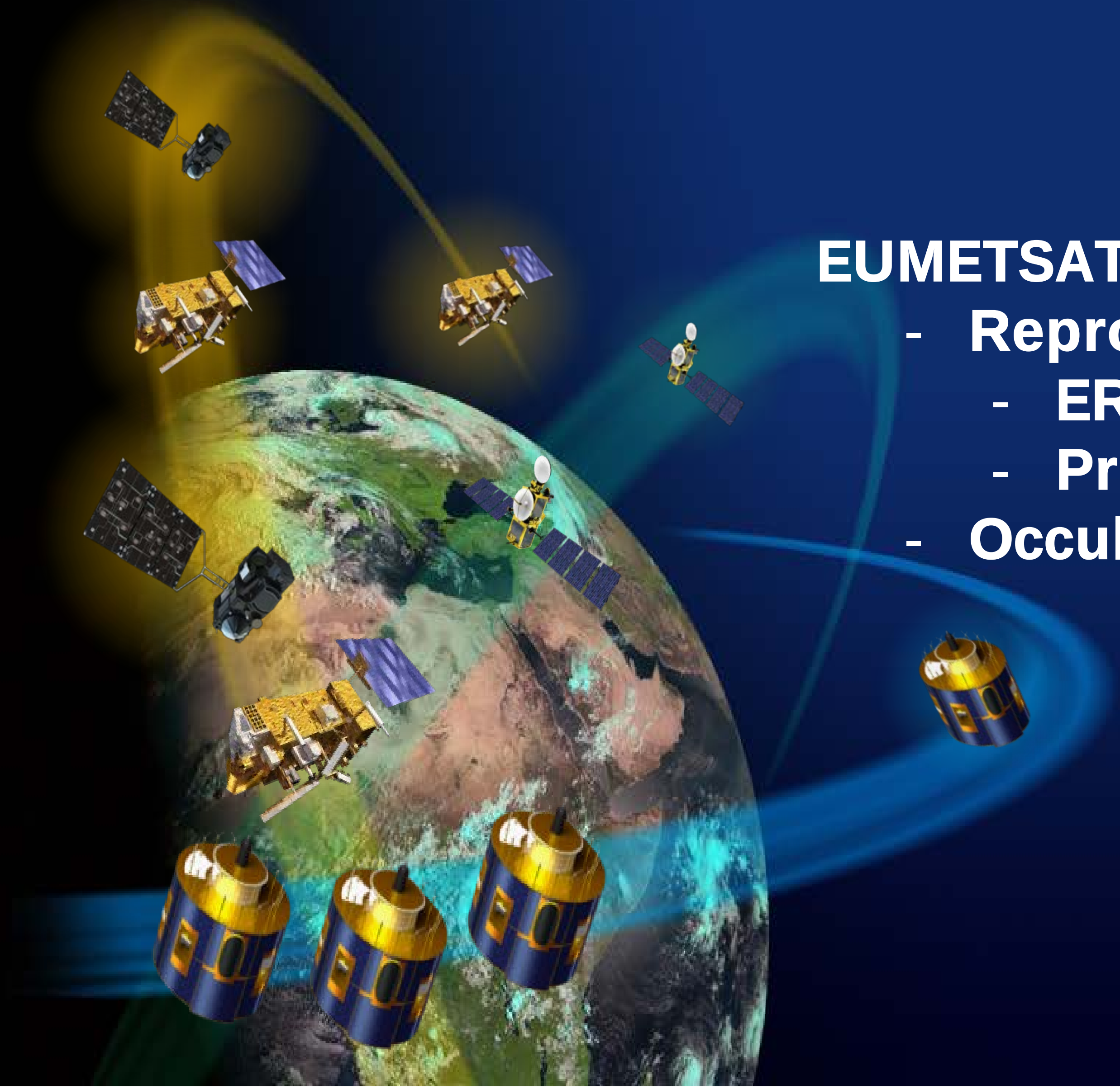

EUMETSAT RO Processing:

- Reprocessing
  - ERACLIM Release-2
  - Preparations for ERA5
- Occultation Predictions

RO Team @ EUMETSAT

Reprocessing: Overview of EUMETSAT Activities

- **GRAS Level 1b Bending Angle FCDR Release 1:**
  - GRAS-A from launch to end 2016
  - Product User Guide, Validation Report available
  - used for ROM SAF CDR 1.0 GRAS reprocessing (link)
- **GRAS Level 1b Bending Angle FCDR Release 2:**
  - GRAS-A and -B from launch to end 2017 (same s/w as Release 1)
  - Validation Report finalized, no issues/discontinuities detected
  - planned release towards end 2019 (or contact us)
- **GRAS Level 1b Bending Angle FCDR Release 3:**
  - GRAS-A, -B, -C from launch to end 2019 (updated s/w to Release 1/2)
  - planned release data Q2/2020 (for ERA6)
- **RO 3rd Party Level 1b Bending Angle FCDR Release 1:**
  - COSMIC/CHAMP/GRACE from launch to end lifetime or 2018/19
  - planned release date Q2/2020 (for ERA6)

This Talk

Reprocessing: Why did we do this?

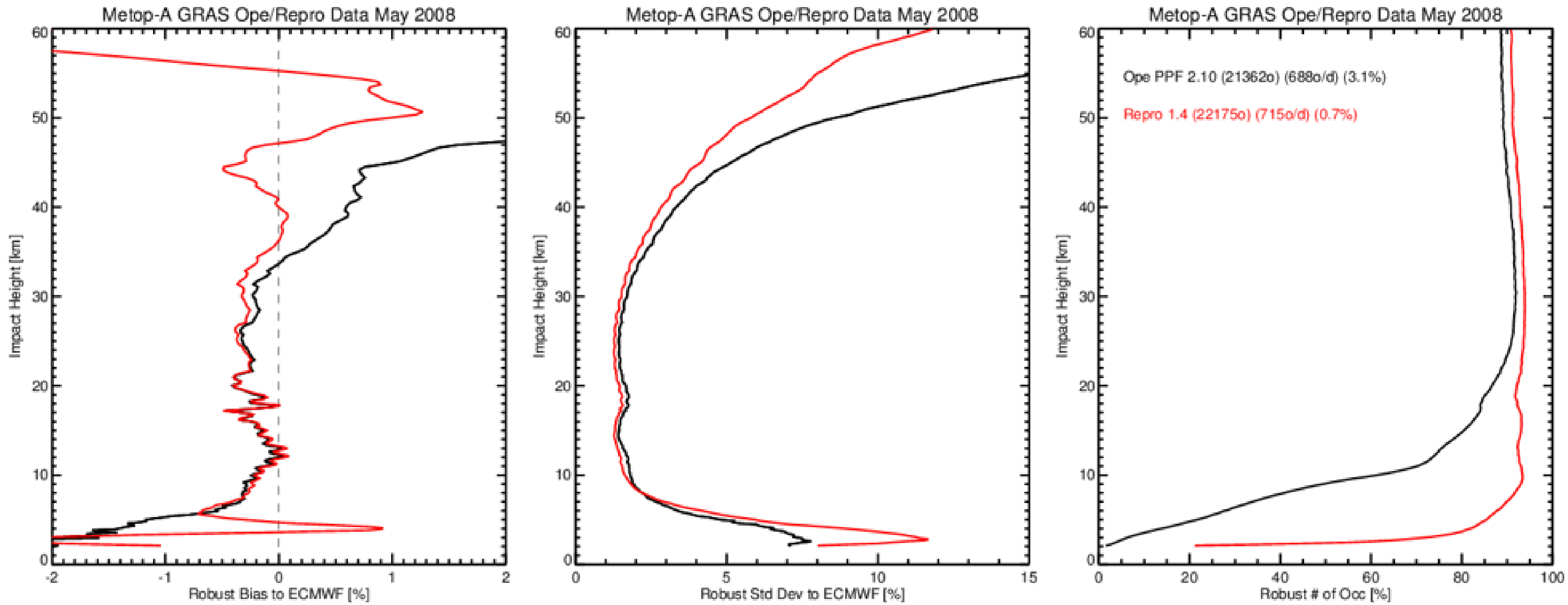

Figure 4: Example for May 2008 illustrating the improvements of operational NRT PPF 2.10 data versus Release 2 - GRAS Level 1b Bending Angle FCDR (v1.4) data. Shown is the global bending angle comparison to ECMWF ERA-Interim forward propagated data. Robust bias (left), standard deviation (centre), outlier distribution (right). In addition, the legend gives the total number of occultations, average occultations per day and the failure rate.

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Reprocessing: Coverage / Sizes

Table 1 Data coverage of Release 2 – GRAS Level 1b Bending Angle FCDR as well as information on the UCAR data availability. Degraded occultations determined from setting of Product Confidence Descriptor [RD 10] or from non-nominal occultations provided by ROM SAF. Average number of occultations per day uses all occultations.

Mission	Start Record	End Record	Tot. Occs / Degr. Occs	Avg. Occs/Day
EUMETSAT Release 2 - GRAS Level 1b Bending Angle FCDR				
Metop-A	2006/10/27 09:57	2017/12/31 23:59	2,708,036 / 260,342	663
Metop-B	2012/09/29 20:56	2017/12/31 23:56	1,267,710 / 78,032	661

Table 5: Size of the Level 1b GRAS data set (in TBs), corresponding to the netCDF format.

