A high spectral resolution global land surface infrared emissivity database

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Background & Overview

An accurate infrared land surface emissivity product is critical for deriving accurate land surface temperatures, needed in studies of surface energy and water balance. An emissivity product is also useful for mapping geologic and land-cover features. Current sensors provide only limited information useful for deriving surface emissivity and researchers are required to use emissivity surrogates such as land-cover type or vegetation index in making rough estimates of emissivity. Inaccuracies in the emissivity assignment can have a significant effect on atmospheric temperature and moisture retrievals. To accurately retrieve atmospheric parameters, a global database of land surface emissivity with fine spectral resolution is required.

A global infrared land surface emissivity database with high spectral and high spatial resolution is introduced. The database is derived from a combination of high spectral resolution laboratory measurements of selected materials, and the UW/CIMSS Baseline Fit (BF) Global Infrared land Surface Emissivity Database (Seemann et al., 2007) by using principal component analysis (PCA) regression. The goal of this work is to create a spectrum of emissivity from 3.6 to 14.3 μm for a given month, for every latitude/longitude point globally at 0.05-degree spatial resolution at 416 wavenumbers. To create a high spectra resolution emissivity dataset the PCs (eigenvectors) of laboratory spectra are regressed against the UW/CIMSS BF emissivity data. The characteristics of the input data, the methodology, how many PCs to use and some tests on laboratory measurements, the SeeBor clear sky training profile database and AIRS clear sky single FOV retrievals are presented.

Reference

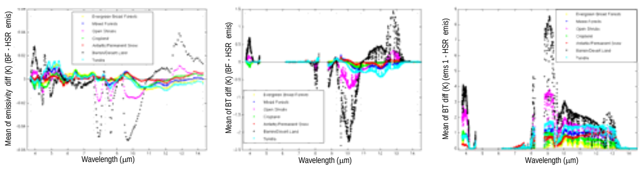
Seemann, S.W., E. E. Borbas, R. O. Knuteson, G. R. Stephenson, H.-L. Huang, 2007: Development of a Global Infrared Land Surface Emissivity Database for Application to Clear Sky Sounding Retrievals from Multi-spectral Satellite Radiance Measurements. Journal of Applied Meteorology and Climatology, in press.

Data access:
Moderate spectral resolution - UW/CIMSS BF Global IR Surface Emissivity Database is available at ***http://cimss.ssec.wisc.edu/iremis***
High spectral resolution - beta version of UW/CIMSS HSR database is available for testing. Contact: Eva.Borbas@ssec.wisc.edu

Sensitivity of calculated IR BT to a change in emissivity

The prototype of the CRTM transmittance model was used to calculate BT for 8583 clear sky land profiles from the SeeBor training dataset to evaluate the sensitivity of emissivity on all 2378 AIRS channels. Average differences of calculated BT using different emissivity spectra (emis=1, BF emis and HSR emis) are plotted separately for some selected IGBP ecosystem types.

The largest differences between BF and HSR emissivities and BT calculated with these two emissivties occur around at 13, 10.2-9.7, 8.5, 7.8 and 4 μm for the IGBP barren/desert land classification.



Averaged differences for 8583 land SeeBor profiles of BF emis and HSR emis for all 2378 AIRS channels.

Averaged differences of BT calculated with BF emis minus those calculated with HSR emis

Averaged differences of BT calculated with emis=1 minus those calculated with HSR emis

Methodology

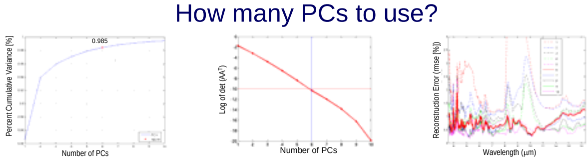
A statistical regression method was used to combine the first Principal Components (PCs) of 123 selected laboratory spectra from the MODIS/USCB and ASTER emissivity libraries (wavenumber resolution between 2-4cm^{-1}, at 416 wavenumbers) and the 10 hinge points of the monthly UW/CIMSS BF emissivity data (see equations below). High spectral resolution emissivity values were determined at each MYD11 latitude and longitude point over land.

