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Geomagnetic secular variation as a precursor of climatic change

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Long period trends in climate are usually associated with solar disturbance[1]. For example, a close similarity has been demonstrated[2,3] between variations in the length of day (LOD) with periods greater than about 10 yr and trends in several climatic indices over the past 150 yr. We point out here a correlation between variations in the Earth's magnetic field, the Earth's rotation rate and some climatic indicators, thus suggesting a possible long term influence of core motions on climate. We suggest that geomagnetic secular variation can be used to forecast a climatic change in the 1990s.

A good correlation has been established[2,3] between LOD variations and either global temperature θ (correlation coefficient 0.85; θ lagging LOD variations by ~5 yr, see Fig. 1) or the long period atmospheric and oceanic excitation function ψ^{T} related to near surface winds, changes in the atmospheric mass distribution and eustatic changes in sea level (correlation coefficient 0.75; ψ^{T} lagging LOD variations by ~15 yr see Fig. 9.6 in ref. 4; ψ^{T} is computed from ground level pressure sea-level data under the geostrophic assumption). Periods of increasing zonal circulation and increasing global surface temperature are found to correspond to periods of Earth acceleration, while periods of decreasing zonal circulation and decreasing global surface temperature correspond to periods of Earth deceleration. It has been further observed[3] that the excitation function ψ^{T} represents only about 10% of the amoun necessary to explain the LOD variations. This led to the conclusion that it is not possible as yet to establish causal relationships between these phenomena and that one cannot decide whether (1) atmospheric circulation causes the long period changes in LOD, or (2) the fluctuations are both a consequence of a third phenomenon, or (3) the fluctuations in LOD cause the observed variations in the atmospheric circulation.

Although A.C. and Lambeck[3] note the problems related to phase lag between θ (or ψ^{T}) and LOD and the insufficien amplitude of the excitation function, they tend to rejec hypothesis (3) because "the total mechanism for exciting the LOD changes remains to be explained".

More recently, Lambeck[4] has reviewed the long period o decade fluctuations in the Earth's rotation and discussed thei geophysical origin. He notes that the role of the core is central for it is the only sufficiently mobile part of the Earth with sufficient mass to modify the rotation by the observed amount on that time scale. Out of the mechanisms proposed for core–mantle coupling, pressure or inertial coupling due to the ellipticity of the core boundary, topographic coupling due to bumps on the core–mantle interface and viscous coupling all seem to be inadequate[4,5]. Only electromagnetic core–mantle coupling as suggested by Bullard *et al.*[6], survives the screening process despite severe uncertainties regarding the conductivity of the lower mantle and the core motions. The key observations required to resolve these uncertainties come from observations of the secular variation, in particular the rate of westward drift of the geomagnetic field. The magnetic observations available to Lambeck did suggest some kind of correlation between LOD and geomagnetic variations, but the evidence was inconclusive

The situation has been improved with the observation[7] that the secular variation of the geomagnetic field had undergone sharp accelerations of global extent. The last and best studied such phenomenon which occurred around 1970 is described in refs 8, 9, 14. The secular acceleration can first be used to infer an upper bound on the electrical conductivity of the lower mantle which is found to be of the order of a few hundred Ω^{-1} m^{-1} (refs 10, 11). This parameter is essential in any computation related to electromagnetic core–mantle coupling.

The correlation[7] between secular variation accelerations and extrema in LOD fluctuations has recently been put on a firmer and more systematic basis[12] with the demonstration of a good correlation between LOD variations and the secular variation of declination, observed for instance in European observatories where the longest records are available: the correlation for the period 1865–1975 is far more convincing than any previously reported (Fig. 1). The correlation coefficient is found to be about 0.8, with the magnetic variations leading LOD fluctuations by about 10 yr. J.L. Le M. and V.C.[13] suggest that model of accelerated westward drift of the upper core based on the original model of Bullard *et al.*[6] accounts both qualitatively and quantitatively for the observations. In this model the Earth's mantle, an upper core layer and the lower core a all electromagnetically coupled. A sudden torque applied the time of a secular variation acceleration on a ~100 km thic upper core layer leads to a very fast response of westward dri as observed at the surface, and to a fast response of the lowe core in the opposite sense. The lower core finally drags th mantle with a longer time-constant, of the order of 10 yr, as typically observed in the decade fluctuations of LOD. Thu these decade fluctuations are probably caused by rearrangements in core motions. Having found a mechanism which ca excite LOD changes, it becomes natural to accept the hypothes that fluctuations in LOD in turn are responsible for changes atmospheric circulation (although the hypothesis of an indepe

