BACHELOR THESIS WORK

DISCUSSION ABOUT THE POSSIBLE EFFECTS OF THE SOLAR ACTIVITY UPON THE RADIATION BALANCE.

By Jan Olof Jonson

ABSTRACT

In searching for the reasons behind the rising temperature a broad scope of potential triggering factors is currently investigated by the scientific community.
Among those are the effects of extraterrestrial origin. For the time span of the last one-and-a-half century it has been shown that there is a negative correlation between the solar activity and the temperature in the Northern Hemisphere. However, beginning with the 1990's, the overall temperature rise has increased to the extent that the scientific community has felt the need to search for new models capable of explaining this new phenomenon. As a physical explanation, variations in the irradiance from the sun have also been considered, but the effects have appeared to be too small to offer a complete explanation of the observed temperature rise.
Secondary effects of the solar activity have also attained increasing interest.
It has among others been assumed that the Galactic cosmic ray flux affects aerosol formation, as decreased solar activity would allow for a deeper intrusion of cosmic rays into the Earth's atmosphere, which in turn is predicted to lead to an increase of the amount of condensation nuclei. Historic records further show that increased cloudiness namely corresponds to a decrease in the solar constant. Higher amount of aerosols leads to higher planetary albedo, and, accordingly to a lower temperature.
The effects of varying cosmic rays have been estimated to be of the same order as the radiative forcing of the increase of carbon dioxide since 1750. Given our knowledge today it is still difficult to judge which the main forcing effects behind the increased temperature are. The results that have been attained tend to corroborate the assumption that Galactic cosmic rays have the effect on temperature, as proposed above. However, there is also a partial ambiguity of the results, which points to the need for further investigation of the field. How each proposed variable affects cloudiness and temperature must further be explored and a serious effort is needed to attain the 'final formula'.

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1. INTRODUCTION – DIFFERENT OPINIONS ABOUT THE ORIGINS TO THE CLIMATE CHANGE

1.1. Motives behind the work

In recent years there have appeared several signs of major climate changes around the world.
Due to the more global consciousness, the effects of major weather events and even catastrophes affect public opinion increasingly.
Especially in connection with the man-made depletion of the ozone layer, it became apparent for the public opinion that mankind is able to affect the atmosphere and hence, the climate. The environmental questions were no more of strictly local nature.
As observational data convincingly showed that the amounts of greenhouse gases had increased substantially since the onset of industrialization, and parallel to this the temperature increased, it was natural to search for a physical connection between those two.
Consequently, the United Nations decided to form a 'climate panel', in order to follow the development globally by fostering vast research projects and organizing the regular grand IPCC (International Panel of Climate Change) meetings.
In good scientific tradition, groups of scientists formed devoting themselves to other possible options than the 'greenhouse' explanation.
This thesis work focuses upon alternative explanations to the observed heating since the 18th century. Generally, the examined explanations involve effects of solar variability on the radiative forcing.

1.2. Basic concepts

Since the Sun provides the basic forcing behind climate upon Earth, through its radiation, it is a rather basic approach to search for changes in the climate due to effects originating in the Sun's behaviour by some means.
Solar radiative forcing contributing to climate changes can be divided into two main domains, direct and indirect effects.
The **direct effects** consist mainly of variations in the radiative output of the radiating source, either the sun or the Galactic Cosmic Ray (GCR),
There is at first a long term radiative increase from the Sun due to the conversion of hydrogen into helium inside the sun. Since the formation of the solar system the luminosity (i.e. the strength of the light) of the sun has increased about 30 % [1]. But assuming a constant rate, this would mean only an increase of order one millionth during the last 200 years.
About the origin of the solar cycle length (SCL) (normally ~11 years) it may be claimed [49] that it is 'a measure of processes occurring within the sun of unknown dynamical origin which manifest themselves in the solar activity within the heliosphere (the outer part of the 'solar atmosphere'). The solar cycle is observed in the number of sunspots, which are rotating around the sun, with maxima and minima respectively ~ every 11 years. These sunspots appear approximately due to the disruption of the outward energy flow from the inner of the sun, caused by strong disturbances in the magnetic field. That gives rise to a lower temperature by 1700K, as compared to the normal sun surface temperature of ~6000K. That is the reason of the 'darkness' of the sunspots.
However, simultaneously there appear 'faculae', i.e. spots that are about 1000K hotter than the rest of the photosphere (i.e. the surface of the sun), and these also cover a much larger fraction of the area of the solar disk than the sunspots, and therefore there is a net increase of the energy flow outward of the sun during the sunspot maxima. [2]
A convenient measure for the solar activity is the solar radiation in the 10.7 cm band, also denoted as F10.7.
The solar activity is in turn affecting the flow of the GCR onto the Earth.
Cosmic rays (GCR) originate from outside the solar system and consist mainly of protons (90%) and of alpha-particles (9%) plus a smaller amount of heavier elements [3], [4].
The direct effect due to the cosmic galactic radiation (GCR) is only of order of billionths of the solar radiative input [5]. There exists a negative correlation between the solar activity (as measured by the F10.7 flux) and the GCR.
The solar activity varies of order 0.1 % during one solar cycle [6], thus causing a change in the incoming radiation at the top of the atmosphere (TOA) of order 0.3 W/m^2, which has to be compared to the mean total of 342 W/m^2 in global average [7], [8].
This so-called solar modulation is the dominant cause of the variations in the GCR, and is usually of the order of ten percent during a typical solar cycle.
The modulation is caused by the interaction of incoming GCR particles with magnetic fields convected outwards by the solar wind plasma (a charged gas), which leads to scattering [9].
The magnetic field of the Sun leads thus to a "shielding" of the solar system from GCR and as the solar magnetic field changes over the solar cycle, so does the GCR flux reaching the Earth, though inversely [10]. The modulation amplitude is thereby larger for the low energy component of the GCR. In this connection the amplitude of the magnetic field of the Earth is causing a spatial distribution of the incoming particles due to their energy content, hence confining the low energy particles to the higher latitudes. It has also to be noted that the geomagnetic field is brought to vary in time with the magnetospheric

currents of the Sun, thus allowing for the low energy particles to penetrate lower latitudes [11].
The GCR becomes increasingly crucial within the realm of the **indirect effects**, which will be treated in the following.

Cloud basics
Clouds are affecting the total energy budget of the Earth due to their albedo.
The higher the albedo, the larger amount of the incoming radiation is being reflected back out into the space. Cloud albedo depends on numerous cloud properties and on the radiation geometry. The albedo also increases with liquid water content of the cloud. Therefore, if more water is being condensated, due to an increase in the amount of condensation nuclei, that would mean a decrease in the amount of radiation reaching the ground and, hence, a decreased temperature [12]. A theoretical approach pointing to the impact of the GCR upon the degree of condensation will be explored within this work.
There are theories among scientists, who have found evidence for an effect of the galactic cosmic ray upon the amount of cloud condensation nuclei (CCNs) that will be treated in this thesis work.
It may in this connection be mentioned that the most important cloud condensation nuclei are the aerosols, i.e. a suspension of liquid or solid in air.
The largest contribution to the total fraction of atmospheric aerosols comes from within the interval of ~0.1-1 μm, simultaneously being the interval most important for the climate.
Important sources of aerosols are among others: gas-to-particle conversion, the bursting of the bubbles of the ocean surfaces, the elevation by wind of mineral dust from dry land surfaces, injection of ash and rock by volcanoes, soot from forest fires, biological emissions like spores and pollen.
[13].
For the reader's convenience is here given common orders of the different stages from ultrafine condensation nuclei (CN) up to water drops.
Ultrafine CN: radius $\geq$ 3 nm
CN: radius $\geq$ 10 nm
CCN: radius $\geq$ 80 nm [14]
Spheric aerosol: radius ~ 0.2-1 μm
Small water drops: radius ~ 270-600 μm [15]

Principal features of cloud formation
Due to the scope of this paper some basics of cloud theory is evidently needed here. Firstly, water vapour is brought to raise either due to buoyancy forces caused by daytime sunshine driven heating, or due to front driven upheaval. As the water vapour rises, the temperature becomes lower due to loss of air pressure with height (the common state law of gases), and accordingly, the relative humidity rises, until the condensation level is achieved. At that level water vapour begins to build small droplets, due to collisions (according to Maxwell-Boltzmann thermodynamics, where temperature equals energy equals velocity of molecules), especially in case of a slight supersaturation. However, that process is not very effective and once condensated liquid water droplets tend to go back into the vapour state.
In order to accumulate liquid water more rapidly, condensation nuclei are needed. They mostly appear as aerosols that can be of different kind, i.e. a suspension of liquid or solid in air (see above). However, a certain level of supersaturation is anyhow required in order

to grant a continued drop growth, but once the co-called critical supersaturation ratio S* has been attained, the growth will continue, independently of any subsequent decrease in supersaturation [16].

The cloud consists of an assembly of tiny droplets with a concentration typically of order hundreds per cubic centimetre and with a radius $\sim 10\mu m$ Precipitation develops when the cloud population becomes unstable, and some drops grow at the expense of others

The Köhler curve describes the circumstances ruling the process of drop growth [17]. Lejenäs [18] illustrates the curve in the following figure. The curve is vital in visualizing the humidity requirements in order to attain the condition for drop growth

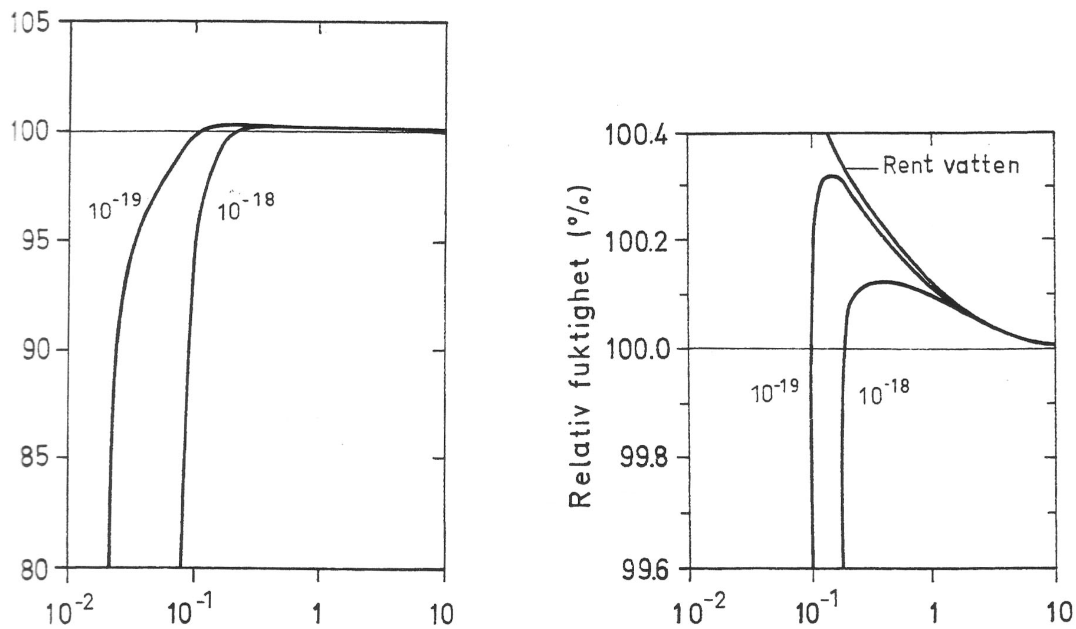

Figure 1. The curves are showing the relative humidity (%) in case of saturation in the vicinity of a droplet containing a condensation nucleus consisting of sodium chloride with the mass 10^{-19} kg respective 10^{-18} kg. The x axes are indicating the drop radius (μ m). The diagram to the right is an enlargement of the figure to the left [18].

