Characterizing the Subsiding Shell of Shallow Cumulus with Doppler lidar

Universität zu Köln

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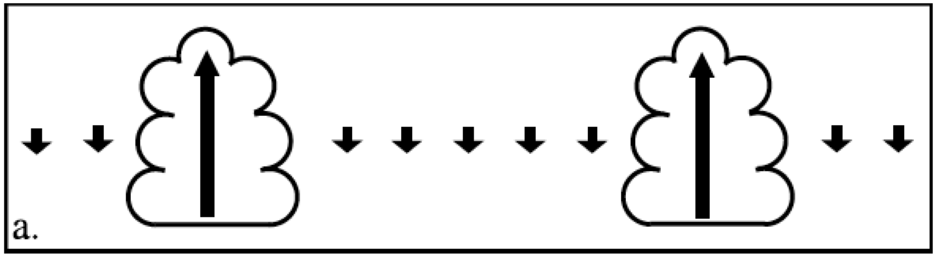
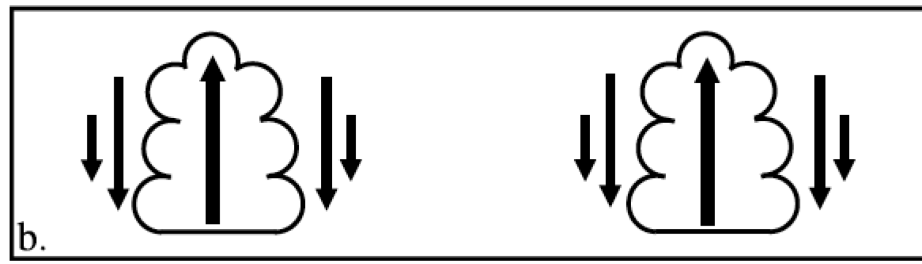
Mass Transport in Shallow Cumulus

Traditional



Alternative



Jonker, H. J. J., T. Heus, and P. P. Sullivan (2008), A refined view of vertical mass transport by cumulus convection, Geophys. Res. Lett., 35, L07810, doi:10.1029/2007GL032606.

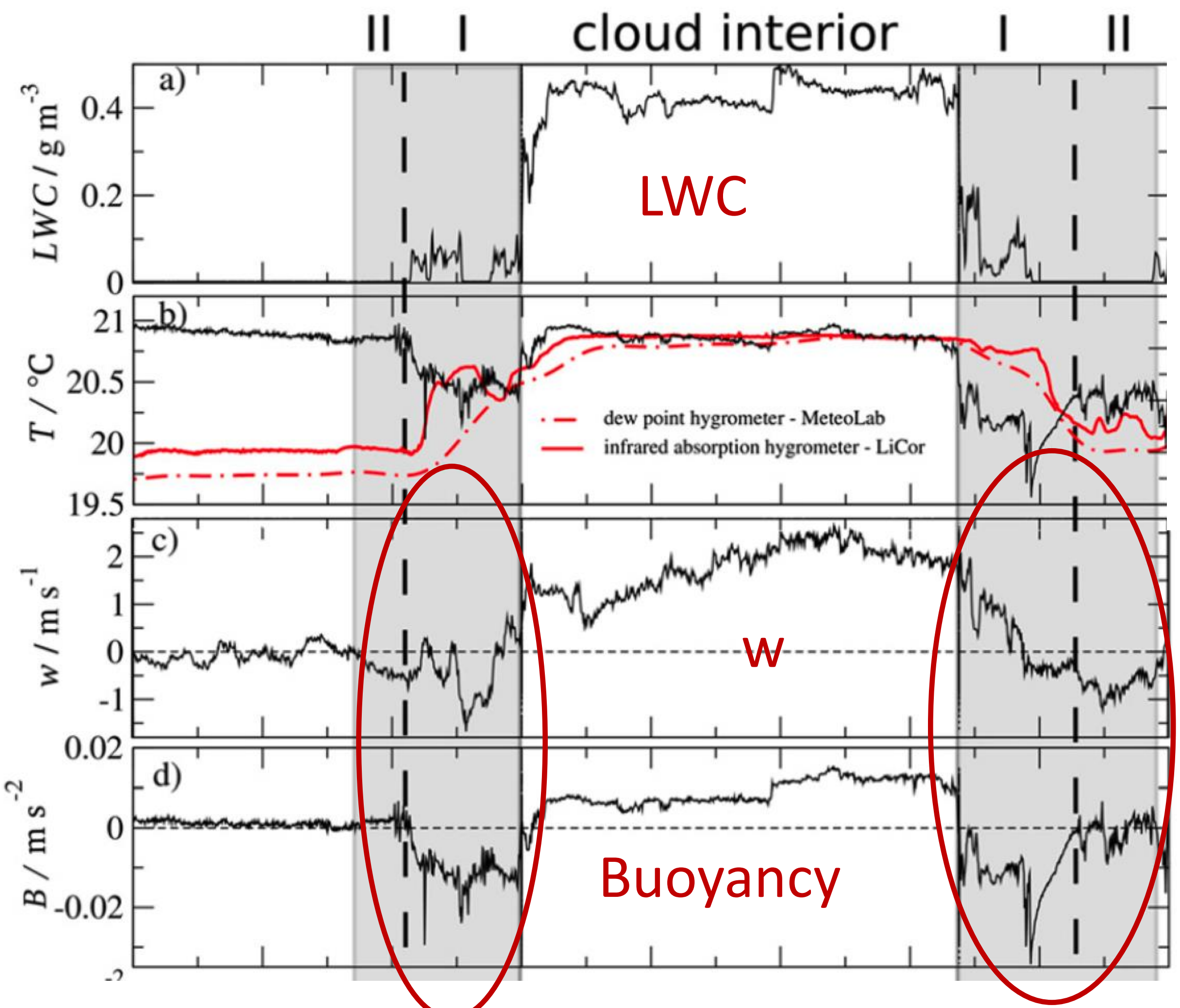
LES of shallow cumulus clouds suggest that

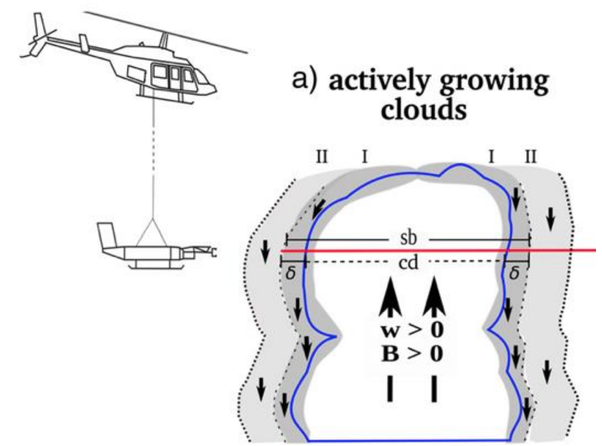
- **upward mass transport** by clouds is strongly dominated by regions close to the edge of clouds rather than by the cloud core region.
- **downward mass transport** is dominated by processes just outside the cloud.

Observations by Katzwinkel et al. 2014

Helicopter-borne measurement platform ACTOS

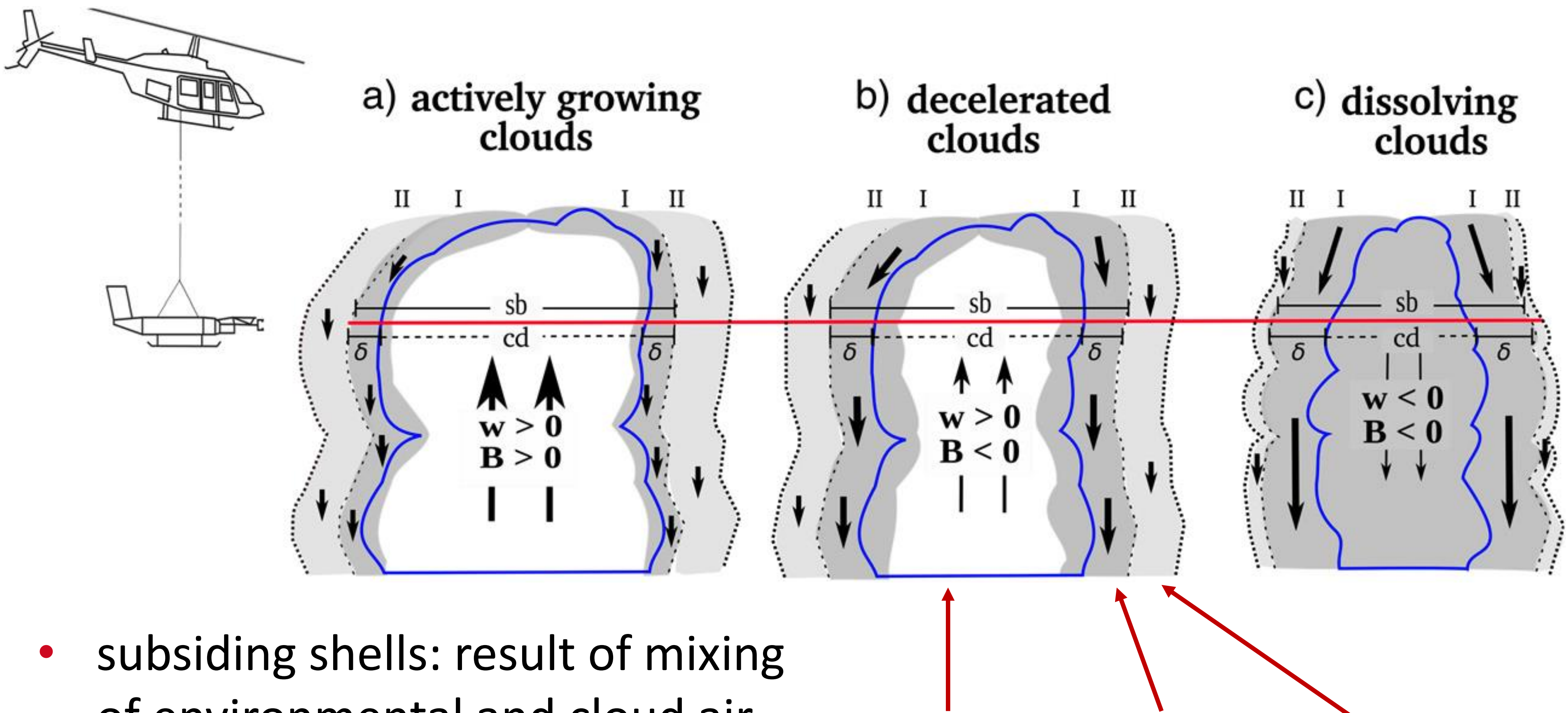
Katzwinkel, J., H. Siebert, T. Heus, and R.A. Shaw, 2014: Measurements of Turbulent Mixing and Subsiding Shells in Trade Wind Cumuli. J. Atmos. Sci., 71, 2810–2822, https://doi.org/10.1175/JAS-D-13-0222.1





Just outside the cloud: downward velocity, buoyant

Analysis of 217 Clouds: 3 Cloud Stages



Cloud interior – inner shell – outer shell

- subsiding shells: result of mixing of environmental and cloud air
- clouds are influenced unequally by the entrainment of environmental air **depending on their stage of development**

Origin of entrained air?
Mechanism driving downward velocity?

Research Questions of this Study..

Focus: Shallow Cumulus

- Can the subsiding shell be **detected** with **Doppler lidar** through analysis of time-height cross sections?
- How often does the subsiding shell **exist**, how **broad** is it?
- Are there relations to **cloud development stage** or cloud macro-physical properties?
- What are the **limitations** of observing time-height cross sections?
- Are the observations **consistent with LES**?

