10.6 EVALUATING MODEL PARAMETERIZATIONS OF ARCTIC PROCESSES

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1. INTRODUCTION

An understanding of the arctic climate system has become a high priority research area because of its importance to global climate change (IPCC 1990). Unfortunately, our studies of this region are in its infancy and we lack a broad knowledge of the Arctic. This is due to the scarcity of observations and difficulties in remotely sensing arctic clouds from satellites (Curry et al. 2000).

Of fundamental importance is a better understanding and more accurate simulations of cloud and radiation processes over the Arctic. A complex combination of drastic seasonal changes, complicated cloud microphysics, turbulent transport, and frequent boundary layer inversions have presented many challenges in developing model parameterizations for these regions (Curry et al. 1996).

To combat this lack of knowledge of the arctic climate system, the United States Department of Energy's Atmospheric Radiation Measurement Program (ARM) has arranged a relatively dense concentration of instruments at the North Slope of Alaska (NSA). The primary purpose of this long-term monitoring site is to improve parameterizations of cloud and radiation processes in models. A desire to improve understanding of (e.g. Curry 1986, Curry et al. 1996, Harrington et al. 1999, Harrington and Olsson 2001b) and create better model parameterizations for arctic cloud processes are of primary scientific research interest in the meteorological community (e.g. Harrington and Olsson 2001a, Doran et al. 2002, Girard and Blanchet 2001).

Arctic clouds play a potentially important role in both the arctic and global climate system. Large seasonal and spatial cloud coverage in the Arctic creates a large impact on the radiation budget of the arctic climate system. For example, cloud/radiation feedback is associated with snow/ice albedo feedback thereby providing a significant positive feedback on global climate change (Curry et al. 1996). Arctic clouds also are linked to changes in the arctic hydrological cycle and the thermohaline circulation (Nakamura 1996).

This need to understand arctic clouds is the prime motivation for the comparison of ARM NSA cloud observations with numerical model results presented in this study. We first provide a description of the data used for the comparison and then describe the methods used in the analysis. Then, we will provide a description of our current results and offer conclusion as well as our future plans for research.

2. DATA

The data used for this study are generated from observations at the Atmospheric Radiation Measurement (ARM) North Slope of Alaska (NSA) site located at Barrow, Alaska.

2.1 *Model Data*

The Model Output Location Time Series (MOLTS) analysis is made available by the National Centers for Environmental Prediction (NCEP). The information that MOLTS provides is a combination of NCEP's mesoscale numerical weather prediction model (NWP) and its associated four-dimensional data assimilation system (EDAS). The NWP, also known as the Early Eta Model (ETA), generates forecasts out to 36 hours from initial states at 00Z and 12Z. The EDAS produces a series of eight 3-hour analyses during each 24 hour period, employing a vast set of observed data (Rogers et al. 1995). MOLTS produces hourly output for various surface and sounding parameters from both ETA and EDAS. Because MOLTS is, in essence, assimilated observational data combined with model parameterizations, the MOLTS output represents perhaps the most accurate cloud cover and thermal structure possible by the ETA model parameterizations. Hence, a comparison with MOLTS should indicate where the ETA model parameterizations are working well and where they are failing over the Arctic.

2.2 Sounding Data

The National Weather Service (NWS) maintains consistent sounding measurements at

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NSA with daily deployments at 00Z and 12Z. Because of this consistency, we use NWS radiosondes for comparison with MOLTS. In the future, we plan to incorporate ARM radiosondes as these produce more accurate measures of atmospheric moisture content at low temperatures than do the NWS radiosondes.

2.3 Cloud Data

In order to assess how well MOLTS, and therefore ETA, represent Arctic cloud cover, we compare the model fields with cloud fraction derived from the Active Remotely-Sensed Clouds (ARSCL) product produced by ARM. ARSCL combines data from active remote sensors to produce an objective determination of cloud location, radar reflectivity, vertical velocity, and Doppler spectral width (Clothiaux et al. 2000). Unfortunately, ARSCL data during the summer months is sparse and sometimes entirely absent, though this is usually the time of year when models compare best with observations.

