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STATISTICAL ANALYSIS OF THE INTERRELATION OF THE DIFFERENT CHANNEL OBSERVATIONS OF DMSP-SSM/I

by
E. Ruprecht
R. Fuhrhop
and
C. Simmer

Institut für Meereskunde, Kiel, Germany

I. INTRODUCTION

The microwave radiances which leave the atmosphere and are received by a satellite-borne radiometer depend on the state of the atmosphere/ocean system. This fact is the base for the microwave remote sensing, but it also reveals a problem with which one is faced when applying this method: A microwave observation at a certain frequency depends in general on more than one parameter (e.g. water vapor and liquid water content, SST or roughness of the sea surface). Thus, in order to retrieve one of these parameters, more than one observation is necessary to correct for the effects of the others.

The question arises: Does an optimum set of frequencies exist to be used by a satellite-borne microwave radiometer? Or: Is there independent information in the different channel observations? To understand the dominant influence, one can calculate with a radiative transfer model the radiances at the top of the atmosphere at different frequencies for varying atmospheric/oceanic states. Or one can derive the weighting functions to determine this part of the atmosphere/ocean system where the main contribution of the signal received by the radiometer comes from. A statistical analysis of the radiances at different frequencies can in principal give no new information, it only compresses the information and supports an easier interpretation.

In our study the frequency-dependent microwave radiances at satellite level are calculated for many different atmospheric/oceanic states given by rawinsonde ascents, and their interrelations are derived by covariance and correlation matrices. These matrices are then analysed by a Principal Component Analysis. Empirical Orthogonal Functions (EOF) are calculated to compress information content and to find independent information in the radiance at different frequencies (channels).

II. MODEL AND DATA

A radiative transfer model was developed by one of the authors (C. Simmer) to compute the radiation intensity distribution between 1 and 1000 GHz within a plane-parallel vertical inhomogeneous atmosphere. The model is based on the solution of the polarisation-dependent radiative transfer equation with the successive order of scattering method (e.g. [1]). The following coefficients and boundary conditions are used:

- absorption coefficients for water vapour after Liebe and Layton [2] with the 1989-version of their Millimeter Propagation Model (priv. communication by Liebe, 1989);
- absorption and scattering coefficients for liquid water within clouds and rain determined from Mie-coefficients computed via Mie-theory [3], using the formulation developed by Deirmendjian [4];
- polarisation-dependent phase functions determined from the Mie-coefficients by the formula-

tion in [5];
- Fresnel reflection of the plane ocean surface (Fresnel-equation after [6]), using the dielectric constants of saline water given in [7];
- influence of wind-induced waves and of foam at frequencies smaller than 40 GHz, with a parametrisation based on measurements by Hollinger [8] and Stogryn [9], respectively. Alternatively (especially for higher frequencies), the surface reflection can be computed by division into individual specular reflecting facets [10] with their wind-dependent angular distribution given by Cox and Munk [11].

The atmospheric conditions and the state of the ocean surface were described by 1400 rawinsonde ascents and the corresponding synoptic observations over the North Atlantic Ocean during April to October 1979 (FGGE). Since observations of the liquid water content LWC are not available, a parametrisation was used. For each radiosonde ascent for which condensation was reached at some level the adiabatic liquid water content was calculated and then reduced according to the profile given by Warner [12].

For the statistical analysis of the satellite data we used the observations from SSM/I over the Atlantic Ocean during October 1989. The Atlantic Ocean was divided into 9 areas, each 10° longitude wide and 60° latitude long (4 from the equator to 60° N and 5 from the equator to 60° S). Only the 5 lower channel observations (19.35 and 37.0 GHz both horizontal and vertical polarization and 22.23 GHz vertical polarization) were used. The 85.5 GHz data was excluded because it was not available for this period.

III. STATISTICAL ANALYSIS

For the statistical analysis a set of 1400 brightness temperatures at the top of the atmosphere was calculated based on the rawinsonde ascents which covers almost all possible weather situations over the North Atlantic. In order to compare the results with the SSM/I observations of the 5 channels between 19 and 37 GHz, we restricted the calculation to the frequency range of 5 to 37 GHz and a satellite zenith angle of 53°. The computations were carried out for 24 frequencies. Instead of the actual brightness temperatures T_B transformed brightness temperatures TT_B were used:

$$TT_B = \ln(280 - T_B).$$

The so transformed brightness temperature decreases almost linearly with increasing precipitable water W.

All brightness temperatures in the given frequency interval are well correlated. The maximum of the correlation and of the covariance is found at the water vapor absorption line at 22.235 GHz. The extension of the correlation maximum in the direction perpendicular to the diagonal (one to one correlation) is due to the symmetry of the absorption line near the centre. The conclusion from these matrices is that there is no frequency channel with an independent information.

