Infrared Continental surface emissivity spectra retrieved from hyperspectral sensors. Application to AIRS observations

Eric PEQUIGNOT

Laboratoire de Météorologie Dynamique (LMD) / IPSL
Team « Atmospheric Radiation Analysis »
Ecole Polytechnique, Palaiseau, France

Infrared RTE (lambertian surface, clear sky, night)

$$I(\lambda,\theta) = \varepsilon_s(\lambda)\tau_s(\lambda,\theta)B(\lambda,T_s)$$

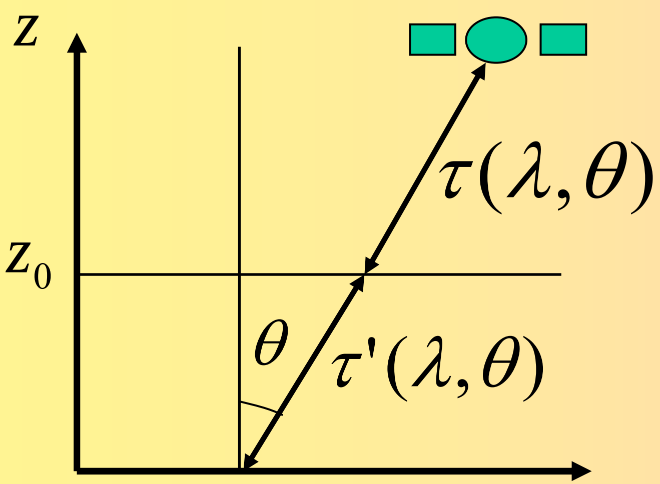
Surface Emission

$$+ \int_{\tau_s(\lambda,\theta)}^{0} B[\lambda,T]\partial\tau(\lambda,\theta)$$

Upwelling Atmosphere Emission

$$+(1-\varepsilon_s(\lambda))\tau_s(\lambda,\theta) \int_{\tau_s(\lambda,\theta)}^{0} B[\lambda,T]\partial\tau'(\lambda,\theta)$$

Reflected Downwelling Atmosphere Emission



$$\tau'(\lambda,\theta)\tau(\lambda,\theta) = \tau_S(\lambda,\theta)$$

Multi-spectral method

$$\varepsilon_s(\lambda) = \frac{I(\lambda,\theta) - \int_{\tau_s(\lambda,\theta)}^{0} B[\lambda,T]\,\partial\tau(\lambda,\theta) - \tau_s(\lambda,\theta) \int_{\tau_s(\lambda,\theta)}^{0} B[\lambda,T]\,\partial\tau'(\lambda,\theta)}{\tau_s(\lambda,\theta)\left\{ B(\lambda,T_s) - \int_{\tau_s(\lambda,\theta)}^{0} B[\lambda,T]\,\partial\tau'(\lambda,\theta) \right\}}$$

The formula holds only for **window channels** $\tau_s(\lambda,\theta) \neq 0$

In order to calculate ε_s one needs:

1) identifying clear sky radiances (MODIS cloud mask)

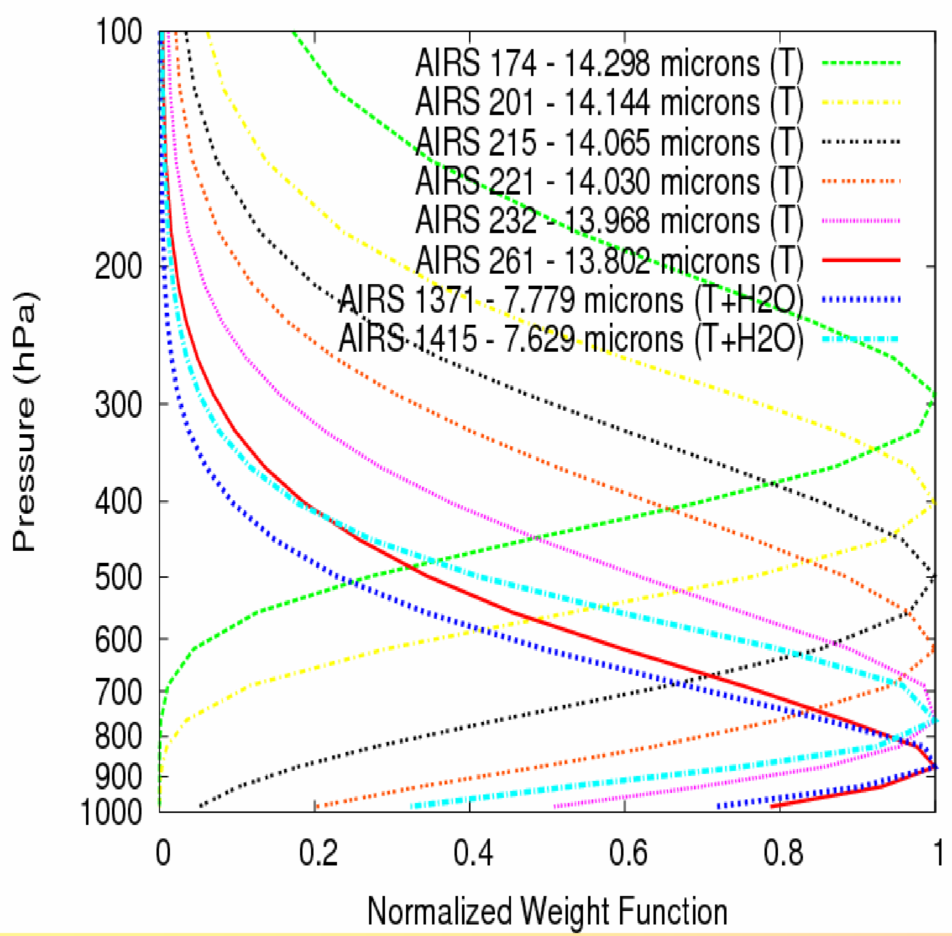
2) knowing the thermodynamic state of the atmosphere (T, H_2O, O_3 profiles)

3) estimating the surface skin temperature

Atmospheric state: proximity recognition in BT

Mean of the closest atmospheric situations in TIGR (Thermodynamic Initial Guess Retrieval) climatological dataset (see http://ara.lmd.polytechnique.fr/)
=> T(p), H_2O(p), O_3(p)

Normalized Weight Functions



Selection of 11 inputs:

