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*Report*

# Summit Greenland environment observatory

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***Abstract:*** A new movement to establish a permanent environment observatory at Summit in Greenland is under way between US and Europe. The initial motivation was to observe exchange processes between the atmosphere and the ice sheet surface to obtain the basic knowledge for the ice-core interpretation. It was, however, soon recognised that the objective necessitated the observations not only on the ice sheet surface, but also for the entire atmosphere including the middle atmosphere and the thermosphere. It became also obvious that the near-surface snow and firn layer should be investigated. To reach the goal the observations should be carried out year-round for a number of years. By the beginning of 1996 the idea was developed to establish an observatory for the integrated environment observation. As the first step a feasibility study for over-wintering at Summit was carried out during the 1997/1998 season with a four-man team. The project started its first year's operation in April 2000 and expects to carry out proposed observations for at least three years, until the final decision is made regarding the precise nature of the "permanent" observatory. The entire observation programme is multi-disciplinary. The author has been participating in the planning of the observatory from the start of the project. The present article was prepared to present an overview of the planned activities at the prospective observatory with emphasis on the field which the author has been primarily engaged in.

## 1. Introduction

Summit of Greenland is the region around the highest point on the Greenland ice sheet. During the summers from 1989 to 1993 Summit was a place of intensive ice-core boring activities. During those years two sites were drilled: GISP2 (72°35′N, 38°30′W, 3150 m a.s.l.) and GRIP (72°35′N, 37°39′W, 3230 m a.s.l.). The high-resolution history of the climate and atmospheric chemistry is being published (Dansgaard *et al.*, 1993; GRIP members, 1993). In the course of the core interpretation, however, a number of uncertainties were encountered. To decode the information archived in the ice cores, it has become necessary to understand the transfer processes of various matters between the atmosphere, the snow cover and firn layers. The initiative for the year-round observation at Summit came from the ice-core community. The other research disciplines joined the ice-core group to observe practically the entire environment in support of the core interpretation and also to pursue goals that can best be observed at this site. The old GISP2 drilling site was augmented to make the year-round observations possible.

## 2. Planned observations

The site of Summit is unique because of the high altitude in the high latitude regions of the Northern Hemisphere. The site is the third highest point within the Arctic Circle only after Gunnbjørns Fjeld (3700 m a.s.l.) and Mont Forel (3360 m a.s.l.). Because of the relatively low altitude of the tropopause in the Arctic the altitude of Summit represents the middle troposphere. The year-round dryness of the atmosphere, homogeneous nature of the snow surface and the large distances from anthropogenic emissions offer a unique opportunity to make various observations which are not possible at lower altitudes in the Arctic. The proposed observations are conceived to take advantage of the conditions prevailing at this site. The observations are grouped in the following themes:

1) Ice-core interpretation and tropospheric chemistry,
2) Energy balance and boundary layer processes,
3) Stratospheric physics and chemistry,
4) Atmospheric electricity,
5) Polar aeronomy and space sciences, and
6) Seismology and geodesy.

In view of the initial motivation of the project, the tropospheric chemistry has a considerable weight in the entire programme. The working process of the core-analyses is a kind of inversion to arrive at the boundary conditions (atmospheric time-series) starting from the solutions (cores). In this working procedure one traces back the natural processes in the opposite direction from how they happened. To proceed in this manner, it is necessary to understand each steps in the normal flow of natural processes, starting with the astronomical and atmospheric processes, covering the snow formation in the atmosphere, the surface deposition and the sintering process in the interior of the ice sheet. Tropospheric chemistry and boundary layer investigations must no doubt occupy the central position in this work. These investigations must be supported by the upper atmosphere studies on nuclear reactions, ionisation and photochemical reactions. Transfer processes from these layers to the ice sheet surface and subsequent transformations have also an important weight in the present programme. To obtain solid answers, the observations must be carried out year-round and over many years. Detailed observations will be carried out on the processes of the molecular-level integration of the atmospheric constituencies in the snow cover, including the snowfall, deposition and sublimation. Gas-phase measurements will include ozone, hydrocarbons, halocarbons and radon (Dibb, 1998). Further, aerosols and their ionic compounds will be considered (Bales, 1999). Besides obtaining a firm basis for chronological dating of ice-cores, it is believed that some of these components will help the core-analysts trace back the origins of air masses, providing hints on the paleo-atmospheric circulation and insights on human influence on the global atmosphere.

