Defining IASI as the Infrared Anchor Reference for the Global Space-based Inter-Calibration System (GSICS)

Tim Hewison
Denis Jouglet, Elsa Jacquette, Dave Tobin
Overview

1. Introducing GSICS

2. GSICS Corrections for Meteosat IR channels
   - Uncertainty analysis

3. Prime GSICS Corrections
   - Merging results from multiple references
   - Anchor Reference Concept

4. Reference Instrument Selection Criteria
   - Scoring Scheme

5. Inter-comparison of Reference Instruments

6. Conclusions
Global Space-based Inter-Calibration System

• What is GSICS?
  – Global Space-based Inter-Calibration System
  – Initiative of CGMS and WMO
  – Effort to produce consistent, well-calibrated data from the international constellation of Earth Observing satellites

• What are the basic strategies of GSICS?
  – Improve on-orbit calibration by developing an integrated inter-comparison system
    • Initially for GEO-LEO Inter-satellite calibration
    • Being extended to LEO-LEO
    • Using external references as necessary
  – Best practices for calibration & characterisation

• This will allow us to:
  – Improve consistency between instruments
  – Reduce bias in Level 1 and 2 products
  – Provide traceability of measurements
  – Retrospectively re-calibrate archive data
  – Better specify future instruments
GSICS Principles

- **Systematic generation of inter-calibration products**
  - for Level 1 data from satellite sensors
  - to compare, monitor and correct the calibration of monitored instruments to community references
  - by generating calibration corrections on a routine operational basis
  - with specified uncertainties
  - through well-documented, peer-reviewed procedures
  - based on various techniques to ensure consistent and robust results

- **Delivery to users**
  - Free and open access
  - Adopting community standards

- **To promote**
  - Greater understanding of instruments’ absolute calibration, by analysing the root causes of biases
  - More accurate and more globally consistent retrieved L2 products
  - Inter-operability for more accurate environmental, climate and weather forecasting products
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GEO-LEO IR - Hyperspectral SNO

- Simultaneous near-Nadir Overpasses
  - of one GEO imager and one LEO sounder
- Select Collocations
  - Spatial, temporal and geometric thresholds

Schematic illustration of the geostationary orbit (GEO) and polar low Earth orbit (LEO) satellites and distribution of their collocated observations.
GEO-LEO IR - Hyperspectral SNO

- Simultaneous near-Nadir Overpasses
  - of one GEO imager and one LEO sounder
- Select Collocations
  - Spatial, temporal and geometric thresholds
- Spectral Convolution:
  - Convolve LEO Radiance Spectra with GEO Spectral Response Functions
  - to synthesise radiance in GEO channels

Example radiance spectra measured by IASI (black), convolved with the Spectral Response Functions of SEVIRI channels 3-11 from right to left (colored shaded areas).
GEO-LEO IR - Hyperspectral SNO

• Simultaneous near-Nadir Overpasses
  • of one GEO imager and one LEO sounder

• Select Collocations
  • Spatial, temporal and geometric thresholds

• Spectral Convolution:
  • Convolve LEO Radiance Spectra with GEO Spectral Response Functions
  • to synthesise radiance in GEO channels

• Spatial Averaging
  • Average GEO pixels in each LEO FoV
  • Standard Deviation of GEO pixels as weight

Illustration of spatial transformation.
Small circles represent the GEO FoVs and the two large circles represent the LEO FoV for the extreme cases of FY2-IASI, where nxm=3x3 and SEVIRI-IASI, where nxm=5x5.
GEO-LEO IR - Hyperspectral SNO

- Simultaneous near-Nadir Overpasses
  - of one GEO imager and one LEO sounder
- Select Collocations
  - Spatial, temporal and geometric thresholds
- Spectral Convolution:
  - Convolve LEO Radiance Spectra with GEO Spectral Response Functions
  - to synthesise radiance in GEO channels
- Spatial Averaging
  - Average GEO pixels in each LEO FoV
  - Standard Deviation of GEO pixels as weight
- Weighted Regression of LEO v GEO rads
  - Evaluate Bias for Standard Radiance Scene
  - Regression coefficients with uncertainty
- GSICS Correction = Function
  - to convert level 1 data to be consistent with calibration of reference
  - Re-Analysis (symmetric time window)
  - Near Real-Time (asymmetric time window) - alternative cal coefficients in L1.5 HDR

**Graph:**

Weighted linear regression of $L_{GEO|REF}$ and $<L_{GEO}>$
for Meteosat-9 13.4μm channel based on single overpass of IASI
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Introducing *Prime GSICS Corrections*

- Define one *Anchor GSICS Reference*
  - For each spectral band/application
  - By consensus agreement within GSICS
- Use others as *Transfer References*
- **Blend** corrections from all references
  - After modifying Corrections to *Anchor GSICS Reference*
- Ensures long-term continuity
  - Without calibration jumps
- Ensures Traceability
  - back to single Anchor Reference
- Simplifies users’ implementation

