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CHARACTERIZATION OF GLOBAL MICROWAVE SURFACE EMISSIVITY OVER LAND

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1. INTRODUCTION

Microwave remote sensing from satellites has proven to be a valuable tool for observing Earth. Microwave satellite products showing such varied parameters as total precipitable water, precipitation, and sea ice are routinely produced and used by forecasters worldwide. Unfortunately many of these fields are only produced over the ocean. The reason many satellite microwave retrievals are possible over ocean and not over land is due to the complex, variable, and poorly known microwave emissivity of land (and snow and ice) surfaces (Jones and Vonder Haar, 1997; Prigent et al., 2002; Bennartz et al., 2002).

Modern weather satellites measure passive microwave radiation in the range from 6 to 183 GHz. Physical models have existed for decades which specify the dielectric properties of seawater in this frequency range as a function of a few variables such as sea surface temperature, wind speed, and salinity. Knowledge of the viewing angle allows the dielectric properties to be converted into emissivity at vertical and horizontal polarizations. Over oceans, the surface emissivity ranges from about 0.5 to 0.7. Over land and ice, the surface is more complex due to variable surface types and vegetation. A typical emissivity value over land might be 0.95, much higher than over ocean. The higher emissivity itself makes it more difficult to sense atmospheric phenomena over land, since the surface appears radiometrically brighter. In addition, time-dependent changes in the surface, such as the seasonal cycle of vegetation, affect the emissivity. Soil moisture changes in the upper few mm of the surface are a large source of variability of the microwave emissivity at 6 to 183 GHz on a timescale of hours to days.

2. RESEARCH GOALS

NOAA has developed a microwave land surface emissivity model which shows promise in enhancing the assimilation of microwave satellite data. The NESDIS Microwave Land Emissivity Model (MEM) (Weng et al., 2001) is used within the NOAA Global Data Assimilation System (GDAS) to determine important surface behaviors for microwave sensors. This includes sensors such as the NOAA Advanced Microwave Sounding Unit (AMSU) and other microwave sensors. The MEM allows the GDAS system to account for background variability of the land surface emissivity, and to obtain a stronger signal of Earth's atmosphere. This results in improved NOAA weather forecasts. Our research focuses on the observational validation of the NESDIS MEM using fairly sophisticated cross-sensor satellite data analysis to verify the integrity of the MEM output.

Our goals are to:

1. Conduct an error analysis of the MEM model via creation of a Global Microwave Surface Emissivity Validation Atlas (GMSEVA).
2. Generalize the error characterization approach to future NESDIS/NWS Observational Operator (OO) needs including new upcoming sensors.
3. A parallel goal is to perform a simultaneous retrieval of water vapor, cloud and temperature profiles over land (Forsythe et al., 2004).

A previous multisensor approach (Jones and Vonder Haar, 1997) has now been generalized to optimize all state variables simultaneously and is hosted within a flexible grid computing system (Jones and Vonder Haar, 2002) that ensures a smooth technology transition path for the complex cross-sensor aspects necessary for this work. This work represents an improved 2nd generation algorithm. Earlier existing emissivity retrieval methods (e.g., Jones and Vonder Haar, 1997; Prigent 1997, 2000; Ruston 2003) tend to rely on IR radiances from the surface that can have significant cloud contamination issues, including their own infrared surface emissivity biases. This can seriously impact the availability of these products in real-time for weather prediction use. This work is important since it substantially improves the availability of the microwave surface emissivity product for operational use. In regions of extremely thick clouds and possible precipitation, a hybrid-model/observational approach would likely be the recommended system to implement for operations. This work attempts to address these operational implementation issues quantitatively.

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In this paper, the new method is discussed and an outline of our approach to the NOAA MEM intercomparisons is presented. Much of the testing is still work in progress. Additional intercomparison work to existing emissivity retrieval methodologies is underway in collaborations with other JCSDA scientists. The latest emissivity results will be presented at the Symposium.

