IROWG 2nd Workshop
28th March - 3rd April 2012,
Stanley Hotel in Estes Park, CO, USA

Implementation of ROSA radio occultation data handling into EUMETSAT and GRAS-SAF processing

R. Notarpietro – *Politecnico of Turin (Italy)*
C. Marquardt, A. Von Engeln, Y. Andres, A. Foresi – *EUMETSAT (Germany)*
K. Lauritsen, K. Kinch, H. Wilhelmsen – *ROM-SAF @ DMI (Denmark)*
A. Zin, S. Landenna – *Thales Alenia Space Italy (Italy)*
V. Catalano, V. De Cosmo – *Italian Space Agency (Italy)*

Introduction

Within this contribution, outcomes from the 16th GRAS – SAF Visiting Scientist activity will be described and main results will be shown.

The 16th GRAS – SAF VISITING SCIENTIST Activity has been mainly focused on:
- evaluation of ROSA data quality (data observed on board OCEANSAT-2 only)
- implementation of ROSA RO data handling into EUMETSAT (**YAROS**) and GRAS-SAF (***ROPP***) processing

Summary

- ROSA (OC-2, SAC-D, Megha Tropiques) description
- ROSA Data and Processing description
- High Rate data
- SNR data
- ROSA data validation strategy
- ROSA raw data Quality Check
- Bending angle statistics
- Impact on L2 extrapolation
- Conclusion & Recomendations

ROSA Description (1/5)

ION 2010 International Technical Meeting Program
January 25-27, 2010 • Catamaran Resort Hotel • San Diego, CA

Kindly provided by A. Zin

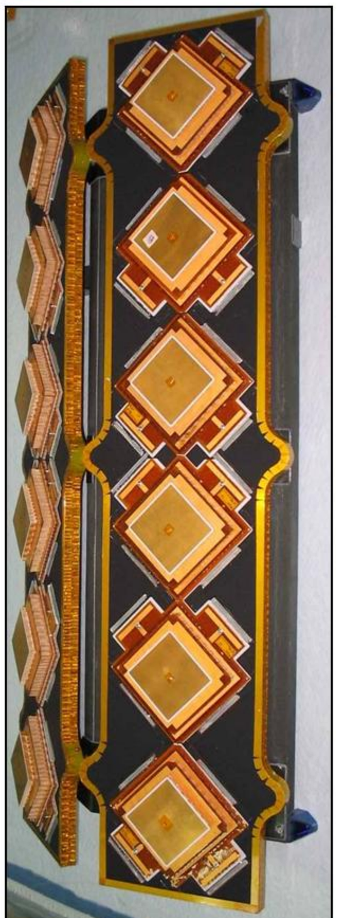
ThalesAlenia Space
A Thales / Finmeccanica Company

The ROSA Instrument

Page 1

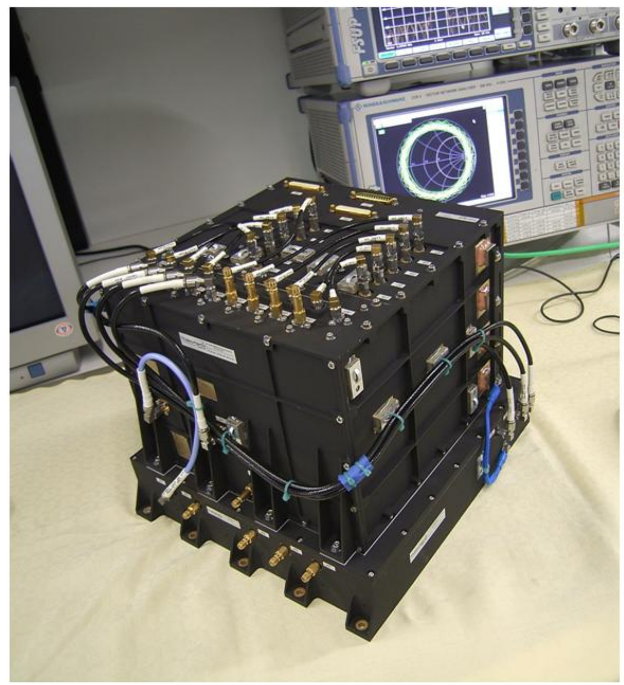
Developed by Thales Alenia Space Italia under ASI contract

Radio Occultation Antenna



POD Antenna

Receiver Unit



THALES

ROSA Description (2/5)

ION 2010 International Technical Meeting Program
January 25-27, 2010 • Catamaran Resort Hotel • San Diego, CA

Kindly provided by A. Zin

ThalesAlenia Space
A Thales / Finmeccanica Company

ROSA Instrument Features

Page 2

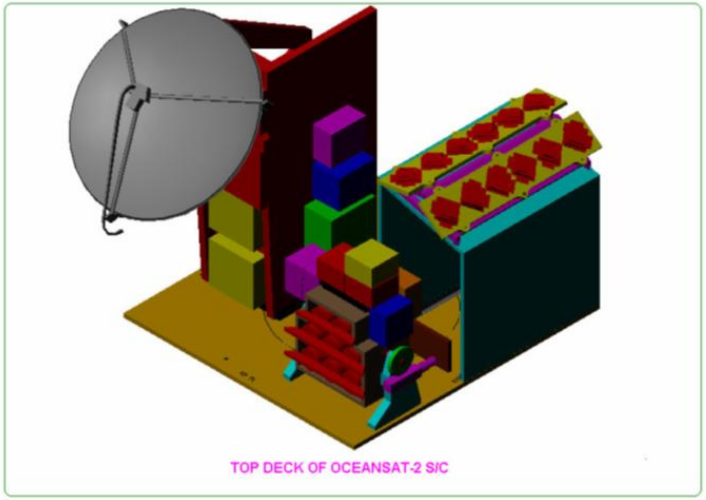
- Space-borne (LEO), Dual-Freq Receiver for Atmospheric Sounding
- 48 single frequency channels configured as 16 L1CA-L1P(Y)-L2P(Y)
- Raw Data (NAV / OCC):
  - L1 C/A, L1P(Y), L2P(Y) Code phase, Carrier phase
  - OL Raw sampling (I/Q) at high frequency (100 Hz)
  - SNR, Amplitude and Noise measurements
- Real-Time Navigation Solution, using GPS L1 C/A code phase (through SPS and EKF - Extended Kalman Filter)
- On-board atmospheric model for excess doppler prediction of occultations (Cira86aQ_UoG climatological Model)
- Rising and setting occultation capabilities (ROA Vel + ROA A-Vel)

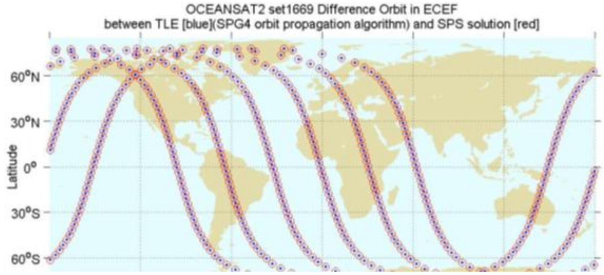
THALES

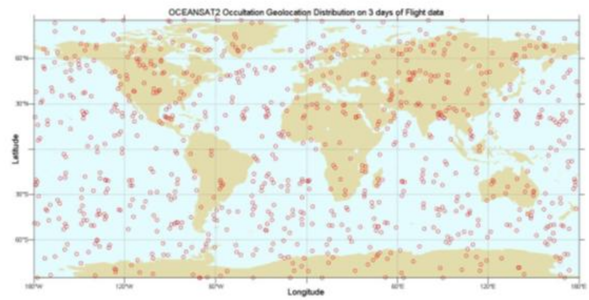
ROSA Description (3/5)

ROSA on OCEANSAT-2

- ISRO OCS-2 mission launched Sept 23, 2009
- Ocean studies, meteorology and prediction of Monsoon
- Opportunity Mission for in-flight Verification of ROSA
- ROSA configuration <u>limited to one directive Velocity antenna (rising only)</u>
- RO +/- 45° azimuth, 0 to -30° elevation
- 15°+20° tilt wrt velocity direction







Kindly provided by A. Zin

ION 2010 International Technical Meeting Program
January 25-27, 2010 • Catamaran Resort Hotel • San Diego, CA

THALES

ROSA Description (4/5)

Kindly provided by A. Zin

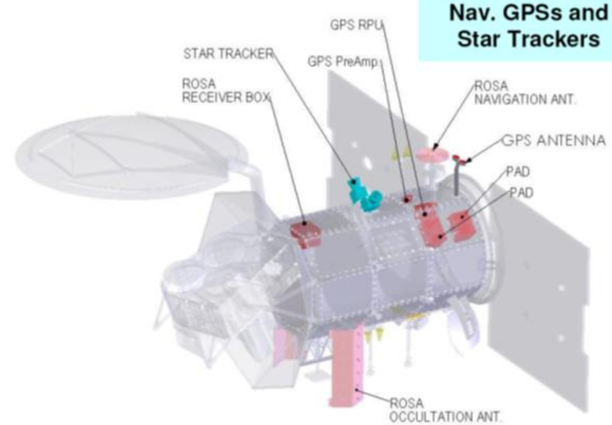
ThalesAlenia Space
A Thales / Finmeccanica Company

asi

ROSA on SAC-D

- CONAE / NASA Earth Science mission, to provide global meas of sea water salinity
- Sun-synchronous orbit, 657 km
- Strong pulsed interference from Aquarius required dedicated RF filter box
- Velocity + Anti-Velocity antennas allow Rising + Setting occultations
- SAC-D satellite has been launched on 10 June 2011
- ROSA instrument has been switched ON the 31 August 2011

