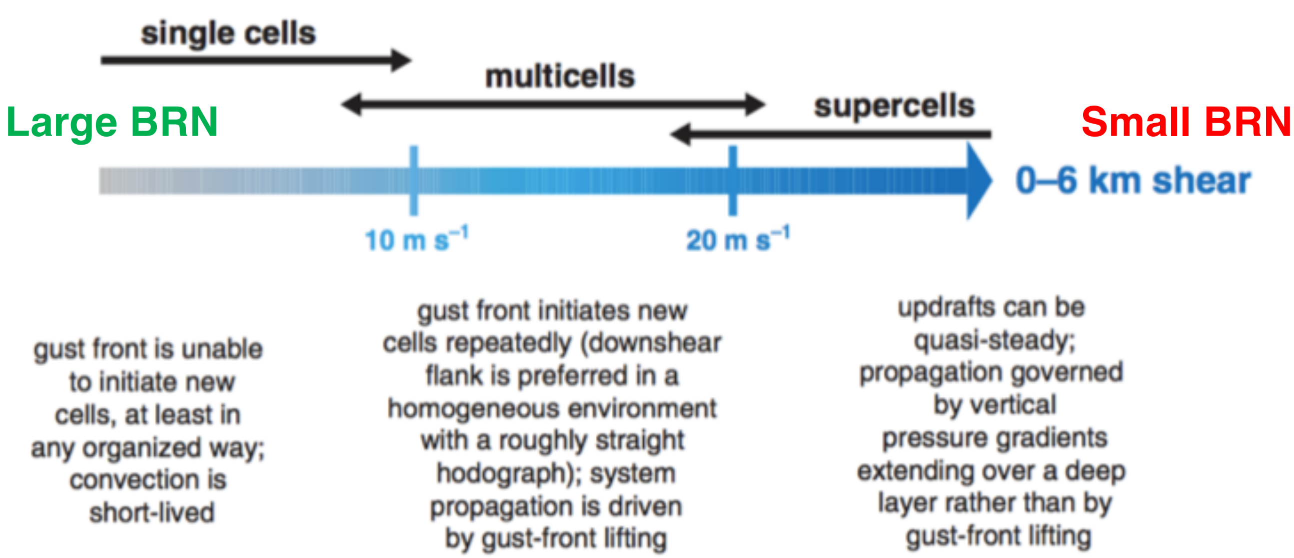
Distinguishing between single cell and multicell environments

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.



Three types of storms evident from WK82 simulations:

1) Single cell
   - short lifetime
   - driven by buoyancy

2) Multi-cell
   - longer lifetime
   - discrete propagation via gust front
   - need some amount of shear

3) Supercell
   - longer lifetime
   - continuous propagation via VPPGF
   - storm splitting
   - large shear

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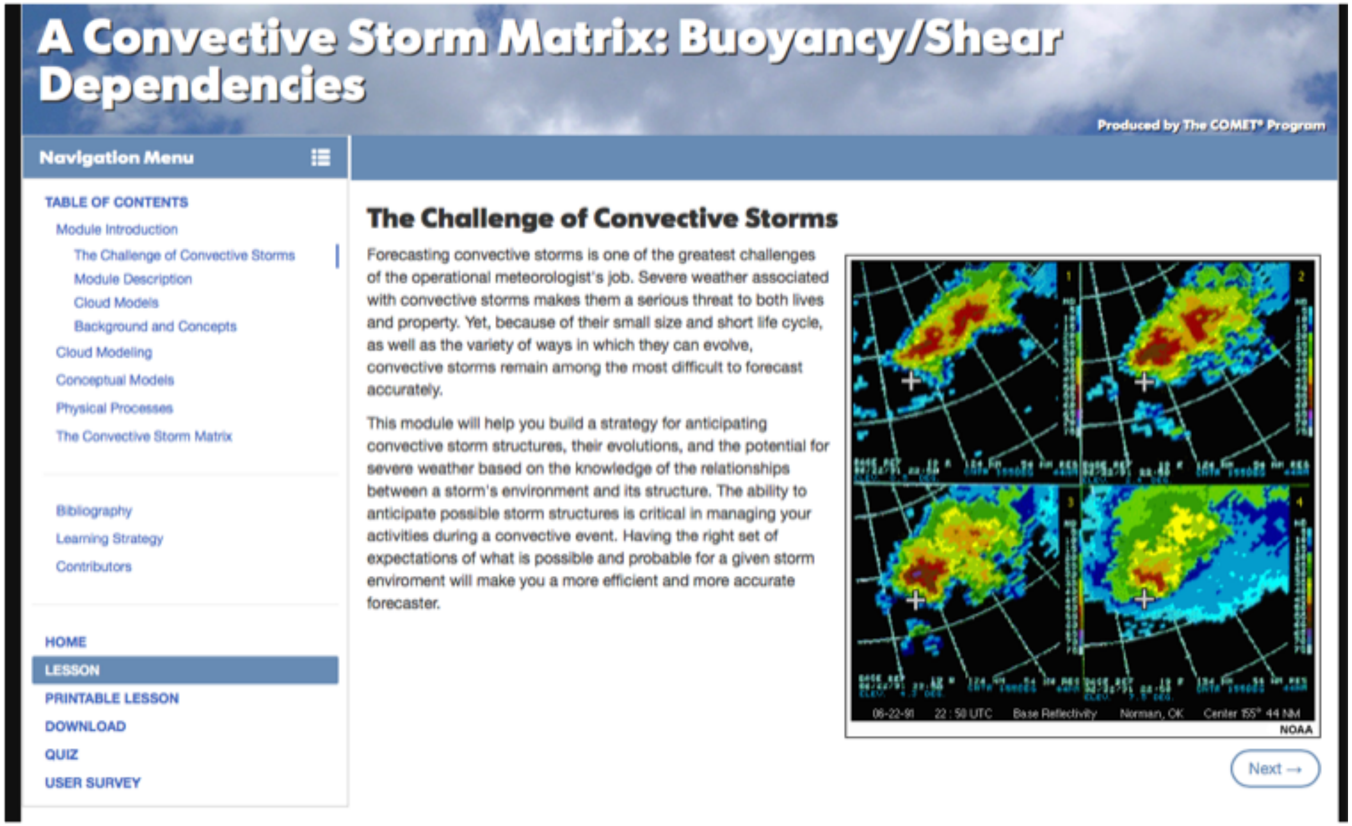

A Convective Storm Matrix: Buoyancy/Shear Dependencies

Produced by The COMET® Program

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The Challenge of Convective Storms

Forecasting convective storms is one of the greatest challenges of the operational meteorologist's job. Severe weather associated with convective storms makes them a serious threat to both lives and property. Yet, because of their small size and short life cycle, as well as the variety of ways in which they can evolve, convective storms remain among the most difficult to forecast accurately.

