MICROWAVE MEASUREMENTS AND THE INFLUENCES OF CLOUDS

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1. INTRODUCTION

A generally overlooked characteristic of microwave measurements is the influence of clouds and preciptiation. The assumption that microwaves are impervious to those aerosols has long been know to be inaccurate, but no sincere effort has been made compensate for the effects.

The SSM/T on the DMSP satellites provides enough spectral information to examine the phenomenon, whereas the MSU on the NOAA satellites is very poorly endowed in this respect. The main purpose of carrying a microwave instrument as part of the TOVS complement of instruments was to monitor the effects of clouds on the infrared measurements. The idea was that the microwave was impervious to clouds and could therefore be used as a quality control on TOVS soundings. However, little thought has been given to the actual effects of clouds and precipitation on the MSU Channel 2, which is the principal quality control device used with the TOVS.

The MSU has only four channels, each sensitive to portions of the atmosphere largely independent from those covered by the other three channels. However, SSM/T on the DMSP satellites is a more complete sounding device, with Channels 1-3 covering approximately the same part of the atmosphere as the MSU Channels 1 and 2. The additional channel sensitive near the surface allows analysis which cannot be done with the MSU.

2. ANALYSIS OF THE SSM/T DATA

An estimate of the total cloud liquid water over oceans has been proposed by Grody (private communication),

$$q = -0.562 + 0.00453T_1 - 0.00172T_2. \qquad (1)$$

It has been found to be rather good algorithm, and it is now used as a filter for deletion of SSM/T soundings.

To exploit this quantitative estimate, some preliminary analysis was done on five days of limb-adjusted (Wark, 1988) SSM/T Channels 1-4. Each hemisphere was divided into four grids of 64 X 64, which is approximately the footprint of the SSM/T. The window channel, Channel 1, was used as the control; each observation was compared with the value at the grid location, and if its value was lower, each of the first four channels replaced the previous value in its appropriate grid point. In this way, the Channel 1 grid became the background, devoid of clouds and with minimum water vapor; the other three grids became observations of Channels 2-4 corresponding to clear conditions but with more or less random meteorological conditions. To assure that areas of persistent cloudiness would not be included, all measurements for which q was greater than 0.02 kg/m^2 were not used. This effectively eliminated most of the ITCZ regions.

The data were examined again, this time computing values of q and finding the differences between individual observations and the grid values. These differences were averaged within increments of q, producing average values of the enhancement of the SSM/T channels versus average values of q at 22 points. The results are given in Table 1; negative values of q represent the effects of noise in Channels 1 and 2. Except for Channel 1, the data are Gaussian in their behaviors about the means, with barely perceptible skewness.

Table 1. Values of modifications of SSM/T Channels 1-4 versus cloud liquid water deduced from the Grody relation. Data were during 21-28 July 1988.

q	ΔT_1	ΔT_2	ΔT_3	ΔT_4	Sample
-0.0427	0.0000	0.0000	0.0000	0.0000	2
-0.0336	0.1855	0.1079	0.0733	0.0018	37
-0.0234	0.5483	0.1423	0.0779	0.0149	346
-0.0140	1.0556	0.3805	0.1624	-0.0017	2012
-0.0045	1.9860	0.4223	0.1286	-0.0104	4717
0.0052	3.3173	0.5007	0.1051	0.0315	7391
0.0149	4.5539	0.6926	0.1235	0.0142	7310
0.0247	6.2730	0.9770	0.2084	0.0758	5083
0.0345	7.9150	1.2341	0.2903	0.1184	3101
0.0446	10.1987	1.6344	0.4308	0.2032	1715
0.0547	12.9725	2.2879	0.6959	0.3058	1044
0.0648	15.5211	2.6342	0.7823	0.2133	638
0.0750	17.9920	2.9753	0.7639	0.1727	386
0.0847	20.3597	3.4384	0.9762	0.2783	310
0.0949	24.4608	4.1507	1.2556	0.1370	214
0.1047	25.5315	3.9295	0.9433	0.0588	168
0.1149	27.5437	3.9783	0.9275	0.0659	122
0.1252	29.9041	3.8300	1.0150	0.2877	80
0.1343	31.0534	3.2389	0.7909	0.1767	59
0.1442	33.3836	3.9971	0.6716	-0.2026	36
0.1548	34.3905	2.7390	0.2511	0.3055	13
0.1635	36.1104	3.7398	0.7604	-0.4295	3

