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REMOTE SENSING OF CLOUD LIQUID WATER DURING ICE'89

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ABSTRACT: The cloud liquid water path, LWP, over the North Sea during the International Cirrus Experiment 1989 (ICE'89) is derived from measurements of the microwave radiometer SSM/I on board of the polar orbiting satellite DMSP and from measurements of a ground-based 33-GHz-radiometer operating on board of the German research vessel 'Poseidon'. Comparisons of maps of LWP compiled from the SSM/I data with time series computed from the ground-based system show no significant bias and agree within the range of uncertainty caused by the different sampling characteristics of the observing systems. Using a combination of SSM/I data and almost simultaneously recorded METEOSAT-IR data offers the possibility to identify different cloud types, e.g. to seperate cirrus clouds and cirrus with underlying water clouds. Both types may have the same IR-brightness temperature but different microwave brightness temperature because ice clouds have a negligible influence on the microwave radiances.

I. INTRODUCTION

The most important reason for using microwaves to derive the LWP is their capability to penetrate clouds. In the microwave region the whole cloud influences the outgoing radiation and not only its top or bottom like in the visible and infrared. Therefore it is possible to determine the vertically integrated liquid water content of clouds. Ice clouds have almost no influence at the microwave frequency range used in this study. Nevertheless a combination of microwave and infrared remote sensing can be used to identify cirrus clouds.
The LWP over the North Sea during International Cirrus Experiment (September 18 - October 20, 1989), ICE'89, is derived both from measurements of the microwave radiometer SSM/I on board of the polar orbiting satellite DMSP and from measurements of a ground-based 33-GHz-radiometer operating on board of the German research vessel 'Poseidon'. The ship operated in the central North Sea during the experiment (September 28 - October 19, 1989). The verification of the microwave-derived LWP is hampered by the lack of comparison data. In this study the comparison of coincident measurements of the satellite-based and the ground-based radiometer serves as a sort of verification.

II. ALGORITHM DEVELOPMENT

The algorithms to estimate the LWP over the ocean were developed using multiple regression analysis. The regression analysis was based on radiative transfer calculations using about 3000 measured atmospheric profiles over the Atlantic Ocean and the North Sea [1]. These profiles do not contain information about the cloud liquid water, therefore the clouds have to be parameterized. The cloud position was fixed according to the relative humidity and a modified adiabatic liquid water content was calculated.

The algorithm derived for the SSM/I radiometer is of the following form:

$$LWP = a_0 + a_1 \ln (280-T_{37V}) + a_2 \ln (280-T_{22V})$$

T_{fV}: brightness temperature at frequency f in vertical polarisation

a_i : regression coefficients

Using a logarithmic relation between LWP and brightness temperature follows from radiative transfer theorie [2]. Before the application of the algorithms correction coefficients have to be used to account for the systematic differences between the modelled temperatures and the SSM/I measurements. These coefficients we derived from coincident SSM/I measurements and radiosonde ascents during ICE'89 are slightly different to those given by Wentz [3].

For the ground-based radiometer an algorithm is developed which depends on the difference between the brightness temperature for a cloudy and a clear atmosphere. Using this difference reduces the influence of changes in the water vapor content and of uncertainties in the calibration of the radiometer. The cloud-free cases are identified by their comparatively small variability. The linear interpolation between the temperatures of the cloud-free spots in the time series yields a reference temperature which is supposed to be cloud-free.

The estimated retrieval accuracy is 0.03 kg/m^2 for the satellite-based and 0.06 kg/m^2 for the ground-based radiometer.

III. COMPARISON OF SATELLITE-BASED AND GROUND-BASED MEASUREMENTS

Unfortunately we have no possibility to verify the microwave-derived LWP with simultaneous in-situ measurements. Instead we compare the satellite-based and the ground-based microwave estimates. Maps of LWP over the North Sea were compiled from SSM/I data. The LWP values at the position of the RV 'Poseidon' are compared to the time-corresponding values in the times series computed from the ground-based measurements. To account for the spatial resolution of the SSM/I (40 km) the time series were averaged over 40 minutes.

