HIGH ACCURACY RADIATIVE TRANSFER IN CLOUDY ATMOSPHERES

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RESEARCH SUMMARY

One of the most important roles clouds play in the atmosphere is in redistributing radiative energy from the sun. Given the ubiquity of cloud coverage, it is imperative that we get the interactions between clouds and radiation correct if we want to accurately predict and observe weather and climate. However, radiative transfer in the atmospheric sciences is generally modeled crudely because of the perceived computational expense. Evidence of a bias due to these crude assumptions has been seen in observed properties from satellites as well as modeled cloud properties.

A model that treats broadband integration and 3-D radiative transfer in a highly accurate and unbiased way is needed to quantify the bias in the simpler models ubiquitously used. This model will serve as a previously nonexistent standard of comparison for other similar models, and provide accuracy bounds for simpler models and parameterizations attempting to capture 3-D effects at lower computational cost. Such a model was not publicly available prior to this project. So, one was developed that uses Monte Carlo methods to capture the 3-D transfer of radiation and sample at high resolution the broad range of the electromagnetic spectrum. Unlike the direct approach to solving the radiative transfer equation, the Monte Carlo approach has the potential to be embarrassingly parallel since the random samples are independent from one another. The overarching goal of this project is to make publicly available to the radiative transfer community the models, tools, data, and products developed to aid in faster and more robust progress in addressing scientific questions about the interactions of clouds and realistic radiative transfer.

A monochromatic, 3-D Monte Carlo community solar radiative transfer model was further developed to include terrestrial emissions in addition to solar sources of radiation. That model was then further developed to include integration over the electromagnetic spectrum to produce the broadband 3-D model discussed above. In addition to these two models, several other products have resulted so far and will be made available to the community. This includes databases of high-spectral resolution, radiative properties of earth's gaseous atmosphere and liquid water clouds. These are the largest and highest resolution publicly available databases of their kind. The tools and workflow to create and subset them will also be made available. This data can be mined to update the decades old broadband parameterizations of cloud radiative properties that are still in wide use today, for example. Each product has been thoroughly vetted for accuracy. The results of these tests will be made available for reproduction by other scientists to test these models or their own. Finally, the first few idealized experiments with long heritage in the literature have been conducted to provide the **first set of benchmark simulation results** that can be used to evaluate other models.

The results shown in the figure demonstrate the impact accounting for 3-D radiative transfer has on the heating rates within a cubic cloud in a broadband simulation of thermal emissions from a cloud and a black surface. The left panel shows a cross section through a plane parallel cloud, which in this context means radiation cannot enter or escape through the sides of the cloud, only the top or bottom and therefore can make no contribution to heating or cooling of the cloud edges. The right panel shows a cross section through a cloud with the same physical properties but a finite horizontal extent, meaning that radiation is free to enter or leave through the cloud sides and can contribute to cloud side heating or cooling. The heating rates at the top and bottom of the plane parallel cloud are within 0.025 K/day of the heating rates at the horizontal center of the finite cloud. However, the cooling at the finite cloud's edges is unaccounted for in the simulation of the plane parallel cloud. In time-integrated simulations of cloudy atmospheres, this cooling that occurs when radiation is allowed to exit through cloud sides is unaccounted for in the temperature at cloud edge, which could ultimately impact the evolution of modeled-cloud physical properties and cloud scale dynamics.

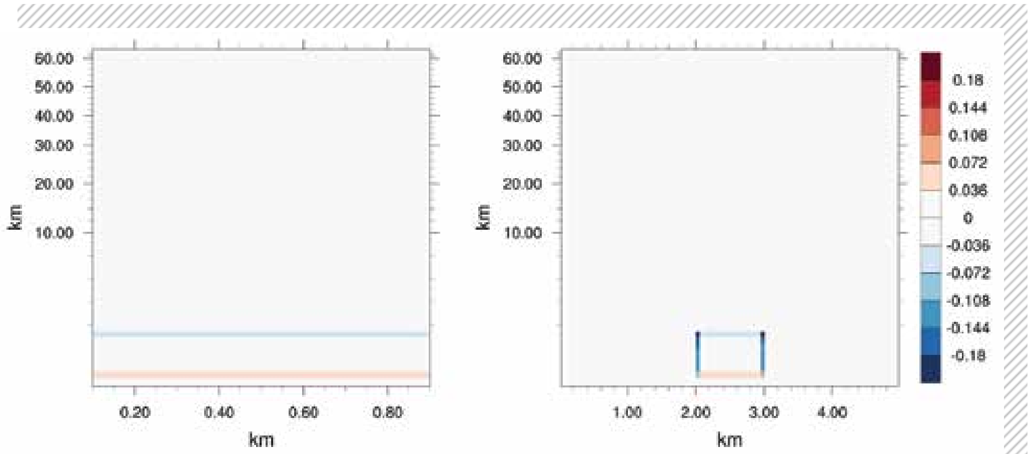

FIGURE 1: Vertical cross section of long wave heating rate K day^{-1} through the center of an isothermal (280 K), homogeneous (effective radius=8.8 microns, liquid water content=0.32583 gm^{-3}) cloud set in a vacuum above a non-scattering surface emitting as a blackbody according to its temperature (290.38 K). The left panel shows a plane parallel cloud whose horizontal extent is effectively infinite and vertical extent is 1km. The right panel shows a 1 km x 1km x 1km cloud set in a 5 km x 5 km x 66 km domain.

WHY BLUE WATERS

Access to debugging and profiling tools such as CrayPat and DDT allowed the development process to progress in a streamlined fashion. Access to a point of contact at SEAS helped me find tailored solutions for problems that otherwise would have delayed progress by weeks. The quick responsiveness of the Blue Waters staff through the JIRA ticket system allowed for limited interruption in progress when small issues or questions arose. My experience as a Blue Waters graduate fellow has been invaluable to my professional development. I hope to make use of Blue Waters for the rest of its lifetime.

Alexandra L. Jones completed her Ph.D. in Atmospheric Science at the University of Illinois at Urbana-Champaign in January 2016. She is currently a postdoctoral researcher in climate science at the Cooperative Institute for Climate Science, a collaboration between Princeton University and the National Oceanographic and Atmospheric Administration's (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL).

"My work on Blue Waters allowed me to hit the ground running, utilizing GFDL's access to another Cray supercomputer, Gaea. I can see how my computational science knowledge and skills, gained during my time as a Blue Waters Graduate Fellow, are enabling me to make faster progress," she says. "My work parallelizing and making the scientific software needed more efficient will enable me to expand the scope of the project and the amount of data I can include as my career continues, I would like to remain at the cutting edge of high performance computing and atmospheric science, whether as a researcher or an advocate."