3B.1 COMPARISON OF SHEBA AND NSA CLOUD PROPERTIES FOR APRIL, MAY, JUNE AND JULY

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1. INTRODUCTION

Cloud radar and radiometer data sets from the Surface Heat Budget of the Arctic (SHEBA), (Uttal et al., 2001) and DOE/Atmospheric Radiation Measurement (ARM) North Slope of Alaska (NSA), (Stokes and Schwartz, 1994) are presently being processed with a suite of retrieval techniques to produce detailed records of cloud microphysical properties. In this paper, the classification of cloud types, and selection of appropriate retrieval techniques necessary for this processing are discussed. Comparison of the statistics of occurrence for all-ice and all-liquid clouds are shown for April, May, June and July for both the SHEBA ice camp which drifted with the ice pack in the Beaufort Sea, and the ARM/NSA site in Barrow, Alaska. Although the SHEBA statistics are for 1998 and the NSA statistics are for 1999 and 2000, this study provides a preliminary examination at differences in Arctic cloud properties between the Arctic ice pack and a coastal Arctic site which is ice free in spring and summer.

2. DATA SETS

During the year-long SHEBA program (Uttal et al., 2001), a 35 GHz cloud radar (Moran et al., 1998), a depolarization lidar (Grund and Sandberg, 1996), and a number radiometers were deployed. The radiometers included a spectral infrared radiometer and a microwave radiometer operating at 23.8 and 31.4 GHz. The radar provided continuous (9 s) height resolved (45 m) measurements or radar reflectivity and Doppler velocity, the lidar provided continuous (5 s), range-resolved (30 m) measurements of lidar backscatter and depolarization ratios, the IR radiometer measured downwelling IR radiance from 20 to 3 μm, and rawinsondes were launched on either a 2/day or 4/day schedule. With the exception of the depolarization lidar, this suite of instrumentation is duplicated and operating continuously (start date March, 1998 for the radar) in Barrow, Alaska.

3. CLOUD CLASSIFICATION

A number of radar-based, related, retrieval techniques have been developed, some of which use only the radar, other of which incorporate additional information from radiometers and lidar. Some of these have been summarized by Matrosov et al., (1999) and generally separate into techniques for all-ice clouds, all-liquid clouds, precipitation, or rough approximations for mixed phase clouds.

In practice, the application of these different retrieval techniques for long data streams as opposed to a few ideal, carefully selected, case studies is a difficult task because of a number of factors. First, clouds must be classified (all-ice, all-liquid, mixed-phase) so that the appropriate retrieval technique can be applied. A large fraction of Arctic clouds have proven to be complex entities with embedded layers of alternating liquid, ice, and mixed-phase which defy simple classification. Second, environmental factors must be evaluated; for instance a boundary layer cloud with liquid may contaminate IR measurements that might otherwise be used in ice retrievals for a upper level cirrus cloud, necessitating the use of a less rigorous retrieval technique. Finally, given the reality of continuously operating several instruments, many of which are complex prototypes in remote locations, there are inevitable calibration issues, along with sometimes prolonged data outages.

At present, cloud classification and retrieval method selection is being done at NOAA/ETL by subjectively examining a combination of radar reflectivities, Doppler velocities, and spectral widths, microwave radiometer measurements of integrated liquid water path, rawinsonde temperature profiles, and IR brightness temperatures near 10.6 μm and for SHEBA, range resolved depolarization data from lidar which provides information on phase.

Figure 1 shows an example of a complex cloud scene for a 24 hour period during which a variety of different cloud types existed. Based on the information from the radar, microwave radiometer and rawinsonde, this day was classified as: 24/24 cloud fraction (24 hours of cloud/24 hours of radar operation) ; 15/24 all-liquid, single layer (00:00-10:00 GMT, 17:00-19:00 GMT, 20:00-21:00 GMT, and 22:00-24:00 GMT), 3/24 all-ice, single layer (11:00-14:00 GMT), 2/24 all-liquid multi-layer

