

EPS Metop-C product validation report GOME-2 level 1

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1 INTRODUCTION

1.1 Purpose and Scope

This Product Validation Report provides the results of the calibration and validation testing of the following product(s) in the context of the EUMETSAT Polar System (EPS) Metop-C satellite and the GOME-2 Metop-C Flight Model 1 (FM1) level 1 product commissioning:

GOME_xxx_1A_M01 (GOME-2 Metop-C / FM1 level 1A data product)

GOME_xxx_1B_M01 (GOME-2 Metop-C / FM1 level 1B data product)

The Metop-C satellite was launched from Kouru on 7 November 2018. The satellite commissioning, including Cal-Val testing, aims to verify the satellite and ground segment capability to provide operational services with the required levels of availability, timeliness, and quality. The main objective of Cal-Val testing is to ensure that the quality of the products satisfies the operational requirements.

This report is submitted to the Product Validation Review Board in order to decide on the validation status of the GOME-2 level 1 products. It is intended for the members of the Science and Products Validation Team (SPVT), as well as to the Metop-C commissioning management.

For the validation of GOME-2 Metop-C / FM1 level 1 products, comparisons are frequently made and documented in this report with the currently operational GOME-2 instruments (FM2 and FM3) flying on board Metop-B and Metop-A, respectively, and to the corresponding level 1 products:

GOME_xxx_1A_M01 (GOME-2 Metop-B / FM2 level 1A data product)

GOME_xxx_1B_M01 (GOME-2 Metop-B / FM2 level 1A data product)

GOME_xxx_1A_M02 (GOME-2 Metop-A / FM3 level 1A data product)

GOME_xxx_1B_M02 (GOME-2 Metop-A / FM3 level 1A data product)

1.2 Applicable and Reference Documents

1.2.1 Applicable Documents

AD 1 EPS Programme Calibration and Validation Overall Plan, EUM.EPS.SYS.PLN.02.004

AD 2 GOME-2 Calibration and Validation Plan, EPS.SYS.PLN.01.010, issue 3.1

AD 3 GOME-2 Level 1 Product Generation Specification, EPS.SYS.SPE.990011 v7

AD 4 GOME-2 Level 1 Product Format Specification, EPS.MIS.SPE.97232 v9

AD 5 GOME-2 / Metop-B instrument, PPF Auxiliary-data Change history, EUM/OPS-EPS/TEN/09/0616, v2

AD 6 GOME-2 MetopC PMD Band Definitions 2.0 and PMD Calibration, EUM/OPS-EPS/DOC/18/1036865, v1Draft

AD 7 TNO Space Systems Engineering Gome 2 FM2-2 Instrument Calibration, MO-AD-TPD-GO-0022, I. 2

AD 8 MetOp GOME-2 In-Orbit Verification: Final Report Metop GOME-2 FM1 IN-ORBIT VERIFICATION REPORT PART 2: PERFORMANCE VERIFICATION MO-RP-TPD-GO-0091, 1052978

AD 9 TNO Space Systems Engineering Gome 2 FM1-3 MO-AD-TPD-GO-0024 issue 1

1.2.2 Reference Documents

- [RD1] MetOp-C GOME-2 In-Orbit Verification Plan, MO.PL.ESA.SY.1100, issue 01
- [RD2] GOME-2 Level 1B Product Validation Report No. 3: Operational Status, EUM/MET/REP/08/0103, 1A
- [RD3] EPS Metop-C GOME SIOV Operations Implementation Plan, EUM/OPS-EPS/PLN/18/926242
- [RD4] GOME2 PPF 6.3 Software Release Note, EUM/RSP/DOC/18/1024021, 1D
- [RD5] EPS Generic Product Format Specification (GPFS), EPS.GGS.SPE.96167, v. 6.6
- [RD6] GOME-2 SPA/PQE Software User Manual, EUM/OPS/SUM/11/2479, v1
- [RD7] Investigation on GOME-2 throughput degradation, EUM/LEO/REP/09/0732
- [RD8] GOME-2 / Metop-A Level 1B Product Validation Report No. 5: Status at Reprocessing G2RP-R2, EUM/OPS-EPS/REP/09/0619, 1F
- [RD9] GOME-2 / Metop-B Level 1B Product Validation Report No. 4: Status at Reprocessing G2RP-R1, EUM/MET/REP/08/0327, 2
- [RD10] GOME Annual In-Flight Performance Review 2011, EUM/OPS-EPS/REP/11/0057,
- [RD11] Auxiliary Data Inventory Update GOME2 - Product Processing Facility version 5, EUM/OPS-EPS/DOC/09/0573, v1B.
- [RD12] GOME-2 Metop C PMD Band Definitions and PMD Calibration, EUM/OPS-EPS/DOC/18/1036865, v1 Draft
- [RD13] Cai, et al, Characterization and Correction of Global Ozone Monitoring Experiment-2 Ultraviolet Measurements and Application to Ozone Profile Retrievals, JGR, submitted, 2012.
- [RD14] Cloud retrieval algorithm for GOME-2: FRESCO+, EUM/CO/09/4600000655/RM, 2011.
- [RD15] Support for upgrade to FRESCO+ in the GOME-2 PPF: Final Report, EUM/CO/09/4600000655/RM, 2011.
- [RD16] GOME-2 Error Assessment Study Final Report, Phases I—IV, EUM/CO/01/901/DK, December 2002
- [RD17] GOME-2 Error Assessment Study Final Report, Phase V, EUM/CO/01/901/DK, April 2004
- [RD18] Hartmann, H.W., C.P. Tanzi, J.M. Krijger, and I. Aben, GOME-2 Polarisation Study - Phase C/D: Final Report, RP-GOME2-003SR, SRON, Utrecht, The Netherlands
- [RD19] Koelemeijer, R.B.A., P. Stammes, J.W. Hovenier and J.F. de Haan, "A fast method for retrieval of cloud parameters using oxygen A-Band measurements from GOME", JGR, Vol 106, 3475-3490, 2001
- [RD20] Wang, P. and P. Stammes, FRESCO-GOME2 project "Additions to EPS/MetOp RAO project #3060" EUM/CO/06/1536/FM, Final Report, September 2007.
- [RD21] O3M SAF VALIDATION REPORT, O3M SAF VALIDATION REPORT, issue 3, 2009.
- [RD22] Final Report for RfQ 10/202689: Support for (V)LIDORT Implementation at EUMETSAT, with Statement of Work (SoW) EUM/MET/SOW/10/0301, 31 December 20.
- [RD23] A. Serdyuchenko *et al.*, High spectral resolution ozone absorption cross-sections: Part I. Measurements, data analysis and comparison around 293K, JQSRT, 2012.
- [RD24] A. Serdyuchenko *et al.*, High spectral resolution ozone absorption cross-sections: Part II. Temperature dependence, JQSRT, 2012.
- [RD25] R. Siddans, B.G. Latter, Analysis of GOME-2 (FM201-3), Slit function Measurements, Final Report Eumetsat Contract No. EUM/CO/04/1298/RM (Rider 3), version 1.0, RAL, 2018.
- [RD26] 48th GSAG, Minutes of Meeting, EUM/RSP/MIN/13/691056, version 1, 2013.
- [RD27] 49th GSAG, Minutes of Meeting, 2013.

[RD28] 53rd GSAG, Minutes of Meeting, 2019

1.3 Acronyms and Abbreviations Used in this Document

<i>Acronym</i>	<i>Meaning</i>
AVHRR	Advanced Very High Resolution Radiometer
BUFR	Binary Universal Form for the Representation of meteorological data
CFR	Cloud FRactions
FFT	fast Fourier transform
FWHM	Full Width at Half Maximum
IFOV	Instantaneous Field of View
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
LIDORT	LInearized Discrere Ordinate Radiative Trasfer
NESDIS	National Environmental Satellite and Data Information Service
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real-Time
PDU	Product Dissemination Unit
PMD	polarization measurement device
PPF	level 0 to 1 Product Processing Facility
SMR	Solar Mean Reference
SZA	Solar Zenith Angle
SIOV	Satellite In-Orbit Verification Phase
WLS	White Light Source

1.4 Description of Validation Environment

The product validation has been performed with the following elements:

EUMETSAT Central Ground Segment (CGS):

EPS GS1 running GOME-2 PPF 6.3.1

EPS GS2 running GOME-2 PPF 6.3.1

Since 12.02.2019

EPS GS1 running GOME-2 PPF 6.3.2

EPS GS2 running GOME-2 PPF 6.3.2

See 0 for details of the PPF configuration, including auxiliary files and instrument operation changes.

[RD3] contains a description of the PPF 6.3.1 and PPF 6.3.2 history and changes.

EUMETSAT offline environment MPSTAR:

EPQM-SPQA and jmonx version 1.0.

All analyses makes use of the MPSTAR monitoring database and use data from the OPE GOME database instance on fodbss02 and its EPS rolling archive [RD6].

1.4.1 EUMETSAT technical computing environment (TCE)

The PPF (6.3.0, 6.3.1 and 6.3.2) is run offline (reprocessing) on TCE (*/tcenas/proj/UVN/proc /PPF-GOME-INST* and */tcenas/proj/UVN/proc/working_root_M03*) for dedicated analysis where necessary. A suite of MATLAB prototype and analysis tools is used for most of the analyses presented in this document. This includes, fetching data from the MPSTAR GOME OPE database and direct reading of data from level 1 data files either provided by the tcdras rolling archive (RA) of MPSTAR (*/tcc1/fbf/tcdras/store/*) or from offline reprocessed data (see before). All analysis scripts are available under */tcenas/home/rlang/proc/matlab/procedures*.

Dedicated results and data analysed are stored in */tcenas/home/rlang/data/ProFig/MetopC/*.

1.4.2 Instrument key-data (FM1-3)

The results of the on-ground pre-launch calibration measurements (FM1-3) are gathered in the “key-data” auxiliary file (*GOME_CAL_xx_M03**), which is then used during level 0 to 1B processing. The initial set of key-data from the ground campaign has been used directly after launch and was contained in V 1.01 of the *GOME_CAL_xx_M03* auxiliary file. Updates to key-data and this auxiliary file are discussed in Section 4. If not otherwise specified (because of such updates), the calibration auxiliary file contains the results of the FM1-3 on-ground calibration campaign carried out by TNO/Selex Galileo/ESA SSST from May 2017 to January 2018 with a final delivery of data in January 2019. All documentation along with the key-data set that was used is available here:

</pub/EPS/out/GOME/Calibration-Data-Sets/Calibration-Key-Data/FM1-Metop-C>

The calibration FM1-3 is the follow-on to the initial FM1 calibration (FM1-1) carried out during October 2011 – February 2012, FM1-2 Calibration (January 2016 –March 2016). Details of this initial calibration are in [AD9].

1.4.3 Auxiliary data used for level 0 to 1B processing

Here we list the initial set of key-data used directly after launch and their subsequent updates. See Section 4 for a description of the updates.

<i>Date</i>	<i>Processor Version</i>	<i>AUX data version</i>	<i>PFS version</i>	<i>PGS version</i>
7/11/2018	6.3.0	INS_FM2_1.10	9	7
Launch		STA_FM2_2.00		
		INS_FM3_2.09		
		STA_FM3_2.00		
		INS_FM1_1.01		
		CAL_FM1_1.01		
		COR_FM1_1.01		
		STA_FM1_2.00		
17/12/2018	6.3.1	INS_FM2_1.11	9	7
GIOV		INS_FM1_2.10		
		INS_FM1_1.02		
		CAL_FM1_1.02		
28/01/2019	6.3.1	INS_FM1_103	9	7
CALVAL		CAL_FM1_103		
21/02/2019	6.3.2	INS_FM2_1.12	9	7
CALVAL		INS_FM3_2.11		
		INS_FM1_1.04		

Table 1: Metop-C / FM1 / GOME-2 Processor and Auxiliary data version update for CGS1/EUMETCast/UMARF. Changes are indicated in blue.

For a description of the auxiliary data types and content, see [RD11].

2 THE INSTRUMENT

The Global Ozone Monitoring Experiment–2 (GOME-2) is an optical spectrometer fed by a scan mirror which enables across-track scanning in nadir, as well as sideways viewing for polar coverage and instrument characterisation measurements using the moon. GOME-2 senses the earth's backscattered radiance and extraterrestrial solar irradiance in the ultraviolet and visible part of the spectrum (240–790 nm) at a high spectral resolution between 0.26–0.51 nm. There are 4096 spectral points from four detector channels transferred per individual GOME-2 measurement (see Figure 1).

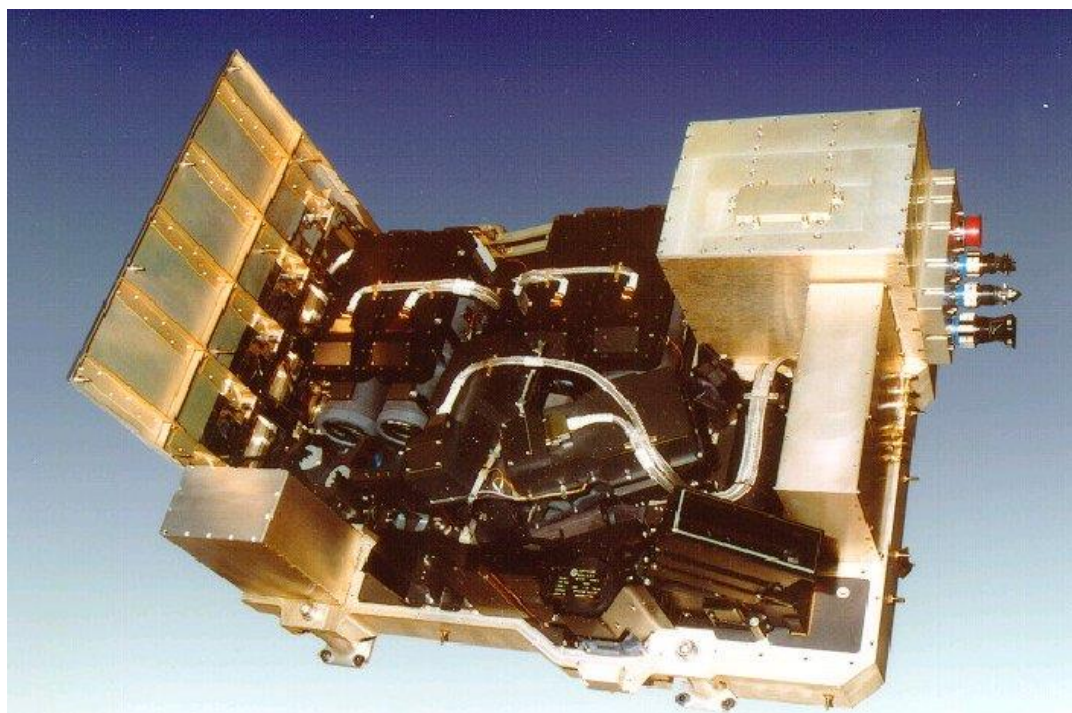


Figure 1: The Global Ozone Monitoring Experiment–2 (GOME-2) Instrument

The footprint size is 80×40 km for main channel data. The instrument also measures the state of linear polarisation of the backscattered earthshine radiances in two perpendicular directions. The polarisation data is down-linked in 15 spectral bands covering the region from 312 nm–800 nm for both polarisation directions with a footprint of 10×40 km.

The recorded spectra are used to derive a detailed picture of the total atmospheric content of ozone and the vertical ozone profile in the atmosphere. They also provide accurate information on the total column amount of nitrogen dioxide, sulphur dioxide, water vapour, oxygen /oxygen dimer, bromine oxide and other trace gases, as well as aerosols and cloud optical properties.

The GOME-2 instrument has been developed by SELEX/Galileo Avionica in Florence, Italy, under a joint contract with EUMETSAT and ESA.

2.1 GOME-2 Optical Layout ([AD2])

The four main channels of the GOME-2 instrument provide continuous spectral coverage of the wavelengths between 240 nm and 790 nm with a spectral resolution full width at half maximum (FWHM) between 0.26 nm and 0.51 nm. Channel characteristics are listed in Table 2 . The optical

configuration of the instrument is shown in Figure 2. Light enters the two-mirror telescope system via the scan mirror. The telescope projects the light beam onto the slit, which determines the instantaneous field-of-view (IFOV) of $0.28^\circ \times 2.8^\circ$ (across-track $\times$ along-track). After it has passed the slit, the beam is collimated again and enters a double Brewster prism for partial split-off to PMD-S, followed by the pre-disperser prism which has two functions. Brewster reflection at the back of the prism splits off part of the p-polarisation direction to PMD-P. The prism furthermore forms a low-dispersion spectrum which is subsequently separated at the channel separator prism into three parts that go to Channel 1 (transmitted beam), Channel 2 (reflected beam), and Channels 3 and 4, respectively. The separation between channels 3 and 4 is performed by a dichroic filter.

A grating in each channel then further disperses the light, which is subsequently focused onto the detector array. Each PMD channel contains a dispersion prism and two additional folding prisms and collimating lenses. PMD-P measures intensity polarised parallel to the spectrometer's slit, and PMD-S measures intensity polarised perpendicular to the spectrometer's slit. The two PMD channels are designed to ensure maximum similarity in their optical properties. The wavelength-dependent dispersion of the prisms causes a much higher spectral resolution in the ultraviolet than in the red part of the spectrum.

Table 2 gives values for GOME-2 FM3. For the overlap regions between the main channels, the wavelengths are given for the 10 % intensity points. For example, at 308 nm, 10 % of the signal is registered in channel 2, and 90 % is registered in channel 1. At 313 nm, 10 % of the signal is registered in channel 1, and 90 % is registered in channel 2. Spectral resolution varies slightly across each main channel; the given values are channel averages.

Channel	Spectral range [nm]	Detector Pixel size [nm]	FWHM [nm]
1	239-313	0.1	0.29
2	308-401	0.1	0.28
3	395-604	0.2	0.55
4	592-791	0.2	0.5
PMD-P PMD-S	312 – 790	0.62 (312 nm)–8.8 (790 nm)	2.9 (312 nm)–37 (790 nm)

Table 2: Channel characteristics of GOME-2 FM1 spectral coverage and resolution (in-flight situation; see also Section 4.7)

The GOME-2 channels can be separated in different bands operating at different integration times. The latter can also vary over the orbit. Nominal integration times in band 1A are 1.5 seconds (6 seconds at high solar zenith angles) and 0.1875 seconds for band 1B to band 4 (1.5 and 0.75 seconds at high SZA). For details on the exact integration times per band during one instrument timeline series, see the GOME-2 monitoring pages in the *timelines* sub-section at this address:

gome.eumetsat.int.->Metop-C

The separation between band 1A and band 1B remains for Metop-C/FM1 at the same position as for FM3 and FM2 on Metop-A and Metop-B respectively, where it was set to detector pixel number 659 on 10 December 2008. This is in accordance with the GOME-1 and SCIAMACHY instrument specifications.

Channel	1	1	2	2	3	4	5/6
Band	1A	1B	2A	2B	3	4	PMD P/S
Used Pixels	659	365	71	787	992	957	256
Valid Spectral Range (nm)	239-283	283-313.5	not valid ¹	308.9-401.9	395.4-603.9	592.6-790	290-790
nm/pixel	0.11	0.11	0.12	0.12	0.21	0.2	2 ²

¹ Because detector pixels are all outside the valid range

² Variable over the channels

Table 3: Main channel band settings of GOME-2 FM2 Metop-C.

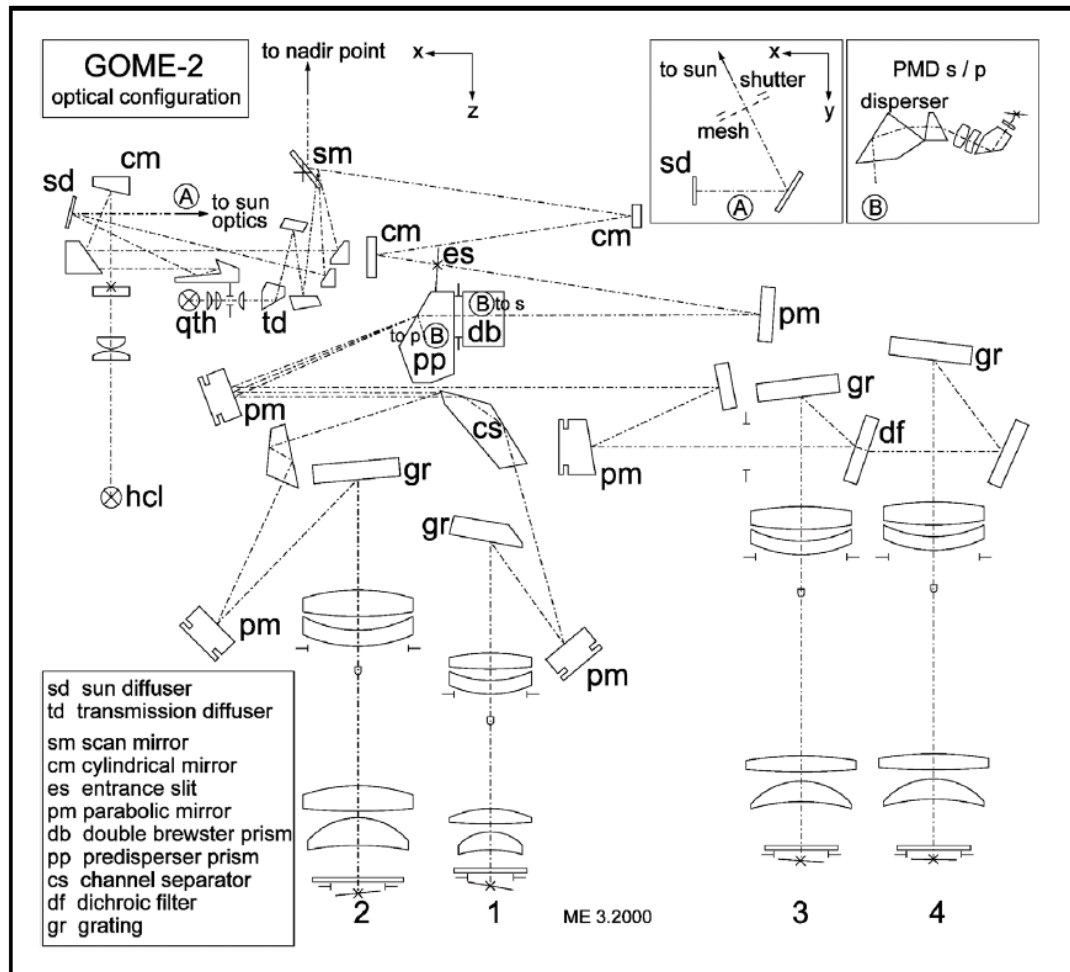


Figure 2: GOME-2 optical layout. The optics lie in one plane (except insets A and B). Nadir is in $-Z$ direction.

2.1.1 Polarisation Measurement Device (PMD) band settings

The 256 detector pixels of both PMD devices of block C, D, and E (see [[RD12]] for specifications) are co-added on board in spectral space and for nominal earthshine measurements in 15 PMD spectral bands. After launch, the PMD settings from version 3.1 from Metop-A/FM3 have been used and are tagged as versions 1.0. These settings were updated during SIOV at 03/12/2018 during orbit 367 to achieve an optimal co-registration between both PMD detectors.

EPS Metop-C product validation report GOME-2 level 1

<i>PMD-P</i>					<i>PMD-S</i>				
<i>Band Nr</i>	<i>Start pixel with respect to Block C</i>	<i>Width</i>	<i>Start</i>	<i>End</i>	<i>Band Nr</i>	<i>Start pixel with respect to Block C</i>	<i>Width</i>	<i>Start</i>	<i>End</i>
0	21	5	311.4841	314.0324	0	21	5	311.6453	314.3629
1	28	4	316.0183	318.0653	1	28	4	316.3703	318.3751
2	36	12	321.5690	329.5130	2	36	12	321.7613	329.6242
3	49	6	331.0130	334.8726	3	49	6	331.1154	334.9539
4	56	5	336.4684	339.7504	4	56	5	336.5411	339.8058
5	83	17	360.9858	378.4973	5	83	17	360.9208	378.3251
6	100	4	379.7173	383.4716	6	100	4	379.5629	383.3848
7	115	19	399.6230	428.0830	7	115	19	399.6670	428.0898
8	137	27	435.2885	493.4616	8	137	27	435.3067	493.5455
9	164	17	496.2063	546.9015	9	164	17	496.2875	547.0117
10	181	2	550.5590	554.2848	10	181	2	550.6785	554.4141
11	185	12	565.8935	614.7271	11	185	12	566.0541	614.9512
12	197	8	619.7339	658.9333	12	197	8	619.9566	658.9582
13	216	4	741.2919	764.8414	13	216	4	741.5233	765.4424
14	222	2	789.9711	798.8035	14	222	2	790.9527	799.8332

Table 4: GOME-2 Metop-C/FM1 PMD band definitions (v2.0) valid from 03./12/2018 (orbit 367).

For more details on the PMD calibration and PMD band settings details, see [RD12] and the summary provided in Section **Error! Reference source not found.**

2.2 GOME-2 Metop-C / FM1 Specifications Summary

<i>Item</i>	<i>Specification</i>
Spectral band (nm)	240-790
Spectral resolution (nm)	0.26-0.51
Spatial resolution (km ²)	80 × 40 (main channels) 80 × 10 (PMD)
Earth coverage (km)	120-1920
Spectral channels	4096 (in four separated optical channels)
Polarization channels	30 (in two separated optical channels)
Calibration system	Spectral lamp, white lamp, solar diffuser (*)
Dimensions	600 mm × 800 mm × 500 mm
Weight	68 kg
Main bus voltage	22-37 V
Power consumption	50 W
Data rate interface	400 kbit

(*) LED source has been disconnected after on-ground testing and it is not available for GOME-2 FM1, WLS source is used for the PPG correction estimate

2.3 GOME-2 Level 1b products

- sun-normalised nadir radiance
- absolute nadir radiance
- absolute sun radiance
- spectral calibration parameters
- sun mean reference spectrum
- effective cloud fraction
- cloud-top pressure
- geo-reference parameters

2.4 GOME-2 Level 2 Products

The Satellite Application Facility (SAF) on Atmospheric Composition Monitoring (AC SAF) has the responsibility for extraction of meteorological or geophysical (level 2) products from GOME. Detailed information on the products, including NRT, offline and data records, with validation and latest images are at this address:

<https://acsaf.org/>

Table 5 contains a product and format cross-reference. The product format type, either HDF5 and/or binary universal form for the representation of meteorological data (BUFR), is given for each product:

	<i>Product</i>	<i>Format Type</i>
<i>NRT product</i>	Total column O3	HDF5 and BUFR
	O3 high- resolution profiles	HDF5 and BUFR
	O3 tropospheric	HDF5 and BUFR
	NO2 column	HDF5 and BUFR
	NO2 tropospheric column	HDF5 and BUFR
	SO2 total column	HDF5 and BUFR
	HCHO total column	HDF5 and BUFR
	Absorbing Aerosol Index	HDF5
	UV index Clear Sky	PNG, HTML
	UV index Cloud corrected	PNG, HTML
<i>Offline products</i>	Total column ozone	HDF5
	O3 high- resolution profiles	HDF5 and BUFR
	O3 coarse-resolution profiles	HDF5
	NO2 column	HDF5
	NO2 tropospheric	HDF5
	SO2 total column	HDF5
	HCHO total column	HDF5
	BrO total column	HDF5
	H2O total column	HDF5
	Absorbing Aerosol Index	HDF5
	Surface UV	
	O3 tropospheric column	HDF5
	O3 tropical tropospheric column	NetCDF

	<i>Product</i>	<i>Format Type</i>
<i>Data Records</i>	Reprocessed Total column ozone	HDF5
	Reprocessed total NO2 column	HDF5
	Reprocessed tropospheric NO2 column	HDF5
	Reprocessed total SO2 column	HDF5
	Reprocessed total HCHO column	HDF5
	Reprocessed total BrO column	HDF5
	Reprocessed total H2O column	HDF5
	Reprocessed OCIO column	HDF5
	Reprocessed LER surface albedo data record	HDF5

Table 5: Level2 AC-SAF Productst and format type list

2.5 Other Useful links

All of the detailed description and specifications are in the GOME-2 Product Guide and on the ESA GOME-2 page. The GOME-2 Product Quality Monitoring website provides summarized information on availability, daily and orbit reports, timelines in use, and product quality. Here is the primary intranet address:

[Home > Service Status > Product Quality Monitoring > GOME-2 instrument](#)

3 GOME FM2 IOV ACTIVITIES

GOME FM1 IOV activities area have been carried out between the LEOP hand-over of the satellite to EUMETSAT/SSST 3 days after launch and the final SIOV meeting on 31 January 2019. The final report issued by ESA-SSST and Selex/Galileo contains all the results of the basic functional and instrument performance tests carried out according to the SIOV plan [RD3]. The results are summarised in the SIOV FM1 report [AD8].

With respect to the purpose of commissioning and calibration/validation activities for the GOME-2 FM1 level 1B product, during this initial IOV phase a couple of essential measures have been implemented predominantly related to the collection of all required data in the MPSTAR OPE and VAL databases for GOME-2/FM1.

In addition to the collection of data and to make sure that all functional requirements for the extraction and analysis of data for level 1b Cal-Val are in place, two additional joint CalVal/IOV activities have been carried out.

1. Adjustment of the on-board PMD band settings.
2. Monitoring and preliminary evaluation of the FM1 IOV phase 4 (cooling down) and the phase 7 throughput-test activities.

A summary of the analysis (point 1) is provided in Section 4.6. The detailed analysis is provided in [RD12]. A summary of the observed signals during the phase 7 test (point 2) and a preliminary summary on the overall signal (throughput) performance is provided in Section 4.12.

Table 6 shows the sequence of timelines which have been issued during the course of the Metop-C / FM1 IOV campaign, as a reference for the current and for future calibration/validation activities, which may involve this timeframe.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
CFM1 IOV timeline schedule																					
Phase	Day L+		1st Timeline start	JD (1-1-2000)	Orbit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	# Orbits per day
1+2	5+6	Mon 12/11										Switch-on and functional tests									
3	7	Wed 14/11	310-01:24:09	8318	100		G11W	G11W	G11W	CAL4W	1920W	change rfo	manoeuvre	manoeuvre	CAL4W	change rfo	G11W	G11W	G11W		13
	8	Thu 15/11	310-22:29:15	8319	113	G11W	G11W	G11W	G11W	G11W	G11W	G11W	manoeuvre	manoeuvre	CAL4W	G12W	G12W	G12W	G12W		14
	9	Fri 16/11	310-22:04:45	8320	127	G12W	G12W	1920W	CAL4W040	CAL4W038	CAL4W	1920W	NADIRW	NADIRW	NADIRW	NADIRW	NADIRW	NADIRW	NADIRW	NADIRW	15
	10	Sat 17/11	321-00:23:43	8321	142	NADIRW	NADIRW	NADIRW	CAL4W	NADIRW	CAL6W	360W	360W	360W	360W	Deleted due to conflict with SSR	360W	360W	360W		14
	11	Sun 18/11	322-00:01:25	8322	156	360W	360W	360W	CAL4W	360W	CAL6W	360W	360W	360W	360W	360W	360W	360W	360W		14
	12	Mon 19/11	322-22:29:07	8323	170	360W	360W	360W	CAL4W	360W	CAL6W	360W	manoeuvre	manoeuvre	G11W	G11W	G11W	G11W	G11W		14
	13	Tue 20/11	323-22:12:25	8324	184	G11W	G11W	G11W	CAL4W	G11W	CAL6W	G12W	G12W	G13W	G13W	G13W	G14W	G14W	G14W		14
	14	Wed 21/11	323-22:56:41	8325	198	NSW	NSW	NSW	CAL4W	NSW	CAL6W	NSW	NSW	NSW	NSW	NSW	NSW	NSW	NSW	NSW	15
	15	Thu 22/11	326-00:17:11	8326	213	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	16	Fri 23/11	326-22:56:16	8327	227	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	17	Sat 24/11	326-22:25:22	8328	241	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	18	Sun 25/11	326-22:14:29	8329	255	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	19	Mon 26/11	326-22:52:26	8330	269	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	15
	20	Tue 27/11	326-00:14:09	8331	284	CAL6W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	MOON2W	1920W	1920W	1920W	MOON2W		14
	21	Wed 28/11	326-22:52:09	8332	298	1920W	MOON2W	1920W	MOON2W	1920W	CAL6W	1920W			1920W	1920W	1920W	1920W	1920W		14
	22	Thu 29/11	326-22:22:15	8333	312	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	QUICKFPA	QUICKPMD	1920W	1920W	1920W	1920W	1920W		14
	23	Fri 30/11	333-22:11:21	8334	326	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	24	Sat 01/12	333-22:50:27	8335	340	1920W	1920W	1920W	CAL4W040	CAL4W038	CAL4W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	15
	25	Sun 02/12	333-00:10:54	8336	355	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	26	Mon 03/12	333-22:49:59	8337	369	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	DSM sat	1920W	1920W	1920W	1920W	1920W	1920W		14
	27	Tue 04/12	333-22:29:04	8338	383	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	28	Wed 05/12	333-22:08:09	8339	397	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	29	Thu 06/12	333-22:47:14	8340	411	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	15
	30	Fri 07/12	341-00:07:41	8341	426	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	31	Sat 08/12	341-22:46:40	8342	440	1920W	1920W	1920W	1920W	1920W	CAL6W	1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
	32	Sun 09/12	342-22:25:50	8343	454	1920W	1920W	1920W	CAL4W	1920W		1920W	1920W	1920W	1920W	1920W	1920W	1920W	1920W		14
4	33	Mon 10/12	343-22:04:54	8344	468	1920W	1920W	1920W	1920W	MOON2W	255K THRUPH4	THRUPH4	THRUPH4	250K THRUPH4	THRUPH4	THRUPH4	245K THRUPH4	THRUPH4	THRUPH4		14
	34	Tue 11/12	344-22:43:58	8345	482	THRUPH4	THRUPH4	THRUPH4	240K THRUPH4	THRUPH4	THRUPH4	DALE/PMD FLT+235K THRUPH4	THRUPH4	THRUPH4	THRUPH4	THRUPH4	THRUPH4	THRUPH4	THRUPH4	THRUPH4	15

5	35	Wed 12/12	22-01-54	8346	497	Change r/o	G11	G11	CAL4	Change r/o	G11	G11	G11	G11	G11	G11	G11	G11	G11	G11		14
	36	Thu 13/12	22-01-54	8347	511		G11	G11	CAL4		G12	G12	G12	G12	G12	G12	G12	G12	G12	G12		14
	37	Fri 14/12	22-01-54	8348	525		G12	G12	G12	G12	CAL6	1920	NADIR	NADIR	NADIR	NADIR	NADIR	NADIR	NADIR	NADIR		14
	38	Sat 15/12	22-01-54	8349	539		NADIR	NADIR	NADIR	NADIR	CAL6	NADIR	NADIR	960	360	360	360	360	360	360		14
	39	Sun 16/12	22-01-54	8350	553		360	360	360	CAL4Q40	CAL4Q38	CAL6	360	360	360	G71	G71	G71	G71	G71	G71	15
	40	Mon 17/12	22-01-54	8351	568		G71	G71	G71	CAL4	CAL5	CAL6	G72	G72	G72	G72	G73	G73	G73	G73		14
	41	Tue 18/12	22-01-54	8352	582		NADIR	PMDRAW	PMDRAW	CAL4	NS	CAL6	NS	NS	1920	1920	1920	1920	1920	1920		14
6	42	Wed 19/12	22-01-54	8353	596		1920	1920	1920	CAL4	1920	CAL6	SHUTTER	CAL0	1920	1920	1920	1920	1920	1920		14
	43	Thu 20/12	22-01-54	8354	610		1920	1920	1920	CAL4	1920	CAL6	CAL0	Co-add CAL01	CAL02	CAL06	CAL03	CAL04	CAL05	CAL0		14
7	44	Fri 21/12	22-01-54	8355	624		1920	1920	1920	CAL4	CAL5	CAL6	CAL0	1920	1920	NADIR	NADIR	PMDRAW	1920	1920	1920	15
	45	Sat 22/12	22-01-54	8356	639		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	46	Sun 23/12	22-01-54	8357	653		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	47	Mon 24/12	22-01-54	8358	667		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	48	Tue 25/12	22-01-54	8359	681		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	49	Wed 26/12	22-01-54	8360	695		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	MOON2	1920	MOON2	1920	1920	1920	MOON2	15
	50	Thu 27/12	22-01-54	8361	710		1920	MOON2	1920	MOON2	1920	CAL6	CAL0	1920	MOON2	1920	1920	1920	1920	1920		14
	51	Fri 28/12	22-01-54	8362	724		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	52	Sat 29/12	22-01-54	8363	738		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	53	Sun 30/12	22-01-54	8364	752		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	54	Mon 31/12	22-01-54	8365	766		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920	1920	15
	55	Tue 01/01	22-01-54	8366	781		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	56	Wed 02/01	22-01-54	8367	795		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	57	Thu 03/01	22-01-54	8368	809		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	58	Fri 04/01	22-01-54	8369	823		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	59	Sat 05/01	22-01-54	8370	837		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920	1920	15
	60	Sun 06/01	22-01-54	8371	852		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	61	Mon 07/01	22-01-54	8372	866		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	62	Tue 08/01	22-01-54	8373	880		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	63	Wed 09/01	22-01-54	8374	894		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	manoeuvre	1920	1920	1920	1920	1920	1920	15
	64	Thu 10/01	22-01-54	8375	909		1920	1920	CAL4	DSM test	235K THRUHP6	THRUHP6	THRUHP6	240K THRUHP6	THRUHP6	THRUHP6	245K THRUHP6	THRUHP6	THRUHP6	THRUHP6		14
	65	Fri 11/01	22-01-54	8376	923		THRUHP6	THRUHP6	250K THRUHP6	THRUHP6	THRUHP6	255K THRUHP6	THRUHP6	THRUHP6	THRUHP6	250K THRUHP6	THRUHP6	245K THRUHP6	THRUHP6	THRUHP6		14
	66	Sat 12/01	22-01-54	8377	937		THRUHP6	THRUHP6	240K THRUHP6	THRUHP6	THRUHP6	235K THRUHP6	THRUHP6	THRUHP6	THRUHP6	THRUHP6	THRUHP6	THRUHP6	THRUHP6	THRUHP6		14
	67	Sun 13/01	22-01-54	8378	951		1920	1920	1920	CAL4	1920	CAL6	CAL0	1920	1920	1920	1920	1920	1920	1920		14
	68	Mon 14/01	22-01-54	8379	965	Ops timeline start using the common 29 days sequence, and synched with Metop-B cycle																

Table 6: GOME-2 Metop-C/ F12 IOV timeline schedule as run.

4 INTERNAL EUMETSAT VALIDATION

For the monitoring of housekeeping data like thermal, electrical, and scanning statistics, please see SIOV report 0

4.1 Monitoring Signals from internal Light sources (A4.2)

The monitoring of the signals of the internal light sources has been carried out during SIOV [AD8] and has been done on a regular basis since start of the routine monitoring activities on MPSTAR OPE and VAL as of 16 November 2018. Orbit, daily and long-term reports are available on the GOME-2 monitoring web site:

<http://gome.eumetsat.int>

The daily reports comprise the average daily white light source (WLS) measurement, the spectral light source measurements (SLS). For the signal performance of the calibration sources, see Section 4.1. In the figures that follow we show some exemplary results for signal and standard deviation of a daily measurement taken 24 January 2019 in Figure 3 and for a spectral light source measurement in Figure 4. The mean signals and standard deviations are within the expected ranges (see also SIOV report [AD8]).

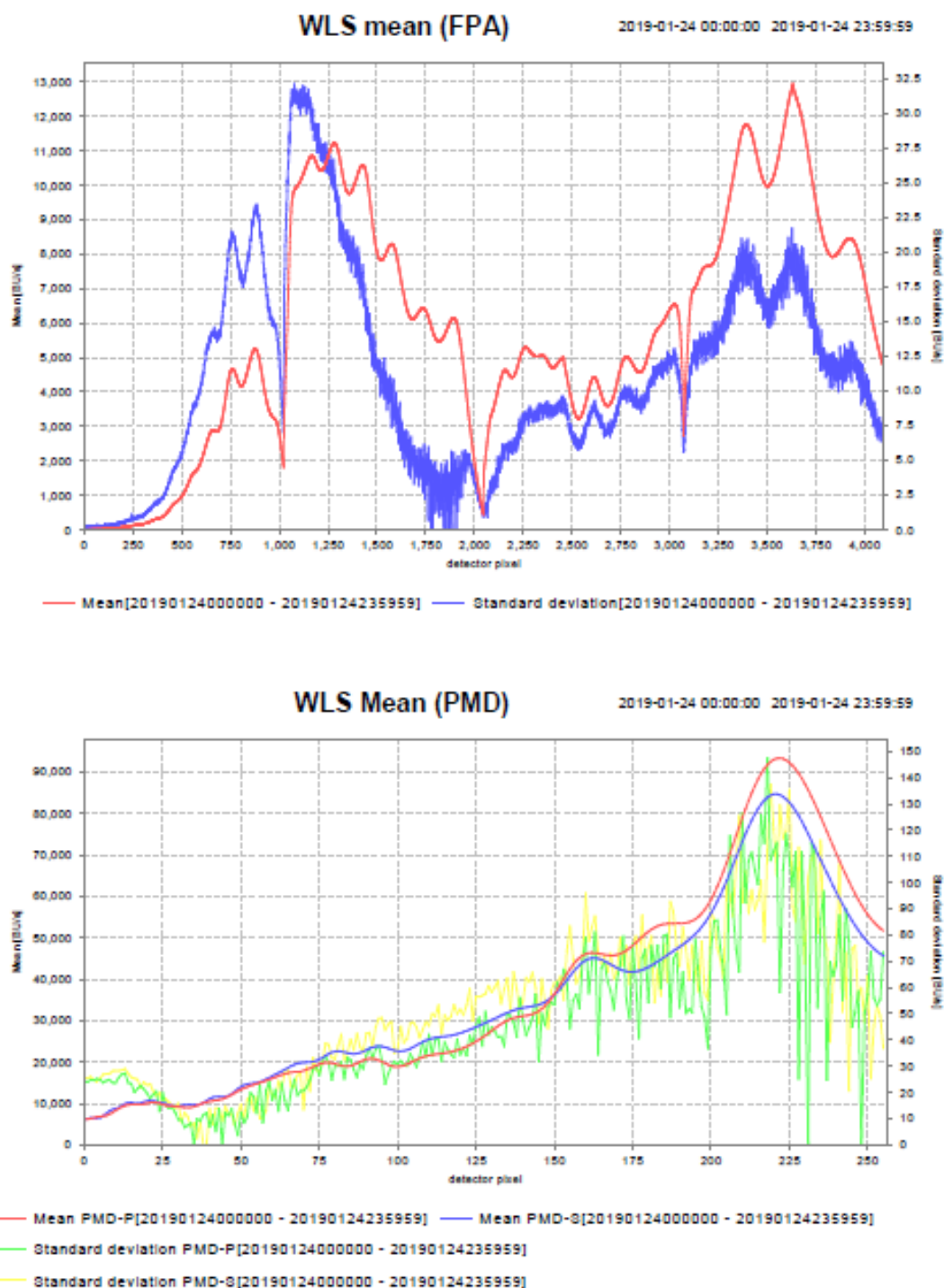


Figure 3: White-light source daily averaged measurements from main channels (upper panel) and PMD channels (lower panel).

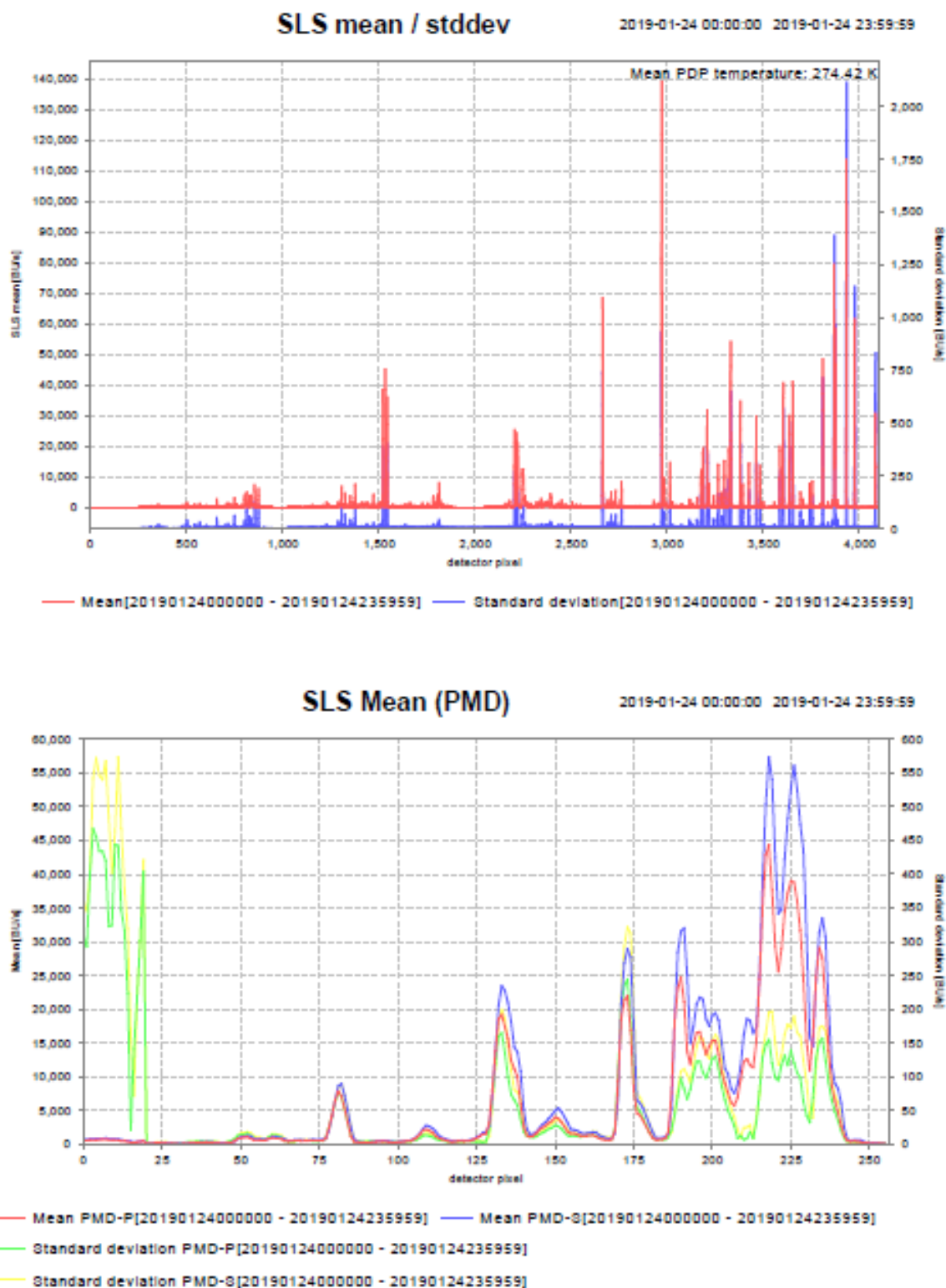


Figure 4: Spectral light source daily averaged measurements from main channels (upper panel) and PMD channels (lower panel).

4.2 Dark signal correction (A4.3.1)

Since 14 November 2018, dark signals have been routinely monitored and reported for Metop-C / FM1. The orbit and daily reports are available on this web page:

<http://gome.eumetsat.int>

(for days before 17 January 2019: <http://oislab.eumetsat.int/epsreports/html/index.php?instrument=GOME&sat=M03>)

A detailed evaluation of the dark-signal performance of FM1 is provided with the IOV report [AD8]. We also provide the longer-term performance of the electronic offset, the leakage current and the dark signal noise.

4.2.1 Dark signal offset

Here we provide the dark signals for the main channel and the PMDs at their most common integration times and at nominal detector temperatures

The mean values provided in Table 7 have been derived from the IOV analysis of dark signals. These values are also used as “default” dark offset values for the processing in the case where no valid dark measurements would be available for a given integration time and detector temperature.

<i>Channel</i>	<i>1</i>	<i>1</i>	<i>2</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5/6</i>
Band	1A	1B	2A	2B	3	4	PMD P/S
Used Pixels	659	365	71	787	992	957	256
Valid Spectral Range (nm)	239-283.2	283.3-313.5	not valid ¹	308.9-401.9	395.4-603.9	592.6-790	290-790
nm/pixel	0.11	0.11	0.12	0.12	0.21	0.2	2 ²
Predefined dark signal electronic offset (BU)	1494.5	1494.5	1490	1490	1495	1498	1500/1500

Table 7: GOME averaged dark signal offset for main channels and PMDs

4.2.2 Dark signal components

The figures in this section show band-averaged results for dark-signal electronic offset (plotted in blue), leakage signal (plotted in orange) and dark-signal noise. Note that the dark-signal measurements for different integration times per band are taken at a different part of the ascending orbit and therefore at different SZAs. Even though all dark measurements ought to be taken “well within” eclipse, recent analysis of the timelines with the new GOME Time Line (GTL) builder tool at EUMETSAT indicates that some of the dark measurements may suffer from (twilight) stray light—especially when taking the variation of the “shallowness” of the eclipse over the seasonal cycle into account. The latter is likely to cause the observed seasonal cycle in the noise signals, which varies significantly with integration time (which are related to different SZA or positions within the eclipse). This effect cannot be totally avoided because there is only a finite amount of time available for which dark-measurements are well in eclipse, and the design of the in-orbit instrument timeline is therefore a trade-off between systematic errors due to stray-light levels and systematic errors related to the amount of measurements, that is to say the acquired measurements statistics and therefore the error on the averaged calibration spectrum.

After the switch to nominal detector temperatures on 11 December 2018, “monthly” calibration timelines have been issued daily till the end of the SIOV timeline sequence (12 January 2019). Therefore, during this intermediate time period, the noise values behave more similar to the noise values taken on the following monthly calibration days. The larger scatter is due to different positions in the eclipse where the dark measurements are derived.

In the graphs in this section the data are presented as follows, unless otherwise noted:

- The band-averaged electronic offset signal range in BU is on the left axis.
- The right axis lists leakage current in BU/sec in orange. The peaks in the leakage current on 12 and 13 January 2019 are due to the Throughput test that has been performed in those days. The behaviour is nominal.
- Band-averaged dark signal noise (for all operational integration times) is in blue in BU.

Note: The Band 2A results are not reported here because the data is outside the valid spectral range. The wavelength range covered per band is again given in Table 6

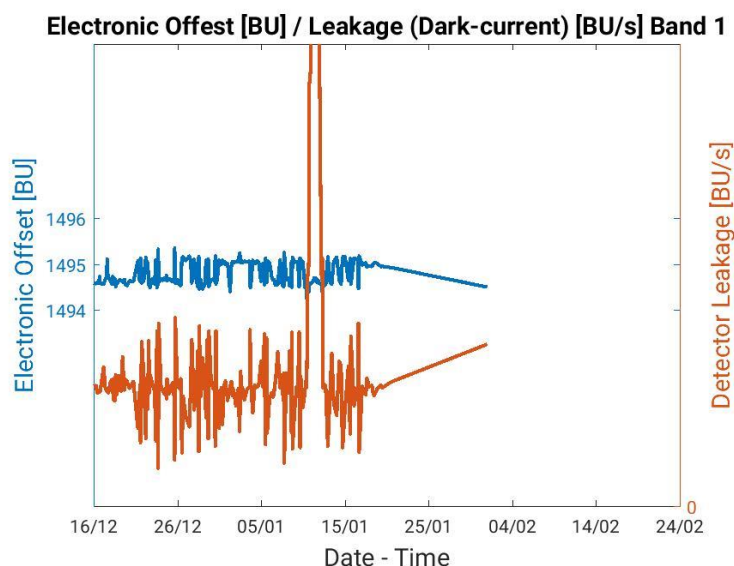


Figure 5: Band 1A averaged electronic offset (blue plots) and leakage current (orange plots).

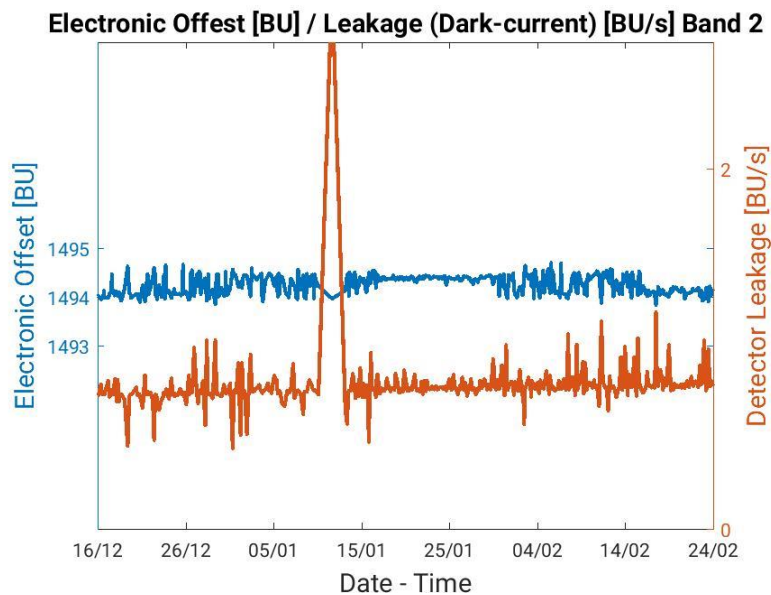


Figure 6: Band 1B averaged electronic offset (blue plots) and leakage current (orange plots).

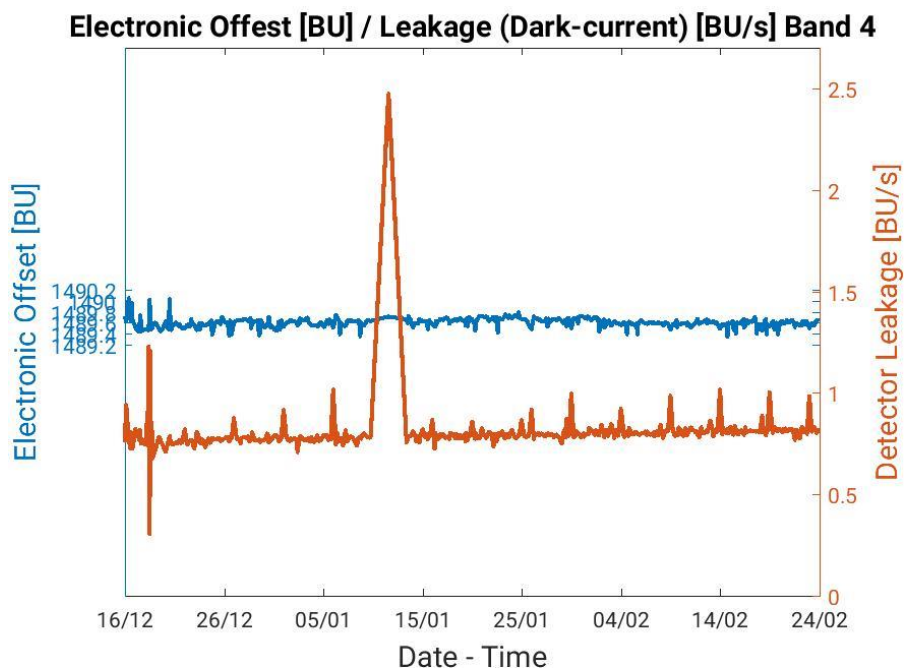


Figure 7: Band 2B averaged electronic offset (blue plots) and leakage current (orange plots).

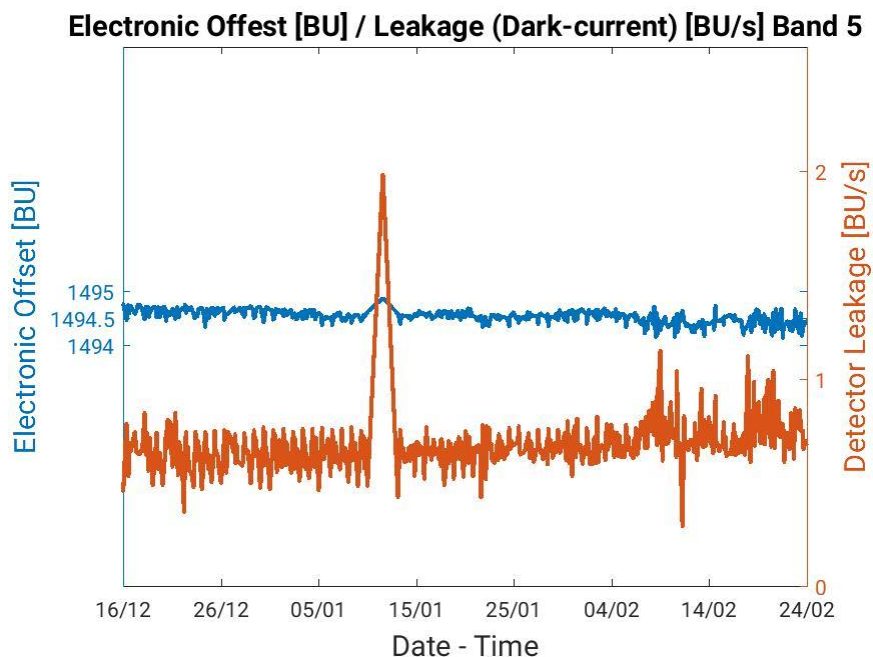


Figure 8: Band 3 averaged electronic offset (blue plots) and leakage current (orange plots).

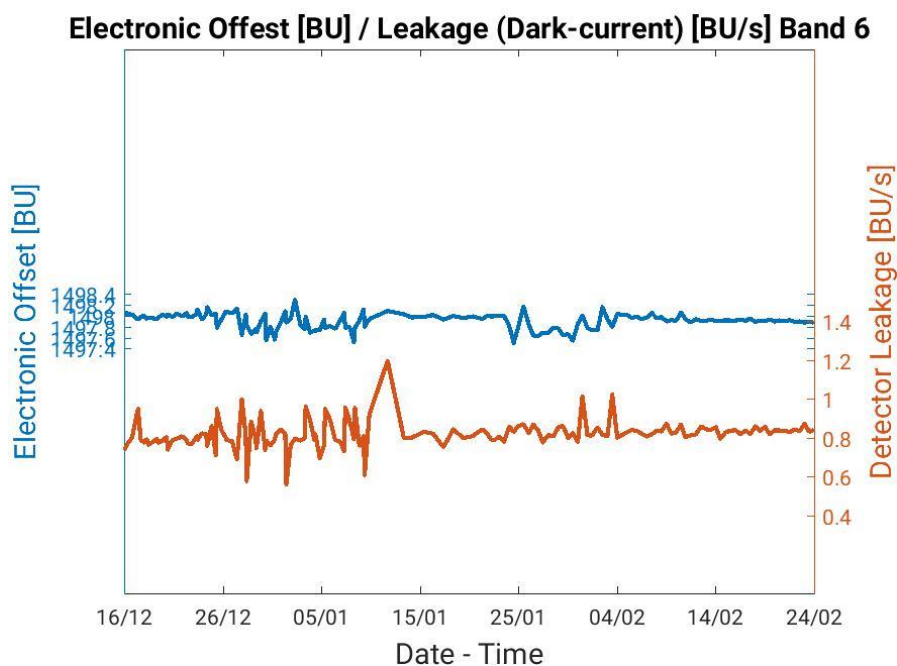


Figure 9: Band 4-averaged electronic offset (blue plots) and leakage current (orange plots).

