Convective Cloud Lifecycles

Lunchtime seminar
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Introduction

Obtain life cycle statistics for clouds in CRM simulations

- Why bother?
- Gathering the statistics
- Some results: lifetimes and composite lifecycles
- Role of events
- Conclusions

Why bother?

Some Issues

- How good are modelled clouds at cloud-permitting resolutions?
- Aerosol effects on lifetime. How to estimate this?
- Could we attempt a simple representation of the life cycle in a parameterization?
- Tracking life cycles in observational data is not straightforward

Some CRM Issues

- More and more use of and interest in models without convective parameterization
- Many such models do not have $\Delta x \ll$ cloud size
- Good to test realism of CRM clouds versus data
- Does a CRM at coarse resolution provide a reasonable representation of individual clouds?

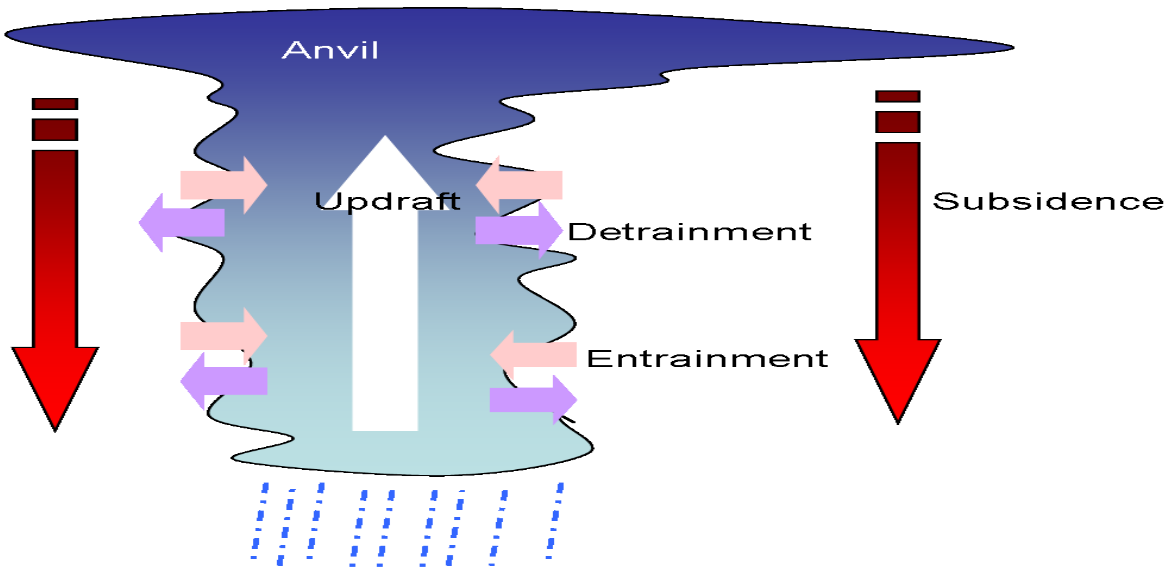
  (Which aspects are well or less-well captured?)
- Little attention so far on the life cycles of individual clouds in a statistical sense

Some Aerosol Issues

- 2nd indirect aerosol effect: aerosol loading could affect lifetime of clouds
- But how should we assess this?
- Lots of LES studies trying to understand competing mechanisms for aerosol effect on Sc and shallow Cu
  Jiang et al 2006, Hill et al 2008, Xue et al 2008 . . .
- But statistical information of the effects on cloud lifetimes seems to be missing

Some Parameterization Issues

- Most convective parameterizations based on entraining/detraining plumes



- NB: plume $\neq$ cloud but dominates the vertical transport

Some Parameterization Issues

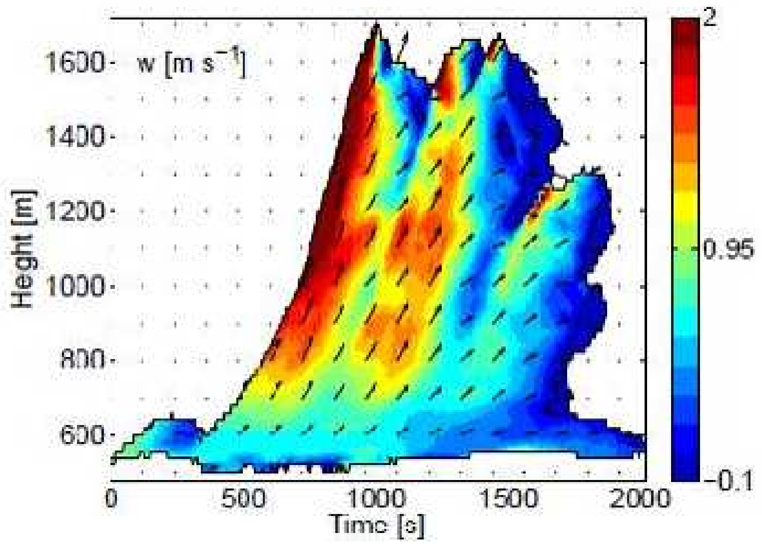
- Convenient for convective parameterization to assume a steady plume
- Implicitly, all the variables in the parameterization are filtered and represent “averages” over a lifecycle
- But can try to incorporate some lifecycle effects

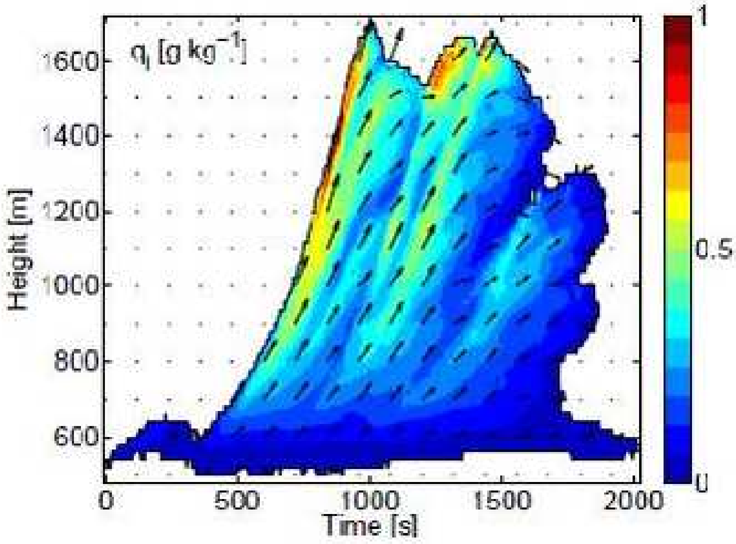
  Fraedrich 1973, Cho 1977 . . .
- Perhaps useful at high-resolution when $\Delta t \lesssim$ cloud lifetime
- Recently, various experiments with prognostic aspects of cloud parameterizations

  PC2 and cloud-decay options in UM, Gerard 2007 in Arpege model

Tracking Issues

Simulation of shallow Cu, w (left) and q_l (right) (Heus et al 2009),





- Pulses are a normal feature of cloud dynamics
- Expect interactions between tracked objects to be commonplace

Tracking Issues

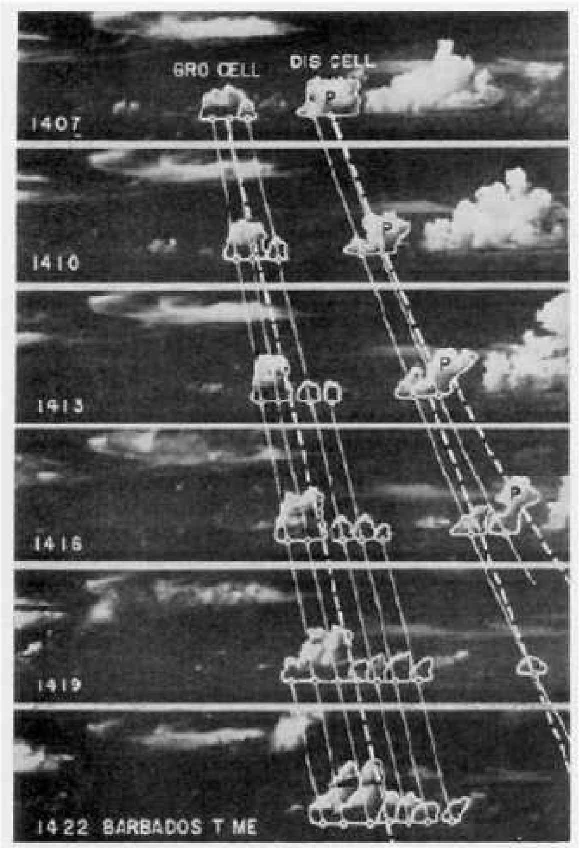


FIG. 3. Horizontal views of multi-turret cumulus cells in their stages of development and dissipation taken from Barbados at 3 min intervals facing south. 1407–1422 Barbados time, 18 July 1969.

- In real data, tracking through life cycle often requires estimate of propagation speed
- But internal dynamics, like pulsing, can make this difficult

Fujita et al 1975

Tracking from Radar

Example tracking of “simple” radar echoes (Lopez et al 1984)

- $\sim$ 60% echoes in one scan only
- Very few last longer than 30min

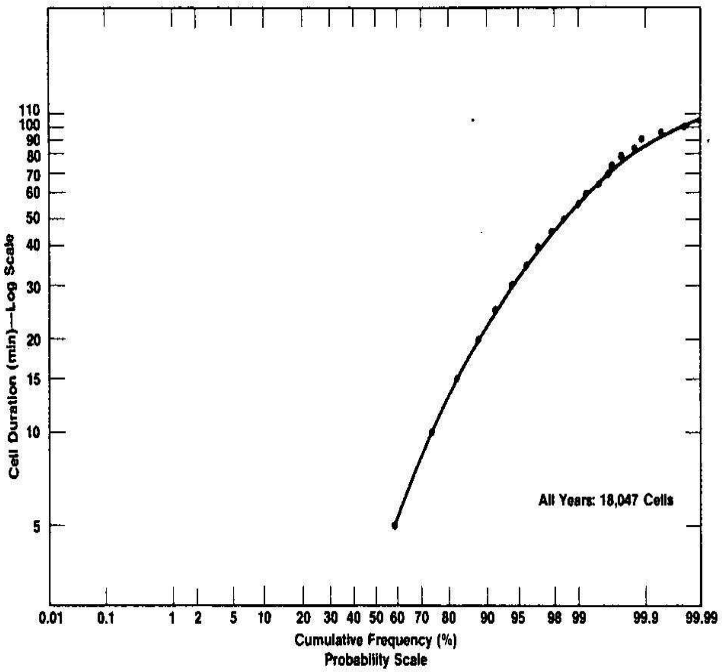


FIG. 12. Cumulative frequency distribution of cell duration in log–probability scales. Data from all of the three summers of FACE-2 have been used.

Tracking from Radar

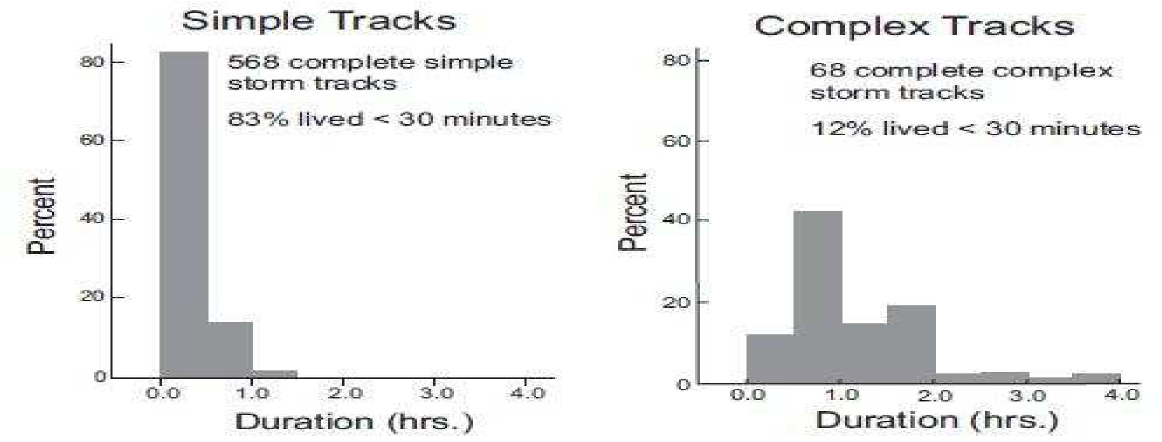


FIG. 1. Histogram showing the lifetime of simple and complex storms observed during the summer of 1991 near Denver, CO, based on data from an automated cell tracking system called TITAN. A simple storm is one that does not merge or split during its lifetime and a complex storm is one that does (from

Wilson et al 1998

- $\sim 10 - 20\%$ of the echoes undergo splits or mergers
- Such storms last much longer, over 30min is very normal

Gathering the statistics

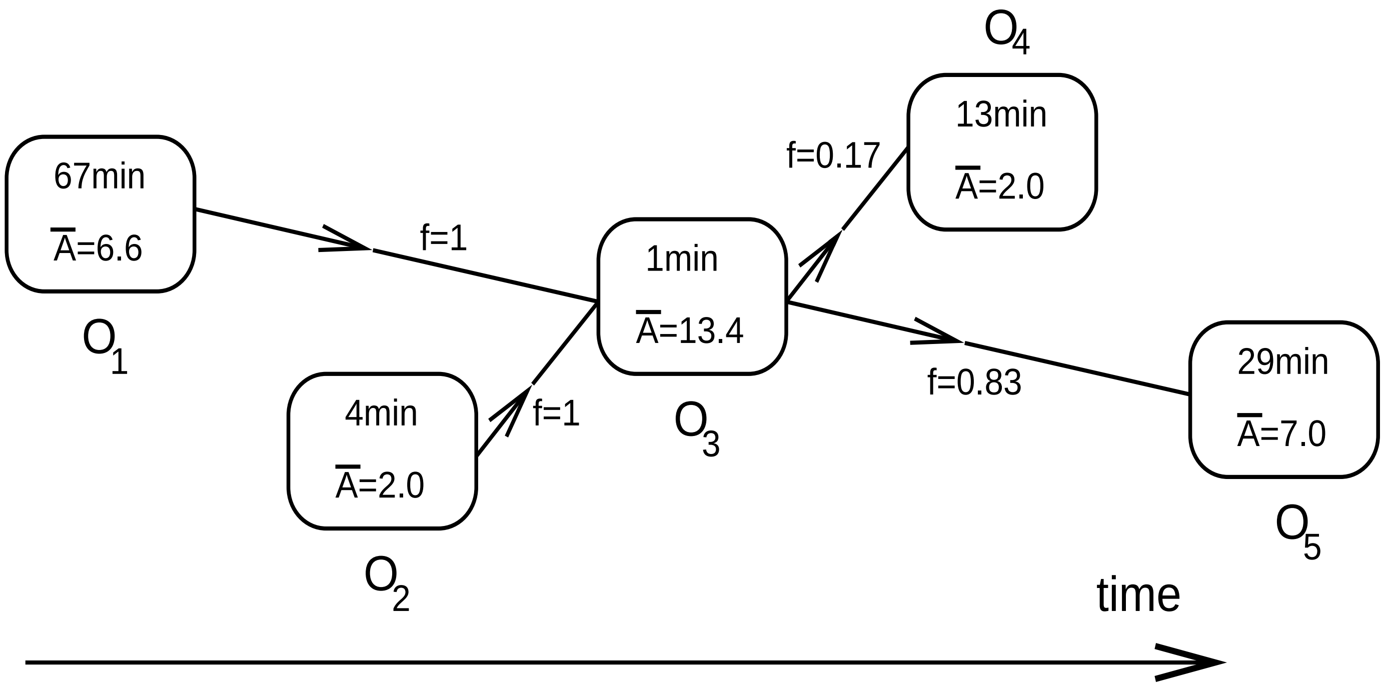
How is the Tracking Performed?

1. Identify the cloud objects present at a given timestep
2. Connect these cloud objects to those identified at the previous timestep
3. Bookeeping

- Comprehensive, automated tracking performed online at every timestep
- Not cheap
- But provides a more complete picture

An example lifecycle

Want to deal with situations like this...