This module will help you build a strategy for anticipating convective storm structures, their evolutions, and the potential for severe weather based on the knowledge of the relationships between a storm's environment and its structure. The ability to anticipate possible storm structures is critical in managing your activities during a convective event. Having the right set of expectations of what is possible and probable for a given storm enviroment will make you a more efficient and more accurate forecaster.

06-22-91 22:50 UTC Base Reflectivity Norman, OK Center 155° 44 NM
NOAA

Next →

Some convective updrafts rotate…

Read *Davies-Jones (1984)*: “Streamwise vorticity: The origin of updraft rotation in supercell storms”

Origins of updraft rotation

(M&R Section 8.4.3)

Start with full vorticity equation…

$$\frac{\mathrm{d}(\boldsymbol{\omega} + f\mathbf{k})}{\mathrm{d}t} = \underbrace{\frac{\partial \boldsymbol{\omega}}{\partial t}}_{\text{local tendency}} \underbrace{+(\mathbf{v} \cdot \boldsymbol{\nabla})(\boldsymbol{\omega} + f\mathbf{k})}_{\text{advection}}$$

$$= \underbrace{[(\boldsymbol{\omega} + f\mathbf{k}) \cdot \boldsymbol{\nabla}]\mathbf{v}}_{\text{tilting/stretching}} \underbrace{+\frac{1}{\rho^2}\boldsymbol{\nabla}\rho \times \boldsymbol{\nabla}p}_{\text{baroclinic generation}}$$

$$\underbrace{+\boldsymbol{\nabla} \times \mathbf{F}.}_{\text{viscous effects}} \tag{2.88}$$

Origins of updraft rotation

Extract vertical vorticity equation…

advection

Tilting/stretching

Stretching of f

$$\mathbf{k}\cdot\frac{\partial\boldsymbol{\omega}}{\partial t}=\frac{\partial\zeta}{\partial t}=-\mathbf{v}\cdot\boldsymbol{\nabla}(\zeta+f)+\boldsymbol{\omega}\cdot\boldsymbol{\nabla}w+f\frac{\partial w}{\partial z}$$
$$+\frac{1}{\rho^2}\left(\frac{\partial\rho}{\partial x}\frac{\partial p}{\partial y}-\frac{\partial\rho}{\partial y}\frac{\partial p}{\partial x}\right)+\mathbf{k}\cdot\boldsymbol{\nabla}\times\mathbf{F}. \quad (2.91)$$

Baroclinic effects

Friction

Origins of updraft rotation

Vertical vorticity equation neglecting baroclinic, viscous, earth's rotation effects…

$$\frac{\partial \zeta}{\partial t} = -\mathbf{v} \cdot \nabla \zeta + \boldsymbol{\omega} \cdot \nabla w$$

$$= -u\frac{\partial \zeta}{\partial x} - v\frac{\partial \zeta}{\partial y} - w\frac{\partial \zeta}{\partial z} + \xi\frac{\partial w}{\partial x} + \eta\frac{\partial w}{\partial y} + \zeta\frac{\partial w}{\partial z}$$

Origins of updraft rotation

Linearize vertical vorticity equation (mean + perturbation; mean = environment)

Neglect non-linear terms (products of perturbations)

$$u = \bar{u} + u' \qquad v = \bar{v} + v' \qquad w = w' \qquad \zeta = \zeta'$$

$$\frac{\partial \zeta'}{\partial t} = \underbrace{-\bar{u}\frac{\partial \zeta'}{\partial x} - \bar{v}\frac{\partial \zeta'}{\partial y}}_{\text{advection}} \underbrace{+\frac{\partial \bar{u}}{\partial z}\frac{\partial w'}{\partial y} - \frac{\partial \bar{v}}{\partial z}\frac{\partial w'}{\partial x}}_{\text{tilting}},$$

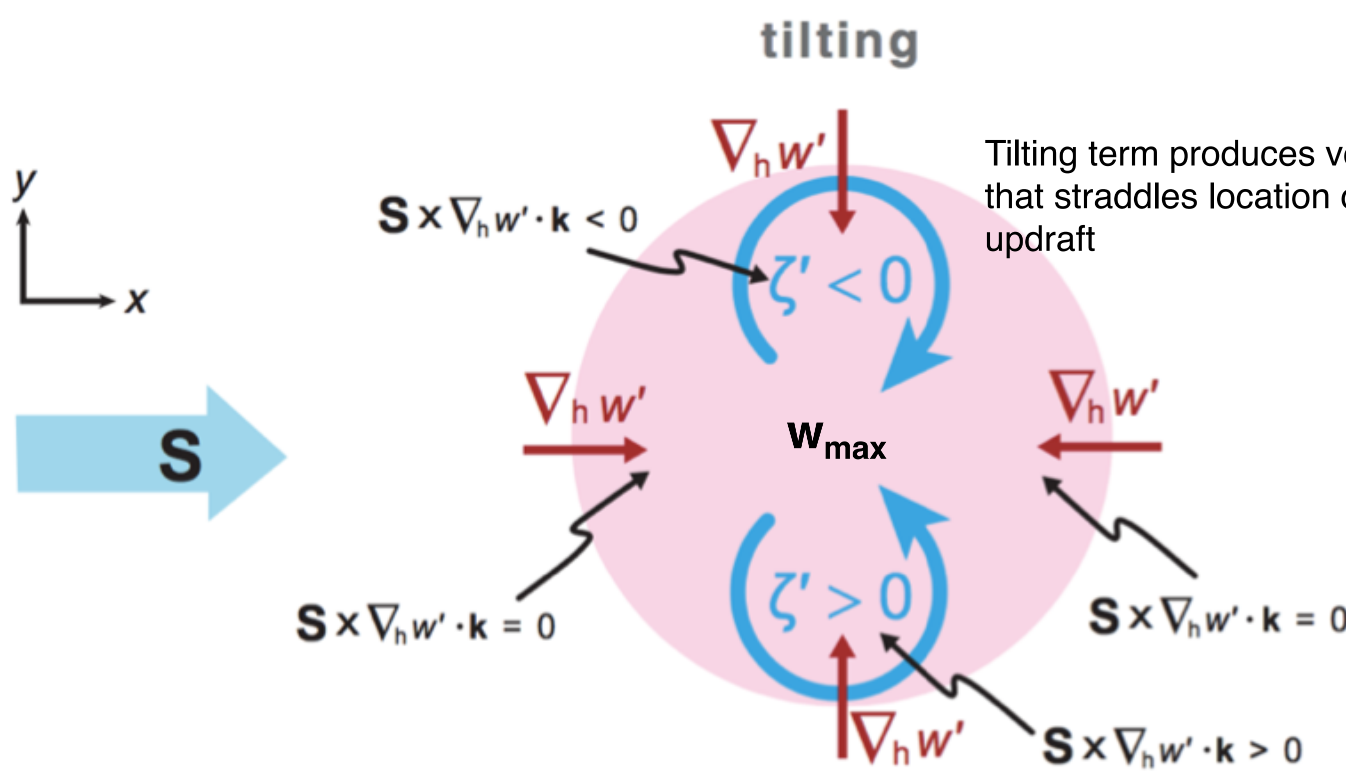
Remember: no nonlinear effects here (perturbations increasing perturbations)!

