The role of ambient horizontal vorticity in near-ground rotation of supercells

Johannes Dahl[1], Matthew Parker[1], and Louis Wicker[2]

[1] Department of Marine, Earth, and Atmospheric Sciences, NCSU, Raleigh, NC
[2] National Severe Storms Laboratory, Norman, OK

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Bob Davies-Jones

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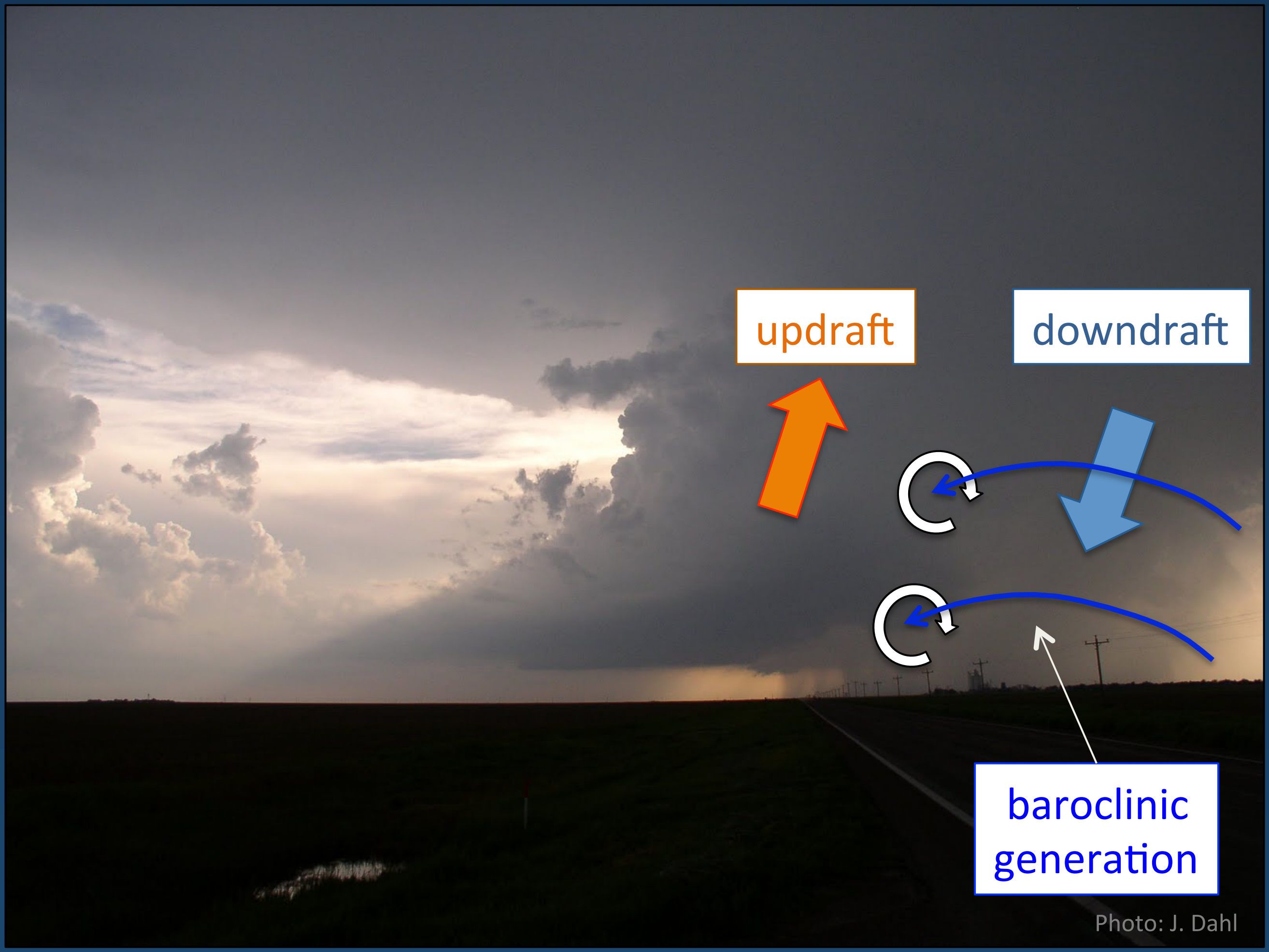
Background

- Supercell tornadogenesis proceeds in three steps:
  1. Rotation aloft ("midlevel mesocyclone")
  2. **Rotation at the ground (requires downdraft)**
  3. Amplification of the surface rotation by convergence

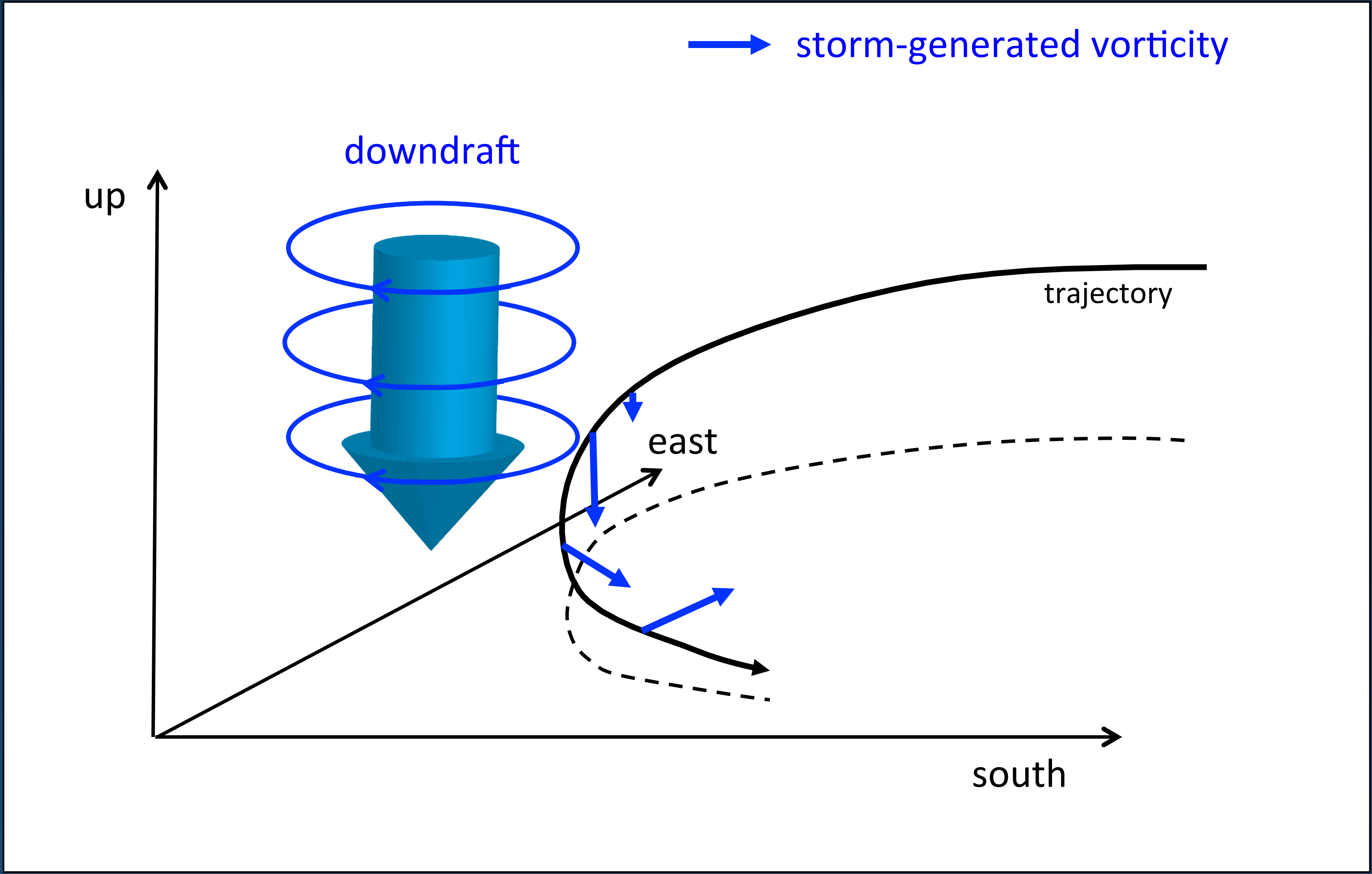
- Numerous studies have demonstrated the importance of storm-generated (baroclinic) vorticity in surface rotation

- The role of *ambient* vorticity in near-surface rotation is not well understood

Baroclinic generation of vorticity

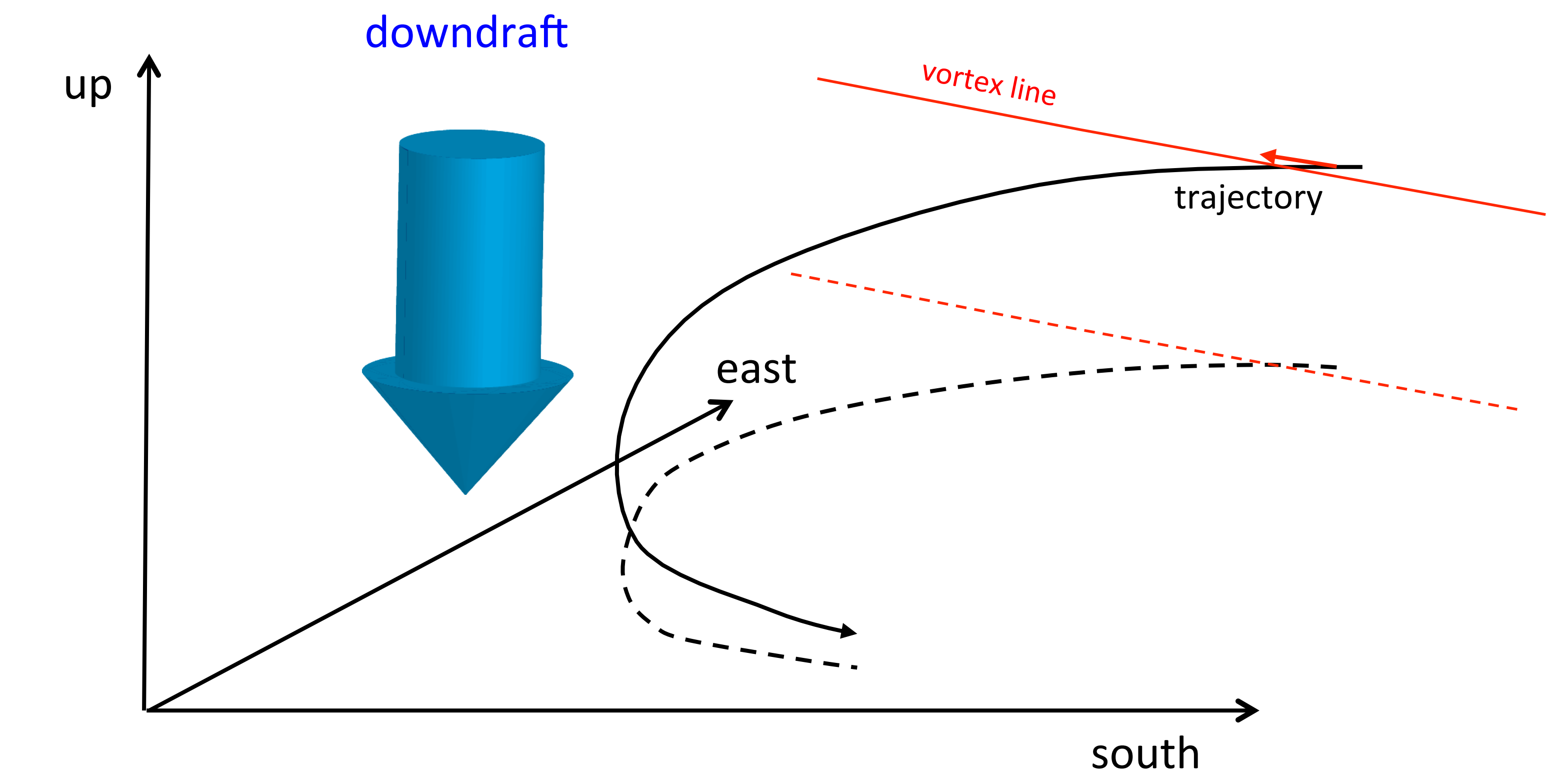


Baroclinic process (storm-generated vorticity)



Barotropic process (imported vorticity)

