Aircraft Validation of Infrared Emissivity derived from Advanced InfraRed Sounder Satellite Observations

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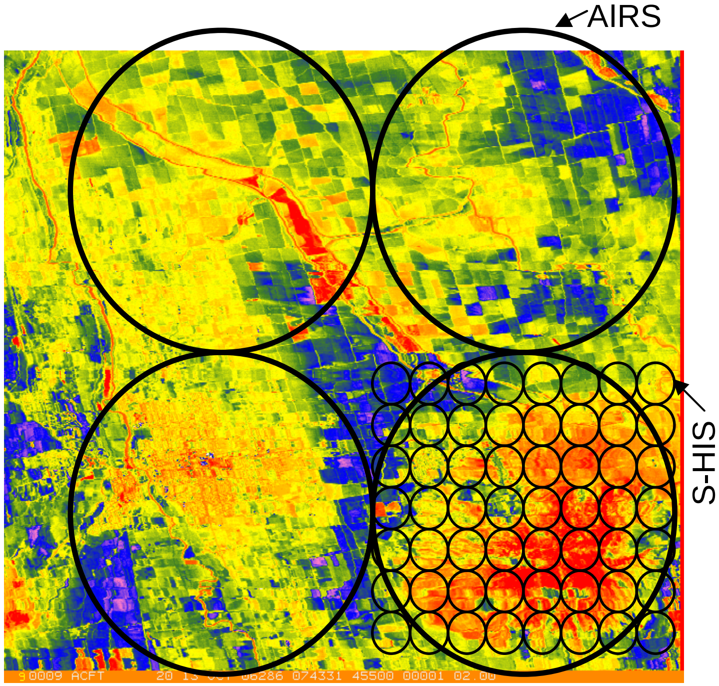
Goal is to increase the utilization of operational advanced IR sounder data over land in geographic regions with spectrally, spatially, or temporally variable land surface emission.



California Central Valley (MAS image)

EUMETSAT/AMS Conference Amsterdam 2007

Topics

- State Objective - *Soundings over land*
- Observations - *IASI, S-HIS, NAST-I*
- Methodology - *Optimal Estimation*
- Preliminary Results - *JAIVEX 19 April 2007*
- Summary - *Consistency?*
- Future Work - *IASI Workshop Nov07*

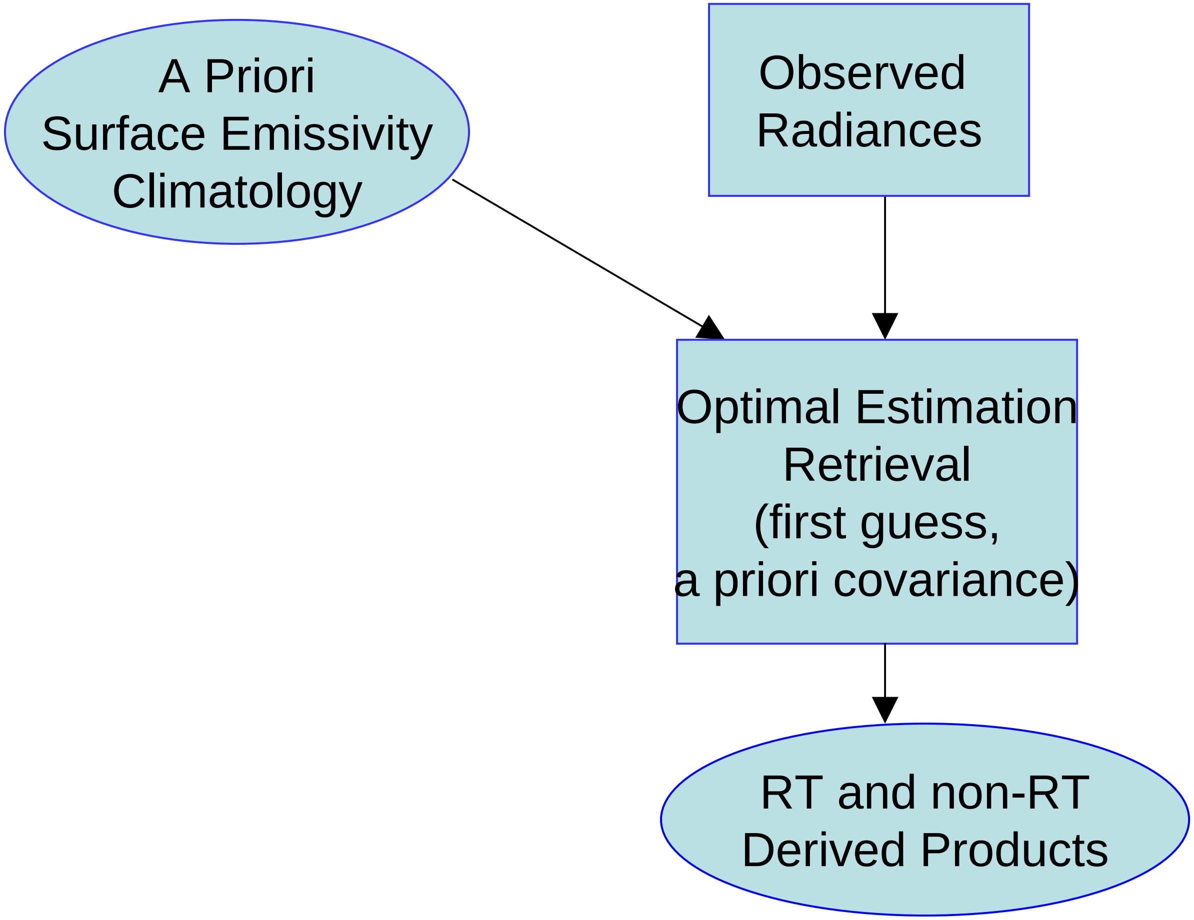
Embarassing Truth:

Operational weather prediction models have difficulty to assimilate thermal emission data over LAND from surface sensitive channels of the operational ATOVS sounder. *How do we solve this long-standing problem of "soundings" over land in the context of the advanced operational IR sounders (IASI and CrIS)?*

Objectives of this Research:

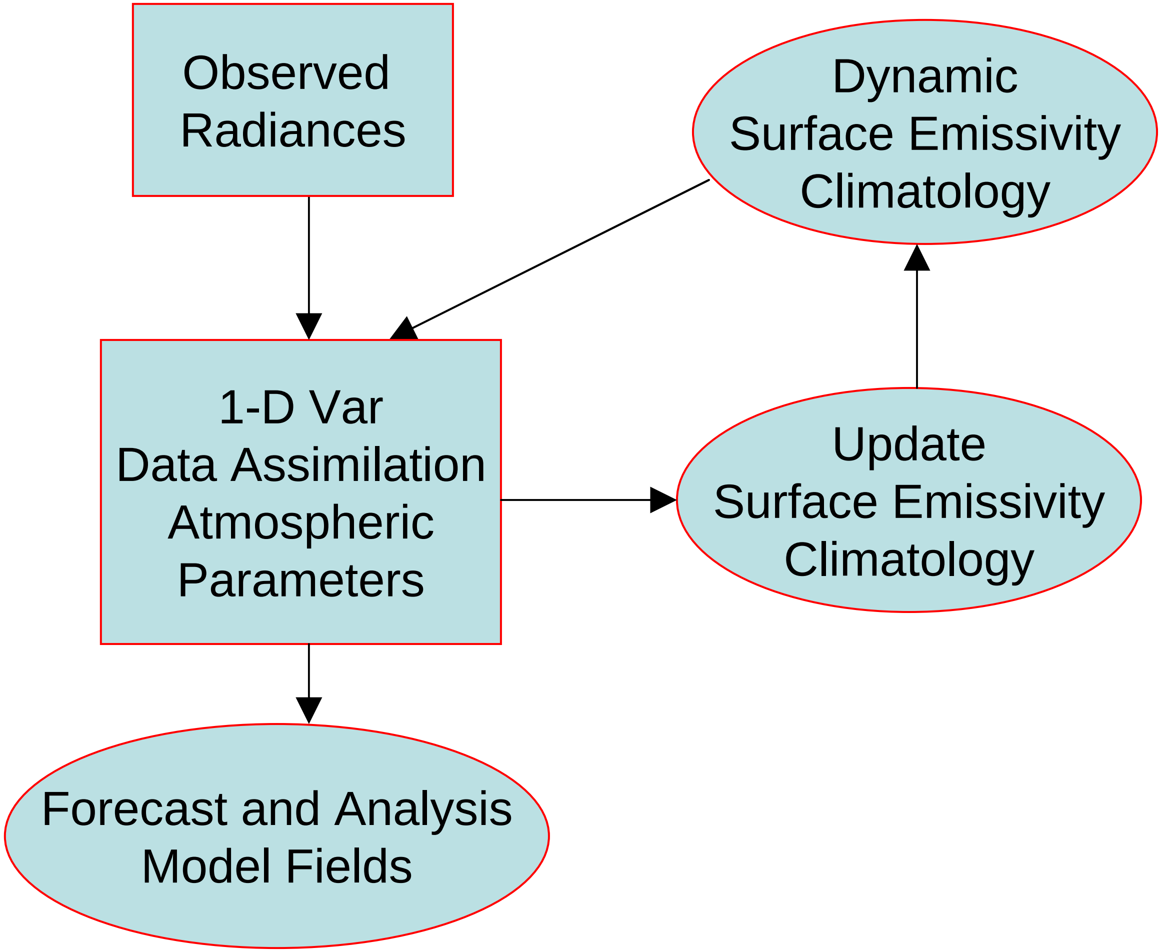
- To develop a land surface climatology that can be used as input to retrieval and 1-D Var methods.
- To provide validation data with variable land IR emissivity for assessment of satellite derived sounding products.

