Radiative Transfer Through Clouds and Its Applications in Support of the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) Mission

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ABSTRACT

The Greenland and Antarctic ice sheets, which contain enough ice to raise sea level by about 7 and 60 m, respectively, are losing mass at an increasing rate. To acquire continuous information of the cryosphere, after the Ice, Cloud, and land Elevation Satellite (ICESat) (2003-2010), NASA is actively planning for the ICESat-2 mission. Both ICESat and ICESat-2 are space-borne lidar altimetry systems. The systems measure the time of flight of the arriving photons that are reflected by the surface to deduce the elevation of the underlying terrain. As one of NASA's top priority missions, ICESat-2 is scheduled to launch in 2016. One of the major science goals of ICESat-2 is to quantify the ice sheet mass balance to determine its contributions to the sea level change and its impacts on ocean circulation (Abdalati et al. 2010). Compared to ICESat, which operates at 40 Hz and records the reflected laser energy as a waveform, the significantly improved ICESat-2 lidar employs a 532 nm micro-pulse photon counting system that operates at a high frequency of 10 kHz with single photon detectability (Yang et al. 2012).

To achieve its science goals, ICESat-2 requires the ability of detecting the elevation change with an accuracy of 0.2 cm/year over the entire ice sheet. Since every photon emitted by the lidar system will travel through the atmosphere, clouds can certainly affect the flight time of the arriving photons. Forward scattering by cloud particles increases the photon path length, thus resulting in biases in ice sheet elevation measurements known as atmospheric path delay (Duta et al. 2001, Yang et al. 2010, 2011). To ensure the accuracy of ICESat-2 surface elevation measurements, it is critical to understand how clouds would affect the travel time of arriving photons.

In this talk, we will first present a framework that simulates the behavior of a space-borne 532 nm micro-pulse photon counting lidar in cloudy and clear atmospheres. To investigate the process of laser propagation through clouds, a 3-D Monte Carlo radiative transfer model is used to simulate the photon path distribution and the Poisson distribution is adopted for the number of photon returns. Since the photon counting system only registers the time of the first arriving photon within the detector "dead time", the retrieved average surface elevation tends to bias towards higher values. This is known as the first photon bias. With the scenarios simulated here, the first photon bias for clear sky is about 6.5 cm. Clouds affect surface altimetry in two ways: (1) cloud attenuation lowers the average number of arriving photons and hence reduces the first photon bias; (2) cloud forward scattering increases the photon path length and makes the surface

appear further away from the satellite. Compared to clear sky, the average surface elevation detected by the photon counting system for cloudy sky with optical depth 1.0 is 4.0 to 6.0 cm lower for the simulations conducted. The effect of surface roughness on the accuracy of elevation retrievals will also discussed.

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