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12.842 / 12.301 Past and Present Climate  
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## Climate Physics and Chemistry

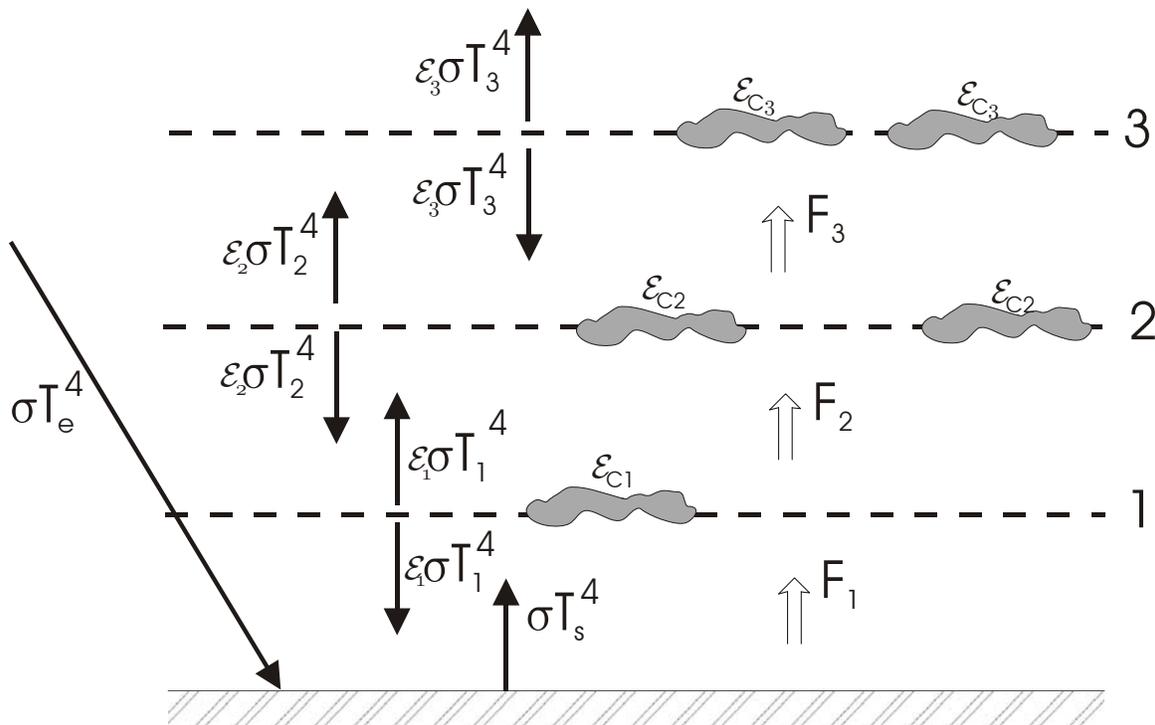
### Problem Set for Atmosphere Section

The object of this problem set is to explore climate sensitivity in a slightly more complex version of the multi-level radiative-convective model discussed in class. This model is complex enough that analytic solutions are not tractable, and so I provide a short MATLAB script that solves the time-dependent problem, converging to a steady-state. You may download that script from

<http://texmex.mit.edu/pub/emanuel/CLASS/Climate/radcon.m>

If you do not have access to a computer running MATLAB, please see K. Emanuel.

The general structure of the model is shown below:



The model consists of three atmospheric layers with clear sky emissivities given by  $\epsilon_n$ , where  $n=1,2,3$ . As in the models discussed on class, the temperature variations from one layer to the next, and from the lowest layer to the surface, are constrained not to exceed critical values determined by a moist adiabatic lapse rate, and convective fluxes  $F_n$  are evoked to maintain criticality, if necessary. Unlike the models discussed in class, each layer is assumed to contain clouds that cover a specified fractional area in each layer. These clouds also have specified albedo, under an assumption of random overlap,

and are assumed to radiate with specified cloud emissivities, at the same temperature as the air at their respective levels.

Run the matlab script *radcon* with the default parameters. (The program may take 10-40 seconds to run.) The graph at the upper left shows the time evolution of the surface temperature. If you do not think that the temperature has converged sufficiently to a stable value, you may increase the parameter *stoptime* by editing *radcon.m*, then re-run the program. The program also prints the final value of the surface temperature to your screen. The graph at upper right shows the temperature at the final time at all three levels and the surface. The lower left graph shows the convective enthalpy flux, as a fraction of the incoming solar flux, and the lower right graph shows the radiative and convective heating rates, which should sum to zero if the model has reached equilibrium.

As a first exercise, explore the sensitivity of the climate to the clear air greenhouse effect by increasing the background clear-sky emissivity of the top layer in increments of 0.1, all the way to 0.95. (This is similar to what would happen if carbon dioxide were increased.) Describe the effect of doing this on the surface temperature, the temperature profile, and the convective enthalpy fluxes, and discuss why the model responds as it does.

Resetting the top layer background clear-sky emissivity to 0.25, as a second exercise, increase the fractional area clouds at the lowest level and describe and discuss the results. Resetting the low cloud fraction to 0.15, do the same experiment for the cloud fraction at the highest level. Discuss the different effects of increasing low versus high cloud.

As a final exercise, create your own climate sensitivity experiment, being careful to discuss the results.