Overview on GRAS
Raw Sampling and Data Quality Aspects

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and the GRAS Raw Sampling Study Team

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September 2010

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Outline

- A bit off-topic: GRAS (and Metop) after 2012
- Issues with GRAS data quality
- 2 Studies
- EUMETSAT's FSI
- Summary & Outlook

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GRAS on Metop

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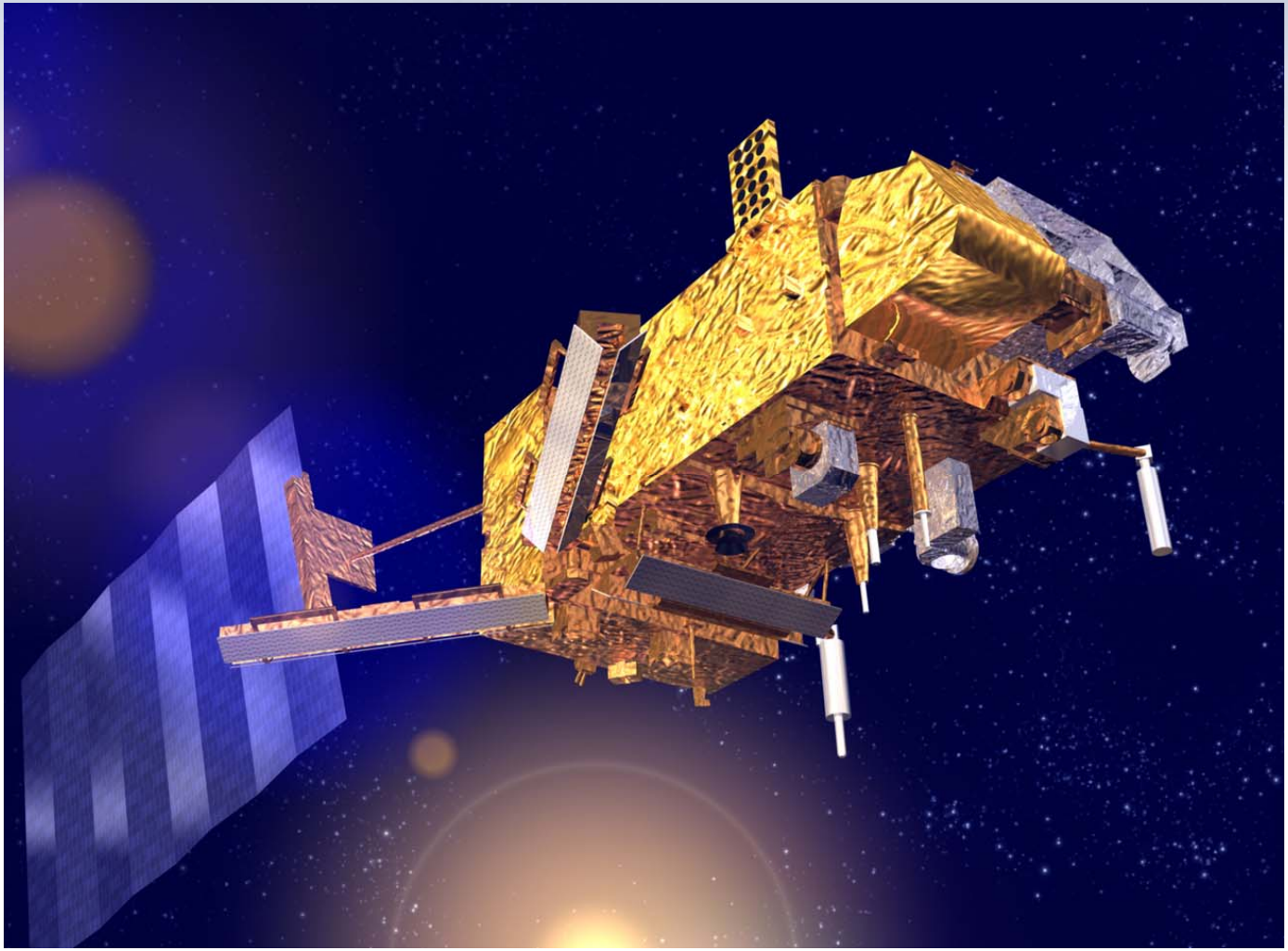
GRAS on Metop: EPS



- Metop-A is the first of three satellites in the European Polar System (EPS)
- Europe's contribution to the Initial Joint Polar-Orbiting Operational Satellite System (IJPS)
- Into 2020's, with identical instruments on each S/C (except for HIRS)
- GRAS (GNSS Receiver for Atmospheric Sounding)
- 1st custom build GPS receiver for operational RO

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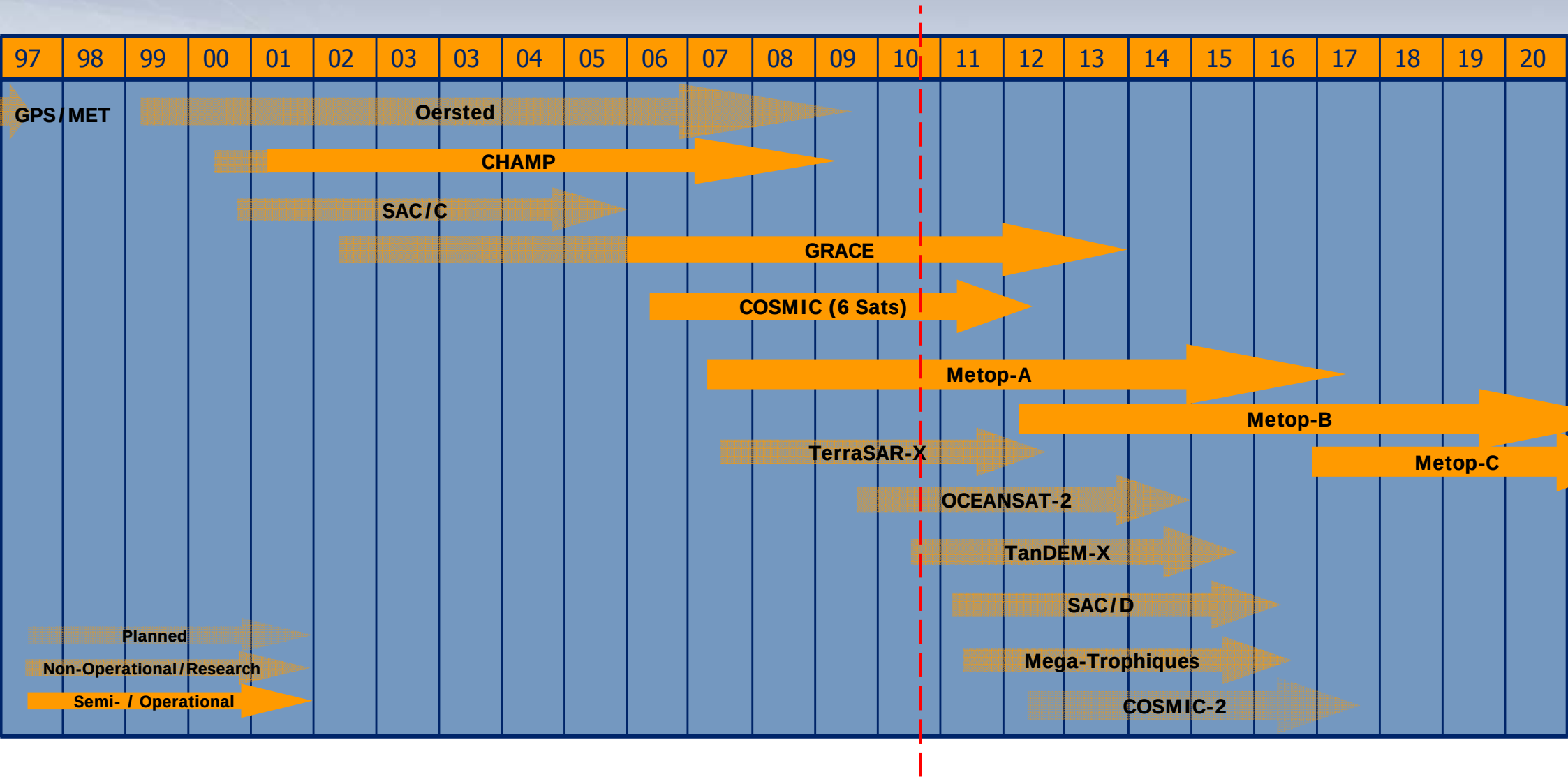
GRAS on Metop: Instruments Overview



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Issues in GRAS data

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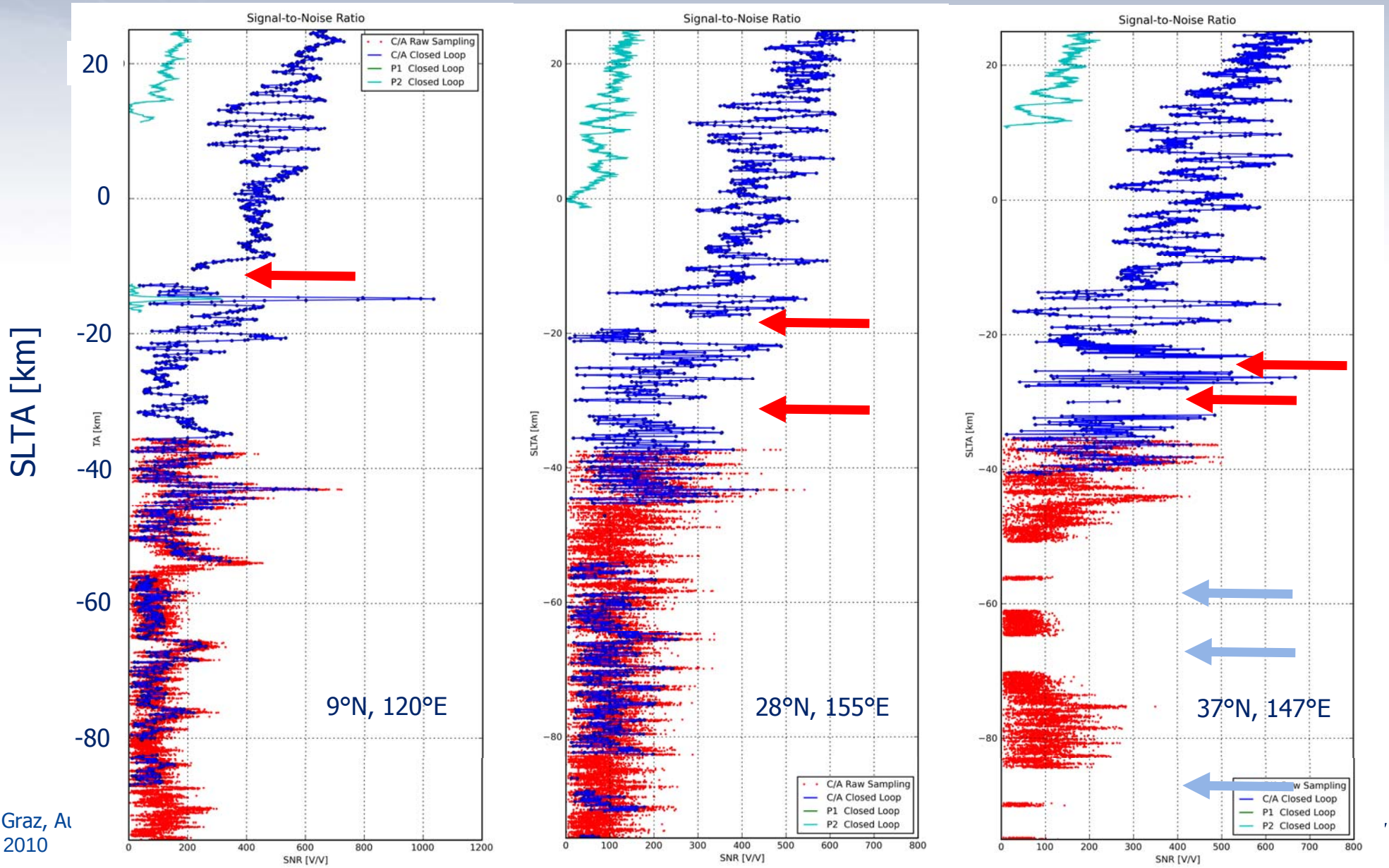
Raw Sampling