Instrumentation

Vertically pointing HALO-Streamline Doppler lidar (~1-2 s integration time)

↓

Attenuated backscatter profile & Doppler velocities

Jülich Observatory for Cloud Evolution

JOYCE – CF

www.joyce.cloud

ARM: Southern Great Plains (SGP) Research Facility

ARM

(No highly-temporally resolved MWR data)

Day Selection

Based on **visual inspection** Doppler lidar backscatter time-height series & Cloudnet (JOYCE) & ARSCL product (SGP)

- Cumulus convection around noon and an increase in the LCL during the day
- Cloud cover is small and cumulus events are isolated
- No precipitation and no significant synoptic-scale activity

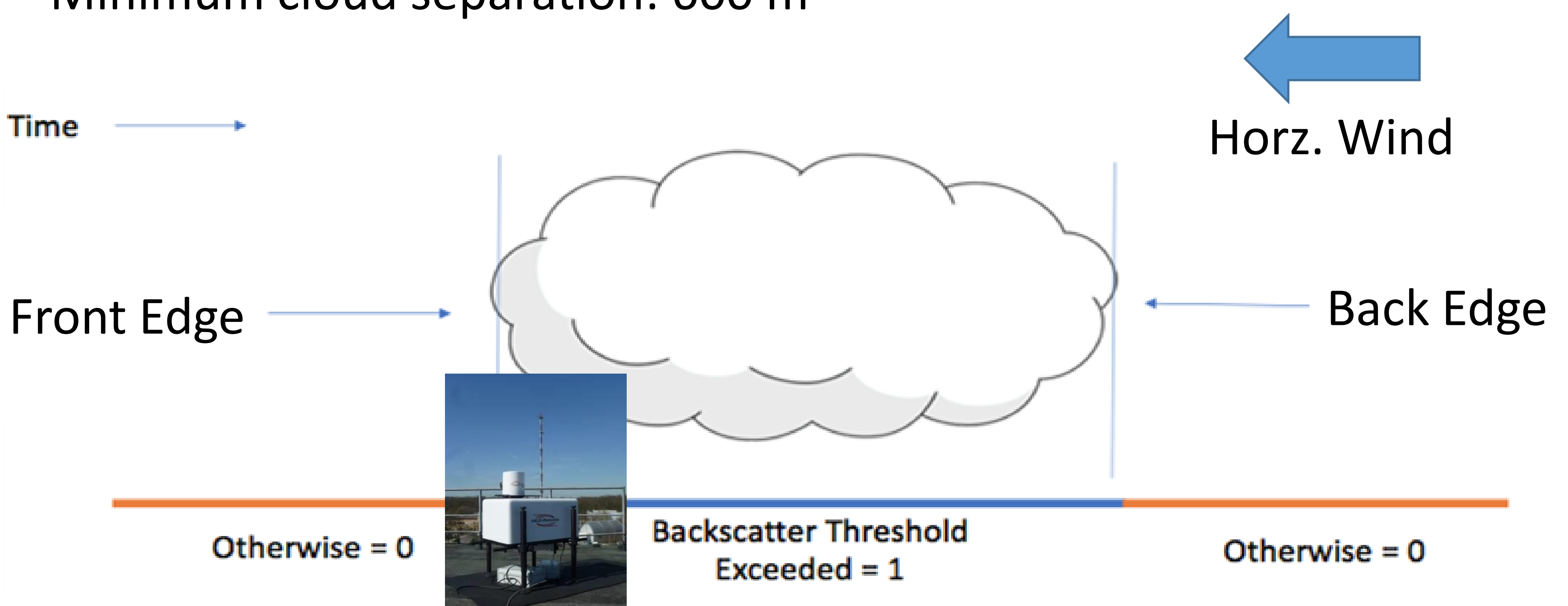
→ 49 SGP days, 146 JOYCE days (unequal time spans analyzed)

Cloud Detection

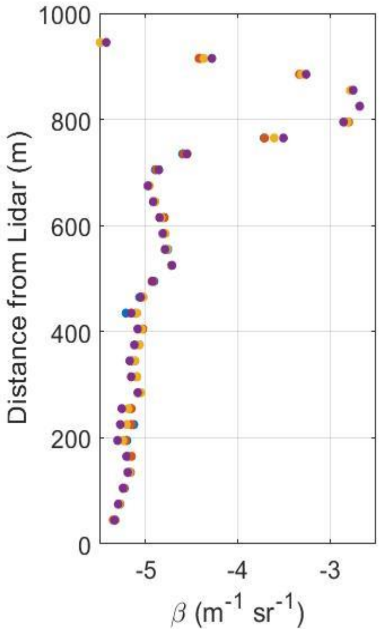
- Cloud base detection from simple backscatter threshold: $\beta > 10^{-4}\ m^{-1}\ sr^{-1}$
- 200 m < Cloud base < 2000 m
- Cloud depth < 1 km, single layer
- Minimum cloud chord length: 100 m
- Minimum cloud separation: 600 m

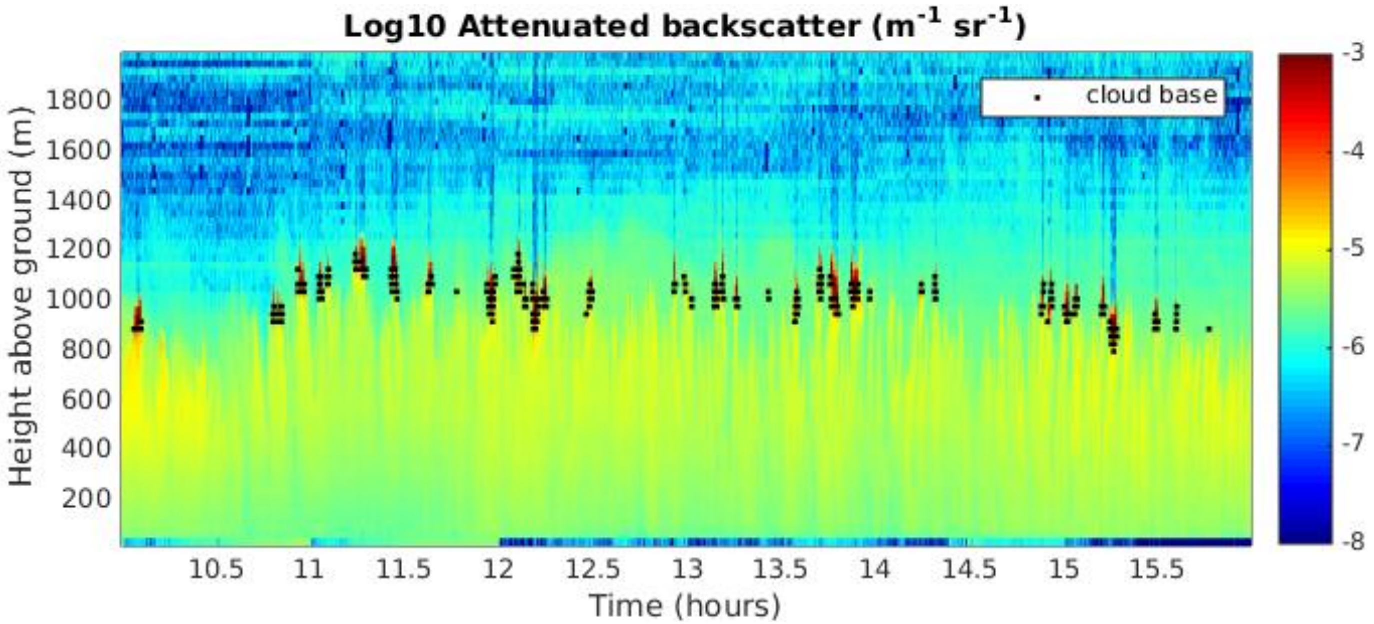
SGP: 110 clouds

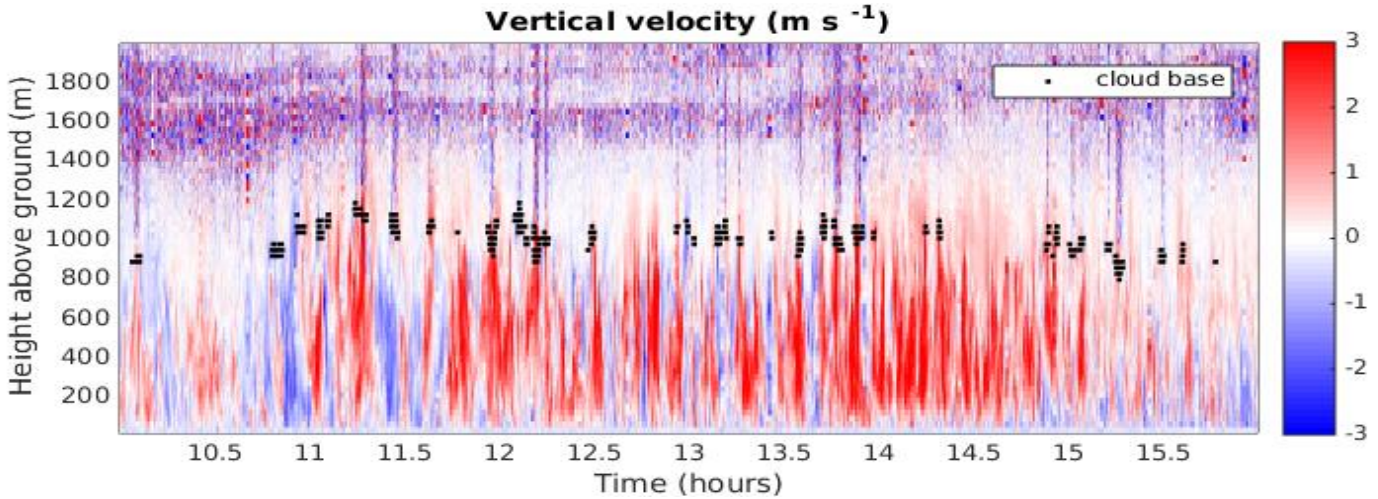
JOYCE: 115 clouds



Example







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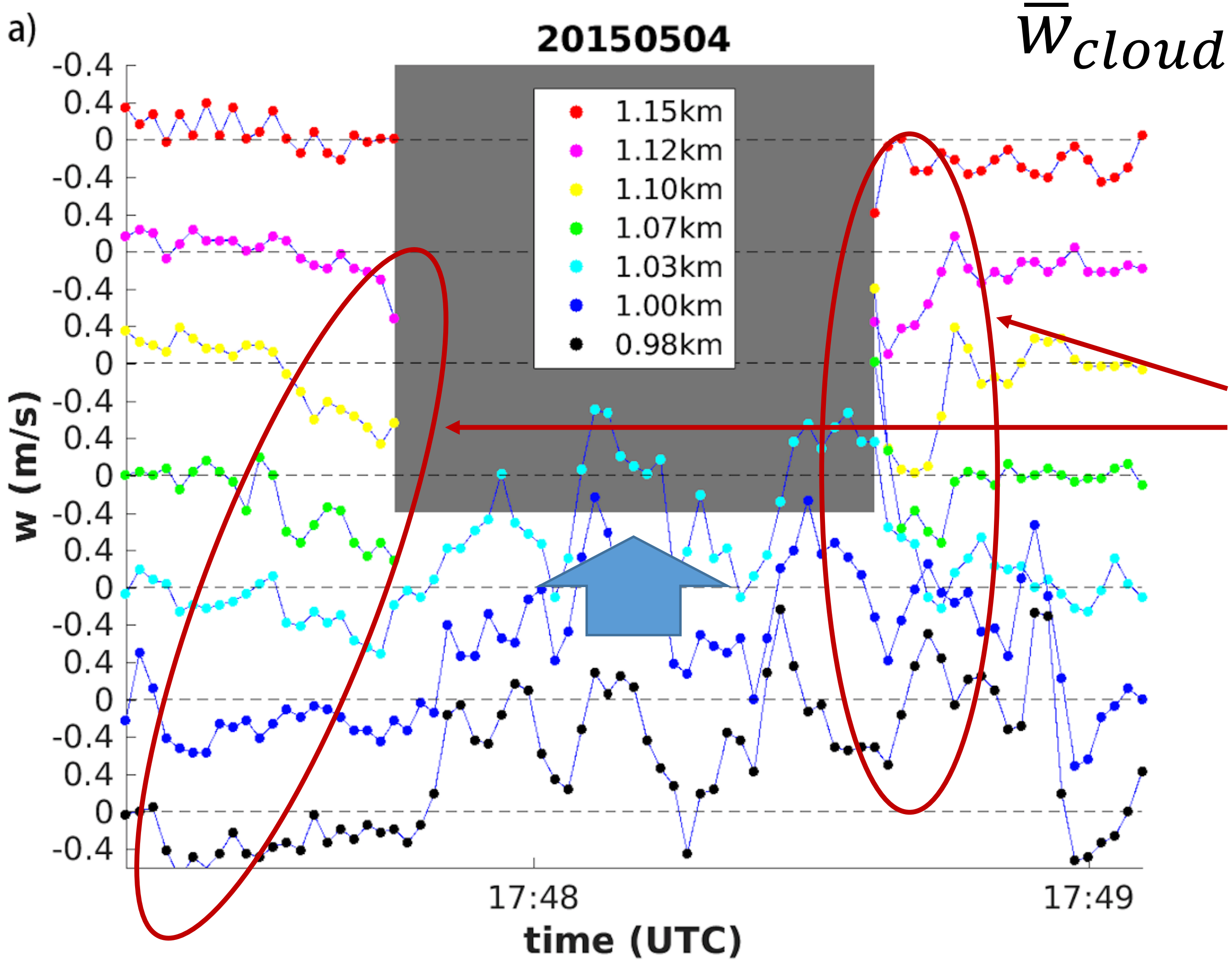
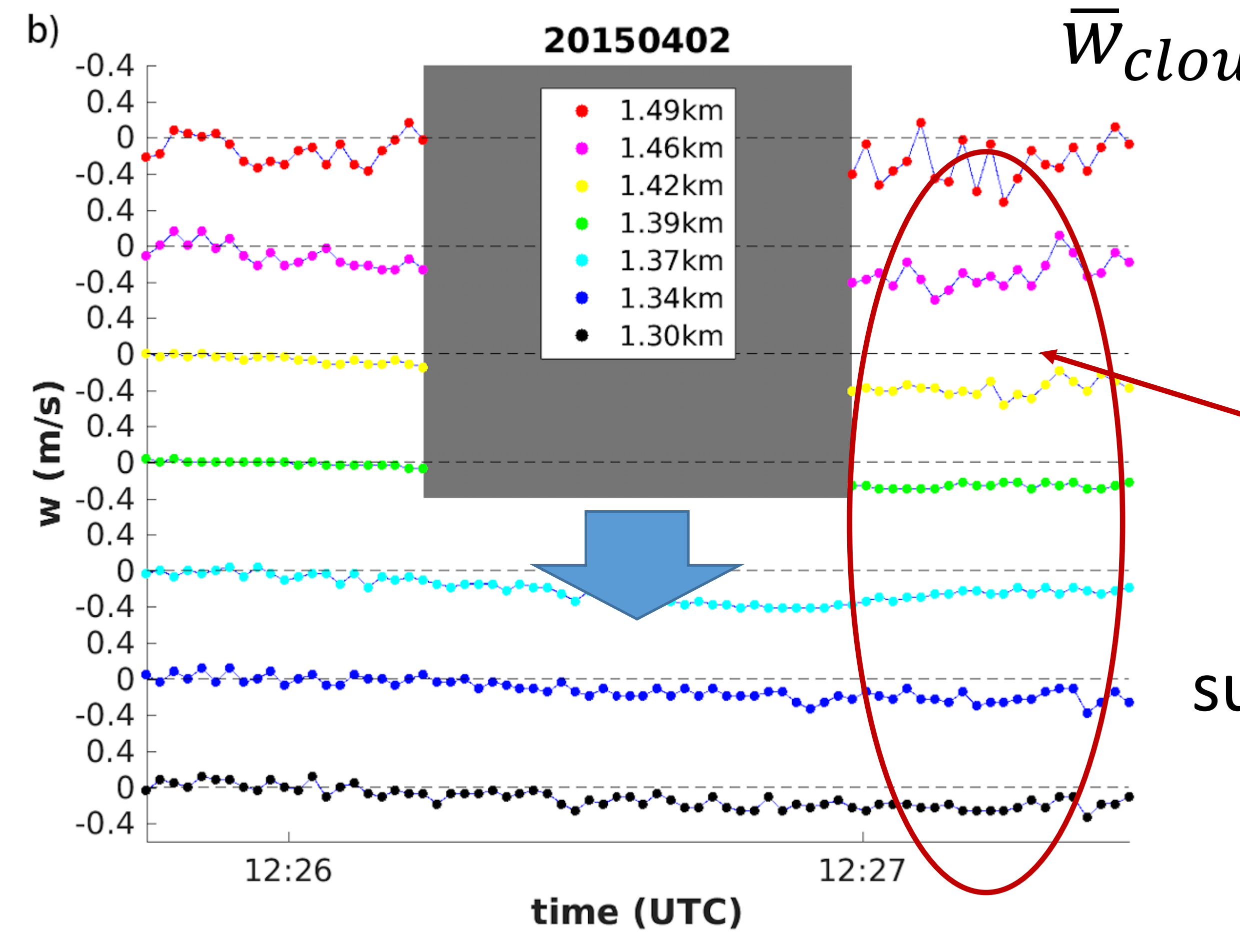
Case Study SGP: Positive Mass Flux



