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

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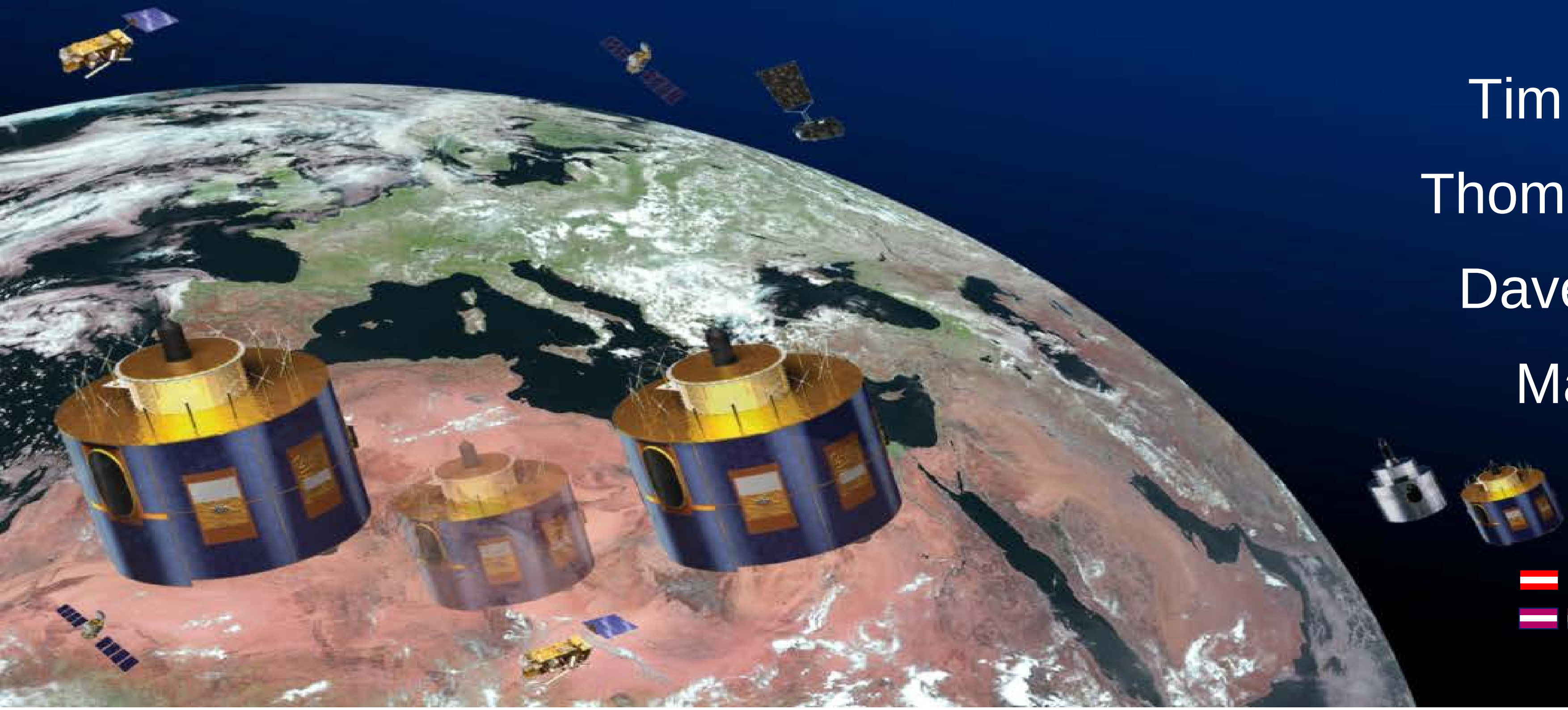


