EUMETSAT Meteosat-IASI Inter-calibration Algorithm

Tim Hewison
Marianne König
Contents

• **Strategy**
  – Traceability, Consistency, Predictability, Integrity, Stability

• **Practice**
  – Radiance Definition
  – Error Analysis
  – 3.9µm missing spectral contribution
  – Non-linearity

• **Summary of Results for Meteosat-7, 8 and 9**
  – Effect of changes to non-linearity corrections

• **Comparison with NWP monitoring statistics**

• **Future Plans**
  – Model variability/predictability
Inter-calibration Strategy

**Principles**
- Instrument Collocations (Time Series)
- NWP Bias Correction Statistics
- Calibration Accuracy Assessment (ref. instrument)

**Methodology**
- Analysis
- Understanding & Predicting Biases
- Operational Corrections

**Results**
- Collocation Requirements (in time, space)
- Consistency between instruments
- Re-analysis for Climate Monitoring

**Benefits**
- Specifications for Future Instruments
- Less Bias in Level 1 & 2 Products
- Consistency between instruments

**EUMETSAT 2007**
**EUMETSAT 2008**
**Liaisons 2008**
IASI and/or AIRS as a reference?

- EUMETSAT: Meteosat-IASI
- NOAA: AIRS-IASI

IASI has no spectral gaps
IASI + HIRS/4 on same platform

A lot of work for us to complete the triangle: Meteosat-AIRS (Integrity check)
Missing Energy in MSG 3.9 µm channel

Black-body Planck function at 290K convolved with Spectral Response Function of MSG
Integrate to calculate Total Radiance
Missing energy not seen by IASI in the Small fraction beyond 2760cm⁻¹
Convert to Brightness Temperatures

Result:
IASI under-estimates MSG 3.9µm radiance by 1.33% of scene radiance, or ~0.17K at 290K (Scene-dependent)

Not accounted for in analysis
Marianne told us all about the new radiance definition
ECP833 also includes changes to non-linearity corrections

As a temporary work around for 2007 data, needed to ensure consistent definition of radiance:
– Read in old IMPF-defined radiances
– Convert to brightness temperatures
– Convert back to effective radiances

Archive Data will be re-processed according to new definition
## Collocation Criteria

<table>
<thead>
<tr>
<th>Meteosat First Generation</th>
<th>Meteosat Second Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta Lat &lt; 30^\circ$, $\Delta Lon &lt; 30^\circ$ of SSP</td>
<td>$\Delta Lat &lt; 30^\circ$, $\Delta Lon &lt; 30^\circ$ of SSP</td>
</tr>
<tr>
<td>$\Delta t &lt; 30$ mins (=scan period)</td>
<td>$\Delta t &lt; 15$ mins (=scan period)</td>
</tr>
<tr>
<td>$</td>
<td>\theta</td>
</tr>
<tr>
<td>$\Delta \theta &lt; 2^\circ$ (Incidence angle diff.)</td>
<td>$\Delta \theta &lt; 2^\circ$ (Incidence angle diff.)</td>
</tr>
<tr>
<td>3x3 MFG pixels / IASI iFoV</td>
<td>5x5 MSG pixels / IASI iFoV</td>
</tr>
</tbody>
</table>

(Corrected Radiance Definition)

Can investigate temporal variability and angular dependence further using Rapid Scan data.
Uncertainty due to Spatial Variability

Estimate uncertainty due to spatial variability as Standard Deviation of Meteosat pixels within collocated IASI iFoVs.

Use as error bars in weighted regression.
Regression – no filtering

Offset $\neq 0$  Slope $\neq 1$ => Difference is scene-dependent

Reference Scene, $L_{REF}$

Weighted Regression
Error bars = Variance
Regression – $\sigma T_b < 0.5K$ filtering

Similar results at Reference Scene

Small dynamic range (clear sky only)
Regression – $\sigma L < 5\% L_{REF}$ filtering

- Larger dynamic range
- Non-linearity check

Similar results at Reference Scene

Outliers = Clouds?

