GC21C-0566

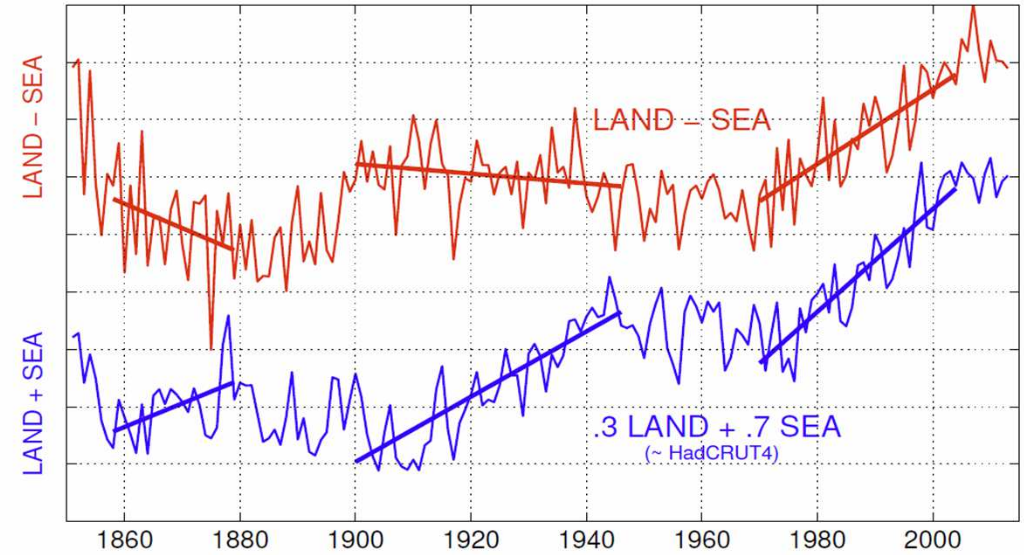
An Ekman Transport Mechanism for the Atlantic Multidecadal Oscillation

Vaughan R. Pratt
Stanford University

1. BACKGROUND

The blue trend lines below show global warming during 1860-1880, 1900-1945, and 1970-2005. This well-documented but poorly understood phenomenon raises two questions:

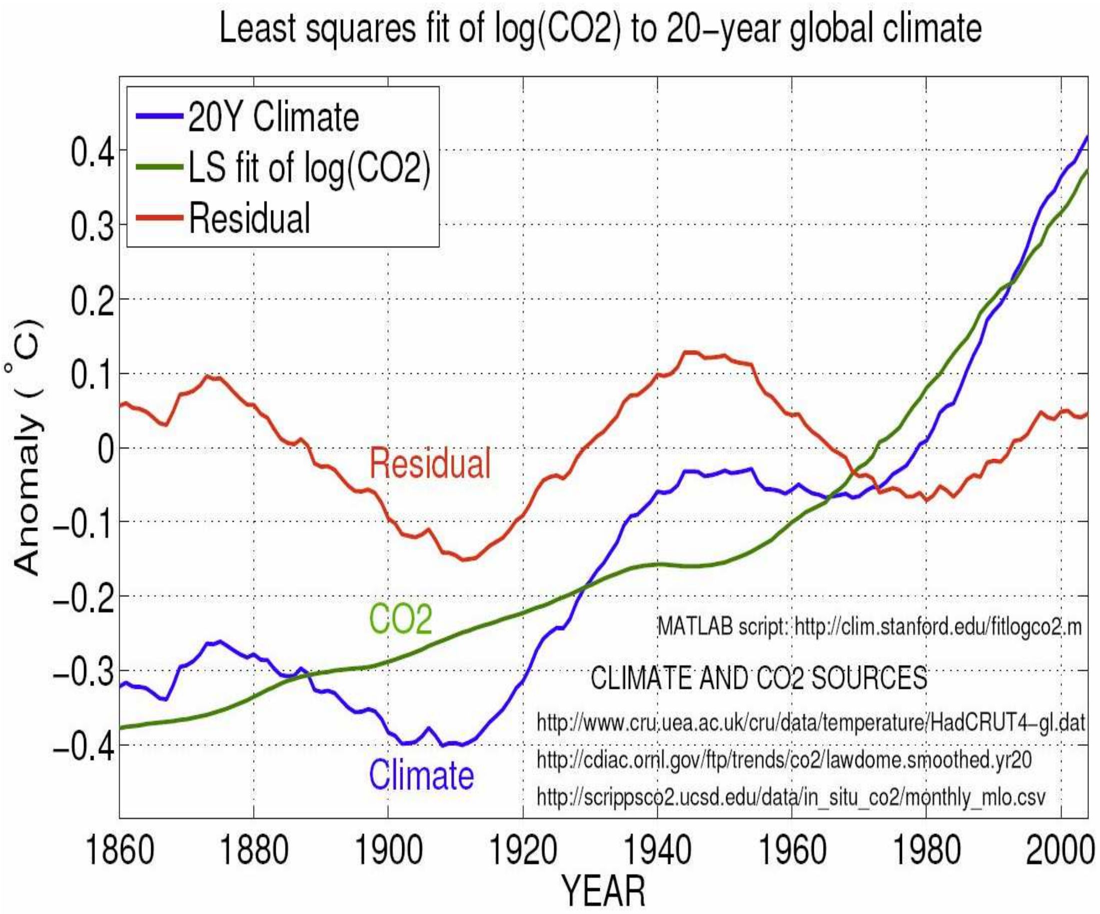
Q1. What explains the first two rises if not CO2?
Q2. How much of the third rise has the same explanation?



