



Max-Planck-Institut  
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## REPORT No. 90

Proceedings  
of the  
Workshop on

**NEW GENERATION OF RADIATION BUDGET  
MEASUREMENTS FROM SPACE  
AND THEIR USE IN CLIMATE MODELLING AND  
DIAGNOSTIC STUDIES**

by

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HAMBURG, SEPTEMBER 1992

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ISSN 0937-1060

Proceedings  
of the  
Workshop on

**New Generation of Radiation Budget  
Measurements from Space  
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Diagnostic Studies**

at the

Max-Planck-Institute für Meteorology

11 June 1992

Edited by L. Dümenil, MPI Hamburg

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This publication contains a collection of abstracts of papers which were presented at the workshop on "New Generation of Radiation Budget Measurements from Space and their use in Climate Modelling and Diagnostic Studies" jointly organized by the GKSS Forschungszentrum in Geesthacht and the Max-Planck-Institute for Meteorology in Hamburg. The workshop was held at the Max-Planck-Institute on 11 June 1992. Its aim was to bring together the research teams that are involved in the provision of satellite data from the **ScaRaB project** and **potential users of these data** in the climate modelling community.

A continuation of space borne measurements of the planetary radiation budget is required in order to investigate the role of clouds and radiation within the climate system. Highly accurate measurements provided by the American ERBE (Earth Radiation Budget Experiment, 1984-87) have proven to be excellent tools for the validation of climate model simulations. Some of the experience that was gained with this data set will be reported in this volume.

It is proposed to employ a new radiation budget instrument ScaRaB, to continue the monitoring of the required quantities from 1993 onwards. The instrument is being built jointly by French, Russian and German groups. In the initial stage, two satellite launches have been confirmed for the autumn 1993 and 1994 on a Russian satellite. Negotiations are underway concerning the payload on the European satellite POEM.

The ScaRaB project is envisaged to fill the data gap in the medium term before further instruments become available around the year 2000 and will help to improve our knowledge of radiative and cloud processes.

1 September 1992

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## Satellite measurements of radiation budget parameters

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### 1. Introduction

The new radiometer ScaRaB (Scanner for Radiation Budget) a joint French-Russian-German project, continues a time series of satellite-borne measurements of the earth's radiation which began with earliest attempts in 1959 and culminated in 1984 to 1990 with ERBE, a three-satellite project. The first ScaRaB-instrument will be launched in fall 1993 onboard of a Russian satellite METEOR 3, the second will follow one year later. Negotiations are now in preparation to fly ScaRaB also onboard the European platform POEM (1998).

Possibly since the ERBE-data were available to the scientific community and since climate and circulation models were more advanced the radiation budget data found wider use, than only for the diagnostics of the earth's radiation budget fields and its temporal changes. The measurements of ScaRaB and later also of the American instrument CERES are expected to continue this evolution of data uses to inspect

- the performance of numerical models for calculations of the present climate over periods of more than 10 years (Sun's cycle),
- the role of all cloud fields and of surface properties in the earth's energy budget components and in particular on the Greenhouse-effect,
- possible variations and trends in the earth's climate system.

These data are now even used to support the initialization of operational weather forecast models. However, in all these and further applications and uses of measurements of the planetary radiation budget, it should not be overseen that their value increases with the availability and uses of other worldwide data containing further informations on the state of various components in our climate system.

Therefore, the success of our efforts within the WCRP and its many subprogrammes, such as GEWEX and WOCE, etc., depends strongly on the accessibility of all these data for the individual researcher. Fortunately the technology provides us means for easy data handling. However, we should also not overlook the need for greatest care to calibrate and validate such data.

### 2. A few historical remarks

Analyses of the earth's radiative energy exchange with space reach back to the last century, when astronomers began to study the energy budgets of all planets. These are all based on climatological data on temperatures and clouds (summaries are given by *Raschke, 1972 ; Kandel, 1983 and in various textbooks*), of which a simple

picture A. Wegener drew in his textbook on "The thermodynamics of the atmosphere" in 1911. These climatological studies, of which some are listed in Table 1, ended possibly with *Katayama's* (1967) thorough analyses. There are now numerous investigations of the radiation budget at the earth's surface over several regions.

*Danjon* (1936) has been possibly one of the first using "remote sensing techniques", when he derived from a number of measurements of the earth's "Gegenschein" on the lunar surface the planetary albedo. *Suomi* (1959) installed onboard the satellite Explorer 7 first spherical radiometers (simple black and white spheres!) to obtain measurements. Later satellite techniques became more complicated, but also more accurate. We should also mention an attempt, to derive the radiation budget from measurements of the radiation pressure on a satellite containing a very sensitive accelerometer.

The development of a stable broad-band radiometer and the use of angular- and spectral correction models, and further the availability of informations on the temporal variability of radiation measured from space brought a major breakthrough to establish longer time series with accuracies, as required for the modern climate research (see for instance report series for GARP and the WCRP).

### 3. A few remarks on sampling problems

Measurements of the upward flux density seem to be simply suited for global analyses. However, their spatial and temporal sampling cause complex smoothing which diminishes considerably their accuracy and interpretation. Therefore, they will be stopped now. Radiance data, as measured for instance with a spatial resolution of 50 km, require on the other side complex inversions with respect to

- spectrally insufficient response of the sensor system,
- angular dependence of outgoing radiation streams,
- areal inhomogeneities (space averaging), and
- time variations of radiation fields.

These are described in detail in the papers by *Diekmann and Smith* (1989) and *Rieland and Raschke*, 1991.

These are all interlinked by their dependence on the observed scenes with their different spectral, angular and temporal characteristics. With the help of additional informations - e.g. derived from other satellite data - these deficiencies could be overcome in part in the analyses of ERBE data (e.g. *Barkstrom et al.*, 1989). The ScaRaB will diminish such possible error sources, since it contains two additional channels for more accurate scene identification.

### 4. Why further measurements of the planetary radiation budget with ScaRaB ?

It is clear that modern climate research requires accurate data on the earth's radiation budget at the top of the atmosphere, at ground and within the atmosphere (vertical flux divergence). They are required to understand energy exchanges and their forcings by circulation systems over periods of more than several years. Further they

should match with same quantities and their variations which are computed for the present climate with numerical models. All these can now also in principle be derived from the basic spectral data sets collected within the ISCCP (International Satellite Cloud Climatology Project) and its supporting subprojects. However, an extremely well calibrated broad-band radiometer, such as the **ScaRaB**, allows to link (and calibrate) these data with absolute radiation standards and, thus, ensures highest consistence in longer data series. Therefore, the WCRP supports strongly such measurements for the next decades despite of the funding needs for other experiments.

## 5. A few numbers

In Fig. 1 (from *Peixoto and Oort, 1987*) we show a summary of the relative partition of energy fluxes in the climate system, where the Sun is the only source. Its annual global irradiance as received on earth amounts to  $342 \text{ Wm}^{-2}$ , of which about 30 % ( $\sim 103 \text{ Wm}^{-2}$ ) is reflected back to space. The earth emits itself about  $239 \text{ Wm}^{-2}$  (in the average). For global studies these values must be known within limits of  $\pm 1$  to  $2 \text{ Wm}^{-2}$ . Regional studies with resolutions of about 200 km and 1 month require somewhat less accurate numbers ( $10 - 15 \text{ Wm}^{-2}$ ), where however, the variance of the net radiation above the tropics is of the same magnitude. Such high accuracies can now be achieved only with specially designed radiation budget instruments in space and the analyses supporting data.

The ScaRaB is built to serve this purpose!

