GSICS UV sub-group: GOME-2 hyper-spectral radiances for cross-calibration and calibration of imager data

Rose Munro, Rűdiger Lang, Gabriele Poli, Antoine Lacan, Christian Retscher, Michael Grzegorski, Alexander Kokhanovsky, Rasmus Lindstrot, Richard Dyer and Ed Trollope

GSICS Global Space-based Inter-Calibration System

EUMETSAT

GSICS UV sub-group

Preliminary ideas on working topics

2013-11-13 : First meeting - Formation of GSICS UV sub-group
2014-12-16: Selection of UV-chair (Rose Munro, EUMETSAT)

Preliminary ideas for working-targets:

- Reflectivity and Aerosol Index comparisons (340 nm - 390 nm) by using vicarious methods for ocean, desert and ice sheet targets.
- Solar measurement comparisons by using high resolution reference data sets along with instrument band-passes and Mg II scale factors.
- Comparisons of radiance/irradiance measurements (240 nm – 290/340 nm) by using initial measurement residuals with respect to a priori ozone profiles
- Identify calibration requirements and capabilities
- ...

GSICS UV sub-group

Preliminary ideas on working topics

2013-11-13 : First meeting - Formation of GSICS UV sub-group
2014-12-16: Selection of UV-chair (Rose Munro, EUMETSAT)

Preliminary ideas for working-targets:

- Reflectivity and Aerosol Index comparisons (340 nm - 390 nm) by using vicarious methods for ocean, desert and ice sheet targets.
- Solar measurement comparisons by using high resolution reference data sets along with instrument band-passes and Mg II scale factors.
- Comparisons of radiance/irradiance measurements (240 nm – 290/340 nm) by using initial measurement residuals with respect to a priori ozone profiles
- Identify calibration requirements and capabilities
- ...

GOME-2 hyper-spectral radiances for (inter-)calibration

Outline

- GOME-2A / GOME-2B calibration
- GOME-2 / OMPS NPP calibration
- GOME-2 / AVHRR Metop calibration
- GOME-2 Metop / Seviri MSG calibration
- AVHRR calibration of GOME-2 pointing and FOV

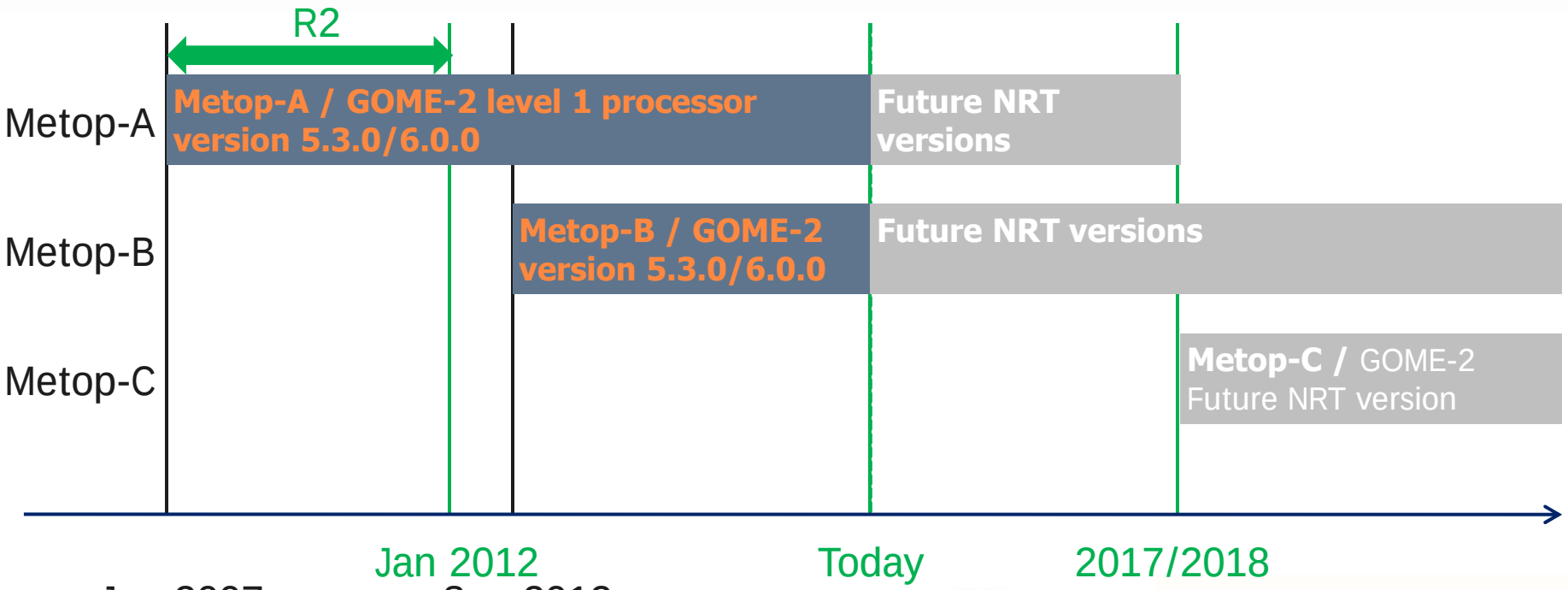
GSICS Global Space-based Inter-Calibration System

EUMETSAT

Timelines for the Metop / GOME-2 level 1 products

Processor versions: Reprocessed and NRT data

- Metop-A GOME-2 (FM3) launched in Oct 2006
- Metop-B GOME-2 (FM2) launched in-orbit 17th September 2012
- Metop-C GOME-2 (FM1) 2018 (TBC)



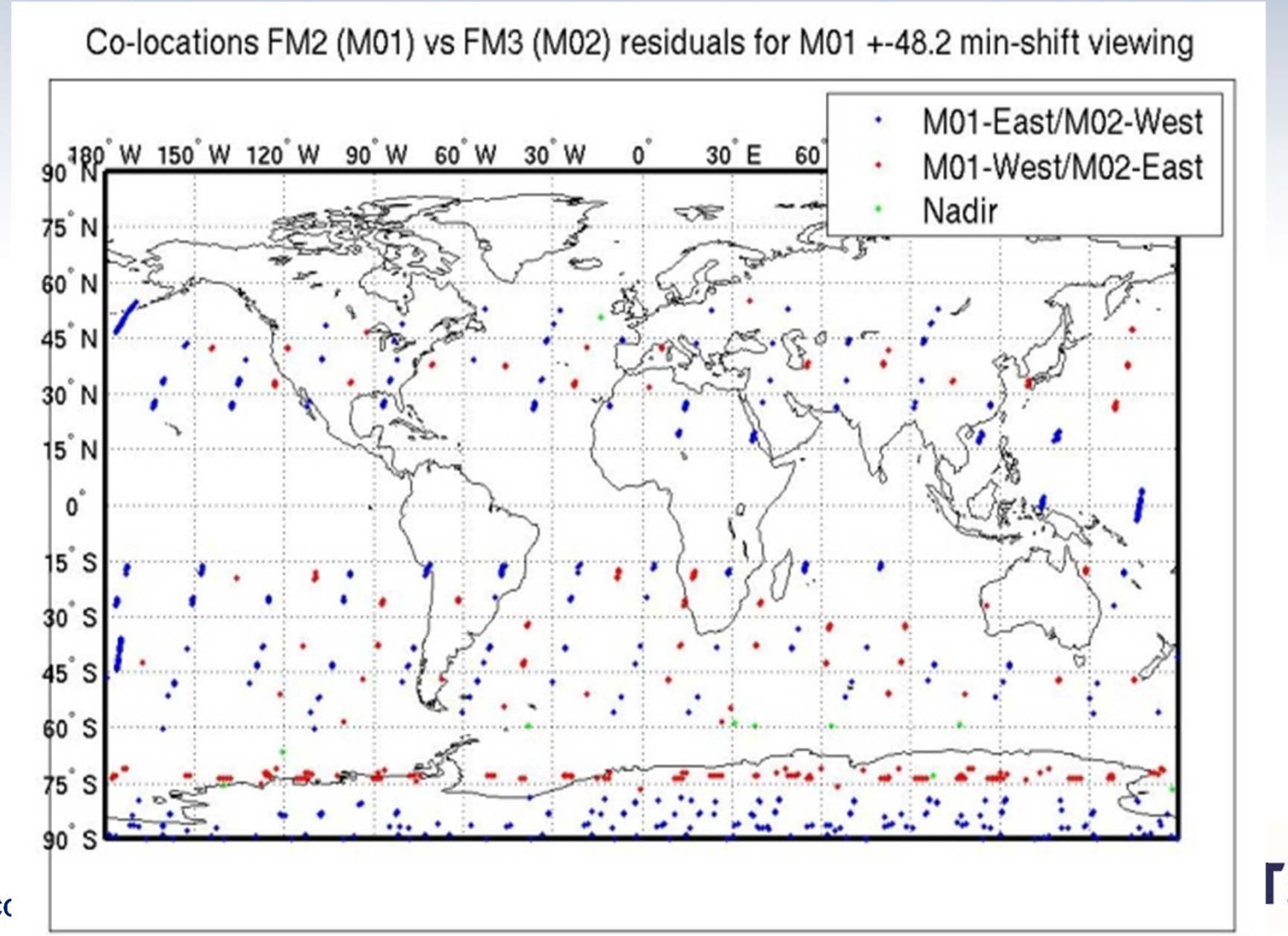
Metop-A/B GOME-2 inter-calibration

Earthshine co-located Metop-A/B measurements – co-locations

GOME-2 FM3
Metop-A

GOME-2 FM2
Metop-B

10th January 2013



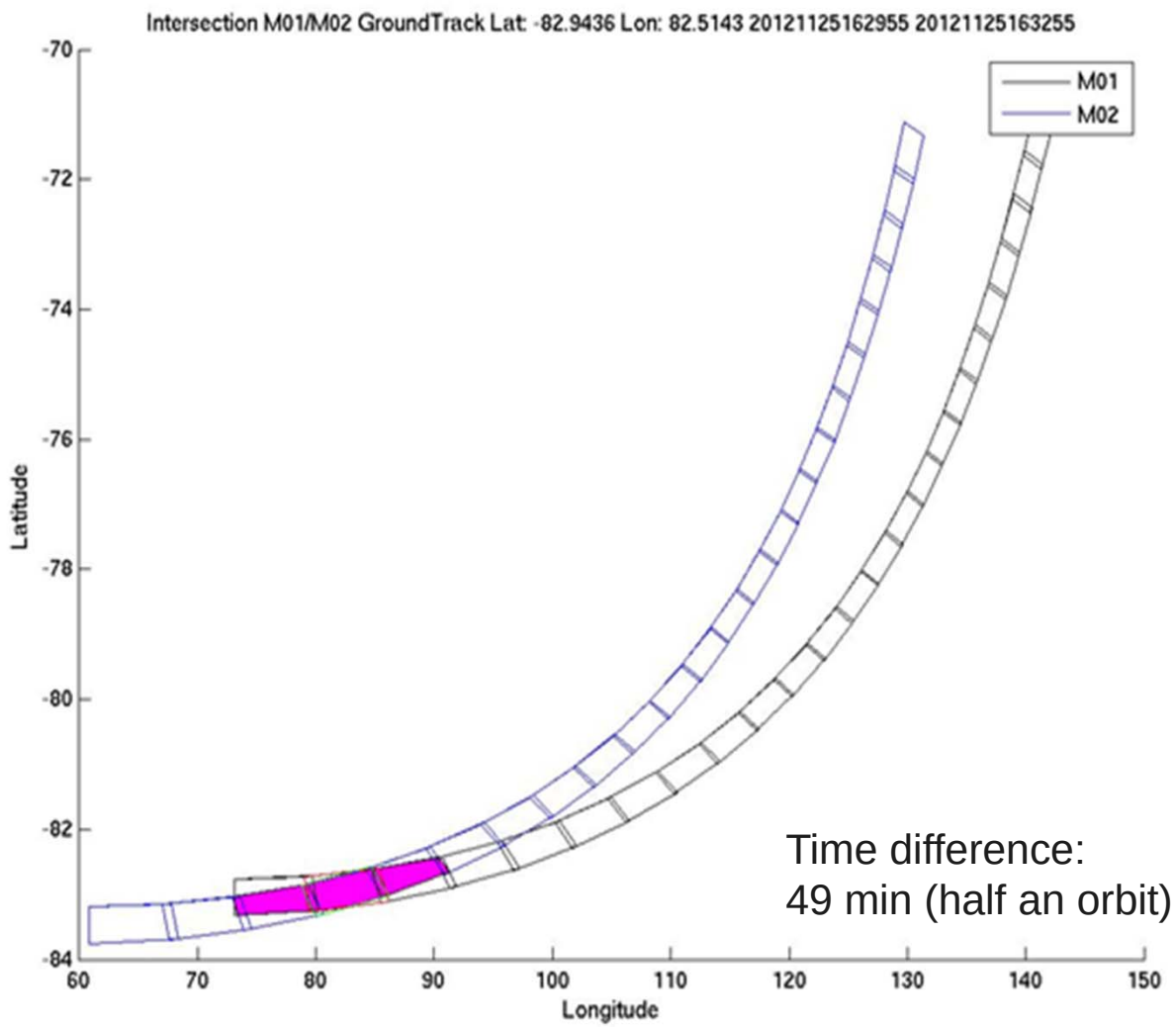
ISAT

Metop-A/B GOME-2 inter-calibration

Earthshine measurement co-location FM2 to FM3 / Co-location criteria

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B



Metop-A (M02): FM3

Metop-B (M01): FM2

Co-location criteria:

- **Area overlap > 80%**
- **Geo. AMF diff < 2%**
- **Relative O_2 A-Band residual (ROR) smaller than empirical threshold**

Global Space-based Inter-Calibration System

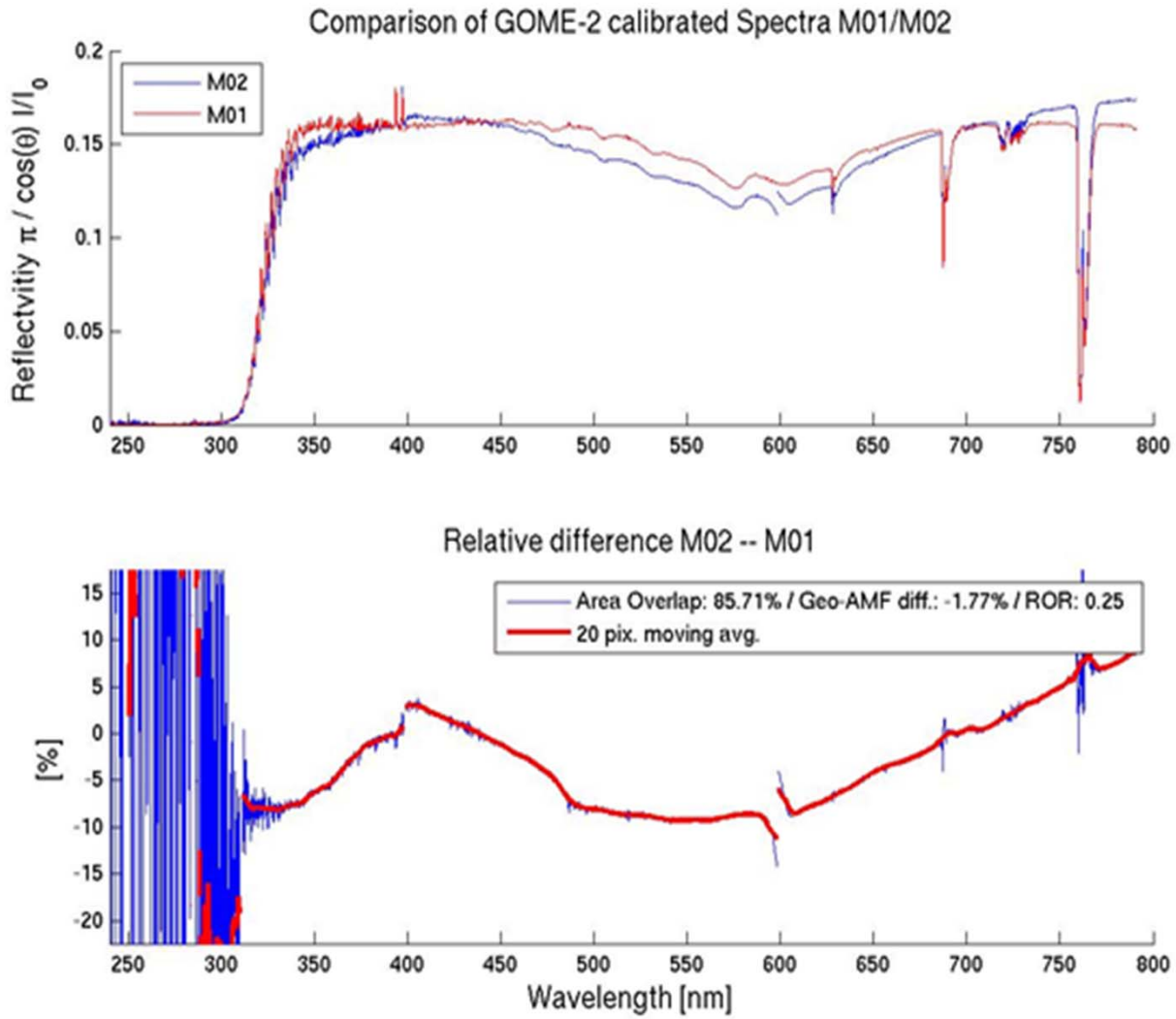
EUMETSAT

Metop-A/B GOME-2 inter-calibration

Earthshine co-located Metop-A/B reflectances and residuals

GOME-2 FM3
Metop-A

GOME-2 FM2
Metop-B



Residual in reflectivity

+ Lin. background subtracted per channel

+ 20 pix. moving average smoothing

+ Relative Oxygen-A band Residual (ROR) selection criterium

Global Space-based Inter-Calibration System

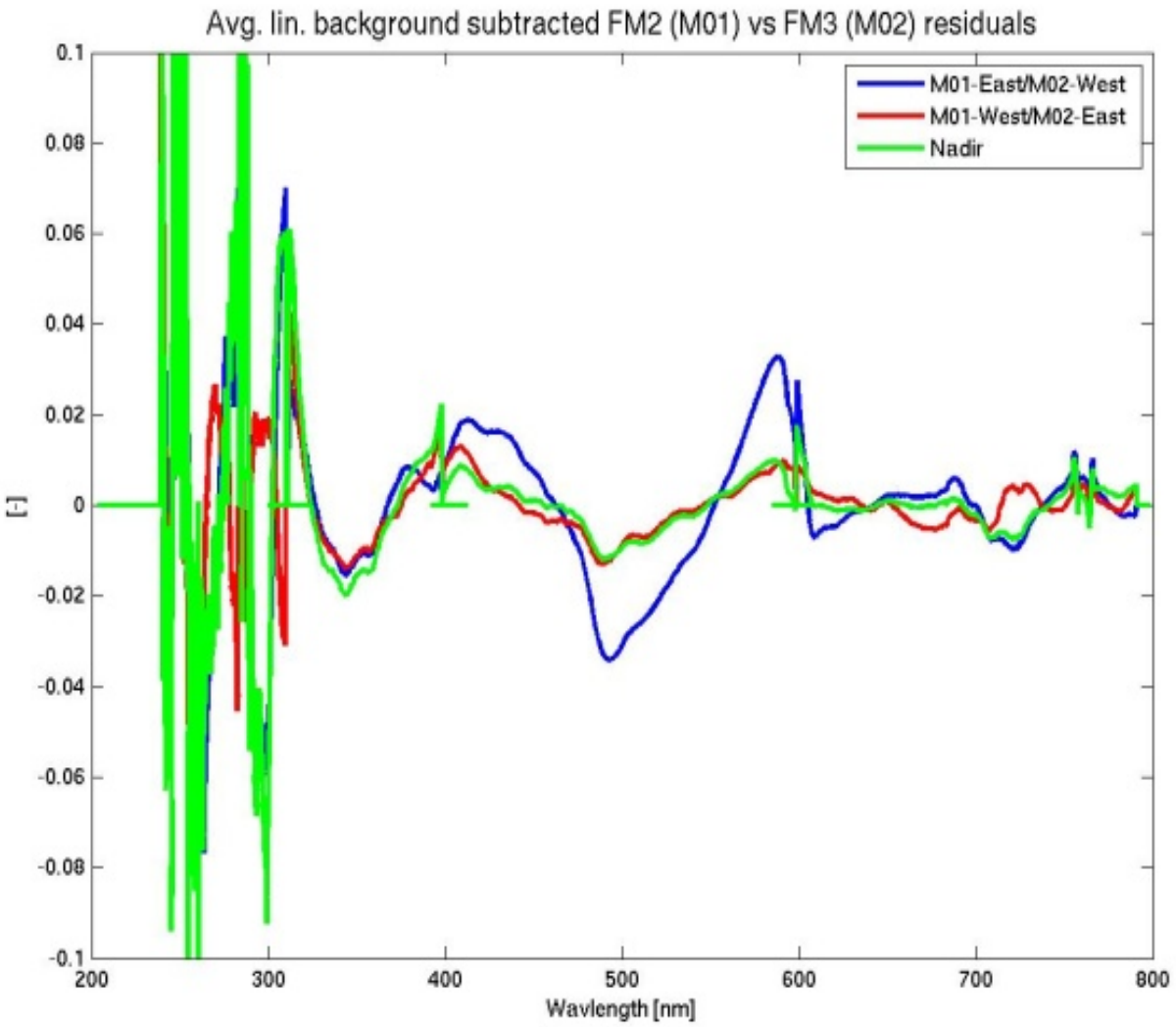
EUMETSAT

Metop-A/B GOME-2 inter-calibration

Earthshine co-located Metop-A/B residuals / Global average with background subtracted