Origins of updraft rotation

$$\frac{\partial \zeta'}{\partial t} = \underbrace{-\bar{\mathbf{v}} \cdot \nabla_{\mathrm{h}} \zeta'}_{\text{advection}} \underbrace{+\mathbf{S} \times \nabla_{\mathrm{h}} w' \cdot \mathbf{k}}_{\text{tilting}},$$

If vertical vorticity zero, no advection can occur, so tilting must first produce vertical vorticity, which can then be advected.

Origins of updraft rotation



Tilting term produces vorticity couplet that straddles location of maximum updraft

Vortex Lines

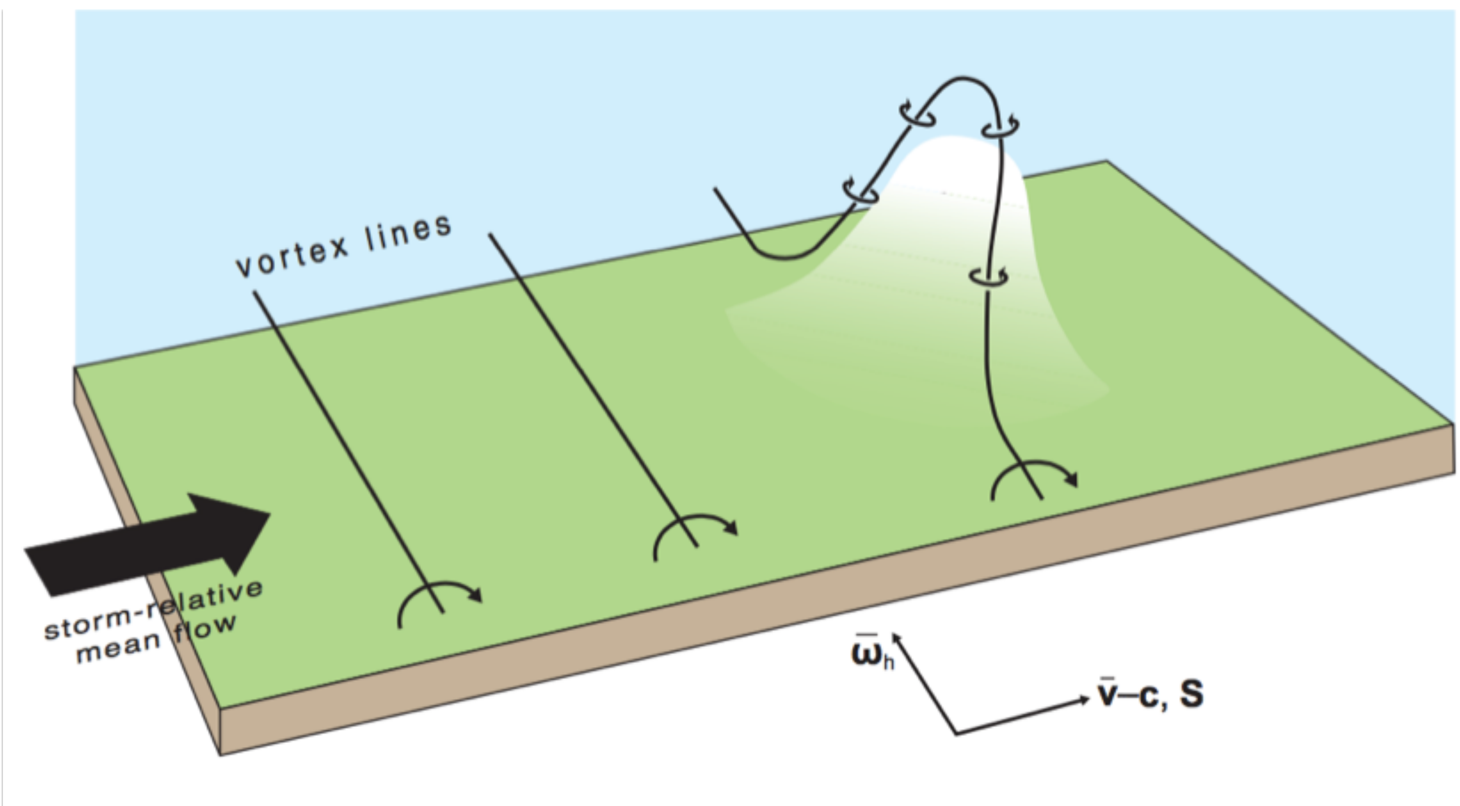
- Curve in fluid tangent to local vorticity vector (same relationship between vortex line/vorticity as streamline/velocity).

