Impact of Satellite Orbits and Clocks on Radio Occultation (RO) Data Processing

Yoke Yoon, Yago Andres, Axel von Engeln, Christian Marquardt
Oliver Montenbruck (DLR), Andres Hauschild (DLR)

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Overview

- Introduction
  - ERA-CLIM project
  - Contribution from EUMETSAT

- Impact of satellite orbit and clock quality in MetOp RO data processing
  - Post-processing using final GPS products (ERA-CLIM)
  - NRT using various NRT and RT GPS products (operational)

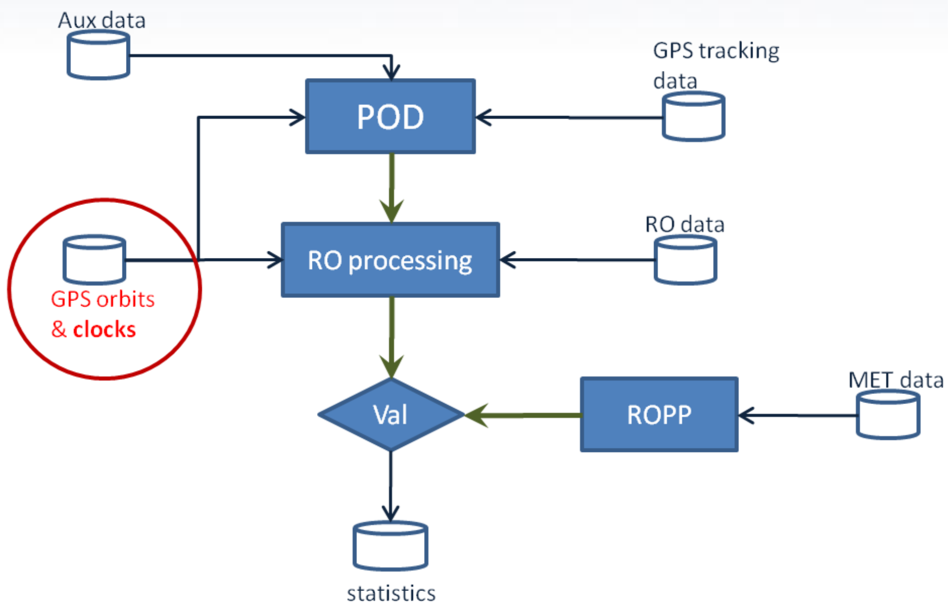
- COSMIC POD at EUMETSAT
  - Results and discussion on achievable accuracy

Introduction

- European Re-Analysis of global CLIMate observations (ERA-CLIM)
  - Project headed by ECMWF
  - Re-analysis of in-situ and satellite observation data in generating consistent global model of Earth's climate system
  - Objective is to improve on numerical weather forecasting
- EUMETSAT RO activity in ERA-CLIM
  - Provide reprocessed GPS RO observations (2001-present) from MetOp, COSMIC, CHAMP, GRACE, etc
    - Maintain consistency in using the type of GPS products
    - Investigation into GPS orbit and clock products and their impact on POD and in turn RO bending angle profile

Impact of satellite clocks in MetOp RO data processing

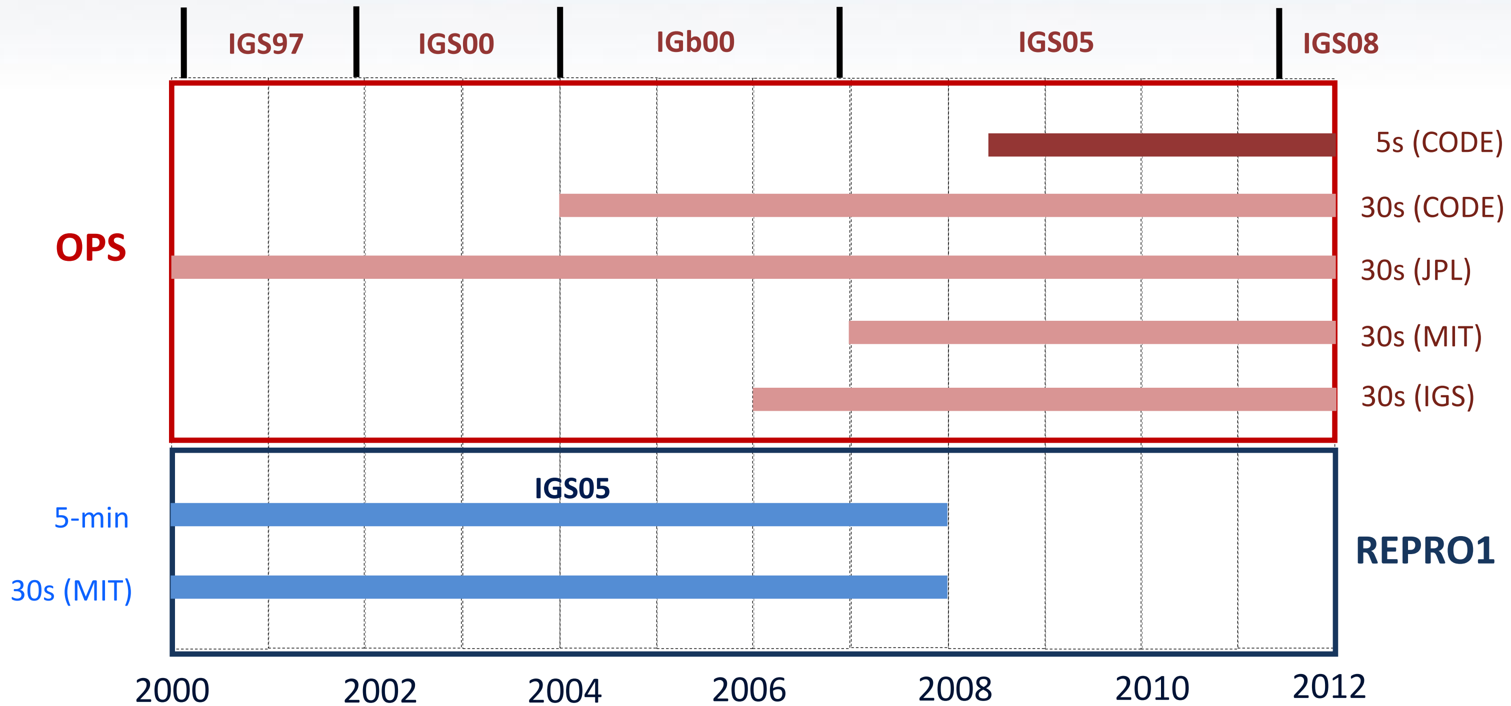
- Simple layout of post-processing architecture
  - GPS raw data processing
  - Precise orbit determination
  - RO data processing
  - Comparison with ECMWF model



