Final Technical Report for project "Parameterization and analysis of 3-D radiative transfer in clouds"

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Technical summary

This report provides a summary of major accomplishments during the project period (6/15/2008 to 6/14/2012).

(1) We developed a multiyear dataset of cloud optical properties at the NSA, SGP, and TWP sites. The dataset combines information from the Microbase, Mergesonde, Cldclass, and Surflog ARM products, and comprises 2D vertical cross-sections of cloud structures that are observed as clouds float over the ARM sites. ARM's time-dependent information from zenith-pointing instruments was converted into 2D vertical cross-sections using wind-speed measurements that specify the distance clouds drift during the time between subsequent measurements of cloud vertical profiles.

Because of its detailed cloud information, long temporal coverage (2-3 years), and high spatial resolution (~50 m), the dataset can yield the typical impact of radiative interactions between neighboring atmospheric columns, which are not considered in most current dynamical models and remote sensing algorithms. Indeed, the dataset has been used for examining horizontal radiative interactions and their impacts on surface- and atmospheric solar heating, as well as on satellite observations used for cloud and aerosol measurements.

(2) We performed broadband solar radiative transfer simulations for the entire cloud dataset. The comparison of results from 1D and 2D radiative simulations for the same clouds provided many insights into the multidimensional nature of radiative processes. Most importantly, the results yielded lower-bound estimates on the importance of 3D radiative processes. (2D calculations cannot consider the impact of cloud variability in the cross-wind direction.)

The results show that 2D effects increase multiyear 24-hour average total solar absorption (including nighttime and clear periods as well) by about 4.1 W/m^2, 1.2 W/m^2, and 0.3 W/m^2 at a the TWP, SGP and NSA sites, respectively. However, 2D effects are often much larger than these average values, especially for high sun and for convective clouds. For example at the TWP site, 2D effects change the total cloud absorption of 1 km-size columns by more than 20% in about a third of cases, and they change the total surface absorption of 10 km-size areas by more than 50 W/m^2

in about a quarter of cases. The results also confirm that horizontal photon transport often enhances solar heating even for oblique sun. This occurs when the incoming direct sunlight slips obliquely under an extensive cloud, and the cloud subsequently intercepts much of the light reflected from the surface.

The results also reveal that the impacts of horizontal cloud variability greatly increase if we consider that most current large-scale and global cloud-resolving simulations use coarser horizontal resolutions than our dataset (usually between 250 m and 4 km). This is because, similarly to the interactions between nearby atmospheric columns, nonlinearities due to unresolved subgrid-scale cloud variability also increase solar absorption. For example, 1 km resolution 1D calculations underestimate multiyear day-and-night average solar absorption by about 1.6, 2.1, and 7.2 W/m^2 at the NSA, SGP, and TWP sites, respectively. These overall biases arise from a combination of horizontal interactions and nonlinearities due to subgrid scale variability, with large portions of the latter coming from increases in cloud coverage when the horizontal resolution is degraded. Naturally, local effects are often much larger, especially for high sun and for convective clouds. While the local impact of 2D processes is most pronounced near cloud edges—where horizontal gradients are largest—, their impacts usually extend up to 5-10 km away, and much farther in clouds with strong internal or cloud top variability.

(3) In order to explore possibilities for estimating the influence of 2D radiative processes in dynamical simulations, we coupled our dataset of observed cloud structures and corresponding simulated radiation fields to a neural net. The neural net was trained for using cloud parameters provided by dynamical cloud models to estimate appropriate corrections to the 1D radiative transfer calculations of the dynamical models. After exploring which cloud parameters help the neural net the most, we found that the neural net can reduce RMS errors due to 2D radiative interactions by up to two thirds, and reduce biases even more. This suggests that statistical approaches can offer viable paths for improving radiative calculations in large-scale dynamical models.

(4) Through discussions and data exchanges we collaborated with a team at Penn State University, which examined the impact of 3D radiative processes on short-term cloud development. The results from that project are reported separately by PI Jerry Harrington.

(4) As a step toward studying fully 3D radiation fields using new ARM scanning radar data, we collaborated with a group at the University of Bonn led by Victor Venema. The goal is to develop a method for filling gaps between subsequent radar scans with interpolated values that have realistic small-scale variability. We developed and tested several techniques using cloud structures from our 2D dataset as well as from 3D dynamical simulations. These tests helped identify the most promising approaches, most notably the one we call stepwise kriging.

We published some of our results in a journal article that provides the first estimates about the long-term average impact of horizontal radiative interactions on radiative fluxes, and examines local effects and the influence of factors such as cloud type. (T. Várnai, 2010: Multiyear statistics of 2-D shortwave radiative effects at three ARM sites. *J. Atmos. Sci*., **67**, 3757–3762) We also presented our results in three invited conference presentations (at the American Meteorological Society's 13th Conference on Atmospheric Radiation, an IAMAS/IAPSO/IACS joint assembly, and an international symposium organized by the Hungarian Meteorological Service and the Hungarian Academy of Science), in several other conference presentations, and at ARM/ASR science team and focus group meetings.