P 1.9 SINGLE-COLUMN MODEL SIMULATIONS OF ARCTIC CLOUDINESS AND SURFACE RADIATIVE FLUXES DURING THE SURFACE HEAT BUDGET OF ARCTIC (SHEBA) EXPERIMENT

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1. INTRODUCTION

Clouds affect the arctic atmosphere and surface energy budget through their interactions with longwave and shortwave radiation. Typical General Circulation Models (GCMs) fail to predict realistic cloud amounts over the Arctic Ocean and this is critical for accurate predictions of Arctic climate changes (Walsh *et al.,* 1998; Chen *et al.*, 1995).

Single-column models (SCMs) with prescribed large-scale forcing are commonly used for testing parameterizations developed for GCMs (Randall *et al.*, 1996). In particular, SCMs have been used for testing cloud parameterizations over the Arctic (Beesley *et al.*, 1999, 2000; Pinto *et al.*, 1999)

We are presenting SCM simulations of arctic cloudiness and surface radiative fluxes during the Surface heat budget of arctic (SHEBA) experiment. Typical winter and summer regimes have been integrated with the SCM. Sensitivity studies to the cloud parameterization have been performed.

2. MODEL DESCRIPTION

The SCM is the single-column version of the National Center for Atmospheric Research (NCAR) Community Climate Model (Hack *et al.*, 1999). It contains the full set of parameterizations of subgrid physical processes that are found in the standard CCM3 package (Kiehl *et al.*, 1996).

2.1. Cloud parameterization

The cloud amount and the associated optical properties are evaluated via a diagnostic method that follows schemes developed by Slingo (1987, 1989).

The diagnosis of cloud fraction depends on relative humidity, vertical velocity, atmospheric stability and the convective mass flux associated with parameterization of moist convection. Three types of clouds are diagnosed by the scheme: convective (C1), layered (C2) and stratus associated low-level inversions of temperature and moisture (C3).

The cloud optical properties are calculated using the cloud liquid water path and the cloud effective radius. Over the ocean, the liquid effective radius is set to 10 μm and the ice effective radius varies between 10 μm and 30 μm as a function of elevation. The clouds are in liquid phase above –10C, in ice phase below –30C, and in mixed phase between these temperatures, with the fraction of ice depending linearly on the temperature.

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2.2. Model initialization, forcing and evaluation

Observational data and reanalysis from the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment are used for initializing, forcing and evaluating the SCM simulations (Beesley *et al.*, 2000; Bretherton *et al.*, 2000; Intrieri *et al.*, 2001).

We explored different methods for prescribing advective tendencies as described in Randall *et al.*, (1999): revealed forcing, horizontal advective forcing and relaxation of T and q to the observations. Surface conditions (i.e. surface temperature, latent and sensible heat fluxes) were both computed by the SCM or prescribed from the ECWMF reanalysis.

3. SIMULATIONS OF SUMMER AND WINTER STANDARD REGIMES

Standard simulations of the winter and summer regimes have been conducted using the standard CCM3 package. January and July have been chosen as typical months of the winter and summer regimes respectively. In our discussion, the different forcing are denoted in the following way: revealed forcing (3D), horizontal forcing (2D), relaxation forcing (relax) and prescribed ECWMF reanalysis surface properties (sfc).

3.1. Profiles of temperature and moisture

The temperature and moisture profiles are shown in Figure 1 and Figure 2. For the winter regime, the model encounters difficulties reproducing the temperature and moisture inversions below 900 mb This has an influence on the type of low-level clouds produced by the model and on the cloud fraction. Above 800 mb, the winter temperature and moisture bias are fairly small. During summer, the model overestimates the temperature and the moisture with a small error under 900 mb and larger error above. However, the lapse rate is fairly well reproduced.

Surprisingly, the revealed forcing produces less accurate temperature and moisture profiles than the horizontal forcing. Prescribing the surface properties has little effect on the thermodynamic profiles.

