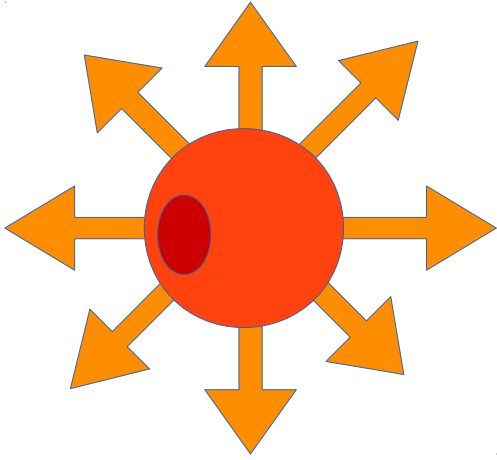


High-resolution simulations of deep convective growth and Meteosat observations

**Fabian Senf, Stephan Lenk, Hartwig Deneke,
Rieke Heinze**

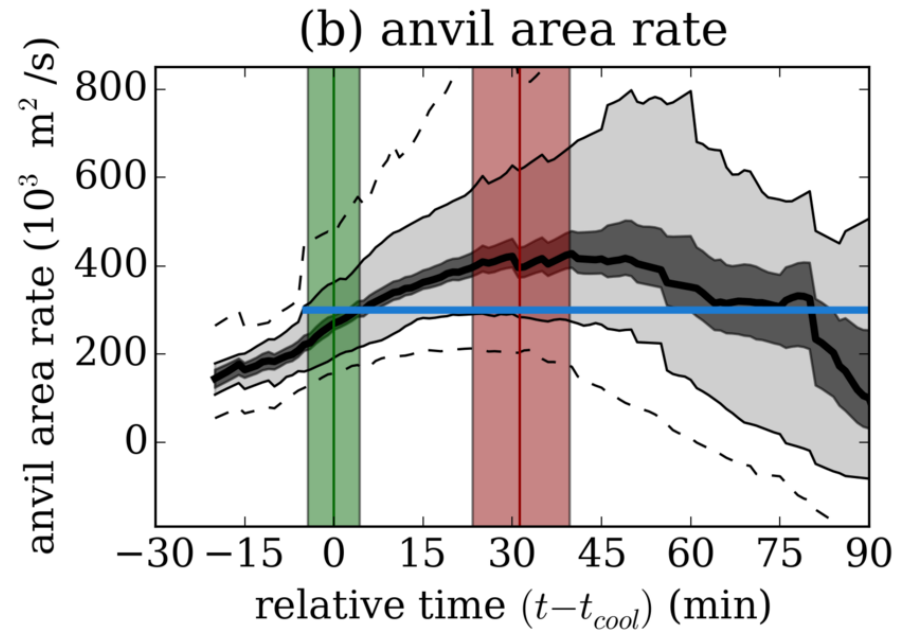
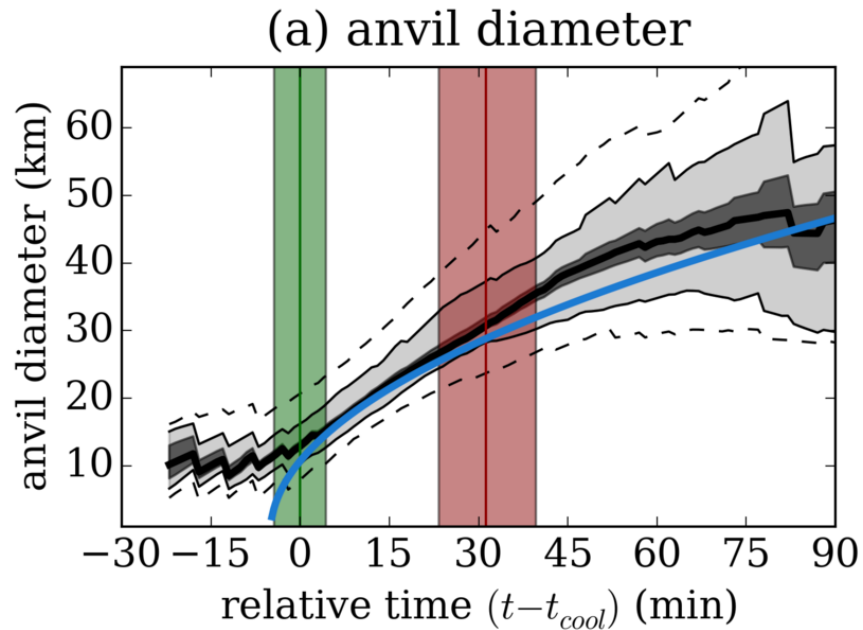
EUMETSAT Convection Working Group Meeting, 2018, Ljubljana

Motivation



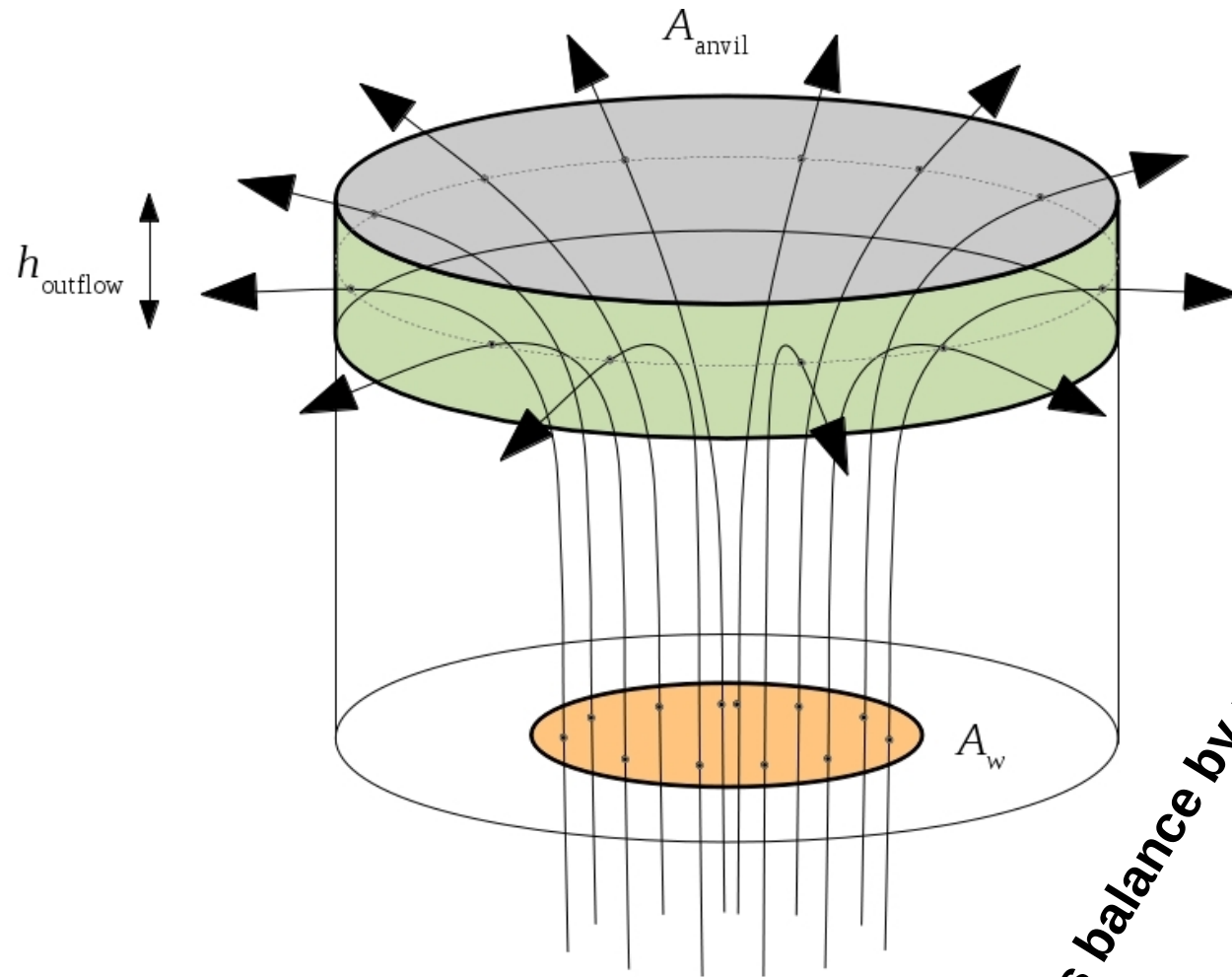
Open questions

- (1) What causes the initial increase in anvil area rate?
- (2) Is the apparent anvil sufficiently attached to the flow?



