Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 26(1), 2023, pp. 49-62

Atmospheric Periodic Oscillations

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ABSTRACT

The North Atlantic Oscillation, Quasi Biennial Oscillation, their negative and positive phases are discussed in presented article An El Niño event is a prolonged period of abnormally high sea-surface temperatures (SST) in the tropical Pacific Ocean. It goes hand in hand with changes in atmospheric conditions and can have strong repercussions on global weather patterns. El Niño can also significantly affect the global average temperature The ECMWF seasonal forecast system has been operational for more than five years and will soon be replaced by an upgraded system SEAS5.

Key Words: *North Atlantic Oscillation (NAO), sea level pressure, Quasi Biennial Oscillation (QBO), sea surface temperature, El NINO.*

Introduction

The North Atlantic Oscillation (NAO) is a prominent "seesaw" of atmospheric surface pressure fluctuation between the Azores and Iceland that has been meteorologically well defined since at least the late 19th century [1]. It is defined using the NAO index, which is typically a normalized mean sea-level pressure (SLP) index between a southern station located in the Azores or continental Iberia and a northern station in western Iceland [2-5]. The NAO has historically been recognized since at least the time of the Vikings; pioneering work based on early instrumental meteorological records was undertaken by Hildebrandsson (1897), who using surface air pressure data discovered the inverse relation between Iceland and Azores pressure, and by Sir Gilbert Walker who in works published in 1924 and 1932 (the latter with Bliss) undertook correlation analysis and constructed a robust multivariate NAO index based on surface air pressure and surface air temperature data from several European stations [6].

The strength of the pressure difference between the high- and low-SLP centers of action exerts a strong control over the strength and direction of the mid-latitude westerly storm tracks. As such, the NAO has been linked to a variety of climatological, biological, hydrological, and ecological variables across several locations [7,8], but is most frequently recognized as directly affecting the west of Europe (from Iberia to Scandinavia) and North America. A greater than normal pressure difference between the Azores and Iceland is a positive NAO, and a weaker than normal pressure difference is a negative NAO. During the winter months, a positive NAO is associated with warmer and wetter conditions across northwest Europe and cooler and drier conditions across southern Europe as the stronger pressure gradient between the Azores and Iceland drives the storm tracks poleward. The opposite is generally true for negative NAO conditions as the weaker pressure gradient generally results in southward-shifted storm tracks, and a SLP reversal will typically result in more easterly conditions. As such, the NAO index is strongly related to favored positions of the North Atlantic atmospheric polar jet stream.

The principal component (PC)–based NAO index [9], uses the first empirical orthogonal function (EOF) of atmospheric pressure variability across the North Atlantic region and is strongly correlated with the station-based index. NAO indices are closely related to the Arctic Oscillation (AO) index—the latter being the first EOF of variability of atmospheric surface pressure across the whole Northern Hemisphere north of 20°N [10], but there are subtle and notable differences in NAO and AO variations [11], and the NAO can perhaps best be seen as the regional Atlantic-wide manifestation of the AO.

The Quasi-Biennial Oscillation (QBO) is an oscillation of equatorial stratospheric zonal winds with a downward propagating phase taking approximately 1 year from the stratopause to the tropopause. It is relevant for interannual variability of stratospheric dynamics and composition, both in the tropics and the Polar Regions. It has also been demonstrated that the QBO affects tropospheric weather, either through its effect on the stratospheric polar or perhaps directly through interaction with tropical convection. Tropospheric imprints were found in the Eurasian region, including the North Atlantic or Arctic Oscillation and Eurasian snow cover. The QBO has also been claimed to affect the Indian monsoon system, Atlantic hurricane frequency.

Direct observations of equatorial stratospheric winds by means of balloons go back to 1908, when Berson, in an expedition to East Africa, reported unexpected westerly winds in the lower. These westerlies were confirmed by van Bemmelen and Braak (1910), who performed observations of upper-level winds in Batavia from 1909 to 1918. Lower stratospheric westerlies were also confirmed by the observations of another volcanic eruption plume (Semeru, 15 November 1911), as reported by Hann and Süring (Hamilton, 2012). Reconciling Berson's westerlies with the expected easterly winds remained a challenge until the discovery of the QBO in the 1960s [12]. Stratospheric wind observations were very sparse prior to the 1950s. The early results were summarized by Schove ([13] and Hamilton [14]. After the 1950s, when a global radiosonde network was built up, stratospheric winds were operationally observed in the equatorial region.

It is known that the QBO affects the atmospheric circulation in the temperate latitudes and its influence propagates to the Earth surface. Regular measurements of the mean zonal wind components are carried by the radiosonde stations of the equatorial belt since 1953.The period of the oscillation is about 28 months. The winds in the eastward phase of the QBO are approximately twice as strong as those in the westward phase. The signal of the QBO cycle was detected not only in the variability of the stratospheric zonal and meridional wind, temperature, and geopotential height [15,16], but also in its influence on the surface meteorological parameters as well, for example, air temperature [17,18], precipitation [19-22], and snow cover [23,24]. In previous studies, the significant QBO signal was detected in September and October precipitation in the period from1953 to the 1980s in the region of the British Isles, in the Central European region and in Belarus. Regions of the eastern Ukraine and adjoined regions of Russia had the significant QBO signal in precipitation in May.

The quasi-biennial oscillation (QBO) is the dominant variability in the equatorial stratosphere characterized by alternating downward easterly and westerly winds every ~28 months on average driven by propagating waves. Though originating in the equatorial region, the QBO is known to influence the Arctic stratosphere, most prominently during boreal winters via the Holton–Tan (H-T) mechanism : During the descending easterly QBO (eQBO) phase, the westerly part of the waveguide for the planetary stationary waves is narrowed and squeezed more poleward, causing greater perturbation of the polar vortex and sometimes resulting in more sudden stratospheric warming events (SSWs conversely, during the descending westerly QBO (wQBO) phase, the waves are less restricted latitudinally and the polar vortex is more stable, resulting in an anomalously cold Arctic stratosphere.

