# Global Space-based Inter-Calibration System (GSICS) Infrared Reference Sensor Traceability and Uncertainty

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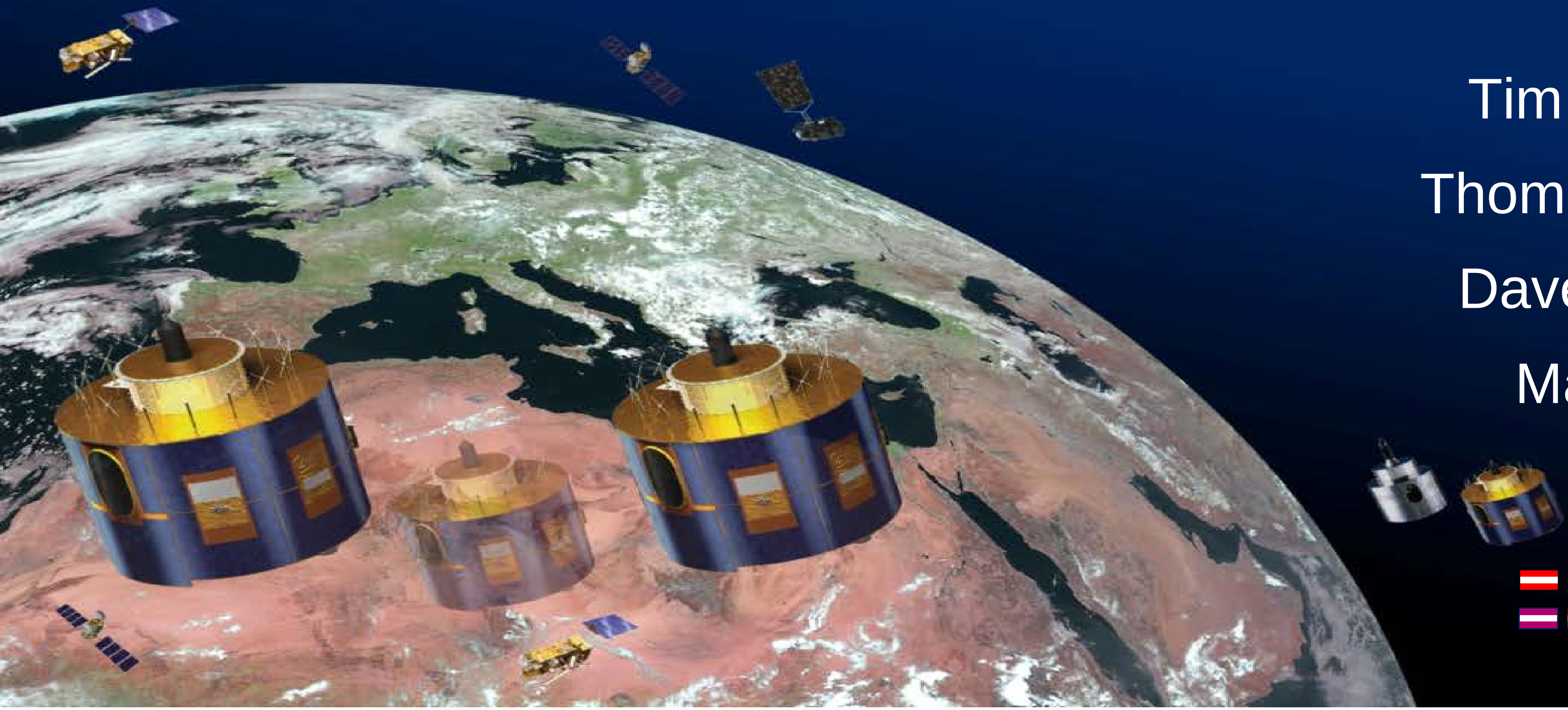


# Global Space-based Inter-Calibration System

- **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
Global Space-based
Inter-Calibration System

| | | |
|---|---|---|
| EUMETSAT | CNES | JMA |
| NOAA | CMA | KMA |
| ISRO | NASA | WMO |
| USGS | NIST | JAXA |
| ROSHYDROMET | IMD | ESA |

# GSICS Correction Products

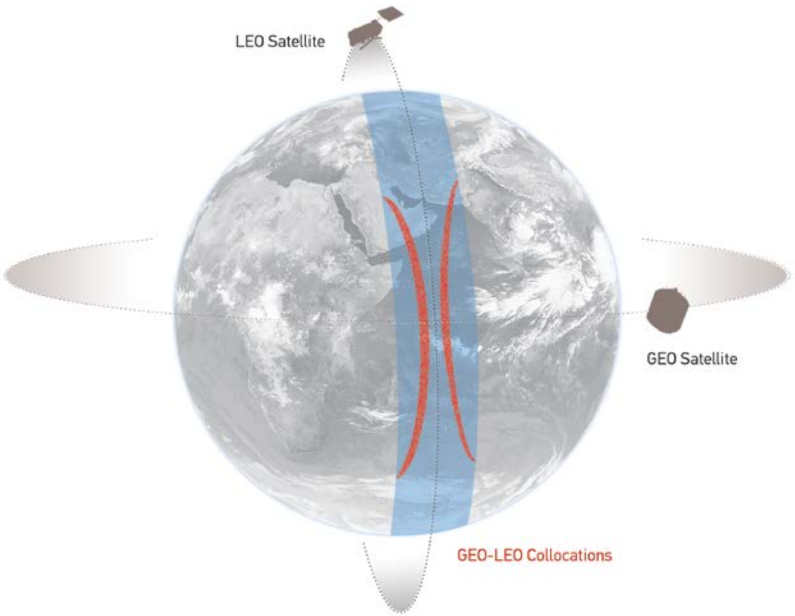
- **Systematic** generation of **inter-calibration** products
  - **for Level 1 data from** satellite sensors
  - **to** compare, *monitor* **and** correct **the calibration of *monitored* instruments to community references**
  - **by generating calibration corrections on a routine operational basis**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

