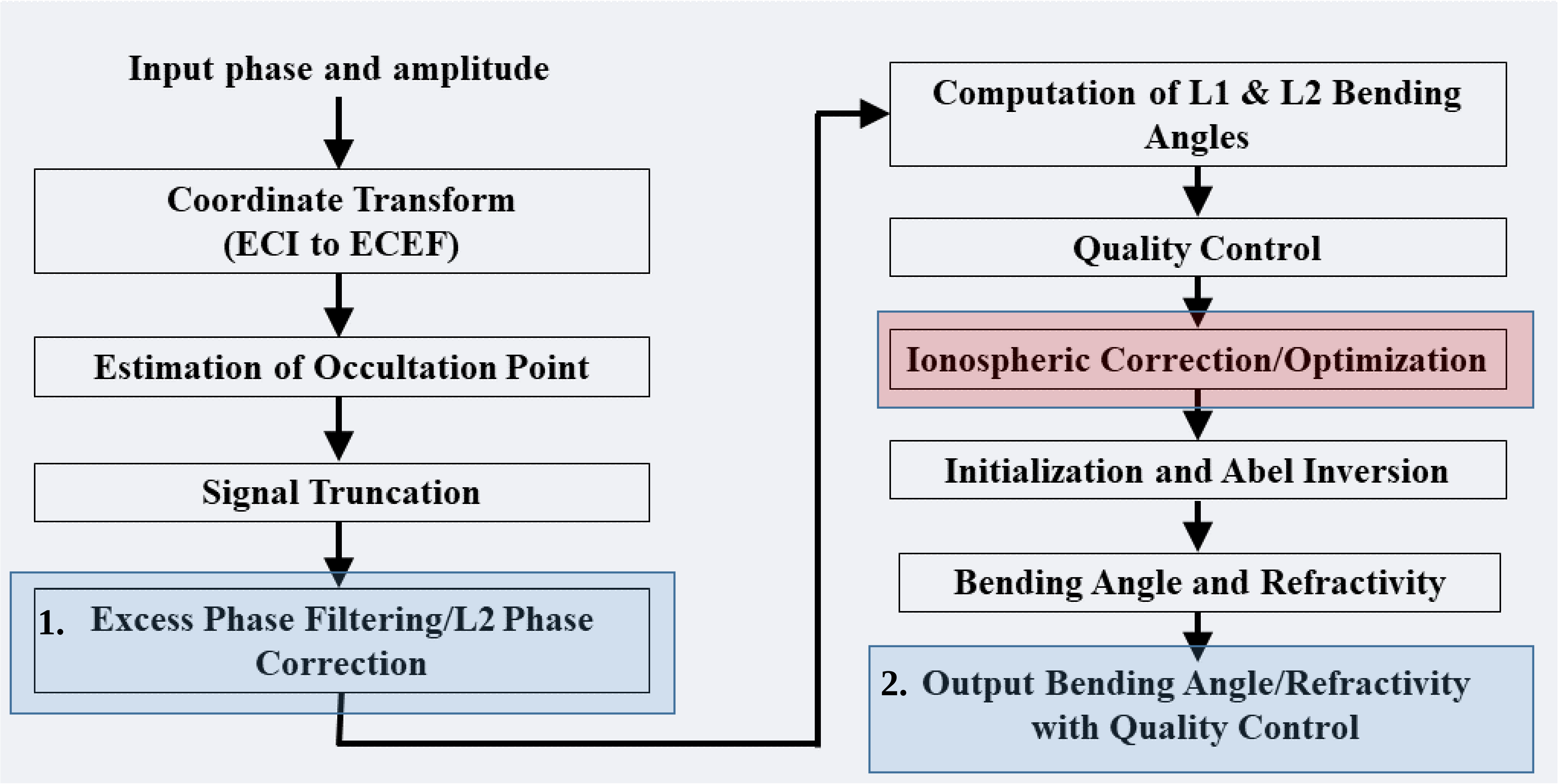
STAR COSMIC-2 L1b to L2 Processing:
Inversion from Phase to Bending Angle and Refractivity

Processing Flowchart



Different steps used in the NOAA STAR inversion of geometry and phase data to bending angle and refractivity profiles

1. Excess Phase Filtering/**L2 Phase Correction**

Why perform noise reduction in L2 Excess Phase

- L2 frequency is has smaller SNR and noisy Doppler
- Measurements on L2 frequency is primarily used for ionospheric correction on L1 bending angle
- Noisy L2 bending angle causes ionospheric corrected bending angle to be noisy and is often flagged as a ‘bad profile’ even when measurements in L1 bands are good.
- A separate correction for random noise in L2 Doppler can increase the number of profiles retrieved from the RO measurements

Rationale

Smoothing the excess phase will add bias to the phase because the excess phase is varies exponentially with time. Smoothing the residual phase reduces the random noise, but does not add bias. When the noise in L2 frequency is not very large compared to L1, the change in the corrected L2 excess phase is small, but for noisy L2 data, smoothing on the residual phase can significantly improve the L2 data quality for use in ionospheric correction.