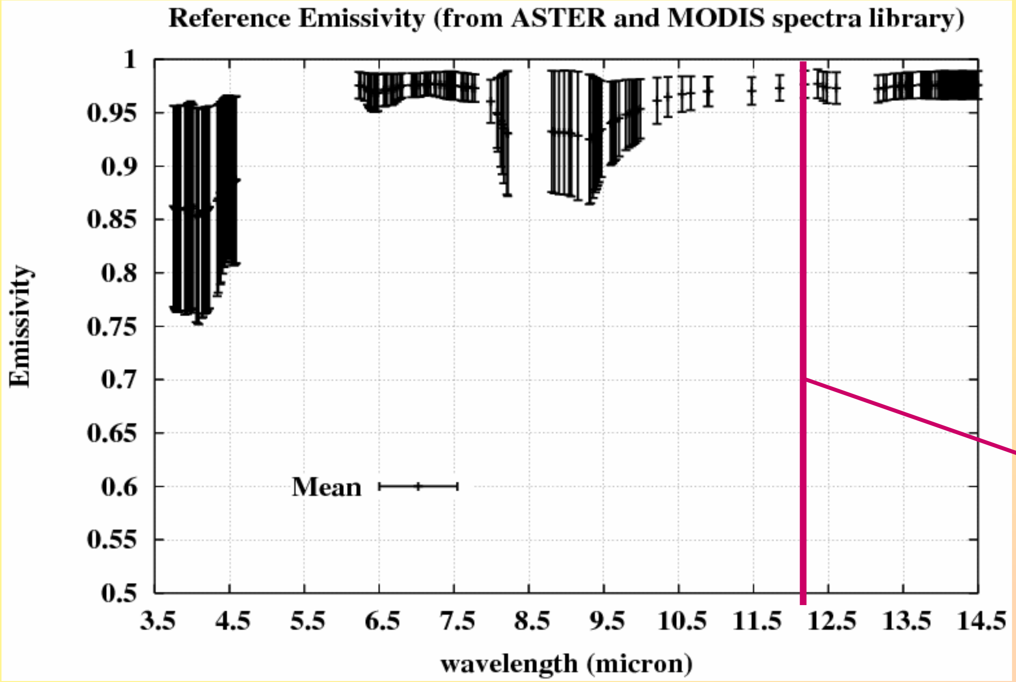
-6 tropospheric sounding channels sensitive to T and $H_2$0

-5 differences of channels to constrain temperature and water vapor gradients

$$D = \sqrt{\sum_{i=1}^{11} \left(\frac{X_{BT_{obs}}(i) - X_{BT_{TIGR}}(i)}{\sigma_{X_{BT_{TIGR}}}(i)} \right)^2}$$

Approach validated on TIGR dataset

Surface skin temperature: semi-transparent single channel method



Emissivity variability of 324 AIRS channels calculated from soil, water and vegetation emissivity spectra of MODIS/UCSB and ASTER/JPL libraries

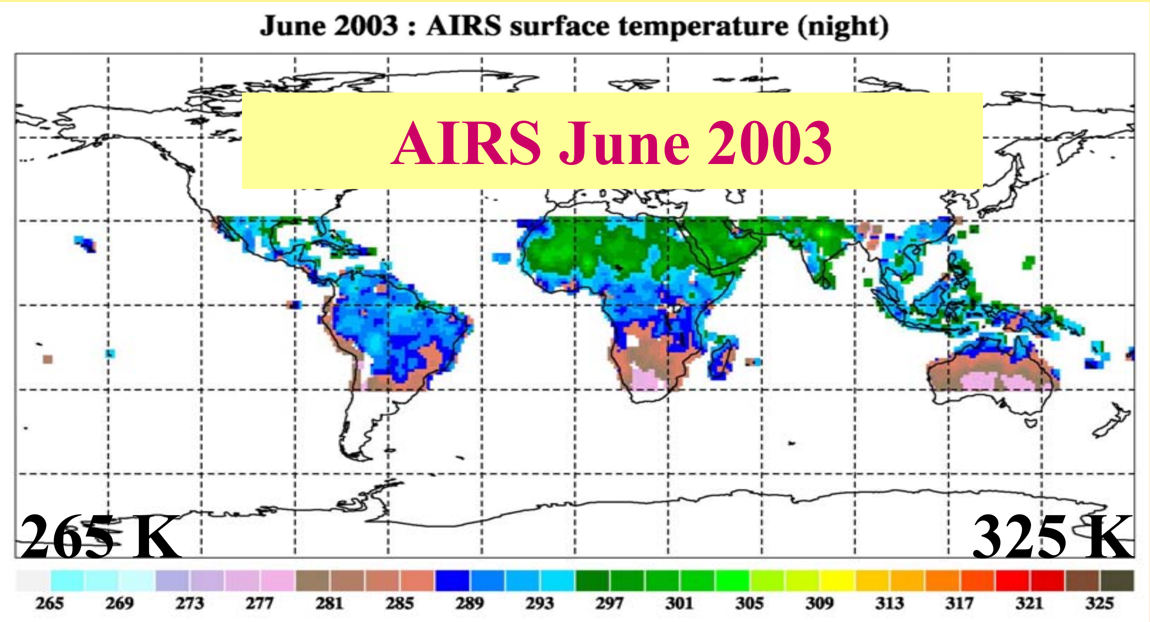
AIRS channel 528 at 12.183 µm

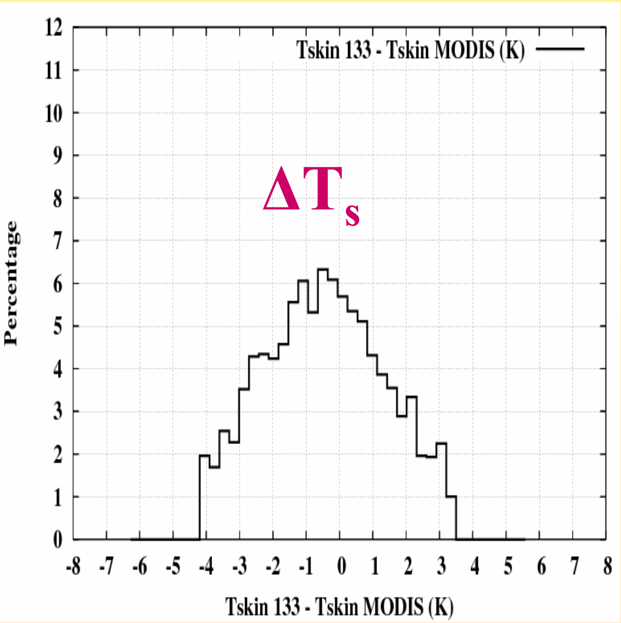
$\tau_S > 0.5$ and $\varepsilon \sim 0.96$