TRACEABILITY / UNBROKEN CHAINS OF COMPARISONS

- **GSICS Corrections**
  - **Radiometric Calibration Corrections**
  - **Applied to operational L1 products in radiance space**
  - **Empirically derived based on inter-calibration individual *Reference Instruments***
  - **For Infrared channels of current Geostationary Imagers:**
    - **Available for Meteosat-8, -9, -10, GOES-12, -13, -15, INSAT-3D, FY2-E, -F, -G, COMS, Himawari-8**
    - **Using Metop-A/IASI, Metop-B/IASI, Aqua/AIRS and/or Soumi-NPP/CrIS**
    - **Multiple reference instruments extend time series & characterise diurnal variations**
    - **But need to ensure consistency & characterise relative calibration**

# 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

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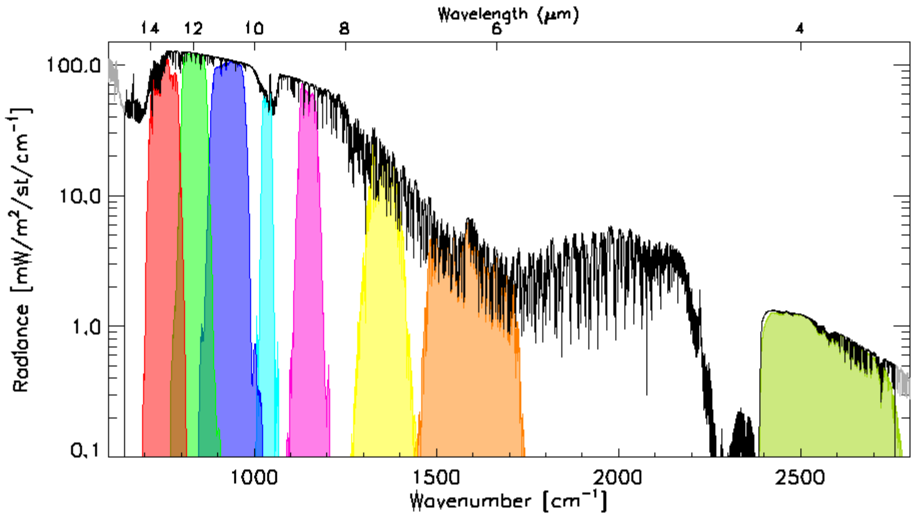
- Spectral Convolution:
  - Convolve LEO Radiance Spectra with GEO Spectral Response Functions
  - to synthesise radiance in GEO channels




**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).**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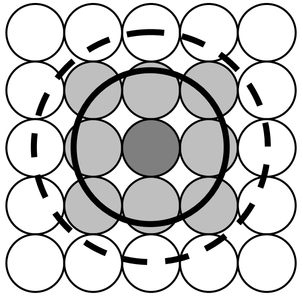
- Spatial Averaging
  - Average GEO pixels in each LEO FoV
  - Standard Deviation of GEO pixels as weight



**LEO FoV～10km**

**～ 3x3 GEO pixels**

**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.**

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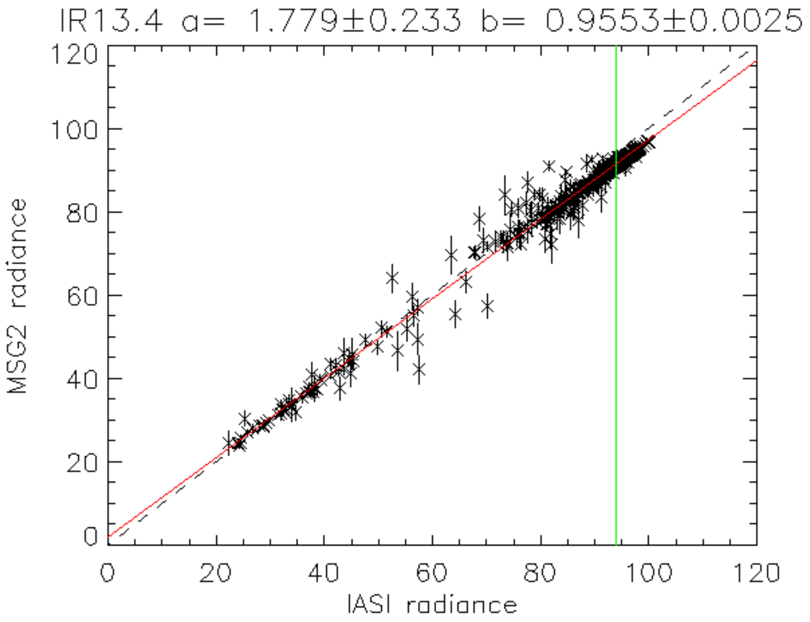
- Weighted Regression of LEO v GEO rads
  - Regression coefficients with uncertainty
  - Evaluate Bias for Standard Radiance Scene




**Weighted linear regression of $L_{GEO|REF}$ and $\langle L_{GEO} \rangle$ for Meteosat-9 13.4µm channel based on single overpass of IASI**



