

Introduction: Atmospheric remote sensing of bending angle/refractivity profiles by the GNSS (Global Navigation Satellite System) radio occultation (RO) method provide valuable input for numerical weather prediction models. The RO-instrument GRAS (GNSS Receiver for Atmospheric Sounding) on-board of EUMETSAT's (European Organisation for the Exploitation of Meteorological Satellites) MetOp satellite has been designed for observing setting and rising occultations from the GPS (Global Positioning System) satellite constellation. A dedicated ESA (European Space Agency, contract 21995/08/NL/EL) funded study was set up to investigate the potential of RO data recorded in RS (raw-sampling) mode.

Results from GRAS RO data recorded in RS mode processed at the GFZ Potsdam are presented. The experimental processing software POCS-X includes FSI (Full Spectrum Inversion) in order to cope with multi-path regions and enables (in connection with RS data) to retrieve bending angle/refractivity profiles down to the Earth's surface. The retrievals are validated against co-located ECMWF (European Centre for Medium-Range Weather Forecasts) profiles. The intercomparison indicates good quality of the retrieved profiles.

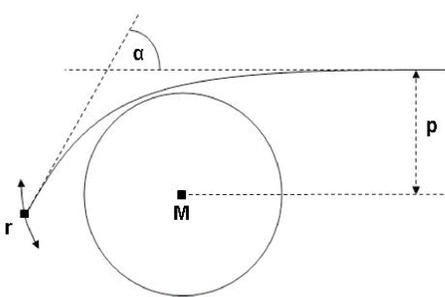


Figure 1: GPS occultation geometry. An incident ray from a GPS satellite propagates through the atmosphere and is refracted. The phase and amplitude of the signal is recorded by a GPS receiver r aboard a low-earth orbiting satellite. The bending angle α as a function of the impact parameter p is determined through geometric/wave optics. The bending angle profile is converted to a refractivity profile.

Processing of GRAS RO data:

Level 2: The phase and amplitude of the entire signal is assembled from closed-loop data recorded at 50Hz and RS data recorded at 1kHz. The residual phase extraction requires knowledge of the navigation data bits. External navigation data bits, collected by GFZ's ground station network, are used. Internal navigation data bits are used if external navigation data bits are not available (25% of all occultation events).

Level 3: The FSI is used to obtain bending angles. The bending angle profiles are truncated at that impact parameter value where the smoothed FSI amplitude drops below 50% of the maximum value. Above 12km ray-height bending angles are replaced by corresponding standard Doppler retrieved bending angles. At high altitudes statistical optimization using auxiliary data (MSIS climatology) is performed. The bending angle profiles are inverted to refractivity profiles using the Abel transform.

Quality Control (QC) is applied at different stages of the processing. The early stage QC (applied at Level 2 & 3) examines data gaps, SNRs and excess Doppler shifts. Entire profiles are rejected if needed. The final stage QC compares the retrieved refractivity profiles to the ECMWF analysis. Profiles with a fractional refractivity deviation $>10\%$ at any altitude between 6 and 30km are rejected. In total 70% of the profiles pass the QC (Figure 2).

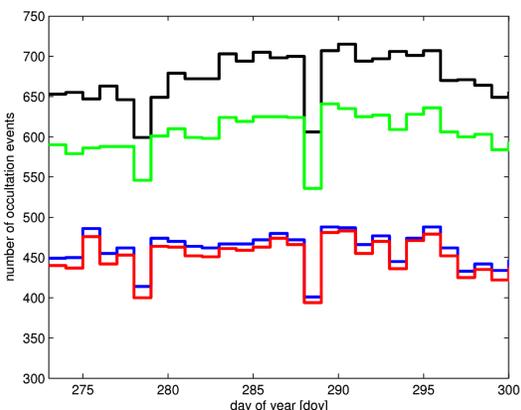


Figure 2: Number of occultation events versus day of year. Total number of occultation events (black), number of profiles after early stage QC Level 2 (green)/Level 3 (blue) and the number of profiles after final stage QC (red).

