Basic convective element?

A review of literature describing building blocks of convective clouds

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https://www.youtube.com/watch?v=0YatiDf9A8A

Overview

1. Models based on similarity theory
2. Contemporary convection schemes
3. Observational evidence
4. Questions for discussion

Models based on similarity theory

"*History of convective elements*"

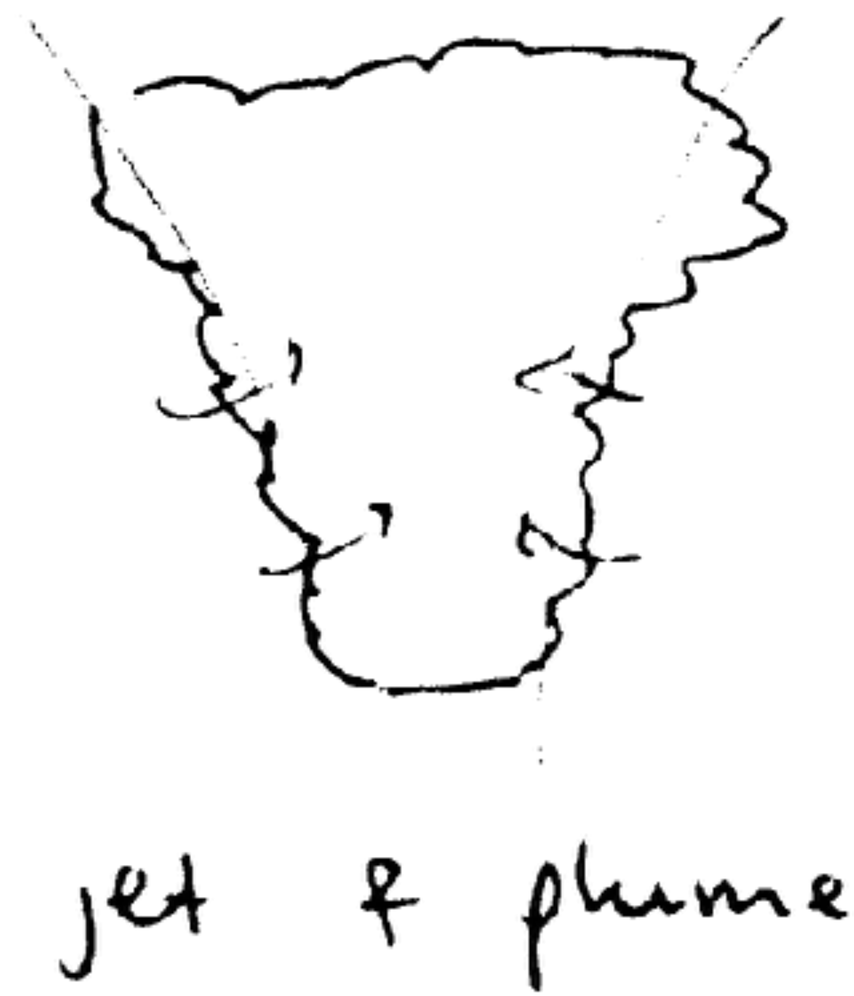
- Jet/plume
- Bubble
- Thermal
- Starting plume

Focus on *structure*, *transient vs steady-state* and *mechanism of entrainment*

Jet/plume (Morton 1956)

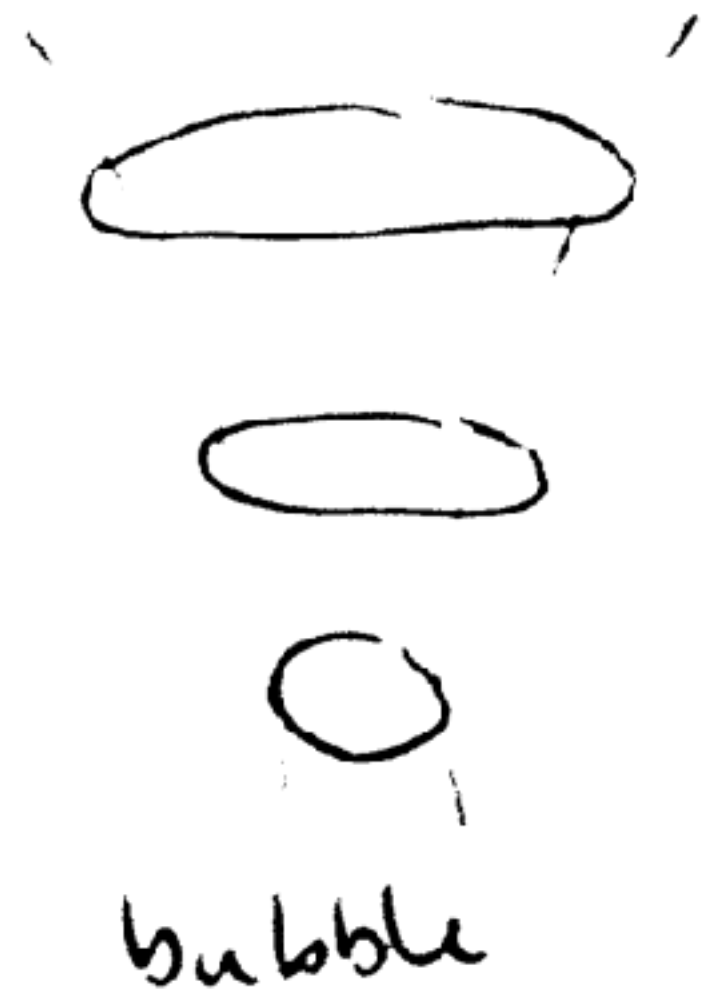
- steady-state
- inertia either from momentum (jet) or buoyancy (plume) at base
- similarity theory of plumes in stably-stratified environment until valid to neutral buoyancy height
- entrainment through plume edge, localised turbulent eddies

$$w_c \frac{Dw_c}{Dz} = B - \mu w_c^2, \mu \propto \frac{1}{r}$$



Bubble (Malkus & Scorer 1955)