Discussion

One current hypothesis to explain possible solar-climate connections is based on the fact that solar ultraviolet (UV) variability in the Schumann-Runge bands (175–200 nm) alters the radiative heating of the equatorial upper stratosphere through changes in ozone photochemistry. Subsequent changes in stratospheric temperatures and winds resulting from this initial heating perturbation could then propagate downward, affecting the tropospheric circulation and climate through a feedback mechanism involving wave-mean flow interactions.

There is observational evidence that the duration of the westerly QBO phase is 3 to 6 months shorter during periods of solar maximum than during solar minimum, and this modulation requires a temperature change of 1–2 K near the equator for the inferred changes in vertical wind shear to balance a solar-induced anomaly in the meridional temperature gradient via the thermal wind relationship [21,22].

The first significant observed deviation from the normal QBO since its discovery in early 1950s was noted beginning in February 2016 when the transition to easterly winds was disrupted by a new band of westerly winds that formed unexpectedly. The lack of a reliable QBO cycle deprives forecasters of a valuable tool. Since the QBO has a strong influence on the North Atlantic Oscillation and thereby north European weather, the coming winter could be warmer and stormier in that region. NASA scientists have been researching to test if the extremely strong El Niño event of 2015/16, climate change, or some other factor might be involved. They are trying to determine if this is more of a once in a generation event, or if this is a sign of the changing climate

The Quasi-Biennial Oscillation can affect the Atlantic jet stream. The speed of the winds in the jet stream weakens and strengthens with the direction of the QBO. The jet stream is an important atmospheric feature that brings us our weather here in the UK, and the risk of winter conditions in Northern Europe can differ depending on the phase of the QBO:

- When the QBO is easterly, the chance of a weak jet stream, sudden stratospheric warming events and colder winters in Northern Europe is increased.
- A sudden stratospheric warming (SSW) is an event in which the polar stratospheric temperature rises by several tens of Kelvin (up to increases of about 50 °C (122 °F)) over the course of a few days. The change is preceded by a situation in which the Polar jet stream of westerly winds in the winter hemisphere is disturbed by natural weather patterns or disturbances in the lower atmosphere.
- When the QBO is westerly, the chance of a strong jet, a mild winter, winter storms and heavy rainfall increases.

QBO and solar variability modulate stratospheric winds in the winter hemisphere, which modifies the propagation conditions for planetary waves and feeds back on winds and temperature. It has been suggested by Holton and Tan [25,26] that, during the westerly QBO phase, the polar vortex is stronger and colder than during the easterly phase. Since then, several authors have shown that this effect holds mainly for early winter months and also depends on the solar cycle phase being significant only during solar minimum

The North Atlantic Oscillation (NAO) is measured as the difference in pressure between the Icelandic Low and the Bermuda-Azores high. Positive NAO occurs with a large pressure difference and a strong storm track, which brings wet and stormy weather to North West Europe; Negative NAO has a small pressure difference and is associated with dry weather in North West Europe. The NAO is associated with the Arctic Oscillation (AO), which is defined as the leading Empirical Orthogonal Function of the NAO and extends up into the stratosphere. Many researches consider the NAO as a \bell", because it is an amplified response to small forthings and is amplified beyond what one might expect compared to the stratospheric / upper tropospheric signal.

Two factors, which force the NAO, are the solar cycle and to a lesser extent the Quasi-Biennial Oscillation QBO); the oscillation between easterly and westerly winds in the equatorial stratosphere. Solar activity is found to influence the NAO such that strongly negative winter NAO values (which cause cold and dry conditions in North West Europe) rarely occur during periods of high solar activity [18,19].

The North Atlantic Oscillation (NAO) is one of the major modes of variability of the Northern Hemisphere atmosphere. It is a large scale see-saw in atmospheric mass between the subtropical high and the polar low exerting a strong control on winter climate in Europe, North America, and Northern Asia. The NAO index is defined as the normalized pressure difference between stations on the Azores and Iceland.

A positive NAO index indicates a stronger than usual subtropical high pressure center and a deeper than normal Icelandic low. The increased pressure difference results in more and stronger winter storms, crossing the Atlantic Ocean on a more northerly track. This results in warm and wet winters in Europe and cold and dry winters in Greenland and Northern Canada, while the eastern United States experiences mild and wet winter conditions. A negative NAO index points to a weak subtropical high and a weak Icelandic low. The reduced pressure gradient results in fewer and weaker winter storms crossing mostly on west-east paths bringing moist air into the Mediterranean and cold air to Northern Europe. The east cost of the United States gets more cold air and snow while Greenland enjoys mild winters

After ENSO, the NAO is one of the most dominant modes of global climate variability. Like El Niño, La Niña, and the Southern Oscillation, it is considered a free internal oscillation of the climate system not subjected to external forcing. It is shown, however, that it is closely linked to energetic solar eruptions. Surprisingly, it turns out that features of solar activity that have been shown to be related to El Niños and La Niñas, also have an impact on the NAO.

Westerly winds blowing across the Atlantic bring moist air into Europe. In years when westerly are strong, summers are cool, winters are mild and rain is frequent. If westerlies are suppressed, the temperature is more extreme in summer and winter leading to heat waves, deep freezes and reduced rainfall.

A permanent low-pressure system over Iceland (the Icelandic Low) and a permanent high-pressure system over the Azores (the Azores High) control the direction and strength of westerly winds into Europe. The relative strengths and positions of these systems vary from year to year and this variation is known as the NAO. A large difference in the pressure at the two stations (a high index year, denoted NAO+) leads to increased westerlies and, consequently, cool summers and mild and wet winters in Central Europe and its Atlantic facade. In contrast, if the index is low (NAO-), westerlies are suppressed, northern European areas suffer cold dry winters and storms track southwards toward the Mediterranean Sea. This brings increased storm activity and rainfall to southern Europe and North Africa.