Stage 1: Identify Clouds

In real data, has been done through:

- brightness-temperature threshold for satellite obs
- radar reflectivity thresholds
- visual inspection of photographs

In models:

- w threshold (strong updraughts), also done in aircraft obs
- model variables for cloud water/ice
- convective transport of boundary layer air diagnosed by passive tracer
- visual inspection in virtual-reality environment

Identification Issues

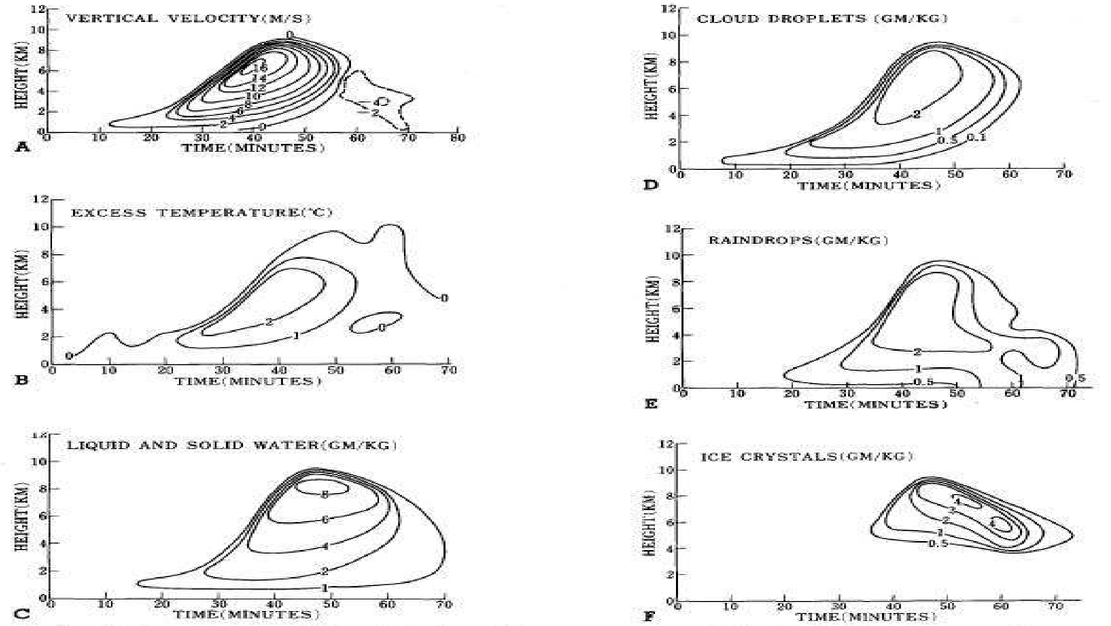


FIGURE 3.—Time-height cross-sections of (A) vertical velocity, (B) excess temperature, (C) liquid and solid water content, (D) content of cloud droplets, (E) content of raindrops, and (F) content of ice crystals for a cloud with microphysical processes; $\Gamma_s = -6.5$°C/km, $C_0 = 0.005$.

Ogura and Takahashi 1971

- Different definitions focus on different aspects of cloud
- visual image $\neq$ radar image $\neq$ dynamical plume

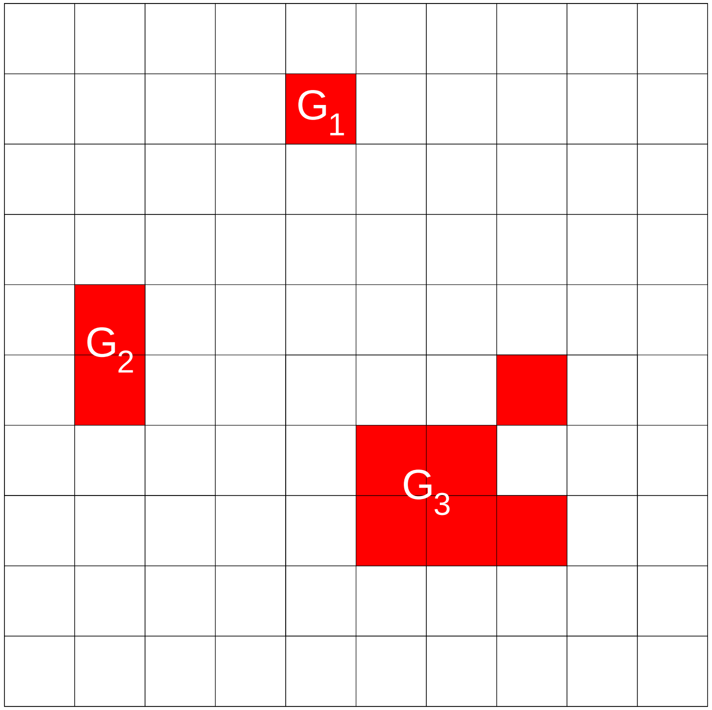
Stage 1: Identify Clouds

A grid box is cloudy if it has:

1. Positive buoyancy
2. Positive cloud liquid water
3. Positive vertical velocity

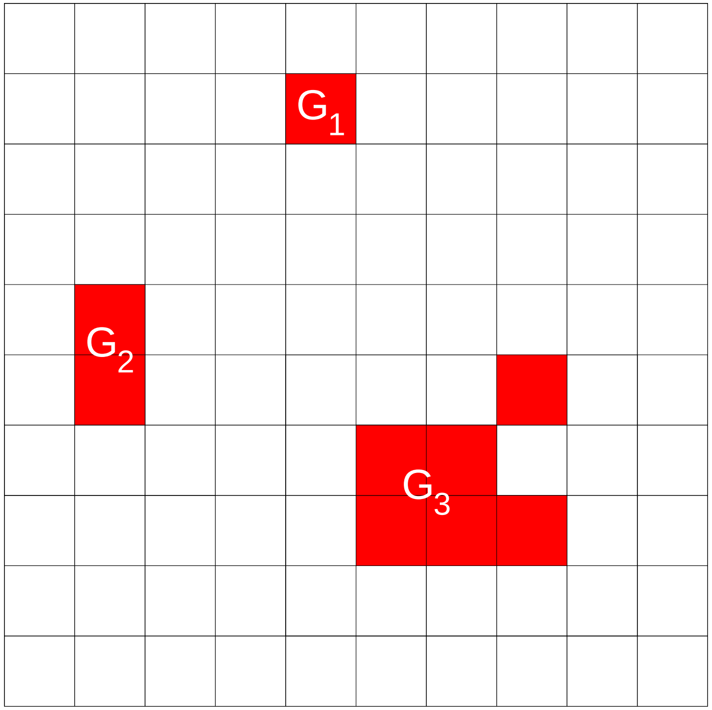
- The “cloud-core” definition
- Provides the best description of dynamical plumes