Location of ROSA, Nav. GPSs and Star Trackers



THALES

ROSA Description (5/5)

IROWG 2nd Workshop

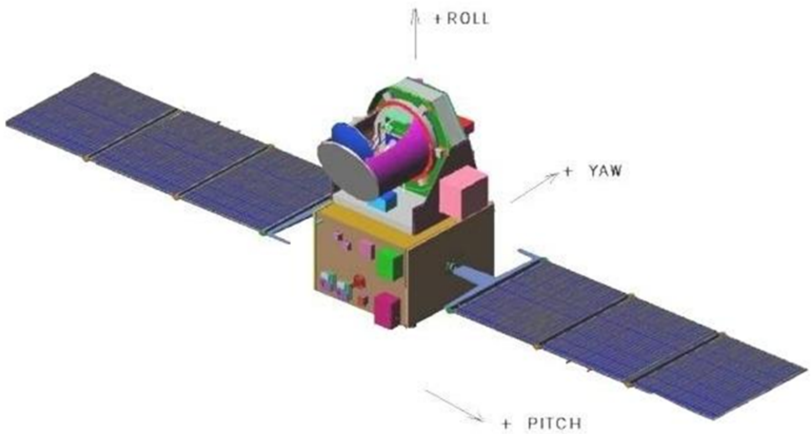
Kindly provided by A. Zin

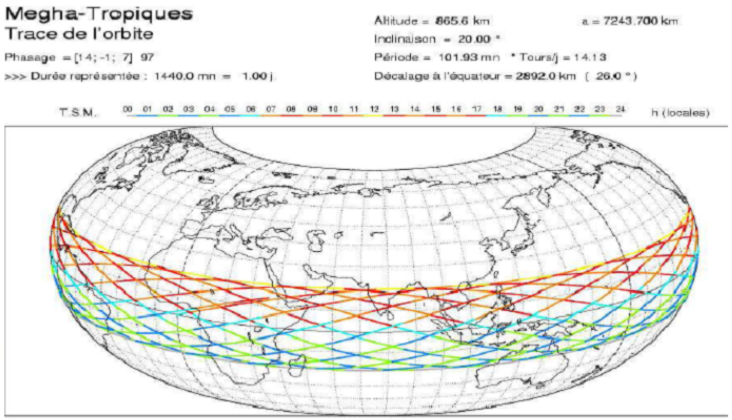
ION 2010 International Technical Meeting Program

January 25-27, 2010 • Catamaran Resort Hotel • San Diego, CA

ROSA on MeghaTropiques

- ISRO mission dedicated to tropical atmosphere studies: 3 radiometric instruments to observe water vapour, condensed water and radiative fluxes
- Highly repetitive sampling of inter-tropical band: latitudes 10°-20°, 870Km
- MT periodically performs yaw axis rotation causing ROSA to exchange velocity ROA with anti-velocity ROA
- RO Antennas are one half 6-patch panel, azimuth FOV limited to ±35°
- MEGHA TROPIQUES satellite has been launched on 12 October 2011
- ROSA instrument has been switched ON 12 October 2011



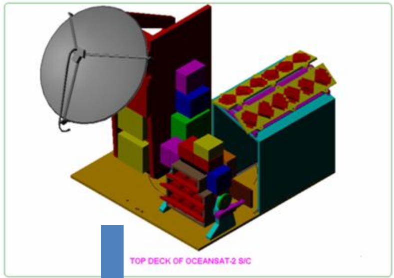


THALES

ROM SAF
Radio Occultation Meteorology
EUMETSAT

Data and Processing Description (1/2)

CGMS COORDINATION GROUP FOR METEOROLOGICAL SATELLITES
CGMS IROWG 2nd Workshop



Indian (Shadnagar) and Italian (Matera) GS

Thales Alenia Space Italy telemetry decoding software

Operative (OBSERVATION) Level 1 Data Files

1. Navigation solution data (Tabular ASCII format)
2. Navigation POD data (Rinex 2.10 format)
3. Observation Low Rate data (Rinex 2.10 format)
4. Observation High Rate data (Rinex 2.10 format)
5. Observation Open loop data (Rinex 2.10 format)

Science data

DEBUG Level 1 Data Files (ASCII format)

1. Navigation Health and Status file
2. Navigation Observable Data Block file
3. Fast Acquisition Information for each Channel file
4. LNA signal and CPU load file
5. Space Vehicle Information file
6. Close Loop Observation from Occultation Antenna file
7. Open Loop Observation from Occultation Antenna file

Science data

Data and Processing Description (2/2)

Italian Space Agency and Thales Alenia Space – Italy 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.
- 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. The records contain UTC Times, Orbits in ECI reference frame and Quaternions in ECI reference frame.

*In the framework of this VS activity, analysis and results has been performed on a shorter time interval. The ~**30** hours **from 13:30 UTC of 24 August, 2010 to 17:40 UTC of 25 August 2010** have been deeply analyzed.*

ROSA native binary data

↓

Thales Alenia Space Italy Telemetry decoding software →

Operative (OBSERVATION) Level 1 Data 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)

Navigation POD data
ROSA attitude data

NAPEOS @ EUMETSAT →

GPS and OC-2 sp3 data
Observation High Rate data

→ YAROS @ EUMETSAT →

Level 1a data (Exc Phases and SNRs)
Level 1b data (bend)

→ ROPP_PP @ DMI →

Bending vs impact parameter (raw, SO) N, Tdry

High Rate Data

Navigation POD data
ROSA attitude data

NAPEOS @ EUMETSAT

GPS and OC-2 sp3 data
Observation High Rate data

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

All these data (taken by the VEL-Antenna) are available at the following sample rates

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).

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 at the same sampling rate of the occulted GPS SV.

Therefore several "limb"-TEC observation at 50 Hz are available for further studies

SNR data (1/3)

Navigation POD data
ROSA attitude data

NAPEOS @ EUMETSAT → **GPS and OC-2 sp3 data**
Observation High Rate data

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

SNRs (CN0 in DB-Hz) are available only in the LOW rate observation files (1Hz sample rate). Here we have **SIGNAL** and NOISE LEVELs. Such data can be combined to obtain SNRs.

SIGNAL power on L1 and L2 is computed as the power available in the I and Q components (sampled at 29 MHz) at the output of the AGGA correlators. Formally,

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

Integration time: 20 ms

combining opportunely **SIGNAL** and NOISE power, the SNR obtained is coherenyt with the one stored in the LOW rate OBSERVATION files

ROM SAF
Radio Occultation Meteorology
EUMETSAT

CGMS COORDINATION GROUP FOR METEOROLOGICAL SATELLITES
IROWG 2nd Workshop

SNR data (2/3)

Navigation POD data
ROSA attitude data

NAPEOS @ EUMETSAT

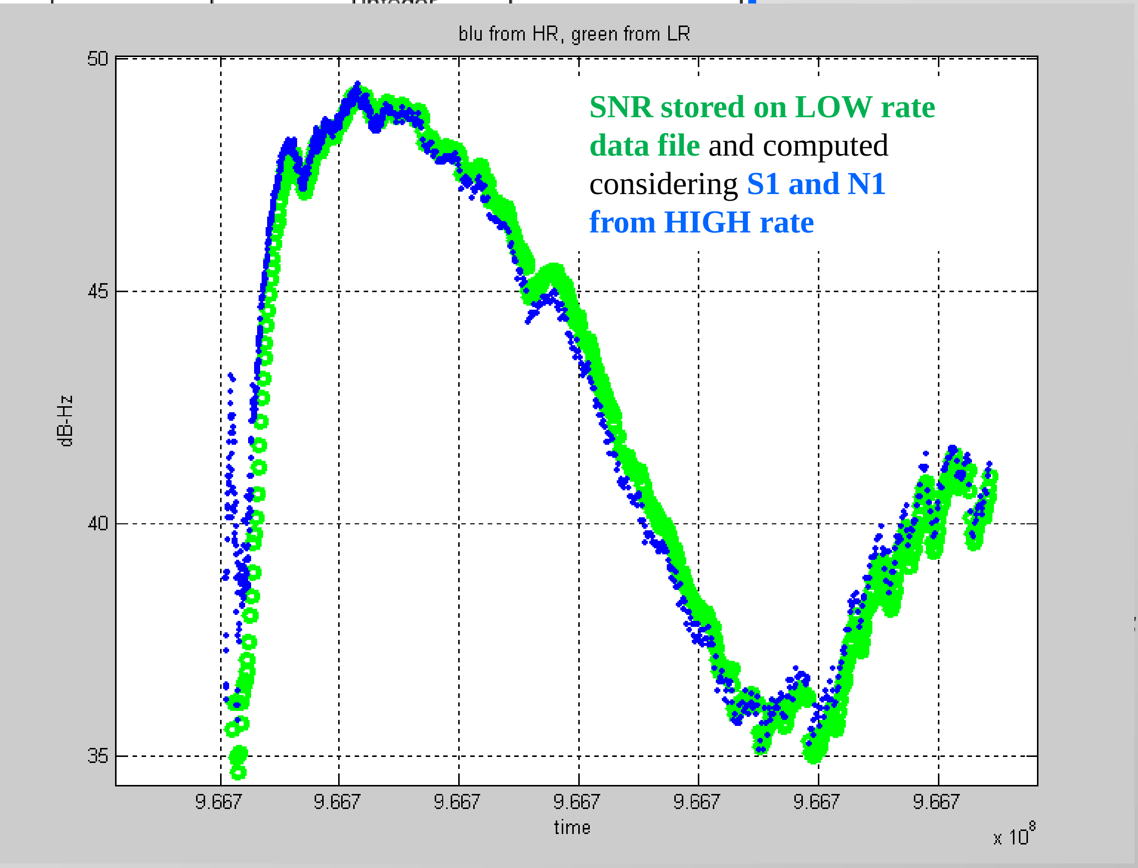
GPS and OC-2 sp3 data
Observation High Rate data

