Validation Report:
NRT Level 2A Refractivity Profiles:
Metop-C (GRM-60)

Version 1.1

8 February 2019

ROM SAF Consortium
Danish Meteorological Institute (DMI)
European Centre for Medium-Range Weather Forecasts (ECMWF)
Institut d'Estudis Espacials de Catalunya (IEEC)
Met Office (UKMO)

Ref: SAF/ROM/DMI/RQ/REP/003

DOCUMENT AUTHOR TABLE

	Author(s)	*Function*	*Date*
Prepared by:	Stig Syndergaard	ROM SAF Project Team	08/02/2019
Reviewed by (Internal):	Johannes K. Nielsen	ROM SAF Project Team	30/11/2018
Approved by:	Kent B. Lauritsen	ROM SAF Project Manager	08/02/2019

DOCUMENT CHANGE RECORD

Version	*Date*	*By*	*Description*
1.0	30 Nov 2018	SSY	First version of validation report for Metop-C, prepared for EUMETSAT PVRB on 7. December 2018.
1.1	8 Feb 2019	SSY	Updated version prepared for EUMETSAT PVRB on 11. February 2019 - Much longer time period; - Changes to figures and table 2.1; - Modified discussions accordingly;

ROM SAF

The Radio Occultation Meteorology Satellite Application Facility (ROM SAF) is a decentralised processing center under EUMETSAT which is responsible for operational processing of GRAS radio occultation (RO) data from the Metop satellites and radio occultation data from other missions. The ROM SAF delivers bending angle, refractivity, temperature, pressure, humidity, and other geophysical variables in near real-time for NWP users, as well as reprocessed Climate Data Records (CDRs) and Interim Climate Data Records (ICDRs) for users requiring a higher degree of homogeneity of the RO data sets. The CDRs and ICDRs are further processed into globally gridded monthly-mean data for use in climate monitoring and climate science applications.

The ROM SAF also maintains the Radio Occultation Processing Package (ROPP) which contains software modules that aid users wishing to process, quality-control and assimilate radio occultation data from any radio occultation mission into NWP and other models.

The ROM SAF Leading Entity is the Danish Meteorological Institute (DMI), with Cooperating Entities: i) European Centre for Medium-Range Weather Forecasts (ECMWF) in Reading, United Kingdom, ii) Institut D'Estudis Espacials de Catalunya (IEEC) in Barcelona, Spain, and iii) Met Office in Exeter, United Kingdom. To get access to our products or to read more about the ROM SAF please go to: `http://www.romsaf.org`.

List of Contents

1 Introduction

1.1 Purpose of document

This document describes the validation results for the ROM SAF NRT level 2A product, GRM-60: NRT refractivity profile from the GRAS instrument on Metop-C (NRPMEC).

The report is submitted for a “Check-Point Review” in order to decide on the validation status of the GRM-60 product after the successful launch of the Metop-C satellite on November 7, 2018.

The document also serves to report on the general quality of the NRT refractivity products from Metop-A (GRM-01) and Metop-B (GRM-40) after new instrument parameter settings were uploaded to these two satellites on August 1, 2018. The GRAS instruments on all three satellites are currently in identical configurations. The quality of the refractivity products from Metop-A and Metop-B before the instrument firmware upgrade on August 1, 2018, including specific issues related to the wave optics (WO) processing at the EUMETSAT Secretariat, was reported in [RD.4]. Results in the present report indicate that the issues related to the WO processing also applies to GRM-60, but they are not analysed or discussed further here.

The product version number of the GRM-60 product validated in this report is 1.6 to match the already existing version numbers for GRM-01 and GRM-40, and indicating that all three products are processed with the same software.

The high-resolution level 1B data are based on EUMETSATs PPF, version 4.6.0. The refractivity is retrieved at DMI using GPAC system version 0.4.2, with ‘Invert’ software version 3.5.044 and ROPP software version 8.1. Quality Control (QC) of the GRAS data analysed in this report is done with version QC-1.3.

1.2 Applicable and Reference documents

1.2.1 Applicable documents

The following list contains documents with a direct bearing on the contents of this document.

[AD.1] CDOP-3 Proposal: Proposal for the Third Continuous Development and Operations Phase (CDOP-3); Ref: SAF/ROM/DMI/MGT/CDOP3/001 Version 1.2 of 31 March 2016, Ref: EUM/C/85/16/DOC/15, approved by the EUMETSAT Council at its 85th meeting on 28-29 June 2016.

[AD.2] CDOP-3 Cooperation Agreement: Agreement between EUMETSAT and DMI on the Third Continuous Development and Operations Phase (CDOP-3) of the Radio Occultation Meteorology Satellite Applications Facility (ROM SAF), Ref. EUM/C/85/16/DOC/19, approved by the EUMETSAT Council and signed at its 86th meeting on 7 December 2016.

[AD.3] ROM SAF Product Requirements Document, Ref. SAF/ROM/DMI/MGT/PRD/001.

[AD.4] ROM SAF Service Specifications, Ref. SAF/ROM/DMI/RQ/SESP/001.

1.2.2 Reference documents

The following documents provide supplementary or background information, and could be helpful in conjunction with this document:

[RD.1] ROM SAF, The Radio Occultation Processing Package (ROPP) User Guide. Part I: Input/Output module, SAF/GRAS/METO/UG/ROPP/002, -.

[RD.2] ROM SAF, The Radio Occultation Processing Package (ROPP) Overview, SAF/ROM/METO/UG/ROPP/001, -.

[RD.3] ROM SAF, WMO FM94 (BUFR) specification for radio occultation data, SAF/ROM/METO/FMT/BUFR/001, Version 2.4.

[RD.4] ROM SAF, Validation Report: Near Real-Time Level 2A Refractivity Profiles: Metop-A (GRM-01, NRPMEA) and Metop B (GRM-40, NRPMEB), SAF/ROM/DMI/RQ/REP/001, Version 1.6, 2016.

[RD.5] ROM SAF, Algorithm Theoretical Baseline Document: Level 2A Refractivity profiles., Ref. SAF/ROM/DMI/ALG/REF/001, Version 1.6, 2018.