  (Siebesma and Cujipers 1995)



Stage 1: Identify Clouds

- Now join-up the cloudy grid boxes
- Use an eight-segmented approach



Constraints

Exclude small, short-lived fluctuations above threshold:

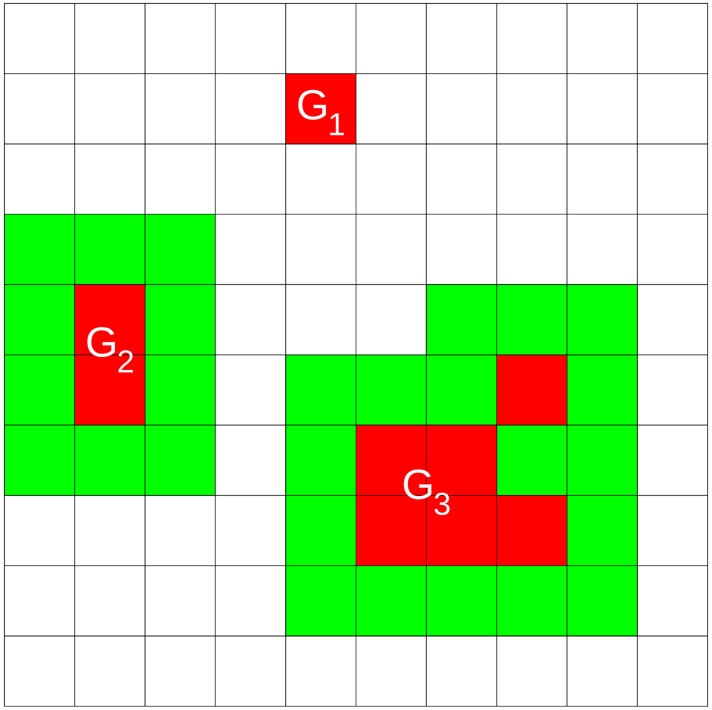
- Need at least two cloudy grid boxes
- Structure must persist for 5 minutes

Final statistics not overly sensitive to details of the thresholding

Stage 2: Tracking

- Which features are common between two time slices?
- Work online and exploit very high time resolution

- Establish all connections: ie, clouds at previous timestep that overlap or adjacent to current clouds
- Comprehensive because of CFL



Connections: What Has Happened?

$p \longrightarrow c$ where p and c are the number of previous (p) and current (c) clouds involved

- $0 \longrightarrow 1$ birth of new cloud.
- $1 \longrightarrow 0$ death of a cloud.
- $1 \longrightarrow 1$ straightforward continuation
- $1 \longrightarrow 2+$ splitting up an old cloud into several pieces.
- $2+ \longrightarrow 1$ merger of old clouds to form a single new cloud.
- $2+ \longrightarrow 2+$ more complicated stuff

Anything with a $2+$ we call an "event"

Stage 3: Bookeeping

- At each timestep, store cloud size, mass flux, precipitation rate...

"*Events, dear boy, events...*"

- When these happen, archive timeseries of contributing clouds
- Start new timeseries for new object
- Can reconstruct full time history through refs to library
- Inter-library refs allow for multiple generations, back to birth of the first contributing cloud element

Stage 3: Bookeeping

- f_i^c estimates fraction of old cloud i that contributes to current cloud c
- For a $2 \rightarrow 1$ merger, $i, j \rightarrow c$

$$f_i^c = f_j^c = 1$$

For a $1 \rightarrow 2$ split of cloud $i \rightarrow c, d$

$$f_i^c = \frac{A^c}{A^c + A^d} \quad ; \quad f_i^d = \frac{A^d}{A^c + A^d}$$

- Easily generalized to multiple generations (product of f's) and to complicated events

Constraints

Purely practical: speed things up without messing up the stats

- Do not allow > 10 generations
- Remove from library if association to current clouds < 0.05

Some results

Example Simulation

Using Met Office LEM to simulate radiative-convective equilibrium with:

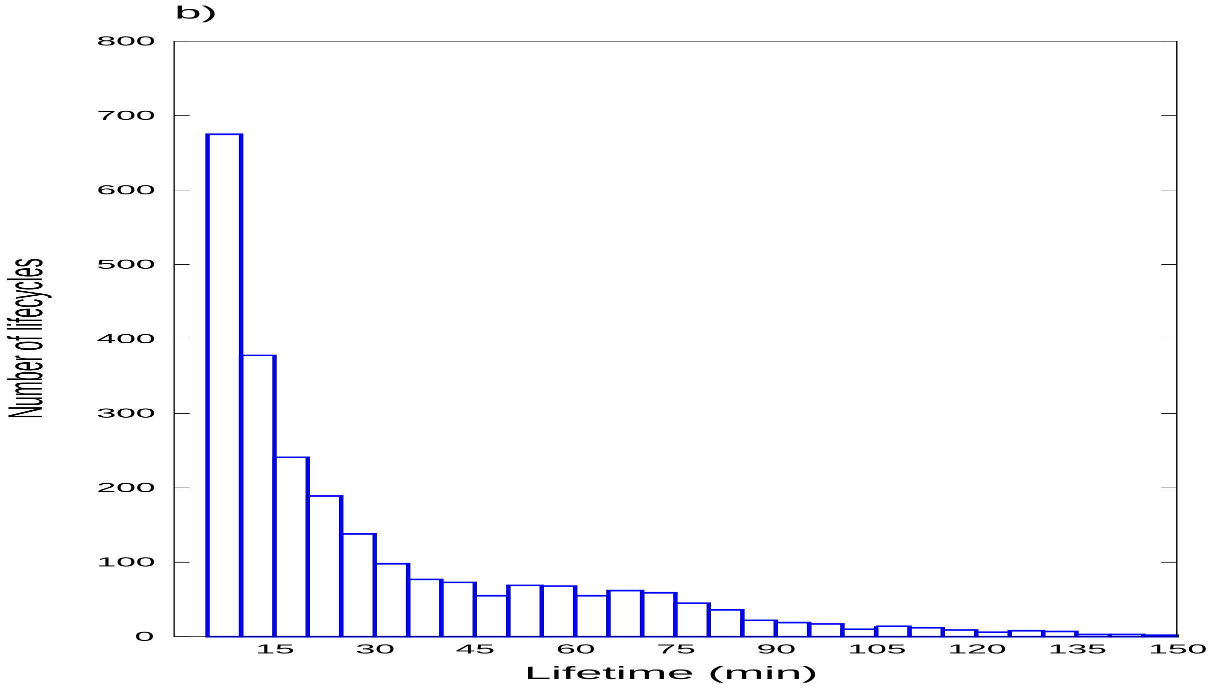
- fixed SST (300K) and imposed 4K/d cooling of troposphere
- $f = 0$, no mean shear
- 2km resolution on a 64x64km domain; 76 levels
- run for 19.5 days to get to equilibrium state
- then run for another 16.5 days to collect statistics for 4617 clouds

Some Basic Numbers

Number of cloudy gridpoints	52.4 ± 6.9
Number of cloudy points not part of clouds	7.0 ± 2.8
Number of clouds	10.0 ± 2.0
Proportion of continuations	1
Proportion of births and deaths	3.0×10^{-4}
Proportion of splits	2.4×10^{-4}
Proportion of mergers	1.7×10^{-4}
Proportion of complicated events	4.2×10^{-6}

Lifetime Distribution

For simple lifecycles, ignoring any with events...

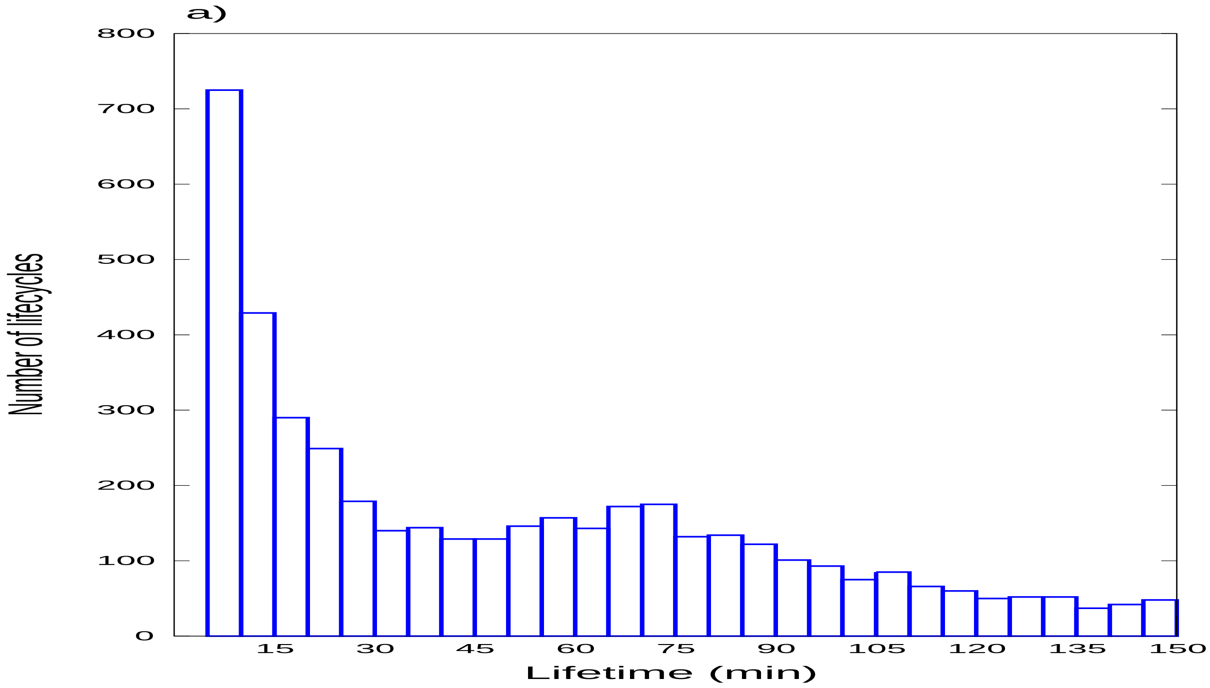


54% of lifecycles have no such events

Mean lifetime = 30min

Lifetime Distribution

Including the more complicated lifecycles...