Effect of smoothing on L2 excess phase -1

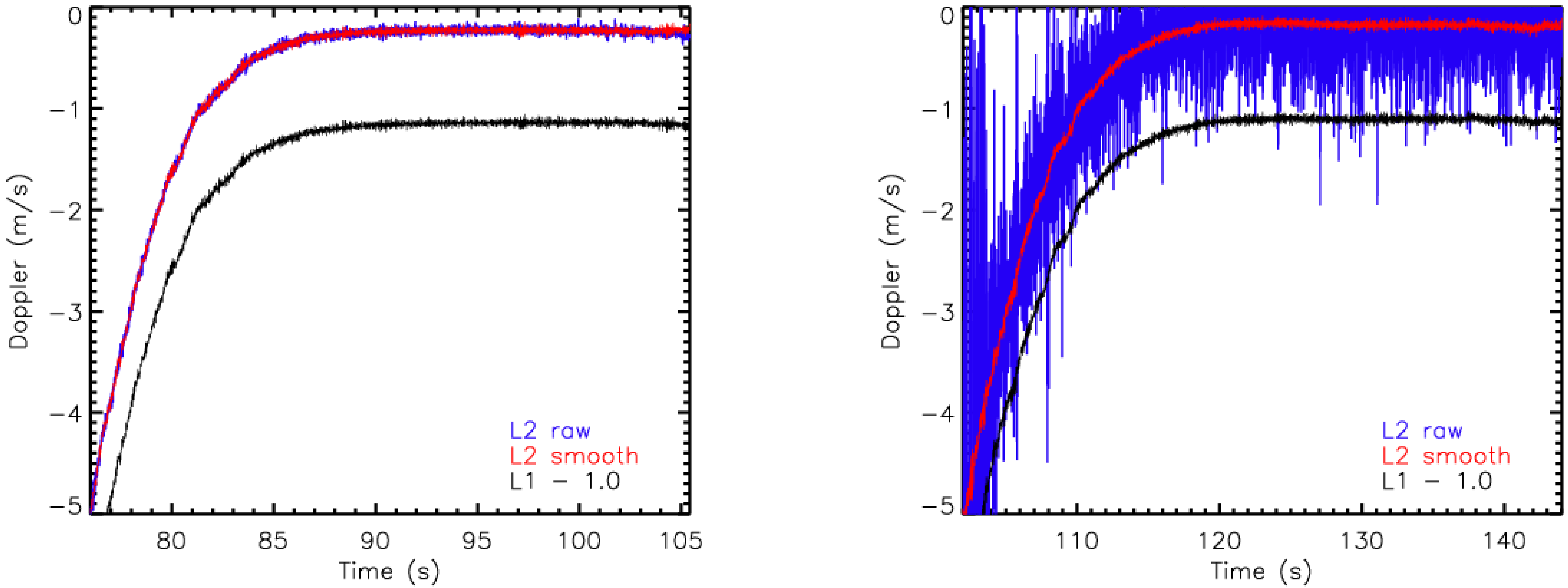


Fig. Raw L2 Doppler (blue), L2 Doppler after smoothing residual phase (red) and L1 Doppler (black). L1 Doppler reduced by 1 m/s for clarity.

The profile on left was flagged as good on the earlier version, but the profile on the right was flagged as bad because of the noisy L2 bending angle. After correction, the profile could be retrieved as a ‘good’ profile.

<u>Data/Method and Impact of L2 Smoothing</u>

Data:
UCAR L1b (conPhs) geometry and phase data for 2019.240 – 2019.256
Number of L1b files with data = 56636

Method:
1. Calculate the difference of L1 and L2 excess phases (***dphs***)
   dphs = L2phs - L1phs
2. Apply 2-seconds smoothing to ***dphs***.
3. Add the smoothed ***dphs*** back to L1phs (***L2phs = L1phs+dphs***)

Impact of L2 smoothing:
- Number of profiles passing QC without L2 correction = 39226 (69%)
- Number of profiles passing QC after L2 correction = 52155 (92 %)
- Correcting for L2 excess phase increase data volume by 23 %

Note: QC is determined by mean difference of L1 and L2 bending angles between 25 – 50 km. If the mean difference > 100 μrad, flag the profile as ‘bad’. <u>This QC removes profiles with bad L2 data</u>.