1.3 Acronyms and abbreviations

BAROCLIM	Bending Angle Radio Occultation Climatology
BUFR	Binary Universal Format for data Representation
DMI	Danish Meteorological Institute
ECMWF	European Centre for Medium-Range Weather Forecasts
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GNSS	Global Navigation Satellite Systems
GPAC	GNSS Processing and Archiving Center
GRAS	GNSS Receiver for Atmospheric Sounding
Metop	Meteorological operational polar
MSL	Mean Sea Level
NCO	Numerically Controlled Oscillator
NRT	Near Real-Time
NWP	Numerical Weather Prediction
PPF	Product Processing Facility
PRD	Products Requirements Document
QC	Quality Control
RO	Radio Occultation
ROM SAF	Radio Occultation Meteorology SAF
ROPP	Radio Occultation Processing Package
SAF	Satellite Application Facility
SNR	Signal-to-noise Ratio
WMO	World Meteorological Organization
WO	Wave Optics

1.4 Definitions

RO data products from the GRAS instrument onboard Metop and RO data from other missions are grouped in *data levels* (Level 0, 1, 2, or 3) and *product types* (NRT, offline, CDR, or ICDR). The data levels and product types are defined below[1]. The lists of variables should not be considered as the complete contents of a given data level, and not all data may be contained in a given data level.

Data levels:

Level 0: Raw sounding, tracking and ancillary data, and other GNSS data before clock correction and reconstruction;

Level 1A: Reconstructed full resolution excess phases, total phases, pseudo ranges, SNRs, orbit information, I, Q values, NCO (carrier) phases, navigation bits, and quality information;

Level 1B: Bending angles and impact parameters, tangent point location, and quality information;

Level 2: Refractivity, geopotential height, "dry" temperature profiles (Level 2A), pressure, temperature, specific humidity profiles (Level 2B), surface pressure, tropopause height, planetary boundary layer height (Level 2C), ECMWF model level coefficients (Level 2D), quality information;

Level 3: Gridded or resampled data, that are processed from Level 1 or 2 data, and that are provided as, e.g., daily, monthly, or seasonal means on a spatiotemporal grid, including metadata, uncertainties and quality information.

Product types:

NRT product: Data product delivered less than: (i) 3 hours after measurement (SAF Level 2 for EPS); (ii) 80 min after measurement (SAF Level 2 for EPS-SG Global Mission); (iii) 40 min after measurement (SAF Level 2 for EPS-SG Regional Mission);

Offline product: Data product delivered from less than 5 days to up to 6 months after measurement, depending on the requirements. The evolution of this type of product is driven by new scientific developments and subsequent product upgrades;

CDR: Climate Data Record generated from a dedicated reprocessing activity using a fixed set of processing software[2]. The data record covers an extended time period of several years (with a fixed end point) and constitutes a homogeneous data record appropriate for climate usage;

ICDR: An Interim Climate Data Record (ICDR) regularly extends in time a (Fundamental or Thematic) CDR using a system having optimum consistency with and lower latency than the system used to generate the CDR[3].

[1] Note that the level definitions differ partly from the WMO definitions: `http://www.wmo.int/pages/prog/sat/dataandproducts_en.php`

[2] (i) GCOS 2016 Implementation Plan; (ii) `http://climatemonitoring.info/home/terminology`

[3] `http://climatemonitoring.info/home/terminology` (the ICDR definition was endorsed at the 9th session of the joint CEOS/CGMS Working Group Climate Meeting on 29 March 2018).

1.5 Overview of this document

Chapter 2 gives the background for the validation, and Chapter 3 contains the validation results. Open issues are listed in Chapter 4, and conclusions are made in Chapter 5.

2 Background

2.1 EUMETSAT bending angle data

The validation in this report is based on high-resolution level 1B bending angle data from the NRT environment at the EUMETSAT Secretariat, PPF 4.6.0. The Metop-C data have been made available to the Metop-C cal/val partners (including DMI) via EUMETCast since November 13, 2018.

2.2 ROM SAF processing

The data presented in this report were processed at the ROM SAF at DMI using GPAC version 0.4.2. Details on the operational processing at DMI can be found in [RD.5]. The GPAC system returns the refractivity in both high-resolution (with a vertical spacing of about 100 m) and in low-resolution (247 pre-defined levels between the surface and 60 km) [RD.2]. The high-resolution refractivity profile is written to a netCDF file together with the EUMETSAT high-resolution bending angle profile and other key parameters. The low-resolution refractivity profile is disseminated in NRT in BUFR format together with the EUMETSAT low-resolution bending angle profile. The bending angle profile in the BUFR dissemination from DMI is identical to that disseminated by the EUMETSAT Secretariat, although very small differences may exist because of round-off errors. The refractivity profile in the BUFR dissemination from DMI is a thinned version of the high-resolution refractivity profile without any smoothing. The high-resolution refractivity profile is based on the EUMETSAT L1 and L2 (extrapolated) high-resolution bending angle profiles.

The validation of GRM-60 in this report is based on 77 days of data from November 16, 2018 to January 31, 2019. A total of 47743 bending angle profiles from Metop-C were input to the GPAC system, of which 93.3% were flagged as nominal from the EUMETSAT Secretariat's side. Of the nominal bending angle profiles, 6.2% failed the GPAC processing, meaning that no refractivity profile was obtained in those cases.

