Influence of Cosmic Rays on the Earth's Climate

Henrik Svensmark
Danish National Space Center, Juliane Maries Vej 30, DK-2100 Copenhagen.

About twice a second an energetic subatomic particle whizzes through your head. It is a secondary cosmic-ray particle, made when primary cosmic rays coming from exploded stars far away in the Milky Way Galaxy hit the Earth's atmosphere. The air is a very good shield, and the cosmic rays are more intense on high mountains or in jet planes.

Our team at the Danish National Space Center has discovered that the relatively few cosmic rays that reach sea-level play a big part in the everyday weather. They help to make low-level clouds, which largely regulate the Earth's surface temperature.

During the 20th Century the influx of cosmic rays decreased and the resulting reduction of cloudiness allowed the world to warm up. Such warming events have happened ten times in the last 12,000 years, and recently in medieval times. In between the warm intervals there were cold periods like the Little Ice Age, which was most severe 300 years ago. We know that cosmic rays were intense during the Little Ice Age because the production of radiocarbon atoms, C14, was at a peak. These atoms, used for dating by archaeologists, are made when cosmic rays hit nitrogen atoms in the air.

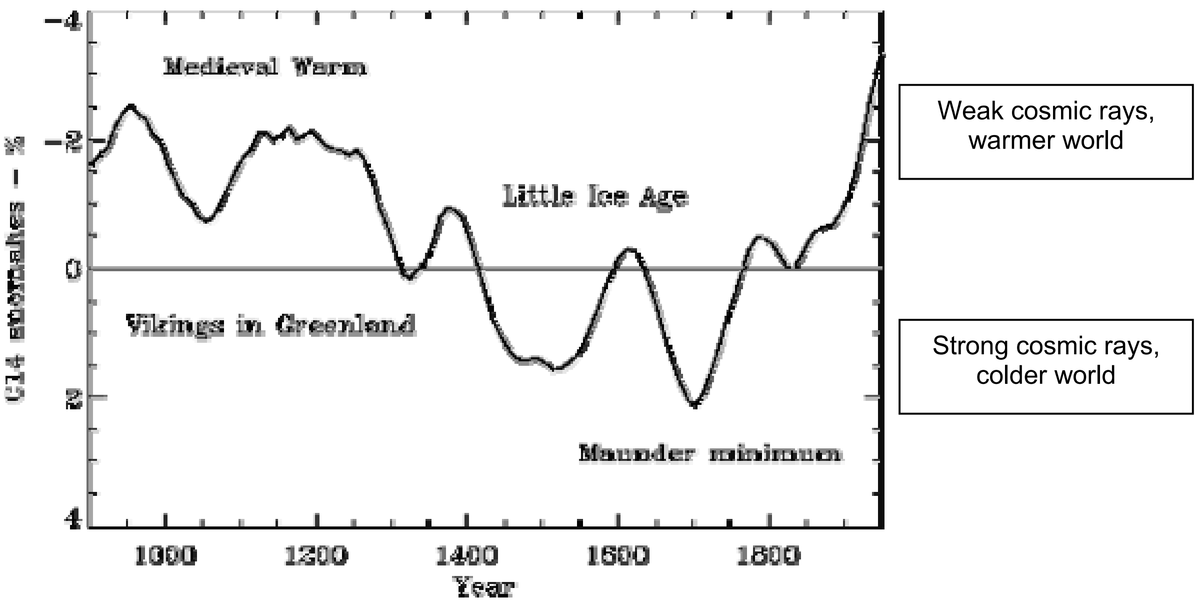

Fig. 1 *Production of radiocarbon, C14, during the last 1000 years, plotted upside down to match temperature changes. The Maunder minimum refers to the period 1645 -- 1715 when very few sunspots where observed on the Sun, indicating weak solar activity. In this period the production of C14 was very high. When the Sun is most active, the production of C14 is low. So the variation in C14 production, and in the cosmic rays that make C14, was caused by changes in solar activity.*

The Heliosphere

Why does the influx of cosmic rays change, from century to century? Below is a figure that illustrates the Heliosphere, the large volume of space that is directly affected by the Sun through the solar wind – a plasma of electrons, atomic nuclei and associated magnetic fields that streams non-stop from the solar atmosphere. The magnetic structure of the solar wind helps to shield the Solar System from many incoming cosmic-ray particles of relatively low energy.