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				
Istantaneous Doppler L2 si… quality				
Carrier phase L1				
Carrier phase L2				
Signal power L1				
Noise power L1				
Signal power L2				
Noise power L2				

SNRs (CN0 in DB-Hz) are available only i… have **SIGNAL** and NOISE LEVELs. Such…

SIGNAL power on L1 and L2 is computed… 29 MHz) at the output of the AGGA correl…

combining opportunely **SIGNAL** and NOI… in the LOW rate OBSERVATION files



SNR data (3/3)

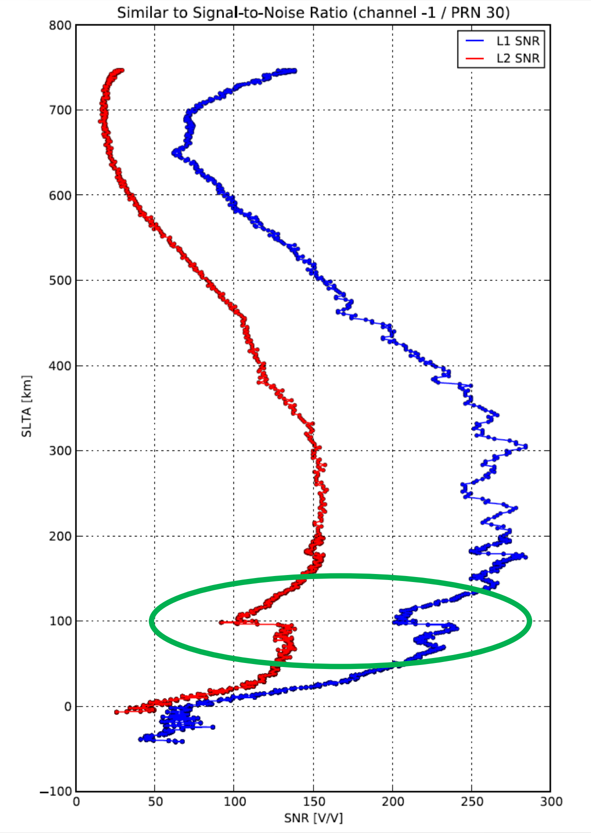
Navigation POD data
ROSA attitude data

NAPEOS @ EUMETSAT

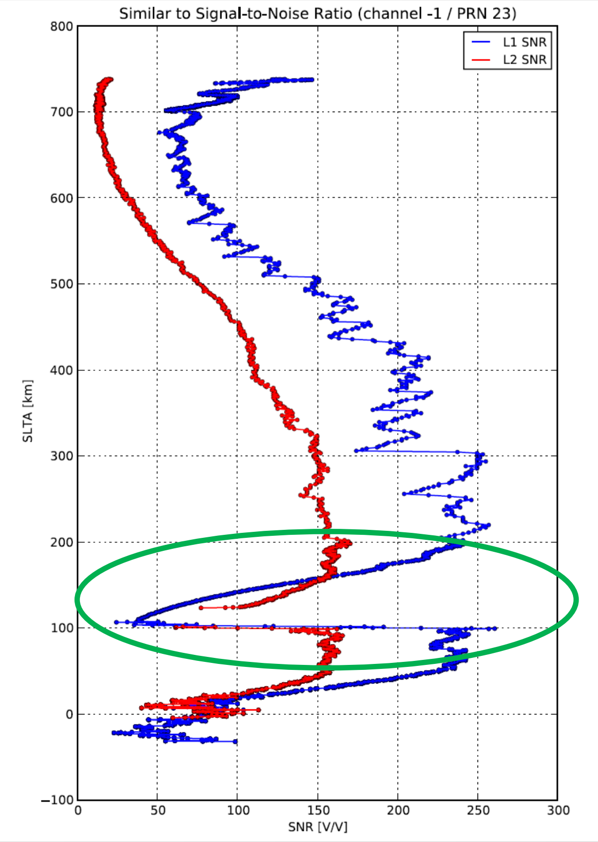
→

GPS and OC-2 sp3 data
Observation High Rate data

Some examples of ROSA SNRs



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

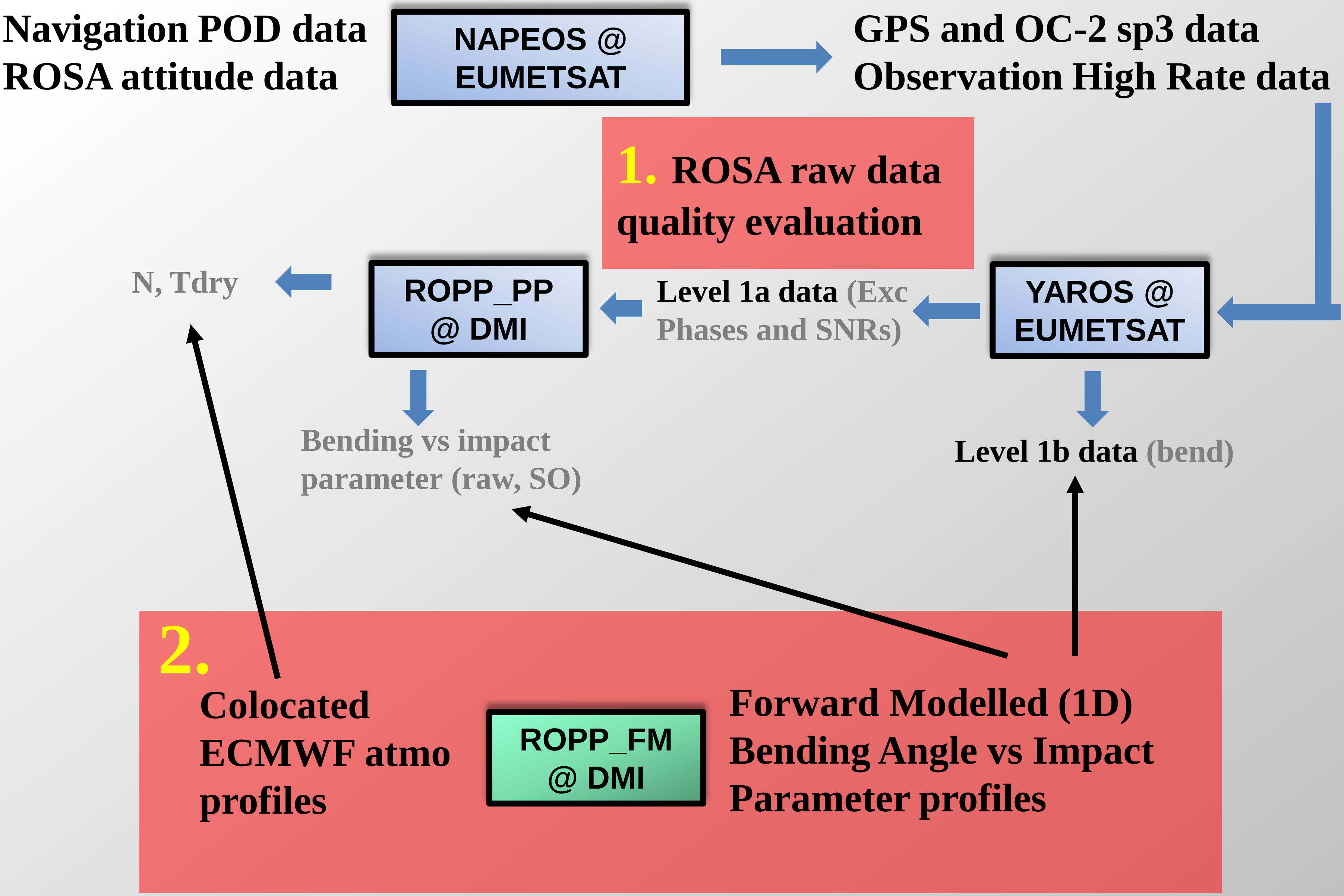


C-N0 [V/V] for the event observed from 20:40:31 UTC, 24 August, 2010

?

Even if this SNR "depression" was observed in a lot of events, it may be related to sporadic E-layer. Further studies will be addressed in the future.

