TN

CI

HIGH ACCURACY RADIATIVE TRANSFER IN CLOUDY ATMOSPHERES

Alexandra Jones, University of Illinois at Urbana-Champaign
2014–2015 Graduate Fellow

EXECUTIVE SUMMARY

One of the most important roles clouds play in the atmosphere is in redistributing the radiative energy from the sun and that which is emitted from the Earth and atmosphere. However, radiative transfer in the atmospheric sciences is generally modeled crudely because of the perceived computational expense. Therefore, we developed a highly accurate open-source model that uses Monte Carlo methods to capture the 3D transfer of radiation between the atmosphere and clouds over a broad range of the electromagnetic spectrum.

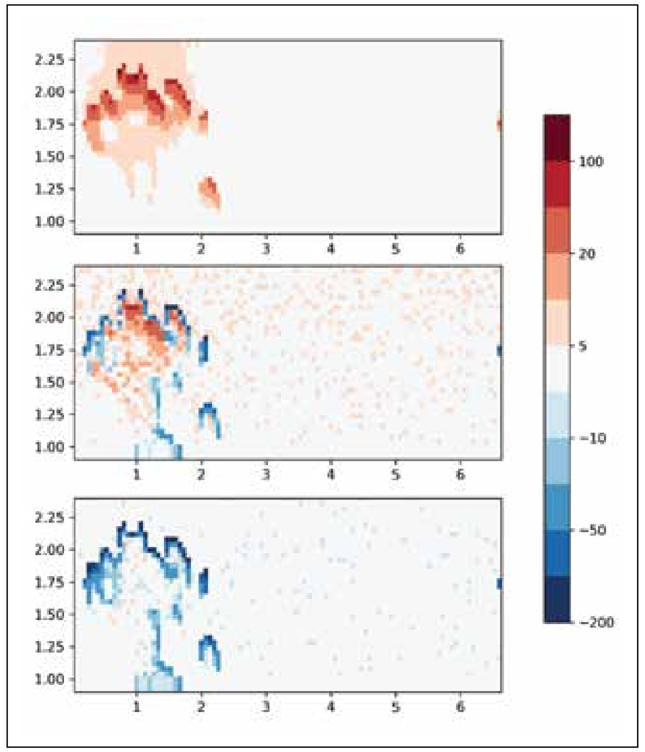

Figure 1: Vertical cross section of the radiative heating rate through a field of shallow cumulus clouds as calculated by MCBRaT-3D. The top image is the heating rate due to solar radiation; the bottom image is the heating rate due to radiation emitted by the clouds, atmosphere, and surface. The middle image is the net heating rate from the two sources.

RESEARCH CHALLENGE

Because of the important role that clouds play in the atmosphere in redistributing the radiative energy from the sun, Earth, and atmosphere as well as the ubiquity of cloud coverage it is imperative that we correctly model the interactions between clouds and radiation in order to accurately predict and observe weather and climate. However, modeling of radiative transfer tends to be crude because of the perceived computational expense. Evidence of a bias due to these crude assumptions has been seen in satellite-observed properties as well as modeled cloud properties.

METHODS & CODES

A model that treats broadband integration and 3D radiative transfer in a highly accurate and unbiased way is needed to serve as a standard of comparison for similar models and provide accuracy bounds for simpler models and parameterizations attempting to capture 3D 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 3D transfer of radiation and sample at high resolution the broad range of the electromagnetic spectrum. It is called MCBRaT-3D and is available for public use and development. Unlike the direct approach to solving the radiative transfer equation, the Monte Carlo approach has the potential to be perfectly parallel, since the random samples are independent of one another.

RESULTS & IMPACT

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. An existing monochromatic 3D Monte Carlo community solar radiative transfer model was further developed to include terrestrial emission in addition to solar sources of radiation. That model was then improved to include integration over the electromagnetic spectrum to produce the broadband 3D model discussed above (MCBRaT-3D). In addition to the development of these two community models, several other products have resulted so far and will be made available to the community. These include databases of high spectral resolution radiative properties of Earth's gaseous atmosphere and liquid water clouds, which 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.

As a usage example, these databases can be mined to update the decades-old broadband parameterizations of cloud radiative properties that are still in wide use today. Each of these products 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 in the literature with long heritage have been conducted to provide the first set of benchmark simulation results that can be used to evaluate other models. As an example, the figure shows cross-sectional snapshots of the heating rate through a cloud field due to the sun (top), due to emission of radiation by the system (bottom), and the net heating from the two (middle). Results such as these can be used as accuracy benchmarks for simpler, less computationally expensive models to characterize their bias.

WHY BLUE WATERS

Access to debugging and profiling tools such as DDT and CrayPat allowed me to streamline the development process. Having access to a point of contact on the Science and Engineering Application Support staff helped me think through issues and find tailored solutions for my problems that would have otherwise had me stuck for weeks. The quick responsiveness of the Blue Waters' staff 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.

PUBLICATIONS & DATA SETS

Jones, A.L., and L. Di Girolamo, Design and Verification of a New Monochromatic Thermal Emission Component for the I3RC Community Monte Carlo Model. *Journal of the Atmospheric Sciences*, 75:3 (2018), pp.885–906.

Jones, A.L., Alexandraljones/imc-emission: Code base plus select benchmark results. *Zenodo*, (2017), DOI:10.5281/zenodo.574872.

Jones, A.L., AlexandraLJones/MCBRaT3D: Initial public release (Version V1.0.0-alpha). *Zenodo*, (2018), DOI:10.5281/zenodo.1313839.

Alexandra L. Jones received her PhD in atmospheric science in May 2016 from the University of Illinois at Urbana-Champaign. She currently is a postdoctoral scholar at the Cooperative Institute for Climate Science, which is a collaboration between Princeton University and the National Oceanographic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory.