Atmos. Chem. Phys. Discuss., 15, 22701–22713, 2015
www.atmos-chem-phys-discuss.net/15/22701/2015/
doi:10.5194/acpd-15-22701-2015

Atmospheric Chemistry and Physics
Discussions
Open Access

Observation of a tidal effect on the Polar Jet Stream

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Received: 20 April 2015 – Accepted: 31 July 2015 – Published: 25 August 2015

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Variations in the Polar Jet Stream directly affect weather across Europe and North America (Francis et al., 2012). Jet Stream dynamics are governed by the development of planetary Rossby waves (Dickinson, 1978) driven by variation of the Coriolis force with latitude. Here we show that increasing atmospheric tides induce the development of Rossby waves, especially during winter months. This changes the flow and direction of the Jet Stream, as measured by the Arctic Oscillation (AO). Although horizontal tidal forces are tiny (10^7 smaller than gravity), they act over huge areas dragging the Jet Stream flow southwards in regular pulses as the earth rotates. This induces a changing Coriolis torque, which then distorts the Jet Stream flow. The data from eight recent winters are studied indicating that the AO is anti-correlated to the horizontal “tractional” component of tides acting between latitude 45 and 60° N. The observed 28 day cycle in Jet Stream flow and extent has a statistical significance $> 99\,\%$. A cross-correlation between all daily AO data since 1950 and the tractional tidal strength shows a significant anti-correlation with a lag time of ~ 5 days. The strongest correlation and largest excursions of the AO are observed during winter 2005/2006 – a maximum lunar standstill year. This declination dependence of tidal forces at high latitudes is the proposed cause of many previous reports of an 18.6 year dependence of continental rainfall and drought.

1 Introduction

Varying tidal forces act both on the oceans and atmosphere particularly at high latitudes. A detailed study (Lindzen, 1981) of atmospheric tides finds that gravitational lunar tidal winds are more important at high altitudes. The horizontal “tractional” component of net tides is responsible for tidal currents in the ocean and for tidal winds in the upper atmosphere. During northern winters the Jet Stream strengthens and shifts northwards. Meanders or Rossby waves (Dickinson, 1978) develop near the eastern

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edges of continental landmasses and oceans. Solar insolation falls each winter to zero inside the Arctic Circle while simultaneously the diurnal solar “expansion” tide disappears over Polar Regions. Gravitational atmospheric tides now dominate near the poles.

Winter storms in the North Atlantic form at the interface where warm Gulf air meets cold Polar air near Newfoundland. This temperature gradient produces baroclinic instability spawning storms that move westward across the Atlantic. The track of these storms follows the Jet Stream and their impact on Europe depends both on their strength and the relative position of the Jet Stream (Francis, 2012). Previous studies (Currie, 1983, 1984; Agosta, 2014; Clegg, 1984) have shown an 18.6 year cycle in rainfall across large continental zones implying a dependence of storm formation on the lunar precession. Others have speculated about a tidal influence on climate over decadal timescales (Ray, 2007). Changes in lunar declination through the 18.6 year cycle mainly affect the strength and sidereal rate of change of tidal forces with latitude.

The cold winter of 2010 corresponded to a Jet Stream positioned lower over the UK drawing cold air down from the North and East. A negative value of the Arctic Oscillation (Thompson, 1998) corresponds to a low-pressure difference between the Icelandic Low and the Azores High resulting in a weaker Jet Stream with larger meandering loops. This allows cold air to spill down from the Arctic and Siberia into mid latitudes. During the winter of 2013/2014 a strong Jet Stream was positioned directly over the UK and a string of powerful storms caused extensive coastal flooding. It was striking how several of these storms also coincided with high spring tides, for example those of 5 December 2013 and 5 January 2014.