Barotropic vorticity: Frozen into the fluid (rearrangement of *existing* vorticity)



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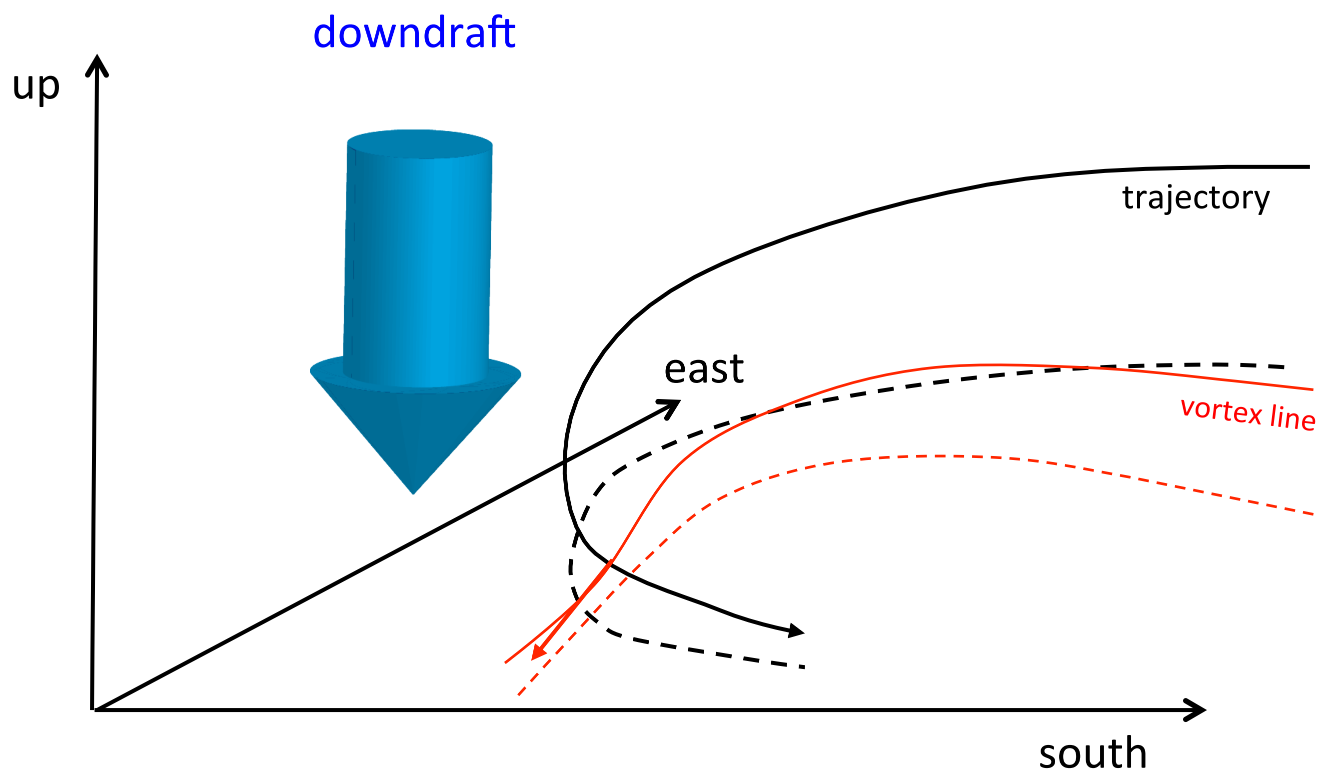
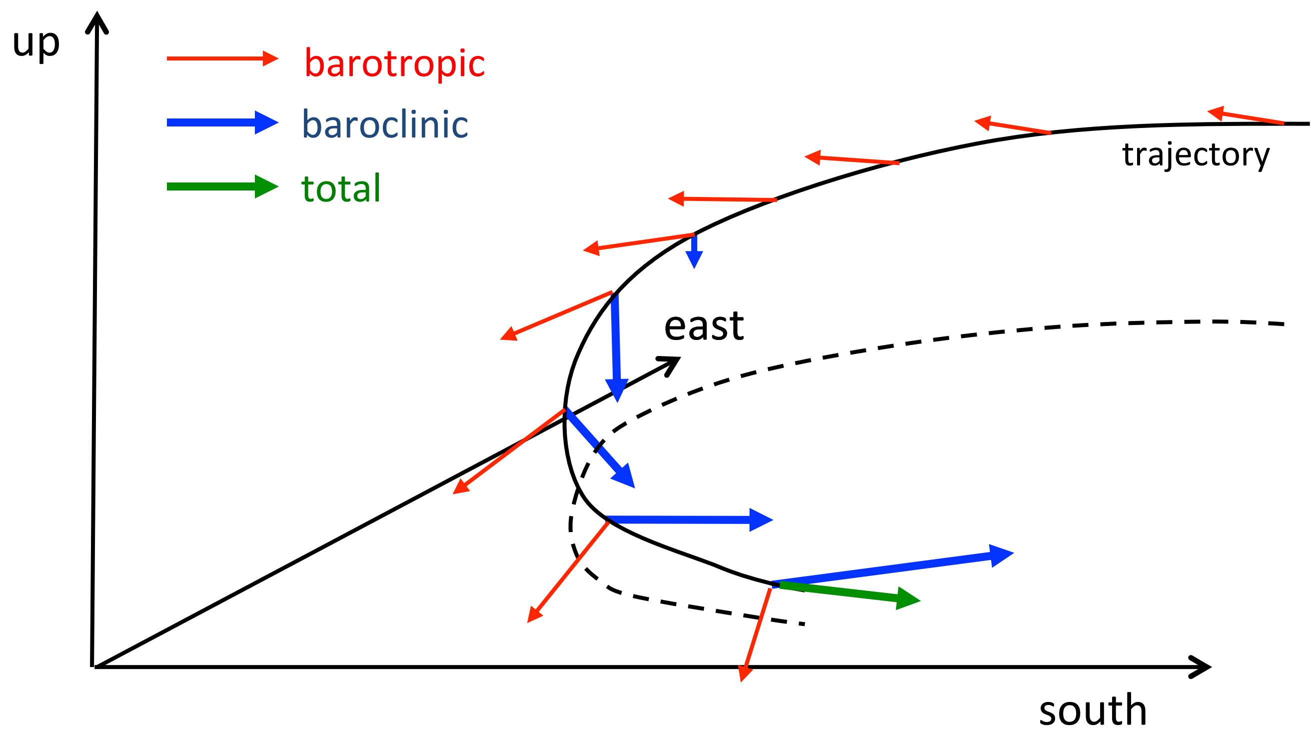


How does this barotropic vorticity contribute to the surface vorticity?

Vorticity decomposition

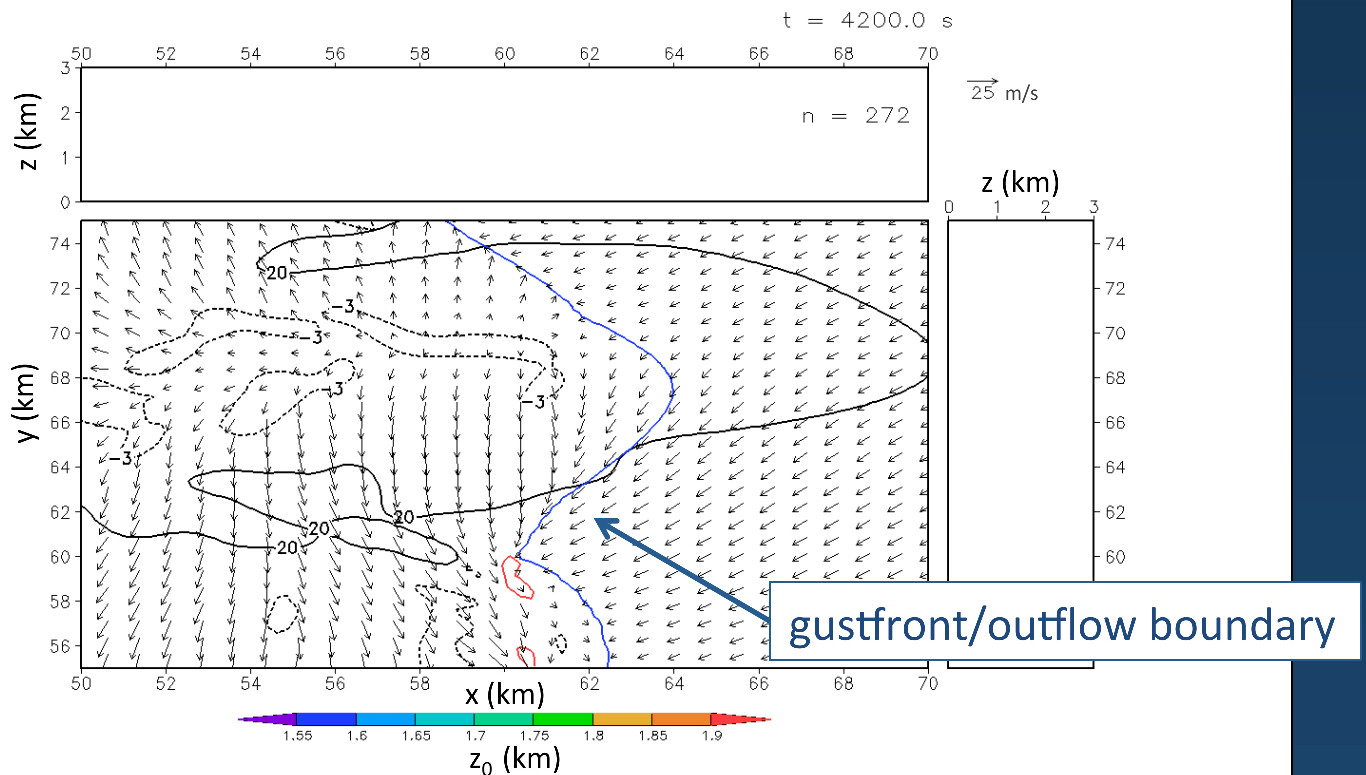
Barotropic vorticity: Frozen into the fluid (rearrangement of *existing* vorticity)
Baroclinic vorticity: Generated baroclinically and subsequently rearranged
Total vorticity: Sum of baroclinic and barotropic parts



Simulation setup

- Bryan Cloud Model 1 (CM1), release 17
- dx = dy = 250 m
- 50 m < dz < 250 m
- Single-moment microphysics
  - adjusted rain-intercept parameter to reduce cold-pool strength
- free-slip lower boundary
- Del City base state
- Initialization: 2K ellipsoidal potential-temperature perturbation
- Restart run with highly accurate forward trajectories
  - Calculated at each time step (dt = 2 s)
  - 4^{th}-order forward integration
  - 4^{th}-order spatial interpolation

