GeoOptics CICERO Radio Occultation Excess Phase Processing at NOAA/STAR

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Abstract

Radio occultation (RO) data provide high sensitivity and significant positive impact on the weather forecast, especially in the short-range 3-5 day forecast. Currently, the number of RO observation data assimilated into Numerical Weather Prediction (NWP) models is less than optimal; more RO data is required to improve the forecast. As one of the selected vendors from NOAA's Commercial Weather Data Pilot (CWDP), GeoOptics operates its nanosatellites' constellation, known as CICERO-Community Initiative for Cellular Earth Remote Observation. Under CWDP's first-round contract, NOAA received one-year GeoOptics near-real-time RO data generated by JPL from October 2018 to October 2019. NOAA recently received second-round one-month (from 15 December 2020 to 14 January 2021) GeoOptics RO data for Delivery Order-1 (DO), generated by University Corporation for Atmospheric Research (UCAR) operational data processing center.

To understand the CICERO data uncertainty induced in each RO processing step, NOAA/STAR developed an independent processing package to convert the pseudo-range and carrier phase observations to excess phases. Understanding and characterizing the processing uncertainty before converting the observed phases to bending angle, refractivity, and atmospheric physical properties is essential to perform the validation and quality assessment. We use the Bernese software to solve the LEO satellite clock bias and precise orbit determination (POD) and use the Radio Occultation Processing Package (ROPP) to convert these derived excess phases to bending angles.

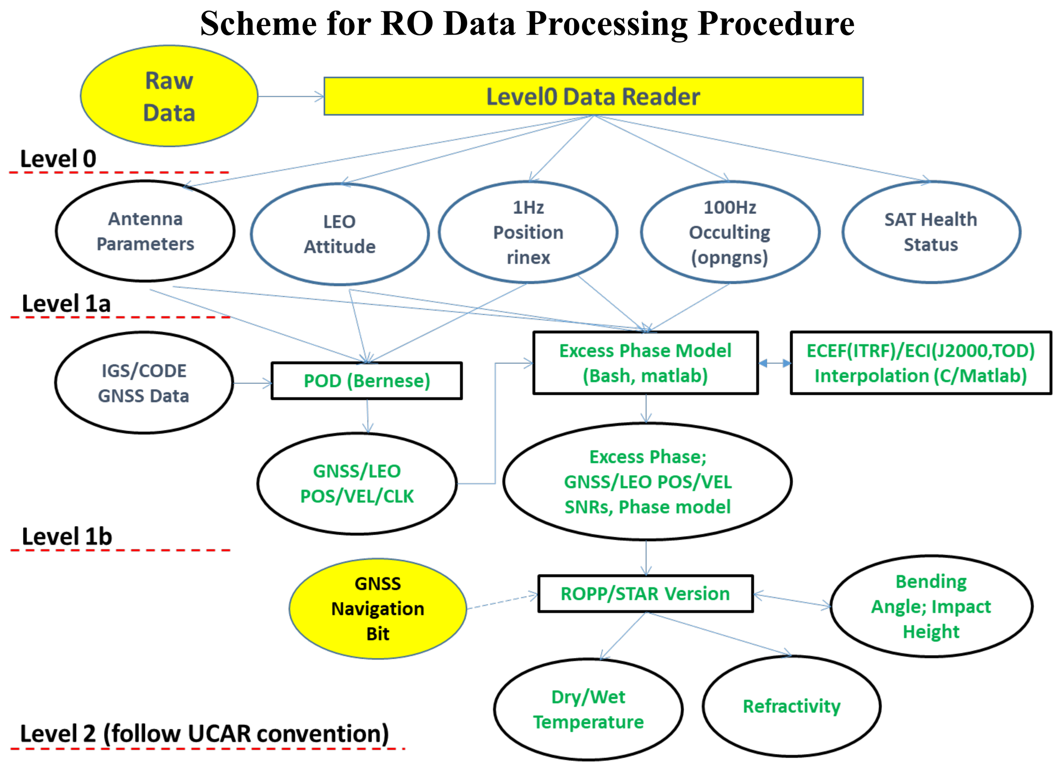
In this study, the comparison results for each step between our processing approach and those derived from UCAR for GeoOptics CICERO will be presented.