→ **High Resolution Simulations** might help to understand this

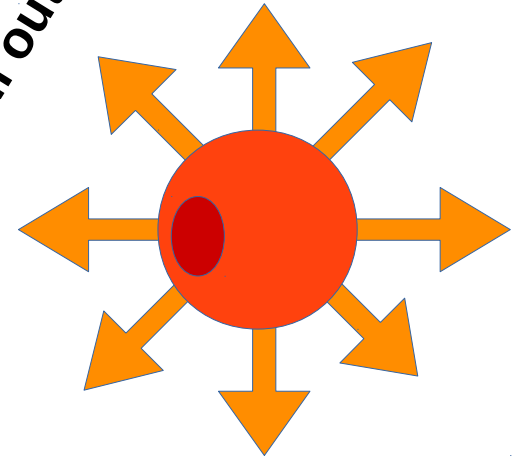
Motivation



Mass flux in the updraft core

$$\langle \bar{\rho} u_c \rangle_h = \frac{A_w}{2\pi r_c h_{\text{outflow}}} \langle \bar{\rho} w_b \rangle_{A_w}$$

is balance by mass flux in the anvil outflow



A_w : updraft core area

h_{outflow} : outflow thickness

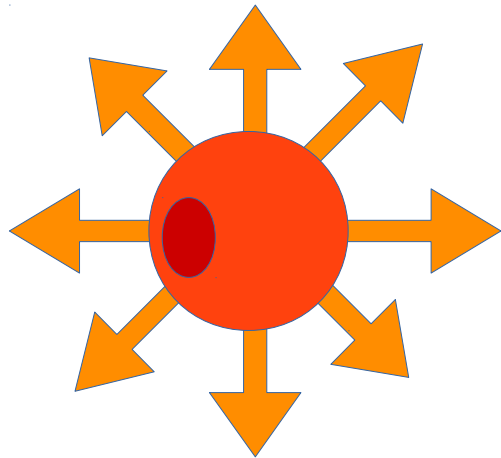
r_c : distance to edge

u_c : horizontal velocity at edge

w_b : vertical velocity at bottom

$\bar{\rho}$: average air density

Motivation



$$\langle \bar{\rho} D_t A_c \rangle_h = 2\pi r_c \langle \bar{\rho} u_c \rangle_h$$

A_c : material area at anvil level
 r_c : distance to edge
 u_c : horizontal velocity at edge
 $\bar{\rho}$: average air density

- a change in material area A_c is induced by the outward motion of horizontal wind u_c
- Is the apparent anvil area change connected to the wind divergence?
- if true: anvil change \Leftrightarrow momentum flux in updraft core
- processes that destroy connection
 - formation or sublimation of ice
 - descending anvil motion

Simulation Data

- special period: Mai – June 2016 with several severe weather events of public interest

Sommer 2016

Deutschland



Simbach



Braunsbach

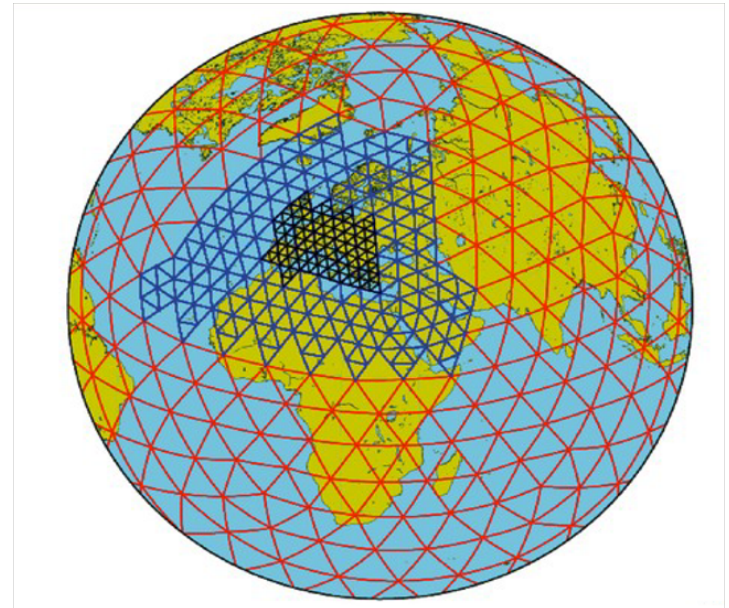


Hamburg
Tornado



Simulation Data

- ICON-LEM: limited area model developed by German Weather Service and Max Planck Institute Hamburg
- Simulations performed at 600 m grid spacing
- 36 days from 26052016T00:00:00 – 30062016T23:00:00 with an output of 5 min; 81 TByte simulation data!
- synthetic Brightness Temperature Data have been derived with RTTOV



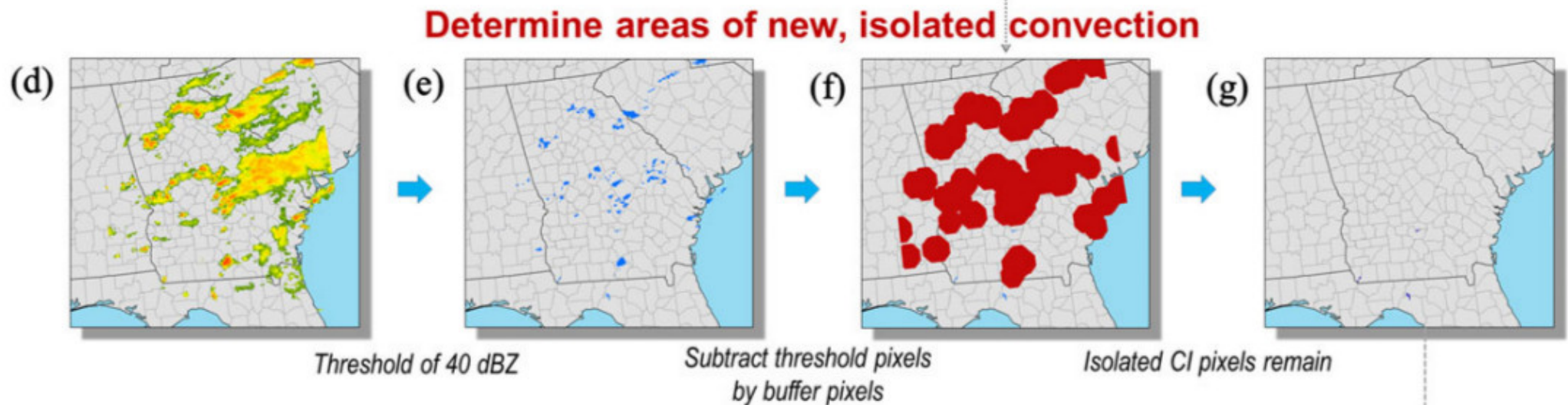
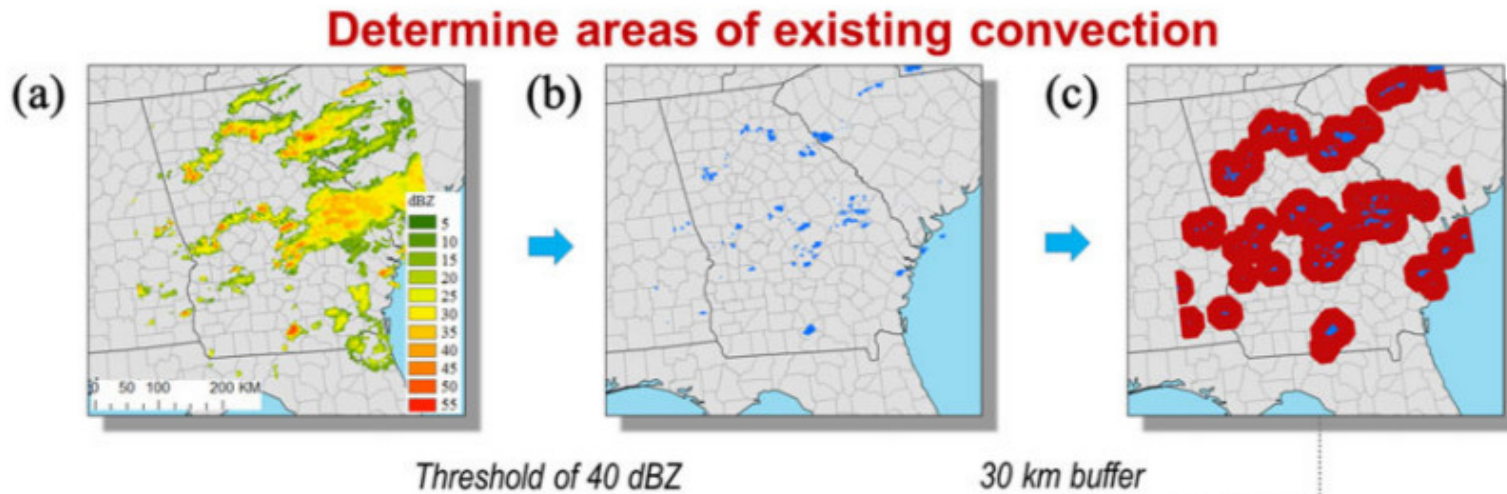
Detection of Growing Anvils

Selection Criteria:

- Temporal Persistence: Anvil lives at least 30 minutes
- Size: Anvil reaches at least 20 km diameter
- Intensity: BT10.8 K smaller than 220 K somewhere

