Solar Wind, Earth’s Rotation and Changes in Terrestrial Climate

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ABSTRACT

Solar variability affects Earth climate. It is proposed that this forcing primarily goes via the interaction of the Solar Wind with the Earth’s magnetosphere, rather than via changes in irradiance, which is generally assumed. The cyclic variations in Solar Wind emission generate corresponding changes in the Earth’s rate of rotation (LOD), as recorded by correlations between sunspot numbers and LOD-variations. Variations in Earth’s rotation affect not only the atmospheric circulation but also the ocean circulation. Because the ocean water has a very high heat storing capacity, changes in the ocean circulation will affect regional climate. The redistribution of oceanic water masses also gives rise of irregular changes in sea level over the globe. During the last 6000 years this redistribution of ocean water masses seems to have been the dominate sea level variable. The El Niño/ENSO events contain a part, which represent an interchange of angular momentum between the solid earth (LOD) and the equatorial ocean circulation in the Pacific. The 60-year solar-terrestrial cycle controlled the climatic conditions and main fish stocks in the Barents Sea via an oceanic beat in the inflow of warm Atlantic water. The major Solar Maxima and Minima of the last 600 years correspond to decreases and increases in the Earth’s rotation, which altered the ocean circulation in the North Atlantic by that generating major climatic changes and sea level changes. Speeding-ups of the Earth’s rotation during the Spörer, Maunder and Dalton Solar Minima forced the Gulf Stream to be concentrated on its southern branch and cold Arctic water to penetrate far down along the European coasts, which lead to Little Ice Age conditions in the Arctic and in northern to middle Europe but extra warm periods in the Gibraltar to northwest African region. During the Solar Maxima, the situation was the reverse. By around 2040, we will be in a new major Solar Minimum and may, therefore, expect a period of cold climatic conditions.

Key words: Solar-terrestrial interaction, Solar Wind, Earth’s rotation, ocean circulation.

1. Introduction

The Sun emits light and energy, known as solar luminosity or solar irradiance, and the Earth’s receives on an average 342 W/m^2 at the top of the atmosphere. The Sun alters between active and quiet stages by a rhythm of ~11 years; the so-called Solar Cycle. The Solar Cycles also exhibit longer-term cycles recorded as Solar Minima and Solar Maxima (or Grand Maxima and Grand Minima). The Solar Minima of the last 600 years seem all to correlate fairly well with cold phases or “Little Ice Ages” (e.g. Eddy, 1976; Mörner, 2010).

The Sun also emits solar plasma, known as the Solar Wind. The velocity varies between ~400 km s^{-1} (slow solar wind) and ~750 km s^{-1} (fast solar wind). The Solar Wind is responsible for the shape of Earth's magnetosphere, and the shape and position of the magnetopause, which implies a controlling effect on the Earth's space environment and space weather.

The shielding capacity of the upper atmosphere against cosmic rays is dependent on the strength of the Earth's magnetic field, which in its turn is the function of the interaction between the Earth's own geomagnetic field and the Solar Wind. Because the Solar Wind pulsates in pace with the solar activity (the 11 years sunspot cycles), the Earth's shielding capacity also changes with the solar activity; being strong at sunspot maxima and low at sunspot minima. Therefore, more cosmic rays enter into the upper atmosphere during sunspot minima, and less during sunspot maxima.

The cyclic variation in the flux of incoming cosmic rays is recorded in the production of ^{14}C in the atmosphere, in the in-fall of ^{10}Be at the Earth's surface and probably also in the formation of clouds (as proposed by Svensmark; e.g. 1998, 2007).

Another effect of the interaction between the Solar Wind and the Earth's magnetic field seems to be that it affects the Earth's rate of rotation where Solar Minima lead to accelerations and Solar Maxima to decelerations (as discussed in previous papers; Mörner, 1989a, 1990, 1995a, 1996a, 2010, 2011, 2012). Several authors have noted a correlation between sunspot activity and Earth's rotation (e.g. Kalinin and Kiselev, 1976; Laptukhov, 1980; Golovkov, 1983; Plakhotniuk, 1983; Mazzarella and Palumbo, 1988; Krymskij, 1993; Gu, 1998; Rosen and Salstein, 2000; Kirov et al., 2002; Abarca del Rio et al., 2003; Mazzarella, 2007, 2008; Mörner, 1996a, 2010, 2011, 2012; Le Mouël et al., 2010) or Solar-planetary cycles and Earth's rotation (Mörner, 1984a, 1984b, 1987, 2012; Scafetta, 2010, 2012a, 2012b; Mackey, 2009; Solheim and Humlum, 2011; Wilson, 2011).

Golovkov (1983) plotted Earth's rate of rotation (spin rate) against sunspot numbers and found that high spin rates correlated with low sunspot numbers and low spin rates with high sunspot numbers. Mörner (2010) plotted LOD against sunspot numbers for the period 1831–1995 and found a linear relationship where low LOD values (high spin rate) correlated with low sunspot numbers adn high LOD values with high sunspot numbers. Consequently, the Earth's rotation accelerates at low solar activity and decelerates at high solar activity.

The relations among solar activity, Solar Wind, variations in Earth's atmospheric shielding capacity and variations in the Earth's rate of rotation are expressed in Fig. 1.

2. Solar-Terrestrial interaction

The climatic changes on Planet Earth – weather short-term or long-term, weather regional or global – cannot (of course, one wants to add) be understood without a central role of the solar-terrestrial interaction (e.g. Fairbridge, 1984; Herman and Goldberg, 1985; Fairbridge and Saunders, 1987; Mörner, 1987, 1996a, 2012; Pittock, 2007; Mackey, 2009; van Geel and Ziegler, 2013). I will here address the climatic changes on a yearly to centennial basis (cf. Mörner & Karlén, 1984) in the context of solar signals and terrestrial responses, as illustrated in Fig. 1.

Friis-Christensen and Lassen (1991) established an excellent correlation, for the last 150 years, between changes in the length of the sunspot cycle and the general changes in global mean temperature (cf. Thejll and Lassen, 2000). This gave evidence of a strong solar-terrestrial linkage, despite the fact that the physics behind this linkage was still unknown.

On the decadal-to-centennial basis, the solar activity exhibits cyclic variations between Solar Maxima and Solar Minima as recorded by instruments, observations, aurora, aa-index, ^{14}C-production, ^{10}Be in-fall, etc (e.g. Stuiver and Quay, 1980; Hoyt and Schatten, 1993; Lean et al., 1995; Cliver et al., 1998; Lean and Rind, 1999; Bard et al., 2000; Bond et al., 2001; Boberg and Lundstedt, 2002; Mazzarella, 2007; Velsco et al., 2008; Scafetta, 2010; Le Mouël et al., 2010, Mufti & Shah, 2011).