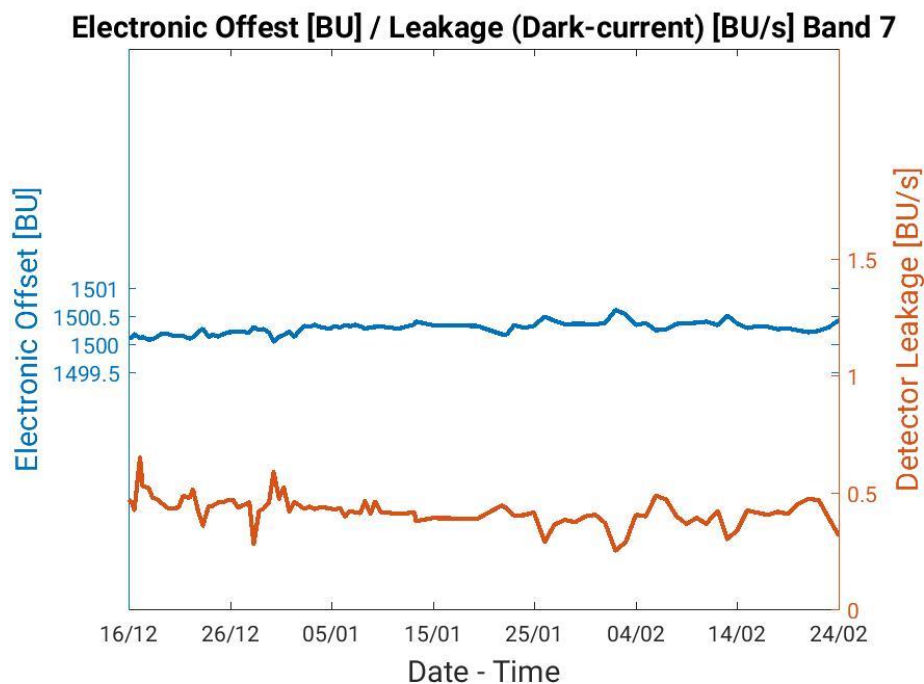


Figure 10: PMD-P-averaged electronic offset (blue plots) and leakage current (orange plots).

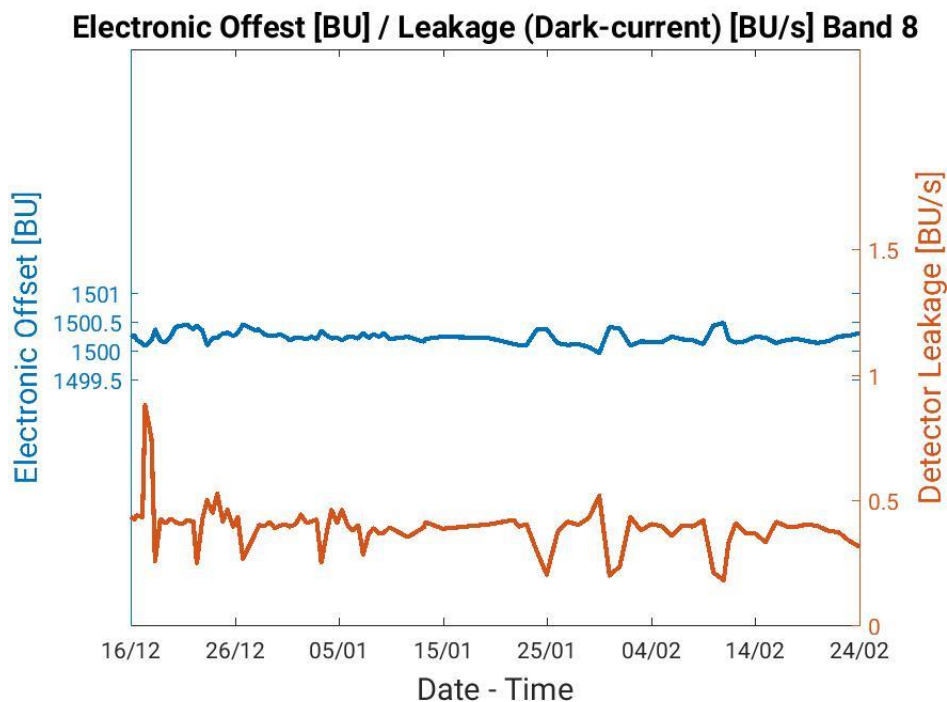


Figure 11: PMD-S-averaged electronic offset (blue plots) and leakage current (orange plots).

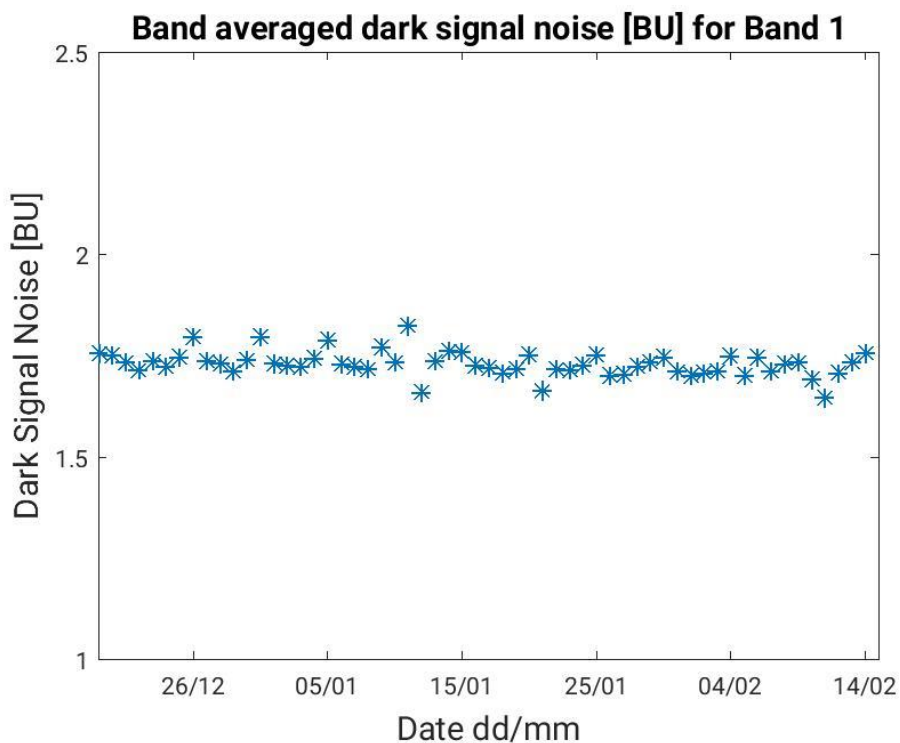


Figure 12: Band 1A-averaged noise.

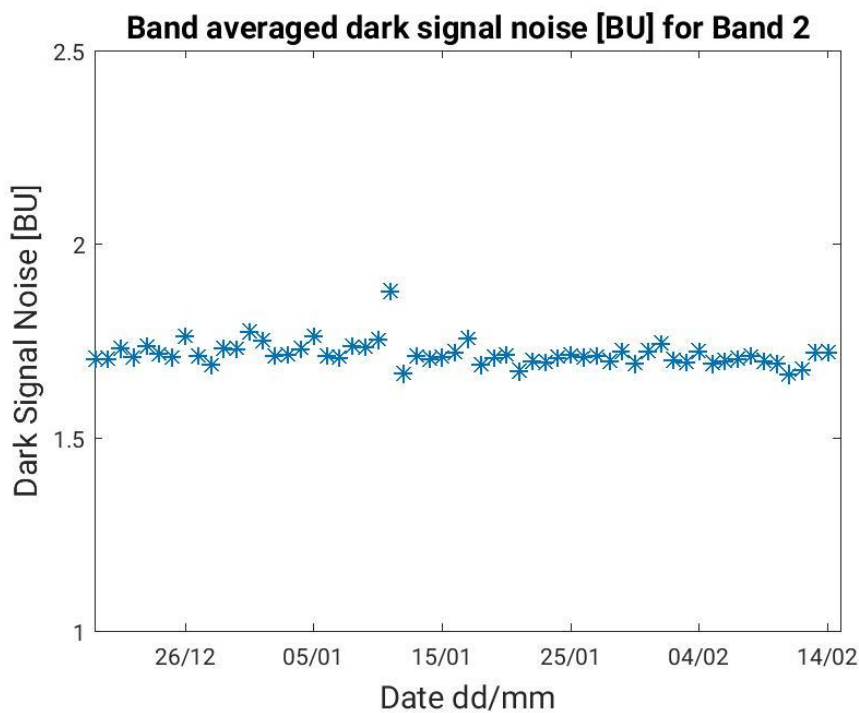


Figure 13: Band 1B-averaged noise.

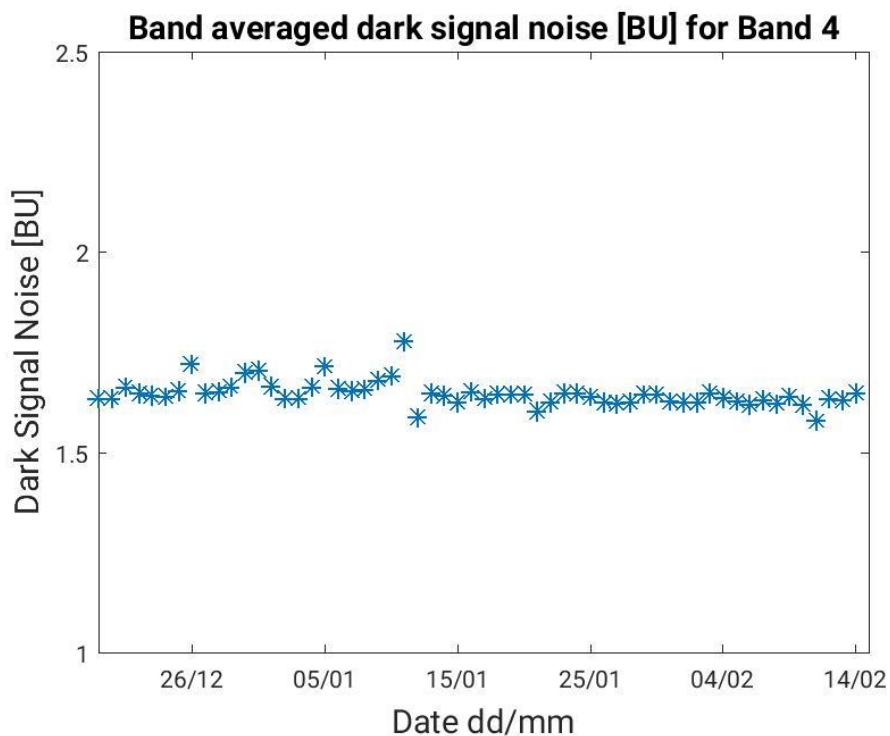


Figure 14: Band 2B-averaged noise.

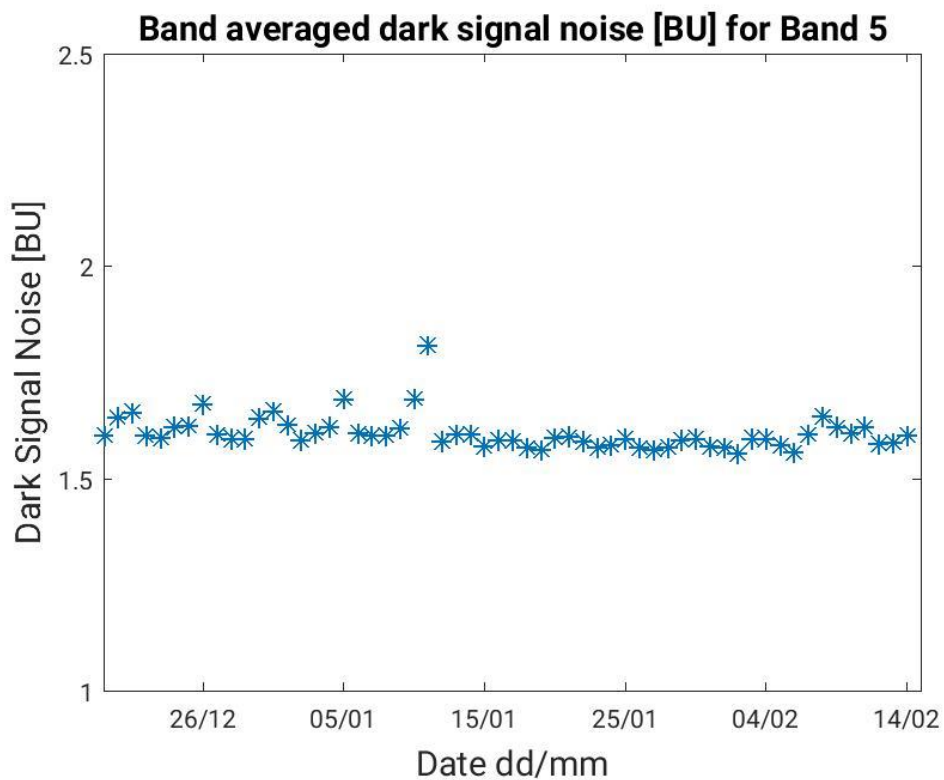


Figure 15: Band 3-averaged noise.

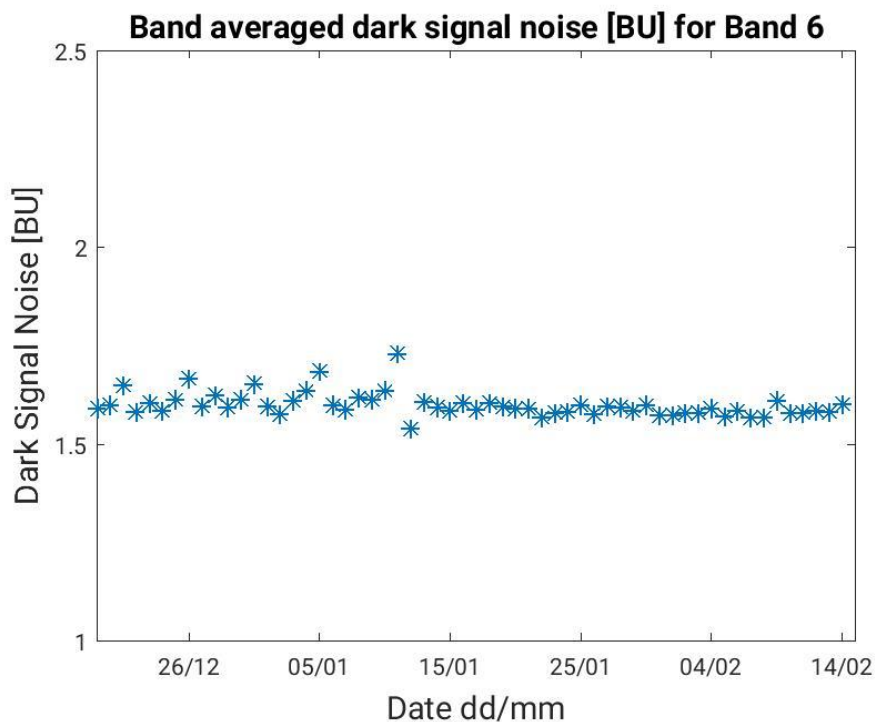


Figure 16: Band 4-averaged noise.

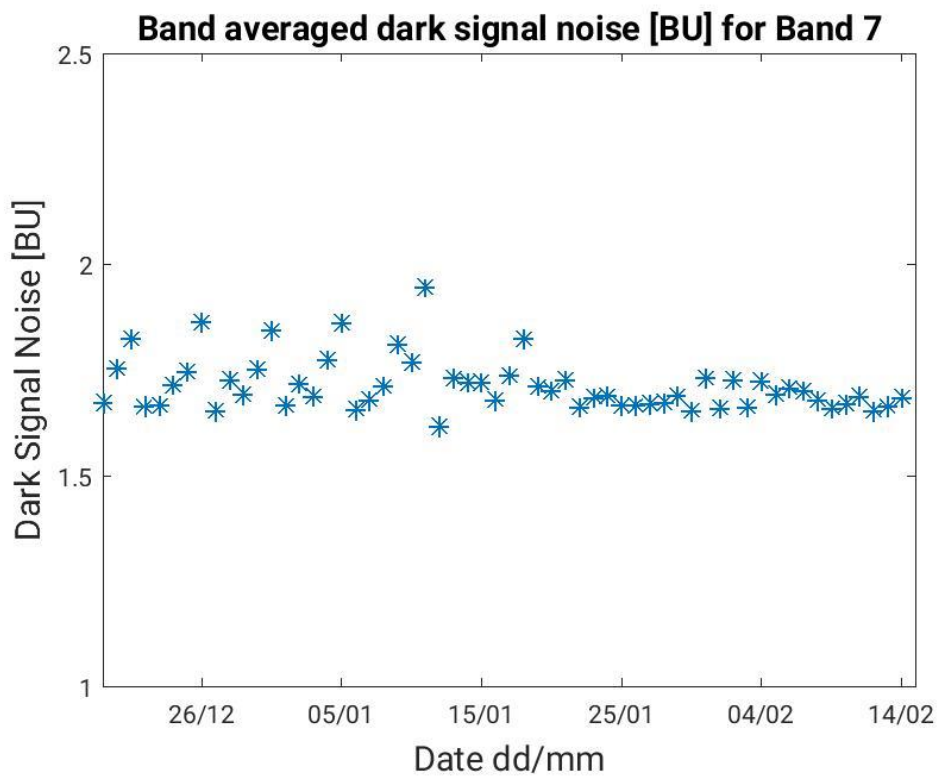


Figure 17: PMD-P-averaged noise.

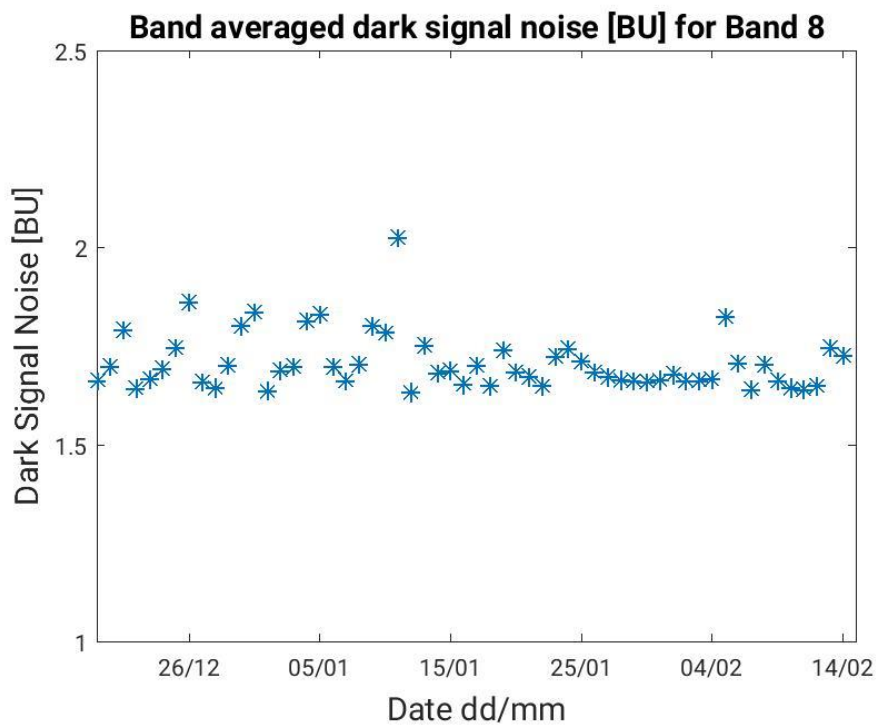


Figure 18: PMD-S-averaged noise.

4.3 PPG correction (A4.3.2)

The pixel-to-pixel gain (PPG) correction is derived from the processing of WLS (see Section 4.1) by the level 0-to-1B processor. For details of this processing, see AD 3.

Figure 19 show the detector pixel-to-pixel gain for channels 1 to 4 and the PMDs for MetopC – FM1 as derived from the WLS calibration measurements.

Figure 20 and Figure 21 show the detector pixel-to-pixel gain for channels 1 to 4 and the PMDs for both Metop-B (FM2) and Metop-A (FM3) as reference.

The contribution of PPG is generally to be expected at the 10^{-4} level, see Figure 19 for Metop-C/FM1 where values of the correction are oscillant in between 1.00025 and 0.99975.

For Metop-A / FM3 and Metop-B/FM2 this values have been increasing by the same level over the last years (see [RD8]). The results shown in Figure 20 and Figure 21 confirm this.

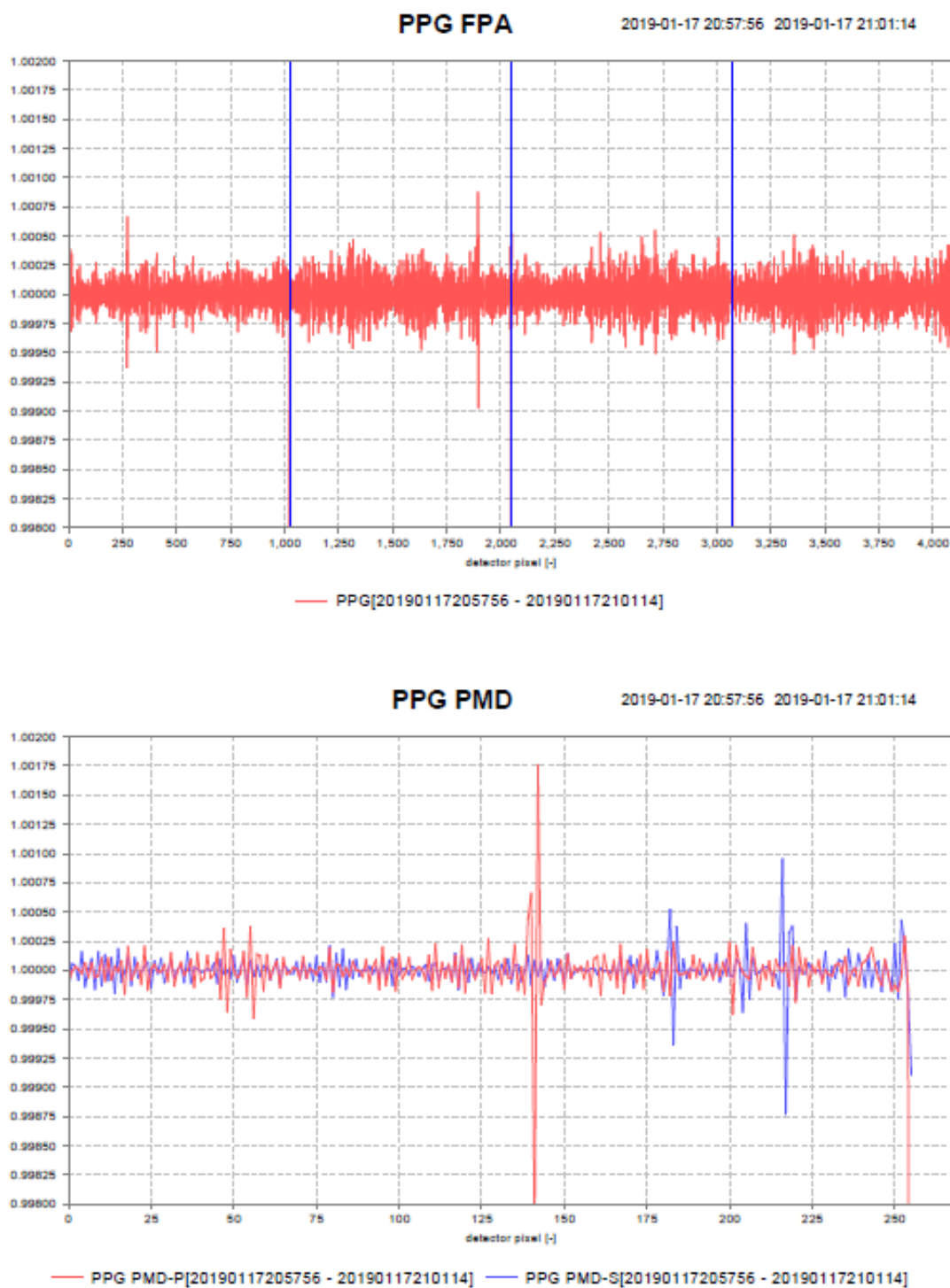


Figure 19: Metop-C / FM1 detector pixel-to- pixel gain (PPG) contribution for main channels (upper panel) and for PMD channels (lower panel) at the 17 th January 2019

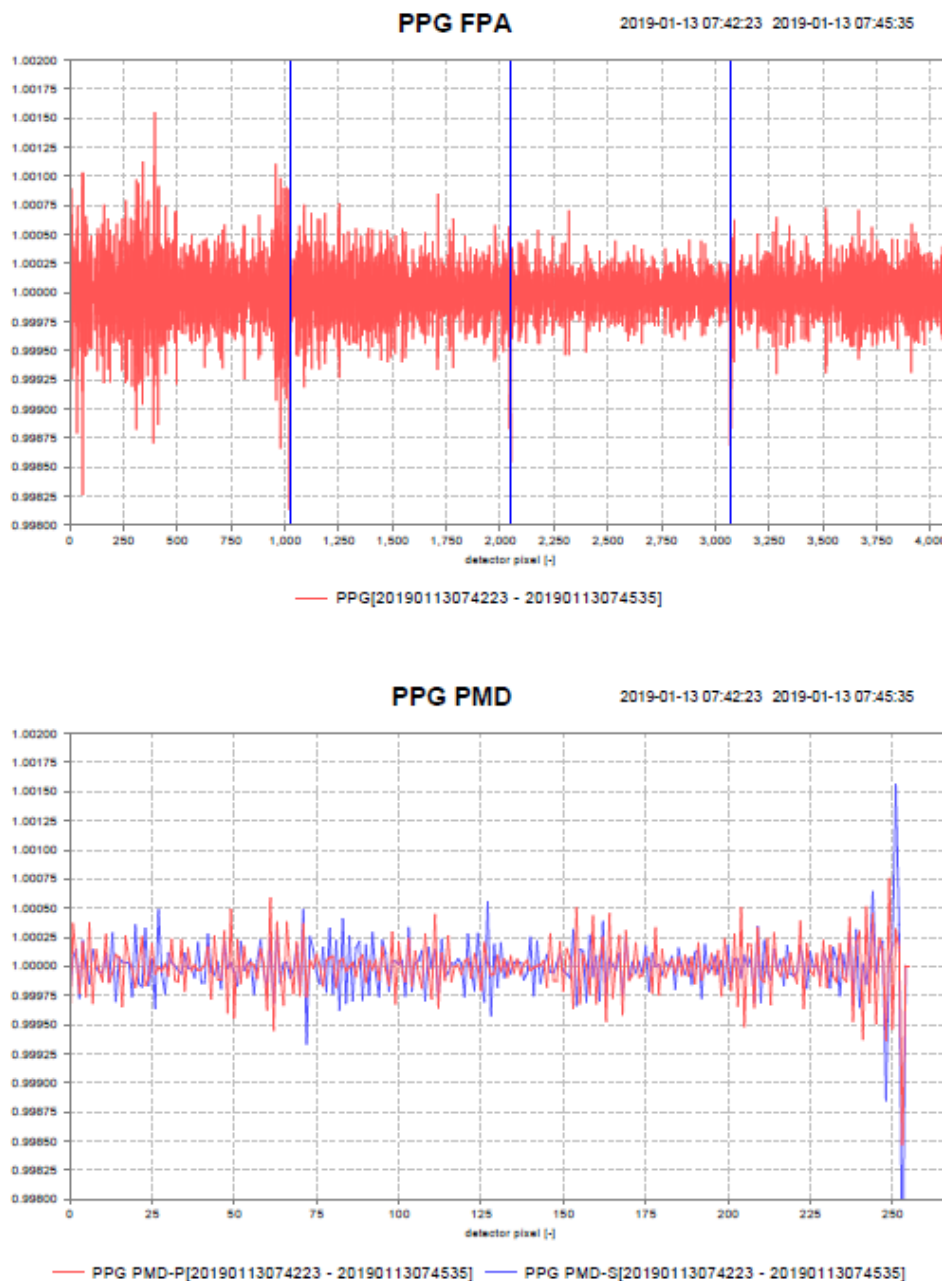


Figure 20: Metop-B / FM2 detector pixel-to-pixel gain (PPG) contribution for main channels (upper panel) and for PMD channels (lower panel) on 13 January 2019.

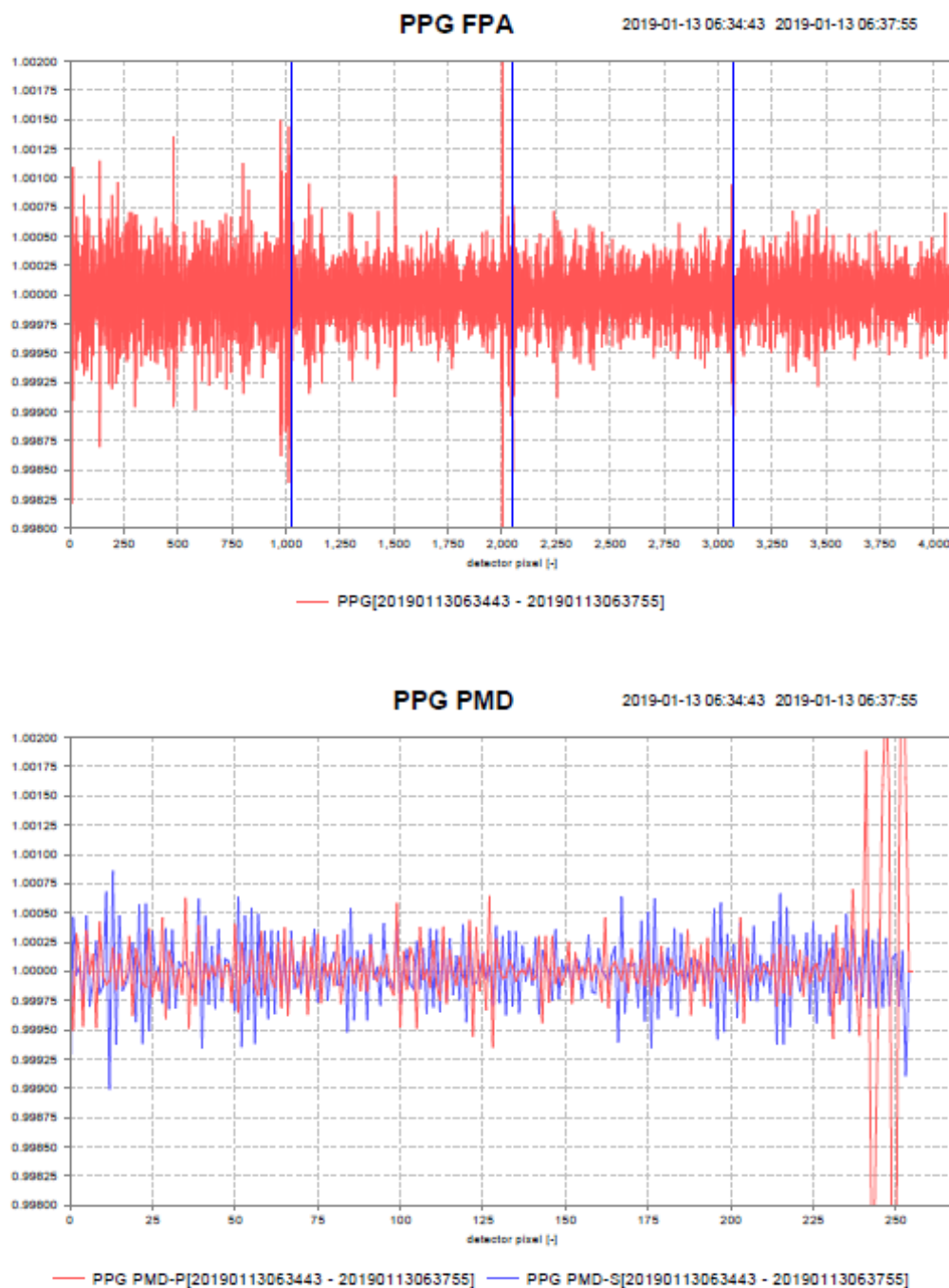


Figure 21: Metop-A / FM3 detector pixel-to-pixel gain (PPG) contribution for main channels (upper panel) and for PMD channels (lower panel) at the 13 January 2019.

4.4 Instrument spectral calibration and stability (A2.13-A2.15, A3.6)

GOME-2 spectral line source (SLS) measurements (see Section 4.1) are used to derive spectral calibration parameters. Under nominal operational conditions, one spectral calibration is carried out on board every day. Spectral stability in orbit, which is a function of pre-disperser prism temperature, appears to be very good for Metop-C / FM1 (see [RD8]).

The spectral stability, both in-orbit and for on-ground to in-orbit transition, is predominantly affected by the thermal environment of the instrument and is not, or not significantly, affected by the signal strength of the lamp (e.g. by the 1g-effect). The accuracy of the spectral calibration is otherwise depending on the performance of the spectral dispersion fitting algorithm for main channels (which is the same for all the FM see 0) and by the settings of the cross-correlation windows chosen for the mapping of the main channel spectral calibration onto the PMDs. This algorithm has been substantially revised for Metop-A/FM3 at the beginning of the mission (see 0) and is working stable since then. Optimised and dedicated cross-correlation windows have been provided for FM1 by the on-ground calibration campaign (see AD 9).

These cross-correlation windows have been implemented already at an early stage during FM1 IOV with INS file version 1.01.

Two dedicated measures of monitoring the on-ground to in-orbit stability and the in-orbit long-term stability, as well as the in-orbit accuracy are applied here and presented in the daily reports. First, the derived dispersion curves are compared to what has been measured on-ground. With this method we predominantly address the stability as laid out before whereas the accuracy is addressed only in so far that the on-ground measurements can be considered reliable in terms of accuracy.

Because of the substantial and successful revision of the PMD spectral calibration algorithm the new approach has also been applied during the on-ground calibration campaign for Metop-C / FM1, for the derivation of spectral reference key-data. We therefore expect that both main channel and PMD on-ground spectra can serve as a reasonable measure of the real changes observed between on-ground and in-flight, as well as a good measure of long-term stability.

In addition, the absolute spectral accuracy is monitored by comparing the observed position of Fraunhofer lines with their catalogued position. This can only be done for well isolated Fraunhofer lines, which however are spectrally not fully resolved by the instrument. So there is an intrinsic limitation in accuracy due to the spectral resolution of the instrument involved in this method reflected in the provided error bars on the results.

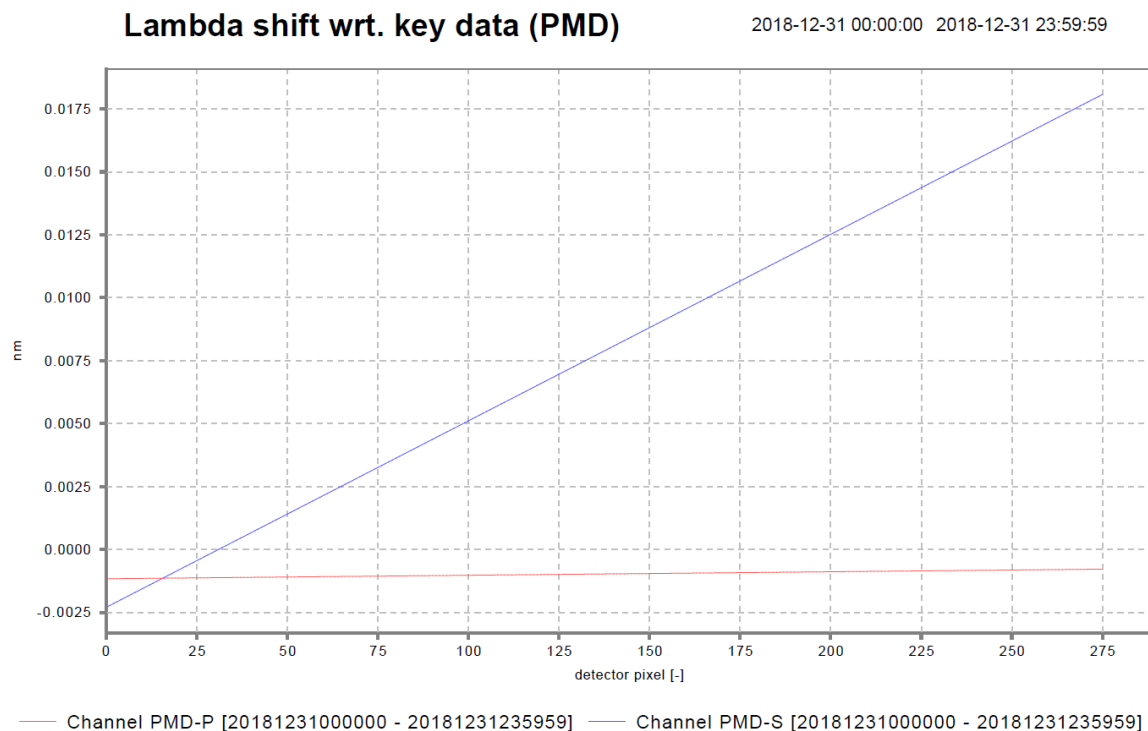
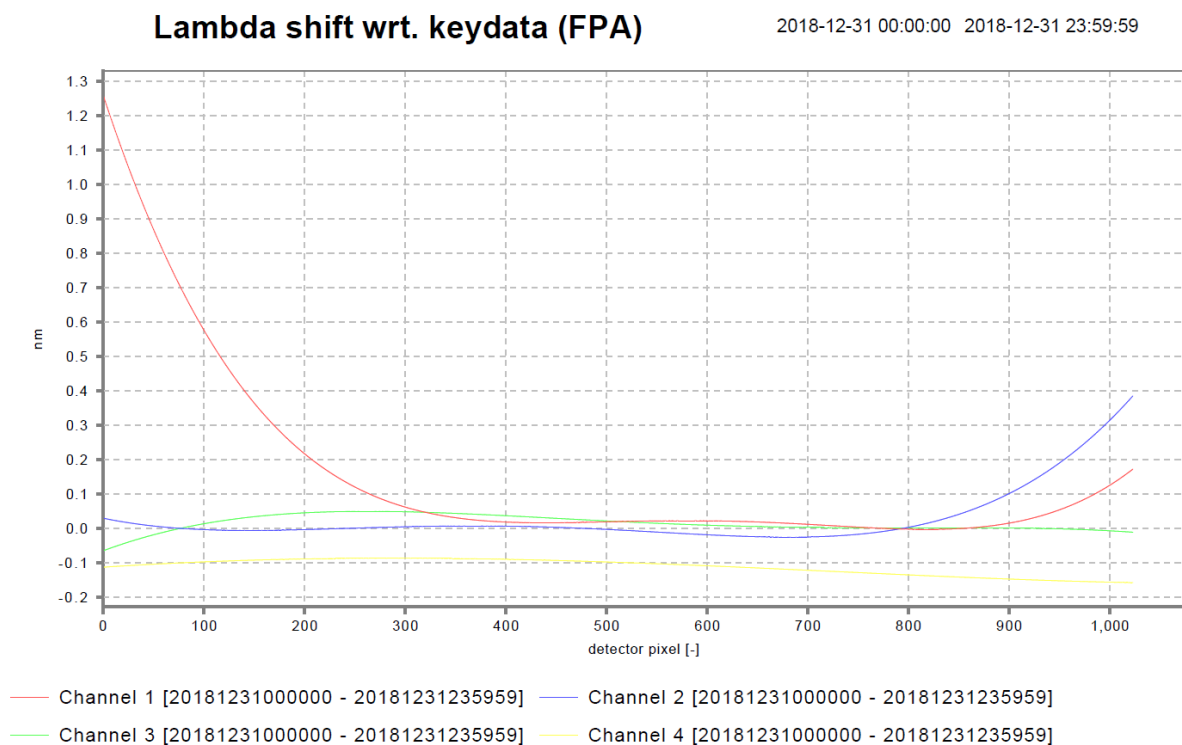


Figure 22 Metop-C / FM1 spectral calibration w.r.t. on-ground key-data for main channel (top) and PMDs (bottom) on 31st December 2018.

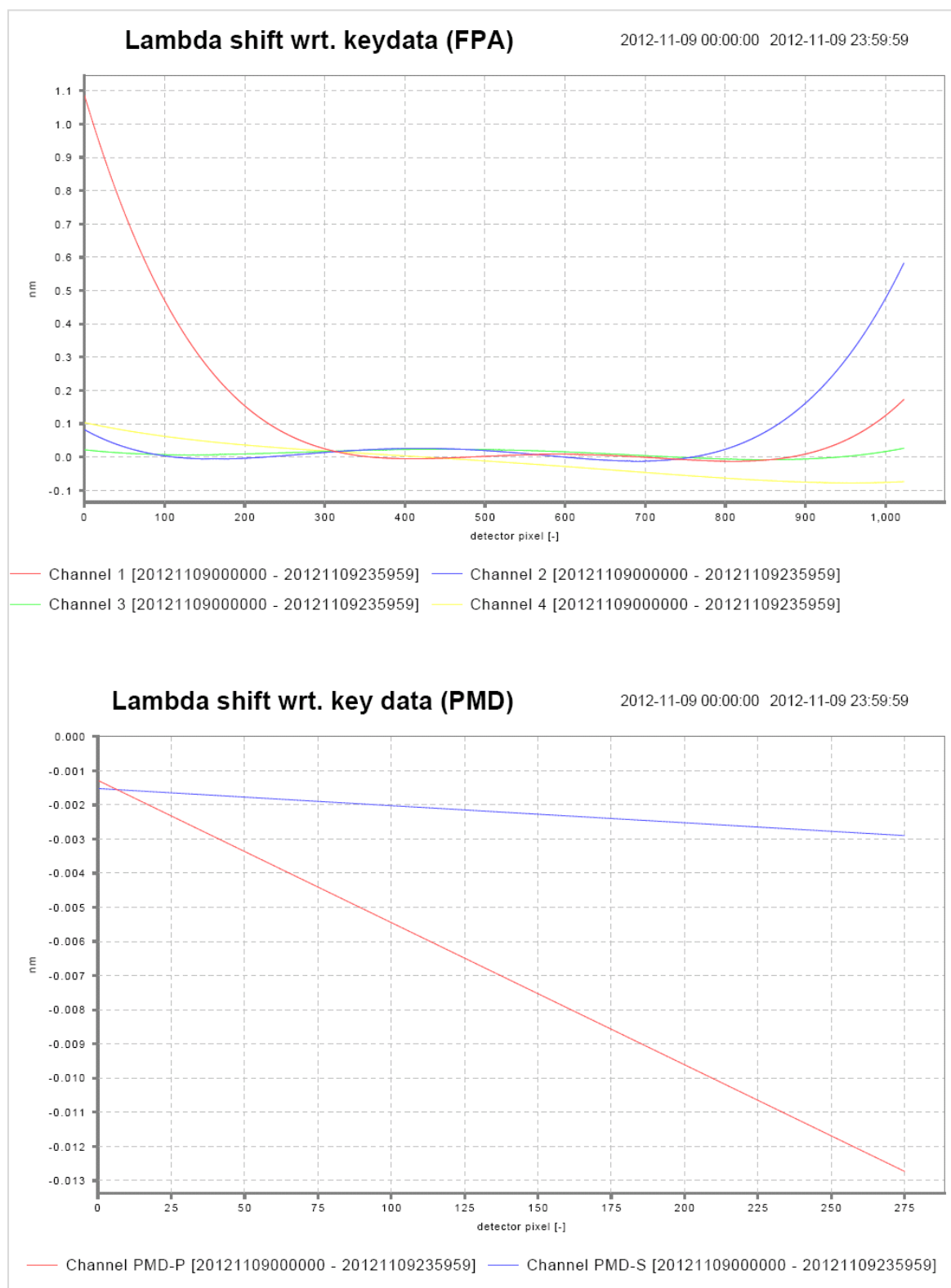


Figure 23: Metop-B / FM2 spectral dispersion curves relative to the on-ground measured dispersion during the FM2-2 calibration campaign. The top panel shows the difference in wavelength for main channels and the lower panel for PMDs on 9 November 2012.

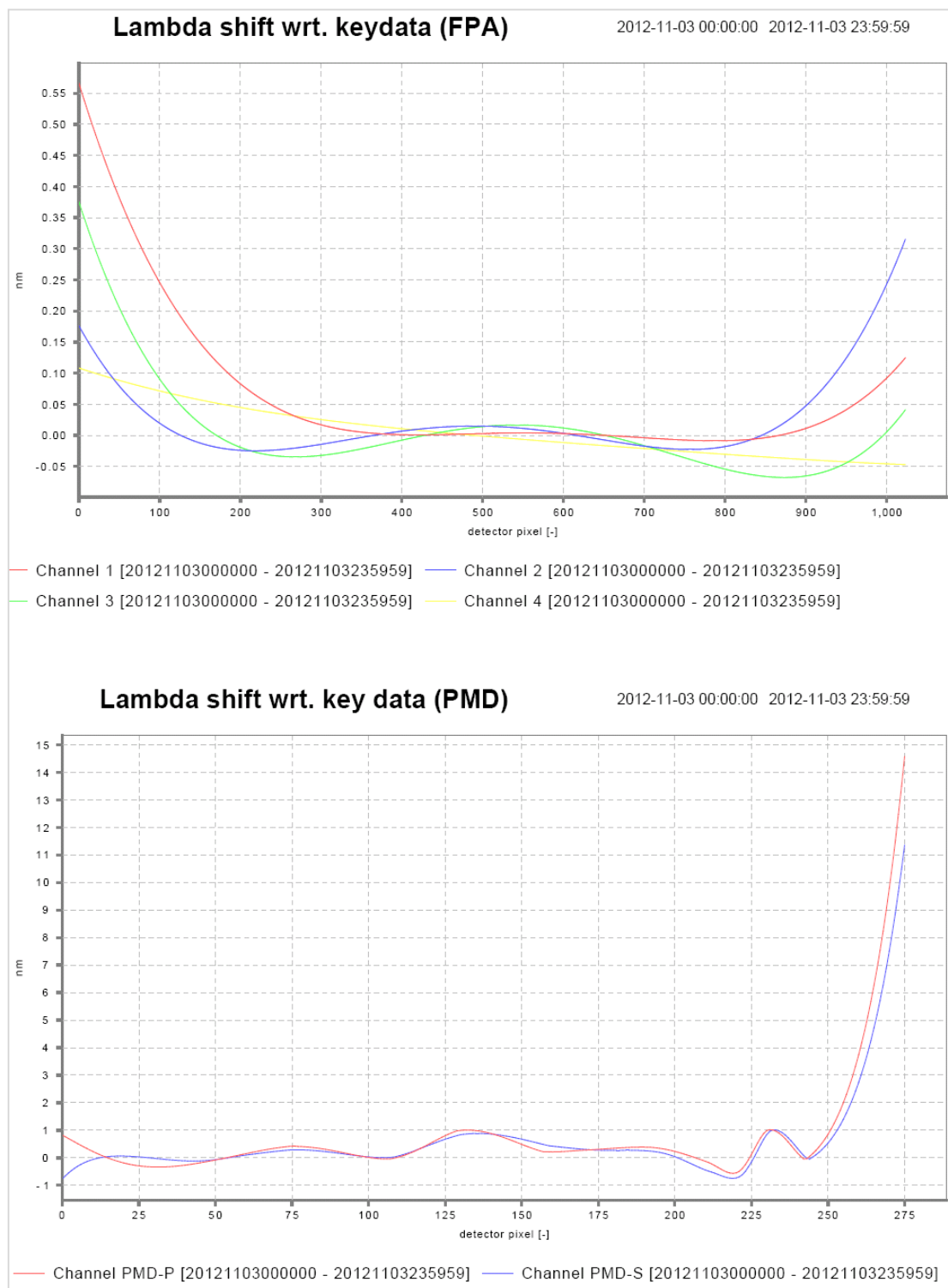


Figure 24: Metop-A / FM3 spectral dispersion curves relative to the on-ground measured dispersion during the FM3 calibration campaign. The top panel shows the difference in wavelength for main channels and the lower panel for PMDs at the 3rd of November 2012.(reference key data employed, base on the old algorithm update for PPF7 METOPA)

4.4.1 Results on stability and consistency of the spectral calibration

Figure 22, Figure 23 and Figure 24 show the main channel (upper panels) and the PMD channels (lower panel) differences to the on-ground measured spectral dispersion curves for Metop C- / FM1, Metop-B / FM-2 and Metop-A / FM3 respectively.

For main channels the differences are overall quite comparable (note the difference in scale) and for FM1 values are very similar to FM3. In particular for channel 2, there seems to be a bit larger shift after launch in the channel 2 to 3 overlap region (around 0.4 nm) which is anyhow lower than the one observed for FM2 (0.6nm) and again comparable to that observed for FM3 (0.3 nm). The consequences of this shift and how to account for it are detailed in Section 4.7

From the results presented in the lower panel of Figure 23 we can however conclude that the PMD spectral calibration is very close to what has been measured on-ground, and that even though the PMDs have a very complex dispersion structure, the on-board spectral calibration processing is very close to the results achieved on-ground.

The Spectral calibration is sensitive to the thermal environment of the instrument. Figure 25 shows the pre-disperser prism temperature of Metop-C / FM1 since launch (c.f. Figure 2). Note that the on-board temperature of the platform clearly displays the end of the warm phase at the 12 December. This pre-disperser prism temperature is overall expected to be slowly increasing during the first two to three years.

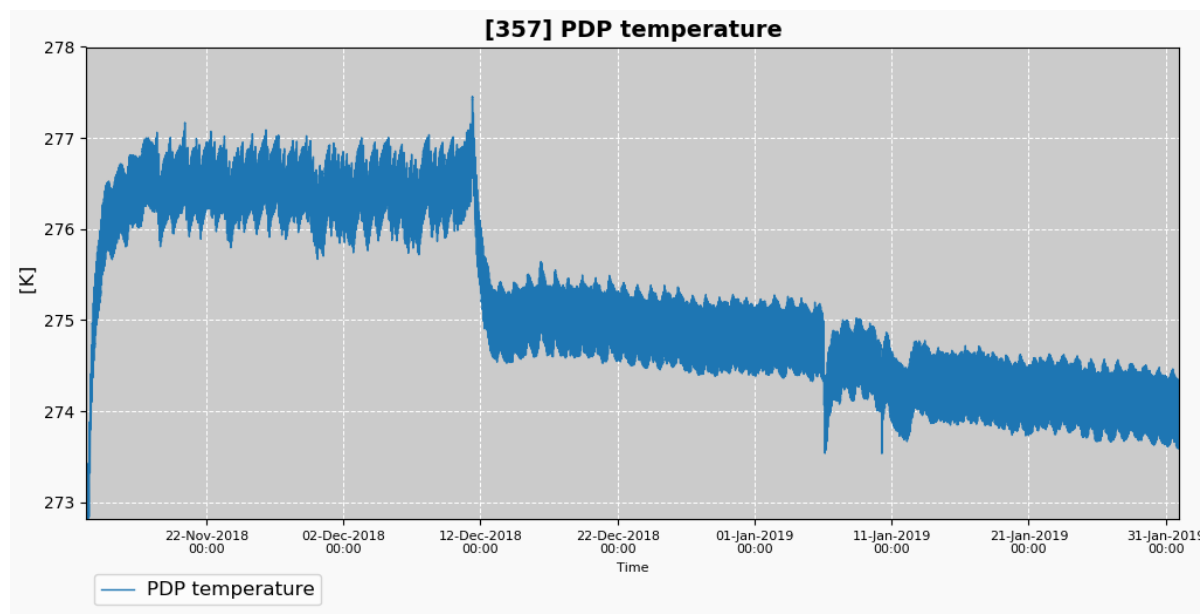
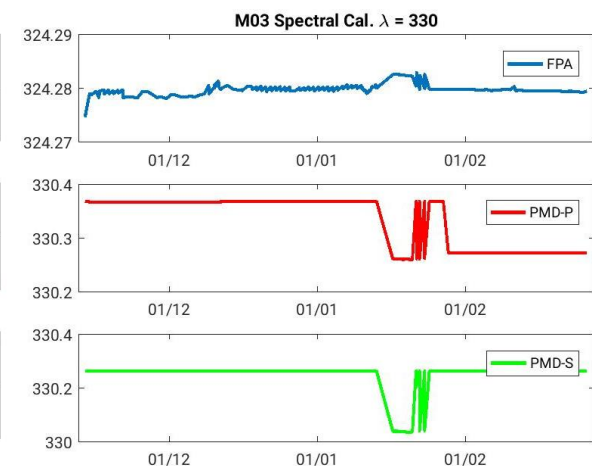
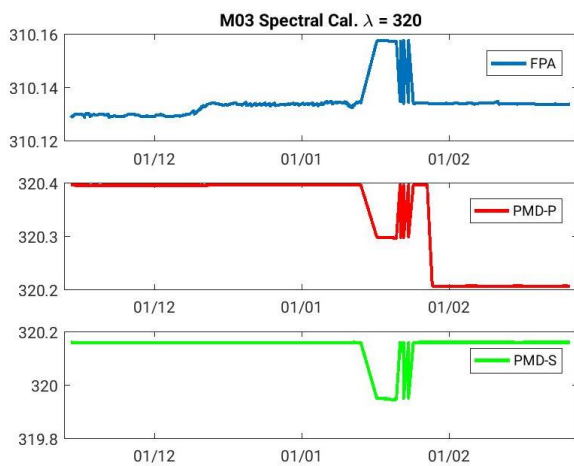
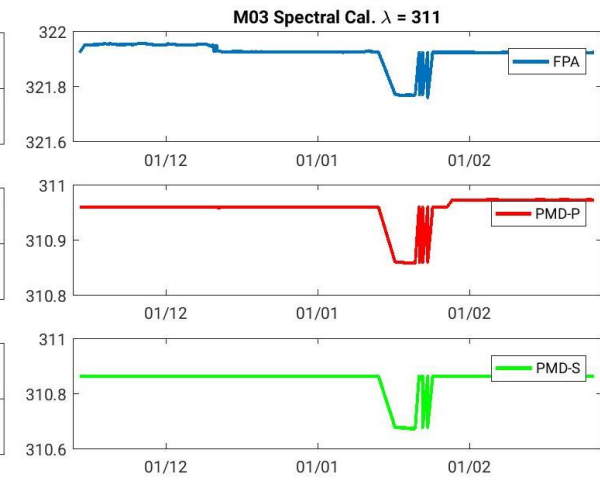
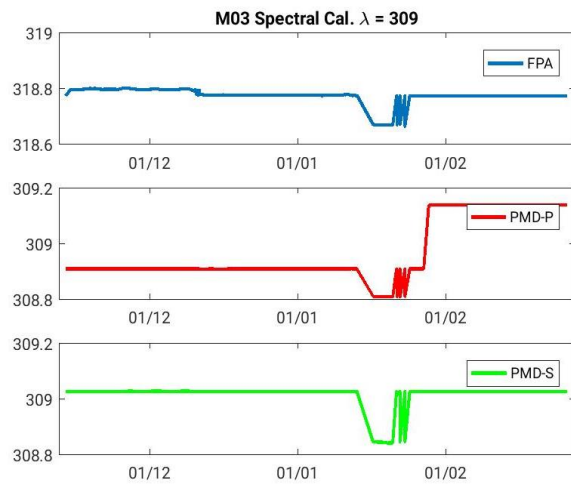
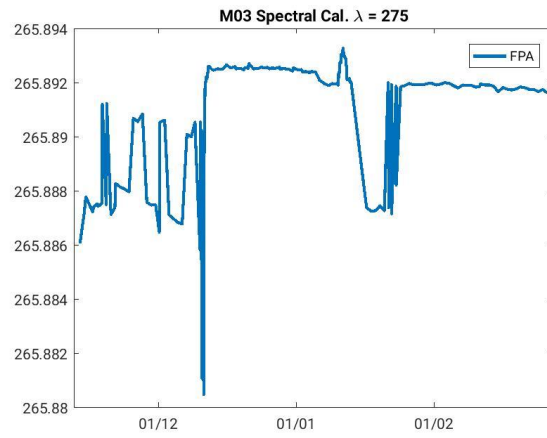
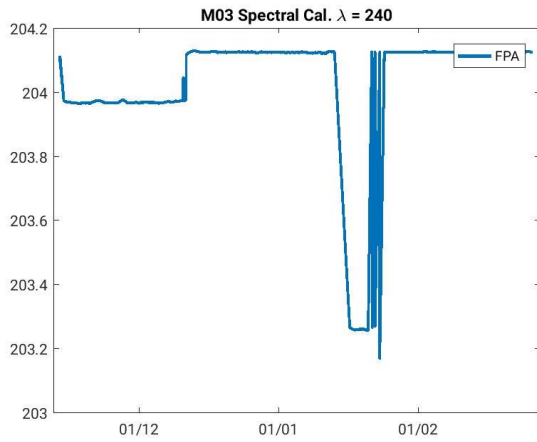


Figure 25: Metop-C / FM1 on-board pre-disperser prism temperature since launch of Metop-B.

Figure 26 shows the results derived from maximum spectral line signals and daily spectral calibrations at various wavelengths. The wavelength that is being measured by a particular pixel is calculated and that trend is displayed throughout the reporting period. The wavelength range covered per pixel is given in Table 7.