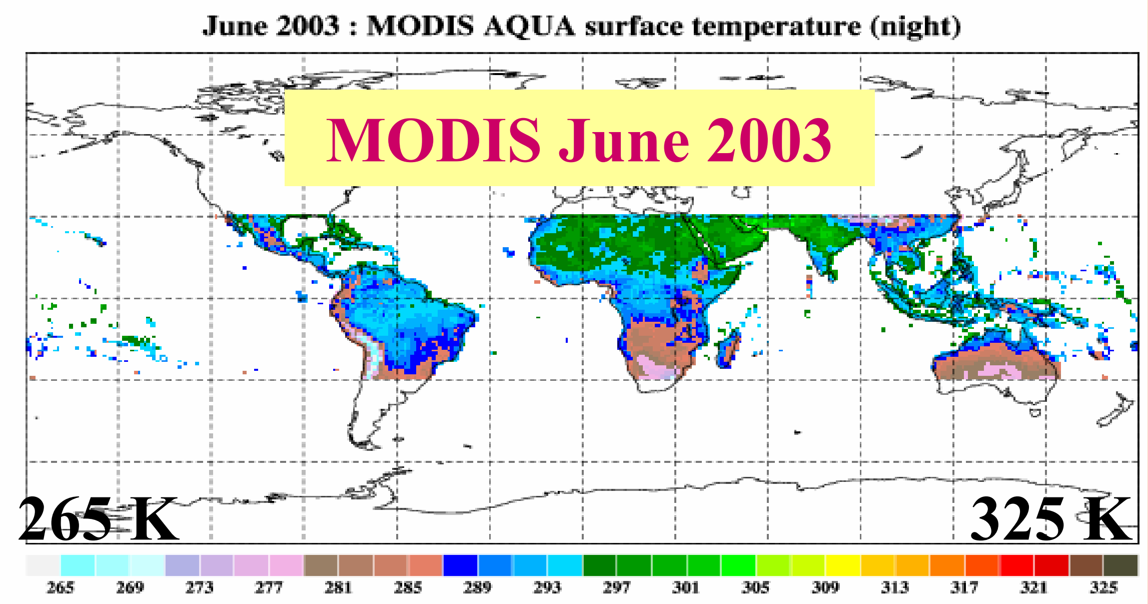
$$T_s = B^{-1}\left(\frac{I_{sat}(\lambda_0,\theta) - \int_{\tau_s(\lambda_0,\theta)}^{1} B[\lambda_0, T(\tau(\lambda_0,\theta))]\,d\tau - (1-\varepsilon_s(\lambda_0))\tau_s(\lambda_0,\theta) \int_{\tau_s(\lambda_0,\theta)}^{1} B[\lambda_0, T(\tau'(\lambda_0,\theta))]\,d\tau'}{\varepsilon_s(\lambda_0)\tau_s(\lambda_0,\theta)} \right)$$

Right hand side determined from the closest atmospheric situation identified previously. Calculation are performed using 4A “line-by-line” code

Comparison with MODIS Tskin (June 2003)







μ=-0.46 K

σ=1.81 K

Values coherent with presently reported accuracies

Summary

$$\varepsilon_s(\lambda) = \frac{\mathrm{I}_{\mathrm{sat}}(\lambda,\theta) - \int_{\tau_s(\lambda,\theta)}^{0} B[\lambda,T]\,\partial\tau(\lambda,\theta) - \tau_s(\lambda,\theta)\int_{\tau_s(\lambda,\theta)}^{0} B[\lambda,T]\,\partial\tau'(\lambda,\theta)}{\tau_s(\lambda,\theta)\left\{B(\lambda,T_s) - \int_{\tau_s(\lambda,\theta)}^{0} B[\lambda,T]\,\partial\tau'(\lambda,\theta)\right\}}$$

In order to calculate ε_s one needs:

1) identifying clear sky radiances → MODIS Cloud mask

2) knowing the thermodynamic state of the atmosphere (T, H_2O, O_3 profiles) → Proximity Recognition in TIGR

3) estimating the surface skin temperature → AIRS channel 528 at 12.183 µm

Infrared Emissivity Spectrum from 3.7 to 14 µm

I)

1) $\varepsilon(\lambda_{AIRS})$ calculated if (Péquignot et al., 2006):

$$\tau_S \geq 0.5$$

and

$$\left|EAF_{Ts}\right| \frac{\partial T_s}{T_s} + \left|EAF_{TB}\right| \frac{\partial T_B}{T_B} \leq 3\%$$

Typically $N_{AIRS} \sim 30 - 50$

2) ε is interpolated at λ_{ref} if λ_{AIRS} close to λ_{ref}

Typically N ~ 25 - 40

II)

MODIS/UCSB and ASTER/JPL very high resolution emissivity spectra librairies

↓

170 representative samples of soils and vegetation undersampled at 0.05 µm from 3.7 to 14 µm

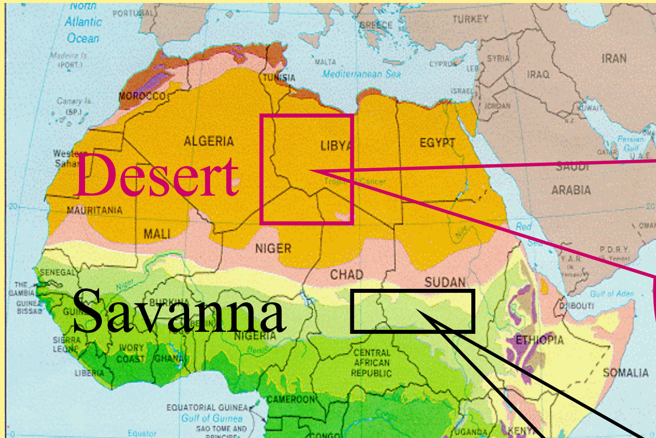
λ_{ref}=[3.70, 3.75,…,13.95,14.0]

(N_{ref} = 207 points)

III) **Proximity recognition (mean square)**

Samples with a distance between D_{min} and $D_{max}=1.4*D_{min}$ are selected and their emissivity spectrum averaged.

Emissivity Spectral variations (1)



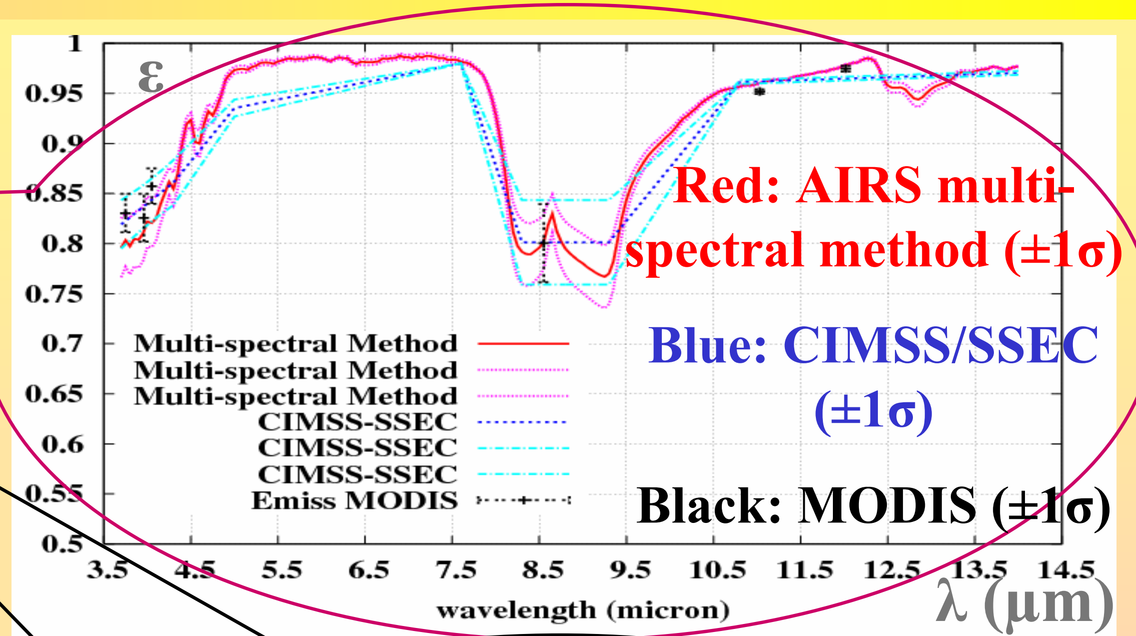
- Quartz reststrahlen bands are well observed and dominate the ε spectra