2. Level L2 Quality Control

Data/Method and Impact on Profile Count

Data:

UCAR L1b (conPhs) geometry and phase data for 2019.240 – 2019.256

Number of L1b files with data = 56636

Number of L2 files with alpha and N retrievals = 55470

(Note: some L1b files have incomplete/short time series covering short profile)

Method:

1. Collocate RO profiles with ERA5 profiles (with interpolation)
2. Calculate the mean absolute fractional difference (*dX*) between RO and ERA5 at 15 – 35 km height range for bending angle and refracitivty
3. If $dX \leq 20$, QC = 0 and if $dx > 20$, QC = 1

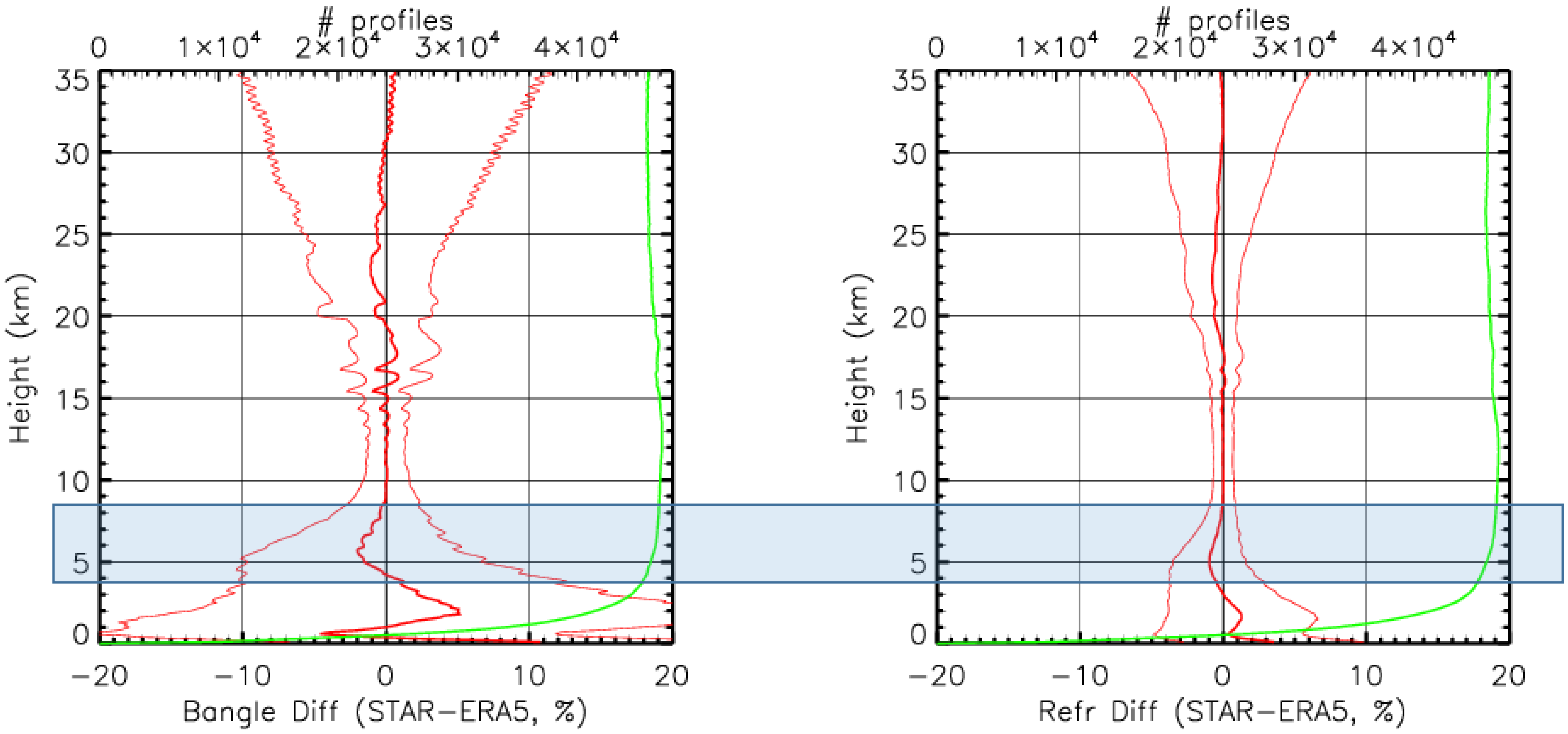
Impact on Profile Count:

- Number of files with QC = 0 = 47240 (85 %)
- Number of files with QC ≠ 0 = 8230 (Profiles labelled as 'bad_profiles')

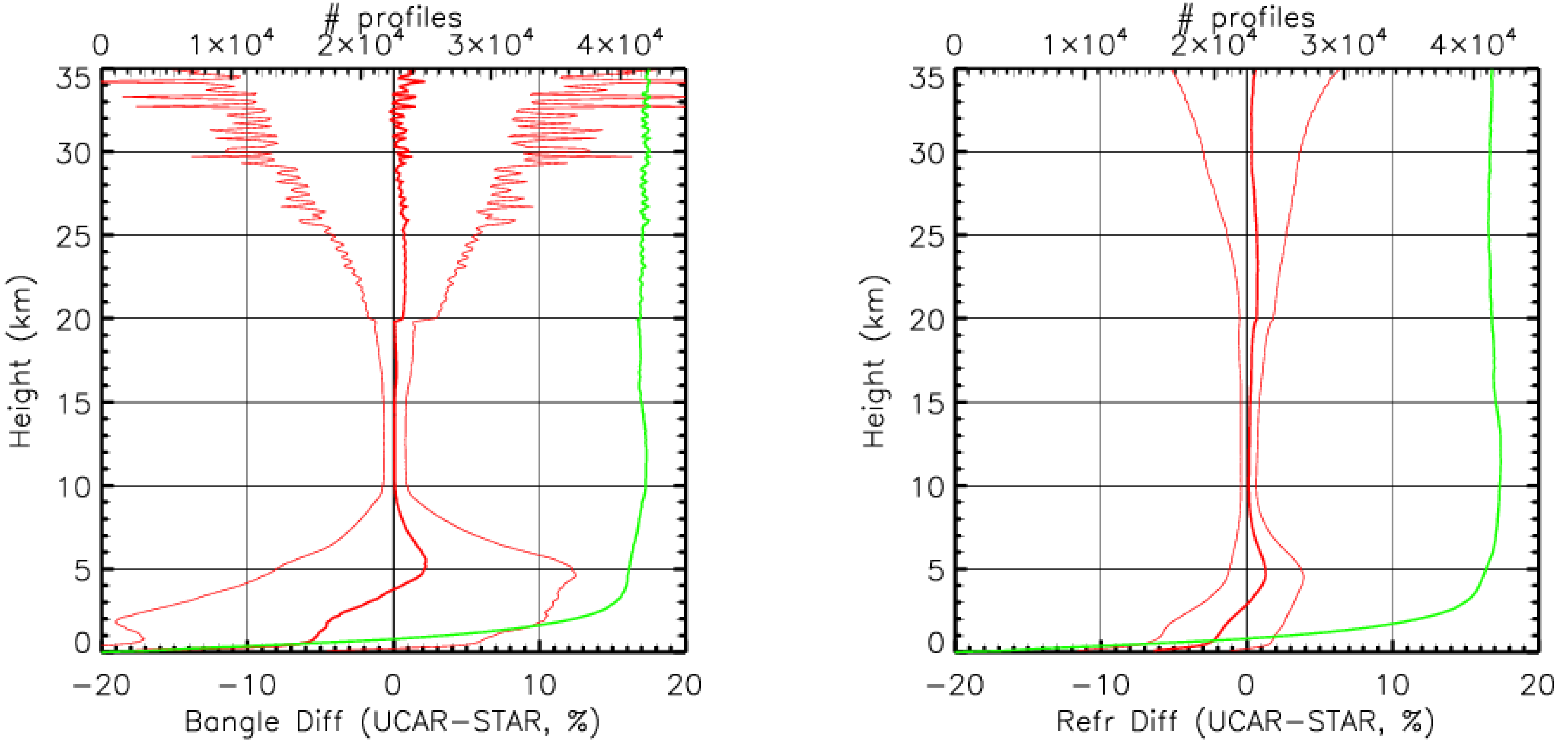
Comparison with ERA5 and CDAAC

- In the comparison, all data over/under 3 sigma are removed

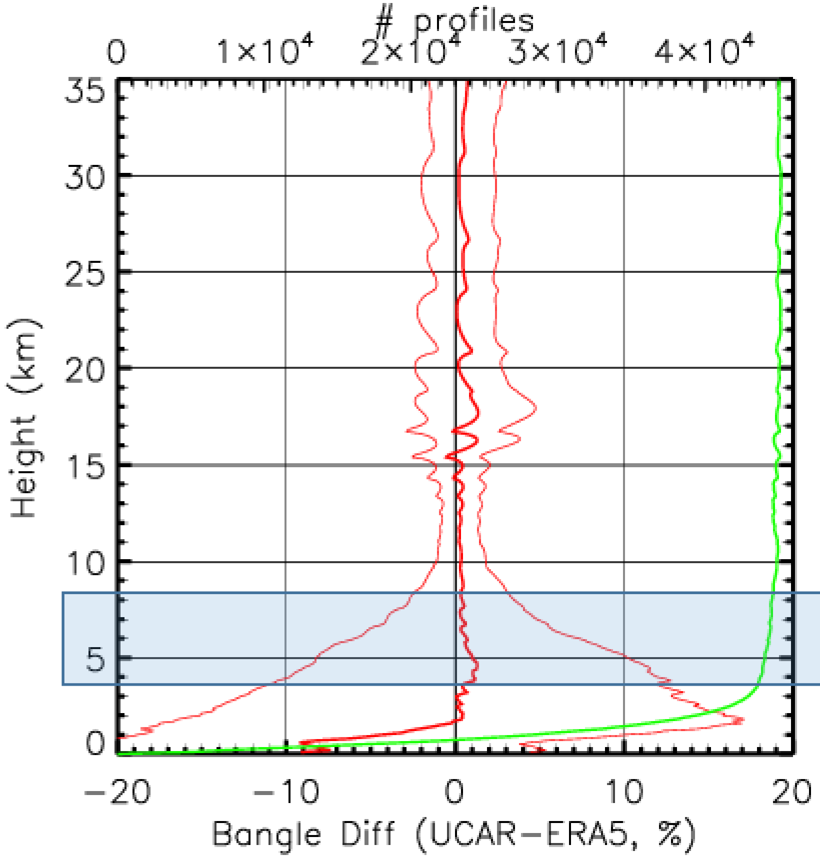
Comparison of Bending Angle and Refractivity with ERA5