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B



FM2-East/FM3-West
FM2-West/FM3-East
Nadir

Separation between East/West/Nadir at +- 20 degree viewing-angle

Global Space-based Inter-Calibration System

EUMETSAT

Metop-A/B GOME-2 inter-calibration

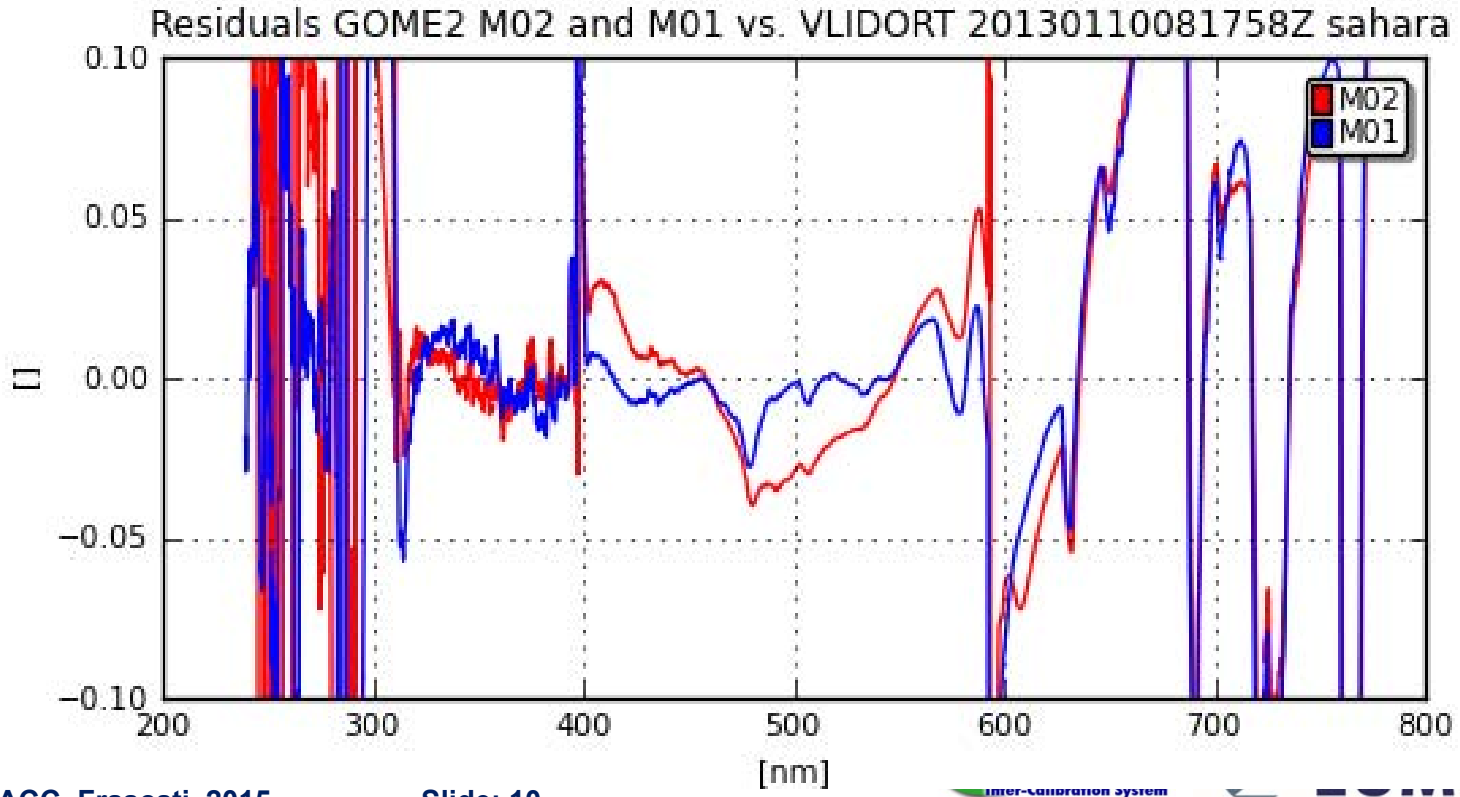
Earthshine co-located Metop-A/B residuals / Interpretation with forward model – V-LIDORT

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

Which instrument model contributes what to the residual?

Left up: **Residual Metop-A with V-LIDORT**
Residual Metop-B with V-LIDORT



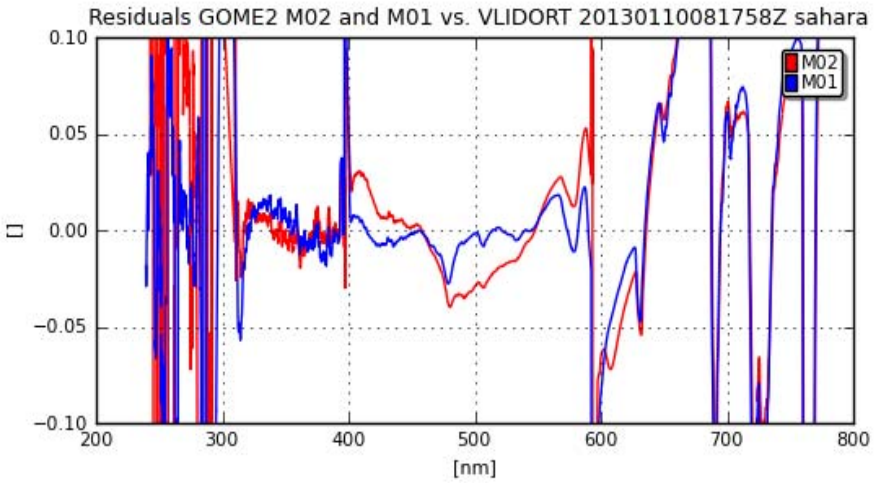
Metop-A/B GOME-2 inter-calibration

Earthshine co-located Metop-A/B residuals / Interpretation with forward model – V-LIDORT

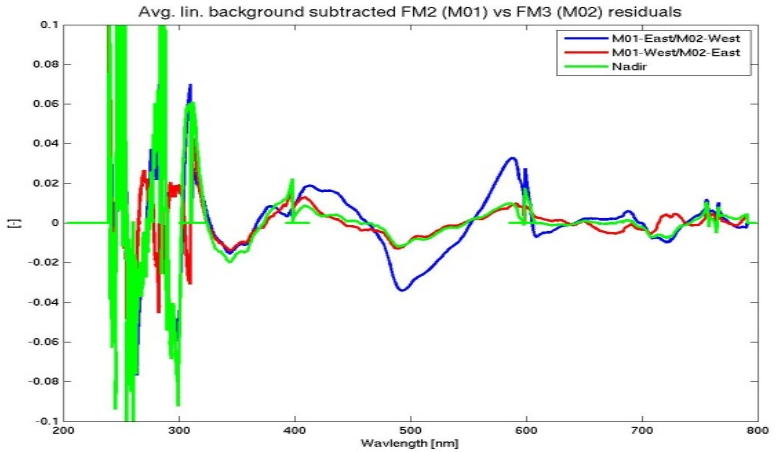
GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

Residual Metop-B with V-LIDORT
Residual Metop-A with V-LIDORT



Residuals between Metop-A and Metop-B



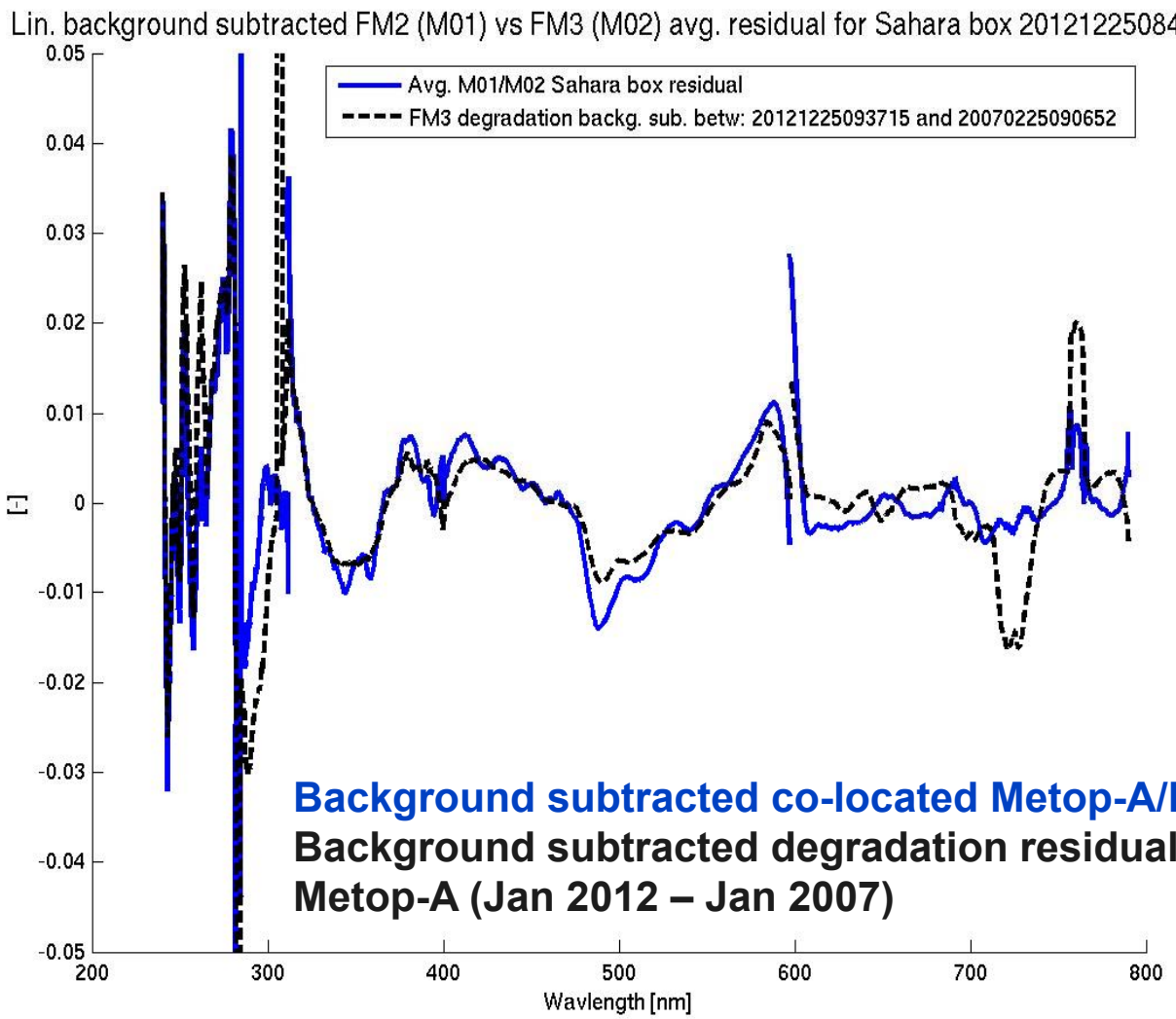
- **Broad-band structure in Metop-A channel 3**
- **Small-scale structures in Metop-B channel 3**

Metop-A/B GOME-2 Radiometric accuracy and calibration

Earthshine co-located Metop-A/B residuals / Background-subtracted plus degradation residual from Metop-A

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B



Background subtracted co-located Metop-A/B residual

Background subtracted degradation residual Metop-A (Jan 2012 – Jan 2007)

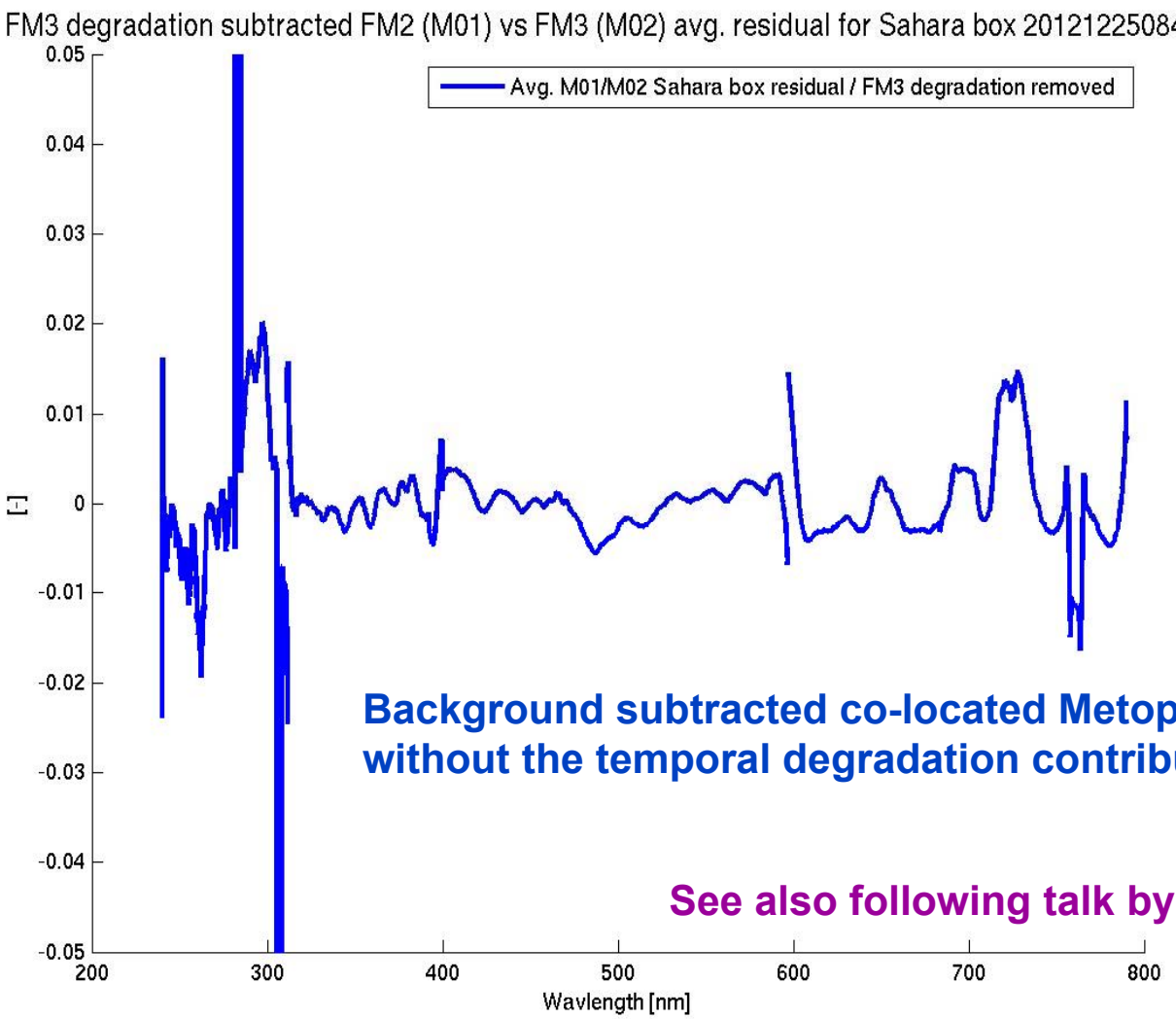
ETSAT

Metop-A/B GOME-2 inter-calibration

Earthshine co-located Metop-A/B residuals / Background-subtracted plus degradation residual from Metop-A subtracted

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B



Background subtracted co-located Metop-A/B residual without the temporal degradation contribution of Metop-A

See also following talk by X. Wu et al

ETSAT

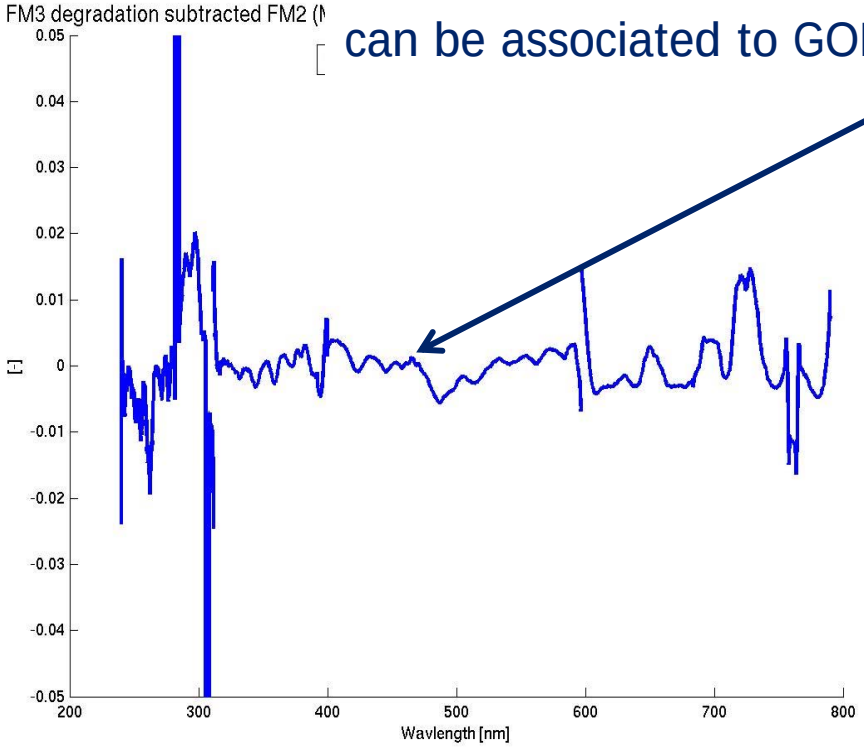
Metop-A/B GOME-2 inter-calibration

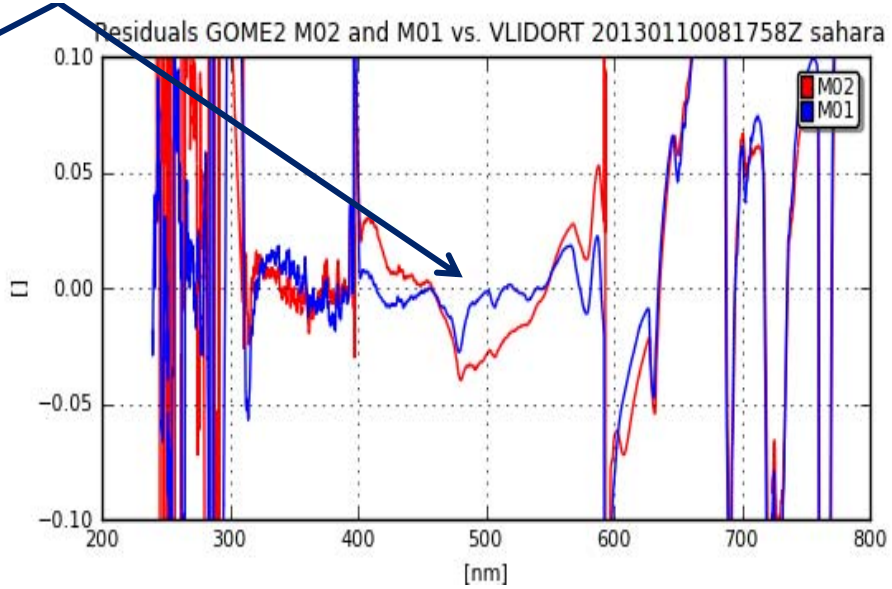
Earthshine co-located Metop-A/B residuals / Background-subtracted plus degradation residual from Metop-A subtracted

