Cosmic Radiation and Clouds

Ice cores provide abundant information about past climate changes. They can also provide answers to very specific questions and the means of testing hypotheses. One such hypothesis proposes that climate changes are caused primarily by changes in the intensity of cosmic radiation. If this is correct, it relegates the enhanced greenhouse effect to a secondary role – a politically explosive hypothesis which demands closer analysis.

In 1997, Danish scientists came before the press and announced, not without some pride, that they had found the explanation for the global climate warming that has occurred over the past 150 years [1]. According to them, the decisive role was played neither by the greenhouse effect nor by the solar constant (see lead article on p. 3), but rather by global cloud cover (see box). Their work suggested that cloud formation is affected by cosmic radiation, which underwent a significant decrease during the 20th century. This work found wide public appeal. Newspaper, magazine, and television reports followed the debate blow by blow, and a book on the subject, "The Manic Sun" [2], also appeared. Since the Danish hypothesis presents global climate warming as a natural process, and therefore exonerates humans of any responsibility for it, it was particularly welcome in those circles of industry and politics which are keen to avoid the necessity of implementing any measures to reduce the emission of greenhouse gases. Here, science was challenged, and also EAWAG entered into the fray [3]. Once again climate change demonstrated itself to be a very complex process which resists explanation in terms of a single process. The major potential causes of climate changes are greenhouse gases, solar irradiance, aerosols, volcanic eruptions and internal variations within the climate system. In the following discussion, we focus on the first two of these.

Greenhouse Gases and Solar Radiation

Since about 1850, the temperature in the northern hemisphere has undergone an almost continuous increase (Fig. 1) [4–6]. Among the possible causal factors under discussion for this climate change are the increase in the concentrations of greenhouse gases present in the atmosphere, and variations in solar activity:

■ If we look, for example, at the behaviour of CO_2, a major greenhouse gas, an exponential increase in its concentration has indeed occurred over the past 150 years. This increase has been particularly steep since the middle of the 20th century (Fig. 1). The cause of the exponential increase is generally acknowledged to be the increasing consumption of fossil fuels. Air temperature, on the other hand, fluctuates greatly. Particularly noteworthy are two temperature rises from 1910 to 1940 and from 1970 to the present. Between 1940 and 1970 there was in fact a slight cooling. These fluctuations do not correspond to the exponentially growing CO_2 concentration.

■ As regards solar radiation, satellite measurements made since 1980 show that the radiation intensity is not constant, but rather fluctuates through an 11-year sunspot cycle (see Fig. 1, p. 8). Looking more closely, however, it can be seen that the solar constant of 1366 W/m^2 varies by less than 2 W/m^2 over a sunspot cycle, which is just 0.15 % – too low to explain the observed temperature fluctuations.

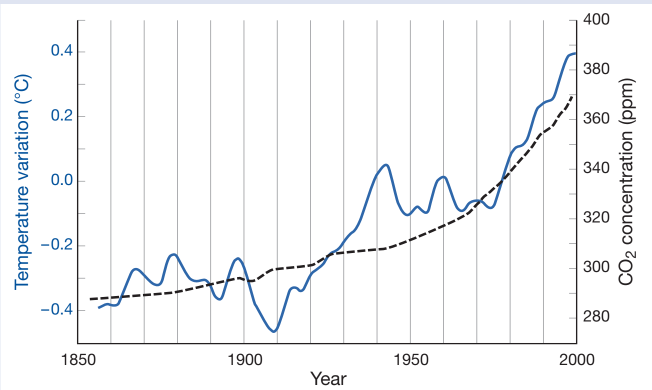

Fig. 1: Comparison of global temperature variations since 1850 (relative to the period 1961–1990) with the concentration of CO_2 in the atmosphere. Temperature curve: average of innumerable measurements from different weather stations [4]. CO_2 curve: data up to 1953 from analyses of air bubbles in the Siple ice core [5]; since 1958 direct CO_2 measurements at Mauna Loa [6]. ppm = parts per million.

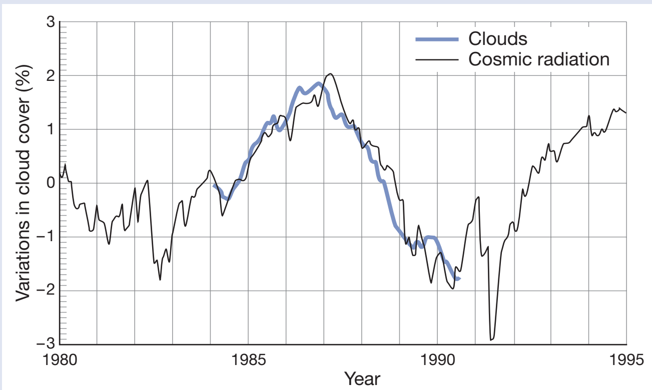

Fig. 2: Cloud cover variations from1980 to 1995, which exceed 2 %, follow the variations in cosmic radiation very well [1]. On the same scale, the 12-month running mean cloud cover (expressed as a percentage change) is plotted against normalized monthly mean measurements of cosmic radiation in Colorado (USA).

