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CDOP Visiting Scientist Report 16:
Implementation of ROSA radio occultation data handling into EUMETSAT and GRAS SAF processing

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The study was performed during November 2011 – February 2012 and included two stays at EUMETSAT Headquarters, Darmstadt, Germany and one longer stay (January 2012) at the Danish Meteorological Institute, Copenhagen, Denmark.

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Executive Summary

Topic of the GRAS-SAF Visiting Scientist activity 16 has been the implementation of ROSA radio occultation data handling into EUMETSAT and GRAS SAF processing tools. ROSA data referred to observations taken on-board OCEANSAT-2 mission. Even if we are talking of standard Radio Occultation data, the format of raw binary data is peculiar, and processing chains already implemented for other Radio Occultation missions, should be adapted to this further format. Moreover, ROSA antennas, ROSA coverage, ROSA sampling rate, etc. are different from GRAS or COSMIC data. Main goals of this VS activity have therefore been the implementation of ROSA processing into the EUMETSAT YAROS prototype (in order to produce excess-phases, amplitudes and bending angles over impact parameter) and into the GRAS SAF ROPP processor (for the processing into bending angle, refractivity and higher level atmospheric profiles), dealing mainly with data interfacing issues.

The first part of the activity was carried out in EUMETSAT, where the YAROS prototype has been adapted to handle ROSA data. Before doing that, an in-depth analysis has been done in order to identify all the ROSA data characteristics and issues. In particular, the Thales Alenia Space "decoding" software has been completely review, in order to understand how these data were formatted inside the native binary ROSA data stream coming from the OCEANSAT-2 telemetry, and inside the standard Level1 Engineered data file available for users. This preliminary analysis allows the definition of several ROSA data structures that could be easily implemented directly inside the YAROS prototype. At the end of this first part, two different releases of the EUMETSAT prototype were available: the first one able to manage only the scientific ROSA engineered data, containing the basic observables for Radio Occultation purposes (the Level 1a data, the one normally made available for users); the second one which implements ad-hoc data structures where all the data generated by the ROSA receiver (and contained in the raw binary format, the Level 0 data) are stored.

About thirty hours of ROSA observations, for which orbit and clocks were already available, were used as input to the adapted YAROS/ROSA prototype and completely analyzed. Only the YAROS prototype adapted to ROSA Engineered Level 1 format was used. A quality check of L1 and L2 basic observables (mainly L1 and L2 Excess-Phase and Signal-to-Noise ratio profiles) contained in the Level 1a YAROS output file has been performed. Even if a complete ROSA dataset is available for one entire month of observations, the production of all the necessary POD products for the entire month was not undertaken. Its in-depth analysis will be carried out in the future, when the Memorandum of Understanding between Italian Space Agency and EUMETSAT for the ROSA data processing will be signed. During this activity we preferred to concentrate the work on the YAROS prototype adaptation to ROSA data, making the prototype ready to handle all the ROSA data available, and not only the one contained in the Level1 Engineered data normally available to the user.

In order to let these NetCDF Level1a YAROS/ROSA output files to be further processed into higher Radio Occultation products, a converter from NetCDF 4.0 to NetCDF 3.0 file (with the required data structures correctly set for the GRAS-SAF ROPP processing). This was performed during the second part of the Visiting Scientist activity at DMI, where YAROS/ROSA Level 1a files were both processed to bending angles, to refractivity and higher level products. Analysis of the bending angle and refractivity data against ECMWF and collocated radio occultation data were also performed, in order to have a preliminary idea on the quality of the final atmospheric products that can be achieved analyzing ROSA data. Moreover, YAROS/ROSA Level 1a files were also processed into Level 1b products (bending angle profiles) using the L1a2L1b YAROS code and compared with the correspondent forward modelled ECMWF collocated data.

As a general comment on the ROSA data quality it has to be noted that, even thought L1 data are in line with that observed by the other Radio Occultation instruments, L2 data shows some problems. Problems which are mainly related to OCEANSAT-2 issues. ROSA on-board OCEANSAT-2 was equipped only with the Velocity Radio Occultation antennas, therefore only rising events can be recorded. Moreover local multipath on-board OCEANSAT-2 is very strong because of solar panels

and because of the scatterometer antenna which both are moving. In particular this local multipath was not modelled or measured on ground, since an in-orbit platform manoeuvre was made necessary and created a permanent and unexpected yaw bias on the platform. And these problems mainly impact L2 tracking, which basically starts too high in atmosphere and which is affected by long data gaps. Only for a small number of events L2 is available in troposphere. In these cases, the quality of atmospheric profiles retrieved using the GRAS-SAF ROPP processing chain is in line with that obtainable from other Radio Occultation missions. But, for all the other cases for which L2 is available higher in the atmosphere, modifications to the L2 extrapolation/interpolations and different Statistical Optimization setting are probably necessary to adapt the GRAS-SAF ROPP_PP Processor to such bad data. From the other point of view, YAROS software correctly handle such ROSA data, even if a high number of rejected profiles are seen with respect what normally happens in processing data from other Radio Occultation observations.

1. Introduction

1.1 Purpose of document

This document summarizes all the activities carried out during the GRAS-SAF Visiting Scientist 16. The document is divided in two main parts. In the first one a summary of ROSA data and instrument is provided. Detailed description of ROSA native and engineered data structures is given in Chapter 2, while Chapter 3 deals with the description of the Thales Alenia Space software tool used to transform binary native data into ROSA Level 1a data. In this chapter, details about the improved releases of this software produced during this Visiting Scientist activity are also given. The first part ended with Chapter 4, which contains an overview of the OCEANSAT-2 platform from the point of view of the Radio Occultation and POD antennas positions with respect to the OCEANSAT-2 Center of Gravity. The second part of the document deals with the handling of ROSA data processing using the EUMETSAT YAROS prototype and the GRAS-SAF ROPP processing chain. The changes implemented inside the YAROS prototype in order to make it able to process ROSA data are described in Chapter 5, while the adaptation of YAROS Level1a ROSA output products to GRAS-SAF ROPP NetCDF input format are overviewed in Chapter 6. ROSA data quality analysis and preliminary results obtained comparing ROPP output and YAROS output to independent collocated profiles (coming from ECMWF or other Radio Occultation profiles) is the topic of the last Chapter 7.

1.2 References

[RD1] "ROSA Instrument Operating Manual" - RD1 – issued by Thales Alenia Space on Dec 2008.

[RD2] "ROSA for OCEANSAT-2 Level 1 Data Processor User Manual" - O2-AASI-MAN-0004-3 – issued by Thales Alenia Space on July 2010.

[RD3] "ROSA on OCEANSAT-2 in flight data format analysis – Technical Note" – O2-AASI-TNO-0004-1 – issued by Thales Alenia Space on May 2011.

[RD4] "ROSA ROSSA – ROSA Data Processing Center Product Specification" – ISMB-ASI-RSA-SPE-001 – Issued by ISMB on April 2010.

[RD5] Fuggetta G., Marradi L., Zin A., Landenna S., Gianell G.M., "Rosa Instrument and Antenna", Paper presented at GNSSRO Pasadena, CA, April 2008.

[RD6] Zin A. S. Landenna, I. Rossi, L. Scaciga, S. Zago, G. Perona, R. Notarpietro, F. Vespe, V. DeCosmo, "Rosa Radio Occultation Sensor: Testing, Performance And Accommodation Aspects On Board Oceansat-2", Navitech, Toulouse, Apr 2008.

2. ROSA Data Structure

ROSA raw data observed from OCEANSAT-2 are coded and interfaced with the satellite bus using the standard MIL-STD-1553B interface. Such data are then merged with observations acquired by all the other OCEANSAT-2 payloads and downloaded to the ground stations through the satellite telemetry channel. At the ground segments, ROSA data are separated from those derived by the other instruments and re-coded in the native binary format (derived by MIL-STD-1553B standard).

All the details of raw binary data formats are described in the document [RD1] provided by TAS-I. Just to give a brief introductory summary it has to be noted that all the data are transferred in packet form with a specific structure as determined by their packet type. Three packet types are implemented:

• **TYPE 1**

They contain *general information* which can be exchanged between the ROSA and the Host satellite and are used in a polling fashion to send information packets to the receiver (e.g.: change a parameter, select a mode, etc.) and get information from the receiver (i.e. current parameter settings, mode selection, diagnostic data, etc.).

• **TYPE 2**

They contain the *Periodic data* observed by the receiver. They are the Scientific data, are composed by Navigation data and Observation Data and are transmitted to the Host satellite at predefined rate.

• **TYPE 3**

These packets are *discrete commands*, used for Operational Mode changes.

Scientific data are therefore supplied by packet **TYPE 2**. Different packets are provided:
• Health & Status packet (packet ID 0xA0)
• Navigation Solution & Space Vehicle Observables Data packet, (packet ID 0xA1)
• Occultation Data packet, (packet ID 0xA2)
• Observation Data packets, (packet ID 0xA3)

Packet 0xA1

Packet 0xA1 is the main output from ROSA; it comprises two main blocks:
- Navigation Solution data. Every second the Navigation Solutions are prepared in two different formats:
• SPS solution, ECEF frame
• NKF solution, ECI frame
- The results of the measurements made by the ROSA instrument on the received GPS signals (Observables data). Three different conditions are foreseen:
• Navigation (1 Hz sampling data rate)
• Observation (close loop) (1 Hz, 10 Hz and 50 Hz sampling data rate)
• Occultation (open loop) (100 Hz sampling data rate)
Since this packet has 1 Hz data rate transmission, Radio Occultation data are stored using another packet (the 0xA3). All the details of such data are shown in the Table provided in the ROSA Instrument Operating Manual [Table pag 112-115 of RD1].

Packet 0xA2

Packet 0xA2 comprises information of the elevation\azimuth of the entire GPS constellation. It is therefore useful to follow the strategy adopted by the receiver in the occultation process.

Packet 0xA3

For the Observation channels (Packet 0xA3) there are different SV Data Sub-Blocks according to the different main observing strategies foreseen (close loop or open loop).
Furthermore, the acquisition frequency of each Observation channel depends on different factors:

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A) Event type: Navigation events are nominally acquired at 1 Hz, while for Observation (i.e. Occultation) events, following cases exist:

Altitude [km]	Sampling Rate [Hz]	
	Close loop	Open loop
800-200	1	N/A
200-50	10	N/A
50-P(*)	50	N/A
P(*)-0	50	100

(the Altitude here is intended to be the Estimated ray tangent altitude derived by climatology, P(*) is a user definable value that can be set through telecommands. It is actually set to 12 km SLTA).

B) For each occulted GPS SV tracked in Close Loop, the receiver selects a reference GPS satellite (pivot SV) and provide observations of this reference GPS SV <u>at the same sampling rate of the occulted GPS SV</u>. Considering all the SV signals tracked by the receiver and acquired by the same ROSA antenna panel (if not available by the other antenna panel), a reference (pivot) SV is set:
- for rising events, when the Close Loop channel is started
- for setting events, when the altitude of the occulted satellite is under 50 km.
While it is reset:
- for rising events, when the altitude of the SV is over 50 km
- for setting events, when the when the Close Loop channel is stopped.

An ad- hoc software developed by TAS-I (the telemetry decoding SW) performs the generation of several "engineered" output files (the Level 1 files) containing data extracted from type 0xA0, 0xA1, 0xA2 and 0xA3 ROSA telemetry packets.

These files are of two basic types:
- OPERATIVE: formatted packet data (Rinex 2.10 or tabular) for scientific use.
- DEBUG: reserved mode containing additional debug data.
Each ROSA binary file taken by telemetry produces one set of Operative and Debug Output files.
Data are time sorted and start/stop times are corresponding to start/stop times in telemetry data.
Hereafter some further details related this engineered data files are given.

2.1 Operative (OBSERVATION) Level 1 Data Files

The operative output files are of 5 types (5 output files):
- Navigation solution data (Tabular ASCII format)
- Navigation POD data (Rinex 2.10 format)
- Observation Low Rate data (Rinex 2.10 format)
- Observation High Rate data (Rinex 2.10 format)
- Observation Open loop data (Rinex 2.10 format)

The content of these data files are detailed in several documents provided by TAS-I [RD1 and RD2]. In what follows, an overview is given.

2.1.1 Navigation Solution Data

The navigation solution is provided both applying Least Square techniques (solution called "SPS") and a Kalman Filter algorithm (solution called "NKF"). The two solutions run in parallel during receiver operational phases. The SPS solution provides the first fix as soon as the minimum number of GPS SVs is available after receiver initialization and then the NKF is started.

Original data are stored in the **0xA1** Navigation Solution & Space Vehicle Observables Data packet. An ASCII tabular format is used to [RD2].

Quantity	Units	Format
		Date and time format string (YYYY/MM/DD hh:mm:ss.nnnn)
Time_sec	[s]	10 base integer
Time_nsec	[ns]	10 base integer
Tracked_SVs		10 base integer
DoingSPS		10 base integer
DoingNKF		10 base integer
NumOfSPSSVs		10 base integer
NumOfNKFSVs		10 base integer
PDOPValue		float
SPS_X_Pos	[m]	float
SPS_Y_Pos	[m]	float
SPS_Z_Pos	[m]	float
SPS_X_Vel	[m/s]	float
SPS_Y_Vel	[m/s]	float
SPS_Z_Vel	[m/s]	float
SPS_ClockBias	[m]	float
SPS_ClockBiasRate	[m/s]	float
SPS_TimeTagSec	[s]	10 base integer
SPS_TimeTagnSec	[ns]	10 base integer
NKF_X_Pos	[m]	float
NKF _Y_Pos	[m]	float
NKF _Z_Pos	[m]	float
NKF _X_Vel	[m/s]	float
NKF _Y_Vel	[m/s]	float
NKF _Z_Vel	[m/s]	float
NKF _ClockBias	[m]	float
NKF _ClockBiasRate	[m/s]	float
NKF _TimeTagSec	[s]	10 base integer
NKF _TimeTagnSec	[ns]	10 base integer

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It has to be noted that
- Reference Frame for NKF solution is ECI True of Date
- Reference Frame for SPS solution is ECEF
- Time Tag: Receiver Internal Time of Navigation solution (i.e. NOT GPS System Time).

Data output rate is 1 Hz.

File name convention:
NAV_POD_SOL_<YYYYMMDD_hhmmss_start_data>_<YYYYMMDD_hhmmss_end_data>.out
(it can be managed from the TAS-I telemetry decoding SW, but the default is the one here shown).

2.1.2 Navigation POD Data

These data refer to the data acquired by the ROSA Navigation antenna. They are necessary for carrying out the POD of OCEANSAT-2. The format is standard Rinex 2.10. The data are provided at a frequency of 1 Hz. The data File content is detailed in the following table, provided by TAS-I [RD1]. Original data are stored in the **0xA1** Navigation Solution & Space Vehicle Observables Data packet.

Quantity	Rinex Observable Code	Units	Format	Precision (C language output format specification)
Pseudorange L1 C/A	C1	[m]	float	14.3
Pseudorange L1 C/A signal quality	N.A.		10 base integer	
Pseudorange L2 P(Y)	P2	[m]	float	14.3
Pseudorange L2 P(Y) signal quality	N.A.		10 base integer	
Carrier phase L1 (from tracking loop L1 C/A)	L1	[cy]	float	14.3
Carrier phase L2 (from tracking loop L2 P(Y))	L2	[cy]	float	14.3
SNR L1	S1	[dB-Hz]	float	14.3
SNR L2	S1	[dB-Hz]	float	14.3

It has to be noted that Time Tag is the Receiver Time (i.e. NOT GPS System Time).
Pseudorange L1 C/A and L2 P(Y) signal qualities are defined in the description of Observation Low Rate data given here below.

Data output rate is 1 Hz.

File name convention:
NAV_POD_OP_<YYYYMMDD_hhmmss_start_data>_<YYYYMMDD_hhmmss_end_data>.out
(it can be managed from the TAS-I telemetry decoding SW, but the default is the one here shown).

2.1.3 Observation Low Rate data

This file contains data taken both by the POD antenna and the RO antenna. In particular, data from each channel in tracking (up to 16 channels) are found in this file. Note that this file contains also the L1 C/A and L2P channels status, necessary for a first quality check of data.
Full sample rate data for occultation and Open-loop data can be found in the remaining two Level 1 files (Observation High Rate and Open Loop data described hereafter). Discrimination of data recorded by the POD antenna and by the RO antenna can be done for example by looking at elevation/azimuth couples.
The format is standard Rinex 2.10. The data File content is detailed in the following table, provided by TAS-I [RD2]. Original data are stored in the **0xA3** Observation Data packets.

Column	Rinex Observation Code	Units	Format	Precision (C language output format specification)
Pseudorange L1 C/A	C1	[m]	float	14.3
Pseudorange L1 C/A signal quality	N.A.		10 base integer	
Pseudorange L2 P(Y)	P2	[m]	float	14.3
Pseudorange L2 P(Y) signal quality	N.A.		10 base integer	
Istantaneous Doppler L1[2]	D1	[m/s]	float	14.3
Istantaneous Doppler L2	D2	[m/s]	float	14.3
SNR L1	S1	[dB-Hz]	float	14.3
SNR L2	S2	[dB-Hz]	float	14.3
Elevation	EL	[deg]	float	14.3
Azimuth	AZ	[deg]	float	14.3
GIP	GI	[m]	float	14.3
AGC L1	A1		float	14.3
AGC L2	A2		float	14.3
Channel ID	CI		float	14.3
L1 C/A status	L2		float	14.3
L1 P status	1P		float	14.3
L2 P status	2P		float	14.3

Just to clearly identify some of the variable meanings:

- **Istantaneous Doppler** is computed considering the pseudorange rate

- **Pseudorange L1 C/A signal quality** is an integer number varying from 0 to 9 which reflects the signal strength. It is computed considering that SNR L1 is a quantity that should vary between 28 dB-Hz and 55 dB-Hz. Each measured SNR L1 value is linearly interpolated (and rounded to the nearest integer) on a scale of integer number varying between 0 and 9.

- **Pseudorange L2 P(Y) signal quality** is an integer number varying from 0 to 9 which reflects the signal strength. It is computed considering that SNR L2 is a quantity that should vary between 14 dB-Hz and 50 dB-Hz. Each measured SNR L1 value is linearly interpolated (and rounded to the nearest integer) on a scale of integer number varying between 0 and 9.

- **L1 C/A status** indicates the tracking status of the channel defined by the following table (pag. 117 of the ROSA Instrument Operating Manual [TAS-I document RD1]):

L1CA Tracking status

Nr.	Name	Description
0	IDLE	The channel is not used
1	WAIT_START	The channel is occupied by a rising event that will start at the next ME=49
2	SIG_SHIFT	For occultation channels only, waiting for the synchronization with ME=0
3	SIG_HOLD	Bit synchronization found, wait during the first symbol, to align the interrupt with the bit edge
4	SIG_SEARCH	Acquisition state, searching the power peak
5	CODE_CHECK	DLL closure after the acquisition state
6	CARR_CHECK	FLL closure after the first DLL closure
7	SIG_CHECK	DLL only for setting CL channels
8	SIG_TRACK	PLL closure, waiting for the bit synchronization
9	LONG_INT	Bit synchronization reached, full track
10	SIG_WAIT	DLL loss from SIG_TRACK or SIG_HOLD
11	WAIT_LONG	DLL loss from LONG_INT
12	FIRST_LONG_INT	Transition from SIG_TRACK to LONG_INT
13	LAST_LONG_INT	Transition from LONG_INT to SIG_TRACK in case of frame synch non found

A value of '9' (long integration on 20 msec integration ntime and bit/frame synchronization reached) indicates that the Receiver channel is tracking a satellite signal and therefore the corresponding measurements in the observables fields are valid. Even if all the other values indicate that the

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measurement is not fully "completed", TAS-I suggested that observables for which L1 C/A tracking status is equal to '8' (short integration on 1 msec integration time) can be safely used.
- **L1 P status** indicates the tracking status of the P code on L1 (possible values 0 or 1)
- **L2 P status** indicates the tracking status of the P code on L2 (possible values 0 or 1)
- **GIP** is synonym of SLTA
- **azimuth** = 0 deg indicates the LEO velocity direction while azimuth = 180 deg indicates the Anti-velocity direction. Azimuth is positive according to the right-hand rule in the RTN system, i.e. from T to N. **Elevation** is the negative elevation angle counted from the Local Horizon as in the following figure.
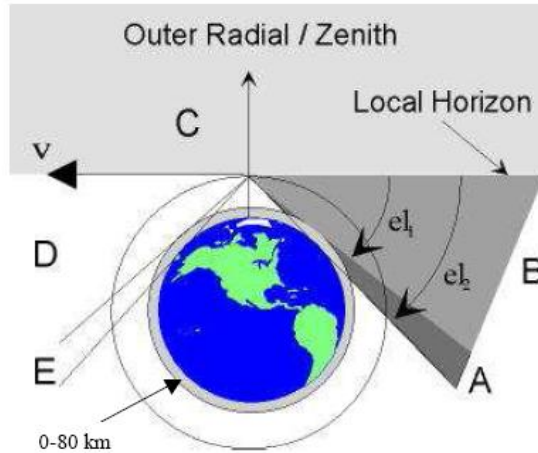
It has to be noted that Time Tag is the Receiver Time (i.e. NOT GPS System Time).

Also in this case, data output rate is 1 Hz.

File name convention:
OBS_LR_OP_<YYYYMMDD_hhmmss_start_data>_<YYYYMMDD_hhmmss_end_data>.out
(it can be managed from the TAS-I telemetry decoding SW, but the default is the one here shown).

2.1.4 Observation High Rate data

The data contained in this file correspond only to observations performed by the RO antenna. The format is standard Rinex 2.10. The data File content is detailed in the following table, provided by TAS-I [RD2]. Original data are stored in the **0xA3** Observation Data packets.

Column	Rinex Observation Code	Units	Format	Precision (C language output format specification)
Istantaneous Doppler L1	D1	[m/s]	float	14.3
Istantaneous Doppler L1 signal quality	N.A.		10 base integer	
Istantaneous Doppler L2	D2	[m/s]	float	14.3
Istantaneous Doppler L2 signal quality	N.A.		10 base integer	
Carrier phase L1	L1	[cy]	float	14.3
Carrier phase L2	L2	[cy]	float	14.3
Signal power L1	S1		float	14.3
Noise power L1	N1		float	14.3
Signal power L2	S2		float	14.3
Noise power L2	N2		float	14.3

Istantaneous Doppler L1 and L2 signal quality are not stored in the Rinex file. Signal and Noise Power definition is given hereafter, in Section 2.3.

It has to be noted that Time Tag is the Receiver Time (i.e. NOT GPS System Time).

The sample rate of each observation depends on different factors, as already discussed previously (pag. 6 of the present document).

File name convention:
OBS_HR_OP_<YYYYMMDD_hhmmss_start_data>_<YYYYMMDD_hhmmss_end_data>.out
(it can be managed from the TAS-I telemetry decoding SW, but the default is the one here shown).

2.1.5 Observation Open Loop data

These data are supplied in an ad-hoc Rinex format and correspond to observations performed by the RO antenna when the receiver is in raw sampling (open loop) tracking. The data File content is detailed in the following table, provided by TAS-I [RD2]. Original data are stored in the **0xA3** Observation Data packets.

Column	Rinex Observable Code		Format	Precision (C language output format specification)
Estimated Doppler	D1	[m/s]	float	14.3
Complex I	I1		float	14.3
Complex Q	Q1		float	14.3

Estimated Doppler is the value computed by the on-board climatological model that drives the carrier NCO . I and Q are the sampling of the correlators @ 100 Hz.

Time Tag is the Receiver Time (i.e. NOT GPS System Time).

The sample rate is 100 Hz.

File name convention:
OBS_OL_OP_<YYYYMMDD_hhmmss_start_data>_<YYYYMMDD_hhmmss_end_data>.out
(it can be managed from the TAS-I telemetry decoding SW, but the default is the one here shown).

2.2 DEBUG Level 1 Data Files

The TAS-I telemetry decoding SW, which is responsible for the generation of "engineered" Level 1 ROSA output files, produces also another set of data files (the "debug" DBG files) which were originally reserved for internal use only. Such files contain all the data stored into the Operative files (described in Sect. 2.1) and some further informations. Seven different DBG files, formatted on an ASCII tabular way, are generated:

- Navigation Health and Status file
- Navigation Observable Data Block file
- Fast Acquisition Information for each Channel file
- LNA signal and CPU load file
- Space Vehicle Information file
- Close Loop Observation from Occultation Antenna file
- Open Loop Observation from Occultation Antenna file

All the details describing the data contained in such files are given in the ROSA Instrument Operating Manual [RD1]. A small summary is given here>

2.2.1 Navigation Health and Status file

Such data contain Health and Status ROSA Receiver parameters, and are defined in the 0xA0 Packet of the ROSA Telemetry. Their description is contained in Sect 6.2.1 Health & Status Packet of [RD1]. Some of these data are also replicated in the Navigation Solution & Space Vehicle Observables Data packet (packet ID 0xA1) [Sect 6.2.2 of RD1].
They are available at a 1 Hz sample rate.
They are stored in the **NAV_HS_DBG** Debug file

Time_sec Time_nsec RealTimeFailure SWModuleStatus EEPROMFailure RAMFailure SWInitFailure BootChksumError BootProtocolError ProgramRestart SWReset	See Table 6.2.1.1-1 Receiver Status, p 104 [RD1]
OperativeModeHiByte OperativeModeLoByteLoPart OperativeModeLoByteHiPart	See Table 6.2.1.1-2 Flight Operative modes, p 105-106 [RD1]
NKFFilterCov RngResidualThrshld PDOPFlag UserEphemeris GPS_Almanac GPSTimeFlag	See Table 6.2.1.1-4 Receiver Health, p 107 [RD1]
VA2L2_failure VA2L1_failure VA1L2_failure VA1L1_failure AVA2L2_failure	See Table 6.2.1.1-5 Integrity Status, p 108 [RD1]

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| AVA2L1_failure
AVA1L2_failure
AVA1L1_failure
FlightChksumError
FlightProtocolError
ExcFreqError
StoreGPSAlmDataError
StoreOscOffsetError
PODL2_failure
PODL1_failure | |

2.2.2 Navigation Observable Data Block (raw data) file

Such data contain observations performed both by POD and Radio Occultation ROSA antennas (in closed and open loop).

They are stored in the 0xA1 Packet of the ROSA Telemetry and a description is given in Sect 6.2.2 Navigation Solution & Space Vehicle Observables Data packet [RD1].

They are available at a 1 Hz sample rate.

Such data are stored in the **NAV_RAW_DBG** Debug file. Such data are also included in both the Operative Observation Low Rate (Sect. 2.1.3) and Navigation POD files (Sect. 2.1.2)

| Time_sec
Time_nsec
sv_number
channel_number
loop antenna
oversampling
L1CA_pseudorange
L2P_pseudorange
L1_doppler
L2_doppler
L1CA_phase
L2P_phase
L1_CN0
L2_CN0
Elev
Azimuth
GIP | See Table p. 113-114
[RD1] |
| L1CA_status
L1PY_status
L2PY_status
FR_on
AS_on | See Table p. 117
[RD1] |

2.2.3 Fast Acquisition Information for each Channel file

Such data contain information about acquisition status of each ROSA channel. They are stored in the 0xA1 Packet of the ROSA Telemetry and a description is given in Sect 6.2.2 Navigation Solution & Space Vehicle Observables Data packet [RD1].

They are available at a 1 Hz sample rate.

Such data are stored in the **NAV_FA_DBG** Debug file.

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Time	See Table p. 117
Fa_ch_1	[RD1]
Fa_time_1	
Fa_ch_2	
Fa_time_2	
Fa_ch_3	
Fa_time_3	
Fa_ch_4	
Fa_time_4	
Fa_ch_5	
Fa_time_5	
Fa_ch_6	
Fa_time_6	
Fa_ch_7	
Fa_time_7	
Fa_ch_8	
Fa_time_8	
Fa_ch_9	
Fa_time_9	
Fa_ch_10	
Fa_time_10	

2.2.4 LNA signal and CPU load file

Such data contain generic information about hardware and software ROSA tracking and observing status strategies. They are stored in the 0xA2 Packet of the ROSA Telemetry and a description is given in Sect 6.2.3 Occultation Data packet [RD1].

They are available at a 1 Hz sample rate.

Such data are stored in the **OCC_GEN_DBG** Debug file.

Time_sec	See Table p. 118-119 – LNA Signal Section
Time_nsec	[RD1]
AGC_AVA1_L1_gain	
AGC_AVA1_L2_gain	
AGC_AVA2_L1_gain	
AGC_AVA2_L2_gain	
AGC_VA1_L1_gain	
AGC_VA1_L2_gain	
AGC_VA2_L1_gain	
AGC_VA2_L2_gain	
AGC_POD_L1_gain	
AGC_POD_L2_gain	
CPU_Load_punctual	See Table p. 118-119 – CPU load and threads info
CPU_Load_worst	[RD1]
Integration_punctual	
Integration_Load_worst	
Tracking_Loop_punctual	
Tracking_Loop_worst	
Bus_1553_punctual	
Bus_1553_worst	
Raw_Measurement_punctual	
Raw_Measurement_worst	
Telemetry_punctual	

Telemetry_worst Solution_punctual Solution_worst Filter_punctual Filter_worst Tracking_Manager_punctual Tracking_Manager_worst Navigation_punctual Navigation_worst	

2.2.5 Space Vehicle Information file

Such data contain Occultation Space Vehicle informations. They are stored in the 0xA2 Packet of the ROSA Telemetry and a description is given in Sect 6.2.3 Occultation Data packet [RD1].
They are available at a 1 Hz sample rate.
Such data are stored in the **OCC_SVI_DBG** Debug file. Such data are also included in the Operative Observation Low Rate (Sect. 2.1.3) file.

Time_sec Time_nsec pivot_sv Have_cf Hot Event Antenna Sv_map Elevation Azimuth Gip t_start table_len	See Table p. 118 – Occultation SVs Info [RD1]

2.2.6 Close Loop Observation from Occultation Antenna file

Such data contain all the observables available during Closed Loop tracking of each SV in view by the Occultation Antennas.
They are stored in the 0xA3 Packet of the ROSA Telemetry and a description is given in Sect 6.2.4 Observation Data packet [RD1].
Sample rates depend on SLTA (as described in the Table shown in pag. 6 of this report).
Such data are stored in the **OCC_CL_DBG** Debug file. Such data are also included in the Operative Observation High Rate data (Sect. 2.1.4) file.

FGR Time_sec Time_nsec Channel Space Vehicle ID Inst_doppler_L1 Inst_doppler_L2 Carrier_phase_L1 Carrier_phase_L2 L1_Signal_Power L1_Noise_Power L2_Signal_Power	See Table p. 121 and p. 122 (observation close loop data) [RD1]

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L2_Noise_Power	

2.2.7 Open Loop Observation from Occultation Antenna file

Such data contain all the observables available during Open Loop tracking of each SV in view by the Occultation Antennas.

They are stored in the 0xA3 Packet of the ROSA Telemetry and a description is given in Sect 6.2.4 Observation Data packet [RD1].

Sample rates is 100 Hz, but the time tag changes with a frequency of 50 Hz. Therefore for each time tag there are 2 samples of Doppler, I and Q. The time tag is the time of when the second sample is observed, and it is intended that the first sample is acquired 10 msec before.

Such data are stored in the **OCC_OL_DBG** Debug file. Such data are also included in the Operative Observation Open Loop data (Sect. 2.1.5) file.

FGR Time_sec Time_nsec Channel Space_Vehicle_ID 1^_Estimated_Doppler 1^_Complex_I 1^_Complex_Q 2^_Estimated_Doppler 2^_Complex_I 2^_Complex_Q	See Table p. 121 and p. 122 (observation open loop data) [RD1]

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2.3 SNR Issues

As far as the measured signal level or Signal to Noise Ratio level are concerned, and since these quantities are necessary for properly apply wave optics based bending angle retrieval algorithms, some further details should be given.

Signal and Noise power (or Signal to Noise Ratio) levels are contained in several data files given in output from the ROSA receiver (and pre-processed using the TAS-I telemetry decoding SW):

- Carrier to Noise Ratios on L1 and on L2 measured in [dB-Hz] are available at 1 Hz for all the signals taken by the Occultation antenna and the POD antenna. They are wrongly called Signal to Noise Ratios, but are Carrier to Noise Ratios measured at the correlators output [see Appendix B.1 of RD1]. In particular,

  ➢ L1_CN0, L2_CNO data are available in the **NAV_RAW_DBG** Debug files (see Sect. 2.2.2) for signals acquired by both the Occultation and POD antennas

  ➢ SNR L1, SNR L2 data are available in the **NAV_POD_OP** Observation files (see Sect. 2.1.2) for signals acquired only by the POD antenna

  ➢ SNR L1, SNR L2 data are available in the **OBS_LR_OP** Observation files (see Sect. 2.1.3) for signals acquired by both the Occultation and POD antennas.

  All these quantities store exactly the same values (Carrier-to-Noise ratios)

- Signal and Noise powers are quantities which can be related to the signal and noise power (and are expressed as dB, even if they are not strictly dB power, see below) acquired by the Radio Occultation antenna only. These quantities are in fact related to signal or noise power available in the I and Q components at the output of the AGGA correlators. Formally speaking, the signal power on L_1, namely S_1, is defined as

$$S_1 = 10 \log_{10} \left(\sum_{\text{integration time}} I^2 + Q^2 \right)_{L1}$$

For example, since for the ROSA case the sampling rate is 29 MHz, each I and Q component is stored using 2 bits and the (coherent) integration time is 20 ms, we can easily compute the power expected. Assuming to have power only on the I component (which assumes the maxima "3" value), each 50 Hz S_1 sample obtained applying the above equation should be something similar to 124 dB (dB is used only to remember that we are computing something as 10 times the logarithm of a quantity).

Signal and Noise powers are available in the following data files:

  ➢ L1_Signal_Power, L2_Signal_Power, L1_Noise_Power, L2_Noise_Power data are available in the **OBS_HR_OP** Observation files (see Sect. 2.1.4)

  ➢ Signal Power L1, Signal Power L2, Noise Power L1, Noise Power L2 data are available in the **OCC_CL_DBG** Debug files (see Sect. 2.2.6)

All these quantities store exactly the same values.

It has to be noted that a small bug should be fixed in the TAS-I telemetry decoding SW (it was not done during this activity, see Sect. 3), since original related data of signal and noise power which are stored in the ROSA telemetry **should be divided by 16** (and this was not implemented inside the current release of the decoding software).

As an example, one profile of Carrier-to-Noise Ratio derived from Low Rate files and the corresponding Signal Power – Noise Power derived by the High Rate files, for the same frequency are here shown.
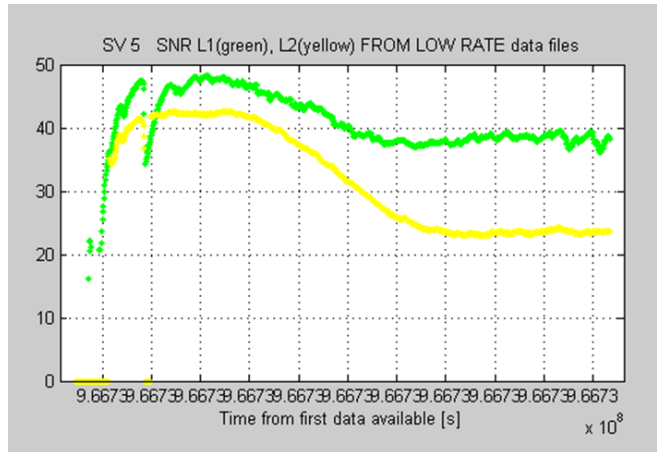
This plot shows Carrier-to-Noise Ratios in [dB-Hz] for L1 (green) and for L2 (yellow) taken by the **OBS_LR_OP** file for the first tracking of SV 5 (data observed by ROSA receiver from 23:27:53 of 2010/08/24 and 04:25:41 of 2010/08/25). The following plot shows profiles of Signal Power (top) and Noise Power (bottom) in [dB] on L1 (blue) and L2 (red) as stored in the **OBS_HR_OP** file for the same tracked signal.
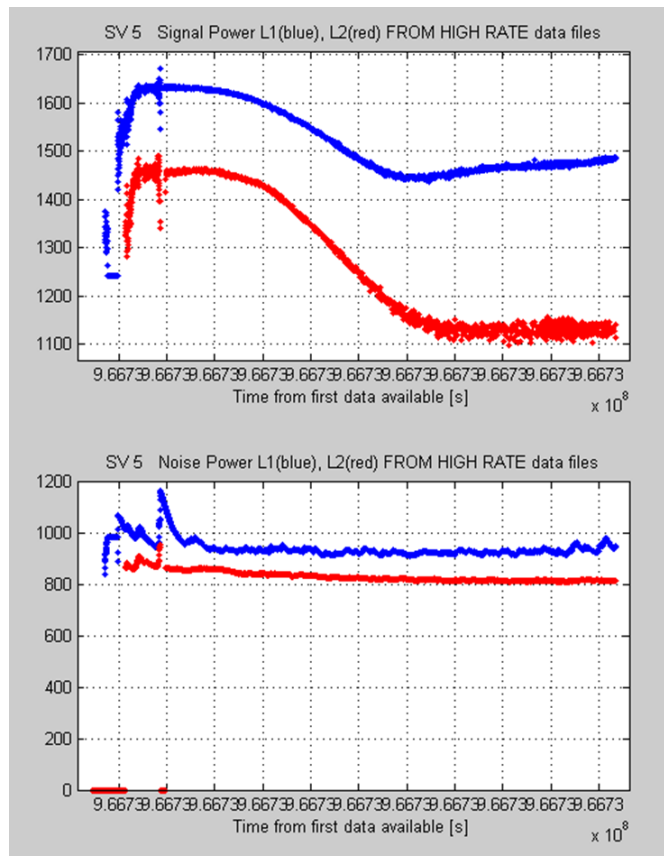
Remembering that, since such Signal and Noise power levels should be divided by 16 (in the dB scale) and that are logarithmic values, if we take Signal – Noise the results obtained should be comparable with the Carrier-to-Noise ratio available from Low Rate files. The following plot should demonstrate this aspect:
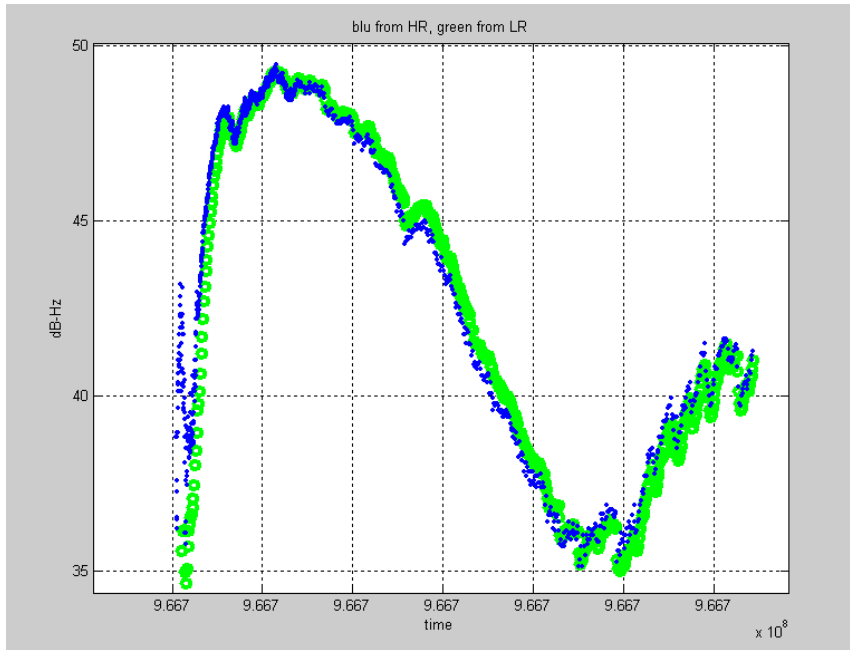
Temporal misalignment up to 0.08 sec may occur because of the different sample rates (50 Hz for High Rate files when SLTA is below 50 km, 1 Hz for Low Rate data). The values are a little bit different because of Carrier-to-Noise ratio is computed considering the noise a constant, while Noise Power from High rate is not constant (it depends on atmospheric propagation effects).

But we have the possibility to combine High Rate Signal and Noise Power levels to get Carrier-to-Noise ratios necessary for Wave Optics algorithms.

Normally the EUMETSAT prototype and the ROPP GRAS-SAF software handle amplitude data (SNR) in the linear scale ([V/V] measuring units). The transformation can be accomplished simply considering that

$$ SNR_{|dB\_} = 20 \cdot \log_{10} SNR^{eff\ value}_{|V/V\_} = 20 \cdot \log_{10} \frac{SNR^{peak}_{|V/V\_}}{\sqrt{2}} $$

Just to give a couple of examples, here are shown SNR profiles really observed by ROSA receiver for a couple of events. Both [dB-Hz] and [V/V] representations in function of time or SLTA are shown. The abrupt decrease around 100 km SLTA for both GPS frequencies seems to be systematic (common to the majority of analyzed events) and should be deeply investigated. As it will be shown in the data quality analysis (Chapter 7), around 100 km SLTA is also present the first systematic L_2 lost of lock (in the occultation observed from SV 23, this lost of lock is evident).
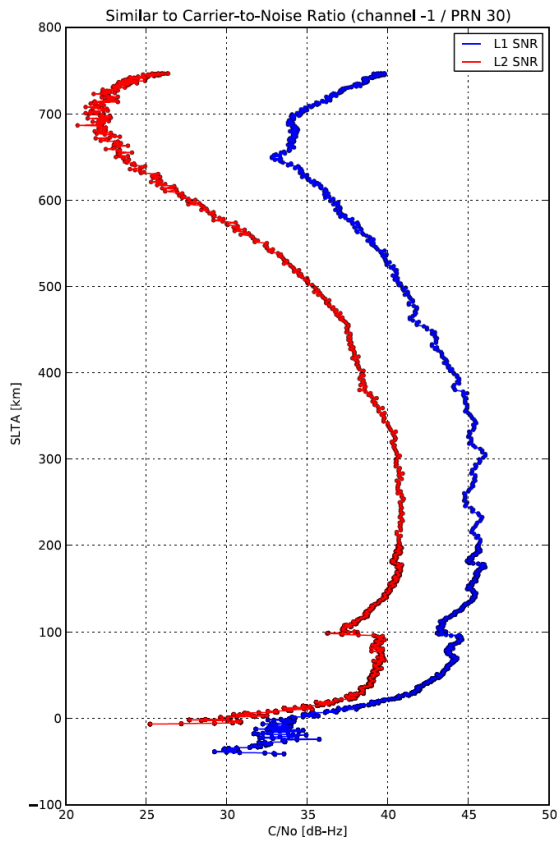
C-N0 for the event observed from 17:33:38 UTC, 24 August, 2010
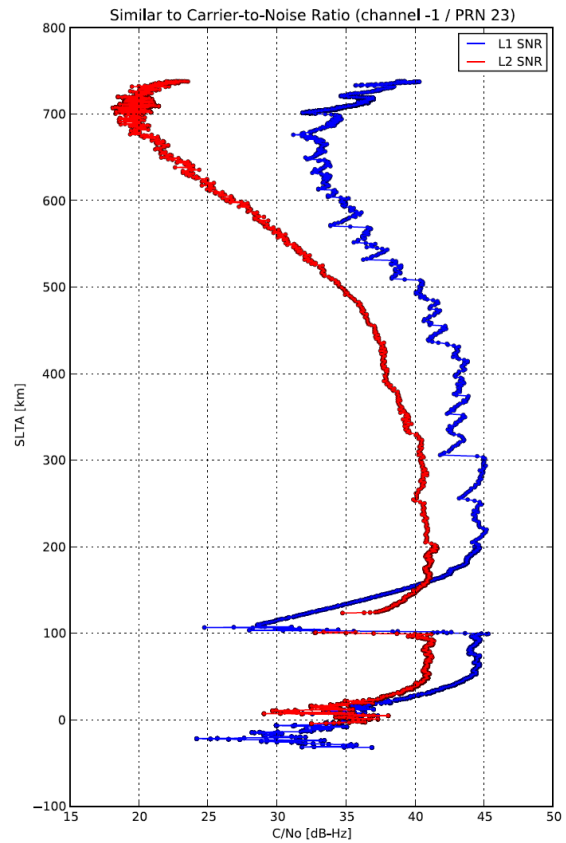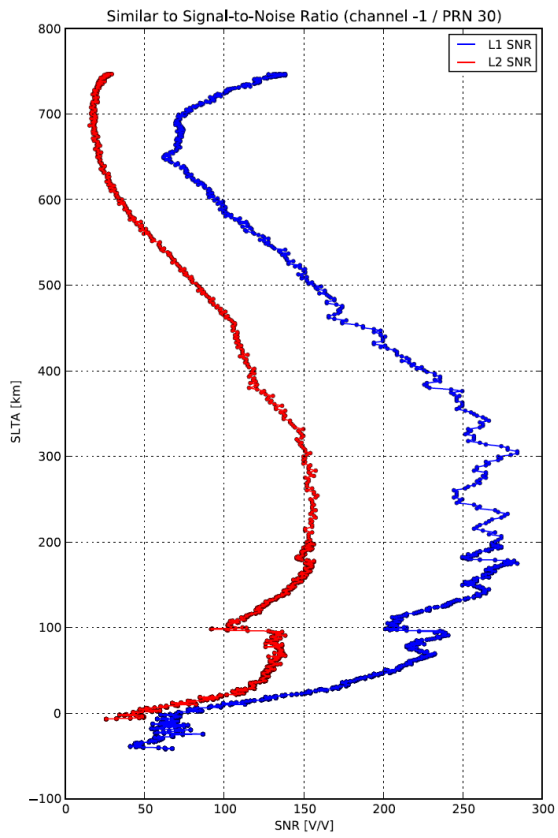

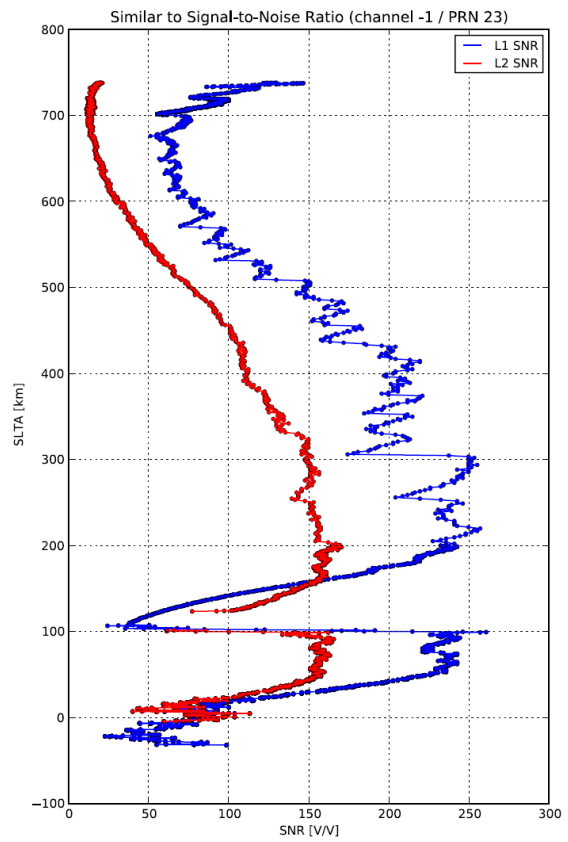C-N0 for the event observed from 20:40:31 UTC, 24 August, 2010
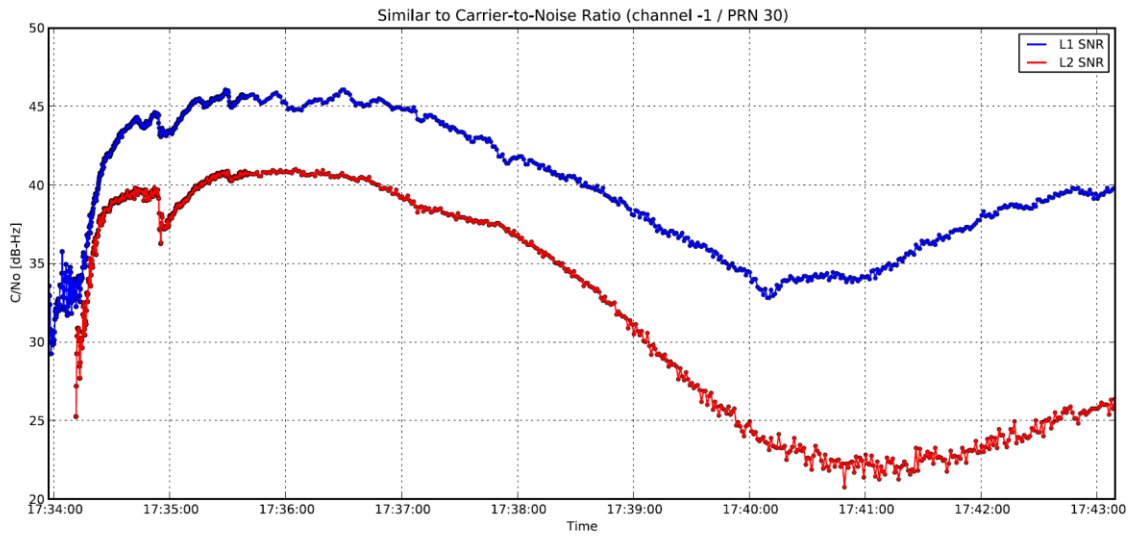
C-N0 for the event observed from 17:33:38 UTC, 24 August, 2010, in function of time
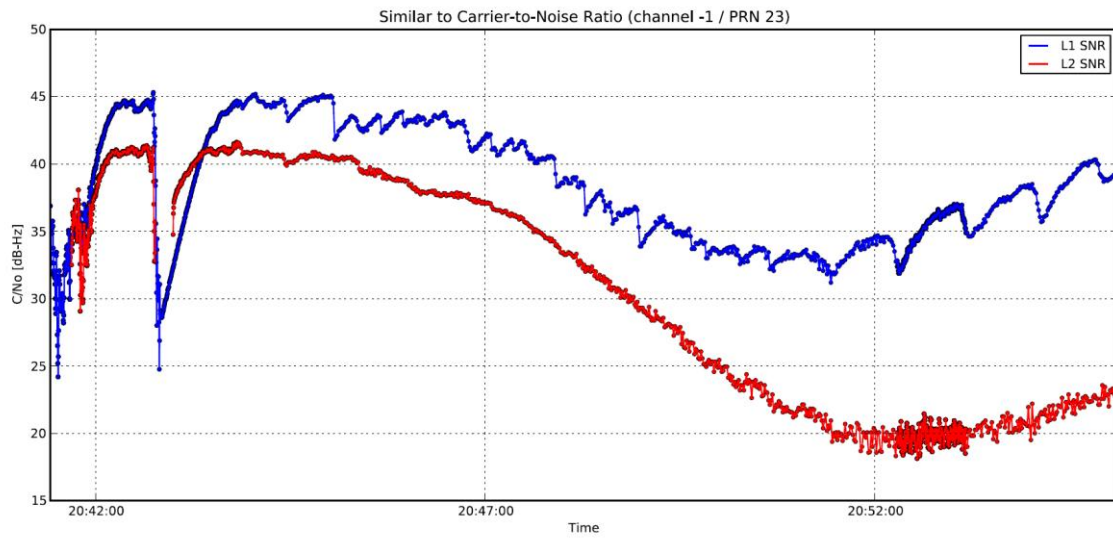
C-N0 for the event observed from 20:40:31 UTC, 24 August, 2010, in function of time

C-N0 [V/V] for the event observed from 17:33:38 UTC, 24 August, 2010

C-N0 [V/V] for the event observed from 20:40:31 UTC, 24 August, 2010

2.4 ROSA data handling in the EUMETSAT Prototype

The EUMETSAT prototype for Radio Occultation data processing (namely YAROS – Yet Another Radio Occultation Software) is an off-line processing chain which is in continuous development under a strictly controlled configuration environment. Inside YAROS, algorithms and data handling procedures are deeply tested before their implementation in the operative EUMETSAT processing chain.

Even if YAROS project was started for the data processing of the GRAS payload on board the ESA/Eumetsat METOP-A satellite, it has been extensively used also for the processing of COSMIC, CHAMP, SAC-C and GPS-Met Radio Occultation data.

In the framework of this 16th Visiting Scientist activity, one task was to interface YAROS also to ROSA data structures, in order to make YAROS able to process ROSA data observed on-board OCEANSAT-2 (and to open the way for the ROSA on board SAC-D and Mega-Tropiques data processing). Even if a clear agreement or Memorandum of Understanding between EUMETSAT and the Italian Space Agency was not available at the time of the VS activity, some data structures containing all the ROSA data were suggested and developed.

