GOES-R AWG Land Surface Emissivity: Retrieval of Land Surface Emissivity (LSE) using Time Continuity

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Executive Summary

- This ABI land surface emissivity (LSE) retrieval algorithm generates one Option 2 product along with a by-product of land surface temperature (LST)
- Software Version 3 was delivered. ATBD (80%) and test datasets are scheduled to be delivered in August 25, 2010.
- The algorithm takes advantage of ABI high temporal resolution (15 minutes) to enhance LSE signals in the window channels in the thermal infrared region; the LSE is assumed to be invariable during a short period of time while LST is variable.
- Sensitivity study: the algorithm is applied to simulated SEVIRI measurements to test the sensitivity on the quality of the first guess, the local zenith angle (LZA), the radiance bias and noise.
- Validation: the retrieval from observed SEVIRI measurements are compared with other LSE products, such as MODIS, AIRS and IASI.

Requirements and Product Qualifiers the land surface emissivity

Name	User & Priority	Geographic Coverage (G, H, C, M)	Horiz. Res.	Mapping Accuracy	Refresh Rate/Coverage Time Option (Mode 3)	Refresh Rate Option (Mode 4)	Product Measurement Precision	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Surface Emissivity	GOES-R	C *	10 km	5 km	6 hours	6 hours	0.05	Quantitative out to at least 67 degrees LZA	Clear conditions associated with threshold accuracy	Over specified geographic area

C * – CONUS

Algorithm Description

Linearization of RT Equation

- **The Linearization of the Radiative Transfer Equation yields:**

$$\delta R = K_{T_s}\delta T_s + K_\varepsilon \delta\varepsilon_\nu + \sum K_T \delta T + \sum K_Q \delta \ln Q + e$$

This equation needs to be simplified for accurate and stable LSE retrievals

- **The atmospheric correction is achieved by using NWP forecast profiles plus**

$$\delta\overline{T}\sum K_T = \sum K_T \delta T + \sum K_Q \delta \ln Q$$

Greatly simplifies the linearization equation by reducing the unknowns of T/Q profiles to just one hybrid variable of $\delta\overline{T}$

- **The simplified linearized RT Equation:**

$$\delta R = K_{T_s}\delta T_s + K_\varepsilon \delta\varepsilon_\nu + \hat{K}_T \delta\overline{T} + e$$

where $\hat{K}_T = \sum K_T$

So, the three variables to retrieve are skin temperature, surface emissivity and mean-layer temperature.

Time continuity

- Time continuity of LSE: the LSE is assumed to be invariable during a short period of time while LST is variable. The geostationary perspective allows for this approach.

- On SEVIRI, there are three window channels (8.7, 10.8 and 12 micrometer), and three time steps are recommended.

- The linearized RT equation looks:

$$\delta\begin{bmatrix} R_1^1 \\ R_2^1 \\ R_3^1 \\ R_1^2 \\ R_2^2 \\ R_3^2 \\ R_1^3 \\ R_2^3 \\ R_3^3 \end{bmatrix} = \begin{bmatrix} K_{T_s,1}^1 & 0 & 0 & K_{\varepsilon,1}^1 & 0 & 0 & \hat{K}_{T,1}^1 & 0 & 0 \\ K_{T_s,2}^1 & 0 & 0 & 0 & K_{\varepsilon,2}^1 & 0 & \hat{K}_{T,2}^1 & 0 & 0 \\ K_{T_s,3}^1 & 0 & 0 & 0 & 0 & K_{\varepsilon,3}^1 & \hat{K}_{T,3}^1 & 0 & 0 \\ 0 & K_{T_s,1}^2 & 0 & K_{\varepsilon,1}^2 & 0 & 0 & 0 & \hat{K}_{T,1}^2 & 0 \\ 0 & K_{T_s,2}^2 & 0 & 0 & K_{\varepsilon,2}^2 & 0 & 0 & \hat{K}_{T,2}^2 & 0 \\ 0 & K_{T_s,3}^2 & 0 & 0 & 0 & K_{\varepsilon,3}^2 & 0 & \hat{K}_{T,3}^2 & 0 \\ 0 & 0 & K_{T_s,1}^3 & K_{\varepsilon,1}^3 & 0 & 0 & 0 & 0 & \hat{K}_{T,1}^3 \\ 0 & 0 & K_{T_s,2}^3 & 0 & K_{\varepsilon,2}^3 & 0 & 0 & 0 & \hat{K}_{T,2}^3 \\ 0 & 0 & K_{T_s,3}^3 & 0 & 0 & K_{\varepsilon,3}^3 & 0 & 0 & \hat{K}_{T,3}^3 \end{bmatrix} \times \delta\begin{bmatrix} T_s^1 \\ T_s^2 \\ T_s^3 \\ \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \overline{T}^1 \\ \overline{T}^2 \\ \overline{T}^3 \end{bmatrix} + \begin{bmatrix} e_1^1 \\ e_2^1 \\ e_3^1 \\ e_1^2 \\ e_2^2 \\ e_3^2 \\ e_1^3 \\ e_2^3 \\ e_3^3 \end{bmatrix}$$

or $\mathbf{Y} = \mathbf{K}\delta\mathbf{X} + \mathbf{e}$

the number in superscript denotes time steps, and the number in subscript denotes channel index

The optimal solution

- A general form of the variational solution is to minimize the cost function:

$$J(\mathbf{X}) = [\mathbf{Y}^{\mathbf{m}} - \mathbf{Y}(\mathbf{X})]'\mathbf{E}^{-1}[\mathbf{Y}^{\mathbf{m}} - \mathbf{Y}(\mathbf{X})] + [\mathbf{X} - \mathbf{X}_0]'\mathbf{H}[\mathbf{X} - \mathbf{X}_0]$$