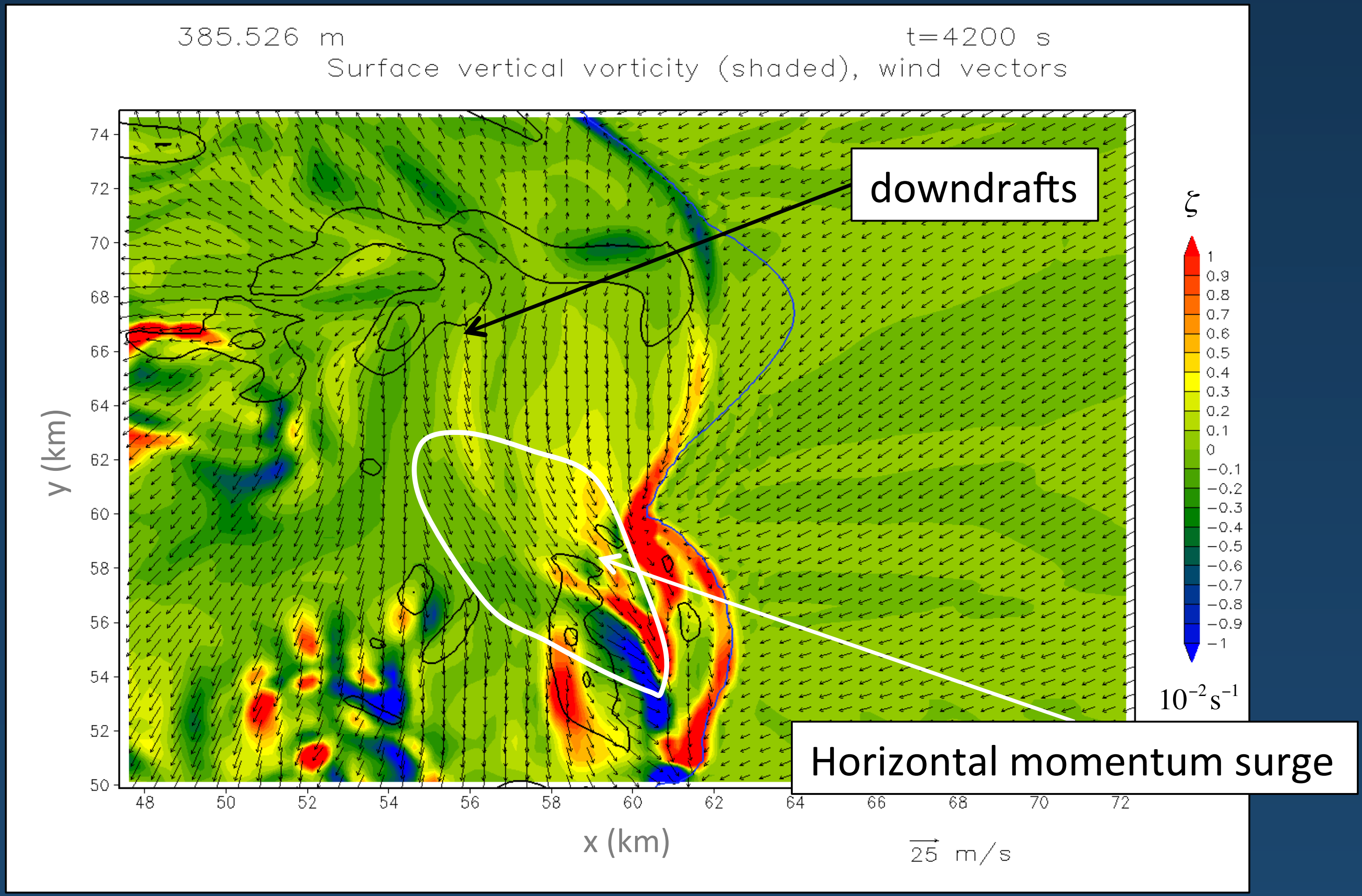
Forward trajectories



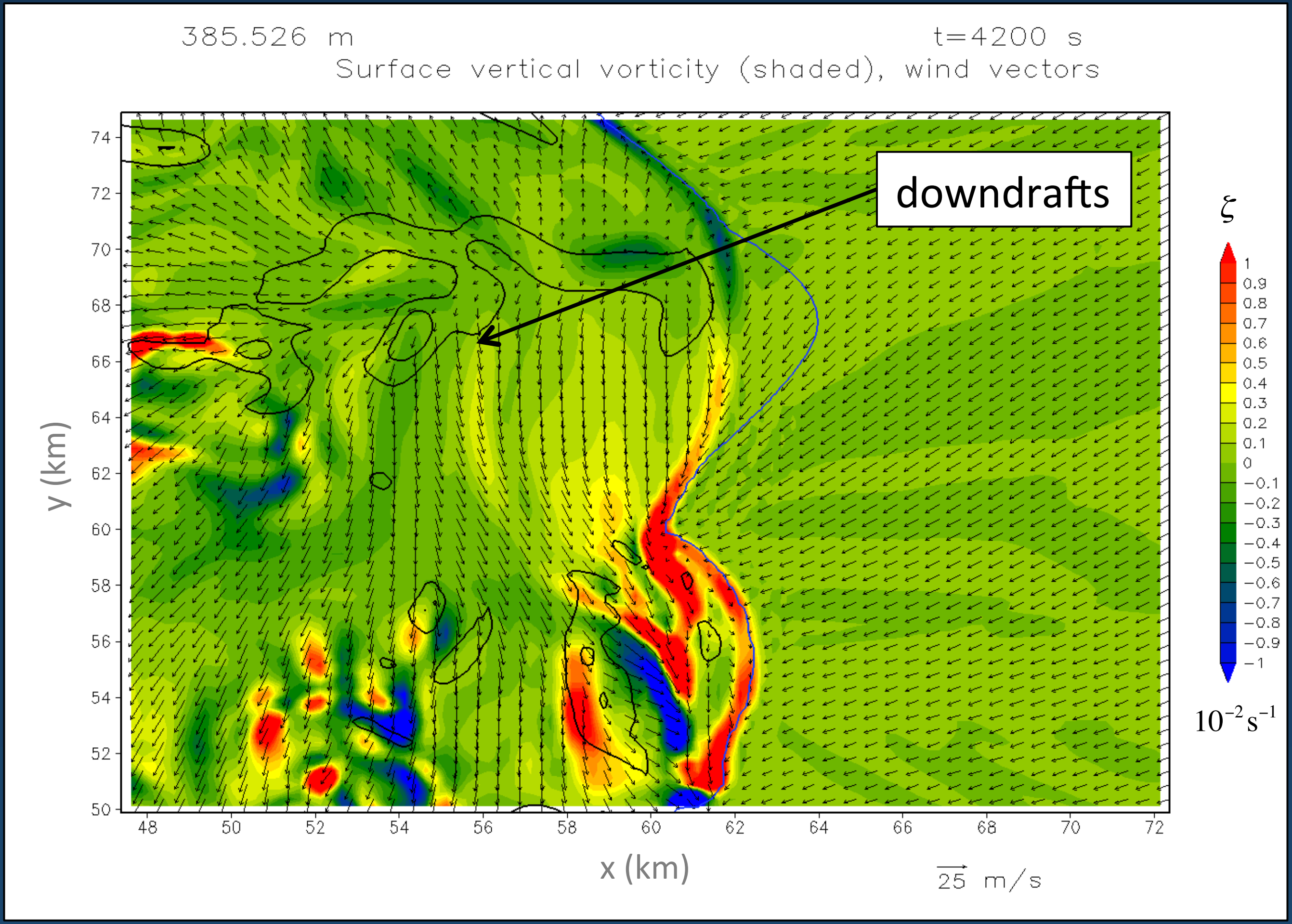
Black solid contour: reflectivity (385 m)
Black dashed contours: downdraft (385 m)
Red contours: surface vertical vorticity

Trajectories analyzed until they reach z_0 = 50 m

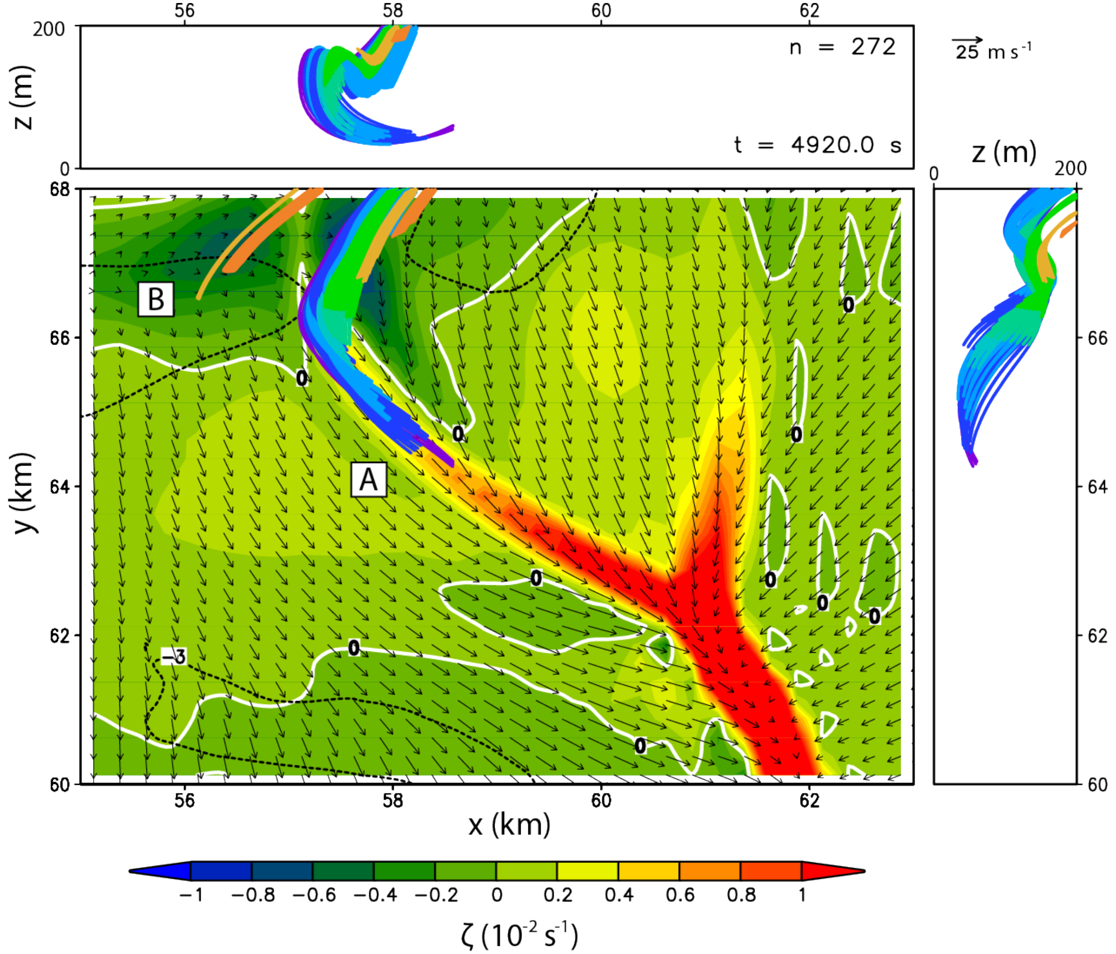
"Rivers" of vertical vorticity in outflow