For Q1 there are two main schools of thought, RADiative and INTernal. A decline in say volcanism or human aerosols raising global temperature will heat land faster than sea due to the latter's high heat capacity, whence land-sea *difference* (upper curve) should also rise. At AGUFM13 [Pratt 2013] we fitted trend lines showing a decline in difference during the first two rises, ruling out RAD, but a rise during the third, consistent with higher CO2.

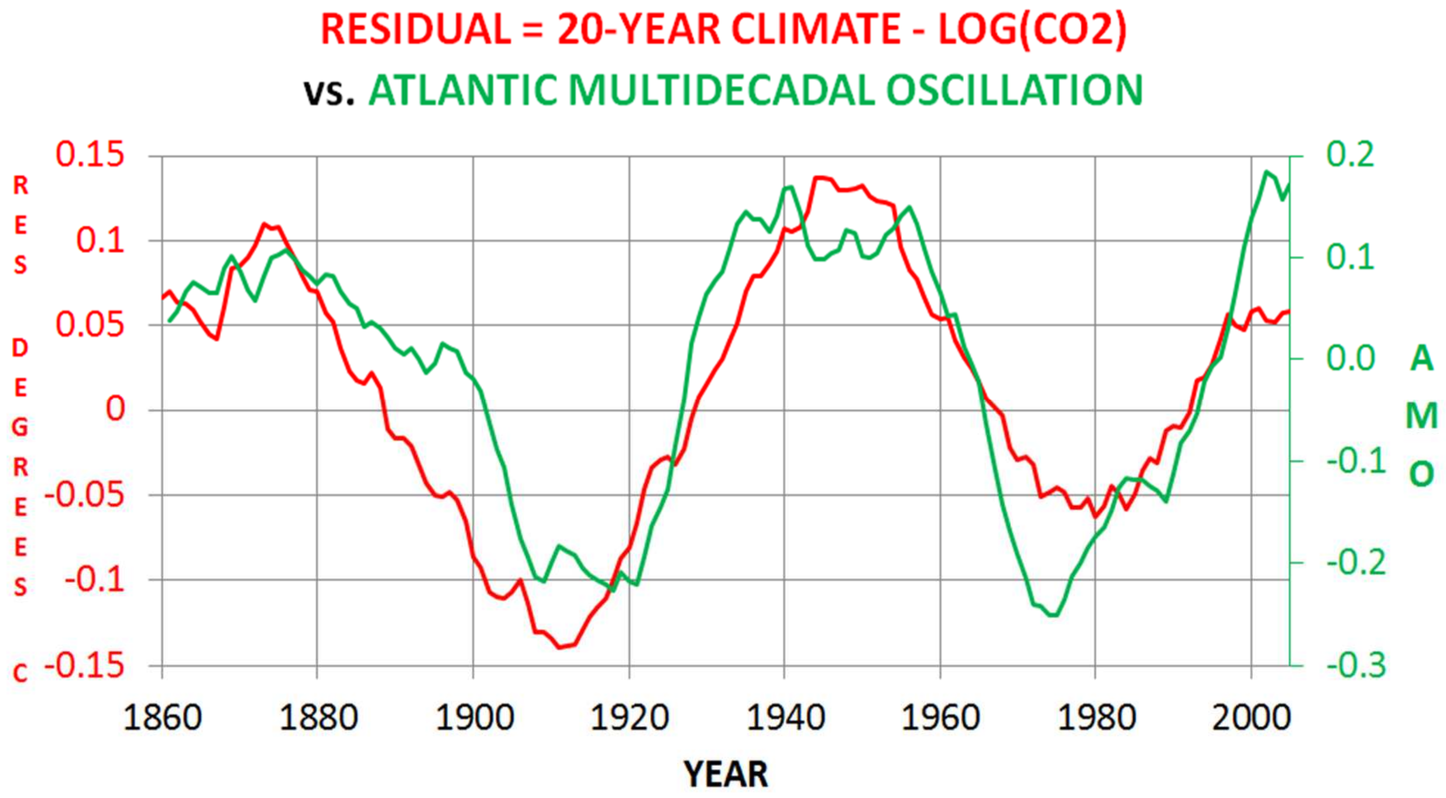
2. ANALYSIS OF 20-YEAR CLIMATE

For Q2 we analyze 20-year climate as CO2-forced warming based on a best-fit estimate of transient climate response (TCR) as 1.9 °C/2xCO2, plus a residual. Data for CO2 for 1850-1960 is from Law Dome, and for 1960-2014 Mauna Loa. We fit log(CO2) (green curve) to 20-year climate (blue curve) leaving an unexplained residual (red curve) as our object of interest.