Where

X:	*state vector*
Y^m:	*observed brightness temperature vector*
Y:	*radiative transfer model (function of X)*
E:	*Observation error covariance matrix (diagonal)*
X$_0$:	*Background state vector from forecast*
H:	*the inverse of the background error covariance matrix*

- Apply Newtonian iteration

$$\mathbf{X}_{\mathbf{n+1}} = \mathbf{X}_{\mathbf{n}} + J''(\mathbf{X}_{\mathbf{n}})^{-1} \bullet J'(\mathbf{X}_{\mathbf{n}})$$

- The quasi-nonlinear iterative form of the solution is

$$\mathbf{X}_{\mathbf{n+1}} - \mathbf{X}_0 = (\mathbf{K}_{\mathbf{n}}'\mathbf{E}^{-1}\mathbf{K}_{\mathbf{n}} + \mathbf{H})^{-1}\mathbf{K}_{\mathbf{n}}'\mathbf{E}^{-1}[\mathbf{Y}^{\mathbf{m}} - \mathbf{Y}_{\mathbf{n}}(\mathbf{X}_{\mathbf{n}}) + \mathbf{K}_{\mathbf{n}}(\mathbf{X}_{\mathbf{n}} - \mathbf{X}_0)]$$

Sensitivity Study

Simulation dataset

- **A match-up database is used to study the sensitivity of the algorithm**
- **The simulated SEVIRI radiances are calculated using PFAAST with**
  - ***RAOBs from ARM program at Southern Great Plains (SGP)***
  - ***The infrared radiometer measured LST***
  - ***Laboratory measured high spectral LSE spectra from MODIS and ASTER emissivity library***
- **The first guesses of the algorithms comes from**
  - ***The GFS/NCEP 6-hour forecast***
  - ***The LST and LSE are generated using***

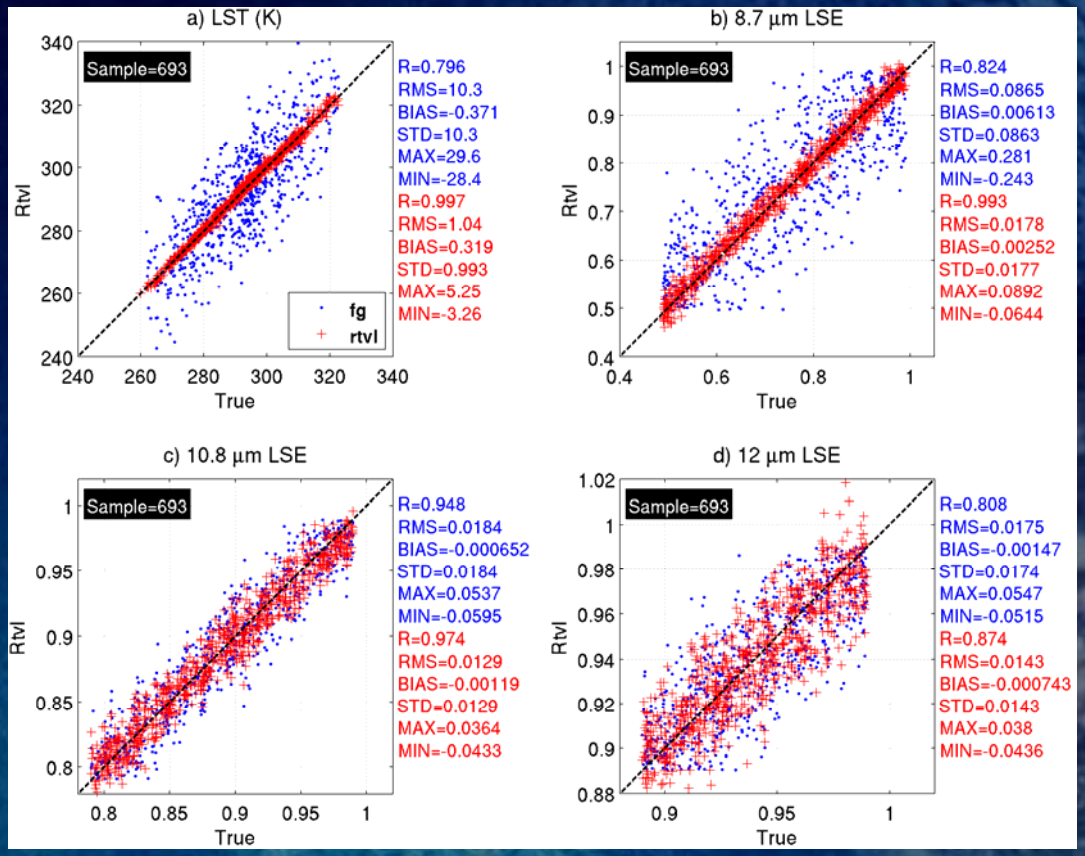
$$x_g = x_t + E(\delta x_t)$$

where, *x_g is the first guess, x_t is the true parameter, and $E(\delta x_t)$ is a random number with a bias of 0 and an standard deviation (STD) of δx_t (10 K, 0.1, 0.02 and 0.02 for LST, and emissivities of 8.7, 11 and 12 μm respectively)*

- **The time coverage is 08/2006 – 08/2009, and the sample size is 693 after cloud clearing**
- **The retrieval is performed 43 times with different LZA from 0 to 84 with an increment of 2 degrees**

