Comparison of Land Surface Infrared Spectral Emissivity Derived from MetOp IASI and Aqua AIRS

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Goal is to increase the utilization of operational advanced IR sounder data over land in geographic regions with spectrally, spatially, or temporally variable land surface emission.

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Land Emissivity Validation Topics

• Jaivex Case Study: 19 April 2007 Oklahoma
• ARM SGP Site Ground-based Data (Knuteson)
• UK Met ARIES “truth” (S. Newman)
• UW SHIS, NASTI, IASI “optimal estimation using a realistic climatology ” (R. Knuteson)
• NASA AIRS L2 “regression/physical” retrieval (J. Susskind, C. Barnet, L. Zhou)

---------------------- talks to follow ----------------------
• UW Single FOV AIRS Retrieval (J. Li)
• NASA NAST-I & IASI (X. Liu)
• UK Met AIRES “1D-VAR” (J. Taylor)
• NASA NAST & IASI retrieval (D. Zhou)

2 Satellite HSR Sensors, 3 Airborne HSR Sensors, 1 Ground-based HSR Sensor
Infrared Radiative Transfer Equation for Lambertian Surfaces for an observer viewing the surface from above:

\[ N^\uparrow_{\nu} = \int B_{\nu}(T(P))d\tau_{\nu} + \tau^{\text{tot}}_{\nu} \cdot e_{\nu} \cdot B_{\nu}(T_S) + \tau^{\text{tot}}_{\nu} \cdot (1 - e_{\nu}) \cdot \overline{N^\downarrow_{\nu}} \]

\[ N^\uparrow_{\nu} \]
\[ N^\text{atm}\uparrow_{\nu} \]
\[ \text{Emission} \]
\[ \text{Reflection} \]

**Most Important Idea (Bill Smith)**

Represent high spectral resolution infrared emissivity as a linear combination of a limited number (e.g. 6) of eigenfunctions of a set of laboratory spectra that covers 3.5 to 18 \( \mu \text{m} \).
Joint Airborne IASI Validation Experiment

• **First US-European collaboration in US focusing on validation of radiance and geophysical products from MetOp-A**

• **Location/dates**
  - Ellington Field (EFD), Houston, TX, 14 Apr – 4 May, 2007

• **Aircraft**
  - NASA WB-57 (NAST-I, NAST-M, S-HIS)
  - UK FAAM BAe146-301 (ARIES, MARSS, Deimos, SWS; dropsondes; *in situ* cloud phys. & trace species; etc.)

• **Ground-sites**
  - DOE ARM CART ground site (RAOBS, Raman Lidar, AERI, etc.)

• **Participants**
  - US: NASA/LaRC, NASA/JSC, UW, MIT-LL, MIT, NOAA, others
  - Europe: UKMO, FAAM, U. of Manchester, EUMETSAT, U of Bologna, ECMWF, others
Oklahoma ARM Program
Southern Great Plains Site
Validation Data
Effective Emissivity for Mixed Scenes at the Southern Great Plains (SGP) Validation Site

$$\hat{\varepsilon}_\nu = \sum_{i,j} w_{i,j} \cdot \varepsilon_{i,j,\nu}$$

UW Ground Survey (Jun 2002)

USGS Database (1992)

RGB assignments: 2.15 microns (R), 1.64 microns (G), 0.55 microns (B)
Surface-Atmospheric Emitted Radiance Interferometer (AERI)

Spectral emissivity measurements of the surface taken by the UW-Madison S-AERI instrument are illustrated above for pasture, wheat and bare soil types.
Results from a Previous ER-2 Campaign at SGP in 2001 (15 km avg.)

- Pure Vegetation
- S-HIS OBS (TX-2001)
- Bare Soil

Legend:
- SHIS (Online/Offline; Ts = 296.1496)
- A: Vegetation
- B: 60% Vegetation 40% Bare Soil
- C: Bare Soil
ARM Best Estimate Emissivity

Jaivex - April

70%
Wisconsin Ground-based Characterization of ARM SGP Site

UW AERIBAGO
(Ground-based)

- 70% Vegetation Fraction shown in Red for reference.
Preliminary UK Met ARIES Surface Emissivity Validation
(Preliminary Data Courtesy of Stewart Newman)

UK FAAM BAe146-301
(from 3000 foot altitude)

- ARIES low altitude footprint is small (50 m)
- Mean ARIES emissivity shown in Black
JAIVEx 19 Apr 2007 Case

[Map and data plots with IASI, NAST-I, S-HIS FOVs and WB-57 indicated.]
Proposed Unified Approach for NWP and Climate

- Observed Radiances
- 1-D Var Data Assimilation Atmospheric Parameters
- Forecast and Analysis Model Fields
- Unified Surface Emissivity Climatology
- Update Surface Emissivity Climatology
- Validation
- Unified Climate Records
- Observed Radiances
- Optimal Estimation Retrieval (first guess, a priori covariance)
- RT and non-RT Derived Products

Focus of this research.
Bootstrapping a HSR Global Climatology

Full UW HSR database contains:
- 6000 spectra in every 50 km sq.
- 60 months (5 years) of data.
- Total greater than 300,000,000 HSR spectra

SEEBOR training set contains:
5993 HSR emissivity spectra located mainly at sonde launch sites.