2 Results

It is the horizontal (tractional) component of tides that produces deep ocean currents and atmospheric pressure gradients in the atmosphere. Can these also affect the Jet Stream flow? To investigate this possibility further, we have calculated the time dependence of tractional tidal forces acting at different latitudes using the JPL ephemeris (Standish, 1990). During northern winters the maxima of such forces occur at each new moon and their strength depends on the relative positions of the earth, moon and sun. Although these tractional forces are only about 10^{-7} times the strength of the earth's gravitational acceleration g, they are still important because they are unaffected by the earth's gravity. These changing tidal forces sweep across the earth daily, generating a variable pull on the Jet Stream of several tons per kilometre.

Figure 1 shows the variation of the AO index compared to calculations of the tidal tractional forces acting at 60 and 45° N for the last 6 winters (see Appendix). These results show visual evidence of an AO signal aligned with the lunar cycle, although not always consistent in time. The approximate 28 day cycle is still however rather striking. A calculation of the correlation between AO and tidal force at 60° N gives a value of −0.2 between October 2009 and March 2010.

To investigate further, we also looked at the recent maximum lunar standstill, which occurred in 2005/06 and resulted in the largest monthly variations of tidal forces for Polar regions. If tractional tides affect the Jet Stream flow one would expect to see a maximum correlation between AO and tidal forces during the 2005/06 winter months. Figure 2a shows the result. There are indeed large swings in the AO, which are again anti-correlated with tractional tidal forces. In particular the coincidence with the 45° N component is striking. This strong tidal effect may also provide an explanation for the many reports that rainfall and droughts in northern continents follow an 18.6 year cycle (Francis and Vavrus, 2012; Currie, 1983; Agosta, 2014), since the path and strength of storms depend on changes in the flow and direction of the Jet Stream. In 2006 there were net swings of the AO index through absolute values of ∼ 6 between consecutive new moons. Figure 2b shows the same results for the current winter 2014/2015, which included a total eclipse of the sun on 20 March coincident with the moon at perihelion (super-moon) resulting in exceptional high tides.

A large negative swing in the AO occurred in coincidence with the 2015 eclipse, with a regular anti-correlated beat beforehand. A very similar situation can be observed for the total eclipse, which occurred on 7 March 1970, and which also happened to be near a lunar standstill (Fig. 2c). The effect is even more striking.

How statistically significant are these observations? Firstly a cross-correlation analysis was performed between all daily AO values, from 1950 to 2015, and the calculated tractional tidal acceleration at latitudes 45 and 60° N for each day. This long time series covers more than 23 800 days. Figure 3 shows the resultant cross-correlation as a function of the tidal lag time. There is a small yet statistically unambiguous anti-correlation of the AO which peaks at a lag time of ~ 5 days with the tides. The effect is strongest for the 45° N component. This confirms that a tidal influence on the Polar Jet stream flow exists, as measured by the AO. The strongest effect occurs, on average, 5 days after a major spring tide. The absolute values of the anti-correlation may be small but the observation of such a continuous time lagged tidal effect on the AO is statistically overwhelming.

As a second test, we analysed just the lunar cycles between December and the end of March for the 8 most recent winters presented in Figs. 1 and 2. Some 40 out of 46 lunar cycles show a visible anti-correlation of the AO with tidal traction. Maxima in tidal traction consistently shift the AO towards negative values, which then relax during tidal minima. The probability of such a run of 40/46 lunar cycles occurring randomly is $< 10^{-6}$, based on an optimistic estimate of a 50 % chance that a single anti-correlation might occur at random.