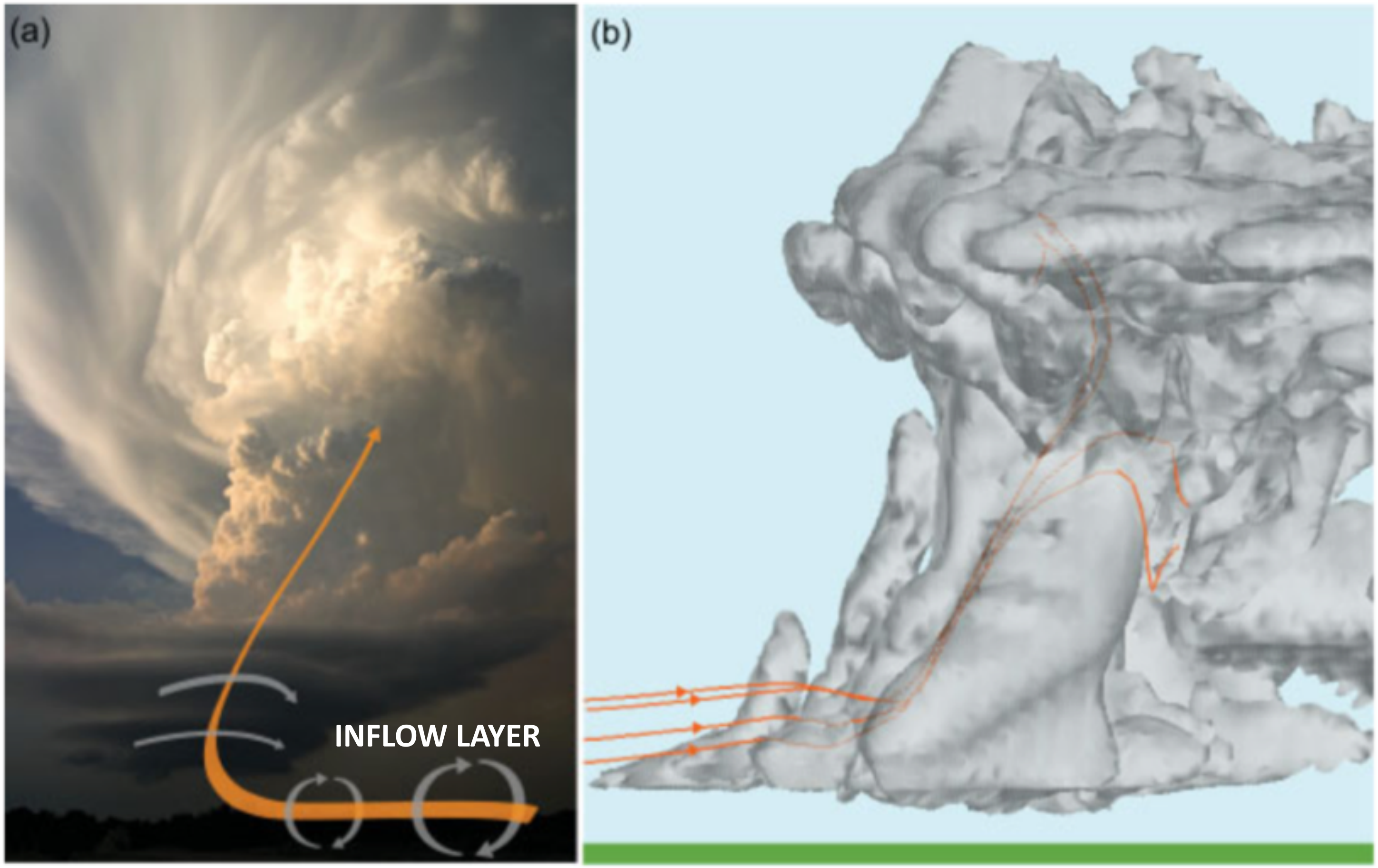
- Vortex lines cannot be broken and can only terminate at a surface (e.g., the ground)

- Vortex tubes are collections of vortex lines

- *Helmholtz's theorem*:
  - Vortex lines move as **material** lines in inviscid, barotopic flow (when friction and baroclinity can be neglected).

Vortex lines in sheared flow, tilted by updraft




(a)
INFLOW LAYER
(b)

Origins of updraft rotation

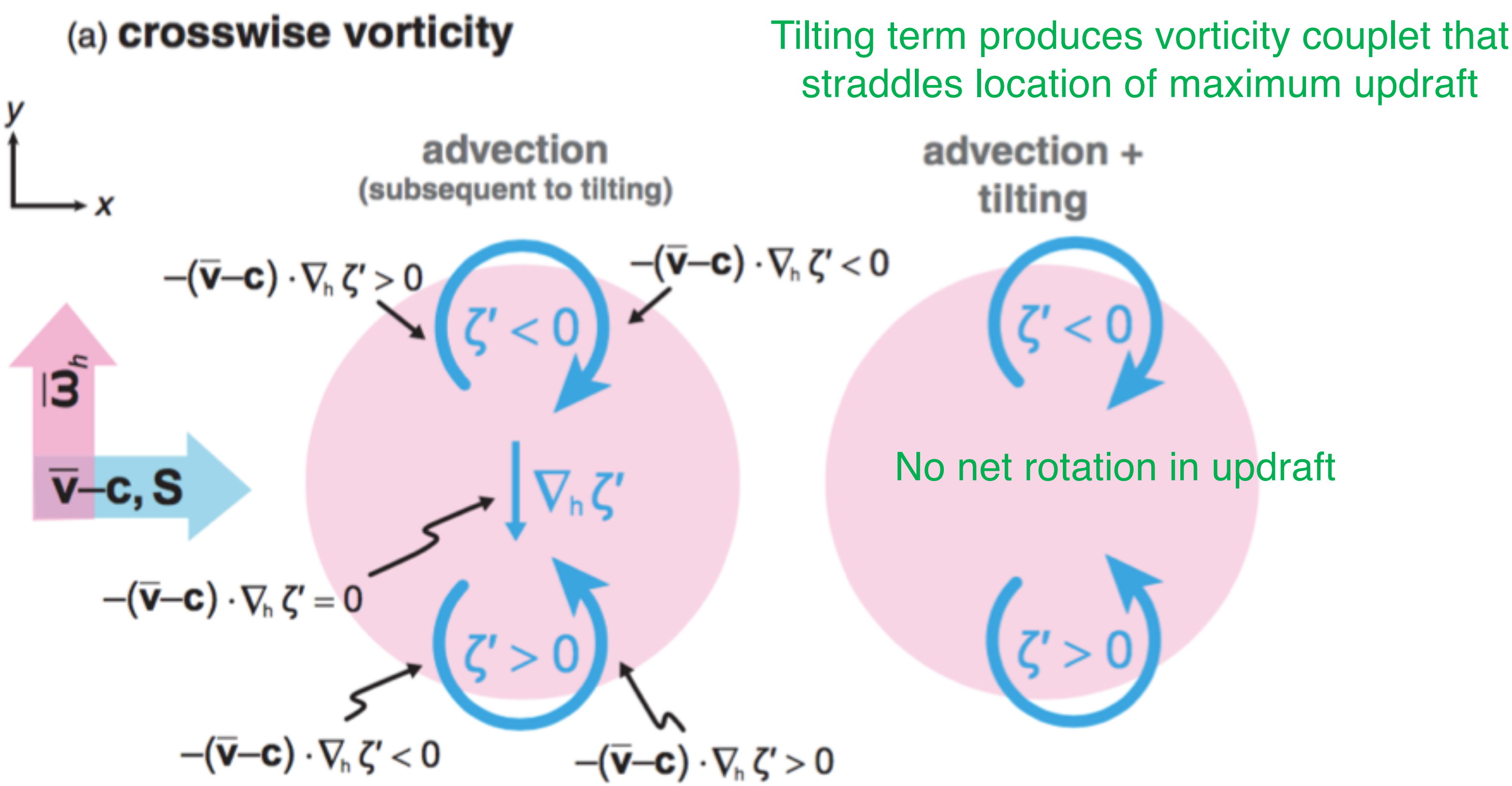
To assess impacts of advection, need to look at changes in storm-relative frame of reference.