Role of Surface Emissivity in IR Sounding of T & WV



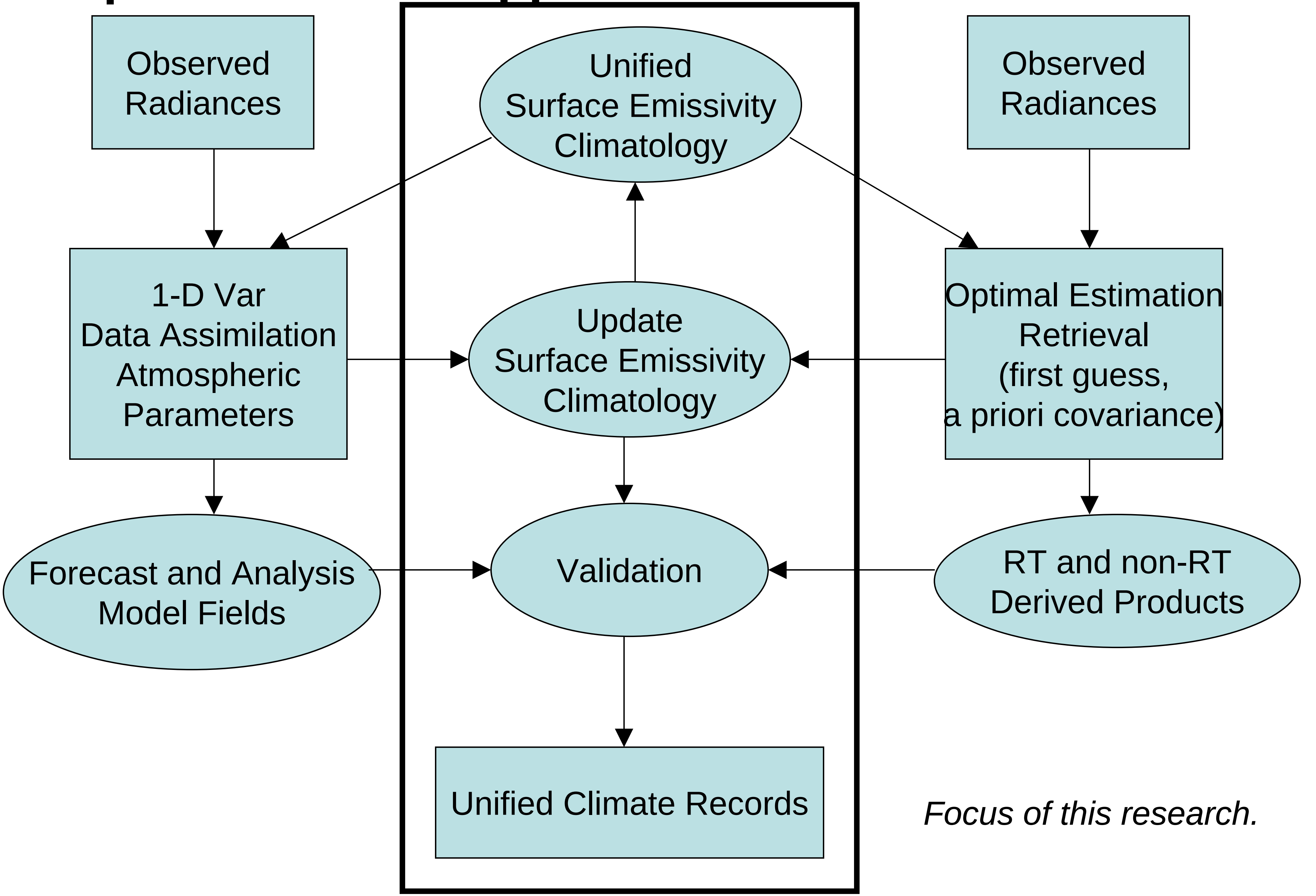
Preferred Sounding Retrieval Methodology if Surface Emissivity climatology Is available.

Role of Surface Emissivity in IR Data Assimilation



John Le Marshall's
Vision of Assimilation
Over Land assuming a preliminary
Surface Emissivity climatology exists.

Proposed Unified Approach for NWP and Climate



So What Is Optimal Estimation Anyway?

Let y be the observation, let x be the unknown, and let F(x) be the forward model.

When x is the “true” solution then the probability that F(x) agrees with y is given by

$$P(y|x) = \exp[-(y - F(x))^2/2S_e]$$

This means that the calculation agrees within the Gaussian measurement noise.

But what we want to know is what is x given y, $P(x|y)$,
i.e. what is the solution given the observation?

Bayes Theorem says that if we know the probability of the solution, $P(x)$, then

$$P(x|y) = P(y|x)\,P(x)$$

If we can assume that the solution is Gaussian distributed about its mean, then the same MULTIVARIATE LINEAR ALGEBRA methods can be used to solve this problem as the original, i.e.   solve for the x for which dP/dx = 0.

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

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

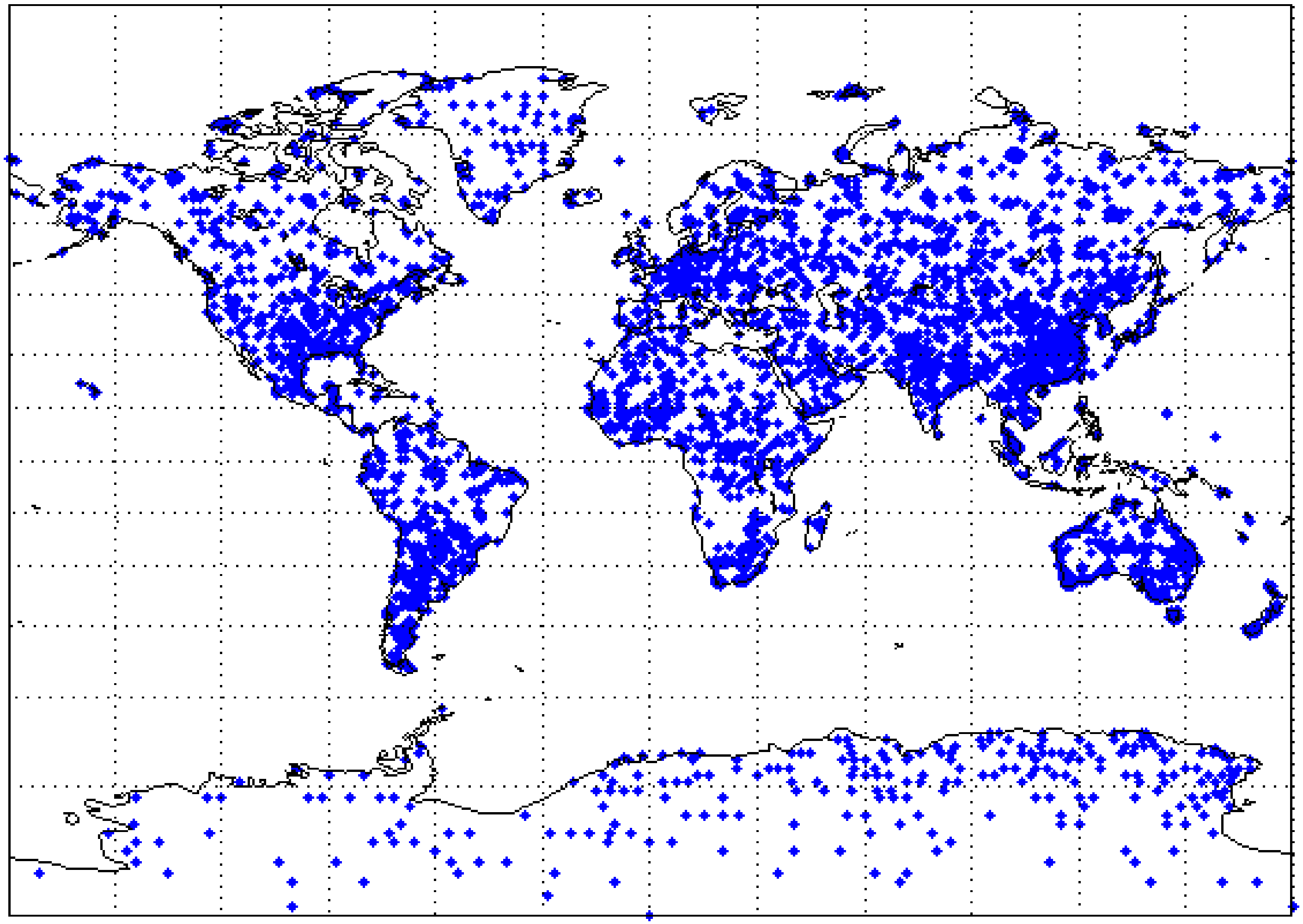
R is the observation, F(x) the forward model, K is the jacobian dF/dx, and S is the covariance where “a” refers to the a priori climatology and “e” to the measurement error covariance.