In order to investigate whether a combination of channels yields separate information, the EOFs were calculated from the covariance matrix. The structure of the first eigenvector, it explains 86 % of the total variance, is very similar to that of the absorption coefficient. That means, it mainly describes the variance of the total precipitable water W. A change in W is followed by a change of T_B at all frequencies in the same direction. The second eigenvector (13% of the total variance) agrees in so far with the first, that the contribution from the lower frequencies (< 15 GHz) is small, that means both are dominantly affected by the atmospheric parameters. For higher frequencies a change of the sign is the striking feature, if the contribution from the frequencies around the centre line is negative, higher frequencies give a positive one and vice versa. This behaviour points to the influence of the liquid water path, LWP. This is also confirmed by the correlation between the principal components c_i; and the atmospheric parameters: c_1 is well correlated with W (-0.85) and c_2 with LWP (-0.79). (The negative sign follows from the transformation of T_B.)

The third eigenvector with about 1 % of explained variance shows a distinct difference between the horizontal and vertical polarized components. The first is negative and nearly constant for all frequencies, the second positive and increasing with increasing frequencies. This points to the fact that it is affected by the surface winds v. That is confirmed by the high correlation between v and c_3 of 0.87.

In order to check the significance and stability of the eigenvectors we used two different methods. According to Farmer [13], the eigenvalues of a covariance matrix produced by random numbers follow an exponential decrease with increasing eigenvectors. Thus according to this qualitative test the first two eigenvectors are clearly significant. The third and fourth deviate only little from the exponential curve and thus are just significant. In order to check the stability we performed an error analysis. We added to each of the T_B an error (normally distributed random numbers σ = 1.5 K) and analyzed the new data in the same way as before. The first two eigenvectors do not change at all, the next two become a little noisier, but have still the same structure, and the 5th and 6th even change their structure. Thus we conclude that there is significant and stable information in the first four EOFs.

The analysis is then applied to actual observations of SSM/I. Since there are 5 channel observations, the eigenvectors have 5 components. These are shown in Fig. 1 for the 9 Atlantic areas and for model results (North Atlantic Ocean as before). The first two eigenvectors agree very well with those of the simulated data. There is also little variance between the 9 areas. The conclusion derived from the model data can therefore be transferred to the actual observations. The variability of the third eigenvector is much larger. The general structure as given in the simulation data is certainly maintained in most areas, but there are a few large differences e.g. for the 19 v and 37 h channels of all North Atlantic areas.

Due to these facts we mainly treat only the first two eigenvectors in the further analysis, for which again the simulated data are used.

For the 5 lower SSM/I channels there exist two significant eigenvectors. Since the eigenvectors are orthogonal, they yield independent information. Thus we can conclude that it is possible to determine two parameters based on these observations. The correlation calculation between the principal components c_i and the atmospheric/oceanic parameters has shown that W and LWP are closely related to the first and the second eigenvector, respectively. But part of their variance is contained in the second or first eigenvector, respectively:

parameter	correlat. coeff.
c_1, W	- 0.85
c_2, W	0.52
c_1, LWP	- 0.59
c_2, LWP	- 0.79

It follows that about 99% (97%) of the variance of W (LWP) can be explained by the two first eigenvec-

