EUMETSAT ROM SAF
RADIO OCCULTATION METEOROLOGY

Algorithm Theoretical Baseline Document:
Level 2C Tropopause Height

Version 2.1

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ROM SAF Consortium
Danish Meteorological Institute (DMI)
European Centre for Medium-Range Weather Forecasts (ECMWF)
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DOCUMENT CHANGE RECORD

Version	Date	By	Description
1.0	14/03/2016	HJS	First version. For PCR-RE1 review.
1.1	12/04/2016	HJS	Revised version. In accordance with PCR-RE1 RIDS: OBJ2_ATBD_TH_Von_001 OBJ2_ATBD_TH_Von_002 OBJ2_ATBD_TH_Von_004 OBJ2_ATBD_TH_Von_021 OBJ2_ATBD_TH_Schroeder_034 OBJ2_ATBD_TH_Schroeder_035
1.2	27/4/2016	HJS	Revised in accordance with discussions at PCR-RE1 meeting. OBJ2_ATBD_TH_Von_003 implemented
1.3	19/3/2018	JKN	Version prepared for DRR-RE1 review: - PCR-RE1 RID OBJ2_ATBD_TH_Von_001 is implemented. This is discussed in Chapter 3 (first subsection). - Chapter 4: Clarified that this chapter does not contain validation results, but only describes the chosen validation method; Chapter 4: The reference tropopause height used in the validation method has been changed from ECMWF temperature lapse rate to ERA-I dry temperature lapse rate.

1.4	4/9/2018	JKN	Updated version implementing the following RIDs for DRR-RE1 \& ORRs review: - RID 175: Ch. 3, ``error'' exchanged with ``uncertainty'' where possible. -RIDs 081, 082, 084, 085, 086, 093, 095, 096, 097, 099, 101, 103, 104,105, 106, 107, 108, 109, 111, 112, 113, 114, 211, 212: Editorial changes implemented. -RID 210 Ch. 3, paragraph 4 was rewritten. [RD.10] left out. In addition the following update was implemented: Reference to new ROPP user guide [RD.10]]
1.5	20/12/2018	JKN	Updated version based on ICDR concept discussions at ROM SAF SG22: - p3, updated ROM SAF description. - Sec 1.1, update GRM table. - Sec 1.4, changed "Definitions". - Ch 5, mentioned ICDR in title.
2.0	19/2/2020	JKN	Updated version for the EPS-SG PDCR review: - Section 1.1: New subsection 1.1.1 - P10 changed NRT/Offline definition - P18 removed CDR ICDR version numbers Updated version for ORR12 review: - None
2.1	14/5/2020	JKN	Updated version prepared for ORR12 Closeout implementing the following: - Sec. 1.1: text about future EPS-SG Day 1 products removed [RIDs 43, 98] - Sec. 1.1.1: text and table about future EPS-SG Day 1products removed [RIDs 43, 98] - Sec. 1.3: removed EPS-SG from acronyms [RIDs 43, 98]

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

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List of Contents

1. Introduction

1.1 Purpose

This ATBD document describes the algorithms used to derive the Level 2C tropopause height produced by the Radio Occultation Meteorology (ROM) Satellite Application Facility (SAF). The document covers Offline, CDR and ICDR-products. The complete list of products covered by this ATBD is provided in Table 1.1. Note that this table may include both products in development and products with operational status. The status of all ROM SAF data products is available at the website: http://www.romsaf.org.

The product requirements baseline is the PRD [AD.3]. The system software package referred to in this ATBD is GPAC 2.4.0.1. It is based on the ROPP-9.0[1] with adaptations made by DMI. Adaptations made by DMI will be included in a future official ROPP release.

Table 1.1 List of products covered by this ATBD:

) The fifth column describes the original data source; satellite/instrument, data-level, institution. "Level 1A" refers to excess phase data.

