

JOINT COLLOQUIUM

BACKGROUND FOR A MODEL OF THE NEXT GLACIATION

Professor H. Flohn

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Professor Flohn, formerly head of the German Weather Service's Research Division, and now Ordinarius at the University of Bonn, opened his talk by saying that this was the first occasion on which he had spoken in public on this topic, and that some of his colleagues might look upon him as being a little crazy for doing so at this stage. However, with the accumulation of evidence indicating that there is a finite - if minute - possibility of a new glaciation of the earth being started within the next few hundred years, he felt that it is time for us to give some serious consideration to this possibility and its very serious implications for humankind.

Professor Flohn then discussed the nature of some of this evidence. Recent findings have indicated that both of the last two interglacial periods lasted for approximately ten to fifteen thousand years; also deep-ocean cores have shown that, overall warm periods made up about 10% of recent geological time. Since a glacial period is of the order of a hundred thousand years, this suggests a figure of about ten thousand years for a warm epoch. There is some evidence that both the last two interglacial periods followed a similar pattern of climatic change; a relatively slow warming of the atmosphere, associated with a retreat of the glaciers, followed by a stable period of several thousand years, and finally a very rapid cooling as the ice advances again. Now the present warm epoch has lasted some eleven thousand years, so that if it follows the previous pattern, a relatively rapid return to glaciated conditions could start within the near future (on a geological time-scale).

More evidence is provided by the study of the Greenland ice-core obtained at Camp Century. If the datings of this core were reliable there are indications during the last hundred thousand years of at least two events associated with very rapid global cooling. In each case, an overall temperature decrease of about 4 to 6°C occurred within a time-span of not more than a few hundred years. Further supporting evidence has been provided by study of very large stalactites in caves in Southern France.

Professor Flohn has used a one-dimensional numerical model developed by Manabe *et al* to study the effect of variations of the solar constant, and of the albedo of the earth-atmosphere system, on the equilibrium temperatures at the surface of the earth. By allocating appropriate albedo values to areas of snow, ice, ocean, forest, desert, *etc* Professor Flohn arrived at an overall albedo of 0.14 for the earth, which agrees well with observational estimates. He then computed equilibrium temperatures that might have been expected during the last ice-age, when the ocean level had been lowered approximately 100 metres. If it was assumed that the northern hemisphere sea-ice did not extend far beyond its present limits, the mean equilibrium temperature was 4.7°C lower than the present value; while if it was assumed that the sea-ice extended to 45°N, the corresponding temperature drop was 6.2°C. Thus, while cooling is the cause of glaciation, glaciation is equally a cause of cooling.

Professor Flohn next discussed some previous theories of glaciation. Wilson, using the fact that parts of the Antarctic ice-sheet probably are close to melting-point near the bottom, suggested that ice-ages were triggered-off by large-scale surges of Antarctic ice. Milankovich had proposed that ice-ages are the result of orbital changes with timescales of the order of 40,000 years - however this hypothesis would require alternation of glaciation in the northern and southern hemispheres, and this has not been observed.

A theory of glaciation involving purely geophysical phenomena, and excluding astronomical or extraterrestrial influences, has been developed by Professor Flohn. In this theory, the initiating process is a series of partial surges of the Antarctic ice, mainly in the Ross and Weddell Sea areas. They seem to be a much more likely proposition than the single catastrophic ice-surge of Wilson's theory. H.H. Lamb has suggested that one such partial ice-surge may have occurred last century. There appears to have been a greater ice-cover on the Southern Ocean between 1840 and 1900 than there is now; there is some evidence that temperatures at high southern latitudes were about 5°C lower. It has been estimated that some 100,000 km³ of ice would have been involved in this surge.

If two or three such ice-surges were to occur within a relatively short time, and form a layer of ice about 20 m thick, then about 1,000,000 km² of the ocean surface would be ice-covered. Cooling, resulting from melting of the additional ice, and from the increased albedo of the surface, would produce a drop of about 1°C in the overall equilibrium surface temperature. If a significant fraction of the additional ice melted at latitudes north of the Antarctic Convergence, the cooling would be transferred to the surface layers of the world oceans, and thence, through the action of surface currents, to the equatorial regions. Studies of the heat budget of the eastern Pacific have shown that, in the area of upwelling near the equator, there is a mean *downward* transfer of sensible heat (from the atmosphere to the ocean), and a well-defined evaporation minimum. Assuming that the evaporation rate is proportional to the air-sea temperature difference, a reduction of 0.1°C in the sea-surface temperature leads to a drop of 2.4% in the evaporation *ie*, the evaporative flux is very sensitive to variations in surface temperature. This indicates that an ice-age would be a period of *arid* climatic conditions in continental areas near the equator and there is some evidence which suggests that this was the case during the last ice-age.

