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Towards the assimilation of surface sensitive infrared channels in the CMC global forecast system

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Why don't we use surface sensitive infrared channels above land?

- Difficulties with cloud detection
- Imperfect knowledge of land surface emissivity and its temporal variations
- Horizontal scale representativeness
- Inconsistencies between real topography and model topography
- Variable T_{air}/T_{skin} error correlation
- Possible issues in the modeling of downward reflected radiation for low emissivity surfaces (e.g. deserts)

Why should we aim at using surface sensitive infrared channels above land?

- To take full advantage of available information
- Positive impact on near surface temperature and water vapor is expected notably in data sparse regions
- Impact on short term forecasts more likely from improved boundary layer than from improvements at higher altitude
- Increments of surface temperature (T_G) are generated from the assimilation of radiances but are currently discarded. A coupling with the surface analysis should be envisaged.

Outline

- Infrared data at CMC
- Current Treatment of surface sensitive channels: AIRS and IASI
- Improvement of surface emissivity
- Results of some assimilation experiments
- Importance of T_{air}/T_{skin} error correlation
- Possible issues with radiative transfer modeling
- Conclusions, perspectives

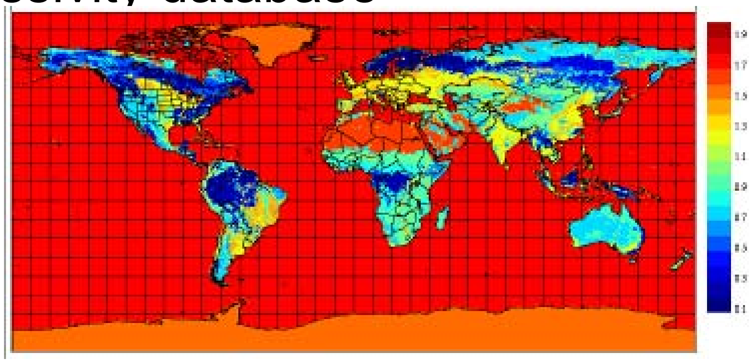
Current Infrared sounders assimilation at CMC

- **GOES**: assimilation of water vapor channel only. We will assimilate METEOSAT and MTSAT soon (same channel). 2 windows channels could be assimilated
- **AIRS**: operational assimilation of 87 channels. Among these channels 20 are surface sensitive and assimilated above ocean only
- **IASI**: experimental assimilation of 128 channels. Among these channels 19 are surface sensitive and assimilated above ocean only
- Radiative transfer code RTTOV 8.7 (will soon switch to 9.3)
- Surface temperature (T_G) used as a sink variable

AIRS and IASI 1/2

- Surface emissivities:
  - Above ocean use of Masuda model (sea surface emissivity is wind dependent but fixed during minimization)
  - Above land use of **CERES static land type classification** and broadband emissivity database

2160x1080 grid:
1/6º resolution

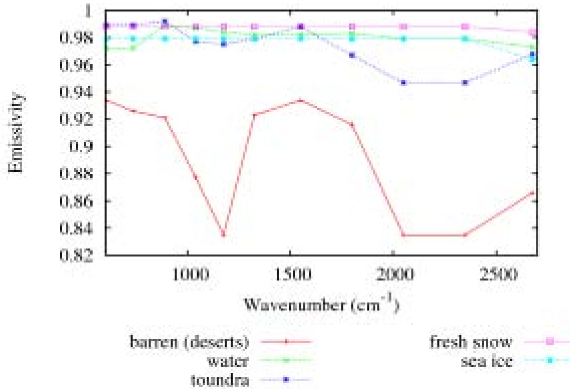


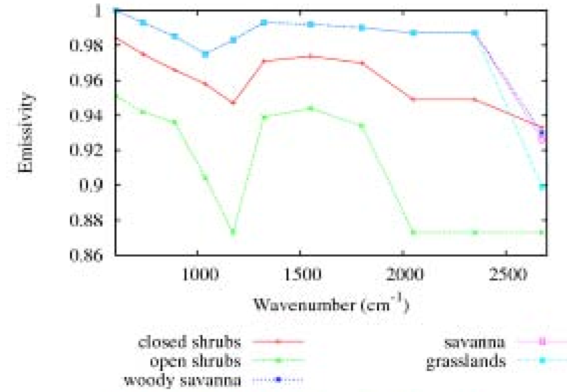
20 surface types:

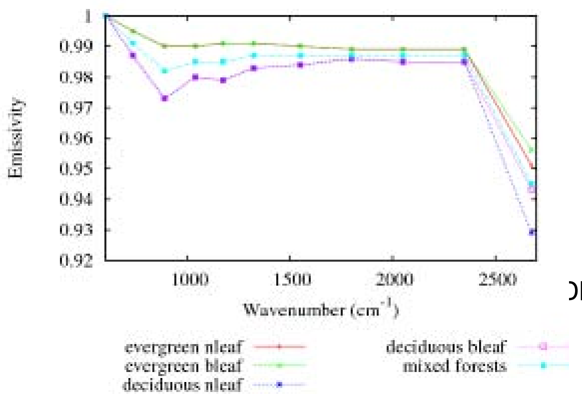
1= evergreen nleaf	2= evergreen bleaf	3= deciduous nleaf	4= deciduous bleaf
5= mixed forests	6= closed shrubs	7= open shrubs	8= woody savanna
9= savanna	10= grasslands	11= perma wet	12= croplands
13= urban	14= mosaic	15= snow	16= barren (deserts)
17= water	18= toundra	19= fresh snow	20= sea ice

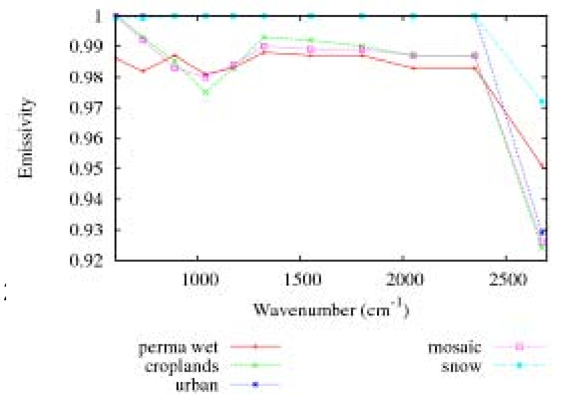
AIRS and IASI 2/2

- Static land type classification is complemented using snow and ice analysis
- Directional effects are not accounted for (negligible for viewing angles lower than 35 degrees)
- For each land type, a low resolution spectrum (12 spectral bands) is interpolated to AIRS or IASI resolution





