GLOBAL RETRIEVAL OF CLOUD LIQUID WATER AND PRECIPITATION OVER SEA FROM SSM/I MEASUREMENTS

Peter Bauer
Deutsche Forschungsanstalt für Luft- und Raumfahrt, HA-SR
Linder Höhe, W-5000 Köln 90, Germany

Peter Schlüssel
Meteorologisches Institut, Universität Hamburg
Bundesstraße 55, W-2000 Hamburg 13, Germany

ABSTRACT

A radiative transfer model based on the matrix-operator-theory has been developed for the simulation of millimetre-wavelength radiances emerging from cloudy and precipitating atmospheres over oceans. The model fully solves for multiple scattering as well as for polarization effects at hydrometeors and at the sea surface. A set of atmospheric profiles from radiosonde ascents distributed over oceans which cover all latitudes and seasonal variations is entered into the radiative transfer calculations in order to simulate the dual polarized radiometer signals as measured in the spectral channels of the Special Sensor Microwave / Imager (SSM/I), located in the 19 to 86 GHz frequency domain. Vertically inhomogeneous distributed water and ice particles have been taken into account for various cloud types and simultaneous occurrence of multiple cloud layers. The effect of wind-induced water surface roughness and foam coverage is included. A multivariate analysis is carried out to derive retrieval algorithms for a measurement of cloud and rain liquid-water paths as well as surface rain rates from satellite observations. Estimated standard errors show values of less than 15% of the deduced parameters. The new retrieval algorithms are applied to passive microwave soundings measured from the SSM/I instrument that is flown on board the DMSP spacecraft to derive global maps of precipitation and cloud liquid-water content. Rain rates as derived from satellite infrared observations, from surface climatology, and from model climatology are compared with the satellite microwave retrievals of surface rain rates.

1. INTRODUCTION

The quantitative mapping of global rainfall distributions is a major objective of climate research. Basically, passive microwave radiometry in current and future satellite systems is known as an effective tool to provide surface rainrates because the thermal signature in the millimetre range of the wavelength spectrum is significantly influenced by the total columns of liquid and ice water and the cloud as well as rain-particle size distributions. Above the radiometrically cold ocean surface increasing amounts of atmospheric water vapour and cloud water enhance the outwelling radiation at the top of the atmosphere by emission, whereas efficient scatter processes at larger drops and particles in clouds and rain reduce the measurable microwave signal.

Recent studies mainly use single- or dual-channel approaches or iterative procedures based on simple radiative-transport models and assumptions about the vertical structure of precipitating systems (e.g. Weinman und Guetter, 1977; Spencer, 1986; Kummerow et al., 1989; Shin et al., 1990). Our objective is to create generalized algorithms using a sophisticated radiative transfer model and highly variable vertical hydrometeor distributions as well as fractional scene coverages in the radiometer's field of view to investigate their specific impact on the simulated microwave signals. Additionally, multi-channel-algorithms for the retrieval of the relevant parameters on a global scale are presented and compared to the corresponding results of other satellite analyses, GCM experiment and climatological data.

2. RADIATIVE TRANSFER SIMULATIONS

In our model the matrix-operator-theory (Plass et al., 1973) is extended to include the full polarization vector instead of radiation intensities. The transfer of polarized radiation is computed through plane parallel atmospheres containing liquid and frozen spherical hydrometeors. The gaseous absorption by water vapour and molecular oxygen is based on the parameterizations of Liebe (1985). Scattering and absorption of droplets is calculated using the Rayleigh-approximation for droplet and ice sphere sizes in the cloud domain and by Mie's formulae for precipitating particles. The emissivity of the flat surface is calculated using the Fresnel and Debye formulae. The dependence of surface roughness on wind velocity and its effect on the polarized reflectivities is taken from Schluessel and Luthardt (1991). Simulations are carried out for stratiform and convective cloud types with appropriate cloud liquid-water content and rainrate distributions. The vertical profiles of cloud water are analytically described by Skatskii (1965). Rainrates are assumed to increase linearly from the cloud top to the freezing level and to decrease below that altitude due to evaporation. Figure 1 illustrates the two regimes for surface rainrates of 3 mm/hr (a) and 21 mm/hr (b), respectively. The cloud and rain water is converted linearly into ice following the temperature. Thus, the convective case in Fig. 1b produces more precipitating ice particles at higher cloud levels, so that the extinction (see Fig. 2) increases at the altitude where the maximum ice concentrations occur and the albedo reaches values between 0.3 and 1 depending on the frequency. The simulated brightness temperatures

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at both polarizations of the stratiform scene are reduced by more than 40 K at 37 GHz and 100 K at 85 GHz where the particle scattering is most efficient.

