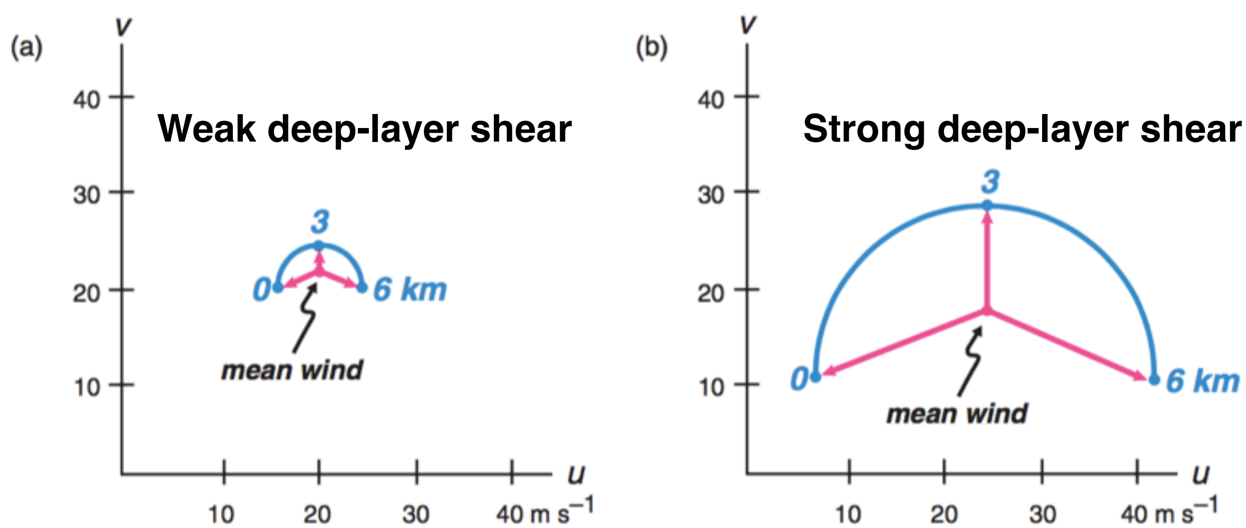
Impacts of vertical wind shear on convection

1) Generation of perturbation pressure gradients (p_b and p_d) – promotes convection
2) Enhances lifting along gust fronts – promotes convection
3) Precipitation trajectories leave updraft – sustains convection

Need large upper-level *storm-relative* winds to advect precipitation downwind.
As deep-layer shear increases, *storm-relative low-level and upper-level winds increase*.



Formation of downdrafts along downshear edge of convective updraft

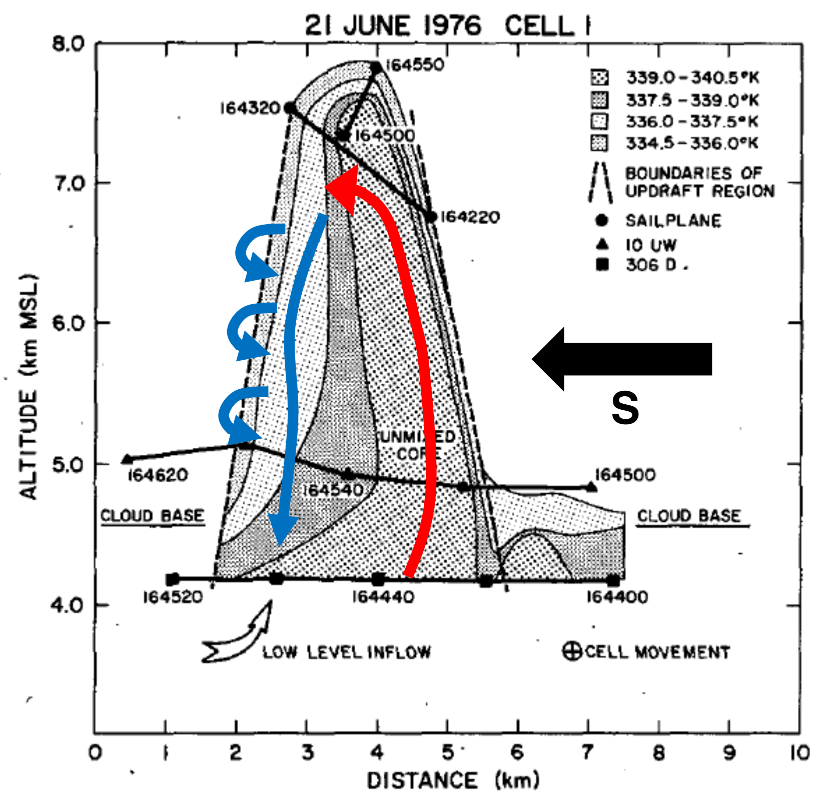
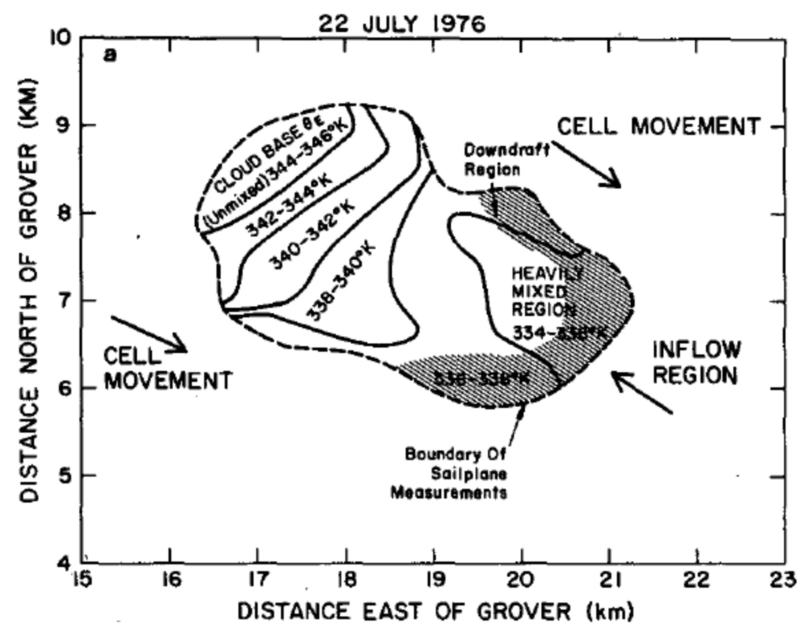
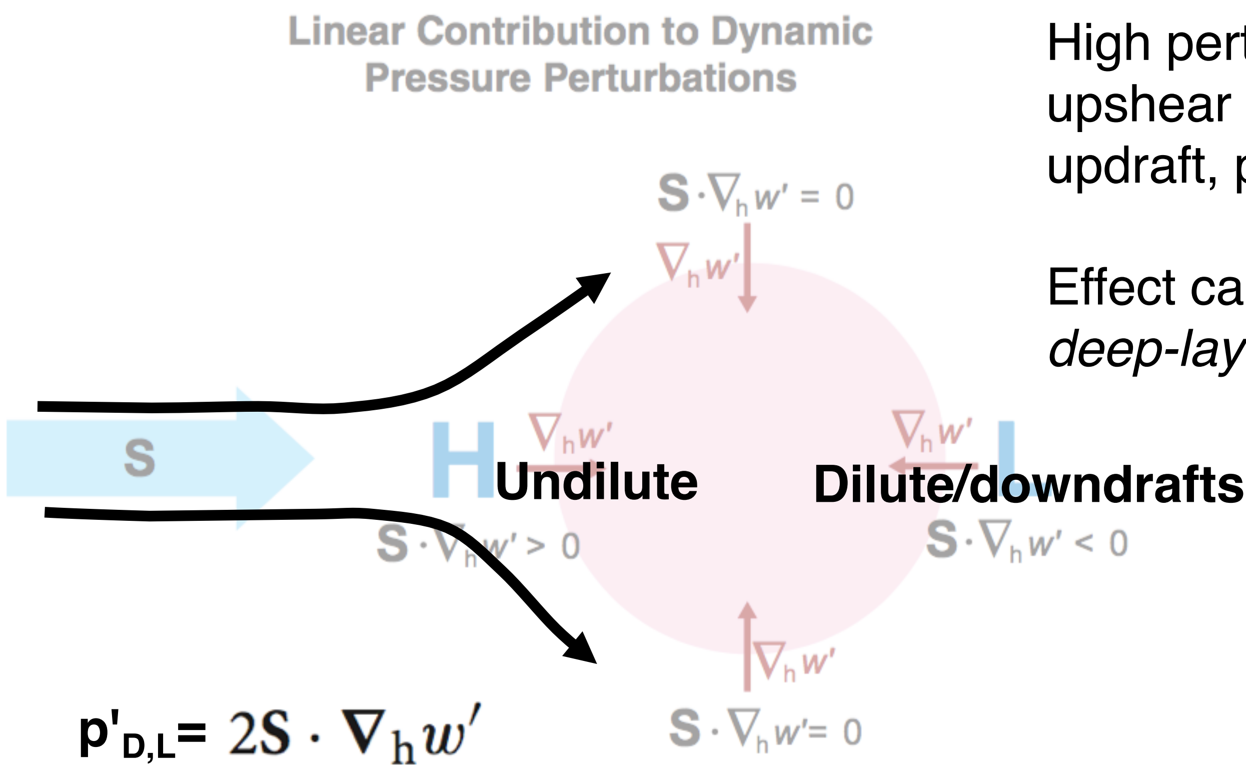


FIG. 4. Vertical section of θ_e data based on measurements from three aircraft plotted nearly perpendicular to the cell motion. Low-level inflow region is positioned on left side of cell. Times of aircraft penetrations are indicated.