Product ID	Product name	Product acronym	Product type	Operational *)) satellite input	Dissemination means	Dissemination format
GRM-24	Tropopause Height	TPH	NRT, Offline Product	All ROM SAF RO products	web	netCDF
GRM-29-L2-C-R1	Reprocessed Tropopause height	RCHMET	Reprocessed Data Record	Metop Level 1A data from EUM Secretariat	web	netCDF
GRM-30-L2-C-R1	Reprocessed Tropopause height	RCHCO1	Reprocessed Data Record	COSMIC Level 1A data from CDAAC	web	netCDF
GRM-32-L2-C-R1	Reprocessed Tropopause height	RCHCHA	Reprocessed Data Record	CHAMP Level 1A data from CDAAC	web	netCDF
GRM-33-L2-C-R1	Reprocessed Tropopause height	RCHGRA	Reprocessed Data Record	GRACE Level 1A data from CDAAC	web	netCDF
GRM-29-L2-C-I1	Reprocessed Tropopause height	ICHMET	ICDR	Metop Level 1A data from EUM Secretariat	web	netCDF

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[1] *ROPP stands for "Radio Occultation Processing Package". It is a software package maintained by ROM SAF. See [RD.28] for an ROPP overview.*

Applicable and reference documents

1.1.1 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 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

1.1.2 Reference Documents

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

[RD.1]   ROM SAF ATBD: 1DVAR algorithms, SAF/ROM/DMI/ALG/1DV/002

[RD.2]   ROM SAF ATBD: Level 2A Refractivity Profiles, SAF/ROM/DMI/ALG/REF/001

[RD.3]   The ROPP User Guide – Part III: Pre-processor module, SAF/ROM/METO/UG/ROPP/004

[RD.4]   World Meteorological Organization (WMO), Meteorology A Three-Dimensional Science: Second Session of the Commission for Aerology, *WMO Bulletin IV(4)*, Geneva, 134-138, 1957.

[RD.5]   Reichler, T., Dameris, M., Sausen, R., Determining the tropopause height from gridded data, *Geophys. Res. Lett., 30(20)*,2042,2003

[RD.6]   Schmidt, T., Visiting Scientist Report 22: Beta testing of ROPP 7.0 SAF/ROM/DMI/REO/VS22/001, Version 1.0, 2013

[RD.7]   Healy, S., Refractivity coefficients used in the assimilation of GPS radio occultation measurements, GRAS SAF Report 09, 2009.

[RD.8]   Smith, E.K., and S. Weintraub, The constants in the equation for atmospheric refractive index at radio frequencies, *Proc. IRE,* 1035-1037, 1953

[RD.9]   The ROPP User Guide – Part II: Forward module and 1D-Var modules, SAF/ROM/METO/UG/ROPP/003

[RD.10] The Radio Occultation Processing Package (ROPP) Applications Module User Guide, SAF/ROM/METO/UG/ROPP/005

1.2   Acronyms and abbreviations

CDOP	Continuous Development and Operations Phase
CDR	Climate Data Record
DMI	Danish Meteorological Institute
ECMWF	European Centre for Medium-range Weather Forecasts
EDC	EUMETSAT Data Centre (former UMARF)
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites
GNSS	Global Navigation Satellite System
GPAC	GNSS Processing and Archiving Center (ROM SAF)
GPS	Global Positioning System (US)
GRAS	GNSS Receiver for Atmospheric Sounding (Metop instrument)
IEEC	Institut d'Estudis Espacials de Catalunya (Spain)
ICDR	Interim Climate Data Record
LEO	Low Earth Orbiter
Metop	Meteorological Operational Polar satellite (EPS/EUMETSAT)
NRT	Near-Real Time
NWP	Numerical Weather Prediction
RO	Radio Occultation
ROM SAF	Radio Occultation Meteorology SAF (EUMETSAT), former GRAS SAF
SAF	Satellite Application Facility (EUMETSAT)
UKMO	The UK Meteorological Office (aka: Met Office)
UMARF	Unified Meteorological Archive & Retrieval Facility (EUMETSAT)
WMO	World Meteorological Organisation

1.3   Definitions

RO data products from the Metop and Metop-SG satellites 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[2]. 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) 150 min after measurement (SAF online products for EPS-SG Global Mission); (iii) 125 min after measurement (SAF online products 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[3]. 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[4].

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[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)

1.4 Overview of this document

This document is organized as follows:

Chapter 1: Contains the introduction

Chapter 2: Contains a very brief summary of the processing from the RO basic observables to higher level data

Chapter 3: Contains the detailed description of the TPH algorithm

Chapter 4: Contains a discussion of some limitations for the algorithm

Chapter 5: Description of differences for NRT, Offline and Reprocessing

Annex A: Contains information about the source code

2. Background

A radio occultation (RO) instrument onboard a low-Earth orbit (LEO) satellite, e.g. the GRAS instrument onboard Metop, measures the L1 and L2 Doppler shifted radio signals from a GNSS satellite as the satellite sets or rises behind the Earth's limb. Through a rather complex sequence of processing steps the Doppler shift as a function of time is converted to neutral-atmosphere profiles of bending angle, refractivity, dry pressure and dry temperature, and finally to 1D-Var pressure, temperature, and humidity. The latter three quantities require *a priori* information taken from an atmospheric model. *A priori* data are also used for bending angle initialization in order to retrieve refractivity.

