Project Report
Validation of CERES Cloud Retrievals Over the Arctic with Surface-Based Millimeter-Wave Radar
Year 4

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Activities over the June 2000 to August 2001 reporting period have fallen into 4 major areas:
1) Developed long time-series of cloud retrievals for the Arctic Barrow Alaska site.
2) Improved and expanded GUI retrieval system utilizing wider variety of retrieval techniques.
3) Developed a website interface for accessing Arctic cloud.
4) Incorporation of Arctic data in radiation models to assess impacts on Arctic radiation budgets.

These are summarized in the following progress report. The objectives stated in the year 4 Statement of Work are restated in **bold type**, with progress on each element summarized after each element.

(1) We will use the GUI system to develop long time series of radar-radiometer based retrieved cloud parameters including cloud phase, particle sizes, concentrations, water content, vertical distribution of cloudiness with height and cloud top temperature and pressure. First priority will be to begin daily real-time processing in the summer of 2000. Second priority will be catch-up processing for the period since February, 2000 when TERRA was launched. Finally, the time period starting in February of 1998 when the radar came on line will be processed forward so a complete data set will be available from the North Slope of Alaska.

The 2000 data set has been processed from March (date of TERRA launch) through December. It is expected that the data for January, February, March, and August of 2001 will be processed by September 30th of 2001. Unfortunately, much of the data from April, May, June and July of 2001 is of insufficient quality because of radar operating problems resulted in degraded, uncorrectable data sets that will prohibit reliable retrievals.

Figure 1 shows the input measurements that are used to make subjective cloud classification masks. These data from radar, the rawinsonde temperature profiles, and the microwave radiometer integrated liquid water path are used to subjectively determine what parts of the cloud scene are liquid, ice, mixed phase, and/or precipitating. Once each part of the cloud has been classified, a number of different retrieval schemes are available to estimate water contents, particle sizes, and concentrations. The retrieval schemes are selected on the basis of both data availability and environmental conditions. For instance, for a single layer, all-ice cirrus cloud, a robust radar-radiometric retrieval can be performed; but if a lower level liquid layer radiometrically obscures the ice, or the radiometer is not operating, then it is still possible to perform a radar-only retrieval using either an empirical relationship between radar reflectivity and water contents (tuned to Arctic conditions), or perform a newly developed radar reflectivity/Doppler velocity technique (Matrosov et al., 2001).