The effect of clouds on short- and long wave radiation and on the energy balance

Clouds have an effect on the incoming and outgoing radiation. This can be described theoretically using the concepts of blackbody radiation and absorption spectra of water. The following figure gives a review over the role different gases have upon the blackbody spectrum.

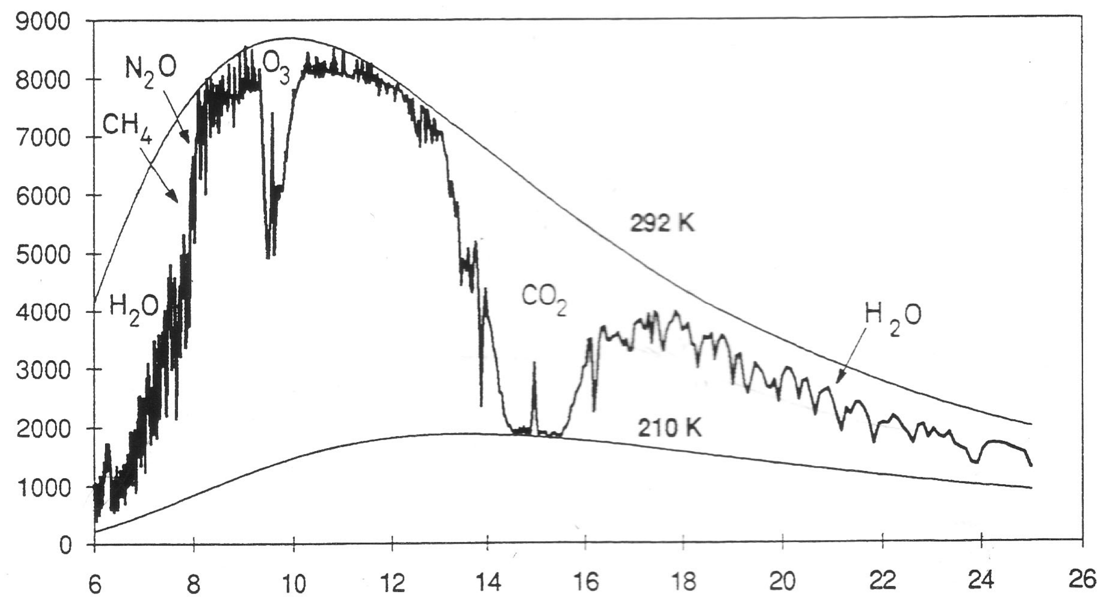

Fig.2. Long wave radiation from the Earth and its atmosphere as a function of the wavelength. The solid curves show the blackbody radiation at the given temperatures. The x axis indicates wavelength of the long wave radiation radiated from the Earth (μm) and the y axis indicates the magnitude of the radiation being emanated $(mW.cm^{-2}.sr^{-1}.\mu m^{-1})$. The absorption bands of different gases have been indicated. (Picture: Donald Murtagh, Stockholm University) [22].

Since the blackbody radiation curve has a downwards peak at around $10\mu m$ and water damp has no absorption band there at normal Earth face temperatures (292 K), heat may radiate out freely. However, the process that decides the net result for the energy balance due to the effect of clouds with respect to its altitude requires a rather sophisticated formal mathematical description. Hartmann has done this in his book 'Global Physical Climatology' [19]. Due to the albedo a cloud has, there is a height above which clouds have a positive net effect on the energy budget, i.e. energy is absorbed by the Earth [20]. Fundamental to the understanding of this is firstly that the energy balance as such may be written $R_{TOA} = \frac{S_0}{4}(1-\alpha_p) - F^{\uparrow}(\infty)$ (1)

thus following the proof by Hartmann [19].

The first term of the right hand expression may simpler be written:

$$\frac{S_0}{4}(1-\alpha_p) = Q_{abs} \qquad (2)$$

The change in the absorbed energy due to a cloud layer may then be written

$$\Delta R_{TOA} = R_{cloudy} - R_{clear} = \Delta Q_{abs} - \Delta F^{\uparrow}(\infty) \qquad (3)$$

The further analysis, thereby using Stefan-Bolzmann's law, gives

$$\Delta R_{TOA} = -\frac{S_0}{4}\Delta\alpha_p + F^{\uparrow}{}_{clear}(\infty) - \sigma T_{Z_{ct}}{}^4 \qquad (4)$$

By setting $\Delta R_{TOA} = 0$, the condition for achieving the altitude defining the turn from net absorption to net reflection of terrestrial radiation can be calculated through usage of the formula $T_{z_{ct}} = T_s - \Gamma z_{ct}$ (5)

The altitude varies from ca 4 km when the albedo change approaches zero and ca. 10 km for a change in albedo of 0.5.

For albedo changes in between this corresponds well to the absorption effect of high cirrus clouds and the reflective properties of low to middle high clouds

Short to speak: Low and middle high clouds have a cooling effect whereas high clouds act heating.

The variables that were being used were according to Hartmannn [21]

R_{TOA}	the net incoming radiation at the top of the atmosphere
S_0	the solar constant
α_p	the albedo
$F^{\uparrow}(\infty)$	the upward flux of terrestrial radiation at the top of the atmosphere
Q_{abs}	absorbed solar radiation
σ	the Stefan-Bolzmann constant
T_z	temperature at the altitude z
z_{ct}	the altitude at the top of the cloud
Γ	the lapse rate

SI units being assumed

About IMN and the creation of CCNs

Tinsley and Yu [23] describe more closely how solar activity through its effect on the GCR could affect the ion mediated nucleation (IMN) (i.e. forming of nuclei due to incoming ions) and electroscavenging (i.e. molecules brought together due to their electric charges).

They refer to the impact of the short-term solar variability and its effects upon the weather by Dickinson [24] according to which the GCR is unable to produce direct condensation of water vapour. Instead sulphuric acid vapour in the atmosphere allows condensation on the ions of H_2SO_4 molecules together with H_2O molecules. If these in turn would be allowed to grow larger, they might be able to act as cloud condensation nuclei (CCN), thereby affecting the particle size distribution and the lifetime of clouds. Through that procedure the GCR would be able to affect the climate.

Yu and Turco [25] write about how the GCR are able to ionize O_2 and N_2 molecules, which in turn are reacting with vapours like H_2SO_4, H_2O and NH_3 and furthermore several organic species. Thereby 'core terminal ions' accumulate ligands, forming a continous distribution of charged clusters.[26] The build-up of clusters is kinetically limited and an important factor promoting ion induced clustering is that the collision kernel for an ion is larger than for a neutral kernel, due to electrostatic effects. Figure 14 explores the different modes of the development of clusters, the upper path illustrating the reactions that ionized oxygen molecules give rise to, the middle path the electrically neutral clustering process and below the reactions that ionized nitrogen molecules give rise to.

Figure 15 is illustrating how the ionization rate affects the concentration of condensation nuclei $N_{d>d_i}$: The effect is largest in the case of a low aerosol surface area, which is the case for the marine boundary layer, where also the H_2SO_4 concentration is high. The upper figure shows the changes induced by ionization, due to the absolute concentrations and the lower figure shows the relative change with respect to the dimensions of the condensation nuclei, hence showing that the smaller size, the larger impact of the ionization rate.

The importance of cloud data.

The analysis above points to the need for accurate cloud data in order to be able to draw the right conclusions about are also very crucial to the research about the dependence between a radiative forcing and cloudiness. There are both the classical manual way of observing clouds and newer methods based upon satellite measurements.
But it is not easy to construct accurate automatic, satellite-based measurement methods neither. This report will frequently use terms like ISCCP-C2 (1983-1990) and D2 (1990-1992) satellite data as well as ‘extended satellite data’ (a combination of both) as well [27]. Sophisticated algorithms are used in order to judge the photos being taken of the Earth, IR (infrared) as well as VIS(visible) photos [28].

2. DIFFERENT SCHOOLS TREATING THE HEATING

2.1. Introduction

Since the theme of the thesis work is to review the effects of solar activity upon climate change, it is felt most convenient to begin with research that gives evidence in favour of that. By logical reasons it seems most natural to begin with the direct effects of solar radiation, proceed with indirect effects – especially galactic cosmic ray – and to finish with critics.

2.2. Theories focusing on the direct solar forcing

2.2.1. Solar forcing of the Northern hemisphere land air temperature

The two scientists P.Thejll and K. Lassen in a study from 2000 [29] make an effort to study one aspect of solar forcing upon the land air temperature, the effects of the solar cycle length (SCL) They use instrumental temperature measurements from 1861 prior to the 1990s.
The basis for the work is several papers, presenting data pointing to a correlation between the smoothed (i.e. rapid variations neglected) solar cycle length and the air temperature. The following figure in their paper clearly illustrates, how close the curves for mean temperature and SCL follow each others.

