6.5 EVALUATION OF AGCM RADIATION PARAMETERIZATIONS IN THE ARCTIC

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1. INTRODUCTION

The net surface radiation flux is arguably the most important component of the Arctic energy budget. Some studies have shown that there are significant discrepancies between observed radiative fluxes in the Arctic region and those simulated by the commonly used radiative transfer models which are used in atmospheric general circulation model (ACGM) parameterizations (Pinto et al. 1997).

Data collected during the Surface Heat Budget of the Arctic (SHEBA; Perovich et al. 1999; Uttal et al. 2002) field experiment are used to evaluate the performance of several commonly used shortwave and longwave codes in AGCM parameterizations. Several aspects of the models, such as the radiative transfer scheme, the surface albedo characterization, and the parameterized cloud and aerosol optical properties, are examined. Broadband and spectral radiative fluxes observed at two surface locations and retrieved at the top of the atmosphere are used to evaluate the codes under a variety of cases, including several clear sky cases, one liquid cloud case, and one ice cloud case. The sensitivity of the simulated fluxes to systematic variations in the input of observed meteorological information, as well as cloud and aerosol properties, surface albedo, and precipitable water vapor, is explored.

2. SHEBA DATA AND MODEL USAGE

The SHEBA program revolved around a year-long experiment that took place on a drifting station in the Arctic icepack, running from October of 1997 to October of 1998. During this year, the program collected various meteorological and climatological data from various instruments on the ice. Land-based observations were also combined with satellite and other remote sensing techniques to provide a detailed picture of the entire Arctic air-sea-ice interaction system.

While the actual field experiment concluded in 1998, the SHEBA project continues in Phase III, which is dedicated to analyzing all of the data collected in various ways, including incorporation of data into GCMs. The data utilized in this particular paper are the radiative fluxes recorded during the SHEBA project, combined with other atmospheric measurements needed to incorporate into the commonly used radiative transfer models, including surface albedo, aerosol optical depth and radiosonde observations of pressure, temperature, water vapor content, and ozone content.

Several radiative transfer models are evaluated for their performance on simulating the actual fluxes measured during the SHEBA field experiment. These include Streamer (Key 2001), the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) model (Ricchiazzi et al. 1998), Atmospheric and Environmental Research's Rapid Radiative Transfer Model (AER-RRTM; Mlawer et al. 1997), Sunray (EC3/CCC; Fouquart and Bonnel 1980; Morcrette and Fouquart 1985), the NCAR Column Radiation Model (CRM) as part of their Community Climate Model (CCM; Ramanathan and Downey 1986; Briegleb 1992; Acker et al. 1996), BugsRad (Stephens et al. 2001), and the UCLA/Harshvardan model (Harshvardan et al. 1987). These models are all commonly used to simulate

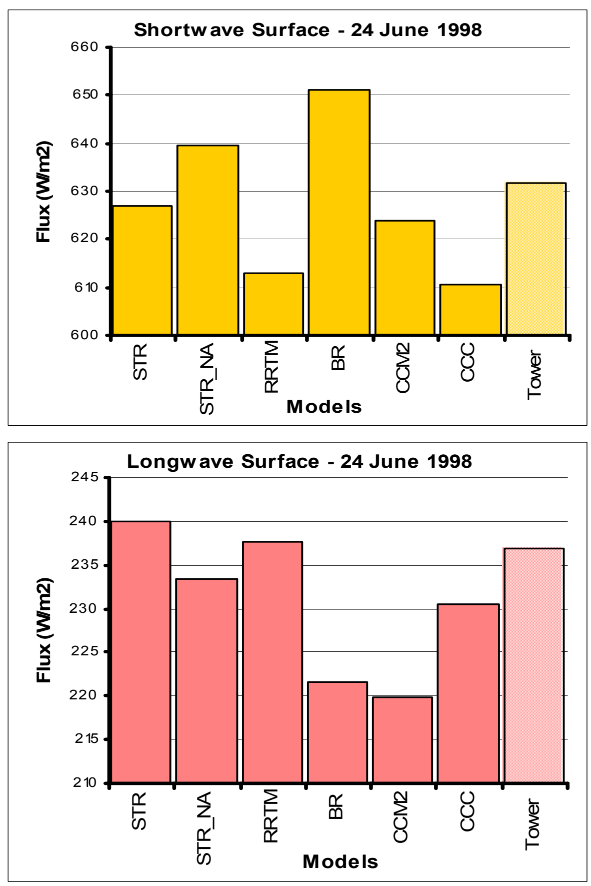

Figure 1: Radiative flux at the surface on 24 June 1998. Note the darker color bars are model output, and the lighter bar is observational data. Note that STR = Streamer (NA = No Aerosols), BR = BugsRad, all other abbreviations mentioned above.

