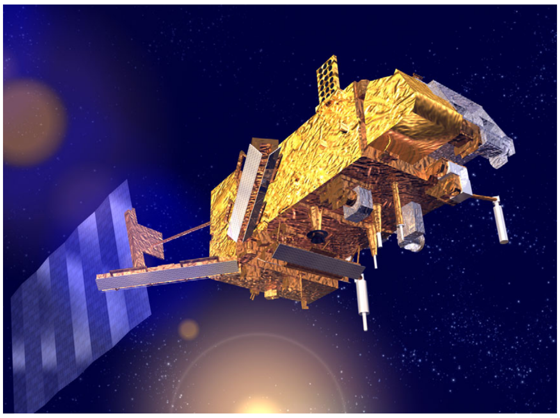
GRAS on MetOp

Instrument Characteristics and Performance Evaluation



Content:

- Study overview
- Instrument performance
- Potential improvements
- Conclusions
- Future instrument and missions

GRAS Study Team:

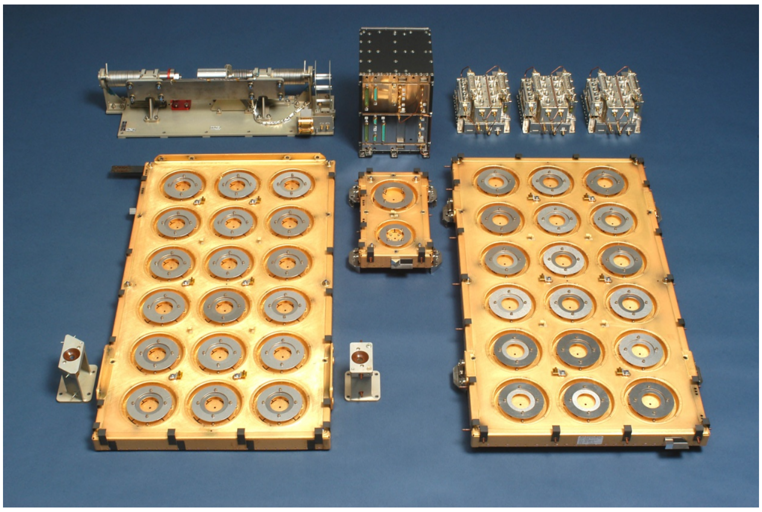
- RUAG
- DMI
- EUMETSAT
- UoG
- DLR
- GFZ

Magnus Bonnedal

GRAS RO Performance Study

- **ESA Study No. 21995/08/NL/EL**
- **Main Objectives:**
  - Validate reconstruction of GRAS open loop data and implement an optimum spectral based processing
  - Evaluate aspects of the POD processing
  - Study difficult measurement conditions
  - Find potential improvements for present and next generation instruments
- **Participants:**
  - DMI, Copenhagen (Presentation by Kent B Lauritsen)
  - EUMETSAT, Darmstadt (Presentation by Christian Marquardt)
  - UoG, Wegener Center, Graz
  - DLR, Munich
  - GFZ, Potsdam (Poster by Florian Zus)
  - RUAG Space, Gothenburg (tem leader)
- **Schedule:**
  - KO, Jan 2008
  - Final presentation, Sept - Oct 2010

GRAS: GNSS Receiver for Atmospheric Sounding



- RUAG-Sweden: Instrument and antennas
- RUAG-Austria: DSP & S/W
- Mass ~30kg
- Power ~40W
- ~20MB per orbit / ~280MB per day
- 650 – 700 occultations / per day
- Setting & Rising Occultations
- GPS dual freq, codeless tracking
- AGGA-2 based

Launched 19th Oct 2006; switched on 27th Oct 2006; worked out of the box.

