Annual Seminar 2015

Physical processes in present and future large-scale models

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Summary

Coupling between clouds and their large-scale environment: using observations to constrain models - Louise Nuijens

How clouds couple to their environment depends on how you view clouds, and there are many ways that clouds can be viewed, and therefore many processes that underlie the coupling between clouds and the environment. This lecture discusses more broadly how observations have been and can be used to inform ourselves about relationships between clouds and their environment. The first part of the lecture discusses successful examples of the past, whereby observations and modeling went hand in hand to improve our understanding of clouds, first as radiative entities, early last century, then as turbulent and multiphase flows, through the middle of the century, and then as a heat source. These examples illustrate that good models were inspired by few, imperfect observations. The second part of the lecture shows recent work whereby I use state-of-the-art remote sensing at a single location to gain insight into the behavior of clouds with changes in the environment, which can be used to validate models.

The first time clouds were considered in climate models was in the late nineteenth century, when Arrhenius was the first to build a simple model to assess the influence of gases on the temperature of the Earth's surface. He noted that clouds also play a role determining how much sunlight reaches the surface and included this effect by prescribing a single layer of cloud with a constant cloud cover and albedo. These numbers evolved over the early twentieth century as energy fluxes through the atmosphere were modeled, informed by more consistent cloud observations made around the world, as well as a developing network of pyrheliometer measurements of solar radiation.

It wasn’t until the seventies that Manabe and Wetherald turned Arrhenius' one layer of cloud into three layers and found that an atmosphere with more low-level cloud amount has a colder Earth's surface, because more solar radiation is reflected, and that an atmosphere with more high-level cloud amount, due to its inference with outgoing infrared radiation, had the ability to warm the surface as long as it has the optical properties close to that of a black body. The effect of clouds on radiation was more formally introduced a few years later by Schneider who introduced the cloud radiative effect, and asked if it is possible that clouds can globally amplify or dampen changes in other components of the climate system. Moreover he advocated that different cloud top heights and a different thickness and absorptivity can have different effects on the surface temperature. This marked the launch of a couple of large observational efforts: the start of the satellite-observing era, such as ISCPP, ERBE and CERES.

The extensive (surface-based) climatology of cloud observations available today show that optically thin high clouds were missed in early observations, so that the Earth is cloudier than initially thought, but overall has a smaller albedo. These climatologies also show that clouds are to a first approximation persistent in space and in time, which raises the question whether clouds are in fact also needed in such places to help maintain the atmospheric dynamics and circulations at play.
Throughout the mid-twentieth century clouds were studied more as prototypes of convection, and bubble or plume models showed analogies to cumulus clouds. The Thunderstorm Project

in 1946 also marked the start of more focused field work on convective clouds. Data from these field campaigns provided insights into aspects of bubble/plume models that did not apply to cumulus clouds: clouds were observed to mix with their environments (entrainment), go through life cycles, have strong downdrafts in addition to updrafts and when larger contained cores relatively protected from mixing with the environment. More important progress was made when Riehl and Malkus postulated that a relatively small sample of about 1500 - 5000 undiluted cloud "towers" (cores) in the deep tropics is responsible for the transport of heat towards the upper atmosphere, where it can be transported poleward, which is necessary to warm other parts on Earth that receive less energy from the sun.

With the establishment of this picture, clouds became a crucial component of the dynamics of the atmosphere as a whole and the need for including them in global models was clear. In the first GCMs, clouds were only crudely treated, such as by prescribing a constant zonal mean cloud distribution. However, the current generation of GCM's include parameterizations that predict cloudiness in every gridbox at every time step. These parameterizations have grown increasingly detailed, and thus complex. An important question that we face today is therefore, do these parameterizations collectively lead to modeled clouds that exert the right effects?

Moving into the second part of the lecture, the current uncertainties in the representation of clouds in GCMs in terms of future climate predictions are discussed. What separates high climate sensitivity models from low climate sensitivity models are predominantly changes in cloud fraction at levels below 800 hPa, in particular in regimes that experience moderate subsidence or weak rising motion (subtropical oceans). In my work I ask how shallow cumulus clouds in such regions behave in response to a changing environment in observations and how global models compare. This question is answered through the use of a ground-based meteorological station at Barbados, which provides a high resolution long time series of cloudiness, temperature and humidity profiling. These data are compared against single-timestep output of CMIP5 models and the IFS at a single gridpoint near Barbados. The comparison shows that models tend to produce a reasonable trade-wind layer structure, for instance, the shallowness of the layer and partial cloudiness, as well as only modest changes in the cloud profile from one season to the next. However, they do so through unrealistic variability at shorter time scales. Models particularly vary the amount of cloud near the lifting condensation level, which in observations is relatively constant when averaged on time scales of a few days or longer. This invariance relates to a negative feedback mechanism through convection itself. Models instead show a larger co-variability between cloudiness at this level and the relative humidity of the mixed-layer and the temperature stratification across the mixed layer top/the cloud base. This hints that models are too sensitive to the changes in the large scale flow and do not reproduce the processes that control cloudiness in these regions in nature.

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