Comparison of Monthly Mean Cloud Fraction and Cloud Optical depth Determined from Surface Cloud Radar, TOVS, AVHRR, and MODIS over Barrow, Alaska

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1. INTRODUCTION

[1]A one year comparison is made of mean monthly values of cloud fraction and cloud optical depth over Barrow, Alaska (71° 19.378' North, 156° 36.934' West) between 35 GHz radar-based retrievals, the TOVS Pathfinder Path-P product, the AVHRR APP-X product, and a MODIS based cloud retrieval product from the CERES-Team. The data sets represent largely disparate spatial and temporal scales, however, in this paper, the focus is to provide a preliminary analysis of how the mean monthly values derived from these different data sets compare, and determine how they can best be used separately, and in combination to provide reliable estimates of long-term trends of changing cloud properties (for example, Wang and Key, 2002). The radar and satellite data sets described here incorporate Arctic specific modifications that account for cloud detection challenges specific to the Arctic environment.

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The year 2000 was chosen for this initial comparison because the cloud radar data was particularly continuous and reliable that year, and all of the satellite retrievals of interest were also available for the year 2000.

Cloud fraction was chosen as a comparison variable as accurate detection of cloud is the primary product that is necessary for any other cloud property retrievals. Cloud optical depth was additionally selected as it is likely the single cloud property that is most closely correlated to cloud influences on surface radiation budgets (Zuidema et al., 2004).

2. ARCTIC CLOUD RETRIEVALS

2.1 Radar based cloud retrievals from Barrow, AK

35 GHz cloud radar measurements have now been collected by the DOE Atmospheric Radiation Measurement (ARM) program in Barrow, Alaska since 1998. This multi-year, surface-based cloud data set provides continuous measurements of reflectivities, Doppler widths, and Doppler spectral widths. The radar data is collected

in vertical beams that are averaged to 1-min averages with 45 m range resolution. Based on the radar data, rawinsondes, and IR/MW radiometers, cloud type classifications and microphysical retrievals have been applied operationally, by the NOAA/Environmental Technology Laboratory. These are described and can be accessed at http://www.etl.noaa.gov/et6/arctic/nsa. This retrieved cloud data set provides information on cloud boundaries, optical depths, ice water path, liquid water path as well as vertical profiles of hydrometeor sizes (droplet and ice crystal), cloud water contents, and extinctions. Retrievals are applied to all cloud scenarios including ice, liquid, mixed-phase, and multiple layers.

2.2 Polar Path-P Cloud Retrievals from the TOVS Sensor

The TIROS-N Operational Vertical Sounder (TOVS) operates on the NOAA satellites. The TOVS is composed of the Infrared Radiation Sounder (HIRS), the Microwave Sounding Unit (MSU) and the Stratospheric Sounding Unit (SSU). The MSU and the SSU have been replaced with the AMSU-A and AMSU-B on newer satellites. The Pathfinder Path-P data set retrieves cloud fraction, cloud top temperature, and cloud top pressure. These data sets are described at: http://psc.apl.washington.edu/pathp/. The TOVS Pathfinder Path P data is a gridded data set that utilizes the EASE-Grid. In this analysis TOVS cloud fraction retrievals within a 200 km radius of Barrow, Alaska were utilized.

2.3 The APP-X Cloud Retrievals from the AVHRR Sensor

The Advanced Very High Resolution Radiometer (AVHRR) operates on the NOAA Satellites. The APP-X data is gridded to a 25 km resolution grid (or 5 km for the cloud masks) and is interpolated in time to 0400 and 1400 LST which is 14.44 (14:26:24) UT and 00.44 (00:26:24 on the following Day) for Barrow. The APP-X data set provides a multi-decadal data set from 1998 to the present. The retrieved APP-X cloud data sets are described at:

http://stratus.ssec.wisc.edu/products/appx/appx.html.

2.3 CERES-Team Retrievals from the MODIS sensor on Terra and Aqua Satellites

The MODIS sensor was launched on the TERRA satellite in 1999. The MODIS sensor is a 36 channel radiometer. The CERES team retrievals for the MODIS sensor over snow use the solar-infrared near-infrared technique (SINT) that employs the MODIS Instrument 3.75, 10.8, and 1.61-µm channels, respectively, to derive cloud particle size, temperature, and optical depth (Minnis et al. 2002).

The technique relies on the 1.6-µm channel to derive optical depth and has been shown to estimate optical depths in water clouds more accurately than the 0.65-µm channel over snow backgrounds. Values presented here were calculated from retrievals calculated for actual overpass times over the Barrow site, and represent data within a 100x100 km box centered on the Barrow, Alaska site.

3. MONTLY MEAN VALUES

In calculating monthly mean values, all available data from each respective sensor/retrieval product is used and no space-time matching is attempted. This approach results in the monthly values that would be calculated in the case that any single one of these data sets were being used for a long-term study of cloud properties alone.