2.3 Quality Control (QC)

The refractivity products are quality-controlled and flagged as non-nominal if one of the following is true:

1. Bending angle profile is flagged as non-nominal by EUMETSAT
2. Retrieved altitude is not monotonically increasing
3. One or more points in the refractivity profile is negative
4. Refractivity profile does not reach below 20 km
5. One or more points in the refractivity profile differ by more than a given threshold below 10 km when compared to a corresponding profile obtained from the most recent ECMWF forecast:
   - The threshold is linearly decreasing from 20% at 0 km to 5% at 10 km

6. One or more points in the refractivity profile differ by more than a given threshold between 10 and 40 km when compared to a corresponding profile obtained from the most recent ECMWF forecast:
   - The threshold is set to 5% between 10 and 30 km
   - The threshold is set to 10% between 30 and 40 km
7. L1 and L2 bending angles for rising occultations diverge beyond a given threshold:
   - The threshold is set to $|\Delta\alpha_{\mathrm{strat}} - \Delta\alpha_{\mathrm{trop}}| > 0.5$ mrad

   where $\Delta\alpha_{\mathrm{strat}}$ is the median of L1−L2 bending angle between 30 and 60 km, and $\Delta\alpha_{\mathrm{trop}}$ is the median of L1−L2 bending angle between 0 and 20 km
8. One or more points in the LC bending angle profile (un-optimized) differ by more than a given threshold between 30 and 70 km when compared to the background bending angle profile used for the statistical optimization:
   - The threshold is set to the maximum of 25% and 5 μrad between 30 and 60 km
   - The threshold is set to 20 μrad between 60 and 70 km

The QC checks are performed in the above order, and when a profile fails a QC check, the remaining checks are not performed for that profile (the first check is an exception: bending angles marked non-nominal by EUMETSAT are still checked further at the ROM SAF, but those that fail one of the remaining checks are not reflected in Table 2.1). If a profile pass all the QC checks it is considered nominal and flagged as such. Additionally, nominal profiles are marked with a percent confidence value (termed 'refrac_qual' in netCDF files; 'percent confidence' in BUFR) of 100 above the ECMWF model surface, but always with a percent confidence value of 0 below the model surface [RD.1, RD.3]. Non-nominal profiles are marked with a percent confidence value of 0 throughout the profile.

This QC is referred to as version QC-1.3, and in the present validation it flaged about 65% of the processed profiles as nominal. For the data investigated in this report, i.e., data in the period from November 16, 2018 to January 31, 2019, Table 2.1 shows the percentage of profiles for all three satellites (out of a total of 48431 for Metop-A; 48841 for Metop-B; 47743 for Metop-C) that failed each of the QC checks (only the first fail in the above order is registered), or did not result in a refractivity profile even though the bending angle was flagged as nominal.

Table 2.1: *Percentage of profiles failing each of the QC checks. The first column with QC check 0 indicates the percentage of profiles that failed the processing at GPAC, even though the bending angle was flagged as nominal. A percentage of 0.0 means that the number is less than 0.05%.*

QC check	0	1	2	3	4	5	6	7	8	All
Metop-A	5.5%	6.3%	0.0%	0.1%	0.0%	8.0%	1.4%	0.0%	18.2%	39.4%
Metop-B	5.1%	5.3%	0.0%	0.1%	0.0%	6.6%	1.5%	0.0%	18.3%	36.8%
Metop-C	5.8%	6.7%	0.0%	0.1%	0.0%	7.8%	1.5%	0.0%	18.7%	40.6%

A total of 28358 Metop-C occultations were thus successfully processed and flagged as nominal, which results in an average of about 368 occultations per day.

3 Validation

3.1 Method

The retrieved refractivity profiles were compared to corresponding ECMWF profiles (forward modeled to refractivity as a function of altitude) by interpolating both to a common vertical grid. The ECMWF profiles were obtained from 6 or 12 hour forecasts (whichever was closest in time to the observation time) originating from analyses at 0 or 12 UTC, and interpolated to the reference locations of the occultations. Statistics were separated into setting and rising occultations, and also binned into high latitudes (above 60°N and below 60°S), mid latitudes (30–60°S and 30–60°N), and low latitudes (between 30°S and 30°N).