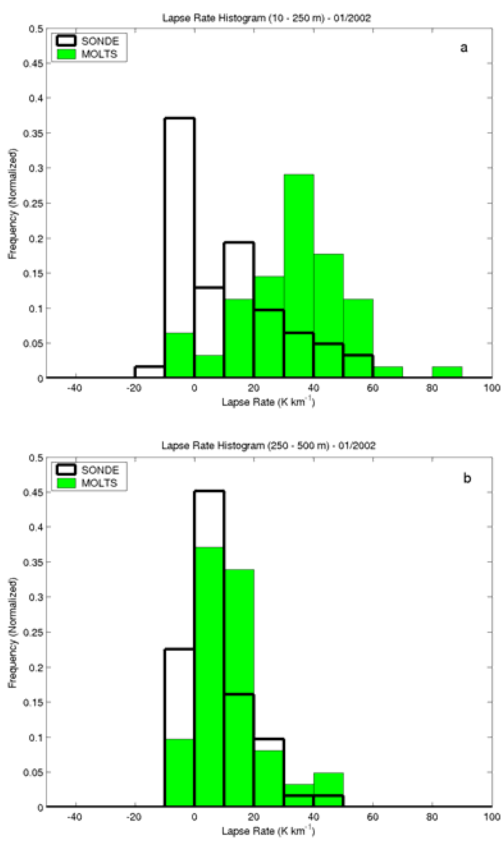

Figure 1. Lapse-rate histogram comparing SONDE and MOLTS for 10 – 250 m (a) and 250 – 500 m (b).

3. METHODOLOGY

Our preliminary analysis of model output with observational data involves two separate components. We first compare MOLTS output to NWS radiosondes (SONDE) measurements. Then, we will look at how MOLTS cloud fraction data compares with cloud fraction derived from ARSCL.

3.1 Atmospheric Variable Comparison

We first examine how MOLTS performs when analyzing atmospheric variables such as temperature. Temperature is an appropriate variable to study since radiosondes usually produce reliable output for this variable. Furthermore, the arctic surface inversion is typically very steep, making it more difficult for models to capture. These observations are measured at 00Z and 12Z everyday whereas MOLTS provides data on an hourly basis. Therefore, for our comparisons, we have extracted the 00Z and 12Z data from MOLTS to produce a direct comparison between the two products. The data for each product was then interpolated to constant height surfaces.

3.2 Cloud Fraction Comparison

MOLTS provides a direct measurement of cloud fraction on an hourly basis which allows for direct comparison with ARSCL since the necessary ARSCL data can easily be converted into a cloud fraction. This conversion was done with measurements obtained by a laser ceilometer (CEIL) and a micropulse lidar (MPL). ARSCL uses data from these instruments to classify a return signal and then assigns each return with a clutter flag (Clothiaux et al. 2000). The different clutter flags along with their definitions are given in Table 1.

TABLE 1. ARSCL clutter flags and their associated definitions.

Clutter Flag	Definition
0	no returns
1	uncontaminated returns
2	partially contaminated returns
3	pure clutter returns
10	bad data

We consider any data that is given a clutter flag of 1 (CF1) or 2 (CF2) to be a hydrometeor return.

Visual inspection of the fields confirms that this is a good measure of cloud fraction. Therefore, we define cloud fraction (in percent) as

$$\text{Cloud Fraction} = \frac{\text{CF1} + \text{CF2}}{\text{CF0} + \text{CF1} + \text{CF2}} \times 100\% .$$

In order to compare the cloud fraction from MOLTS and ARSCL, we calculated the average cloud fraction for different layers of the atmosphere. For this study, we chose to average over 500 meter height bins.

4. PRELIMINARY RESULTS

Although we have analyzed data for both 2001 and 2002, we will present our results using one month of data because most of the other months were either missing a large amount of data or the results were similar. Our discussion will make use of the data available for January 2002.

4.1 MOLTS versus SONDE Temperature

To visualize how MOLTS temperature structure compares to SONDE measurements, we calculated the environmental lapse rate for 10 to 250 m and 250 to 500 m for January 2002. Figure 1 shows the histogram of these calculations for both layers. Upon inspection of Figure 1a, we note that MOLTS tends to overestimate the environmental lapse rate in the 0 to 250 m layer, which is a surprising result. In fact, the histogram shows that observed profiles are roughly isothermal in the lower 250 m. MOLTS, on the other hand, produces lapse rates that are frequently of 40 K km^{-1}, which is a very strong inversion. Such excessive inversion strength will lead to significant differences in computer calculated surface energy exchanges. Figure 1b shows that the same effect, though not as great, occurs in the 250 m to 500 m.

We also note that temperature differences in excess of 5 K occur in the surface layer as shown in Figure 2. Such large differences in surface temperatures would significantly impact model computations of surface fluxes.

4.2 MOLTS versus ARSCL Cloud Fraction

The pseudocolor plot shown in Figure 3 represents the cloud fraction as a function of time and height for January 2002. The derived cloud fraction from ARSCL is plotted in Figure 3a and the calculated cloud fraction from MOLTS is plotted in Figure 3b. A general overview of Figure 3 illustrates that ARSCL shows cloud cover from 0 to 5 km throughout the month while MOLTS does not. There is a greater disagreement between the two products as height decreases. ARSCL and MOLTS tend to agree above 5 km.