As deeply described in Sect. 2.1 and 2.2, ROSA observations are available at least in three big data format:

- the **binary data format** (the Level 0 data) which is the native ROSA data format downloaded from OCEANSAT-2 through the telemetry channel (see the introduction of Ch. 2). This format is strictly "mission dependent": it is expected to be different for data taken from OCEANSAT-2, SAC-D and Mega-Tropiques;
- the **operative** or **observation data format** (Level 1 data) given in output to the TAS-I telemetry decoding SW (see Sect. 2.1). In the past, these are the official ROSA Level 1 products intended for distribution;
- the **debug data format** (Level 1 data) also given in output to the TAS-I telemetry decoding SW (see Sect. 2.2), up to now restricted to TAS-I internal use.

From the formal point of view, EUMETSAT-ASI should agree if ROSA data could be handled by EUMETSAT prototype processing chain (and eventually by the operative one), starting from their binary (native – Level 0) "mission-dependent" format or from the engineered Level 1 data.

In any case, EUMETSAT data processors should be able to manage all the information provided by the ROSA receivers and not only the science data taken by Radio Occultation and POD antennas. During this Visiting Scientist activity, the complete data structures containing ROSA observables has been defined. Their final implementation inside the EUMETSAT YAROS prototype is actually under investigation, since it is strictly related to the final decision that will be taken between EUMETSAT and ASI.

Under the hypothesis that TAS-I should be always in charge for the ROSA binary format management, the TAS-I telemetry decoding SW has been tentatively modified (a new release of the software – namely the release 7 – was created and uploaded in the EUMETSAT repository), in order to create the complete ROSA data structures. Such structures are filled in before the creation of the standard output of the telemetry decoding SW we described in Sect. 2.1 and 2.2 (the **operative** and the **debug** data files) which is in this case deactivated. In this scenario, the EUMETSAT YAROS prototype will "call" the TAS-I telemetry decoding SW (as an external executable function) before the entire processing chain is started.

In what follows, the defined data structures are detailed. Since during the Visiting Scientist activity a formal EUMETSAT-ASI agreement was not available, the ROSA data processing performed using

YAROS and using the GRAS-SAF ROPP software was based on the use of ROSA operative Rinex data files (namely the High Rate data file described in Sect. 2.1.4) as input files.

The eight structures implemented reflects mainly the content of the debug files content. The following table summarizes their content:

STRUCTURE NAME (VARIABLE containing its dimension)	Output SW file prefix name	Comments	MAX DIMENSION
NAV_SOL_DATA (idx_NAV_SOL_DATA)	NAV_POD_SOL*.out	it contains navigation solution (ROSA packet 0xA1) computed on board the ROSA receiver (1Hz sample rate)	~ 3600 * hh
NAV_HS_DATA (idx_NAV_HS_DATA)	NAV_HS_DBG*.out	it contains data included in the Health and Status ROSA packet 0xA0 (1Hz sample rate)	~ 3600 * hh
NAV_RAW_DATA (idx_NAV_RAW_DATA)	NAV_RAW_DBG*.out	it contains observations collected by each ROSA channel both from POD and from RO antennas (CL and OL tracking) at 1 Hz sample (ROSA packet 0xA2)	~ 60000 * hh
NAV_FA_DATA (idx_NAV_FA_DATA)	NAV_FA_DBG*.out	it contains information related to each channel used at 1 Hz sample rate	~ 3600 * hh
OCC_GEN_DATA (idx_OCC_GEN_DATA)	OCC_GEN_DBG*.out	it contains information and other parameters related to the ROSA receiver at 1 Hz sample rate	~ 3600 * hh
OCC_SVI_DATA (idx_OCC_SVI_DATA)	OCC_SVI_DBG*.out	it contains information related to the elevation/azimuth of the entire GPS constellation, at 1 Hz sample rate	~ 120000 * hh
OBS_CL_DATA (idx_OBS_CL_DATA)	OBS_CL_DBG*.out	it contains CLOSED LOOP Occultation observations at 50, 10 and 1 Hz, depending on SLTA	~ 75000 * hh
OBS_OL_DATA (idx_OBS_OL_DATA)	OBS_OL_DBG*.out	it contains OPEN LOOP Occultation observations at 100 Hz	~ 15000 * hh

- MAX DIMENSION strictly depends on the input file size and is defined as a rule of thumb to better define the maximum dimension of each structure
- hh is the length (in hours) of the time interval related to the input file
- just as an order of magnitude, ROSA data observed in one hour from OCEANSAT-2 require a 9-10 MB telemetry file.

The eight data structures are here detailed.

2.4.1 struct NAV_SOL_DATA

Details are given in Sect. 2.1.1.

```
struct NAV_SOL_DATA
{
int time_sec;
int time_nsec;
short Tracked_SVs;
short DoingSPS;
short DoingNKF;
short NumOfSPSSVs;
short NumOfNKFSVs;
double PDOPValue;
double SPS_XPosition;
double SPS_YPosition;
double SPS_ZPosition;
```

```
double SPS_XVelocity;
double SPS_YVelocity;
double SPS_ZVelocity;
double SPS_ClockBias;
double SPS_ClockBiasRate;
int SPS_SolutionTimeTagSec;
int SPS_SolutionTimeTagnSec;
double NKF_XPosition;
double NKF_YPosition;
double NKF_ZPosition;
double NKF_XVelocity;
double NKF_YVelocity;
double NKF_ZVelocity;
double NKF_ClockBias;
double NKF_ClockBiasRate;
int NKF_SolutionTimeTagSec;
int NKF_SolutionTimeTagnSec;
};
```

2.4.2 struct NAV_HS_DATA

Details are given in Sect. 2.2.1.

```
struct NAV_HS_DATA
{
int time_sec;
int time_nsec;
unsigned char Unused1 :1;
unsigned char RealTimeFailure :1;
unsigned char SWModuleStatus :1;
unsigned char EEPROMFailure :1;
unsigned char RAMFailure :1;
unsigned char Unused2 :2;
unsigned char SWInitFailure :1;
unsigned char BootChksumError :1;
unsigned char BootProtocolError :1;
unsigned char ProgramRestart :1;
unsigned char SWReset :1;
unsigned char Unused3 :4;
unsigned char OperativeModeHiByte;
unsigned char OperativeModeLoByteLoPart :4;
unsigned char OperativeModeLoByteHiPart :4;
unsigned char Unused6;
unsigned char NKFFilterCov :1;
unsigned char RngResidualThrshld :1;
unsigned char PDOPFlag :1;
unsigned char Unused11 :1;
unsigned char UserEphemeris :1;
unsigned char Unused7 :1;
unsigned char GPS_Almanac :1;
unsigned char GPSTimeFlag :1;
unsigned char VA2L2_failure :1;
unsigned char VA2L1_failure :1;
```

```
unsigned char VA1L2_failure :1;
unsigned char VA1L1_failure :1;
unsigned char AVA2L2_failure :1;
unsigned char AVA2L1_failure :1;
unsigned char AVA1L2_failure :1;
unsigned char AVA1L1_failure :1;
unsigned char FlightChksumError :1;
unsigned char FlightProtocolError :1;
unsigned char ExcFreqError :1;
unsigned char StoreGPSAlmDataError:1;
unsigned char StoreOscOffsetError :1;
unsigned char Unused10 :1;
unsigned char PODL2_failure :1;
unsigned char PODL1_failure :1;
unsigned char TrackedSVs :6;
unsigned char DoingSPS :1;
unsigned char DoingNKF :1;
unsigned char NumOfSPSSVs :4;
unsigned char NumOfNKFSVs :4;
double PDOPValue;
};
```

2.4.3 struct NAV_RAW_DATA

Details are given in Sect. 2.2.2.

```
struct NAV_RAW_DATA
{
int time_sec;
int time_nsec;
unsigned char sv_number;
unsigned char channel_number : 4;
unsigned char loop : 1;
unsigned char antenna : 3;
unsigned char L1CA_status :4;
unsigned char L1PY_status :1;
unsigned char L2PY_status :1;
unsigned char FRon :1;
unsigned char ASon :1;
unsigned char oversampling;
double L1CA_pseudorange;
double L2P_pseudorange;
double L1_doppler;
double L2_doppler;
double L1CA_phase;
double L2P_phase;
double L1_CN0;
double L2_CN0;
double Elev;
double Azimuth;
double GIP;
};
```

2.4.4 struct NAV_FA_DATA

Details are given in Sect. 2.2.3.

```
struct NAV_FA_DATA
{
double time;
unsigned short fa_data_0a;
unsigned short fa_data_0b;
unsigned short fa_data_1a;
unsigned short fa_data_1b;
unsigned short fa_data_2a;
unsigned short fa_data_2b;
unsigned short fa_data_3a;
unsigned short fa_data_3b;
unsigned short fa_data_4a;
unsigned short fa_data_4b;
unsigned short fa_data_5a;
unsigned short fa_data_5b;
unsigned short fa_data_6a;
unsigned short fa_data_6b;
unsigned short fa_data_7a;
unsigned short fa_data_7b;
unsigned short fa_data_8a;
unsigned short fa_data_8b;
unsigned short fa_data_9a;
unsigned short fa_data_9b;
};
```

2.4.5 struct OCC_GEN_DATA

Details are given in Sect. 2.2.4.

```
struct OCC_GEN_DATA
{
int time_sec;
int time_nsec;
unsigned char agc0;
unsigned char agc1;
unsigned char agc2;
unsigned char agc3;
unsigned char agc4;
unsigned char agc5;
unsigned char agc6;
unsigned char agc7;
unsigned char agc8;
unsigned char agc9;
double CPUPunctual;
double CPUWorst;
double IntegrPunctual;
double IntegrWorst;
double TrkLpPunctual;
double TrkLpWorst;
double BusPunctual;
```

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```
double BusWorst;
double RwMeasPunctual;
double RwMeasWorst;
double TlmPunctual;
double TlmWorst;
double SolPunctual;
double SolWorst;
double FiltPunctual;
double FiltWorst;
double TrkMngPunctual;
double TrkMngWorst;
double NavPunctual;
double NavWorst;
};
```

2.4.6 struct OCC_SVI_DATA

Details are given in Sect. 2.2.5.

```
struct OCC_SVI_DATA
{
int time_sec;
int time_nsec;
unsigned char pivot_sv;
unsigned char Have_cf;
unsigned char Hot;
unsigned char Event;
unsigned char Antenna;
unsigned char Sv_map;
double Elevation;
double Azimuth;
double Gip;
unsigned short t_start;
unsigned short table_len;
};
```

2.4.7 struct OBS_CL_DATA

Details are given in Sect. 2.2.6.

```
struct OBS_CL_DATA
{
short fgr;
int time_sec;
int time_nsec;
short channel;
short SV_ID;
double inst_dop_L1;
double inst_dop_L2;
double carr_ph_L1;
double carr_ph_L2;
short signal_L1;
short noise_L1;
short signal_L2;
```

Ref: SAF/GRAS/DMI/REP/VS16/001
Version: 1.2
Date: 03 March 2012
Document: grassaf_cvs16_rep_v1.2

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```
short noise_L2;
unsigned int OverSampl;
};
```

2.4.8 struct OBS_OL_DATA

Details are given in Sect. 2.2.7.

```
struct OBS_OL_DATA
{
short fgr;
int time_sec;
int time_nsec;
short chn;
short sv;
double est_dop_L1;
double I1;
double Q1;
double est_dop_L2;
double I2;
double Q2;
};
```

Ref: SAF/GRAS/DMI/REP/VS16/001
Version: 1.2
Date: 03 March 2012
Document: grassaf_cvs16_rep_v1.2

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2.5 Data available for the Visiting Scientist Activity

In the framework of this Visiting Scientist activity, Italian Space Agency and Thales Alenia Space - Italy (on behalf of ASI) provided the following data:

- one month of ROSA native binary data (Level 0), observed on-board Oceansat-2, from 15 August 2010 to 14 September 2010. An example of their naming convention is the following:
  *sdf**d**qra005163_SAN_os2.14sep2010*, for telemetry files downloaded observed during **daily** hours; the number 005163 is referred to the download orbit number
  *sdf**n**qra005171_SAN_os2.14sep2010*, for telemetry files downloaded observed during **nightly** hours.

- corresponding one month of Oceansat-2 attitude data (orbits and quaternion data). Such files are transmitted together ROSA binary data sharing the same telemetry channel and with the same frequency (when the satellite is in view from the Indian and Italian ground stations). An example of their naming convention is the following one:
  *rosaoat**d**qra005163_SAN_os2.14sep2010* for telemetry files downloaded observed during **daily** hours
  *rosaoat**n**qra005171_SAN_os2.14sep2010* for telemetry files downloaded observed during **nightly** hours.
  Such files are ASCII files with multiple records (state vectors). The records contain UTC Times, Orbits in ECI reference frame and Quaternions in ECI reference frame.

  Time in UTC: seven integer values, blank separated, namely:
  YYYY   year
  MM   month
  DD   day
  HH   hour
  MM   minutes
  SS seconds
  FRAC   fraction of seconds

  ECI Satellite Position [km]: three floating point values, blank separated, namely:
  px
  py
  pz

  ECI Satellite Velocity [km/s]: three floating point values, blank separated, namely:
  vx
  vy
  vz

  Attitude quaternion in ECI reference frame (normalized such as $q_1^2 + q_2^2 + q_3^2 + q_4^2 = 1$):
  four floating point values, blank separated, namely:
  q1
  q2
  q3
  q4

  An example is shown in the following picture:

Ref: SAF/GRAS/DMI/REP/VS16/001
Version: 1.2
Date: 03 March 2012
Document: grassaf_cvs16_rep_v1.2

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```
2009  9 27  1  6 15 2058    109.408709 -1024.618973 7019.609230    -7.466269   -0.620080    0.024879   -0.7552334728   0.0537981028   0.5474493131   0.3564090560
2009  9 27  1  6 16 2298    101.776933 -1024.941081 7020.133648    -7.466507   -0.618916    0.016881   -0.7555146230   0.0536581282   0.5470199546   0.3564935187
2009  9 27  1  6 17 2538     94.135431 -1025.449689 7020.342633    -7.466673   -0.617742    0.008881   -0.7557898975   0.0535095731   0.5465909097   0.3565904287
2009  9 27  1  6 18 2778     86.490719 -1026.035174 7020.416853    -7.466800   -0.616565    0.000881   -0.7577764675   0.0534258421   0.5482225458   0.3579654896
2009  9 27  1  6 19 3018     78.841898 -1026.666044 7020.412946    -7.466895   -0.615385   -0.007121   -0.7600200710   0.0541290548   0.5429587562   0.3619978450
2009  9 27  1  6 20 3258     71.193869 -1027.295666 7020.401228    -7.466982   -0.614205   -0.015122   -0.7622020421   0.0547734910   0.5376855937   0.3660895919
2009  9 27  1  6 21 3498     63.545761 -1027.924284 7020.381696    -7.467059   -0.613023   -0.023124   -0.7643210673   0.0553582865   0.5324044275   0.3702411849
```

As far as the documentation is concerned, the following documents containing all the available informations on the instrument had been provided together with the previously described data, in support to this GRAS-SAF activity:

- ROSA Instrument Operating Manual [RD1] which describes the details of the ROSA telemetry content
- ROSA for OCEANSAT-2 Level 1 Data Processor User Manual [RD2] which describes the TAS-I telemetry decoding SW and the details of ROSA Level 1 Engineered data (Observation data only)
- ROSA on OCEANSAT-2 in flight data format analysis – Technical Note [RD3] which describe both Level1 ROSA data and, more important, all the aspect related to the OCEANSAT-2 platform (ROSA Antennas issues and their position with respect to the Satellite Center of Gravity)

All the data and documents are contained in a DVD made available to the GRAS SAF. The DVD was given to EUMETSAT during the first part of the Visit. Its content was also copied in the hard disk of the PC made available in EUMETSAT.

It has to be noted that, even if data are available for one entire month, analysis and results has been performed on a shorter time interval. The thirty hours from 13:30 UTC of 24 August, 2010 to 17:40 UTC of 25 August 2010 have been deeply analyzed, using both the EUMETSAT YAROS prototype and the GRAS-SAF ROPP software.

During the Visiting Scientist Activity, TAS-I and ASI provided the following documents and presentations helpful to better understand issues related to Antenna's positions, Antenna's radiation patterns, orbits and attitude data files:
- ROSA ROSSA – ROSA Data Processing Center Product Specification [RD4] which describes the details of the ROSA products given in input and processed by the Italian Radio Occultation processing software. Here you can find a further description of the Operational Level 1 ROSA Ascii Files and of the Orbit/Attitude data files.
- ROSA Instruments and Antenna [RD5] which is a presentation given by TAS-I at the GNSSRO Workshop (Pasadena, CA, 2009). In this presentation further details on ROSA Radio Occultation antenna characteristics and radiation patterns are shown.
- Zin A. et al., (2008), "ROSA Radio Occultation sensor: Testing, Performance and Accomodation on board Oceansat-2", European Navigation Conference, Toulouse. In this paper the measurement carried on also on the ROSA Radio Occultation Antenna are described and results are shown.

Finally, TAS-I provided and made available also the last release of the TAS-I telemetry decoding SW, which was necessary to transform Level 0 binary data into the Level 1 Engineered data described in Sect 2.1 and 2.2. The software manual is the ROSA for OCEANSAT-2 Level 1 Data Processor User Manual [RD2] mentioned above. During the Visiting Scientist activity I made some small changes to this software in order to fix a couple of small bugs (see Chapter 3) and to create the ROSA data structures described in Sect. 2.4. All the new releases created have been kept under configuration control and stored into the EUMETSAT Sub Version Repository. Source codes were also sent to ASI and TAS-I.

3. TAS-I telemetry decoding SW

3.1 SW compiling and run instructions

The TAS-I telemetry decoding SW allows the production of "engineered" ROSA Level 1 data (both the Operative and the Debug files) from native binary data (Level 0) extracted from telemetry. Details are deeply analyzed in Chapter 2.
Here a small summary of this decoder is reported for completeness. The reference documentation for this is the ROSA for OCEANSAT-2 Level 1 Data Processor User Manual [RD2].

This TAS-I telemetry decoding SW was developed in C code. It is delivered in 3 source files: Level1.c, Level1.h and Level1Functions.h:
Level1.c is the application code of the Level1 functions.
Level1.h contains all the constants, data declaration and definition.

Level1Functions.h: is the Level1 software interfaces (function calls) to external word declaration.

The code can be easily compiled using the following Linux OS based commands:

```
gcc -c -DLINUX -DHWPCI -I. Level1.c
ar r liblevel1.a Level1.o
gcc -c -DLINUX -DHWPCI decoder.c
gcc lev1.o liblevel1.a -o decoder
```

Once the program is compiled and the executable decoder.exe is created, it can be run together a configuration file which contains relevant informations on input/output file location and name

./decoder –c *config.cfg*

An example of the configuration file *config.cfg* is here reported (the contents is quite clear and no further comments are given here)