RO Processing Procedure with GeoOptics Data

We developed an independent Radio Occultation processing package, especially for the excess phase derivation, mainly focusing on data conversion from occultation carrier phase observations to the Excess Phase:

- Data acquisition
- POD setup and validation
- Excess phase/bending angle retrieval and validation
- Developing the capability for multi-RO L1b data processing: COSMIC-1/2, CWD RO sensors such as GeoOptics and Spire, and future missions

Scheme for RO Data Processing Procedure

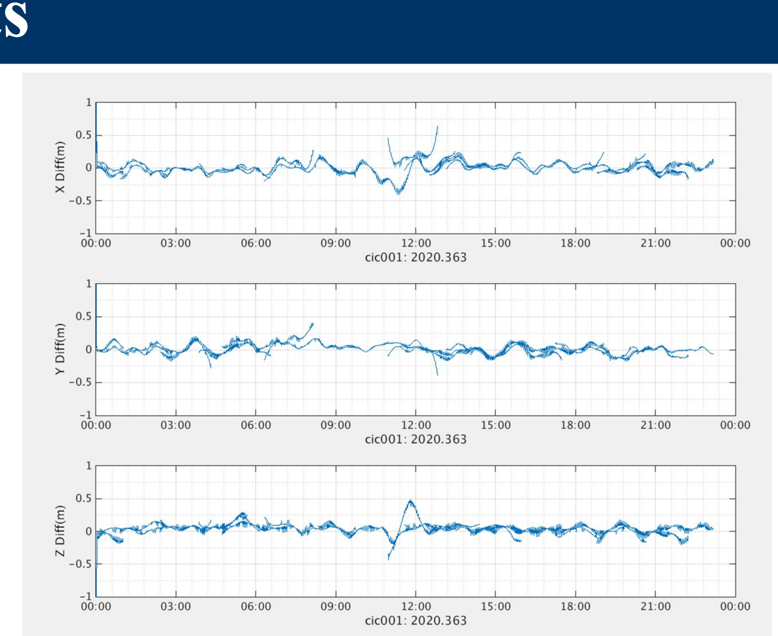


Delivery Order-1: (one month data)

- CICERO OP1-A (085): 2020.350 – 2021.014
- CICERO OP1-C (087): 2020.350 – 2021.014
- L1a: leoAtt, opnGns, podCrx (rinex211)
  - RINEX format 211 (1 Hz): 6 C1 L1 L2 P2 S1 S2
  - opnGns (100 Hz): L1C (residual) L1C (M) S1C L2L (residual) L2L (M) S2L
- L1b: conPhs, leoOrb
- L2: atmPrf, wetPf2, bfrPrf, avnPrf, echPrf

Results

- POD information (GPS/LEO POS/VEL/CLK) were successfully generated using Bernese software
- The UCAR POD has multiple segments the same as COSMIC-2 (real time process)
- Shows not only the UCAR/STAR difference, but also the different solutions for the different segments from UCAR
- Can not tell which one is better given UCAR's results jump high some time among different solutions (around 12PM)
- POD requirements for GeoOptics (usually 10-15 cm for COSMIC-1/2). Certainly the POD difference in UCAR's operational products is more than that.