Validation against ECMWF: ECMWF refractivity is computed from pressure, temperature and specific humidity. Interpolation between grid points and linear interpolation in time is performed between 6h ECMWF analysis fields. Bending angle profiles are computed through the inverse Abel transform. The focus is on data from October 2007 (Day of Year: 273-300) provided by EUMETSAT.

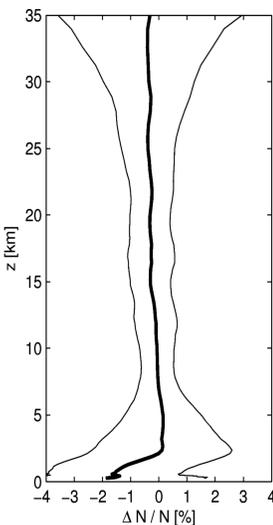
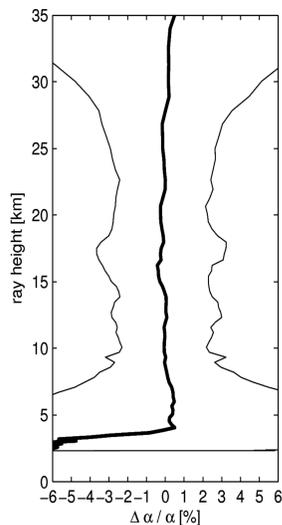


Figure 3: Fractional bending angle/refractivity deviation versus ray height/altitude. The thick solid line indicates the mean, the thin solid line indicates the one-sigma standard deviation.

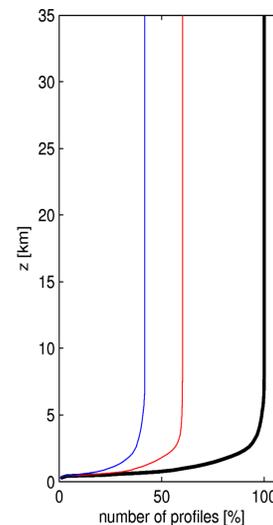
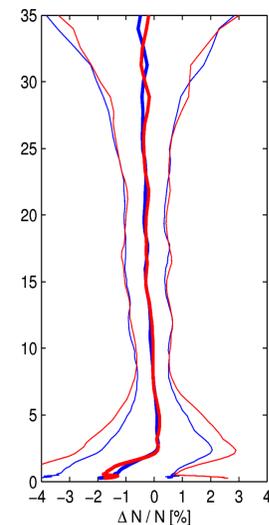


Figure 4: Fractional refractivity deviation versus altitude and number of retrieved data points at a given altitude for setting/rising occultations (red/blue). All occultations (black).

Main Features: (1) The enhanced bending angle standard deviation can be explained by the filter width used in the standard Doppler retrieval of bending angles (high altitude) and the downsampling rate of the FSI retrieved bending angles (low altitude) (2) The 50% altitude is 780m. The refractivity deviation reaches -1.8% close to the surface (3) From 10 to 35 km the refractivity deviation is increasing, ranging from -0.1% to -0.4% . Tests indicate that the climatology MSIS, which is used in the statistical optimization at high altitudes, contributes to this bias. If observations are out-weighted the bias reaches its maximum, putting more weight to the observations tends to reduce the bias (4) At low altitudes the refractivity standard deviation of rising and setting occultations differs by up to 1%. This feature is accompanied by a difference in the number of retrieved data points at a given altitude; setting occultations extend deeper into the lower troposphere.

