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Seasonal Variations and Connections to the North Ocean Pulsations

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Abstract

The primary objective of this investigation is to thoroughly examine the substantial and interconnected climate systems that profoundly influence Earth's weather patterns, ocean temperatures, and atmospheric circulation. The task involves completing the search for oceanic oscillations worldwide. The subsequent part of this discussion will direct its attention to the influence of these oscillations on Earth's weather patterns, ocean temperatures, and atmospheric circulation in the global oceans, examining in detail the influences of the three principal oscillations, namely the North Atlantic Oscillation (NAO), the Pacific North American Oscillation (PNO), and the Arctic Oscillation (AO). Additionally, it examines how oscillations will affect global climate patterns.

Keywords

Northern Ocean Oscillations, Earth's Connections, Climate Changes

1. Introduction

Northern Hemisphere oceans drive global climate change through heat transport, ice-albedo feedback, and carbon absorption. However, regional warming and melting ice pose risks of disrupting crucial circulation systems. The interaction between these oceans and climate dynamics involves several critical mechanisms:

- Ocean Circulation (AMOC): The Atlantic Meridional Overturning Circulation moves warm water from the tropics to Northern Europe. Climate change is weakening this system by adding freshwater from melting glaciers and ice sheets. If this system slows too much, it could trigger profound winter cooling across Europe, overriding global warming trends.
- Ice-Albedo Feedback: In the Arctic, rapidly retreating ice exposes darker ocean water. Because water absorbs sunlight rather than reflecting it as ice does, this

accelerates both localized and global warming.

- Heat Storage and Redistribution: While Southern Hemisphere oceans currently absorb most of the global anthropogenic heat, Northern Hemisphere waters remain crucial for releasing heat into the atmosphere to moderate mid- to high-latitude climates.
- Carbon Absorption: Northern oceans naturally draw down massive amounts of carbon dioxide. Changes in water density and stratification, however, could impair the ocean's ability to pull carbon from the atmosphere and safely store it in the deep ocean.

One way the world's oceans affect weather and climate is by helping keep our planet warm. Most of the Sun's radiation is absorbed by the ocean, particularly in tropical waters around the equator, where the ocean acts like a massive, heat-retaining solar panel. Land areas also absorb some sunlight, and the atmosphere helps retain heat that would otherwise radiate quickly into space after sunset.

The ocean does not just store solar radiation—it also helps distribute heat around the globe. When water molecules are heated, they exchange freely with the air in a process called evaporation. Ocean water constantly evaporates, increasing the temperature and humidity of the surrounding air and forming rain and storms, which are then carried by trade winds. In fact, almost all rain that falls on land starts in the ocean. The tropics are particularly rainy because heat absorption and, thus, ocean evaporation are highest in this area.

Outside Earth's equatorial regions, weather patterns are driven largely by ocean currents. Currents are continuous flows of ocean water, created primarily by surface winds but also by temperature and salinity gradients, Earth's rotation, and tides. Major current systems typically flow clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, following circular patterns that often trace coastlines.

Ocean currents act like a conveyor belt, transporting warm water and heat from the equator toward the poles and cold water from the poles back to the tropics. Thus, ocean currents regulate global climate, helping to counteract the uneven distribution of solar radiation reaching Earth's surface. Without ocean currents, regional temperatures would be more extreme—super hot at the equator and frigid toward the poles—and much less of Earth's land would be habitable.

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. Therefore, this study will divide the Earth's oceans into zones as follows:

- North Atlantic Ocean Oscillation—NAO
- Associated with the Pacific-North American Pattern—PNO
- Arctic Oscillation—AO

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.

In this paper, we are going to consider the Northern Oscillations, such as the North American Oscillation, the Pacific North American Oscillation, and the Arctic Oscillation, 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 worldwide climate. All data used in this work are based on the NOAA catalogs; for each specified zone, the North Atlantic Oscillation, Pacific-North American Pattern, and Arctic Oscillation are provided at the end of this article with their respective data.

2. North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is a weather phenomenon over the North Atlantic Ocean characterized by fluctuations in the sea level pressure (SLP) difference between the Icelandic Low and the Azores High. Through fluctuations in the strength of the Icelandic Low and the Azores High, it controls the strength and direction of westerly winds and the location of storm tracks across the North Atlantic [1]. Its positive, negative, and neutral phases dramatically dictate winter weather patterns across eastern North America, Greenland, and Europe (**Figure 1**).

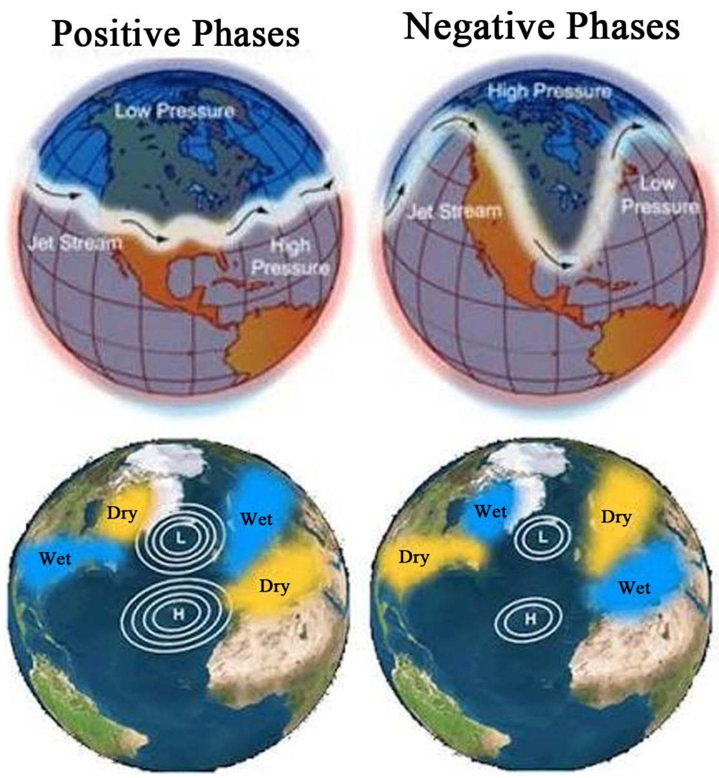

Figure 1. Positive and negative phases of the North Atlantic oscillations.

The NAO was discovered through several studies in the late 19th and early 20th centuries [2]. Unlike the El Niño-Southern Oscillation in the tropical Pacific, the NAO is a largely atmospheric mode. It is one of the most important manifestations of climate fluctuations in the North Atlantic and surrounding humid climates [3].

2.1. The Three Phases of the NAO

2.1.1. Positive Phase (NAO+)

The pressure difference is larger than average. The Icelandic Low is exceptionally deep, and the Azores High is unusually strong. Eastern North America: Brings warmer and drier weather with fewer cold-air outbreaks. Greenland & Northern Canada: Results in colder and drier conditions.

Europe: The strong pressure gradient creates a fast, west-to-east Atlantic jet stream. This funnels strong storms, warmer air, and heavy precipitation into northern Europe, while southern Europe experiences dry, cooler conditions [4].

