Assessment of the relevance of the mass fluxes used in Emanuel's convection scheme

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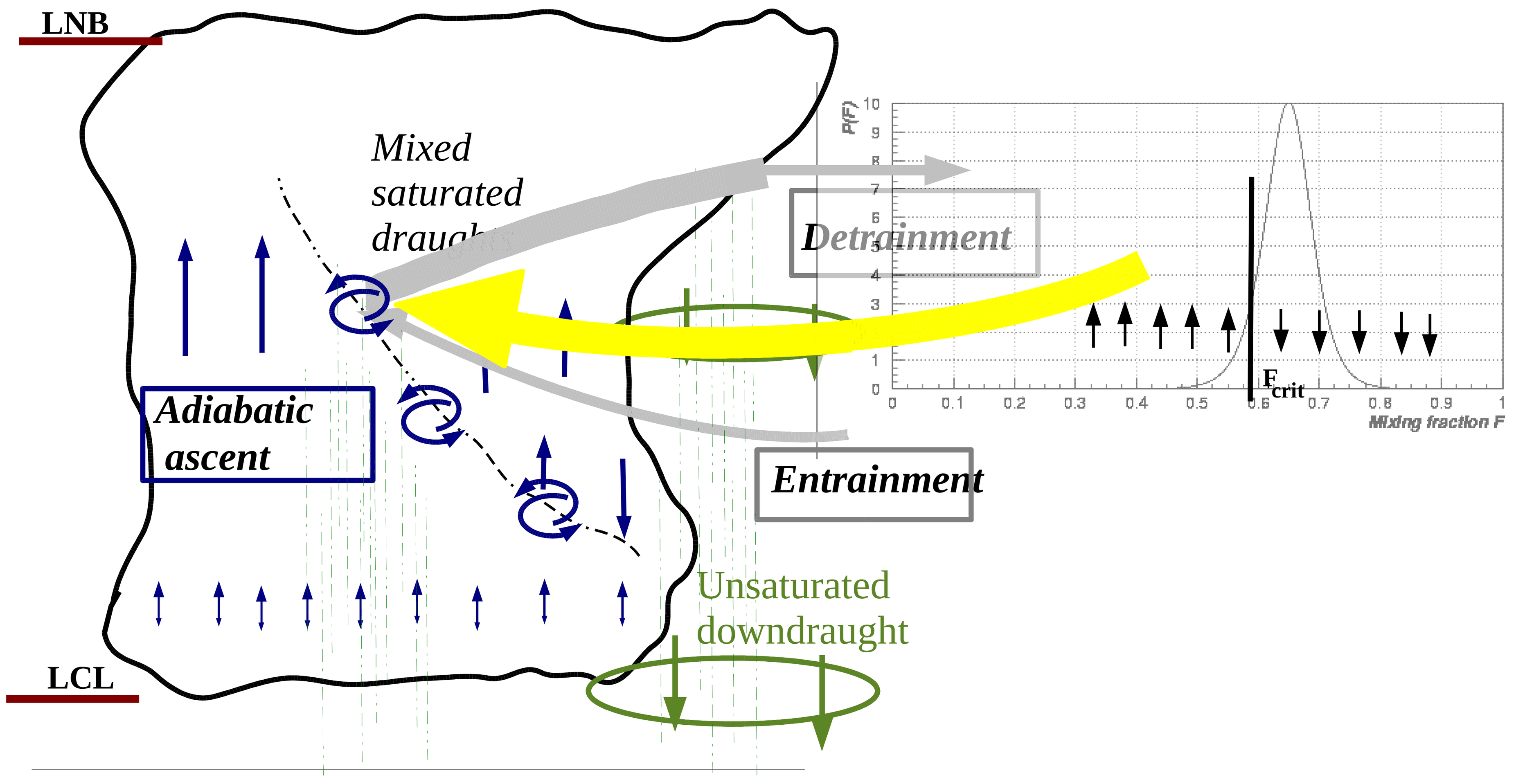
Introduction

Mass fluxes are key variables in many convection parametrizations. Unfortunately these fluxes are internal variables and come into play only indirectly through their effect on large scale variables. Thus the comparison with CRM results is far from trivial.