$$\vec{\mathbf{e}} = \vec{\mathbf{c}}\mathbf{U} \qquad \vec{\mathbf{c}} = \vec{\mathbf{e}} * \mathbf{U}^{\mathrm{T}}(\mathbf{U}\mathbf{U}^{\mathrm{T}})^{-1}$$

$\vec{\mathbf{e}}$ is the HSR emissivity spectra $\vec{\mathbf{c}}$ is the PCA coefficient vector $\mathbf{U}$ is the matrix of the first PCs of the lab emissivity spectra

The accuracy of the new UW/CIMSS HSR emissivity database is dependent upon the input BF emissivity data and the MODIS MYD11 measurements. The BF approach uses selected laboratory measurements of emissivity to derive a conceptual model, or baseline spectra, and then incorporates MODIS MYD11 measurements (at six wavelengths: 3.8, 3.9, 4.0, 8.6, 11, and 12 μm) to adjust the emissivity at 10 hinge points (3.6, 4.3, 5.0, 5.8, 7.6, 8.3, 9.3, 10.8, 12.1, and 14.3μm).

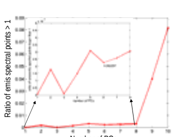
How many PCs to use?



Percentage Cumulative Variance function of the 123 selected laboratory measurements as a function of the number of PCs

Magnitude of determinants of (AA)^T as a function of the number of PCs, where A is the matrix of the PCs of the 123 selected laboratory measurements

RMSE [%] differences between the 123 original and the reconstructed emissivity spectra with the first 10 PCs



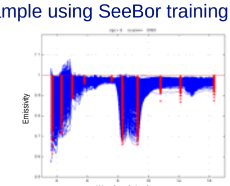
Ratio of emissivity spectral points larger than 1 in the land SeeBor training data as a function of the number of PCs

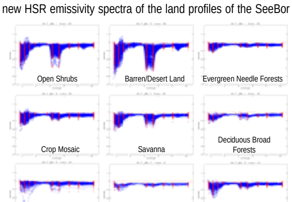
In the PCA technique the first PCs with highest eigenvalues represent real variations in the data while the last, least significant PCs most often represent random white noise. In this study the maximum number of PCs allowed is 10 due to the number of spectral points of the input BF emissivity.

To determine the number of PCs to use, the following functions/tests were performed: the percentage cumulative variance function of the 123 lab data, the magnitude of the determinant of the inverse matrix in the equation of the PCA coefficients (see above), the reconstruction error of the lab data and the ratio of the emissivity spectral points larger than 1 in the SeeBor training dataset. These tests indicate that in this study the optimal number of PCs is 6. A larger number of PCs makes the results unstable.

Using the first 6 PCs, the new HSR emissivity spectra of the land profiles of the SeeBor training data is shown below.

Example using SeeBor training data



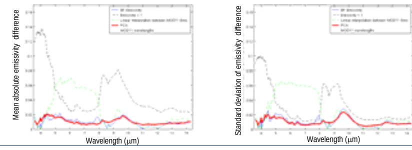


HSR emissivity spectra computed for the all 5993 different land SeeBor profiles (left) and separated by IGBP ecosystem types (right) using the first 6 PCs. The red dots indicate the BF emissivity values.

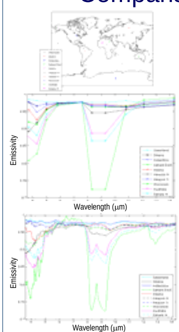
Test on laboratory data

Mean absolute difference (left) and standard deviation of emissivity difference (right) between 123 laboratory spectra and that derived by the BF method (blue) and PCA regression method (red, using the first 6 PCs). The lab emissivity values at the 6 MYD11 wavelengths and at the 10 inflection points were input into the BF and HSR schemes respectively to get the corresponding 123 reconstructed lab spectra.

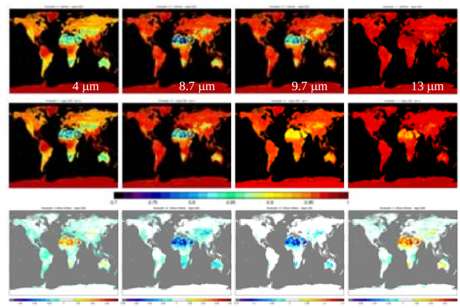
Differences are also shown for a constant emissivity of 1.0 (black) and those derived by linear interpolation between MYD11 wavelengths (green), both compared with the same 123 laboratory spectra. This analysis is intended to illustrate how well these schemes can reproduce a full spectrum of emissivity.