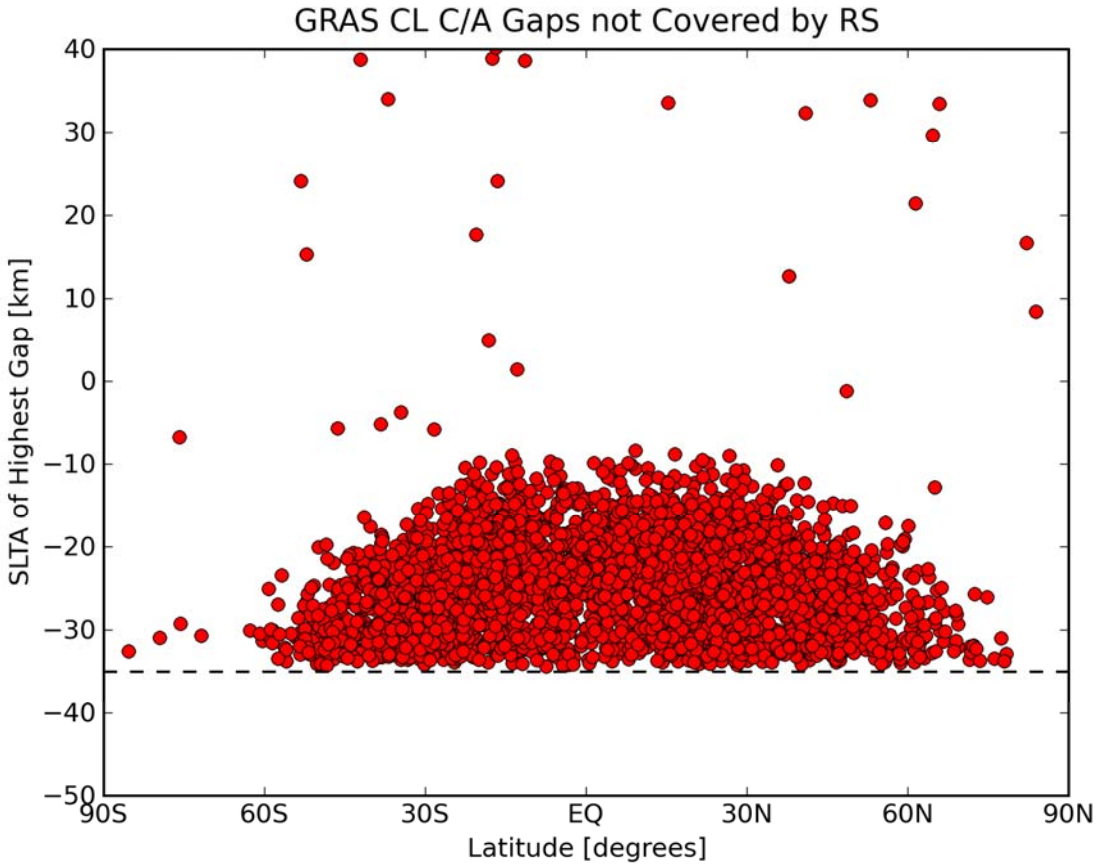
- **Dual Frequency Carrier Tracking:** code and carrier for L1 and L2 are tracked; both (+ C/A) are reported @ 50 Hz
- **Single Frequency Carrier Tracking:** C/A code and carrier phase are tracked; C/A code and carrier are reported @ 50 Hz
- **Single Frequency Raw Sampling:** C/A code tracked, 1 kHz sampling of carrier

- SF carrier tracking and raw sampling can occur simultaneously
- Either L2 or RS
- GRAS requires the C/A code being tracked even in Raw Sampling mode
- Tracking state information available

Closed Loop Data Gaps in Rising Occ's



Closed Loop Data Gaps in Rising Occ's (cont'd)



- SLTA of highest gap in C/A carrier phase data (from October 2007)
- About 33% of rising occultations are affected, 16% in total
- Will have to live with this in "historic" data; workarounds and maybe a fix in the GRAS firmware in the future
- In addition: most occultations have gaps in the RS part due to C/A *code* tracking losses

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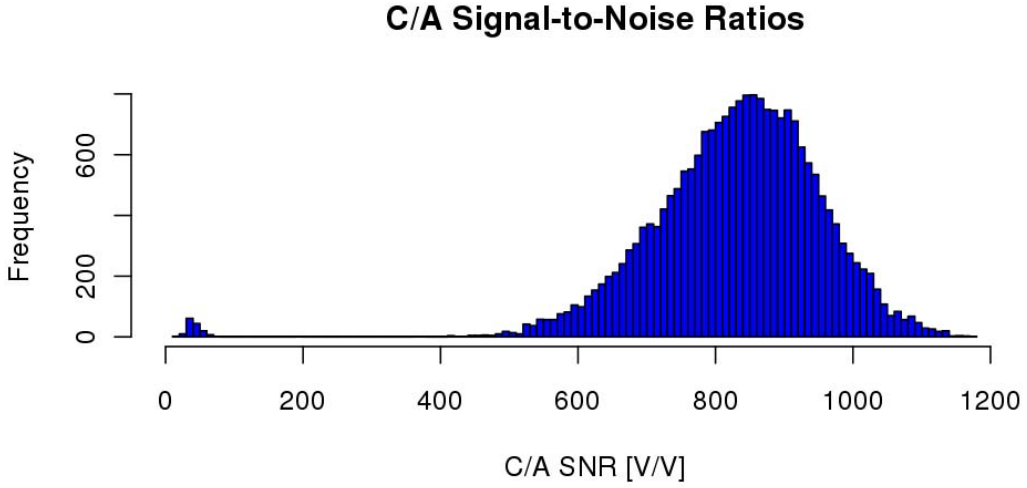
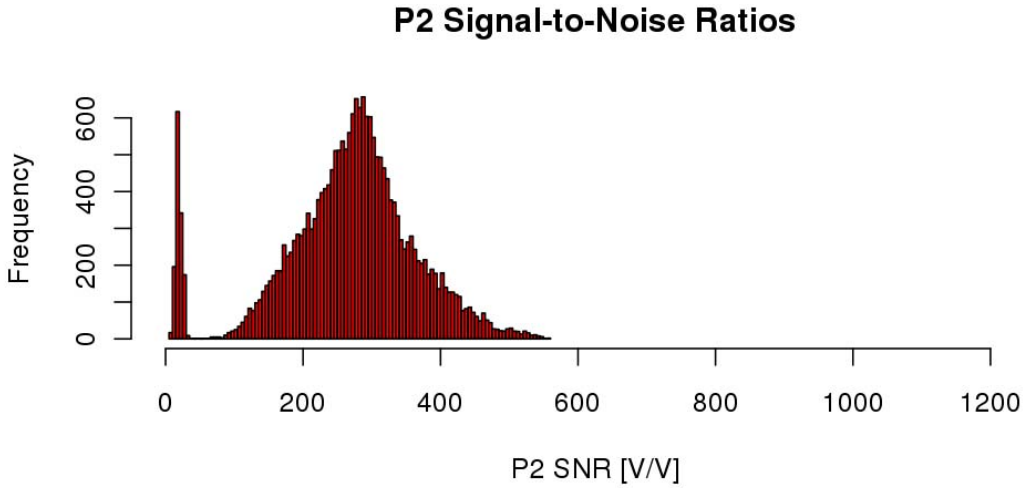
Low L2 SNR





- C/A SNR < 200 for ≤ 1% of all occultations
- P2 SNR < 50 for ≤ 7% of all occultations
- no relation to rising/setting
- Magnus says: GRAS tracks wrong portion of the code
- in effect: large number of cycle slips in L2 phase data
- Retrievals are either significantly noisier, or not useful at all; will flag these profiles as 'bad'

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Studies

Note: We will concentrate on bending angles in the following…

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ESA Study on GRAS Data Quality (21995/08/NL/EL)

Formal study team:

RUAG (talk by Magnus)	DLR (POD)
DMI (talk by Kent)	ESA/ESTEC
Uni Graz	EUMETSAT

supported by

Michael Gorbunov (GRAS SAF visiting scientist)	Arne Jensen (EUM visiting scientist)

and even by (without funding – thank you *very* much!)

GFZ Potsdam (poster by Florian)

Study aims:

- Validation of reconstructed GRAS amplitude and phase data (RUAG was happy with us at the end;-)
- Initial assessment of GRAS performance and different advanced retrieval algorithms in the troposphere

Note:

- All results of this study are based on the same level 1a data set (and orbits) produced by EUMETSAT
- Possible retrieval differences highlight structural uncertainties in the level 1b processing

EUM Study on Structural Uncertainty in RO Retrievals

Study team:

UCAR (talk by Chris) EUMETSAT

Study aims:

- Structural uncertainty issues in low level reconstruction
- EUMETSAT wanted to initiate / support
  - GRAS data reconstruction independent from EUMETSAT
  - offline or even operational processing of GRAS data outside of EUMETSAT

Note:

- Initially targeted GO retrievals only, but UCAR proposed an extension (with DMI) to study tropospheric data as well – will start in November (but see early work in Doug's talk)
- UCAR developed their own GRAS reconstruction system and used their own orbits (but had visibility of the EUMETSAT prototype)
- Possible retrieval differences highlight structural uncertainties in both level 1a and level 1b processing (and POD)