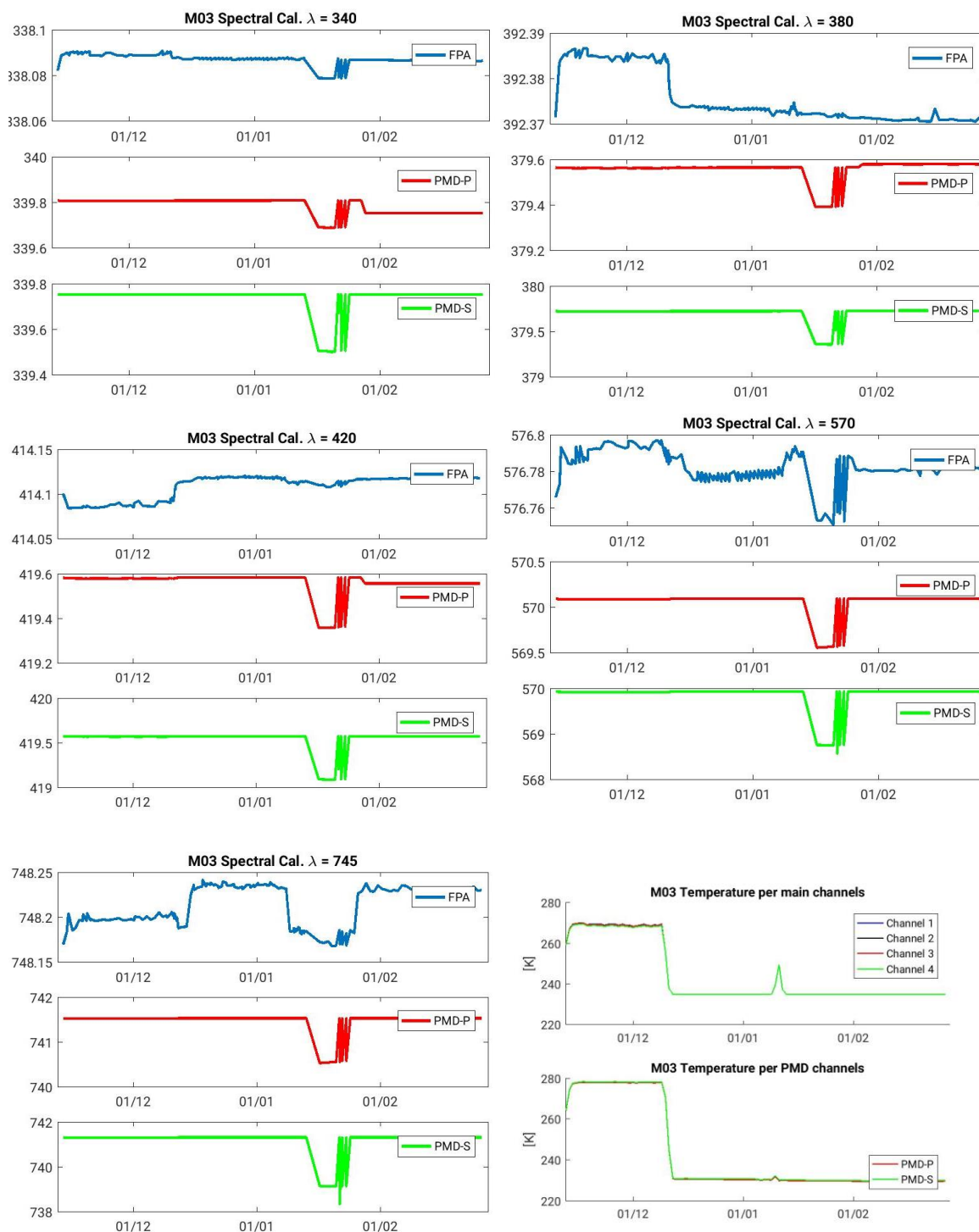


Figure 26: Spectral stability at various wavelengths between 12 November 2018 and 28 February 2019 and for main channels and PMD channels at 275, 280, 309, 311, 320, 330,340, 380, 420, 570 and 745 nm (top left to bottom left). The bottom right plot shows the detector temperatures during the same time period.

From Figure 26 it can be seen that spectral stability is high at all wavelengths and generally follows the change of the pre-disperser prism temperature, except for periods of strong temperature change or for detectors operated at higher temperature variability (uncontrolled). One such event was the warm

phase of the SIOV before mid-December 2018 and another was the throughput test around 12 January 2019.

Figure 27 shows the stability of the spectral co-registration between PMD-P and S per detector pixel spectral width. The results demonstrate the strong stability of the co-registration outside the special events regime and its overall close relation to the on-board temperature.

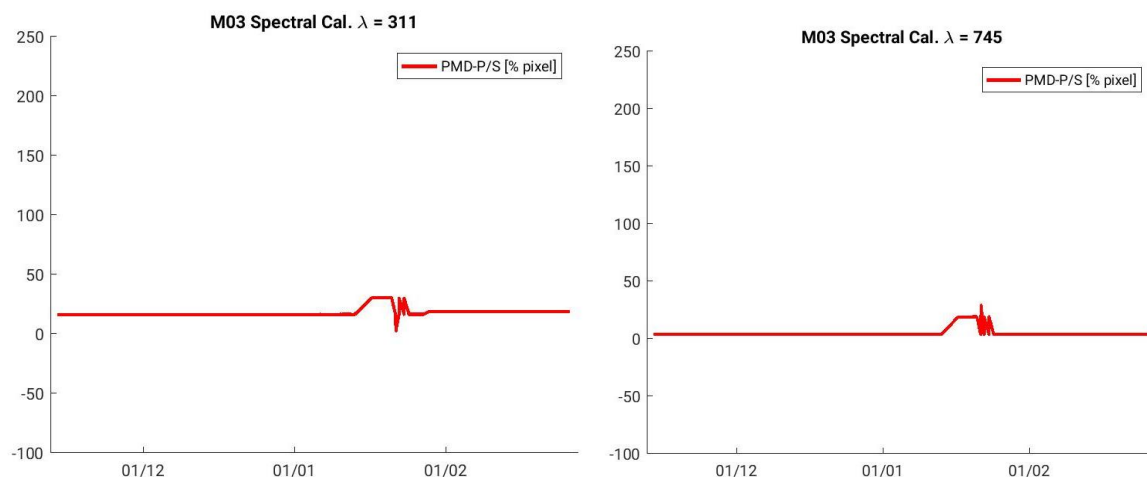


Figure 27: Spectral stability of the co-registration between PMD-P and S in percentage of fractional detector pixel around 311 & 745 nm.)

The very high stability of the PMD spectral calibration is not least thanks to the significant amount of time and effort that has been spent on this part of the calibration during the FM1-2 on-ground calibration campaign.

4.4.2 Results on the accuracy of the spectral calibration

Figure 28, Figure 29 and Figure 30 present the results on the comparison of the spectral calibration with catalogued positions of selected (and reasonably isolated) Fraunhofer lines in the spectrum. The results present the accuracy of the spectral calibration within the limits of the method (predominantly within the limit of the spectral resolution of the instrument).

For FM1/ Metop-C the accuracy is quite good and in the order of 0.01 to 0.05 nm. This accuracy is well below the spectral sampling size of the instrument (0.1 nm in channels 1 and 2 and 0.2 nm in channels 3 and 4).

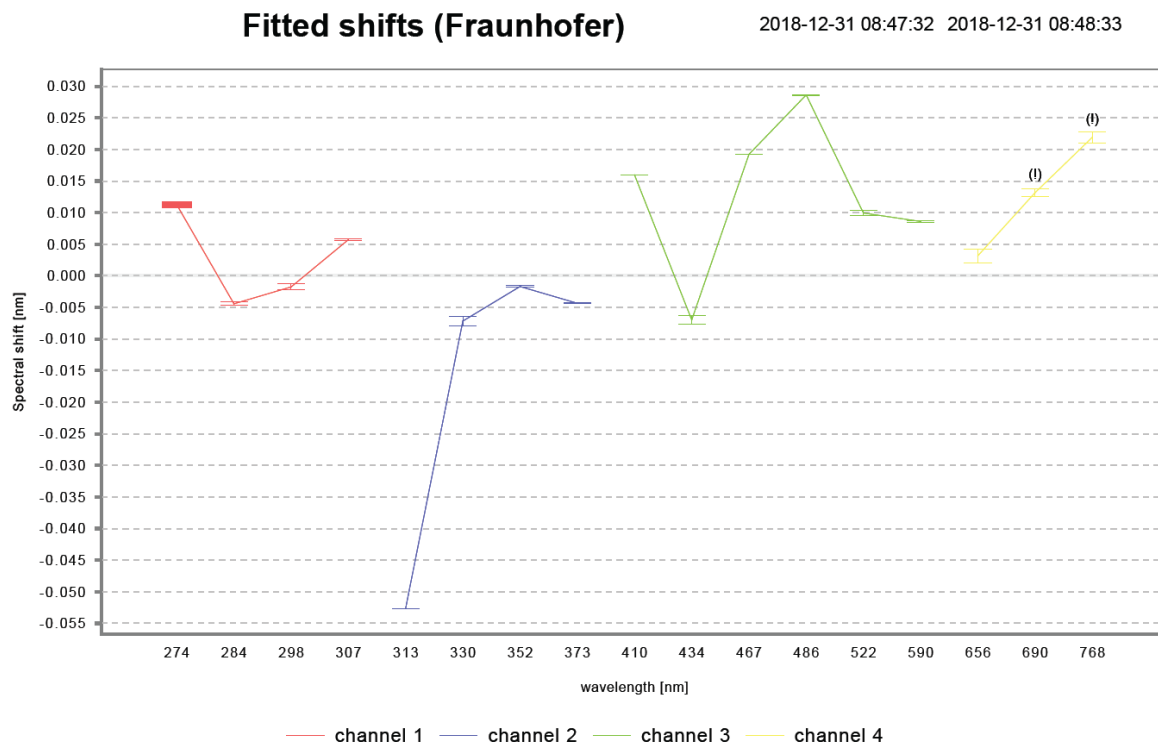


Figure 28 Metop-C / FM1 spectral calibration difference to selected Fraunhofer line positions for main channel data on 31st December 2018

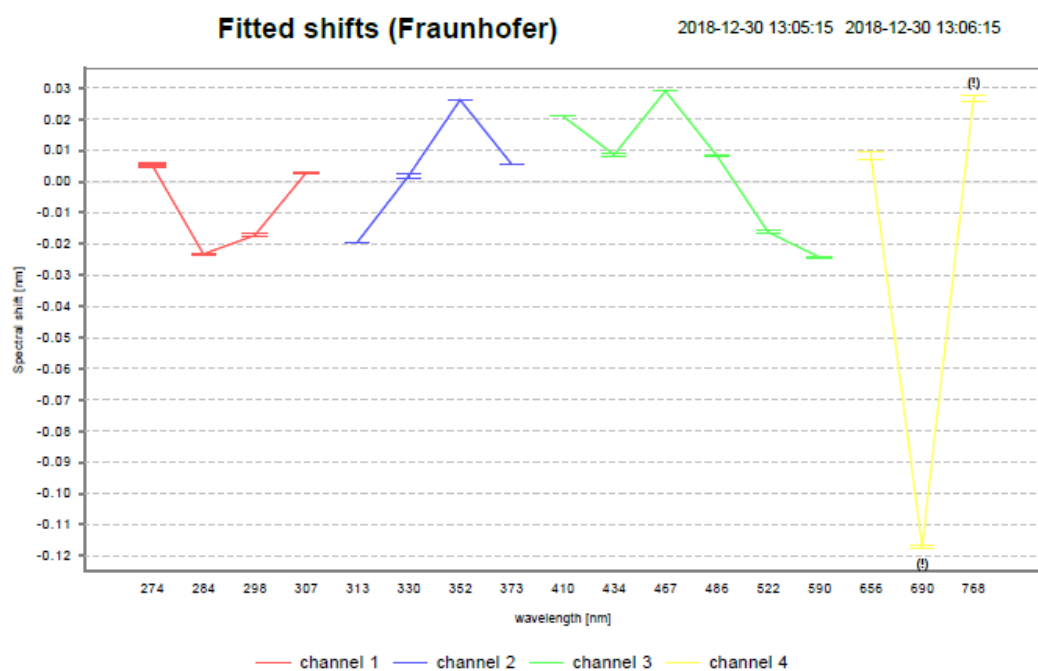


Figure 29: Metop-B / FM2 spectral calibration difference to selected Fraunhofer line positions for main channel data on 31 december 2018

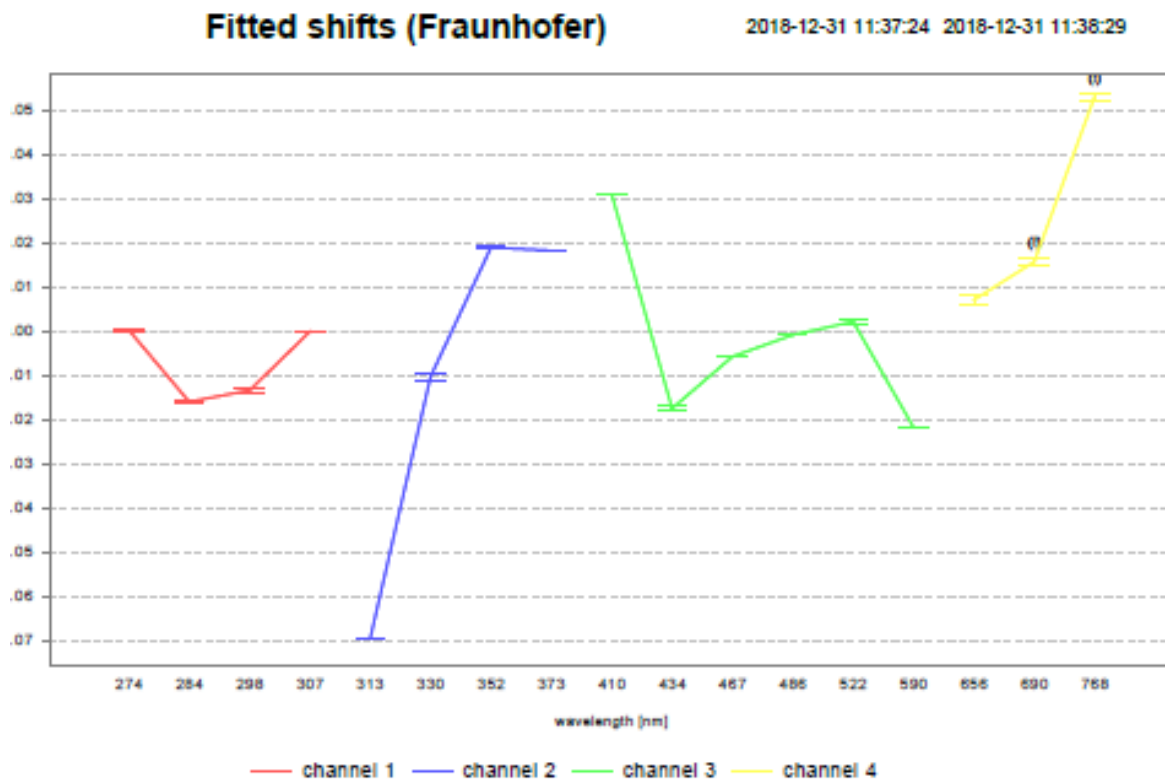


Figure 30: Metop-A / FM3 spectral calibration difference to selected Fraunhofer line positions for main channel data at the 31 december 2018

4.5 Slit-function stability – FWHM monitoring

We derive the FWHM (spectral resolution) stability of the instrument applying a simple Gaussian fit to some well-isolated lines from the daily averaged SLS spectrum (see Section 4.1). Note that the slit-function response is not purely Gaussian which is why this is an approximation. However this is sufficient for the monitoring of potential changes in the FWHM. It is less accurate of course for determining the true FWHM of the instrument at any wavelength as is done by the dedicated slit-function study as carried out by RAL [RD25].

From the derived FWHM at certain spectral positions, both a potential on-ground to in-orbit change in the slit-function as well as a potential in-orbit long-term change can be detected.

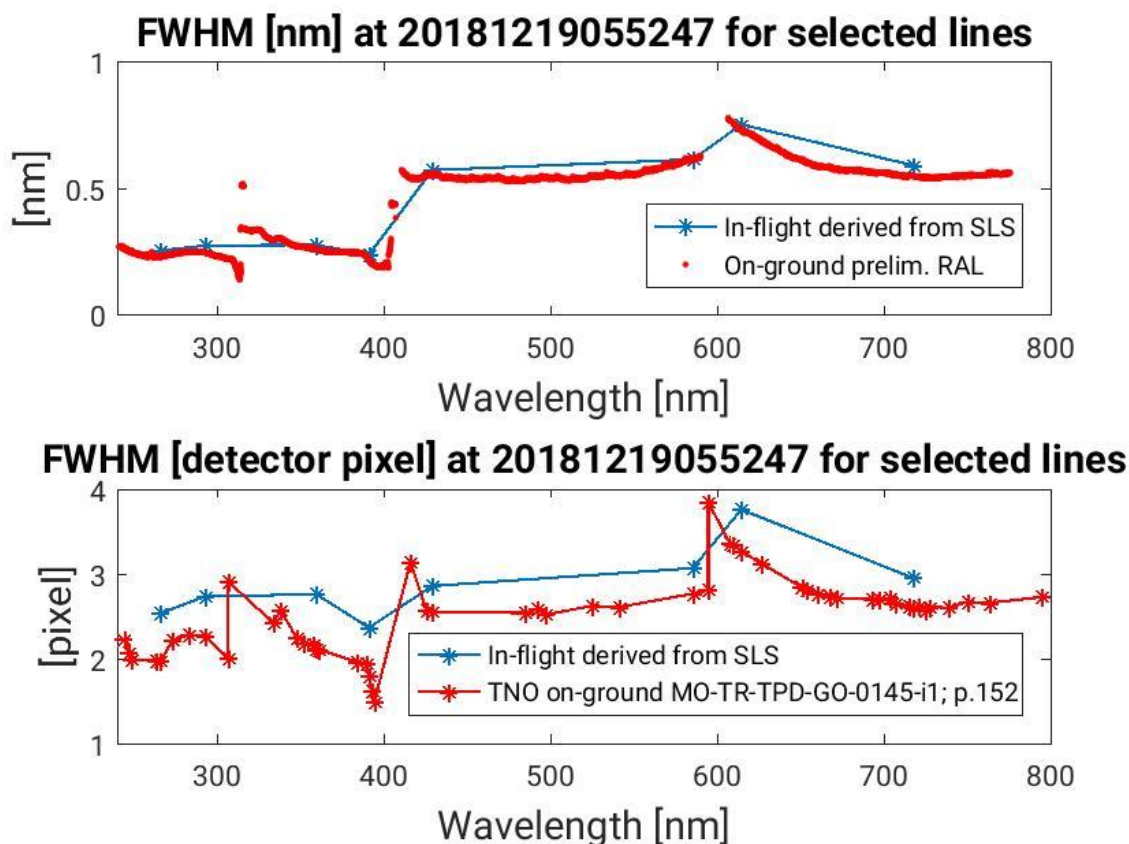
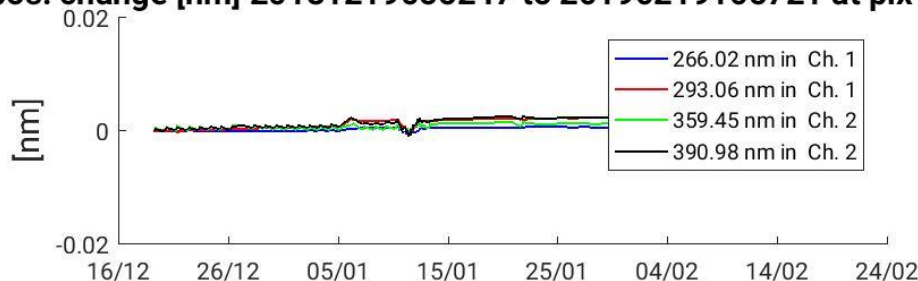


Figure 31: Metop-C / FM1 derived FWHM from a Gaussian fit to selected lines of the averaged SLS daily measurement 18December 2018. The results are shown with the blue lines and are compared the derived FWHM from the dedicated slit-function study carried out by RAL (prelim results) (upper panel) using the on-ground data as derived by TNO in (lower panel) in wavelength space.

In Figure 31 we compare the FWHM measured in-flight to the FWHM estimated by RAL and on-ground measured by TNO. Once we compare it to the derived FWHM from the dedicated and much more accurate slit-function campaign carried out by RAL in wavelength space and once the data is compared to data derived by TNO from on-ground SLS measurements during the campaign.

The comparison to the RAL data results indicate that there was hardly any shift in the FWHM with respect to the on-ground situation occurring for FM1.

pos. change [nm] 20181219055247 to 20190219105721 at pix res.



pos. change [nm] 20181219055247 to 20190219105721 at pix res.

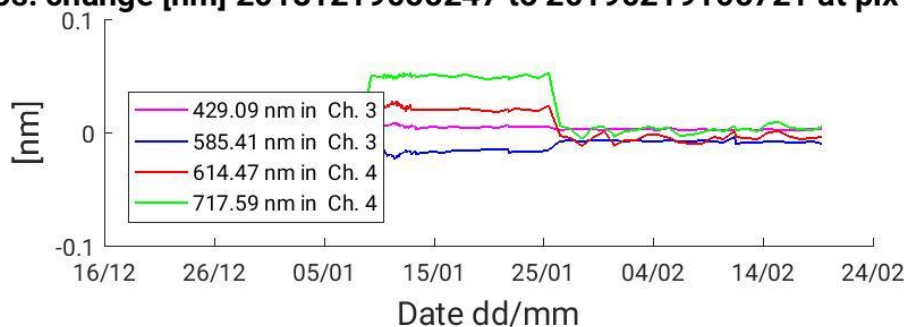


Figure 32: Metop-C / FM1 SLS line position change over time

We monitor potential changes in the FWHM as observed on Metop-C / FM1 since 17 December 2018 using the on-board spectral line source spectra (see Figure 4) making use of a selection of distinct lines (separated well enough from neighbouring lines to allow for a robust fitting). We first interpolate from the instrument spectral binning (0.1/0.2 nm), which usually is representing a line in maximum of 4 measurements, to a high resolution artificial grid using linear interpolation. Then we fit a Gaussian curve through it, assuming a symmetric slit-function. This is only a fair assumption because we are predominantly interested in the relative change of the FWHM than in its absolute values.

Figure 33 shows the result indicating a variation of the FWHM following the on-board optical bench temperature. All FWHM are currently converging again after an initial spreading. Similar behaviour was found for MetopB (Figure 35), while in the long-term a narrowing of FWHM values has been observed for Metop-A / FM3 [RD8] in Figure 35.

Currently there are no evident effect, no longer term effect can be detected now.

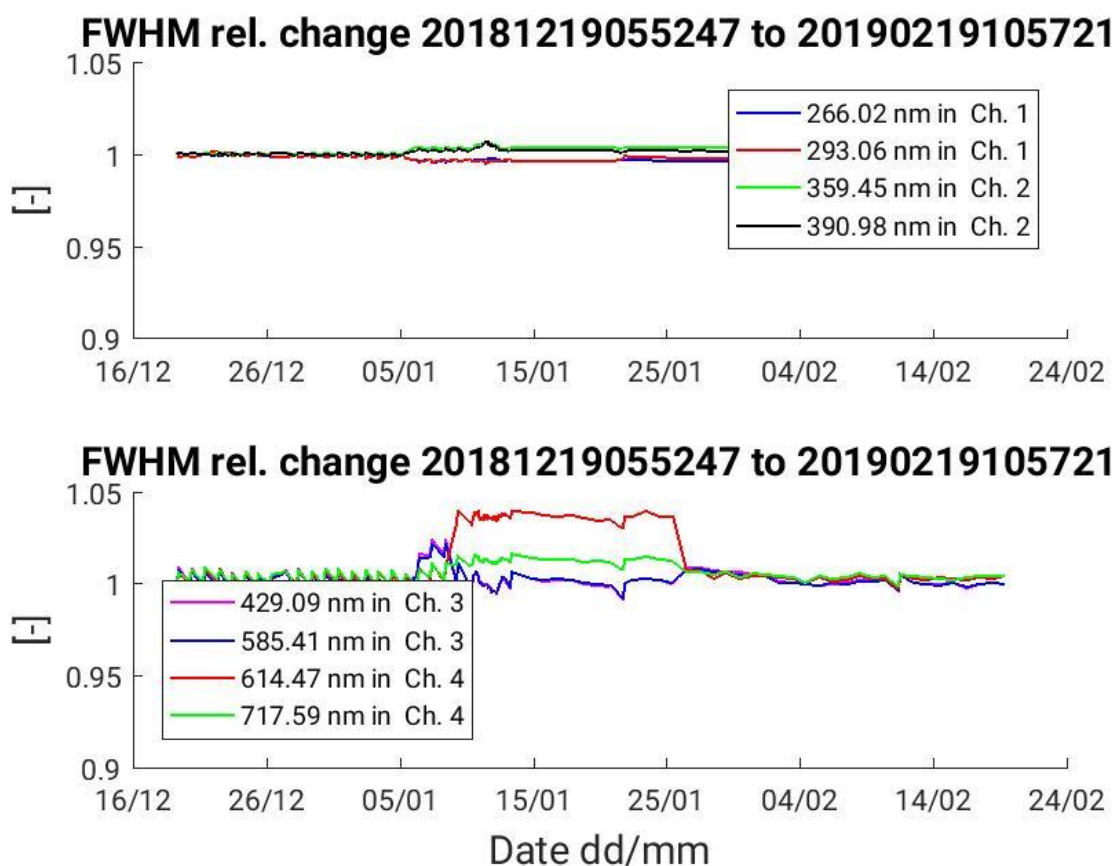


Figure 33: Metop-C / FM1 derived FWHM from a Gaussian fit to selected lines (see legend) of the averaged SLS daily measurement relative to 19 December 2018.

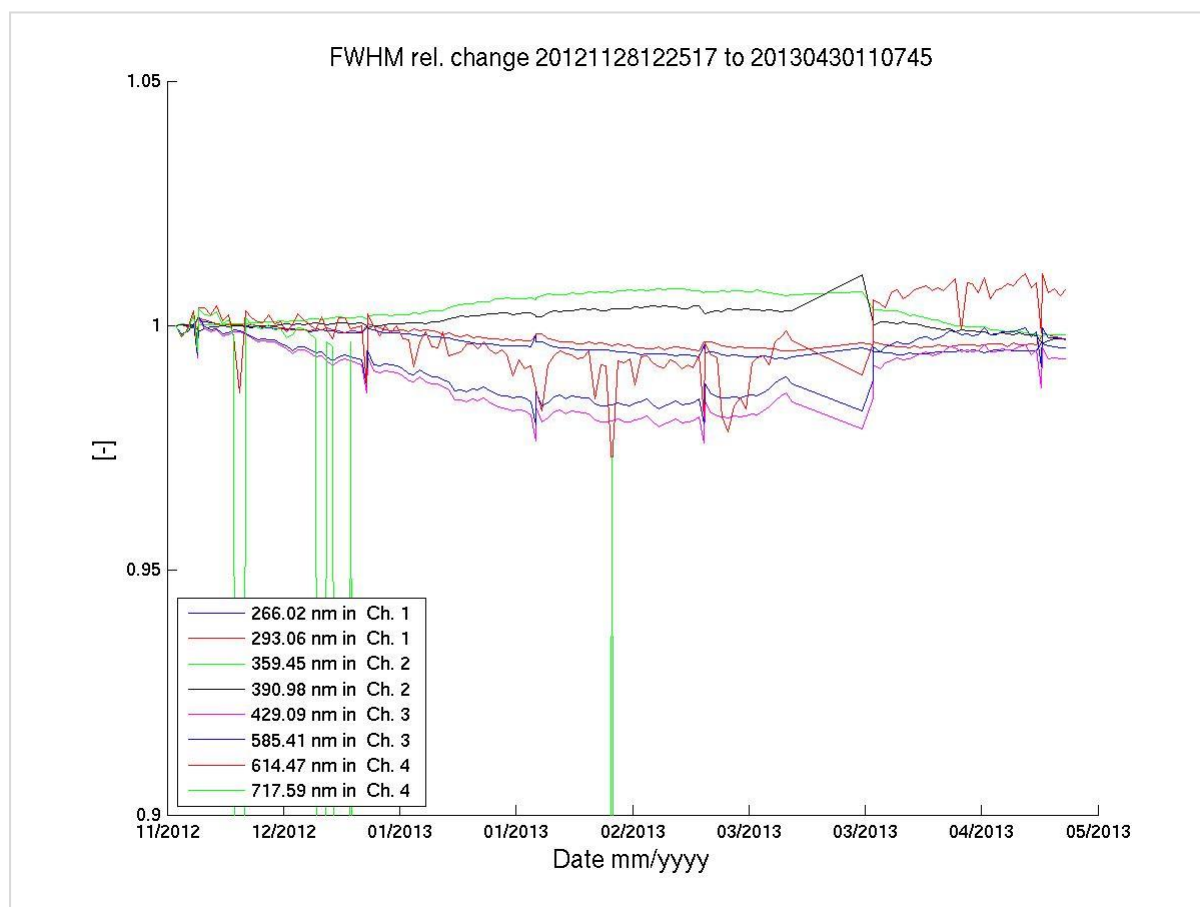


Figure 34: Metop-B / FM2 derived FWHM from a Gaussian fit to selected lines (see legend) of the averaged SLS daily measurement relative to 28 November 2012.

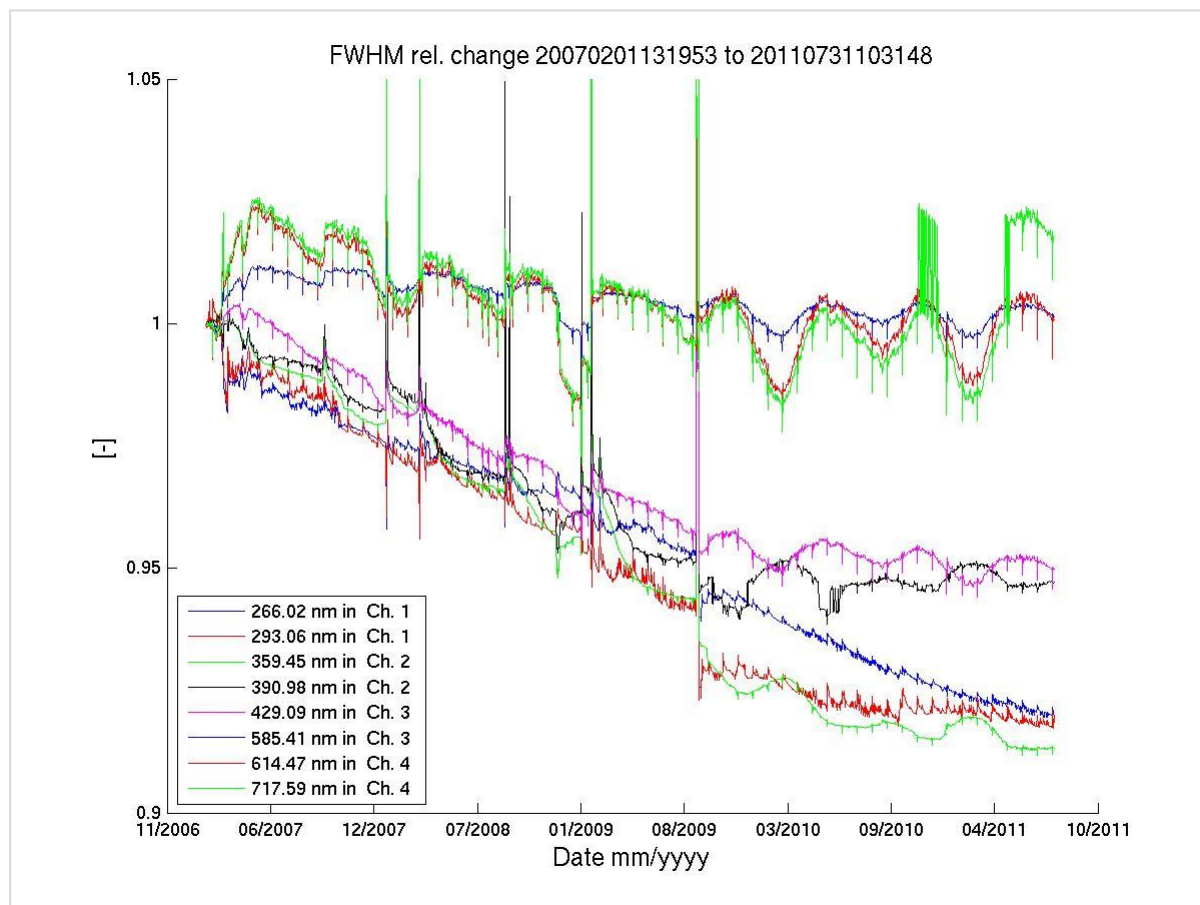


Figure 35: Same as

Figure 34 but for Metop-A / FM3.

4.6 PMD co-registration and PMD band settings (IOV / CalVal task)

The co-registration between the two PMD detector band definitions is important since the closer two band values for P and S are, the more accurate the derived Stokes fraction values (which in turn determine the accuracy of the polarisation correction or of retrievals making direct use of the latter). Since the definition of the bands is defined on-board in detector-pixel space, any shift of the spectral calibration between on-ground and in-orbit will compromise the optimal co-registration of the uploaded definitions, provided they are not adapted accordingly.

To upload the optimal settings for the PMD in-orbit situation is a “routine” task and has been foreseen in the planning of the IOV to be carried out as part of the IOV/CalVal activities (see also Section 3). The procedure which has already been applied for Metop-B / FM2 and Metop-A / FM3, it has been applied for MetopC / FM1has and the detailed steps and results are documented in [AD 6].

The upload of the optimised definitions versions 2.0 (see Table 4) has been carried out during orbit 367 on 03/12/2018.

Figure 36 and Figure 37 show the centre positions of the PMD bands S and P after the co-registration updated (green vertical lines) with respect to the targeted positions as suggested by the GSAG. The blue vertical lines show the positions as they were before the upload for PMD band definition version 1.0 (the current FMS definitions).

Note: Because of the detector pixel discretisation and the very low spectral resolution in the red part of the spectrum for PMDs, the optimal line position will never fully overlap the targeted positions.

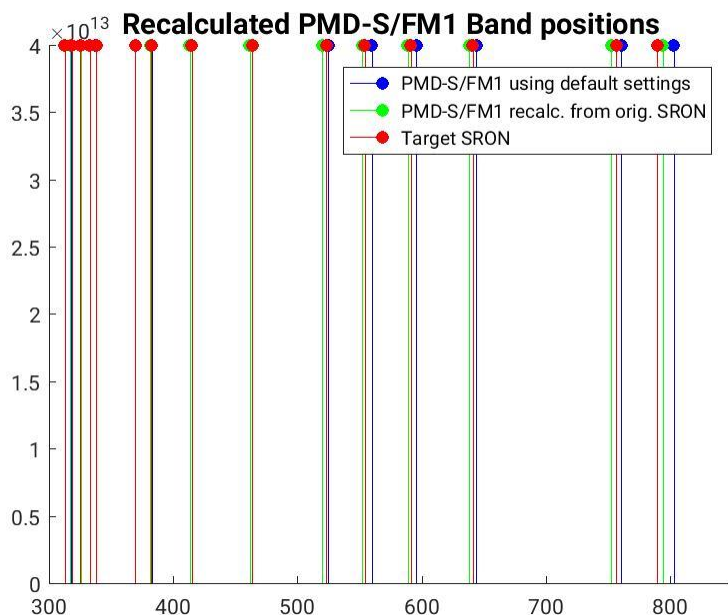


Figure 36: Centre band position of PMD-S Metop-C/ FM1 after co-registration shift (green) with respect to the old position from band definitions version 1.0 (blue) and the target positions recommended by the GSAG (red). In case only the red line is visible the green line is hidden below the red line.

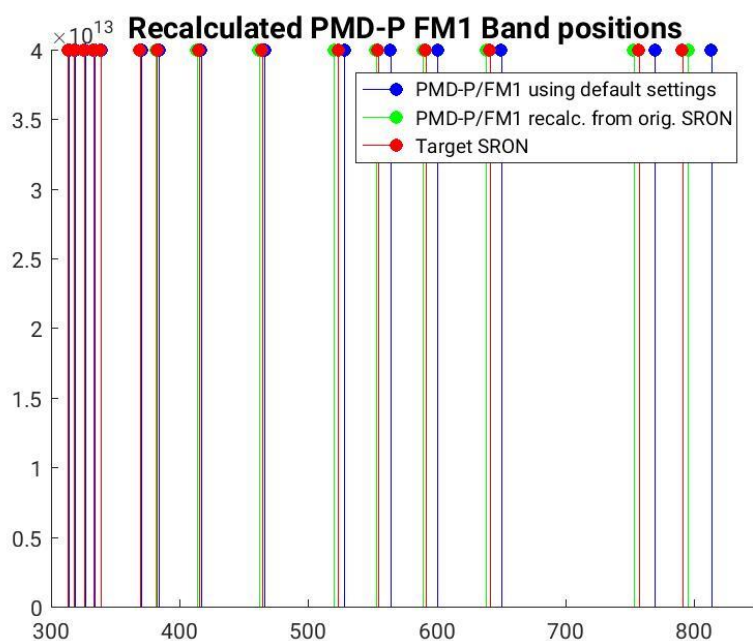


Figure 37: Centre band position of PMD-P Metop-C/ FM1` after co-registration shift (green) with respect to the old position from band definitions version 1.0 (blue) and the target positions recommended by the GSAG (red). In case only the red line is visible the green line is hidden below the red line.

Figure 38 shows that the chosen line definitions for version 2.0 are optimal in terms of spectral co-registration between the two PMDs since, both the centre and the edges of the bands are within half a detector pixel difference between PMD-P and S when translated from wavelength space back into detector pixel space.

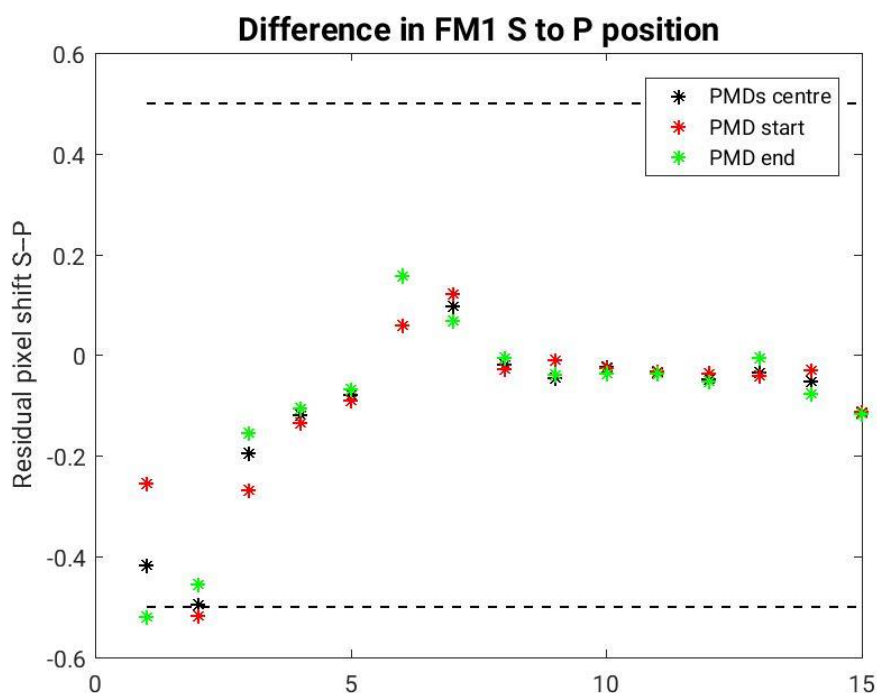


Figure 38: Band centre and edges detector pixel co-registration at sub-pixel range after adjustment of the PMD band definitions following the rules laid out in this section.

These settings then result in an essential detector pixel co-registration shift PMD S-P of 0 detector pixel (with respect to the default upload v1.0 of -1) (see Figure 39), (see references in [AD 6]).

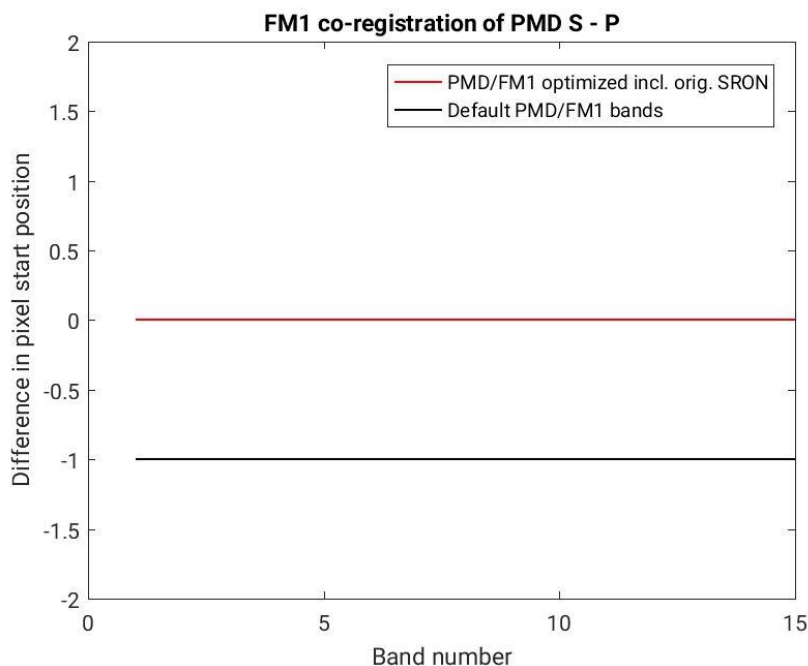


Figure 39: Detector band centre pixel co-registration for the adjustment of the PMD band definitions following the rules laid out in this section

4.7 Channel Overlap Point Adjustment and Etalon Correction

4.7.1 Background

From our GOME-2 Metop-A / FM3 experience, we expected that the launch itself could trigger a slight shift of the channel separator prism (“cs” in Figure 2), thereby causing a shift in the projection of the dispersed beams onto the main channel detector pixel assembly (FPAs; see optical layout in Figure 2).

While the centre part of the radiometric response functions measured on-ground during the calibration campaign FM1-3 (see Section 1.4) remain valid, this is not true in the channel overlap regions where the energy is distributed between the two channels changes and where, in addition, the response functions exhibit very steep gradients towards zero (see Figures of radiometric response functions below). As a result, the response functions are not valid in the overlap regions resulting in large errors in the radiometric calibration. This is clearly visible in both Earthshine and the solar spectrum. Since for solar spectrum there exist reference spectra of acceptable quality (not readily available for the earthshine spectra) the channel separation “jumps” show up in the derived residual between measured and reference spectra as shown in the lower panel of Figure 40 around 310 (channel 1 to 2 separation) and 400 nm (channel 2 to 3 separation) and around 600 nm (channel 3 to 4 separation). The “jumps” are also visible in the Earthshine spectrum (see Figure 38).

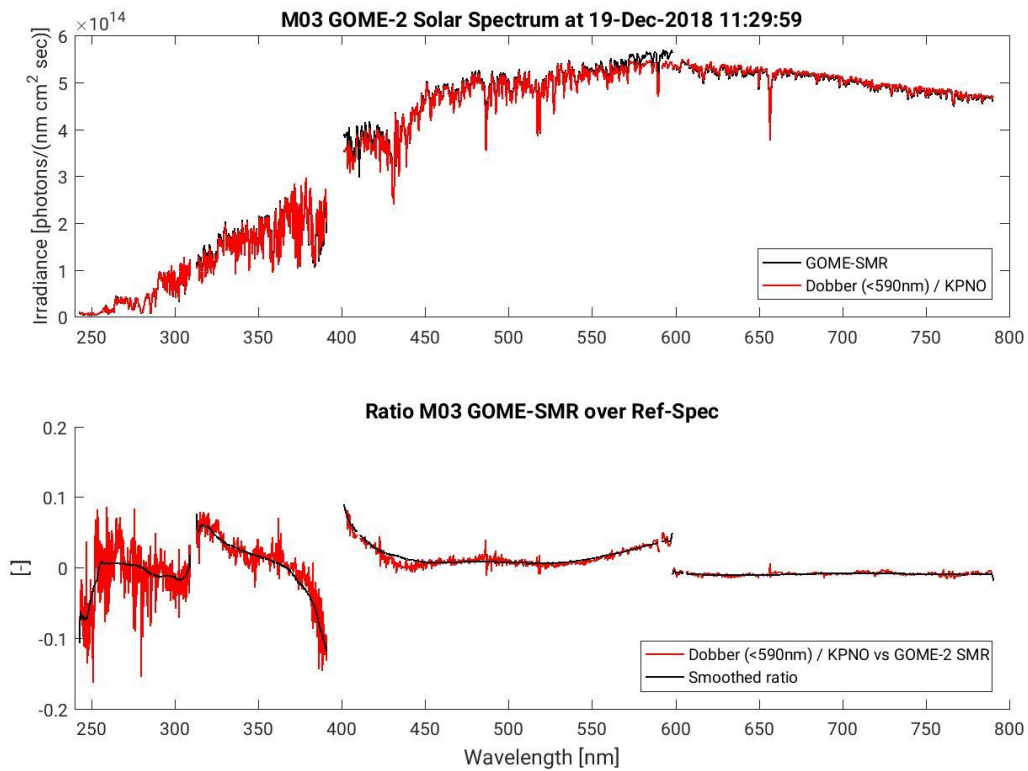


Figure 40: GOME-2 FM1 first calibrated solar spectrum as (upper panel; black line) compared with a reference spectrum by Dobber et al. (Solar Phys (2008) 249: 281–291) below 590 nm (upper panel, red line). Above 590 nm the KPNO/AFGL spectrum of 2004 is used. The lower panel shows the residual between both (red line) and a moving average to guide the eye.

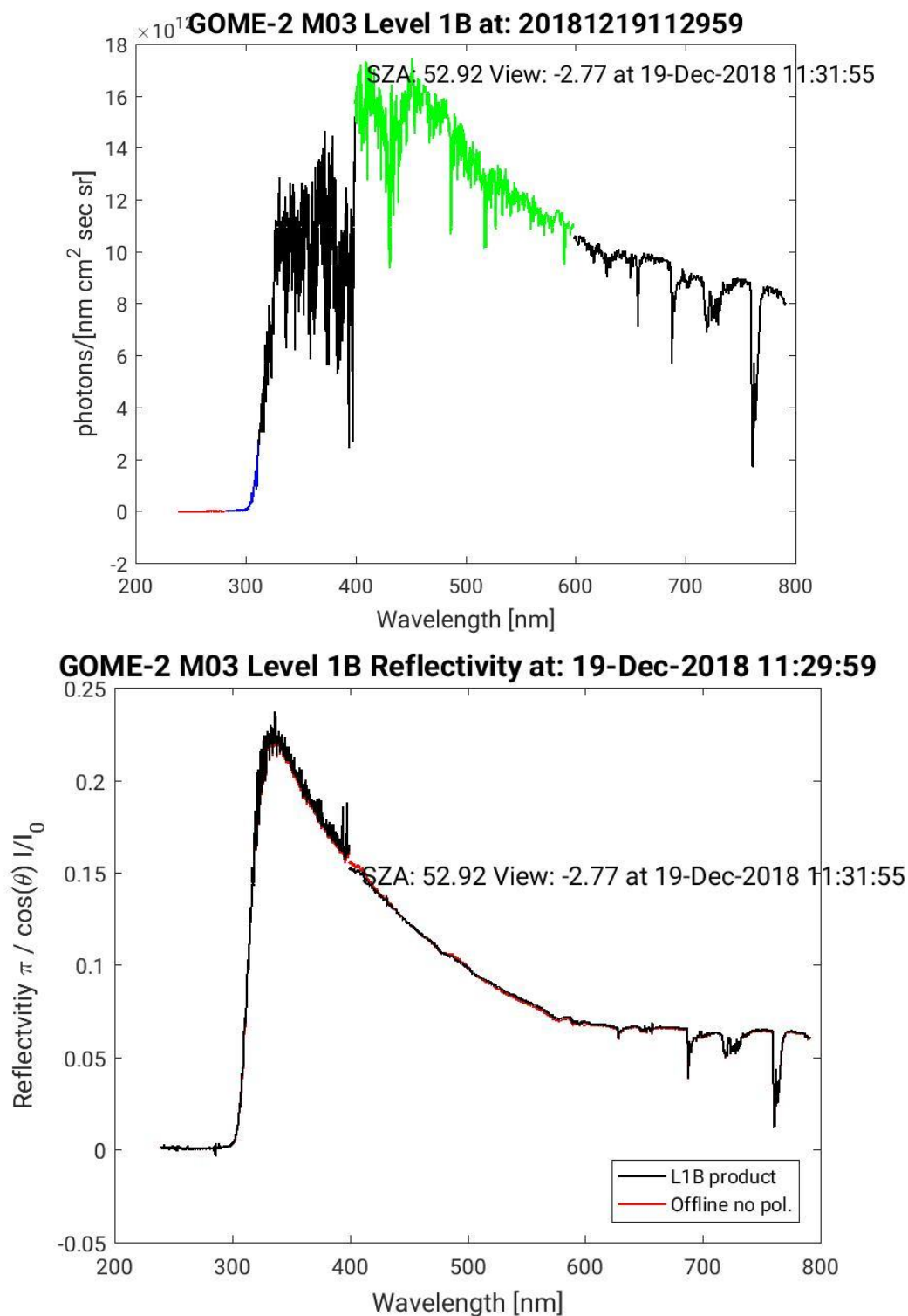


Figure 41: GOME-2 FM1calibrated Earthshine spectrum (upper panel) with alternating colours for the different bands. IN the lower panel, the correspond Reflectivity shows the “jump” jumps” between channel 2 and 3(bottom.)

For FM3 on Metop-A, a procedure has been developed by ESA/SSST (Michael Eisinger) to adjust the radiometric response functions (RA_IRR_ABS*¹, RA_RAD_ABS*, RA_SUN_CAL_IRR_ABS*²) together with the channel overlap positions (WL_OVERLAP) using the in-flight white-light source comparison to the on-ground measured white-light source reference spectrum (RA_WLS_*), which is also available in the key-data.

This approach, which was followed for FM2, will also be followed for FM1. It was successful to the extent that it corrected the “jumps” (closing them) of the overlap regions by adequately and “smoothly” adjusting the radiometric response functions in the channel overlap regions. However, this approach had the drawback that it was applied (and still is for Metop-A / FM3) without taking an in-time varying etalon correction in these regions into account (because the approach implicitly not only fixes the response to the overlap shift but also corrects for the on-ground to in-orbit etalon effect in the region of the overlap at this, but only for this, point in time). As a result, the etalon correction derived once per day on-board from the white-light source measurements to account for both the on-ground to in-orbit etalon changes, as well as the in-flight long-term etalon changes - and which is applied during level 0 to 1B processing to all calibrated and dispersed spectra - cannot be applied anymore correctly to the overlap region (for details on the etalon correction in the level 0 to 1B processing see 0).

Therefore, as it has been done for FM2, for FM1 the adjustment procedure - which will be explained in detail in the following section - has been extended to also include the effect of the on-ground to in-orbit etalon change by making use of the observed etalon at the point in time when the overlap correction is derived, and apply both to the radiometric response key-data. As a consequence, the in-orbit derived etalon changes (which are then much smaller than the etalon changes including the on-ground to in-orbit transition) can be applied to the whole valid region of the detector array per channel and the overlap regions can be consequently exploited by level 2 retrievals.

This is a significant achievement considering that, for example, the region between 312.8 nm and 316.5 nm—which is important for the retrievals of, for example, ozone and SO₂—could not be exploited up-to-date for Metop-A / FM3 (see Section 7.4 in [RD8]).

In the following we will show the step-by-step derivation of the radiometric adjustments needed and their impact on the spectra as shown in Figure 40 and Figure 41. The procedure will also lead to an optimised set of Etalon settings (GOME_INS_xx_M01) used for level 0 to 1B processing of FM2 data.

¹ Name of key-data files in the provided key-data set for FM2; see Section 1.4.

² Newly derived key-data set for FM2-2

4.7.2 Adjustment procedure

4.7.2.1 Observed overlap point shift.

Following launch, the overlap point has been monitored using the WLS spectra by the operational monitoring database.

The on-ground to in-orbit changes in the overlap points result in a shift of -0.393, -0.930 and -0.009 nm respectively, which has also been confirmed by the GIOV report (AD8). As a consequence, the original key-data file for the overlap point definitions in CAL 1.01 can be updated taking this shift into account in version 4.0 of WL_OVERLAP.201 key-data file to be used in CAL 1.03 (see Table 8).

Overlap	First channel 90% point [pixel]	First channel 50% point [pixel]	First channel 10% point [pixel]	Wave-length 90% point [nm]	Wave-length 50% point [nm]	Wave-length 10% point [nm]	Second channel 10% point [pixel]	Second channel 50% point [pixel]	Second channel 90% point [pixel]
1	892.9236	913.6355	935.1907	308.5095	310.8480	313.0643	85.785	103.8068	122.6088
2	810.6767	841.0170	867.7506	394.4286	398.0730	401.0664	13.5171	29.6739	43.9254
3	956.4247	981.3118	1008.342	592.3720	598.0070	603.708	34.8809	59.6331	86.8535

Table 8: Newly evaluated 90%, 50%, 10% overlap points based on the observed shift of the 50% point using the WLS on-board measurements from the operational monitoring database..

Figure 42 shows the newly-defined 90%, 50%, and 10% overlap point for the WLS spectrum derived on 31 December 2018.

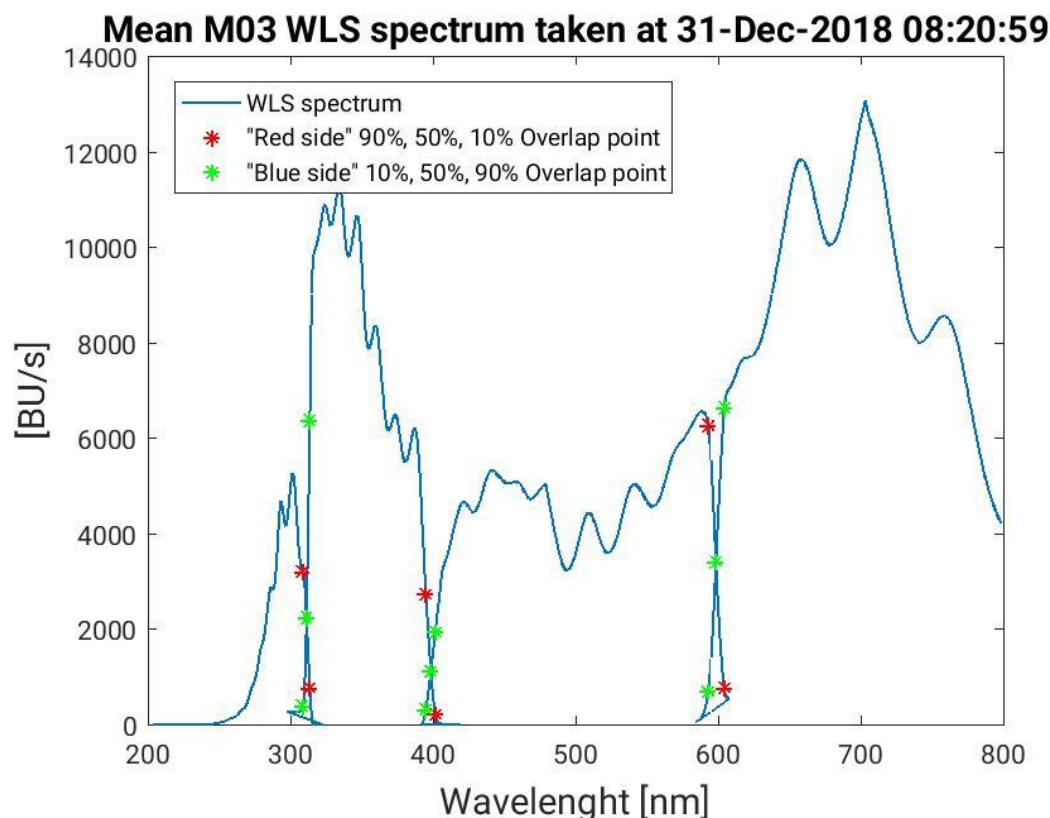


Figure 42: GOME-2 FM2 90, 50, and 10% overlap point position (stars) for a WLS spectrum as derived on-board on 31 December 2018.

4.7.2.2 Offline-derived Etalon

To be able to evaluate and adjust the derived etalon and overlap region setting, offline analysis tools in TCE are used and will be compared to the “as is” as well as to the modified PPF level 1B product results.

We start off with the initial settings of processing using version 1.02 of the INS processing settings and version 1.02 (original TNO data set, with a fix for problem with hard coded PMD SLIT weights in WL_SLIT_PMDx.201) of the GOME_CAL key-data as have been used for Figure 40 and Figure 41. The etalon correction in this original configuration is derived from the in-flight and on-ground white-light source (WLS) spectrum as shown in Figure 43. The etalon correction is derived (both with the PPF and offline) according to Section 5.2.18 in [AD 3], with the only difference that for the “offline” derived etalon correction slightly modified start and end points have been used. These points fall just outside the overlap regions, taking the observed shift of the overlap points (previous section) into account. This is done so that the residual of the shifted and the un-shifted radiometric response function is lower or equal to the on-ground calibration measurement error of response functions at the start and end points (ets/ete).

Note: Finding these optimal points, which define both the regions inside and outside of the overlap regions, involves a certain amount of manual interaction. This manual interaction is not shown here. Table 9 shows the start / stop detector pixels per channel as used for FM1 after launch as the region for which the etalon correction is derived and applied (PPF-derived etalon correction in lower panel of Figure 44; blue line). They therefore implicitly define the region of the overlap outside the etalon correction region.

	Channel 1	Channel 2	Channel 3	Channel 4	PMD-P	PMD-S
ets	310	85	14	37	751	750
ete	929	880	1013	991	1000	999

Table 9: Start (ets) / Stop (ete) detector pixel per channel which fall outside the overlap region. Launch SIOV settings for FM1 (INS 102)

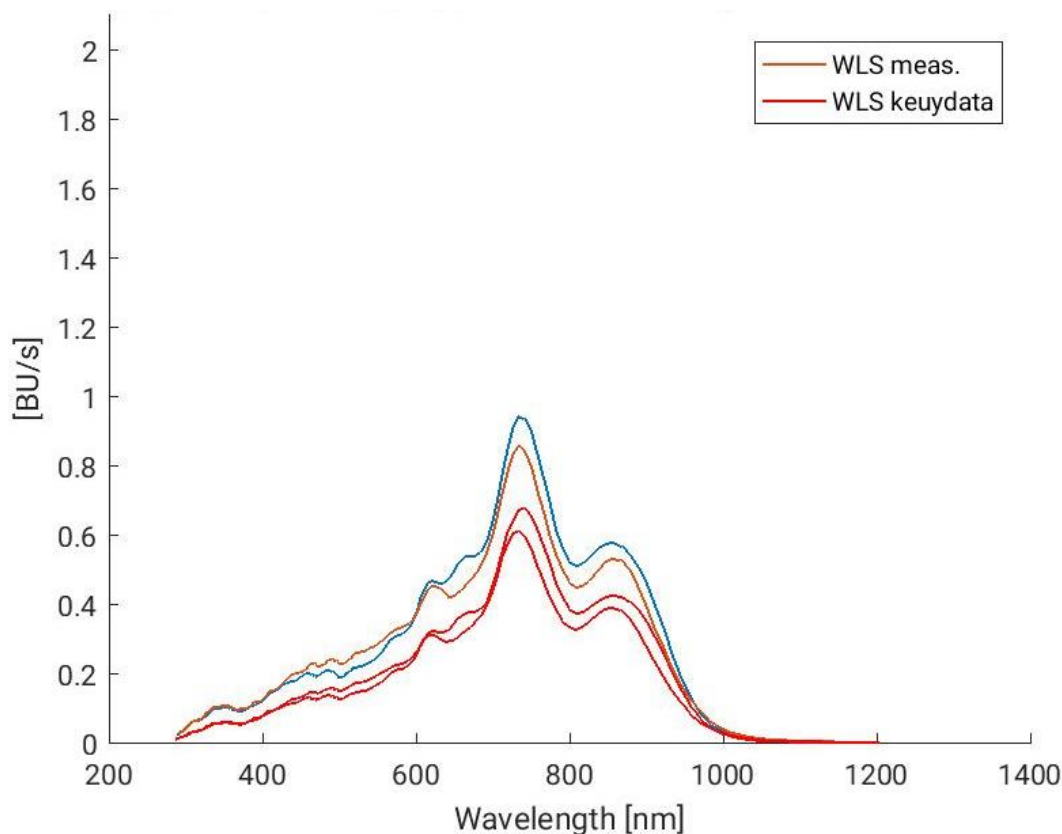


Figure 43: GOME-2 FM1 white-light source spectra measured in flight on 31 Decemebr 2018 (blue curve) and as measured on ground for the FM1-2 campaign. Note that the difference in overall signal strength is an expected 1g to 0g effect of the lamp output.