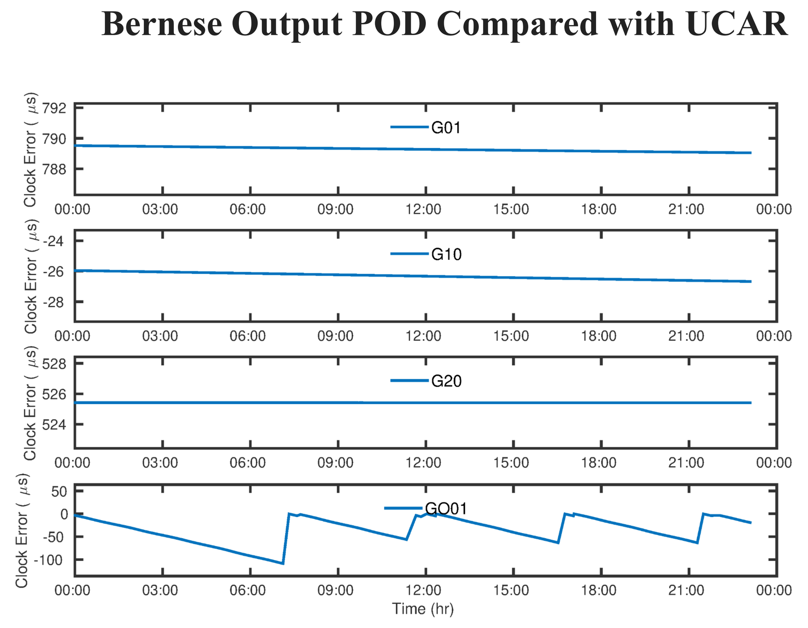
Bernese Output POD Compared with UCAR

GPS Clock

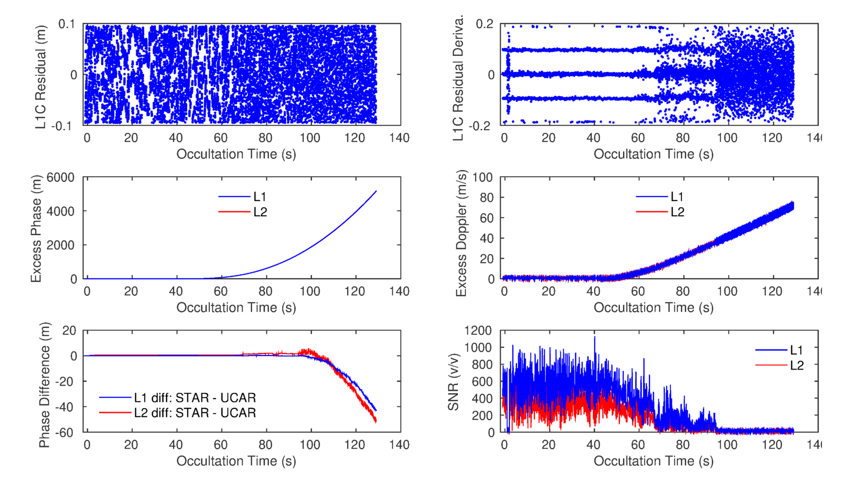
- Using CODE 30 seconds product
- Some GPS satellite bias may be large (0.8 ms), but relatively stable (<1us/day)
- Zero differencing requires high rate clocks.
- C*ΔT.
- High rate estimation need ground station

LEO Clock

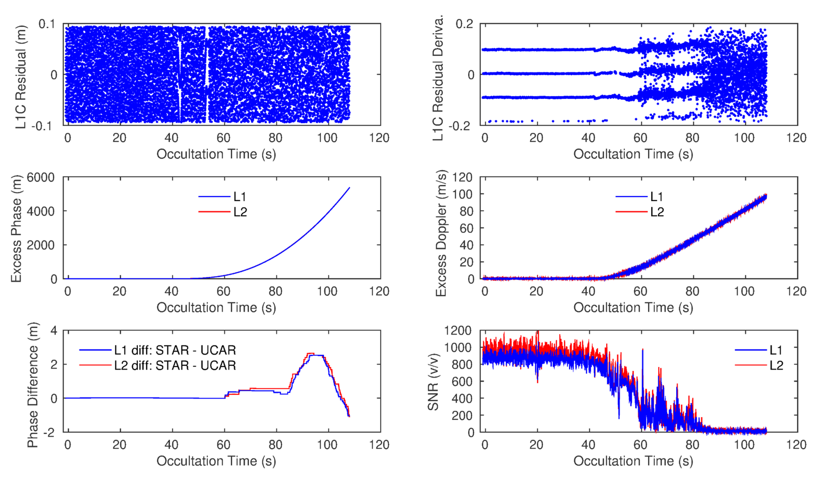
- Bernese final solution
- The clock has been constantly adjusted every few hours, changing between 0 to -100 µs, not as stable as GPS
- Interpolation problem.
- -C*ΔT (significant effects on excess phase). Single differencing is needed.



