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Physical processes in present and future large-scale models

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Summary

Evaluating and improving simulation of clouds - Andrew Gettelman

Cloud Evaluation and Impacts in Large Scale Models

It is hard to overstate the impact of clouds for weather & climate. Most impacts of extreme weather occur through cloud processes, except for windstorms, heat and cold. This includes precipitation (or lack thereof) that directly relates to flooding and droughts. It includes severe weather such as thunderstorms, hail, tornadoes and ice storms. Clouds also play a key role in tropical cyclone dynamics. Clouds are also the largest uncertainty in our ability to predict future climate change. Cloud radiative effects globally average about 20 Wm^{-2} of cooling, so small changes to cloud radiative effects as the surface temperature changes result in feedbacks that can significantly impact the radiation balance (Stephens, 2005). Cloud processes also play a role in the possible changing frequency of extreme weather. There are many biases that remain the prediction of clouds for both weather and climate. This talk describes how clouds are predicted in models, and how we evaluate clouds in models.

Clouds are predicted in models using a suite of parameterizations in global models, because we cannot resolve important cloud processes at the grid scale. This includes a series of parameterizations for moist turbulence such as deep and shallow convection, often represented separately, and planetary boundary layer turbulence. There is also a large-scale condensation scheme, which usually contains significant sub-grid assumptions about clouds and moisture to represent fractional cloudiness. Finally there is a parameterization for cloud microphysical processes that determines the evolution of cloud processes, the precipitation, and the properties of clouds critical for radiation. Perhaps one of the biggest problems in global modeling is the connection between all of these representations, which needs to be treated carefully.

Each of these cloud parameterizations is like a complex animal. They are often developed or 'trained' separately, and then they need to be harnessed together like the dogs of a sled, to pull the model state forward in time. The parameterizations may behave very differently when coupled together. The representation of clouds in a large-scale model is thus like a dog-sled trying to move forward efficiently. One development path is to generate more complex and realistic parameterizations for cloud turbulence, microphysics, etc. However, care must be taken to make sure the coupling of parameterizations is appropriate. A complementary development path is to improve the coupling and consistency between parametrizations. This can be done with more complete and unified closures for moist turbulence. These include unified deep and shallow convection schemes, or higher order closure schemes that combine shallow turbulence with boundary layer schemes.

There then likes the problem of evaluation of clouds. One factor that needs to be considered is that observations of clouds are imperfect. We except that models of clouds are imperfect, and the level of realism often degrades with the necessity to treat larger size grid boxes, largely due to the coupled sub-grid variability of clouds and dynamics.

We realize that models are imperfect, and struggle to evaluate cloud models against observations. But observations are imperfect too. Different observations observe different parts of the cloud and different cloud properties, and have their own sources of uncertainty and error. These need to be carefully understood. Aircraft only sample parts of clouds in-situ, and rarely in some of the deepest convective cores. Satellites are sensitive to different parts of the cloud. They are also sensitive to different cloud properties, and may also have biases in their space and time observational strategy.

We often take too little heed of these issues when evaluating models against observations, particularly for clouds. Using the ‘fraction of clouds’ is an easy metric, but what is a cloud? It is condensed water: but different instruments will see condensed water (liquid or ice) in different ways, and so cloud fraction can be very different. Furthermore, cloud fraction does not usually provide the clearest information on clouds: for weather we need to understand precipitation, and for climate we need to understand radiative effects, neither of which are described by cloud fraction. Traditionally and conveniently we often use summary metrics, either means or mean skill or error scores, but these often do not get at the processes we need to improve clouds.

So first, evaluation should focus on variability, and second on processes. Variability can be better explored by summaries of high frequency output, often with composites, such as composite cyclones. Processes are often easier to evaluate in case studies: often used for weather forecast evaluation, but they can also be sued for climate models as well, to get a better understanding of cloud processes. Finally, to better compare models to observations, the use of forward models inside of large scale models is a very effective technique to ‘simulate’ instruments. In many cases, interpretation of observations is aided by these simulators, where many of the assumptions used in the observational retrieval are applied to the model to generate a simulated retrieval, or when the model fields are used to produce an observation such as simulated radiance or reflectivity (e.g. Bodas-Salcedo et al 2011, Kay et al 2012). These are best practices for cloud evaluation.

The challenges in cloud modeling come from cloud scales. Cloud scales are hard to observe and harder to simulate. Getting models to simulate clouds across scales is difficult. We are trying. Some ‘dogs’ may be better than others for this. And fewer parameterizations may be better than more complex parameterization interactions. We must remember that improving processes sometimes breaks key metrics because of compensating errors, and the challenge is to improve model clouds through evaluation and process improvement

References

Bodas-Salcedo, A., M. J. Webb, S. Bony, H. Chepfer, J.-L. Dufresne, S. A. Klein, Y. Zhang, et al. “COSP: Satellite Simulation Software for Model Assessment.” *Bull. Amer. Met. Soc.* 92 (2011): 1023–43. doi:10.1175/2011BAMS2856.1.

Kay, J. E., and others. “Exposing Global Cloud Biases in the Community Atmosphere Model (CAM) Using Satellite Observations and Their Corresponding Instrument Simulators.” *J. Climate,* 25 (2012): 5190–5207. doi:10.1175/JCLI-D-11-00469.1.

Stephens, G. L. “Cloud Feedbacks in the Climate System: A Critical Review.” *J. Climate* 18, no. 2 (2005): 237–73.