A One-Dimensional Radiative Convective Model with Detailed Cloud Microphysics

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The Arctic is a key element in determining the radiation budget of the earth. Within the polar regions, the net radiation (incoming solar radiation minus outgoing infrared radiation) is negative. To understand the role this energy deficit plays in the overall radiation budget, one must examine the prevalent atmospheric features of the Arctic. One such feature is a persistent layer of low-altitude, stratiform clouds found over the central Arctic predominantly from April to September (Tsay et al. 1984). These Arctic stratus clouds (ASC) modulate the earth's radiation budget by contributing to the vertical transport of heat (Curry 1986). It is, therefore, crucial to understand the radiative properties of Arctic stratus clouds.

We believe that the radiative properties of ASC are strongly coupled with their cloud microphysics. Our aim is to develop a model that will determine if this coupling is sufficient to describe the observed characteristic properties, such as lifetime and the multi-layered structure, of ASC. In addition, we hope to provide useful input to measurement programs at the Atmospheric Radiation Measurement Program's North Slope of Alaska site by isolating the measurable parameters that influence the overall radiative properties of ASC.

Several features of ASC have been integrated directly into the one-dimensional model currently being developed. Generally, ASC cover large areas and exhibit reasonable horizontal homogeneity but extensive vertical inhomogeneities (Tsay et al. 1988). Therefore, in our model, we have assumed radiative processes are important in determining vertical structure while not considering horizontal transport. In addition, ASC occur in defined, multi-layered structures (Tsay et al. 1988). This feature of the ASC, in conjunction with their horizontal homogeneity, justifies the use of radiative transfer theory for plane-parallel geometry with multiple scattering. Finally, ASC are generally long-lived and precipitate little during their lifetimes. Therefore, the integration time of the model may be on the order of only a few days, without including effects of precipitation, coalescence and gravitational settling of water droplets.

To offer insight into the detailed interaction of radiation and cloud microphysics, we must construct a model built upon a detailed microphysics scheme and solid, comprehensive radiative transfer code.

Initially, we specify the atmospheric temperature, humidity and aerosol profile, and ground conditions appropriate for the Arctic during the time period being considered. We also specify the number and duration of the iterations over which the model is run. For each iteration, we perform a radiative transfer calculation and invoke the microphysics routine to determine where a cloud will form or dissipate for the local conditions. We also update the temperature profile and cloud parameters such as liquid water content and cloud equivalent radius.

We use an existing radiative transfer code, DISORT (DIScrete Ordinate Radiative Transfer) to solve the radiative transport equation for wavelength bands from the ultraviolet to the infrared (Stamnes et al. 1988). The optical properties of clouds are computed from the cloud equivalent radius and liquid water content calculated in the microphysics code. We use the radiation module to compute radiative heating/cooling rates in the atmospheric profile in the presence of cloud layers generated in the microphysics module.

The one-dimensional cloud microphysics module computes the full droplet size distribution and performs convective adjustments on unstable layers. The routine begins with a temperature, aerosol, and water vapor profile. As the air cools radiatively and supersaturation is reached in a given layer, aerosol particles become activated. The size distribution, to be used in the next iteration, is calculated by integrating the diffusion equation for droplet growth. If, however, a level is subsaturated, droplets evaporate. Complete evaporation of a droplet returns the nuclei to the aerosol distribution and the water vapor to the atmosphere.

The convective adjustment, or mixing of layers, is performed when a layer of air becomes convectively unstable. The stability of a layer is determined by comparing the actual temperature gradient with the dry or wet (depending on whether a cloud is present in the layer) adiabatic lapse rate. The droplet and aerosol size distributions of two adjacent layers are also mixed, which leads to a broadening of the size distribution.

Finally, the latent heat released/absorbed due to evaporation/growth of a droplet is calculated in the model at each altitude level.

From the divergence of the net radiation flux, and the latent heat calculated in the microphysics module, the local warming/cooling rate is computed, from which the temperature profile is updated.

The one-dimensional model, as outlined above, is now being developed. In the future, we are planning to improve the method of time-stepping through the radiative transfer calculation and the microphysics scheme, use more realistic aerosol/cloud condensation nuclei (CCN) spectra, and incorporate the entrainment of dry air. As a long-term goal, we plan to use real measurements as input and for comparison to our model.

We realize that there are still many avenues to explore and improvements to be made on the current one-dimensional model. We hope this model will eventually be used as a tool to gain a fundamental understanding of the physics controlling the formation, maintenance, and removal of Arctic stratus clouds. This knowledge will enhance our comprehension of energy exchange processes between the earth-atmosphere system and space.

References

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