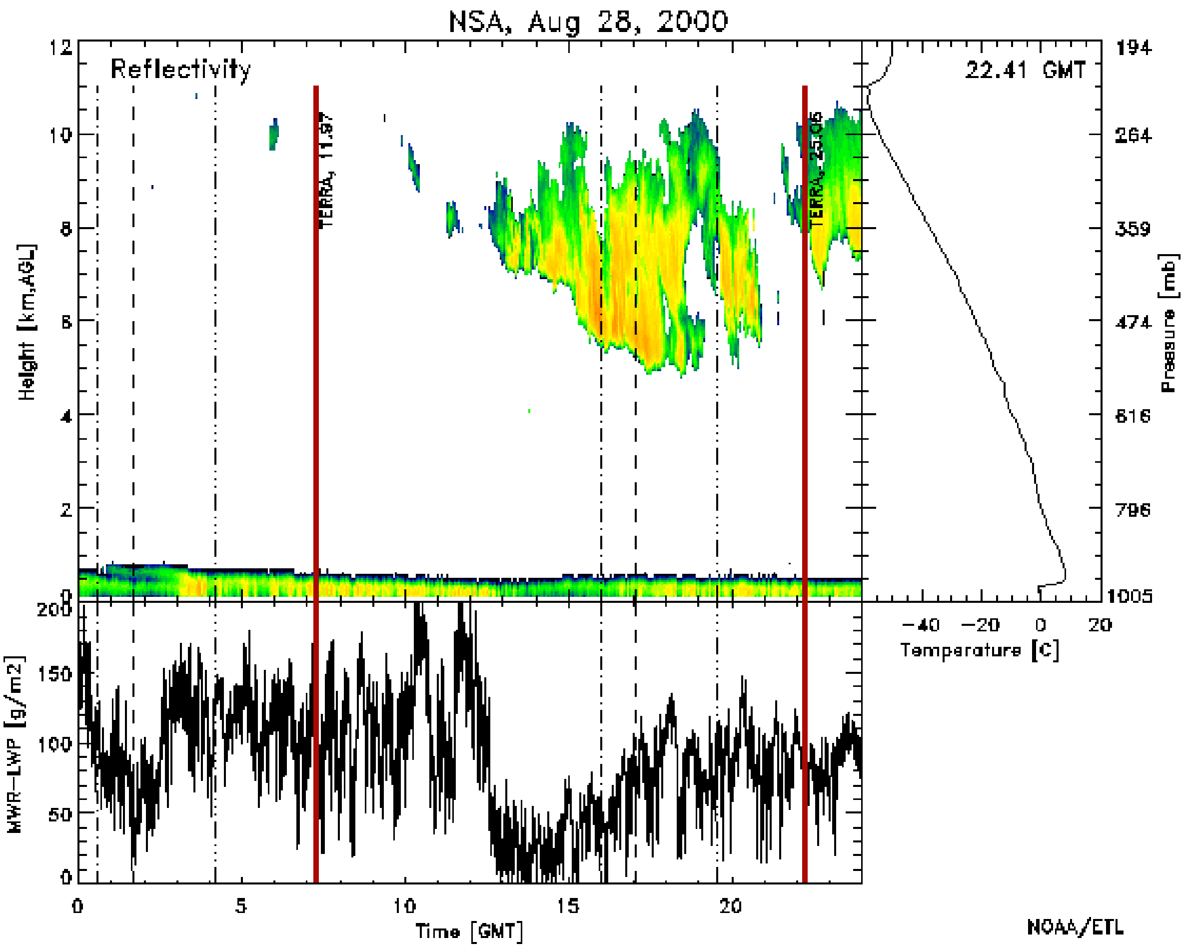

Figure 1 Radar, radiometer and rawinsonde measurements used for subjective classifications of cloud type.

Figure 2 shows the subjective cloud classification mask for August 28, 2000 where the low level cloud has been classified as liquid (atmospheric temperatures above 0 °C through depth of cloud) and the upper layer cloud has been classified as all-ice. Note that the key on figure 2 shows the range of possible classifications types ranging from ranging from rain to snow, with ice, liquid and mixed phase in between. Figure 3 shows the retrieved water contents for this cloud using two distinct ice and liquid retrieval techniques, with ice retrievals referenced to the blue-green color bar and liquid retrievals referenced to the red-yellow color bar.

It should be noted that Figures 1-3 also show satellite overpass times for those overpass times where viewing angles are less then 30 degrees. TERRA overpasses are shown in bold red lines, and NOAA-11, NOAA-12, NOAA-14, NOAA-15 and NOAA-16 are by keyed by dashed and dash-dot lines (See web site for details).

