Processing COSMIC-2 Data at NOAA/STAR Using the Full Spectrum Inversion Method

Loknath Adhikari, Shu-peng Ho, and Xinjia Zhou

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Motivation

- GNSS RO observations are important part of NOAA's operational weather forecasting
- Due to multiple GNSS RO missions, NOAA STAR needs to develop capabilities for quality control of data
- NOAA STAR's quality control can be best performed by developing capabilities to process RO data from different sources
- NOAA STAR processed data provides additional RO data source for public use

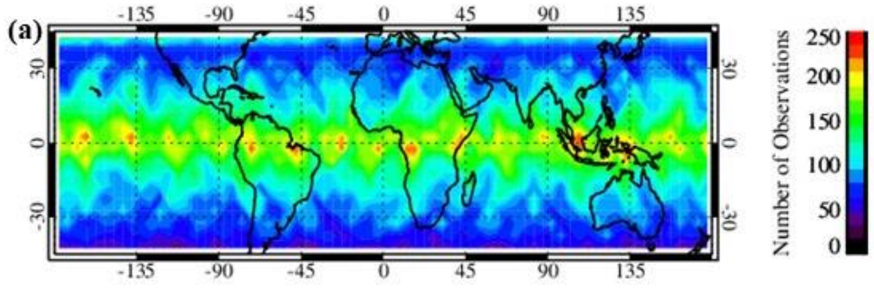
Salient Features of NOAA STAR Processing

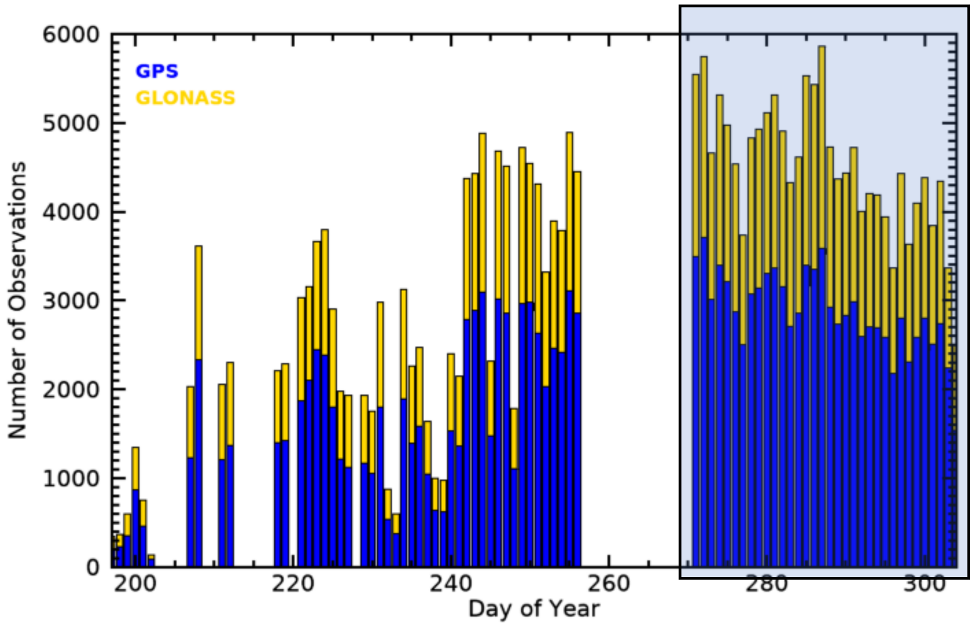
- FSI method uses FFT of the complete profile, making processing computationally efficient
- Single inversion method at all vertical levels makes the vertical resolution independent of height

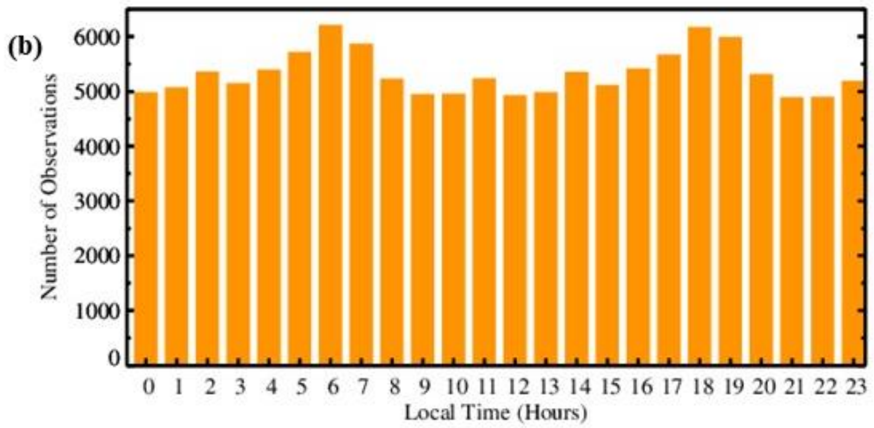
Data

- UCAR processed COSMIC-2 Level 1b (time series of geometry and phase) and Level 2 (bending angle and refractivity profiles) data for October 2019
- European Center for Medium Range Weather Forecasts (ECMWF) Reanalysis (ERA-5) temperature, pressure and specific humidity profiles for October 2019

