Determination of Cloud Liquid Water Content Using the SSM/I

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***Abstract*—As part of a Calibration/Validation effort for the special sensor Microwave/Imager (SSM/I), coincident observations of SSM/I brightness temperatures and surface-based observations of cloud liquid water were obtained. These observations were used to validate initial algorithms and to derive an improved algorithm. The initial algorithms were divided into latitudinal-, seasonal-, and surface-type zones. It was found that these initial algorithms, which were of the D-matrix type, did not yield sufficiently accurate results. The surface-based measurements were used to derive new matrix coefficients. Various combinations of channels were investigated; however, the 85V channel was excluded because of excessive noise. It was found that there is no significant correlation between the SSM/I brightness temperatures and the surface-based cloud liquid water determination when the background surface is land or snow. A high correlation is found between brightness temperatures and ground-based measurements over the ocean.**

I. Introduction

CLOUDS have been regarded as harbingers of weather since the earliest times. Initially, observations were made with the unaided eye, but now satellites provide meteorologists with visible and infrared images of clouds for monitoring storms and their development. Microwave radiometry extends the capability to discern information about clouds. The longer wavelengths of the microwaves permit viewing into and through the cloud. Microwaves are absorbed from 10 to 100 times more by liquid water clouds than by ice clouds. This fact permits the deduction of the liquid water content of clouds if there is sufficient information to account for the effects of water vapor.

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Previous investigations have established the capability of satellite-borne microwave radiometers to make what appear to be reasonable estimates of cloud liquid water content, although validation has been qualitative. Nimbus E (5) Microwave Spectrometer (NEMS) and Electrically Scanning Microwave Radiometer (ESMR) data [1] were used for case studies and cross sections of cloud liquid water. Scanning Microwave Spectrometer (SCAMS) data [2] was used to produce monthly means of cloud water in the Pacific. The Seasat Scanning Multichannel Microwave Radiometer (SMMR) has been used to make cloud liquid water determinations in the North Atlantic [3].

The Special Sensor Microwave/Imager (SSM/I) is a seven-channel four-frequency radiometer whose frequencies are 19.35, 22.235, 37.0, and 85.5 GHz. All frequencies are received in vertical (V) and horizontal (H) polarization, except 22 GHz, which is received in vertical polarization only. The SSM/I has a conical scan with a swath width of 1400 km and operates continuously. The Effective Fields-of-View (EFOV) of the SSM/I channels are 43 × 60, 40 × 50, 28 × 37, and 13 × 15 km, respectively. The SSM/I is described more fully in [4].

One of the purposes of the Calibration/Validation effort was to establish how well the SSM/I and the corresponding algorithms [5] could measure the amount of cloud liquid water in the atmosphere. If the initial values were not sufficiently accurate, improvements in the algorithm were to be attempted.

II. Surface Measurements

To assess the initial algorithm, it was necessary to have surface-based measurements of cloud liquid water that were coincident with the satellite measurements. One of the very few sources of routine cloud liquid water measurements is the NOAA Profiler Network based in Colorado and operated by NOAA's Wave Propagation Laboratory (WPL) [6]. To validate the SSM/I's capability for measuring cloud liquid water over the ocean, it was necessary to arrange for special observations. These were made from San Nicolas Island by NOAA-WPL personnel as part of Project FIRE, and from Kwajalein Island by University of Massachusetts (UMass) personnel.

NOAA operates dual-channel microwave radiometers at four locations in Colorado: Denver's Stapleton Airport

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(39.8°N, 105°W), Flagler (39.1°N, 103°W), Fleming (40.6°N, 103°W), and Platteville (40.2°N, 105°W). Radiometric data at 20.6 and 31.65 GHz are processed to produce integrated amounts of atmospheric water vapor and cloud liquid water. The radiometers at Denver also have channels in the 60-GHz oxygen complex to determine vertical temperature profiles.

Validation of the initial algorithm required surface observations over a range of surface conditions and seasons. To ensure such a range, data from the Profiler Network were acquired for two periods: July 15–October 15, 1987, and January 15–April 15, 1988. The characteristics of the Profiler Network radiometers are summarized in Table I. The Profiler Network observations are transmitted to a "hub" in Boulder.

