Supplementary Analysis Paper #2

Solar Changes and the Climate

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1. Time Scales

The sun plays a role in our climate in direct and indirect ways. The sun changes in its activity on time scales that vary from 11, 22, 80, 180 years and more. A more active sun is brighter due to the dominance of faculae over cooler sunspots with the result that the irradiance emitted by the sun and received by the earth is higher during active solar periods than during quiet solar periods. The amount of change of the solar irradiance based on satellite measurements since 1978 during the course of the 11 year cycles of just 0.1% (Fröhlich and Lean 1998) has caused many to conclude that the solar effect is negligible. But many questions still remain about its variance on the longer term (over centuries).

The irradiance reconstructions of Hoyt and Schatten (1993), Lean et al. (1995), Lean (2000), Lockwood and Stamper (1999) and Fligge and Solanki (2000) assumed the existence of a long-term variability component in addition to the known 11-year cycle, such that during the seventeenth century Maunder Minimum total irradiance was reduced in the range of 0.15% to 0.4% below contemporary solar minima. Until, recently the value often used in climate models was 0.25% over the 300 year period. In 2005, simulations of the eruption, transport and accumulation of magnetic flux during the past 300 years using a flux transport model with variable meridional flow (Wang et al., 2005) suggested a change that was only 0.27 of the lower end of that range (0.037%). This is the assumption used in the solar forcing in the latest IPCC AR4. This contrasts sharply with other estimates such as Lockwood and Stamper, (1999) which showed how the total magnetic flux leaving the sun has increased by a factor of 2.3 since 1901.
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Irregardless, this does not take into account the sun's eruptional activity (flares, solar wind bursts from coronal mass ejections and solar wind bursts from coronal holes) which may have a much greater effect than flux alone. Labitzke (2001) and Shindell (2000) have shown how the ultraviolet radiation which changes as much as 6-8% even during the 11 year cycle, can produce significant changes in the stratosphere that propogate down into the mid troposphere. The work of Svensmark and Friis-Cristensen(1997), Bago and Butler (2000) Tinsley and Yu (2002) and Shaviv (2005) and many others have documented the possible effects of the solar cycle on cosmic rays and through them the amount of low cloudiness. It may be that through these other indirect factors, solar variance is a much more important driver for climate change than it is currently assumed. It may be that solar irradiance measurements are useful simply as a surrogate for the total solar effect.

2. Correlations with Total Solar Irradiance

As already noted, studies vary on the importance of direct solar irradiance, especially in recent decades. Lean et al (1995) finds that there is hardly any increase after 1950. Based on the Wang et al model (2005) which suggests a much smaller TSI increase, the IPCC AR4 estimates that the solar forcing is 70% smaller than earlier thought with no significant effect in the last half century.

As noted this conflicts with many prior and more recent studies. Lockwood and Stamper (1999), estimated that changes in solar luminosity can account for 52% of the change in temperatures from 1910 to 1960 but just 31% of the change from 1970 to 1999. Scafetta and West (2006) argued that total solar irradiance accounted for up to 50% of the warming since 1900 and 25-35% since 1980.The authors noted the recent departures may result "from spurious non-climatic contamination of the surface observations such as heat-island and land-use effects [Pielke et al., 2002; Kalnay and Cai, 2003]". Their analysis was done using the global data bases which may also suffer from station dropout, improper adjustment for missing data which increased in the 1990s, and questionable siting and urban adjustment issues (see supplement on Data Isssues).

The United States Historical Climatology Network (USHCN) data base, though regional in nature, provides a useful check on these findings, as it is more stable, has less missing data (and a better scheme for adjusting for missing data), some adjustment for changes to location and urbanization. However, Pielke (2006) and Pielke et al. (2006) have shown that even there, adjustments for poor location may not entirely correct the data.

Figure 1 shows the 11 year running mean of USHCN mean temperature data over the period from 1895 to 2005 and the Total Solar Irradiance (TSI) data for the same interval obtained from Hoyt and Schatten (1993, updated in 2005). The Hoyt-Schatten TSI series which uses five historical proxies of solar irradiance, including sunspot cycle amplitude, sunspot cycle length, solar equatorial rotation rate, fraction of penumbral spots, and decay rate of the 11-year sunspot cycle.

It confirms a strong correlation (r-squared of 0.59). The correlation increases to an r-squared value of 0.64 if temperature is lagged 3 years, close to the 5 year lag suggested by Wigley (1988) and used by Scafetta and West (2006).