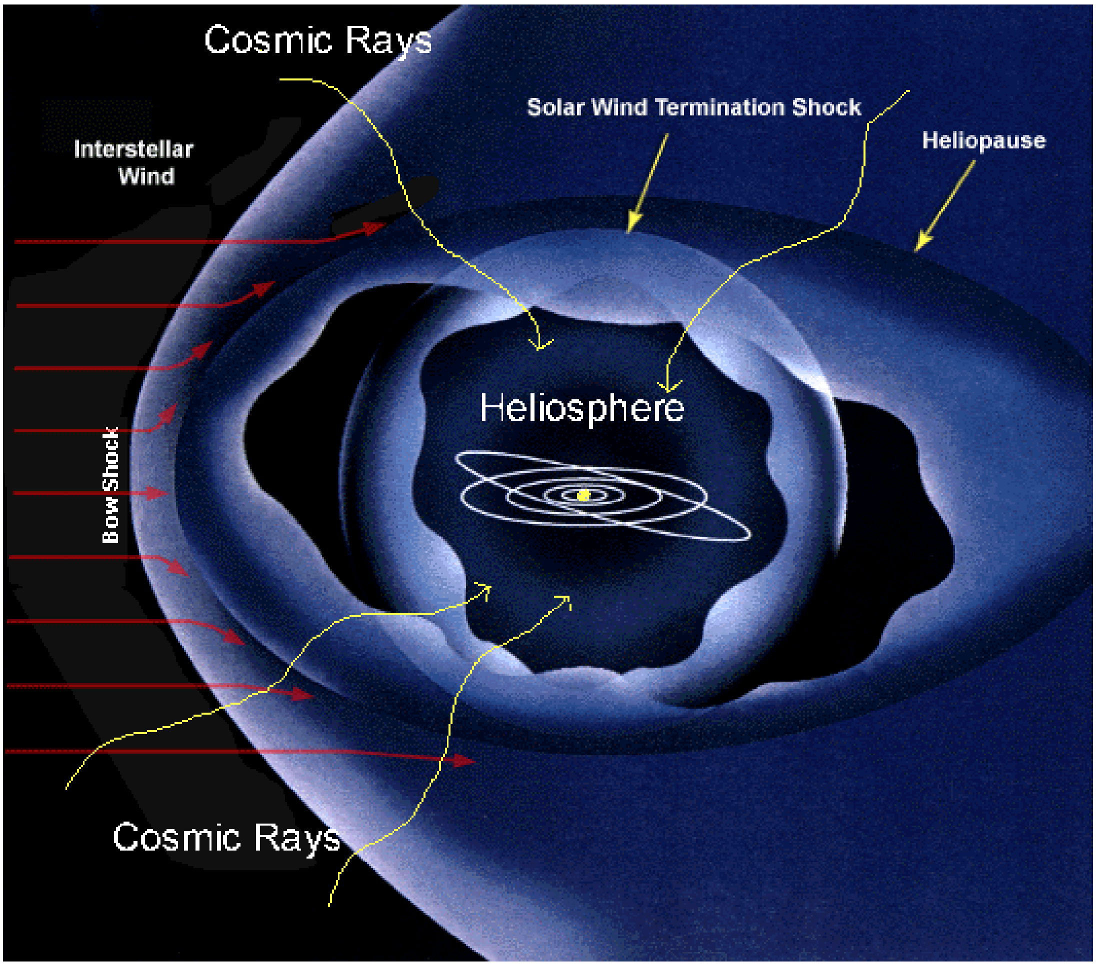

Fig. 2 *The Heliosphere is a big bubble in space blown by the solar wind. Its magnetic field shields the Earth from many cosmic rays coming from the Galaxy. (More about the solar wind plasma can be found here) (Sune check this, it doesn´t work)(Check credit)*

If solar activity were constant, the cosmic-ray flux on Earth would be constant too. But the Sun's behaviour varies, and so does the solar wind. The best known variation is the sunspot cycle. The number of dark spots on the Sun's visible face increases and decreases every 11 years or so, but the Sun's magnetic field also reverses, so that a full cycle is about 22 years. The sunspots are one sign of intensified magnetic activity. Others are a stronger solar wind and a reduction in the influx of cosmic rays reaching the Earth.

Instrumental recordings of cosmic-ray variations started around 1935. The first measurements were done with ion chambers, recording mainly the flux of muons, which are heavy electrons. The muons are responsible for most of the ionization in the lowest part of the atmosphere. The curve in the middle of Figure 3 shows the varying flux of high energy cosmic rays recorded by ion chambers over the period 1937 to 1994. Figure 3 also shows data for 1953 to 1995 from the Climax neutron monitor in Colorado, which measures low energy cosmic rays. For comparison the relative sunspot number is plotted, which follows closely the flux of 10.7 cm radio waves from the Sun.