Heymsfield et al. (1978)

Impacts of vertical wind shear on convection

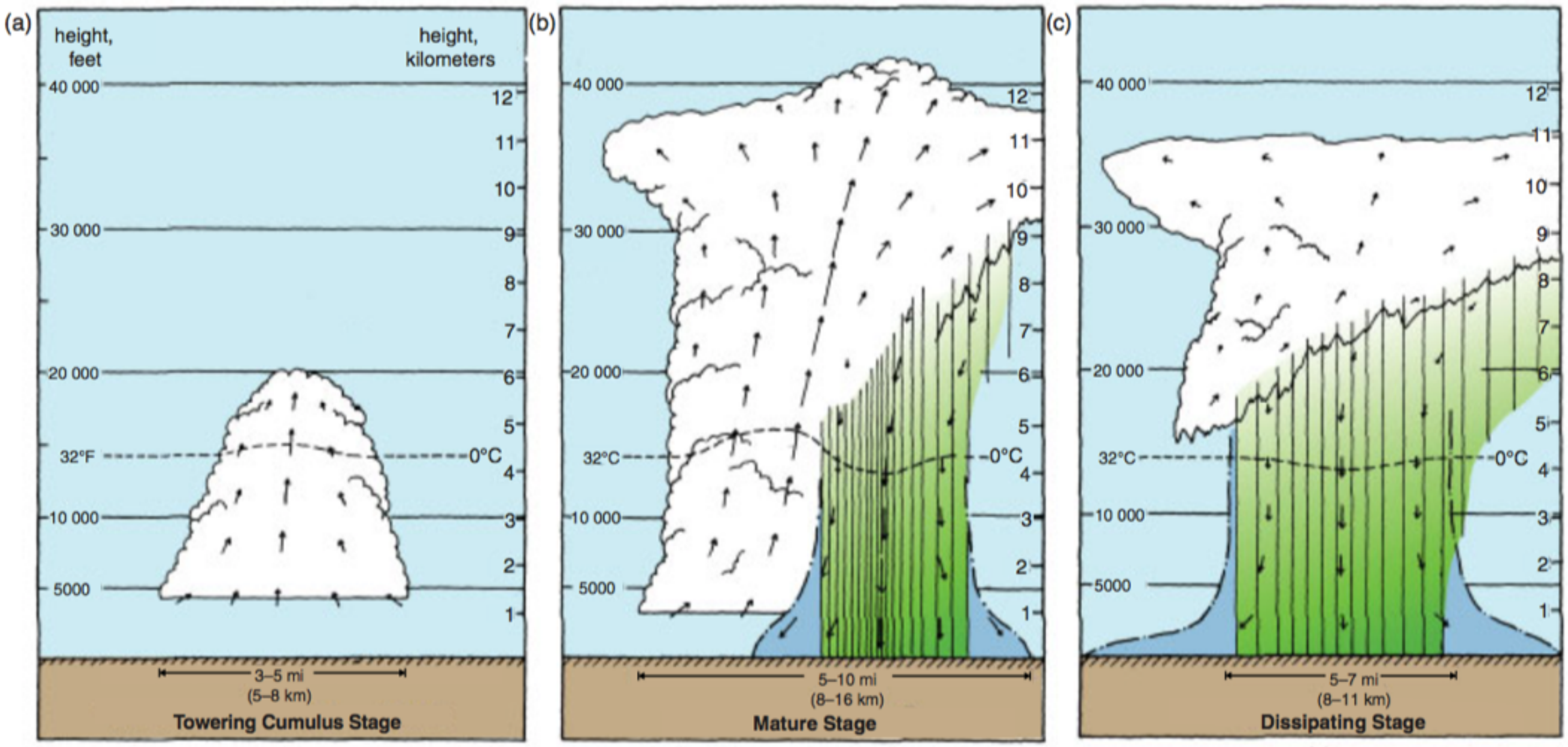


High perturbation pressure upshear **diverts flow** around updraft, protecting upshear edge.

Effect can act even with *weak deep-layer shear*.

$p'_{D,L} = 2S \cdot \nabla_h w'$

Lifecycle of a single convective cell (in weak vertical wind shear)



Updraft --> Precipitation --> Downdraft (Byers and Braham 1949)

Lifecycle of a single convective cell (in weak vertical wind shear)

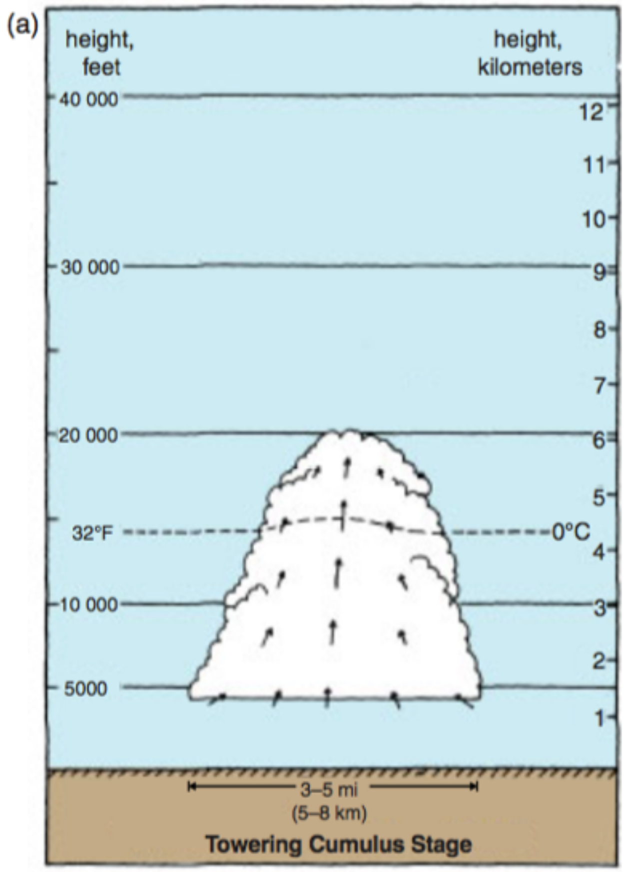
$$\tau \sim \frac{H}{w} + \frac{H}{v_t}$$

Lifecycle estimated by time it takes air to rise through updraft (**H / w**), plus time for precipitation to fall to the ground. (**H / v**).

If **H** ~ 10 km, **w** ~ 5 – 10 m s^{-1}, $\mathbf{v_t}$ ~ 5 – 10 m s^{-1},

τ ~ 30 – 60 min.

Lifecycle of a single convective cell (in weak vertical wind shear)



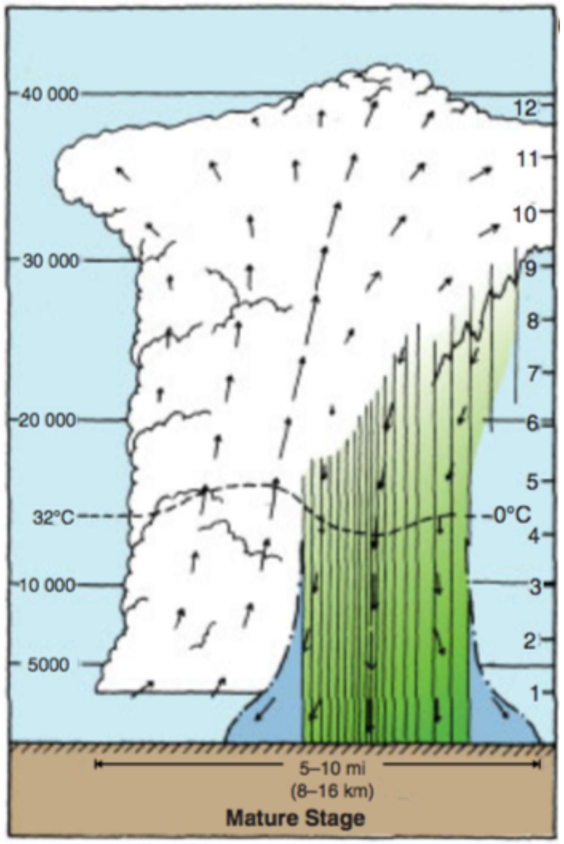
In surface-based convection, thermals originating at surface will reach the LCL, producing **shallow cumulus clouds** with modest updraft speeds (~1 m s^{-1}).

Entrainment of drier environmental air will cool air within the developing updraft and dilute parcel buoyancy, potentially preventing growth of deep convection.

But, mixing will **moisten environmental air** due to evaporation of cloud droplets, making the environment more favorable for later sustaining deep convection.

***Convection favored in areas where this process persists*.**

Lifecycle of a single convective cell (in weak vertical wind shear)



Once deep convection is sustained, updraft speeds increase due to deep vertical accelerations.

Deep convection often occupies regions above and below freezing, leading to a potentially deep **mixed phase region** of the cloud. Here, ice may rapidly consume liquid water via the **Bergeron process** in the upper portions of the cloud.

Precipitation will form via warm-rain and cold-cloud processes, be advected by storm-relative winds, and **fall near updraft**, evaporating in sub-saturated air.