Observation count for October 2019





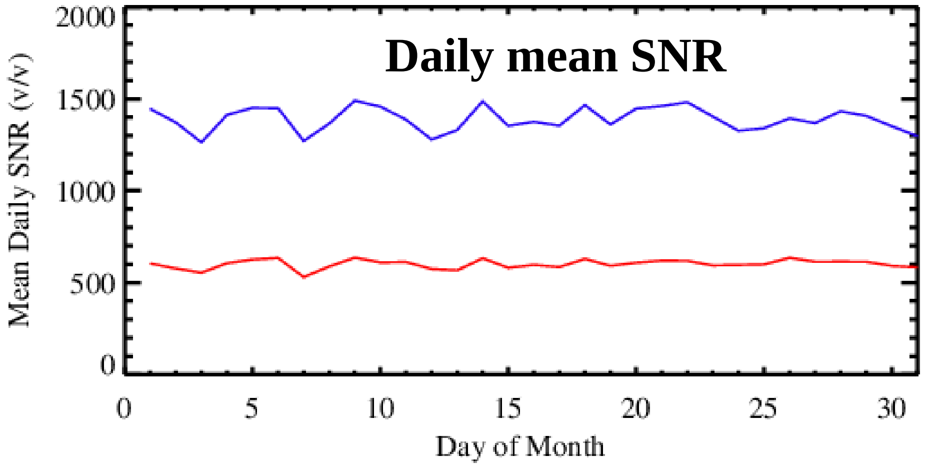


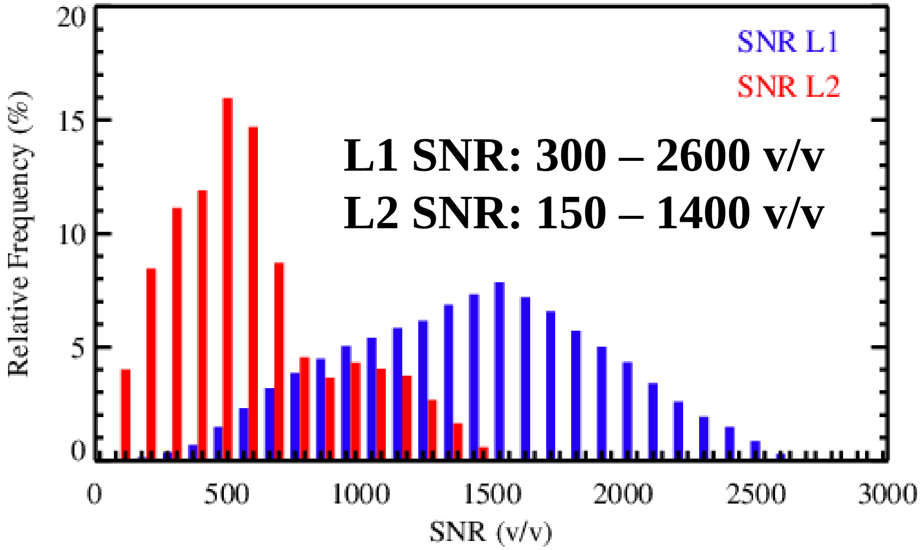
Daily Observation Count for GPS and GLONASS

Observation count based on local solar times

Signal-to-Noise Ratio (SNR)

