LIFT IN THE VERTICAL SHEAR OF SOUTHERLY JET: A MECHANISM OF NOCTURNAL CONVECTION IN THE ABSENCE OF BOUNDARIES

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INTRODUCTION

- Roughly one-third of Great Plains nocturnal convection develops in the absence of pre-existing air mass boundaries.
- Models have difficulty simulating pristine convection initiation (CI).
- While the mechanism for lifting at the nose of the Great Plains low-level jet (GPLLJ) is well understood, CI often occurs on the eastern flank, and the mechanisms are poorly understood.
- We propose a new lifting mechanism, analogous to the Kutta-Joukowski lift theorem (fig. 1).
- The circulation interacts with the zonal flow to produce faster (slower) westerly flow above (below) the cylinder, and negative (positive) pressure perturbations.
- Better understanding the lifting mechanisms responsible for pristine nocturnal CI is necessary to improving model forecasts.

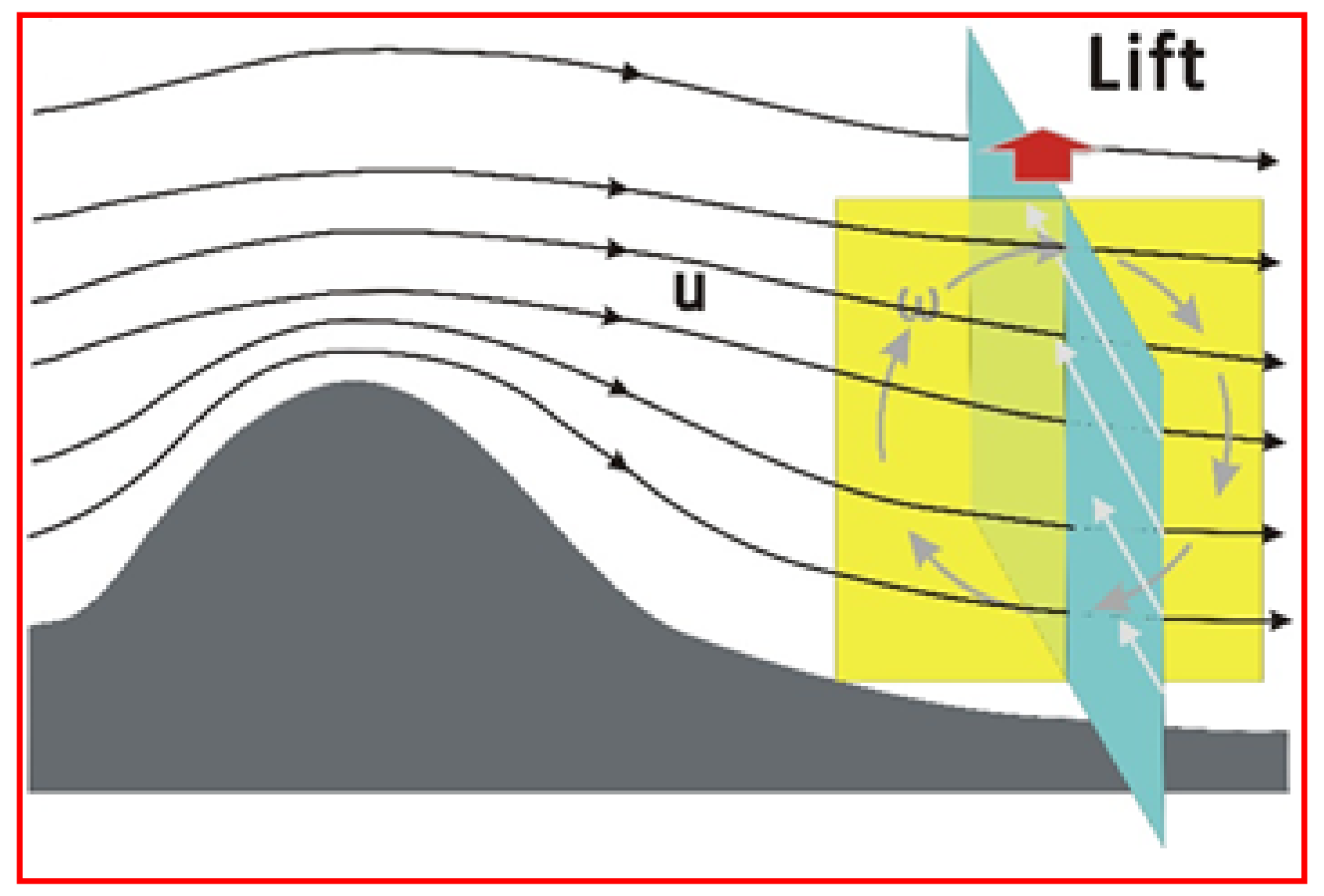

Figure 1: A diagram of the Kutta-Joukowski lift theorem, in which westerly zonal flow interacts with a horizontally-rotating circulation to generate ascent

METHODOLOGY

- Two-dimensional simulations of an east-west cross-section of the GPLLJ, conducted with the Cloud Model 1 (CM1) release 19.8.
- Initialized with a uniform westerly zonal flow (*u*) and one (jet; fig. 2a) or two (vortex; fig. 2b) perturbations (*u′*), which describe the veering of the GPLLJ due to the inertial oscillation.
- Statically stable, with theta increasing by 3 K/km in the lowest 8 km of the domain and 10 K/km above 8 km.
- Free slip lower boundary, open east and west lateral boundaries, and no moisture.
- 500 m horizontal grid spacing, with a vertically stretched grid ranging from 100 m in the lower atmosphere to 500 m in the upper atmosphere.
- Westerly perturbations maintained by nudging every 30 seconds.