Validation of the retrievals using simulation data

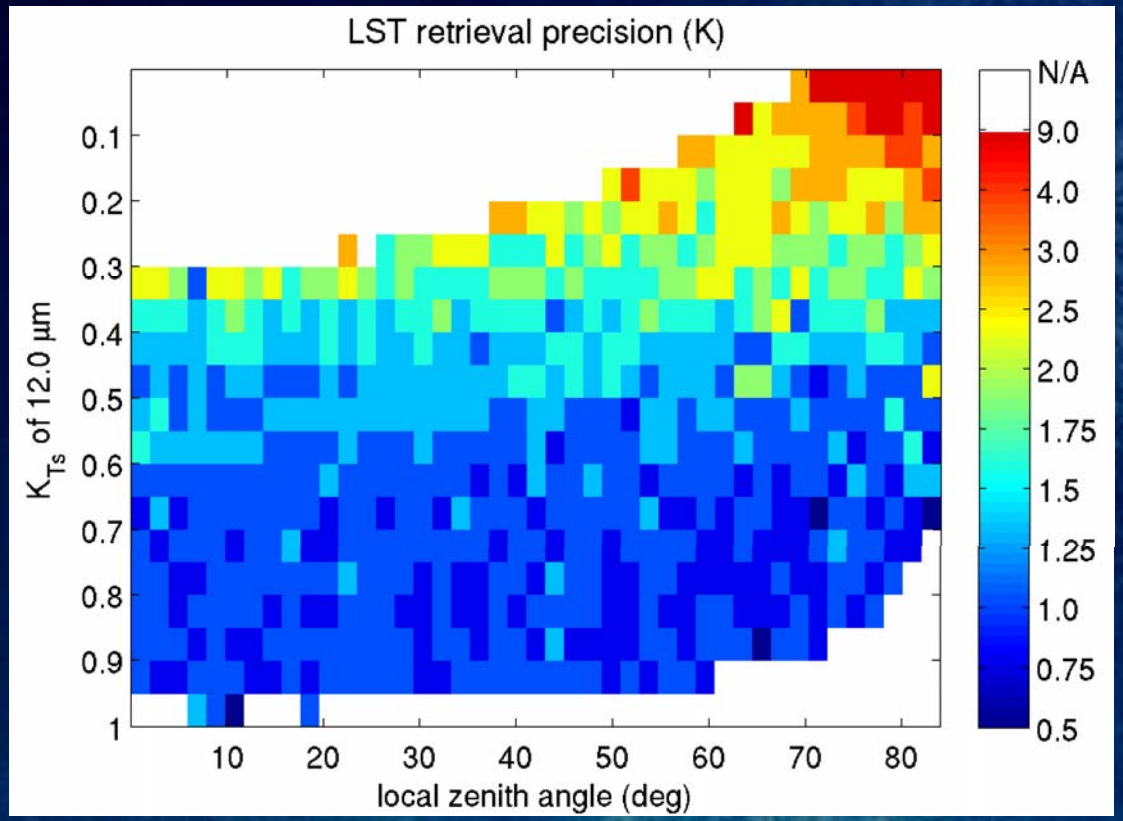
The retrievals with LZA of 0 degree are compared with the true



The algorithm successfully brings the retrieval parameters closer to the true values, especially for LSE of 8.7 micrometer and LST.

Sensitivity to LZA and LST weighting function

The retrieval precision of LST as a function of LZA and 12 micron LST weighting functions



1. *LESS Sensitive to LZA*

2. *A cut-off LZA of 65 degree is recommended for two reasons:*
   - **Reduce cloud contamination**
   - **Reduce impacts from radiative transfer calculation errors**

3. *Very sensitive to 12 micrometer LST weighting functions*

4. *Along as the weighting functions of LSE and LST are large enough, the retrieval precision is good.*