Therefore neither of these two factors alone can explain the climate warming. So much for the level of understanding today, with which the Danes are in agreement. But how do the Danes argue further?

Influence of Clouds

The Danish scientists wondered whether the cosmic radiation could have an effect on our climate. According to their idea (see box), the more cosmic radiation that reaches the earth from space, the greater the global cloud cover should be. To test this hypothesis, they examined satellite pictures of the cloud cover from the years 1980 to 1995, and compared them to the intensity of the cosmic radiation. They found that the cloud cover in this period varied by about 2% and followed the variation in cosmic radiation exactly (Fig. 2). Their hypothesis appears to be fundamentally able to explain past observed climate fluctuations. Nevertheless, the work of the Danes stands on wobbly legs, since their data analysis is limited to a tiny time window of only 15 years. To strengthen their hypothesis, it would be necessary to obtain further data on cosmic radiation and climate over the past few hundred or even thousand years. EAWAG has found such additional information in the Greenland ice core.

Weak Cosmic Radiation in the Past 300 Years

If we look back over the past 300 years, we see that the cosmic radiation has in general decreased. On the one hand, we know this from direct measurements of cosmic radiation by neutron monitors which have been operating since the 1950s; on the other hand, we can use radionuclides such as beryllium-10 (^{10}Be) and chlorine-36 (^{36}Cl), which are deposited in Greenland, as indirect parameters for the reconstruction of the cosmic radiation in the past. The reduction in cosmic radiation would seem to be due to increased solar activity (see Figs. 2 and 3, p. 9). According to the Danish hypothesis, one would expect for this period,

Fig 3: Cosmic radiation arrives with high energy from outer space and penetrates the atmosphere, where it collides with the atoms in the air. This produces secondary particles, which in turn collide with other air atoms, splitting them into cosmogenic radionuclides. At the same time the primary and secondary particles ionize the air, so that – according to the Danish hypothesis – more clouds are formed. The above illustration is a montage. It shows at which height in the atmosphere the various processes occur.

The Cloud Hypothesis

The hypothesis of the Danish scientists Svensmark and Friis-Christensen [1] appears simple and enlightening: cosmic radiation – high-energy particles from deep space – penetrates the atmosphere and ionizes the air (Fig. 3). Moisture in the air condenses on these ions to form small water droplets, resulting in cloud formation. The more clouds that are present, the less solar radiation reaches the earth's surface, and temperatures fall. As a corollary to this, it gets warmer if there are fewer clouds in the sky and the sun's rays can reach the earth's surface unhindered.

How much cosmic radiation can reach the earth's atmosphere depends on the interplay of two factors: solar activity and the earth's magnetic field. The sun is continually spewing out glowing gas into space. This gas expands to form the so-called solar wind, and in the process carries with it the sun's magnetic field. The solar magnetic field forms an external protective shield around the earth, which prevents the cosmic radiation from entering the earth's atmosphere (see Fig. 4 on page 5). In addition, the earth's magnetic field provides an internal protective shield, reinforcing the external shield. The more active the sun is and the stronger the magnetic field, the less cosmic radiation enters the earth's atmosphere.