EUM/UCAR Study on Structural Uncertainty

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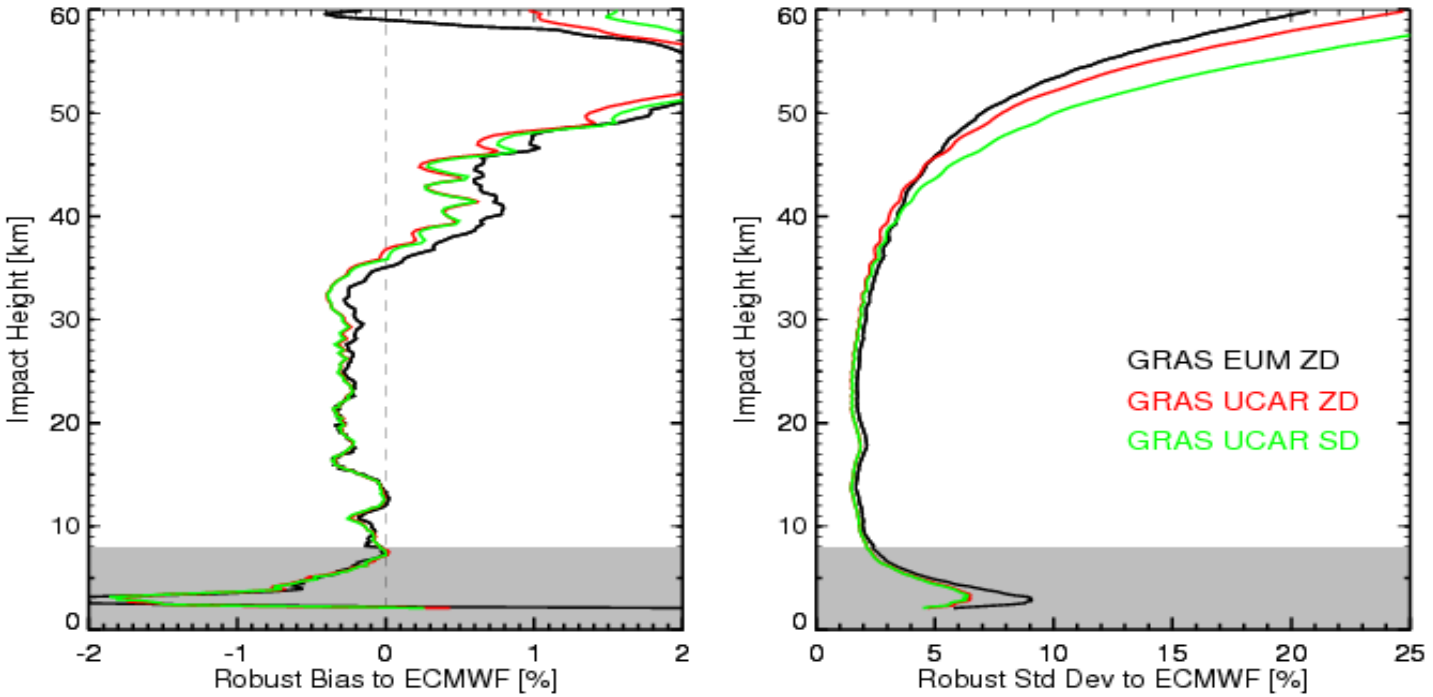
GRAS Statistics vs. ECMWF



- UCAR based processing of GRAS data (Oct 2007)
- EUMETSAT provided prototype processor for guidance
- ZD: Zero differencing, SD: Single differencing.
- Grey shaded area indicates GO-related limitation due to multi-path.

Note: The bias structure GRAS/UCAR and GRAS/EUM is interesting; we see a similar one between COSMIC/EUM and GRAS/EUM.

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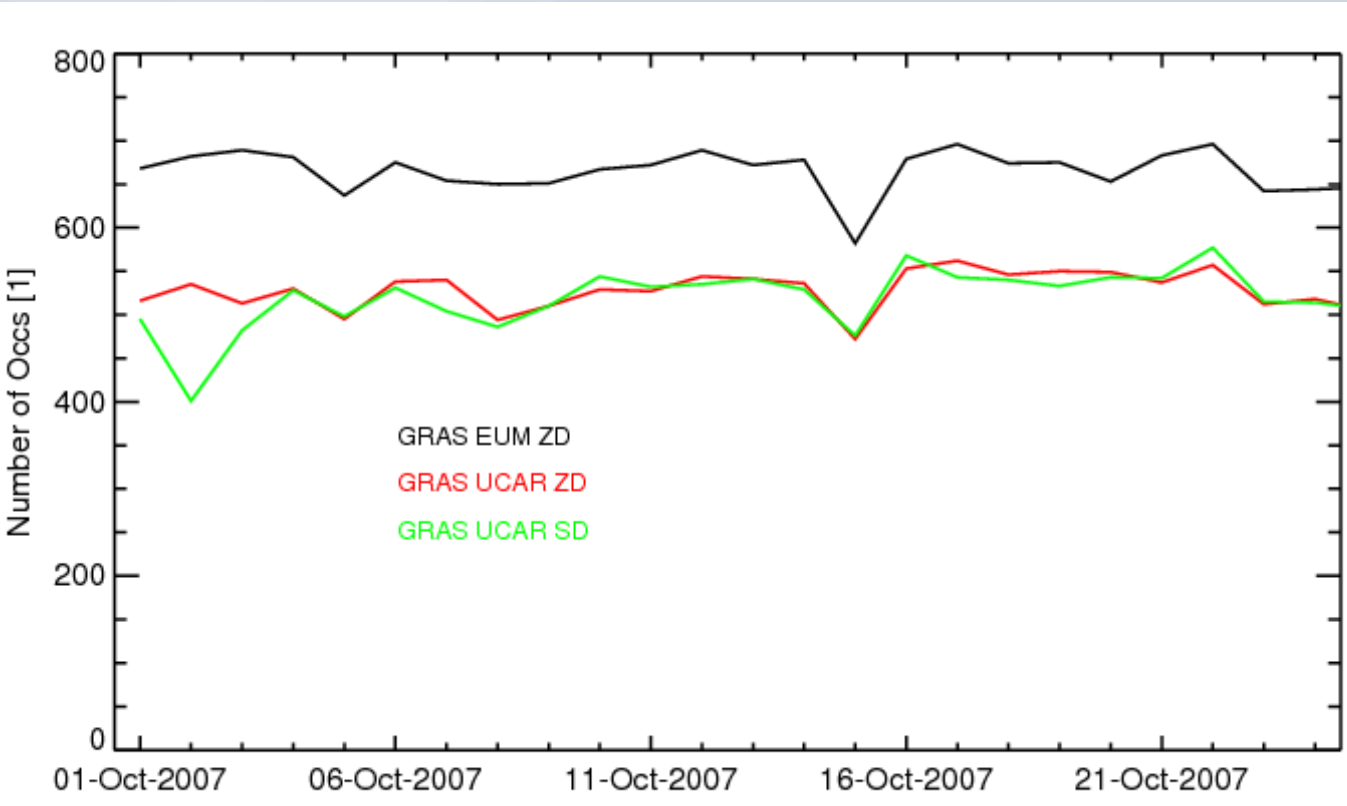
Number of Occultations



- UCAR based processing of GRAS data (Oct 2007) including independent POD and level 0 reconstruction
- ZD: Zero differencing, SD: Single differencing.
- UCAR certainly applies a strict QC to the profiles they deliver (15% of profiles less than what's available)

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ESA Study on GRAS Data Quality

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Study Period and Special Thanks

- Study period: 30. September 2007 – 31. October 2007
- Reconstructed (level 1a) data provided by EUMETSAT
- Special thanks for the provision of navigation bit data for this study:
  - Chris Rocken (UCAR – ~ 75% coverage)
  - Georg Beyerle (GFZ – ~ 75 % coverage)
  - Yoaz Bar-Sever (JPL – 100 % coverage)

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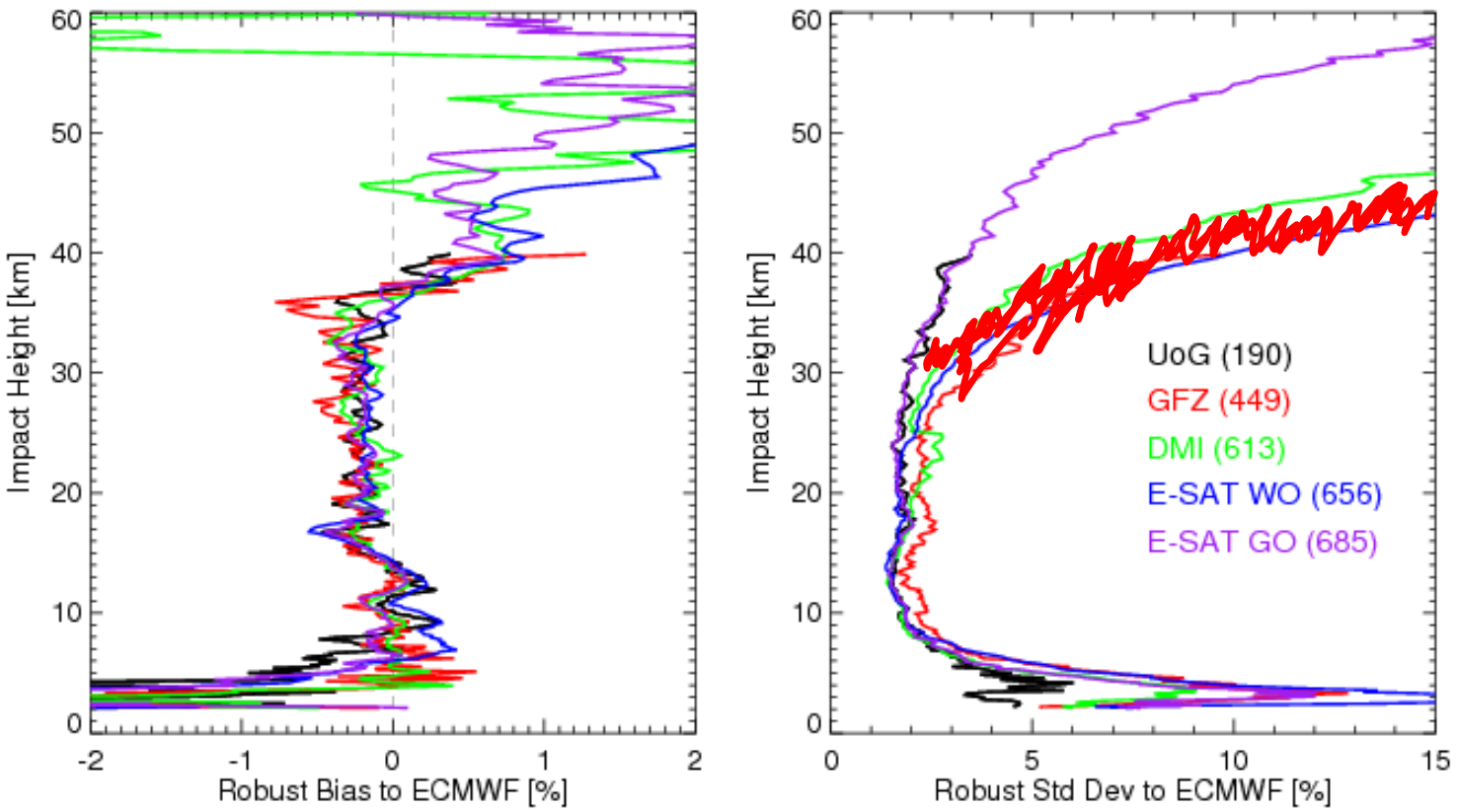
Processing Setups

Centre	Algorithms	Filter	Remarks
DMI	CT2 < 25km, GO above	radioholographic filtering; combined ionosphere & stat opt	missing navbits replaced by internal navbit estimates
	FSI		
GFZ	FSI < 12 km, GO above	GO: 40 points	only if external navbits are available iono correction requires L2 at certain altitudes
Graz	CT in troposphere, GO above		setting occs only
	GO only		
EUM	FSI everywhere	altitude dependent	internal navbit estimates fine tuning ongoing
	GO only	GO: 75 points	