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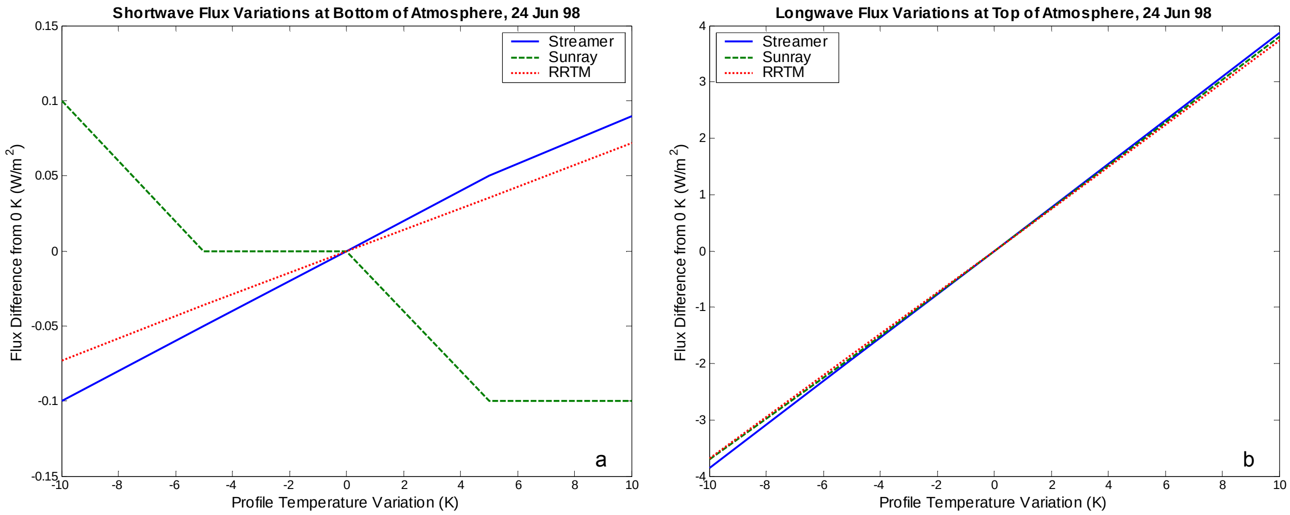

Figure 2: The effects of varying temperatures throughout a column of measurements on radiative flux. The graphs show difference in flux from the calculated flux at the measured temperatures (0 K variation). Panel (a) depicts the shortwave flux incident at the bottom of the atmosphere, while (b) depicts the longwave flux leaving the top of the atmosphere.

radiative transfer either as stand-alone models or as parameterizations in AGCMs, and so studying each model's capability when dealing with Arctic data is a key component to understanding how well AGCMs will predict Arctic weather and climate. A sample of some model output from 24 June 1998, along with observational data, is depicted in Figure 1.

The primary focus of this manuscript is an exploration of the sensitivities of the various models to slight biases in the input atmospheric profiles of temperature and water vapor, and to changes in the input surface albedo.

3. TEMPERATURE VARIATIONS

The first analysis was performed on the temperatures throughout the entire atmospheric profile. In order to assess how sensitive the models are to temperature variations, the input profiles for the various days studied were varied by up to ±10 K at each level in the profile, which would be considered a "worst case scenario." The results of these tests on several of the models for data from 24 June 1998 are shown in Figure 2a for the shortwave and 2b for the longwave.