Operational bending angles April 2008, ECMWF May 2008, MetO July 2008

Bending Angle Noise

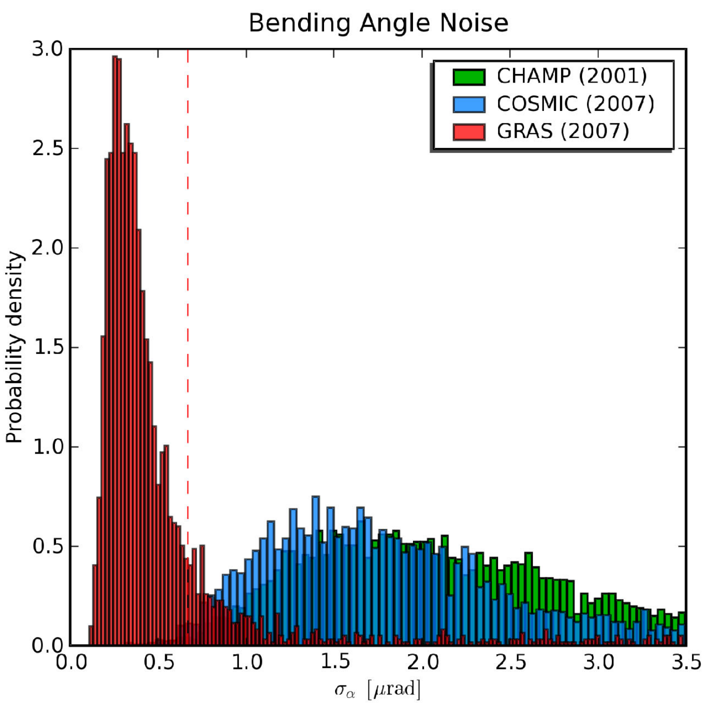
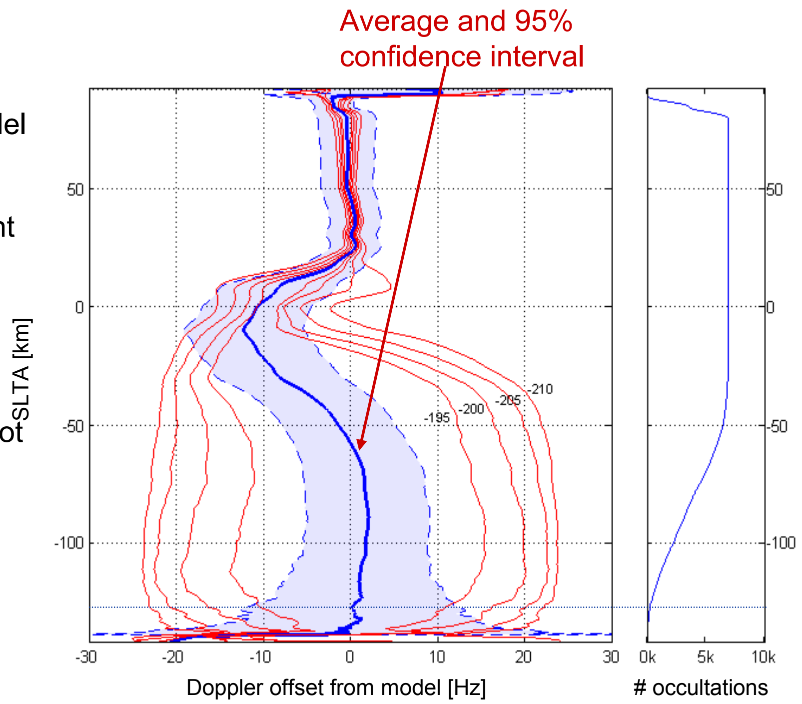


Figure courtesy of Christian Marquardt, EUMETSAT

- GRAS Bending Angle requirement:
  σ < 0.64 μrad 30-80 km
- GRAS has very low measurement noise.
  (Antenna gain + USO enabling zero differencing processing)
- All data processed by EUMETSAT, identical settings, noise in estimates vs. CIRA / MSIS between 60 and 80 km

GRAS Doppler Model

- 10 Hz on-board Doppler model accuracy.
- ±25 Hz captures all significant power in the occultations
- OL sampling rate of 100 Hz is sufficient
- Closed loop carrier tracking not needed in future (if no codeless tracking)



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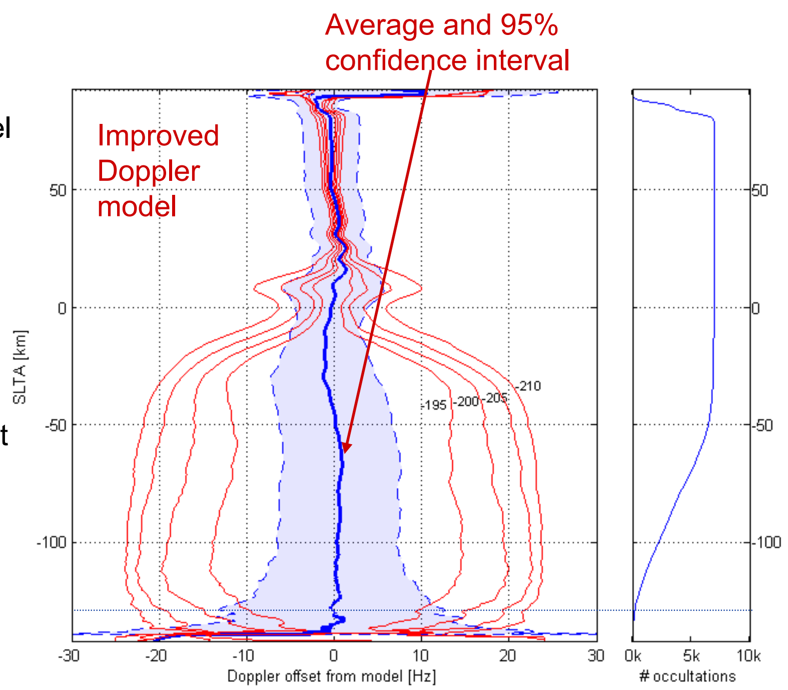
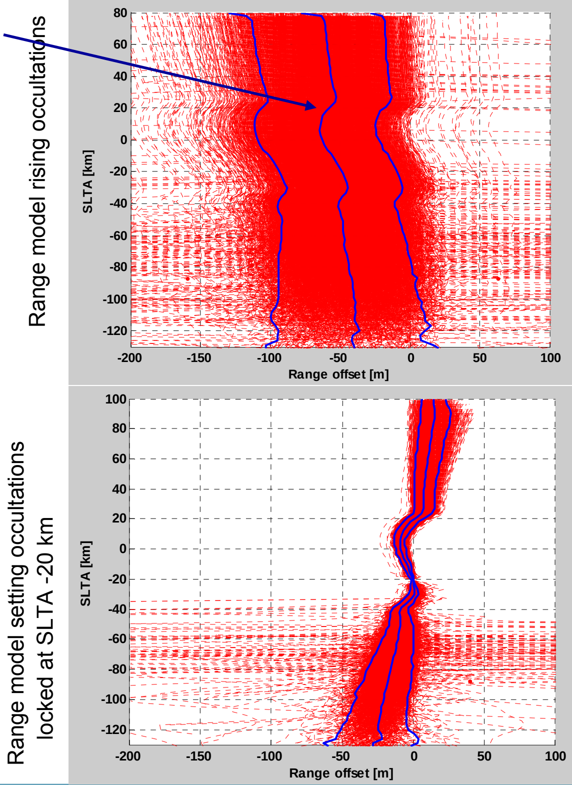


