P3.16 COMPARISON OF MODELED AND RETRIEVED MICROWAVE EMISSIVITIES FROM AMSU OVER NORTHERN AFRICA AND THE MIDDLE EAST

Benjamin Ruston* and Nancy Baker
Naval Research Laboratory, Monterey, California

1. INTRODUCTION

Precise knowledge of the microwave land emissivity allows accurate land surface temperature retrievals, increases the sensitivity of profiling retrievals to lower tropospheric temperature, and allows better diagnosis of cloud properties over land surfaces. Characterization of the global microwave emissivity at spatial scales of 10 – 60 km typical of a satellite footprint is needed for all surfaces whether they are vegetated, snow covered, or arid barren areas. A forward Microwave Emissivity Model (MEM) has been developed by Fuzhong Weng et al. (2001) with additions by Banghua Yan in the Office of Research and Applications (ORA) at the National Environmental Satellite, Data, and Information Service (NESDIS). Soil and vegetation types and coverages are required as input to the MEM, along with an estimate of the soil moisture content. The Global Land Data Assimilation System (GLDAS) has compiled static databases to characterize the land surface soil and vegetation, while the soil moisture estimates are given by the boundary layer model in the National Centers for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS). Using these input data, the MEM can generate emissivities for any microwave frequency and viewing angle. These modeled emissivities are compared to a retrieval of the microwave emissivity performed for the AMSU/A instrument. The observational retrieval employs short-term forecasts from the Navy Operational Global Atmospheric Prediction System (NOGAPS) and satellite data from both the High Resolution Infrared Radiation Sounder Version 3 (HIRS/3) and the Advanced Microwave Sounding Unit (AMSU). The HIRS/3 and AMSU sensors fly aboard the same satellite bus, so there is no need for temporal interpolation of the instrument data. The infrared data from the HIRS/3 instrument is used to retrieve the land surface temperature in the observational retrieval. Minimizing error in the land surface temperature is of importance because the dominant component in the microwave emissivity error budget is the land surface temperature. The comparisons of observed and modeled microwave land emissivities are used to evaluate the performance of the MEM, and analyze the precision to which the emissivity can be prescribed on a regional basis.

**Corresponding author address*: Benjamin Ruston, Naval Research Laboratory, 7 Grace Hopper MS2, Monterey, CA, 93943-5502; email: ruston@nrlmry.navy.mil.

2. DATA

This study employs data from infrared and microwave satellite sensors, forecasts from a numerical weather prediction model, databases of soils and vegetation, outputs from a boundary layer model, and an infrared spectral reflectance library. The time period of interest includes the months of March and April of 2003, and the spatial domain ranges from 5S – 55N latitude, and 0E – 80E longitude.

2.1 HIRS/3 Instrument

The High Resolution Infrared Radiation Sounder (HIRS/3) is a discrete stepping, line-scan instrument designed to measure scene radiance in 20 spectral bands. Data from two shortwave channels (3.76 and 4.0 μm) and one longwave channel (11.11 μm) are obtained for the case study temporal and spatial domain. The instrument provides cross-track scanning in 56 increments of 1.8 degrees. The instantaneous FOV for each channel is approximately 1.4 degrees in the shortwave IR and 1.3 degrees in the longwave IR band which, from an altitude of 833 kilometers, encompasses an area of 20.3 kilometers and 18.9 kilometers in diameter, respectively, at nadir on the Earth.

Table 1. Characteristics of HIRS/3 channels from Kidwell et al. (2000).

Channel	Wavelength (μm)	NEΔT (K)
8	11.11	0.10
18	4.00	0.002
19	3.76	0.001

2.2 AMSU/A Instrument

The Advanced Microwave Sounding Unit (AMSU) flies aboard the National Oceanic and Atmospheric Association (NOAA) satellites 15, 16, and 17. AMSU is a cross-track scanning radiometer and measures at 20 discrete frequencies. Characteristics of the AMSU-A window channels are shown in Table 2. The polarization received by the AMSU instrument varies with scan angle due to a rotating mirror, which reflects into a fixed feed horn. The AMSU consists of two instruments named AMSU-A and AMSU-B. The range of lower frequency and resolution channels on AMSU-A is from 23.8 – 89.0 GHz. The range of higher frequency and resolution channels on AMSU-B is from 89.0 – 183 GHz. AMSU-B data will not be used in this study.