• Expand the emissivity using eigenfunctions of laboratory spectra and solve for the coefficients of the eigenfunctions in the retrieval.

Bootstrapping a HSR Global Climatology

SeeBor HSR Training Set adds high spectral resolution emissivity to a global set of T, WV, Ozone profiles. (NOAA-88, TIGR, and ECMWF are matched with MODIS land surface emissivity measurements to obtain global coverage.)

Location of 5993 HSR Emissivity spectra of SeeBor training database



SeeBor Training Set contains 5993 HSR Emissivity Spectra.

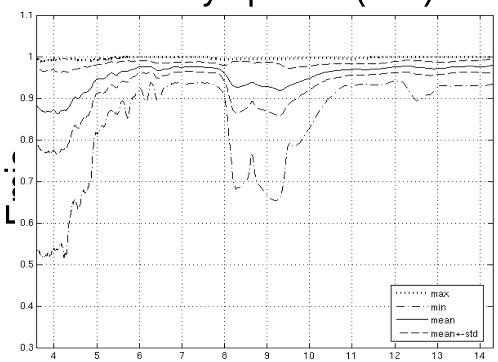
Full UW HSR Database Contains 6000 spectra in every 50 km sq.

(60 months of 5 km data)

Bootstrapping a HSR Global Climatology

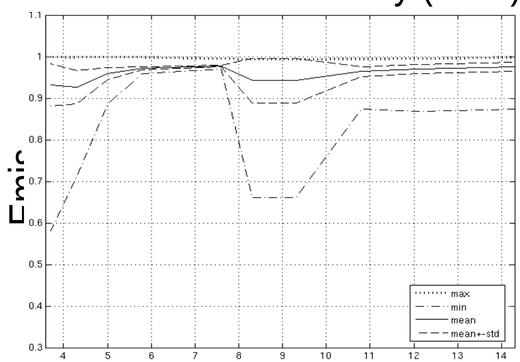
- Eva Borbas & Suzanne Seeman (Poster in Retrieval Session) “A high spectral resolution global land surface infrared emissivity database “
- Combines Laboratory High Spectral Resolution measurements with a climatology of Earth emissivity measurements at four MODIS channels.

Laboratory spectra (123)



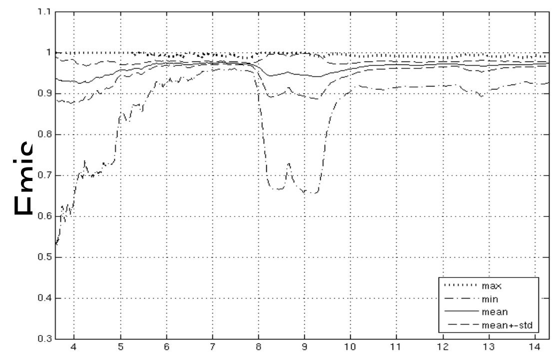
4 µm 14 µm

SeeBor BF emissivity (5993)



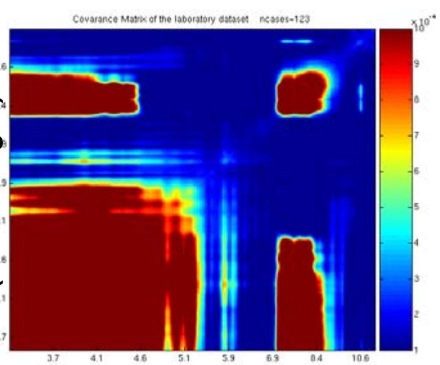
4 µm 14 µm

SeeBor HSR emissivity (5993)

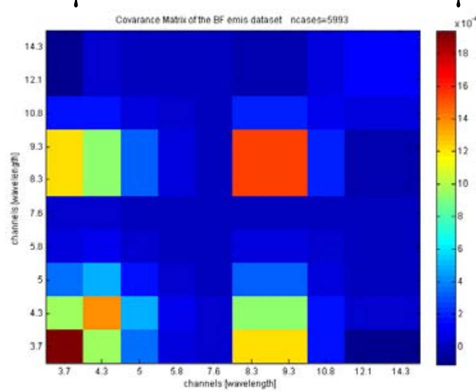


4 µm 14 µm

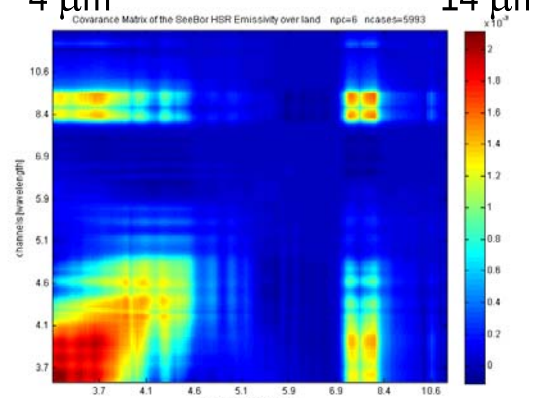
Channels (wavelength)



Channels (wavelength)