“Rivers” of vertical vorticity in outflow

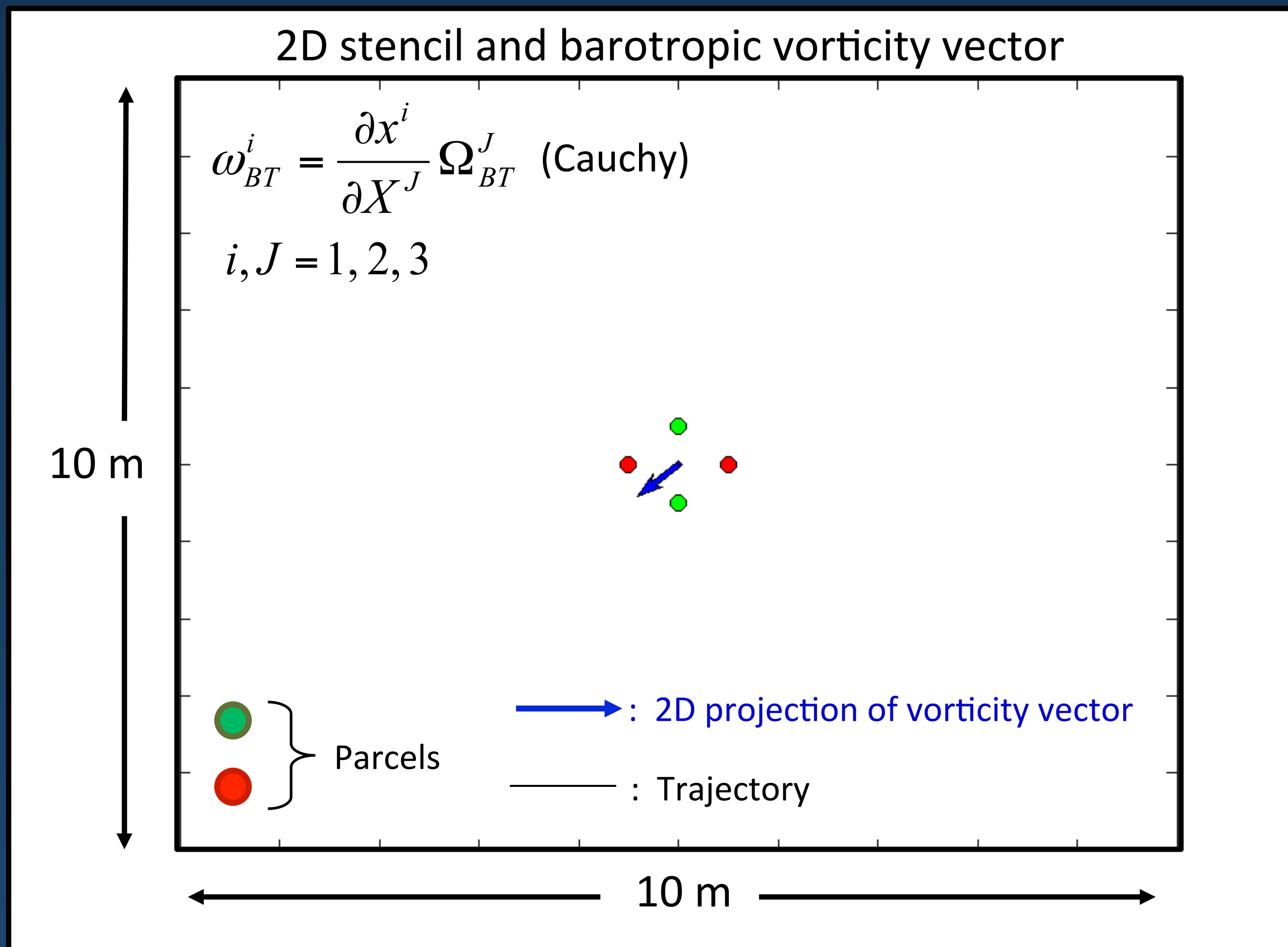


Forward trajectories and vorticity rivers

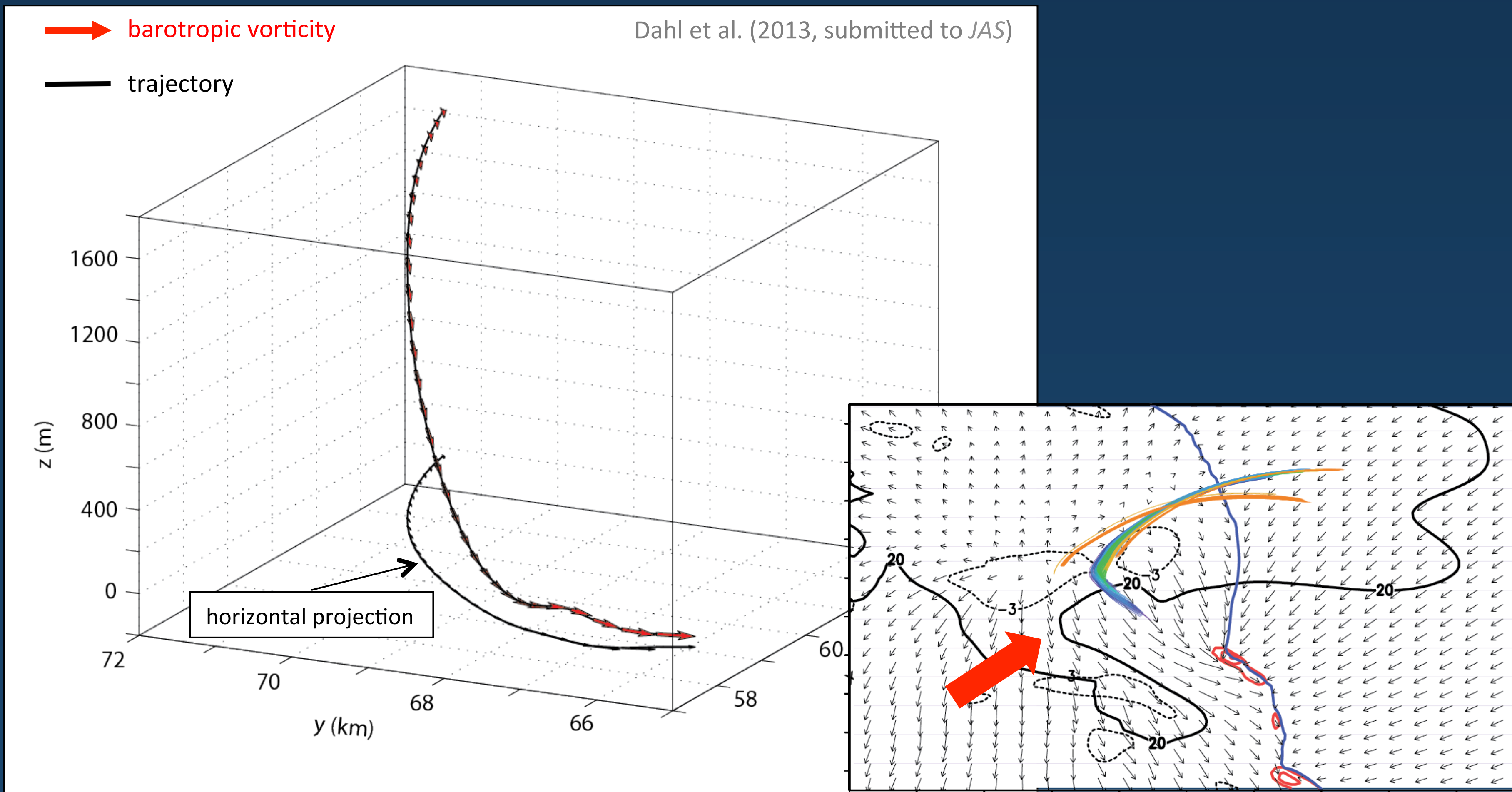


Dahl et al. (2013)

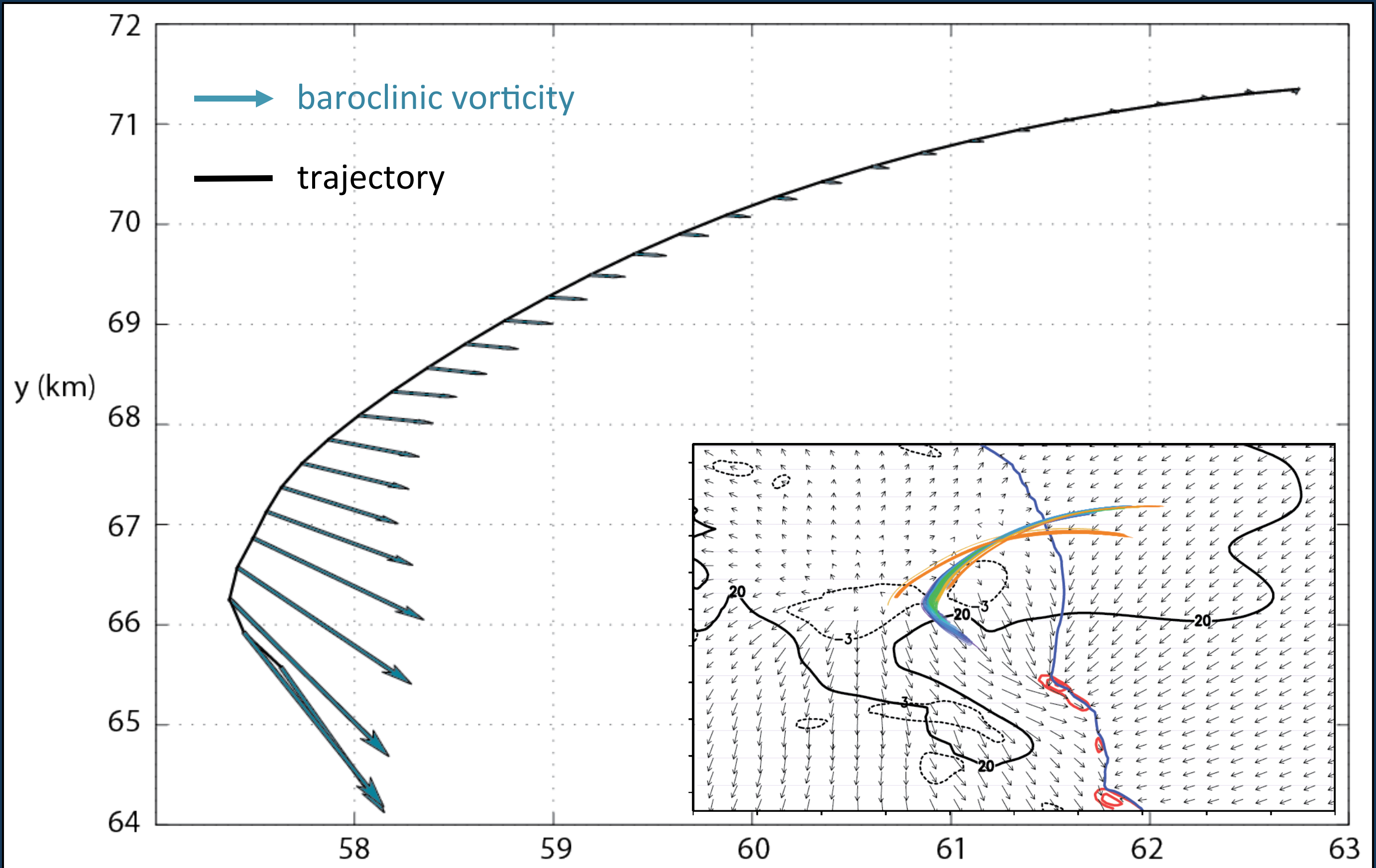
Example of barotropic vorticity frozen into a stencil



Barotropic vorticity



Storm-generated (baroclinic) vorticity



Dahl et al. (2013, submitted to *JAS*)

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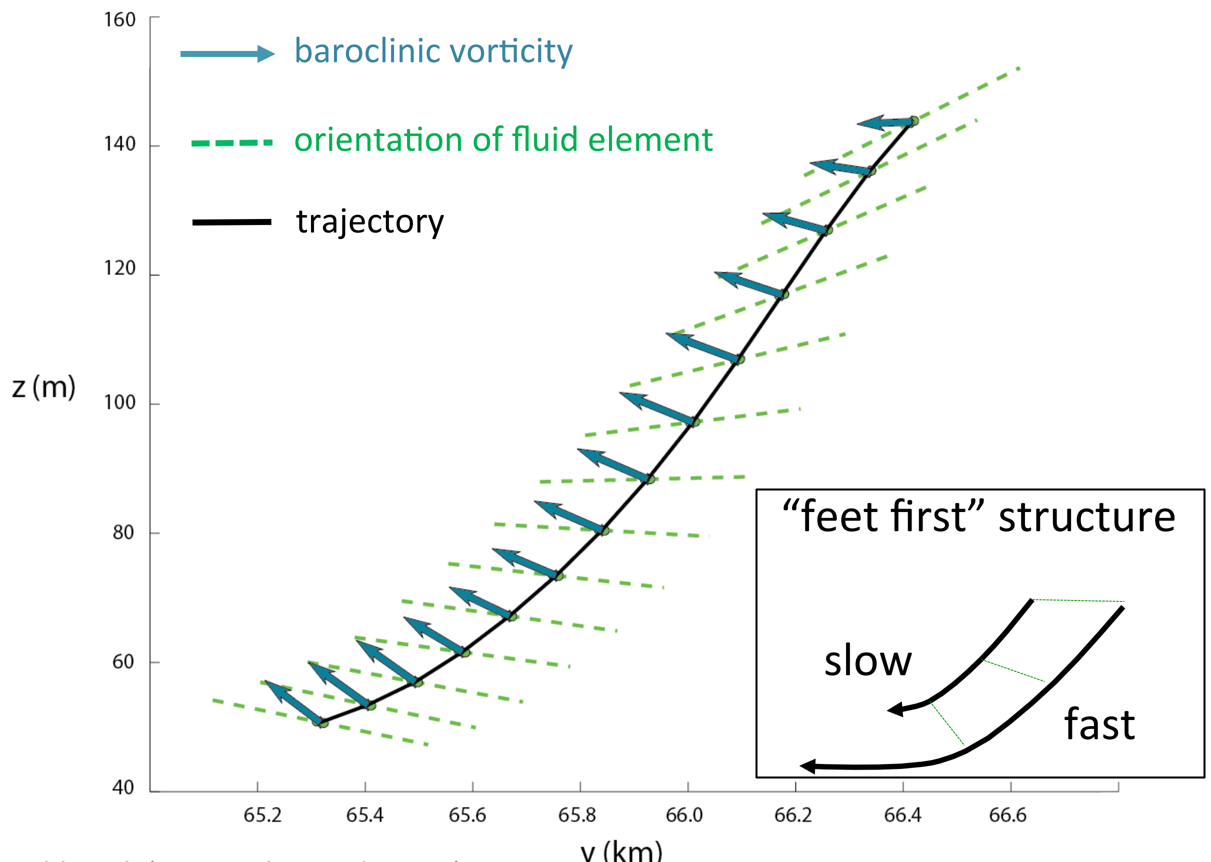