GNSS and LEO Clock Error



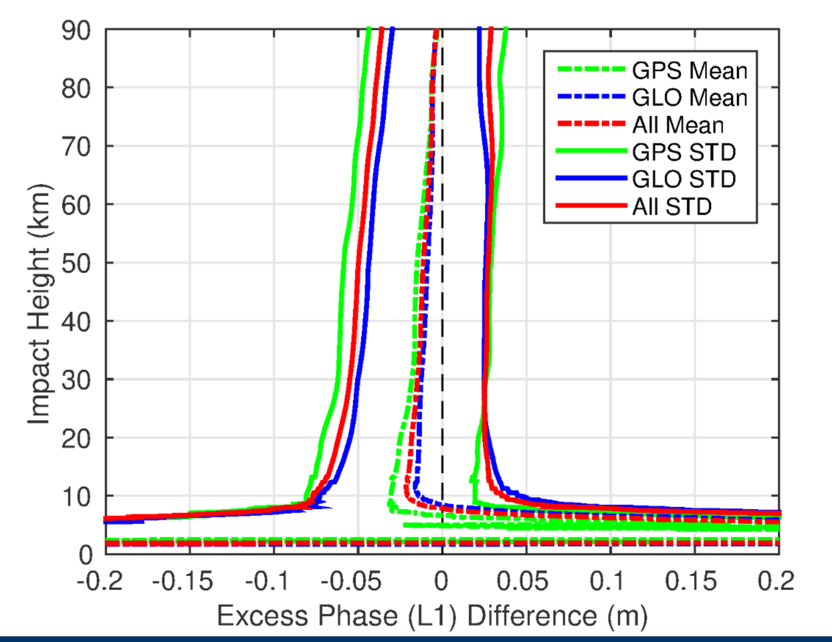
Carrier Phase to Excess Phase (GPS Example)



Carrier Phase to Excess Phase (GLONASS Example)

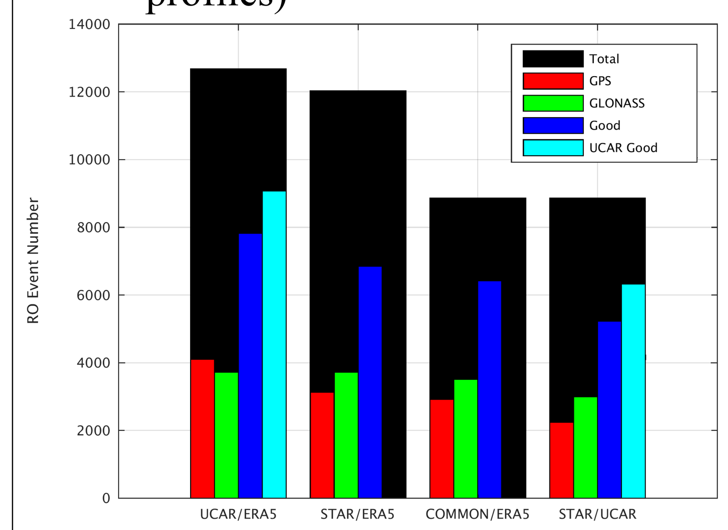
From carrier phase to excess phase conversion with GPS (left) and GLONASS (Right): The top row shows the phase residual (carrier phase minus receiver phase model) before cycle slip removal (left) and its derivative (right). The second row shows the final excess phase after cycle slip removal (left) and the excess Doppler (right). The third row shows excess phase comparison between STAR and UCAR results (left) and SNR (right) for both L1 and L2.

The mean excess phase bias and standard deviation between STAR and UCAR over one day for GeoOptics on 28 December, 2020. -0.023 ± 0.046m for GPS profiles and -0.014 ± 0.042m for GLONASS, and -0.017 ± 0.044m for all profiles within 10 – 35 km (those with large departure in excess phase not included). The bias and standard deviation increase with lowering altitude.