An important consequence of a reduction in equatorial sea-surface temperatures would be the accompanying decrease in the overall baroclinicity of the northern hemisphere. The resulting low-index circulation pattern would feature quasi-permanent large-scale troughs, in which cold air would tend to persist for long periods. It seems likely that such synoptic-scale circulation features are necessary for the "nucleation" of a period of glaciation - direct cooling alone would not be sufficient to create a permanent snow cover which would last through the summer months. In low-index situations, troughs are normally found over northeastern North America and eastern Europe, while a warm anticyclone persists in the Alaskan region; this might well explain why northern Labrador and northern Finland, but *not* Alaska, have been regions of nucleation of the northern hemisphere ice-caps, even though all three areas fulfill the other necessary conditions, in that they have considerable areas of elevated land at high latitudes.

The formation of a permanent snow-cover in the vicinity of a quasi-permanent large-scale trough would be assisted by a feedback mechanism, first proposed by C.E.P. Brookes, who pointed out that the existence of a large area of snow at the surface would help to create a lower-troposphere cold pool; migratory cyclones would thus tend to intensify in the area, leading to more snowfalls and probable increase in the snow-cover. This mechanism appears to play a significant role in maintaining extensive snow-covers in Europe during severe winters; but it is not by itself capable of generating a truly permanent snow-cover, unless there is a significant change towards more or less continuous low-index circulation patterns.

Opening the discussion which followed Professor Flohn's address, Mr R. Clarke asked what role does variation in cloud cover play in the process of initiating glaciation. Professor Flohn replied that he had not considered this aspect of the problem in any detail, but agreed with Mr Clarke that cloud cover is an important variable. Mean cloudiness would increase in the vicinity of the quasi-permanent upper troughs, and this would cause significant changes in the energy budget, particularly in higher latitudes. Dr F. Loewe pointed out that the survival of coral reefs in equatorial waters implied that the cooling there must have been less than

5°C in magnitude. Professor Flohn implied that it was not necessary in his model for equatorial water temperatures to fall at any time below 21°C (the survival limit for corals). Dr Loewe asked whether there was any supporting evidence for the rapid changes in the water-levels that must have accompanied glaciation. Professor Flohn pointed out that these changes were "rapid" on a geological time-scale - this means that they took place over a period of the order of a few hundred years, and need not necessarily have been catastrophic. Professor C. Bentley asked how the retreat of the glaciers was envisaged to come about. In reply, Professor Flohn quoted H. Hoinkes, who has suggested that during a continental ice-age, large areas of the northern hemisphere continents lying equatorward of the glaciated region would eventually become extremely arid, and that as a consequence of this the glaciers would become covered with loess during the summer season, resulting in an albedo reduction, and extensive melting. This would occur on the continental ice-caps, but not to any significant extent in Antarctica or Greenland. Dr U. Radok commented that Shumskij's work had highlighted the differences between the controls on the mass-budgets of continental ice-caps and those bordering on oceans.

Dr W. Budd stated that observations had revealed the existence of surges in some small ice-caps, and that surges could occur for different lobes of the same ice-cap at different times. The time-scale of the ice advances was always very short. He queried whether Antarctic ice-surges could have a significant effect on the northern hemisphere circulation. Professor Flohn replied that they could certainly do so, as a result of the action of ocean surface currents. Dr Budd stated that the stability or instability of an ice-cap (*ie*, the nature of the feedback processes, following nucleation) was at present being studied numerically here. Professor Flohn said that he will be attempting a numerical version of his ice age model after he returns to Germany. At this stage, numerical simulation of the real earth is far too complicated a task, but it is hoped that a two-dimensional model (in the meridional plane) will provide useful information.

T.T.G.