Simulations are carried out for atmospheric conditions of all latitudes and seasons taken from globally distributed radiosonde ascents. The computations are run for cloudfree, cloudy and precipitating cases. Inhomogeneous scenes are introduced by merging the above cases with randomly varying fractional coverages. Thus, the brightness temperatures used in the regressions are the combined results of ocean, clear sky, cloud, and rain signatures, respectively.

The regression equations are linear combinations of channel combinations, i.e. polarizations and different frequencies:

$$log_{10}(IWP),\ log_{10}(TWP),\ log_{10}(R) = a_0 + \sum_i a_i f_i(T_B) \quad (1)$$

where the $f_i(T_B)$ are specific functions linearizing the relations between the atmospheric parameters and the simulated brightness temperatures. The logarithm is applied to the ice

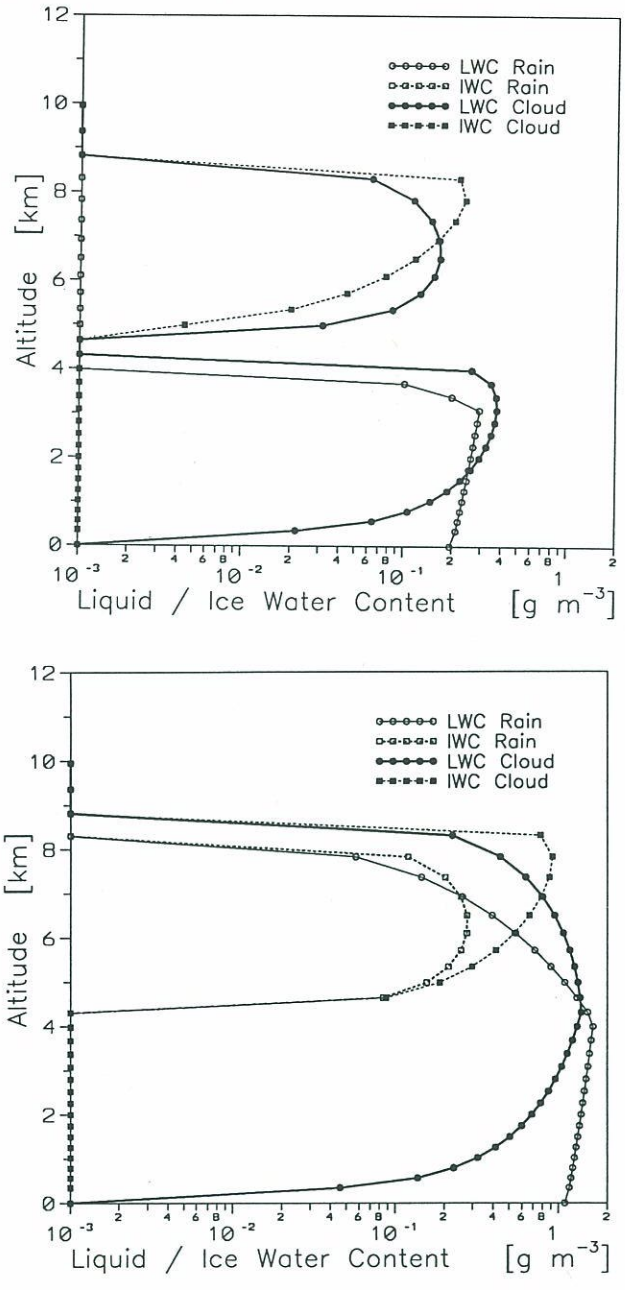

Fig. 1 Vertical distribution of cloud water and ice concentrations as well as rain water for a model atmosphere with two cloud layers and light rainfall of 3 mm/hr (a), and for a situation with a single convective cloud with heavier rainfall of 21 mm/hr (b).