2.1.2. Negative Phase (NAO−)

The pressure difference is smaller than average. Both the Icelandic Low and the Azores High are weak, leading to a flatter, west-to-east orientation of the Atlantic jet stream. Eastern North America: Brings an increase in winter storms, cloud cover, and stronger, more frequent cold-air outbreaks. Greenland & Northern Canada: Results in milder winters compared to normal. Europe: Northern Europe experiences cold, dry weather because a weakened jet stream allows Arctic air masses to push south. Conversely, southern Europe and the Mediterranean experience increased storminess, above-average precipitation, and warmer temperatures.

2.1.3. Neutral Phase (NAOn)

Neither the high nor the low-pressure systems are anomalously strong or weak. Conditions are in equilibrium, with neither positive nor negative weather patterns dominating. Rather than a strict climate pattern, it represents a period when seasonal probabilities of wet/dry or warm/cold weather return to their long-term historical averages, essentially offering an equal (50/50) chance of either weather regime.

Those three phases outline possible atmospheric changes and the weather impacts in the region.

3. Arctic Oscillations Description

The Arctic Oscillation (AO), also known as the AO index, is one of Earth's most important atmospheric climate cycles. It occurs over the Arctic and influences mid-latitude weather patterns over the entire Northern Hemisphere. It is primarily tracked using the AO Index (AOI), a metric that quantifies the rate at which polar air penetrates the mid-latitudes. This climate phenomenon manifests as a "ring-like" anomaly in sea-level pressure or geopotential fields, characterized by atmospheric pressure conditions in the Arctic (20˚ - 90˚N) that are opposite to those found in the mid-latitude band of 37˚ - 45˚N (**Figure 2**).

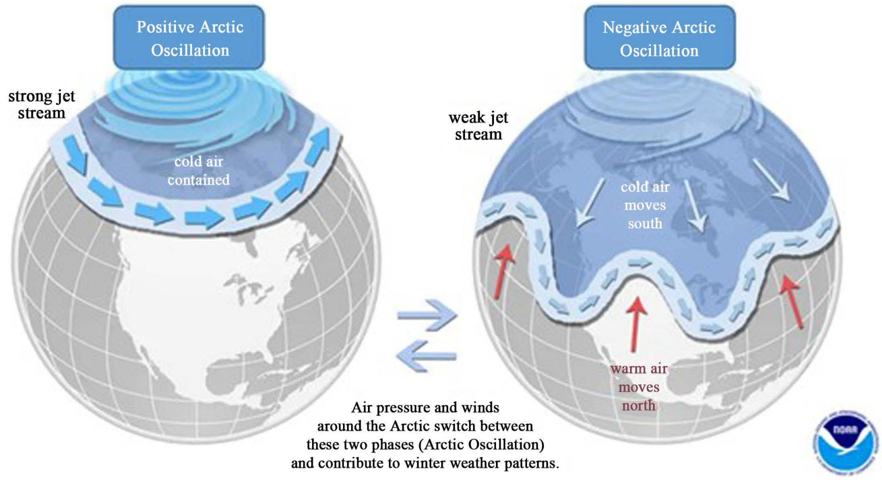

Figure 2. Arctic oscillations and the two main phases.

Technically, the AO's loading pattern is identified as the leading empirical orthogonal function (EOF) mode from an EOF analysis of long-term sea-level pressure data. The AO index time series is simply the projection of these pressure anomalies onto the loading pattern, standardized with respect to a specific historical base period. The current value of the AO index is determined by applying the loading pattern to current sea-level pressure data. On average, low pressure is centered over the North Pole. This tropospheric vortex tends to be stronger in Winter than it is in summer, and thus the influence of the Arctic Oscillation is greater in Winter than it is in summer.

The AO phase is a major driver of winter weather variability, as discussed below. Negative AO index values are particularly important. During a negative phase, the polar vortex and upper-level westerly winds tend to weaken, allowing cold Arctic air to spill southward into the United States, Northern Europe, and Asia.

Conversely, a positive phase is associated with the opposite conditions, typically trapping cold air near the pole, allowing the mid-latitudes to remain relatively mild during Winter. The Arctic Oscillation is a dominant driver of Northern Hemisphere winter climate variables but less important during summer. Defining the AO Index has become more challenging as Earth's mean climate state changes, potentially shifting the AO and altering the apparent strength of its teleconnections. Nevertheless, the AO index remains a critical tool for long-range forecasters to assess the likelihood of specific conditions.

The jet stream remains locked up north. Canada and the northern US experience milder winters, while Alaska and regions like the UK experience stormier weather. Europe: Winds sweep mild ocean air across the continent. Northern Europe tends to see warmer temperatures and more rain, while the Mediterranean experiences dry conditions.

The jet stream weakens and meanders, allowing high pressure to build over Greenland. Arctic air spills southward, triggering brutal cold-air outbreaks and severe winter storms across the central, eastern, and mid-western US. Canada can alternate between trapped cold in the east and mild anomalies in the north. In Europe, weakened high pressure allows the jet stream to dip. Western and central Europe endure prolonged cold continental air, while southern Europe and the Mediterranean receive increased rainfall.

In the **negative phase**, the polar low-pressure system (also known as the polar vortex) over the Arctic is weaker, which results in weaker upper-level winds (the westerlies). The weaker westerlies mean cold Arctic air can push farther south into the US, while the storm track remains farther south. The opposite is true when the AO is positive: the polar circulation is stronger, which forces cold air and storms to remain farther north. The Arctic Oscillation often shares phase with the North Atlantic Oscillation (NAO), and its phases directly correlate with the phases of the NAO. The degree to which Arctic air penetrates middle latitudes is related to the AO index, which is defined by surface atmospheric pressure patterns. When the AO index is positive, surface pressure is low in the polar region. This helps the middle-latitude jet stream blow strongly and consistently from west to East, thus keeping cold Arctic air locked in the polar region. When the AO index is negative, there tends to be high pressure in the polar region, weaker zonal winds, and greater movement of frigid polar air into middle latitudes.

In the **positive phase**, higher pressure at mid-latitudes drives ocean storms farther north, and changes in the circulation pattern bring wetter weather to Alaska, Scotland, and Scandinavia. At the same time, drier conditions occur in the western United States and the Mediterranean. In the positive phase, frigid winter air does not extend as far into the middle of North America as it would during the negative phase of the Oscillation. This keeps much of the eastern United States warmer than normal but leaves Greenland and Newfoundland colder than usual. Weather patterns in the negative phase are, in general, "opposite" to those of the positive phase. Concerning implications on the weather across the US [5] [6].

The Arctic Oscillation (AO) anomalies in recent years have been highly variable, characterized by deep episodic negative phases that drive extreme winter weather and long stretches of record-breaking warmth. In recent years, the Arctic has experienced some of its warmest surface air temperatures on record.

The AO oscillates between positive and negative phases. When the AO is in its negative phase (which peaked in recent Januarys like 2021 and 2026), the pressure over the Arctic is higher than normal, causing a weaker and wavier polar vortex. This allows freezing Arctic air masses to plunge far south into the mid-latitudes of Eurasia and North America, while the Arctic itself remains unseasonably warm. Surface air temperatures across the Arctic over recent autumn and winter periods ranked as the warmest on record. This long-term warming trend influences the frequency of AO patterns by reducing sea ice, thereby increasing air-sea coupling and altering atmospheric circulation.

