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HIGH ACCURACY RADIATIVE TRANSFER IN CLOUDY ATMOSPHERES

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EXECUTIVE SUMMARY

One of the most important roles clouds play in the atmosphere is in redistributing radiative energy from the sun and that which is emitted from the Earth and atmosphere. 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 satellite-observed properties as well as modeled cloud properties.

RESEARCH CHALLENGE

A model that treats broadband integration and 3D 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 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 to sample at high resolution the broad range of the electromagnetic spectrum.

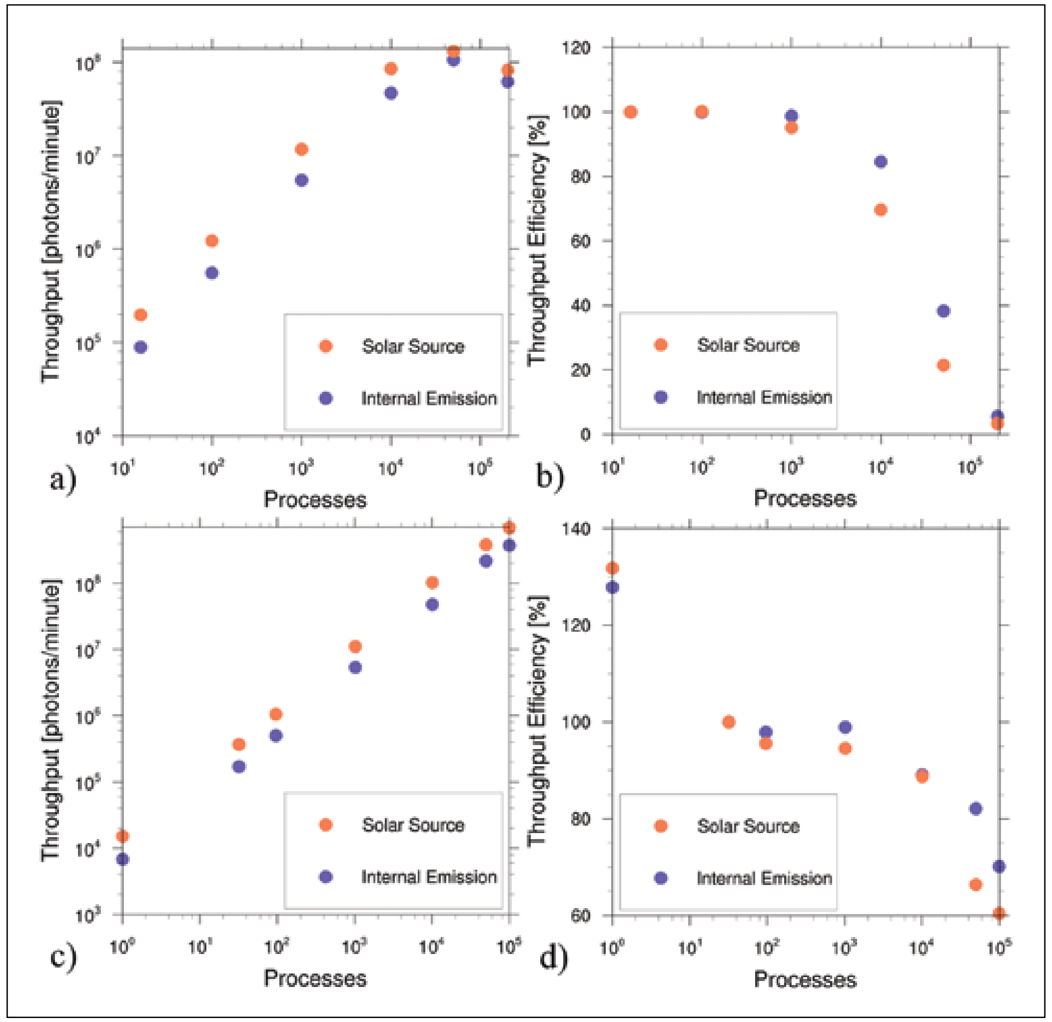

Figure 1: Performance of the "IMC+emission" model runs in both internal emission mode and solar source mode for strong scaling experiments (a-b) and weak scaling experiments (c-d). Throughput (a, c), defined as the number of photons simulated per minute of wall-clock time, and throughput efficiency [%] (b, d) are shown as a function of number of processes. Note that logarithmic spacing is used on the horizontal axis in all panels and on the vertical axis for panels a and c.

METHODS & CODES

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 figure shows weak and strong scaling tests for both solar and internal sources of photons for the monochromatic model, "IMC+emission," in terms of throughput, or number of photons simulated per minute, and throughput efficiency. For both weak and strong scaling experiments, the solar source of photons exhibits a faster drop-off in efficiency but has an overall higher throughput than the internal source of photons. The "IMC+emission" model shows better weak scaling efficiency than strong scaling efficiency for both sources of photons over the range of processes tested.

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 further developed to include integration over the electromagnetic spectrum to produce the broadband 3D model discussed above. 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, 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. These 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.

WHY BLUE WATERS

Access to debugging and profiling tools such as CrayPat and DDT allowed me to streamline the development process. Having access to a point of contact on the SEAS staff helped me think through issues and find tailored solutions for my problems that would have otherwise delayed progress for weeks. The 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.

PUBLICATIONS AND DATA SETS

Jones, A. L., Development of an Accurate 3D Monte Carlo Broadband Atmospheric Radiative Transfer Model (doctoral dissertation—2016), University of Illinois, Urbana, Ill.

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

Alexandra L. Jones received her Ph.D. in May 2016 in atmospheric science 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.