Xiaolei
Zou
ESSIC, University of Maryland
Shengpeng Yang, Nanjing University of Information Science & Technology, China
Oral
The GPS RO refractivity observations in ice clouds were found to be systematically greater than the refractivity calculated from the ECMWF analysis. The fractional N-bias (GPS minus ECMWF) could be as high as 1.8% within deep convective clouds. The 0.6% contribution of 1 g m-3 IWC to the total refractivity based on CloudSat ice measurements was found to be consistent with those derived from a theoretical model accounting for the effects of liquid and ice clouds on the propagation of the GPS radio signals (Zou et al., 2012). In a recent study (Yang and Zou, 2017), the RO ice cloudy profiles during a seven-year period from 2007 to 2013 over the globe are firstly selected and grouped into four types of ice clouds (e.g., nimbostratus, deep convective, cirrus, altostratus) based on collocated CloudSat data. Vertical temperature profiles within ice clouds below -20oC are then retrieved from GPS RO refractivity observations, in which the vertical profiles of ice water content required by the forward model of refractivity are obtained from CloudSat retrievals of ice water content. Vertical distributions of relative humidity and lapse rate within clouds are finally examined in terms of their occurrences, mean values and standard deviations. It is found that ice clouds have preferred values of relative humidity and lapse rate depending on cloud types and altitudes. Most altostratus ice clouds are located between 4-8 km with relative humidity between 55-75%. The cirrus clouds have a relative humidity around 60% and are located mostly above 6 km to as high as 13 km. Difference from cirrus and altostratus ice clouds, nimbostratus ice clouds that occur mostly in polar regions are found at all altitudes below 10 km with a relative humidity decreasing linearly from about 90% near the surface to about 60% around 6 km. Within deep convective ice clouds, the relative humidity also decreases linearly from about 100% around 2.5 km to about 60% around 9 km. The lapse rate slightly increases with altitude and its value ranges between 5-8oC km-1 within nimbostratus, deep convective and altostratus ice clouds. The lapse rate within cirrus clouds varies from 6oC km-1 to 9oC km-1. Vertical variations of the lapse rate derived from GPS RO cloudy retrievals compared favorably to those derived from radiosonde profiles. Both showed that the mean lapse rate increases with altitude from about 5oC km-1 around 3 km to about 7oC km-1 around 7 km, and the standard deviations are much smaller than the mean lapse rate.

Zou, X., S. Yang, and P. Ray, 2012: Impacts of ice clouds on GPS radio occultation measurements. J. Atmos. Sci., 67(12), 3670-3682.
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