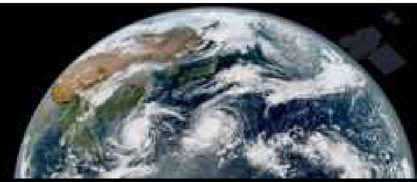

# Re-calibrated Infrared and Water Vapor channels' Measurements from JMA and EUMETSAT Historical Geostationary Meteorological Satellites

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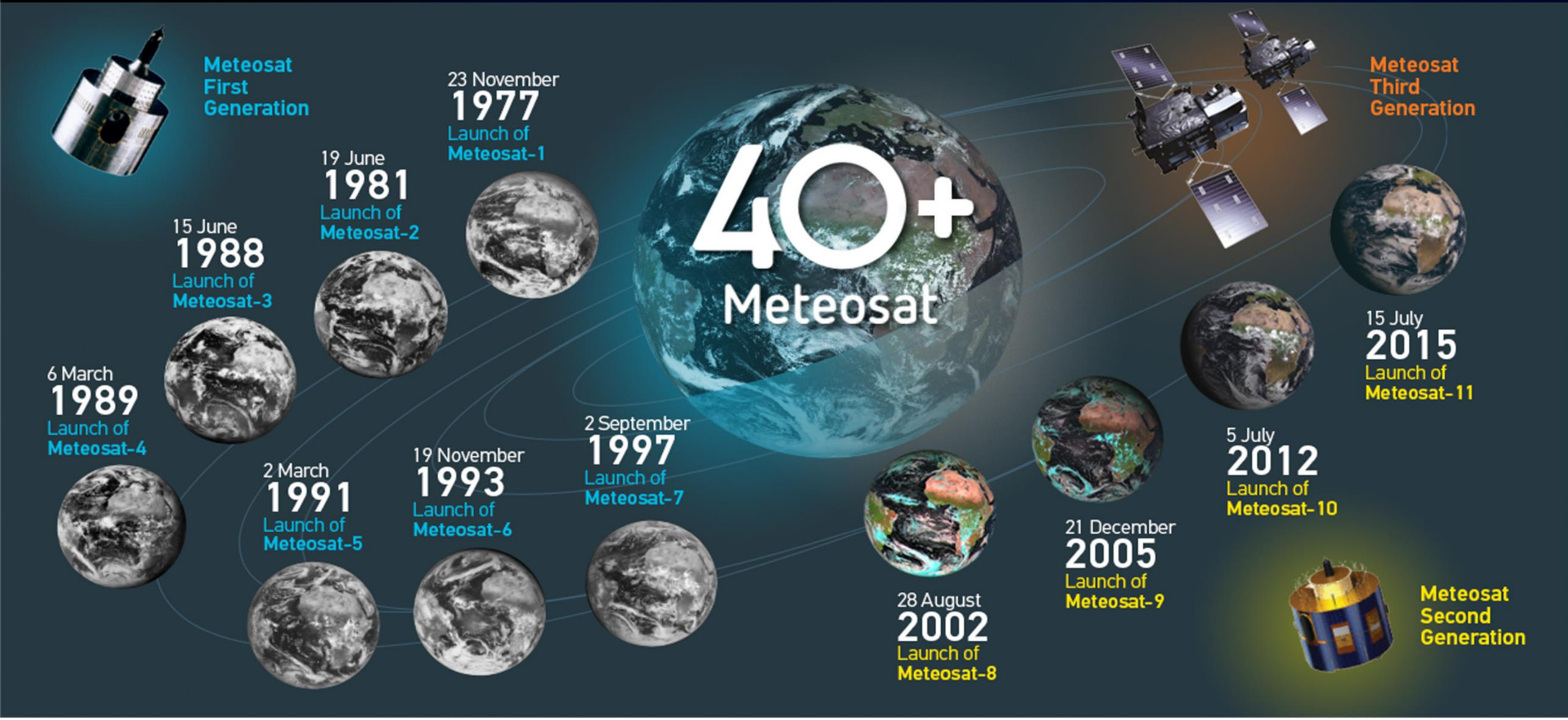
気象庁 Japan Meteorological Agency

EUMETSAT

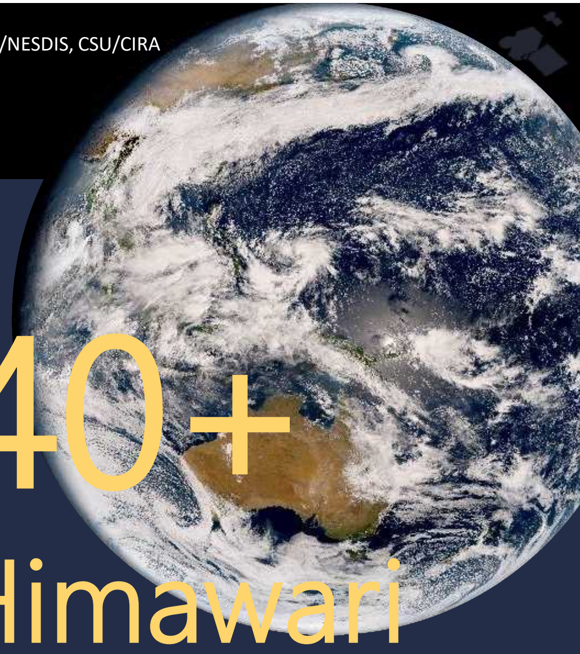
GSICS Global Space-based Inter-Calibration System

SCOPE • CM

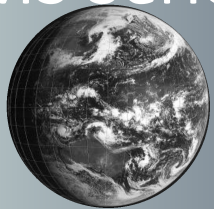
# 40+ Years of Meteosat (EUMETSAT)



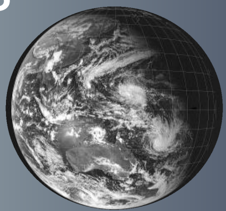
# 40+ Years of Himawari (JMA)