```
CNFG_MODE=BOTH
SWAP_SYNC=NOSWAP
SWAP_FRAME=NOSWAP
END_MODE=BIG_ENDIAN
LOG_LEVEL=0
FRAME_SYNC=00 28 F2 2C EA 7D 0E 67 36 CC 26 54 58 00 FE 04
; Input files
INPUT_ARCHIVE=/ROSA/IN/sdfnqra004880_SAN_os2.25aug2010
; Output files
NAV_HS_DBG_OUT_PREFIX=/ROSA/OUT/DBG/nav_HS_DBG_
NAV_RAW_DBG_OUT_PREFIX=/ROSA/OUT/DBG/nav_RAW_DBG_
NAV_FA_DBG_OUT_PREFIX=/ROSA/OUT/DBG/nav_FA_DBG_
OCC_GEN_DBG_OUT_PREFIX=/ROSA/OUT/DBG/occ_GEN_DBG_
OCC_SVI_DBG_OUT_PREFIX=/ROSA/OUT/DBG/occ_SVI_DBG_
OBS_CL_DBG_OUT_PREFIX=/ROSA/OUT/DBG/obs_CL_DBG_
OBS_OL_DBG_OUT_PREFIX=/ROSA/OUT/DBG/obs_OL_DBG_
;
NAV_POD_OP_OUT_PREFIX=/ROSA/OUT/OBS/nav_POD_op_
OBS_LR_OP_OUT_PREFIX=/ROSA/OUT/OBS/obs_LR_op_
OBS_HR_OP_OUT_PREFIX=/ROSA/OUT/OBS/obs_HR_op_
OBS_OL_OP_OUT_PREFIX=/ROSA/OUT/OBS/obs_OL_op_
NAV_POD_SOL_OUT_PREFIX=/ROSA/OUT/OBS/nav_POD_SOL_
```

3.2 Small bugs fixed

Some problems mainly related to the unwrapping phase procedure applied by the TAS-I telemetry decoding SW both for High Rate and Low Rate L1 data carrier phase data were highlighted and corresponding code bugs were fixed. A new version of such code (rel 5.1) has been created and stored on the EUMETSAT SubVersion Repository. ASI and TAS-I had been informed on such changes (see mail sent on 21 November, 2011 @ 18:37). A brief description of the changes applied and of the results obtained is here provided.

L_1 High Rate unwrapping procedure:
When L_1 signal status (Table pag. 11, Sect. 2.1.3) is lower than 9 (LONG_INT reached) and greater than 5 (CODE_SEARCH ended), L_1 Carrier Phases show some unwanted "0" values at a sample rate of 1 Hz. As defined by the original procedure, the phase unwrapping is performed when the difference between the current phase value and the previous one is greater than a given threshold (174762 cycles, which is the maximum phase value storable considering the data representation used). The introduction of this "0" values made this threshold unreachable. The unwrapped phase shows constant values (0 plus the reached offset) followed by a "wrapped" values. It has to be noted that this problem does not appear when the L_1 signal status is definitively 9 (when the carrier phase data is "safely" usable).

In order not to modify too much the TAS-I decoding software, we changed the "0" current phase values with the linearly extrapolated one evaluated considering the two previous elements. Setting this new value as the current one allows the unwrapping procedure to work correctly. In order to do that we allocated new variables for storing the two previous values (See Level1_r5.c source code, row 2962) and we stored that value each time a L_1 High Rate Phase value is extracted from the data packet (Level1_r5.c source code, row 3077).

In the following picture an example of unwrapping "errors" for high rate (blue) and low rate (green) L_1 data (left picture) is shown. This example is related to carrier phase data ROSA taken for the first occurrence of SV 05 between the time interval (20100824**232753**_20100825**042541**). It has to be noted that the problem seems to be present only when CA L_1 status (black values in the top of left picture) is lower than 9 (these values are plotted on the same scale of carrier phase value. Anyway, when the line is stabilized, the status is 9, the other steps show all the other status, from 4 to 8).
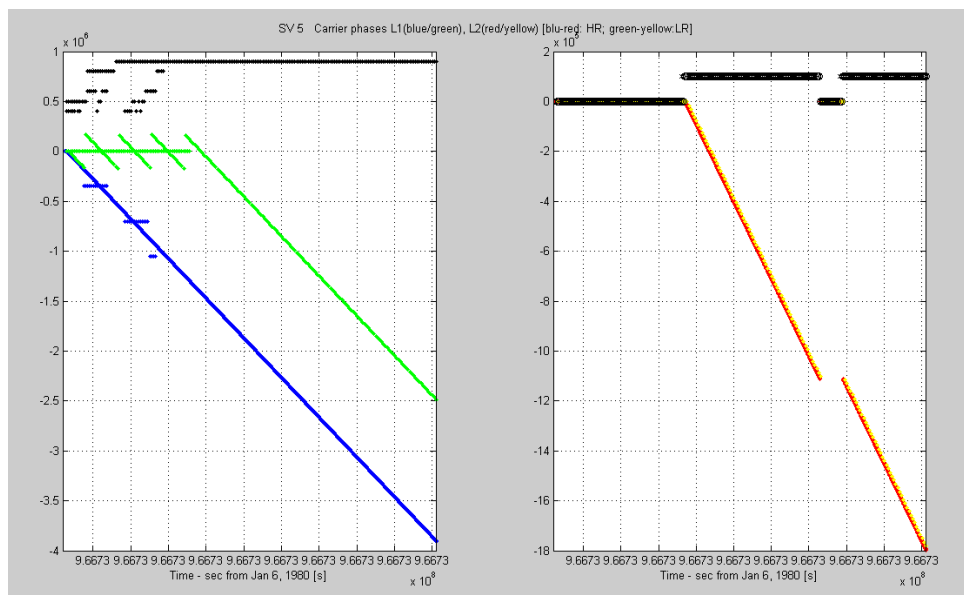
L_2 data (right subplot) seem not to be impacted by this error.

<u>L_1 Low Rate unwrapping procedure:</u>

For the L_1 Low Rate case, it has to be said that this is an independent low rate (1 Hz) measurement of the L_1 carrier phase, not a decimation of High Rate L_1 carrier phase observations. When the L_1 CA code coming from an occulted satellite starts to be tracked, both Open Loop and Close Loop chains contemporaneously work. Two different receiver channels are allocated and start to collect data. At each second, the L_1 carrier phases measured value and one "0" value are respectively (and contemporaneously) stored from the Closed loop and the Open loop chain. Therefore a duplicated value is always present at each second. And both of them impact the unwrapping procedure (which fails because the threshold defined previously is never reached).

We simply do not take care of the L_1 Low Rate Carrier Phase value stored by the Open Loop dedicated channel. The change is made on the Level1_r5.c source code, in the row 1691.

Next plot shows carrier phase profiles obtainable after having corrected both these bugs. Another example is here considered: data related to the occultation with SV 21 (its second occurrence inside the time interval from 23:27:53 to 04:25:41 of 2010/08/24) (blu/green: High/Low rate L1 Carrier Phase data; red/yellow: High/Low rate L2 Carrier Phase data; black: signal status).

On the left the L_1 and L_2 carrier phases profiles obtained by the original unwrapping procedure, on the right the same values obtained after having fixed the unwrapping bug.
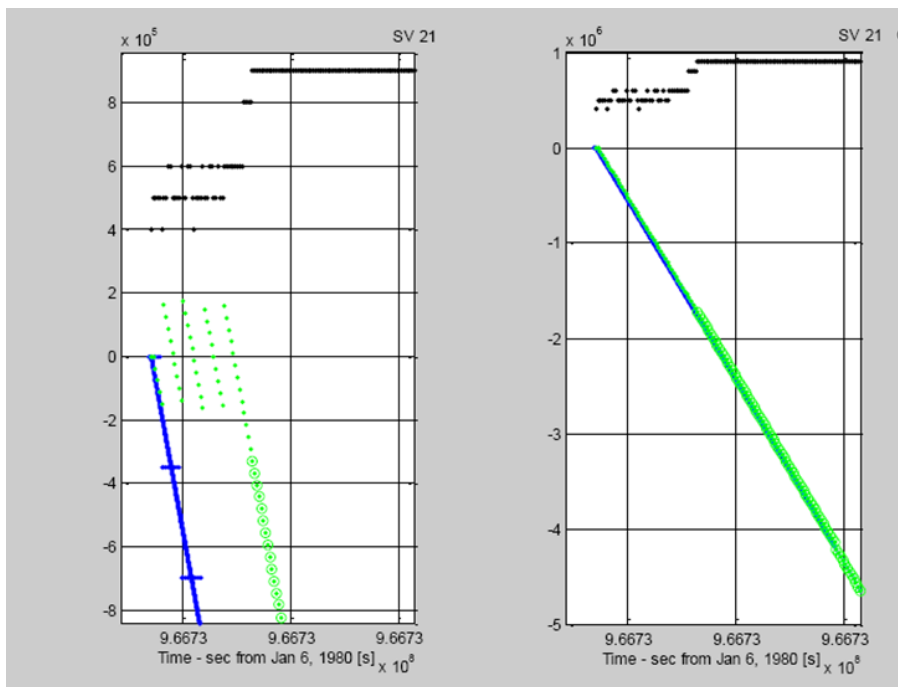
Another small bug was identified and fixed in the TAS-I telemetry decoding SW, related to the evaluation of the signal quality flag introduced in the Low Rate Rinex operative data files (Pseudorange L1 C/A and L2 P(Y) Signal Quality, see Sect. 2.1.3). This indicator is an integer number varying from 0 to 9 which reflects the signal strength. It is computed linearly interpolating SNR data on a scale of integer number varying between 0 and 9. Sometimes the linear interpolation failed because of not availability of SNRs. In that case wrong values for signal qualities were stored. The new source code solved this problem. Both ASI and TAS-I were updated also about this change.

3.3 Release for the EUMETSAT Prototype

As discussed in Sect. 2.4, since not all the available ROSA raw data (extracted by telemetry) were contained inside the five RINEX observations files generated as output by TAS-I telemetry decoding SW, but they are contained inside the seven debug (DBG) files, it was decided to modify the decoding software in order to create several data structures, which store all the data available.

Summarizing, after the Visiting Scientist activity, two different and new releases of this decoding software were available, both of then uploaded into the EUMETSAT repository:
-    the Rel 5.1 (r6 //svnssh@exsvn.eumetsat.int/rosa/trunk), which reflects all the changes made to correct small bugs previously described
-    Rel 7 (r7 //svnssh@exsvn.eumetsat.int/rosa/trunk), which reflects all the changes made to correct small bugs previously described and creates all the ROSA data structures, as described in Sect. 2.4.

Anyway, the ROSA data processing performed in the framework of this VS activity using the EUMETSAT YAROS prototype and using the GRAS-SAF ROPP software, was based on the use of ROSA operative Rinex data files (namely the High Rate data file described in Sect. 2.1.4) as input files. Such files were generated considering the Rel 5.1 of the TAS-I telemetry decoding SW.

4. ROSA antennas positions

Following the documentation made available by TAS-I [RD3], the positions of phase centres of Radio Occultation Velocity Antenna and POD Antenna were estimated as follows.
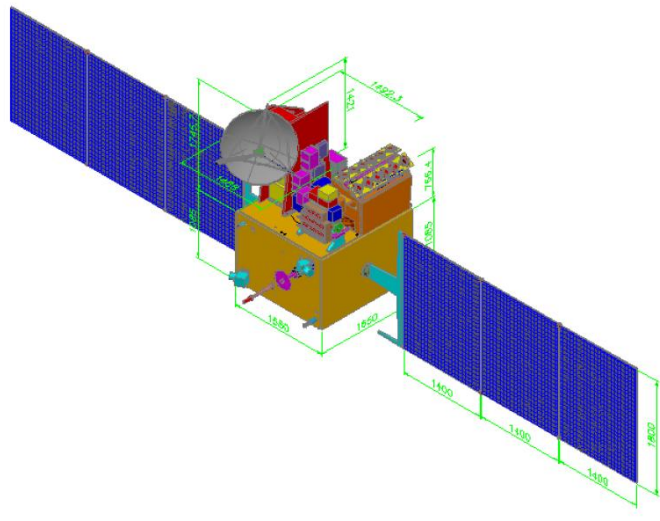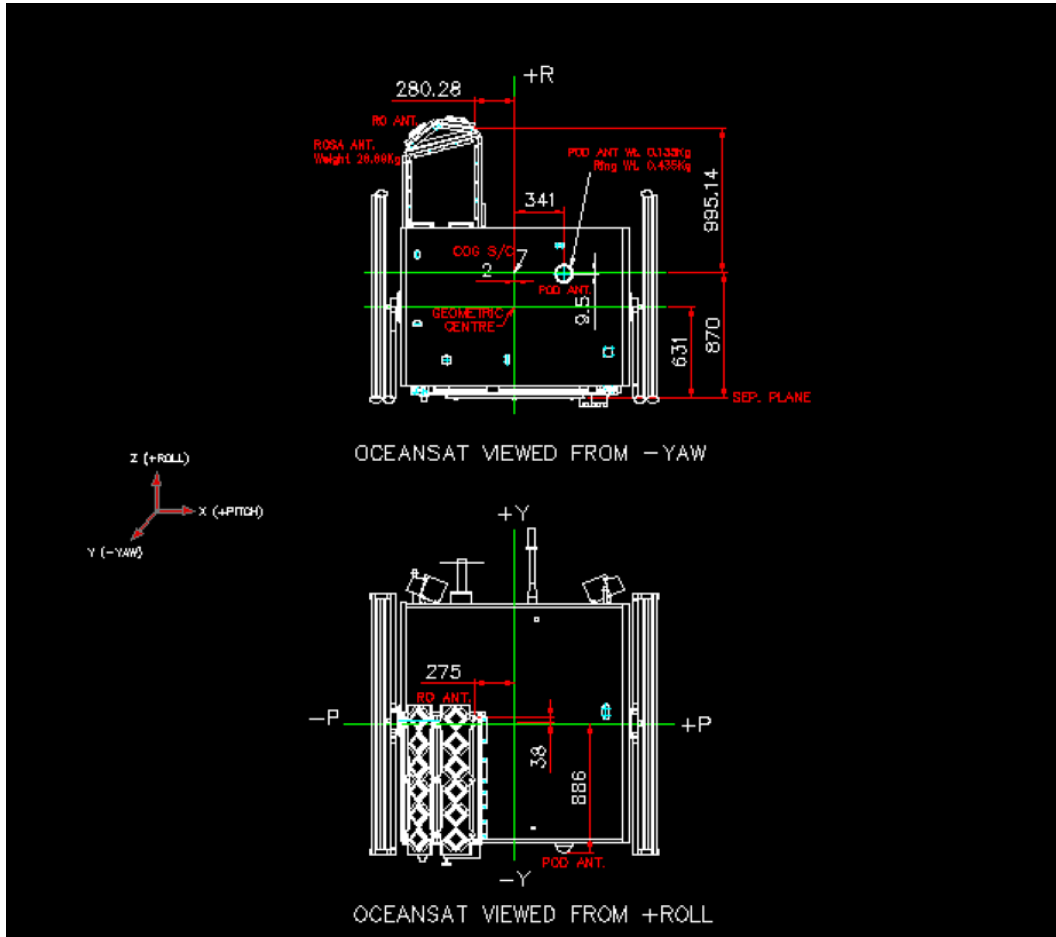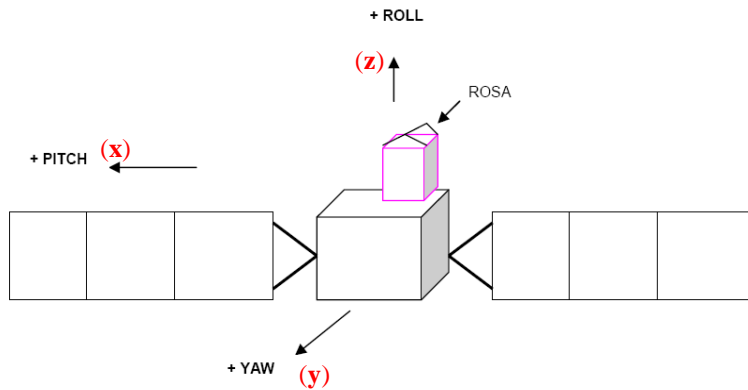
Fig. 4.1 ROSA on-board OCEANSAT-2 schema [RD3]

Considering the yaw (**y** - nadir), roll (**z** - ~velocity) and pitch (**x** - cross direction) axis directions shown in the bottom of Fig. 4.1 (in this document, (**x,y,z**) is defined as right hand Cartesian reference system, as shown in the bottom of Fig. 4.1) and taking values from the original technical pictures shown in Fig. 4.1 (top), we sketched the satellite structure Fig. 4.2, where we highlighted the position of the reference hole (gray corner) for the Radio Occultation Velocity Antenna (green object) and of the POD antenna (blue object), with respect the S/C Center of Gravity (COG S/C - red point). It has to be noted that the COG S/C is defined with an uncertainty of ~2 mm along the pitch axis. This can be seen in Fig. 4.1 (top).
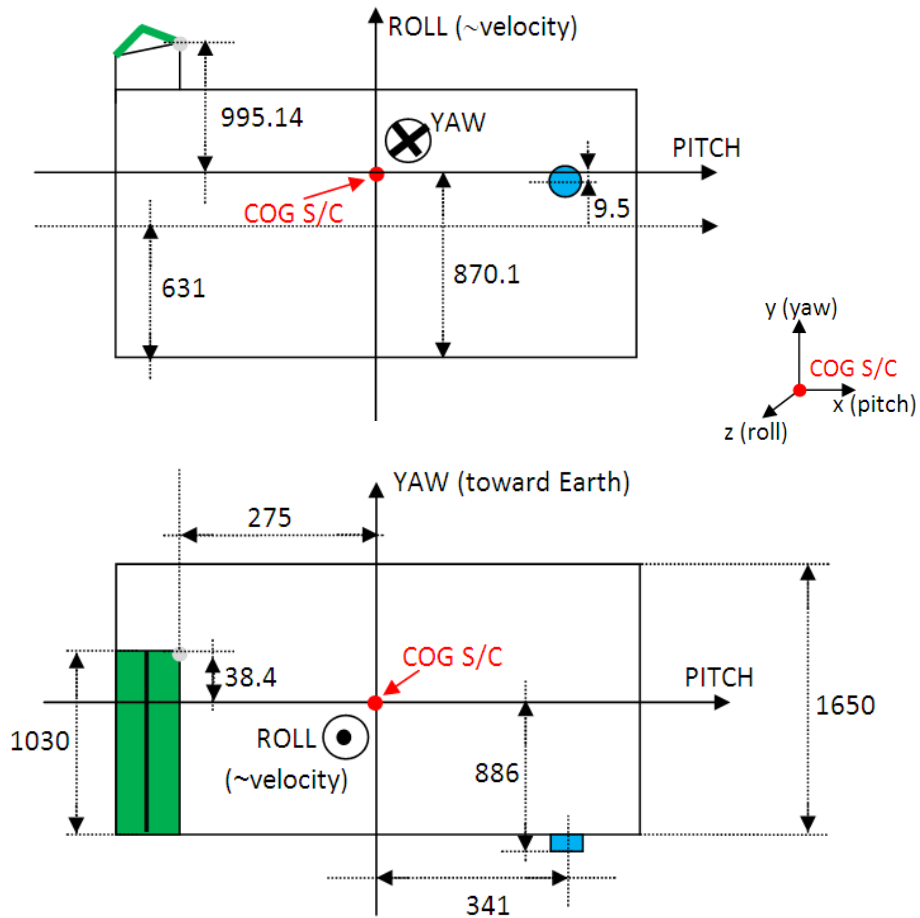
Fig. 4.2 – Oceansat -2 "quoted" sketch. Data are derived by original documentation shown in Fig. 4.1

Even if the documentation is not so clear, and after exchanges with TAS-I, we agreed in identifying the following coordinates for both the antennas with respect to the COG S/C:

POD Antenna (center of the blue object)
x (pitch) = 341 mm (with an uncertainty of 2.1 mm, see Fig. 4.1 (top))
y (yaw) = - 886 mm (top of the POD radome antenna)
z (roll) = -9.5 mm

Radio Occultation Velocity Antenna (Reference hole – gray corner in Fig. 4.2)
x (pitch) = - 275 mm
y (yaw) = + 38.4 mm
z (roll) = 995.14 mm

One point which is somehow critical, is the identification of the Antenna phase centers. As far as the POD Antenna is concerned, as written in the TAS-I ROSA Instrument Operating Manual [Sect. 3.3 RD1], such antenna is a COTS model C146-10 made by Dorne & Margolin (a datasheet can be found in http://www.ppmgmbh.de/ppm%20ov/pdf_e/Brochure%20webpage%20e/GPS%20Hardware/GPS%20Antennen/Choke_Ring.pdf). The datasheet shows (see Fig. X15 here below) where L1 and L2 phase centers should be, with respect to the antenna's basement.
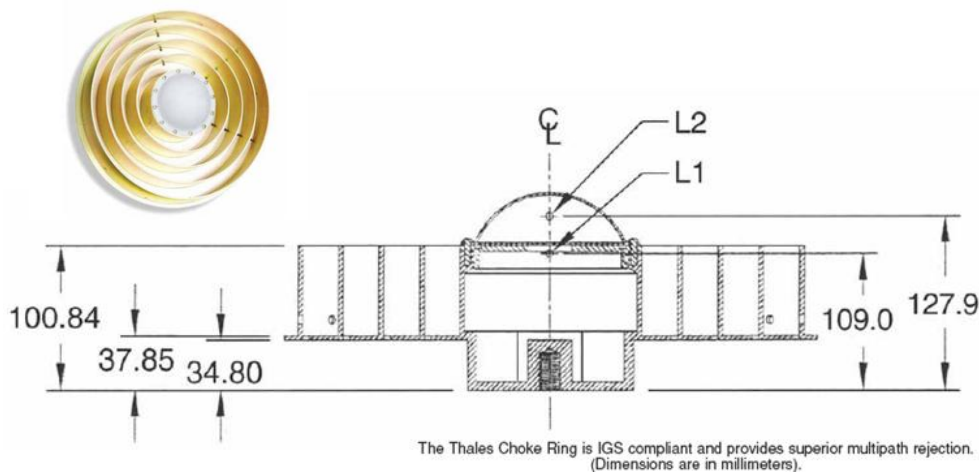
Fig 4.3 – Sketch of the ROSA POD Antenna (taken from the C146-10 Dorne & Margolin model datasheet, available on internet)

From Fig. 4.1 (top), and from the sketch shown in Fig. 4.2, it seems that 886 mm is the **y** distance from the COG S/C and the top of the POD antenna radome. If the Fig. 4.3 is on scale the height of the POD antenna from the choke ring basement and the radome top is ~ 100 mm. Moreover, from Fig. 4.3 it is quite clear that the distance (in the **y** axis direction) of the L1 and L2 phase centers from the choke ring basement is:
for L1: 109.0 – 34.8 = 74.2 mm
for L2: 127.1 – 34.8 = 92.3 mm

Making the hypothesis that the POD antenna is mounted directly from the choke ring basement, the POD Phase Center position with respect to the COG S/C (red point in Fig. 4.1) should be:
for L1:
x (pitch) = 341 mm (with an uncertainty of 2.1 mm, see Fig. 4.1 - top)
y (yaw) = - 786 mm (basement) – 74.2 mm = -860.2 mm
z (roll) = -9.5 mm

for L2:

x (pitch) = 341 mm (with an uncertainty of 2.1 mm, see Fig. 4.1 (top)

y (yaw) = - 786 mm (basement) – 92.3 mm = -878.3 mm

z (roll) = -9.5 mm

For what concerns the Radio Occultation Velocity Antenna (green object) phase centres, we should define its position from the reference hole (gray corner). In order to do that we can use the table made available in Fig 5.13.0 of [RD3], pag 33, here shown for completeness:

	+X Panel			-X Panel		
	X [mm]	Y [mm]	Z [mm]	X [mm]	Y [mm]	Z [mm]
Lower Band L2	0	9	19	13.5	6.6	26.7
Upper Band L1	4.5	-6.7	39.2	13.5	0.7	24.3
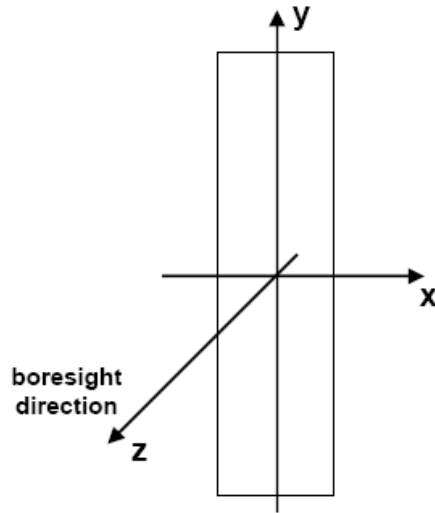
Figure 5.13.0: Used coordinate system

Fig. 4.4 – Reference system for each antenna panel

Also in this case, the available document is not clear. Anyway, under the agreed hypothesis suggested by TAS-I that the reference point here shown is in the middle of each panel, and that the panel +X or –X refers to the panel direction with respect to the pitch axis, it is quite easy to identify the phase center positions on both the frequency bands wrt the S/C COG (the grey corner in Fig. 4.1). The z position is referred to each antenna's panel ground plane (see pag. 32 [RD3]).

In order to be more precise, it is necessary to consider that
- the Radio Occultation Velocity Antenna boresight is not coincident with the OCEANSAT-2 roll axis, but it was rotated 15° in order to reduce local multipath effects (see below).
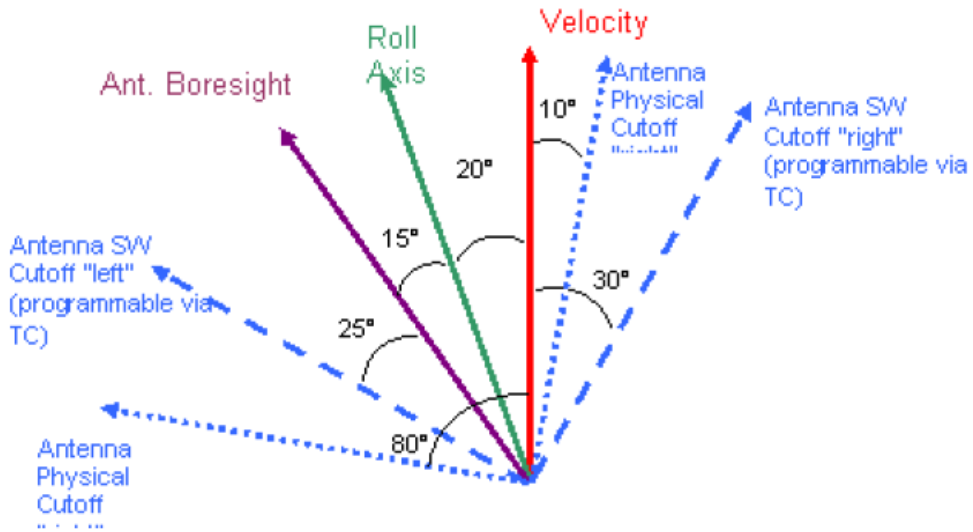
Fig. X3, pag 12 [RD3]

Therefore in computing L1 and L2 Center Phases positions with respect to the S/C Center of Gravity, these aspects should also be taken into account. The example here below can be used to refer (x,y,z) values in the table shown above Fig. X2 to the Reference Hole of the Radio Occultation Velocity Antenna. Black dots are the reference points (0,0,0) of the reference system shown in Fig. X2 (bottom), while the gray dot is the Reference Hole.
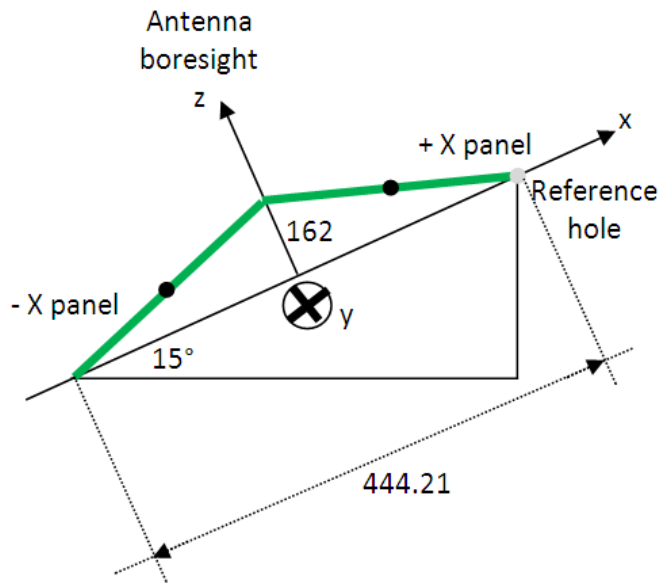

Fig. 4.5 – Sketch of the Occultation antenna displacement with respect to Reference hole

Numerical data shown in Fig. 4.5 are taken from a couple of plots provided by TAS-I. The first one shows the entire ROSA occultation antenna as seen from its boresight (Alberto Zin, personal communication). See Fig 4.6 here below. The second is taken by a presentation made by TAS-I in the framework of the GNSS RO workshop held in Pasadena, 2009 [RD5] (see Fig. 4.7). From the geometry sketch in Fig. 4.5 it will be quite easy to find the displacement of the center of each panel from the reference hole. Using then Table shown in Fig. 4.4, L1 and L2 phase centers can be easily related to the center of each panel.
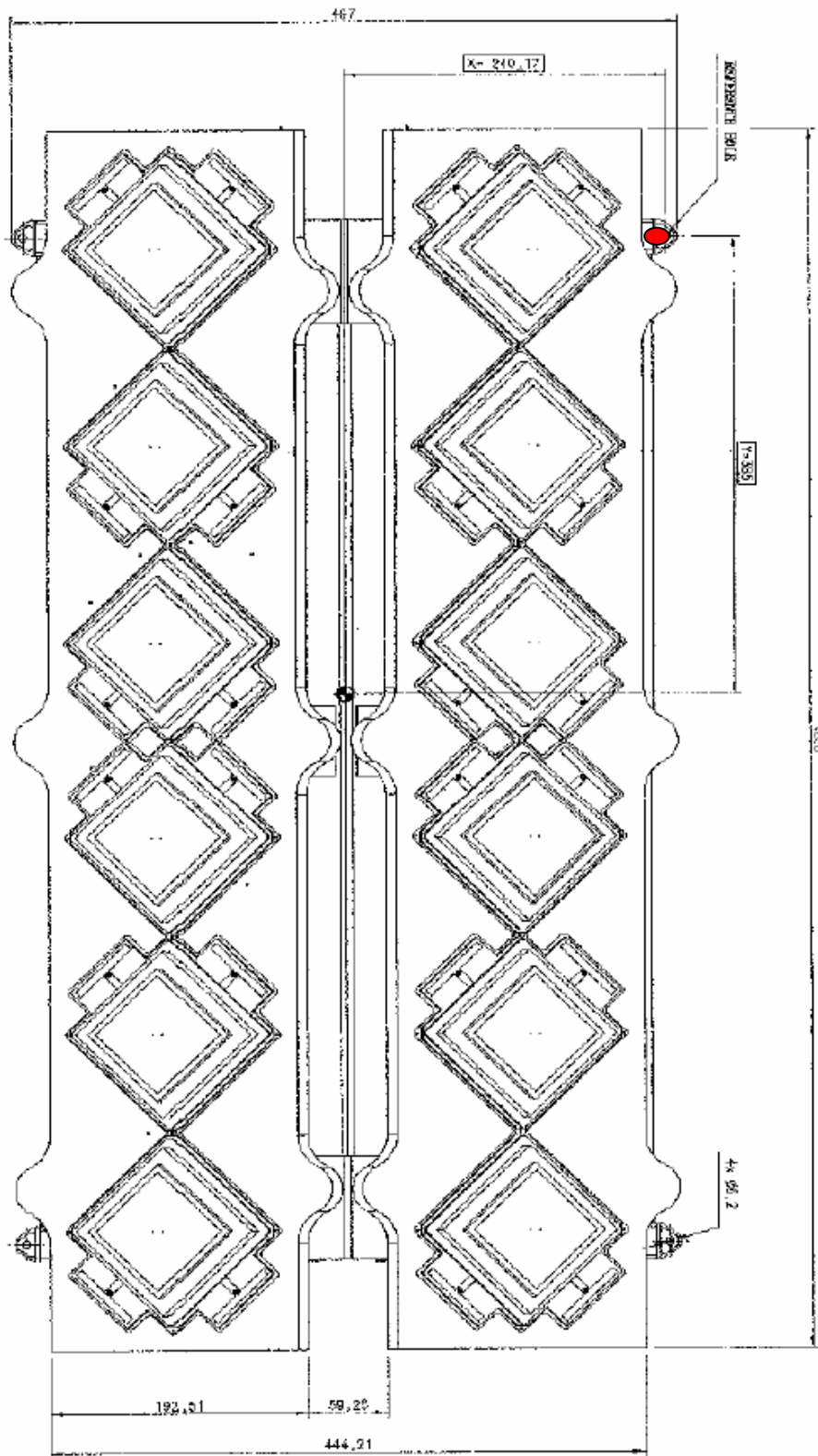
Fig. 4.6 – ROSA Radio Occultation antennas dimensions. The reference hole, whose displacement from COG S/C is shown in Fig. X1 (grey corner), is here hilighted in red.
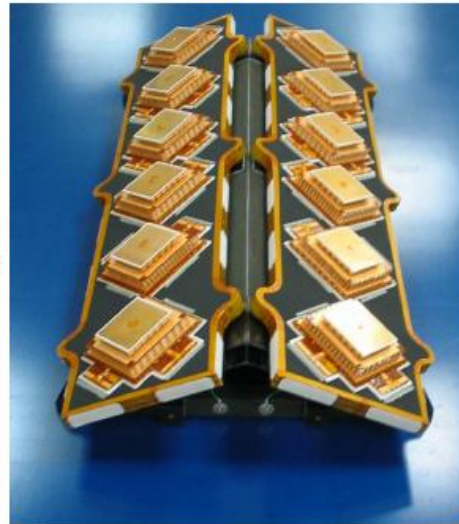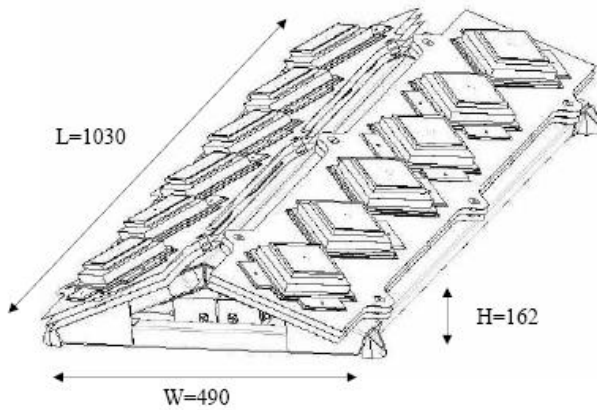
Fig 4.7. – Further ROSA Radio Occultation antenna dimensions.

Considering the documentation provided by Thales Alenia Space [RD5], amplitude (Fig 4.8) and phase (Fig. 4.9) ROSA Radio Occultation antenna radiation pattern on L1 and L2 were available on a plot format. Such data were based on simulations performed on the ROSA RO antenna Flight Model (Fig. 4.10). In these pictures, the ROSA RO antenna field of view is identified by a quasi rectangular shape. The Earth's surface is supposed to be in the top of the figure. The smaller rectangle is the occultation (or "reduced") Antenna coverage, while the bigger one is the space weather (or "extended") Antenna coverage.
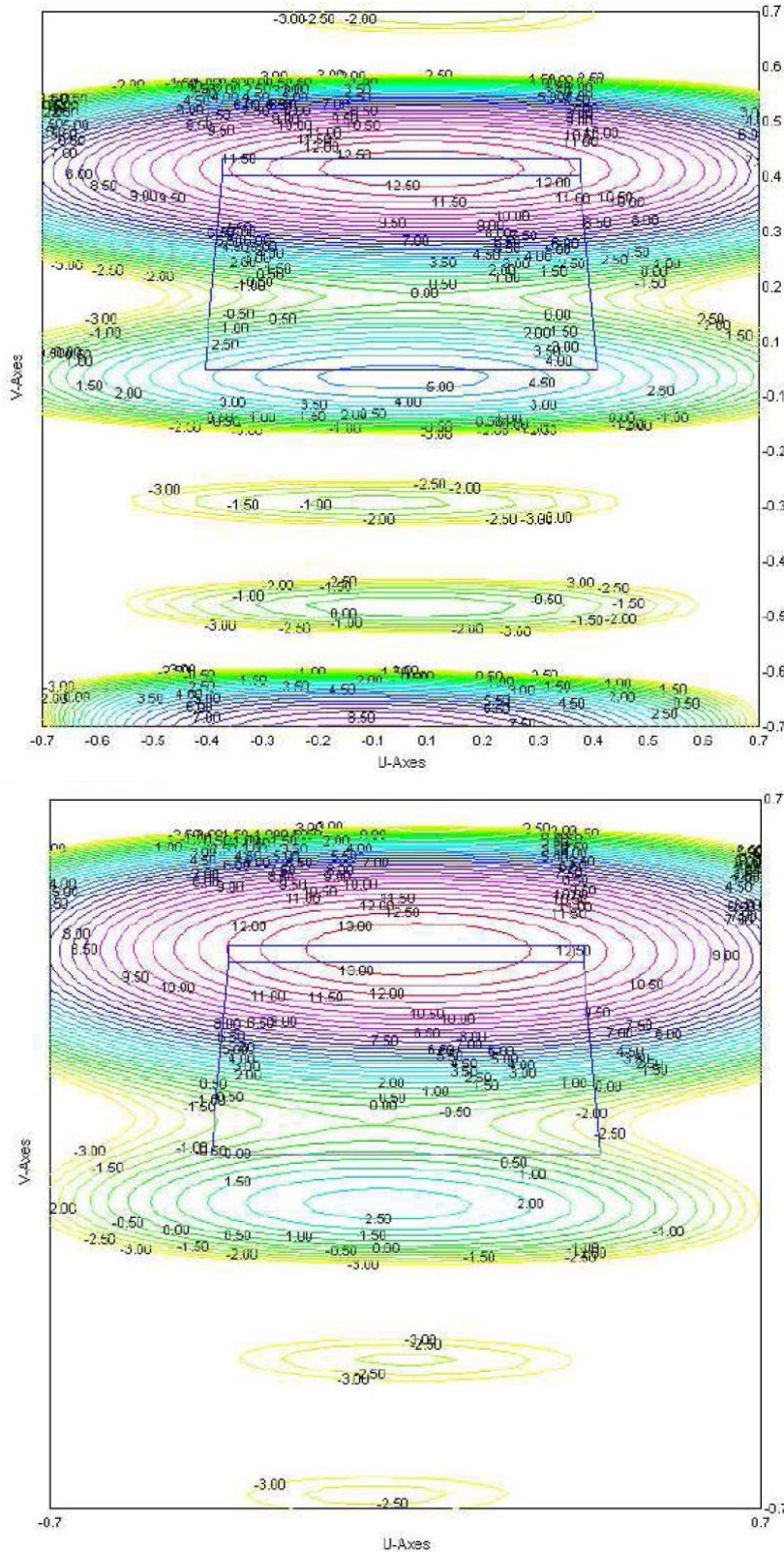
Fig 4.8 – L1 (top) and L2 (bottom) ROSA RO antenna radiation **amplitude** pattern. Contour levels shown antenna's gain in dB
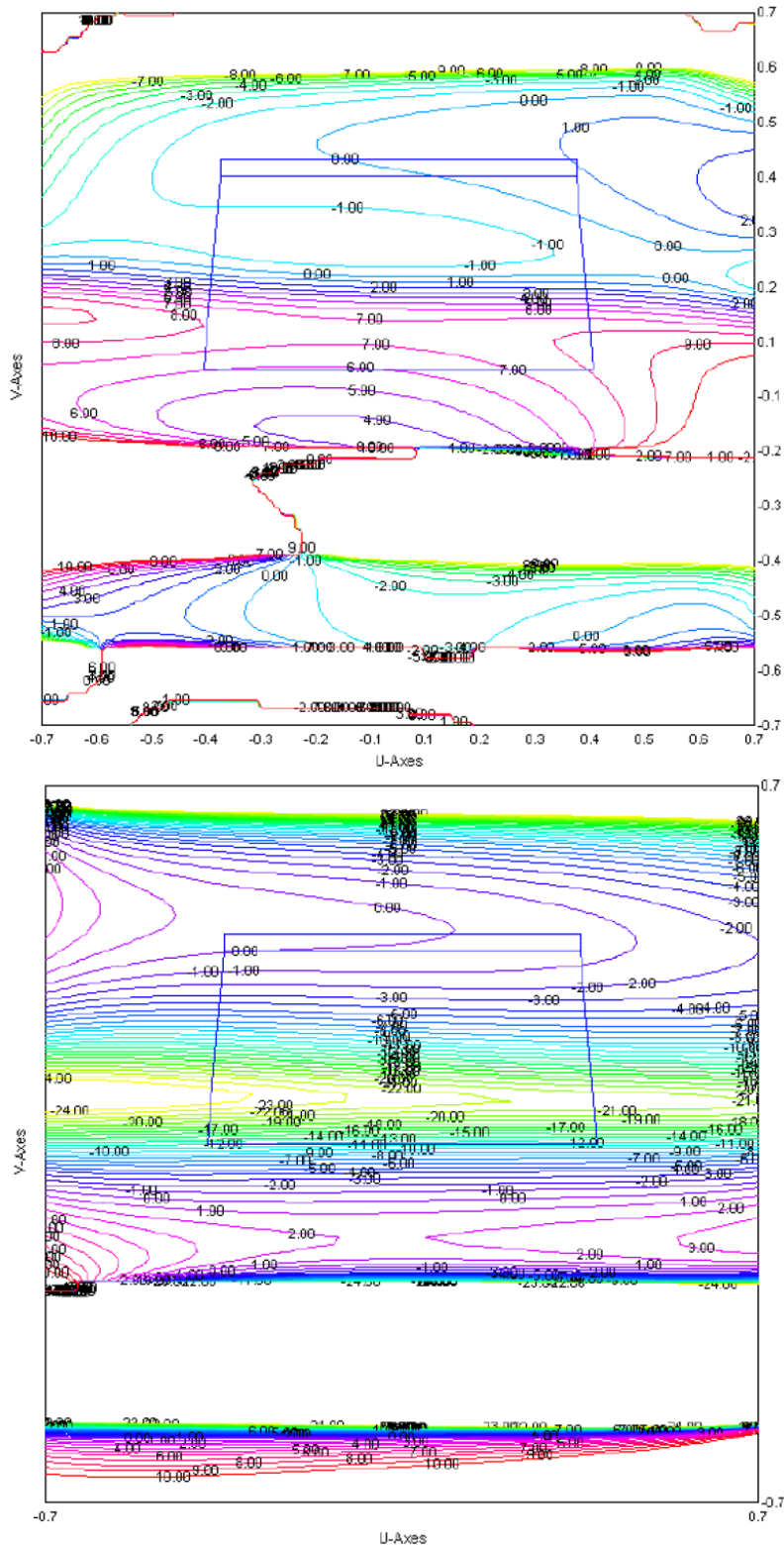
Fig 4.9 – L1 (top) and L2 (bottom) ROSA RO antenna radiation **phase** pattern (in [deg])
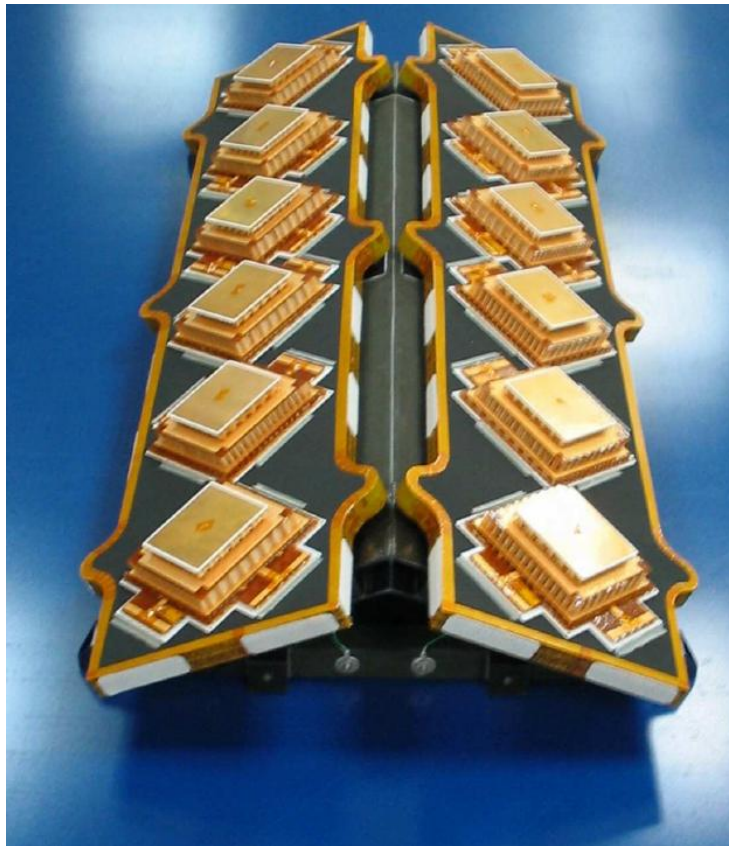
Fig 4.10 – The ROSA RO Antenna

From another point of view, a measurement campaign in an anechoic chamber was carried out considering the antenna alone, in order to identify the error on the L1 and L2 antenna phase centers in function of azimuth and elevation of the incoming ray. Results, taken by [RD3] are plotted in Fig. 4.11. It can be noted that, even though these results are obtained in a "controlled" measuring setup and on the ROSA RO antenna alone, the phase variations are very small when only the reduced coverage (the neutral atmospheric occultation observation) is taken into account. As an example, it is possible to evaluate such total phase variations as about 1 deg at L_1 frequency (top picture in Fig. 4.11) for vertical occultations tracked in the centre of the antenna field of view, inside the overall reduced coverage (i.e. ∼80 km which are scanned in ∼90 s). This means about ∼$6 \cdot 10^{-6}$ m/s in terms of Excess Doppler.

A multipath analysis tailored for OceanSat-2 Satellite was carried out by TAS-I and subcontractors in the framework of the accommodation studies of the ROSA Instrument onboard the Indian satellite. As an example, an electromagnetic modelling of ROSA antenna and its validation was carried out. Details are given in the paper [RD6]. Anyway, considering a freezing satellite geometry (solar panels and OCANSAT-2 Scatterometer Antenna are moving with time), and supposing to rotate Antenna boresight of 15° wrt the velocity direction, the simulated multipath minimizes. Results of residual amplitude and phase errors evaluated for the worst panel (the +X one, see Fig 4.5) are shown in Fig. 4.12. A more detailed analysis on the impact of this multipath error on the final retrievals should be performed, considering also the extra -20° yaw bias of the Oceansat-2 platform.
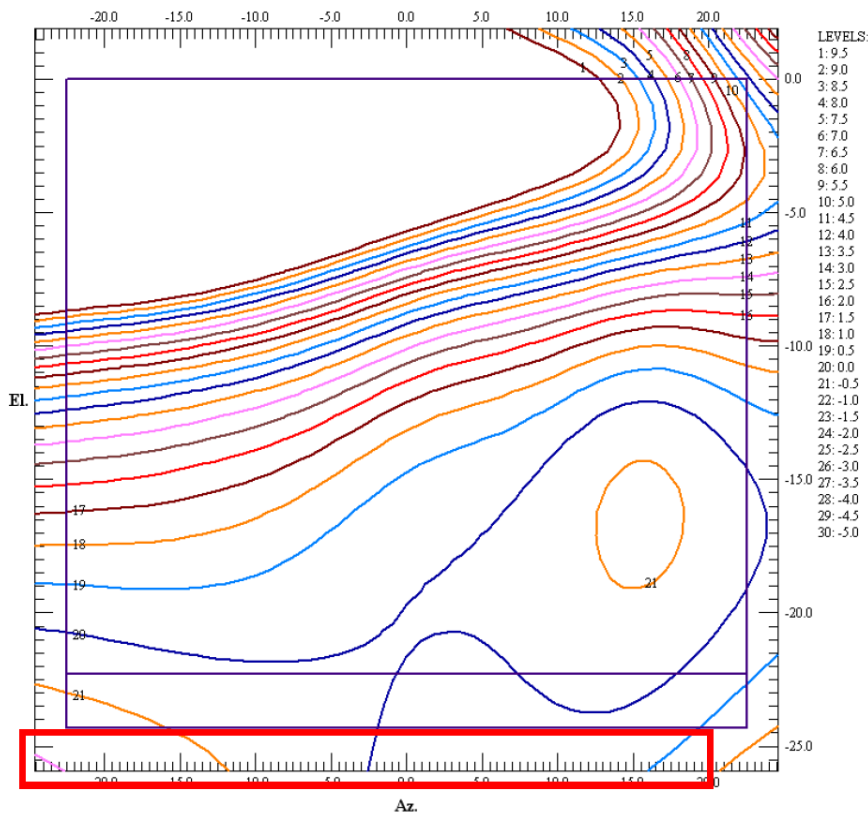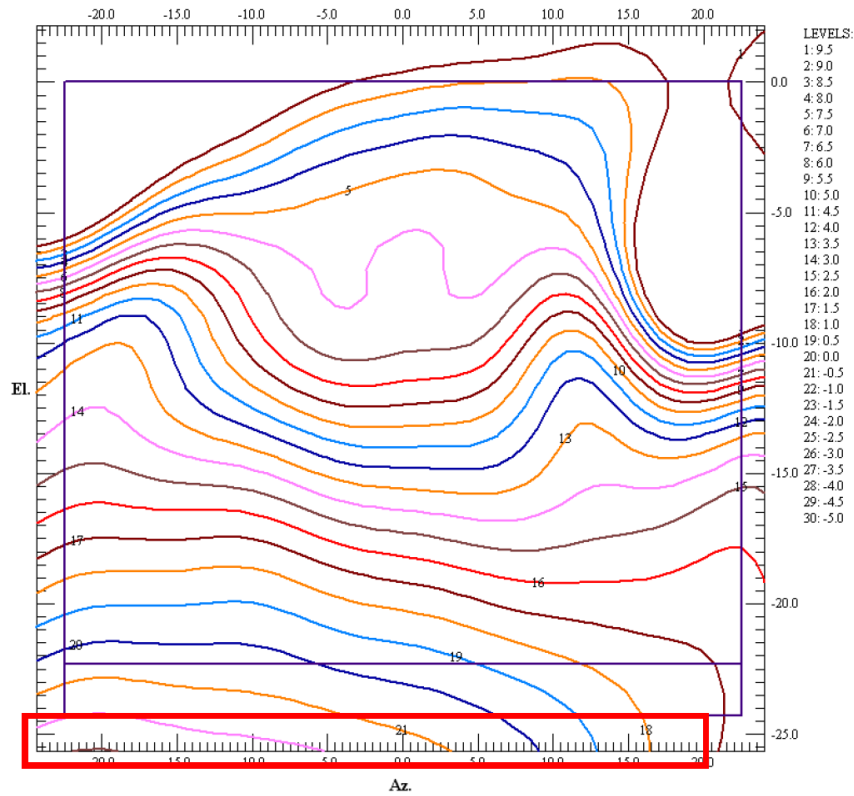
Fig 4.11 – L1 (top) and L2 (bottom) ROSA RO antenna phase error in function of azimuth and elevation of incoming ray. The reduced coverage is represented by the pink small rectangle, which extends from -22° to -25° in the Elevation axis.
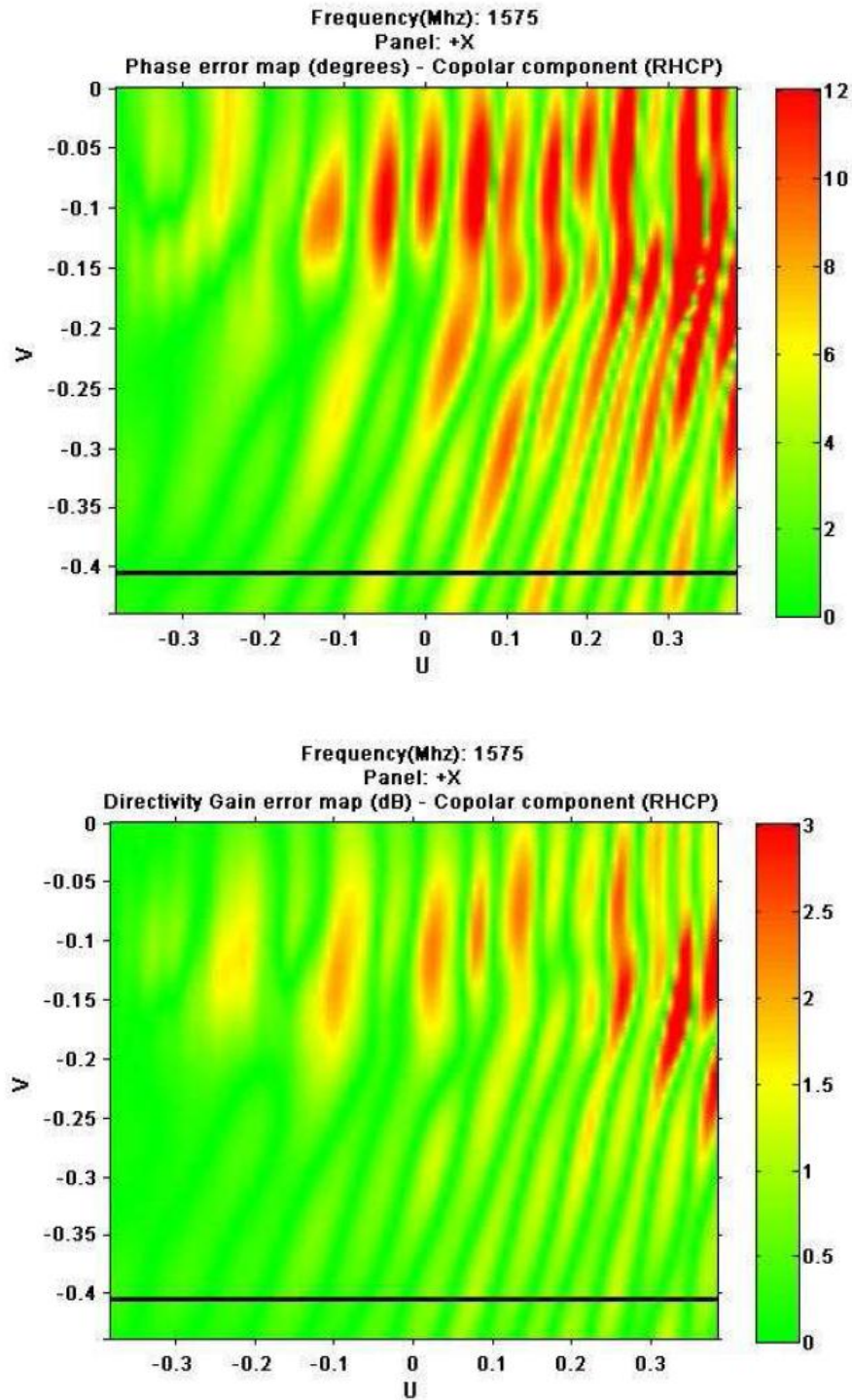
Fig 4.12 – L1 Phase Error (top) and L1 Gain Error (bottom) caused by local multipath, considering a freezing OCEANSAT-2 geometry, and a rotation of the antenna boresight of 15° anticlockwise from the velocity direction. The reduced coverage is shown in the black rectangle in the bottom part of each plot.

5. YAROS prototype for ROSA data processing

An attempt of using the EUMETSAT YAROS prototype with ROSA data was already made before this Visiting Scientist activity. Therefore a copy of the entire YAROS chain, with some modification, was already available.

During the activity, a complete review to adapt the *rinex2l1a.py* YAROS code and its function *occultation.py* (available in *~python/yaros/yaros.rosa/yaros/rosa/*) to process ROSA data was carried out. In particular, its complete debug allow me to understand all the data management and algorithm necessary to create Level1a data (not only profiles of excess phases and Signal-to-Noise ratios, but also all the other information stored in the corresponding NetCDF4.0 output files). In debugging the Python code, I mainly made some changes in order to adapt all the YAROS input data structures to the most important ROSA data available in the High Rate Rinex observing files (described in Sect. 2.1.4).

Christian Marquardt and Yago Andes made a great work in installing all the YAROS environment on my laptop, giving me the possibility to work with YAROS also after the end of the EUMETSAT visit.

Several releases of the *rinex2l1a.py* (and sub-functions *carrier_phase.py* and *occultation.py*) source were produced. The first "stable" one was uploaded in the EUMETSAT SubVersion repository on 20/12/2011 (release #2197 available in: svn+ssh://svnssh@exsvn.eumetsat.int/yaros/trunk). This release interpolates all ROSA raw L1 and L2 data gap smaller than 1.3 sec from when they are available up to 100 km SLTA at least. Since these interpolations procedures gave unsatisfactory results (see the description given in Sect. 5.1), I came back to the previous release. Currently, the latest release (# 2272, committed on 11/01/2012) manages all the ROSA data contained in the High Level files, better manages the transition between 50 Hz, 10 Hz and 1 Hz sample rate but do not tries to interpolate within such transitions. Main changes were applied to the *extract_segments()* methods and *read()/write()* methods of the *occultationL1a* class.

As far as the EUMETSAT POD software is concerned, we modify also the *attitude.py* python source code in order to make it able to manage OCEANSAT-2 quaternions data (which are available through a different OS-2 download channel with respect the one used for OS-2 instrument data, as described in Sect. 2.4). The EUMETSAT SubVersion repository was update accordingly (rel #2127).

Finally, between 27 and 29 February, 2012, several changes to the write/read methods contained in the the *occultation.py* YAROS code for the ROSA data handling were made, in order to make L1a output file to be correctly handled by the latest version of the L1a2L1b YAROS software (the one which process Excess-Phases and Signal SNRs into bending angle profiles). This allowed the possibility to carry out a statistical analysis at the bending angle level (against forward modelled ECMWF atmospheric data) also for the YAROS products related to ROSA observations.

5.1 ROSA data up-sample

Because of the particular sample rate of ROSA occultation data (for a rising case: 100 Hz in OL from the acquisition of the CA code [DLL closed] to ~12 km SLTA, 50 Hz in CL from the acquisition of L1/CA and P2 carrier phase to ~50 km SLTA, 10 Hz from 50km to 200 km SLTA, 1 Hz ~ up to the OCEANSAT-2 orbit), it was decided to change the EUMETSAT YAROS prototype which should manage ROSA data in order to up-sample observation data at 50 Hz everywhere, from 50 km at least to 100 km SLTA.

Such changes were directly applied to the *occultation.py* function called by the *rinex2l1a.py* "main". One new class and corresponding methods were created and tested. The handling of the new class *RosaL1aUpsampled* is called from the *__init__* method of the *OccultationL1a* class inside *occultation.py*. The *__init__* method of the new class *RosaL1aUpsampled* is called instead of the original *OccultationL1aCL* around row 3138 of the *occultation.py* source code. Upsampling is managed inside this *__init__* method (see the code starting from row 2528 of *occultation.py*). New *quality_control()*, *finalize()*, *write()* methods were created for the new *RosaL1aUpsampled* class.

Results were obtained for the thirty hours analyzed, but were not satisfactory. Upsampling data at 50 Hz sample rate was handled both by linearly interpolating raw carrier phases (and Signal-to-Noise ratios) and by linearly interpolating the logarithm of raw carrier phases.
The upsampling has been applied to all the ROSA raw data, each time a data gap (on time tag) < 1.3 s is found. Below 200 km SLTA these data gap
- should be given by real data missing (in lower troposphere). In that case, the linear interpolation was applied even if I was not so sure that this was good (that's why the data are interpolated only when a gap LESS THAN 1s is found)
- are due to the under-sampling at 10 Hz from 50 to 200 km SLTA.

In terms of corresponding Excess phase profile, both the linear interpolations do not work well, since orbits (which are necessary to subtract the geometry from the raw observables) and clock biases are automatically interpolated by YAROS procedures following different laws. Ant this cause bad behavior in the interpolated pieces.

An example is shown here. This is a generic L_1 Excess Phase profile, obtained linearly interpolating L1 raw carrier phases.
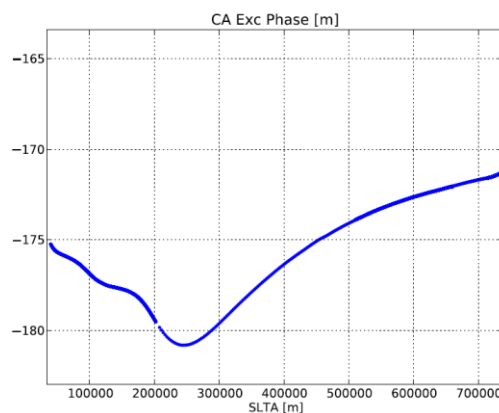

Looking at the details of this profile at different SLTAs, the bad effects of this linear interpolation are well evident, and their impact is more "dangerous" when the atmospheric effect is more strong (at lower SLTAs).
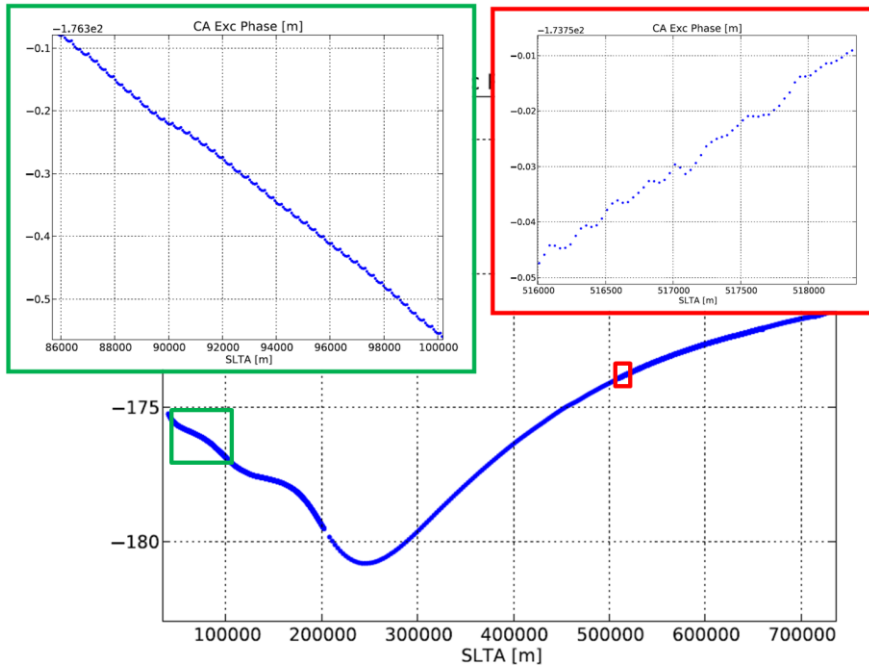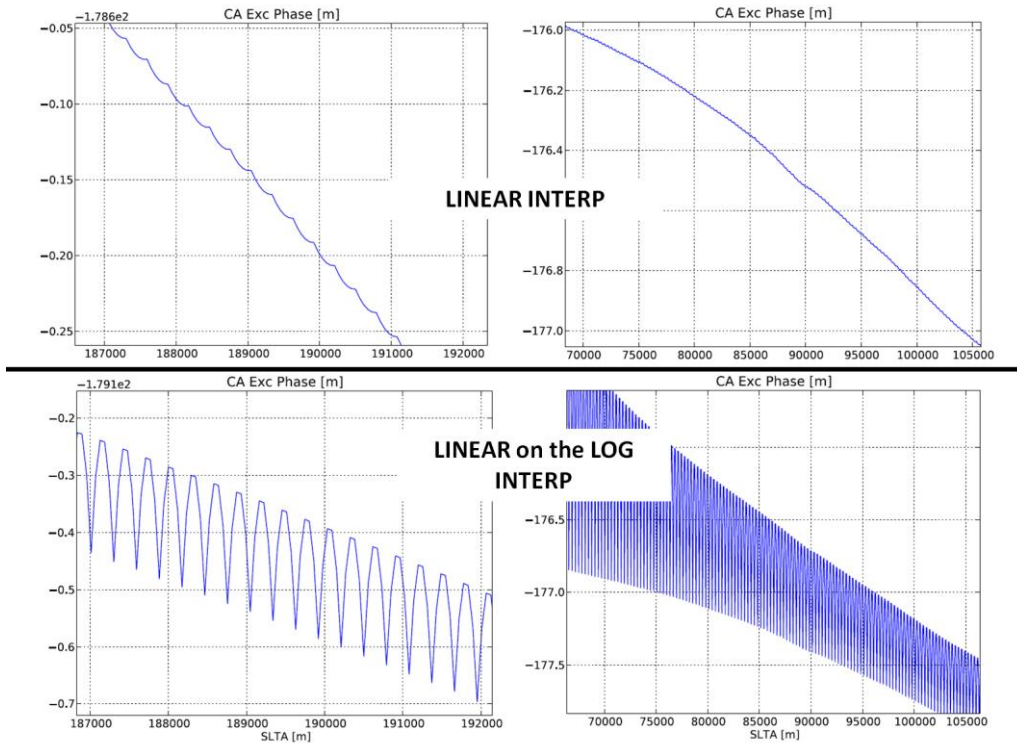
The "ondulations" in the Excess Phase interpolated profile are caused because of
- Carrier phases are linearly interpolated
- Orbits and clocks are interpolated using different laws

The same effect is obviously also well evident in the L2 Excess Phase profile:
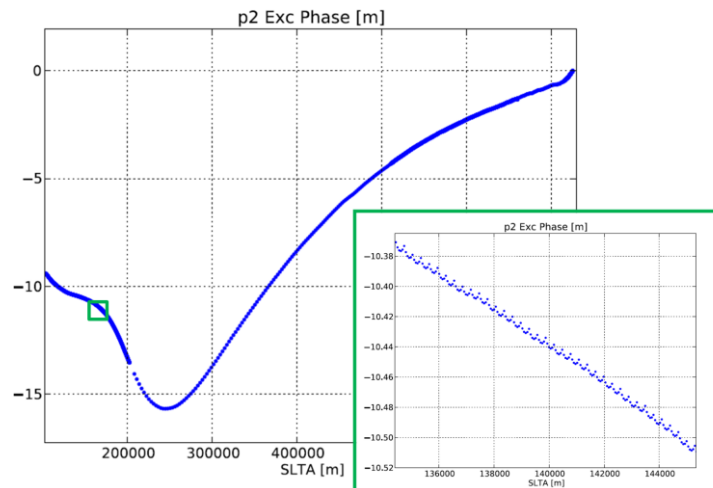
The behavior of raw carrier phase profile could be thought as following an exponential instead of a linear law. Therefore it is possible to expect an improvement, linearly interpolating the logarithm of carrier phase. But, also in this case, since the standard interpolation laws applied to orbits and clocks are different, results were not acceptable:

Ref: SAF/GRAS/DMI/REP/VS16/001
Version: 1.2
Date: 03 March 2012
Document: grassaf_cvs16_rep_v1.2

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Even if it is possible to try to interpolate in some way excess-phases profiles, we decided to not apply interpolations strategy to ROSA data at the Level 1a. Therefore we decided to come back to the previous YAROS/ROSA release, leaving interpolation issues to the following step of the processing chain.

The current version of YAROS/ROSA software will generate Level1a NetCDF 4.0 files, one for each recognized occultation event, and it generates an output on the Linux shell on which important geometric characteristics of each continuous segment of data (recognized inside the occultation event) are given. Small gaps < 1.3 sec are not considered "discontinuities" (even if following processing stages will interpolate them using standard YAROS and ROPP procedures already implemented for GRAS and COSMIC data processing).

Such geometric characteristics were used to implement a quality check procedure for the ROSA data at their first processing level. Overall results of the analysis performed for the thirty hours analyzed in the framework of this activity (from 13:30 UTC of 24 August, 2010 to 17:40 UTC of 25 August 2010) will be given in Chapter 7. I show here a couple of examples. The first one is related to one occultation event with SV 30, recognized between 17:33:38 and 17:43:09 (24 August, 2010).

```
INFO          Sat G30 (rising)
...
...
INFO              CL data: 2010-08-24 17:33:38.26 - 2010-08-24 17:43:09.20 / 570.94 secs /  3951 data points
INFO              Geolocation: occ:  68.5 W / 53.4 S / 138.1 azimuth
INFO                           leo:  88.7 W / 31.5 S
INFO                           gns:  55.6 E / 38.4 S
INFO          Extracting continuous data segments...
INFO          CL data has 1 CA segment:
INFO              CL segment: 2010-08-24 17:33:38.26 - 2010-08-24 17:43:09.20 / 570.94 secs /  3951 data points / -89.78 - 746.51 km
INFO          CL data has 1 P2 segment:
INFO              CL segment: 2010-08-24 17:34:11.16 - 2010-08-24 17:43:09.20 / 538.04 secs /  2306 data points / -7.54 - 746.51 km
ORIGINAL DATA QUALITY CONTROL
WARNING    Noise calculation deactivated for ROSA Rinex data for CA_exphase_noise_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data CA_exphase_noise_local_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data for L2_exphase_noise_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data L2_exphase_noise_local_lf, set to missing.
WRITE ORIGINAL to NETCDF
INFO              Writing /home/ricky_notar/data/ROSA/level1a/rosa_l1a_oc2_20100824173338Z_20100824174309Z_20120118145925Z.n4... successful.
...
...
```

Within this event no gaps (> 1.3 sec) were identified on both L1 (CA) and L2 (P2), and 1 continuous segment has been extracted for each carrier. The SLTA interval for which the L1 (CA) segment is available is form -89.78 km to 746.51 km, while the SLTA interval for which the L2 (P2) segment is available is form -7.54 km to 746.51 km.

In this other case things are not so good. In this second example the SV 15 is occulted 4 times during the interval which input data refers to. The first occultation happens between 11:15:05 and 11:24:23 UTC (25 August, 2010) and the recognized event is very "segmented" for both L1 and L2 observations.

```
INFO          Sat G15 (rising)
INFO             Satellite G15 with 4 occultations:
INFO                CL data: 2010-08-25 11:15:05.28 - 2010-08-25 11:24:23.20 / 557.92 secs /  7694 data points
INFO                Geolocation: occ:  26.8 E / 52.6 N / -168.3 azimuth
INFO                             leo:  50.9 E / 77.3 N
INFO                             gns:  14.4 E / 22.9 S
INFO             Extracting continuous data segments...
INFO                CL data has 4 CA segments:
INFO                   CL segment: 2010-08-25 11:15:05.28 - 2010-08-25 11:17:18.20 / 132.92 secs /  3649 data points / -114.34 - 224.24 km
INFO                   CL segment: 2010-08-25 11:17:20.20 - 2010-08-25 11:21:37.20 / 257.00 secs /  3881 data points / 228.76 - 648.88 km
INFO                   CL segment: 2010-08-25 11:21:39.20 - 2010-08-25 11:24:17.20 / 158.00 secs /   159 data points / 650.82 - 731.32 km
INFO                   CL segment: 2010-08-25 11:24:19.20 - 2010-08-25 11:24:23.20 /   4.00 secs /     5 data points / 731.39 - 731.45 km
INFO                CL data has 5 P2 segments:
INFO                   CL segment: 2010-08-25 11:15:58.68 - 2010-08-25 11:16:29.20 /  30.52 secs /   589 data points / 30.59 - 108.13 km
INFO                   CL segment: 2010-08-25 11:16:41.20 - 2010-08-25 11:17:18.20 /  37.00 secs /   281 data points / 137.54 - 224.24 km
INFO                   CL segment: 2010-08-25 11:17:20.20 - 2010-08-25 11:21:37.20 / 257.00 secs /  3881 data points / 228.76 - 648.88 km
INFO                   CL segment: 2010-08-25 11:21:39.20 - 2010-08-25 11:24:17.20 / 158.00 secs /   159 data points / 650.82 - 731.32 km
INFO                   CL segment: 2010-08-25 11:24:19.20 - 2010-08-25 11:24:23.20 /   4.00 secs /     5 data points / 731.39 - 731.45 km
ORIGINAL DATA QUALITY CONTROL
WARNING    Noise calculation deactivated for ROSA Rinex data for CA_exphase_noise_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data CA_exphase_noise_local_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data for L2_exphase_noise_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data L2_exphase_noise_local_lf, set to missing.
WRITE ORIGINAL to NETCDF
INFO             Writing /home/ricky_notar/data/ROSA/level1a/rosa_l1a_oc2_20100825111505Z_20100825112423Z_20120118161201Z.n4... successful.
```

6. YAROS to ROPP

In order to use Level1a NetCDF 4.0 files generated by the EUMETSAT YAROS prototype as input for the GRAS-SAF Radio Occultation Processing Package ROPP_PP, I created a python script which manages the transformation into NetCDF 3.0 files, with all the data structures already prepared for the ROPP_PP processing. In this way we were able to process ROSA data up to the bending and to the refractivity and dry temperature level. In Appendix A I provided the code of the python method able to do this transformation, on which all the variables are identifible.

A Matlab script is also produced in order to generate a list of geometrical parameters extracted for each occultation input file available in NetCDF 3.0 ROPP-like format. For each occultation, the list contains the following information:
- Level1a_file_name,
- gns_sv_id,
- year,
- month,
- day,
- hour,
- minute,
- second,
- latitude,
- longitude

(time data and spatial data are referred to the SLTA = 0 condition). The list was used at DMI to provide, for each occultation, the ECMWF collocated profile. ECMWF variables were stored in a NetCDF 3.0 file, one file for each occultation event.

The ROPP_PP software was then used to produce atmospheric profiles, given as input files the Level1a files processed by YAROS/ROSA prototype. Such results were compared with corresponding ECMWF collocated profiles.

ECMWF profiles were also used as input to the ROPP_FM (Forward Modelling) package, which produces corresponding bending angle profiles, to be compared with ROPP_PP bending angle output profiles.

All the results obtained considering the thirty hours analyzed in the framework of this activity (from 13:30 UTC of 24 August, 2010 to 17:40 UTC of 25 August 2010) are shown in the following Chapter.

7. ROSA data quality and preliminary results (30 hours data)

In this Chapter results related the data quality analysis performed on the ROSA data, processed both by the updated release of the EUMETSAT YAROS processor and by the GRAS-SAF ROPP_PP processing chain, are given.

As it has already be introduced in the Sect. 2.5, it has to be noted that, even if data are available for one entire month, analysis and results has been performed on a shorter time interval. The thirty hours from 13:30 UTC of 24 August, 2010 to 17:40 UTC of 25 August 2010 were deeply analyzed during the Visiting Scientist activity, using both the EUMETSAT YAROS prototype and the GRAS-SAF ROPP software.

ROSA Engineered Level 1 High Rate files are given in input to the YAROS/ROSA prototype, which produced Level1a and Level1b output, one NetCDF 4.0 file for each identified occultation event and for each level.

Geometrical parameters related to L1 and L2 Excess-phases continuous segments were statistically analyzed, in order to check the quality of such raw occultation observables.

Level1a file were converted to ROPP_PP NetCDF 3.0 file format, in order to be directly handled by the GRAS-SAF processing chain. The YAROS routine L1a2L1b was also used to produce bending angle profiles (L1b data) from the Level 1a data.

Bending angle profiles, refractivity and dry temperature profiles derived in output from the ROPP_PP processing chain were then individually compared with collocated ECMWF data (refractivity and temperature) and with collocated Occultation products (bending angles, refractivity, temperature) derived by other missions (COSMIC, METOP-A and TERRA SAR-X) and by other processing software (CDAAC).

Finally, ROPP_FM Forward Model 1D propagator was used to derive, for each collocated ECMWF profile, the corresponding bending angle profile. Such profiles were compared with those produced both by ROPP_PP and by YAROS/ROSA and a final statistics is evaluated also for these intermediate products.

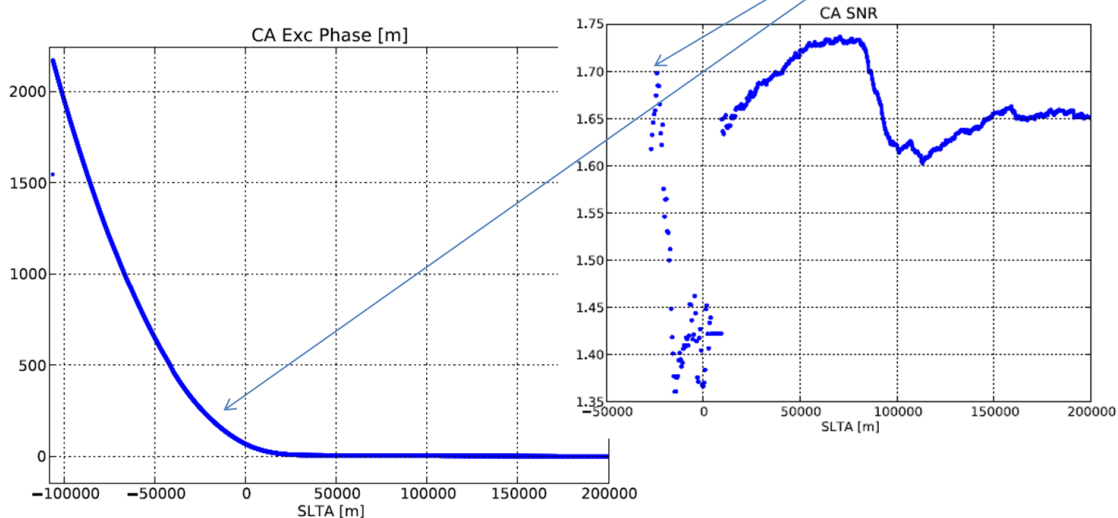## 7.1 ROSA Excess Phases and SNR profiles (YAROS Level1a output)

Just to give some examples of standard ROSA L1 and L2 Excess Phases and Signal(Carrier)-to-Noise ratios, in what follows some plots are shown. In particular, for each occultation shown, the output from the *extract_segment()* method (mentioned in the Chapter 5 introduction and at the end of Sect. 5.1) are also shown. It has to be noted that the minimum SLTA for the L1 C/A segment was computed here considering the availability of SNR data. In ROSA data this happens only when the CA tracking status flag is 9. But, as we have discussed in Sect. 3.2, L1 carrier phase data can probably "safely" used even before this happen. Considering the first availability of L1 carrier phase data (even if tracking status is < 9), such minimum SLTA value varies normally around -100 km (a couple of examples are shown at the end of Sect. 5.1). The current YAROS/ROSA release (#2272 available in: svn+ssh://svnssh@exsvn.eumetsat.int/yaros/trunk) provides such values in output of *extract_segment()* method. It has to be noted that, when complete ROSA data structures will be managed by the YAROS prototype, also CA tracking status will be available. In that case, "safe" L1 carrier phase data should be considered those for which CA tracking status are greather or equal to 8. In that case, the minimum SLTA value for each L1 segment will probably be higher than -100 km.
The examples here shown consider as minimum SLTA availability the one for which SNR is different from "NaN". Moreover in these qualitative examples, output from the release which manages the data upsampling to 50 Hz are considered (therefore, in most cases, maximum SLTA is limited to 200 km).

7.1.1 Qualitative examples on Excess Phase profiles

The first example is related to the first occultation with SV02 (25/08/2010 from 11:04:45 to 11:15:05). In this case we have identified one CA segment (and SNR is available from -27 km SLTA) and 2 L2 segments. The behavior of L1 segment is quite "nice", even if the SNR is quite "disturbed".

The first L2 segment starts too high in atmosphere (~30 km minimum SLTA) and the behavior is shown here below.



```
INFO        Extracting and calibrating occultation data...
INFO        Sat G02 (rising)
INFO          Satellite G02 with 1 occultation:
INFO            CL data: 2010-08-25 11:04:45.30 - 2010-08-25 11:15:05.20 / 619.90 secs /  4378 data points
INFO            Geolocation: occ: 121.5 E / 61.4 N / -115.2 azimuth
INFO                         leo: 178.1 E / 61.4 N
INFO                         gns: 60.1 E /  0.6 N
INFO          Extracting continuous data segments...
INFO            CL data has 1 CA segment:
INFO              CL segment: 2010-08-25 11:05:18.00 - 2010-08-25 11:06:57.18 /  99.18 secs /  4960 data points / -27.01 - 199.98 km
INFO            CL data has 2 P2 segments:
INFO              CL segment: 2010-08-25 11:05:41.34 - 2010-08-25 11:06:23.70 /  42.36 secs /  2119 data points / 29.29 - 127.02 km
INFO              CL segment: 2010-08-25 11:06:52.90 - 2010-08-25 11:06:57.18 /   4.28 secs /   215 data points / 190.87 - 199.98 km
ROSA data Quality control
WARNING    Noise calculation deactivated for ROSA Rinex data for CA_exphase_noise_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data CA_exphase_noise_local_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data for L2_exphase_noise_lf, set to missing.
WARNING    Noise calculation deactivated for ROSA Rinex data L2_exphase_noise_local_lf, set to missing.
```
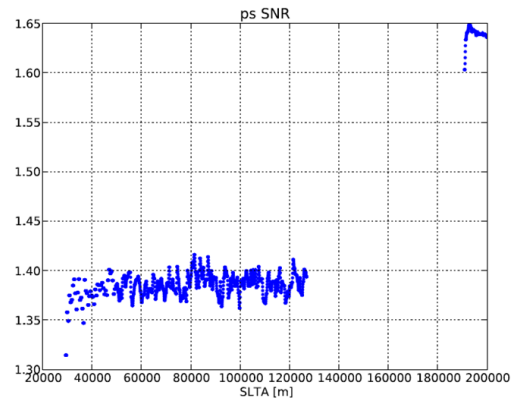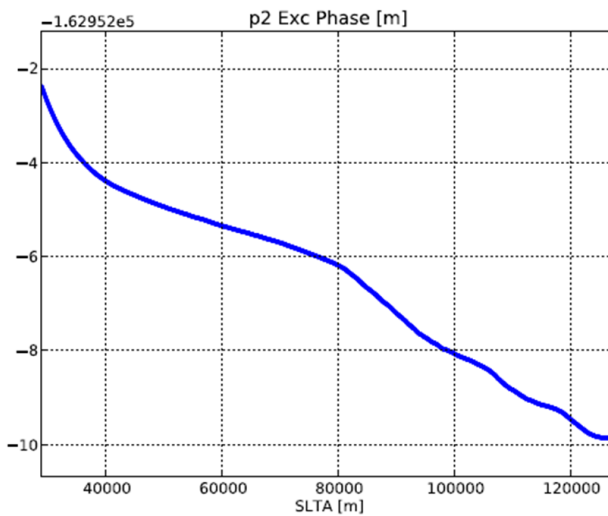

Another case is the following one, which involves the first occultation with SV03

```
Sat G03 (rising)
  Satellite G03 with 2 occultations:
    CL data: 2010-08-25 04:25:44.22 - 2010-08-25 04:32:28.20 / 403.98 secs /  8033 data points
    Geolocation: occ:  98.7 W / 76.9 N / -30.6 azimuth
                 leo:  77.5 W / 52.7 N
                 gns: 114.5 E / 25.3 N
  Extracting continuous data segments...
    CL data has 2 CA segments:
      CL segment: 2010-08-25 04:25:45.00 - 2010-08-25 04:26:38.20 /  53.20 secs /   664 data points / 40.02 - 202.35 km
      CL segment: 2010-08-25 04:26:40.20 - 2010-08-25 04:32:28.20 / 348.00 secs /  7330 data points / 208.09 - 736.40 km
    CL data has 2 P2 segments:
      CL segment: 2010-08-25 04:26:05.20 - 2010-08-25 04:26:38.20 /  33.00 secs /   331 data points / 103.82 - 202.35 km
      CL segment: 2010-08-25 04:26:40.20 - 2010-08-25 04:31:38.50 / 298.30 secs /  5825 data points / 208.09 - 724.89 km
```

This case is not interested for neutral atmospheric studies, but it could be qualitatively taken into account to reveal the ROSA capability in sounding also the ionosphere. In fact, L1 and L2 Excess-phase profiles reveal ionospheric behavior, and the uncalibrated TEC can be easily extracted considering their difference. All such plots are shown here below.
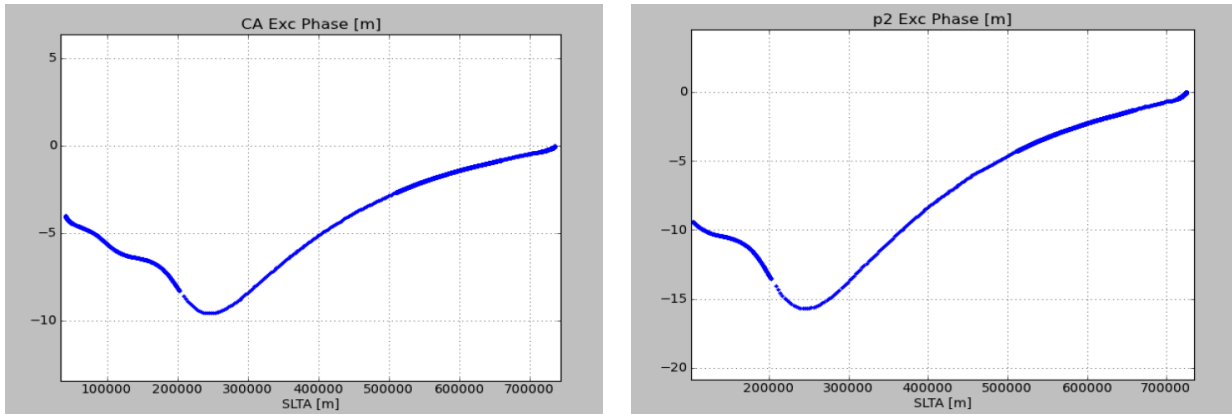
L1 (left) and L2 (right) Excess Phase profile (the data gap around 200 km SLTA is also shown)
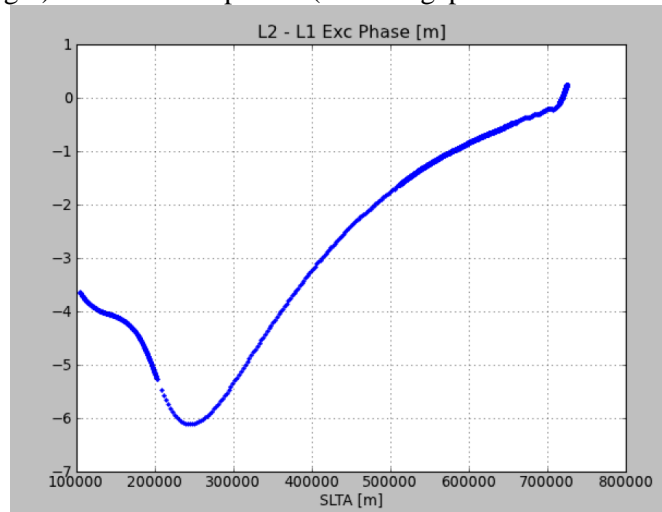
Uncalibrated TEC (L1 – L2) profile

Another nice example is the one also involving SV03 (its second occultation), whose data are observed between 05:53 and 06:01 (25/08/2010)

```
INFO            CL data: 2010-08-25 05:53:05.26 - 2010-08-25 06:01:06.20 / 480.94 secs /  6877 data points
INFO            Geolocation: occ: 105.8 W / 34.4 N / -36.4 azimuth
INFO                          leo:  90.3 W / 12.4 N
INFO                          gns: 141.4 E / 51.4 N
INFO            Extracting continuous data segments...
INFO            CL data has 1 CA segment:
INFO                CL segment: 2010-08-25 05:53:05.26 - 2010-08-25 06:01:06.20 / 480.94 secs /  6877 data points / -136.67 - 728.43 km
INFO            CL data has 1 P2 segment:
INFO                CL segment: 2010-08-25 05:54:04.68 - 2010-08-25 06:01:06.20 / 421.52 secs /  3922 data points / 53.13 - 728.43 km
```

Also in this case data are not so good for neutral atmospheric studies (L2 starts to be tracked too high), but the ionospheric observation reveals a nice uncalibrated TEC behavior, as shown by the following plots. It has to be highlighted the structure at ~100 km SLTA. It is not clear if this is caused by a systematic effect (see end of Sect. 2.3) or if it is related to some ionospheric structures (sporadic E layers ?)

L1 (left) and L2 (right) Excess Phase profile
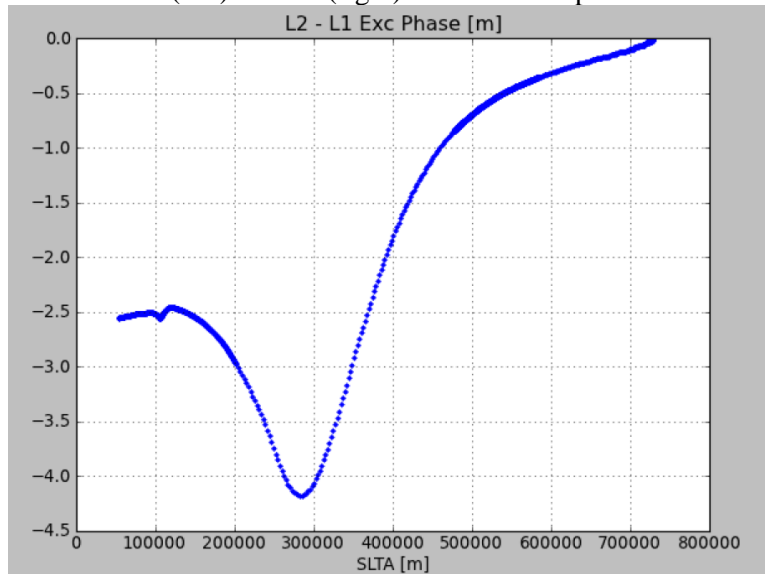
Uncalibrated TEC (L1 – L2) profile

Another similar example follows.