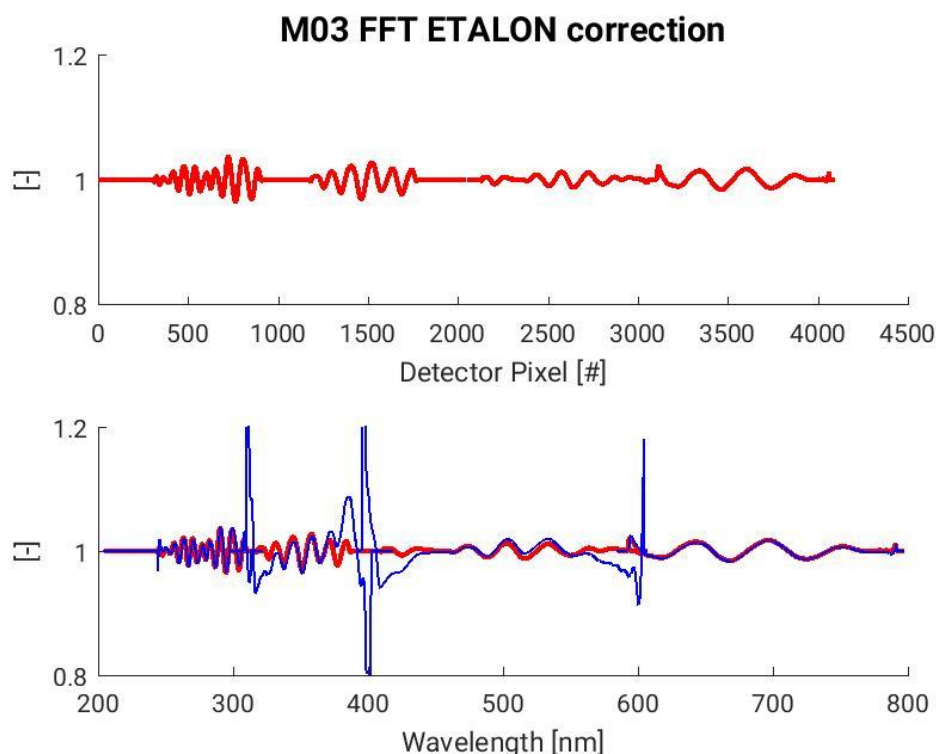


Figure 44: GOME-2 FM1 derived etalon correction from the WLS spectra in Figure 43 according to PGS 7.1. The lower panel shows the etalon correction as derived from the PPF (blue line) using the original INS 1.01 settings (Table 9) and the “offline” derived Etalon.

Figure 45 and Figure 46 show the crossing point of the shifted and the un-shifted radiometric response functions, according to the described procedure and the position of the selected overlap region start/stop points on the derived residuals (of the shifted and un-shifted response spectra). The results show that it is difficult to reach the 3 % residual point in channel 1 (Figure 45; lower panel red star) but it works reasonably well for all other transition points. In order to make a “smooth” transition the gradient of the response functions need also to be taken into account, and this is not reflected in the residuals.

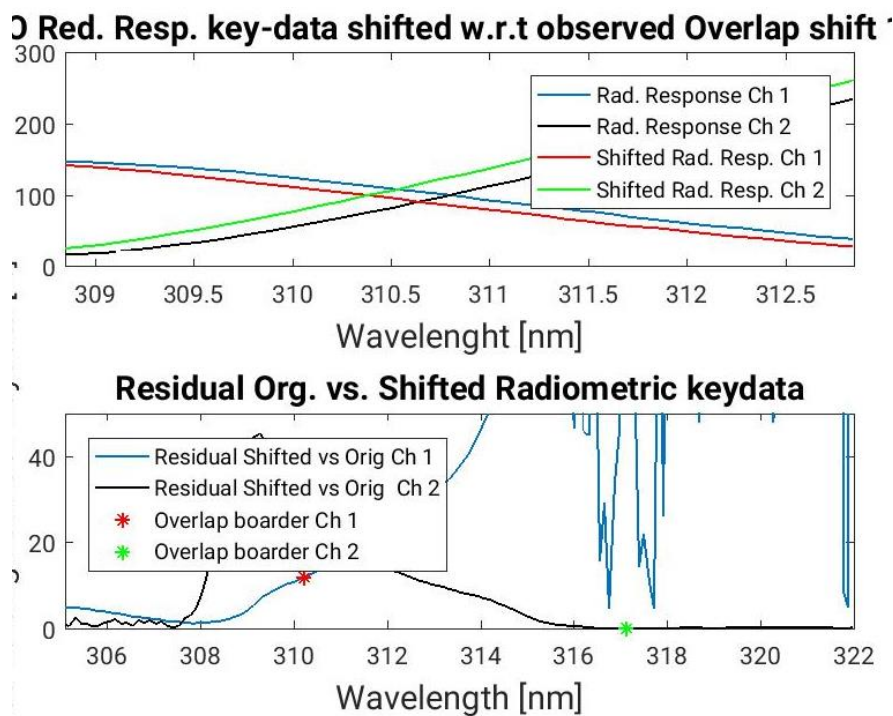


Figure 45: Shifted and un-shifted radiometric response function according to the observed overlap shift (upper panel) in the channel 1 to 2 transition region. The lower panel shows the residual of the shifted and the un-shifted spectra, as well as the position of the chosen start/stop of the overlap region.

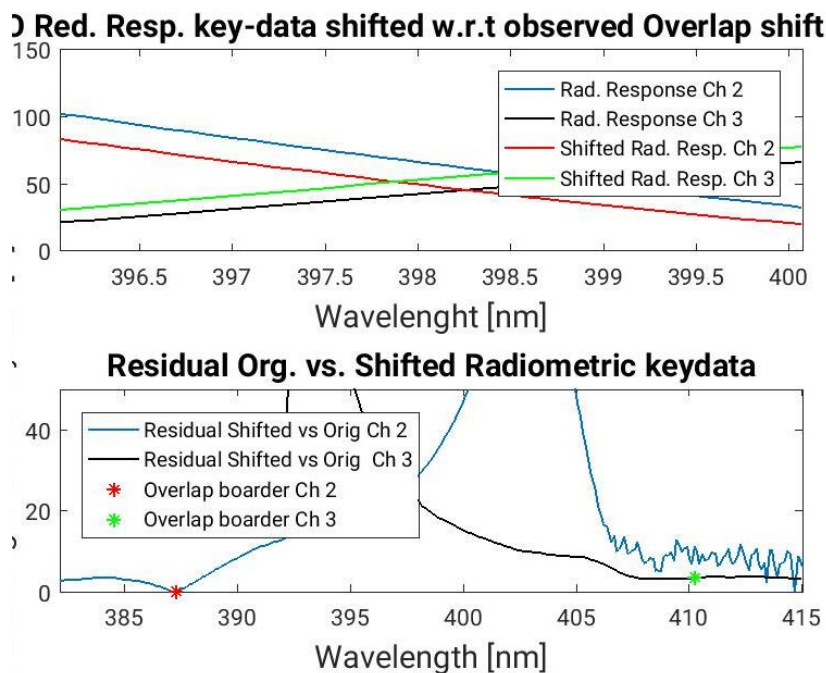


Figure 46: Shifted and un-shifted radiometric response function according to the observed overlap shift (upper panel) in the channel 2 to channel 3 transition region. The lower panel shows the residual of the shifted and the un-shifted spectra, and the position of the chosen start/stop of the overlap region

4.7.2.3 Derivation of the overlap region adjustment of the radiometric response functions

First the ratio of the on-ground to in-orbit WLS spectrum of Figure 43 for channels 1 and 2, and for channels 2 and 3 are combined for the treatment of the overlap region 12 and 23 respectively.

Note: In the analysis and illustrations in this section, the treatment of the channels 3 to 4 overlap is omitted since the shift is assumed to be 0 there.

From the ratio, a third order polynomial fit (same degree as for the etalon correction background fit, see PGS 7.1) is fitted to the combined ratio spectra but excluding the overlap region in the fit, (see Figure 47). Then, this background is removed by taking the ratio of fit and combined ratio-spectra and the part of the resulting spectrum outside the overlap region is set to 1 (See Figure 48).

Finally, we replace the region outside of the overlap region (set to 1 in Figure 48) with the etalon correction derived offline in Figure 44, lower panel, red line (this is the additional step not applied to FM3 on Metop-A). The result is the final correction spectrum for the overlap region 12 and 23 as shown in Figure 49. In this way the etalon correction of the on-ground to in-flight situation on 11 November 2012 is now taken into account implicitly in the correction spectra for the radiometric response key-data. Therefore, this type of corrected key-data can only be applied if the in-flight acquired WLS spectrum of Figure 43 is used as reference WLS spectrum (RA_WLS*) in the updated key-data.

The resulting corrected radiometric and IRR-radiometric response function key-data spectra are shown in Figure 50. The results also show that the choice of the overlap region start/stop definitions were adequate because there is a very smooth transition between the overlap-adjusted and etalon-adjusted regions.

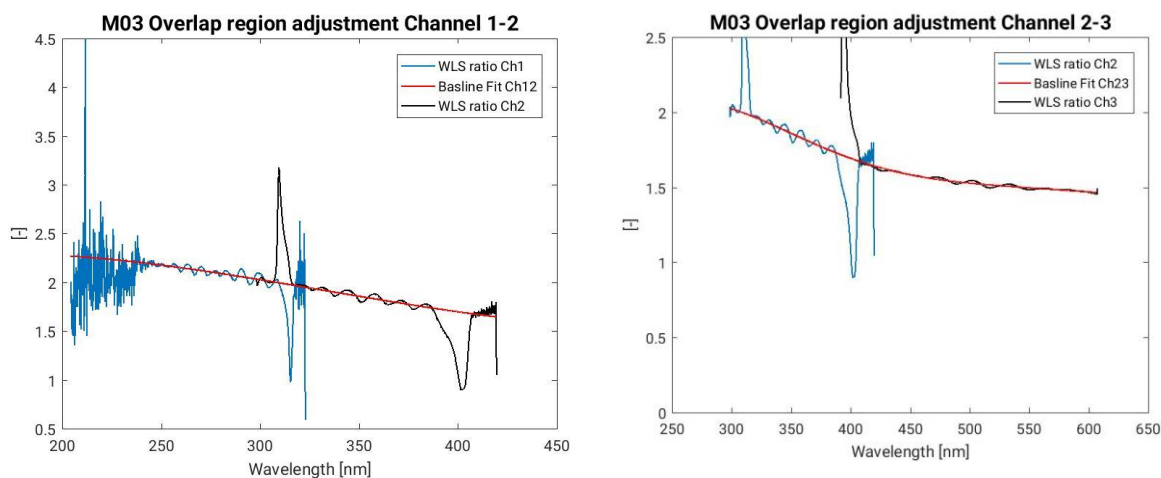


Figure 47: WLS spectra ratio between a spectrum measured on 31 December 2018 in-flight by FM1 and the on-ground measured WLS reference spectrum as contained in the CAL 1.00 key-data set (FM1-2). The figure also shows a third order polynomial fit excluding the overlap regions (red line). The left panel shows the result for channel 1 and 2 and the right panel for channel 2 and 3 (blue and black line respectively).

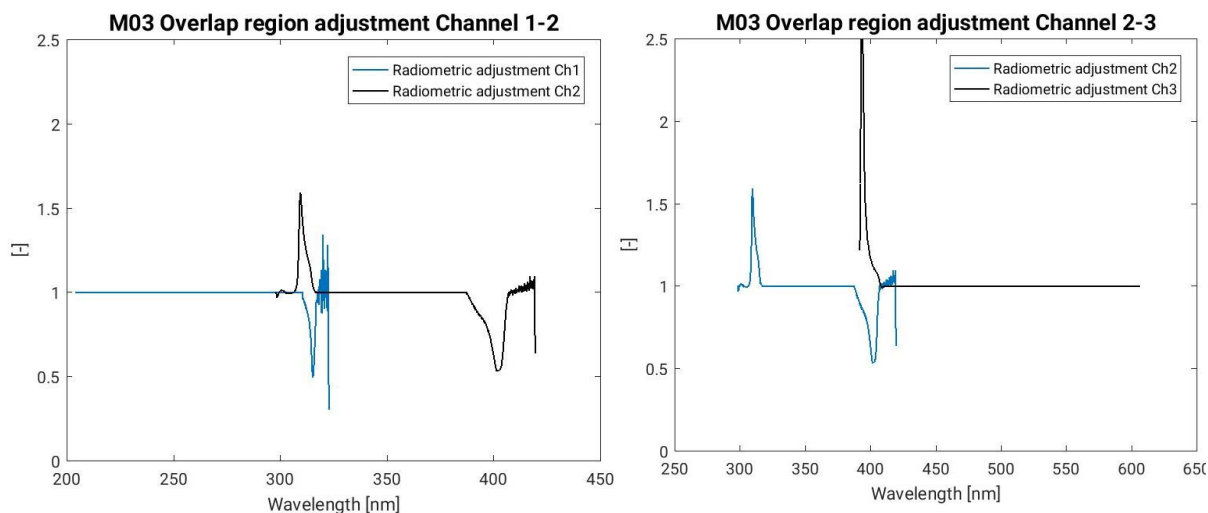


Figure 48: WLS spectra ratio between a spectrum measured on 31 December 2018 in-flight by FM1 and the on-ground measured WLS reference spectrum as contained in the CAL 1.00 key-data set (FM1-2), but the ratio is to the background fit results and the part of the spectrum outside the overlap regions is set to 1.

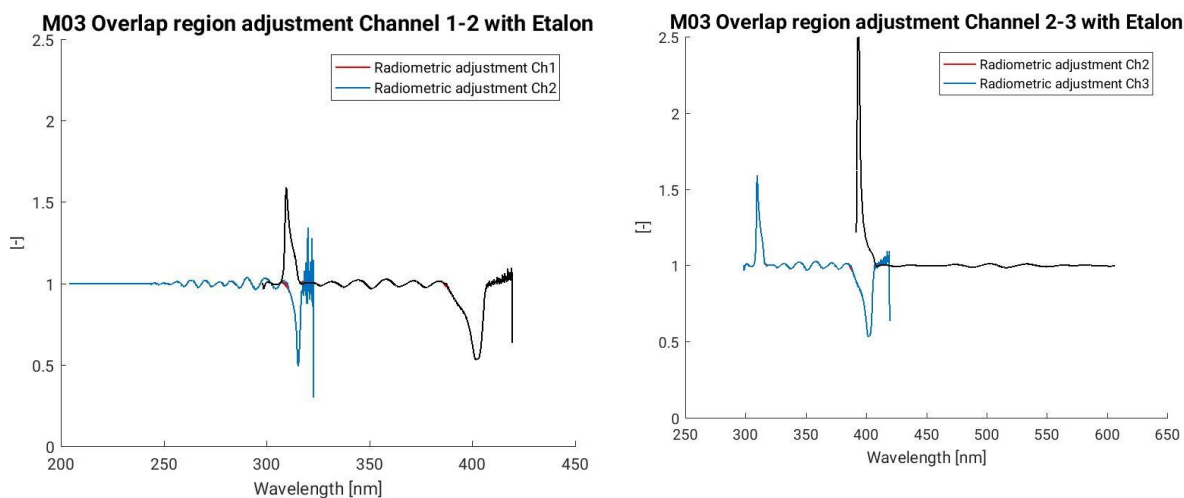


Figure 49: WLS spectra ratio between a spectrum measured on 31 December 2018 in-flight by FM1 and the on-ground measured WLS reference spectrum as contained in the CAL 1.00 key-data set (FM2-2). The region outside the overlap is replaced by the etalon correction as derived from the same date (see Figure 44).

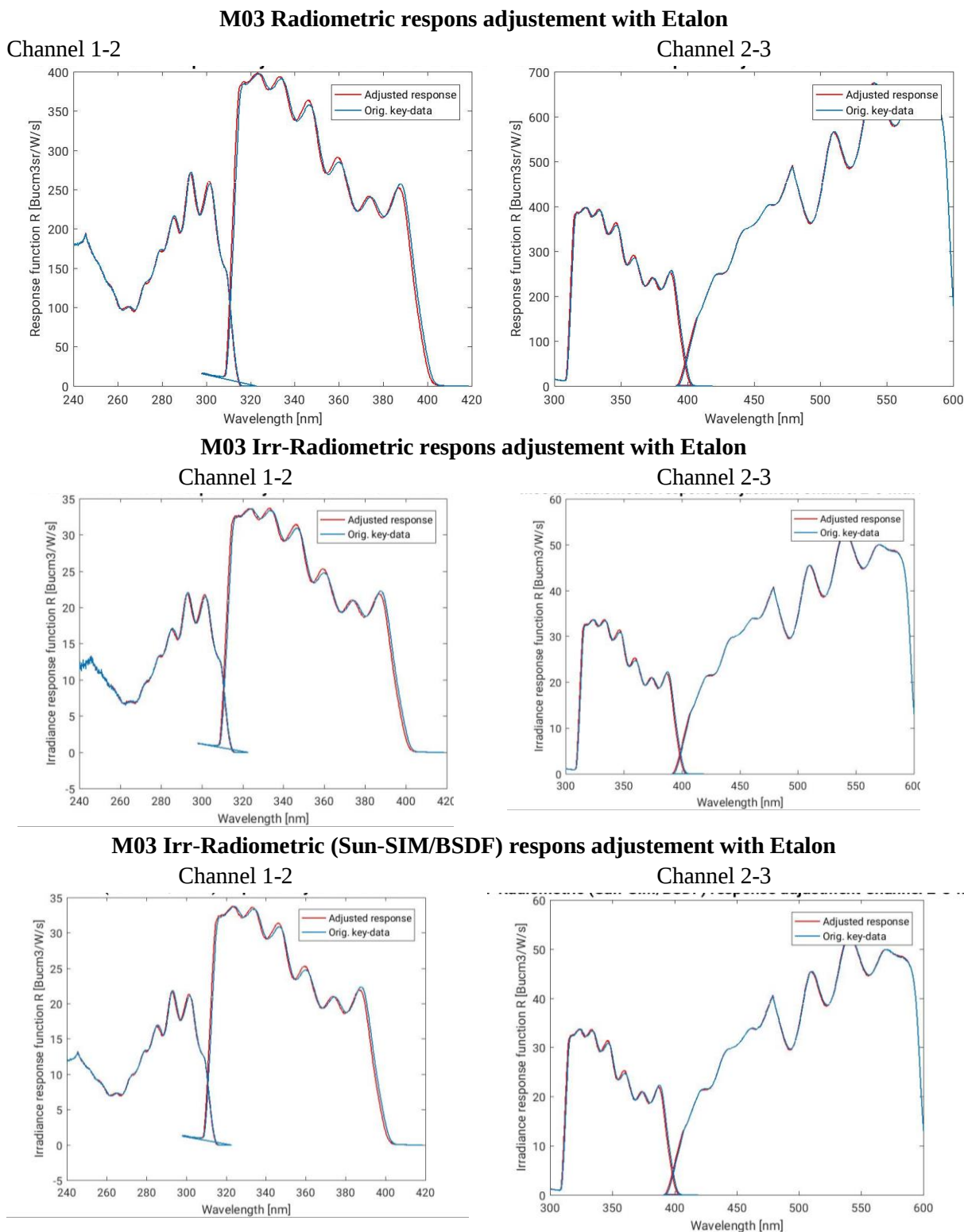


Figure 50: Adjusted set of key-data response functions (CAL 1.01) using the correction spectra of Figure 49 (red curve). The blue curve shows the original key-data response functions (CAL 1.00/ FMI-2 campaign). The left panels show the overlap 12 and the right panel the overlap 23 regions. Upper panel show the radiometric response functions (RA_ABS_RAD_MAIN*), the middle

panel the irr-radiometric response functions (RA_ABS_IRR_MAIN), and the lower panel the irr-radiometric response functions as derived from the suns-simulator and the BSDF (RA_SUN_CAL_ABS_IRR_MAIN*).*

4.7.2.4 Derivation of etalon after adjustment (verification) and updated etalon settings

To verify the functional, quantitative, and qualitative performance of the adjustment, the updated radiometric response data—together with the updated WLS reference spectrum and the updated overlap definitions—has been combined in a new key-data set CAL version 1.03 (see also Section 4.7.2.6) which has then been used to derive an etalon correction from the same in-flight WLS measurement taken on 31 December 2018. At the same time, the settings for the etalon correction valid region have also been altered to be extended to the borders of the valid region of detector pixels per channel. This is in contrast with the original settings (INS 1.02; Table 8). The new settings are listed in Table 10.

Figure 51 shows the result for an etalon correction with the updated key-data set at the same scale as used for Figure 44. As required, the etalon correction is very close to 1, with some residual resulting only from the intrinsic accuracy of the background fitting, interpolation and fast-fourier-transform (fft; for details see PGS 7.1).

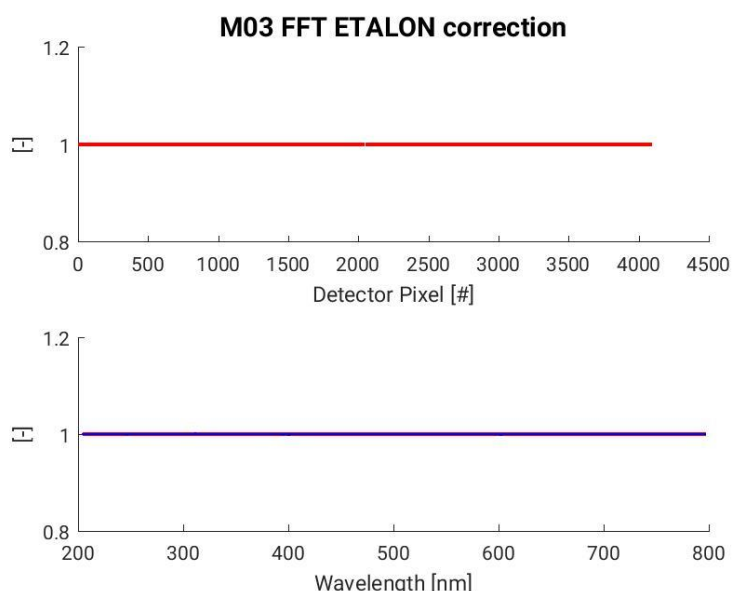


Figure 51: Etalon correction as a function of detector pixel (upper panel) and of wavelength (bottom panel) on 31 December 2018 with the updated key-data set CAL 1.03 at the same scale as used for Figure 44.

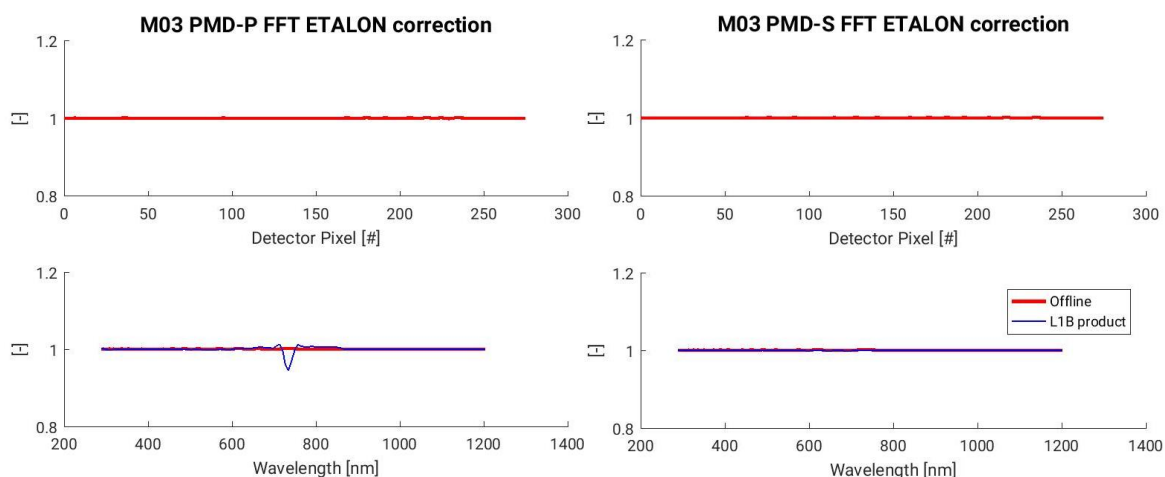


Figure 52: Derived etalon correction after the adjustment with CAL 1.01 key-data for PMD-P and S (left and right panel).

Overall, the derived etalon correction shows the typical etalon structure though on a much smaller scale than for CAL 1.00/INS1.01 (Figure 44) as expected. It also shows that there can be small differences, especially in the overlap region between the “offline” derived and the PPF derived etalon correction due to the intrinsic background fitting and fft accuracies involved (note, that these differences are smaller than 0.1 %).

4.7.2.5 Treatment of PMD data.

To be consistent with the approach taken for the main channel data, the etalon correction derived from the 31 December 2018 WLS spectra is also applied to the radiometric response data for PMDs in the same way as described above. Of course, there is no need to carry out any overlap region adjustment. Table 10 lists the updated start /stop etalon settings for PMD that cover the complete spectral region of the PMDs.

	Channel 1	Channel 2	Channel 3	Channel 4	PMD-P	PMD-S
ets	310	104	30	60	751	750
ete	913	841	981	991	997	997

Table 10: Start (ets) / Stop (ete) detector pixel per channel which have been extended for the use with the adjusted response key-data set of CAL 1.01 in INS 1.04

Figure 52 shows results for the derived etalon correction after the adjustment with CAL 1.01 key-data for PMD-P and S. Note the very small vertical scale (sub-percentage level). Again, the differences between the PPF-derived and the offline-derived correction (blue and red line) are due to the intrinsic accuracies of background correction and fft.

4.7.2.6 Updated key-data set (summary)

During the course of the GOME2 IOV, Moon Observation opportunities have been exploited (see section 4.11.2). From the first moon calibration a significant offset in the short wavelength in the PMD-P has been observed. Following this finding, there has been a re-delivery of the key data from TNO for on 14 January 2018, accounting for this straylight correction (FM1-3a).

During the course of the adjustment procedure described in the previous section, the following set of key-data has been modified, creating version 3 (CAL 1.03; see file headers) from version 2 (CAL 1.02).

Channel overlap	WL_OVERLAP
WLS reference spectrum	RA_WLS_MAIN,RA_WLS_PMD_P,RA_WLS_PMD_S
Radiometric Response	RA_ABS_RAD_MAIN, RA_ABS_RAD_PMD_P RA_ABS_RAD_PMD_S
IR radiometric Response	RA_ABS_IRR_MAIN, RA_ABS_IRR_PMD_P RA_ABS_IRR_PMD_S
IR radiometric Response -using the sun-simulated and BSDF derived data	RA_SUN_CAL_ABS_IRR_MAIN RA_SUN_CAL_ABS_IRR_PMD_P RA_SUN_CAL_ABS_IRR_PMD_S

4.7.3 Verification of Earthshine and validation of solar spectra after adjustment

In this exercise, we verify the impact on the earthshine spectrum using the new CAL 1.03 auxiliary key-data set by both visual inspection and by comparison to the spectrum displayed in Figure 41 (CAL 1.01).

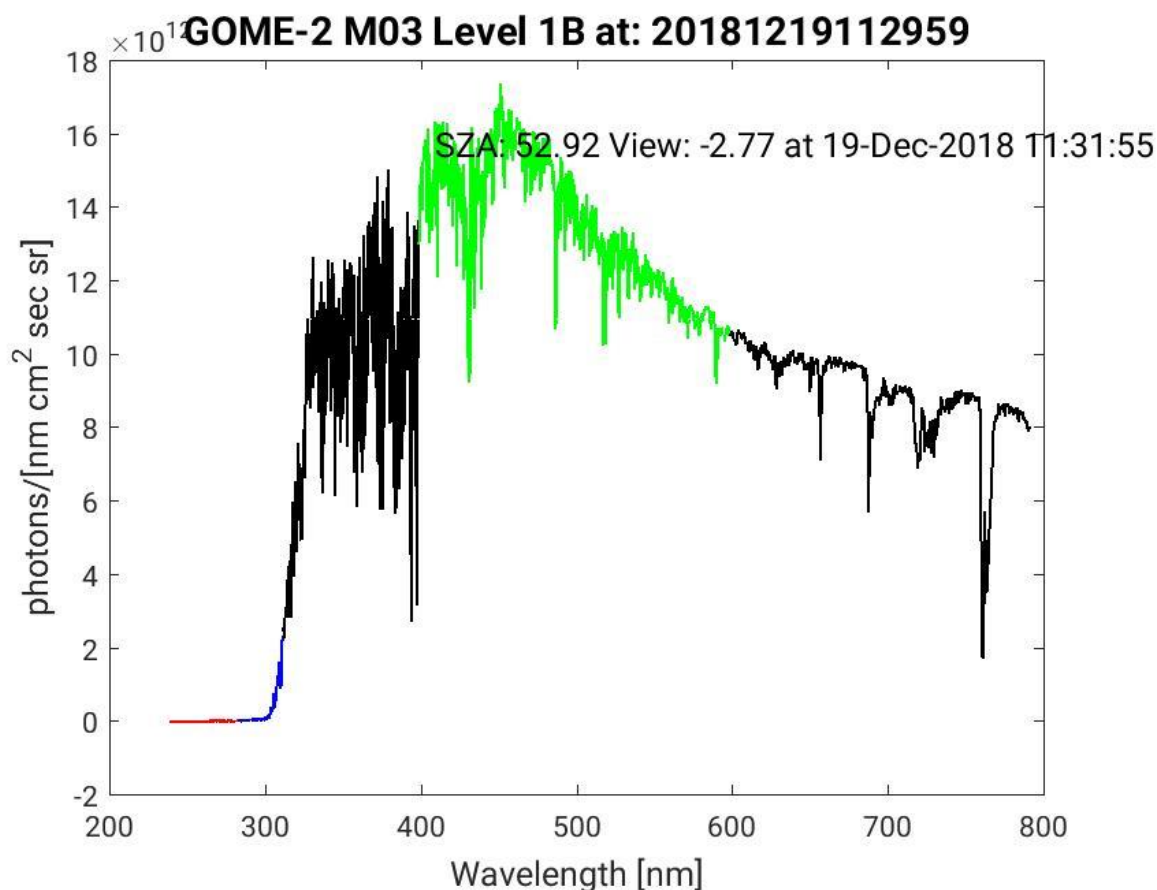


Figure 53: GOME-2 FM1 calibrated Earthshine spectrum (upper panel) with alternating colours for the different bands processed with CAL 1.03 updated parameters.

Figure 53 shows a calibrated level 1B earthshine spectrum taken on 30 October 2012 using the PPF and the updated key-data set CAL 1.01. Now, the focus panel on the two overlap regions show a very smooth transition between the channels. The spectra also do not show any visible etalon-residual effect.

This becomes even clearer when comparing the two spectra of Figure 41 and Figure 54. Since the net result of the etalon adjustments outside the overlap region should be zero, we expect the overlap region correction itself to be the only visible difference in the comparison, within the limits of the accuracies as described in the previous sub-sections. Indeed the residual is around 1 % outside the overlap region and on the order of the applied corrections (Figure 49) inside the overlap regions.

We compare the differences in fully calibrated reflectivity values and radiance values for M03 at level-1B and between the products produced in CGS2 with INS and CAL file version 1.03 and the products produced in CGS1 with INS and CAL file version 1.02. Figure 54 shows the results for radiances and Figure 55 for reflectances.

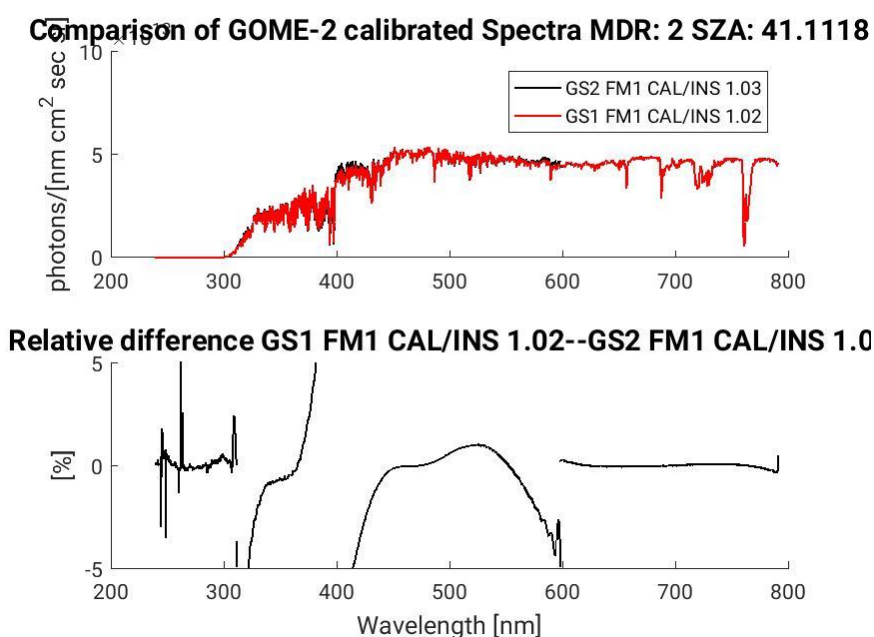


Figure 54: Top panel: Main channel radiance spectrum from M03 (FM1) for a given observation geometry (see labels) for GS1: PPF 6.3.1 INS/CAL 1.02 (black line) and GS2: PPF 6.3.1 INS/CAL 1.03 (red line). Lower panel: Relative difference between the spectra. The black line is the residual of the comparison of the end product and the red line without the polarisation correction applied

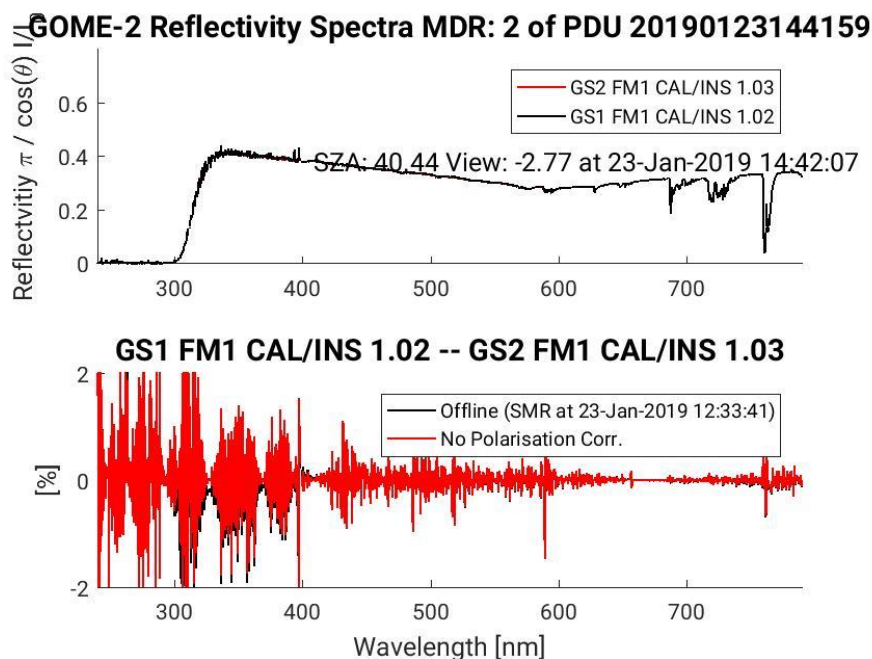


Figure 55: Same as Figure 54 for reflectance values.

Results show the variation between more than 5% in the channel overlap region and around 1% in the channel centres for radiance comparison residuals (Figure 54). For reflectances (Figure 55) the broad band structure cancel out but a small shift in spectral assignment between solar and radiance data leads to high frequency structures.

Figure 56 shows the solar spectrum displayed already in Figure 40, but derived with the CAL 1.01/INS 1.02 setting by the level 0 to 1B processor. This compares to our standard reference spectrum by Dobber et al./KNPO (see previous sections). Indeed, the large residuals in the overlap regions are now gone or significantly reduced when compared to the result in Figure 40, demonstrating that the new approach results in both significantly improved data quality in the overlap region together with the capability of continuous correction of these regions by the derived on-board etalon according to PGS 7.1.

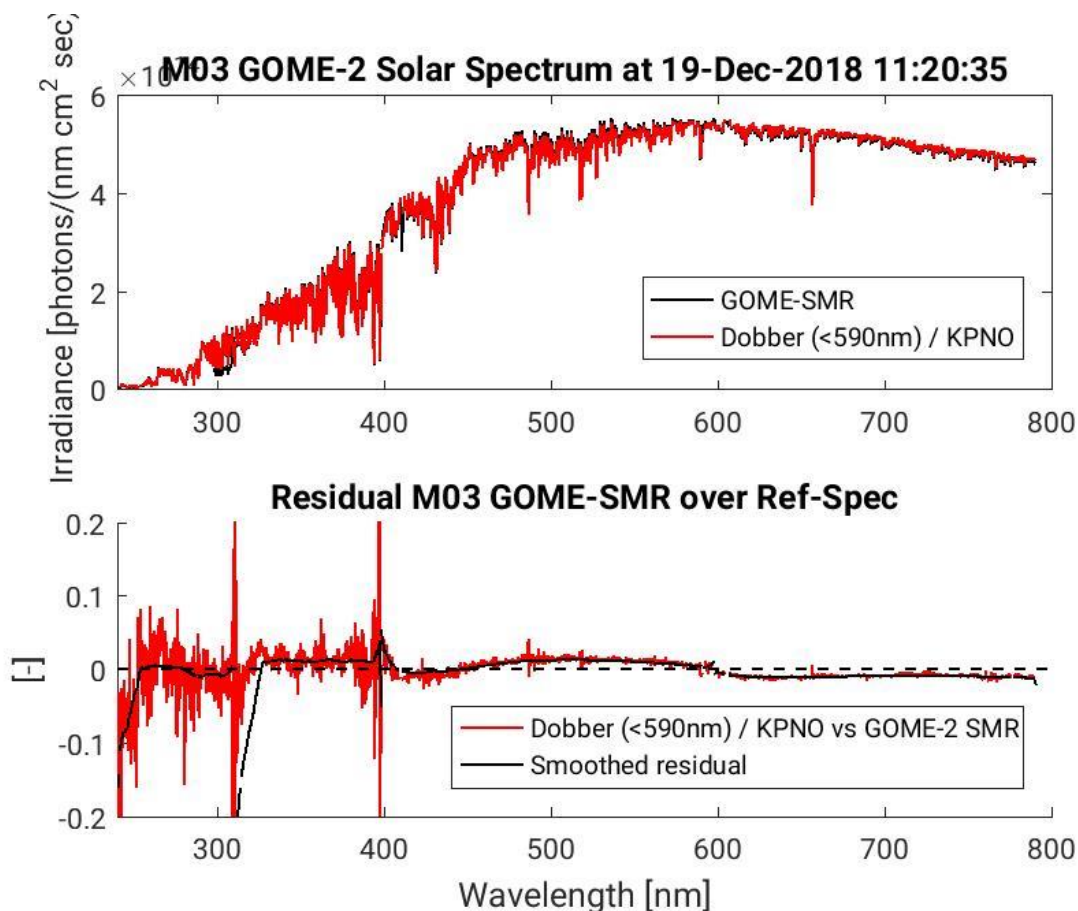


Figure 56: GOME-2 FM1 calibrated solar spectrum (upper panel; black line) compared with a reference spectrum by Dobber et al. (Solar Phys (2008) 249: 281–291) below 590 nm (upper panel, red line). Above 590 nm the KPNO/AFGL spectrum of 2004 is used. The lower panel shows the residual between both (red line) and a moving average to guide the eye.

Finally, we compare also the PMD-P to S ratios for the solar spectra data in Figure 57. This ratio should generally be close to one since the solar irradiance is un-polarised (for details see also [AD 3] on the monitoring of solar stokes fractions). Actually, this ratio has never been close to one for either FM3 on Metop-A or FM2 in the previous processor configuration (See CAL 1.00; left panel Figure 57).

With the etalon-adjusted irradiance response data for PMDs (CAL 1.03) Figure 57 shows the PMD-P to S ratio.

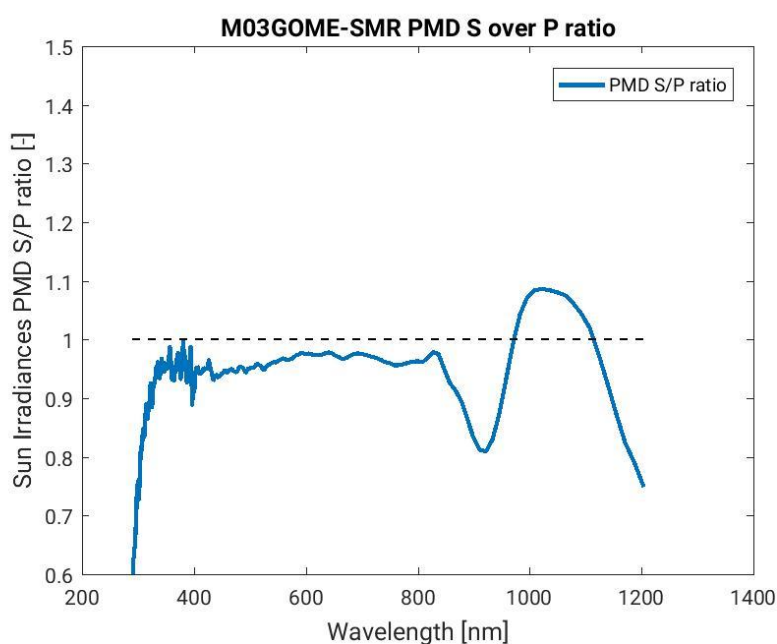


Figure 57: GOME-2 FM1calibrated solar spectrum PMD S over P ratio. results for the new processor and key-data configuration (CAL 1.03 / INS 1.32).

4.8 Keydata “cleaning”

The key data derived from the GOME2 FM1 3rd completed calibration campaign (identified as FM1-3) for the polarization response have been composed by Xe lamp results for FPA 1 and 2, and QTH lamp results for FPA 3 and 4. The PMD results are based on the Xe lamp results as these have shown previously to be less affected by the emission lines [AD9].

The Xenon lamp has prominent emission line features at wavelengths in FPA 3 and 4. This was observed during the initial analysis of level 2 retrieval residual spectral structures during the pre-operational commissioning phase of GOME-2MetopB.

The Xe lamp results show in some cases small irregularities at these wavelengths. These are most likely caused by remaining non-linearity effects of the detector or stray light / slit function effects in the spectrometer. The QTH lamp has a smooth spectrum and does not show these features, but has very low signal in the UV and the results are thus affected by noise.

Since one of the tasks of the PVRB for the pre-operational status was to monitor the quality of PMDs and the following polarization correction, the key data cleaning procedure - using FFT filtering in spectral space - already adopted for GOME-2 MetopB has been performed also for GOME-2 FM1 Metop-C.

4.8.1 Cleaning procedure

The cleaning of key-data is carried out using a FFT type of filtering and follows the scheme specified for Etalon retrievals in the PGS, Section 5.2.18, Algorithm option 1 (A2.16.3.1). The following filter coefficients have been used (see A2.16.3.1 in [AD3]):

```
[0 0 25 50
 0 0 25 50
 0 0 25 50
 0 0 25 50
 0 0 25 50
 0 0 25 50],
```

where the vertical dimension are the channel numbers for which the four coefficients are applied.

Figure 58 shows the result for the applied FFT filtering in spectral space for the ζ -sensitivity key-data..

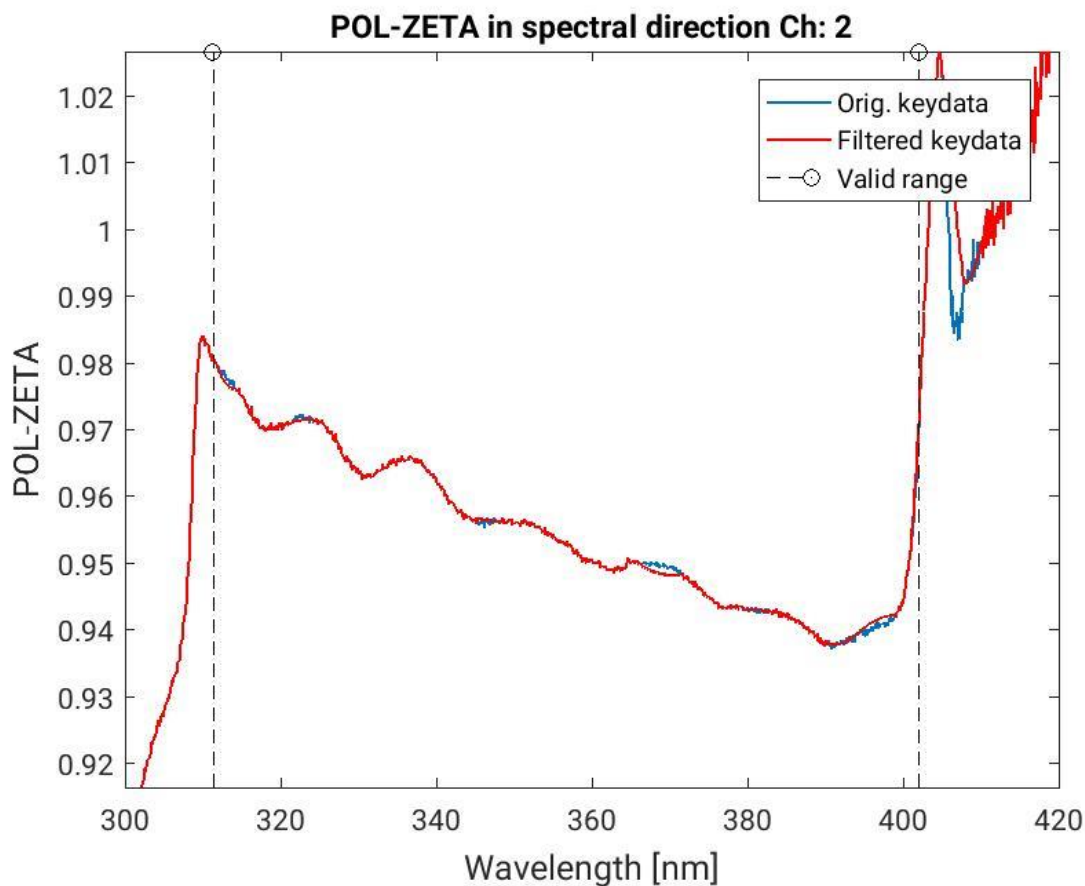


Figure 58: FFT-Filtered ζ -sensitivity key-data spectrum (red-line) as compared to the original data (blue line). Since FFT filtering may introduce artefacts at the boards, the valid key-data region is indicated by the vertical dashed lines.

Figure 59 shows the angular dependence key-data for ζ , called χ_ζ , for which the original key-data (underlying red lines) show some pronounced outliers in angular dimension (the key-data is measured at 28 reference angles), while one expects the key-data to be smooth in this dimension.

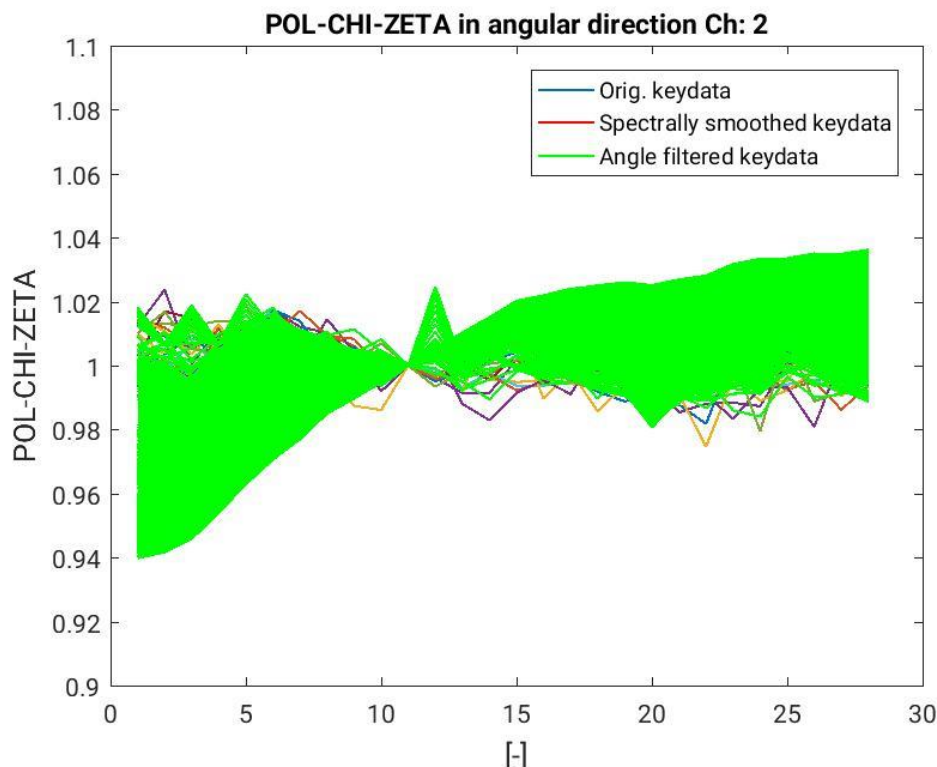


Figure 59: Angular dependence of ζ -sensitivity key-data for all wavlength (lines) over 28 reference angles. The red and colored lines show the original key-data overlaid by “spline” smoothed keydata in green (for details see body of the text).

For “cleaning” of key-data in the angular direction, a simple spline method has been used: identify the outliers manually and spline over these masked angular points. This is shown in Figure 59 for the “cleaned” results—in green.

Both cleaning methods have been applied consistently for the key-data in either one (FFT only) or two (FFT and spline) dimensions.

The following key-data has been cleaned:

POL_ZETA.104
POL_KAPPA.104
POL_CHI_ZETA.104
POL_CHI.104
POL_ETA.104

As it can be seen in Figure 58 and Figure 59, the cleaning procedure was not highlighting any critical spectral or angular behaviour. The cleaned key data are not currently used in the processing of Level1 GOME-2 C data.

An evaluation of impact of the this “cleaning” on the Level2 retrieved data is anyhow planned, in the Study conducted by IUP - University of Bremen on the Scientific Support for Analysis of GOME-2 FM1 MetopC In-Orbit Performance.

4.9 Polarisation correction – Stokes fraction quality (A4.4/A5.3)

The quality of the polarisation correction of main channel data (see [AD 3]) and the quality of the derived Stokes fraction (for direct use, for example, on aerosol optical properties retrievals) is evaluated using the following measures:

- Limiting Atmosphere Method (Earthshine data)
- Stokes fractions for special geometries (Earthshine data)
- Quality flagging on missing and “degraded” Stokes fractions
- PMD S/P ratio for solar measurements
- Stokes fractions derived from solar measurements

The results shown here are derived from one orbit of MetopC/FM1 (31 December 2018)
Metop-B / FM2 (and Metop-A / FM3 for reference) data on 28 November 2012

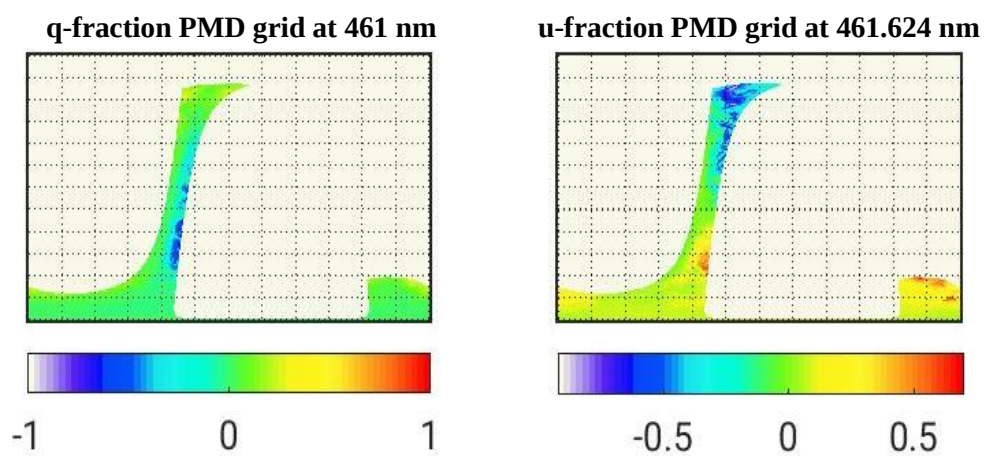
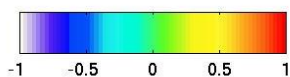
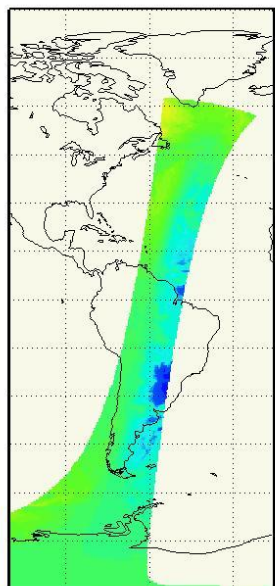
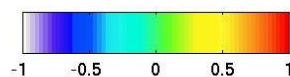
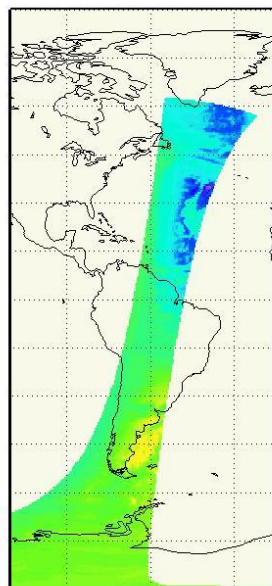


Figure 60: q-Stokes and u-Stokes fractions at PMD spatial resolution for MetopC / FM1 for one orbit on 31 December 2018

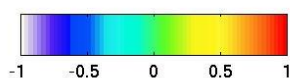
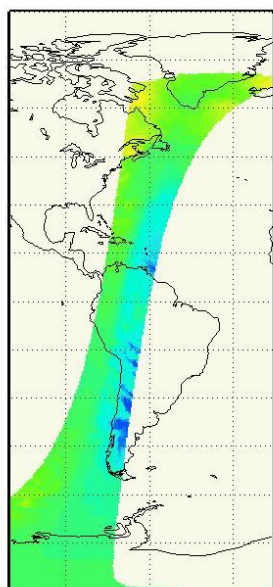
q-fraction PMD grid at 413.8198 nm



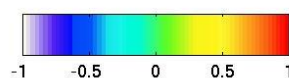
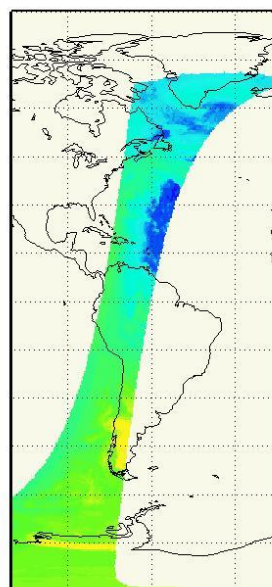
u-fraction PMD grid at 413.8198 nm



q-fraction PMD grid at 414.4576 nm



u-fraction PMD grid at 414.4576 nm



Metop-B / FM2 (upper panels) and Metop-A / FM3 (lower panel) for one orbit on 28 November 2012

4.9.1 Limiting Atmosphere Method

To monitor and validate the measured GOME-2 Stokes fractions under all viewing conditions a general approach is used—the “Limiting-Atmosphere” approach. This approach is based on a statistical analysis developed by SRON under contract to ESA. It can be shown that the general behaviour of the Stokes fraction, q , along the orbit is primarily determined by molecular (Rayleigh) scattering, in particular over dark ocean surfaces, and that variability in q is caused by the presence of clouds and aerosols. It has been observed that the measured polarisation values are always clearly between extreme limiting values. These limiting values lie between the Rayleigh single scattering values and $q = 0$. Furthermore, for a large number of measurements, the measured polarisation values are influenced by largely cloudy scenes, which depolarise the light leading to a measured Stokes fraction of $q = 0$. The assumption upon which the generalised validation of q is based is that the minimum Stokes fractions observed are representative of a *limiting atmosphere* with minimum depolarisation – a combination of minimum ground-albedo and minimum aerosol loading. In the case of little or no instrument degradation, these limiting values will be constant in time and can be used as an empirical validation method for both the short-term and long-term in-flight monitoring of polarisation measurements. Figure 61 shows Stokes fractions calculated from earthshine scanning measurements with respect to the single scattering Stokes fractions (the diagonal line) and $q = 0$. Red points lie *inside* the physically reasonable range while blue points lie *outside* the physically reasonable range. The plots one full day-side orbit period (lower panels) for the three instruments: FM1 left panels, FM2 in the middle panels, FM3 in the right panels.

The results shown in Figure 61 demonstrate that Metop-C / FM1 results are of a good quality and presents a good agreement with those for the MetopB/ FM2 and Metop-A / FM3 products. The first PMD channel would need to be revisited as it can be derived also from the PMD-P to S ratio shown in Figure 57.

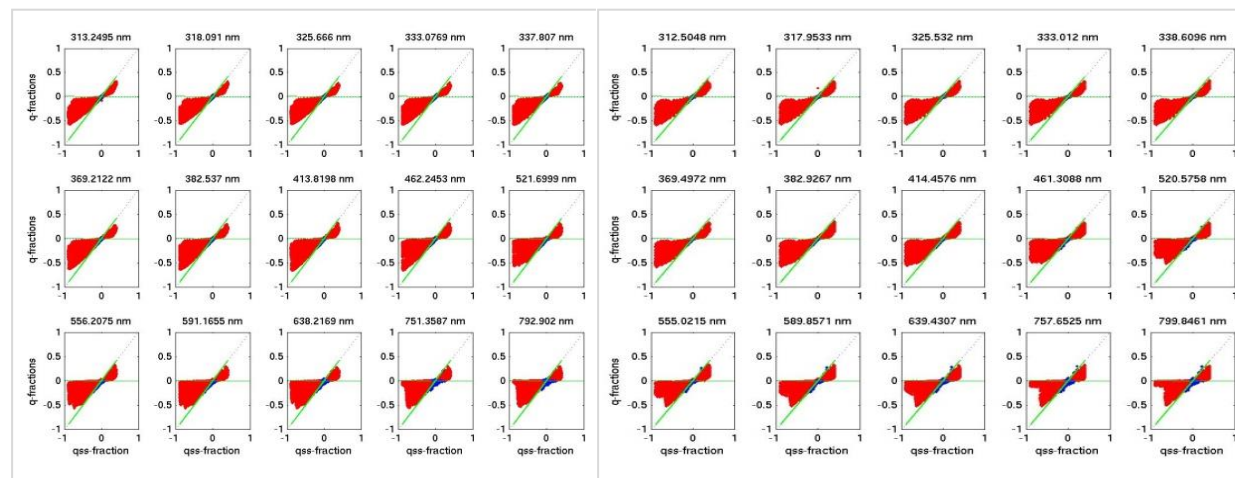
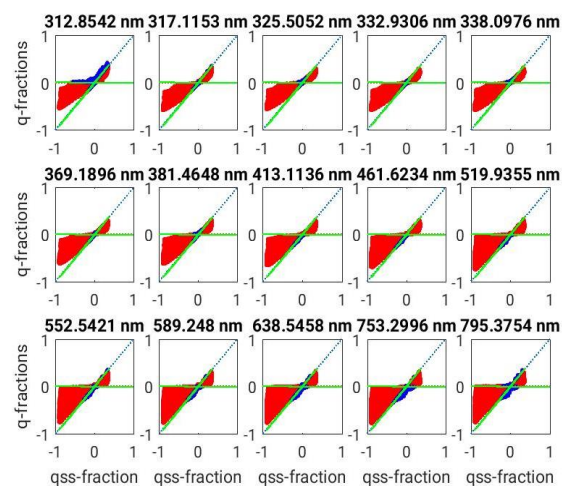


Figure 61: The plots show one full day-side orbit period (lower panels) for the three instruments(FM1 left panels, FM2 center panels, FM3 right panels) on 31 December 2018. Red plots are inside the required limiting atmosphere limits and blue plots are outside the required limiting atmosphere limits.