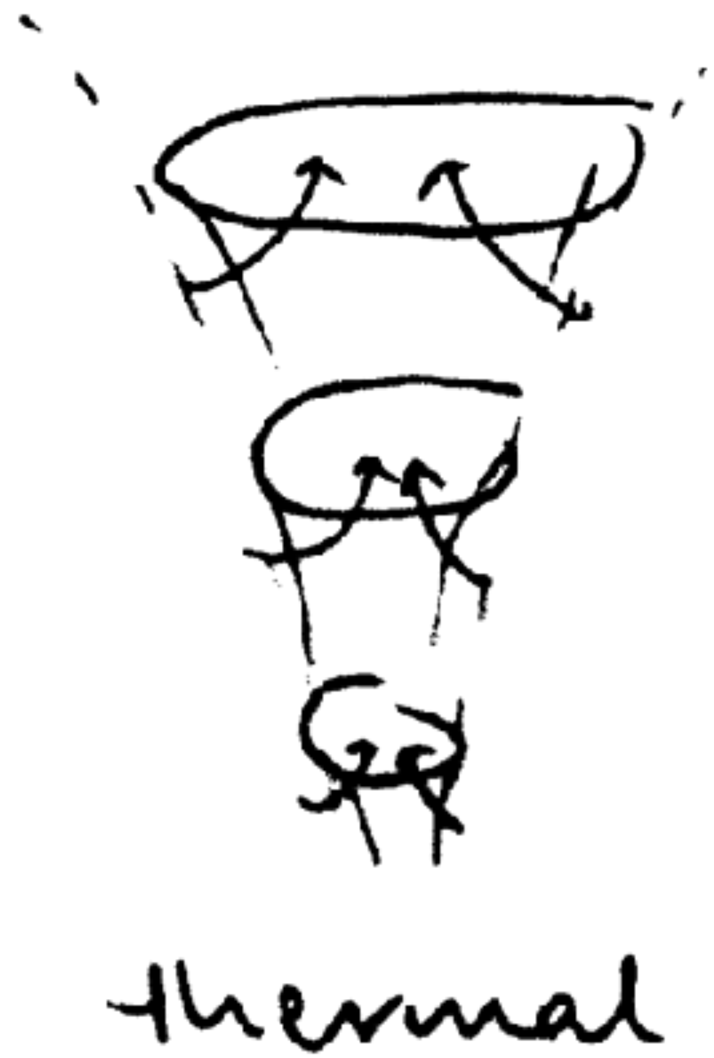
- transient rising bubbles
- assumed spherical in shape
- shrink as environmental air erodes bubble surface as air moves around bubble
- buoyant elements do not entrain, however drag term has same functional form



$$w_c \frac{Dw_c}{Dz} = B - D_B, D_B \propto A w_c^2 \text{ (A: area)} \Rightarrow D_B \propto \frac{1}{r} w_c^2$$

Thermal (Woodward 1959)

- transient, rising element
- entrains by engulfing air in large eddies
- ~3x faster entrainment rate than jet (according to Houze)
- mean motion similar to axisymmetric spheroidal vortex