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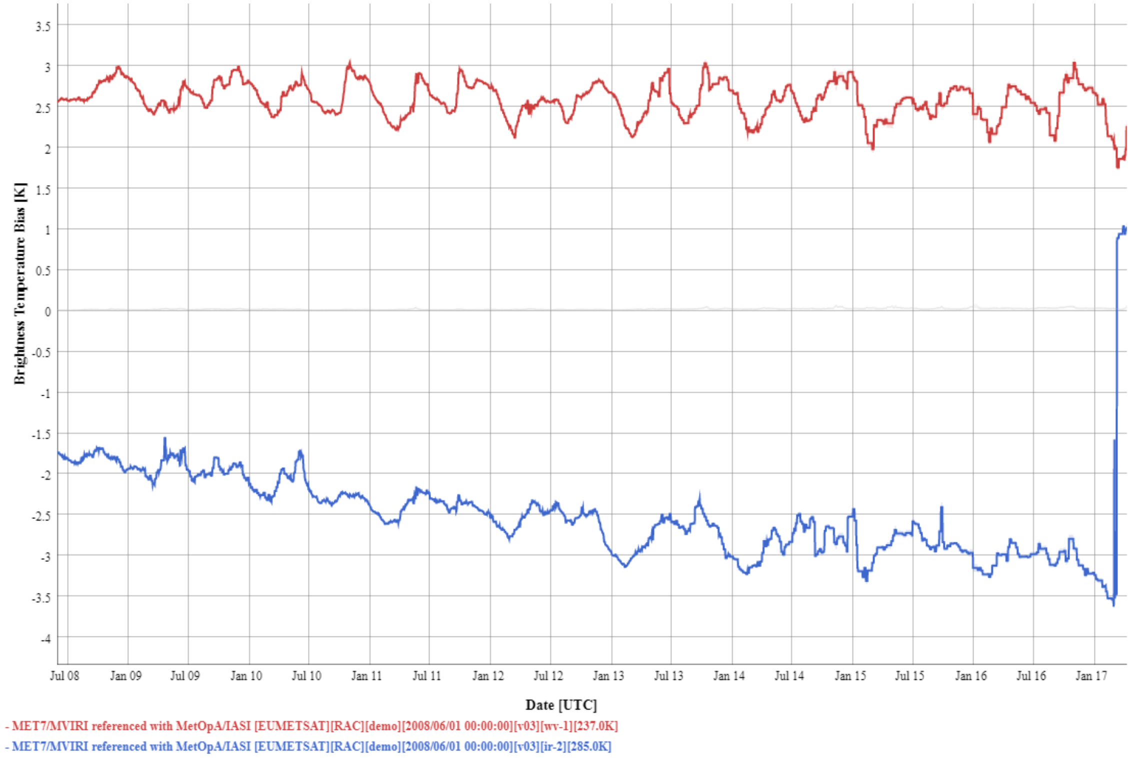
  - Regression coefficients with uncertainty
- Plot time series of Bias
  - GSICS Plotting Tool
  - Monitor calibration of SEVIRI, MVIRI, HIRS, …

