The assimilation of hyperspectral infrared radiances over land

Ed Pavelin
Met Office, Exeter, UK
Outline

• Assimilation of AIRS and IASI at the Met Office
• Effects of surface properties on IR radiances
• Surface emissivity: retrieval in 1D-Var
• Simulation study
• Results of real 1D-Var analysis over land
• Forecast impact trials
• Conclusions
Outline

• Assimilation of AIRS and IASI at the Met Office
• Effects of surface properties on IR radiances
• Surface emissivity: retrieval in 1D-Var
• Simulation study
• Results of real 1D-Var analysis over land
• Forecast impact trials
• Conclusions
Assimilation of AIRS and IASI radiances

- **AIRS**: Warmest FOV; Up to 141 channels
- **IASI**: Most homogenous FOV; Up to 138 channels
- **1D-Var** analysis in OPS (before 4D-Var)
- **QC**: Check for convergence *before* 4D-Var
- Retrieve auxiliary parameters not analysed in 4D-Var
  - Cloud top height, cloud fraction
  - Surface temperature
- **Assimilate radiances directly in 4D-Var**
Outline

• Assimilation of AIRS and IASI at the Met Office
• **Effects of surface properties on IR radiances**
  • Surface emissivity: retrieval in 1D-Var
  • Simulation study
  • Results of real 1D-Var analysis over land
  • Forecast impact trials
• Conclusions
1D-Var fit to observations

Window channel, Assuming $\varepsilon = 0.98$

Over sea: Use ISEM emissivity model (pretty accurate)

Over land: Assume emissivity=0.98

Large mis-fit
Land surface emissivity (8.5\(\mu m\))
(From NASA AIRS product, June-August 2008)
Source: UCSB MODIS emissivity database
Surface sensitivity of IASI
(US Standard Atmosphere)

Channels previously used over land

Emissivity = 0.98

© Crown copyright Met Office
Assimilation of IR radiances over land at the Met Office

• Until July 2011:
  • Assumed infrared emissivity $\varepsilon = 0.98$ over land
  • Not good enough – can’t use channels peaking below $\sim 400\text{hPa}$

• Options to increase data use over land
  • Use fixed emissivity “atlas”
  • Use land surface model / surface type atlas
  • Retrieve surface emissivity from observations
Outline

- Assimilation of AIRS and IASI at the Met Office
- Effects of surface properties on IR radiances
- **Surface emissivity: retrieval in 1D-Var**
  - Simulation study
  - Results of real 1D-Var analysis over land
  - Forecast impact trials
- Conclusions
How can we retrieve emissivity in 1D-Var?

• IR surface emissivity has large spectral variability

• Retrieving emissivity in $n$ channels adds $n$ unknowns to 1D-Var state vector

• Use principal component analysis to “compress” the emissivity spectrum
  • Just a few unknowns
Advantages of PC-based emissivity analysis

• PC-based approach
  • Use prior knowledge of spectral variation of emissivity (from lab measurements)
  • Constrains solution to realistic values
  • Retains realistic correlations between channels

→ Helps to separate $T_{\text{skin}}$ and $\varepsilon(\lambda)$
Reconstruction errors

Training dataset: Based on UCSB MODIS library.
146 natural surface types used

NB:
Log scale!

Use 12 PCs
(instead of 140 channels!)
Outline

• Assimilation of AIRS and IASI at the Met Office
• Effects of surface properties on IR radiances
• Surface emissivity: retrieval in 1D-Var
• Simulation study
• Results of real 1D-Var analysis over land
• Forecast impact trials
• Conclusions
**Experiment:** 1D-Var analysis from simulated AIRS radiances

- **Objective:** To demonstrate 1D-Var analysis of emissivity
- Radiance simulated using RTTOV
- 13495 atmospheric profiles from ECMWF ERA40 dataset
- Surface emissivity from *UWisc/CIMSS IR emissivity atlas* (2006 data used)
- Simulated observation errors added to radiances
- Fixed emissivity first guess = 0.98 over land
- 1D-Var includes simultaneous T, q retrieval
Sea

Bare soil?

Vegetation?

Desert

Sea Vegetation?

Bare soil?