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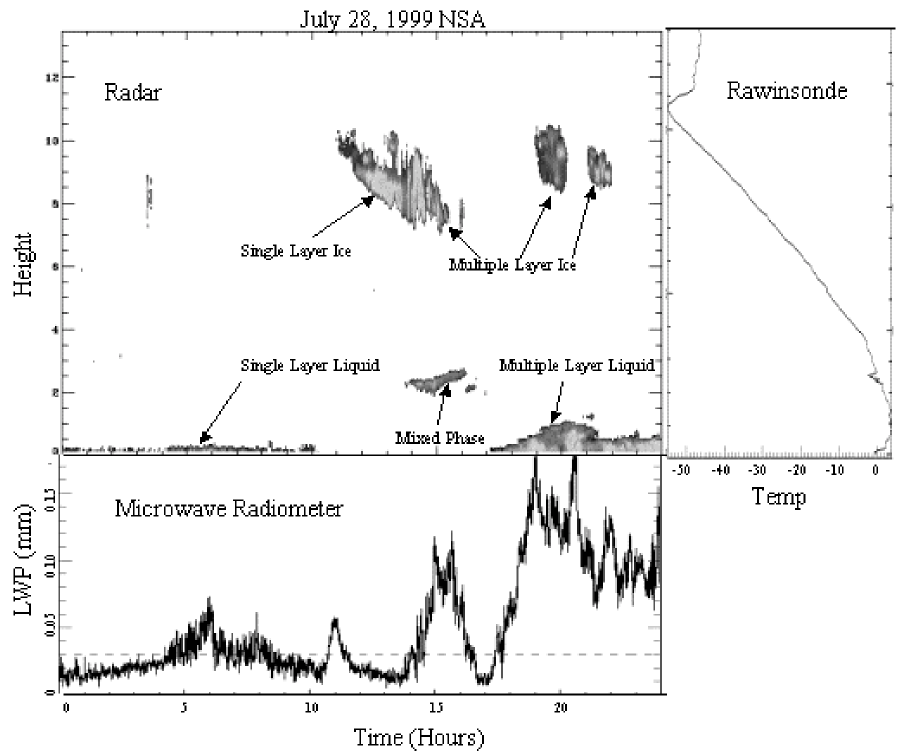

Figure 1: Time-Height (0:00-24:00 GMT and 0-13 km) cross-section of radar reflectivities and corresponding integrated liquid water path from microwave radiometer and rawinsonde temperature profile. Cloud classification notations indicated in radar panel are discussed in text.

(19:00-20:00 GMT and 21:00-22:00 GMT), and 4/24 all-ice, multi-layer (14:00-16:00 GMT, 19:00-20:00 GMT and 21:00-22:00 GMT). The cloud at 2 Km AGL between 14:00-16:00 GMT was classified as mixed phase.

4. RESULTS

Table 1 shows cloud classification statistics for SHEBA for April, May, June and July of 1998. The numbers for all-liquid clouds are different from those reported by Shupe et al., (2001) as the criteria that the cloud base be above the lowest range gate of the radar (100 m AGL) was not used. That additional criteria was used to select of clouds for which full base to top retrievals could be run, and reduced the percent of all-liquid clouds, particularly those in single layers by a factor of about 3. Table 2 shows corresponding results for NSA determined from April, May, June and July of 1999 and 2000. A major radar outage occurred between June 5 1999 and July 20 1999 at NSA, so statistics in Table 2 for June and July are primarily from 2000.

Cloud fractions are quite similar between the two sites ranging from monthly cloud fractions of 87.7 to 93.1 % at SHEBA and 71.2 to 92.2 % at NSA, with 4-month averages of 90.7% and 85.2%.

All-liquid layers were more frequent at NSA then at the SHEBA ice camp which may represent latitudinal influences (Barrow is about 73° N compared to 76°N to 78°N for the SHEBA ice camp which was drifting North during April-July). In addition, warmer surface temperatures would be expected at Barrow with an increasingly snow free tundra and ice-free ocean in the spring-summer transition period , compared to the constant 0°C +/- 1.5°C surface temperatures over the ice pack.

All-ice clouds were also more frequent in Barrow (21.0% to 62.5% compared to 15.0% to 23.4%), with corresponding larger numbers of single-layer all-ice clouds. The NSA site also had a much higher incidence of deep systems with precipitation, mixed phase layers, embedded layers of liquid within ice layers, and convective elements. While these systems were not possible to classify (Figure 2), they likely were producers of some of the higher ice clouds that appear to be less frequent at SHEBA.

	Cloud Fraction	All-Liquid (Single layer)	All-Ice (Single layer)
April	93.1	16.6(14.9)	21.3 (7.0)
May	88.0	35.6(30.0)	17.5 (6.1)
June	87.8	15.8 (8.5)	23.4 (7.9)
July	93.9	12.7 (9.7)	15.0 (5.9)
Average	90.7	20.2(15.9)	19.3 (6.7)

Table 1: Cloud classification for spring-summer transition season at SHEBA ice camp (1999). Cloud Fraction is percentage of time clouds were observed by radar; other values are percentages of time that clouds were present. Clouds that were single layer as well as single phase are shown in parenthesis (from Shupe, et al., 2001).

	Cloud Fraction	All-Liquid (Single Layer)	All-Ice (Single Layer)
April	71.2	3.7 (2.5)	62.5(39.1)
May	90.2	43.2(25.1)	36.8(11.7)
June	87.4	31.9(23.7)	43.4(15.2)
July	92.2	41.2(24.2)	21.0(4.1)
Average	85.2	30.0(18.9)	40.9(17.5)

Table 2: Cloud classification for spring-summer transition season at NSA (1999 and 2000) Cloud Fraction is percentage of time clouds were observed by radar; other values are percentages of time that clouds were present. Clouds that were single layer as well as single phase are shown in parenthesis.

