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Changes in the Earth's Rotation Rate Due to Global Warming

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Abstract

The earth's is rotation rate varies slightly as a function of time. This paper uses a very simple model to discuss the effect of global warming on the earth's rotation rate. Global warming slightly increases the earth's moment of inertia due primarily to the melting of glaciers which should slow the rotation rate of the earth. This paper, also, discusses how the changes in the moment of inertia reduces the earth's rotational kinetic energy and hence increase in the earth's internal temperature which may cause an unexpected increase or decrease in the earth's rotation rate.

Keywords: Earth; Rotation rate; Global warming; Earth's moment of inertia; Oceans

Introduction

A couple of years ago the earth was spinning slightly faster than at any time in the past 50 years by about a few parts in 10^{-9} (See Peter Whibberley: https://news.yahoo.com/earth- 185517872.html). Since then it has slowed down a bit. This indicates that either the earth's moment of inertia has slightly decreased and then increased or that a torque has acted on the earth's mantle. It is well known that the earth is experiencing global warming [1]. There are good calculations of the forcing of the climate due to the energy in long wavelength radiation emitted by the earth being less than the energy in short wavelength radiation from the sun absorbed by the earth [2]. This paper addresses whether and how the changes of earth's rate of rotation and global warming are related. The melting of glaciers increases the earth's moment of inertia and thereby reduces the rotation rate of the earth. In addition this paper proposes a mechanism that results in the heating of the interior of the earth due to the earth's loss of rotational kinetic energy. This may result in either an unexpected increase or decrease in the rotation rate of the earth.

One result reported in this paper is that the thermal expansion of the earth's oceans results in a very small increase in the earth's sea level and moment of inertia compared to the increase in the sea level and moment of inertia due to the melting of earth's glaciers and ice caps. Previously results reported by the Mitrovica group at Harvard [3] have shown that at the present time global sea-level change is driven primarily by glacial melting.

The Earth's Moment of Inertia

The earth is not a perfect sphere, but is instead better approximated as an oblate spheroid. The moments of inertia about the axis of rotation and an axis and through the center of the earth and the equator are slightly different. The moment of inertia about the axis of rotation is given by Lambeck [4] as $I = 8.034 \times 10^{37}$ kg m^2 and by Stacey [5] as $I = 8.038 \times 10^{37}$ kg m^2. The moment of inertia about an axis through the center of the earth and the equator is given by Lambeck as 8.008×10^{37} kg m^2 and by Stacey as 8.012×10^{37} kg m^2. That the two earth's moments of inertia are almost the same indicates that the earth is nearly spherical. The earth's moment of inertia varies slightly in time due to the tides and other effects. The small effects due to the earth being an oblate spheroid and due to the tides and other small effects are ignored in this paper as are effects due to the uneven composition of the earth. We consider the earth simply as a sphere with a moment of inertia $I = 8.0 \times 10^{37}$ kg m^2.

How Global Warming Affects the Earth's Moment of Inertia.

Since the mass of the atmosphere is much less than the solid earth, the largest effect global warming has on the mass distribution of the earth and therefore its moment of inertia is due to changes in the global sea levels. Between 1993 and 2013 the sea level increased by 6.6 cm [6-10]. This rise was due to two effects, the tiny effect due to thermal expansion of the oceans and the somewhat larger effect due to the melting of glaciers and ice caps.

Thermal Expansion of the Oceans

Global warming heats the upper layer of the ocean, causing the water to expand thereby raising the sea level. The increase in the sea level causes the moment of inertia of the earth to increase. The increase of the sea level is treated in a very simplified manner by considering the oceans as a spherical shell about the earth. The CRC Handbook gives the mass of the oceans as $M_w = 1.4 \times 10^{21}$ kg. Since the depth of oceans are much less than the earth's radius, the moment of inertia of this thin spherical shell of ocean water is given by, $I_w = (2/3)M_w R^2 = 3.8 \times 10^{34}$ kg m^2. The mass of the oceans is not altered by global warming. Both the density and depth of the ocean are altered. The average density decreases due to thermal expansion and the depth changes as the ocean's surface area increases. The increase in the moment of inertia of the oceans is therefore $\Delta\,(2/3)\,M_w R^2 = (2/3)\,M_w\,\Delta\,(R^2) = (4/3)\,M_w\,R\Delta R$ since $\Delta\,(R^2) = 2R\Delta R$ where ΔR is much smaller than R. Thus the fractional change in the moment of inertia of the oceans is $\Delta I_w / I_w = 2\Delta R / R$, where ΔR is taken as the increase in the sea level due to the thermal expansion of the oceans. From 1993 until 2013 the sea level increased a total of 6.6 cm [6, 11]. The fractional change in the ocean's moment of inertia is predicted by our model is $\Delta I_w / I_w \approx 2 \times 10^{-8}$ for the 6.6 cm increase of the sea level. The change in the oceans moment of inertia is about $\Delta I_w \approx 8 \times 10^{26}$ kg m^2. This leads to a fractional change in the earth's moment of inertia of