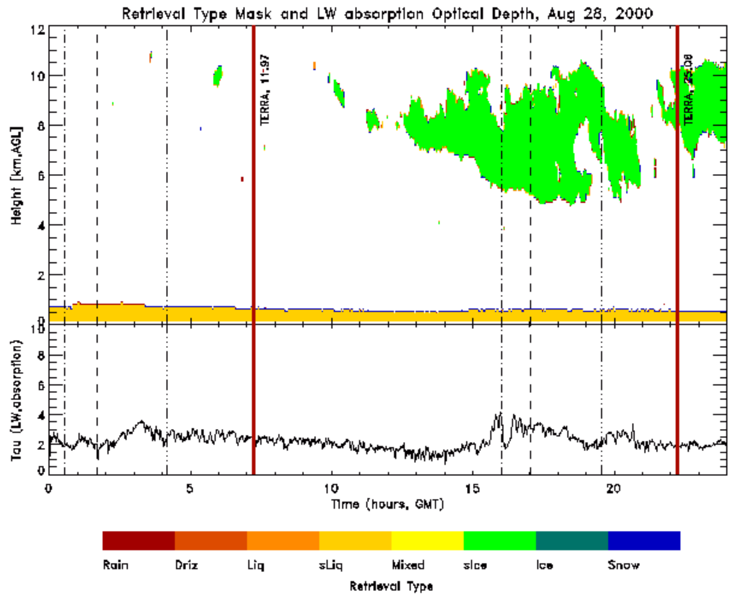

Figure 3 Cloud classification mask for August 18, 2000

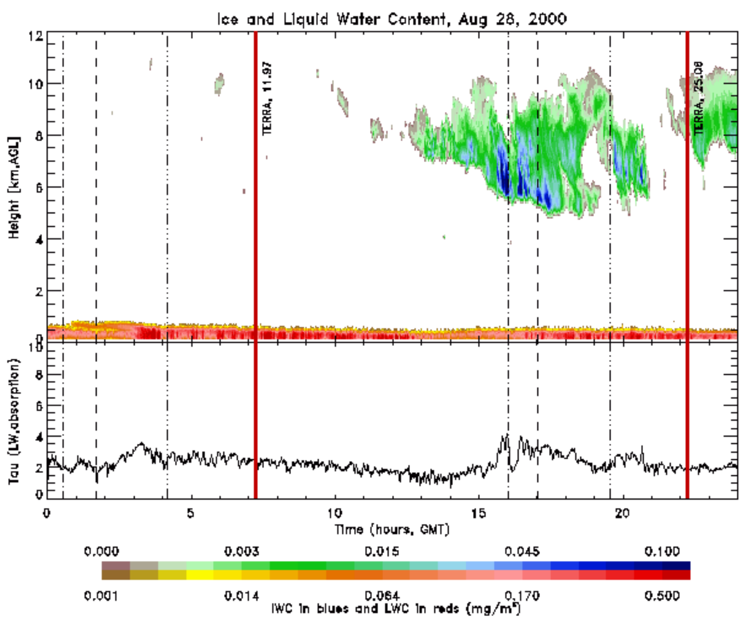

Figure 2 Water contents for liquid cloud (below) and ice cloud (above)

Based on the TERRA overpass times, the data are being partitioned into lists for "all-ice", "all-liquid", and "single layer" overpasses. An overpass is classified based on the characteristics of a two-hour window around the overpass time. For instance, in the example shown in Figure 2, the first TERRA overpass near 7:00 GMT would be classified as both single layer and all-liquid. The second, more complex and multi-layered overpass would not fall into any of the special categories which are designed to facilitate cloud comparisons with TERRA data from CERES, MODIS and MISR.

Resulting from discussions with the MODIS and CERES teams, it is likely that additional categories will be added including "clear" categories based on surface-retrieved optical depth thresholds to further facilitate ground-surface cloud comparisons. Improving calculations of optical depth from the radar-radiometer surface data is a major issue described in the 5th year work plan, especially for mixed phase clouds.

(2) We will develop an web site at NOAA/ETL which not only will provide access to the NSA retrieved data sets, but will also serve as an integrated front door to Arctic research activities at NOAA/ETL linking MTPE objectives to the NASA/FIRE-ACE program and the NSF/ SHEBA and SEARCH programs.

A web site can be viewed at http://www.etl.noaa.gov/arctic . The data for the North Slope of Alaska site is found as one of the links under "Data Sites". This page also describes complementary NOAA/ETL Arctic cloud programs such as the NASA Fire/Arctic Clouds (ACE) Experiment, the Surface Heat and Budget of the Arctic (SHEBA) program, and the International Satellite Cloud Climatology Project (ISCCP). This website presently shows images of cloud retrievals for the North Slope of Alaska ARM site, the SHEBA ice camp, and a comprehensive inventory of surface data for the FIRE-ACE program during aircraft overflight times. Publications with lead-authors from the NOAA/ETL Arctic Research Group are posted at this site. Periodic notifications are sent to members of the Arctic cloud research community research including CERES and MODIS science team members, DOE/ARM, the SHEBA science team and the GCSS Polar Working Group to inform them of latest developments.