Comprehensive descriptions of how the primary observables, phase and amplitude of the Doppler shifted signals, are processed to atmospheric profiles can be found in [RD.1, 2, 3].

3. Tropopause Height

The tropopause height (TPH) is most often derived from the rate of decrease of temperature with height, the lapse-rate.

In the ROPP processor apps module, the TPHs are derived via the tool: `ropp_apps/tools/ropp_apps_tph_tool` which allows diagnosing the TPHs from profiles of bending angle (level 1B product), refractivity (level 2A), dry temperature (level 2A) or (wet) temperature (level 2B). For each of the two temperature-based TPH's two tropopause estimates are produced; one based on the lapse-rate and one based on the cold point.

The operational ROM SAF TPH product is defined to be the dry temperature lapse rate which is described in this document. The dry temperature lapse rate TPH is based on the standard WMO lapse-rate criterion and validation against other TPH results (radiosondes) is simple. Information on the other TPHs (internal products) can be found in the ROPP documentation [RD.10].

In [RD.6] (T. Schmidt, VS 22) some recommendations are listed regarding the TPH algorithms. One of the points raised in [RD.6], was to search for a TPH/CPT between 500 hPa and 70 hPa only. Instead of the 500 hPa and 70 hPa limits recommended, a latitude dependent TPH min and max height has been implemented (See Sec. 3.2 point 2). In [RD.6] it is also recommended to limit the cold point tropopause product to be nominal in the tropics (-30 deg to +30 deg), (implemented) and to add variables for recording the overall temperature minimum and height for all profiles (not implemented). Furthermore, [RD.6] recommends not to disregard cases with multiple tropopauses. This has also been implemented, but only the lowest (height) tropopause is reported.

3.1 Description of algorithm

The algorithm is developed to derive the TPH according to the WMO definition, where TPH is defined as "the lowest level at which the lapse-rate (Γ_{WMO}) decreases to 2° C/km or less, provided that the average lapse-rate between this level and all higher levels within 2 km does not exceed 2° C/km." [RD.4]

The lapse rate method described by Reichler et al. (2003) [RD.5] is applied. The algorithm uses a thermal definition of the tropopause, based on the concept of a threshold lapse-rate. Interpolation is performed to identify the pressure at which this threshold is reached and maintained. In the event of multiple vertical levels meeting these criteria, the tropopause is assigned to the lowest position of occurrence. Furthermore, the derived tropopause height must be within a latitude dependent height range corresponding to approximately 75 hPa to 550 hPa to be accepted.

The algorithm is expressed in terms of pressure, which is not available as level 2A field in ROPP. Thus, dry pressure calculated from refractivity and dry temperature (both level 2A) is used in the steps below as proxies for the full pressure and temperature. [RD.3]

3.2 Processing steps

Below the main steps in the algorithm are described.

1. Ensure that the geometric heights (h_i) are in ascending order and that enough level 2a data exist. If not, return to `ropp_apps_tph_tool`

2. Check numerical and scientific robustness of the input temperature.
   2.1) There must be at least three temperature – refractivity pairs (T_i, N_i) of valid data and a valid latitude value defined. This is a technical limit, profiles with only two or less valid data points will be excluded in the following steps.
   2.2) The geometric heights (h_i) must start below or at $TPH_{min} = 2.5(3 + \cos(2 * lat))$ and
   2.3) continue to or above $TPH_{max} = 2.5(7 + \cos(2 * lat))$

3. Calculated dry pressure (p) from the refractivity (N) and dry temperature (T) using: $p = \frac{NT}{\kappa_1}$. The standard value [RD.8] of $\kappa_1 = 77.6x10^{-2}\ KPa^{-1}$ is used here. Recent studies have indicated the need for a small revision of the values, and have shown a weak dependence on deviations from the ideal gas law [RD.7]. When using a non-ideal gas law in applications that include forward modelling from model data, the coefficient u sed is instead $\kappa_1 = 77.643x10^{-2}\ KPa^{-1}$ [RD.9]. This small change of coefficient will cause a change of the derived TPH of only a few meters.