Detection of Growing Anvils

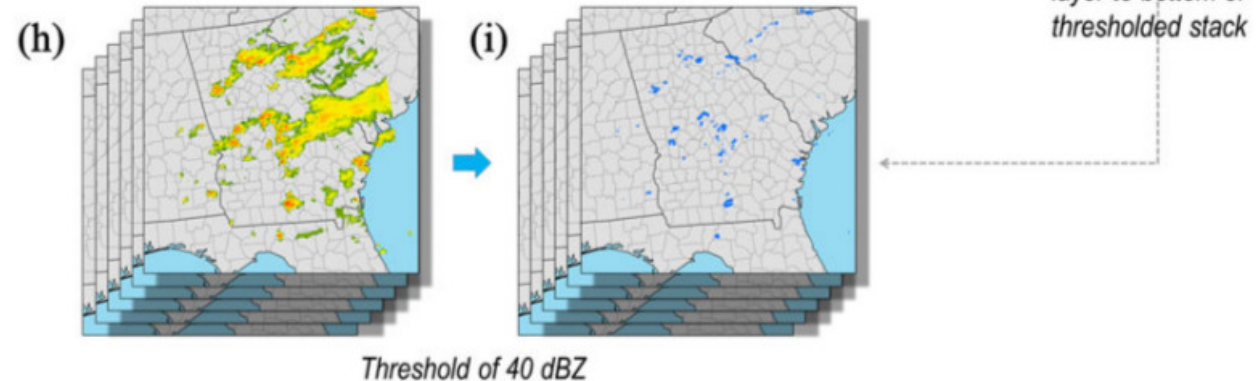
Haberlie et al. (2015) QJRMS Method



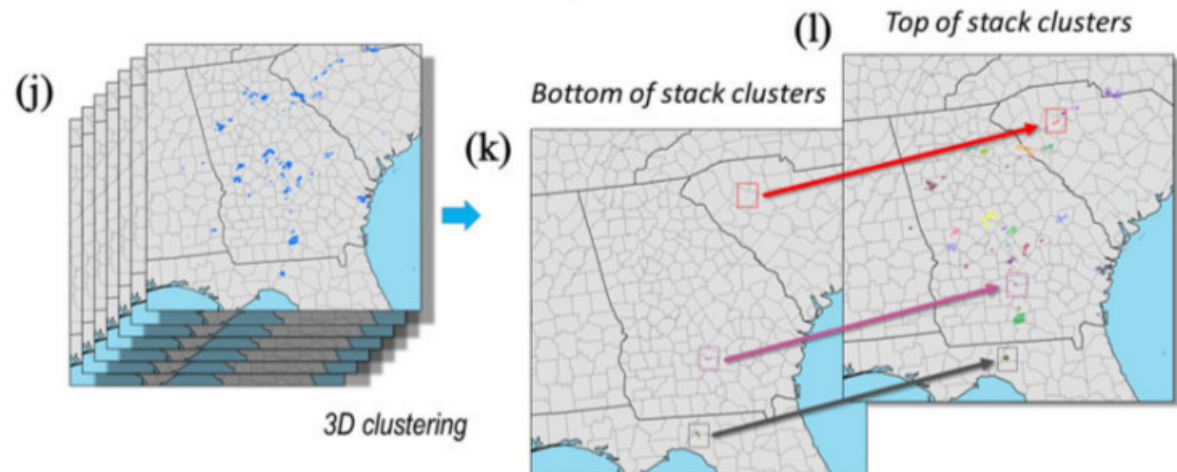
Detection of Growing Anvils

Haberlie et al. (2015) QJRMS Method

Extract convective pixels from next six scans



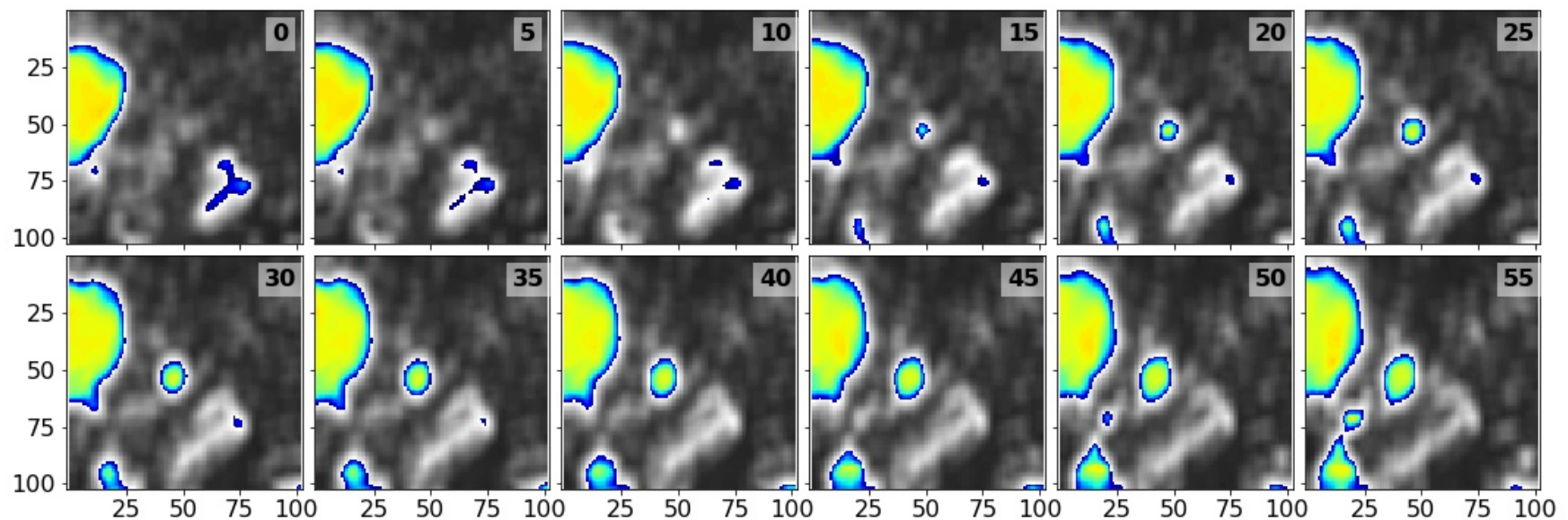
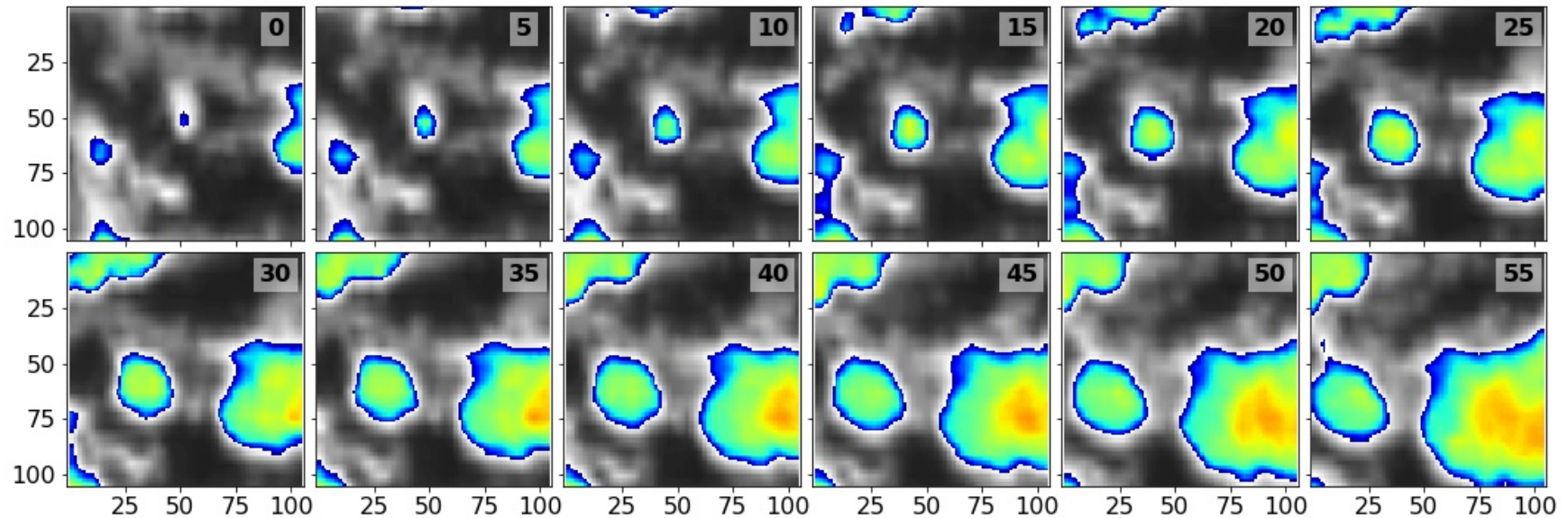
Determine if isolated CI element develops into a thunderstorm using 3D clustering