It is planned that this site will be continue to be updated and expanded and will eventually include access to netCDF files and ASCII files of cloud properties for those researchers needing more quantitative data than can be provided by the images alone. Plans also include posting of project reports, latest scientific developments and increased focus on how various activities are integrated to address the issues of Arctic clouds and impacts on the Earth's radiation budget.

(3) A substantial effort will be made to initiate comparisons between the surface based radar data sets and the retrieved cloud products produced by the MODIS and CERES science teams. Comparisons will also be made between cloud fraction, cloud optical depth, and cloud top height/pressure/temperature to a number of existing satellite-based detection algorithms including CASPR, TOVS, and the AVHRR-based methods utilized by Patrick Minnis at NASA Langley. ISCCP data sets will be used to put the NSA data sets in climatological perspective.

There has been no significant progress in actual comparisons of the retrieved Arctic cloud data sets to satellite retrievals, largely due to delays in satellite cloud products from TERRA over the Barrow, Alaska site and unanticipated delays with processing of the surface data sets. This item will be a major objective of year 5 work. These comparisons will be greatly facilitated by the preliminary work in creating the partitioned data sets into specific cloud classes as described in element (2) above.

In addition, the NOAA/ETL Arctic research group has acquired a NRC post doc (Paquita Zuidema) who is conducting comparisons between the surface-based cloud retrievals and MISR data sets. Some results from

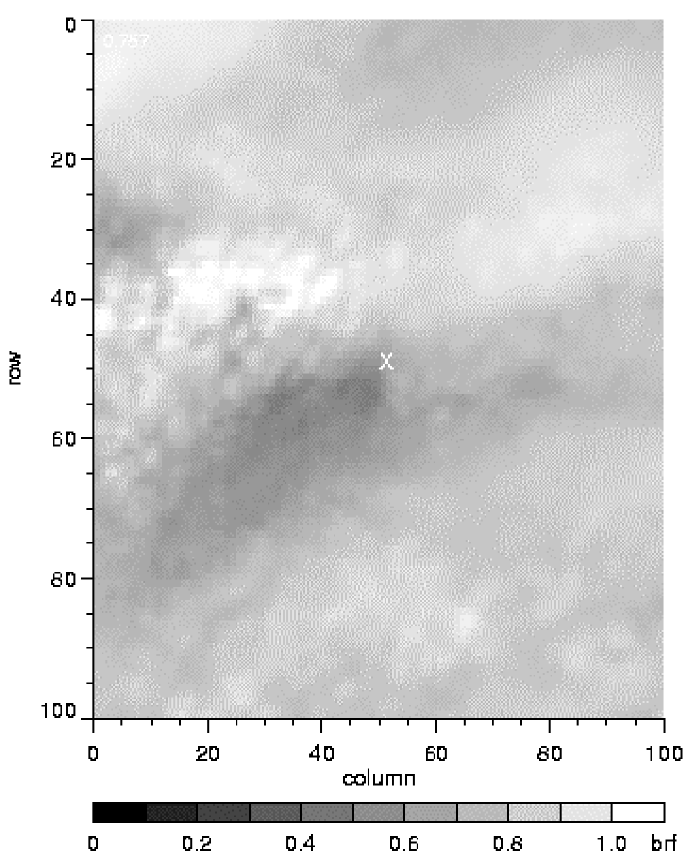

Figure 4 MISR reflectances

this analysis are for the DOE Southern Great Plains site are shown in Figure 4-6. Figure 4 shows MISR reflectances, Figure 5 shows MISR derived cloud heights, with values mostly in the range of 4.0 km in the scene with occasional indication of higher level cloudiness at 8-10 km. Figure 6 shows cloud boundaries from the ground-based MMCR which indicates actual cloud layers between 0 and 2 km, with tops increasing to about 4 km, and a cirrus layer between 6-8 km AGL. This is a complicated cloud scene, and suggests that the MISR retrieval may be blending the reflectances from the low level boundary layer cloud, and the upper level cirrus to retrieve virtual mid-level cloud layer with hybridized properties of the upper and lower level.