ROSA data validation strategy



ROM SAF Radio Occultation Meteorology

EUMETSAT

ROSA raw data Quality Check (1/3)

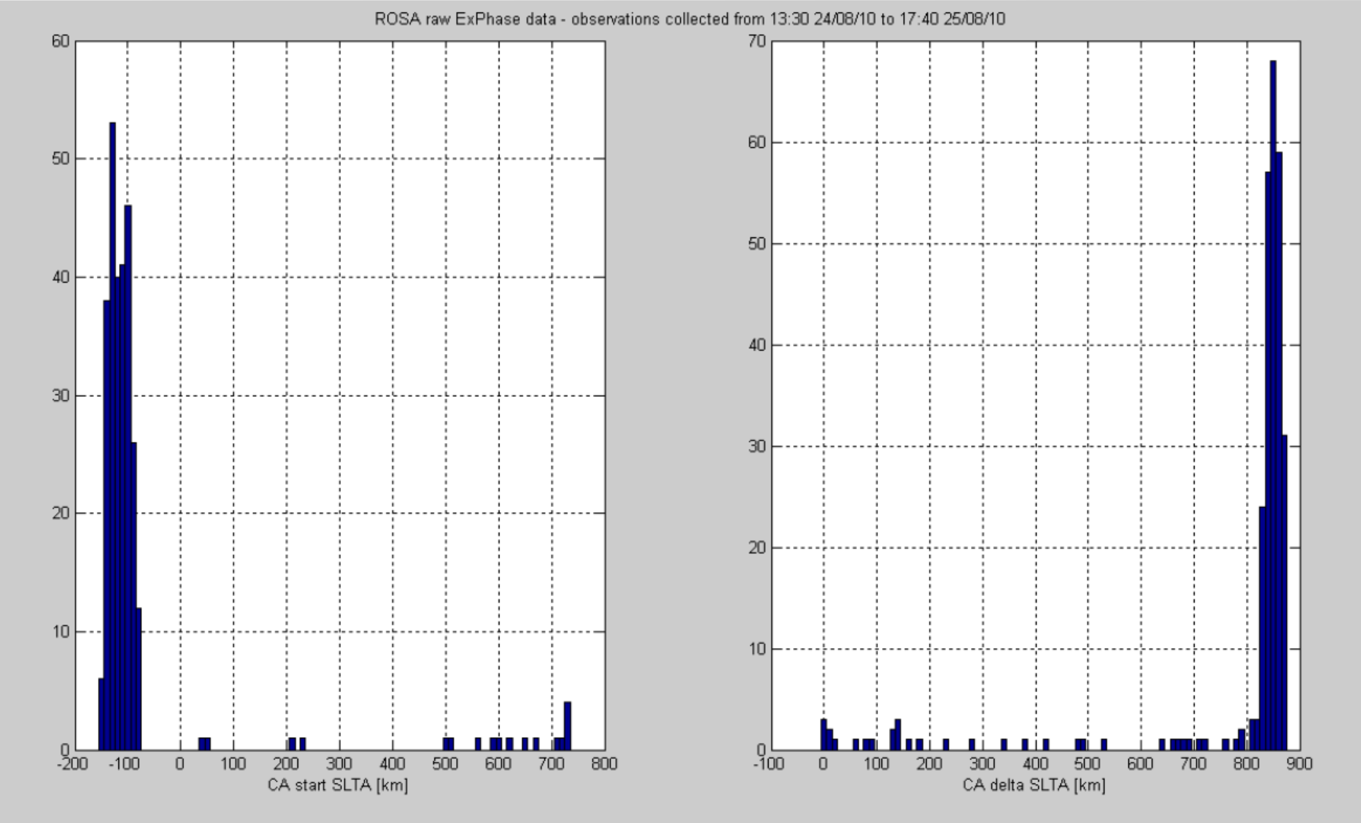
CGMS COORDINATION GROUP FOR METEOROLOGICAL SATELLITES CGMS IROWG 2nd Workshop

The QC analysis on the level1a YAROS output provided:
- the number of continuous L1 and L2 Excess-phase segments,
- the minimum SLTA from which L1 and L2 Excess-phases are available
- the length of the continuous segments can be performed

Input Data Set:
ROSA observ collected from 13:30 (UTC) of 24/08/10 to 17:40 of 25/08/10

L1 CA

280 continuous L1 CA segments are recognized and, without considering a very small number of outliers, CA tracking starts below -100 km SLTA (left histogram) and it continues without interruptions up to the orbit height (~800 km – see the right histogram)



ROSA raw data Quality Check (2/3)

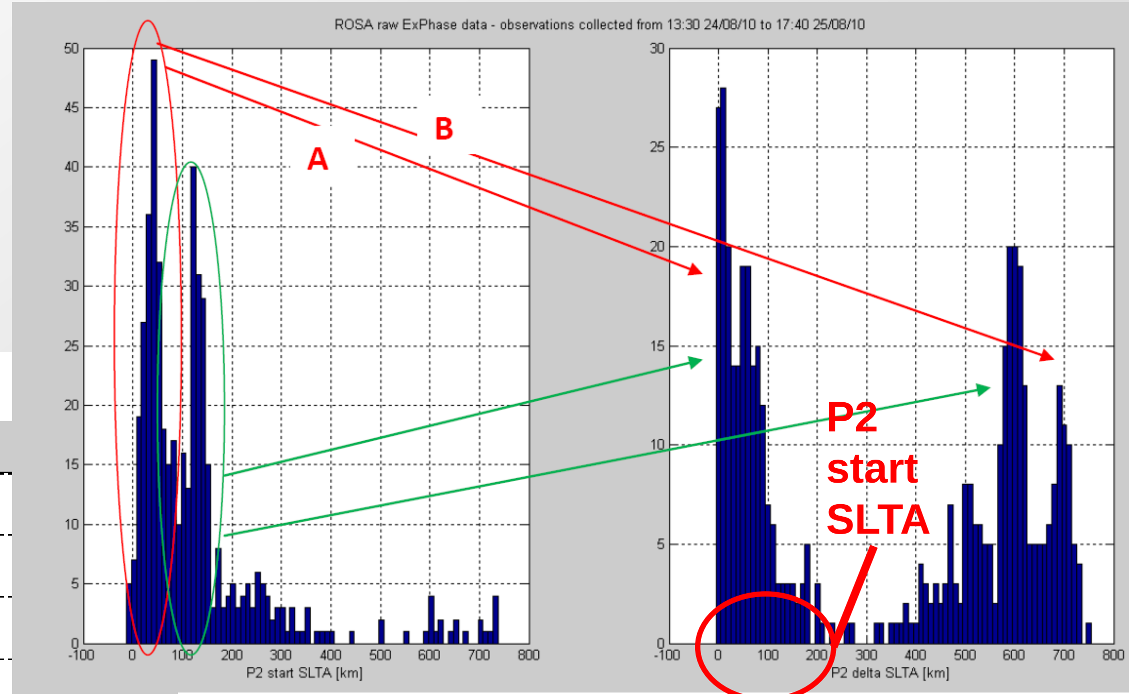
CGMS COORDINATION GROUP FOR METEOROLOGICAL SATELLITES

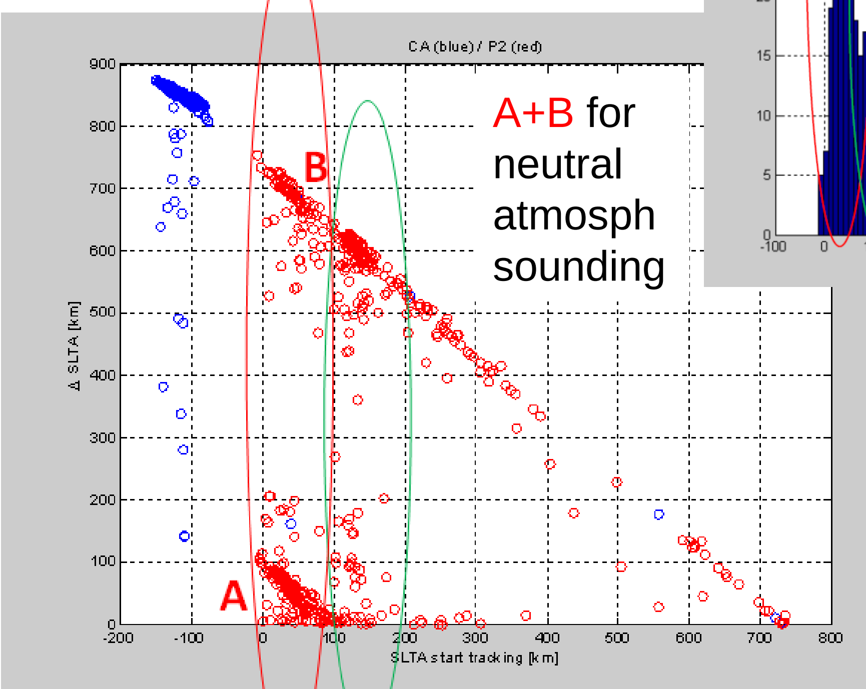
IROWG 2nd Workshop

Input Data Set: ROSA observ collected from 13:30 (UTC) of 24/08/10 to 17:40 of 25/08/10

L2 P

477 continuous segments are recognized. **200** data gaps (**477** L2 segments – **280** L1 segments) greater than 1.3 sec were observed.





~**240** continuous segments out of 477 (~**50%**) are characterized by a minimum SLTA < 100 km (**A+B** cases highlighted in the previous plot).