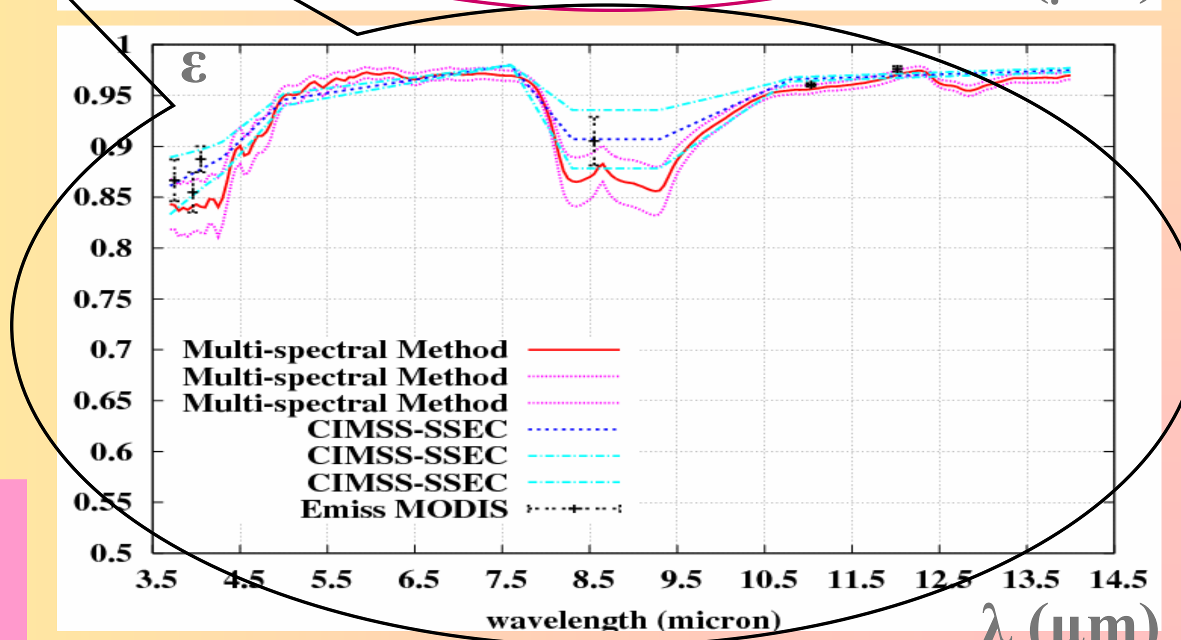
- In quartz reststrahlen bands ε increases with the % of vegetation.

(Example of Savannas)

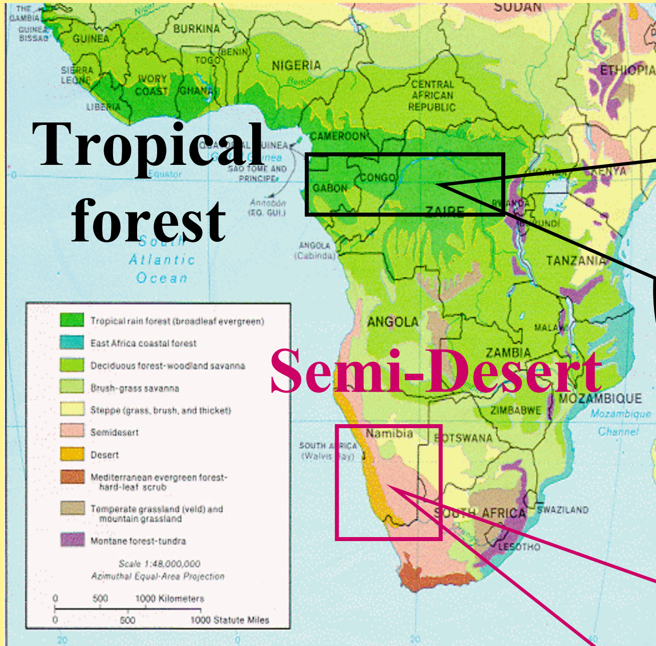
LMD : 25 to 40 λref (AIRS)

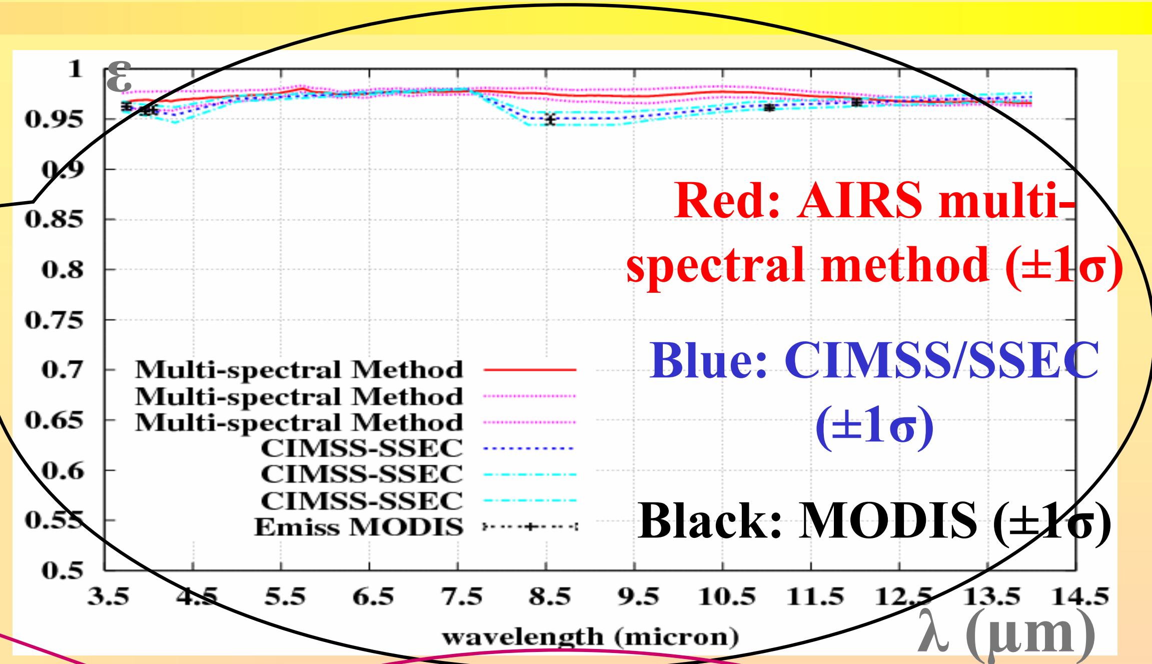
CMISS : 6 λref (MODIS)