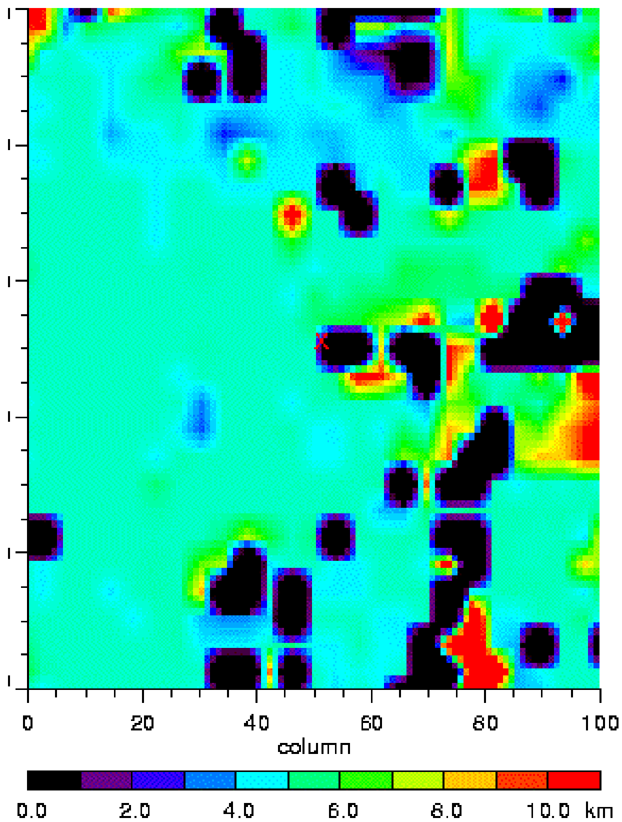

Figure 5 MISR derived cloud heights

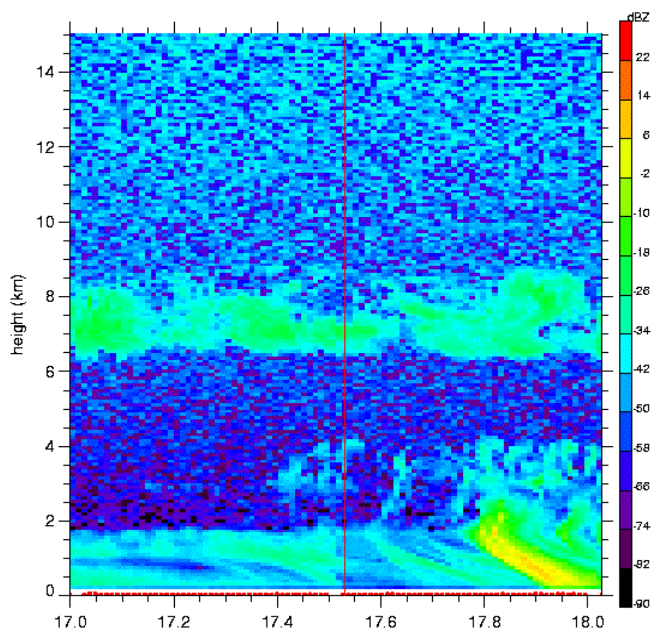

Figure 6 Radar cloud boundaries with MISR overpass time indicated in red.

These kinds of comparisons will be greatly expanded to include the Arctic cloud data sets. These comparisons will provide the basis to evaluate with the CERES, MISR and MODIS cloud retrievals perform reliably for a number of cloud types and cloud scenes.

(4) Using profiles of cloud microphysical properties from the radar-radiometer retrievals, we will perform preliminary radiative transfer calculations with a combination of the CSU/GCM radiation code and a STREAMER type code to assess the radiative importance of Arctic clouds. This activity will be focused on determining the impact of the complex layering and mix of liquid and ice clouds which are frequent in the Arctic. It is intended that this work will provide guidance on which areas of the complex mixed-phase problem will require the most emphasis.