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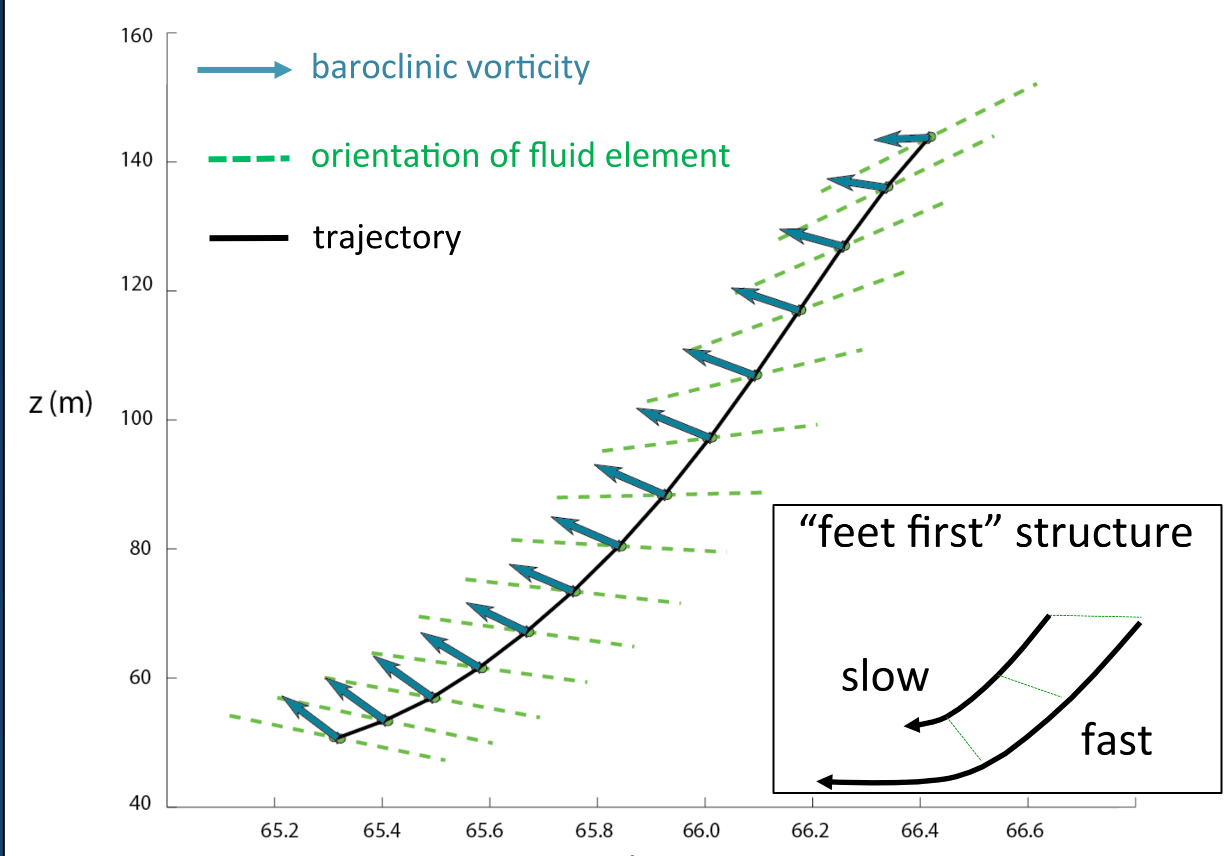
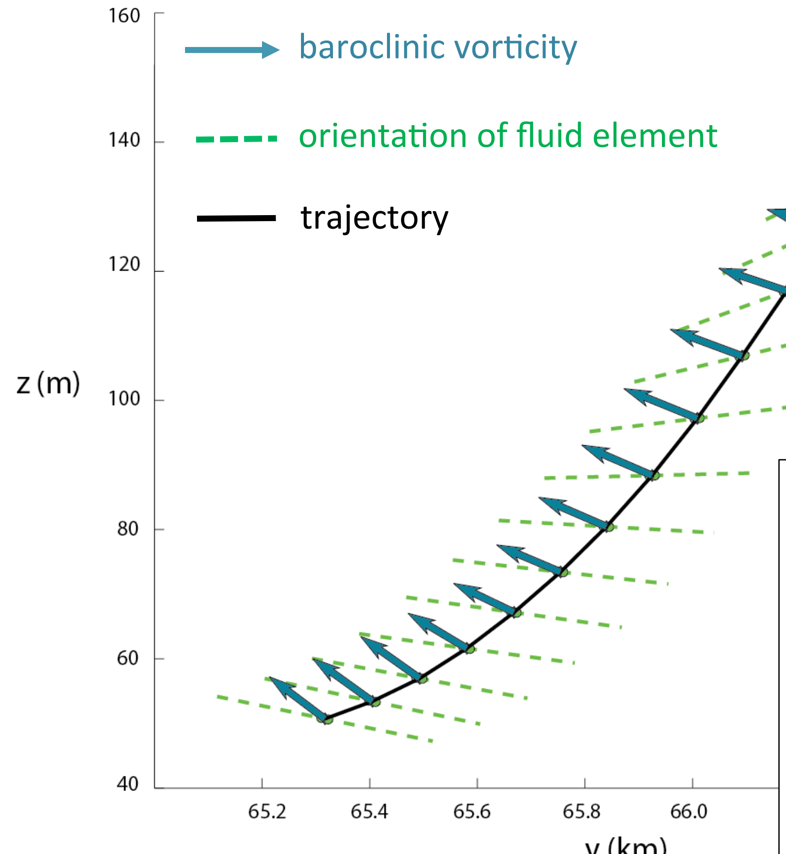


Dahl et al. (2013, submitted to *JAS*)

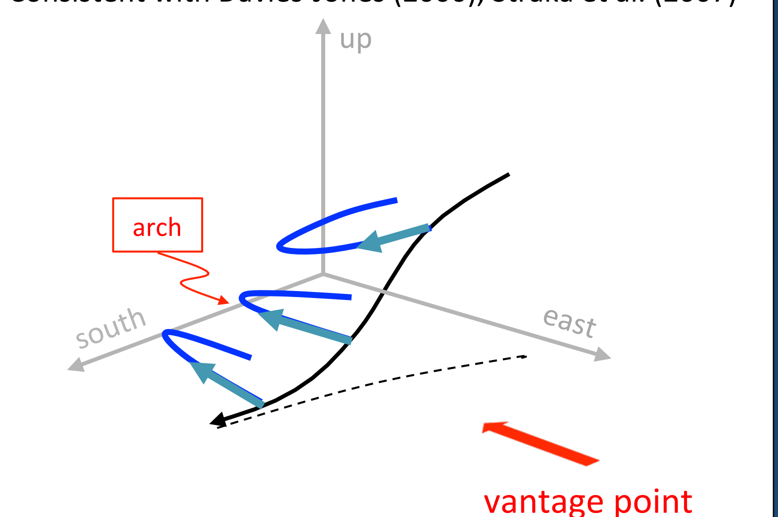
This process was suggested by Davies-Jones and Brooks (1993)

Storm-generated (baroclinic) vorticity

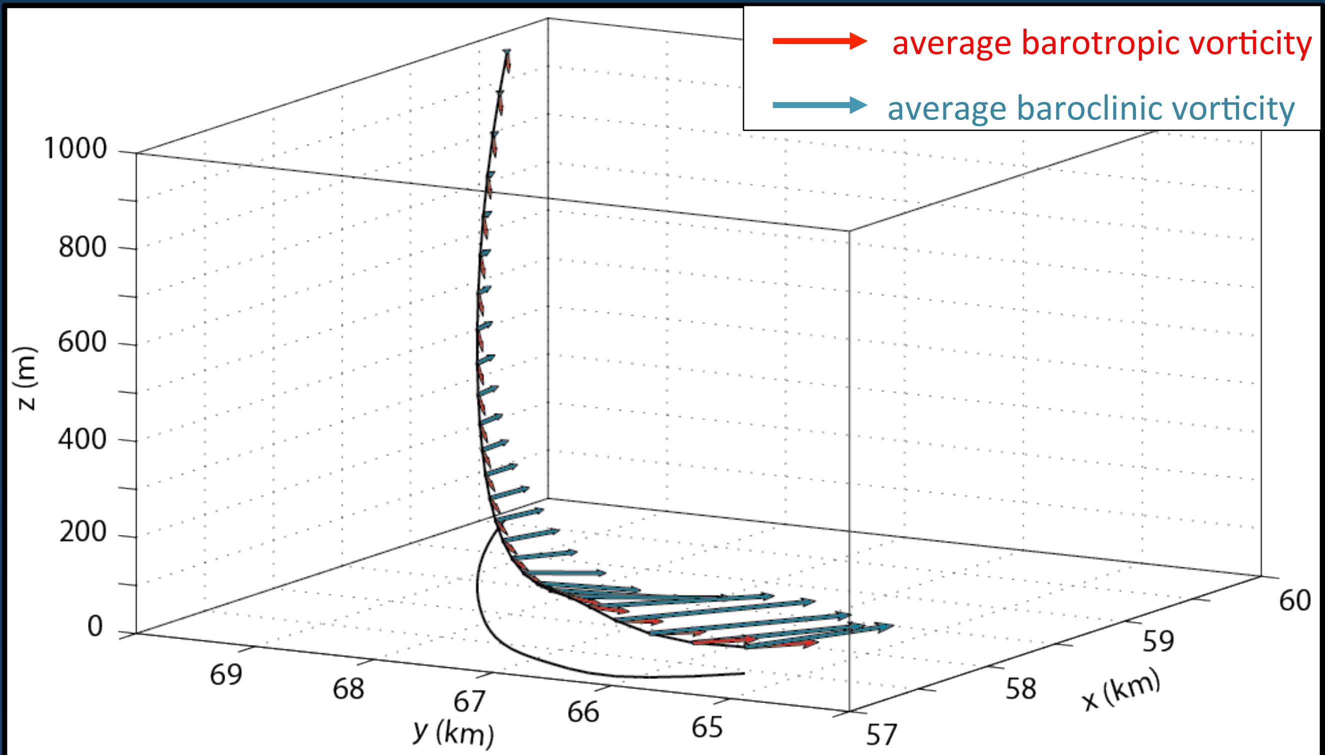


Dahl et al. (2013, submitted to *JAS*)

Consistent with Davies-Jones (2000), Straka et al. (2007)



Average over all trajectories: barotropic and baroclinic vorticity



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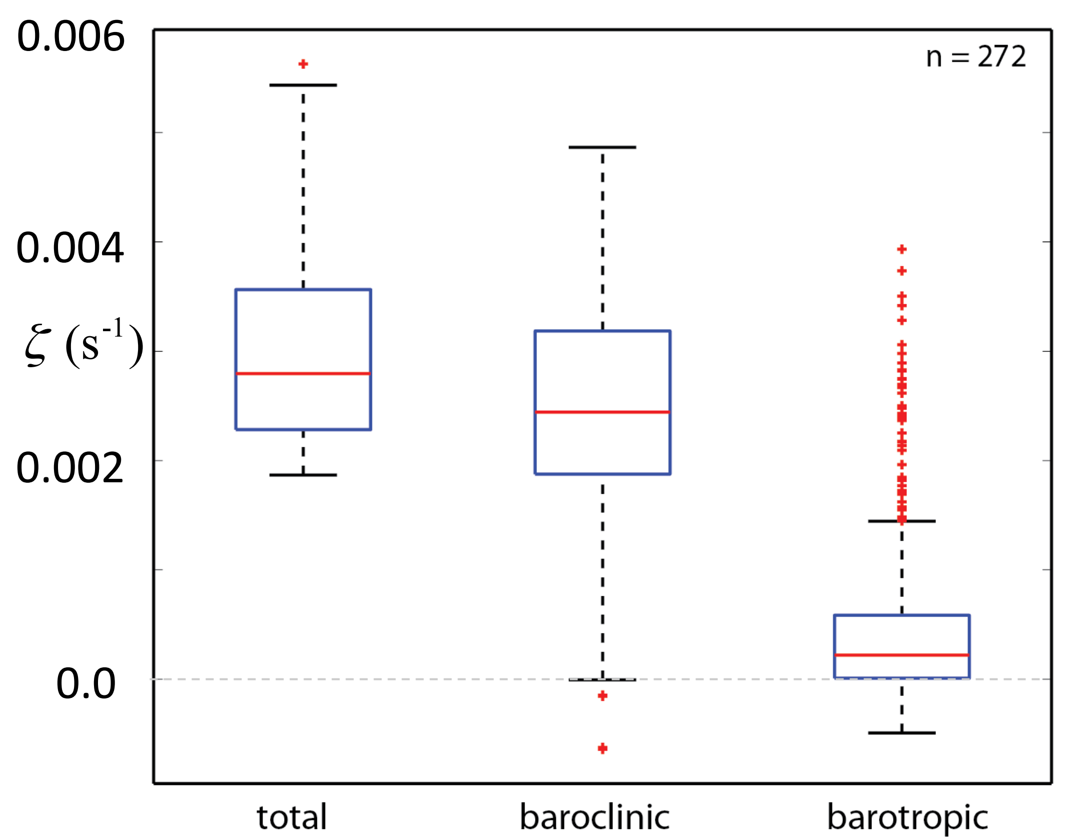
Vertical-vorticity distributions