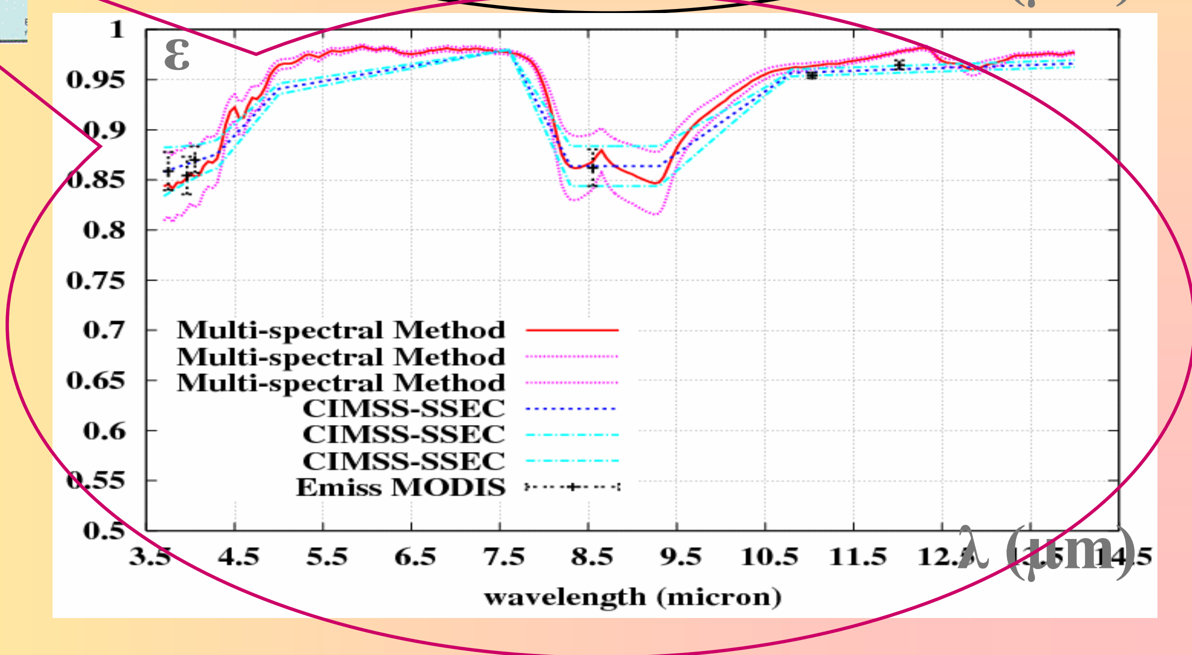




Emissivity Spectral variations (2)



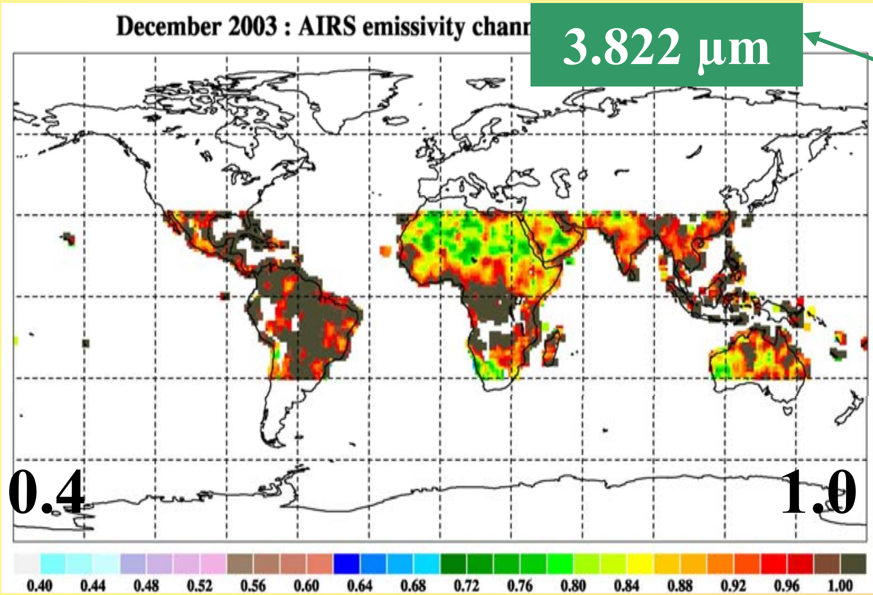


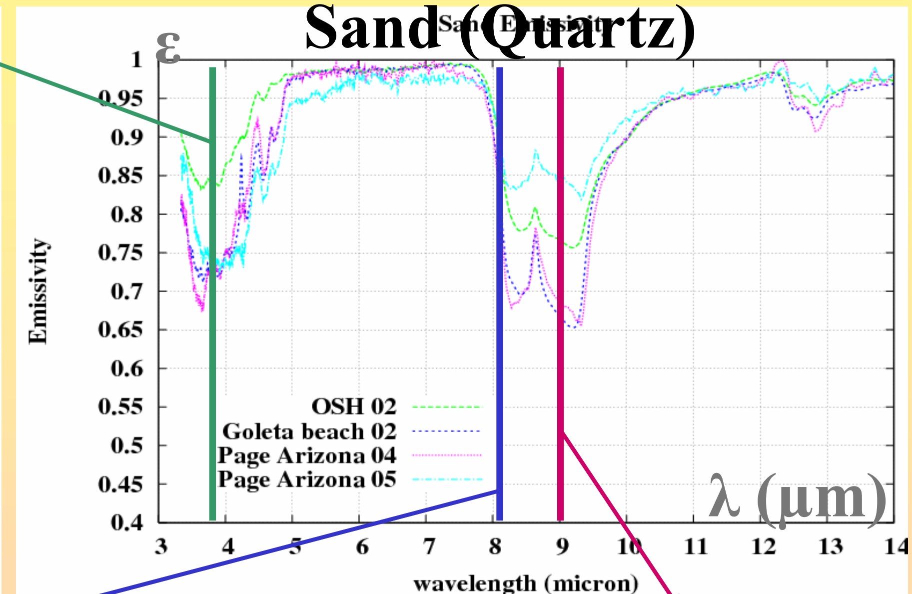


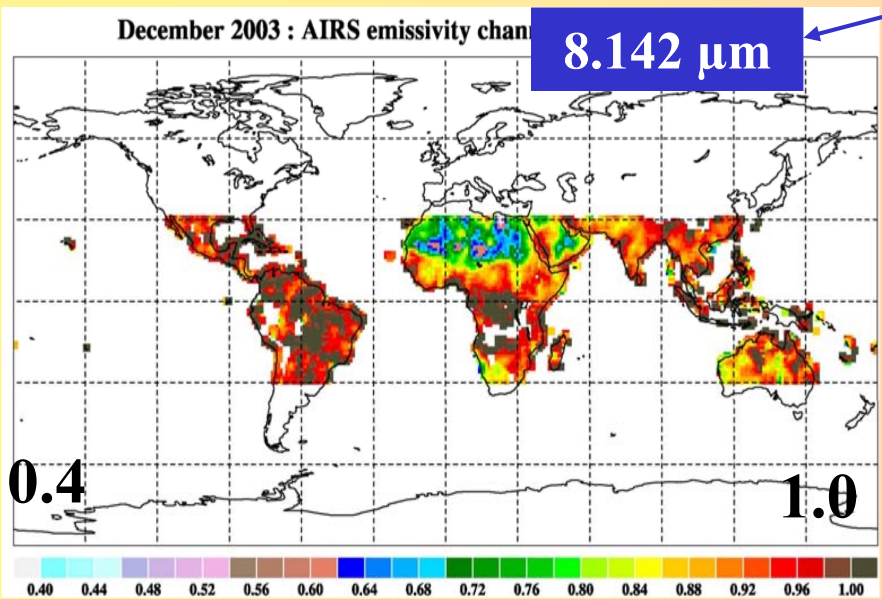
Tropical forest emissivity close to 1 (as expected)