4. Smooth pressure and temperature profiles according to

$$T_i \rightarrow \frac{T_{i-1} + T_i + T_{i+1}}{3}$$
$$p_i \rightarrow \frac{p_{i-1} + p_i + p_{i+1}}{3}$$

5. Calculate Exner pressure (Π)

$$\Pi_i = \left(p_i/p_{ref}\right)^{\kappa}\text{where } \kappa = R_{dry}/C_p \approx 0.285$$

R_{dry} and C_p being the dry air specific gas constant and heat capacity, and calculate lapse rate (Γ)

$$-\Gamma_{i+1/2} = \left(-g/C_p\right)\frac{T_{i+1} - T_i}{\Pi_{i+1} - \Pi_i}\frac{\Pi_{i+1}+\Pi_i}{T_{i+1}+T_i}$$

6. Go through the profile and for each point (i): if $-\Gamma_{i+1/2}$ and the average over the 2 km above is greater than $-\Gamma_{WMO}$ = -2 K/km and the previous,$-\Gamma_{i-1/2}$,is less than $-\Gamma_{WMO}$, so that points i-1/2 and i+1/2 enclose the critical lapse rate, then the first estimate of the index of the lapse rate tropopause is taken to be i.

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7. Calculate TPH by linear interpolation of Γ with Π, followed by linear interpolation of $log(p)$ with height h.

$$2\Pi_{tph} = (\Pi_i + \Pi_{i-1}) + \frac{\Pi_{i+1} - \Pi_{i-1}}{\Gamma_{i+1/2} - \Gamma_{i-1/2}}\left(\Gamma_{WMO} - \Gamma_{i-1/2}\right)$$

$$p_{tph} = p_{ref}\Pi_{tph}^{1/\kappa}$$

$$h_{tph} = h_{i-1} + \frac{h_i - h_{i-1}}{log(p_i/p_{i-1})}log\left(p_{tph}/p_{i-1}\right)$$

$$T_{tph} = T_{i-1} + \frac{T_i - T_{i-1}}{log(p_i/p_{i-1})}log\left(p_{tph}/p_{i-1}\right)$$

8. Check that the derived TPH is within the range TPH_{min} to TPH_{max} as defined above in step 2.

9. Overall profile minimum temperature and its geometric height are calculated.

10. Fill quality flags, lapse rate TPH and dry temperature at the TPH, and the entire profile heights and temperatures to their equivalents in the ROPP structure.
Thus, the dry temperature derived TPHs are on geometric heights.

In step 6 above, the cold point tropopause is also calculated, as being the height of the minimum temperature between TPH_{min} and TPH_{max}. If this height differs by more than 2 km from h_{tph} , then use the minimum temperature in the height interval $h_{tph} \pm 2km$. Note that the cold point TPH is not an operational ROM SAF product, and that the cold point definition of THP is not meaningful outside the tropics.
Therefore, at latitudes polewards of 30º, a bit is set to the cold point TPH QC flag and a missing value to the cold point TPH variable.

3.3   Quality control

The TPHs are associated with a 'bit-wise' encoded quality control flag as described in the ROPP documentation. [RD.3]

The flag is initialised at ropp_MIFV=-999, and otherwise encoded bit by bit as:

$$tph\_qc\_flag = \sum_{r=0}^{7} l(r)2^r$$

The 8 components (r) are described as:

   r=0 Input data validity check
   r=1 Input data depth check

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r=2 Input data height check
r=3 Covariance transform sharpness above TPH check
r=4 Covariance transform sharpness below TPH check
r=5 Double tropopause height
r=6 TPH minimum height check
r=7 TPH maximum height check

The value $l(r)$ is 0 if the check is passed or irrelevant and 1 if the data check is not ok, e.g., if the derived dry temperature TPH is below the minimum accepted height, then $l(6) = 1$ and this bit contributes with $2^6 = 64$ to the *tph_qc_flag*

The relevant components for the dry temperature derived TPH are $r = 0,1,2,6$ and 7:

r=0 relates to step 2.1 in section 3.2
r=1 relates to step 2.2
r=2 relates to step 2.3
r=6 and *r=7* relates to step 8 in section 3.2

If the QC flag is zero, the diagnosed TPH is considered to be good, any other values indicate some problems with the integrity of the derived TPH, problems that can be identified using the value of *tph_qc_flag*.

QC flags are copied to the ROPP variable: ro_data%lev2c%tph_tdry_lrt_flag

4. Assumptions and limitations

The dry temperature lapse rate tropopause depends on the vertical resolution of the profile which will lead to differences between model and observation tropopauses. Especially in double tropopause cases the observational dry temperature and model dry temperature may occasionally "catch" different tropopause estimates.