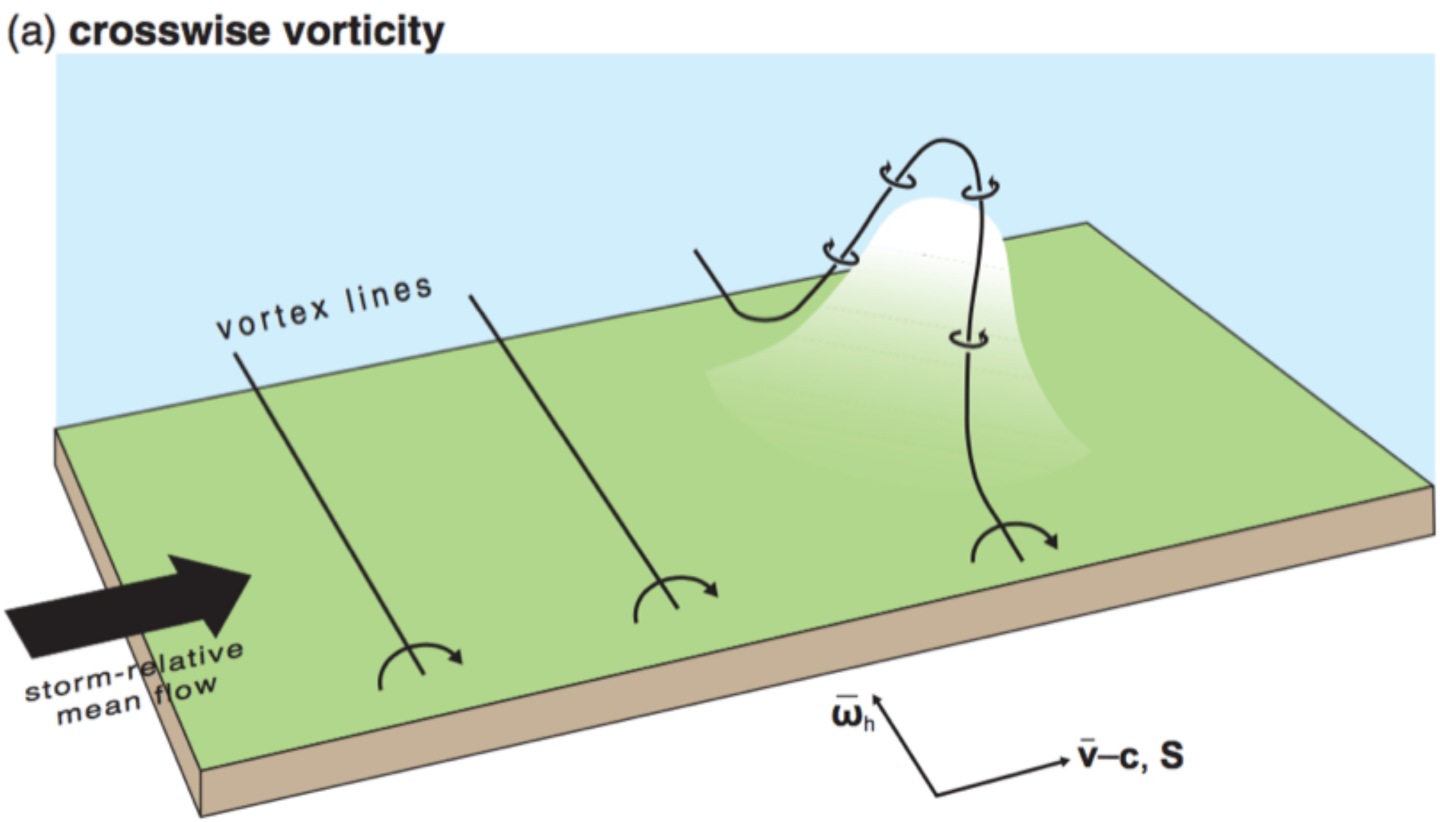
That is, how does vertical vorticity change in the reference frame of the storm?

$$\left(\frac{\partial \zeta'}{\partial t}\right)_{\mathrm{sr}} = \underbrace{-(\overline{\mathbf{v}} - \mathbf{c}) \cdot \nabla_{\mathrm{h}} \zeta'}_{\text{advection}} \underbrace{+\mathbf{S} \times \nabla_{\mathrm{h}} w' \cdot \mathbf{k}}_{\text{tilting}},$$