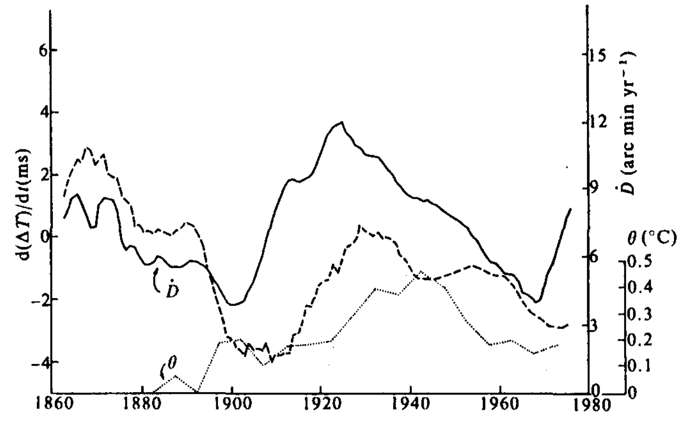

Fig. 1 Plot of the secular variation of geomagnetic declination $\dot{D}$ (solid curve), of the excess length of day d(ΔT)/dt (dashed curve) and of successive 5 yr averages of the temperature θ over the whole Earth (expressed as departures from the means for 1880–84, after Fig. 18.2 of ref. 1, dotted curve).

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ant common cause cannot be rejected). The observed phase between ψ^T and LOD and the amplitude of ψ^T are then at least qualitatively accounted for. There is an attractive causal chain whereby, over the decade period range, angular momentum is transferred from the core to the mantle and finally to the atmosphere (although details of the transfer mechanism remain to be studied).

Lambeck and A.C.[3] point out that LOD variations can be used as an indicator of future climatic trends. Lamb (ref. 1, p. 10) in his review of scientifically based climate forecasts notes that variations are commonly associated with long term variations of solar disturbance. He notes a considerable measure of agreement between the various forecasts, with a trend towards colder climates with weakened general atmospheric circulation which is expected to continue into the twenty-first century, in some cases with a sharp further cooling about 1980 and easier conditions for a time in the first half of the next century. The geomagnetic results referred to here suggest that changes in secular variation can be used as indicators of future LOD fluctuations[12,13] and, with an even longer time lead of 15–25 yr, as indicators of climatic changes, in particular changes in global surface temperature. The clearly established 1970 secular acceleration, which has now been maintained for a decade, suggests a correlated positive acceleration in LOD in the immediate future and the beginning of a period of steady increase in average global temperature around 1990 (±5 yr). K. Brian (personal communication) has recently pointed out a possible correlation between the frequency of geomagnetic reversals and deep ocean temperature over the past 55 Myr, thus suggesting another (very) long term relationship between climate and the Earth's magnetic field.

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Spore–pollen evidence for early Oligocene high-latitude cool climatic episode in northern Canada