## 3. Energy balance and boundary layer processes

The author had the responsibility for formulating the European programme for investigating the ice sheet surface and atmospheric exchange processes. From the viewpoint of the primary objective of the ice-core interpretation, it is obvious that the goal can not be achieved if the observation remains in the framework of conventional micrometeorology by observing only surface fluxes. The surface exchange must be understood in relation to large-scale atmospheric processes. This standpoint compels us to investigate the transport processes throughout the entire boundary layer by observations. Further, the results must be condensed in such a manner that they can be used to support the GCM-based numerical experiments. As a result the observation of the entire boundary layer combined with modern radiometry is proposed.

*3.1. Boundary layer under stable conditions*

The fluxes of various atmospheric characteristics are the result of the interaction of the atmosphere with the surface. Therefore, the processes in the entire boundary layer must be investigated in addition to the measurements of the consequences of the interaction. This is the basic frame of the experimental programme of the present study and aims at improving knowledge in the least understood regions in micrometeorology; namely the exchange processes in the stable atmosphere near the earth's surface. The investigation of the boundary layer under a stable stratification has been hindered by the fetch-effect that can survive over many kilometres. In the normally accessible areas it is not easy to gain ideal topographic conditions which satisfy the observational requirements for investigating the stable boundary layer. The area around Summit is one of the rare regions in the world that can be regarded as an ideal laboratory for experiments on the stable boundary layer. Firstly, the fetch is practically unlimited. Secondly, the surface is extremely homogenous, and thirdly high stability occurs frequently. From the wind-profile measurements of previous experiments on the Greenland ice sheet, the thickness of the planetary boundary layer is estimated to fluctuate between 200 m and 500 m above the surface (Ohmura, 1992; Ohmura *et al*., 1994; Forrer and Rotach, 1997; Forrer, 1999). Within this layer and often within the lower half of the planetary boundary layer a thermocline appears which has a profound effect on the turbulent fluxes on the surface and the internal waves above the thermocline. Within the surface boundary layer turbulent fluxes and irradiances seem to be no longer constant. The divergences of sensible heat flux and radiative flux are, however, closely related. To grasp all these processes, the site will be equipped with a 50 m meteorological tower with 8 levels instrumented with sonic anemo-thermometers and Ly-$\alpha$ hygrometers, radiometers for radiative flux divergence measurement, a SODAR for continuous measurement of the height of the inversion, a wind-profiler which reaches up to 3000 m, a radio-sonde system and an aircraft equipped with the turbulence measuring system. Reliable turbulence measurements must be supported by high quality radiation data.

*3.2. Radiation observation*

Radiometry at Summit has three objectives that can be achieved on a medium time scale, that is, several years. The first objective is to provide accurate broad band irradiances to close the energy balance of the surface flux observations mentioned in the previous section. The second objective is to investigate the radiative characteristics of the atmosphere at a site with relatively small water vapour content and small amounts of low and middle clouds (Konzelmann and Ohmura, 1995). The third objective is the observation of the radiative divergence in the boundary layer to investigate its relationship with sensible heat flux. The atmospheric conditions at Summit are ideally suited for investigating the missing absorption of solar radiation and also for observing radiative characteristics of the cirro-type cloud layers. The vast surface area with a homogenous snow cover helps accurate divergence measurements of radiative fluxes. To fulfil the accuracy requirements for these purposes, it was decided to adopt the scheme proposed for the Baseline Surface Radiation Network (BSRN) of the World Climate Research Programme (WCRP) (Ohmura *et al.*, 1998).

## 4. Long-term monitoring of atmospheric radiation

One of the most important goals in climate research is climate prediction. Presently, climate predictions are mostly based on models. In view of the possibility of grave economic and political influences of climate predictions, the prediction should not be based only on one method. The risk of all models committing the same error is too high. It is necessary to develop another climate prediction method that is independent of the model-based prediction method. This redundant prediction scheme is an added security, in case one of the above mentioned methods fails. The prediction of a natural phenomenon is possible in principle, if the precursor is detected early enough for organising response strategies. Such a prediction scheme must identify the very beginning of the processes which ultimately causes the phenomenon which we wish to predict. One example in other areas of earth science is the prediction of tsunamis by detecting the initiating earthquake. Another example in the climate system is the prediction of ENSO by knowing the start of the