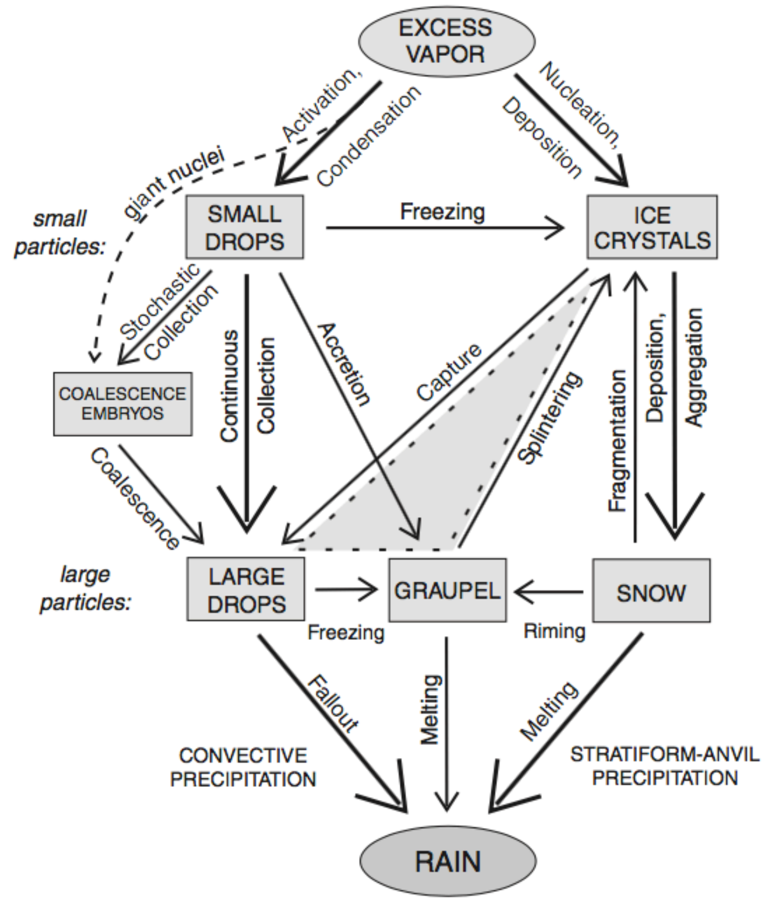


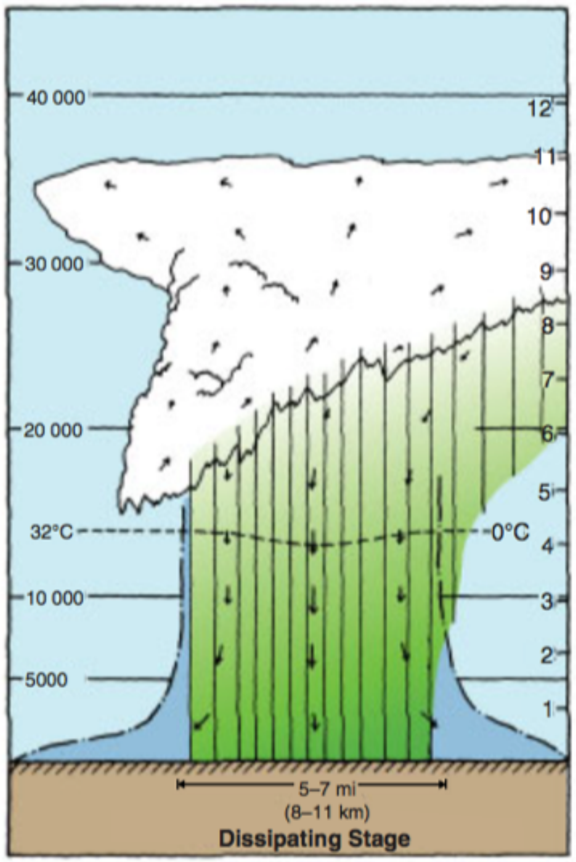
Figure 12.1 Schematic diagram of particles and processes involved in the formation of rain in cold clouds. Particle categories are shown in boxes, processes of interactions as arrows. The shaded triangle identifies a feedback loop important for the glaciation of some clouds. Adapted from Lamb (2001).

Precipitation physics!

Warm-rain processes:
Condensation and collison-coalescence

Cold-cloud processes:
Deposition, accretion, aggregation, freezing, splintering.

Lifecycle of a single convective cell (in weak vertical wind shear)



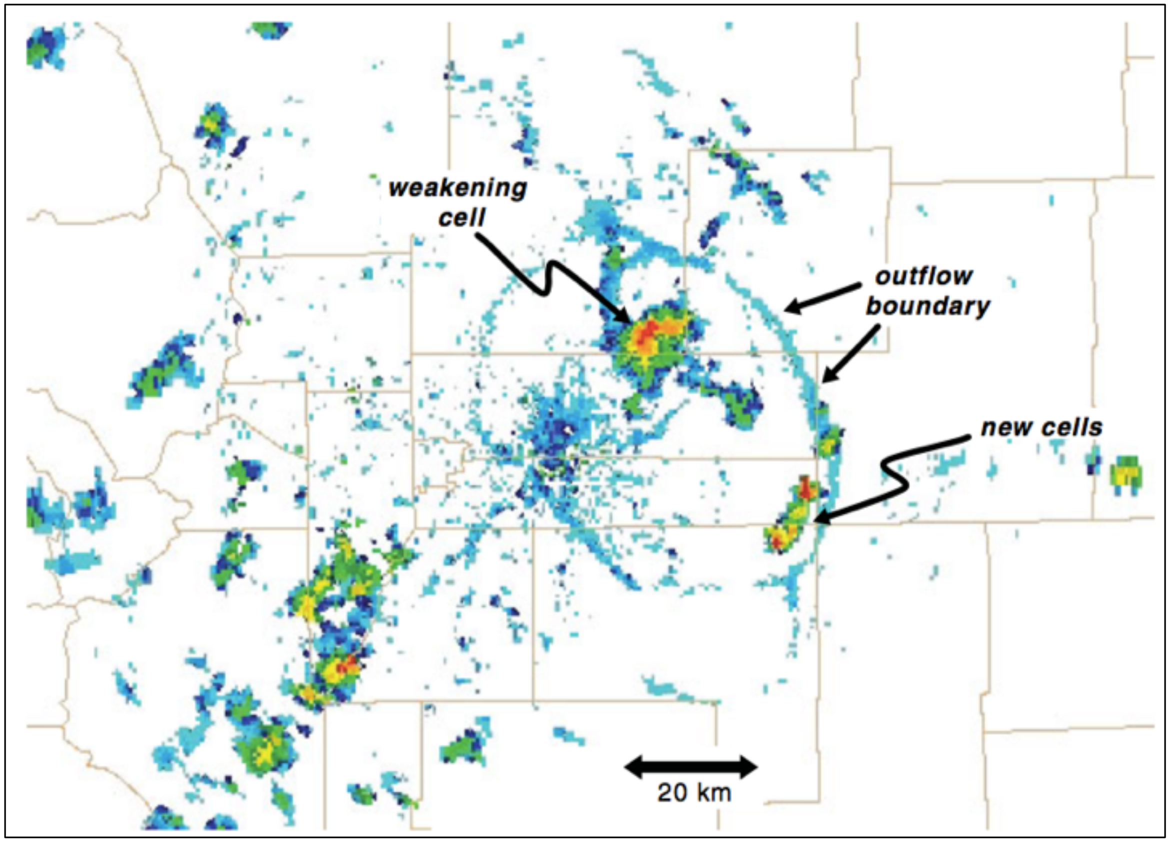
The development of precipitation leads to negative buoyancy due to **evaporation/sublimation** of rain/ice and **hydrometeor drag** as precipitation fall-speed increases.

This results in the development of a **cold pool** at the surface, with associated **gust fronts** along the leading edge.

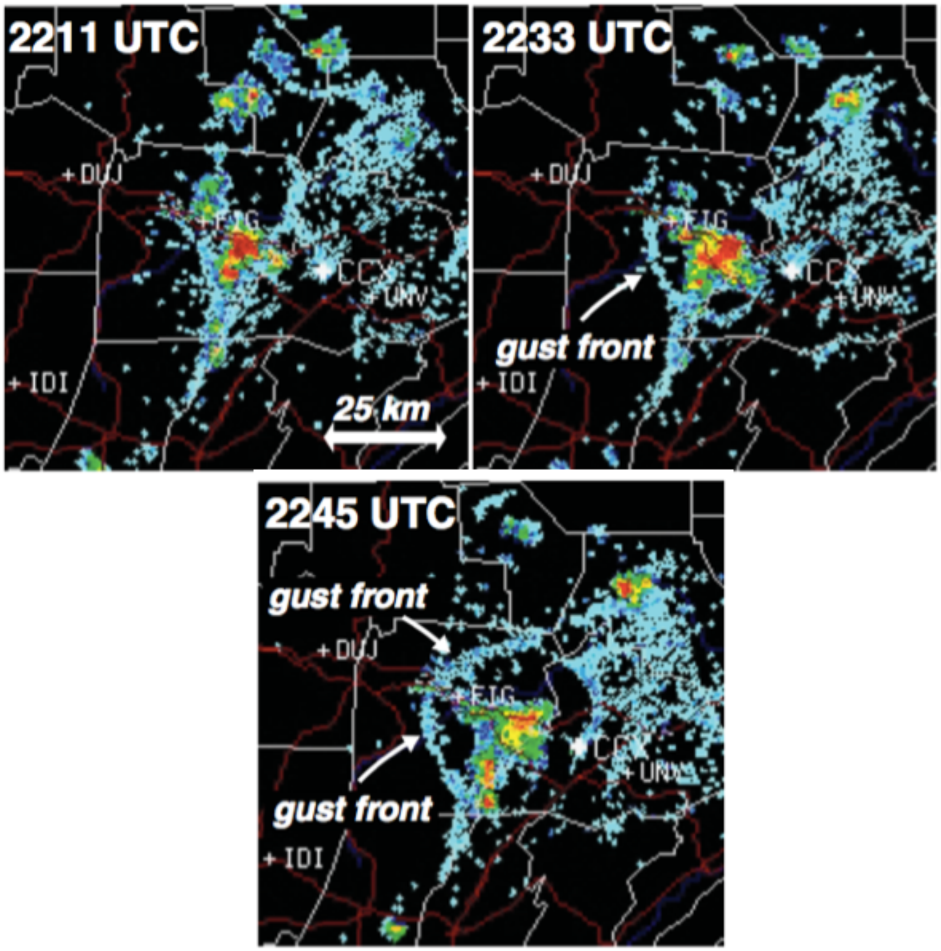
The behavior and properties of the cold pool is extremely important to determine if convection will be sustained or will dissipate.