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

After subtracing GOME-2 /MetopA long-term degradation residuals most of the remainder in the spectral structure can be associated to GOME-2 / Metop-B





➢ **Metop-B spectral structures will be addressed in forthcoming processor version 6.1.0 (June 2015)**

EUMETSAT

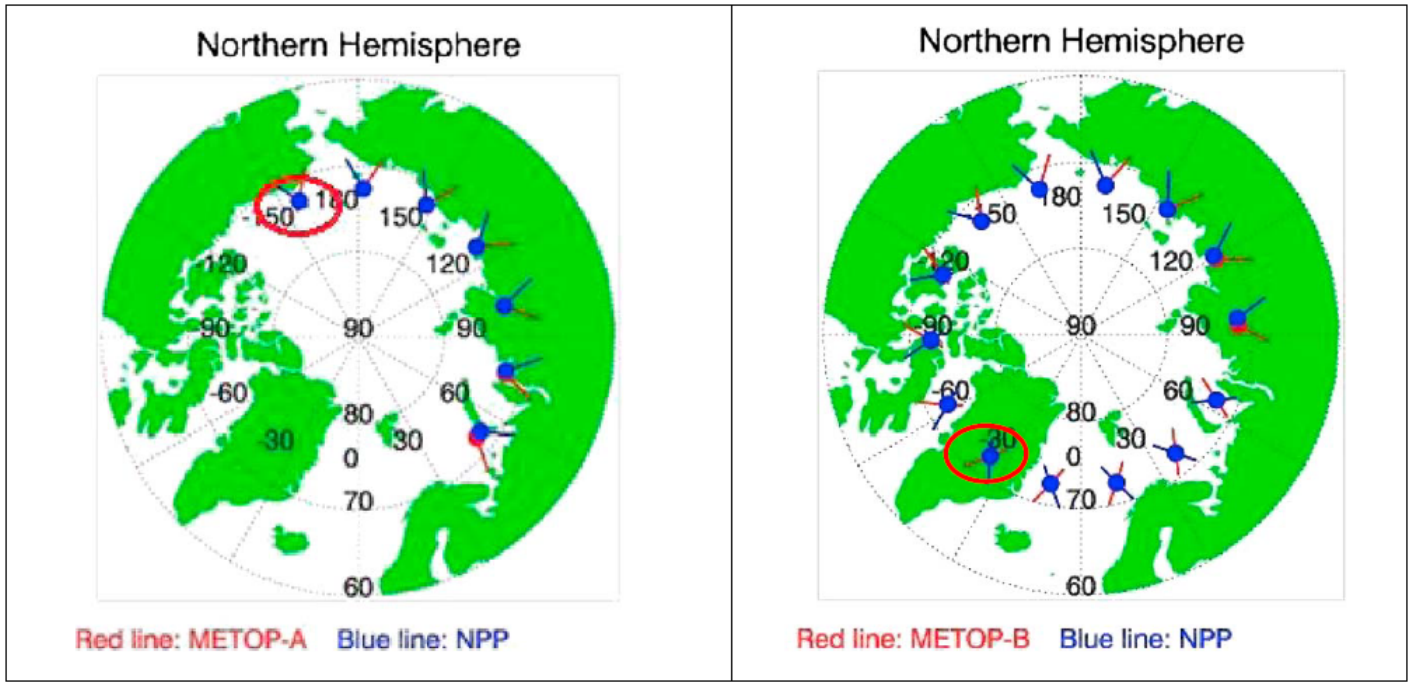
Metop-A/B GOME-2 / OMPS

Wu et al., JGR, 2014

GOME-2 FM3
Metop-A

GOME-2 FM2
Metop-B

NPP/Metop-A/B SNRs



Courtesy Wu et al., JGR, 2014, NOAA/NESDIS

EUMETSAT

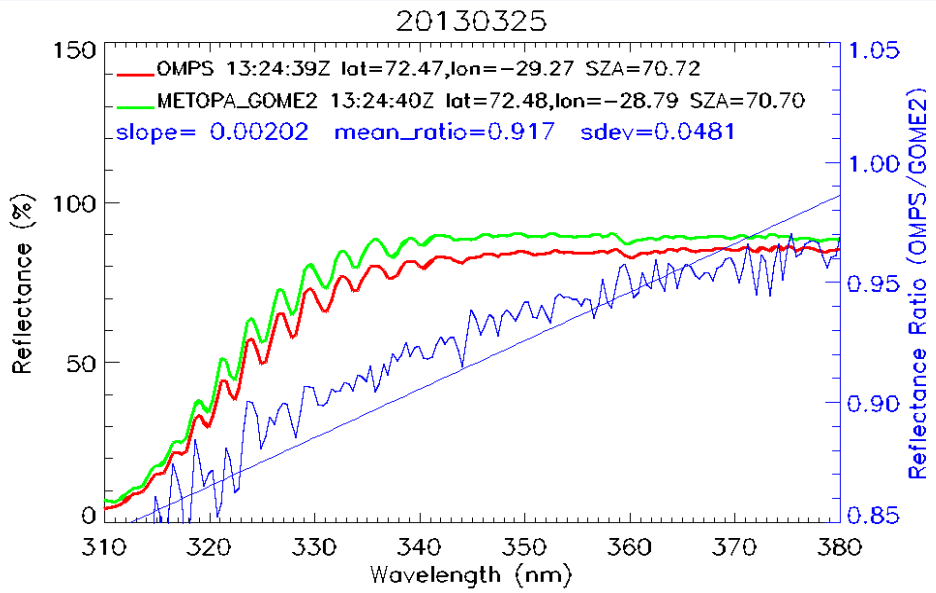
Metop-A/B GOME-2 / OMPS

Wu et al, JGR 2014

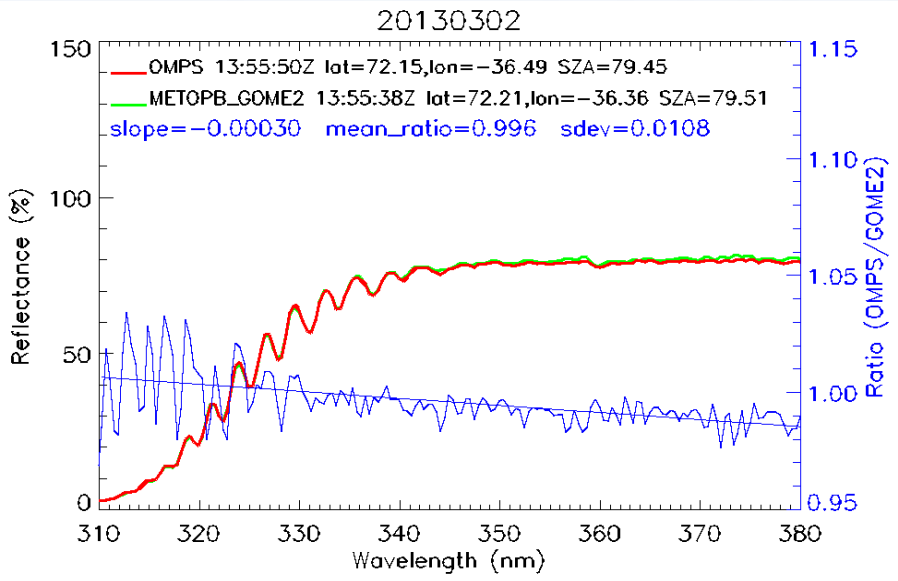
GOME-2 FM3
Metop-A

GOME-2 FM2
Metop-B

GOME-2 Metop-A vs OMPS



GOME-2 Metop-B vs OMPS



Courtesy Wu et al., JGR, 2014, NOAA/NESDIS

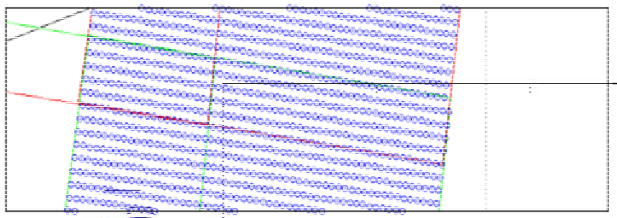
Data from March 2013

EUMETSAT

GOME-2/AVHRR reflectivity inter-calibration

AVHRR ch 1/ Metop-A

GOME-2 FM3
Metop-A



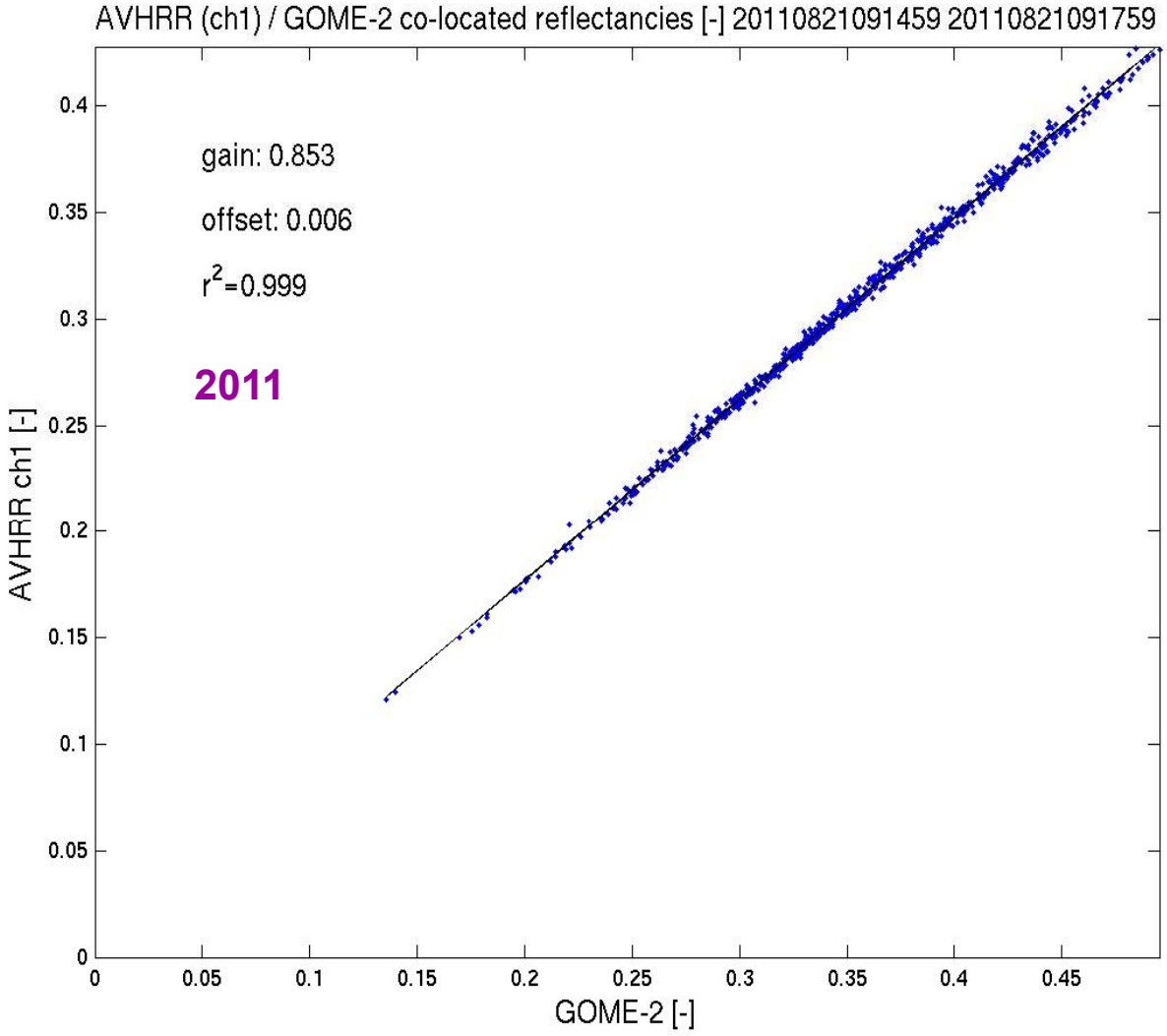
Global Space-based Inter-Calibration System

EUMETSAT

GOME-2 / AVHRR reflectivity inter-calibration

AVHRR ch 1/ Metop-A

GOME-2 FM3
Metop-A



AVHRR channel 1 to GOME-2/Metop-A gain in reflectivity ~10% (AVHRR < GOME-2)

Results indicate that the gain has been quite stable from 2007 to 2011.

see GSICS Quarterly Newsletters, vol 5, number 3, *Latter et al.*

spatial aliasing accounted for

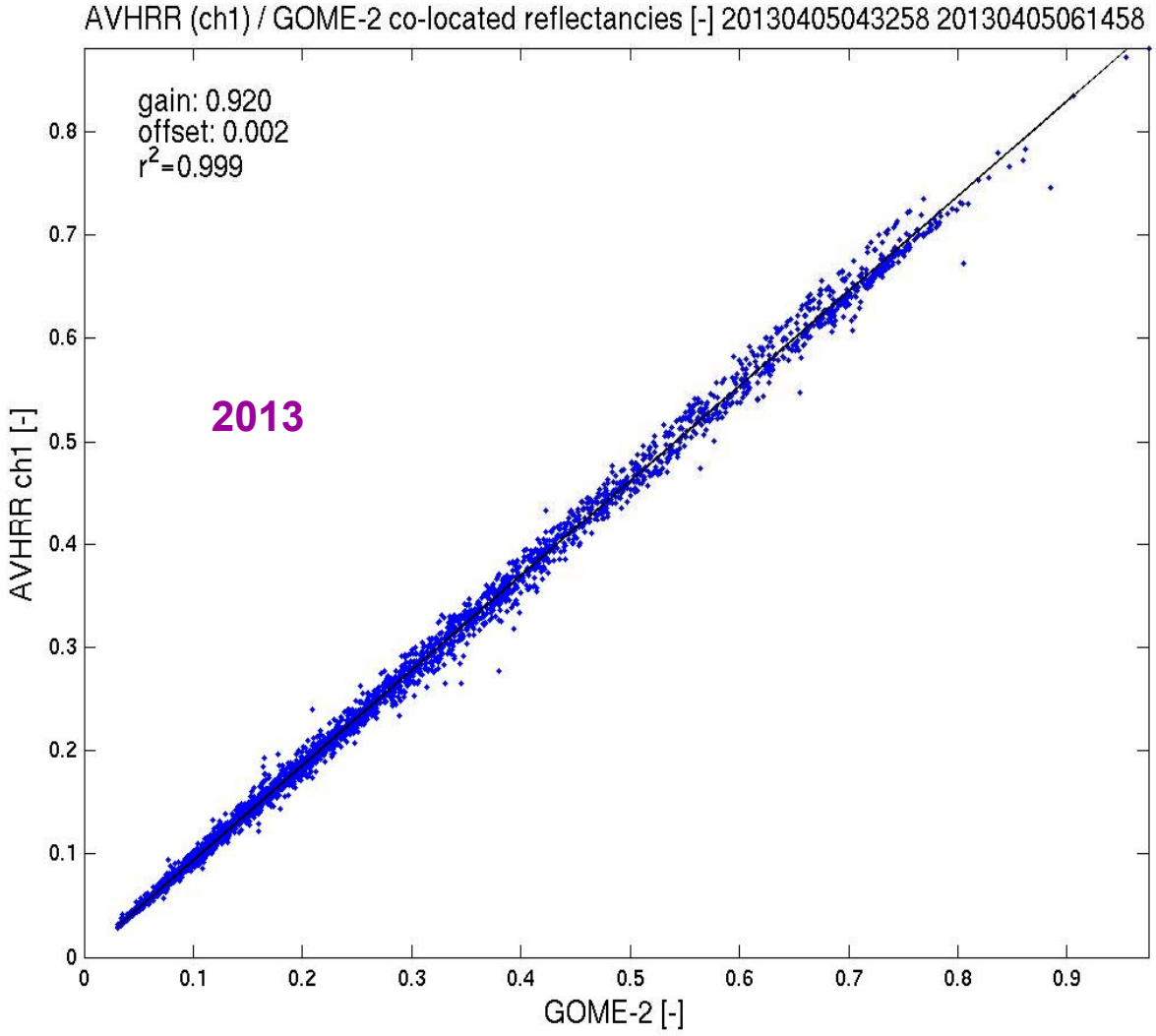
Global Space-based Inter-Calibration System

EUMETSAT

GOME-2 / AVHRR reflectivity inter-calibration

AVHRR ch 1/ Metop-A

GOME-2 FM3
Metop-A



AVHRR channel 1 to GOME-2/Metop-A gain in reflectivity <8% (AVHRR < GOME-2)