The Solar Minima – the Dalton Minimum 1800–1820, the Maunder Minimum 1645-1705, the Spörer Minimum 1420-1500 and the Wolf Minimum 1290-1350 – have attracted special attention because they have been proposed to correlate with cold periods or Little Ice Ages (e.g. Eddy, 1976). In the west European records, there are quite clear cold minima at 1440-1460, 1687-1703 and 1808-1821 (Mörner, 1995a, 2010), i.e. right within the last three Solar Minima. Because of the cyclic repetition of those maxima and minima, one may access the timing of the next Solar Minimum.

The date of the first Future Solar Minimum was assigned at around 2030 by Landscheidt (2003), at around 2040 by Mörner et al. (2003), at 2030-2040 by Herrera (2010), at 2042 ±11 by Abdassamatov (2010), at 2030-2040 by Easterbrook (2011) and at 2030-2040 by Sancetta (2012), implying a fairly congruent picture despite somewhat different ways of transferring past signals into future predictions. In analogy with the past Solar Minima, one may assume that the future minimum at ~2040 will also generate Little Ice Age climatic conditions (Mörner, 2010, 2011, 2012).

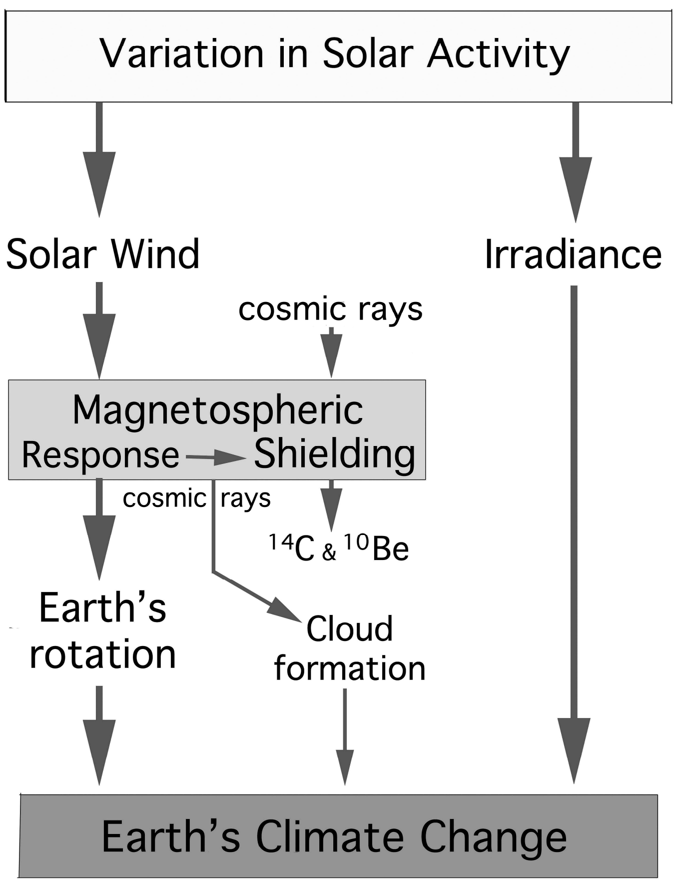

Fig. 1. Variations in solar activity lead to changes in the Solar Wind and in solar irradiance, both of which may affect Earth's climate (modified from Mörner, 2011). The variations in irradiance are known to be small or even minute. The variations in Solar Wind are large and strong; via the interaction with the Earth's magnetosphere, it affects

Earth's rate of rotation, by that affecting the oceanic and atmospheric circulation systems, both of which have a strong effect of terrestrial weather and climate. Changes in the shielding capacity affect the flux of incoming cosmic rays, which controls ^{14}C production, in-fall of ^{10}Be and cloud formation.

2.1. Solar irradiance

The solar-terrestrial interaction is often explained in terms of variations in Solar irradiance over the sunspot cycle and it multiples (e.g. White et al., 1997). The variation in energy output during a sunspot cycle is found to be far too low, however, or only in the order of 0.2 % (Willson, 1997). Therefore, this mechanism can hardly be used to explain the decadal-to-centennial changes in climate as recorded during the last millennia. Only by assuming unknown and hypothetical amplifying forcing-functions may it be converted to effects large enough to explain observed changes in climate (e.g. Lean et al., 1995). However, Zhang et al. (1994) have shown that the solar luminocity (brightness) may have ingreased by 0.2–0.6% since the Maunder Mimimum in the 17th century (also addressed by Hoyt and Schatten, 1993).

2.2. Solar Wind and cosmic rays in-fall

In a number of papers, Svensmark (e.g. 1998, 2007) has proposed that Earth climate may be strongly controlled by cloud formation driven by cosmic rays, which, in its turn, is modulated by the interaction of the Solar Wind with the Earth's geomagnetic field (Fig. 1). Svensmark has proposed that this mechanism is responsible not only for the short-term changes in climate, but also for the long-term changes throughout the Earth's history (Svensmark & Calder, 2007). This is an exciting novel theory.

2.3. Solar Wind and Earth's rate of rotation

The correlation between solar variability and Earth's rotation seems well established (cf. above). The Solar Wind interaction with the magnetosphere (Fig. 1) seems to provide physical means of understanding this correlation (in opposite to changes in Solar irradiance).

The changes in the rate of Earth's rotation (LOD) lead to compensational changes in the atmospheric and oceanic circulation, and sometimes even in the core/mantle conditions (geomagnetism).

I have previously discussed the interchange of angular momentum between the solid earth and the hydrosphere (Mörner, 1984a, 1988, 1989, 1990, 1993a, 1993b, 1995b, 1996b) and also proposed an origin in the Solar Wind interaction with the Earth's magnetosphere (Mörner, 1995a, 1996a, 2010, 2011, 2012). In this paper I will expand on the relations among variations in Solar Wind, LOD and ocean circulation.

Alternatively, a solar-planetary beat may act not only on the Sun, its emission of Solar Wind and the interaction with the magnetosphere, but also directly, via its gravitational-rotational forces, on the Earth-Moon system (as illustrated in Figs. 2 and 3).

2.4. A combination of factors

Finally, there are all reasons to believe that mechanism 2 and 3 may interact and operate simultaneously. The same may apply among effects from variations in the solar irradiance (e.g. Scafetta, 2011, 2012b), which may generate additional effects to those generated by the Solar Wind emission (Fig. 1).

In this paper, however, the focus will be on the possible effects of variations in the Solar Wind upon terrestrial climate via changes in the Earth's rate of rotation.