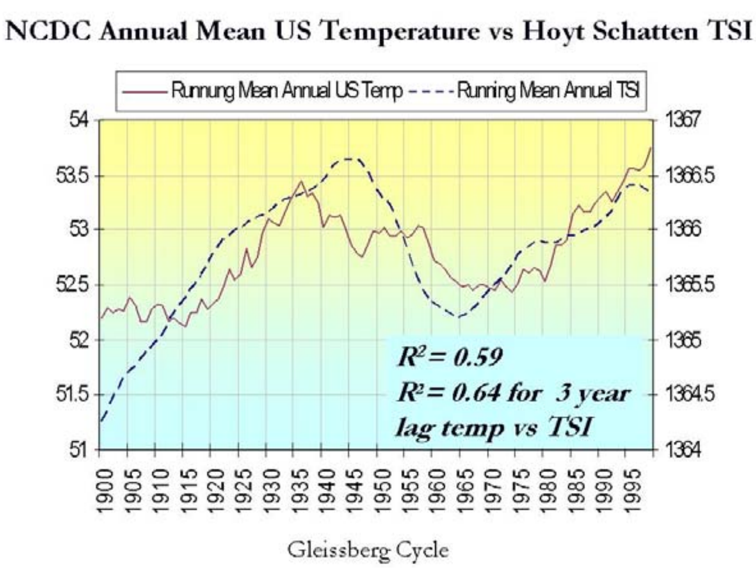

Figure 1. Running mean of USHCN mean annual temperature versus Total Solar Irradiance, 1900—2000.

In recent years, satellite missions designed to measure changes in solar irradiance, though promising, have produced their own set of problems. As Judith Lean noted (Fröhlich and Lean 1998), the problem is that no one sensor collected data over the entire time period from 1979 "forcing a splicing of data from different instruments , each with their own accuracy and reliability issues, only some of which we are able to account for". Fröhlich and Lean (1998) gave an assessment which suggested no increase in solar irradiance in the 1980s and 1990s.

However, Willson et al. (2003) found specific errors in the dataset used by Lean and Froh to bridge the gap between the ACRIM satellites. His reanalysis suggested a recent trend of 0.05% per decade, sufficient to account for warming since 1979. Frohlich and Lean have disputed this in their 2004 paper.

Two other recent studies that have drawn clear connections between solar changes and the Earth's climate are Soon (2005) and Kärner (2002). Soon (2005) showed that arctic air temperatures correlated with solar irradiance far better than with the greenhouse gases over the last century (se Figure 2). For the 10 year running mean of total solar irradiance (TSI) vs Arctic-wide air temperature anomalies (Polyakov et al., 2002), he found a strong correlation of (r-squared of 0.79) compared to a r-squared correlation vs greenhouse gases of just 0.22.

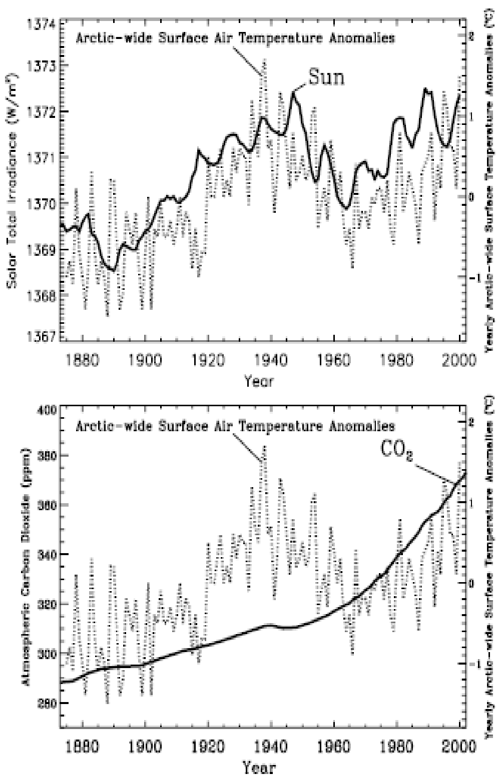

Figure 2: From Soon (2005). Top: correlation between solar output and Arctic air temperature anomalies; Bottom: relationship with CO_2 is much weaker.