$$\Delta I_w / I \approx 10^{-11}.$$

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That the change is this tiny results from the fact that the mass of the ocean is not changed by global warming. Even though the sea level increases the ocean remains a thin shell about the earth so that $I_w = (2/3) M_w R^2$ is barely changed. The above calculation assumes that the entire sea level change is entirely due to thermal expansion of the ocean. Since more than half of the rise in sea level is due to the melting of glaciers the true fractional increase in the earth's moment of inertia due to thermal expansion by this mechanism is substantially less than $\Delta I_w / I \approx 10^{-11}$. This is shown in the next section to be negligible compared to the fractional increase in I caused by the melting of glaciers and ice caps.

Melting Glaciers and Ice Caps

If floating sea ice melts it will not change the sea level until it heats up due to global warming, and even then the global sea rise due to heating will be very small. If a glacier of mass, M_G, is located at latitude θ and a height, h, above the surface of the earth then moment of inertia of the glacier about the earth's axis of rotation is $I_G = M_G (R+h)^2 (\cos \theta)^2$, where the glacier is treated as a point mass. If a mass, m, of the glacier melts and the melt water eventually reaches the ocean then the mass of the oceans is increased by m. The earth's moment of inertia is then increased by

$$\Delta I_G = 2/3mR^2 - m\,(R+h)^2 (\cos^2\theta). \quad (1)$$

The first term is the increase in the moment of inertia about the axis of rotation is due to the sea level rise from the glacial melt water and the second term is the decrease in the moment of inertia due to the reduction in the moment of inertia of the glacier. Summing this expression for all of the world's glaciers is far beyond the scope of this paper. Nevertheless, it may be possible to estimate the effect of the melting of the world's glaciers. Since h is very small compared to R the increase in the earth's moment of inertia can be approximated as

$$\Delta I = mR^2 [(2/3-\cos^2\theta)] - 2mhR\,(\cos^2\theta). \quad (2)$$

Where the term in h^2 is ignored. Since R>>2h, the first term is much larger than the second term unless $2/3-\cos^2\theta$ is very near zero which would require the glacier to be located within ±35°of the equator. While some glaciers in the Andes and Himalayas are within this zone, the most significant glaciers are in Greenland and the Antarctic and are well outside this zone so the second term is ignored. Indeed, if all the melting occurred at 90° north or south where cosθ is zero then the only contribution to the change in the earth's moment of inertia would be due to the change in sea level which is $2/3mR^2$. If the melting occurred primarily near at the arctic or Antarctic circles the change in the moment of inertia would be about $1/3mR^2$ since $\cos^2\theta$ is about 1/3 near the arctic or Antarctic circles. We take this as a reasonable approximation and believe it is clear that the main contribution of the melting of glaciers is due to the resulting increase in sea level. At the present time the change in sea level is thought to be primarily due to the melting of the glaciers.[2, 4] Assuming the oceans cover (2/3) of the earth surface, a 1 cm layer of water about the earth corresponds to a mass of $m_{1cm,W} = (2/3)\,\rho\,(4\,\pi R^2\,\Delta r) = 3.4\times10^{15}$ kg. If we assume that approximately 6 cm of the 6.6 cm rise in sea levels from1933 to 2013 is due to the melting of glaciers, it would fractionally increase the earth's moment of inertia by

$$\Delta I_G/I \sim (1/3mR^2)/\,[(0.87)2/5MR^2] \sim 2m/M = 3.2\times10^{-9}. \quad (3)$$

This change in I, while small, is nevertheless more than 100 times larger than change in the moment of inertia caused the rise of sea level due to thermal expansion. Although the discussion of the change in the earth's moment of inertia is very simplified, it does not seem reasonable to believe that a more complete discussion in which the changes in sea level at different locations on the earth and hence a redistribution of the mass of the oceans, would result in a significant change in the moment of inertia nor a big difference in the fractional change in the moment of inertia. Hence we believe that the crude estimate in this section is adequate for our purpose.