Especially during the months of November to April, the NAO is responsible for much of the variability of weather in the North Atlantic region, affecting wind speed and wind direction changes, changes in temperature and moisture distribution and the intensity, number and track of storms. Research now suggests that the NAO may be more predictable than previously assumed and skillful winter forecasts may be possible for the NAO.

The North Atlantic Oscillation is usually described as a movement of atmospheric mass between the Arctic and the subtropical Atlantic [27]. There is no unique way to define the NAO. However, there are two pressure areas often used when describ-ing the phenomenon, the Icelandic low- and the Azores high-pressure systems. The variations in sea level pressure between these two areas generate a pres-sure gradient. Because of this pressure gradient, west-erly winds over the North Atlantic are generated [27]. The westerly winds, also known as “jets”, reach their maximum speed of 40 m/s at about 12 km up in the troposphere [1].

The NAO exhibits considerable inter-seasonal and inter-annual variability, and prolonged periods (several months) of both positive and negative phases of the pattern are common. The wintertime NAO also exhibits significant multi-decade variability [2, 28]. For example, the negative phase of the NAO dominated the circulation from the mid-1950's through the 1978/79 winter. During this approximately 24-year interval, there were four prominent periods of at least three years each in which the negative phase was dominant and the positive phase was notably absent. In fact, during the entire period the positive phase was observed in the seasonal mean only three times, and it never appeared in two consecutive years.

An abrupt transition to recurring positive phases of the NAO then occurred during the 1979/80 winter, with the atmosphere remaining locked into this mode through the 1994/95 winter season. During this 15-year interval, a substantial negative phase of the pattern appeared only twice, in the winters of 1984/85 and 1985/86. However, November 1995 - February 1996 (NDJF 95/96) was characterized by a return to the strong negative phase of the NAO.

When measuring the NAO different statistical methods can be used, either station-based or pattern-based [27]. A station-based index is measured as the normalized sea level pressure differences between two monitoring stations in the vicinity of the Icelandic low and Azores high. Alternatively, a spatial-based index, or a principal component based index, can be calculated from performing principle component analysis on the mean sea level pressure anomalies over the North Atlantic sector (usually between 20-80ºN and 90ºW-40ºE) [27]. The NAO is described as being in an either positive or negative phase (see Fig. 1). These phases are describing the strength of the circulation pattern. In a positive (NAO+) state the Icelandic low and the Azores high are well developed, resulting in a greater pressure gradient between these two areas. A greater pressure gradient causes stronger and more northern westerly winds. In a negative (NAO-) phase the pressure anomalies at the nodes of the NAO are less developed than normal and as a result the westerly winds get weaker and are positioned further south. However it is important to point out is that there is not only a confined positive and negative phase of the NAO, but also everything in between [27]. The NAO affects the climate mainly during wintertime when the NAO accounts for more than one-third of the total sea level pressure variance over the North Atlantic Ocean [1]. During summertime the spatial extent of the NAO and the sea level pressure variance are smaller than during winter. Atmospheric variations are lager during wintertime which makes the effect of the NAO on surface climate bigger than during summertime. Because of this, most research on the NAO is restricted to wintertime, however the NAO is still noticeable all year around [1]. There have been periods when the NAO persisted in an either positive or negative phase. During the beginning of the last century until approximately 1930 the NAO winters were characterized by a positive phase. During the 1960s the NAO winters instead showed persistent negative NAO anomalies [1]. Although decadal NAO trends is shown, it is observed that variations in the NAO can occur on very different timescales, making it hard to assess any preferred timescale of the NAO variability. The positive and negative NAO phases are also connected to different patterns of precipitation as a result of variations in the strength and paths of storms generated over the Atlantic. During a positive NAO the North Atlantic storm track is usually directed more north-eastward over northern Europe than during negative NAO winters [1]. This makes positive NAO phases associated to precipitation anomalies above normal in northern Europe and Scandinavia, while the precipitation levels over southern and central Europe are below average. The opposite precipitation pattern is notable during negative NAO phases.

The Southern Oscillation and the North Atlantic Oscillation are comparable climate phenomena though located in different world regions. So I adopted the working hypothesis that the NAO, if subjected to solar forcing, would be related to the same phases of eruptional activity within the 11-year sunspot cycle as ENSO events. To test this hypothesis, I investigated yearly means of the NAO index covering 1825 to 2000. Jones et al. **(1997)** used early instrumental data to extend the index back to 1825. These data are available at the Climate Research Unit of the University of East Anglia **(2001)**. When I subjected the time series to 5-year moving window Gaussian kernel smoothing **(Lorczak)**, the smoothed curve displayed 36 extrema (maxima and minima). I related the dates of these NAO extrema to the respective sunspot cycles normalized to 11 years [14,15,16]. An analysis of the normalized positions of the extrema within the 11-year cycle showed that just the points **a**, **d**, **a/d**, and **d/a**, which play a major role in the relationship with ENSO events, show a close connection with NAO extrema when the data are shifted to offset a 1.5-year lag of the NAO maxima and minima. As to ENSO events in the Pacific, such lags reach at most a few months. A wider lag in the North Atlantic is acceptable as its location is far north of the equator where El Niño and La Niña develop in a climate with a much higher energy potential. Thermal inertia of the oceans and marine currents may be involved

The North Atlantic Oscillation (NAO) index is based on the surface sea-level pressure difference between the Subtropical (Azores) High and the Subpolar - Low. The positive phase of the NAO reflects below-normal heights and pressure across the high latitudes of the North Atlantic and above-normal heights and pressure over the central North Atlantic, the eastern United States and Western Europe. The negative phase reflects an opposite pattern of height and pressure anomalies over these regions. Both phases of the NAO are associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track, and in large-scale modulations of the normal patterns of zonal and meridional heat and moisture transport, which in turn results in changes in temperature and precipitation patterns often extending from eastern North America to western and central Europe.

