values after 2000, and the behavior of this Ocean does not match that of the other two locations.

As a final result, we present a comparison of the three oscillation anomalies, and it is clear that the results from last year's Summer show a strong increase (**Figure 12**).

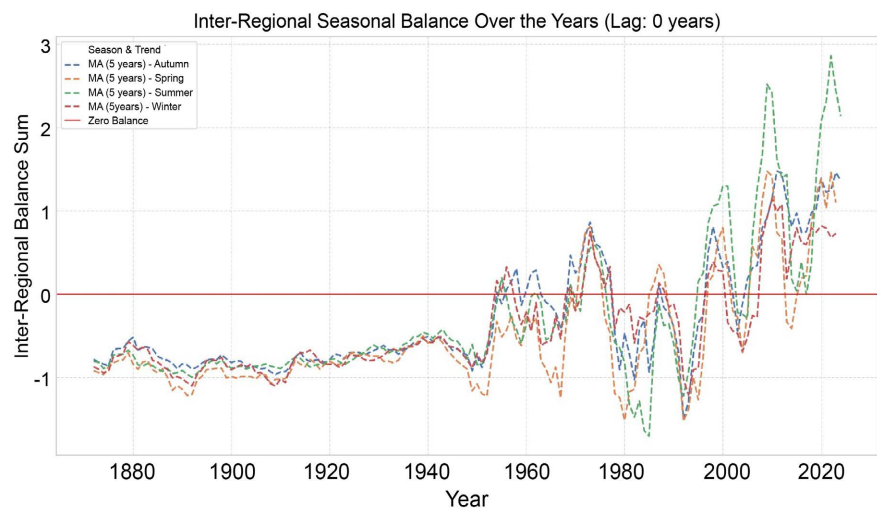


Figure 12. The inter-regional seasonal balance over the years between the three oceanic regions shows the enhancement evolution for all of them.

Our **Figure 12** shows that three anomalies have increased rapidly since 2000. It shows that during the Summer, those anomalies are stronger. The deceleration of the anomalies appears to decrease slightly during Winter and remains stable in Spring and fall. Nevertheless, over the last ten years or so, anomalies across the three oceans have been increasing, leading to an unexpected result.

9. Conclusion

The examination of ocean oscillations in the Southern Hemisphere shows that, over the last decade or so, the oscillation anomalies have been rising faster than in the previous 50 years. Although Antarctica lacks sufficient historical data, it seems that ENSO and AAO play a consistent role, with an increasing number of anomalies since 2010. Meanwhile, IOD shows an increase in evolution, with no minimum events. The alleged rise in temperatures across several continents may be better explained if the oceans' influence were included in today's analyses. Since those pulsations, whether negative or positive, are increasing in intensity and varying with the seasons, a more extensive study would be necessary to account for parameters unknown to climate analysts. However, further research is necessary to complete this study of the Northern Hemisphere, the second part of this investigation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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