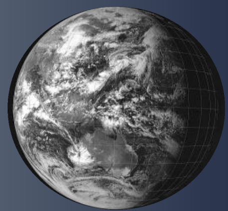

## GMS Series



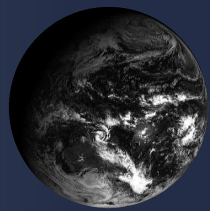
14 July
**1977**
Launch of
**GMS**



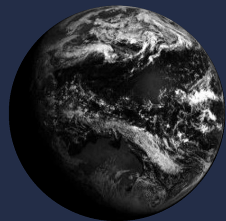
11 August
**1981**
Launch of
**GMS-2**



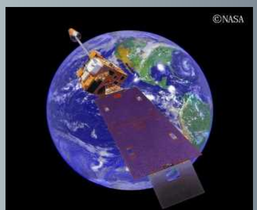
3 August
**1984**
Launch of
**GMS-3**



6 September
**1989**
**Launch of**
**GMS-4**

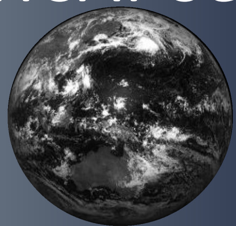


18 March
**1995**
Launch of
**GMS-5**




**March 2003 – June 2005**
Backup operation by
**GOES-9**

## MTSAT Series



26 February
**2005**
Launch of
**MTSAT-1R**

18 February
**2006**
Launch of
**MTSAT-2**

## Himawari-8,9

7 October
**2014**
Launch of
**Himawari-8**

2 November
**2016**
Launch of
**Himawari-9**


Himawari is "sunflower" in Japanese

気象庁
Japan Meteorological Agency

# Motivation

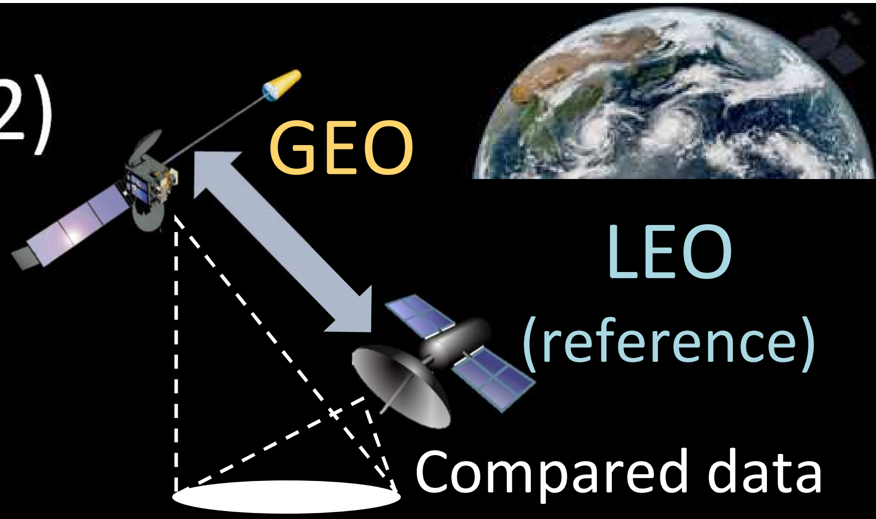
Background

- Geostationary meteorological satellites have observed the earth for 40+ years.
  - Initial purpose was weather monitoring.: Qualitative use
  - Wide coverage / frequent observation: useful for climate study
- Climate analysis requires high quality data.: Quantitative use
  - High accuracy (~0.1K) / time stability (No artificial trend) / homogeneity

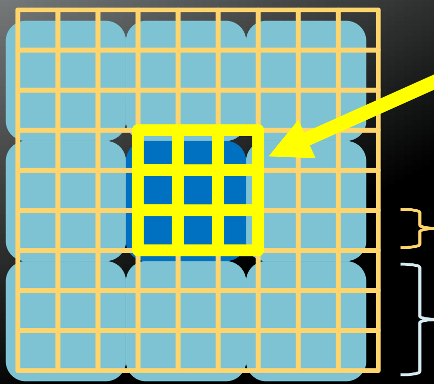
Goal of this study

- Re-calibration of Infrared and Water Vapor channels of imagers on EUMETSAT and JMA historical geostationary satellites
  - Common methods are applied to all historical satellites.
  - Re-calibration of Visible (VIS) channel is the next challenge.
    - Have already done for MFG/MVIRI.

# Five Steps for Re-calibration (1/2)




(1) Collocated GEO and LEO measurements, considering FOV size




Averaged GEO measurements were compared with collocated LEO measurements.

(2) Applied "Spectral Band Adjustment Factor (SBAF)" to LEO measurements

$$LEO^{OBS} \xrightarrow{\text{converted}} LEO^{GEO}$$

Observed LEO measurements

Pseudo-GEO measurements from observed LEO measurements

| Instrument | Satellite | Period |
|---|---|---|
| MVIRI / SEVIRI | Meteosat series | 1977– |
| VISSR / JAMI / IMAGER | Himawari series | 1978– |
| HIRS2 | TIROS-N<br>NOAA-6–NOAA-14 | 1978–<br>2006 |
| AIRS | Aqua | 2002– |
| IASI | Metop-A/-B/-C | 2007– |

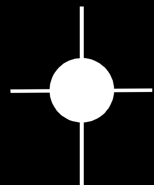
# Five Steps for Re-calibration (2/2)

## (3) Filtered collocations

- Small time difference
- Small zenith angle difference
- Latitude $\leq 35^{\circ}$

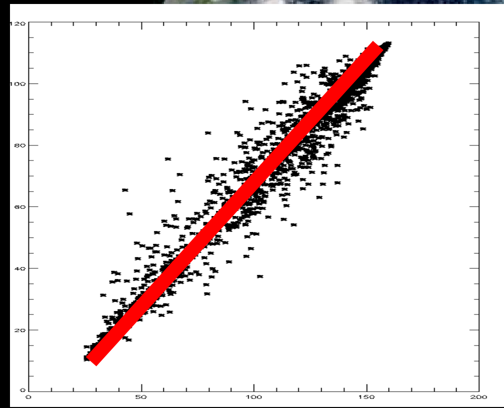
## (4) Computed re-calibration coefficients

Each plot has uncertainty in x and y axis.



$LEO^{GEO}$

Pseudo-GEO measurements from observed LEO measurements



$GEO^{OBS}$

Observed GEO measurements

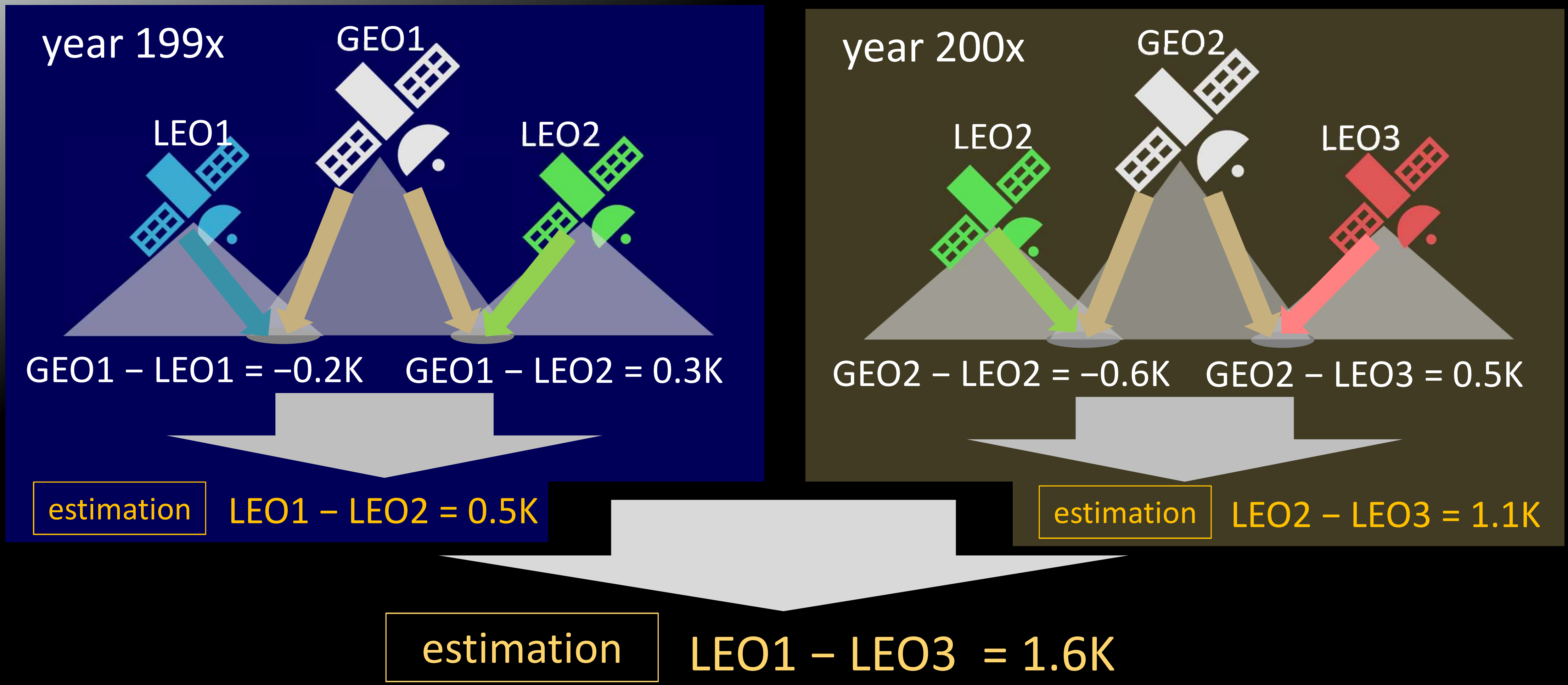
To derive a certain day's coefficients, utilized collocated data from the day and from within 2 days ($D_0 \pm 2$days )