Table 2. Characteristics of selected AMSU-A channels adapted from Grody et al. (2001).

Channel	Frequency (GHz)	NEΔT (K)	Beamwidth 3dB Measured
1	23.8	0.3	3.5°
2	31.4	0.3	3.4°
3	50.3	0.4	3.7°
15	89.0	0.5	3.5°

The AMSU-A does not have a nadir view angle and has 15 discrete scanning angles from 1.7 – 48.3° to each side of nadir, corresponding to local zenith angles of 1.9 – 57.6°. The AMSU-A instrument has 12 of 15 channels located throughout the oxygen absorption maxima centered at 60 GHz, and is designed primarily as a temperature sounding instrument.

2.3 Navy Operational Global Atmospheric Prediction System (NOGAPS) Model

The Navy Operational Global Atmospheric Prediction System (NOGAPS) (Hogan and Rosmond, 1991) is the primary Numerical Weather Prediction (NWP) system providing global weather guidance for all branches of the Department of Defense (DoD). The NOGAPS system is an operational global spectral forecast model run four times each day performing forecasts to 144 hours. All research and development of NOGAPS is undertaken at the Marine Meteorology Division of the Naval Research Laboratory (NRL) in Monterey, CA. This system includes the NRL Atmospheric Variational Data Assimilation System (NAVDAS) (Daley and Barker, 2001), a newly operational three-dimensional variational data assimilation suite for generating atmospheric state estimates. NAVDAS is formulated in observation space, and includes forward operators for assimilation of AMSU radiance data.

NOGAPS forecast fields were obtained for March and April of 2003, on a vertical pressure coordinate system at ½-degree resolution. Variables used in this study are the isobaric profiles of relative humidity, and temperature. The model forecasts were generated every 6 hours beginning at 00 UTC. These forecasts are coarse temporally and spatially, but in the 1DVAR retrieval used later in this study, the NAVDAS system interpolates the model fields spatially and temporally to the satellite observation points.

2.4 Land Characterization (GLDAS and GDAS)

The GDAS system (Derber et al., 1991) is used to provide estimates of soil moisture over the globe at 6-hourly intervals. Static databases of soil and vegetation types and coverages are also incorporated into this study. These soil and vegetation databases are those used by the Global Land Data Assimilation System (GLDAS). The vegetation classification and coverage fractions are derived from the 1 km database of Hansen et al. (2000), while the soil types and fraction are derived from Reynolds et al. (1999). The GLDAS effort is led by scientists at NASA's Goddard Space Flight Center (GSFC) and NOAA's National Centers for Environmental Prediction (NCEP), in collaboration with researchers at Princeton, the University of Washington, and the National Weather Service Office of Hydrology.

2.5 Spectral Reflectance Library

The John Hopkins University (JHU) spectral reflectance library is used to aid in creation of an infrared surface emissivity look-up table. This library contains 41 soil samples, 4 vegetation samples, and 4 water samples covering the spectral range of 715 - 5000 cm^{-1} (2 – 14 micrometers) at approximately 4 cm^{-1} resolution and is based on the laboratory measurements of Salisbury and D'Aria (1992). Salisbury and D'Aria (1992) report that the reflectance measurements were made using an interferometer spectrometer with an integrating sphere coated with a diffusely reflecting gold surface. The entrance port was 10° off the vertical and the detector port was placed at an angle 90° to the principle plane of the sphere.

3. METHODOLOGY

The retrieval of microwave emissivity from AMSU/A measurements begins with infrared data from the HIRS/3 instrument which is used to screen cloud contaminated scenes. Atmospheric profiles of temperature and moisture from the NOGAPS model are used to calculate infrared extinction coefficients for the infrared radiative transfer. An iterative procedure with spatially varying infrared land emissivity retrieves the LST by reproducing HIRS/3 observations. To retrieve the microwave land emissivity, the atmospheric profiles are used to calculate microwave extinction coefficients for the microwave radiative transfer, and the LST is set to the retrieved value. Details on the cloud screening, LST retrieval, and microwave emissivity retrieval procedures are presented in the following paragraphs.