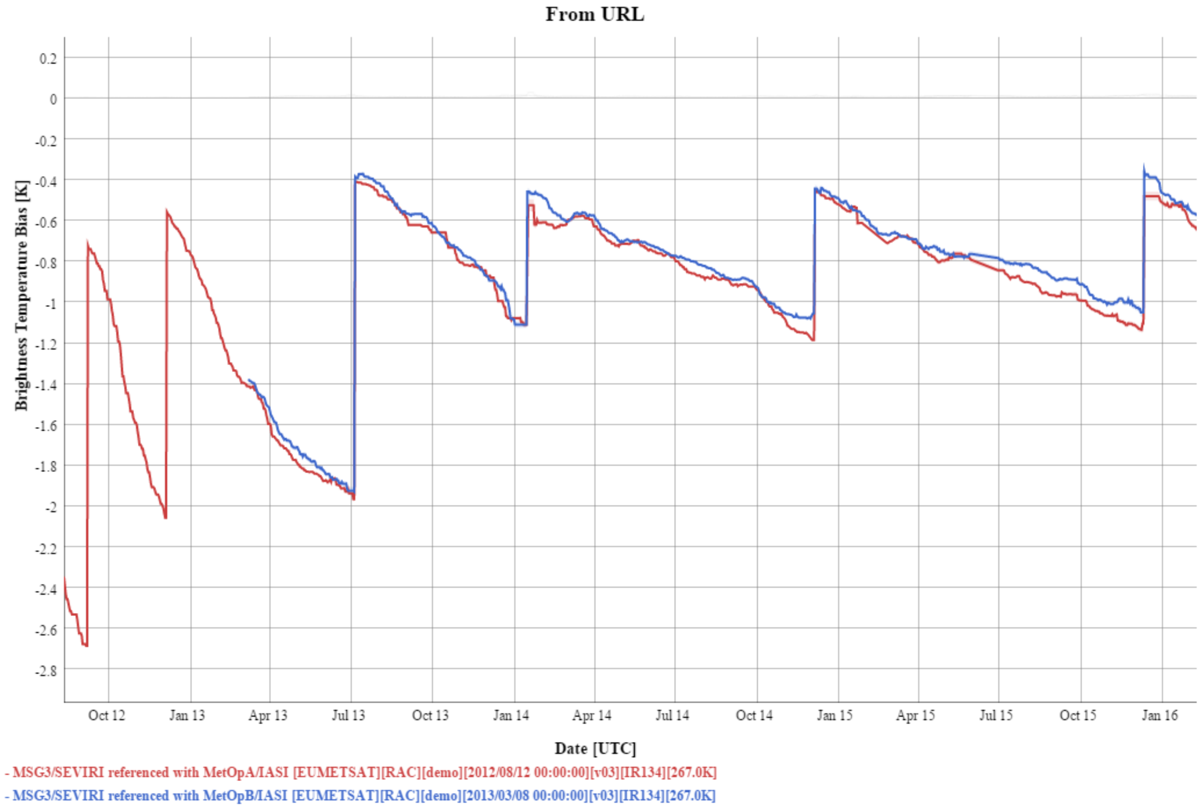



Time Series of Bias in WV and IR channels of Meteosat-7/MVIRI from inter-calibration with IASI-A

- Expressed in Brightness Temperature Bias for Standard Scene Radiance
- Long-term drift in IR channel: -1.8K in 2008 to -3.5K in 2017
- Reset by Decontamination at End of Life

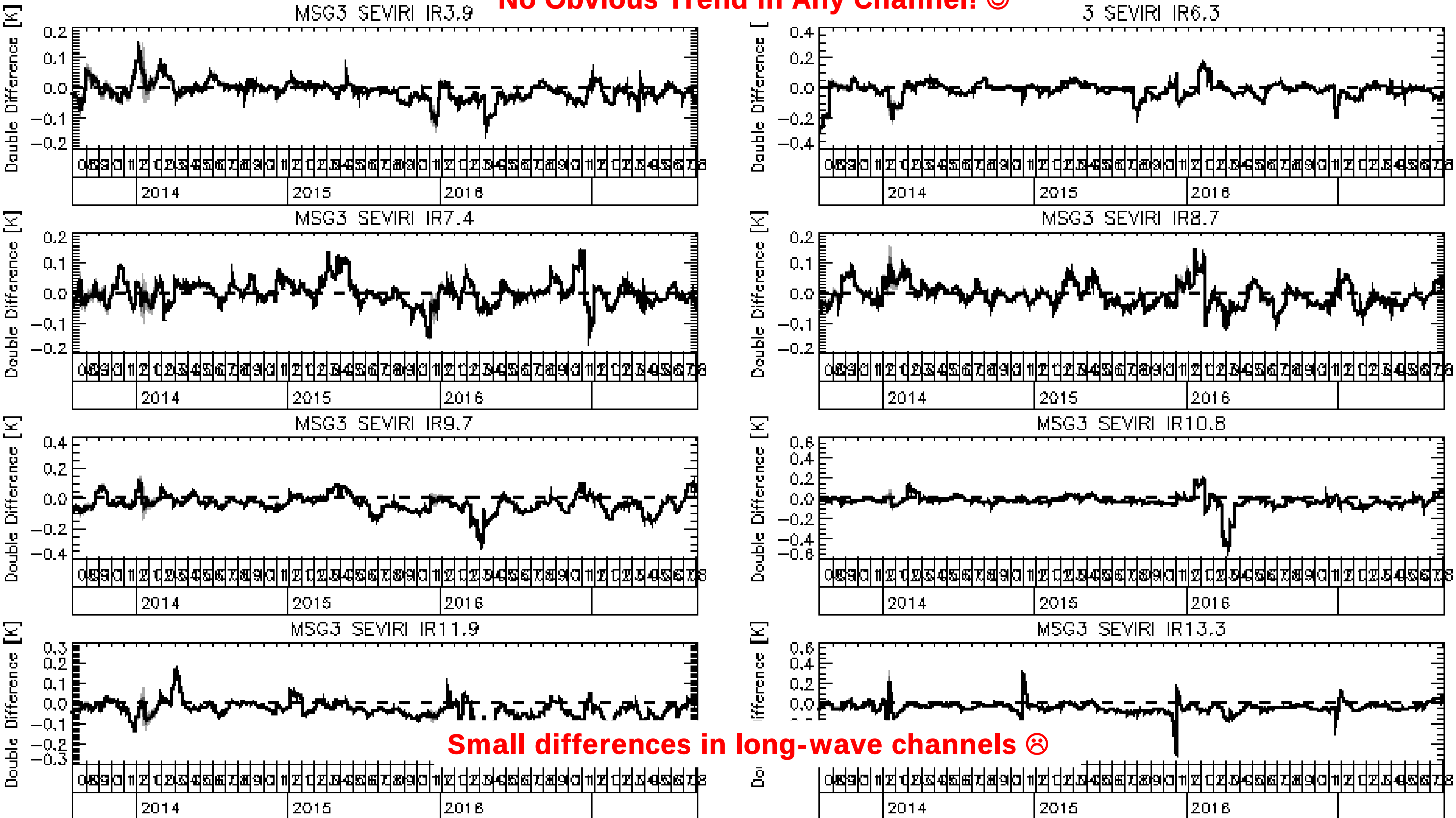
# GSICS GEO-LEO IR Double Differences

- 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 (SEVIRI-IASIA)-(SEVIRI-IASIB)