In the shortwave portion of the spectrum, RRTM had the smallest variation in downwelling flux, of approximately 0.15 W/m^2 over the total temperature variation of 20 K. For Streamer, the variation in flux was only about 0.2 W/m^2 over a temperature change of 20 K. Sunray demonstrated comparable sensitivity to Streamer, except with a negative slope, indicating that the flux decreased slightly with higher temperatures. Also important to note is the line shape, indicating that Sunray only has a resolution of 0.1 W/m^2, preventing more sensitive variations

In the longwave portion, however, all three models performed very similarly. All three models calculated more longwave flux leaving the top of the atmosphere with increased temperature (as would be expected). In the longwave wavelengths, all of the models were between 7 W/m^2 and 8 W/m^2 over the 20 K total temperature variation.

These tests demonstrate that in the shortwave, the Streamer, RRTM, and Sunray models were all rather insensitive to a ±10 K error in column temperatures. In the longwave, all three models showed about the same sensitivity to as much as a ±10 K offset in the temperature profile. All three models had significantly greater sensitivity in the longwave than they did in the shortwave.

4. WATER VAPOR CONTENT VARIATIONS

The second variation analysis was performed on the observed water vapor content throughout the entire atmospheric profile. In order to assess the sensitivity of the models to water vapor, the input profile for each day was varied by up to ±10% in the vapor content throughout the entire profile. The results of these tests for data from 24 June 1998 from several of the models are shown in Figure 3a for the shortwave and 3b for the longwave.

In the shortwave portion of the spectrum, Streamer had the least variation in shortwave radiative flux at the surface caused by as much as a 20% variation in water vapor content, with slightly less than 4 W/m^2 of variation over the entire spread. RRTM and Sunray both had very similar shortwave variations when the water vapor content at each level was varied. Each model had about 5 W/m^2 change in the downwelling shortwave radiation for a total water vapor content variation of 20%.

In the longwave portion of the spectrum, Streamer, RRTM, and Sunray all showed incredibly similar variations in radiative flux over the range of possible water vapor bias, resulting in approximately 2 W/m^2 change in the outgoing longwave radiation for a vapor content variation of 20%.

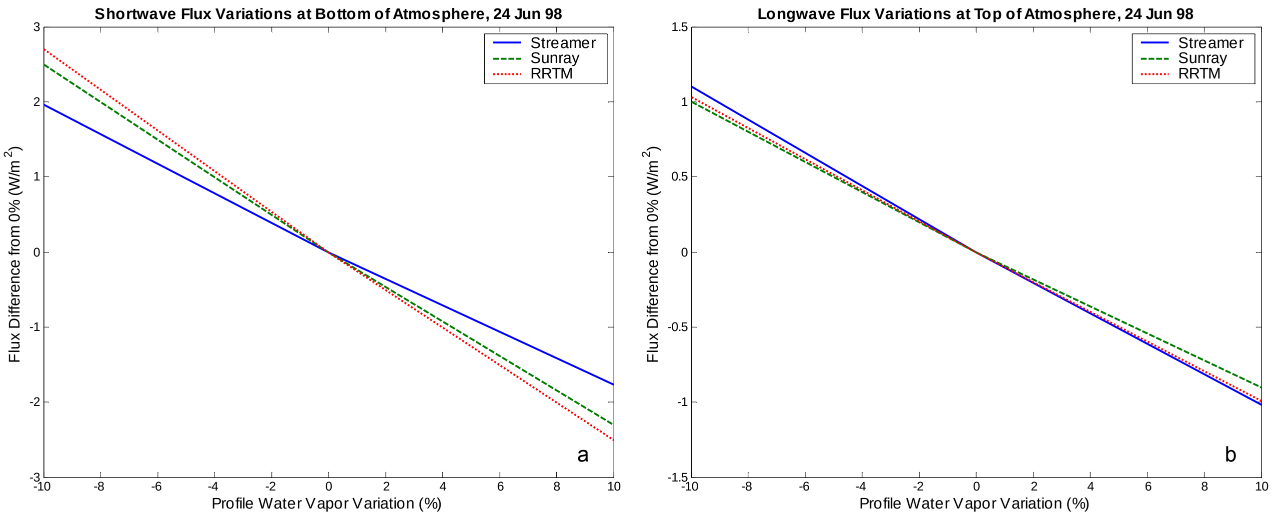

Figure 3: The effects of varying water vapor content throughout a column of measurements on radiative flux. The graphs show difference in flux from the calculated flux at the measured vapor content (0% variation) where (a) depicts the shortwave flux incident at the bottom of the atmosphere, and (b) depicts the longwave flux leaving the top of the atmosphere.

