



**EUMETSAT**

**ROM SAF**

RADIO OCCULTATION METEOROLOGY

## **ROM SAF CDOP-2**

### **ROPP Change Log: v8.0 to v9.0**

**Version 1.0**


**28 February 2017**

Danish Meteorological Institute (DMI)

European Centre for Medium-Range Weather Forecasts (ECMWF)

Institut d'Estudis Espacials de Catalunya (IEEC)

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## DOCUMENT AUTHOR TABLE

	<i>Author(s)</i>	<i>Function</i>	<i>Date</i>	<i>Comment</i>
Prepared by:	D Offiler, I Culverwell	ROPP Development Team ROPP Development Manager	28/02/2017	
Reviewed by:	C Burrows	ROPP Development Team	28/02/2017	
Approved by:	K B Lauritsen	ROM SAF Project manager	28/02/2017	

## DOCUMENT CHANGE RECORD

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## ROM SAF

The Radio Occultation Meteorology Satellite Application Facility (ROM SAF) is a decentralised processing centre under EUMETSAT which is responsible for operational processing of GRAS radio occultation data from the Metop satellites and radio occultation (RO) data from other missions. The ROM SAF delivers bending angle, refractivity, temperature, pressure, and humidity profiles in near-real time and off-line for NWP and climate users. The off-line profiles are further processed into climate products consisting of gridded monthly zonal means of bending angle, refractivity, temperature, humidity, and geopotential heights together with error descriptions.

The ROM SAF also maintains the Radio Occultation Processing Package (ROPP) which contains software modules that will 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>

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## Executive Summary

This document summarizes the significant differences between the Radio Occultation Processing Package (ROPP) version 9.0 and the previous release, version 8.0.

# 1. Introduction

## 1.1 Purpose of the document

This document summarizes the significant differences between the Radio Occultation Processing Package (ROPP) version 9.0 and the previous release, version 8.0. For guidance on downloading and installing the ROPP software, and the available documentation, please refer to the ROPP Release Notes [RD.1]. All comments on the ROPP software should, in the first instance, be reported via the ROM SAF Helpdesk at <http://www.romsaf.org>.


## 1.2 Reference documents

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

- [RD.1] ROPP-9 (v9.0) Release Notes  
Ref: SAF/ROM/METO/SRN/ROPP/001 – Version 9.0.
- [RD.2] ROPP User Guides  
Ref: SAF/ROM/METO/UG/ROPP/001 – Overview  
Ref: SAF/ROM/METO/UG/ROPP/002 – ROPP\_IO module  
Ref: SAF/ROM/METO/UG/ROPP/004 – ROPP\_PP module  
Ref: SAF/ROM/METO/UG/ROPP/005 – ROPP\_APPS module  
Ref: SAF/ROM/METO/UG/ROPP/006 – ROPP\_FM module  
Ref: SAF/ROM/METO/UG/ROPP/007 – ROPP\_1DVAR module
- [RD.3] WMO FM94 (BUFR) specification for radio occultation data  
Ref: SAF/ROM/METO/FMT/BUFR/001

## 1.3 Acronyms and abbreviations

1DVAR	1D-Var module of ROPP
AIX	Advanced Interactive eXecutive (IBM)
API	Application Programming Interface
BUFR	Binary Universal Form for the Representation of data (also: FM94) (WMO)
CDOP-2	Second Continuous Development and Operations Phase (EUMETSAT)
DMI	Danish Meteorological Institute; ROM SAF Leading Entity
ECMWF	The European Centre for Medium-range Weather Forecasts
EPS	EUMETSAT Polar Satellite System
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites
FM	Forward Model module of ROPP
GCC	GNU Compiler Collection (not to be confused with <b>gcc</b> , the GCC C-compiler)
CHAMP	Challenging Mini-satellite Payload (Germany)
GNOS	GNSS Radio Occultation Sounder (China)
GNU	GNU's Not Unix
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
COSMIC	Constellation Observing System for Meteorology Ionosphere and Climate (USA/Taiwan)
GRAS	GNSS Receiver for Atmospheric Sounding (EPS/Metop)
GRIB	GRIdded Binary format (WMO)
HDF5	Hierarchical Data Format version 5
IBM	International Business Machines Corporation
IO	Input and Output module of ROPP
I/Q	In-phase and Quadrature signal components
IEEC	Institut d'Estudis Espacials de Catalunya
Met Office	Meteorological Office of the United Kingdom
MetDB	Meteorological DataBase (Met Office)
Metop	Meteorological Operational Polar satellite (EUMETSAT)
NCO	Numerically Controlled Oscillator
netCDF	Network Common Data Format
NRT	Near Real Time
OS	Operating System
POSIX	Portable Operating System Interface
PP	Pre-processor module of ROPP
RHEL	Red Hat Enterprise Linux
RO	Radio Occultation (also: GPS-RO)
ROM SAF	Radio Occultation Meteorology SAF (formerly GRAS SAF)
ROPP	Radio Occultation Processing Package
RS	Raw Sampling
SAF	Satellite Application Facility (EUMETSAT)
SNR	Signal to Noise Ratio
TanDEM-X	German Earth observation satellite carrying an RO sounder
TerraSAR-X	German Earth observation satellite carrying an RO sounder
UCAR	University Center for Atmospheric Research (Boulder, CO, USA)
UTILS	Utility module of ROPP