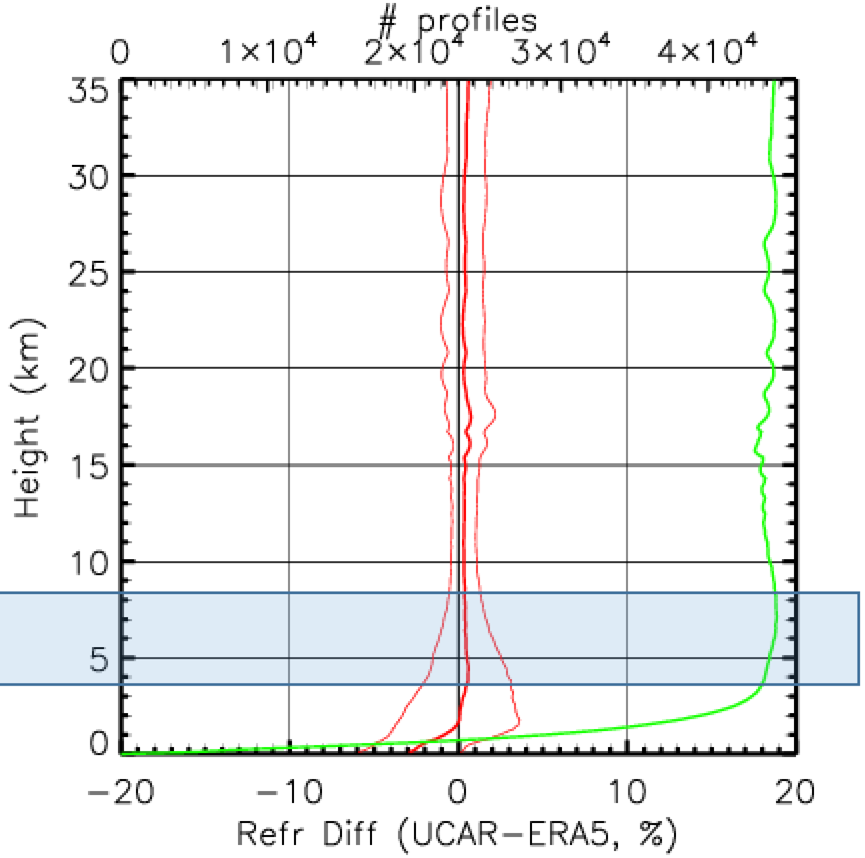


Comparison of Bending Angle and Refractivity with CDAAC