In addition to the operational radiometer system just described, WPL also operates a portable radiometer with a fully steerable antenna beam [7]. This radiometer operates at 20.6, 31.65, and 90 GHz. As part of a regional cloud properties experiment (Project FIRE), the NOAA steerable radiometer was transported to San Nicolas Island (33°N, 119°W), and measurements were made between June 29 and July 19, 1987, coincident with the launch of the SSM/I. The data from the steerable radiometer have the same format as the data from the Profiler Network. The characteristics of the steerable beam radiometer are also summarized in Table I.

The important features of the NOAA profiler network radiometers are summarized in Table I. The EFOV's, presented in Table I, are characterized by both their 3 dB beamwidth and "footprint" size at 1 km.

The accuracy of the NOAA profiling radiometer's retrievals of cloud liquid water has been estimated to be 5.2×10^{-3} kg/m^2 [8].

The Kwajalein upward-looking cloud liquid water measurements were made using the UMass autocorrelation radiometer (CORRAD) [9] and an auxiliary single-frequency radiometer at 37 GHz. The CORRAD operates between 20.5 and 23.5 GHz spanning the water vapor line at 22.235 GHz. Data were taken from Kwajalein Island (8.7°N, 167.7°E) between March 24 and April 7, 1988.

The operating characteristics of the CORRAD are presented in Table II. The radiometer's beam is steerable.

The precision of the CORRAD determinations has been estimated [10] to be 0.008 kg/m^2. Uncertainties in the calibration of the radiometers could yield a bias of 0.03 kg/m^2. The CORRAD retrieval algorithm uses 21.0-, 22.2-, and 37-GHz channels to retrieve CLW and water vapor by minimum squared error matrix inversion of the radiative transfer equation (RTE). The uncertainties were estimated using measured radiometer parameters and the RTE.

Data from the NOAA profiling radiometers were supplied to NESDIS by WPL on computer compatible tapes. The cloud liquid water retrievals were at the sampling interval frequency. The CORRAD data were received in tabular form also at the sampling interval. The SSM/I data were matched against the profiler's latitude and longitude, and a 2° × 2° array of brightness temperatures was saved. Only the brightness temperatures from the closest SSM/I pixel were used in the data analysis.

TABLE I
CHARACTERISTICS OF NOAA PROFILING RADIOMETERS

NOAA Profiler Network	EFOV		Sampling Time
	Degrees	Spot	
Denver	2.5	44 m	2 min
Fleming	4	70 m	2 min
Flagler	4	70 m	2 min
Platteville	4	70 m	2 min
Steerable Radiometer	2.5	44 m	1 min

TABLE II
CHARACTERISTICS OF CORRAD

RF Bandpass	20.5–23.5 GHz
Time Delays	−0.2 to 6.1 ns (0.1 ns steps)
Frequency Resolution	160/100 MHz (3 dB)
Receiver Noise Temp.	2000 K
Noise Floor (ΔT)	0.5 K/(s)$^{1/2}$
EFOV	2°
Footprint @ 1 km	35 m
Sampling Time	10 min

An obvious problem in the analysis is the disparate sizes of the EFOV's of the upward- and downward-looking radiometers. We attempted to compensate for this difference by averaging the upward-looking radiometric observations. We averaged the NOAA profiling data for ±1 h from the satellite overpass time. The SSM/I data are sampled on a 25 km grid (12.5 km for the 85 GHz data). The 2-h average thus corresponds to a wind speed of about 13 km/h. For the UMass (CORRAD) data, we only averaged the data ±1/2 h from the satellite overpass. The difference in procedures is due to the differences in recording procedures. The NOAA profiling radiometers are automated and record data every 1 or 2 min. The CORRAD is manually operated and takes data every 10 min. The 1/2 h averaging time was a compromise between extending the field of view and keeping as many data points as possible. In some instances, the CORRAD observations were not available 1 h after the satellite overpass.

The data taken at San Nicolas Island attempted to characterize marine stratus clouds. Typically, marine stratus are low-level clouds, composed of liquid water, and comparatively thin optically. Their liquid water content is usually low, but they tend to be relatively uniform over an extended region. The Kwajalein Island data set comes from the tropics and shows greater liquid water values than the San Nicolas Island data set.