- applied for simulated and observed BT10.8 with threshold = 240 K

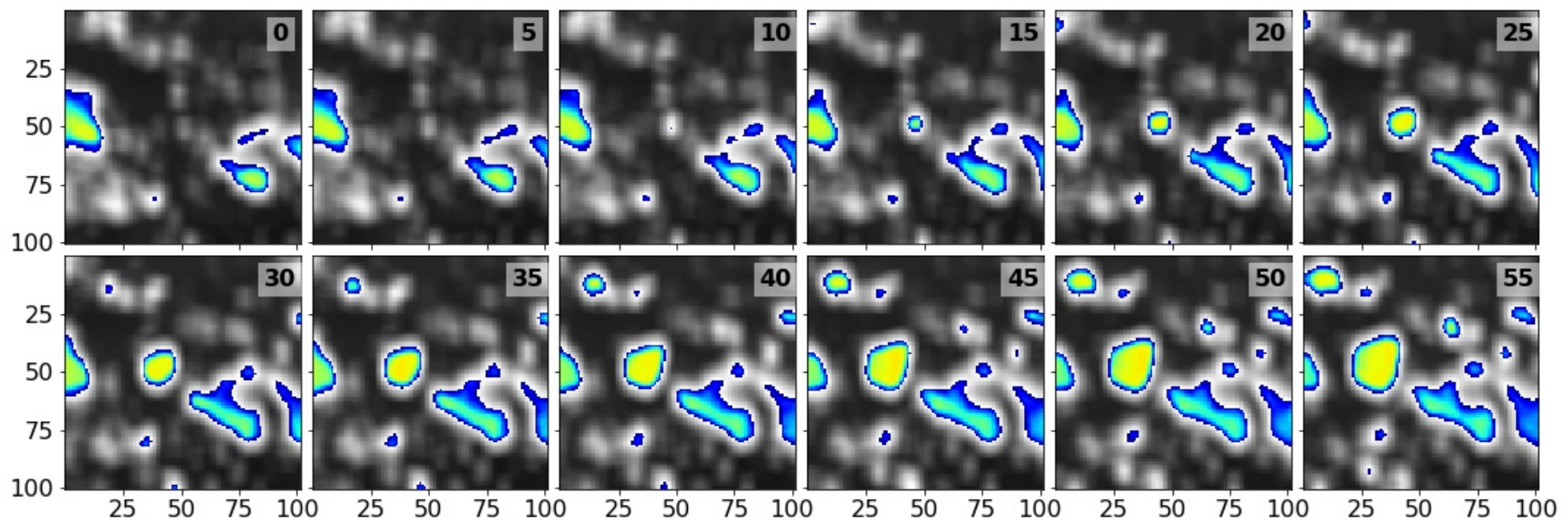
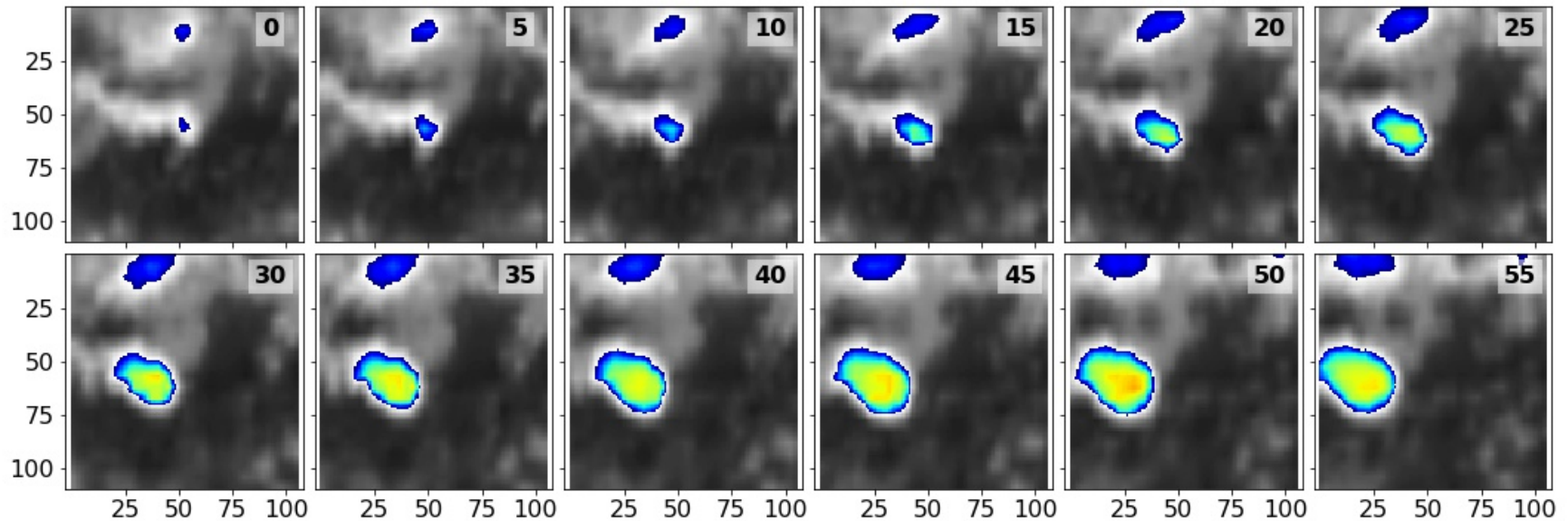
Detection of Growing Anvils

Examples: Which one is the observation?



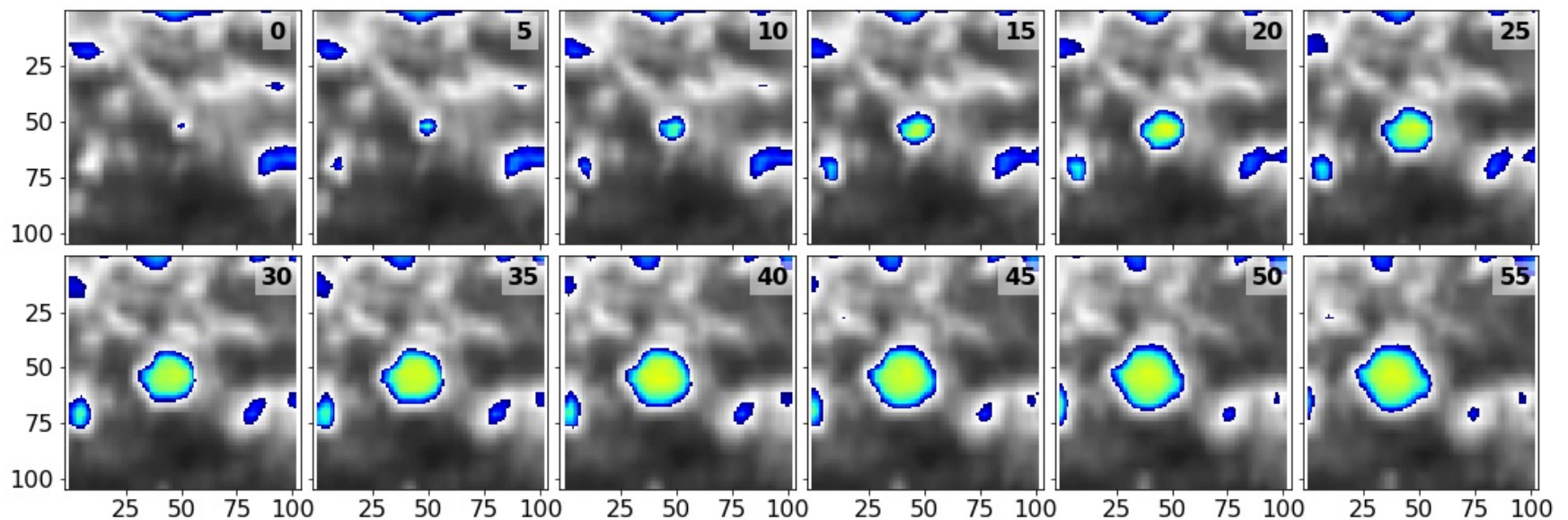
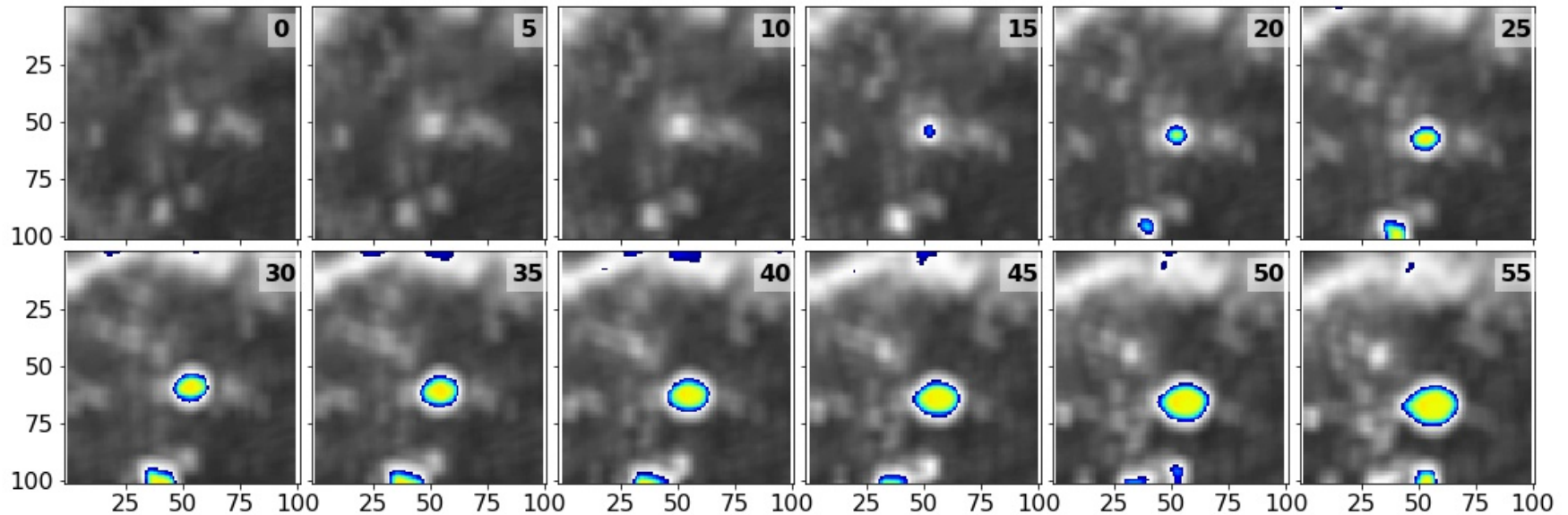
Detection of Growing Anvils

Examples: Which one is the observation?