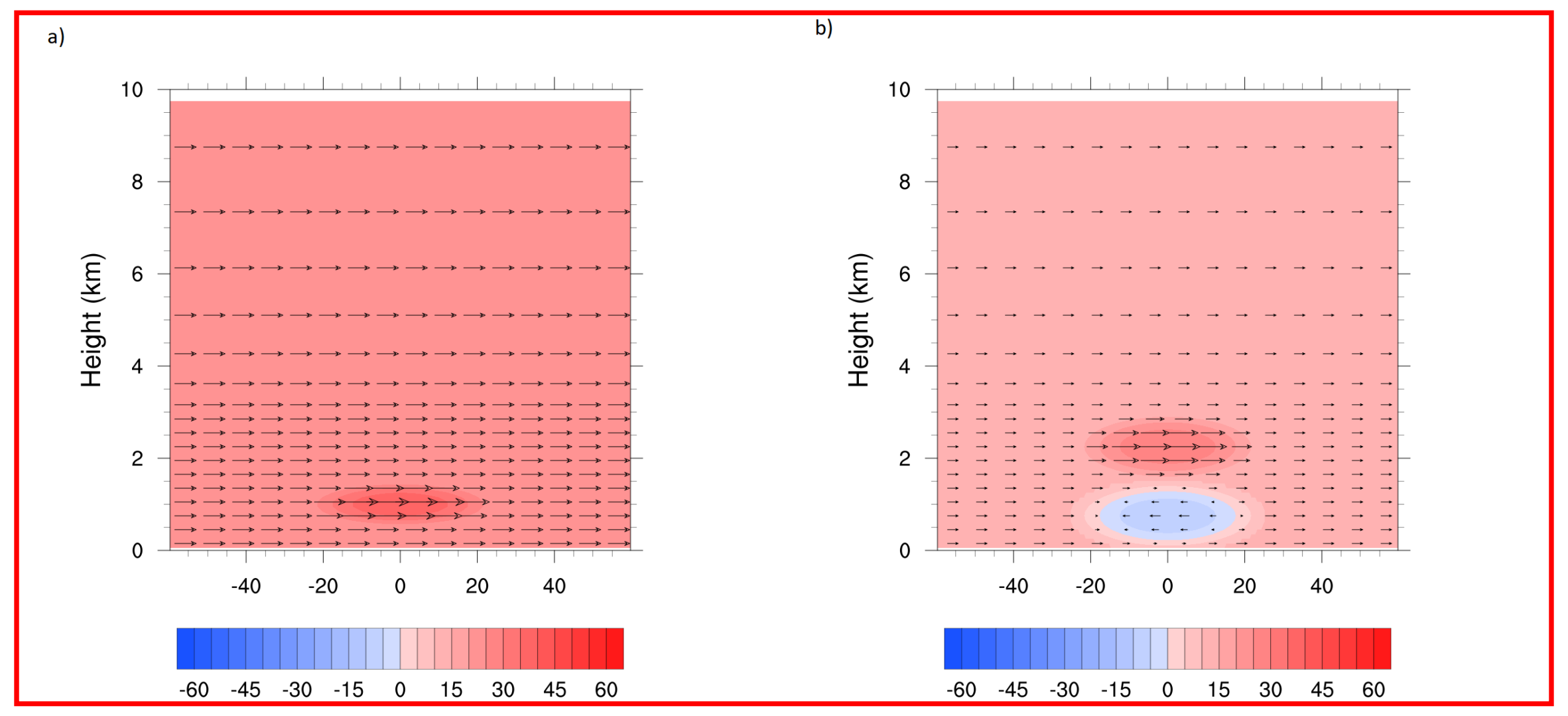

Figure 2: Examples of the initial conditions for the jet (panel a) and vortex (panel b) simulations. For vortex simulations, the upper perturbation is *u′* and the lower perturbation is -*u′*. Wind perturbations are specified according to a quadratic function.