## (5) Adjusted inter-bias of reference measurements

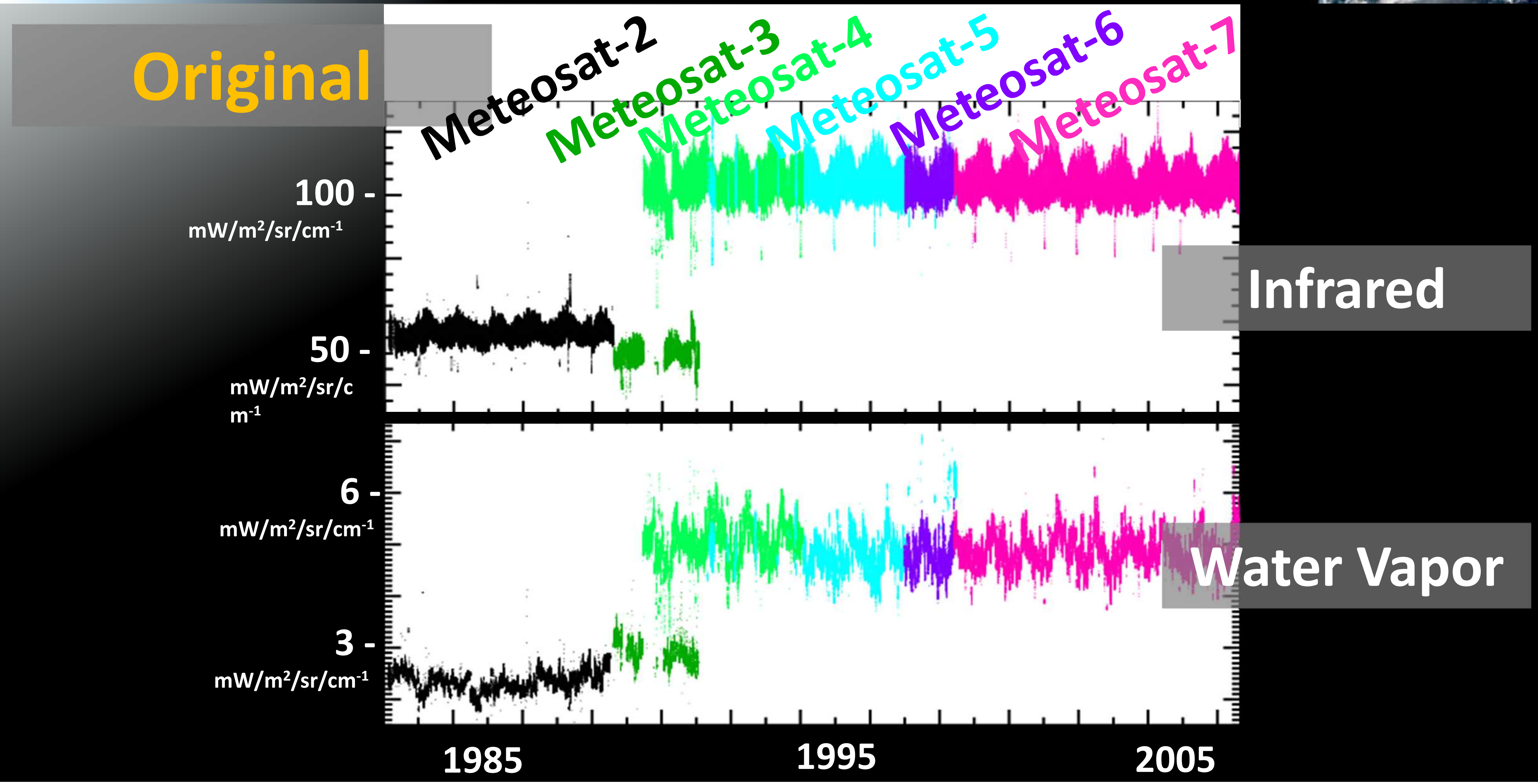
- Considered Metop-A/IASI as prime reference
- Estimated and filled difference between measurements of prime reference and those of other reference (LEO)