Note: all setups are under permanent development…

Stratospheric Bending Angles vs. ECMWF



Data from 30. Sep 2007

- All retrievals are based on identical level1a data!
- Biases above 40 km are a (known) ECMWF problem
- Biases between 15 and 35 km are also an issue in ECMWF data (and it's 0.2% only anyway…)
- Different numbers due to different processing options
- Different sdevs may reflect different filter settings in data preprocessing…
- …or simply a bug in the orbit processing we discovered recently… :-((

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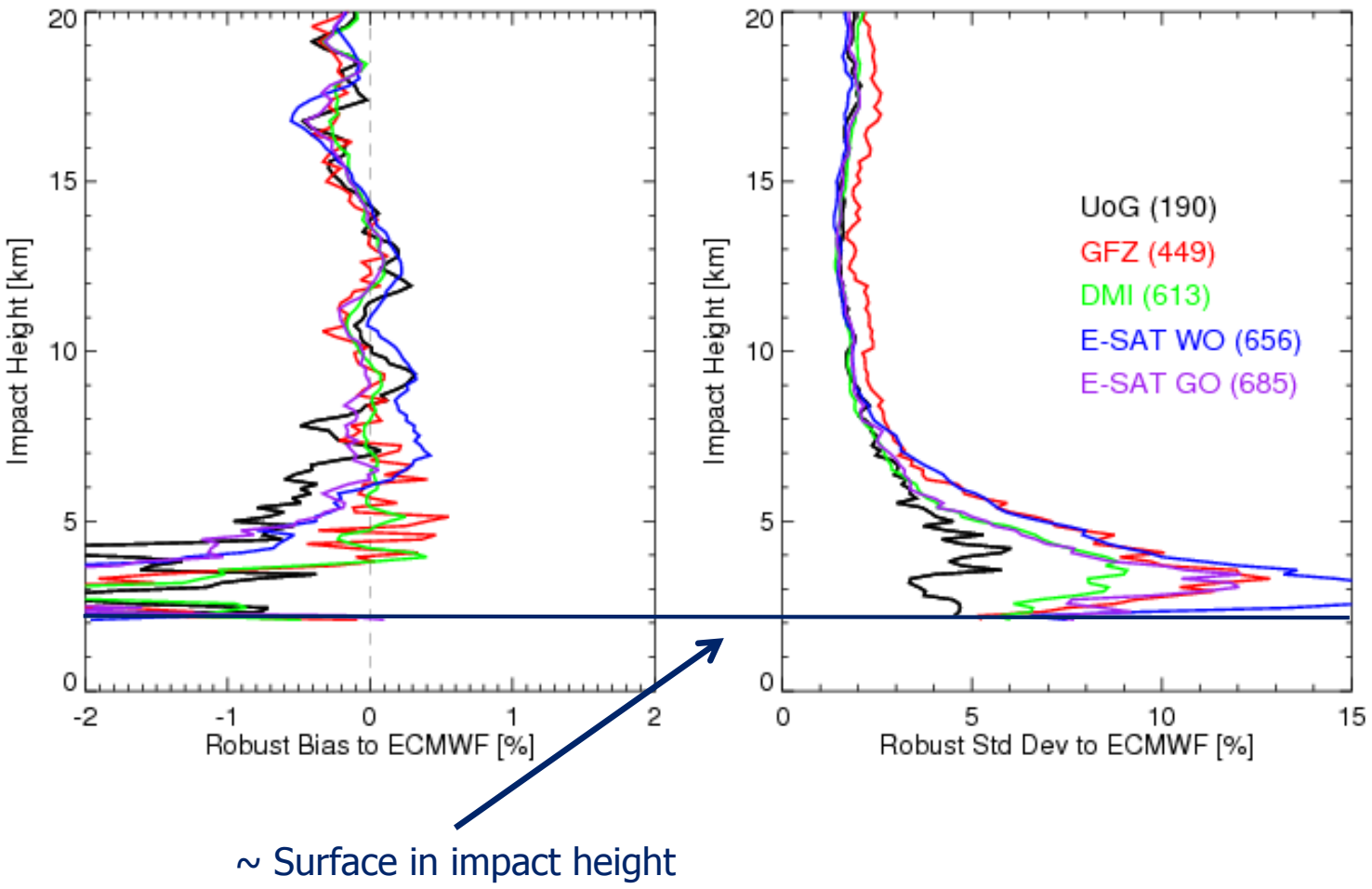
Tropospheric Statistics vs. ECMWF



Data from 30. Sep 2007

- All retrievals are based on identical level1a data!
- Results above ~10 km impact height are all highly consistent; below it gets interesting…
- EUMETSAT FSI shows slightly positive bias between 5 and 10 km
- Below 3-5 km impact height (~2-3 km real height), negative biases prevail
- Different sdevs probably reflect different processing options (or bugs) as well…

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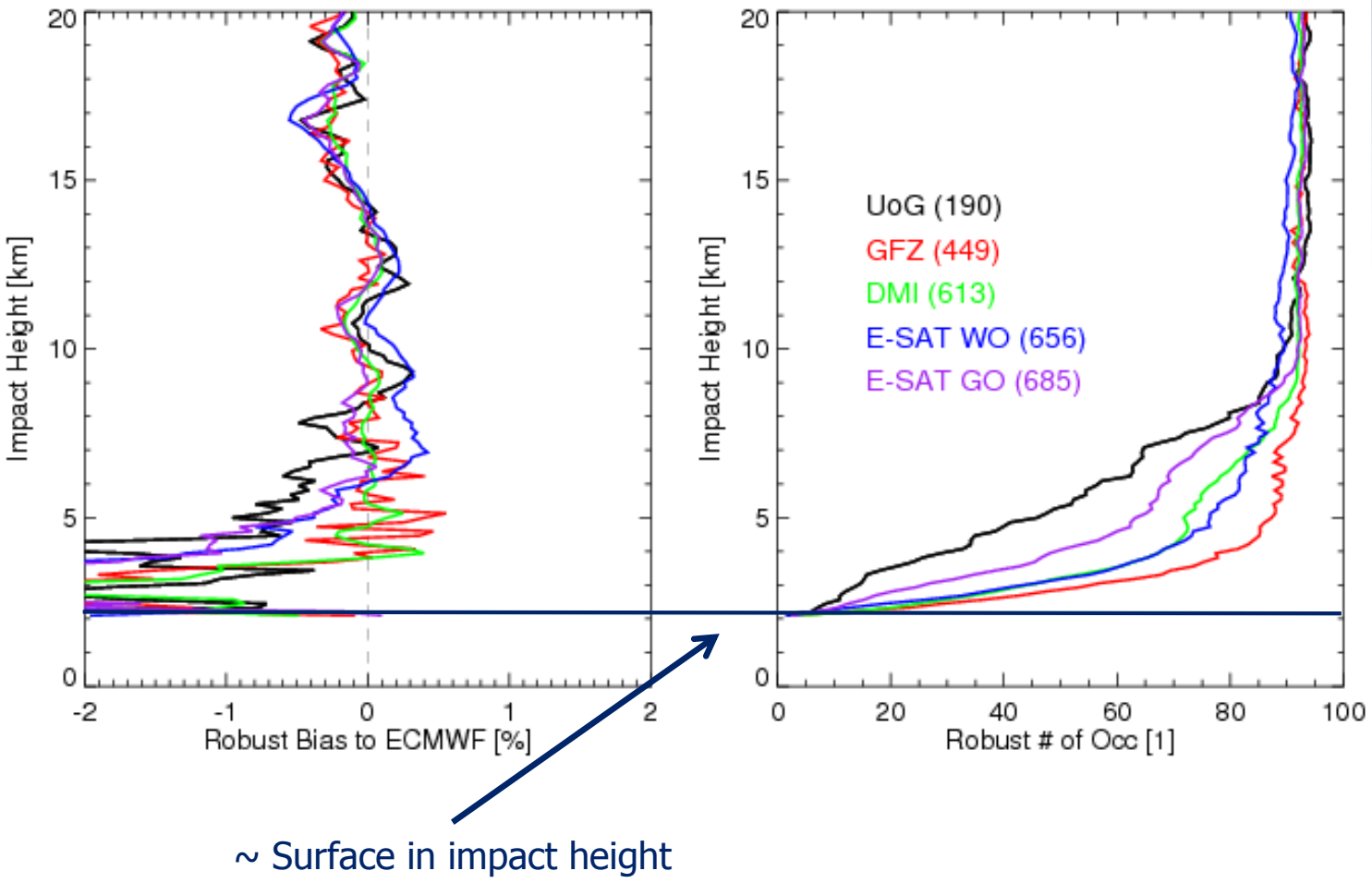
Tropospheric Statistics vs. ECMWF (cont'd)



~ Surface in impact height

Data from 30. Sep 2007

- All retrievals are based on identical level1a data!
- Retrievals below ~10 km impact height strongly depend on level 1b processing options:
  - Cut-off criteria for CT/FSI
  - Smoothing / Filtering
  - Data gap handling
  - QC
  - Navbits, …
- General remark: We interpret ECMWF as a reference source for comparisons, *not* as truth.