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# THE ATMOSPHERIC HEAT ENGINE

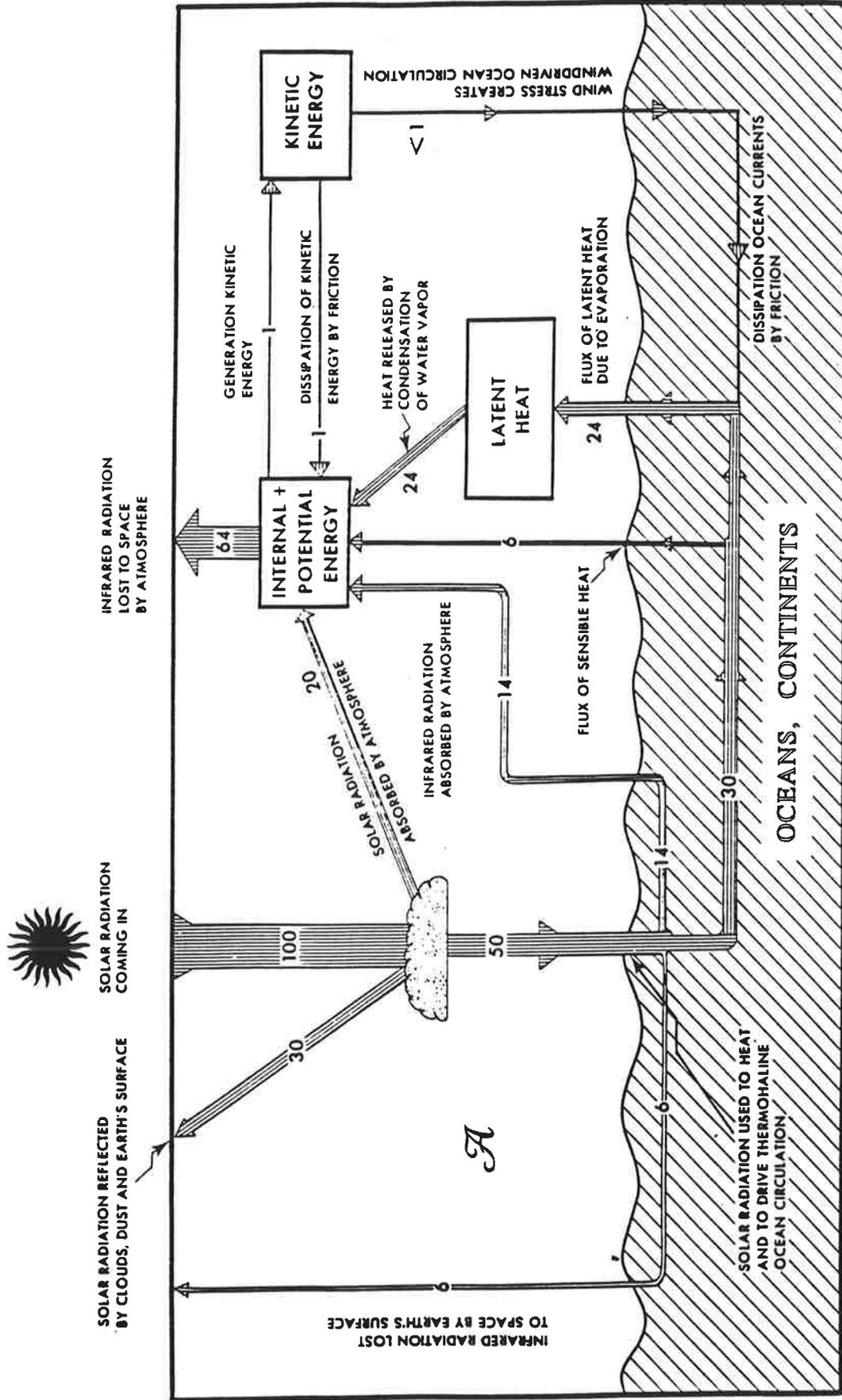


Fig. 1: Radiation budget and latent heat release by clouds in the global energy cycle - expressed in relative units of solar irradiance (from Peixoto and Oort, 1983).

## ScaRaB and its Subsystems

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### Abstract

The technical aspects of the ScaRaB radiometer are briefly described. The instrument measures the radiance at the top of atmosphere in four channels (visible, solar, total, atmospheric window). The resolution is  $48 \times 48$  mrad. Lamps and blackbodies are used for on-board calibration. These sources are calibrated themselves on ground before launch.

### 1 The Platform

The METEOR3 is an operational Russian weather satellite. The orbit has an inclination of approximately  $82^\circ$  and a mean orbital altitude of 1200 km above sea level. The time period for one orbit is about 102 minutes. The satellite orbit is not sun synchronous. It covers a full day cycle within 70 days.

The platform is three-axis-stabilized with an accuracy of  $0.5^\circ$ . There are two stations for data reception: Lannion in France and Obninsk in Russia (*Kandel, 1991*).

### 2 The Radiometer

The ScaRaB radiometer consists of four parallel telescopes. These are identical except for the optical filters. Each telescope represents one spectral channel: visible, solar, total and atmospheric window (Table 1). The ERB parameters are derived from the measurements of the total and solar channel. The visible channel and the atmospheric window are used for scene identification which is needed in the data inversion procedures.

The telescopes are located in a cylindrical drum, the scan head, that rotates around its axis. The outer hull of the scan head has openings for the earth view and the sources. The optics consist of only one spherical mirror for each channel. The detector is located in the center of the ring-shaped entrance aperture (Figure 1). This design allows rather flat spectral responses of the channels (Figure 2) as well as an insensitivity to polarization which is an advantage of symmetry of the telescope.

The optical filters are fitted between the spherical choppers and the telescope (Figure 1). The thermal radiation of the filters is not modulated and therefore, it does not disturb the measurements. For calibration and test purposes, a filter wheel allows the movement of additional filters in front of the solar and total channel (C2, C3). Table 2 gives a survey of the ScaRaB system (*Monge et al., 1991*).

### 3 Calibration

Pyroelectric detectors are not stable. Temperature has a large influence on their sensitivity. Therefore, an on-board calibration is necessary during the experiment. For this purpose, various calibration sources are available. Table 3 shows the purposes of the various sources. The chosen procedure allows cross checks between different sources.

Calibration lamps  $L_{22}$  and  $L_{23}$  consist of tungsten filament lamps. Their light is distributed by an optical fiber on the solar and total channel (C2, C3). Each channel receives light from all lamps so that a possible degradation will affect both channels to the same extent. This allows a calibration of solar channel by the means of blackbody  $B_3$  via the total channel.

Calibration lamps  $L_{12}$ ,  $L_{32}$  and  $L_{33}$  are used for test purposes and stability checks. These sources consist of filament lamps too. The visible channel is calibrated once a month by  $L_{11}$ . These rare occasions are acceptable because this channel is used for scene identification only.

The thermal channels will be calibrated with blackbody-simulators of 310 K temperature.

Space provides a dark reference for total and the window channel (C3, C4). The blackened instrument cover is dark reference for the visible and solar channel (C1, C2) (Leroy, 1992).

All on-board sources have to be calibrated themselves before launch. The basic idea of a ground calibration is to use the ScaRaB instrument as a transfer-radiometer. The ScaRaB instrument is calibrated by the means of a ground based standard. Then the on-board sources are calibrated by the means of the ScaRaB instrument. The ScaRaB instrument is considered to be stable because both the measurement of the on-board source and the ground standard source are performed nearly simultaneously.

The blackbody simulators will be calibrated in a vacuum chamber provided by France. Standard sources are a set of calibrated cavity radiators developed in Germany. The cavity sources allow a link to the international temperature standard ITS90.

The lamps will be calibrated by the means of a reference diffusor that is illuminated by the sun. The incoming solar flux is measured by a calibrated pyrhelimeter. The actual solar spectrum is monitored by a spectrometer. This calibration facility is now under construction in Germany. The pyrhelimeter is a link to the world radiance reference WRR (Mueller, 1991). The calibration will be performed at the Kiepenheuer Observatory on Tenerife in February 1993.