Desert
RETRIEVAL: 9.32 μm (Mineral signal)
1D-Var simulation results

\( \varepsilon = 0.98 \)

\( \varepsilon \) from 1DVar

**T\text{skin}**

Bias

920hPa

T RMS

© Crown copyright   Met Office
Profile retrieval errors (simulation)

Land

Sea

Improvement due to 1D-Var emissivity
The effect of cloud

Need good ε and Tskin to detect cloud

Need knowledge of cloud to analyse sfc!
Need good $\varepsilon$ and $T_{\text{skin}}$ to detect cloud

Need knowledge of cloud to analyse sfc!

Use a priori emissivity atlas

Use CIMSS / UWisc IR emissivity atlas for first guess
Outline

• Assimilation of AIRS and IASI at the Met Office
• Effects of surface properties on IR radiances
• Surface emissivity: retrieval in 1D-Var
• Simulation study
  • Results of real 1D-Var analysis over land
• Forecast impact trials
• Conclusions
IASI: 1D-Var fit to observations
(Variable emissivity, **fixed first guess**)

BIAS

- Poor fit due to strong mineral reflectivity
- Poor fit to window channels

RMS

- Poor fit due to strong mineral reflectivity
- Poor fit to window channels

© Crown copyright  Met Office
IASI: 1D-Var fit to observations
(Variable emissivity, **first guess from atlas**)

**BIAS**

![Bias plot showing residuals](image)

**RMS**

![RMS plot showing better fit and residual misfit](image)

- **Better fit here using atlas**
- **Residual misfit due to mineral reflectivity**
Some problems…

18Z Run

Day

Night

06Z Run

Night

Day

LW Fit

Poor fit

$\Delta T_{\text{skin}}$

$T_{\text{skin}}$ bias
Day/Night biases
Model surface temperature?

- Large surface temperature increments (>10K)
  - Hot / desert surfaces
  - Daytime

- Probably seeing systematic biases in the model surface temperature

- Could be related to…
  - Soil temperature?
  - Surface heating/cooling rates?
  - Fluxes?
  - Soil thermal properties (conductivity, heat capacity)?
  - Soil moisture?
Day/Night biases
How to deal with them…

• Interim solution:
  • Use data over land operationally at NIGHT ONLY

• Longer term:
  • Introduce QC / data filtering
    • Avoid “hot” surfaces during daytime? ( > 300K )
    • Filter observations by size of \( T_{\text{skin}} \) increments?
  • Need a better understanding of model \( T_{\text{skin}} \) biases
  • Assimilation of IASI \( T_{\text{skin}} \) in land surface scheme
Outline

• Assimilation of AIRS and IASI at the Met Office
• Effects of surface properties on IR radiances
• Surface emissivity: retrieval in 1D-Var
• Simulation study
• Results of real 1D-Var analysis over land
  • **Forecast impact trials**
• Conclusions
NWP Forecast Trial Results

• Trial: Use same IASI channel set over land and sea (excluding window channels over land) with 1D-Var emissivity analysis

IALSI OVER LAND IMPACT SUMMER EMISS SHDMI-SHDMH (JUN10)  
VERIFICATION VS OBSERVATIONS  
OVERALL CHANGE IN NWP INDEX = 0.138

IALSI OVER LAND IMPACT WINTER SHDMC-SHDMB (DEC10)  
VERIFICATION VS OBSERVATIONS  
OVERALL CHANGE IN NWP INDEX = -0.022

• Modest improvements in Summer in most fields
• Smaller/neutral impact in Winter

© Crown copyright  Met Office
Outline

• Assimilation of AIRS and IASI at the Met Office
• Effects of surface properties on IR radiances
• Surface emissivity: retrieval in 1D-Var
• Simulation study
• Results of real 1D-Var analysis over land
• Forecast impact trials

• Conclusions
Conclusions

• Until July 2011, low-peaking IR sounding channels were rejected over land
• Improvements now implemented for IASI:
  • Analysis of spectrally-varying surface emissivity
  • Assimilate same channels over land and sea (except window channels)
  • “First-guess” global emissivity atlas helps with cloud analysis
• Poor fit to observations over daytime deserts
  • Systematic biases in model surface temperature (work underway to investigate this)
• Using surface-sensing channels at night only gave positive impact in trials
  • Modest improvement in NWP accuracy
Questions and answers