Satellite	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*Total*
Metop-A	0.1	0.9	1.0	1.1	1.1	1.1	1.2	1.2	1.5	1.5	1.6	1.7	**14**
Metop-B							0.3	1.4	1.4	1.4	1.5	1.6	**7.6**

Data Sets going to be made available:

- **L1B (netCDF-4, complete set of POD, L1A, L1B; upon request could provide BUFR or ROPP format)**
- **RINEX**
- **NavBits**

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Reprocessing: Data Sets validated / used as Reference

Table 1 Data coverage of Release 2 – GRAS Level 1b Bending Angle FCDR as well as information on the UCAR data availability. Degraded occultations determined from setting of Product Confidence Descriptor [RD 10] or from non-nominal occultations provided by ROM SAF. Average number of occultations per day uses all occultations.

Mission	**Start Record**	**End Record**	**Tot. Occs / Degr. Occs**	**Avg. Occs/Day**
EUMETSAT Release 2 - GRAS Level 1b Bending Angle FCDR				
Metop-A	2006/10/27 09:57	2017/12/31 23:59	2,708,036 / 260,342	663
Metop-B	2012/09/29 20:56	2017/12/31 23:56	1,267,710 / 78,032	661
ROM SAF Data used for Validation				
Metop-A GRM-29-R1	2006/10/27 09:57	2016/12/31 21:54	2,463,439 / 237,832	662
Metop-B GRM-29-R1	2012/09/29 20:56	2016/12/31 21:55	1,023,235 / 104,449	658
Metop-A Offline	2017/01/01 01:19	2017/12/31 23:45	248,559 / 26,271	681
Metop-B Offline	2017/01/01 00:30	2017/12/31 23:59	249,091 / 26,922	682
COSMIC GRM-30-R1	2006/04/22 00:27	2016/12/31 21:45	6,682,309 / 1,881,997	1710
UCAR Data used for Validation				
CHAMP	2001/05/19 00:10	2008/10/05 02:24	468,029 / 39,471	174
COSMIC	2006/04/22 00:27	2014/04/30 23:52	5,516,372 / 883,989	1882
Metop-A	2007/10/01 00:01	2015/12/31 23:07	1,791,657 / 138,207	594
Metop-B	2013/02/01 00:00	2015/12/31 23:57	642,372 / 34,635	604

ECMWF ERA-Interim, collocated to RO profile, also used (ROPP 9 for forward modelling)

Reprocessing: General GRAS Characteristics

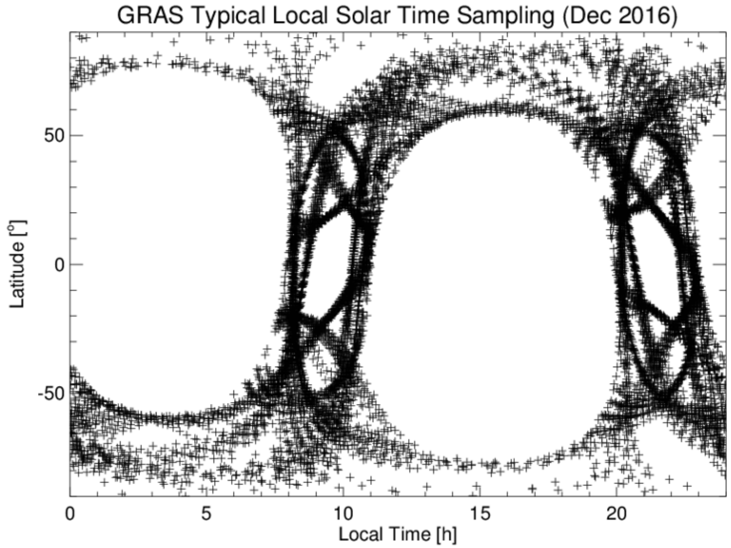
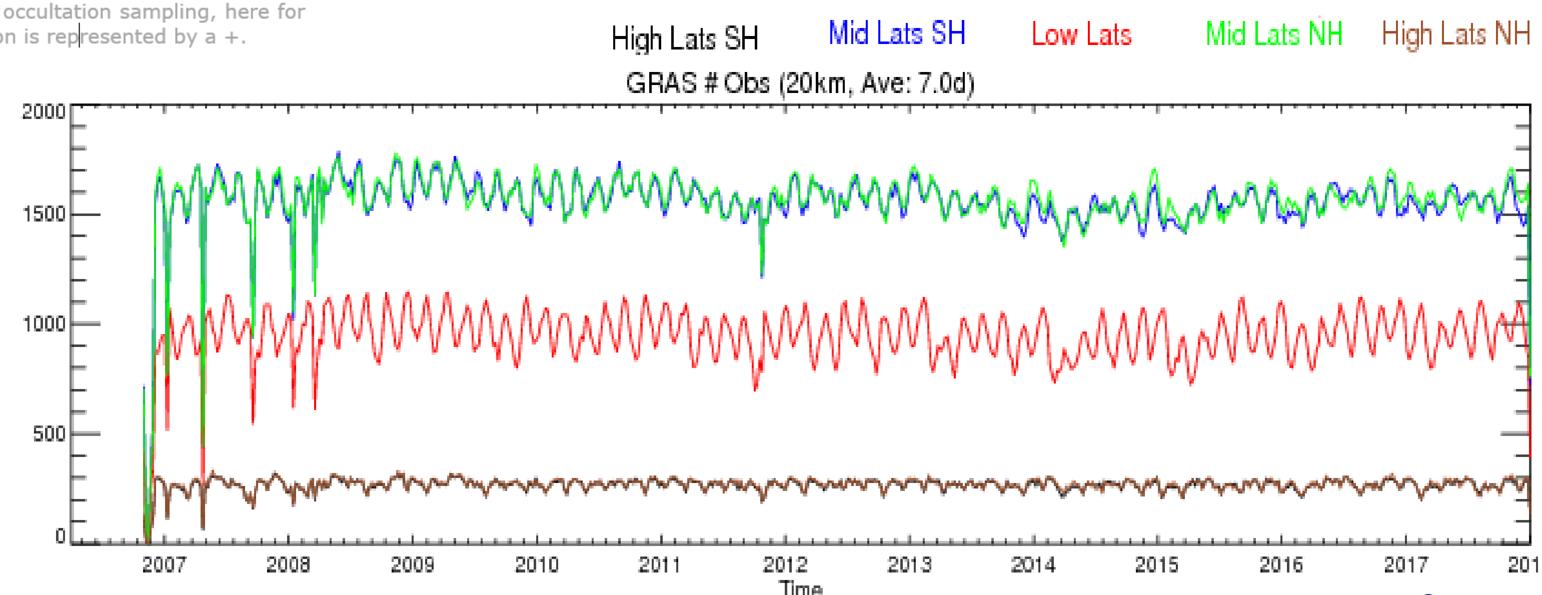


Figure 7: Typical local solar time of GRAS occultation sampling, here for 1 month (December 2016), each occultation is represented by a +.

Left Top: Example of typical GRAS local time sampling at 9:30 / 21:30 over the Equator (example for Dec 2016); Bottom Right: Number of occultations available over 7 days for different latitude bands of Metop-A Release 2 data.



Reprocessing: Validation against ERA-I

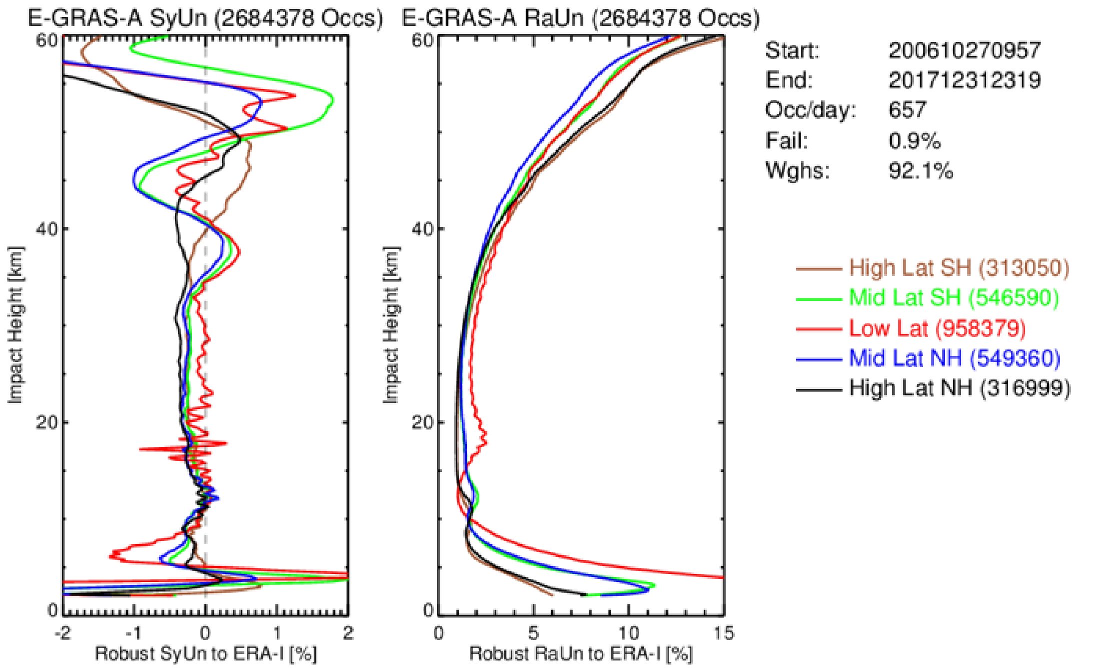


Figure 23 (O-B)/B statistics of EUMETSAT Metop-A Release 2 - GRAS Level 1b Bending Angle FCDR with ERA-Interim data for different latitude bands on the Southern (SH) and Northern Hemisphere (NH) using robust statistics; (left) systematic uncertainty, (right) random uncertainty (1 sigma). Otherwise as Figure 10.