Kärner (2002) studied the time series properties of daily total solar irradiance and daily average tropospheric and stratospheric temperature anomalies. He showed that average temperature anomalies exhibit a temporal evolution characterized by antipersistency, in which the variance expands as the observed sample length increases on all time scales, but at a diminishing total rate. CO_2 forcing is not antipersistent, instead it has a steadily increasing trend, implying persistency. But Kärner showed that total solar irradiance is antipersistent, implying a discriminating hypothesis: the dominant forcing mechanism will endow the atmospheric temperature data with its time series property. Since the temperature series is antipersistent this implies that solar forcing dominates. The test supported this finding on all available time scales, from daily to decadal. He concluded that:

> "The revealed antipersistence in the lower tropospheric temperature increments does not support the science of global warming developed by IPCC [1996]. Negative long-range correlation of the increments during last 22 years means that negative feedback has been dominating in the Earth climate system during that period. The result is opposite to suggestion of Mitchell (1989) about domination of a positive cumulative feedback after a forced temperature change. Dominating negative feedback also shows that the period for CO2 induced climate change has not started during the last 22 years. Increasing concentration of greenhouse gases in the Earth atmosphere appeared to produce too weak forcing in order to dominate in the Earth climate system." (Kärner 2002)

3. Warming Due To Ultraviolet Effects Through Ozone Chemistry

Though solar irradiance varies slightly over the 11 year cycle, radiation at longer ultraviolet (UV) wavelengths are known to increase by several percent with still larger changes (factor of two or more) at extremely short UV and X-ray wavelengths (Baldwin and Dunkerton 2004). Palamara (1998) reports that during a solar flare, extreme ultraviolet can increase by a factor of 10 (Foukal 1998).

Ozone in the stratosphere absorbs this excess energy and converts it to heat, which has been shown to propagate downward and affect the general circulation in the troposphere. Shindell et al.(1999) used a climate model that included ozone chemistry to reproduce this warming during high flux (high UV) years. Labitzke and Van Loon (1988) and later Labitzke in numerous papers has shown that high flux (which correlates very well with UV which she notes changes 6-8% over the 11 year cycle) produces a warming in low and middle latitudes in winter in the stratosphere and then penetrates down into the middle troposphere.

The winter of 2001/02, when cycle 23 had a very strong high flux second maxima, provided a good test of Shindell and Labitzke and Van Loon's work.

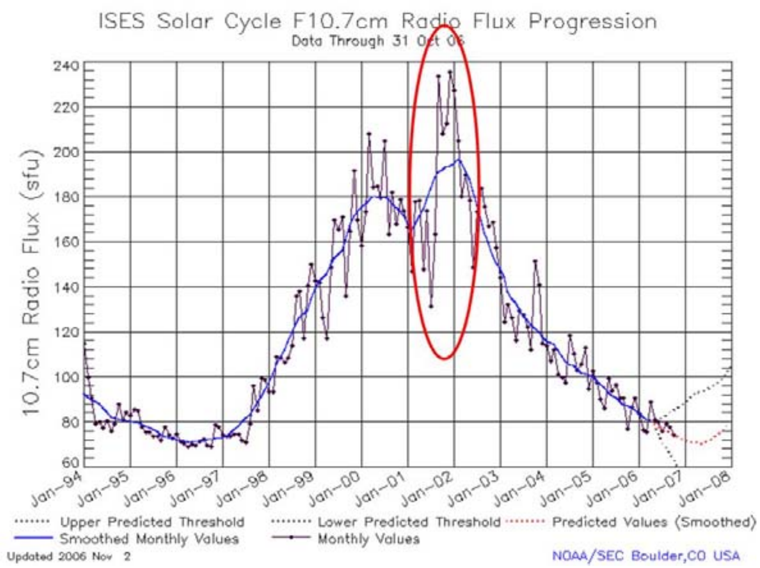

Figure 3. Solar cycle 23, strong high flux second maximum around January 2002.

The warming that took place with the high flux from September 2001 to April 2002 caused the northern winter polar vortex to shrink shrink resulting in an extremely warm winter in low and middle latitudes and the southern summer vortex to both contract and and for a time even break into two centers for the first time ever observed. This disrupted the flow patterns and may have contributed to the brief summer breakup of the Larsen ice sheet observed at that time.