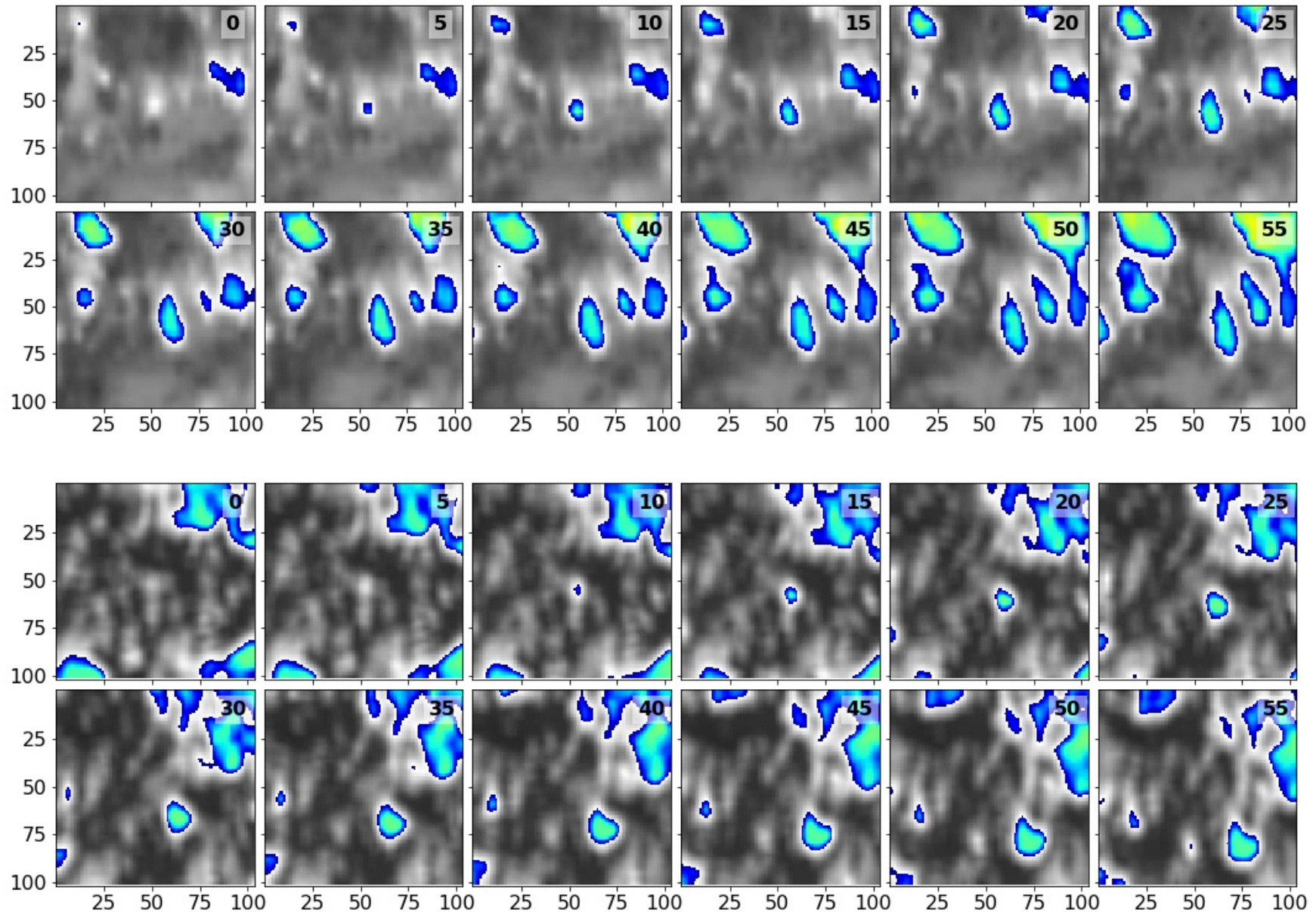
Detection of Growing Anvils

Examples: Which one is the observation?



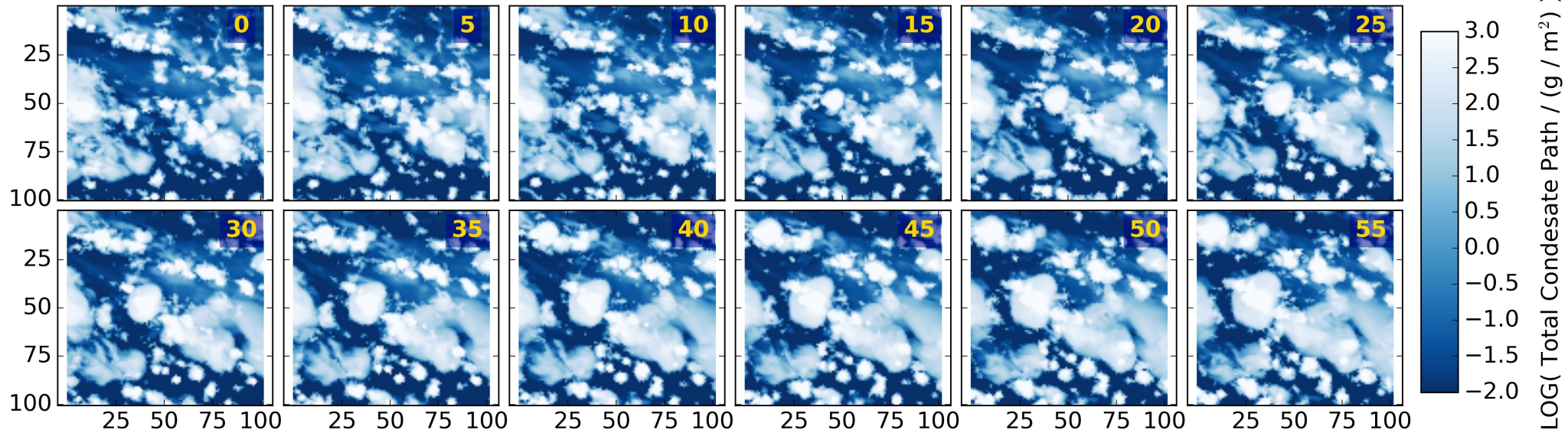
Detection of Growing Anvils

Examples: Which one is the observation?



Step-wise Analysis

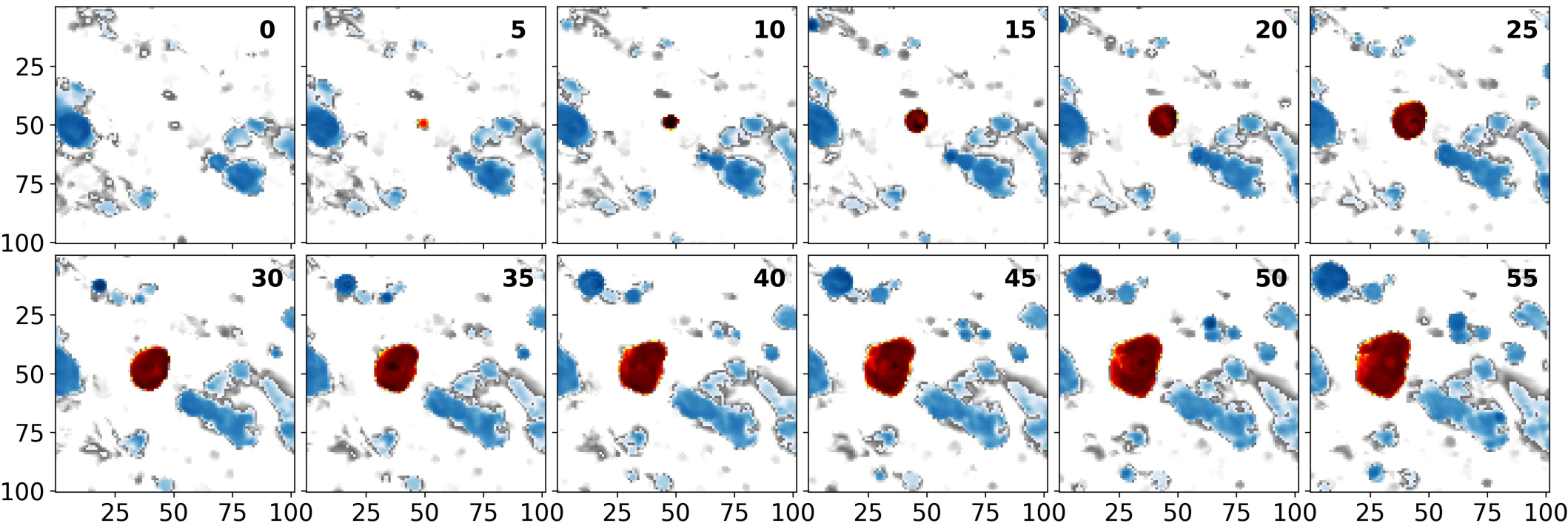
Temporal Sequence of Total Condensate Path