Global Space-based Inter-Calibration System

- **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

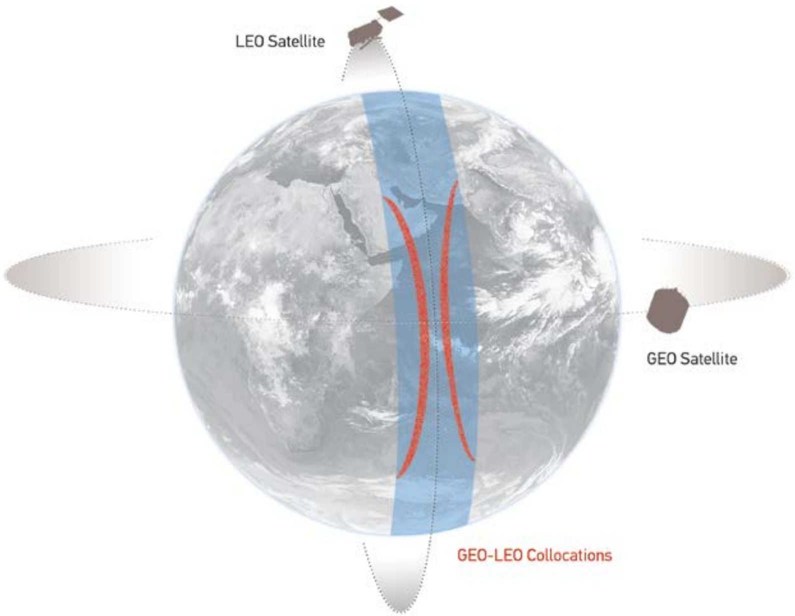
- **Systematic** generation of **inter-calibration** products
  - **for Level 1 data from** satellite sensors
  - **to** compare**,** *monitor* **and** correct **the calibration of *monitored* instruments to community references**
  - **by generating calibration corrections on a routine operational basis**
  - **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

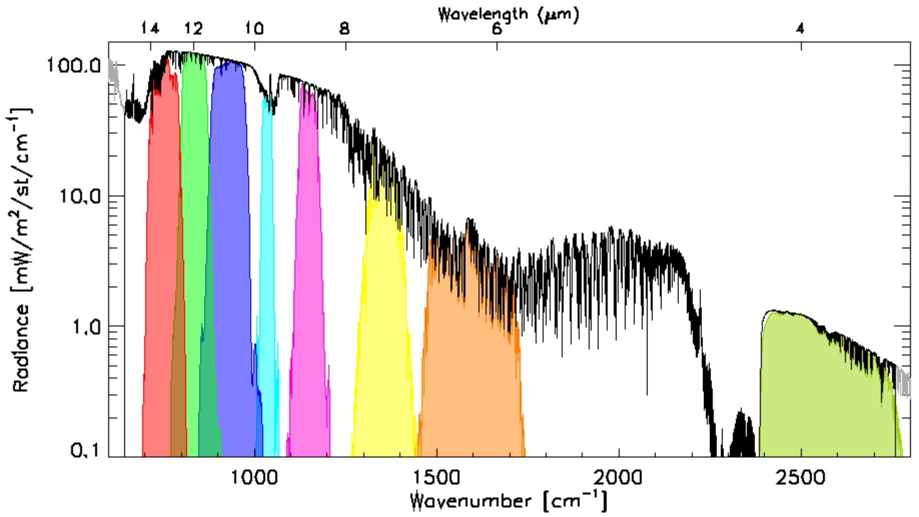
- Simultaneous near-Nadir Overpasses
  - of one GEO imager and one LEO sounder
- Select Collocations
  - Spatial, temporal and geometric thresholds



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

- 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).

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  - to synthesise radiance in GEO channels
- Spatial Averaging
  - Average GEO pixels in each LEO FoV
  - Standard Deviation of GEO pixels as weight

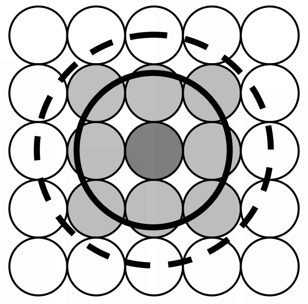

Illustration of spatial transformation.
Small circles represent the GEO FoVs and the two large circles represent the LEO FoV for the extreme cases of FY2-IASI, where nxm=3x3 and SEVIRI-IASI, where nxm=5x5.

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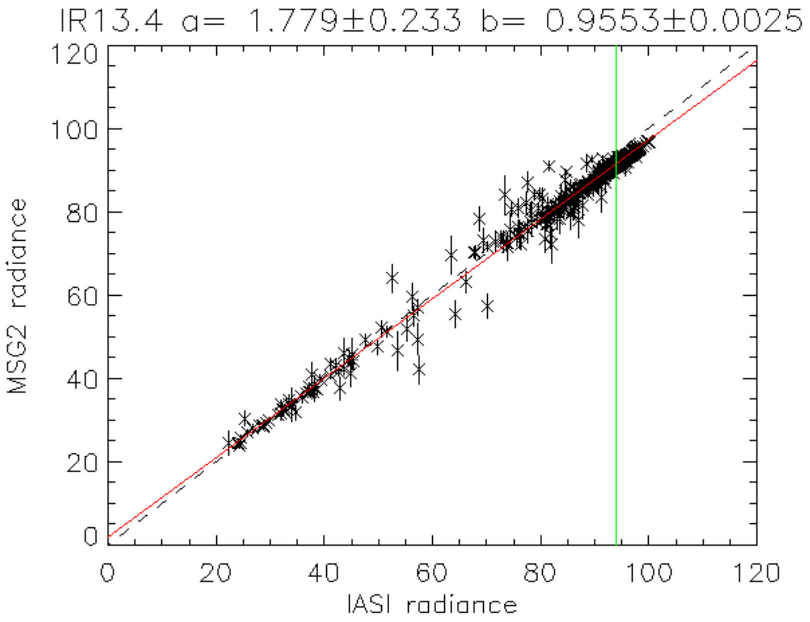
    with GEO Spectral Response Functions
  - to synthesise radiance in GEO channels
- Spatial Averaging
  - Average GEO pixels in each LEO FoV
  - Standard Deviation of GEO pixels as weight
- Weighted Regression of LEO v GEO rads
  - Regression coefficients with uncertainty
  - Evaluate Bias for Standard Radiance Scene