Yano et alii (2004) propose an "effective mass flux" approach to improve convection parametrizations.

Here we consider a mere diagnostic tool based on the definition of statiscal quantities that make sens for both CRMs and parametrizations (and, hopefully, for observations): the **mass flux spectra** with respect to transported quantities (we shall limit ourselves to water transport).

Emanuel scheme



Analysing mass flux spectra wrt transported quantities

Method: at any given altitude z, build weighted histograms H of the transported variable (say q_t). The value H of the histogram in the bin $[q_t, q_t + \delta q_t]$ reads:

$$H_{[q_t,q_t+\delta q_t]} = \sum_{q_t < q_{ti} < q_t+\delta q_t} W_i$$

the weights W_i being: (i) for CRMs, the mass flux ($\delta M_i = \rho_i \; w_i \; \delta x \; \delta y$) in each grid box whose water content lies in the bin; (ii) for SCMs, the mass flux M_j whose water content q_{tj} lies in the bin.

In order to deal with positive densities, separate histograms are made for positive and negative mass fluxes.

Finally, this yields two densities $\frac{dM^+}{dq_t}$ and $\frac{dM^-}{dq_t}$ such that the transport flux Φ_q reads:

$$\Phi_q = \int q_t \frac{dM^+}{dq_t} dq_t - \int q_t \frac{dM^-}{dq_t} dq_t$$

Emanuel scheme structure

The convective clouds are represented by **multiple buoyancy sorted saturated draughts** (both ascending and descending).

The backbones of the convective clouds are regions of **adiabatic ascent** originating from some low-level layer and ending at their level of neutral buoyancy (LNB).

Shedding from adiabatic ascents $\longrightarrow$ at each level, set of **mixed draughts** which are mixtures of adiabatic ascent air (from which some precipitation is removed) and environmental air.

Mixed draughts move adiabatically up or down to levels where, after further removal of precipitation and evaporation of cloudy water, they are at rest at their new levels of neutral buoyancy.

There is one single **unsaturated downdraught**. It is parametrized with an entraining plume model driven by the evaporation of precipitation.

The version of Emanuel's scheme used here is derived from a code delivered by K. Emanuel in 1995, which implements a model very similar to Emanuel (1993) model. Our version differs from Emanuel's in the removal of most explicit grid dependencies $\longrightarrow$ smoother variation of convection intensity with time and a weaker dependence on vertical resolution.

Two mixing laws

In the standard versions of Emanuel scheme, at each entrainment event, the generated mixed draughts obey a probability law whose density is uniform in terms of the mixing fraction F of environment air.