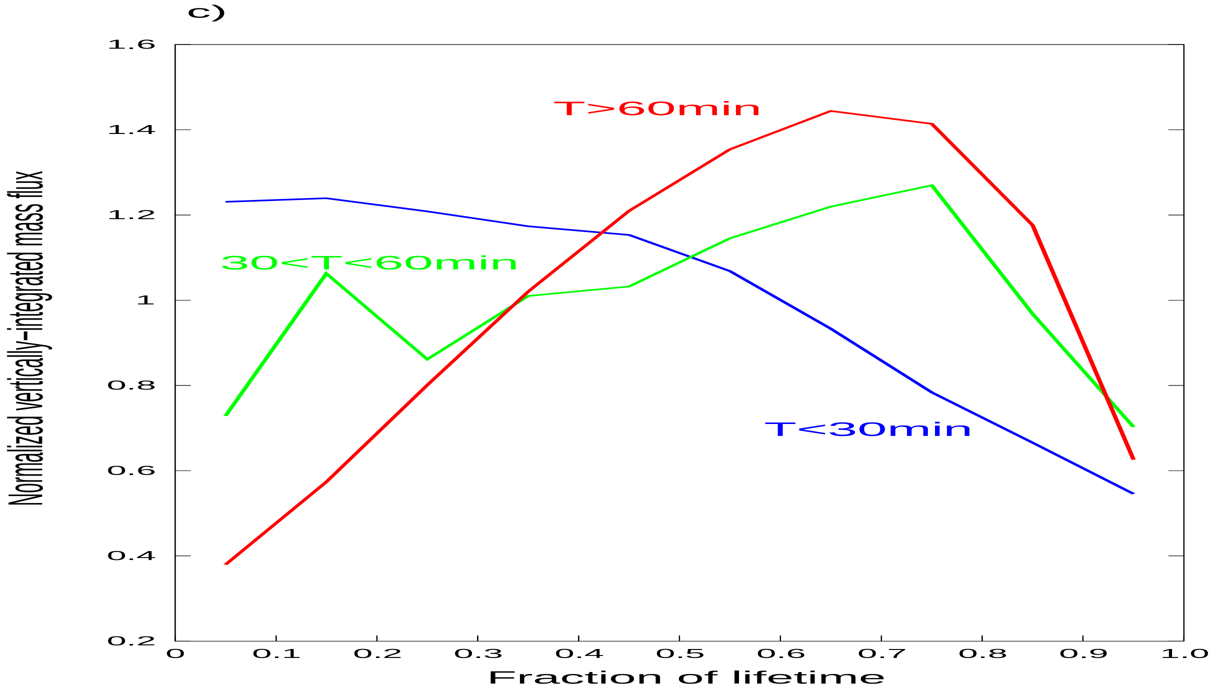


Mean lifetime = 55 min

More later...

Composite Cloud

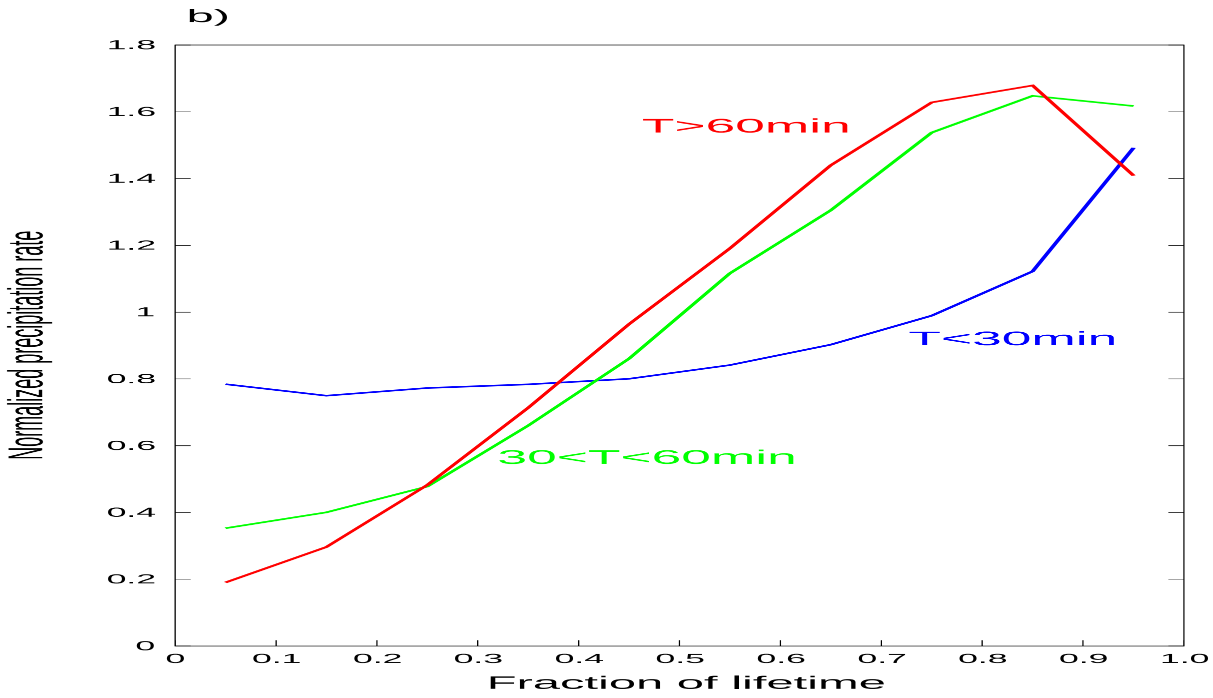
Normalize timeseries for each cloud and composite to produce an averaged lifecycle



Evolution over lifecycle of vertically-integrated mass-flux

Composite Cloud

Evolution over the lifecycle of rate of precip.