Climatological studies indicate that the spatial pattern of AO's Arctic center alternates across decades. Recent years have shown a strong tendency for dual troughs (over the Ural Mountains and North America). This specific pattern typically follows the pattern "cold Arctic-warm Eurasia-cold Qinghai-Xizang Plateau".

4. North Pacific Oscillation

The North Pacific Oscillation Index (NPOI) measures atmospheric pressure variations between the Aleutian Low and the subtropical high near Hawaii, influencing weather patterns across North America and the Pacific. A positive NPOI typically brings cooler, wetter conditions to western North America and warmer, drier conditions in the southwest. The Arctic Oscillation (AO) describes large-scale fluctuations in atmospheric pressure at polar latitudes; a positive AO strengthens the polar vortex, keeping cold air confined to the Arctic, while a negative AO allows cold air to spill southward, causing harsh winter weather. PDSI (Palmer Drought Severity Index) quantifies drought or moisture conditions over time using temperature, precipitation, and soil moisture. It helps assess how climate oscillations, such as the NPI and the Arctic Oscillation (AO), affect regional water availability.

In positive NPOI years, summer PDSI is higher than normal, and North China experiences more summer floods; in negative NPOI years, summer PDSI is lower than normal, and North China experiences more summer droughts. Possible mechanism analysis shows that, when in positive (negative) NPOI years, in 850hPa wind anomaly, the common action of anti-cyclonic (cyclonic) in Ural Mountains, the cyclone (anti-cyclonic) of Lake Baikal, and the anti-cyclonic (cyclonic) anomaly circulation in West Pacific, have strengthened (weakened) the convergence of southwest warm and humid air flows of low layer in North China region. Also, during positive (negative) NPOI years, the 500 hPa geopotential height anomaly wave train and the West Pacific subtropical high are stronger (weaker)/shifting northwest (southeast) relative to normal years, so cold- and warm-air activities produce more (less) rainfall over China [6]-[10]. The PNO pattern reflects the wave-like shape of the jet stream, defined by pressure anomalies in the North Pacific and the southeastern US (**Figure 3**).

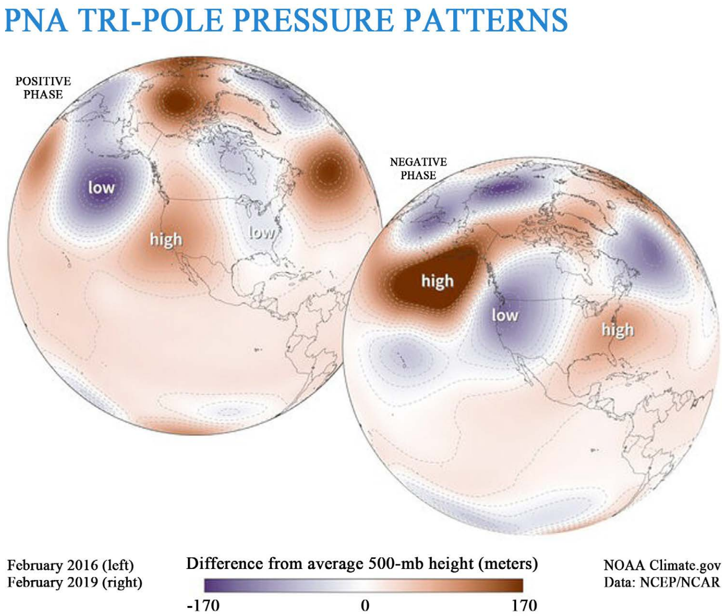

Figure 3. Pacific North Oscillation positive and negative phases.

Positive Phase (+PNO): Features a strong ridge of high pressure over western North America and a deep trough over the eastern US. This brings warm, dry conditions to the West, and pushes bitterly cold, snowy weather into the eastern half of the continent.

Negative Phase (−PNO): Features a trough (low pressure) over western North America and a ridge (high pressure) in the East. This causes stormy, wet conditions in the Pacific Northwest and unusually warm weather across the eastern US. Because the Pacific North American (PNO) oscillation is typically characterized by monthly or seasonal averages, as illustrated here for December through February, it is understood as a climate pattern, even though its weekly fluctuations can be substantial. Tropical rainfall can modulate the PNO because the rising air and atmospheric heating that accompany tropical cloud formation can drive strong motion in the upper atmosphere (first image in this post). That motion and the rotation of our planet can help extend or retract the jet stream. Shifts in the jet stream cause large changes in pressure not only near the jet stream but also downstream, because a big change in pressure in one area can subsequently affect nearby regions.

5. Atmospheric Circulation

Atmospheric circulation is the large-scale movement of air and, together with ocean circulation, redistributes thermal energy on Earth's surface. The wind belts girdling the planet are organized into three cells in each hemisphere—the Hadley, Ferrel, and polar cells. Those cells exist in both the northern and southern hemispheres. The vast bulk of the atmospheric motion occurs in the Hadley cell. The high-pressure systems acting on Earth's surface are balanced by the low-pressure systems elsewhere (**Figure 4**).

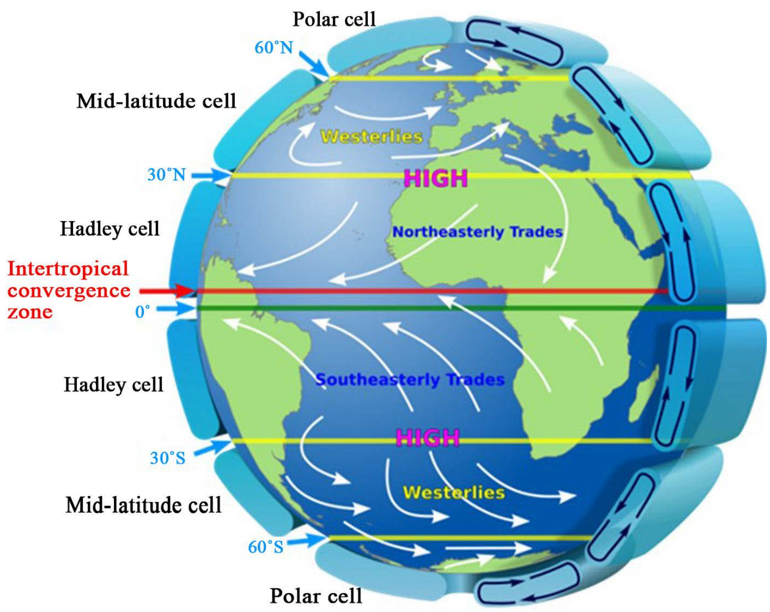

Figure 4. An idealized view of three large circulation cells showing surface winds.

As a result, there is a balance of forces acting on Earth's surface. The horse latitudes are an area of high pressure at about 30˚ to 35˚ latitude (north or south) where winds diverge into adjacent zones of the Hadley and Ferrel cells, and are typically characterized by light winds, sunny skies, and little precipitation [11]-[14].

