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A PASSIVE MICROWAVE OPTIMAL-ESTIMATION ALGORITHM FOR NEAR REAL-TIME WATER VAPOR PROFILING

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1. INTRODUCTION

Knowledge of the horizontal and vertical distribution of water vapor on the global scale is required for applications ranging from numerical weather forecasting to climate modeling and climate change studies. Because of their global clear and cloudy sky water vapor measurement ability, passive microwave satellite sensors, such as the Advanced Microwave Sounding Unit (AMSU), are a primary source of data for fulfilling this requirement. Due to the complex nature of the atmosphere and the increasing volume of data in the Earth Observing System (EOS) era, sophisticated and efficient and methods are needed to extract water vapor fields from these data. An optimal-estimation algorithm has therefore been developed for the retrieval of water vapor profiles from passive microwave observations.

The algorithm described herein uses the method of Rodgers (1976) to simultaneously retrieve profiles of temperature and water vapor as well as cloud water path and surface emissivity. Because of the highly coupled nature of the atmosphere and the sensitivity of microwave measurements to each of these parameters, more accurate retrievals of each can be achieved through a simultaneous retrieval. Furthermore, the retrieval method is quite general, making it flexible in terms of data used and parameters retrieved. New data sources and retrieval parameters can be added easily, and in a more physical manner given the simultaneous retrieval ability, relative to statistical regression real-time algorithms.

The algorithm has been tested using simulated data (McKague et al. 2001). In this paper, the algorithm is demonstrated using data from AMSU with comparisons to an independent retrieval of total precipitable water. The algorithm is shown to be accurate while also being efficient enough to be run in real-time.

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2. ALGORITHM DESCRIPTION

The retrieval algorithm is a physically based iterative optimal-estimation scheme (OE algorithm) adapted from the method of Engelen and Stephens (1999). The algorithm can take data from AMSU-B, from AMSU-B and AMSU-A combined, from SSM/T-2, or from the upcoming SSMIS instrument. A variety of parameters can be retrieved including profiles of water vapor mixing ratio, joint water vapor and temperature profiles (including surface temperature), and water vapor and temperature profiles along with microwave surface emissivities.

The retrieval scheme requires a first guess of the water vapor and temperature profiles as well surface emissivities at the relevant microwave frequencies. This first guess comes from climatology. An a priori distribution of the retrieval parameters is used to constrain a non-linear iterative optimal-estimation scheme which uses the method of Rogers (1976) to minimize the cost function Φ to find the optimal solution x, where:

$$\Phi = (x - x_a)^T S_a^{-1} (x - x_a) + \{y - F(x)\}^T S_y^{-1} \{y - F(x)\}$$

where x is the vector of parameters to be retrieved, x_a is the a priori vector, y is the set of observations, F(x) is a forward radiative transfer model used to compute radiances given x, and S_a and S_y are the error covariance matrixes of the a priori data and the observations, respectively. The vector of retrieval parameters may include the profile of water vapor mixing ratio alone, or may include the temperature profile and surface emissivities as well. The a priori error covariance matrix includes the variances of and correlations between the retrieval parameters, thus providing a constraint on the solution from a priori knowledge. The error covariance matrix of the observations includes forward model errors and uncertainty in the observed radiances.

For the forward radiative transfer, monochromatic microwave brightness temperatures are computed using numerical integration of the radiative transfer equation for a plane parallel, absorbing atmosphere together with Liebe's MPM92 (Liebe and Hufford 1993) model of microwave atmospheric attenuation. Only liquid clouds are included. An analytic Jacobian has been developed for the radiative transfer model. The ocean surface model of Yueh (1997) is used to compute microwave emissivities at the appropriate frequencies.

3. NEAR REAL-TIME PROCESSING

Near real-time processing of AMSU data through the OE algorithm has been producing profiles of water vapor and temperature as well as cloud water path and surface emissivity estimates for the NOAA-15 and NOAA-16 satellites since August of 2002. Retrievals are produced only in non-precipitating areas over open ocean. The Microwave Surface and Precipitation Products System (MSPPS) precipitation screen was used to eliminate precipitating pixels. The mean fields for the combined NOAA-88 and TIGR datasets of temperature and water vapor mixing ratio have been used for the first guess. For the first guess surface emissivity, the temperature of the lowest level was input to the model of Yueh (1997). The MSPPS algorithm was used as the first guess for cloud water path.