3 Discussion

The evolution of the Jet Stream and generation of Rossby waves is an immensely complicated process. Winter weather in the Northern Hemisphere is dominated by the strength and flow direction of the Jet Stream. The intensity of flow varies from one year to another. The Arctic Oscillation is just one scalar measurement of this evolution. Despite this, we have demonstrated that there is strong statistical evidence of a sidereal tidal effect on the AO, especially during winter months. Strong tides increase the southward drag on the Jet Stream generating a Coriolis torque as the tides sweep east–west around the rotating earth, perhaps playing a role in triggering storms. It is noticeable how many of the damaging UK winter storms of 2013/2014 also coincided with high spring tides. The total effect depends both on the maxima and on the rate of change of the tractional tidal component. These both vary within the 18.6 year lunar cycle. The work reported here provides strong evidence that increasing tractional tidal forces do change the direction and speed of the Jet Stream, especially during winter months with a lag time of about 5 days. One of the authors has been using tidal variations combined with ECMWF (2013) models to improve short to medium-term weather forecasting (Madrigali, 2013). It is therefore proposed that the accuracy of medium-range weather forecasting would be improved by including quantitative gravitational tidal forcing on the Polar Jet Stream into Global Circulation Models.

Appendix: Tractional tides

The tractional (tangential) tidal force at any point ***a*** whose position vector subtends an angle θ to the lunar position vector ***r*** is defined as in Fig. A1.

The net force per unit mass acting on point ***a***, assuming $\varphi = 0$ is simply

$$\frac{Gm}{(r - R\cos\theta)^2} - \frac{Gm}{r^2} \cong \frac{2GmR\cos\theta}{r^3}$$

However for finite angle φ the tidal force acquires a vertical component (Fig. A2).

The distance $a - m$ is given by

$$\sqrt{R^2\sin^2\theta + (r - R\cos\theta)^2} \rightarrow \sqrt{R^2 + r^2 - 2rR\cos\theta}$$

Gravity acting on point ***a*** is therefore

$$\frac{Gm}{R^2 + r^2 - 2rR\cos\theta}$$

The tidal force now has 2 components

$$F_x = Gm\left(\frac{\cos\phi}{R^2 + r^2 - 2rR\cos\theta} - \frac{1}{r^2}\right)$$

and

$$F_y = \frac{-Gm\sin\phi}{R^2 + r^2 - 2rR\cos\theta}$$

where

$$\cos\phi = \frac{r - R\cos\theta}{\sqrt{R^2 + r^2 - 2rR\cos\theta}}$$

and

$$\sin\phi = \frac{R\sin\theta}{\sqrt{R^2 + r^2 - 2rR\cos\theta}}$$

The tractional component (parallel to the surface) can be calculated using the JPL ephemeris to derive the net lunar-solar tidal vector for any given date and time. All computer software used is available from the authors on request (see also Supplement).

Note: A simulation of tractional tides experienced during the winter period 2005/2006 can be viewed at https://www.youtube.com/watch?v=rebJTFo3XQQ.

The Supplement related to this article is available online at doi:10.5194/acpd-15-22701-2015-supplement.

Author contributions. Calculations by C. H. Best 2015.

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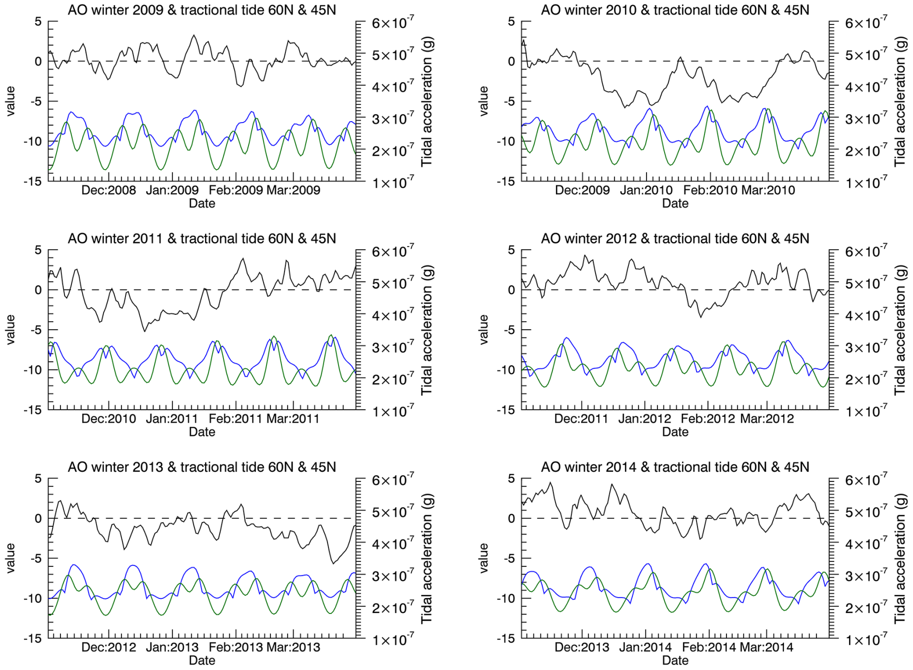