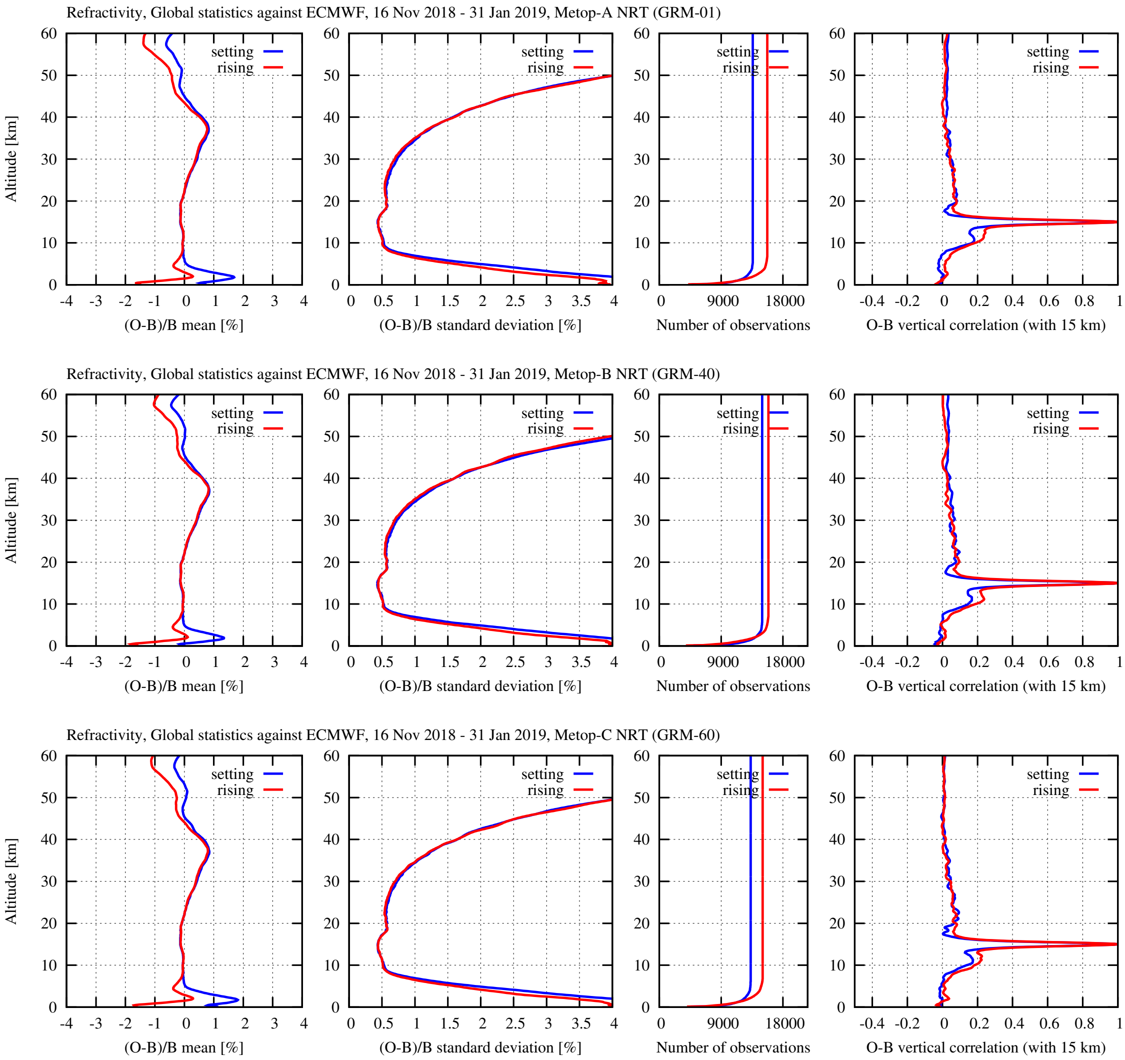

Figure 3.1: *Global statistics (77 days; separated into setting and rising occultations) comparing refractivity to corresponding profiles from ECMWF forecasts. Top: Metop-A. Middle: Metop-B. Bottom: Metop-C. From left to right: Mean; standard deviation; number of observations; and correlation at 15 km with the rest of the profile. All as a function of altitude above MSL.*

3.2 Results

Figure 3.1 shows the global refractivity statistics, for Metop-A in the top panels, Metop-B in the middle panels, and Metop-C in the bottom panels. The figure (as does the following figures) includes only the occultations that passed the QC checks described in Section 2.3. The panels from left to right show the mean difference to ECMWF profiles, the standard deviation, the number of observations, and the correlation of the difference at 15 km with that over the rest of the profile. The correlation is the ordinary Pearson correlation using relative differences. The number of samples included is generally different at each level, depending on how far down the profiles reach. Figures 3.2–3.4 show the same as Figure 3.1, but for low, mid, and high latitudes, respectively. Figure 3.5 shows the bending angle statistics for high latitudes for the same occultations as in Figure 3.4.

3.3 Discussion

The difference between setting and rising occultations between 8 km and 40 km is small at all latitudes. Before the instrument firmware upgrade on August 1, 2018, the standard

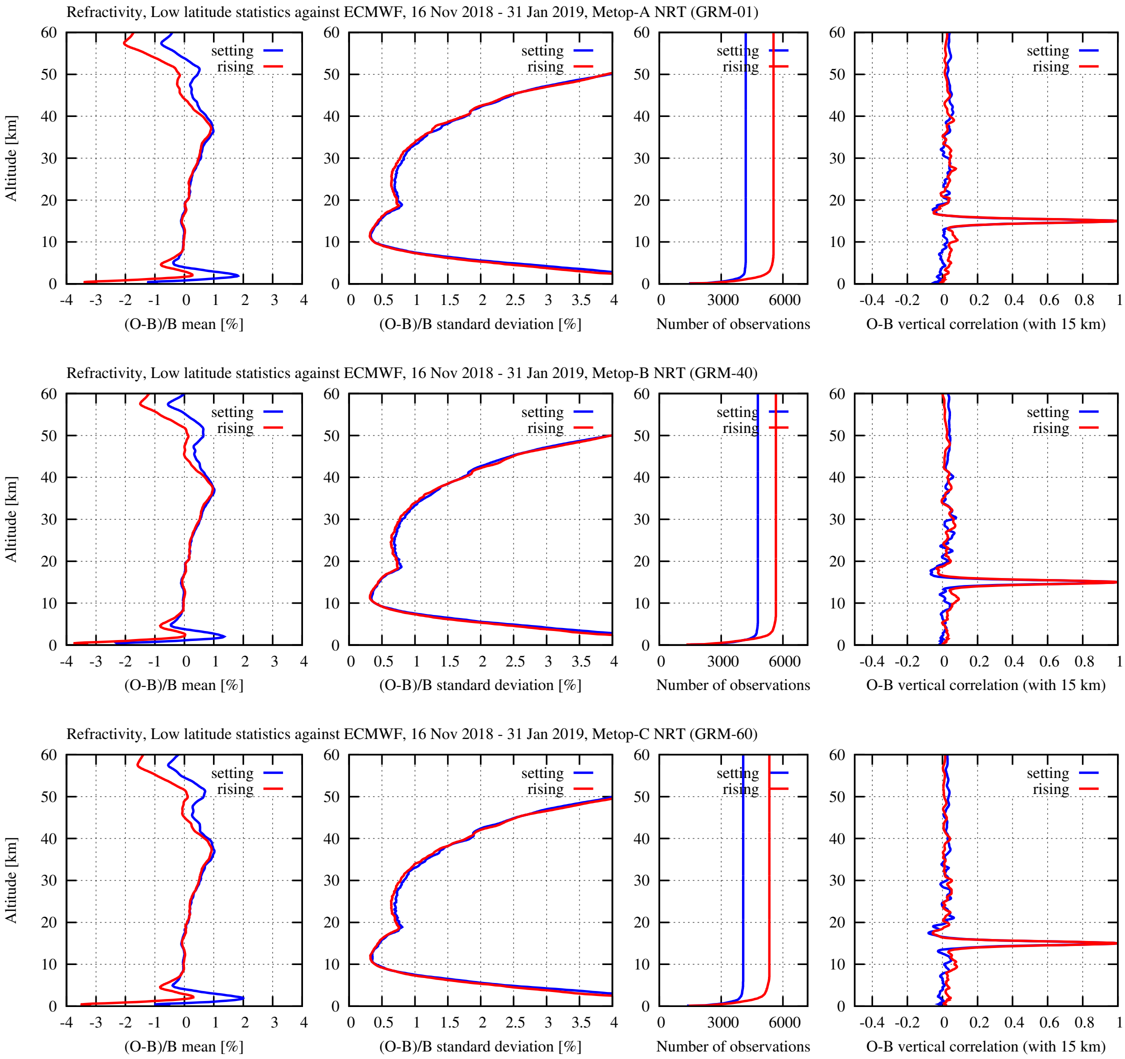

Figure 3.2: Low latitude statistics. Otherwise same as Figure 3.1.