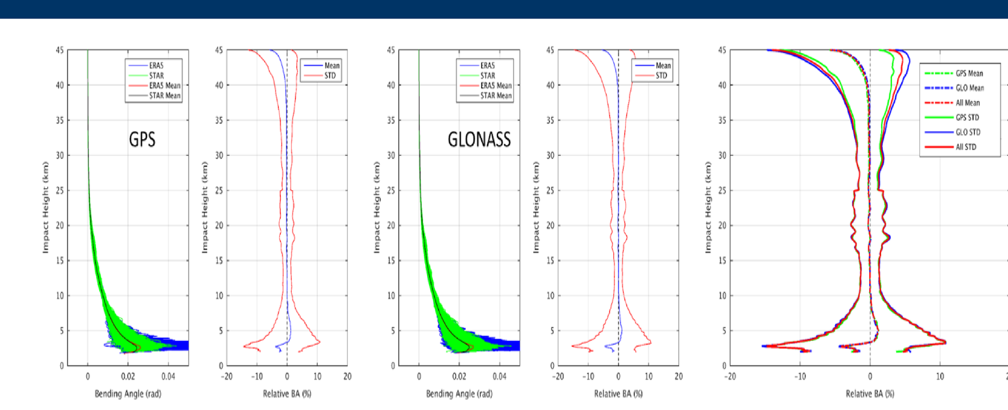


Bending Angle Comparison with UCAR and ERA-5 Simulation

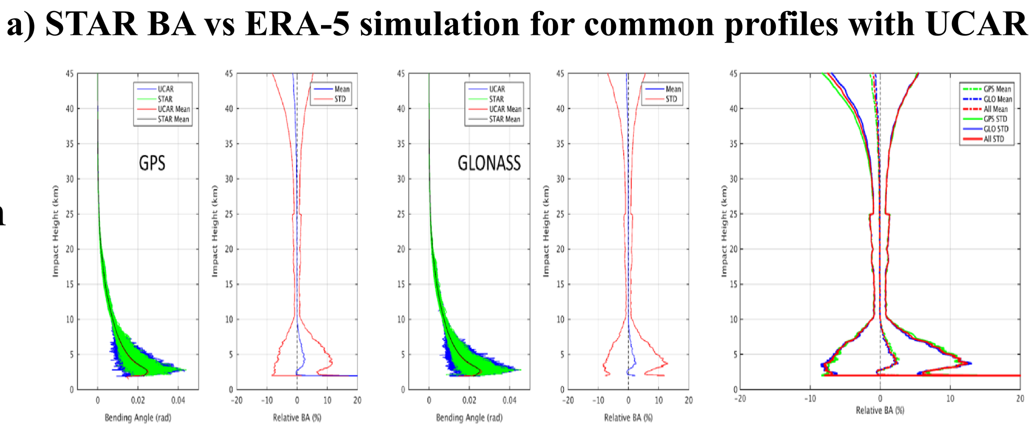
- The whole month GeoOptics (CICERO OP1-A 085) L1b data (excess phase profiles) and bending angle profiles using ROPP are generated
- Simulated bending angle profiles are generated by a forward model using ERA-5 as input with spatially and temporally interpolating to each RO event observational location and time
- Four comparisons:
  a) STAR BA vs ERA-5 simulation for common profiles with UCAR
  b) STAR BA vs UCAR BA for common profiles
  c) STAR BA vs ERA-5 simulation
  d) UCAR BA vs ERA-5 simulation
- Quality control for bending angle comparison with ERA-5 simulation:
  1. remove the profiles if (O-S)/S*100 > 100
  2. remove the profiles if |(O-S)/S*100 – mean((O-S)/S*100)| > 5 * standard deviation
  3. If UCAR data are involved, the qc flag is also used (remove bad=1 profiles)