```
INFO        Sat G29 (rising)
INFO            Satellite G29 with 2 occultations:
INFO                CL data: 2010-08-25 05:26:30.28 - 2010-08-25 05:34:12.20 / 461.92 secs /  5915 data points
INFO                Geolocation: occ:  84.1 W / 59.7 S / -19.2 azimuth
INFO                             leo:  25.0 W / 80.2 S
INFO                             gns: 103.3 W / 14.9 N
INFO            Extracting continuous data segments...
INFO                CL data has 1 CA segment:
INFO                    CL segment: 2010-08-25 05:26:30.28 - 2010-08-25 05:34:12.20 / 461.92 secs /  5915 data points / -95.98 - 744.41 km
INFO                CL data has 1 P2 segment:
INFO                    CL segment: 2010-08-25 05:27:22.70 - 2010-08-25 05:34:12.20 / 409.50 secs /  3552 data points / 71.46 - 744.41 km
```
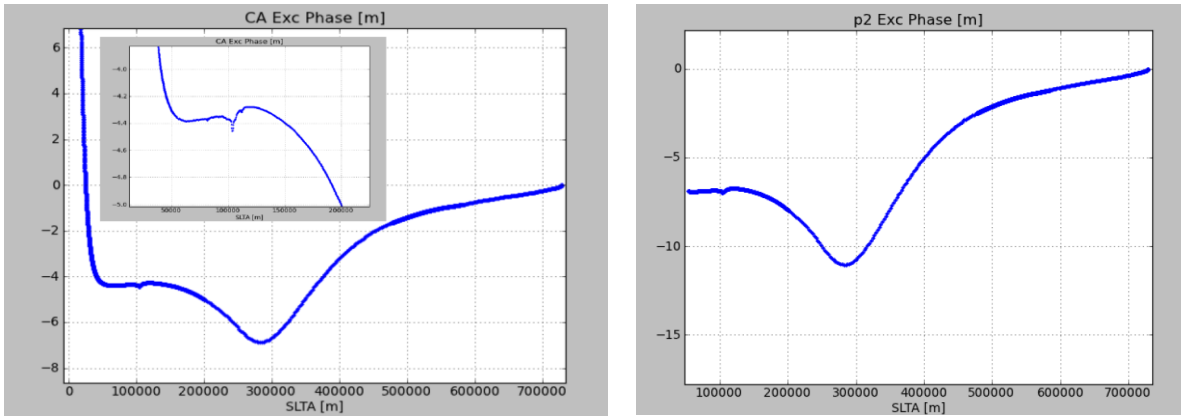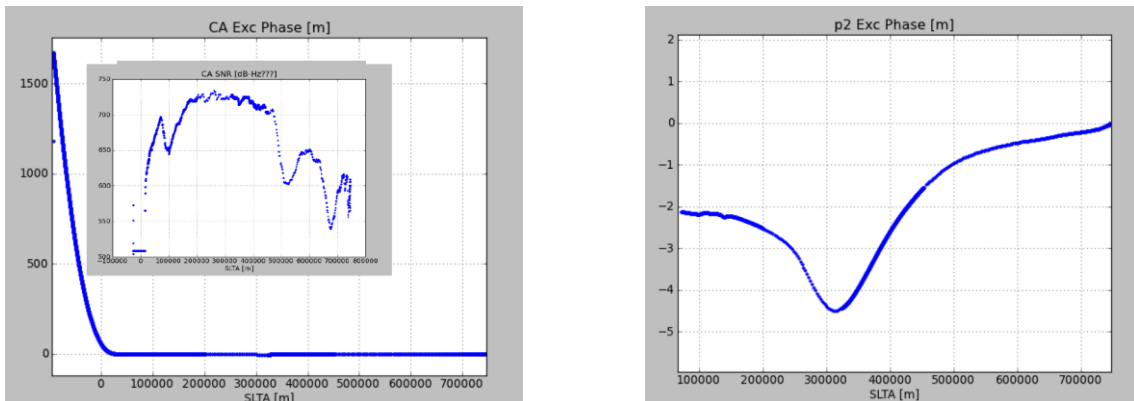

L1 (left) and L2 (right) Excess Phase profile
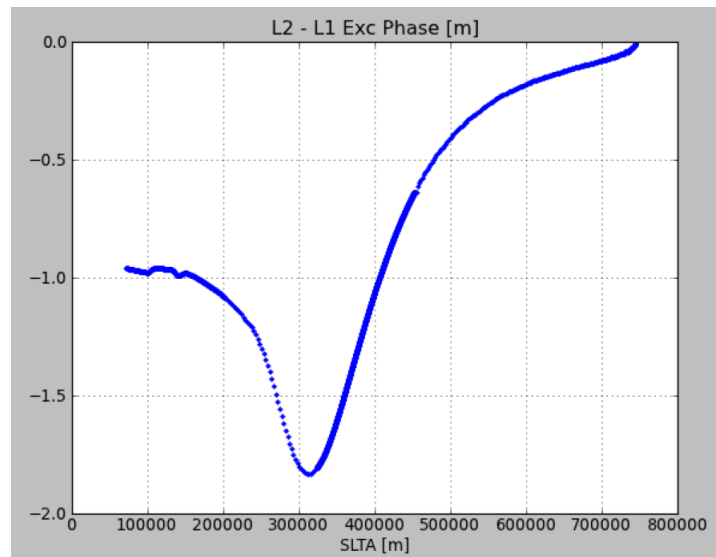
Uncalibrated TEC (L1 – L2) profile

Generally speaking, as an overall "raw" qualitative comment, the proper ROSA tracking on L1 CA reveals good L1 Excess-phases profiles, even if the corresponding SNR profiles are quite noisy and shows an abrupt depression around 100 km SLTA. It has to be confirmed the minimum SLTA when L1 is "safely" tracked, but we thought it is in line with all the other Radio Occultation missions.

On the other hand, L2 profiles are not so good. The cause is probably dependent on the particular configuration of the ROSA payload on-board OCEANSAT-2 and on the strong (and not controllable, because of the jaw bias introduced on the platform after its in-orbit displacement) local multipath. Anyway, considering the entire thirty hours dataset, they start too high in the atmosphere and this will probably require ad-hoc algorithm for their extrapolation down to where L1 excess-phases are available. Moreover they show several data gaps (greater than 1.3 sec) at different heights.

7.1.2 Quality Check of raw data availability

In order to make a more quantitative quality analysis, the output of the *extract_segment()* method was further processed through an ad-hoc Matlab script, in order to create some statistics. The entire output file created cannot be shown here because of its length. As a sake of example, it is here reported the part related to occultations identified for the first SV02 (bold lines identify the 4 occultations)

```
INFO       Extracting and calibrating occultation data...
INFO         Sat G02 (rising)
INFO           Satellite G02 with 4 occultations:
INFO            CL data: 2010-08-24 14:42:08.34 - 2010-08-24 14:49:53.20 / 464.86 secs /  3666 data points
INFO             Geolocation: occ: 141.0 E / 23.7 S / -11.7 azimuth
INFO                 leo: 148.9 E / 49.3 S
INFO                 gns: 123.0 E / 50.7 N
INFO             Extracting continuous data segments...
INFO             CL data has 1 CA segment:
INFO               CL segment: 2010-08-24 14:42:08.34 - 2010-08-24 14:49:53.20 / 464.86 secs /  3666 data points / -130.11 - 731.14 km
INFO             CL data has 1 P2 segment:
INFO               CL segment: 2010-08-24 14:43:05.18 - 2010-08-24 14:49:53.20 / 408.02 secs /   860 data points / 54.95 - 731.14 km
ORIGINAL DATA QUALITY CONTROL
WARNING   Noise calculation deactivated for ROSA Rinex data for CA_exphase_noise_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data CA_exphase_noise_local_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data for L2_exphase_noise_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data L2_exphase_noise_local_lf, set to missing.
WRITE ORIGINAL to NETCDF
INFO       Writing
/home/ricky_notar/data/ROSA/level1a/rosa_l1a_oc2_20100824144208Z_20100824144953Z_20120118145142Z.n4... successful.
INFO          CL data: 2010-08-24 20:30:14.28 - 2010-08-24 20:38:00.20 / 465.92 secs /  6686 data points
INFO             Geolocation: occ: 127.6 W / 21.9 N / -166.4 azimuth
```

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Document: grassaf_cvs16_rep_v1.2

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```
INFO   leo: 118.8 W / 47.2 N
INFO   gns: 149.3 W / 51.8 S
INFO   Extracting continuous data segments...
INFO   CL data has 1 CA segment:
INFO   CL segment: 2010-08-24 20:30:14.28 - 2010-08-24 20:38:00.20 / 465.92 secs / 6686 data points / -140.23 - 726.37 km
INFO   CL data has 2 P2 segments:
INFO   CL segment: 2010-08-24 20:31:23.16 - 2010-08-24 20:31:25.74 /   2.58 secs /   130 data points / 81.68 - 89.46 km
INFO   CL segment: 2010-08-24 20:31:41.14 - 2010-08-24 20:38:00.20 / 379.06 secs / 2343 data points / 135.04 - 726.37 km
ORIGINAL DATA QUALITY CONTROL
WARNING   Noise calculation deactivated for ROSA Rinex data for CA_exphase_noise_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data CA_exphase_noise_local_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data for L2_exphase_noise_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data L2_exphase_noise_local_lf, set to missing.
WRITE ORIGINAL to NETCDF
INFO   Writing
/home/ricky_notar/data/ROSA/level1a/rosa_l1a_oc2_20100824203014Z_20100824203800Z_20120118145148Z.n4... successful.
INFO   CL data: 2010-08-24 22:00:44.26 - 2010-08-24 22:09:18.20 / 513.94 secs / 4496 data points
INFO   Geolocation: occ: 119.5 W / 50.9 N / -175.9 azimuth
INFO   leo: 111.5 W / 77.0 N
INFO   gns: 123.9 W / 25.3 S
INFO   Extracting continuous data segments...
INFO   CL data has 1 CA segment:
INFO   CL segment: 2010-08-24 22:00:44.26 - 2010-08-24 22:09:18.20 / 513.94 secs / 4496 data points / -118.35 - 731.82 km
INFO   CL data has 2 P2 segments:
INFO   CL segment: 2010-08-24 22:01:47.20 - 2010-08-24 22:01:59.30 / 12.10 secs /   122 data points / 68.03 - 101.56 km
INFO   CL segment: 2010-08-24 22:02:29.20 - 2010-08-24 22:09:18.20 / 409.00 secs / 1165 data points / 181.12 - 731.82 km
ORIGINAL DATA QUALITY CONTROL
WARNING   Noise calculation deactivated for ROSA Rinex data for CA_exphase_noise_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data CA_exphase_noise_local_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data for L2_exphase_noise_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data L2_exphase_noise_local_lf, set to missing.
WRITE ORIGINAL to NETCDF
INFO   Writing
/home/ricky_notar/data/ROSA/level1a/rosa_l1a_oc2_20100824220044Z_20100824220918Z_20120118145152Z.n4... successful.
INFO   CL data: 2010-08-24 23:25:32.30 - 2010-08-24 23:27:03.20 / 90.90 secs / 2950 data points
INFO   Geolocation: occ: 41.3 W / 52.8 N / -94.8 azimuth
INFO   leo: 0.7 W / 47.5 N
INFO   gns: 119.2 W / 8.0 N
INFO   Extracting continuous data segments...
ORIGINAL DATA QUALITY CONTROL
WARNING   Noise calculation deactivated for ROSA Rinex data for CA_exphase_noise_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data CA_exphase_noise_local_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data for L2_exphase_noise_lf, set to missing.
WARNING   Noise calculation deactivated for ROSA Rinex data L2_exphase_noise_local_lf, set to missing.
WRITE ORIGINAL to NETCDF
INFO   Writing
/home/ricky_notar/data/ROSA/level1a/rosa_l1a_oc2_20100824232532Z_20100824232703Z_20120118145155Z.n4... successful.
```

Thanks to this output file, an analysis on the number of continuous L1 and L2 Excess-phase segments, on the minimum SLTA from which L1 and L2 Excess-phases are available and on the length of the continuous segments can be performed.

In the following plot, histograms of minimum SLTA L1 CA start and SLTA length of continuous L1 CA data segments are shown. **280** continuous L1 CA segments are recognized and, without considering a very small number of outliers, CA tracking (with channel status between 5 and 9) starts below -100 km SLTA (left histogram) and it continues without interruptions (greather than 1.3 sec) up to the orbit height (~800 km – see the right histogram).
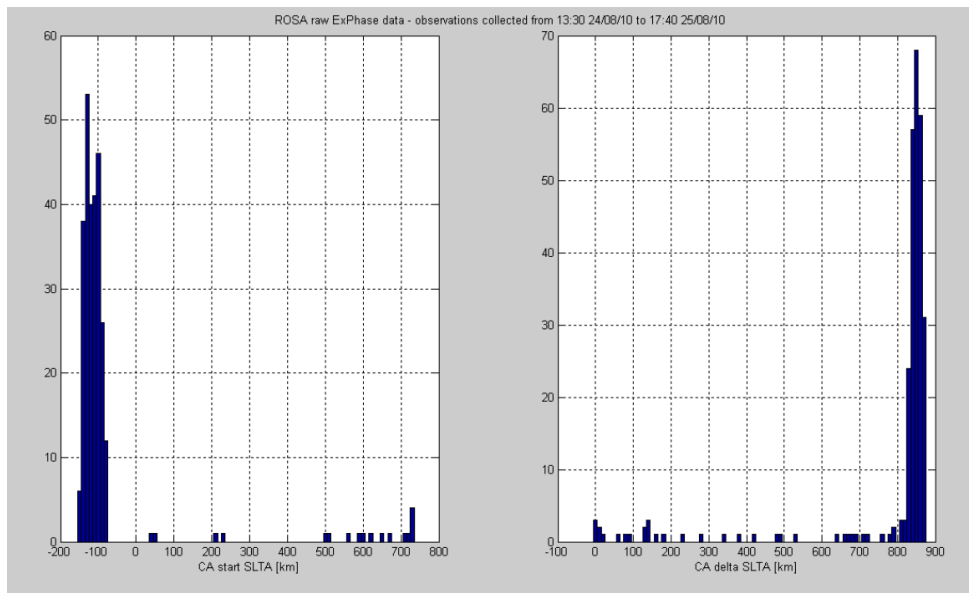
Quite different results are obtained analyzing L2 continuous segment. First of all, **477** continuous segments are recognized. Therefore it is expected that, more or less, we have **200** data gaps (**477** L2 segments – **280** L1 segments) greater than 1.3 sec. The histograms showing minimum SLTA for which L2 is tracked and SLTA interval lengths of continuous L2 Excess Phase segments are reported here below.
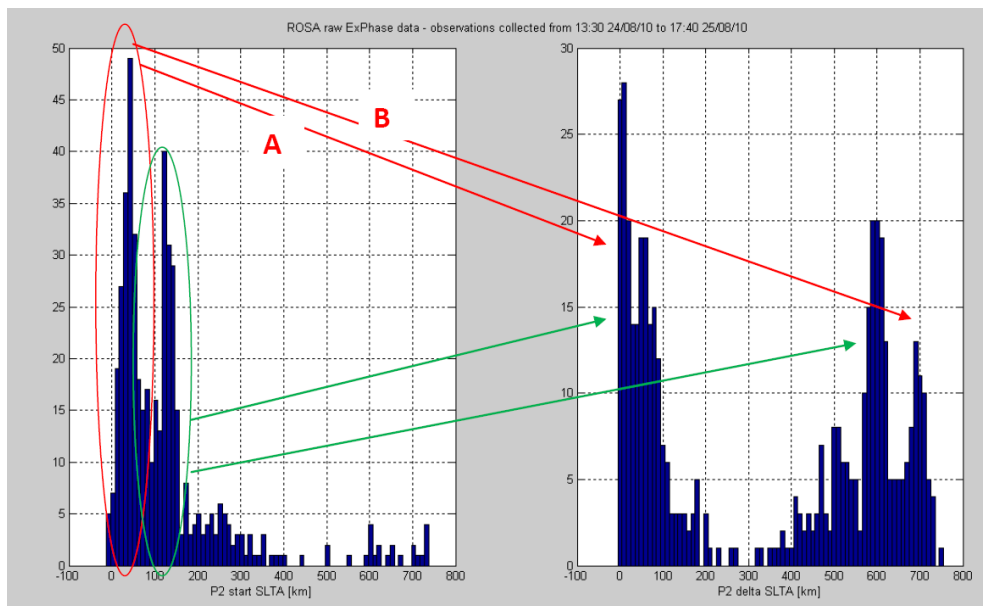


L2 Excess Phase data quality is different from the L1 one. In particular:
- **~240** continuous segments out of 477 (**~50%**) are characterized by a minimum SLTA < 100 km (A+B cases highlighted in the previous plot).
- for **~130** of these (**~28%** of the total), the SLTA interval length (up to the first data gap) is < 100 km (case A highlighted in the previous plot)
- **~110** of the remaining continuous L2 Excess Phase profiles (**~17%** of the total) last up to the height orbit (the SLTA continuous data interval length is more than 600 km)

The following scatter plots further summarize this analysis
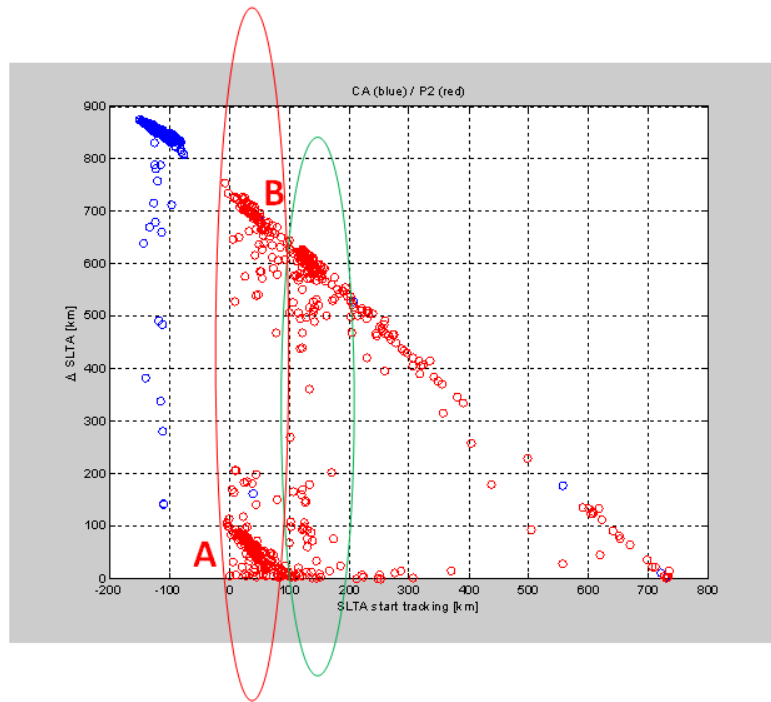
In this scatter plot, each point represents a couple minimum SLTA (start tracking) – SLTA interval length of continuous tracking (L1 CA in blue, L2 P2 in red). We can easily identify couples belonging to A and B ensembles.

All these A+B continuous events should be in principle used for neutral atmospheric sounding. Unfortunately the minimum SLTA where L2 starts to be tracked is not constant but, as it is shown in the plot in the page before, is distributed between ~0 and ~100 km SLTA, with an averaged value around 50 km SLTA. And this poses several problems for lower tropospheric retrievals.

Next plot shows the cumulative distribution of the identified continuous L2 Excess Phase segments belonging to the A + B ensemble (240 events), in function of the start SLTA for which they are tracked. These events last at least up to 100 km.
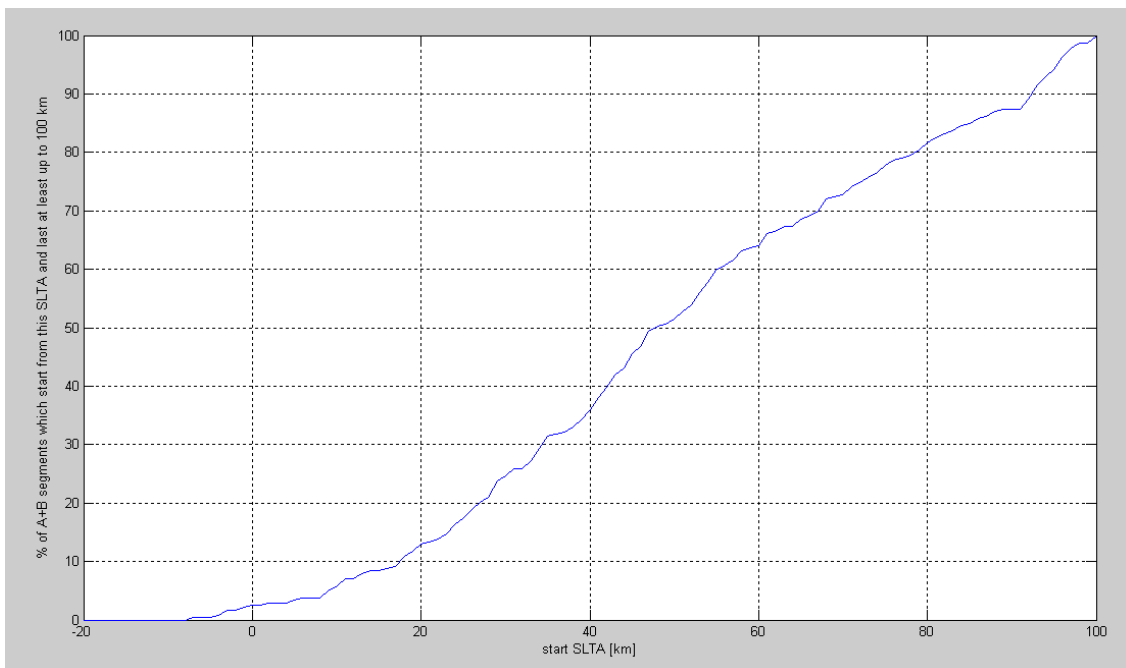
From this plot we can see that
- for ~3% of the 240 events (7 events), L2 starts to be tracked below 0 km SLTA
- for ~8% of the 240 events (20 events), L2 starts to be tracked below 10 km SLTA
- for ~20% of the 240 events (50 events), L2 starts to be tracked below 25 km SLTA

Finally, a distribution of data gaps (greater than 1.3 sec) can also be shown, for both L1 CA and L2 P2 Excess Phase data.
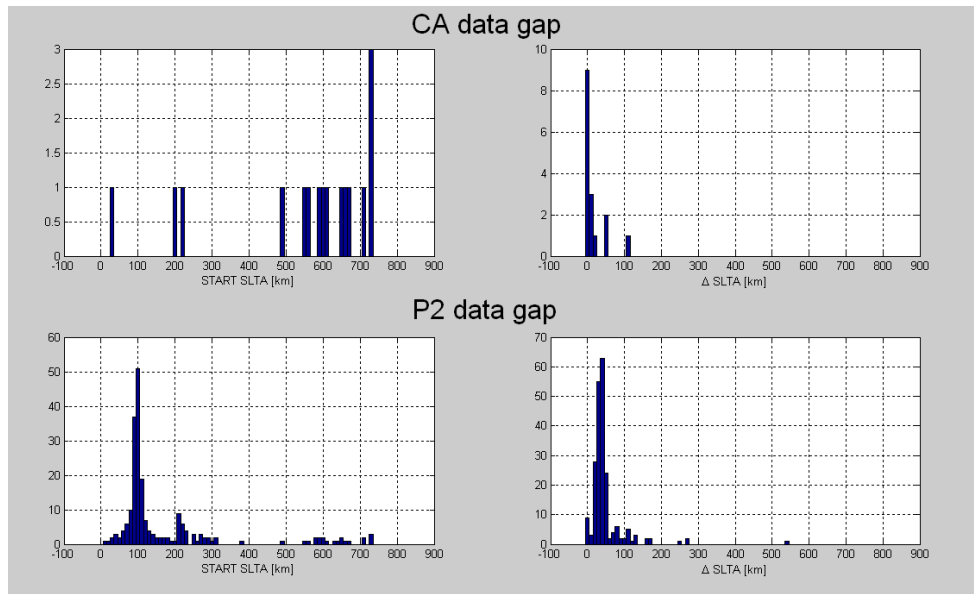


In the analyzed dataset, 16 L1 data gaps were identified (top plot). Looking at the distribution of start SLTA tracking (top left), these can be considered as outliers in the overall distribution.
As far as the L2 Excess Phase profiles are concerned, 215 data gaps are identified (bottom plot). In average they are placed at 100 km (bottom left), with one second minor mode at 200 km SLTA. The averaged length of these gaps is ~30 km (see bottom right plot).

In the following section, a quantitative analysis on the products generated both by the GRAS-SAF ROPP_PP software at the bending angle, refractivity and dry temperature levels and by the EUMETSAT YAROS prototype at the bending level will be shown. In Appendix B it is reported a table which summarizes minimum SLTA values for L1 and L2 identified for all the segments analyzed, ordered by the minimum SLTA for which L2 is tracked.

## 7.2  Quality check of atmospheric profiles (ROPP_PP products only)

In this section a quantitative analysis describing the results obtained applying the GRAS-SAF ROPP_PP software to Level1a data produced by the YAROS/ROSA prototype is provided.
The analysis is performed on each single profile. For each profile, the truth is considered to be:
- the corresponding collocated ECMWF profile (the profiles were made available by DMI on the basis of the geometrical characteristics of each identified ROSA occultation event (see Chapter 6)
- the corresponding collocated profile observed by one of the other operative Radio Occultation missions. In this case, collocations are searched
  - on a box of +/- 10° lat and long centered on the ROSA occultation reference point (the lat, long corresponding to the point for which SLTA = 0)
  - +/- 1.5 hours around the ROSA occultation reference time (the time for which SLTA = 0)
  A dataset is created considering occultations derived by COSMIC, METOP-A and TERRA SAR-X.

For each of the best identified ROSA occultations (the goodness of the profile is based on the minimum SLTA for which L2 is available), several comparisons will be shown:
- Tdry and Refractivity profiles against corresponding ECMWF collocated profiles
- Tdry, Refractivity and Bending Angle profiles against corresponding collocated profiles derived by other Radio Occultation mission and processing software (all the data are taken by the CDAAC archive)

Results will be detailed for some of the events for which L2 is available at least from 10 km SLTA (the table here below – which is extracted by the one in Appendix B – lists such events). Events highlighted in red didn't produce any output (because L2 was lost very soon). Results obtained for all the other events for which L2 is available at least from 10 km SLTA, are shown for completeness in Appendix C.

| | | LAT | LONG | min L1 SLTA | max L1 SLTA | min L2 SLTA | max L2 SLTA |
|---|---|---|---|---|---|---|---|
| 1 | occ_20100824_173338_OCS2_G030.nc | -53,42 | -68,46 | -89784,42 | 746508,26 | -7541,92 | 746508,26 |
| 2 | occ_20100824_204031_OCS2_G023.nc | -12,46 | -113,52 | -126462,02 | 737771,02 | -4861,87 | 101494,75 |
| 3 | occ_20100825_131659_OCS2_G026.nc | -24,07 | -3,95 | -112445,91 | 741210,11 | -3973,11 | 101191,59 |
| 4 | occ_20100825_021129_OCS2_G005.nc | -53,11 | -57,62 | -76015,60 | 731515,44 | -3308,72 | 731515,44 |
| 5 | occ_20100825_145258_OCS2_G009.nc | -12,01 | -25,82 | -125113,95 | 736426,62 | -2742,09 | 98401,52 |
| 6 | occ_20100824_234850_OCS2_G005.nc | 24,90 | -149,16 | -118431,78 | 729235,65 | -1003,11 | 112366,91 |
| 7 | occ_20100825_144218_OCS2_G018.nc | 26,21 | -11,51 | -116755,98 | 730285,66 | -335,57 | 98660,24 |
| 8 | occ_20100825_082822_OCS2_G016.nc | -55,33 | 71,02 | -86909,36 | 747908,08 | 686,84 | 6427,67 |
| 9 | occ_20100825_050929_OCS2_G030.nc | -52,35 | 123,44 | -84516,57 | 748366,12 | 3049,31 | 85518,83 |
| 10 | occ_20100824_155643_OCS2_G012.nc | -55,77 | -33,62 | -81616,44 | 749986,67 | 4131,85 | 173273,17 |
| 11 | occ_20100825_170454_OCS2_G018.nc | -54,24 | 78,76 | -76635,10 | 732171,64 | 5348,97 | 37697,12 |
| 12 | occ_20100825_154642_OCS2_G021.nc | 18,02 | 99,01 | -127712,89 | 728833,17 | 5649,41 | 652477,63 |
| 13 | occ_20100824_211309_OCS2_G032.nc | -53,28 | 19,79 | -79086,80 | 733358,32 | 8051,46 | 733358,32 |
| 14 | occ_20100824_141646_OCS2_G026.nc | -60,64 | -19,54 | -82036,30 | 734887,33 | 8330,41 | 171239,57 |
| 15 | occ_20100825_172401_OCS2_G016.nc | 13,84 | 78,22 | -133437,76 | 727559,27 | 8889,34 | 727559,27 |
| 16 | occ_20100824_150548_OCS2_G021.nc | 43,59 | 93,92 | -119726,02 | 735956,39 | 9543,48 | 735956,39 |
| 17 | occ_20100825_124850_OCS2_G027.nc | 59,55 | 65,04 | -96442,03 | 727900,10 | 9612,77 | 727900,10 |
| 18 | occ_20100825_000425_OCS2_G008.nc | -32,08 | -169,29 | -105083,63 | 739739,98 | 9797,01 | 214743,22 |
| 19 | occ_20100824_152721_OCS2_G014.nc | 37,74 | -32,64 | -128949,03 | 727438,59 | 9931,69 | 92848,80 |
| 20 | occ_20100824_190649_OCS2_G031.nc | -33,33 | -95,06 | -104336,49 | 740286,19 | 10193,59 | 102360,28 |

It has to be said up to know that algorithms implemented on ROPP_PP were not tailored to ROSA Level1a data (derived by Yaros). Only some trials were made considering applications of different approaches and settings for the statistical optimization. Moreover, only GEOMETRICAL OPTICS

algorithms were used to process ROSA data with ROPP_PP. Finally, the major impact on the final results is thought to be caused by the not tailored procedures already implemented for the data gap interpolation. As it is clear ROSA L2 data on-board Oceansat-2 suffer for this problem.

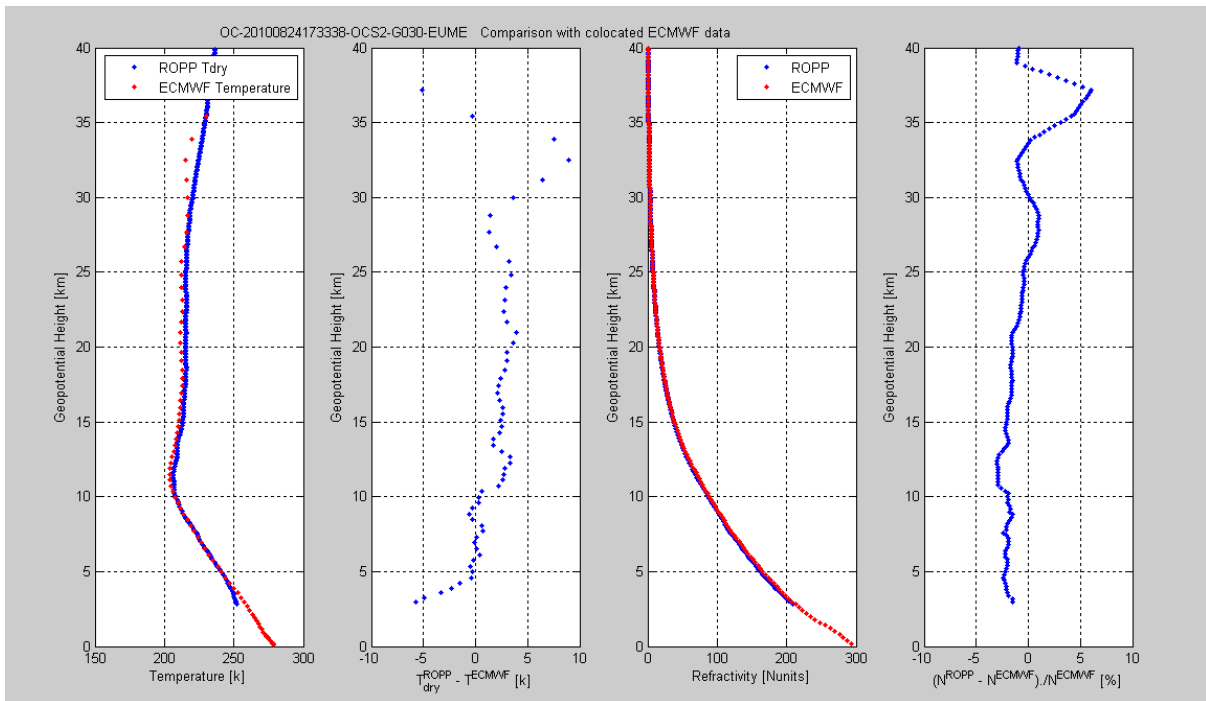# Event #1

# Single profiles
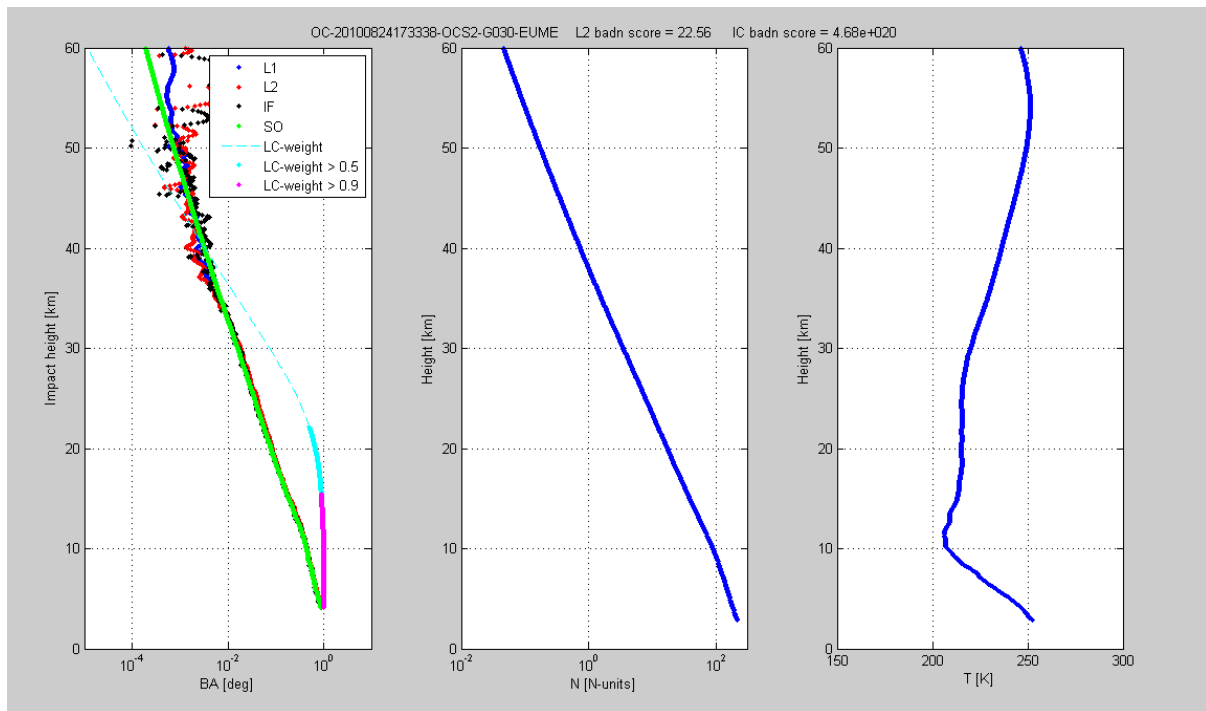


LC_weight is a measurement on how much the Iono-Free (IF) and Statistically Optimized (SO) bending angle profile is expected to be derived by data (LC_weight = 1) and how much is derived by L2 modelling/climatology. Cyan is used to identify LC_weight < 0.5 (= 0.5 when cyan dots start), magenta when LC_weight >= 0.9.

## COMPARISON AGAINST CO-LOCATED ECMWF PROFILE

## COMPARISON AGAINST OTHER CO-LOCATED OCCULTATIONS
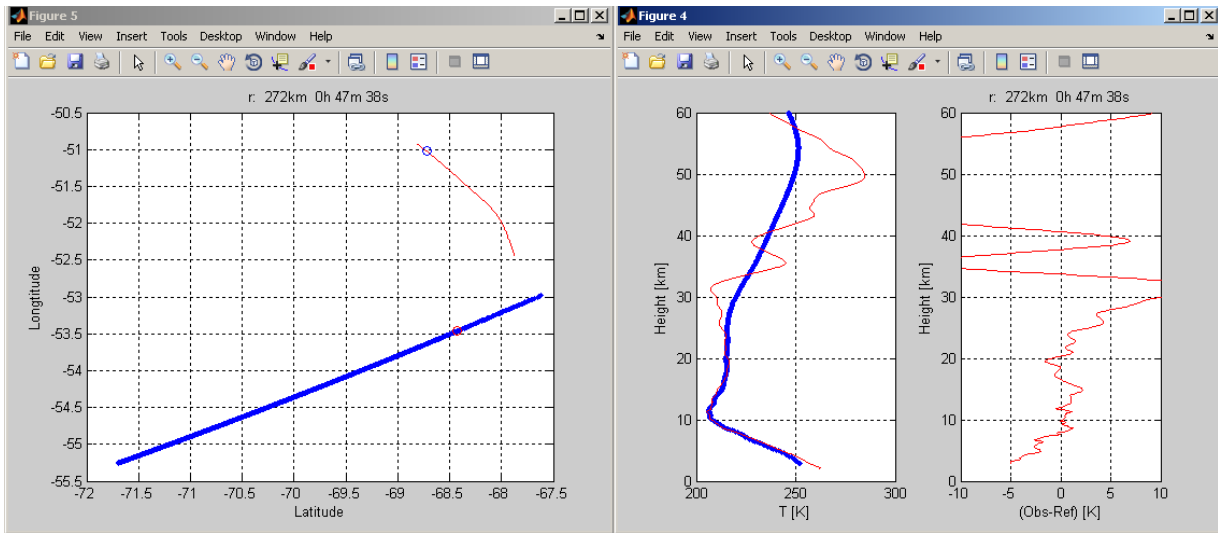


Dots shown the geographical position of the Straight Line perigee when SLTA = 0 (for the ROPP derived profile) and when Excess Phases is 500 m (for the CDAAC derived profile). The title of the left plot is the euclidean distance between these two points and the time interval between the two events.

A list of the collocated occultation profiles is the following

```
% 1 - 10 deg, 1.5 h
% ropp_pp_occ_20100824_173338_OCS2_G030.nc -53.46 -68.42
% atmPrf_C005.2010.236.16.46.G22_2010.2640_nc -51.02 -68.72
file_ropp=['ropp_pp_occ_20100824_173338_OCS2_G030.nc'];        blue
file_cosm=['atmPrf_C005.2010.236.16.46.G22_2010.2640_nc'];     red
file_meta=[];
file_trsx=[];
```
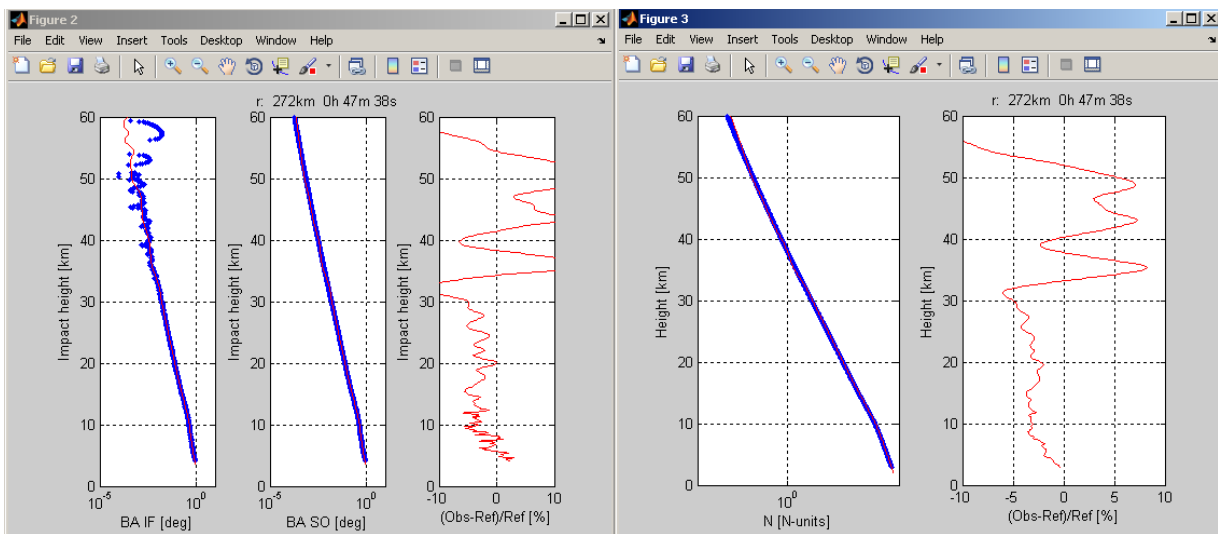

In order to identify some impact of the new statistical optimization algorithm applied by the standard version of ROPP_PP to raw bending angle profile, it is deactivated and data were also processed with the older version of the stratospheric optimization. Results in terms of bending angle profiles do not practically change, as it is shown in the following plot:
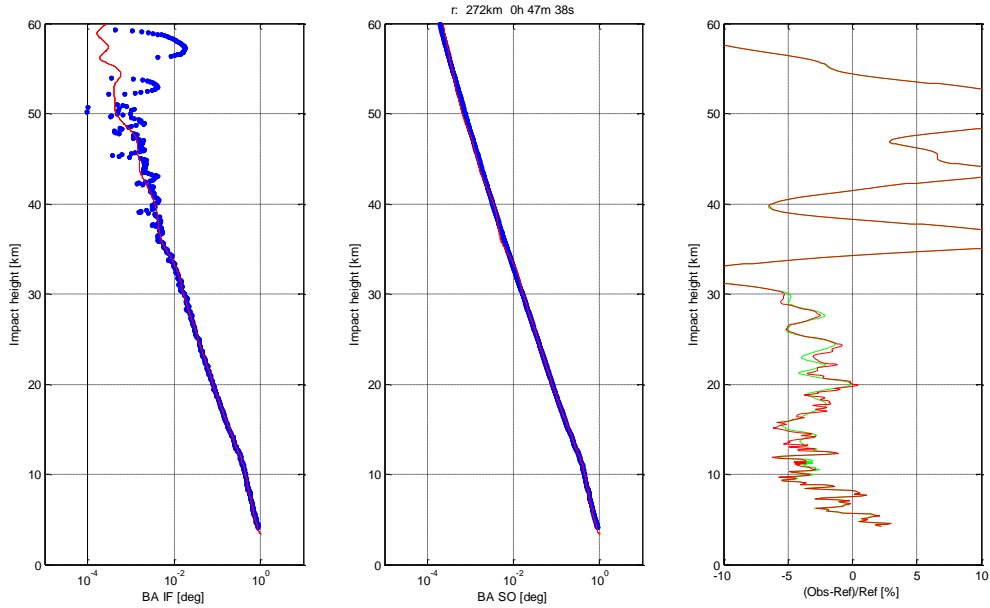
In the right plot, green is used to plot the fractional error obtained when the statistical optimization (SO) is activated while in red fractional error obtained without statistical optimization (LCSO algorithm). Also impacts on Refractivity and Dry Temperature are minimum (see below).
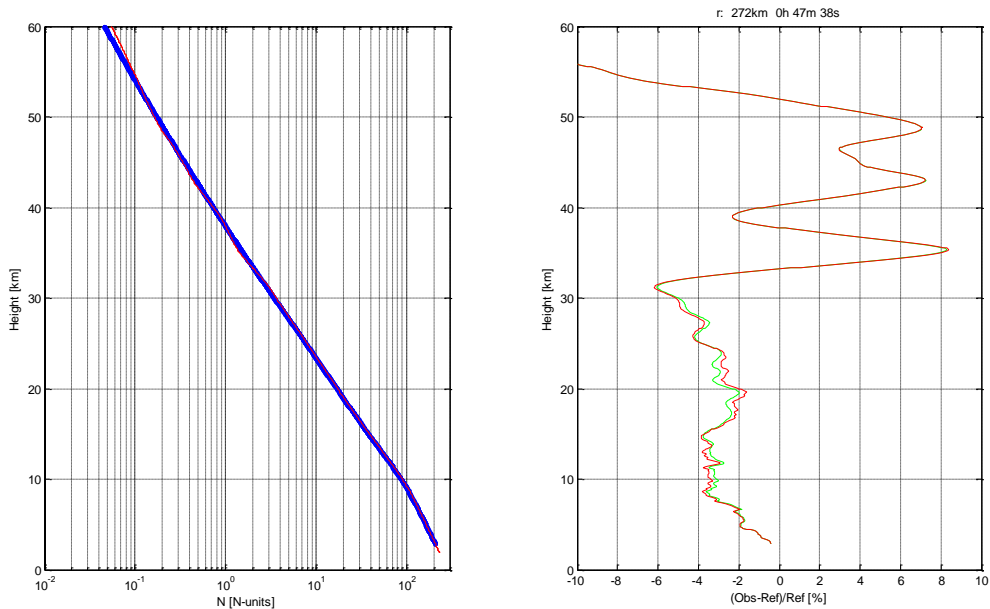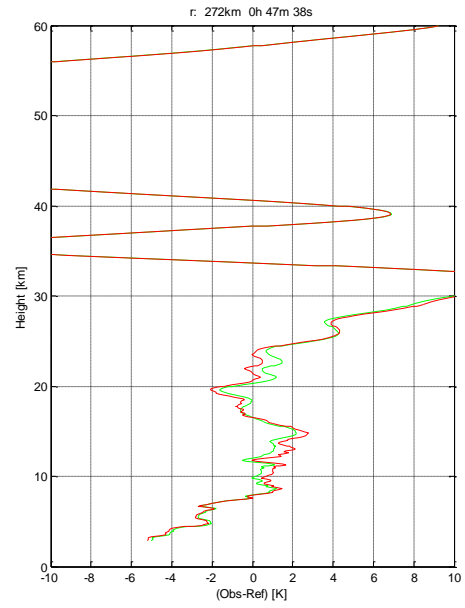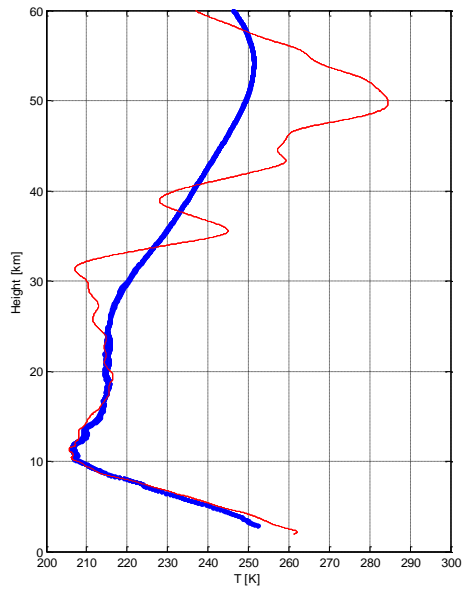
Event #3