The Pacific Ocean cell plays a particularly important role in Earth's weather. This entirely ocean-based cell results from a marked difference in the surface temperatures of the western and eastern Pacific. Under ordinary circumstances, the western Pacific waters are warm, and the eastern waters are cool. The process begins when strong convective activity over equatorial East Asia and subsiding cool air off South America's west coast create a wind pattern that pushes Pacific water westward and piles it up in the western Pacific (Water levels in the western Pacific are about 60 cm higher than in the eastern Pacific) [15]-[18].

In this paragraph, the main atmospheric phenomena that influence the Oceans and the wind circulation in the Northern Hemisphere are described. In this paper, we will analyze, through ocean oscillations, the quasi-adiabatic system formed between the Oceans and the atmosphere. The interaction between the atmospheric cells and the Pacific Ocean is well known, as is the process that warms or cools the water [19] [20].

In the next paragraphs, the results obtained by each Northern Ocean are described and analyzed, and the possible consequences of climate change are discussed.

6. Northern Ocean Oscillations Discussion

a) North Atlantic Oscillation (NAO)—oscillation variations (**Figure 5**).

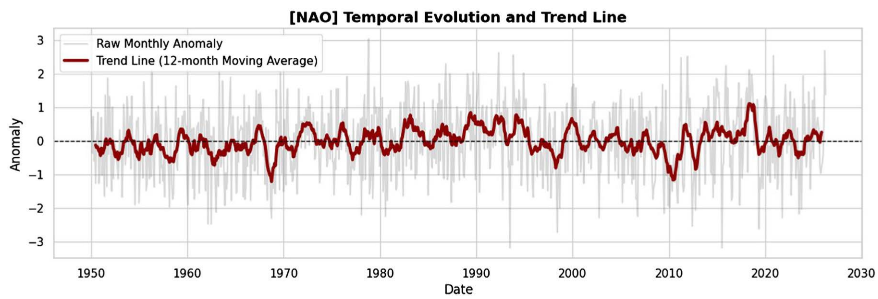

Figure 5. Shows the red average line for the period 1950-2026, highlighting the highest and lowest positive and negative anomaly values during this interval.

The graph illustrates the temporal evolution of the NAO anomaly. The light grey line represents the raw monthly anomalies, showing short-term fluctuations. The prominent dark red line indicates the 12-month moving average, which smooths monthly variations to reveal longer-term patterns and overall trends in the anomaly data. A black dashed line highlights the baseline for anomalies. It is observed that the last few years, after 2010, are mostly positive, with a peak around 2015. There was a deep minimum in 2010, like that in 1968, and an upward trend afterward. The second plot displays the monthly and seasonal average anomalies for the NAO region. The monthly average anomalies illustrate the typical deviation from the long-term mean for each month, while the seasonal average anomalies are showing the distributions by season.

Aggregated deviations by season (Winter, Spring, Summer, Autumn) in the Northern Hemisphere. This helps identify consistent patterns of positive or negative anomalies during specific periods of the year.

Figure 6 presents two distinct perspectives derived from the data: first, it shows anomaly events broken down by month; second, it shows the distribution of these events across seasons. The results indicate a strong anomaly in the Winter, triple or four times that of any other season, in the period studied. The results from NAO will be compared with those of the other two oscillations in the next paragraphs.

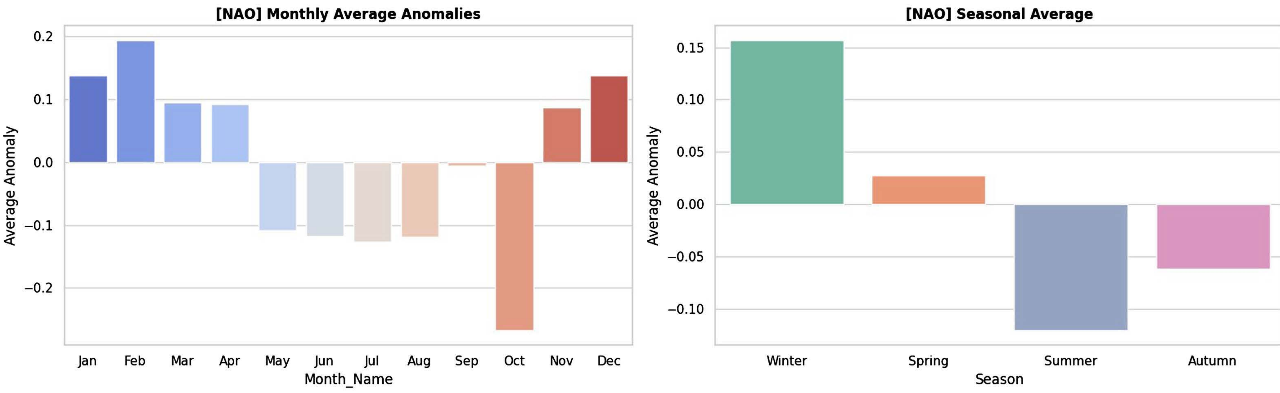

Figure 6. The monthly and seasonal average anomalies in the NAO region.

b) Arctic Oscillation

Figure 7 shows the maximum and minimum of Arctic oscillations.

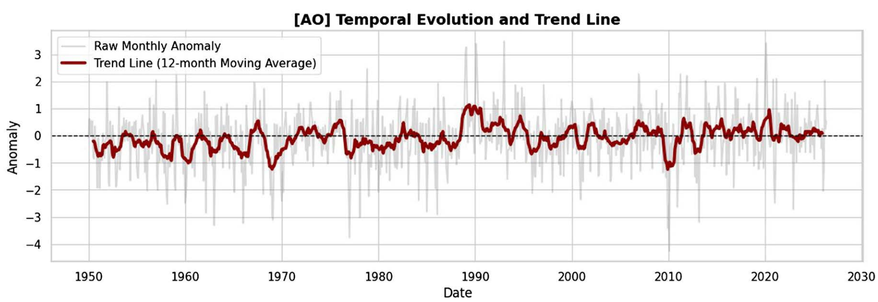

Figure 7. Temporal evolution and 12-month moving-average trend for AO.

Describes hemisphere-wide shifts in atmospheric pressure between the Arctic and the mid-latitudes of both the North Pacific and the North Atlantic. In the positive phase, lower pressure in the Arctic traps cold air at the pole, while in the negative phase, this cold Arctic air pushes into mid-latitude regions. The highest positive anomalies in the Arctic Oscillation were in January (1990) and Feb

(2020). The lowest negative during Winter was -4 in 2010, which was also a solar minimum (Figure 8).