**No Obvious Trend in Any Channel! ☺**




**Small differences in long-wave channels ☹**

# Statistics of Double Difference Time Series

**(MSG3-IASIA)-(MSG3-IASIB) OPE RAC Std Bias over 2013-03-18/2017-08-02:**

| Channel | Double Difference Trend [K/yr] | Mean Double Difference [K] |
|---|---|---|
| IR3.9 | -0.003 ± 0.004 | -0.010 ± 0.005 |
| IR6.3 | -0.007 ± 0.004 | -0.002 ± 0.004 |
| IR7.4 | -0.007 ± 0.003 | 0.001 ± 0.003 |
| IR8.7 | -0.005 ± 0.002 | -0.013 ± 0.003 |
| IR9.7 | 0.003 ± 0.008 | -0.048 ± 0.007 |
| IR10.8 | -0.008 ± 0.003 | -0.024 ± 0.003 |
| IR12.0 | -0.007 ± 0.002 | -0.029 ± 0.003 |
| IR13.4 | -0.006 ± 0.002 | -0.040 ± 0.003 |

- No statistically significant trend
  - in any channel
- Within standard uncertainty of ~3mK/yr
  - Can combine entire period
- 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



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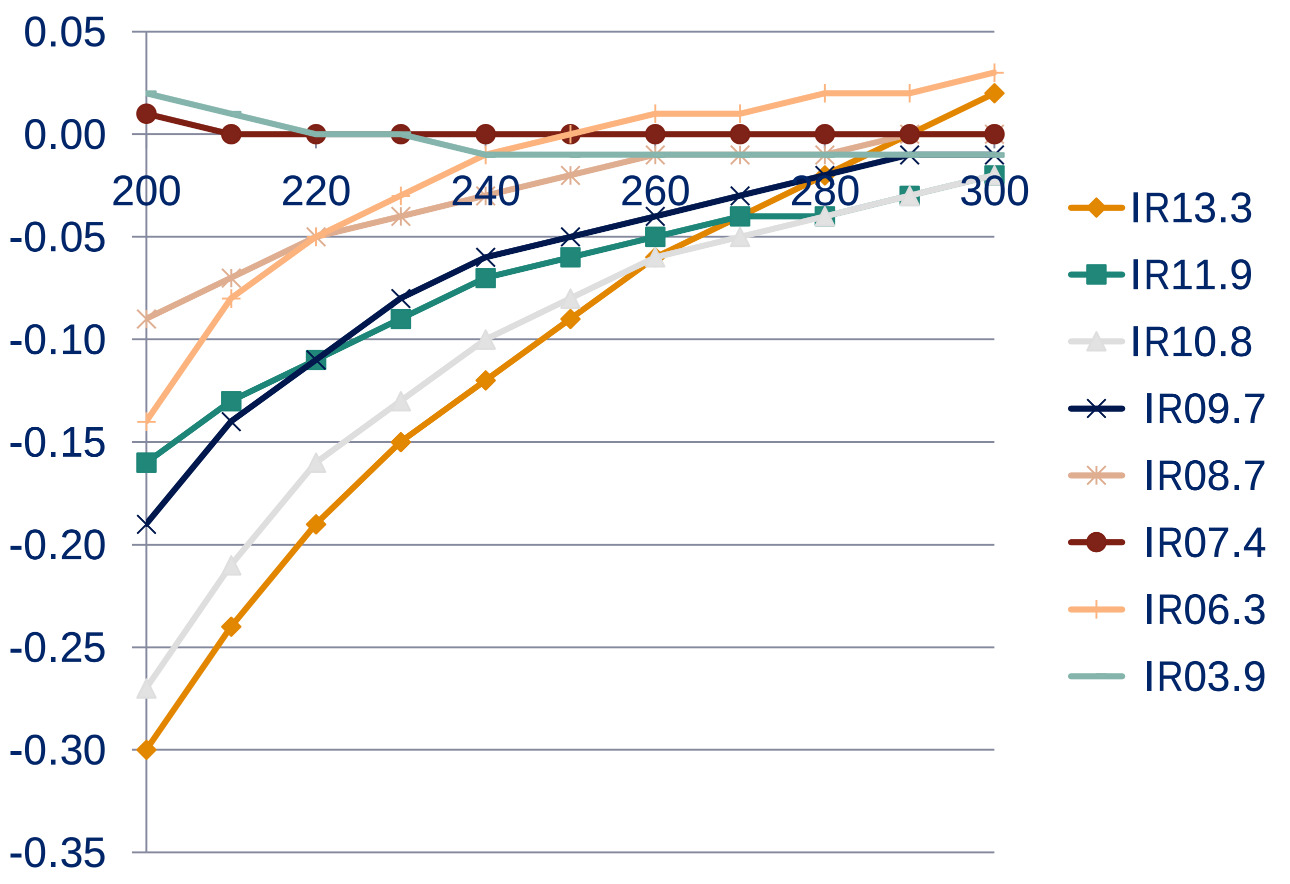
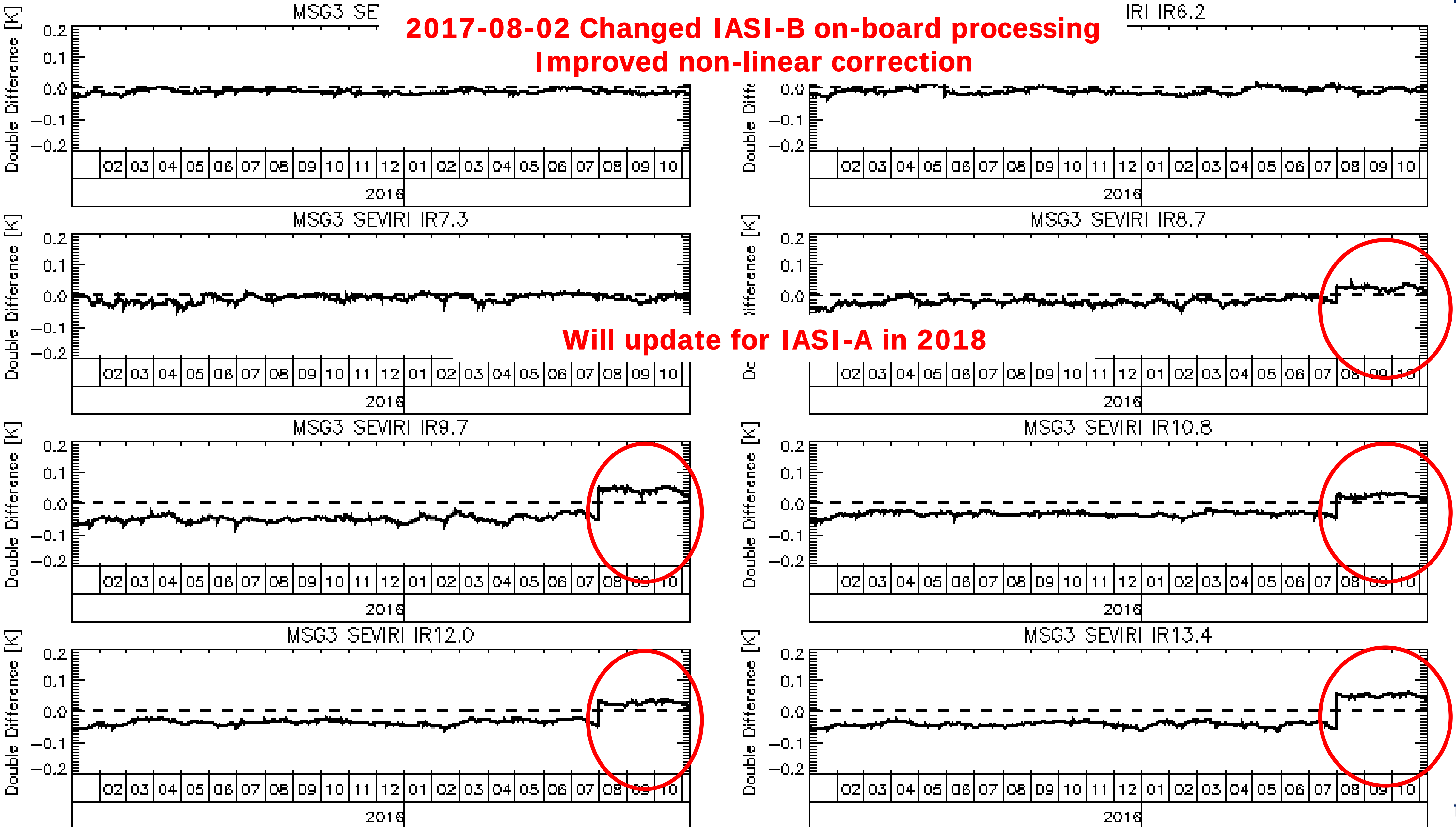
# 2013-03/2017-03 (SEVIRI-IASIA)-(SEVIRI-IASIB) - Tb