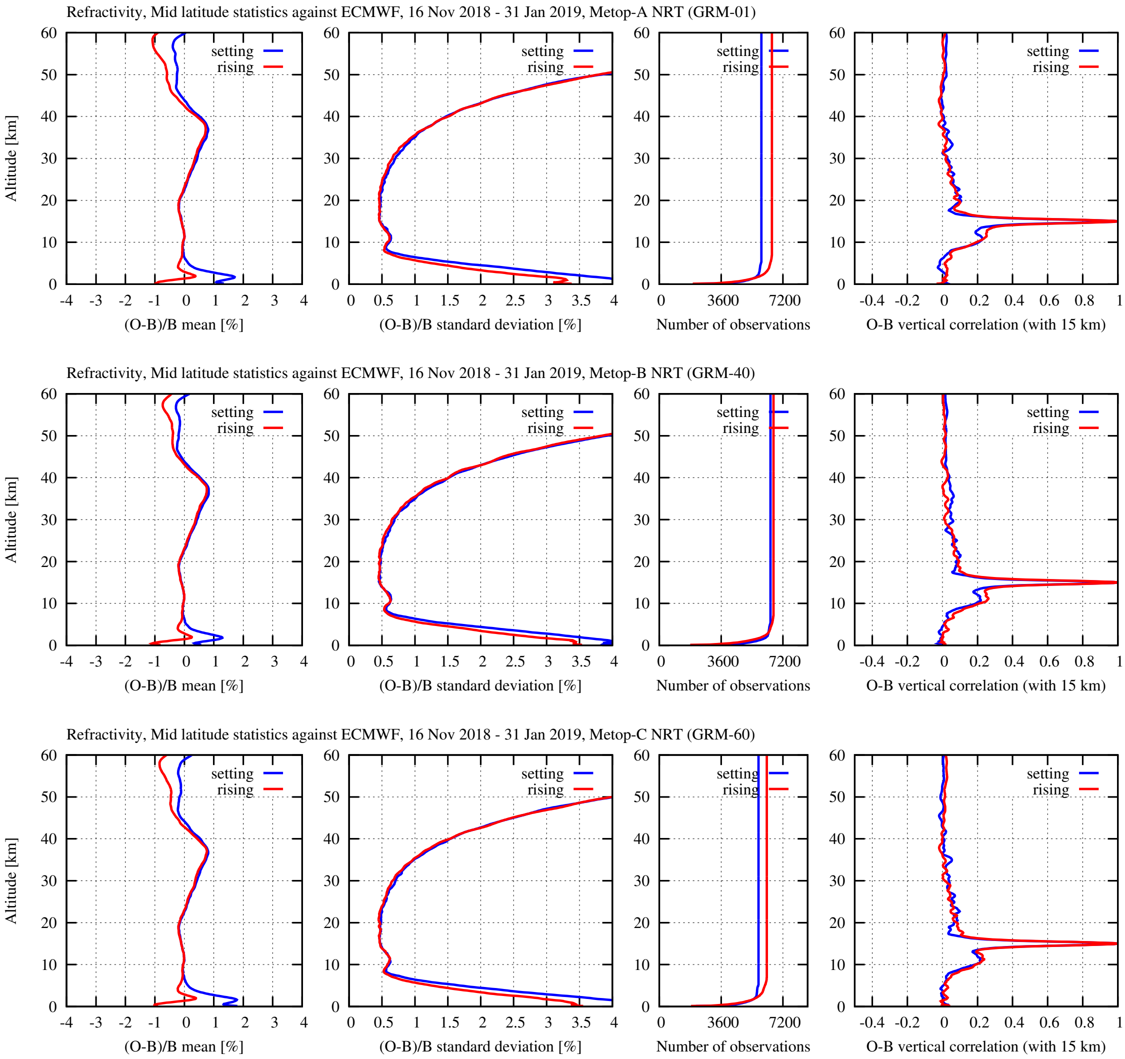

Figure 3.3: *Mid latitude statistics. Otherwise same as Figure 3.1.*

deviations and vertical correlations for rising occultations (for Metop-A and Metop-B) were significantly larger than for setting occultations between 10 and 20 km. The reason for the upgrade was to reduce the standard deviation and vertical correlations for rising occultations, and the results here show that this has been successfully accomplished.

There is, however, a clear difference between rising and setting occultations below about 8 km, both in the mean and in the standard deviation, and mostly so at high latitudes where there is a large positive mean difference and larger standard deviation for setting occultations. These differences are not fully understood, but are consistent with similar differences in the bending angle, and they are basically the same for all three satellites.

There is also a clear difference between rising and setting occultations above 40 km in the mean, mostly at low and mid latitudes. Also these differences are not fully understood, but are again consistent with similar differences in the bending angle (not shown), and they are basically the same for all three satellites.