Backgrounds are created from the ascending and descending passes for each of the three NOAA satellites (NOAA 15, 16, and 17). The backgrounds are created on ¼° grids for three week intervals. The first two backgrounds are the warmest $T_{B11.11}$, and the warmest negative $T_{B11.11}$ - $T_{B3.76}$ difference. The application of the 11.11 μm background test assumes anything 20 K colder than the background is cloud contaminated. The warmest negative $T_{B11.11}$ - $T_{B3.76}$ difference is a daytime test, where the shortwave 3.76 μm channel has solar radiation contributions. Clouds are typically better reflectors of solar radiation than the land surface. By taking the warmest negative difference, the background is essentially the difference between the land reflectance at 3.76 and 11.11 um. The third nighttime background is created after screening the $T_{B11.11}$ - $T_{B3.76}$ differences for pixels where the $T_{B11.11}$ is 20 K colder than the background warmest $T_{B11.11}$ image. It was noticed that after screening for cold clouds, the remaining differences had a sharply peaked most likely value ranging between –1 and 5 K over land surfaces. A histogram is performed on the screened $T_{B11.11}$ - $T_{B3.76}$ differences, and a spatial distribution of the most likely brightness temperature difference ($T_{B11.11}$ - $T_{B3.76}$) is recorded, as well as the standard deviation about these most likely values. The thresholds used in the cloud testing procedure are $T_{B11.11}$ 20 K colder than the 11.11 um background. A daytime $T_{B11.11}$ - $T_{B3.76}$ difference that is 5 K colder than the background, or a nighttime $T_{B11.11}$ - $T_{B3.76}$ difference that is 1 standard deviation warmer or colder than the most likely value. At this point, qualitative comparisons of the cloud mask to other cloud products from MODIS and AVHRR have been examined, but a full validation of this cloud screening procedure is still necessary.

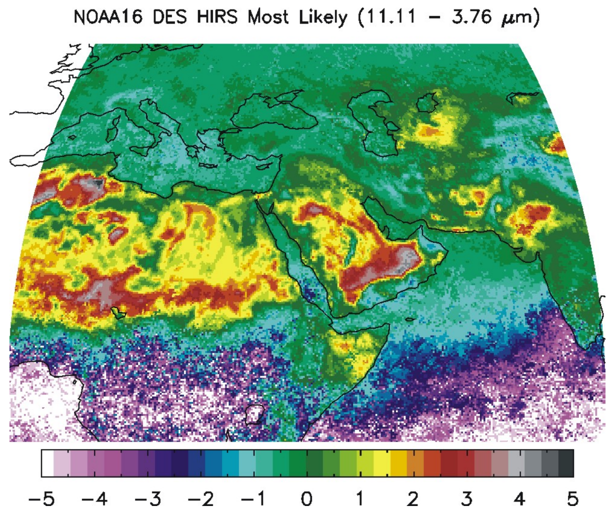

Figure 1. Most likely 11.11 – 3.76 μm difference from the first three weeks of March 2003 after removing cold clouds.

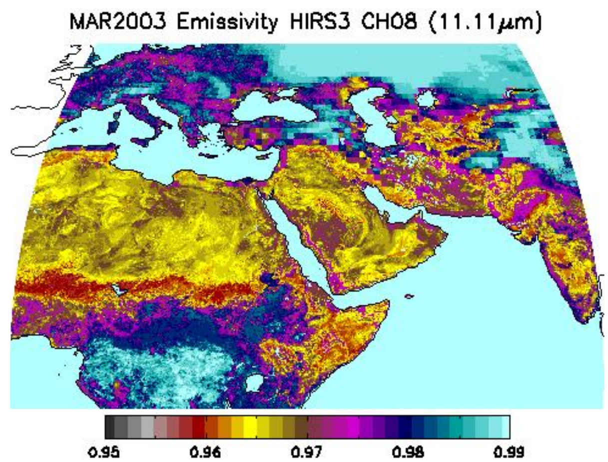

Figure 2. Infrared land emissivity background used in the LST retrieval.

The LST retrieval is straightforward with the satellite radiances and NOGAPS profiles of temperature and moisture considered to be truth. Only the 11.11 μm channel from the HIRS/3 instrument is used in the LST retrieval. The infrared emissivity is estimated using an infrared emissivity atlas which uses the soil and vegetation databases acquired from GLDAS in a procedure similar to that used in a previous study by Ruston and Vonder Haar (2004). The procedure multiplies the sand, silt, and clay fractions by the mean emissivity profiles for these soils. Vegetation type is also matched to the vegetation types in the spectral library, and the resulting vegetation and soil emissivities are weighted by the vegetation cover fraction. Monthly mean greenness fractions have been acquired from GLDAS, and are used to weight the senescent grass sample into the mean vegetation emissivity spectra. In addition, snow cover is estimated from the Special Sensor Microwave Imager (SSM/I) by researchers at the NOAA/NESDIS/Office of Research and Applications (Ferraro et al., 1996). The medium grain snow in the spectral library is used for all snow types.