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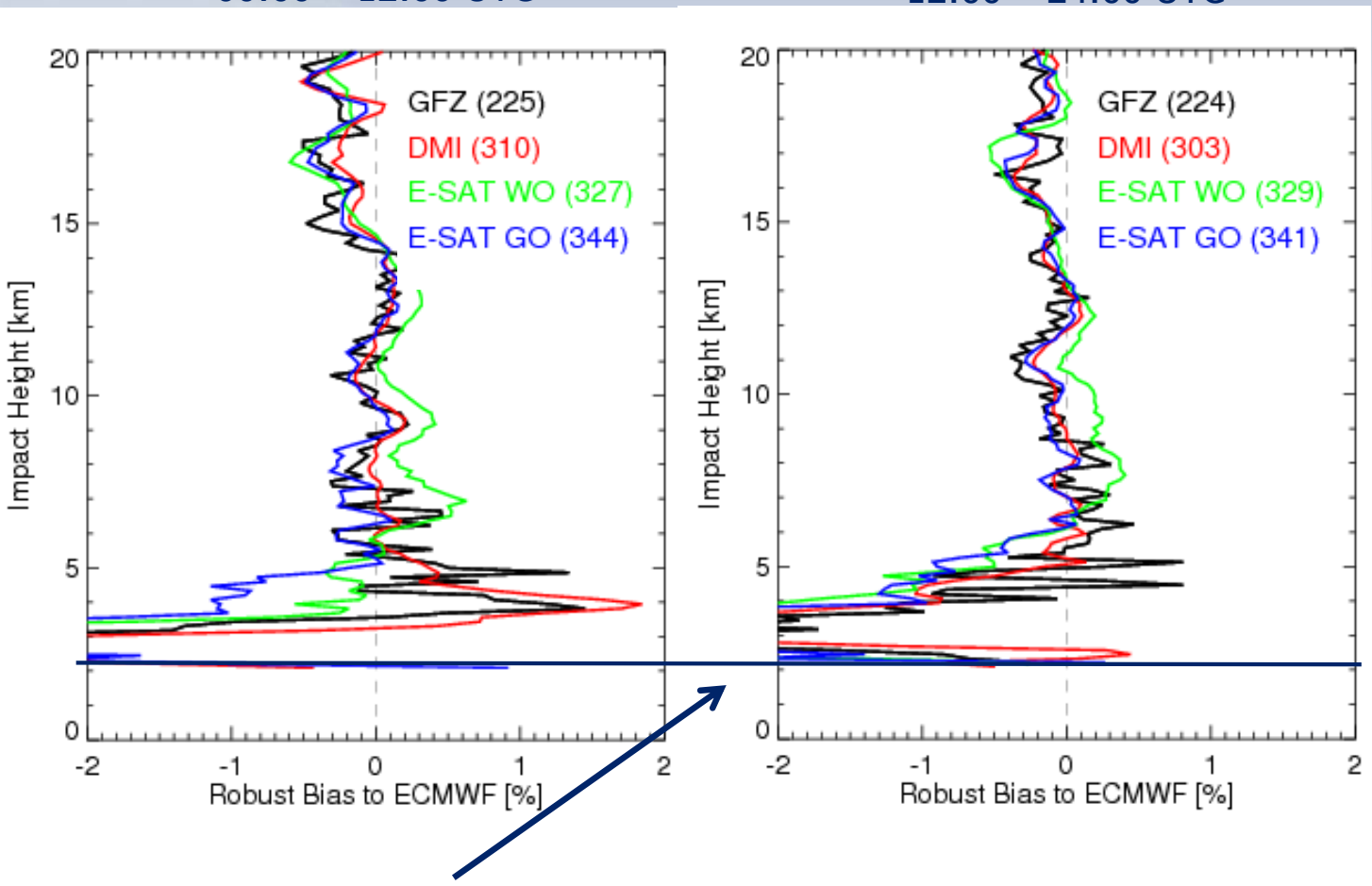
Tropospheric Statistics vs. ECMWF (cont'd)

00:00 – 12:00 UTC



12:00 – 24:00 UTC

~ Surface in impact height

Data from 30. Sep 2007

- All retrievals are based on identical level1a data!
- A single day is hardly enough to draw conclusions based on statistics, obviously…
- General remark: We interpret ECMWF as a reference source for comparisons, *not* as truth.

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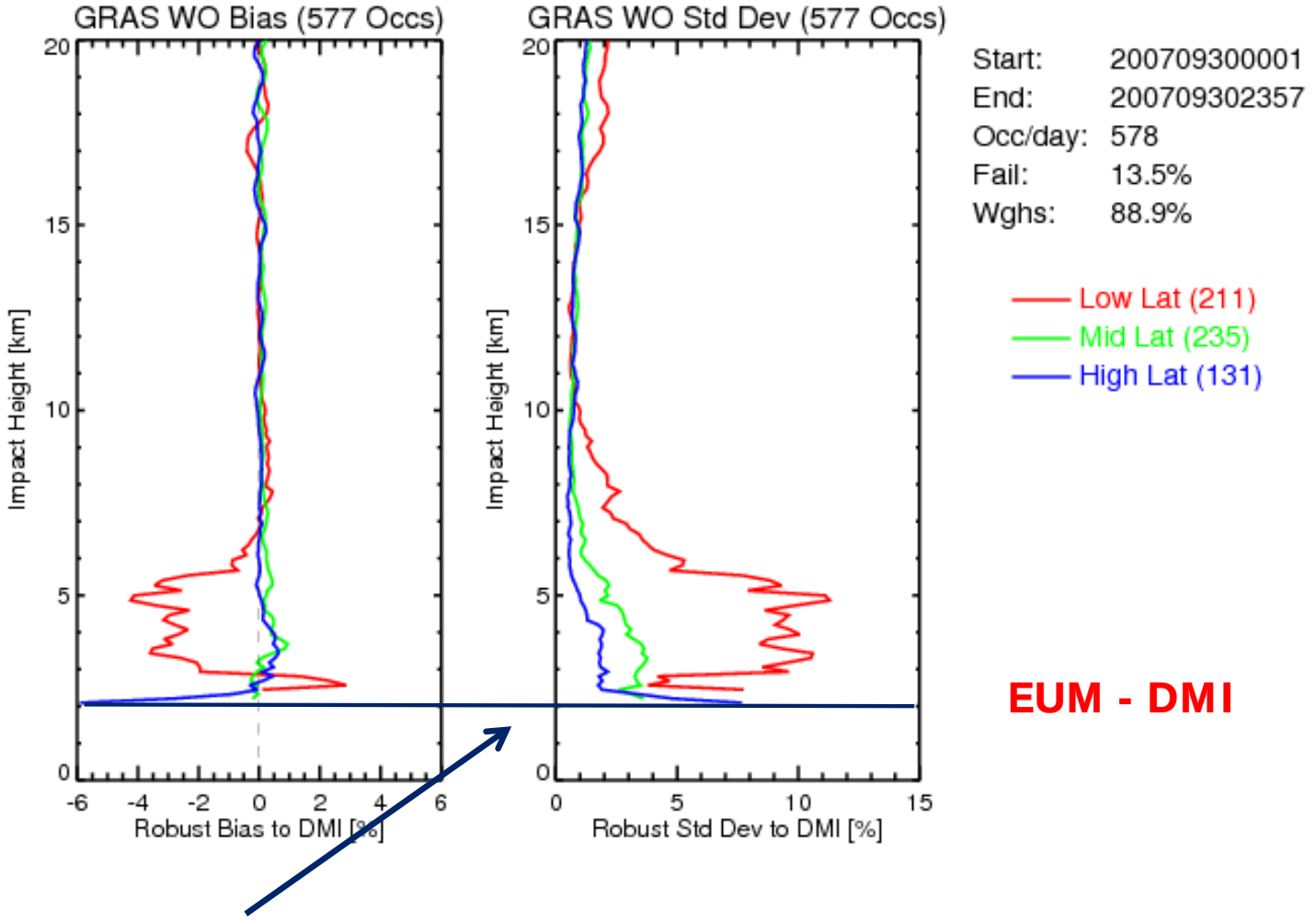
Tropospheric Statistics – Matching Profiles



Data from 30. Sep 2007

- All retrievals are based on identical level1a data!
- Profile-by-profile matching suggests :
  - reasonable or good agreement (≤0.2% bias / ≤1% sdev) in mid/high latitudes and above altitudes affected by multipath in the tropics…
  - …but significant structural uncertainties where humidity is abundant
- We need to look into that in more detail.

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EUMETSAT's FSI

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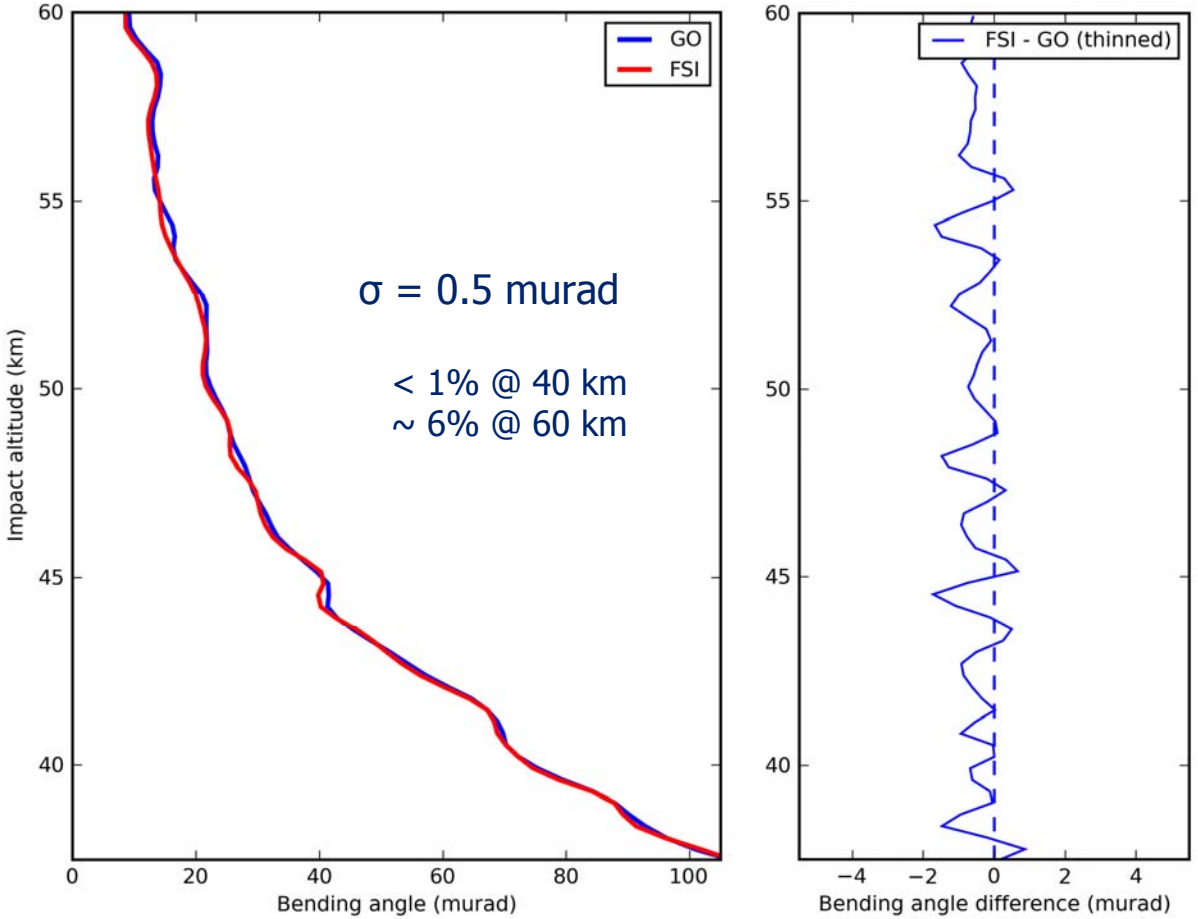
FSI over the entire altitude range



- Small vertical scale noise: finite differencing of the Fourier-transformed phase
  - Kaiser-Filter (Kaiser & Schafer, 1980) with a – 100 dB stopband
  - doubling current filter width produces no systematic effects / biases
- Larger scale noise: variable bandwidth local polynomial regression filter (Loader, 1995; Wand & Jones, 1995) in impact parameter space
  - NWP / thinned data: tied to 247 level grid of thinned GRAS products, ~ 1 Fresnel diameter
  - Additional higher resolution profiles for science applications (TBD)
- FSI-GO deviations are in the order of GRAS bending angle noise