3. Solar variability

First, we may consider the origin of the variations in solar activity or the so-called Solar Cycles; e.g. the 11-year sunspot cycle, the 22-year Hale cycle, the 60-year cycle, the 80-year Gleissberg cycle, the 120-year VMV cycle, the 240-year de Vries cycle and possible longer cycles. The origin of those changes in solar activity may be internal Solar or external Planetary.

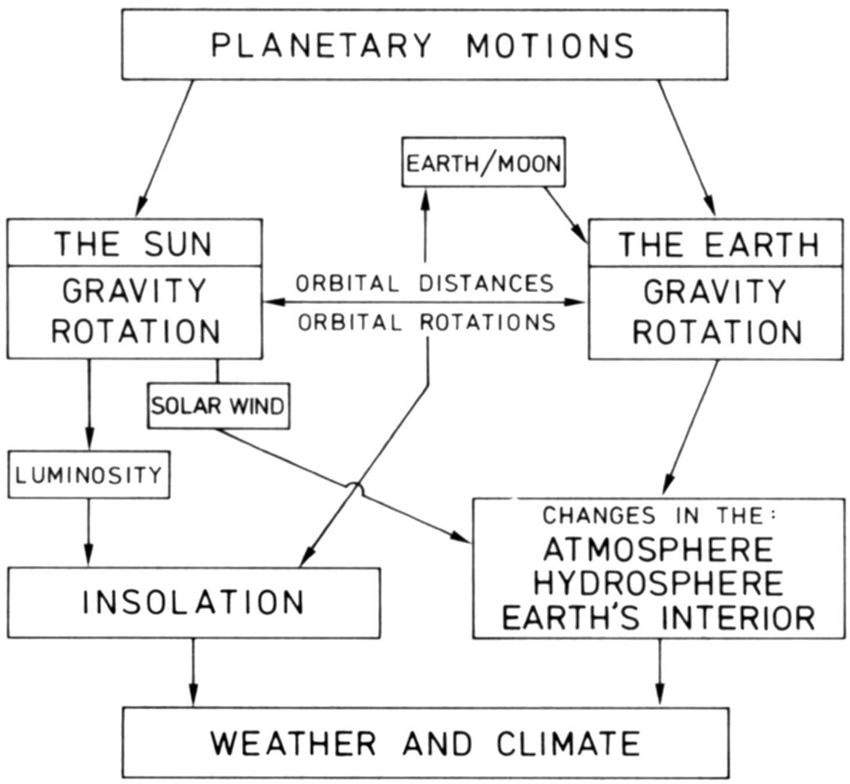

Fig. 2. Hypothetical interactions of planetary forces driving the solar variations in emission of luminosity (irradiance) and Solar Wind (from Mörner, 1984a).

Whilst Dicke (1978) talked about "a chronometer hidden in the Sun", others started to seek the origin in a planetary beat on the Sun and the Sun's circular motions around the common centre of mass (e.g. Landscheidt, 1976; Mörth and Schlamminger, 1979; Fix, 2011; Wilson, 2011). The theory of constant planetary and solar adjustments in their motions with respect to the centre of mass (CM) implies a paradigm shift from strict "keplerian" motions of the planets around the Sun to "vibrational" multi-body motions around the common centre of mass. In this system neither the orbital distances nor the orbital speeds can remain constant. This was illustrated in an old picture (Mörner, 1984a,

Fig.13), here reprinted as Fig. 2. A new and updated version (Mörner, 2012) is presented in Fig. 3.

Scafetta (2010) has recently shown that "astronomical oscillations and solar changes drive climate variations", and that the planetary beat plays a central role. The correlation between the 60 years terrestrial LOD cycle and the 60 years cycle of changes in the orbital speed of the Sun around the centre of mass of the solar system is striking (Scafetta, 2010, Fig 14). More comprehensive analyses are given in Mörner (2012) and Scafetta (2012b).

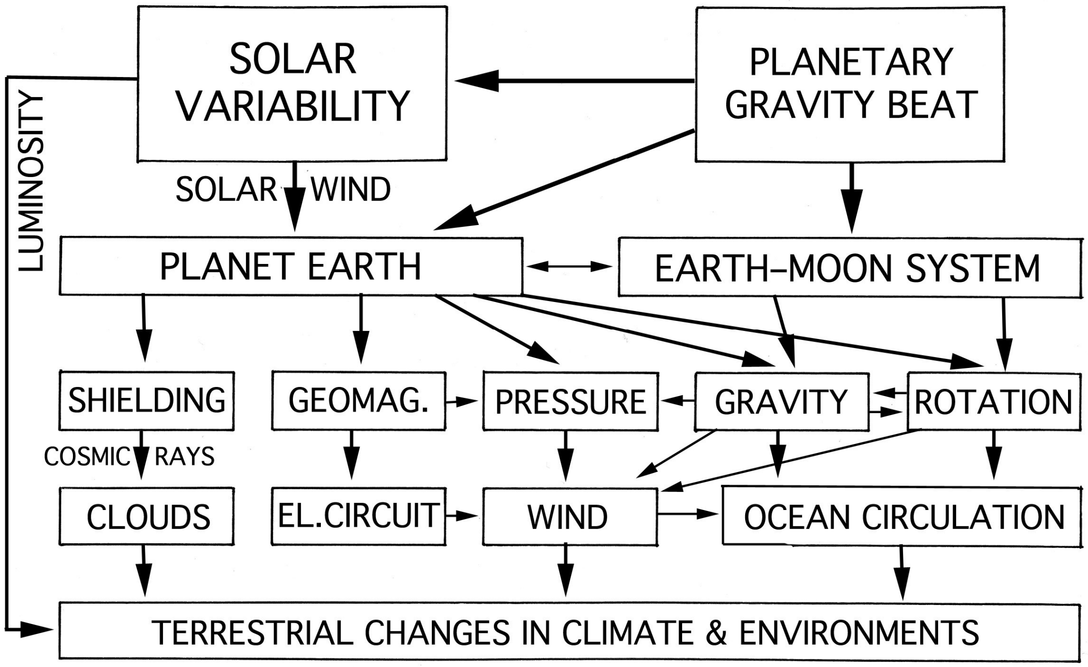

Fig. 3. The interaction between planetary gravitational beat and solar variability, and the observed changes in climate and environments (from Mörner, 2012).

4. Solar Wind and Earth's rotation

The correlations established (cf. above) between changes in solar activity and Earth's rate of rotation can only be understood in terms of the interaction of the Solar Wind with the magnetosphere and its effects on Earth's rotation (as illustrated in Fig. 1).