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## 5 Tables

No	channel	spectral range		filter
1	visible	0.5 – 0.7	$\mu\text{m}$	interference
2	solar	0.2 – 4	$\mu\text{m}$	fused silica
3	total	0.2 – 50	$\mu\text{m}$	none
4	atm. window	10.5 – 12.5	$\mu\text{m}$	interference

Table 1: Spectral channels of ScaRaB

No. of Channels (Table 1)		4
Dynamic Range	solar	up to $425 \text{ W m}^{-2} \text{ sr}^{-1}$
	total	up to $500 \text{ W m}^{-2} \text{ sr}^{-1}$
Instantaneous Field of View (square)		$48 \times 48 \text{ mrad}^2$
	at nadir	$60 \times 60 \text{ km}^2$
Scan Angle		$100^\circ$
Pixels / Scan		51
Sampling Interval		34 mrad
Sampling Period		62.5 ms
Scan Period		6 s
Usefull Scan Time		3.18 s
Relative Accuracy		$\pm 0.25 \text{ W m}^{-2} \text{ sr}^{-1}$
NER (total channel)	(measured on TM)	$0.1 \text{ W m}^{-2} \text{ sr}^{-1}$
	(expected for FM1)	$0.07 \text{ W m}^{-2} \text{ sr}^{-1}$
Mass		40 kg
Power		42 W
Size		$614 \times 512 \times 320 \text{ mm}$

Table 2: Survey of the Characteristics of ScaRaB

No	channel	usage:	1/1 month	1/ 12 hours	1/ 20 minutes	continuous
1	visible		$L_{11}$			
2	solar		$L_{32}$	$L_{12}$	$L_{22}$	
3	total		$L_{33}$		$L_{23}$	$B_3$
4	atm. window					$B_4$

Table 3: On-board Calibration Sources for ScaRaB. (Nomenclature:  $L$  = lamp, subscript = (number of lamp set, number of channel);  $B$  = blackbody Simulator, subscript = number of channel)

6 Figures

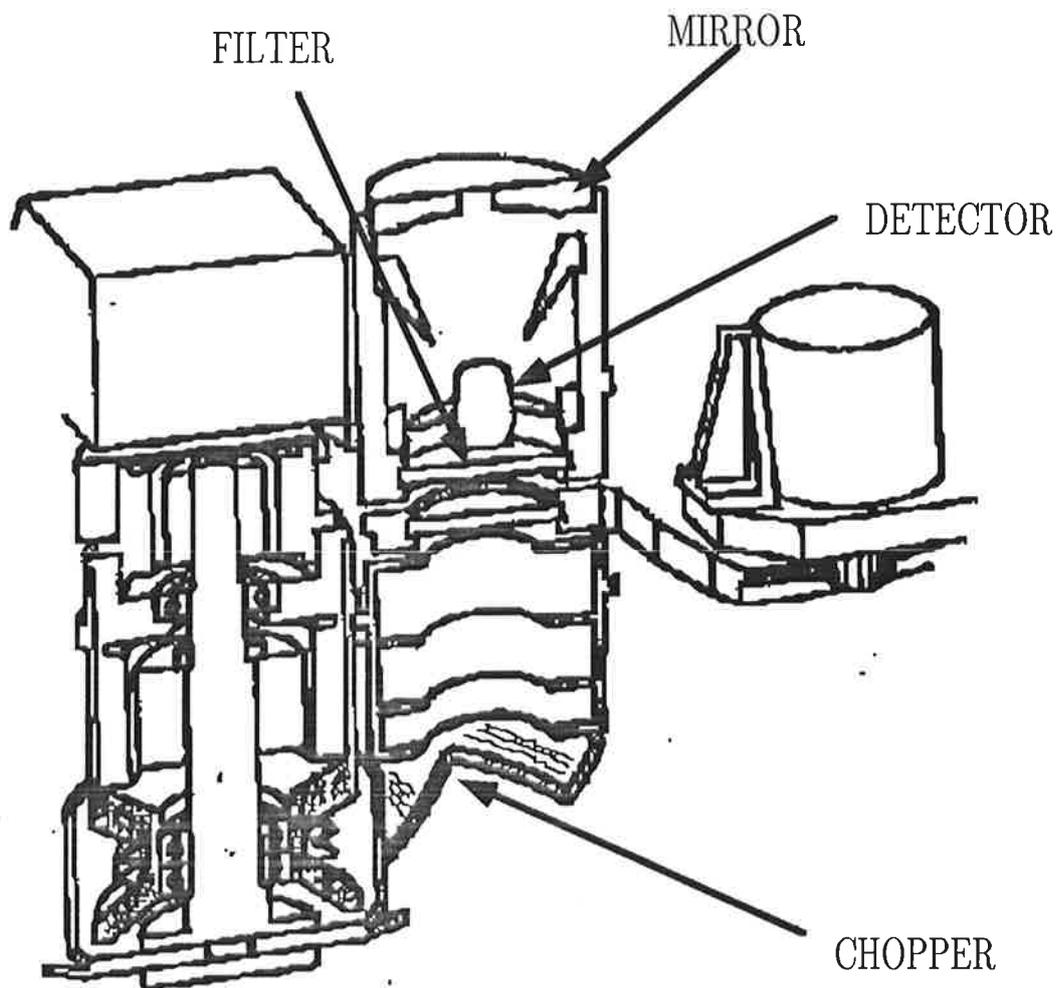


Figure 1: The Telescopes.

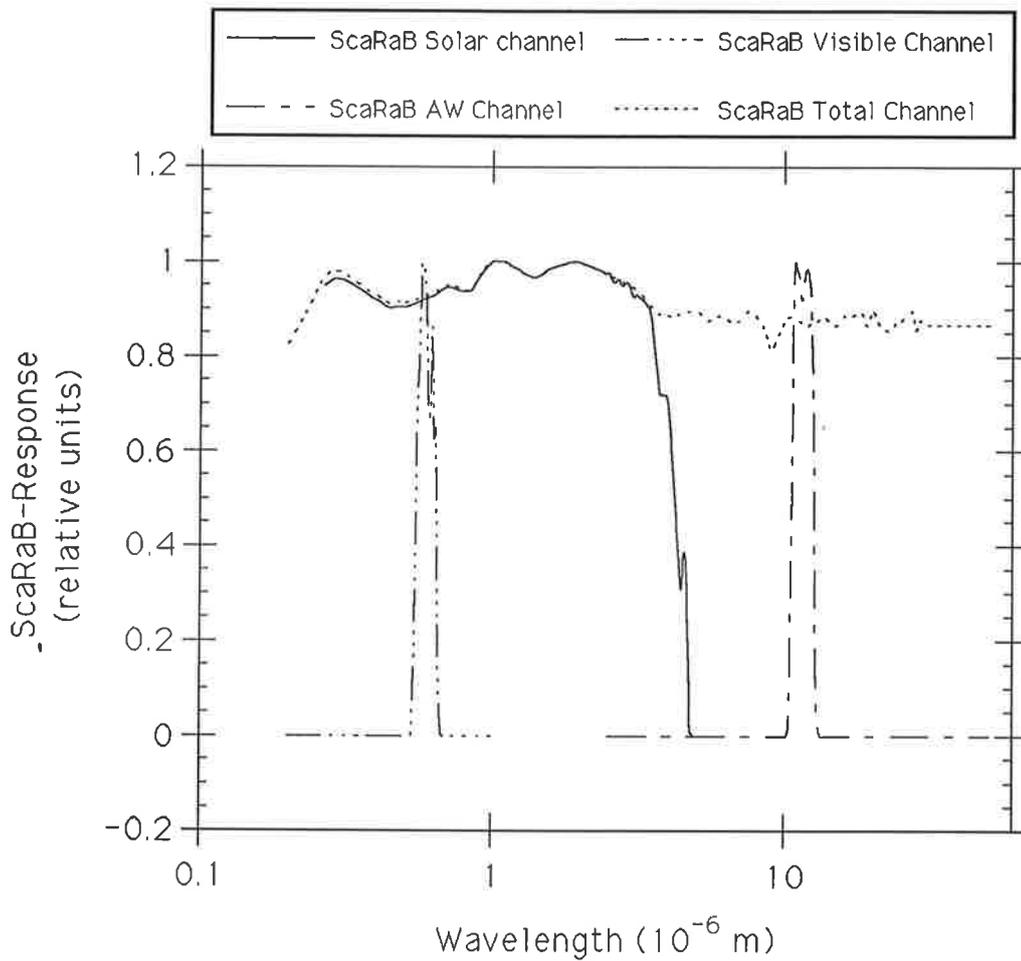


Figure 2: The Spectral Response of ScaRaB Channels in Arbitrary Units.