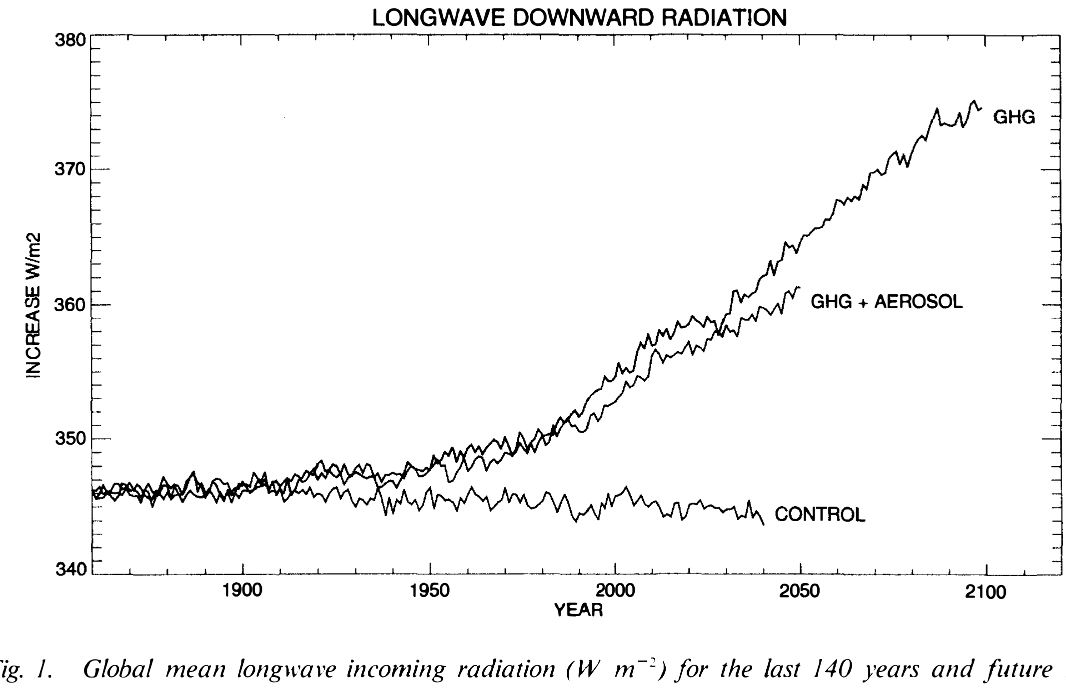


*Fig. 1. Global mean longwave incoming radiation (W $m^{-2}$) for the last 140 years and future 100 years. The computation was made with ECHAM4/OPY3 T42 transient experiment based on the observed gas concentrations for 1860–1990. The future concentration is due to scenario IS92a. GHG denotes the scenario with only greenhouse gases. GHG + AEROSOL indicates the development with additional direct and indirect aerosol effect ($SO_2$) plus tropospheric ozone (Roeckner et al., 1999).*

eastward movement of the warm water body in the tropical west Pacific.

In the case of climate change in the immediate future, it is envisaged that the enhanced greenhouse effect will become in due time powerful enough to dominate other climate factors. The enhanced greenhouse effect begins with an increase in longwave incoming radiation at the earth's surface. The author proposes to use the long-term monitoring of the longwave incoming radiation at the earth's surface as a means for predicting the onset of the greenhouse climate change. Figure 1 shows the simulated course of the global mean longwave incoming radiation for the next 100 years with ECHAM4 T42 coupled transient experiment, based on the scenario IS92a, carried out by Roeckner *et al.* (1999). The average rate of the IR increase is 2 W $m^{-2}$ per decade. The increasing rate shows considerable regional variation. Figure 2 shows the global distribution of the increase in IR radiation, indicating the larger IR increase for the regions with smaller amounts of low and middle clouds. They are the desert and Polar regions of high altitudes. The site of Summit falls in such a fortunate spot on the Greenland ice sheet, indicating a 5 W $m^{-2}$ change per decade. A zone of relatively large increase is seen over the sub-arctic oceans. This increase, however, is mainly caused by the temperature increase as the result of the recession of the sea-ice margins, and is outside the present consideration. Given the presently available accuracy of the longwave measurement of 3 W $m^{-2}$ (Philipona *et al.*, 1995; Ohmura *et al.*, 1998), it must be possible to detect a systematic increase in longwave atmospheric radiation in about a decade or two at the location of Summit. This early detection of climate changes with the