III. Initial Algorithm

The initial algorithm [5] used to retrieve cloud liquid water was a linear, four-channel algorithm that was generated by regression using brightness temperatures calculated from simulated clouds and a radiative transfer model. The algorithm was divided into latitudinal and seasonal segments called climate codes. There were 11 climate codes per hemisphere. Over the ocean there were nine distinct sets of coefficients that used the 19*H*, 22*V*, 37*V*, and 37*H* channels. Over land there was one set of coefficients per climate code which used the 19*V*, 19*H*, 37*V*, and 85*V* channels. Another set of coefficients was used to retrieve cloud water over snow. This set of coefficients was used for all climate codes and utilized the 22*V*, 37*H*, 85*V*, and 85*H* channels.

Hemispherically, the latitude zones were 60°–90°, the polar zone; 55°–60°, a transition zone; 25°–55°, the temperate zone; 20°–25°, a transition zone; and 0°–20°, the tropical zone. The opposite hemisphere is seasonally adjusted so that seasonal algorithms are used in the appropriate season and latitude zone.

Two special categories of retrievals were created: out-of-limits and indeterminate. All geophysical retrievals are tested to determine whether they are within a physically possible range of values. If they are outside the physically possible range, they are assigned an out-of-limits value, usually 1 less than the maximum number of counts allocated for that parameter. The indeterminate classification implies that certain logical conditions are not being met or the pixel under consideration may be part ocean and part land (i.e., coastal). The indeterminate category is assigned the maximum count value.

We found that more than 90% of all retrieved values of cloud liquid water were either out-of-limits or indeterminate values. This percentage was found at all test sites and before and after the SSM/I's shutdown during December 1987 and January 1988. Because of this finding, we decided to improve the algorithm.

IV. Improved Algorithm

The approach taken to find a cloud liquid water algorithm was to use the upward-looking radiometer determinations of cloud liquid water as "truth." Surface values and brightness temperatures were matched, and standard linear regression techniques were used to find the best set of channels and coefficients. The land and ocean cases were separated, and the land cases were further divided into snow and no-snow groups by using 19–85*H* > 8 K (for snow) and NWS maps of weekly snow cover. The 85*V* channel was excluded from consideration because of its increased noise level.

Initial correlations on the land data set, which consisted of clear and cloudy cases, yielded very low correlation coefficients. Next, clear cases or very thin clouds (CLW's < 0.005 kg/m^2) were excluded from the land data set. For the remaining cases, the correlation coefficient is improved. The best values are given in Table III. The channels which give the best correlation are 19*V*, 19*H*, 37*V*, and 85*H*.

The snow data set was analyzed for cloud liquid water content in the same way. First, the entire data set was analyzed, and then the cases where the CLW content was <0.005 kg/m^2 were excluded. The results are presented in Table III.

TABLE III
CLOUD LIQUID WATER RESULTS

No. Obs.	Cor. Coeff.	Mean (kg/m^2)	Rms Diff. (kg/m^2)
		Land	
232	0.214	0.005	0.021
		CLW > 0.005	
32	0.445	0.037	0.045
		Snow	
201	0.185	0.007	0.031
		CLW > 0.005	
41	0.369	0.032	0.063

In Table III, Rms Diff = the rms difference between the SSM/I value and the upward-looking value, and the Mean is the sample mean as determined from the upward-looking measurements.

Results over the ocean were much better than those over land. We analyzed the data from San Nicolas Island and Kwajalein as a combined data set. The combined data sets have a mean value of 0.136 kg/m^2 and a standard deviation of 0.077 kg/m^2. The correlation coefficient for the combined data set is 0.89. This is from the best four-channel fit to the combined data set and uses the 19*H*, 22*V*, 37*V*, and 85*H* channels. Fig. 1 is a scatter plot of the combined data set.

We investigated, and are continuing to investigate, many combinations of channels. Because the existing retrieval software is configured for 4-channel retrievals, we concentrated our efforts on finding the best 4-channel algorithm. Because of its increased noise, Channel 6, 85*V*, was excluded from consideration. The remaining 15 combinations were investigated.

Our retrieval equation is linear in brightness temperature and of the form $CLW = a_0 + \Sigma\, a_i * T_{Bi}$, $i = 1, 2, \cdots, 7$ (1) where the a_i's are coefficients and the T_{Bi}'s are brightness temperatures. They are further defined in Table IV.

Because of the limited size of the ocean data set, further statistical analysis was performed following procedures outlined in [11]. First, we generated a quasi-independent data set by using 19 of the 20 points as dependent data and predicting the 20th. This was repeated until all 20 points had been predicted independently. We used the same four channels that gave the lowest rms difference for the completely dependent data set. This procedure is sometimes called cross validation [11].