Quadratic fits, with the negative values of q deleted and with equal weights assigned to each value, yield the relations

$$\begin{aligned}\Delta T_1 &= 0.6049 + 246.5410q - 151.8555q^2 \pm 0.7162, \\ \Delta T_2 &= -0.3116 + 64.6047q - 256.9063q^2 \pm 0.3723, \\ \Delta T_3 &= -0.2028 + 22.6095q - 111.4969q^2 \pm 0.1593, \text{ and} \\ \Delta T_4 &= -0.0491 + 7.3530q - 48.8764q^2 \pm 0.1459.\end{aligned} \tag{2}$$

The intercepts have no physical meaning, and are the products only of the procedures followed. It is gratifying to note that the quadratic term is negative for every channel, which is in accord with theory and is confirmed by a study of Fleming (private communication) which used computationally derived radiances.

Using Eq. (2) for Channel 2, the sample shows the difference exceeds the noise of 0.392K for that channel about 46% of the time. The operational standard for the deletion of SSM/T soundings is $q > 0.06\ kg/m^2$. This encompasses 15% of all oceanic soundings, and represents a cutoff of increased Channels 1-4 radiance temperatures by cloud liquid water at about 14.8K, 2.6K, 0.8K, and 0.2K for Channels 1-4. The result is that a very significant portion of the SSM/T data are warmer than they would be in clear conditions, and the ensemble contains a mixture of pure and tainted data.

3. THE EFFECTS ON RETRIEVED SOUDINGS

Temperature soundings are produced from the SSM/T measurements by a regression procedure involving matched SSM/T data and radiosonde data. In such a procedure the mean retrieval should be the same as the mean of the radiosondes, but the clear soundings will be too cold in the troposphere and the cloud-contaminated soundings will be too warm. This produces an increase in the RMS errors, which contributes a share to the comparison statistics which are regularly produced by NOAA and the ECMWF.

To give an estimate of influence of cloud contamination on RMS errors, the data were examined once more. Eliminating all data for which q was greater than $0.6\ kg/m^2$, the means and standard and maximum deviations of the temperature enhancements of Channels 1-4 from Eq. (1) were found to be

Channel 1	3.4251 ± 4.9953,	maximum 10.8204,
Channel 2	0.7604 ± 1.1653,	maximum 2.1910,
Channel 3	0.2525 ± 0.3943,	maximum 0.7027,
Channel 4	0.0741 ± 0.1206,	maximum 0.1911.

At each level of the atmosphere, the effect of this "noise" on the retrieved soundings will be proportional to the weighting functions,

$$e^2(p) = \{\sum_i [d\tau_i/d\log(p)]\sigma_i^2\}/\sum_i [d\tau_i/d\log(p)] \qquad (3)$$

where e^2 is the variance, p is pressure, τ is transmittance, i is channel, and σ is the standard deviation caused by clouds. The standard and maximum deviations, e(p) and m(p), for the troposphere are given in Table 2.

Table 2. Standard and maximum deviations of soundings caused by clouds.

Pressure (mb)	e(p) (K)	m(p) (K)
1000	1.14	2.15
850	1.08	2.04
700	0.96	1.80
500	0.71	1.33
400	0.60	1.12
300	0.52	0.96
250	0.49	0.90
200	0.46	0.84
150	0.38	0.70
100	0.23	0.42

The situation is less favorable for the TOVS soundings, particularly the "cloudy" cases in which the HIRS-2 data are not used for the troposphere. The use of a "physical" solution does not allow the same freedom to account for the influence of clouds, although "tuning" does compensate in a similar way. However, the separation of TOVS soundings into three classes of cloudiness cannot fail to result in soundings which are incompatible. The MSU Channel 2, which is similar to the SSM/T Channel 3, must surely suffer from the same degradation, namely about 0.8K to 1.0K for all "cloudy" soundings.

There does not appear to be any easy solution to this dilemma with the current TOVS system, but the emergence of the AMSU on the NOAA-K satellite should provide a literal spectrum of information to permit some adjustments to the observations and to provide quantitative tools for the elimination of hopelessly contaminated data.

The procedures given here are not recommended for adjusting SSM/T data without further study.

4. REFERENCE

Wark, D. Q., 1988: "Adjustment of Microwave Spectral Radiances of the Earth to a fixed angle of Propagation", NOAA Technical Report NESDIS-43, 40 pp.

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