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

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Motivation

• Emissivity effect on sounding retrievals
  – Plokhenko and Menzel (2000); Seemann et al (2008);
• Hyperspectral IR radiance 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 radiance measurements
The variational retrieval algorithm has been developed
Retrieval Algorithm

Atmospheric measurement equation

\[ y = F(x) + e \]

\[ y = (R_1, R_2, \ldots, R_n)^T; \]

\[ x = (t(p); w(p); o(p); t_s; \epsilon_1, \ldots, \epsilon_n)^T \]

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

\[ x = \sum_{i} a_i \phi_i = a \phi; \]

\[ \left\{ \begin{array}{c}
\phi: \text{eigenvector matrix}; \\
 a: \text{eigenvector coefficients to be retrieved}
\end{array} \right. \]
Hyperspectral IR emissivity spectrum data base – from laboratory measurements

Database processed by E. Borbas (CIMSS)

AIRS spectral coverage

IASI spectral coverage

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

<table>
<thead>
<tr>
<th>Emissivity impact on soundings</th>
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<tbody>
<tr>
<td>Using Const Emis</td>
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<tr>
<td>First guess</td>
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<tr>
<td>Fixed Emis from reg</td>
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<td>Simultaneous Emis</td>
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<th>Tskin RMS (K)</th>
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<tr>
<td>Reg</td>
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<tr>
<td>Rtv</td>
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<tr>
<td>Fixed emis</td>
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<tr>
<td>Emis= 0.98</td>
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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.
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; Evergreen broad 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

AIRS emissivity (CH: 1265/8.21μm)

Lat: 35 ~ 40N
Lon: 110 ~ 115W

CIMSS/UW
AIRS emissivity (CH: 1265/8.21μm)

Lat: 20~30S  Lon: 130~135E

Lat: 70~75S  Lon: 45~50W
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)
Aqua MODIS IR SRF Overlay on AIRS Spectrum
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.
8.55 µm
MODIS and AIRS agree very well for 8.55 µm spectral band, differences are less than 0.02 for most regions.
11.02 µm
AIRS and MODIS agree well for 11.02 µm spectral band, differences are less than 0.02 for most regions.
AIRS Convolved Emissivity (MODIS CH: 32/12.04 µm)

MODIS emissivity (MYD11C2/CH: 32/12.04 µm)

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