Reply

G. L. STEPHENS

Colorado State University, Atmospheric Science Department, Ft. Collins, CO 80523

14 January 1985 and 20 April 1985

In their comments Harshvardham and Randall (1985; hereafter H and R) once again expose the possible difficulties associated with parameterizing subgrid radiative transfer processes. These difficulties cannot be stressed often enough and I welcome their comments for again exposing them.

The integrated cloud liqud water (LWP) is a parameter that is crucial to the description of cloud optical properties. While it is a necessary parameter, it is not likely to be totally sufficient in order to define these optical properties unambiguously in all cases. This should always be considered when using cloud-radiation schemes that rely solely on the LWP as a means of specifying cloud optical properties. Certainly cloud microphysical features cannot always be totally excluded (e.g., Wiscombe *et al.*, 1984). For the problem of subgrid scale radiative transfer, it may even be that some other information about the grid scale distribution of liquid water will be required.

It is true that the parameterization schemes outlined in my review paper do not attempt to describe methods for treating subgrid scale parameterization. The schemes described in that review are based on one-dimensional (vertical) radiative transfer calculations. The extension to a full three-dimensional atmosphere is complex and very much a problem for present and future research. Thus, the uncertainties in using one-dimensional assumptions to approximate a three-dimensional atmosphere are unknown. It is the very essence of the H and R comment to suggest that large errors are likely when this assumption is invoked.

Unfortunately, the results that H and R present are inconclusive and even confusing. In fact, they even make assumptions that are philosophically similar to those for which they accuse me of being overly optimistic. That is, they assume that the albedo α and emissivity ϵ averaged over some domain can be derived by averaging succession of one-dimensional calculations. Therefore, the issue raised by H and R is not the important one of how to calculate the radiative properties of a grid box incorporating subgrid scale irregularities (in LWP) but more an issue of adequately specifying the irregularities in the LWP itself.

Unfortunately the problem of subgrid scale radiative transfer is not even as simple as H and R might have us suspect. In fact, the two issues raised above, one of calculating radiative transfer within a (spatially) inhomogeneous medium and one of defining the relevant parameters with sufficient resolution, are not separable. This aspect together with the rather obvious but inconclusive nature of the H and R results can be best illustrated by the following. Consider the relationships between cloud emissivity ϵ and LWP (W) and the cloud albedo α and W as derived from 1D theory (as an example, refer to Stephens, 1978; or Fouquardt and Bonnel, 1980). It takes little to realize that these relationships [denoted here as $g(W)$ for ϵ and $h(W)$ for α] are nonlinear functions of W. That is, it is immediately clear that:

$$\bar{\epsilon} = \frac{1}{\bar{W}} \int g(W) dW \neq g(\bar{W}),$$

$$\bar{\alpha} = \frac{1}{\bar{W}} \int h(W) dW \neq h(\bar{W}).$$

Hence the results of H and R (their Figs. 2 and 3) are obvious.

As indicated above, the problem of deriving a mean $\bar{\epsilon}$ and $\bar{\alpha}$ for some distribution of liquid water is not this simple as the functions $g(W)$ and $h(W)$ are not applicable to a medium that is other than horizontally homogeneous. Thus, some other relationships must be established such as:

$$\bar{\epsilon} = g'(\bar{W}, \sigma_w, \cdots),$$

$$\bar{\alpha} = h'(\bar{W}, \sigma_w, \cdots),$$

which, as hinted above, will quite likely depend on other statistical information about the distribution of LWP (such as a standard deviation σ_w). Before we can accept the results of H and R as offering any sort of clarification to this issue, it is necessary to establish the extent to which the following approximations apply

$$h'(\bar{W}, \sigma_w, \cdots) \approx h(W),$$

$$g'(\bar{W}, \sigma_w, \cdots) \approx g(W).$$

The functions h' and g' are likely to vary from one distribution of W to another. It may even be that h' and g' are more linear then their one-dimensional counterparts in some circumstances. In any event, establishing these functions is a problem of ongoing research and there are far more rigorous ways of determining $\bar{\epsilon}$ and $\bar{\alpha}$ using complex computational radiative transfer techniques from which it may be possible to obtain h' and g' or at least some insight to the way these functions behave.

Thus, I do not believe that the comments of H and R shed any meaningful insight on this complicated issue.

Acknowledgments. The work was supported by the National Science Foundation through Grant ATM 841-5127.

REFERENCES

Fouquardt, Y., and B. Bonnel, 1980: Computation of solar heating of the Earth's atmosphere. A new parameterization. *Contrib. Atmos. Phys.*, **53**, 35–62.

Harshvardham and D. A. Randall, 1985: Comments on "The Parameterization of radiation for numerical weather prediction and climate models. *Mon. Wea. Rev.*, **113**, 1832–1833.

Stephens, G. L., 1978: Radiative properties of extended water clouds. Part II. Parameterizations. *J. Atmos. Sci.*, **37**, 435–446.

Wiscombe, W., R. M. Welch and W. D. Hall, 1984. The effects of very large drops or cloud absorption. Part I: Parcel Models. *J. Atmos. Sci.*, **41**, 1336–1355.