GEOS 615 (Sea-ice geophysics), Assignment #1:
Shortwave radiation, albedo and summer melting of Arctic multiyear ice: Data vs. model

1. Introduction

In the past decade, significant reductions in summer sea-ice extent have been observed in the Arctic. Large-scale climate models are also predicting substantial reductions in ice extent associated with enhanced warming due to the accelerating release of greenhouse gases into the atmosphere. More detailed analyses, however, indicate that there are distinct seasonal discrepancies between model predictions and observations, with the former predicting ice retreat mostly during winter and the latter indicating summer retreat to be most substantial. Such deviations in predicted and observed behaviour of the climate system can have several origins, such as deficiencies in the model design and architecture, problems with the forcing data that drive the simulations, a fundamental lack of understanding of the physics of these components of the climate system, problems with the remote-sensing data sets that the observations are based on etc. etc.

Some of these issues are touched upon by this assignment and associated problem set, requiring comparisons between the amount of shortwave radiation supplied to the ice surface as determined from field measurements and by a general-circulation model (GCM).

The field data have been collected as part of the Project "Surface Heat Budget of the Arctic Ocean" (SHEBA). More information on the SHEBA project is available on the web at http://sheba.apl.washington.edu/ .
A detailed description of the snow and ice data sets collected at SHEBA can be found at http://data.eol.ucar.edu/codiac_data/sheba/data/perovich/ICEWEB/index.htm .

One of the primary purposes of the SHEBA program was to assemble a data set pertaining to the annual cycle of ocean-ice-atmosphere interaction in the Arctic in order to improve, among other things, the representation of sea ice in GCMs and further understanding of the underlying processes. The current lab focusses on a key component of model validation and the improvement of parameterizations of processes that cannot be explicitly formulated in a large-scale model.

2. Data set

On the web page for this lab you'll find links to the web sites mentioned above. They contain further background information on the SHEBA program, as well as data and in particular graphics that might be helpful in interpreting the data to be analysed here.

The course's lab web page also contains the data set that will be analysed in this lab (both as a plain text and a MS Excel file). The data in the file include the following:
(1) mean and standard deviation of albedo as measured along the SHEBA albedo line (details at http://data.eol.ucar.edu/codiac_data/sheba/data/perovich/ICEWEB/albedos.htm) between May 11 and September 27, 1998
(2) 2 m mean daily air temperatures measured at the SPO Tower (details at http://data.eol.ucar.edu/codiac/dss/id=13.107)
(3) daily average downwelling shortwave irradiative fluxes measured at the SPO tower (see above)
(4) mass balance data (snow melt, ice surface melt, ice bottom melt) as measured at mass balance gauge #128 (Atlanta); details of measurements explained at http://data.eol.ucar.edu/codiac_data/sheba/data/perovich/ICEWEB/mass.htm

3. The problem

In light of what has been stated above, accurate predictions of the amount of shortwave radiation supplied to the Arctic ice and ocean during spring and summer are a key objective of large-scale studies and numerical simulations of the Arctic Ocean region. Of particular importance in this context is the evolution of ice albedo during the course of spring and summer. This assignment addresses two main questions: (1) how well do measurements and GCM parameterization schemes of summer ice albedo compare and how large is the discrepancy in terms of solar heating and melting of ice during summer, and (2) to what an extent do the observed ice ablation patterns (bottom, surface melt) reflect estimates of partioning of shortwave radiation?

4. Analysis

4.1. Two parameterization schemes for ice albedo during spring and summer are those by Manabe et al. (1992) and Weatherly et al. (1998).

GFDL GCM (Manabe et al., 1992):

$$\alpha^* = \begin{cases} \alpha_i & \text{for } T_s \geq T_m \\ \alpha_i + 0.025(T_m - T_s) & \text{for } (T_m - 10) < T_s < T_m \\ \alpha_s & \text{for } T_s \leq (T_m - 10) \end{cases}$$

$$\alpha^* = f(z_i) \quad \text{for } z_i < 1 \text{ m}$$

$$\alpha_i = 0.55, \alpha_s = 0.8$$

The sea-ice albedo α^* is assumed to depend on relative proportions of bare ice albedo α_i and snow-covered ice albedo α_s, parameterized as a function of surface temperature T_s in relation to the surface melting temperature T_m. Here and below assume a surface melting temperature T_m of 0 ˚C and that the surface temperature $T_s = T_{air}(2m)$. The albedo of bare ice thinner than z_i = 1 m, is treated separately, but since all ice found at SHEBA was thicker than 1 m, this is not of importance in the context of this assignment.

NCAR CSM (Weatherly et al., 1998):

$$\alpha^* = f_i\alpha_i + (1 - f_i)\alpha_s$$

$$\alpha_s = \begin{cases} 0.82 & \text{for } T_s < 0^\circ C \\ 0.70 & \text{for } T_s = 0^\circ C \end{cases}$$

$$\alpha_i = \begin{cases} 0.6 & \text{for } T_s < 0^\circ C \\ 0.50 & \text{for } T_s = 0^\circ C \end{cases}$$

This parameterization is based on the areal fractions f_i and f_s of bare and snow-covered ice albedos, respectively. The albedos of bare and snow-covered ice are also assumed to vary with temperature.

Based on the data provided for the SHEBA site, derive the ice albedo as determined according to both of the schemes shown above for all days that albedo measurements exist. Assume that the snow cover vanishes completely as the mass-balance gauge data indicate a snow depth of 0 cm (i.e., $f_i = 0$ for d < 173, $f_I = 1$ for d ≥ 173).

4.2. Compute the (arithmetic) mean albedo for the two parameterization schemes and the measured values. Compute the mean absolute difference between measured and simulated albedo for all days (i.e., $\Delta = 1/N * \Sigma|a_{meas}-a_{sim}|$). Please compare these different values and explain discrepancies and similarities in terms of the variability of the shortwave flux (seasonal and short-term) as well as changes at the ice surface.

4.3. Compute the total amount of solar shortwave energy absorbed by ice and upper ocean for the three different cases (assuming that the melt season lasts from June 1 to August 31, 1998). If all this energy (consider only the measurements in this case and disregard the parameterizations) were expended in melting ice ($L = 330$ J/g, $\rho = 0.9$ g/cm^3), how much ablation (m of ice) would have taken place during the summer? How do you explain the differences between this number and the actual observation? Specify mean absorbed rad (gaps in days)

4.4. Based on a simple Beer's law approximation of radiative transfer, what fraction of the incoming shortwave energy would you expect to contribute directly to heating and melting at the surface? What fraction would be transferred to the ocean over bare ice (with a rough, back-of-the-envelope calculation based on an extinction coefficient of 10 m^{-1} in the upper 10 cm and 1 m^{-1} for the 1.9 m of lower ice)? Is the observed ratio between surface and bottom melt commensurate with such a calculation? If not, how would you explain the discrepancies?