Strong positive phases of the NAO tend to be associated with above-normal temperatures in the eastern United States and across northern Europe and below-normal temperatures in Greenland and oftentimes across southern Europe and the Middle East [29,30]. They are also associated with above-normal precipitation over northern Europe and Scandinavia and below-normal precipitation over southern and central Europe. Opposite patterns of temperature and precipitation anomalies are typically observed during strong negative phases of the NAO. During particularly prolonged periods dominated by one particular phase of the NAO, abnormal height and temperature patterns are also often seen extending well into central Russia and north-central Siberia. The NAO exhibits considerable interseasonal and interannual variability, and prolonged periods (several months) of both positive and negative phases of the pattern are common.

The NAO index is obtained by projecting the NAO loading pattern to the daily anomaly 500 millibar height field over 0-90°N. The NAO loading pattern has been chosen as the first mode of a Rotated Empirical Orthogonal Function (EOF) analysis using monthly mean 500 millibar height anomaly data from 1950 to 2000 over 0-90°N latitude.

The NAO has been linked with a variety of meteorological and non-meteorological effects across a wide spatial and multiple temporal scales, and only a selection of these impacts can be mentioned here. For example, in [31] showed a strong relationship between the mass balance of Scandinavian glaciers and the NAO due to the controlling influence of the storm tracks by the NAO, which influenced precipitation amounts, and glacier mass balance as a result. Coincidentally, the NAO has been shown to explain a large amount of the variance in Norwegian streamflow (55%) and hydropower output (30%), influencing electricity consumption and prices [32,33]. Baltic sea-ice extent is also strongly related to NAO changes [33]. In work [34]) found an influence of the NAO as far south as 20°N in coastal upwelling-inducing winds along the northwest African coastline. The great-circle distance between northwest Africa and Scandinavia is ~5,700 km, indicating the great spatial extent of the NAO influence. Recent NAO–climate linkages literature includes a strong signal of the (non-summer) NAO on precipitation in Iraq [35], an influence on sea-ice breakup date in south-central Ontario [36]) and even a Southern Hemisphere influence, via a decadal-scale mechanism, on subtropical eastern Australian rainfall [37].

Table 1. Five lowest and five highest NAO years for each calendar month and season, based on the Hurrell PC NAO index and the January 1899–February 2016 period, updated from [11,22].

Month	5 lowest	5 highest
Jan	1966, 1969, 1940, 1963, 1945	1993, 1989, 1983, 1928, 1990
Feb	1947, 2010, 1978, 1942, 1960	1990, 1989, 1997, 2000, 1959
Mar	2013, 1962, 1958, 1931, 1952	1986, 1990, 1913, 1920, 1994
Apr	1966, 1978, 1988, 1979, 2008	1947, 2011, 1943, 1990, 1904
May	1993, 2008, 1954, 1952, 1909	1956, 1963, 2009, 1914, 2015
Jun	1902, 1903, 2009, 1982, 2011/2012	1994, 1961, 1967, 1922, 1919
Jul	2015, 1907, 1962, 2009, 1918,	1964, 1920, 1946, 1935, 1975
Aug	1943, 1964, 1958, 2011, 1966	1991, 1971, 1983, 1961, 2013
Sep	1998, 1930, 1968, 1939, 1915	1975, 1947, 2009, 1917, 1950
Oct	2006, 1960, 2012, 1966, 1968	1986, 1957, 1983, 1938, 1935
Nov	1910, 1947, 1955, 1915, 1965	1978, 1982, 1992, 1953, 1913
Dec	2010, 2009, 1961, 1995, 1978	2011, 2006, 1951/1982, 2004

Particular increase in the NAO between the 1960s and 1990s was widely noted in previous work and was thought to be related to human-induced greenhouse gas forcing. However, since then this trend has reversed, with a significant decrease in the summer NAO since the 1990s and a striking increase in variability of the winter especially December—NAO that has resulted in four of the six highest and two of the five lowest NAO Decembers occurring during 2004–2015 in the 116-year record, with accompanying more variable year-to-year winter weather conditions over the United Kingdom. These NAO changes are related to an increasing trend in the Greenland Blocking Index (GBI; equals high pressure over Greenland) in summer and a significantly more variable GBI in December. Such NAO and related jet stream and blocking changes are not generally present in the current generation of global climate models, although recent process studies offer insights into their possible causes. Several plausible climate forcing and feedbacks, including changes in the sun's energy output and the Arctic amplification of global warming with accompanying reductions in sea ice, may help explain the recent NAO changes. Recent research also suggests significant skill in being able to make seasonal NAO predictions and therefore long-range weather forecasts for up to several months ahead for northwest Europe [3,38]. However, global climate models remain unclear on longer-term NAO predictions for the remainder of the 21st century.

Climate phenomena subject to MJO influences include the monsoons and several climate modes such as ENSO, the North Atlantic Oscillation (NAO), the AO and Antarctic Oscillation (AAO), the Pacific North American (PNA) pattern, and the Indian Ocean Dipole (IOD). While these climate modes all feed back to the MJO, discussions in this section focus on MJO effects on them.

During winter, the positive (negative) phase of the AO, also known as the Northern Annular Mode (NAM), is twice as likely to occur as the opposite phase when MJO convection is enhanced (suppressed) over the Indian Ocean. When MJO convection is enhanced (suppressed) in the Eastern Hemisphere, especially over the Maritime Continent, the number of days of positive (negative) AO phase becomes large. In November–March, 18–21% of the variance in extratropical 1000-hPa geopotential height is related to the MJO. The MJO influence on the AO is also through Rossby wave trains excited by MJO convection and propagating from the tropical Pacific into the extratropics.