(reconstructed HSR at 4 µm)
HSR Emissivity Covariance

- Eva Borbas & Suzanne Seeman “A high spectral resolution global land surface infrared emissivity database” (Eumetsat Conference Paper)
- Fit Laboratory HSR eigenfunction coefficients to measurements at four MODIS channels (12, 11, 8.5, and 4 µm).
HSR Global Climatology Eigenfunctions (# PCs = 6)

Mean
Dominated by silicates (quartz)

PC1
Silicate features explain most of variance

PC 2 to 6
Carry the non-quartz information
HSR Global Climatology of Projection Coefficients

- Statistics are nearly Gaussian. Use to compute covariance.
The JAIVEx training set consists of 8025 standard NWS rawinsonde profiles, 5813 of which are classified as clear. The sondes were launched at either 0 or 12 UTC, from NWS sites within the JAIVEx spatial domain.

The time period over which the training set was assembled was 2003-2006. Only sondes from April through mid-May were included, such that the training set would most closely simulate the possible atmospheric conditions during JAIVEx.
Optimal Estimation Physical Retrieval Method

• The retrieval method used here is the Bayesian optimal estimation technique known as the Maximum A Posteriori (MAP) method (as promoted by Clive Rodgers).

• A line-by-line forward model (AER LBLRTM v10.3) was used to compute analytic jacobians (Tony Clough). Very flexible, accurate.

• The Newton-Gauss method was implemented to find the zero of the derivative of the joint probability distribution (pdf) corresponding to the optimal solution. The actual form follows from analytic differentiation

\[
x = x_a + (K^T S_e^{-1} K + S_a^{-1})^{-1} K^T S_e^{-1} [(R-F) + K (x-x_a)]
\]

R is the observation, F(x) the forward model, K is the Jacobian dF/dx, and S is the covariance where “a” refers to the a priori climatology and “e” to the measurement error covariance.

• Expand the emissivity using eigenfunctions of laboratory spectra and solve for the coefficients of the eigenfunctions in the retrieval.
IASI Observed Spectrum and Final Calculation

Radiance (RU)

wavenumber (cm\(^{-1}\))

Observation
Calculation

final Obs-Calc residual (RU)

wavenumber (cm\(^{-1}\))
 Retrieval Iteration and Convergence

[Graph showing retrieved emissivity against wavenumber (cm\(^{-1}\)).]
S-HIS, NAST-I, and IASI Retrieval from JAIEX

S-HIS, NAST-I, and IASI from JAIEX 19 April 2007

Obs-Calc Residual

Retrieved Emissivity

S-HIS
NAST-I
IASI Obs.

O₃  CH₄  CO
T & WV Validation with Vaisala RS92 Radiosondes

![Graphs showing temperature and water vapor profiles](Image)

- **Left Graph:**
  - Y-axis: Pressure (mb)
  - X-axis: Temperature (K)
  - Lines represent different sources:
    - S-HIS: $T_s=284.48K$
    - NAST-I: $T_s=284.64K$
    - IASI: $T_s=285K$
  - Circles highlight specific data points:
    - Sonde 02:35 UTC
    - Sonde 03:31 UTC

- **Right Graph:**
  - Y-axis: Water Vapor (g/kg)
  - X-axis: H2O (g/kg)
  - Lines represent different sources:
    - S-HIS
    - NAST-I
    - IASI
    - Sonde 1
    - Sonde 2
  - Circles highlight specific data points:

**Note:** The graphs illustrate the validation of temperature ($T_{dry}$) and water vapor profiles using Vaisala RS92 Radiosondes.
Aqua AIRS 04 April

MetOp IASI 19 April 2007
Very Large Range
Considering 15 km Spatial Average
NO CORRELATION.
(Implies Tskin error and Emiss error are largely independent.)
Surprisingly close agreement with AIRS L2 Emissivity

AIRS L2 uses different emissivity shape model
- All consistent with 60 to 70 % vegetation fraction at 8.5 and 4 µm
- All are about 2 % less than surface measurements at 12 µm but roughly agree with each other.
Conclusions

1. Jaivex provided the first low altitude HSR emissivity measurements of the ARM SGP site (BAE-146). These preliminary measurements are in quantitative agreement with a linear combination (vegetation fraction) of UW HSR ground-based observations.

2. The new UW HSR SeeBor emissivity combines high spectral (< 3 cm⁻¹), high spatial (5 km), and high temporal (monthly to daily) to create a global five year climatology.

3. HSR emissivity *a priori* has been applied using an optimal estimation method to coincident IASI, S-HIS, and NAST-I measurements with agreement at the 1 % level. Preliminary comparison with AIRS L2 product (which uses an independent retrieval method) is encouraging.