Impact of satellite clocks in MetOp RO data processing

GPS Final Orbit and Clock Products

- GPS orbit product – 15 mins interval
- GPS clock product – 5-min, 15-min interval (standard) and others (table)



Impact of satellite clocks in MetOp RO data processing

- Studying impact of GPS clock products on RO

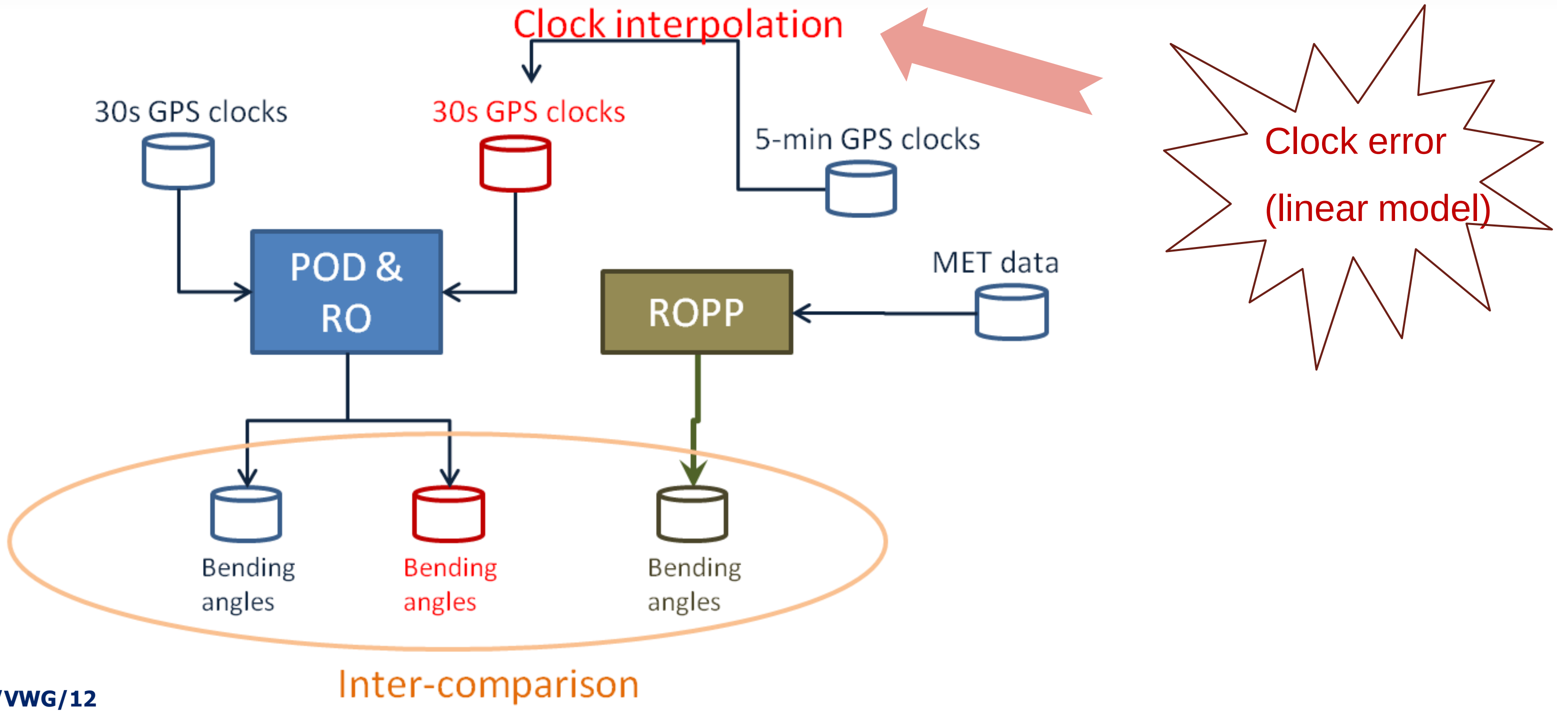
  - MetOp GRAS data from 30 Sept 2007 – 31 Oct 2007 (~1 month)
  - Generated two sets of solution
    - ESOC Repro1 (interpolated 30s GPS clocks)
    - CODE OPS (estimated 30s GPS clocks)