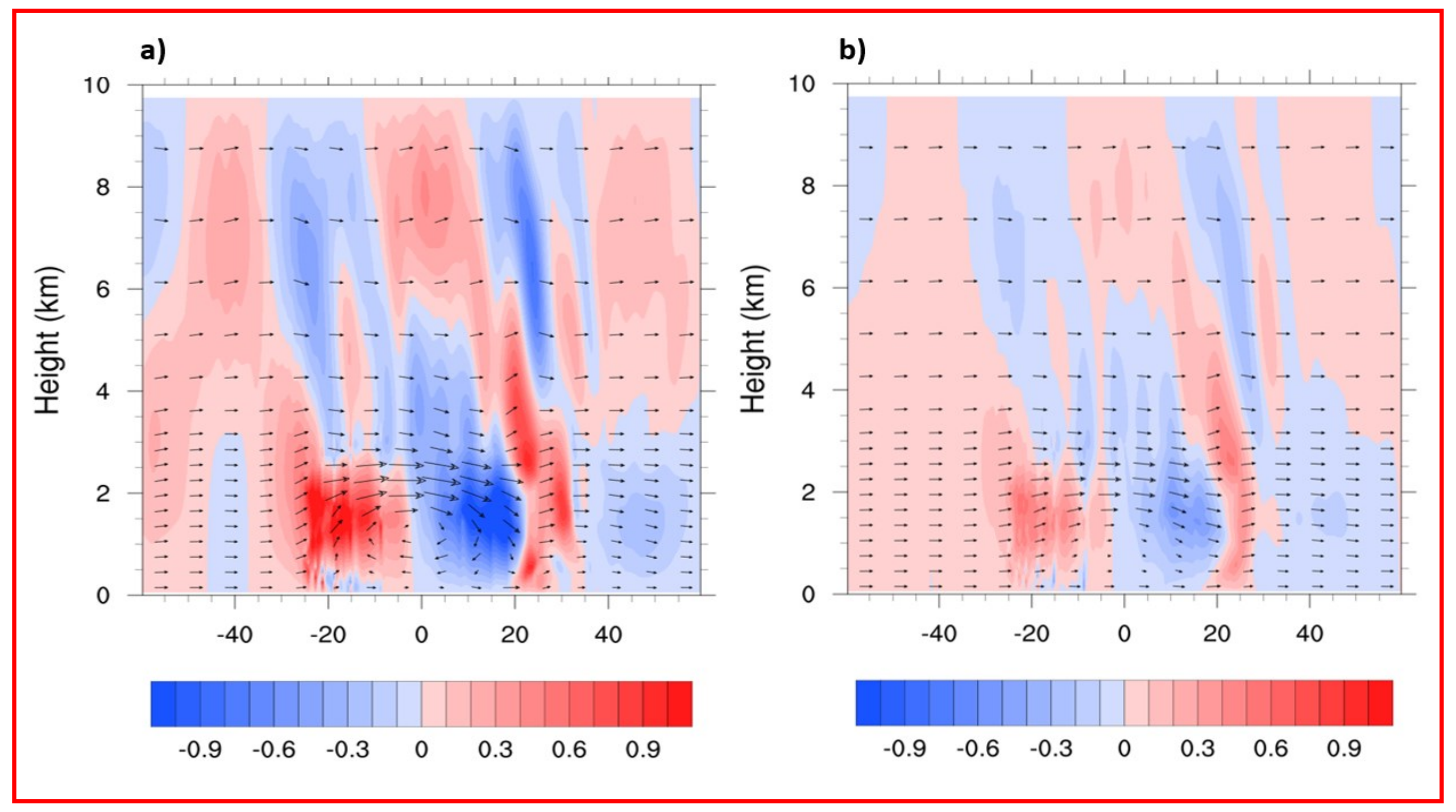

Figure 3: Vertical velocity (m/s; color fill) and *u*-*w* wind vectors at 1800 s into the simulation. Vertical component of the wind vectors is scaled by a factor of 10. Panel a is for *u* = 10 m/s and *u′* = 20 m/s while panel b is for *u* = 10 m/s and *u′* = 8 m/s.

RESULTS OF VORTEX SIMULATIONS

- Ascent occurs above the western flank of the vortex, in a westward tilted band (fig. 3).
- Parcels descend as they move over the top of the vortex, again in a westward tilted band.
- Strong ascent occurs on the eastern flank of the vortex, particularly in the lower atmosphere just above the top of the vortex.
- This general pattern occurs with strong (fig. 3a) and weak (fig. 3b) vortices, though vertical velocity is stronger with increasing *u′*.
- Parcel trajectories (fig. 4) show that ascent on the eastern flank is due to parcels being mechanically forced downward while passing above the vortex, then rapidly ascending on the eastern flank due to positive buoyancy and the sudden release of the downward forcing.
- This result is consistent across a wide range of *u′* values.
- Increasing *u* seems to slightly suppress ascent on the eastern flank of the vortex, except around *u* = 10 m/s (fig. 5). Suppression is particularly pronounced when *u* is very large.
- For *u* = 6-18 m/s, ascent is concentrated in a wide band on the eastern flank of the vortex (fig. 6).
- We propose that around *u* = 10 m/s, parcels are mechanically forced downward as they move atop and toward the eastern flank of the vortex, then the sudden release of the downward forcing allows rapid ascent due to positive buoyancy.
- For *u* > ~20 m/s, residence time within the mechanical descent is too short to allow for parcels to acquire much positive buoyancy.
- For *u* < ~6 m/s, parcels acquire strong positive buoyancy, but begin ascending while still within weaker downward mechanical forcing, resulting in overall weaker ascent.
- Parcels rising due to positive buoyancy overshoot their original level, which is probably needed for CI to occur.