# Adjustment using a prime reference (Concept)

Estimate the bias between references by the Double Difference method

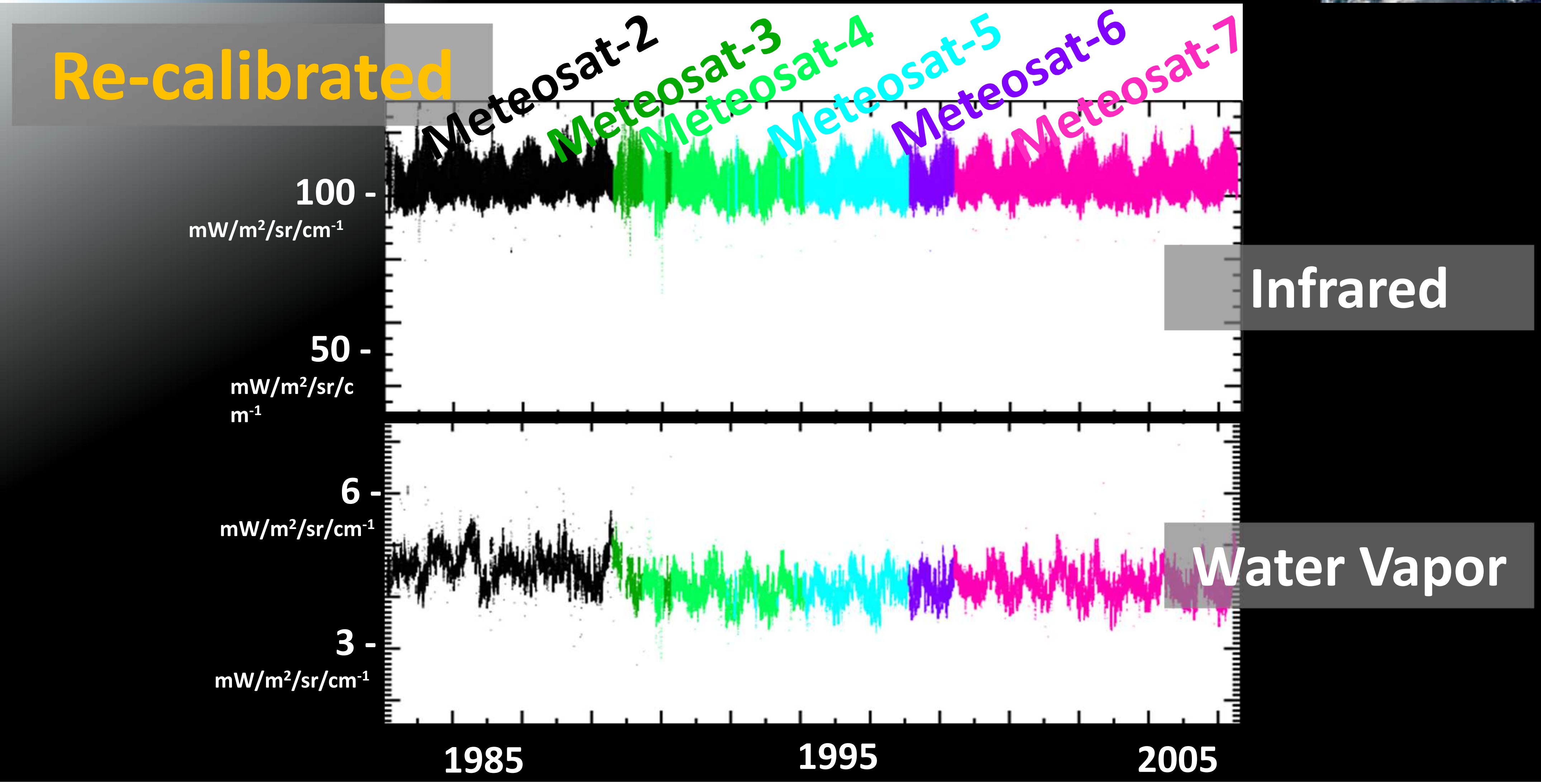


# Results (MFG)



Original
Meteosat-2
Meteosat-3
Meteosat-4
Meteosat-5
Meteosat-6
Meteosat-7
100 -
mW/m²/sr/cm⁻¹
50 -
mW/m²/sr/cm⁻¹
Infrared
6 -
mW/m²/sr/cm⁻¹
3 -
mW/m²/sr/cm⁻¹
Water Vapor
1985
1995
2005

# Results (MFG)



Re-calibrated
Meteosat-2
Meteosat-3
Meteosat-4
Meteosat-5
Meteosat-6
Meteosat-7
100 -
mW/m²/sr/cm-1
50 -
mW/m²/sr/cm-1
Infrared
6 -
mW/m²/sr/cm-1
Water Vapor
3 -
mW/m²/sr/cm-1
1985
1995
2005

# Results (MFG(METEOSAT-7/MVIRI) – MSG(METEOSAT-8/SEVIRI))

- METEOSAT-7 positioned at 0° longitude (1997–2006)
- METEOSAT-8 positioned at -3.4° longitude (2004–2008)