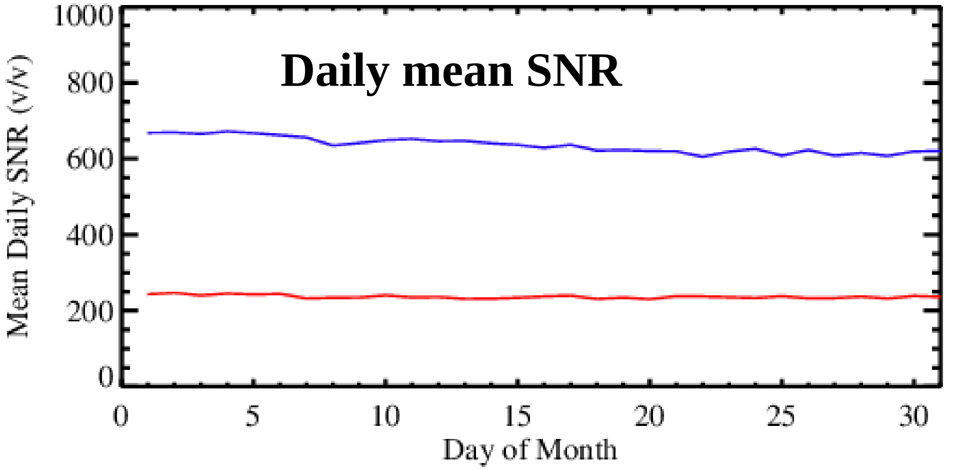
COSMIC-2

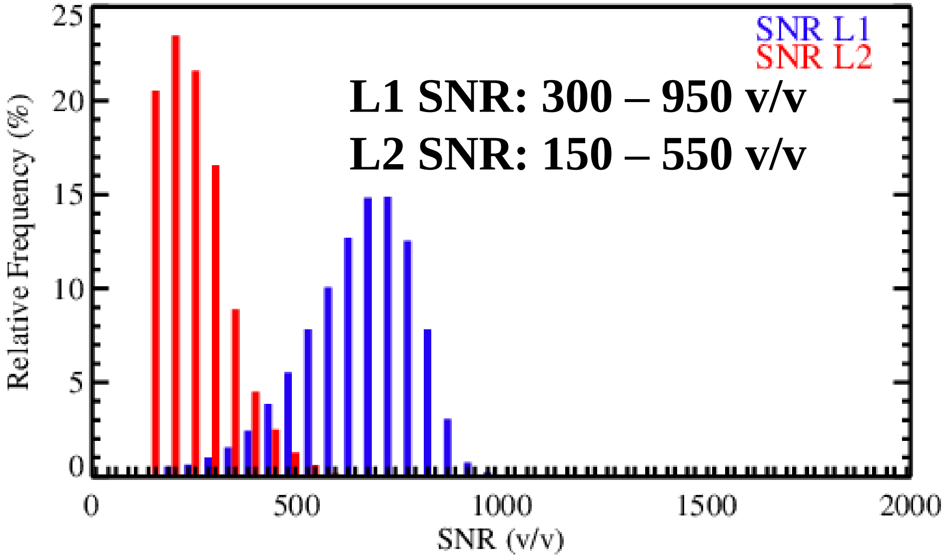




Two peaks in L2 SNR caused by GPS GLONASS L2 SNR differences

COSMIC





COSMIC only tracked GPS

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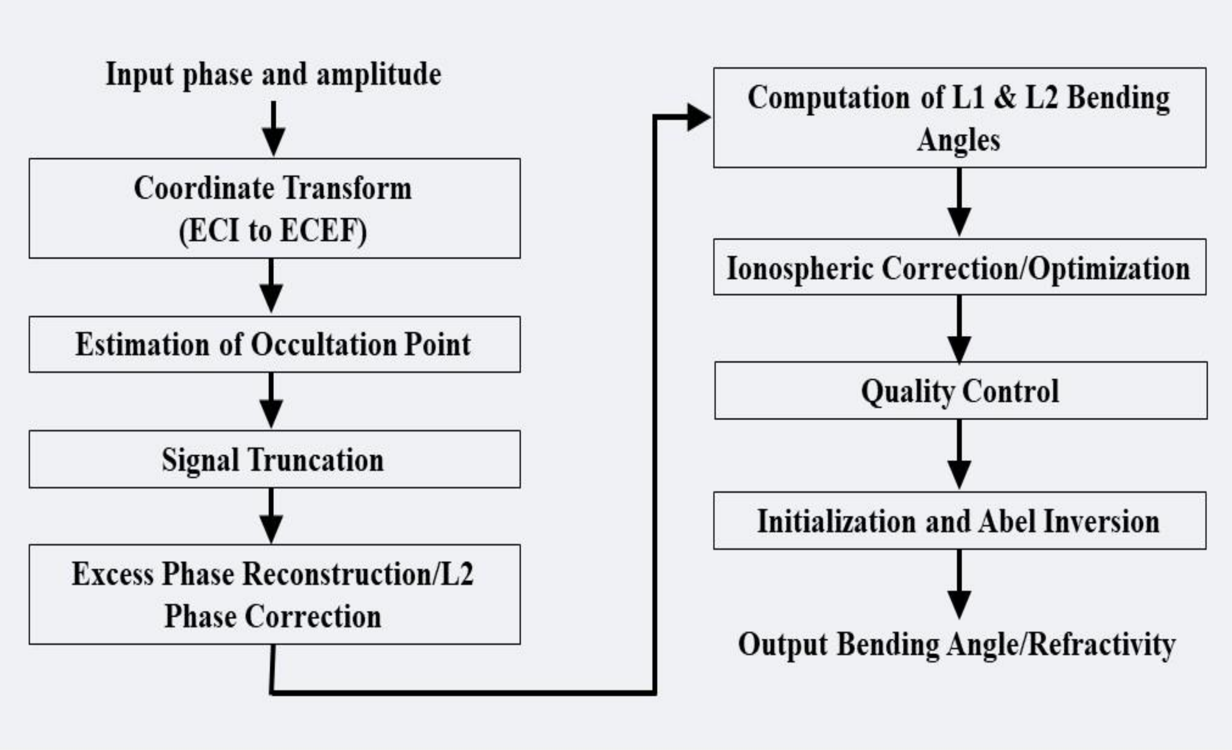
NOAA STAR Processing System: Phase Data to Refractivity