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Climatic cooling in the Eocene leading to markedly lower temperatures in the Oligocene has been documented in oxygen isotope studies in the North Pacific[1,2], New Zealand[3], South Pacific[4] and North Sea[5]. These lower temperatures in the Oligocene correspond to palaeoclimatic interpretations of North American leaf floras[6,7] which suggest a profound cooling occurring towards the end of the Eocene, indicated also in the southeastern United States from studies on mid-Tertiary spores and pollen[8]. Recently, Collinson *et al.*[9] have shown palaeobotanically that in southern England cooling occurred gradually starting in the latest early Eocene leading to two major periods of floristic change before the end of the Eocene. Thick Tertiary sections in the subsurface Mackenzie Delta region, Northwest Territories[10,11] provide well-preserved Palaeogene palynofloras[12] discussed here which indicate a cooler climate in the Oligocene following warm-temperate conditions in the Eocene. This widespread early–middle Oligocene cool episode is thus represented in both high-latitude and lower-latitude floras and seems to have been of global extent, persisting until towards the end of the Oligocene, but its precise dating remains a problem. In northern Canada it is followed by an amelioration of the climate in the late Oligocene which persisted probably until the middle Miocene. The rate of cooling during the Eocene and Oligocene may have varied depending on locality, but once established the cooler Oligocene climate exerted a profound influence on biotic development.

The subsurface Mackenzie Delta region (lat. 69 °N, long. 134 °W) includes a thick Tertiary molasse pile[11,13,14] deposited in the Richards Island Basin, representing several regressive depositional events formed by prograding deltas with marine deposits at the base. A relatively continuous Tertiary section is available here from the Palaeocene through to the Quaternary[11,12,15,16] but a major unconformity removes much of the Palaeogene in the southern part of the basin. The Imperial Nuktak C-22 well in the northern part of the basin has a relatively complete Tertiary section (Fig. 1) down to TD 12,650 ft in the middle Eocene part of the Richards Formation[12], a prodeltaic mudstone unit in excess of 5,000 ft thick which passes laterally southwards into the upper part of the Palaeocene–middle Eocene deltaic Reindeer Formation[11]. The Richards Formation is largely middle to late Eocene on the basis of the *Haplophragmoides* foraminiferal assemblage[11] and the presence near the base[12] of *Pistillipollenites mcgregorii* Rouse and the dinoflagellate cysts *Glaphyrocysta ordinata* (Will., and Dow) Stover and Evitt, *Cordosphaeridium gracile* (Eis.) Dav. and Will., and *Wetzeliella* sp. cf. *W. hampdenensis* Wilson. The precise placement of the Eocene–Oligocene boundary has not been achieved yet because ranges of terrestrial palynomorphs are uncertain at these high latitudes[12,15,17]. It probably occurs almost 1,700 ft below the top of the Richards Formation (Fig. 1) if Rouse[17] is correct in limiting the range of *Integricorpus* sp. (which probably does not occur below 9,500 ft in the Nuktak C-22 well) to the Oligocene. This interpretation is supported by the presence in the upper 1,700 ft of the Richards Formation of spore–pollen species from the putative Lower Oligocene of northeastern China[18].

The terrestrial flora of the middle–late Eocene part of the Richards Formation is diverse and contains taxa which can be

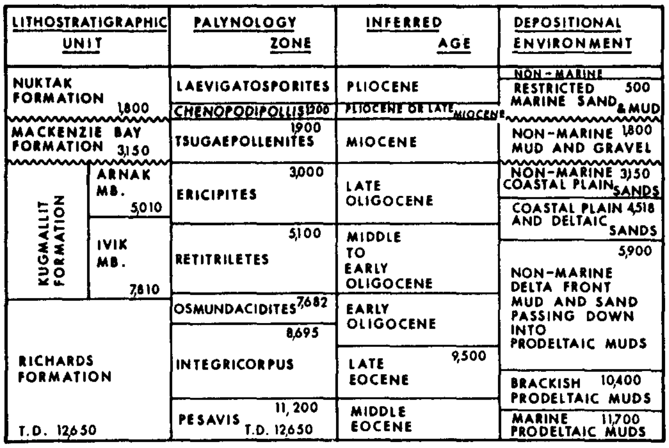

Fig. 1 Tertiary stratigraphy of Imperial Nuktak C-22 well. Palynostratigraphy, zonal names and age according to ref. 12, but Eocene–Oligocene boundary may occur lower (see text for discussion). Lithostratigraphy after Young and McNeil[11]. Numbers give the depth in feet.

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