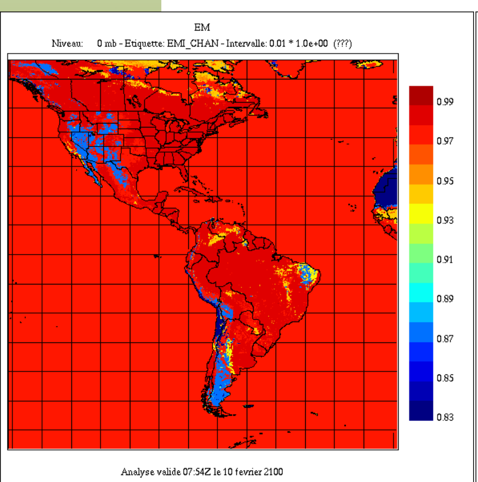




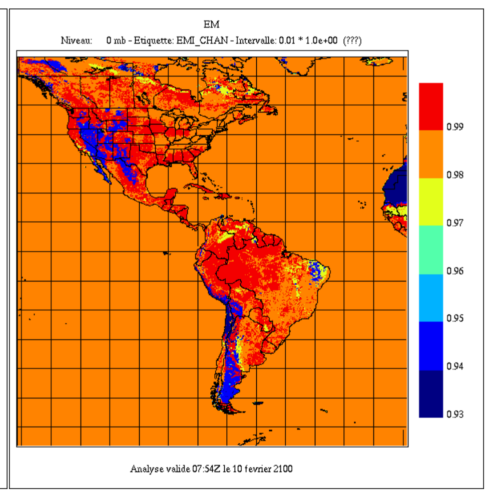
GOES

- Static emissivity maps extracted from CERES are used
- No information from ice and snow analysis is used

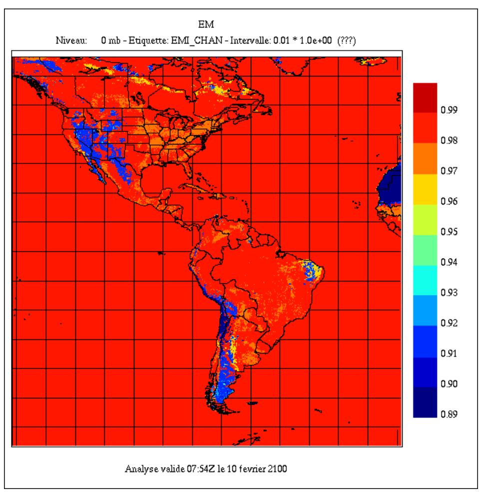
CHANNEL 2
(3.9 µm)



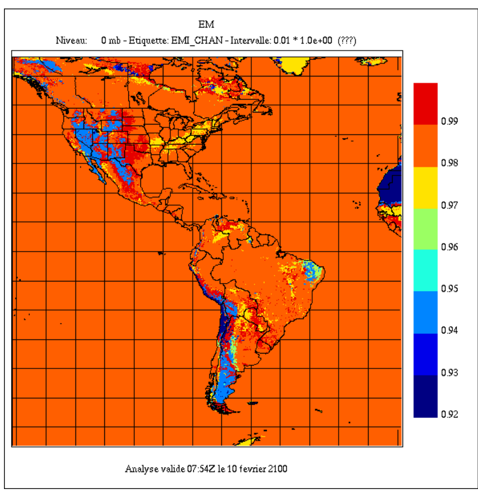
CHANNEL 3
(6.7 µm)



CHANNEL 4
(10.7 µm)



CHANNEL 5
(12 µm)



Improvement of infrared surface emissivity climatologies

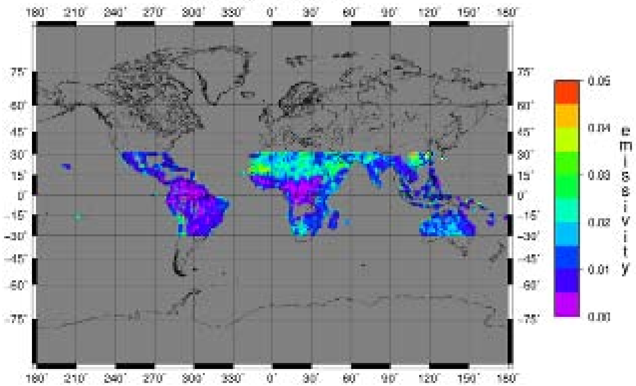
- Several high spectral resolution emissivity atlases are now available:
  - University of Wisconsin High Spectral Resolution emissivity database derived from MODIS Baseline Fit. Monthly global maps at 0.05º resolution (Borbas et al. 2007)
  - NOAA/NESDIS AIRS Emissivity Global Datasets. Monthly global maps at 3.0ºlon. x 3.0ºlat. or 0.5ºlon x 2ºlat. (Zhou et al. 2008)
  - LMD AIRS emissivity maps. Monthly, Tropical maps [-30º;+30º] at 1.0º resolution (Péquignot et al. 2007)

Emissivity maps comparisons

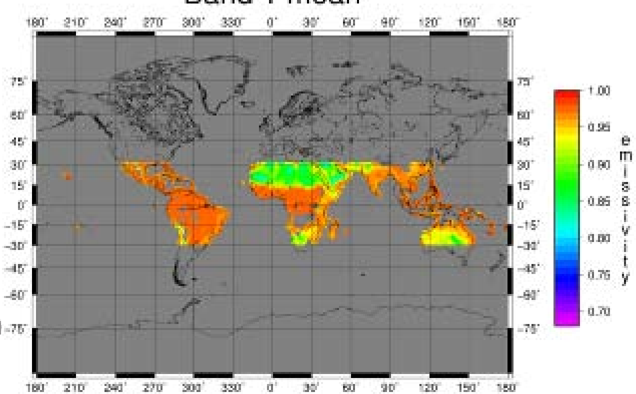
Band 1: 2702.7 cm^{-1} (3.7μm)

LMD: 1 year average (2007)

Band 1 STD

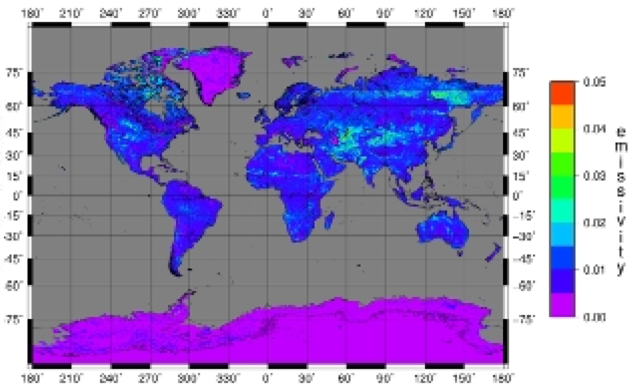


Band 1 mean

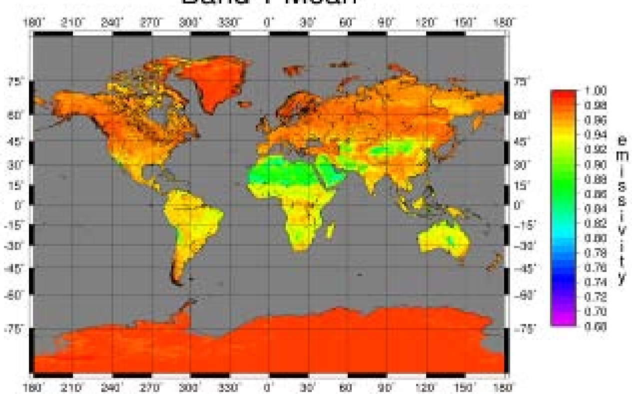


HSR: 2 year average (2007-2008)