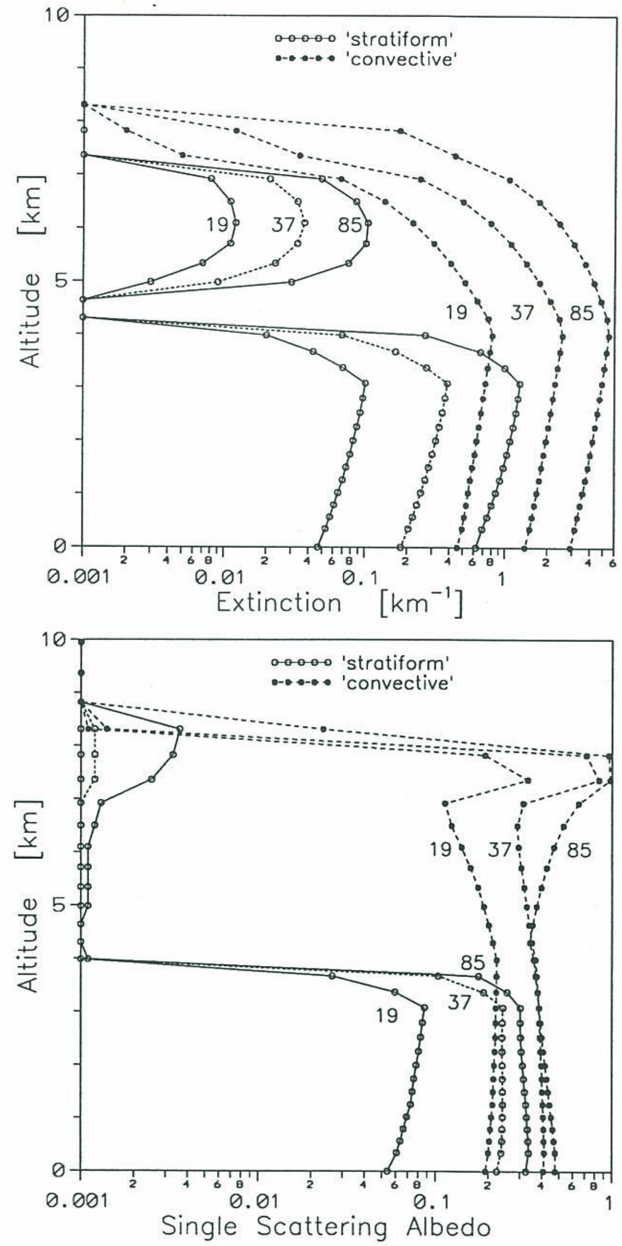

Fig. 2 Vertical profiles of extinction coefficients (a) and single scattering albedoes (b) for 19, 37 and 85 GHz frequencies as calculated for the model clouds of Fig. 1.

