Global Snowfall Measurement with the CloudSat Space-borne Radar

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I. Overview

Since mid-2006, the NASA CloudSat mission has been collecting data with its 94 GHz Cloud Profiling Radar (CPR). Liu (2008) derived a relationship between CloudSat Radar Reflectivity and snowfall rates (Z-S relationship), and applied this to near-surface CloudSat data to develop a unique picture of global snowfall. Kulie and Bennartz (2009) discussed various sources of error and possible improvements to the methodology for deriving Z-S relationships and choosing optimal 'near-surface' radar bins.

This work considers CloudSat-derived snowfall rates from a global perspective similar to Liu (2008), but with a focus on the various issues presented in Kulie and Bennartz (2009), such as sensitivity to ice particle model, attenuation, ground clutter, and the various thresholds used for determining snowfall cases. All global plots are averages of CloudSat data from July 2006 - June 2007.

Complex Terrain of Eastern Greenland (Wikipedia)

CloudSat (NASA Earth Observatory)

Snowflakes (Wikipedia)

II. Methodology: Derivation of Z-S relationships

1. For a given snowfall rate *S*, the ice particle size distribution (PSD) is first derived using the Field et al. (2005) parameterization.
2. PSD + backscatter coefficient data from DDA calculations of various ice particle models (Hong 2007; Kim et al. 2007; Liu 2008b) is used to calculate *Z* for 25 different ice particle model and 3 different temperatures. See Fig. 1 for example Liu (2008b) ice habits.
3. Best-fit line derived using power law relationship (1-σ fits also derived to define upper and lower bounds). (Fig. 2)

QuickTime™ and a decompressor are needed to see this picture.

Fig. 1: Examples of ice particle shapes used in deriving Z-S relationships, from Liu 2008(b)

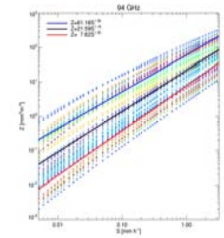

Fig. 2: For each snowrate, 75 corresponding radar reflectivities are shown: 25 ice models at -5, -10, and -15˚C. A best fit (black line) and upper(blue line)/lower(red line) bound are then determined based on these data points.

III. Sensitivity to Vertical Continuity Tests

- Kulie and Bennartz (2009) required reflectivity to be greater than -15 dBZ from 6th-11th CPR bins above the surface (~1.3-2.5km) to help eliminate ground clutter contamination.
- However, this is likely eliminating shallow snowfall cases, especially over oceanic areas.
- This significantly affects snow frequency and has some effect on mean snowrate in these areas (Figs. 3 and 4); but it is unclear if it is accurate to make the assumption that these shallow cases are actually precipitating at the surface.
- **Suggested Improvement: use vertical continuity test over land but not over oceans.**

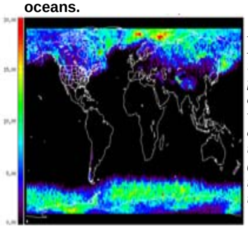

Fig. 3: Difference in snow frequency due to vertical continuity test (%) (no test minus with test)

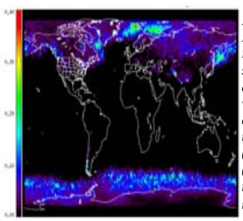

Fig. 4: Difference in mean snowrate due to vertical continuity test (mm/day) (no test minus with test)

V. Sensitivity to Reflectivity Threshold

- Liu (2008) used -10 dBZ threshold for differentiating between precipitating and non-precipitating cases; Kulie and Bennartz (2009) used -15 dBZ threshold.
- This is significant from a frequency of occurrence perspective (Fig. 6).
- **However, the effect of this different threshold on the mean snowrate is negligible (Fig. 7).**

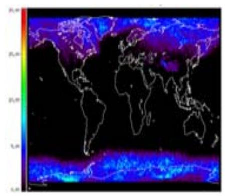

Fig. 6: -15 dBZ threshold minus -10 dBZ threshold, precipitation frequency (%)

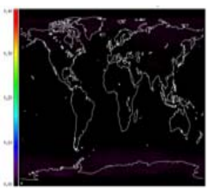

Fig. 7: -15 dBZ threshold minus -10 dBZ threshold, mean snowrate (mm/day)

