Convective parameterization at $\sim$ 4 to 50km Some assumptions that breakdown

Bob Plant

Department of Meteorology, Reading

12th January 2011

The University of Reading

Traditional picture

Arakawa and Schubert (1974), Figure 1

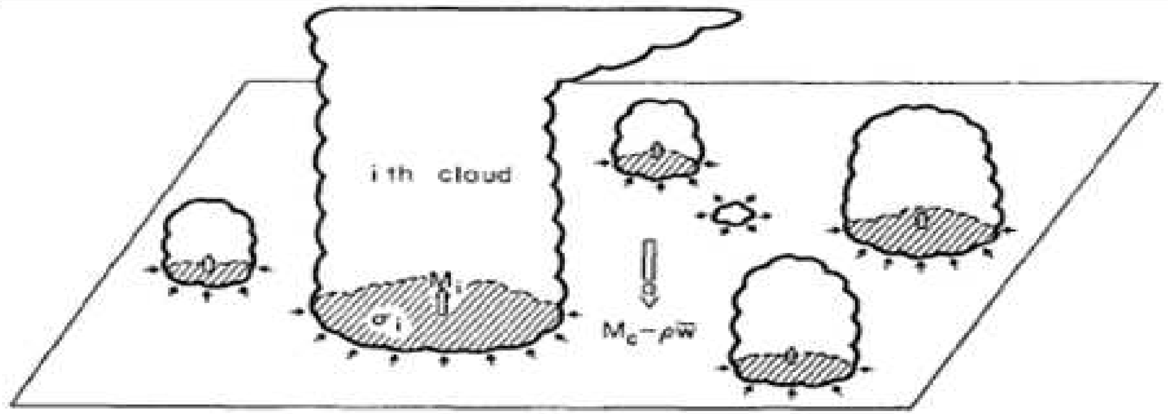
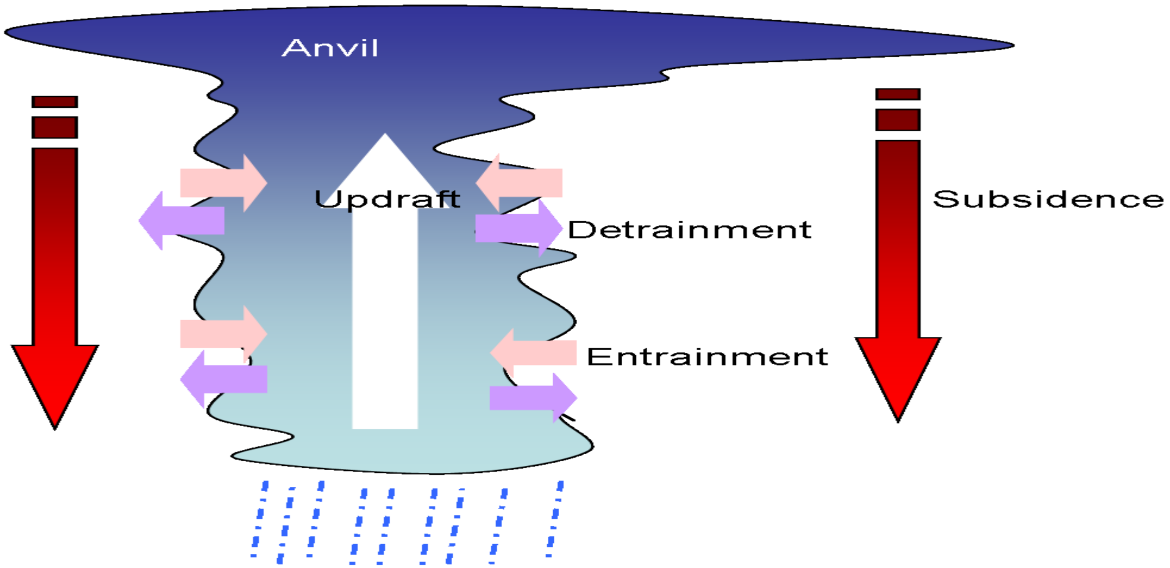


FIG. 1. A unit horizontal area at some level between cloud base and the highest cloud top. The taller clouds are shown penetrating this level and entraining environmental air. A cloud which has lost buoyancy is shown detraining cloud air into the environment.