Single profiles
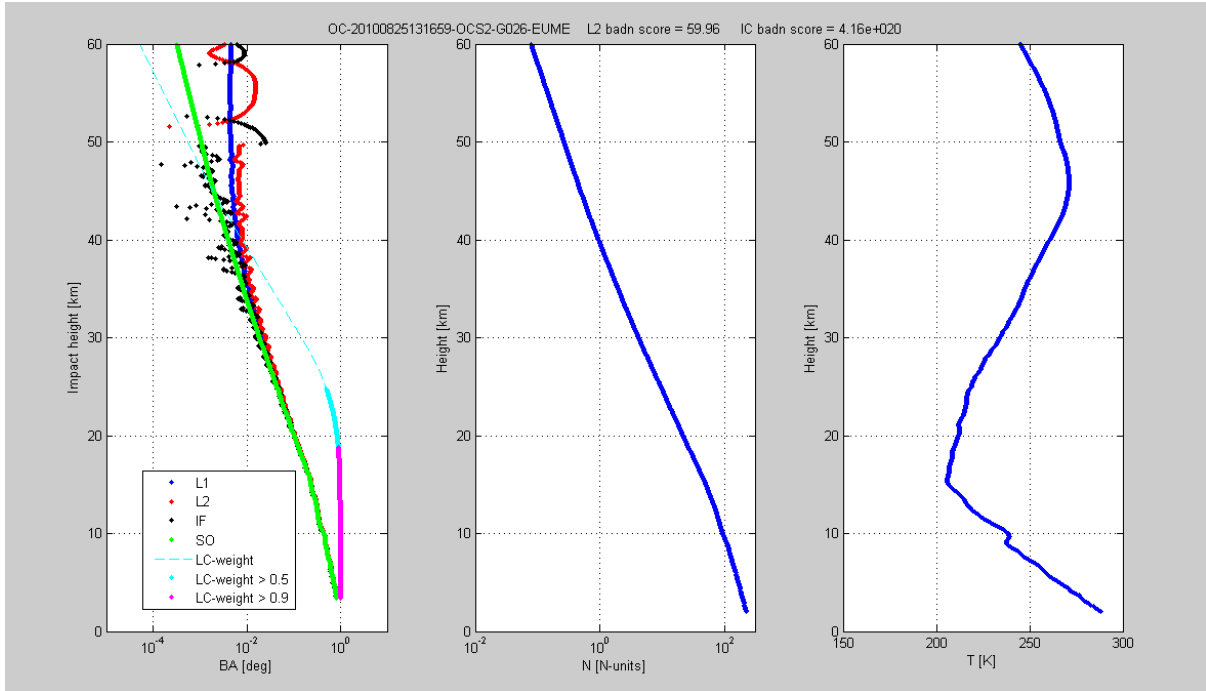
COMPARISON AGAINST CO-LOCATED ECMWF PROFILE
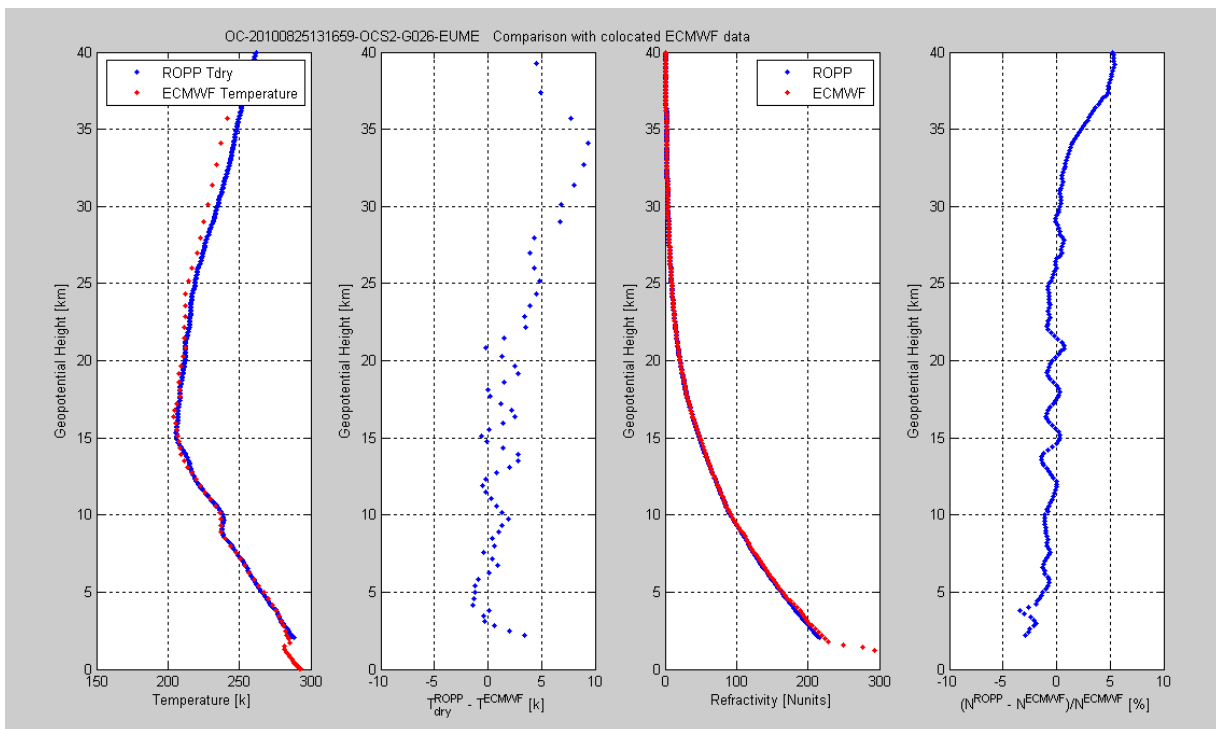
COMPARISON AGAINST OTHER CO-LOCATED OCCULTATIONS
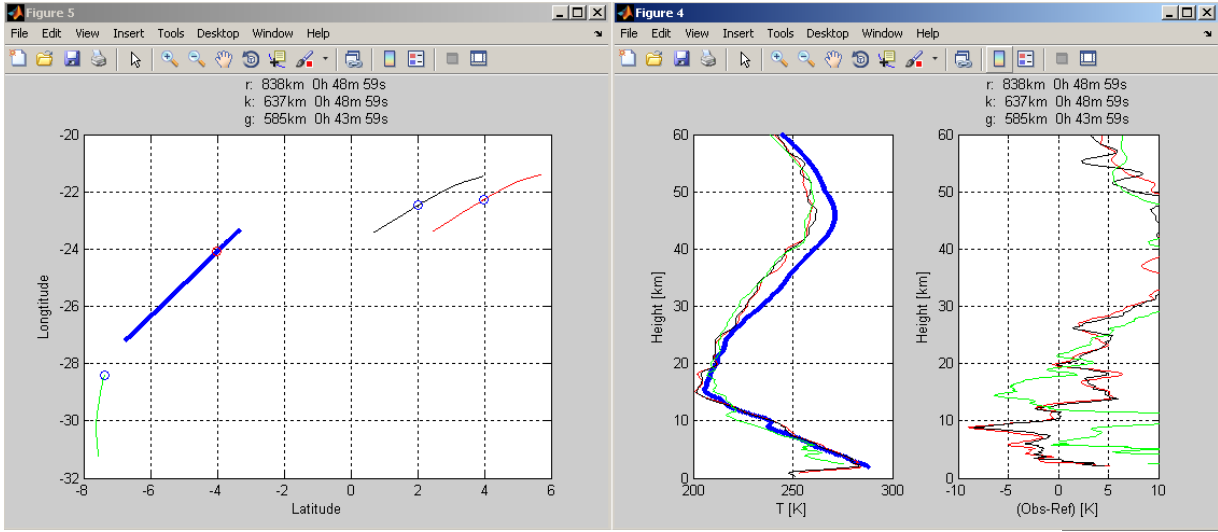

```
% 3

% ropp_pp_occ_20100825_131659_OCS2_G026.nc -24.09 -4.00
% atmPrf_C004.2010.237.12.28.G25_2010.2640_nc -22.27  3.99
% atmPrf_C004.2010.237.12.28.G30_2010.2640_nc -22.47  2.01
% atmPrf_C004.2010.237.12.33.G16_2010.2640_nc -28.39 -7.38
file_ropp=['ropp_pp_occ_20100825_131659_OCS2_G026.nc'];        blue
file_cosm(1,:)=['atmPrf_C004.2010.237.12.28.G25_2010.2640_nc']; red
file_cosm(2,:)=['atmPrf_C004.2010.237.12.28.G30_2010.2640_nc']; black
file_cosm(3,:)=['atmPrf_C004.2010.237.12.33.G16_2010.2640_nc'];  green
file_meta=[];
file_trsx=[];
```
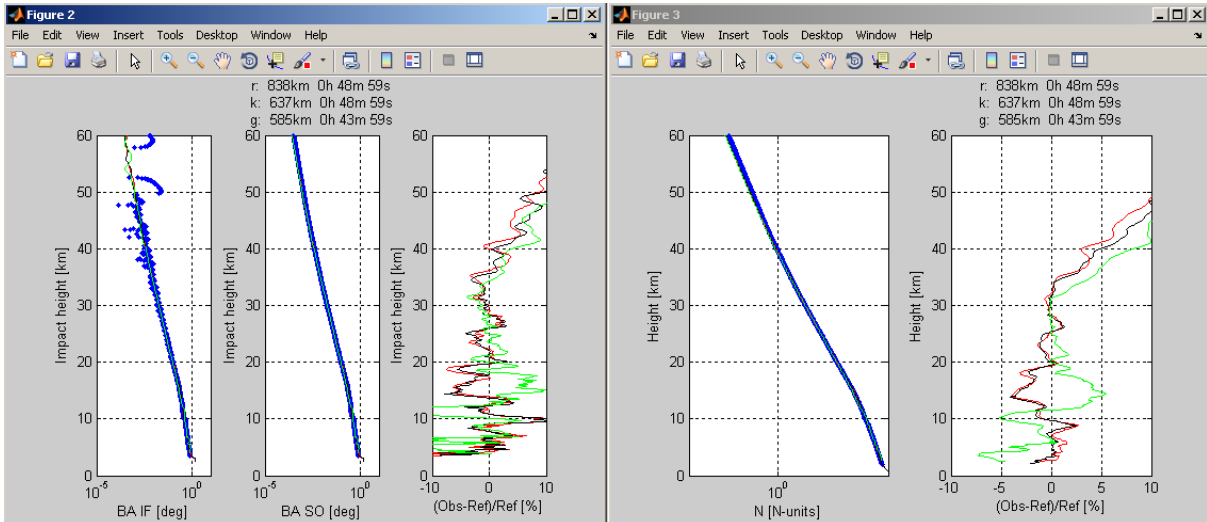
Event #4

Single profiles
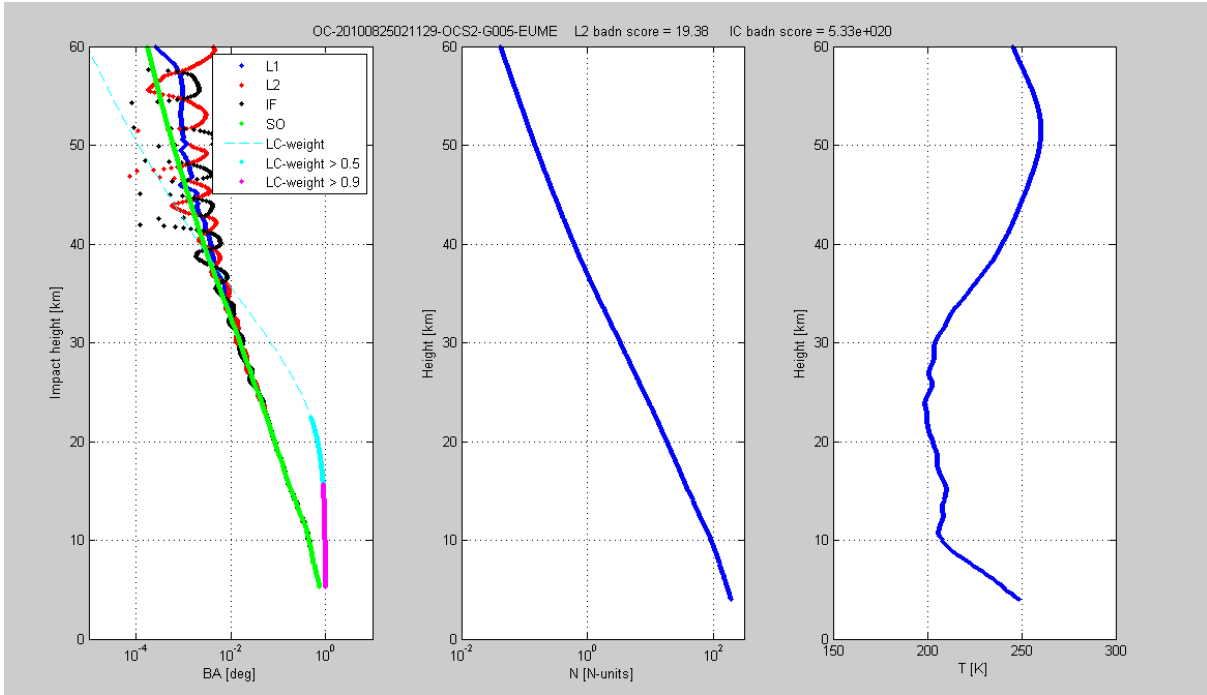
COMPARISON AGAINST CO-LOCATED ECMWF PROFILE

Ref: SAF/GRAS/DMI/REP/VS16/001
Version: 1.2
Date: 03 March 2012
Document: grassaf_cvs16_rep_v1.2

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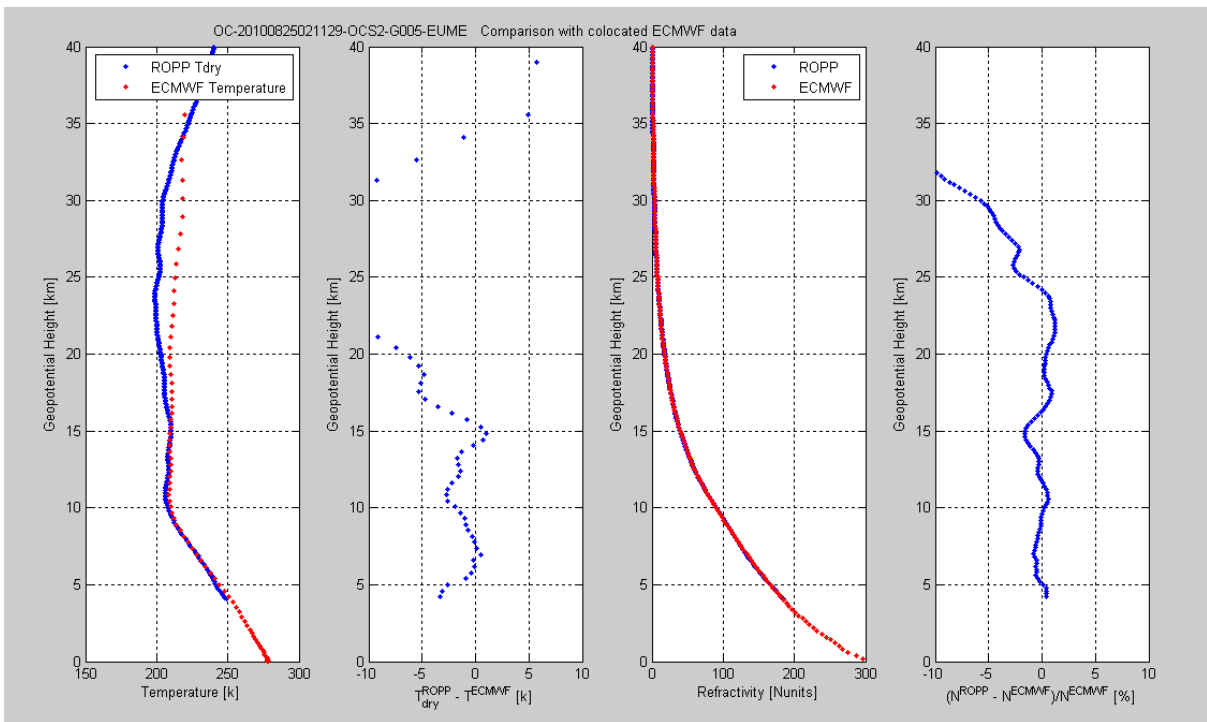
COMPARISON AGAINST OTHER CO-LOCATED OCCULTATIONS
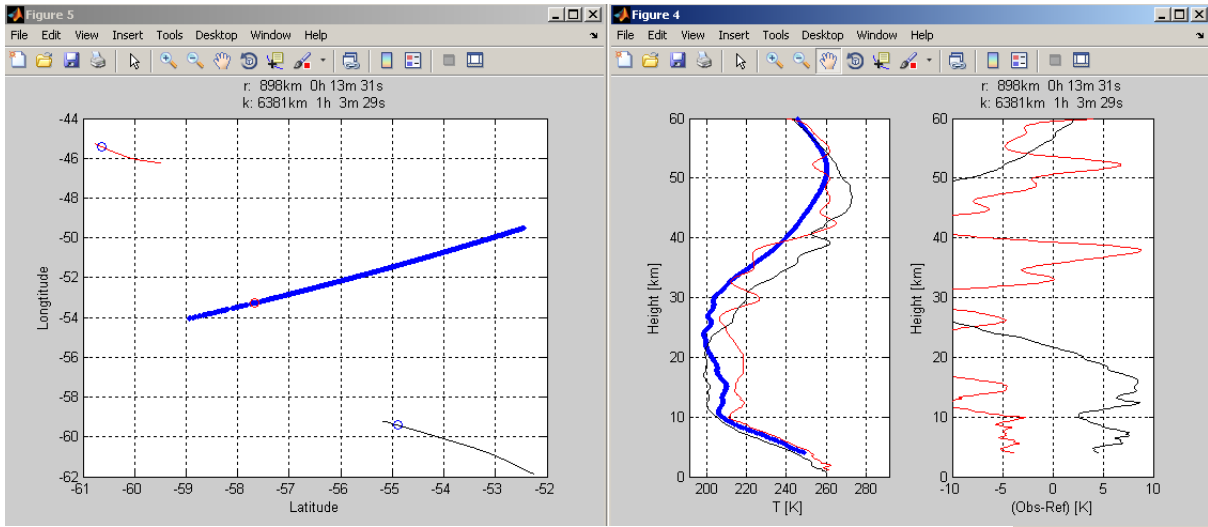

```
%  4
%  ropp_pp_occ_20100825_021129_OCS2_G005.nc -53.27 -57.67
%  atmPrf_C001.2010.237.02.25.G22_2010.2640_nc -45.44 -60.64
%  atmPrf_TSRX.2010.237.01.08.G11_2010.2640_nc -59.41 -54.90
file_ropp=['ropp_pp_occ_20100825_021129_OCS2_G005.nc'];      blue
file_cosm=['atmPrf_C001.2010.237.02.25.G22_2010.2640_nc'];   red
file_meta=[];
file_trsx=['atmPrf_TSRX.2010.237.01.08.G11_2010.2640_nc'];  black
```
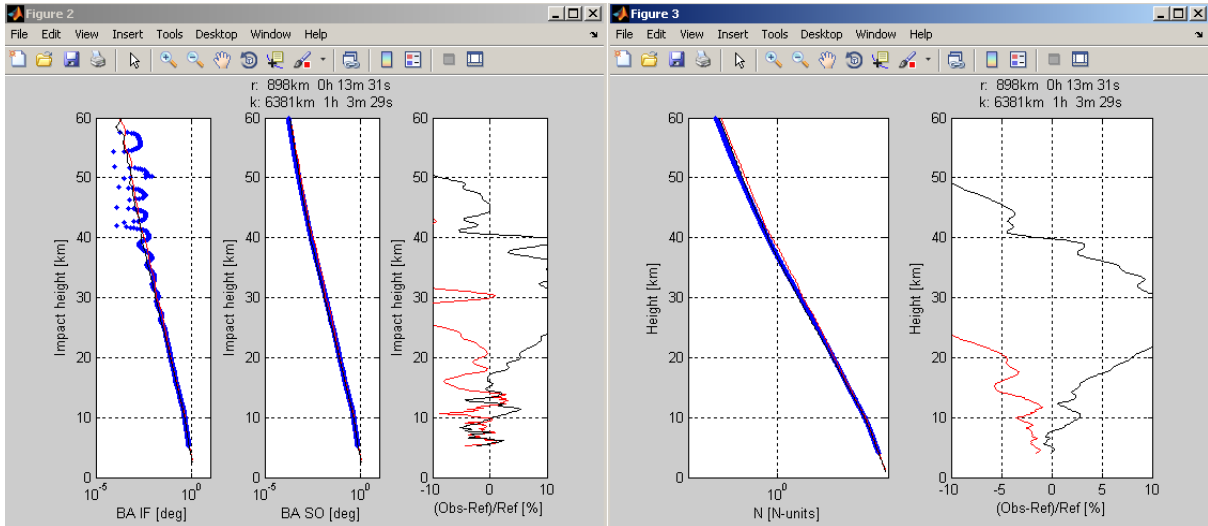
7.3 Global quality check at the bending angle level considering ROPP_PP output and Level1b data processed by Yaros

Finally, a global analysis is performed considering a statistical comparison between the bending angle profiles obtained using ROPP_PP and YAROS/ROSA, and the corresponding profiles obtained applying the ROPP_FM (Forward Model) to ECMWF co-located data.

The analysis is carried out taken into account
-   all the available profiles for which L2 is available at least from 10 km SLTA (see the table in the introduction of Sect. 7.2)
-   all the available profiles for which L2 is available below 40 km SLTA (see the table in Appendix B)

Results for the first case are shown here below. In this first case it is evident that, for that occultation events, bending angle generated by ROPP_PP and by YAROS are very similar, even if the statistics was made considering a very small number of events:

L2 available starting from 0 – 10 km SLTA

ROPP_PP
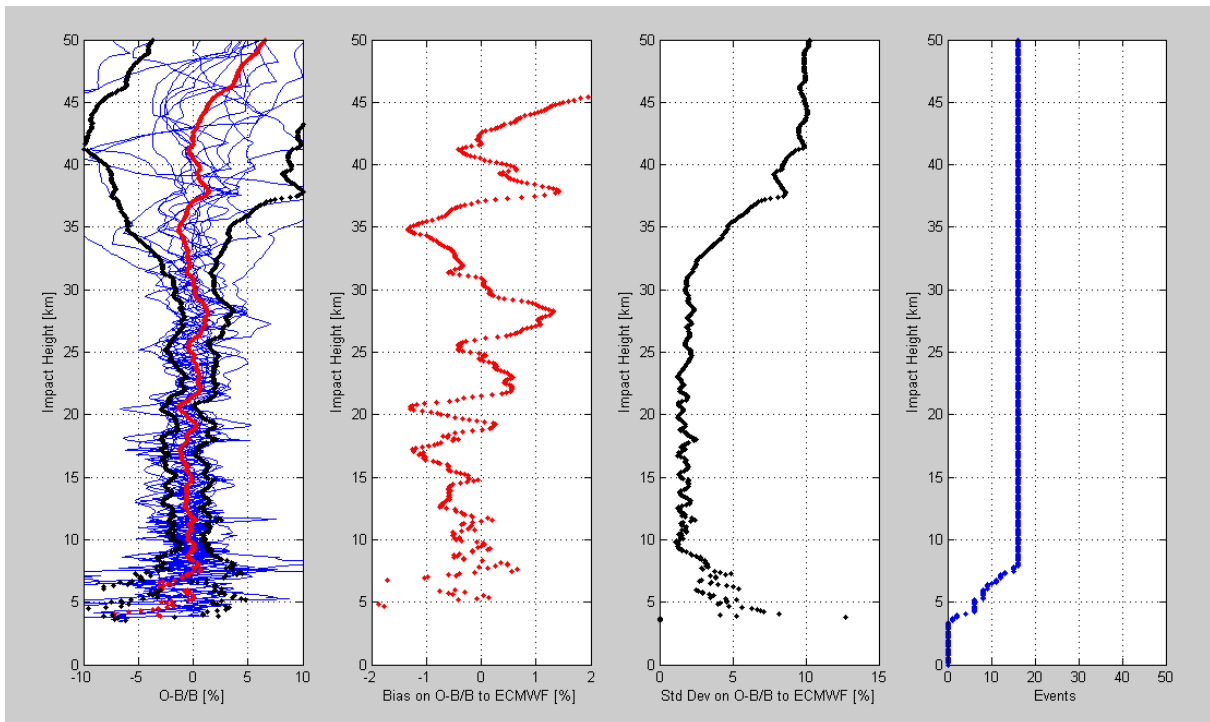
YAROS
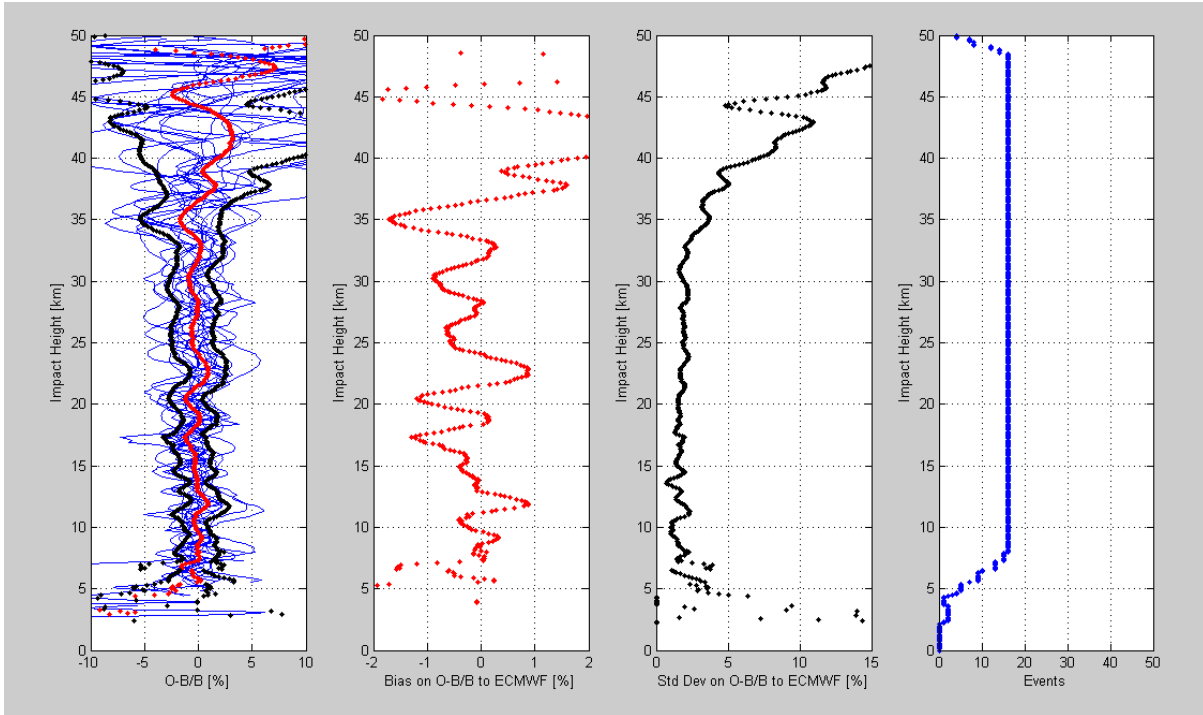
Superimposing the bias and standard deviation of the fractional error, the comparison show the similarities (it has to be noted that outlier rejection for robust statistics evaluation is not performed). Red is used for YAROS results, purple for ROPP_PP.
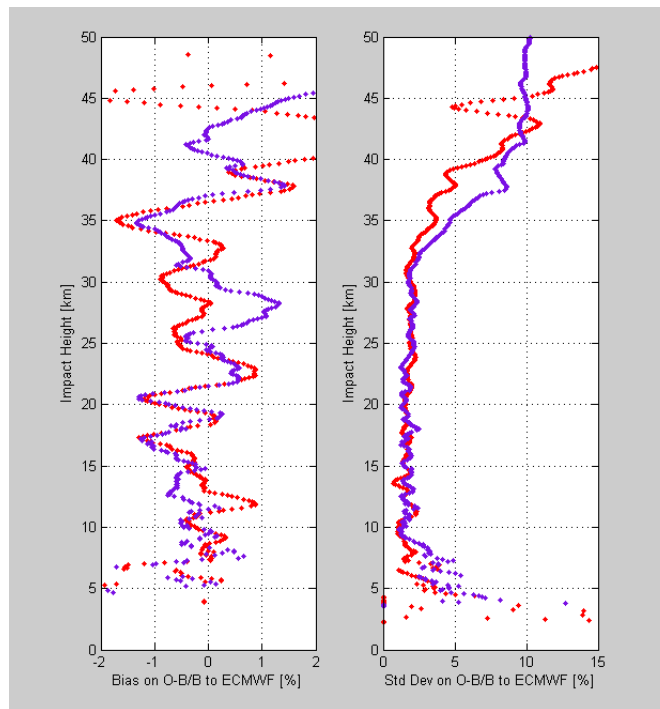
Unfortuntely, when ROSA profiles start to be impacted by the L2 data missing in the first part of the rising occultations, results from the two software are not so similar. In particular, considering ROPP_PP processing, the LC weights shown for the single event case (Sect. 7.2 Event 1 result description) really seem to indicate that the climatology gets too much weight and influences the

output at too low impact height. Moreover, extremely high IC, L2 and SO badness SCORE values are seen in output (these values are not reported here for the overall events, but only for the single cases shown in Sect. 7.2 and Appendix C). Finally, the ROPP_PP source code for interpolation was not adapted to fill in ROSA data gaps that may often happen, as described in Sect. 7.1.2. This could explains the reason for the observed discrepancies between ROPP_PP and YAROS L1b products that will be shown here below.

We have reported here statistics of bending angle profiles between ROPP_PP retrieval (top subplot of each figure) or YAROS retrieval (bottom subplot of each figure, on which is superimposed also the previously shown ROPP output using gray color) and "forward modeled" ECMWF data. For each YAROS generated profile, co-located ECMWF profiles are extracted. Refractivities profiles are computed and corresponding bending angle and impact parameter profiles are evaluated using ROPP_FM code. Error profiles (observed – background fraction errors) and their statistics (bias and standard deviation, after rejection of some outlier which were visually detected) are evaluated.

Such statistics are evaluated considering the following situations:

L2 available starting from 35 – 40 km SLTA (9 events)

ROPP_PP
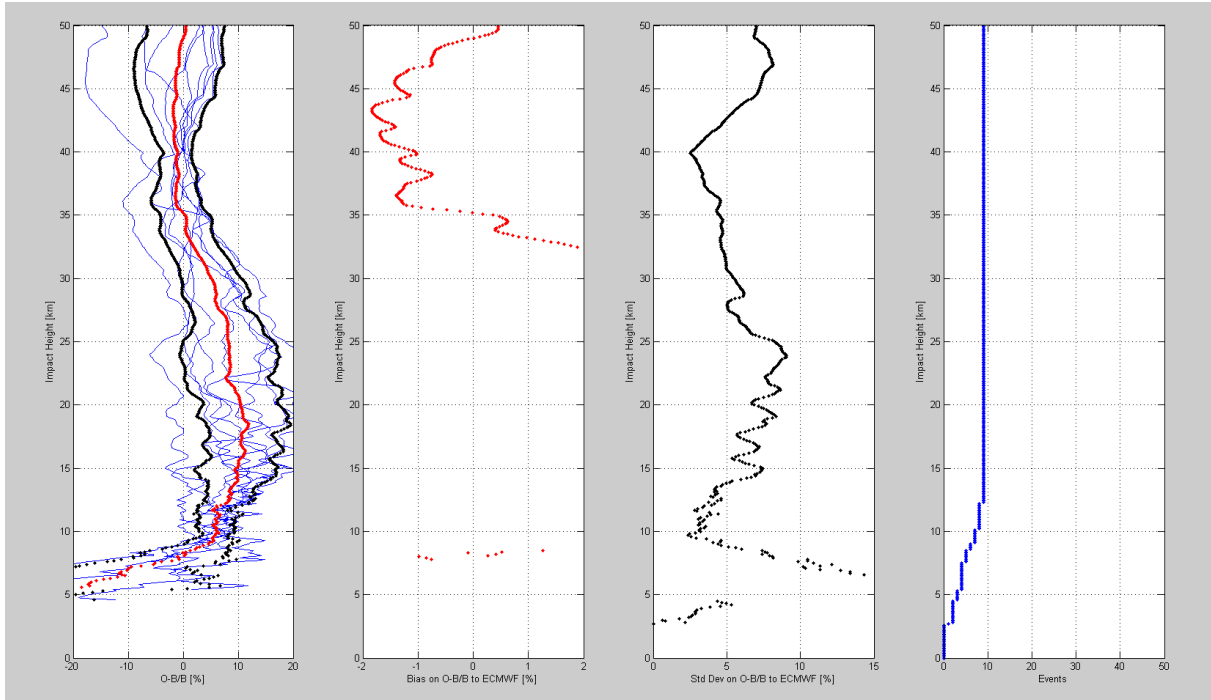
YAROS
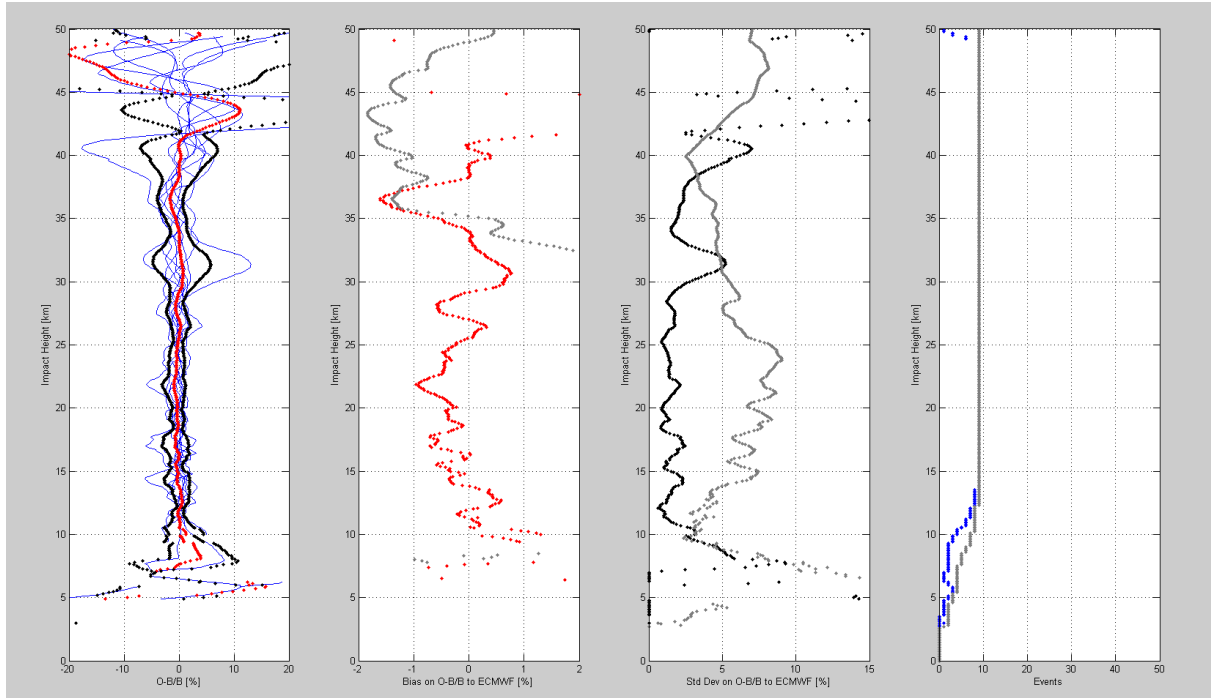
It is quite evident here that ROPP_PP should be adapted to ROSA data handling in this very difficult situation (even if the statistics cannot be considered significative). Therefore these events will not be taken into account in the next statistics in order to not impact too much the final results. which will shown the agreement considering profiles for which L2 starts to be available in the SLTA intervals 30 km ÷ 25 km, 25 km ÷ 35 km, 20 km ÷ 35 km, 10 km ÷ 35 km and from the lowest to 35 km.

L2 available starting from 30 – 35 km SLTA (15 events)

ROPP_PP
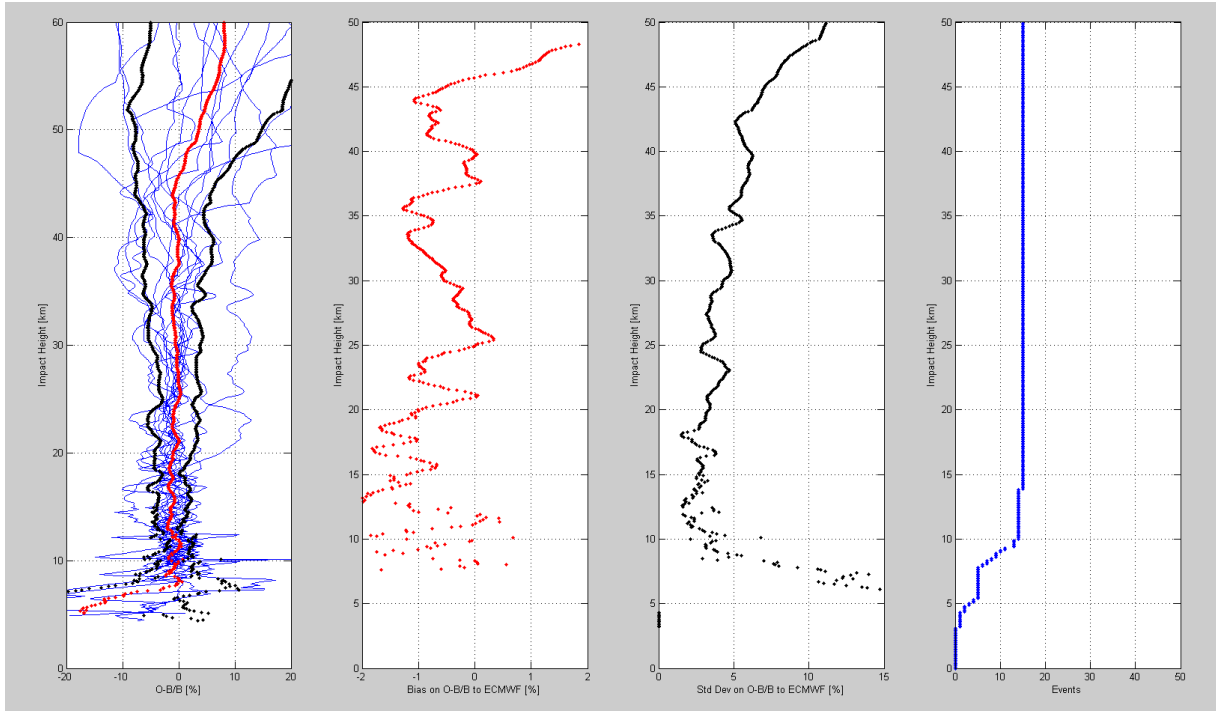
YAROS
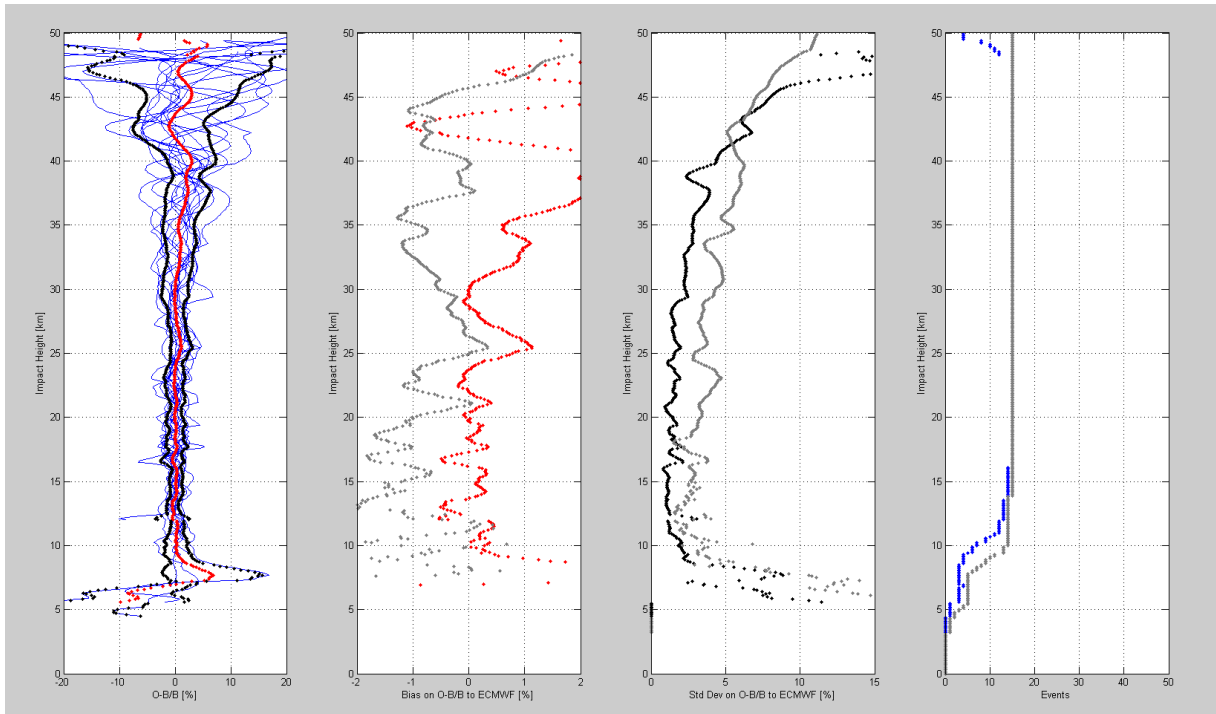
L2 available starting from 25 – 35 km SLTA (33 events)

ROPP_PP

YAROS

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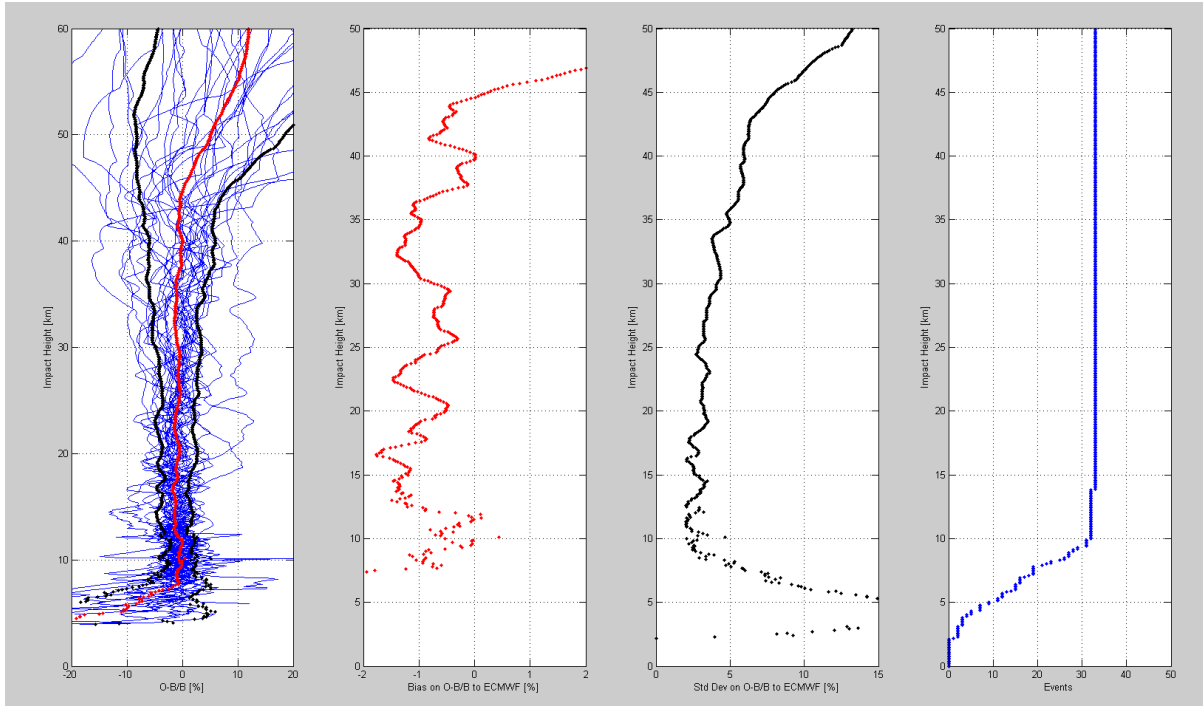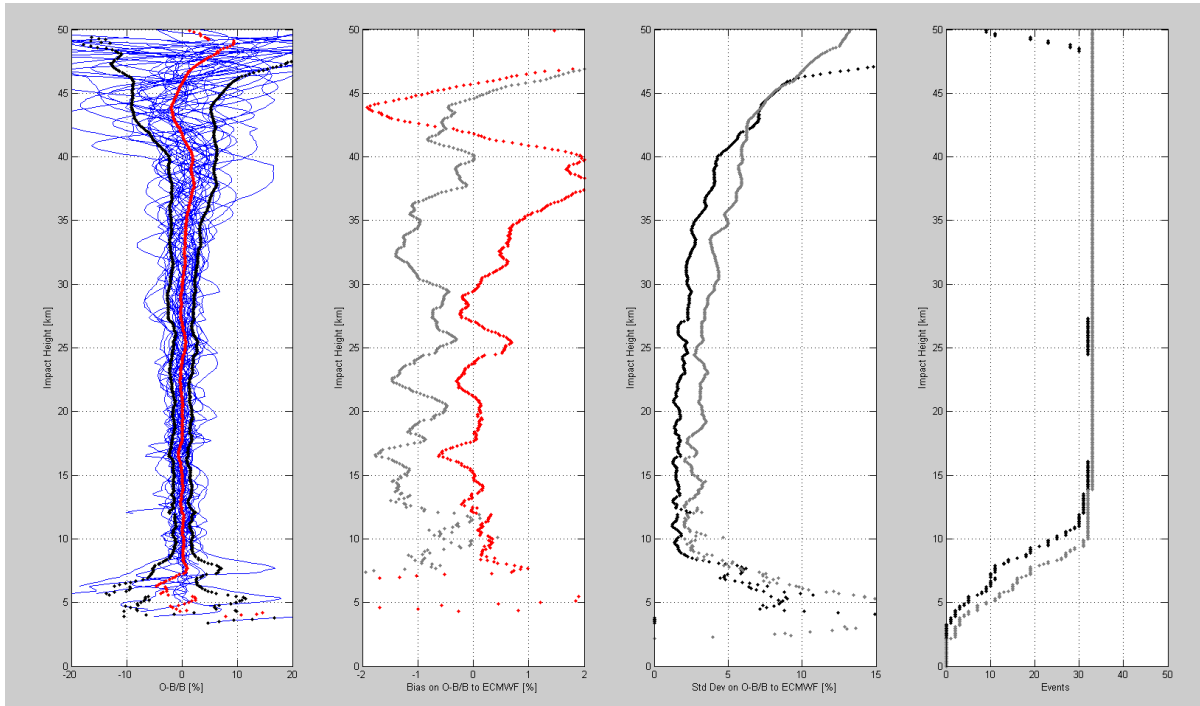
L2 available starting from 20 – 35 km SLTA (46 events)

ROPP_PP
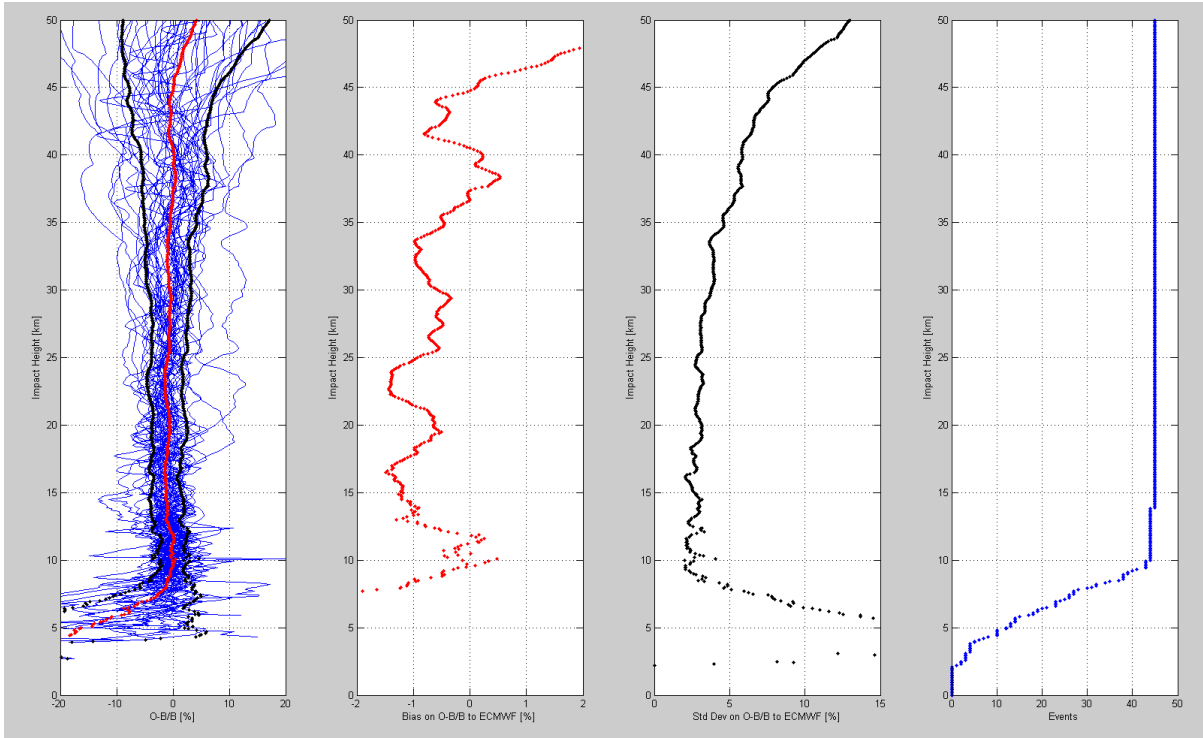
YAROS
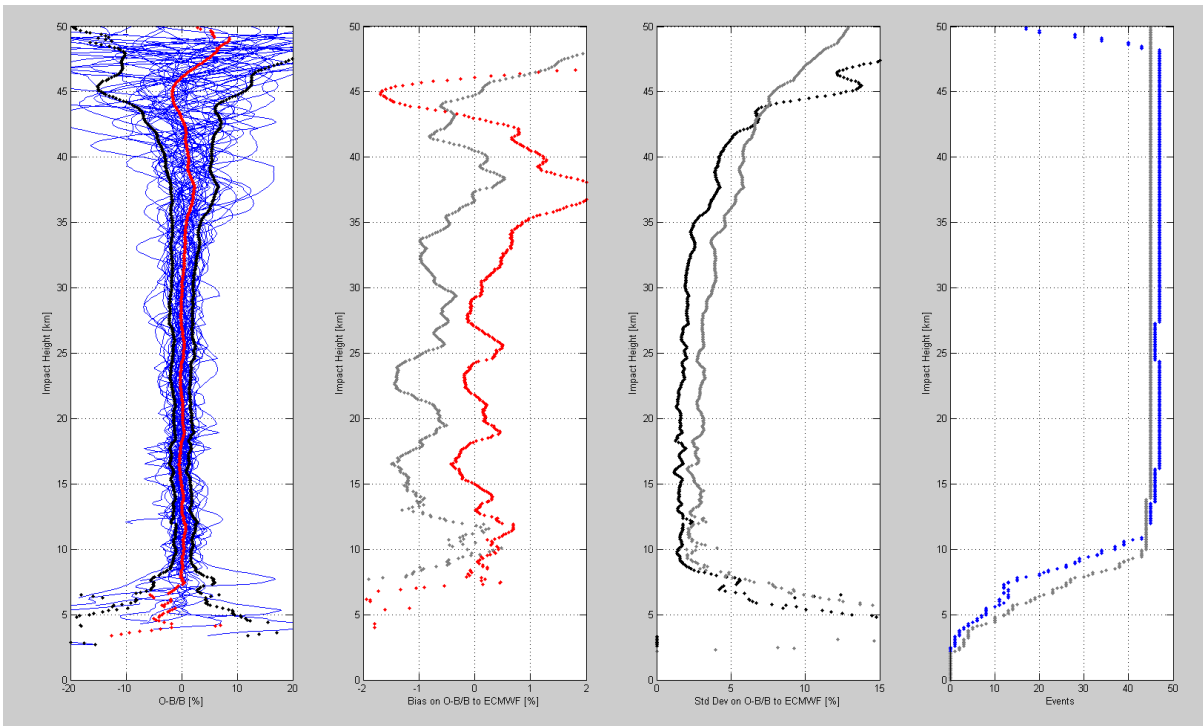
Since ECMWF forward modelled profiles are "coupled" to all the YAROS Level 1a products, differences on the number of couples involved in the ROPP_PP statistics are due both to the missing of a corresponding profile generated by ROPP_PP exactly in the same geographic positions (often happened that the profile was not processed PP because of bad L2 signal to noise ratio).