Least squares fit of log(CO2) to 20–year global climate

3. ATLANTIC MULTIDECADAL OSCILLATION

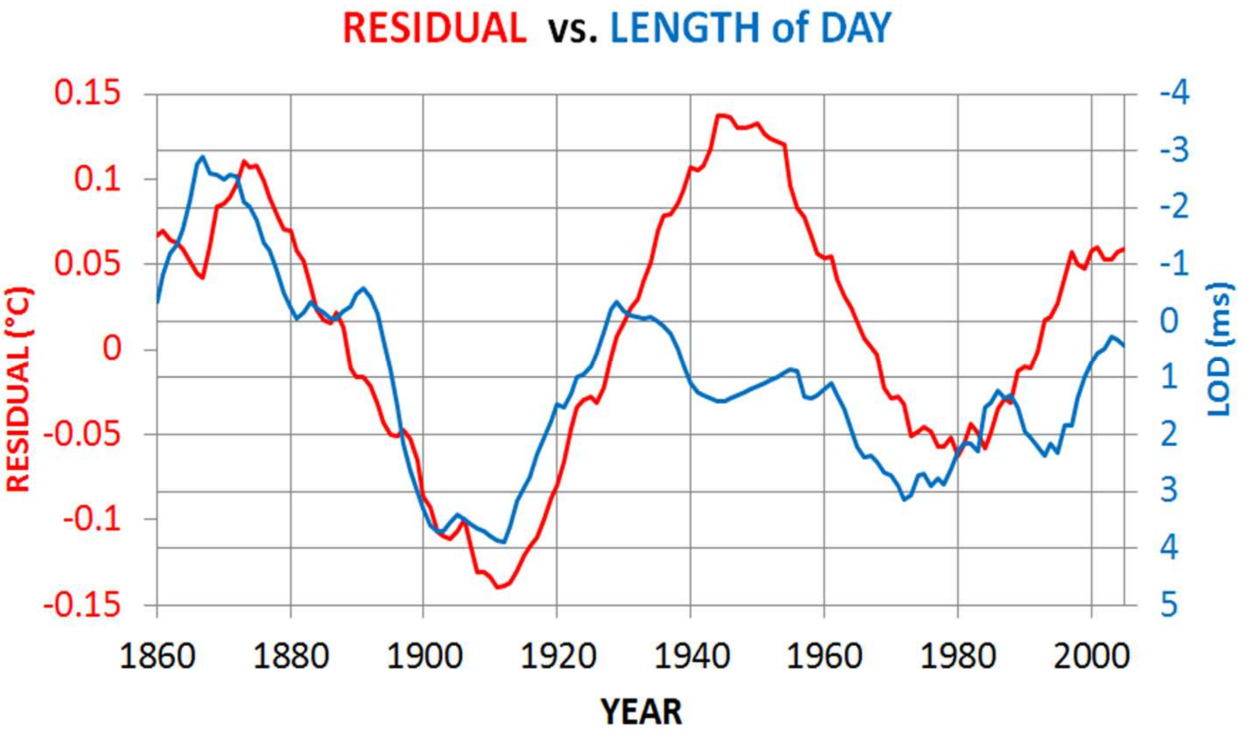
The version of the AMO shown below is a 10-year smoothing of that derived by NOAA from [Kaplan 1998], with which the residual correlates strikingly well.



That both curves are obtained by detrending makes the correlation less surprising. Whether the appearance of oscillation is accidental or will continue is unclear. For now