After the LST retrieval has been performed the emissivity is retrieved for AMSU/A for channels 1, 2, 3, and 15 corresponding to frequencies of 23.8, 31.4, 50.3, and 89.0 GHz respectively. Only these four channels are considered, which typically have clear-sky atmospheric transmissions greater than 0.4. At the time of writing this manuscript only the first week of March 2003 has been processed; however, the results from March and April of 2003 will be presented at the conference session. In retrieving the AMSU/A emissivity, the NOGAPS profiles, HIRS/3 retrieved LST, and the satellite radiances are assumed to be perfect. At the time of the emissivity computation from an AMSU/A observation, the satellite scan position, the observation geolocation, and the nearest 6-hour date time group are given to the Microwave Emissivity Model (MEM). Using this information the MEM produces estimates of the vertical and horizontal polarization components of the emissivity. Grody et al. (2001) propose a mixing formula, which neglects cross-polarization terms, to combine horizontal (ε_H) and vertical (ε_V) components of emissivity at a given scan angle θ_s and local zenith angle θ,

$$\varepsilon = \varepsilon_V(\theta)\cos^2\theta_s + \varepsilon_H(\theta)\sin^2\theta_s . \qquad (1)$$

This equation is appropriate for those channels with vertical nadir polarization. If the nadir polarization is horizontal, $\varepsilon_H(\theta)$ should be multiplied by the $\cos^2(\theta_s)$ term, and $\varepsilon_V(\theta)$ by $\sin^2(\theta_s)$.

4. RESULTS

Emissivities have been retrieved from all three NOAA satellites for the first week of March 2003, covering the spatial domain that ranges from 5S – 55N latitude, and 0E – 80E longitude. Statistics covering the entire two-month time period of March and April 2003 will be presented at the P3.16 poster. A histogram of the first week of retrieved AMSU emissivities from all satellites from all times is shown in Figure 3. Though a variety of local zenith angles are included (and different mixtures of polarizations) the emissivities show a well-behaved histogram structure with all frequencies peaking near a value of 0.95.

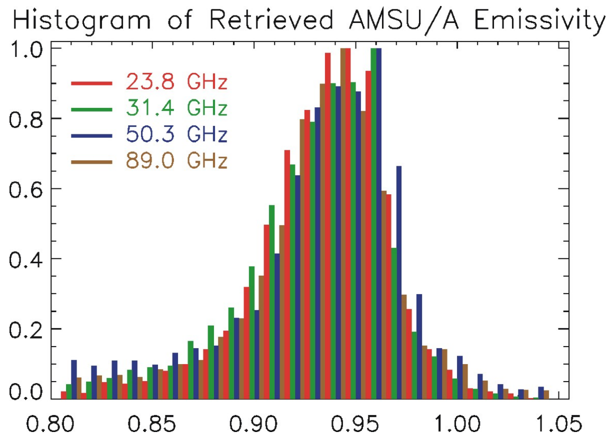

Figure 3: Normalized histogram of the retrieved emissivity for the first week of March 2003.

When comparing these retrieved emissivities to those from the MEM, the first comparison made is to find the mean difference between the retrieved and modeled emissivity as a function of scan position. The mean difference, and one standard deviation about the mean are shown in Figure 4. There is no apparent bias by scan position (or local zenith). The modeled and retrieved emissivities have the greatest mean difference at 89 GHz, and also exhibit the largest standard deviation at this higher frequency.

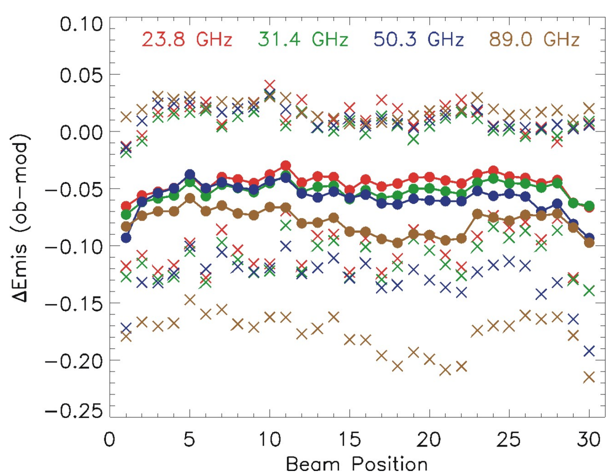

Figure 4: Mean difference of retrieved minus observed emissivity for the first week of March 2003. The 'x' symbol designates one standard deviation above and below the mean value.