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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GEO-LEO IR - Hyperspectral SNO

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  - to synthesise radiance in GEO channels
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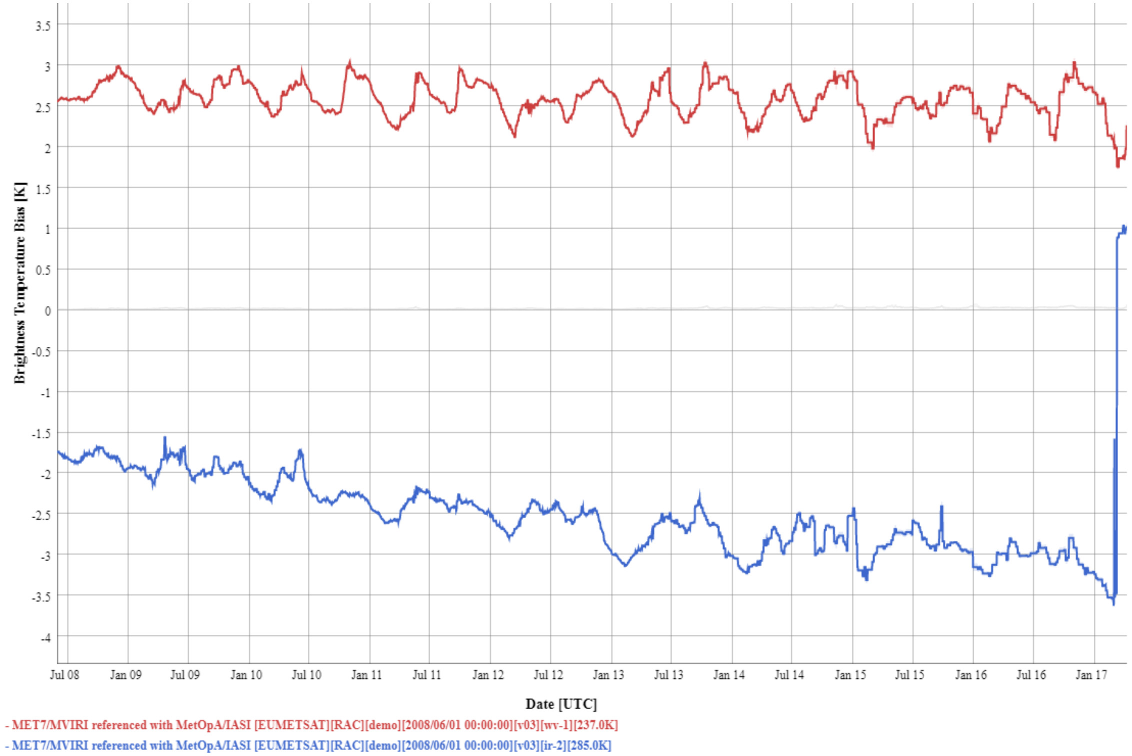
- Weighted Regression of LEO v GEO rads
  - Evaluate Bias for Standard Radiance Scene
  - Regression coefficients with uncertainty
- Plot time series of Bias
  - GSICS Plotting Tool
  - Monitor calibration of SEVIRI, MVIRI, HIRS, …