The southern hemispheric counterparts of the NAM and AO are the Southern Annular Mode (SAM) and AAO. They are also influenced by the MJO. Negative (positive) phases of the AAO in austral winter tend to occur when MJO convection is enhanced (suppressed) over the central Pacific. The SAM reaches its maximum positive phase immediately after MJO convection peaks over the equatorial Indian Ocean. The Antarctic circumpolar transport can be accelerated by MJO-enhanced surface westerly wind associated with the SAM that covers almost the entire latitude circle at 60° S.

The NAO/NAM pattern is a result of the eddy-driven extratropical atmospheric circulation: specifically, the transport of heat and momentum by stationary eddies (longwaves or planetary waves in the northern polar jet stream) and transient eddies (cyclones and anticyclones forming within or along the jet stream) ([22,39]. The polar jet stream is directly related to NAO changes and has mean latitude somewhere between 50°N and 60°N over the eastern North Atlantic. The strongest westerly winds (of up to about 200 km/hr in the core of the jet near the tropopause) are typically experienced at these latitudes, and there is a clear clustering of extratropical storm tracks along the polar jet stream. The prevailing direction is westerly due to the Coriolis Effect of earth’s rotation, which deflects air masses to the right of their direction of motion in the Northern Hemisphere. Longwaves develop in the jet stream because of orographic obstacles (e.g., the Rocky Mountains over North America) or east–west heating contrasts between land and sea, or variations in latent heating due to condensation and rainfall. Low- and high-pressure systems form due to strong horizontal contrasts in temperature, typically where cold polar air meets relatively warm tropical air masses. These transient eddies are very important in providing energy for maintaining the polar jet stream flow and mid-latitude westerlies, otherwise friction with the surface would slow and eventually halt the winds. However, a significant contribution to maintaining the westerlies-greater than in the Southern Hemisphere—comes from the stationary eddies: this is due to the much stronger land–ocean contrast effects in northern mid-latitudes [40,41].

Being linked with the jet stream, there is a deep and pronounced vertical structure to the AO and NAO, which extends up into the stratosphere; this is most notable for the AO, which lies further north and is more directly linked with the polar vortex. What happens in the stratosphere in polar winter can also have a big bearing on conditions in the troposphere: for example, stratospheric sudden warming are associated with a weakening and sometimes reversal of the polar vortex and development of negative NAO/ AO that sometimes occurs in mid- to late winter [38,42]. Stratosphere–troposphere interaction and coupling is not very well understood, yet is important for NAO dynamics [43]. It appears from theory and observations that planetary-scale Rossby waves can propagate upwards from the troposphere into the stratosphere under conditions of moderate westerly flow during boreal winter; the stratosphere is effectively decoupled from the troposphere in other seasons. If the wintertime polar vortex is weak (strong), the upward-propagating waves can (cannot readily) interact with and slow the upper-level westerly flow. There is also a kind of reverse effect where airflow anomalies in the stratosphere can propagate down to affect the near-surface circulation [44] Baldwin & Dunkerton, 2001). The time of operation of these changes is typically 2–3 weeks, although dynamical couplings range over timescales from daily to multidecadal [43].

Between the 1960s and 1990s the NAO was becoming more positive, but since then this trend has tended to reverse. Recently updated observational records and reanalyses showed increasing variability of winter NAO and AO, which is a feature not just of the 2000ts and early 2010ts but has been ongoing during the 20th century.

Conclusion

The forecasting systems were predicting the development of a potentially major El Niño – a warming of the equatorial Pacific Ocean which has impacts on weather patterns around the world. The 2015/16 El Niño turned out to be in the same class as the biggest such events recorded in the 20th century. Its evolution was well predicted by ECMWF forecasts as well as by EUROSIP multi-model forecasts. The latest forecasts for 2017 at the time of going to press are indicating the possibility of another El Niño developing later this year. El Niño is the warm phase of the El Niño Southern Oscillation (ENSO). The cool phase is known as La Niña. The two strongest El Niños of the 20th century were those of 1982/83 and 1997/98, each of which was considered at the time a 'once-in-a-century' event. The El Niño of 2015/16 is in the same class as those of 1982/83 and 1997/98, and it set new records in the NINO4 and NINO3.4 regions in the western and central Pacific.

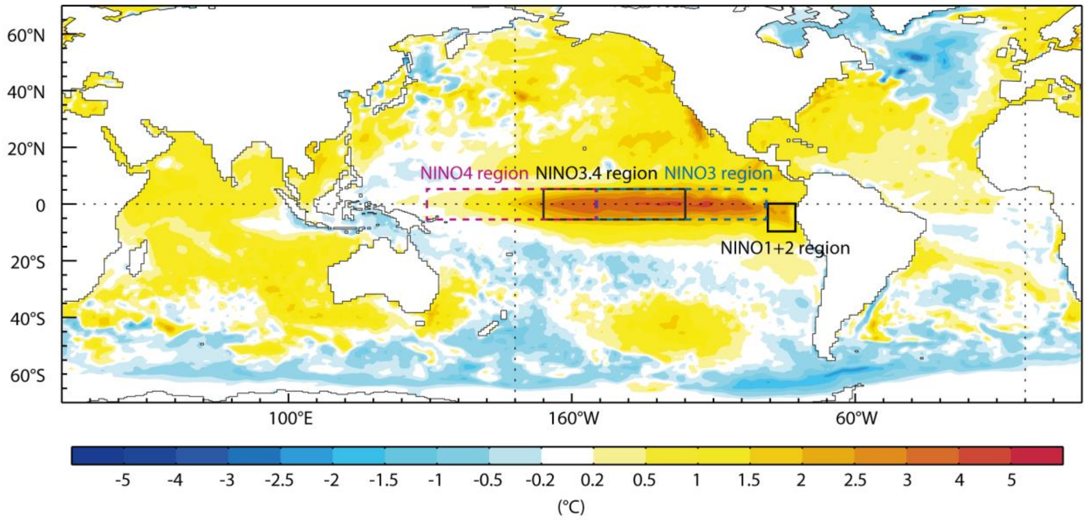

Fig. 1. Average sea-surface temperature anomalies in November 2015, when the El Niño event peaked in the NINO3.4 region. The chart shows SST anomalies compared to the 1981–2009 average.