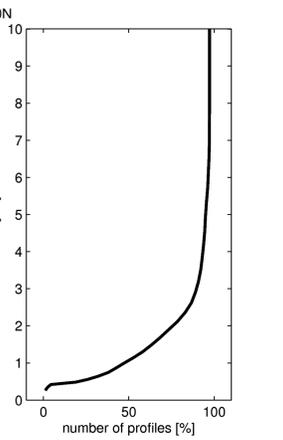
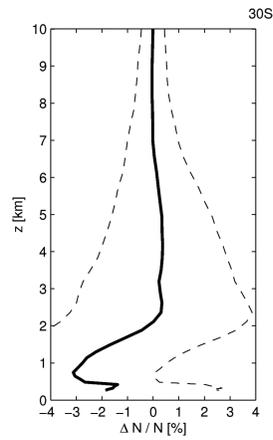
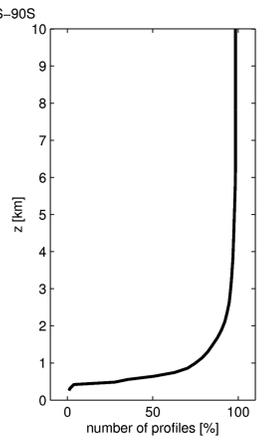
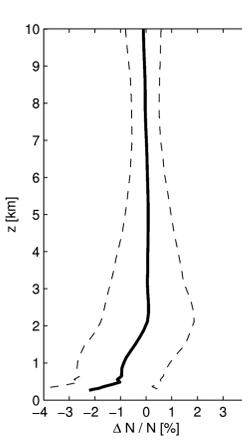
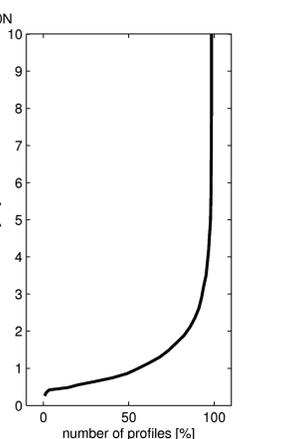
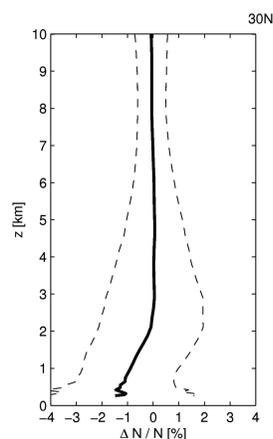
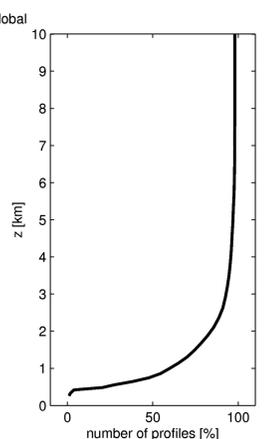
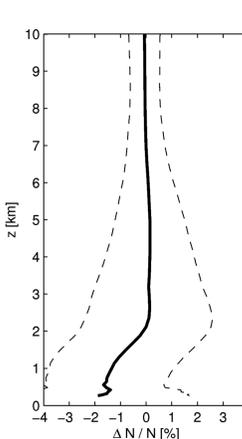


Figure 5: Fractional refractivity deviation versus altitude and number of retrieved data points at a given altitude for different latitude bands. Global (upper left panel), northern hemisphere (upper right panel), southern hemisphere (lower left panel) and tropics (lower right panel). The solid line indicates the mean, the dashed line indicates the one-sigma standard deviation.

Main Features: (1) The 50% altitude is 1km for the tropics, 880m for the northern hemisphere and 640m for the southern hemisphere (2) In the northern/southern hemisphere biases are insignificant from 2km to 10km (3) The meridional distribution of the refractivity deviation at low altitudes shows that the negative/positive bias mainly stems from the tropical lower troposphere. A possible explanation of the enhanced negative bias below 2km is the presence of critical refraction; in particular in the tropics a frequently observed phenomenon. In addition recent investigations by S. Sokolovskiy (presentation at the 4 COSMIC Data Users Workshop) point to that the truncation and filtering of RO signals have a large influence on the biases in the tropical lower troposphere.

Conclusion & Outlook: Preliminary validation efforts of retrievals derived from GRAS RS data indicate good quality. RS and the application of an advanced retrieval algorithm work as intended, allowing for improved bending angles and refractivity profiles that extend deeper into the lower troposphere. Currently 70% of the occultations pass QC. An increased yield of the retrievals is work in progress. For a profile-to-profile intercomparison with other teams participating in the GRAS RS study see the OPAC presentation of C. Marquardt.