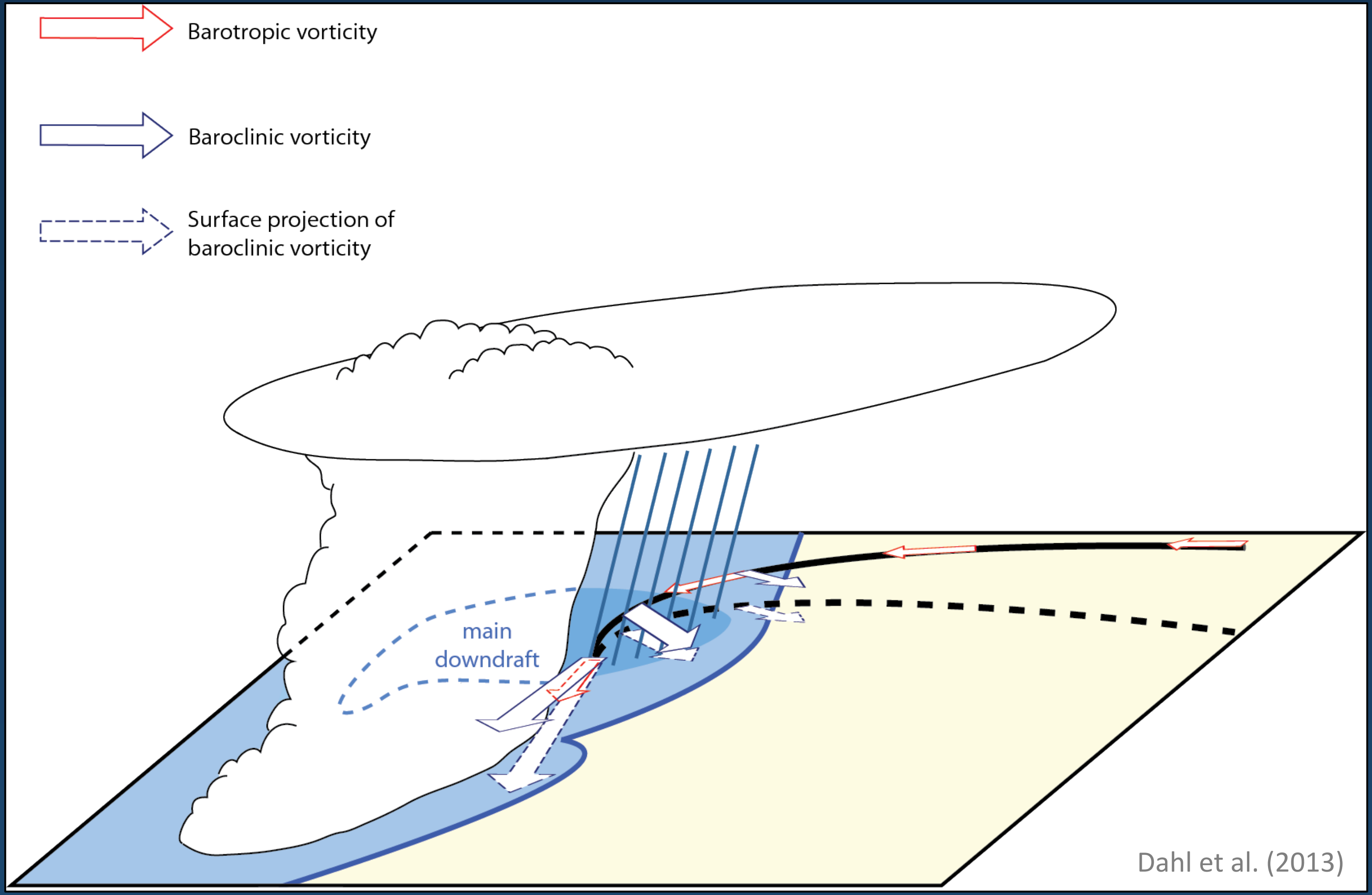
Dahl et al. (2013, submitted to *JAS*)

Conclusions

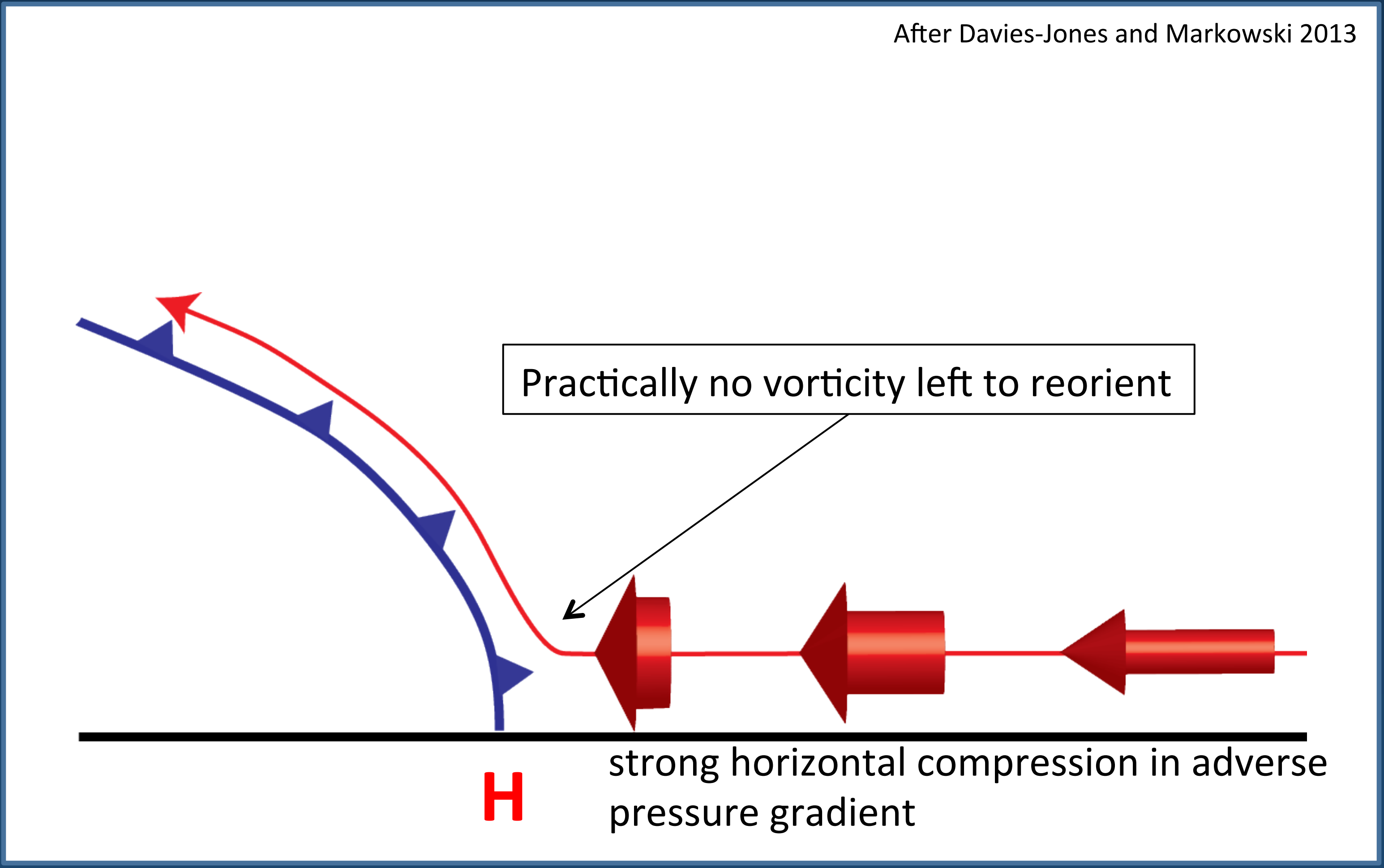
- In this simulation, the barotropic vorticity does not contribute as much to near-ground as the baroclinic vorticity.
- It is likely that the importance of the barotropic vorticity varies based on the orientation of the ambient vorticity:
  - wind shear important at altitudes where downdraft air originates?
- The development of ground-level rotation in supercells is an outflow phenomenon (if there is no vertical vorticity in the environment).

Supplemental slides

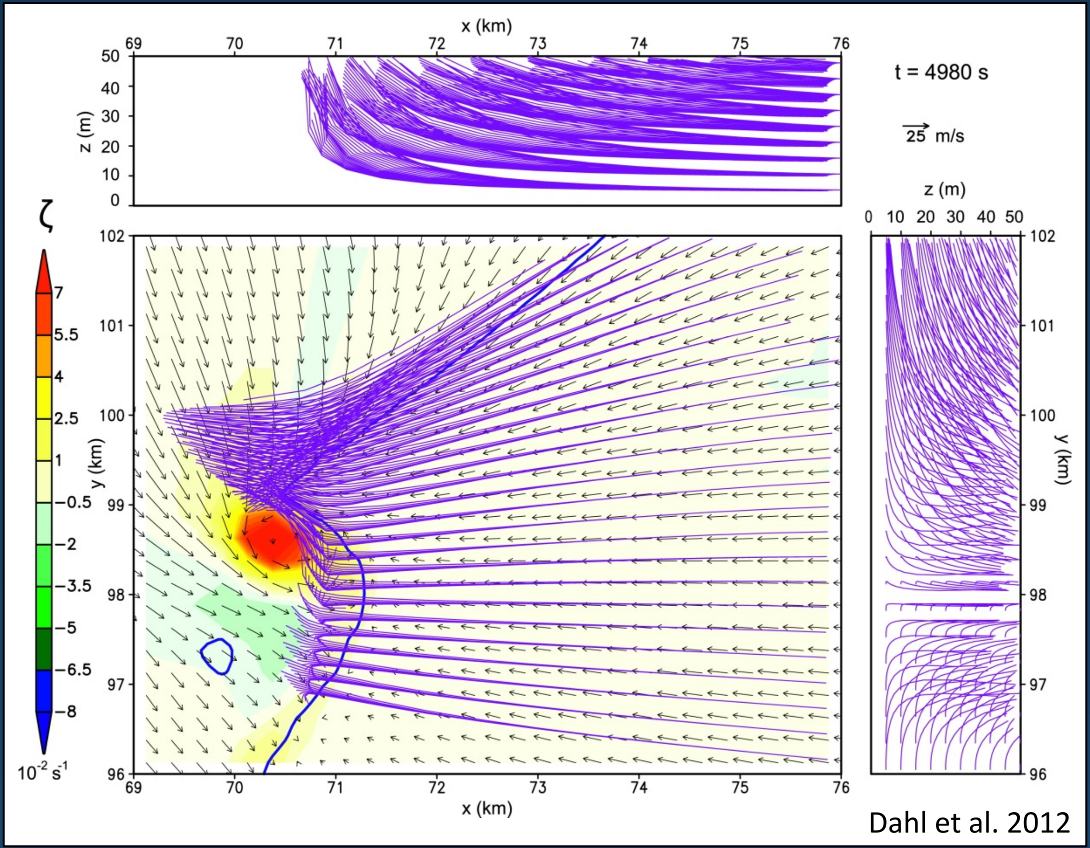
Summary


Barotropic vorticity
Baroclinic vorticity
Surface projection of
baroclinic vorticity
main
downdraft
Dahl et al. (2013)

Can a strong gustfront do the trick?

