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Comment on “Variation of cosmic ray flux and global cloud coverage - a missing link in solar - climate relationships” by Henrik Svensmark and Eigil Friis-Christensen

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Introduction.

An often used method in geophysical investigations is to correlate the time series of two phenomena, and if a “good” correlation is found, a cause-effect relation is implied.

In their search for a physical mechanism that might explain the correlations between solar activity and the earth’s climate which have been reported in innumerable papers during the past two centuries (see Hoyt and Schatten, 1997 and references therein) Svensmark and Friis-Christensen (1997), henceforth SF-C, compared observations of cloud cover and cosmic particles and concluded that variation in global cloud cover was correlated with the cosmic ray flux from 1980 to 1995. They proposed that the observed variation in cloud cover seemed to be caused by the varying solar activity related cosmic ray flux and postulated that an accompanying change in the earth’s albedo could explain the observed correlations between solar activity and climate.

In this paper we claim that an observed change in cloud cover can be attributed to a change in the flux of cosmic particles only if 1) there is a significant correlation between the flux of cosmic particles and the observed impact on cloud cover, 2) the impact has a physical basis, and 3) other explanations can be ruled out. We will show that neither of these requirements are fulfilled, and accordingly that evidence supporting the mechanism of cosmic rays affecting the cloud cover and hence climate does not exist.

Observations of cloud cover.

Based on an assessment of the characteristics of cloud variations Rossow and Cairns (1995) found that one of several necessary attributes of a cloud monitoring system is that complete global coverage with uniform density is necessary to obtain an unbiased estimate of cloud change and an estimate of the reliability with which that change can be determined. Rossow and Cairns (1995) also concluded that global coverage cannot be accomplished with observations from one satellite, and that the minimum satellite observing system for cloud monitoring is two satellites. SF-C are aware of these requirements, but an ideal cloud data set does not exist, and they choose the following, on which the cloud variation in their Figure 4 is based:

April 1979 to March 1985: Observations from the Nimbus-7 satellite. Coverage: Southern hemisphere oceans, i.e. 41% of the earth's surface.

July 1987 to November 1995 with data gaps in December 1987 and from July 1990 to December 1991: Observations from the DMSP satellites. Coverage: Southern hemisphere oceans, i.e. 41% of the earth's surface.

July 1983 to end of 1992: Observations from geostationary satellites in the ISCCP (International Satellite Cloud Climatology Project) data sets. Coverage: Ocean excluding latitudes between 22.5°S and 22.5°N. Because useful cloud observations from the geostationary orbit can be made up to latitudes of about 55° only (Rossow and Cairns, 1995), the total area covered in this data set is about 44% of the earth's surface. Since only observations over water are used, data from regions amounting to about one third of the earth's surface are being used from the geostationary satellites.

During a total of barely 5 years between July 1983 and 1992 data from both the polar orbiting and the geostationary satellites are available. During these periods the coverage of the earth is a maximum of 55%. Through the rest of the more than 15 year period considered the observations are made by one satellite only, and the coverage is 41% or less.

A 6-year climatology of subvisual and opaque cloud occurrence frequencies between 70°N and 70°S was established by Wang et al. (1996) based on the solar occultation observations from the Stratospheric Aerosol and Gas Experiment (SAGE) II satellite between 1985 and 1990. They found that there are three favorable major regions for opaque cloud development. One is located near the equator and the other two are centered at about 60°N and 60°S. It is apparent that these three regions are not well covered in the data set used by SF-C. Wang et al. (1996) found no apparent trends in the total cloud frequency from 1985 to 1990 between 55°N and 55°S (poleward of these latitudes no samplings are available during the boreal/austral winter).

Other global cloud observations have been reported by Wylie et al. (1994). Using measurements between June 1989 and May 1993 by the NOAA polar-orbiting High-Resolution Infrared Radiation Sounder (HIRS) they found that a significant change in cirrus cloud cover occurred in 1991, where cirrus observations increased from 35% to 43% of the data. They also found that other cloud forms decreased by nearly the same amount, and that the overall cloudiness changed very little during this period.