$\overline{w}_{cloud\ base} > 0$

Subsiding shell?

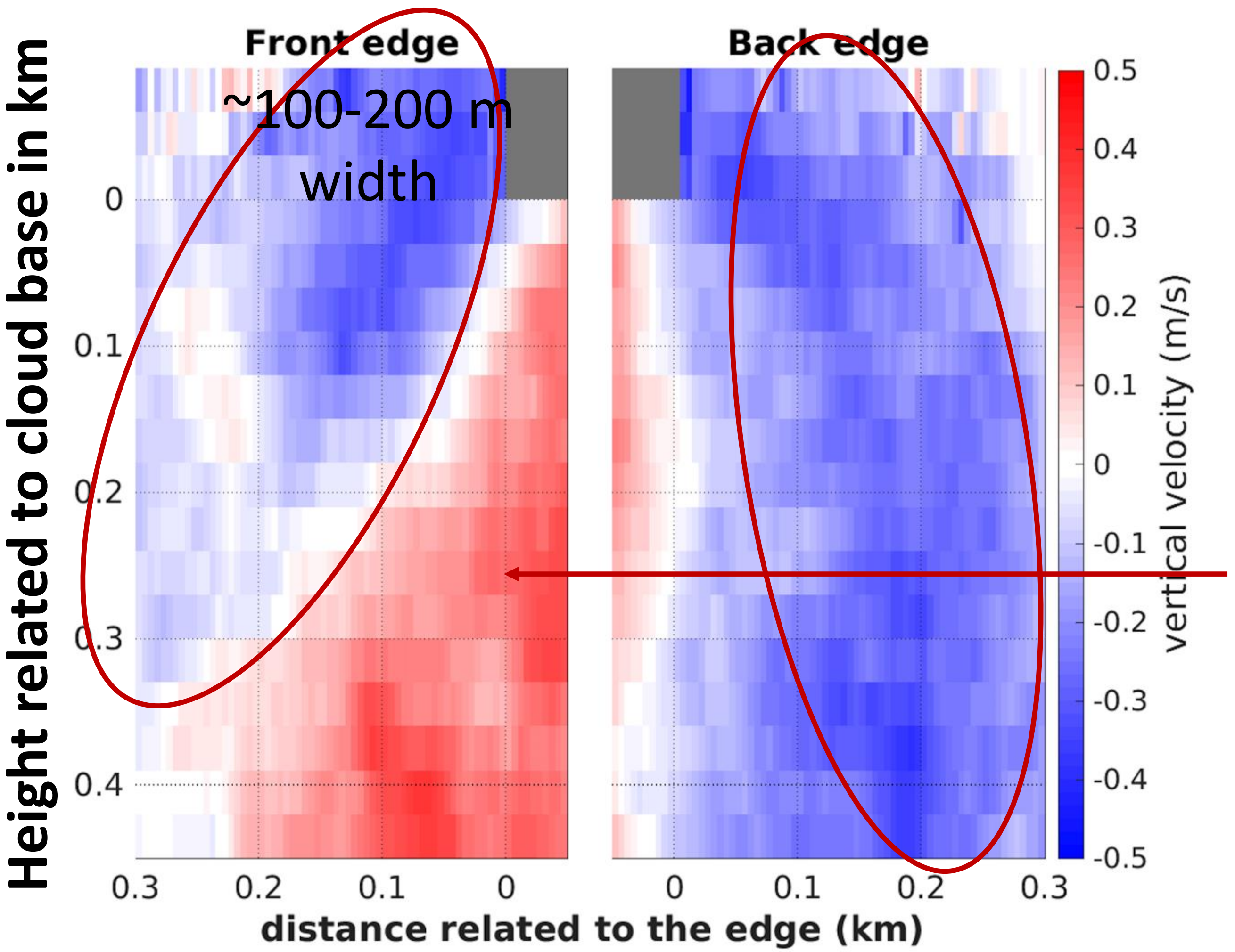
Case Study SGP: Negative Mass Flux



$\bar{w}_{cloud\ base} < 0$

Weaker, but broader subsiding shell?

All 110 Clouds (Median w) @ SGP



Subsiding shell features extending well below cloud base

Clear asymmetry visible in shape of updraft region

Related to cloud development stage?

Distance calculation based on horiz. velocity measured below cloud base

Positive Mass Flux Clouds @ SGP (N=68)

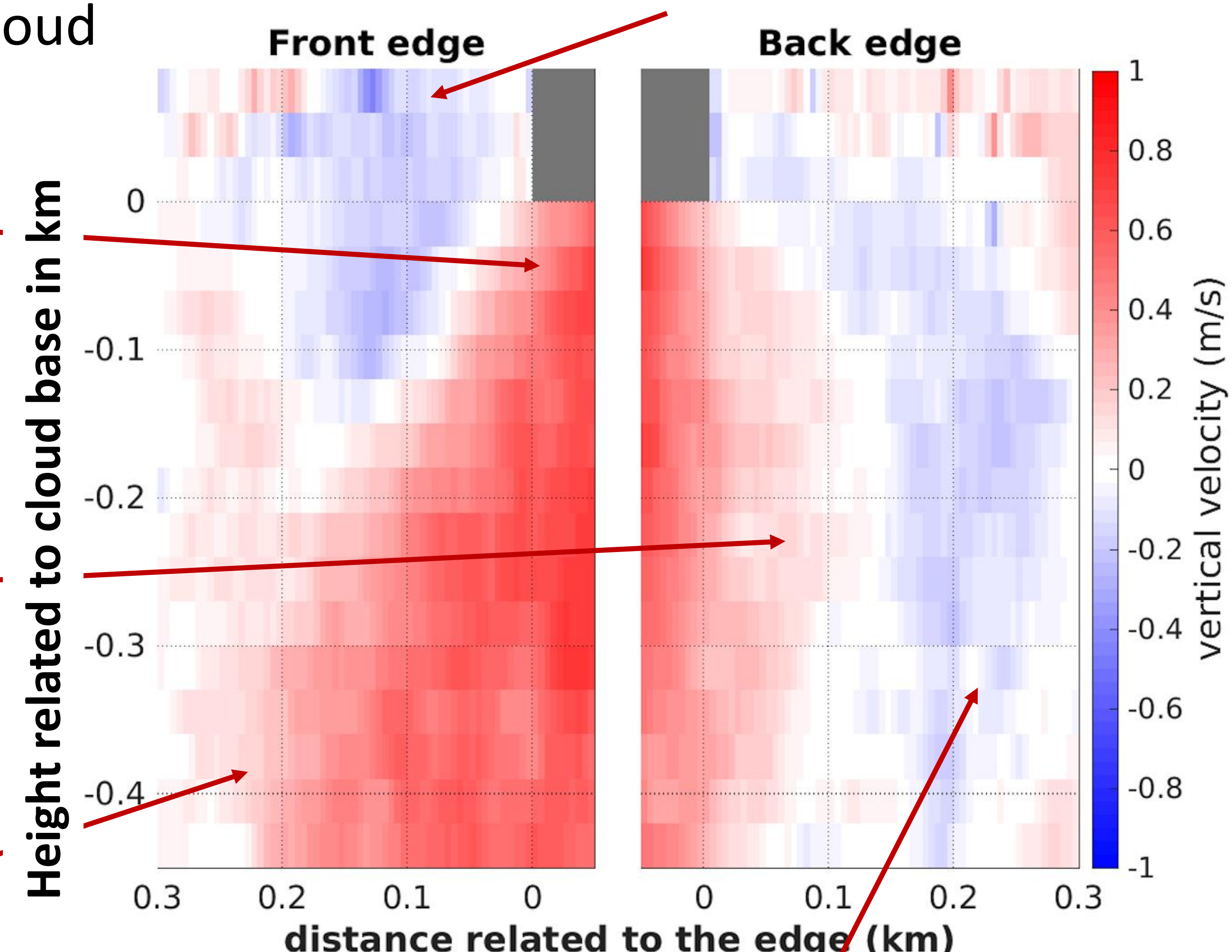
Asymmetry remains..
→ non-static cloud structure

