Analysis of Updraft Characteristics from a Micro-pulsed Doppler Lidar During FIREX-AQ

Edward J. Strobach[1,2], W. Alan Brewer[2], Brandi McCarty[1,2], Amanda Makowiecki[1,2] Robert Banta[1,2]
[1]CIRES/University of Colorado, Boulder, [2]NOAA Chemical Sciences Laboratory

Motivation

- Recent climate shifts have increased wildfire frequency in areas of drought
- Boundary layer assumptions break down over wildfires
- There is a dearth of high spatiotemporal resolution observations to target the fine structure of wildfire plumes, updraft/downdrafts, and their vortical nature
- The mixing properties of buoyant wildfire plumes with the environment is not well understood
- Research has suggested an important role of rotating updrafts in fire weather

Doppler Wind Lidar and Fire Temperature Observations

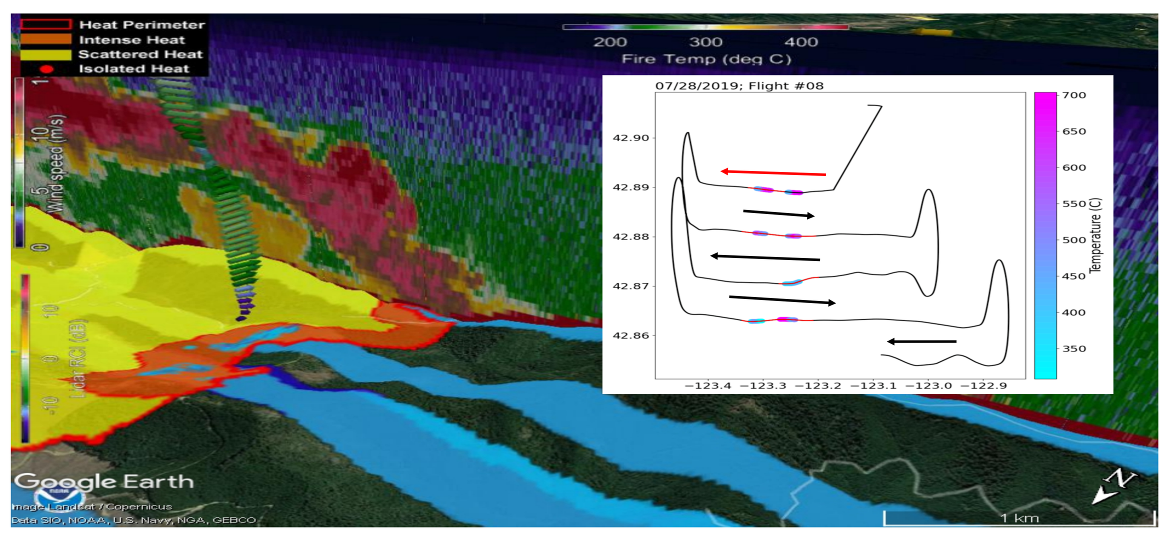

Figure 1: Vertically sampled slice of the Milepost 97 fire during 07/28/2019. The shading represents range corrected intensity (RCI) while horizontal winds measured from a different time are superimposed. Overlaid is the fire perimeter, fire temperature, and the flight configuration (inset—also with fire temperature). The red arrow represents the leg shown.

Identifying Updrafts Over Wildfire Source Points

Step 1: Collocate flagged values of enhanced fire temperature with wind measurements

Step 2: Geo-locate flagged values and near-surface positive vertical velocities to build updraft profile over source points