## The use of ERBE data for climate studies

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The shortwave radiation budget of the earth/atmosphere system is influenced by the amount of solar radiation incident at the top of the atmosphere, the clouds (amount, type), the state of the atmosphere, and the spectral surface reflectance. In this study we focus our discussion on the contribution of clouds to the shortwave radiation budget. To do so, we apply the concept of 'cloud radiative forcing' to different satellite data sets to estimate the cloud forcing on the absorbed shortwave radiation at the top of the atmosphere, the surface, and within the atmosphere itself. All calculations for the top of the atmosphere are based entirely on measurements of the Earth Radiation Budget Experiment. For the radiation budget at the surface, the incoming solar radiation at the surface is derived from METEOSAT data and the surface albedo is calculated from ERBE clear sky planetary albedo measurements by applying an atmospheric correction scheme. The results may be summarized as follows:

The absorption of solar radiation at the top of the atmosphere and at the surface is greatly affected by clouds. The cloud forcing terms for both, the top of the atmosphere ( $CF_{TOA}$ ) and the surface ( $CF_{SUR}$ ), are well correlated ( $R = 0.95$ ) and show almost the same magnitudes. The correlation with cloud amount for both is 0.83. We could show, that for regions of a small solar insolation (large solar zenith angles) the cloud forcing at the top of the atmosphere,  $CF_{TOA}$ , is (slightly) larger than that at the surface  $CF_{SUR}$ , while the opposite was found for regions of a larger solar insolation (small solar zenith angles). As a result we conclude, that for the same increase in cloudiness the absorption of solar radiation at the surface is more reduced in the Tropics than in the Midlatitudes. This finding is in agreement with the results of *Ramanathan and Collins (1991)* for the thermodynamic regulation of ocean warming by thick high level cirrus clouds. An increase in convective cloudiness over the tropical oceans, having cloud tops at high atmospheric levels, should lead to a remarkable reduction of solar radiation to be absorbed at the ocean surface.

The atmospheric cloud forcing,  $CF_{ATM}$ , is calculated as the difference between  $CF_{TOA}$  and  $CF_{SUR}$ . This atmospheric cloud forcing is about one order of magnitude less in comparison to those at the top and the surface, and is not very highly correlated with the mean cloud cover ( $R=0.37$ ). For example, the largest solar absorption in the atmosphere is located in regions of low cloudiness above the high reflecting surface of the Sahara. In contrast, the smallest solar absorption within the same latitudinal belt

is located in regions of maximum cloudiness above the dark ocean surface. As a result we conclude, that the influence of clouds on solar absorption in the atmosphere is not determined by the cloud properties alone, but in combination with the spectral surface reflectance properties.

We tried also to investigate the dependence of cloud forcing on different cloud types, characterized by low, middle, and high level clouds as identified by ISCCP. But, the amount of data was not sufficient to derive any statistics to specify such significant influences. We were only able to study the cloud forcing as a function of the total cloud amount in more detail for ocean regions. Here clouds tend to increase the shortwave absorption in the atmosphere, especially for high solar insolation and overcast conditions. For lower solar insolation, e.g. for the Midlatitudes, the contribution by clouds is generally small and could change sign, which means that only under these conditions could clouds cool the total atmospheric column.

In Table 1 the global shortwave radiation budget has been assessed. Based only on the satellite retrievals discussed above, we calculate the shortwave radiation budget for our area of investigation,  $\pm 60^\circ$  longitude and latitude, as presented in Table 3 and summarized below.

For our investigation we calculate the cloud forcing terms to be  $CF_{TOA} = 50 \pm 4 \text{ Wm}^{-2}$  at the top of the atmosphere,  $CF_{SUR} = 55 \pm 6 \text{ Wm}^{-2}$  at the surface, and  $CF_{ATM} = -5 \pm 10 \text{ Wm}^{-2}$  for the atmosphere. Thus, compared to a cloud free atmosphere, the annual mean cloudiness, as it was present in our area of investigation, reduces the absorption of solar radiation for the total earth/atmosphere system by about 16 %, and for the surface by about 2 - 5 %. On the contrary, for the atmosphere itself this cloudiness increases the solar absorption by about 6 %, compared to that of a cloud free atmosphere.

The contribution of clouds to the absorption of solar radiation in the atmosphere, as specified by several other investigators, was given at the beginning of our paper to be 2 - 5 %. To compare our satellite based result of the atmospheric cloud forcing,  $CF_{ATM}$ , with these previous estimates on absorption of solar radiation in the atmosphere by clouds, we relate  $CF_{ATM}$  to the annual averaged solar insolation  $\langle I \rangle = 354 \text{ Wm}^{-2}$  for the area of our investigation.

We calculate a value of 1.4 % as the mean cloud contribution on the absorption of solar radiation in the atmosphere, which is slightly lower than the previous estimates. From the error assessment we deduce the range of uncertainty for this cloud absorption to be -1.4 % to +4.2 %. From these findings we conclude that the clouds' contribution to the solar absorption within the atmosphere is positive but small. An increase in amount of high level clouds, in particular if it occurs in the Tropics, will force this positive contribution by clouds to zero.

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Incoming Solar Radiation $342\text{Wm}^{-2}$
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	SW Absorption	SW Reflection
Top of the atmosphere	$237\text{Wm}^{-2}$	$105\text{Wm}^{-2}$
Atmosphere	$68\text{Wm}^{-2}$	$84\text{Wm}^{-2}$
Surface	$169\text{Wm}^{-2}$	$21\text{Wm}^{-2}$

**Tab.1** Global estimates of the shortwave radiation buget at the top of the atmosphere, the atmosphere and the surface (Ramanathan et al., 1989).

	Regional $2.5^{\circ} \times 2.5^{\circ}$ monthly averages	Regional $2.5^{\circ} \times 2.5^{\circ}$ annual averages	'Global' ( $\pm 60^{\circ}$ ) annual averages
$\Delta A_{\text{TOA}}$ $\Delta A^{\circ}_{\text{TOA}}$	$8(2)\text{Wm}^{-2}$ $2(2)\text{Wm}^{-2}$	$4(2)\text{Wm}^{-2}$ $2(2)\text{Wm}^{-2}$	$2(2)\text{Wm}^{-2}$ $2(2)\text{Wm}^{-2}$
$\Delta A_{\text{SUR}}$ $\Delta A^{\circ}_{\text{SUR}}$	$15(3)\text{Wm}^{-2}$ $15(3)\text{Wm}^{-2}$	$7(3)\text{Wm}^{-2}$ $7(3)\text{Wm}^{-2}$	$3(3)\text{Wm}^{-2}$ $3(3)\text{Wm}^{-2}$
$\Delta A_{\text{ATM}}$	$19(5)\text{Wm}^{-2}$	$9(5)\text{Wm}^{-2}$	$5(5)\text{Wm}^{-2}$
$\Delta \text{CF}_{\text{TOA}}$		$6(4)\text{Wm}^{-2}$	$4(4)\text{Wm}^{-2}$
$\Delta \text{CF}_{\text{SUR}}$		$11(6)\text{Wm}^{-2}$	$6(6)\text{Wm}^{-2}$
$\Delta \text{CF}_{\text{ATM}}$		$15(10)\text{Wm}^{-2}$	$10(10)\text{Wm}^{-2}$

**Tab.2** Error assesment of the absorbed solar radiation,  $\Delta A$ , and the shortwave cloud forcing,  $\Delta \text{CF}$ . The numbers in parentheses indicate the magnitude of the systematic part of the error. The indices TOA, SUR, ATM are for top of the atmosphere, surface, and atmosphere. The additional index,  $^{\circ}$ , specifies the uncertainties for the clear sky earth/atmosphere system. 'Global' average means averaged within the field of view of METEOSAT,  $\pm 60^{\circ}$  longitude and latitude.