| Channel | 50% [cm-1] | 50% [cm-1] | Mean Difference dTb [K] 200 | 210 | 220 | 230 | 240 | 250 | 260 | 270 | 280 | 290 | 300 | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Meteosat-10/SEVIRI IR** | | | | | | | | | | | | | | K |
| IR12.0 | 800 | 870 | | | | | | | | | | | | K |
| IR10.8 | 885 | 971 | | | | | | | | | | | | K |
| IR9.7 | 1018 | 1047 | | | | | | | | | | | | K |
| IR8.7 | 1124 | 1177 | | | | | | | | | | | | K |
| IR7.3 | 1316 | 1409 | | | | | | | | | | | | K |
| IR6.2 | 1493 | 1724 | | | | | | | | | | | | K |
| IR3.9 | 2385 | 2751 | | | | | | | | | | | | K |




 Hewison et al. 2017 ITSC [EUM/RSP/VWG/17/961216]

# Time series of Double Differences – IASIB-IASIA - Zoom 2016/7



# IR Reference Sensor Traceability & Uncertainty Report

- Aims
  - To support choice of reference instruments for GSICS
  - To provide traceability between reference instruments (IASI, AIRS, CrIS)
  - To seek consensus on uncertainties in absolute calibration of reference sensors
  - By consolidating pre-launch test results and various in-flight comparisons

- Limitations
  - No new results, just expressing results of existing comparisons in a common way,
  - reformatting where necessary, to allow easy comparisons

1. Error Budget & Traceability
   - Focus on radiometric and spectral calibration – for AIRS, IASI, CrIS

2. Inter-comparisons
   - Introduction: Pros and Cons of each method
   - Direct Comparisons: Polar SNOs, Tandem SNOs (AIRS+CrIS), Quasi-SNOs,
   - Double-Differencing: GEO-LEO, NWP+RTM, Aircraft campaigns
   - Other Methods: Regional Averages ("Massive Means"), Reference Sites (Dome-C..)