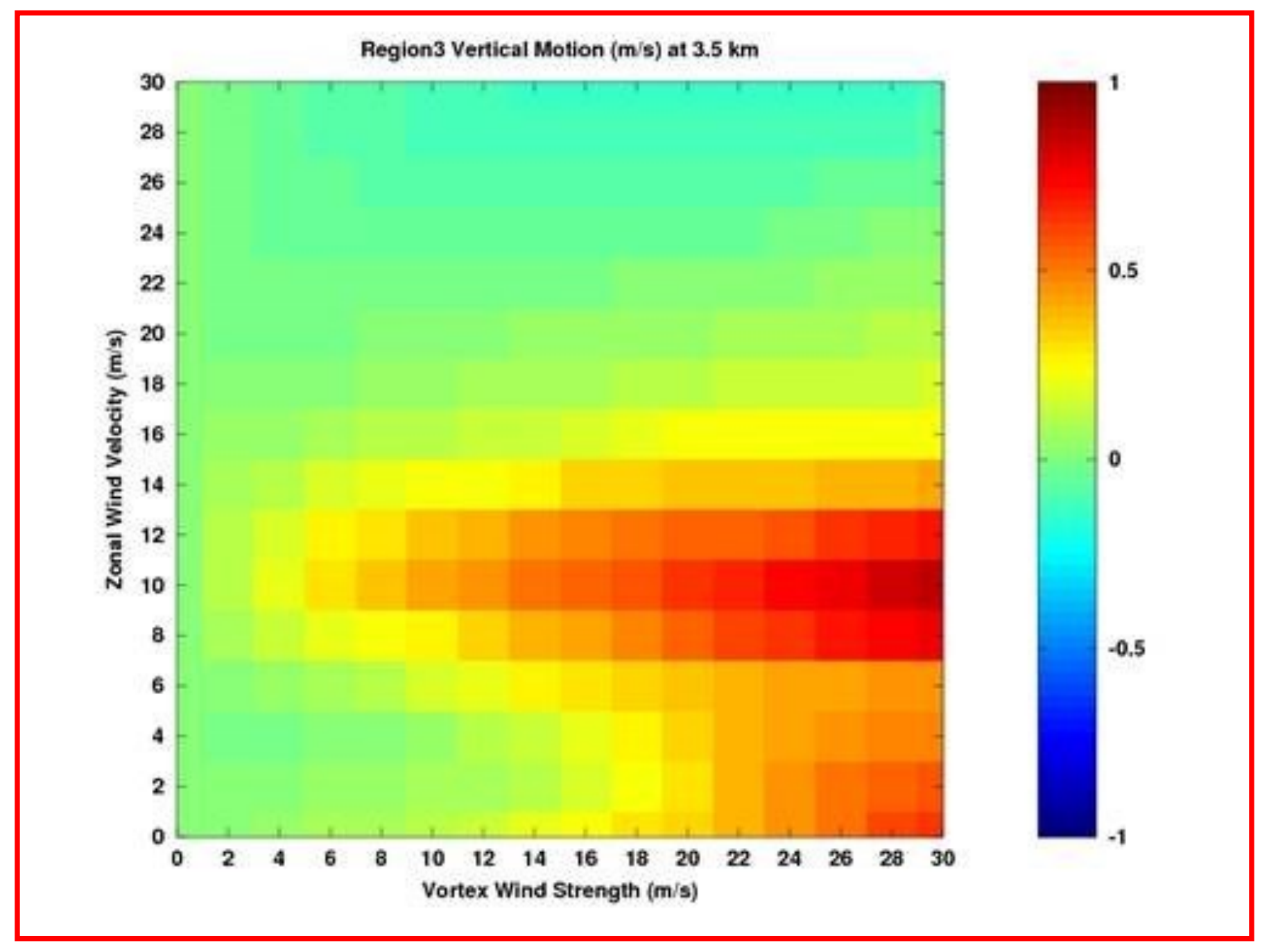

Figure 5: Average vertical velocity (m/s) 18-25 km east of the domain center from 1800-3600 s into the vortex simulations, depending on *u′* (x axis) and *u* (y axis).