Increases across lifecycle

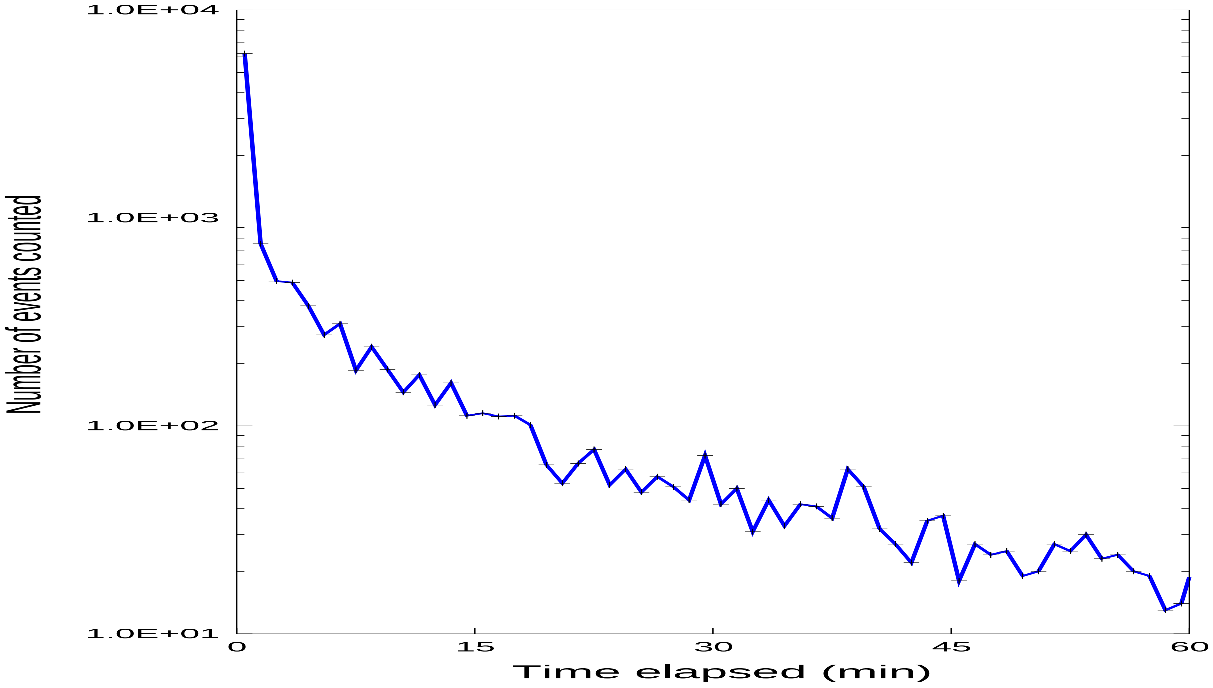
Highlights the relevance of cloud definitions

The University of Reading

Role of events

Separation of events

Distribution of times that separate consecutive events

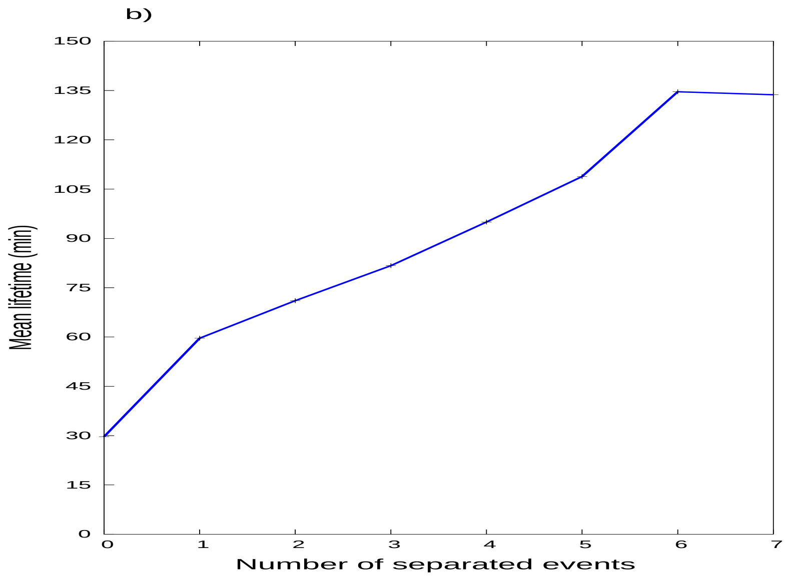


Often within tens of seconds ($\sim$ 50% of separations $<$ 1min)

Splits and mergers are often not "clean"

Effects on lifetime

More useful to look at well-separated events (must be 5min apart)



Each well-separated event increases the mean lifetime by $\sim$ 15min

Comparison with Another Case

- Forcing for convection is the same, but instead of fixing the SST, fix the surface heat and mositure fluxes
- Expect this to alter the horizontal structure of the boundary layer
- Convection over a slowly-evolving “land”-surface

	Fixed SST	Fixed fluxes
Mean lifetime, overall (min)	55	37
Mean lifetime, no events (min)	30	28

Comparison with Another Case

	Fixed SST	Fixed fluxes
Mean lifetime, overall (min)	55	37
Mean lifetime, no events (min)	30	28
Lifecycles with events	46%	44%
Lifecycles with separated events	41%	38%

- Plumes do not seem stronger in the fixed-SST case, and the plumes interact about as often
- But interactions more effective for fixed SST

Conclusions

- Useful tool to generate cumulus life cycle statistics
  (Difficult to get such information any other way)
  (Easy to adapt code to other features in other models)
- Cloud definitions are important
- $20 - 30$min is ok as a rule of thumb for lifetime of simple convective plumes
- $\sim 40\%$ of lifecycles contain splits and/or mergers, which increase lifetimes considerably
- “Events” complicate things, but can be brought into a single framework that demonstrates their impact
- The underlying boundary layer seems to be an important control on their impact