Incoming Solar Radiation	$354\text{Wm}^{-2}$
Planetary Albedo	28%
Clear Sky Planetary Albedo	14%
Surface Albedo	12%
Cloud Cover	62%

	SW all sky absorption	SW clear sky absorption	cloud forcing SW	cloud forcing/ clear sky absorption
TOA	$255\text{Wm}^{-2}$	$305\text{Wm}^{-2}$	$50\text{Wm}^{-2}$	16%
ATM	$87\text{Wm}^{-2}$	$82\text{Wm}^{-2}$	$-5\text{Wm}^{-2}$	-6%
SUR	$168\text{Wm}^{-2}$	$223\text{Wm}^{-2}$	$55\text{Wm}^{-2}$	25%

**Tab.3** Shortwave radiation budget and cloud forcing at the top of the atmosphere, TOA, the atmosphere, ATM, and the surface, SUR, estimated from satellite data for the METEOSAT area,  $\pm 60^\circ$  longitude, latitude.

## Satellite validation of GCM-simulated annual cycle of the Earth radiation budget and cloud forcing

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Earth Radiation Budget Experiment (ERBE) data are used to validate radiative fluxes and cloud radiative forcing simulated by the LMD GCM. We consider first regional and zonal distribution of actual and clear-sky fluxes to validate the general description of the Earth radiation budget of the model. Part of the article is nevertheless dedicated to the development of some tests to get more significant elements of comparison between models and observations. These tests are applied to the actual radiation budget but also to the clear-sky fluxes and to the Cloud Radiative Forcing (CRF).

An important task for the validation of the CRF described by a model is to test the consistency between the solar of shortwave (SW: 0.2 to 5  $\mu\text{m}$ ) and longwave (LW: 5 to 50  $\mu\text{m}$ ) cloud forcing. This is done here by computing the mean cloud perturbation of the planetary albedo as a function of the LW cloud forcing for both model results and ERBE observations.

Concerning the seasonal variations in the SW spectral domain, the consideration of total SW fluxes does not provide very constraining elements of validation because most of the observed variations is prescribed (incoming solar radiation, solar zenith angle). We therefore distinguish the part of the SW seasonal variation related only to the insolation from the part which arises from the combined variation of internal climate parameters (mainly cloud albedo and snow/ice cover) with the insolation. Fourier analysis is used to study the amplitude and the phase of the seasonal variation of the CRF.

Main results are as follows:

- 1) Comparison of annual zonal averages of the radiative fluxes shows that the cloud radiative forcing is overestimated in the model. There also are disagreements related to a shift of the main convergence zones in the tropics and to the absence of boundary layer stratiform clouds in subtropical and polar regions.
- 2) Compared to observations, the cloud albedo perturbation simulated by the model is too large relative to the cloud longwave forcing. This is suspected to be mostly attributable to the parameterization of the cloud droplet size distribution.

- 3) Analysis of the seasonal variation of clear-sky fluxes shows a too persistent simulated snow/ice cover in the model.
- 4) The observed seasonal variation of both albedo and LW cloud forcing essentially reflects the seasonal migration of large cloud systems (ITCZ and mid-latitudes baroclinic activity). The seasonal variation of the cloudiness is approximately in (out of) phase with the insolation in low and high latitudes (mid-latitudes). As a result, the seasonal variation of the cloudiness reduces (enhances) the seasonal amplitude of the absorbed SW flux in low and high latitude (mid-latitudes). The LMD GCM reproduces quite well these relative seasonal phases but fails in reproducing the seasonal amplitudes.

Finally, we show that the seasonal variation of the cloudiness has a relatively weak impact on the variation of the net CRF ( $< 10 \text{ W m}^{-2}$ ).

## THE SEASONAL VARIATION OF THE CLOUD RADIATIVE FORCING: COMPARISON OF ECHAM MODEL SIMULATIONS WITH ERBE DATA

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The third-generation atmospheric GCM ECHAM3 which has been developed from an earlier version of the ECMWF medium range weather forecast model is used for studying the impact of clouds on the radiation budget at the top of the atmosphere. The horizontal resolution is T42 (corresponding to a Gaussian grid of approximately  $2.8^\circ$ ), and there are 19 layers in the vertical.

The model was forced with observed sea surface temperatures between 1979 and 1988 so that there is a four-year overlap with ERBE data (1985-1988). Results are presented for one year (Feb. 1985 to Jan. 1986) for which scanner measurements made by the ERBS and NOAA9 satellites are available.

According to Fig. 1, there is generally good agreement between the simulated and observed zonal-mean cloud forcing for 1985. The near-cancellation of SWCF (top) and LWCF (middle) in the tropics is well simulated. In the middle latitudes the LWCF is systematically too small in the simulation.

The seasonal variation of the zonal mean errors of the cloud forcing for 1985 are shown in Fig. 2. The errors are generally smaller than the uncertainties of the ERBE data of about  $10 \text{ Wm}^2$ . The largest errors are found in the shortwave component at mid-latitudes during summer, when the (negative) SWCF is underestimated by more than  $20 \text{ Wm}^{-2}$  in the zonal mean (observed  $-100$  and simulated  $-80 \text{ Wm}^{-2}$ , respectively).

The ERBE data can also be used to study the cloud variations due to internal temperature variations such as the El Nino Southern Oscillation cycle (ENSO) or the seasonal cycle. Fig. 3 shows the response of the cloud forcing to seasonal temperature variations for July 1985. The shortwave component (top) has a warming tendency (relative to the annual mean) in the mid-latitudes of the Northern Hemisphere (summer) and a weak cooling in the Southern Hemisphere (winter). These changes are related to changes of cloud cover (reduction in summer), cloud height (cloud top higher in summer), and cloud optical properties. In the tropics, the changes associated with the seasonal shift of the ITCZ are larger in the model than in the observations. The longwave component (middle) which has the opposite sign is generally smaller than the shortwave component and the latter determines the sign of the net effect (bottom) in most parts of the globe. In July, the model and ERBE indicate a warming of the summer hemisphere relative to the annual mean, but the model shows a different behaviour in the tropics. Here, the albedo change associated with the seasonal shift of the ITCZ is obviously too large in the model.

