The role of tropospheric humidity and stability on the detrainment of deep convection.
“Entrainment, but what about Detrainment?”

Pier Siebesma, Steef Boing, Dirk-Jan Korpershoek, Roel Neggers and Harm Jonker
Motivation

Derbyshire et al. QJRMS (2004)

New ECMWF entrainment parameterization (Bechtold 2008  QJRMS)

\[ \varepsilon = \varepsilon_0 \left( 1.3 - RH(z) \right) f_{scale} \]

Larger entrainment rates: lower cloud top height.

Is this justified?
\[ \frac{\partial}{\partial z} \ln M = \epsilon - \delta \]

• Fractional inflow rate \( \epsilon_0 \)

• Assume uniform distribution of all possible mixtures
  (Bretherton et al. MWR 2004,
  Raymond & Blyth JAS 86)

• Entrainment/Detrainment rate dependent on buoyancy
Kain_Fritsch mixing (2) (Kain Fritsch JAS1990)

\[
\epsilon = 2 \int_0^{\chi_c} \chi p(\chi) d\chi = \epsilon_0 \chi_c^2
\]

\[
\delta = 2 \int_{\chi_c}^{1} (1-\chi) p(\chi) d\chi = \epsilon_0 (1-\chi_c)^2
\]

\[
\frac{\partial}{\partial z} \ln M = \epsilon_0 (2\chi_c - 1)
\]

\[
\chi_c = \left( \frac{c_p \pi}{L} \right) \frac{\Delta \theta_v}{q_{se}(\beta - \alpha)(1 - RH) - \alpha q_{lu}}
\]

\[
\Delta \theta_v \uparrow \Rightarrow \chi_c \uparrow
\]

\[
RH \uparrow \Rightarrow \chi_c \uparrow
\]

De Rooy and Siebesma MWR 2008
Incorrect sensitivity for entrainment in plume models

Larger RH $\Rightarrow$ larger $\chi_c$ $\Rightarrow$ higher entrainment $\Rightarrow$ lower cloud top

But what about detrainment...?

Deep Convection: the case

Similar set up as in: Wu, Stevens, Arakawa JAS 2009

• Domain Size 75X75X25km
• $\Delta x=\Delta y=150m$ $\Delta z=40\sim190m$
• Fixed surface fluxes:
  • LHF $\sim350W/m^2$
  • SHF $\sim150W/m^2$
• No windshear
• No radiation

Most cases repeated 5 times with different random initialisation (200 simulations)
Time evaluation of entrainment and detrainment

Concentrate on 7th and 8th hour
moister

More unstable

entrainment and detrainment (hour 7 & 8)
• Detrainment decreases with increasing humidity
• Detrainment decreases with increasing instability
• Variations of Entrainment small........compared with the variations of detrainment
entrainment and detrainment (2000~3000m)

• Entrainment decreases with increasing RH, instability .... But differences are much smaller
Precipitation and cloud top height increase with increasing RH, instability.

Cloud height $\sim 0.01 M_{\text{max}}$

![Graph showing precipitation and cloud height variations](image)
How about $\chi_{\text{crit}} (2\sim 3 \text{km})$?
$\chi_{\text{crit}}$ as the key parameter (2~3km)

\[
\frac{\partial}{\partial z} \ln M = \epsilon - \delta
\]

\[M \equiv \rho_0 \sigma w_c\]

Variation due to cloud core fraction or due to incore vertical velocity?
Cloud fraction and vertical velocity

\[ \frac{\partial}{\partial z} \ln M = \frac{\partial}{\partial z} \ln \sigma + \frac{\partial}{\partial z} \ln \rho_0 + \frac{\partial}{\partial z} \ln w_c \]
Simplified Physical Picture
The simplest mass flux parameterization

- Directly parameterize $\frac{\partial}{\partial z} \ln M = \epsilon - \delta$ as a function of $\chi_c$
- Use $\chi_c$ between 2 and 3 kilometers
- Fit: using relation between $\chi_c$ and $\epsilon - \delta$ below $z/z_{\text{top}} = 0.5$
- Cloud top requires separate parameterization

- Fit: $\delta - \epsilon = 0.003 - 0.006 \chi_c$
What about entrainment?
Conclusions and outlook

• Strong dependency of moist convection on tropospheric relative humidity and stability

• Mostly related to detrainment and due to the cloud height distribution

• Allows for simpler and more realistic convection parameterization (get around detrainment)

• No need to separate shallow and deep convection

• We are only beginning to constrain deep convection parameterizations

• More systematic exploration of the phase space is needed (and can be done)
Outlook

- Bulk parameterizations of Mass flux
  \[
  \overline{w'\phi'} = -K \frac{\partial \overline{\phi}}{\partial z} + M(\phi_c - \overline{\phi})
  \]

- Multiplume parameterizations
  \[
  \overline{w'\phi'} = -K \frac{\partial \overline{\phi}}{\partial z} + \sum_{i=1}^{l} M_i(\phi_i - \overline{\phi})
  \]

- Use cloud size distribution shape as (only) closure

- HOC?