Figure 62 shows the location of those Stokes fractions which are either missing due to low PMD signal levels (below 5 BU above noise) or are flagged as “bad” because they lie outside the limiting atmosphere criteria (blue plots in lower panels Figure 61). Bad Stokes fractions are usually found in the vicinity of the area where the Stokes q-fraction approaches zero (see upper left plot), which we previously have tagged as the “c-shape” area” in which a special treatment of the “singularity”-issue for calculation of Stokes fractions is applied (see [AD 3]) and where also the “limiting-atmosphere criterion approaches a singularity. Some “bad” Stokes fractions can be expected within the “c-shape” area, but none are expected outside this area.

The results in Figure 62 show there are no bad Stokes fractions for the investigated orbit outside the “c-shape” area for Metop-C / FM1 processing.

q-fraction at 461.6234 nm BAD q-fractions at 461.6234 nm

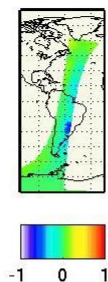


Missing q-fractions at 461.6234 nm Scattering Angle

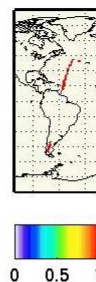


Figure 62: The upper four panels show q-Stokes fractions, “bad” Stokes fractions, missing Stokes fractions and the corresponding scatter angle for MetopC / FM1

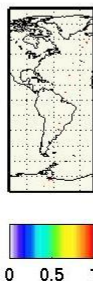
q-fraction at 413.8198 nm



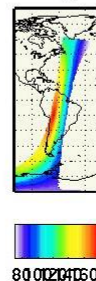
BAD q-fractions at 413.8198 nm



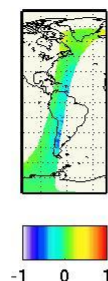
Missing q-fractions at 413.8198 nm



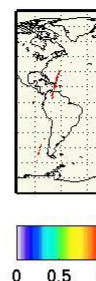
Scattering Angle



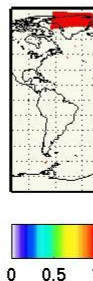
q-fraction at 414.4576 nm



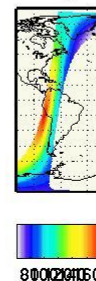
BAD q-fractions at 414.4576 nm



Missing q-fractions at 414.4576 nm



Scattering Angle



, the central four panels show the same for Metop-B / FM2 and the lower four panel for Metop-A / FM3.

4.9.2 Stokes fractions for special geometries

The Stokes fraction q depends on the degree of linear polarisation P and the polarisation angle with respect to the reference plane χ in the form $q = P \cdot \cos 2\chi$. Assuming that the polarisation angle at all wavelengths is similar to its single scattering value, χ_{ss} , then $q = 0$ when $\cos(2\chi_{ss}) = 0$ independent of the degree of linear polarisation, P , and regardless of the actual atmospheric scene observed. Therefore, specific locations can be found, taking into account the illumination geometry, where the Stokes fraction q of the light reflected by the earth's atmosphere is exactly zero. Any systematic deviations from zero in spectral and viewing angle space may then be attributed to deficiencies in the calibration. This approach is also used for the online correction of Stokes fractions, which has been already applied to the results presented in the following using the most recent correction acquired by the operational processor.

The panels that follow show the results for those special geometries cases 31 December 2018 for special geometries acquired over one full orbit (Figure 63)

The results indicate that Metop-C/FM1 Stokes fractions are already, and on average, of very good quality (comparable to the other instruments) following the applied online correction.

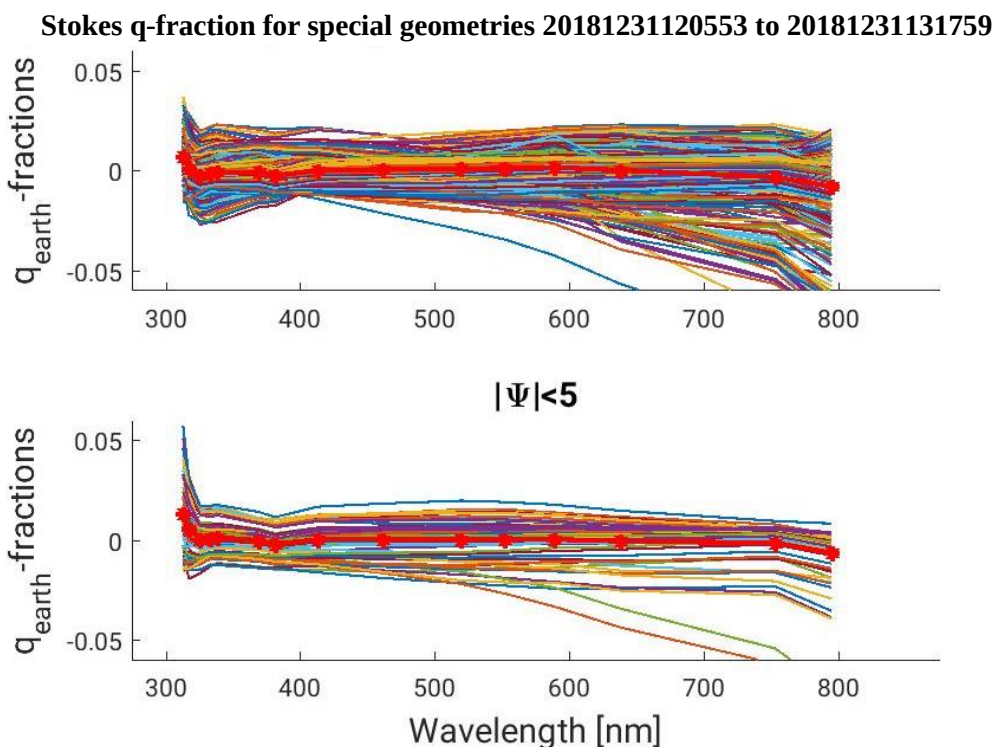


Figure 63: The plots show q-Stokes fractions for special geometries over the full Metop-C / FM1 orbit. The red line is the average over the orbit. The upper panel shows all derived special geometry Stokes fractions. The lower shows only those restricted to a viewing angle of ± 5 degrees

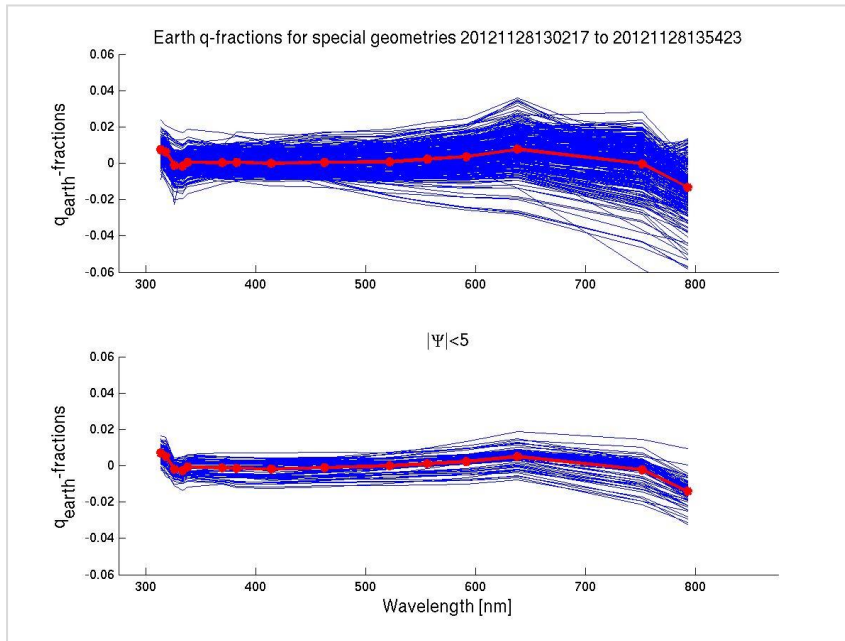


Figure 64: The plots show q -Stokes fractions for special geometries over the full Metop-B / FM2 orbit. The red line is the average over the orbit. The upper panel shows all derived special geometry Stokes fractions. The lower shows only those restricted to a viewing angle of ± 5 degrees.

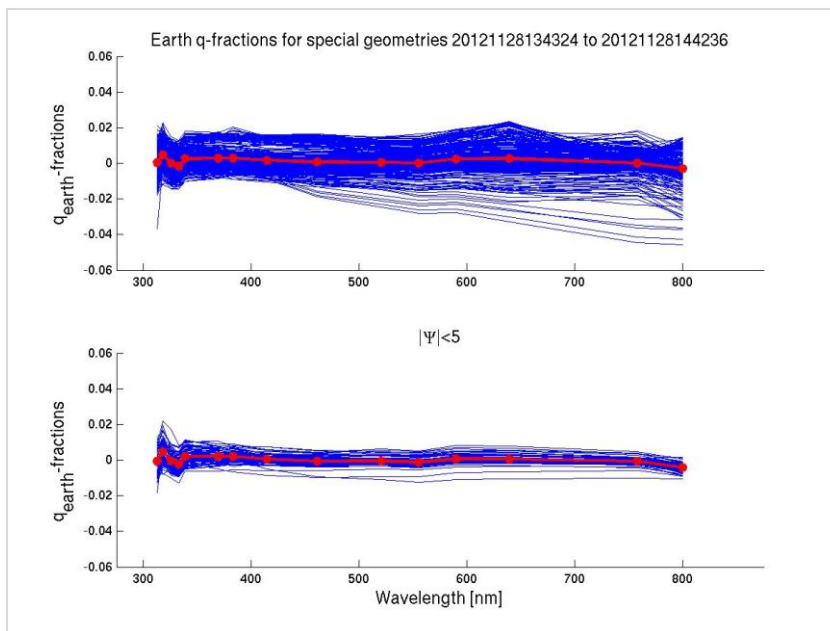


Figure 65: The plots show q -Stokes fractions for special geometries over the full Metop-A / FM3 orbit. The red line is the average over the orbit. The upper panel shows all derived special geometry Stokes fractions. The lower shows only those restricted to a viewing angle of ± 5 degrees.

S/P ratio response offset BAND values 20190220203208 to 20190220203220

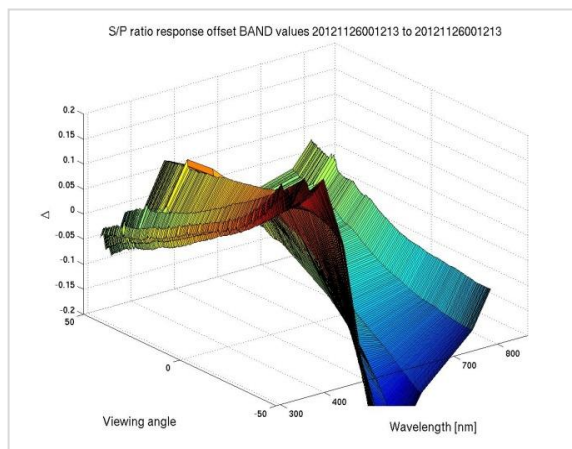
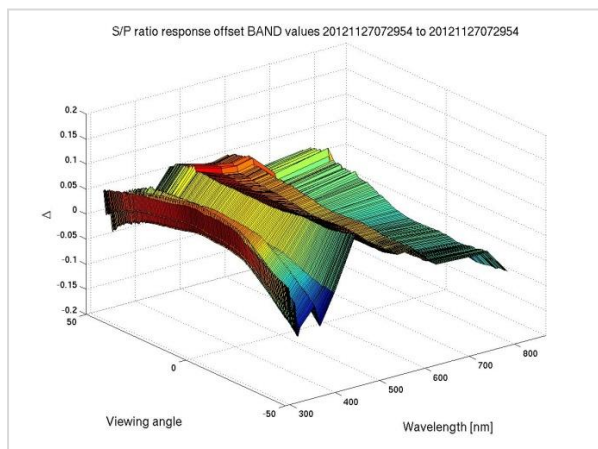
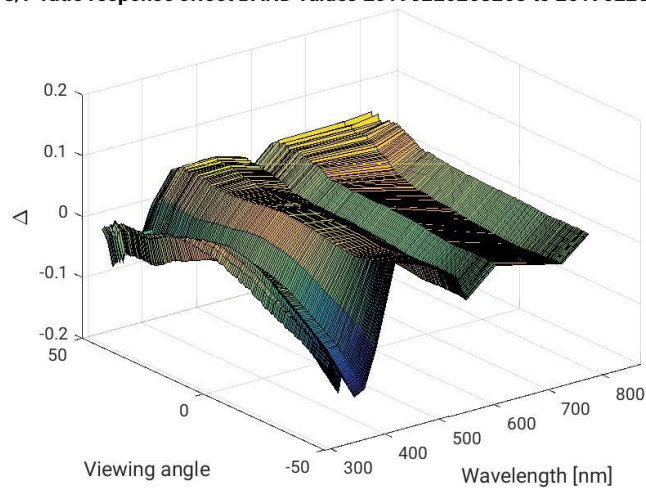


Figure 66: Online -derived PMD S over P correction surface for MetopC / FM1 (20 Feb 2019)(top panel)

Metop-B / FM2 (left panel; 27 Nov 2012) and for Metop-A / FM3 (right panel, 26 Nov 2012).

Earthshine for special geometries – TCE FM! PPF 6311 CAL103INS103 MethodB 20181219112035

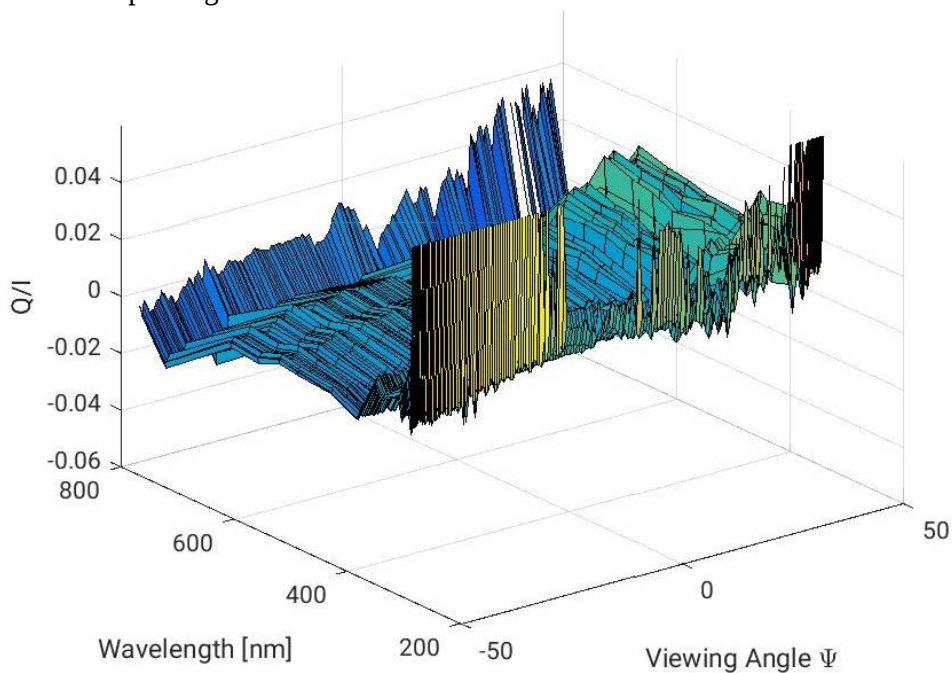


Figure 67: Averaged q-Stokes fractions for special geometry in dependence of wavelength and viewing angle and for one orbit of Metop-C / FM1 data

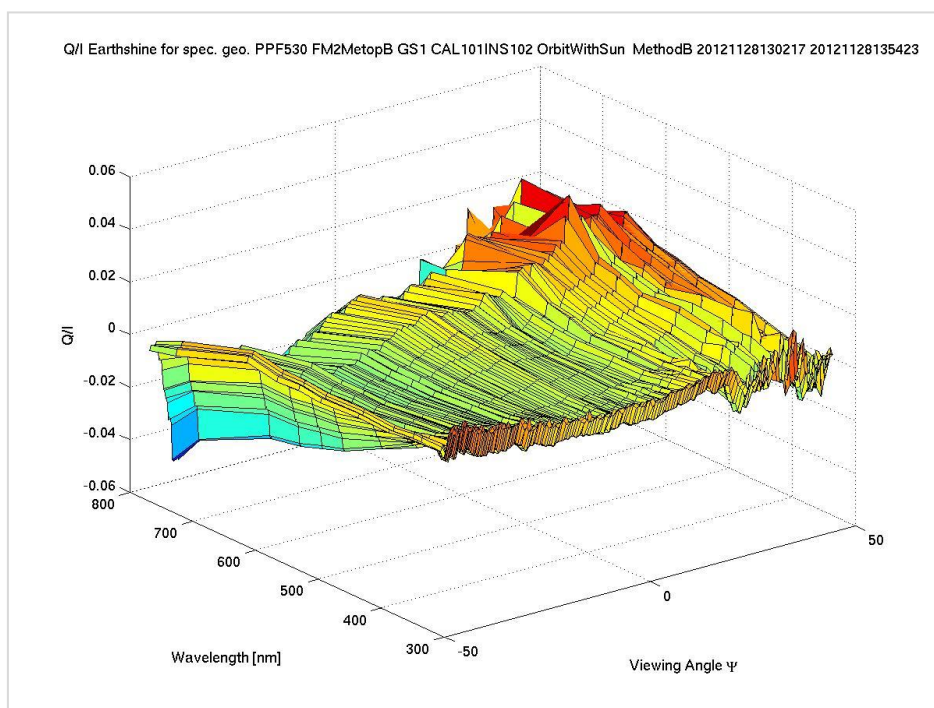


Figure 68: Averaged q -Stokes fractions for special geometry in dependence of wavelength and viewing angle and for one orbit of Metop-B / FM2 data.

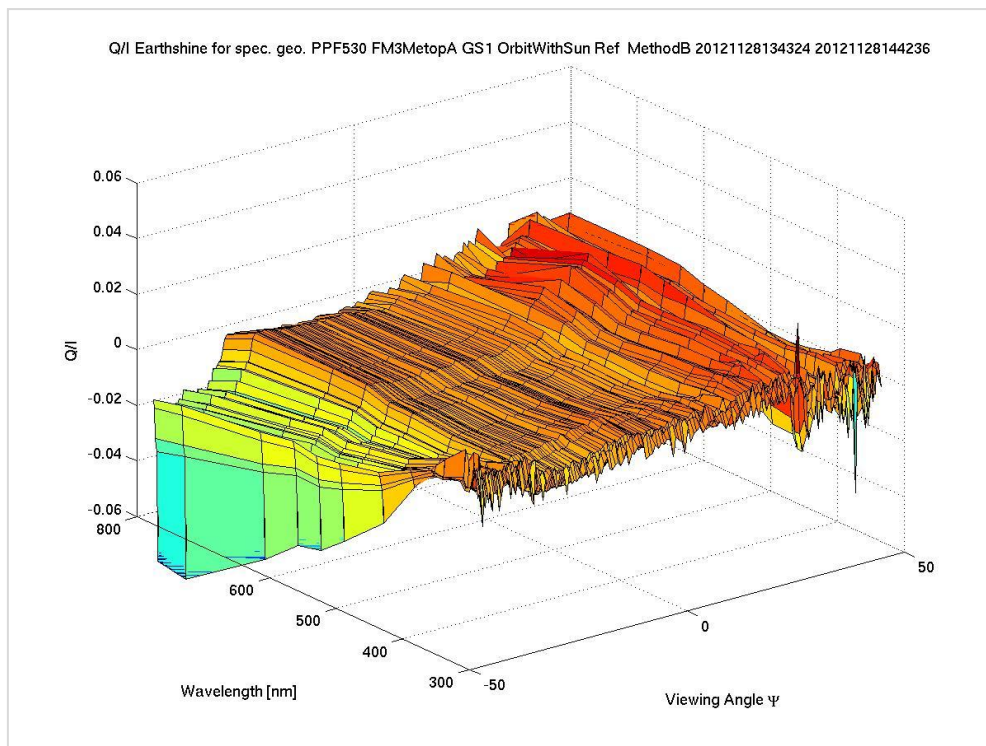


Figure 69: Averaged q -Stokes fractions for special geometry in dependence of wavelength and viewing angle and for one orbit of Metop-A / FM3 data.

Figure 67 shows that the main discrepancies with respect to the zero value for the wavelength region below 400nm (behaviour observed also in Figure 63) are mostly coming from negative viewing angles.

4.9.3 PMD S over P ratio from Solar Measurements

The S over P ration from measurements of the solar spectrum using the PMDs is a measure of the calibration accuracy and quality of the individual PMD irradiance spectra. In the most optimal situation the ratio should be one, since the calibration of the radiometric response key-data for PMDs provides and end-to end calibration of the polarisation sensitivity of the optical path from the sun-port to the PMD detectors (involving the calibration unit; see Figure 2) and the solar irradiance is un-polarised. For Metop-A / FM3 it has however been observed that the ratio was never really one and always exhibited a persistent spectral pattern as shown in the example provided in Figure 70.

The same ratio for Metop-B / FM2 is show in Figure 71 and for Metop-C/FM1 in Figure 72.

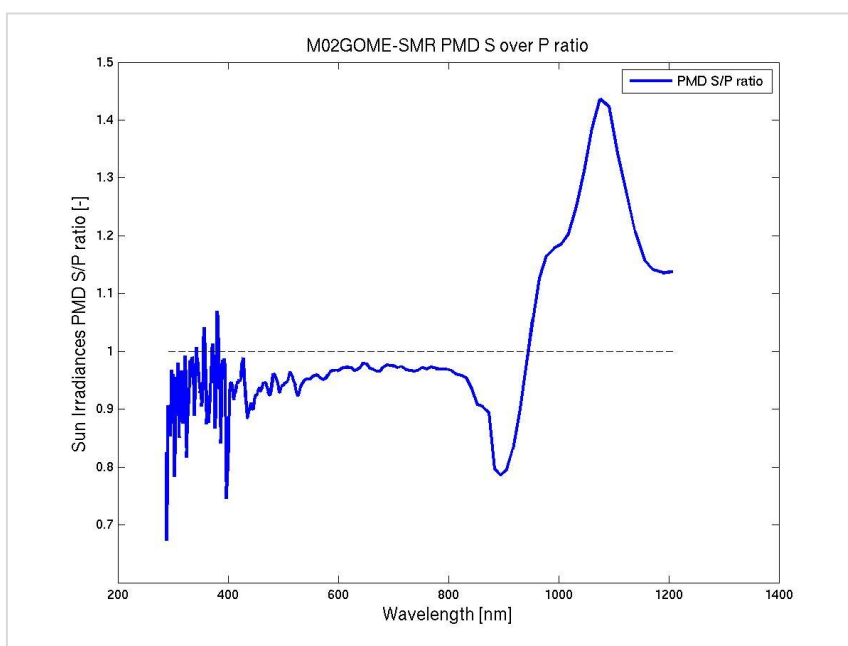


Figure 70: Metop-A/FM3 PMD S over P ratio from the solra mean reference data.

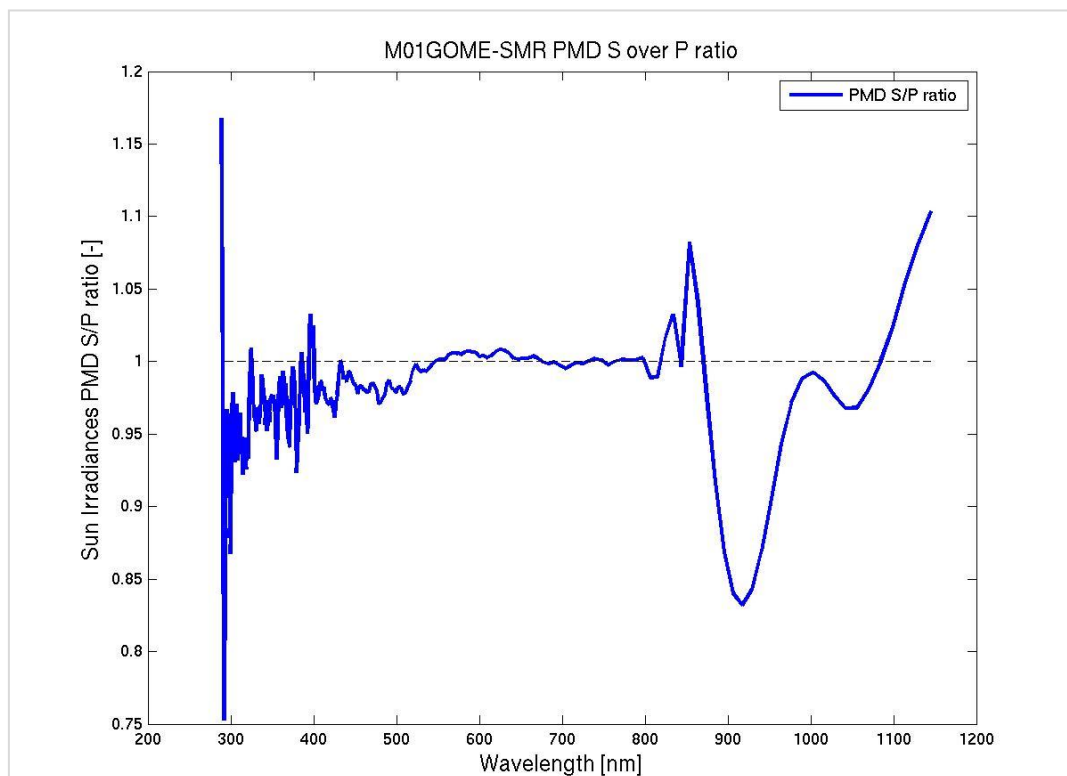


Figure 71: Metop-B/FM2 PMD S over P ratio from the solar mean reference data.

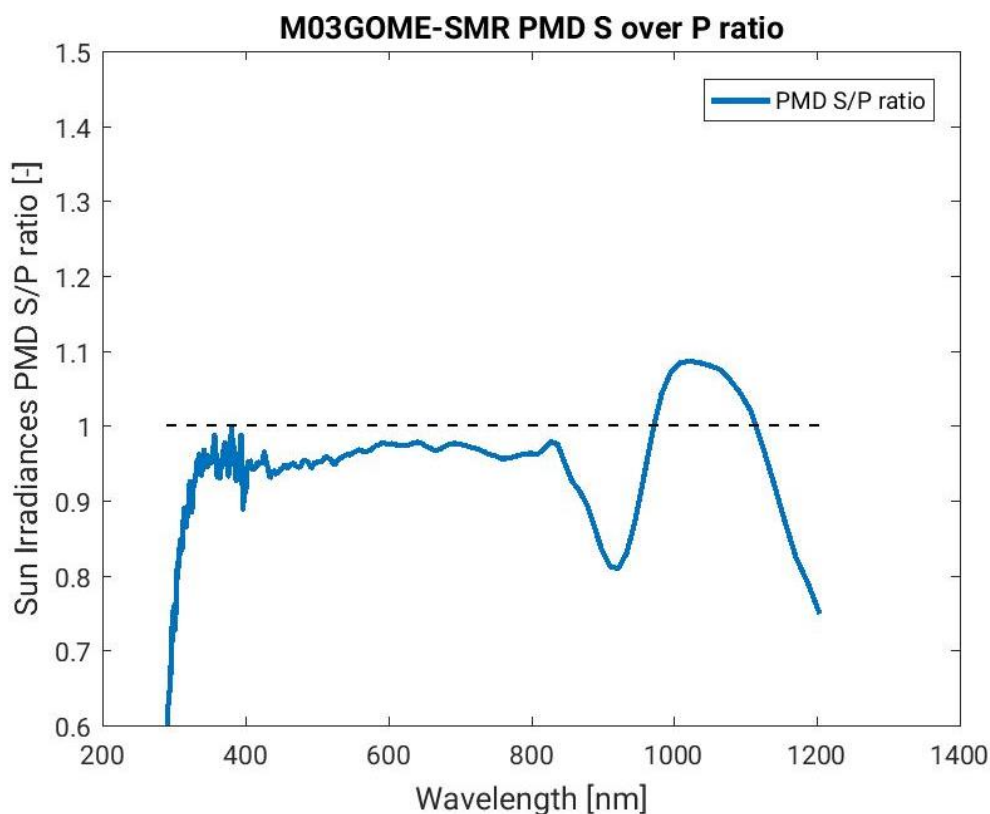


Figure 72: MetopC/FM1 PMD S over P ratio from the solar mean reference data.

Generally, a comparison of Figure 70, Figure 71 and Figure 72 shows that the calibration of the irradiances from PMD measurements for Metop-C / FM1 is similar to MetopA / FM2. The spectral fine structure below 400 nm in both results might be due to top errors in the spectral co-registration between both measurements. Note also that the calibration key-data is not valid for a wavelength higher than 800 nm, and therefore no Etalon correction is applied in this region.

4.9.4 Q-Stokes fractions derived from solar measurements

From the S over P ratio from solar measurements Stokes fraction values can be derived applying different key-data (see PGS 7.1, Section 5.2.23, Eq. 176, [AD 3]) like the relative radiometric response of S and P as well as all key-data involved in the calculation of the Mueller Matrix elements 2 and 3 (see PGS 7.1, Section 5.2.3, [AD 3]).

Ideally, the solar Stokes fractions should be close to 0. However, due to residual polarisation introduced by the optics in the calibration unit, some remaining offset from 0 structures are expected. This is in contrast to the P to S ratio, for which the end-to-end calibration should take out any residual polarisation effect. In its current formulation in PGS 7, the derived Stokes fractions for solar measurements are mostly used in order to monitor any long-term changes in this residual polarisation, which would invalidate the on-ground end-to-end IR radiometric calibration of the PMDs.

Figure 73 shows the derived Stokes fractions from solar measurements using three different formulations of the Sun-Stokes fraction equation. The nominal equation is provided in PGS 7, Eq. 176 AD 3 and is shown as an average over the individual measurements (red line). The other two curves are calculated by using uncorrected M1s/M1p MME key-data (see [AD 3]) for which the online correction for Stokes fractions has not been applied. The other one is using the previous formulation as provided in PGS 6.1, Eq. 229, which uses the MMEs from the end-to end solar irradiance calibration measurements.

Overall, the Stokes fractions show some spectral structures and a positive offset in the central region, as it was observed also for MetopB / FM2 . (Figure 74). This offset is ascribed to the residual polarisation introduced by the calibration unit and needs to be monitored over time, see daily reports on Solar Stokes fractions on <http://gome.eumetsat.int>).

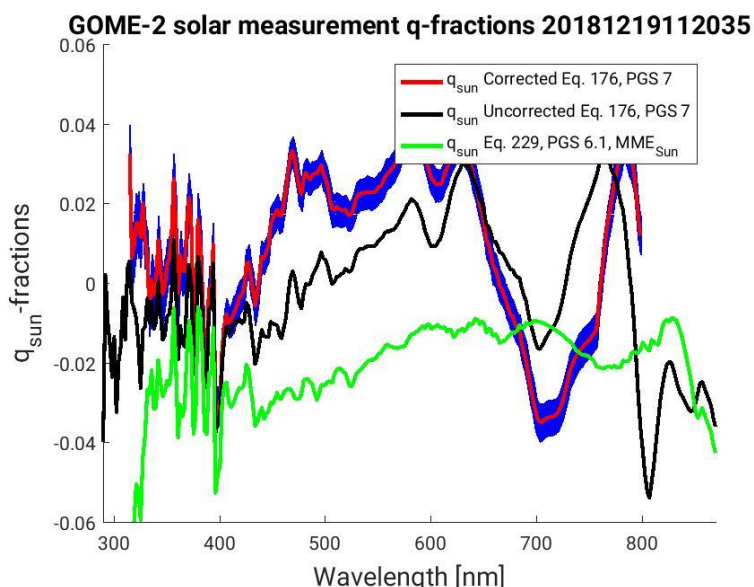


Figure 73: Metop-C/FM1 solar Stokes fraction data from individual measurements (blue line) and their average (red line) applying the definition as provided in PGS 7, Eq. 176 using the corrected M1s/M1p MME ratio. The other two curves show the average Stokes fractions but using the uncorrected M1s/M1p MME ratio (black line) and the definition has used previously in PGS 6.1 Eq. 229.

229.

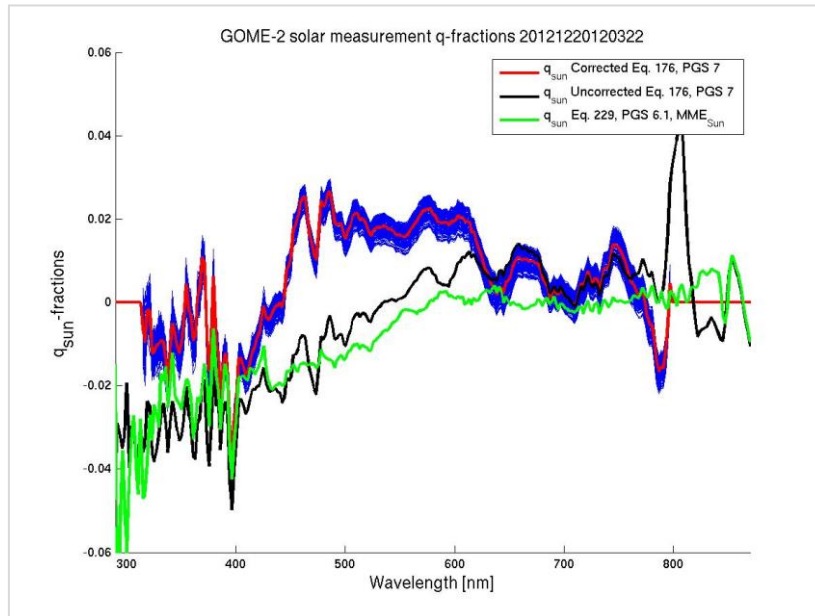


Figure 74: Metop-B/FM2 solar Stokes fraction data from individual measurements (blue line) and their average (red line) applying the definition as provided in PGS 7, Eq. 176 using the corrected $M1s/M1p$ MME ratio. The other two curves show the average Stokes fractions but using the uncorrected $M1s/M1p$ MME ratio (black line) and the definition has used previously in PGS 6.1 Eq.

229.

4.10 Summary of Level 0 to 1B Calibration Steps

In this section we summarise the most important calibration step applied by the level 0 to 1B processing for Metop-C / FM1 on 31 December 2018.

For reference, we also provide the same for for Metop-B / FM2 and Metop-A / FM3.

M03 calibration components

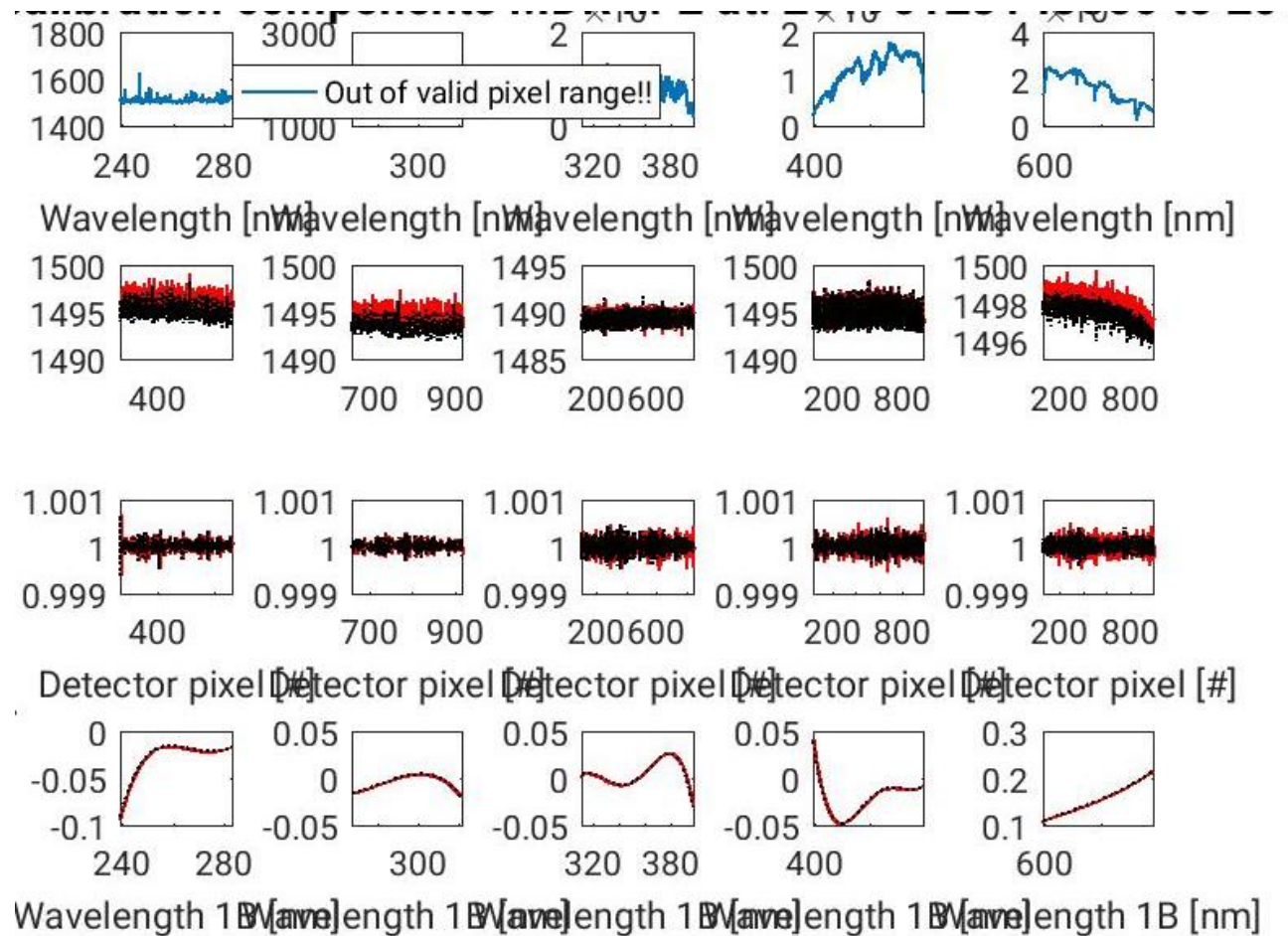
Figure 75: GOME-2 Metop-C / FM1 calibration spectra for the level 0 to 1b processing of one spectra taken on 28 January 2019. Band 1a, 1b, 2b, 3 and 4 are displayed in the columns from left to right. Band 2a is omitted because all detector pixel of this band fall outside the valid region.

1st row: Raw level 0 signals.

2nd row: Dark signal offset.

3rd row: Pixel-to-Pixel gain

4th row: Difference between the in-flight and the on-ground spectral calibration.



M03 calibration components

Figure 76: GOME-2 Metop-C / FM1 calibration spectra for the level 0 to 1b processing of one spectra taken on 28 January 2019. Band 1a, 1b, 2b, 3 and 4 are displayed in the columns from left to right. Band 2a is omitted because all detector pixel of this band fall outside the valid region.

1st row: Raw level 0 signals.

2nd row: Etalon correction.

3rd row: Radiometric response correction.

4th row: Polarisation correction.

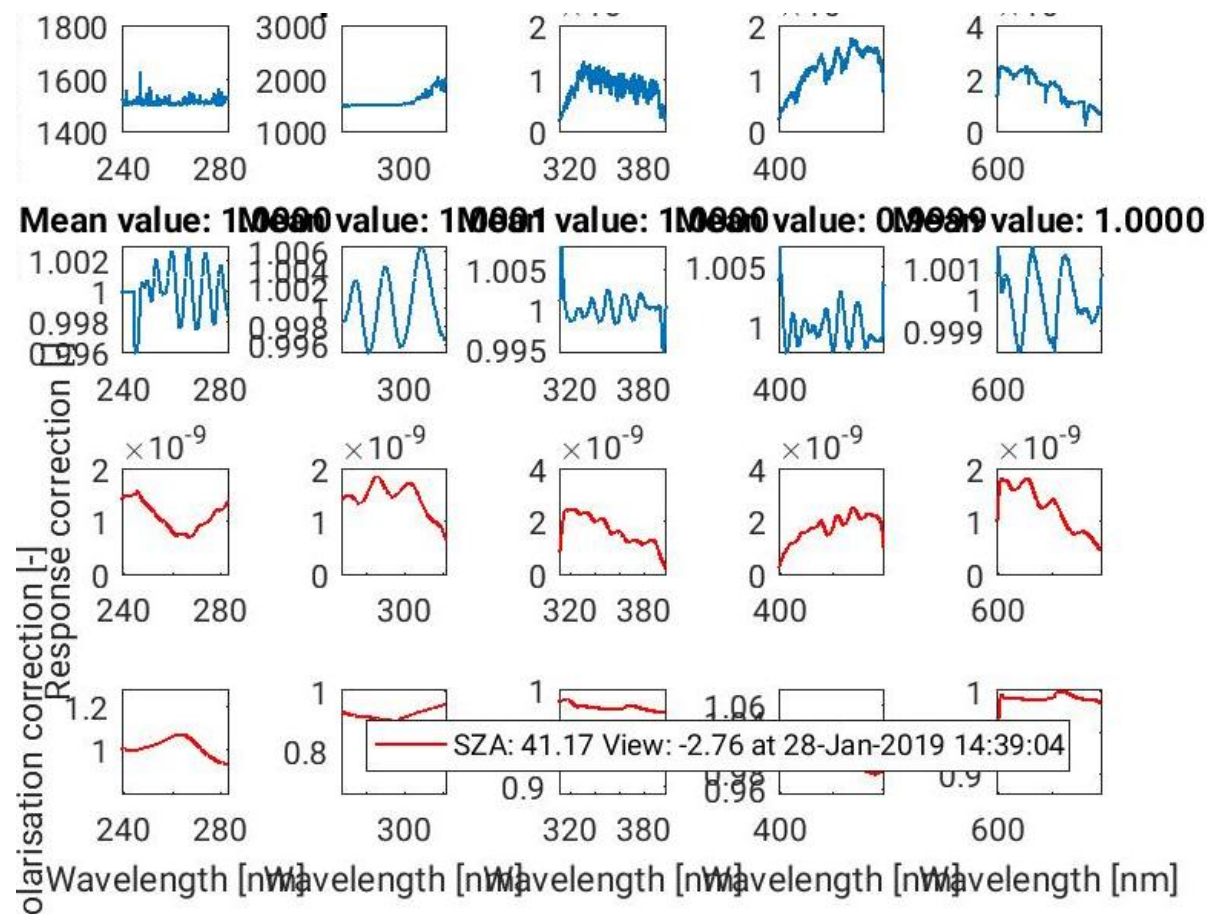


Figure 77: GOME-2 Metop-B / FM2 calibration spectra for the level 0 to 1b processing of one spectra taken on 28 November 2012. Band 1a, 1b, 2b, 3 and 4 are displayed in the columns from left to right. Band 2a is omitted because all detector pixel of this band fall outside the valid region.

1st row: Raw level 0 signals.

2nd row: Dark signal offset.

3rd row: Pixel-to-Pixel gain

4th row: Difference between the in-flight and the on-ground spectral calibration.

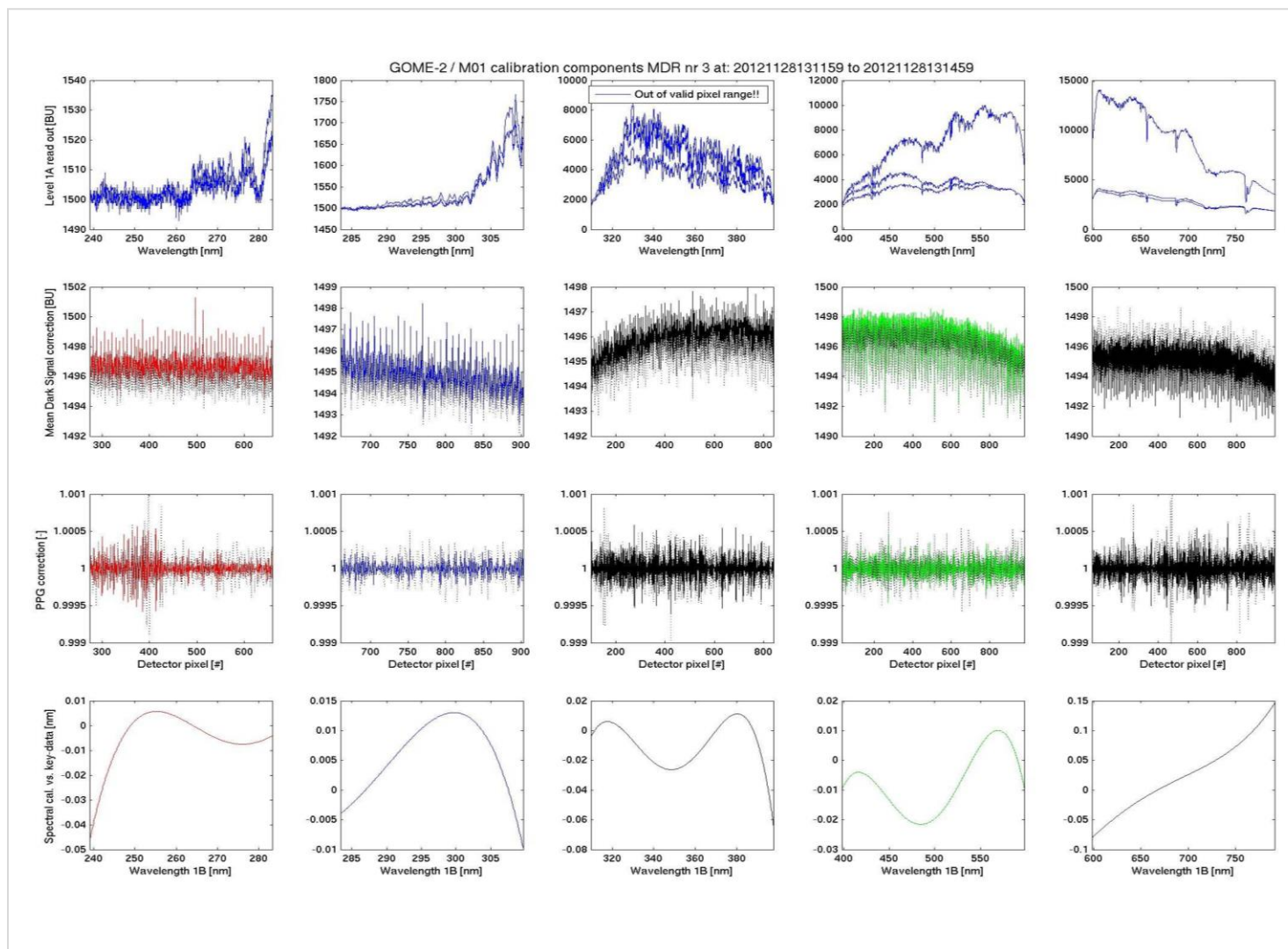


Figure 78: GOME-2 Metop-B / FM2 calibration spectra for the level 0 to 1b processing of one spectra taken on 28 November 2012. Band 1a, 1b, 2b, 3 and 4 are displayed in the columns from left to right. Band 2a is omitted because all detector pixel of this band fall outside the valid region.

1st row: Raw level 0 signals.

2nd row: Etalon correction.

3rd row: Radiometric response correction.

4th row: Polarisation correction.

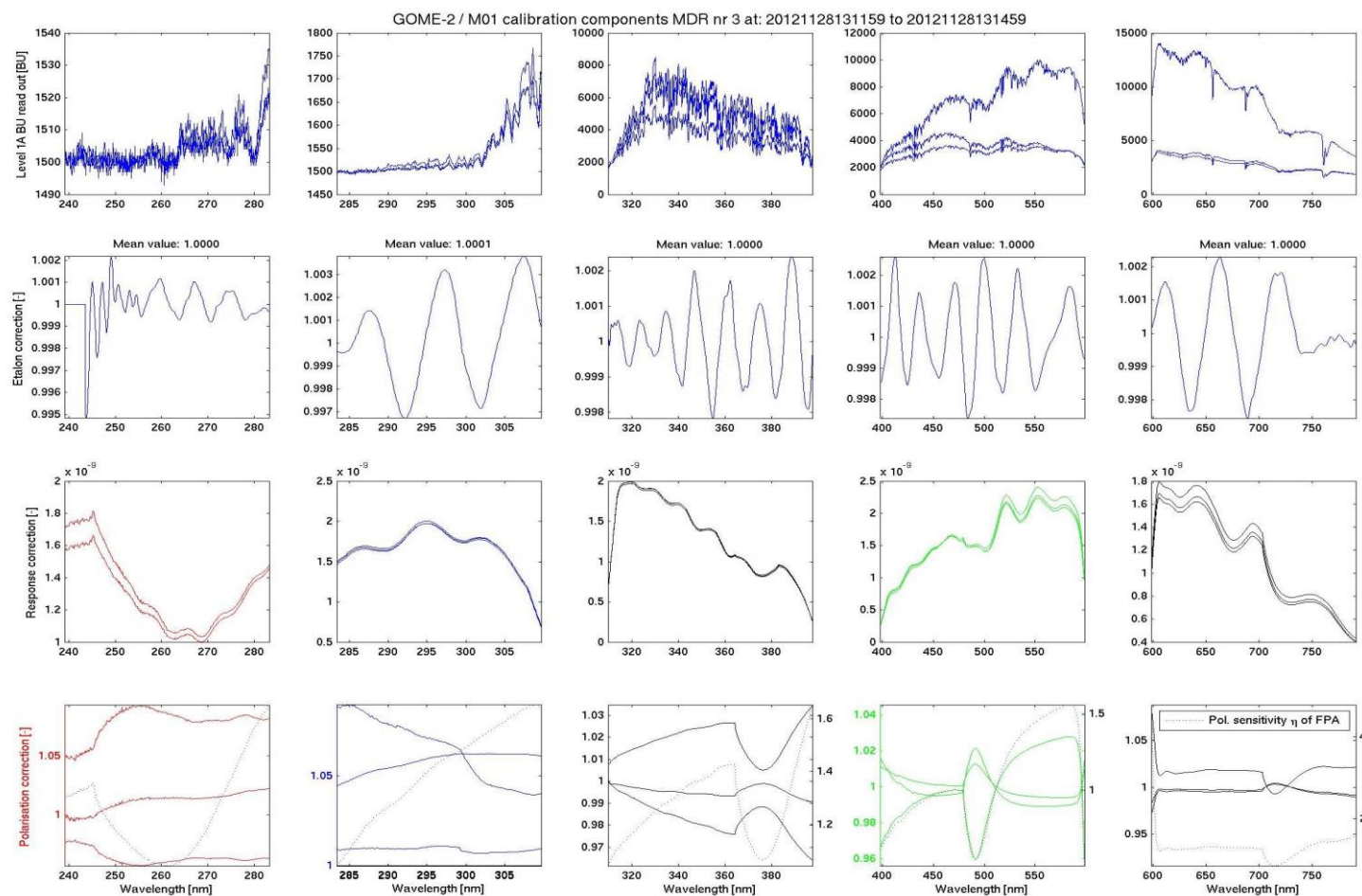


Figure 79: GOME-2 Metop-A / FM3 calibration spectra for the level 0 to 1b processing of one spectra taken on 28 November 2012. Band 1a, 1b, 2b, 3 and 4 are displayed in the columns from left to right. Band 2a is omitted because all detector pixel of this band fall outside the valid region.

1st row: Raw level 0 signals.

2nd row: Dark signal offset.

3rd row: Pixel-to-Pixel gain

4th row: Difference between the in-flight and the on-ground spectral calibration.

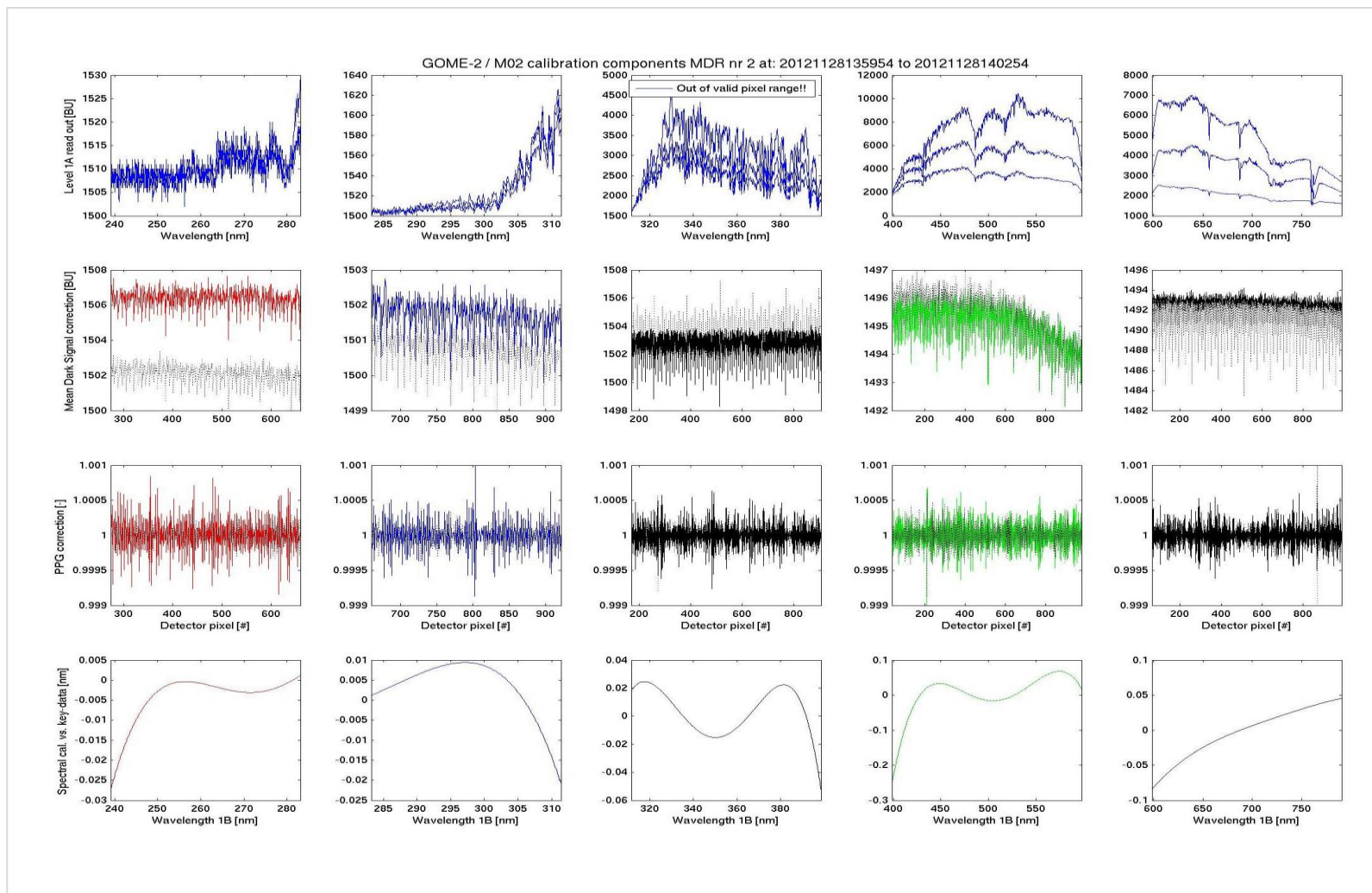


Figure 80:: GOME-2

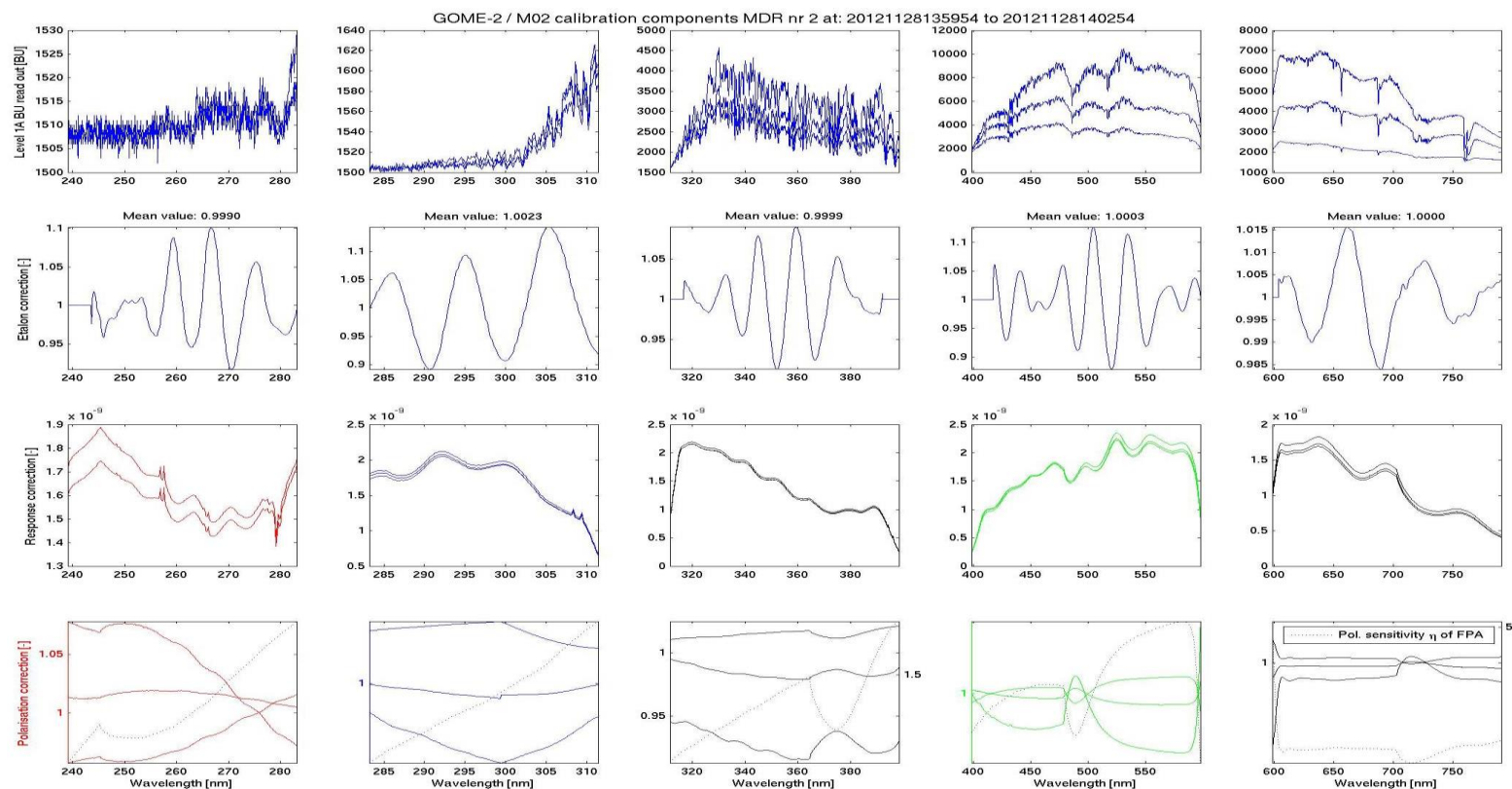
Metop-A / FM3
calibration spectra for
the level 0 to 1b
processing of one
spectra taken on 28
November 2012. Band
1a, 1b, 2b, 3 and 4 are
displayed in the columns
from left to right. Band
2a is omitted because
all detector pixels of this
band fall outside the
valid region.