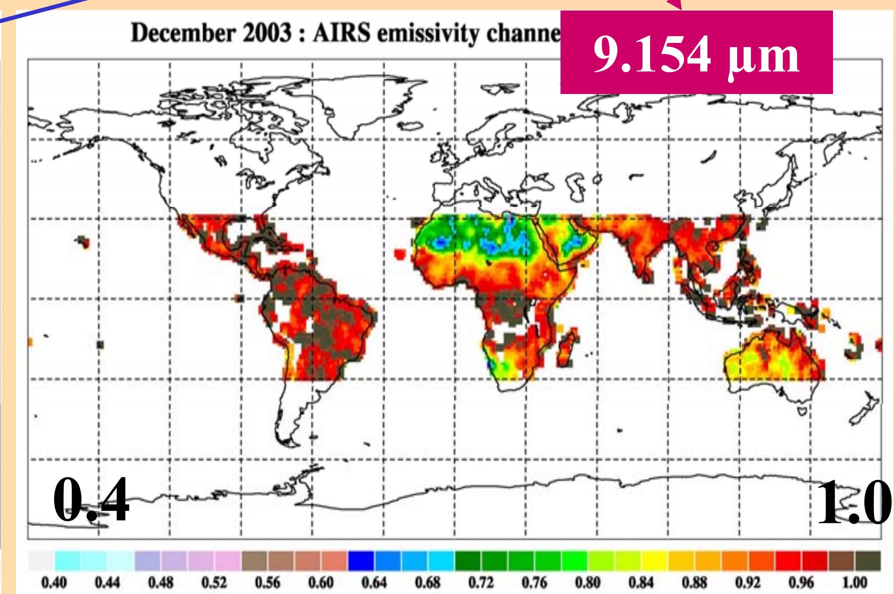
For semi-desert areas emissivity still influenced by quartz reststrahlen bands

Emissivity Regional Variations (1)