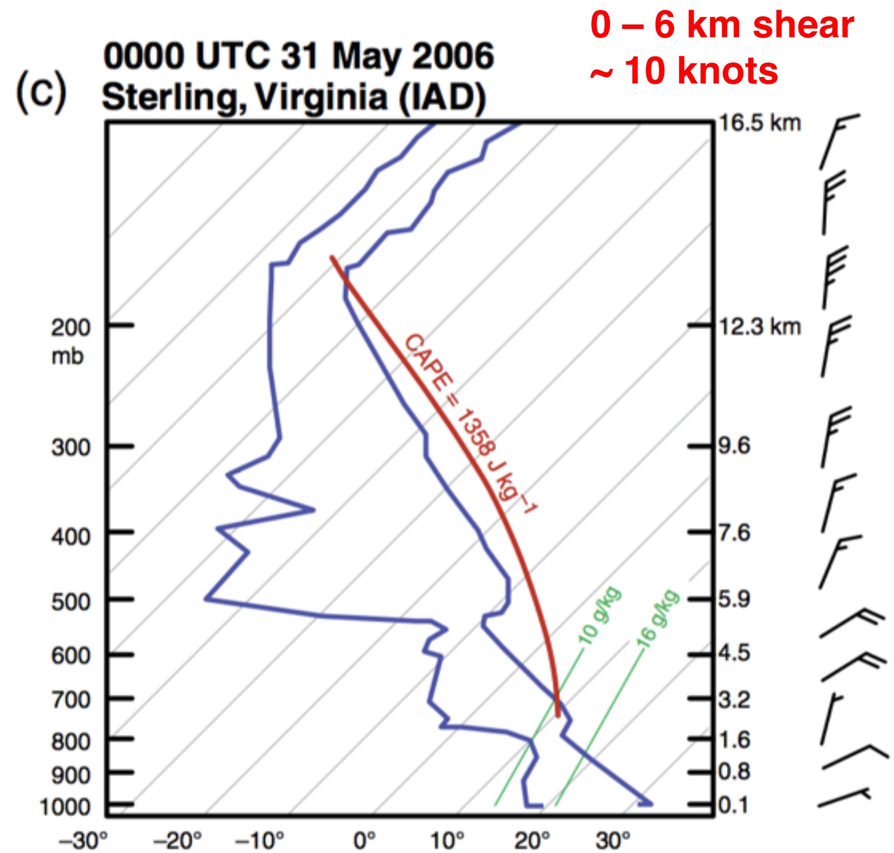
With single-cell convection, precipitation and cold pool **cuts off updraft.**