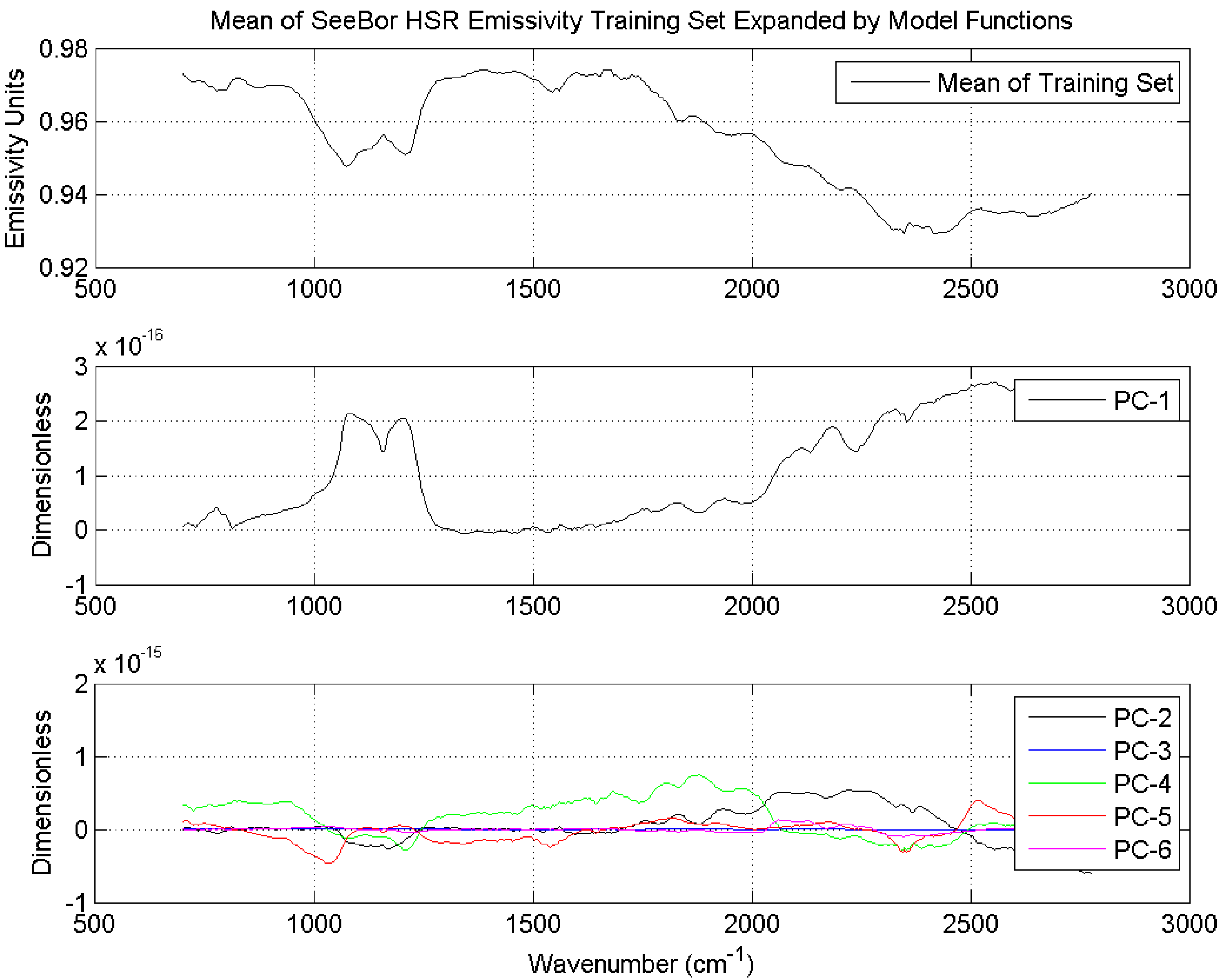


Channels (wavelength)



Channels (wavelength)

HSR Global Climatology Eigenfunctions (# PCs = 6)



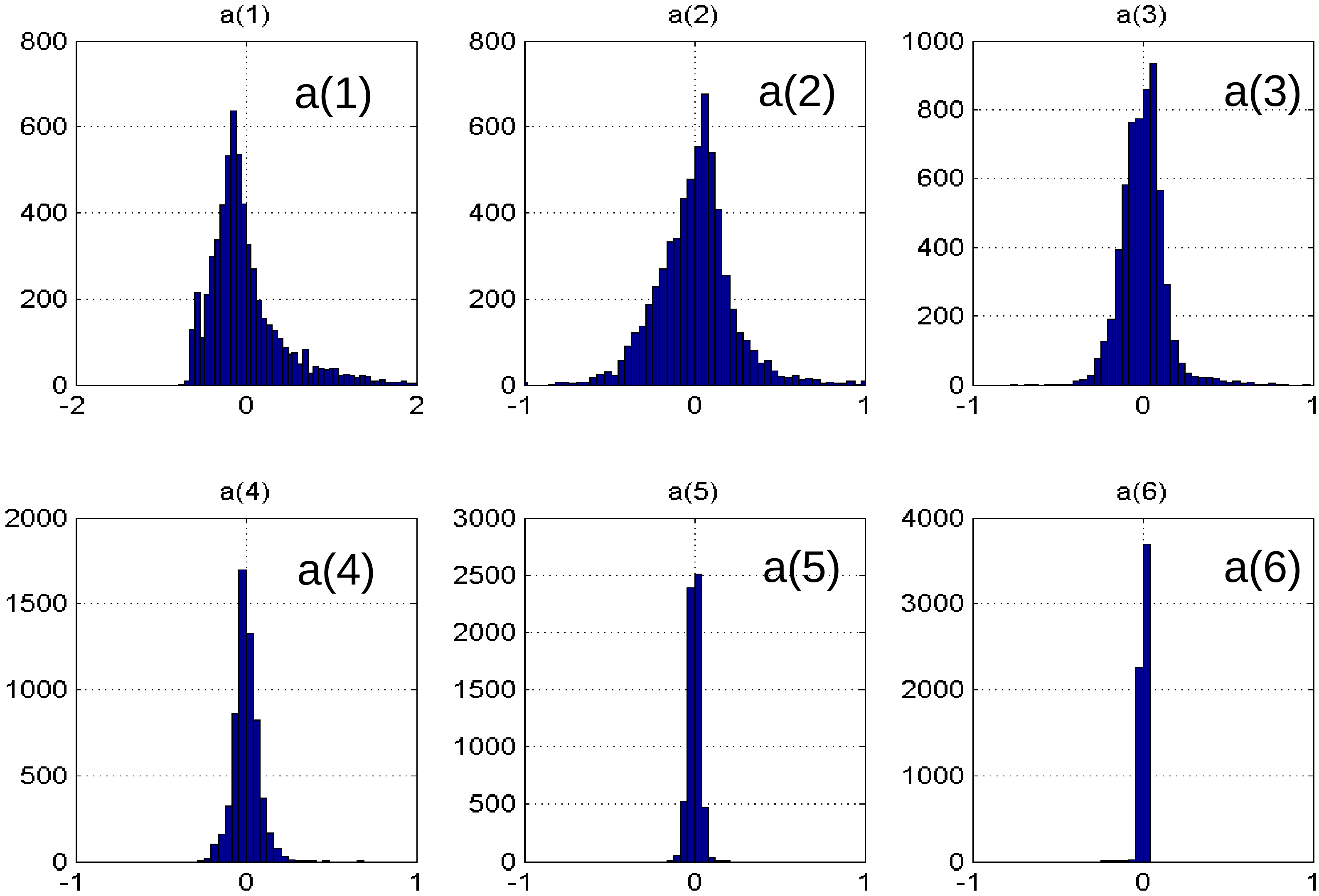
Mean
Dominated
By Silicates
(Quartz)

PC1
Silicate
Features
Explain
Most of
Variance

PC 2 to 6
carry the
Non-quartz
information

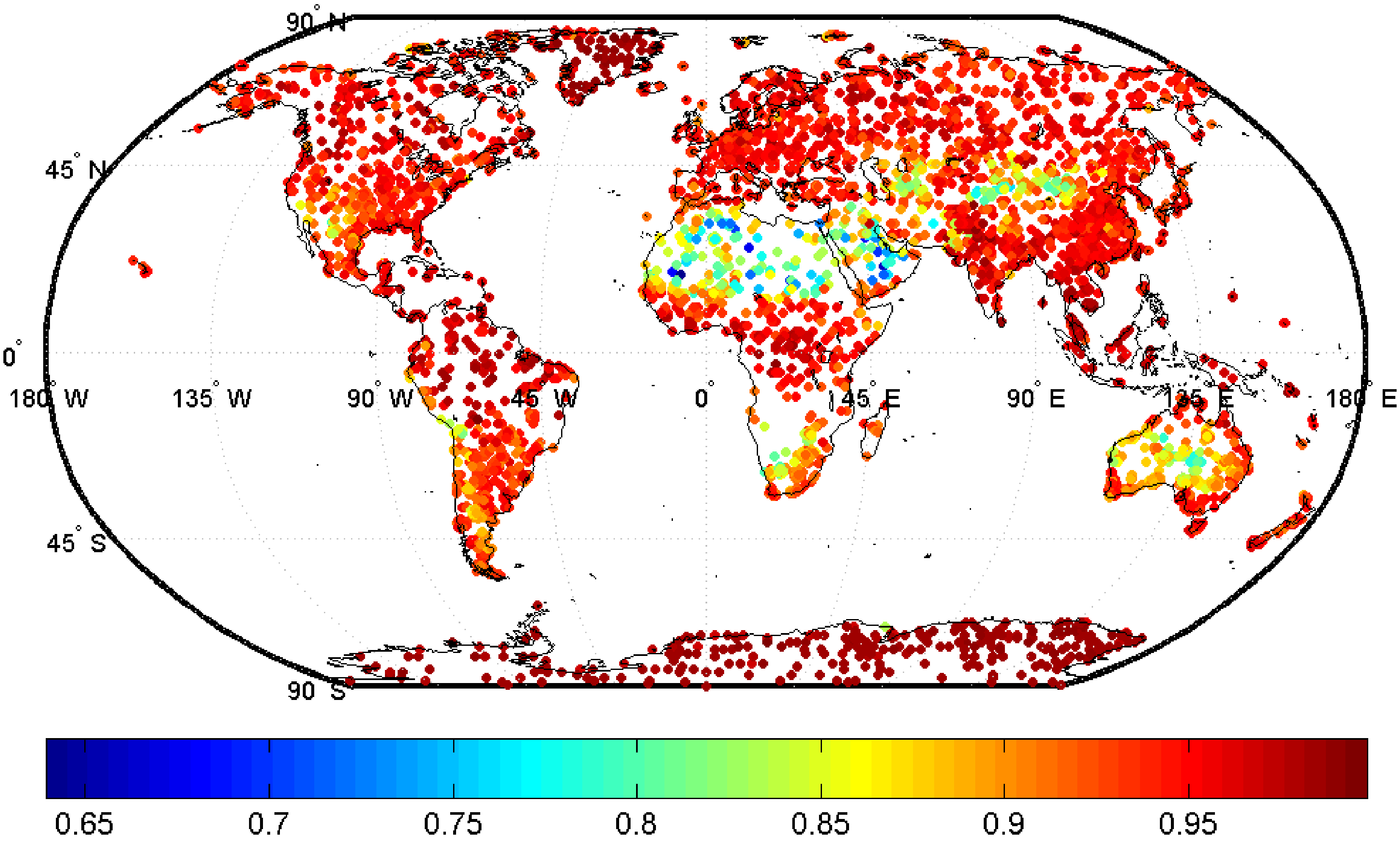
HSR Global Climatology of Projection Coefficients

