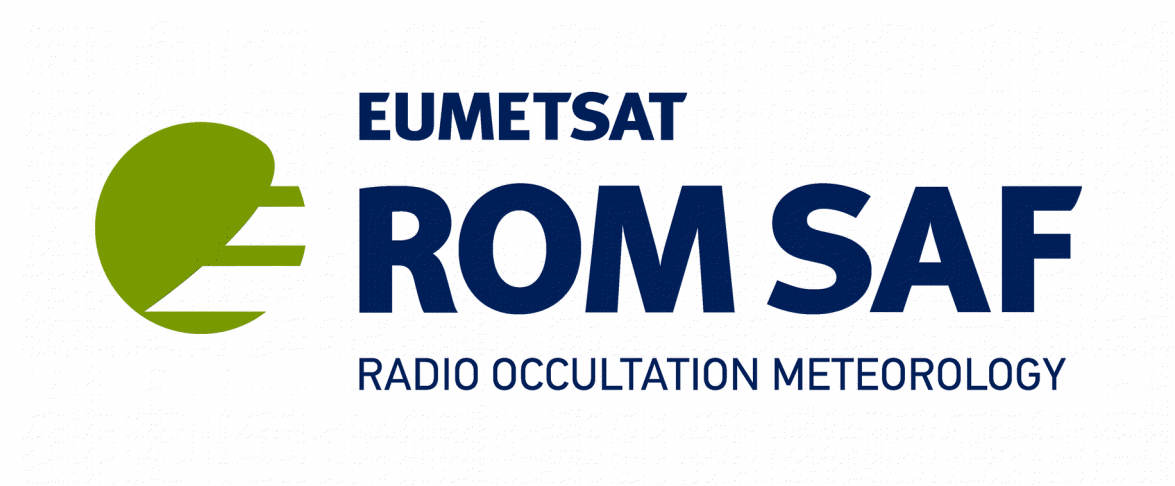

ROPP Change Log: v10.0 to v11.0

Version 1.0

31 December 2021

The ROM SAF Consortium

Danish Meteorological Institute (DMI)

European Centre for Medium-Range Weather Forecasts (ECMWF)

Institut d'Estudis Espacials de Catalunya (IEEC)

Met Office (METO)

Ref: SAF/ROM/METO/SRN/ROPP/018

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DOCUMENT CHANGE RECORD

Issue/Revision	*Date*	*By*	*Description*
1.0	28/02/2017	IC	1st version in 'standard' ROM SAF format, for ROPP9.0
2.0	30/06/2019	IC	ROPP9.1 version
3.0	30/09/2020	IC	ROPP10.0 version
4.0	31/12/2021	IC	ROPP11.0 version

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 radio occultation (RO) data from the Metop and Metop-SG 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.

Intellectual Property Rights

List of Contents

Executive Summary

This document records the significant differences between the Radio Occultation Processing Package (ROPP) version 11.0 and the previous release, version 10.0, which are:

- The introduction of ionospheric 1dvar retrieval code, based on the difference between bending angles at two different frequencies;
- An update to the recommended ecCodes BUFR/GRIB library, from 2.12.5 to 2.22.0, which allows use of the newer RO BUFR Master Table Version of 35;
- I/O support for new LEO satellites.

1. Introduction

1.1 Purpose of the document

This document summarizes the significant differences between the Radio Occultation Processing Package (ROPP) version 11.0 and the previous release, version 10.0. 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, which can be found on the ROM SAF home page at http://www.romsaf.org. Throughout this report, information for the general user appears in black; information mainly for developers appears in blue, and items to be noted by all users, usually because they may change the previous behaviour of ROPP, appear in red.

1.2 Applicable and reference documents

1.2.1. Applicable documents

The following documents explain the context of ROPP within the ROM SAF.

1.2.2. Reference documents

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

[RD.1] ROPP-11 (v11.0) Release Notes
Ref: SAF/ROM/METO/SRN/ROPP/018.

[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
Ref: SAF/ROM/METO/UG/ROPP/008 – ROPP_UTILS 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)
Beidou	Chinese GNSS navigation system. Beidou-2 also known as COMPASS
CDOP	Continuous Development and Operations Phase (EUMETSAT)
CDR	Climate Data Record
CMA	Chinese Meteorological Agency
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
FY-3C/D	GNSS radio occultation receivers (CMA)
GCC	GNU Compiler Collection (not to be confused with **gcc**, 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 (generic GPS/GLONASS/Galileo/Beidou)
COSMIC	Constellation Observing System for Meteorology Ionosphere and Climate (USA/Taiwan)
GRACE-A/B	Gravity Recovery and Climate Experiment (Germany/USA)
GRACE-FO	GRACE Follow-on experiment (Germany/USA)
GRAS	GNSS Receiver for Atmospheric Sounding (EPS/Metop)
GRIB	GRIdded Binary format (WMO)
HDF5	Hierarchical Data Format version 5
ICDR	Intermediate Climate Data Record
IBM	International Business Machines Corporation
I/Q	In-phase and Quadrature signal components
IEEC	Institut d'Estudis Espacials de Catalunya
ISRO	Indian Space Research Organisation
KMA	Korean Meteorological Agency
KOMPSAT-5	GNSS radio occultation receiver (KMA)
Megha-Tropiques	Tropical water cycle (and RO) experiment (India/France)
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
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)