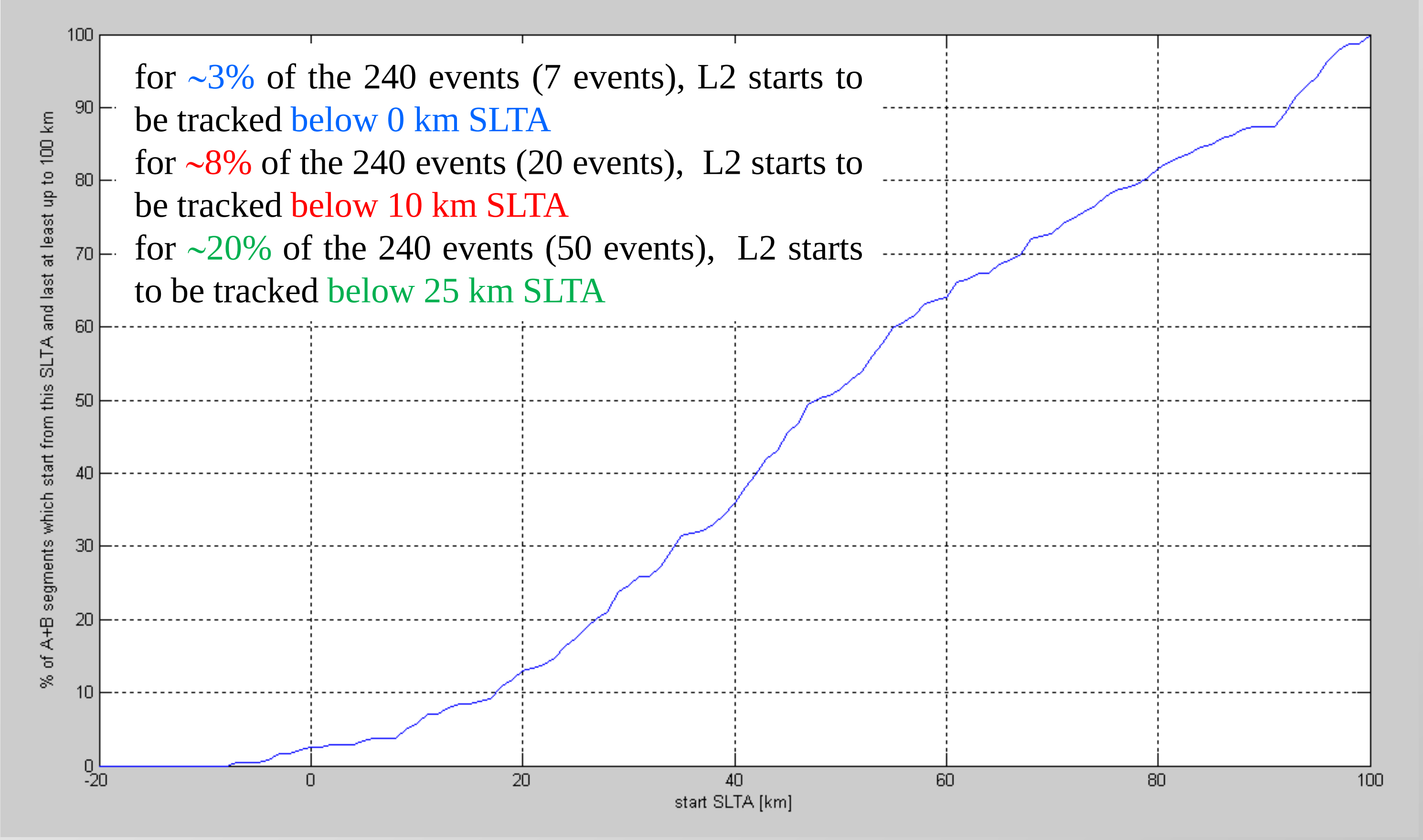
for ~130 of these (~**28%** of the total), the SLTA interval length (up to the first data gap) is < 100 km (**case A** highlighted in the previous plot)

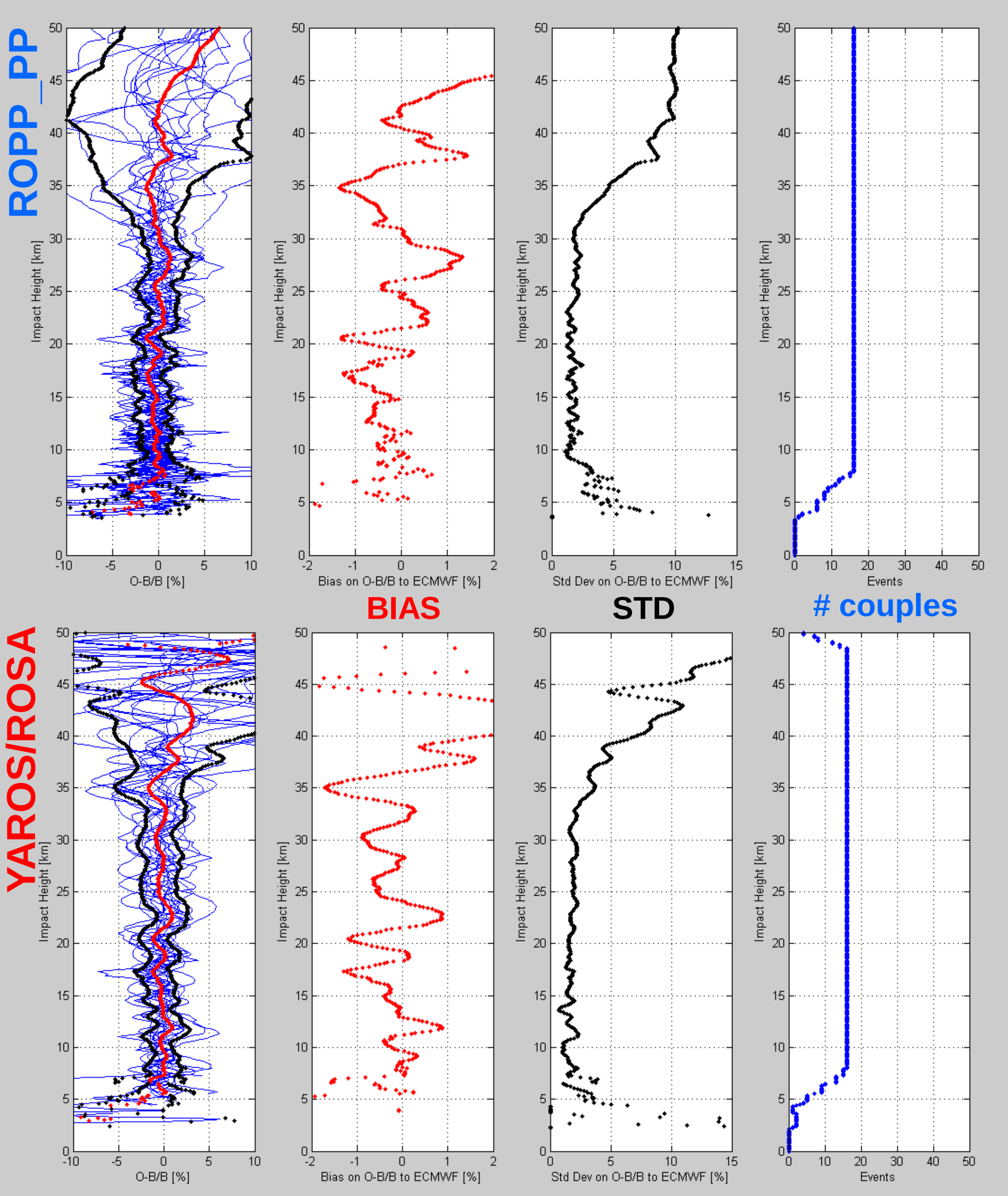
~**110** of the remaining continuous L2 Excess Phase profiles (~**17%** of the total) last up to the height orbit (the SLTA continuous data interval length is more than 600 km)

ROSA raw data Quality Check (3/3)

Input Data Set: ROSA observ. collected from 13:30 (UTC) of 24/08/10 to 17:40 of 25/08/10

cumulative distribution of the identified continuous L2 Excess Phase segments belonging to the A + B ensemble (240 events), in function of the start SLTA from which they are tracked.





BENDING ANGLE STATISTICs

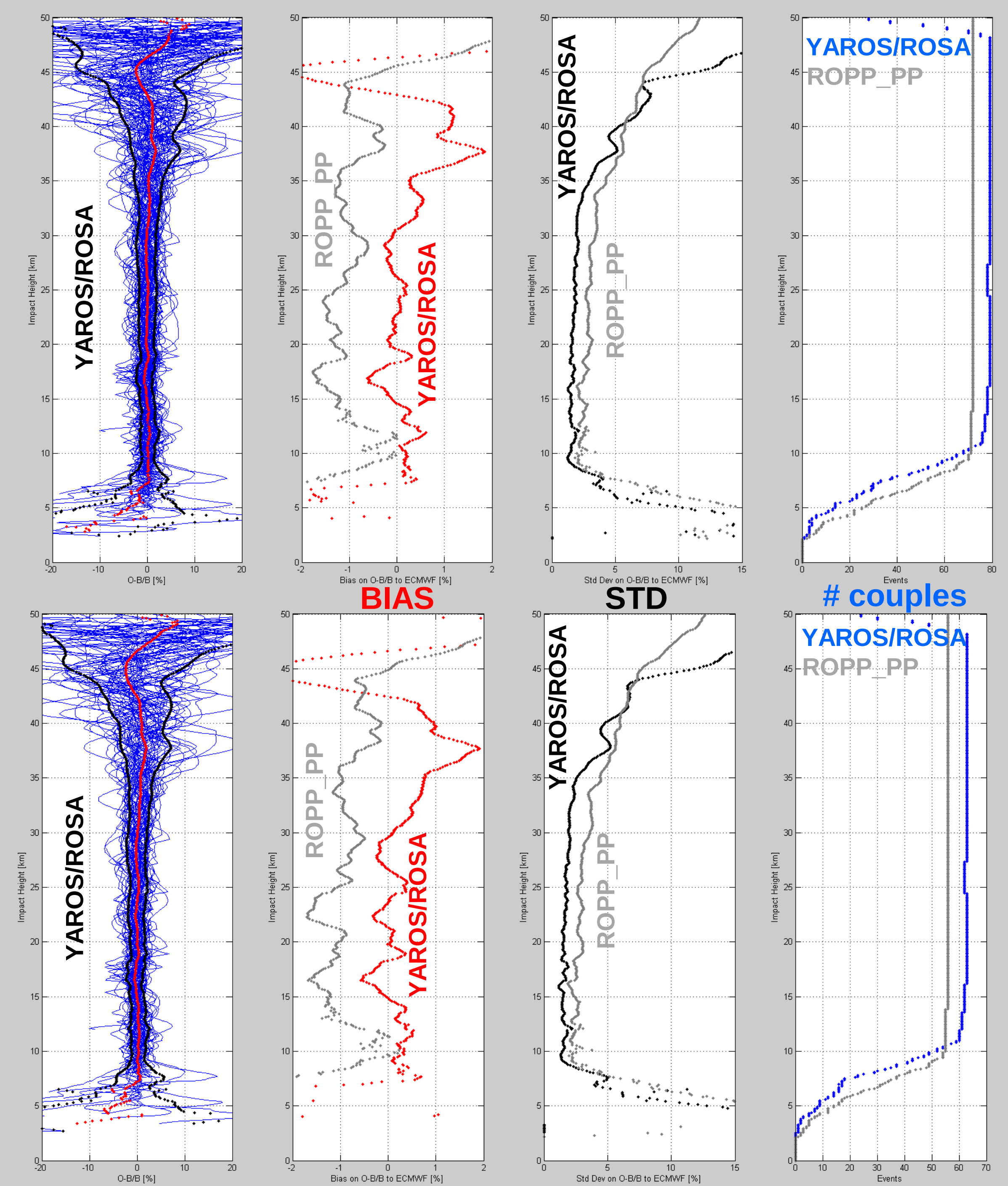
A global analysis was performed considering the statistical comparison (**no automathic outlyer rejection**) between the bending angle profiles obtained using ROPP_PP and YAROS/ROSA, and the corresponding profiles obtained applying the ROPP_FM (Forward Model) to ECMWF co-located data.