Subsiding shell begins to develop

Thermal reaches LCL

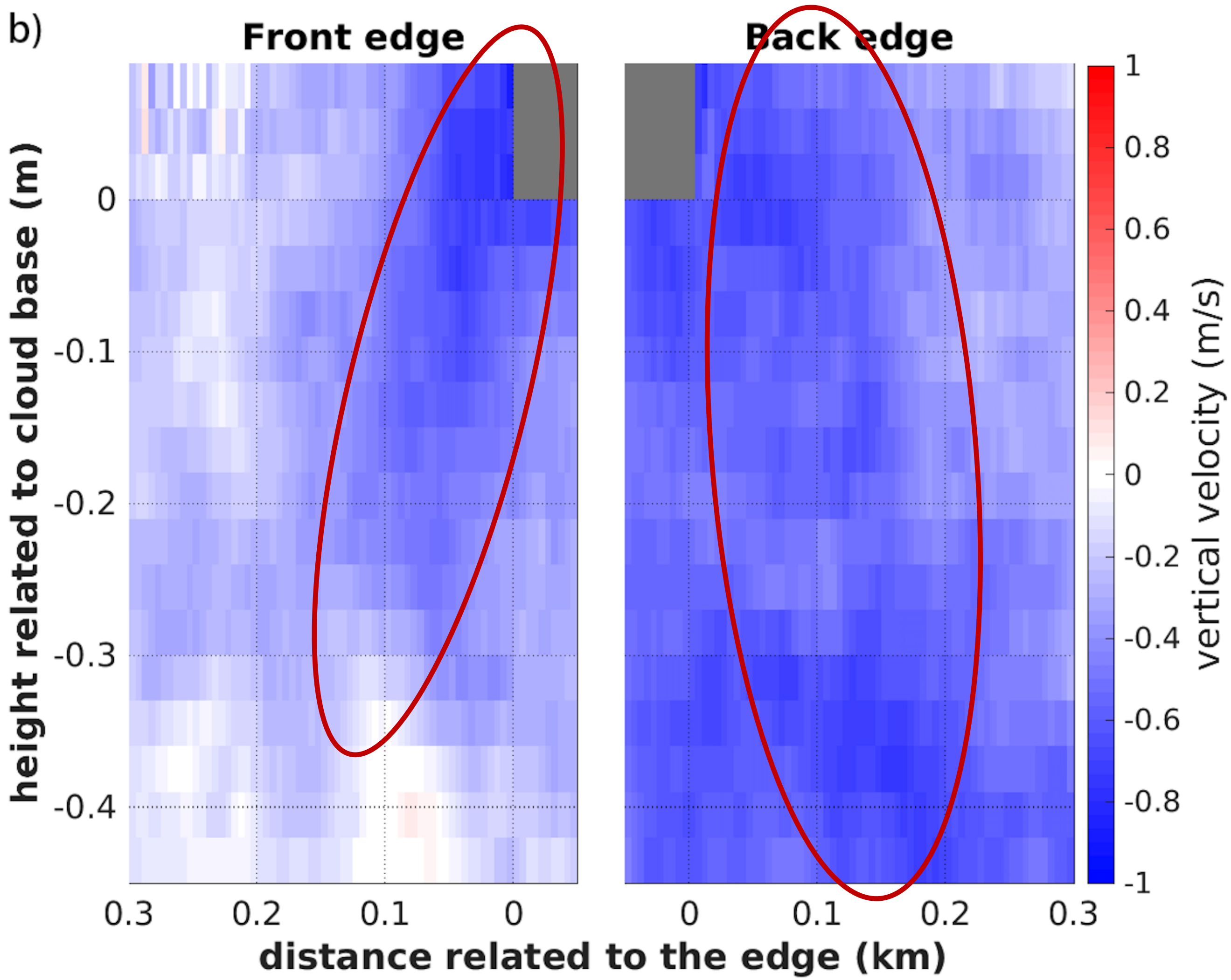
Thermals don't make it to LCL anymore

Beginning of rising thermal



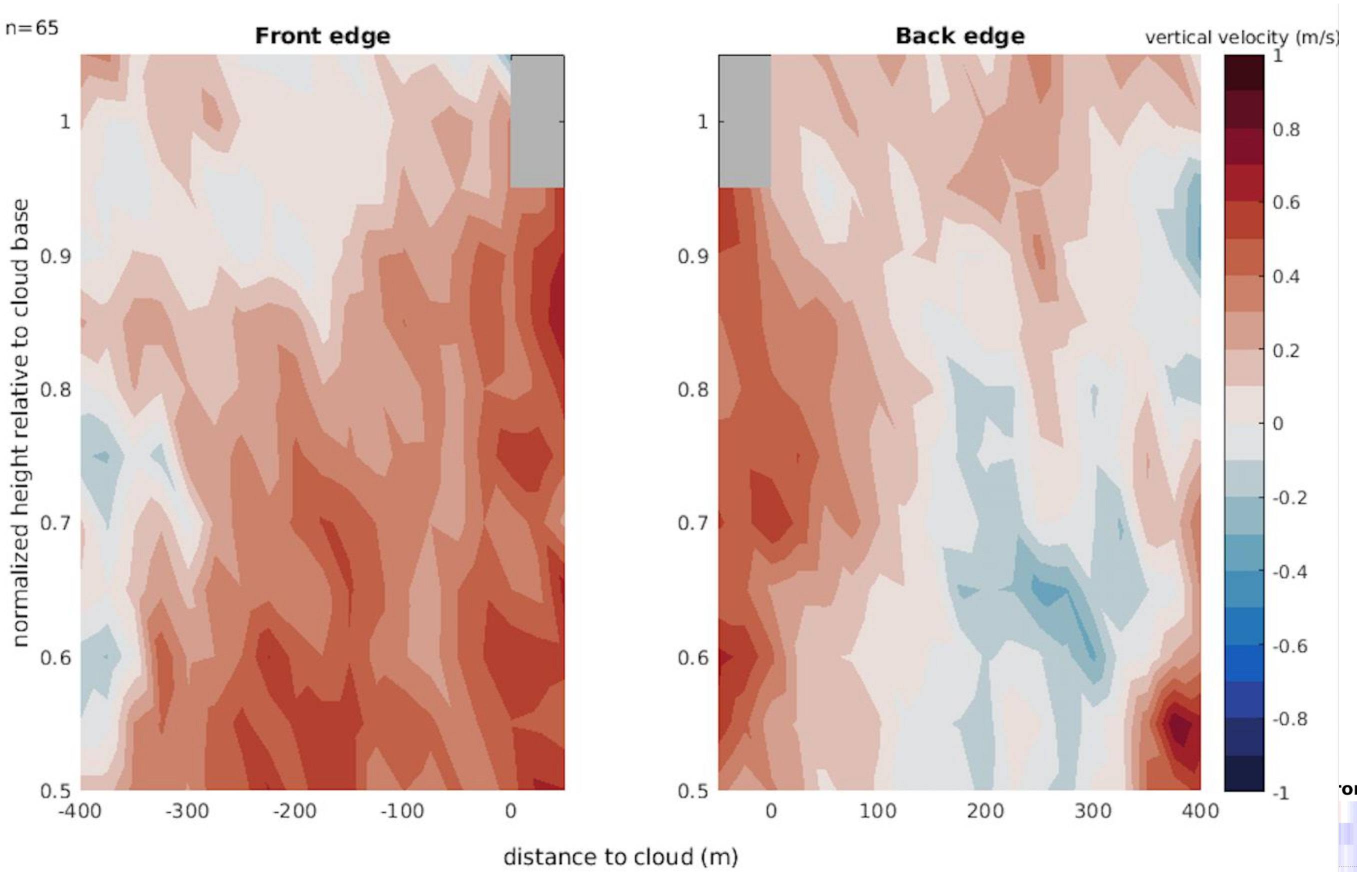
Subsiding shell descends further down

Negative Mass Flux Clouds @ SGP (N=42)

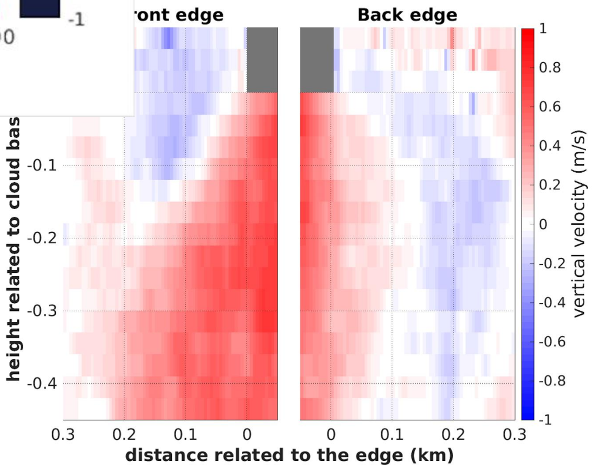


Weak asymmetry pointing towards on-going cloud decay?

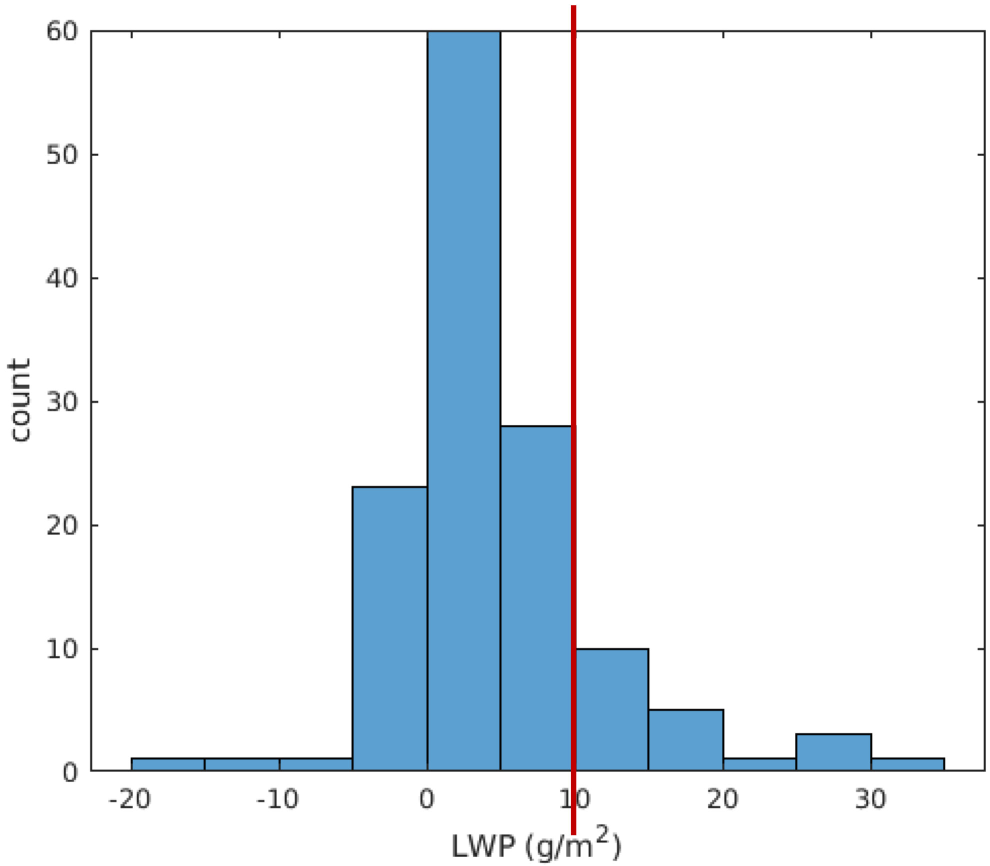
Positive Mass Flux Clouds @ JOYCE (N=65)



- More pronounced subsiding shell and stronger vertical velocities @ SGP
- Similarity in asymmetry



LWP Analysis @ JOYCE

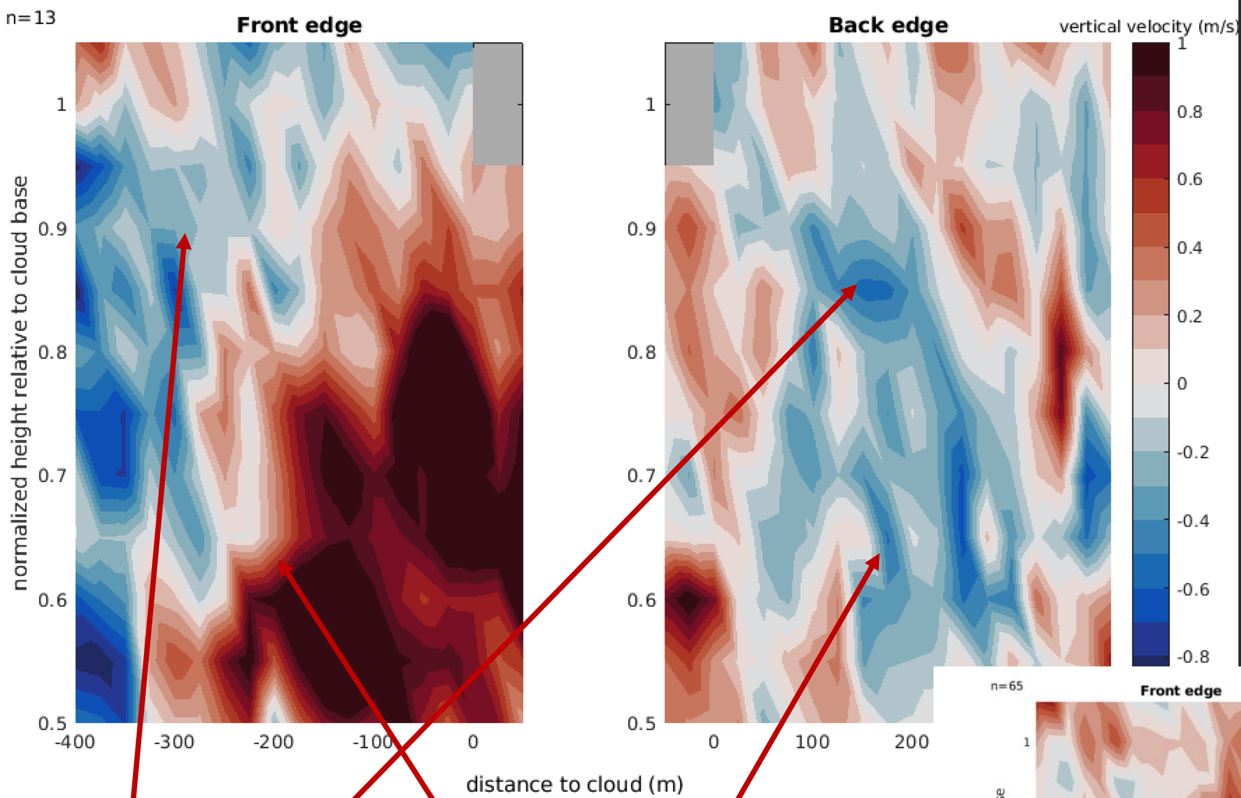


HATPRO LWP retrievals on temporal resolution of ~2s (similar to Doppler lidar, although larger footprint)

