

The impacts of the Luni-Solar oscillation on the Arctic oscillation

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[1] The Arctic Oscillation (AO) has a major impact on climate variability in the extra tropical regions of the Northern Hemisphere. In this study, we show that specific alignments between the Sun, the Moon and the Earth known as the Luni-Solar Oscillation (LSO) that occur at frequencies of nearly 9 and 18 years are unambiguously correlated with the AO since the mid-1960's. The occurrence of the LSO peaks is predictable and, as a result, it improves climate predictability. Furthermore, we hypothesize that the recent observed increase in the AO amplitude maybe due to ice melting in the Arctic and SST increases at northern latitudes combined with the recent LSO peaks. **Citation:** Ramos da Silva, R., and R. Avissar (2005), The impacts of the Luni-Solar oscillation on the Arctic oscillation, *Geophys. Res. Lett.*, 32, L22703, doi:10.1029/2005GL023418.

1. Introduction

[2] The Arctic Oscillation (AO) is an important characteristic of the Northern Hemisphere climatic variability, whose magnitude and decadal variability seem to have increased since the 1960's [Thompson *et al.*, 2000]. A positive AO index is associated with lower than normal atmospheric pressure over the Arctic that leads to stronger than normal westerly winds that trap cold air masses in the northern latitudes. As a result, North America has warmer than normal winters, Europe gets heat and moisture from the stronger westerlies, the Mediterranean suffers from drought, and the northeastern trade winds grow stronger. By contrast, a negative AO index is associated with higher than normal atmospheric pressure over the Arctic, weaker than normal westerly winds, and further south transport of cold air masses. As a result, North America, Northern Europe and Asia have colder winters, the Mediterranean Basin experiences more precipitation, and the northeastern trade winds weaken [Thompson and Wallace, 1998; Thompson *et al.*, 2000]. Thus, understanding the AO mechanism has significant implications for climate analysis and prediction. It has been speculated that solar or volcanic variability, or internal non-linear processes are possible forcings of the AO [Moritz *et al.*, 2002]. However, none of these forcings fully explain its behavior.

[3] Recent studies have reported an 18.6-year signal in various climatological records in the Northern Hemisphere such as the number of tropical cyclones in North Atlantic [Currie, 1996], and the Arctic air and ocean temperatures [Royer, 1993]. They coincide with alignments of the sun and the moon in such orbits that their gravity force on the earth's surface is modified. The link between this Luni-Solar Oscillation (LSO) and climate seems to be associated

with oceanic tidal dynamics [Keeling and Whorf, 1997]. The gravitational force of the Moon into our planet is about twice that of the Sun due to its proximity to Earth [Wood, 2001a]. Thus, the Moon-Sun-Earth alignment during syzygy (full or new moon) that repeats itself twice every 29.5 days leads to stronger tides. The Moon and the Sun relative inclination also affect the tide forcing. Twice every 27.2 days the Moon crosses the plane of the ecliptic (the nodical month). The moon reaches a maximum declination of $28^{\circ}40'$ during its ascending node every 18.6 years (the nodal tide). Since this cycle repeats itself when the Moon is on its descending node, it produces a cycle of about 9.3 years [Wood, 2001a]. At those times, diurnal and semi-diurnal tides are stronger at high northern latitudes [Wood, 2001b]. In its elliptical orbit the Moon reaches its closest distance to Earth during the perigee, every 27.5 days. Similarly the Sun is in its nearest approach to Earth at the perihelion (03 January). Maximum tides happen during special astronomical combinations of syzygy, perigee, solar eclipse, and perihelion. The highest frequency during which these combinations occur is nearly 18 years. At high latitudes, we can expect stronger tides during perigee-syzygy events, in January, and in the years when the lunar declination is at its maximum.