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## 1.4 Definitions

RO data products from the GRAS instrument onboard Metop and RO data from other data providers are grouped in levels and are either NRT or offline products:

### 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 phase, SNR, amplitude, orbit information, I/Q, and NCO values, and navigation bits;

*Level 1b:* Bending angles and impact parameters, annotated with Earth location, metadata and quality information;

*Level 2:* Refractivity profiles (Level 2a), pressure, temperature, and specific humidity profiles (Level 2b) and surface pressure – and other single-level parameters – (Level 2c), annotated with Earth location, metadata and quality information;

*Level 3:* Gridded Level 1 and 2 offline profile products in the form of, e.g., monthly and seasonal zonal means, metadata, and quality information;

### Product types:

NRT product: data product delivered less than 3 hours after measurement;

Offline product: data product delivered less than 30 days after measurement (the timeliness for some offline level 3 products may be up to 6 months).

## 2. General changes

- The recommended 'external dependency packages' (netCDF, BUFR etc) have been brought more up to date. As part of that move, ROPP build support for 'classic' netCDF-4 has been dropped. This implies a requirement for HDF5 and (optionally) zlib. Full details are given in the Release Notes ([RD.1]).
- The recommended netCDF package, being later than v4.2, is split into a netCDF-Core library, written in C, and a netCDF-Fortran interface. They need to be built separately.
- A new module, ROPP\_APPS, has been introduced at ROPP-9.0, which is intended to hold ROPP 'applications', that is, 'ad-hoc' specific processing tools. In the first instance, it contains tropopause height diagnostic tools (transferred from the ROPP\_PP module in earlier releases of ROPP) and boundary layer height diagnostic tools (new at ROPP-9.0).
- The rather unwieldy ROPP (FM & 1DVAR) User Guide has been split into separate FM and 1DVAR User Guides.
- A new User Guide has been written for the ROPP\_APPS module.
- The `ropp_<module>_compare.f90` routines now say which profile failed a comparison test.
- The `georef` element of the ROPprof structure has been extended to include 'reference' POD information on the LEO and GNSS satellites. This is the 'nominal' POD information that is written to and from the BUFR files by the ROPP tools `{eum, ropp}2bufr` and `bufr2ropp` respectively. (This change has been introduced because EUMETSAT datasets differentiate between level 1a satellite POD data and 'reference' POD data, and previously an ROPP data file could not contain both, because the reference POD, if needed for BUFR output, was placed in a level1a data structure of length 1 – and, moreover, in the wrong reference frame.)




### 3. ROPP\_UTILS


- The nominal azimuth is now between 0 and 360 deg (rather than -180 to 180 deg) in `ropp_utils/coordinates/occ_point.f90`. This agrees with the convention adopted for `azimuth_tp`, and the BUFR definition of azimuth.
- The radius of curvature calculation in `ropp_utils/coordinates/curvature.f90` has been made fully robust (to avoid a singularity at the pole).
- A bug in `datum_hms1` that prevented the code searching for geopotential coefficients and corrections if the file names existed but were null, has been fixed.