3.2. Cloud and surface radiative fluxes

Figure 3 shows the monthly averages of cloud fraction and net longwave fluxes at the surface during winter and summer. In winter, the predicted cloud cover is too low when the relaxation term is used while it is too large for the other forcing types. This difference between the relaxed experiment and the others may be correlated to the bias of the temperature and moisture inversion profiles. The

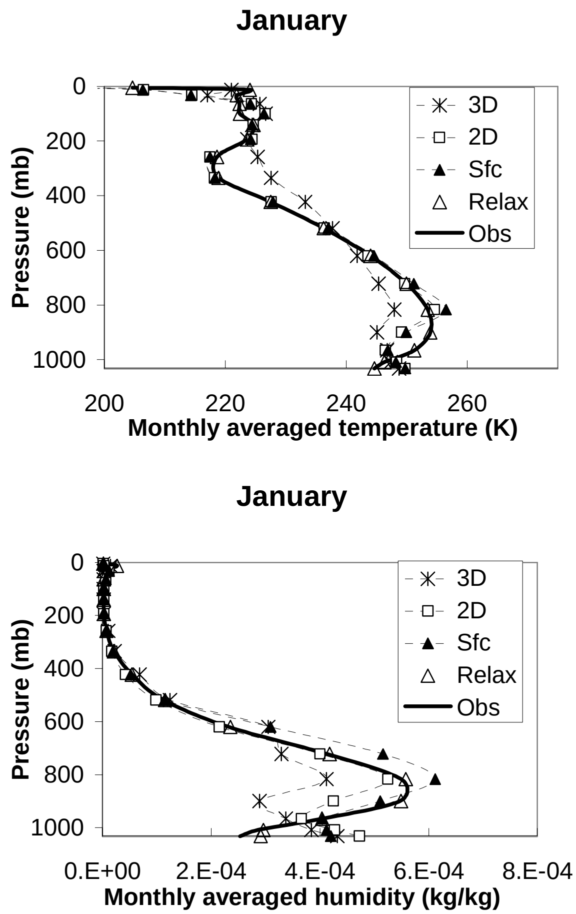

Figure 1: Monthly averages of temperature and humidity profiles during winter.

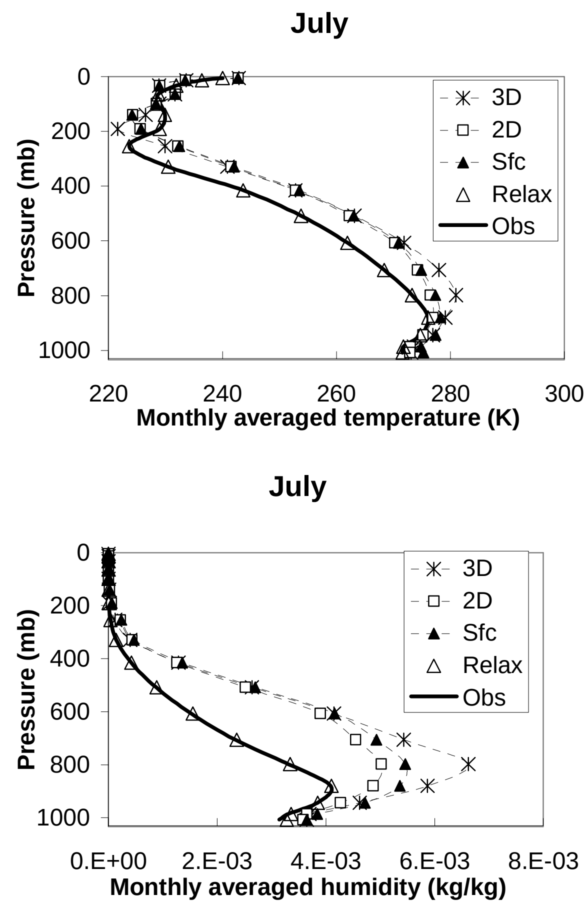

Figure 2: Monthly averages of temperature and moisture profiles during summer.

model produces C3 type clouds less often when the relaxation term is used than with other types of forcing. This may influence the cloud fraction amount.