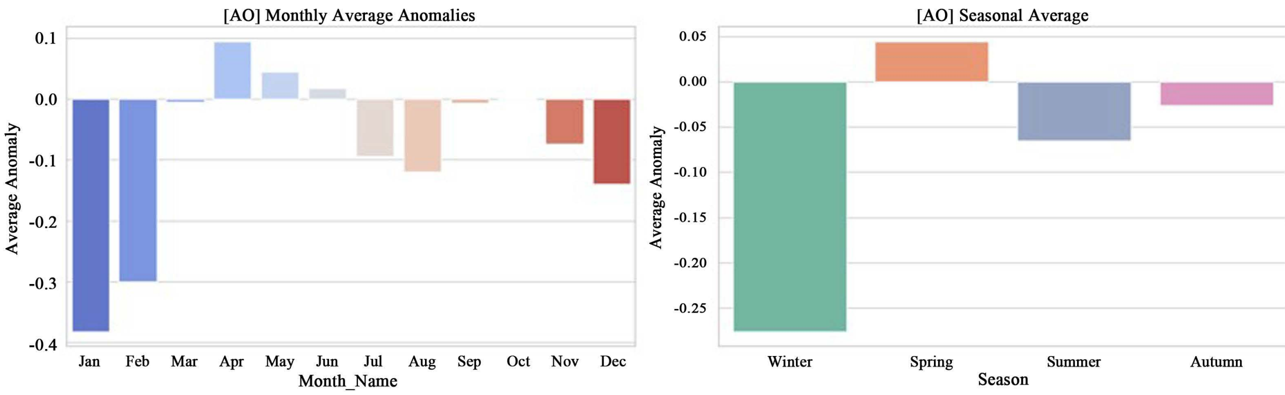

Figure 8. Maxima and Minima of the Arctic Oscillation in the period 1950-2023: note that the minimum occurred in 2009 at −3.41. The maximum happened in 2020, at 3.42.

In Spring, the maximum (1.2) was observed in 1980, and the minimum (−2) in 1968. In summer, the Arctic Oscillation is not very active, and the minima or maxima do not surpass |1.5|. Examining oscillation evolution in the Arctic, we observed that 1990 and 2020 had the oscillations, with values above 3. In 2010, a minimum occurred in February. The positive oscillations rose after 1985. Negative oscillations increased, with more negative values after 1980. Overall, Arctic generated more positive and fewer negative occurrences after 2010. In the positive phase, higher pressure at mid-latitudes drives ocean storms farther north, and changes in the circulation pattern bring wetter weather to Alaska, Scotland, and Scandinavia. Drier conditions occur in the western USA and the Mediterranean. In the negative phase, weather patterns are opposite to those in the positive phase.

c) The North Pacific Oscillation

The North Pacific Oscillation (NPO), as reflected in sea-level pressure and its upper-air geopotential-height signature, and the West Pacific (WP) teleconnection pattern constitute a prominent mode of winter mid-latitude variability. Its mature-phase expression is identified as the second-leading mode in a principal component analysis of monthly sea-level pressure variability, just behind the Pacific-North American pattern [21].

The NPO features high pressure near Hawaii and low pressure over Alaska; this pressure difference strengthens westerly winds in the central Pacific. North America's west coast experiences mild winter temperatures, but the US Southwest and Eastern Siberia become colder than usual. Alaska and the Great Plains see more rain or snow than normal (Figure 9).

In the negative phase, the pressure pattern flips. There is high pressure over Alaska and low pressure near the central North Pacific. This leads to weaker trade winds and pushes storm tracks southward. North America experiences colder winters, while the Pacific Northwest tends to be wetter. Think of the NPO like a seesaw in a park. When one ends up (high pressure), the other goes down (low pressure). This seesaw changes how ocean currents and winds move across the Pacific Ocean, shifting storm paths to different parts of North America and Asia.

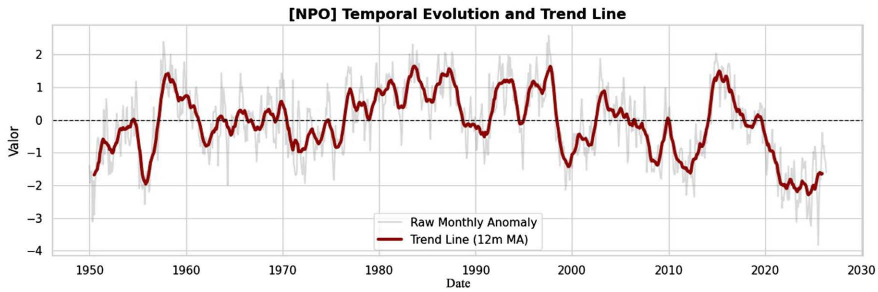

Figure 9. Temporal evolution of the NPO anomaly.

The hemispheric height anomalies at upper levels resemble the climatological stationary wave pattern attributed to transient eddy forcing. NPO/WP divergent circulation is thermal wind restoring, pointing to independent forcing of jet fluctuations. Figure 11 illustrates the temporal evolution of the NPO anomaly; the light gray line shows the raw monthly anomalies, which exhibit short-term fluctuations. The prominent dark red line indicates the 12-month moving average, which smooths monthly variations to reveal longer-term patterns and overall trends in the anomaly data—observed the increase in anomalies around 2010 and the lowest values after 2019. Figure 10 shows the pressure difference between a high-pressure zone near the Azores and a low-pressure zone near Iceland.

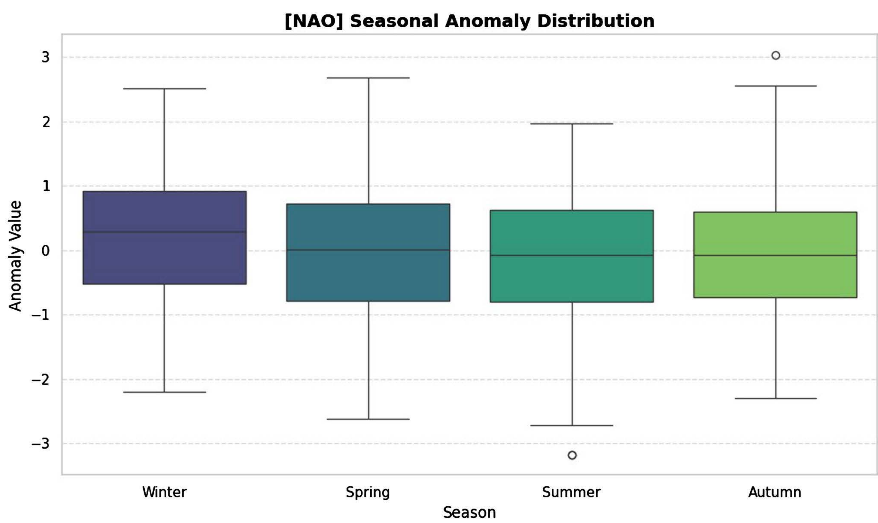

Figure 10. Shows the anomaly balance for each NAO season.

Finally, and perhaps most importantly, NPO/WP is strongly linked to variability in the marginal ice zone of the Arctic seas, with an influence that surpasses that of other Pacific modes. Although NPO/WP variability and impacts have not been as extensively analyzed as those of their Pacific cousins (NPO, ENSO), they are more consequential for Arctic sea ice and North American winter hydroclimate.

7. Northern Ocean Oscillation Seasonality Variations

7.1. The North Atlantic Oscillation/Seasons

The North Atlantic Oscillation (NAO) is a large-scale atmospheric pressure pattern across the North Atlantic. It dictates wind strength, storm paths, and seasonal temperatures in North America and Europe. While the NAO is present year-round, its intensity, location, and impacts change dramatically with the seasons.

