Quantifying the Bias and Uncertainty Propagation From the COSMIC2 POD to the RO Excess Phase and Bending Angle for Climate Applications

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Introduction

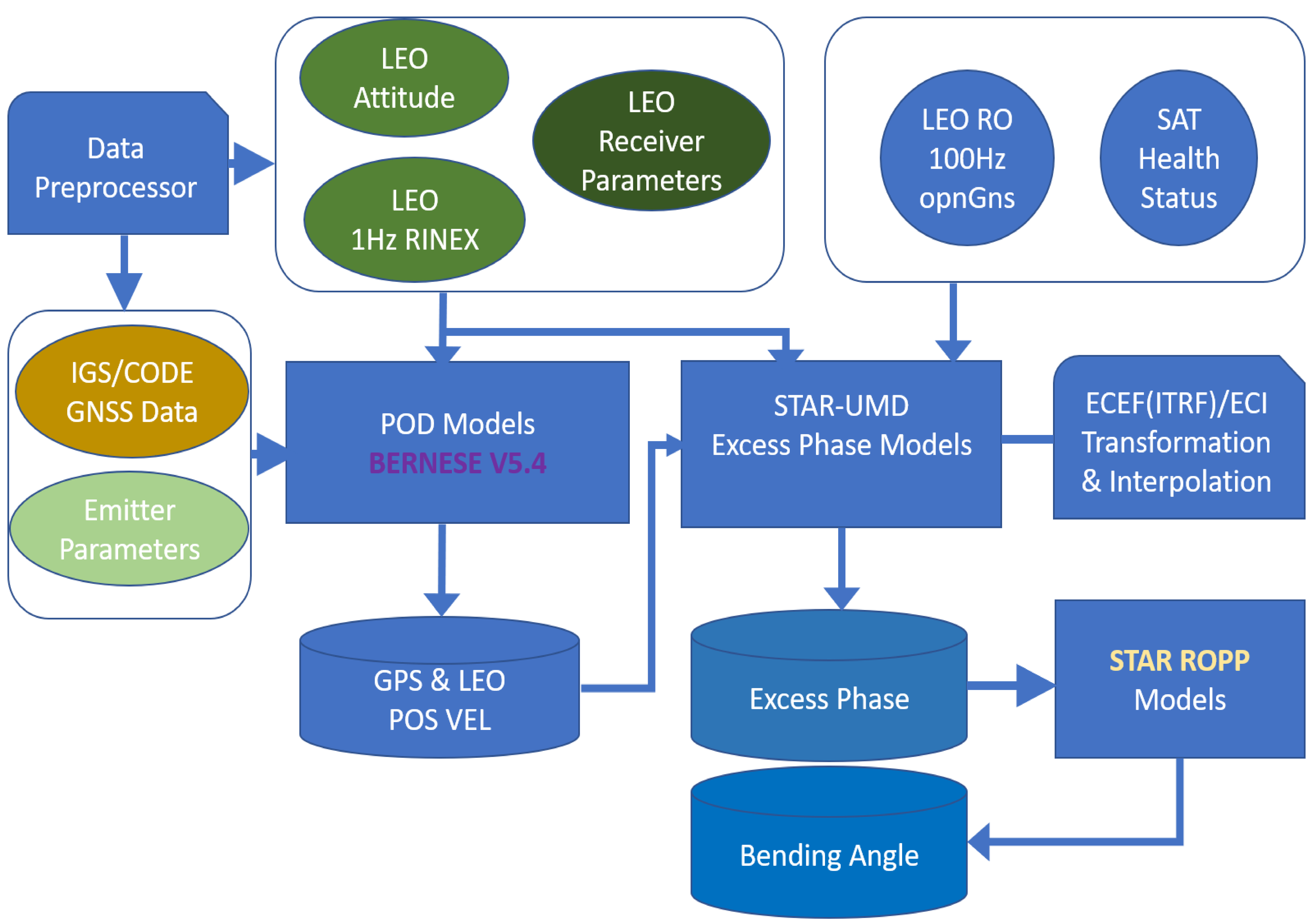
The accuracy and utility of the RO measurements rely essentially on the precise orbit determination (POD) solutions. The orbiting bias of RO satellites will propagate to the RO signal processing and can be even amplified in the higher-level RO data products. It is therefore essential in practice to ensure the POD accuracy and to quantify the impact of its uncertainty on the subsequent RO data products.