the term "AMO" supplies this residual only with a (widely used) name and not an explanation.

4. LENGTH OF DAY

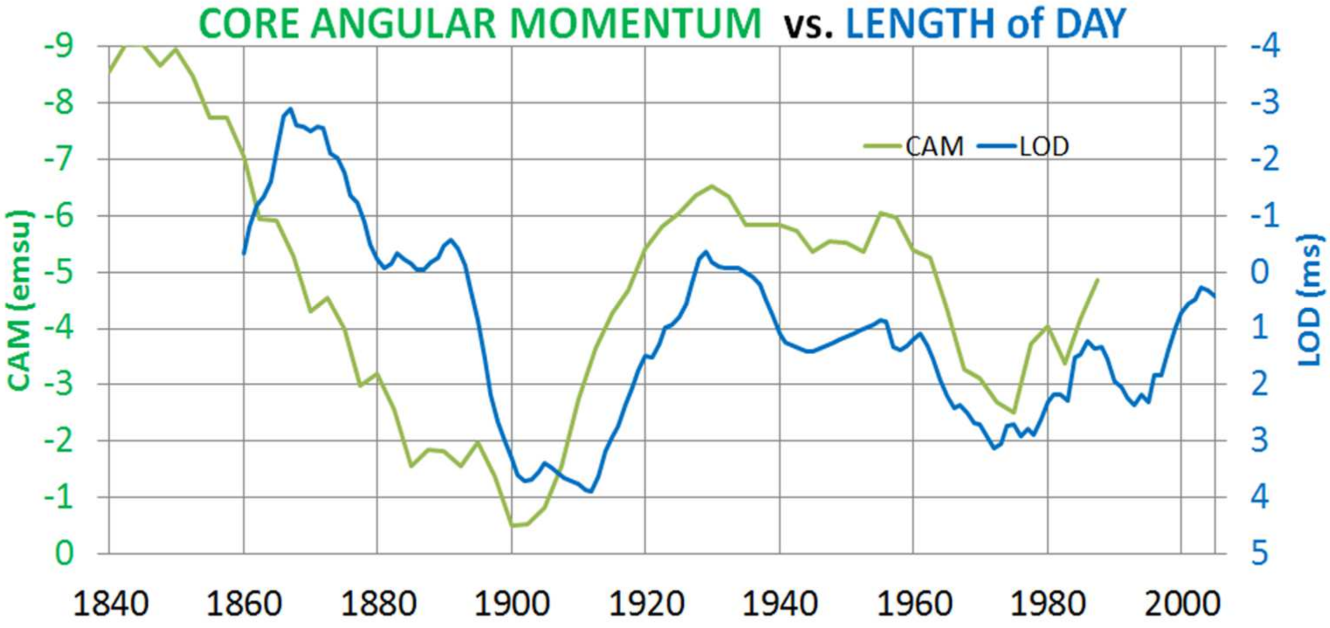
The correlation in the figure below of the residual with $-$LOD or Earth's spin angular velocity $\omega_{\oplus}$, while not quite as good as with the AMO (the residual took 20 years to respond to the LOD increase that started in 1930), is however much less expected and therefore that much more interesting.