L2 available starting from 10 – 35 km SLTA (63 events)

ROPP
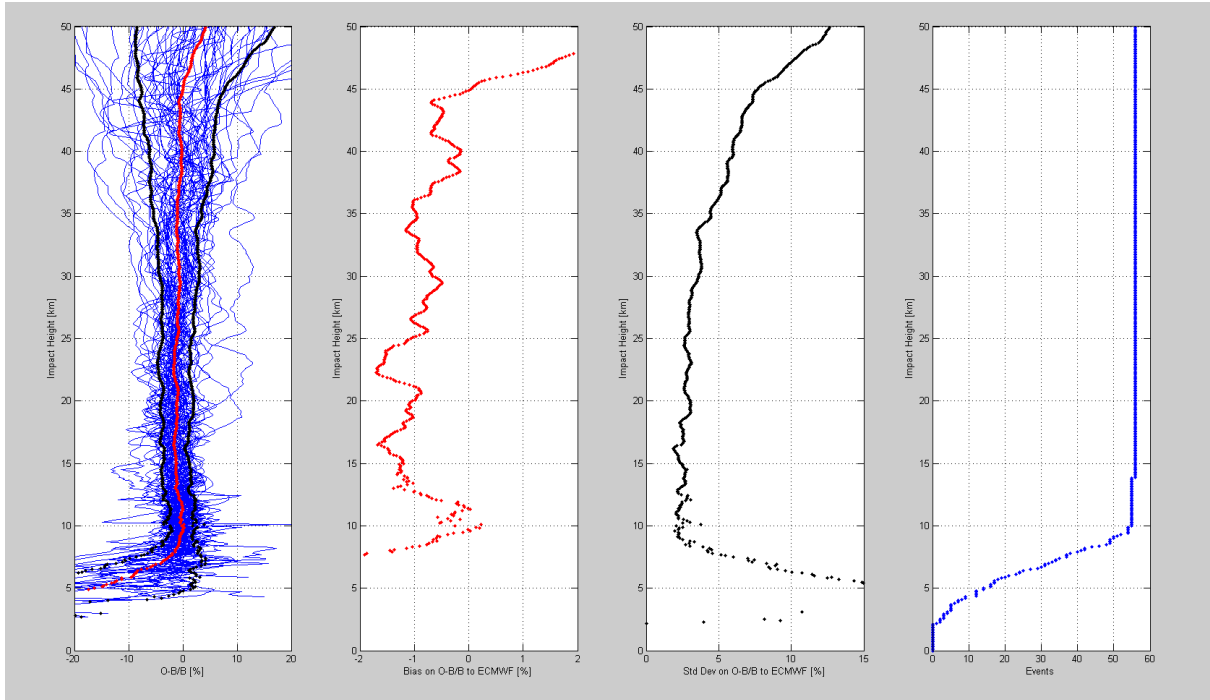
YAROS
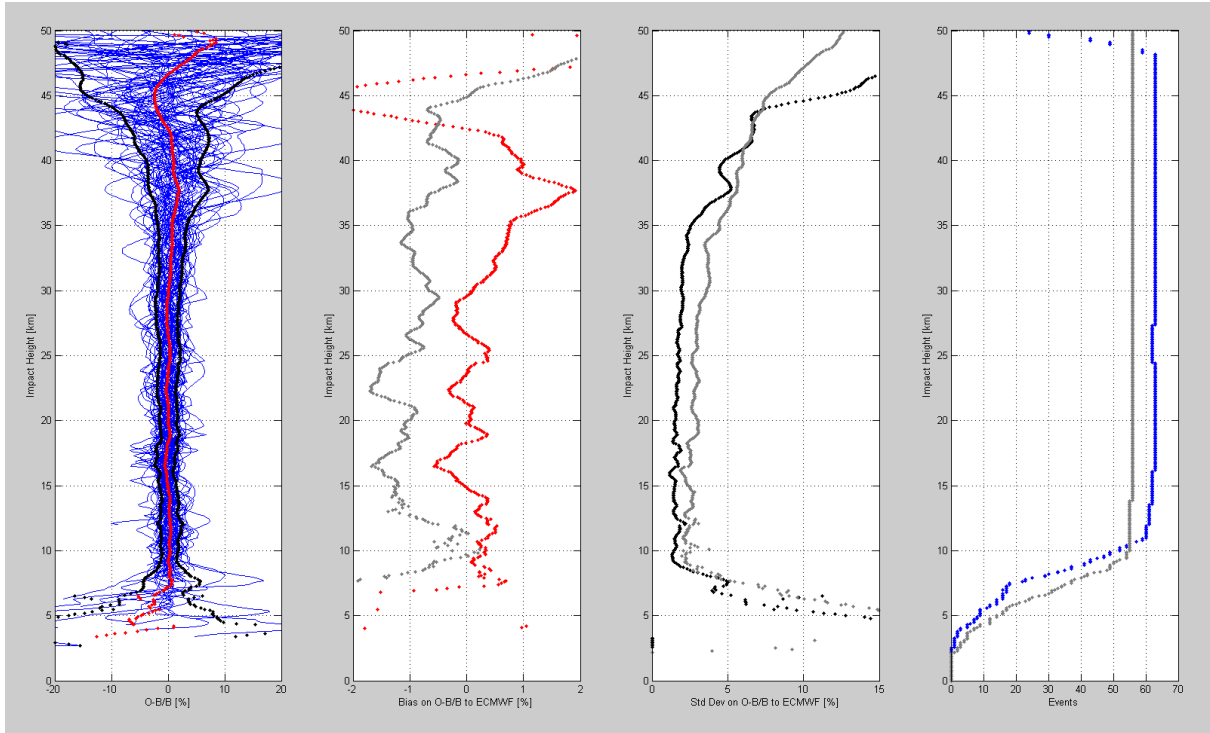
L2 available starting from 0 – 35 km SLTA (80 events)

ROPP
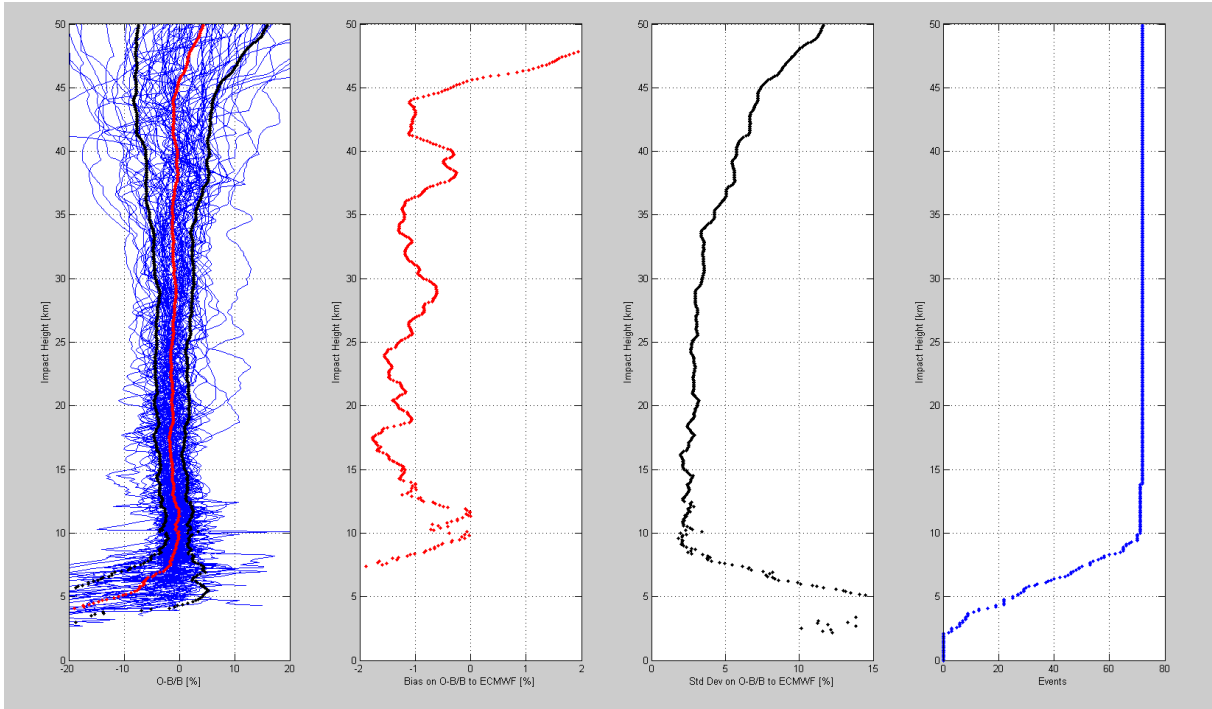
YAROS
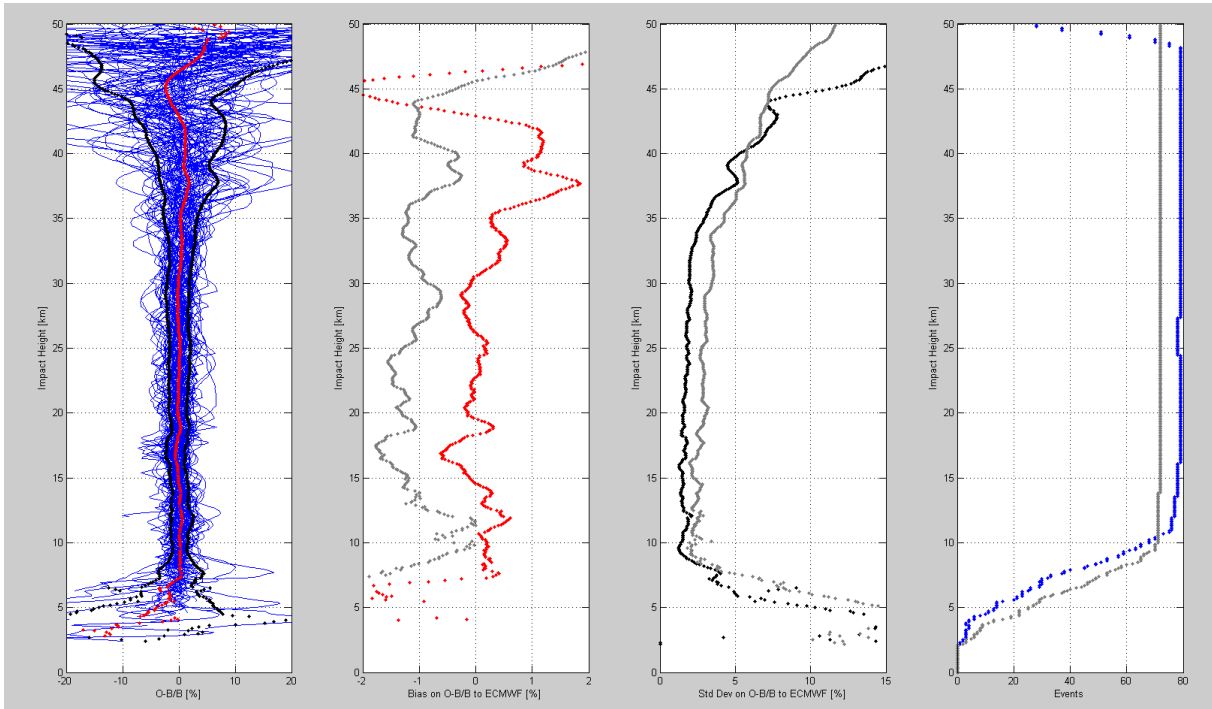
The negative bias of 1% observed from the ROPP_PP results is probably due to the impact of L2 extrapolation downward, which is surely not optimized for ROSA data. From the other point of view, YAROS seems not to be impacted too much by L2 estrapolation downward problems. It can be also seen considering the results from another point of view. That is if we consider the statistics starting taking into account all the events fro which L2 starts to be available at least to 10 km, to 20 km, to 25

km, to 30 km, to 35 km and to 40 km SLTA. Results here shown took into account YAROS output only:
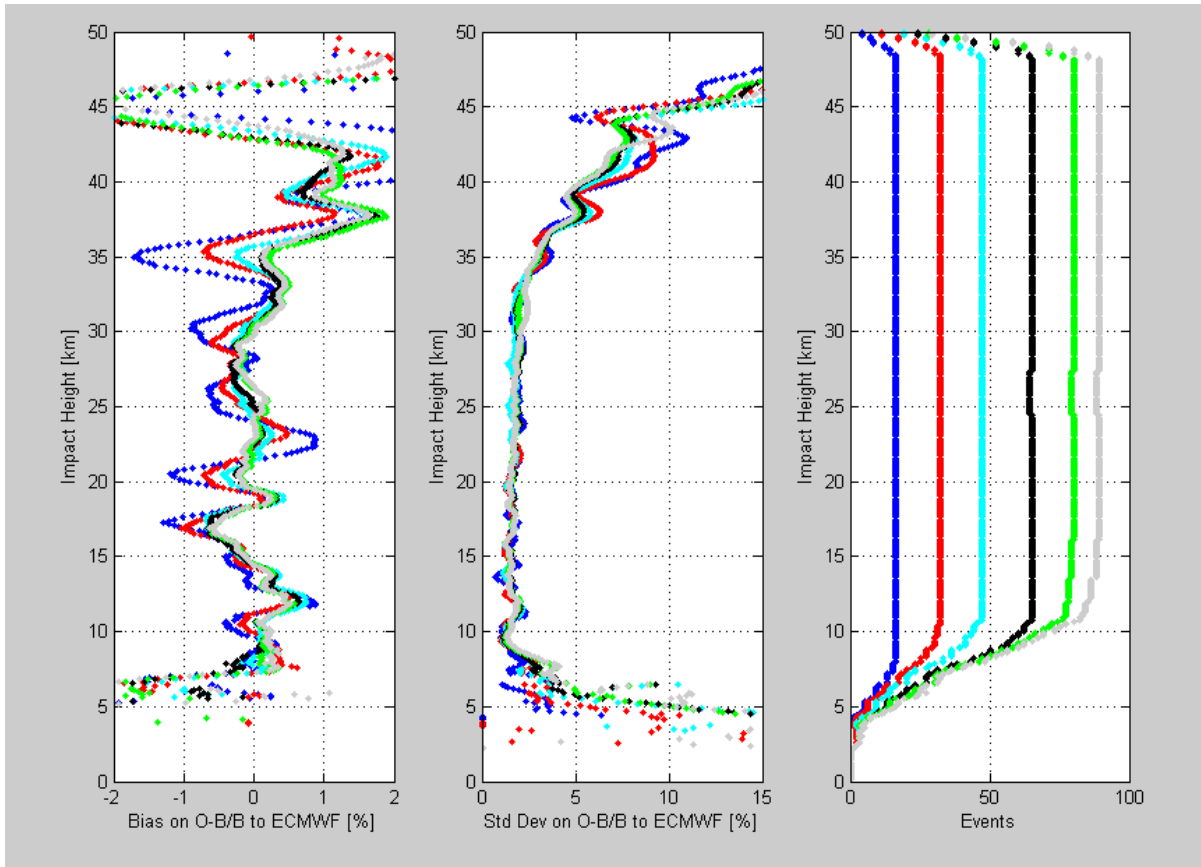
Gray: L2 available at least below 40 km (**90** events / 290 -> **31%**)
Green: L2 available at least below 35 km (**80** events / 290 -> **27.6%**)
Black: L2 available at least below 30 km (**65** events / 290 -> **22.4%**)
Cyan: L2 available at least below 25 km (**47** events / 290 -> **16.2%**)
Red: L2 available at least below 20 km (**32** events / 290 -> **11%**)
Blue: L2 available at least below 10 km (**16** events / 290 -> **5.6%**)

Such results are coherent with those already generated in EUMETSAT (see next plots – Axel Von Engeln courtesy), with the difference that in last case a robust statistic evaluation was made. These results were separated for latitude bands. The number of events seems to be slightly different. But in this last YAROS statistics, all the profiles available were taken into account, while in the previous one (the plot just here above) only profiles for which L2 was available at least below 40 km maximum (90 events) were considered.

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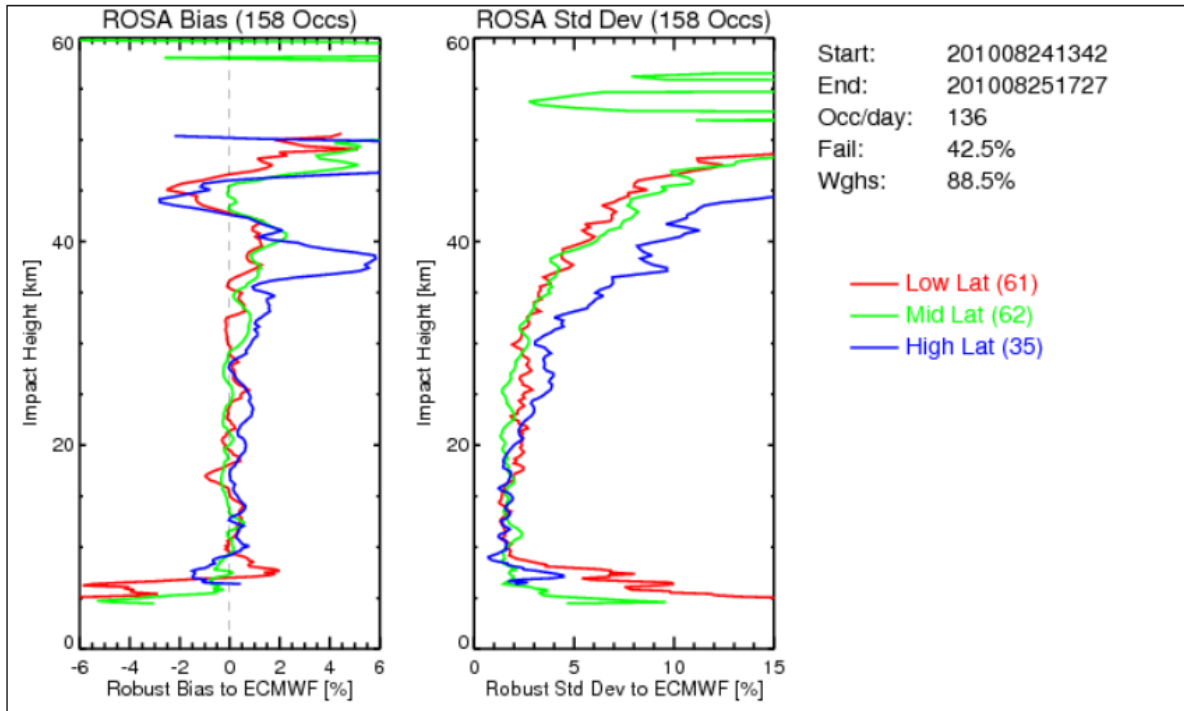
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8. Conclusion

Thanks to this GRAS-SAF Visiting Scientist activity 16, ROSA Radio Occultation data handling has been implemented and tested into EUMETSAT and GRAS SAF processing tools.

Several activities were implemented and carried out during this visit. These activities has been necessary to "setup the scene", since it was the first time that ROSA data were made available and processed by standardized Radio Occultation processing chains.

Considering the work done, some tasks can be considered as definitively consolidated, other should be analyzed more deeply in the next future, considering the agreement between Italian Space Agency and EUMETSAT to introduce also ROSA data in the operative and Near Real Time Radio Occultation data processing. All the ROSA data available inside the binary native data streaming coming within the OCEANSAT-2 telemetry were analyzed and their meaning was understood. Corresponding data structures, able to store all such informations (not only the entire dataset of scientific "standard" observables at different sample rates, but also health and status receiver information, tracking status, onboard position, velocity and clock solutions, geometrical parameters such SLTA, azimuth and elevation of the occulted satellite) were arranged inside the EUMETSAT YAROS prototype. It has to be understood if, for normal operations, it will be better to run the Thales Alenia Space telemetry decoding software and to store in such data structures all the variables (all the source code is prepared for doing this) or if the telemetry decoding software could be directly implemented inside EUMETSAT YAROS prototype. In the framework of this activity, even if some work was done on this direction, ROSA available data started to be processed following a more standard approach which foresaw the use of Level1a Engineered ROSA data, which were the one available for users (but were absolutely not sufficient for operative purposes).

In waiting for the final agreement between ASI and EUMETSAT, about thirty hours belonging to the available one month of data were completely analyzed. About 290 rising occultation profiles are identified (ROSA on board OCEANSAT-2 is equipped with the only velocity Radio Occultation antenna). Even if ROSA on board OCEANSAT-2 suffers for a lot of problems related to the platform (including a first yaw bias forced on the occultation antennas boresight to reduce the impact of the strong local multipath due to moving solar panels and scatterometer antenna, and a second yaw bias forced in the same direction caused by an in-orbit OCEANSAT-2 manoeuvre), L1 data quality seems to be of the same level of that characterizing all the other known Radio Occultation instruments. Unfortunately L2 observables were not so good. Platform issues severely impact on L2 data quality. L2 signal starts to be properly tracked too high in the atmosphere (for only less than 3% of the identified event L2 starts to be tracked below 0 km SLTA, percentage that increase to 8% and to 20 % if we consider the number of events for which L2 starts to be tracked respectively below 10 km and 25 km SLTA). Several data gaps worsen L2 data quality, in particular for ionospheric soundings. The first data gap happens in average around 100 km SLTA (and lasts 30 km in average).

Such raw data quality analysis has been performed on the Level1a data files provided in output to the EUMETSAT YAROS prototype adapted for ROSA data processing. These data were also given in input to the standard YAROS processor for Level 1b retrieval (bending angle over impact parameter profiles) and to the GRAS-SAF ROPP processing chain, to produce bending angle profiles (only geometric optics algorithms were applied), refractivity and dry temperature profiles. Before doing this, a script which transforms YAROS Level1a output files (NetCDF 4.0) into corresponding ROPP-like input file (NetCDF 3.0) is implemented and used.

The statistical analysis performed to ROPP output profiles (bending angle, refractivity and dry temperature) reveals the ROSA data goodness only when L2 observables are available below 10 km SLTA. Comparisons with collocated ECMWF data and with collocated Radio Occultation profiles retrieved from the other available missions (COSMIC, METOP-A and TERRA SAR-X) were performed. Unfortunately ROPP algorithms were not tailored to such bad data, in particular those algorithms in charge of extrapolate downward L2 data when they are not available. An in-depth work is necessary in future to adapt such algorithms to the ROSA on board OCEANSAT-2 L2 peculiar behaviour.

The bending angle statistical analysis performed considering EUMETSAT YAROS Level 1b output reveals instead a better agreement with corresponding ECMWF Forward Modelled bending angle profiles (this forward model was performed using the ROPP_FM 1D propagator, starting from collocated ECMWF atmospheric profiles).

Even though L2 ROSA data on-board OCEANSAT-2 platform are quite difficult to be processed for tropospheric studies, they seems to be more effective for ionospheric studies. Above 100 km and up to the OCEANSAT-2 orbit height, both L1 and L2 data are more or less always available. Vertical profiles of quite horizontal TEC measurements always reveal the F2 peak. Just above 100 km (very near to a systematic dip on both L1 and L2 Signal-to-Noise ratios) is often present a structure on such "uncalibrated" TEC which may be caused by sporadic E-layer.

Moreover, L1 and L2 Carrier Phase and amplitude limb sounding observations were often available at 50 Hz also during ionospheric sounding, because of a particular sounding strategy adopted by the ROSA receiver (which oversample at 50 Hz data taken for those very high SVs that can be used as pivot satellites for single difference computations at the receiver side). These data can be considered as value-added products for scintillation studies in ionosphere and can open the door to future in-depth analysis.

Considering that ROSA data are available not only from the OCEANSAT-2 missions, but also from the Argentinean SAC-D and the Indian-France Megha-Tropiques (it seems that L2 data observed in the framework of these other missions are better than the one collected onboard OCEANSAT-2), some further efforts should be still done, in particular if the agreement between ASI and EUMETSAT for the ROSA data operational processing will be defined.

First of all, from the receiver point of view, an in-depth analysis for a better understanding on the causes of L2 tracking problems is suggested, trying to correlate such data problems to the OCEANSAT-2 platform. It is also recommended to analyze the signal from 90 km to 110 km SLTA, in order to understand if SNR strong fadings (and corresponding L2 data gaps) are due to ionospheric perturbations or to receiver/platform problems. From the software point of view, EUMETSAT YAROS and GRAS-SAF ROPP processing chains are the state of the art of Radio Occultation processing software. Their fine tailoring to ROSA data should be finalized, since it will have a great impact for the future of Radio Occultation exploitation in Europe and in the world, in particular from the next few months when COSMIC data will be no longer available. Further studies and activities on this sense are also recommended.

Appendix A. Python code for Level 1a YAROS to ROPP transformation

```
def rosa2ropp (input_filename):

    data_cut = 1
    nc = netcdf.Dataset( input_filename, "r")
    print input_filename

    # read all the netCDF4 data contained in the input lev1a ROSA data generated by yaros.rosa
    # Global variables
    utc_start_absdate = nc.getVariable("/level_1a/start_time_absdate")[0]
    utc_start_abstime = nc.getVariable("/level_1a/start_time_abstime")[0]
    utc_ref = abs20002utc(utc_start_absdate, utc_start_abstime)

    # Occultation variables (geographical/geometrical data are for SLTA = 0)
    sat_occ = nc.getVariable("/occultation/prn")[0]
    chn = nc.getVariable("/occultation/channel")[0] #MISSING INFO
    georef_t_absdate = nc.getVariable("/occultation/georef_time_absdate")[0] #stored after conversion using utc2absdate2000()
    georef_t_abstime = nc.getVariable("/occultation/georef_time_abstime")[0] #stored after conversion using utc2abstime()
    georef_utc = abs20002utc(georef_t_absdate,georef_t_abstime)
    lon = nc.getVariable("/occultation/longitude")[0] #[deg]
    lat = nc.getVariable("/occultation/latitude")[0] #[deg]
    az_N = nc.getVariable("/occultation/azimuth_north")[0] #[deg]
    radius_curvat = nc.getVariable("/occultation/r_curve")[0] #[m]
    radius_curvat_centre = nc.getVariable("/occultation/r_curve_centre")[:] #[m] J2000
    undul = nc.getVariable("/occultation/undulation")[0] #[m] EGM96
    lon_RX = nc.getVariable("/occultation/longitude_rec")[0] #[deg] deg-East
    lat_RX = nc.getVariable("/occultation/latitude_rec")[0] #[deg] deg-North
    alt_RX = nc.getVariable("/occultation/altitude_rec")[0] #[m] above WGS84
    lon_SV = nc.getVariable("/occultation/longitude_gns")[0] #[deg] deg-East
    lat_SV = nc.getVariable("/occultation/latitude_gns")[0] #[deg] deg-North
    alt_SV = nc.getVariable("/occultation/altitude_gns")[0] #[m] above WGS84
    ant_az = nc.getVariable("/occultation/azimuth_antenna")[0] #[deg] antenna azimuth angle (from AV)
    ant_el = nc.getVariable("/occultation/zenith_antenna")[0] #[deg] antenna zenith angle (wrt zenith)

    # Closed Loop Level1a data
    dtime = nc.getVariable("/level_1a/closed_loop_50Hz/dtime")[:] #Measurement epoch
    ref_time = abs20002utc(utc_start_absdate,utc_start_abstime)
    utcs = ref_time + dtime*oneSecond
    slta = nc.getVariable("/level_1a/closed_loop_50Hz/slta")[:] #SLTA [m]
    #srate = nc.getVariable("/level_1a/closed_loop_50Hz/samplerate")[0] #To be modified since we can have different sample rates
    l1_ph = nc.getVariable("/level_1a/closed_loop_50Hz/phase_ca")[:] #L1 Carrier Phase - CK bias [m]
    l2_ph = nc.getVariable("/level_1a/closed_loop_50Hz/phase_p2")[:] #L2 Carrier Phase - CK bias [m]
    l1_exph = nc.getVariable("/level_1a/closed_loop_50Hz/exphase_ca")[:] #L1 ExPhase = Carrier Phase - CK bias - geometry [m]
    l2_exph = nc.getVariable("/level_1a/closed_loop_50Hz/exphase_p2")[:] #L2 ExPhase = Carrier Phase - CK bias - geometry [m]
    S1 = nc.getVariable("/level_1a/closed_loop_50Hz/signal_L1")[:] #Estimates of Signal Power on L1 (integrated for 20 msec @29 MHz
and LPF @1Hz) in output to the correlator [dB]
    S2 = nc.getVariable("/level_1a/closed_loop_50Hz/signal_L2")[:] #Estimates of Signal Power on L2 (integrated for 20 msec @29 MHz
and LPF @1Hz) in output to the correlator [dB]
    N1 = nc.getVariable("/level_1a/closed_loop_50Hz/noise_L1")[:] #Estimates of Noise Power on L1 in output to the correlator [dB]
    N2 = nc.getVariable("/level_1a/closed_loop_50Hz/noise_L2")[:] #Estimates of Noise Power on L2 in output to the correletor [dB]
    l1_snr = nc.getVariable("/level_1a/closed_loop_50Hz/snr_ca")[:] #S1-N1 [dB]
    l2_snr = nc.getVariable("/level_1a/closed_loop_50Hz/snr_p2")[:] #S2-N2 [dB]
    l1_snr_mean = nc.getVariable("/level_1a/closed_loop_50Hz/snr_ca_mean")[0] #average (computed on linear) l1_snr [dB]
    l2_snr_mean = nc.getVariable("/level_1a/closed_loop_50Hz/snr_p2_mean")[0] #average (computed on linear) l2_snr [dB]
    S1_mean = nc.getVariable("/level_1a/closed_loop_50Hz/signal_power_ca_mean")[0] #S1 average (computed on linear) [dB]
    S2_mean = nc.getVariable("/level_1a/closed_loop_50Hz/signal_power_p2_mean")[0] #S2 average (computed on linear) [dB]
    N1_mean = nc.getVariable("/level_1a/closed_loop_50Hz/noise_power_l1_mean")[0] #N1 average (computed on linear) [dB]
    N2_mean = nc.getVariable("/level_1a/closed_loop_50Hz/noise_power_l2_mean")[0] #N2 average (computed on linear) [dB]
    l1_exph_noise = nc.getVariable("/level_1a/closed_loop_50Hz/exphase_ca_noise")[0] #Mean phase noise of L1 carrier phase
measurements [m]
    l2_exph_noise = nc.getVariable("/level_1a/closed_loop_50Hz/exphase_p2_noise")[0] #Mean phase noise of L2 carrier phase
measurements [m]
    slta_l1_min_all = nc.getVariable("/level_1a/closed_loop_50Hz/slta_ca_min_all")[0] #Minimum overall SLTA on L1 data [m]
    slta_l1_max_all = nc.getVariable("/level_1a/closed_loop_50Hz/slta_ca_max_all")[0] #Maximum overall SLTA on L1 data [m]
    slta_l1_min_main = nc.getVariable("/level_1a/closed_loop_50Hz/slta_ca_min_main")[0] #Minimum SLTA of main (longest) L1 data
segment [m]
```

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```
    slta_l1_max_main = nc.getVariable("/level_1a/closed_loop_50Hz/slta_ca_max_main")[0] #Maximum SLTA of main (longest) L1 data
segment [m]
    slta_l1_min_select = nc.getVariable("/level_1a/closed_loop_50Hz/slta_ca_min_select")[0] #Minimum SLTA of L1 data segment selected
for processing [m]
    slta_l1_max_select  = nc.getVariable("/level_1a/closed_loop_50Hz/slta_ca_max_select")[0]  #Maximum SLTA of L1 data segment
selected for processing [m]
    slta_l2_min_all = nc.getVariable("/level_1a/closed_loop_50Hz/slta_p2_min_all")[0] #Minimum overall SLTA on L2 data [m]
    slta_l2_max_all = nc.getVariable("/level_1a/closed_loop_50Hz/slta_p2_max_all")[0] #Maximum overall SLTA on L2 data [m]
    slta_l2_min_main = nc.getVariable("/level_1a/closed_loop_50Hz/slta_p2_min_main")[0] #Minimum SLTA of main (longest) L2 data
segment [m]
    slta_l2_max_main = nc.getVariable("/level_1a/closed_loop_50Hz/slta_p2_max_main")[0] #Maximum SLTA of main (longest) L2 data
segment [m]
    slta_l2_min_select = nc.getVariable("/level_1a/closed_loop_50Hz/slta_p2_min_select")[0] #Minimum SLTA of L2 data segment selected
for processing [m]
    slta_l2_max_select  = nc.getVariable("/level_1a/closed_loop_50Hz/slta_p2_max_select")[0]  #Maximum SLTA of L2 data segment
selected for processing [m]
    x_rec = nc.getVariable("/level_1a/closed_loop_50Hz/x_rec")[:] #OC-2 interpolated x-position on J2000 ECI reference system [m]
    y_rec = nc.getVariable("/level_1a/closed_loop_50Hz/y_rec")[:] #OC-2 interpolated y-position on J2000 ECI reference system [m]
    z_rec = nc.getVariable("/level_1a/closed_loop_50Hz/z_rec")[:] #OC-2 interpolated z-position on J2000 ECI reference system [m]
    vx_rec = nc.getVariable("/level_1a/closed_loop_50Hz/vx_rec")[:] #OC-2 interpolated x-velocity component on J2000 ECI reference
system [m/s]
    vy_rec = nc.getVariable("/level_1a/closed_loop_50Hz/vy_rec")[:] #OC-2 interpolated y-velocity component on J2000 ECI reference
system [m/s]
    vz_rec = nc.getVariable("/level_1a/closed_loop_50Hz/vz_rec")[:] #OC-2 interpolated z-velocity component on J2000 ECI reference
system [m/s]
    clk_rec = nc.getVariable("/level_1a/closed_loop_50Hz/clk_rec")[:] #ROSA interpolated clk [s]
    x_gns = nc.getVariable("/level_1a/closed_loop_50Hz/x_gns")[:] #GNS interpolated x-position on J2000 ECI reference system [m]
    y_gns = nc.getVariable("/level_1a/closed_loop_50Hz/y_gns")[:] #GNS interpolated y-position on J2000 ECI reference system [m]
    z_gns = nc.getVariable("/level_1a/closed_loop_50Hz/z_gns")[:] #GNS interpolated z-position on J2000 ECI reference system [m]
    vx_gns = nc.getVariable("/level_1a/closed_loop_50Hz/vx_gns")[:] #GNS interpolated x-velocity component on J2000 ECI (???) reference
system [m/s]
    vy_gns = nc.getVariable("/level_1a/closed_loop_50Hz/vy_gns")[:] #GNS interpolated y-velocity component on J2000 ECI (???) reference
system [m/s]
    vz_gns = nc.getVariable("/level_1a/closed_loop_50Hz/vz_gns")[:] #GNS interpolated z-velocity component on J2000 ECI (???) reference
system [m/s]
    clk_gns = nc.getVariable("/level_1a/closed_loop_50Hz/clk_gns")[:] #GNS interpolated clk [s]
    sl_traveltime = nc.getVariable("/level_1a/closed_loop_50Hz/sl_traveltime")[:] #travel time on straight line traj between GNS and OC-2
[s]
    sl_distance = nc.getVariable("/level_1a/closed_loop_50Hz/sl_distance")[:] #OC-2  -  GNS distance [m]
    nc.close()


    # Write data to netCDF-3 file
    fill_not_known = -99999000.
    id_sv = str(sat_occ)
    if len(id_sv) == 2:
        id_sv = 'G0' + id_sv
    else:
        id_sv = 'G00' + id_sv
    id_ro = 'OCS2'

    if data_cut == 1:
    # find continuous data available both for L1 and L2...
        min_slta = min(slta_l1_min_select, slta_l2_min_select)
        max_slta = 80000;
        idx = where((slta>=min_slta)&(slta<=max_slta))

        slta = slta[idx]
        dtime = dtime[idx]
        l1_snr = l1_snr[idx]
        l2_snr = l2_snr[idx]
        l1_exph = l1_exph[idx]
        l2_exph = l2_exph[idx]
        x_gns = x_gns[idx]
        y_gns = y_gns[idx]
        z_gns = z_gns[idx]
        vx_gns = vx_gns[idx]
        vy_gns = vy_gns[idx]
        vz_gns = vz_gns[idx]
        x_rec = x_rec[idx]
        y_rec = y_rec[idx]
        z_rec = z_rec[idx]
```

```
    vx_rec = vx_rec[idx]
    vy_rec = vy_rec[idx]
    vz_rec = vz_rec[idx]

output_filename = create_filename_from_input_filename(input_filename,id_sv,id_ro)

nc3 = Dataset(output_filename,'w',format = 'NETCDF3_CLASSIC')

nc3.createDimension('dim_unlim', None)
nc3.createDimension('dim_char04',5)
nc3.createDimension('dim_char20',21)
nc3.createDimension('dim_char40',41)
nc3.createDimension('dim_char64',65)
dim = len(dtime)
nc3.createDimension('xyz',3)
nc3.createDimension('dim_lev1a',dim)

occ_id = nc3.createVariable('occ_id', 'c', ('dim_unlim','dim_char40',))
setattr(occ_id, "long_name", "Occultation ID")

gns_id = nc3.createVariable('gns_id','c',('dim_unlim','dim_char04',))
gns_id[0] = '%-5s'%id_sv
setattr(gns_id, "long_name", "GNSS satellite ID")

leo_id = nc3.createVariable('leo_id','c',('dim_unlim','dim_char04',))
leo_id[0] = '%-5s'%id_ro
setattr(leo_id, "long_name", "LEO satellite ID")

start_time = nc3.createVariable('start_time','f',('dim_unlim',)) # Occultation effective start in Seconds from 2000-01-01
start_time[:] = utc2js(utc_ref)
setattr(start_time, "long_name", "Starting time for the occultation")
setattr(start_time, "units", "seconds since start of the day")

year = nc3.createVariable('year','i',('dim_unlim',))
year[:] = utc_ref.year
setattr(year, "long_name", "Year")
setattr(year, "units", "years")
setattr(year, "valid_range", "1995, 2099")

month = nc3.createVariable('month','i',('dim_unlim',))
month[:] = utc_ref.month
setattr(month, "long_name", "Month")
setattr(month, "units", "months")
setattr(month, "valid_range", "1, 12")

day = nc3.createVariable('day','i',('dim_unlim',))
day[:] = utc_ref.day
setattr(day, "long_name", "Day")
setattr(day, "units", "days")
setattr(day, "valid_range", "1, 31")

hour = nc3.createVariable('hour','i',('dim_unlim',))
hour[:] = utc_ref.hour
setattr(hour, "long_name", "Hour")
setattr(hour, "units", "hours")
setattr(hour, "valid_range", "0, 23")

minute = nc3.createVariable('minute','i',('dim_unlim',))
minute[:] = utc_ref.minute
setattr(minute, "long_name", "Minute")
setattr(minute, "units", "minutes")
setattr(minute, "valid_range", "0, 59")

second = nc3.createVariable('second','i',('dim_unlim',))
second[:] = int(utc_ref.second)
setattr(second, "long_name", "Second")
setattr(second, "units", "seconds")
setattr(second, "valid_range", "0, 59")

msec = nc3.createVariable('msec','i',('dim_unlim',))
msec[:] = int((utc_ref.second-second[:][0])*1000)
setattr(msec, "long_name", "Millisecond")
```

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```
setattr(msec, "units", "milliseconds")
setattr(msec, "valid_range", "0, 999")

# THIS IS NOT AVAILABLE
pcd = nc3.createVariable('pcd', 'i', ('dim_unlim',))
setattr(pcd, "long_name", "Product Confidence Data")
setattr(pcd, "units", "bits")
setattr(pcd, "valid_range", "0, 32767")

# THIS IS NOT AVAILABLE
overall_qual = nc3.createVariable('overall_qual', 'f', ('dim_unlim',))
setattr(overall_qual, "long_name", "Overall quality")
setattr(overall_qual, "units", "percent")
setattr(overall_qual, "valid_range", "0., 100.")

time = nc3.createVariable('time','f',('dim_unlim',)) # Occultation reference start in Seconds from 2000-01-01: is is equal to start_time
time[:] = utc2js(utc_ref)
setattr(time, "long_name", "Reference time for the occultation")
setattr(time, "units", "seconds since Start of the day")

time_offset = nc3.createVariable('time_offset','f',('dim_unlim',))# Time offset from time_start for georeferencing (SLTA = 0)
time_offset[:] = utc2js(georef_utc)-utc2js(utc_ref)
setattr(time_offset, "long_name", "Time offset for georeferencing (since start of occ.)")
setattr(time_offset, "units", "seconds")
setattr(time_offset, "valid_range", "0., 239.999")

lat_occ = lat
lat = nc3.createVariable('lat','f',('dim_unlim',))
lat[:] = lat_occ
setattr(lat, "long_name", "Reference latitude for the occultation")
setattr(lat, "units", "degrees_north")
setattr(lat, "valid_range", "-90., 90.")

lon_occ = lon
lon = nc3.createVariable('lon','f',('dim_unlim',))
lon[:] = lon_occ
setattr(lon, "long_name", "Reference longitude for the occultation")
setattr(lon, "units", "degrees_east")
setattr(lon, "valid_range", "-180., 180.")

undulation = nc3.createVariable('undulation','f',('dim_unlim',))
undulation[:] = undul
setattr(undulation, "long_name", "Geoid undulation for the reference coordinate")
setattr(undulation, "units", "metres")
setattr(undulation, "valid_range", "-150., 150.")

roc = nc3.createVariable('roc','f',('dim_unlim',))
roc[:] = radius_curvat
setattr(roc, "long_name", "Radius of curvature for the reference coordinate")
setattr(roc, "units", "metres")
setattr(roc, "valid_range", "6200000., 6600000.")

r_coc = nc3.createVariable('r_coc','f',('dim_unlim','xyz',))
r_coc[0] = radius_curvat_centre
setattr(r_coc, "long_name", "Centre of curvature for the reference coordinate")
setattr(r_coc, "units", "metres")
setattr(r_coc, "valid_range", "-50000., 50000.")
setattr(r_coc, "reference_frame", "??? J2000 - ECI")

azimuth = nc3.createVariable('azimuth','f',('dim_unlim',))
azimuth[:] = az_N
setattr(azimuth, "long_name", "GNSS->LEO line of sight angle (from True North) for the reference coordinate")
setattr(azimuth, "units", "degrees_T")
setattr(azimuth, "valid_range", "0., 360.")

time_occ = dtime
dtime = nc3.createVariable('dtime','f',('dim_unlim','dim_lev1a',))
tmp = time_occ[:] - time_occ[0]
idx = where(isnan(tmp))
tmp[idx]=fill_not_known
dtime[0] = tmp
```

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```python
setattr(dtime, "long_name", "Time since start of occultation")
setattr(dtime, "units", "seconds")
setattr(dtime, "valid_range", "-1., 600.000")


snr_L1ca = nc3.createVariable('snr_L1ca','f',('dim_unlim','dim_lev1a',))
tmp = sqrt(2.) * 10**(l1_snr / 20.) # similar to V/V
if isnan(tmp[0]):
    tmp[0] = 0.
idx = where(isnan(tmp))
tmp[idx]=fill_not_known
snr_L1ca[0] = tmp
setattr(snr_L1ca, "long_name", "Signal-to-noise ratio (L1, C/A code)")
setattr(snr_L1ca, "units", "volt / volt")
setattr(snr_L1ca, "valid_range", "0., 10000.")


# THIS IS NOT AVAILABLE
snr_L1p = nc3.createVariable('snr_L1p','f',('dim_unlim','dim_lev1a',))
setattr(snr_L1p, "long_name", "Signal-to-noise ratio (L1, P code)")
setattr(snr_L1p, "units", "volt / volt")
setattr(snr_L1p, "valid_range", "0., 10000.")


snr_L2p = nc3.createVariable('snr_L2p','f',('dim_unlim','dim_lev1a',))
tmp = sqrt(2.) * 10**(l2_snr / 20.) # similar to V/V
if isnan(tmp[0]):
    tmp[0] = 0.
idx = where(isnan(tmp))
tmp[idx]=fill_not_known
snr_L2p[0] = tmp
setattr(snr_L2p, "long_name", "Signal-to-noise ratio (L2, P code)")
setattr(snr_L2p, "units", "volt / volt")
setattr(snr_L2p, "valid_range", "0., 10000.")


phase_L1 = nc3.createVariable('phase_L1','f',('dim_unlim','dim_lev1a',))
tmp = l1_exph
idx = where(isnan(tmp))
tmp[idx]=fill_not_known
phase_L1[0] = tmp
setattr(phase_L1, "long_name", "Excess Phase (L1)")
setattr(phase_L1, "units", "meters")
setattr(phase_L1, "valid_range", "-10000, 10000.")


phase_L2 = nc3.createVariable('phase_L2','f',('dim_unlim','dim_lev1a',))
tmp = l2_exph
idx = where(isnan(tmp))
tmp[idx]=fill_not_known
phase_L2[0] = tmp
setattr(phase_L2, "long_name", "Excess Phase (L2)")
setattr(phase_L2, "units", "meters")
setattr(phase_L2, "valid_range", "-10000, 10000.")


r_gns = nc3.createVariable('r_gns','f',('dim_unlim','xyz','dim_lev1a'))
r_gns[0] = (x_gns, y_gns, z_gns) # x_pos is simply the array defined as nc3.variables['r_gns'][0]
setattr(r_gns, "long_name", "GNSS transmitter position")
setattr(r_gns, "units", "meters")
setattr(r_gns, "valid_range", "-43000000., 43000000.")
setattr(r_gns, "reference_frame", "ECI-J2000")


v_gns = nc3.createVariable('v_gns','f',('dim_unlim','xyz','dim_lev1a'))
v_gns[0] = (vx_gns, vy_gns, vz_gns)
setattr(v_gns, "long_name", "GNSS transmitter velocity")
setattr(v_gns, "units", "meters/seconds")
setattr(v_gns, "valid_range", "-10000., 10000.")
setattr(v_gns, "reference_frame", "ECI-J2000")


r_leo = nc3.createVariable('r_leo','f',('dim_unlim','xyz','dim_lev1a'))
r_leo[0] = (x_rec, y_rec, z_rec)
setattr(r_leo, "long_name", "LEO transmitter position")
setattr(r_leo, "units", "meters")
setattr(r_leo, "valid_range", "-10000000., 10000000.")
setattr(r_leo, "reference_frame", "ECI-J2000")


v_leo = nc3.createVariable('v_leo','f',('dim_unlim','xyz','dim_lev1a'))
```

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```
v_leo[0] = (vx_rec, vy_rec, vz_rec)
setattr(v_leo, "long_name", "LEO transmitter velocity")
setattr(v_leo, "units", "meters/seconds")
setattr(v_leo, "valid_range", "-10000., 10000.")
setattr(v_leo, "reference_frame", "ECI-J2000")

# THIS IS NOT AVAILABLE
phase_qual = nc3.createVariable('phase_qual','f',('dim_unlim','dim_lev1a',))
setattr(phase_qual, "long_name", "Quality value for phase (and SNR)")
setattr(phase_qual, "units", "percent")
setattr(phase_qual, "valid_range", "0., 100.")

# THIS IS NOT AVAILABLE
open_loop = nc3.createVariable('open_loop','f',('dim_unlim','dim_lev1a',))
setattr(open_loop, "long_name", "Open Loop Phase Model")
setattr(open_loop, "units", "1")
setattr(open_loop, "valid_range", "-1000000., 1000000.")

# GLOBAL ATTRIBUTES:

setattr(nc3, "title", "ROSA level1a netCDF3 data generated by YAROS for ROPP processing")
setattr(nc3, "institution", "EUMETSAT-ASI")
setattr(nc3, "Conventions", "None")
setattr(nc3, "format_version", "ROPP I/O V1.1")
setattr(nc3, "processing_centre", "EUMETSAT")
setattr(nc3, "processing_date", input_filename.split("_")[5][:-4])
setattr(nc3, "pod_method", "FIT")
setattr(nc3, "phase_method", "zero-differencing")
setattr(nc3, "bangle_method", "UNKNOWN")
setattr(nc3, "refrac_method", "UNKNOWN")
setattr(nc3, "meteo_method", "UNKNOWN")
setattr(nc3, "thin_method", "UNKNOWN")
setattr(nc3, "software_version", "UNKNOWN")
setattr(nc3, "_Fillvalue", -99999000.)


print  output_filename,  lat_occ,  lon_occ,  slta_l1_min_select,  slta_l1_max_select,  slta_l2_min_select,  slta_l2_max_select,
slta_l1_min_main, slta_l1_max_main, slta_l2_min_main, slta_l2_max_main


nc3.close()
```

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APPENDIX B. Occultation event list

		LAT	LONG	min L1 SLTA	max L1 SLTA	min L2 SLTA	max L2 SLTA
1	occ_20100824_173338_OCS2_G030.nc	-53,42	-68,46	-89784,42	746508,26	-7541,92	746508,26
2	occ_20100824_204031_OCS2_G023.nc	-12,46	-113,52	-126462,02	737771,02	-4861,87	101494,75
3	occ_20100825_131659_OCS2_G026.nc	-24,07	-3,95	-112445,91	741210,11	-3973,11	101191,59
4	occ_20100825_021129_OCS2_G005.nc	-53,11	-57,62	-76015,60	731515,44	-3308,72	731515,44
5	occ_20100825_145258_OCS2_G009.nc	-12,01	-25,82	-125113,95	736426,62	-2742,09	98401,52
6	occ_20100824_234850_OCS2_G005.nc	24,90	-149,16	-118431,78	729235,65	-1003,11	112366,91
7	occ_20100825_144218_OCS2_G018.nc	26,21	-11,51	-116755,98	730285,66	-335,57	98660,24
8	occ_20100825_082822_OCS2_G016.nc	-55,33	71,02	-86909,36	747908,08	686,84	6427,67
9	occ_20100825_050929_OCS2_G030.nc	-52,35	123,44	-84516,57	748366,12	3049,31	85518,83
10	occ_20100824_155643_OCS2_G012.nc	-55,77	-33,62	-81616,44	749986,67	4131,85	173273,17
11	occ_20100825_170454_OCS2_G018.nc	-54,24	78,76	-76635,10	732171,64	5348,97	37697,12
12	occ_20100825_154642_OCS2_G021.nc	18,02	99,01	-127712,89	728833,17	5649,41	652477,63
13	occ_20100824_211309_OCS2_G032.nc	-53,28	19,79	-79086,80	733358,32	8051,46	733358,32
14	occ_20100824_141646_OCS2_G026.nc	-60,64	-19,54	-82036,30	734887,33	8330,41	171239,57
15	occ_20100825_172401_OCS2_G016.nc	13,84	78,22	-133437,76	727559,27	8889,34	727559,27
16	occ_20100824_150548_OCS2_G021.nc	43,59	93,92	-119726,02	735956,39	9543,48	735956,39
17	occ_20100825_124850_OCS2_G027.nc	59,55	65,04	-96442,03	727900,10	9612,77	727900,10
18	occ_20100825_000425_OCS2_G008.nc	-32,08	-169,29	-105083,63	739739,98	9797,01	214743,22
19	occ_20100824_152721_OCS2_G014.nc	37,74	-32,64	-128949,03	727438,59	9931,69	92848,80
20	occ_20100824_190649_OCS2_G031.nc	-33,33	-95,06	-104336,49	740286,19	10193,59	102360,28
21	occ_20100824_185222_OCS2_G032.nc	20,65	-75,81	-116944,47	737307,06	10505,45	104166,61
22	occ_20100825_001352_OCS2_G028.nc	-57,57	-156,74	-80742,01	750166,20	10792,98	217489,23
23	occ_20100825_063758_OCS2_G031.nc	-17,58	96,89	-119701,58	737948,81	11217,08	98921,40
24	occ_20100825_042844_OCS2_G031.nc	60,58	-147,10	-99000,07	732036,26	11248,86	17930,22
25	occ_20100825_101158_OCS2_G023.nc	-73,05	47,23	-82435,56	750428,29	11381,88	97710,25
26	occ_20100824_221639_OCS2_G007.nc	-0,24	-133,40	-126818,85	735394,90	12190,77	735394,90
27	occ_20100825_112013_OCS2_G026.nc	33,99	29,32	-126944,44	588972,69	13365,61	93386,87
28	occ_20100825_162448_OCS2_G014.nc	12,20	-48,06	-126991,96	727309,24	14885,98	88277,52
29	occ_20100825_032537_OCS2_G027.nc	-42,52	136,00	-94591,91	742153,77	15794,46	102874,95
30	occ_20100825_092458_OCS2_G008.nc	58,69	149,97	-100127,09	733059,30	15909,50	666173,69
31	occ_20100825_161124_OCS2_G024.nc	55,52	-20,55	-115042,06	732715,20	16489,04	103439,21
32	occ_20100824_143843_OCS2_G005.nc	-41,98	124,75	-91900,60	731595,46	17066,89	731595,46
33	occ_20100825_145728_OCS2_G027.nc	-29,12	-31,41	-108393,27	739628,32	17377,56	104121,29
34	occ_20100824_163019_OCS2_G021.nc	1,06	95,01	-144103,92	724955,21	18116,82	724955,21
35	occ_20100824_220950_OCS2_G010.nc	21,43	-131,51	-127132,48	725715,89	18502,81	100858,17
36	occ_20100825_173353_OCS2_G024.nc	40,86	59,02	-123693,84	281599,15	18755,32	281599,15
37	occ_20100825_151500_OCS2_G026.nc	-85,49	139,18	-84903,26	749406,79	19113,45	104975,82
38	occ_20100824_234805_OCS2_G026.nc	24,03	-157,82	-126225,40	725536,94	19277,33	99897,83
39	occ_20100824_183621_OCS2_G011.nc	65,75	-39,78	-112142,82	736100,44	20058,34	83375,08
40	occ_20100825_032209_OCS2_G009.nc	-28,60	142,45	-110037,61	739196,67	20071,47	99532,77