  - Results from analysis
    - MetOp orbit (POD)
    - Bending angle (using geometric optics processing)

Impact of satellite clocks in MetOp RO data processing

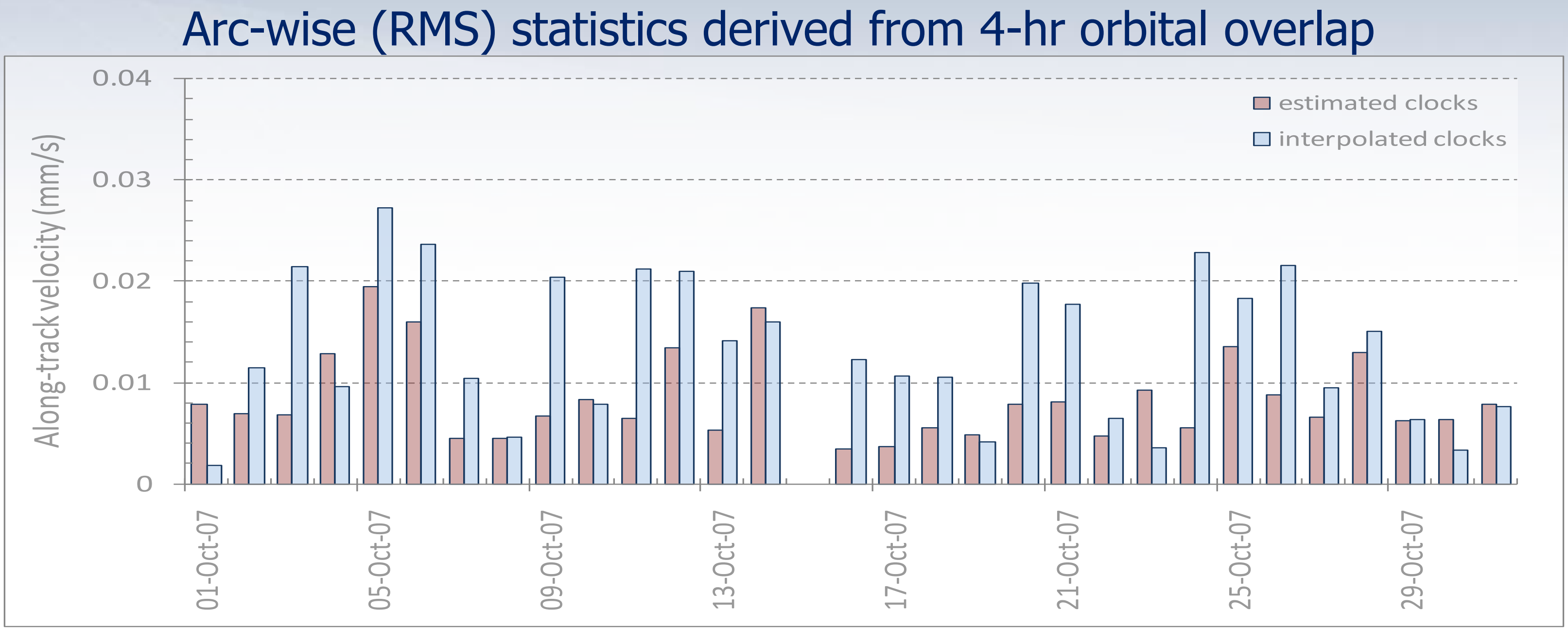
- Studying impact of GPS final products on RO

  - ESOC Repro1 (5 min clocks) vs CODE OPS (30s clocks)



