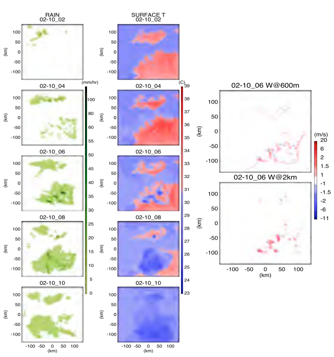
Cold Pools --- a First Step in Representing Convective Organiztion in GCMs

Anthony Del Genio[1] ***Mao-Sung Yao[2]*** ***Jingbo Wu[3]*** ***Audrey Wolf[3]***

[1]NASA GISS, New York, NY [2]Trinnovim LLC, New York, NY [3]Columbia University, New York, NY

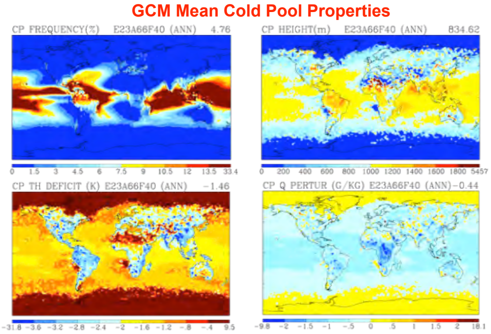
Introduction

Cumulus parameterizations often assume a quasi-equilibrium between a destabilizing large-scale flow and a stabilizing convective response. Stabilization is often accomplished in these schemes by downdrafts that bring low moist static energy air to the boundary layer and mix it with existing warm, humid air. In reality, though, cold downdraft air remains distinct for hours and spreads as a cold pool, forcing convergence at its leading edge that lifts the ambient air and regenerates convection there. An example of this evolution in the rain, surface temperature, and vertical velocity fields from our TWP-ICE WRF simulations (Del Genio et al. 2012) is shown below. Cold pools introduce "memory" into the system, create departures from quasi-equilibrium, extend convection to later times of day, and begin the process of mesoscale organization.



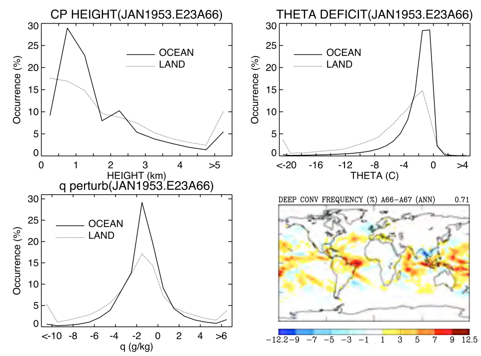
We are developing an intermediate complexity parameterization of cold pools for the GISS GCM. It assumes a well mixed cold pool that is initiated at the PBL depth when cold downdraft air enters the PBL. The cold pool area increases at a rate determined by the virtual potential temperature contrast between the cold pool and undisturbed PBL air, and the depth evolves based on deepening by subsequent injections of downdraft air and shallowing by the cold pool spread. Thermodynamic properties of the cold pool evolve according to the properties of the added downdraft air and a relaxation to the ambient PBL properties with a fixed relaxation time (3, 12 hr for ocean, land). The cold pool affects subsequent convection by (1) allowing updraft plumes to form from undisturbed PBL air, (2) lifting air over the cold pool depth at a fixed velocity, (3) a reduced entrainment rate experienced by any such plumes.

GCM Mean Cold Pool Properties



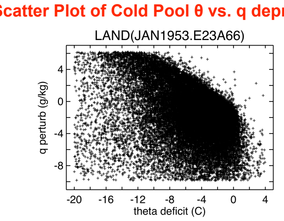
Cold pools form in the GCM primarily over the tropical oceans, and secondarily over tropical land (especially the Maritime Continent and Amazon Basin) and the midlatitude storm tracks. They are infrequent over the U.S. except for the southeast. Cold pools are deepest over the continental ITCZ and warm pool, a bit less deep over other ocean areas, and shallowest at the convective margins. Relative to ambient PBL air, cold pools are coldest and driest over the continents and only moderately colder and drier over the oceans.