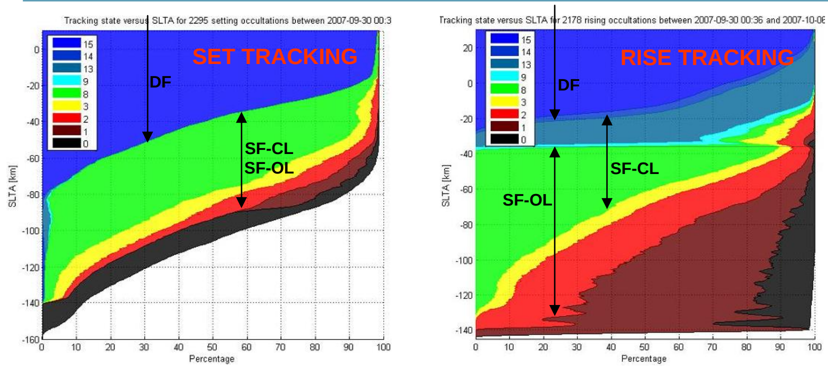
GRAS Range Model

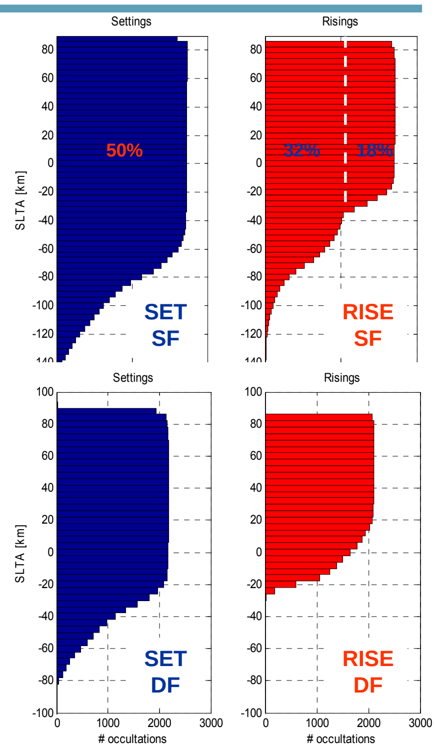
Average and 95% confidence interval

- Absolute range better than 150 m. (Improvable to ~50 m)
- Relative range ~20 m over 100 km SLTA
- Range model is used for acquisition and tracking aiding
- Acquisition search window can be reduced from ±8 chip to ±0.5 chip
  - Eliminate sequential search
  - Faster acquisition
- **Conclusion**
  - More trust in on-board Doppler & Range models for tracking and acquisition



Measurement Altitudes





Conscious SF & DF Data

Extension to Lower Altitudes:

- Increased trust in Doppler & Range models
- Extend coherent integration time
- Lower cut-off for Loss of Lock detector
- Adapt further to signal dynamics