There might also be direct gravitational-rotational effects on the Earth from the planetary beat on the coupled Earth-Moon system and the Earth itself (as illustrated in Figs. 2 and 3).

Le Mouël et al. (2010) have shown that there is an excellent correlation among the last 4 sunspot cycles, the changes in the length of day (LOD) and the atmospheric flux of cosmic rays. I interpret this as firm evidence that the solar forcing (cf. Fig. 1) must be the changes in Solar Wind, its effects on the shielding capacity of the Earth's magnetosphere and the causative changes in Earth's rate of rotation. It seems, however, that differential rotation is also involmed with the interchange of angular momentum between the solid earth and the atmosphere (cf. Section 4.3).

Kirov et al. (2002) recorded a correlation between the 22-year solar rotation cycle and Earth's rotation and proposed an origin in Solar Wind transfer of angular momentum.

The 60-year cycle has been identified by several authors in solar activity, in changes in LOD and in changes of various terrestrial climatic data (e.g. Mazzarella, 2007, 2008;

Klyashtorin et al., 2009; Scafetta, 2010, Chambers et al., 2012; Mörner, 2012; Mezzarella ans Scafetta, 2012).

The 120-year and 240-year cycles as recorded in the long-term changes between Solar Maxima and Solar Minima of the last 600 years was found to correspond to periods of rotational decelerations and accelerations (Mörner, 1996a, 2010, 2011, 2012; Velasco et al., 2008).

4.1. Differential rotation of the Earth's sub-layers

The Earth is composed of several layers and sub-layers that may be subjected to differential rotation (Mörner, 1984a, 1987, 1988, 1989b); i.e. the atmosphere with its sub-layers, the oceans with their surface circulation and deep-water circulation, the lithosphere resting on a semi-liquid asthenosphere, the core/mantle boundary and maybe even the outer/inner core boundary. This is illustrated in Fig. 4.

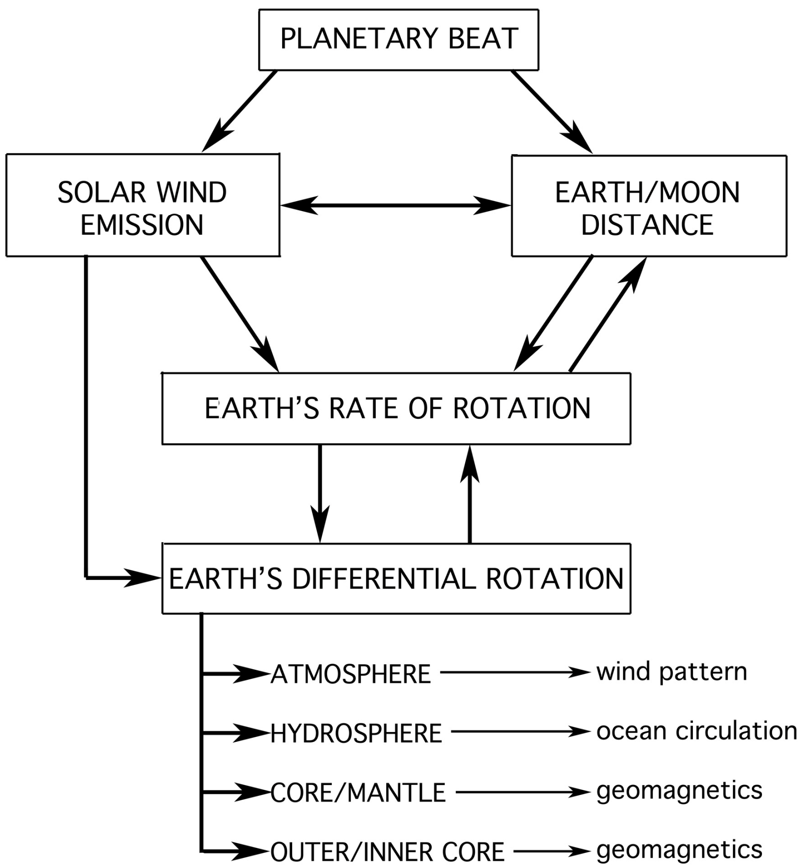

Fig. 4. Earth's total and differential rotation as a function of planetary beat and Solar Wind emission.

Changes in Earth's rate of rotation have to be compensated by readjustments of the Earth–Moon distance (Marsden and Cameron, 1966; Dieke, 1966) and of the Sun–Earth distance (Mörner, 1884b). The glacial eustatic changes in sea level alter the radius of the Earth, which affects the rate of rotation (Mörner, 1984a, 1988, 1992, 1993b, 1996a) and hence must be compensated by the Earth–Moon distance. Variations in the intensity of

Solar Wind lead to increases and decreases in the rate of rotation via the interaction with the Earth's magnetosphere (Mörner, 1996a, 2010, 2012).

The Earth's differential rotation implies the interchange of angular momentum between "the solid Earth" and its sub-layers (Fig. 4); i.e. the atmosphere (Hide and Dickey, 1992), the hydrosphere (Mörner, 1984a, 1988), the core (Braginskiy, 1982; Rochester, 1984; Duhau and Martinez, 1995), the inner core (Mörner, 1991) and maybe also the asthenosphere (Mörner, 1984a, 1987, 1989b).

Obviously there exist a delicate interaction of different variables, as indicated by the 60-year cycle, which is documented in the LOD changes, in atmospheric circulation (e.g. Mazzarella, 2007), in oceanic circulation (Mörner, 2010; 2013) and in geomagnetic changes (Braginskiy, 1982; Boberg and Lundstedt, 2002; Roberts et al., 2007; Mufti and Shah, 2011).

4.2. The atmospheric circulation

According to Bucha (1983, 1984) changes in the atmospheric circulation play a central role in the solar-terrestrial interaction. Because he records correlations between changes in the geomagnetic field and changes in the atmospheric circulation, the forcing function must go via the Solar Wind and not via the solar irradiance (as illustrated in Figs 1 and 3).

Stronger and weaker geomagnetic activity makes the Arctic circulation to switch between zonal and meridional circulation according to Bucha (e.g. 1984). This beat was later termed the Arctic Oscillation or AO (Thompson and Wallace, 1998; cf. Lorenz, 1951).

Le Mouël et al. (2010) assume that the changes in LOD as a function of the sunspot cycle affect only the atmospheric circulation. This is also the case with 60-year cycle as presented by Mazzarella (2007, 2008) and Scafetta (2010). I should be noted, however, that most the terrestrial 60-year cycles refer to marine records and the Pacific Decadal Oscillation (PDO), indicating that the oceanic circulation is also involved (Scafetta, 2012d; Mazzarella and Scafetta, 2012; Mörner, 2012, 2013). The same seems to be the case with the North Atlantic Oscillation (NOA) as shown by Boberg and Lundstedt (2002) and Mazzarella and Scafetta (2012).