NOAA STAR processing system

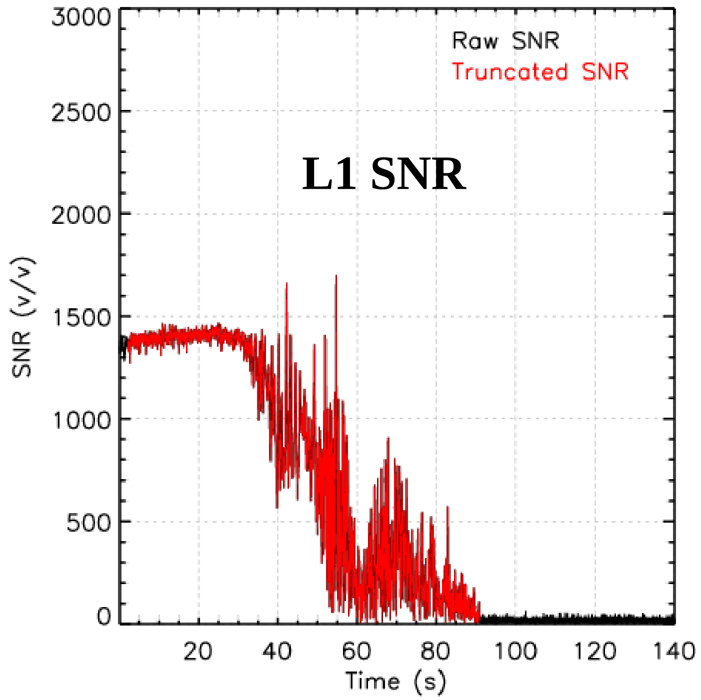


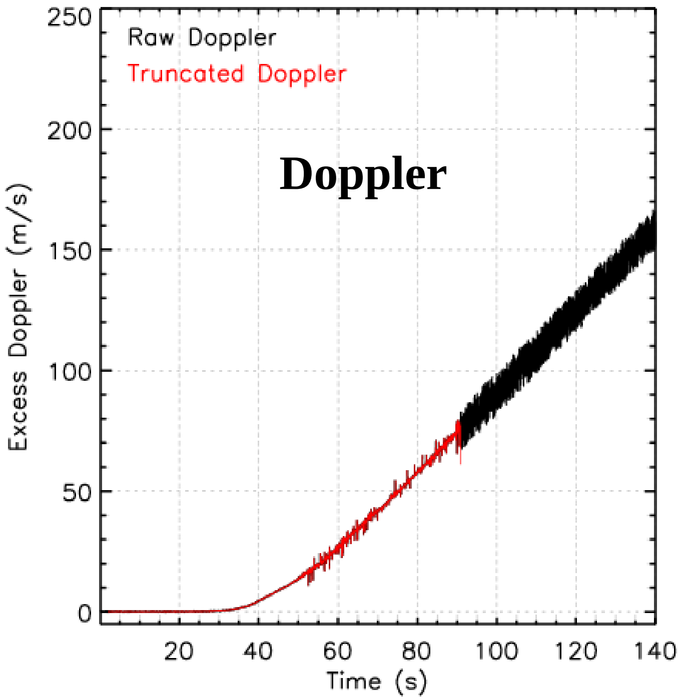
Overview of the implementation of the NOAA STAR processing system

Processing Step	Implementation Approaches
Input data	Input UCAR orbit in Cartesian ECI coordinates, L1 and L2 excess phase and SNR data
Coordinate Transform	Transforming ECI coordinates to ECEF Coordinate
Signal Truncation	Based on L1 SNR, truncating signals using threshold on calculated base SNR
Excess Phase Reconstruction	Computation of excess phase after Fourier filtering of Doppler using 0.5-second window
Bending Angle Computation	Full Spectrum Inversion
Ionospheric Correction	Linear combination and statistical optimization of L1 and L2 bending angles
Quality Control	Mean L1 – L2 difference at 25 – 50 km < 100 μrad, mean fractional bending angle difference (COSMIC2-CIRAQ) at 25 – 40 km < 0.5
Initialization	Exponential fit above 55 km
Refractivity Calculation	Abel inversion of the ionospheric corrected bending angle with the exponential fit

NOAA STAR Processing System: Determination of Truncation Point

- Calculate the noise level SNR for each profile:
  - Calculate a 3-seconds moving average of L1 SNR (smoothed SNR)
  - The noise level SNR is the mean of the 10-seconds of smoothed SNR starting from the lowest tangent point
- Starting from the lowest tangent point, determine time the smoothed SNR exceeds 3 times the noise level SNR
- From the first point, go backwards towards lower tangent point in the time series where the SNR drops below 1.5 times the noise level SNR



