Retrieval of Global Hyperspectral Surface Emissivity Spectra from Advanced IR Sounder Radiance Measurements

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ITSC-XVI: Angra dos Reis, Brazil, 7-13 May 2008
Motivation

- Emissivity effect on sounding retrievals
  - Plokhenko and Menzel (2000); Seemann et al (2008);
- Hyperspectral IR radiances assimilation over land
- Other products with IR radiances
  - Cloud-top pressure
  - Dust/aerosol
  - Land surface temperature
  - Trace gas
- Emissivity effect on climate (Jin and Liang 2006)

**Goal:** To derive global IR surface emissivity spectra with hyperspectral IR radiances measurements
Physical retrieval of surface emissivity spectrum from hyperspectral infrared radiances

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Received 9 May 2007; revised 25 July 2007; accepted 30 July 2007; published 23 August 2007.

[1] Retrieval of temperature, moisture profiles and surface skin temperature from hyperspectral infrared (IR) radiances requires spectral information about the surface emissivity. Using constant or inaccurate surface emissivities typically results in large temperature and moisture profile errors, particularly over semi-arid or arid areas where the variation in emissivity is large both spectrally and spatially. A physically based algorithm has been developed to retrieve a hyperspectral IR emissivity spectrum simultaneously with the temperature and moisture profiles, as well as the surface skin temperature. To make the solution stable and efficient, the hyperspectral emissivity spectrum is represented by eigenvectors, derived from the laboratory measured hyperspectral emissivity database, in the retrieval process. Experience with Atmospheric InfraRed Sounder (AIRS) radiances shows that simultaneous retrieval of the emissivity spectrum and the sounding improves the surface skin temperature and temperature and moisture profiles, particularly in the near surface layer. Citation: Li, J., J. Li, E. Weisz, and D. K. Zhou (2007), Physical retrieval of surface emissivity spectrum from hyperspectral infrared radiances, Geophys. Res. Lett., 34, L16812, doi:10.1029/2007GL030543.

[4] Surface emissivity for a given channel is often not updated simultaneously with profiles in the physical iterative process, for example, using emissivities from a regression approach [Li et al., 2000; Zhou et al., 2006]. Some physical algorithms also retrieve emissivities together with the sounding, but only at selected channels and spectral bands. Hayden (1988) retrieved emissivities at two spectral bands (longwave and shortwave IR bands) in GOES sounding processing. Zhou et al. [2007] and Susskind et al. [2003] used approximately 40 and 4 channels, respectively, for emissivity retrieval in AIRS retrieval processing. It is difficult to retrieve emissivities of all channels directly in the sounding step, due to a large number of unknowns in the

The variational retrieval algorithm has been developed
Retrieval Algorithm

Atmospheric measurement equation

\[ y = F(x) + e \]
\[ y = (R_1, R_2, ..., R_n)^T; \]
\[ x = (t(p); w(p); o(p); t_s; \varepsilon_1, ..., \varepsilon_n)^T \]

Regularization and discrepancy principle (Li and Huang 1999)

(Cost function)

\[ J(x) = (y_m - y_c(x))^T E^{-1} (y_m - y_c(x)) + (x - x_0)^T S_0^{-1} (x - x_0) \]

Too many parameters need to be retrieved if including all channels’ emissivities !!!

EOF expansion

\[ x = \sum_i a_i \phi_i = a\phi; \]
\[ \{ \phi: \text{eigenvector matrix; } a: \text{eigenvector coefficients} \text{ to be retrieved} \]
Hyperspectral IR emissivity spectrum data base – from laboratory measurements

Database processed by E. Borbas (CIMSS)

Hyperspectral IR emissivity spectrum data base – from laboratory measurements

AIRS spectral coverage

IASI spectral coverage

The first 10 emissivity eigenvectors
Simulated Retrieval for Desert (32 profiles)

### Emissivity

![Emissivity Graph](image)

- **Tskin RMS (K)**
  - Reg: 0.624
  - Rtv: 0.540
  - Fixed emis: 0.822
  - Emis=0.98: 9.544

### Temperature

![Temperature Graph](image)

- Using Const Emis
- First guess
- Fixed Emis from reg
- Simultaneous Emis

### Relative Humidity

![Humidity Graph](image)
Emissivity signal in IR is small (e.g., 0.01 emissivity results in ~0.5 K change in window region), but its impact on boundary sounding is significant. Weaker signals in short wave region make it hard to retrieve.
AIRS 9.3 µm (single channel) emissivity retrieval with regression as first guess. Color plot is the 9.3 µm surface emissivity, while black/white plot are 9.3 µm AIRS brightness temperature (K).
AIRS 9.3 µm emissivity retrieval with first guess of 0.98 for all channels and all footprints

Retrieved AIRS Emissivity Difference (9.30µm)

Histogram for Retrieved Emissivity Difference (9.30µm)

AIRS 9.3 µm emissivity retrieval with first guess from regression
8-day composite of global hyperspectral IR emissivity spectrum from AIRS SFOV clear sky radiances between Jan. 1 and Jan. 8 of 2004 – CIMSS research product (gridded to 0.5 by 0.5 degree)
**Re-group from IGBP category:**
- **Forests:** Evergreen needle forests; Deciduous needle forests; Deciduous broad forests; mixed forests;
- **Shrubs:** Opened shrubs; Closed shrubs;
- **Savanna:** Woody savanna; Savanna;
- **Cropland:** Cropland; Crop mosaic;
- **Snow/Ice:** Snow; Ice; Tundra;
- **Desert:** Desert/Barren;
Emissivity spectra over Arizona and Utah

CIMSS/UW
Comparison with operational MODIS emissivity product (collection 4.0)

• Shortwave IR window regions
  – 3.97 um
  – 4.06 um

• Longwave IR window regions
  – 8.55 um
  – 11.02 um
  – 12.04 um

AIRS emissivity spectra are convolved with MODIS spectral response functions (SRFs)
3.97 µm
MODIS underestimate emissivity by approximately 0.025 for 3.97 µm spectral band when compared with AIRS.
4.06 µm
MODIS underestimates emissivity by approximately 0.025 for 4.06 µm spectral band when compared with AIRS.
MODIS and AIRS agree very well for 8.55 µm spectral band, differences are less than 0.02 for most regions.
AIRS and MODIS agree well for 11.02 µm spectral band, differences are less than 0.02 for most regions.
12.04 µm
AIRS and MODIS agree well for 12.04 µm spectral band, differences are less than 0.02 for most regions.
Summary

• Global hyperspectral IR surface emissivity map has been created.
  – The hyperspectral IR emissivity product agrees with the broad band operational MODIS emissivity product (collection 4.0) in longwave region, differences are less than 0.02
  – MODIS underestimates the emissivity by approximately 0.025 for shortwave region when compared with AIRS

• The spectral and spatial variations of hyperspectral IR surface emissivity spectra well reflect the ecosystem land surface type properties

• Applications of hyperspectral IR emissivity data include
  – Data assimilation of hyperspectral IR radiances over land
  – Data base for other products (e.g., dust, aerosol, TPW, LST, CTP, etc.) with IR radiances
  – Climate modeling and prediction
International TOVS Study Conference, 16th, ITSC-16, Angra dos Reis, Brazil, 7-13 May 2008.
Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center,
Cooperative Institute for Meteorological Satellite Studies, 2008.