4. Geomagnetic activity weather and climate

As early as 1976, Bucha speculated on the variations of geomagnetic activity, weather and climate. In recent years Bochnicek et al (1999), Bucha and Bucha (1998) have shown statistically significant correlations between geomagnetic activity and the atmospheric winter circulation patterns in high and mid-latitudes as controlled to a large degree by the Northern and Southern Annular modes (NAM and SAM) and modulated by the Quasi-Biennial Oscillation (QBO). They have found the tendency for the modes to be cold during the east QBO at solar minimum and west QBO at solar maximum and warm at the west phase during the solar minima and east at solar max. This relates to the strength of the stratospheric vortex which Baldwin and Dunkerton (2004) show control the tendencies in the middle and lower atmosphere for the phase of the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO). Since the QBO alternates east and west approximately each year, this would suggest a tendency for winters to alternate cold and warm near solar max or min but would not argue for long term changes.

5. Helio- and Geomagnetic activity, Solar Winds, Cosmic Rays and Clouds

A key aspect of the sun's effect on climate may well be the indirect effect on the flux of Galactic Cosmic Rays (GCR) into the atmosphere. The theory has it that cosmic rays have a cloud enhancing effect through ionization of cloud nuclei. As the sun's output increases the solar wind induced atmospheric magnetic field shields the atmosphere from GCR flux. Consequently the increased solar irradiance is accompanied by reduced cloud cover, amplifying the climatic effect. Likewise when solar output declines, increased GCR flux enters the atmosphere, increasing cloudiness (and thus planetary albedo) and adding to the cooling effect associated with the diminished solar energy

Le Mouel et al. (2005) showing a strong correlation of geomagnetic indices and global temperature over the last century with some departure after 1990 perhaps indicating anthropogenic effects (or we may later find data issues).

In an excellent treatise on the geomagnetic solar factors, Palamara (1998) noted how Forbush was the first to conclude that there was a relationship between geomagnetic activity and cosmic ray decreases (called the Forbush decrease). Ney (1959) proposed a chain of events whereby solar activity influences atmospheric temperatures via cosmic rays and ionization, with the greatest effects in Polar Regions. Dickinson (1975) proposed that cosmic rays could modulate the formation of sulphate aerosols which could serve as cloud nuclei. Tinsley and coauthors in a series of papers, proposed instead that cloud cover changes could relate to changes in atmospheric electricity brought about by ionization (see discussion in Tinsley and Yu 2004). These theories were points of contention among researchers concerning the mechanisms proposed. There was little evidence to support any of them until Svensmark and Friss-Christensen (1997) found changes of 3 to 4% in total cloud cover during the solar cycle 21.

This paper was also quickly challenged. Among the challenges, Kristjansson and Kristianson (2000) and Jorgensen and Hansen (2000) disputed the theoretical mechanisms linking cosmic rays to clouds, the latter arguing the changes in clouds might be explained by the El-Nino Southern Oscillation (ENSO) or volcanic eruptions. Kernthaler et al. (1999) repeated Svensmark's work but included the Polar Regions, where it was though the effects would be greatest because that is where the cosmic ray attenuation was greatest. They found that by including the polar region, the correlations were weakened. Friis Chrisetnsen (2000) reported this latter work was based on data derived with instrument calibration issues and that with the adjusted cloud data, Kernthaler's work could not be reproduced. Though they acknowledged some effect on cloudiness could be attributed to ENSO, they could not rule out the cosmic ray influence.

Svensmark's work received support from papers by Tinsley and Yu (2002),and Palle-Bago, and Butler (2001). The latter showed that low clouds in all global regions changed with the 11 year cycle in inverse relation to the solar activity extending over a longer period than the original Svensmark 1997 study. Here should be added the paper by Usoskin et al. (2004).

The effect seemed to greatest with low clouds and at mid to low latitudes, where low clouds are water droplet clouds. The conjectured mechanism connecting GCR flux to low cloud formation received experimental confirmation in the recent laboratory experiments of Svensmark et al. (2006) and Svensmark (2007), which demonstrated that cosmic rays trigger formation of water droplet clouds.

Shaviv (2004) showed that when including the changes in cosmic rays over the last century, the total solar influence could be responsible for 0.47C (± 0.19C) or roughly 77% of the total reported warming.

This issue is yet to be resolved but may indeed turn out to be an important solar climate link considering the plethora of correlations of climate trends with the GCR proxies (eg. cosmogenic nuclides; Solanki et al., 200x), over a multitude of time scales, as compiled in Veizer (2005) and Scherer et al. (2006).