The a priori error covariance matrix S_a was computed using the combined NOAA-88 and TIGR profile datasets. The error covariance matrix for the observations, S_y, was computed using the AMSU characteristics in Table 1. The AMSU channels were assumed to be uncorrelated. Forward model error was not included in S_y. AMSU-B observations are averaged to the scale of the AMSU-A before being input to the retrieval algorithm.

The processing is done on four 1.6 GHz Pentium IV equipped PCs. One day of AMSU data (14 orbits) can be processed in approximately 4.25 hours for full water vapor profile, temperature profile, cloud water path, and surface emissivity retrievals. This level of processing efficiency is largely due to the use of an analytic Jacobian in the OE algorithm; if a numerical Jacobian were used, processing requirements would increase by about a factor of 15.

Figures 1 through 5 show example output from the algorithm. Figure 6 shows a comparison of total precipitable water retrievals, computed by integrating the water vapor profile and adding cloud water path, with MSPPS total precipitable water retrieved from AMSU-A. The two retrievals match well, with a correlation of 99%.

	Channel	Frequency (GHz)	NEDT (K)
AMSU-A	1	23.8	0.3
	2	31.4	0.3
	3	50.3	0.4
	4	52.8	0.25
	5	$53.596 \pm .115$	0.25
	6	54.4	0.25
	7	54.94	0.25
	8	55.5	0.25
	9	$57.290344 = f_0$	0.25
	10	$f_0 \pm .217$	0.4
	11	$f_0 \pm .3222 \pm .048$	0.4
	12	$F_0 \pm .3222 \pm .022$	0.6
	13	$f_0 \pm .3222 \pm .010$	0.8
	14	$F_0 \pm .3222 \pm .0045$	1.2
	15	89.0	0.5
AMSU-B	1	89.0	2.0
	2	150.0	2.0
	3	183.31 ± 1.0	2.0
	4	183.31 ± 3.0	2.0
	5	183.31 ± 7.0	2.0

Table 1. AMSU characteristics used in retrievals.

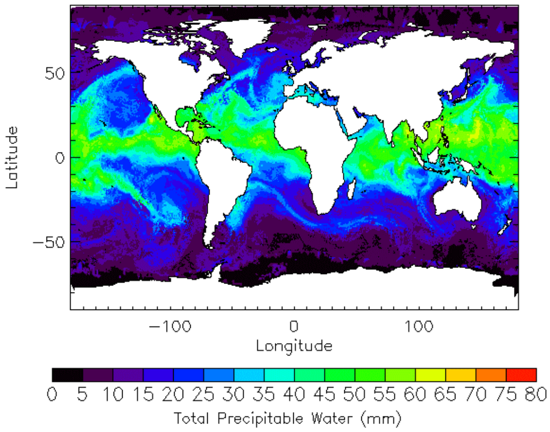

Figure 1. Global distribution of total precipitable water from the NOAA-16 AMSU on September 20, 2002 using the OE algorithm.

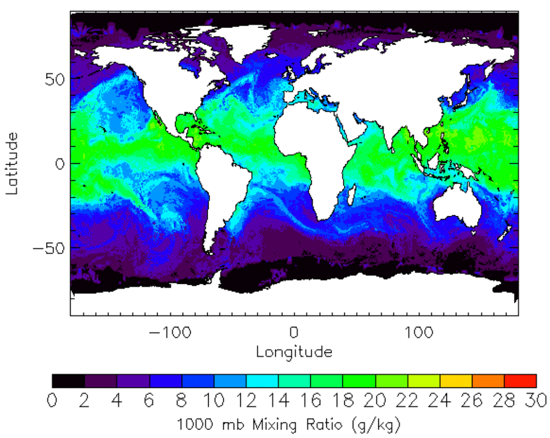

Figure 2. Global distribution of 1000 mb water vapor mixing ratio from the NOAA-16 AMSU on September 20, 2002 using the OE algorithm.

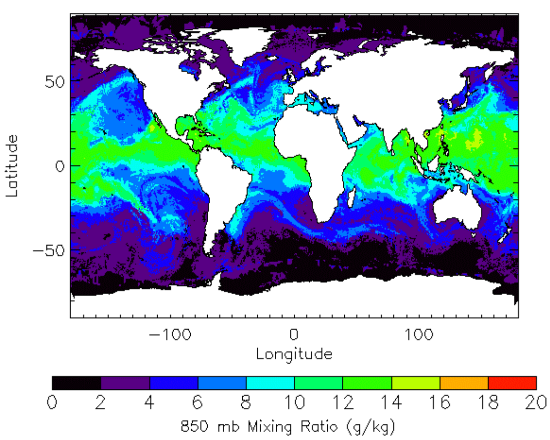

Figure 3. Global distribution of 850 mb water vapor mixing ratio from the NOAA-16 AMSU on September 20, 2002 using the OE algorithm.