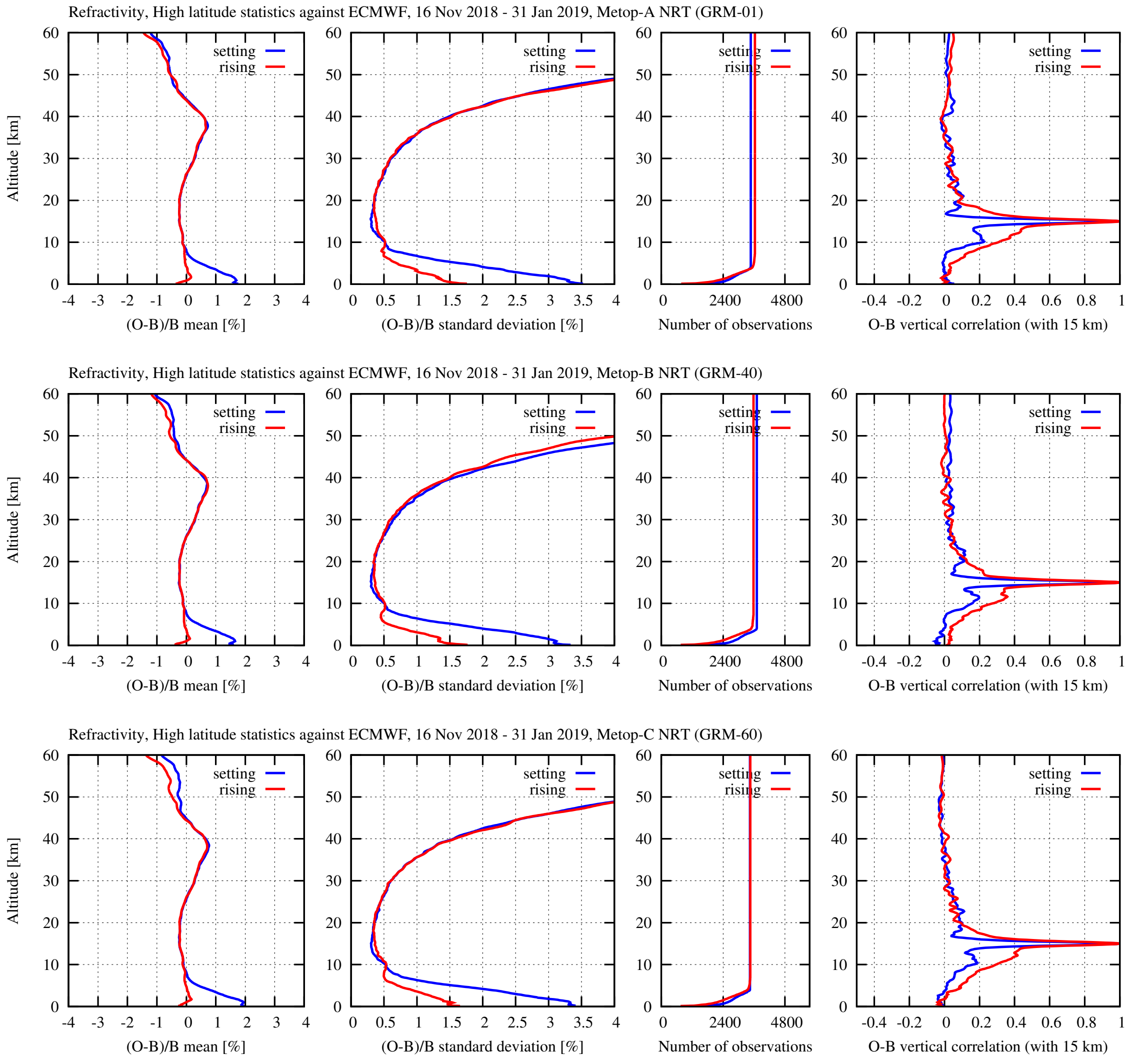

***Figure 3.4:** High latitude statistics. Otherwise same as Figure 3.1.*

The differences in the mean and standard deviation (against ECMWF forecasts) for the three Metop satellites are smaller (or at most of similar size) than the usual day-to-day variations in the statistics for either satellite (not shown).

The number of nominal occultations is slightly smaller for Metop-C, but so was the number of input bending angle profiles. The statistics and the percentages in Table 2.1, gives evidence to the conclusion that the quality of the Metop-C data is very similar to that of Metop-A and Metop-B, although small differences seem to indicate that the quality of the Metop-B data is slightly better than that of Metop-A and Metop-C.

3.4 Compliance with requirements

The formal requirements for the ROM SAF data products are stated in the Products Requirements Document (PRD) [AD.3]. The particular requirements applicable to the level 2A refractivity products are here reiterated in Table 3.1.

Disregarding the results below 8 km, Figure 3.6 shows that the mean plus/minus the standard deviation of the refractivity products (including that of GRM-60) is close to or within the