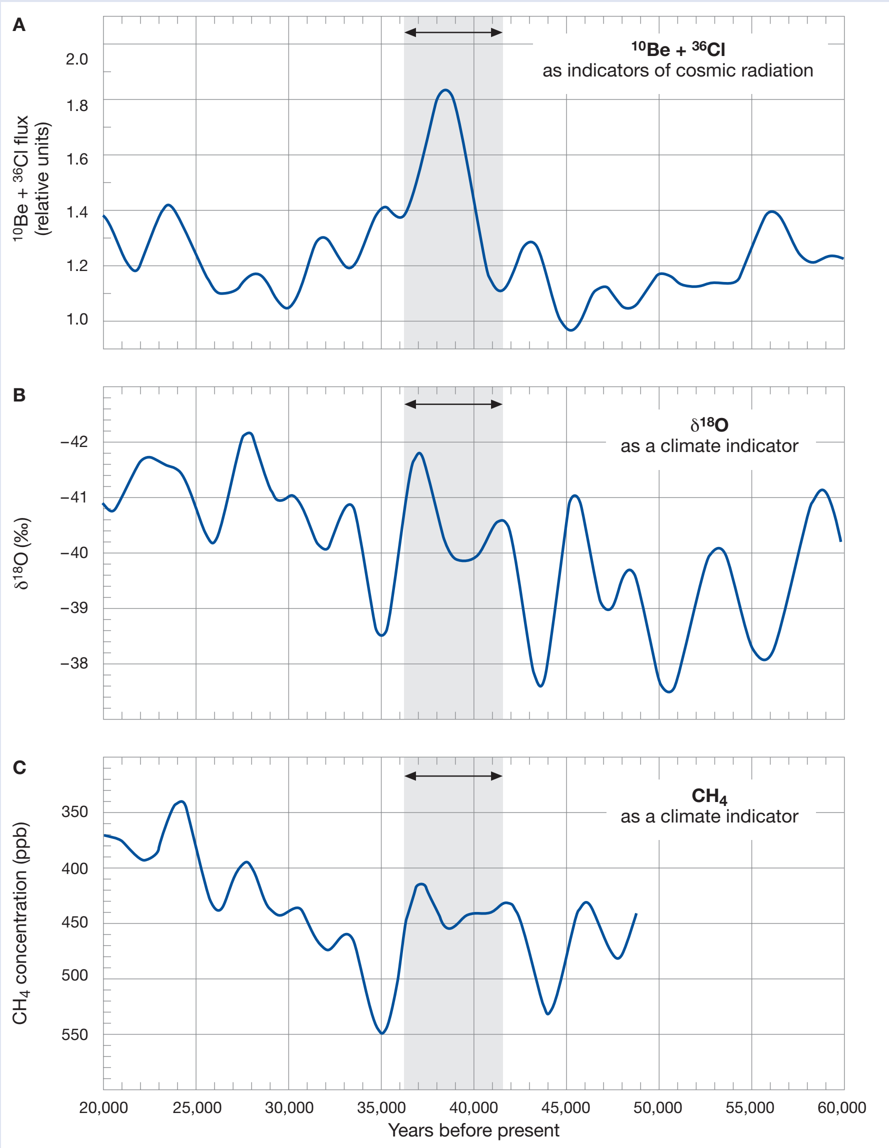

Fig. 4: Comparison of combined ^{10}Be and ^{36}Cl data (A) with the two climate parameters δ^{18}O (B) and CH_4 (C) in the GRIP ice core. Resulting from a weakening of the earth's magnetic field around 40,000 years before present (grey area), the intensity of the cosmic radiation increased, and more ^{10}Be and ^{36}Cl was formed. Contradicting the Danish theory, neither of the climate parameters shows any indication of a climate cooling. The calculated correlation coefficients approach zero. ppb = parts per billion.

with its decreasing intensity of cosmic radiation, a matching decrease in cloud cover, and thereby climate warming. So far so good for the cloud hypothesis.

Strong Cosmic Radiation 40,000 years ago

If we go even further into the past, the situation changes. About 40,000 years ago we find a period of about 3000 years during which the cosmic radiation was relatively strong. During this period the earth suddenly lost its protective shield, and the cosmic radiation penetrated the earth's atmosphere with a considerably increased intensity. The cause lay in the earth's magnetic field, whose intensity at that time had sunk to about 10% of today's value. If the Danish hypothesis is true, the cloud cover in this period should have increased, resulting in a significant climate cooling [3].

Once again the Greenland ice core provides ample information to test this hypothesis. Fig. 4A shows the combined ^{10}Be and ^{36}Cl data. In this figure, a peak around 40,000 years ago springs to the eye. This radionuclide peak meets our expectations exactly, since stronger cosmic radiation increases radionuclide production. At the same time, two climate parameters, δ^{18}O and methane, were measured in the ice core. According to the cloud hypothesis, it should have become significantly colder, so we would expect a clear reduction in δ^{18}O and methane to have occurred during this same period. This is, however, not the case (Figs. 4B and C). The two climate parameters δ^{18}O and methane correspond well with each other, but do not match the ^{10}Be/^{36}Cl curve. Our results clearly contradict the cloud hypothesis. Since all the parameters are measured in the same ice core, this important result does not depend on how well the ice core is dated.

Too Ambitious Interpretations

In the meantime, further disagreements have arisen, in particular with regard to the analysis of the latest cloud data, which no longer follow the cosmic radiation data. At the moment it looks bad for the cloud hypothesis, although the last word has not yet been uttered. Once again it has been made apparent that climate is a complex beast, and that changes in climate cannot be explained in terms of a single, simple mechanism. On the other hand, evidence is mounting that prior to 1970 the sun played a very central role, not in terms of cosmic radiation, but directly, through variations in the intensity of solar radiation (see article by M. Vonmoos, p. 8). The strong warming that has occurred over the past 30 years can nevertheless not be explained by the sun. There is every indication that it is the result of increases in anthropogenic emissions of greenhouse gases. In a few years we will know with certainty, but with no possibility of avoiding the consequences.

Jürg Beer, portrait on p. 5.

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