- quite complex cloud scenery
- Eulerian cutouts

Step-wise Analysis

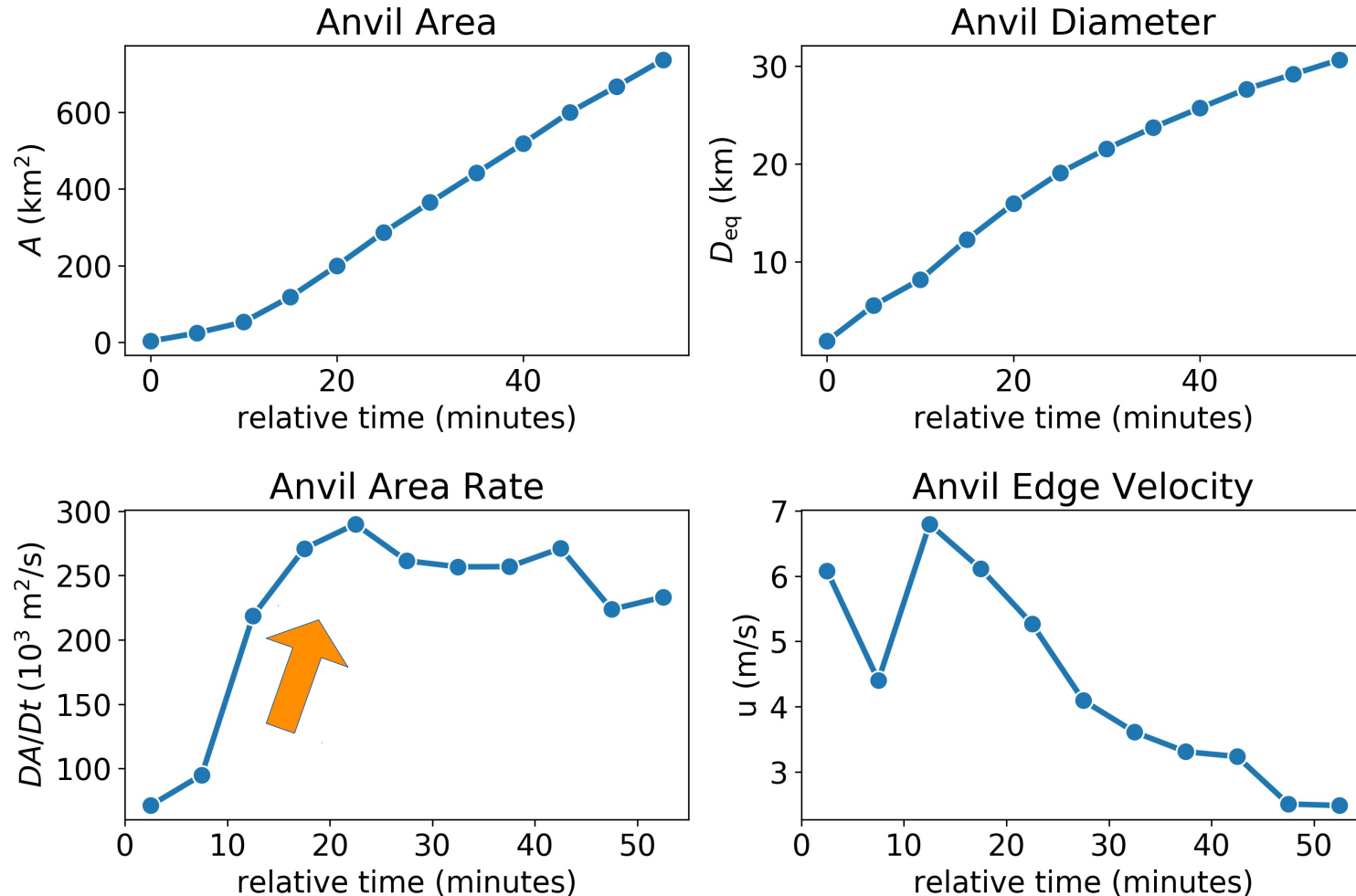
Temporal Sequence of Simulated Brightness Temperature at $10.8\ \mu\text{m}$



- Cold Cloud Cover with BT10.8 < 240 K shown in colors
- Target anvil development shown in red

Step-wise Analysis

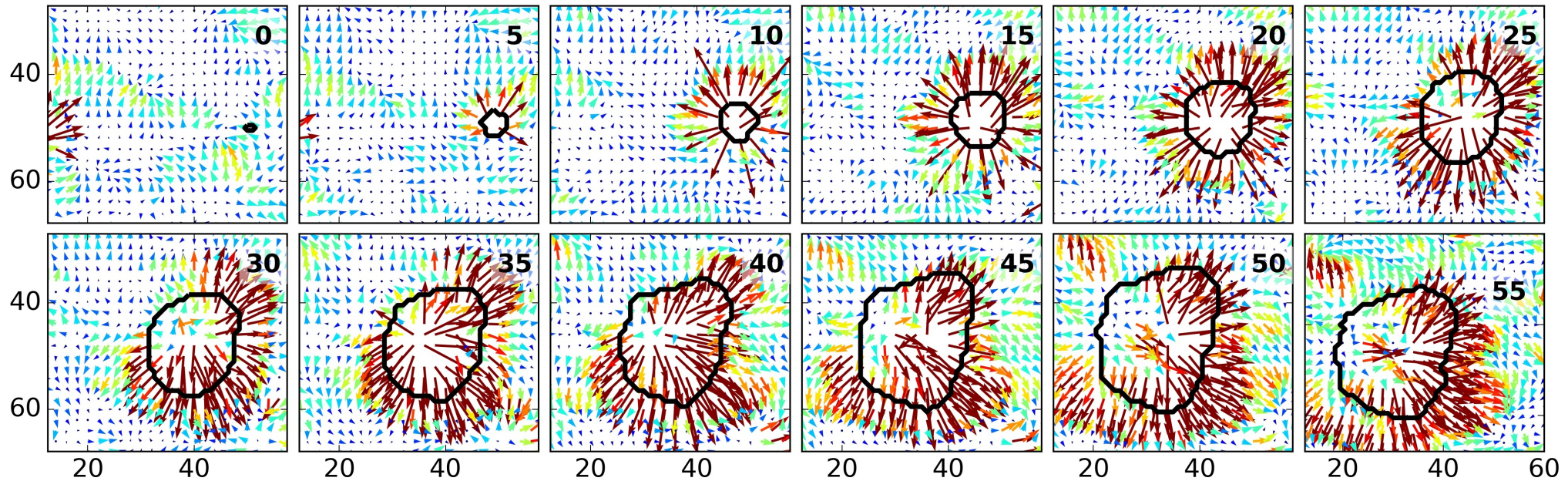
Characteristics of Anvil Growth



- Analysis of segmented BT10.8 field
- anvil area rate strongly increases in the beginning

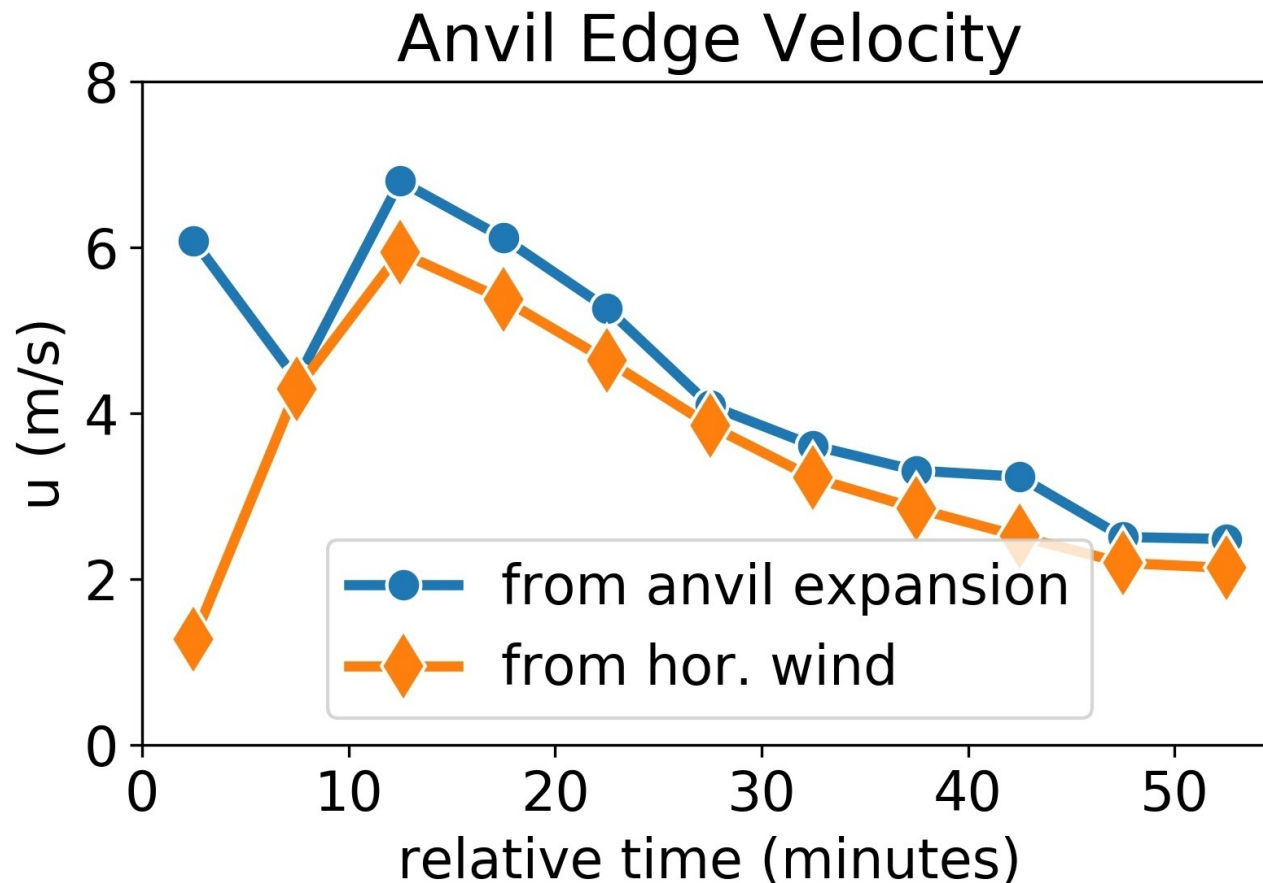
Step-wise Analysis

Temporal Sequence of Horizontal Wind at 250 hPa



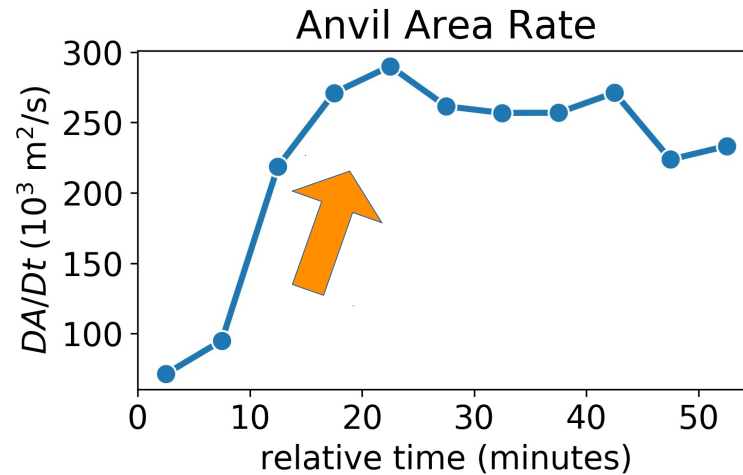
- diverging wind component at anvil levels
- this flow is ~ 10 minutes to develop