Evaluation

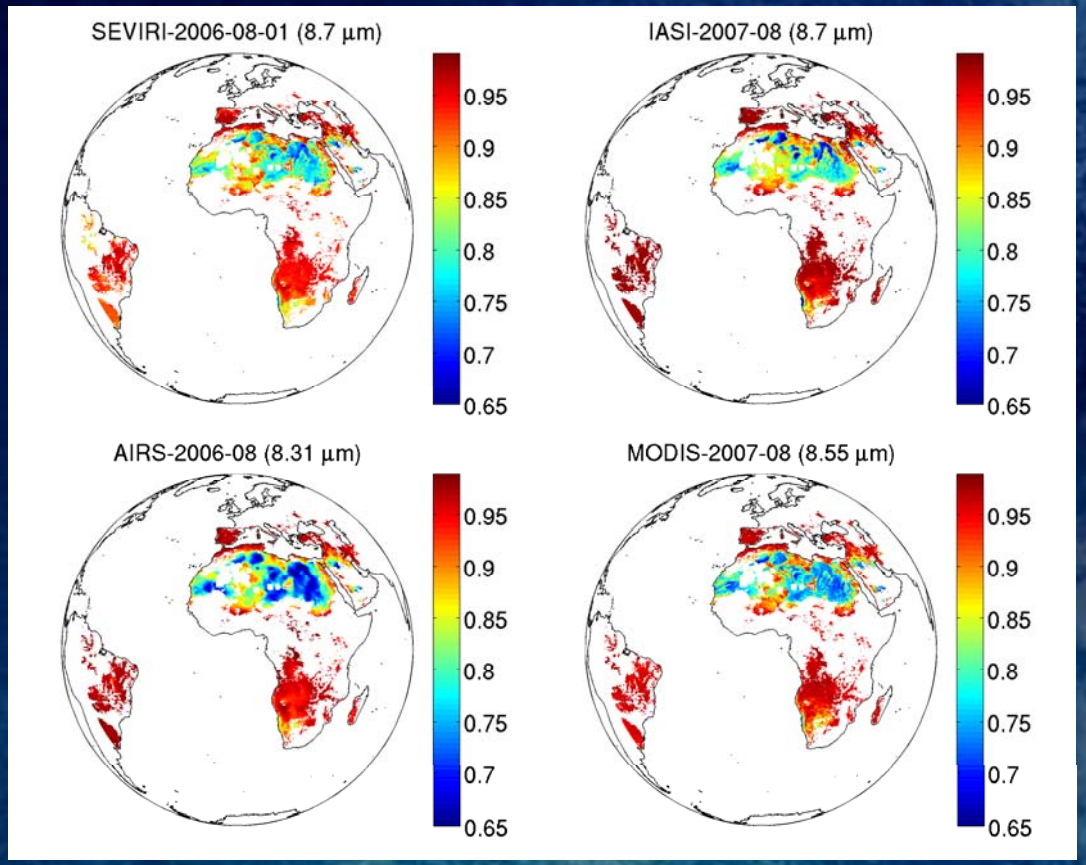
Evaluation Approach

- Direct validation of LSE retrievals using laboratory measurements are difficult due to
  - » Measurement scale inconsistency (point versus area); very few areas are homogeneous enough for this comparison.
  - » Naturally temporal variation of LSE
  - » Expensive

- Practical methods to evaluate LSE retrievals include
  - » Inter-comparison: compare with other LSE databases, such as ABI/SEVIRI, MODIS, AIRS and IASI
  - » Apply the LSE database to retrieval to see if they provide positive impacts, i.e. on sounding retrievals
  - » Apply the LSE database in radiance data assimilation over land to see if they provide positive impacts
  - » Compare observation radiances with calculated radiances with LSE database
  - » Objective way to evaluate LSE retrievals -- An objective algorithm is being developed to quantitatively evaluate the uncertainty of LSE

Inter-comparison: SEVIRI LSE products -- 8.7 um

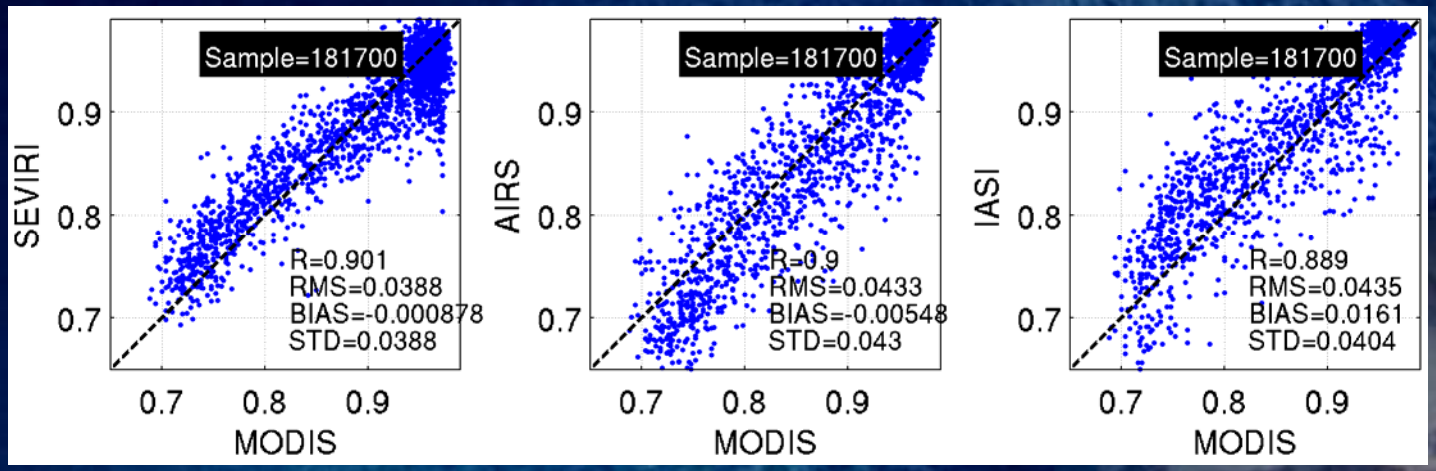
- The algorithm is applied to SEVIRI observations on August 1 2006. The retrievals are compared with MODIS (collection 4.1), AIRS and IASI monthly LSE databases.



8.7 um

Inter-comparison: Compared with MODIS -- 8.7 um

- Using MODIS monthly LSE database as reference, other three databases are quantitatively evaluated



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Using MODIS as a reference,
SEVIRI > IASI > operational AIRS

