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Discussions

Interactive comment on "Observation of a tidal effect on the Polar Jet Stream" *by* C. H. Best and R. Madrigali

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Our paper proposes the hypothesis that regular changes to Jet Stream flow are influenced by strong lunar tides in polar regions, especially in winter. The paper is not arguing that this is the only influence on Jet Stream flow, just that its effect is important.

To test our hypothesis of a lunar influence, we calculated the net tractional (meridional) tidal force acting at typical latitudes covering Jet Stream location. This was done for each day for which Arctic Oscillation(AO) data are available between 1950 and 2015.

Response to Reviewer's points 1 2: The strong evidence presented in the paper that such an effect exists is as follows:

1 The Arctic Oscillation in winter months shows a regular variation consistent with a

period of 28 days. Can this be a simple coincidence or is there a genuine connection with the lunar cycle?

2 The minima of the AO during the last 7 winters plus 2005/6 show a coincidence of minimum values of AO with maximum tidal traction for 40 out of the 46 lunar cycles observed. If we assume the null hypothesis and that the AO is simply chaotic, then by pure chance we might expect a 50% chance of a single coincidence. Therefore the probability of observing 40 coincidences out of 46 tries is $(46!/(40! \times 6!))/(2^{46}) = (9366819)/(7.04x10^{13}) = 1.3 \times 10^{-7}$. The statement that the probability of a random occurrence being < 10^{-6} is essentially correct.

3. The strong anti-correlation for two successive total lunar eclipses occurring at the March equinox is also striking. Such perfect alignment of the sun and moon bring the highest spring tides, especially with the moon at perigee.

4. Figure 3 shows something different. Here we take all 23800 daily values of the AO from 1950 to 2015 and perform a cross-correlation analysis with the calculated daily tractional tidal forces acting at 60N and 45N. This includes the summer months when we know that atmospheric tides are dominated by diurnal solar heating. Yes it is true that the absolute value of the anti-correlation is very small, but the analysis still shows a clear unambiguous time lag of the AO reacting to tidal 'forcing' of 5 days. The uniform smoothness of the lag-time distribution when averaged over 65 years is proof that a causal effect emerges above the noise.

The reviewer writes in point 3: *"It is very risky to make the jump from correlation to causation without some evidence from basic physics to support the attribution. The authors appear to acknowledge that their hypothesized forcing is very weak. Instead, they rely on the time-series plots to convince the reader. However, it cannot to emphasized too strongly: correlation is not causation."*

I agree with the basic point made by the reviewer that correlation is not necessarily causation. However, the physics case is clear. The very same tractional tidal forces that cause oceanic tides also act on the atmosphere. Normally these are dominated by thermodynamics and thermal tides induced by the sun, but during long polar winters gravitational tides become evident [1]

The reviewer writes in point 4: *"In addition, the 28-day periodicity in Northern Hemisphere winter has been identified as an atmospheric normal mode (also called a free Rossby wave); see the review paper by Madden (2007). There is both theoretical and observational support for the existence of this wave. Through periodic interference with the quasi-stationary planetary wave, this normal mode can cause variations in the large-scale dynamical fields with a 28-day time scale."*

Madden also states in the same paper: *"Even free waves need some kind of excitation in order to exist in the face of dissipation by radiation and friction".* He confirms the observation of this 28-day periodicity mode in NCEP/NCAR Reanalysis data. It is therefore highly plausible that this 28-day wave would indeed be excited by the 28-day lunar cycle. Madden also refers back to an earlier paper by Kassahari from 1980, the abstract of which references the tidal-equation and coriolis effects quote :

"Solutions of the linearized global shallow-water equations (Laplace tidal equations) including the effect of a mean zonal flow are obtained by the Galerkin-transform method. Free oscillations of the first kind (gravity-inertia modes) are little affected by the zonal flow. Solutions of the second kind (rotational modes of the Rossby-Haurwitz type) are significantly affected by a zonal flow different from solid rotation. "

Therefore we maintain that the conclusions of our paper remain both statistically and physically robust. The evidence presented shows that it is very likely that the observed 28-day cycle in Jet Stream flow is indeed 'excited' by the changing tidal forcing during the lunar cycle.

[1] Long term observations of the wind field in the Antarctic and Arctic mesosphere and lower thermosphere at conjugate latitudes, H. Iimura et al. Journ. Geophys. Res. Vol 116 (2011)

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