41	occ_20100824_175815_OCS2_G018.nc	-36,12	81,17	-104781,40	732255,05	21183,85	732255,05
42	occ_20100825_115748_OCS2_G013.nc	-79,67	-165,59	-85808,80	748540,86	21266,71	42539,66
43	occ_20100824_160540_OCS2_G015.nc	-82,04	117,85	-86459,32	748776,53	22106,59	140169,39
44	occ_20100825_080244_OCS2_G013.nc	30,24	78,59	-124930,03	726216,55	22548,81	93548,44
45	occ_20100825_090353_OCS2_G011.nc	3,65	-152,27	-143242,07	724690,09	22719,45	724690,09
46	occ_20100825_073816_OCS2_G008.nc	58,03	-133,44	-115642,35	734034,51	22720,00	734034,51
47	occ_20100824_192252_OCS2_G014.nc	-87,14	70,79	-85032,14	749555,98	23308,17	749555,98
48	occ_20100825_014712_OCS2_G026.nc	-42,86	167,85	-88816,02	746570,17	23432,27	746570,17
49	occ_20100824_200954_OCS2_G007.nc	61,25	-9,51	-103030,56	736194,07	23618,88	206226,80
50	occ_20100825_171522_OCS2_G021.nc	-11,15	91,75	-141478,14	726610,26	23695,15	726610,26
51	occ_20100824_183915_OCS2_G013.nc	62,45	-82,00	-111336,07	733710,13	23822,97	99013,62
52	occ_20100825_030725_OCS2_G022.nc	22,29	153,36	-128668,58	725521,40	24228,86	101290,92
53	occ_20100824_223553_OCS2_G003.nc	-71,39	173,91	-97029,45	748532,52	24417,05	107471,84
54	occ_20100824_153221_OCS2_G022.nc	23,55	-27,86	-121394,58	726584,84	24729,12	98144,21
	occ_20100825_053204_OCS2_G018.nc	-43,53	-98,67	-90400,53	732356,00	25190,10	732356,00
	occ_20100825_005344_OCS2_G012.nc	27,33	-32,88	-134198,36	728312,16	25289,42	728312,16
	occ_20100825_150842_OCS2_G015.nc	-67,87	-27,00	-82786,37	750321,91	25319,63	750321,91
	occ_20100824_155251_OCS2_G027.nc	-52,29	-58,71	-92067,99	744434,47	25378,32	105634,06
	occ_20100825_114340_OCS2_G007.nc	-48,68	6,78	-91949,50	743425,47	25461,98	120579,28
	occ_20100825_054542_OCS2_G016.nc	0,52	-107,51	-139837,22	726536,31	25935,22	34614,41
	occ_20100825_062708_OCS2_G032.nc	19,95	106,53	-124312,58	727000,78	25961,93	97659,47
	occ_20100824_220904_OCS2_G005.nc	22,63	-146,54	-136054,39	726120,52	26435,37	88117,77
	occ_20100825_002522_OCS2_G013.nc	-68,53	10,50	-89183,65	746361,67	26500,71	746361,67
	occ_20100824_193704_OCS2_G006.nc	-38,60	55,51	-108028,82	734505,99	26644,30	602250,84
	occ_20100825_124543_OCS2_G009.nc	61,52	84,74	-99569,71	732739,51	26940,78	687966,52
	occ_20100825_153107_OCS2_G005.nc	-26,95	124,89	-121141,45	730950,41	27272,18	730950,41
	occ_20100824_215229_OCS2_G004.nc	63,21	-57,11	-108040,73	736283,31	27571,22	32353,87
	occ_20100825_100107_OCS2_G013.nc	-33,61	44,55	-100577,01	744339,44	27786,87	744339,44
	occ_20100825_043259_OCS2_G024.nc	61,50	176,95	-111097,89	734578,78	28147,20	105005,21
	occ_20100824_134226_OCS2_G021.nc	55,63	15,41	-114697,80	732920,26	28253,66	102645,50
	occ_20100825_133734_OCS2_G017.nc	-77,83	172,72	-94917,67	749475,38	28564,25	74691,31
	occ_20100825_004214_OCS2_G004.nc	-11,01	-19,55	-143940,70	726572,61	28617,93	726572,61
	occ_20100824_213315_OCS2_G028.nc	18,61	16,51	-133492,57	727532,22	28619,36	727532,22
	occ_20100825_110445_OCS2_G002.nc	61,44	121,53	-108628,23	736971,42	28865,16	127024,57
	occ_20100825_073940_OCS2_G011.nc	49,93	-155,18	-115944,91	735364,46	28870,55	735364,46
	occ_20100824_193901_OCS2_G022.nc	-27,80	65,17	-120065,52	731428,58	29092,19	731428,58
	occ_20100825_001021_OCS2_G007.nc	-55,75	170,77	-93200,79	745177,65	29246,18	745177,65
	occ_20100824_205216_OCS2_G016.nc	-55,03	-121,91	-92042,25	745784,32	29817,00	95580,16
	occ_20100825_035629_OCS2_G005.nc	-23,70	-55,94	-127699,90	730521,55	30194,75	214995,42
	occ_20100825_104344_OCS2_G017.nc	7,73	-174,47	-145563,28	724676,94	30537,15	104740,75
	occ_20100825_111505_OCS2_G015.nc	52,55	26,80	-114341,32	224244,89	30593,97	108134,14
	occ_20100825_112411_OCS2_G005.nc	22,48	31,99	-125290,83	726091,39	31391,58	97407,13
	occ_20100825_024125_OCS2_G031.nc	61,21	-63,78	-113593,96	547024,14	32036,31	40862,13
	occ_20100824_203056_OCS2_G013.nc	19,25	-108,95	-124757,85	726005,91	32575,30	101982,62

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occ_20100824_172417_OCS2_G014.nc	-20,76	-65,50	-116297,91	740338,80	32634,71	99659,10
occ_20100825_072114_OCS2_G024.nc	-6,32	-122,87	-144799,25	725236,88	32665,78	89283,47
occ_20100825_135022_OCS2_G010.nc	-34,87	142,84	-104024,23	731547,47	32763,14	731547,47
occ_20100824_154959_OCS2_G009.nc	-40,83	-49,64	-98452,15	741614,31	33035,99	101805,89
occ_20100825_120407_OCS2_G023.nc	-55,16	-165,20	-90975,01	741684,13	33100,12	695652,20
occ_20100825_050745_OCS2_G012.nc	-53,06	106,99	-95680,92	743844,73	33149,83	66197,86
occ_20100824_181509_OCS2_G024.nc	15,98	62,10	-128727,27	728638,94	33169,01	728638,94
occ_20100824_174842_OCS2_G029.nc	-68,35	96,45	-99564,17	747418,58	33838,31	747418,58
occ_20100825_170423_OCS2_G029.nc	-50,64	98,03	-98354,38	740599,03	33862,12	75982,74
occ_20100824_210654_OCS2_G003.nc	-71,01	37,11	-94820,68	747494,71	34004,26	99238,87
occ_20100825_093111_OCS2_G004.nc	61,72	98,03	-111142,68	734761,25	34018,35	734761,25
occ_20100825_061416_OCS2_G011.nc	60,34	123,75	-119119,93	734516,59	34230,03	92707,89
occ_20100824_205443_OCS2_G031.nc	-62,28	-164,66	-91810,59	748487,71	34250,09	742303,04
occ_20100824_213902_OCS2_G017.nc	43,74	15,66	-131837,00	730365,33	34631,30	730365,33
occ_20100824_231405_OCS2_G004.nc	19,60	-13,34	-128241,39	729081,64	34689,32	729081,64
occ_20100824_210443_OCS2_G006.nc	-77,67	52,22	-94814,51	749361,59	34728,08	88814,63
occ_20100825_140736_OCS2_G030.nc	22,64	126,56	-130638,89	728630,73	35052,11	728630,73
occ_20100825_071842_OCS2_G003.nc	-16,43	-122,71	-134468,77	726703,37	36601,68	88112,60
occ_20100824_234215_OCS2_G015.nc	43,65	-157,86	-124777,09	728916,96	37009,23	94691,47
occ_20100825_084223_OCS2_G006.nc	-69,51	-133,01	-97097,45	747342,38	37203,13	747342,38
occ_20100824_152722_OCS2_G024.nc	38,17	-34,78	-135097,88	729003,74	37614,84	90472,15
occ_20100824_182126_OCS2_G019.nc	47,10	63,17	-128740,31	731377,63	37798,22	219706,50
occ_20100824_200427_OCS2_G008.nc	59,50	27,89	-112765,62	735497,29	38477,33	735497,29
occ_20100825_121929_OCS2_G004.nc	-5,37	162,26	-143631,32	725047,99	38521,11	76000,35
occ_20100824_145514_OCS2_G029.nc	19,42	121,15	-138309,83	725747,41	38542,55	725747,41
occ_20100825_143232_OCS2_G014.nc	56,70	-21,41	-114433,44	732267,33	38619,11	101937,82
occ_20100825_005736_OCS2_G030.nc	46,50	-25,41	-126808,13	730494,30	39216,16	730494,30
occ_20100825_012011_OCS2_G021.nc	48,32	-172,64	-122994,35	725933,36	39596,56	93456,34
occ_20100825_040815_OCS2_G021.nc	8,60	-82,71	-135336,28	726218,63	39707,32	726218,63
occ_20100825_123031_OCS2_G012.nc	35,57	155,16	-134893,59	728939,14	39819,33	104513,46
occ_20100825_030434_OCS2_G024.nc	31,29	143,79	-138141,88	727623,78	39820,02	87647,76
occ_20100824_224025_OCS2_G023.nc	-87,23	-107,68	-85113,19	749945,77	39852,16	100943,00
occ_20100824_144138_OCS2_G010.nc	-25,28	141,37	-125600,01	730681,56	40200,09	730681,56
occ_20100825_141503_OCS2_G031.nc	57,69	135,37	-116737,85	733697,54	40398,00	733697,54
occ_20100825_014820_OCS2_G028.nc	-50,91	149,19	-98983,73	742333,03	40454,40	94167,05
occ_20100825_103256_OCS2_G011.nc	-27,75	-158,98	-124402,94	732339,18	40502,55	732339,18
occ_20100825_113545_OCS2_G008.nc	-16,93	22,68	-120422,52	737671,89	40666,98	100520,92
occ_20100824_200035_OCS2_G011.nc	38,05	29,00	-128617,17	732866,67	40676,21	732866,67
occ_20100825_065441_OCS2_G014.nc	-79,11	95,49	-84016,42	750540,25	40785,61	750540,25
occ_20100824_185033_OCS2_G020.nc	23,78	-80,42	-127877,65	725767,77	40904,73	90624,92
occ_20100824_190930_OCS2_G030.nc	-43,83	-120,64	-104878,23	740307,17	41637,02	103456,00
occ_20100825_043120_OCS2_G019.nc	77,15	135,71	-109169,12	736729,59	41684,52	105618,58
occ_20100825_034246_OCS2_G026.nc	-73,49	-40,29	-87751,31	747532,95	41688,74	54167,91
occ_20100825_042159_OCS2_G006.nc	65,33	-92,02	-119268,76	372197,10	41743,19	59763,72

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occ_20100824_215715_OCS2_G026.nc	64,96	-131,98	-109659,09	734052,22	41916,57	102940,06
occ_20100824_182327_OCS2_G007.nc	58,05	72,44	-114834,18	733982,41	42091,59	729901,03
occ_20100825_094447_OCS2_G010.nc	21,02	49,69	-132604,76	725900,81	42456,61	90597,86
occ_20100824_164415_OCS2_G006.nc	55,65	86,27	-123061,80	657811,65	42690,34	657811,65
occ_20100825_045404_OCS2_G014.nc	-2,70	123,35	-132860,67	732905,26	42983,78	102261,46
occ_20100825_100331_OCS2_G016.nc	-45,21	18,36	-101853,47	740597,64	43036,93	68704,39
occ_20100825_061753_OCS2_G023.nc	49,65	102,43	-116183,44	730621,63	43095,79	91028,23
occ_20100825_072601_OCS2_G019.nc	10,97	-125,42	-142562,61	724901,26	43097,33	107404,33
occ_20100825_071506_OCS2_G018.nc	-23,23	-100,30	-128052,52	730088,11	43433,64	98523,36
occ_20100824_194738_OCS2_G019.nc	-0,35	50,67	-149690,65	725008,80	43756,20	183975,46
occ_20100825_035929_OCS2_G029.nc	-17,25	-70,63	-136815,53	727726,18	44027,09	94324,87
occ_20100825_022952_OCS2_G030.nc	10,81	-59,46	-131601,66	728079,40	44168,58	728079,40
occ_20100825_091026_OCS2_G028.nc	28,35	-156,55	-135581,39	728128,91	44246,73	583950,48
occ_20100825_064537_OCS2_G030.nc	-48,34	70,82	-99082,38	741650,46	44419,75	104949,05
occ_20100825_033733_OCS2_G015.nc	-83,59	162,20	-83714,09	750156,31	44746,32	47772,23
occ_20100825_172737_OCS2_G006.nc	32,00	80,84	-139592,06	728138,02	44763,28	728138,02
occ_20100824_225824_OCS2_G032.nc	-23,97	20,76	-127032,45	730434,24	44898,96	711220,61
occ_20100825_103204_OCS2_G020.nc	-33,69	-167,58	-106726,68	731163,96	45090,41	731163,96
occ_20100824_225540_OCS2_G011.nc	-34,57	20,45	-116235,87	735542,79	45547,18	735542,79
occ_20100825_011418_OCS2_G009.nc	58,38	-123,43	-94935,04	630971,50	45787,86	630971,50
occ_20100825_055926_OCS2_G019.nc	57,52	-115,45	-122991,16	556451,41	45910,94	81377,50
occ_20100824_191710_OCS2_G029.nc	-69,65	-142,31	-98570,52	748416,55	46116,72	732436,23
occ_20100824_170722_OCS2_G011.nc	36,60	-70,81	-137679,65	728949,19	46121,09	85547,66
occ_20100825_015953_OCS2_G017.nc	-83,22	34,84	-95076,07	750488,18	46144,45	117000,93
occ_20100825_055653_OCS2_G007.nc	52,12	-90,30	-114939,36	672316,46	46367,53	83547,67
occ_20100824_194013_OCS2_G003.nc	-28,19	52,63	-120561,52	730012,08	46650,95	730012,08
occ_20100824_164722_OCS2_G003.nc	67,89	82,47	-117628,07	316878,81	46751,57	90581,12
occ_20100825_062545_OCS2_G020.nc	22,56	100,41	-131297,42	725843,04	46893,35	90989,42
occ_20100825_065452_OCS2_G029.nc	-78,27	27,35	-98117,53	750105,44	46948,35	90070,77
occ_20100825_164345_OCS2_G012.nc	-54,05	-59,60	-91295,13	745589,67	46967,89	107200,53
occ_20100824_171102_OCS2_G032.nc	22,88	-70,81	-134184,39	726190,19	47585,30	87550,47
occ_20100824_173142_OCS2_G012.nc	-50,59	-86,20	-96981,67	742307,13	47779,94	95595,80
occ_20100825_061150_OCS2_G013.nc	72,93	102,91	-103318,63	735355,66	47785,98	79927,93
occ_20100824_162117_OCS2_G029.nc	-27,87	105,26	-123196,02	730950,81	47803,74	588680,05
occ_20100824_135255_OCS2_G018.nc	21,73	-10,96	-129167,41	725788,67	49476,34	90158,18
occ_20100825_052852_OCS2_G015.nc	-47,68	-65,34	-95331,38	738705,06	49746,36	686747,73
occ_20100824_202843_OCS2_G010.nc	27,66	-128,55	-134552,75	726610,71	49839,89	88436,00
occ_20100825_003152_OCS2_G017.nc	-48,57	-14,21	-101032,87	739708,13	50437,59	739708,13
occ_20100824_150740_OCS2_G031.nc	62,40	96,40	-111472,83	736010,42	50831,73	736010,42
occ_20100825_122717_OCS2_G002.nc	16,27	150,19	-131089,49	727697,59	51184,22	95544,71
occ_20100825_101108_OCS2_G006.nc	-71,11	-3,15	-99498,33	748686,68	51639,93	747377,44
occ_20100825_135608_OCS2_G002.nc	-12,62	143,32	-143297,15	726958,64	51747,26	57748,89
occ_20100825_023326_OCS2_G029.nc	30,61	-55,19	-137874,95	727652,08	51835,87	636329,26
occ_20100825_141131_OCS2_G029.nc	41,49	128,13	-136050,74	729822,97	52027,05	729822,97

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occ_20100824_222707_OCS2_G016.nc	-39,25	-171,93	-107877,43	739051,62	52461,97	92158,58
occ_20100824_231938_OCS2_G012.nc	51,84	9,76	-119506,05	638304,85	52895,06	638304,85
occ_20100824_135143_OCS2_G022.nc	25,94	-25,28	-133862,32	726571,72	52919,33	90725,12
occ_20100824_162144_OCS2_G005.nc	-21,66	123,24	-128853,48	729621,96	53079,73	718959,68
occ_20100825_055305_OCS2_G003.nc	34,44	-105,81	-136670,24	728438,97	53129,42	728438,97
occ_20100825_152720_OCS2_G002.nc	-38,78	143,40	-108417,07	737172,15	53978,69	680407,40
occ_20100825_160902_OCS2_G019.nc	69,26	-55,39	-114274,33	735582,79	54054,85	103282,89
occ_20100825_162153_OCS2_G011.nc	23,25	-69,23	-139154,04	726257,14	54138,28	87406,62
occ_20100824_230522_OCS2_G017.nc	-3,63	1,41	-149440,48	725211,17	54509,30	73988,92
occ_20100824_202517_OCS2_G004.nc	38,29	-110,94	-135923,24	729223,54	54797,34	90065,12
occ_20100825_081042_OCS2_G023.nc	4,21	75,23	-130935,76	730677,34	54803,98	102637,65
occ_20100825_091659_OCS2_G017.nc	54,03	-161,79	-121564,64	732451,18	54867,38	732451,18
occ_20100824_144208_OCS2_G002.nc	-23,68	141,03	-130110,14	731145,97	54950,87	731145,97
occ_20100825_085217_OCS2_G019.nc	-35,03	-140,93	-113925,25	733767,19	54966,65	626883,87
occ_20100825_164653_OCS2_G027.nc	-64,50	-102,49	-92173,09	748800,99	55327,77	718471,60
occ_20100824_184511_OCS2_G023.nc	40,53	-82,81	-126506,66	728326,75	55543,80	91785,80
occ_20100825_044529_OCS2_G032.nc	26,22	110,18	-134179,07	726411,54	55948,05	88201,91
occ_20100825_001047_OCS2_G019.nc	-53,45	153,52	-100379,51	744200,78	56077,66	709534,52
occ_20100825_071517_OCS2_G006.nc	-28,10	-120,13	-119442,28	730303,67	56473,30	64855,09
occ_20100825_004858_OCS2_G002.nc	7,29	-31,64	-138259,84	725605,95	56766,33	725605,95
occ_20100825_150554_OCS2_G017.nc	-58,91	-71,00	-98868,97	745611,55	57330,40	105278,91
occ_20100825_082823_OCS2_G031.nc	-60,02	35,65	-93182,67	747020,58	57739,58	110340,79
occ_20100825_092952_OCS2_G026.nc	75,37	52,55	-102785,64	735686,10	57765,35	697079,72
occ_20100825_105313_OCS2_G004.nc	31,46	166,32	-124698,69	663868,07	58049,73	78620,00
occ_20100824_181110_OCS2_G006.nc	9,23	72,79	-142778,89	725063,55	58462,88	725063,55
occ_20100824_223329_OCS2_G006.nc	-61,76	176,69	-98359,59	746368,66	59738,16	76529,75
occ_20100824_180128_OCS2_G021.nc	-21,42	88,95	-135868,74	730321,93	60390,28	730321,93
occ_20100824_171016_OCS2_G020.nc	26,95	-78,52	-133497,08	726560,36	60623,52	84061,53
occ_20100824_211419_OCS2_G019.nc	-44,58	35,73	-102544,91	738127,48	60798,37	738127,48
occ_20100824_142212_OCS2_G017.nc	-79,46	-90,04	-96151,09	614333,90	61986,62	69063,71
occ_20100824_201056_OCS2_G017.nc	82,27	-17,50	-108876,23	737182,77	62118,90	737182,77
occ_20100825_144223_OCS2_G022.nc	22,03	-25,66	-131589,59	725771,01	62496,06	89270,64
occ_20100825_132429_OCS2_G028.nc	-53,72	-17,44	-95229,53	743996,72	62537,81	92632,12
occ_20100824_165338_OCS2_G019.nc	81,85	-3,33	-108329,87	737194,76	62978,87	734383,29
occ_20100825_173105_OCS2_G003.nc	45,33	78,14	-131656,87	688586,22	63709,75	96928,61
occ_20100825_003121_OCS2_G023.nc	-46,08	10,02	-96205,85	737925,13	64710,61	725271,17
occ_20100825_012612_OCS2_G022.nc	29,73	155,51	-133588,99	726498,78	64748,70	89994,02
occ_20100824_161019_OCS2_G026.nc	-62,64	135,02	-89341,74	744516,79	64963,08	743869,91
occ_20100825_055417_OCS2_G024.nc	27,66	-117,77	-124655,50	705358,88	65448,45	102742,12
occ_20100825_012747_OCS2_G018.nc	22,13	169,93	-134962,48	725760,24	66084,46	90101,94
occ_20100825_155127_OCS2_G016.nc	47,07	113,42	-126638,87	730584,24	67371,72	719206,87
occ_20100825_114839_OCS2_G019.nc	-63,38	-26,23	-97848,17	747138,05	67657,68	114106,29
occ_20100825_103253_OCS2_G032.nc	-27,51	-158,19	-120425,13	731116,46	67811,47	731116,46
occ_20100825_093813_OCS2_G002.nc	43,54	55,77	-131231,96	730373,46	67972,52	90720,81

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occ_20100824_220044_OCS2_G002.nc	50,93	-119,53	-118348,68	731817,75	68030,70	101561,40
occ_20100825_164419_OCS2_G009.nc	-58,50	-82,62	-91567,56	746118,59	69818,52	105330,83
occ_20100824_225739_OCS2_G020.nc	-28,78	11,72	-117685,42	731245,78	70855,68	731245,78
occ_20100825_160236_OCS2_G003.nc	85,04	61,02	-102930,23	737082,39	70958,19	706092,20
occ_20100825_032800_OCS2_G017.nc	-48,66	107,09	-101249,08	742340,74	71395,14	682669,72
occ_20100825_052630_OCS2_G029.nc	-59,70	-84,09	-95981,90	744413,69	71458,33	744413,69
occ_20100824_200008_OCS2_G028.nc	48,76	53,46	-124193,41	730964,56	72237,52	106562,23
occ_20100825_124335_OCS2_G029.nc	81,37	104,54	-108154,08	736971,15	72478,86	736971,15
occ_20100824_173703_OCS2_G009.nc	-63,44	-122,78	-90686,31	749408,78	72952,38	663869,17
occ_20100824_234929_OCS2_G021.nc	20,05	-179,10	-137517,21	725929,22	73006,55	78419,19
occ_20100825_114214_OCS2_G003.nc	-40,29	-13,81	-108927,79	739532,24	73448,23	118633,21
occ_20100825_021608_OCS2_G010.nc	-29,29	-37,84	-115021,06	731465,83	74322,34	731465,83
occ_20100824_151539_OCS2_G006.nc	82,03	-23,23	-107495,45	736965,00	75893,08	108554,20
occ_20100824_163835_OCS2_G016.nc	34,83	93,29	-135448,80	728913,22	79403,41	230258,20
occ_20100824_223106_OCS2_G013.nc	-52,21	-143,28	-84301,07	748273,62	79678,35	748273,62
occ_20100825_025318_OCS2_G006.nc	74,41	139,55	-109478,44	736028,77	79880,18	87778,97
occ_20100825_073616_OCS2_G028.nc	52,08	-114,10	-118958,04	731739,97	80574,88	659936,32
occ_20100825_123341_OCS2_G030.nc	50,40	167,04	-119428,84	731227,26	81523,02	688117,73
occ_20100824_203014_OCS2_G002.nc	21,95	-127,59	-140226,43	726368,73	81680,07	89456,52
occ_20100824_133630_OCS2_G014.nc	82,14	-12,20	-97770,08	736369,13	82316,20	103179,62
occ_20100825_085300_OCS2_G024.nc	-28,67	-125,94	-124463,77	733045,35	84378,20	87400,26
occ_20100825_135043_OCS2_G004.nc	-29,56	159,07	-121891,93	733445,67	84747,75	715670,93
occ_20100825_101322_OCS2_G003.nc	-79,88	-8,96	-96918,53	749971,01	84769,94	99150,48
occ_20100824_233726_OCS2_G029.nc	64,45	-173,87	-116817,30	734424,35	85952,55	102888,69
occ_20100825_010553_OCS2_G029.nc	73,64	-54,58	-113898,77	736034,95	86070,38	736034,95
occ_20100825_132524_OCS2_G008.nc	-56,93	-36,29	-94664,46	745737,76	87178,73	104600,36
occ_20100825_125735_OCS2_G021.nc	40,99	3,56	-136425,62	729789,42	88226,69	92308,56
occ_20100824_141204_OCS2_G028.nc	-46,47	-42,96	-103149,67	740815,09	88433,31	103710,81
occ_20100824_135549_OCS2_G024.nc	13,36	-35,73	-142012,73	725754,39	90952,10	98645,93
occ_20100824_140643_OCS2_G015.nc	-23,73	-15,25	-111996,61	742729,78	91484,07	99589,32
occ_20100825_084624_OCS2_G014.nc	-51,54	-113,77	-93045,32	740218,98	92733,93	701440,09
occ_20100825_130235_OCS2_G018.nc	23,62	-9,31	-133830,85	726341,32	92968,42	116807,76
occ_20100825_074834_OCS2_G017.nc	81,64	99,70	-107274,32	737014,23	93729,73	103649,23
occ_20100825_080715_OCS2_G002.nc	16,38	53,51	-138512,15	725918,33	93748,01	101333,18
occ_20100825_160130_OCS2_G031.nc	61,84	53,16	-102905,81	736420,79	96569,78	736420,79
occ_20100824_224231_OCS2_G019.nc	-80,24	59,73	-95383,99	750137,03	97075,42	105532,60
occ_20100825_094345_OCS2_G005.nc	25,29	34,33	-133712,82	726526,91	97958,73	109931,77
occ_20100825_130647_OCS2_G015.nc	10,50	2,02	-126768,09	728335,17	99303,86	728335,17
occ_20100825_105928_OCS2_G027.nc	64,38	161,58	-112375,43	167944,02	99811,81	167944,02
occ_20100824_211346_OCS2_G014.nc	-42,37	60,62	-96747,84	735844,84	99982,06	606451,11
occ_20100825_105759_OCS2_G009.nc	61,81	174,28	-112426,05	370237,87	101461,58	370237,87
occ_20100825_080226_OCS2_G004.nc	31,61	68,04	-140007,83	727989,30	101736,13	209919,68
occ_20100825_053822_OCS2_G021.nc	-16,26	-89,88	-140713,16	728271,83	102962,46	106990,18
occ_20100825_021906_OCS2_G002.nc	-18,07	-38,08	-138444,85	729131,66	103620,74	729131,66

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|						
occ_20100825_042544_OCS2_G003.nc	76,92	-98,67	40020,78	202351,11	103819,66	202351,11
occ_20100825_142430_OCS2_G021.nc	62,43	63,59	-108556,10	736640,21	104373,31	108898,89
occ_20100825_144137_OCS2_G024.nc	25,09	-36,46	-138118,94	726732,16	105992,34	272545,88
occ_20100825_153746_OCS2_G029.nc	-6,17	113,56	-148283,40	725573,39	106197,04	725573,39
occ_20100824_145102_OCS2_G030.nc	-4,39	115,22	-133433,36	727212,99	107307,75	632268,96
occ_20100825_021337_OCS2_G004.nc	-36,11	-20,26	-111918,44	736207,20	111795,29	688762,54
occ_20100825_013611_OCS2_G015.nc	-4,69	173,49	-130228,94	734905,72	113097,18	734905,72
occ_20100825_161946_OCS2_G032.nc	30,86	-68,90	-132051,50	726693,39	114795,61	682496,20
occ_20100825_051043_OCS2_G009.nc	-62,13	77,80	-92726,37	747871,67	114832,65	134968,39
occ_20100825_044437_OCS2_G011.nc	29,86	109,57	-138785,73	727401,55	115173,02	125528,24
occ_20100825_070947_OCS2_G021.nc	-42,11	-87,94	-104200,07	738306,01	115567,42	621827,29
occ_20100824_211556_OCS2_G024.nc	-35,15	54,84	-115492,89	735534,97	116319,21	688938,23
occ_20100825_074314_OCS2_G007.nc	62,64	-171,39	-107350,82	737098,44	116363,43	737098,44
occ_20100825_054929_OCS2_G006.nc	20,77	-103,10	-137123,13	726127,68	117766,99	726127,68
occ_20100825_102010_OCS2_G019.nc	-73,46	-141,88	-96511,86	748792,33	121062,41	125645,25
occ_20100825_015134_OCS2_G008.nc	-59,03	125,50	-91007,01	747524,64	122419,51	715020,28
occ_20100824_165359_OCS2_G024.nc	61,94	23,42	-109025,34	736360,03	125780,25	736360,03
occ_20100824_181455_OCS2_G003.nc	22,97	70,12	-136741,86	726548,47	130030,39	726548,47
occ_20100824_194407_OCS2_G024.nc	-11,47	55,43	-144111,72	494617,99	133006,51	494617,99
occ_20100825_170139_OCS2_G015.nc	-56,87	118,83	-90763,83	742516,58	134296,96	742516,58
occ_20100825_025954_OCS2_G014.nc	47,17	153,33	-117824,94	729728,38	137961,80	729728,38
occ_20100825_155938_OCS2_G006.nc	74,44	86,49	-114452,36	-90958,26	144018,82	313064,52
occ_20100825_024519_OCS2_G021.nc	55,12	-96,34	-109892,91	33314,08	152592,15	155479,07
occ_20100825_071327_OCS2_G022.nc	-32,18	-114,02	-112000,74	731880,41	202320,44	731880,41
occ_20100825_120954_OCS2_G017.nc	-38,89	169,23	-108444,13	735089,50	220757,69	735089,50
occ_20100824_212553_OCS2_G011.nc	-4,77	25,40	-147280,54	725163,03	230145,42	725163,03
occ_20100825_084444_OCS2_G003.nc	-62,23	-140,83	-95646,46	744331,22	239616,92	744331,22
occ_20100825_041507_OCS2_G016.nc	41,71	-77,42	-134668,61	729754,37	246328,86	708512,87
occ_20100825_042544_OCS2_G006.nc	65,73	-90,20	505405,22	598543,55	505405,22	598543,55
occ_20100824_232423_OCS2_G009.nc	63,69	-27,03	-110874,18	28948,60	nan	nan
occ_20100825_042500_OCS2_G003.nc	77,01	-97,56	nan	nan	nan	nan
occ_20100825_112629_OCS2_G021.nc	14,63	2,03	-141273,57	725839,65	nan	nan
occ_20100825_173719_OCS2_G019.nc	67,36	63,37	nan	nan	nan	nan
occ_20100824_232552_OCS2_G027.nc	64,74	-39,58	nan	nan	nan	nan
occ_20100824_232532_OCS2_G002.nc	52,80	-41,33	nan	nan	nan	nan

APPENDIX C. Qualitative ROPP_PP output profiles comparisons

In this Appendix it will be shown all the comparisons between ROPP_PP products and co-located ECMWF or other occultation-derived profiles, for those events for which L2 is available at least from 10 km SLTA (the table here below – which is extracted by the one in Appendix B – lists such events). Events highlighted in red didn't produce any output (because L2 was lost very soon).

		LAT	LONG	min L1 SLTA	max L1 SLTA	min L2 SLTA	max L2 SLTA
1	occ_20100824_173338_OCS2_G030.nc	-53,42	-68,46	-89784,42	746508,26	-7541,92	746508,26
2	occ_20100824_204031_OCS2_G023.nc	-12,46	-113,52	-126462,02	737771,02	-4861,87	101494,75
3	occ_20100825_131659_OCS2_G026.nc	-24,07	-3,95	-112445,91	741210,11	-3973,11	101191,59
4	occ_20100825_021129_OCS2_G005.nc	-53,11	-57,62	-76015,60	731515,44	-3308,72	731515,44
5	occ_20100825_145258_OCS2_G009.nc	-12,01	-25,82	-125113,95	736426,62	-2742,09	98401,52
6	occ_20100824_234850_OCS2_G005.nc	24,90	-149,16	-118431,78	729235,65	-1003,11	112366,91
7	occ_20100825_144218_OCS2_G018.nc	26,21	-11,51	-116755,98	730285,66	-335,57	98660,24
8	occ_20100825_082822_OCS2_G016.nc	-55,33	71,02	-86909,36	747908,08	686,84	6427,67
9	occ_20100825_050929_OCS2_G030.nc	-52,35	123,44	-84516,57	748366,12	3049,31	85518,83
10	occ_20100824_155643_OCS2_G012.nc	-55,77	-33,62	-81616,44	749986,67	4131,85	173273,17
11	occ_20100825_170454_OCS2_G018.nc	-54,24	78,76	-76635,10	732171,64	5348,97	37697,12
12	occ_20100825_154642_OCS2_G021.nc	18,02	99,01	-127712,89	728833,17	5649,41	652477,63
13	occ_20100824_211309_OCS2_G032.nc	-53,28	19,79	-79086,80	733358,32	8051,46	733358,32
14	occ_20100824_141646_OCS2_G026.nc	-60,64	-19,54	-82036,30	734887,33	8330,41	171239,57
15	occ_20100825_172401_OCS2_G016.nc	13,84	78,22	-133437,76	727559,27	8889,34	727559,27
16	occ_20100824_150548_OCS2_G021.nc	43,59	93,92	-119726,02	735956,39	9543,48	735956,39
17	occ_20100825_124850_OCS2_G027.nc	59,55	65,04	-96442,03	727900,10	9612,77	727900,10
18	occ_20100825_000425_OCS2_G008.nc	-32,08	-169,29	-105083,63	739739,98	9797,01	214743,22
19	occ_20100824_152721_OCS2_G014.nc	37,74	-32,64	-128949,03	727438,59	9931,69	92848,80
20	occ_20100824_190649_OCS2_G031.nc	-33,33	-95,06	-104336,49	740286,19	10193,59	102360,28

Event #2

Single profiles
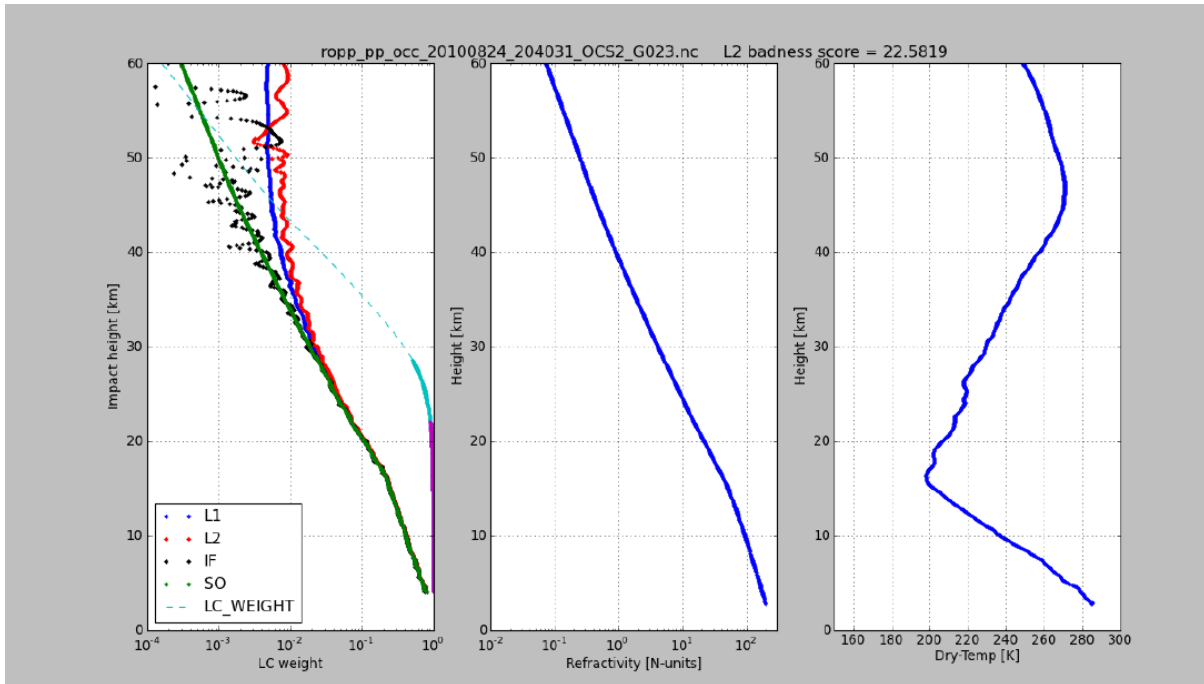
NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT
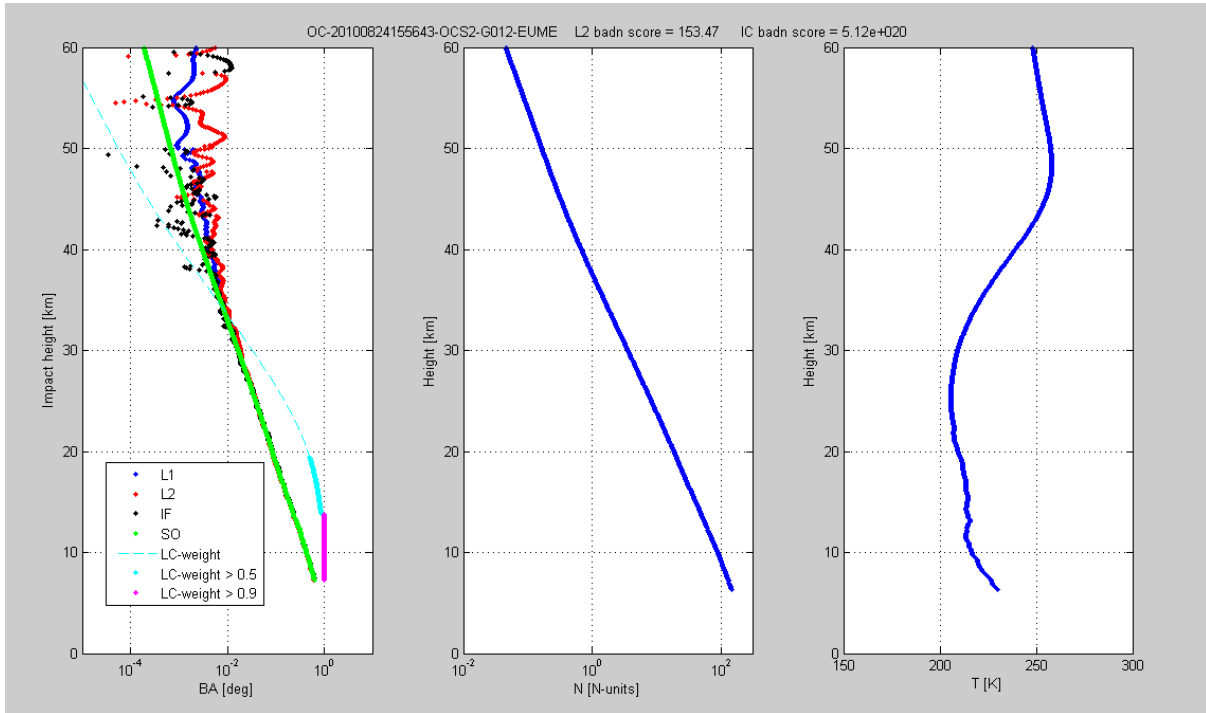
Event #5

Single profiles
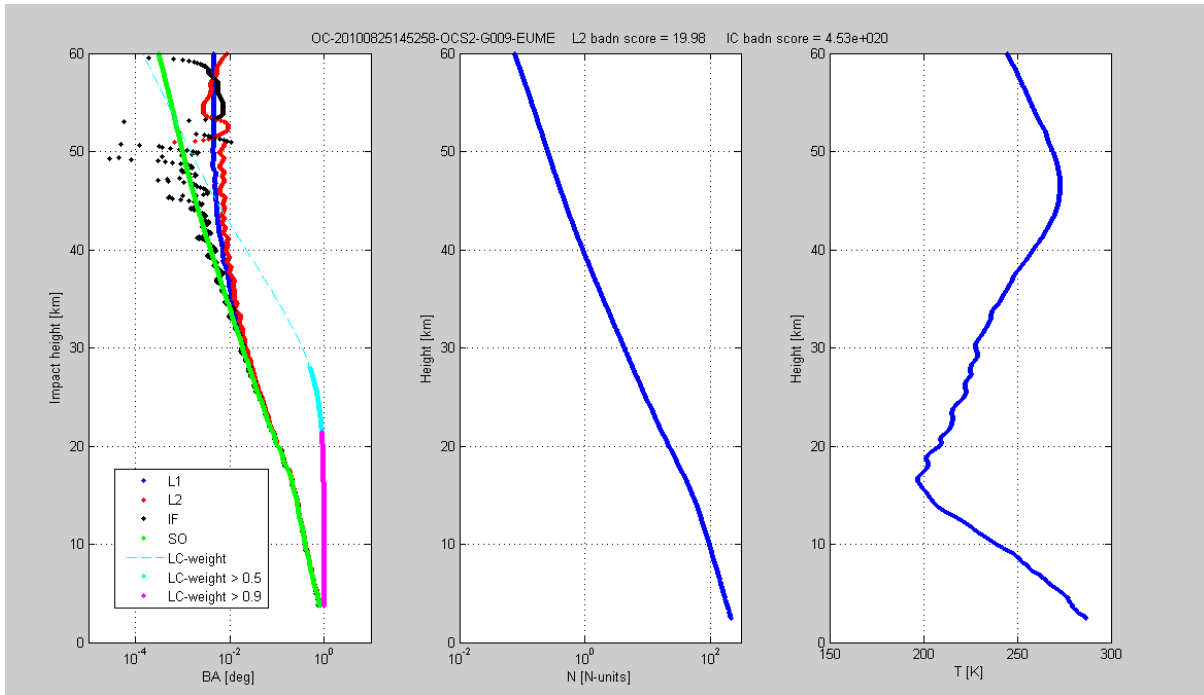
COMPARISON AGAINST CO-LOCATED ECMWF PROFILE

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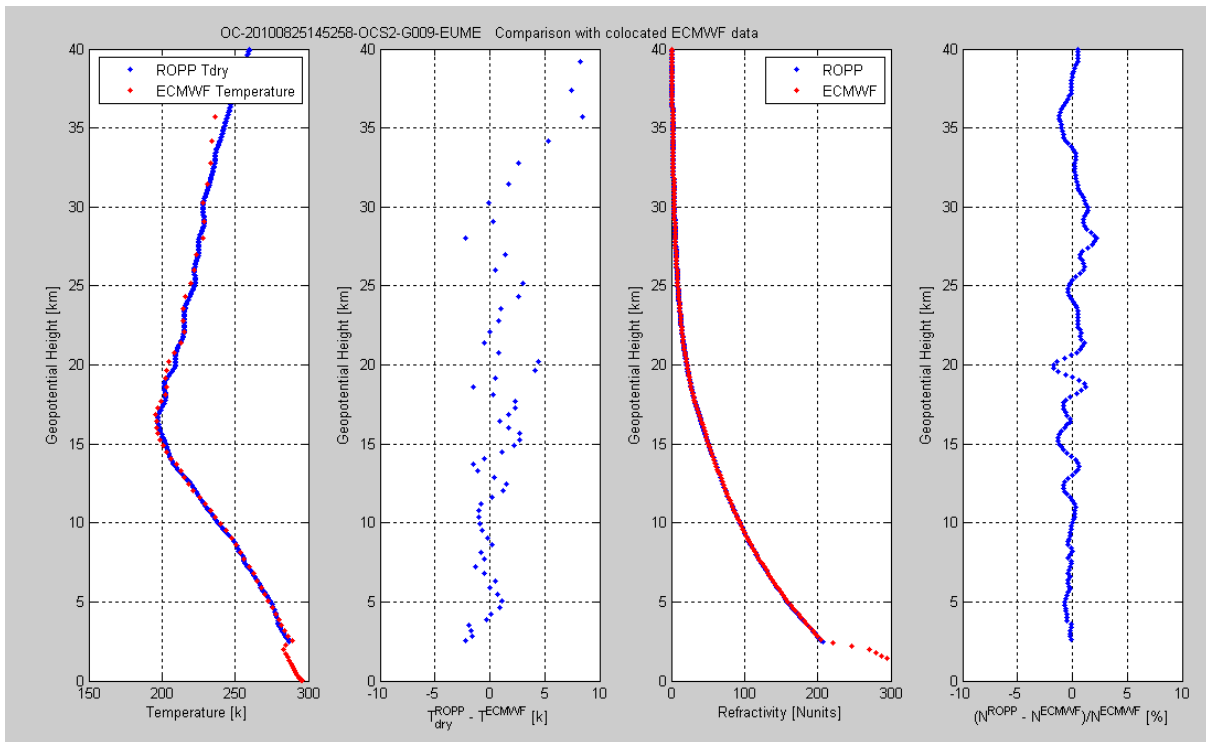
COMPARISON AGAINST OTHER CO-LOCATED OCCULTATIONS
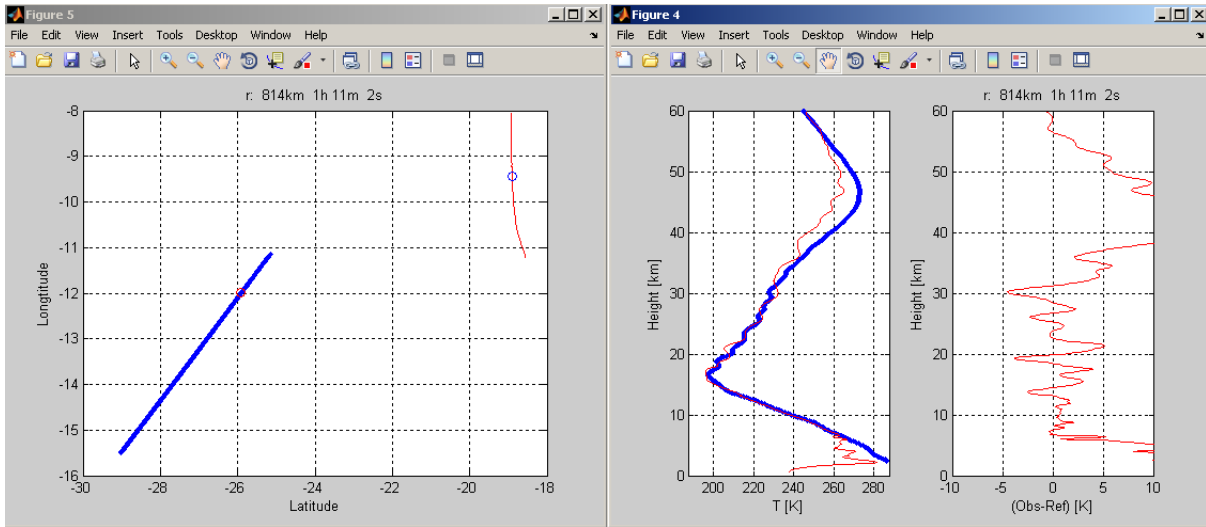

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file_cosm=['atmPrf_C006.2010.237.16.04.G32_2010.2640_nc'];  red
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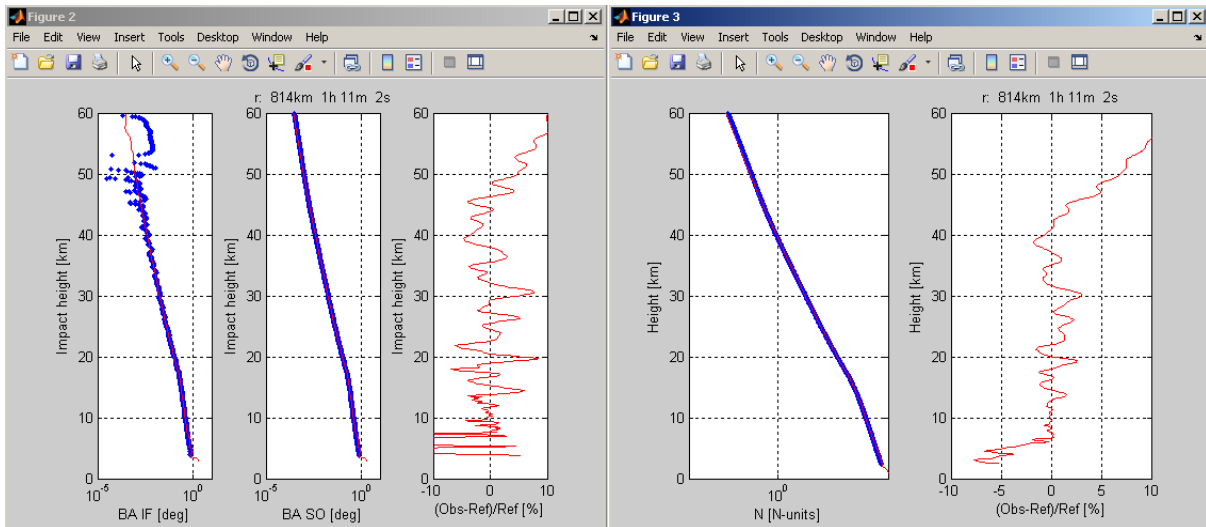
Event #6

Single profiles
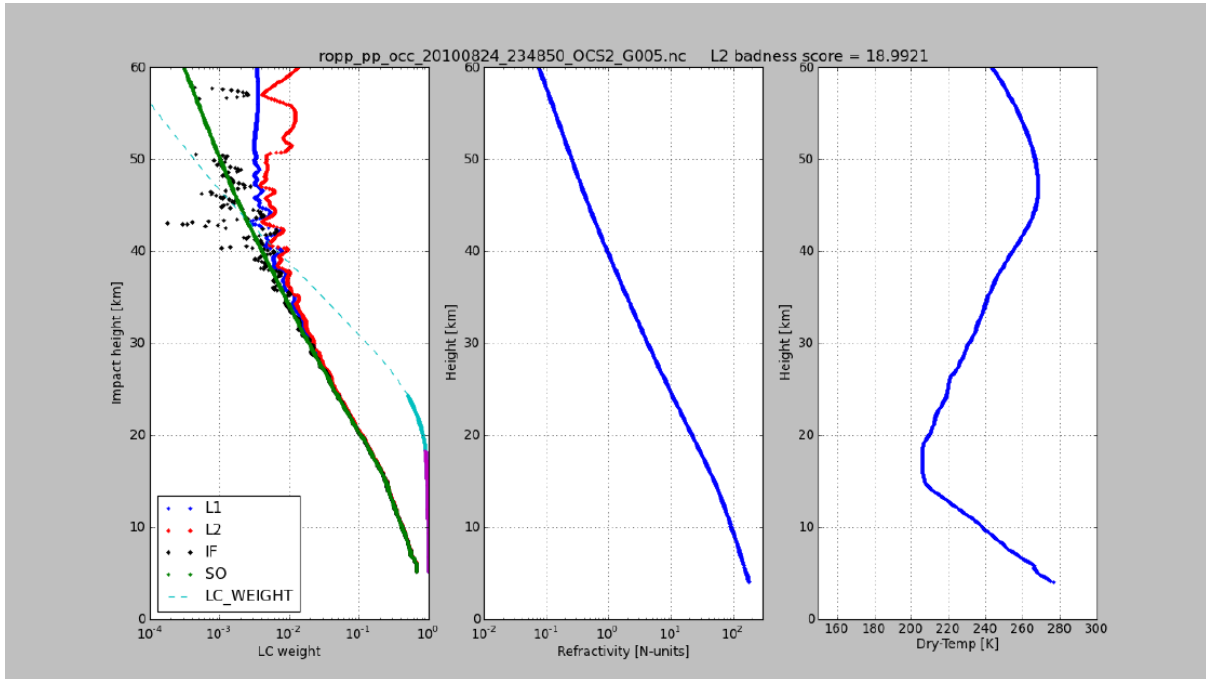
NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT