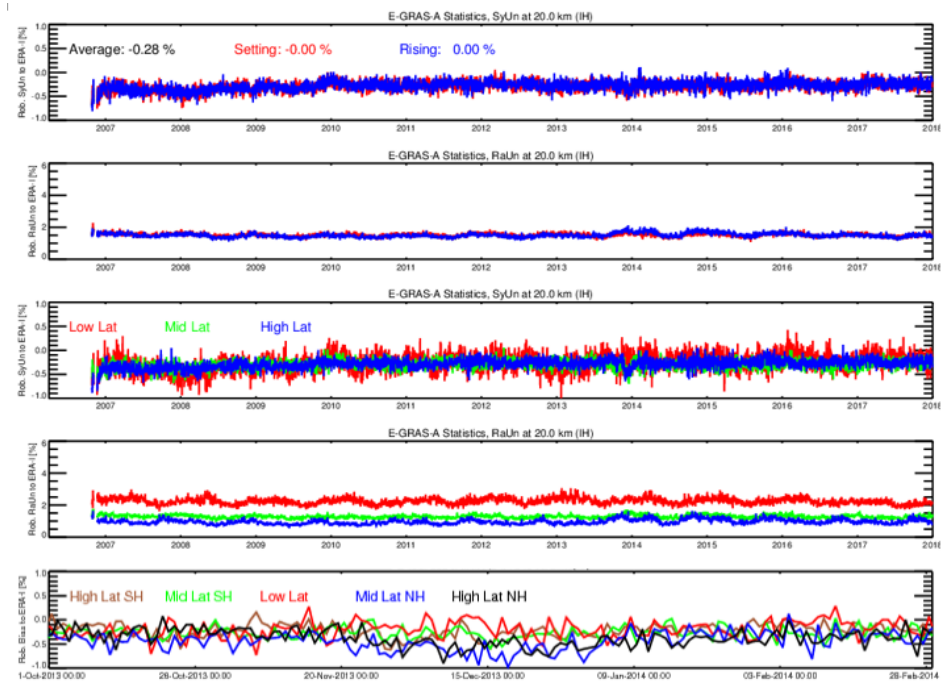


Figure 24 (O-B)/B statistics of EUMETSAT Metop-A Release 2 - GRAS Level 1b Bending Angle FCDR against ERA-Interim data at 20km, daily averaged using robust statistics; (top) systematic uncertainty, (second plot) random uncertainty for all/setting/rising; (third plot) systematic uncertainty, (fourth plot) random uncertainty for different latitude bands. Average systematic uncertainty is also given, separated for setting/rising/all. The bottom plot shows the 3rd plot with a focus on the period where ERA-Interim did not assimilate RO data end 2013, early 2014, here separated by latitude bands and hemisphere.

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Reprocessing: Validation against UCAR/GRAS

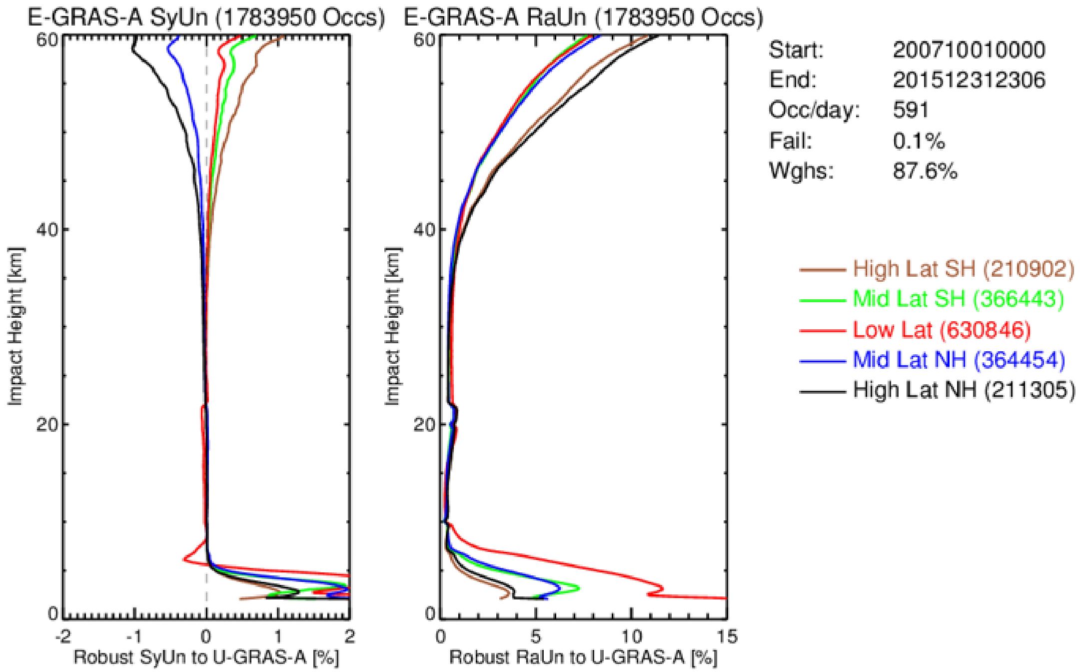

Figure 10 (O1-O2)/O2 matches of Metop-A Release 2 - GRAS Level 1b Bending Angle FCDR with UCAR Metop-A 2016 data for different latitude bands on the Southern (SH) and Northern Hemisphere (NH) using robust statistics; (left) systematic uncertainty, (right) random uncertainty (1 sigma), legend gives further information on the data coverage, the average number of matched occultations per day, the number of failures (e.g. if no overlapping data is found), as well as the robustness/weight of the statistics. The total number of occultations entering, as well as per latitude band, is given in brackets in title/legend.

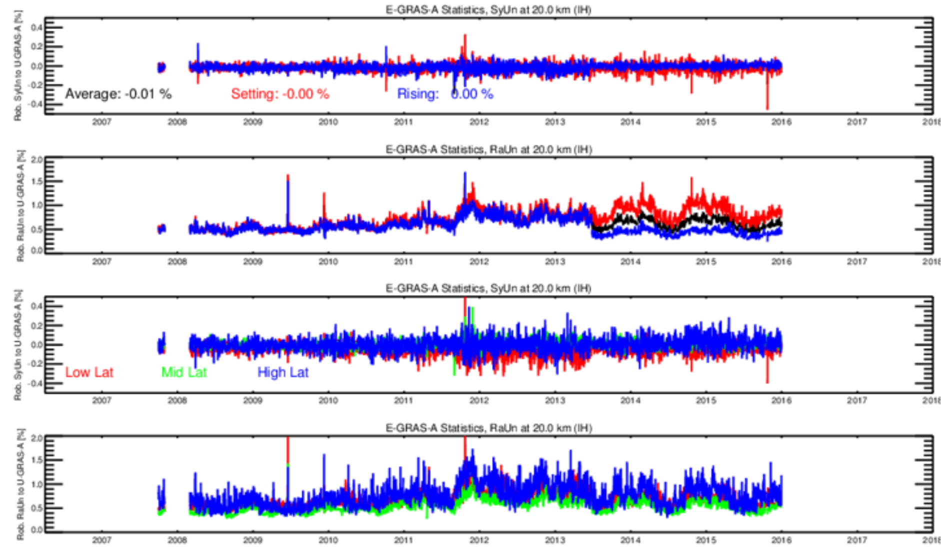

Figure 11 (O1-O2)/O2 matches of Metop-A Release 2 - GRAS Level 1b Bending Angle FCDR with UCAR Metop-A 2016 data at 20km, daily averaged using robust statistics; (top) systematic uncertainty, (middle top) random uncertainty (1 sigma) for all/setting/rising; (middle bottom) systematic uncertainty, (bottom) random uncertainty (1 sigma) for different latitude bands. Average systematic uncertainty is also given, separated for setting/rising/all.

Reprocessing: Validation against ROM SAF/GRAS

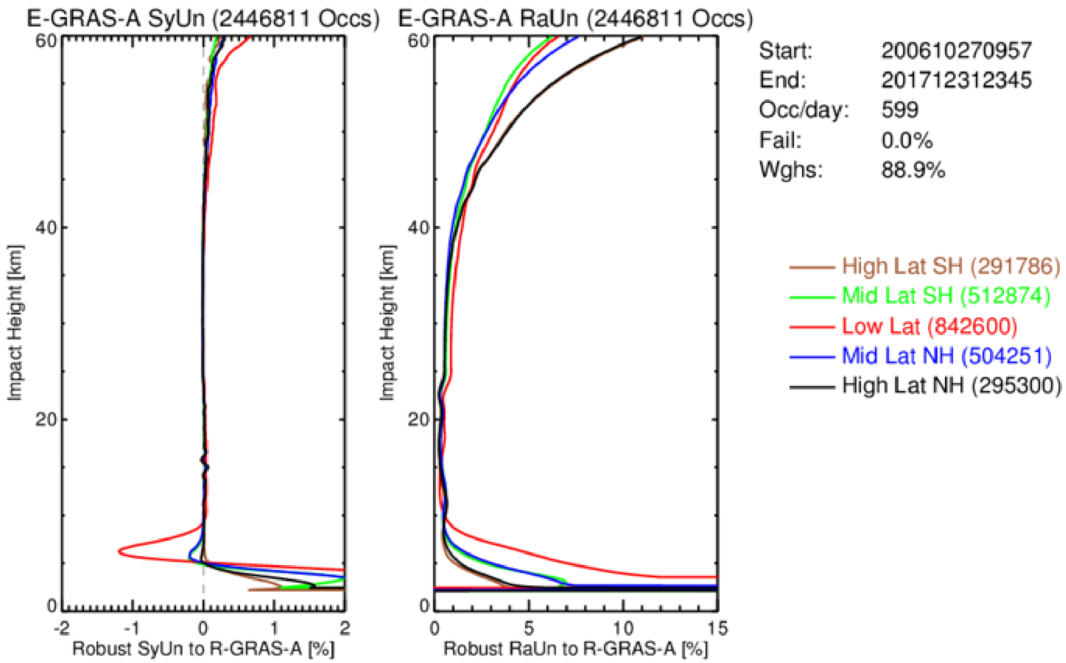

Figure 14 (O1-O2)/O2 matches of Metop-A Release 2 - GRAS Level 1b Bending Angle FCDR with ROM SAF Metop-A CDR v1.0/Offline data for different latitude bands on the Southern (SH) and Northern Hemisphere (NH) using robust statistics; (left) systematic uncertainty, (right) random uncertainty, otherwise as Figure 10.