6. Long time scales

The review in the IPCC Fourth Assessment Report of million-year timescale climate change overlooks the work of Veizer et al. (2000), showing greenhouse periods asynchronous with high CO_2 as modeled by Berner and Kothavala (2001). This research was published independently of, but simultaneously with research by Shaviv (2002), demonstrating a variable flux of cosmic rays impinging on our solar system that follows a 140 million year cycle. This most serendipitous of scientific alignments resulted in the observation that climate over the past 600 million years is highly synchronous with cosmic radiation. The mechanistic connection between this correlation is the well established theory of ionization and cloud nucleation in the atmosphere, leading to a measurable increase in cloudiness. Largely ignored by the atmospheric modeling community, a one percent variation in cloudiness can engender, through changes in albedo, a 2 to 3 W/m^2 change in forcing. Cloudiness, by IPCC statements, remains one of the greatest sources of uncertainty in climate simulation modeling.

References:

Baldwin, M.P., Dunkerton, T.J.: (2004): The solar cycle and stratospheric-tropospheric dynamical coupling, JAS 2004 incomplete

Baliunas, S., and R. Jastrow, (1990): Evidence for long-term brightness changes of solar-type stars. Nature, 348, 520-522.

Berner, R.A. and Z. Kothavala (2001): "GEOCARB III: A Revised model of atmospheric CO_2 over Phanerozoic time." *American Journal of Science* , 301, 182—204.

Bucha, V.,and Bucha, V. Jr (1998): Geomagnetic forcing of changes in climate and the atmospheric circulation, J. Atmos. Terr. Phys. 60, 145-169

Bucha, V. (1976): Variations of the geomagnetic field ,the climate and weather, Studies of Geophy. Geod, 20, 149-167

Bucha, V.(1993): Impact of solar perturbations on changes in the atmospheric circulation, in The Earth and the Universe, Ed. W. Schroder, Newsletters of the ICH of IAGA, pp 129-132

Bochnicek, J., Bucha, V., Heijda, P., Pycha, J. (1996): Relation between the northern hemisphere winter temperatures and geomagnetic or solar activity at different QBO phases, J. Atmos. Terr. Phys. 58, 883-897

Bochnicek, J., Bucha, V., Heijda, P., Pycha, J. (1999): Possible geomagnetic activity affects on weather, Ann. Geophysicae 17, 925-932

Dickinson, R.E. (1975), Solar variability and the lower atmosphere, Bulletin of the AMS, 56, 1240-1248

Feynman, J. and Ruzmaikin, A. (1999): Modulation of cosmic ray precipitation related to climate. Geophysical Research Letters 26: -2060.

Fligge, M., and S.K. Solanki, (2000): The solar spectral irradiance since 1700. Geophys. Res. Lett., 27, 2157-2160.

Friis-Christensen, E. (2000): Sun, clouds and climate – an editorial comment . Climate Change 47, 1-5….?

Foukal, P. (1998): Solar irradiance variations and climate. In "From the sun: Auroras, magnetic storms, solar flares, cosmic rays" (S.T. Suess, B.T. Tsurutani, Eds) pp 105-112, AGU, Washington

Fröhlich, C., and J. Lean, (1998):The sun's total irradiance: Cycles, trends, and related climate change uncertainties since 1976: *Geophys. Res. Lett.*, **25**, 4377–4380

Fröhlich, C., and J. Lean, (2004): Solar radiative output and its variability: Evidence and mechanisms. Astronomy and Astrophysics Review, 12, 273-320

Gleissberg, W. (1958): the 80-year sunspot cycle, Journal of Britih Astronomy Association 68, pg 150

Hoyt, D.V. (1979): Variations in sunspot structure and climate, Climate Change, 2, pp 79-92

Hoyt, D.V. and Schatten, K.H. (1997): The role of the sun in climate change, New York Oxford, Oxford University Press, 1997

Jorgensen, T.S., Hansen, A.K., (2000): Comments on "Variation of cosmic ray flux and global cloud cover- a missing link in solar -climate relationships, Journal of Atmospheric and Solar Terrestrial Physics, 62, 73-77

Kalnay, E., Cai, M., (2003): Impact of urbanization and land-use change on climate , Nature, 423, 528-531

Kärner, O. (2002): On non-stationarity and anti-persistency in global temperature series. J. Geophys. Res., vol. 107, D20, doi 10.1029/2001JD002024.