This study quantifies the position and velocity differences of different COSMIC-2 POD solutions, which consists of the comparison of the multi-GNSS POD solution with the traditional single-GPS POD solution, and the inter-comparisons of the POD solutions in light of the orbiting model parameter variations. The latest Bernese software package (BSW5.4) is employed to calculate the precise COSMIC-2 orbits. BSW5.4 supports multi-GNSS (GPS, GLONASS, Galileo, BeiDou, and QZSS) and single-GPS POD processing. More importantly, observation-specific signal bias (OSB) can be set up for individual satellite in the multi-GNSS processing mode, which ensures the optimized weighting of individual observations in the POD solutions.

The multi-GNSS COSMIC-2 POD solution shows better performance in general than that using the traditional single GPS product although the difference is slight. In contrast, about 10cm difference may be found between the NRT POD solution and the post-processed solution, which may result in 10m difference in the excess-phase at low impact heights. More RO observation profiles may be constructed from the post-processed POD solutions, where more GNSS observations are available in comparison with the NRT processing. The bending-angle and refractivity may have about 5% relative difference among different POD solutions at lower impact heights.

The inclusion of GLONASS in the POD solution doesn't show advantage over the traditional single-GPS solution, which may be due to the insufficient handling of the inter-frequency bias in the MGEX products. Further efforts are needed to properly utilize the MGEX data products.

Diagram of STAR-UMD COSMIC-2 POD and Bending Angle Processing



1. Bernese POD Inputs and Orbit Model Parameters

The latest Bernese 5.4 supports multi-GNSS processing, including GPS, GLONASS, Galileo, BeiDou, and QZSS. Notably, it allows for the setup of observation-specific signal biases (OSB) for both the receiver and the GNSS satellites. When combining individual observations, each one contributes to the overall OSB parameters, ensuring optimized weighting in the orbiting determination solutions. This presentation focuses on post-processing solutions using single daily arcs.

❑ Key Bernese Model Parameters:

- Non-gravitational forces (direct solar radiation pressure, Earth radiation pressure, air drag and lift) based on satellite macro model
- Zero-difference ambiguity resolution based on L1 and L2 pseudo-range and carrier phase observations
- GNSS Satellite antenna calibration based IGS20 standard, LEO nadir offsets applied but no phase center variations
- White-noise stochastic estimation of LEO receiver clocks
- Kinematic orbit solution **(KN)** and reduced-dynamic **(RD)** orbit solution
- Three POD solution sets with different GNSS satellite input options:
  1) Traditional single GPS
  2) GPS of multi-GNSS
  3) GPS and GLONESS of multi-GNSS

❑ GNSS satellite orbit data is the product of the Center for Orbit Determination in Europe (CODE):

- Traditional CODE single GPS data and the multi-GNSS (MGEX) data
- orbits, station positions, EOP, clock solutions, bias
- Data source: http://ftp.aiub.unibe.ch

❑ COSMIC-2 Level-1a

- leoAtt (Leo Attitude), podCrx (Leo observations of GNSS), opnGns (Leo RO event observations)
- Data source: https://data.cosmic.ucar.edu/gnss-ro/cosmic2/nrt/
- COSMIC-2 NRT Level -1a is preprocessed for the BERNSE daily post-processing.

2. POD Solutions and Analysis

Three sets of the POD solutions for the period 06/01/2021 to 06/30/2021 are generated and used in this study, which correspond to the three different GNSS orbit inputs, CODE GPS (**CODE**), MGEX GPS (**MGEX-G**) and MGEX GPS and GLONESS (**MGEX-GR**). Table 1 summarizes the monthly mean differences of RD-KN of the COSMIC-2 six satellites. The UCAR RD-KN values were calculated using the UCAR Level 1b leoOrb data.

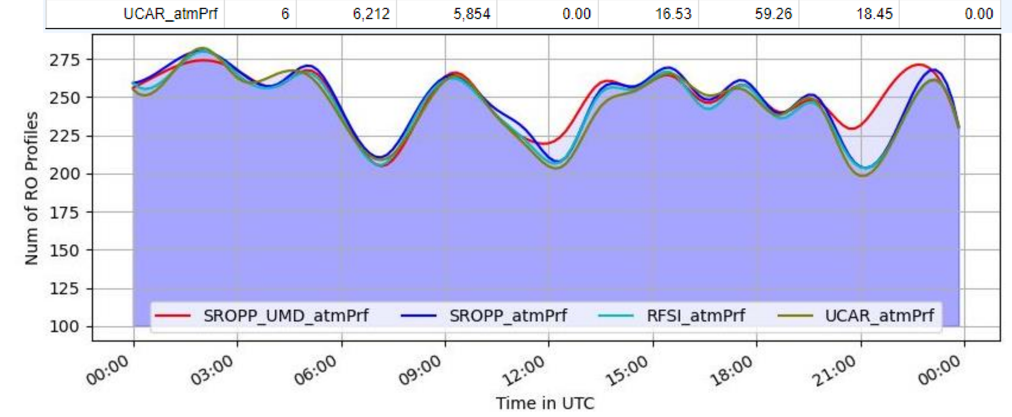
Table 1. The monthly mean differences of RD-KN of the COSMIC-2 six satellites