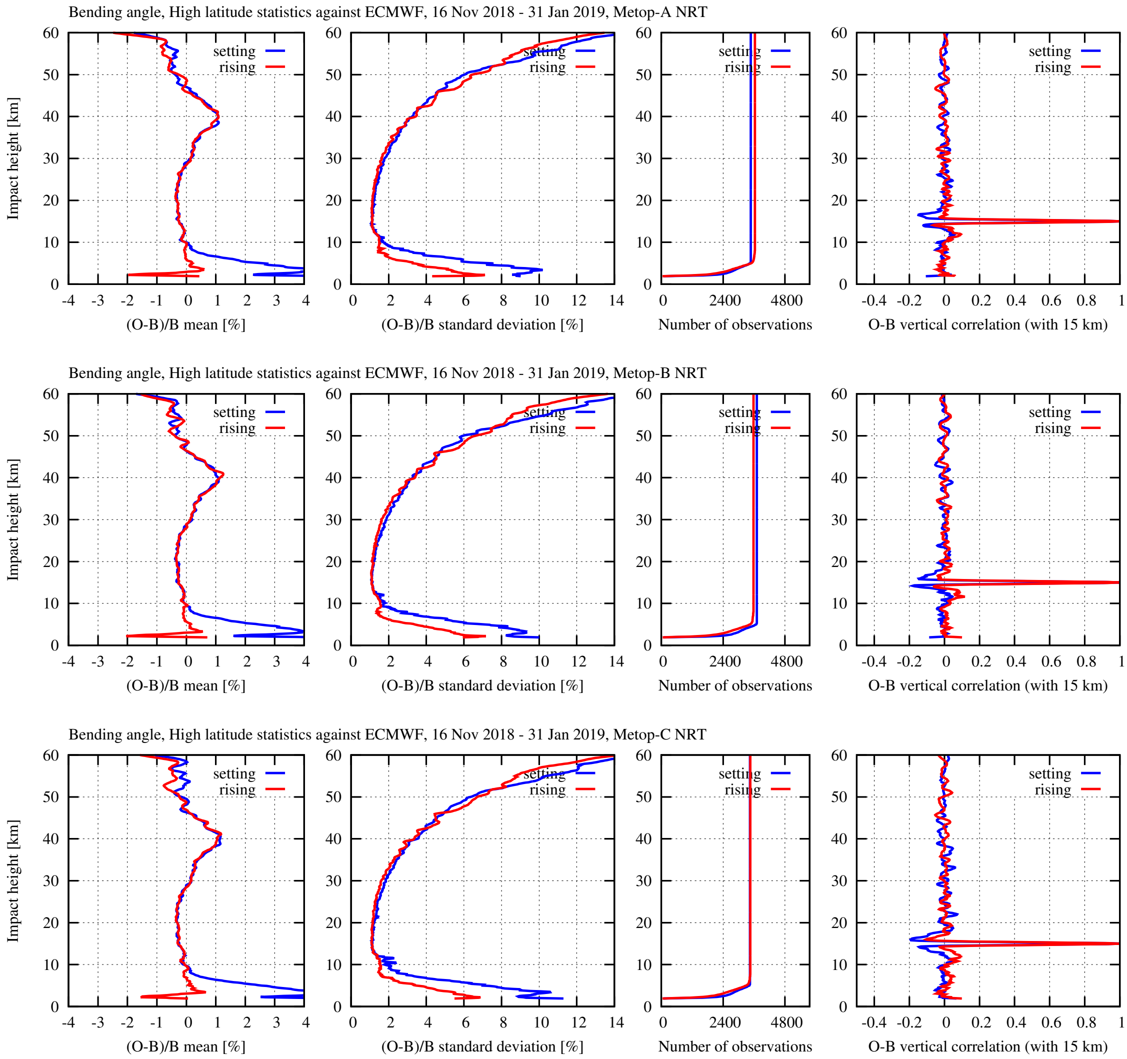

Figure 3.5: *High latitude statistics comparing the EUMETSAT bending angle to corresponding profiles from ECMWF forecasts. To be compared with Figure 3.4.*

target requirement, for both rising and setting occultations. Below 8 km, compliance with the PRD in terms of the target is not possible, but compliance in terms of the threshold is.

Table 3.1: *Threshold, Target, and Optimal accuracies for GRM-01, GRM-40, and GRM-60 according to the PRD [AD.3].*

Threshold	Target	Optimal
0–5 km: 1.8%–6% 5–30 km: 1.8% 30–50 km: 0.09 N-units	0–5 km: 0.6%–2% 5–30 km: 0.6% 30–50 km: 0.03 N-units	0–5 km: 0.3%–1% 5–30 km: 0.3% 30–50 km: 0.02 N-units

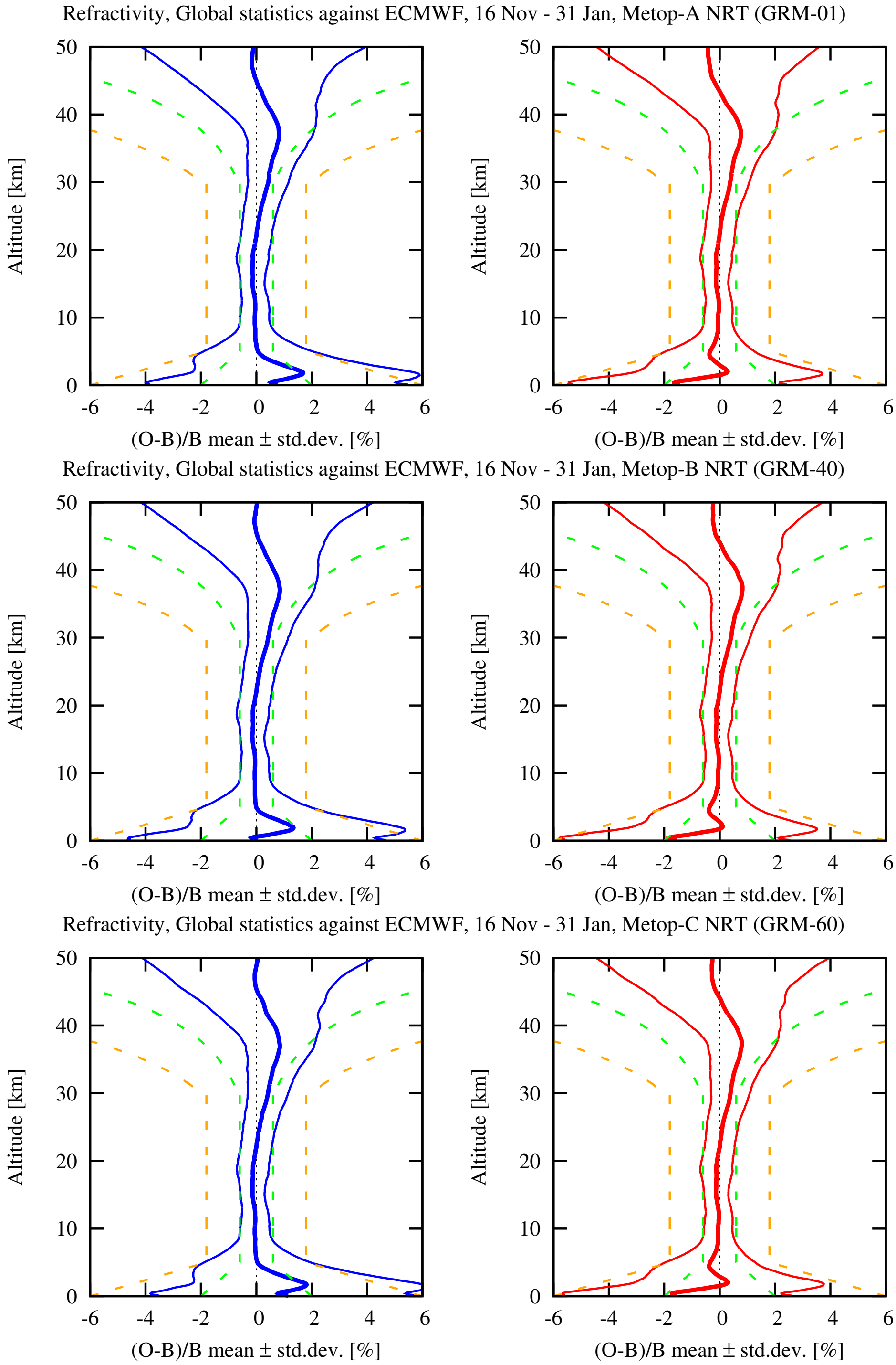

Figure 3.6: *Mean plus/minus standard deviation relative to ECMWF forecasts. Top: Metop-A. Middle: Metop-B. Bottom: Metop-C. Left: Setting. Right: Rising. Dashed lines superimposed indicates the target (green) and threshold (orange) accuracies for NRT refractivity according to the PRD [AD.3].*