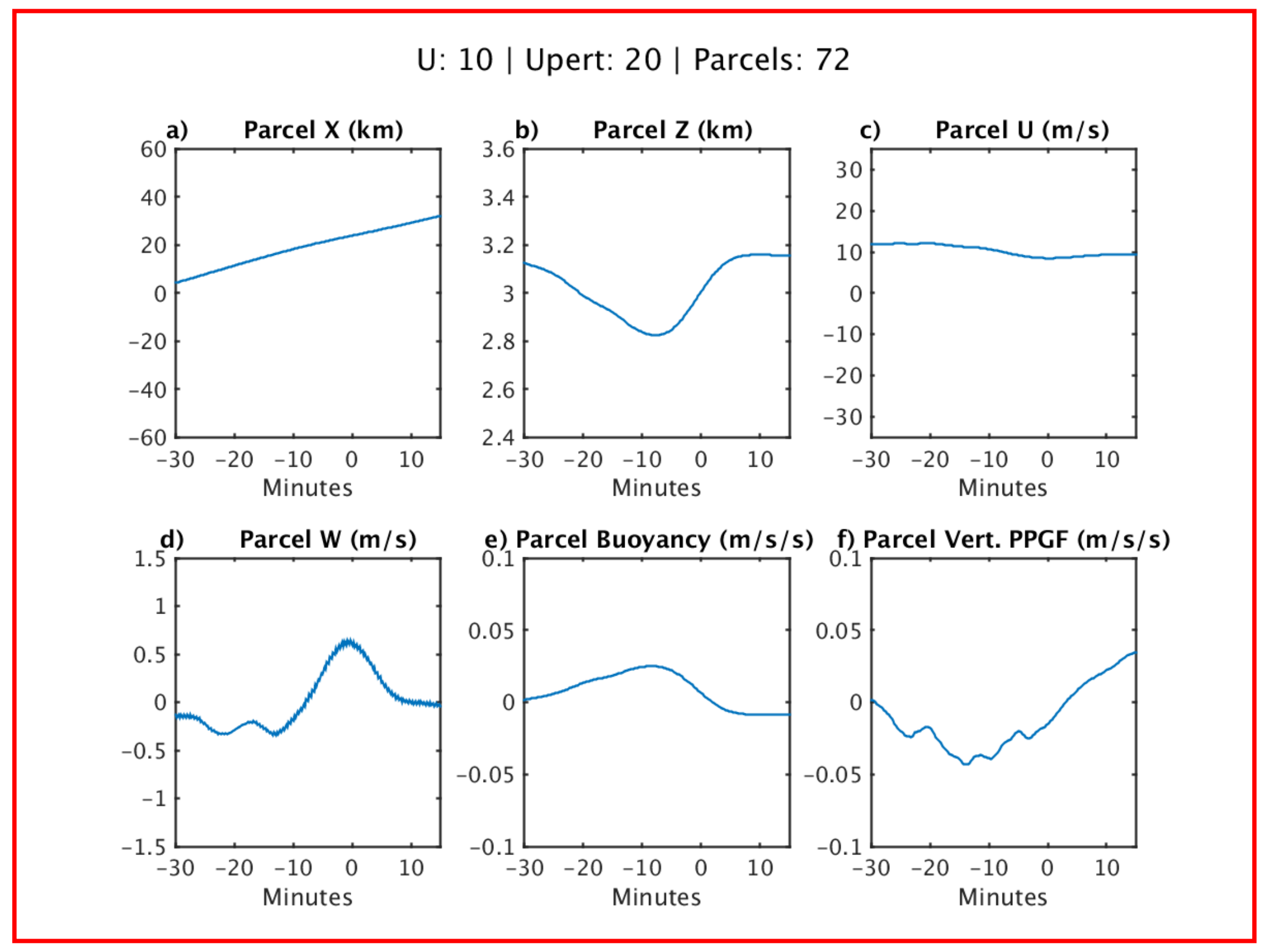

Figure 4: Parcel trajectories for *u* = 10 m/s and *u′* = 20 m/s. In this figure, *t* = 0 when parcels first ascend through a region 3 km above ground level and between 20-30 km east of the domain center, during 1800-3600 s after the start of the simulation.