Larger dynamic range
- Non-linearity check
Non-linearity

Compare linear regression with quadratic fit:

V. little difference at ref. scenes <0.05K

Difference increases for low $T_b$
As expected for non-linear errors
Only significant for MSG 7.3µm channel and still <1K at $T_b=220K$

But differences are v. variable
Error bars currently underestimated
Linearily interpolate SEVIRI radiances before and after IASI observation, \( L(t_b) \) and \( L(t_a) \), to time, \( t_0 \):

\[
L(t_0) = \left( \frac{t_0 - t_b}{t_a - t_b} \right) L(t_a) + \left( \frac{t_a - t_0}{t_a - t_b} \right) L(t_b)
\]

The variance of 2 groups \( m \) MSG pixels per IASI FoV:

\[
S_0 = \frac{1}{2m-1} \left[ \left( w_a^2 S_a + w_b^2 S_b \right) + 2 \left( w_a L(t_a) - L(t_0) \right)^2 + \left( w_b L(t_b) - L(t_0) \right)^2 \right]
\]

Where \( S_a \) and \( S_b \) are the variances of the MSG pixels before and after the IASI observation and the weighting are given by:

\[
w_b = \left( \frac{t_a - t_0}{t_a - t_b} \right), \quad w_a = \left( \frac{t_0 - t_b}{t_a - t_b} \right)
\]

to linearly interpolate between observations at time \( t_b \) and \( t_a \).
Time series of brightness temperature differences between Met7-IASI for typical clear-sky radiances: Each Met7 infrared channel is shown in a different color, with different symbols, following the legend. Error bars represent statistical uncertainty on each mean bias (may be very small).
Time series of brightness temperature differences between MSG1-IASI for typical clear-sky radiances. Each MSG infrared channel is shown in a different color, with different symbols, following the legend. Error bars represent statistical uncertainty on each mean bias (may be very small).
Time series of brightness temperature differences between MSG2-IASI for typical clear-sky radiances. Each MSG infrared channel is shown in a different color, with different symbols, following the legend. Error bars represent statistical uncertainty on each mean bias (may be very small).
Contamination of MSG2 13.4µm filter

Possible explanation:
Build-up of ice on filter

Use spectral response function of different thickness ice
To modify 13.4µm channel’s nominal SRF
Repeat IASI comparison for each case
Test contaminated/nominal ratio is consistent with trend
<table>
<thead>
<tr>
<th>Channel (µm)</th>
<th>3.9</th>
<th>6.2</th>
<th>7.3</th>
<th>8.7</th>
<th>9.7</th>
<th>10.8</th>
<th>12.0</th>
<th>13.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref Scene $T_{b_{ref}}$ (K)</td>
<td>290</td>
<td>240</td>
<td>260</td>
<td>290</td>
<td>270</td>
<td>290</td>
<td>290</td>
<td>270</td>
</tr>
<tr>
<td>Meteosat-7</td>
<td>Mean Bias (K)</td>
<td>+2.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std. Dev. (K)</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meteosat-8</td>
<td>Mean Bias (K)</td>
<td>0.46</td>
<td>0.56</td>
<td>0.77</td>
<td>0.22</td>
<td>0.19</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>Std. Dev. (K)</td>
<td>0.09</td>
<td>0.08</td>
<td>0.18</td>
<td>0.09</td>
<td>0.14</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Meteosat-9</td>
<td>Mean Bias (K)</td>
<td>0.17</td>
<td>0.61</td>
<td>0.25</td>
<td>0.02</td>
<td>0.00</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Std. Dev. (K)</td>
<td>0.10</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.07</td>
<td>0.06</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Brightness Temperatures, $T_b$, for Reference Scenes and Mean Difference between Meteosat and IASI during 2007.

Statistically significant (at >95% level) biases highlighted in **bold**.
Meteosat-9 results Before and After new radiance definition & non-linearity corrections

<table>
<thead>
<tr>
<th>Channel (µm)</th>
<th>3.9</th>
<th>6.2</th>
<th>7.3</th>
<th>8.7</th>
<th>9.7</th>
<th>10.8</th>
<th>12.0</th>
<th>13.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref Scene $T_{bref}$ (K)</td>
<td>290</td>
<td>240</td>
<td>260</td>
<td>290</td>
<td>270</td>
<td>290</td>
<td>290</td>
<td>270</td>
</tr>
<tr>
<td>Meteosat-9 BEFORE</td>
<td>Mean Bias (K)</td>
<td>0.17</td>
<td>0.61</td>
<td>0.25</td>
<td>0.02</td>
<td>0.00</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Std. Dev. (K)</td>
<td>0.10</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.07</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>New-Old (non-linear corr\textsuperscript{n})</td>
<td>Mean Bias (K)</td>
<td><strong>-0.14</strong></td>
<td><strong>-0.55</strong></td>
<td><strong>-0.11</strong></td>
<td><strong>-0.06</strong></td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>Std. Dev. (K)</td>
<td>0.01</td>
<td>0.04</td>
<td>0.02</td>
<td>0.00</td>
<td>0.01</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>Meteosat-9 AFTER</td>
<td>Mean Bias (K)</td>
<td>0.03</td>
<td>-0.04</td>
<td><strong>0.14</strong></td>
<td>-0.04</td>
<td>-0.01</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Std. Dev. (K)</td>
<td>0.10</td>
<td>0.06</td>
<td>0.04</td>
<td>0.04</td>
<td>0.07</td>
<td>0.07</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Brightness Temperatures, $T_b$, for Reference Scenes and Mean Difference between Meteosat-9 and IASI during 2007.