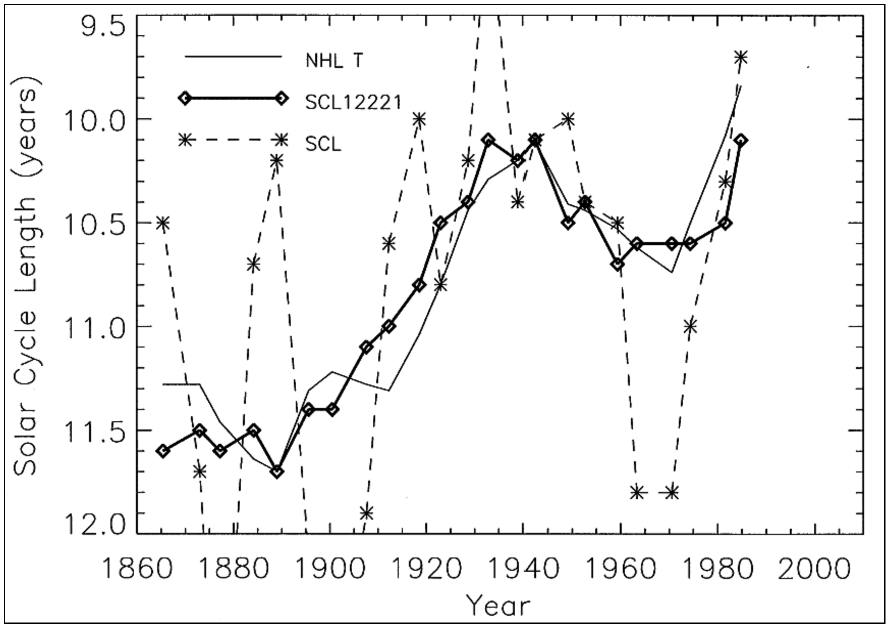

Fig.3. Observed cycle mean temperatures (thin solid line) and best fitting (1-2-2-2-1) SCL model (thick solid line with diamonds). This is a reconstruction of Fig. 2 in FCL91 with update of the last values of SCL12221, now calculated as the rest of the points on the curve but in 1991 represented by unsmoothed cycle length values. Also shown in the figure is the unsmoothed time series of the unfiltered SCL (dashed line with asterisks) to illustrate that the association found is between the long-term variation of the cycle length and the temperature, not the instantaneous values. Notice how the two properly calculated values of SCL12221 in the 1980s lie lower than the two preliminary values used in FCL91. The use of preliminary SCL values in FCL91 suggested a better fit between temperatures and the SCL model than is the case with the actual weighted values [30].

The authors are discussing different methods to calculate the smoothed SCL and find significant correlations between the SCL and temperature data, of order 0.8-0.9. However, the correlations drop in the 1990s and the authors are unable to explain why. Without further explanations they propose that ***the sudden rise in mean temperatures maybe is due to human activity.***

Nonetheless it is interesting to read that many scientists have found a correlation, even back to the 1200s, thereby through the study of ice-cores from Greenland. A spectral analysis of two dominant peaks in measurement data has been interpreted as originating from changing conditions of the sun. [31].

The benefit of this paper is that it gives an overview over a solar forcing hypothesis.

In spite of very little theoretical analysis supporting the data, all evidence of relevance to the full understanding of solar radiative forcing is of course important.

The fact that the correlation between the air temperature and the SCL disappears in the 1990s may lead to the conclusion that the correlation only was of random nature. On the The time that has passed is too short to allow for convincing evidence.

Apparently, more evidence must be gathered and further efforts must be done in order to find the most appropriate theoretical explanations.

Even Svensmark[32] and Kuang et al [33] are both mentioning the possibility of a dependence of the solar cycle length(SCL) and the latter even points to the ENSO, but neither of them is able to present any consistent proof of their assumptions.

They are pointing to the statistical coincidences during rather short time periods, ~7 yrs. The latter mention among others that the mean cloud optical thickness (MCOT) is varying in phase with the ENSO cycle and the SCL respectively, and that the amount of thin clouds from the High resolution Infra Red Sounder (HIRS) is varying with the GCR [34].

2.2.2. Reconstruction of solar irradiance since 1610 and implications for climate change

Lean, Beer and Bradley in their paper [35] perform a reconstruction of the solar irradiance since 1610. They thereby combine long-term solar cycle fluctuations and compare with independent records of solar activity obtained from cosmogenic isotopes in tree-rings and ice-cores and find a good correlation between solar irradiance and surface temperatures. Up to about one half of the warming since the 17th century they ascribe these irregularities in solar irradiance, provided smoothed values are being used.
They determine linear correlations between the thus reconstructed irradiance with NH (northern hemisphere) surface temperature anomalies (i.e. the difference with respect to the mean value of the actual latitude). This is illustrated in Fig. 4 below. This makes it possible to deduce the extent to which solar induced surface temperatures can account for the post industrial warming [36]

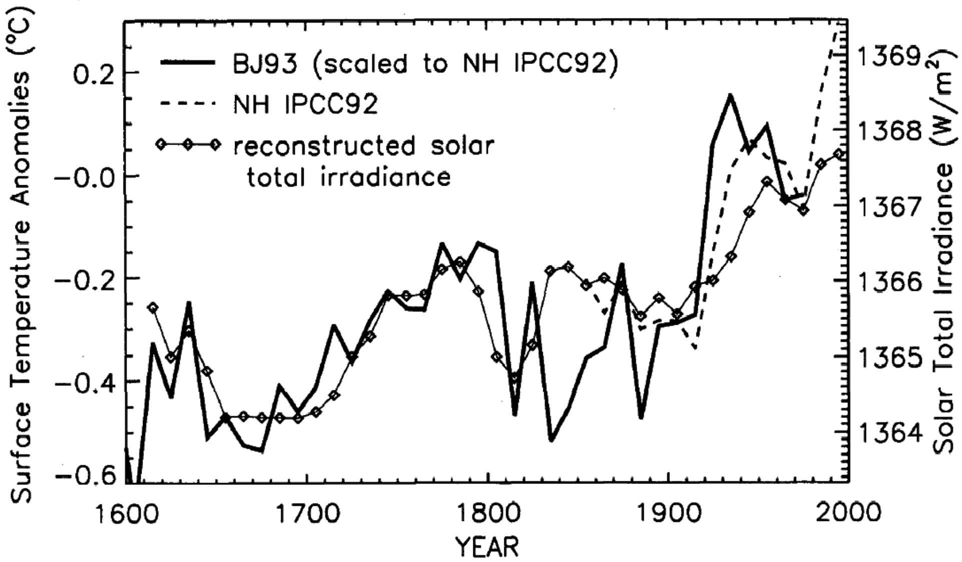

Fig.4. Compared and decadally averaged values of reconstructed solar irradiance (diamonds) and NH temperature anomalies from 1610 to the present. The Bradley and Jones [1933] (BJ93). NH summer temperature anomalies (solid line) have been scaled to match the IPCC [1992]. NH annual data (dashed line) during the overlap period [37].© AGU.

The correlation appears to be rather strong: 0.86 for the period 1610-1800.
It is interesting to read their judgement that since 1860 about one half of the observed 0.55°C surface warming is attributed to direct solar forcing, i.e. the solar irradiance, but 0.36°C of this heating has occurred since 1970 and solar forcing during this short period is only able to account for 0.11°C of this.
For the longest time period, that beginning with 1610, prior to modern times, solar variability may have contributed 0.51°C [38].
They thence conclude that solar variability may have played a larger role in recent global temperature than what has been commonly believed.
In order to attain the degree of change of the solar irradiance since 1610 they analyze the different irregularities in solar activity that have been observed thus far, long term changes as well as short-term. The deduction of long-term changes in solar activity is based upon parameterizations of sunspot darkening and facular brightening, using the sunspot record of activity for the last four centuries.
The reconstruction is based upon two separate components the 11-year cycle (the Schwab cycle) and a slowly varying background. They are also comparing with similar stars, with an absent sunspot period like the Maunder minimum and are thereby able to deduce changes in the irradiance of the Sun.
They are also tracking independent records of solar activity, inferred from ^{14}C and ^{10}Be cosmogenic isotopes.
It can thus be observed how the curve of the decadal averaged values of the reconstructed solar total irradiance (diamonds) roughly follows the curve of NH temperature anomalies. The dips in temperature curve during the 19th century (which is not accompanied by the solar irradiance) [39] the authors relate to the extended volcanic activity during this period.

2.2.3. Solar radiation proposed as driving force behind variations in cloudiness

In another paper Kristjánsson, Staple, Kristiansen and Kaas [40] present recent discoveries, indicating that solar irradiance is correlating better with low cloud cover than cosmic ray fluxes.
Table 1 shows among others the correlation coefficients between GCR and the amount of low clouds and between solar irradiance and the amount of low clouds respectively.

Data handling	GCR vs. IR-Low	GCR vs. Daytime Low	Solar vs. IR-Low	Solar vs. Daytime Low	Sunspots vs. IR-Low	Sunspots vs. Daytime Low
Raw	0.209	0.117	*−0.365*	−0.325	−0.299	−0.178
No ann. cycle	0.308	0.124	**−0.571**	−0.405	−0.436	−0.238
Low Pass	0.399	0.190	**−0.741**	−0.537	−0.541	−0.323
High Pass	*−0.147*	−0.204	0.027	0.015	0.036	0.094
Annual mean	0.456	0.175	*−0.800*	*−0.608*	−0.619	−0.345

Table 1.Correlation Coefficients Between Solar-Related Parameters and Different Estimates of Low Cloud Cover for the Period July 1983- December 1999. From ISCCP [41]. © AGU

The measurements are from the years 1983-99. Low clouds are thereby identified using IR(infrared)-low ISCCP **satellite data.** The GCR data are from the Huancayo-Hawaii site [42], which they assume are representative for variations in GCR flux globally. Practically**,** IR photos are taken from the satellites and to the largest part IR echoes are indicating low clouds.
They succeed rather well in showing a correlation between solar irradiance and low clouds, thereby attaining correlation coefficients of the order of -0.6 to -0.8, dependent on which cloud category is being studied.
The authors also describe how the satellite data have been treated statistically. Since these data have been collected only during the years 1983-1999, the total number of data points is rather low with respect to statistical methods, only 198. Since they cannot more than partially be regarded as statistically independent, there arises a significance problem in the analysis. Using the analysis of Quenouille [43], they attain a lower effective number of data points, between 4 and 13. They accordingly computed the statistical significance using the 'non-parametric' method of Ebisuzaki [44].

2.3. Research favouring Galactic Cosmic Rays as an important factor behind the warmer climate

2.3.1. Investigation of the covariation of galactic cosmic rays and temperature

The interest for a plausible dependence of the temperature on galactic cosmic rays (GCR) has been fostered especially by Svensmark and Friis-Christensen, who in a paper 1997 [27] were announcing a discovery that the global cloud cover is correlating closely with the intensity of the galactic cosmic ray (GCR). They claim the variation of cloud cover to be 3-4 % during the recent solar cycle, thereby displaying a strong correlation with the GCR flux. This was soon followed by a very broad research project, leading to the so-called ***cloud proposal*** [45].
Svensmark and Friis-Christensen are first referring to several reports, presenting direct and indirect links between solar radiation and changes in the radiation balance of the Eartth, but finally they conclude that the variations in solar irradiance are too small to be able to account for the climate changes that have already occurred [32].