1st row: Raw level 0
signals.

2nd row: Etalon
correction.

3rd row: Radiometric
response correction.

4th row: Polarisation
correction.



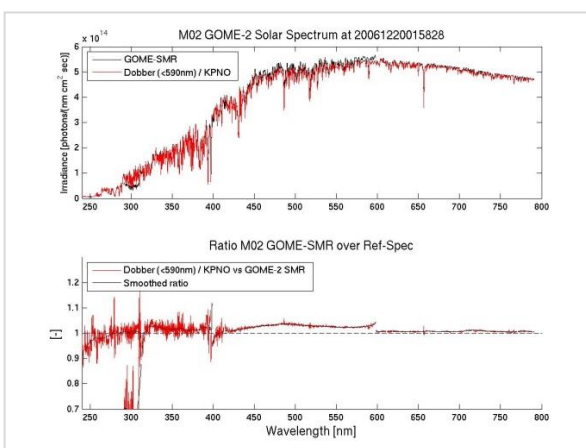
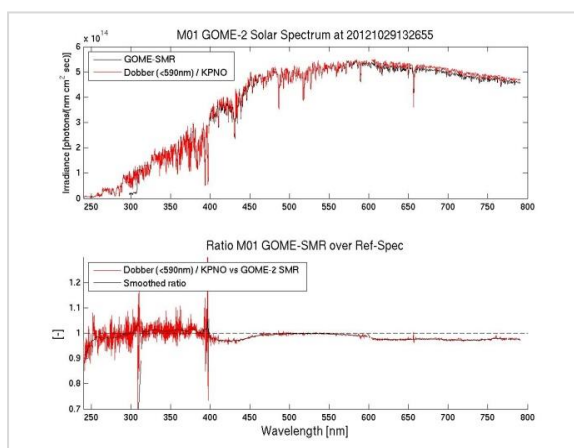
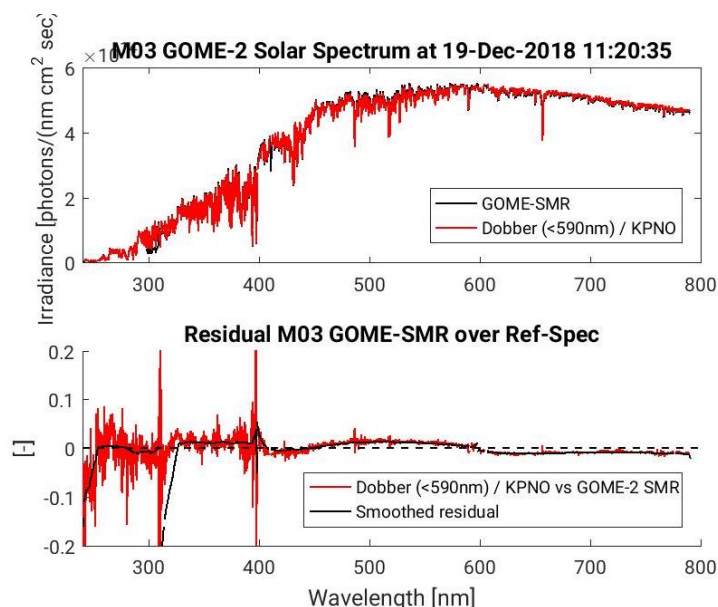
4.11 Radiometric accuracy (Solar and Earthshine) – (A5.6)

4.11.1 Solar measurements

We compare the first calibrated solar measurement taken on 19 December 2018 with a solar reference spectrum by Dobber et al., (Solar Phys (2008) 249: 281–291), which has been combined above 590 nm with the Kitt-Peak National Observatory KPNO/AFGL spectrum of 2004. The measured GOME-2 spectrum has been reprocessed with the latest CAL 1.03 and INS 1.03 auxiliary files to take the new overlap region and etalon treatment into account. (See also Section 4.7 for comparison with results before the auxiliary data update).

We compare the results with the results derived for the first and reprocessed solar spectrum taken by Metop-B/ FM2 on 29 October 2012 and Metop-A / FM3 at the 20th of December 2006.

Both reference spectra are based on original high-resolution Kitt-Peak Fourier transform measurement data, which have been convolved with the spectral response (slit) function for the GOME-2 instruments.



*Figure 81: First solar spectrum for MetopC – FM1 taken at 19 December 2018 as compared to the reference (upper central panel)
Metop-B / FM2 main channels (left panels) taken at the 29th of October 2012 and as compared to the reference (lower left panel)
The lower right panles show the corresponding first Metop-A / FM3 spectrum (reprocessed; see text) from the 20th December 2006.*

Figure 81 shows the good agreement of M03 SMR with the reference spectrum the baseline of the residual close to the zero value, improved after the whole correction process, with respect the same baseline shown in Figure 40 (before corrections). Still some residual can be detected in the 400-600 nm wavelength region. Comparison with the GOME2-A and GOME2_B corresponding plot, shows that GOME-2C is closer to GOME-2A performances than GOME2-B.

The overall baseline of the reference spectrum is considered to be of higher quality for the wavelength region below 590 nm, the region of the Dobber et al. spectrum which has been developed as reference specifically for this type of instrumentation. This includes an improved UV-VIS accuracy; see Solar Phys (2008) 249: 281–291. The jump at 590 nm in the residual is therefore probably due to lower accuracy of the reference spectrum.

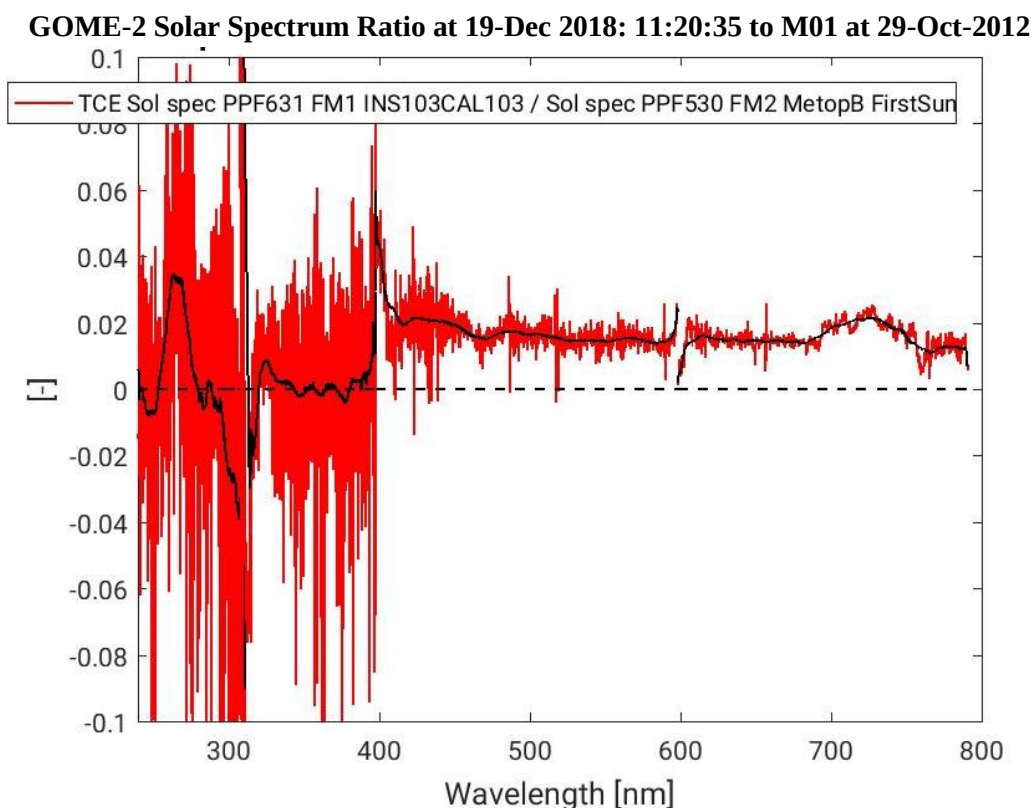


Figure 82: Residual of the first solar spectrum for Metop-C / FM1 main channels taken at the 19h of december2018 with the first solar spectrum of Metop-B / FM2 taken at the 29th of October 2012

The residual between the first solar spectrum of Metop-C / FM1 and the first solar spectrum of Metop-B / FM2 as displayed in Figure 82 shows that the FM1 spectral values were higher than those of FM2 but also that the overlap regions were (are) treated differently—with results in quite significant residuals in the region of the channels 1 and 2 overlap, and channels 2 and 3 overlap.

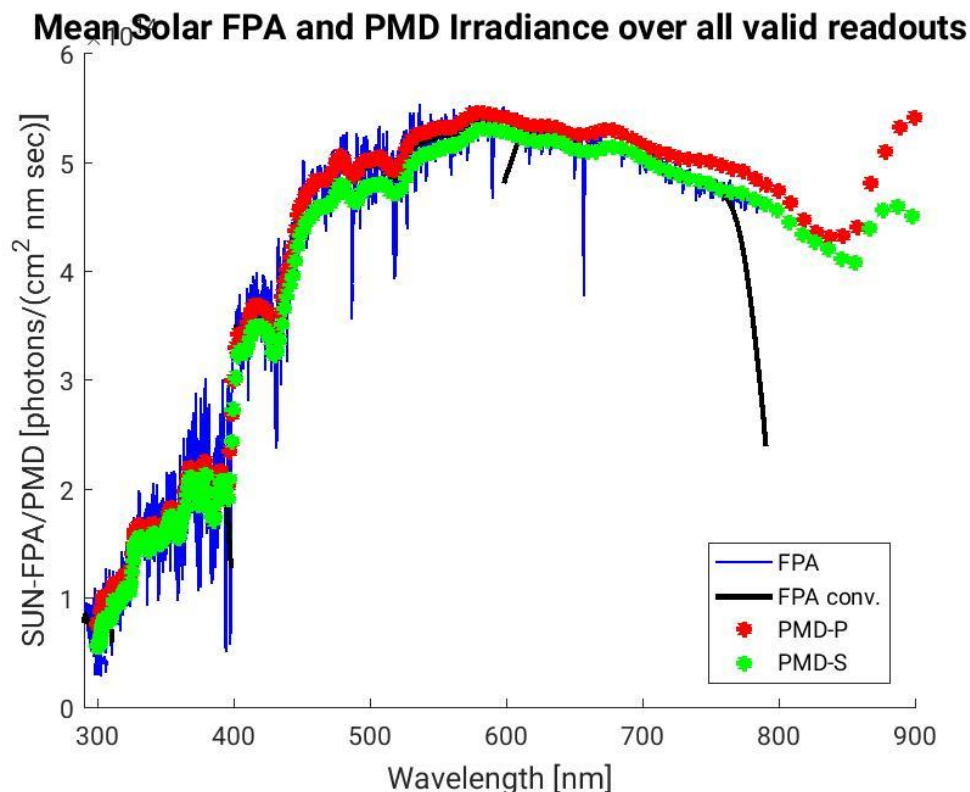


Figure 83: First solar spectrum for the Metop-C / FM1 PMD-P (red filled circles) and PMD-S (green filled circles) channel data taken at the 19h of december2018 . The spectra are compared to the main channel spectrum (blue line) and a convolved version of the main channel spectrum using the slit-function key-data definitions for PMD-P (black line).

Figure 83 shows the PMD-P and S solar spectra compared with convolved main channel spectra. For the targeted consistency between main channel data and PMDs, the differences between the convolved main channel and the PMD spectrum should be minimal and overall this goal is achieved. still PMD-P and PMD-S shows slightly different values with respect each other.

4.11.2 MOON

The first GOME-2 Moon observations were taken on 26th and 27th December 2018.

Figure 84 shows the Moon reflectance for FPA channels (black line) PMD-P (blue) and PMD-S (green) processed with PPF 6.3.1 and calibration data CAL 1.02. It can be clearly seen that FPA and PMDs have different behaviour in the far UV region. After the update of key data (CAL 1.03), the data were reprocessed and the results are presented in Figure 85. With the CAL1.03 reprocessing, FPAs and PMDs present a good correspondence, while some small etalon features residuals can be seen which may require further examination.

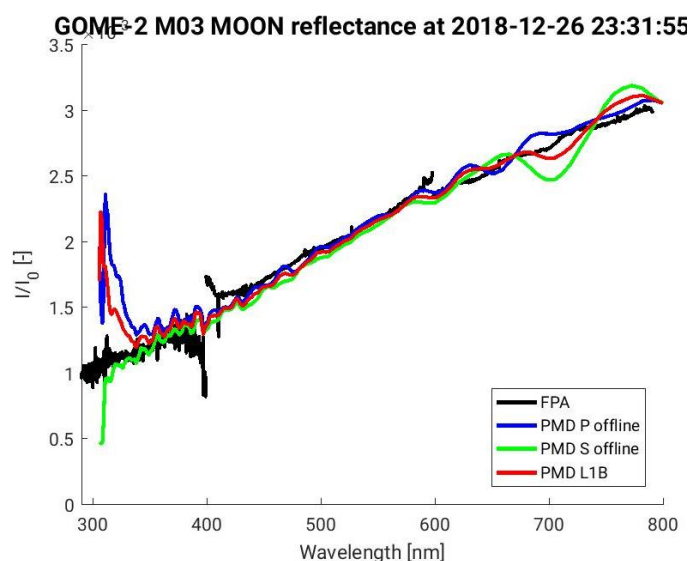


Figure 84: First Moonobservation for Metop-C / FM1 FPA chanel (black line), PMD-P (blue line) and PMD-S (greenline) taken at the 26 Ddecember2018 processed with PPF 6.3.1 and calibration data CAL 1.02

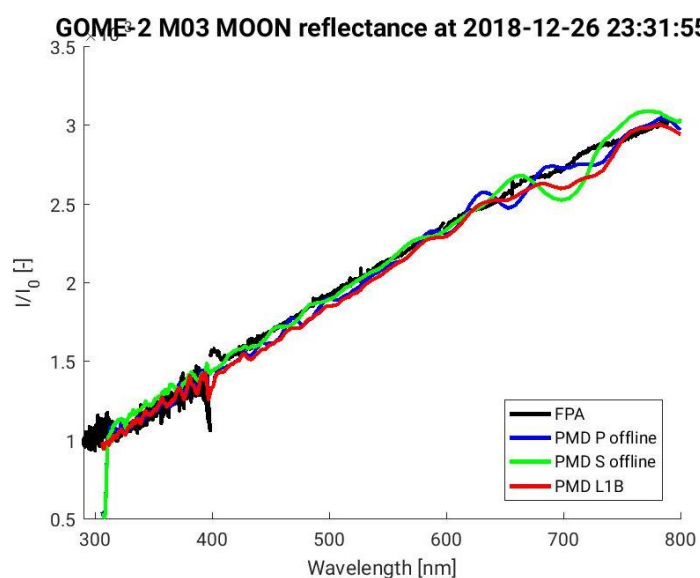


Figure 85: First Moonobservation for Metop-C / FM1 FPA chanel (black line), PMD-P (blue line) and PMD-S (greenline) taken at the 26 december2018 processed with PPF 6.3.1 and calibration data CAL 1.03

4.12 Signal levels (A4.3.5) –

Degrading signal throughput levels have been a concern for both FM3 / Metop-A and FM2/MetopB throughout their current missions. Throughput decrease for FM3 has been quite strong before September 2009 (second throughput test) especially in channel 1 and 2, and has significantly decreased afterwards. For a detailed summary of the changing throughput level issue on Metop-A / FM3, see [RD7].

As it has been done for Metop-B / FM2 (IOV phase), and Metop-A/ FM3 (January 2009, first throughput test) during the IOV phase of Metop-C/FM1 we decided to carry out a similar throughput test.

In this test, the detector temperatures have been increased from nominal operations temperature levels at 235 K up to 255 K (in step of 5 K), just below the temperature of the optical bench. This test was meant to serve two objectives:

- To investigate if the observed immediate response of signal levels to temperature changes in FM3 and FM2 was also present for FM1.
- To provide a reference for the long-term monitoring concerning the magnitude of 1. For FM3 it has been observed that this magnitude was increasing over time.

In the following section, we provide a summary of the observed FM1 signal levels during the Cal/Val time frame. FM1 signal levels are also compared to the FM3 and FM2 in corresponding time frame early in their mission lifetime.

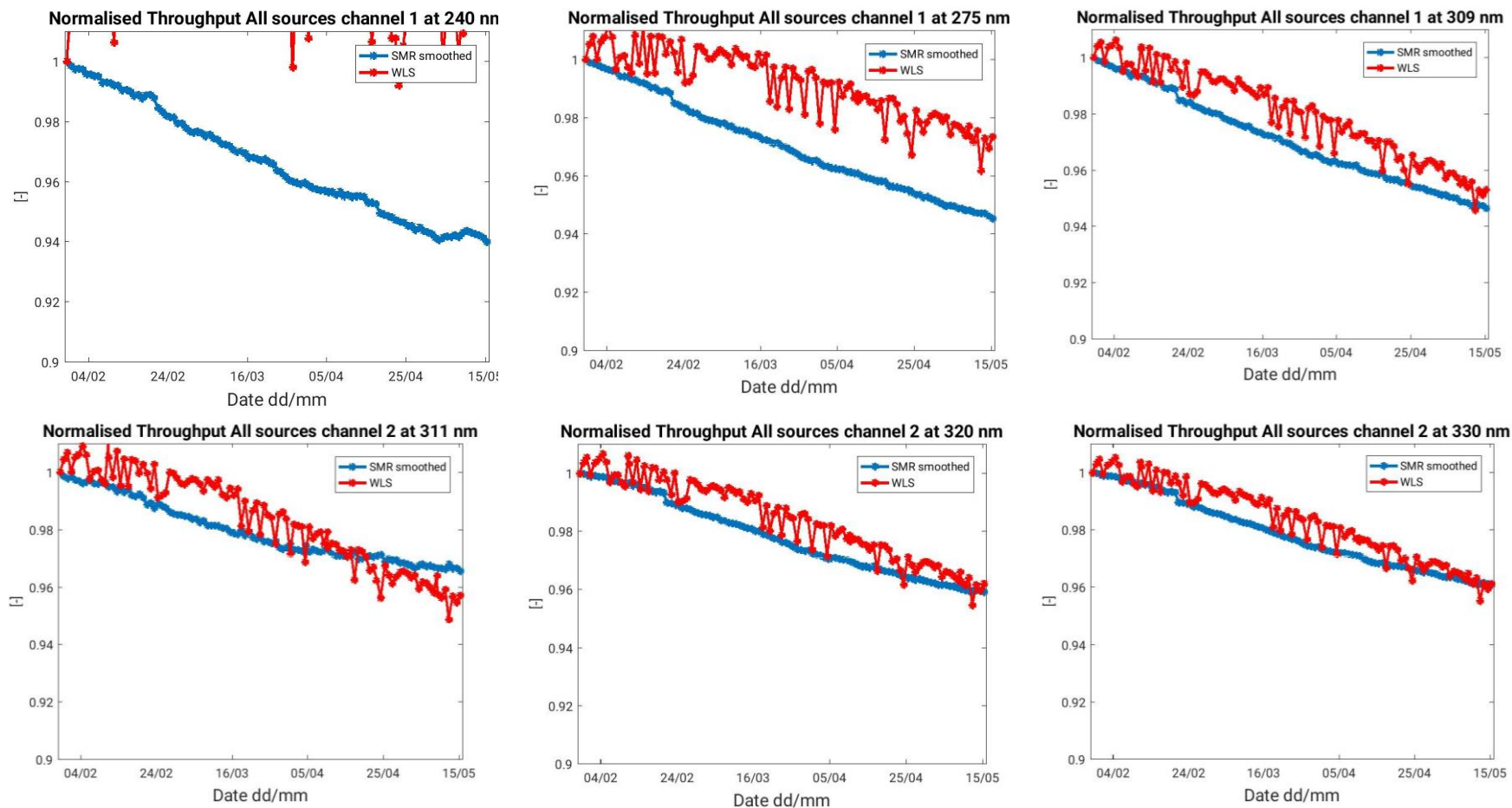
4.12.1 Signal Throughput of Metop-C / FM1 – Commissioning Period

Figure 86 presents normalised signal levels for Metop-C / FM1 with respect to 29 January 2019 (after radiometric key-data update CAL 1.03) at different wavelengths. The results present white light source data (WLS) and solar mean reference data (SMR). Spectral light source data is omitted because this source is not stable enough (as for FM3 and FM2).

When comparing the two at 275nm, strangely the WLS does not show the same loss of throughput as the SMR while at 309nm they seem to degrade at a similar rate. This is not understood and need to be investigated. This behaviour was also not seen on GOME-2A or GOME-2B. The strongest degradation is observed in the UV with a decreasing degradation rate towards the NIR, with the exception that the WLS degrades more strongly at 745nm than at 570 nm (as observed on FM3, FM2).

Figure 87 shows the SMR ratio for FPAs relative to FM3, FM2 and FM1 using three months of data. The instruments have been in orbit for 187 days. GOME-2 FM3 shows higher degradation in the UV as compared to the VIS-NIR as expected but overall somewhat higher degradation than GOME-2 FM2 and GOME-2 FM1. The three instruments show different behaviour in Channels 1 and 2 and in Channels 3 and 4 GOME-2 FM1 is more similar to GOME-2 FM3.

A Broadly similar behaviour is seen for the SMR PMD-P and PMD-S between all three flight models as it is reported in Figure 84 although FM3 appears to be losing throughput at a slightly higher rate, as for the FPAs.

EPS Metop-C product validation report GOME-2 level 1


EPS Metop-C product validation report GOME-2 level 1

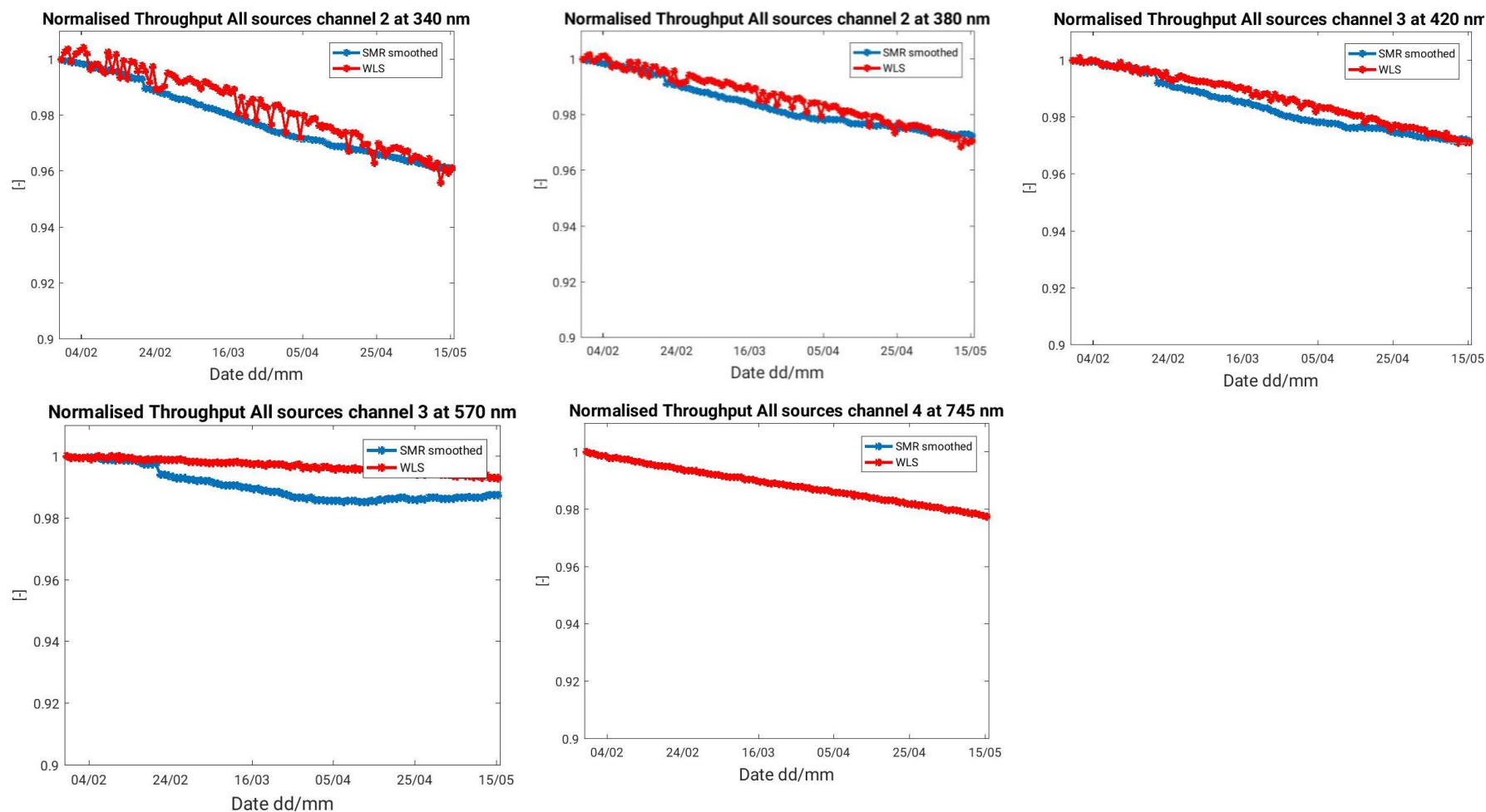


Figure 86: Signal levels for Metop-C / FM1 at various wavelength (see panel title) normalised to 29 January 2019 until 15 May 2019. Solar mean reference (SMR) measurements are shown in blue, while light source (WLS) measurements in red

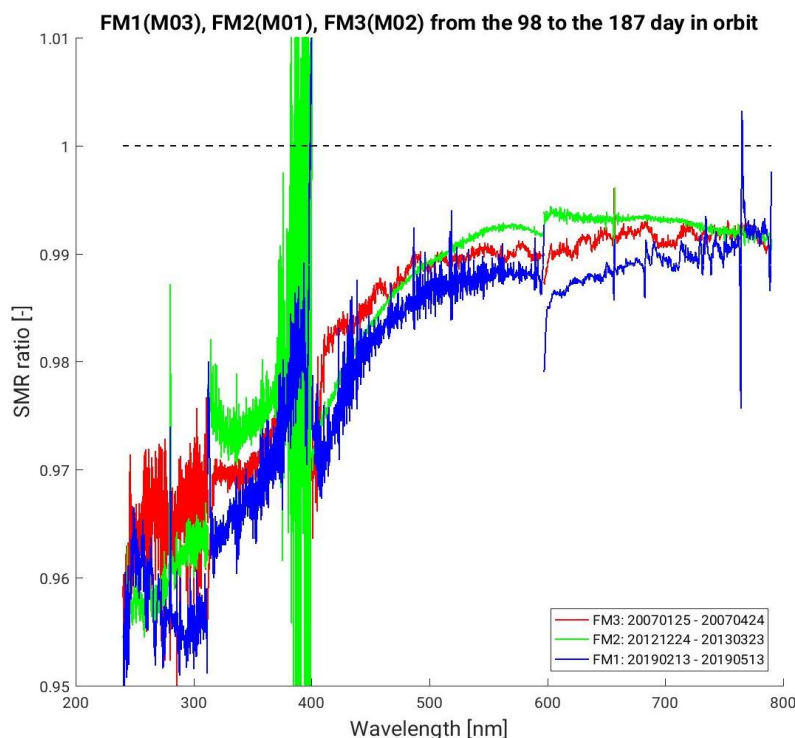
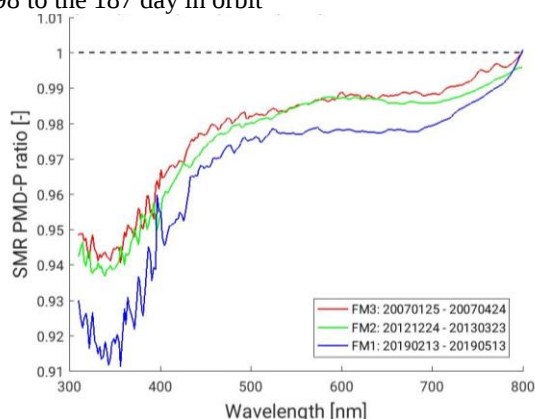


Figure 87: ratio of the solar mean reference spectrum (SMR) of Metop-C / FM1 taken on 13 May 2019 with respect to the SMR taken at th 13 February 2019 02 13 (blue line) is compared with the SMR ratio for Metop-B / FM2 (green line) taken at the 23 Mrch 2013 with respect to the 24 December 2012 and with the SMR ratio for Metop-A / FM3(red line) taken at the 24 April 2007 with respect to the25 January 2007. All instruments mark 187 days in orbit.The ratio covers a time span of exactly 89 days for the three instruments

PMD-P FM1(M03), FM2(M01), FM3(M02) from the 98 to the 187 day in orbit



PMD-S FM1(M03), FM2(M01), FM3(M02) from the 98 to the 187 day in orbit

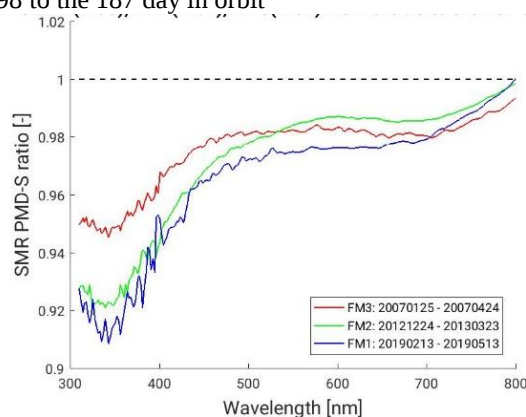


Figure 88: Ratio of the solar mean reference spectrum (SMR) PMD-P (left panel) and PMD-S (right panel) of Metop-C / FM1 taken on 13 May 2019 with respect to the SMR taken at th 13 February 2019 02 13 (blue line) is compared with the SMR ratio for Metop-B / FM2 (green line) taken at the 23 Mrch 2013 with respect to the 24 December 2012 and with the SMR ratio for Metop-A / FM3(red line) taken at the 24 April 2007 with respect to the25 January 2007s

4.13 Geo-referencing (A5.1)

Geo-location parameters are processed during level 0-to-1B processing both for a fixed grid of 32 read-outs per scan and for an individual grid based on the actual integration time of an instrument band. For reference, GOME-2 channels 1 and 2 are separated into two bands each, as are the PMD channels—both short-wave and main PMD bands—such that there are ten bands in total that potentially can be commanded with different integration times, leading to different ground footprints. In practice, GOME-2 instrument timelines include only four different integration times per scan:

- IT1 for band 1a
- IT2 for band 1b to 4
- IT3 for PMD main channels
- IT4 for PMD short-wave channels.

However, IT1 and IT2 change over the orbit from longer to shorter integration times along decreasing solar zenith angles.

For GOME-2 level 1 processing, predicted orbit state vectors are used for near real-time processing. The accuracy of the predicted orbit is significantly less than 100 m. Therefore, an upper limit bias on the calculated geo-referencing parameters of 1 % of across-track pixel size for PMDs (0.25 % along track) and 0.6 % for main channels (0.25 % along track) are estimated with respect to dedicated corrected orbits for reprocessing. The effect is considered negligible with respect to the pointing accuracy of the instrument.

For the evaluation of the geo-pointing accuracy, we convolve GOME-2 radiances in channels 3 and 4 with the AVHRR spectral response function and compare the result to the averaged radiometric signal from AVHRR within one GOME-2 ground pixel (using IT2 for channel 3 and 4). The geo-location data for the GOME-2 ground pixel box is subsequently modified in an iterative process and re-fitted with the averaged AVHRR radiances until an optimal correlation between both, GOME-2 and AVHRR averaged radiances, is achieved. Along-track, the delta on the GOME-2 geo-location data should be zero, whereas across-track there is an offset of 5-15 % of the (varying) pixel size expected due to spatial aliasing. Spatial aliasing can be defined as the time that has to be accounted for during the duration of read-out of the detector arrays of GOME-2, a time period during which the spacecraft moves. For more details, see PGS 7, Section 5.3.16 and [AD3].

During the Metop-C SIOV campaign a relative pointing offset with respect to AVHRR, has been detected for GOME-2 (FM1). The issue has been reported in EUM/EPS/AR/18445.4. the observed offset was along-track offset of up to 5 km and a potential additional across-track pointing offset of up to 3 km.

An analysis of the GOME-2 pointing (main channel footprint 40km ALT 80km ACT of 24 ground pixels per scan) using AVHRR level-1b geo-location and radiance data from the 31st of shows an along track offset of 0 km in the west part of the swath and up to 5km in the East. (AVHRR pointing was corrected at the 13th of December). That was a clearly significantly above the offset along-track observed for Metop-B and Metop-A, which should be close to zero. Across track we expected an offset of 20% of an across track pixel (approx.18km) but do observe slightly higher values for GOME-2 Metop-C (approx. 3km too high).

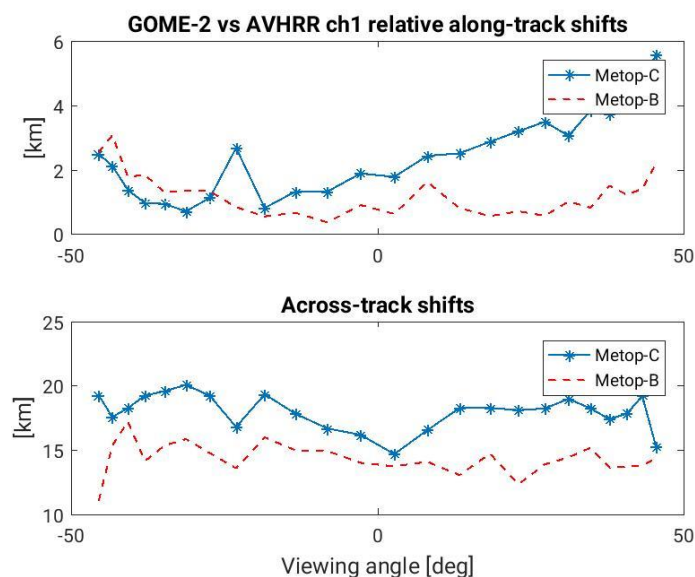


Figure 89: Metop-C FM1 along-, and across track shift (top and bottom resp.) w.r.t. AVHRR in km. Metop-B results are provided as red dashed line.

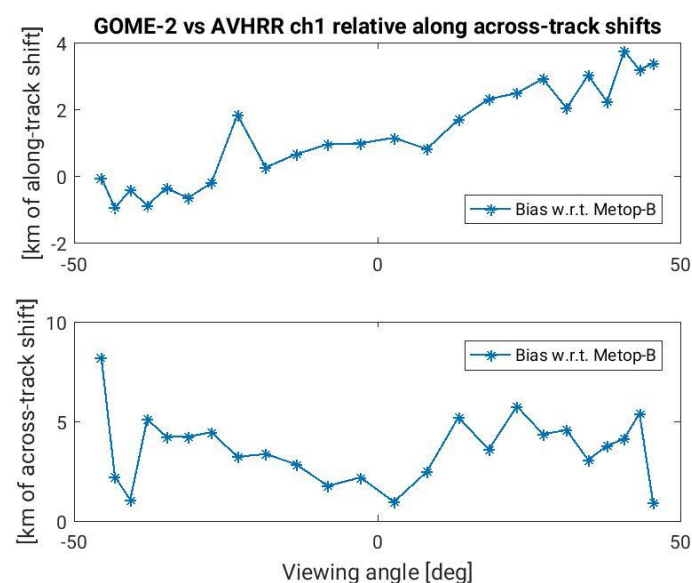


Figure 90: Metop-C FM1 bias w.r.t Metop-B FM2 along-, and across track shift (top and bottom resp.) using AVHRR co-location in km. with no mispointing correction

On the basis of these plots and the geolocation data of one GOME-2 scan line a first estimate of GOME-2 mispointing has been estimated by FD as ground shift of (pitch, roll, yaw): 0.75, 5.0, ± 0.5 km. FD has then calculated a corresponding set of correction coefficients to be applied in the GOME L1 data processing to take into account for this offset :

pitch, roll, yaw $\Rightarrow$ +0.051463, -0.343088, +0.051463 deg

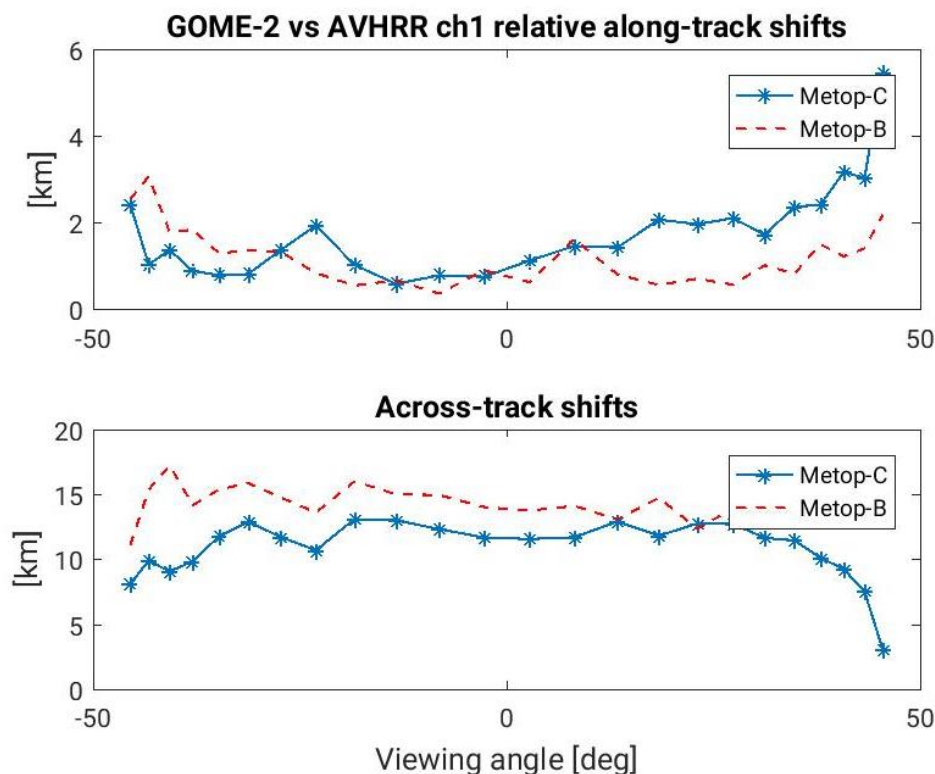


Figure 91: Metop-C FM1 along-, and across track shift (top and bottom resp.) w.r.t. AVHRR in km. Metop-B results are provided as red dashed line after mispoing correccion

Some spectral differences in fully calibrated radiance values at level-1B, and an additional offset in the reflectivity values, due to the change in the solar pointing (and consequently a change in the application of solar diffuser key-data). The changes are introduced by PPF 6.3.2 with pointing offsets introduced in INS file version 1.04 correcting for the observed difference in pointing with respect to AVHRR. Figure 92 shows the results for radiances and Figure 93 for reflectances.

The results confirm the expectation that for M03 with a pointing adjustment carried out the observed residuals in radiances (Figure 4) are small with some additional spectral structure. For reflectance (Figure 5) there is an additional offset observed with origins form a changed pointing to the solar diffuser and consequently the application of slightly different diffuser key-data.

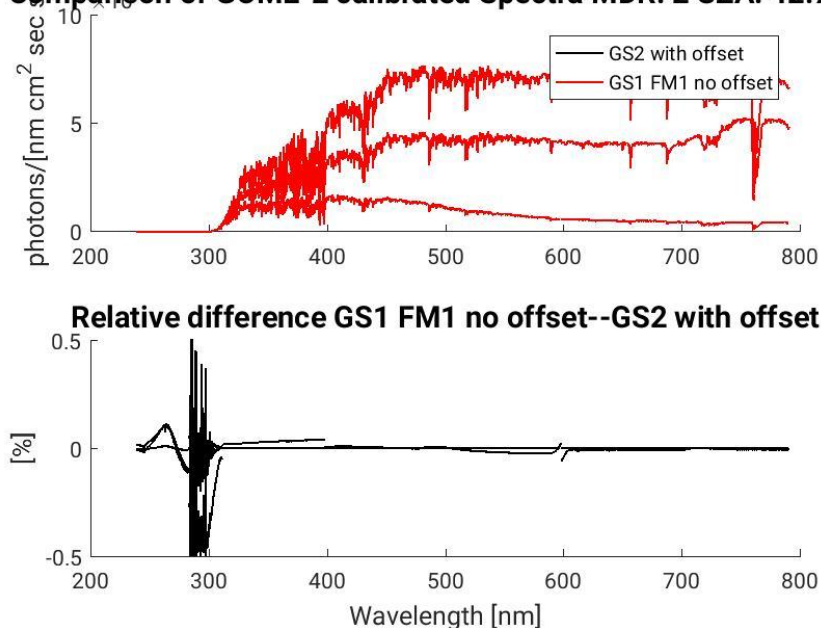
Comparison of GOME-2 calibrated Spectra MDR: 2 SZA: 42.7455


Figure 92: Main channel radiance spectrum from M03 (FM1) for a given observation geometry (see labels) for GS1: PPF 6.3.1 INS 1.023 (black line) and GS2: PPF 6.3.2 INS 1.04 (red line). Lower panel: Relative difference between the spectra. The black line is the residual of the comparison of the end product and the red line without the polarisation correction applied

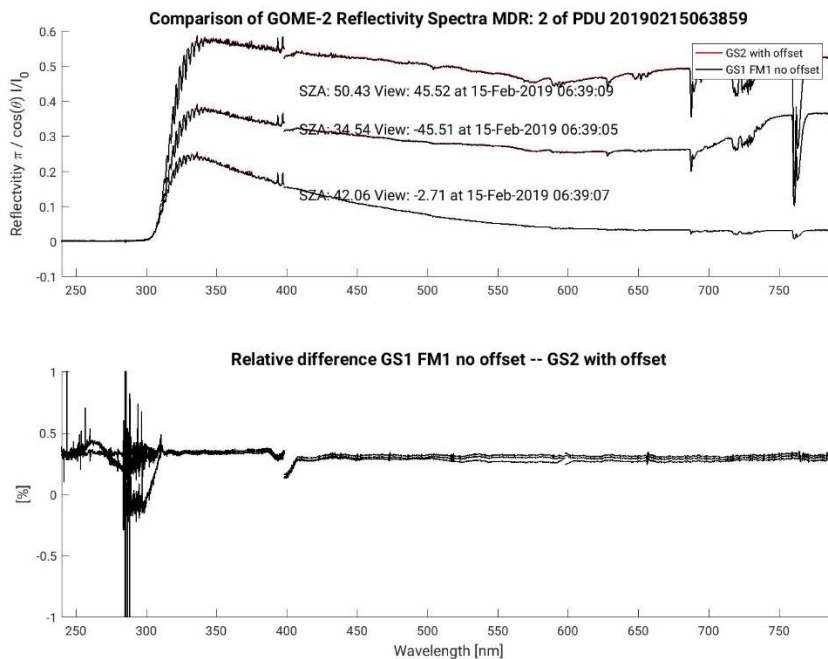


Figure 93: Same as Figure 92 above but for reflectance values.

5 EXTERNAL PARTNER VALIDATION

5.1 Scope of Validation

External partner validation is based (and restricted to) the demonstrational and pre-operational phase of GOME-2 Metop-C / FM1 level 1 data dissemination. The list of Cal-Val partners involved in this phase included all operational level 2 data producers from the Atmospheric Composition Monitoring SAF, ACSAF (<https://acsaf.org/>) and its partners, the University of Bremen, the Institute for Environmental Physics, the Max Planck Institute für Chemie, ECMWF and NOAA.

In the AC-SAF PT meeting on 20 March 2019, a first feedback on the data from all the partners has been provided.

Furthermore, the 53rd GSAG has been held on 20-21 May 2019 where a status on the Metop-C and in particular of GOME-2 FM1 Cal/Val has been presented. Together with this, evaluations on the GOME-2 lev1 quality using non-operational lev2 retrievals and a status of the AC-SAF Level2 products for GOME-2C has been provided by the University of Bremen, DLR and KNMI, respectively. The AC_SAF level2 validation is still ongoing and the corresponding Operational Readiness Review is planned in Autumn 2019.

In the following section, we are summarising the results on Level2 presented in these occasions. Some validations have also been focussed on sensitivity studies and fit residual evaluations, which are summarised here to the extent that they are relevant for on-going analysis on residual spectral patterns.

Note: The wavelength region provided in the header title for each product is only a rough indication, since individual products may cover slightly different spectral regions

5.2 Validation results

5.2.1 Level 2

5.2.1.1 *Evaluation of GOME2C lv1 quality using non-operational lv2 retrievals – IUP – Uni Bremen*

Considering spectral resolution changes, GOME2C channel 2 spectral resolution remained very stable so far with only some small decrease in FWHM. In comparison channel 3 spectral resolution is seen to have decreased since early March with stabilisation in early May which matches the behaviour seen in NO₂ fits with a fixed SMR. The channel 3 results do however appear much more variable which may indicated some other unknown problem. (see results reported in Figure 94)

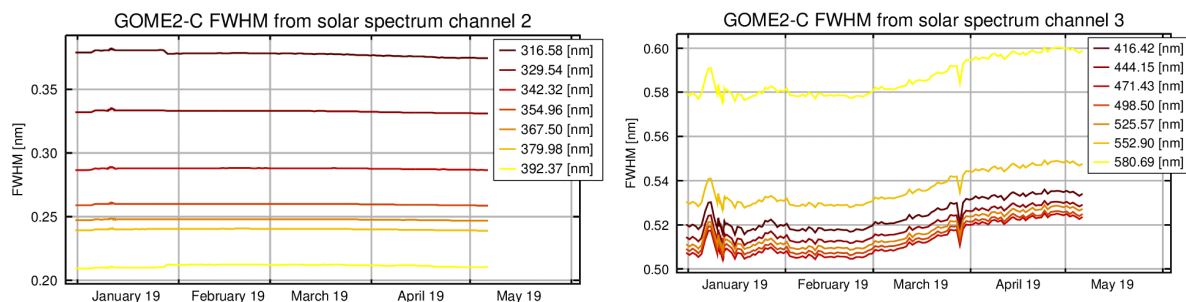


Figure 94: GOME-2 FWHM temporal variation for channel 2 (left panel) and channel 3 (right panel)..

Analysis of solar spectra also indicated that the channel 2 irradiance spectral calibration is relatively stable with changes in the order of < 0.01 nm. Channel 3 irradiance spectral calibration is also relatively stable with changes on the order of < 0.01 nm but showing more “noise”, potentially indicating another unknown problem.

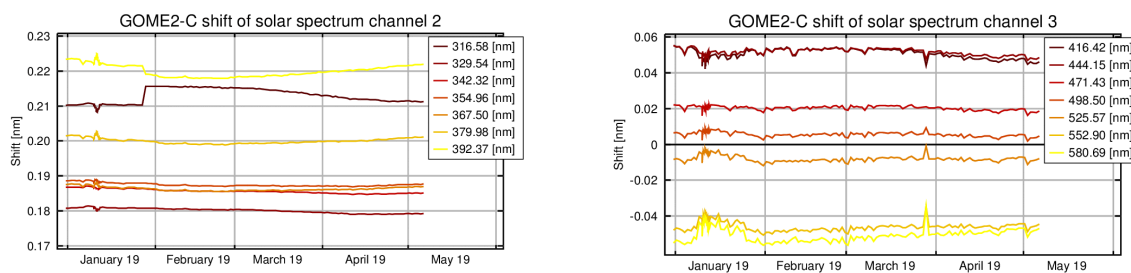


Figure 95: GOME-2 shift of solar spectrum in channel 2 (left panel) and channel 3 (right panel)..

For radiance measurements, channel 2 fits (BrO is used as an example in Figure 96) show small spectral shifts on the order of < 0.01 nm with the expected patterns e.g. at the location of intensity gradients such as ice edge or cloud edges (inhomogeneous scenes) or along orbit changes (temperature change).

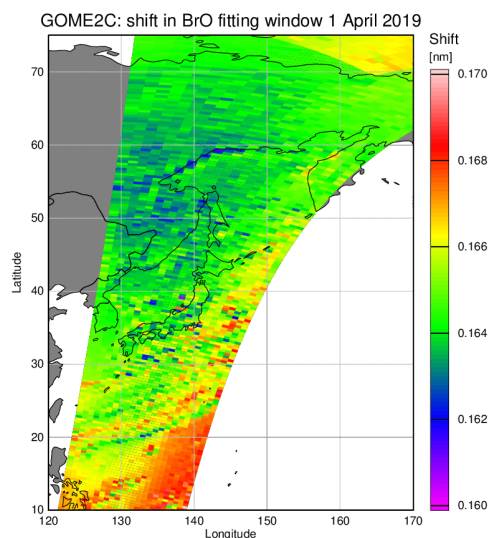


Figure 96: GOME-2 C shift of in BrO fitting window

Channel 3 fits (NO₂ is used as an example) however, show a strange chessboard pattern of spectral shifts on the order of > 0.02 nm. Blocks extend over 1 – 2 pixels across track and 2 – 5 pixels along track. In this analysis no level 1 calibration information is used so this effect is a real spectral shift. The back-scans show similar pattern.

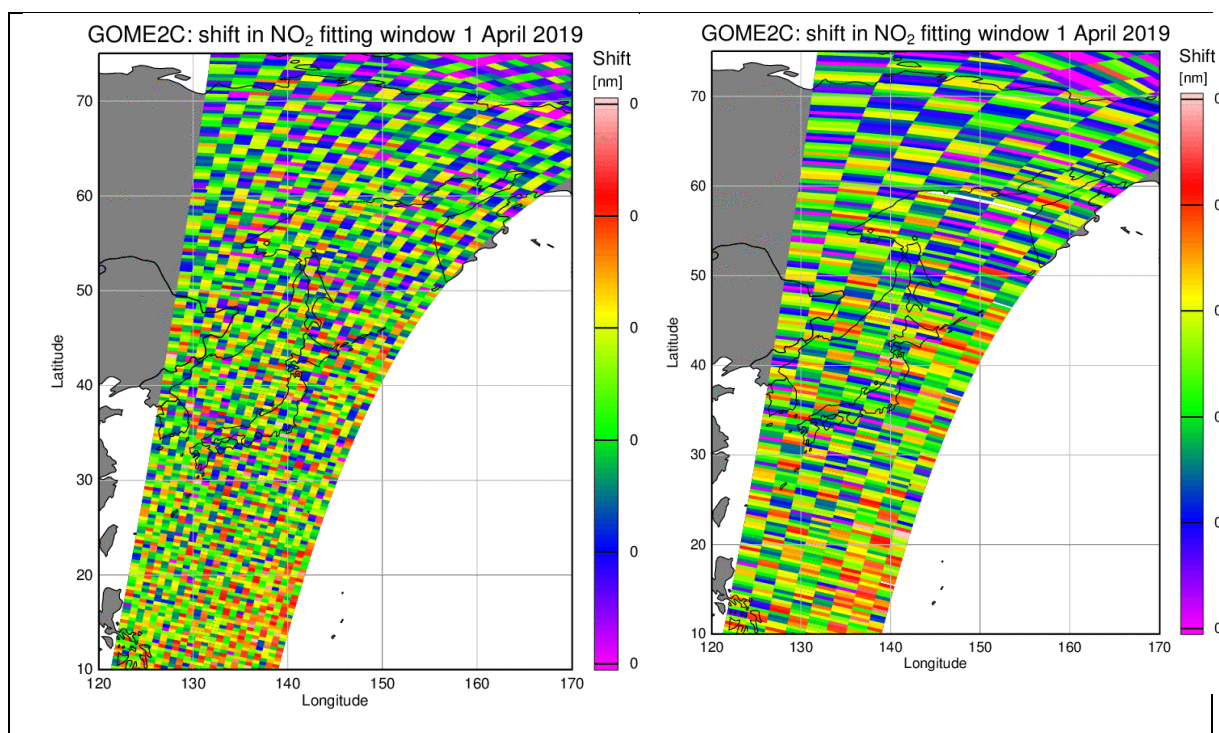


Figure 97: GOME-2 C shift of in NO₂ fitting window for forward scan (left panel) and right scan (left panel)

One of the hypothesis is whether this could be an electronic effect, for example from variable smear during readout, or a real wavelength shift from mechanical changes in the dispersive optics. Option is also considering whether this can this be linked to higher noise in irradiance wavelength/slit calibration and the NO₂ fits. A check on orbits with a static mirror showed a similar pattern of spectral shifts which suggests that the effect is not linked to potential platform vibrations or mirror movements. The retrieval of the spectral position of Fraunhofer lines along the orbit shows that this is really a spectral shift which is more or less uniform over channel 3.

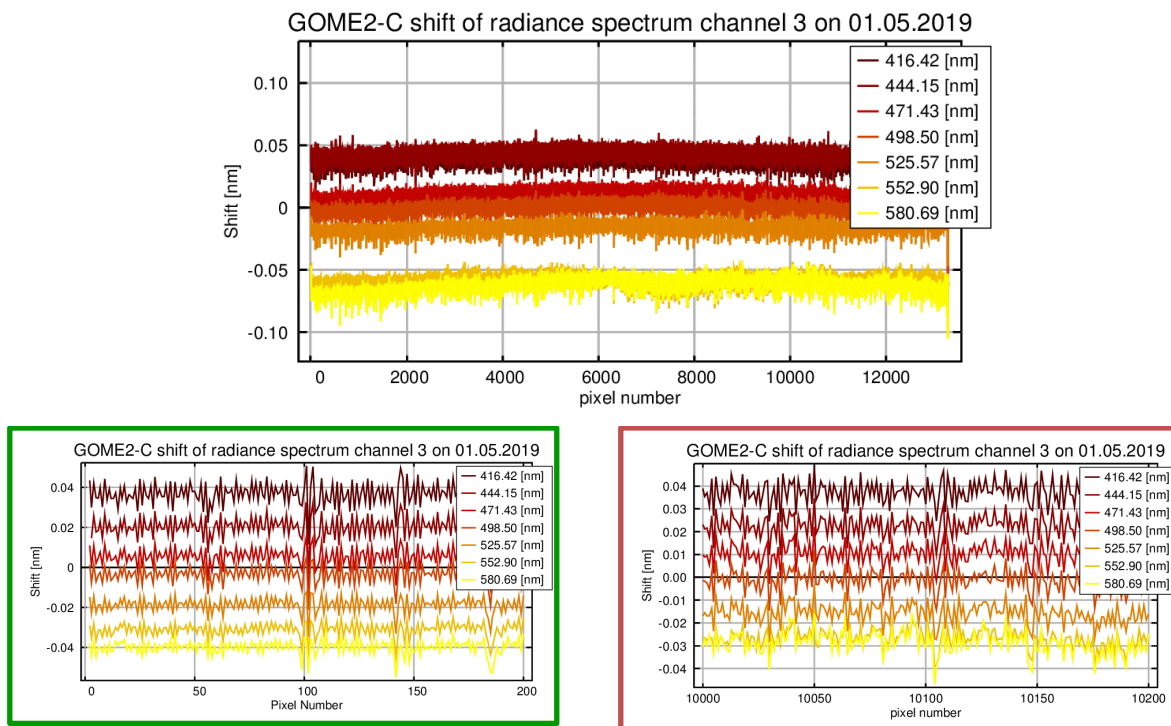


Figure 98: GOME-2 C shift of radiance spectrum in channel3 (top panel) as function of pixel number, together with zoom for two 200 pixel regions (0-200 on the left bottom panel; 10000-10200 on the right bottom panel).

5.2.1.2 Evaluation of GOME2C lv1 quality KNMI

For the GOME-2C instrument spectral response function, a comparison was made between a measured irradiance spectrum and a simulated spectrum created by convolving a high resolution reference spectrum with the RAL slit function. Problem areas are seen in Channel 1 from 285.63 – 288.46nm and Channel 2 from 313.94 – 314.92nm.

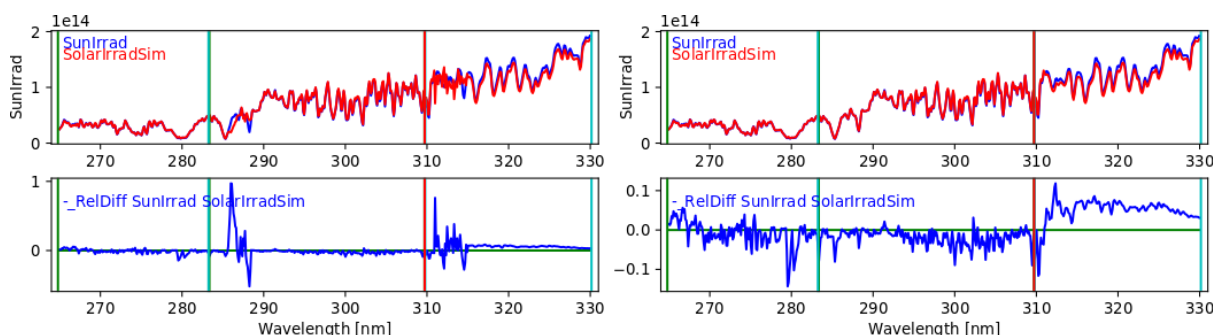


Figure 99: GOME-2 C measured irradiance spectrum(blue) and simulated (red)

A GOME-2C instrument spectral response function fit was also investigate with fit parameters being offset, gain, displacement (shift) and squeeze. Overall the day to day variation of the slit function fit is too large to use on an operationally basis.

The GOME-2 C initial spectral bias - show in Figure 100 - was calculated from the ratio between measured GOME-2C reflectances and simulations based on McPeters/Labow 2013 O3 climatology where the O3 columns are scaled with assimilated AC SAF GOME-2A total ozone column. For the date presented which was the 13th of May 2019 and instrument bias in the order of approximately -2% to +7% was observed.