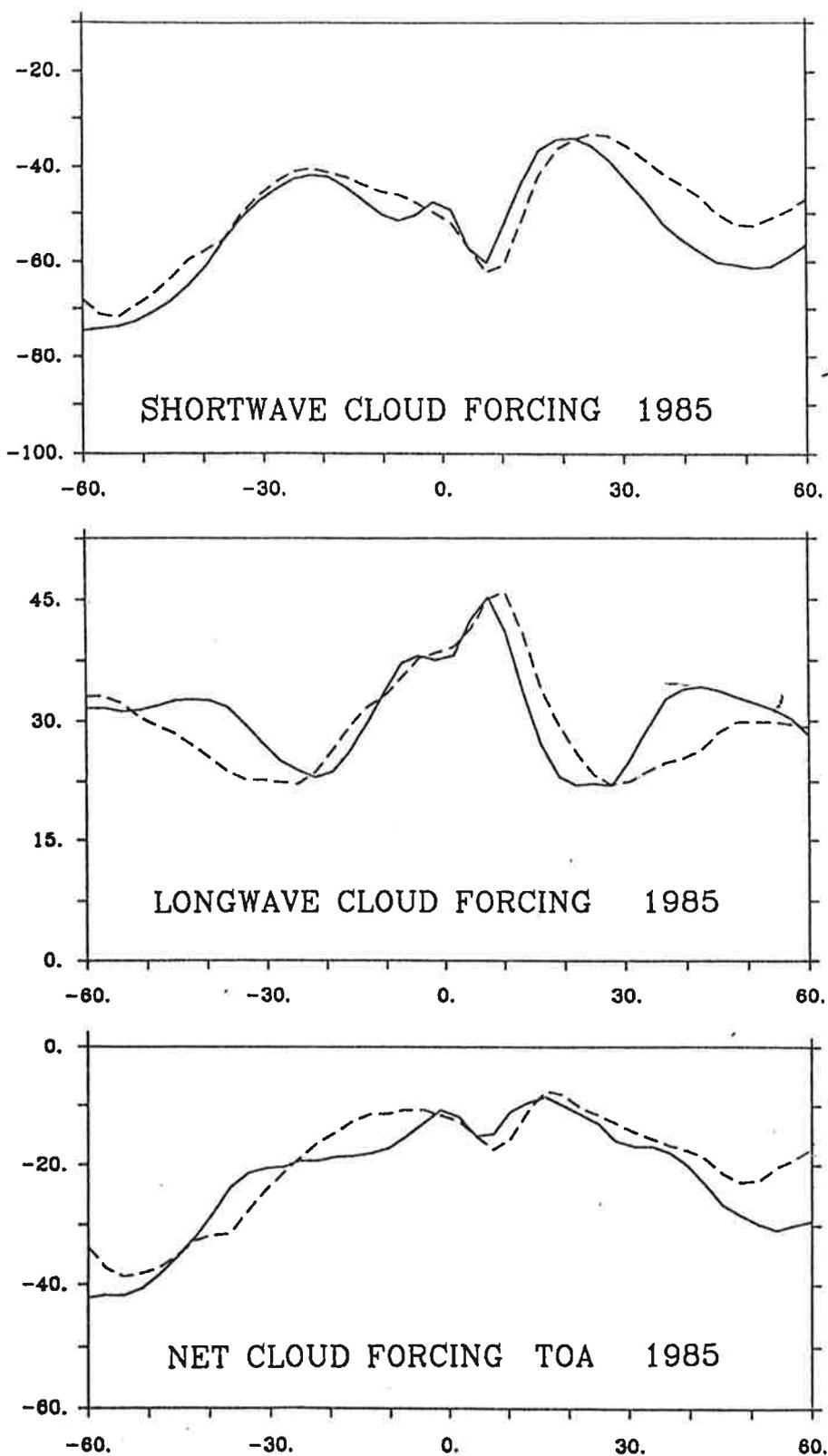


Figure 1 Annual zonal mean cloud forcing between 60°S and 60°, as simulated by the ECHAM3/T42 model (dashed) and as analysed from ERBE data (full). Units are  $\text{Wm}^{-2}$ .

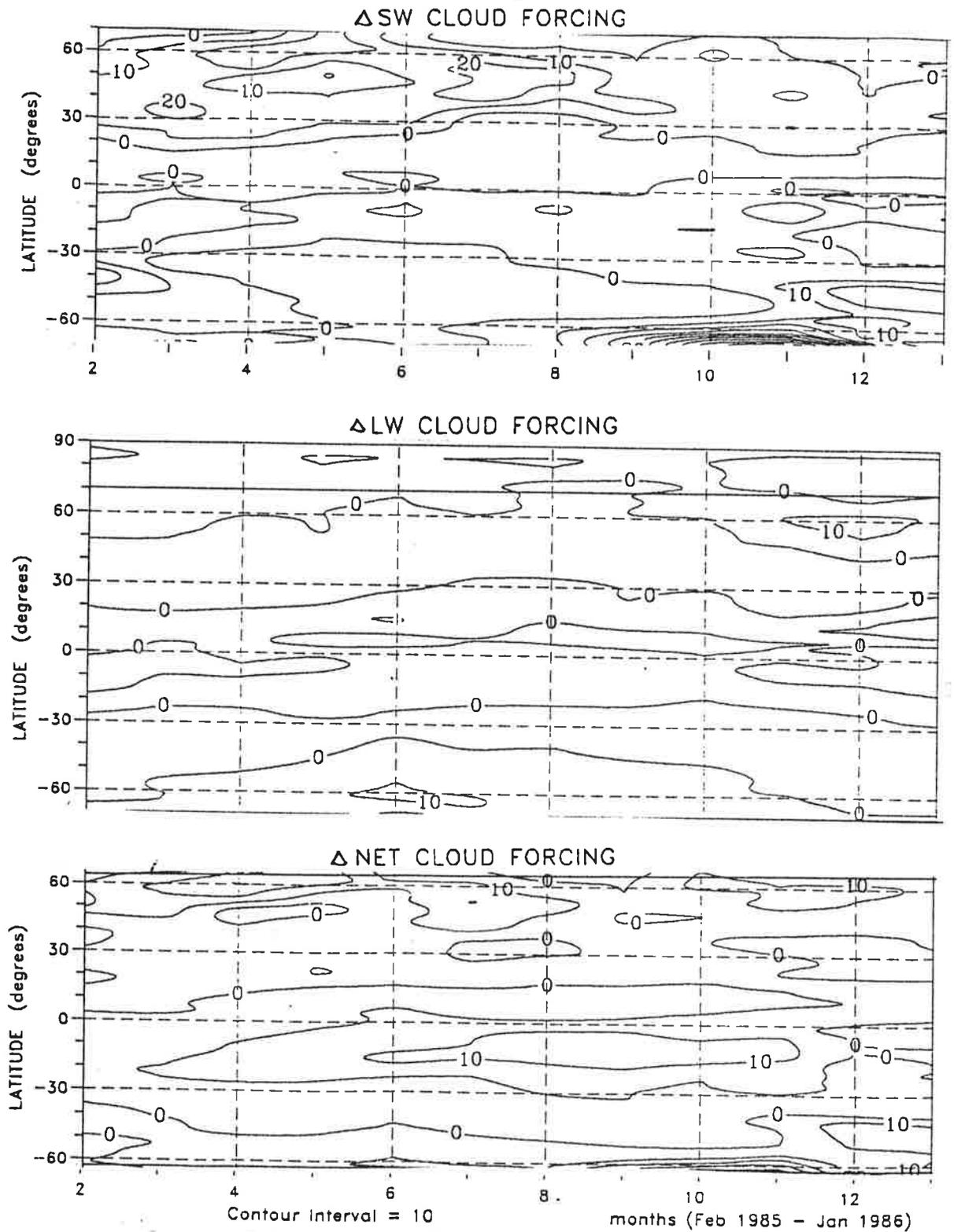
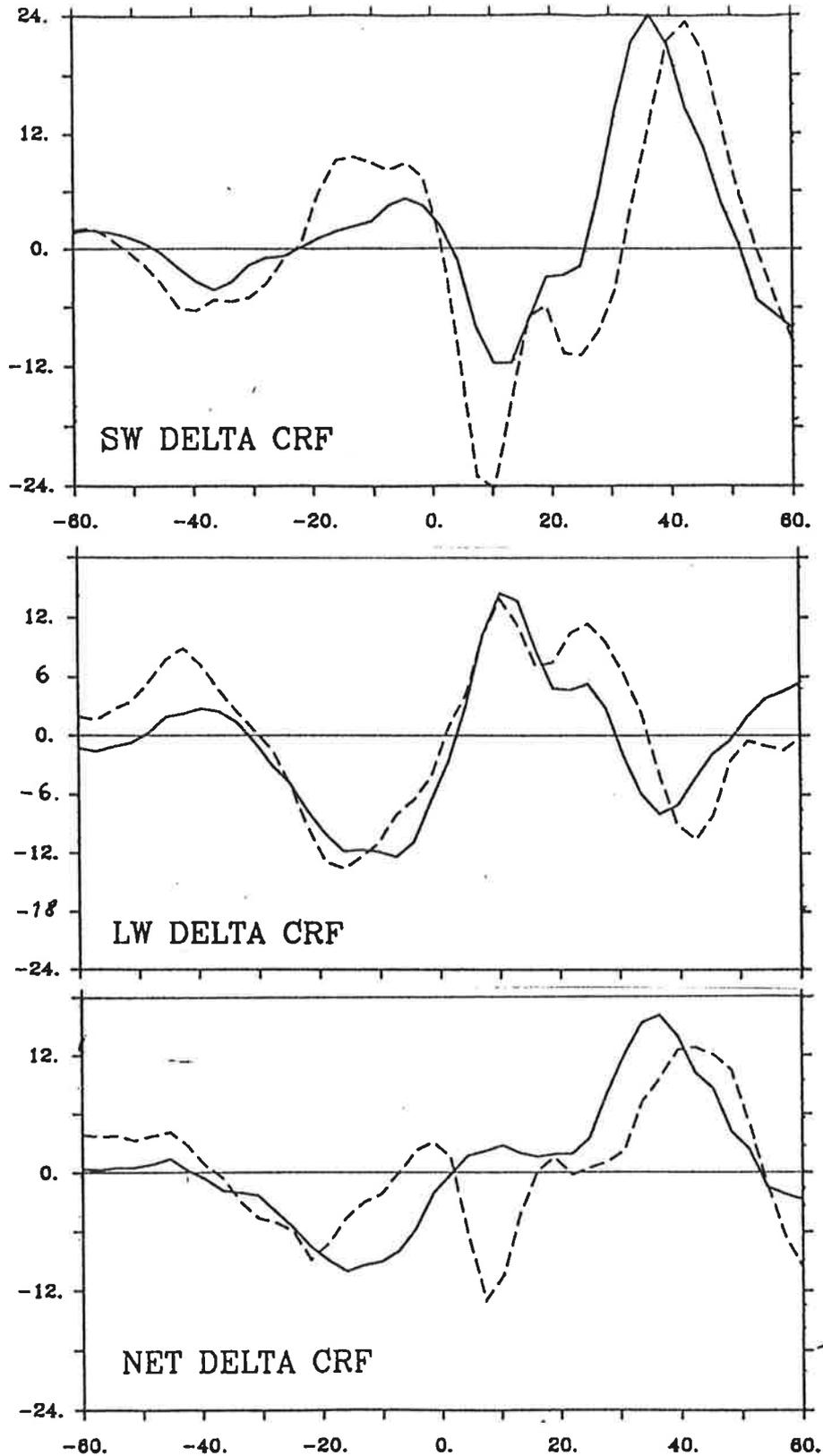