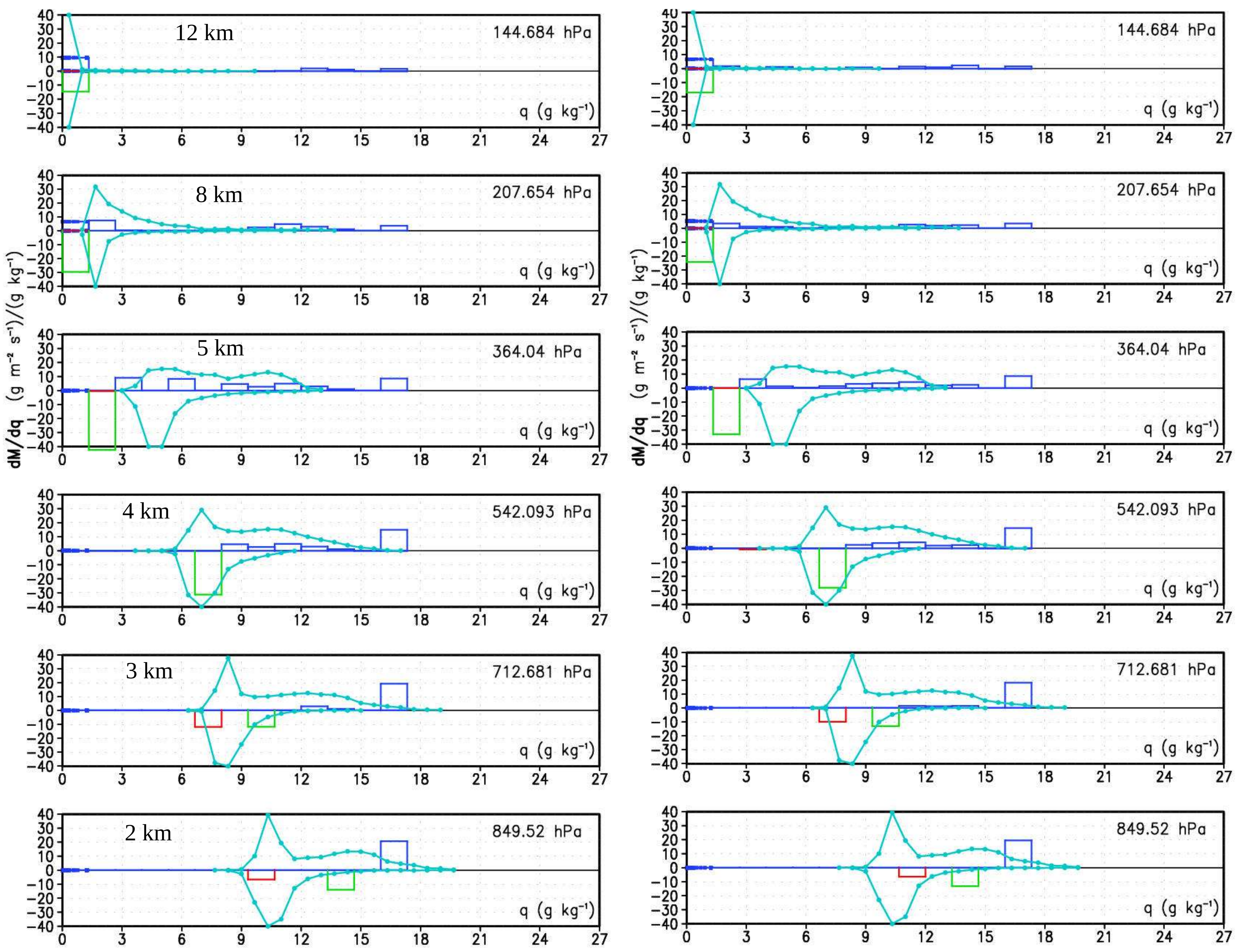
The present scheme has been modified during EUROCS project in order to use various mixing probability laws (Derbyshire et alii, 2004; Grandpeix et alii, 2004). We shall compare results obtained with the **standard uniform density** with results obtained with a **bell shaped density** (centered at $F = 0.65$ with width 0.05) which improved the sensitivity of the scheme to environment humidity.

Comments

The two plots on the left display CRM and SCM results (with the two mixing probability laws) at a time of maximum convection, that is at times 24 h for the SCM and 30 h for the CRM during simulations of GCSS case 2 (TOGA COARE, December 1992).

- **CRM simulations display mass flux spectra spanning a whole range of q_t, as do the multiple mass fluxes of Emanuel scheme.**
- there is no trace of any adiabatic ascent in CRM simulations.
- CRM simulations display often a peak in the updraught spectrum located close to environment humidity. This feature is absent from SCM simulations except above $z = 8km$.
- clearly there are not enough mixed draughts at low levels in SCM simulations.
- the bell shaped distribution is in better agreement with CRM results, as it was in EUROCS case study.

Mass flux spectral density with respect to q_t



Bell shaped mixing probability density — Uniform mixing probability density

Saturated draughts (adiabatic ascent, with constant q_t, on the right; mixed draughts spreading down to environment q)
Environment
Precipitating downdraughts (only q is taken into account; adding q_l shifts the signal by 10 g/kg)
CRM results

Conclusion

The multiple mass fluxes used in Emanuel scheme appear to correspond to existing features of CRM simulations.

The method of mass flux spectrum analysis appears to yield another measure of the departure between CRMs and convective parametrizations.

There remain to apply the same method to observations.

References: Derbyshire et al., QJRMS (2004), 130, 3055-3079.
Grandpeix et al., QJRMS (2004), 130, 3207-3222.
Emanuel, AMS Meteor. Monographs (1993), 24 (46), 185-192.
Yano et al., JAS (2004), 61, 829-842.