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Cloud water and ice contributions to bending angle profiles in GPS radio occultation technique

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The dependency of radio signals on atmospheric conditions in radio occultation measurements is expressed in terms of bending angle, which is mostly due to horizontal gradients of the refractive index with main contributions from gaseous constituents such as pressure, temperature and water vapor. GPS frequencies are commonly considered to be unaffected by liquid and solid water in the atmosphere associated with clouds. However, small-scale refractivity contributions accumulated along relatively large distances between GPS transmitter and low-Earth orbiter can become significant under severe weather conditions. By statistical analysis of radio occultation profiles co-located with tropical cyclones in 2016 we assessed the impact of liquid and ice water content on bending angles. Abel transform was used in forward modeling of refractivity profiles at tangent points derived from Global Forecast System in cloudy conditions. Induced residuals were compared with uncertainties of bending angle retrieval and showed two times larger magnitude at liquid cloud top altitude of around 9 km. Ice water can affect radio occultation profiles up to the top height of 19 km, with the impact being one order of magnitude smaller than liquid clouds. For selected occultations we performed simulations with multiple phase screen method in non-spherically symmetric atmosphere to restore 2-dimensional structures of bending angle profiles, neglecting out-of-plane refractivity components. Horizontal and vertical distributions of liquid and ice clouds within occultation plane together with introduced inhomogeneity is presented and discussed. The refractive index of liquid water in the cyclone eyewall exceeded value of 2.5 ppm which corresponds to cloud mixing ratio on the level of 20 g/kg. This causes the bending angle to differ by over 1.5 % with respect to retrievals with zero clouds contributions. The highest fractional difference of the bending angle due to ice water reached 0.5 %.