[4] Oceanic tidal forcing can modify effectively the intensity of vertical eddy diffusion mixing in shallow waters and deep waters [Egbert and Ray, 2001; Garrett, 2003]. Indeed, while wind drag energy for mixing oceanic waters is about 1.2 terawatts, tidal energy is about 3.5 terawatts [Munk and Wunsch, 1998]. Until recently, it was believed that in the open oceans tides would not be effective at dissipating energy. But using data collected by the TOPEX/Poseidon radar altimeter satellite Egbert and Ray [2001] showed that about one terawatt is dissipated by the semi-diurnal tide in these regions, mainly over rough floor such as oceanic ridges. These findings are supported by a series of recent observational campaigns (e.g., Rudnick *et al.* [2003], who found large internal tidal waves peak-to-peak amplitudes of up to 300 meters and strong dissipation over the Hawaiian Ridge). It is worth noting that Polzin *et al.* [1997] also found very large mixing rates throughout the water column above the Mid-Atlantic Ridge. Furthermore, Egbert and Ray [2001] show that the strongest tidal mixing on Earth is located in the European Shelf and in the Hudson Bay near the Labrador Sea, with intensities of about 200 and 250 gigawatts, respectively. They also found that the tidal energy flux passing from the South Atlantic into the North Atlantic is as large as 420 gigawatts, in addition to large fluxes entering the European Shelf, the Norwegian, Greenland, Northeastern Pacific, and Labrador seas. Analysis of air temperature variability in Alaska by Royer [1993] shows that the next most important signal to an annual amplitude of 6.5°C , has a frequency of 18.6 years and an amplitude of

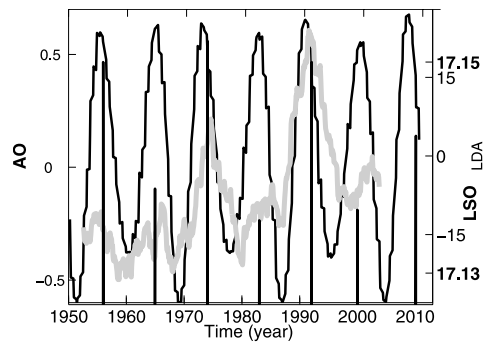


Figure 1. Arctic Oscillation (AO) Index (gray), Luni-Solar Oscillation (LSO) represented by the Moon's angular speed [degrees/day] (bars), and Lunar Declination Angle (LDA) at the perigee [degrees] (black). The AO index, which is available from NCEP, was smoothed using 5-year running means.

0.3°C. Based on these findings, we hypothesize that the LSO may affect the AO.

2. Data and Methods

[5] The AO signal can be detected from the first principal component (PC) of the Empirical Orthogonal Function (EOF) analysis applied to the observed monthly-mean, 1000-hPa height anomalies poleward of 20°N [Thompson and Wallace, 1998]. The data for the current analysis were obtained from NCEP (available at: www.cpc.ncep.noaa.gov). The seasonal cycle has been removed from the monthly mean height field. To ensure equal area weighting for the covariance matrix, the data is weighted by the square root of the cosine of latitude. The associated spatial pattern explains 19% of the variance. Monthly AO indices are constructed by projecting the monthly mean height anomalies onto the leading EOF mode and the AO time series is normalized by the standard deviation of the monthly index for the period 1979–2000.

[6] The LSO can be represented by the Moon's angular speed, which is magnified during the alignments of the Earth, Sun and Moon. The mathematical formulation commonly used to describe this speed has no analytical solution, because of the non-linearities created by the interactions of the Sun, Moon and Earth on their oscillating orbits. However, a nearly accurate solution can be obtained through a series expansion of harmonic functions representing the fundamental elements that affect the gravity forces, as suggested by Laplace [Cartwright, 1999]. This method which is described in the special treatise on tidal dynamics by Wood [2001a, Table 16] is currently used to predict potential tidal flooding in coastal areas.

[7] In addition, we use here the lunar declination angle (LDA) at the perigee obtained also from Wood [2001a, Table 16] to demonstrate the relationship between the AO and such astronomical alignments.

[8] Sea-surface temperature (SST) is obtained from the extended dataset of Smith and Reynolds [2004]. Analysis is performed for the Labrador Sea [60N, 60W]. In that region tides are expected to have a strong effect on the SST variability and, as a result, on the AO spatial pattern.