3. 1DVAR EMISSIVITY RETRIEVAL METHOD

By using radiances from the Advanced Microwave Sounding Unit (AMSU) A and B instruments, 20 channels are available to retrieve atmospheric profiles and surface properties. However the method is fully generalizable to other microwave sensors, and efforts are currently underway to also use WindSat data in a similar fashion for soil moisture retrievals (Jones et al., 2004) and related surface emissivity characterizations.

The retrieval algorithm is a physically-based optimal-estimation (OE) scheme adapted from the method of Engelen and Stephens (1999). The algorithm takes combined data from AMSU-A and AMSU-B. Since it is a physical retrieval, it is flexible to allow insertion of future sensors, only the channelization and instrument noise must be specified. The retrieval scheme requires a first guess of the water vapor and temperature profiles as well as surface emissivities at the relevant microwave frequencies. This first guess for moisture can come from climatology, or from global model output such as from GDAS. 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 to find the optimal solution x, where:

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

where x is the vector of parameters to be retrieved, xa 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 Sa and Sy are the error covariance matrixes of the a priori data and the observations, respectively. 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. One of the objectives of this work is to refine the knowledge of the correlation matrix between emissivities at various frequencies. Currently, we use a loose correlation constraint to allow the retrieval to iterate to a solution. A maximum of 12 iterations is currently specified, which is exceeded only 1 – 2% of the time. Causes for this include inadequate precipitation detection. The error covariance matrix of the observations includes forward model errors and uncertainty in the observed radiances.

4. RESULTS

The current system is now fully integrated within the Data Processing and Error Analysis System (DPEAS) (Jones and Vonder Haar, 2002). This allows for grid computing technologies to be employed to spread the computations around normal desktop computers for parallel processing. This substantially reduces the cost for implementing such a computationally intensive system. Recent improvements to the system include a flexible pressure coordinate system with a false pseudo-top, that can be computationally adjusted dynamically further reducing computational costs and improving the radiative transfer modeling (RTM) accuracies. In addition fractional surface layers have been added to more finely adjust the RTM within regions of high topographic relief. Current validation activities using sounding data sets over ocean islands have been used to test and drive development of a new AMSU-B antenna pattern correction algorithm (APC) (Nielsen et al., 2004). These results are being further validated using the current system.

A fairly strong signal to noise ratio for emissivity signal has been found in the initial results with observation to apriori variance strength ratios being on the order of 2-3 for most window channels. Thus the observations are driving adjustments to the emissivity model first guess fields, which were specified to be “state-of-the-art”. This suggests that the observational value and worth of the emissivities is strong. However, these results are preliminary at this time, and further comprehensive validation is necessary before general conclusions can be made, but the results are very encouraging.

Intercomparisons to the NOAA MEM first guess fields, and to the NRL emissivity retrievals using HIRS land surface temperature retrievals is also currently underway. The initial period for the intercomparison is March-April 2003, and Sep. 2003. This work will focus on the differences between the approaches, and suggest areas for further improvements.

5. CONCLUSIONS

Key features of the new system are:

- Realtime performance capabilities, due to a fast analytic RTM Jacobian, and automatic parallelization capabilities,
- Graceful degradation is implemented for partial channel loss,
- Implemention of a new AMSU-B APC method allows the minimization of known systematic biases from the validation effort,
- Simultaneous cross-sensor methodology is not limited to a single platform, or fixed viewing geometries. This means that results are not “staged”, i.e., incrementing from one sensor product to another, instead information flows are bidirectional between sensors, as it ideally should be,
- Intercomparisons against several other (non-native) emissivity measurement methods are now possible using the newly constructed generalized framework,
- New sensors can be easily used (microwave and infrared), thus research experiments

regarding the cloud impacts and other sensor-dependent phenomena can be systematically analyzed,

- There is also well-planned and demonstrated technology-transfer path (versions of the CIRA DPEAS system are running at NESDIS/OSDPD and the Army Research Laboratory).

This feature set makes the current system a rich research environment for improvements to the understanding and characterization of the microwave surface emissivity over land. This work has applications to future microwave platforms such as NPP and NPOESS CMIS, each of which carry passive microwave imagers and sounders. In particular, improved knowledge of global land surface emissivity values and their variance and covariance will be needed before these measurements can achieve their full potential in weather prediction data assimilation systems.

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