Impact of satellite clocks in MetOp RO data processing

Assessment of MetOp POD

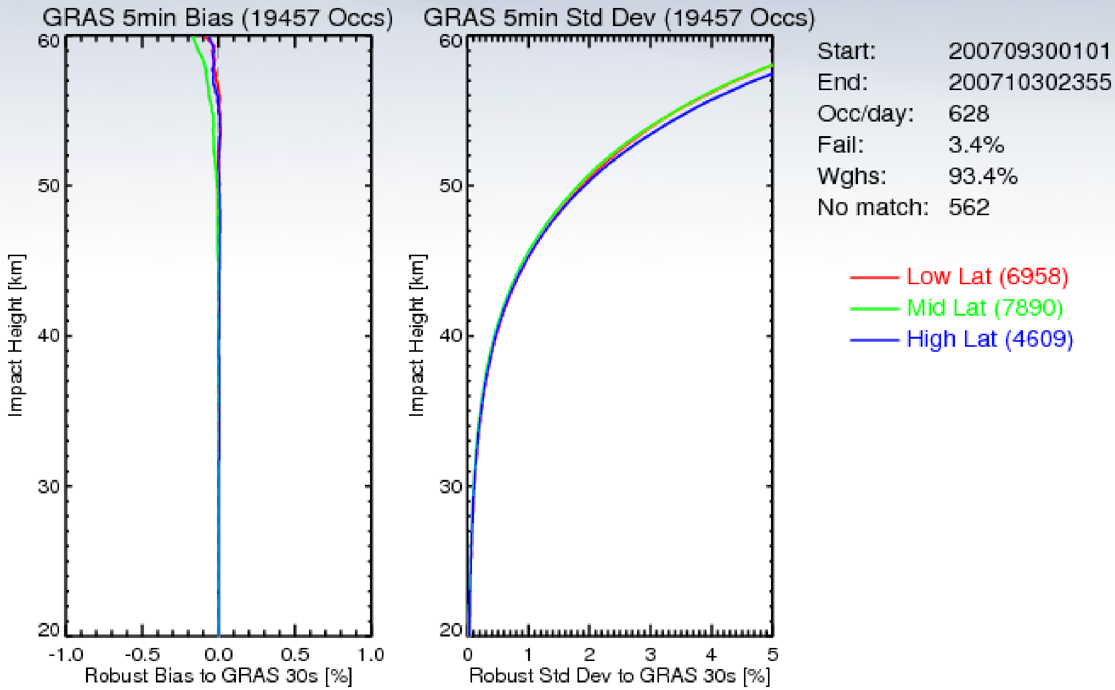


	estimated clocks	interpolated clocks
✓ Along-track velocity	< 0.02 mm/s	< 0.03 mm/s
✓ Median	0.007 mm/s	0.012 mm/s

3D Position (due to interpolated GPS clock errors) : < 2 cm (RMS)

Impact of satellite clocks in MetOp RO data processing

Assessment of bending angle



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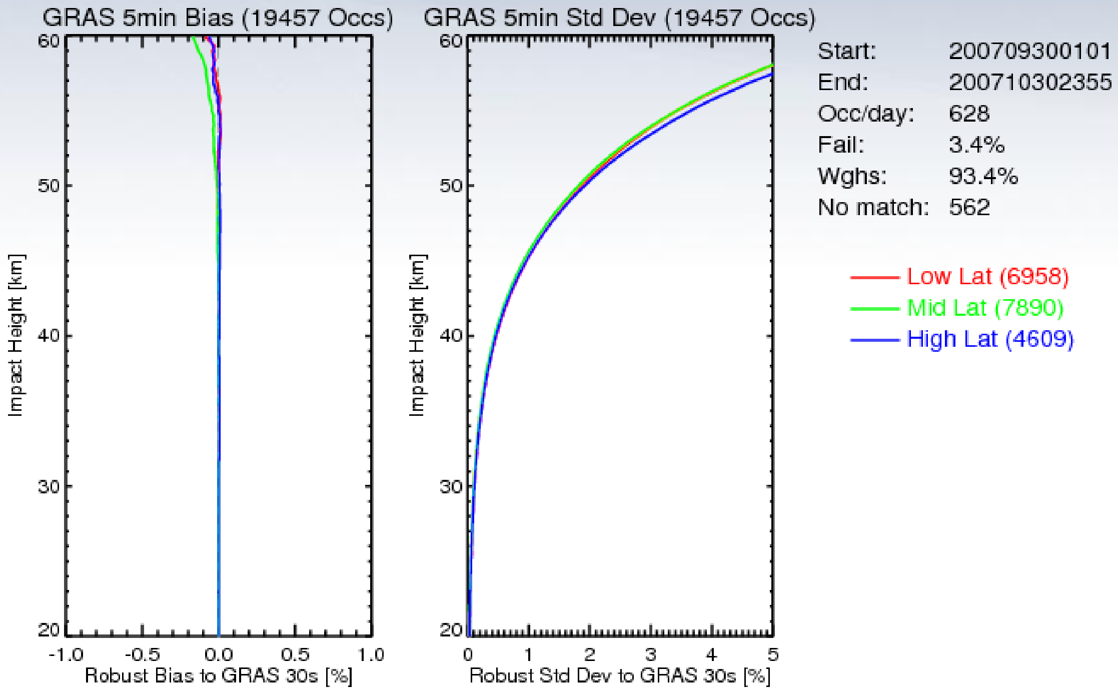
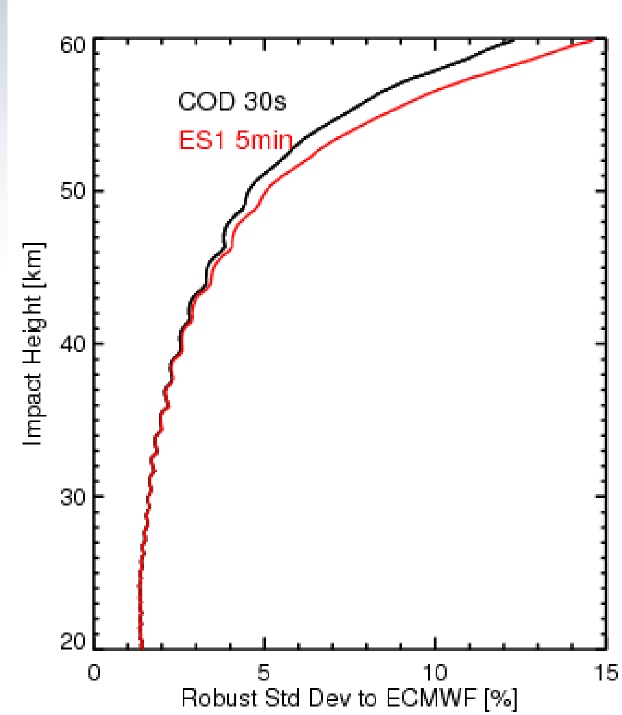
Assessment of bending angle