## 4. ROPP\_IO

- A change has been made to allow profiles with missing-but-calculable geopotentials to pass the range-checking. This enables the ROPP forward model to work on 137L ECMWF background files distributed by the ROM SAF.
- The correct LEO IDs have been encoded in the atmPrf/atmPrf (CDAAC-generated data) readers and the ROPP-format data readers. (Earlier, inconsistent values were preventing the correct satellite codes being put into the BUFR files.)
- The appropriate WMO-approved COSMIC-2 code names and numbers have been introduced into ROPP's BUFR encoding/decoding routines.
- A minimum threshold of 1.0 km/s ( $\sim 0.1\sqrt{(gR_e)}$ ) has been included in the range-checking of the magnitude of the satellite velocities in ropp\_io\_rangecheck. (Change unlikely to have much effect.)
- A bug that prevented ropp2ropp (or the overloaded operator R0prof1 = R0prof2) from copying the 'R0prof%BG' substructure has been fixed.
- A bug has been fixed in the overloaded SIZE(vlist) function, although the buggy version is never used in ROPP.
- The vlist\_print subroutine has been improved to show the rank and dimensions of each 'extra data' field.
- A bug that caused a netCDF crash when the user requested 'extra data' whose name matched that of an existing extra data field, has been fixed. (ROPP now issues an error message in such cases, and declines to add the new field to the R0prof structure.)
- A bug that prevented valid\_range netCDF attributes being attached to some tropopause height diagnostics has been fixed.
- **ucar2ropp**
  - ucar2ropp no longer erroneously copies atmPrf dry temperature data into ROPP level 2b temperature.
  - ucar2ropp now puts UCAR software processing code, as deduced from filename, into processing\_software global attribute.
  - A bug, which was preventing ucar2ropp from producing the correct software\_version global attribute when run on ???Prf files, has been fixed.
  - ucar2ropp now takes the GNSS\_ID from the fileStamp netCDF global attribute.
  - ucar2ropp now defines the ROPP Product Confidence Data (PCD) values more accurately.
- **eum2ropp** and **eum2bufr**
  - The ROPP I/O User Guide has been updated to include a table describing the mapping between EPS-SG RO Level 1 data variables and the corresponding BUFR data fields.
  - eum2ropp now has options for the type of level 1a data that is extracted with the -1 option: none, closed loop only, closed loop concatenated with open loop, or closed loop concatenated with raw sampling.

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- eum2ropp and eum2bufr now have an option ('-e') to use the EUMETSAT-generated extrapolated L1–L2 bending angles to generate the L2 bending angles.
- eum2ropp and eum2bufr now use the netCDF `quality/o1_data_used` variable to define the 'open\_loop' element of the PCD.
- eum2ropp and eum2bufr now use the netCDF `satellite_prn` attribute (of the `/data/transmitter/satellite` group) to define the `GNSS_ID`.
- eum2ropp and eum2bufr now use the netCDF `environment` global attribute to define the 'offline' element of the PCD field.
- eum2ropp and eum2bufr now encode the bending angle processing method as part of the `software_version`.
- **gfz2ropp**
  - gfz2ropp has been updated to read in L1 and L2 bending angles, if available.
  - gfz2ropp now uses the `PRODUCT_ID` element of the `.dsc` file to infer the family of the GNSS satellite, if the files are suitably recent.
  - gfz2ropp encodes the SOFTWARE PACKAGE as the `processing_software` netCDF global attribute.
- **test2ropp**
  - test2ropp has been extended to allow “B” as a valid GNSS identifying letter (for Beidou).
  - A bug that generated 'valid' example `leo_ids`, like `CO01` rather than `C001`, has been fixed.

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## 5. ROPP\_PP

- A new wave optics propagation tool, **ropp\_pp\_wopt\_tool**, has been included in the PP module. This tool calculates the excess phase delay that would be incurred by an occulting radio signal which passes through a spherically symmetric neutral refractivity field near the surface of the earth. It does this by propagating the radio wave through a series of refractivity 'screens'. The signal received at the LEO is calculated by decomposing the final screen into a set of mini-screens, over each of which the signal phase and amplitude is assumed to vary linearly with distance. Example datasets, build tests, manual pages and documentation have been provided.
- A switch (`-w`) has been added to **ropp\_pp\_occ\_tool** to allow it to process the idealised excess phase data produced by the wave optics propagation code. A new configuration file, containing suitable parameters for processing such data, has also been provided.
- Tropopause height diagnostics have been transferred to the new module ROPP\_APPS.
- The 'BAROCLIM-3' option for the 'climatological' bending angles used in the statistical optimisation scheme has been introduced. Naturally, supporting datasets have been included in the distribution. *Note that backward compatibility when using the `-m` MSIS option (i.e., a 'local search' for the best climatological profile) has been slightly broken as a result of this change, but the physical consequences of this are likely to be of little significance.*
- Optional arguments have been added to the code that calculates the dry temperature. These allow the user to specify the scale height above the upper boundary, and the integration step size. (Not used by default.)
- Level 1a, level 1b and level 2a data, rather than 'Tdry' data, can now be output from **ropp\_pp\_occ\_tool** and **ropp\_pp\_invert\_tool** via configure file options.
- The User Guide has been updated to stress that the dry temperature calculation is for an *ideal* gas (with no non-unity compressibility factors).