It is true that the annual LOD changes seem well balanced by changes atmospheric angular momentum (e.g. Barnes et al., 1983). For longer-term LOD changes, the situation becomes more complicated and the oceanic circulation and core/mantle coupling must also be considered.

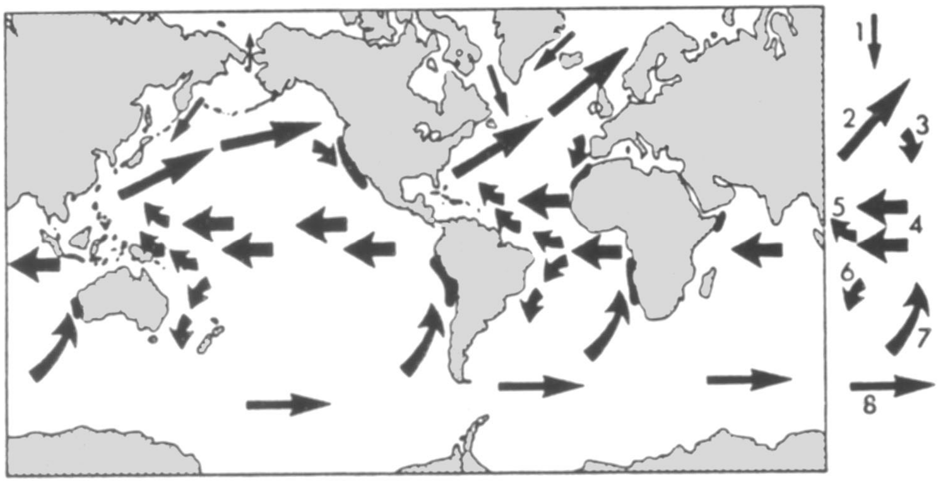

Fig. 5. Major ocean surface current systems (Mörner, 1984a); (4) the major lagging-behind equatorial currents, (2) the Kuroshio and Gulf Stream systems bringing warm equatorial water to mid and high latitudes, (7) the Southern Hemisphere currents bringing cold Arctic water to low latitudes and being responsible to significant coastal up-welling, (8) the main circum-Antarctic current and (1, 3, 5) some other currents not discussed in this paper.

4.3. The ocean circulation

The oceanic surface current systems (Fig. 5) must (of course, one would like to add) be strongly dependent upon the Earth's rate of rotation. The equatorial currents are obviously lagging-behind the general rotation of the solid Earth (Mörner, 1988, 1989a, 1990, 1995a, 1996a). The Gulf Stream and the Kuroshio Current bring hot equatorial water masses from low latitudes to high latitudes in the Northern Hemisphere, which must be strongly controlled (in feed-back coupling) by rotation (Mörner, 1984a, 1988). The Circum-Antarctic Current is strongly feed-back coupled to the rate of rotation. The 3 current systems bringing cold water from high latitudes to low latitudes in the Southern Hemisphere (7 in Fig. 5) must be influenced/coupled to changes in rotation. Besides they have a strong effect on coastal up-welling and ocean ventilation.

Therefore, I have always claimed that changes in the ocean surface circulation have a very strong effect on the global redistribution of heat and water masses (Mörner, 1984a, 1988, 1989a, 1990, 1993a, 1995a, 1996a, 1996b, 2010, 2011, 2012; cf. Mazzarella et al., 2012); i.e. climate and sea level.

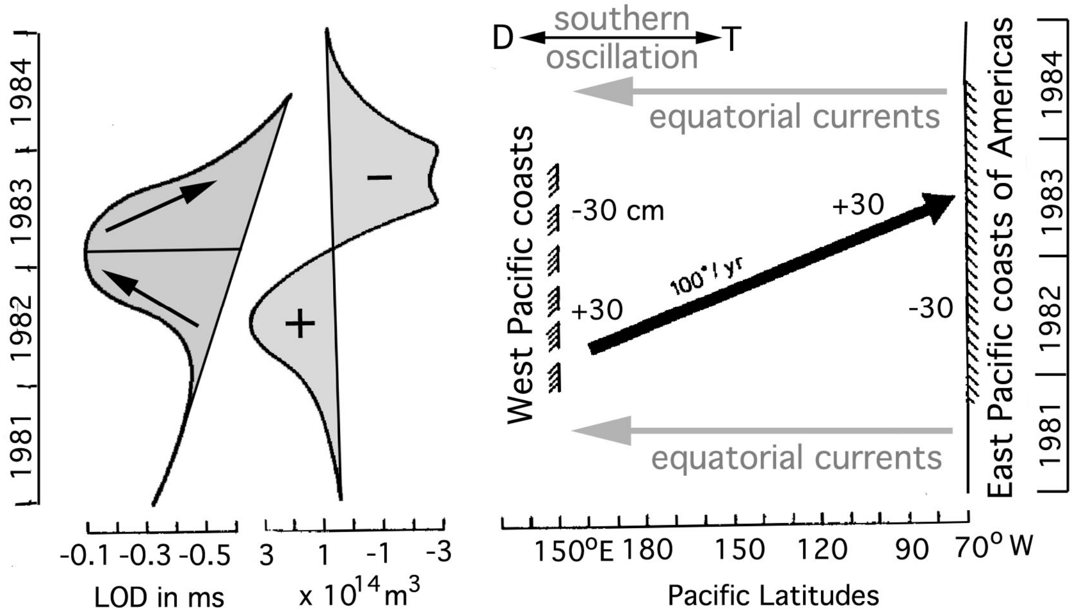

Fig. 6. The 1982-1983 El Niño/ENSO event (modified from Mörner, 1989a). Column 1 gives LOD signal of the ENSO event after subtracting the atmospheric and secular LOD trends. Column 2 gives changes in the hot equatorial water bulge outside the west Pacific coasts. Column 3 gives the E–W changes in equatorial current transport and the corresponding changes in sea level. D–T marks the southern oscillation between Darwin and Tahiti. In 1982, the solid earth lost about 0.4-0.5 ms (LOD) to the ocean equatorial current system, which reversed its direction of flow (black arrow). When the water masses hit the American east coast, angular momentum started return to the solid earth and the event was over in mid to late 1983.