LOD for 1860-1930 varies here at ~15 ms/cy. This is superimposed on a much slower 1.7 ms/cy average rate of rise for 500BC-2000AD [Stephenson 2002] and an even slower 1.2 ms/cy since 620Mya [Williams 2000]. Tidal drag explains the slow millennial rate, but what of the fast decadal?

5. CORE ANGULAR MOMENTUM

Hide *et al* [2000] have inferred the angular momentum of Earth's core from core flow velocities just below the core-mantle boundary (CMB), which in turn they inferred from the geomagnetic secular variation (GSV) data obtained *inter alia* from 150 years of ships' logs. The figure plots core angular momentum (CAM) in "equivalent ms units" (emsu) where 1 emsu is the additional CAM needed to add 1 ms to LOD, indexed to LOD of +5 ms.



Although the CAM variations do not completely account for the LOD variations, the fit is sufficient to account broadly for the general shape of the LOD, and hence that of the residual.   Since the core can both accelerate (1850-1900) and decelerate (1900-1930), albeit far from sinusoidally, any spring action on either side of the CMB could support oscillation powered by turbulence at the CMB as the core rotates ahead of the mantle. While this picture does not guarantee continued oscillation it at least makes it quite plausible.

6. LINKING LOD TO AMO

The foregoing combination of CAM-from-GSV, its good correlation with LOD, and conservation of angular momentum to convert that correlation to causation, rules out the atmosphere, ice accumulation, and other candidate explanations of the AMO-like shape of the LOD. What remains wide open is any mechanism that would link LOD fluctuations to either the AMO as surface temperature fluctuations of the North Atlantic or the similarly shaped fluctations in CO2-detrended global mean surface temperature, our residual.

Although a number of hypotheses for the AMO have been proposed, few are internal, but these are the ones we have chosen to focus on here based on the behavior of land-sea difference.

1. Erratic behavior of the North Atlantic branch of the MOC. Though LOD fluctuations have not been offered by way of explanation, conceivably they could disrupt the MOC.
2. Heat generated by flexing of the crust as it becomes more oblate with decreasing LOD.
3. Increased thermal conductivity of crustal rock as increasing oblateness stresses it.
4. Increasing oblateness hastening the opening of ridges.

A problem for any account in terms of heat generated at or below the ocean floor is how to get that heat through the massive oceanic heat sink in order to reach the surface within the requisite 30 years before the cycle reverses. Possibilities:

1. Plumes and thermals (interrupted plumes) rising from hot spots directly to the surface.
2. Entrainment of thermals by ocean currents, e.g. the Meridional Overturning Circulation (MOC).

7. FLOOR HEAT ESCAPE VIA EKMAN TRANSPORT

During 1880-1940 the residual in Panel 2 declines and rises at about 0.25 °C in 30 years, much too fast for the large volume and low speed of the MOC. We need a lighter and faster current.