Winter (December-March): The NAO is at its strongest. It dictates most of the weather during this time, controlling heavy snowfall in northern regions and the rainfall pattern, depending on the phase.

Spring & Summer (April-August): The pressure difference weakens as the temperature contrast between the equator and the poles decreases. The pattern also shifts slightly, becoming the Summer North Atlantic Oscillation (SNAO). The SNAO influences summer drought patterns and rainfall in northern Europe.

NAO does not directly dictate the path of the North Atlantic jet stream (the fast-flowing air current that guides storms). A positive NAO shifts the jet stream north, while a negative NAO buckles the jet stream, sending cold air south.

The NAO creates a "tripole" pattern in ocean surface temperatures. The atmosphere drives short-term changes in sea surface height, but long-term oceanic changes feedback to influence atmospheric variations.

NAO does not interact with other teleconnections (long-distance climate links). For example, the El Niño-Southern Oscillation (ENSO) in the Pacific can shift the phase of the NAO from early Winter to late Winter. NAO varies from year to year and over decades. For instance, a negative NAO dominated the mid-1900s, while a mostly positive phase dominated the late 1990s. NAO changes wind and storm paths over the North Atlantic.

This system drives major seasonal weather changes in North America and Europe. In Winter, the NAO is strongest. A positive phase means a strong Icelandic Low and Azores High. This brings mild, wet winters to the US East Coast and Northern Europe. It brings cold, dry weather to Southern Europe. A negative phase reverses this. Fall behaves similarly, driven by changes in the stratospheric polar vortex. In Spring and summer, pressure differences shrink. The Summer NAO (SNAO) centers over Northern Europe. A positive SNAO brings warm, dry conditions to Northern Europe. A positive winter NAO also leads to drier, hotter summers and reduced water availability. Winter NAO strongly controls warm-season water. Positive winter phases lead to less stream flow and groundwater later in the year. The summer NAO influences have decreased since the 1990s. Meanwhile, early Winter has become much more unpredictable.

7.2. Arctic Oscillation/Seasons

The Arctic Oscillation (AO) is a shifting of atmospheric pressure between the Arctic and mid-latitudes. Its influence changes greatly by season. The National Weather Service notes that the AO exhibits the greatest variability during the cold season, whereas its overall influence is much weaker during the summer. Fall and Winter:

During the fall and winter, the AO index controls the polar vortex—a strong ring of winds high in the atmosphere. The winds form a tight, neat circle. The jet stream (the river of air that steers storms) stays far to the north. This keeps cold air trapped in the Arctic, creating milder winters for the rest of the world. The winds weaken and become wavy. The jet stream dips far south. This allows Arctic air to spill into mid-latitudes, causing severe cold snaps and heavy snowfall (Figure 11).

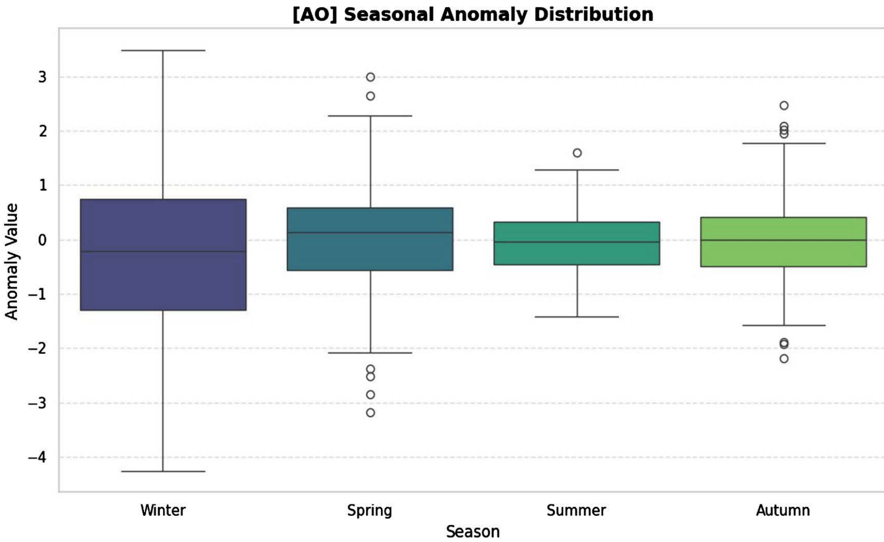

Figure 11. Shows the distribution of anomalies for the AO region and the anomaly data for each season.

In the Spring and summer, the pressure difference between the Arctic and the mid-latitudes shrinks. The tropospheric vortex is much weaker, so the AO has a much smaller effect on daily, localized weather. A positive AO in the Spring can predict future weather. Studies show that a positive spring AO helps trigger an El Niño event, followed by predictable patterns in the Pacific.

The AO pattern mostly affects sea surface temperatures and ice melt. Because the pressure patterns are less intense, the AO has little effect on non-summer air temperatures or local rainfall trends.

7.3. North Pacific Oscillations (NPO)/Seasons

A seesaw pattern in the atmospheric sea-level pressure is the fundamental characteristic that defines the North Pacific Oscillation (NPO). This process is responsible for initiating and sustaining the substantial alterations in global climate observed across different seasons. As the weather transitions into Fall and Winter, there is a noticeable trend of pressure declining close to Alaska and intensifying near Hawaii. This mechanism propels oceanic storms and simultaneously initiates the El Niño-Southern Oscillation (ENSO) cycle. As the seasons transition into Spring and summer, a noticeable reduction in the intensity of pressure patterns occurs, shifting the emphasis of our observations to sea surface temperatures, which are predominantly shaped by wind forcing. The Northern Pacific Oscillation (NPO) behaves like a massive seesaw, characterized by fluctuations in air pressure across the North Pacific Ocean. Earth orbits the Sun each year, and its axial tilt exerts a discernible influence on the atmosphere and, in turn, alters ocean conditions. During the cooler months, fall and Winter, the Aleutian Low (a semi-permanent area of low pressure) becomes very active and reaches its peak intensity. High pressure near Hawaii and low pressure near Alaska create strong winds. These winds alter ocean currents and temperatures, which can kickstart ENSO (El Niño or La Niña). This pressure steers powerful winter storms into the Pacific Northwest. It also creates weather patterns that affect rainfall and temperature across the rest of North America.