Recently Kernthaler et al. (1999) extended the approach by SF-C with a study of the different cloud types, restricting their analysis to the period 1985 to 1988 during which the ISCCP calibration is believed to be stable. They found no clear relationship between individual cloud types and cosmic ray flux. Inclusion of data at high latitudes decreased the amplitude of the apparent correlation, although ionisation by cosmic rays is greatest at high latitudes. Kernthaler et al. (1999) found that the combined effect of the changes in cloud types suggests an almost monotonic increase in cloud radiative forcing between 1985 and 1988 which is not related to cosmic ray activity.

SF-C claim that they have measured changes in the global cloud cover, but they have only measured changes in the limited regions mentioned above, and a partially-global cloud cover value is not necessarily representative of the global cloud cover. This is simply because a measured change of cloud cover in a limited region could be caused by clouds moving from one region to another without a change in the global cloud cover. Therefore the cloud changes derived from the data sets used by SF-C cannot be interpreted as global changes (Rossow and Cairns, 1995; Rossow, personal communication, 1998), and accordingly the correlation presented by SF-C between changes in global cloud cover and cosmic ray flux is not significant.

Another point is that it is the cloud reflectivity determined by both the cloudiness (defined as cloud occurrence frequency in ISCCP) and the cloud optical thickness rather than the cloudiness alone which determines the cloud albedo and the effect of that on climate. Based on a detailed analysis of the cloud data obtained by the ISCCP in the years 1983-1991 Kuang et al. (1998) have shown that besides the variation in cloudiness reported by SF-C, the global mean cloud optical thickness has a significant variation which is out of phase with the cloudiness. They find that the cloudiness and cloud optical depth vary together in such a way that the reflectivity remains approximately constant, and conclude that the combined effect of the two opposing variations may be a null effect. Kuang et al. (1998) mention that these results are consistent with the Total Ozone Mapping Spectrometer (TOMS) reflectivity measurements outside of ozone absorption bands which contain information on clouds.

Ions and clouds.

SF-C hypothesize, as originally proposed by Ney (1959), that changes in the distribution of cloudiness could be caused by changes in the galactic cosmic ray flux, and that the change in cloud cover and hence albedo would cause climate change. However, they also state that the actual micro-physical explanation of a relationship between the intensity of cosmic radiation and cloudiness is still lacking, but that it is expected to depend on free charges or ions in the lower stratosphere and in the troposphere produced by the energetic cosmic radiation.

Ney (1959) showed that the percentage change in atmospheric ionization during a solar cycle increases with altitude, i.e. the presumed change of cloudiness during a solar cycle would be expected to increase with altitude and so be most marked in the upper troposphere. However, Ney (1959) points out that the kind of climatological effects the change in ionization might produce is speculation.

Mohnen (1990) assessed stratospheric ion chemistry, its potential link to aerosol formation and the subsequent transport of stratospheric aerosols to upper tropospheric regions favourable for cirrus cloud formation. He found that ion induced nucleation and any other known phase transitions involving ions and sulfuric acid vapour are not likely to be efficient processes for stratospheric aerosol formation. They cannot compete with condensation of sulfuric acid on preexisting particles larger than about 0.15 μm radius of surface (volcanoes) or meteoritic origin. Hence, galactic cosmic rays can not have a significant impact on the stratospheric aerosol population. Mohnen (1990) found that changes in the stratospheric aerosol burden due to volcanic activities (injection of both particles and sulfur bearing molecules which eventually are oxidized to sulfuric acid) are by up to two orders of magnitude larger than changes in ion densities. Consequently, there exists a possibility for a volcanic modulation of cirrus cloud radiative properties, and since the stratospheric aerosol has lifetimes of up to a few years (see the discussion below), such modulation could extend over long time periods and would dwarf any possible influence of solar induced events that involve stratospheric ion chemistry.

In a brief discussion of climate change and the global atmospheric electrical system Harrison (1997) concludes that whether a change in ion flux can contribute to significant climate feedbacks via clouds and aerosol depends on unravelling the many remaining uncertainties of electrical cloud microphysics.

Phenomena influencing cloud cover.