Figure 1. Comparison of the Arctic Oscillation (AO) with tractional tidal forces acting at 60° N (blue) and 45° N (green) for the last six winters 2009–2014.

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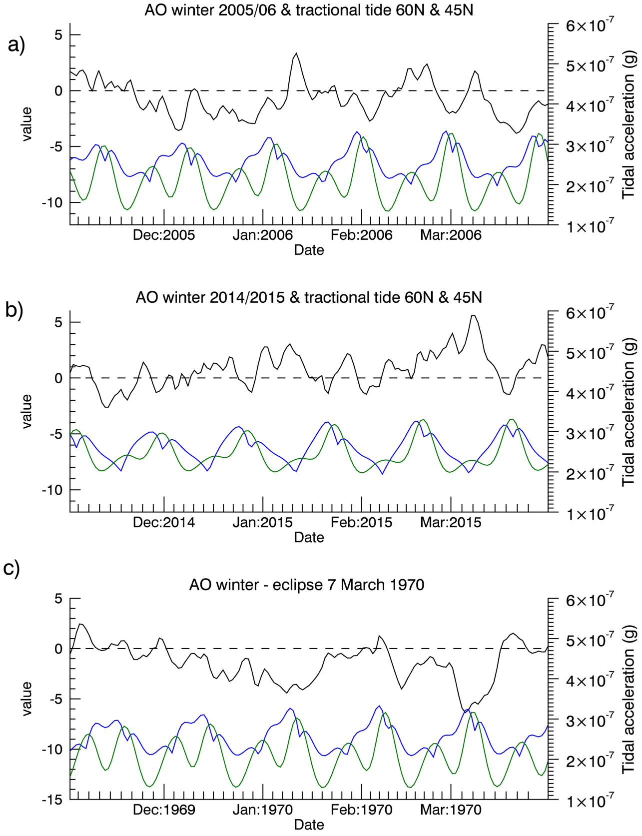

Figure 2. (a) Variations in the AO which show an anti-correlation with the tractional tidal forces at 45° N (green) and 60° N (blue) during the Maximum lunar standstill (2005/2006). **(b)** A similar study for the current Winter 2014/2015. A steep drop in AO is observed coincident with the solar eclipse on 20 March. **(c)** A previous total eclipse, which occurred on 7 March 1970 and produced a similar steep drop in AO. Lunar declination in 1970 was near maximum.