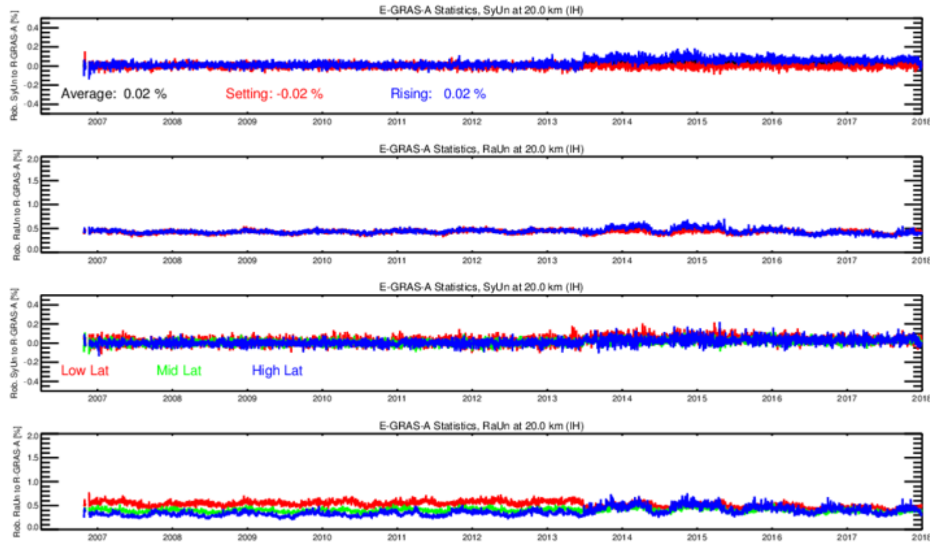

Figure 15 (O1-O2)/O2 matches of Metop-A Release 2 - GRAS Level 1b Bending Angle FCDR with ROM SAF Metop-A CDR v1.0/Offline data at 20km, daily averaged using robust statistics; (top) systematic uncertainty, (middle top) random uncertainty for all/setting/rising; (middle bottom) systematic uncertainty, (bottom) random uncertainty for different latitude bands. Average systematic uncertainty is also given, separated for setting/rising/all.

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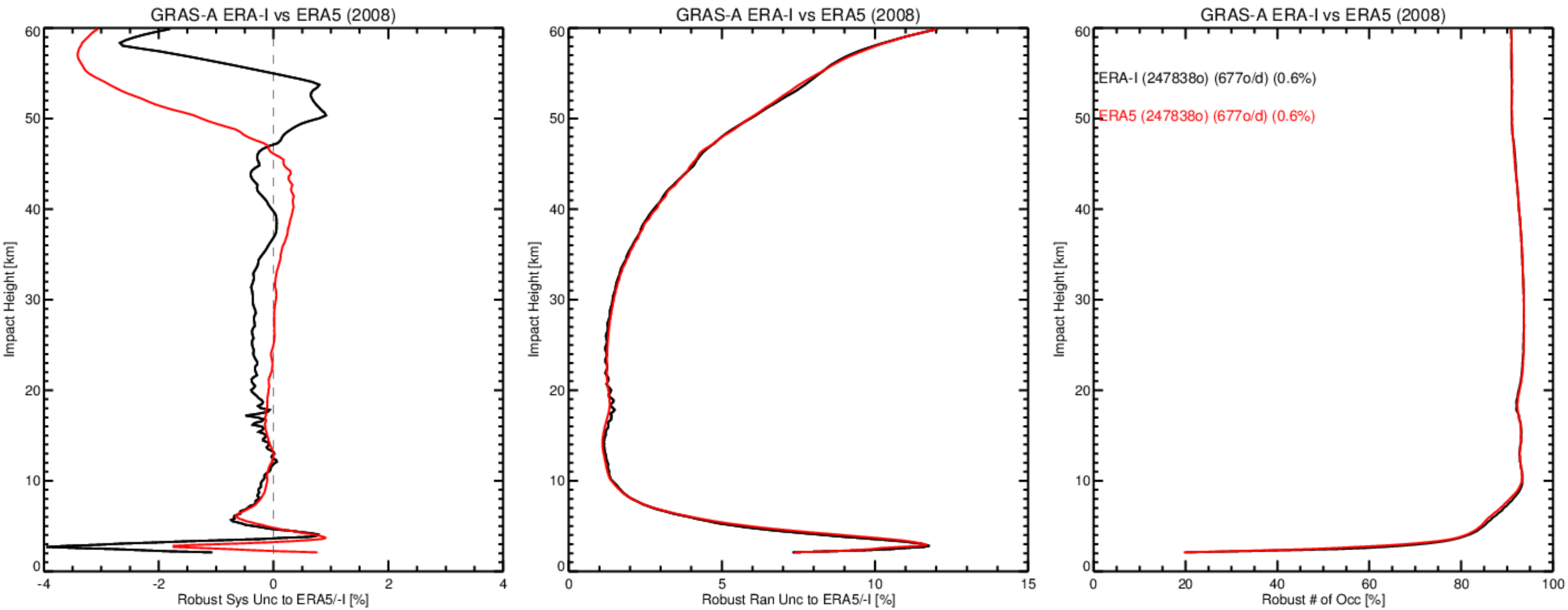
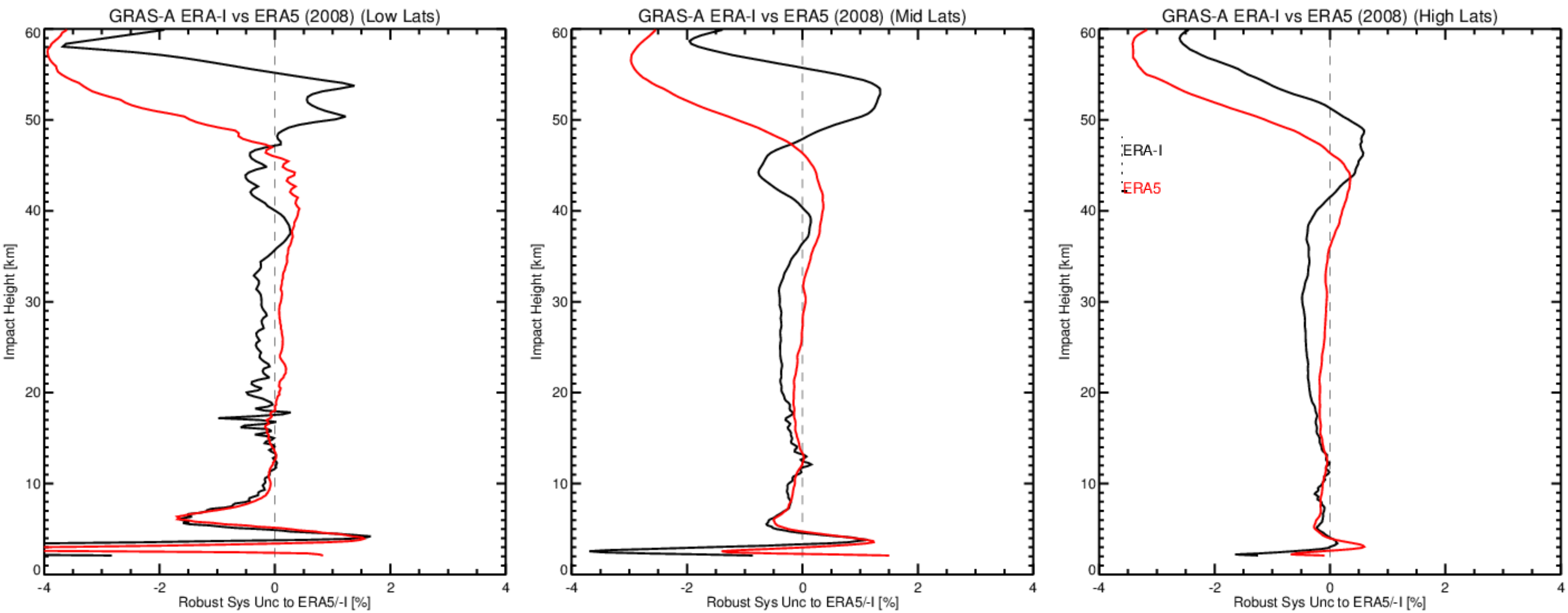
Reprocessing: Preparations for ERA5 Use