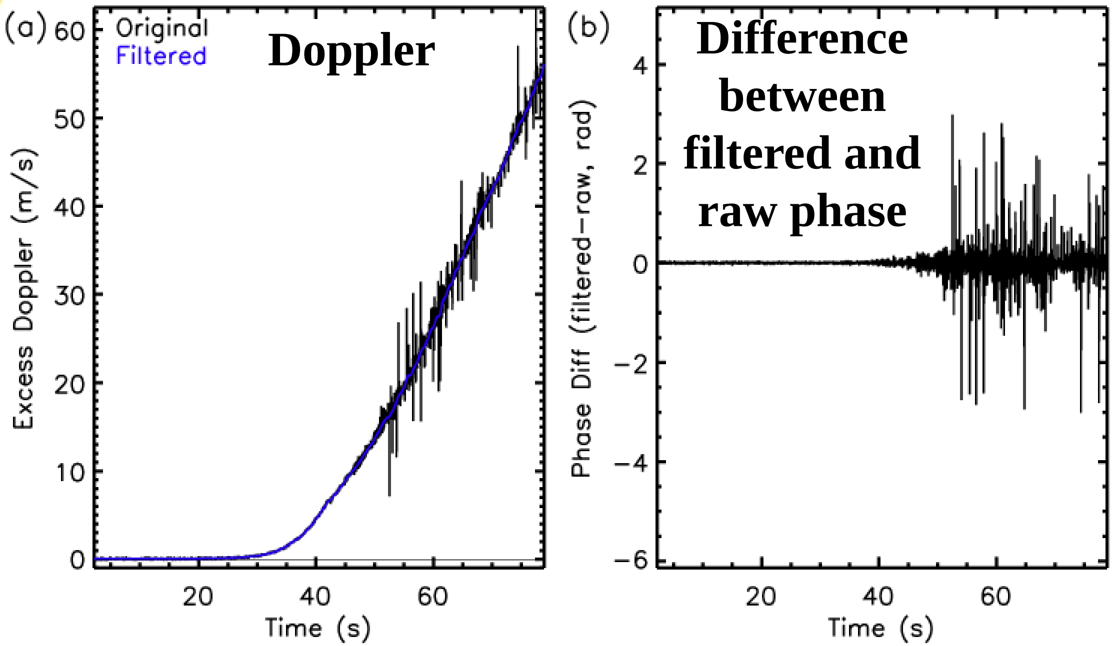


After 90 s, noise is dominant

SNR at noise threshold (10 – 20 v/v)

Doppler variations > 10 m/s

Preprocessing and Bending Angle Retrieval

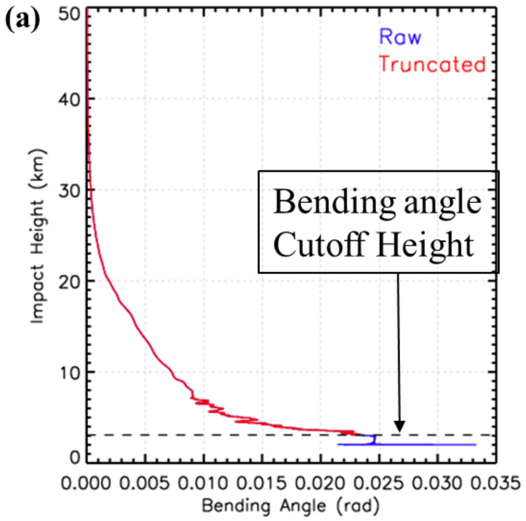


1. **Noise Filtering of the signal**
   - Calculate derivative of excess phase (excess Doppler)
   - Above 10 km straight line impact height, apply 0.5 s Fourier filter of excess Doppler
   - Recalculate phase from excess Doppler

2. **Apply FSI to retrieve bending angle in L1 and L2 bands**
   - Use noise filtered signal for FSI input
   - Retrieve L1 and L2 bending angles as function of impact parameter