Colorado single-cell convection



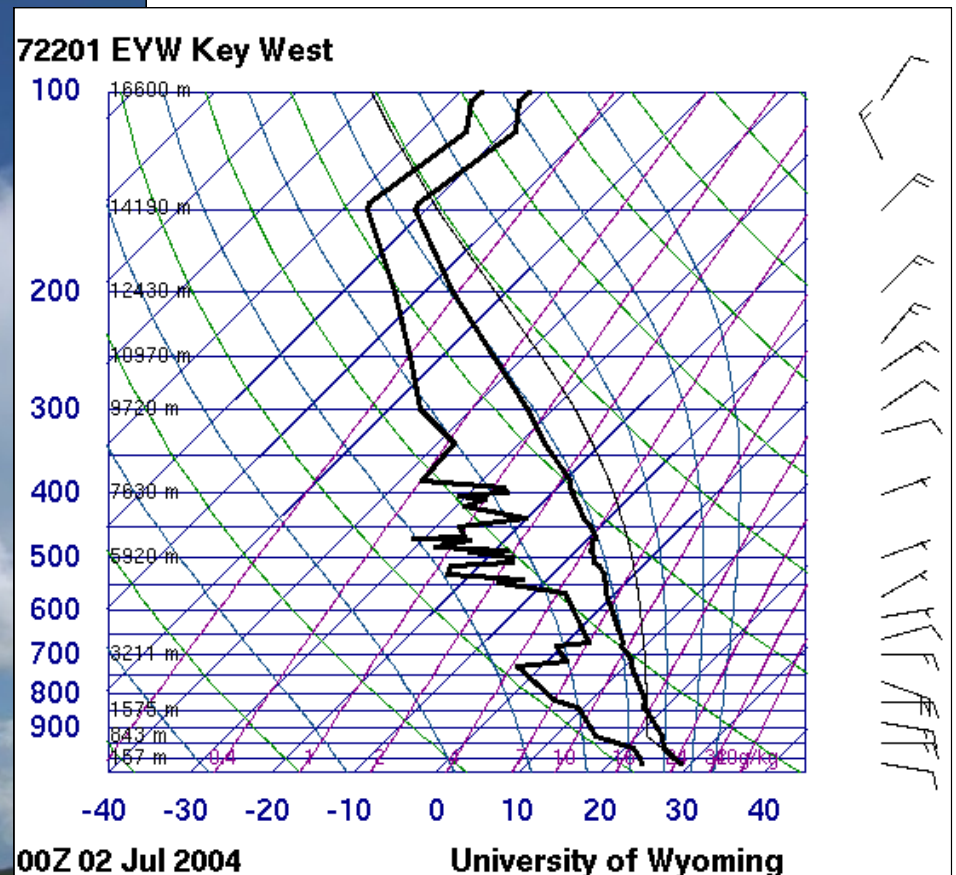
Mid-latitude single-cell convection

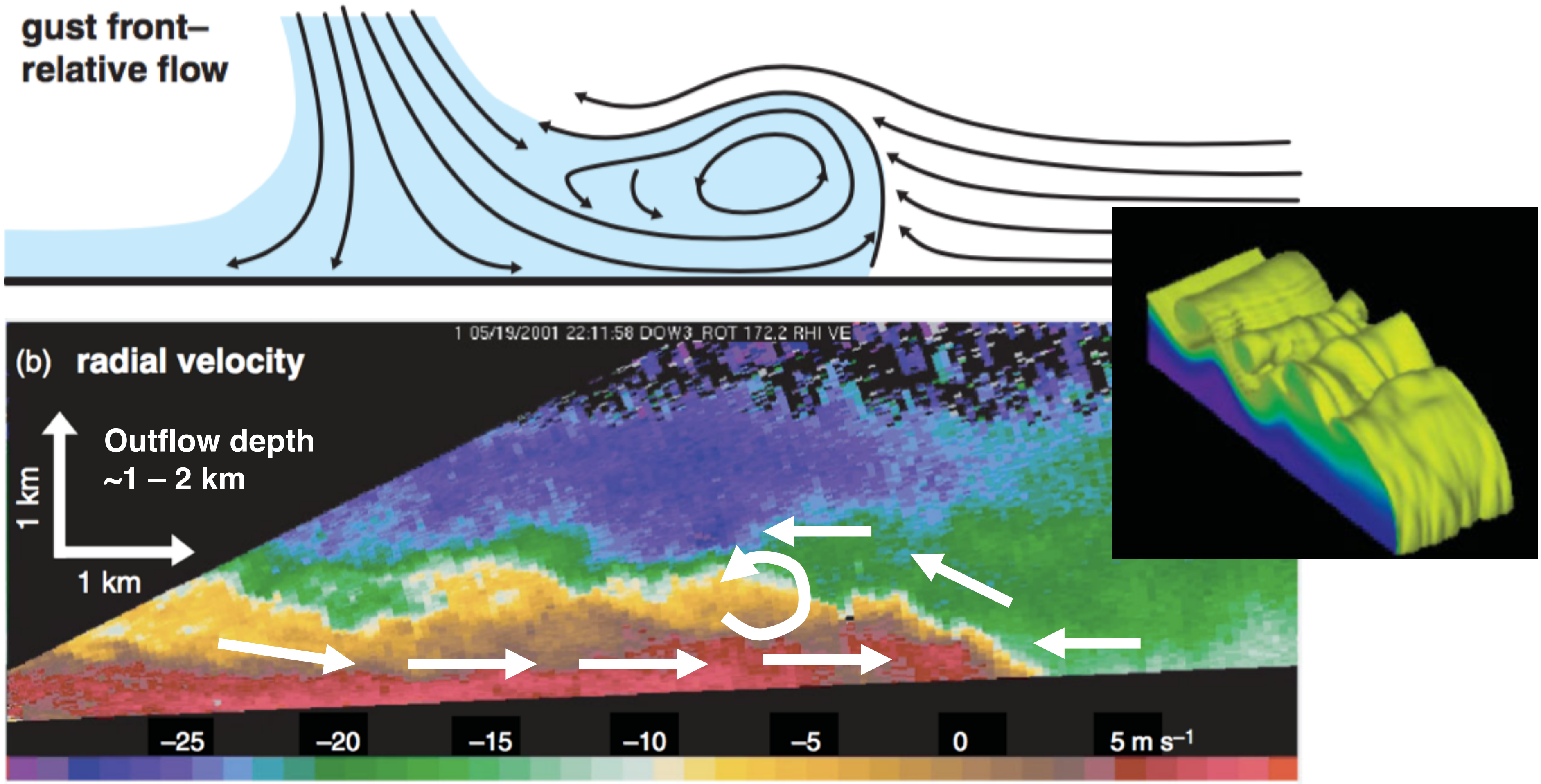


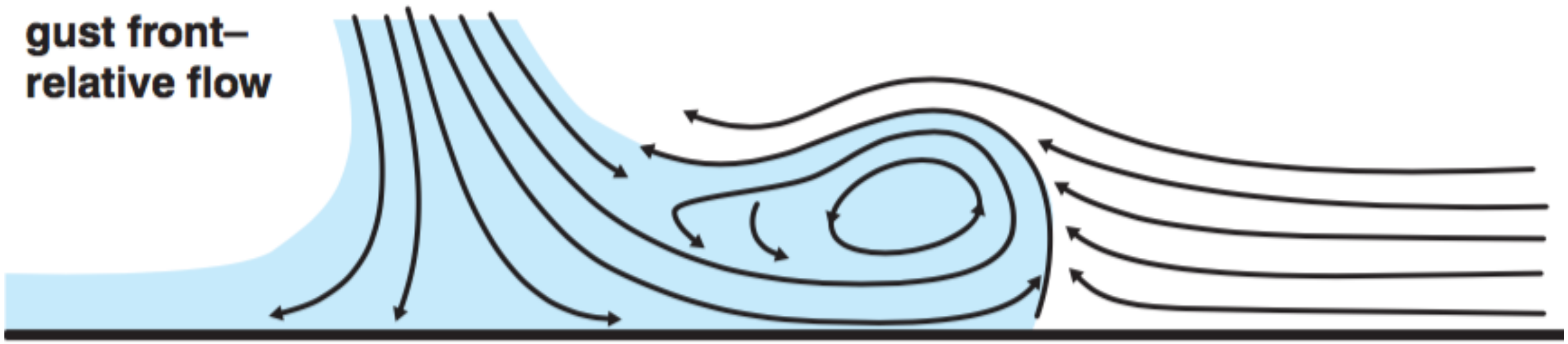


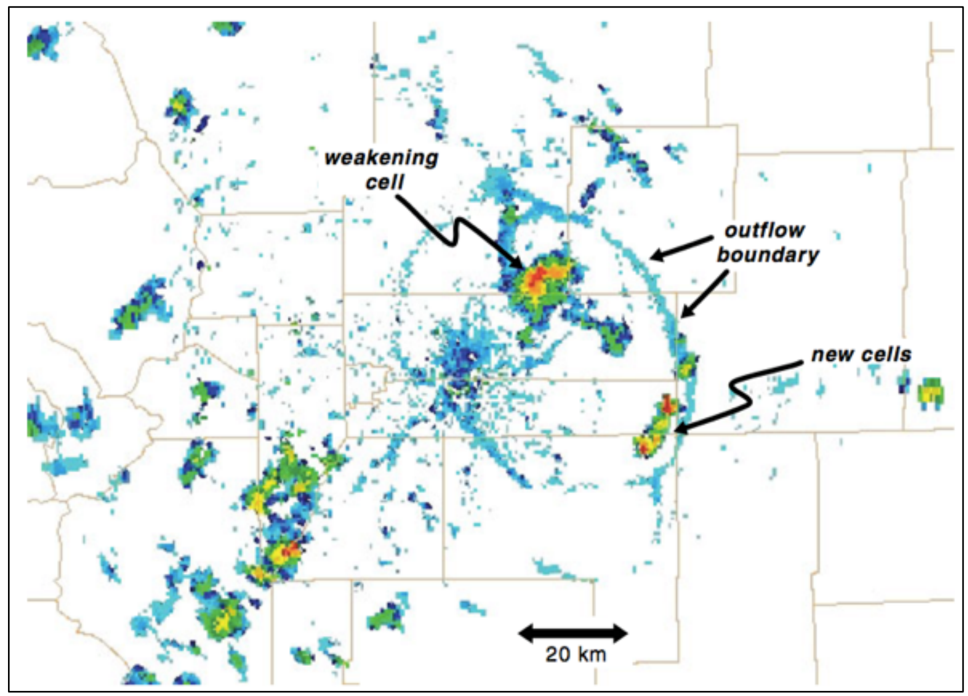
Tropical single-cell convection

0 – 6 km shear
~ 5 knots




gust front–
relative flow
1 05/19/2001 22:11:58 DOW3_ROT 172.2 RHI VE
(b) radial velocity
Outflow depth
~1 – 2 km
1 km
1 km
–25
–20
–15
–10
–5
0
5 m s–1



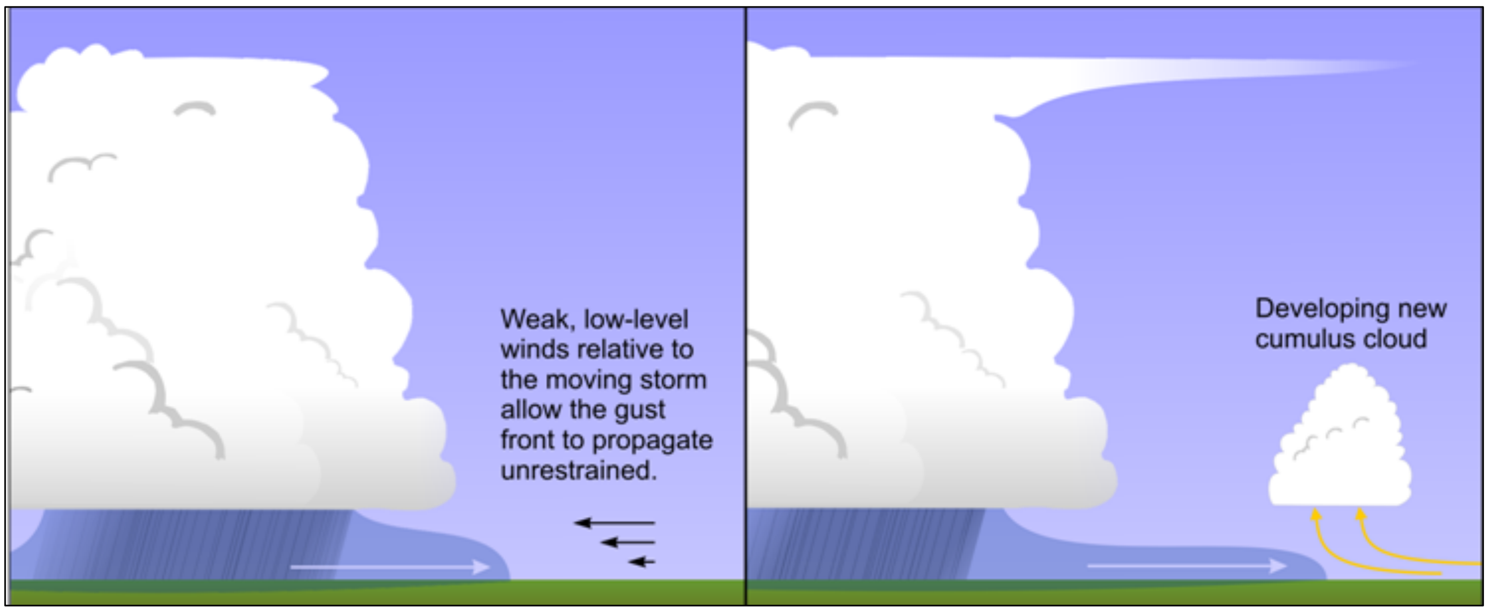


In single-cell storms, storm's outflow is unrestrained, moving far away from parent updraft, cutting off source of inflow.

What constrains outflow from surging away from updraft?

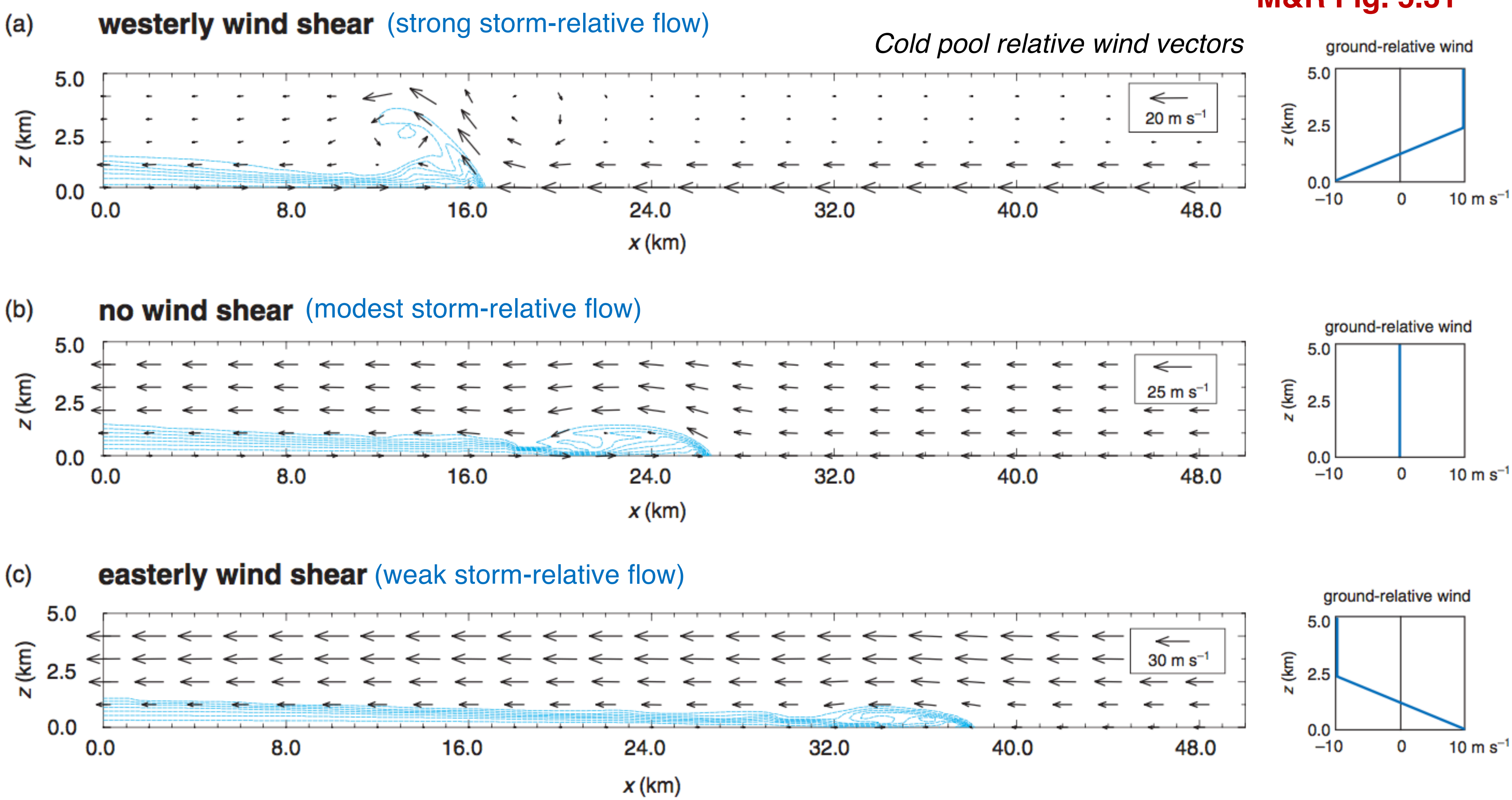
Weak vertical wind shear usually means **weak storm-relative surface flow**.