The Change in the Earth's Rotation Rate

The earth's angular momentum about its axis of rotation is given by, L = Iω, where I is the earth's moment of inertia and where ω is the rotation rate of the earth about its axis. The rotational rate of the earth is $L = 7\times10^{-5}$ rad/s. Since L is constant, in the absence of a torque, the fractional change in the moment of inertia of the earth is equal to the negative of fractional change in the rotation rate. Between 1993 and 2013 the sea level increased about 6.6 cm. The fraction of the rise in the sea level due to the melting of glaciers is not certain, but for the last two decades it is believed to be significantly greater than the fraction of the rise due to thermal expansion of the oceans [2, 4]. As an estimate we assume that 6 cm of the sea level rise is due to the melting of glaciers. The fractional change in the earth's rotation rate is therefore about $\Delta\omega/\omega = -3.2\times10^{-9}$ due to melting glaciers and ice caps. It should be noted that this number is similar in magnitude to the measured increase in the rate of rotation of the earth except that it is in the opposite direction. Thus the increase in the rate of rotation must be due to some effect that overcomes the increase in the moment of inertia due to global warming. Sections 5 and 6 of this paper propose a method by which global warming may increase the earth's moment of inertia but nevertheless result in an increased rate of rotation of the earth.

The Internal Heating of the Earth

The rotational kinetic energy of the earth about its axis is $KE = (½) I\omega^2 = (½) L\omega$. Since L is constant it follows that the fractional change in the rotational kinetic energy of the earth is equal to the fractional change in the rotational rate of the earth about its axis. The rotational kinetic energy of the earth is $KE = (½) I\omega^2 = 4\times10^{29}$ J. Thus the earth's kinetic energy of rotation should decrease by about $\Delta KE = -1.2\times10^{21}$ J for a 6 cm change in the sea level due to the melting of the glaciers. Although this is very small compared to the rotational energy of the earth, it is nevertheless on an absolute scale an extremely large energy. A decrease in the rotational energy of the earth must appear as heating of the earth. One might ask where this heat is generated. Some of the rotational energy loss will result in strains in the earth's mantle, which will in time be released as heat. Some of the heat will result in as heating of the oceans. As the mantle's rotation rate decreases due to friction between the mantle and the liquid core it, will result in heating the core and the rock near the mantle-liquid core interface. The author suspects that a significant part of the energy loss may occur at the mantle-core interface.

Comments on the Change in the Rotation Rate of the Earth

This paper has shown that the increase in sea level due to global warming should at first appear to result in a small decrease in the earth's rotation rate. For the earth then to increase its rotation rate either the earth's mantle must be experiencing a torque or its moment of inertia must have decreased. Perhaps the increase in the sea level has compressed some part of the earth's interior thereby decreasing the moment of inertia, although this seems unlikely. If this is not the case then there must be torque acting on the earth. We dismiss far out explanations such as a torque resulting from the earth interacting gravitationally with a clump of rotating dark matter. The liquid part of the core has a circulation that carries a current which produces the earth's magnetic field. If this circulation changes in magnitude and/or direction so that the angular momentum of the core changes then it would exert a torque on the earth's mantle, which would cause the rotation rate of the earth to change. We believe that the internal heating of the earth by the initial decrease in earth's moment of inertia may result in a change in the cores circulation. If the change in the core's circulation were in such a direction as to more nearly align with the earth's rotation then the earth's rotation rate would slowly increase. If the change is opposite it may slow the earth's rotation rate.

A self-sustaining dynamo like the one that produces the earth's magnetic field is susceptible to being affected by extremely small alterations in the conditions. Perhaps a small change in the rotation of the earth due to internal heating of the earth that has resulted slowly in a small but measurable change in the direction and/or the magnitude of circulation of the liquid part of the core and hence a change in both the earth's angular momentum and its magnetic field even though the previous change in the earth's rotation rate was very small. Repeated small changes in the moment of inertia might thereby produce a small net increase in the earth's rate of rotation even though the earth's moment of inertia is increasing. The earth's magnetic field is moving rapidly toward Siberia at the present time [12]. It has been concluded that the polar drift in the 1990s was primarily due to the melting of terrestrial glaciers [13]. Since the motion of earth's magnetic pole has been altered by the melting of the glaciers, which must have changed the motion of liquid core, the change in the motion of the liquid core will exert a torque on the earth's mantle, which can alter the earth's rotation rate. Thus it seem reasonable that both the polar drift and the increased rotation of the earth are related to the melting of the glaciers and ice caps, and are therefore are indirectly the result of global warming and the resulting increases the sea level.

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