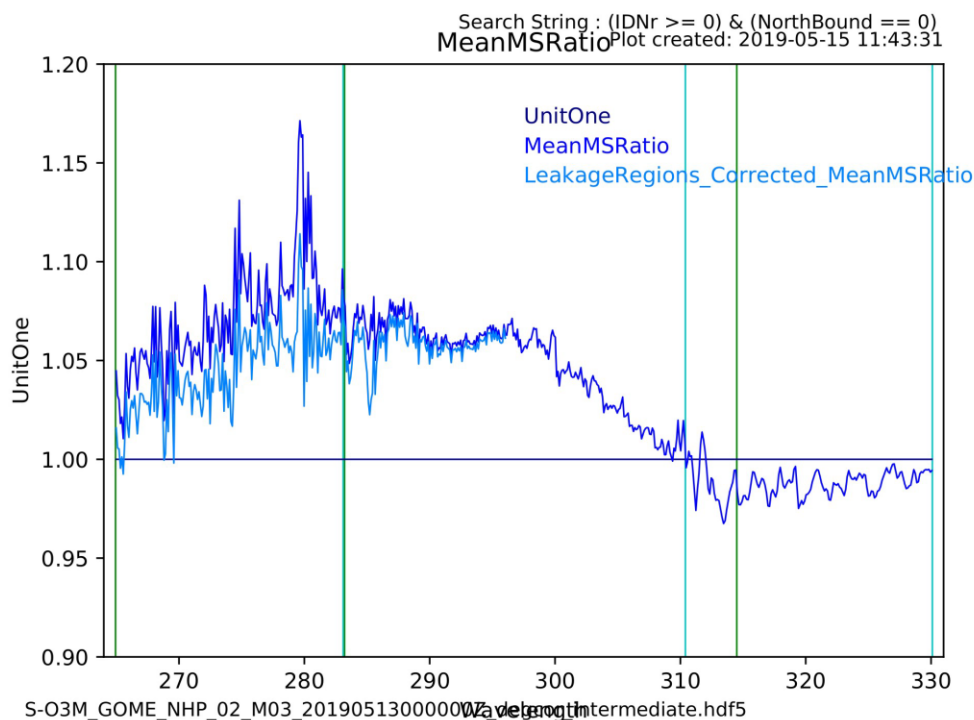
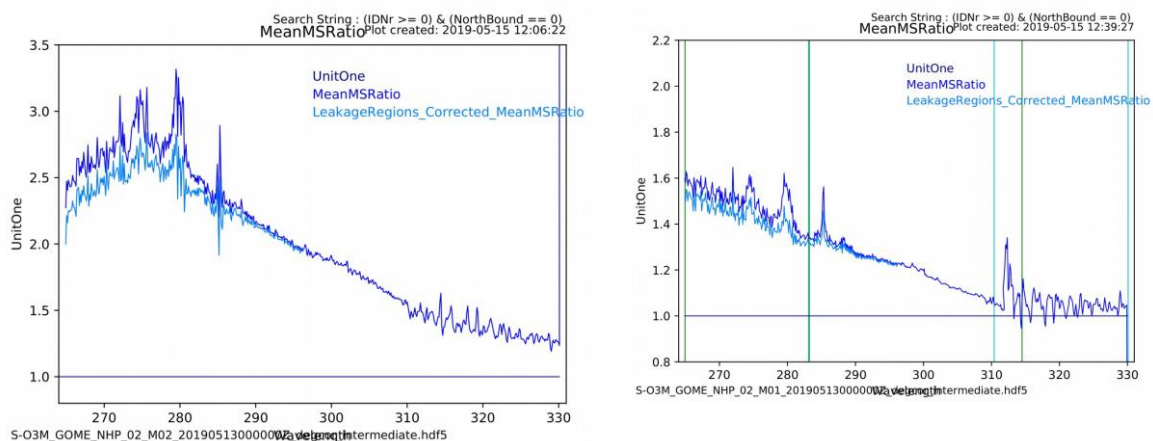


Figure 100: GOME-2 C Initial Spectral instrument bias

By comparison to GOME-2B at the same point in the mission, biases are also seen for GOME-2B. The spectral shape is slightly different but the order of magnitude is not dissimilar. Comparing GOME-2A, GOME-2B and GOME-2C at the current point in all missions, the comparison is dominated by throughput degradation effects.



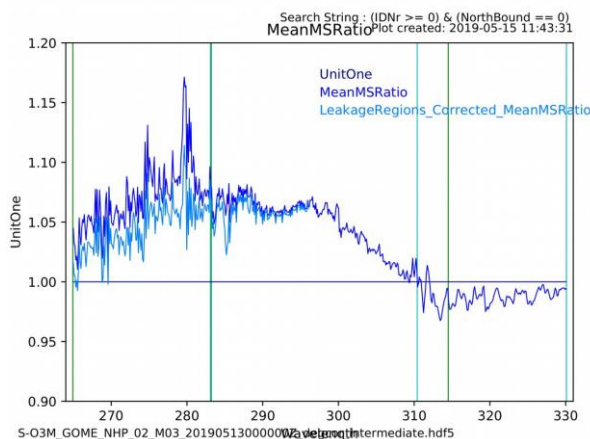


Figure 101: GOME-2 Current Spectral instrument bias comparison: GOME2-A top left panel, GOME2-B top right panel GOME2-C center bottom panel.

5.2.2 Level 2

5.2.2.1 Total ozone: 320 nm-335 nm; Channel 2

5.2.2.1.1 Institute für Umweltphysik (IUP) Bremen

The IUP Bremen is providing some preliminary results on total ozone content, applying the WFDOAS retrieval technique in the 325-335 nm spectral range.

The slit function of GOME-2/MetopC retrieved correspondingly is nearly identical to actual GOME-2/MetopB, as it can be seen in Figure 102: IUP-Bremen derived ISRF for the three instruments. Figure 102 GOME-2C ozone is somewhat – on the basis of the data analysed up to now - higher than 2A and 2B by 2-3% (Figure 104).

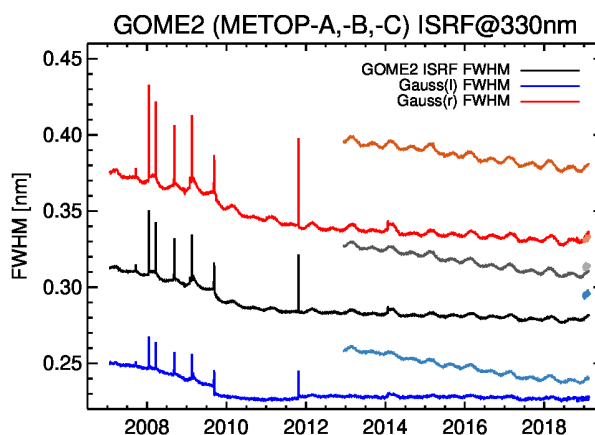


Figure 102: IUP-Bremen derived ISRF for the three instruments.

An offset is – at this moment – detected in the GOME2-C Ozone values with respect to GOME2-A and GOME2-B by 2-3%, as it can be seen in Figure 104.

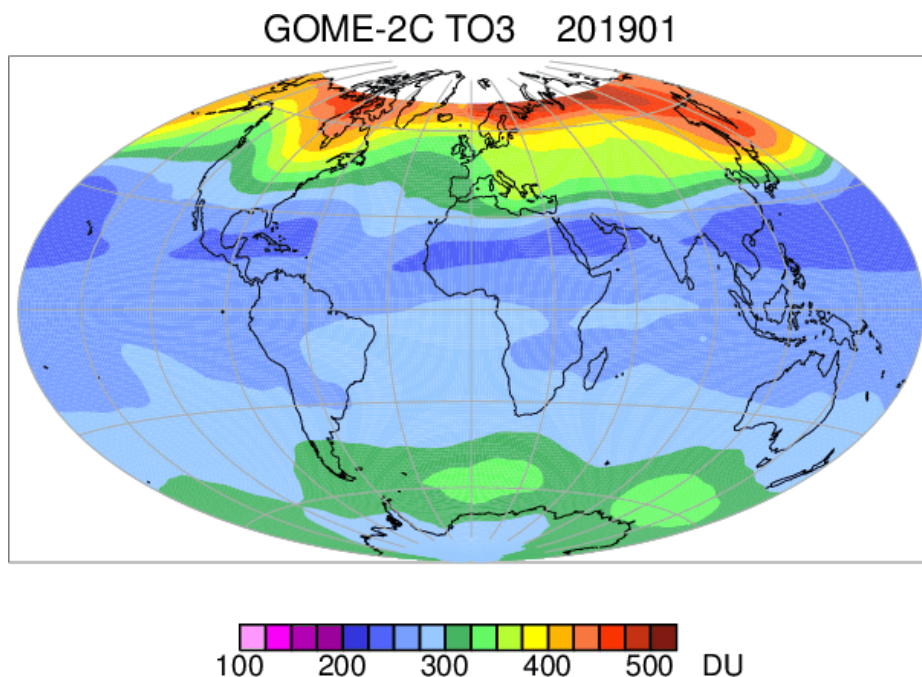


Figure 103: IUP-Bremen derived total ozone column for Metop-C / FM1 – January 2019 Monthly average.

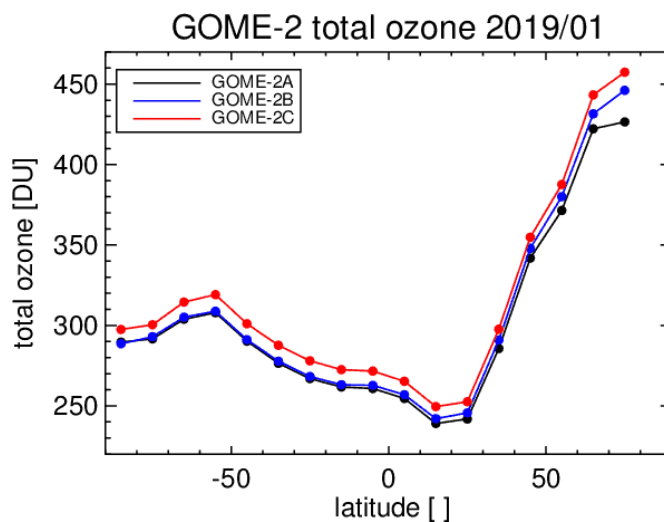


Figure 104: IUP-Bremen derived total ozone column for Metop-C / FM1

5.2.2.1.2 AC-SAF – DLR

In Figure 105, GOME-2A (before the solar gap) and GOME-2B total column ozone are compared. There is a mean difference of -0.53 ± 3.05 %. For the comparison between GOME-2C and GOME-2B Figure 106 the differences are larger and there is quite some variability with $+1.88 \pm 2.86$ %. GOME-

2C values are higher. QDOAS slit function fitting produces a similar resolution but slightly different shape as compared to the key data. Using this optimised slit improves the comparison - reported in Figure 107 -for GOME-2C but if the same procedure is applied to GOME-2B the results are somewhat degraded so it is not clear that this is a valid way to proceed. University of Bremen also sees a high bias in GOME-2C ozone data, using slit function fitting.

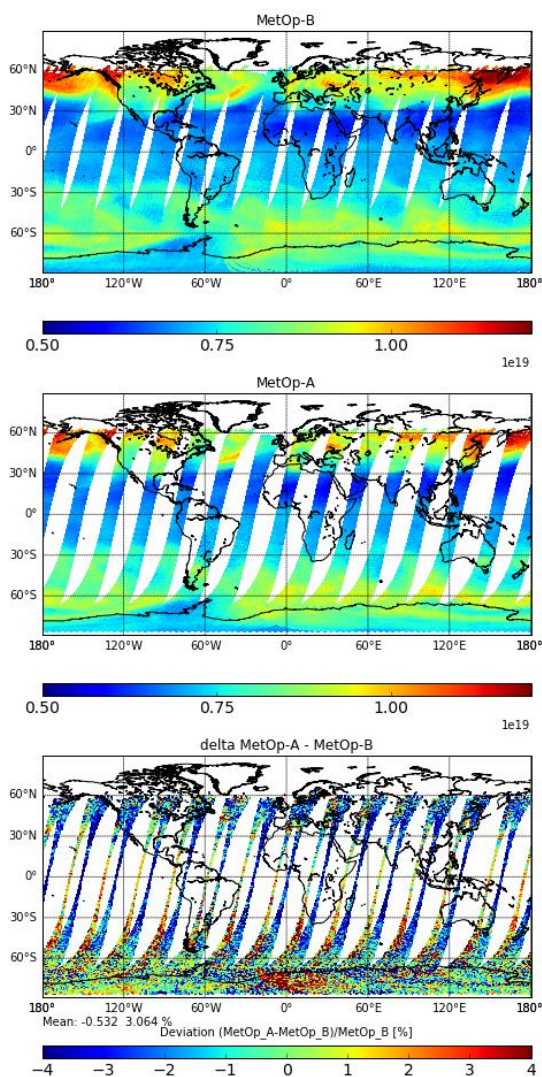


Figure 105: Total column Ozone –comparison Metop A &B - 14 Dec 2018 (before GOME-2A solar gap)

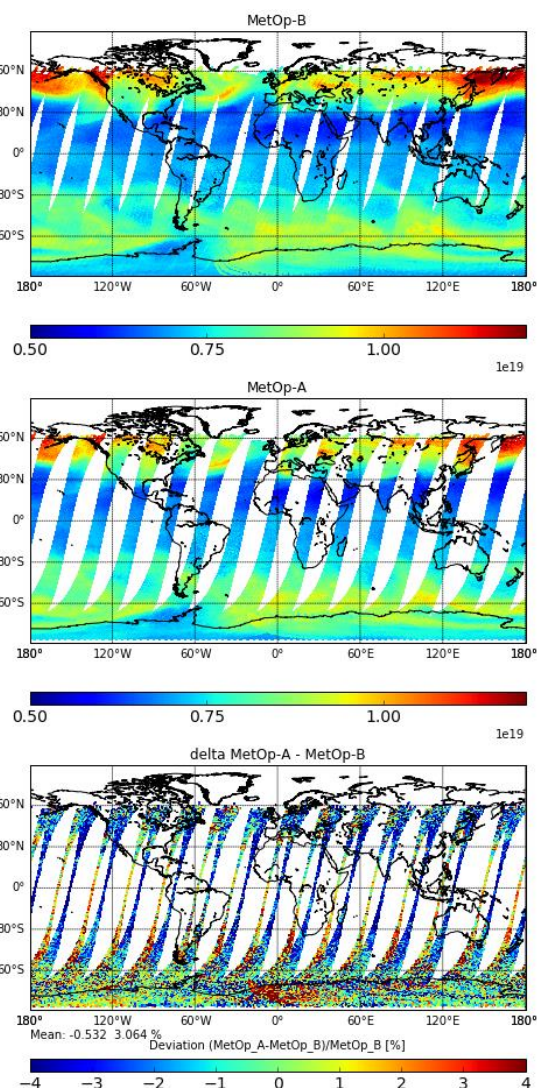


Figure 106: Total column Ozone –comparison Metop C & B - 6 Feb 2019

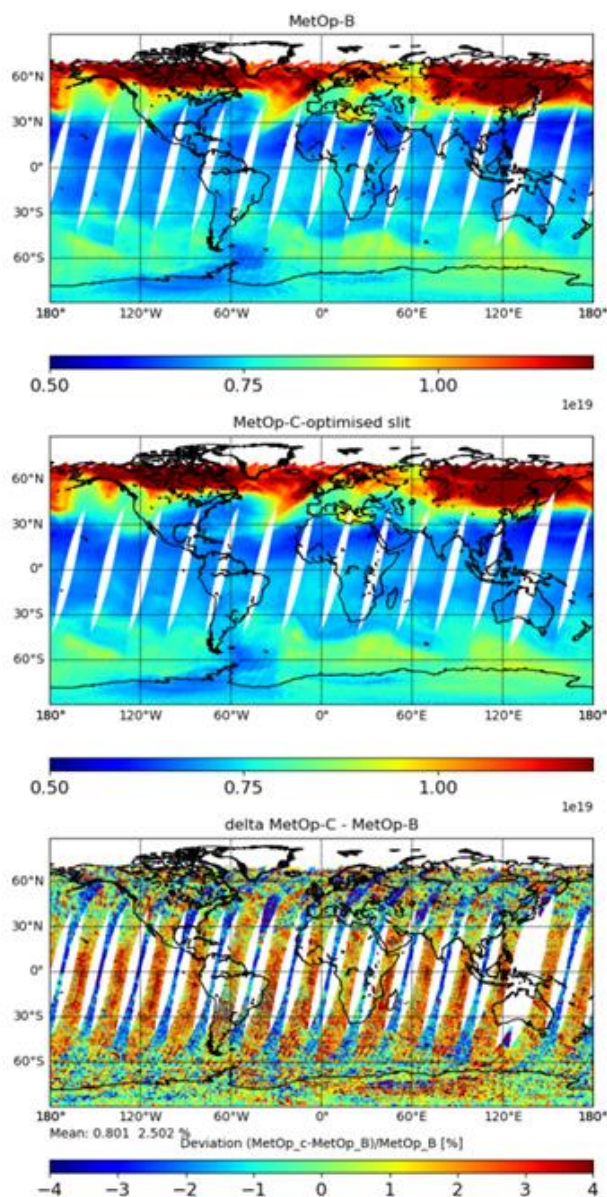


Figure 107: Total column Ozone using QDOAS optimised slit in pre-convolution –comparison Metop C & B - 6 Feb 2019

5.2.2.2 Ozone vertical profile;; Channel 1 and Channel 2

5.2.2.2.1 AC-SAF KNMI

The spectral ranges used for the retrieval of the ozone vertical profile are B1a: 265.0 -284.0; B1b: 283 – 310.0 nm; B2b: 311 – 330.0 nm. At this point in time of the analysis, no issues with convergence of the retrievals has been found.

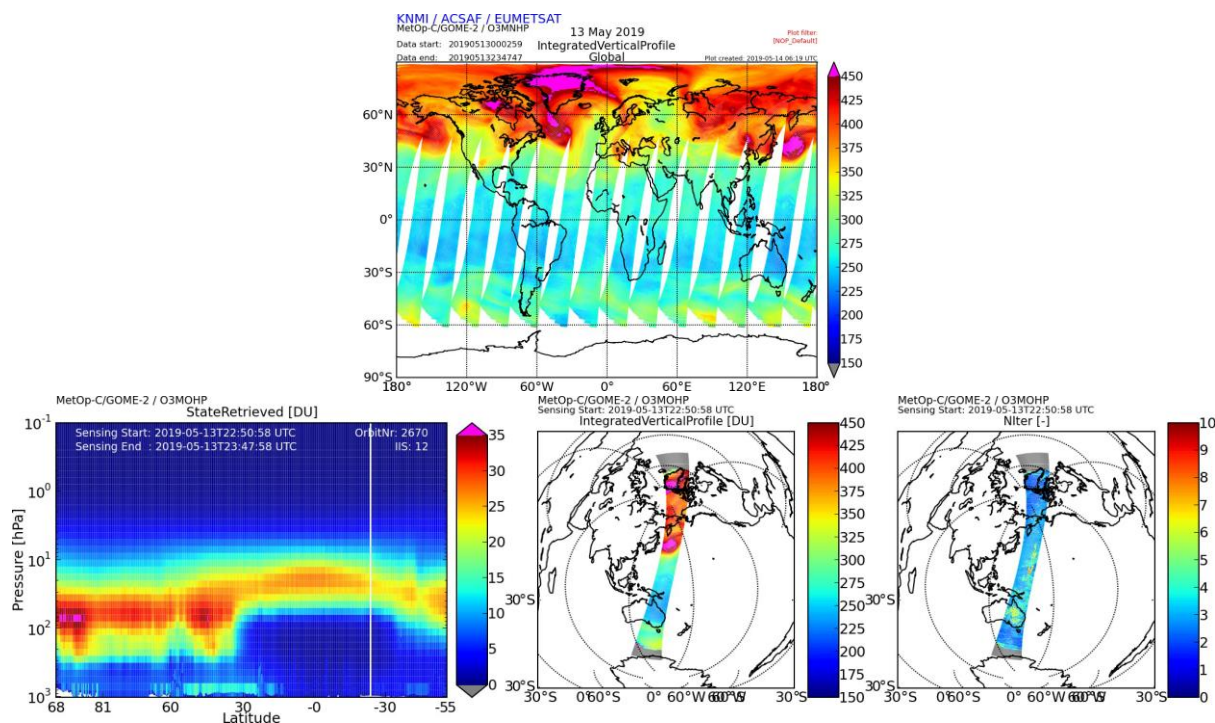


Figure 108: GOME-2 Metop-C vertical profile : integrated vertical profile (top panel) state retrieved as a function of latitude (bottom panel)

5.2.2.3 HCHO 328 nm-348 nm; Channel 2

5.2.2.3.1 AC-SAF – BIRA

HCHO retrieval from GOME2-C has been compared to HCHO from GOME2-B, in Figure 109: HCHO content and corresponding RMS from GOME2-C on 01 -02-2019 and Figure 110: HCHO content and corresponding RMS from GOME2-BC on 01 -02-2019a case study is presented relative to 01 february 2019.

For GOME-2C a strong East-West dependency is visible, although it appears from the presentation that there may be structures cross the scan rather than a simple East-West dependency. When a background correction is used (see Figure 102, Figure 103) the comparison improves but the scan angle dependence (or across-track structures) remain.

Moreover, a comparison on a day such that the two instruments have the same age has been done and it is reported in Figure 104 and Figure 105. IN this case, GOME-2C presents larger RSM values

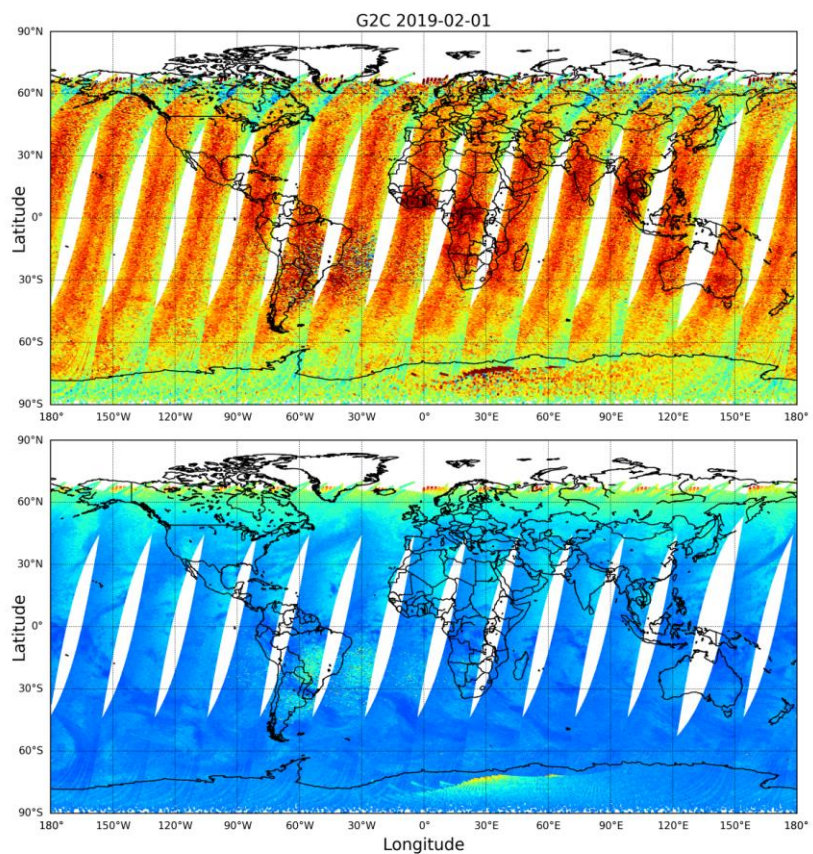


Figure 109: HCHO content and corresponding RMS from GOME2-C on 01-02-2019

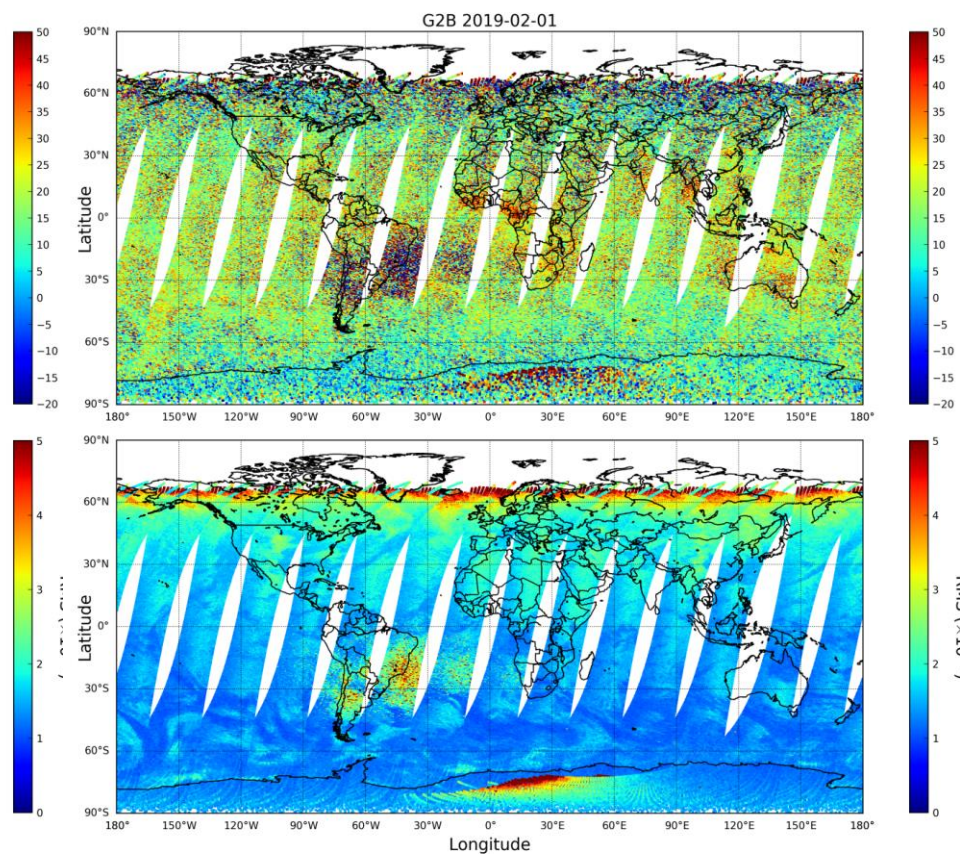


Figure 110: HCHO content and corresponding RMS from GOME2-BC on 01-02-2019

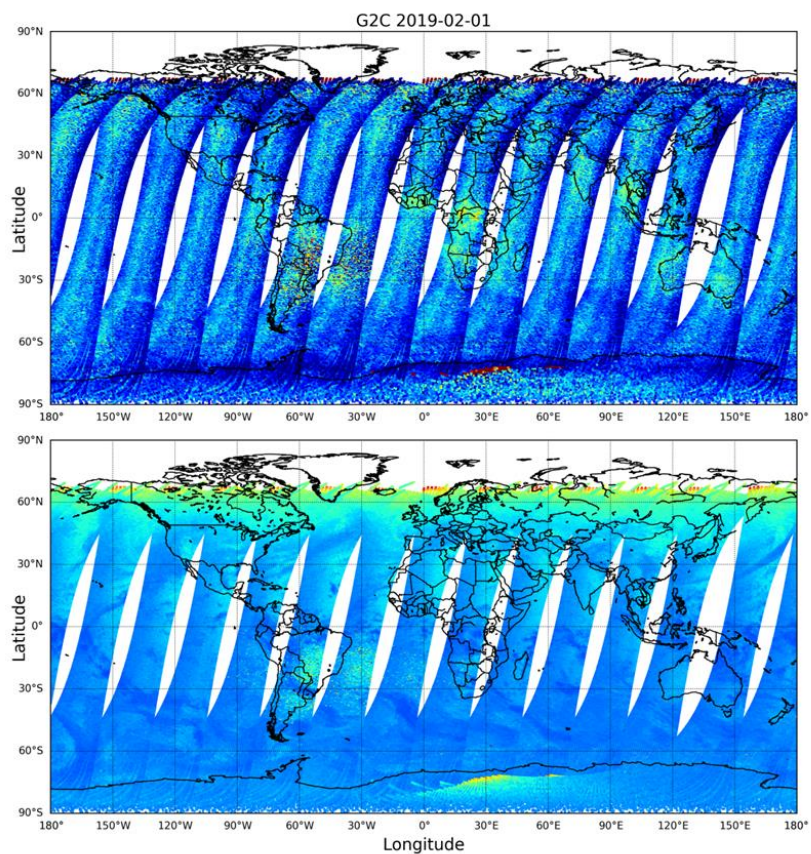


Figure 111: HCHO content and corresponding RMS from GOME2-C on 01-02-2019 with a corrected background

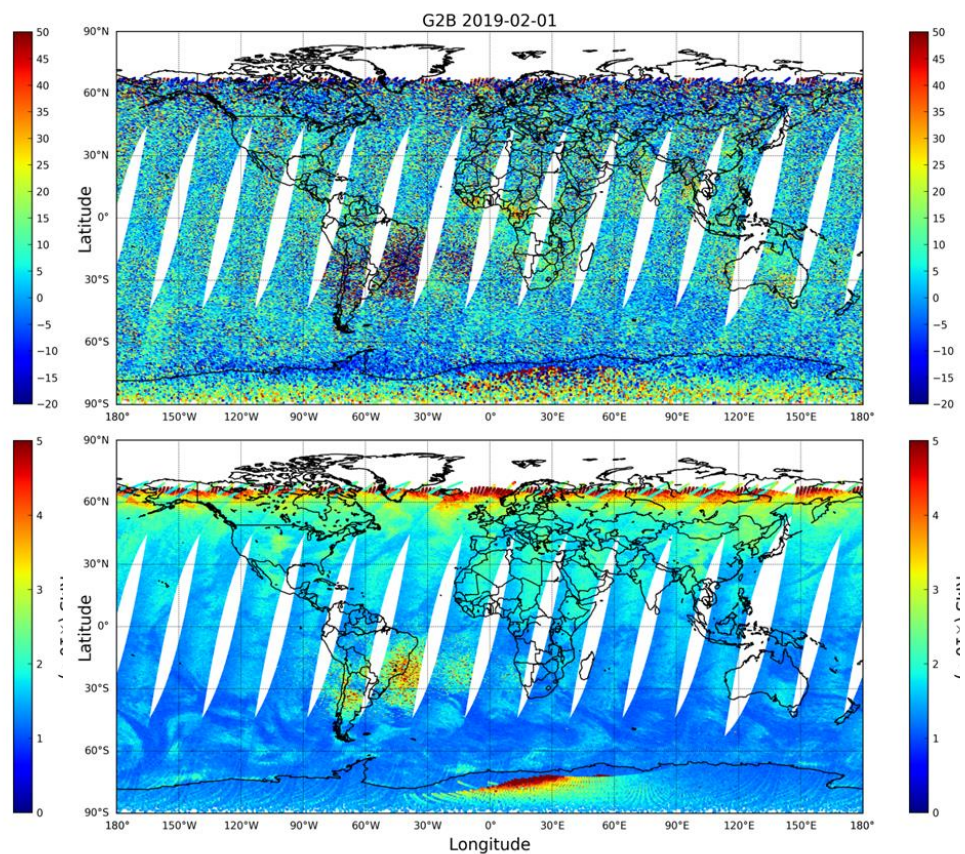


Figure 112: HCHO content and corresponding RMS from GOME2-BC on 01-02-2019 with a corrected background

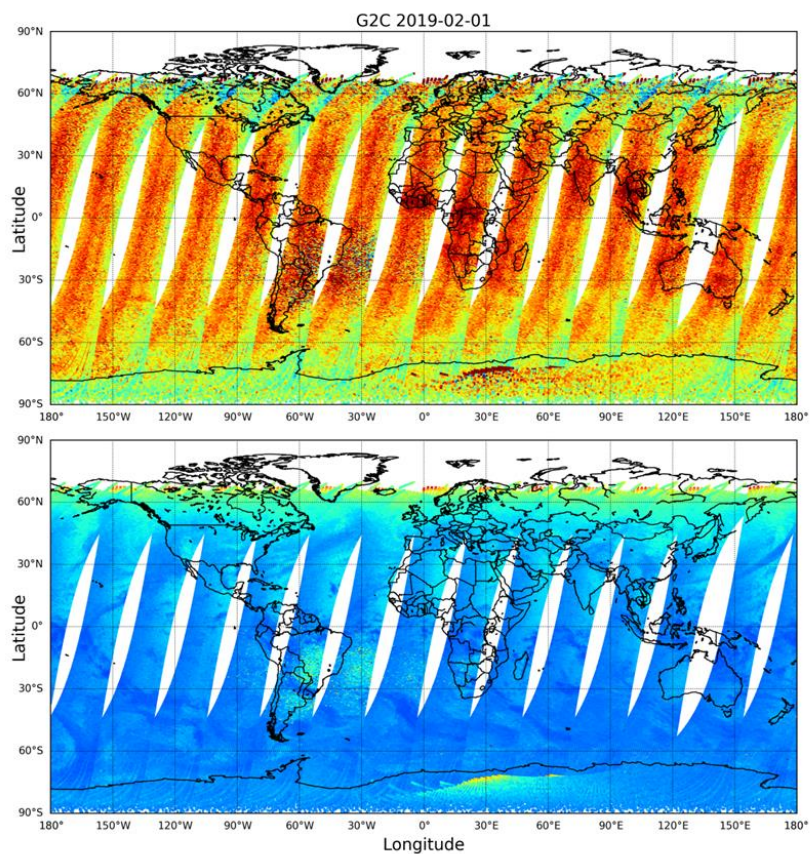


Figure 113: HCHO content and corresponding RMS from GOME2-C on 01-02-2019

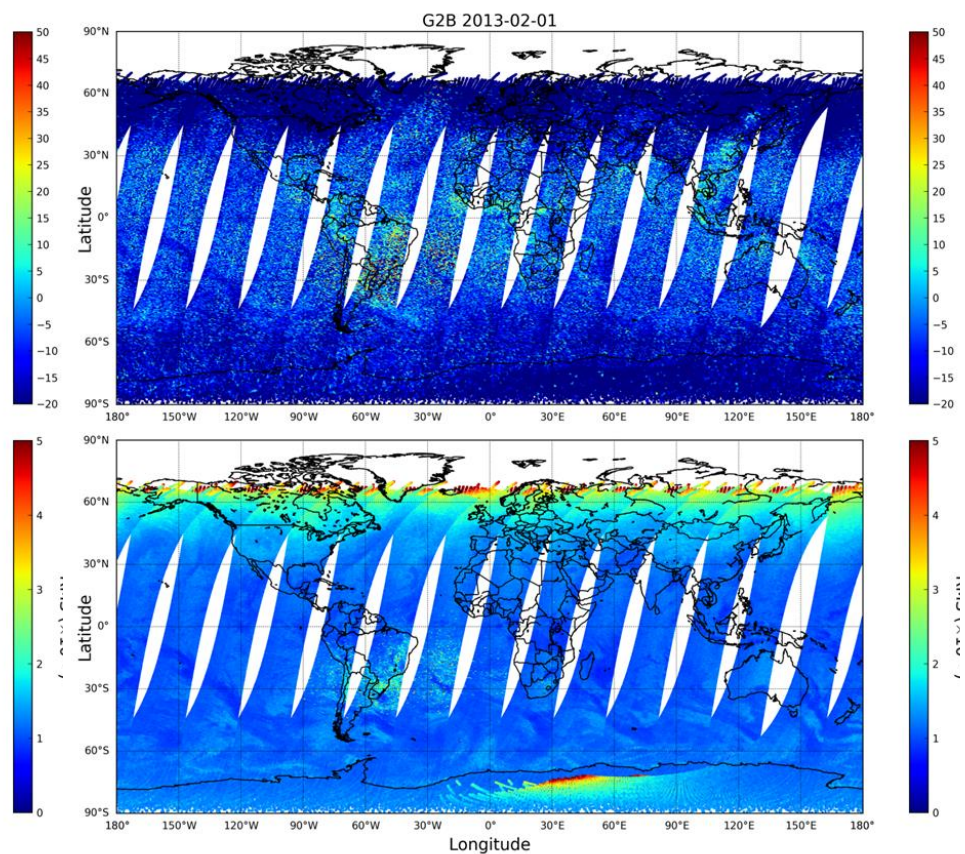


Figure 114: HCHO content and corresponding RMS from GOME2-BC on 01-02-2013 – same instrument age, for RMS comparison

5.2.2.4 BrO 332 nm-359 nm; Channel 2

5.2.2.4.1 AC-SAF – BIRA

BrO retrieved from GOME2- MetopC on 01-02-2019 has been compared to retrieval from GOME2-B. The behaviour shown by BrO retrieved values is the same found for formaldehyde.

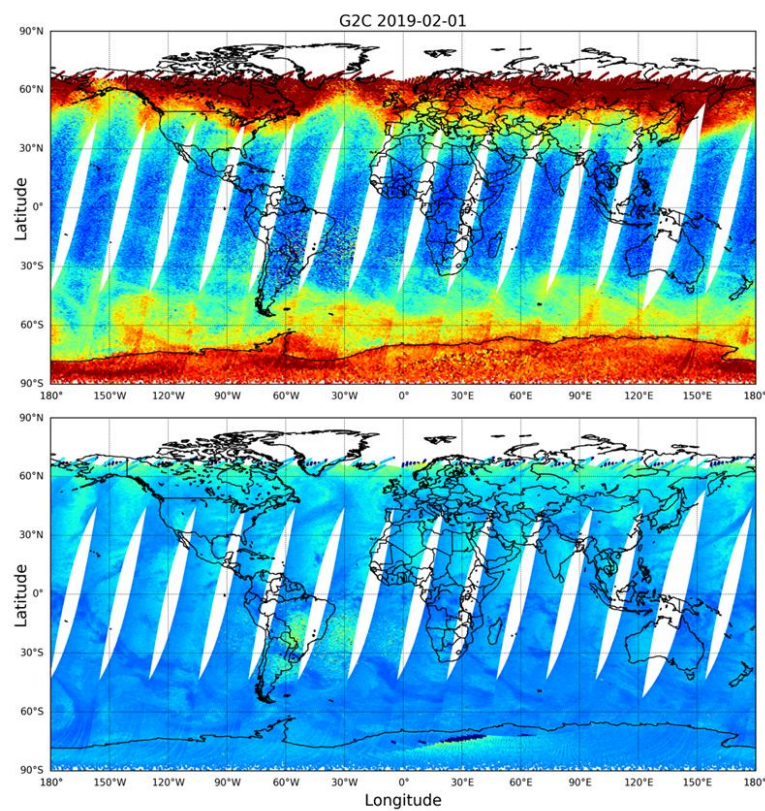


Figure 115: BrO content and corresponding RMS from GOME2-C on 01-02-2019

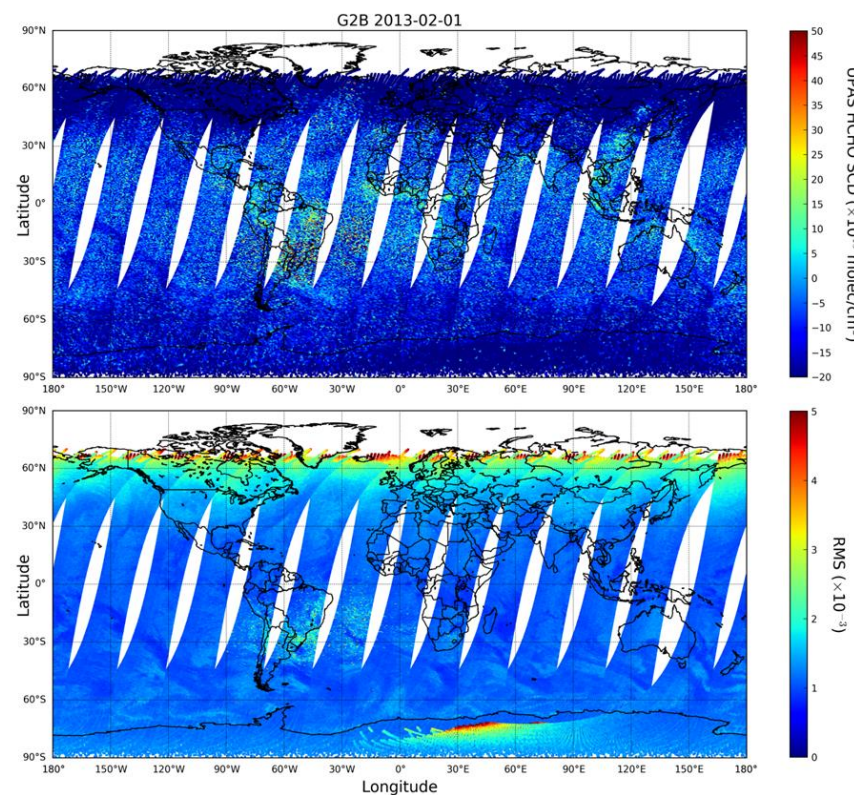


Figure 116: BrO content and corresponding RMS HCHO content and corresponding RMS from GOME2-BC on 01-02-2019 with a corrected background

5.2.2.5 NO₂: 425 nm- 450/500 nm; Channel 3

5.2.2.5.1 IUP Bremen

In the frame of the Study on the Scientific Support for Analysis of GOME-2 FM1 MetopC In-Orbit Performance, IUP University of Bremen has made a detailed analysis on the in the GOME-2 Channel3 NO₂ retrievals. Several groups have also reported that NO₂ retrievals show an offset if the fitting window starts at wavelengths < 430 nm. A more detailed analysis has been carried out which shows that the variation in NO₂ column also starts at other wavelengths. (see Figure 117)

A similar variability but with different patterns is found for GOME2-B and GOME2-A so the problem is not limited to GOME2-C. (see Figure 118)

As it can be seen in Figure 119 and Figure 120 a change in the end-wavelength also results in changes in the offsets found.

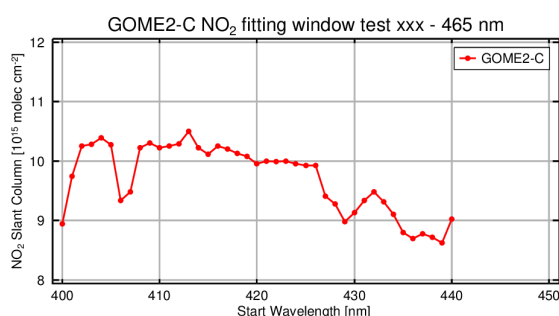


Figure 117: GOME-2C NO₂ Slant column as a function of the fitting window initial wavelength

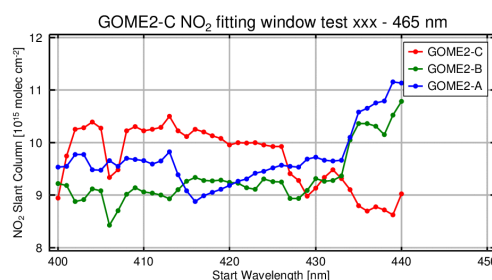


Figure 118: GOME-2C (red), GOME2B (green) and GOME2A (blue) NO₂ Slant column as a function of the fitting window initial wavelength

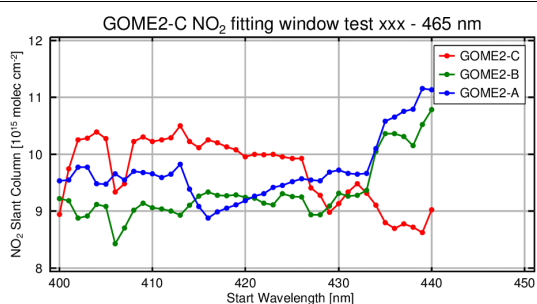


Figure 119: GOME-2C NO₂ slant column as a function of the fitting window initial wavelength, with an extended range to 465 nm

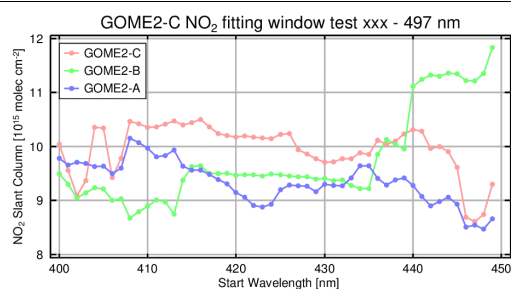


Figure 120: GOME-2C (red), GOME2B (green) and GOME2A (blue) NO₂ slant column as a function of the fitting window initial wavelength with an extended range to 465 nm

It is a complex problem introducing uncertainties in the NO₂ SC of more than 1×10^{15} molec cm⁻². TROPOMI/S5P appears to be much less affected by this type of problem so it is not a fundamental DOAS problem but likely somehow related to GOME-2 instruments calibration.

When averaging NO₂ fits by subset over the Pacific (little across track variability is expected), a strange pattern emerges which is stable over time and which is considered to be related to calibration. Figure 121 reports the results for GOME2-C. For GOME2-A and GOME2-B, reported in Figure 122 different but also stable patterns emerge so the problem is not limited to GOME2-C.

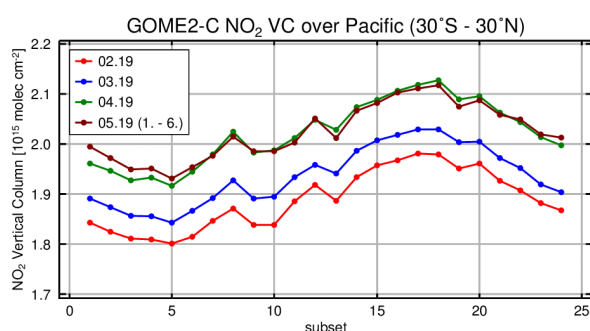


Figure 121: GOME2-C NO₂ vertical column over the Pacific as function of the subset

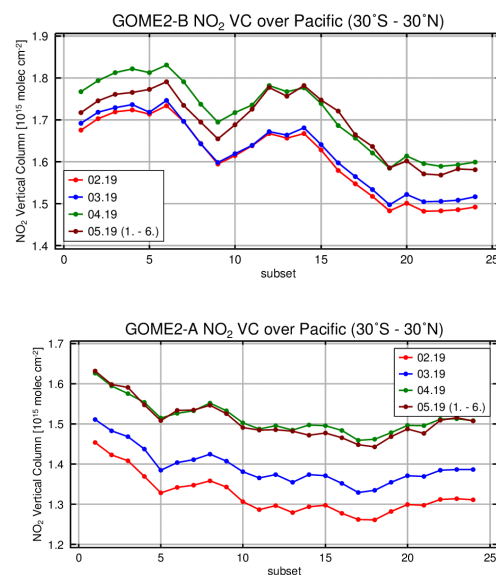


Figure 122: GOME2B (top plot) and GOME2A (bottom plot) NO₂ vertical column over the Pacific as function of the subset

Evaluation of the long-term evolution of the subset anomaly of GOME2-A NO₂ over the Pacific shows very consistent results with changes mainly linked to changes in calibration. There is no strong fingerprint of degradation and the throughput test is not associated with any change in the pattern.

NO₂ fitting residuals are a combination of systematic structures, random noise from the instrument, and random photon shot noise. The random component should decrease with intensity as (relative) photon shot noise decreases. NO₂ fit RMS over one orbit are reported in Figure 123 (top panel) showing a two branches of behaviour which are associated with the northern and southern hemisphere.

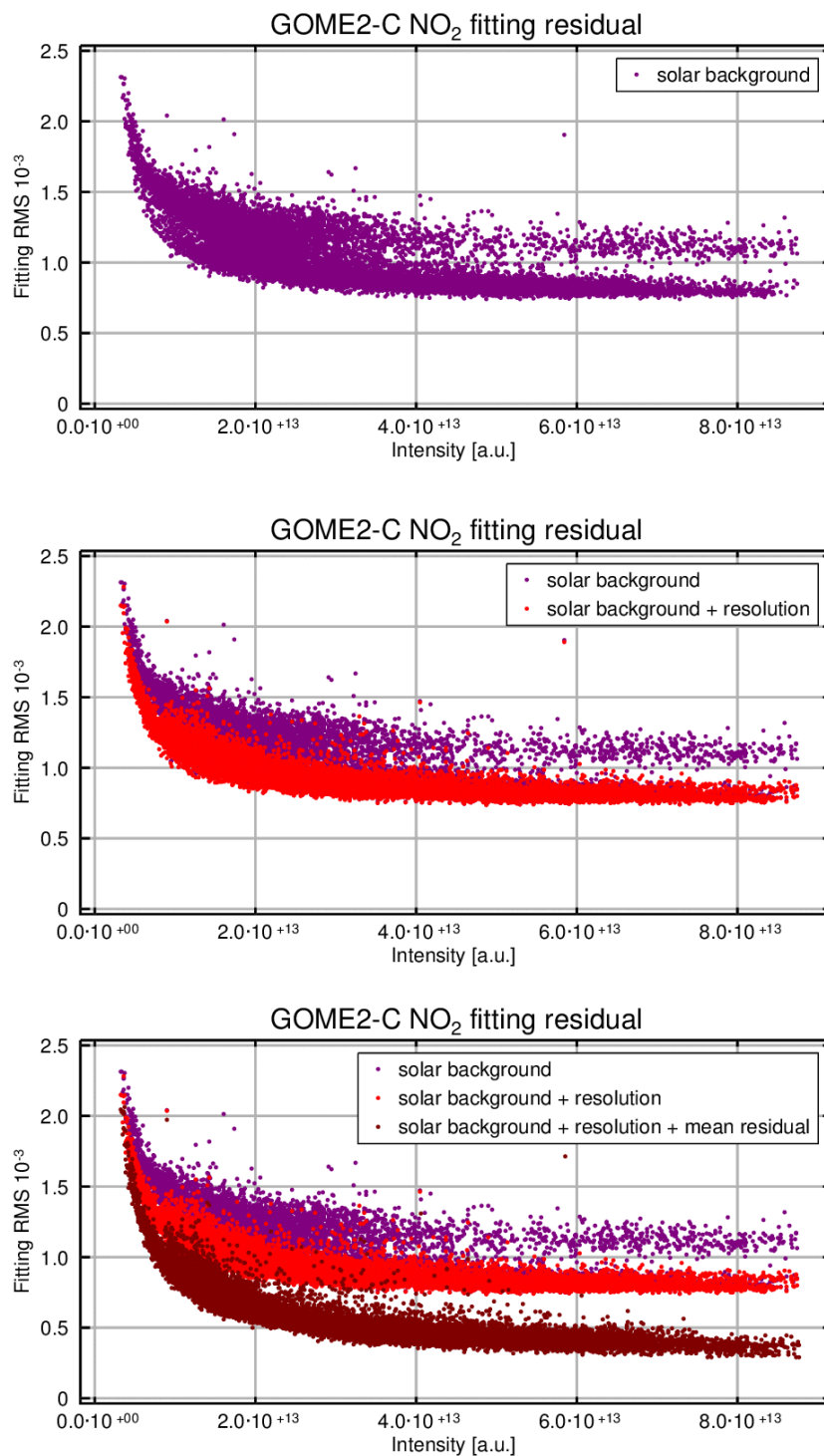


Figure 123: GOME-2C NO₂ fitting residuals over one orbit

If a spectral resolution correction is included in the fit, (Figure 123 , central panel) the separation of the fitting RMS into NH and SH branches is almost removed indicating that the resolution changes over the orbit and that this needs to be corrected.

When a mean residual is included (Figure 123 , bottom panel), the RMS can be reduced by 5×10^{-4} (factor of 2) at high intensities indicating that systematic patterns contribute about half of the residual.

If a Pacific background is used instead of the solar irradiance as it is reported in the top panel of Figure 124, then the RMS is as low as when the solar irradiance plus a mean residual is used suggesting in part issues with the solar irradiance, as other contributions such as a reduced Ring effect are also included. Including, in addition, a (new) mean residual in the fits with the Pacific background (bottom panel of Figure 124) leads to a further reduction in RMS, mainly in the SH suggesting that the resolution correction is probably not perfect.

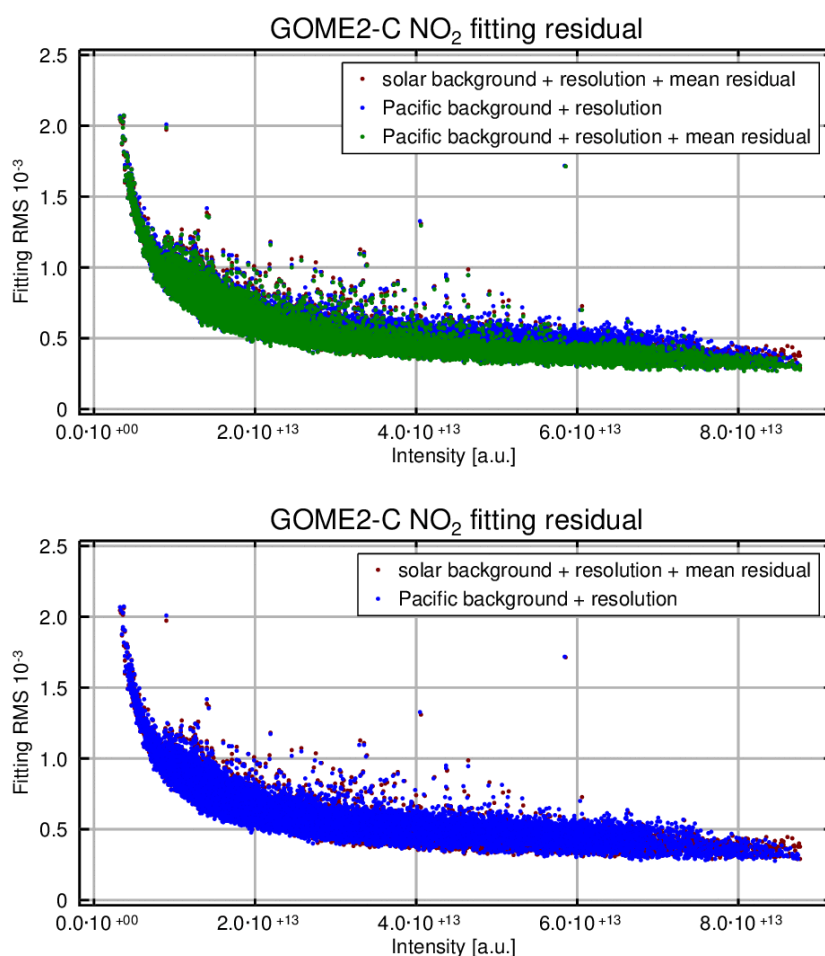


Figure 124: GOME-2C NO₂ fitting residuals over one orbit

Mean values of fitting NO₂ RMS are plotted in Figure 125, the main effect is from the choice of background (or inclusion of mean residual). The resolution correction is important but other improvements are small on average.

A comparison between small and large fitting windows is reported in Figure 126. In the top panel the fitting windows taken into account is 425- 497 nm, while in the bottom panel the fitting windows is 430- 497 nm. only small differences, with RMS in the small fitting window being slightly lower

overall. The differences between the solar background and the Pacific background are very similar. This implies that there is no specific problem with the solar spectrum at wavelengths < 430 nm.

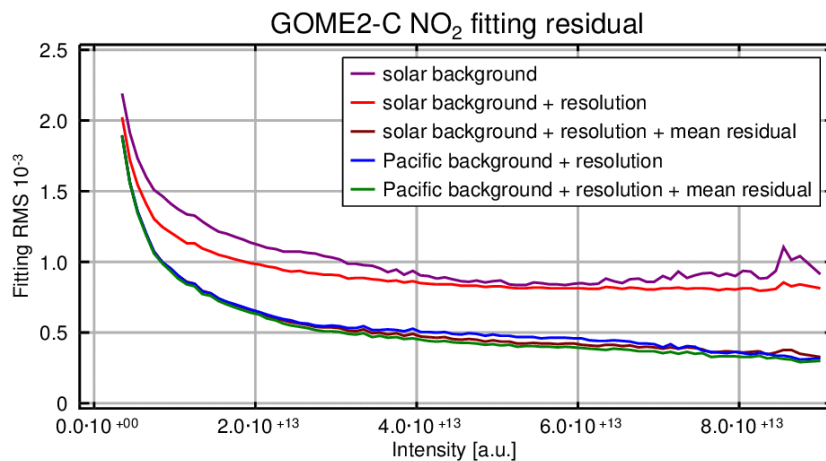


Figure 125: GOME-2C NO₂ fitting residuals over one orbit

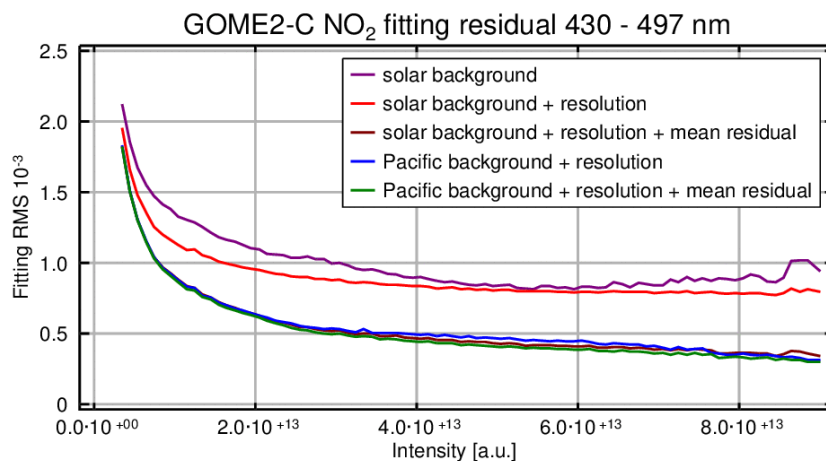
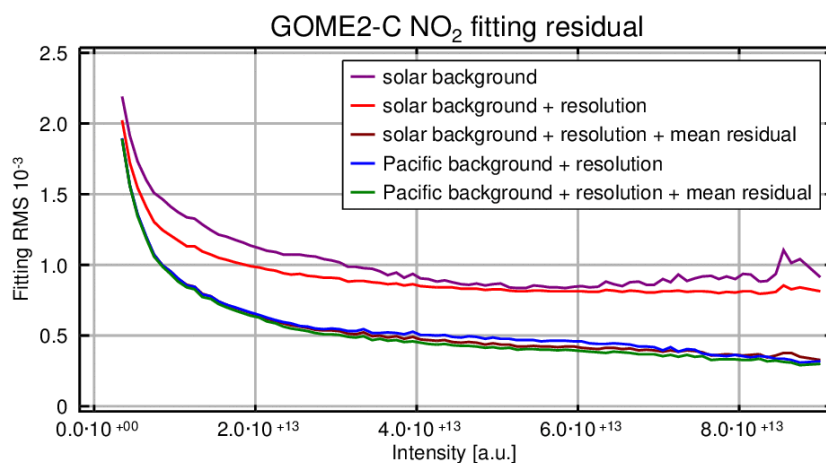


Figure 126: GOME-2C NO₂ fitting residuals over one orbit

The comparison with GOME2-B NO₂ fitting RMS results – reported in Figure 127 - shows a very similar pattern, although with lower intensity in GOME2-B as a result of throughput loss, and there is less difference between the solar irradiance and the Pacific background.