Already the inter-annual ENSO (El Niño / La Niña) changes contain a part of the LOD signal, which must be understood in terms of hydrospheric changes. This is illustrated in Fig. 6 (from Mörner, 1989a), where the following sequence of events is identified:

1	mid 1981	hot water starts to accumulate in the west
2	1981/1982	LOD starts to be transferred to the hydrosphere
3	mid 1982	the LOD transfer increases the hot water bulge culminates with a +30 cm sea level the hot water bulge starts to move eastwards at a rate of 100° Long./year
4	early 1983	the transfer of water masses hits the American side where sea level rises to +30 cm LOD starts to become transferred back to solid Earth
5	mid 1984	the ENSO event is over

The LOD transferred from the solid earth to the hydrosphere and back again amounted to 0.4-0.5 ms, and it forced about 3.5 x 10^{14} m^3 of water (30 cm sea level equivalent) to reverse the general lagging-behind motion and to move eastwards at a speed of 100 longitude degrees per year.

On a longer-term base, there is the Pacific Decadal Oscillation (PDO) with a cyclicity of about 60 years. It is generally interpreted in terms of changes in the wind stress. Parker (2013) has recently shown that the 60-year cycle is a fundamental cycle in sea level changes. In analogy with the ENSO event just discussed, it seems highly likely that there also is an interchange of angular momentum between the solid earth and the surface water circulation in the Pacific.

A feed-back interchange of angular momentum between the solid earth and the hydrosphere (the surface circulation) was recorded in North Atlantic time-series of marine biota, sea level changes and regional temperature, where 16 separate pulses were recorded within the Holocene period (Mörner, 1984a, 1995b). These variations were also picked up in the global circulation system (Fig. 4), especially in a west-east back-and-forth "wave" of equatorial water masses, and a SW–NE current beat along the Gulf Stream and Kuroshio Current (Mörner, 1988, 1993a, 1995a, 1996a). This seemed to explain the irregular changes in sea level over the globe during the last 6000 years, and the similarity in sea level changes in regions controlled by the beat of the Gulf Stream and the Kuroshio Current (Mörner, 1984, 1988, 1995a, 1996a).

This interchange of angular momentum between the oceanic surface circulation and the solid earth were also identified for the period 10,000-20,000 BP (Mörner, 1993b, 1995a, 1996a, 1996b).

The 60-year cycle recorded in solar activity and Earth's rotation (Mazzarella, 2007, 2008; Scafetta, 2010) must also have affected the oceanic circulation, judging from its recording in the marine environments (e.g. Black et al., 1999; Patterson et al., 2004; Klyashtorin et al., 2009) and in sea level changes (Parker, 2013). The data from the Arctic (Klyashtorin et al., 2009) are especially relevant, because they seem to confirm the proposal by the present author that the Gulf Stream distribution of water is subjected to a beating activity due to the interchange of angular momentum between the hydrosphere and the solid earth (Mörner, 1984, 1989a, 1990, 1996a, 2010, 2011, 2012).

In the Northwest European and Northeast Atlantic region, Mörner (1989a, 1990, 1996a) identified six periods of alternating cooling and warming over the last 200 years; i.e three cooling/warming cycles of about 60 years. The periods correladed well with the decadal changes in LOD; coolings at accelerations and warmings at decelerations. The warming phases were linked to periods of sea level rise, and the cooling phases to periods of stability or fall in sea level.

The same mechanism seems to be recorded by Klyashtorin et al. (2009), though they interpret the correlations observed in terms of temperature forcing. The situation is as follows: the stocks of herring and cod in the Barents Sea fluctuates with a 60-year periodicity (the cods lagging by 8-10 years), which correlates with the changes in Arctic temperature, in ocean water temperature and in ice cover conditions in the Barents Sea (with a lag-time of 8-10 years); all exhibiting an ~60-year periodicity. The authors note that the changes in ice cover reflects the "delivery of warm Atlantic water to the region" and that "the main source of heat delivered to the Arctic basin is warm water inflow from the North Atlantic Stream" as recorded by Nikolaev and Alexeev (1998). This implies that the Gulf Stream system must exhibit beating cycle of 60 years, just as the LOD cycle and solar activity cycle, in full agreement with the proposal of Mörner (1984, 2010, and especially 2011). This is illustrated in Fig. 7, where the base data of Klyashtorin et al. (2009) have been put in the context of the main Solar Wind–Earth rotation model proposed (Fig. 1).

It is interesting that their extrapolations of the 60-year cycles of herring and cod stocks give a low at around 2040 (the cod with a 8-10 yrs lag). This is in full agreement with the extrapolation of the longer-term solar cycles (Mörner, 2010, 2011).

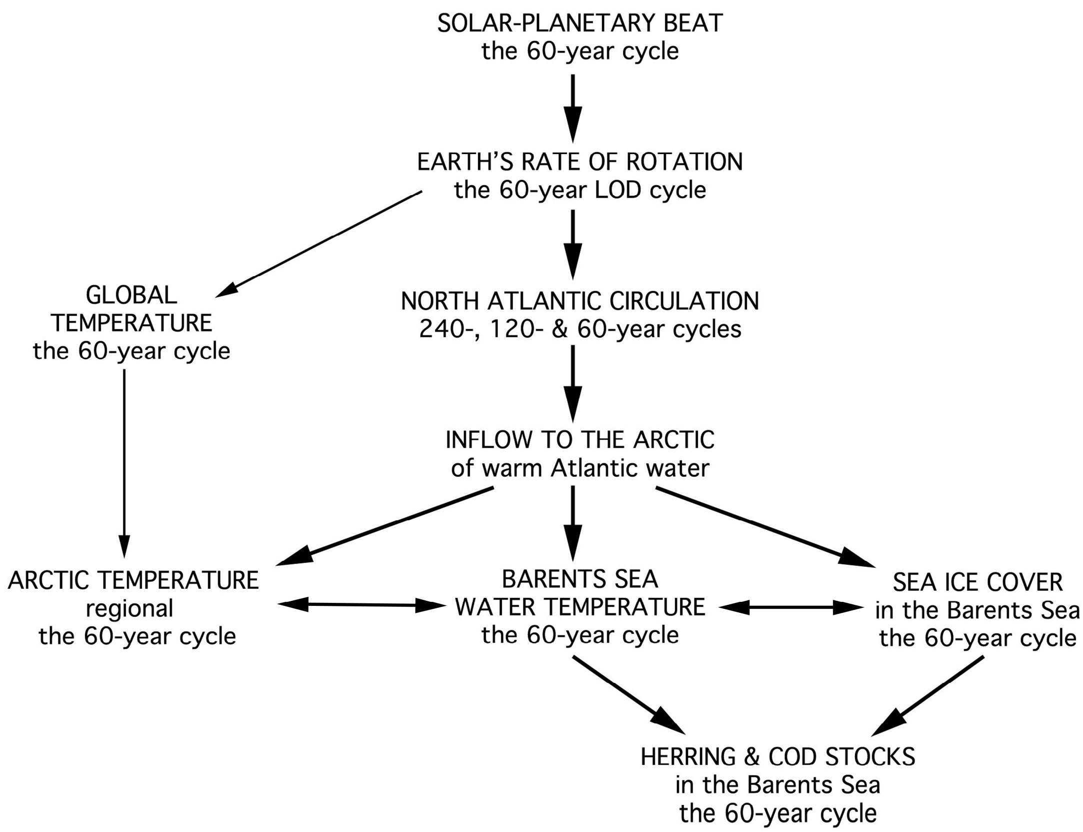

Fig. 7. Interpretation of the forcing functions behind the changes observed and the correlations established by Klyashtorin et al. (2009) in the context of the effects of cyclic Solar Wind changes on the Earth's rate of rotation (Fig. 1; Mörner, 2010).