Closed Loop Data Gaps in Rising Occ's

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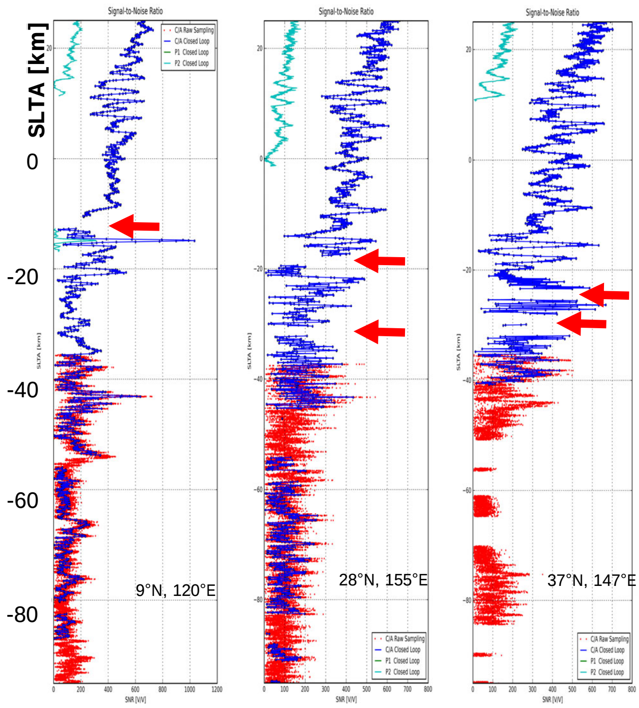
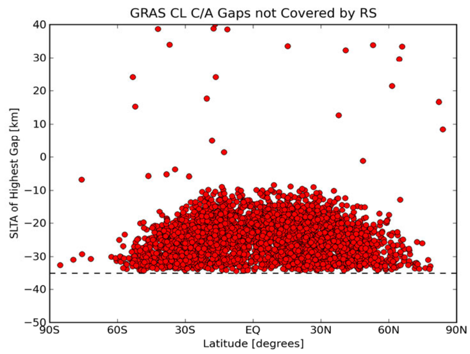


- Rising SF data gaps at SLTA > -35 km for ~18% of all occs, mainly low latitude
- Related to H/W resources (RS or L2)
- Mitigation on GRAS:
  - a. Raise SLTA L2 & Extend iono extrap.
  - b. Update on-board S/W
- Future: Adapt S/W

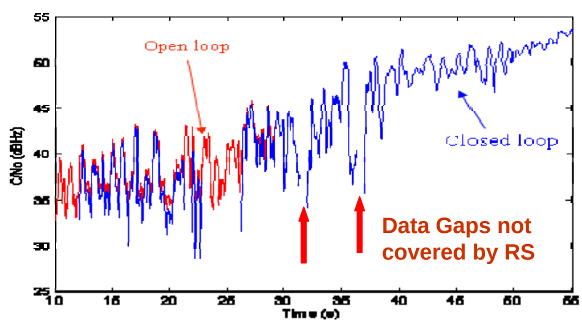


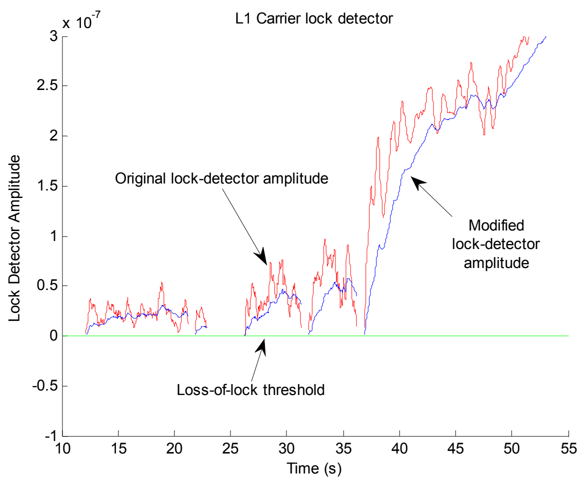
CL Loss-of-Lock (Carrier Loop)

RUAG

- Carrier tracking lost due to Loss-of-Lock (LoL) detection.
- Amplitude detector is exposed to
  - Local fades
  - Fluctuations due to noise and ground interf.
- Extend integration to get across fades
- Improve referencing relative noise floor
- Can be fixed by patching a S/W parameter

Red - LoL on GRAS
Blue - Changed LoL parameter

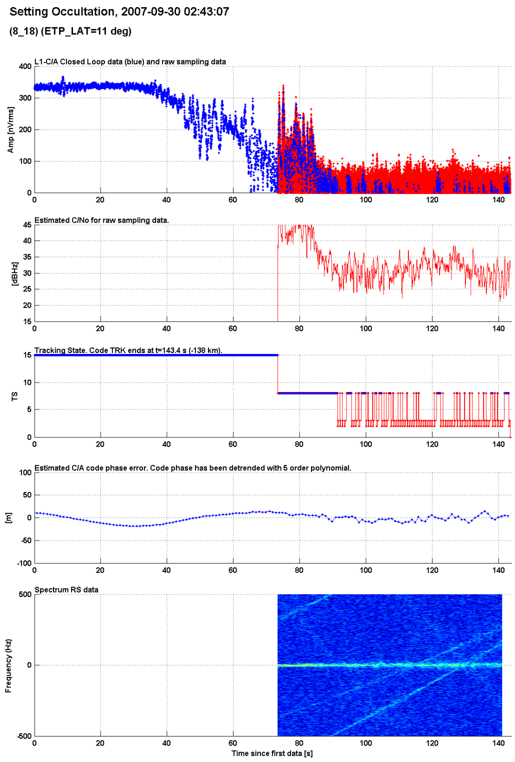




RS Loss-of-Lock (Code Loop)