- Statistics are nearly Gaussian. Use to compute covariance.



Bootstrapping a HSR Global Climatology

Using the projection coefficients and the eigenfunctions we can reconstruct the HSR emissivity at any wavelength. For example, the 4 micron emissivity is shown here, the desert regions indicate low emissivity values in blue.

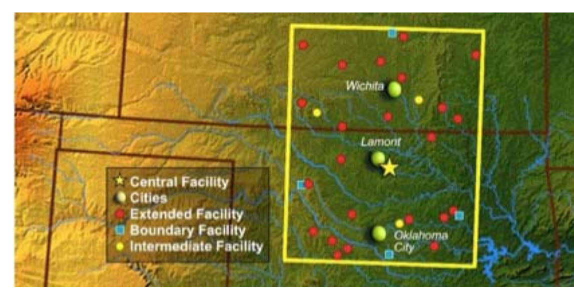


Joint Airborne IASI Validation Experiment

- *First US-European collaboration in US focusing on validation of radiance and geophysical products from MetOp-A*
- *(1st advanced sounder in the US/European Joint Polar System)*

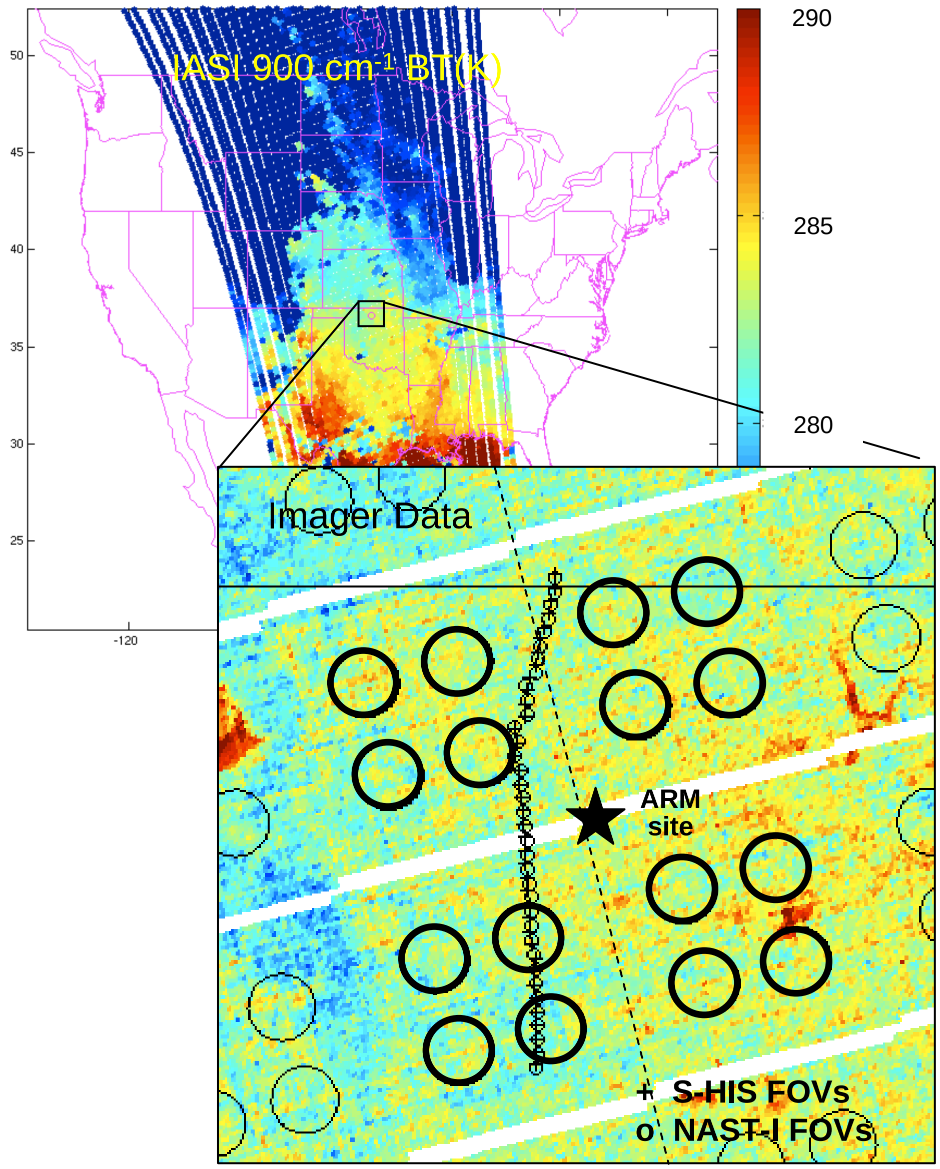
- **Location/dates**
  - ***Ellington Field (EFD), Houston, TX,*** **14 Apr – 4 May, 2007**
- **Aircraft**