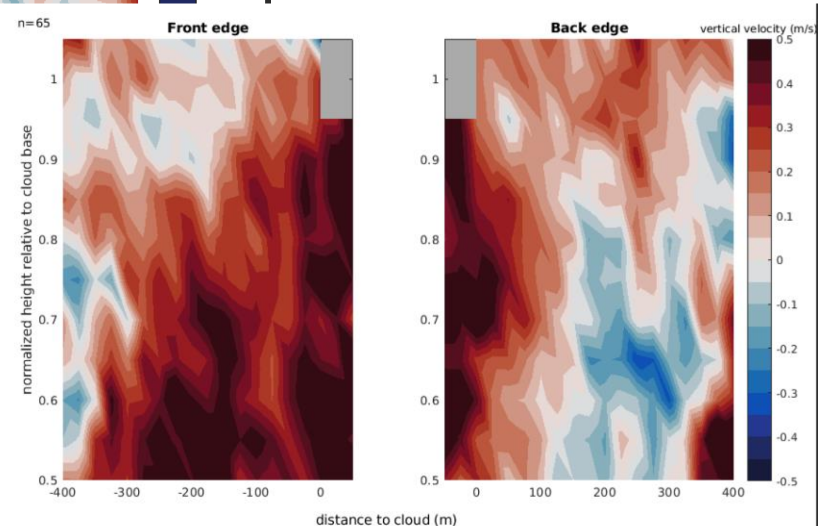
Very low values of LWP in case of shallow cumulus clouds investigated

But still: discriminate between clouds with LWP larger or smaller than 10 gm^{-2}

Positive Mass Flux and “high LWP“ (N=13)

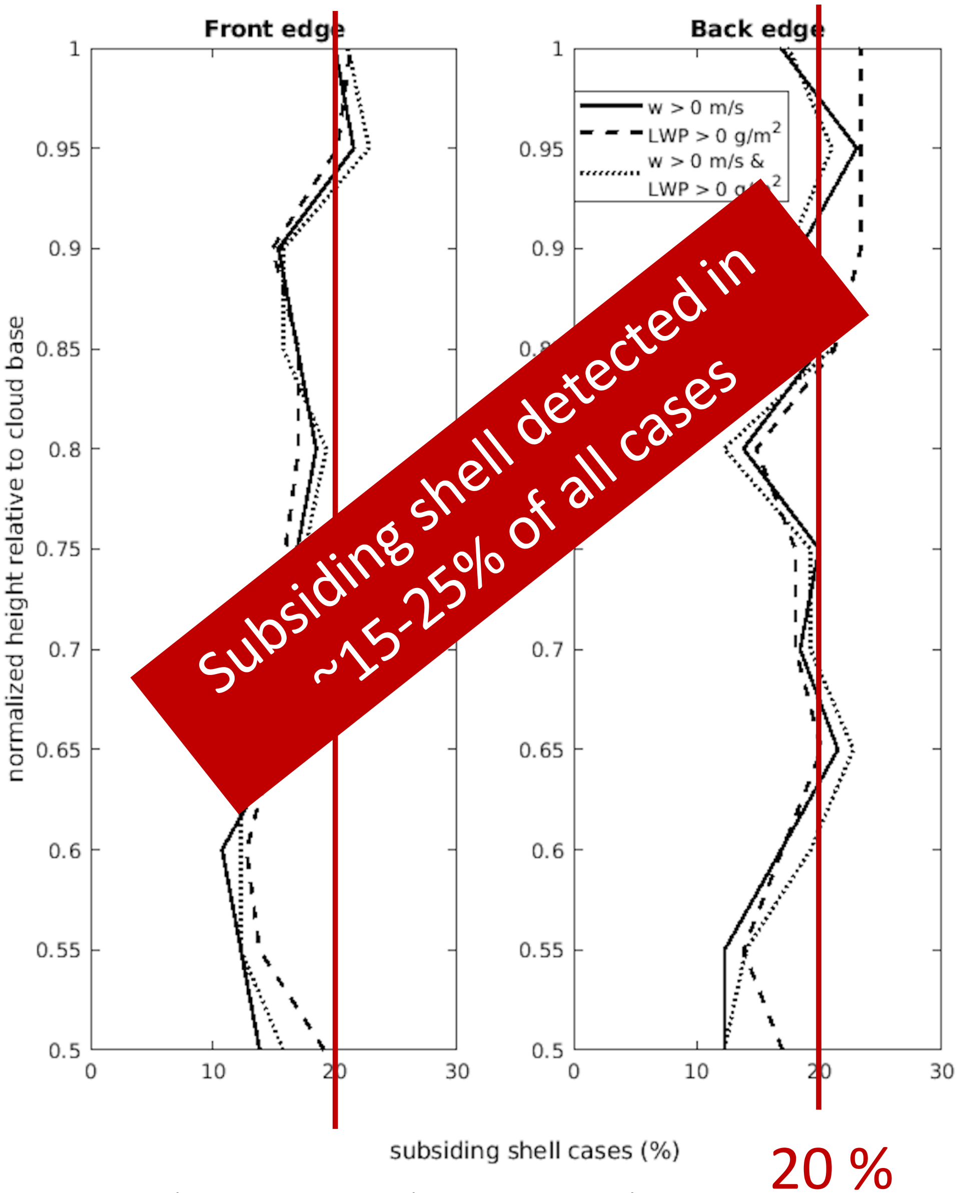


Only Pos. MF

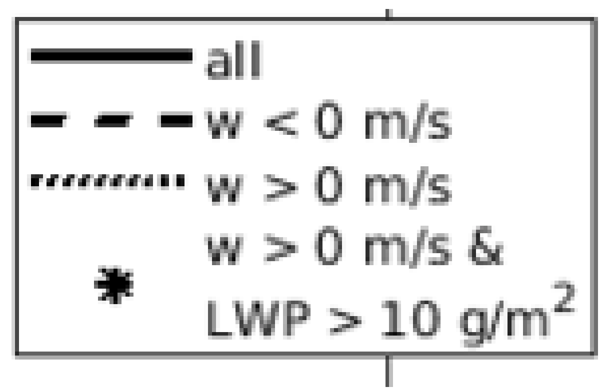


Higher LWP: more pronounced subsiding shell features & asymmetry

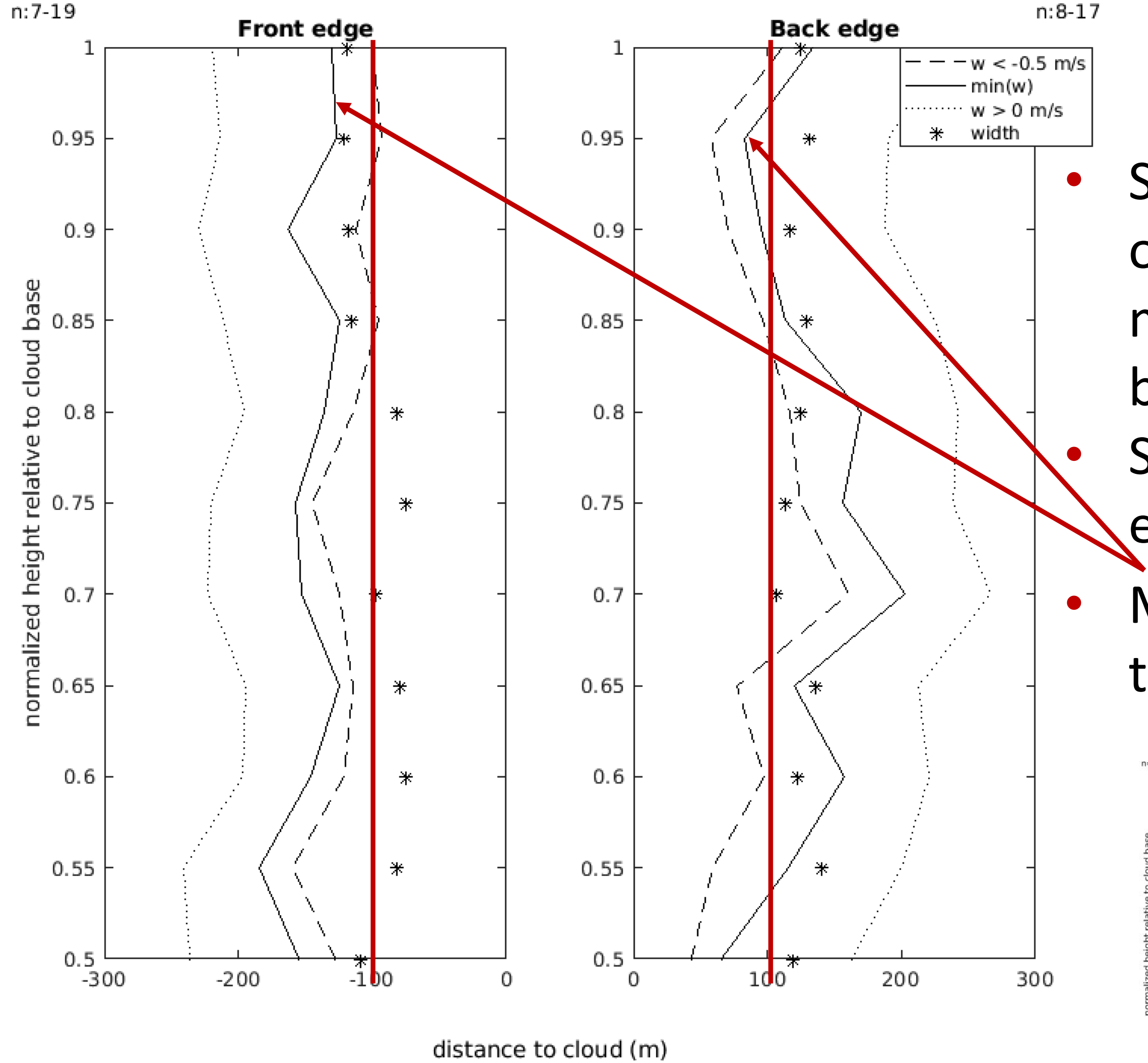
Simple Method: Subsiding Shell Detection



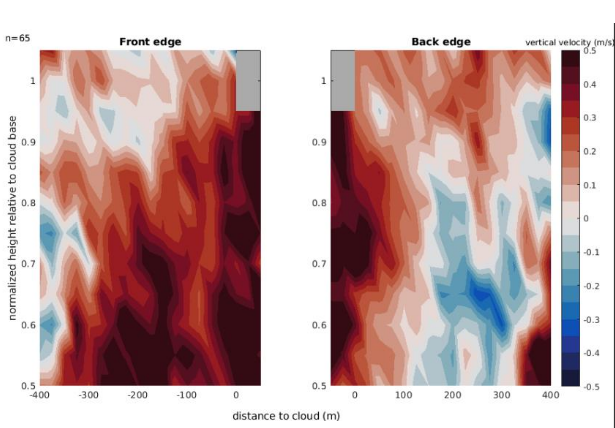
- Apply thresholds in w to determine **position** and **width**
- Perform statistics on subsiding shell **occurrence** as a function of height
- Consider different subsets:



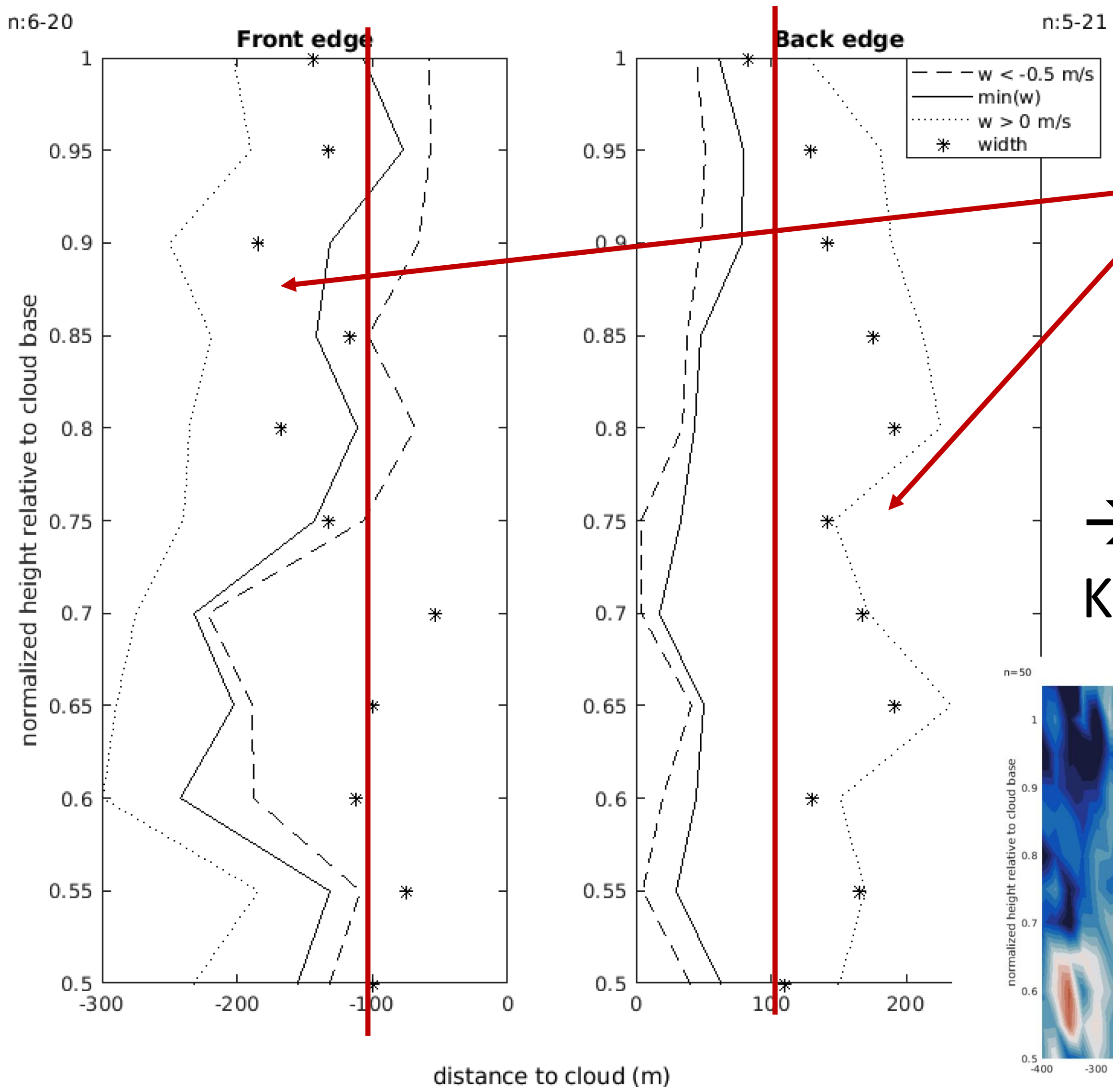
JOYCE: Subsiding Shell Width (Pos. Mass Flux)