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

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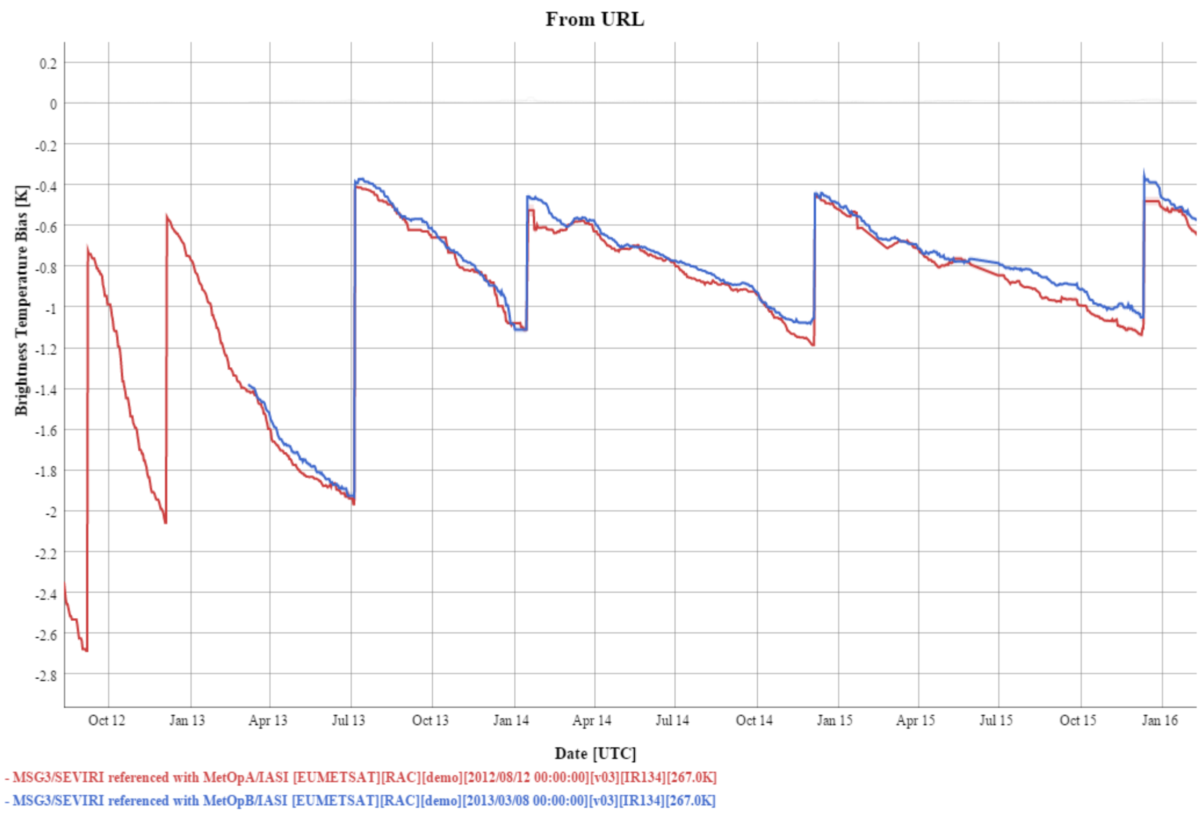
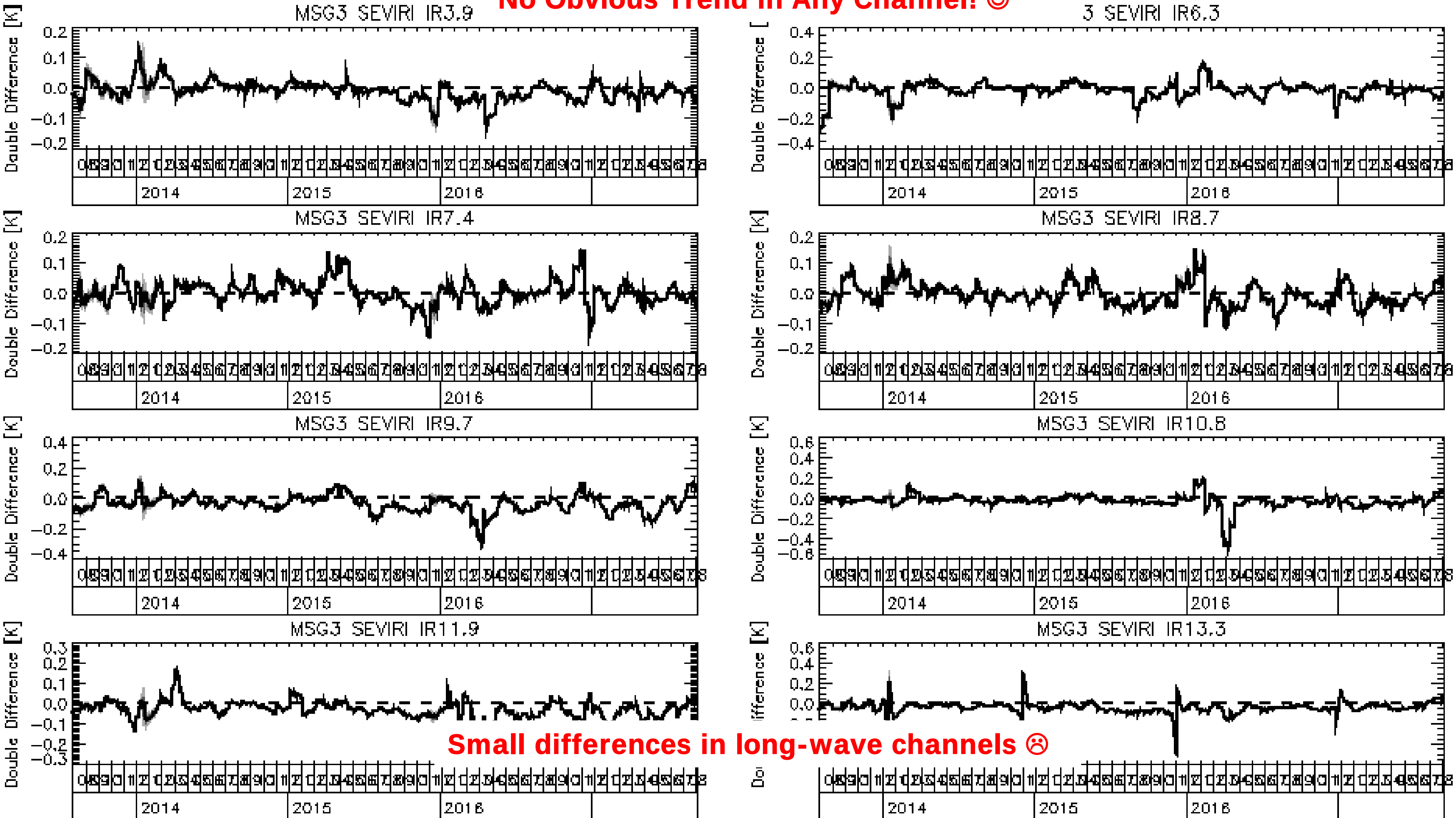
GSICS GEO-LEO IR Double Differences