Inter-comparison: SEVIRI LSE products----10.8 um

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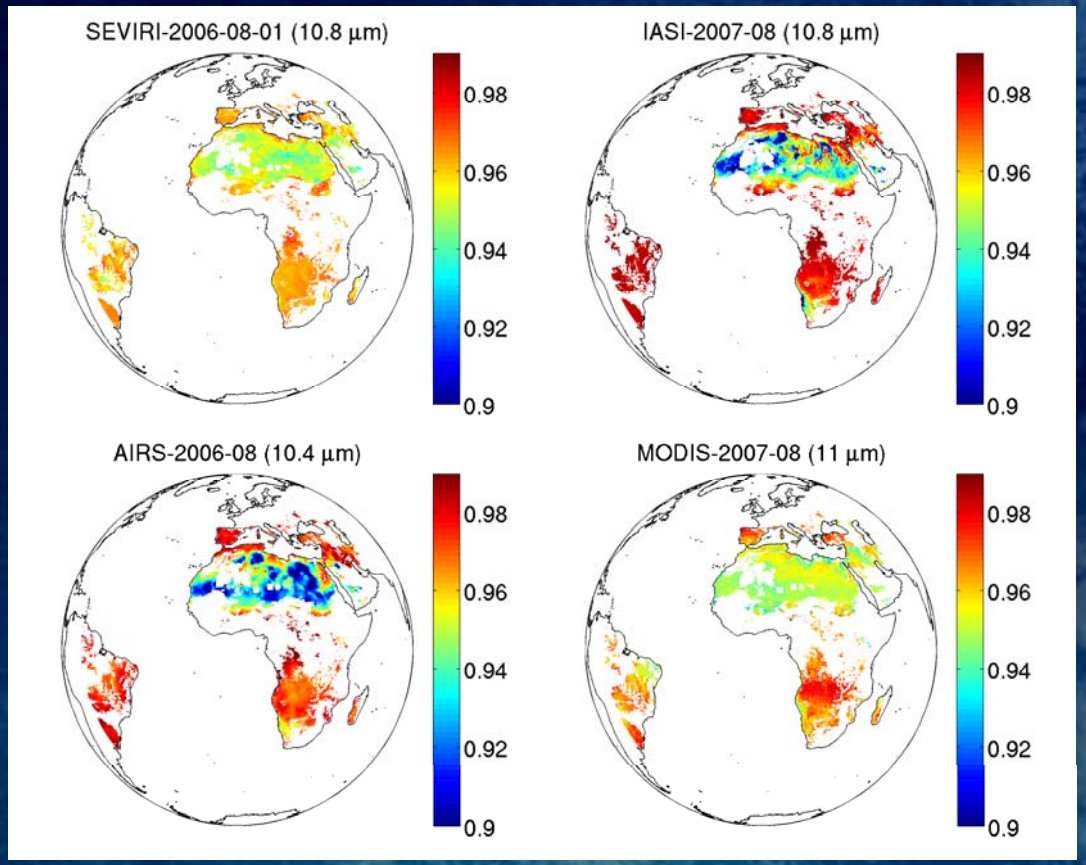