For example during the Maunder sunspot minimum around the year1700 the total irradiance (the amount of incoming solar energy) is assumed to have been reduced by 0.25 %. But even this reduction they think is too low to explain the colder temperatures observed during that period.
Searching for a more plausible dependence on the solar flux, they refer to discoveries by Dickinson [24] who concluded that ‘the most plausible source of notable changes in the lower atmosphere due to solar activity changes would be significant changes in the absorption of solar radiation or the emission of infrared radiation by the lower atmosphere and Earth’s surface’. This assumption lead him into believing that it would be possible to see changes in cloudiness due to ionization effects (i.e. neutral molecules that becomes electrically charged) by the galactic cosmic rays, affecting the sulphate aerosol formation (small droplets with a radius ~ 0.2-1 μm)
and cloud nucleation in the vicinity of the tropopause.
The connection between the solar flux and the GCR is due to the shielding effect of the solar wind, thus limiting the strength of the GCR during solar maxima. The relationship is claimed to be roughly inverse.
Svensmark and Friis-Christensen find that the observed variation of the global cloud cover during the actual solar cycle is strongly correlated with the solar flux.
However, they mention several difficulties with respect to the satellite cloud data. They recognize the need for a global coverage and frequent sampling (of the order of six times a day). A further obstacle to corroborating a theory claiming a correlation between cloudiness and the GCR is that the observations over the continents and in the tropics do not show any correlation. Satellite data among others tend to show too low cloudiness values over continents, they say.
The dataset used is one of the longest and most comprehensive sets of cloud cover data, compiled by the International Satellite Cloud Climatology Project (ISCCP) [24]
The D2 series, being used during the three last years of the study, comprise an improved measurement technique, which enables to detect high cirrus clouds and low clouds over snow- and ice-covered areas [46]. Svensmark et al. furthermore claim that the C2 dataset (i.e. the dataset available prior to 1990), comprising a compilation of several satellite datasets, systematically underestimates the amount of clouds over the land masses [27]. The differences between the two datasets are further explored in the paper [47].
The authors resolve the problem with lacking evidence for a GCR dependence of cloudiness in the mentioned areas by referring to ‘different atmospheric processes’ and to ‘increased difficulties with the interpretation of the satellite data over land’, neither specifying those.
In order to visualize the above discussion figures 5 and 6 below are chosen from their paper. They show the cloud cover variation over the oceans and in the tropical zone respectively, the GCR being simultaneously displayed (performed approximately 1980-1995).

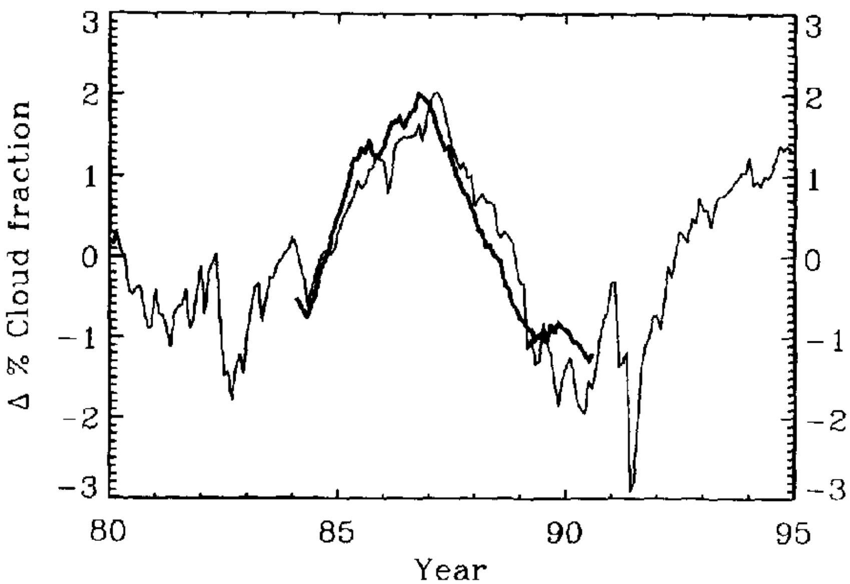

Fig.5. The thick curve displays the 12 months running average of total cloud cover given as changes in per cent (ISCCP-C2 monthly data). The data are from the area over the oceans covered by geostationary satellites [48]. The thin curve represents the normalized monthly mean counting rate of cosmic ray intensity from Climax, Colorado. © Elsevier Ltd.

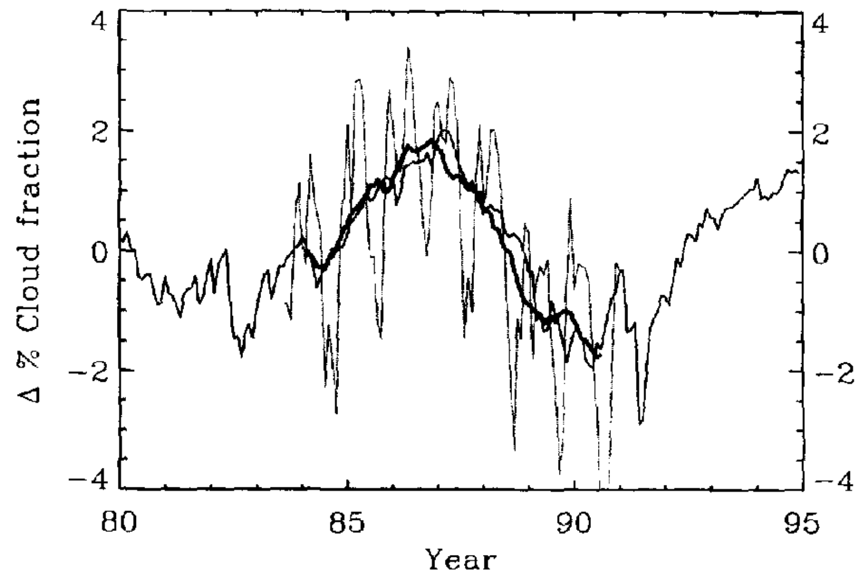

Fig.6. Same as Fig. 5 except that the cloud data exclude the tropical zone 22.2°S to 22.5°N and that the unsmoothed monthly values of cloud cover are included [49].

In another paper Svensmark [32] compares the effects of solar irradiance and that of the GCR upon temperature. The GCR, which consists mainly of very energetic particles (most protons), give rise to nuclear processes when they come into the atmosphere, leading to the production of secondary particles, which can penetrate still deeper in the atmosphere. He claims even that ionization in the lower atmosphere almost exclusively is due to GCR, or more specifically, due to muons (a kind of elementary particle) that are secondary particles following the GCR interaction with the atmosphere.

This was found already (prior to 1967) by Lal and Peters [50]

With this background it is interesting to study figure 7 in which the GCR, 10.7 cm solar flux and the global cloud cover are displayed simultaneously from ca 1980-1995. Svensmark shows that the Earth's cloud cover most closely follows the variations seen in the GCR and not the variations in the 10.7 cm signal. In fact, there is a 1.5-2 yrs lag between the GCR and the 10.7 cm 'radio signal'.

The delay occurs due to the influence of the heliosphere of the Sun. It can take up to one year for disturbances to reach the Sun's surface, the heliopause. This delay exists with respect to the 10.7 cm signal, whereas the dependence on the GCR shows no such delay. This impels the authors to conclude that it is primarily the GCR that is responsible for the change in cloudiness.

For convenience, please see Fig.7 in section 2.3.3 below.

The cosmic ray fluxes have been measured by CLIMAX, satellite data ISCCP-C2, ISCCP-D2 and DMSP. It is unclear how and where these signals were measured, but since the following figure in that same paper is referring to CLIMAX, too, one may infer that the Climax neutron monitor in Colorado is meant, which measures the low energy nucleonic part of the GCR spectrum.[51]. It is unclear where the radio signal has been measured.

Later in this paper Svensmark makes the connection between the solar cycle length (SCL) and the GCR, and finds the most direct correspondence between those two. Svensmark discusses the origin of the SCL [32], claiming that it is 'a measure of the processes occurring within the sun of unknown dynamical origin which manifest themselves in the

solar activity within the heliosphere that modulates the GCR'. Svensmark by the end of the paper discusses the degrees of forcing and what temperature they are expected to give rise to.
Using a general circulation model there would be expected a sensitivity of 0.7-1°C/Wm^{-2} for Δ S = 0.25%, where S is the solar constant $(1367 Wm^{-2})$ [52]. The normal variability of the solar constant is ca. 0.11% [53] However, due to the different angles under which the sun radiation falls onto the Earth, the global mean is only $(342 Wm^{-2})$ [52].

Due to this, the changes in the solar irradiance would cause a 0.1 °C temperature change, whereas the cloud forcing would give rise to a 0.3-0.5 °C change, which appears to be better in accordance with the experienced temperature rise. He even claims that this gives the potential to explaining nearly all of the temperature changes in the period being studied.
In this short paper Svensmark is gathering further support in favour of his GCR approach.

2.3.2. The 'cloud proposal'
The **'cloud proposal'** [54] begins with referring to the paper by Svensmark and Friis-Christensen from 1997 [27], in which they were announcing their discovery that global cloud cover correlates closely with the GCR intensity. The ***cloud proposa***l of 2000 was the result of a broad international effort, aiming at the study of the links between cosmic rays and clouds at CERN.
In spite of the fact that the variation, in galactic cosmic rays (GCR) is relatively high (ca. 15%), it corresponds to only one billionth of the solar irradiance, but yet-to-be known indirect effects seem to cause a remarkably large change in the cloud fraction of order 1-2 %. This occurs in phase with the GCR, according to Svensmark and Friis-Christensen.

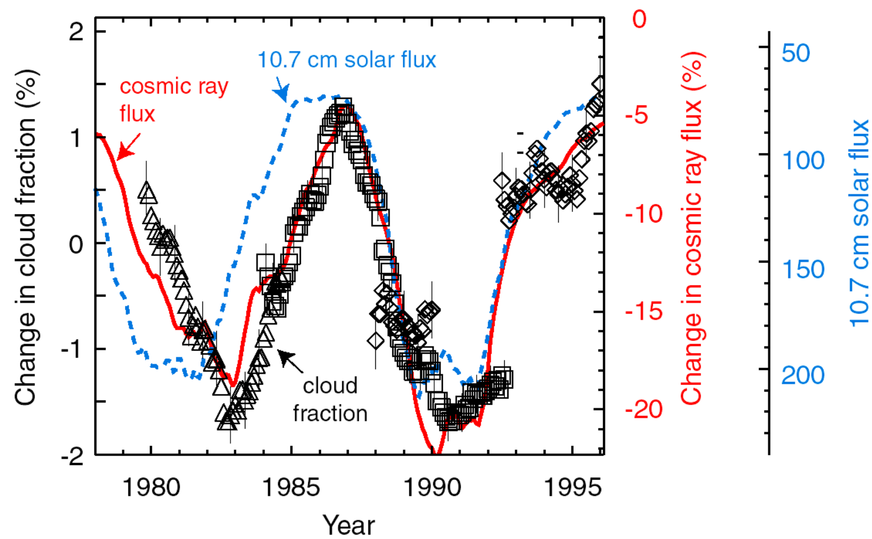

Fig.7. Absolute percentage variation of total cloud cover observed by satellites (data points; left hand scale) and relative percentage variation of cosmic ray flux (solid curve, normalised to May 1965; near-right hand scale). Also is shown the solar 10.7 cm microwave flux (dashed curve, in units of 10^{-22} Wm^{-2} Hz^{-1}; far-right hand scale. The cloud data are restricted to the oceans. (...) [55]

In order to show whether there is dependence between GCR and temperature they infer that the area fraction of the Earth with a correlation coefficient between the GCR intensity and low IR cloud-top temperature is 29.6% [54], [57]. The probability to attain that value from a random signal is only 0.01% [58].
They also show that the correlation disappears at higher levels, above 3 km altitude [59] Using coronal source flux data, going back to 1868, they have been able to estimate the GCR intensity over the last 140 years, indicating a net GCR radiative forcing of 1.2 Wm^{-2} over the last century, which they think corresponds rather well with the observed rise of 0.6°C in global temperatures during that same period. The effects of solar activity consist of ***scattering, gradient and curvature drifts caused by the heliospheric magnetic field***, which altogether are preventing the GCR from arriving to the Earth, a statement that is corroborated by near-Earth interplanetary space measurements beginning in1964, that show a rise in the coronal source flux a factor 1.4 [60]. Calculations by Lockwood et al going back to 1901, indicate an increase estimated to be 2.3 for that period [61].