The analysis is carried out taken into account

- **all the available profiles for which L2 is available from 0 km to 10 km SLTA (here shown)**
- all the available profiles for which L2 is available below 35 km SLTA (see next slides)

CGMS COORDINATION GROUP FOR METEOROLOGICAL SATELLITES

IROWG 2nd Workshop



BENDING ANGLE STATISTICs

Here the global analysis (statistic without automatic outliers rejection) is shown **considering all the available profiles for which L2 is available below 40 km SLTA**

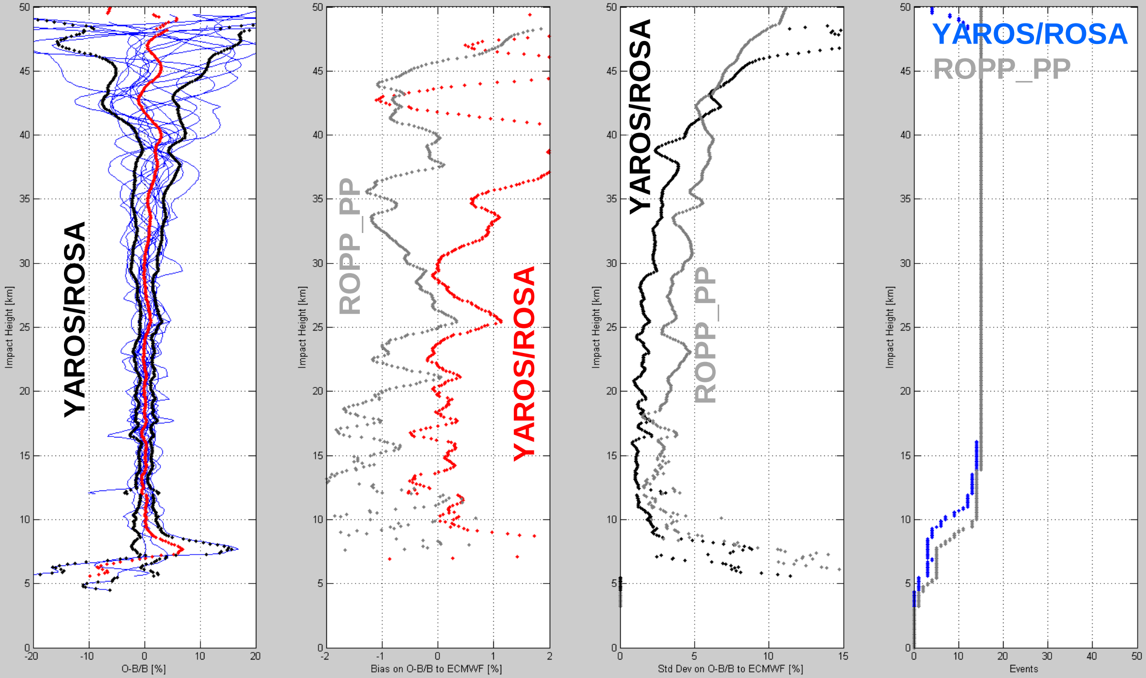
L2 available starting from
0 – 35 km SLTA
(80 events)

The negative bias of 1% observed in the ROPP_PP results is probably due to the impact of L2 downward extrapolation for those events for which L2 starts to be tracked to high in atmosphere

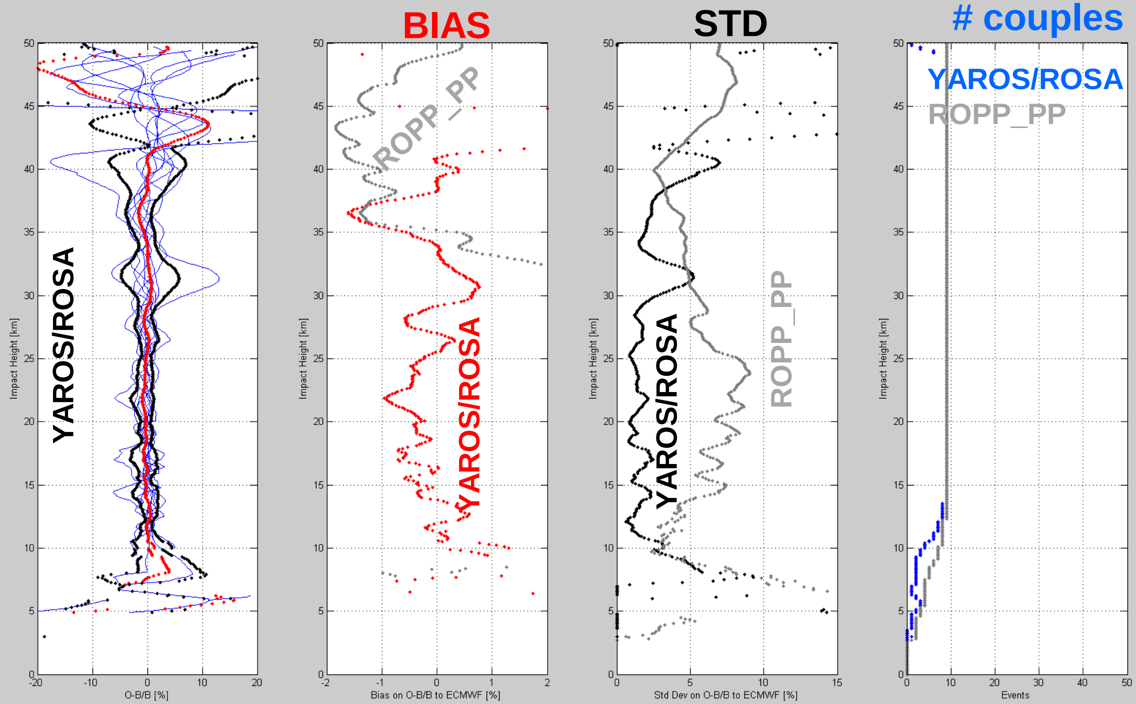
L2 available starting from
10 – 35 km SLTA
(63 events)

BENDING ANGLE STATISTICs

Here the global analysis (statistic without automatic outliers rejection) is shown **considering all the available profiles for which L2 is available below 40 km SLTA**



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



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

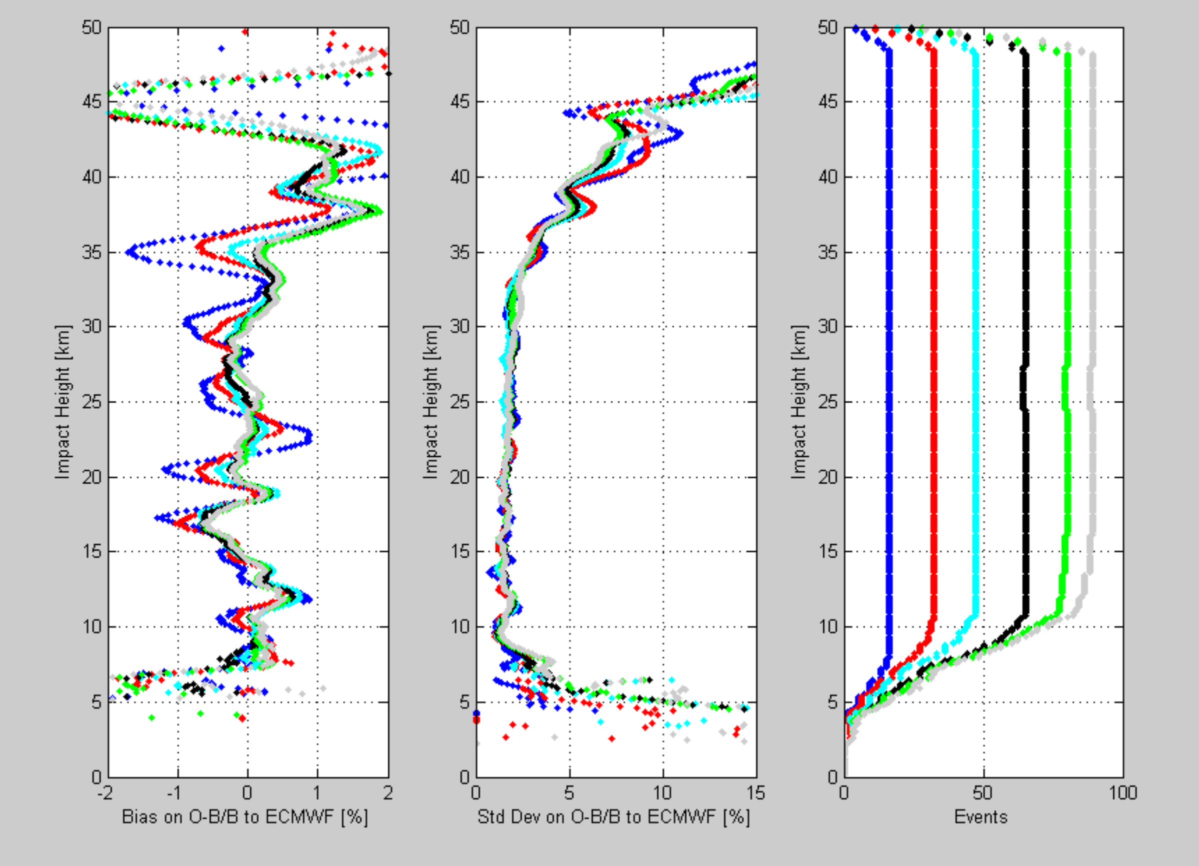
Impact on L2 extrapolation (1/4)