- Mostly data from 2008
- Metop-A GRAS data
- ERA-I, ERA5 data (with ROM SAF ROPP forward operator)
  - ERA-I:
    - 60L, 1Degx1Deg, 6h steps
    - Early RO assimilation schema, mostly using NRT RO data
    - Analysis/Forecasts
    - Size/Day: 63.8MByte
  - ERA5:
    - 137L, 0.25Degx0.25Deg, 6h steps
    - Improved RO assimilation schema, using also reprocessed RO data
    - Analysis/Forecasts
    - Size/Day: 2.3GByte

Reprocessing: ERA5 Global (O-B)/B



Reprocessing: ERA5 Latitudinal (O-B)/B – Bias



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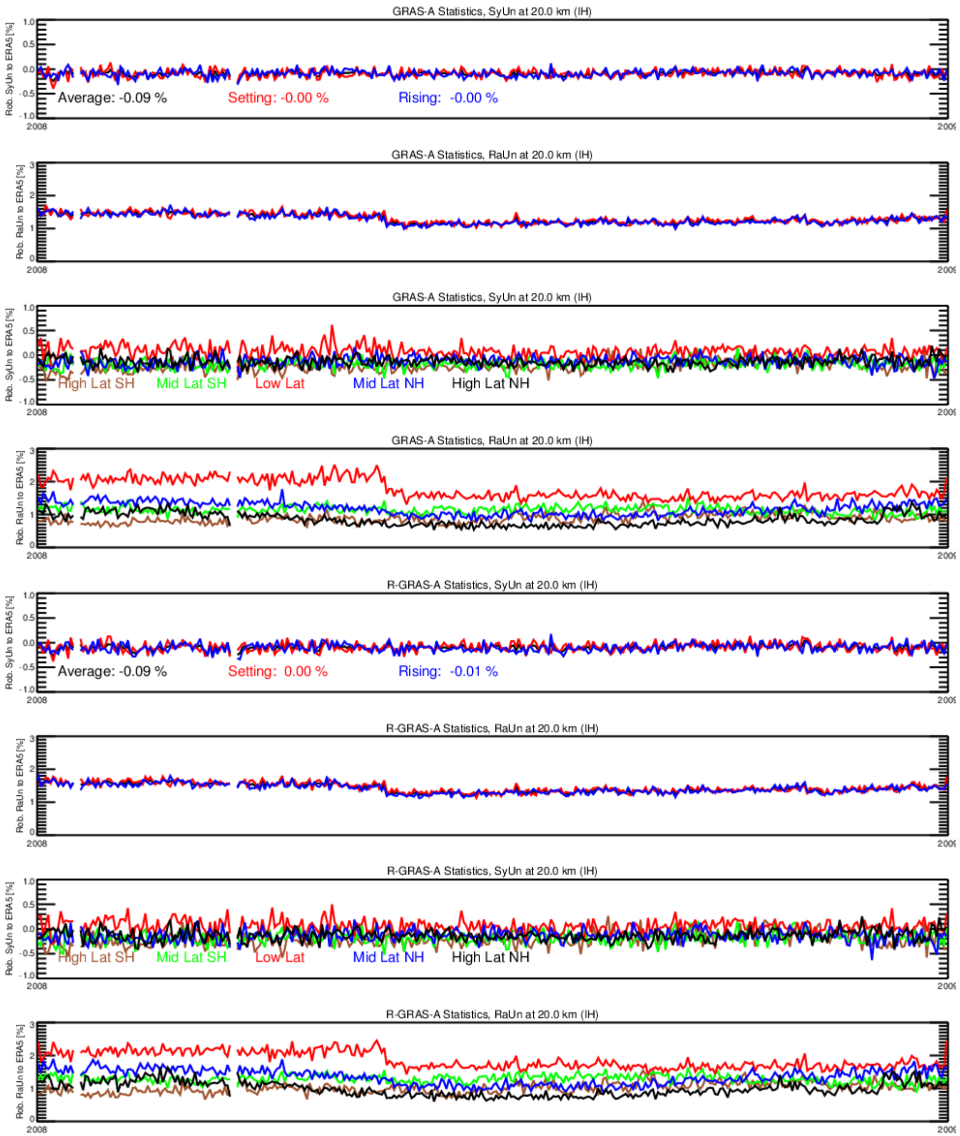
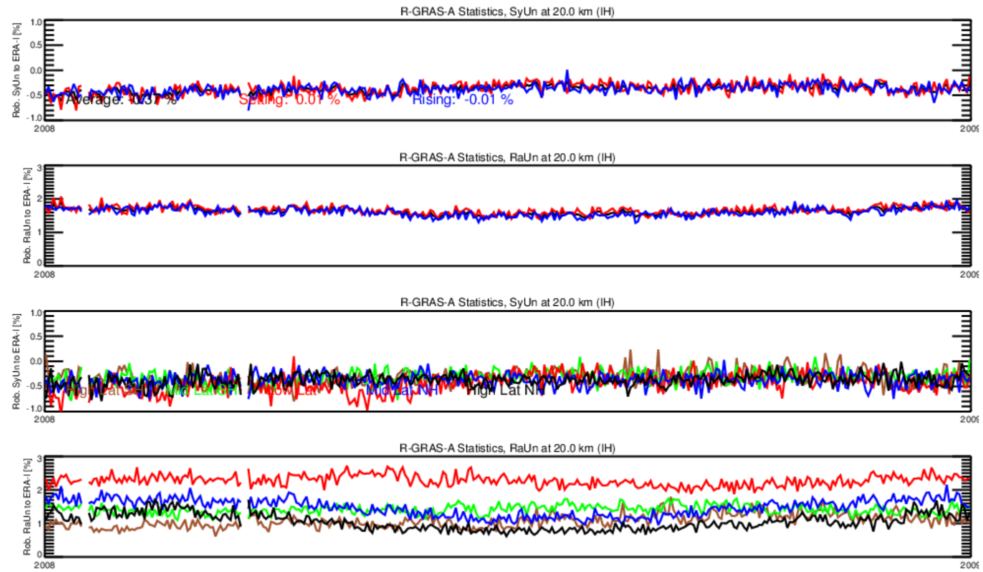
Reprocessing: ERA5 2008 Time Series @20km





Left Top: GRAS-A/EUM 2008 time series at 20km against ECMWF ERA5 re-analysis; Left Bottom: as top, but GRAS-A/ROM SAF data; Left Top: as Left Bottom, but ERA-I data. All plots top 2 plots: bias, std dev separated setting/rising; bottom 2 plots: bias, std dev for five latitude bands.

GRAS operational May 2008 data impact visible at low latitudes std dev.

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Occultation Prediction

Background:

- since June 2017, provided as “best effort / semi-operational” service; see also: link.
- provided for all Metop, GRAS instruments (thus now including Metop-C)

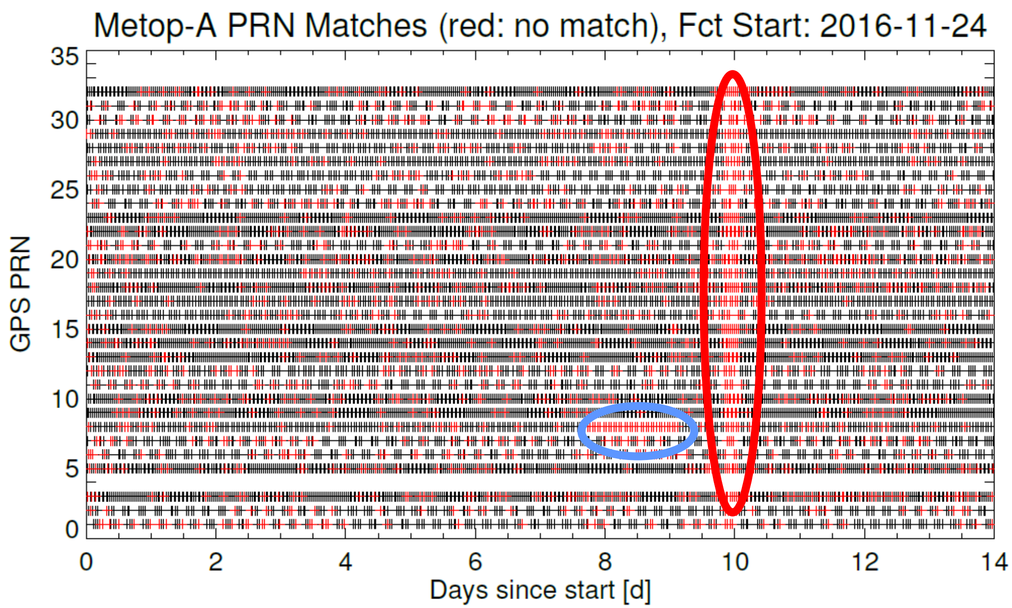
Status:

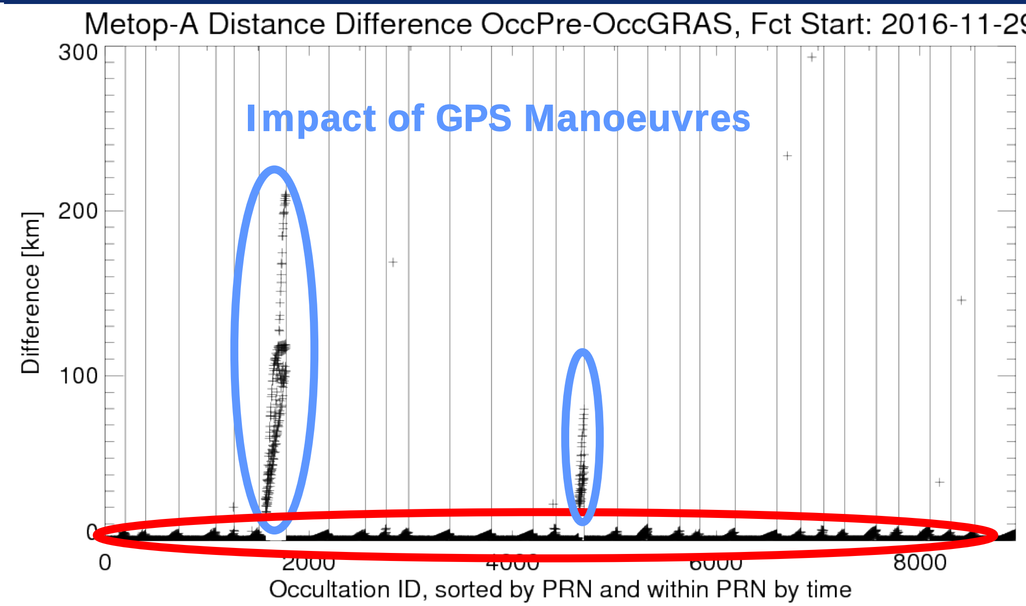
- providing all possible occultations over the next 14 days, plus the sub satellite points
- daily generation, usually provided within first 6h of the day
- generally 80+% are actually observed by GRAS instrument
- sonde station / occultation / overpass match information send to GRUAN stations

Next Steps:

- identified more robust environment within EUM infrastructure, working on way forward for implementation
- work on improved prediction quality indicator:
  - identifying cause for GRAS failures and flag those, err on the side of caution
  - removing very short occultations (are currently marked with quality = 0 already)
  - include GNSS ~~and scheduled LEO maneuver~~ (and campaigns) where possible
  - provide information on better setting occultation quality
  - further analysis instrument vs. predictions to understand limitations
  - further analyze the actual GRAS data quality vs. the prediction
- within GSN to RSN transition, identified also short GNSS clock gaps as cause for not processed occultations, mitigation options are investigated
- use for operational monitoring of EPS-SG performance (RO instrument, RSN provider)

Occultation Prediction: General Characteristics





GNSS Data Outage (NANU) due to Manoeuvre

Metop Data Outage due to Manoeuvre

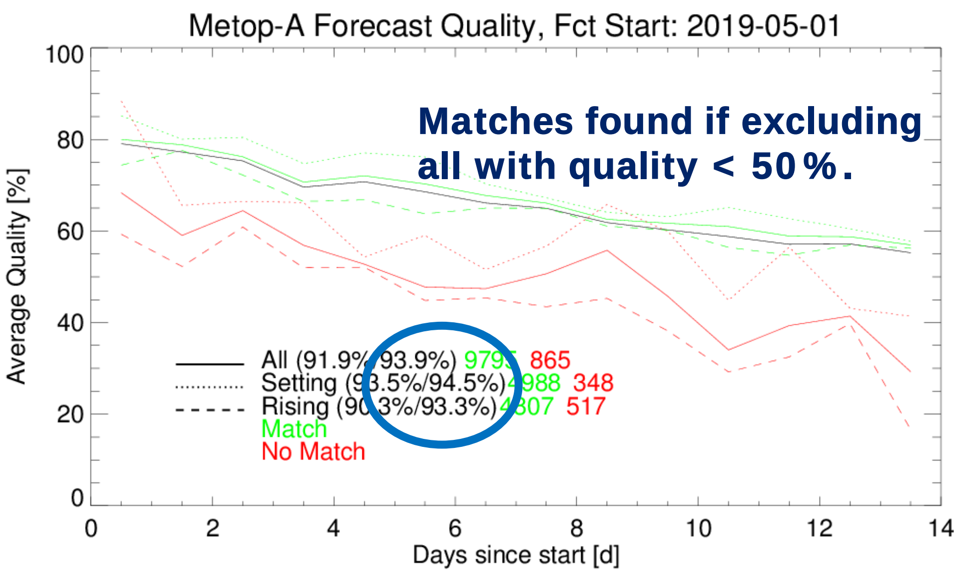
Impact of LEO Manoeuvre

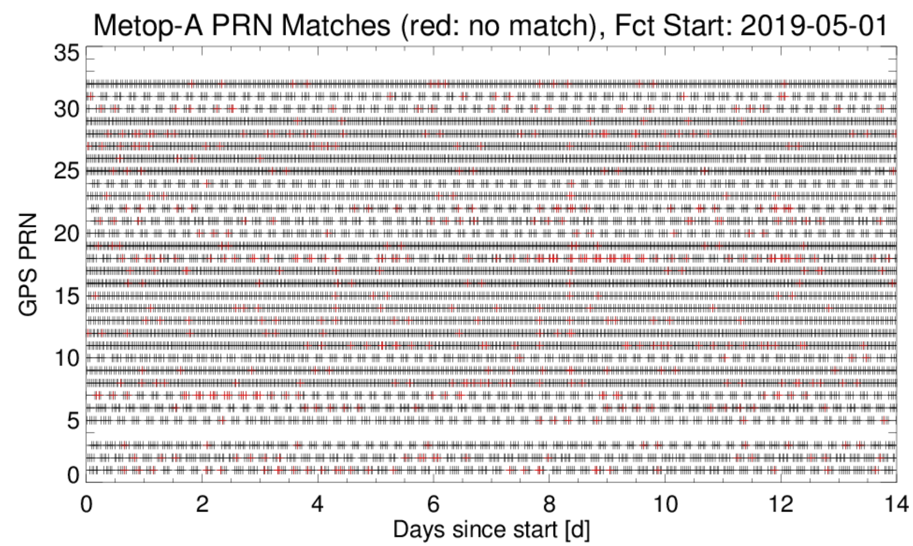
(left) Example of GPS occultation prediction matches against GRAS observations over the 14 day prediction period (on average about 85% or predicted also observed by GRAS);

(right) generally high accuracy in reference position prediction achieved, but LEO and GPS maneuvers impact the predicted occultation location accuracy; small LEO maneuver impact (on day 9) visible for each GPS satellite towards the end of prediction period (small ripples); large impact of GPS PRN 08 and 17 visible for these GPS satellites.

Occultation Prediction: Reassessing Failures

- Geometry impacts whether an occultation is tracked by the instrument
- however, several other “unpredictable” factors do this too, e.g.
  - GPS age / reliability (partly not covered in NANUs)
  - NRT GNSS information unavailability (would though be available in reprocessing)
  - Collision avoidance maneuvers





New quality settings

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Summary / Future Steps

- Reprocessing:
  - First Metop-A, -B 2006-2017 available; Metop-A, -B to 2019 in Q2 2020, as well as 3rd Party missions (CHAMP, COSMIC, etc)
  - Validation shows high quality / stability, some issues at the upper and lower altitudes needs addressing
- Occultation Predictions:
  - 14 days in advance; targeting e.g. sonde launches
  - Prediction Quality Improvements
  - Other possible future improvements
  - GRUAN community would like to see this available for all RO missions