The impact of the Sun on cloudiness is an indirect effect .The GCR flux has in turn been shown to correlate negatively with the percentage of low clouds, using the ISCCP-D2 satellite data during about one decade (~1983-1994), cosmic rays measured by the Climax neutron monitor [62], and low clouds are in turn known to act lowering on temperature. Concluding, this chain of events brings about a change in the net radiation arriving down to the Earth, estimated over the past 140 years to be ~1.2 Wm^{-2}.
Svensmark and Friis-Christensen also mention the observed dip in temperature between 1945 and 1970, which they claim is impossible to explain to be due to the 'greenhouse effect', with its much more smooth and slow trend. Instead, they point to the decrease in the Sun's activity during that period [8].

Interesting is also how they are showing that during the cold weather period 'little ice-age' or the Maunder minimum (1645-1715) there was an almost complete absence of sunspots, corresponding to a high cosmic ray flux, and therefore, under the present hypothesis, to an increased low-level cloudiness. [63].

Figure 8 gives a record of the history of deviations in the relative atmospheric ^{14}C concentration from tree-ring analysis for the last millennium. From the historic record it is known that the minima correspond to warm periods and maxima to cold periods

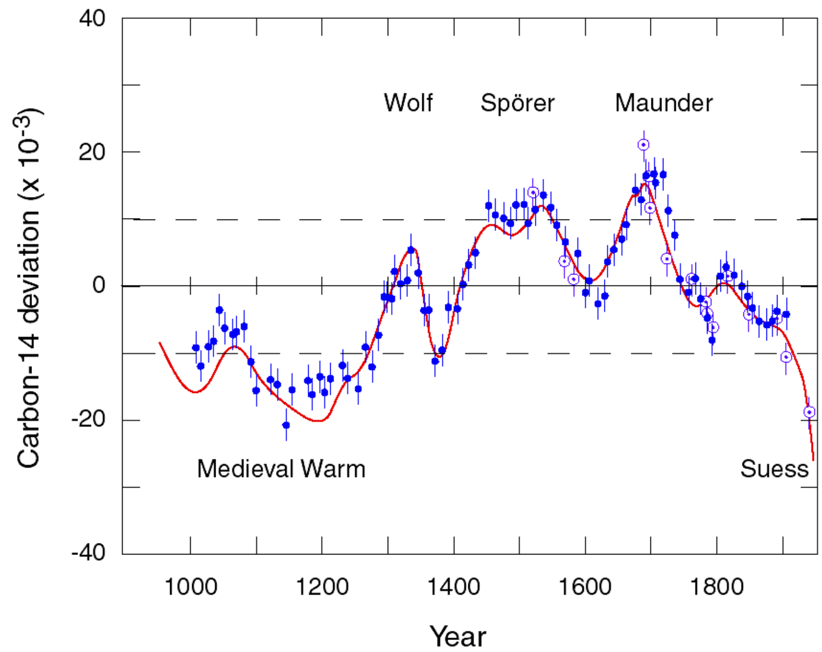

Fig.8. History of deviations in the relative atmospheric ^{14}C concentration from treering analyses for the last millennium. The data points (dots and open circles) are two independent high-precision measurements. The solid curve represents a combined fit to a large number of medium precision measurements. The dashed lines indicate ^{14}C deviations of 10 parts per million [64].

Analysis of the Greenland ice core indicates that the GCR intensity has decreased during the last century, simultaneously with the temperature rise. The authors are able to draw that conclusion, pointing to an analysis of ^{10}Be concentration in a Greenland core, indicating a steadily decreasing GCR flux during the recent century, saying that today (i.e.~year2000) it is weaker than it was at its minimum around 1900 (Figure 9)

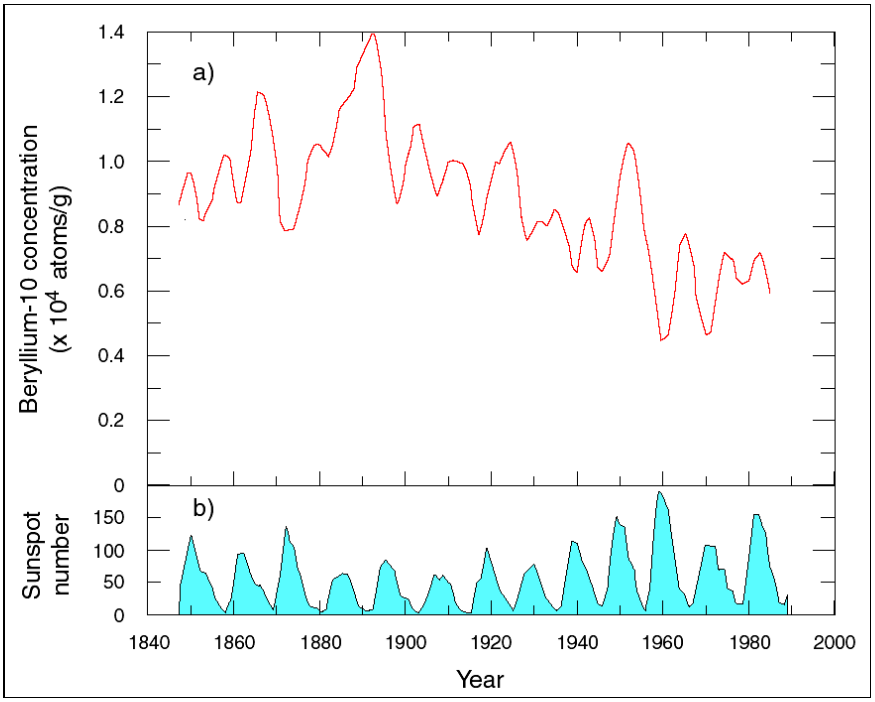

Fig.9. a)Concentration of ^{10}Be in a 300 m ice core from Greenland spanning the last 150 years. The data are smoothed by an approximately 10 year running mean and have been shifted earlier by 2 years to account for settling time.
b) The sunspot cycle over the same period, which shows a negative correlation with the short-term (~11 year) modulation of the ^{10}Be concentration [65].

The judgement of the authors of the cloud proposal is of interest for those who have read the Svensmark paper [32] and studied figure 9. They explore the causes to the delay between solar activity and the GCR on the Earth, as being caused by processes close to the Sun, among others: disturbances in the solar wind, which are scattering the cosmic rays, involving events like coronal mass ejections and co-rotating interaction regions [66].

To conclude, the 'cloud proposal' is indeed very impressive, with respect to the depth of the study and the items being studied and judged. All proposal ideas they are supported using a manifold of evidence.

In a paper **Masarik and Beer** are discussing among others the Svensmark discoveries, giving good reasons to believe in a GCR flux able to affect ionization at low troposphere levels [9]. They describe, how incoming GCR flux, mainly consisting of protons with energies ~1GeV gives rise to cascades of secondary particles with continuously lower energies with increasing atmospheric depth. They are thereby giving an extensive exposé in particle physics. They conclude there is an approximately inverse correlation between solar activity and cosmic ray flux [67]. Two figures in a paper of Tinsley and Yu visualizes the processes, when the GCR is modulated appropriately [23].
Please see Figure 10 and Figure 11

Fig. 10 illustrates the interplay between Sun radiation and galactic cosmic rays when approaching the Earth atmosphere. This causes changes in among others the column resistance and this in turn modulates the electric current that flows from the ionosphere into the clouds [23].

Fig. 11 shows a graphic over how incoming galactic radiation affects the rate of CN creation through the Ion Mediated Nucleation process [69].

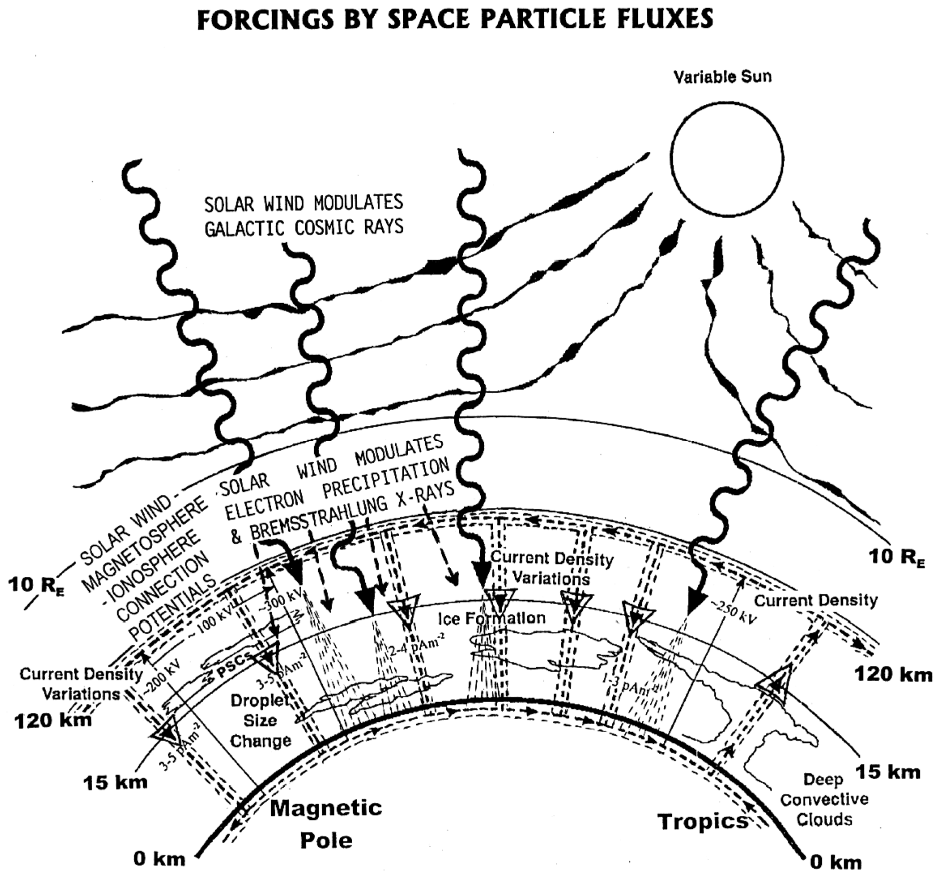

Fig.10. Solar wind variations moderate the fluxes of GeV galactic cosmic rays and the MeV electrons coming into the atmosphere, and the ionospheric potential in the polar caps. The fluxes of energetic particles change the vertical column resistance between the ionosphere and the surface, particularly at mid-high latitudes, and this together with the variations in ionospheric potential, change the electrical currents flowing from the ionosphere into clouds [68]. © AGU.