The net longwave radiative flux depends on the cloud fraction. Clouds absorb longwave radiation and reduce the net longwave radiative flux by decreasing the longwave flux returning directly back to the space. We may expect that an overestimation of the cloud cover yields unrealistically small values of the net surface longwave radiative fluxes and vice-versa. In winter, this appears to be the case. In summer, it is only the case for the relaxed simulation.

4. SENSITIVITY TO CLOUD PARAMETERIZATION

Several simulations have been conducted to determine the issues of the cloud parameterization for the Arctic. Each simulation is identical to the standard runs except for the changes made to the particular parameter, which is being tested.

In a first set of experiments, we have tested the standard parameterization of the cloud amount over the Arctic by evaluating the influence of convective clouds (C1) and stratus associated to low-level inversions (C3). In a second set of cloud sensitivity runs, we have evaluated the impact of the cloud microphysics itself i.e. the fraction of ice amount and the effective radius of ice droplets.

4.1. Influence of cloud amount diagnostic

The convective clouds are usually considered not very important over the Arctic. Moreover, the parameterization of clouds associated with low-level inversions is especially suited for subtropical latitudes. We looked at the influence of these types of clouds with simulations where they are set to zero.

Figure 4 shows the monthly averages of cloud fraction and net longwave fluxes where the surface fields are prescribed and the horizontal advective forcing is used. The simulations are denoted as follows: standard simulation (Sdt), simulation with no C1 type clouds (C1 off) and simulation with C3 type clouds turned off (C3 off). When the convection is turning off, the cloud fraction and surface fluxes are nearly identical to the standard runs indicating that convection is negligible. Turning off the clouds associated with low-level inversions results in increased cloudiness. The effect is larger in winter when the model was diagnosing this type of clouds more often.

4.2. Influence of the cloud microphysics

The microphysical properties of clouds strongly influence their radiative properties. Factors such as hydrometeor size and distribution of water in the cloud determine how clouds affect radiative heating profiles in the atmosphere (Curry *et al.*, 1992).

By default, the SCM sets the effective radius of ice droplets between 10 μm and 30 μm. Shupe *et al.*, (2001) found that during April-July time period during SHEBA experiment, the ice effective ranges from 7 to 300 μm with a mean value of 60 μm. The SCM underestimates the ice effective radius and therefore may overestimate the net longwave flux. This appears to be the case in standard simulations (Figure 3).

The impact of ice effective radius during winter is shown in Figure 5. In these simulations, the effective radius is set successively to 40, 100, 200 μm to 300 μm. An ice effective of 80 μm reproduces the observed net longwave flux. During summer, the ice effective radius has little impact as clouds are fairly in liquid phase.

As explained above, the model initiates ice clouds below –10C and turns off the liquid phase below –30C. Lidar and radar observations have shown that during SHEBA experiment Arctic clouds may contain ice at temperatures above –10C and supercooled water may be present up to –34C (Intrieri *et al.*, 2001, Bretherton *et al.*, 2000). We have performed simulations using the fraction of liquid taken from the observations instead of the original parameterization (see Figure 6). We have found the impact of using the fraction of liquid taken from the observations has minor impact on the simulations.

5. CONCLUSIONS

We have investigated SCM simulations of Arctic cloudiness and surface radiative fluxes during the SHEBA experiment and performed sensitivity studies to examine the model cloud parameterization. Our results suggest that reproducing the thermodynamics inversions is important for the cloud parameterization; increasing ice effective radius improves the net radiative fluxes; and prescribing the ice fraction in cloud water from the observation has minimal impact. The next step in our study is to examine daily values of cloud fraction and radiative surface fluxes in order to better understand the model results.