Additional Material

Occultation Prediction: Quality Indicator / Background

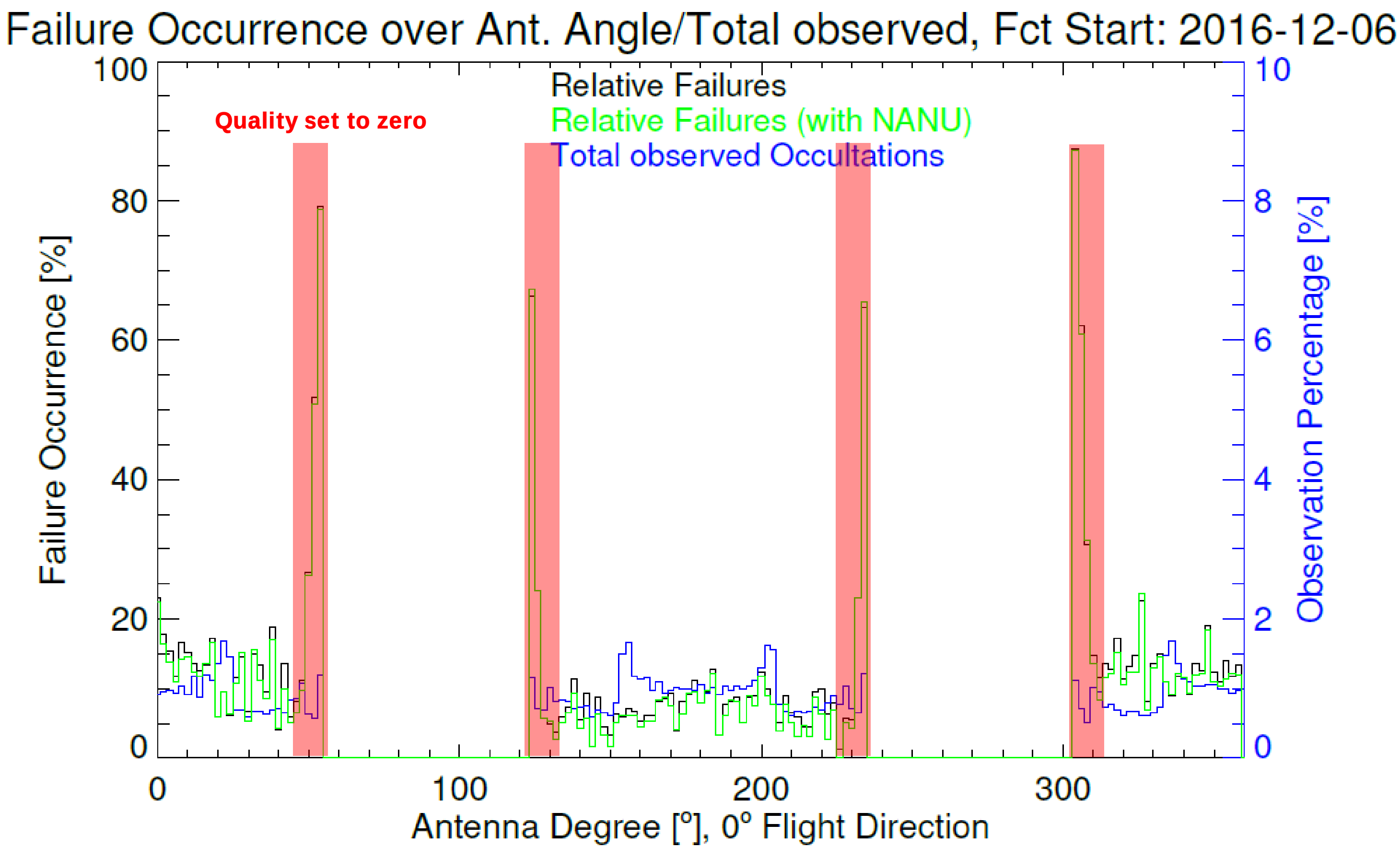
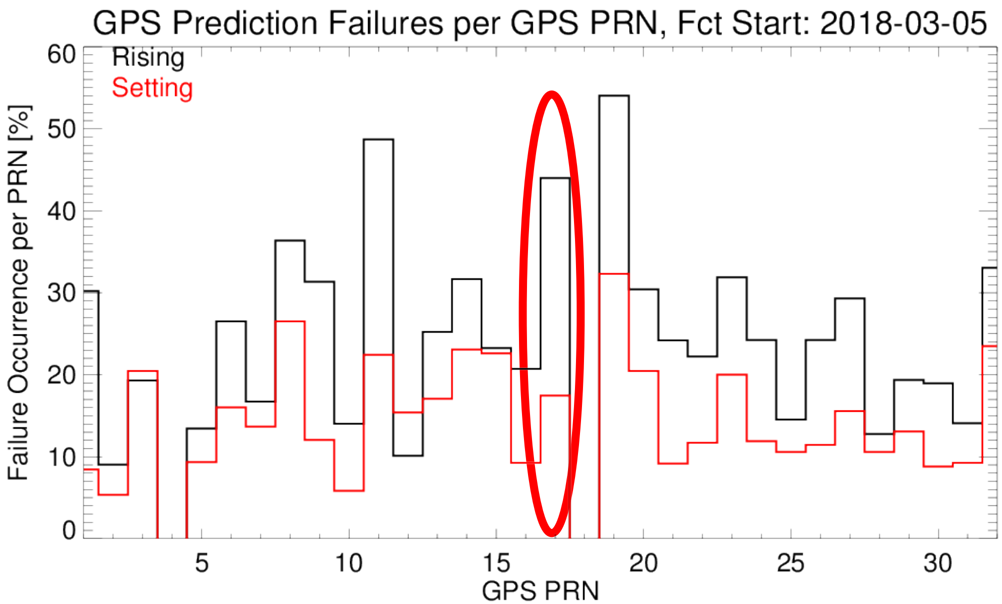
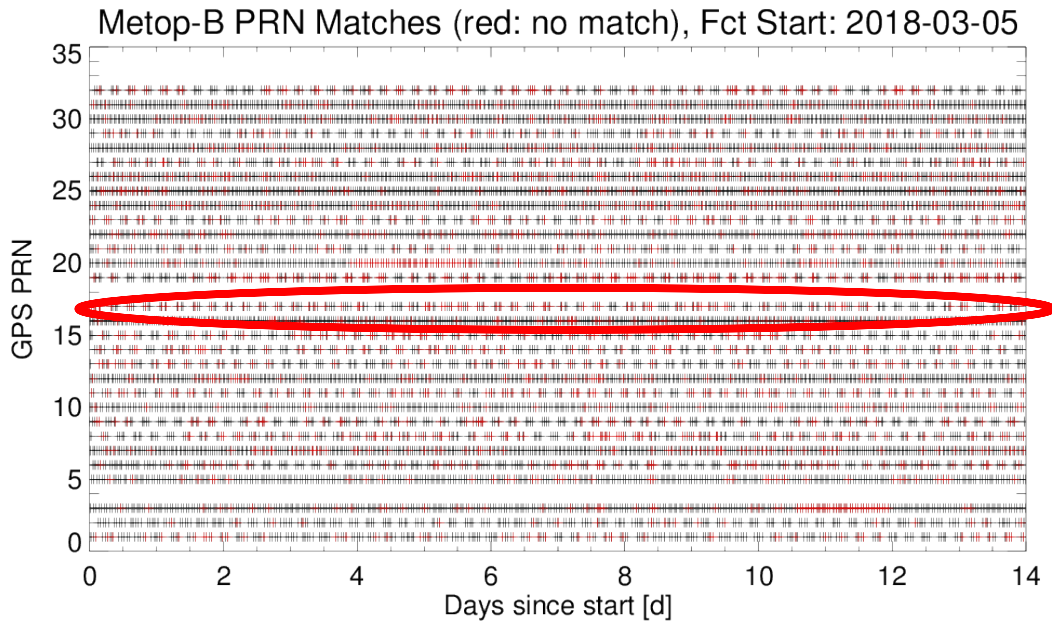


Fig. 4.6: Normalized occultation prediction failures over antenna azimuth, 0 Degrees is flight direction (rising occultations). Bin-size for all histograms is 2 Degrees, failures are shown without NANU (black) and with NANU information (green) taken into account; also shown in blue (right y-axis) is the normalized number of occultations per bin-size.

Occultation Prediction: Reassessing Failures (1)

Prediction vs. actual observations separated in setting/rising and per GPS PRN (left) and failures per GPS PRN (right)





Fairly large difference between rising and setting for some satellites, e.g. PRN 17

PRN 17 also with few occultations predicted

-> indicates rising occultations more difficult to track when generally low number of predictions are made for a certain GPS satellite

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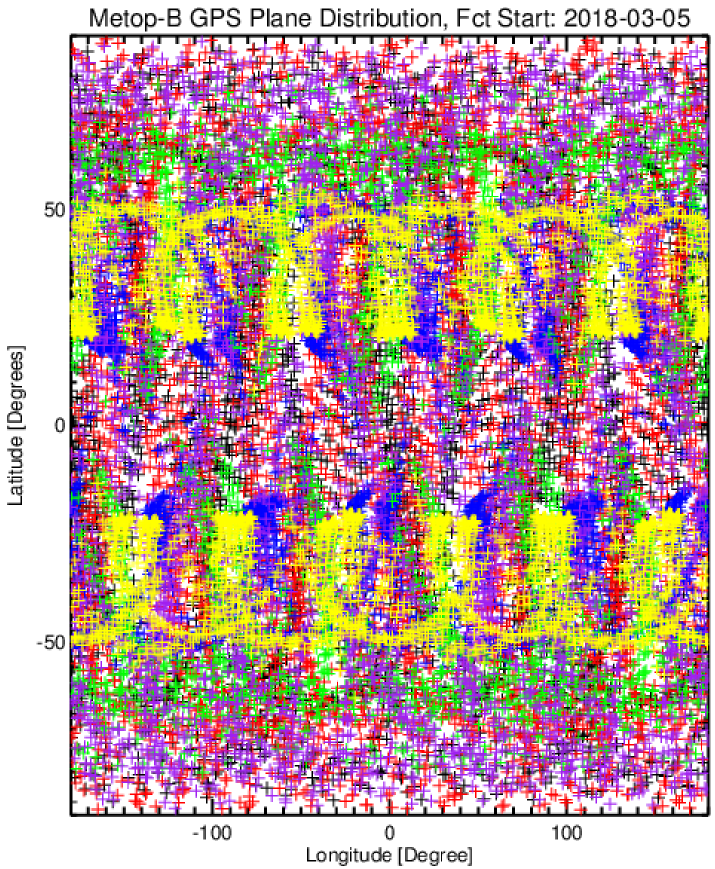
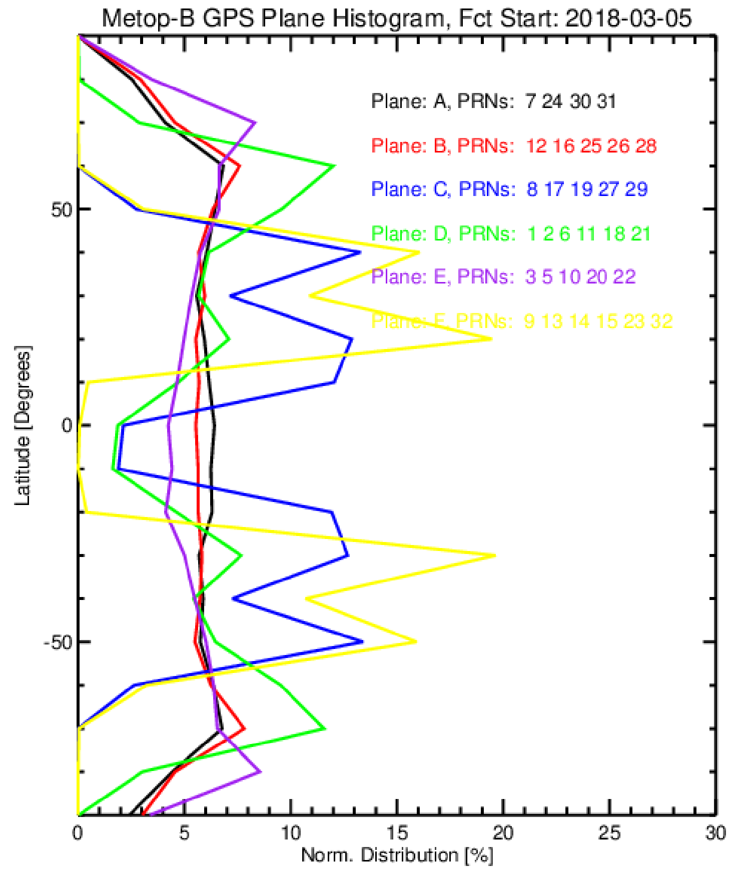
Occultation Prediction: Reassessing Failures (2)