2011 - 2013

see GSICS Quarterly Newsletters, vol 5, number 3, *Latter et al.*

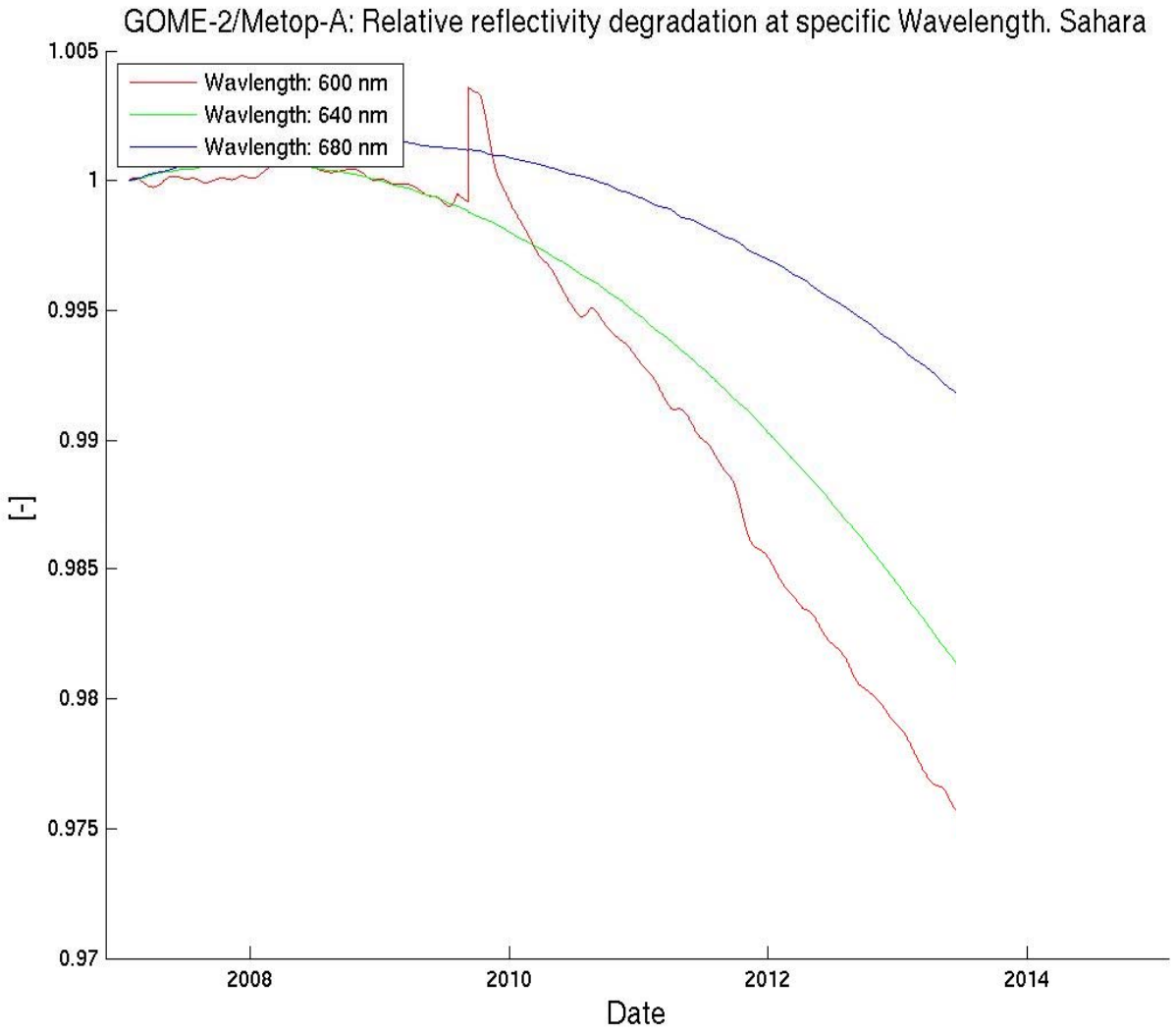
spatial aliasing accounted for

EUMETSAT

GOME-2 Metop-A degradation component modelling

Sahara – Reflectivity Degradation / AVHRR ch1-domain

GOME-2 FM3
Metop-A



R2 campaign
Jan 2007– Jan 2012
OPS phase (same PPF 5.3)
Jan 2012 – Oct 2013

Reflectivtiy Degradation

600 nm
640 nm
680 nm

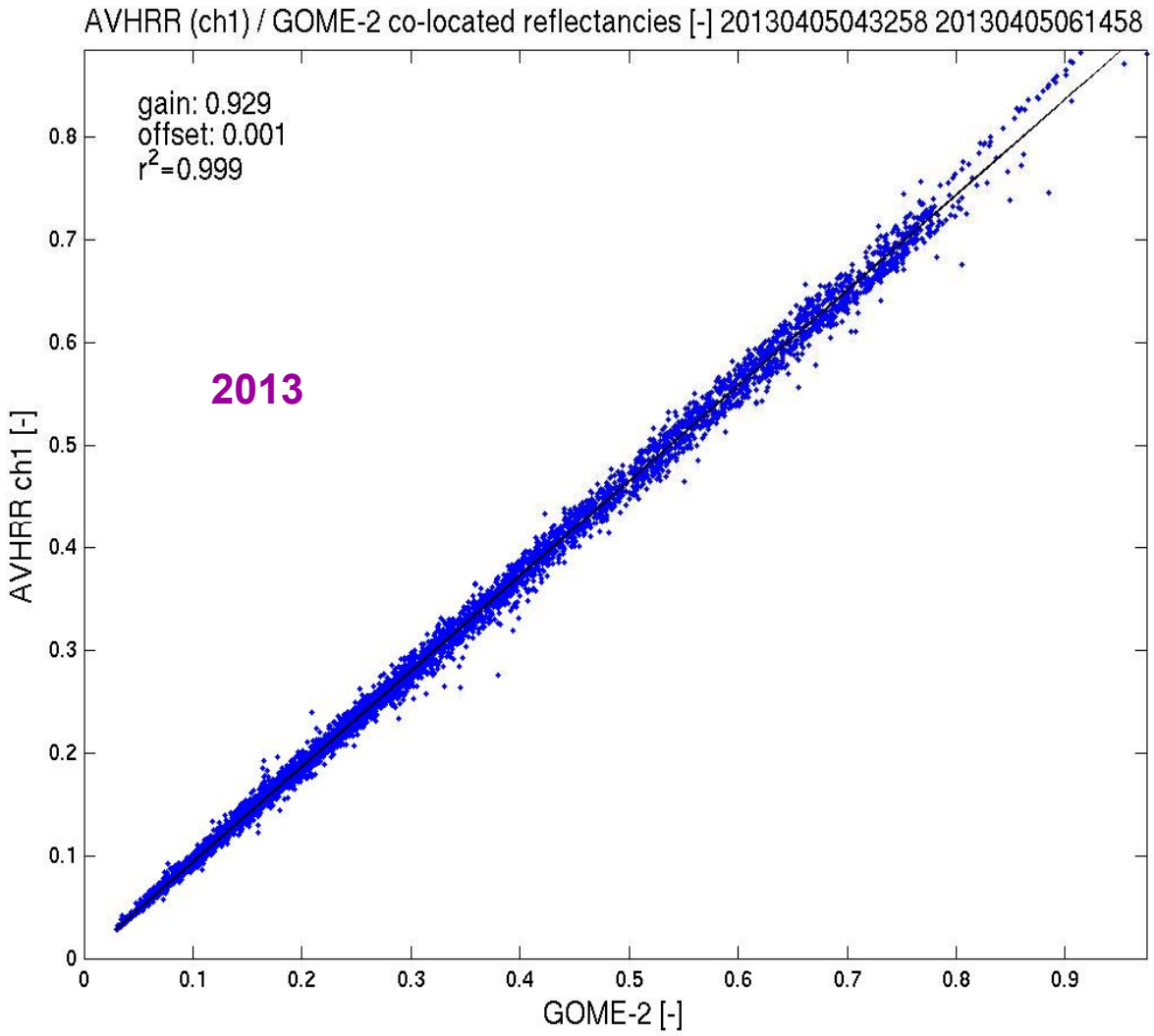
Average over all GOME-2 viewing angles

EUMETSAT

GOME-2/AVHRR reflectivity inter-calibration

AVHRR ch 1/ Metop-A

GOME-2 FM3
Metop-A



AVHRR channel 1 to GOME-2/Metop-A gain in reflectivity <8% (AVHRR < GOME-2)

2013
Corrected /
Un-corrected

see GSICS Quarterly Newsletters, vol 5, number 3, *Latter et al.*

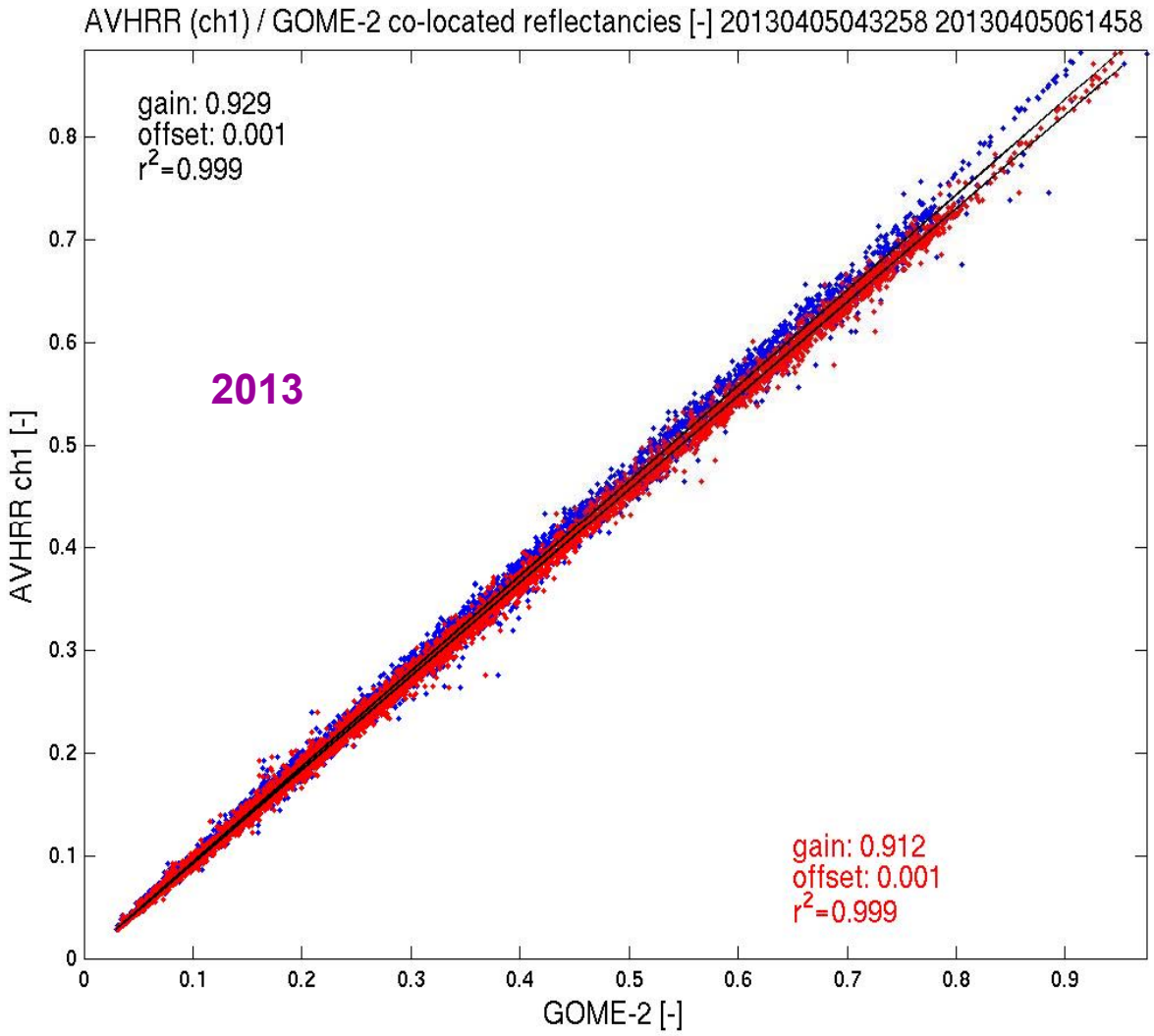
spatial aliasing accounted for

EUMETSAT

GOME-2/AVHRR reflectivity inter-calibration

AVHRR ch 1/ Metop-A

GOME-2 FM3
Metop-A



AVHRR channel 1 to GOME-2/Metop-A gain in reflectivity <8% (AVHRR < GOME-2)

2013
Corrected /
Un-corrected

see GSICS Quarterly Newsletters, vol 5, number 3, *Latter et al.*

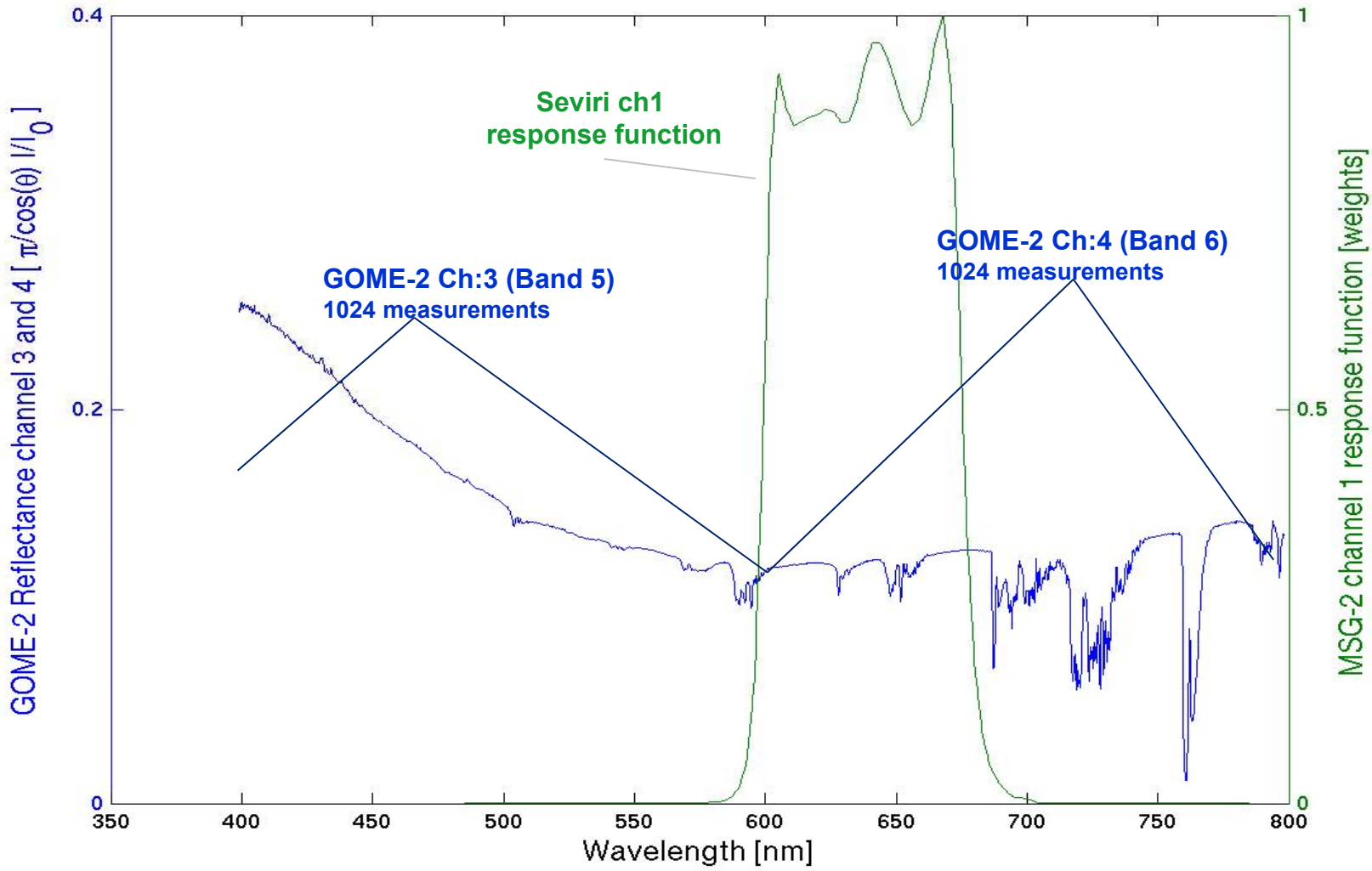
spatial aliasing accounted for

EUMETSAT

GOME-2 / Seviri reflectivity inter-calibratio

GOME-2 FM3
Metop-A

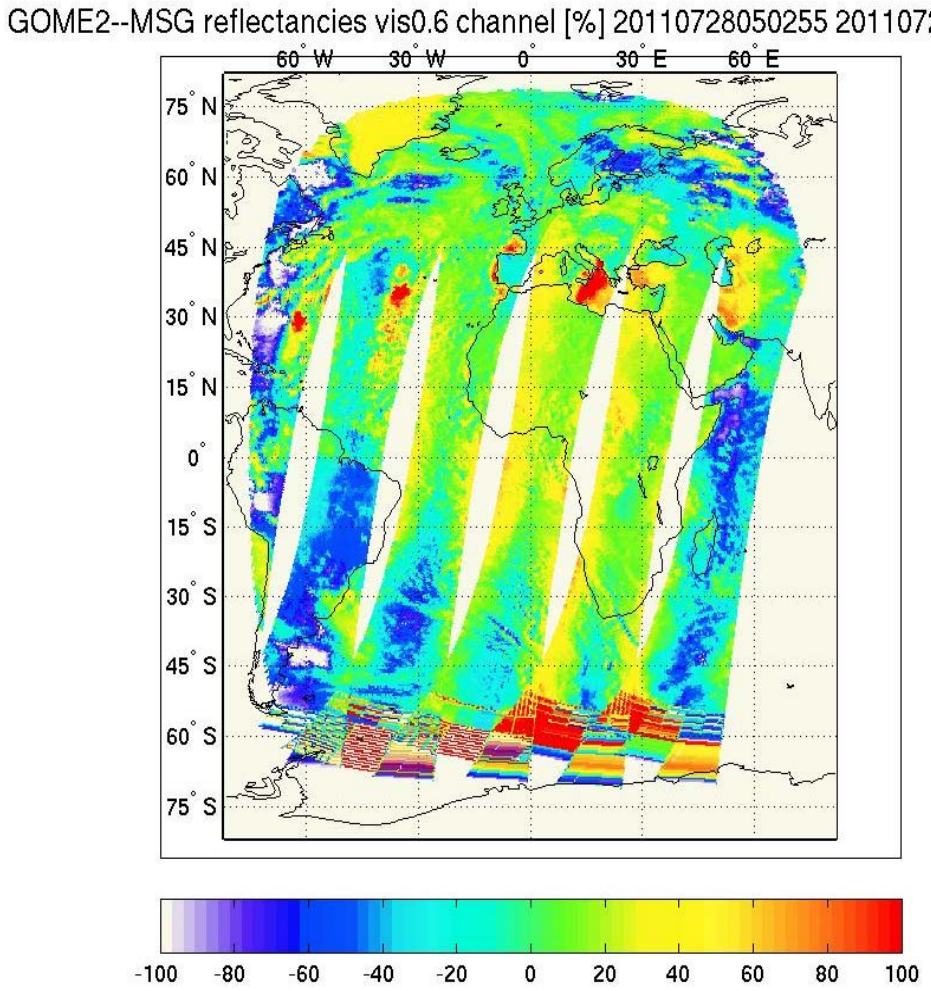
SEVIRI ch1/ MSG-2 – preliminary results



GOME-2 / Seviri reflectivity inter-calibration

SEVIRI ch1/ MSG-2 – preliminary results

GOME-2 FM3
Metop-A



Co-location of GOME-2 Metop-A with Seviri / MSG data.

Spatial collocation:
Average of all Seviri measurements (~4km) in one GOME-2 ground pixel (40 by 80 km)

Temporal collocation:
Within +- 15 min of sensing time.