Since the DMSP satellite passes only twice a day there are only a few chances for direct comparisons. Fig.1 shows the SSM/I-derived LWP versus the LWP estimated from the ground-based measurements. The LWP values agree within the range of uncertainty caused by the diffe-

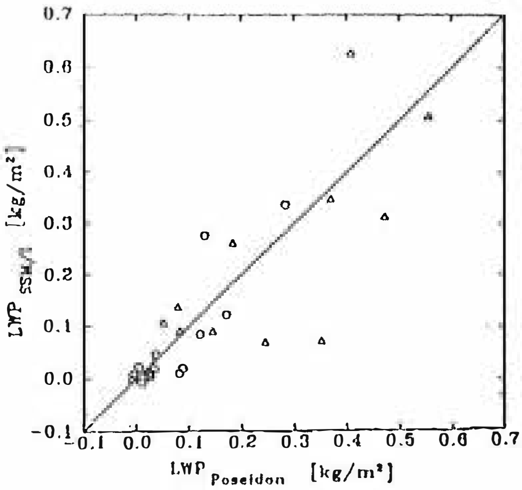

Fig. 1: Direct comparison of satellite-based and ground-based measurements. The ground-based LWP is averaged over 40 minutes.

Δ homogeneous clouds, rms = 0.048 kg/m^2, bias = 0.003 kg/m^2.

o scattered clouds, rms = 0.126 kg/m^2, bias = 0.028 kg/m^2

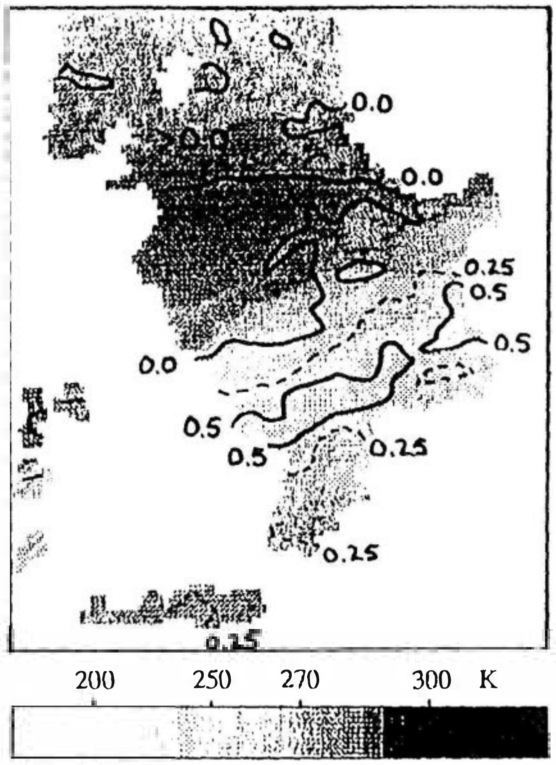

Fig. 2: METEOSAT-IR-temperatures with superimposed SSM/I derived LWP (kg/m^2) for the North Sea, October 13, 1989, 5:25 UT.

rent sampling characteristics of the observing systems. Differences tend to be smaller for homogeneous cloud decks than for clouds small compared to the spatial resolution of the satellite radiometer.

IV. COMBINATION OF SSM/I- AND METEOSAT-DATA

The satellite-based microwave data are blended with almost simultaneously recorded METEOSAT data. Since SSM/I measurements are available at about 6:00 and 18:00 local time, we can use only data from the infrared channel of METEOSAT in the month of October. Fig.2 shows the IR-temperatures with the superimposed LWP pattern derived from SSM/I data for October 13. The LWP-maxima are found in the center of the cloud region but they do not always correspond to the lowest IR-brightness temperatures. Low clouds with relatively warm IR-temperatures and LWP larger than 0.2 kg/m^2 are located in the British Channel. The scattered clouds in the northern part are characterized by variable IR-temperatures and have only low LWP values because these values always represent an average over 40 km, i.e. approx. 16 - 20 IR-pixels. At the north western part of the cloud system the low IR-temperatures in combination with no liquid water indicate cirrus clouds.
The possibility to distinguish between different cloud types using a combination of the informations from the microwaves and the infrared

spectral range is shown in the 2-dimensional histogram compiled from the SSM/I-derived LWP and the IR-temperatures (Fig.3). It is possible to seperate e.g. dense cirrus from cirrus with underlying water clouds, although they have the same IR-temperature.