Rising occultation on 30/09/2007 09:43 UTC, 60°E, 13°S

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Gaps in rising occultations

If the receiver doesn't have a measurement…

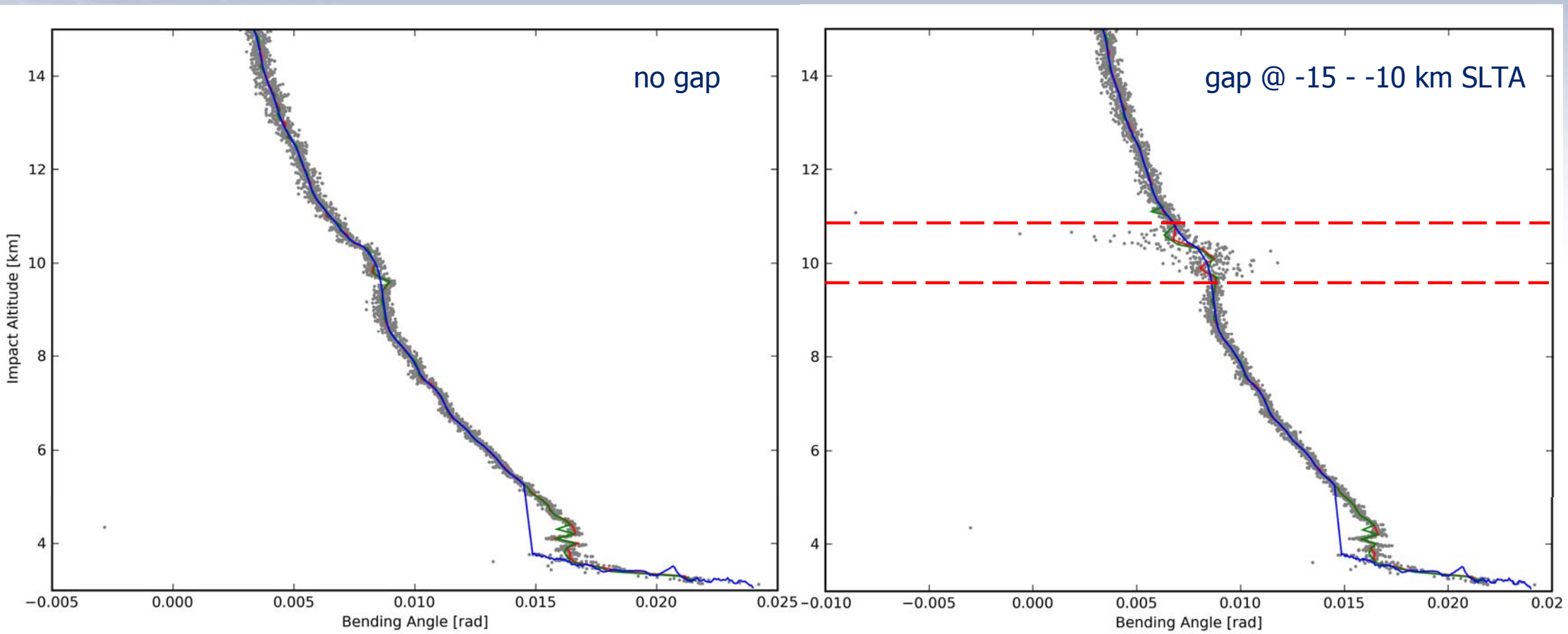
- …we fill the "measured" complex signal with zero…
- …do the usual FSI…
- …and remove / flag the "interpolated" data as missing.
    - assumes that data gaps affect retrievals locally (and can be identified in impact parameter / bending angle space)

- Alternatively process data segments individually (as we do in our GO retrieval)

- We want to avoid interpolating over gaps – if the receiver didn't measure anything, we don't want to pretend otherwise

- Caveats:
    - Refractivity users will have to do their own interpolation over gaps
    - We haven't yet done a robust implementation of this

Simulation



- gaps are mapped into localized regions with increased uncertainty in arrival times / bending angles
- other parts of the profile do not seem to be affected

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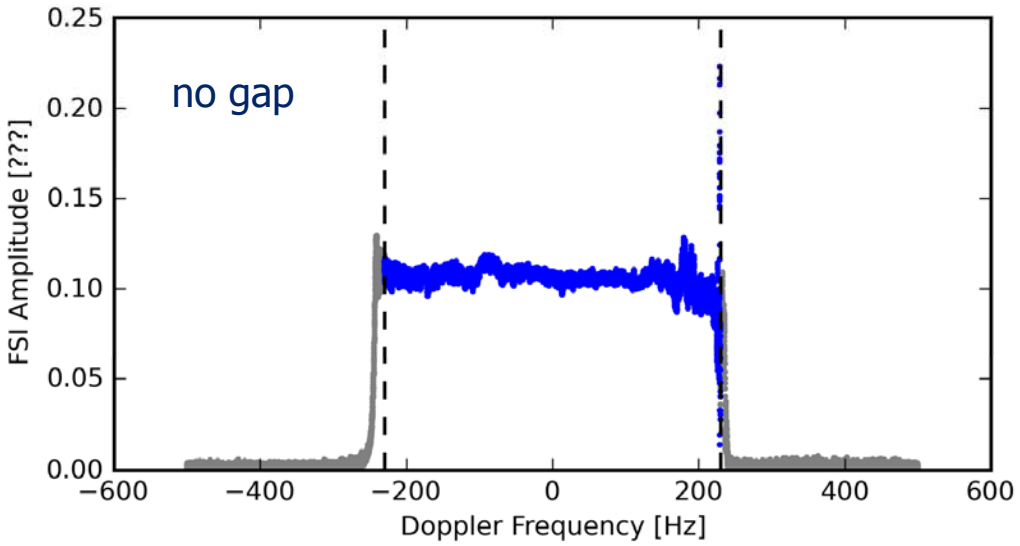
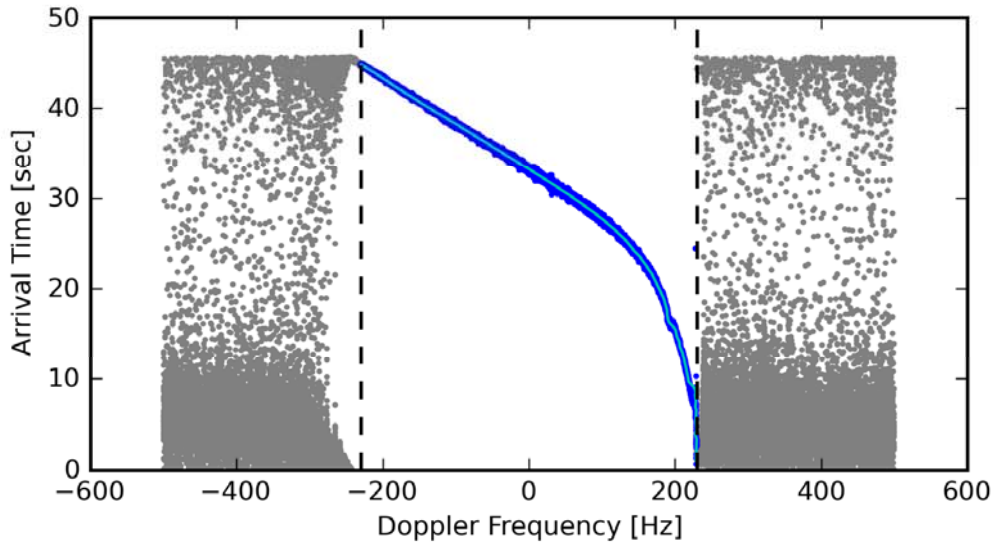
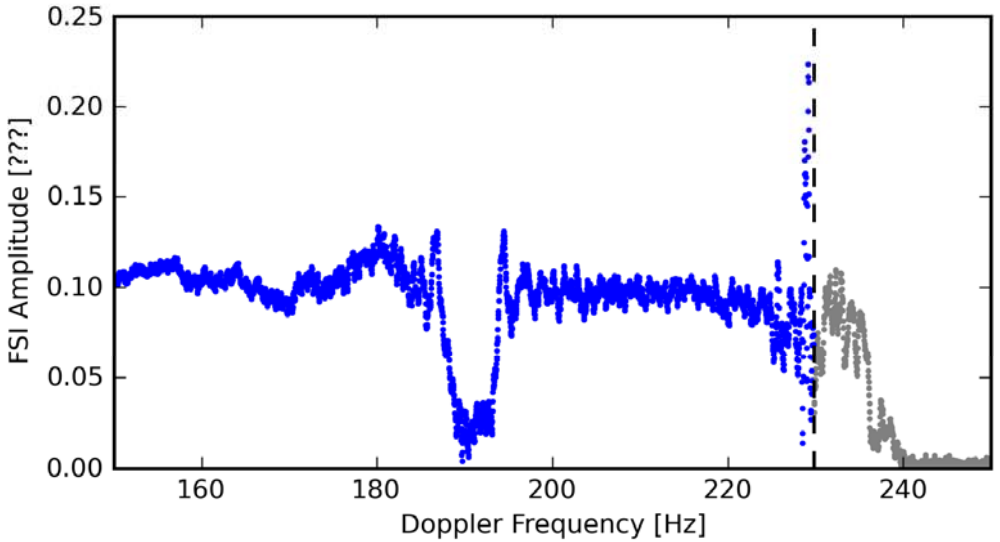
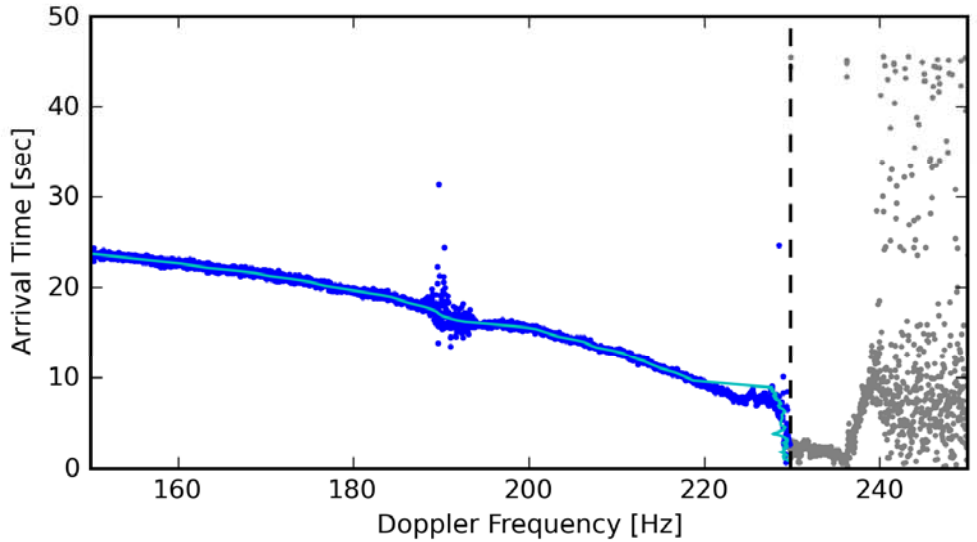
Simulation (cont'd)