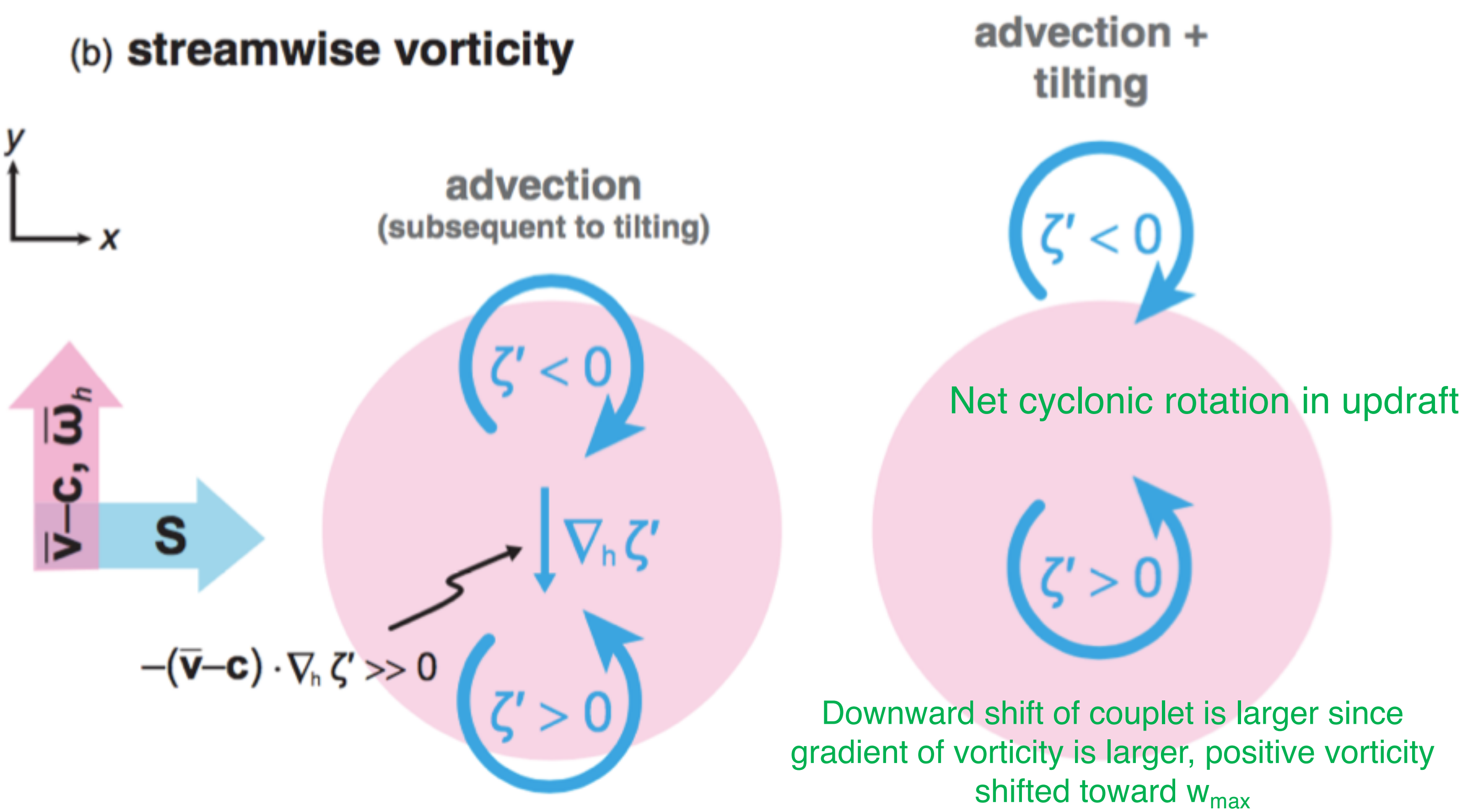
Tilted vorticity couplets can be advected in various directions…