Step-wise Analysis



- reasonable comparison between anvil edge velocity and horizontal wind at anvil edge
- apparent anvil change is not too much impacted by other factors than wind divergence

Step-wise Analysis



$$\langle \bar{\rho} D_t A_c \rangle_h = \frac{A_w}{h_{\text{outflow}}} \langle \bar{\rho} w_b \rangle_{A_w}$$

Diagram illustrating the relationship between the equation and three variables:

- Anvil Area Rate (indicated by an arrow pointing left from the equation)
- Updraft Core Area (indicated by an arrow pointing down from the equation)
- Updraft Magnitude (indicated by an arrow pointing right from the equation)

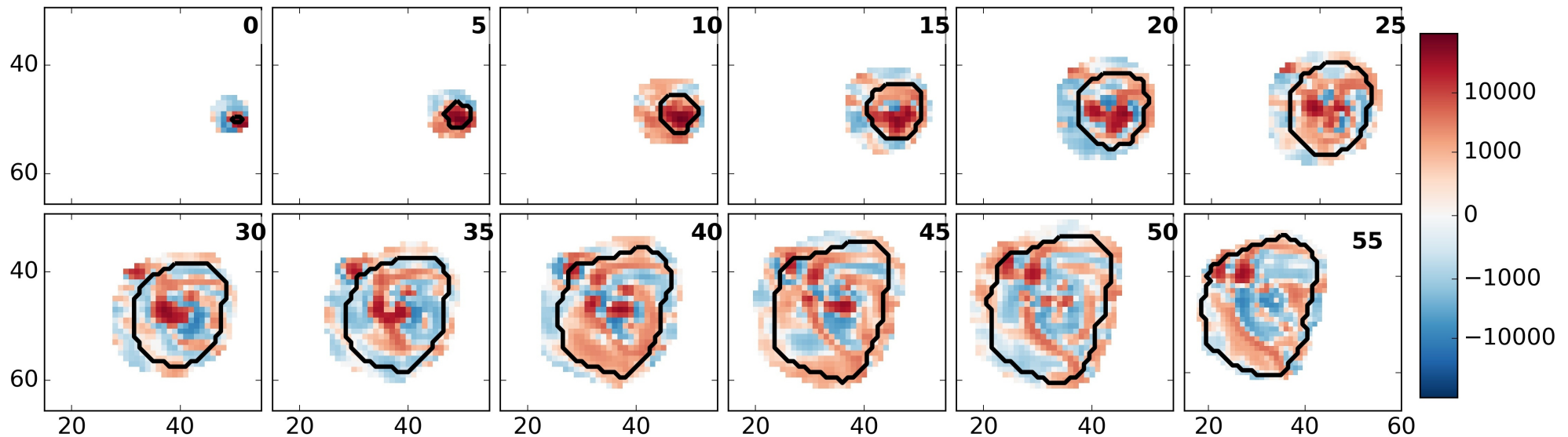
Step-wise Analysis

$$M = \int dz \rho w$$

w : vertical velocity

ρ : air density

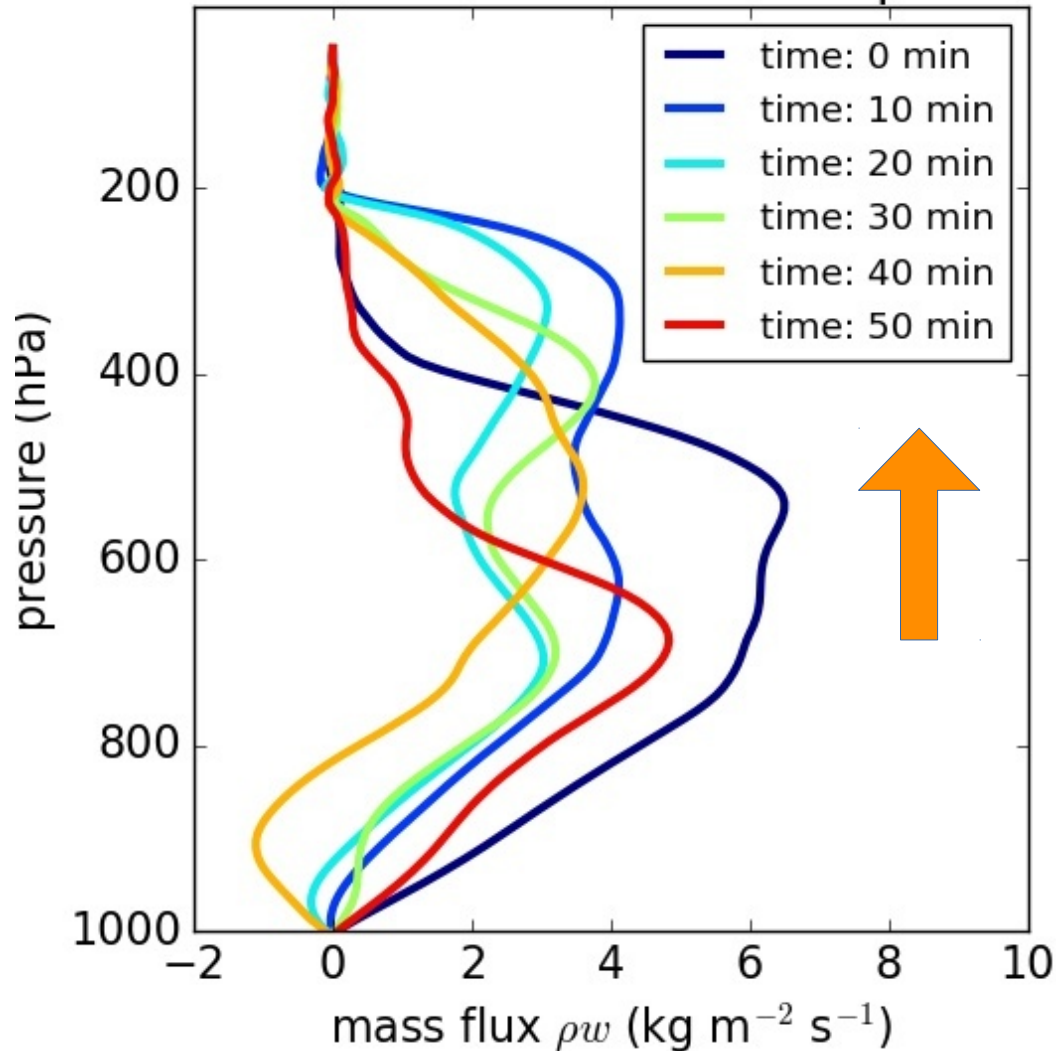
Temporal Sequence of Integral Vertical Mass Flux



- complex updraft structure below the anvil (black contour)
- multiple cores

Step-wise Analysis

Mean Mass Flux Profiles in the Updraft Cores

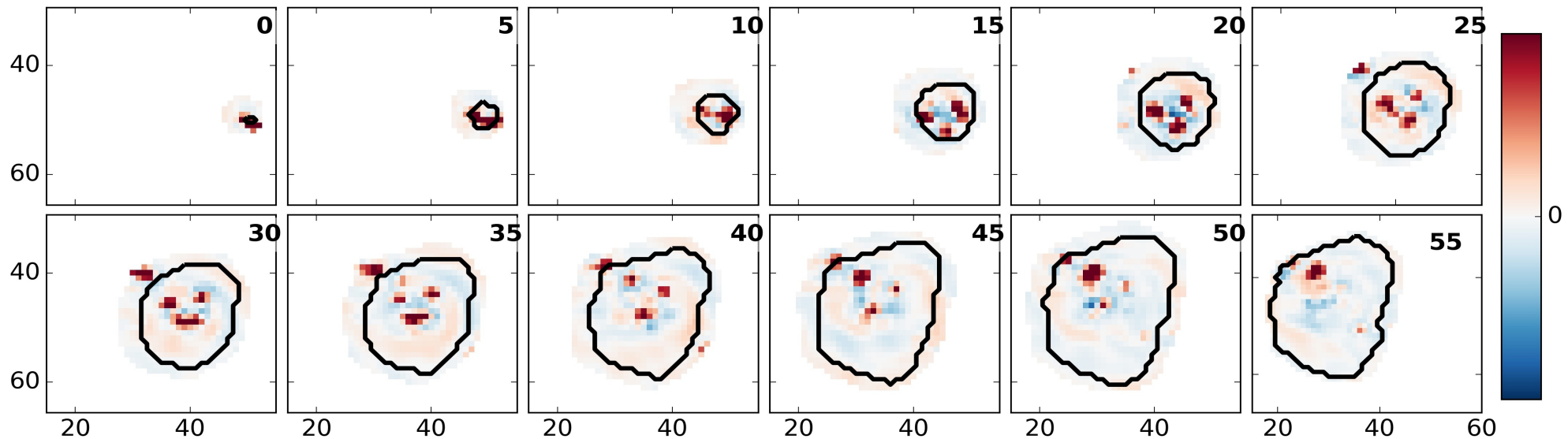


- several updraft pulses are rising
- multiple cores at different stages lead to multi-modal vertical mass flux structure