[9] Continuous Morlet wavelet transform is used to evaluate the time-frequency oscillations of the AO, the LDA, and the Labrador SST. This approach helps localizing intermittent oscillations in these variables. Wavelet coherence is used to measure the intensity of their covariance [Jevrejeva *et al.*, 2003] and the Monte Carlo method with red noise is used to determine the statistical significance level of the coherence [Grinsted *et al.*, 2004].

3. Results

[10] Figure 1 shows the variation of the AO, the LSO, and the LDA from 1950 to present time. The AO varies in remarkable coupling with the LSO and the LDA. Strong LSO peaks occurred on 29 December 1955, 08 January 1974 (the greatest of the century), and 19 January 1992, i.e., with a frequency of nearly 18 years. These occurred within just a few days from the perihelion (03 January), emphasizing the enhancement of gravity forces applied by the Sun when it approaches the Earth [Wood, 2001a]. The auxiliary Table 1¹ (available online) displays the characteristics of these strong LSOs along with the peaks of the LDA presented in Figure 1. The greatest LSO peaks coincide with the high LDA values and the closest lunar distance from the Earth (i.e., at the perigee). Smaller peaks in the AO time series are also well synchronized with weaker (yet significant) LSO peaks, which also have a frequency of nearly 18 years and are shifted nearly nine years as compared to the strongest peaks (Figure 1). This close relationship between the LSO and LDA with the AO emphasizes the key impact of the strong tides on the AO. Figure 1 also indicates that the AO is superimposed on an increasing trend in the last decades. The mechanism associated with this trend is still uncertain [Thompson *et al.*, 2000], but recent studies suggest a relationship with anthropogenic activity [Yukimoto and Kodera, 2005].

[11] The wavelet analysis presented in Figure 2 confirms the strong 9- and 18-year cycles that characterize the temporal variability of the AO index. To evaluate the common variability between the January AO index and the LDA, a wavelet coherence analysis was performed for the winter season (Figure 2b). A significant coherence is obtained at a period of 8–10 years, since the 1960's. The consistent positive phase depicted in Figure 2b emphasizes the strong relationship that exists between the AO and the LDA. Thus, in the winter, the AO index is high when the Moon is at a close approach to Earth (at the perigee) and its declination angle is high.

[12] The link between strong tides and climate has to be expressed through changes in the SST. The January Labrador SST experienced a remarkable decrease in the years 1972 (−1.68°C), 1983 (−1.76°C), and 1993 (−1.5°C) (Figure 3a). These events happened at the time when the LDA was positive, emphasizing their relationship with the nodal tides. The wavelet power spectrum of the SST shows a 3–7-year oscillation around the 1980's and the nearly 8–10-year and 18-year periodicity during the most recent years (Figure 3b). The wavelet coherence shows a significant common variability between the SST and the AO at those

¹Auxiliary material is available at <ftp://ftp.agu.org/apend/gl/2005GL023418>.

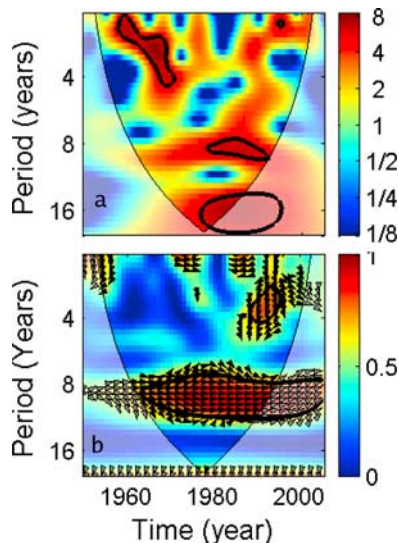


Figure 2. (a) Wavelet power spectrum of the AO index; (b) wavelet coherence and phase between AO and the LDA. The vectors indicate the phase difference between the AO and the LDA (a horizontal arrow pointing from left to right signifies in phase). The thick black line is the 95% confidence level and the thin black line indicates the region affected by the edges of the data.

frequencies (Figure 3c). The consistent negative phase also points out the correlation between the AO and the decrease of the Labrador SST. Similar coherence is obtained between the SST and the LDA (not shown), emphasizing the strong relationship between the AO, the SST, and the LDA.

