

## Sea Ice Summer School, Longyearbyen, 9 July, 2007

Exercises using the single-column, thermodynamic sea ice model from Bitz and Lipscomb (1998) coded in MATLAB.

To familiarize yourself with the model, run it once with the default parameters and forcings by typing `column` in the MATLAB command window. When it is finished, type `help column` in the same window to learn how to vary the model options.

**Part 1** Investigate the model sensitivity to varying the downward longwave radiative flux  $F_{\text{LW}}$ . Perturb the downward longwave flux (i.e.,  $F'_{\text{LW}}$ ) in all months of the year and make a table of the corresponding annual mean thickness  $\bar{h}$  and mean February-March surface temperature  $T_{\text{FM}}$  in the final year of the run (the model displays these statistics in the command window). If necessary, increase the number of run years so the model reaches an approximate equilibrium by the time it finishes. Vary  $F_{\text{LW}}$  between  $\pm 10 \text{ W m}^{-2}$  in increments of about  $2 \text{ W m}^{-2}$ , but do not reduce  $F_{\text{LW}}$  so much that the snow does not melt in summer. Plot  $T_{\text{FM}}$  as a function of  $\bar{h}$ .

Options to consider

- 1) Why does the time to reach equilibrium vary?
- 2) Why is the plot of  $T_{\text{FM}}(\bar{h})$  nonlinear?
- 3) Using a hierarchy of models can be useful for understanding model results. Even the column thermodynamic model coded in MATLAB is quite complex. You are encouraged to try to relate your results to an analytical model of sea ice. One such model is Thorndike's toy model (Thorndike, 1992) with the following basic relations:

### Winter Energy Balance

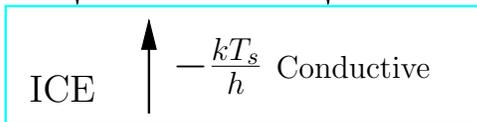
Net Longwave

$$F_{\text{LW}} - (A + BT_s)$$



Net Shortwave

$$\approx 0$$



Ice-Ocean  $F_W$

The flux balance at the top surface is

$$F_{\text{LW}} - (A + BT_s) = \frac{kT_s}{h},$$

where surface outgoing longwave  $\epsilon\sigma T_s^4$  is approximated as  $A + BT_s$ , turbulent heat fluxes are neglected, and the temperature profile in the ice is assumed to be linear.

The equation may be simplified to

$$W - BT_s = \frac{kT_s}{h},$$

Solve this equation for  $h(T_s)$ .

Assume this equation can be related to  $\bar{h}(T_{\text{FM}})$ , and plot it on the curve you created with output from the MATLAB model. Use the following parameters:  $W = -160 \text{ W m}^{-2}$ ,  $B = 4.6 \text{ W m}^{-2} (\text{deg C})^{-1}$ , and  $k = 2 \text{ W m}^{-1} (\text{degC})^{-1}$ , to give you  $h$  in meters (not centimeters as in the MATLAB model).

## Summer Energy Balance

The same picture applies in summer, except the net shortwave is not zero and the surface temperature is assumed to be zero Celsius. When the ice reaches an equilibrium thickness, the annual heat input into the ice must be zero. In the spirit of Thorndike (1992), let

$$\tau_W(W - BT_s) + \tau_S S + (\tau_W + \tau_S)F_w = 0$$

where  $T_s$  is from the winter season,  $S$  is the net downward radiative flux in summer,  $\tau_{W,S}$  is the length of the winter or summer (and no other seasons exist). After substituting from the winter energy balance, we arrive at

$$\tau_W(kT_s/h) + \tau_S S + (\tau_W + \tau_S)F_W = 0,$$

Solve for  $T_s(h)$  and plot it on your figure. Use  $S = 22 \text{ W m}^{-2}$ ,  $F_W = 2 \text{ W m}^{-2}$  and for simplicity  $\tau_W = \tau_S$ . The intersection of the two analytical expression from the toy model gives an approximate solution to the Thorndike toy model.

**Part 2** A climate modeler faced with biases in their model will often tune the surface albedo. This question invites you to explore some of the consequences. Find two different combinations for  $F_{\text{LW}}$  and surface albedo  $\alpha$  that give roughly the same  $T_{\text{FM}}$ ,  $\bar{h}$  state. Vary  $\alpha$  (0.05 is sufficient) by editing the script “calc\_albedo.m” and vary  $F_{\text{LW}}$  as in part 1. Be sure to apply the perturbations by the same amount all year.

Now perturb the downward longwave further by  $\delta F_{\text{LW}} = 2 \text{ W m}^{-2}$  for each  $F_{\text{LW}}$ ,  $\alpha$  pair and find the thickness sensitivity  $\delta h / \delta F_{\text{LW}}$ . Do they differ substantially? Why or why not?

Compute  $\delta h / \delta F_{\text{LW}}$  for your MATLAB runs from part 1 and note that it varies considerably. Why?

**Part 3** How do  $F_{\text{LW}}$  perturbations in winter or summer only affect the ice thickness? Design your own experiments to investigate this question. Type *help column* in the matlab command window to find a quick way to perturb  $F_{\text{LW}}$  in winter or summer only. Recall from the lecture that the time of year when downward longwave has the most spread among models is winter, because climate models have large spread in their simulation of wintertime cloud fraction.

If you have extra time, think about the extent to which these exercise are applicable to global climate modeling. If you have a lot of extra time, try varying the sea ice salinity profile in the script `salinity_prof.m` or vary the albedo in summer only and repeat part 2.

MATLAB plotting hints.

Given a table of data:

x	y
2	4
4	16
6	36
8	64

MATLAB commands to plot the data are

```
x = [2 4 6 8];  
y = [4 16 36 64];  
plot(x,y,'o');
```

To add a line for the function  $y = x^2$  type

```
x = 0:1:10; % creates an array  
hold; plot(x,x.*x,'r-'); hold  
xlabel('x'); ylabel('y');
```

The dot before the star is needed when multiplying array elements. Type *help plot* to see more options. Note that you can also plot( $\sqrt{x}$ ),x,'r-').

See the MATLAB “file” pulldown menu to open a new window with an editor to create new files. You can place all commands in a file, save it with the name myfile.m, and then type *myfile* in the MATLAB command window to run it.