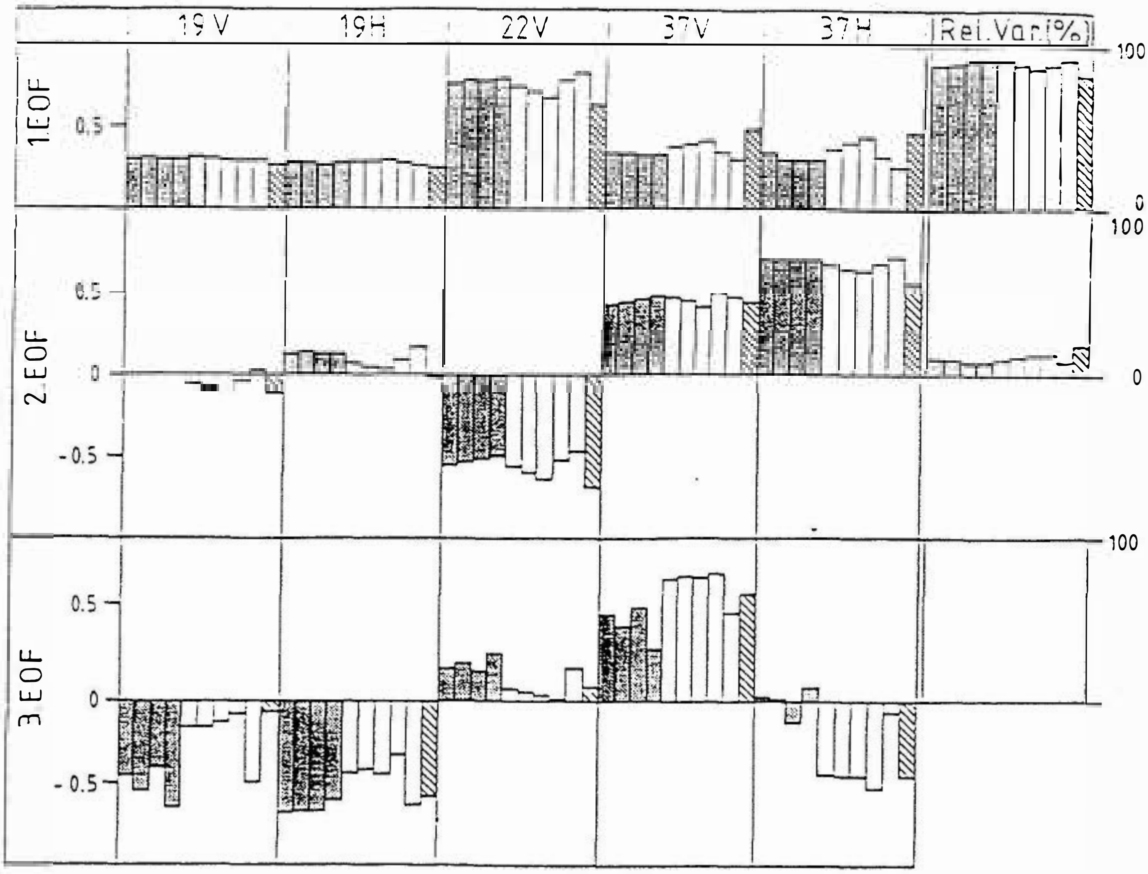

Fig. 1 First three eigenvectors of the brightness temperatures for the 5 lower channels of SSM/I for the 4 North Atlantic regions (full columns), 5 South Atlantic regions (open columns) and the simulated T_B (hatched columns); on the right contribution of each eigenvector to the total variance.

tors. This relation can be used to determine W and LWP through the knowledge of the two eigenvectors. The accuracy is 1.4 Kg/m^2 for W and 0.04 Kg/m^2 for LWP. About the same numbers are obtained with algorithms which use only two observations e.g. of the channels at 22 GHz and 37 GHz vertical polarized. The situation changes, however, when only cloudfree data is included in the analysis. Then the wind shows a dominant effect in the second eigenvector. And, very important, the information in the two eigenvectors can be clearly separated. In this situation it is possible to determine the surface wind speed with an accuracy of 1.6 m/s.

IV. CONCLUSION

The observations of the 5 lower SSM/I channels contain only 4 independent informations, since we found 4 significant eigenvectors. This is, however, only the case, if the measurement errors are small. The last two eigenvectors are very sensitive to errors. Thus, in many situations two significant, independent informations are available. The two parameters which can be retrieved are total precipitable water and liquid water path, in cloudfree areas it is W and the surface wind. Whether wind speed can be determined from the third eigenvector will be investigated in the future. We shall also include the 85 GHz channel and study the optimum frequencies for a retrieval of the vertical moisture distribution.

RERERENCES

[1] Weinman, J.A. and P.J. Guetter: Determination of rainfall distributions from microwave radiation measured by the Nimbus 6 ESMR. J. Appl. Meteorol., 16, 437-442, 1979.

[2] Liebe, H.J. and D.H. Layton: Millimeter-wave properties of the atmosphere: Laboratory studies and propagation modelling. NTIA Report 87-224, U.S. Department of Commerce, National Telecommunications and Information Administration, Institute for Communication Sciences, 325 Broadway, Boulder, CO 80303-3328, 80 p., 1987.

[3] Mie, G.: Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen. Annalen der Physik, 25, 377-445, 1908.

[4] Deirmendjian, D.: Electromagnetic scattering on spherical polydispersions. American Elsevier Publ. Comp., New York, 290 p., 1969.

[5] Tsang, L., J.A. Kong and R.T. Shin: Theory of microwave remote sensing. John Wiley & Sons, New York, 613 p., 1985.

[6] Jackson, J.D.: Classical electrodynamics. Wiley & Sons, New York, 1962.

[7] Ulaby, F.T., R.K. Moore and A.K. Fung: Microwave remote sensing, active and passive, Vol. III: From theory to application. Addison-Wesley Publ., 1065-2162, 1986.

[8] Hollinger, J.P.: Passive microwave measurements of sea surface roughness. IEEE Trans. Geosci. Electron., GE-9, 165-169, 1971.

[9] Stogryn, A.: The emissivity of sea foam at microwave frequencies. J. Geophys. Res., 77, 1658-1666, 1972.

[10] Wilheit, T.T.: A model of the microwave emissivity of the ocean's surface as a function of wind speed. IEEE Trans. Geosci. Electron., GE-17, 244-249, 1979.

[11] Cox, C. and W. Munk: Measurement of the roughness of the sea surface from photographs of the sun glitter. J. Optical Soc. Am., 44, 838-850, 1954.

[12] Warner, J.: The water content of cumuliform cloud. Tellus, 7, 449-457, 1955.

[13] Farmer, S.A.: An investigation into the results of principal component analysis of data derived from random numbers. The Statistician, 20, 63-72, 1971.