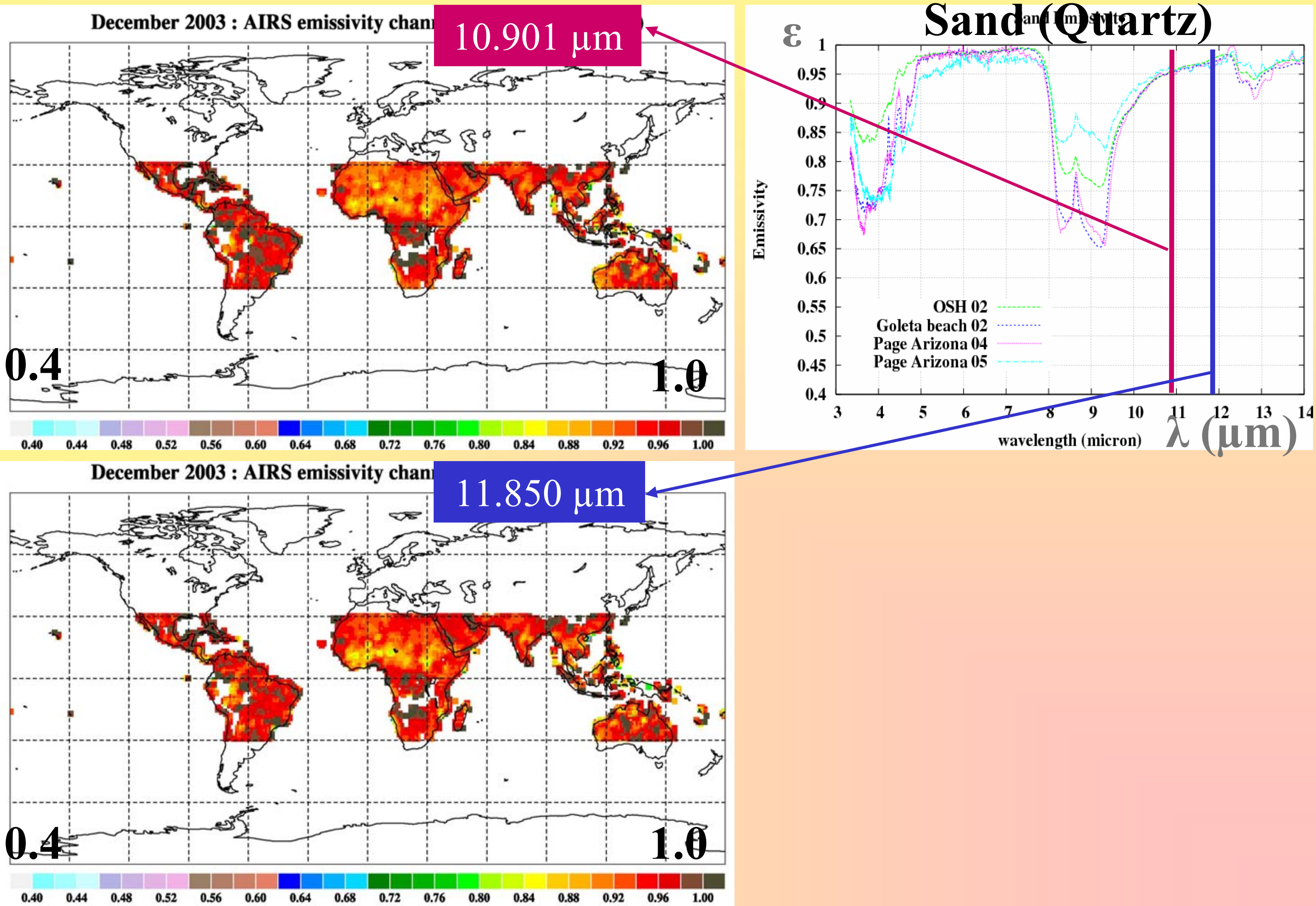




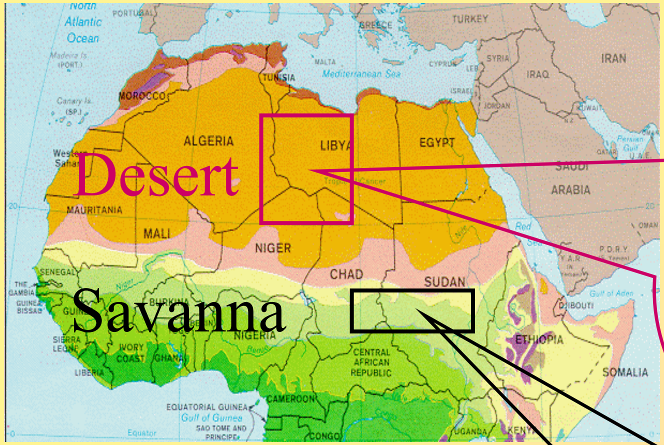


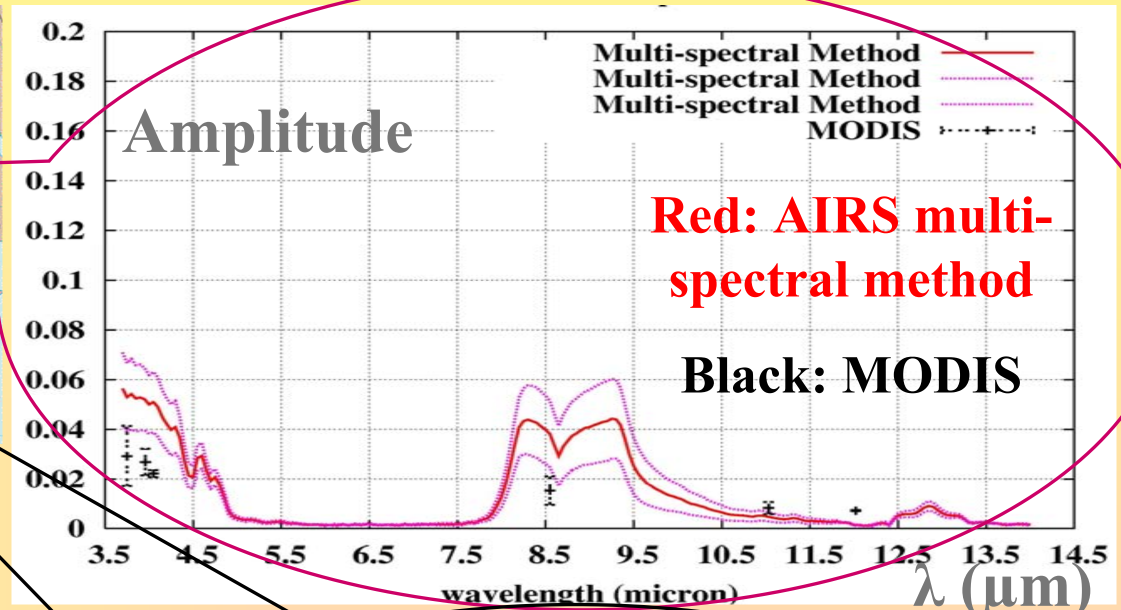


Emissivity Regional Variations (2)

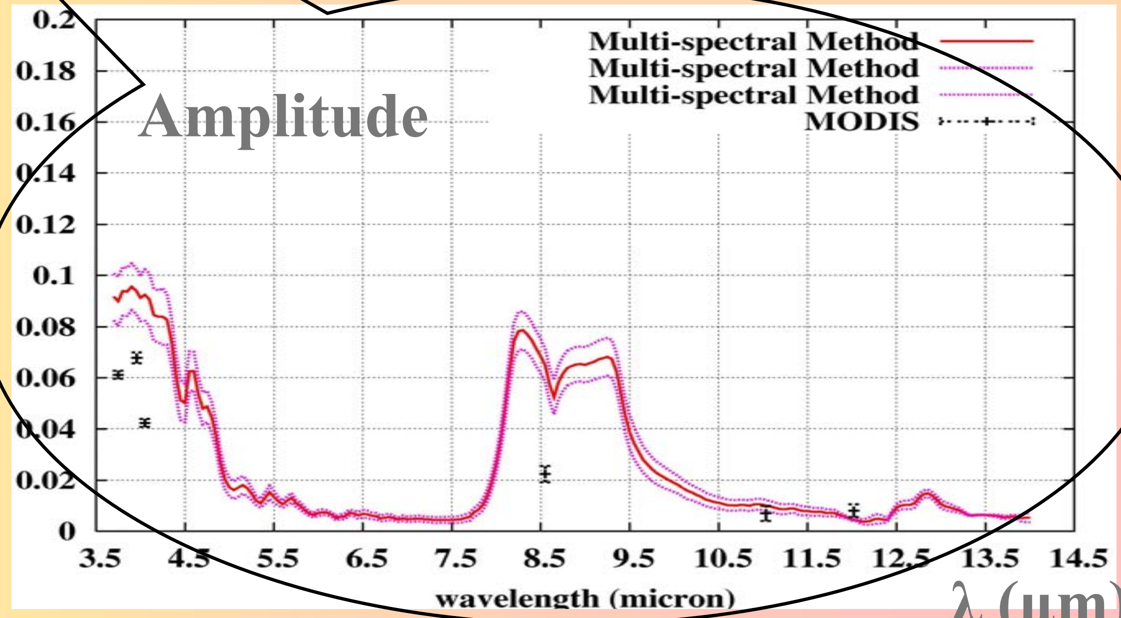


Emissivity Seasonal variations (1)

