THE DIURNAL CYCLE OF CONTINENTAL CONVECTION

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Cloud-Resolving Model

GCM Parameterization Developer
~ 1 GCM gridbox

courtesy M. Khairoutdinov
Continental rainfall rates tend to peak in mid-late afternoon or evening

Time of peak rainfall, TRMM PR

Hirose et al. (2008)
But not in GCMs, which like to rain near noon

Eta, GFS 36-60 hr US forecast (Janowiak et al., 2007)

IPCC AR4 models (Dai, 2006)
Many factors influence the timing of continental precipitation (Nesbitt and Zipser, 2003; Yang and Smith, 2006; Sato et al., 2009; etc.):

- External factors (land-sea breeze, monsoon, topography, low level jet, etc.) – in principle can be resolved by GCMs

- Physics of convective cloud systems (triggering, entrainment, downdrafts, mesoscale organization, propagation) – parameterized in most GCMs

Let’s focus on entrainment and downdrafts – what can CRMs tell us?
GCM cumulus parameterizations are not sensitive enough to free troposphere humidity to capture the transition from shallow to midlevel to deep convection (Derbyshire et al., 2004)

Need stronger entrainment, decreasing as convection deepens (Grabowski et al., 2006; Kuang and Bretherton, 2006; Khairoutdinov and Randall, 2006)
MJO shallow-deep transition controlled by entrainment of dry vs. humid air into rising cumulus clouds?

Fig. 10 Relative frequency of occurrence (RFO) of each cloud regime at seven lag periods in pentads of eight MJO events in 4 November–April periods from 1999 to 2003. The color scheme for the cloud regimes is the same as in Fig. 9.

red = deep convective
orange = anvil
yellow = congestus
green = thin cirrus
blue = shallow Cu
violet = marine Sc

(Chen and Del Genio, 2009)
GCM climate sensitivity is sensitive to entrainment due to shift in convection depth and detrainment of water vapor and condensate (Sanderson et al., 2008).
Monsoon break has continental-style diurnal cycle

Figure 2. Diurnal cycle of total rainfall of in situ observation from 7 full wet seasons (DJF, 2001-2008) at Darwin Australia and its categorization according to three phases of the MJO.

Rauniyar and Walsh (2009)
Once parcels penetrate CIN layer, undilute ascent would produce deep convection by noon; RH dry enough for entrainment to be a factor.
WRF simulation:

• Gradual transition from shallow to deep convection
• Precipitation and downdrafts intensify at ~ 2 PM
• Peak precipitation several hours later

(Del Genio and Wu, 2009)
Frozen moist static energy (Kuang and Bretherton, 2006): 
\[ h = c_p T + g z + L_e q_v - L_s q_i \]

Conserved for undilute ascent

\[ \frac{dh_u}{dz} = -\varepsilon (h_u - h_e) \] indicates effect of entrainment
Entrainment weakens as convection deepens...but how to predict that as parcel rises from cloud base?
Gregory (2001) entrainment rate parameterization:

\[ \varepsilon(z) = \frac{CB}{w^2} = \frac{Cg \left( \frac{T_v'}{T_v} - q_h \right)}{w^2} \]

Evaluation using WRF B, w, and inferred \( \varepsilon \) in convective cells: Gregory scheme works if \( C \) (fraction of buoyant TKE generation used for entrainment) increases with \( z \)

Note: Bechtold et al. (2008) (\( \varepsilon = f(RH) \)) – currently used in ECMWF IFS – does not reproduce the WRF behavior
Convective cluster structure and lifecycle

Zipser (1977)
TRMM lifecycle composites: Rain peaks in mature stage; mature stage in late afternoon-early evening, ~6-8 hr after onset
(Futyan and Del Genio, 2007)

How can we sustain convection in GCMs?
Downdraft cold pools converge high-MSE air at gust front

Khairoutdinov and Randall (2006)
Largest cloud base $w$ in deep convective cells, coincident with downdrafts and cold pools – $\varepsilon \sim 1/w^2$ in Gregory scheme.
Conclusions

• GCMs rain too early in the day over land

• Entrainment too weak for proper sensitivity to environmental humidity

• Gregory (2001) entrainment parameterization simulates shallow-deep transition timing well

• Need to sustain deep convection for ~6-8 hr after onset to get right timing of rainfall peak

• Downdraft cold pool effect on cloud base is important for smaller entrainment rate of deep convection?
TWP-ICE Experiment

WRF 600 m/50 L resolution simulations of monsoon break
Bechtold et al. (2008)
Detection and tracking of tropical convective clusters

GERB OLR thresholds define cluster; track via maximum overlap

Evolution of cluster radius and height defines lifecycle phases

Futyan and Del Genio (2007)

*** Possible only with geostationary data ***
Mapping of non-geostationary low earth orbit data (TRMM) onto geostationary lifecycle phase allows composite lifecycle to be constructed.

Example: Cluster in mature phase passing over AMMA site.