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Energy Balance of the Earth

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In opening his talk, Professor Holopainen from the Department of Meteorology, Helsinki University, pointed out that over the past three decades or so the central thrust in meteorological research has been towards weather forecasting and in this area the important processes in the atmosphere have become increasingly better understood. More recently, the focus has shifted to the climate prediction problem and here we do not know what are the essential counterparts to the basic weather forecasting equations. He saw as a fundamental task the investigation of the energy balance of the earth/atmosphere system. Although some features of this balance have been known for about fifty years, recent satellite data combined with conventional aerological observations have yielded more precise estimates of these, not only of their long-term averages but of their annual cycles.

Professor Holopainen first reviewed the basic concepts of the annual heat budget. The global average of the energy received from the sun at the top of the atmosphere (1/4 × the so called solar constant) is estimated at the 340 wm^{-2} ± 1%. The uncertainties in this basic quantity result from its being measured from within the atmosphere; as well, some workers have suggested that it may vary by as much as 2.5 per cent due to sunspot activity. Part of the solar radiation is reflected, mostly by clouds, and part is absorbed by the earth and re-radiated to space. Although the global average of the sum of the reflected and re-radiated energies must balance the solar input, there is not necessarily a local balance. The surplus at low and deficit at high latitudes result in energy transports and hence the atmospheric circulations and weather. The fluxes of energy were to be the main subject of his lecture.

The speaker went on to outline the classical long-term annual mean radiation budget similar to that proposed by Baur and Philipps in 1935, but with the latest estimates of many of the fluxes. In particular, he noted the steady decrease in estimates of the albedo from about 0.43 in the 1930s to the present satellite-derived values of 0.28.

He then considered the energy balance in a column which included the atmosphere, ocean, ice, and land and deduced the equations of energy balance, which involved the vertical fluxes through the top and bottom of the atmospheric section of column, storage in the atmosphere, ocean, ice, and land, and horizontal fluxes in the atmosphere and ocean. If we had sufficiently detailed global atmospheric and oceanic observations we would be in a position to determine how the energy balance is maintained. However, such data are not available; especially poorly known are the oceanic fluxes.

Professor Holopainen introduced the concepts of 'required' and 'observed' horizontal fluxes. The former, which came first in the meteorological literature, and are still all we have for the oceans, can be deduced from a knowledge of heat sources and sinks, while the observed fluxes can be calculated from a knowledge of the distributions of temperatures, pressure, and moisture. For the oceans, the critical factor is the downward energy flux (the sum of the radiation, latent heat, and sensible heat fluxes) at the surface and here the speaker paid tribute to the climatological atlases of Budyko and co-workers. He then outlined the picture in the late 1960s of the contributions by the atmosphere and the oceans

to the mean annual required poleward energy fluxes in the ocean-atmosphere system and pointed out that the mid-latitude flux maxima were about 500 times man's energy production. Fair agreement was demonstrated between the required and observed atmospheric fluxes over the northern hemisphere.

Moving to the more recent estimates using satellite measurements of fluxes, Prof. Holopainen first briefly outlined the difficulties involved in interpreting and correcting the data and then presented the latest picture of the annual mean transports. Especially significant is the greater role of the oceanic heat fluxes than was previously believed. He then showed the annual cycle of the net incoming radiation, rates of heat storage in oceans and atmosphere, and horizontal fluxes in atmosphere and oceans, the latter being found as residual. Definite cross equatorial transports from the summer to the winter hemisphere were evident, especially in the oceans. Both oceans and atmosphere were important in the horizontal exchanges but in different latitudes; in the middle latitudes a type of handover appears to occur from one to the other.

The geographical variations in the mean annual net radiation were illustrated using data from the Numbus 3 satellite. These showed net radiation deficits over many continental regions and surpluses over oceans. It is important that aerological data be used to investigate the reasons for these anomalies and discover how the ocean-to-continent flux occurs. The speaker contrasted the results derived for the net radiation from satellite measurements with those obtained by Simpson almost fifty years ago using surface temperature and cloud data and assumed stratospheric temperatures. Overall, the early estimates stood up remarkably well, although there were marked differences in some areas, especially over the continents.

Looking to the future, Prof. Holopainen suggested that the First GARP Global Experiment may, for the first time, allow estimates of the ocean fluxes in the southern hemisphere to be deduced. These would have to be estimated as residuals as he believed data would be insufficient in either hemisphere to allow calculations of observed oceanic fluxes for some considerable time. He also stressed the importance of the study of aperiodic fluctuations and the exchanges between the atmosphere and oceans to the understanding of climate.

P.G.P.