Satellite	UMD RD-KN (cm)			UCAR RD-KN(cm)
	CODE	MGEX-G	MGEX-GR	
C2E1	-0.42	-0.61	-0.96	-18.79
C2E2	-0.61	-0.69	-0.96	-17.85
C2E3	-0.30	-0.017	-0.48	-17.60
C2E4	-0.31	-0.068	-0.89	-20.78
C2E5	0.034	-0.047	-0.67	-21.62
C2E6	0.23	0.23	-0.016	-16.80
ALL	-0.23	-0.20	-0.66	-18.90

The difference between the reduced-dynamic (RD) and kinematic (KN) orbit solutions is generally expected to be on the order of centimeters. The results show that the POD using the MGEX GPS-Only (MGEX-G) preformed best overall, with only a slight difference compared to the CODE GPS solution. Interestingly, the orbit solution using MGEX GPS and GLONASS (MEGX-GR) exhibited a larger bias than the GPS-only solution, likely due to the insufficient handling of the inter-frequency bias in the MGEX products.

Figure 1

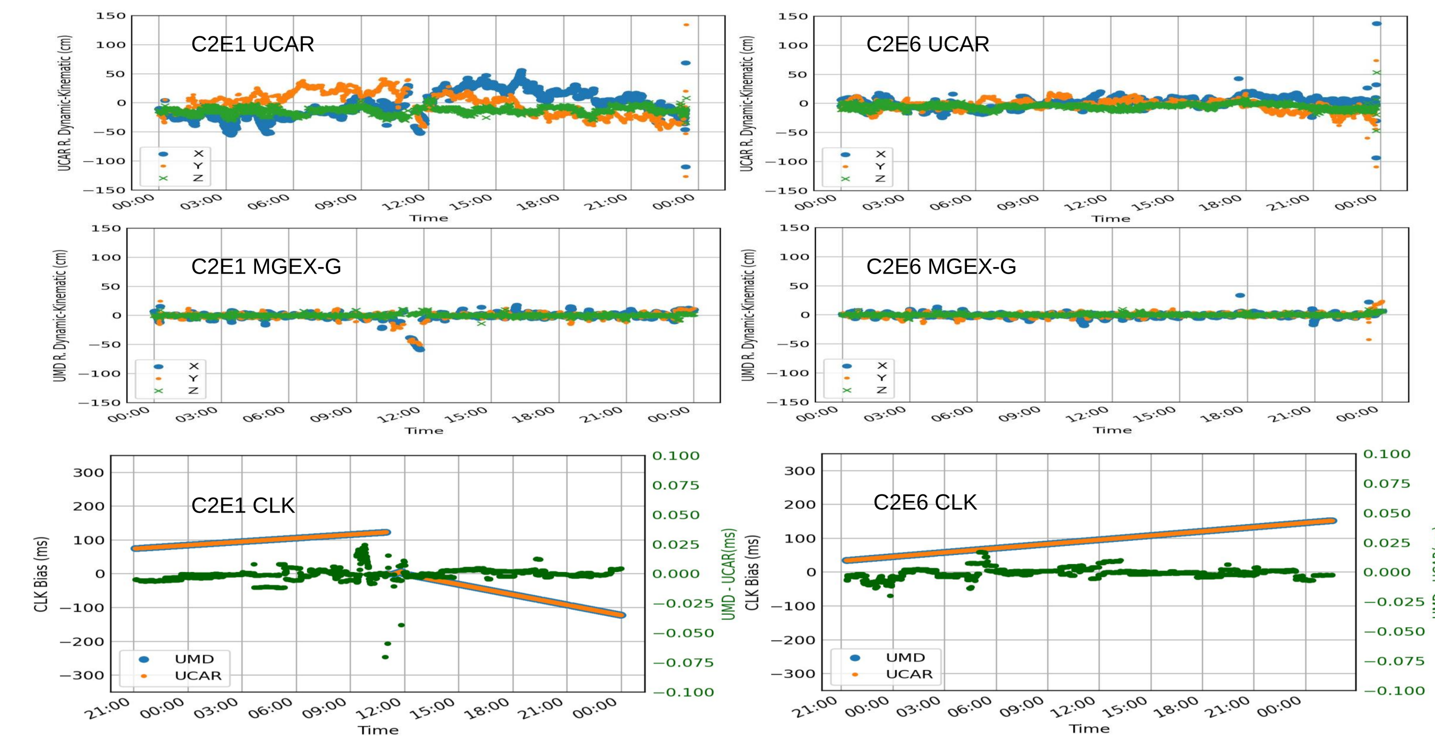
Publisher	Num of Leo	N_Obs, (Global)	N_QC, (Global)	N_QC, % (N90-N60)	N_QC, % (N60-N20)	N_QC, % (N20-S20)	N_QC, % (S20-S60)	N_QC, % (S60-S90)
RFSI_atmPrf	6	6,302	5,870	0.00	16.71	59.08	17.36	0.00
SROPP_UMD_atmPrf	6	6,324	5,876	0.00	16.79	58.32	17.81	0.00
SROPP_atmPrf	6	6,311	5,943	0.00	16.99	59.15	18.03	0.00
UCAR_atmPrf	6	6,212	5,854	0.00	16.53	59.26	18.45	0.00