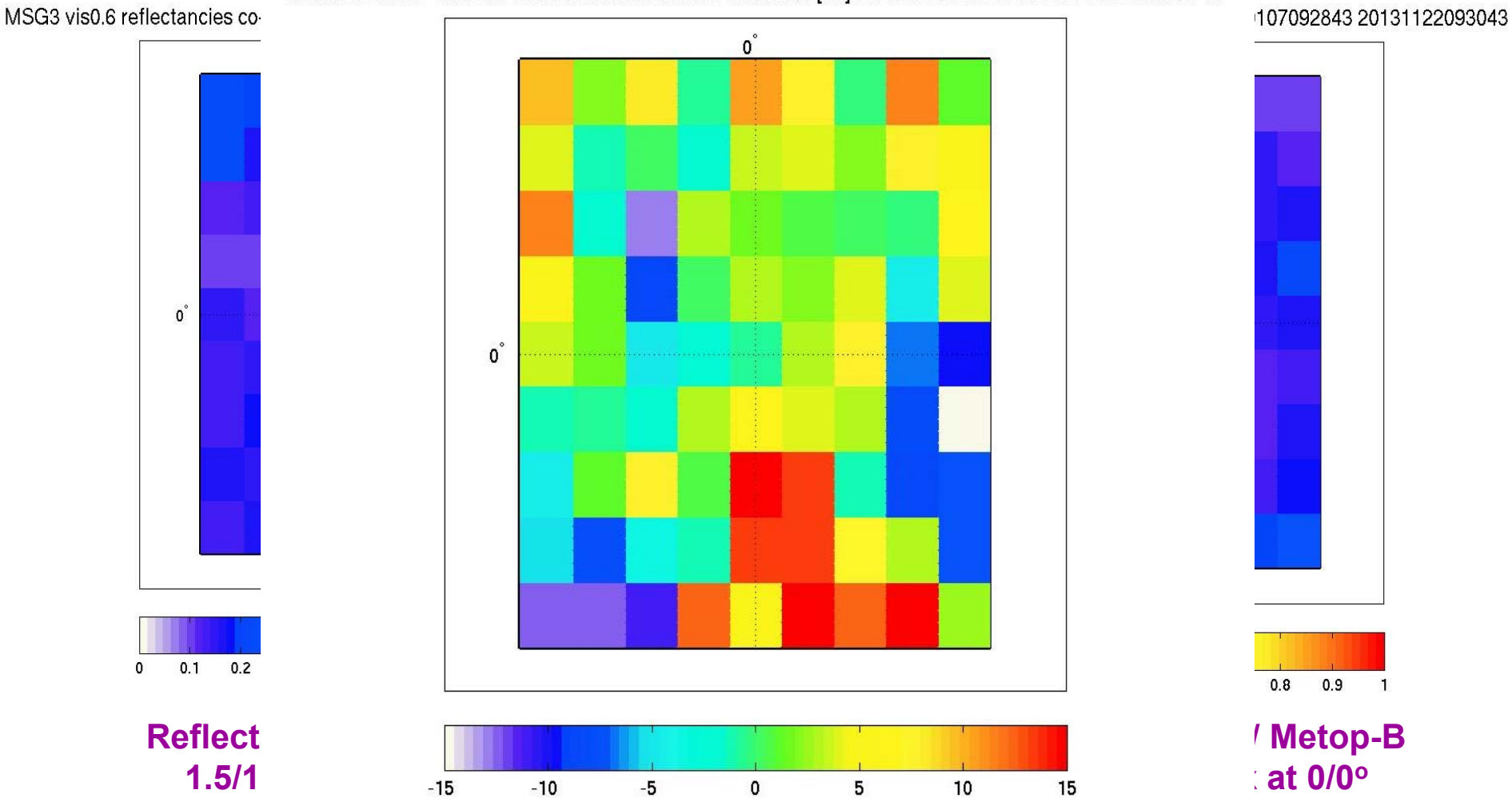
No spatial aliasing correction

EUMETSAT

GOME-2/Metop-B reflectivity inter-calibration

SEVIRI ch1/ MSG-3 – preliminary results

GOME-2 FM2
Metop-B



Reflect
1.5/1

/ Metop-B
at 0/0°

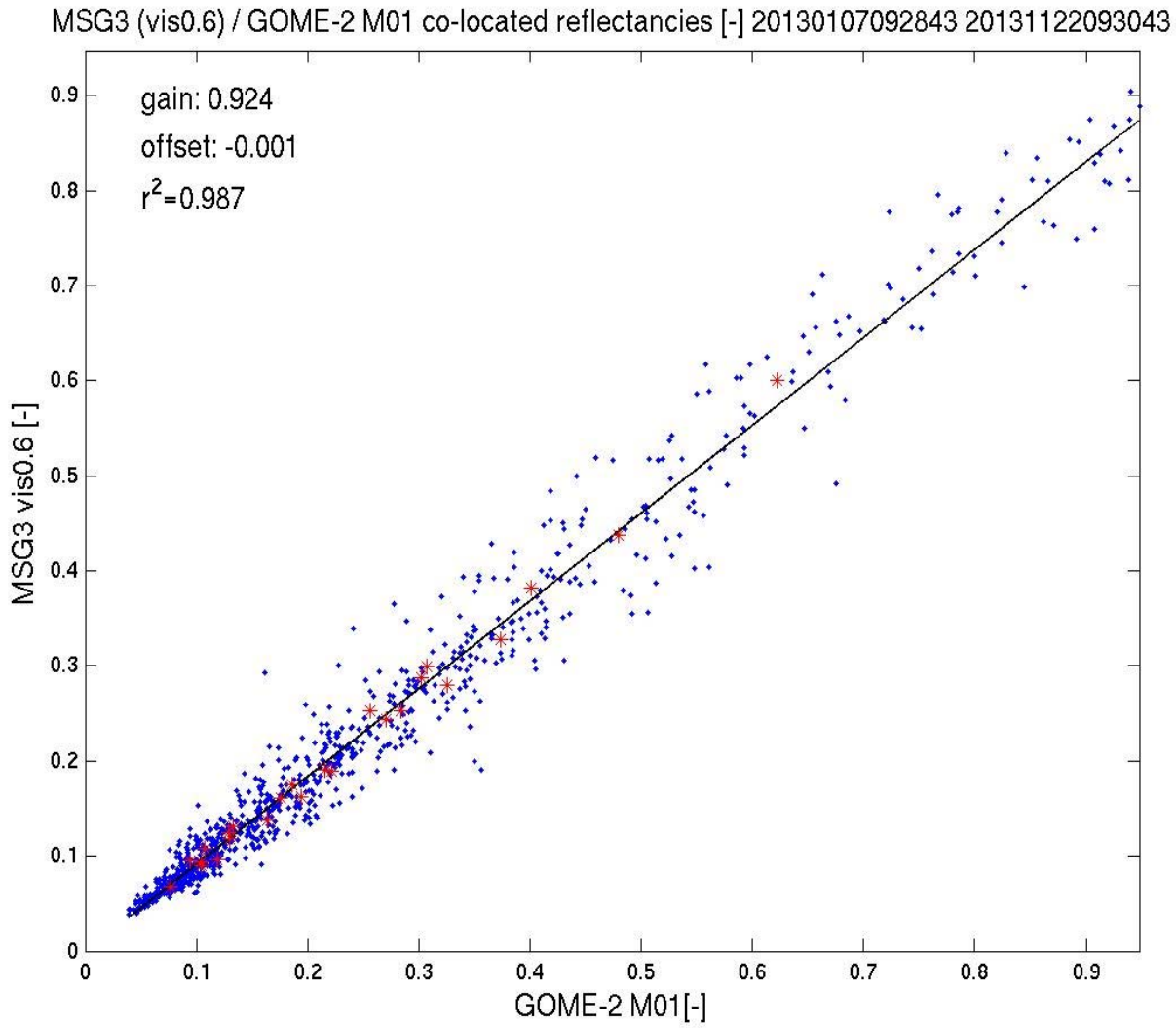
Residual MSG-3 /Seviri vs GOME-2 / Metop-B [%]
1.5/1.5 degrees box at 0/0°

METSAT

GOME-2/Seviri reflectivity inter-calibration

SEVIRI ch1/ MSG-3 vs GOME-2/Metop-B – preliminary results

GOME-2 FM2
Metop-B



MSG-3 / Seviri ch 1 to GOME-2/Metop-B gain in reflectivity ~8%
(Seviri < GOME-2)

1st Jan to 22nd Nov 2013

*** bi-weekly average**

EUMETSAT

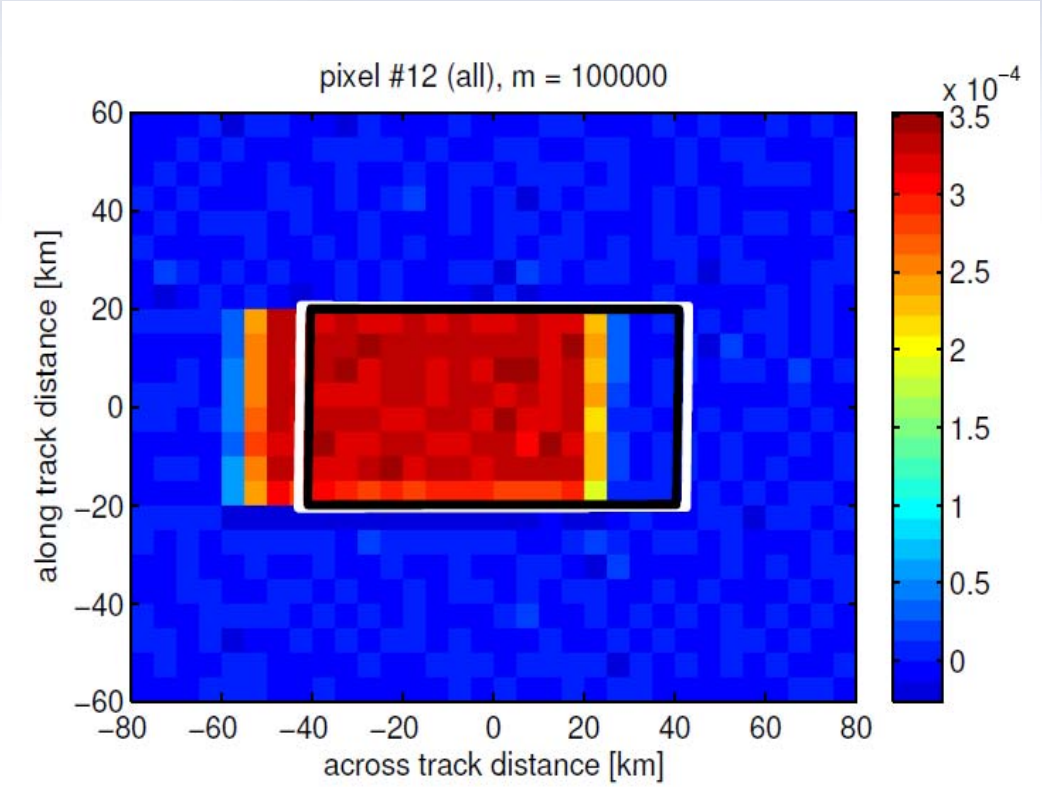
GOME-2 pointing and Geo-referencing
Forward and Back-scan – spatial aliasing / preliminary results!

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

GOME-2 scanning: forward scan nadir viewing pixel

Using accumulated AVHRR channel 1 radiances, convolved with spectral response function within reported geo-location of one GOME-2 ground pixel



Plot shows:

- Area of highest correlation (colored)
- Geo-reference footprint of one pixel as reported in GOME-2 level-1 product (black square)

Courtesy: H. Sihler, *MPIC, Mainz*

GSICS Global Space-based Inter-Calibration System

EUMETSAT

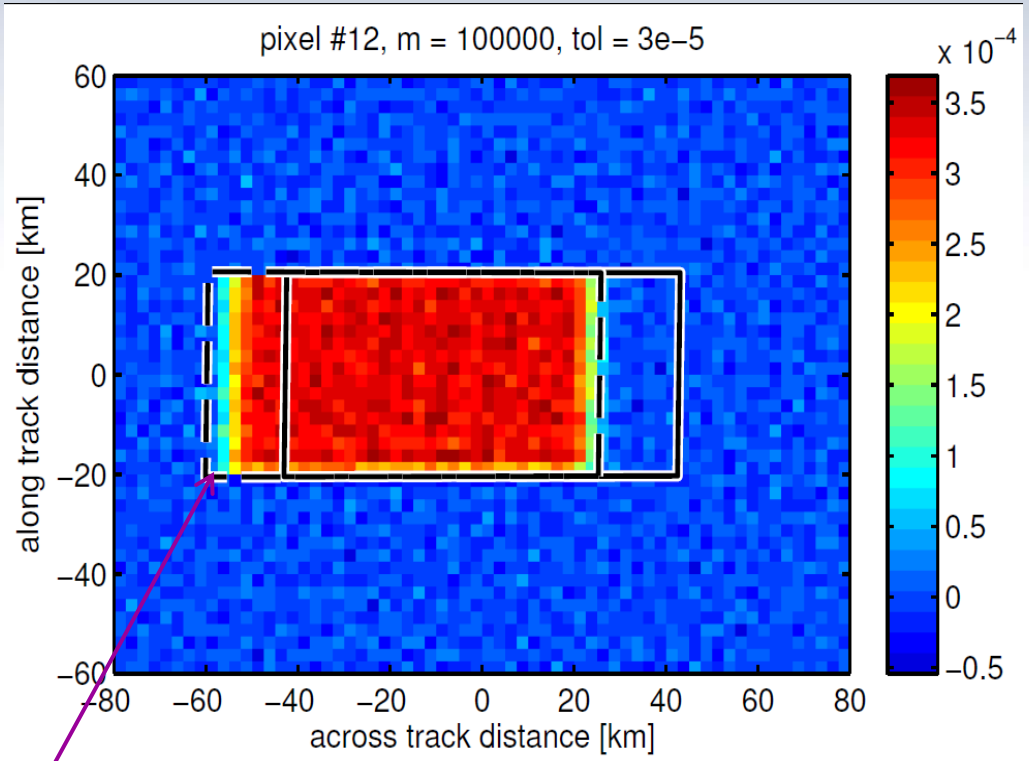
GOME-2 pointing and Geo-referencing
Forward and Back-scan – spatial aliasing / preliminary results!

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

GOME-2 scanning: forward scan nadir viewing pixel

Using accumulated AVHRR channel 1 radiances, convolved with spectral response function within reported geo-location of one GOME-2 ground pixel



Plot shows:

- Area of highest correlation (colored)
- Geo-reference footprint of one pixel as reported in GOME-2 level-1 product (black square)

Corrected according to detector read-out timing: *spatial aliasing*

Courtesy: H. Sihler, *MPIC, Mainz*

GSICS Global Space-based Inter-Calibration System

EUMETSAT

GOME-2 pointing and Geo-referencing

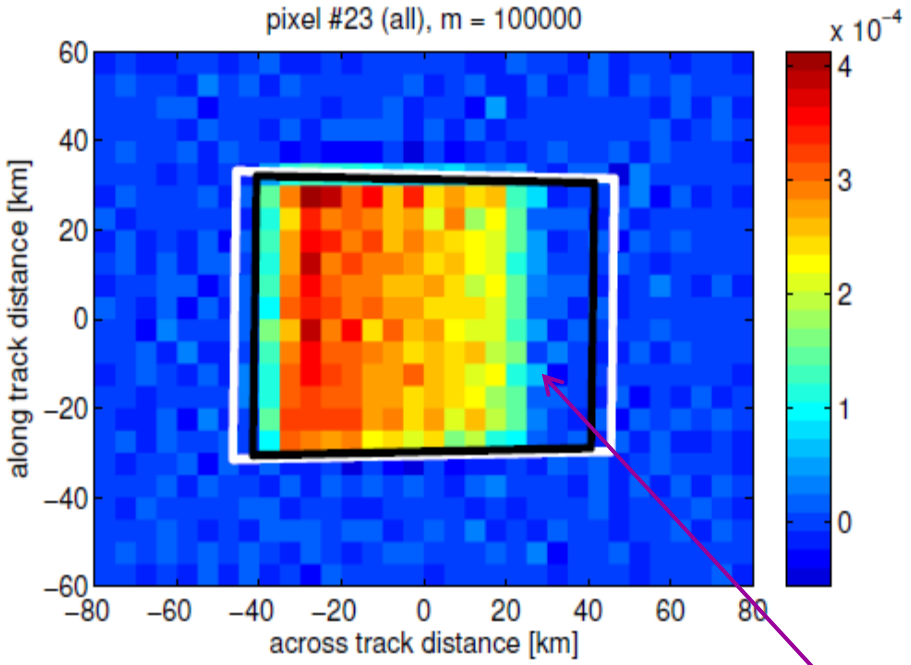
Forward and Back-scan – spatial aliasing / preliminary results!

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

Using accumulated AVHRR channel 1 radiances, convolved with spectral response function within reported geo-location of one GOME-2 ground pixel

pixel 23 – western swath edge



Plot shows:

- Area of highest correlation (colored)
- Geo-reference footprint of one pixel as reported in GOME-2 level-1 product (black square)

Distorted (squeezed) Western pixel because of scan mirror turn during detector read-out

Courtesy: H. Sihler, *MPIC, Mainz*

GSICS Global Space-based Inter-Calibration System

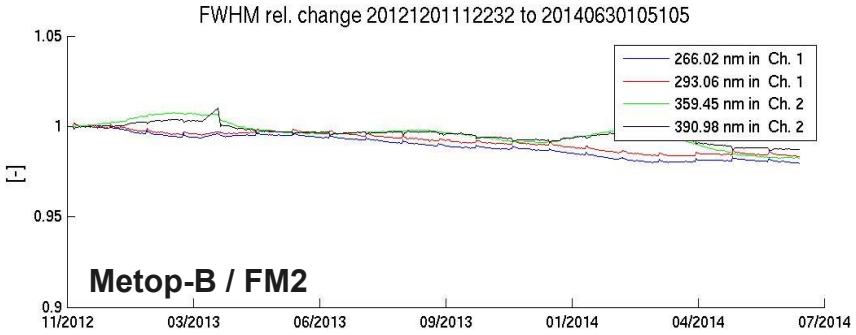
EUMETSAT

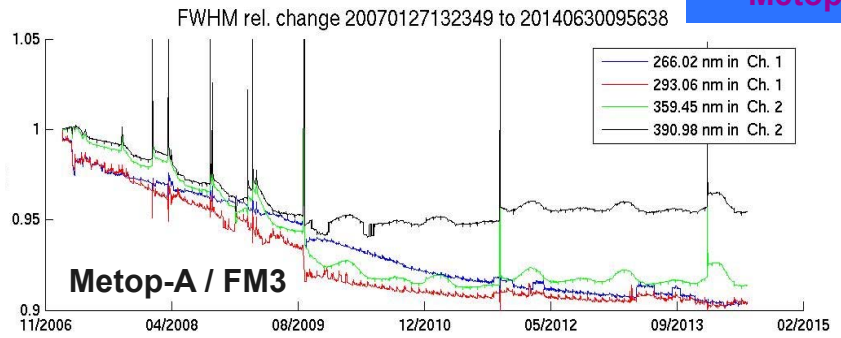
ISRF in-orbit monitoring – FM2/FM3

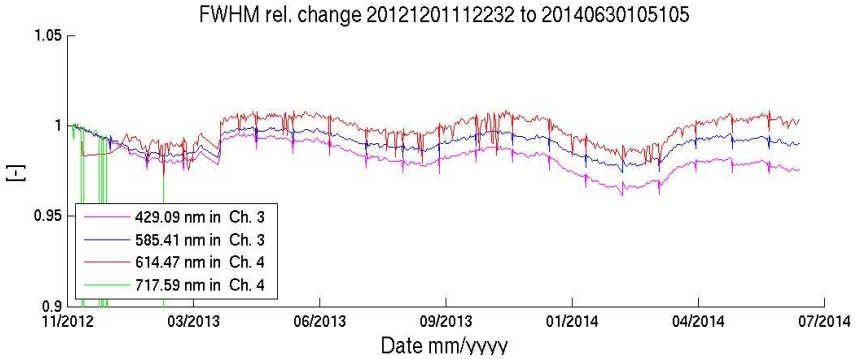
FWHM FM2/FM3 from on-board spectral light source – Long-term stability in