- Subsiding shell feature on the order of ~100 m wide below cloud base
- Slightly wider on back edge of cloud
- Minimum(w) skewed to cloud edge

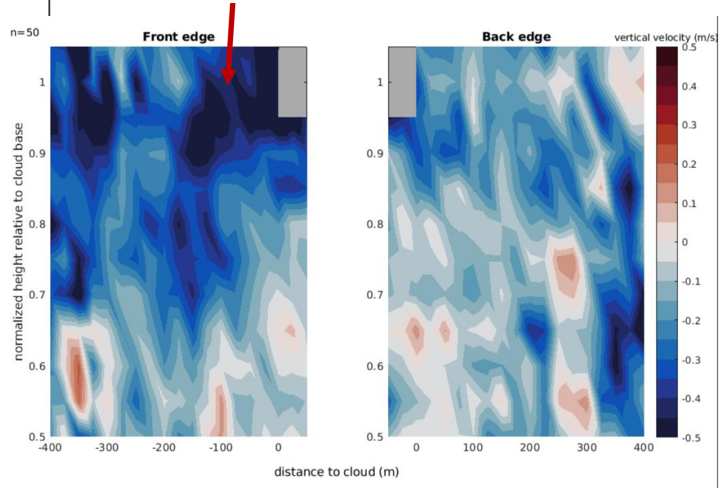


JOYCE: Subsiding Shell Width (Neg. Mass Flux)

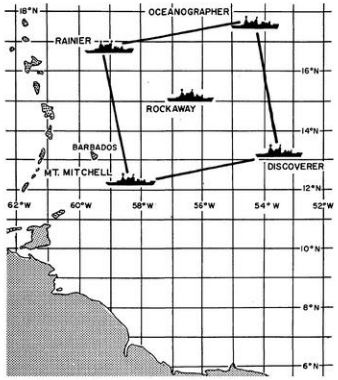


Subsiding shell wider (and stronger) than in pos. mass flux case: ~150 m

→According to Katzwinkel et al. 2014

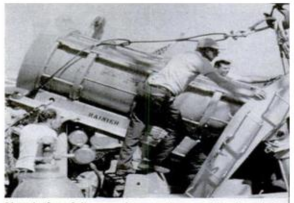


High-resolution Modelling: Simulated BOMEX Case



Barbados Oceanographic and Meteorological EXperiment (BOMEX)

Flip floats normally while being towed into position by its tugs. The tubular aftersection is then filled with water to become a vertical support.



Novel free-fall mooring system with its six-ton clump anchor took a bit of handling when loaded aboard the station ship Rainier at Gulfport, Miss

Large probes like this one hold the instruments that automatically measure salinity, temperature, and depth as they are lowered to the ocean bottom.

http://tornado.atmos.colostate.edu/public/paulc/BOMEX/bomex2.htm

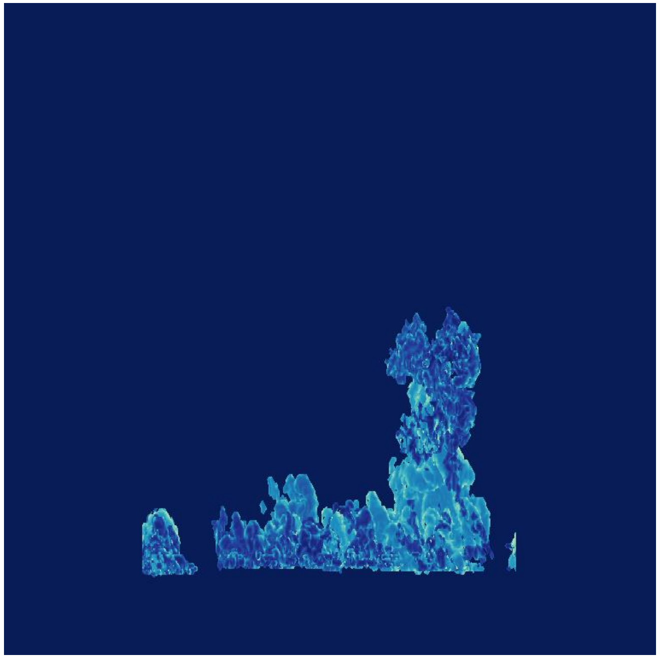
- System for Atmospheric Modeling (SAM)
- Prescribed radiative cooling profile, surface fluxes and large-scale subsidence
- Single-moment bulk microphysics
- grid spacing: **10 m** (240x240x360)
- 6 hour run with 1s time step
- Number of time steps analyzed: 200 (from 18000-18300 s), so ~3 min of 1 s 3D data

Output: Virtual Lidar and Static Cloud Boundary

Lidar transects:

- Every 100 m in the y-direction
- 7 usable cloud transects
- Almost all cloud chord lengths > 300 m

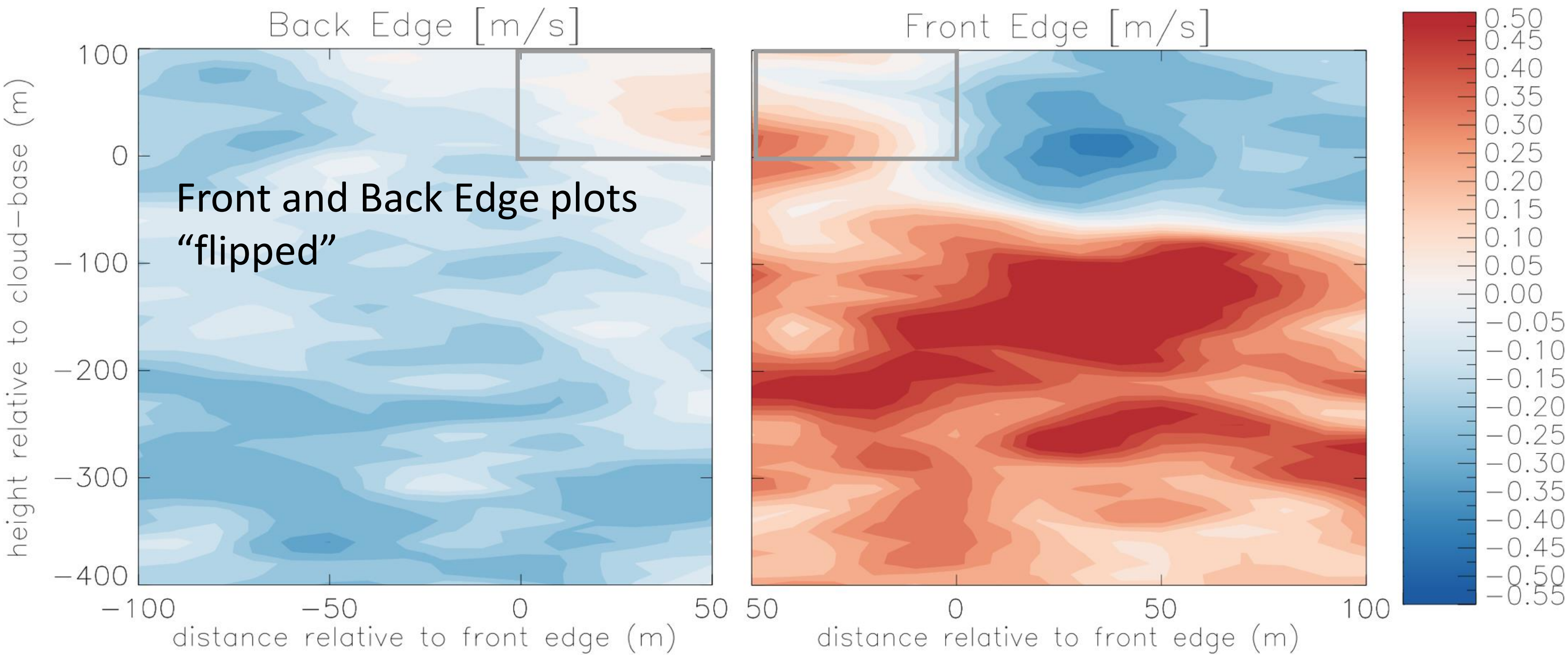
Cloud definition: at least 10 clear air profiles on each side of 10 cloud profiles.



Static cloud boundary:

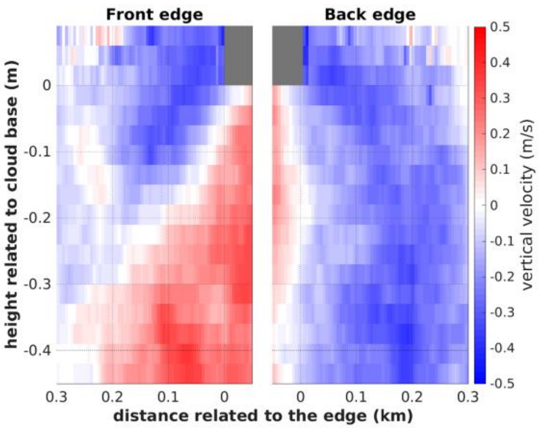
- Snapshots of cross sections where lidar were located
- 18 useable cloud transects

Virtual Lidar in LES (7 transects)

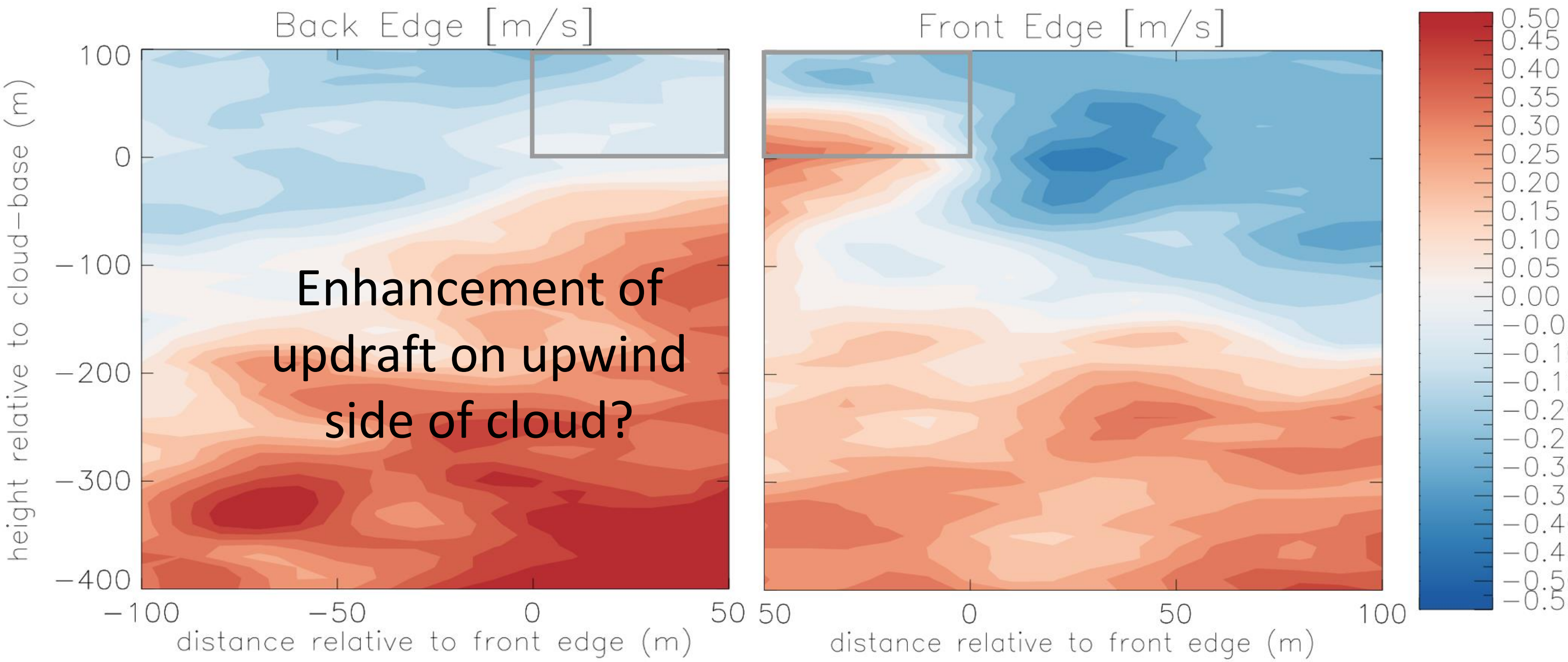


Front and Back Edge plots "flipped"

Similar asymmetry than in case of observations!