---

**Modified References**

- Mon
- Ref1
- Ref2
- Ref3

**Simple Weighting of Each Reference**

- %Ref1
- %Ref2
- %Ref3
Correcting the Corrections & Blending References

Reference-1 (Anchor)

Monitored Instrument

Reference-2 (Transfer)

GSICS Correction, $g_1$

Mon $\rightarrow 1$

GSICS Correction, $g_2$

Mon $\rightarrow 2$

Delta Correction, $g_{1/2}$

2 $\rightarrow 1$

Corrected Correction, $g_{2,1/2}$

Mon $\rightarrow 2 \rightarrow 1$

Prime GSICS Correction, $g_0$

Mon $\rightarrow 1$

Mon $\rightarrow 1$

Derived by GSICS

Applied by User
Users’ Application of Prime GSICS Correction

Monitored Instrument

Prime GSICS Correction, $g_0$
Mon $\Rightarrow$ 1

Mon $\Rightarrow$ Ref1
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Reference Instrument Selection Criteria

• Most basic requirements are **essential** properties:
  • Is it available for the date in question?
  • Does it cover *at least part of* the spectral range?
  • Does it generate *sufficient* collocations?
  • Is its calibration *sufficiently* stable?
  • Can it transfer the calibration to other Reference sensors?

• Additional **desirable** requirements
  - reflect reduced uncertainties in inter-calibration,
  - up to a *saturation* point:
    • Does it cover the *full* spectral range?
    • At *sufficiently* high spectral resolution?
    • Is the full supporting documentation published?
    • Is it routinely monitored against other Reference sensors?
    • Does it belong to a committed series of sensors?
## Draft Scoring Scheme

<table>
<thead>
<tr>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Min</th>
<th>Max</th>
<th>Weight</th>
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<tr>
<td>Date Range</td>
<td>2015</td>
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<td>Spatial Coverage: Lat</td>
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<td>5</td>
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<td>0.001</td>
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<td>10</td>
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<td>Radiometric Noise</td>
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<td>0.001</td>
<td></td>
<td>10</td>
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<td><strong>Total</strong></td>
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<td></td>
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</tbody>
</table>
### Draft Scores for GSICS GEO-LEO IR NRTC

#### Scoring Scheme for GSICS Near-Real-Time Correction for 2015 Geostationary Imager IR Channels

<table>
<thead>
<tr>
<th>Metric</th>
<th>Threshold</th>
<th>Saturation</th>
<th>Metop/IASI</th>
<th>Aqua/AIRS</th>
<th>SNPP/CrIS (in FSR mode)</th>
<th>NOAA/HIRS/2</th>
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</thead>
<tbody>
<tr>
<td>Date Range Year</td>
<td>2015 2015</td>
<td>2006 2030</td>
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<td>OK 5.8</td>
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<td>-90 90</td>
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<td>OK 1.0</td>
<td>OK 1.0</td>
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<td>Spatial Coverage: Lon deg</td>
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<td>OK 1.0</td>
<td>OK 1.0</td>
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<tr>
<td>Dynamic Range K</td>
<td>270 300</td>
<td>180 330</td>
<td>2</td>
<td>OK 1.7</td>
<td>OK 1.7</td>
<td>OK 1.7</td>
</tr>
<tr>
<td>Spectral Range SWIR µm</td>
<td>3.75 3.92</td>
<td>3.48 4.36</td>
<td>2.2</td>
<td>OK 1.6</td>
<td>OK 1.2</td>
<td>NOK 1.1</td>
</tr>
<tr>
<td>Spectral Range MWIR µm</td>
<td>6.25 7.35</td>
<td>5.35 7.85</td>
<td>1.4</td>
<td>OK 2.6</td>
<td>OK 1.4</td>
<td>OK 2.1</td>
</tr>
<tr>
<td>Spectral Range LWIR µm</td>
<td>8.70 13.40</td>
<td>8.30 14.40</td>
<td>1.8</td>
<td>OK 5.2</td>
<td>NOK 2.6</td>
<td>NOK 2.6</td>
</tr>
<tr>
<td>Geometric Range: VZA deg</td>
<td>5 15</td>
<td>0 90</td>
<td>2</td>
<td>OK 1.2</td>
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<tr>
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<td>10</td>
<td>OK 2.8</td>
<td>OK 2.8</td>
<td>OK 2.8</td>
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<td>Spatial resolution km</td>
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<td>1</td>
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<td>Spatial sampling km</td>
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<td>OK 0.4</td>
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<tr>
<td>Geolocation accuracy km</td>
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<td>5 0.5</td>
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<td>Radiometric Stability K/yr</td>
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<td>1</td>
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<td>OK 0.2</td>
</tr>
<tr>
<td>Radiometric Noise K</td>
<td>10 0.1</td>
<td>1 0</td>
<td>1</td>
<td>OK 0.7</td>
<td>OK 0.5</td>
<td>OK 0.5</td>
</tr>
<tr>
<td>Uncertainty from SBAF K</td>
<td>1 0.01</td>
<td>10 10</td>
<td>1</td>
<td>OK 10.0</td>
<td>OK 1.0</td>
<td>NOK 0.3</td>
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<td>Spectral Resolution cm-1</td>
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<td>OK 0.0</td>
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<tr>
<td>Spectral Stability cm-1/yr</td>
<td>2 0.01</td>
<td>0 0</td>
<td>1</td>
<td>OK 0.0</td>
<td>OK 0.0</td>
<td>OK 0.0</td>
</tr>
<tr>
<td>Absolute Cal Acc</td>
<td>1 0.001</td>
<td>10 10</td>
<td>1</td>
<td>OK 0.2</td>
<td>OK 0.2</td>
<td>OK 0.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td><strong>97% 52% 91% 37% 88% 36% 82% 39%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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GSICS GEO-LEO IR Double Differences