5. SURFACE ALBEDO VARIATIONS

The radiative transfer models were also evaluated in terms of their sensitivity to the input surface albedo. In order to assess the sensitivity of the models to albedo, the albedo value used in the particular model was varied by ±0.1 from the actual value measured on the sample days, and its effects on the downwelling shortwave radiation was examined. The results of these tests on several of the models using data from 24 June 1998 are shown in Figure 4.

The graph illustrates that the variation in shortwave flux at the surface is anywhere between 10 W/m^2 and 20 W/m^2 for a total albedo variation of 0.2. This is a large change in albedo, so a significant change in flux would be expected and is demonstrated. RRTM was the least sensitive to surface albedo variations, falling at around 10 W/m^2. Sunray was slightly more sensitive, having a variation of approximately 11 W/m^2 over the surface albedo change. The Streamer model was moderately more sensitive, with a flux variation of around 16 W/m^2 over the broadband surface albedo change. Finally, the SBDART model was the most sensitive, with approximately 20 W/m^2 difference in flux from one extreme to the other.

6. CONCLUSIONS

Understanding the influence that errors in observational measurements can have on radiative transfer models is key to being able to use the models properly, particularly in a region as sensitive to discrepancies between modeled fluxes and observed fluxes as the Arctic region. Because of this, the trials performed to analyze the model sensitivities to biases in the input atmospheric profiles and surface albedo are important to the success of modeling Arctic radiative transfer.

Using a selection of the radiative transfer models commonly employed in AGCMs, sensitivities to offsets in temperature profiles, water vapor profiles, and surface broadband albedo were tested. For a surface temperature variation of ±10 K, RRTM and Streamer models demonstrated small sensitivities in the shortwave and longwave portions of the spectrum, while the Sunray model didn't have the resolution necessary to demonstrate this as well in the shortwave. However, this lack of resolution is indicative that observational temperature errors should not have any significant impact on the shortwave radiative flux calculated by this and the other models.

For water vapor, the models tested were somewhat more sensitive than they were for temperature. This is to be expected, since the influence of water vapor as a

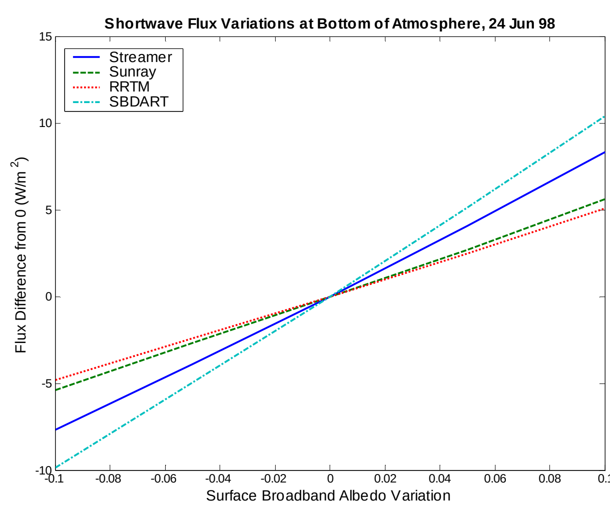

Figure 4: The effects of varying the surface broadband albedo value on radiative flux. The graph shows difference in short-wave flux from the calculated flux at the measured albedo (0 variation) incident at the bottom of the atmosphere.

greenhouse gas would impact radiative flux more than a similar measurement error in temperature. Despite this, all three models performed remarkably well, showing very small sensitivity, even with a 20% range of water vapor content variation.

Surface albedo showed more significant variations in downwelling flux at the surface. A total variation of 0.2 in albedo represents a significant change.

Finally, it is significant to note that the sensitivities of the models to the above factors, that is the variability between output of the various models and the actual observations of radiative flux (illustrated in Figure 1), are of similar magnitude to the difference among the models in output fluxes relative to observations.

7. REFERENCES

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