Ionospheric Correction/Optimization and Refractivity Retrieval

1. **Impact parameter cutoff**: based on FSI amplitude

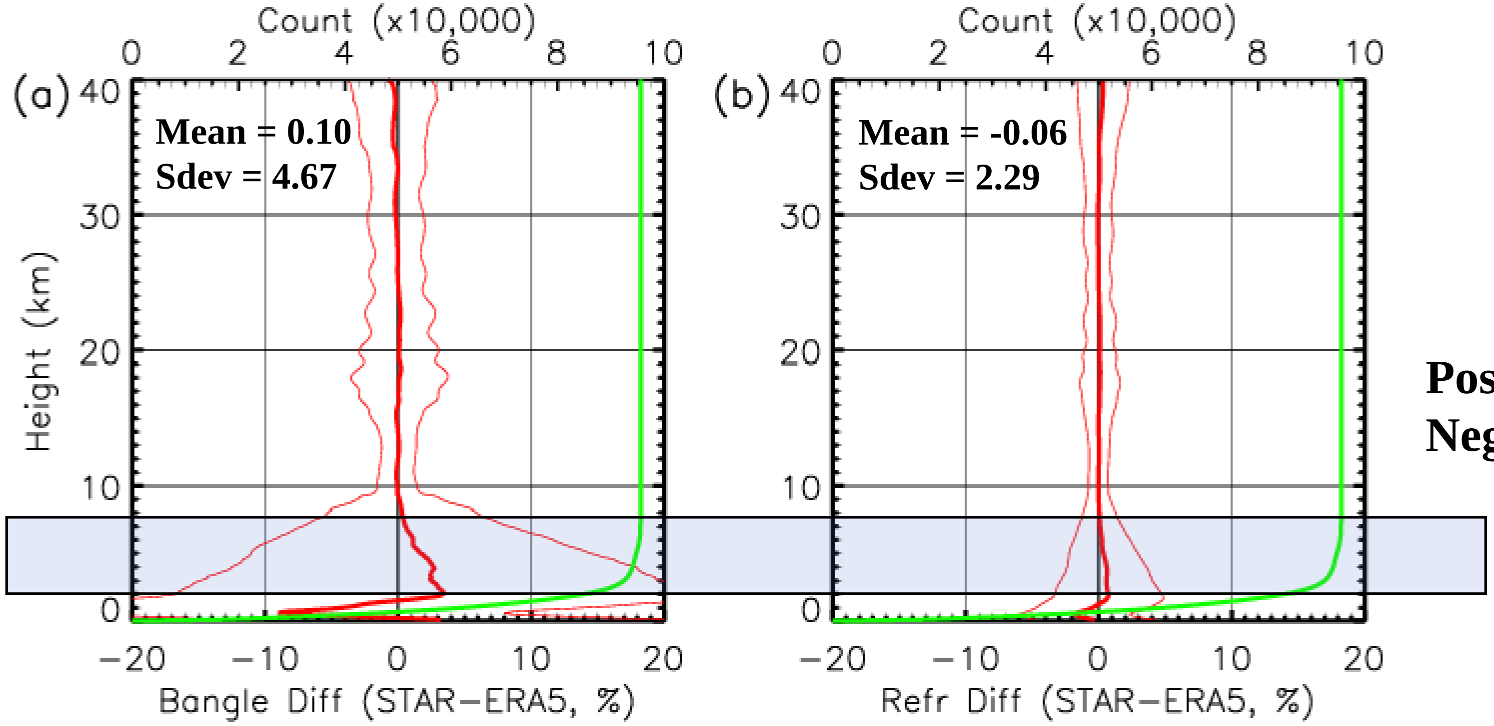


Impact parameter cutoff determines profile's penetration depth

2. **Ionospheric Correction**
   - Statistical optimization method using CIRA86aQ_UoG climatological model
   - In the lower troposphere with no L2 signal, constant ionospheric correction
3. **Bending angle QC flag**
   - Minimum L2 impact height < 20 km flagged 'bad'
   - Mean 35 – 50 km L2 – L1 bending angle > 100 μrad flagged 'bad'
   - Mean 25 – 40 km optimized – model bending angle > 50 % flagged 'bad'
4. **Inverse Abel integration to retrieve refractivity**