Kernthaler, S. C. Toumi, R., Haigh, J.D., (1999): Some doubt concerning a link between cosmic rays anc global cloudiness, Geophys. Res. Lett., 26, 863-865

Kniveton, D.R. and Todd, M.C. (2001): On the relationship of cosmic ray flux and precipitation. Geophysical Research Letters 28: 1527-1530.

Kristjansson, J.E., Kritiansen, J. (2000): Is there a cosmic ray signal in recent variations of global cloudiness and cloud radiative forcing. JGR, 105, 12851-12863

Labitzke, K., (2001): The global signal of the 11-year sunspot cycle in the stratosphere: Differences between solar maxima and minima, *Meteorol. Zeitschift*, **10**, 83–90.

Landscheidt, T, (2000): Solar wind near earth, indicator if variations in global temperatures in Vazquez,M. and Schmiedere, E, ed.: The solar cycle and terestrial climate, European Space Agency, Special Publication 463, 497-500

Lean, J., J. Beer, and R.Bradley, (1995): Reconstruction of solar irradiance since 1610: implications for climate change. Geophys. Res. Lett., 22, 3195-31982057

Le Mouel, J-L., Kossobokov, V. and Courtillot, V. (2005). On long -term variations of simple geomagnetic indices and slow changes in magnetospheric currents: The emrgence of anthropogenic global warming after 1990 ? Earth Planet. Sci. Lett. , 232, 273-286.

Lockwood M., Stamper R., Wild, M.N., (1999): A doubling of the sun's coronal magnetic field during the past 100 years, Nature, 399, 437-439

Mitchell J.F.B. (1989): The greenhouse effect and climate change. Rev. Geophys., vol. 27, 115-139.

Marsden, D. and Lingenfelter, R.E. (2003): Solar activity and cloud opacity variations: A modulated cosmic ray ionization model. Journal of the Atmospheric Sciences 60: 626-636.

Marsh, N.D. and Svensmark, H. (2000): Low cloud properties influenced by cosmic rays. Physical Review Letters 85: 5004-5007.

Marsh, N., and H. Svensmark, (2003) Galactic Cosmic ray and El Niño-Southern Oscillation trends in ISCCP-D2 low-cloud properties, J. Geophys. Res., 108(D6), AAC 6-1, doi:10.1029/2001JD001264.

Marsh, N., and H. Svensmark, (2003) Solar influence on earth's climate, Space Sci. Rev., 107, 317-325.

Ney, E. R.: (1959): 'Cosmic Radiation and the Weather', Nature 183, 451–452. ...

Palamara, D., (2003) Solar activity and recent climate change: evaluating the impact of geomagnetic activity on atmospheric circulation, University of Wollongong http://www.library.uow.edu.au/adt-NWU/uploads/approved/adt-NWU20040924.142821/public/02Whole.pdf

Palle Bago, E., and Butler, C.J. (2000): The influence of cosmic rays on terrestrial clouds and global warming, Astron. Geophysics, 41, 4.18-4.22

Palle Bago, E., and Butler, C.J. (2001): Sunshine records from Ireland: Cloud factors and possible links to solar activity and cosmic rays, International Journal of Climatology 21, 709-729
One of Palle references not cited in text

Polyakov, I., Walsh, D., Dmitrenko, I., Colony, R.L. and Timokhov, L.A. (2003a). Arctic Ocean variability derived from historical observations. Geophysical Research Letters 30: 10.1029/2002GL016441.

Polyakov, I.V., Alekseev, G.V., Bekryaev, R.V., Bhatt, U.S., Colony, R., Johnson, M.A., Karklin, V.P., Walsh, D. and Yulin, A.V. (2003b). Long-term ice variability in Arctic marginal seas. Journal of Climate 16: 2078-2085.

Scafetta, N.,and West, B.J. (2006). Phenomenological Solar Signature in 400 years of Reconstructed Northern Hemisphere Temperature Record", GRL. Incomplete

Scherer, K., Fichtner, H., Borrmann, T., Beer, J., Desorgher, L., Fluekiger, E., Fahr, H-J., Ferreira, S.E.S., Langner, U.W., Potgieter, M.S., Heber, B., Masarik, J., Shaviv, N. and Veizer, J. (2006): Interstellar-terrestrial relations: variable cosmic environments, the dynamic heliosphere, and their imprints on terrestrial archives and climate. Space Sci. Reviews. DOI:10.1007/s11214-006-9126-6.