In this case, cold pool can move away from updraft without any resistance.

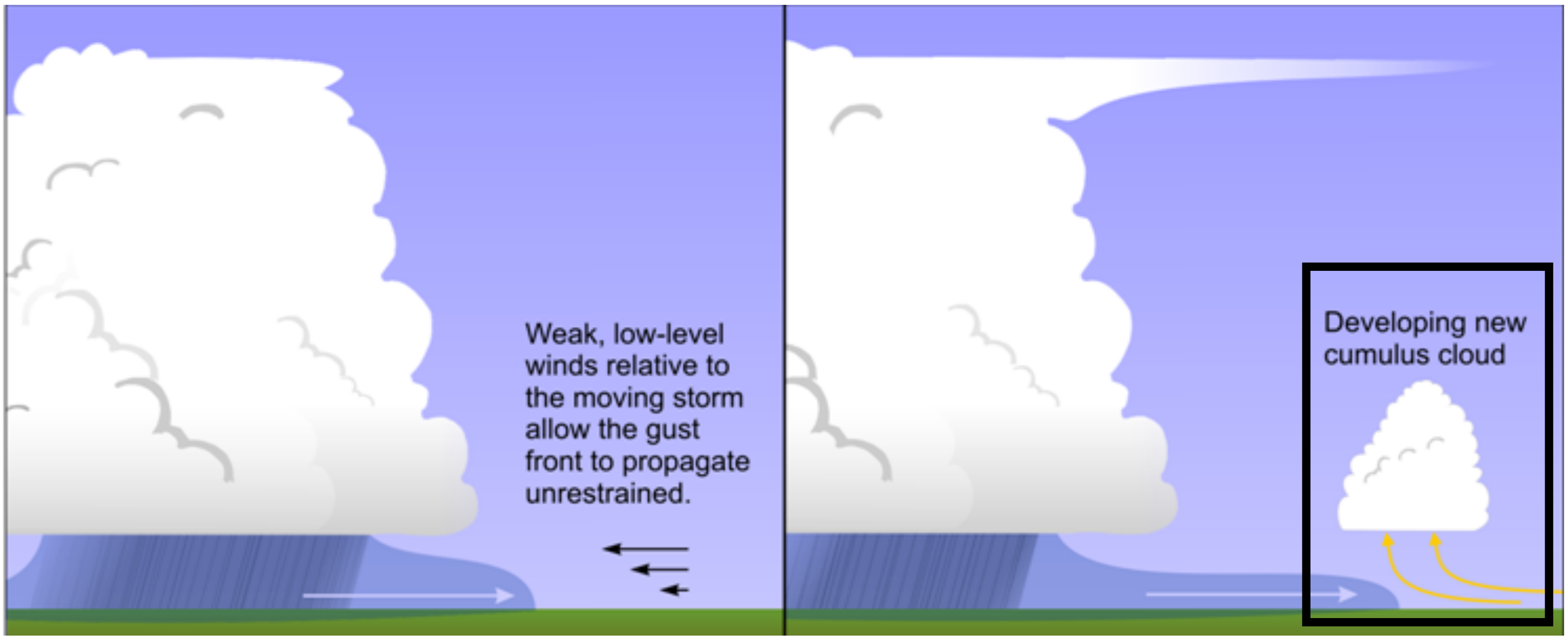


Simulations of a “density current”

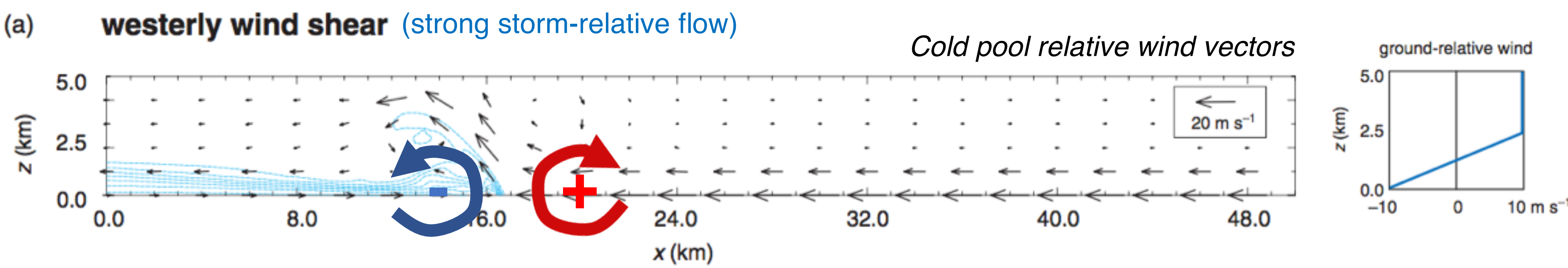
M&R Fig. 5.31



To move from single-cell convection to multi-cell convection, need to develop new updrafts along gust front associated with cold pool.



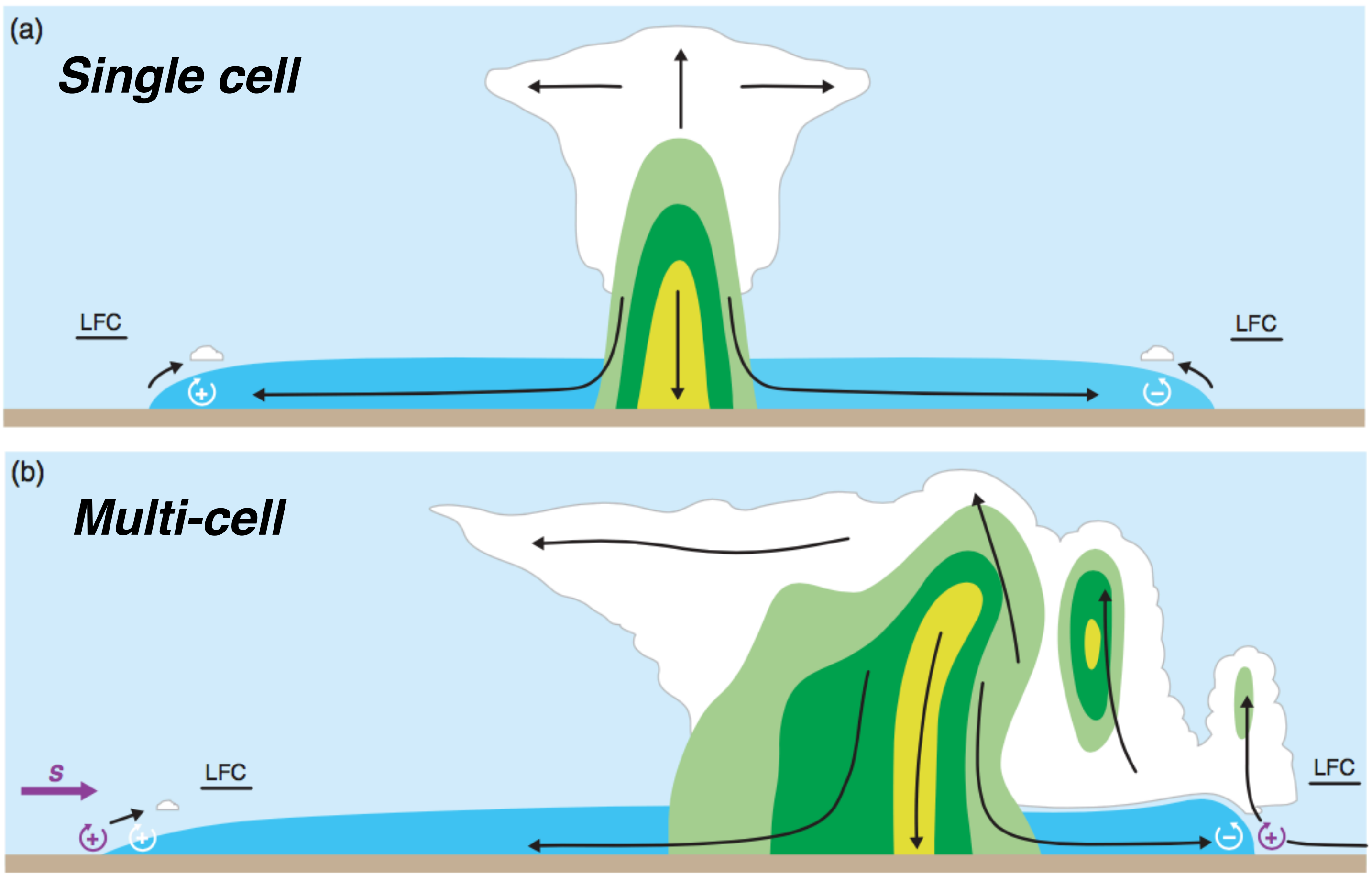
What conditions favor this?