This mechanism is likely to be the ultimate reason why Soon and Legates (2013) found a correlation between total solar irradiance (here translated to Solar Wind activity) and the Equator-to Pole surface temperature gradien (EPTG) in the northern hemisphere.

The Gulf Stream system must be extremely sensitive to changes in the rate of rotation, and vice versa in a feed-back coupling, implying that a change in rotation may be compensated by a change in water mass transport within this system, or that a change in the water transport (volume as well as direction) should affect the Earth's rate of rotation (Mörner, 1984). The transport of warm equatorial water in the Gulf Stream may be primarily directed along its northern branches to northwestern Europe and the Arctic basin, or along the southern branch to southwest Europe and northwest Africa (Mörner, 1996a, 2010). Paleoclimatic time series with an annual resolution have made it possible to record the temporal and spatial changes in climate for the last millennium over the east Atlantic to west European region (Mörner, 2010).

During the Spörer, Maunder and Dalton Solar Minima Arctic water penetrated all the way down to mid-Portugal and the Gulf Stream transport was concentrated along the southern branch. This lead to Little Ice Age conditions in the north and central Europe, and opposed warming conditions in Gibraltar region and Northwest Africa.

During the Solar Maxima the situation was reversed; the warm Atlantic water was transported far up into the Barents Sea region, making west Europe and the Arctic unusually warm, whilst the Gibraltar region and northwest Africa suffered cool conditions because of decreased transport along the southern branch of the Gulf Stream.

The switches between those two modes of ocean circulation in the North Atlantic are driven by a speeding-up of the Earth's rotation at Solar Minima and a slowing-down at Solar Maxima (Mörner, 1996a, 2010, 2011). This is illustrated in Fig. 7.

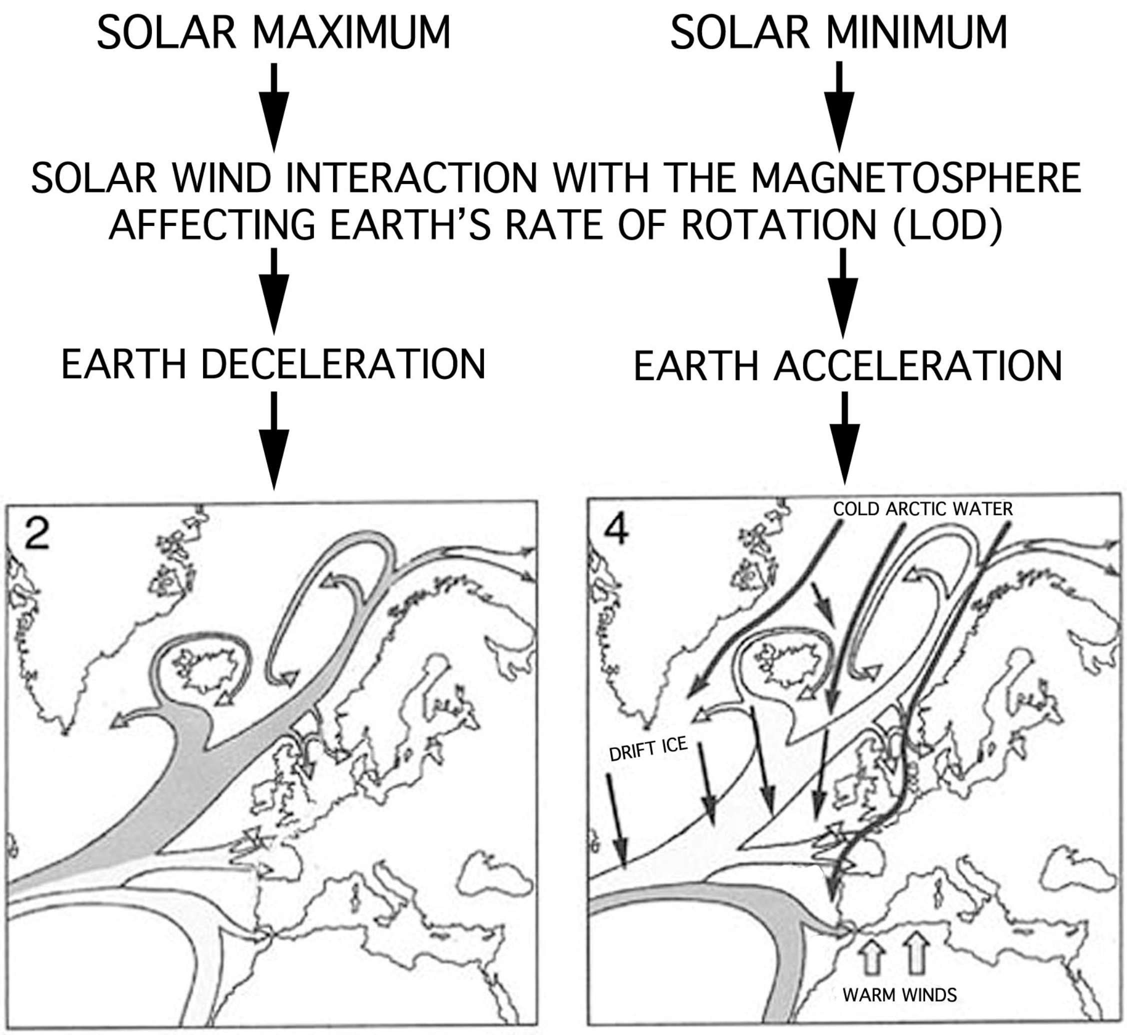

Fig. 8. Alternations between the major centennial Solar Maxima and Minima lead to decelerations and accelerations of the Earth's rate of rotation, which make the ocean circulation in the North Atlantic to switch between two major modes; one warming the north (2) and one cooling the Arctic and northern and central Europe (4) so that "Little Ice Ages" climatic conditions were established.