Static Cloud Boundaries in LES (18 Transects)



"East cloud edge - Upwind"

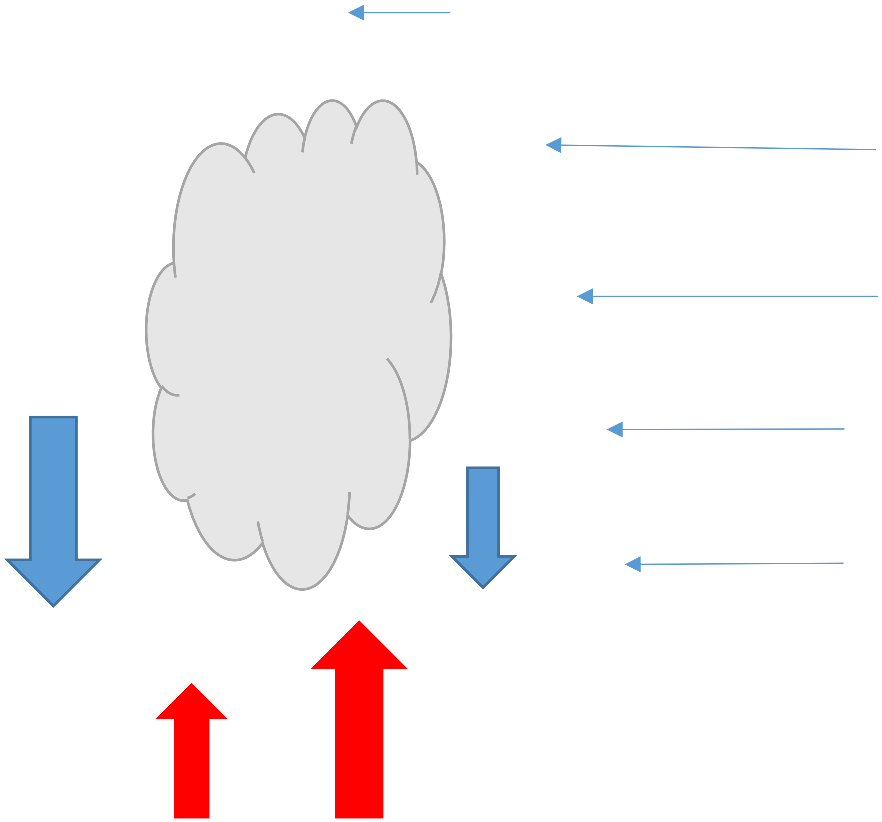
"West cloud edge - Downwind"

If "snapshots" are taken asymmetry effects disappear..

→ Endorsement of cloud evolution effect causing asymmetry in observations!

Displacement of Strongest Vertical Velocities

Simulated BOMEX case
Weak cloud-layer shear vector
in total ~1.8 m/s from surface to cloud top



Enhancement of updraft on upwind side of **cloud shear related**?

Summary on Shallow Cumulus Study

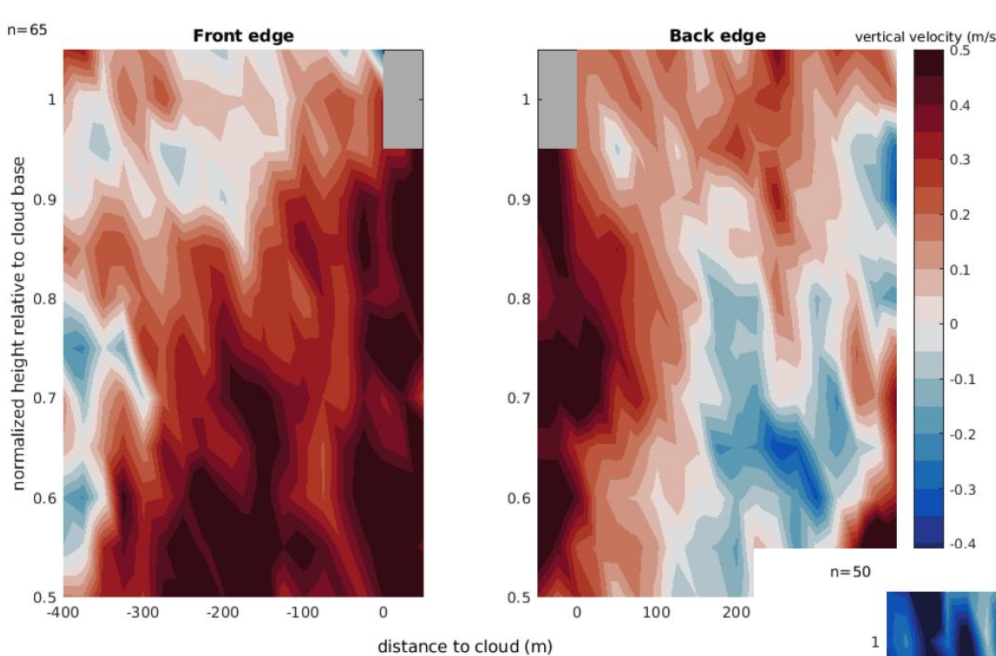
- Both SGP and JOYCE Doppler lidar observations **show subsiding shell features** extending down to at least half of the cloud base-surface distance
- **Difficult to detect** subsiding shell objectively (20 % of all cases)
- Subsiding shell features are to shown to be on the order of **~100 m width**; dissipating clouds show wider shell feature (as proposed by Katzwinkel et al. 2014)
- Features are more **prominent around growing clouds** (pos. mass flux) and in cases of higher LWP
- Observed **asymmetry** (back / front edge) most probably due to **”cloud evolution effect”** → confirmed with LES

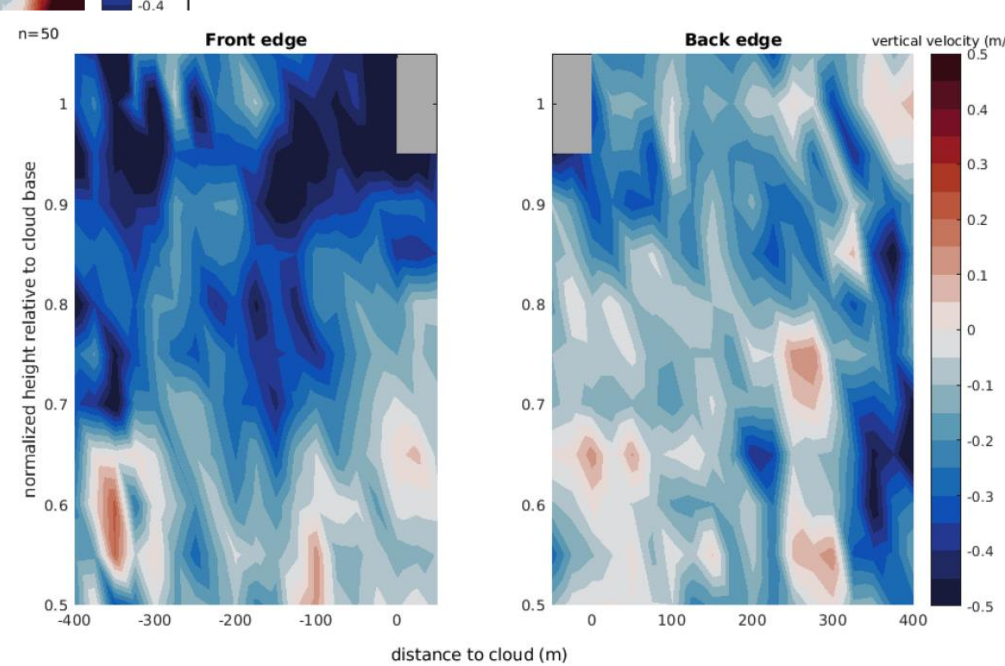
Outlook

- Focus on cloud development stages
  - Analyze more data (shallow Cu)
  - Need accurate vertical cloud boundary determination high-temporal resolution with LWP (→ **dilution factor!**)
- Detection of ”**humidity halos**”?
  - MWR: only IWV
  - WV lidar: integration time issue?
  - DAR: only feasible below cloud base..

Thank you! Questions?

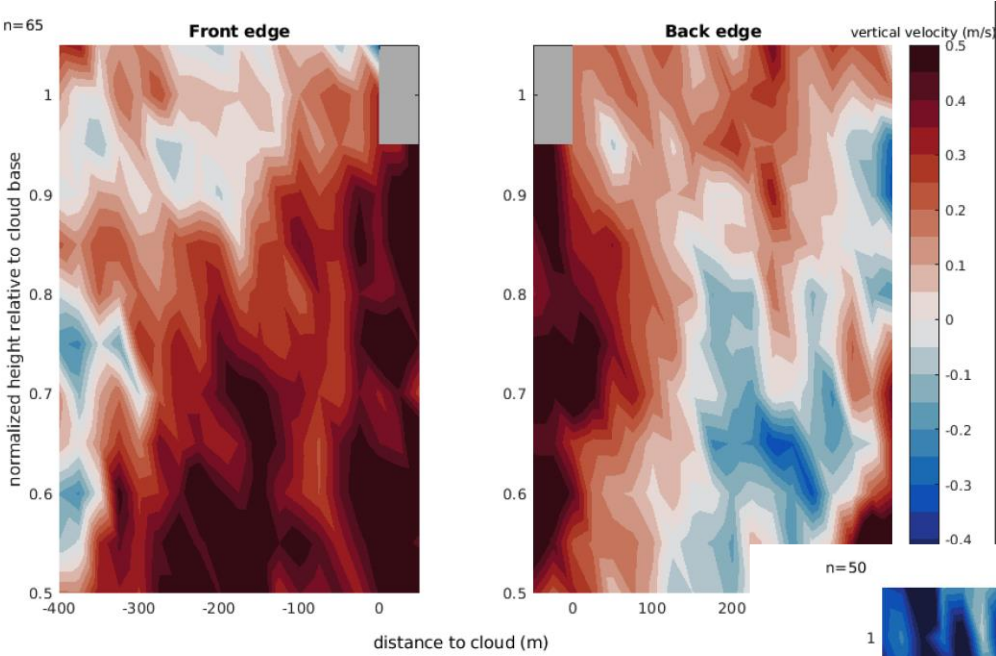
Positive Mass Flux Clouds @ JOYCE and SGP

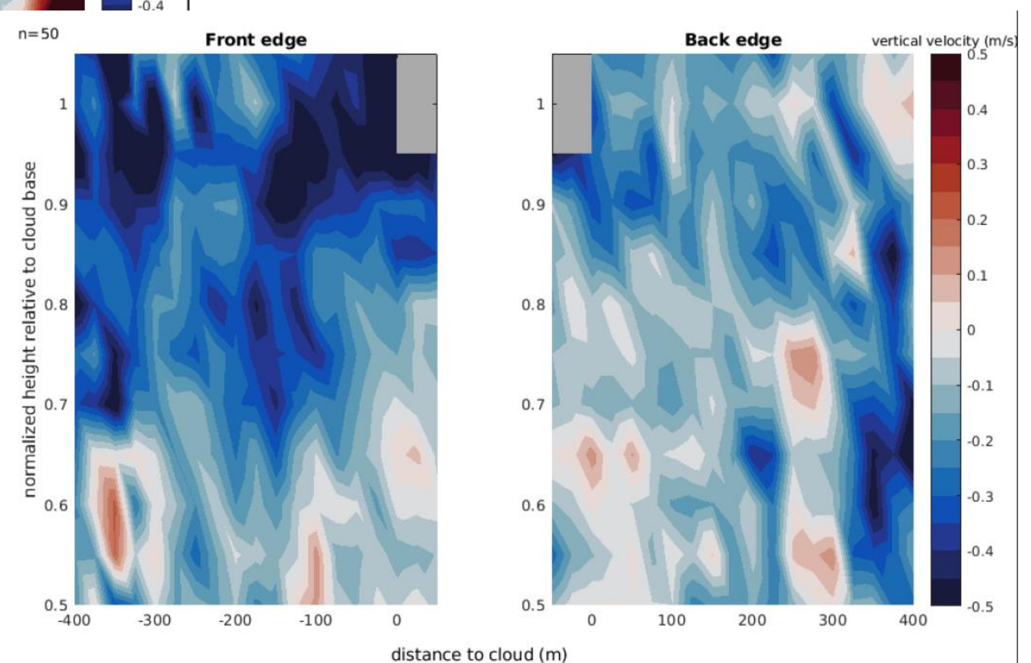




Investigate asymmetry with LES..