Origins of updraft rotation

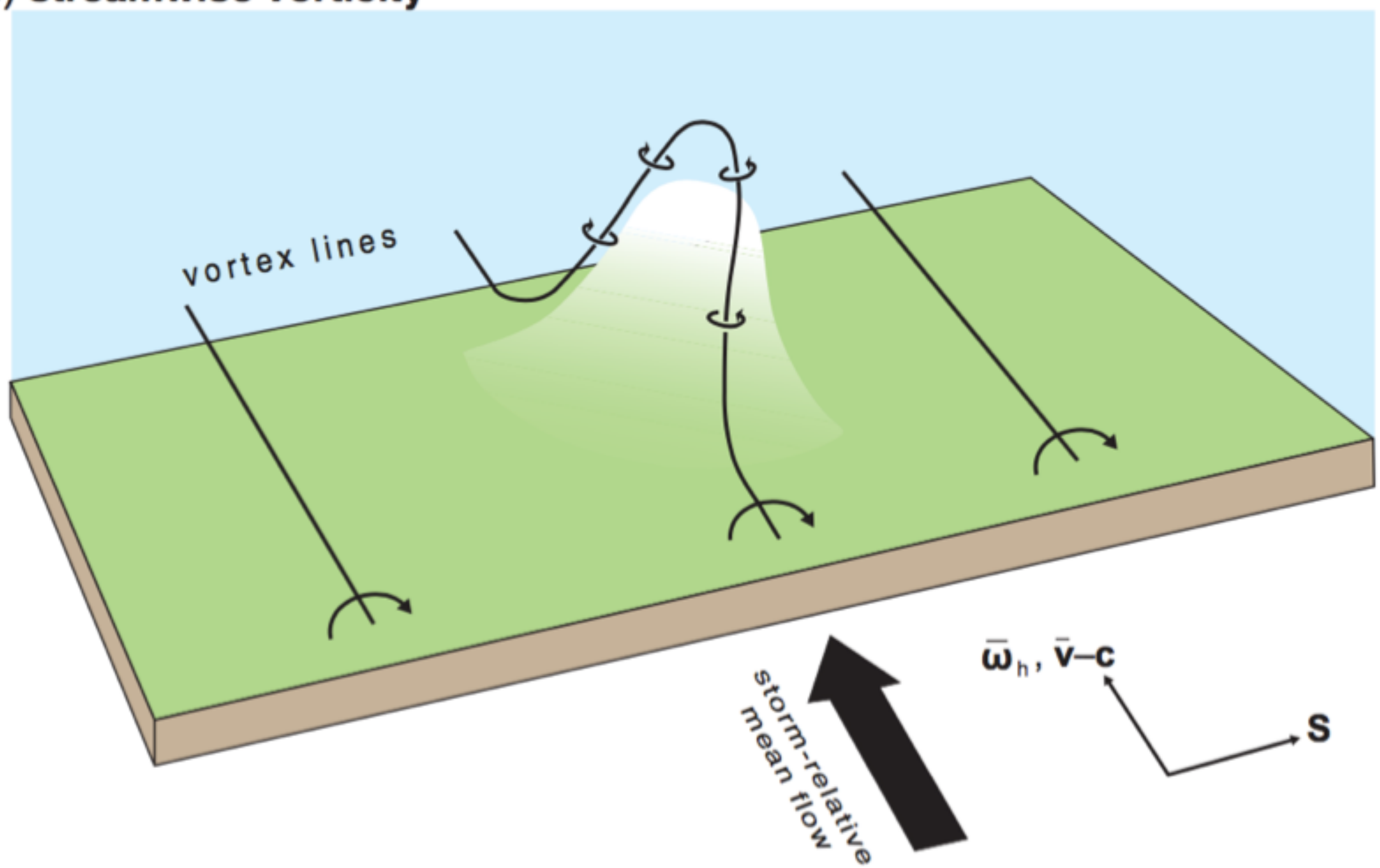



(a) crosswise vorticity
vortex lines
storm-relative
mean flow
$\bar{\omega}_h$
$\bar{v}-c$, S

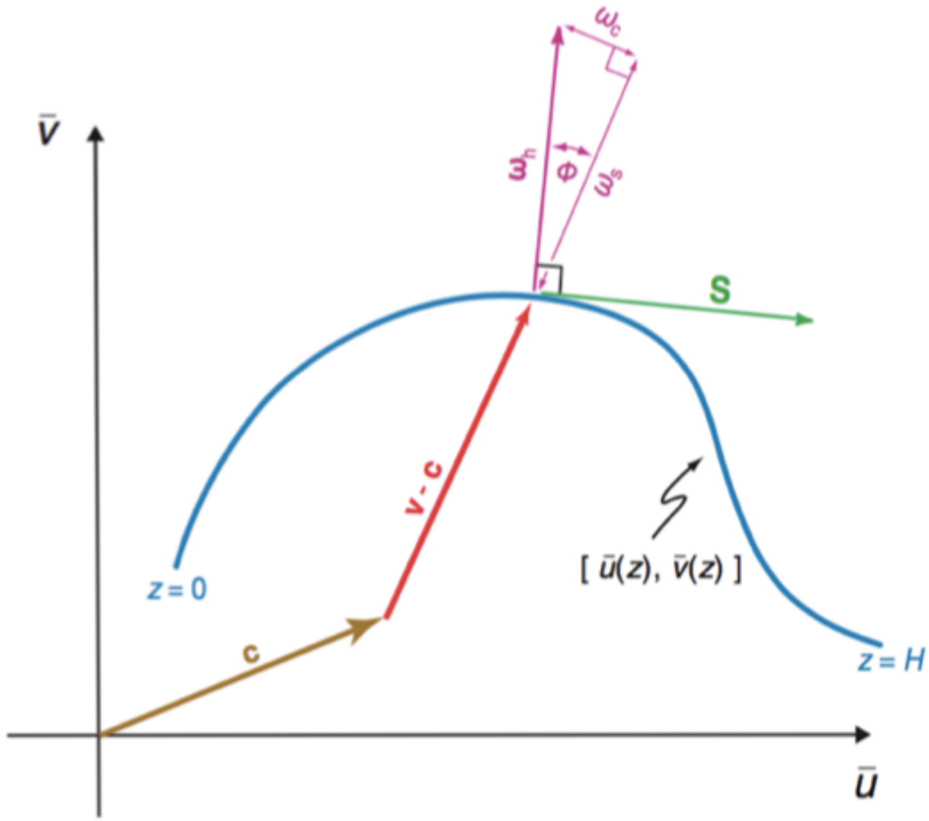
Origins of updraft rotation



(b) **streamwise vorticity**



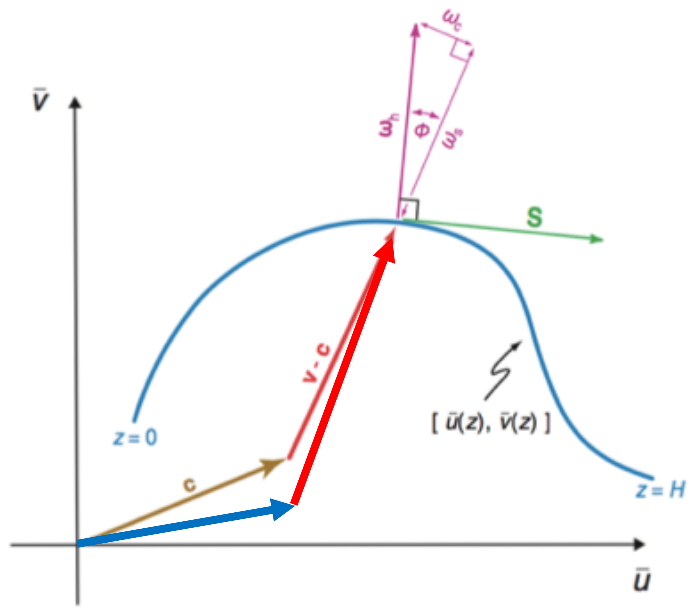
Streamwise and crosswise vorticity at particular level on hodograph