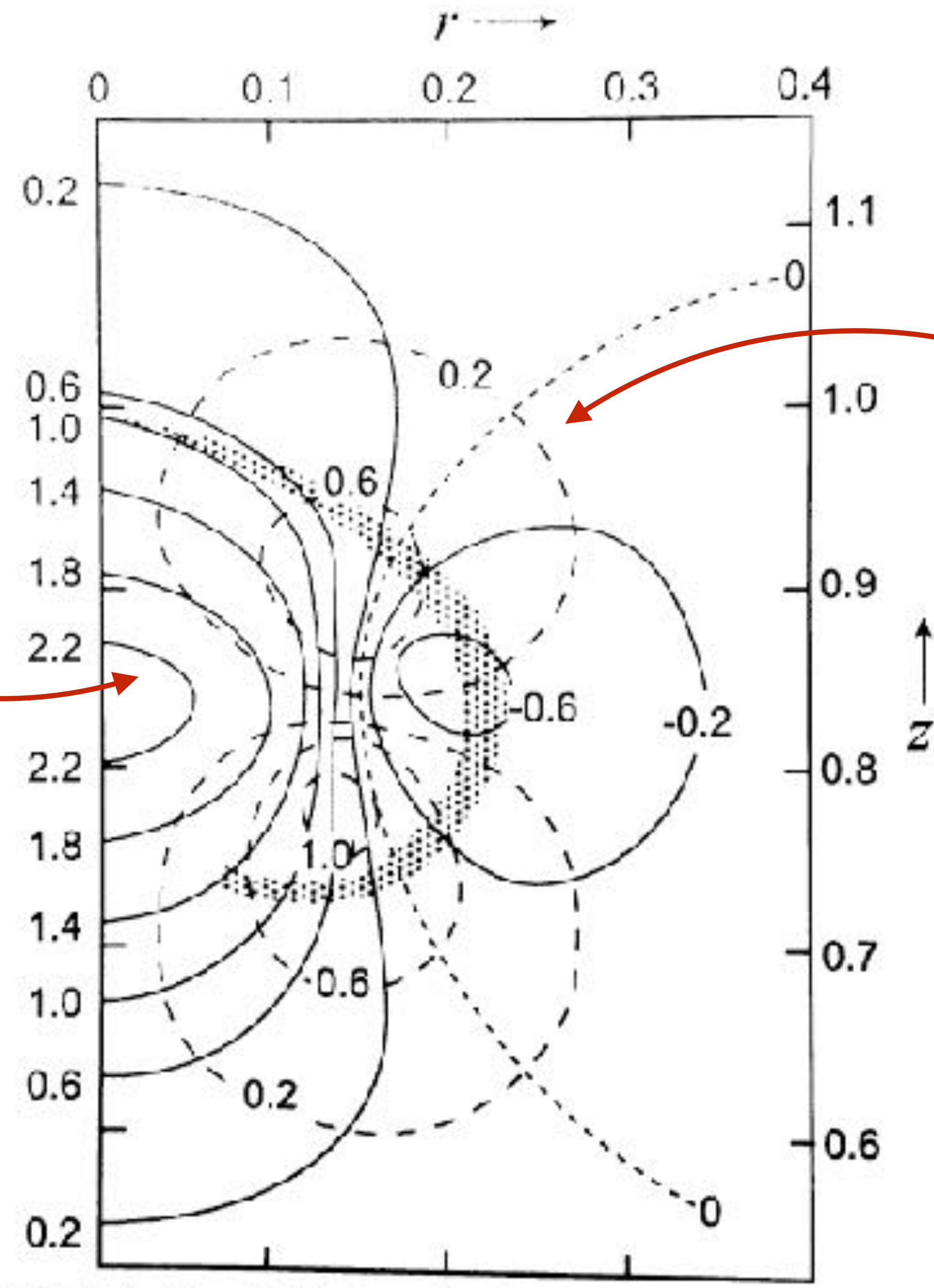


$$w_c \frac{Dw_c}{Dz} = B - D_B - \mu w_c^2$$

μ ~3x value for jet/plume

Thermal (Woodward 1959)

Vertical velocity contours



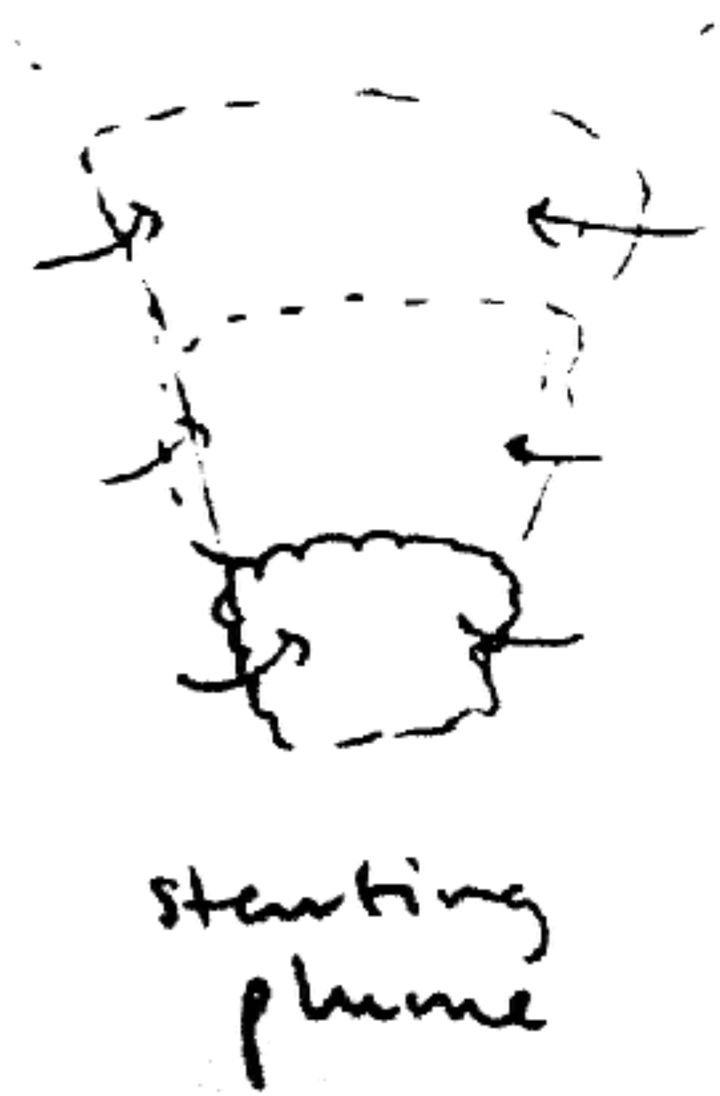
Radial velocity

FIGURE 7.8 The distribution of velocity in a laboratory thermal. The outline of the buoyant fluid is shaded. The values of the vertical velocities (solid lines) and radial velocities (dashed lines) are expressed as multiples of the vertical velocity of the thermal cap. *Adapted from Woodward (1959). Republished with permission of the Royal Meteorological Society.*

From Houze 1993

Starting plume (Turner 1962)