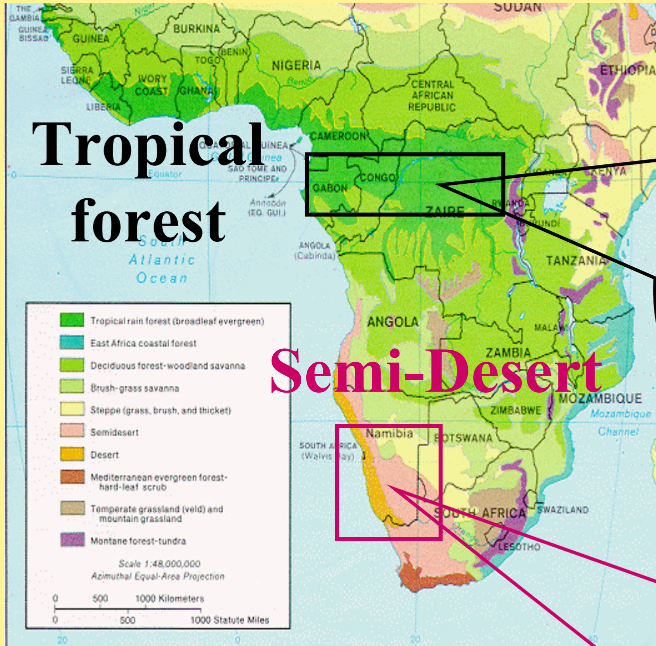


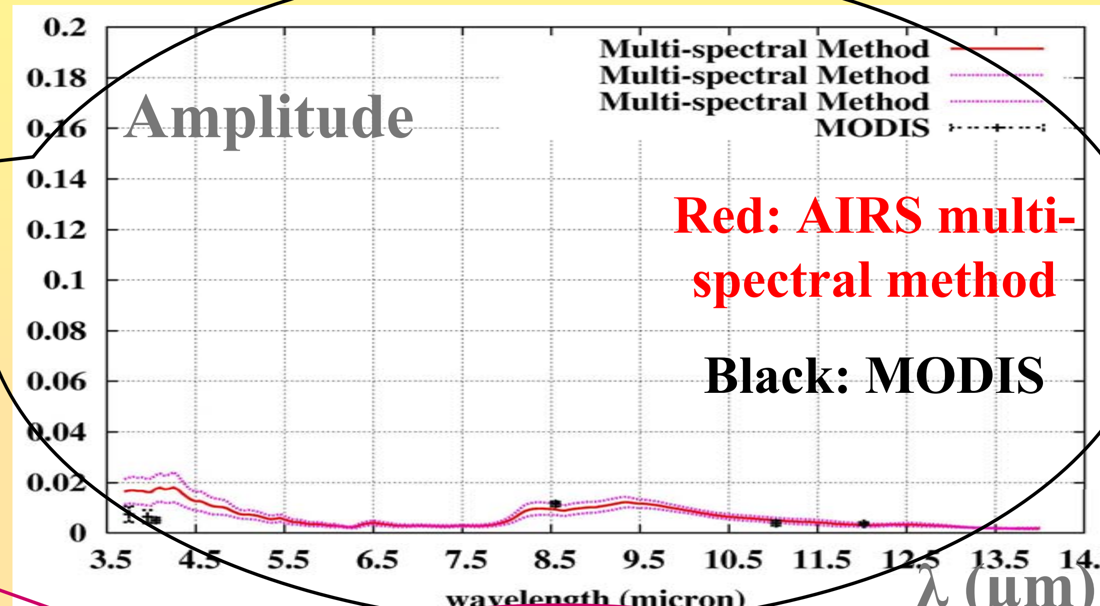


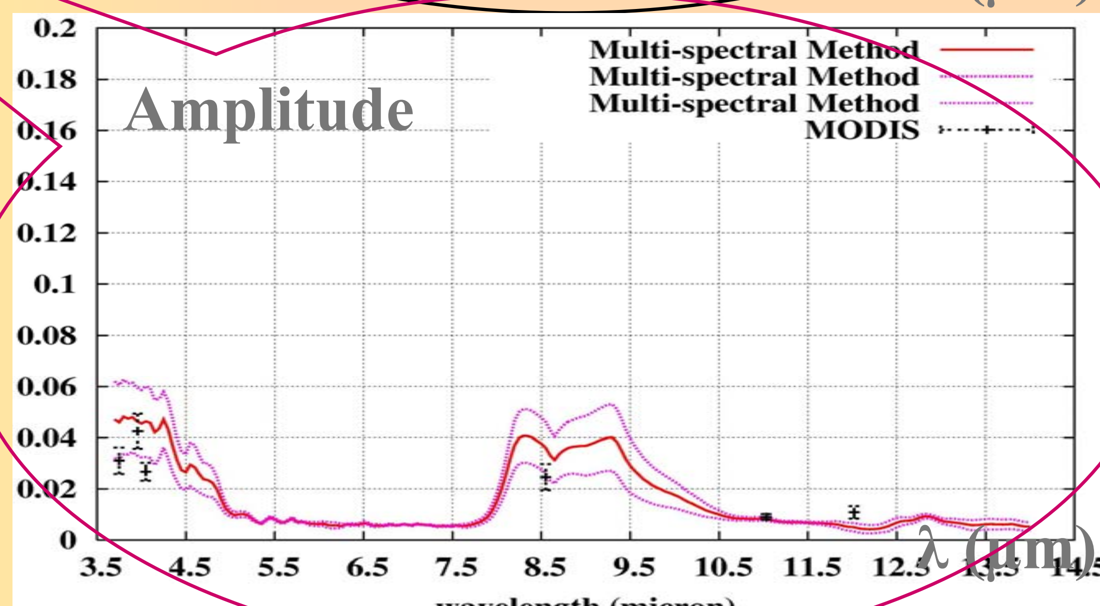
Sparsely vegetated area emissivity responds to the rate of precipitation and the % of vegetation
=> High emissivity seasonal cycle amplitude
(For more details see Péquignot et al, submitted)



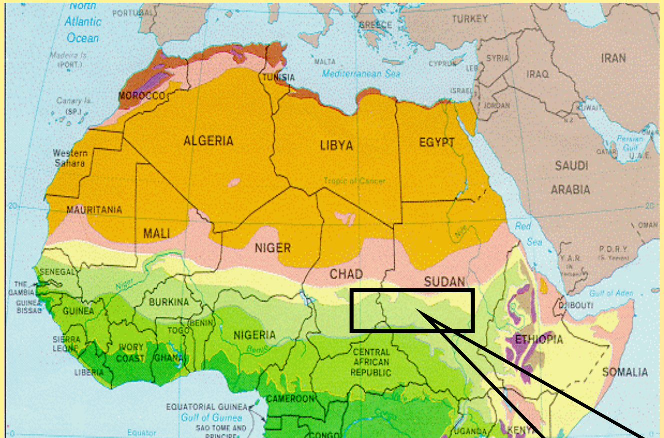
Emissivity Seasonal variations (2)

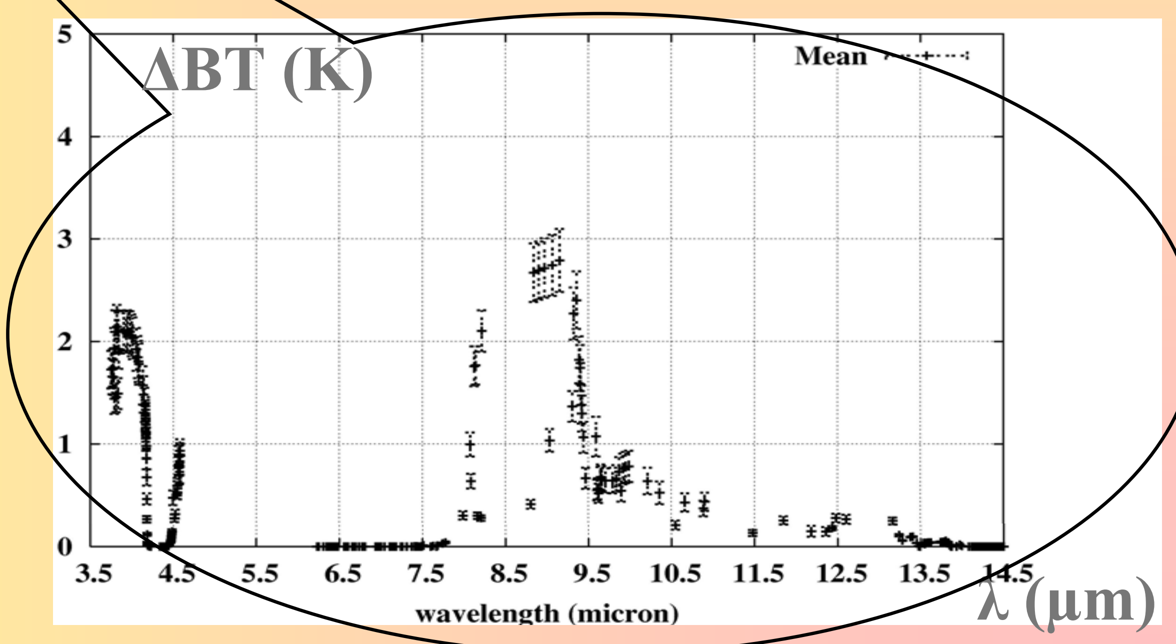






Impact of the emissivity seasonal cycle on AIRS BT





Conclusions

1) Emissivity multi-spectral method works well and is adapted to instrument with high spectral resolution.

2) Difficulty to go further with comparisons because we lack retrieved emissivity databases at very high spectral resolution.

3) Such emissivity spectra and surface skin temperature 3 years climatology of tropical zone (30°S-30°N) should help improving models of the earth surface-atmosphere interaction and the retrieval of meteorological profiles and cloud characteristics (in particular semi transparent cirrus) from infrared vertical sounders.

4) Easy to implement the Multi-Spectral Method in assimilation process of data from hyperspectral sensors (AIRS/IASI).

5) With IASI (spectral continuity) we can probably skip the proximity recognition within MODIS/UCSB and ASTER/JPL emissivity libraries.