Fig. 1 shows the spatial structure of the El Niño at its peak in November 2015. The vast extent of the event – more than 10,000 km in zonal (east–west) extent – and its ability to influence the deep tropical convection that drives the general circulation of the atmosphere is what gives El Niño its global impact. El Niño variability is generally monitored by the use of indices, calculated from average sea-surface temperatures (SST) over the regions marked on the map. NINO3.4, covering the central region of the equatorial Pacific, is most commonly used as a measure of the overall strength of an ENSO event.

The 2015/16 El Niño can best be understood by looking at the evolution of NINO3.4 SST (Fig. 2). In a normal year, there is a pronounced seasonal cycle in SST, as indicated by the red line. El Niño conditions are normally monitored as anomalies with respect to this mean seasonal cycle. At the beginning of 2015, the equatorial Pacific was already warm, as a leftover from borderline El Niño conditions which developed during 2014. The SST warmed at the usual rate during March, but continued warming through April and into May, with temperatures approaching 29°C. Normally, the ocean surface cools from June to September, as zonal winds strengthen and upwell cooler water at the equator, but in 2015/16 equatorial waters stayed warm for a whole year, with peak temperatures reached in November. Thus the usual seasonal cycle was completely upended. Due to the nature of the coupling between ocean and atmosphere in the equatorial Pacific, this dramatic change in SST was both a symptom and a cause of corresponding major changes in atmospheric winds and precipitation patterns.

The 2015/16 El Niño broke warming records in the central Pacific, represented by the NINO3.4 and NINO4 indices. At its peak in November 2015, the NINO3.4 SST anomaly reached 3.0°C, breaking the previous record of 2.8°C set in January 1983. In the NINO4 region, large positive anomalies are hard to achieve because average conditions are already warm. In 2015, the anomaly reached 1.7°C, a substantial increase of 0.4°C on the previous record, set in 2009. SST analyses become less precise going back in time, but the size of the anomalies in NINO4 and NINO3.4 means we are fairly confident that these are record values for the whole of the observational period back to 1860. By contrast, in the eastern Pacific (monitored by indices for the NINO3 and NINO1+2 regions) the El Niño remained below the level of the 1982/83 and 1997/98 events. It must be borne in mind that the anomaly records depend on the reference climate, which in this case is a 30-year climate (1981–2010).