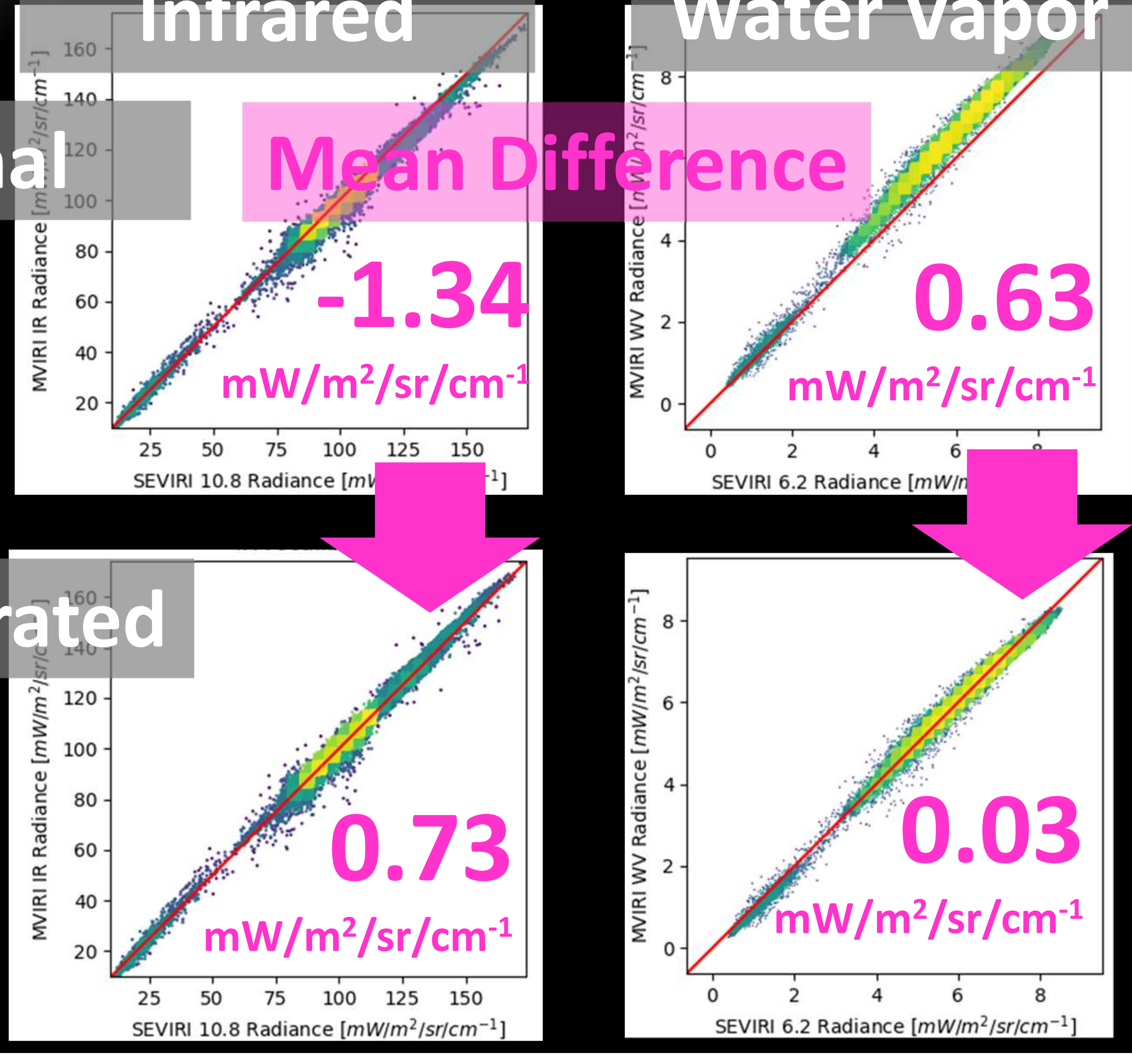
Directly comparable

**Infrared** | **Water Vapor**

**Original**

**Re-calibrated**

**Mean Difference**

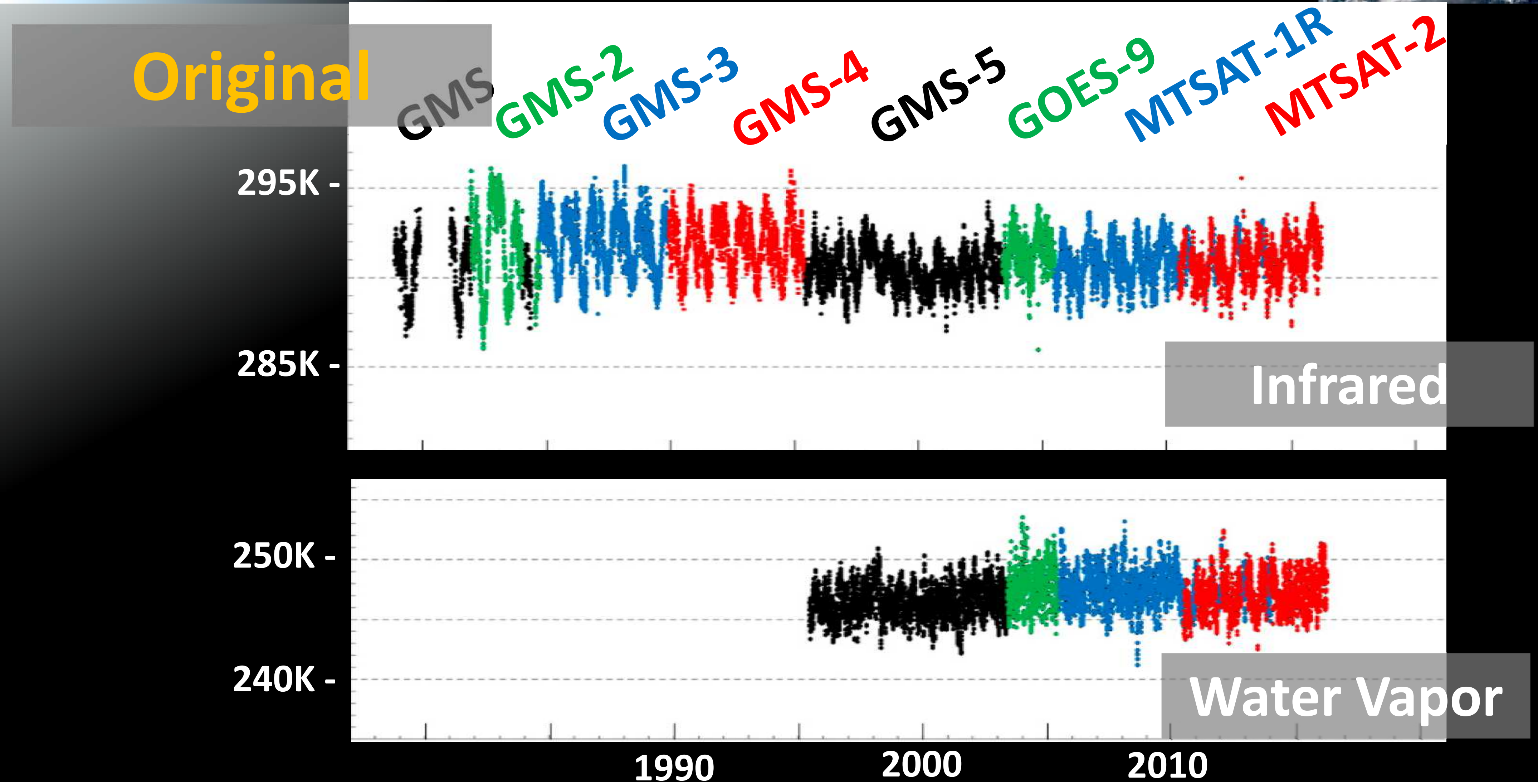



## Comparison in August 2004

Meteosat-7 MVIRI operational (top) and recalibrated (bottom) measurements against Meteosat-8 SEVIRI operational measurements

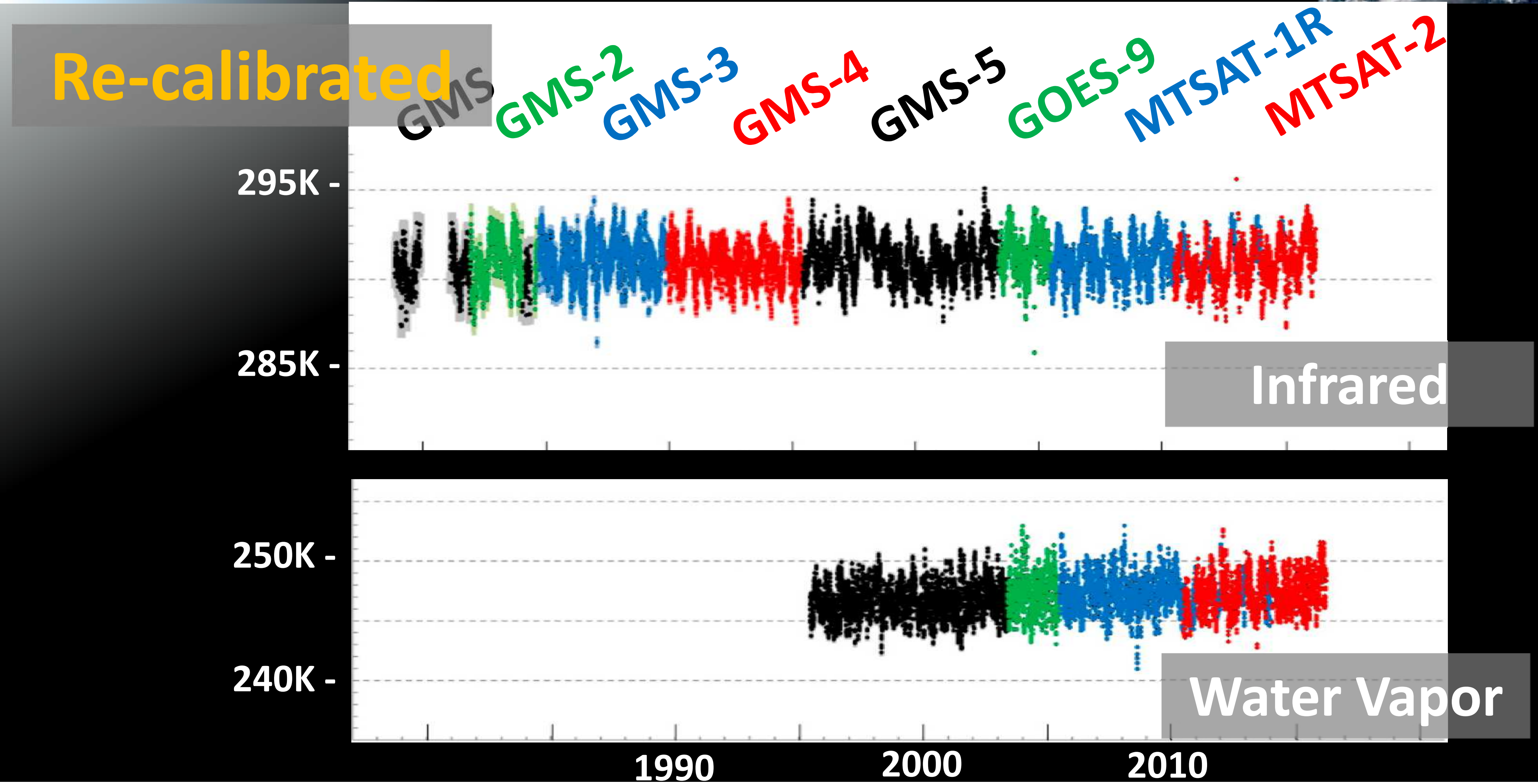
# Results (Himawari)