3.1 Cloud Fraction

Figure 1 shows the monthly mean values of cloud fraction calculated by the radar, APPX, CERES and TOVS. Barrow is a relatively cloudy site, and cloud fraction estimates from all products indicate high summer time average cloudiness ranging from 85-95% and winter time average cloudiness ranging from 30-65%. Figure 2 shows the difference between the monthly values from the radar and the three

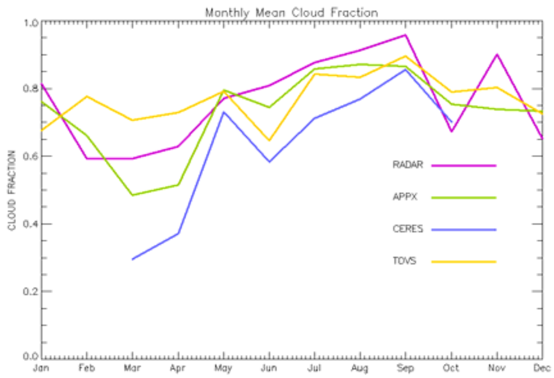

Figure 1 Monthly Mean Cloud Fractions for Radar, APPX, CERES and TOVS

satellite products. The APPX has the closest agreement with radar estimates of cloud fraction with differences generally within 10% with some months with higher and some months with lower estimates of cloud fraction. The CERES product has lower estimates of cloud fraction for all months (from 5 to 30%) with the exception of October when CERES indicates a slightly higher monthly cloud fraction (4%). The TOVS sensor shows

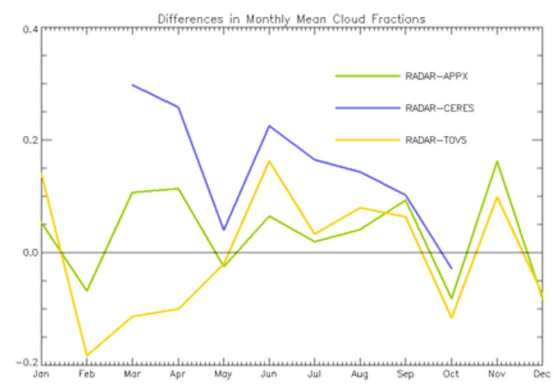

Figure 2 Difference in monthly mean cloud fraction for Radar-APPX, Radar-CERES and Radar-TOVS. Positive values indicate that the satellite product has a lower estimate of cloud fraction and negative values indicate the satellite product has a higher estimate of cloud fraction.

both higher and lower cloud fractions depending on month, ranging from +/- 20% in comparison with the radar estimates. Because the TOVS shows a tendency for higher cloud fractions than the radar in winter, and lower in the summer, it does not appear to catch the full amplitude of the annual variation of cloud fraction between summer and winter.

3.2 Cloud Optical Depth

Figure 3 shows the monthly mean cloud optical depths from the radar, APPX and CERES (the TOVS Path-P cloud product does not include optical depth). The radar-radiometer retrievals of cloud optical depth

Figure 3 Monthly mean cloud optical depth from radar, APPX and CERES

indicates a pronounced annual cycle which is a product of the increased amounts of liquid water (typically supercooled) in Arctic clouds. In Figure 4, differences between the radar and APPX and CERES monthly means are shown respectively. The APPX product appears to have slightly higher optical depth estimates in the winter, and

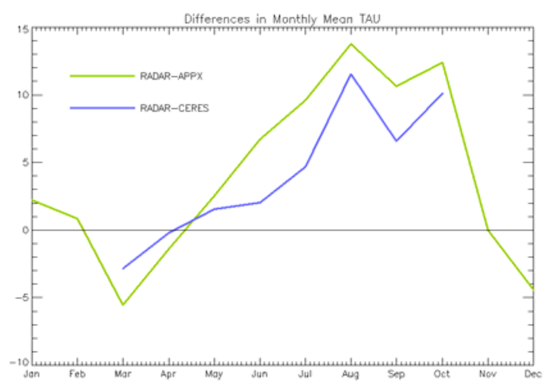

Figure 4 Difference in optical depth for Radar-APPX and Radar-CERES. Positive values indicate that the satellite product has a lower estimate of optical depth and negative values indicate the satellite product has a higher estimate of cloud optical depth.

significantly lower optical depth estimates in the summer, and therefore does not the same annual trend. The CERES sensor has lower estimates of optical depth than the radar throughout the year, however it appears to be more in agreement with the radar in terms of observing increased summer optical depths compare to winter values

4. DISCUSSION

There are a number of reasons that the radar and satellite sites may show large discrepancies in estimates of cloud fraction and cloud optical depth. These include mismatches in space-time sampling, the fact that the radar is not an ideal instrument for determining cloud optical depth (a lidar would be better suited, especially for optically thin clouds), and the fact that Barrow, being a coastal site is not ideal for satellite retrievals as both over-land and over-ocean pixels must be blended to determine aggregate footprint/grid values. However, it is likely that a more refined comparison for longer time periods will indicate that the satellite sensors and the radar have good agreement for particular parts of the season. Identification of certain key months where sensors show good agreement may be an important exercise for tracking long-term trends. For instance, in the year 2000 presented here, the radar and all 3 satellite products had good agreement on cloud fraction for May, September and October for cloud fraction and during April and May for cloud optical depth. If this result can be further observed in other comparison years this will be particularly important, especially since May and September represent transition months. This exercise may also lay the groundwork for blending the longer-term measurements from the AVHRR and TOVS sensors with the shorter-term but more robust measurements of the modern MODIS based measurements. Finally, surface cloud radars may become an important element in long-term operational calibration of the satellite products, especially as the network of operational cloud radars and radiometers is expanded in the Arctic region.

5. REFERENCES

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