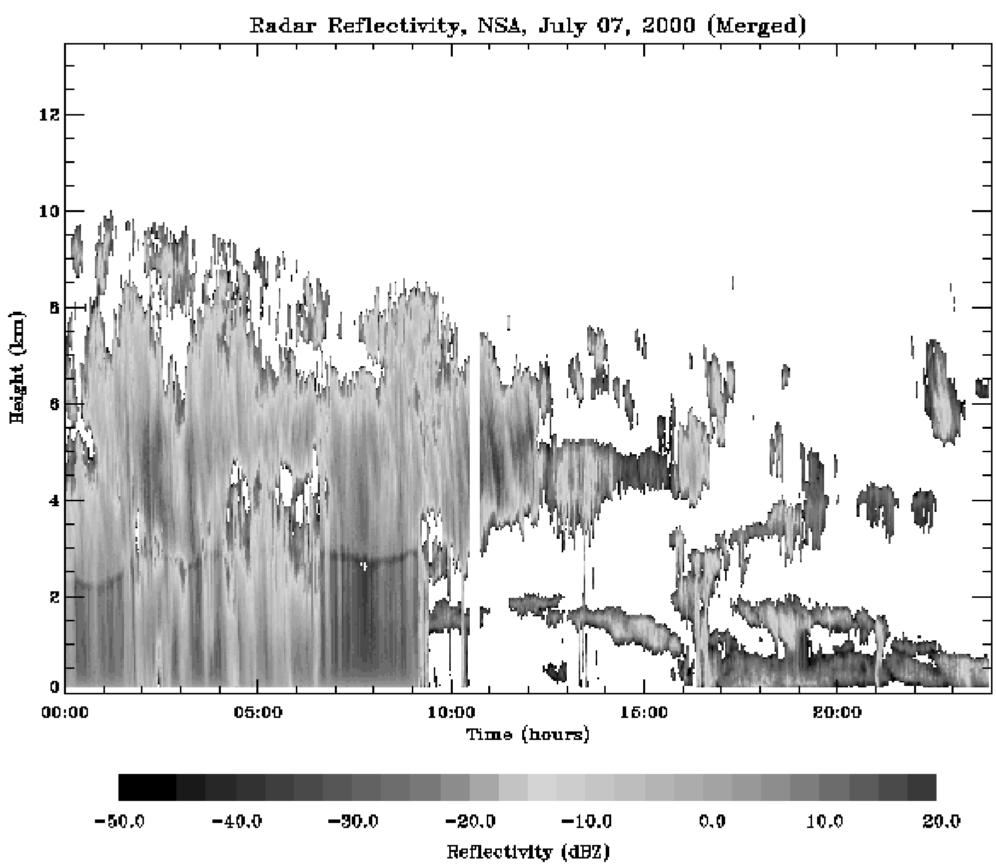

Figure 1: Time-Height (0:00-24:00 GMT and 0-13 km) cross-section of radar reflectivities for complex precipitating, multi-layered system on July 7 at NSA.

5. DISCUSSION

The most conclusive result presented in this study is that both the SHEBA and NSA sites recorded similar cloud fractions that for most months were near 90%. The NSA site appeared to have a larger fraction of clouds that could be classified as all-ice or all-liquid, this will increase the number of cases for which it will be possible to run radar-based retrievals of cloud water contents, particle/droplet sizes, concentrations and optical depths. However, a some caveats should be considered.

At present, classification is being done largely by inspection and has a subjective element. This is especially an issue for this preliminary study as statistics for SHEBA and NSA were developed by two different analysts. Cloud classification schemes are presently being standardized and automated to reduce the subjectivity factor, however automation of classification techniques will be an extremely complex process. It is likely that best possible automated techniques for cloud classification will be largely based on probability distribution functions that will have to be generated from large retrieved data sets that are first done on a subjective basis.

Another important factor is the depolarization lidar which operated at SHEBA but is not operated at NSA. This instrument can detect cloud phase details that presently are difficult or impossible to deduce with the radar alone. For instance, the lidar at SHEBA detected supercooled liquid water at temperatures as low as -36°C and as altitudes high as 6 km AGL in clouds that might otherwise have been classified as all-ice. Another frequent condition would be liquid-topped surface clouds with underlying precipitation which could be erroneously classified as all liquid because of low temperatures and reflectivities. It is likely that the use of the lidar during SHEBA significantly reduced the number of clouds that were classified as single-phase, and it is anticipated that the lidar will also make possible the application of hybrid retrieval techniques based on information on the location of simultaneous ice and liquid layers in clouds. Therefore, it is possible that the absences of a depolarization lidar at the DOE/ARM/NSA site may have considerable impact of the number and quality of cloud cases for which reliable retrievals will be available.

These cloud classification statistics also indicate that the majority of Arctic clouds are complex, mixed-phase, multi-layer entities for which it will be inappropriate to run existing, single-phase retrievals from either the surface or from space. At present the cloud radiation/climate/remote sensing research community is largely focused developing techniques for modeling and observing the properties of single-phase and single-layer clouds. It will clearly be necessary to develop methods to approximate the radiative properties of complex mixed-phase cloud systems before a full understanding of clouds impacts on radiation budgets will be possible.

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