- Gaussian plume below rising cap (thermal-like top)
- transient to steady-state
- buoyancy reduced due to dilution from entrainment
- entrainment as for plume



Contemporary convection parameterisations

- Tiedtke scheme, ECHAM
  - Bulk entraining plume model
- Plant-Craig scheme, ICON
  - Multiple entraining plumes
- - ?, MetOffice
  - Bulk entraining plume model

Operational schemes are bulk entraining plume models. *I think* this because of convenience of model formulation, *not* because of physical evidence

Examining evidence for similarity-theory models

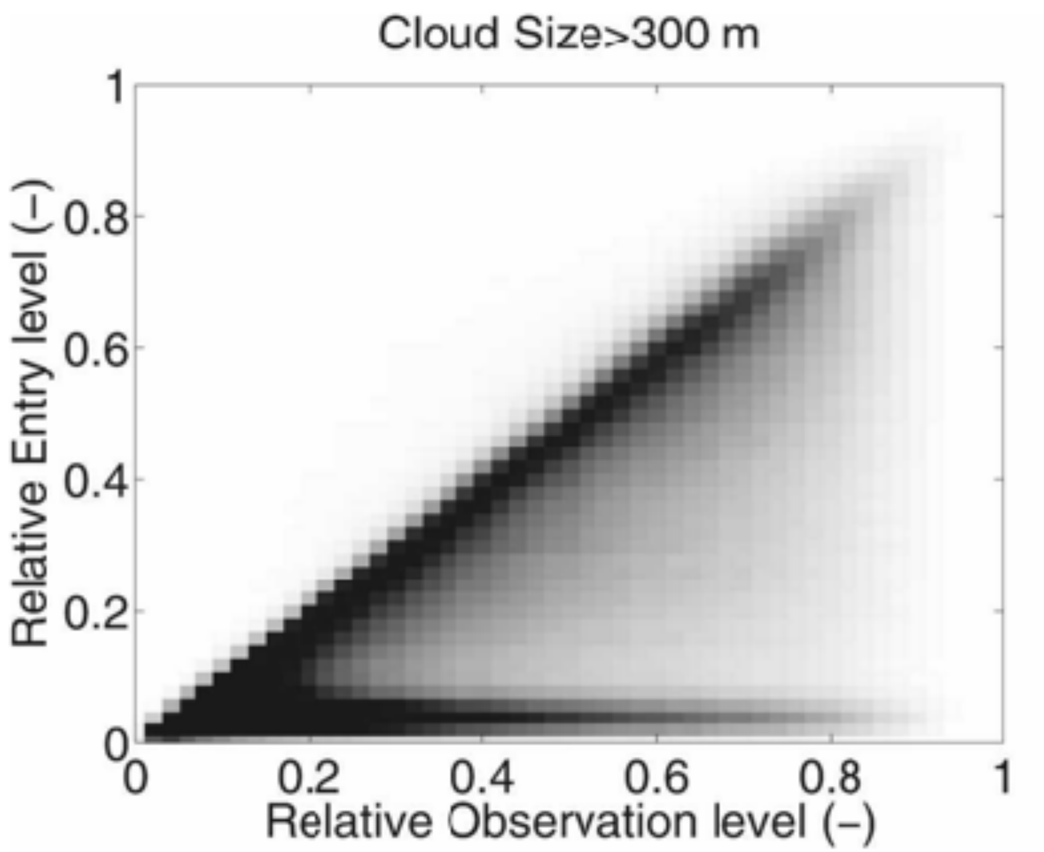
- similarity theories assume mixing is:
  - **lateral** through cloud edges
  - **instantaneous** creating uniform horizontal state
  - **continuous** as cloud element rises
- inertia from momentum through cloudbase (jet) or buoyancy from initial buoyancy (plume), rising in stable environment
- similarity theory only valid when $w_{base} \neq 0$, however often w_{base} can be very small $\Rightarrow$ "lazy plume"

Examining evidence for choice model of convective element

- shallow cumulus LES suggests lateral entrainment, not cloud-top (Heus et al 2008)
    - is this true also in deep convection?
- large variation in in-cloud state seen in large regions near edge of cloud, undiluted core (Austin et al 1985)
- Through three cross-sections cloud air appears to be mixture of cloud-base air and immediately above observation level => thermal (Blyth 1988)
- inertia from locally produced buoyancy (latent heat of condensation), flow becomes locally *unstable* locally, *not* initial inertia working against stable stratification