# Suomi-NPP CrIS Radiometric Uncertainty Estimates – D. Tobin

Differential error analysis of the calibration equation, aimed at providing a useful estimate of the absolute accuracy of the mean of a large ensemble of observations. Input parameter uncertainties are based on the design of the sensor and engineering estimates of the calibration parameters; i.e. no external information via external "Cal/Val" used.
Tobin et al. (2013), Suomi-NPP CrIS radiometric calibration uncertainty, J. Geophys. Res. Atmo

## Simplified On-Orbit Radiometric Calibration Equation:

$$R_{Earth} = \mathcal{Re}\{(C'_{Earth} - C'_{Space}) / (C'_{ICT} - C'_{Space})\}\, R_{ICT}$$

with:

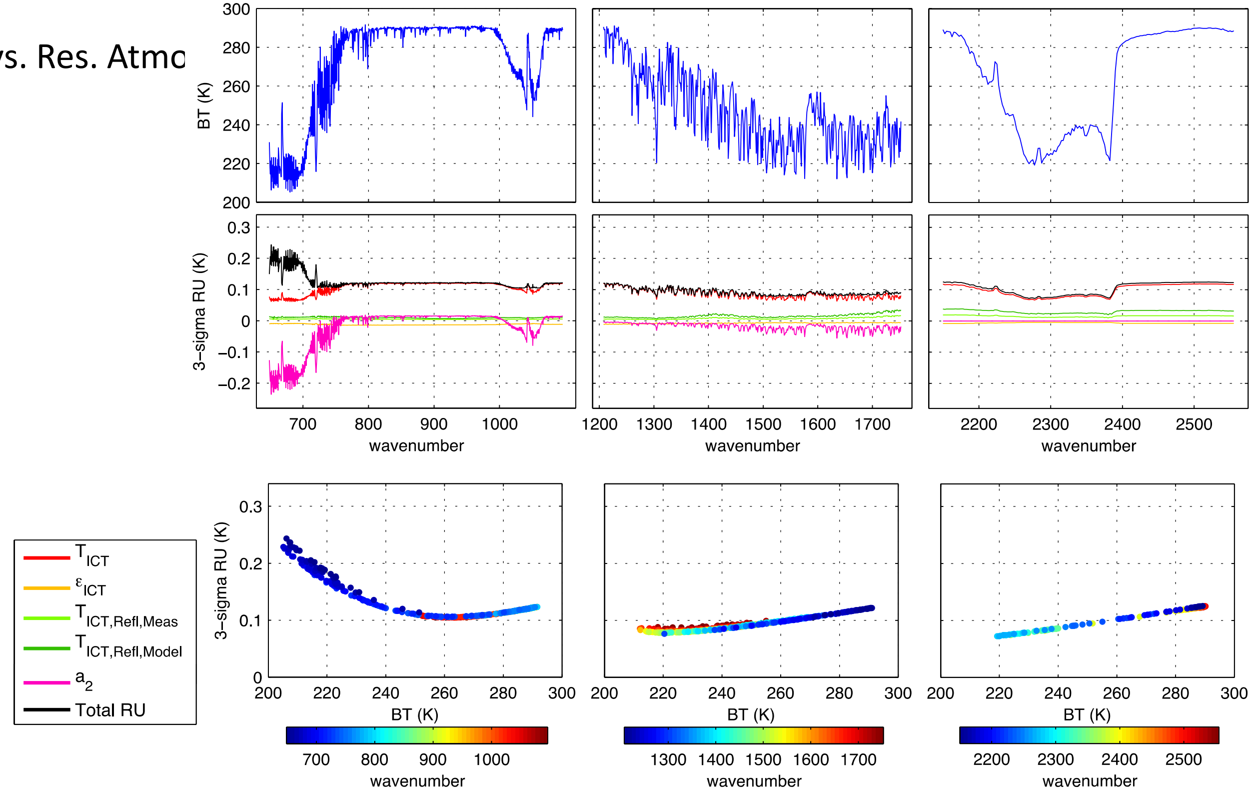
Nonlinearity Correction: $C' = C \cdot (1 + 2\, a_2\, V_{DC})$

ICT Predicted Radiance:

$$R_{ICT} = \varepsilon_{ICT}\, B(T_{ICT}) + (1-\varepsilon_{ICT})\, [\, 0.5\, B(T_{ICT,\, Refl,\, Measured}) + 0.5\, B(T_{ICT,\, Refl,\, Modeled})]$$

| Parameter | Nominal Values | 3-σ Uncertainty |
|---|---|---|
| $T_{ICT}$ | 280K | 112.5 mK |
| $\varepsilon_{ICT}$ | 0.974-0.996 | 0.03 |
| $T_{ICT,\, Refl,\, Measured}$ | 280K | 1.5 K |
| $T_{ICT,\, Refl,\, Modeled}$ | 280K | 3 K |
| $a_2$ LW band | 0.01 – 0.03 $V^{-1}$ | 0.00403 $V^{-1}$ |
| $a_2$ MW band | 0.001 – 0.12 $V^{-1}$ | 0.00128 – 0.00168 $V^{-1}$ |