3.5 Service specifications

The Service Specifications [AD.4] describes the commitments by the ROM SAF related to the services and products provided to the users. These commitments include a set of operational accuracy targets that should be met by the Level 2A refractivity products, and which is monitored regularly and documented as part of normal operations.

Even though these targets should be consistent with the PRD [AD.3], they are not necessarily identical to the PRD requirements. Compliance to the service specifications of the operational products is reported in biannual operations reports. The validation results in this chapter indicate that the GRM-60 product (Metop-C) meet the current service specifications for GRM-01 (Metop-A) and GRM-40 (Metop-B). Thus, the service specifications for GRM-60 are given in Table 3.2. The percentages in a given altitude interval in the table should be understood as an average over that interval.

Table 3.2: *Service specifications for GRM-60 according to the Service Specifications document [AD.4].*

	$<(O-B)/B>$ bias	$<(O-B)/B>$ standard deviation
0–8 km	1.0% (global)	4.0% (global)
8–30 km	0.2% (global)	0.8% (global)
30–40 km	0.4% (global)	2.0% (global)
40–50 km	1.5% (global)	6.0% (global)
Verification/Validation Methods	Vertical averages of absolute deviations from ECMWF short-term forecasts	

4 Open issues

There are a few open issues and improvements that could be implemented in future updates. They are listed and discussed below.

4.1 Quality control and processing failures

The current QC flags about 35% of all processed profiles as non-nominal. Additionally, about 5% of profiles that are initially flagged as nominal by EUMETSAT fails the processing to refractivity at the ROM SAF and no refractivity profile is produced. Technically, the profiles fail when the bending angle differs too much from the background bending angle profile used for the statistical optimization.

There are basically two different reasons why the bending angle differs too much from the background bending angle profile. One is ionospheric scintillations at high altitudes, which is responsible for about half of the failures. The other reason is the erroneous oscillations in the WO processing discussed in [RD.4]; the largest of these are responsible for the other half of the failures. With the introduction of the WO processing in 2016, the ROM SAF implemented a QC check at high altitudes to catch many more of these cases with erroneous oscillations, such that users can still have confidence in the refractivity products at high altitudes. This is QC check number 8, which flags a significant amount of all profiles (cf. Table 2.1).

While it is difficult to mitigate the effects of ionospheric scintillations, it should be possible to avoid the erroneous oscillations, as they did not appear in earlier versions of the EUMETSAT data. Thus, there is reason to believe that the number of both failed and non-nominal profiles can be significantly reduced in future versions of the refractivity products.

Also, in a future version of the processing software at the ROM SAF, the ROM SAF will strive to process all profiles, such that all those profiles where the bending angle differs too much from the background bending angle profile, are just marked as non-nominal.

4.2 Processing in the lower troposphere

Although the data provided by EUMETSAT is based on open loop tracking (raw sampling mode) in the lower troposphere, and processed using WO, there are a number of cases were the refractivity and the bending angle are quite different from the corresponding ECMWF forecasts, and where the bending angle gradient (and corresponding refractivity and dry temperature) becomes suspiciously large below 8 km. With the introduction of the WO processing in 2016, this prompted the implementation of a QC check in the troposphere, which in the present validation marks about 8% of all Metop-C refractivity profiles as non-nominal (the QC percentages varies significantly over time, which may explain the larger numbers in this report compared to [RD.4]). Still, there are suspicious cases left that are marked nominal [RD.4], especially at high latitudes, and there are also differences in the bias and standard deviation between rising and setting occultations that are not well understood. The ROM SAF is working with EUMETSAT to fully understand these issues, and possibly the data quality will improve in future versions of the processors at EUMETSAT and the ROM SAF.

4.3 Use of new climatology

The ROM SAF is working to improve the statistical optimization by using a new climatology called BAROCLIM, which eventually will replace the current MSIS-90 bending angle climatology. Together with other adjustments of the statistical optimization, this will result in higher accuracy and smaller standard deviation at high altitudes (above 40 km). BAROCLIM has already been implemented for ROM SAF off-line and reprocessing products, but later also the NRT products will benefit from the anticipated improvements.

4.4 Biases at high altitudes

It has long been recognized that the ECMWF model has a positive refractivity bias around 40 km. When ECMWF upgraded their model in June, 2013, the bias was reduced significantly when compared to GRM-01 and GRM-40 products (evident from the ROM SAF operations reports). When ECMWF upgraded their model in July, 2017, the bias increased again. It is therefore likely that the bias around 40 km is primarily a bias in the ECMWF model, and that the GRM-01, GRM-40, and GRM-60 products are less biased around this altitude and above.

5 Conclusions

The statistical comparisons presented in this report (using only nominal profiles) show that the quality of GRAS/Metop-C refractivity (GRM-60) is on par with that of GRAS/Metop-A (GRM-01) and GRAS/Metop-B (GRM-40). Differences in the statistics (against ECMWF forecasts) in the period investigated exist, but are on a level comparable to or smaller than day-to-day variations in the statistics from either of the satellites. The statistics over longer time periods will be reported in biannual operations reports.

The mean difference and standard deviation (against ECMWF forecasts) below 8 km for setting occultations for all three satellites is significantly larger than for rising occultations, in particular at high latitudes. Thus, they are at least in part due to biases in the refractivity products. These biases below 8 km are consistent with biases in the input bending angles and the ones for GRM-60 are similar to the ones for GRM-01 and GRM-40.