Band 1 STD

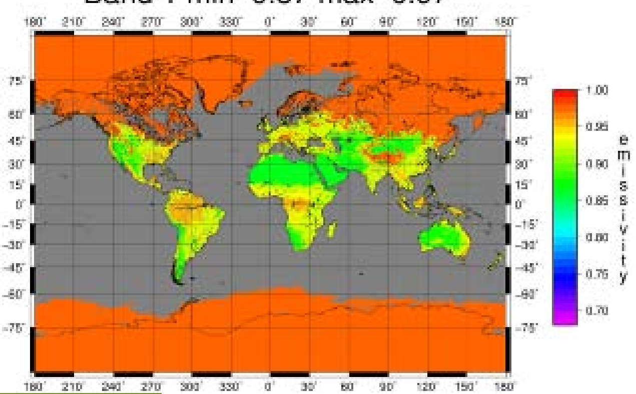


Band 1 Mean



CERES

Band 1 min 0.87 max 0.97



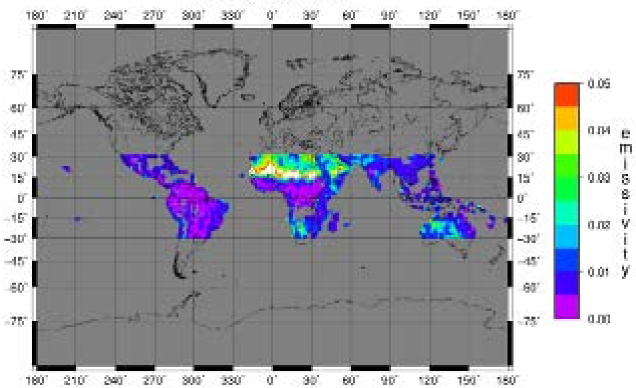
Emissivity maps comparisons

Band 6: 1204.8 cm^{-1} (8.3 μm)

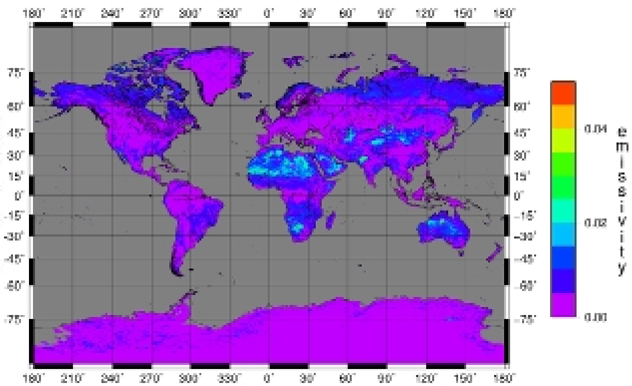
LMD: 1 year average (2007)

HSR: 2 year average (2007-2008)

Band 6 STD

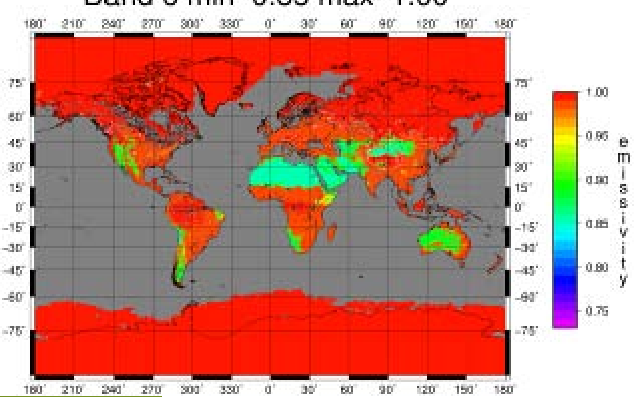


Band 6 STD

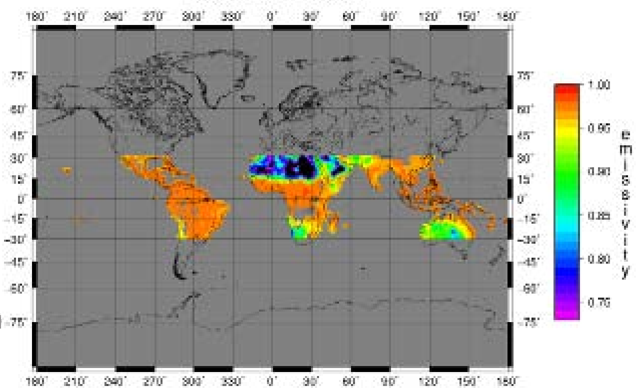


CERES

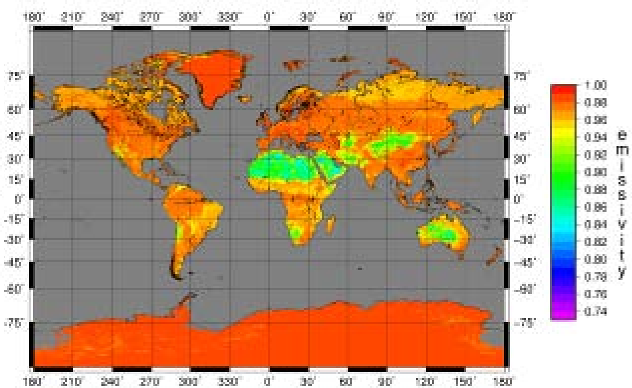
Band 6 min 0.85 max 1.00



Band 6 mean



Band 6 Mean

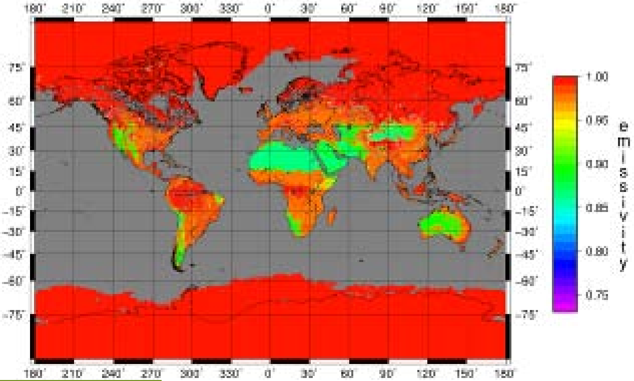


Emissivity maps comparisons

Band 7: 1075.2 cm^{-1} (9.3 μm) (Possible O_3 contamination)