Tinsley and Yu also claim that the GCR flux is responsible for almost all of the production of ionization below 15 km altitude [69] and also propose ion-mediated nucleation (IMN) as the leading process that makes the GCR participating in the creation of CCN [11].

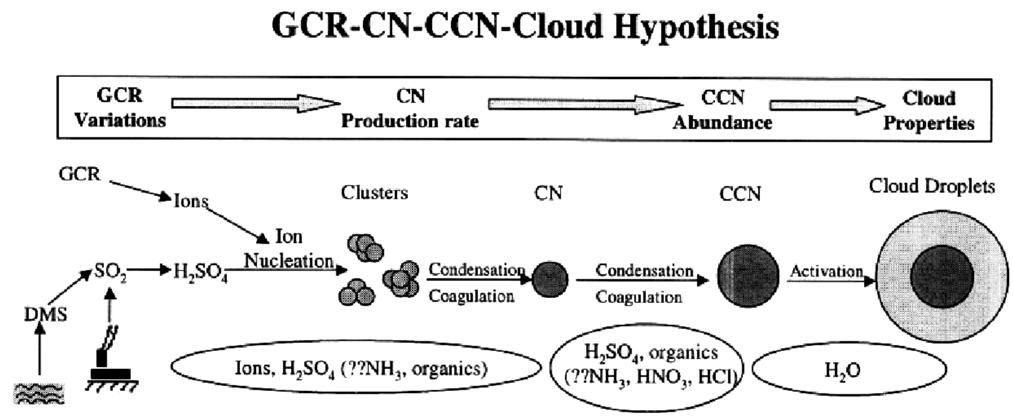

Fig.11. Schematic illustrating of GCR-CN-CCN-Cloud hypothesis that, if confirmed, might explain the correlation between variations of GCR flux and low cloud cover. The possible dominating species involved in the different phases of CN formation and growth processes are also indicated. The organic species may play an important role in growing the CN into the size of CCN [70]. © AGU.

Finally, they describe how the aerosols flow into the CCNs more rapidly thanks to the electric charges the GCR have inferred onto them, a process called electroscavenging [5] (Figure 12).

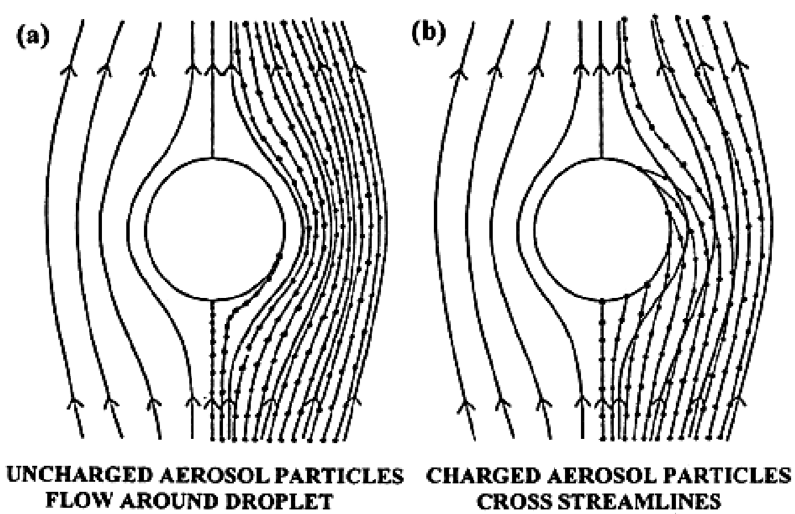

Fig.12. (a) Schematic of aerosol flow around a falling droplet in the absence of electrical forces. (b) Schematic of effect of electrical forces in moving aerosol particles across streamlines [71].© AGU.

2.3.2 Changes in diffuse radiation due to galactic cosmic rays
The two scientists R.Giles Harrison and David B. Stephenson in a paper [72] provide convincing empirical evidence in favour of the GCR approach.
They, too, are using the data measured by the University of Chicago at CLIMAX, Colorado, years 1951-2000, i.e. the daily mean neutron count rate, and compare with the diffuse solar radiation, measured at several UK surface sites. That means practically that the amounts of neutrons being caught are counted. The connection to GCR is due to the formation of neutrons by the GCRs, and it has elsewhere been found that the cosmic ray ion production coincide with the amounts of neutrons being created [73].
In this work the diffuse solar radiation is used as a measure of cloudiness, since the cloudiness is accompanied by the fraction of diffuse radiation. They argue that part of the diffuse radiation arises from the scattering of the solar light by clouds (and aerosol), and hence, the diffuse component is able to provide a measure of the cloud presence. In the UK, hourly solar radiation data extend back to 1947.
The interest in diffuse solar radiation is due to the measured sensitivity of average temperatures to the diffuse fraction (DF), which has been estimated to be -0.2K per 0.01 change in DF at Reading (for 1997-2004). [59]
Harrison and Stephenson present the measurement results twofold, firstly the mean DF on high neutron days as a function of mean DF on low neutron days, secondly the amount of overcast days as a function of the overcast odds (Figure 13).

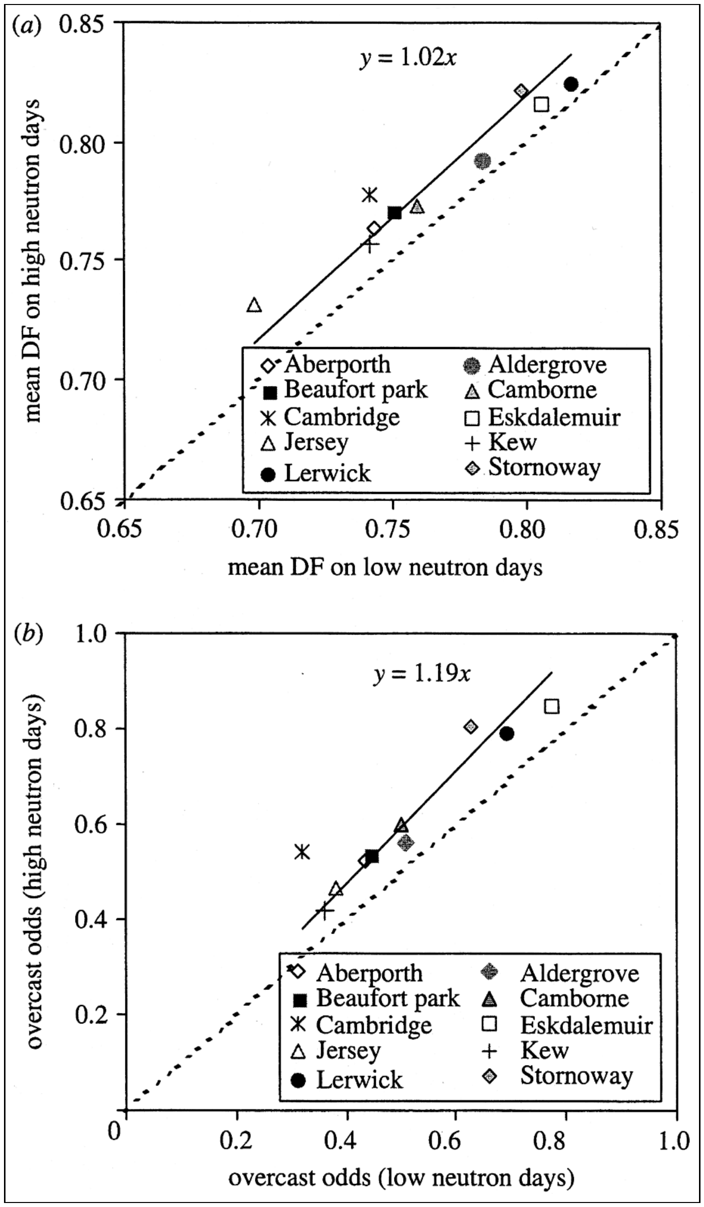

Fig.13. (a) Mean diffuse fraction DF for days having high neutron count rates ($X>3600X10^2\ h^{-1}$) plotted against DF for days having low neutron count rates ($X<3600X10^2\ h^{-1}$), for the UK radiation measurement sites. (b) Odds of an overcast day (defined as a day with DF>0.9) for high neutron rates ($X>3600X10^2\ h^{-1}$) plotted against the odds of an overcast day with low neutron rates ($X<3600X10^2\ h^{-1}$), (The 1:1 line is shown dotted in each case) [74]. © The Royal Society.

An overcast day is defined as a day with a DF greater than 0.9. The diffuse fraction increases by 2 % and the chance of an overcast day by 19 % for days with high neutron count rates (i.e. more than 360,000 counts h^{-1}), and they show accordingly that the diffuse radiation changes are unambiguously due to cosmic rays. Using statistic methods it is further shown that the results are significant at the 0.1 % level [53]

Contrary to Kristjánsson et al. [75], Harrison and Stevenson claim that cosmic rays produce molecular cluster ions throughout the atmosphere, down to the surface However, Harrison and Stephenson say that 'vertical motion of ions through cloud-forming regions occurs continuously due to large potential differences between the ionosphere and the surface. The resulting vertical current density has also been regularly observed in the UK. [76], [77]. This indicates the possibility that ions created at higher levels of the atmosphere are rapidly being transported down to lower levels and can thereafter be used as e.g. CCNs.
The process, through which the cluster ions, thus created, are being used, is a bit more complex than straightforwardly becoming condensation nuclei. The reason is assumed to be that the degree of water vapour supersaturation is many times smaller than what is required in a cloud chamber. They are referring to indirect physical mechanisms, as have been outlined recently, such as through growth of cosmogenic ions to form aerosol and by electric charge effects on aerosol-cloud microphysics. [78]
Seemingly, there will be required a great deal of both theoretical and experimental work, before these processes can be fully understood.
They are also critical concerning the origin of the effects on cloudiness, thus referring to the fact that the neutron flow is modulated by solar changes [79]. In the next section the effects of galactic cosmic rays on aerosol creation, ultimately cloud formation, will be explored.