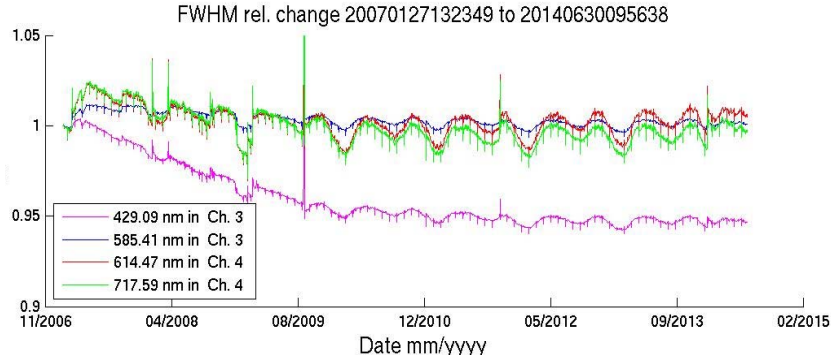
GOME-2 FM3 Metop-A

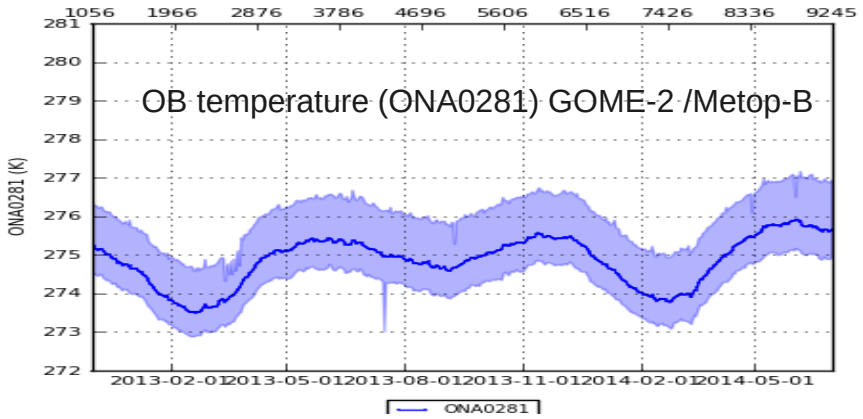
GOME-2 FM2 Metop-B

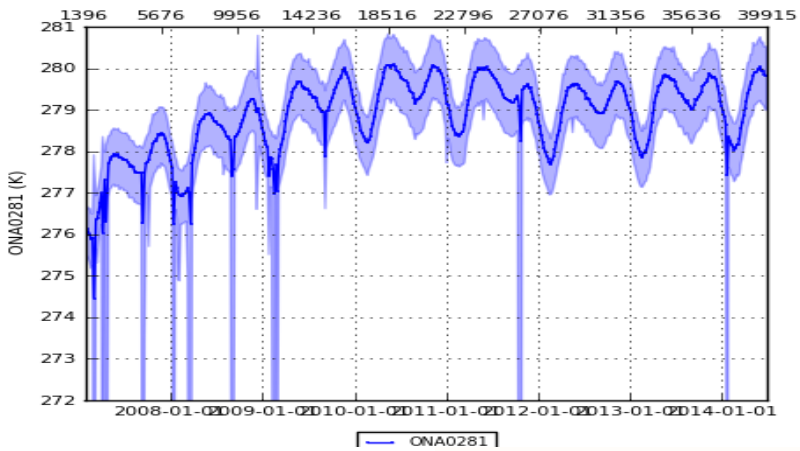












Goniometry: Angular dependence for Solar Measurements (AIRR)

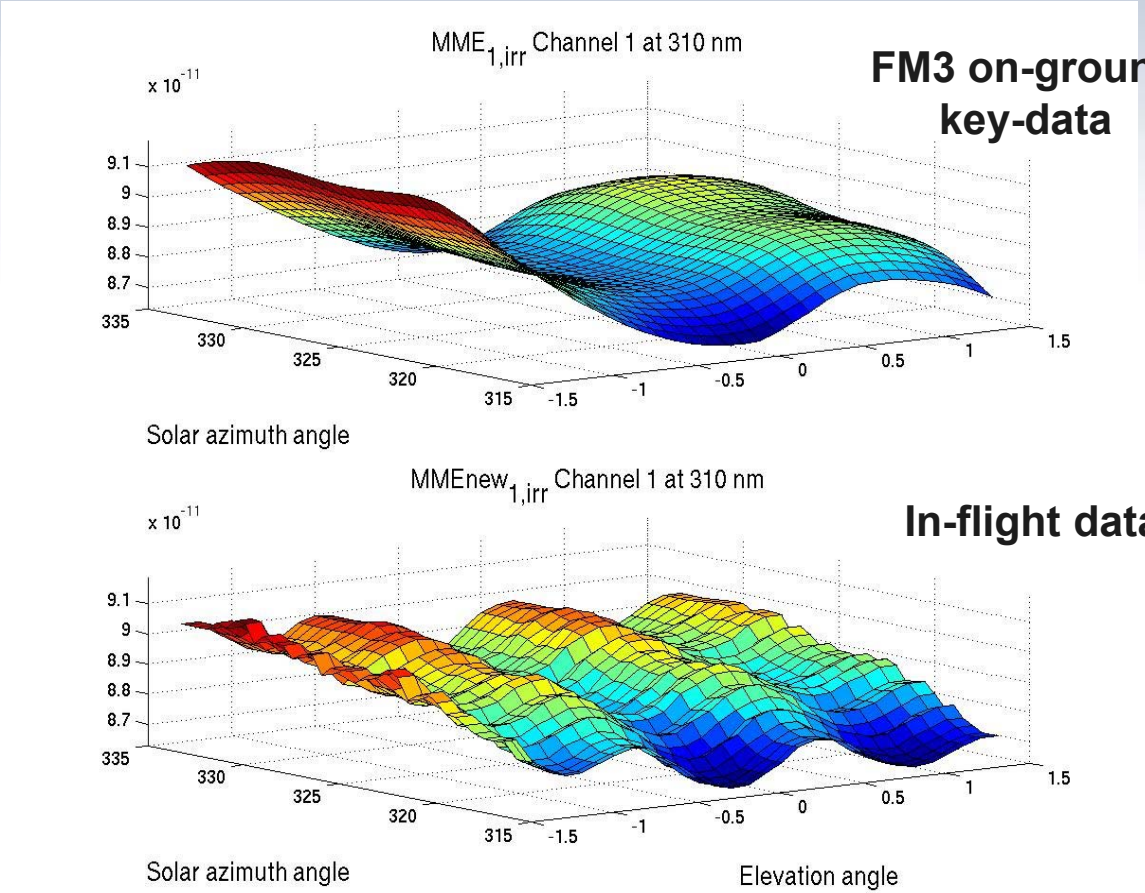
Comparison between current key-data and high res. elevation angle grid

GOME-2 FM3
Metop-A

The Angular dependence of irradiance on the diffuser in elevation and solar azimuth $I_0(\phi,e)$ is

- difficult to measure on-ground (long-measurement period / in vacuum)
- but one can derive it from in-flight data
- 1 year of in-flight data needed

Of relevance also for other current and future missions!

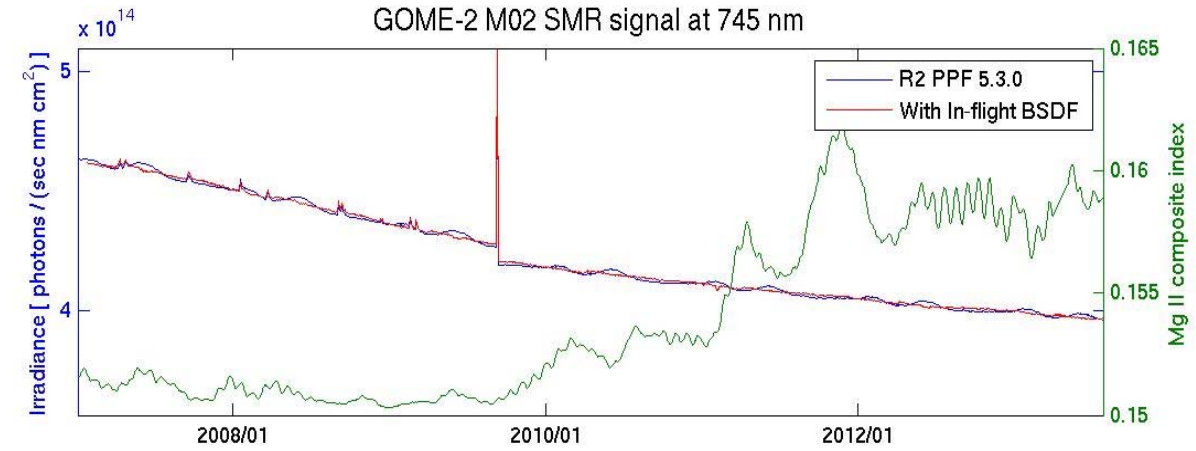


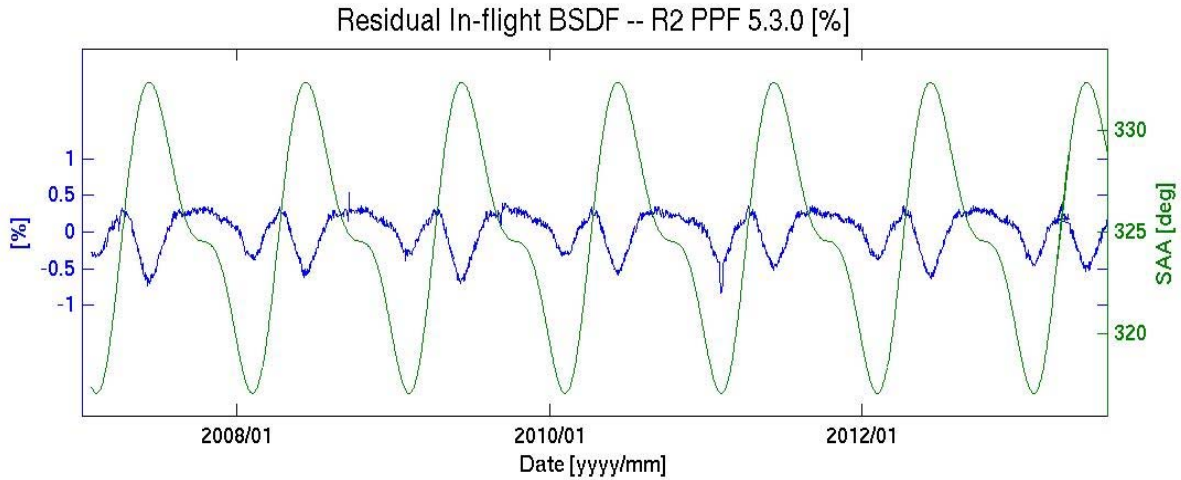
EUMETSAT

Goniometry: Angular dependence for Solar Measurements (AIRR)

Application of in-orbit derived slit-function 745 nm

GOME-2 FM3
Metop-A





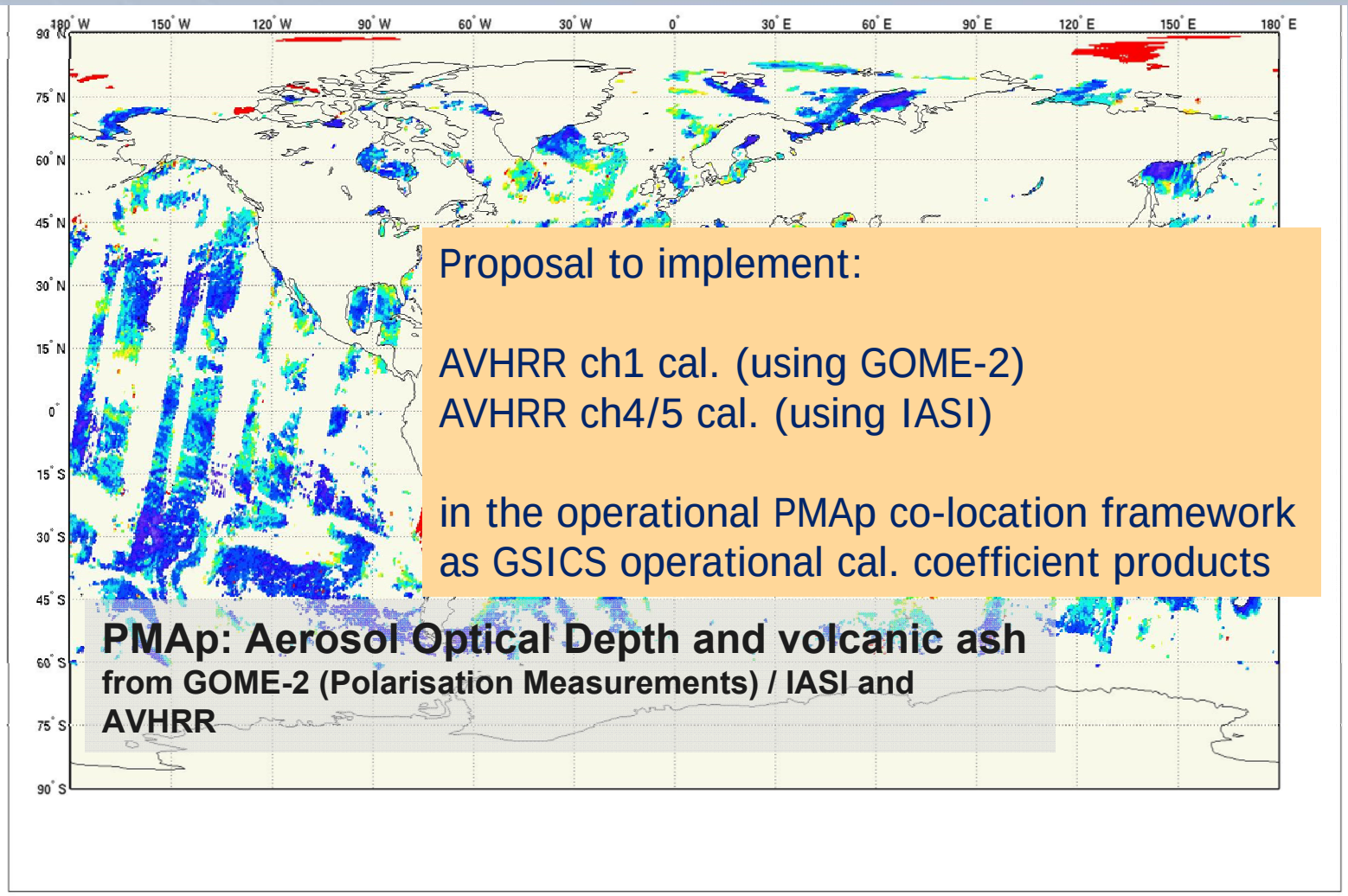
EUMETSAT

AOD / volcanic ash retrieval from two Metop – PMAp

Multi-sensor aerosol properties retrieval using GOME-2 PMDs (I,q), AVHRR and IASI

GOME-2 FM3
Metop-A

GOME-2 FM2
Metop-B

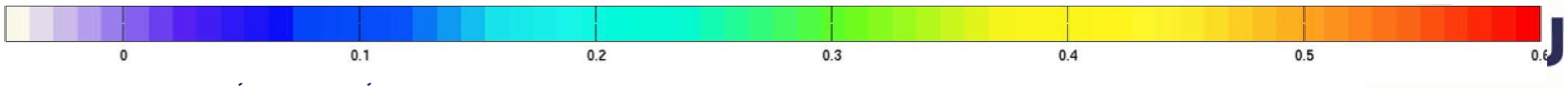


Proposal to implement:

AVHRR ch1 cal. (using GOME-2)
AVHRR ch4/5 cal. (using IASI)

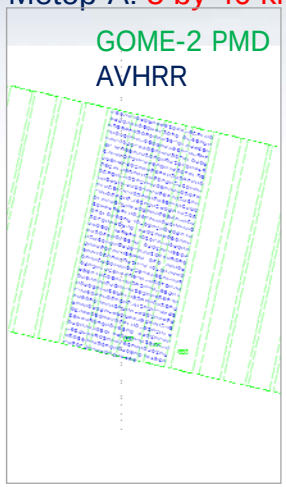
in the operational PMAp co-location framework as GSICS operational cal. coefficient products

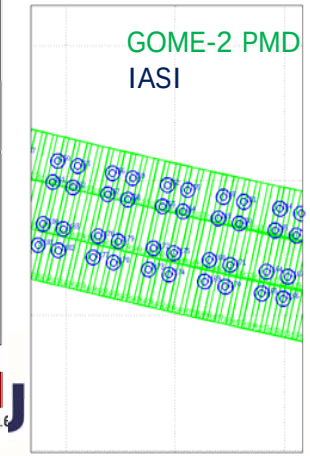
PMAp: Aerosol Optical Depth and volcanic ash
from GOME-2 (Polarisation Measurements) / IASI and AVHRR



GOME-2 PMD - ground pixel sizes

Metop-B: 10 by 40 km
Metop-A: 5 by 40 km



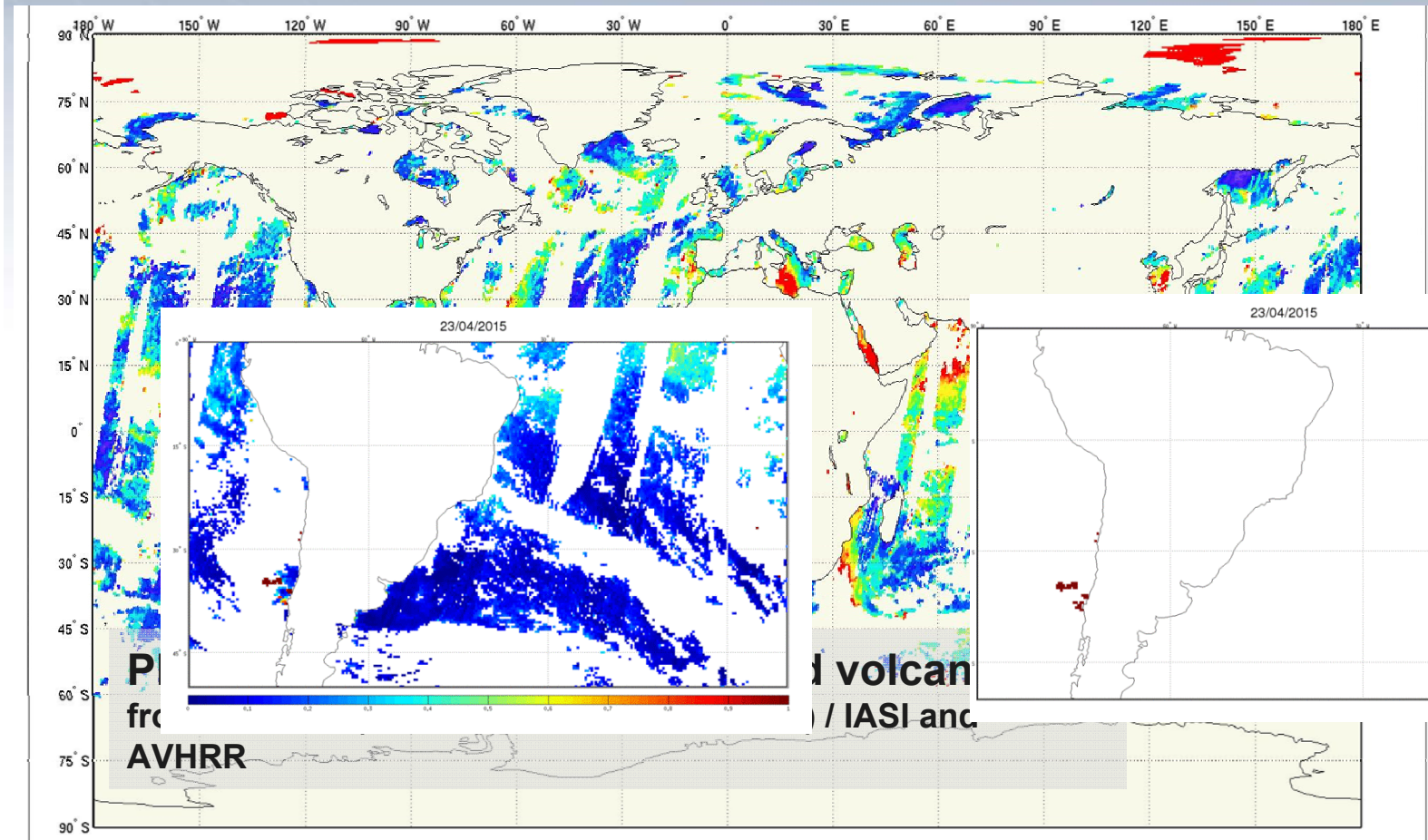


AOD / volcanic ash retrieval from two Metop – PMAp

Multi-sensor aerosol properties retrieval using GOME-2 PMDs (I,q), AVHRR and IASI

