Lapse Rate Characteristics in Ice Clouds Inferred from GPS RO and CloudSat Observations

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GPS Radio Occultation (RO) 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 -20°C 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 5-8°C km⁻¹ within nimbostratus, deep convective and altostratus ice clouds. The lapse rate within cirrus clouds varies from 6°C km⁻¹ to 9°C km⁻¹. Vertical variations of the lapse rate derived from GPS RO cloudy retrievals compared favorably to those derived from radiosonde profiles. Both show the mean lapse rate increases with altitude from about 5°C km⁻¹ around 3 km to about 7°C km⁻¹ around 7 km, and the standard deviations are much smaller than the mean lapse rate.