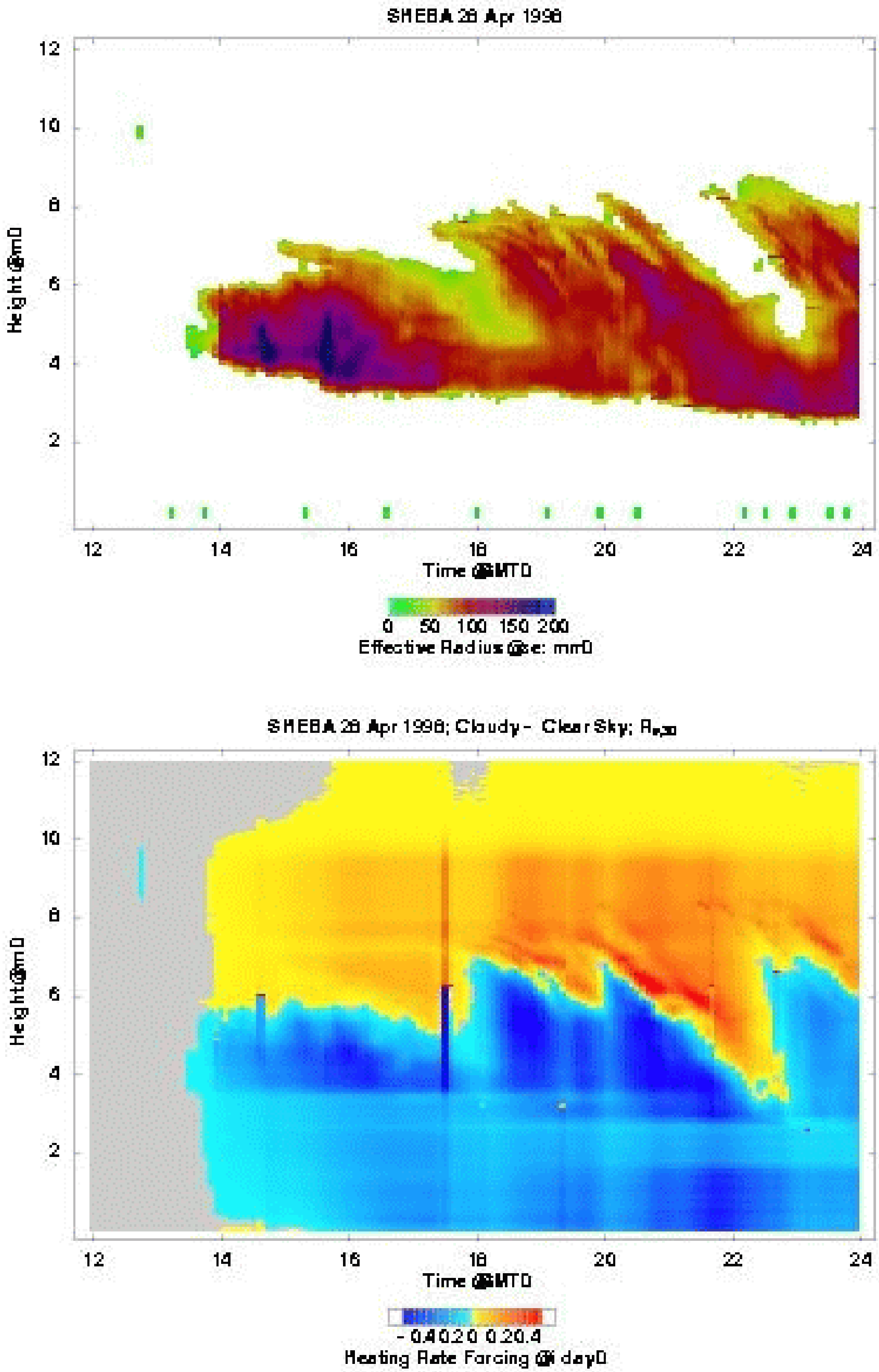

Figure 7 Radar-radiometer derived cloud particles sizes, and resulting time-heigh calculations of cloud forcing using the CSU BUGS/RAD model.