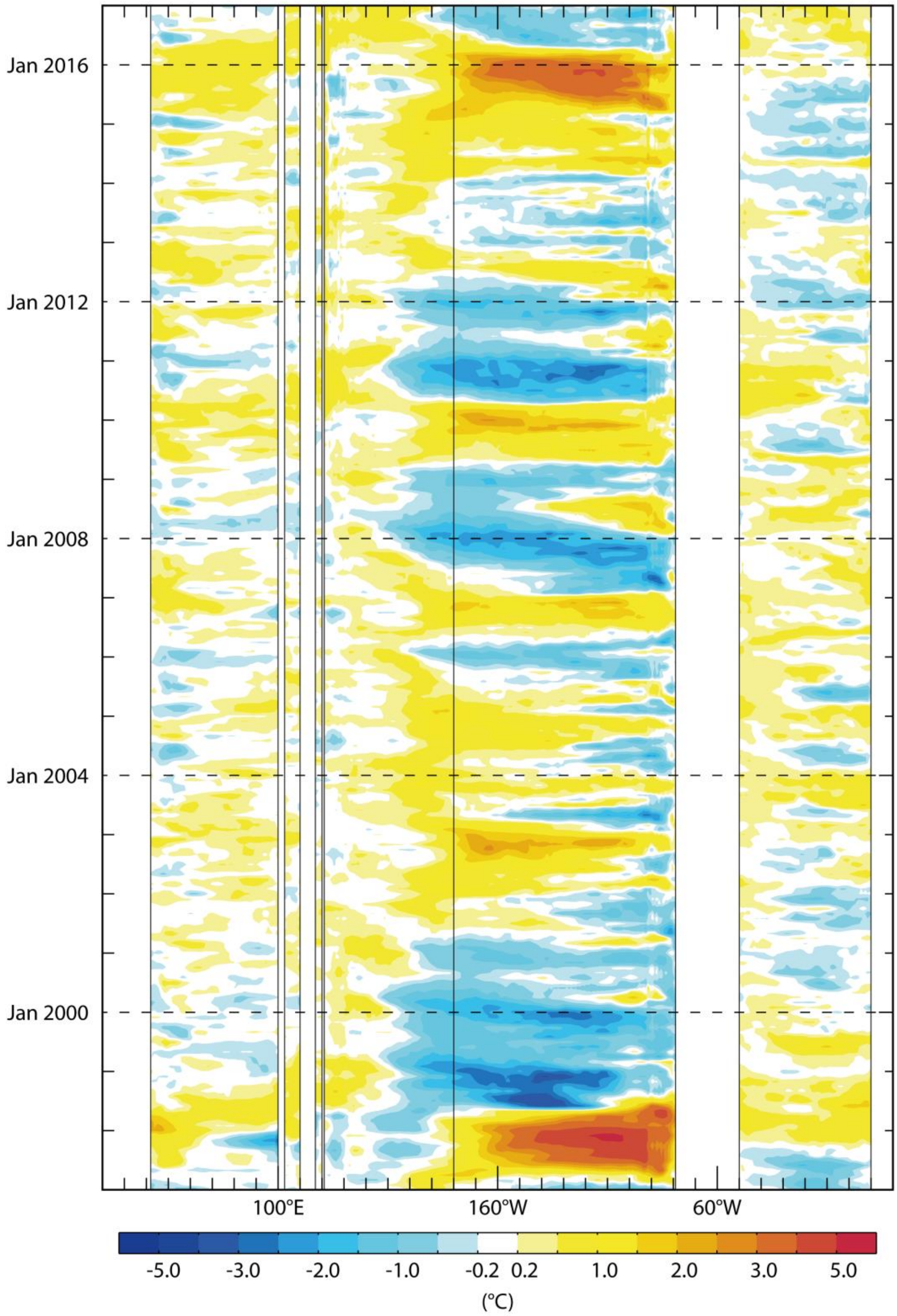

Fig. 2. Observed sea-surface temperature anomalies at the equator from January 1997 up to December 2016, compared to the 1981–2009 average.

Fig. 2 puts the current event in the context of the last 20 years. It shows the evolution of SST anomalies at the equator from January 1997 (bottom) to December 2016 (top), with conspicuous spikes in 1997/98 and at the end of 2015. It shows that at the equator the 2015/16 event was exceptionally strong, but not quite as strong as 1997/98. The peak warm anomalies were not so long-lived either, decaying quickly after November 2015. The aftermaths of the events are also remarkably different: 1997/98 was followed by an intense and long-lived cold La Niña episode, while the 2016 La Niña has been weak and short-lived. In between, the chart shows fluctuations between warm El Niño conditions and colder La Niña episodes in the central and eastern Pacific.

Although ENSO is a coupled ocean–atmosphere phenomenon centered over the tropical Pacific, its fluctuations affect the climate in other parts of the globe. During an ENSO event, the enhanced convection over the warm waters in the central and eastern tropical Pacific triggers changes in the strength of the Hadley circulation, leading to modifications in circulation patterns worldwide including, for example, the position of the jet stream that flows from west to east over the North Pacific in winter months. By strengthening the Hadley circulation, ENSO can trigger a cascade of deviations from normal rainfall and temperature patterns around the globe. These remote impacts are called ENSO teleconnections. ENSO teleconnection patterns are reflected in historical observations and are the basis of any empirical model.

The predictive skill of any dynamical model is strongly associated with the ability to accurately reproduce ENSO teleconnections. It follows that in years when ENSO is active, seasonal predictions are expected to be more accurate than in years when ENSO is in neutral conditions [45].

The year 2015 was hotter than any previous year in global datasets going back more than 130 years. Global near-surface temperature was well over 0.4°C warmer than the 1981–2010 average and almost 0.1°C warmer than the previous warmest year. The year 2016 was in turn nearly 0.2°C warmer than 2015 and about 1.3°C warmer than pre-industrial levels, according to data released by the EU-funded Copernicus Climate Change Service run by ECMWF. El Niño 2015/16 undoubtedly contributed to the record-breaking global temperatures. The size of that contribution will not be addressed here. It is, however, important to note that because of the warmer climate some of the ENSO impacts detected in historical data might not necessarily materialise. Indeed, the challenge of seasonal prediction is to forecast ENSO impacts in a changing mean climate. Dynamical models such as the one used by ECMWF have the potential to simulate the effects of ENSO in a warming climate.

The ECMWF seasonal forecast system has been operational for more than five years and will soon be replaced by an upgraded system, SEAS5. SEAS5 will benefit from the latest IFS cycle upgrades, bringing increased resolution in the ocean and atmospheric components. In a development of special interest for Europe, it will for the first time include a dynamic sea-ice model.

In a separate development, the Copernicus Climate Change Service (C3S) is trialling a prototype seasonal forecast service which offers multi-model El Niño forecasts and is expected to replace the EUROSIP multi-model system in due course. The core providers for this service are ECMWF, the UK Met Office and Météo-France. In addition, Italy's Euro-Mediterranean Center on Climate Change (CMCC) and Germany's National Meteorological Service (DWD) will start submitting data for inclusion in the service's product suite in the course of 2017. They are now set to be joined by NCEP and JMA

SST anomalies in the tropical Pacific are already above zero, and all forecasts included in the C3S seasonal multi-system predict that they will most likely continue to rise over the next few months. There is, however, still considerable uncertainty about how strong the event will be.

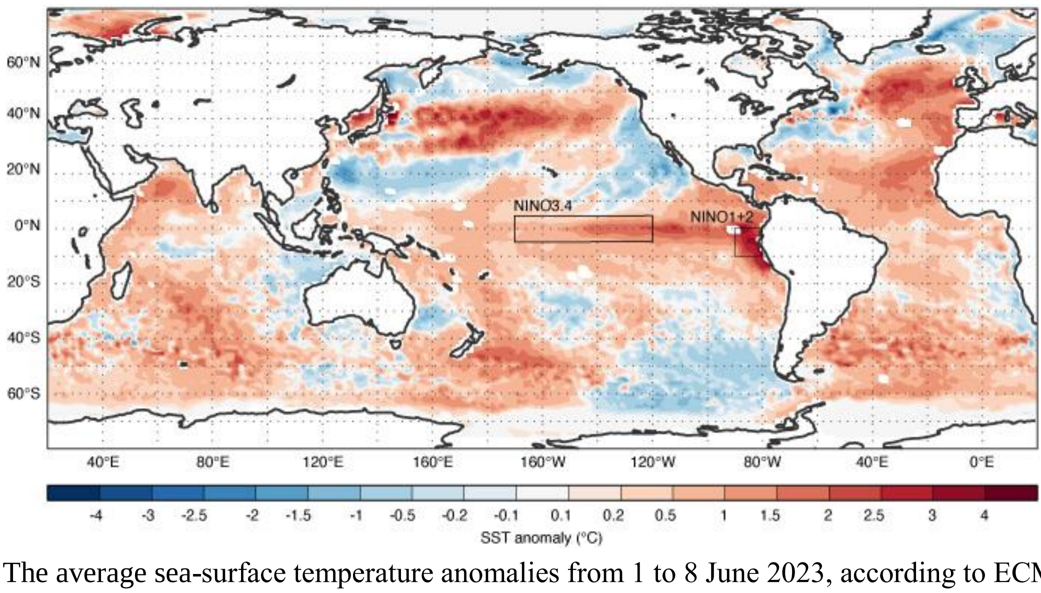

Fig. 3. The average sea-surface temperature anomalies from 1 to 8 June 2023, according to ECMWF's Ocean Reanalysis System 5 (ORAS5).