RUAG

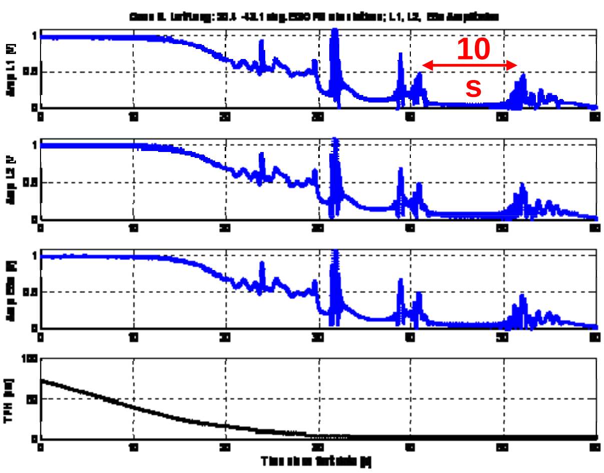
- C/No and code phase error are evaluated at loss-of-lock, LoL, instances.
- Code phase is seldom out of range at LoL.
- Energy is usually sufficient for tracking at LoL, but the LoL amplitude detector has triggered due to a noisy amplitude estimate and most likely also due to varying ground interference.
- Also most of the multiple Rising acquisition attempts are tracking phase correctly.
- Potential solutions: longer integration of amplitude estimate or continued tracking until SLTA low limit ⇨ parameter change in S/W



Examples of other effects

RUAG

- **Long fades in tropical regions**
  - ➢ **Predict where energy re-appears**
  - ➢ **Open-loop tracking**
- **Ground Based Interference**
  - – RO gain peaks on earth
  - – Noise level fluctuate several dB
  - – GND Radar Saturates Rx
  - ➢ High selectivity required
    GRAS: 80 dB front-end, 180 dB total
- **Co-channel interference**
  - – Interf. GNSS 30 to 40 dB above desired signal
  - – C/A orthogonality: 25 – 30 dB
  - ➢ Discriminate on Doppler
  - ➢ Re-confirm acquisitions



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- **Long fades in tropical regions**
  - ➢ Predict where energy re-appears
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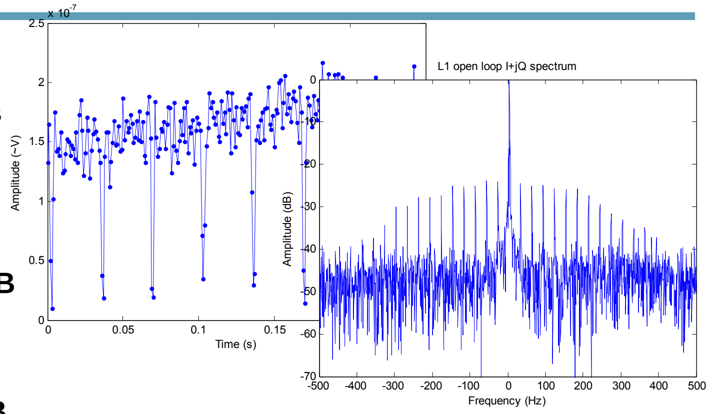
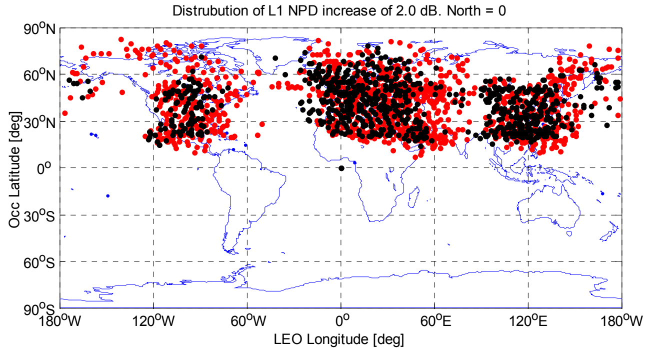


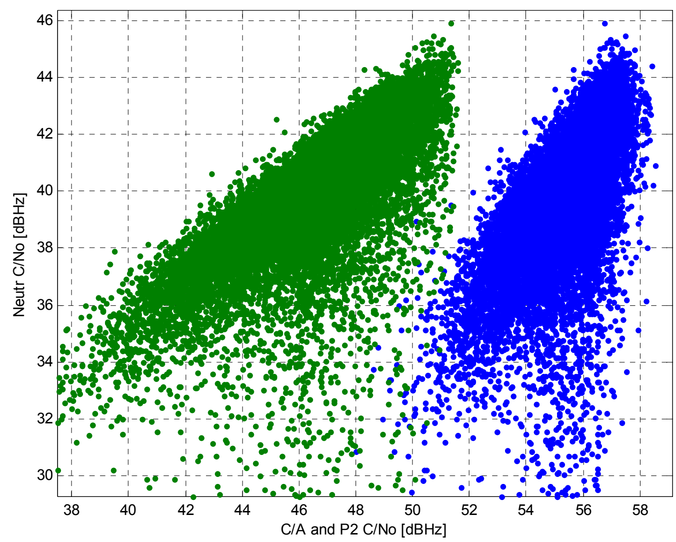


Examples of other effects

RUAG

- **Ground Based Interference**
  - **▬Y-axis: C/No from std of neutral phase**
  - **▬X-axis: C/A and P2 C/No from amplitude and thermal noise**
  - **▬High correlation, std is degraded by iono fluctuations.**
  - **➢Ground based interference affect signal quality.**
  - **➢But not identified in retrieval error?**