- ✓ No visible impact at < 40 km impact height
- ✓ Better STDEV from estimated 30s clocks > 40 km impact height

Near Real Time Analysis

Impact of satellite clocks in MetOp NRT RO data processing

- STUDY (Collaboration with GSOC/DLR)
  Assess different GPS based NRT POD concepts with GRAS data
  (Nov 15 to Dec 15 2011)
  - Different NRT GPS products
  - Different POD s/w tools

  $\Rightarrow$ Focus on:

  achieved along-track velocity accuracy

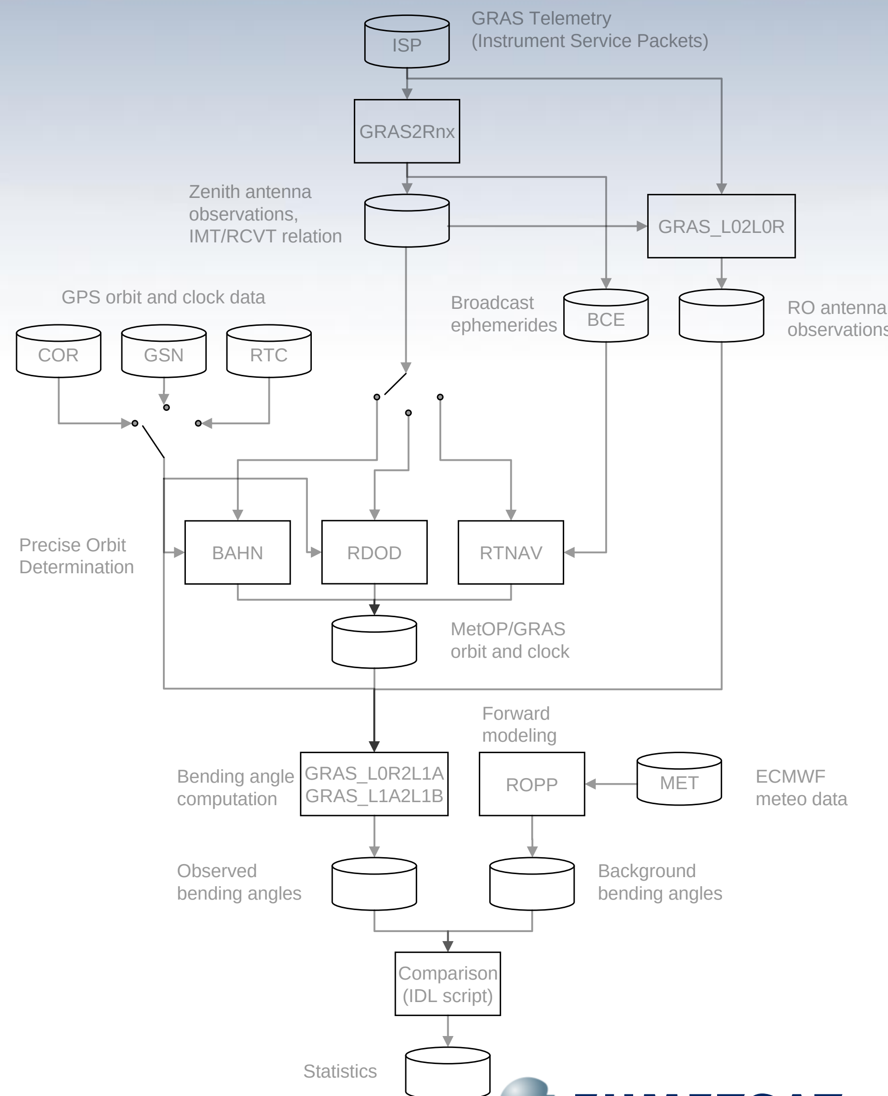
  resulting bending angles

- MOTIVATION
  - Better understand the effect of NRT LEO and GPS orbits in RO
  - Provide design recommendations/ requirements for future RO missions

Impact of satellite clocks in MetOp NRT RO data processing

System Setup

- GPS products:
  - CODE rapid (reference)
  - GSN/ESA
  - RETICLE/DLR
  - Broadcast Ephemeris (BCE)
- POD tools
  - ESA/NAPEOS (BAHN) (Batch Filter)
  - DLR/GHOST (Batch Filter)
  - DLR/RTNAV (Extended Kalman Filter)
- ECMWF forward modelling for comparison of Bending Angles (BA)



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Impact of satellite clocks in MetOp NRT RO data processing