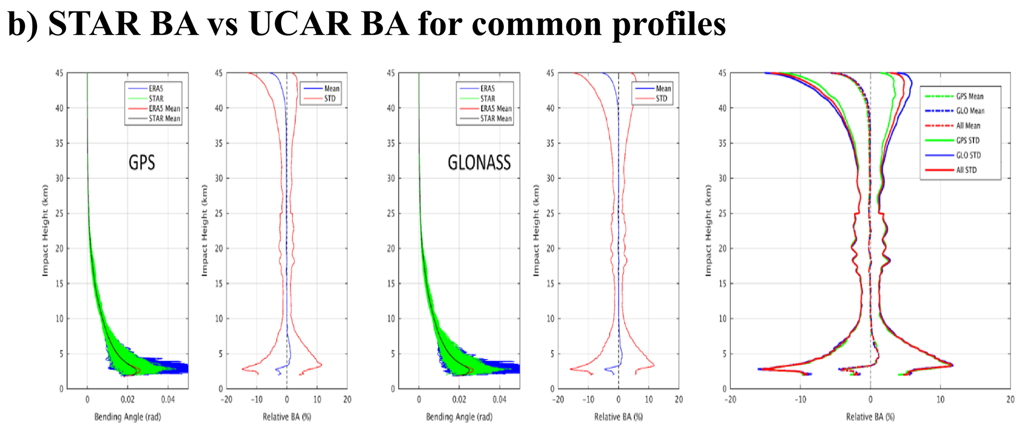
Good RO Profile Numbers Comparison



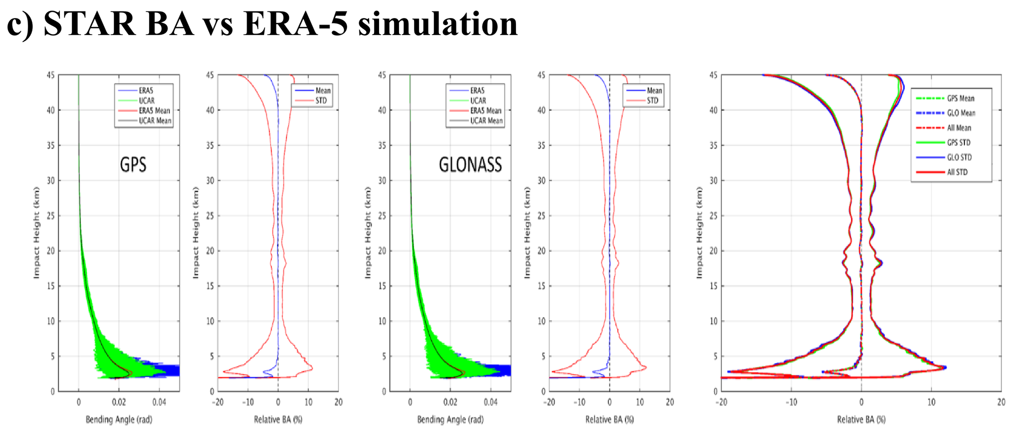
a) STAR BA vs ERA-5 simulation for common profiles with UCAR



b) STAR BA vs UCAR BA for common profiles



c) STAR BA vs ERA-5 simulation



d) UCAR BA vs ERA-5 simulation

Conclusion

- We developed an independent Radio Occultation processing package for the excess phase derivation, mainly focusing on data conversion from occultation carrier phase observations to the Excess Phase. This package can process COSMIC-1/2, CWD RO sensors (such as GeoOptics and Spire), KOMPSAT-5, as well as future missions.
- We have illustrated possible error sources in calculation of excess phase down to centimeter levels, however, correcting each term is not trivial:
  - Position/velocity inaccuracy, attitude errors
  - Cycle slip detection (esp. in the open loop stage).
  - Clock error from both Leo and GNSS satellites
  - Operational versus reprocessing
  - Each error term is evaluated in the processing procedure.
- The comparison results show good agreement in excess phase above 10 km and gradually the bias and standard deviation increase below that level.
- The results show excellent agreement in the relative bending angle compared with EAR-5 simulated bending angle profiles and UCAR CDAAC bending angle profiles.

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