ENSO (El Niño-Southern Oscillation) periods, which occur irregularly every few years, are a major perturbation of the Earth’s climate system that involves large-scale changes in winds, rainfall, sea surface temperature (SST), and surface pressure (Harrison and Larkin, 1998), so large-scale changes in cloud cover may also be expected in connection with ENSO events.

As mentioned above Wylie et al. (1994) found large changes in cirrus and high cloud cover in spring-summer 1991, and they also noted that these cloud frequency increases occurred in concert with the 1991/92 ENSO and the Mt. Pinatubo eruption. A similar increase in cloud cover was reported in the 1982/83 ENSO by Weare (1992) using the Nimbus-7 infrared analysis of Stowe et al. (1988). An increase in both the amount of cloud (all altitudes) and the average cloud height was found. The height increase indicated more high cloud in late 1982 and most of 1983 during the height of the ENSO. This is a similar trend that the HIRS analysis by Wylie et al., (1994) finds for the 1991/92 ENSO.

Other observations indicating that ENSO effects on global cloud cover may exist have been reported by Rossow and Cairns (1995), Kent et al. (1995), Wang et al. (1996), and Kuang et al. (1998).

Harrison and Larkin (1998) used a global surface data set to describe statistically significant patterns of SST (sea surface temperature), surface wind, and surface pressure changes that on average are associated with the 10 ENSO periods between 1946 and 1993. They presented these average anomaly results as an “ENSO composite” and labeled the year in which the major ENSO period changes first occur as Yr(0). The Yr(0)s of the last three of the 10 ENSO periods were found to be 1982, 1987, and 1991 indicating a phase relationship between ENSO events and the changes in cloud cover observed by SF-C (see their Figure 4). The 1982 and 1991 ENSO events were closely related in time with rather abrupt changes from decreasing to increasing cloud cover, and during the 1987 ENSO the cloud cover began to decrease. In this connection it may be of interest that the three ENSO periods depart from the schematic ENSO composite behaviour in various ways. In particular, 1982 and 1991 have South American coastal warm anomalies that were not significant during the onset phase.

Another possible source of changes in the global cloud system may be volcanic eruptions which can produce significant perturbations to the Earth-atmosphere system by injecting material into the stratosphere where, depending on the magnitude and altitude of the injection, it may persist for several years (McCormick et al., 1995). In addition to the direct radiative effect of stratospheric aerosols of scattering and absorbing solar and terrestrial radiation, it is also possible that the aerosols might indirectly affect the climate by altering the optical characteristics of clouds (Minnis et. al., 1993) and by acting as cloud condensation nuclei. Jensen and Toon (1992) examined the potential impact of volcanic aerosols on nucleation of ice crystals in the upper tropospheric cirrus clouds from a microphysical perspective. Their simulations suggested that at temperatures below about -50°C the concentrations of ice crystals which nucleate may be as much as a factor of 5 larger when volcanic aerosols are present. Jensen and Toon (1992) found that under certain conditions, cirrus clouds might form only if volcanic aerosols are present. That is, the presence of volcanic aerosols is likely to increase the frequency of cirrus clouds. Sassen (1992) presented evidence that cirrus clouds observed in 1991 were influenced by volcanic aerosols from the Pinatubo eruption, and Knollenberg et al., (1993) found that sulfate aerosols are effective cloud condensation nuclei, and that significant amounts of volcanically produced aerosols may be available for incorporation into the formation of clouds after volcanic eruptions that can inject large amounts of SO_2 into the stratosphere, especially for high-altitude cirrus clouds near the tropopause. The observations by Wylie et al. (1994) of more cirrus after the eruption of Mt. Pinatubo are consistent with the hypothesized indirect effect of aerosols, which would cause more high thin cirrus to be produced and to be longer lasting. Also Wang et al. (1995) have investigated the effect of volcanic aerosols on high-altitude clouds observed by the Stratospheric Aerosol Measurement (SAM) II and SAGE II satellite instruments from 1985 to 1990, and their results indicate that the aerosols alter the frequency distribution of the clouds in such a manner that the occurrence of clouds with high extinction coefficients is suppressed while that of clouds having low extinction coefficients is enhanced.