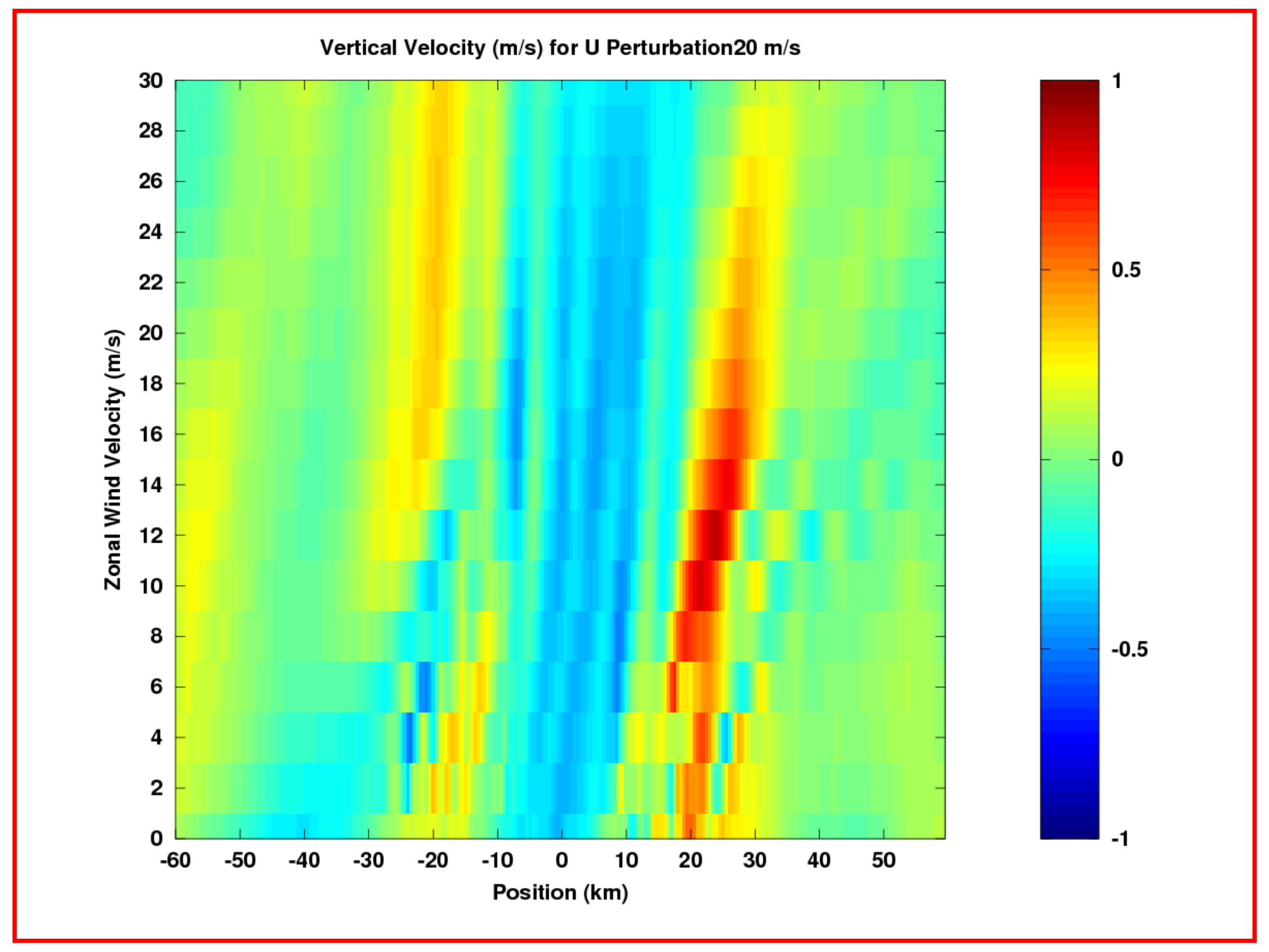

Figure 6: Vertical velocity (m/s) at 3 km above ground level at 1800-3600 s into the simulations for *u* = 20 m/s, as a function of *u′* (y axis) and the horizontal position within the domain (x axis).

RESULTS OF JET SIMULATIONS

- An easterly *u′* perturbation develops beneath the westerly u′ that is imposed.
- Vertical velocity is generally similar to the vortex simulations (fig. 7).
- For jet simulations, increasing both *u* and *u′* increases vertical velocity (fig. 8).
- Parcel trajectories (fig. 9) are generally similar to those in the vortex simulations.
- As with the vortex simulations, ascent on the eastern flank is initially due to previously-acquired positive buoyancy when eastward momentum carries parcels past downward mechanical forcing.
- Later, pressure perturbations can support a small amount of additional ascent.
- Negative buoyancy later in the parcel trajectories indicates that parcels have ascended beyond their original level, which is likely needed for CI.