The CSU-GCM radiative transfer scheme (BUGSRad), has been applied to several Arctic cloud cases from SHEBA ice camp cases, with microphysics specified by the radar-radiometer retrievals and the thermodynamic state of the atmosphere was interpolated from radiosondes. The surface albedos were determined from the surface measurements. An example is presented in Figure 7, which shows the ice water contents and net heating rate forcing (all-sky - clear-sky) for a 12 hour period on April 28, 1998. This methodology will be applied to DOE/North Slope of Alaska data sets for TERRA overpass times to determine radiative impacts of different cloud types, as well as to compare to surface measurements and calculations of TOA fluxes to satellite TOA fluxes.

Summary

Radar and radiometer data from the North Slope of Alaska DOE/ARM CART site is being automatically ingested on a weekly basis at NOAA/ETL, and subjective retrievals using a GUI tool that incorporates a suite of sophisticated retrieval routines are being applied to develop a long-term sophisticated data set of Arctic cloud properties. These data sets are being partitioned into "satellite-friendly" subsets on the basis of TERRA overpass times including "ice-only", "liquid-only". These data are being incorporated into a number of cloud-radiation science studies involving observed cloud statistics and modeling studies. It is expected that these data sets will now be in optimum shape to facilitate comparisons with satellite retrievals of cloud properties from MISR, MODIS and CERES. These vertically resolved data sets will be particularly useful in assessing what part of a cloud the satellite is most sensitive for a variety of cloud types and combinations of cloud types. It is anticipated that the cloud comparisons will be quite sensitive to averaging periods for the surface data sets which may need to be varied as a function of height in the atmosphere.

The following publication list shows some results. Note that many of these publications were listed in last years progress report as submitted, and now have full references.

Matrosov, S.Y., Alexie V. Korolev, A.J. Heymsfield, "Profiling cloud ice mass and particle characteristic size from Doppler radar measurements", J. of Atmos. and Ocean. Tech., (accepted).

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Hobbs, P.V. ; A. L. Rangno, M. D. Shupe, and T. Uttal. Airborne studies of cloud structures over the Arctic Ocean and comparisons with retrievals from ship-based remote sensing measurements. J. Geophys. Res. 106 , 15,029-15,044, 2001.

Pinto, J. O., J.A. Curry, and J.M. Intrieri, Cloud-aerosol interactions during autumn over Beaufort Sea, J. Geophys. Res., 106, 15,077-15,098, 2001.

Khvorostyanov, V. I. ; J.A. Curry, J.O. Pinto, M.D. Shupe, B.A. Baker, and K. Sassen, Modeling with explicit spectral water and ice microphysics of a two-layer cloud system of altostratus and cirrus observed during the FIRE Arctic Clouds Experiment, J. Geophys. Res., 106, 15,099-15,112, 2001.

Minnis, P., D. R. Doelling, V. Chakrapani, D. C. Spangenberg, L. Nguyen, R. Palikonda, T. Uttal, R. F. Arduini and M.D. Shupe, Cloud coverage and height during FIRE ACE derived from AVHRR data, J. Geophys. Res., 106, 15,215-15,232, 2001.

Uttal T. and 26 co-authors, 2001: The Surface Heat Budget of the Arctic Ocean (SHEBA), *Bull. Amer. Meteor. Soc.,* 2001*,* (accepted*).*

Key, J.R., and J.M. Intrieri, 2001: Cloud particle phase determination with the AVHRR. *J. Appl. Meteor*., vol. 39, 1797-1804.

Schweiger, A., R. Lindsay, J. Francis, J. Key, J. Intrieri, M. Shupe, 2000: Validation of TOVS Path-P data during SHEBA. *J. Geophys. Res*. (In press).

Intrieri, J.M., M. Shupe, B.J. McCarty, T. Uttal, 2000:Annual Cycle of Arctic Cloud Geometry and Phase from Radar and lidar at SHEBA *J. Geophys. Res*. (submitted).

Intrieri, J.M., C.F. Fairall, O.G.P. Persson, M.D. Shupe, E.L Andreas, and R.M. Moritz, 2000: Annual cycle of cloud forcing over the Arctic. *J. Geophys. Res*. (submitted).