4.4. Integration of variables

The Solar Wind interaction with the Earth's magnetosphere affects the shielding capacity towards cosmic ray flow into the atmosphere, Earth's rotation, Earth's geomagnetic activity, the electrical circuit in the ionosphere and the pressure distribution in the atmosphere (Fig. 3). Those variations, in their turn, generate changes in the ocean current circulation (leading to the redistribution of ocean-stored heat and water volumes) and the atmospheric wind conditions. The relations among the variables here discussed are given in Fig. 9.

High (maximum)	SOLAR ACTIVITY	Low (minimum)
Strong	SOLAR WIND	Weak
Strong	SHIELDING CAPACITY	Weak
Slowing down	EARTH'S ROTATION	Speeding-up
High	GEOMAGNETICS	Low
Strong	ELECTRIC CIRCUIT	Weak
Decreased	CLOUD FORMATION	Increased
Zonal	ARCTIC WIND	Meridional
Positive	AO	Negative
High	BARENT SEA CATCH	Low
more NW (2)	GULF STREAM BEAT	more SW (4)
Positive	NOA	Negative
Positive	PDO	Negative
Warmer	CLIMATE CHANGE	Colder

Fig. 9. Relations among different variables discussed. The major Solar-Terrestrial interaction is proposed to go via; the Solar Wind, the response in Earth's rate of rotation and its effects on the oceanic circulation, which redistributes the ocean-stored heat (recorded in climate) and the oceanic water volumes (recorded in sea level).

Consequently, the changes in Solar Wind strength as a function of the solar cycles affect the terrestrial climate. This is especially true for the so-called Grand Solar Maxima and Minima (Fig. 8).

5. Conclusions

Solar variability obviously affects Earth's climate. Changes in solar irradiance seem too weak to have more than marginal effects. Changes in Solar Wind are proposed as the major means of affecting Earth's climate (cf. Fig. 1).

The Solar Wind interacts with the Earth's magnetosphere, affecting Earth's rate of rotation, the flux of cosmic rays and the geomagnetic field configuration (Fig. 3). Changes in the rate of rotation affect the atmospheric and oceanic circulation. Changes in cosmic rays flux affects Earth's cloud cover (according to Svensmark). Changes in the geomagnetic field are related to changes in the atmospheric wind system (according to Bucha).

The motions of the Sun and planets around their common centre of gravity may not only drive changes in the solar activity, but may also generate direct rotational-gravitational effects on the Earth-Moon system (Figs. 2-4).

The interchange of angular momentum between the solid Earth and the ocean circulation system is of special interest because it implies the redistribution of heat stored in the ocean water (recorded in paleoclimatic data) and the redistribution of ocean water volumes (recorded in sea level changes).

The 1982-1983 ENSO/El Niño event included a component of interchange of angular momentum between the solid Earth and the Pacific equatorial surface water flow (Fig. 6). The 60-year cycle has had a strong controlling effect on the paleoclimate of the 20th century (Fig. 7). The major Solar Minima (Spörer, Maunder and Dalton) of the last 600 years correspond to periods of rotational speeding-ups forcing the Gulf Stream transport to be concentrated on its southern branch and allowed cold Arctic water to penetrate far down along the European coasts (Fig. 8), which lead to Little Ice Age conditions in the Arctic and in northern to middle Europe but extra warm periods in the Gibraltar to northwest African region. During the Solar Maxima, the situation was the reverse (Fig. 8). By around 2040, we will be in a new Solar Minimum and may, therefore, expect a period of cold climatic conditions (maybe a new "Little Ice Age").

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

AO: Arctic Oscillation
ENSO: El Niño – Southern Oscillation
LOD: Length Of Day (standard method of measuring Earth's rotation)
NOA: North Atlantic Oscillation
PDO: Pacific Decadal Oscillation
BP: Before Present (in age determination)

Figure Captions

Fig. 1. Variations in solar activity lead to changes in the Solar Wind and in solar irradiance, both of which may affect Earth's climate (modified from Mörner, 2011). The variations in irradiance are known to be small or even minute. The variations in Solar

Wind are large and strong; via the interaction with the Earth's magnetosphere, it affects Earth's rate of rotation, by that affecting the oceanic and atmospheric circulation systems, both of which have a strong effect of terrestrial weather and climate. Changes in the shielding capacity affect the flux of incoming cosmic rays, which controls ^{14}C production, in-fall of ^{10}Be and cloud formation.

Fig. 2. Hypothetical interactions of planetary forces driving the solar variations in emission of luminosity (irradiance) and Solar Wind (from Mörner, 1984).

Fig. 3. The interaction between planetary gravitational beat and solar variability, and the observed changes in climate and environments.

Fig. 4. Earth's total and differential rotation as a function of planetary beat and Solar Wind emission.

Fig. 5. Major ocean surface current systems (Mörner, 1984); (4) the major lagging-behind equatorial currents, (2) the Kuroshio and Gulf Stream systems bringing warm equatorial water to mid and high latitudes, (7) the Southern Hemisphere currents bringing cold Arctic water to low latitudes and being responsible to significant coastal up-welling, (8) the main circum-Antarctic current and (1, 3, 5) some other currents not discussed in this paper.

Fig. 6. The 1982-1983 El Niño/ENSO event (modified from Mörner, 1989a). Column 1 gives LOD signal of the ENSO event after subtracting the atmospheric and secular LOD trends. Column 2 gives changes in the hot equatorial water bulge outside the west Pacific coasts. Column 3 gives the E–W changes in equatorial current transport and the corresponding changes in sea level. D–T marks the southern oscillation between Darwin and Tahiti. In 1982, the solid earth lost about 0.4-0.5 ms (LOD) to the ocean equatorial current system, which reversed its direction of flow (black arrow). When the water masses hit the American east coast, angular momentum started return to the solid earth and the event was over in mid to late 1983.

Fig. 7. Interpretation of the forcing functions behind the changes observed and the correlations established by Klyashtorin et al. (2009) in the context of the effects of cyclic Solar Wind changes on the Earth's rate of rotation (Fig. 1; Mörner, 2010).

Fig. 8. Alternations between the major centennial Solar Maxima and Minima lead to decelerations and accelerations of the Earth's rate of rotation, which make the ocean circulation in the North Atlantic to switch between two major modes; one warming the north (2) and one cooling the Arctic and northern and central Europe (4) so that "Little Ice Ages" climatic conditions were established.

Fig. 9. Relations among different variables discussed. The major Solar-Terrestrial interaction is proposed to go via; the Solar Wind, the response in Earth's rate of rotation and its effects on the oceanic circulation, which redistributes the ocean-stored heat (recorded in climate) and the oceanic water volumes (recorded in sea level).