GMS, -2, -3 and -4 do not carry WV channel

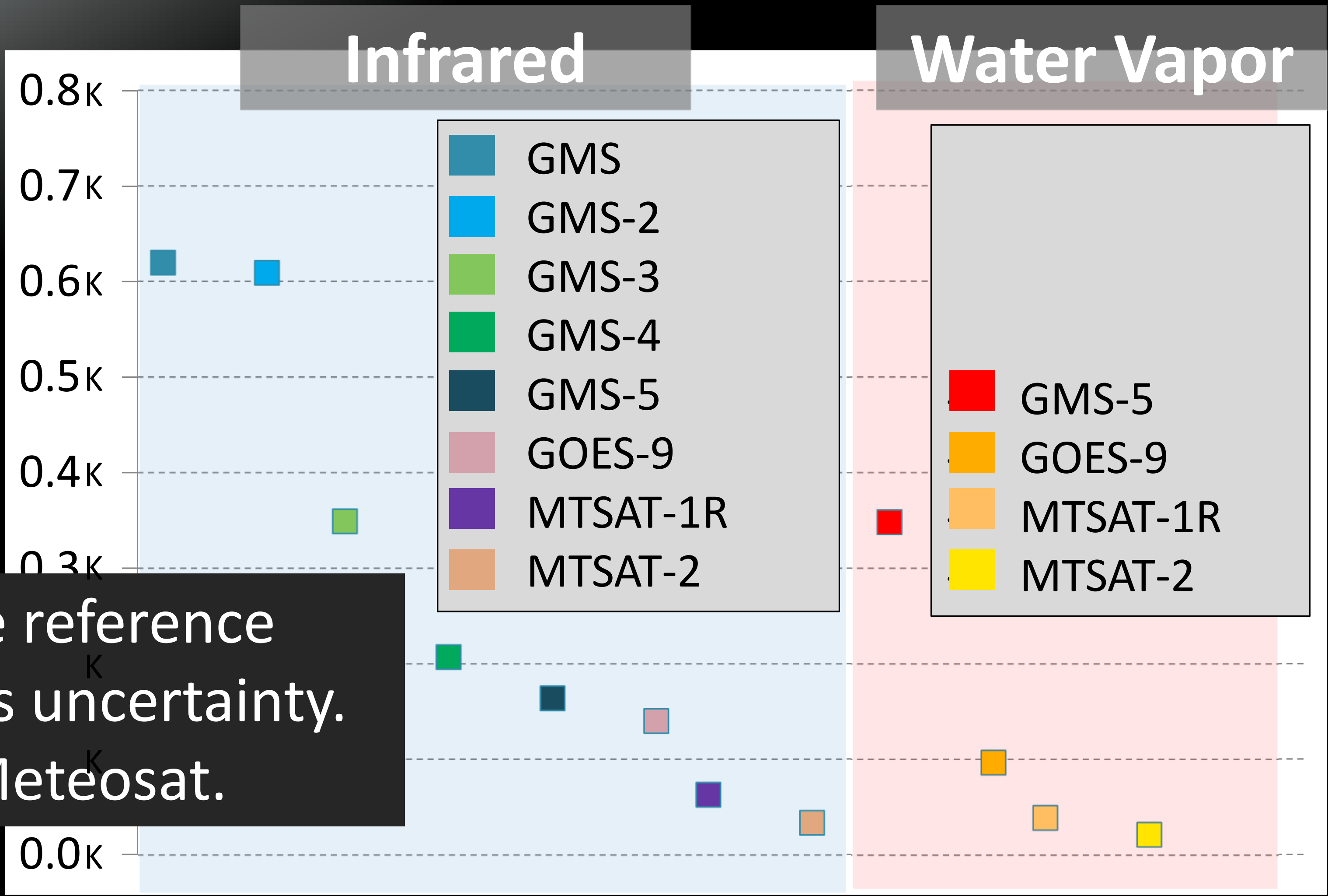


# Results (Himawari)

GMS, -2, -3 and -4 do not carry WV channel



# Average of Uncertainties



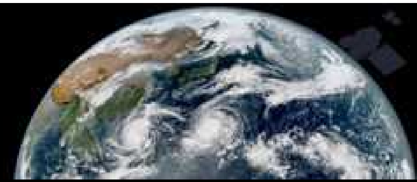

A long chain to prime reference significantly increases uncertainty. This also applies to Meteosat.

# Summary

Infrared and Water Vapor channels of historical GEO imagers were re-calibrated.

- The method was jointly developed by EUMETSAT and JMA.
  - Reference: IASI, AIRS, HIRS    Prime reference: Metop-A/IASI
- Old GEO imagers exhibit rather large biases (~3K) compared to new more accurate instruments such as on MTSAT-1R and 2 as wells as MSG
- The recalibration exercise has significantly reduced such biases and makes the data useful for climate studies
- In such studies one needs to be aware that the uncertainty of the recalibrated radiance significantly increases the further away in time the measurement is from the prime reference.
- Re-calibration coefficients are planned to be published.