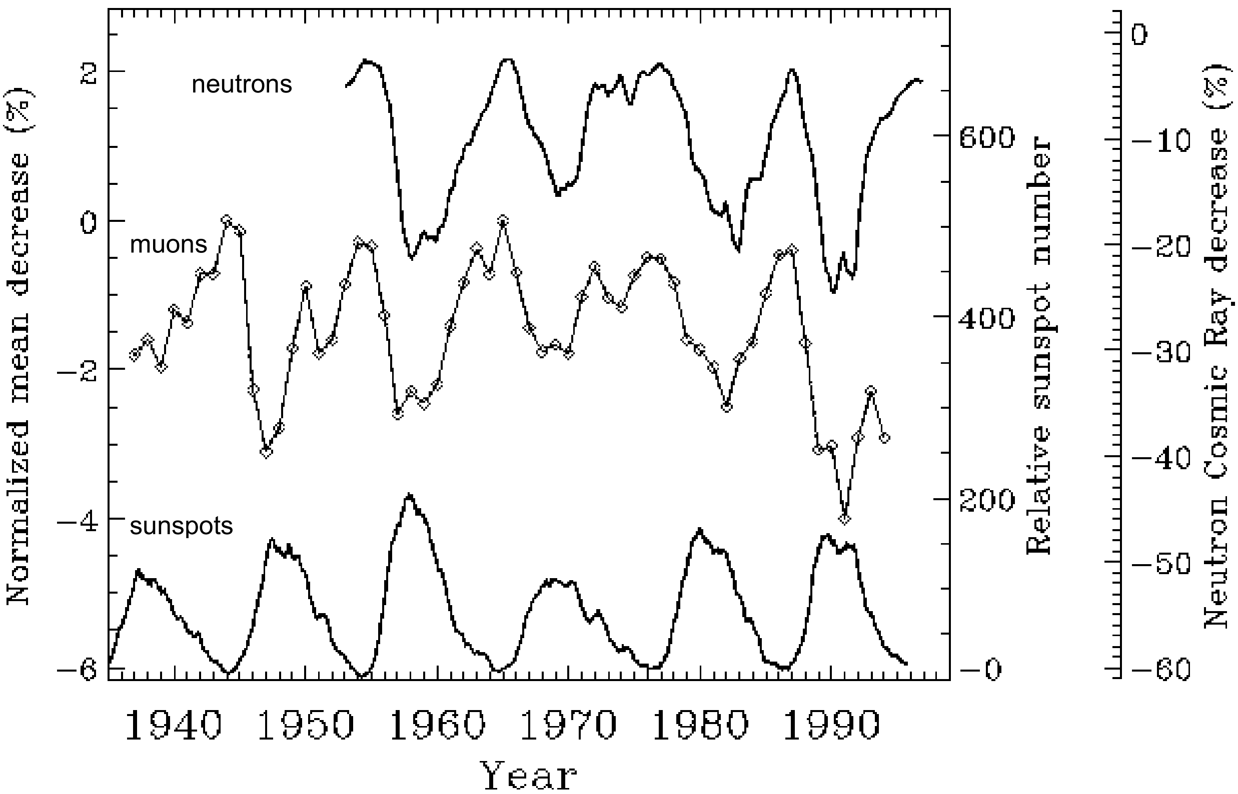

Fig. 3 *Top curve is the cosmic-ray flux from the neutron monitor in Climax, Colorado (1953 - 1996). Middle curve is annual mean variation in cosmic-ray flux as measured by ionization chambers (1937 - 1994). Bottom curve is the relative sunspot number. Even though there is a clear solar cycle modulation of the cosmic-ray flux, the amplitudes are not well correlated.*

Notice that the amplitudes of the solar activity cycle and the amplitudes of cosmic-ray variations are not precisely related. That is fortunate since it allows us to distinguish between effects due to cosmic rays and those due to variations directly linked to the sunspot count.

The influence of cosmic rays on low-altitude clouds

In 1996 we reported at a space science meeting in Birmingham, England, that the Earth's cloudiness, observed by satellites, is strongly correlated with the galactic cosmic-ray flux. Further investigation confirmed that the clouds are clearly linked with cosmic rays rather than with other solar phenomena such as sunspots or the emission of visible light, ultraviolet and X-rays. On closer examination of the satellite data (Figure 4) it turned out that clouds at high and middle altitudes are unaffected by variations in the cosmic rays, but low level clouds are influenced. A simple interpretation is that there are always plenty of cosmic rays high in the air, whatever the Sun does, but they are in short supply at low altitudes, so that increases or decreases due to solar magnetism have important consequences.