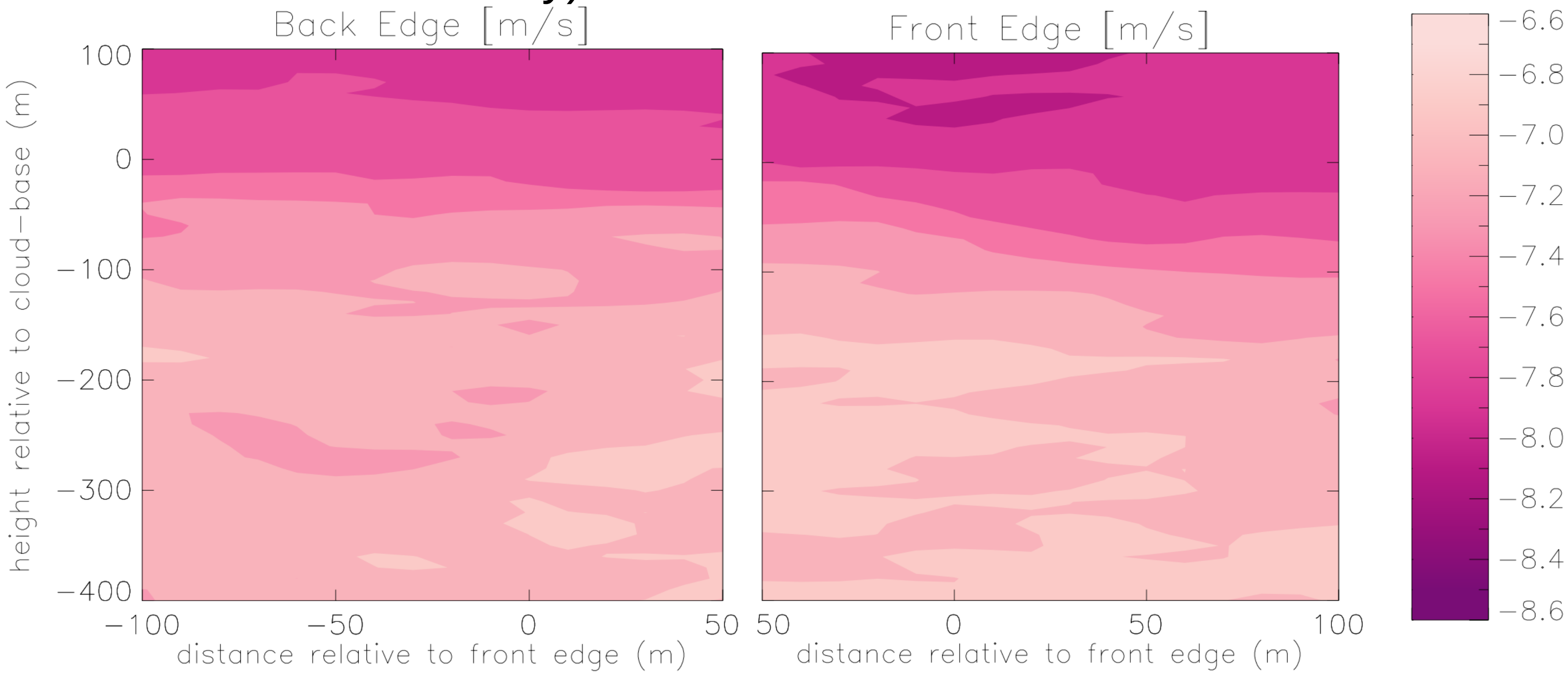
Positive vs. Negative Mass Flux Clouds @ JOYCE



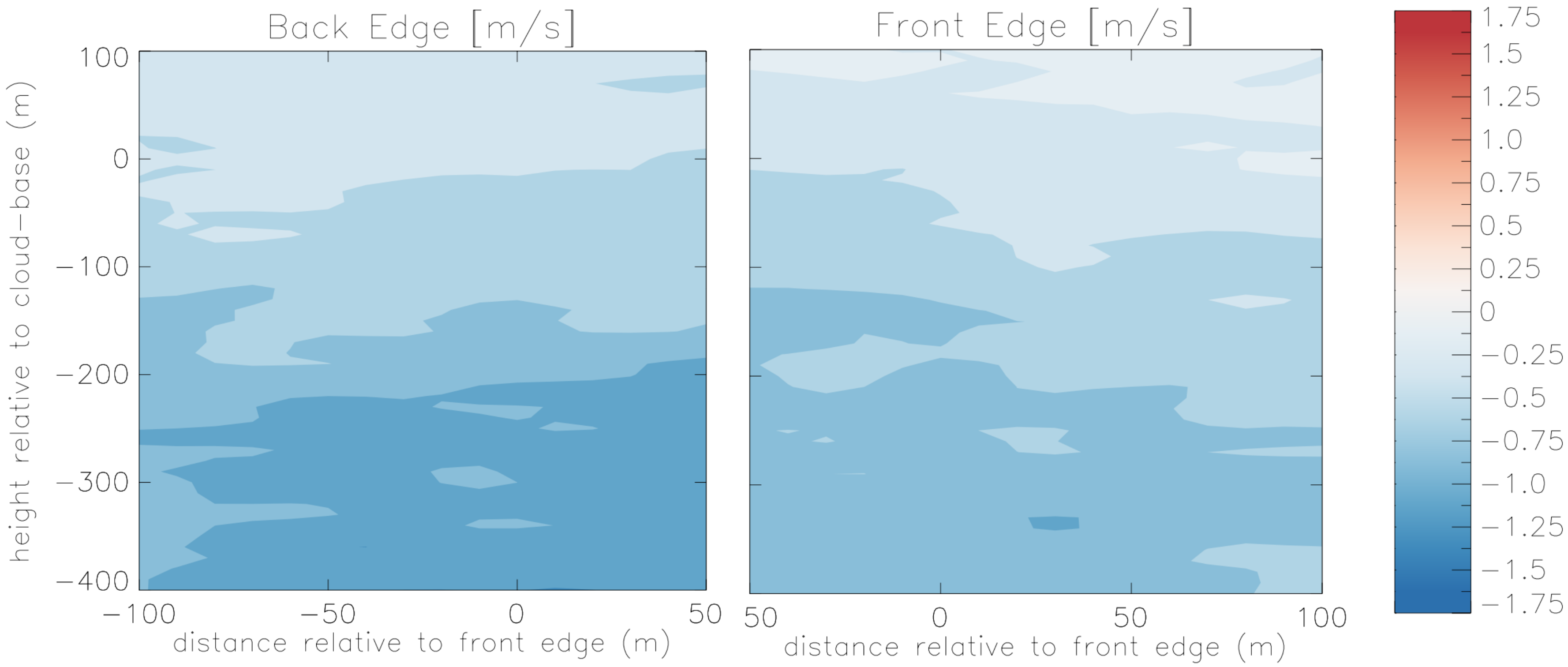


Investigate asymmetry with LES..

Static front and back cloud edges (U – velocity)

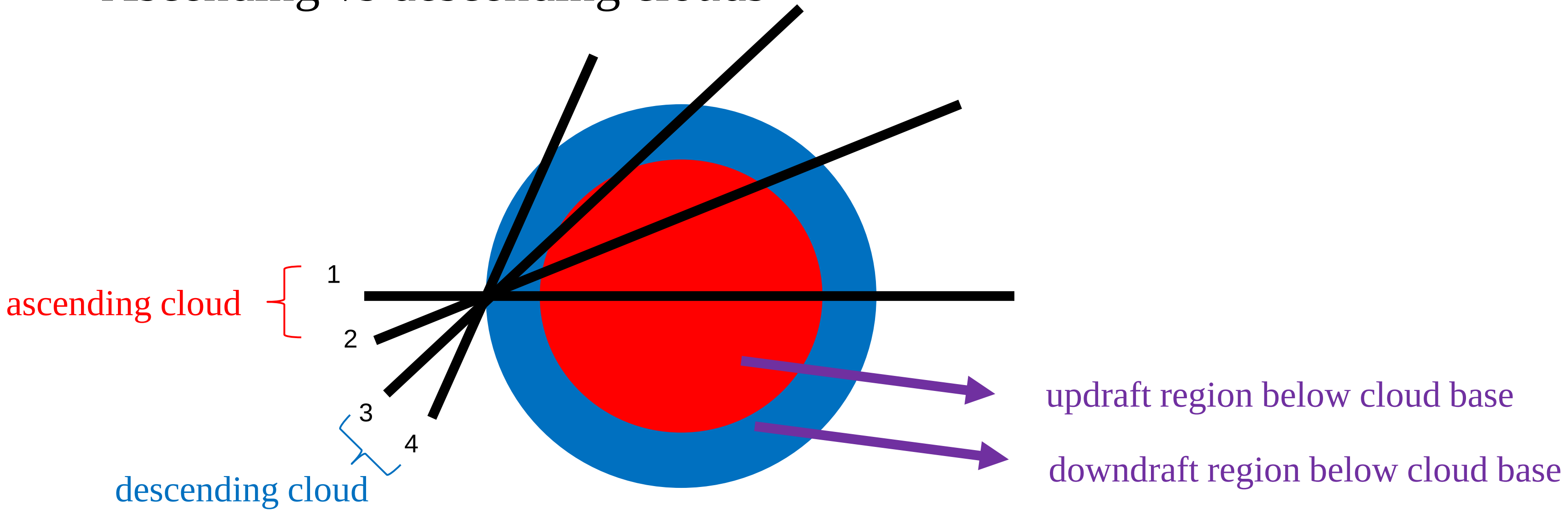


Static front and back cloud edges (V – velocity)

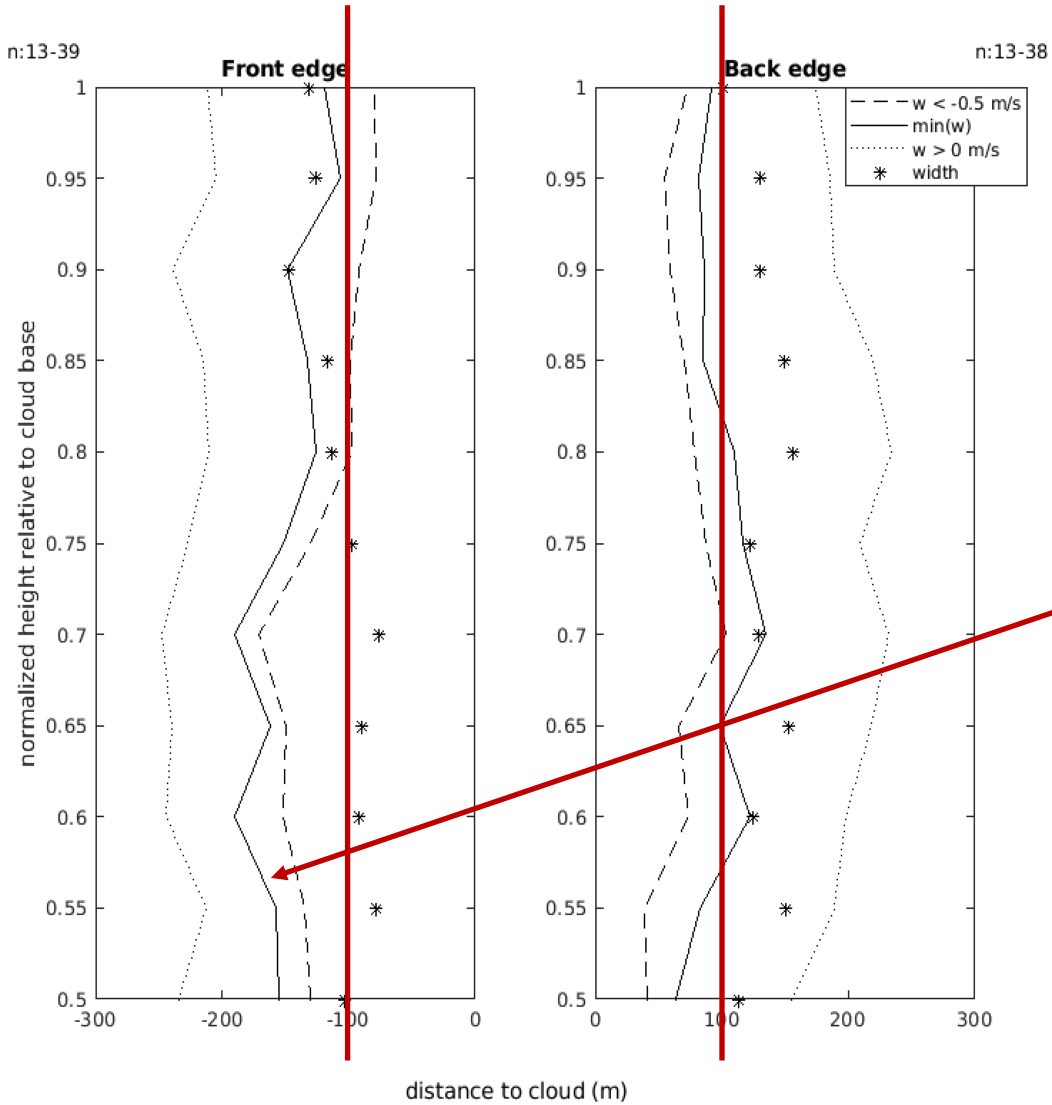


Shortcomings

- Horizontal wind speed
- Ascending vs descending clouds



Subsiding Shell Position & Width - All Clouds@JOYCE



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