10.8 um

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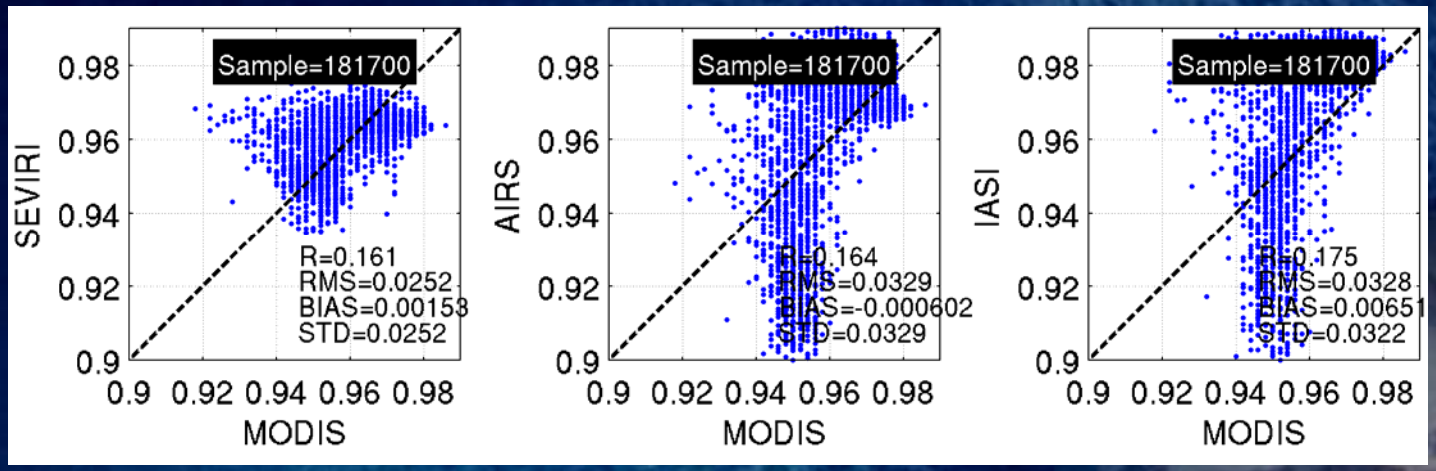
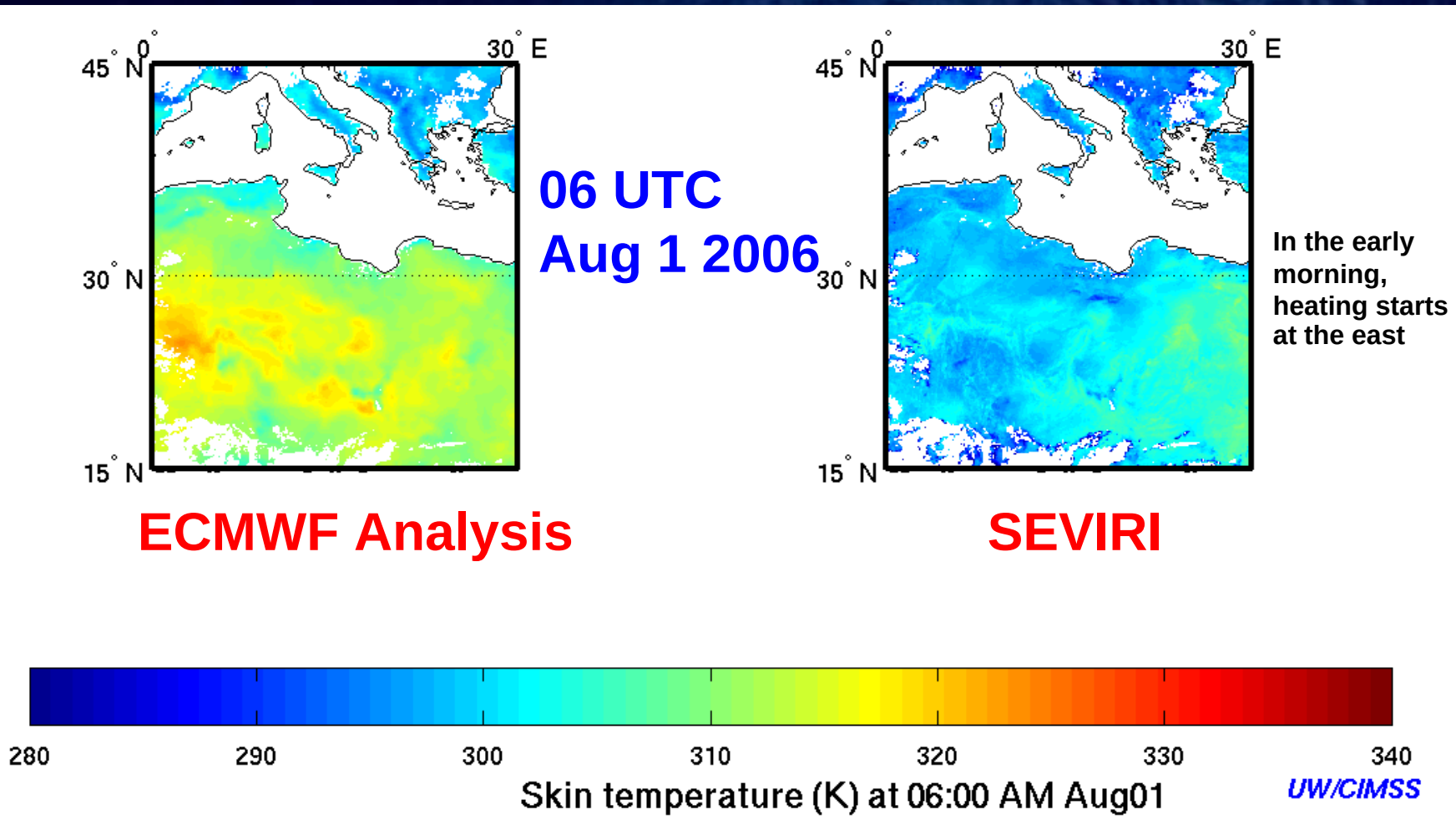