C/No from std of neutral phase



C/A & P1 C/No from amp. and thermal noise

Examples of other effects

RUAG

- **Long fades in tropical regions**
  - ➢ Predict where energy re-appears
  - ➢ Open-loop tracking
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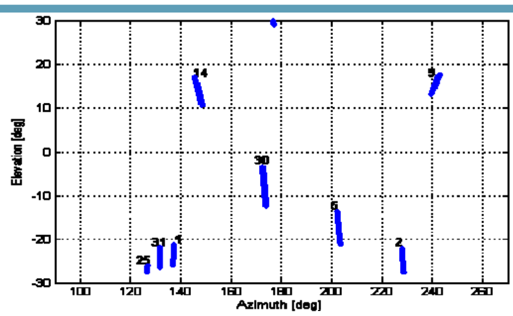
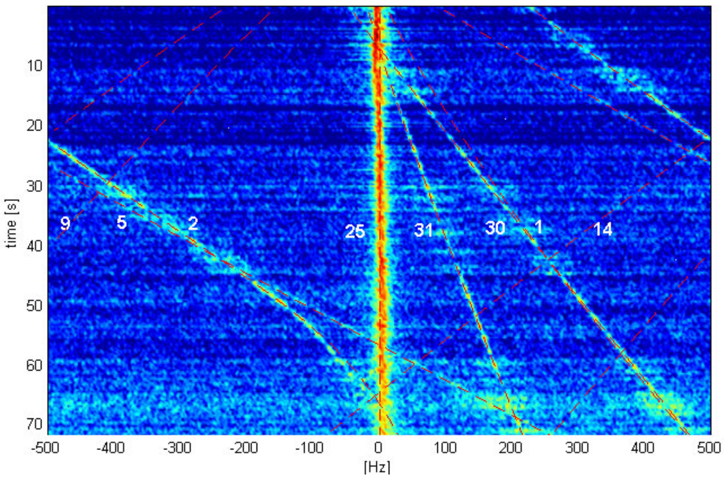
  - — **C/A orthogonality: 25 – 30 dB**
  - ➢ **Discriminate on Doppler**
  - ➢ **Re-confirm acquisitions**
  - ➢ **No impact on retrieval**





GRAS OL: Surface Reflections (SR)

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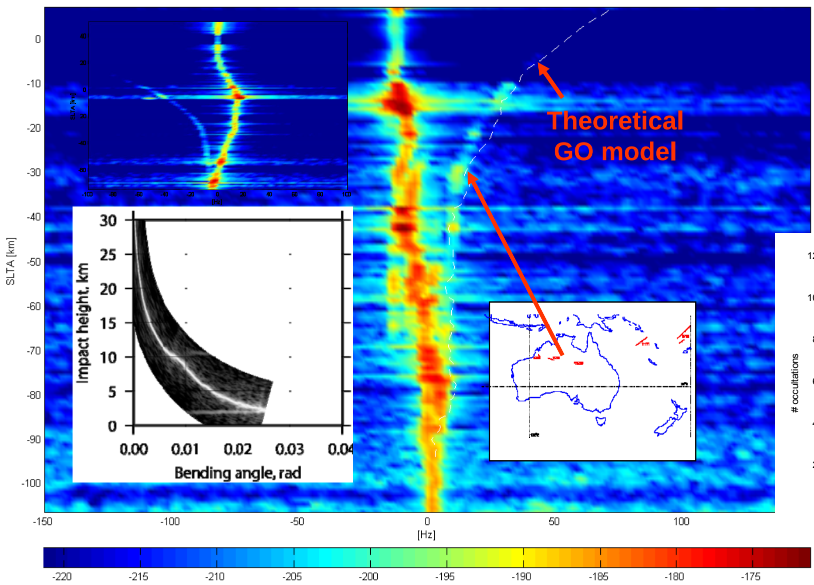
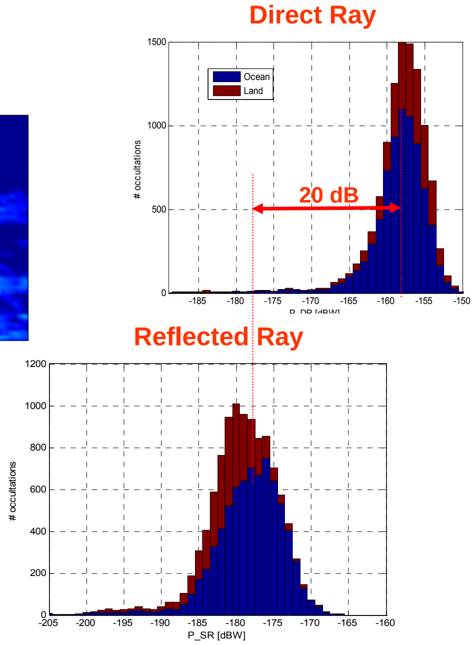
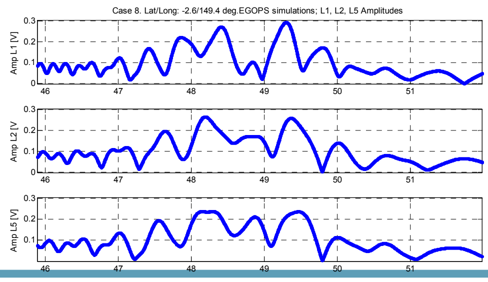
- Surface Reflections are frequently observed
- SR typically 20 dB below Direct Ray
- SR resolved by FSI (and similar inversions)