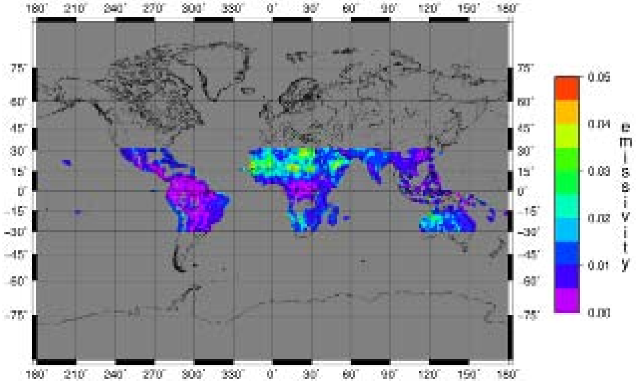
CERES

Band 7 min 0.87 max 1.00

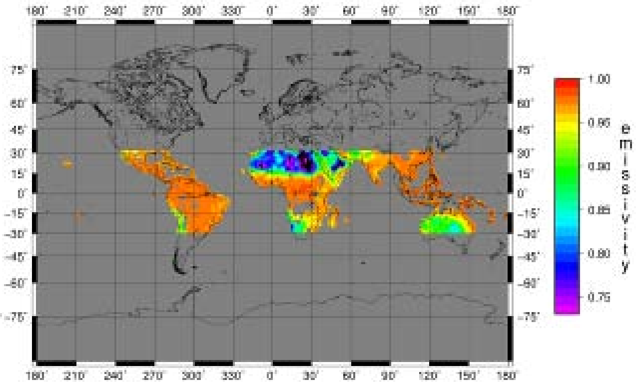


LMD: 1 year average (2007)

Band 7 STD

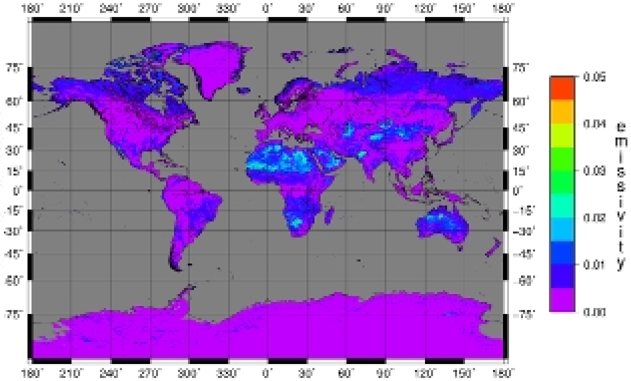


Band 7 mean

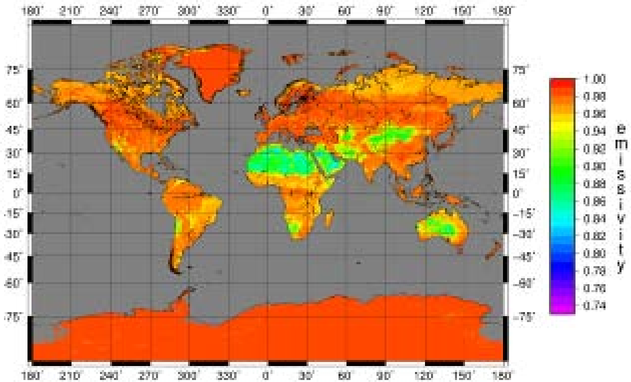


HSR: 2 year average (2007-2008)

Band 7 STD



Band 7 Mean



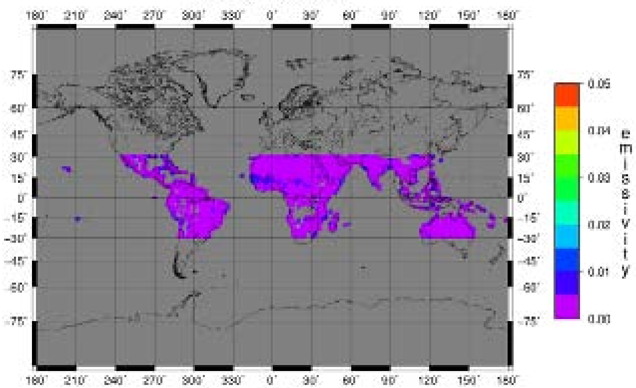
Emissivity maps comparisons

Band 8: 925.9 cm^{-1} (10.8 μm)

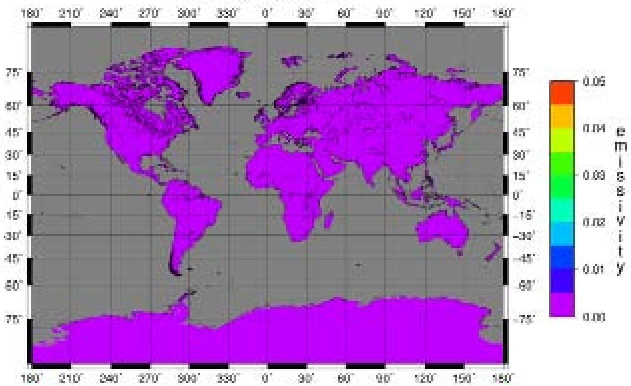
LMD: 1 year average (2007)

HSR: 2 year average (2007-2008)

Band 8 STD

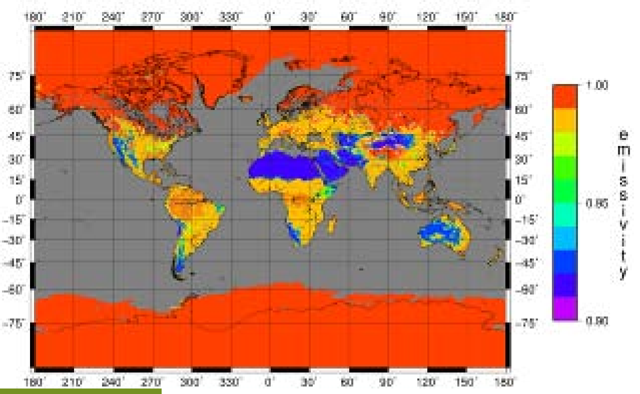


Band 8 STD

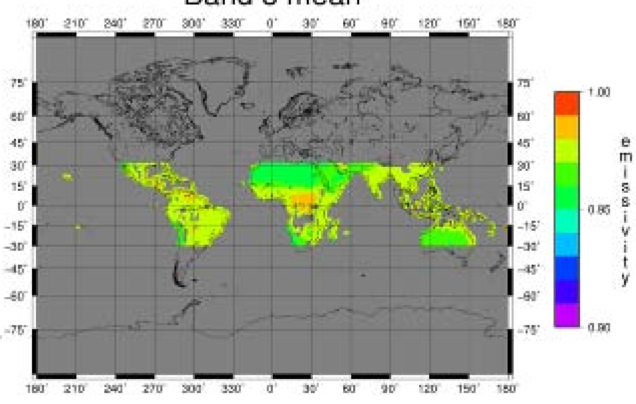


CERES

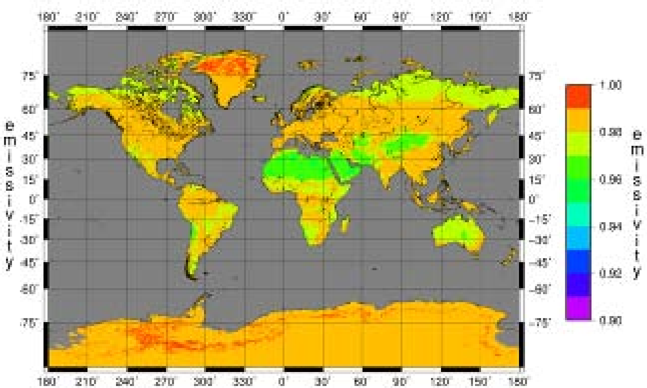
Band 8 min 0.91 max 1.00



Band 8 mean



Band 8 Mean



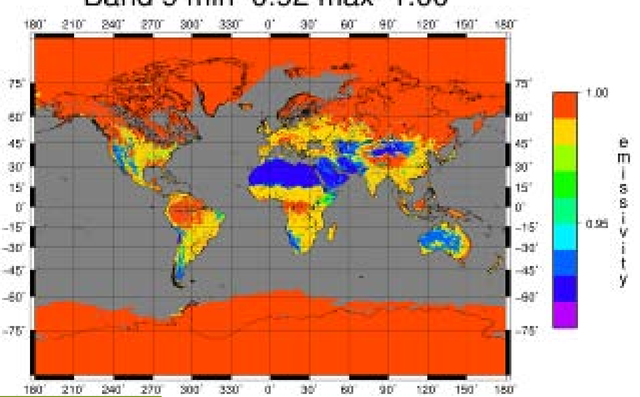
Emissivity maps comparisons

Band 9: 826.4 cm^{-1} (12.1 μm)