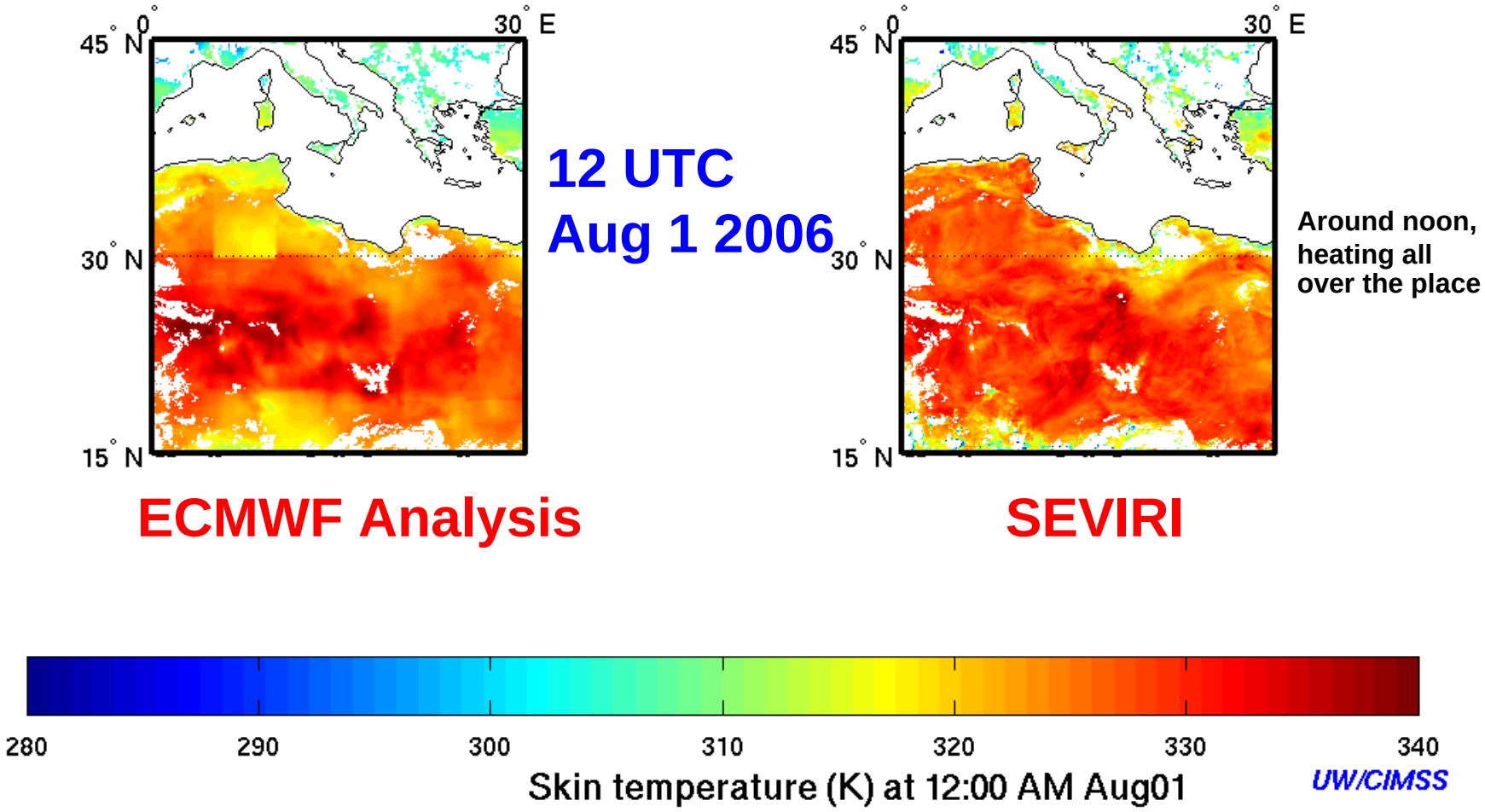
10.8 um

Using MODIS as a reference,
SEVIRI > IASI > operational AIRS

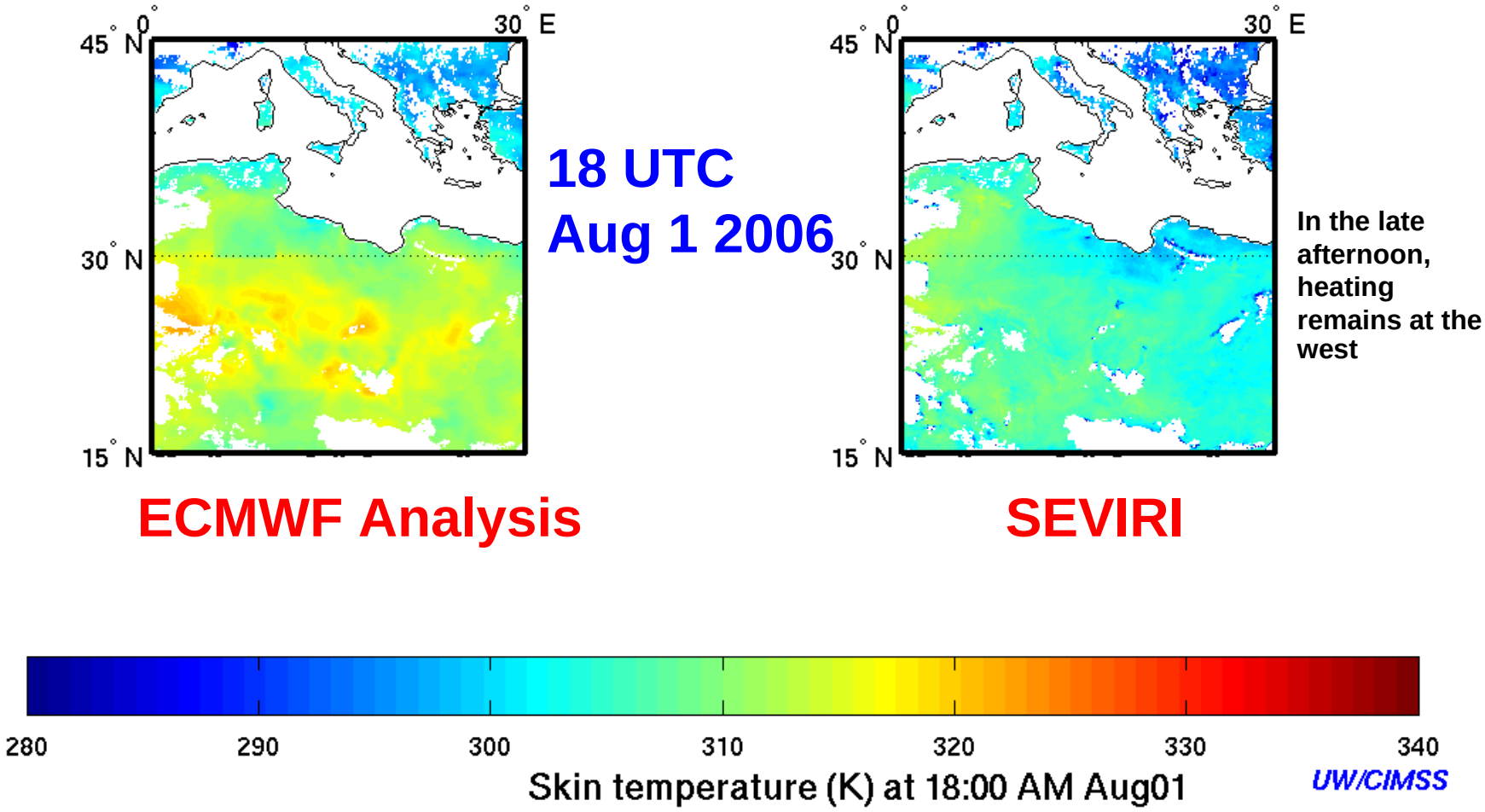
Indirect:
LST Compared to ECMWF Analysis



