Satellite Instrument Calibration Issues: Experience Gained from SSMIS

W. Bell, S. English, S. Swadley\textsuperscript{1} & G. Kelly\textsuperscript{2}

\textsuperscript{1} Naval Research Laboratory, Monterey, CA, US
\textsuperscript{2} ECMWF, Reading, UK

Acknowledgements: B. Candy, F. Hilton, A. Smith, N. Atkinson, J. Eyre
organisers & participants in SSMIS mini-workshop, NRL, Oct 2005

Bias Estimation and Correction in Data Assimilation, ECMWF, 8-11 November 2005
Outline

• Background

• Instrumental biases & correction strategies:
  • Warm load solar intrusions
    ➢ Intrusion mapping (Met Office)
    ➢ Gain correction (NRL, NOAA)
  • Reflector emission
    ➢ Empirical correction
    ➢ Physical basis

• Radiance monitoring & analysis increments

• Initial forecast impact studies at ECMWF

• Future developments

• Summary & conclusions
Background: Instrument and scan geometry

Main Reflector

Cold Calibration Reflector

Warm Load Feedhorns

Special Sensor Microwave Imager/Sounder (SSMIS)
Background: SSMIS Channels

SSMIS = SSMI channels +
13 T sounding \((O_2\) line) chs +
3 q sounding \((H_2O\) line) chs +
150 GHz channel
Background - orbit coverage of operationally assimilated sounders / imagers

ATOVS (T & q)

AIRS (T & q)

SSMI (WS)

SSMIS (T, q, WS)

F17 – F20 planned for 2006 - 2011
Background: Accuracy Requirements and Initial Performance
Background: two step approach to bias correction

Pre-Processor
- Remapping
- Averaging
- Intrusion flagging
- Reflector correction
- BUFR I/O

1D-Var
- Analysis of:
  - T, \( Q_{\text{tot}} \) (\( q_l + q \)),
  - WS.
  - QC & channel selection

2D-Step:
- Correct instrumental biases

4D-Var
- Control variables:
  - T, q, u10, v10
  - (\( q_l \) from 1D Var used in forward calculation)

1st Step:
- Correct cross scan, RT and model biases using predictor scheme

See Nigel Atkinson presentation tomorrow for details.
Time series of averaged innovations continue to be a useful tool for the study of SSMIS calibration issues.
Instrumental Biases: warm load solar intrusions

Visualisation Software (DGS)
Mike Warner, Aerospace Corp.
Offline signal processing to detect solar intrusions / gain anomalies

2nd derivative of gain wrt time plotted as a fn of local solar zenith/azimuth angle
Solar intrusion map

Map is 2D array (360×180) of 0’s & 1’s, indexed by az, zen

Should be complete after 1 year (assuming orbit stable)?

Final map produced by 2D convolution of original map with gaussian – to account for temporal extent of intrusions
Intrusion flagging: coverage

Yellow: rejected
Black: OK
(30 - 40% data flagged)
Gain Correction using Fourier Filtering: no correction

Steve Swadley, NRL

DMSP F-16 SSMIS (OB) – ECMWF (BK) Ch. 4 54.4 GHz V

Temperature Departure [K]

Start Scan Time [sec]

DTG: 2005100406
TDR Revs: 10121–10123
Gain Correction using Fourier Filtering: corrected

Steve Swadley, NRL

DMSP F-16 SSMIS (GCOB) – ECMWF (BK) Ch. 4 54.4 GHz V

Temperature Departure [K]

Start Scan Time [sec]

DTG: 2005100406
TDR Revs: 10121–10123

OB–BK
Lat
Elevation
T_Rflct_Arm
Azimuth
T_Rflct
Shadow
Reflector Emission: entering Earth shadow

Main reflector
Exposed to direct sunlight
Reflector Emission: emerging from Earth shadow
Problems in ascending node not evident in descending node
Reflector emission correction

$T_{obs} = (1 - \varepsilon)T_{scene} + \varepsilon T_{ant}$

$T_{scene} = \frac{T_{obs} - \varepsilon T_{ant}}{1 - \varepsilon}$

$\Delta \varepsilon = \Delta T_{scene} \left[ \frac{\partial T_{scene}}{\partial \varepsilon} \right]^{-1}$

$\Delta T_{ant} = \Delta T_{scene} \left[ \frac{\partial T_{scene}}{\partial T_{ant}} \right]^{-1}$

Compute tolerable errors in $\varepsilon$ and $T_{ant}$ ($\Delta \varepsilon$ & $\Delta T_{ant}$) given tolerable errors in $T_{scene}$ ($\Delta T_{scene}$)
### Required accuracy in estimate of antenna emissivity and temperature

<table>
<thead>
<tr>
<th>Ch #</th>
<th>pol</th>
<th>$\Delta T_{\text{scene}}$ /K</th>
<th>$\varepsilon_{\text{nom}}$</th>
<th>$\Delta \varepsilon$</th>
<th>$\Delta T_{\text{ant}}$ /K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 5</td>
<td>V</td>
<td>0.1</td>
<td>0.01</td>
<td>0.0008</td>
<td>10</td>
</tr>
<tr>
<td>6,7,19-24</td>
<td>RC</td>
<td>0.1</td>
<td>0.02</td>
<td>0.0010</td>
<td>5</td>
</tr>
<tr>
<td>9 - 11</td>
<td>H</td>
<td>0.5</td>
<td>0.04</td>
<td>0.0060</td>
<td>12</td>
</tr>
<tr>
<td>12 - 16</td>
<td>V/H</td>
<td>0.5</td>
<td>0.00</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