2.3.3. Laboratory studies of the effect of galactic cosmic rays upon aerosol formation
FangqunYu and Richard P. Turco in a paper of 2001 [25], propose an explanation to the photochemical process involved in order to form ultrafine particles.
Mentioning a series of competing processes involved in the creation of aerosols, they emphasize that electrically charged embryos have an advantage over similar neutral embryos, due to electrostatic interaction. Simulations of a major nucleation event in connection with the Pacific Exploratory Mission (PEM) Tropics-A were able to explain most of the observed features in the ultrafine particle behaviour. They found further that systematic variations in the ionization levels due to the modulation of the galactic cosmic radiation (GCR) by the solar cycle are sufficient to cause a significant variation in aerosol production.
The relevance of performing a closer study of the process of aerosol radiative forcing becomes apparent, as the authors claim that the uncertainty in aerosol radiative forcing is large enough to compensate for the effect of greenhouse gases.
Also the origin of the ultrafine aerosols throughout the troposphere has still not been accurately determined. Two nucleation models, the BHN(binary homogeneous nucleation) and the THN(ternary homogeneous nucleation) predict the amount of ultrafine aerosols 10 times too low.
In the past researchers have alluded to ions as potential nucleation embryos, however without performing quantitative studies.
Yu and Turco do this, thus 'demonstrating that charged molecular clusters, condensating around natural air ions, can grow significantly faster than corresponding neutral clusters'
It is interesting that they show that in the case of particle formation on ambient ions the processes are rather similar to those controlling aircraft aerosols.
Concerning the generation of ambient ions due to GCR the rate is highest in the upper troposphere (~20-30 ion-pairs $cm^{-3} s^{-1}$) and lowest at ground level (~2 ion-pairs $cm^{-3} s^{-1}$). They have constructed a figure that describes the related processes leading to the formation of particles. The GCR thereby ionizes O_2 and N_2

Concerning their concrete findings, it must be mentioned that they realize that the ion-induced nucleation makes its greatest contribution, when ambient ionization rates are relatively small and background aerosol surface area densities are also small, as is the case over the oceans. Under these circumstances, CN (condensation nuclei) formation is limited and is **modulated by the ionization.** [80]. This may provide an explanation to the weak points in Svensmark et al [27] as viewed by Sun and Bradley [81] , when they fail to explain the lack of correlation between GCR and cloudiness over vast land areas (continents). And also Svensmark et al. recognized this problem.
Yu and Turco [83] accordingly succeed in simulating, how a 25% change in the background ionization rate (a typical range over the 11-year solar cycle) under MBL (marine boundary layer) conditions would lead to a ~16% maximum change in the number of ultrafine particles larger than 3 nm. Fig. 14 below illustrates this [82].

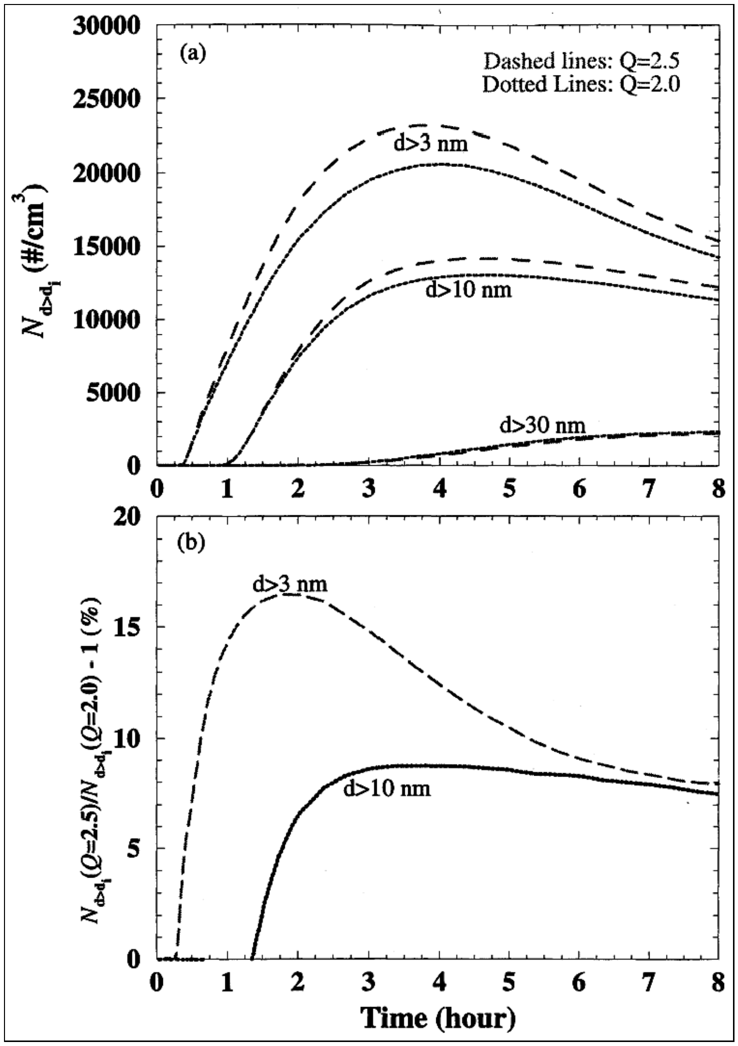

Fig.14. Predicted differences in the total concentration of condensation nuclei $N_{d>di}$ **(** $d_i = 3$, 10 and 30 nm), **for two different assumed GCR ionization rates** (Q=2.0 and 2.5 ion-pairs $cm^{-3}\,s^{-1}$). **All other parameters conform to the case shown in Figure 3 and 4 (of the cited paper). (a) Absolute particle concentrations for** $d_i = 3$, 10 and 30 nm (i.e. the chosen reference cross sections); **(b) Relative fractional changes (in percent) in the integrated concentrations**
(i.e., . $F = N_{d>di}(Q = 2.5) / N_{d>di}(Q = 2.0) - 1$) **[82]** © AGU

2.4. Opponents to galactic cosmic rays as a driving force behind the warmer climate

2.4.1. Galactic cosmic rays dismissed as driving force behind variations in cloudiness

Kristjánsson and Kristiansen are in a paper from 2000 [75] treating the question whether there is a cosmic ray signal in the recent variations in global cloudiness and, hence, whether that implies an indirect radiative forcing. They conclude that it is not possible to find any physical mechanism that can account for a correlation between cosmic rays and an enhanced growth of low clouds.

The decrease in the total global cloud cover they have found between 1986 and 1995 cannot be related to the variations in cosmic ray activity. They claim that it is impossible, since cosmic rays are mainly affecting the ionization at 10-20 km height and that their effect is rapidly decreasing both above and below this region. In order to give rise to CCNs at lower heights it would be necessary for the GCR to come down to the appropriate levels. **.** This seems to indicate a conflict with the position by other researchers [72], which may not be overcome, provided one part is not capitulating, or a better explanation is found.

According to Figure 15b below there exists a correlation between global cloud cover as well as midlatitude ocean cloud cover and the GCR for a substantial part of the period being studied, though increasingly distorted, beginning in 1989, measured by the CLIMAX station in Colorado. The authors are apparently focusing upon the parts of the curves in especially Fig. 15a that are deviating from each others when arguing against the GCR. This inherent conflict again awakens the discussion of the difference between the radiative circumstances over the oceans and over the continents respectively.

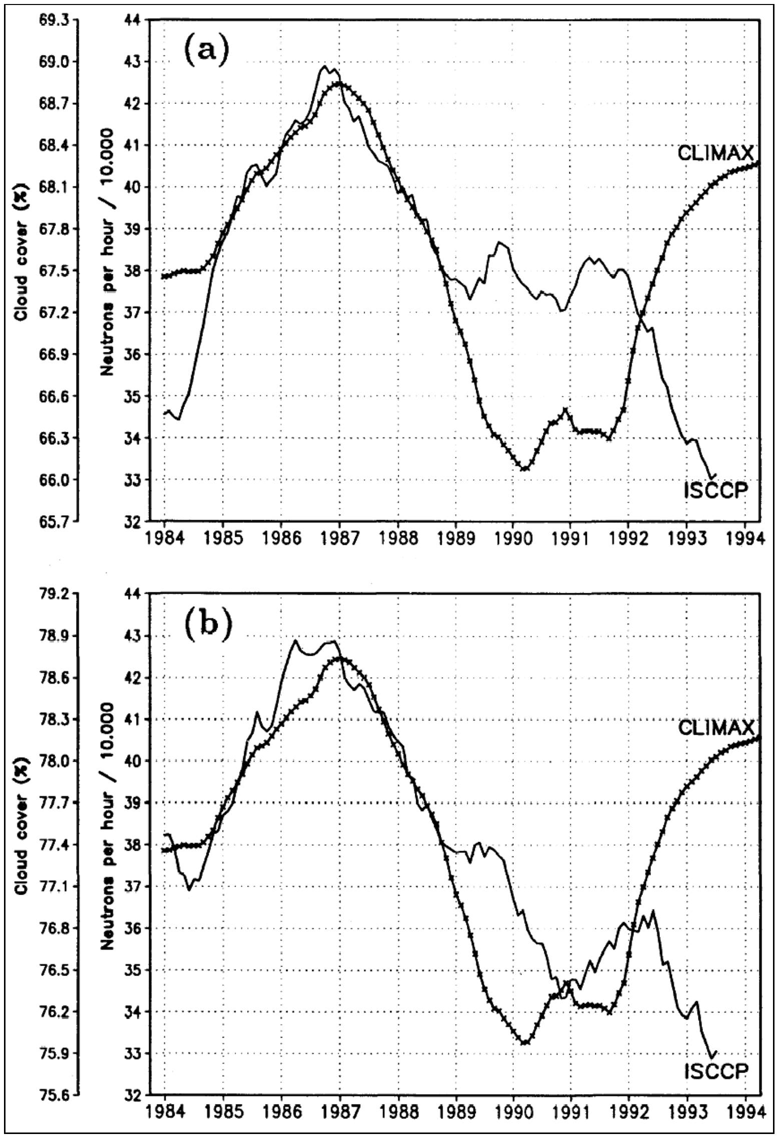

Fig.15(a) Variation of global cloud cover and cosmic radiation over the period 1984-1993. The combined set of ISCCP C2 and D2 (solid line). Cosmic ray flux observed at station CLIMAX in Colorado (crosses). Units: number of neutrons per hour, divided by 10,000. Fig.15(b) As in Figure 15(a), but over midlatitude oceans [84]. © AGU

Kristjánsson and Kristiansen also treat the synoptic observations that have been performed since 1952 and these are compared with the observed GCR during the same period.
In this case there is an upward trend in the observed cloudiness, but a discussion concerning the reliability of manual observations reveals that observers tend to overestimate cumulus cloudiness and underestimate stratus cloudiness.
Due to the difficulties in judging the reliability of manual observations and due to the relative smallness of the changes in cloudiness – of the order of 2 % - it seems best not to use these data in the general discussion about GCR and cloudiness.