VII. How Important is Mixed Precipitation?

- Liu (2008) counted 2m temperature less than 2˚C as snow cases. In order to consider dry snowfall only, Kulie and Bennartz (2009) used 0˚C.
- Due to the difficulty of modeling partially-melted precipitation, this study does not attempt to estimate the contribution of mixed precipitation to annual liquid-equivalent precipitation amounts.
- Instead, the following plots show occurrence of precipitation cases with 2m temperature of 0-4˚C compared to dry snowfall cases (less than 0˚C) (Figs. 10 and 11)
- **The frequency of occurrence of mixed precipitation can be many times that of dry snowfall in the mid-latitudes, and still significant in northern hemisphere continental regions.**

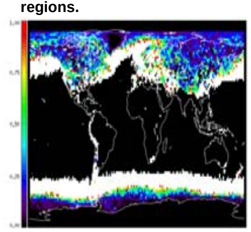

Fig. 10: Ratio of mixed (0-4C) profiles to snow (<=0C) profiles. White areas are where the ratio is greater than 1.

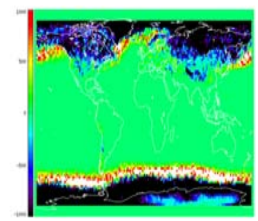

Fig. 11: Number of mixed (0-4C) profiles minus number of snow (<=0C) profiles. In white areas, the difference is greater than 1000. In black areas, the difference is less than -1000.

IV. Effect of Attenuation

- The CloudSat 94-GHz radar signal is heavily affected by attenuation, making it difficult to use for heavy rainfall cases. But is attenuation significant when studying snowfall?
- 2-way attenuation calculated for the following atmospheric constituents: water vapor (ECMWF), cloud liquid water (AMSR-E over oceans only), and frozen hydrometeors (CPR).
- **For snowfall, attenuation appears to be most important over southern ocean and northern hemisphere storm track regions (Fig. 5).**
- **This effect is significant enough that we consider attenuation correction to be a useful addition to the methodology for determining snow rates from CloudSat.**

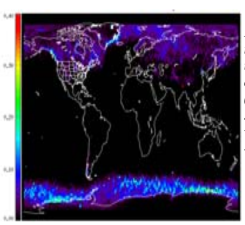

Fig 5: Difference in mean snowrate due to attenuation correction (mm/day) - middle-ZS relationship, no vertical continuity, -10 dBZ threshold

VI. Sensitivity to Z-S relationship

- In section (II), various ice models from three databases were averaged, resulting in three Z-S relationships that represent the average of these models as well as an upper and lower bound.
- This can be thought of as a rough estimate of the amount of error in derived Z-S relationships due to the ice model chosen.
- The derived global mean snowfall rates are extremely sensitive to this assumption; the choice of ice model is a very large source of error in this study.
- **The error due to assumptions about ice particle is in many areas comparable to the actual magnitude of mean snowfall rate (Fig. 9).**

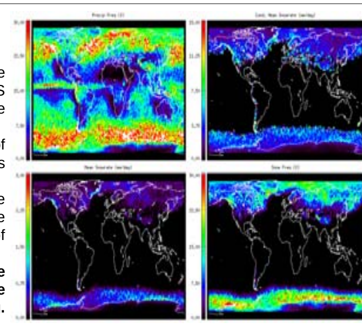

Fig. 8: Global plots for middle-ZS relationship, with attenuation correction, no vertical continuity test, and -10 dBZ threshold depicting precipitation frequency (top left), conditional mean snowrate (top right), snow frequency (bottom right), and mean snowrate (bottom left)

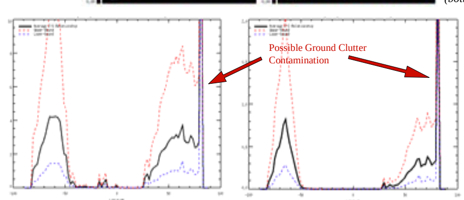

Fig. 9: Zonally averaged conditional mean snowrate (left) and mean snowrate (right). Snowrates are provided in units of mm/day. The middle-ZS relationship is in black, the upper-bound in red, and the lower-bound in blue. Averages include full year's data (cold and warm season).

Future Work

1. Use ground-based conventional snowfall measurements to validate CloudSat-derived snowfall rates, both for specific cases as well as long-term averages.
2. Improve models for frozen and mixed precipitation.

References

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