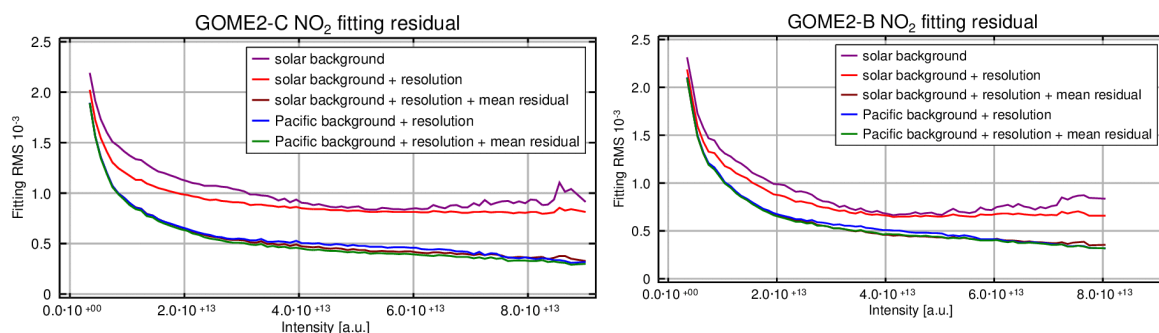
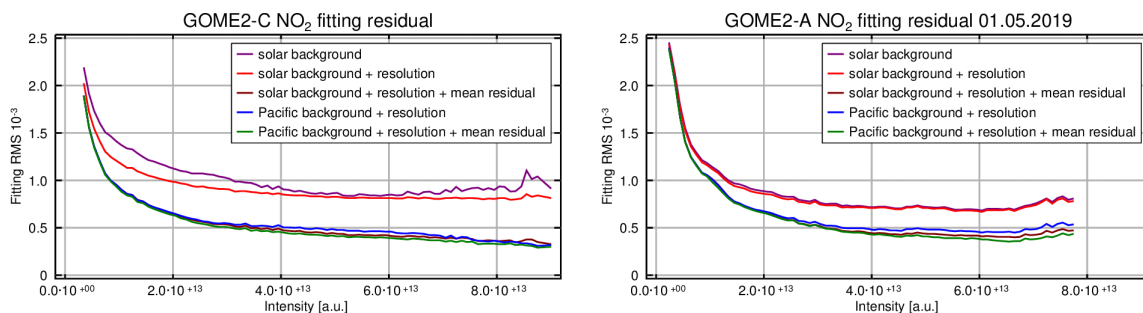


Figure 127: GOME-2C NO₂ fitting residuals over one orbit

Figure 128 shows the comparison with GOME2-A results and this also shows a very similar pattern and again much less difference between solar irradiance and Pacific background, nearly no effect of resolution correction, and again lower signal due to throughput loss. When comparing to GOME-2A at the beginning of life one find lower RMS for the same intensity level. These results imply that GOME2-C irradiance calibration should be improved.



Figure

123

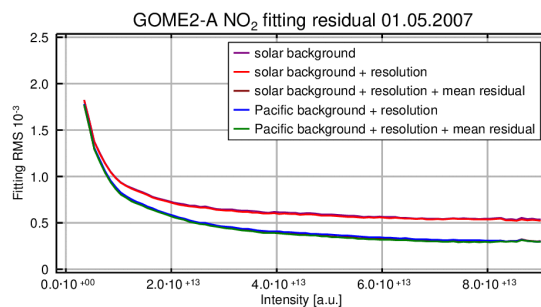


Figure 128: GOME-2C NO₂ fitting residuals over one orbit

In summary, the GOME2-C spectral resolution is changing in channel 3, something unexplained is happening with the spectral alignment of GOME2-C channel 3, NO2 SCs depend on the exact choice of fitting window, NO2 SCs show a systematic dependence on subset, although the last two effects are not restricted to GOME-2C.

GOME2-C NO2 fits show a clear signature of resolution change over the orbit and problems with the irradiance calibration. Small additional issues exist which have not yet been clarified

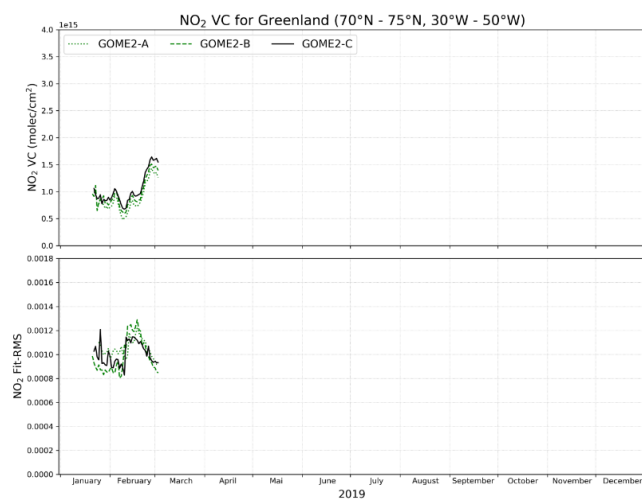
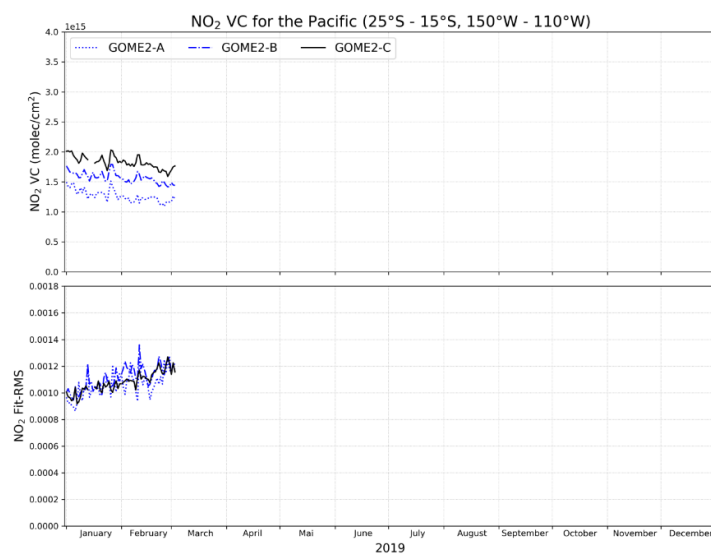
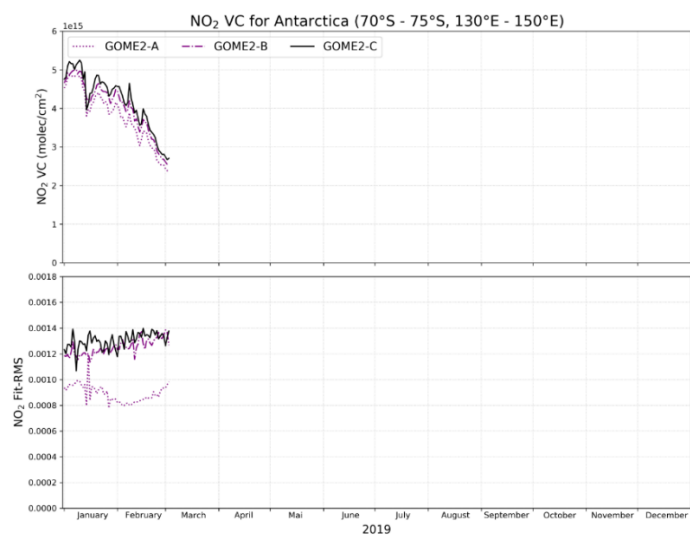


Figure 129: Time patterns of retrieved total vertical columns of NO₂ by IUP Bremen for Metop-C / FM1, Metop-B / FM2 and Metop-A FM3 for selected reference areas in Antarctica, Pacific Ocean and Greenland (January – March 2019).

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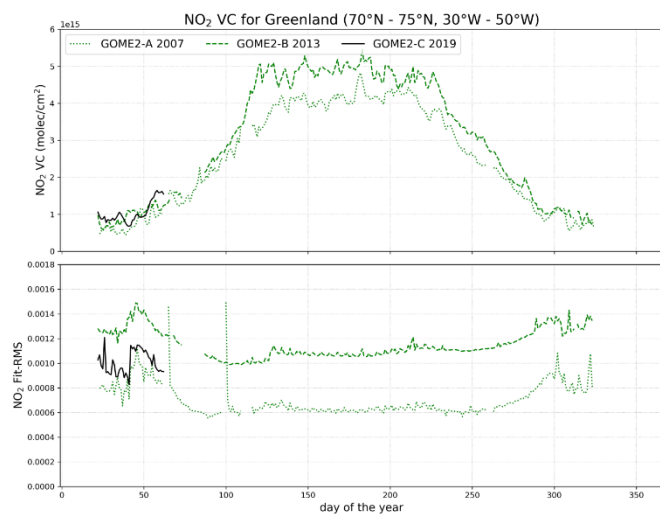
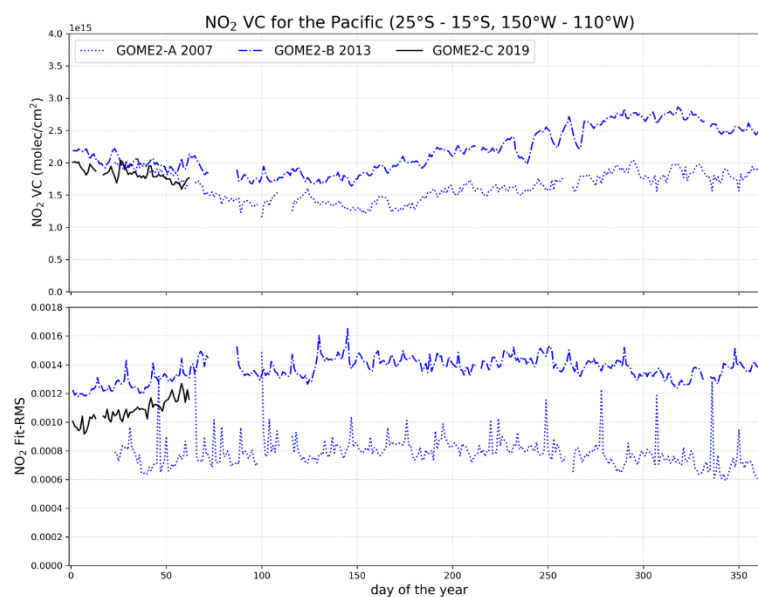
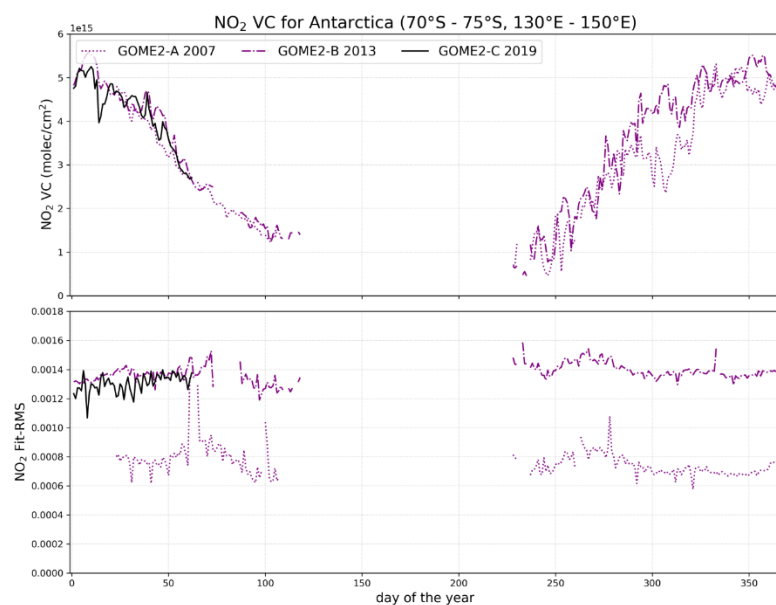


Figure 130: Time patterns of retrieved total vertical columns of NO₂ by IUP Bremen for Metop-C / FM1, Metop-B / FM2 and Metop-A FM3 for selected reference areas in Antarctica, Pacific Ocean and Greenland in the corresponding first year of measurements .

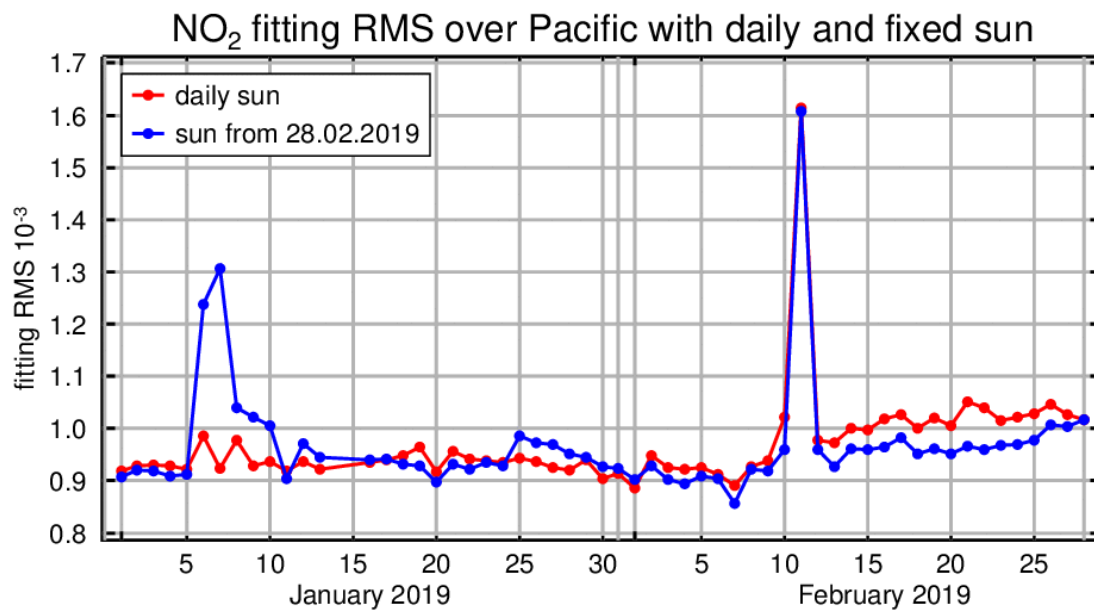


Figure 131: NO₂ fitting RMS over Pacific ocean with daily and fixed sun, for Metop-C / FM1

5.2.2.5.2 AC-SAF – DLR

NO₂ vertical column from GOME-2 C are compared to corresponding GOME2-B as reported in. Figure 132. It appears that there is an offset in the VCD. It is not still clarified whether this is a true offset. It is to be checked. In Figure 133 it is noticeable that the fitting RMS is approx. 2x higher for GOME-2C as compared to GOME-2B and there seem to be some systematic structures. When the fitting window for NO₂ is changed in the DOAS retrieval from 420-450 nm (Figure 132) to 430-450nm the differences in the VCD between GOME2C and GOME2B decreases significantly as it can be seen in Figure 134.

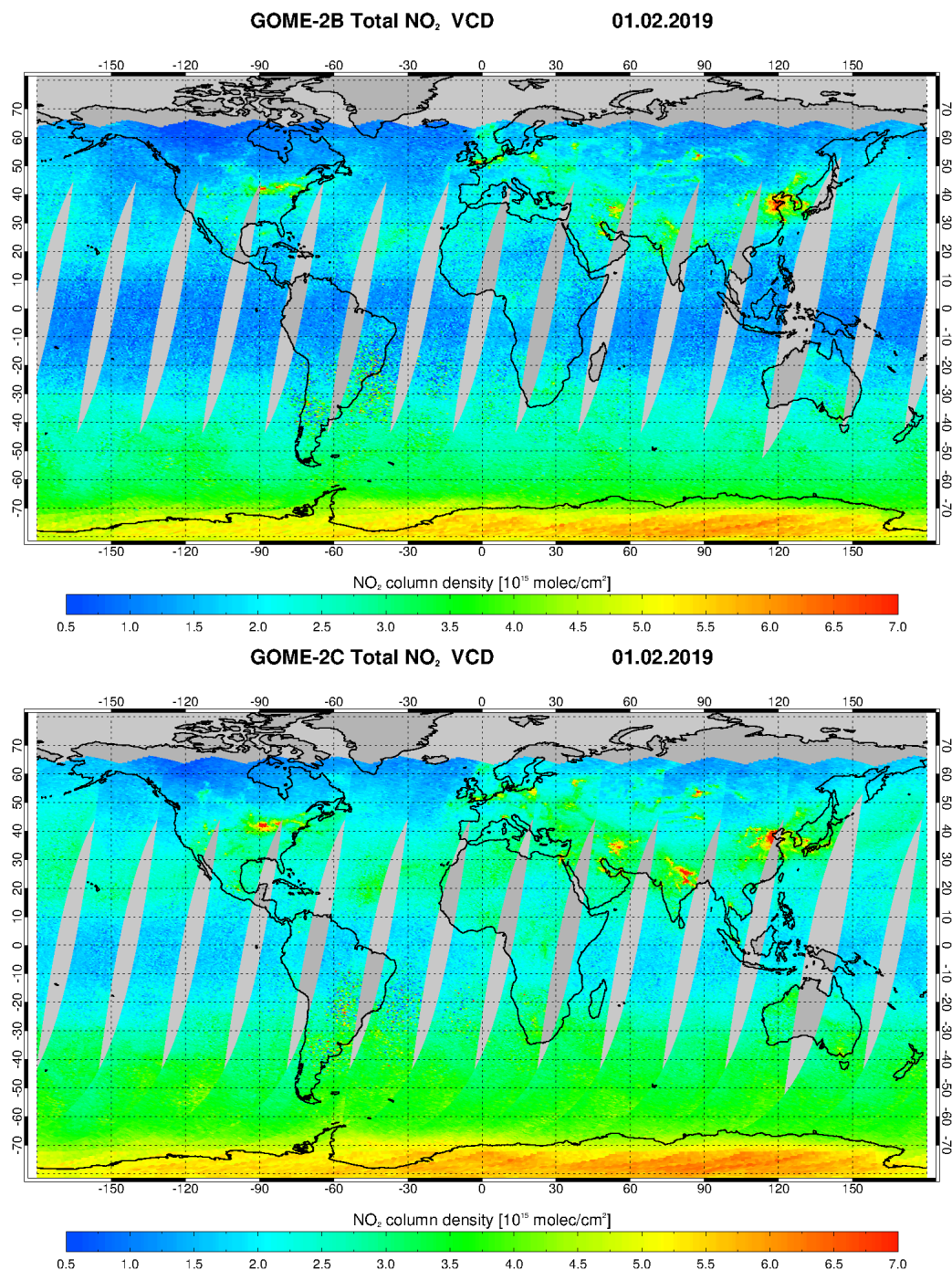


Figure 132: GOME2 NO2 total Column Metop B (upper plot) Metop C (bottom plot) fitting window 425 -450 nm

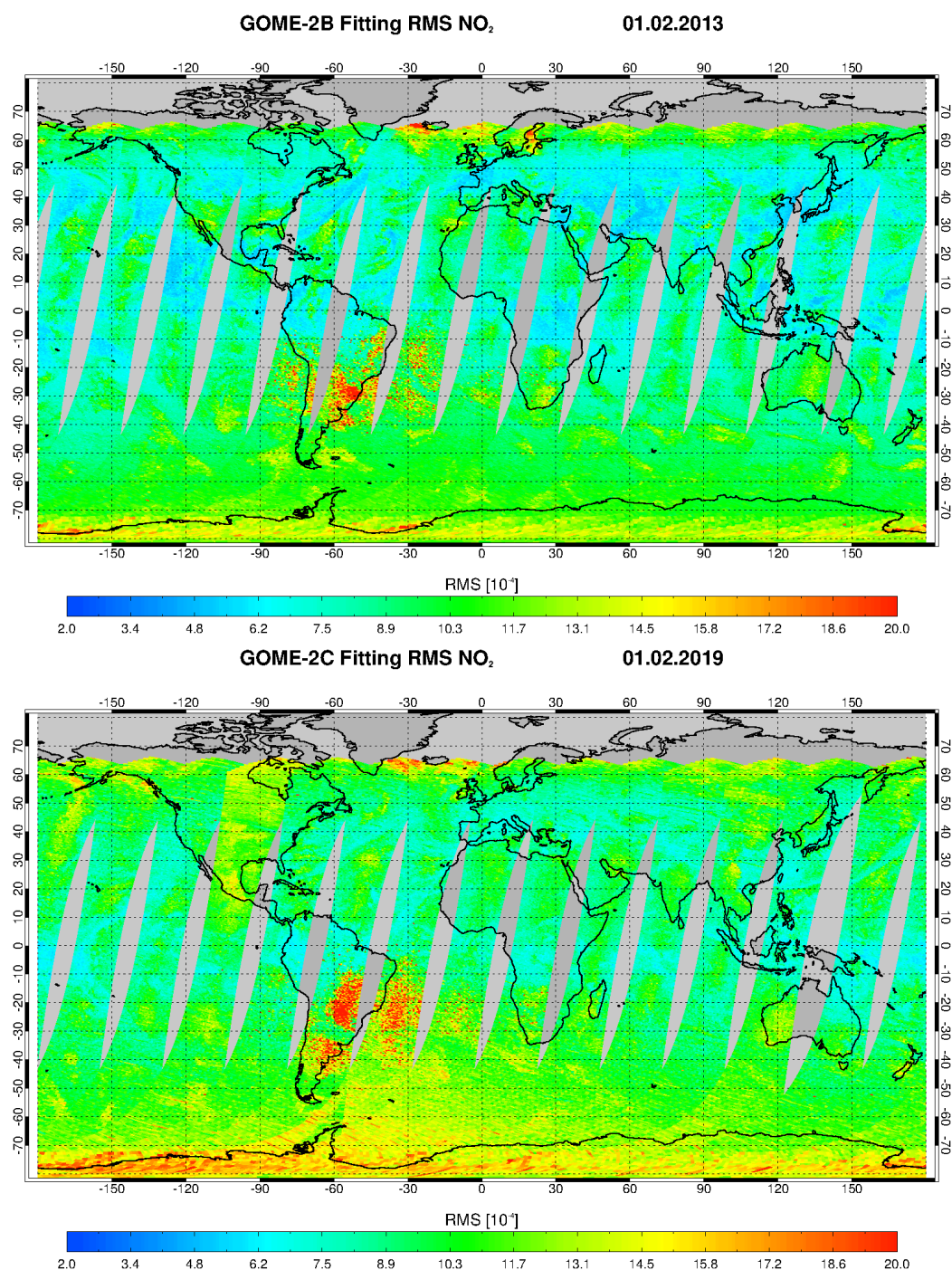


Figure 133: DOAS fitting residula (RMS) Metop B (upper plot) Metop C (bottom plot)

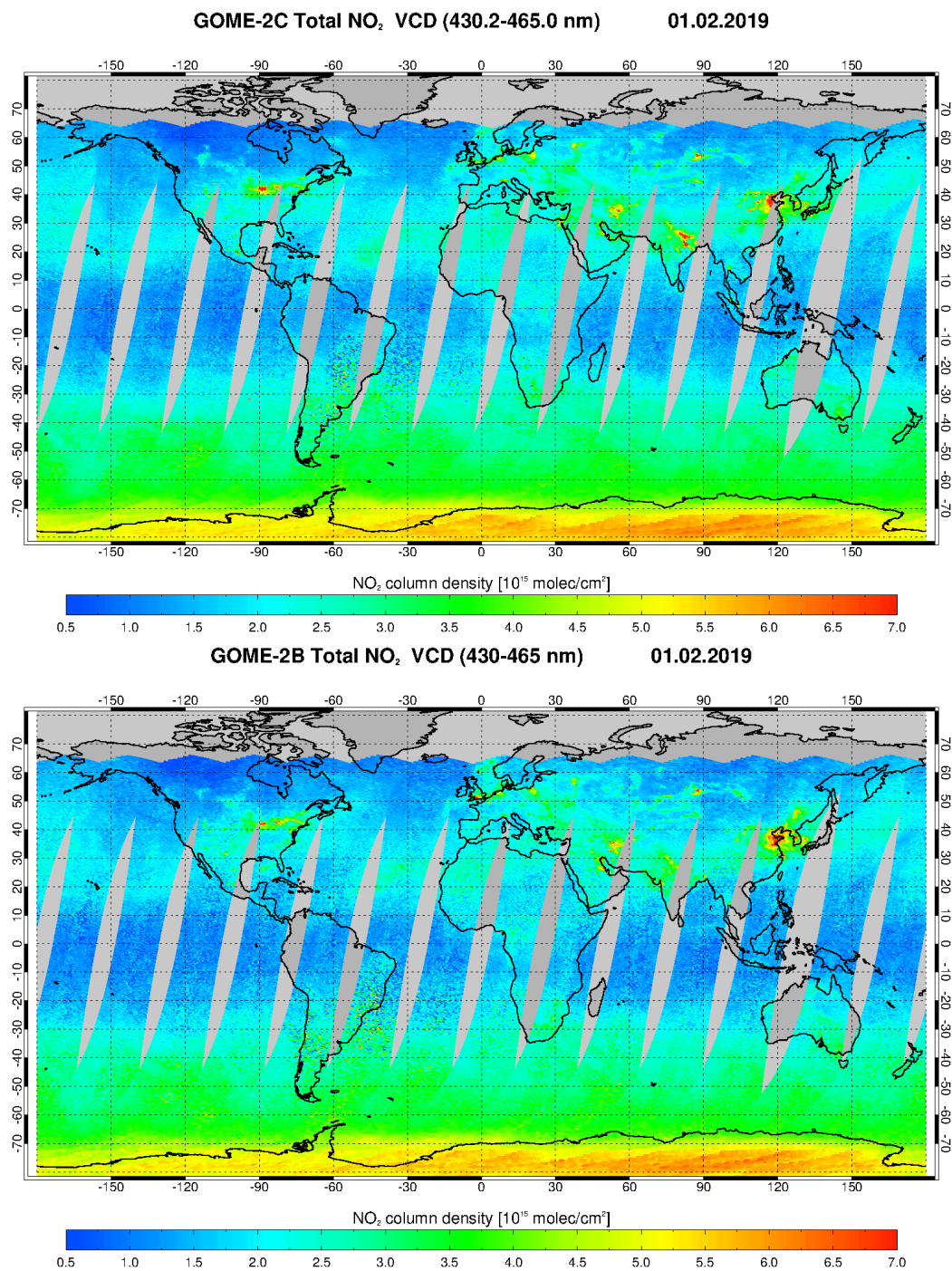


Figure 134: DOAS GOME2 NO2 total Column Metop B (upper plot) Metop C (bottom plot) fitting window 430 - 450 nm

5.2.2.6 H_2O : 688-700 nm; Channel 4

5.2.2.6.1 AC-SAF DLR

In Figure 135 retrieval of the water vapour column from GOME-2-C is reported for 06.02.2019. Same retrieval for GOME2-B and GOME2-A is reported in Figure 136 and Figure 137, respectively. The agreement is good and There are no obvious issues noted suggesting that the performance of GOME-2C channel 4 is good, in contrast to channels 2 and 3 where there might be open issues related to the level 1b data in these channels.

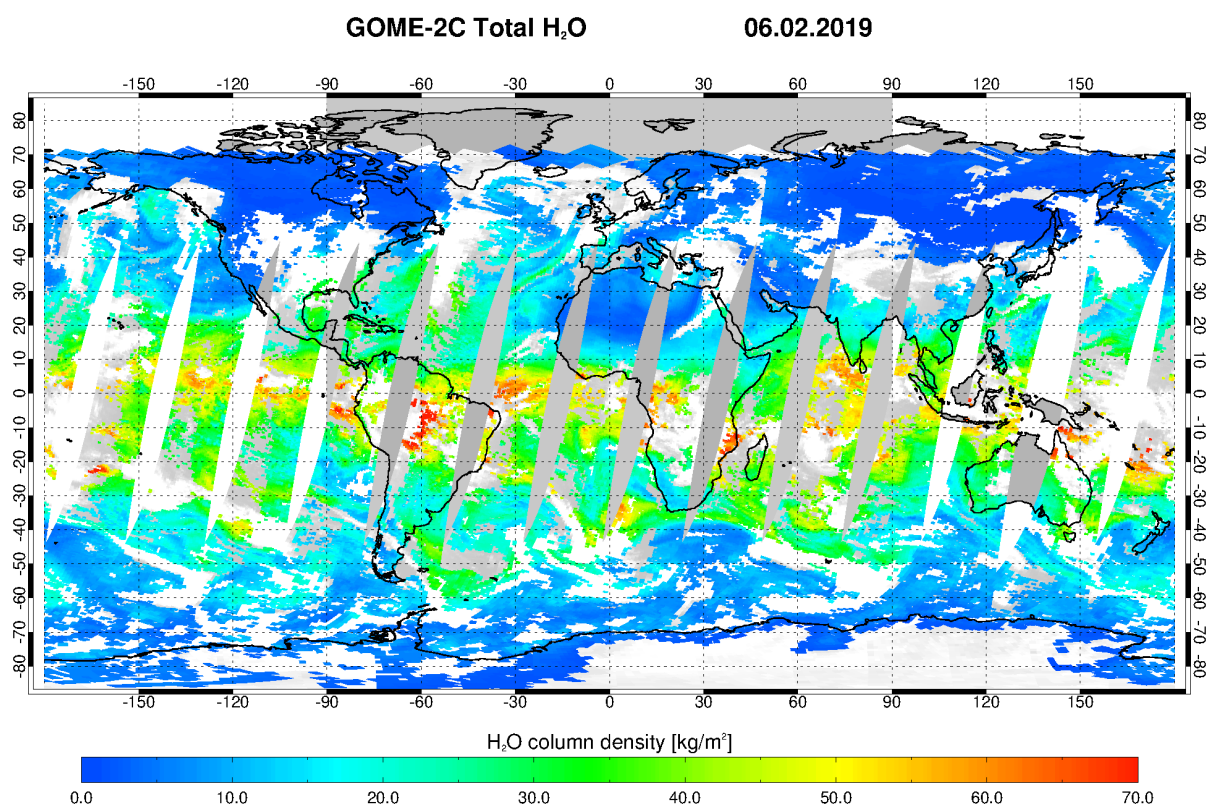


Figure 135: DOAS GOME2- C Water Vapour Total Content on 06.02.2019

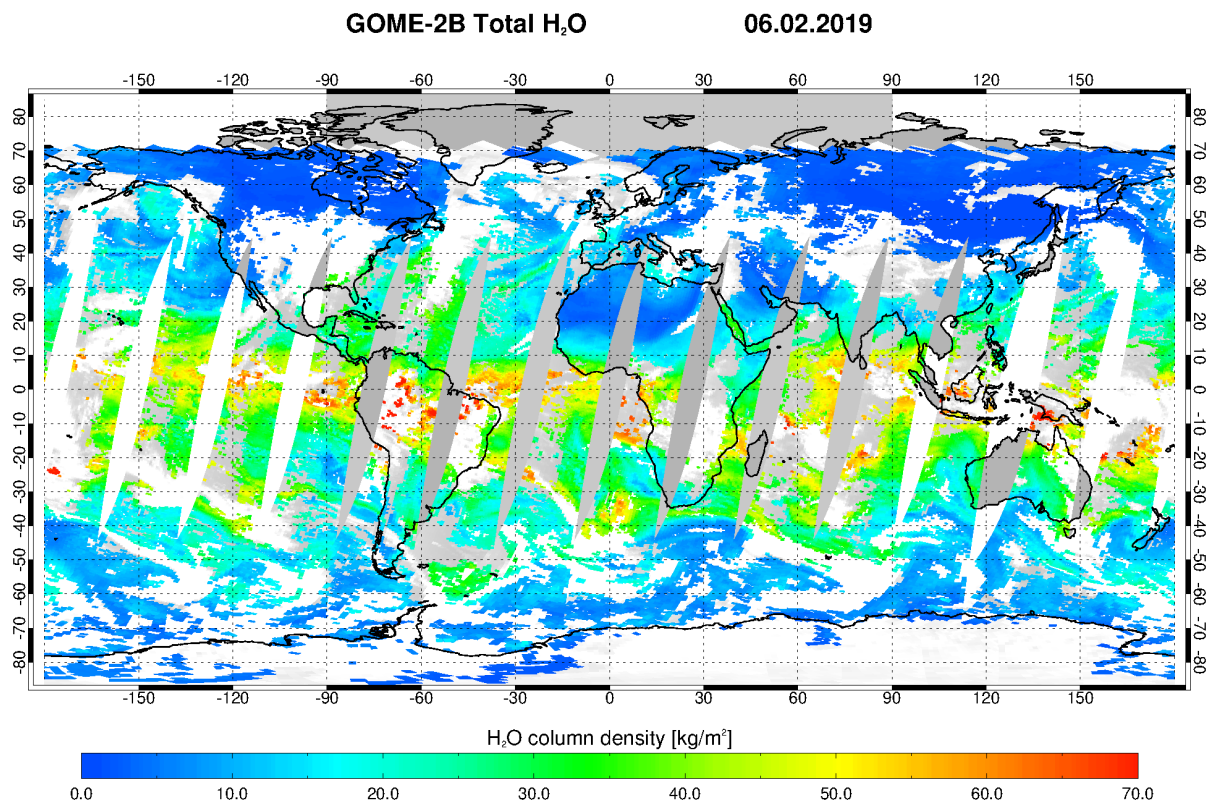


Figure 136: DOAS GOME2- B Water Vapour Total Content on 06.02.2019

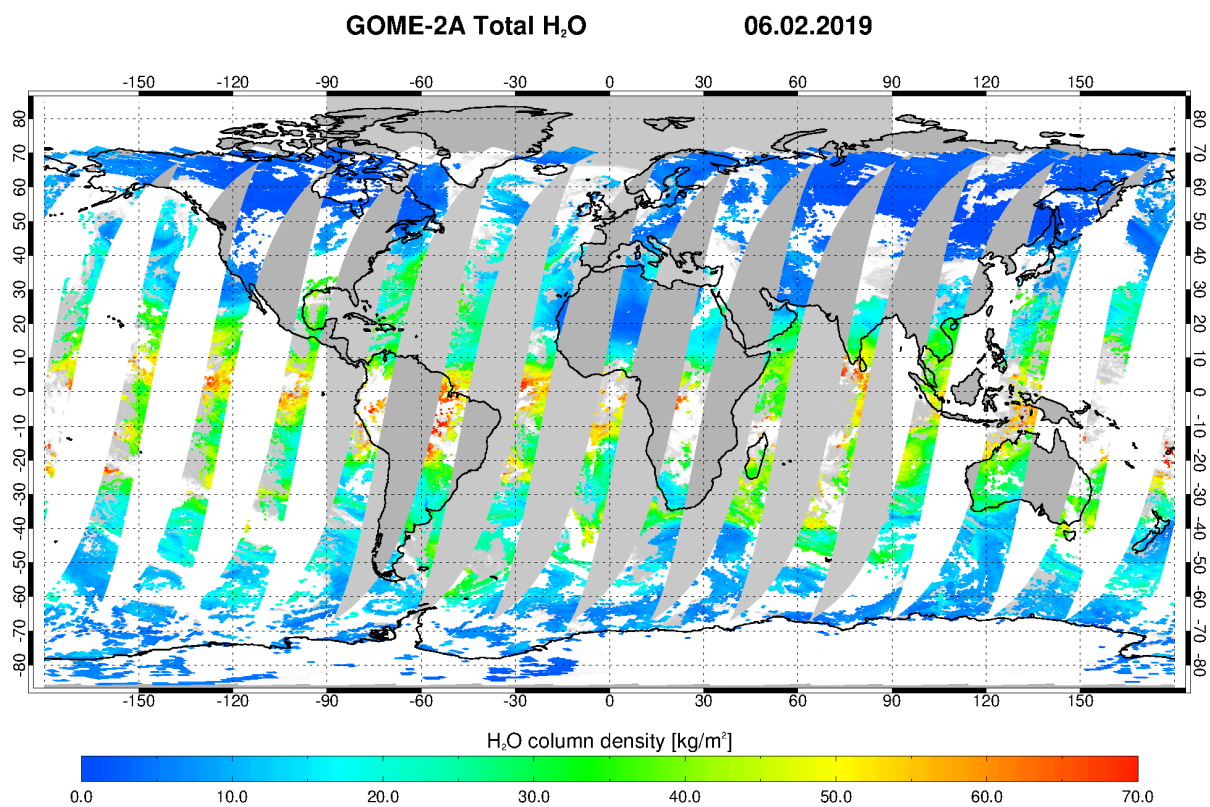


Figure 137: DOAS GOME2- A Water Vapour Total Content on 06.02.2019

5.2.2.6.2 IUP Bremen

IUP Uni-Bremen uses a modified DOAS approach developed for the retrieval of total column water vapour which takes into account saturation effects (non-linear relation between absorber amount and absorption depth).

Fit window for this retrieval algorithm is 688 – 700 nm.

The Fast algorithm is using pre-calculated radiative transfer database and the fit of O₂ absorption to correct for differences between true atmosphere / light path and the assumptions made for the data base (air mass correction factor – AMCF). AMCF is also used as quality filter, it removes scenes which deviate too much from data base assumptions, especially cloudy scenes.

The algorithm applied to GOME-2C has been originally developed for GOME (Noël et al., GRL 1999), later successfully applied to SCIAMACHY and GOME-2(A/B) (see e.g. Noël et al., ACP 2004; 2008); application to S5p under development.

Same data base as for other instruments, but convolved using a Gaussian ISRF with FWHM 0.59 nm as determined from best fit residuals (GOME-2A/B: 0.50/0.55 nm).

Statistics for daily data: 20190101, 2019020.

Does not take into account possible changes / degradation of instruments

Total columns agree quite well, especially Metop-B and –C. The differences for Metop-A sometimes larger and this is mainly due to the smaller swath which implies different spatial coverage). Product errors (determined from fit residuals) are similar, but slightly larger for Metop-C.

The retrieval is running regularly. Overall no major Metop-C problems detected so far - even for early January data.

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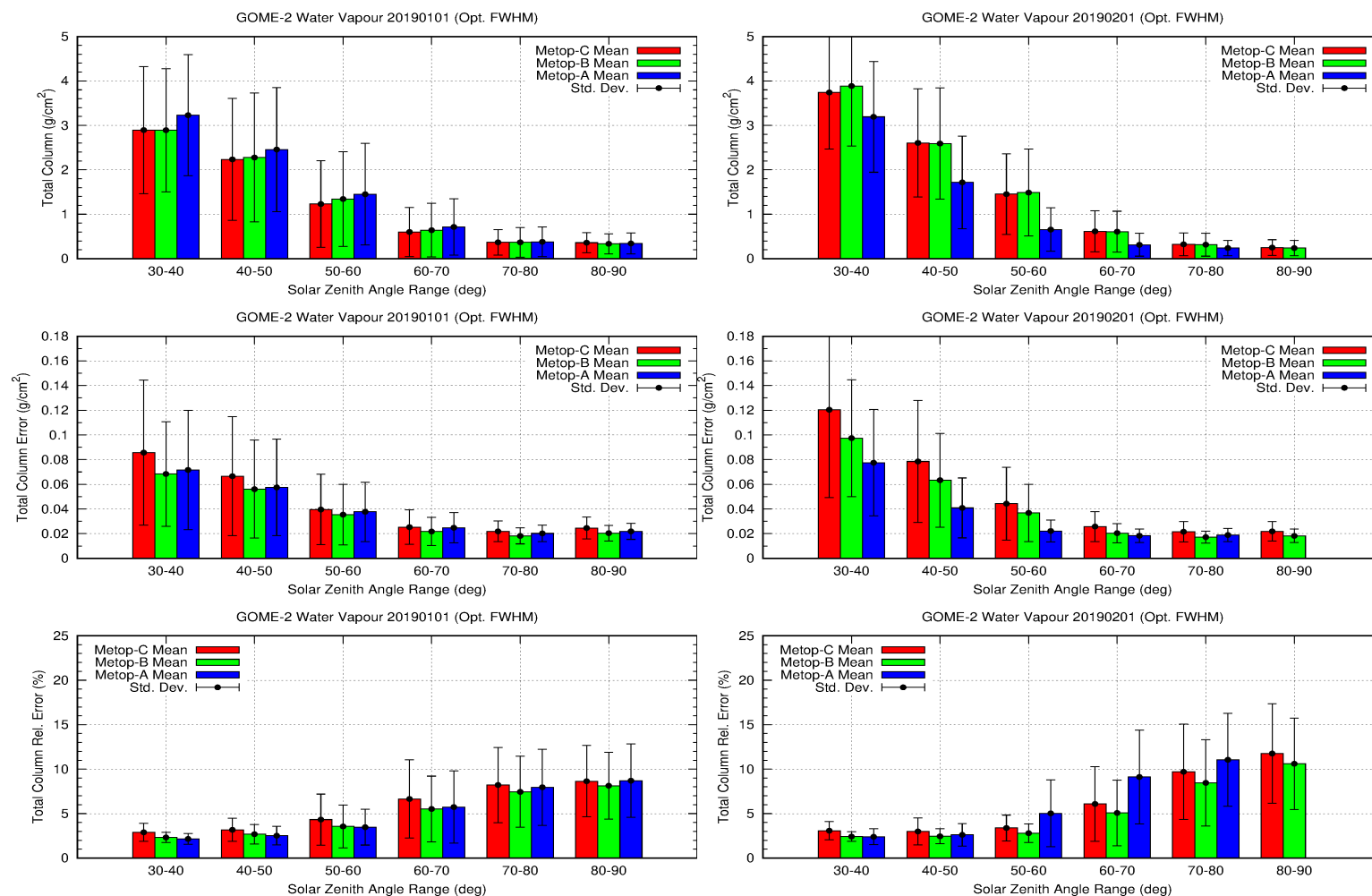


Figure 138: Water vapour total column retrieval for Metop-C / FM1 for 20190101 (right column panels) and 20190201 (left column panels). Total vertical column (upper panels), Total Column Error (central panels), Total Column Relative error (bottom panels).

5.2.2.7 SO₂

5.2.2.7.1 AC-SAF – DLR

The SO₂ column algorithm has been improved (GDP 4.9) with an extended fit windows from the previous 315-326 nm range to 312- 326 nm range, implementation of new SO₂ cross-sections and enhanced SO₂ detection flag.

When comparing GOME-2A, GOME-2B and GOME-2C the comparison is completely dominated by the effects of degradation on signal to noise and cannot learn too much. The extended fit window leads to lower noise levels, especially in SAA region, and an increased RMS due to broader fit window (expected). The improved SO₂ cross-sections leads to a lower SO₂ noise level, a slightly lower SCD for increased SO₂ (volcanic eruptions) and lower RMS.

An example of SO₂ detection for a volcanic eruption is shown in Figure 139 for the eruption of the Popocatepeti volcano on 17 February 2019 showing also the potential of the composite of the constellation of the three sensors . GOME2-C is characterized by lower noise values and the SO₂ signal turns out to be clearly visible. In Figure 140 the SO₂ SCD, the corrected SCD and the RMS for the GOME2 /A/B/C is reported as a function of latitude

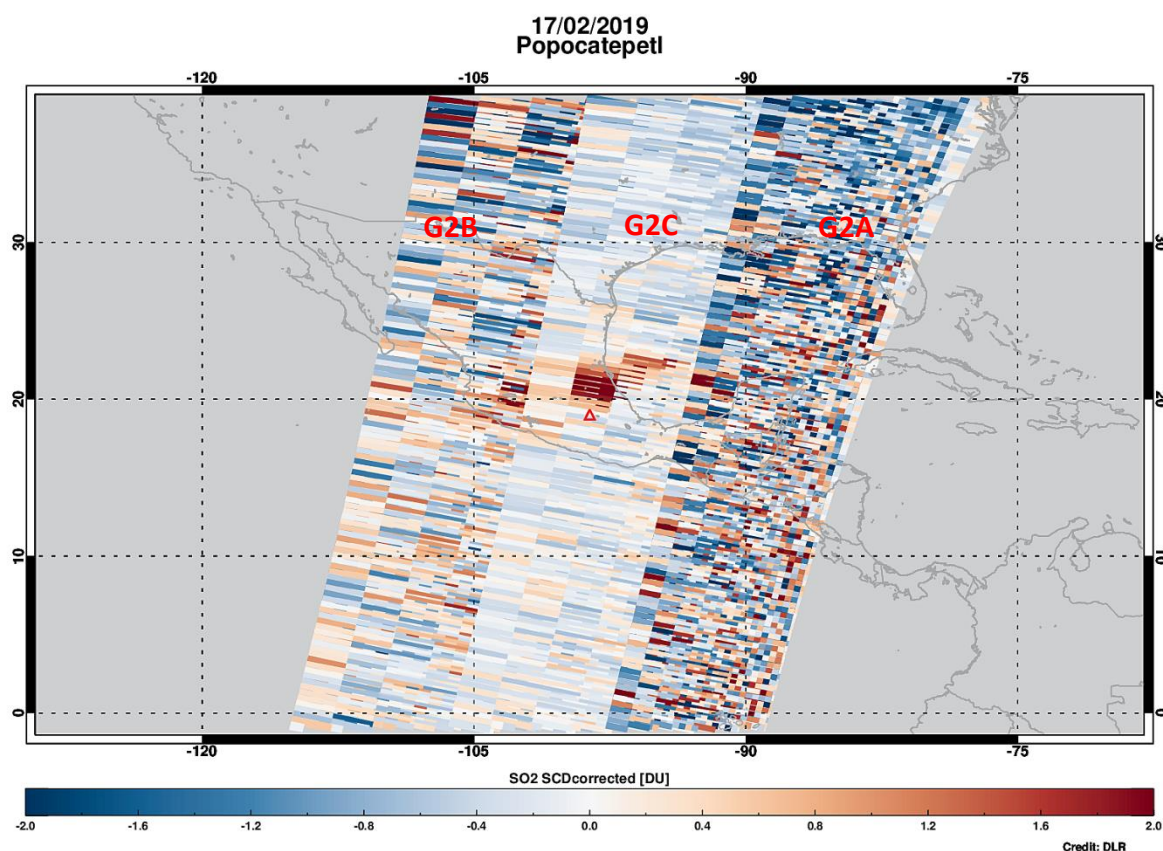


Figure 139: GOME2 A/B/C SO₂ SCD for the Popocatepeti volcanic eruption on 17-02-2019

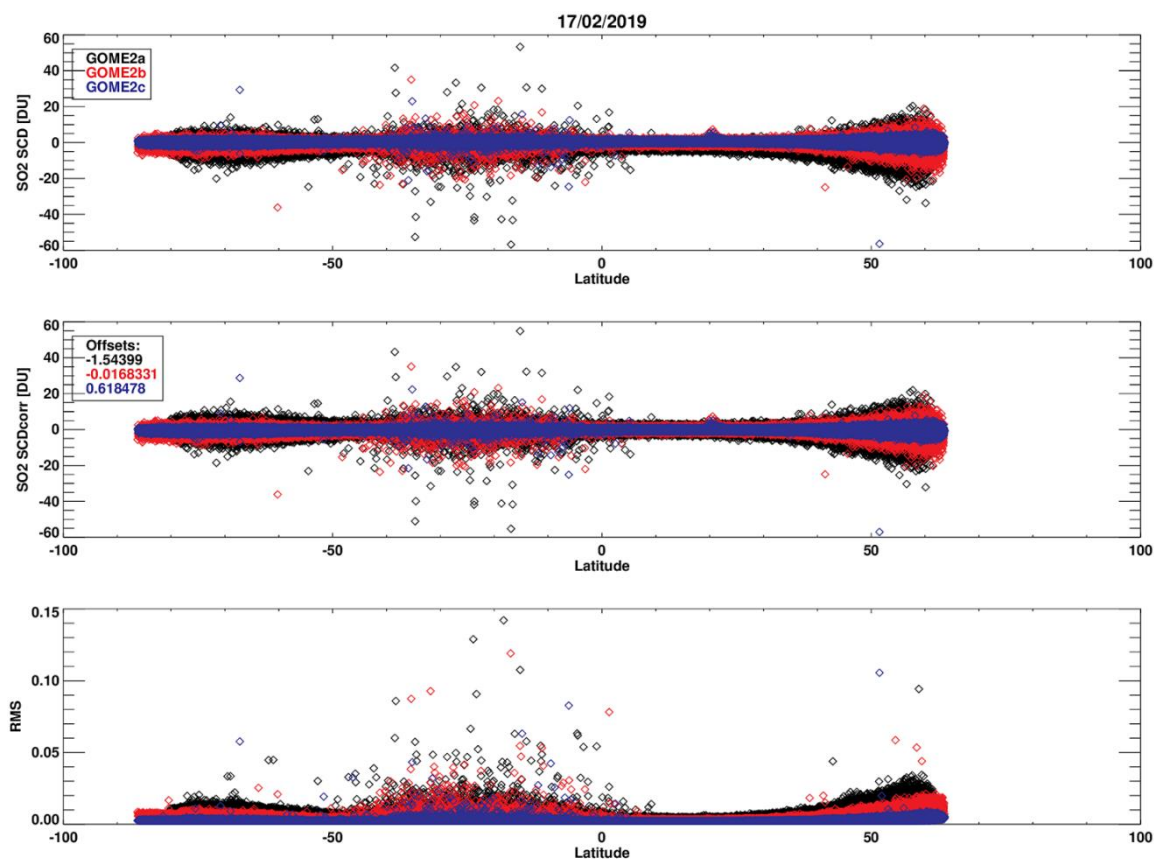


Figure 140: GOME2 A/B/C SO₂ SCD as a function of latitude on top panel, SCD corrected in the middle panel and RMS in the bottom panel on 17-02-2019

5.2.2.8 Absorbing Aerosol Index AC-SAF: KNMI

GOME-2C Absorbing Aerosol Index, analysis of the PMD based AAI using daily global means shows a jump on 28 January 2019. This is not unexpected and is related to the key data change. Also visible are strong peaks in the nadir direction when VZA=0. When analysing GOME-2C PMD raw values along the orbit there is a visible ‘seam’ around nadir most evident in the southern part of the orbit.

When analysing GOME-2C PMD reflectance, the peaks in nadir direction can be seen in reflectance/radiance, both at 380 and 340nm as reported in Figure 142. They are also visible in the back scan and the point at which they increase significantly does not exactly coincide with the key data change. Note that very small peaks can also be seen in GOME-2A and GOME-2B data but they remain very small and do not develop as has been observed for GOME-2C. Note that it has been clarified after the GSAG that the peaks can be seen in both PMD-P and PMD-S data.

With the exception of these peaks the AAI data – corrected for the orbit anomaly - appear nominal (see Figure 143).

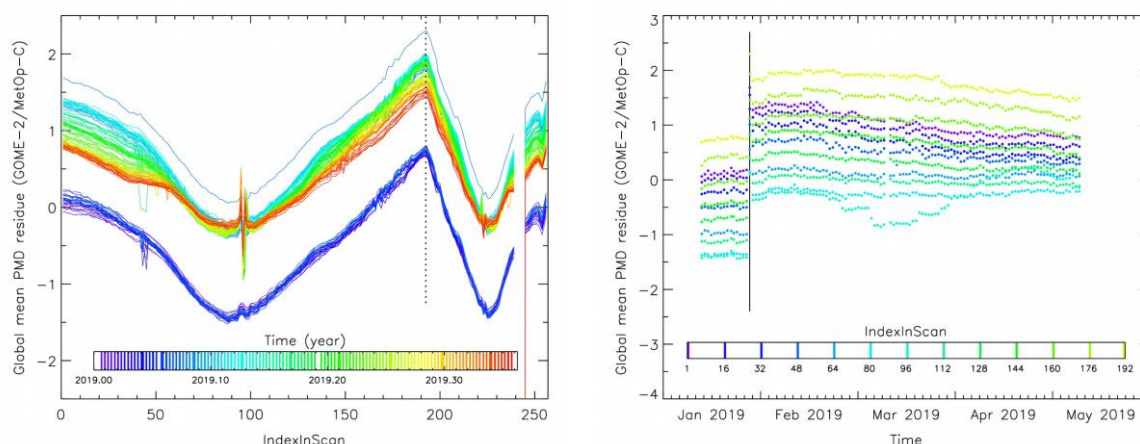


Figure 141: GOME2 C Global PMD residuals as function of the scan index from beginning of 2-19, the discontinuity at 28 January is clearly visible.

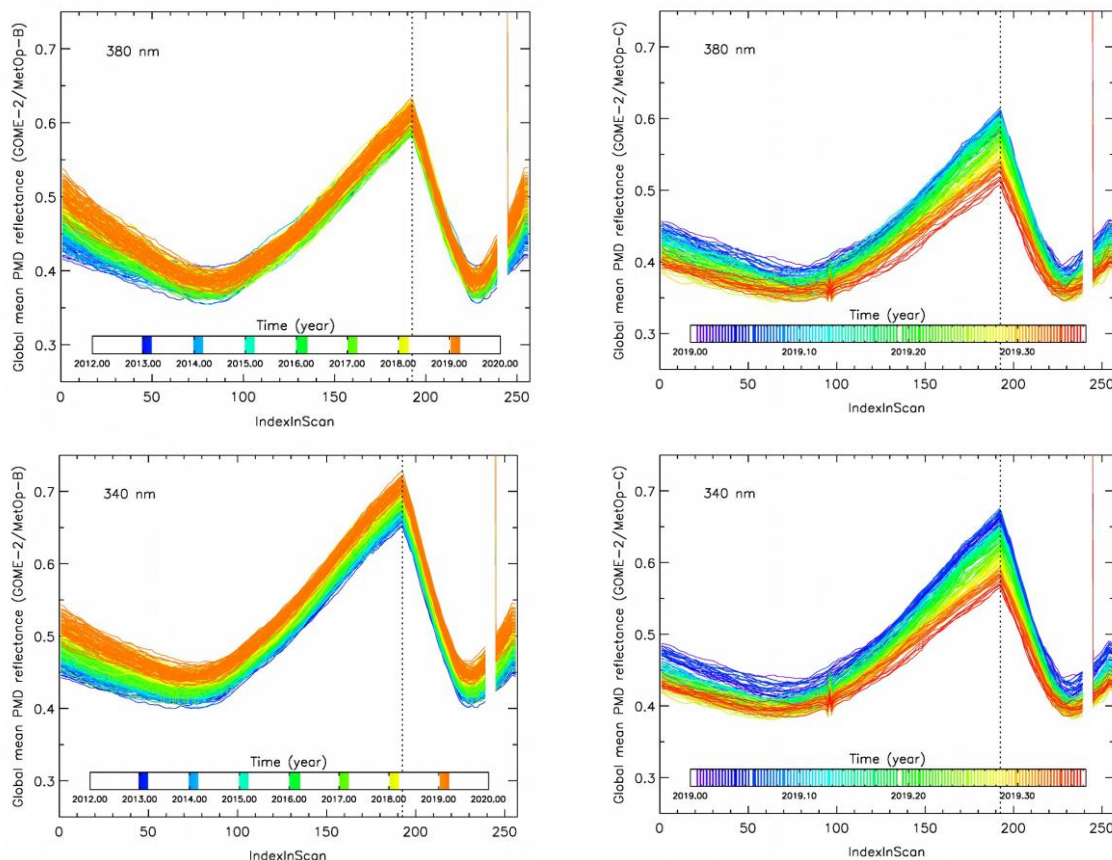


Figure 142: Global mean PMD reflectances as function of the scan index at 380 nm (upper row) and 340 nm (bottom row) for GOME2B and (left column) and GOME2C (right column).

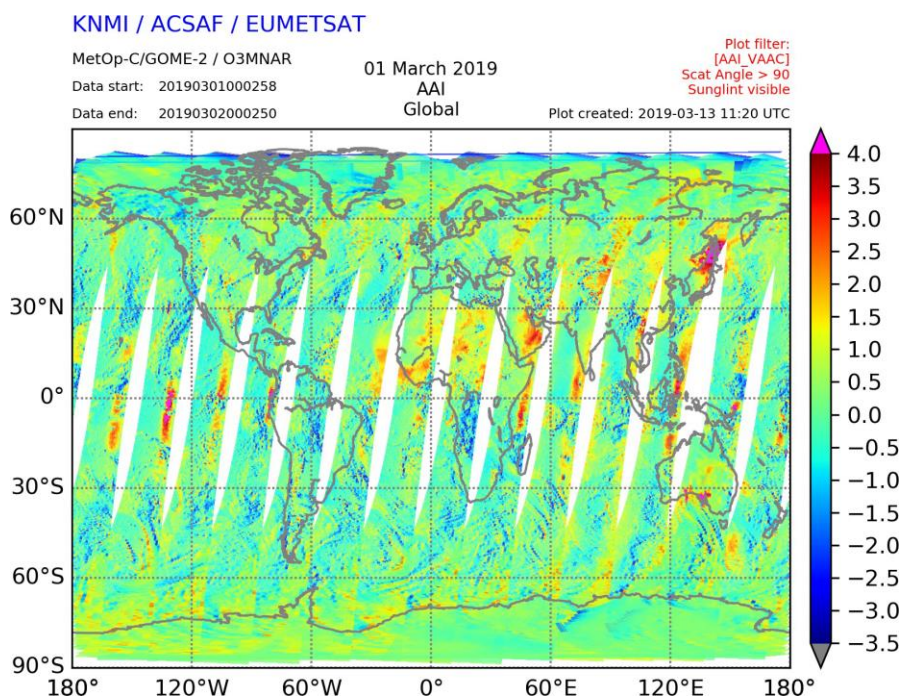


Figure 143: GOME2-C global AAI maps for 01 – 03 – 2019

5.2.2.9 Aerosol: GOME-2 PMD, IASI and AVHRR multi mission product

Detailed description on the PMAp Multisensor Aerosol Product performance for Metop-C is given in the validation report prepared for the PMAp v2.1 PVRB (on 25.06.2019) for evaluating the pre-operational dissemination of the product.

5.2.3 Status by End of Commissioning and Conclusion

By the 53rd GSAG, the users had already expressed their satisfaction with the observed data quality [RD26].

Table 11 summarises the status from a level-2 perspective.

<i>Channel</i>	<i>Status</i>	<i>Issue/Action</i>	<i>Comments</i>
Channel 1	OK		OK with respect to the requirements for operational status. Issues as addressed in the text will need to be done as part of normal work cycle.
Channel 2	Some issues with level-2 offsets and persistent residuals identified	Evaluation of	NOT Blocking
Channel 3	Some issues with spectral resolution	Monitoring the quality of the spectral calibration and evaluation of possible improvements	NOT Blocking
Channel 4	OK		OK with respect to the requirements for operational status. Issues as addressed in the text will need to be done as part of normal work cycle.

Table 11: Summary of level-2 product status at the 49th GSAG 25 April 2013 using pre-operational level 1 data.

6 CONCLUSIONS

6.1 Product Validation Summary

We consider the current level 1B GOME-2 / FM1 product of sufficient quality for calibrated radiances, spectral calibration as well as geo-referencing parameters. . Currently, the product is of similar quality with respect to operational level 1B product released in May 2013 Metop B/FM2 and in July 2007 for Metop-A / FM3. It should be released with operational status to all users.

6.2 Product Validation Issues

Tasks to be undertaken:

<i>Task</i>	<i>To be Done during</i>
Monitoring offset and instrument degradation levels	routine operations
Monitoring the quality of the PMD calibration and – in particular - the first PMD channel	routine operations
Monitoring the quality of the spectral and radiometric calibration in channel 2	Normal work assignment for FM1
Monitoring the quality of the spectral calibration and improve if possible the spectral assignment in channel 3	Normal work assignment for FM1
Evaluate the impact of the cleaned key-data on the Lev2 retrieval	Scientific Support for Analysis of GOME-2 FM1 MetopC In-Orbit Performance – Ongoing Study conducted by IUP, University of Bremen
Detailed evaluation of the observed level-2 fit residuals and product offsets in relation to possible remaining key-data deficiency need to be carried out during the evaluation of the SAF products for operational status	SAF review cycle
Coordinate, implement, and oversee the recommendation for tandem operations (see recommendation by the 53rd GSAG),	normal work based on GSAG recommendations

6.3 Actions for Product Rollout

Dissemination to all users with “operational” status can start without further updates.

6.3.1 Time Schedule

We propose the notification to users on the operational status update by the 25 June 2019.

6.3.2 User Notification

Users have already been notified on the overall planned timeframe for change of status at the last AC SAF Project Tem Meeting in March 2019 and GSAG meeting on May 2019 and via the dedicated e-mails.

A further dedicated e-mail to inform the users on the start of dissemination will be sent just after the PVRB, pending a positive decision by the PVRB board.

6.3.3 Web Update

The product navigator will be updated as needed. This validation report will be published in the technical documents section on the EUMETSAT web-pages.

7 RECOMMENDATION

Based on the analysis and verification contained in this product validation report, we recommend updating the status to operational.