Péquignot et al. tested this band with the assumption of spatially constant emissivity close to 0.96. Notice spatial uniformity and low stdev

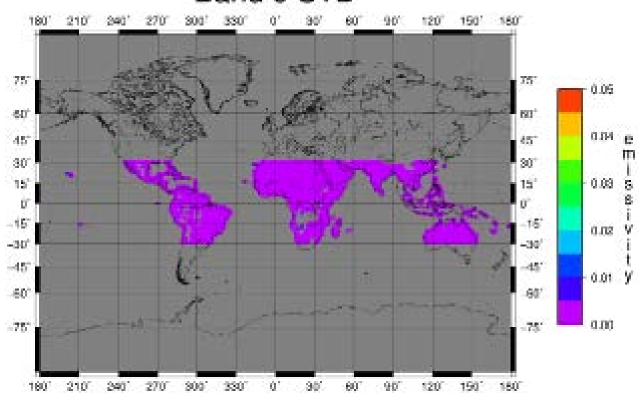
CERES

Band 9 min 0.92 max 1.00

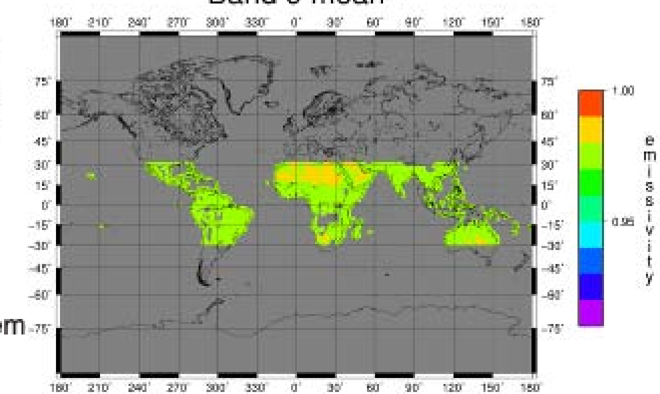


LMD: 1 year average (2007)

Band 9 STD

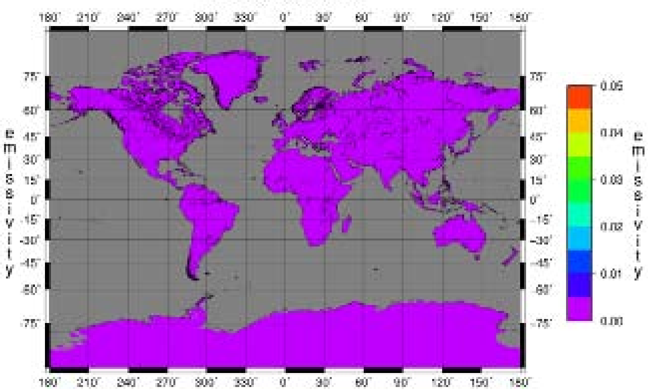


Band 9 mean

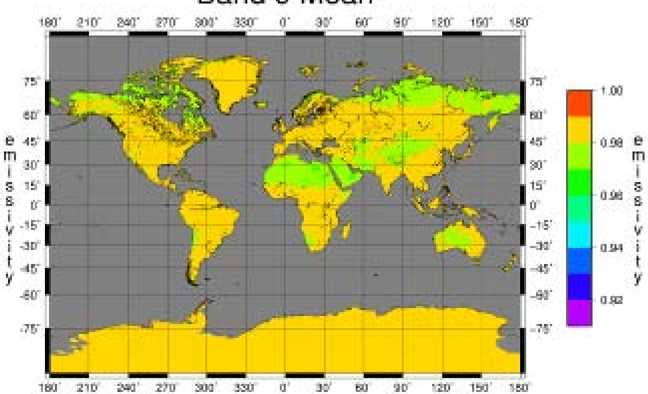


HSR: 2 year average (2007-2008)