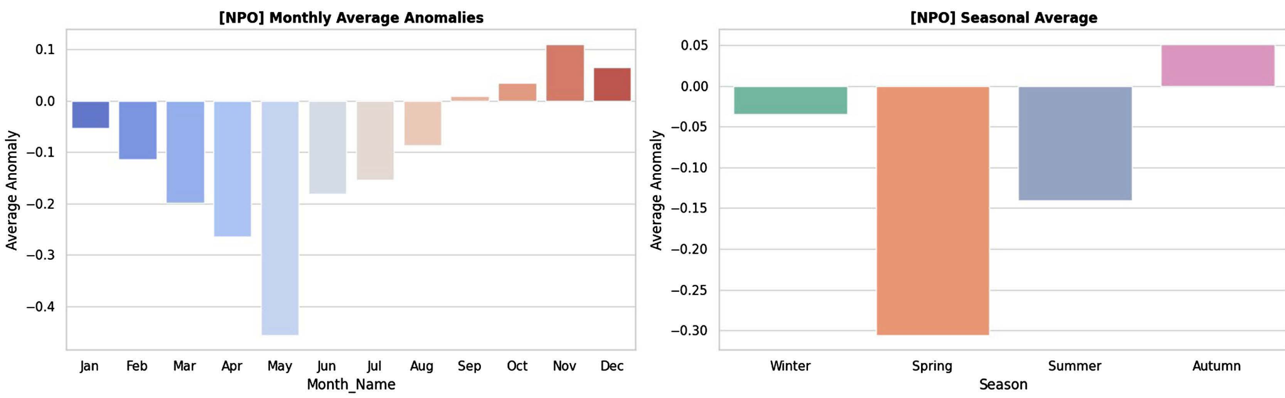

Figure 12. The North Pacific Oscillation balance for each season.

As the Northern Hemisphere warms in Spring and Summer, the pressure systems retreat. The Aleutian Low weakens, and the North Pacific High takes control of the region. The shift in winds cools parts of the ocean. Atmospheric variations during this time affect the paths of summer storms. The NPO's influence during these months affects typhoon and tropical cyclone formation and determines how much rain falls in East Asia and North America. It also shapes upwellings—deep, cold water rising to the surface—on which marine life depends (Figure 12).

The North Pacific Oscillation (NPO) is a see-saw pattern of sea-level pressure across the North Pacific. It changes dramatically with the seasons, governing winter storms, summer monsoons, and shifts in global weather. How the NPO Changes by Season: Boreal Winter (December-February): The NPO acts as a north-south dipole (a pair of low- and high-pressure zones). A positive NPO phase brings low pressure near Alaska and high pressure near Hawaii. This shift directs the polar jet stream. It steers severe winter storms and cold air into East Asia and North America.

8. Northern Hemisphere Inter-Regional Balance (NAO + AO + PNO)

Figure 13 shows each node representing an index, with edges indicating correlations between them. Green edges denote a positive correlation, while red edges represent a negative correlation. The edge thickness is proportional to the absolute value of the correlation, indicating the strength of the relationship. This visualization helps in understanding the interconnectedness and co-variability of these major climate patterns. In this picture it was included ENSO since this oscillation located at the Equatorial region will influence the entire system at the Northern or southern.

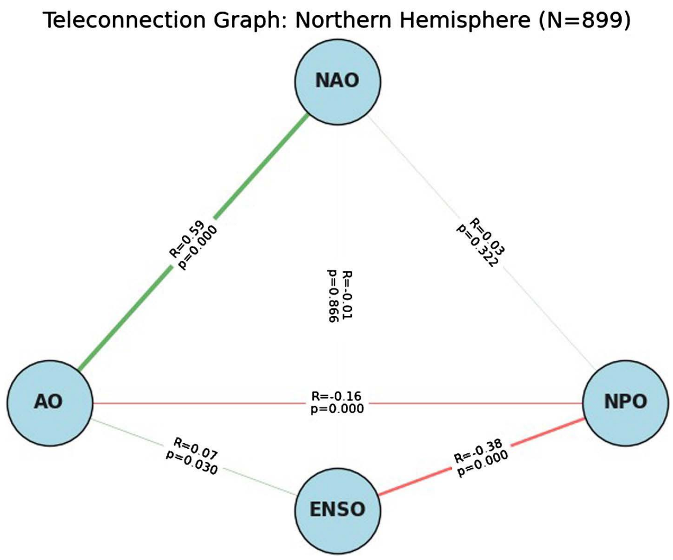

Figure 13. The teleconnection among the three Ocean Oscillations: AO to PNO is negative, AO to NAO is positive, and NAO to PNO is negative. ENSO is included in the next calculations (next paper).

The next plot investigates the "conservation law" by summing the anomalies of NAO, AO, and PNO to form a "global balance". Figure 14 shows the light purple line representing the monthly sum of anomalies, while the thick blue line shows the 12-month moving average of this balance, highlighting the overall trend. A red dashed line at zero points to a state of perfect conservation. Deviations from these zero lines reveal periods when the combined anomalies of these major patterns are consistently positive or negative, suggesting potential systemic shifts or persistent extreme conditions in the Northern Hemisphere.

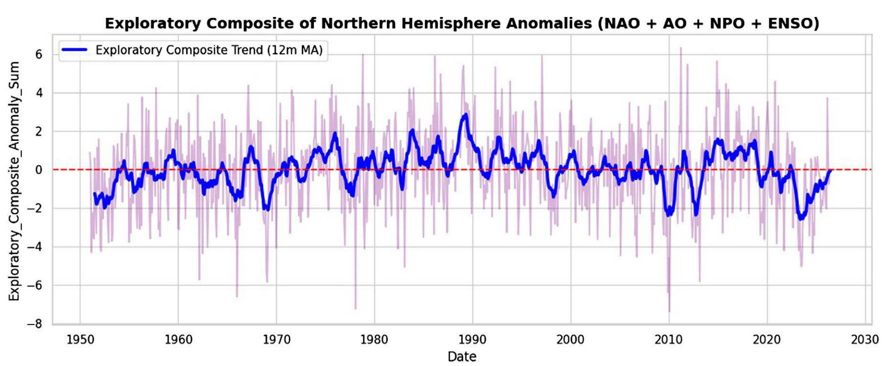

Figure 14. The total number of anomalies in the Northern Hemisphere.

The figure presents an "Exploratory Composite of Northern Hemisphere Anomalies" by summing the *standardized* (Z-scored) anomalies of NAO, AO, NPO, and ENSO. Standardizing the indices before summing ensures that each teleconnection contributes equally to the composite, preventing any single index with larger absolute values from dominating the sum. The light purple line shows the monthly sum of standardized anomalies, while the thick blue line represents the 12-month moving average of this composite, highlighting the overall trend. A red dashed line at zero indicates the baseline of no combined anomaly. Deviations from this zero line indicate periods when the combined standardized anomalies of these major patterns are consistently positive or negative, suggesting potential systemic shifts or persistent extreme conditions in the Northern Hemisphere. The standardization addresses concerns about the statistical basis of simply summing raw anomaly values.

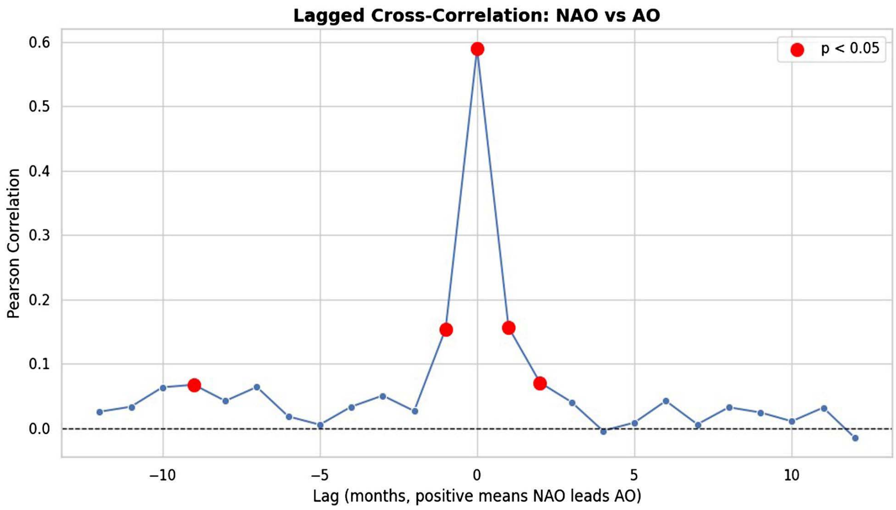

Figure 15. Showing the lagged cross-correlation: NAO vs AO.