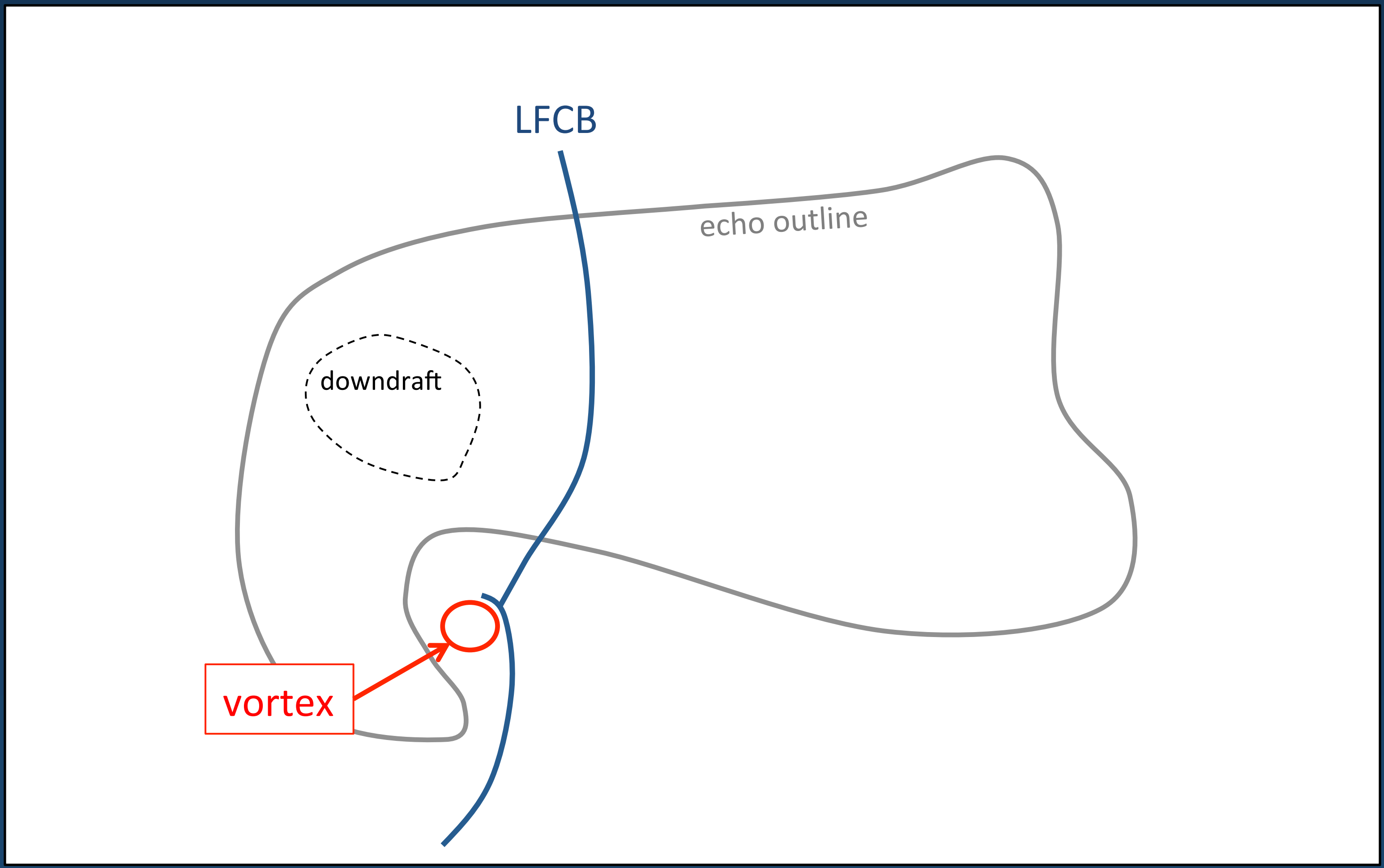


“Inflow” parcels



Dahl et al. 2012

Forward trajectory errors?



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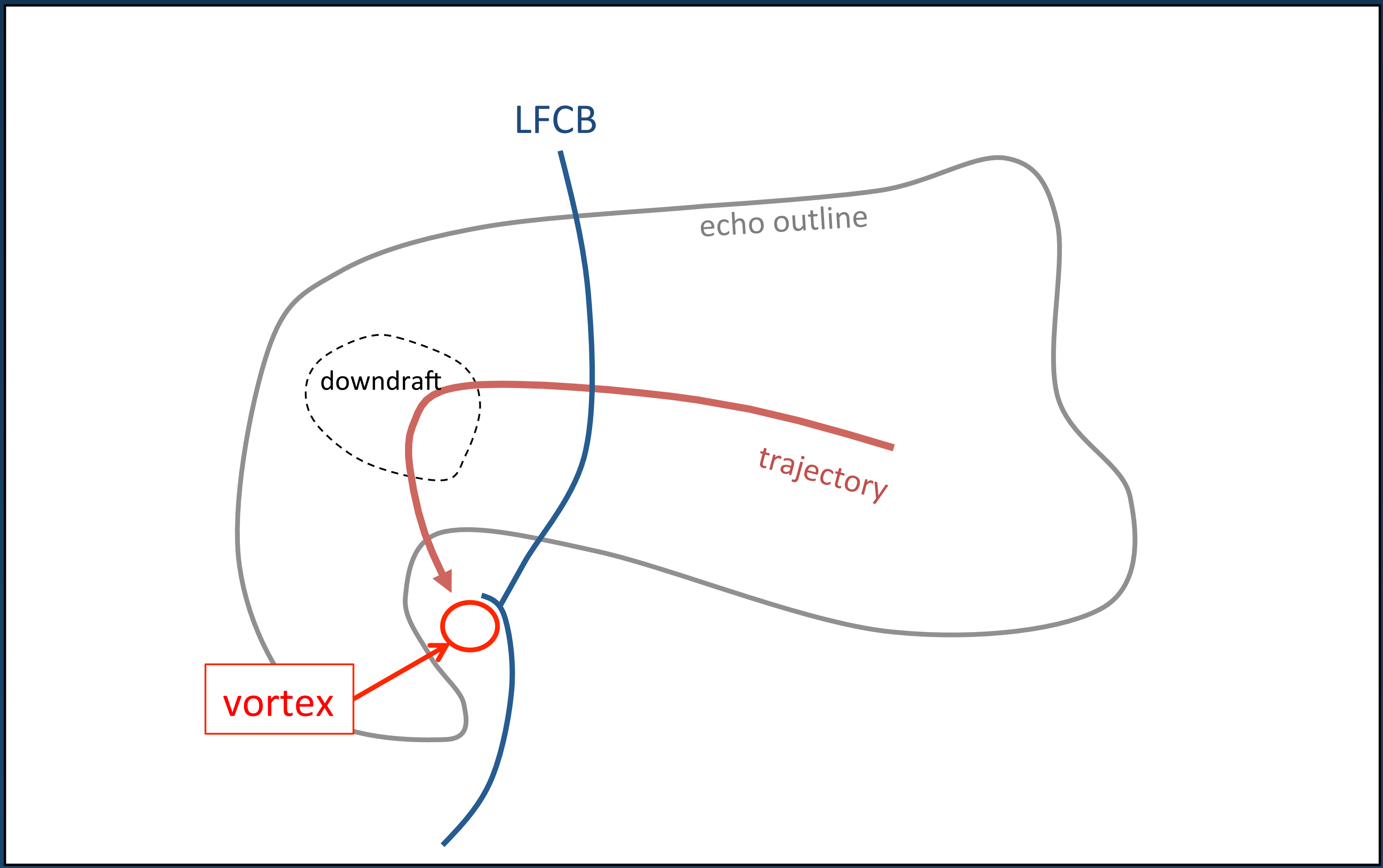

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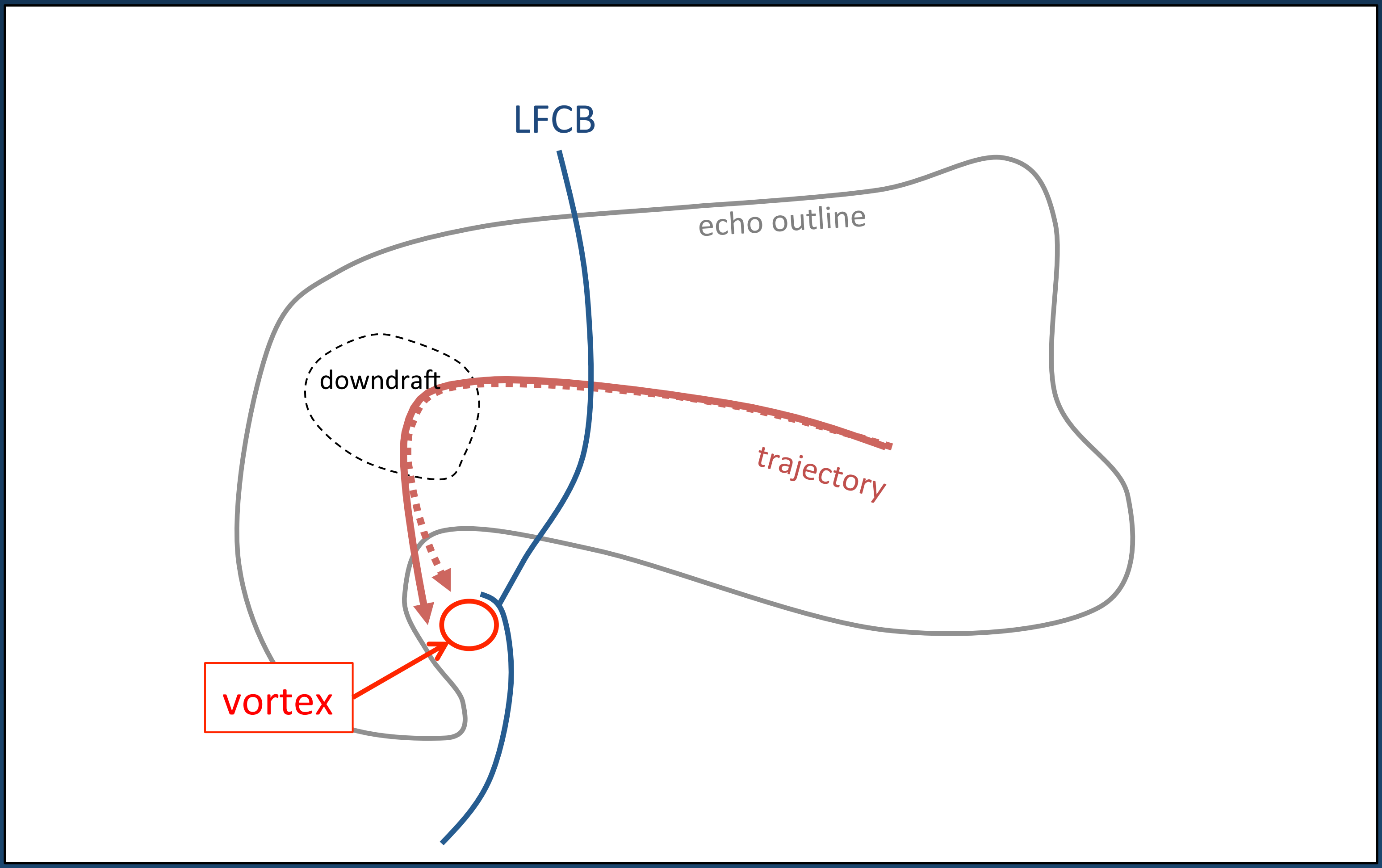
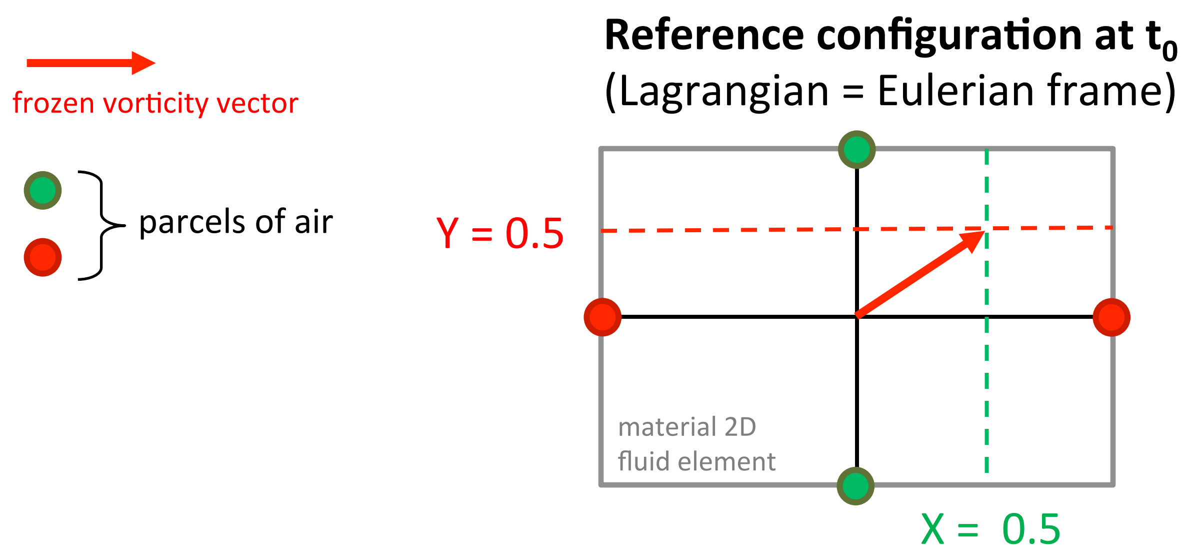
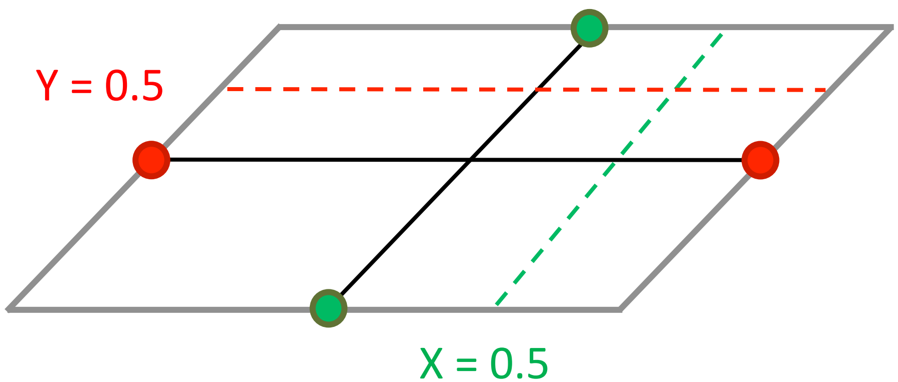