2.4.2. Sun and Bradley: Strongly against the GCR models for heating.
The two scientists Bomin Sun and Raymond S. Bradley are strongly opposing the thesis by Svensmark et al. that there is a cosmic ray forcing upon climate [81].
They criticize Svensmark et al. [27] for restricting their study to the oceans, thereby avoiding land C2 data, since their behaviour is different from the cloud cover over land areas, and hence, don't support the GCR thesis. (The C2 data set is a compilation based on different satellite instruments with different observational coverage from July 1983 to December 1990 [47]).On page 5-7 of their paper the authors show graphically that the fluctuations in the GCR measured by CLIMAX show a very weak, if any, coincidence with cloud cover over contiguous U.S., China (east of 110E) and the former USSR (south of 60N).
However, they recognize a correlation over the Atlantic Ocean, but using 'extended ISCCP satellite cloud cover data' they show that the correlation is strongly weakened. Referring to ship observations, made 1953-1995, no correlation at all is found, but the reliability of manual observations has been questioned elsewhere, by Kristjánsson et al. [85]

3. Discussion

The effects of solar radiation upon climate have become a branch of climate research, which has encountered increased interest, especially after the papers of Svensmark et al. in the mid-90s. In spite of some early records a hundred years ago, it seems that this school has succeeded in focusing upon the radiative effects due to the Sun and the galactic cosmic rays (GCR) and their interplay. Some of its proponents, as among others the authors of the 'cloud proposal' of 2000 [45], even claim that these are the most important factors behind the recent climate changes. Contrary to this, recent climate events have given widespread support to the proponents of the greenhouse effects and from some papers one can even perceive a deep animosity between the two main schools. However, as also appears clearly from its title, this thesis work does not deal with the greenhouse effect at all.
Its task has been solely to judge the climate-relevant effects, independently of the greenhouse effect. This has been done in the preceding sections contained in chapter 2. Going through the papers it becomes apparent that the results are ambiguous.
The proponents are presenting evidence in support of solar/GCR effects, both due to GCR and solar irradiance. Different kinds of proofs are presented from very different points of view. This altogether speaks in favour of radiative effects upon climate.
However, the counterarguments are often convincing, but it is in no respect possible to completely reject a solar variation-climate relationship. Instead it seems to be needed much more research in order to gain clarity concerning all the features.

3.1. Discussion of the observations

Some scientists claim evidence for effects from cosmic or solar radiation upon global temperature. The effects of the direct solar radiation upon the temperature rise is mostly believed to be too low in order to give a plausible explanation, but some one school nonetheless makes efforts to corroborate a direct solar forcing of the land air temperatures (on the Northern Hemisphere), using instrumental temperature measurements since the

1860s, thus comparing the results with the solar cycles, but they admit, too, that the effect is too small (up to one half) to solely explain the recent heating [40].

The direct heating effects of the cosmic radiation have also been estimated, but they are to the extent negligibly small in order to have any impact upon temperature changes [86]. But concerning the possible indirect forcing effects, it has been shown that the cloud cover is correlated to the GCR [87],[27], [88],[72], [56]. However, these results have been questioned, as they are not unambiguous. Among others it has been successfully shown that over the continents it is impossible to verify a correlation [81], [87]. The problems appear in connection with the analysis of satellite data. An important objection to the evidence of a correlation that has been impossible to reject by the opponents is that the period of observation is to the extent short (of order 10 years) that other, yet-to-be known forcing factors would be responsible for the observations.
Another forcing due to the Sun has been proposed by Thejll and Lassen [29], who have observed a significant correlation between the solar cycle length (SCL) and the temperature data, but regrettably this correlation suddenly disappears in the 1990s.

What is strengthening the position of the proponents of the GCR effect upon temperature is that a completely different kind of observational data exists, that corroborate the correlation, i.e. land-based observations of diffuse solar radiation and cloudiness respectively in UK at several Met. Office sites for a period of almost 60 years [88], [72]

It appears that manual measurements are inherited with certain man-dependent faults, which can affect the very possibility of detecting small changes in cloudiness, as is the case in the search for a relationship with solar variations. Their benefit is the longer historical record

One factor that strengthens the GCR theory is that different ways of defining cloudiness, one using satellite measurements with one type of definition, the other using land based cloud data, furthermore defining cloudiness in two separate ways, both show a GCR dependence.

A complication arises when dealing with the observational evidence presented by different authors. One remarkable such case is that the cloud proposal [86] in figure 3 and Kristjànsson and Kristiansen [89] in figure 9 report different cloud cover curves from 1992 onwards. Maybe that is due to the use of different cloud data, C2 prior to 1989 and D2 thereafter.
But the curves show also a time lag between them, also before, when the C2 data is being used. It should be interesting to be able to study the raw data they were using. Around 1992 there is an upwards jump in the curve in figure 3 of the cloud proposal [86]. This might be due to the change in analysing collected data from C2 to D2 in 1990, since there is a new satellite coverage, instrumentation and algorithms used to derive the cloud cover [90]. A similar figure appears also in [47], containing the same characteristic upwards jump. The reason that it appears first some two years after the moment when datasets were changed seems to be due to the 12 months running mean procedure. However, Kristjànsson and Kristiansen [75] use a ‘combined set’ of C2 and D2 data, which may explain the absence of the charcteristic jump in their figure. They also at another occasion show that there is a significant gap between the C2 and the D2 curves.
Concluding, the divergence of the GCR curve and the cloud curve from around 1992 constitutes an obstacle to the GCR proponents.

3.2. Discussion of the mechanisms

The casual relationship between direct solar radiation and cloudiness is rather straightforward. Increased solar radiation implies an increased energy input into the atmosphere which can be transformed into a temperature change. The main problem in this respect is to determine the numerical extent of that effect, but all agree that this effect can by no means alone explain the climate change [8], [36].

However, the Sun is also, due to the magnetic storms and streams of energetic particles, affecting the ability of the galactic cosmic ray from outside of the solar system that can reach the Earth. It has been shown that there is an inverse relationship between solar activity and the strength of the GCR [91]

Some scientists are drawing the conclusion of the observed relationship between galactic cosmic rays (GCR) and cloudiness that these indicate a causal relationship [3],

Others find other explanations refuting a solar effect upon the climate change [59], again others resume a reluctant position due to ambiguous data, e.g. a lack of GCR dependence over huge areas [92]. One way of refuting a possible correlation between the GCR and cloudiness is to show that the GCRs are unable to reach the troposphere, where the GCR has been presumed to affect the creation of CCNs [93]. The opposite position is taken by others, who show that the GCR may give rise to the creation of secondary particles, which can travel down to the bottom of the atmosphere, thus ionizing particles they encounter [91], [76], [31].

An explanation to the absence of observed correlation over the continents is that the land dust is inherited with radioactivity, and hence, since the effects of the GCRs are relatively small, they might be invisible due to the overall 'noise' that the dust is causing [26]. Further, the amount of CCNs is also hugely greater over land masses, and that makes the creation of CCNs rather insensitive to the relatively small increase due to the GCR effect. Others, as Kristjánsson [89], deny that GCR would be able to affect the creation of cluster ions close to the Earth, but again others, as Harrison et al [78], [62] are referring to the observed vertical motion of the ions through cloud-forming regions, due to large electric potential difference between the ionosphere and the surface. That offers a plausible explanation of how the GCR would be able to affect cloudiness in the troposphere, even though the ionizations takes place in the upper stratosphere.

Another option, as proposed by Masarik and Beer [23], [11], is the creation of secondary particles as muons as a result of a chain reaction, initiated by the first collisions of the GCRs with molecules in the stratosphere.

It has been claimed [32] that the GCR flux is responsible for almost all of the production of ionization below 15 km altitude that determines the conductivity in that region. This implies the appearance of a surplus of charges, hence promoting electroscavenging as well as ion-mediated nucleation [11]. Electroscavenging means that the charged aerosols thanks to their image charges on the falling droplets are being increasingly attached to those, hence speeding up the growth of the droplet size.

It has also been claimed that the IMN (ion mediated nucleation)theory physically can explain the enhanced growth rate of order 10 of sub-nanometer clusters. CNs are unable to act as CCN and very high supersaturation is applied, unless their diameter is brought to increase about 10 times, if the IMN process were allowed to take place in reality, the increase in the amount of CCNs would contribute to the overall CCN abundance measurably and hence, corroborate the effect of the alleged effect of the GCR [11].

Yu and Turco [25] have been able to explain most of the observed features in the ultrafine particle behaviour and also found systematic variations in the ionization levels due to the

modulation of the galactic cosmic radiation (GCR) by the solar cycle to be sufficient to cause a significant variation in aerosol production.
However, other scientists show just as rigorously that the modulation of the GCR by the solar cycle is sufficient to cause observable variations in the production of CNs in the marine boundary level. The increased amount of CCNs also affects cloud properties, thereby leading to a higher droplet concentration, and, accordingly, to a higher albedo [93]. The conclusion to be drawn is that this indicates a cooling due to the increased albedo, when the GCR is increased. Later in [93] a figure is showing the relations described above concerning the effects of the IMN

4. Conclusions

The conclusion to be made fromthe above overviewis that there is an effect upon earth temperatures both due to solar irradiance and due to the galactic cosmic ray (GCR), when regarded separately. Thereby the solar activity is inversely affecting the stream of GCRs towards the Earth.
The effect by the direct solar irradiance is unquestionable, but small, and insufficient in order to explain the climate change.
The effect of the GCR seems to have been sufficiently corroborated and there exist theoretical models that support different aspects of GCR-climate connections. But the partly lacking coincidence between theory and experimental evidence make it clear that much research is necessary in order to bring all the pieces together

5. Outlook

The coupling between atmospheric science and particle physics, indicated among others by the references being made to hadronic processes and muons, seems to open up a new and potentially very fruitful research field. Thus far meteorology (and climatology) has been deeply separated from particle physics. It means probably the settling point for a new era when these two disciplines now necessarily meet each other.

It can also be added that recently it has been decided that CERN will continue working upon the radiation approach. The reason is claimed to be due to the success of an earlier CERN report [45]. Experiments simulating galactic cosmic rays (GCR) will be performed through the usage of the CERN accelerator as an “adjustable source of galactic cosmic rays” [94]. It will be used in order to investigate GCR induced cloud nucleation processes in an organized fashion. A cloud chamber is currently being constructed with the goal to begin experiments in 2009.

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