Indirect:
LST Compared to ECMWF Analysis

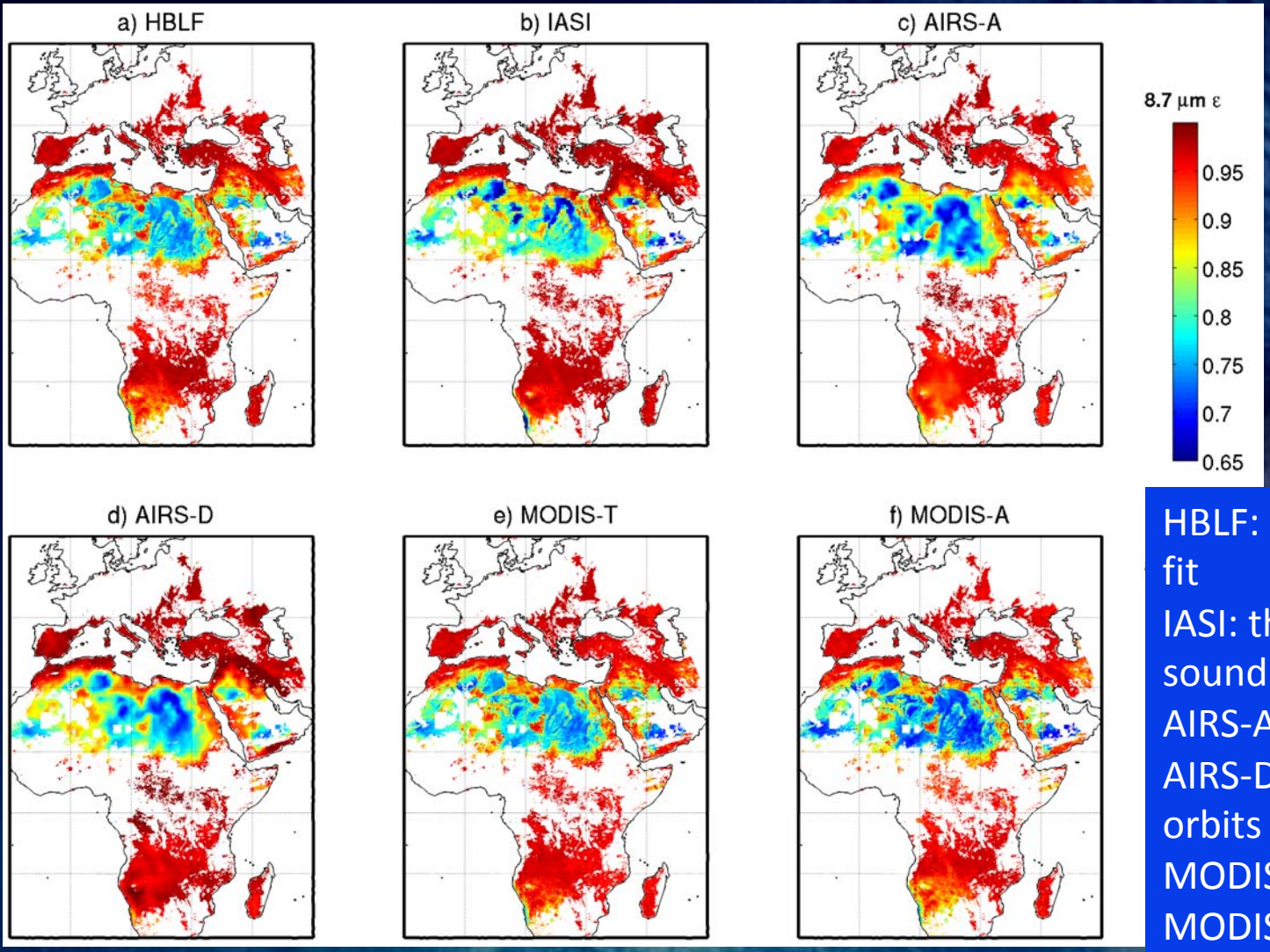


Indirect:
LST Compared to ECMWF Analysis



In the late afternoon, heating remains at the west

Objective way – quantitative evaluation of LSE uncertainty



HBLF: hyperspectral baseline fit

IASI: the infrared atmospheric sounding interferometer

AIRS-A: AIRS ascending orbits

AIRS-D: AIRS descending orbits

MODIS-T: MODIS/Terra

MODIS-A: MODIS/Aqua

Objective way - the estimated LSE precision

	8.7 μm	10.8 μm	12 μm	Average
HBLF	0.027	0.009	0.016	0.018
IASI	0.038	0.017	0.016	0.024
AIRS-A	0.036	0.020	0.035	0.030
AIRS-D	0.035	0.024	0.028	0.029
MODIS/Terra	0.028	0.010	0.017	0.018
MODIS/Aqua	0.029	0.009	0.017	0.018

- The precision is the standard deviation of errors; no bias errors are included.
- SEVIRI observations at 6 UTC on August 1 2006 are used.
- AIRS/IASI can provide emissivity information in the absorption band region.

Steps to reach 100%

- Compare the BLF (Baseline Fit) and regression emissivity to determine which is better for ABI LSE physical retrieval input.
- Further improve atmospheric correction.
- Quality control of ABI LSE.
- Test the algorithm on proxy ABI data (4 channels for ABI VS 3 channels for SEVIRI).
- More validation/evaluation, via both direct and indirect methods.

Summary

- The ABI LSE algorithm based on time continuity of LSE is developed to simultaneously retrieve LSE in window channels and LST.
  - » LSE is assumed invariable during a short period of time
  - » LST is variable
- Sensitivity study using simulation data shows that the algorithm is
  - » LESS sensitive to the quality of the first guesses of LST and LSE of 8.7 micron, but sensitive to that of 10.8 and 12 micron
  - » LESS sensitive to LZA, but sensitive to the weighting functions of LSE and LST
  - » WEAKLY sensitive to observational noise and the forward model uncertainty
  - » Partially sensitive to radiance bias in 8.7 micron due to dust contamination (only LSE of 8.7 micron is strongly affected); sensitive to radiance bias in 12 micron due to radiative transfer bias.
- The SEVIRI LSE retrievals are compared with operational MODIS monthly LSE products along with operational AIRS monthly database and IASI research database, the results show that
  - » SEVIR > IASI > AIRS
- Also an objective algorithm is being developed to quantitatively evaluate the uncertainty of LSE, this method will be applied to ABI/SEVIRI LSE evaluation
- The SEVIRI LST retrievals are found to depict the surface heating pattern over Sahara better than ECMWF analysis