ROM SAF Radio Occultation Meteorology
EUMETSAT
CGMS COORDINATION GROUP FOR METEOROLOGICAL SATELLITES
IROWG 2nd Workshop

Impact of L2 extrapolation

YAROS/ROSA seems not to be impacted too much by L2 downward estrapolation problems (in this YAROS release, the new extrapolation technique developed by **Culverwell & Healy approach** is used [see presentation **Ionospheric correction of RO signals by direct modelling of ionosphere** expected for March 29th]**)**.

It can also be seen considering the results from another point of view. That is if we consider the statistics starting taking into account all the events for 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.



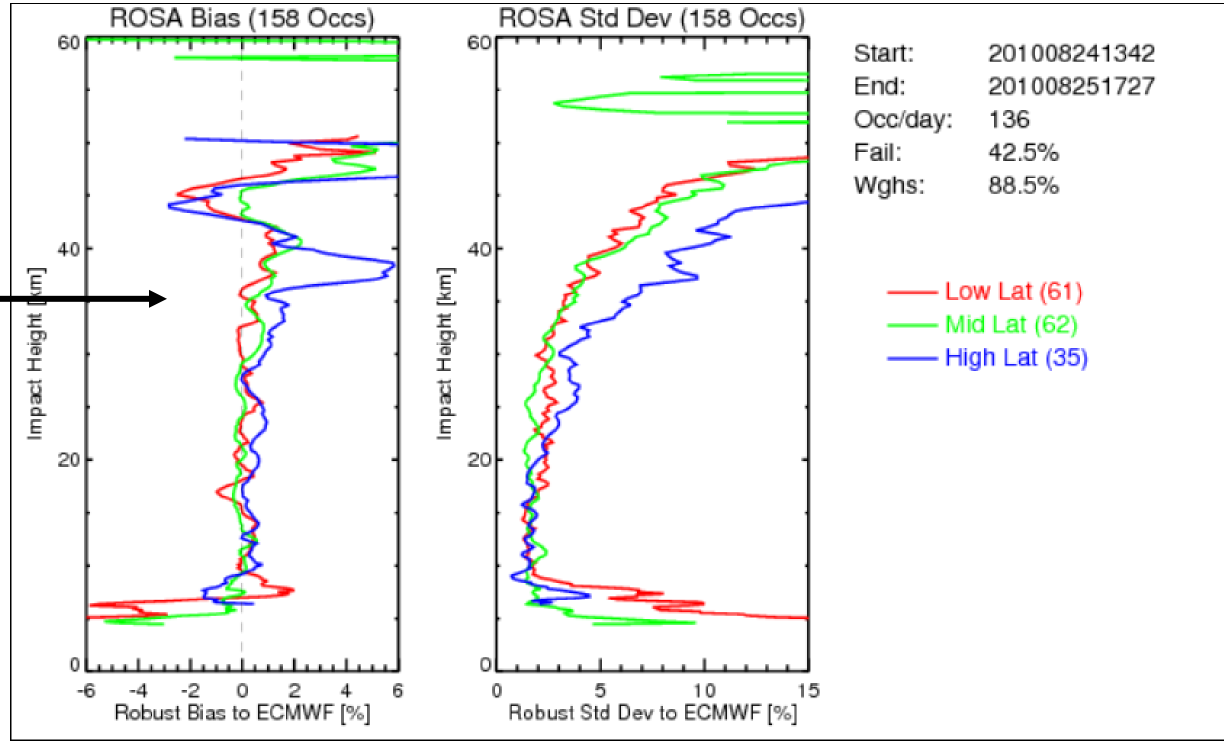
Gray: L2 available at least below 40 km (**90** events / 290 -> **31%**)
Green: L2 available at least below 35 km (**80** events / 290 -> **27.6%**)
Black: L2 available at least below 30 km (**65** events / 290 -> **22.4%**)
Cyan: L2 available at least below 25 km (**47** events / 290 -> **16.2%**)
Red: L2 available at least below 20 km (**32** events / 290 -> **11%**)
Blue: L2 available at least below 10 km (**16** events / 290 -> **5.6%**)

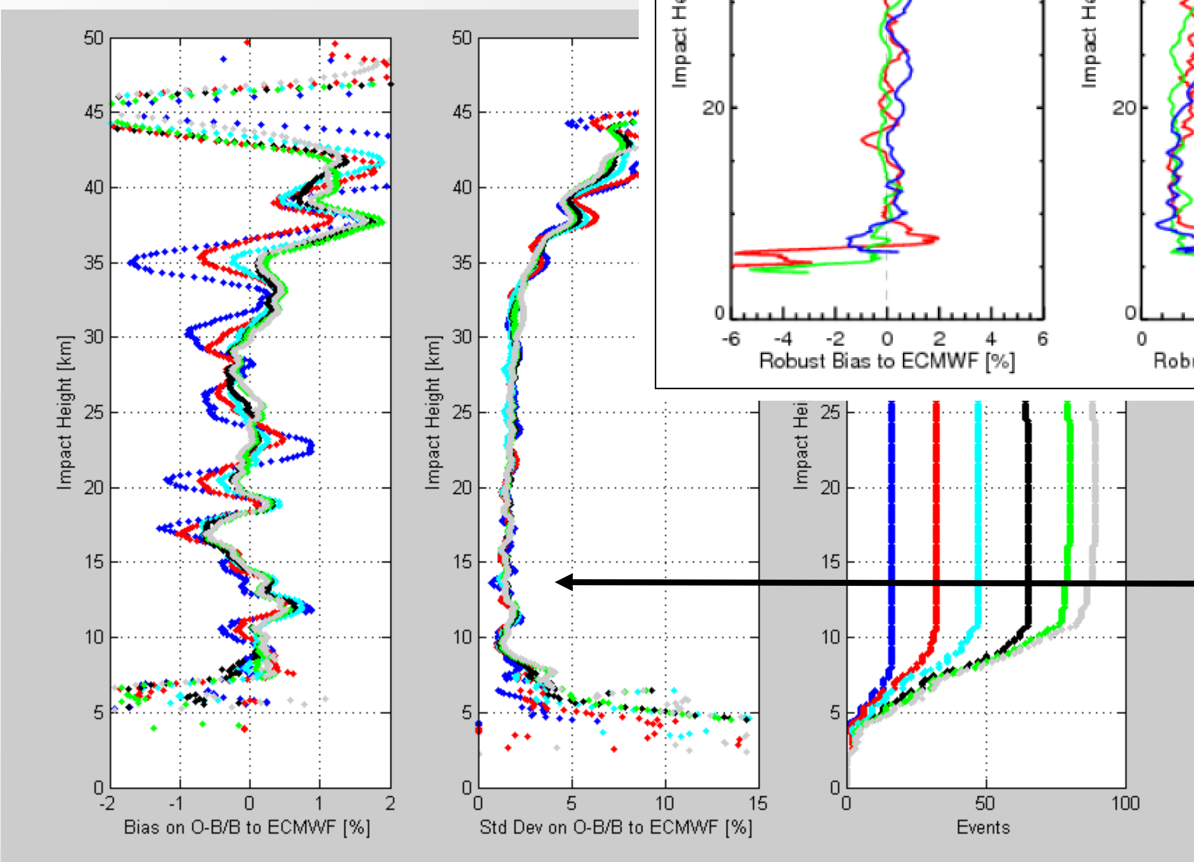
Impact on L2 extrapolation (2/4)

IROWG 2nd Workshop

Considering the same input dataset:

Robust Statistic on the overall events (bias and std profile wrt latitude)