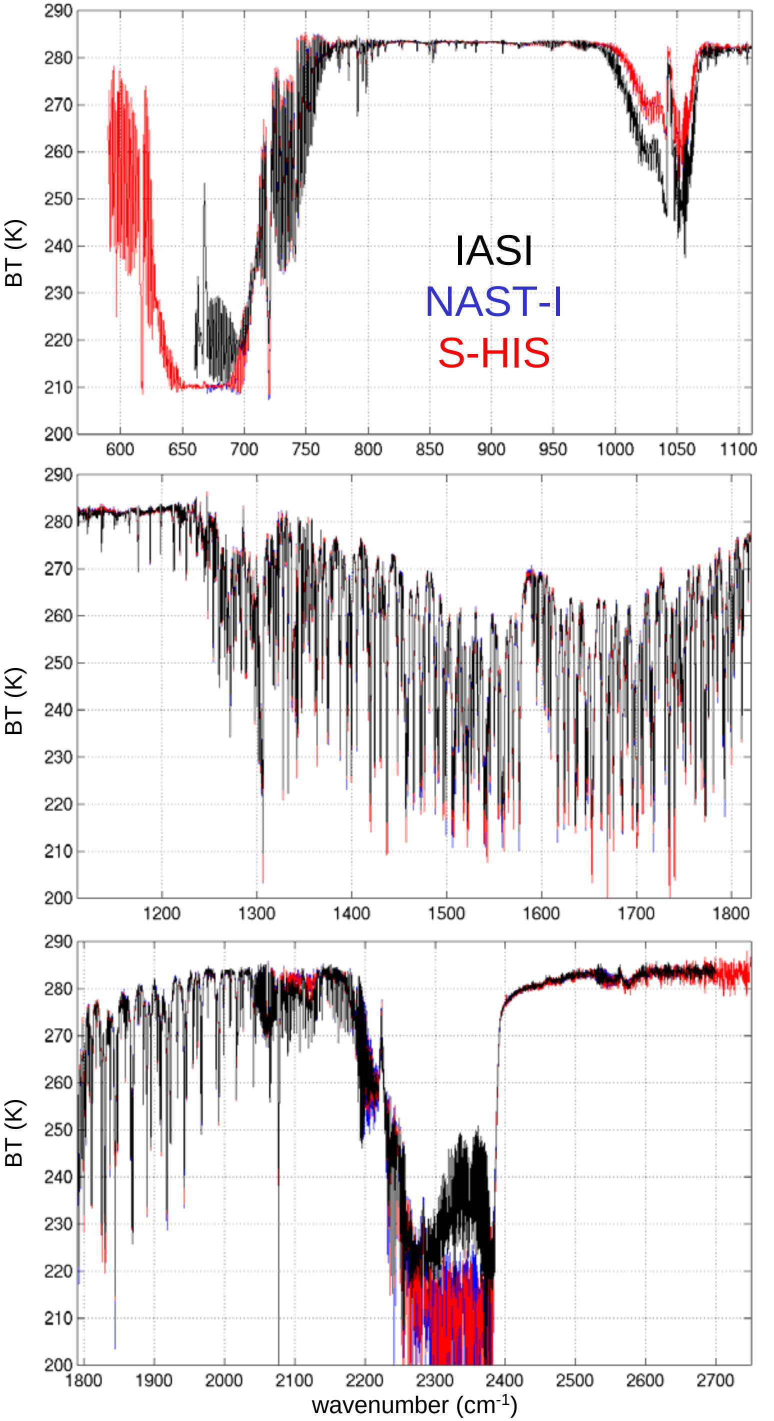
  - **NASA WB-57 (NAST-I, NAST-M, S-HIS)**
  - **UK FAAM BAe146-301 (ARIES, MARSS, Deimos, SWS;**
  - **dropsondes; in-situ cloud phys. & trace species; etc.)**
- **Ground-sites**



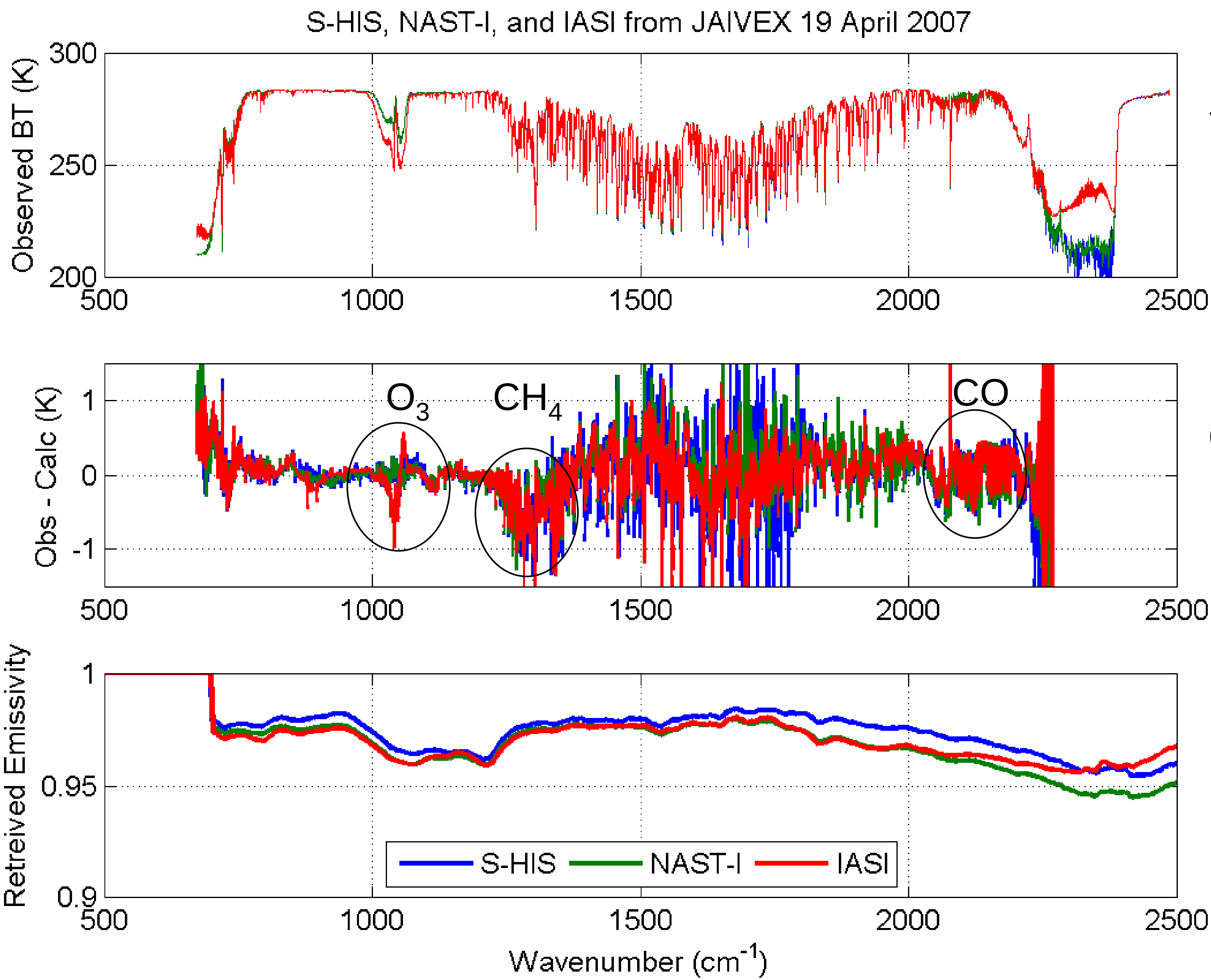
  - **DOE ARM CART ground site (RAOBS, Raman Lidar, AERI, etc.)**
- **Satellites**
  - **MetOp-A (IASI, AMSU, MHS, AVHRR, HIRS, GOME, SBUV, ACAT)**

JAIVEx 19 Apr 2007 Case





Optimal Estimation Retrieval of T, WV, O3, Ts, a(1-6)