The plot shows average sea-surface temperature anomalies from 1 to 8 June 2023, according to ECMWF's Ocean Reanalysis System 5 (ORAS5). The SST anomalies are calculated based on the 1993–

2016 average. The boxes show commonly used areas for which anomalies are forecast. Areas around islands are left blank (Fig. 3).

An El Niño event temporarily increases global average 2-metre temperatures in the year after the peak of the event. That is why the WMO is saying that global temperatures will probably ”surge to record levels” over the next few years.

Substantial El Niño events are also associated with significant changes in weather patterns, especially in areas close to the tropical Pacific. The eastward movement of the warming of surface waters in the tropical Pacific brings higher than average pressure and less rain to the western Pacific, and lower pressure and more rain to the eastern Pacific.

El Niño events also contribute to other climate anomalies around the world. The specifics of the anomalies can differ from event to event, and the effects over Europe are particularly uncertain.

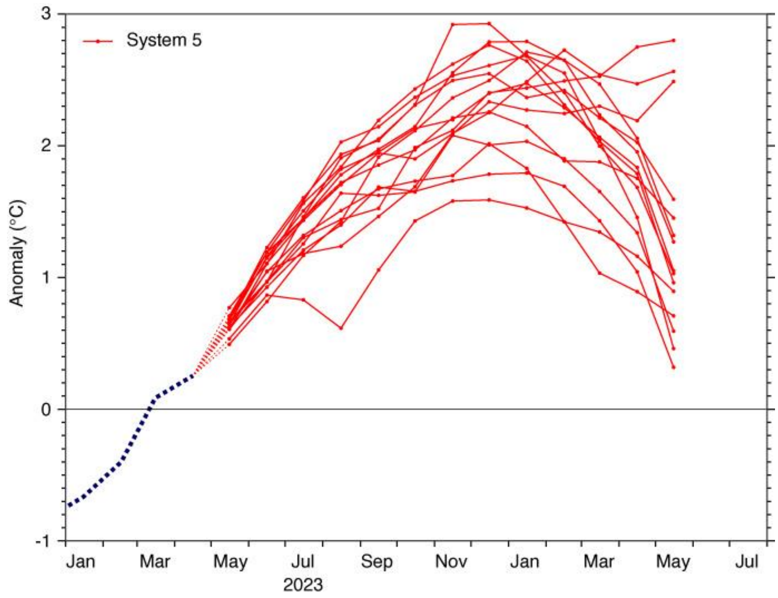

Fig. 4. 13-month NINO3.4 SST anomaly plume in an ECMWF forecast from 1 May 2023. The monthly mean anomalies are calculated relative to the 19812010 climatology.

ECMWF also issues 13-month NINO3.4 anomaly forecasts on 1 February, May, August and November as part of its open access forecasts. The May forecast suggests that high values are likely to dissipate in the first part of next year, although it predicts a small chance that high anomalies will continue well into 2024 (Fig. 4).

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ატმოსფეროს პერიოდული ოსცილაციები

მ. ტატიშვილი, ა. ფალავანდიშვილი

რეზიუმე

ჩრდილო ატლანტიკური ოსცილაცია, კვაზი ბინალური ოსცილაცია, მათი უარყოფითი და დადებითი ფაზები განხილულია წარმოდგენილ სტატიაში. El Niño მოვლენა არის ზღვის ზედაპირის არანორმალურად მაღალი ტემპერატურის (SST) ხანგრძლივი პერიოდი ტროპიკულ წყნარ ოკეანეში. იგი ხდება ატმოსფერული პირობების ცვლილებებთან ერთად და შეიძლება ჰქონდეს ძლიერი გავლენა გლობალურ ამინდზე. ელ ნინიოს ასევე შეუძლია მნიშვნელოვნად იმოქმედოს გლობალურ საშუალო ტემპერატურაზე. ECMWF სეზონური პროგნოზის სისტემა ფუნქციონირებს ხუთ წელზე მეტი ხნის განმავლობაში და მალე ჩაანაცვლებს განახლებული სისტემით, SEAS5.UDC 551.576

საკვანძო სიტყვები: ჩრდილო ატლანტიკური რხევა (NAO), ზღვის დონის წნევა, კვაზი ორწლიანი რხევა (QBO), ზღვის ზედაპირის ტემპერატურა, ელ-ნინიო.

Атмосферные периодические колебания

М.Р. Татишвили, А.М. Палавандишвили

Резюме

В представленной статье рассмотрены Североатлантическое колебание, квазидвухлетнее колебание, их отрицательная и положительная фазы. Явление Эль-Ниньо – это длительный период аномально высоких температур поверхности моря (ТПМ) в тропической части Тихого океана. Он идет рука об руку с изменениями атмосферных условий и может иметь серьезные последствия для глобальных погодных условий. Эль-Ниньо также может существенно повлиять на глобальную среднюю температуру Система сезонных прогнозов ЕЦСПП работает уже более пяти лет и вскоре будет заменена модернизированной системой SEAS5.

Ключевые слова: Североатлантическое колебание (NAO), давление на уровне моря, квази двухлетнее колебание (QBO), температура поверхности моря, Эль-Ниньо.