Step-wise Analysis

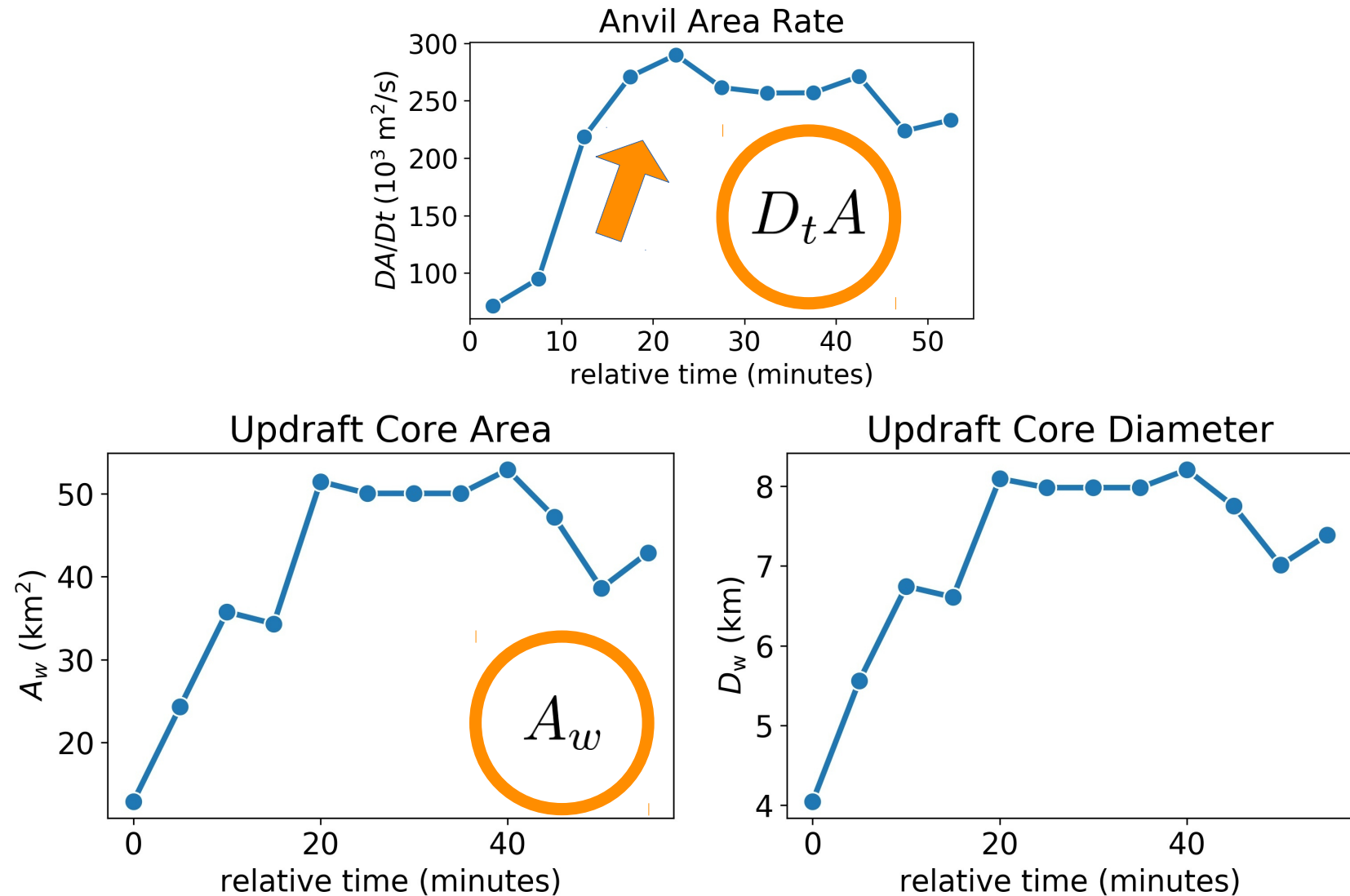
mass flux $m(750 \text{ hPa}) = \rho w(750 \text{ hPa})$

Temporal Sequence of Vertical Mass Flux at 750 hPa



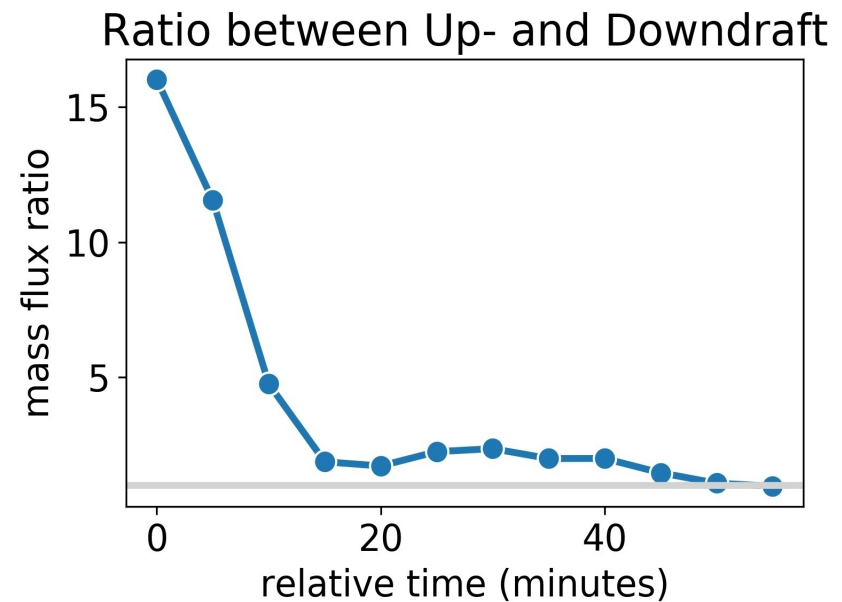
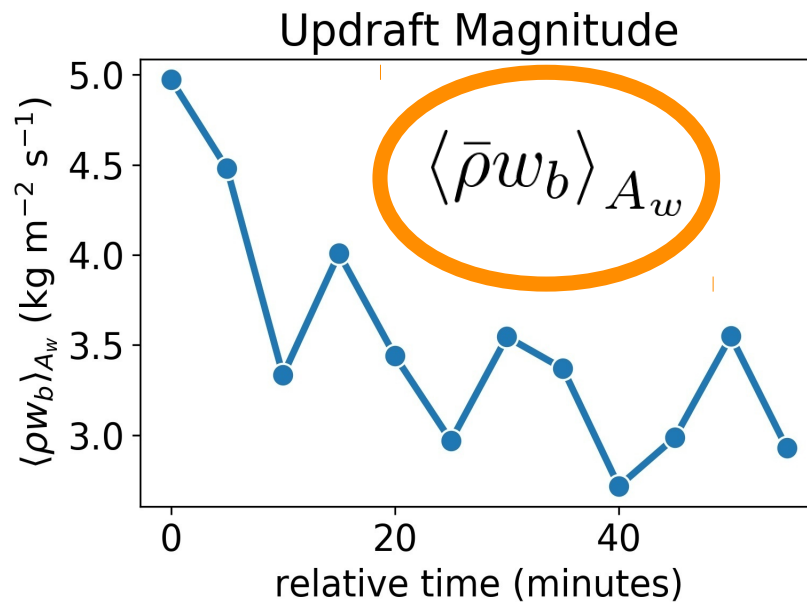
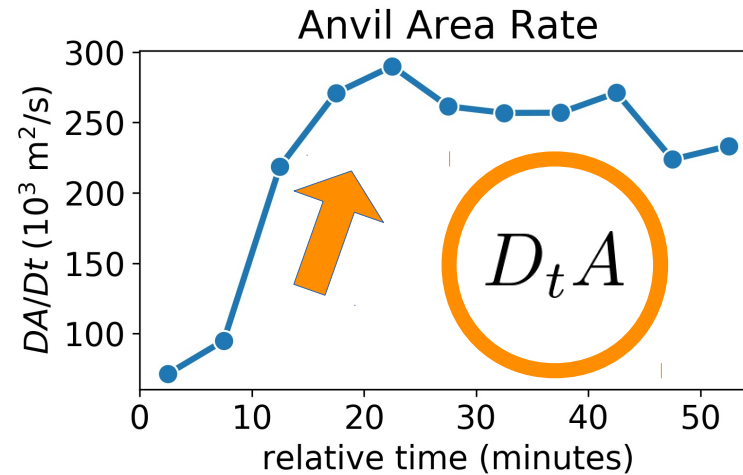
- complex updraft structure - multiple cores
- simulated updraft cores have short life times, $\sim 10 - 20$ minutes and resemble rising plumes

Step-wise Analysis



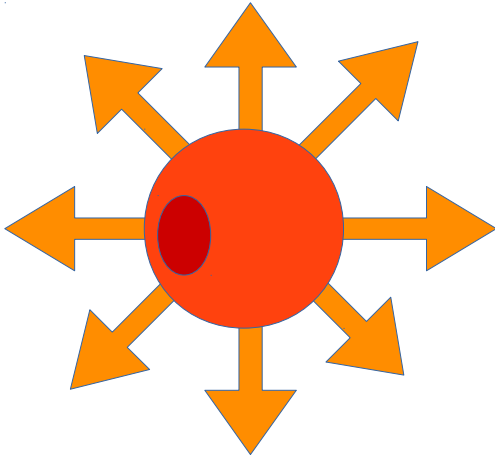
- updraft core area increases in the initial anvil growth phase

Step-wise Analysis



- updraft magnitude slightly decreases
- downdrafts become important after ~ 20 minutes

Conclusions



(1) What causes the initial increase in anvil area rate?

- strong increase in updraft core area leads to increase updraft mass flux
- the increase is mainly due to the formation of multiple updraft cores that behave like rising plumes
- downdrafts become important after ~ 20 minutes

(2) Is the apparent anvil sufficiently attached to the flow?

- the apparent anvil change is in good agreement with changes from horizontal wind divergence at anvil level
- changes of anvil radiative properties are of minor importance (e.g. formation / sublimation of ice)
 - **anvil change can be related to mass balance during convective growth**

Outlook

- **apply the analysis to the set of identified anvil growth cases**
- closer look at lateral entrainment
- environments with higher wind shear