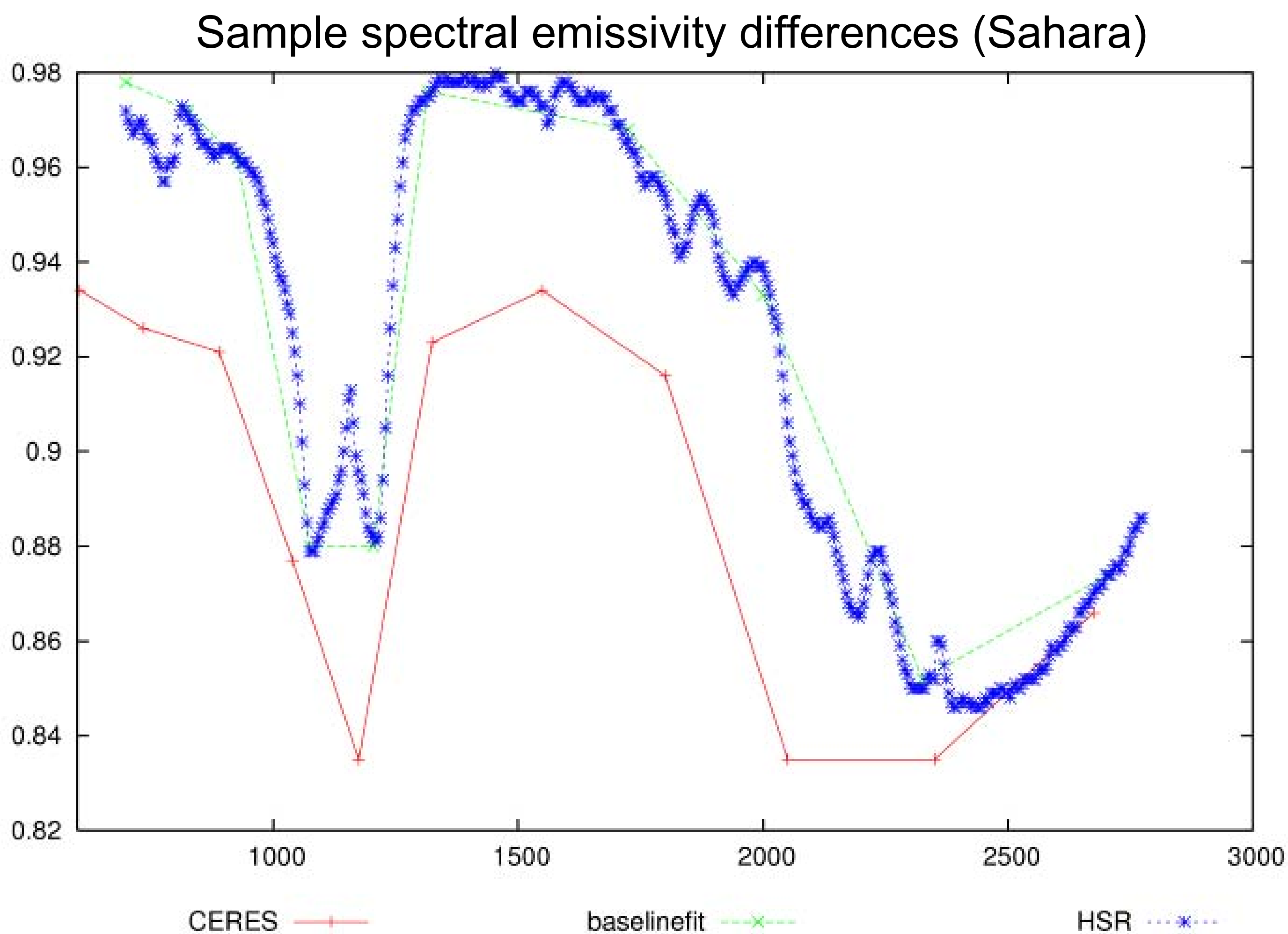
Band 9 STD



Band 9 Mean

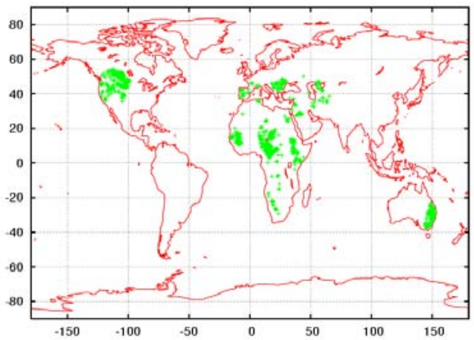


Emissivity spectrum comparisons

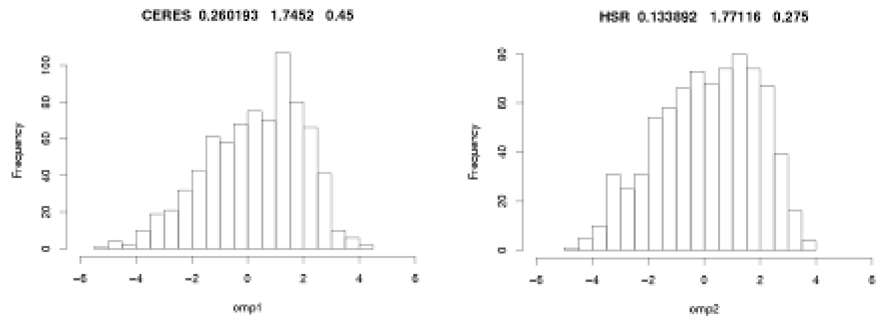


Tests with U of Wisconsin emissivity 1/2

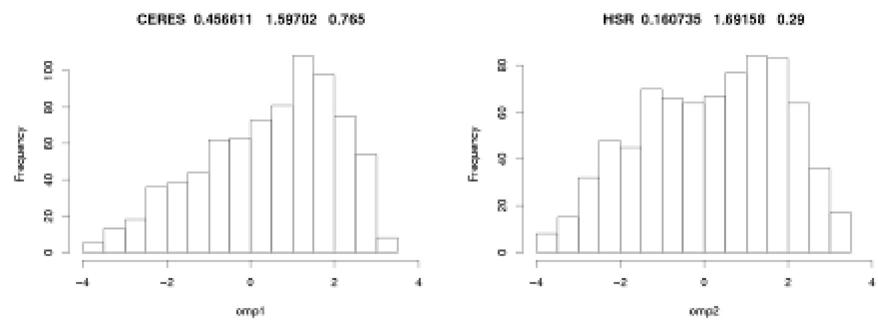
Impact on AIRS O-F (6 hour) (no bias correction)



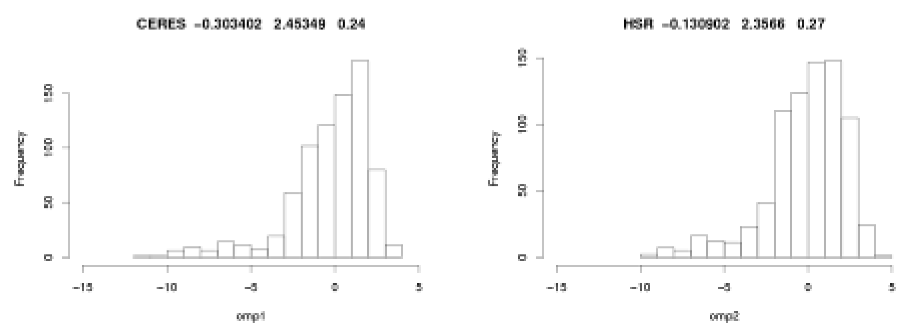
843.805 cm^{-1}
(11.85 µm)



917.21 cm^{-1}
(10.90 µm)



1072.38 cm^{-1}
(9.32 µm)



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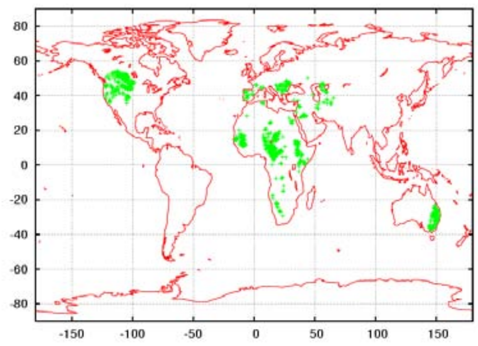
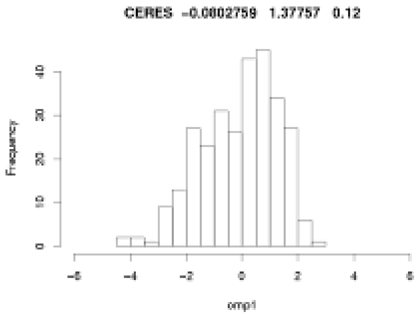
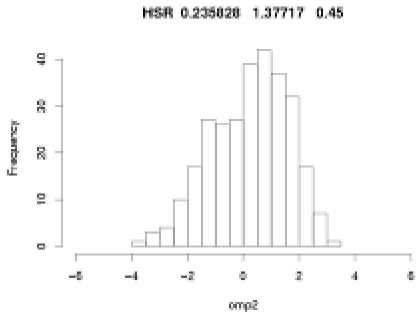
Tests with U of Wisconsin emissivity 2/2

Impact on AIRS O-F (6 hour) (no bias correction)



2419.56 cm^{-1}
(4.13 μm)

