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 $T_{\text{air}} / T_{\text{skin}}$ 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 $T_{\text{air}}/T_{\text{skin}}$ 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:
1/6° 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 0.05° resolution (Borbas et al. 2007)
  - NOAA/NESDIS AIRS Emissivity Global Datasets. Monthly global maps at 3.0°lon. x 3.0°lat. or 0.5°lon x 2°lat. (Zhou et al. 2008)
  - LMD AIRS emissivity maps. Monthly, Tropical maps [-30°;+30°] at 1.0° resolution (Péquignot et al. 2007)
Emissivity maps comparisons

Band 1: 2702.7 cm\(^{-1}\) (3.7\(\mu\)m)

LMD: 1 year average (2007)

HSR: 2 year average (2007-2008)
Emissivity maps comparisons

Band 6: 1204.8 cm\(^{-1}\) (8.3 \(\mu\)m)

- LMD: 1 year average (2007)
- HSR: 2 year average (2007-2008)

CERES

Band 6 min 0.85 max 1.00
Emissivity maps comparisons

Band 7: 1075.2 cm\(^{-1}\) (9.3 µm) (Possible O\(_3\) contamination)

LMD: 1 year average (2007)

HSR: 2 year average (2007-2008)
Emissivity maps comparisons

Band 8: 925.9 cm\(^{-1}\) (10.8 \(\mu\)m)

LMD: 1 year average (2007)

HSR: 2 year average (2007-2008)
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

LMD: 1 year average (2007)

HSR: 2 year average (2007-2008)
Emissivity spectrum comparisons

Sample spectral emissivity differences (Sahara)
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)
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

- AIRS+IASI with emissivity threshold
- GOES only
- AIRS+IASI without emissivity threshold
- Reference
- AIRS only
- AIRS+IASI with emissivity threshold
- GOES only
- AIRS+IASI without emissivity threshold
- Reference
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 $T_{\text{air}}$-$T_G$ correlation on $T_G$ increments from assimilation of GOES window channels

No correlation

With correlation

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 $T_{\text{air}}$-$T_G$ cor = 0.

Ref: Garand et al 2004
Radiative transfer issues

- In RTTOV, clear sky radiance is calculated as:

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

Surface emission  Atmospheric upward emission  
Atmospheric downward emission  “reflected” by surface

This is only an approximation.

More rigorously, for a Lambertian surface:

\[ + \left(1 - \varepsilon_s\right) \tau_s(\theta) \int \cos \theta' \, d^2\Omega' \int B(\nu, T(\tau'(\theta'))) \, d\tau'(\theta') \]

- 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 \(\tau_s \sim 0.55\) and low surface emissivity (i.e. desert \(\varepsilon_s \sim 0.7\) in some spectral bands)

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