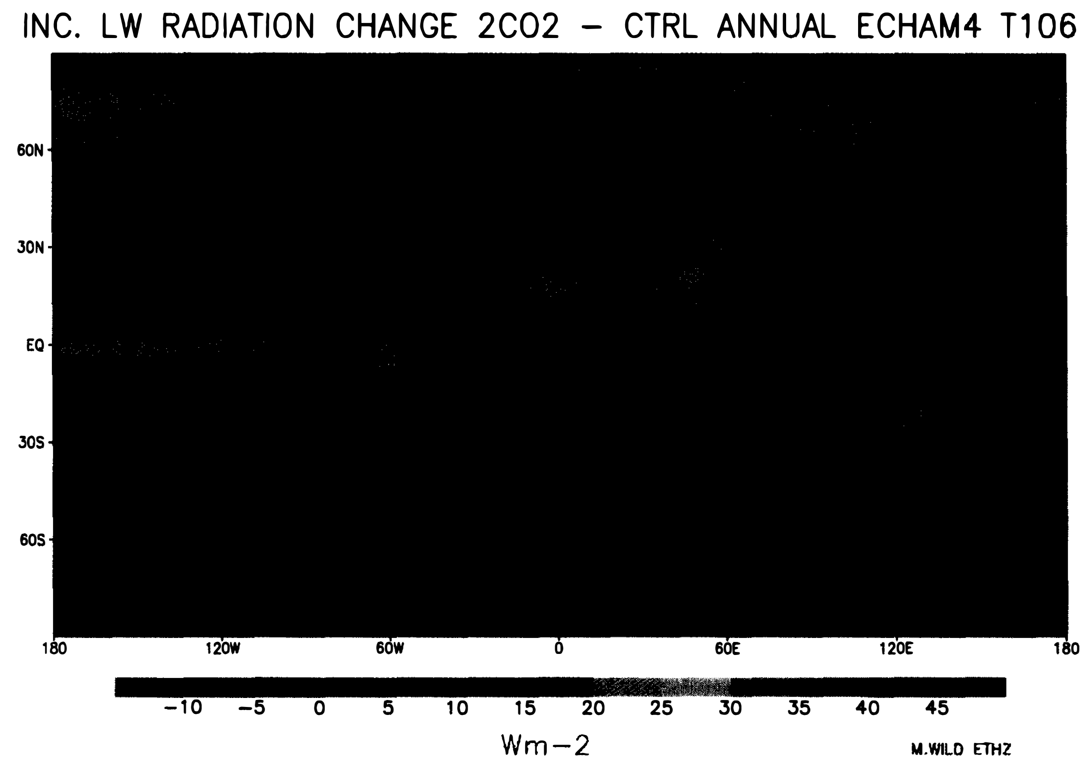


*Fig. 2. Expected increase in annual mean longwave incoming radiation for the last decade in 21st century in W $m^{-2}$ (based on the same experiment as in Fig. 1).*

IR-monitoring is expected to happen at least one decade prior to the possible detection of the subsequent rise in air temperature. This fortunate delay in the temperature response is partly due to the storage of heat in the climate system, especially in oceans. The main reason for the early detection of a climate change from radiation rather than air temperature is, however, due to an extremely small year to year variation in longwave incoming radiation, which makes it easier to detect a long-term trend.

Besides longwave observations, the site will be equipped with instruments for all other shortwave and longwave components, including the Precision Filter Radiometer. This instrument will measure the change in aerosol optical depth for direct solar radiation. This measurement is meant to numerically evaluate the change in the direct aerosol effect, which could counter the enhanced greenhouse effect.

## 5. Closing remarks

The proposed Summit Greenland Environment Observatory offers a unique platform for environment observations, which are not possible in other regions of the Northern Hemisphere. It is especially suited for detecting long-term variation in radiation fields, which may cause climate changes. The activities at the observatory also provide an opportunity for cross-Atlantic co-operation which has proven to be a fruitful stimulation not only for scientific advancement but for training young scientists to understand different ways of thinking and behaviour between the similar but by now different cultures.

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