Using a procedure known as jackknifing [11], [12], we generated another independent estimate of the retrieved mean, standard deviation, and rms difference between the retrievals and the ground based cloud liquid water measurements. The relationship [11] $(PARMSTAR)_i = 20 * PARMALL - 19 * (PARM)_i$; where PARMALL is the parameter from the completely dependent data set, and PARM is the parameter when it is calculated from a data

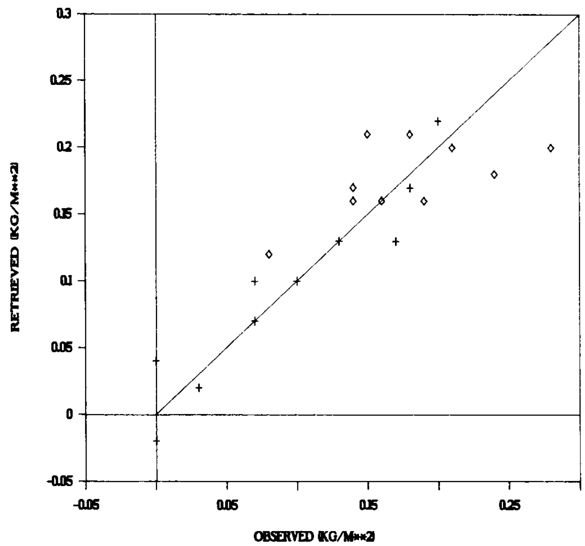

Fig. 1. A plot of retrieved versus observed cloud liquid water for the combined San Nicolas and Kwajalein data sets. The units are in kg/m^2. The San Nicolas points are shown as pluses and the Kwajalein points are shown as diamonds. The solid line is the "perfect agreement" line. The retrieved values are from the dependent data set.

TABLE IV

Coefficient	4-Channel	Symbol	Channel
a_0	-3.14559		
a_1	0	T_{B1}	19V
a_2	$6.0257\,E-3$	T_{B2}	19H
a_3	$-4.8803\,E-3$	T_{B3}	22V
a_4	$1.9595\,E-2$	T_{B4}	37V
a_5	0	T_{B5}	37H
a_6	0	T_{B6}	85V
a_7	$-3.0107\,E-3$	T_{B7}	85H

TABLE V

	Obs.	Regr.	Cross-Val.	Jackknife
Number of Cases	20	20	20	20
Minimum	0.00	−0.02	−0.04	—
Maximum	0.28	0.22	0.23	—
Mean	0.136	0.136	0.140	0.136
SD	0.077	0.067	0.068	0.077
Rms Diff.	—	0.035	0.048	0.040

set of 19 points. The jackknifed values presented in Table V are averages of 20 such computations of PARMSTAR for each parameter. Table V presents a summary of the observed and three retrieved data sets.

The three retrieved data sets are quite consistent. All have a negligible bias about the mean when compared to the observed data set. The standard deviations of the retrieved values are slightly smaller than the standard deviation of the observed value—a fact not uncommon to regression algorithms. The rms differences are remarkably similar for the three computations. Even though the sample size is small, there are 4 predictors and 15° of freedom. The algorithm presented in Table IV seems to be statistically significant and "robust."

V. Conclusions and Discussion

We examined six months of data over land for a variety of surface conditions and found very low correlations between SSM/I brightness temperatures and measured amounts of cloud liquid water. As a second step, we excluded very small or zero values of measured cloud liquid water from the data set. In effect, we only attempted to predict liquid water when we knew liquid water was present. Even here, the correlation coefficients indicated little skill in predicting cloud liquid water over land. It may be that the polarization difference at 85 GHz is a useful predictor for cloud liquid water, but we were unable to give serious consideration to this because of the excessive noise in the present SSM/I's 85V channel and the requirement to improve the present retrievals of cloud liquid water. Precipitation would also complicate using the 85V to retrieve cloud liquid water.

Colorado may not be the ideal locale for this kind of experiment because of its altitude and rather dry climate. It does appear that the measurement of cloud liquid water over land will not be easily solved.