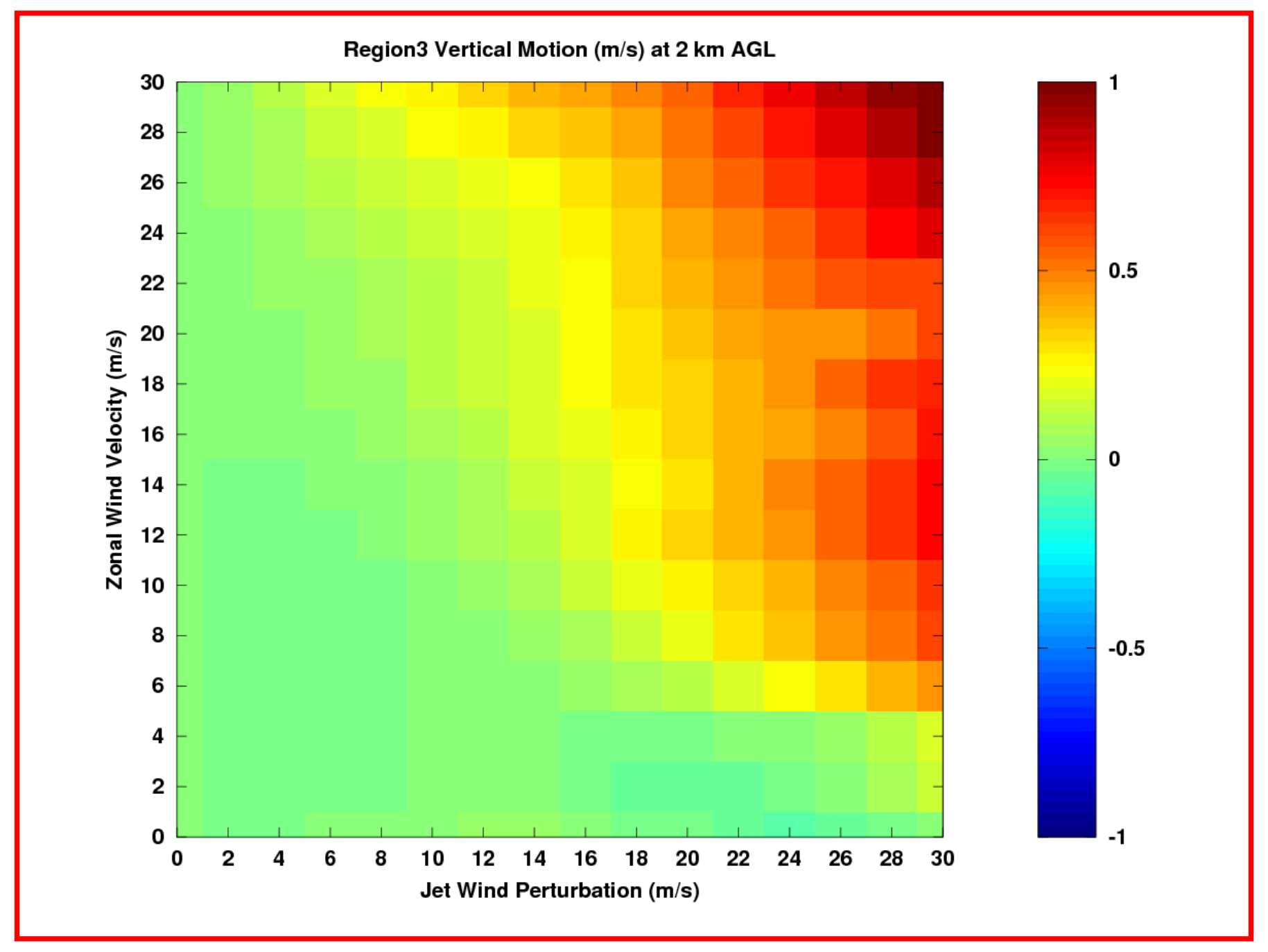

Figure 8: Average vertical velocity (m/s) 20-30 km east of the domain center from 1800-3600 s into the jet simulations, depending on *u′* (x axis) and *u* (y axis).

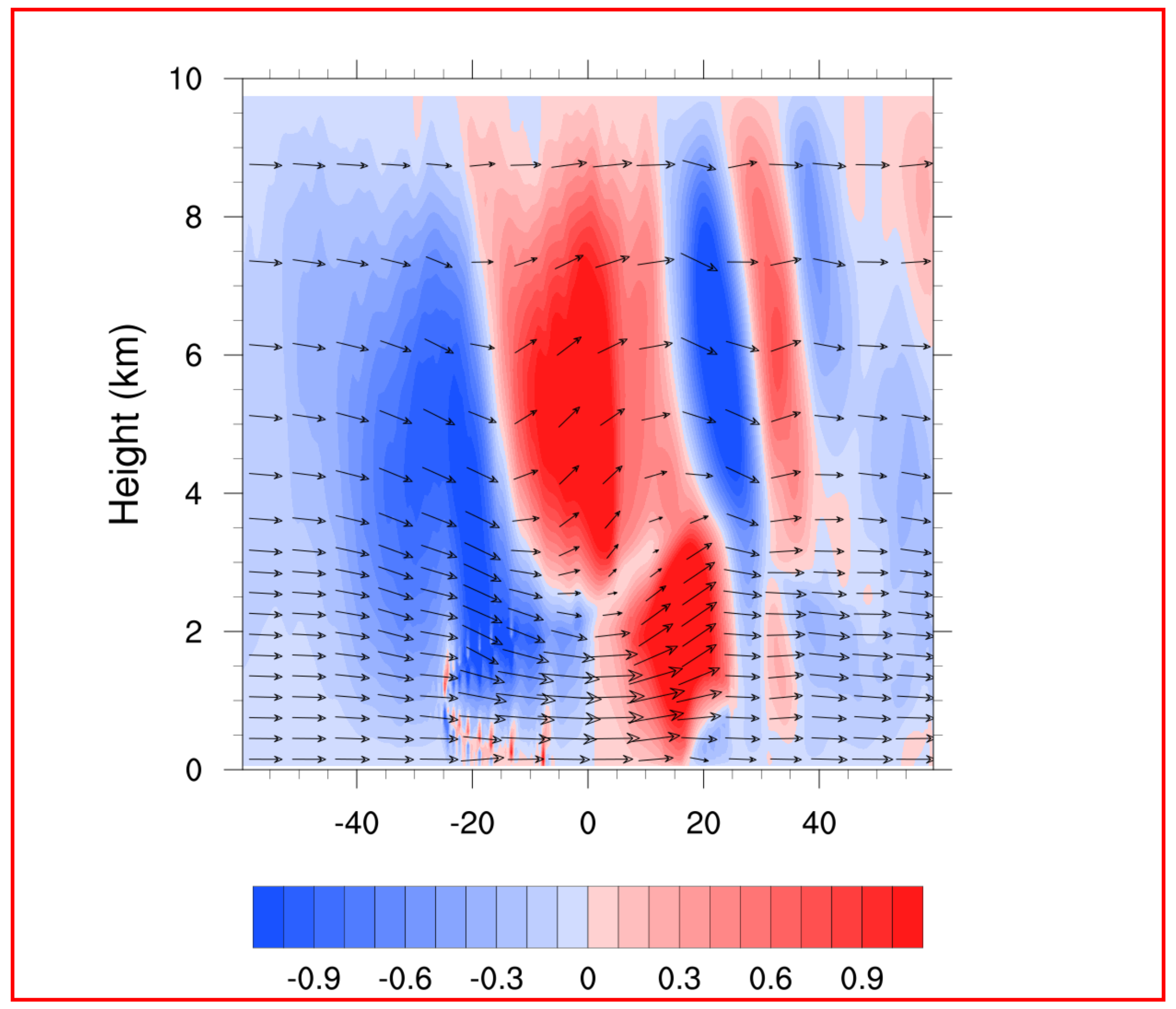

Figure 7: Vertical velocity (m/s) at 1800 s into the jet simulation for *u* = 20 m/s and *u′* = 20 m/s. Arrows are *u*-*w* wind vectors and the *w* for the vectors is scaled by a factor of 10 to make the vertical motion easier to identify.