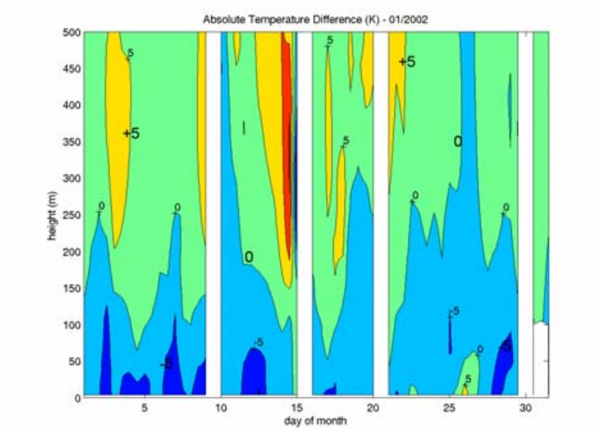

Figure 2. Contour plot of absolute temperature difference for January 2002 between SONDE and MOLTS.

Our comparison of MOLTS versus SONDE in Section 4.1 shows that MOLTS does not resolve temperature in the boundary layer properly and, since temperature strongly alters cloud fraction predictions (e.g. Hannay et al. 2003), one would expect this to be the case for cloud fraction as well. To examine this, we looked at millimeter cloud radar (MMCR) data for the month of January and observed consistent measurements with that of ARSCL. MOLTS therefore significantly underestimates cloud fraction at low levels.

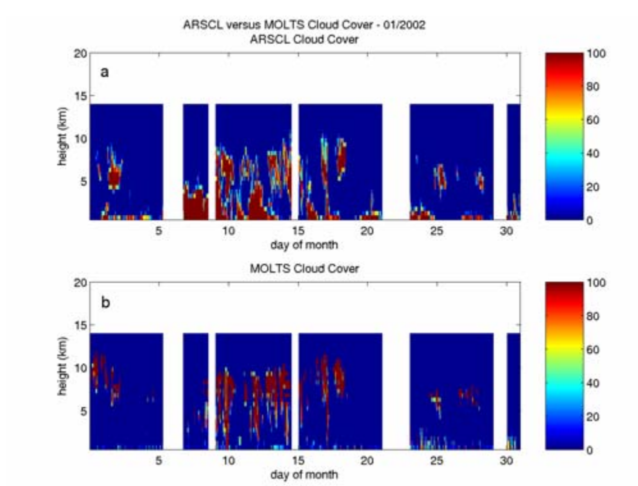

Figure 3. Cloud fraction plot as function of time and height for ARSCL (a) and MOLTS (b) for January 2002.

Since arctic cloud cover is greatest at low levels, we now take a closer look at the 0 to 500 m layer and compare results from ARSCL and MOLTS for the entire month. Figure 3 provides a histogram of cloud fraction for the month of January for both products. Because observations show fairly solid cloud cover over the Arctic, it is perhaps not surprising that ARSCL shows a bimodal result between zero and 100 percent cloud fraction. The values between zero and 100 percent are few and likely represent only edges of clouds. Figure 4 shows MOLTS cloud fraction has significant errors. We also show that MOLTS underestimates cloud fraction at the lower levels showing a clear sky trend throughout the month when there is really a cloudy sky trend.

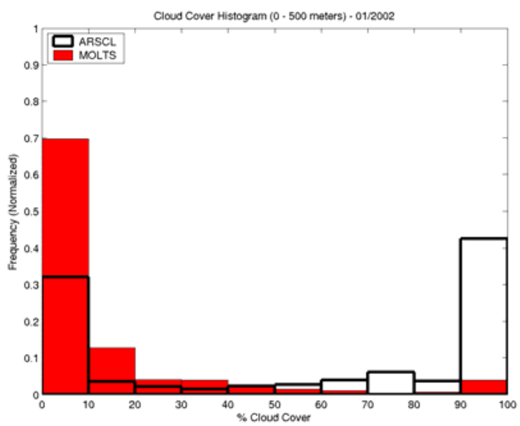

Figure 4. Cloud cover histogram comparing ARSCL and MOLTS for January 2002.

Given that Hannay et al. (2003) showed strong low cloud fraction reductions during anomalously cold episodes for a single column model study, it seems likely that the strong surface cold bias in MOLTS is responsible for the incorrect cloud fraction predictions.

5. CONCLUSION AND FUTURE WORK

We have provided initial results as to how MOLTS, and therefore the ETA model, perform in the Arctic. Temperature and cloud fraction were compared between observations from SONDE and ARSCL, respectively, and numerical calculations from MOLTS. Our analysis has shown discrepancies with the ETA analysis provided by MOLTS, and therefore problems with ETA parameterizations in the Arctic. The greatest discrepancies lie in the boundary layer.

Future analysis will consist of comparisons of surface radiation fields, precipitation, and vertical moisture budgets over NSA. Additionally, we will use the Regional Atmospheric Modeling System (RAMS) (Cotton et al. 2002) for detailed studies of cloud systems and their parameterizations over the Arctic.

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