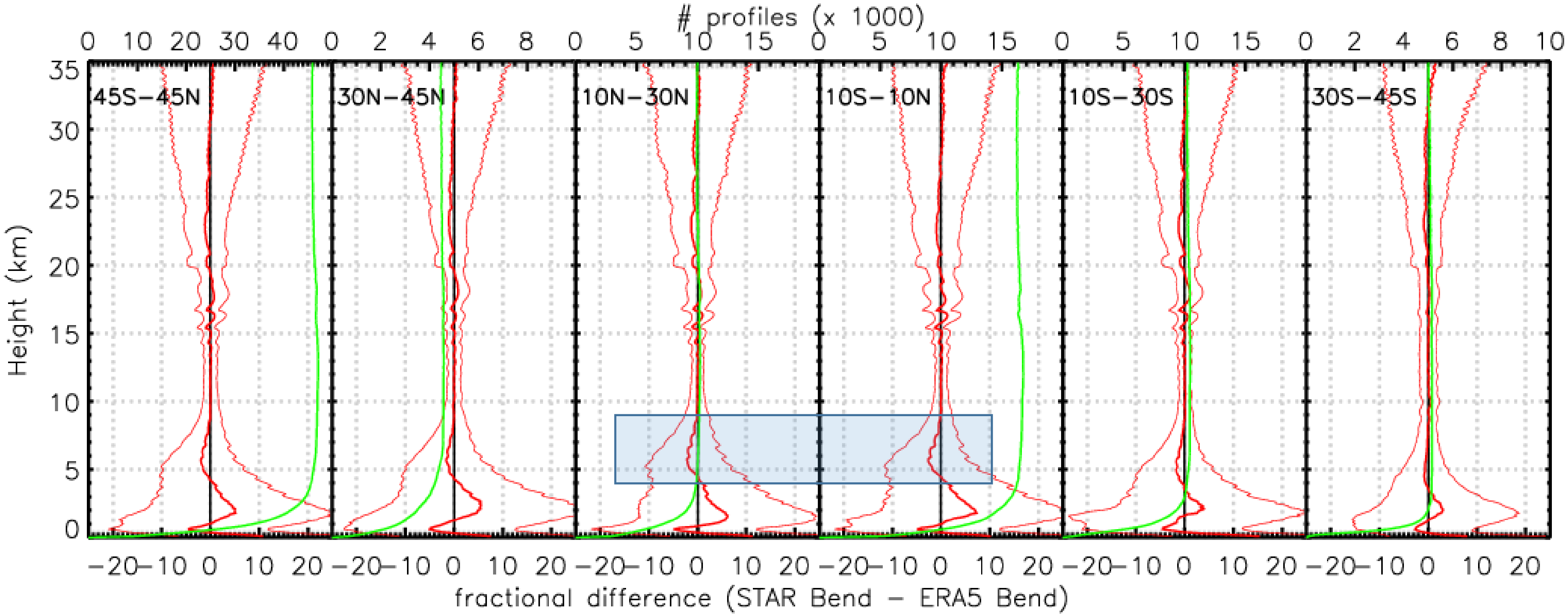


Comparison of CDAAC Bending Angle and Refractivity with ERA5

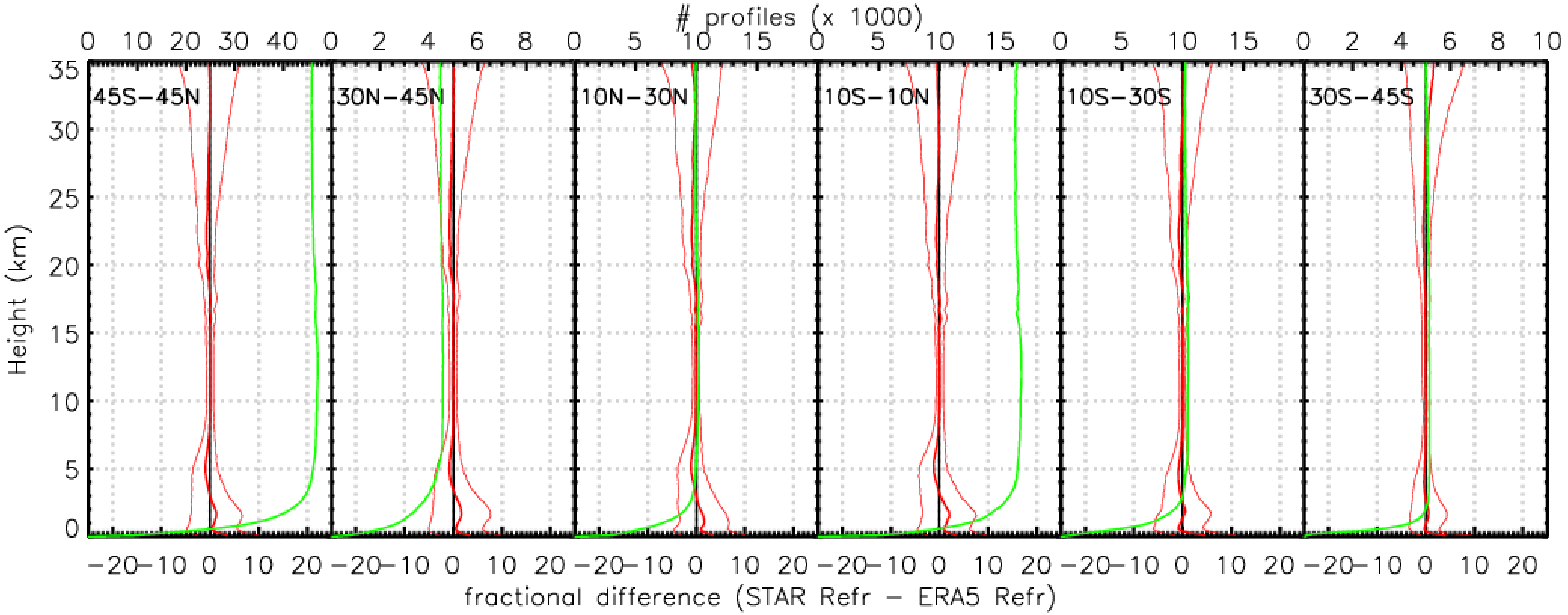