Over the ocean, the SSM/I brightness temperatures are highly correlated with cloud liquid water amounts in nonprecipitating clouds. A correlation coefficient of 0.89 was obtained. Rms differences between surface and satellite measurements are about 30%. Fig. 1 suggests that the algorithm may have difficulty retrieving zero CLW values. As is well known, regression algorithm work best around the mean value of the dependent data set.

We examined all possible four-channel combinations, and also an algorithm using six channels. The two additional channels added very little to the quality of the retrievals. The explained variance increased and so did the rms error, due to the reduced number of degrees of freedom. As part of our extended statistical analysis, we found the 37V channel alone to be a very good predictor of CLW. The correlation coefficient for 37V alone is 0.87. In the algorithm presented in Table IV, the 37V channel is from 15 to 29 times more important than any of the other three channels.

It should be noted that the SSM/I data are not contiguous in their coverage because the swath width is only 1400 km. Thus, there will be days when the SSM/I data will not be available or when only a single overpass will be available. During the Project FIRE data collection period, the SSM/I experienced its initial overheating problems and was on and off. Also, there were occasional data dropouts during all data taking periods.

When allowances for EFOV differences and SSM/I gridding problems are made, these results must be considered very encouraging for the operational production of useful cloud liquid water amounts.

Since the preparation of this paper, the 85H channel has failed. We have developed a four-channel algorithm that uses the 19*H*, 22*V*, 37*V*, and 37*H* channels. Results are slightly less accurate than the algorithm presented in the text.

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REFERENCES

[1] D. H. Staelin *et al.*, "Remote sensing of atmospheric water vapor and liquid water with the Nimbus 5 microwave spectrometer," *J. Appl. Meteor.*, vol. 15, pp. 1204-1214, 1976.
[2] N. C. Grody, A. Gruber, and W. C. Shen, "Atmospheric water content over the tropical Pacific derived from the Nimbus-6 scanning microwave spectrometer," *J. Appl. Meteor.*, vol. 19, pp. 986-996, 1980.
[3] K. B. Katsaros, P. K. Taylor, J. C. Alishouse, and R. G. Lipes, "Quality of SEASAT SMMR (Scanning Multichannel Microwave Radiometer) atmospheric water determinations," in *Oceanography From Space*, J. F. R. Gower, Ed. New York: Plenum, 1981, pp. 691-706.
[4] J. P. Hollinger, J. L. Peirce, and G. A. Poe, "SSM/I instrument evaluation," *IEEE Trans. Geosci. Remote Sensing*, this issue, pp. 781-790.
[5] J. Hollinger, R. Lo, G. Poe, R. Savage, and J. Peirce, *Special Sensor Microwave/Imager Users Guide*, Naval Res. Lab., Washington, DC, 1987, 120 pp.
[6] D. C. Hogg *et al.*, "An automatic profiler of the temperature, wind and humidity in the troposphere," *J. Clim. Appl. Meteor.*, vol. 22, pp. 807-831, 1983.
[7] D. C. Hogg, F. O. Guiraud, J. B. Snider, M. T. Decker, and E. R. Westwater, "A steerable dual-channel microwave radiometer for measurement of water vapor and liquid in the troposphere," *J. Clim. Appl. Meteor.*, vol. 22, pp. 789-806, 1983.
[8] P. Ciotti, E. R. Westwater, M. T. Decker, A. J. Bedard, and B. B. Stankow, "Ground based microwave radiometric observations of the temporal variations of atmospheric geopotential height and thickness," *IEEE Trans. Geosci. Remote Sensing*, vol. GE-25, pp. 600-615, 1987.
[9] C. S. Ruf and C. T. Swift, "Atmospheric profiling of water vapor density with a 20.5-23.5 GHz autocorrelation radiometer," *J. Atmos. Ocean. Tech.*, vol. 5, pp. 539-546, 1988.
[10] C. S. Ruf, Jet Propulsion Lab., Pasadena, CA, 1989 (unpublished manuscript).
[11] F. Mosteller and J. W. Tukey, *Data Analysis and Regression*. Reading, MA: Addison-Wesley, 1977, pp. 588.
[12] B. W. Tichelaar and L. J. Ruff, "How good are our best models?" *EOS*, vol. 70, no. 20, pp. 593-606, 1989.

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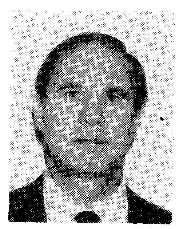

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