Examining evidence for choice model of convective element

shallow cumulus LES suggests lateral entrainment, not cloud-top



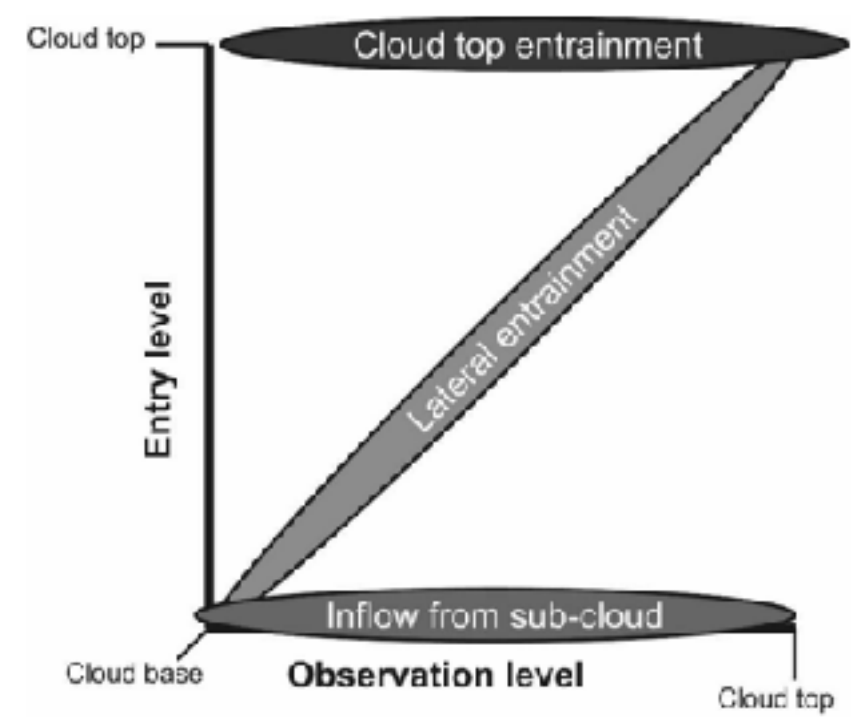
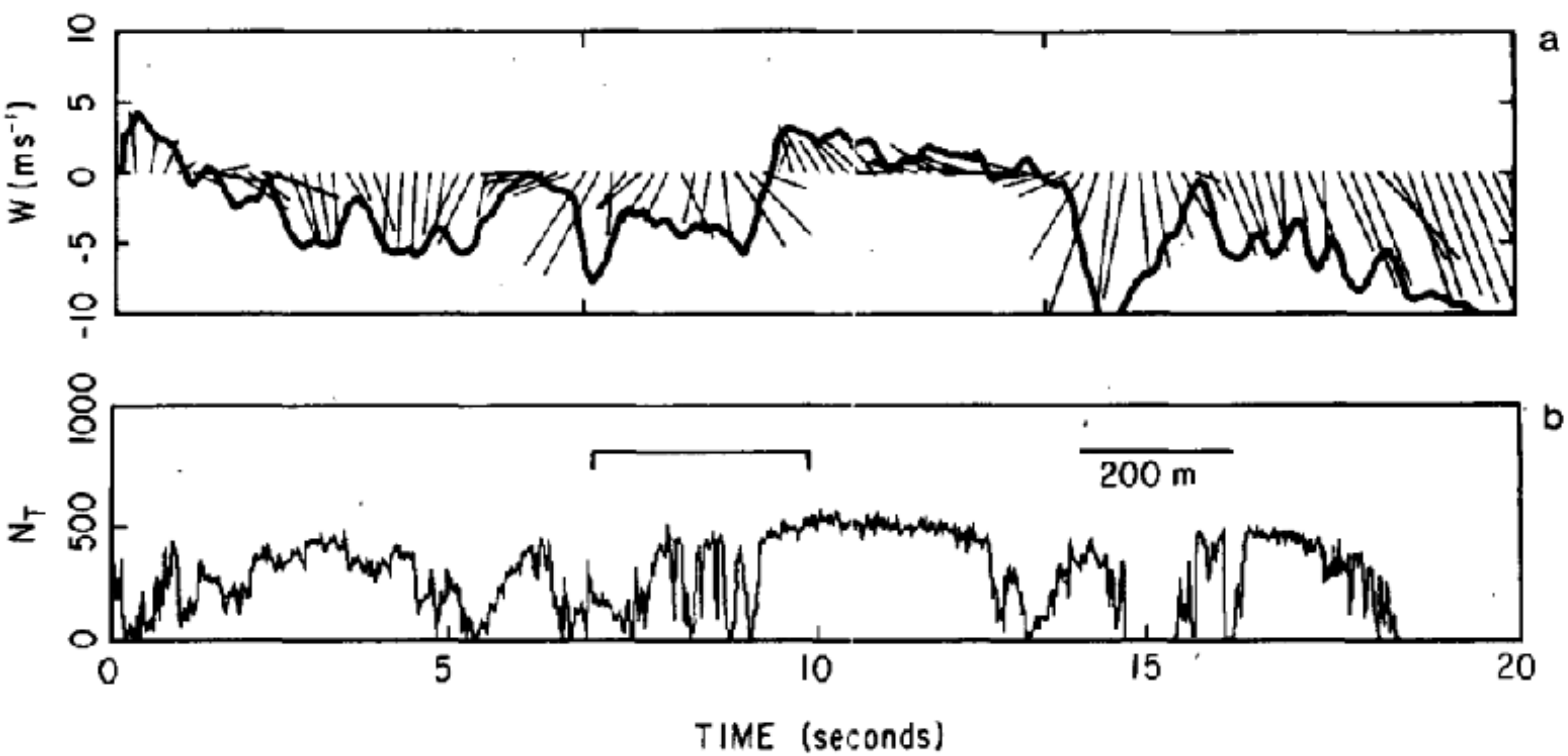


FIG. 9. Conceptual picture of an observation- vs source-level diagram. Inflow from the subcloud layer will show up at the base of the graph, and cloud-top entrainment will appear at the top; the diagonal signifies lateral entrainment.