Figure 2 Seasonal variation of the simulated (ECHAM3/T42) minus observed (ERBE) zonal monthly mean cloud forcing for the period Feb. 1985 (month 2) to Jan. 1986 (month 13) between 60°N and 60°S. The contour spacing is 10  $Wm^{-2}$ .



**Figure 3** Response of the cloud forcing to seasonal thermal forcing for July 1985 between 60°S and 60°N. The full lines denote ERBE analyses and the dashed lines denote the model simulations. Units are  $Wm^{-2}$ . Positive values correspond to warming relative to the annual mean and negative values correspond to the cooling.

## Use of satellite data for validation of the ECHAM models

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The ECHAM3 models originate from the ECMWF model. It resembles the version of their cycle 36 but with considerably modified parameterization of sub-grid scale processes. Improvements in respect to earlier versions of ECHAM in the general circulation statistics are being published elsewhere. It is intended to use the model for simulating future climates, e.g. to show the impact of increase CO<sub>2</sub>. For that it is needed to demonstrate that the model is able to simulate the present climate.

From models any quantity is readily available in any possible way of presentation but the validation is extremely hampered but the lack of knowledge of the truth. In earlier days any climatological estimate was sufficient to show the deficiencies of the models but now in many respects the differences between e.g. the precipitation climatologies by Jaeger and Legates are larger than between the model results and any of them and a measure of reliability of observed or climatological data become more and more important.

It is no longer sufficient to compare climatological means but one has to investigate also the interannual variability. For this we investigated the impact of sea surface temperatures (SSTs) on the inter-annual variability in the model by running several experiments with different initial states but with the same observed SST. For the inner tropics the impact of the SST turned out to be extremely strong. For a tropical area over the eastern Pacific precipitation or OLR anomalies are repeated by all experiments and it would be extremely interesting to know if also the real atmosphere had the same interannual variability. It is planned to use observations by satellite to investigate this further. Here it is important to have model independent data available. If we find an interesting feature e.g. over the tropical Pacific in our model simulations and compare them with analysis data, we are facing the following problem: If model and analyses agree, it may be due to the model involved in the analysis scheme, or if they do not agree, the simulation may still be realistic because there are only few reliable observations in that area available for the analysis. The best strategy would be to compare model output quantities which can reliably be observed, e.g. OLR.

We would like as well to get some information about the diurnal cycle, at least for some areas with reliable observations. Geostationary satellite should be able to provide some data in this respect.

There are only few observations of snow amount and coverage available. For Canada climatological snow amounts at some stations have been used for a comparison. A too slow melting of snow in spring in the simulations becomes apparent. However, we would like to know how representative such station observations are. Satellite observations should also be able to give indications of changes in the albedo in this area due to the aging of snow.

## Simulation of Clear-Sky Outgoing Longwave Radiation over the Oceans using Operational Analysis

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(presented by A. Jones)

We have developed a system for the Simulation and Analysis of Measurements from Satellites using Operational Analyses (SAMSON). In this initial study, simulations of clear-sky Outgoing Long-wave Radiation (OLR) over the oceans are compared with data from the Earth Radiation Budget Experiment (ERBE). The calculations were performed with a Malkmus narrow-band radiation scheme, including the effects of all the radiatively important gases. Sea surface temperatures were taken from the National Meteorological Center's blended analyses, and ozone data from the Nimbus 7 Solar Backscatter Ultraviolet experiment. Atmospheric temperatures and humidities came from operational analyses. Parallel simulations were performed with the analyses produced both by the European Centre for Medium-range Weather Forecasts (ECMWF) and by the United Kingdom Meteorological Office (UKMO).

Simulations for the period February 1985 to October 1986 were compared with ERBE data. Differences between the humidity data in the analyses have a significant impact on the calculated clear-sky OLR. The changes to the ECMWF model in May 1985 reduce the differences compared with ERBE. After this time, the differences are consistent with two known systematic errors: a small overestimate in the ERBE data, and a tendency for the ECMWF analyses to be too dry in the ITCZ and too moist in the sub-tropics. The simulations with the UKMO analyses generally show slightly larger differences compared with ERBE. Tests show the sensitivity of the ECMWF results to diurnal sampling of the analyses and to the temporal resolution employed to calculate the monthly means. These tests reveal instances of extremely low humidities in the ECMWF analyses in the upper troposphere over the tropical East Pacific.

Over most of the domain, the simulations are within  $5\text{-}10\text{ Wm}^{-2}$  of the ERBE data. The clear-sky OLR can thus be computed from operational analyses with an accuracy comparable with that of ERBE. This indicates the potential of such simulations and has implications for the planning of future radiation budget observations.