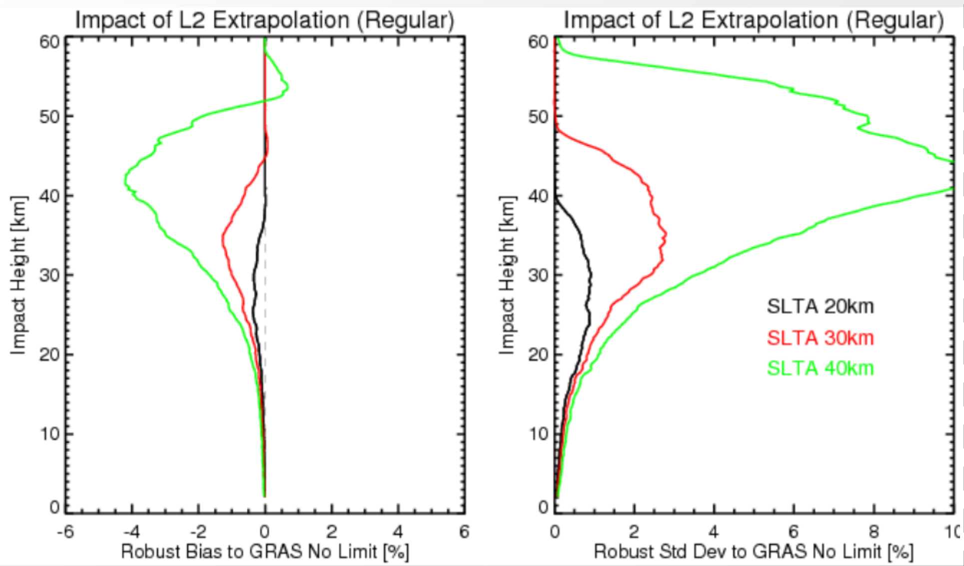


Non Robust Statistic (see gray plot to have a reasonable comparison with Robust Statistic results)

Impact on L2 extrapolation (3/4)

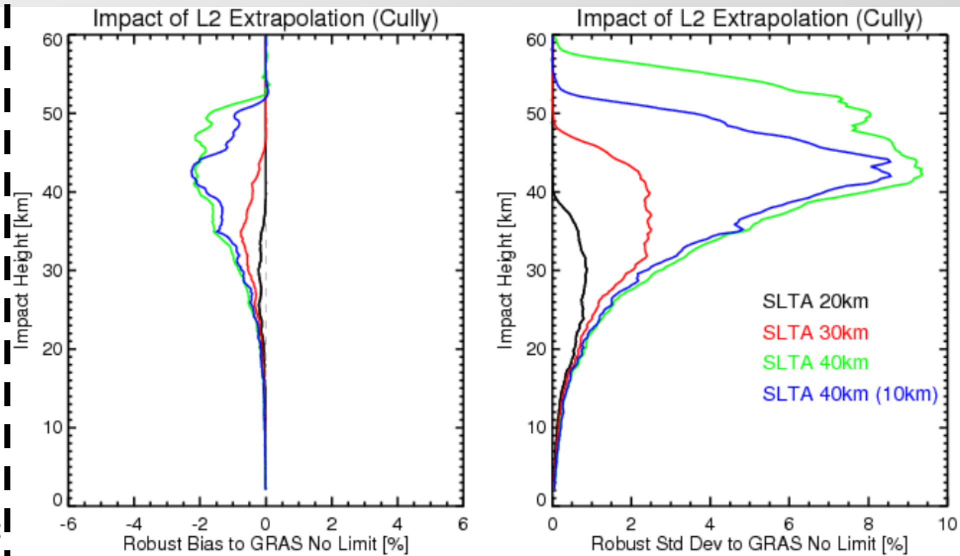
Impact of L2 extrapolation

A further attempt was made by *Axel Von Engeln* in better understanding the effect of L2 data **UNAVAILABILITY** below a certain SLTA. He run some GRAS retrievals where he just removed the L2 data up to a certain SLTA altitude (20, 30, 40 km) and compared them to the retrieval where all GRAS L2 data is available.



"regular" L2 extrapolation (robust fit of the L1-L2 data over 15km, extrapolated downwards, transition over 15km)

No bias below 15 km
Maximum (and high) bias near to the low boundary of the transition zone



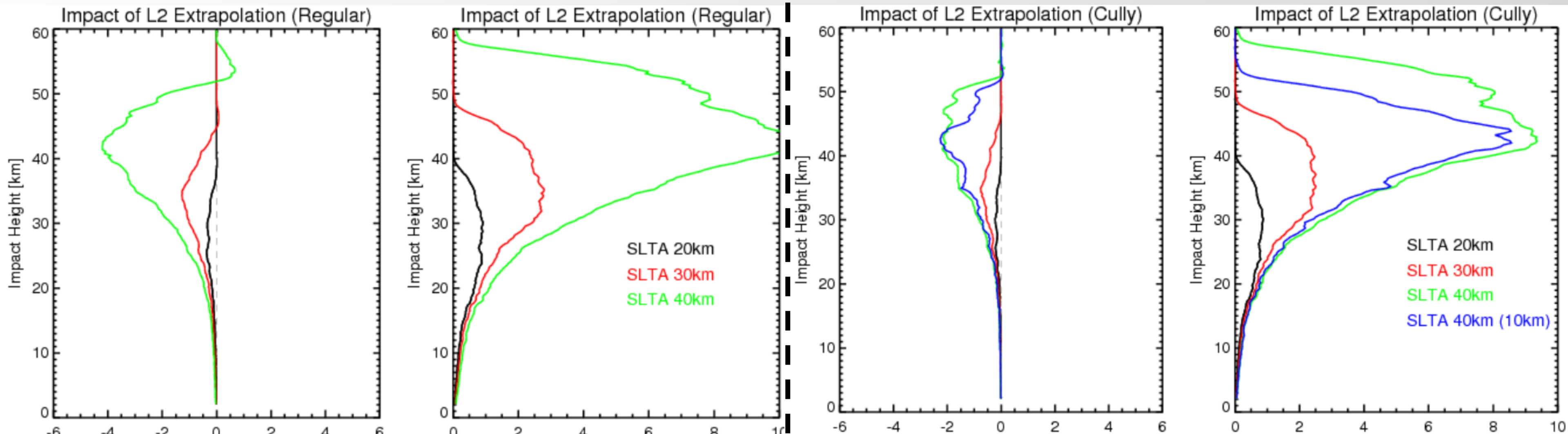
Culverwell-Healy (Cully) approach (similar setup, with 15km [10 km] transition, robust fit).

No bias below 20 km
Maximum bias near to the low boundary of the transition zone

Impact on L2 extrapolation (4/4)

Impact of L2 extrapolation

A further attempt was made by *Axel Von Engeln* in better understanding the effect of L2 data **UNAVAILABILITY** below a certain SLTA. He run some GRAS retrievals where he just removed the L2 data up to a certain SLTA altitude (20, 30, 40 km) and compared them to the retrieval where all GRAS L2 data is available.



Lesson learned:

- If L2 is not available above a certain SLTA level (in the average, 40 km for the ROSA observations onboard OC-2), degraded results are expected between ~ 20 ÷ 50/60 km (errors appears also in the region where observations are fitted)
- The impact of ionospheric extrapolation/compensation seems to be negiglible in the troposphere
- **Culverwell-Healy (Cully)** approach performs better than the standard one

Conclusions (1/2)

✓ ROSA Radio Occultation data handling has been implemented and tested into EUMETSAT and GRAS-SAF processing tools.

✓ Even if ROSA on board OCEANSAT-2 suffers for a lot of problems related to the platform, **L1 data quality seems to be similar** of that characterizing all the other known Radio Occultation instruments.

✓ **Platform issues severely impact on L2 data quality**. L2 signal starts to be properly tracked too high in the atmosphere. Several data gaps worsen L2 data quality.

✓ The statistical analysis performed to ROPP output profiles (bending angle, refractivity and dry temperature) reveals the ROSA **products goodness only when L2 observables are available below 10 km SLTA**. Unfortunately ROPP algorithms seemed actually not tailored to such bad data, in particular those algorithms in charge of extrapolate downward L2 data when they are not available.

✓ The bending angle statistical analysis performed considering YAROS Level 1b output reveals instead a good agreement with corresponding ECMWF Forward Modelled bending angle profiles. A better impact of the new Culverwell & Healy L2 extrapolation algorithm wrt the standard one is demostrated.

Conclusions (2/2)

✓ ROSA data on-board OCEANSAT-2 platform **seems to be 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 is often present a structure on such "uncalibrated" TEC, which may be caused **by sporadic E-layer (TBC)**.

✓ L1 and L2 Carrier Phase and amplitude limb sounding observations were often available at 50 Hz also during ionospheric sounding. These data can be considered as value-added products for **scintillation studies in ionosphere** and can open the door to future in-depth analysis

Recommendations

✓ 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**, some further efforts should be still done.

✓ From the receiver point of view, an in-depth analysis for better understanding the causes of L2 tracking problems is suggested.

✓ 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.

✓ The activity for updating YAROS/ROPP to ROSA data management is not ended. Their fine tailoring to ROSA data should be finalized.

IROWG 2nd Workshop
28th March - 3rd April 2012,
Stanley Hotel in Estes Park, CO, USA

CGMS COORDINATION GROUP FOR METEOROLOGICAL SATELLITES

Implementation of ROSA radio occultation data handling into EUMETSAT and GRAS-SAF processing

R. Notarpietro – *Politecnico of Turin (Italy)*
C. Marquardt, A. Von Engeln, Y. Andres, A. Foresi – *EUMETSAT (Germany)*
K. Lauritsen, K. Kinch, H. Wilhelmsen – *ROM-SAF @ DMI (Denmark)*
A. Zin, S. Landenna – *Thales Alenia Space Italy (Italy)*
V. Catalano, V. De Cosmo – *Italian Space Agency (Italy)*

Thank you very much!!!