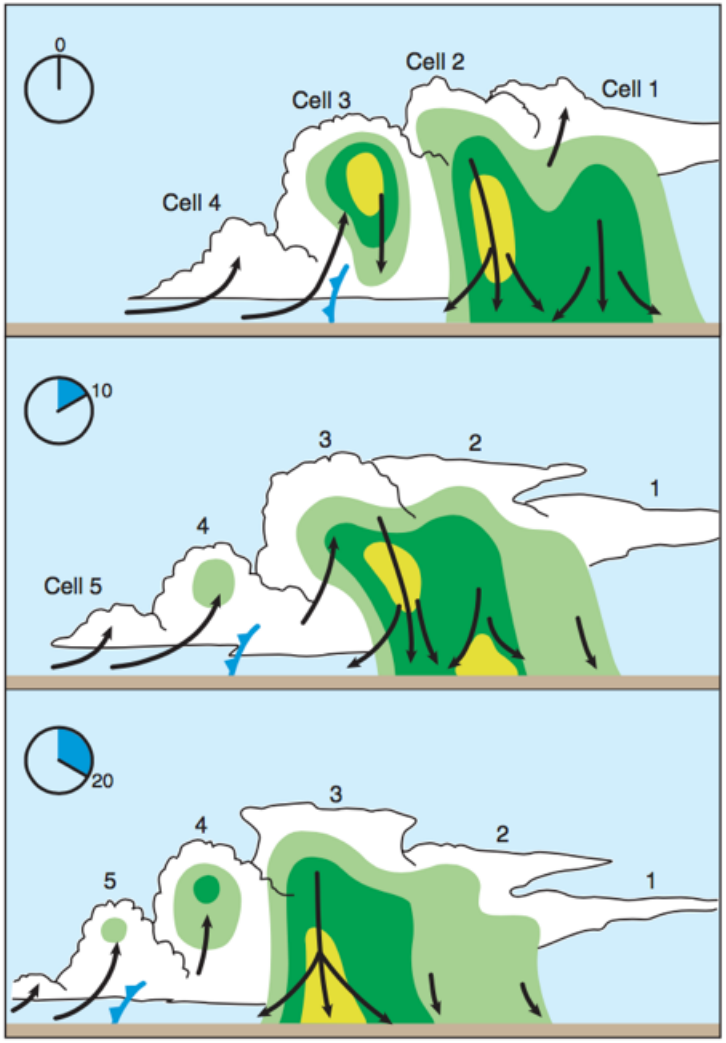
Vertical lifting maximized along edge of gust front occurs when:

1. *storm-relative flow is strong*
   leads to larger updraft speeds due to mass continuity
   occurs where low-level storm-relative wind is a maximum

2. *environmental horizontal vorticity (over cold pool depth) is of **opposite sign** to baroclinically generated horizontal vorticity in cold pool*
   leads to upward oriented stream of air parcels
   occurs **downshear** of low-level shear vector



(a)
Single cell
LFC
LFC
(b)
Multi-cell
S
LFC
LFC



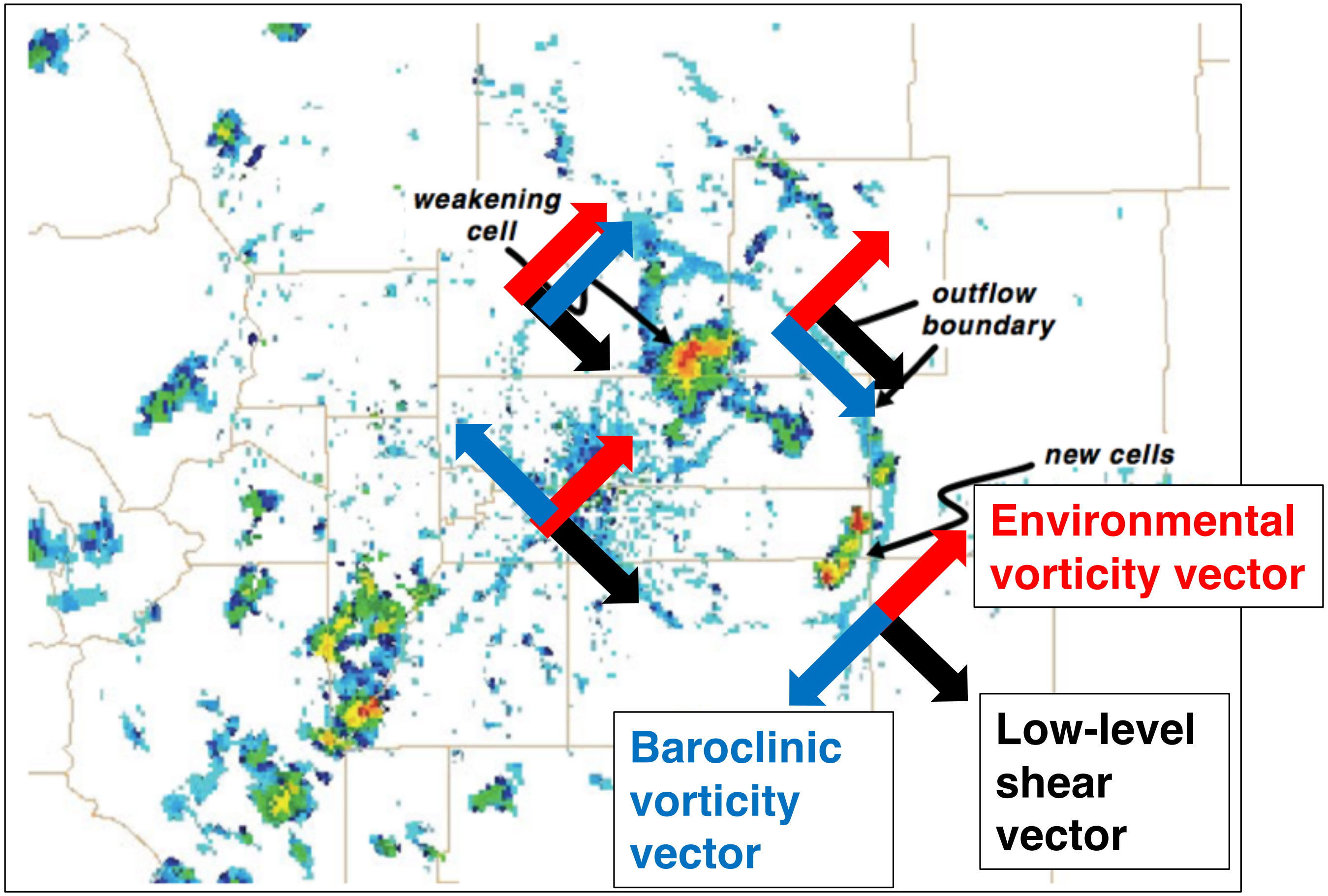
If gust front is able to initiate multiple convective cells, then storm referred to as **multi-cell convection**.

Various individual convective cells are at different stages of single cell lifecycle.

While individual cells move with mean cloud-bearing wind speed/direction (**advection**), multi-cells have more complicated motion due to **advection** + **propagation**.

This "discrete" propagation component can be in a different direction relative to the advection component of overall storm motion.

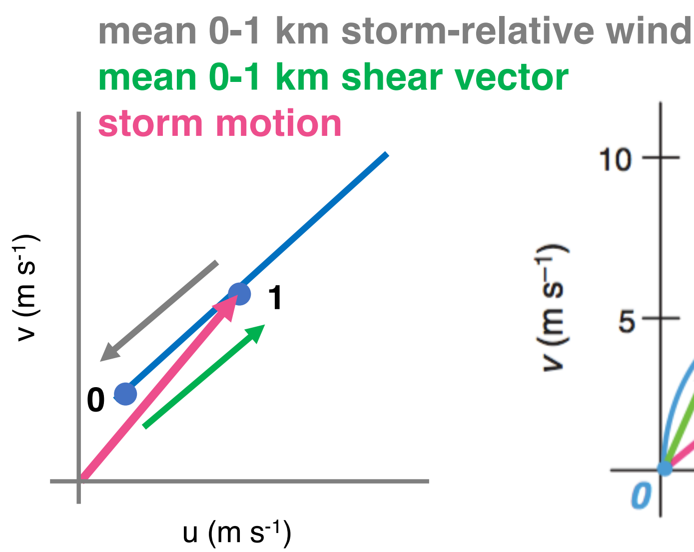
Downshear propagation along gust front



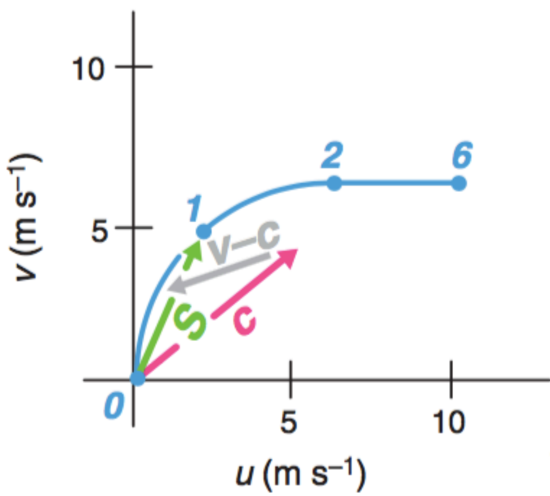
Effects of low-level hodograph shape

With **straight hodograph**, downshear of low-level shear vector and maximum low-level storm-relative flow are in *same direction*.