During the period October 1984 to May 1991 an important influence on the upper troposphere was downward transfer of volcanic aerosol from the stratosphere (Kent et al., 1995). The maximum tropospheric volcanic loading was observed within the 40°-60° latitude band in each hemisphere, where a substantial enhancement of material occurred down to altitudes 2-3 km below the tropopause. In the latitude regions 40°S-20°S and 20°N-40°N stratospheric material was apparently descending into the upper troposphere from 1984 to 1986 and possibly up to 1988. It was thus found that in the mid 1980es volcanic aerosol still present from the eruption of El Chichón in 1982 resided in the upper troposphere. These findings were supplemented in an analysis of SAGE I and II measurements between 1979 and 1998, where Kent et al. (1998) found that stratospheric volcanic material penetrated into the upper troposphere 3-4 years following the El Chichón and Mount Pinatubo eruptions.

A possible volcanic influence on the cloudiness is indicated, when the cloud variation from 1980 to 1995 found by SF-C (see their Figure 4) is compared with the volcanic activity during that period in which two major eruptions occurred. These were El Chichón in April 1982 and Mt. Pinatubo in June 1991. They both coincided in time with the changes from decreasing to increasing cloud cover which may have been caused by the volcanic aerosols descending from the stratosphere to the troposphere as discussed above.

There is no proof that the changes in cloud cover observed by SF-C are caused by ENSO events and/or volcanic activity, but the relationships mentioned above suggest that such phenomena may influence the large scale cloudiness, and that their effects on this cannot be ruled out. Furthermore, in contrast to an unknown cloud condensation mechanism involving ions, well known physical mechanisms exist which may explain variation in cloudiness caused by ENSO and volcanic activity.

The Sun-Climate relationship.

SF-C relate their finding of a high correlation between cosmic rays and cloud cover to a correlation between surface temperature and solar activity (Friis-Christensen and Lassen, 1991). As the cosmic ray flux and solar activity are inversely correlated, they argue that a cause-effect relationship between the Sun and climate on Earth can be established based on a cloud formation mechanism involving ions produced by cosmic rays. It is here understood, that clouds formed according to their proposed mechanism will result in a negative radiative forcing of the climate through an increased albedo of the the Earth.

The total cloud cover is exerting a net negative radiative forcing of the climate system, because the reflection of solar radiation is stronger than the greenhouse effect in the IR-part of the spectrum. There are differences between low and high clouds in this respect. High clouds tend to heat the system because of their relatively low albedos and their low cloud top temperatures. In comparison low clouds have a stronger cooling effect due to the combination of a higher albedo and higher cloud temperatures (Houghton, 1994).

SF-C consider the total cloud cover only. It is debatable how this can be interpreted. One may argue, that to a first approximation any cloud cover change caused by the cosmic ray mechanism must have a height distribution following the vertical profile of the ions produced by the cosmic particles. Therefore on should expect a larger signal in high clouds than in low clouds. If this is what SF-C is indeed seing in their total cloud data, then the climate impact of the ion induced clouds should be opposite of what follows from SF-C's analysis. On the other hand, if the changes in total cloud cover are dominated by changes in low clouds, or the changes are of the same magnitude in both high and low clouds, then the physical mechanism is much more complex.

Conclusions.

SF-C claim that they have found a strong correlation between global cloud cover and the cosmic ray flux, but they have investigated a partially-global cloud cover only, and changes in this cannot be interpreted as global changes. Furthermore, in the discussion of the effect of cloud variations on climate SF-C take only cloud cover but not the equally important optical thickness of the clouds into account.

SF-C propose that the connection between cloudiness and the intensity of cosmic radiation may be due to free charges or ions produced by the cosmic radiation. However, evidence of ions affecting condensation of clouds in the atmosphere does not seem to exist, and in addition an ENSO event and/or volcanic activity during the period considered may explain the observed variations in cloudiness.

Since the height distribution of ions formed by cosmic rays has a pronounced maximum around 15 km, their impact on cloud cover should be strongest for high clouds leading to a climatic impact opposite to what SF-C find.

We conclude that there is a serious lack of evidence for climatic changes caused by changes in the solar activity through a modulation of the cosmic ray flux.

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