Ekman transport is a poleward current at the ocean surface generated by geostrophic balances in both the atmosphere and the ocean. It is confined to the top 50 m or so, and travels at about 3 cm/sec or 1000 km/yr. It is fed by upwellings (Ekman suction) at ±2° latitude, and dives down (Ekman pumping) at around ±30°. In the simplest account the cycle is completed by an equatorward current of the same speed and thickness

To evaluate feasibility, take the area of the participating 50m surface layer as 10^{14} m^2 (about 1/3 of the ocean), making the volume of the top and bottom 50m layers 10^{16} m^3. 3.85×10^6 joules heats one cubic meter of seawater 1 °C so 10^{22} J of heat suffices for a rise of 1/3.85 = 0.26 C. The 30 years 1910-1940, or 10^9 seconds, can achieve this with a power of $10^{22}/10^9$ watts = 10 TW, corresponding to an eminently feasible variation of about ±10% of the mean 47 TW of Earth's total geothermal release.

The equatorward current will most naturally follow an isopycnal (constant density) surface in preference to the ocean bottom. This half of the cycle can be elaborated in two ways.

1. The current may be faster, and hence thinner, by a factor f.
2. Each such cycle may induce a counter-rotation cycle below it, with n such cycles between the surface and the bottom of the ocean.

Provided f > n the above feasibility analysis remains sounds. The slower the return current, and the more of them needed to reach the bottom, the harder it becomes to extract the requisite heat from the various heating mechanisms responding to LOD fluctuations.

8. SUMMARY AND CONCLUSION

We have proposed a physical mechanism by which the first two of the three warmings shown in Panel 1 could have arisen by heat that was either propagated through or generated within the crust in response to fluctuations in the Earth's angular momentum, and then carried to the surface of the ocean by Ekman transport. Any such proposal calls for an assessment of its plausibility. To this end we identify the following possible weaknesses of this account.

1. The requirement that the speed of the return current (relative to the poleward surface current) exceed the number of counter-rotating copies of the uppermost cycle requires firstly a demonstration that such copies even exist, and secondly either a measurement or a theoretical assessment of those speeds (and of course ideally both).
2. What is the magnitude of the fluctuation in geothermal warming possible with the stresses and strains induced by the known fluctuations in LOD? This depends on the mechanism, which may be stress-induced variation in thermal conductively of the (thin) oceanic crust, acceleration of oceanic spreading centers such as the Mid-Atlantic Ridge, the East Pacific Rise, etc. Preliminary calculations have convinced us that a 4 ms variation in LOD over 2-3 decades could only generate the requisite heat fluctuation at the surface if it caused a larger variation in thermal conductivity than we are presently able to explain. Amplification of plumes and thermals from ocean vents on the other hand may make it easier to generate the requisite flux.

On the positive side of the ledger, we have given evidence favoring an internal mechanism for the AMO over a radiatiave one, and also given a reason to suppose there is an ongoing if not particularly regular oscillation. And we have indicated what we feel is, while far from a definitive answer to the origin of the AMO, at least a promising direction to pursue further.

References

Hide, R., D.H. Boggs and J.O. Hickey (2000), “Angular momentum fluctuations within the Earth's liquid core and torsional oscillations of the core–mantle system”, Geophysical Journal International, 143:3, 777-786.

Kaplan, A., M.A. Cane, et al (1998), “Analyses of global sea surface temperature 1856-1991”, J. Geophysical Research, 103:C9, 18567-18589.

Pratt, V.R. (2013), “Reconciling multidecadal global land-sea warming with rising CO2”, AGU FM 2013, SWIRL session “Understanding 400 ppm Climate: Past, Present and Future”, oral presentation GC53C-06.

Stephenson, F.R. (2002), “Historical eclipses and Earth’s Rotation”, Astronomy and Geophysics, 44, 2.22–2.27

Williams, G.E. (2000), “Geological Constraints on the Precambrian History of the Earth’s Rotation and the Moon’s Orbit”, Reviews of Geophysics, 38:1, 37-59.