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

No Obvious Trend in Any Channel! ☺



Small differences in long-wave channels ☹

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Statistics of Double Difference Time Series

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

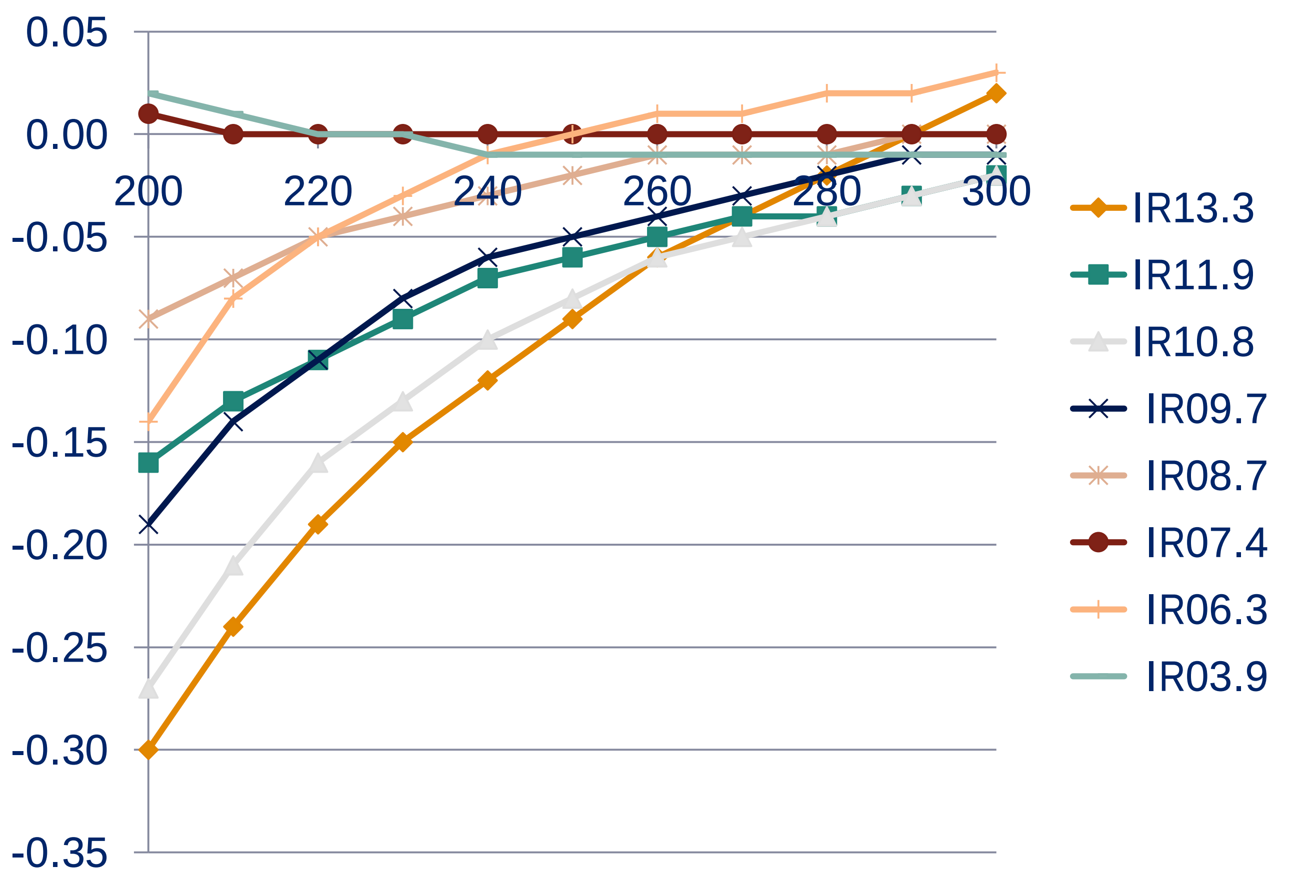
Channel	Double Difference Trend [K/yr]	Mean Double Difference [K]
IR3.9	-0.003 ± 0.004	-0.010 ± 0.005
IR6.3	-0.007 ± 0.004	-0.002 ± 0.004
IR7.4	-0.007 ± 0.003	0.001 ± 0.003
IR8.7	-0.005 ± 0.002	-0.013 ± 0.003
IR9.7	0.003 ± 0.008	-0.048 ± 0.007
IR10.8	-0.008 ± 0.003	-0.024 ± 0.003
IR12.0	-0.007 ± 0.002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