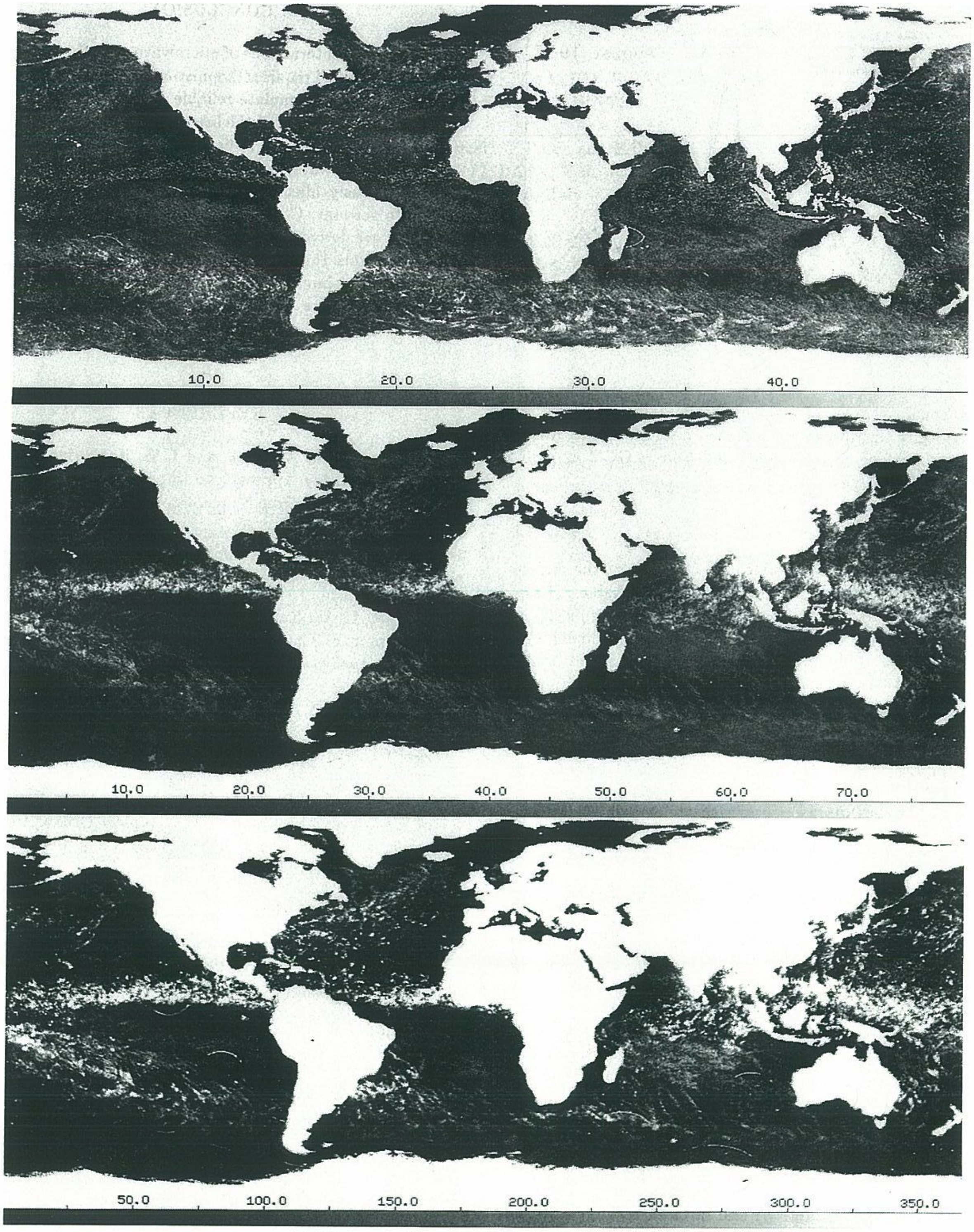

Fig. 3 Global maps of monthly averages of ice water paths in mg/cm^2 (a), total water paths in mg/cm^2 (b), and monthly sums of rainfall in mm (c) over sea as derived from SSM/I measurements of August 1987.

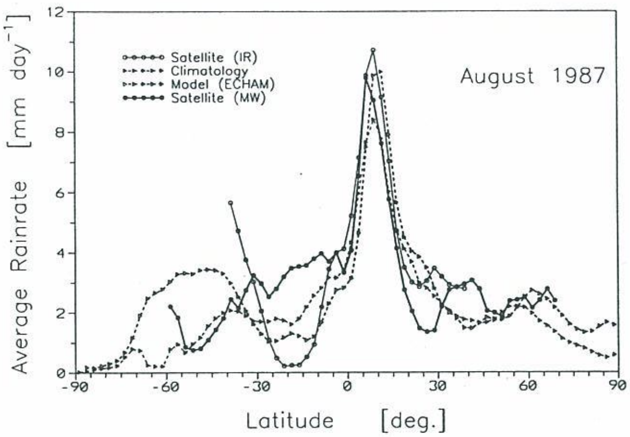

Fig. 4 Zonal averages of mean daily rainfall derived from satellite microwave and infrared data as well as from land surface measurements and from a GCM experiment for August 1987.

water path (IWP), the total water path (TWP) and the surface rain rate (R) due to their accumulation at low values. Basically, all SSM/I frequencies are used in the regression equations. The retrieval algorithms are chosen by optimizing criteria, as there are minimum standard errors of the retrievals, statistically stable channel constellations and minimum number of used frequencies. Finally, we obtain standard deviations between the atmospheric parameters entering the simulations and those resulting from the regressions which lie below 15% . This estimates the expected retrieval errors.

3. RESULTS

Figures 3a-c show the resulting global distributions for SSM/I data of August 1987 with monthly averages of the ice paths (a), total water paths (b), and the monthly sums of rainfall (c). The ITCZ is well expressed with maximum rain amounts of 1500 mm in the summer monsoon areas as well as over the Pacific atolls. The corresponding water paths show values of 50 - 100 mg/cm^2, the ice water paths are below 30 mg/cm^2. The algorithms generally tend to overestimate low amounts of ice and rain because small precipitating drops and particles are not separated from cloud droplets. Zonal averages over 2.5° - areas are built and compared to results of satellite infrared data, land surface measurements and a GCM experiment with the European Center HAMburg Version (ECHAM) model. Figure 4 shows reliable distributions with an overestimation of the rain amounts by the infrared technique in the tropics and higher latitudes, whereas the microwave algorithm coincides very well with the ground based measurements and the model results.

4. CONCLUSIONS

The complex interactions of microwave radiation with clouds and precipitation requires sophisticated radiative-transport models to properly simulate reliable relations between the atmospheric parameters and the brightness temperatures as measured by passive satellite radiometers. The variability of vertical profiles of water and ice in clouds and rain as well as inhomogeneously filled radiometer's fields of view have to be taken into account. Global fields of cloud ice and water as well as rainfall are derived from SSM/I measurements using the retrieval methods that have been developed by a multivariate analysis of the simulated data sets. The zonal distribution of the results compare well with data from other satellites, surface measurements, and GCM experiments.

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Olavi Kärner
Institute of Astrophysics and Atmospheric Physics
Estonian Academy of Sciences
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