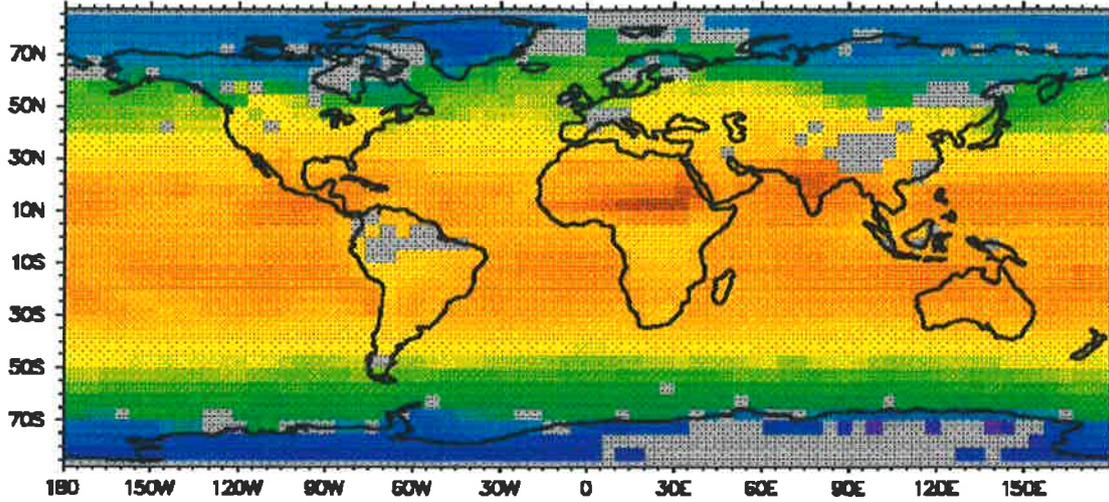
The colour plots illustrate some more recent comparisons between the SAMSON simulations and the ERBE data, for April 1986. As expected, the simulations show the broad nature of the clear-sky OLR field, with high emission from the warm tropics and the decline in emission towards the colder mid-latitudes and polar regions. More importantly, they also capture much of the detail at low latitudes, such as the relative minimum over the equator (where water vapour densities are largest) and the maxima over the sub-tropics, where the water vapour densities are relatively low.

Note, for example, the maxima to the south of Mexico, over the Atlantic and over the Indian Ocean. Because of the relative uniformity in atmospheric and sea surface temperatures in the tropics, such Variations in the emission are forced primarily by variations in the water vapour densities, so they are a direct measure of variations in the contribution of water vapour to the greenhouse effect. Simulations of this quality should allow greater understanding of this effect, because through SAMSON we have the ability to relate the observed radiation budget to the geophysical parameters which control it.

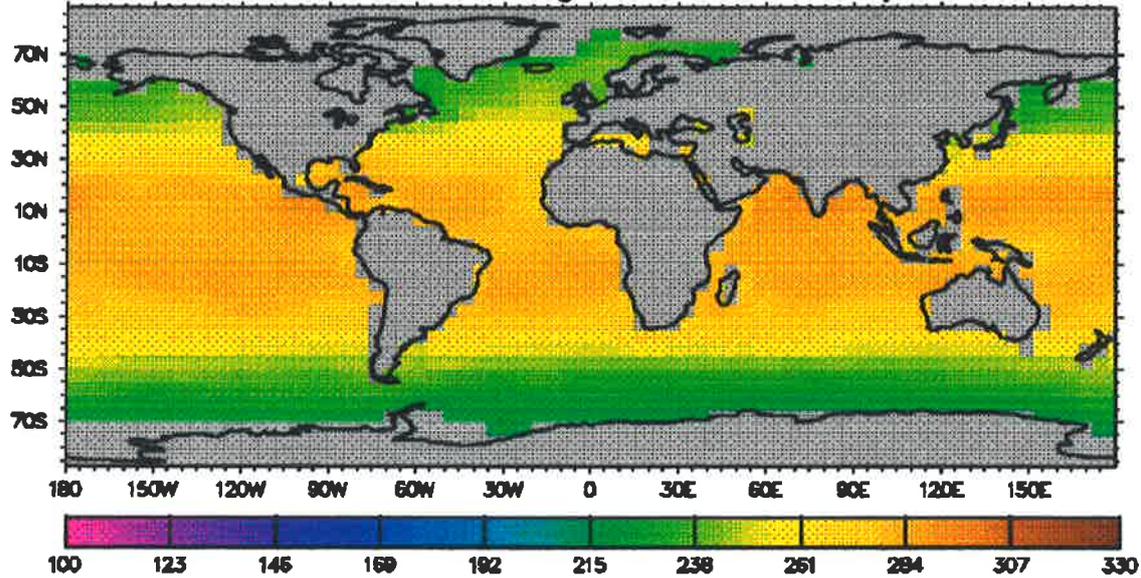
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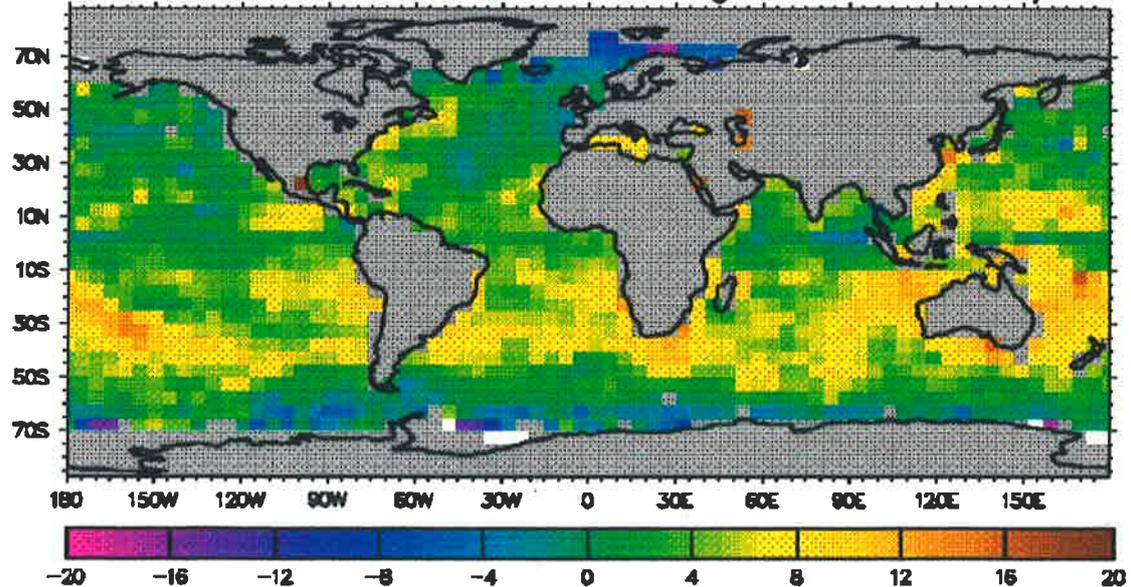
Clear-sky OLR - April 1986  
ERBE data



Clear-sky OLR - April 1986  
Simulated using ECMWF Analyses



Clear-sky OLR - April 1986  
ERBE minus simulation using ECMWF analyses



## **Use of satellite data for validation of operational forecast models and operational analyses**

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The development of parameterization schemes for large scale forecast models is an ongoing process which requires high quality observational data for validation. In an operational environment like that of a NWP-centre real time data would be most suitable, which could also be incorporated into four dimensional data assimilation systems. However, the postprocessing of satellite measurements like radiation fluxes has in the past led to a rather long time delay in the availability for the majority of users. Therefore, only space and time averages were used for model validation.

At ECMWF the operational forecast fluxes of radiation at the top of the atmosphere are monitored by comparing zonal and monthly means to the appropriate part of a fixed annual cycle of ERBE fluxes averaged in the same way. Some information on the general performance of the forecast model characteristics can be gained from scatter diagrams, one useful example is a scatter diagram of the greenhouse function over sea surface temperature.

A synchronous comparison of ERBE and model fluxes for periods more than one to two years ago is only of limited use for the validation of the present model formulation. At ECMWF we have therefore repeated the data assimilation for a period when a good coverage of satellite data was available (July and August 1987). By using the model and analysis formulation of July 1991 it was possible to evaluate the more recent changes in the parameterization of cloud-radiation interaction.

The synchronous comparison allows the validation of single circulation systems like the extra-tropical cyclones, tropical cloud cluster or tropical easterly waves. Additionally a comparison of observed and predicted monthly means and standard deviations of daily values give a good indication where the cloud-radiation interaction is still unsatisfactory.