GPS products and POD setups

	COR	GSN	RTC	BCE
Description	CODE rapid products	GSN orbit and clock products	RETICLE	Broadcast Ephemerides
Category	post-processed	near-real-time	real-time	real-time
Originator	CODE	ESA/ESOC	DLR/GSOC	GPS
Network	IGS	GSN	IGS R/T & DLR	GPS
Arc length	24 h	orbit: 24 h + 19 h(pred) clock: 30 m	-	2 h
Update interval	24 h	orbit: 3 h clock: 15 m	-	2 h
Latency	12 h	orbit: 60-90 m clock: <45 m	<10s	-
Step size	orbit: 15 m, clock: 30 s	orbit: 15 m clock: 30 s	10 s	-

6 different processing chains:

Napeos: COR (24h arc, daily), GSN (6h arc, 1.5h freq.), RTC (6h arc, 1.5h freq)

GHOST: COR (24h arc, daily), RTC (6h arc, 1.5h freq)

RTNAV: BCE (simulated real time)

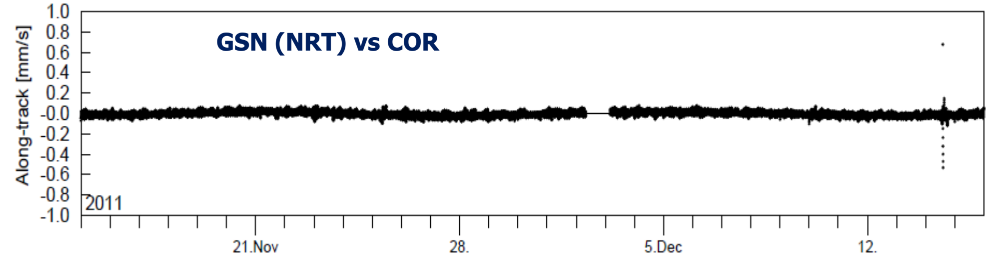
Impact of satellite clocks in MetOp NRT RO data processing

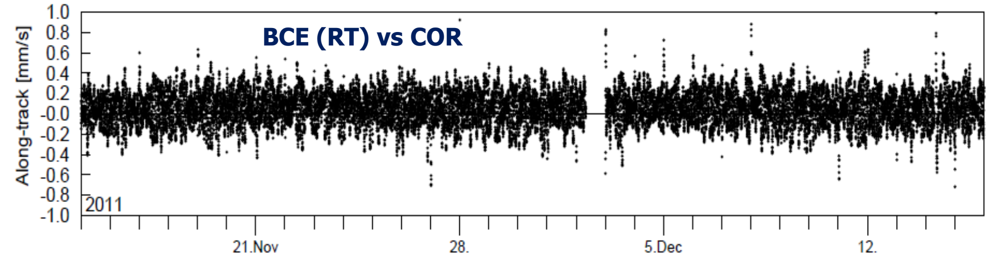
Results - POD

Solution	Radial [mm]	Along-track [mm]	Cross-track [mm]	Position (3D rms, [mm])
OFF_COR_N	-6 ± 16	-2 ± 40	+23 ± 13	51
NRT_RTC_N	-7 ± 19	+1 ± 39	+23 ± 16	52
NRT_RTC_G	+1 ± 18	-3 ± 36	-1 ± 14	43
NRT_GSN	-6 ± 18	-2 ± 39	+23 ± 15	51
RT_BCE	+7 ± 195	+157 ± 329	+25 ± 228	473

Solution	Radial [mm/s]	Along-track [mm/s]	Cross-track [mm/s]	Velocity (3D rms, [mm/s])
OFF_COR_N	0.00 ± 0.03	-0.01 ± 0.03	0.00 ± 0.02	0.05
NRT_RTC_N	0.00 ± 0.03	-0.01 ± 0.03	0.00 ± 0.02	0.05
NRT_RTC_G	0.00 ± 0.03	0.00 ± 0.02	0.00 ± 0.01	0.04
NRT_GSN	0.00 ± 0.03	-0.01 ± 0.03	0.00 ± 0.02	0.05
RT_BCE	-0.15 ± 0.34	+0.06 ± 0.16	0.01 ± 0.24	0.48

- All NRT solution < 0.1mm/s along track
- Offline & NRT solutions (NAPEOS vs Ghost) agreement ~ 5cm
- Small inter-agency biases in radial (6mm) and cross-track (23mm)
- Simulated RT orbit have a factor 10 larger error in MetOp pos. and vel., but only a factor 2 for along track vel.