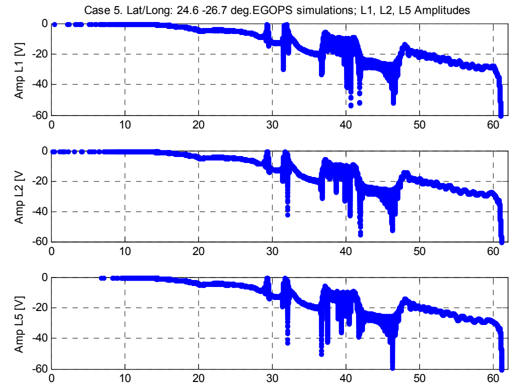


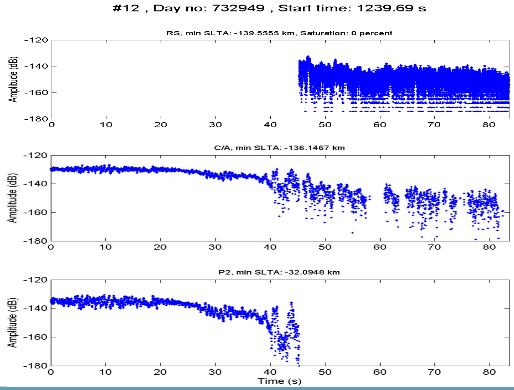


EGOPS WOP Simulations 1/2

- EGOPS WOP simulations have been evaluated, code phase calculated.
- Some of WOP simulations correspond to the Study Case, (closest in time ±6h and space)
- Right, example of good agreement.
- Several examples of signal that recovers after e.g. critical refraction. Important to capture this energy.
- The simulations useful to analyse signal tracking, the entire occultation is included, noise can be added separately.