- Convection characterised by ensemble of cumulus clouds
- Scale separation in both space and time between cloud-scale and the large-scale

The entraining/detraining “plume”



Key variable is the mass flux,

$$M_i = \rho A_i \overline{w}_i$$

$$\rho \overline{q'w'} = (1/A_{\mathrm{tot}}) \sum_i M_i (q_i - q_{\mathrm{env}})$$

Bulk parameterizations

- A common approach in practice (MetUM, ECMWF, WRF...)
- Start from the plume equations, and sum over plumes
- Get back essentially the same equations with in-plume values replaced by bulk values,

$$\chi_B = \frac{\sum_i M_i \chi_i}{\sum_i M_i}$$

Just one “bulk plume” now, so all is much simpler...

Ingredients I

- Everything is local to the grid box
  - i.e. grid-box state assumed to be a decent approximation of the "large-scale" state
  - Breaks down as Δx approaches cloud scales
  - May need some communication with neighbouring grid points
  - Horizontal fluxes may become important
- Clouds in the ensemble assumed non-interacting except via a homogeneous environment
  - We do not attempt to represent any sub-grid organization
  - Is it possible to devise a self-consistent picture of organization as Δx changes?

Ingredients II

- Assume a closure for the mass flux at cloud base
  - Equilibrium closures likely to break down as Δx decreases
  - Is any existing diagnostic method more defensible than others as Δx decreases?
  - Is a prognostic closure (or some other memory component) necessary?
- Neglect cloud lifecycle: get rid of $\partial / \partial t$ in plume equations
  - Breaks down only as both $\Delta t / t_{\text{life}}$ and N_{clouds} become small

Ingredients III

- Sub-grid fluxes well approximated by mass flux formula
  - Mass flux has issues anyway, but do they become significantly worse as Δx decreases?
  - $\sigma \ll 1$ may not always hold as $\Delta x \rightarrow$4km
- Formulate the microphysics
  - Usually very simple. Does it need to be more complicated?
  - Answer may depend in part on other physics schemes and how important are the interactions with them?

Ingredients IV

- Specify entrainment and detrainment
  - More later today, I suspect...
  - Important to bear in mind whether it is for a bulk plume or a spectrum of plume types...

The trade-off for a bulk scheme

Worth revisting this issue at smaller Δx?

- It may be easier to set and to control the bulk entrainment $E = \sum_i E_i$ rather than specifying both the individual E_i and the spectral distribution of mass flux
- Simpler, and cheaper to run
- Requires large N_{clouds}
- Works because the plume equations are (almost!) linear

The price of a bulk scheme

- Linearity is needed in the microphysics and radiation terms
  - By construction, a bulk scheme is committed to having crude microphysics and cumulus-radiation interactions
  - If non-linear then need to know how cloud liquid water (say) is partitioned between the clouds
  - NB: to have a non-linear dependence of microphysics on w, no longer sufficient to deal with mass flux only, but also need its partition into σ_i and w_i

Other Issues

- I have focussed about deep convection, but how should we handle shallow convection, and how should the line between them be drawn?
- Stochastic effects from finite N_{clouds}
  (Plant-Craig is actually quite traditional in relying on equilibrium ideas. Going beyond that to say, a prognostic system, would need work but the main conceptual issue is how to develop the prognostic system, not how to develop the stochastic form of it)
- Is there really any meaningful scale separation at all?

General questions of approach

- Should we seek a better physical description of convection, with the hope that this leads to better resolved scale behaviour, or should we focus on specific systematic errors in the parent models?
- How far should we consider interactions of convection scheme with boundary layer, large-scale rain, radiation...?

Why have a parameterization?

1. To stop the model crashing!
2. Sub-grid scale phenomena important for resolved-scale behaviour

Aim today is to think about better methods for #2, but we shouldn't lose sight of #1