GOME-2 FM3
Metop-A

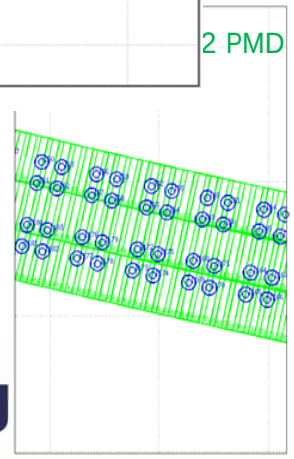
GOME-2 FM2
Metop-B



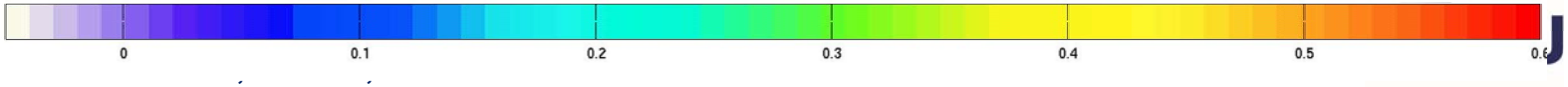
P… …d volcan…
fr… …) / IASI and…
AVHRR

GOME-2 PMD - ground pixel sizes

Metop-B: 10 by 40 km
Metop-A: 5 by 40 km



PMAp data available at: www.eumetsat.int > Data > Product Navigator



Summary

GOME-2 inter-calibration (AVHRR/Seviri/PMAp)

- GOME-2 / Metop-A channel 3/4 vs AVHRR / Metop-A channel 1

Scale factor of 0.89

(*2007 to 2011, 2011 to 2013 after correction of GOME-2 data, spatial aliasing accounted for by empirical correlation optimisation)*

- GOME-2 / Metop-B channel 3/4 vs Seviri / MSG-3 channel 1

Scale factor of ~0.92

(*2013, no correction of GOME-2 data, no spatial aliasing)*

- PMAp: GOME-2/(IASI) AVHRR inter-calibration

Towards continuous (operational) calibration for consistency with GOME-2 main science channels

- AVHRR inter-calibration of GOME-2 geo-reference data

Calibrating aspects of spatial aliasing and its radiometric effect in GOME-2 radiances by using AVHRR co-relation statistics

GSICS Global Space-based Inter-Calibration System

EUMETSAT

PMAp – Multi-sensor co-location for aerosol optical depth retrievals

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

Instrument		Spatial resolution	Spectral range	comments
GOME	Main science channel	80 x 40 km	240nm -800nm, res. 0.25-0.5nm	AAI, low spatial resolution, not used
	Polarization Monitoring Device	10 x 40 km Metop-B 5 x 40 km Metop-A	311nm-803nm, 15 bands	AOD, aerosol type, AAI
AVHRR	-	1.08 x 1.08 km	580nm-12500nm, 5 bands	Clouds, scene heterogeneity, dust/ash
IASI	-	12km (circular)	3700–15500nm, resolution 0.5 cm^{-1}	desert dust, volcanic ash aerosol heights
Auxiliary data	ECMWF wind speed (forecasting)	Temporal interpolation necessary	-	Required for retrievals over ocean
	surface albedo, Surface elevation	-		Required for retrievals over land

Target spatial resolution

PMAp – Multi-sensor co-location for aerosol optical depth retr

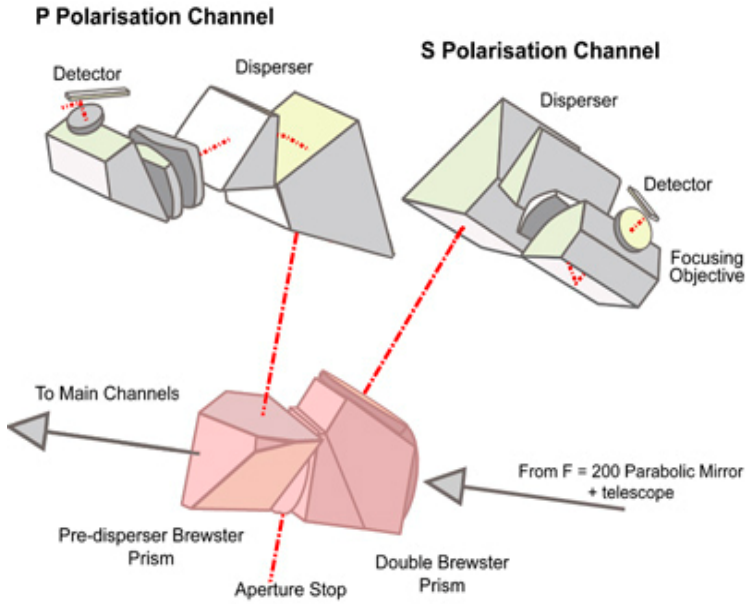
The GOME-2 Polarisation Measurement Devices

GOME-2 FM3
Metop-A

GOME-2 FM2
Metop-B

Band-S				
No.	pix1	pixw.	wav1	wav2
1	22	5	311.709	314.207
2	30	4	316.762	318.720
3	37	12	321.389	329.139
4	50	6	330.622	334.443
5	57	6	336.037	340.161
6	84	17	360.703	377.873
7	102	4	380.186	383.753
8	117	19	399.581	428.585
9	138	27	434.083	492.066
10	165	18	494.780	548.756
11	183	2	552.474	556.262
12	187	11	568.070	612.869
13	198	9	617.867	661.893
14	218	4	744.112	768.269
15	224	2	794.080	803.072

- Radiances & stokes fraction
- better spatial resolution
- stokes fraction s = Q/I



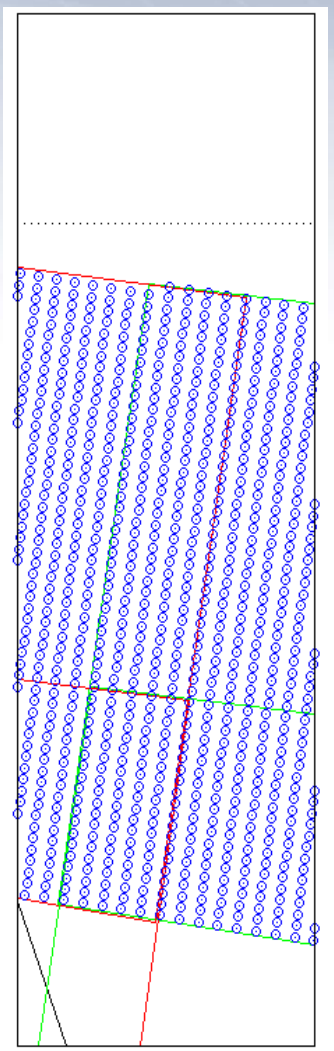
EUMETSAT

PMAp – Multi-sensor co-location for aerosol optical depth retrievals

The GOME-2 PMD / AVHRR / IASI co-location

GOME-2 FM3
Metop-A

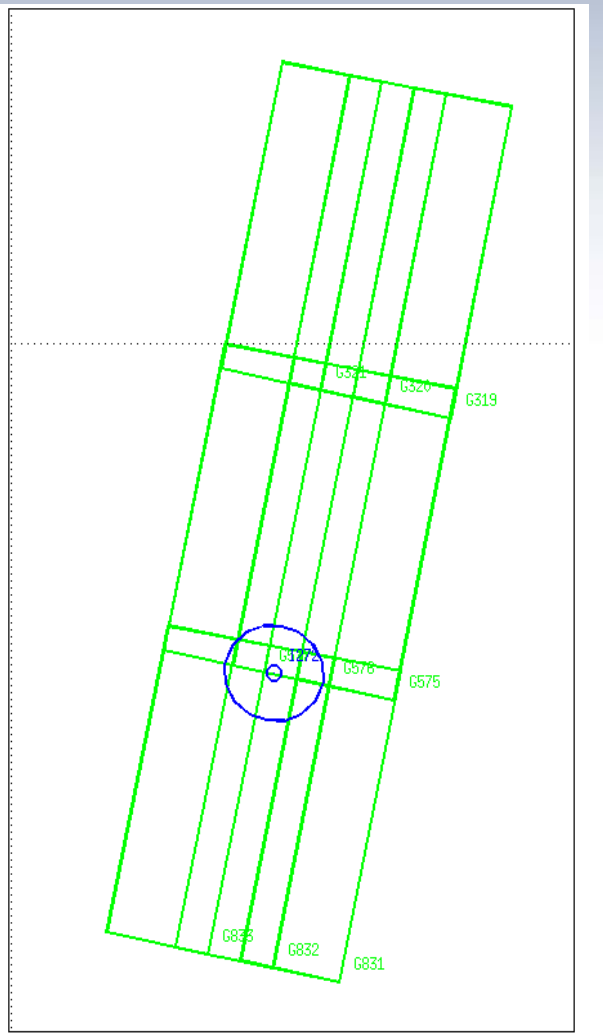
GOME-2 FM2
Metop-B



AVHRR collocation:
an AVHRR pixel is collocated to a GOME-2 PMD pixel if it is inside the GOME-2 pixel

Spatial aliasing due to read-out timing of detectors is taken into account!

IASI collocation:
a IASI pixel may span up to 6 GOME-2 PMD pixels. Which GOME-2 pixel should it be collocated to?



EUMETSAT

PMAp – Multi-sensor co-location for aerosol optical depth retri

Towards continuous calibration of AVHRR channels

GOME-2 FM3 Metop-A

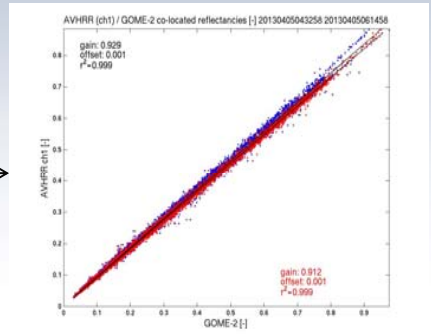
GOME-2 FM2 Metop-B

For PMAp a consistent and continuous AVHRR – GOME-2/IASI radiometric inter-calibration is needed!

AVHRR channels

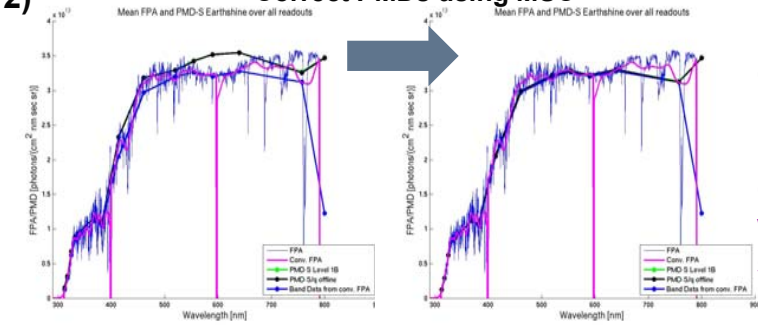
Channel	Central wave-length[µm]	Wavelength range [µm]
1	0.630	0.580 - 0.680
2	0.865	0.725 - 1.000
3A	1.610	1.580 - 1.640
3B	3.740	3.550 - 3.930
4	10.800	10.300-11.300
5	12.000	11.500-12.500

1)



AVHRR vs GOME-2:
Use GOME-2 Main channels to calibrate AVHRR ch 1 and 2

2) **Correct PMDs using MSC**



GOME-2 PMD vs Main channels (MSC):
Make PMDs consistent with main science channel radiances

3) **AVHRR vs IASI:**
Use IASI to calibrate AVHRR ch 3 to 5

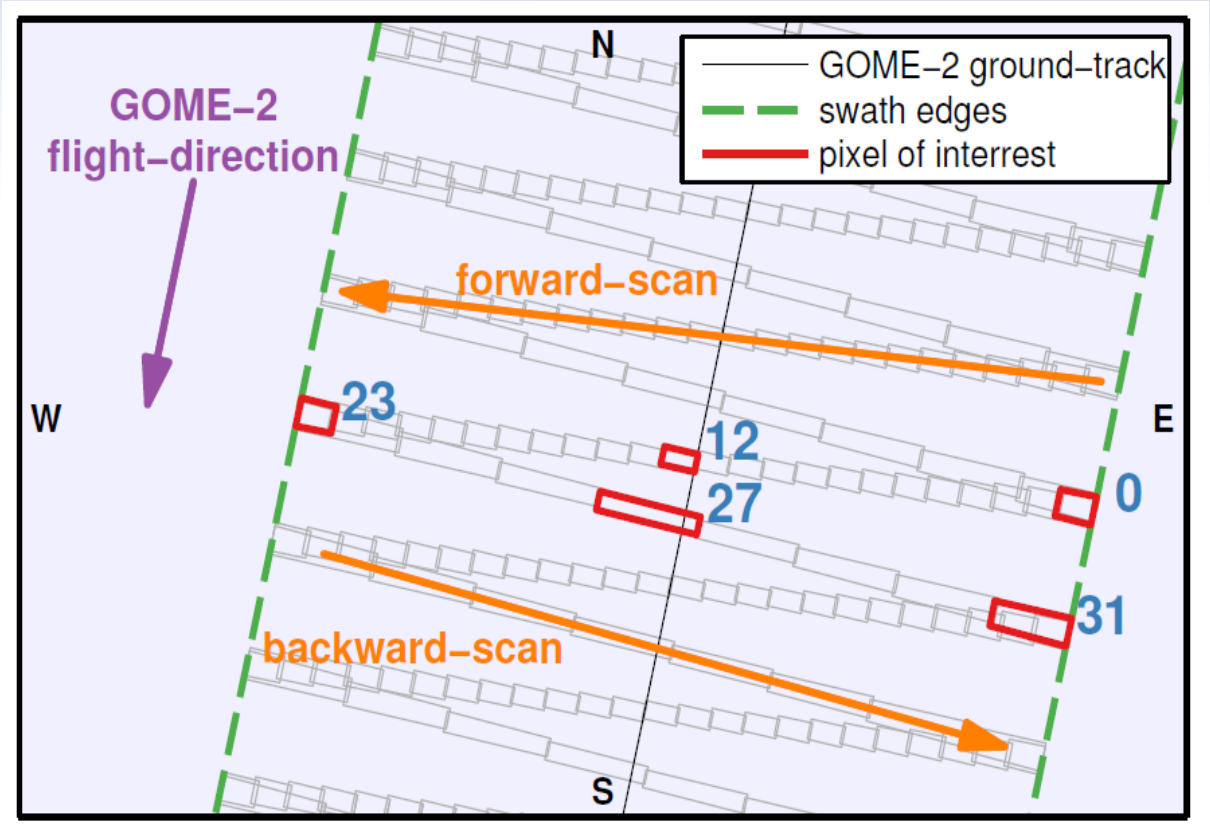
EUMETSAT

GOME-2 pointing and Geo-referencing
Forward and Back-scan – spatial aliasing

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

GOME-2 scanning: 4 seconds forward direction (24 pixel)
2 seconds backward direction (8 pixels)