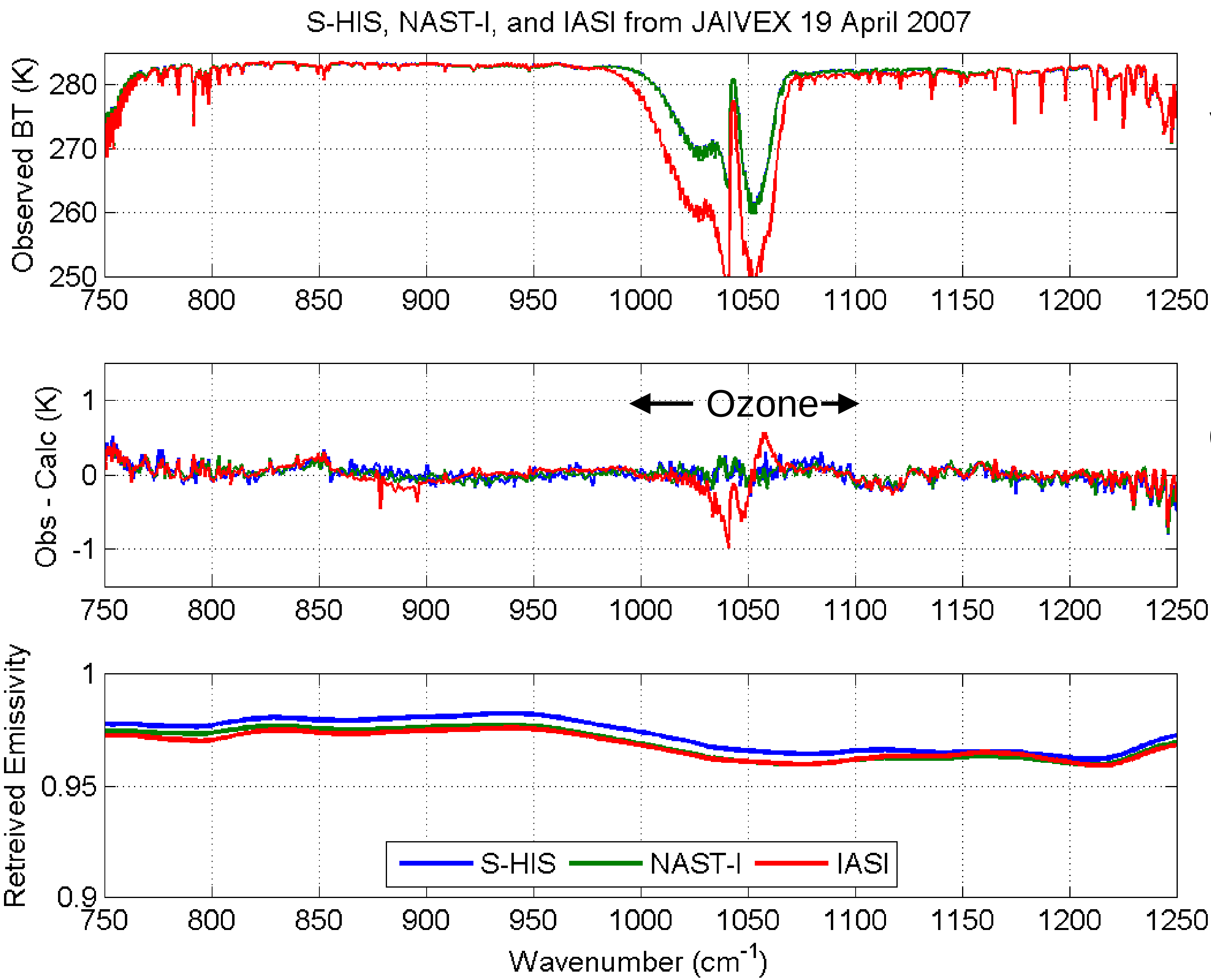


S-HIS NAST-I IASI Obs.

Obs-Calc Residual

Retrieved Emissivity

Optimal Estimation Retrieval of T, WV, O3, Ts, a(1-6)



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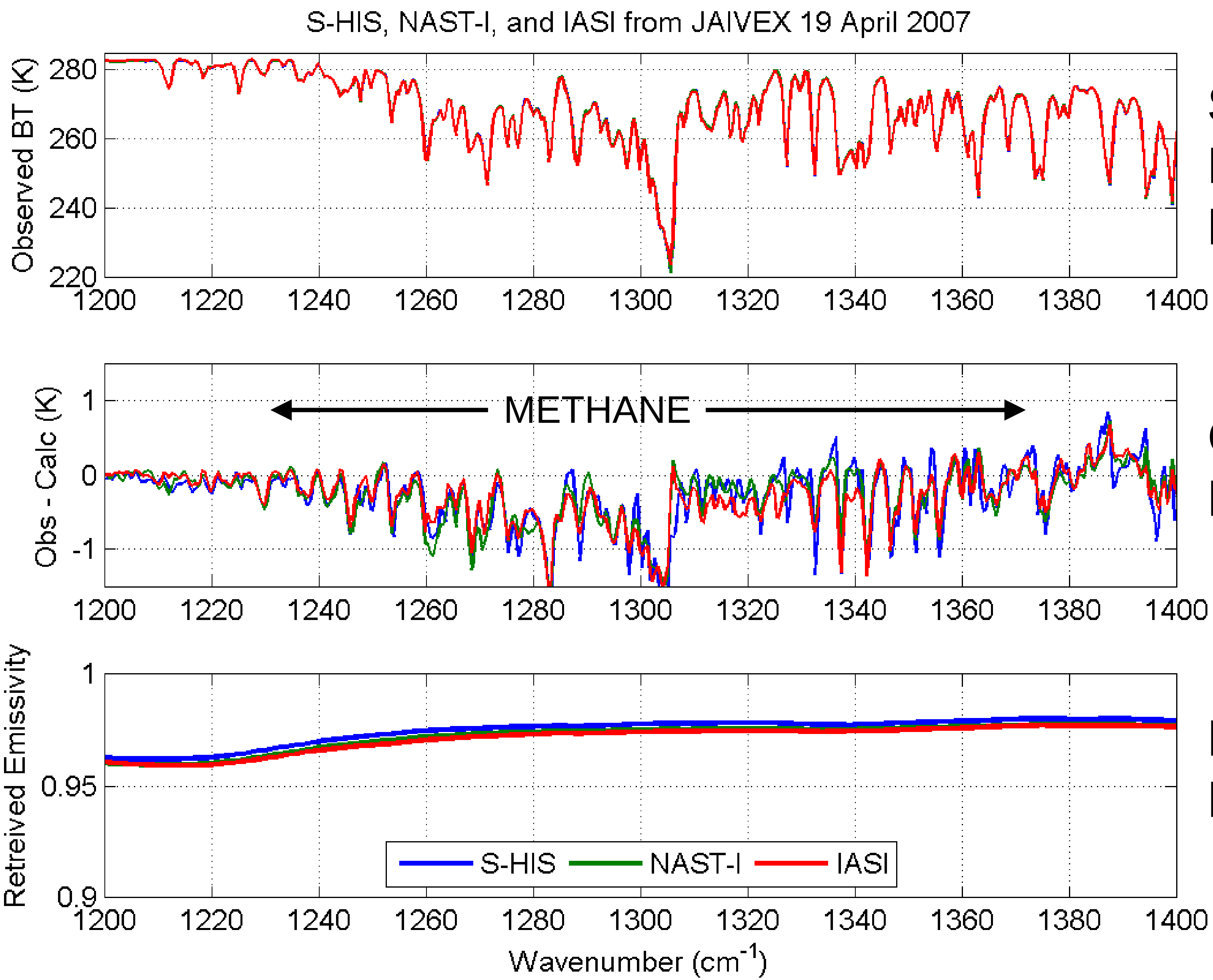

S-HIS
NAST-I
IASI Obs.