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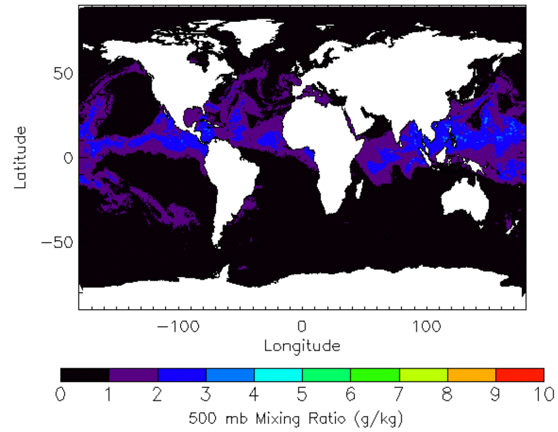

Figure 4. Global distribution of 500 mb water vapor mixing ratio from the NOAA-16 AMSU on September 20, 2002 using the OE algorithm.

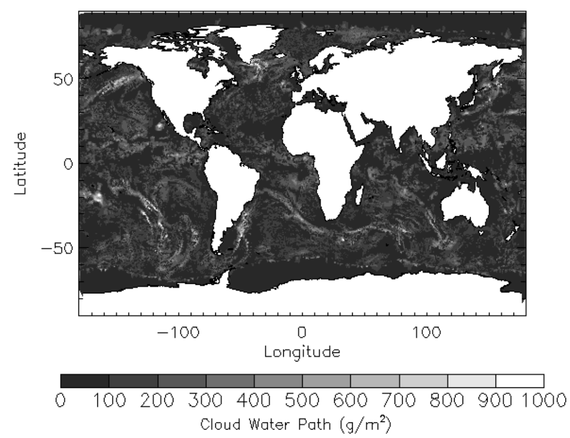

Figure 5. Global distribution of liquid cloud water path from the NOAA-16 AMSU on September 20, 2002 using the OE algorithm.

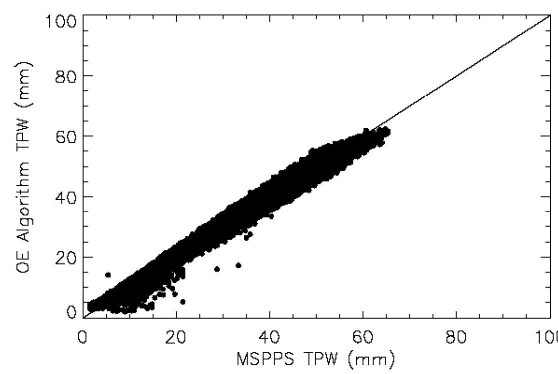

Figure 6. Comparison of OE algorithm derived total precipitable water and MSPPS AMSU-A retrieved total precipitable water for September 20, 2002. Correlation between the two is 99%.

4. CONCLUSIONS AND FUTURE WORK

An algorithm for the retrieval of water vapor profiles from passive microwave satellite observations has been presented. The algorithm is quite general, in that it can be applied to data from AMSU as well as other satellite platforms such as SSM/T-2 and the upcoming SSM/IS instrument. Water vapor profiles can be retrieved with or without profiles of temperature profiles, cloud water path, and surface emissivities. The algorithm is efficient enough to process data in real-time and compares well with an independent total precipitable water algorithm.

A number of upgrades will be made to the algorithm in the future. These include:

- Averaging AMSU-B observations to the AMSU-A using Backus-Gilbert processing (Jones et al. 2003)
- Integration of the algorithm into CIRA's DPEAS processing environment (Jones and Vonder Haar 2002)
- Including the effects of scattering in the radiative transfer model and associated Jacobian
- Including the ice clouds in the retrieval
- Assessing retrieval performance in light precipitation
- Producing covariance matrixes of land surface emissivities for the retrieval of profiles over land
- Comparison of retrieved profiles with rawinsonde data
- Additional sources of data will be added starting with the AMSU on board NOAA-17 and SSMIS
- IR data will also be added for improved cloud retrievals

5. ACKNOWLEDGMENTS

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