Modeling the Sensitivity of Convection to Tropospheric Humidity

ARM CLIMATE RESEARCH FACILITY

Research Highlight

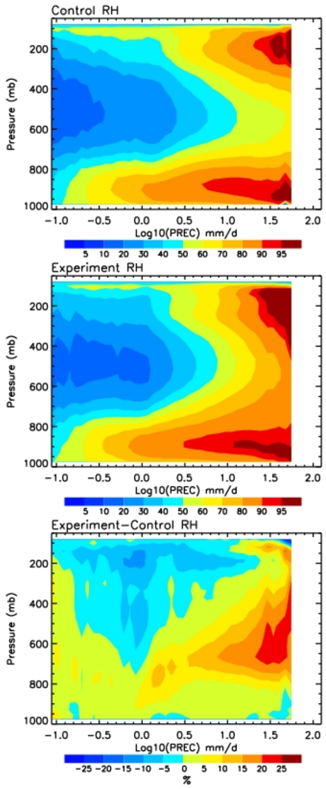
Among the most important uncertainties in global climate models are those involving moist convection. Convection affects the atmosphere via its vertical redistribution of heat, moisture, condensate, and momentum; the precipitation it produces and latent heat it releases; and the resulting anvil and cirrus clouds it generates. Cumulus parameterization has been a priority of model development for decades, yet progress has been very slow. A new review paper focuses on what may be the most important shortcoming of current parameterizations: the extent to which convection interacts with water vapor.

Several years ago Brian Mapes and colleagues suggested a "stretched building block" paradigm as a useful way to think about convection on many times scales. Over the lifetime of an individual convective cluster (12-24 hours or so), there is typically a progression from shallow/congestus clouds that heat and moisten the lower troposphere, to deep convective clouds that heat the entire troposphere, to a final stage of mesoscale organization characterized by upper level stratiform rain and anvil heating, lower-level rain evaporation cooling, and drying of the troposphere. Mapes et al. argued that on longer time scales up to several months on which various large-scale oscillations occur, the evolution of convection could be viewed simply as a modulation of the frequencies of occurrence of these three basic convection building blocks.

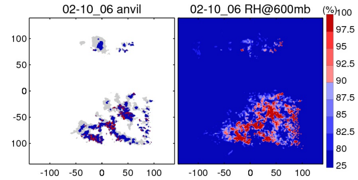
Viewed from this standpoint, it is easy to see why GCMs continue to have difficulty simulating observed convective variability. Historically, cumulus parameterization has focused on individual deep convective cells (the second building block) and devoted less effort to the earlier shallow/congestus and later stratiform phases. It was believed that deep convection interacted weakly with the environment around it, and thus that how humid the troposphere is mattered little. Several papers have made clear, though, that the depth and organization of convection is quite sensitive to the humidity of the environment. Ignoring this sensitivity may explain why current climate models incorrectly simulate the diurnal cycle of continental precipitation and major modes of tropical variability such as the Madden-Julian Oscillation. It may also explain why high cloud and water vapor feedbacks are similar in the models – we are all making the same mistakes.

Modelers are now beginning to pay attention to the other two building blocks of convection. In recent years there has been a renewed emphasis on the entrainment of environmental air into convective updrafts. GCM simulations can sometimes be improved merely by strengthening a specified entrainment rate, but a predictive capability for climate change necessitates a physically based representation of entrainment that responds to changes in the environment and the properties of the convective parcel. Several such formulations have been proposed and implemented in CMIP5 models (GISS, MIROC), but fundamental observational constraints on the entrainment process remain elusive.

Not only does the environment affect convection, but convection modifies the environment as well through the evaporation of falling precipitation. Models with stronger entrainment and rain evaporation have a stronger variation in mid-troposphere humidity between lightly and heavily raining situations (Figure 1), consistent with ARM soundings at Nauru Island analyzed by Christopher Holloway and David Neelin. For many models this is a predictor of whether the model simulates the Madden-Julian Oscillation well. Such models are better able to produce shallow convection when the column is dry and moistens the atmosphere rather than raining heavily and drying it immediately, thus delaying the onset of disturbed conditions.



Composite vertical profiles of relative humidity versus precipitation for a version of the GISS GCM that does not produce an MJO (upper panel), a version with stronger entrainment and rain evaporation that does produce an MJO (middle panel), and the difference between the two (lower panel).



Simulations of convective cluster structure during the TWP-ICE monsoon break period by the WRF model at cloud-resolving (600 m) resolution. Left: Cloud classification mask, with red = deep convective updrafts, blue = transition region, gray = stratiform rain region. Right: Corresponding 600 mb relative humidity field.

Improving the GCM diurnal cycle of precipitation also depends on entrainment, since GCMs rain too early in the day, but entrainment alone does not solve the problem. The missing ingredient is mesoscale organization of convection. GCM downdraft parameterizations immediately mix cool downdraft air with undisturbed warm moist boundary layer air, thus stabilizing the column and shutting down the convection. In reality, downdraft cold pools remain distinct for hours and lift undisturbed boundary layer air at their edges, promoting further deep convection. In cloud-resolving models the air around the updraft is more humid than the average environment (Figure 2), making deep convection more likely. Furthermore, convective air that detrains into a humid upper troposphere is more likely to organize on the mesoscale, shifting the diurnal cycle peak to later times.

ASR science has much to contribute to these research frontiers. Recent ARM field experiments such as MC3E and AMIE, and continued analysis of the TWP-ICE and AMMA data sets, promise to produce important insights that will help modelers advance the state of the art in cumulus parameterization.

Reference(s)

Del Genio AD. 2011. "Representing the sensitivity of convective cloud systems to tropospheric humidity in general circulation models." Surveys in Geophysics, , doi:10.1007/s10712-011-9148-9.

Contributors

Anthony D. Del Genio, *NASA*

Working Group(s)

Cloud Life Cycle