4. Concluding Remarks

[13] In their study of sea-ice concentration and sea-level pressure at latitudes higher than 40°N , Venegas and Mysak [2000] also identified 9- and 18-year modes of oscillations since the 1960's, similar to those described here for the AO. Strong tides modulated by the LDA can explain these modes of variability. Indeed, strong tides can mix and cool the sea-surface waters at northern latitudes. At the same time, such a mixing can warm the Arctic Ocean waters because during the winter, in that region, cold water lays above warm water. Thus, tide force is a physical mechanism that can produce these apparently contradictory processes between the Arctic and the mid-latitude northern oceans, and establish the patterns of the AO.

[14] The mechanism responsible for generating the AO is still unknown. Baldwin and Dunkerton [2001] have proposed that it is originated in the stratosphere. However, climate models with the capability of representing stratospheric processes could not reproduce the observed temperature changes that it induces [Gillett et al., 2002]. The evidence provided here that ocean tidal mechanism influences it adds a new perspective to this key issue.

[15] The positive trend of the AO may be associated with various recent changes in the Arctic region, e.g., its warming and ice melting. Indeed, the Arctic ice cover has decreased by about 7.7% per decade since the mid-1970's [Stroeve et al., 2005]. Furthermore, the AO was found to be strongly correlated with ice thinning at northern latitudes

[Rigor et al., 2002] and the Hudson River water discharge [Dery and Wood, 2004]. Also, during years of stronger tides, ice calving in the Arctic and the number of icebergs observed at low latitudes increase [Wood, 1995]. Based on these evidences, we hypothesize that the ongoing ice melting enables a larger area of liquid water to respond to tidal forces, thus enhancing their effects. Another possible reason is associated with changes in the oceanic stratification caused by the global warming that could affect the mixing efficiency [Munk and Wunsch, 1998]. Consequently, stronger tides may become more effective as the polar ice melts and/or the SST increases.

[16] Cerveny and Shaffer [2001] have shown that the lunar declination variability correlates also with the El Niño Southern Oscillation Index. Thus, astronomical alignments effects on both the tropics and the Arctic suggest that tidal dynamics may have implications of global magnitude. The findings by Egbert and Ray [2001] showing the importance of tides on energy dissipation in the various shallow seas and mid-ocean ridges may explain why the 18.6-year nodal signal is observed in so many climatological signals [Currie, 1996]. Indeed, acting on the entire planet, tidal forces can affect the thermocline and trigger local changes in SST, which in turn can affect the climate of coastal regions.

[17] The relationship between AO and the tidal forcing identified here provides a physical mechanism that explains

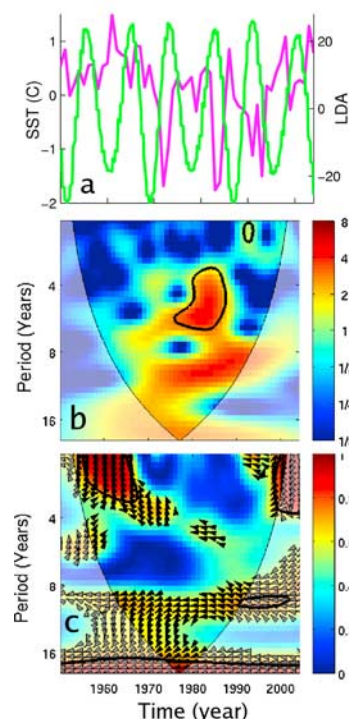


Figure 3. (a) January Labrador Sea Surface Temperature (SST) [magenta] and LDA (green); (b) wavelet power spectrum of the SST; (c) wavelet coherence and phase between the AO and SST. The vectors pointing to the left indicate a negative phase difference between the AO and SST. The thick black line is the 95% confidence level and the thin black line indicates the region affected by the edges of the data.

the AO variability. Since this astronomical alignment is a deterministic signal, it can be used to predict the AO peaks. For instance, the next LDA peak will happen in December 2008 (Figure 1 and auxiliary Table 1) and, at that time, we can anticipate a peak in the AO with all its associated climate impacts.

[18] Finally, we note that the current generation of global climate models that are broadly used to produce various climate change scenarios do not account for long-term tidal dynamic effects. This may be a significant flaw worth investigating carefully.

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