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

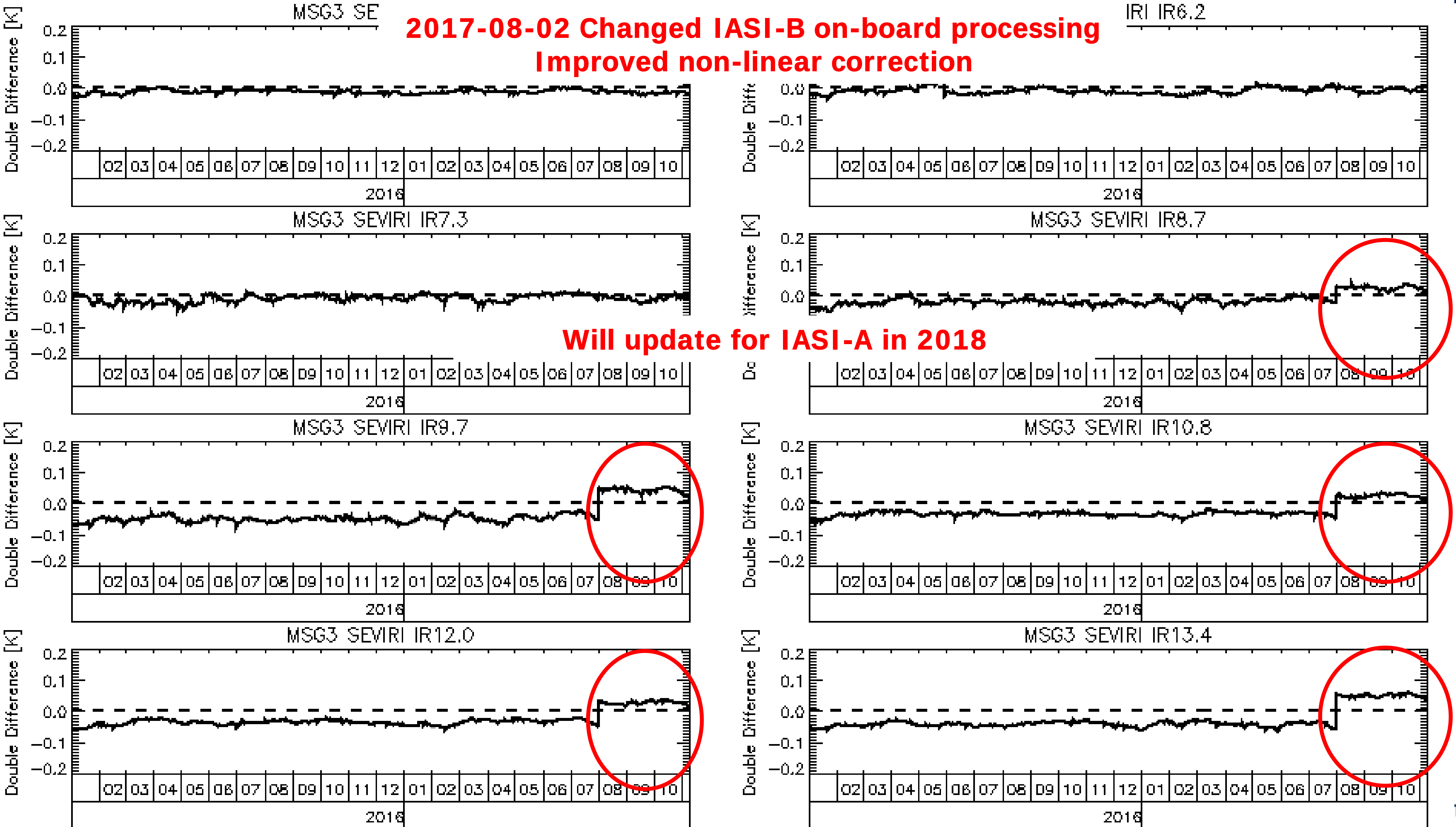
Channel	50% [cm-1]	50% [cm-1]	Mean Difference dTb [K] 200	210	220	230	240	250	260	270	280	290	300	K
Meteosat-10/SEVIRI IR														K
IR12.0	800	870												K
IR10.8	885	971												K
IR9.7	1018	1047												K
IR8.7	1124	1177												K
IR7.3	1316	1409												K
IR6.2	1493	1724					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