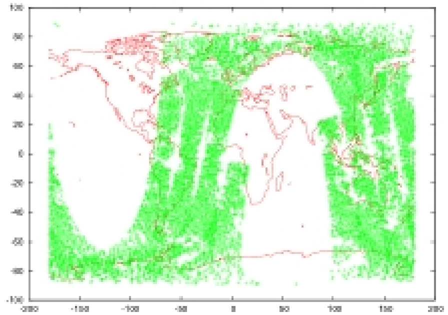




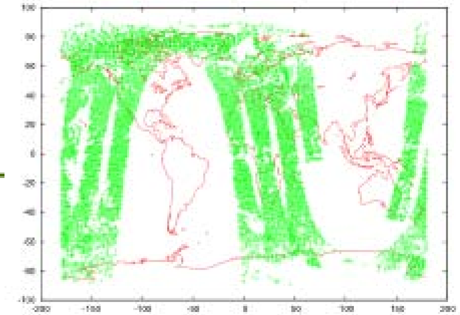
- Positive impact on the bias in particular for longwave windows
- Less impact on shortwave
- Impact on standard deviations not obvious

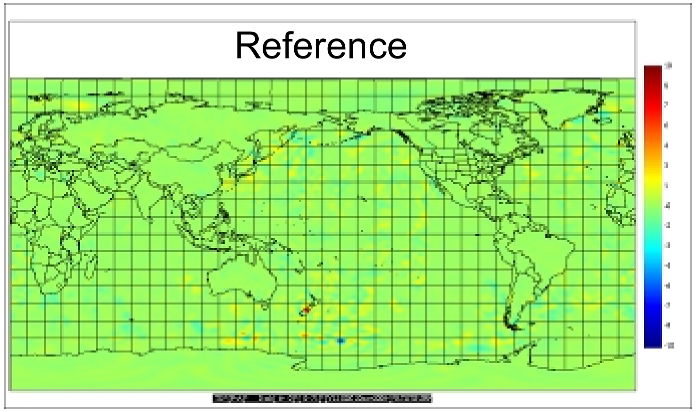
Results of some assimilation experiments: impact on TG increments

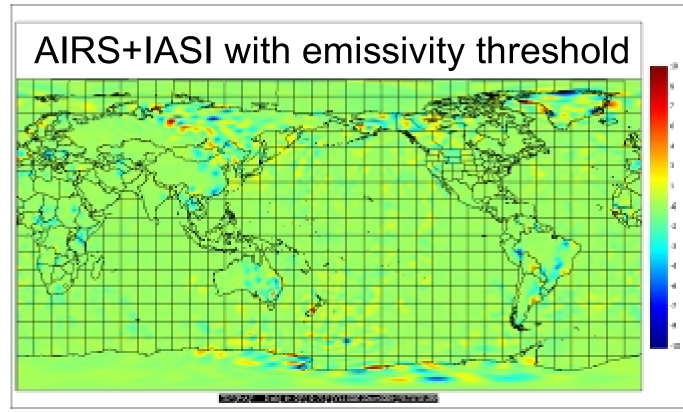
IASI

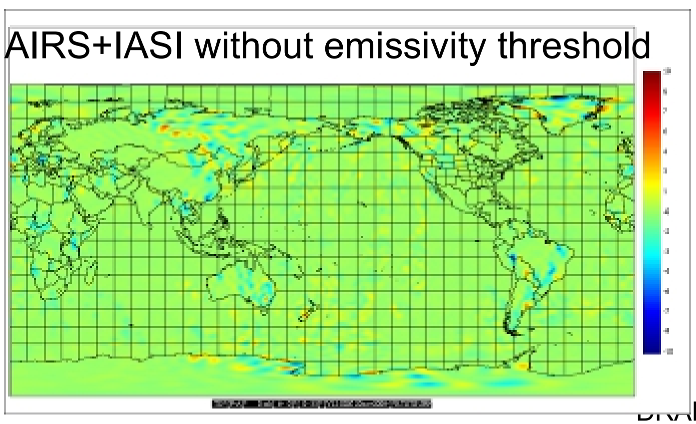


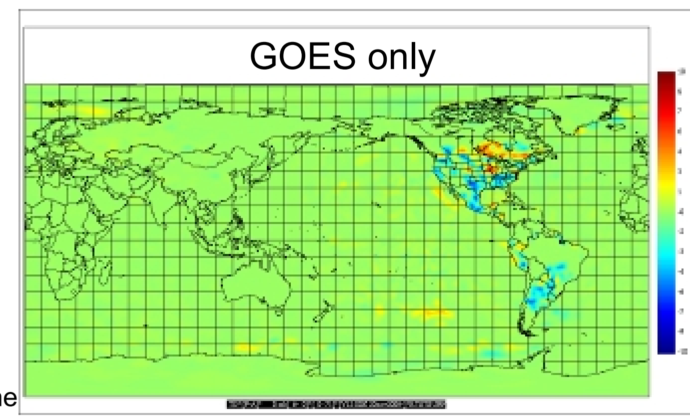
AIRS




Reference


AIRS+IASI with emissivity threshold


AIRS+IASI without emissivity threshold

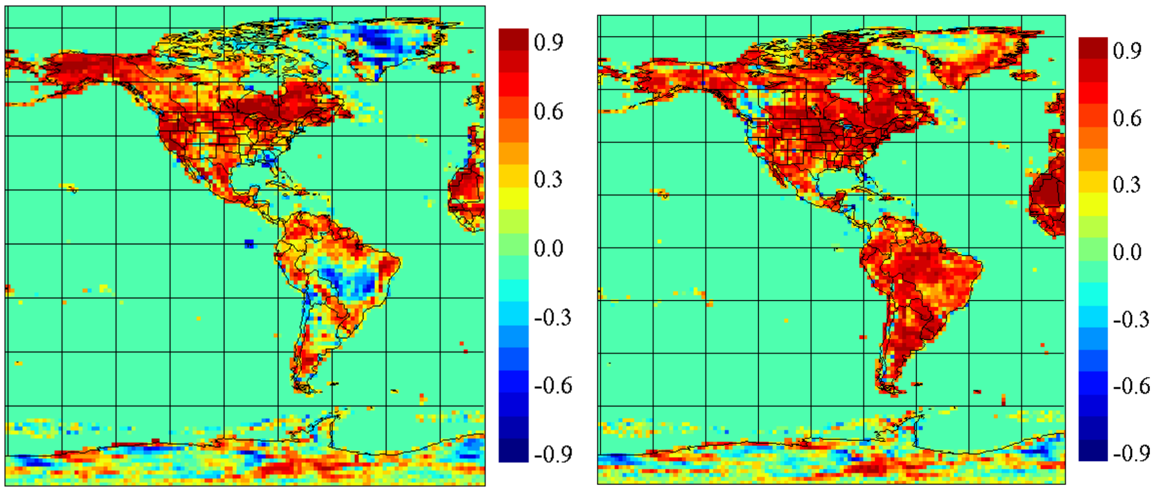

GOES only

T_{air}/T_{skin} error correlation

- According to "**Background Error Correlation between Surface Skin and Air Temperatures: Estimation and Impact on the Assimilation of Infrared Window Radiances" Garand et al. 2004:**
  - Error correlation between T_s and T_a is generally high excepted in case of low inversions).
  - It is shown that background error correlation has an important impact in general, on the analysis of both T_s and the T_a in the boundary layer (of the order of 0.3-0.5 K).
  - This impact is often maintained in 6 hour forecasts.
  - The assimilation of surface sensitive infrared channels will be best accomplished at resolutions below 50 km.