**Before** and **after** reprocessing with new radiance definition and non-linearity corrections
Statistically significant (at >95% level) biases highlighted in **bold** – only 7.3 and 13.4µm
Comparison with NWP bias monitoring

- Part of Assimilation cycle:
- Systematic comparison of observations with NWP model
  - FG = First Guess
  - AN = Analysis
  - Mean difference + Std Dev.
  - Can break-down by:
    - Geographic area
    - Scan angles
    - Time of Day

- Compare with inter-calibration
- BUT includes NWP errors

Example from ECMWF website
## ECMWF bias monitoring for AIRS & IASI

<table>
<thead>
<tr>
<th>Channel (µm)</th>
<th>&lt;AIRS-FG&gt; (K)</th>
<th>&lt;IASI-FG&gt; (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.98</td>
<td>-3.3</td>
<td>&lt;-2</td>
</tr>
<tr>
<td>14.33</td>
<td>-0.3</td>
<td>-0.1</td>
</tr>
<tr>
<td>14.03</td>
<td>-0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>10.90</td>
<td>-0.6</td>
<td>-0.1</td>
</tr>
<tr>
<td>9.622</td>
<td>+0.1</td>
<td>-1.6</td>
</tr>
<tr>
<td>8.840</td>
<td>-0.3</td>
<td>-0.5</td>
</tr>
<tr>
<td>7.513</td>
<td>-0.1</td>
<td>-0.1</td>
</tr>
<tr>
<td>7.130</td>
<td>+0.8</td>
<td>-0.2</td>
</tr>
<tr>
<td>6.426</td>
<td>+2</td>
<td>+0.1</td>
</tr>
<tr>
<td>4.426</td>
<td>+0.9</td>
<td>+0.6</td>
</tr>
<tr>
<td>4.186</td>
<td>+1.5</td>
<td>+0.4</td>
</tr>
<tr>
<td>4.175</td>
<td>-0.5</td>
<td>-0.5</td>
</tr>
<tr>
<td>4.013</td>
<td>+1.1</td>
<td>+0.6</td>
</tr>
</tbody>
</table>

- **Jan 2008**
- **Tropics, Clear Skies over Sea**
- **Day and night**
  - But different orbits!
- **Mean OBS-FG estimated**
  - Same AIRS-IASI channels
- **Significant biases (>95%) shown in bold:**
  - 4 channels for AIRS
  - 2 channels for IASI
MVIRI on Meteosat-7 – IASI on Metop

Time series of brightness temperature differences between Met7-IASI for typical clear-sky radiances:
Each Met7 infrared channel is shown in a different color, with different symbols, following the legend.
Error bars represent statistical uncertainty on each mean bias (may be very small).

<table>
<thead>
<tr>
<th>Ch.</th>
<th>$T_{b, \text{ref}}$</th>
<th>Met7-IASI</th>
<th>ECMWF Obs-AN</th>
</tr>
</thead>
<tbody>
<tr>
<td>WV-1</td>
<td>245K</td>
<td>+2.57±0.12K</td>
<td>+4.5±1.0K</td>
</tr>
<tr>
<td>IR-2</td>
<td>295K</td>
<td>-1.63±0.19K</td>
<td>-2.5±1.0K</td>
</tr>
</tbody>
</table>

Large biases!
~½ ECMWF
EUMETSAT Inter-calibration Plans: 2008

IASI – Meteosat intercalibration:
- Investigate impact of MSG radiance definition
- Include temporal variability in error propagation
- Investigate angular dependence using Rapid Scan at ~40°N
- Compare with NWP bias monitoring statistics
- Assess collocation requirements – WV, window, O₃ channels

Extend inter-calibration to HIRS:
- Compare HIRS/4-IASI on Metop-A
- Compare HIRS-Meteosat-8 and -9
- Build-up time series with older HIRS and MVIRI

Set-up GSICS Data and Products server
# Coordinating Inter-calibration Activities

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MET-9 SEVIRI</td>
<td>0E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET-8 SEVIRI</td>
<td></td>
<td>0E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET-7 MVIRI</td>
<td>57E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET-6 MVIRI</td>
<td></td>
<td>57E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET-5 MVIRI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Metop-A IASI</td>
<td>09:30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aqua AIRS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Metop-A HIRS/4</td>
<td>13:36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-18 HIRS/4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-17 HIRS/3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-16 HIRS/3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-15 HIRS/3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-14 HIRS/2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Complete**
- **Planned**

**EUMETSAT**

**NOAA**

**Other**