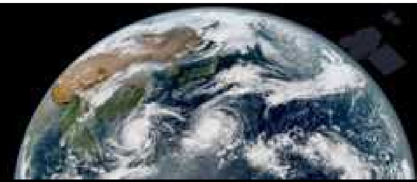
# Published Papers



John, V.O.; Tabata, T.; Rüthrich, F.; Roebeling, R.; Hewison, T.; Stöckli, R.; Schulz, J. On the Methods for Recalibrating Geostationary Longwave Channels Using Polar Orbiting Infrared Sounders. Remote Sens. 2019, 11, 1171

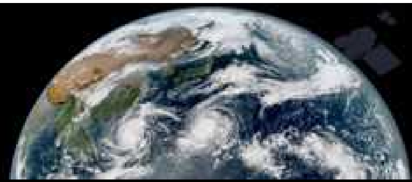
Tabata, T.; John, V.O.; Roebeling, R.A.; Hewison, T.; Schulz, J. Recalibration of over 35 Years of Infrared and Water Vapor Channel Radiances of the JMA Geostationary Satellites. Remote Sens. 2019, 11, 1189.

Rüthrich, F.; John, V.O.; Roebeling, R.A.; Quast, R.; Govaerts, Y.; Woolliams, E.R.; Schulz, J. Climate Data Records from Meteosat First Generation Part III: Recalibration and Uncertainty Tracing of the Visible Channel on Meteosat-2–7 Using Reconstructed, Spectrally Changing Response Functions. Remote Sens. 2019, 11, 1165.



# Backup slides

# Outline



- Geostationary (GEO) meteorological satellites have been observing the earth for more than 40 years. Initially, these satellites were built for weather monitoring. In recent years, climate analysis requires even higher-quality satellite measurements.

- In this study, measurements of historical low earth orbit (LEO) meteorological satellites were used as references for re-calibration of GEO satellite measurements. Inter-bias among reference satellite measurements were also considered.

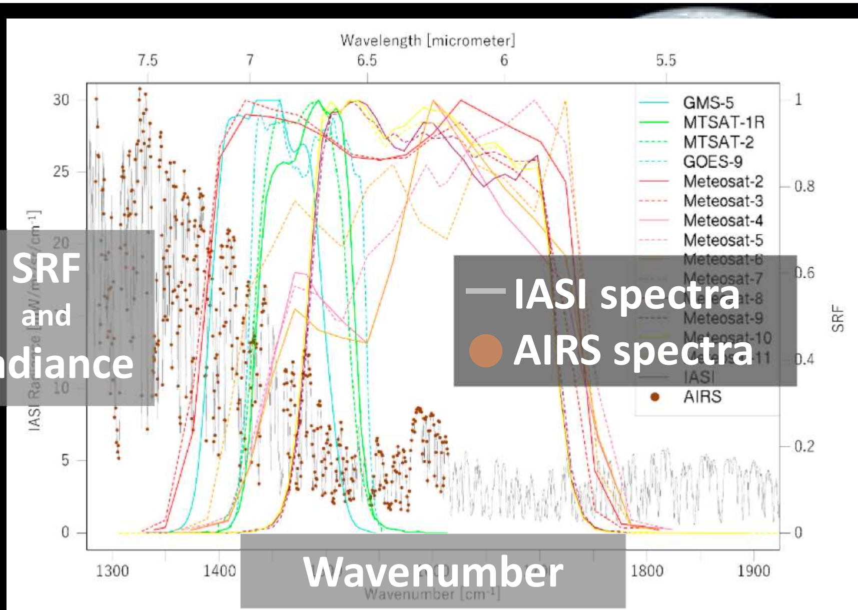
- Re-calibrated coefficients improved the qualities of historical GEO satellite measurements.

# How to Create SBAF (1/2)

(1) IASI --> GEO

Just convolved IASI with GEO SRF

IASI spectra covers whole GEO SRF.




(2) HIRS --> GEO (GEO1 --> GEO2)

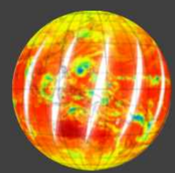
$$HIRS^{GEO} = A \times HIRS^{OBS} + B$$

Pseudo-GEO measurements from observed HIRS measurements

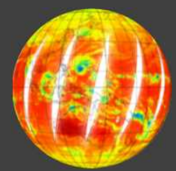
Observed HIRS measurements

**How to get A & B**

IASI data
(~10,000 footprints)
(actual measurement)

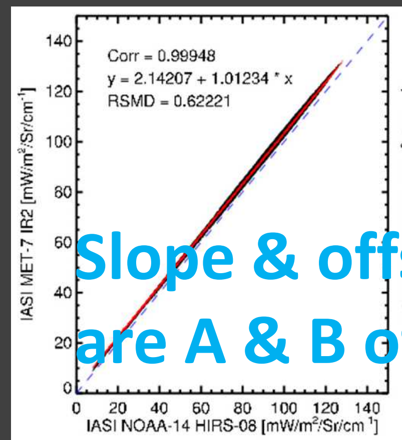


$IASI^{GEO}$



$IASI^{HIRS}$

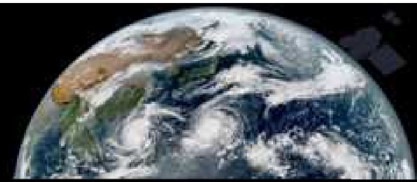
$IASI^{GEO}$



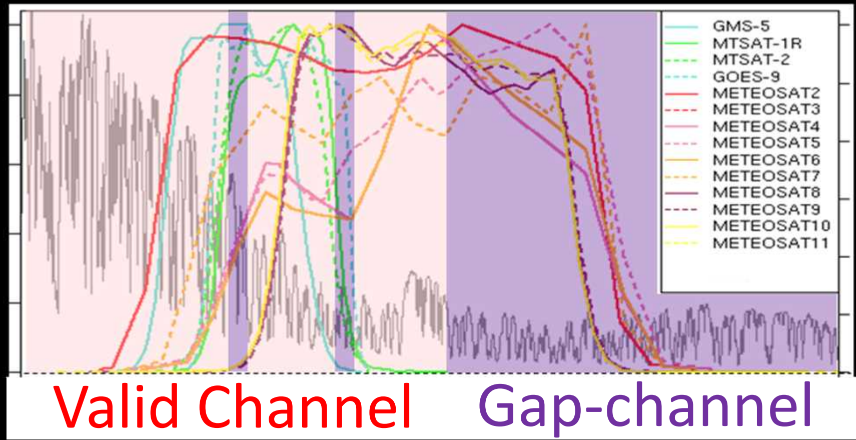

Slope & offset are A & B of SBAF

$IASI^{HIRS}$

# How to Create SBAF (2/2)



(3) AIRS --> GEO



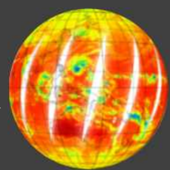

$$AIRS^{GEO} = c_0 + \sum_{k=k_{min}}^{k_{max}} c_k \, AIRS_k^{OBS}$$

$AIRS^{GEO}$: Pseudo-GEO measurements from observed AIRS measurements

$AIRS_k^{OBS}$: Observed AIRS measurements

## How to get $c_0$ & $c_k$

IASI data
(~10,000 footprints)
(actual measurement)

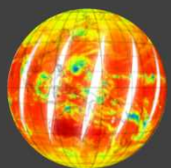


$IASI^{GEO}$

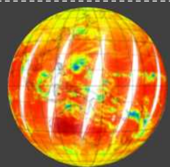
**Multi-linear regression:**

$$IASI^{GEO} = c_0 + \sum_{k=k_{min}}^{k_{max}} c_k \, IASI_k^{AIRS}$$

(where $c_k$ = 0 for $AIRS_k^{OBS}$ has bad-flag)

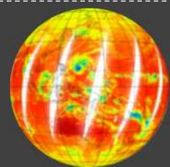


$IASI^{AIRS\_ch(kmin)}$



$IASI^{AIRS\_ch(kmin+1)}$

…



$IASI^{AIRS\_ch(kmax)}$

# Adjustment using a prime reference (Actual)

- Radiance unit (not Tbb unit) was used.
- The linear regression was introduced for the adjustment.
- SBAFs between two GEO instruments were also considered.