## 6. ROPP\_FM

- **ropp\_fm\_bg2ro\_1d** has been extended as follows:
  - Input parameters can be read from a namelist;
  - The impact heights of the bending angles need no longer coincide with the altitudes of the refractivities, which allows ...
  - ... the user to forward model refractivities or bending angles independently.
- A '-best' option to **ropp\_fm\_bg2ro\_1d**, and a corresponding namelist, have been introduced. These provide the means for a user to use the 'best' scientific and configurational options to the 1D forward model. Currently, the 'best' options consists of: non-ideal gas compressibility factors, the 'new' interpolation schemes, refractivities on 300 uniformly spaced geopotential levels, bending angles on the 247 'standard' levels, and the bypassing the calculation of the gradients of refractivity and bending angle.
- A bug in **ropp\_fm\_bg2ro\_1d** when the code was run with compressibility factors and the new interpolation scheme at the same time has been fixed.
- A bug in the new interpolation scheme that caused NaNs to appear when **ropp\_fm\_bg2ro\_1d** was used to generate refractivities above the top of the model, has been fixed. ROPP now generates missing data in such regions. (The old interpolation scheme generated valid, if increasingly meaningless, refractivities above the model top because it just linearly extrapolated the log of the refractivity.) For consistency, refractivities from this scheme are now also set to missing data above the model top.
- **ropp\_fm\_bg2ro\_1d** can now work on the 137L ECMWF background files distributed by the ROM SAF, for reasons described in the ROPP\_IO section.
- An extrapolation bug in **ropp\_fm\_interpol.f90** (etc) has been fixed. (In fact this is never called, because ROPP uses **ropp\_fm\_interpol\_log.f90** (etc) instead.)
- A bug that sometimes caused the incorrect undulations to appear in the output file when **ropp\_fm\_bg2ro\_1d** was run on multifiles, has been fixed.
- The radius of curvature and undulation in the ionospheric modelling test codes **t\_iono**, **t\_ion\_tl** and **t\_iono\_ad** were unnecessarily hardwired. Now they are read from the input file, if possible. (The test dataset also needed updating to provide a valid RoC.)
- A bug in the **check\_qsat** option of **ropp\_fm\_bg2ro\_1d** has been fixed. This was preventing the check against air saturation not always being made as often as it should have been. *This could affect results in warm (> 0°C) air, in the unlikely – and not recommended – case that the user runs ropp\_fm\_bg2ro\_1d with the -check\_qsat option.*

## 7. ROPP\_1DVAR

- A new method of specifying the background covariances, *RSFC*, has been implemented. This method uses fixed *fractional* errors on specific humidity ( $q$ ) and surface pressure ( $p^*$ ), and multiplies them by the profile  $q$  and  $p^*$  values to generate errors on the background  $q$  and  $p^*$  fields. The absolute temperature error is fixed, as are the correlations. (This is the method used by DMI operationally.) Suitable example background covariance files have been included in the distribution.
- Some redundant files (`tests/example_tests.jpg` and `tests/example_tests.log`) have been removed from the distribution.
- A bug in the calculation of the O-A and O-B diagnostics has been fixed. (Now returns `ropp_MDFV` if either O or A (B) is missing, not just if O is.)

## 8. ROPP\_APPS

- This is a new module containing tools and supporting software that allow the user to calculate:
  - Tropopause heights (TPHs) from profiles of bending angle, refractivity, dry temperature and background temperature; and
  - Planetary boundary layer heights (PBLHs) from profiles of bending angle, refractivity, dry temperature, background temperature, background specific humidity and background relative humidity.
- The TPH code has been transferred from the ROPP\_PP module; the PBLH code is new to this release.