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Retrieved Emissivity

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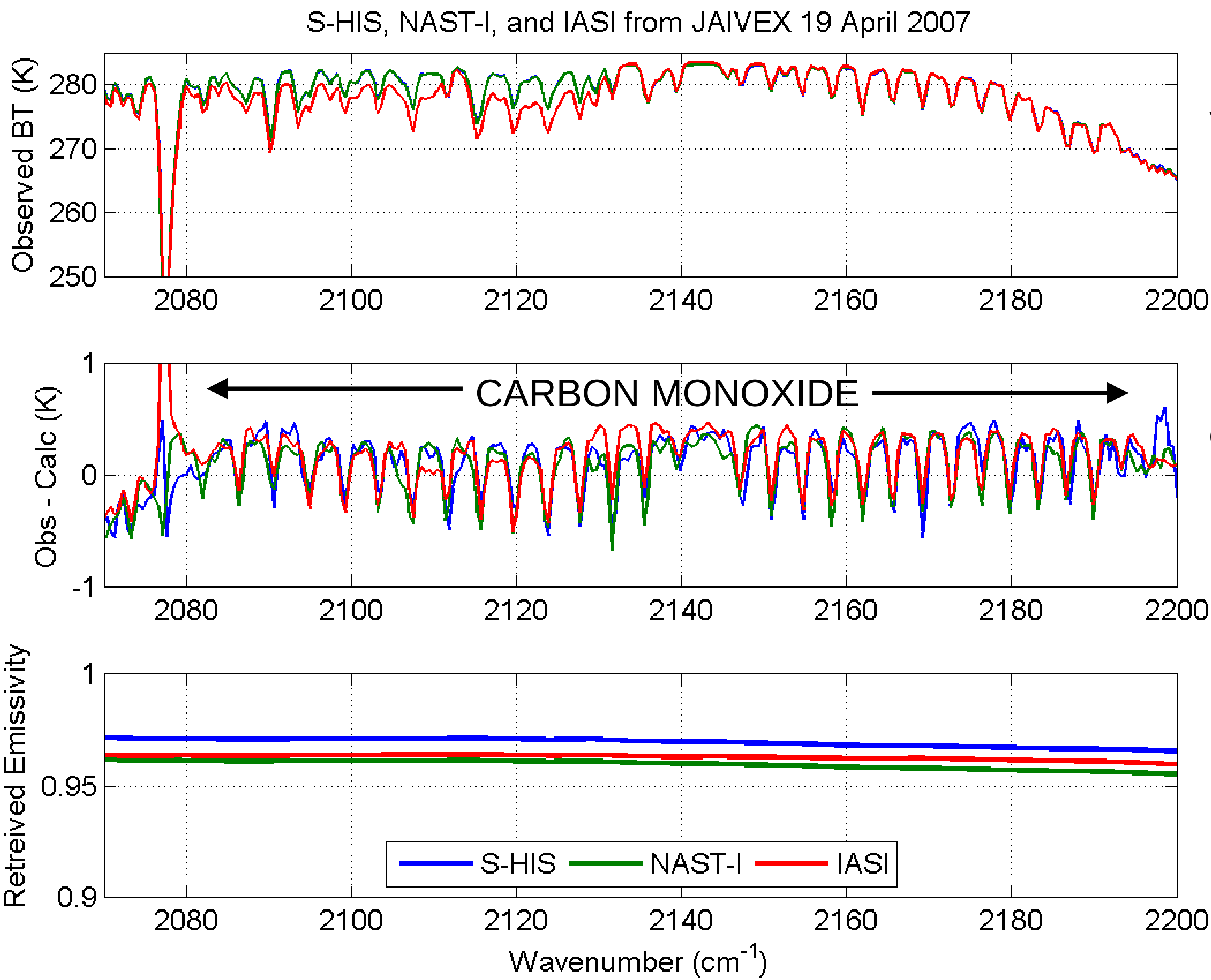
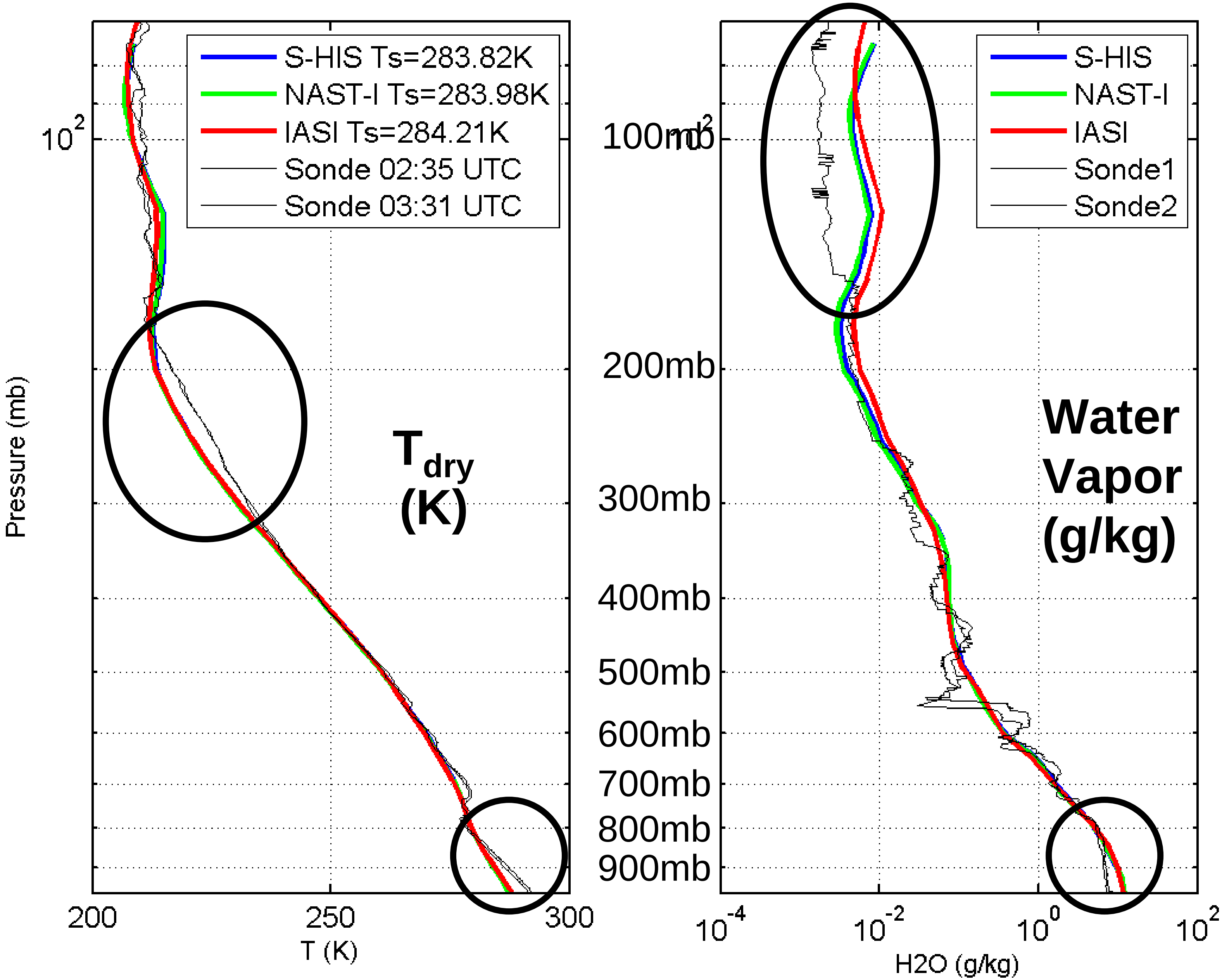


S-HIS
NAST-I
IASI Obs.

Obs-Calc
Residual

Retrieved
Emissivity

T & WV Validation with Vaisala RS92 Radiosondes



Summary

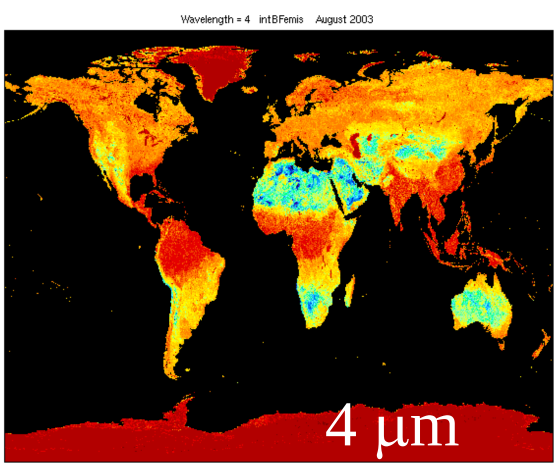
- The new UW HSR SeeBor emissivity training set adds high spectral resolution to a profile climatology that includes MODIS global emissivity observations.

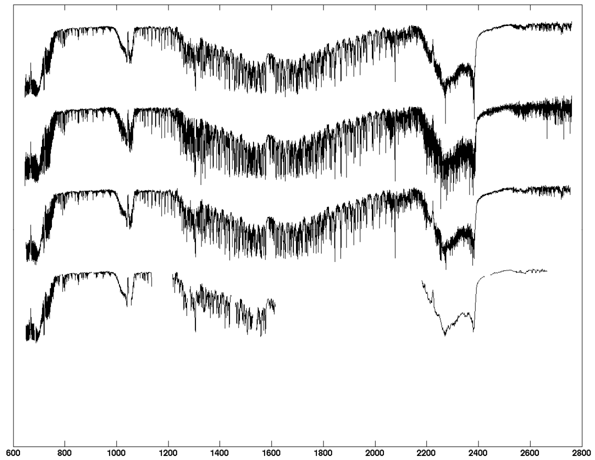
- We have demonstrated how a realistic global HSR emissivity database can be applied to high spectral resolution observations in a manner consistent with optimal estimation retrieval.

- Application to the JAIVEx satellite (IASI) and high altitude aircraft observations (S-HIS and NAST-I) over the Oklahoma ARM truth site provide an example of how infrared surface emissivity can be validated at the 1 % level using aircraft observations.

Future Work

• Demonstrate use of the UW Global Gridded HSR dataset to create a climatology at 5 km spatial resolution by extracting the 5 year time variation by month.
• Application to global IASI datasets at native resolution and at CrIS resolution (Tobin method).
• Collaboration with 1-D var data assimilation experts to demonstrate impact of soundings over land to NWP.





IASI – 1C
IASI – NAST-I
IASI – S-HIS
IASI – CrIS

Acknowledgements

• Supported by the Integrated Project Office (IPO) for Government Studies / IV&V at the University of Wisconsin Space Science and Engineering Center.

<u>FOR MORE INFORMATION:</u>

• Eva Borbas & Suzanne Seeman (Poster in Retrieval Session) “A high spectral resolution global land surface infrared emissivity database “

• Dr. Henry Revercomb (invited talk tomorrow morning in Retrieval Session) for additional details on aircraft and advanced sounder radiometric comparisons.