Comparison on SRF of GMS-4


double difference

$$R_{N14\_pseudoG4} = \underbrace{R_{N12\_pseudoG4}\, slope_{DD1} + offset_{DD1}}_{F_1(R_{N12\_pseudoG4})}$$

Apply SBAF (GMS-4 to GMS-5)

Comparison on SRF of GMS-5


double difference

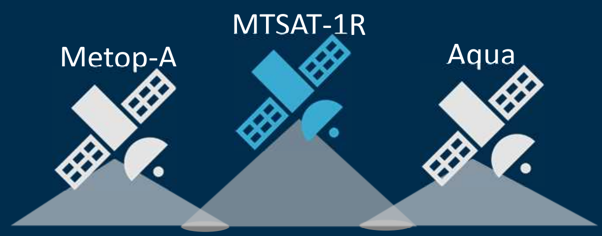
$$R_{AQUA\_pseudoG5} = \underbrace{R_{N14\_pseudoG5}\, slope_{DD2} + offset_{DD2}}_{F_2(R_{N14\_pseudoG5})}$$

$$R_{N14\_pseudoG5} = \underbrace{F_1(R_{N12\_pseudoG4})\, slope_{SBAF1} + offset_{SBAF1}}_{G_1(F_1(R_{N12\_pseudoG4}))}$$

$$R_{AQUA\_pseudoG5} = F_2(G_1(F_1(R_{N12\_pseudoG4})))$$

Apply SBAF (GMS-5 to MTSAT-1R)

Comparison on SRF of MTSAT-1R




double difference

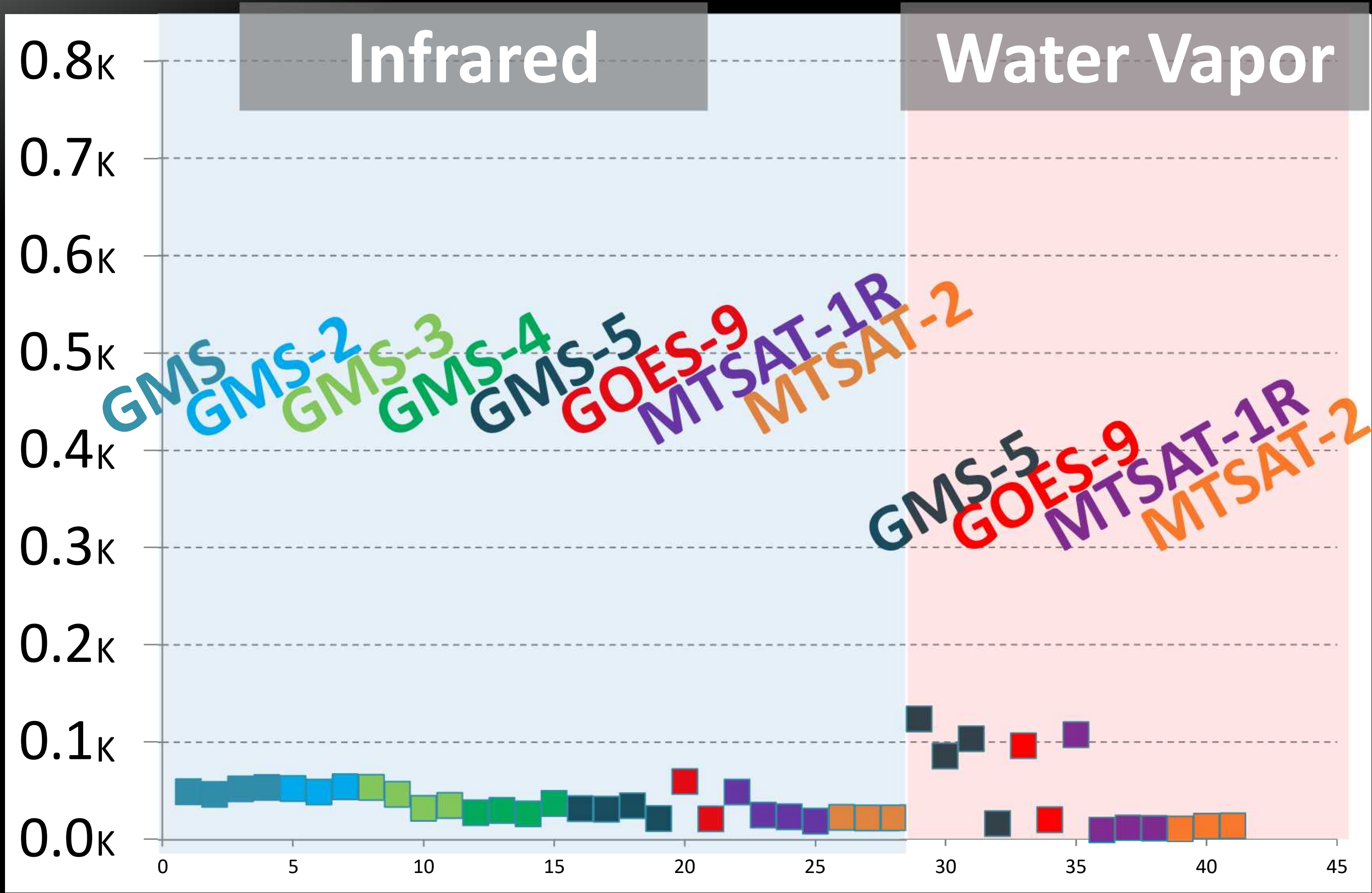
$$R_{M02\_pseudoMT1R} = \underbrace{R_{AQUA\_pseudoMT1R}\, slope_{DD3} + offset_{DD3}}_{F_3(R_{AQUA\_pseudoMT1R})}$$

$$R_{AQUA\_pseudoMT1R} = \underbrace{F_2(G_1(F_1(R_{N12\_pseudoG4})))\, slope_{SBAF2} + offset_{SBAF2}}_{G_2(F_2(G_1(F_1(R_{N12\_pseudoG4}))))}$$

$$\underbrace{R_{M02\_pseudoMT1R}}_{R_{M02\_pseudoG4}\, slope_{SBAF(G4toMT2)} + offset_{SBAF(G4toMT2)}} = F_3(G_2(F_2(G_1(F_1(R_{N12\_pseudoG4})))))$$

# Average of Uncertainties

**Before adjusting inter-bias of reference measurements**



# Path to the Prime Reference (Metop-A/IASI)