T_S-T_G error correlation from ensemble 6-h forecasts for a given day

06 UTC June 2 2002 18 UTC same day



Correlation typically > 0.5, but can be negative in inversion situations
Ensembles do not modify SST so no correlation over oceans

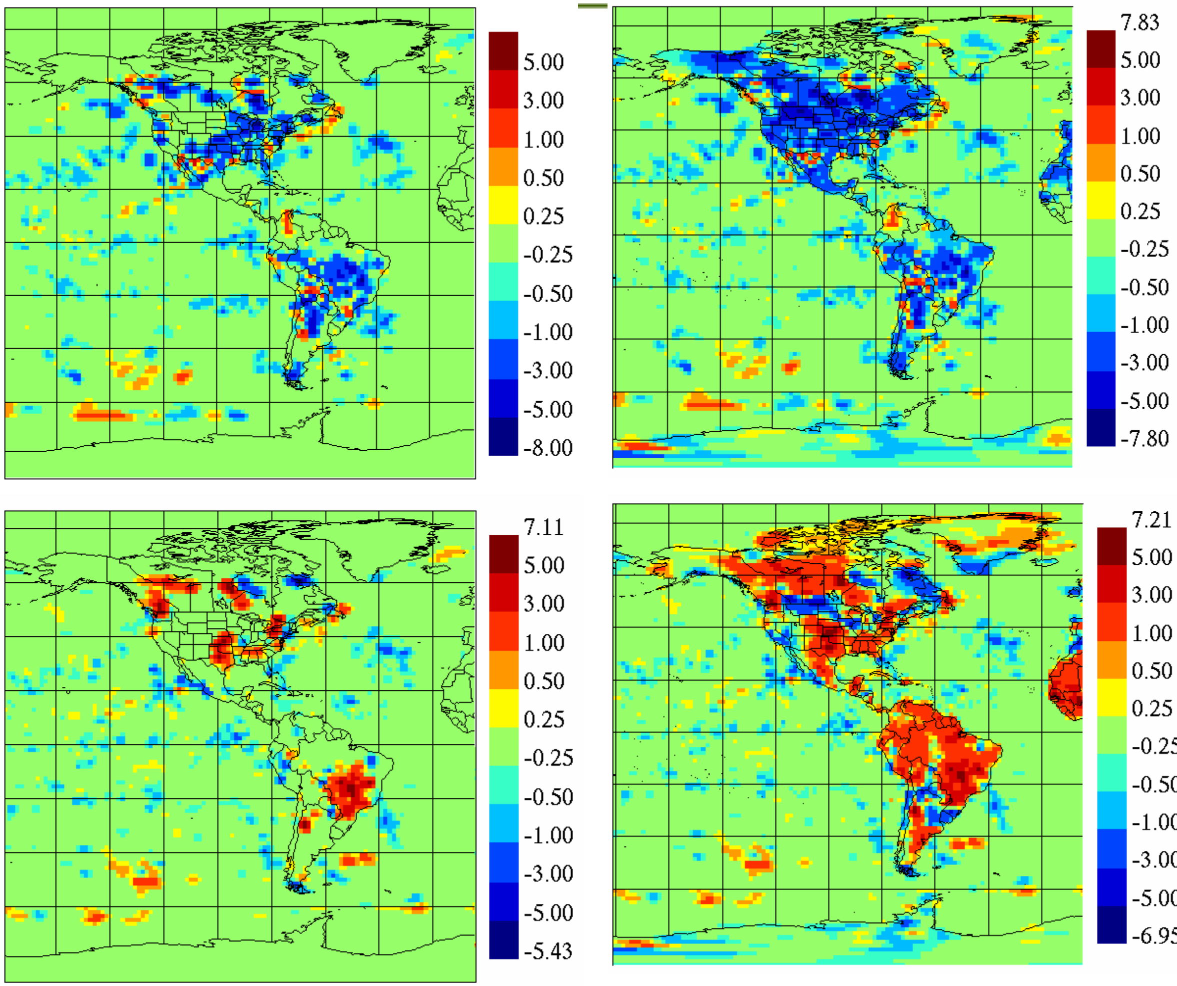
Ref: Garand et al., 2004

Effect of T_{air}-T_G correlation on T_G increments from assimilation of GOES window channels

No correlation | with correlation

06 UTC

18 UTC



With correlation, surface Obs participate to T_G analysis. Without cor, only GOES radiances participate.

It is seen sfc obs correct in the same way (sign) as sat obs: good.

18 UTC (day) corrections are mostly positive (red) and 06 UTC mostly negative (night) due to deficiencies in model diurnal cycle.

No impact over oceans because T_{air}-T_G cor = 0.

Ref: Garand et al 2004

Radiative transfer issues

- In RTTOV, clear sky radiance is calculated as:

$$I_{clear}(\nu,\theta) = \varepsilon_s \tau_s(\theta) B(\nu,T_s) + \int_{\tau_s(\theta)}^{1.0} B[\nu,T(\tau(\theta))]\, d\tau(\theta) + (1-\varepsilon_s)\tau_s(\theta) \int_{\tau_s(\theta)}^{1.0} B[\nu,T(\tau'(\theta))] d\tau'(\theta)$$

Surface emission | Atmospheric upward emission | Atmospheric downward emission "reflected" by surface

This is only an approximation.

More rigorously, for a Lambertian surface: $+(1-\varepsilon_s)\tau_s(\theta)\iint \cos\theta' d^2\Omega' \int_{\tau_s(\theta')}^{1.0} B[\nu,T(\tau'(\theta'))]\, d\tau'(\theta')$

- A possibility to account for this approximately using a diffusivity factor (typical value 1.66)
- The green term is important for semi-transparent channels with τ_s~0.55 and low surface emissivity (i.e. desert ε_s~0.7 in some spectral bands)

See "Systematic errors inherent in the current modeling of the reflected downward flux term used by remote sensing models", D.S. Turner, Applied Optics, Vol. 43, No. 11, April 2004
for the HIRS instrument
and "Revisiting the Attenuated Reflected Downward Flux Term of the radiative transfer equation" D. S. Turner, Proceedings of the 12th TOVS conference
for HIRS and AIRS instrument.

Conclusions, Perspectives

- U of Wisconsin HSR emissivity database appears superior to CERES emissivity from O-P statistics
- LMD's emissivity has much more annual variability over deserts than HSR
- Other high spectral resolution emissivity dataset could be evaluated such as NOAA/NESDIS AIRS Emissivity Global Datasets.
- Geostationary is of interest because of continuous availability and pixel size of about 5 km
- Impact of T_{air}/T_g error correlation is very important in 3D/4D assimilation. This can be derived from ensemble forecasts.
- The assimilation of surface sensitive IR channels should be limited to regions of relatively uniform topography at the scale of ~50 km
- All is in place for conducting assimilation cycles on analysis grid of order ~35 km