- Time series of Bias
  - in Meteosat-10/SEVIRI IR13.4
  - wrt IASI-A
  - wrt IASI-B
  - For standard scene radiance (267K)
  - Over 3 yr overlap

- Biases vary
  - Ice contamination
  - Range -0.4 to -2.7K

- Differences <0.1K
Time series of Double Differences

No Obvious Trend in Any Channel! 😊

Small differences in long-wave channels 😍
Statistics of Double Difference Time Series

(MSG3-IASIA)-(MSG3-IASIB) Demo RAC Standard Bias over 2013-03/2016-02:

<table>
<thead>
<tr>
<th>Channel</th>
<th>Double Difference Trend [K/yr]</th>
<th>Mean Double Difference [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR3.9</td>
<td>-0.016 ± 0.008</td>
<td>0.001 ± 0.005</td>
</tr>
<tr>
<td>IR6.3</td>
<td>-0.003 ± 0.015</td>
<td>-0.015 ± 0.010</td>
</tr>
<tr>
<td>IR7.4</td>
<td>-0.002 ± 0.010</td>
<td>0.002 ± 0.007</td>
</tr>
<tr>
<td>IR8.7</td>
<td>0.002 ± 0.008</td>
<td>0.000 ± 0.006</td>
</tr>
<tr>
<td>IR9.7</td>
<td>-0.005 ± 0.011</td>
<td>-0.027 ± 0.007</td>
</tr>
<tr>
<td>IR10.8</td>
<td>0.004 ± 0.009</td>
<td>-0.016 ± 0.006</td>
</tr>
<tr>
<td>IR12.0</td>
<td>-0.009 ± 0.009</td>
<td>-0.018 ± 0.006</td>
</tr>
<tr>
<td>IR13.4</td>
<td>-0.011 ± 0.008</td>
<td>-0.042 ± 0.006</td>
</tr>
</tbody>
</table>

- No statistically significant trend
  - in any channel
- Within standard uncertainty of 10mK/yr
- Consistent results from other Meteosats
  - But larger uncertainties
- No statistically significant difference
  - between IASI-A and -B
  - in Short- and Mid-bands
  - in any channel
- Small, but significant difference
  - in long-wave band
  - Larger for colder scenes
Statistics on “quasi-SNOs” (50min delay, ~off-nadir)
Focus on homogeneous and stable scenes, night, as many “A before B” as “A after B”

Results:
- Biases between 0 and ~0.1K
- Highest bias for long wavelengths
  - Very good cross calibration
  - Same behaviour as the previous years, no degradation
  - Shape in B1 under investigation

[Slide from Denis Jouglet, CNES]
Radiance Dependence of IASI-A/B Double Difference

- \((\text{MSG3}-\text{IASIA})-(\text{MSG}-\text{IASIB})\) larger for cold scenes
- Must be careful comparing results from different domains!
  - Mean \(\Delta T_b\) from polar SNOs \(\neq\) Mean \(\Delta T_b\) from global QSNOs
  - Should compare in radiance bins
- Due to non-linearity differences?
- Consistent with CNES SIC Tool:

Radiance-dependence of \((\text{MSG3}-\text{IASIA})-(\text{MSG}-\text{IASIB})\) Double Difference
Error bars represent \(k=1\) uncertainty on mean difference
Red diamond = standard scene
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Conclusions

• Metop-A/IASI used as reference for first operational GSICS product:
  • Inter-calibration corrections for IR channels of Meteosat/SEVIRI

• Extension of concept to merge results from multiple references
  • Correcting all to be consistent with one Anchor Reference – Metop-A/IASI
  • Based on series of double-differences wrt SEVIRI
  • IASI-B and IASI-A calibration stable in all channels over 3 years
  • No significant differences in short- and mid-wave bands
  • Small differences in long-wave channels (<0.05K) – Radiance-dependent

• Selection of Anchor reference based on coverage/performance
  • According to uncertainty contributions
  • To be supported by error budgets
  • Inter-comparisons of different reference instruments

• GSICS Infrared Reference Sensor Traceability & Uncertainty Report
  • Error Budgets, Traceability and Inter-Comparisons
Thank You!