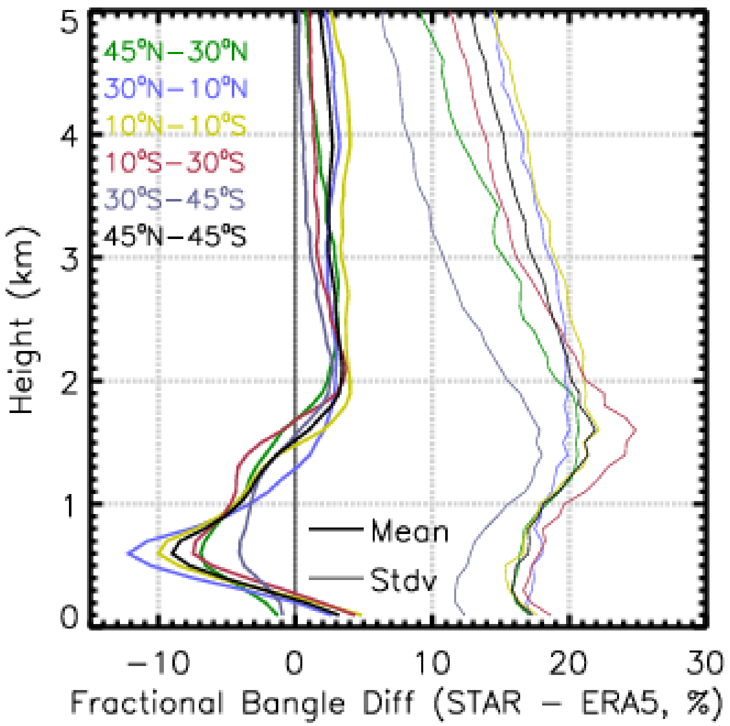
Validation: Comparison with ERA-5

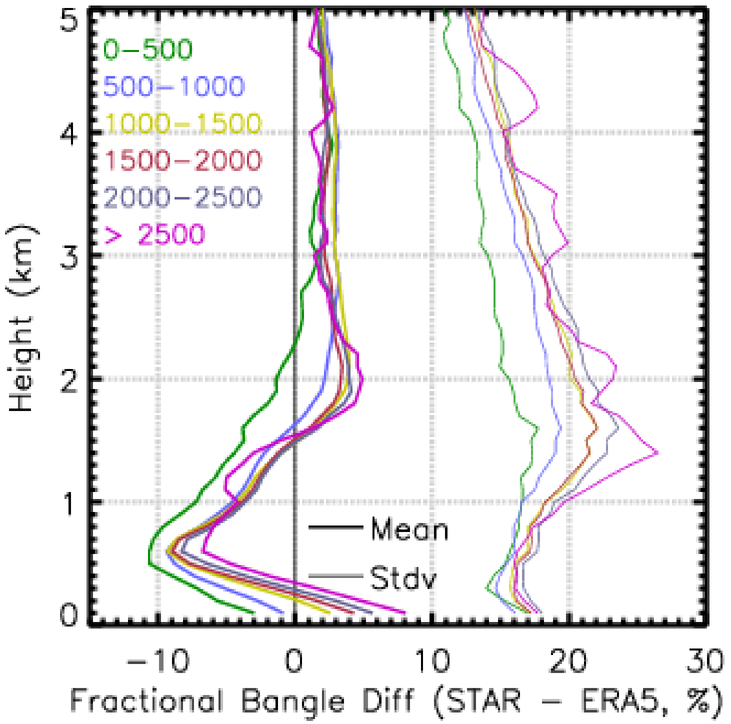
- Interpolate ERA-5 temperature, pressure, and specific humidity to COSMIC-2 reference tangent point location and time
- Calculate Refractivity (N) as $N = 77.6\frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2}$
- Use Abel integration with the COSMIC-2 reference radius of curvature to calculate ERA-5 bending angle profiles corresponding to each COSMIC-2 profile



Positive bias above BA cutoff
Negative bias at cutoff

Validation: Comparison with ERA-5 at Different Latitude and SNR Bands





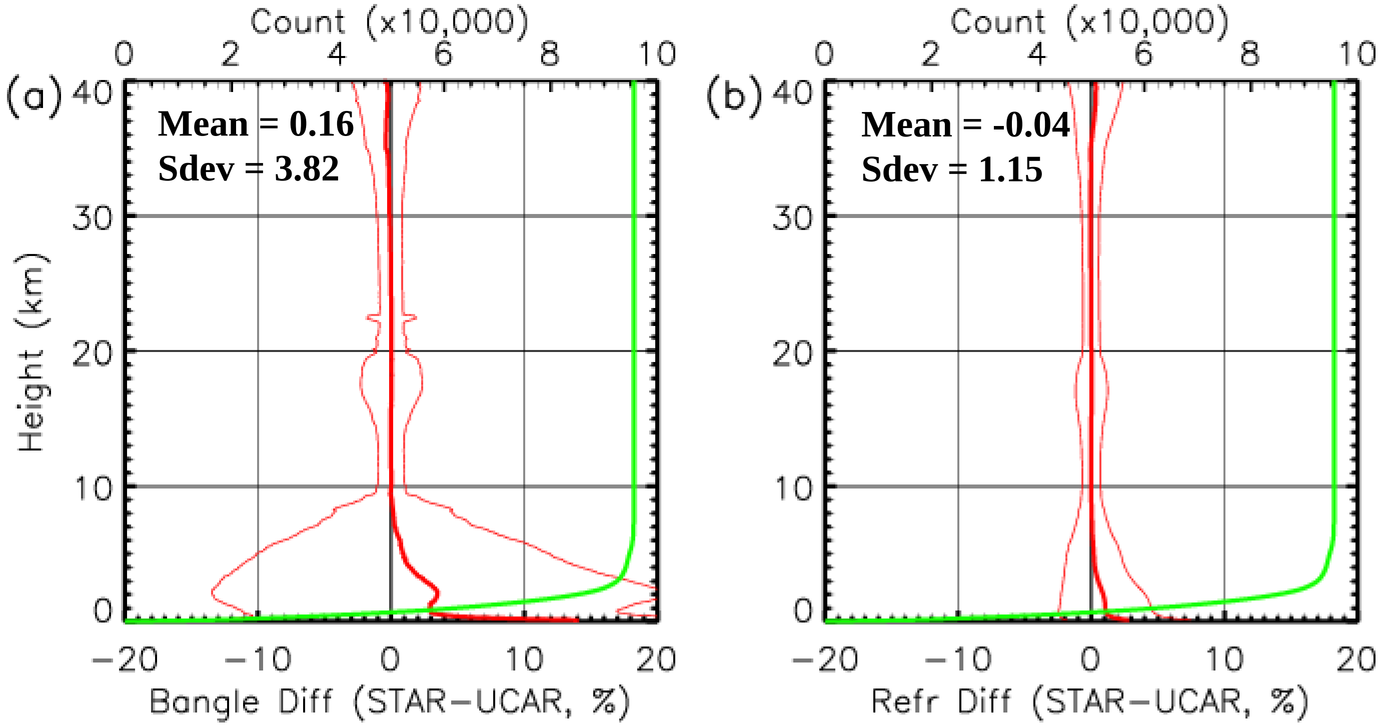
30˚S - 45˚S: smallest mean and standard deviation