Cold Pool Statistics from GISS GCM



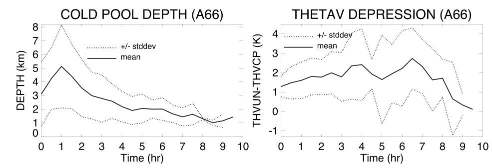
The properties of cold pools in the GCM are not surprisingly very sensitive to the properties of convective downdrafts and thus might be used to inform downdraft parameterization. In our initial tests, cold pools formed very infrequently and were extremely shallow because downdrafts often did not reach the boundary layer and often had a weak mass flux when they did. To increase the downdraft mass flux into the PBL, we (1) assumed that downdrafts form from cloud-environment mixtures that maximize negative buoyancy rather than equal mixtures, and (2) increased the entrainment rate into downdrafts from 20 to 50%/km. This sometimes produced cold pools with unrealistically cold θ_v, so we also limited rain evaporation in the downdraft to 10% of the precipitating condensate per layer. The resulting pdfs of cold pool properties (above) indicate that very deep, cold, and dry cold pools are more frequent over land than over ocean, which appears to be consistent with (admittedly anecdotal) field experiment and CRM inferences, although some are still too extreme to be plausible. The majority of cold pools are dry, but a non-negligible fraction are moist, also a seemingly realistic result. Deep convection occurrence frequency increases by ~10% relative to its GCM climatological value in the absence of cold pools, suggesting that a modest amount of gust front regeneration of convection may be occurring.

Scatter Plot of Cold Pool θ vs. q depression



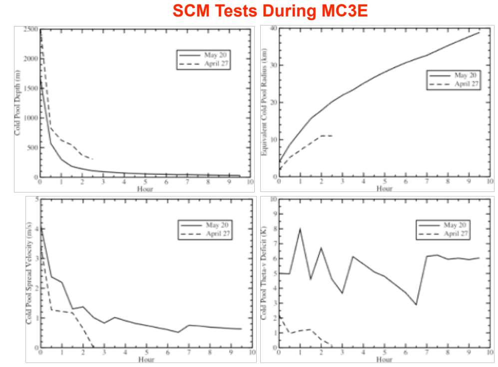
Cold pool θ and q depressions relative to ambient PBL air are noticeably negatively correlated over both land and ocean (only the land result is shown above). Thus the primary contribution to cold pool variability is apparently due to varying degrees of rain evaporation, presumably associated with cold pools that form in environments with varying relative humidities and lapse rates. Superimposed on this, however, is a considerable degree of scatter. Based on anecdotal inspection of individual cases, we believe this to be due largely to downdrafts that form at different altitudes and thus have more or less opportunity to develop significant contrasts in their thermodynamic properties relative to those of the boundary layer. Note also that a small but non-negligible fraction of cold pools are physically warmer than the ambient boundary layer. Most of these are associated with large q depressions, so that cold pool θ_v is still smaller than that of the environment, i.e., the cold pool is denser than its surroundings even though it is warmer. This occurs approximately whenever $|\Delta q| > \Delta\theta/\theta$, which amounts to a q depression of ~3 g/kg per 1 K cold pool warm anomaly. Likewise, anomalously moist cold pools can also occur in combination with large temperature depressions. Exceptions to these are most likely former cold pools that are on the verge of terminating.

Amazon Basin Cold Pool Evolution



We sampled a 5-day period in January during which the GCM produced 25 distinct cold pool events that lasted for at least 4 hr. The figure above shows the mean ± standard deviation of cold pool depth evolution with time of these 25 events. On average cold pools deepen during the first hour as downdraft mass is added and then decay after that, but remain deeper than 2 km for many hours thereafter, which may contribute to whatever convective regeneration the parameterization produces. Some of the initial cold pool depths are unrealistically large, because we do not have a physically intuitive way to initialize the depth. For these cases, on average the θ_v depression maximizes ~4-7 hr into the lifecycle and decreases rapidly after that.

SCM Tests During MC3E



We tested the cold pool parameterization using the GISS SCM forced at the SGP with the constrained variational analysis produced for the MC3E IOP. Convection at the SGP is difficult to initiate and maintain since it propagates into the domain (which an SCM cannot simulate) rather than being triggered *in situ*. The convective events that form tend to have weak mass fluxes and thus cold pools quickly become shallow and are ineffective at regenerating convection. Some improvement occurs if we increase the convective adjustment time from 1 to 5 hr, but even the best examples for two major MC3E rain events (May 20 and April 27) shallow quickly, do not grow to large size, and spread slowly, although they have reasonable intensity. Imposing a uniform 300 mb lifting of parcels after cold pool formation to mimic the effect of low-level wind shear has no effect.

Conclusions

✧We have implemented a relatively simple parameterization of convective cold pools and their effect on convection in the GISS GCM.

✧ Cold pools are most frequent over the tropical oceans and less frequent over tropical land, but the deepest, strongest ones are continental. GCM cold pools are infrequent in the extratropics except in the storm tracks.

✧ There is some evidence that cold pools extend the lifetime of GCM convective events, although premature triggering of deep convection over land still occurs and biases the diurnal cycle.

✧SCM tests at the SGP during the MC3E IOP are less successful than the behavior of the GCM. Cold pools rapidly decay in depth and have no effect on convective lifetime. The situation slightly improves when we increase the convective adjustment time but deepening of parcel lifting that mimics the effect of wind shear has little effect. This may be a by-product of the organized convection sampled by MC3E, which propagates into the domain rather than being forced locally (as parameterizations assume).