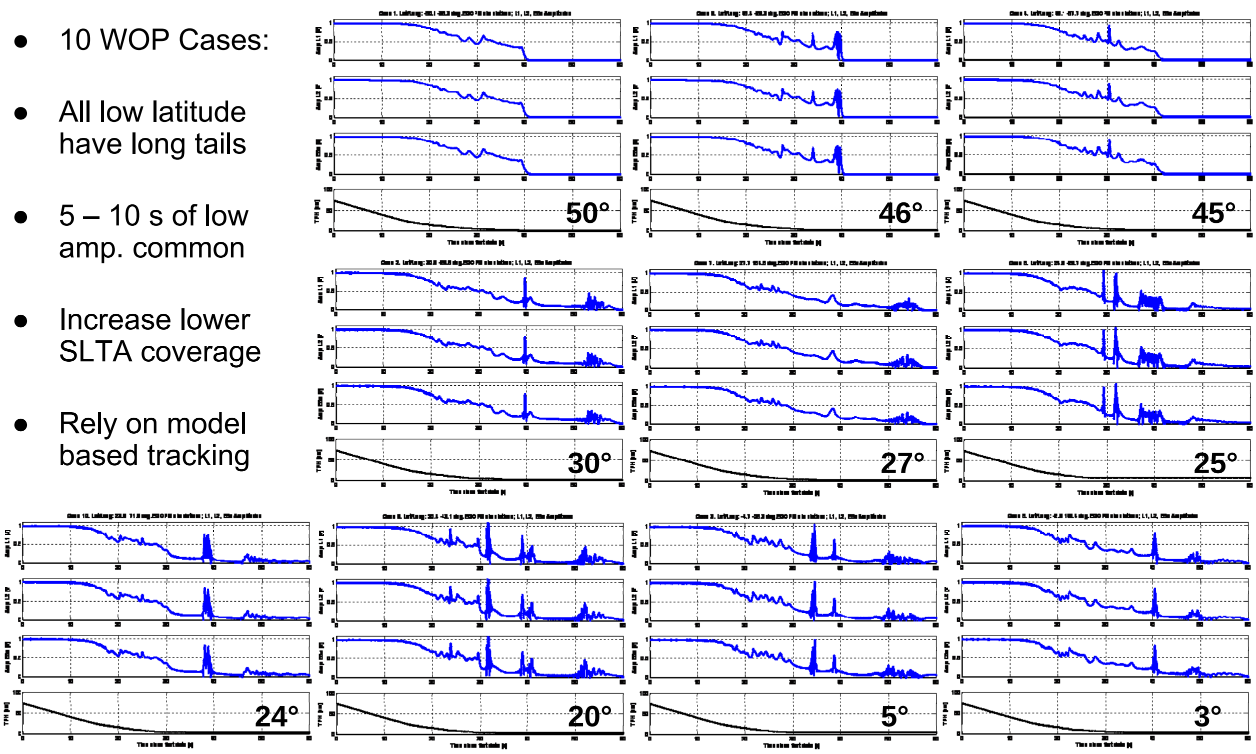






EGOPS WOP Simulations 2/2

- 10 WOP Cases:
- All low latitude have long tails
- 5 – 10 s of low amp. common
- Increase lower SLTA coverage
- Rely on model based tracking



Conclusions 1/2

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- We can trust the Doppler (±25 Hz) and Range models (±50 m), reduce search windows, and use stronger aiding of tracking loops. This leads to faster acquisitions, fewer false acquisitions, and more robust tracking through fades and to lower altitudes, both rising and setting
- Increased knowledge of signal dynamics (larger amplitude and smaller phase variations than expected) can be used to adapt acquisition and tracking algorithms.
- Coherent integration can be increased in order to make acquisition faster and tracking more robust.
- With modernised open signals, open loop carrier tracking is sufficient.
- The ground interference noise varies considerably. Tracking and loss-of-lock detection can be adapted to mitigate the disturbance.

RUAG GNSS Receivers

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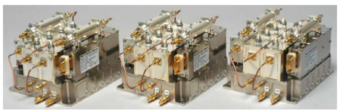
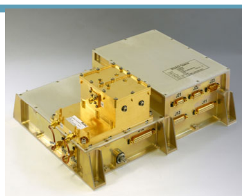




RO
GRAS MetOp A
B
C
Operational

RO
GPSOS NPOESS
EDU

POD
IGPS Pre-Developm.

POD
SWARM
Production Phase
6 units
New Generation:
- Modular
- Compact
- Front end RFASICS
- UART i/f
- Compact antenna

POD
Sentinel-1 A
Sentinel-2 A
Sentinel-3 A
Production Phase
6 units
New Features:
- 1553 i/f
- Dynamic Nav solution
- Choke ring antenna
- S/C multipath analysis

POD
Sentinel-1 B
Sentinel-2 B
Sentinel-3 B
2:nd generation ordered
6 units
EartCARE

POD
Sentinel-1 C
Sentinel-2 C
Sentinel-3 C
3:rd generation anticipated
6 units
RO
Post EPS

GPS: L1 C/A + L2 Codeless tracking
GPS: L2C
GPS: L2C +L5 Galileo, Compass

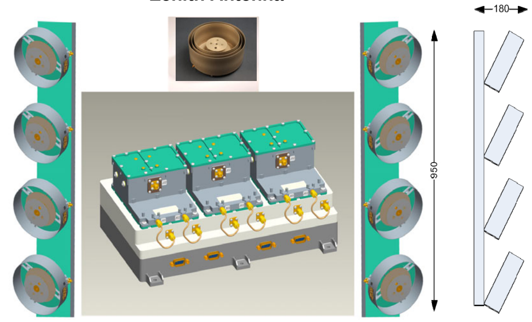
GNSS Sensor on Future Missions

RUAG

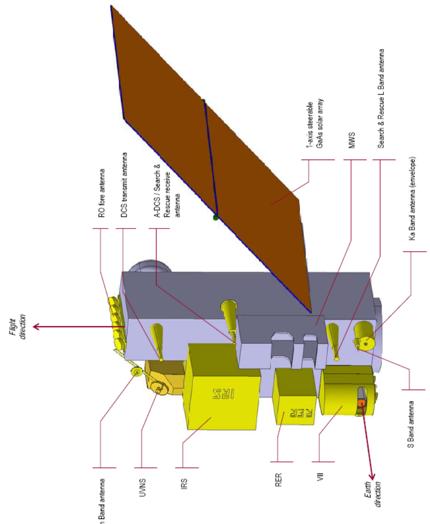
Possible missions:

- MetOp Second Generation
- Iridium NEXT
- CLARREO
- COSMIC Second Generation

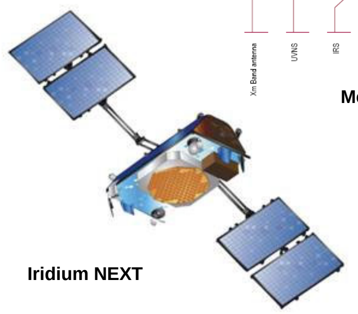
Zenith Antenna



Occultation Antenna **RO Electronics** **Occultation Antenna**



Iridium NEXT



MetOp Second Generation

RO Sensor Modular Design

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RO SENSOR