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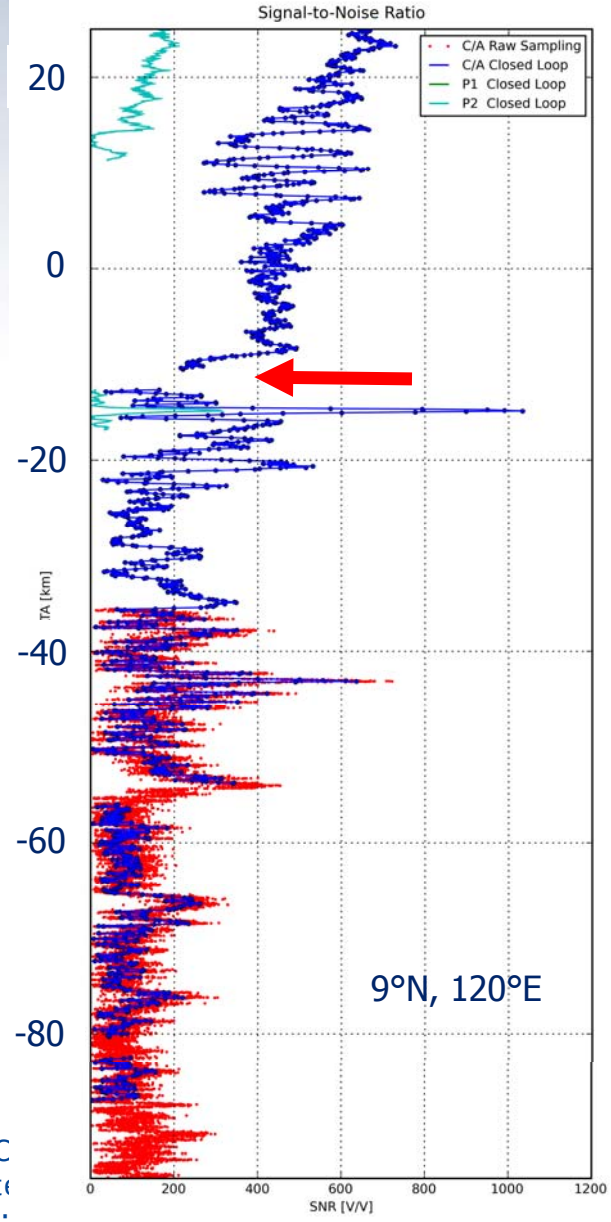
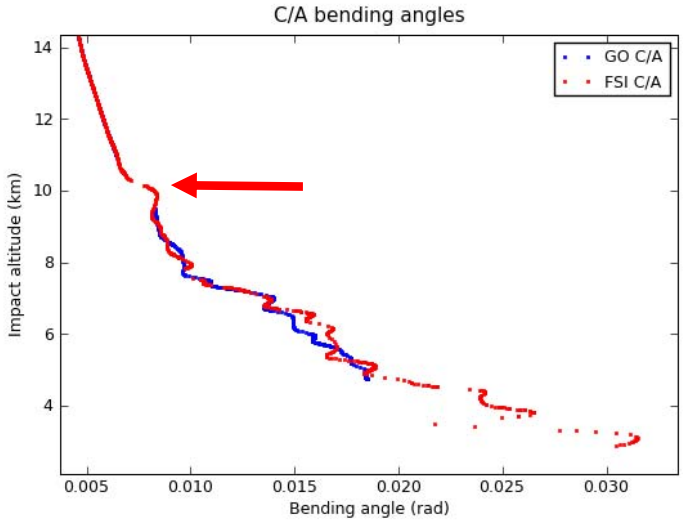
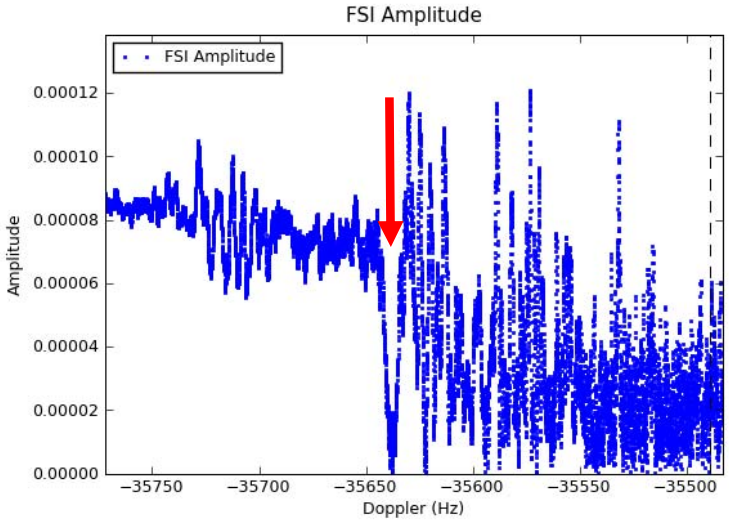
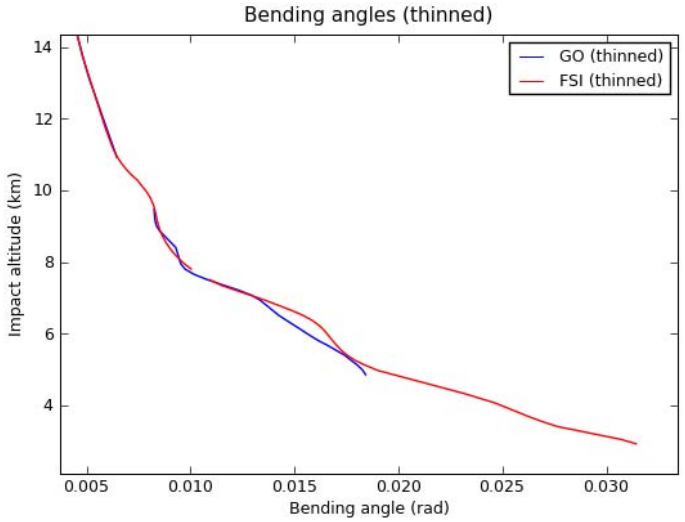
Real Example

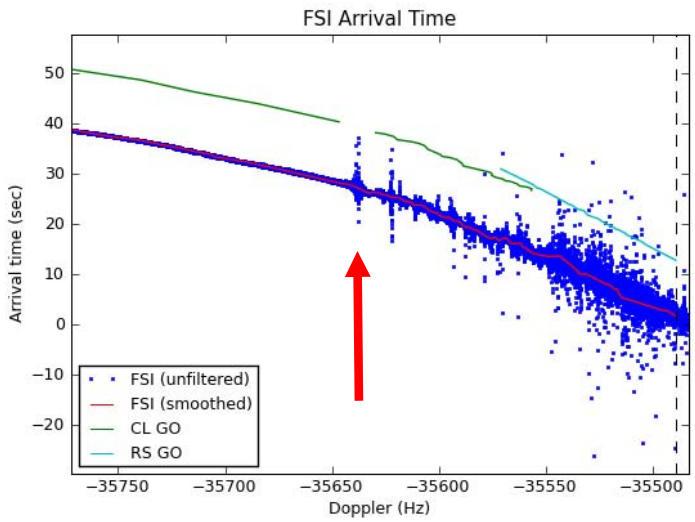


SLTA [km]









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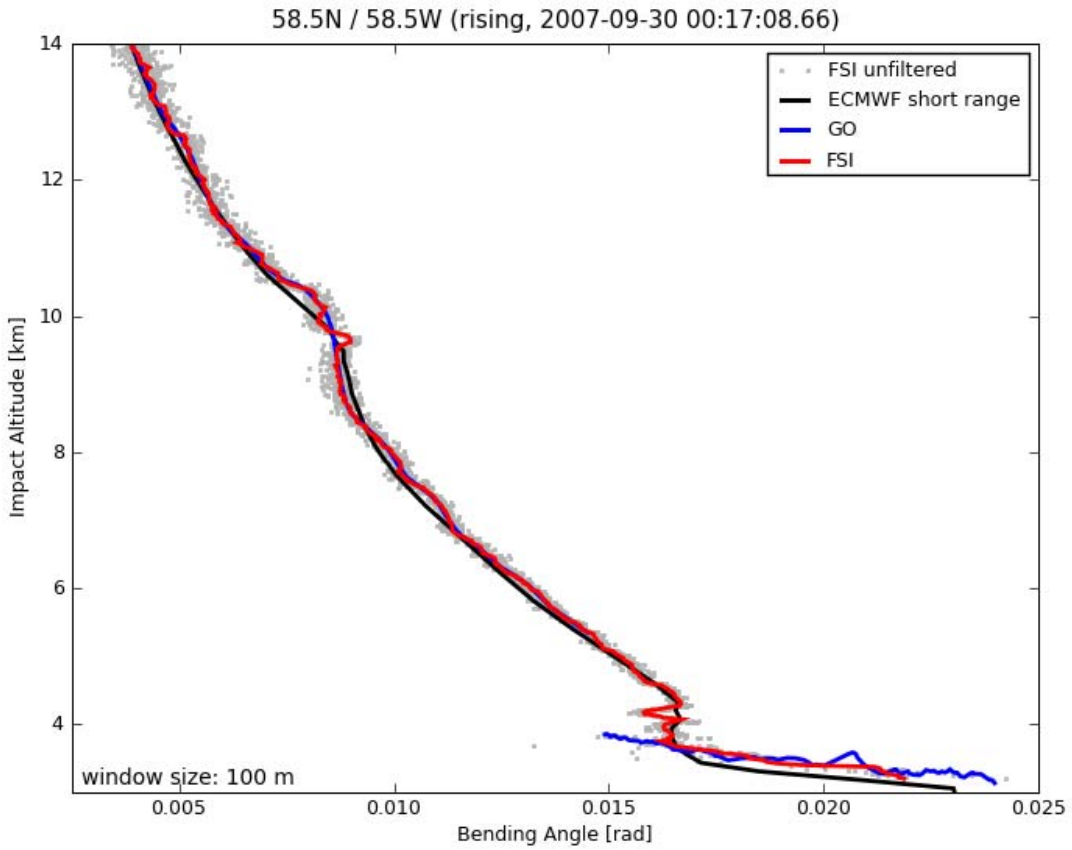
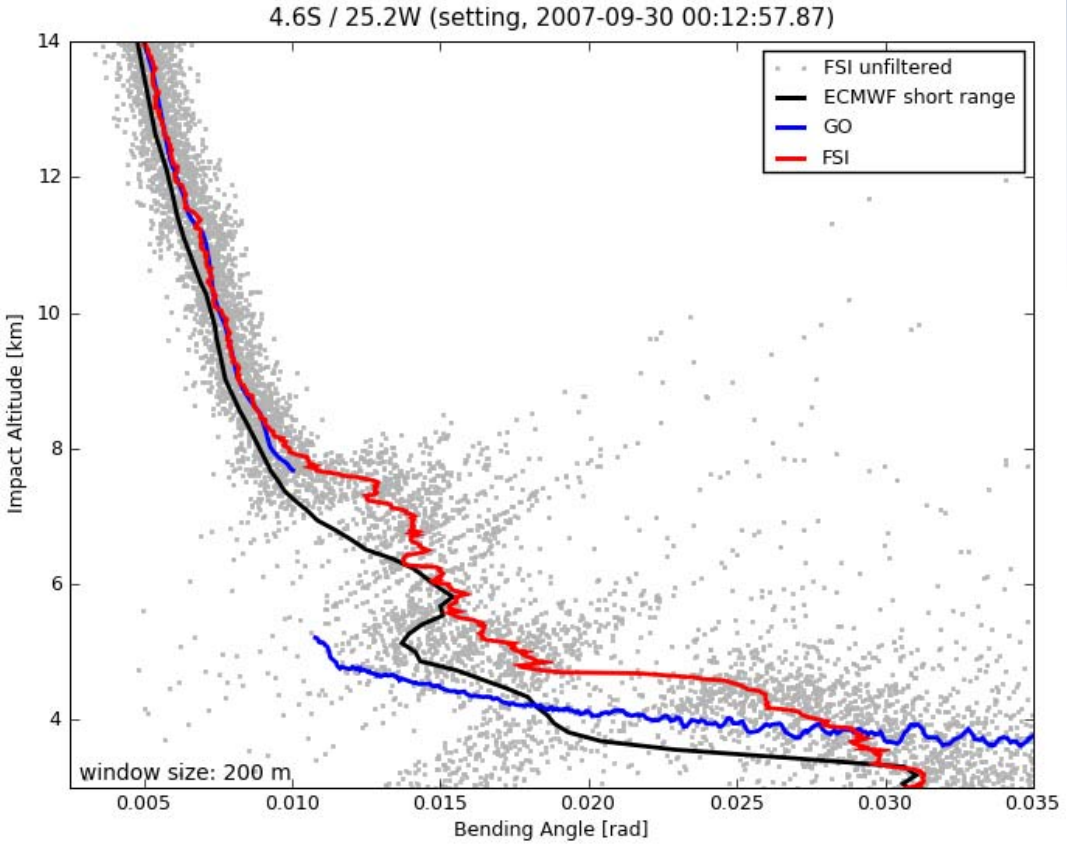
Bending Angle Example – High Latitudes