Event #7

Single profiles
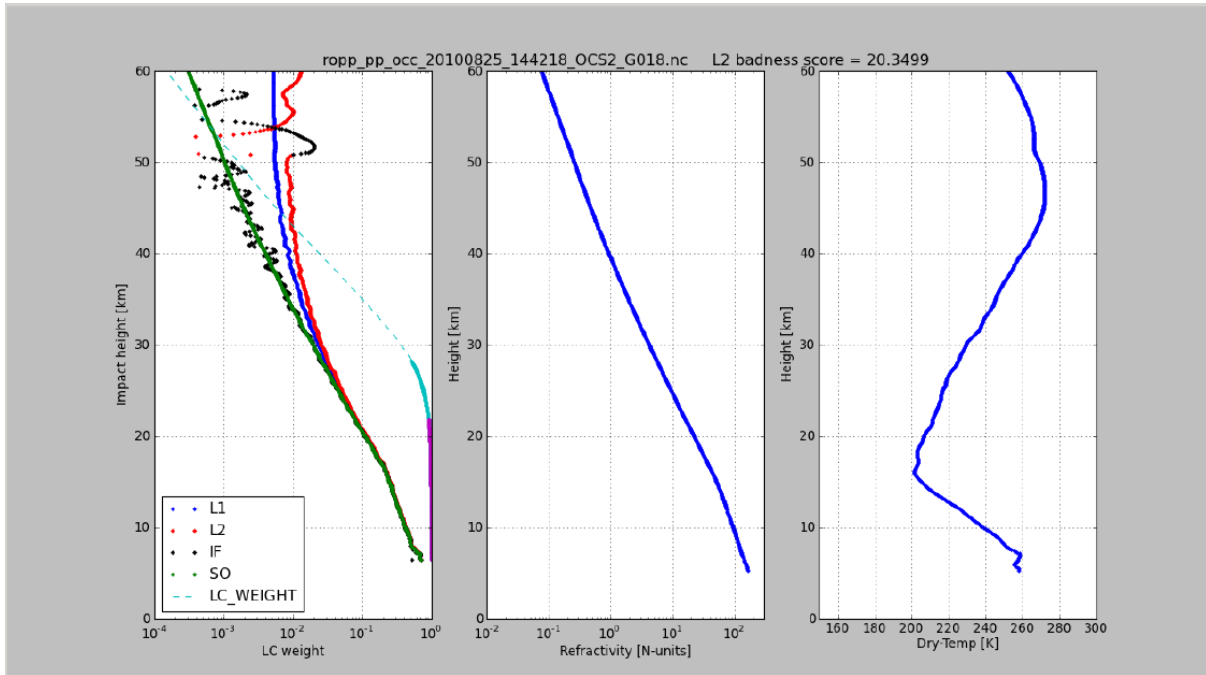
NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT

Event #8

Single profiles
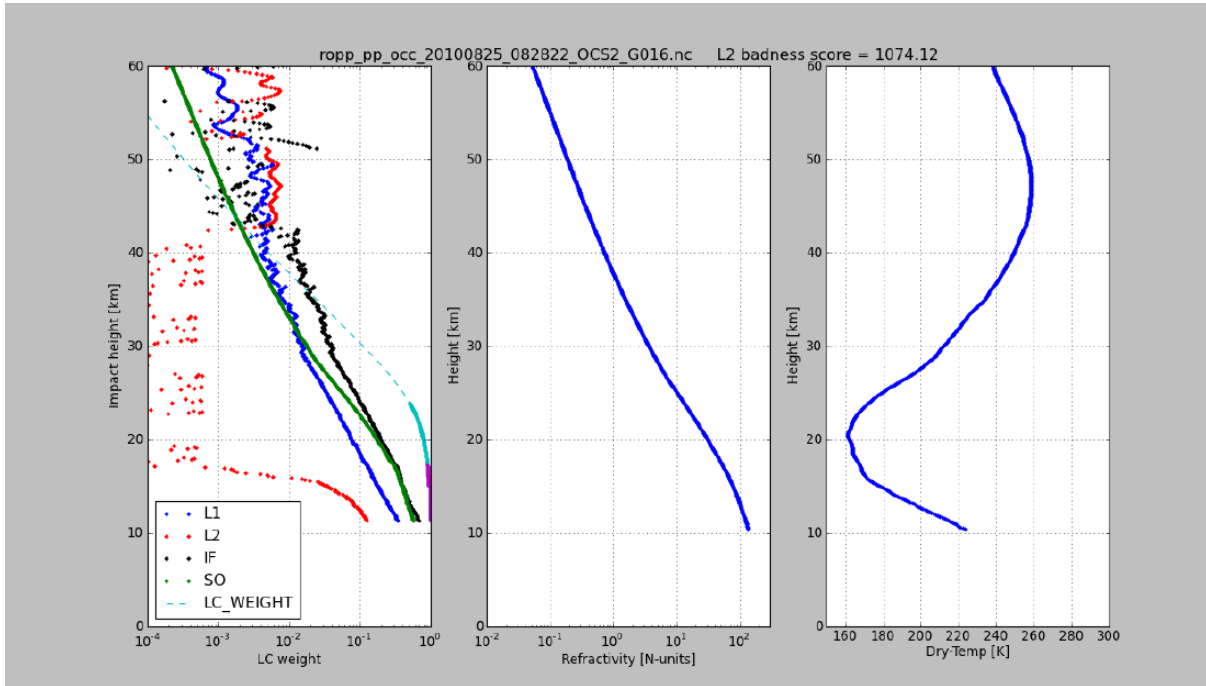
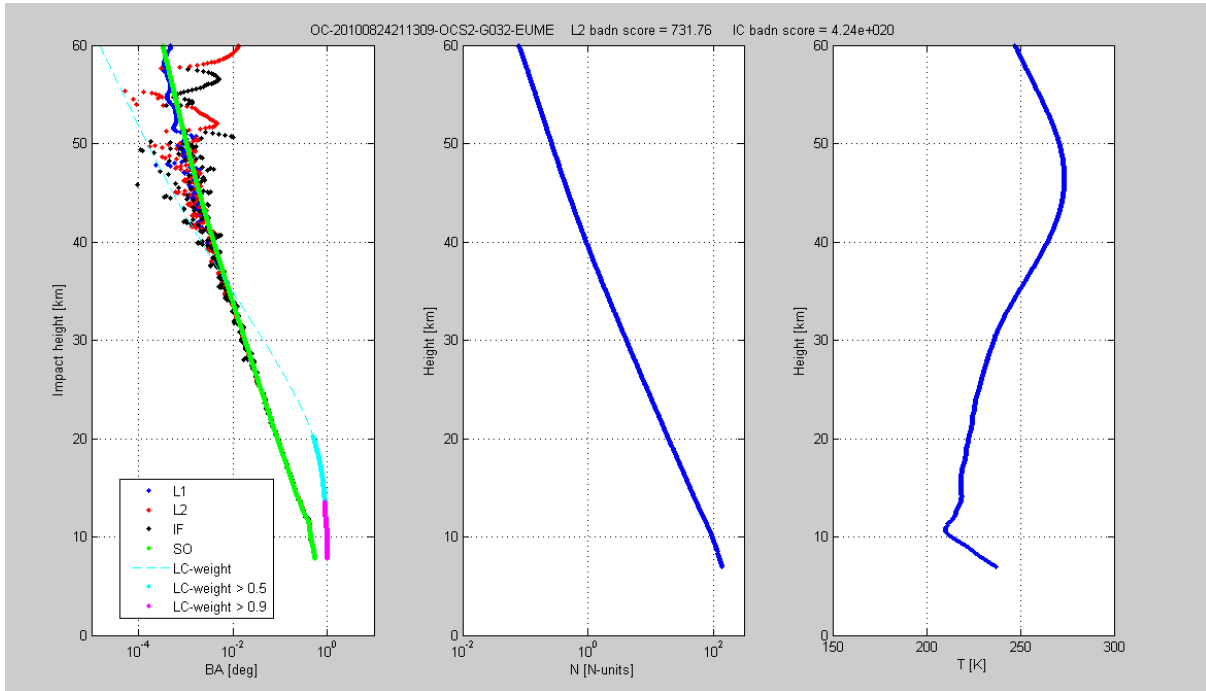**NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT**

Event #9

Single profiles
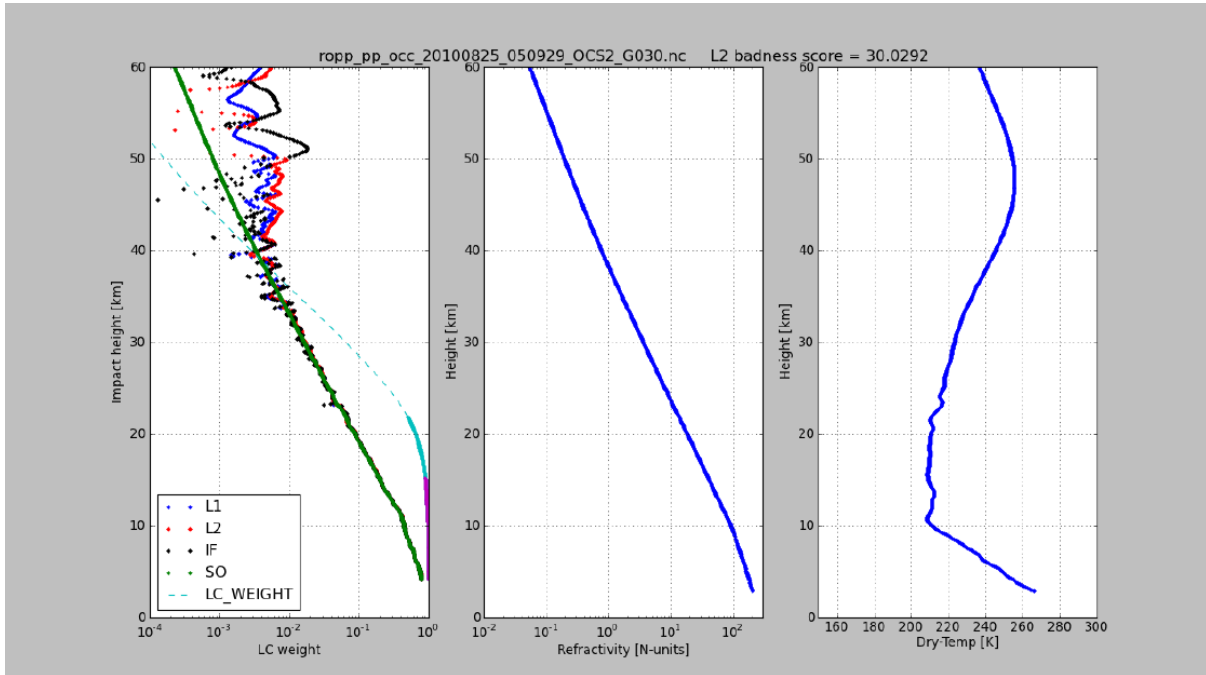
NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT

Event #10

Single profiles

COMPARISON AGAINST CO-LOCATED ECMWF PROFILE

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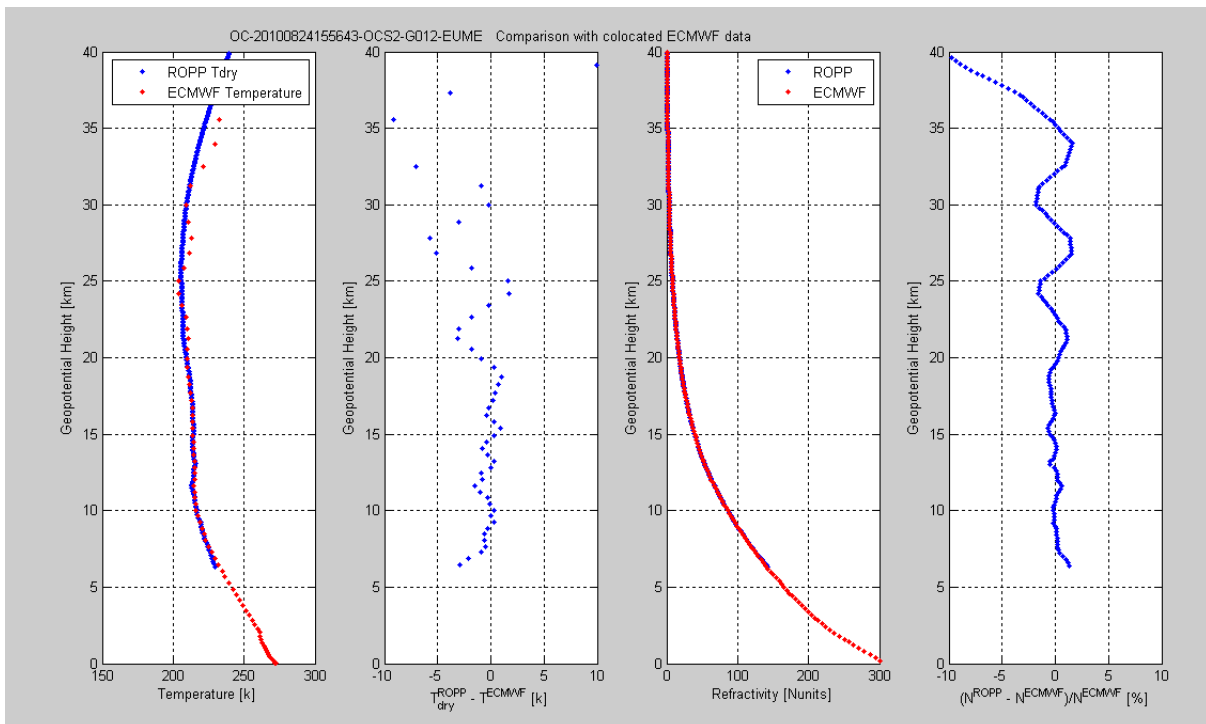
COMPARISON AGAINST OTHER CO-LOCATED OCCULTATIONS
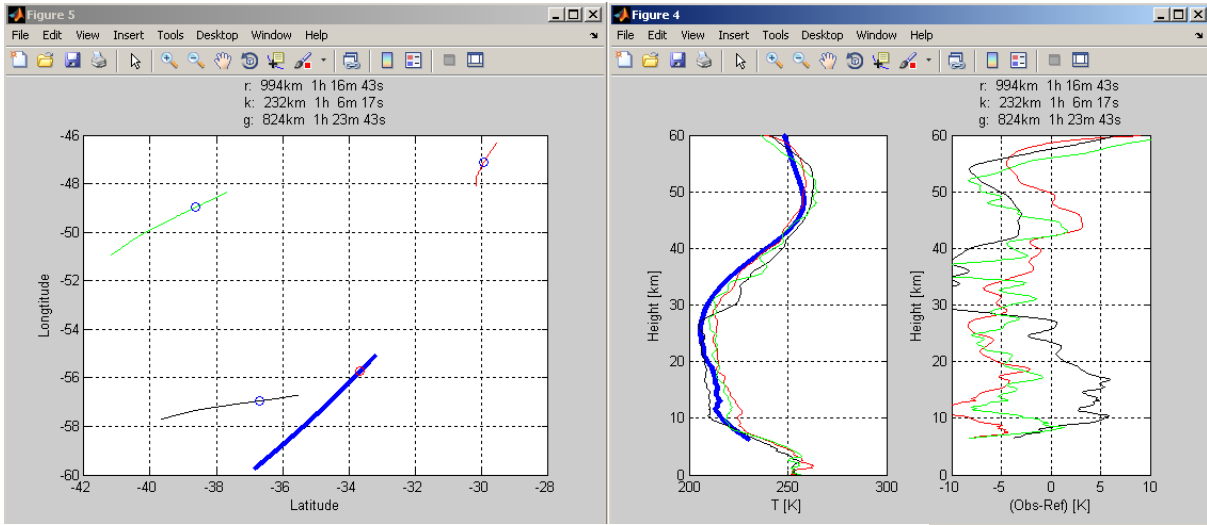

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% atmPrf_C005.2010.236.17.03.G23_2010.2640_nc -56.95 -36.69
% atmPrf_C006.2010.236.14.33.G32_2010.2640_nc -48.98 -38.63
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file_cosm(3,:)=['atmPrf_C006.2010.236.14.33.G32_2010.2640_nc'];   green
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file_trsx=[];
```
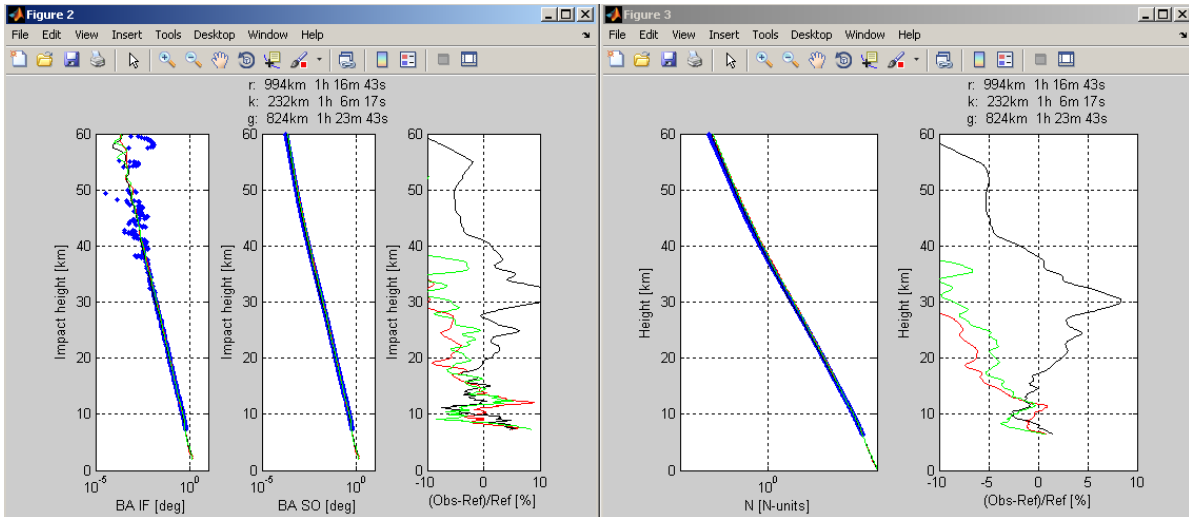
Event #11

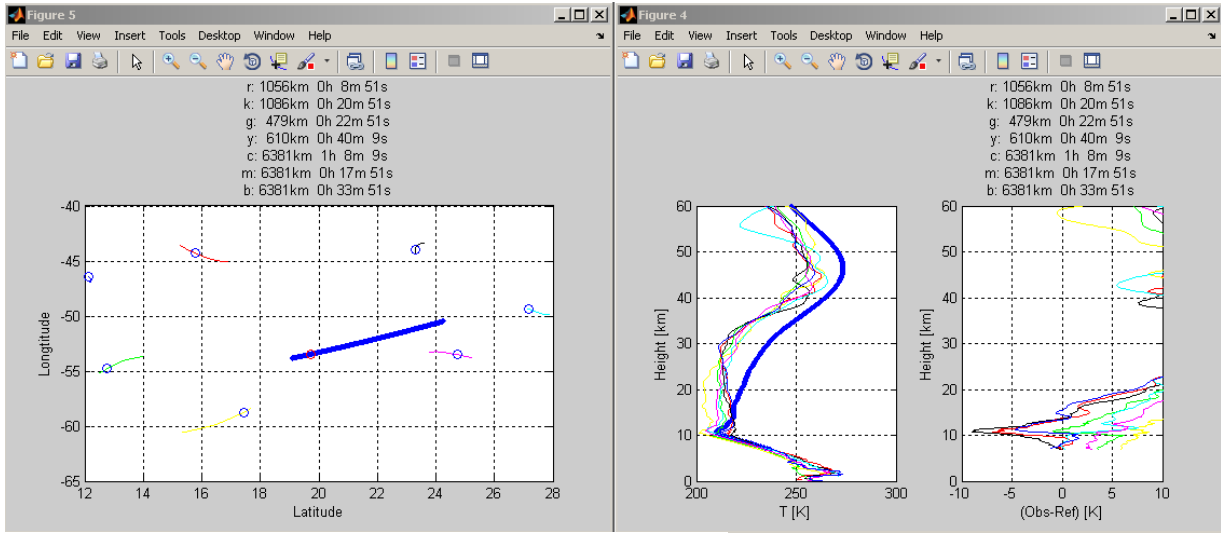# Single profiles
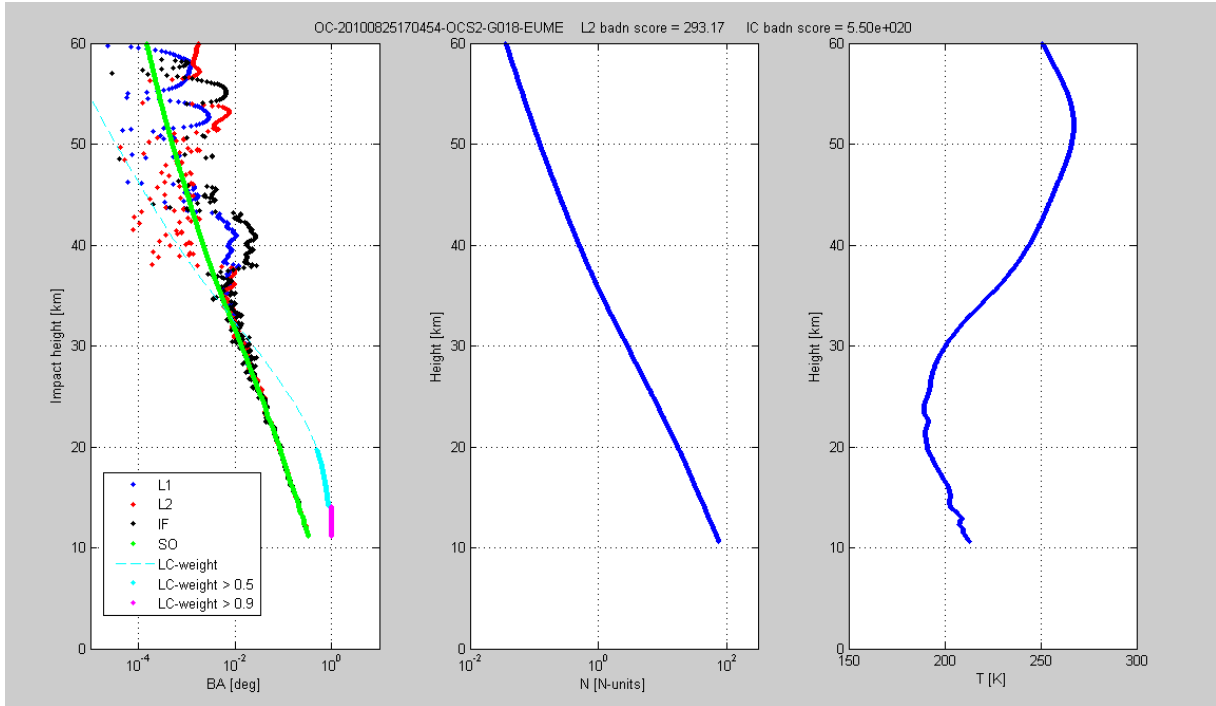
COMPARISON AGAINST CO-LOCATED ECMWF PROFILE
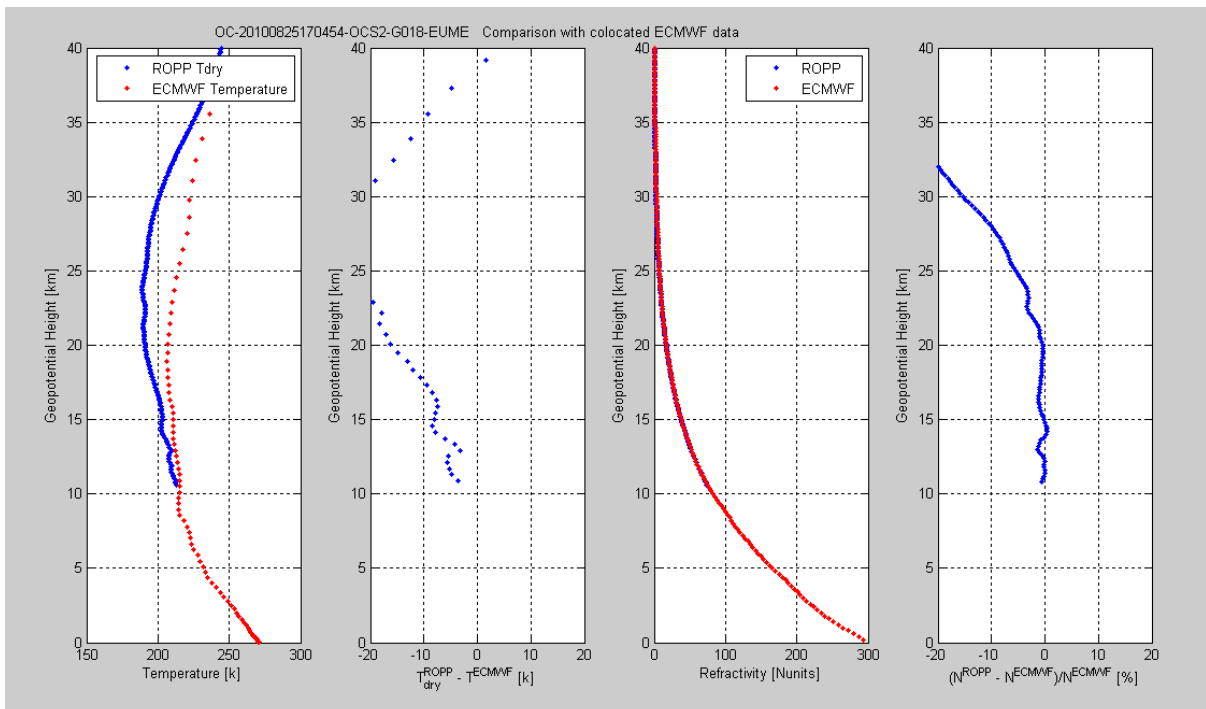
COMPARISON AGAINST OTHER CO-LOCATED OCCULTATIONS
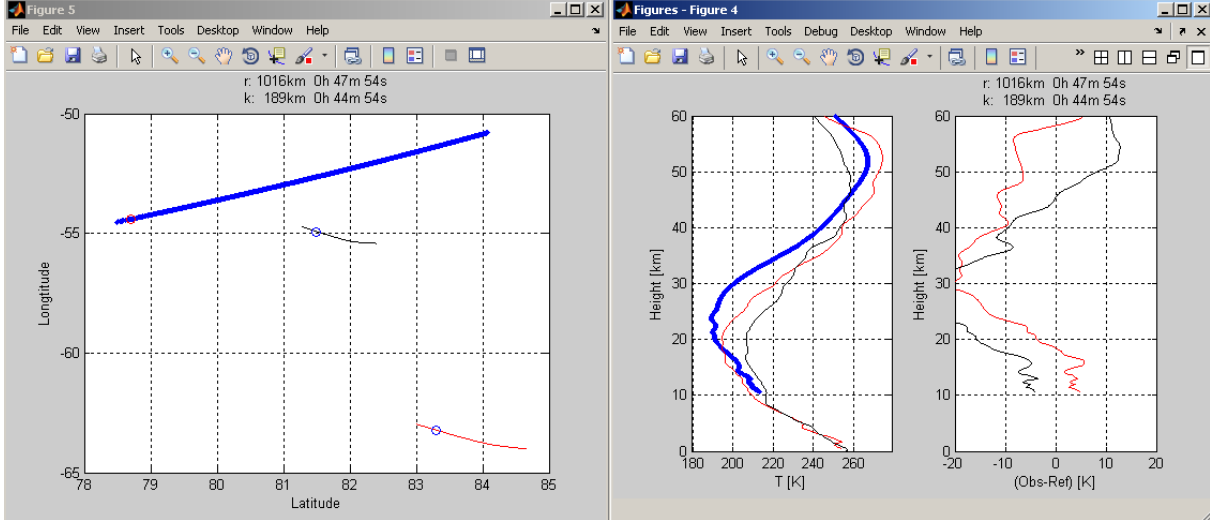

```
% 11
% ropp_pp_occ_20100825_170454_OCS2_G018.nc  -54.40 78.70
% atmPrf_MTPA.2010.237.16.17.G32_2010.2640_nc  -63.22 83.30
% atmPrf_MTPA.2010.237.16.20.G11_2010.2640_nc  -54.93 81.50
file_ropp=['ropp_pp_occ_20100825_170454_OCS2_G018.nc'];          blue
file_cosm=[];
file_meta(1,:)=['atmPrf_MTPA.2010.237.16.17.G32_2010.2640_nc'];   red
file_meta(2,:)=['atmPrf_MTPA.2010.237.16.20.G11_2010.2640_nc'];  black
file_trsx=[];
```
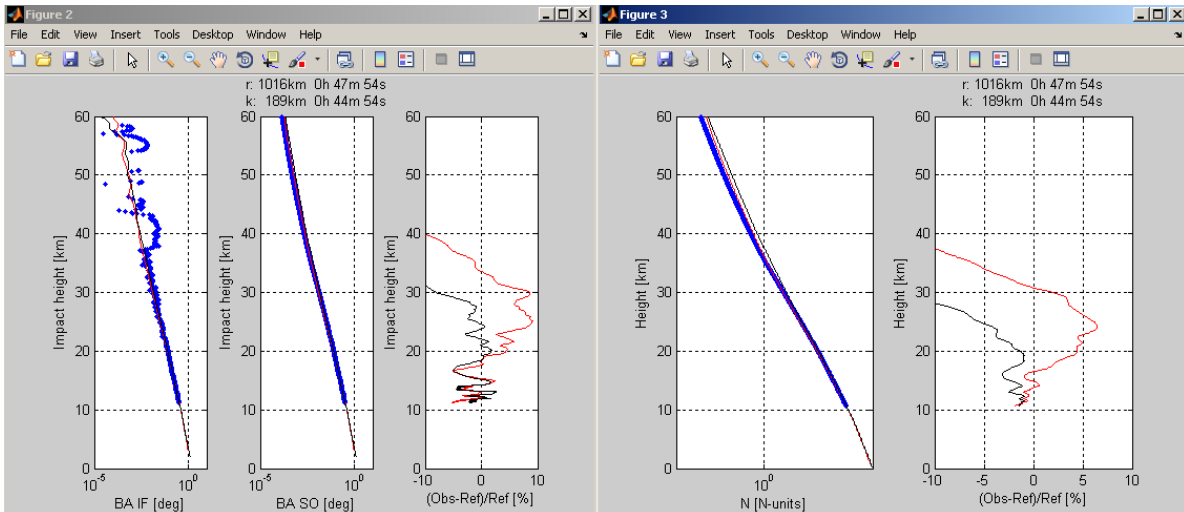
Event #12

Single profiles
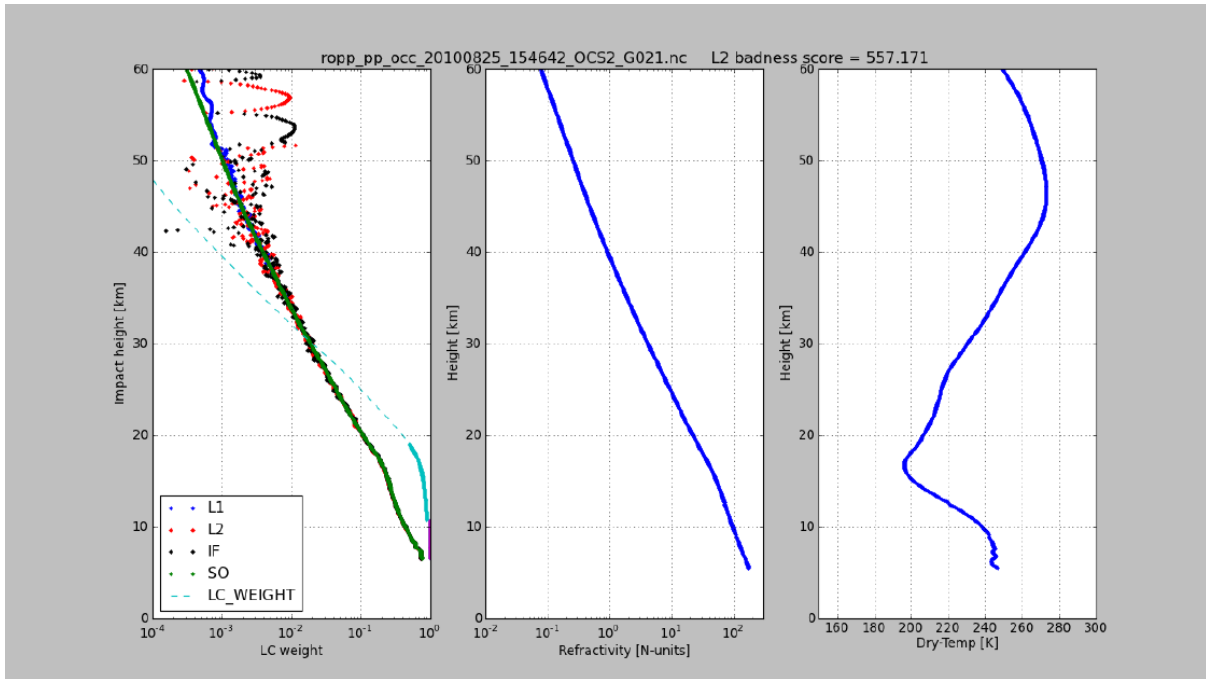
NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT

Event #13

Single profiles

COMPARISON AGAINST CO-LOCATED ECMWF PROFILE

Ref: SAF/GRAS/DMI/REP/VS16/001
Version: 1.2
Date: 03 March 2012
Document: grassaf_cvs16_rep_v1.2

GRAS SAF CDOP
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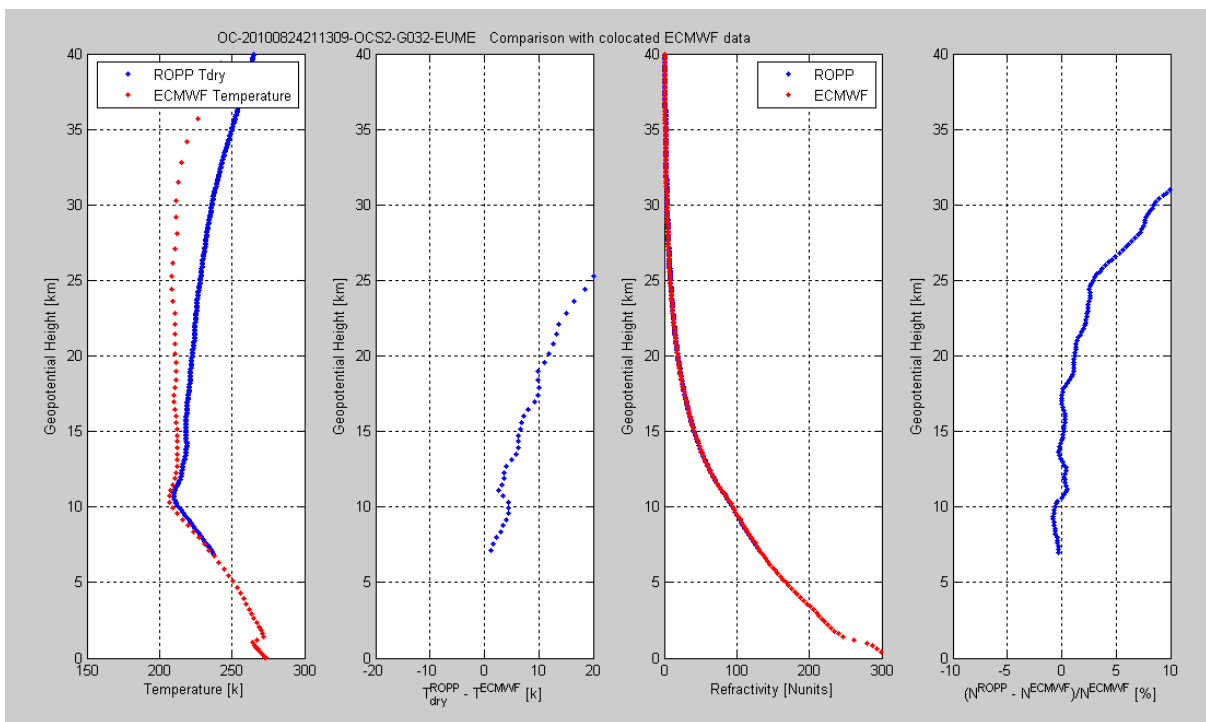
COMPARISON AGAINST OTHER CO-LOCATED OCCULTATIONS


```
% 13
% ropp_pp_occ_20100824_211309_OCS2_G032.nc -53.45 19.73
% atmPrf_C001.2010.236.21.22.G10_2010.2640_nc -44.31 15.77
% atmPrf_C001.2010.236.21.34.G32_2010.2640_nc -43.97 23.30
% atmPrf_C001.2010.236.21.36.G20_2010.2640_nc -54.79 12.74
% atmPrf_C005.2010.236.20.33.G25_2010.2640_nc -58.78 17.43
% atmPrf_MTPA.2010.236.20.05.G02_2010.2640_nc -49.39 27.18
% atmPrf_MTPA.2010.236.21.31.G19_2010.2640_nc -53.51 24.74
% atmPrf_MTPA.2010.236.21.47.G29_2010.2640_nc -46.47 12.14
file_ropp=['ropp_pp_occ_20100824_211309_OCS2_G032.nc'];          blue
file_cosm(1,:)=['atmPrf_C001.2010.236.21.22.G10_2010.2640_nc'];
file_cosm(2,:)=['atmPrf_C001.2010.236.21.34.G32_2010.2640_nc'];
file_cosm(3,:)=['atmPrf_C001.2010.236.21.36.G20_2010.2640_nc'];  colors=['r','k','g','y','c','m','b'];
file_cosm(4,:)=['atmPrf_C005.2010.236.20.33.G25_2010.2640_nc'];
file_meta(1,:)=['atmPrf_MTPA.2010.236.20.05.G02_2010.2640_nc'];
file_meta(2,:)=['atmPrf_MTPA.2010.236.21.31.G19_2010.2640_nc'];
file_meta(3,:)=['atmPrf_MTPA.2010.236.21.47.G29_2010.2640_nc'];
file_trsx=[];
```
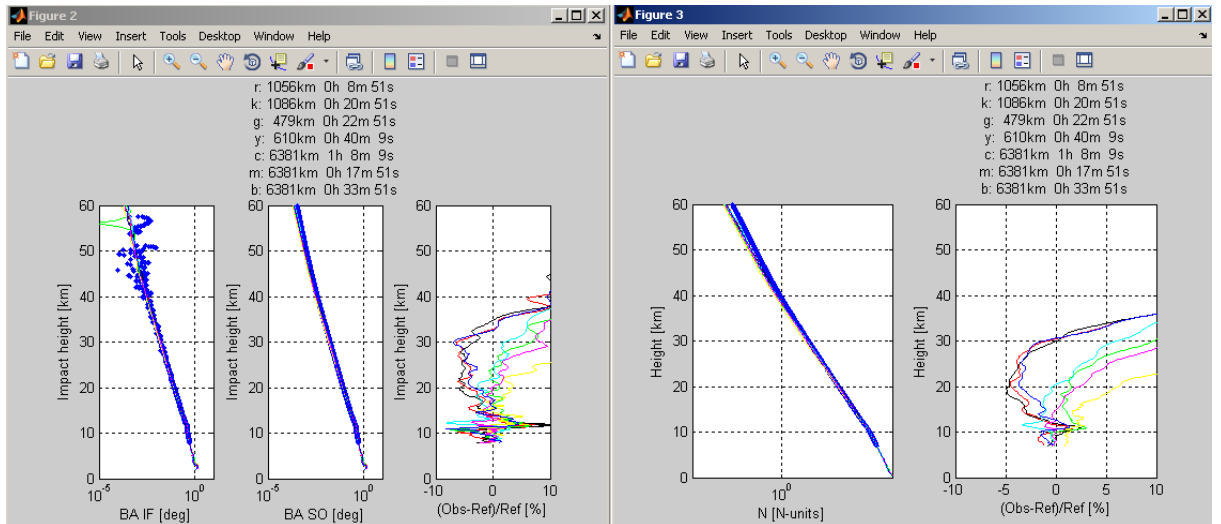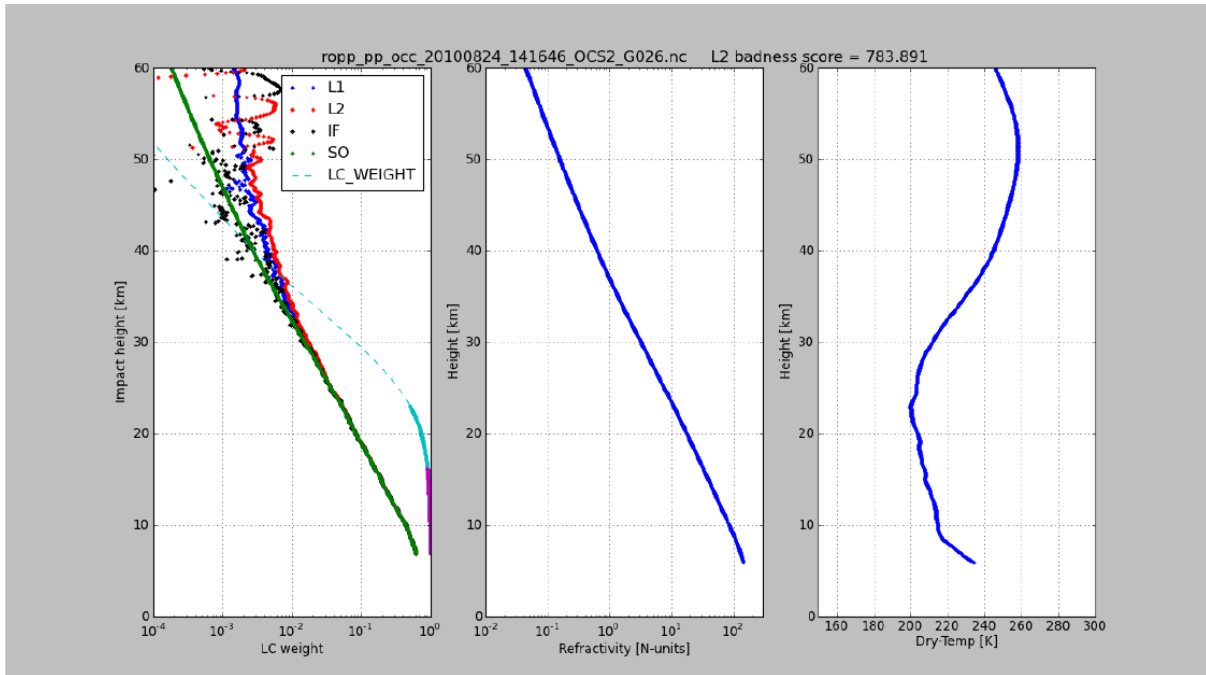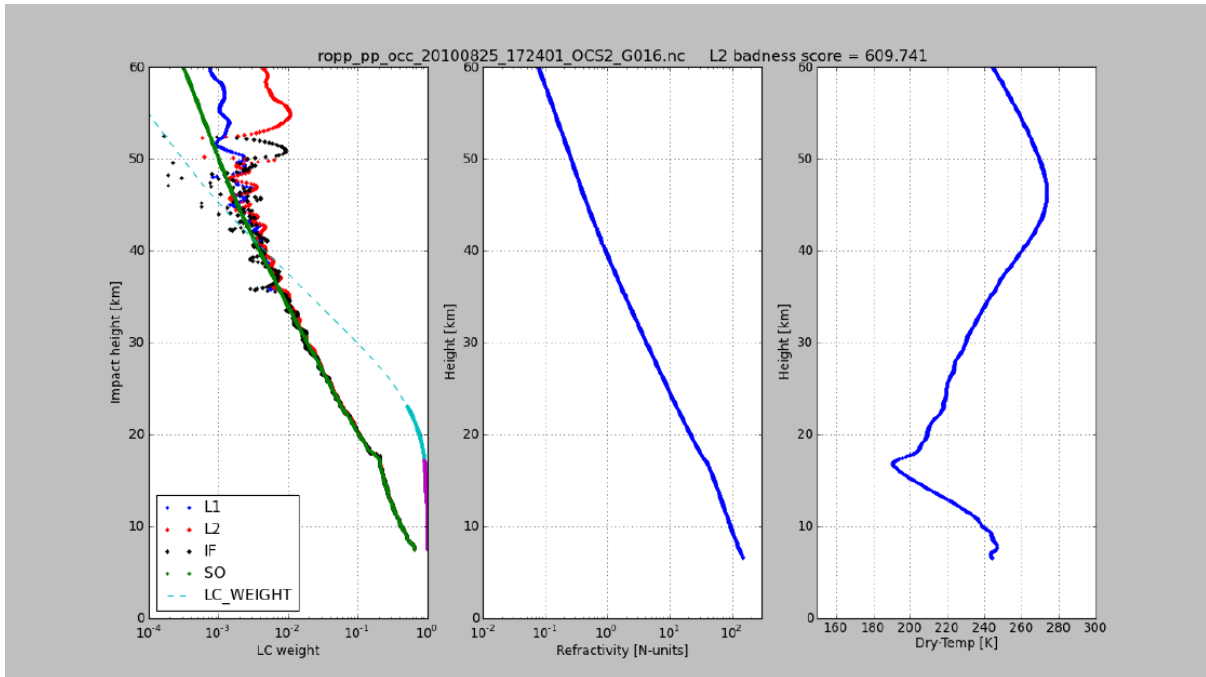
Event #14

Single profiles

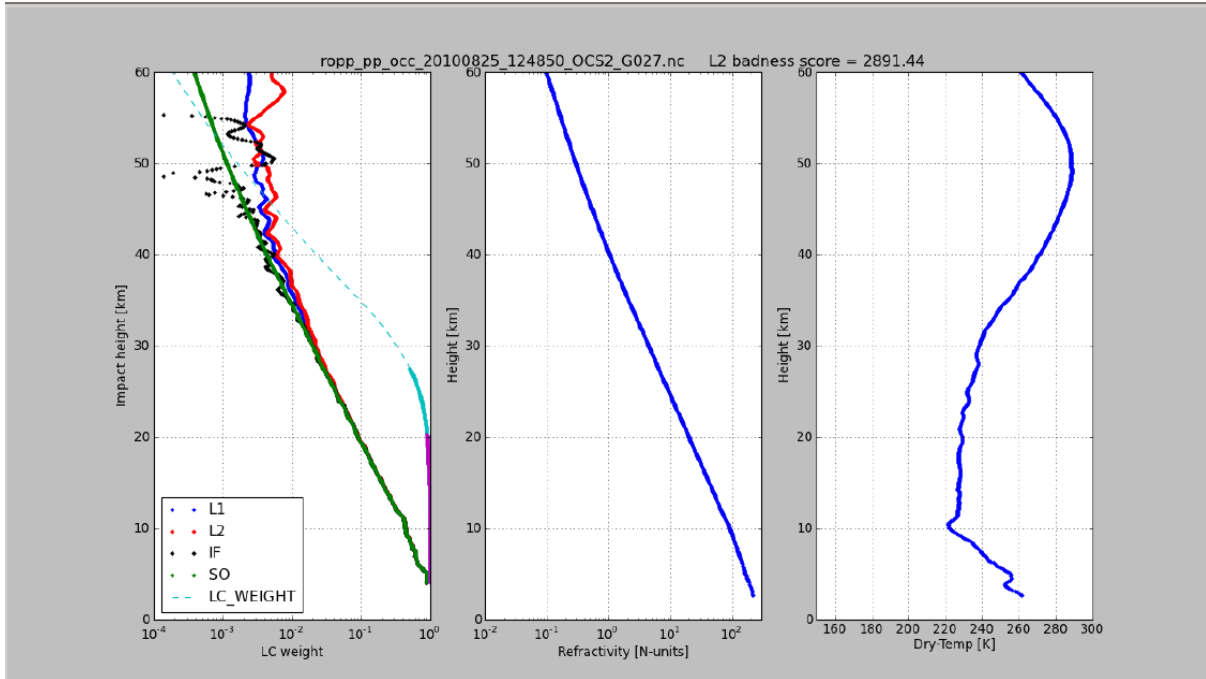**NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT**

Event #15

Single profiles

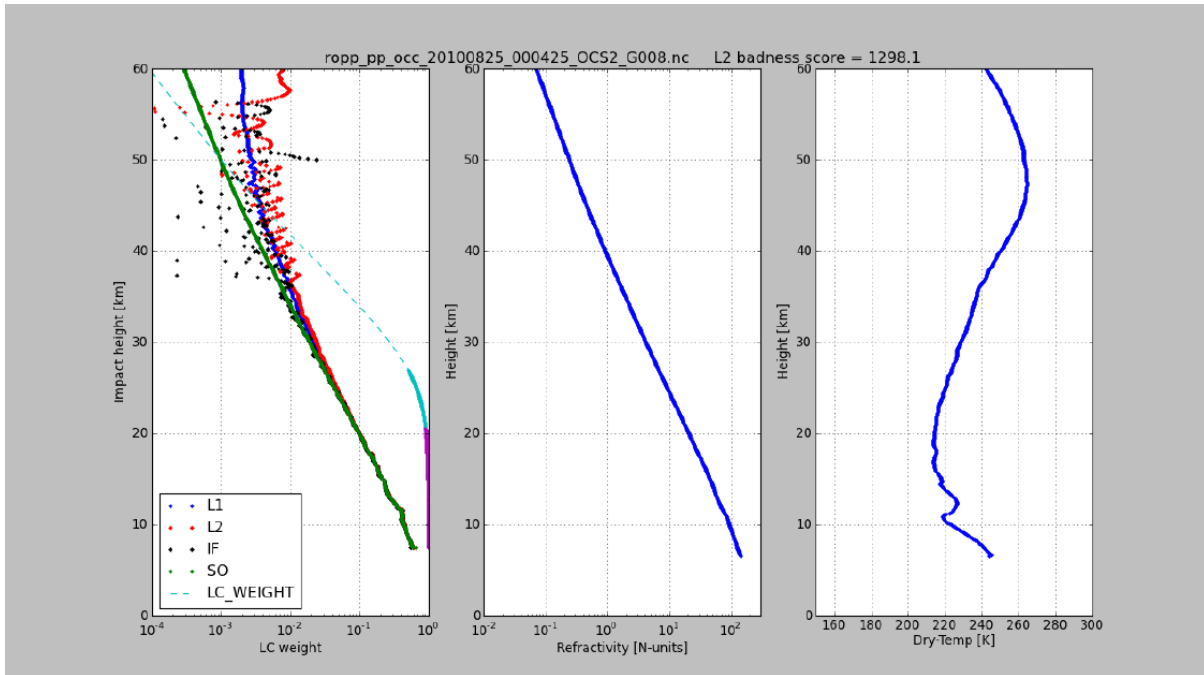**NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT**

Event #17

Single profiles
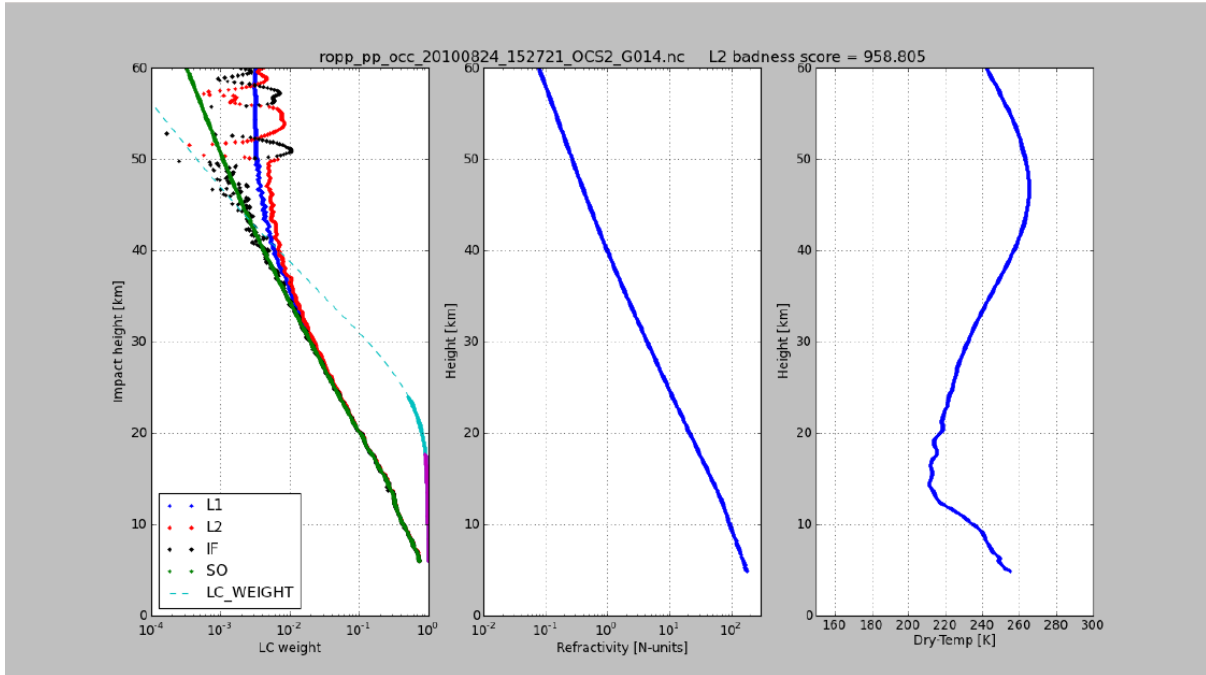

NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT

Event #18

Single profiles

NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT

Event #19

Single profiles

NO COLOCATED EVENTS ARE FOUND FOR THIS EVENT