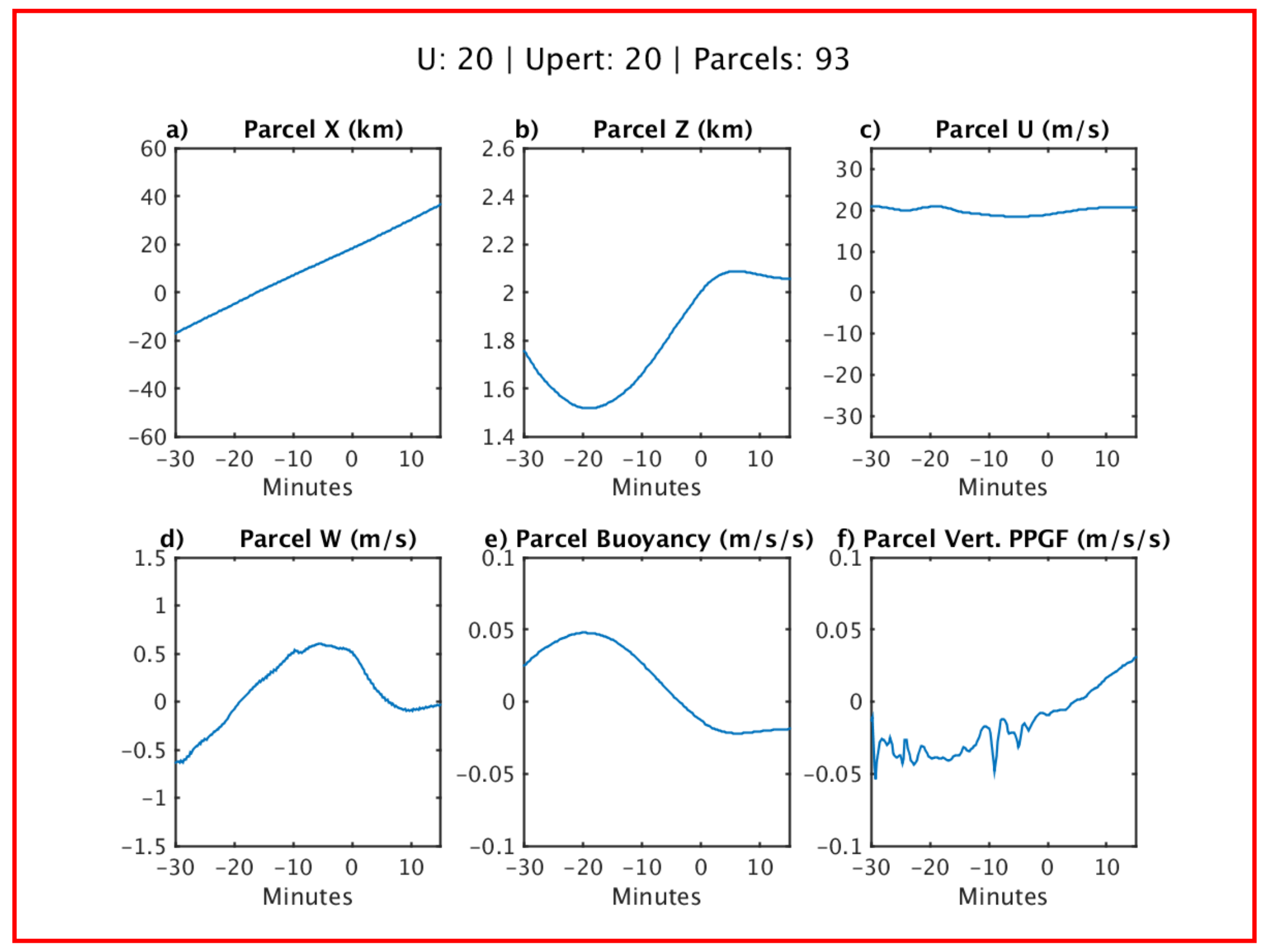

Figure 9: Parcel trajectories for *u* = 20 m/s and *u′* = 20 m/s. In this figure, *t* = 0 when parcels first ascend through a region 2 km above ground level and between 20-30 km east of the domain center, during 1800-3600 s after the start of the simulation.

SUMMARY

- Parcels moving over the top of the veered low-level jet are forced downward.
- Positive buoyancy, acquired through mechanical descent, accelerates parcels upward once they move past the zone of downward forcing.
- Buoyancy primarily drives ascent on the eastern flank of the jet.
- A stronger westerly perturbation in the jet will generally produce stronger ascent on the eastern flank.
- Results differ from the Kutta-Joukowski lift theorem partly because the rotating cylinder is air rather than a solid body, and also because the theorem does not account for the effects of buoyancy.

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