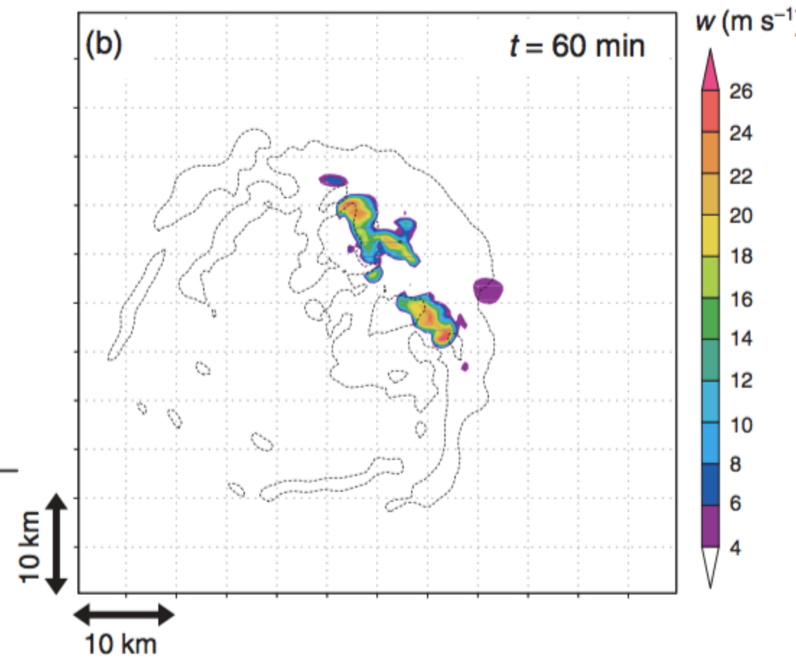
With **curved hodograph**, they may differ…

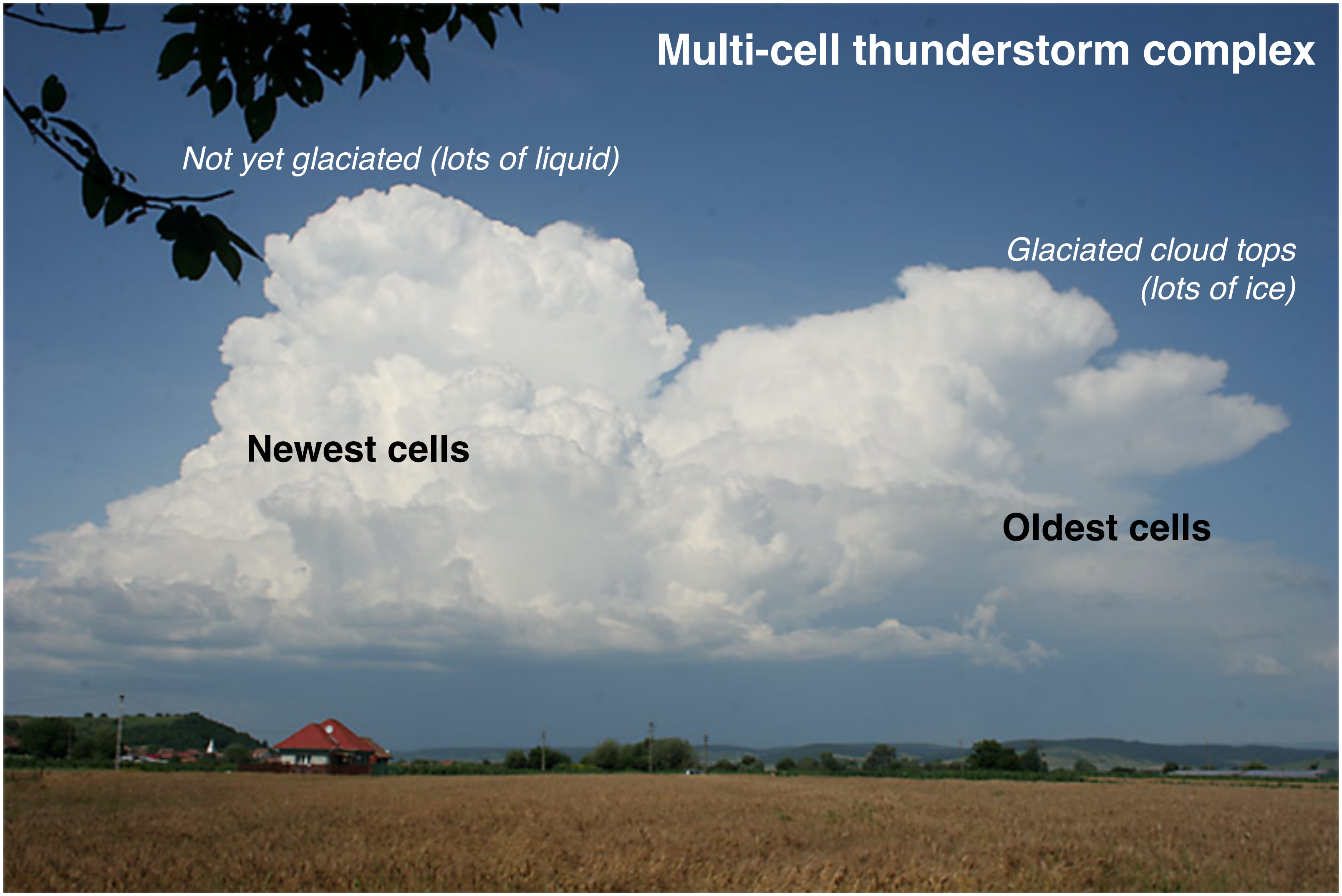


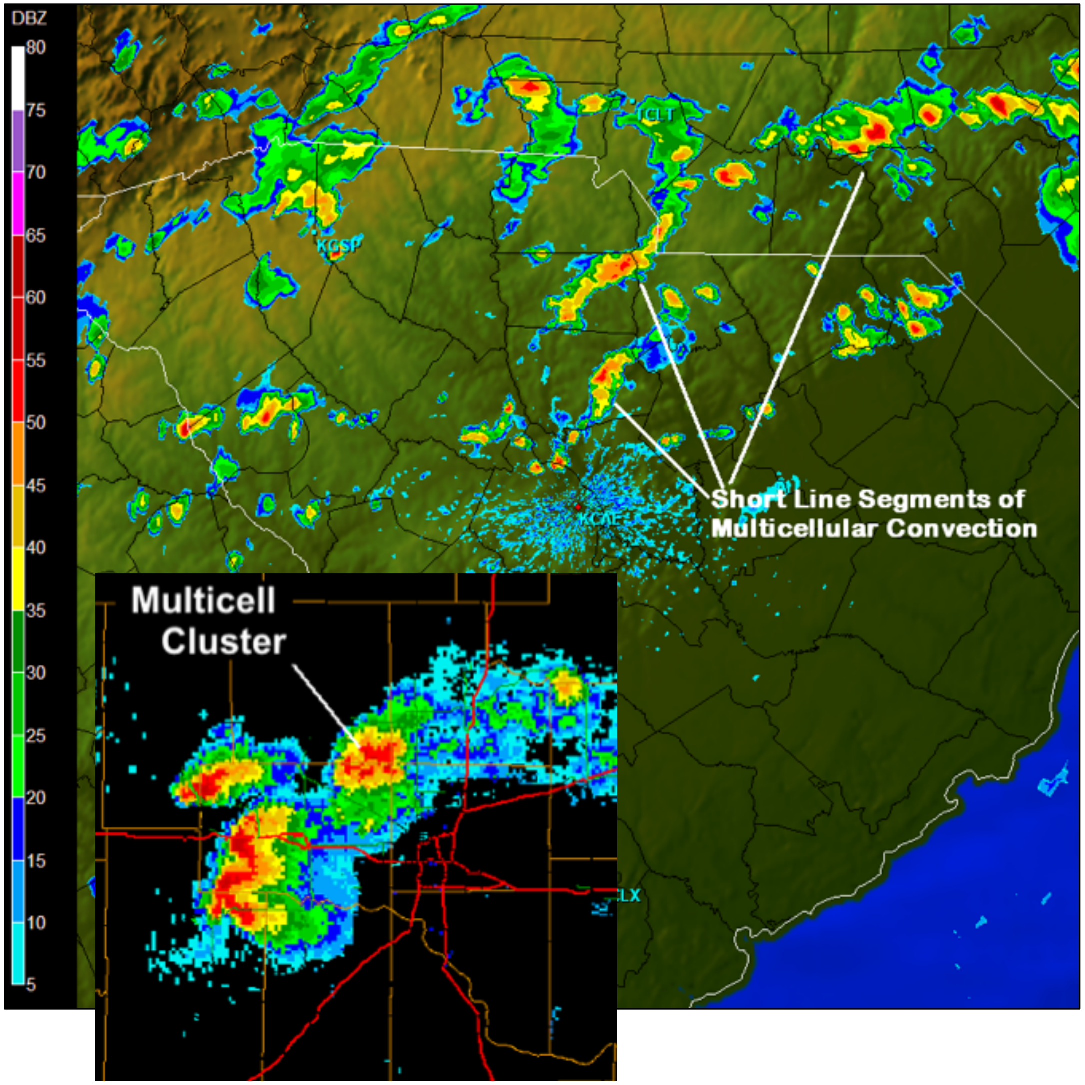
Straight hodograph



Curved hodograph




Multi-cell thunderstorm complex
Not yet glaciated (lots of liquid)
Glaciated cloud tops
(lots of ice)
Newest cells
Oldest cells



Mix of single-cell and multi-cell clusters of storms on this day.

Multi-cell clusters can form from an individual cold pool, or cold pools merging from separate storms.

When cold pools collide, this could initiate many cells along the gust front. Difficult to distinguish between single cells or multi-cells on many days with weak wind shear.

Distinguishing between single cell and multicell environments

Bulk Richardson Number (BRN) = CAPE / (0.5*U^2)

U – magnitude of vector difference between 0 – 6km mean wind and 0 – 500 m mean wind.