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

2017-08-02 Changed IASI-B on-board processing
Improved non-linear correction

Will update for IASI-A in 2018



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..)

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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:

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

with:

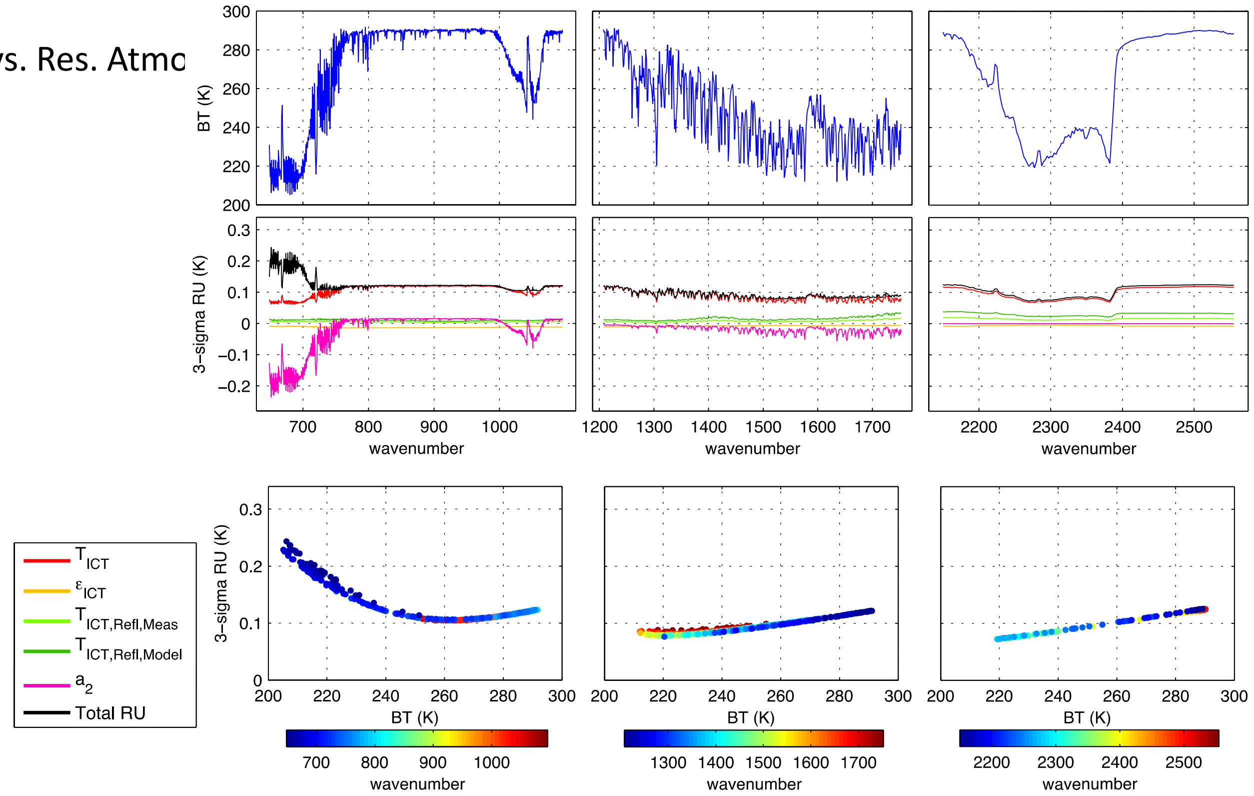
Nonlinearity Correction: $C' = C \bullet (1 + 2\, a_2\, V_{DC})$