1.4 Definitions

RO data products from the Metop, Metop-SG and Sentinel-6 satellites and RO data from other missions are grouped in *data levels* (Level 0, 1, 2, or 3) and *product types* (NRT, offline, NTC, 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, SNR's, 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 (ROM SAF Level 2 for EPS); (ii) 150 min after measurement (ROM SAF Level 2 for EPS-SG Global Mission); (iii) 125 min after measurement (ROM SAF Level 2 for EPS-SG Regional Mission);

Offline and NTC products: Data product delivered from about 5 days to up to 6 months after measurement, depending on the applicable 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 sofftware[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

This document is organized as follows:

Chapter 1 contains the introduction;

Chapter 2 lists the changes to ROPP that are common to all modules, such as changes to the build system, and large structural changes;

Chapters 3, 4, 5, 6, 7 and 8 list the changes to the UTILS, IO, PP, FM, 1DVAR and APPS modules respectively;

Chapter 9 directs users to the location of the source code and to the ROM SAF Helpdesk.

2. General

This document records the differences between the Radio Occultation Processing Package (ROPP) version 11.0 and the previous release, version 10.0, the most significant of which are:

- The introduction of ionospheric 1dvar retrieval code, based on the difference between bending angles at two different frequencies;
- An update to the recommended ecCodes BUFR/GRIB library, from 2.12.5 to 2.22.0, which allows use of the newer RO BUFR Master Table Version of 35;
- I/O support for new LEO satellites.

3. ROPP_UTILS

- A new **math** module has been introduced. This will hold mathematical routines that could be useful throughout ROPP. Currently it only contains **lngamma.f90**, which calculates the logarithm of the absolute value of the gamma function $\Gamma(x)$, for real x.

4. ROPP_IO

- A new `Lev2e` substructure of the `ROprof` structure has been introduced. This is designed to contain ionospheric data. Currently it holds a profile of electron density `n_e` (and its uncertainty `n_e_sigma`), and the defining parameters `{n_e_peak, r_peak, h_zero, h_grad}` of a model 'VaryChap' ionospheric electron density layer. Any number of levels are allowed in the former; any number of layers are allowed in the latter.

- The recommended ecCodes BUFR/GRIB library has been updated from 2.12.5 to 2.22.0. This allows use of the newer RO BUFR Master Table Version of 35, although this option is not currently effected in the ropp2bufr code. The mini-configure scripts have necessarily been updated, to use `cmake3` rather than `cmake`.

- LEO codes have been introduced for Spire, PlanetiQ, GeoOptics and Sentinel-6 satellites.

- The upper limit of the `valid_range` of the level 1a variable `dtime` has been increased from 240 s to 540 s, to allow ionospheric profiles to be processed.

5. ROPP_PP

- No changes.

6. ROPP_FM

- A new `State0DFM` structure has been introduced. This contains VaryChap model ionosphere parameters.

- Routines have been introduced to calculate f2 - f1 differenced bending angles from the VaryChap parameters in a `State0DFM` structure. Tangent linear and K-matrix equivalents have also been introduced.

- Routines have been introduced to calculate model electron density profiles from the VaryChap parameters in a `State0DFM` structure. Tangent linear and K-matrix equivalents have also been introduced.

- A routine has been introduced to calculate the vertically integrated TEC from a hybrid ionospheric layer comprising a VaryChap layer above the peak height and a standard Chapman later below.

7. ROPP_1DVAR

- A new tool, `ropp_1dvar_dbangle`, has been introduced. This undertakes 1dvar retrievals of VaryChap ionospheric parameters using background estimates of these parameters and observed f2 - f1 bending angle differences. Background and observed covariance matrices have been included in the ROPP distribution. Quality control routines have been extended to generate O - Bs, analysis covariances, etc.

- `ropp_1dvar_dbangle` has been based on `ropp_1dvar_bangle`, so that users familiar with the latter routine should be able to run the former without difficulty.

- The default minimiser has been changed from minROPP to Levenberg-Marquardt. (This will have no effect if `minropp_method` is specified through a configuration file, which is likely.)

8. ROPP_APPS

- No changes.

9. Conclusions

This document has summarised the significant differences between the Radio Occultation Processing Package (ROPP) version 11.0 and the previous release, version 10.0. Full guidance on downloading and installing the software can be found at the ROM SAF Software download page http://www.romsaf.org/ropp/index.php. All enquiries should be made through the ROM SAF Helpdesk at http://www.romsaf.org/helpdesk.php.