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Summary: GRAS Issues

- Gaps in RS data due to loss of C/A code tracking (expected by GRAS design)
- Gaps in CL data not covered by RS in rising occultations (33% of rising / 16% of all occultations)
  - will rise uppermost RS SLTA as mitigation (October?)
  - firmware changes under discussion
- low P1/P2 SNR (7% of all occultations)
  - retrieval "noisier" (more like CHAMP) than the average GRAS occultation,
  - some are completely useless
- occasional amplitude saturation events in RS under moderately high SNR conditions
  - probably not much of an issue, especially if RS data is downsampled to 50Hz

Summary: Studies

- European study to investigate GRAS RS data characteristics comes to an end
  - CL data / stratospheric (geometrical optics) retrievals
    - generally in good agreement, in particular w.r.t biases (< 0.1% between centres from 10 - 30 km)
    - differences in sdev mostly understood in terms of filtering as far as GO algorithms are concerned (there might also be the one or other bug at EUM ☹…)
  - RS data / tropospheric retrievals
    - all centres have capability to process GRAS raw sampling data with advanced retrieval algorithms (all independent)
    - structural uncertainty issues below 10 km in the troposphere, especially if data is affected by multipath

- Structural uncertainty study (UCAR) focusing on GO processing of GRAS data nearly complete completion
  - GRAS low level processing implemented at UCAR
  - stratospheric GO retrievals show good agreement between 10 and 30 km, also with independent level 0 data reconstruction and POD
  - strong quality control at UCAR, removing about 15% of occultations
  - extension focussing on tropospheric data (w/ DMI) beginning soon

Outlook / Ideas

GRAS Operations:

- Metop A will continued to be operated in parallel to Metop B…
- …doubling the number of occultations from GRAS instruments in mid 2012

Raw Sampling:

- Based on study results, we re-engineer the operational processing software for GRAS to include tropospheric processing
- Planned to become operation mid-2011 (early parallel data stream for testing available in October 2010)

Overall:

- need to work on structural uncertainty issues in tropospheric retrievals
- we do not yet fully exploit GRAS specific data characteristics – nearly everyone just downsampled the 1 kHz RS data to 50 Hz to make it look like COSMIC…
- need to implement mitigations for receiver issues, in particular data gaps in rising occultations

Thank you.

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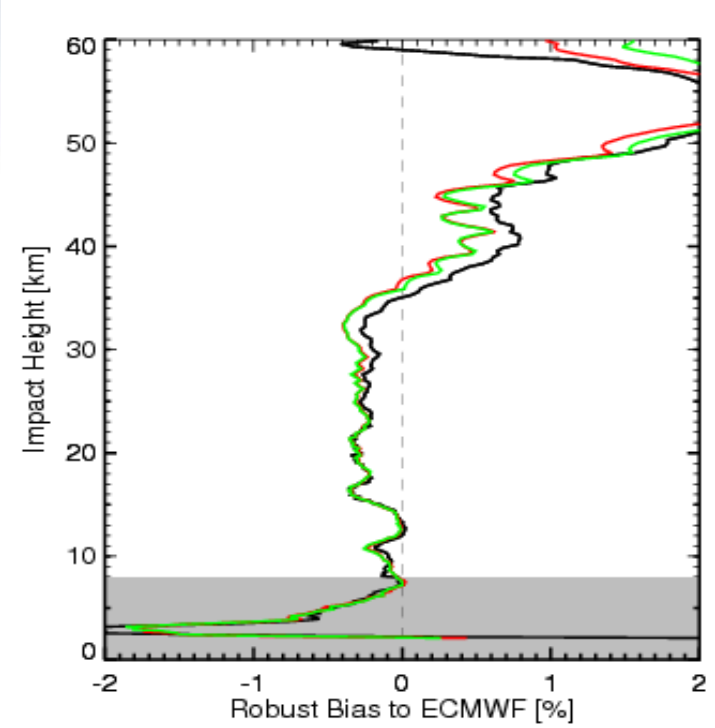
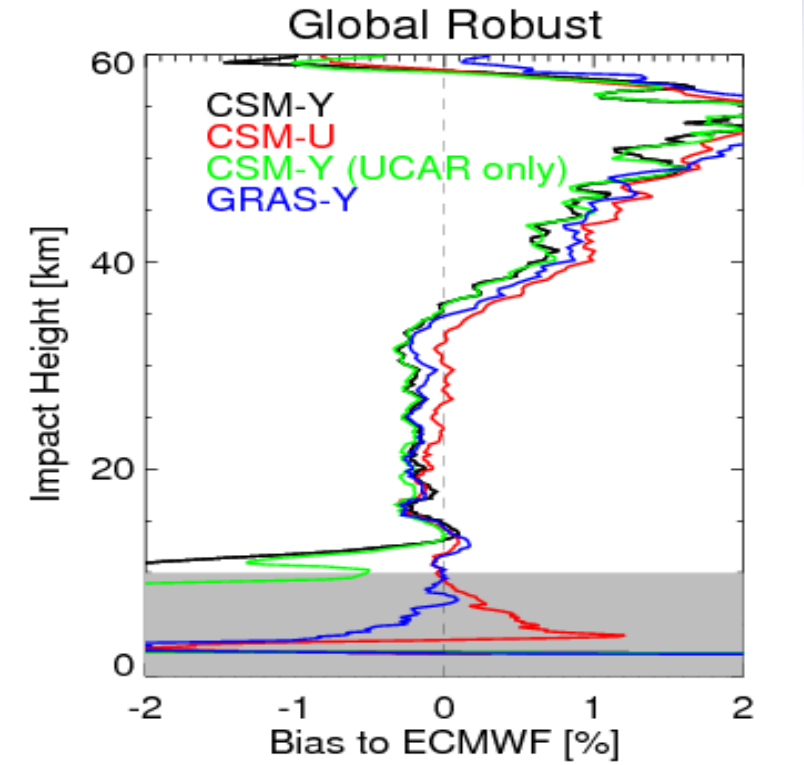
GRAS Stats vs. ECMWF





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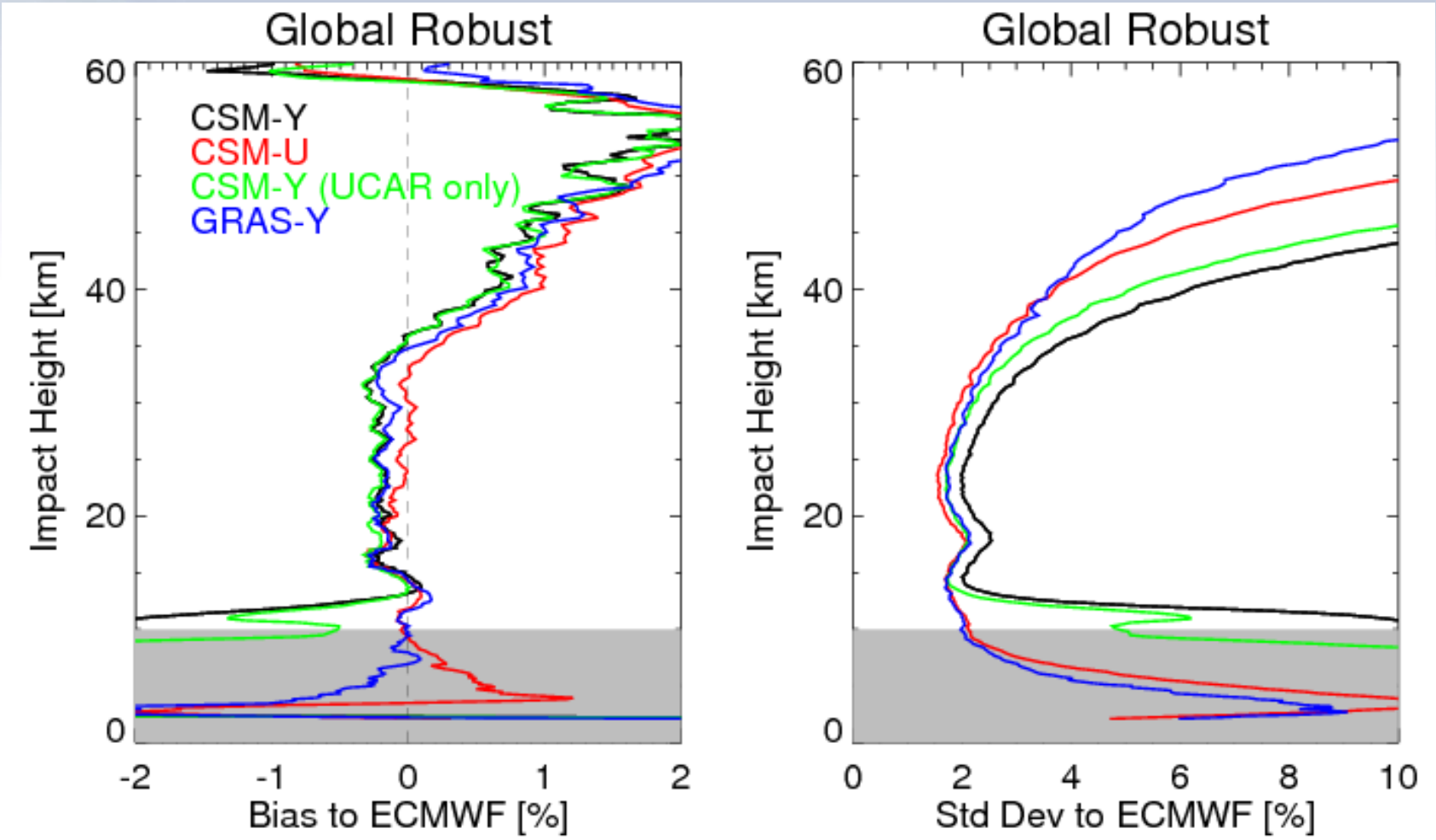
COSMIC and GRAS Statistics vs. ECMWF



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