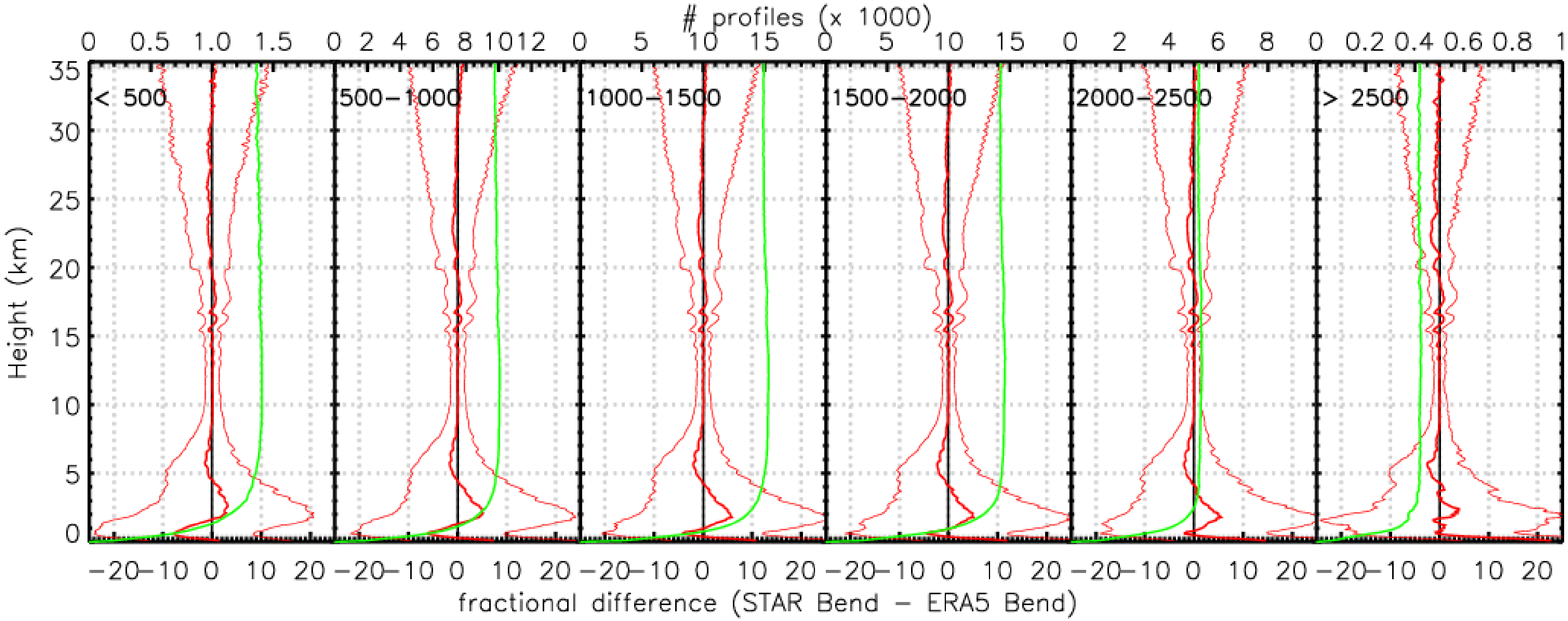
Comparison of Bending Angle with ERA5 at Different Latitude Bins