Shaviv, N.J., (2002): The Spiral Structure of the Milky Way, Cosmic Rays, and Ice Age Epochs on Earth, New Astronomy, 8, pp 39-77

Shaviv, N. J., (2005): "On Climate Response to Changes in the Cosmic Ray Flux and Radiative Budget", *JGR-Space*, vol. 110, A08105.

Shaviv, N.J. and Veizer, J. (2003): Celestial driver of Phanerozoic climate? GSA Today 13 (7): 4-10.

Shindell, D.T., D. Rind, N. Balachandran, J. Lean, and P. Lonergan, (1999): Solar cycle variability, ozone, and climate, *Science*, 284, 305–308

Solanki, S.K., Schussler, Mursula, K., Alanko, K, (2004): Unusual Activity of the Sun during recent decades compared to the previous 11,000 years, Nature, 431, 1084-1087, Solanki, S.K., Schussler, M. and Fligge, M. (2000): Evolution of the sun's large-scale magnetic field since the Maunder minimum. Nature 408: 445-447.

Solanki, S.K., M. Schüssler, and M. Fligge, (2002): Secular variation of the sun's magnetic flux. Astronomy and Astrophysics, 383, 706-712.

Soon, W., (2006): "Variable Solar Irradiance as a Plausible Agent for Multidecadal Variations in the Arctic-Wide Surface Air Temperature Record of the Past 130 years " GRL, vol 32 (http://www.agu.org/pubs/crossref/2005/2005GL023429.shtml)

Soon, W.H., Posmentier, E., Baliunas, S.L. (1996): Inference of solar irradiance variability from terrestrial temperature changes 1880-1993: an astrophysical application of the sun-climate relationship. Astrophysical Journal 472, 891-902

Svenmark, H, Friis-Christensen, E.: (1997): Variation of cosmic ray flux and global cloud cover- a missing link in solar -climate relationships, Journal of Atmospheric and Solar-Terrestrial Physics, 59, pp 1125-32

Svensmark, H. (1998): Influence of cosmic rays on Earth's climate, Physical Review Letters 22: 5027-5030

Svensmark, H., Marsh, N., Pepke Pederson, J.O., Enghoff, M., Uggerhoj, U., Experimental Evidence for the role of Ions in Particle Nucleation under Atmospheric Conditions".(2006) Proceedings of the Royal Society A".

Svensmark, H. (2007): Cosmoclimatology: a new theory emerges. A&G, 48, 1.18-1.24.

Theijl, P. and Lassen, K. (2000): Solar forcing of the northern hemisphere land air temperature, Journal Atmospheric Solar Terrestrial Physics, 62, 1207-1213

Tinsley, B.A., and Yu, F. (2004): Atmospheric ionization **and** clouds as links between solar activity and climate. AGU monograph,141, 321-340....

Usoskin, I.G., N. Marsh, G.A. Kovaltsov, K. Mursula, and O.G. Gladysheva, (2004): Latitudinal dependence of low cloud amount on cosmic ray induced ionization. Geophys. Res,Lett., 31, L16109-

Veizer, J. (2005): Celestial climate driver: a perspective from four billion years of the carbon cycle. Geoscience Canada, 23, 13-28.

Veizer, J., Godderis, Y.,François, L.M. (2000) : Evidence for decoupling of atmospheric CO2 and global climate during the Phanerozoic eon. Nature, 408, 698-701.

Wang, Y.M., J.L. Lean, and N.R. Sheeley, (2005): Modeling the sun's magnetic field and irradiance since 1713. Astrophysical Journal, 625, 522-538

Wigley T.M., (1988) The Climate of the Past 10,000 years and the role of the sun In Stephenson, F.R., Wolfendale, A.W. (Eds) Secular Solar and Geomagnetic Variations in the Last 10,000 years, Klower, Dordecht

Willson, R (1997): Total solar irradiance trend during solar cycles 21 and 22: Science ,277, 1963-1965

Willson, Richard C. and Mordvinov, Alexander V., (2003): Secular total solar irradiance trend during solar cycles 21–23. GRL Vol. 30, No 5, 1199,

Yu, F., (2002): Altitude variations of cosmic ray induced production of aerosols: Implications for global cloudiness and climate: Journal of Geophysical Researchv. 107DOI: 10.1029/2001J000248.

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