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
ε_{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:

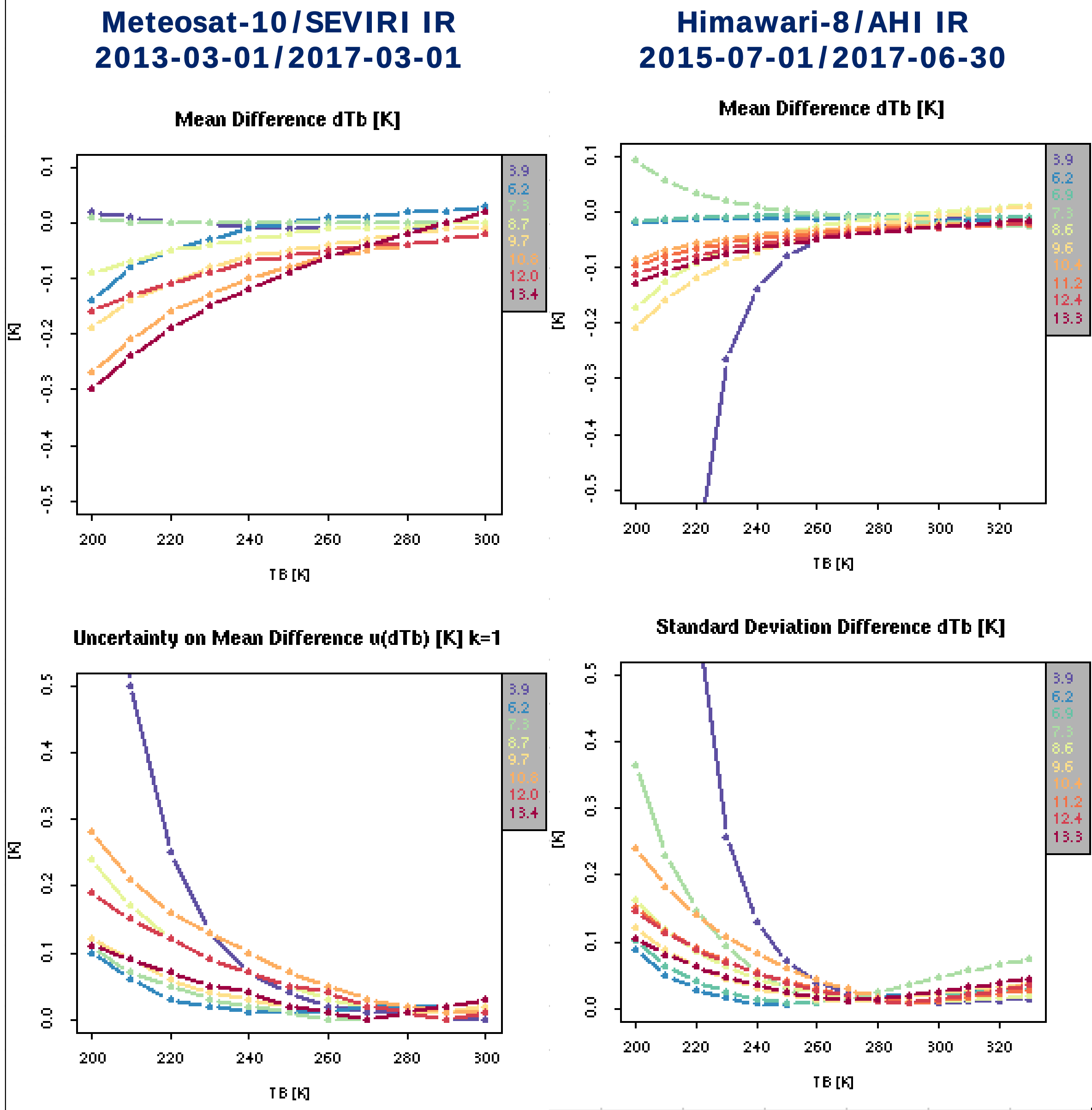


- **RU is generally 0.2K 3-sigma or less, and similar results for JPSS-1 CrIS**
- **Currently working to include (relatively small) polarization effects into the calibration algorithm and corresponding RU estimates**

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

		Pseudo Channel [cm-1]	Min Freq [cm-1]	Max Freq [cm-1]	Mean Difference dTb [K] 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	GSPR	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!