(Heus et al 2008)

Examining evidence for choice model of convective element

large variation in in-cloud state seen in large regions near edge of cloud, undiluted core



(Austin et al 1985)

Examining evidence for choice model of convective element

Through three cross-sections cloud air appears to be mixture of cloud-base air and immediately above observation level => thermal

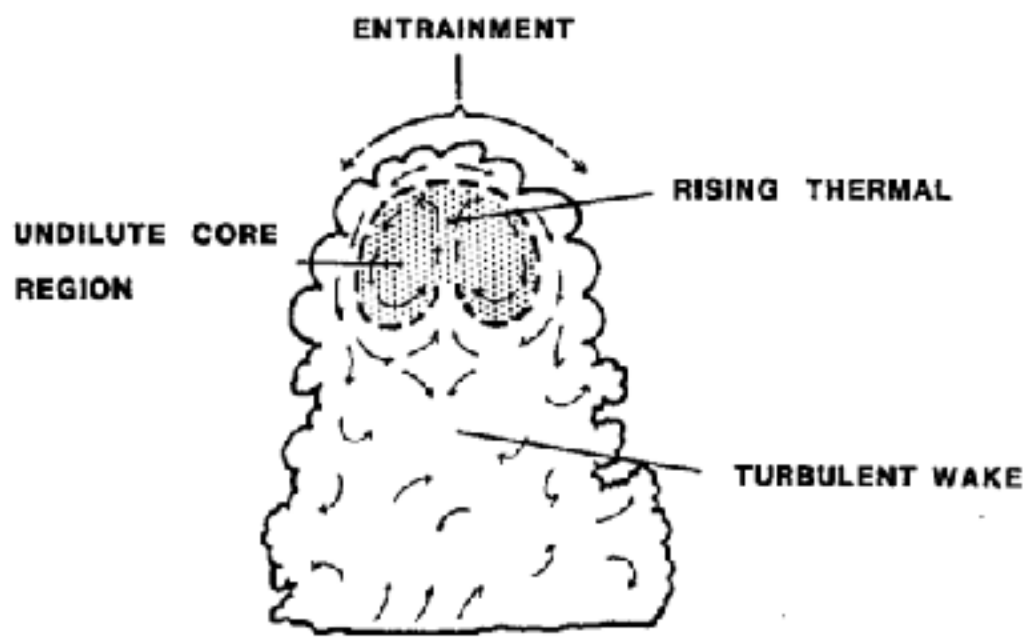


FIG. 14. Schematic model of a cumulus cloud showing a shedding thermal that has ascended from cloud base. Continuous entrainment into the surface of the thermal erodes the core, and the remaining undiluted core region continues its ascent, leaving a turbulent wake of mixed air behind it. See text for further discussion.