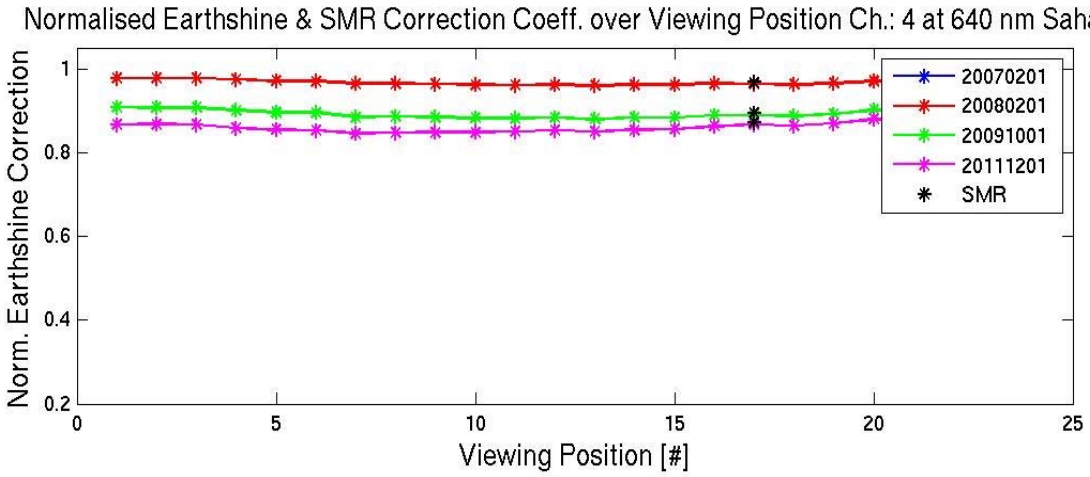


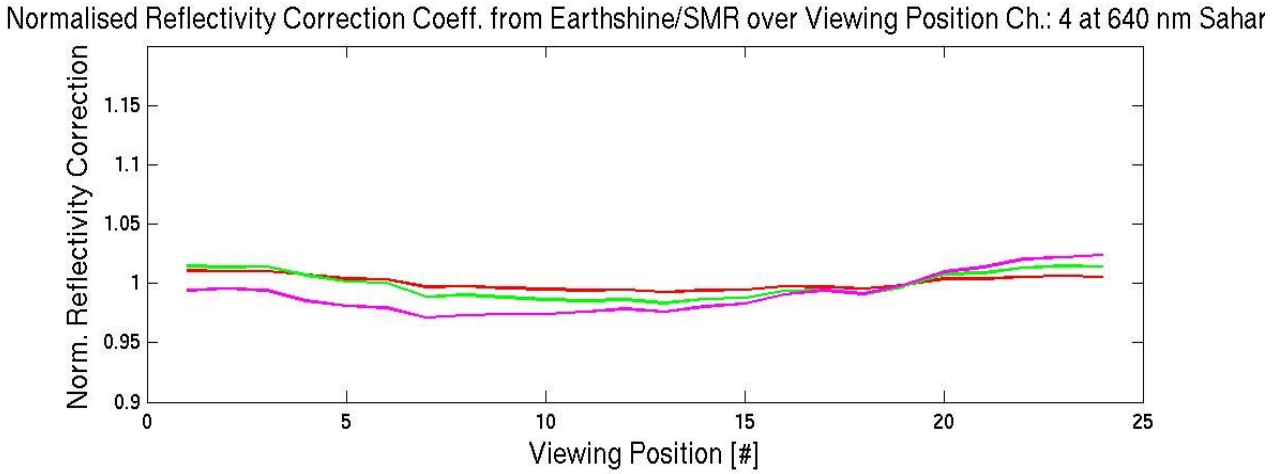
Courtesy: H. Sihler, *MPIC, Mainz*

GOME-2 Metop-A degradation component modelling

Sahara – Reflectivity Degradation / AVHRR ch1-domain

GOME-2 FM3
Metop-A





R2 campaign
Jan 2007– Jan 2012
OPS phase (same PPF 5.3)
Jan 2012 – Oct 2013

Reflectivtiy Degradation

640 nm

Over all GOME-2 viewing angles

at

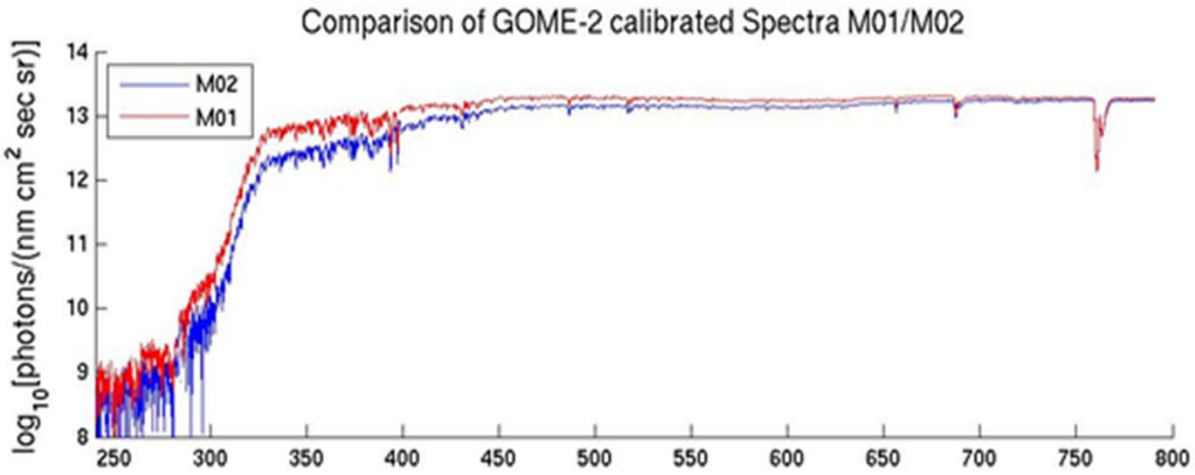
2008/02/01
2009/10/01
2011/12/01

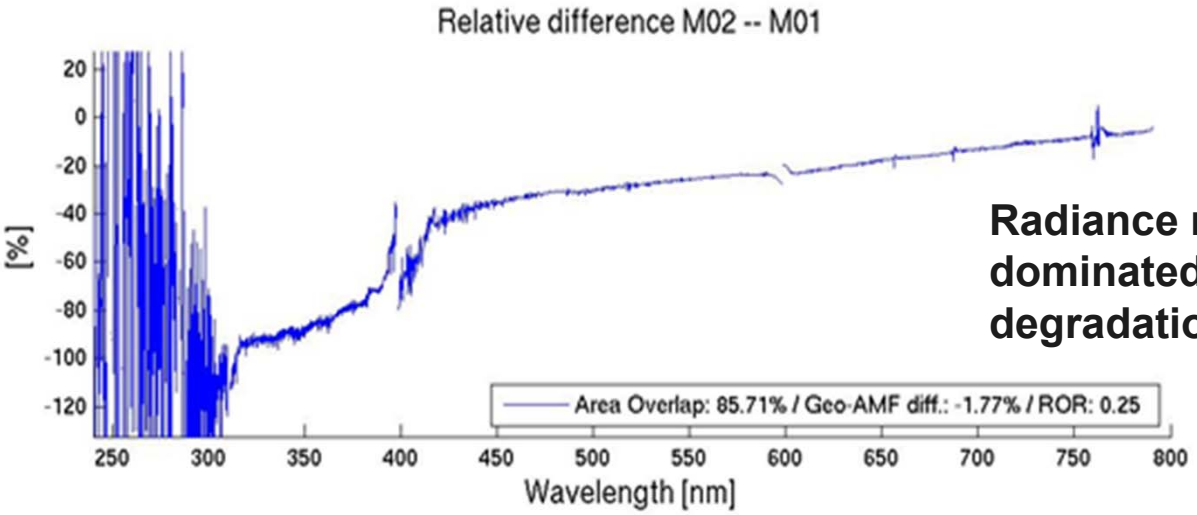
Metop-A/B GOME-2 inter-calibration

Earthshine measurement co-location to Metop-A / FM3 / Radiances

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B





Radiance residuals are dominated by FM3 degradation signature

Global Space-based Inter-Calibration System

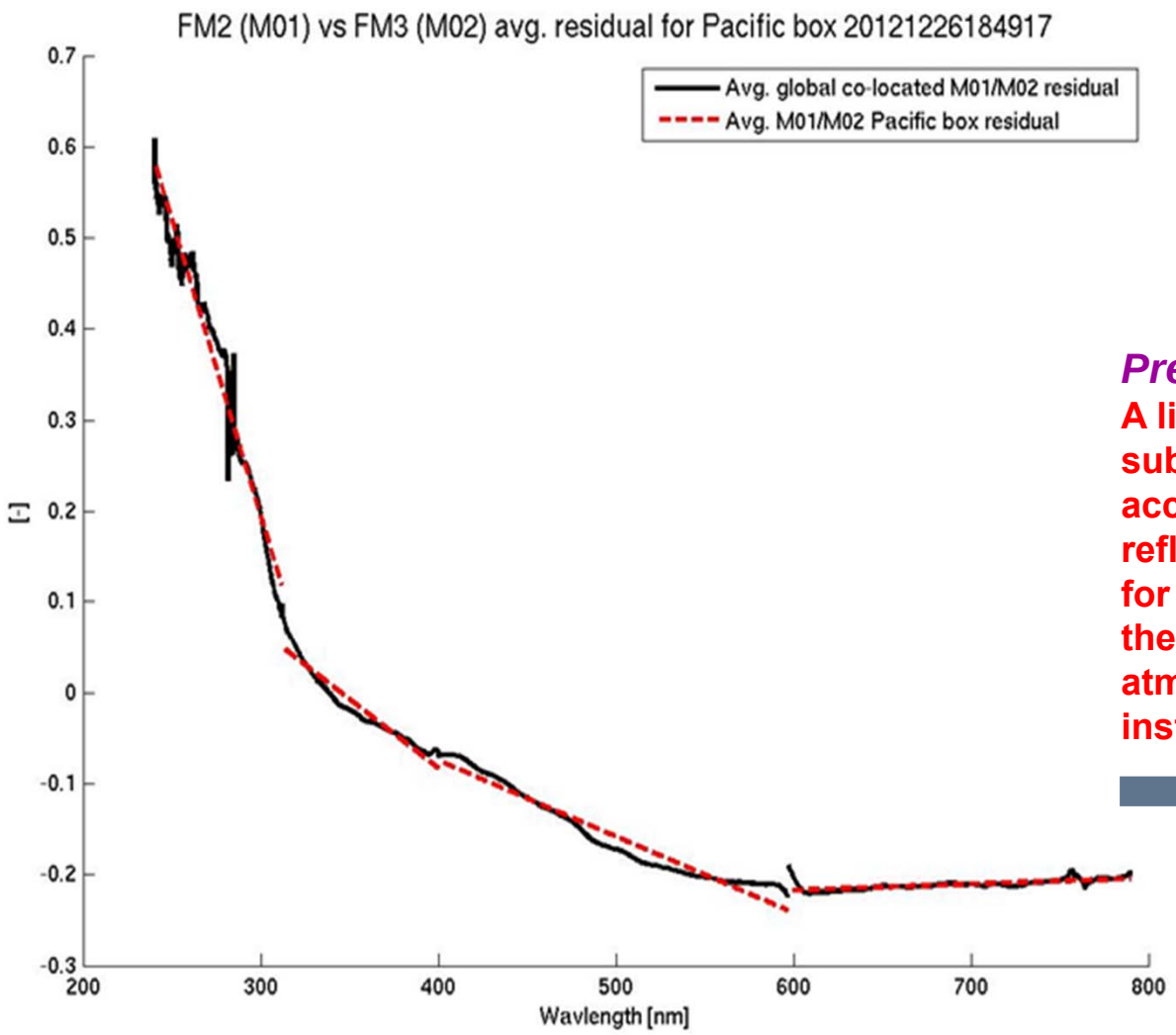
EUMETSAT

Metop-A/B GOME-2 inter-calibration

Earthshine co-located Metop-A/B residuals
Background predominantly from Metop-A degradation

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B



Example for an average over multiple FM2/FM3 residuals in reflectivity.

Prelim. Approach:

A linear background is subtracted per channel to account for the difference in reflectivity-degradation and for broad-band differences in the different observed atmospheric paths per instrument.

Looking for the small scale structures per channel

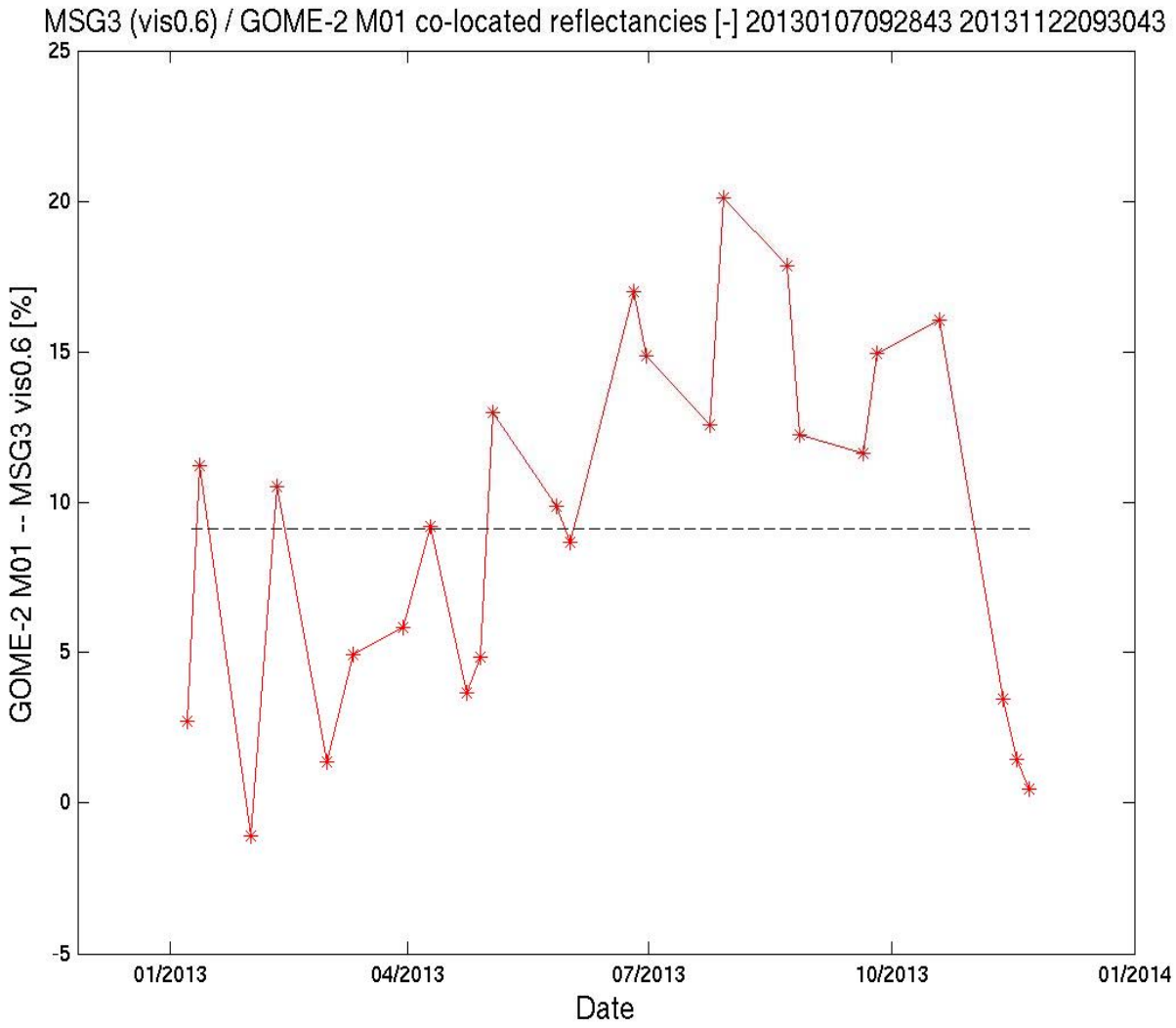
Global Space-based Inter-Calibration System

EUMETSAT

GOME-2/Metop-B reflectivity inter-calibration

SEVIRI ch1/ MSG-3 – preliminary results

GOME-2 FM2
Metop-B



MSG-3 / Seviri ch 1 to GOME-2/Metop-B gain in reflectivity ~8.5%
(Seviri < GOME-2)

1st Jan to 22nd Nov 2013

No spatial aliasing correction yet

No correlation with SZA found

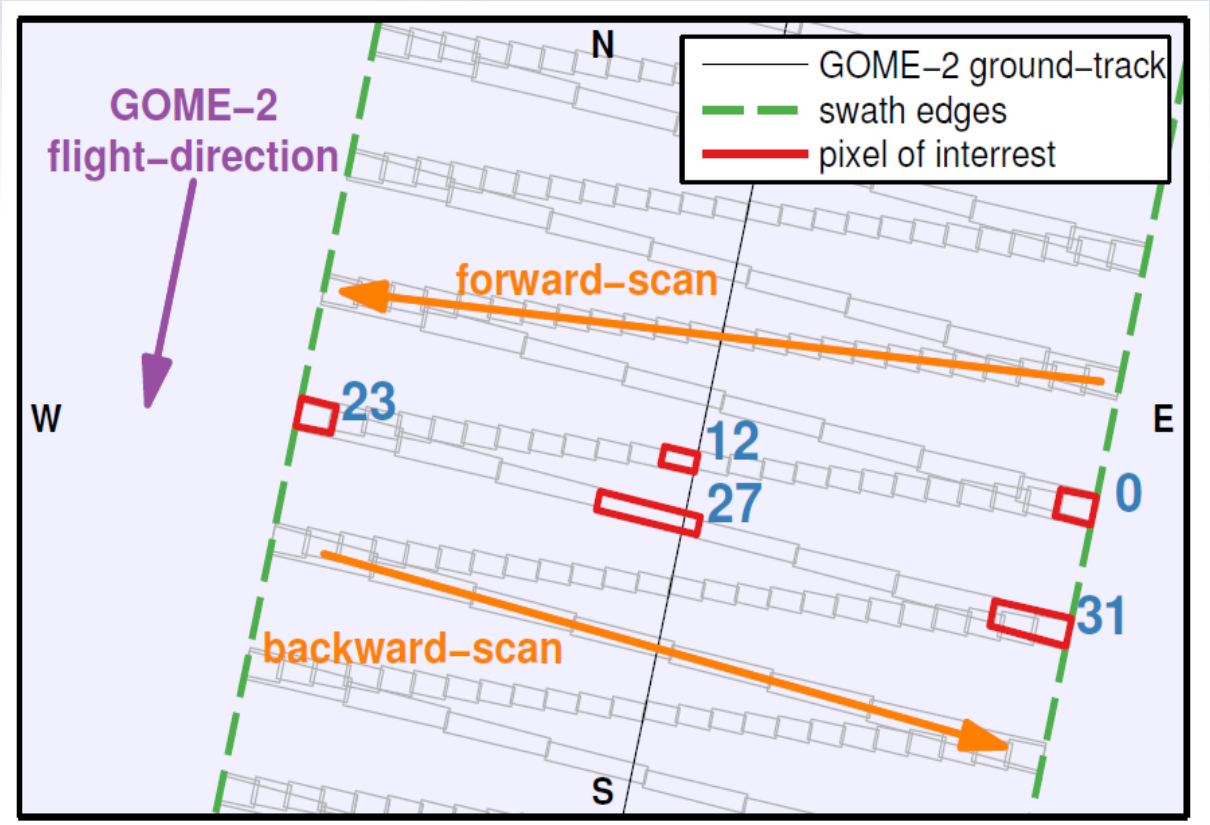
EUMETSAT

GOME-2 pointing and Geo-referencing
Forward and Back-scan – spatial aliasing

GOME-2 FM3 Metop-A

GOME-2 FM2 Metop-B

GOME-2 scanning: 4 seconds forward direction (24 pixel)
2 seconds backward direction (8 pixels)



Courtesy: H. Sihler, *MPIC, Mainz*

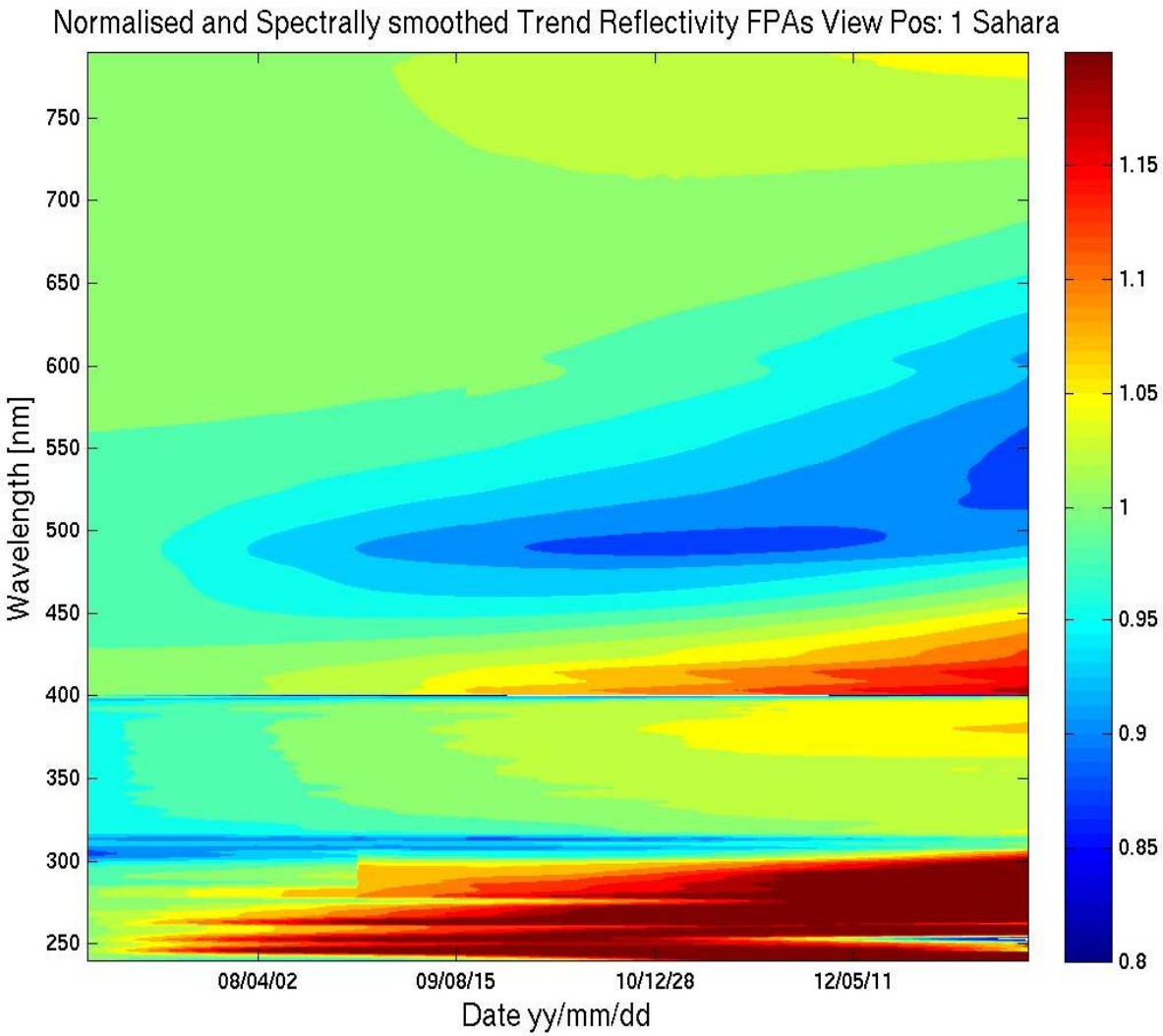
GSICS Global Space-based Inter-Calibration System

EUMETSAT

GOME-2 Metop-A degradation component modelling

Sahara reflectivity – spectral and temporal domain

GOME-2 FM3
Metop-A



R2 campaign
Jan 2007– Jan 2012
OPS phase (same PPF 5.3)
Jan 2012 – Oct 2013

Reflectivity Trend

EUMETSAT