Streamwise and crosswise vorticity at particular level on hodograph

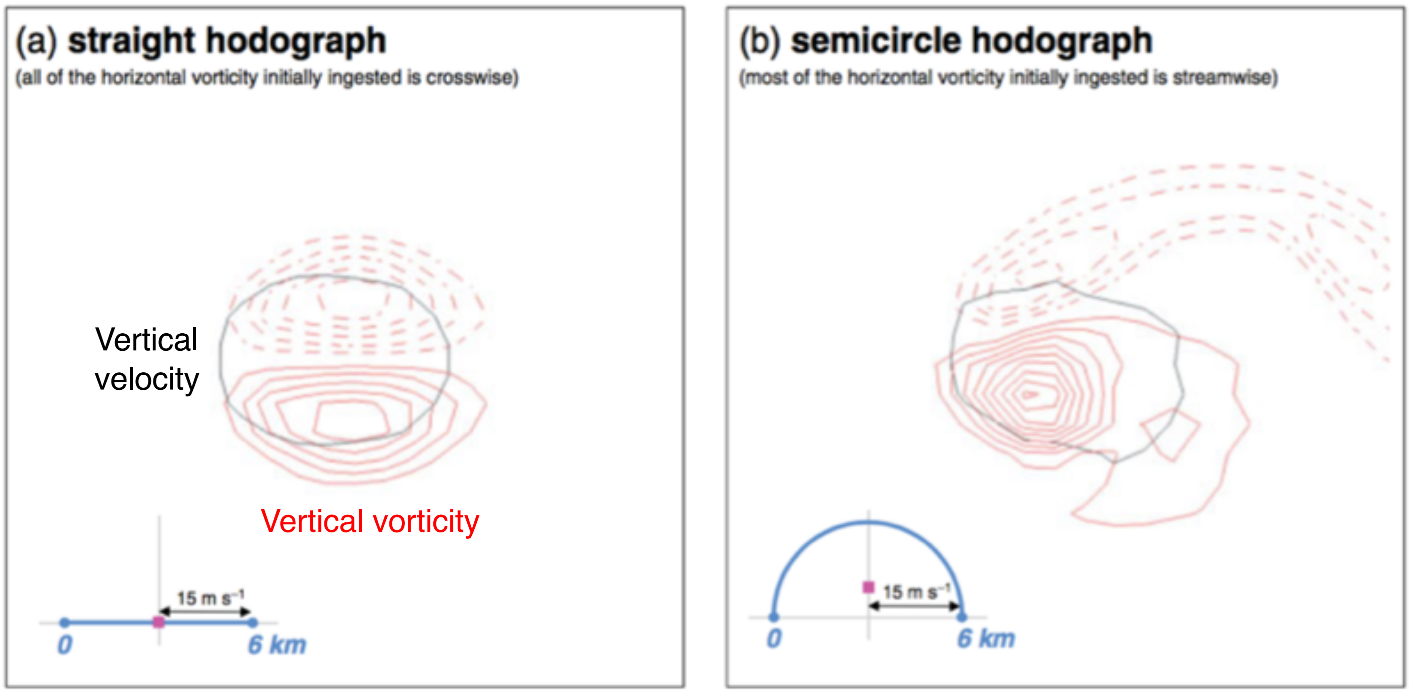
Correlation of updraft speed with positive vertical vorticity depends on magnitude of environmental crosswise vs. streamwise vorticity in storm inflow.

Storm motions that deviate to right of mean wind usually result in larger streamwise vorticity:



Summary of development of mid-level rotation in an updraft

- vorticity couplet develops due to tilting of environmental horizontal vorticity into the vertical
- couplets immediately advected by storm-relative winds in a way that depends on horizontal streamwise vs. crosswise vorticity
- if largely streamwise, updraft maximum and vorticity maximum can become co-located, leading to non-linear effects.



(a) straight hodograph
(all of the horizontal vorticity initially ingested is crosswise)
Vertical velocity
Vertical vorticity
15 m s⁻¹
0
6 km
(b) semicircle hodograph
(most of the horizontal vorticity initially ingested is streamwise)
15 m s⁻¹
0
6 km

Helicity

Helicity is a measure of the degree to which the direction of fluid motion is aligned with the vorticity of the fluid (related to streamwise vorticity).

$$\mathcal{H} = \mathbf{v} \cdot \boldsymbol{\omega} = \mathbf{v} \cdot \nabla \times \mathbf{v}$$

Dot product of velocity vs. vorticity vector (0 if perpendicular; Beltrami flows)

Before, we were really just assessing streamwise vorticity at one level within the storm. Need to look at depth that matters to storm (inflow)…

$$\mathcal{H} = \int_0^d \overline{\mathbf{v}} \cdot \overline{\boldsymbol{\omega}}_{\mathrm{h}}\, \mathrm{d}z \qquad \overline{\boldsymbol{\omega}}_{\mathrm{h}} = \left(-\frac{\partial \overline{v}}{\partial z}, \frac{\partial \overline{u}}{\partial z}\right) = \mathbf{k} \times \mathbf{S}$$

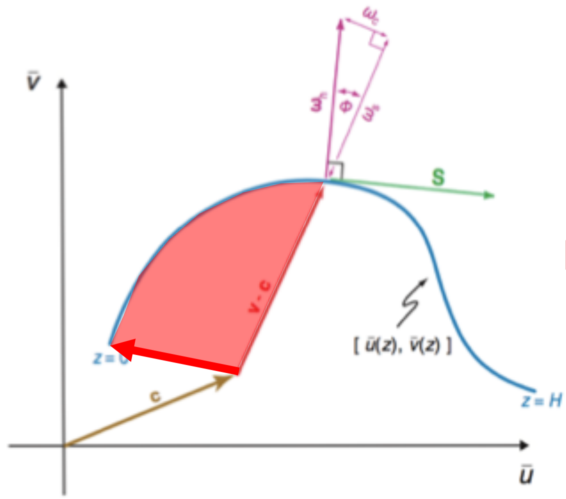
Overbars indicate environmental wind

Helicity

Again, only helicity in storm-relative reference frame is relevant…

Storm-relative helicity (or storm-relative environmental helicity)

$$\mathrm{SRH} = \int_0^d (\overline{\mathbf{v}} - \mathbf{c}) \cdot \overline{\boldsymbol{\omega}}_\mathrm{h}\, \mathrm{d}z = \int_0^d |\overline{\mathbf{v}} - \mathbf{c}|\, \omega_\mathrm{s}\, \mathrm{d}z$$



Magnitude of SRH is twice shaded area.

Helicity

SRH is positive if area is associated with streamwise vorticity (negative if associated with antistreamwise vorticity).

Can also compute with a set of wind observations…

$$\mathrm{SRH} = \sum_{n=1}^{N-1} [(u_{n+1} - c_x)(v_n - c_y) - (u_n - c_x)(v_{n+1} - c_y)]$$