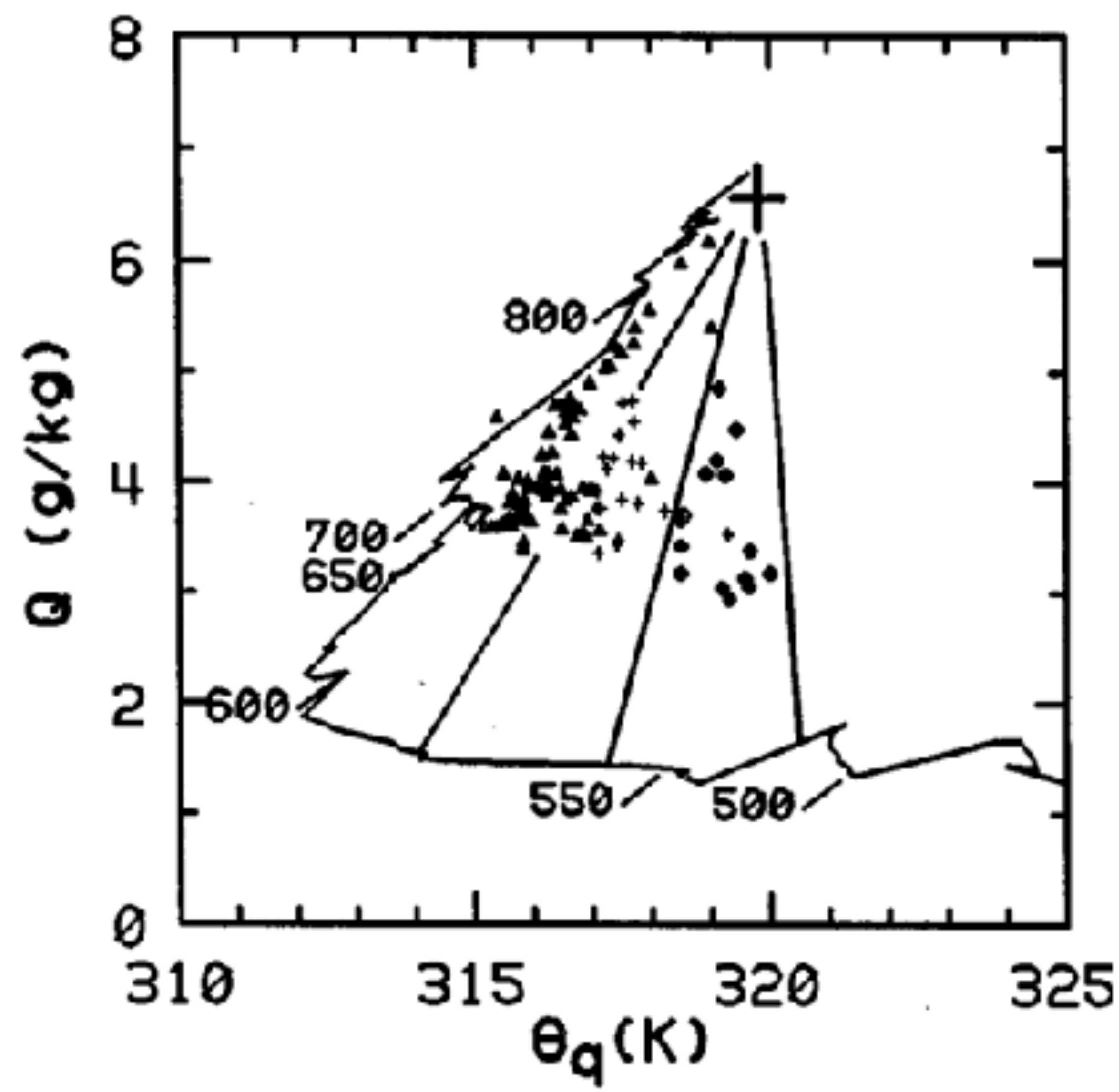


FIG. 6. As in Fig. 4, but for cloud 3 on 20 July 1978. The in-cloud observations from three passes are shown as ● (535 mb), + (575 mb) and △ (615 mb). The cloud-base value is shown with a large + and the lines indicate the approximate separation between the points on the three passes.

(A. Blyth 1988)

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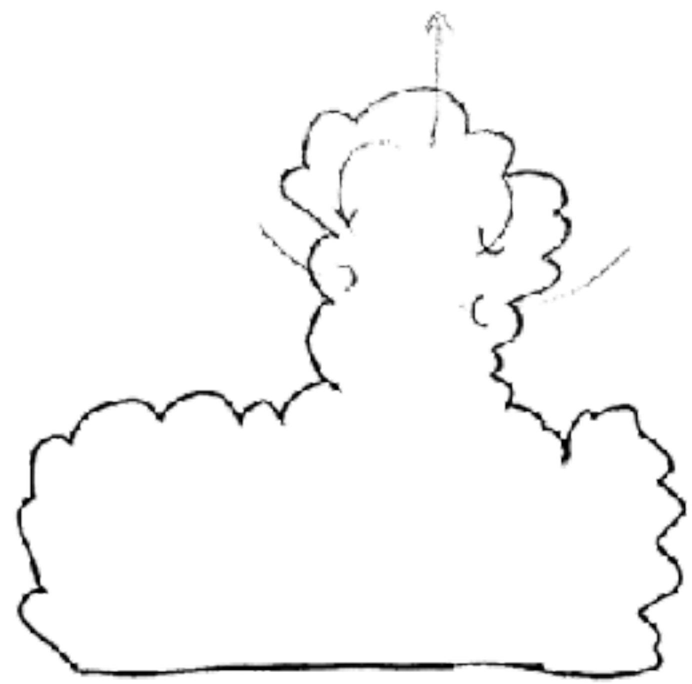
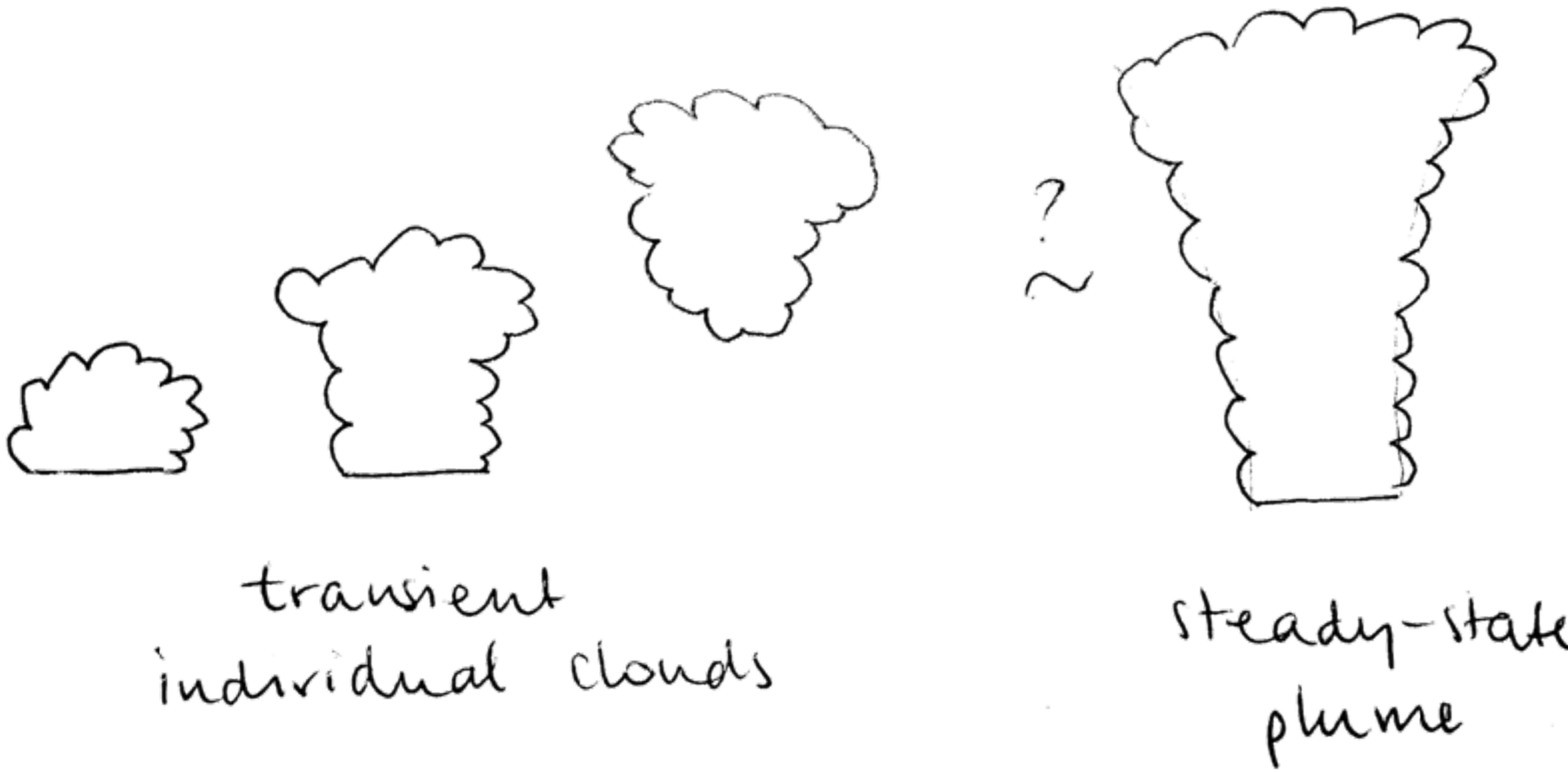
Questions for discussion