Figure 15 shows the lagged cross-correlation between the NAO and AO indices. A positive lag (e.g., Lag +6) indicates that NAO values are correlated with AO values from 6 months later, suggesting NAO leads AO. A negative lag (e.g., Lag −6) indicates AO leads NAO. The red dots highlight statistically significant correlations (p-value < 0.05). This analysis helps to identify potential causal relationships or consistent preceding patterns between the two teleconnections, moving beyond mere contemporaneous correlation.

Figure 16 shows the lagged cross-correlation between the NAO and PNO indices. A positive lag (e.g., Lag +6) indicates that NAO values are correlated with PNO values from 6 months later, suggesting NAO leads PNO. A negative lag (e.g., Lag −6) indicates PNO leads NAO. The red dots highlight statistically significant correlations (p-value < 0.05). This analysis helps to identify potential causal relationships or consistent preceding patterns between the two teleconnections.

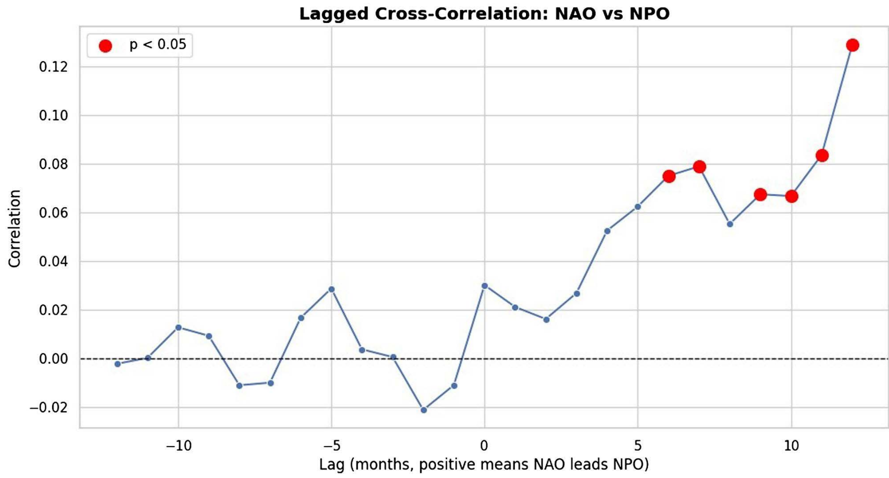

Figure 16. Lagged Cross-Correlation NAO vs or PNO (Pacific North Oscillation).

Figure 17 shows the lagged cross-correlation between the AO and PNO indices. A positive lag (e.g., Lag +6) indicates that AO values are correlated with PNO values from 6 months later, suggesting AO leads PNO. A negative lag (e.g., Lag −6) indicates PNO leads AO. The red dots highlight statistically significant correlations (p-value < 0.05). This analysis helps to identify potential causal relationships or consistent preceding patterns between the two teleconnections.

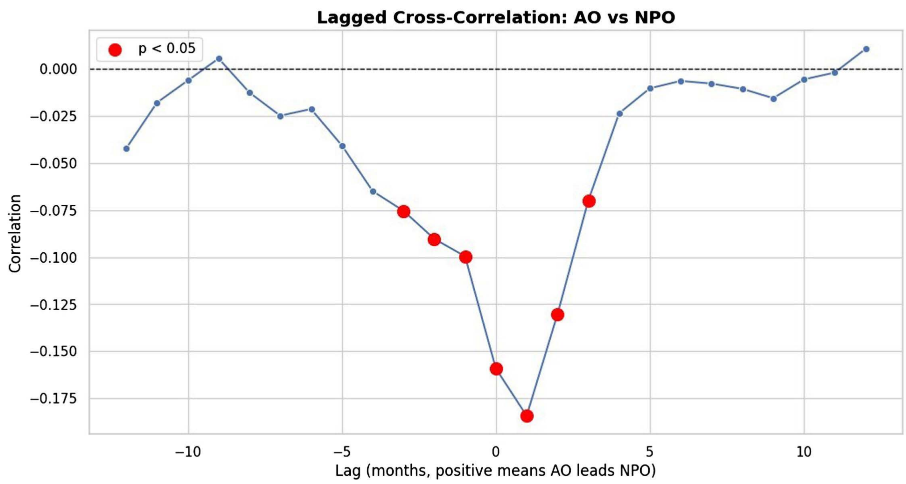

Figure 17. Lagged Cross-Correlation AO vs PNO.

9. Final Observations

This paper shows that the oscillations in the Northern Hemisphere are slightly cyclical and strongly influenced by the seasons. Some of those oscillations, such as NAO and AO, depend on Winter, while the PNO depends on Spring.

These differences among the three oscillations, NAO and AO, show that the PNO influences the others, contributing to the negativity observed over the last two decades. A review of the three Northern Ocean oscillations suggests that certain months or time frames displayed a somewhat cyclical pattern of development.

The major problem is that these cycles exhibited different maxima and minima, not connected to solar cycles. Instead, it seems to be associated with the seasons. Some seasons are more positive or negative than others. Ocean oscillations have been shown to vary with season; however, it is necessary to determine how these variations affect the climate and ocean-related hazards, such as hurricanes, cyclones, typhoons, and other events that most prominently move from the oceans to land, or vice versa.

10. Conclusion

This second paper on ocean oscillations demonstrated that the North Atlantic Oscillation interacts with itself. Data from 1950 and relevant catalogs were analyzed, considering solar cycles and seasonal variations. Although no strong correlations were discovered between the maxima and minima of the solar cycle, we did identify a variation in the synchrony between the Oscillation and the changing seasons. Future research on equatorial oceanic oscillations will primarily aim to identify hazard events intrinsically linked to these phenomena. Note: All the data, the calculations, and the results are based on the NOAA catalogs.

Author Contributions

Seasonal variations and "North Ocean pulsations" (*i.e.*, periodic ocean/atmosphere oscillations in the North—often studied using signals from the North Pacific/Arctic region) are scientifically useful because they help separate the "natural clockwork" of the climate system from unusual events and quantify cause-effect relationships. Here, we contribute by studying North Ocean pulsations and their connections to seasons and other atmospheric variables, such as winds, sea-ice extent, and storm tracks. By determining the timing and amplitude of these cycles, we will improve climate monitoring and seasonal forecasts. Marilia Hagen, the first author, collected and analyzed the data and constructed the tables. The second author, Anibal Azevedo, created a comprehensive AI language model.

Conflicts of Interest

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

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