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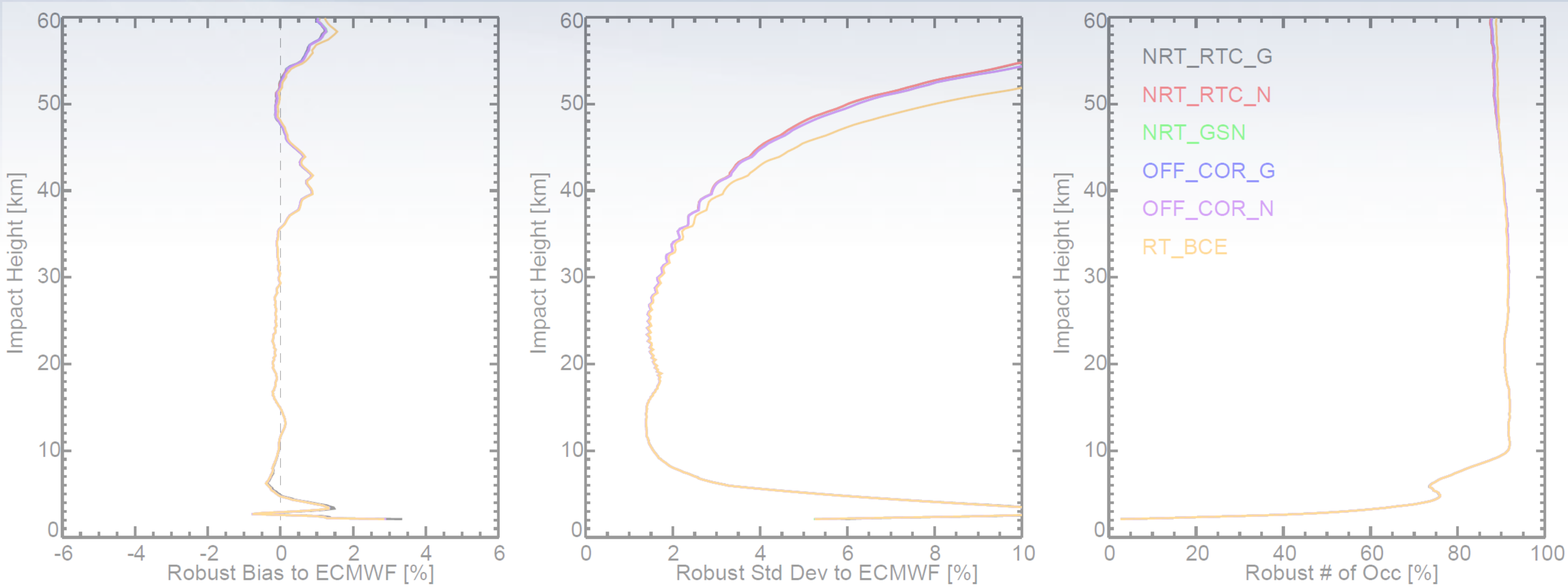
Impact of satellite clocks in MetOp NRT RO data processing

Results – NRT Bending Angle

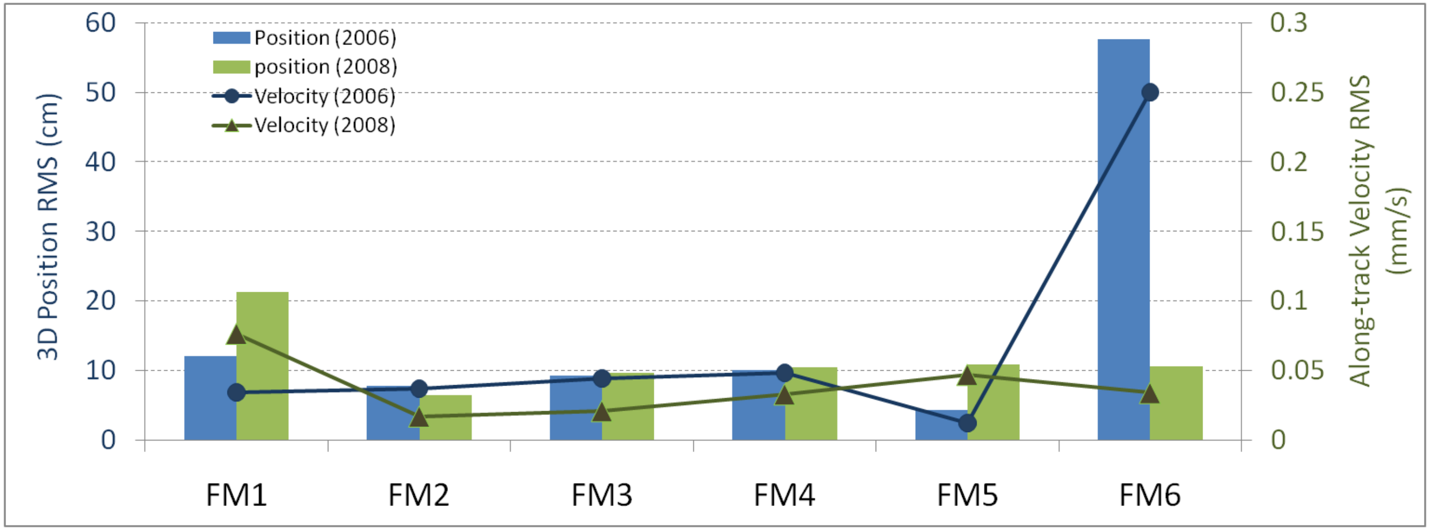


- 15100 rising and setting occultation events, only Geometric Optics processing
- Offline (one day lag) processing provides up to 10% more occultations (unhealthy satellites)
- All NRT solutions provide an almost identical bending angle performance
- Slight deviation at high altitude from BCE-derived BA