Comparison with the input BF emissivity data



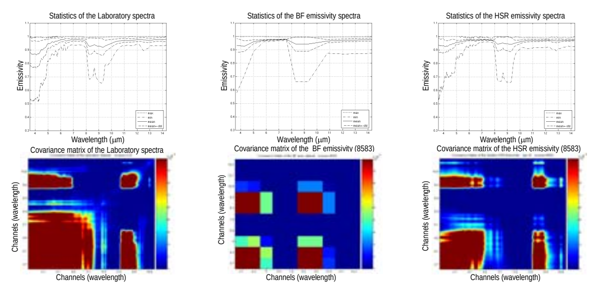
Emissivity spectra for August 2003 at 10 locations (top) created by the BF (middle) and PCA regression method (bottom).



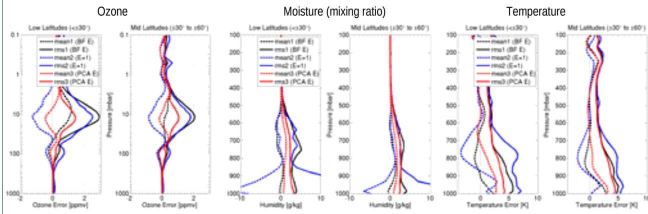
UW/CIMSS BF emissivity (top), UW/CIMSS HSR emissivity (middle) and their differences (bottom) at selected wavelengths for August 2003.

Test on AIRS retrievals

Clear sky AIRS retrievals were compared to the ECMWF analyses on September 2, 2003. The UW-Madison IMAPP single FOV AIRS algorithm was used for getting temperature, moisture and ozone retrievals. A constant emissivity of 1.0, the UW/CIMSS BF emissivity, and the UW/CIMSS HSR emissivity were each assigned to the SeeBor training dataset and subsequently used to derive the synthetic regression coefficients for the AIRS retrievals. The MODIS MYD35 cloud mask products were used for finding the clear sky scenes.



The statistics and covariance matrices of the 123 selected laboratory measurements (left), the UW/CIMSS BF emissivity data (middle) and the UW/CIMSS HSR emissivity data (right) assigned to the SeeBor training data over land.



Profiles of mean and rms differences between ECMWF analyses and AIRS retrievals for 240 granules calculated using emissivity=1 (blue), the UW/CIMSS BF emissivity (black) and UW/CIMSS HSR (PCA) emissivity (red) assigned to the training profiles for clear sky scenes on September 2, 2003.

Conclusions and Future Work

A methodology to create a high spectral resolution emissivity database from the moderate spectral resolution UW/CIMSS BF emissivity dataset was described. A Software Tool to extract the high spectral resolution emissivity database from the UW/CIMSS BF emissivity dataset will be available in early 2008. A beta version is available for testing.

The comparison of the UW/CIMSS BF and UW/CIMSS HSR emissivities indicated that the largest differences occur around at 13, 10.2-9.7, 8.5, 7.8 and 4 μm for arid and semi arid regions.The test with lab data showed that the HSR emissivity data can capture the quartz-reststrahlen band with the peak around 8.5 μm.
Using the HSR emissivity data in the IMAPP AIRS algorithm showed a positive effect on temperature, moisture and ozone retrievals when compared with using a constant emissivity or the BF emissivity data. This case study indicated that the HSR emissivity data can better capture the emissivity spectra in the ozone absorption band.

- Future work will include more comparisons with other emissivity datasets and validation with ground-based measurements.
- We intend to apply similar methodologies to emissivity products from other platforms such as AIRS.
- Monthly temporal resolution may not be sufficient for some applications. We are planning to work on a granule based HSR emissivity data.

Acknowledgments: This research was supported by the NOAA Cooperative Agreement grant NA06NES4400002. We gratefully acknowledge Zhengming Wan of UCSB for providing the emissivity library of laboratory emissivity spectra.