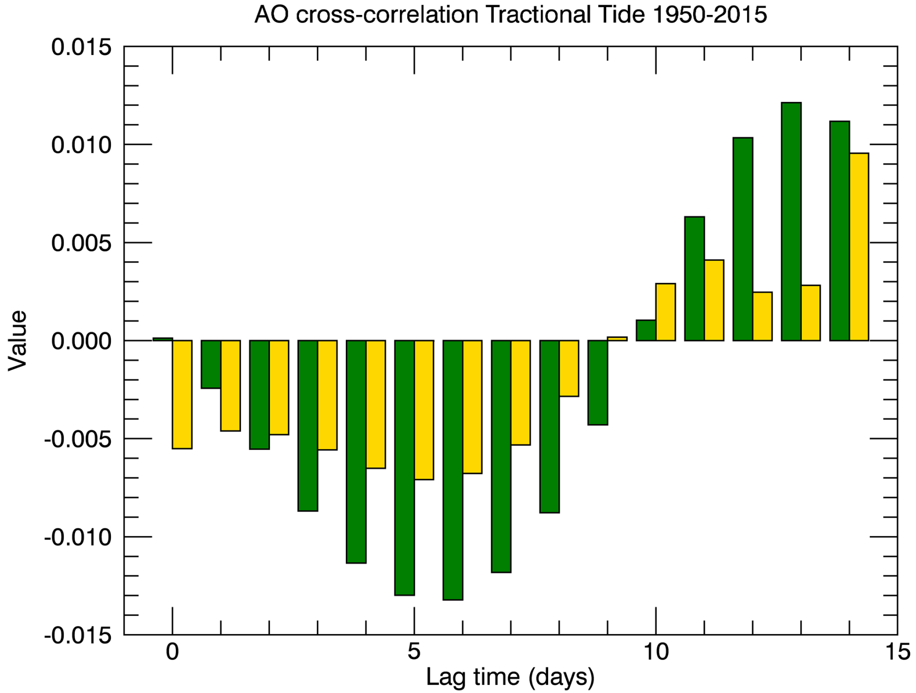

Figure 3. Cross-correlation of the Arctic Oscillation with tractional Tidal acceleration since 1950. The green values are for the tractional acceleration at 45° N and the gold values are those for 60° N. Both are anti-correlated to the AO with a time lag. The 45° N component in particular shows a lag time peaking at 5 days.

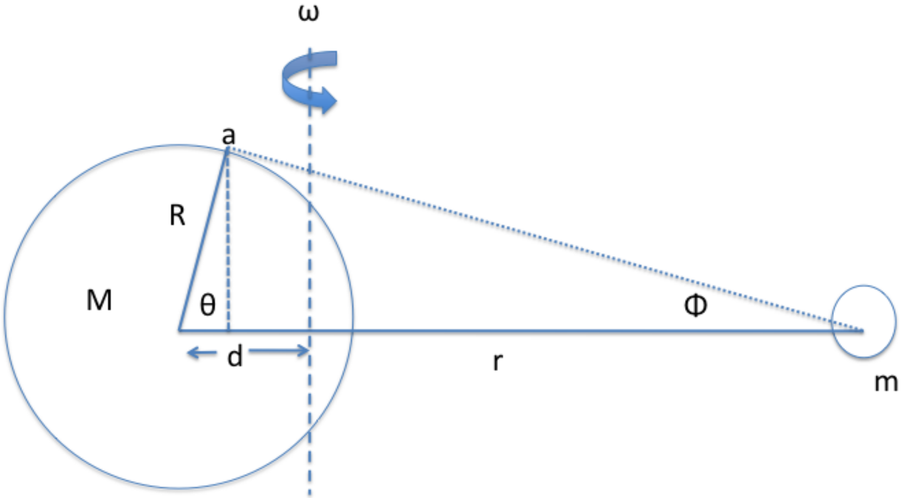

Figure A1. Schematic of the Earth-Moon system.

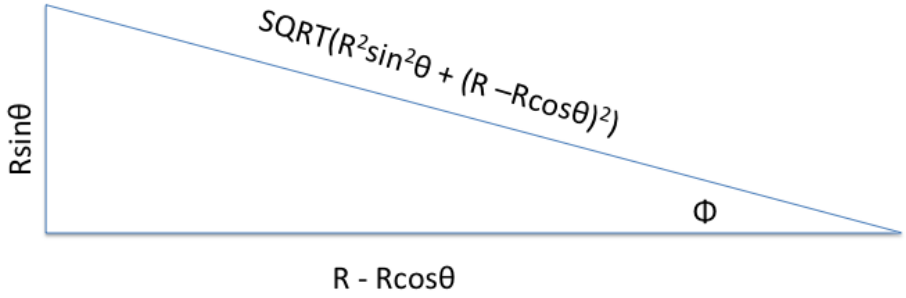

Figure A2. Evaluation of angle ϕ.

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