Assessment of COSMIC POD

COSMIC Precise Orbit Determination

- Two sets of statistics for 6 COSMIC s/c
  - 2-10 August 2006
  - 26 Nov – 3 Dec 2008
- Internal (orbit overlap) assessment (stats based on median)
  - 3D position (RMS) < 25 cm [exclude FM6 in 2006]
  - Along-track velocity (RMS) < 0.1 mm/s



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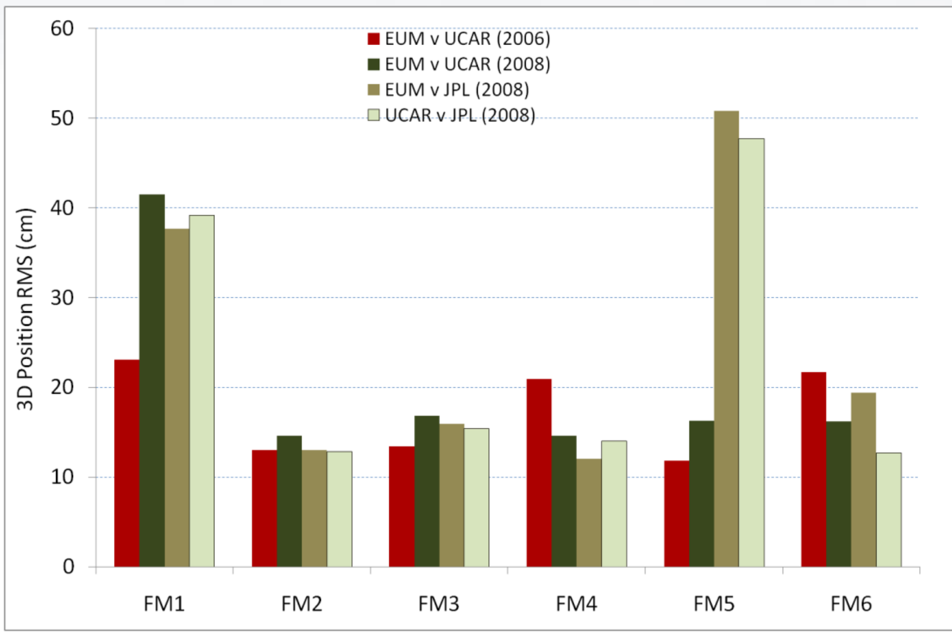
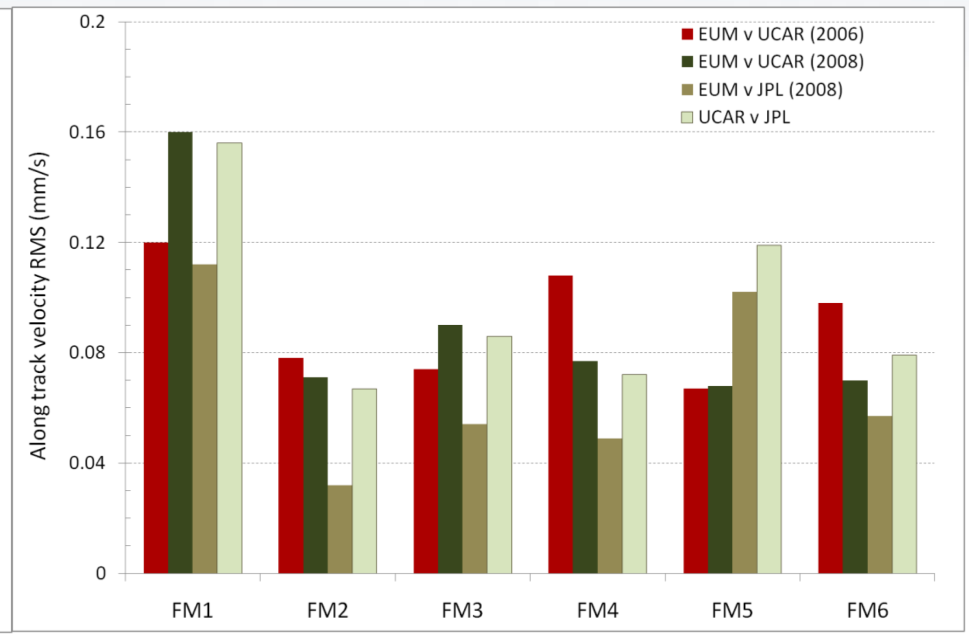
COSMIC Precise Orbit Determination

External orbit assessment (stats based on median)

- ❑ CDAAC (online products)
- ❑ JPL (reprocessed orbits)





3D position < 60 cm

Along-track velocity < 0.2 mm/s

Summary and Conclusions

- Impact of satellite orbit & clocks on RO processing
  - POD performance and bending angle statistics from post-processing (ERA-CLIM) and NRT (operational) have been assessed using one month of MetOp data
  - MetOp along-track velocity accuracy (POD)
    - ✓ Post-processed < 0.02 mm/s
    - ✓ NRT < 0.05 mm/s
    - ✓ RT ~ 0.2 mm/s
  - Bending angle performance
    - ✓ Clock interpolation error (5min→30s) induced no significant difference
    - ✓ NRT and rapid solutions are identical
    - ✓ RT compatible with NRT for height up to 40km
- COSMIC POD
  - Overall POD (EUM, UCAR, JPL) results show good agreement