Barotropic vorticity: Frozen into the medium



Barotropic vorticity: Frozen into the medium

Configuration at t
(Lagrangian frame)



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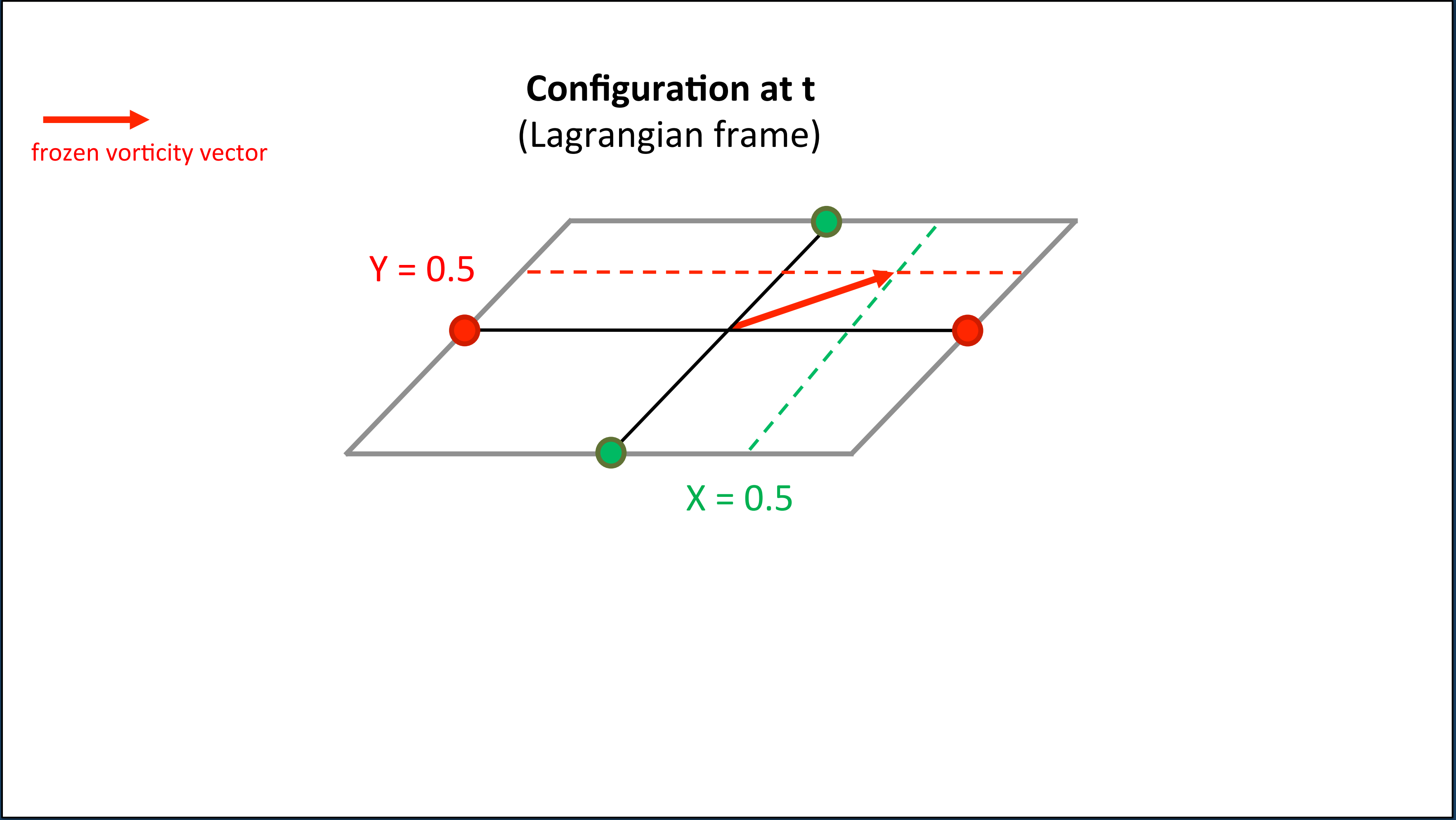
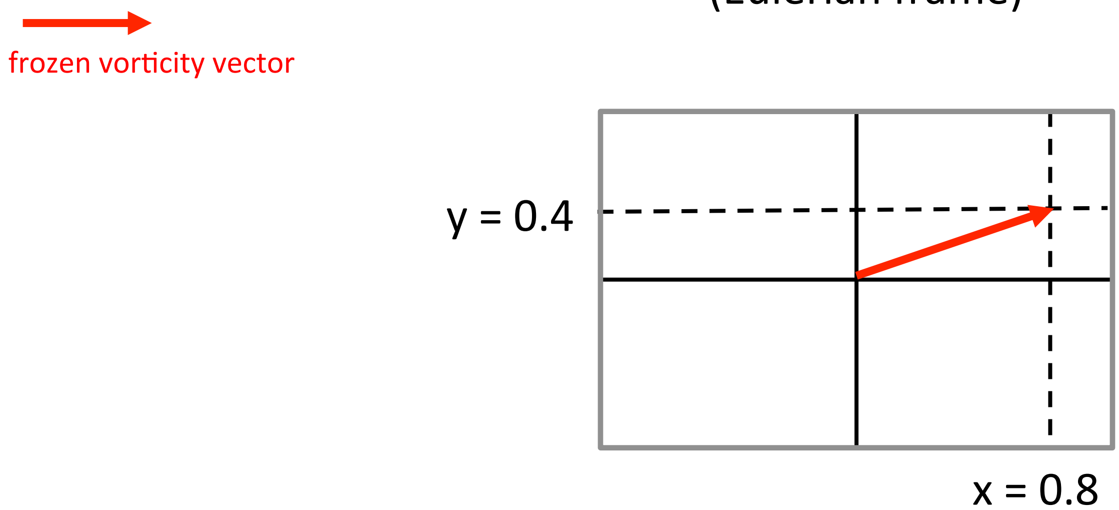


Transformation to Cartesian grid

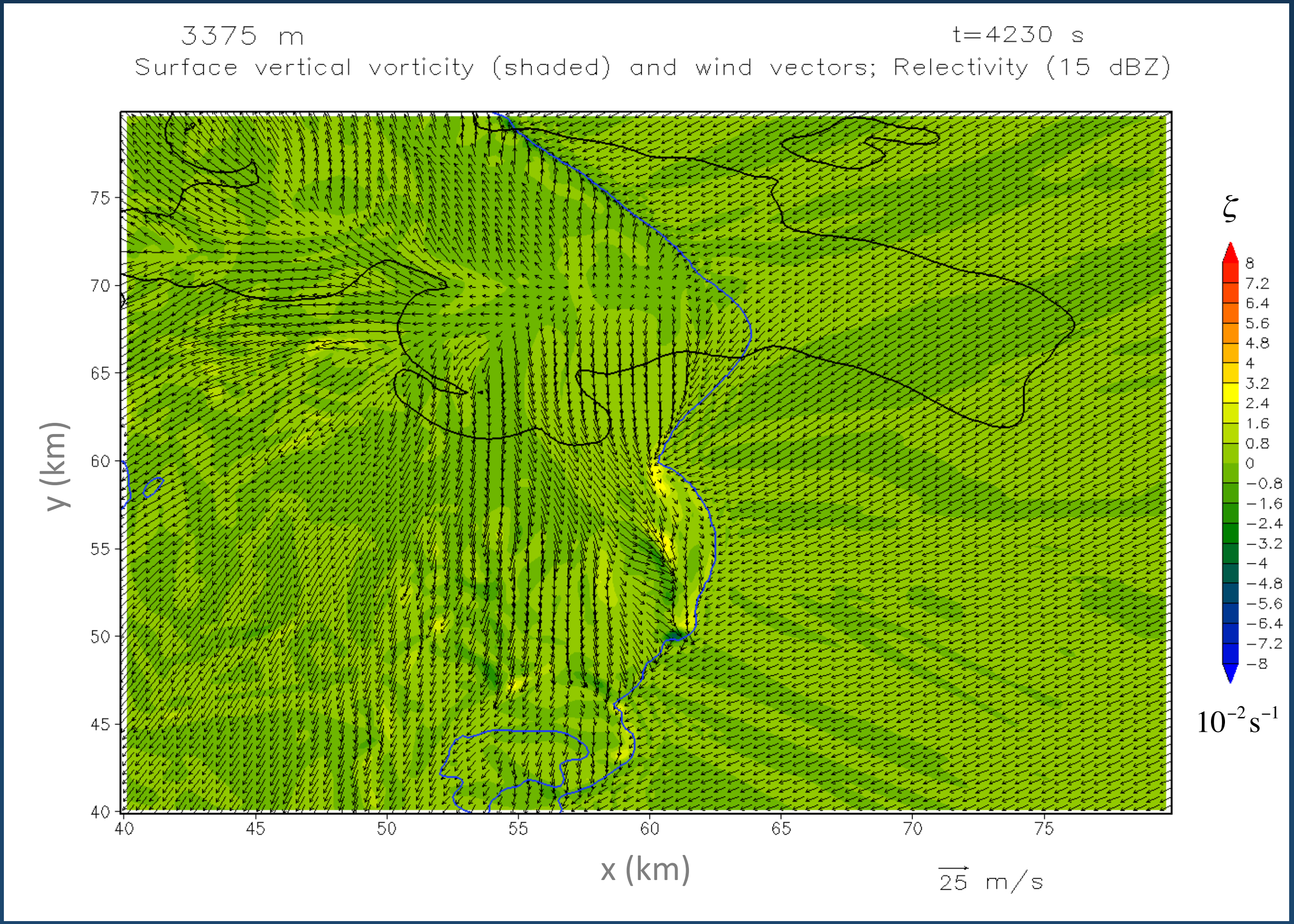
Configuration at t
(Eulerian frame)



A coordinate transformation yields the barotropic vorticity in spatial coordinates (Cauchy's formula):

$$\omega^i_{BT} = \frac{\partial x^i}{\partial X^J}\Omega^J_{BT} \qquad i, J = 1, 2, 3$$

Surface vertical vorticity



Storm-generated (baroclinic) vorticity