A spatial distribution of the mean retrieved minus modeled differences is shown in Figure 5. Many of the regions where the retrieved values are greater than the observed occur in the complex arid terrain of Northern Africa, the Arabian Peninsula, Pakistan, and Iran. In these areas, the retrieved versus modeled differences display distinct patterns of the surface and can be linked to known terrain features. Lower retrieved emissivities lie in the desert regions of the Northwest African coast, the Salt Desert of Iran, and the arid region at the border of Iran, Pakistan, and Afghanistan. However, not all the desert areas have differences between the retrieved and observed emissivities; for example, the area covered by the Empty Quarter on the Arabian Peninsula shows good agreement between the retrieved and modeled emissivities. Misrepresentation of the terrain in the static soil and vegetation databases could contribute to the divergence of these values. A dynamic method to update these static databases has potential to bring the two emissivity estimates into closer agreement. The detection of day-to-day snow cover change is not yet included in the current study. As a consequence, some snow-covered areas have modeled emissivities generated from a surface considered to be void of snow. This results in many large differences in the northern areas of Russia, Kazakhstan, etc.

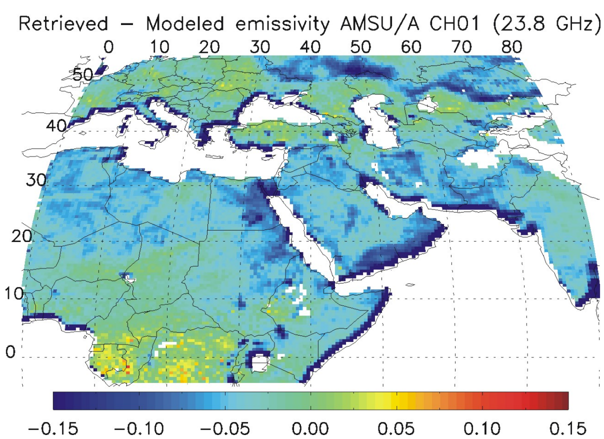

Figure 5: Spatial distribution of the mean difference of retrieved minus observed emissivity for the first week of March 2003.

5. SUMMARY AND FUTURE PLANS

Microwave emissivities have been retrieved over Northern Africa and the Middle East using static databases of soil and vegetation type and coverage, measurements from infrared and microwave satellite instruments, and short-term numerical weather forecasts. The Land Surface Temperature (LST) was retrieved using a single channel (11.11 μm) on the HIRS/3 instrument, and was screened for cloud contamination using a longwave and shortwave channel (11.11 and 3.74 μm). The retrieved LSTs were used with AMSU/A data to retrieve estimates of the microwave emissivity. Static databases of soil type and vegetation type and coverage fraction were used in conjunction with soil moisture forecasts from the Global Data Assimilation System (GDAS) as inputs to a Microwave Emissivity Model (MEM) to produce a second estimate of the microwave land emissivity for comparison with the retrieved values. Over the course of the first week of March 2003, the MEM was found to overestimate the microwave emissivity in relation to the retrieved values. The difference between the retrieved and modeled emissivities showed no apparent dependence on scan angle (and resulting local zenith), and the poorest agreement was seen at the higher frequencies. A spatial distribution of the differences shows distinct terrain features. It is proposed that the static soil and vegetation types may be affecting the modeled emissivities agreement to those retrieved.

The emissivities will be retrieved for the remainder of the study time period, which covers March and April of 2003. The robustness of the preliminary results will be examined, along with methods to dynamically change the inputs to the MEM for a closer fit of the retrieved and modeled emissivities. An examination of the HIRS/3 cloud screening methodology in comparison to operational cloud masks, such as that from MODIS, will be undertaken to give some quantitative knowledge of the effectiveness of the screening procedure. Similarly, the LSTs will be compared to other operational LST products which will help to quantify error estimates in this parameter. Lastly, a robust error analysis will be undertaken to give estimates of the error in both the retrieved and modeled emissivities needed for the NRL Atmospheric Variational Data Assimilation System (NAVDAS).

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