5. Description of differences for NRT, Offline CDR and ICDR

The algorithm is the same for all four types of processing.

Appendix A

A.1 Running the program

Calling the ROPP module for calculating TPH:

```
ropp_apps_tph_tool  <inputROPPfile> -o <outputROPPfile>
```

Options:

-o	<output_file>	name of ROPP netCDF output file
-b		calculate bending angle-based TPH only
-n		calculate refractivity-based TPH only
-y		calculate dry temperature-based TPH only
-t		calculate temperature-based TPH only
-h		help
-d		output additional diagnostics
-v		version information

If none of the -b,-n,-y or -t options are specified, the tool will attempt to calculate all four TPHs.

All TPHs are present in output netCDF file, if not calculated then filled with missing values.
If -d option is present the lapse rate (section 3.2, step 5) and corresponding geometric heights are added to the output file.

A.2 Input files

Input data: For any GNSS RO satellite sensor supported: profiles of bending angle, refractivity, dry temperature or temperature

NRT:

The NRT file name version is the filename version that is used in the NRT processing chain, for both level 1 and level 2 products. It contains 6 fields separated by underscores:

<TYPE><DATE>_<TIME>_<MISSION_ID>_<OCC_ID>_<MODE><SWVER>_<FREEE>.<EXT>

Where:

- <TYPE> can be one of "atm", "bfr", "bgr", "dis", "occ" or "wet"
  For the calculation of TPH the following types are used.
  "atm" files contain ROPP level 1A and 2A data, necessary for calculating dry temperature TPH (as well as bending angle TPH, refractivity TPH)

"occ" files contain ROPP level 1A data, necessary for bending angle TPH

"wet" files contain ROPP level 2B data, necessary for (wet) temperature TPH

- <DATE>_<TIME> is the start date and time of the observation, as YYYYMMDD_HHMMSS.
- <MISSION-ID> is the EPS name of the observing satellite.
- <OCC_ID> is the occultation id (EPS format which includes id of occulting satellite)
- <MODE> is the processing mode and one of "N" (Near Real Time), "T" (Test), "V" (Validation).
- <SWVER> is a four digit code denoting the system software version
- <FREE> is a free field, "XXXX"
- <EXT> is the extension, "nc" for NetCDF, "bin" for BUFR

Offline:

The offline level 1 and 2 file name version is the filename version that is used in the offline and re-processing chain. It contains 8 fields separated by underscores:

<TYPE>_<DATE>_<TIME>_<MISSION_ID>_<OCC_ID>_<MODE><SWVER>_<FREE>.<EXT>

Where:

- <TYPE>, <DATE>_<TIME>, <MISSION-ID>, <SWVER>, and <EXT> is as explained above.
- <OCC_ID> is an ID that identifies the GNSS satellite used for the specific occultation.
- <MODE> is the processing mode and one of "O" (offline), "R" (Reprocessing), "T" (Test), "V" (Validation)

A.3 Outputs

The output variables in the ROPP structure (ro_data%lev2c%):

tph_tdry_lrt	Dry temperature-based TPH derived from lapse rate
tpt_tdry_lrt	Tropopause dry temperature, based on tph_tdry_lrt
tph_tdry_lrt_flag	Dry temperature-based TPH QC flag (lapse rate)
tph_bangle	Bending angle-based TPH
tpa_bangle	Tropopause bending angle, based on tph_bangle
tph_bangle_flag	Bending angle-based TPH QC flag

tph_refrac	Refractivity-based TPH
tpn_refrac	Tropopause refractivity, based on tph_refrac
tph_refrac_flag	Refractivity-based TPH QC flag
tph_tdry_cpt	Dry temperature-based TPH derived from cold point
tpt_tdry_cpt	Tropopause dry temperature, based on tph_tdry_cpt
tph_tdry_cpt_flag	Dry temperature-based TPH QC flag (cold point)
tph_temp_lrt	Temperature-based TPH derived from lapse rate
tpt_temp_lrt	Tropopause temperature, based on tph_temp_lrt
tph_temp_lrt_flag	Temperature-based TPH QC flag (lapse rate)
tph_temp_cpt	Temperature-based TPH derived from cold point
tpt_temp_cpt	Tropopause temperature, based on tph_temp_cpt
tph_temp_cpt_flag	Temperature-based TPH QC flag (cold point)