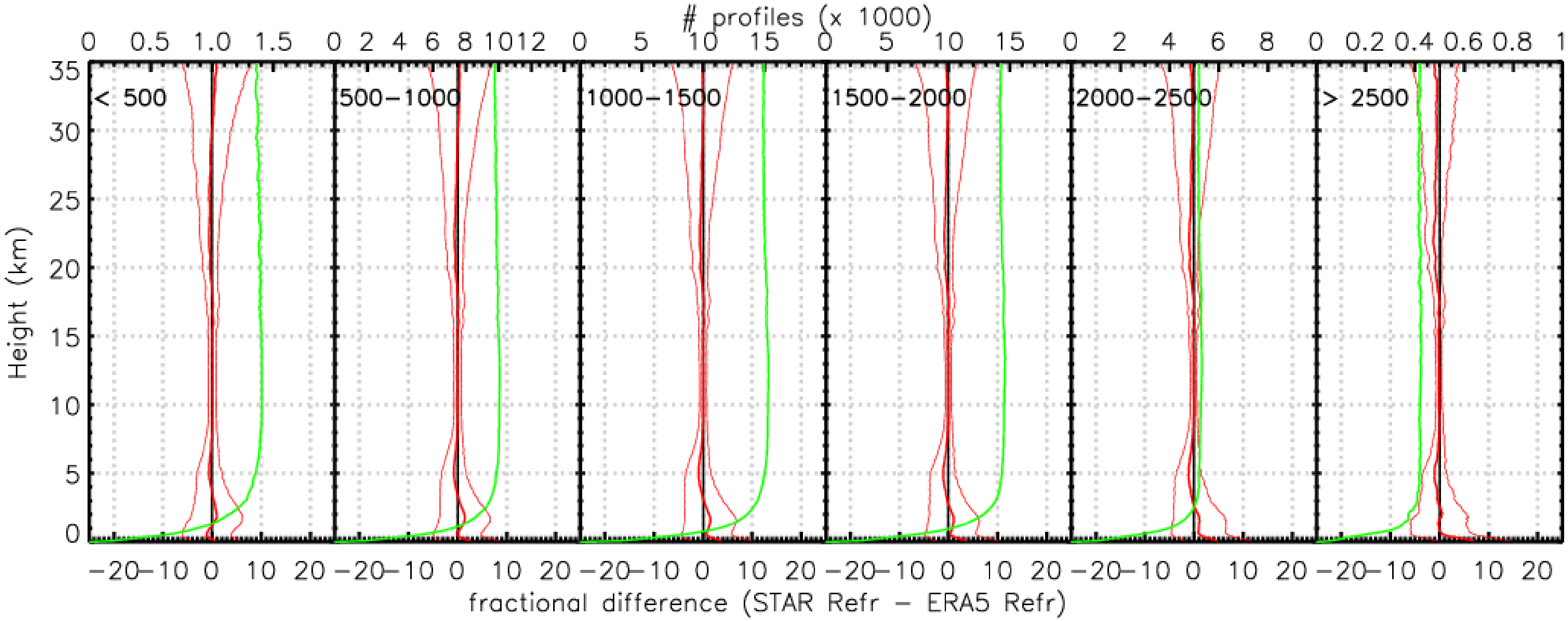
Comparison of Refractivity with ERA5 at Different Latitude Bins



Comparison of Bending Angle with ERA5 at Different SNR Bins



Comparison of Refractivity with ERA5 at Different SNR Bins



Summary, Conclusion and Current Work

Summary:

- Smoothing on L2 excess phase results in an increase in the number of GNSS profiles
- Level 2 QC flags ~15 % of the total profiles as 'bad profiles'
- The STAR standard deviation is larger than CDAAC standard deviation compared to ERA5
- STAR bending angle and refractivity have a negative bias near 5 km altitude compared to ERA5, which is not observed in CDAAC data. The negative bias is larger in the tropics.

Conclusion:

- The large standard deviation is the result of insufficient reduction of the noise in the bending angle during ionospheric correction. In using linear combination of L1 and L2 bending angles, the fraction f2^2/(f1^2-f2^2) used for ionospheric correction enhances the noise and spreads the bending angle profile. Optimizing the bending angle by using some external constraint (e.g. climatological data) can help reduce the bending angle spread.

Currently Working on:

- Optimization of bending angle using CIRA+Q climatological data