$\Rightarrow$ Require $T_{\text{ANT}}$ to be accurate to 5K and emissivity estimates to be good to $\sim 0.0008$ for $T$ sounding channels to keep $T_{\text{SCENE}}$ errors below 0.1K
SSMIS – antenna emission correction using constructed antenna T

\[ T_{\text{ant}}(t) = T_{\text{arm}}(t) + c_1 \frac{dT_{\text{arm}}}{dt} \]

\[ T_{\text{ant}}(t) = T_{\text{arm}}(t) + c_1 \int_0^T c_2 e^{-\frac{t-\tau}{\sigma}} \frac{dT_{\text{arm}}}{dt} (t - \tau) d\tau \]
Characterising $T_{ANT}$ & $\varepsilon$: Chs 2 – 7

Ch 1 - 5: $\varepsilon = 0.01$

6,7 : $\varepsilon = 0.02$

$T_{corr} = 30 - 40$ K

(effectively calibrating reflector emissivity using NWP T fields!?)
Determination of $\varepsilon$ and $T$ less precise due to larger uncertainties in NWP $q$ fields.
ε = 0

(\textit{i.e} reflector emissivity shouldn't be a problem for SSMI like - channels)
Heat transfer equation for support arm:

\[ c_i \frac{\partial T_{arm}}{\partial t} = c_2 f(t) - (c_3 T_{arm}^n - c_4 T_0^n) \]

In earth shadow, \( f(t) = 0 \)

Plot time derivative of \( T_{arm} \) vs \( T_{arm} \)

Indicates \( n = 1 \).

*ie* arm cools conductively to sink at 218K
Physical basis for empirical reflector correction (2)

\[
\frac{c_2}{c_3} f(t) = (T_{arm} - T_0) + \frac{c_1}{c_3} \frac{\partial T_{arm}}{\partial t}
\]
Assuming reflector cools conductively, \( T_{\text{ant}}(t) \) can be obtained from the solution of:

\[
T_{\text{ant}}(t) = T_{\text{arm}}(t) + a_1 \int_0^T c \, \exp(\tau/\sigma) \, dT_{\text{arm}}(t-\tau) \, d\tau
\]

\[
\frac{\partial T_{\text{ant}}}{\partial t} = a_1 f(t) - a_2 (T_{\text{ant}} - T_0)
\]

Difference usually < 5K

Need to check \( a_1 \) and \( a_2 \) (fitted) are plausible given thermal properties of main reflector
Performance of reflector emission correction

CHANNEL 4 (54.40 GHz)

- Ocean, flagged
- Ocean, unflagged
- All obs, low pass filtered
- Ocean, unflagged, corrected
- Ocean, unflagged, corrected and lp filtered

O - B / K

TIME RELATIVE TO 18Z 06/06/05 / mins
Typically, in 1D Var:

- 48% are rain or intrusion flagged
- 8% don't converge
- 2% bad background
- <1% fail in rttov, or fail gross O-B check

ie 58% rejected at 1D Var step.

Further rejections in 4D Var based on retr LWP

Better handling of duplicate orbits

Modified intrusion map
Radiance monitoring: LAS channels 2, 3 & 4

- Change in Operational model
- Implement bias correction

52.8 GHz

53.6 GHz

54.4 GHz
Radiance monitoring: IMA channels 9, 10 & 11

- Channel 9: $183 \pm 6.6$ GHz
- Channel 10: $183 \pm 3.0$ GHz
- Channel 11: $183 \pm 1.0$ GHz
Radiance monitoring: ENV channels 12, 13 & 14

19 GHz (H)

19 GHz (V)

22 GHz (V)
Analysis increments

Channels 2 – 7
Obs errors: 0.25K (2 - 4)
0.5K (5 - 7)
LWP < 5 g.m⁻²

Warm bias on ascending part of orbit

Cold bias on descending part of orbit & N polar region

Unflagged intrusion region
Channels 2 – 4 ONLY
Obs errors: 0.25K (2 - 4)
LWP < 5 g.m\(^{-2}\)

\[ T_{\text{CORR}} = 25K \]

Adjusted lag
Forecast Impact Studies at ECMWF

Graeme Kelly

Pre-processed data:
- 40% flagged
- limited coverage
- tuning ongoing
- T sounding chs only
- 0.5K obs errors
Forecast Impact Studies at ECMWF

SH

T+48

T+90

AC

RMS

© Crown copyright 2005
Future developments

• Best correction algorithms (from NRL, Met Office and NOAA) will be incorporated in a pre-processor to be run at FNMOC, Monterey to produce a new data stream. Expected early 2006.

• Hardware modifications are in place for F17:
  • Fence to prevent direct solar intrusions
  • Temp sensor re-sited at centre of (back of) reflector (?)

• F17 launch June – Dec 2006
Summary & Conclusions

• In the 2 years since launch a number of important instrument biases in F16 SSMIS have been investigated and are now understood

• Correction algorithms have been developed and the best will be incorporated in a pre-processor to be run at FNMOC

• Baseline forecast studies show the impact of F16 SSMIS to be > 50% impact of AMSU-A on N-15

• Further improvements expected as coverage is improved, corrections are tuned and more channels are used

• SSMIS should be an important component of NWP DA systems over the next 10 years
Summary & Conclusions (contd)

• Some instrumental biases are not easily dealt with in conventional predictor based schemes, new diagnostics are needed to study these and develop correction algorithms

• Ever more complex radiometry (conical scan, aperture synthesis, imaging interferometric) may pose even more complex bias problems – we need to be flexible in developing solutions

• NWP fields can be very useful in instrument Cal/Val – we should be prepared to contribute to Cal/Val efforts
The End ..................

.............Thanks.