Recent prediction vs. actual observations separated per GPS Plane over latitude and longitude (left) and histogram of predictions per GPS plane (right)





-> indicates certain GPS planes have only observations at certain latitudes, e.g. Plane F, likely due to unfavorable geometry. This can be used as additional quality indicator, flagging in particular rising occultations within this geometry.

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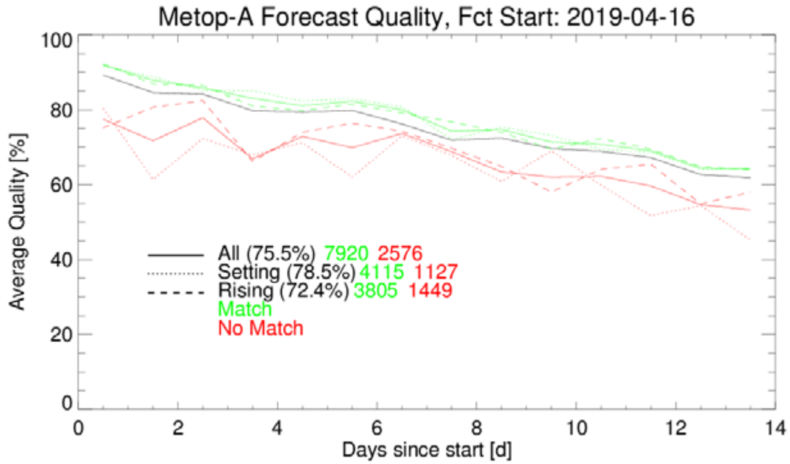
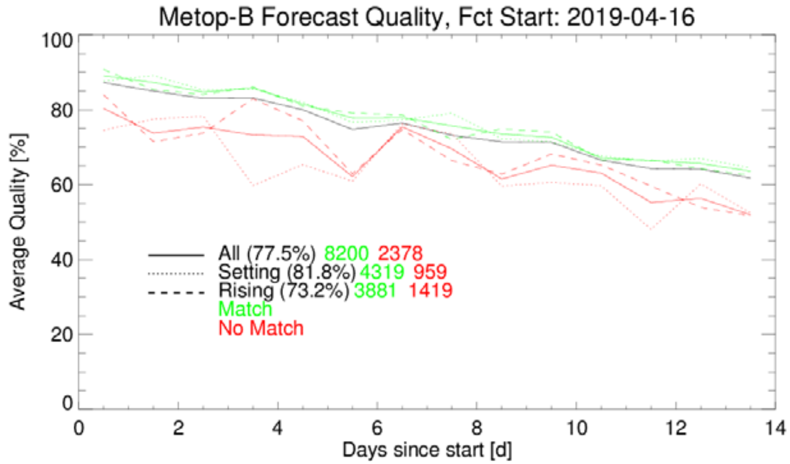
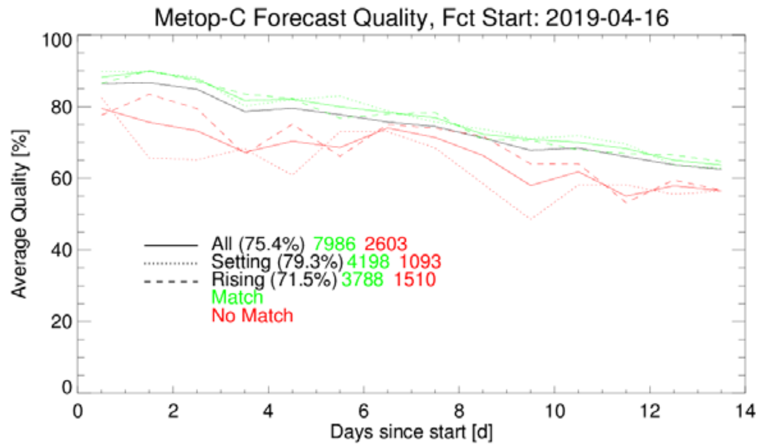
Occultation Prediction: Quality Indicator





Examples of GPS current occultation prediction quality, separated for setting/rising and for those actually matched/unmatched, over the 14 day prediction. Current quality setting are based on:

- reduced quality over time (linear, by 30% over 14 days)
- occultation is on the edge of the occultation antenna
- Note: setting/rising quality the same, though obvious that this impacts predictions
- Note also: this is an example with GPS aux data outage around day 6 (would be available in reprocessing)



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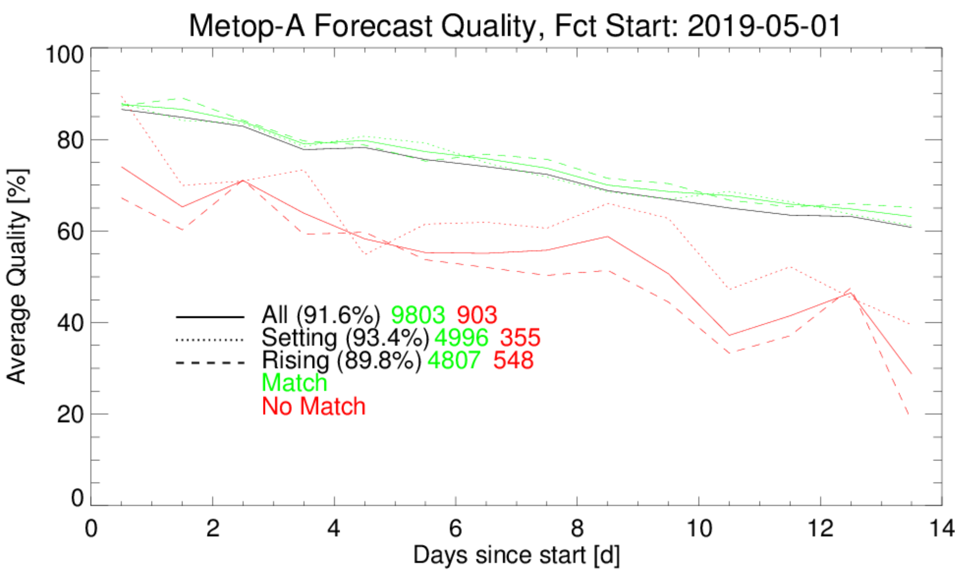
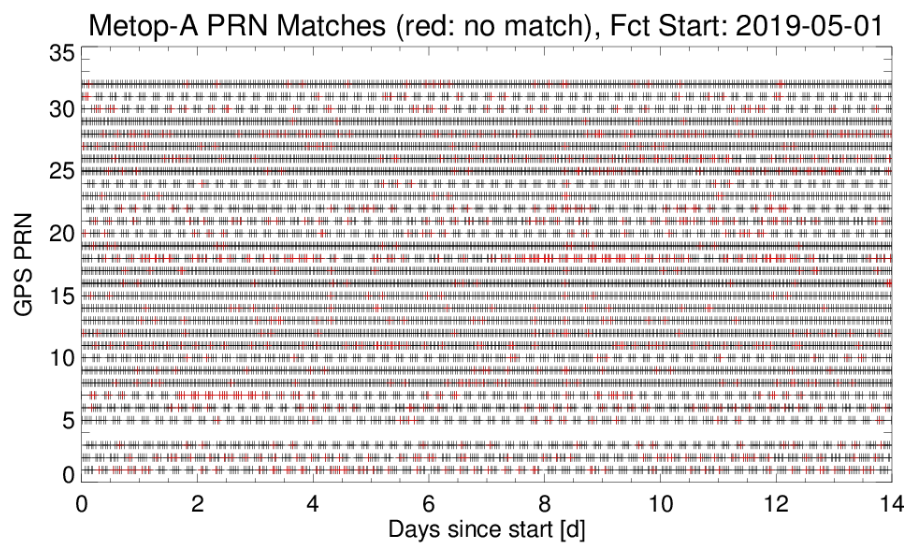
Occultation Prediction: Reassessing Failures (3)

Summary:

- **Geometry impacts whether an occultation is tracked by the instrument**
- **however, several other "unpredictable" factors do this too, e.g.**
  - **GPS age / reliability (partly not covered in NANUs)**
  - **NRT GNSS information unavailability (would though be available in reprocessing)**
  - **Collision avoidance maneuvers**





Old quality settings