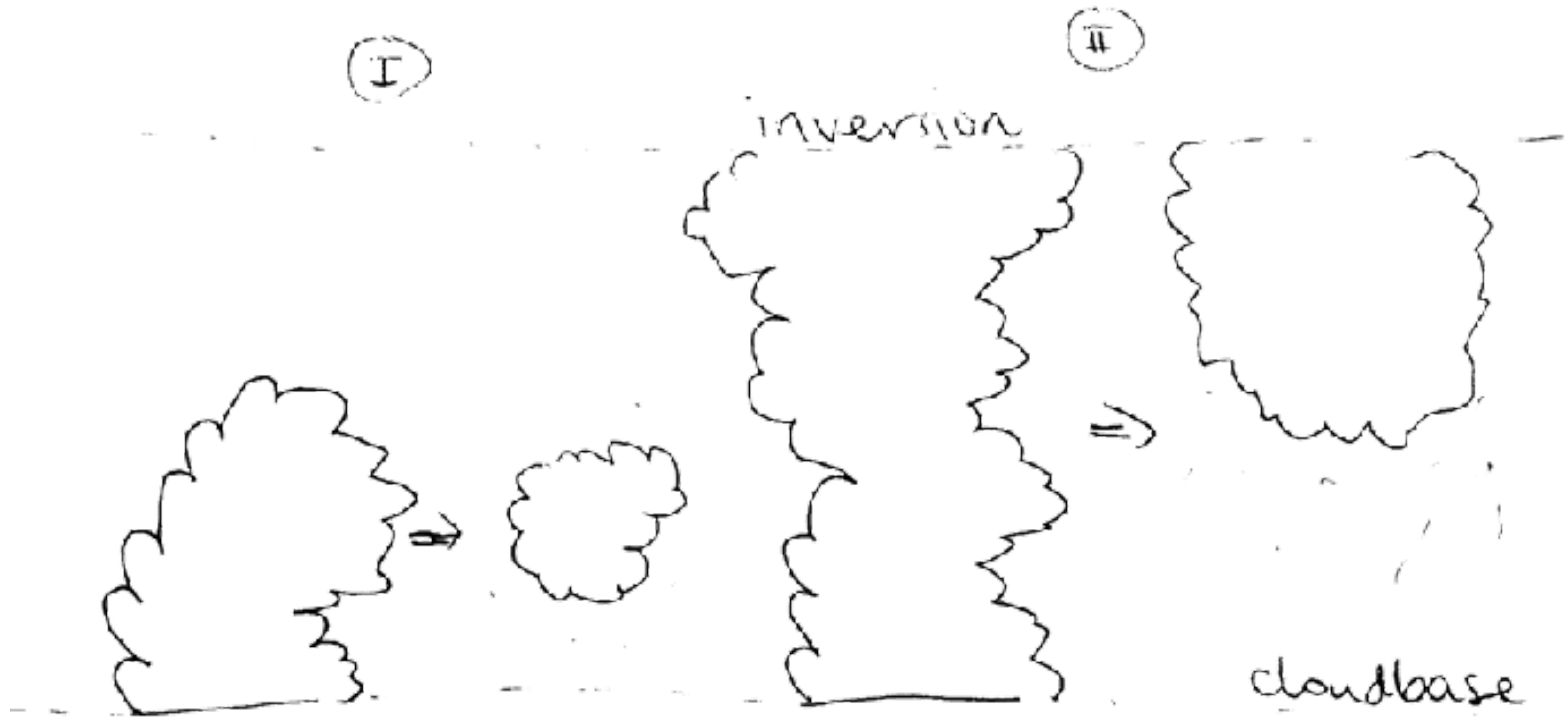
1. Do the similarity theory models apply to convective components of a larger cloud? How might we examine this?

Questions for discussion



2. Is it reasonable to represent the convective transport of multiple transient thermals as a steady-state plume? And if so how many thermals? Over what time- and length-scale would this apply?

Questions for discussion



3. Why does the condensate evaporate in thermals that don't reach the inversion (I) whereas it persists for thermals that do (II)?