**Example 3-sigma RU estimates for a typical warm, ~clear sky spectrum:**




- RU is generally 0.2K 3-sigma or less, and similar results for JPSS-1 CrIS
- Currently working to include (relatively small) polarization effects into the calibration algorithm and corresponding RU estimates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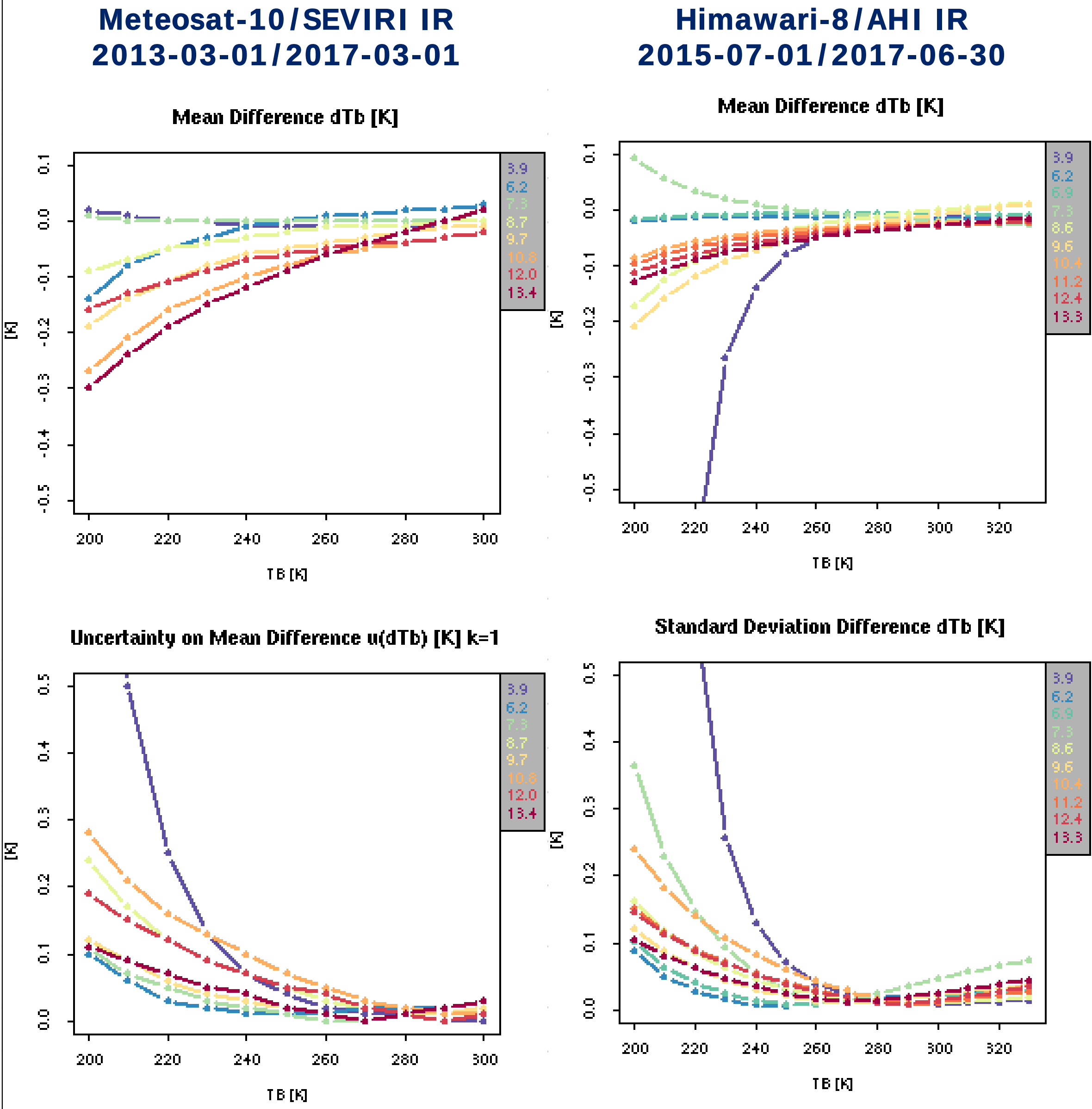
# IR Reference Sensor Inter-Comparisons

- Form consensus on relative calibration
  - Re-binning results of existing comparisons
- Biases with respect to Metop-A/IASI
  - With standard uncertainties (k=1)
- At full spectral resolution
  - In 10cm-1 bins within AIRS bands
  - Or average results over broad-band channels
- Converted into Brightness Temperatures
  - For specific radiance scenes
  - i.e. 200K, 210K, … 300K
- For all viewing angles
  - and/or for specific ranges - e.g. nadir ±10°
- Over specific period
  - Common 4-year period from IASI-B start

| | | | | | Mean Difference dTb [K] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pseudo Channel [cm-1] | Min Freq [cm-1] | Max Freq [cm-1] | 200 | 220 | 240 | 260 | 280 | 300 |
| Start date | 2013-08-01 | 655 | 650 | 660 | -0.11 | -0.10 | -0.08 | NaN | NaN | NaN |
| Processing Version | GSPP | 885 | 880 | 890 | 0.12 | 0.11 | 0.07 | 0.04 | 0.03 | 0.15 |




 Hewison et al. 2017 ITSC [EUM/RSP/VWG/17/961216]

# Conclusions

- GSICS provides operational calibration corrections
  - for IR channels of geostationary imagers
  - based on inter-calibration with reference instruments (IASI, AIRS, CrIS)
  - establishing routine comparison of results to monitor relative calibration
- IR Reference Sensor Traceability & Uncertainty Report
  - supports choice of GSICS reference instruments
  - provides traceability between reference instruments
  - consolidates pre-launch test results and various in-flight comparisons
  - forms consensus on uncertainties in absolute calibration of reference sensors
- IASI Changes
  - IASI-A/B double difference was stable over >4yr
  - Small differences in long-wave band – addressed by changes to non-linearity
  - Gradual roll-out allows characterization of impact
  - Cannot be completely corrected in re-processing

# Thank You!