In this analysis, the UCAR RD-KN has a relatively large bias. This is likely because UCAR's leoOrb is a near-real-time (NRT) data product, while all UMD solutions in this study are based on post-processing. The accuracy of the LEO position can be improved by about 10cm with more GNSS observations available during post-processing. Additionally, more number of RO observation profiles can be constructed using the post-processed LEO POD data, as shown in **Figure 1**.

Figure 2 shows the RD-KN and CLK bias at each epoch on 06/25/2021 in ECEF. The RD-KN bias in Figure 2 aligns with the statistics summarized in Table 1 but offers more detailed insights on a daily scale, highlighting a possible connection between the larger UCAR RD-KN bias and the CLK bias solution.

Figure 2. RD-KN and CLK bias at each epoch of 06/25/2021 in) ECEF



3. Impact of POD Solutions on high-level RO Data Quality

Figure 3 illustrates the impact chain from POD to excess-phase (doppler shift), bending angle and refractivity during example RO events. The excess-phase between UCAR NRT data and the UMD post-processed data is about 10m, which is consistent to the CLK bias difference. The bending angle and refractivity using the traditional single-GPS may have about 5% difference relative to that using the MGEX at the near surface impact heights..

Figure 3

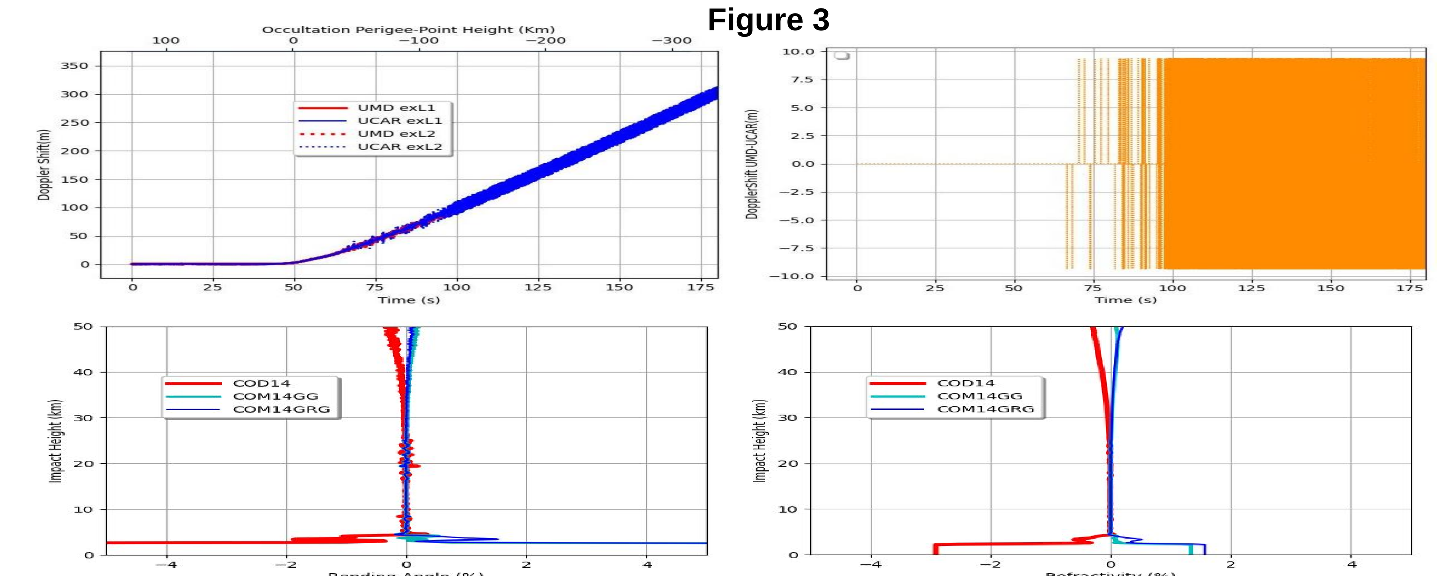


Figure 4. Bending angle bias profiles in comparison with ERA5 forward simulations on 06/25/2021. MGEX-G (red) generally has better performance at low pressure levels.

Figure 5 shows the monthly banding angle bias & std time series at 500hPa, MGEX-G (red) consistently shows better performance.

Figure 4

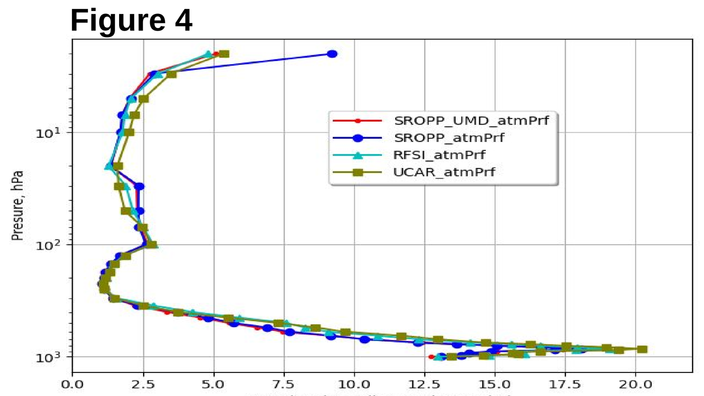
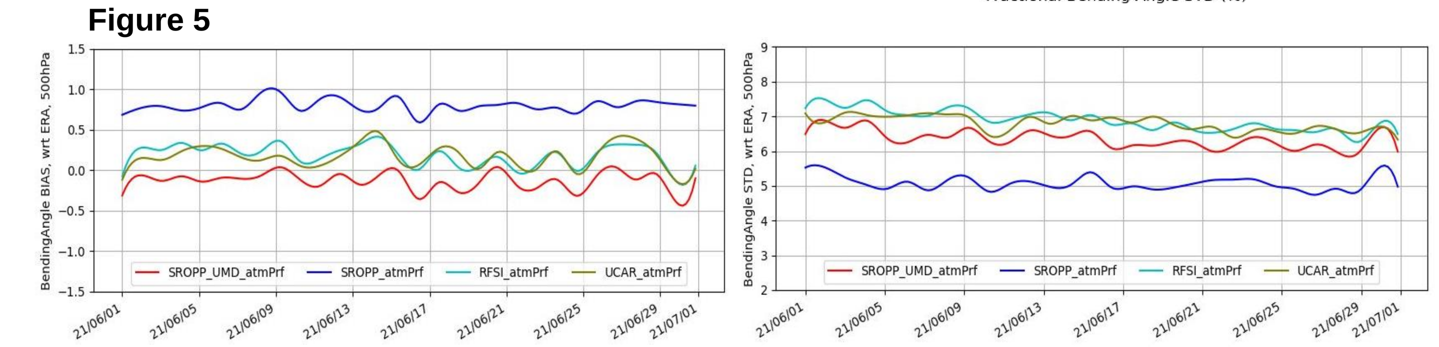


Figure 5



Summary and Further Efforts

- The COSMIC-2 POD using the MGEX satellite data products shows better performance in general than using the traditional single GPS product. The inclusion of MGEX GLONESS needs more efforts to handle the inter-frequency and the inter-system bias.
- Different POD solutions may result in significant exPhs difference at lower impact height levels, which consecutively affect the banding angle retrievals. The impact on the Level 2 RO product quality will be further investigated.
- The POD difference resulting from the NRT and the post-processing needs further analysis, which manifests the importance of the post-processing POD in real applications.

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