Low SNR: large mean, small standard deviation

High SNR: small mean, large standard deviation

Validation: Comparison with UCAR Level 2 data

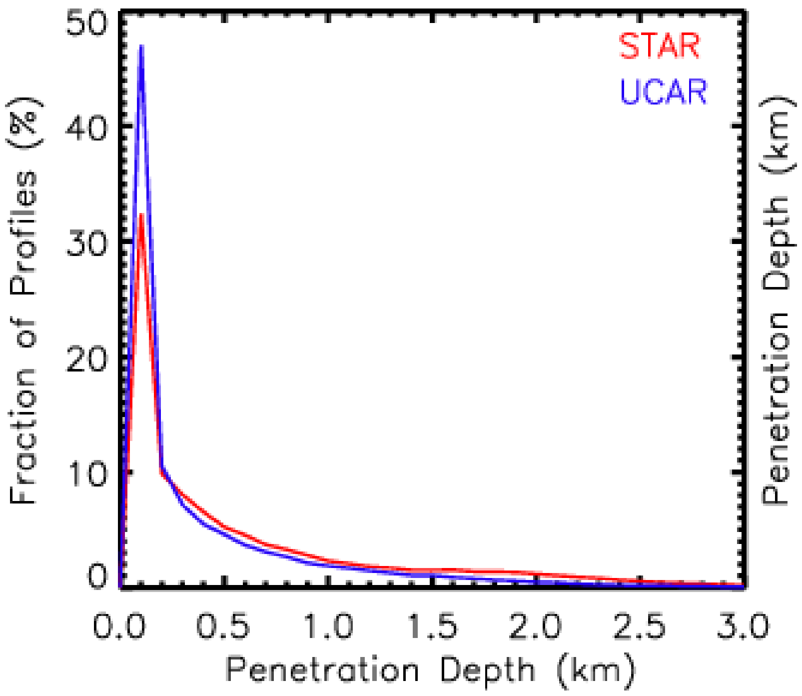
- Profile-to-profile comparison for all profiles that pass NOAA STAR quality control and UCAR quality control

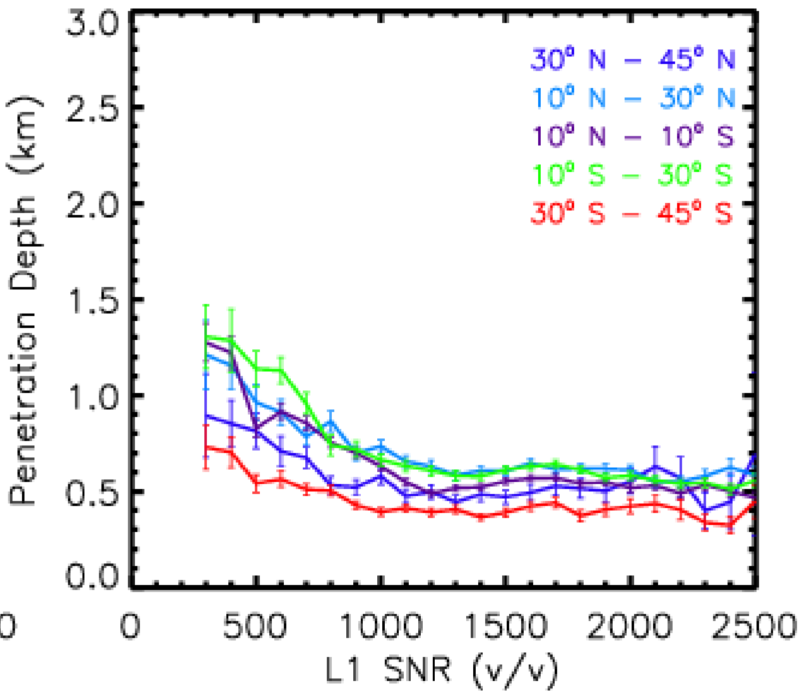


Positive bias in the fractional difference in both bending angle and refractivity in the lower troposphere below 7 km.

Penetration Depth

Over Oceans





- **50 % profiles penetrate below 0.3 km**
- **80 % profiles penetrate below 1 km**
- **Penetration Depth improves with increasing SNR**

Summary and Conclusion

- NOAA STAR Inversion method of time series of the geometry and phase data to profiles of bending angle and refractivity using FSI method for the complete profile
- NOAA STAR processed bending angle and refractivity are validated with (1) ERA-5 interpolated to COSMIC-2 tangent point position and time, and (2) profile-to-profile comparison with UCAR profiles for October 2019 COSMIC-2 data
- The bias and standard deviation of the fractional bending angle and refractivity with ERA-5 profiles are similar in magnitude to UCAR
- The NOAA STAR processed data provide independent source of RO data