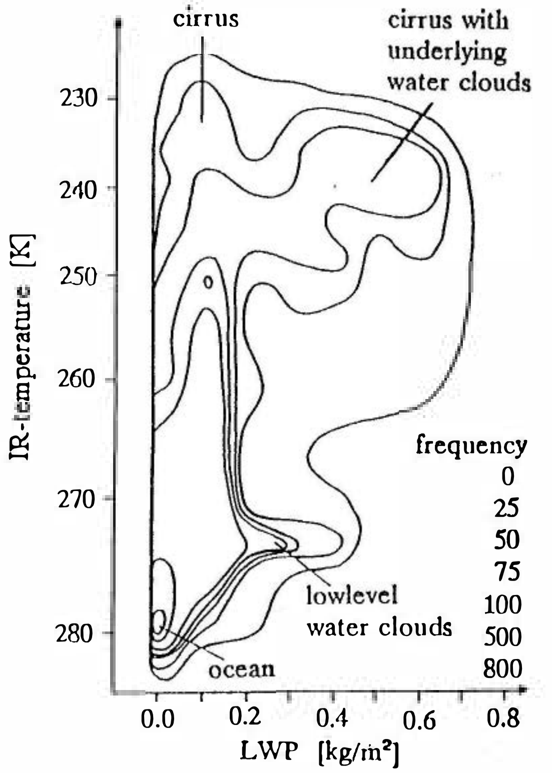

Fig. 3: 2-dim. histogram for October 13, 1989, 5:25 UT.

The IR-temperatures give an indication of the cloud top heights. Since cloud top height has only a slight influence on the microwave-derived LWP we can classify the clouds with regard to their top height and LWP.
Using this classification the image can be reconstructed. Fig.4 shows the distribution of different cloud types over the North Sea for October 13.

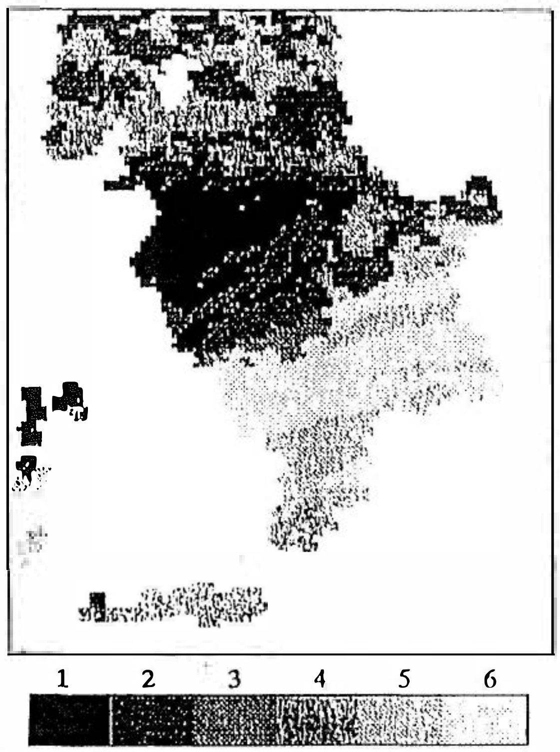

Fig. 4: Distribution of different cloud types over the North Sea, Oct. 13, 1989, 5:25 UT
1 ocean
2 broken cirrus
3 dense cirrus
4 lowlevel water clouds
5 midlevel water clouds
6 cirrus with underlying water clouds

V. SUMMARY AND CONCLUSIONS

In this study algorithms to estimate the cloud liquid water from microwave observations are presented. Maps of LWP over the North Sea were compiled from SSM/I measurements for September 28 - October 19. The accuracy of the derived LWP can be partially inferred from the results for the clear-sky cases. Supposing the clear-sky cases are correctly identified from the IR-data, the variability in LWP of 0.0 ± 0.035 kg/m^2 is an indication of the overall accuracy. The deviations are mainly associated with uncertainties in wind speed and water vapor content.

This study has demonstrated that the combination of the information available from microwave with that available in the infrared region offers the possibility to identify different cloud types. But as we combine measurements of a polar orbiting and a geostationary satellite, the amount of simultaneous observations is limited.

Furthermore, we intend to use SSM/I-derived monthly-mean LWP over the Atlantic Ocean for a comparison with the simulated LWP of the ECHAM climate model [4]. The microwave-derived LWP constitutes a useful dataset for a quantitative verification of the cloud parametrisation scheme of climate models, in which the cloud water is a prognostic variable. Instead of adjusting the cloud parameters in the climate model using simulated radiation fluxes the microwave remote sensing offers the possibility for a direct comparison of the microphysical parameter LWP.

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