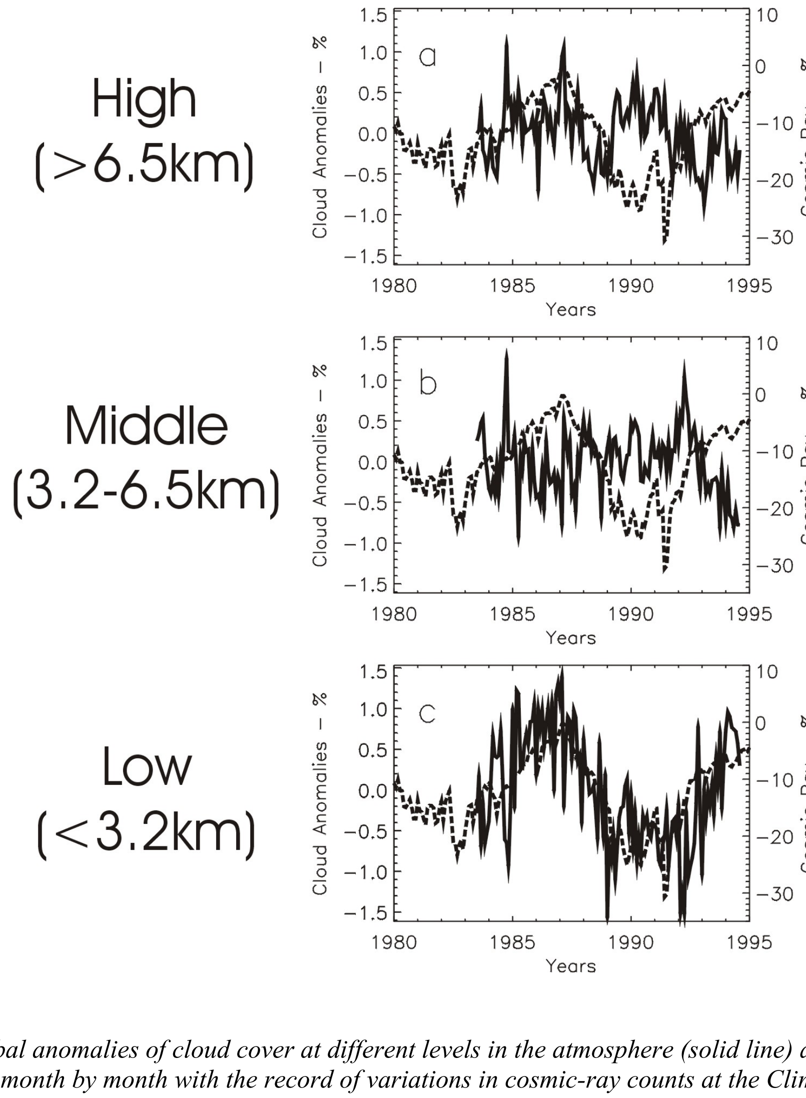

Fig 4 *Global anomalies of cloud cover at different levels in the atmosphere (solid line) are compared month by month with the record of variations in cosmic-ray counts at the Climax station (broken line). While there is no match at the higher altitudes, there is a close correspondence between clouds and cosmic rays low in the atmosphere.*

The climatic significance of this association is that low-level clouds cover more than a quarter of the Earth and exert a strong cooling effect at the surface. (For clouds at higher altitudes there is quite a complicated trade-off between cooling and warming effects.) The 2 % changes in low cloud cover in just 5 years, as seen in Figure 4, should vary the heating at the Earth's surface by an average of about 1.2 watt per square metre. That figure can be compared with about 1.4 watt per square metre estimated by the Intergovernmental Panel on Climate Change for the greenhouse effect of all of the increase in carbon dioxide in the air since the Industrial Revolution.

In 1900 the cosmic rays were generally more intense than now and most of the warming during the 20th Century can be explained by a reduction in low cloud cover. Going back to 1700 and the even higher intensities of cosmic rays, the world must have seemed quite gloomy as well as chilly, with all the extra low-level clouds.

William Herschel, a famous astronomer in England, suggested in 1801 that the price of wheat was high when there were few sunspots. That link is now explained – a shortage of sunspots implies more cosmic rays and cloudy, cool summers. The recent discovery by our team in Copenhagen of the chemical mechanism of cosmic-ray action on cloud formation thus brings to a climax a scientific quest that has lasted two centuries.