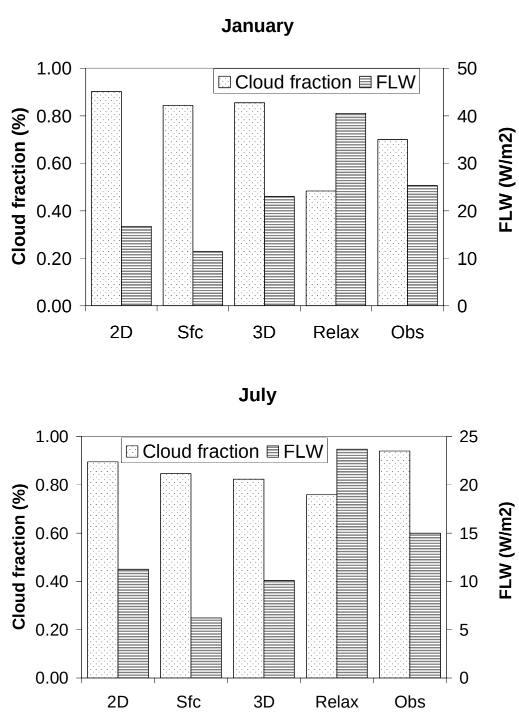

Figure 3: Monthly averaged cloudiness and longwave fluxes at the surface.

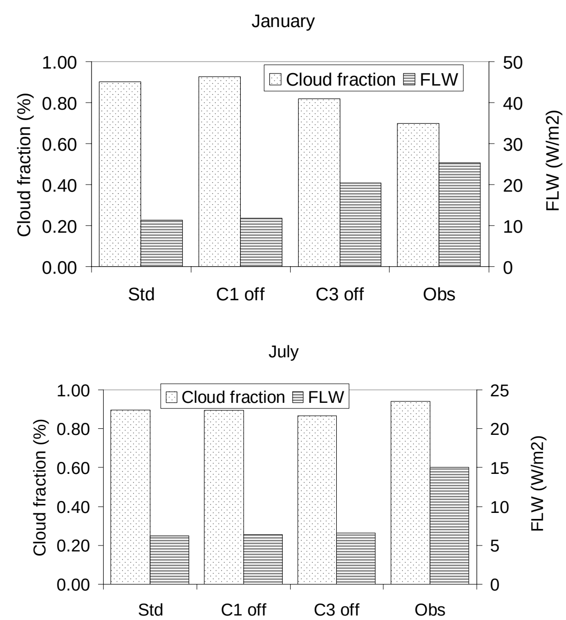

Figure 4: Influence of cloud amount diagnostic

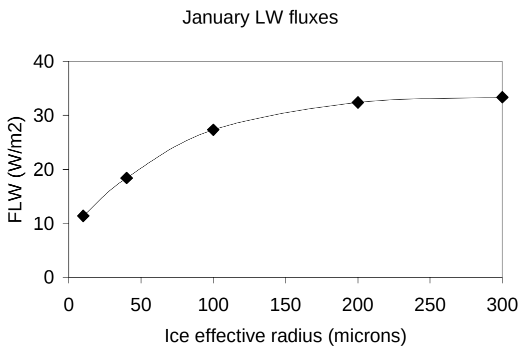

Figure 5: Influence of ice effective radius

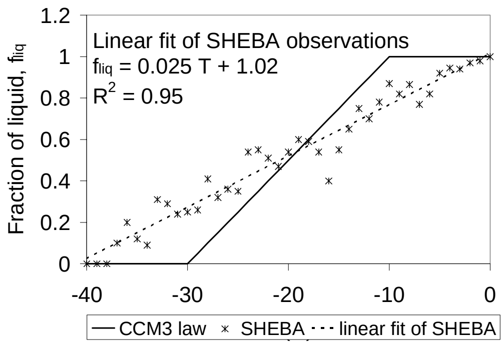

Figure 6: Temperature dependence of liquid fraction. SHEBA observations are taken from Bretherton et al., 2000.

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