Step 3: Subjectively determine identification of updrafts

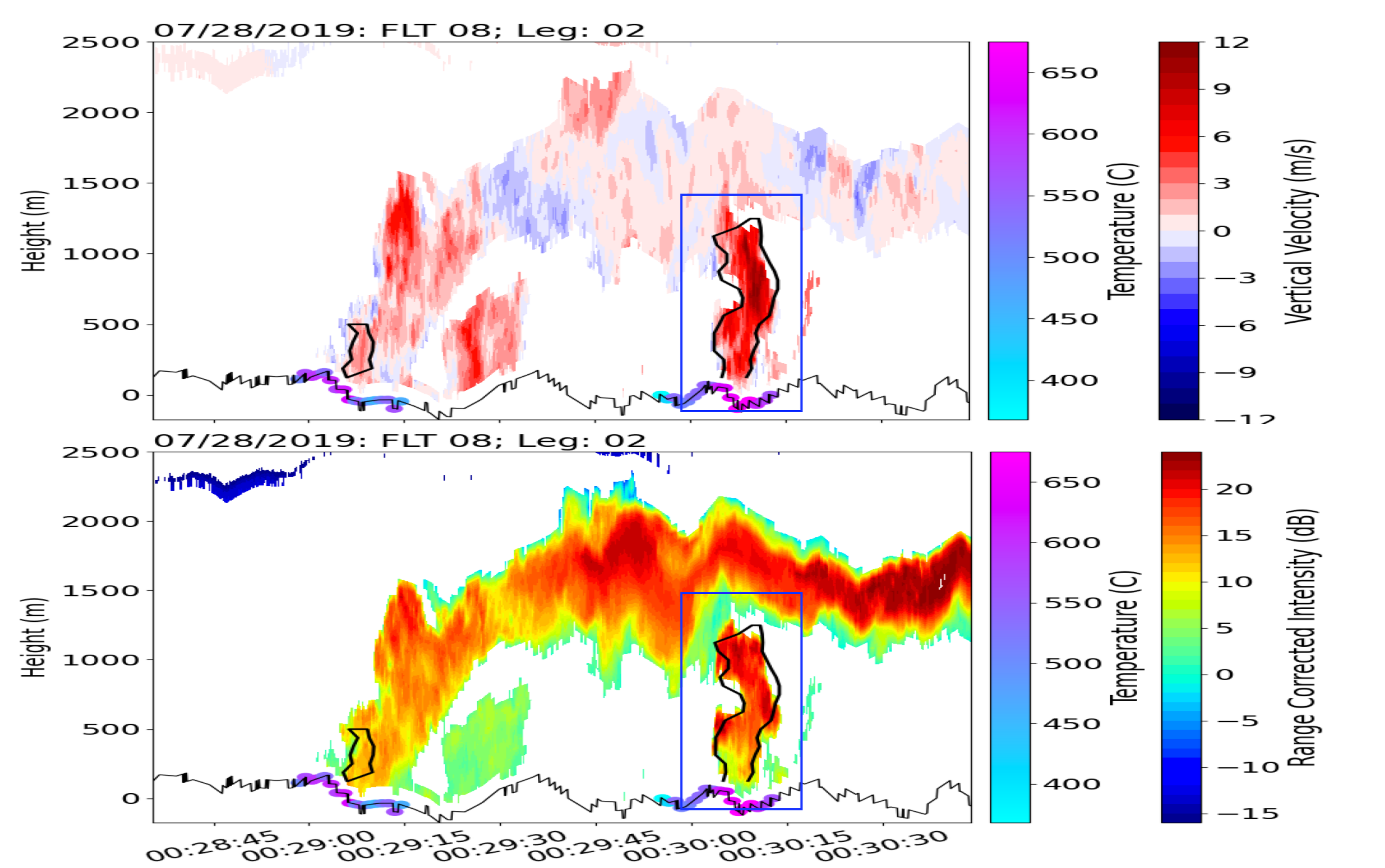

Figure 2: Example of vertical wind (top) and RCI (bottom) for the second leg of the Milepost 97 fire. Overlaid is the terrain (black line) and fire temperature (cyan→purple shading). Blue outline shows updraft analyzed in Fig. 7a,b,d.

Core Updraft Structure/Variability and Plume Width

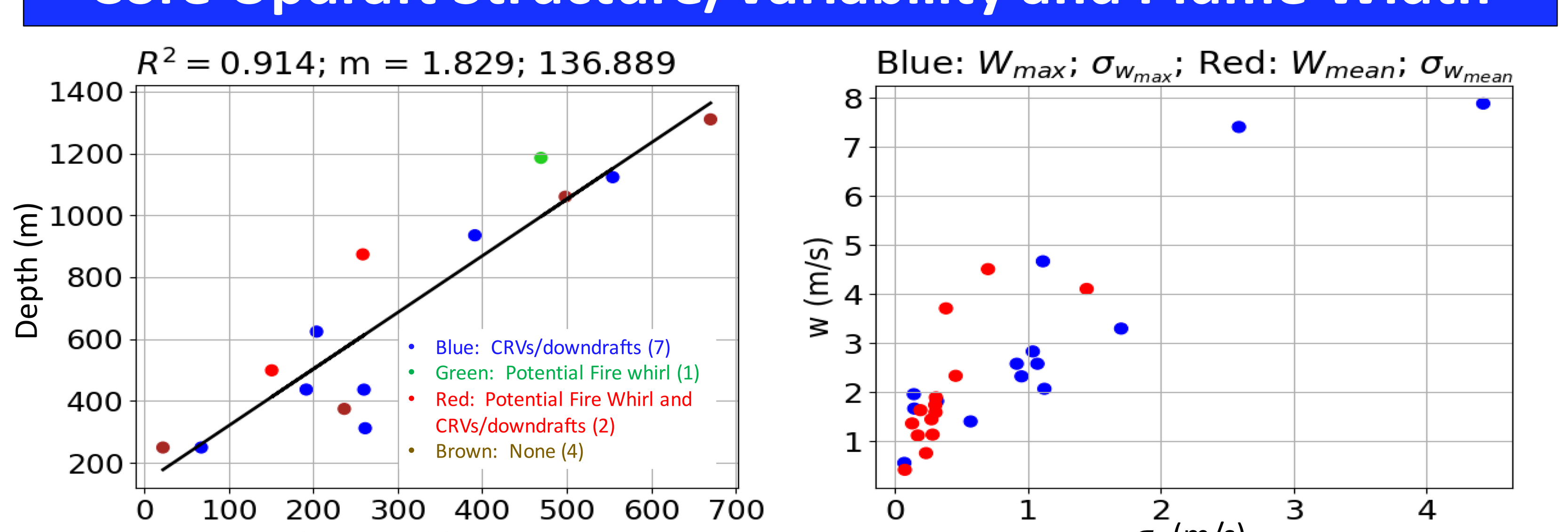

Figure 3: Comparisons of (left) estimated plume depth v. plume width and (right) peak vertical velocity v. horizontal variability across updraft from isolated updrafts identified during FIREX-AQ.

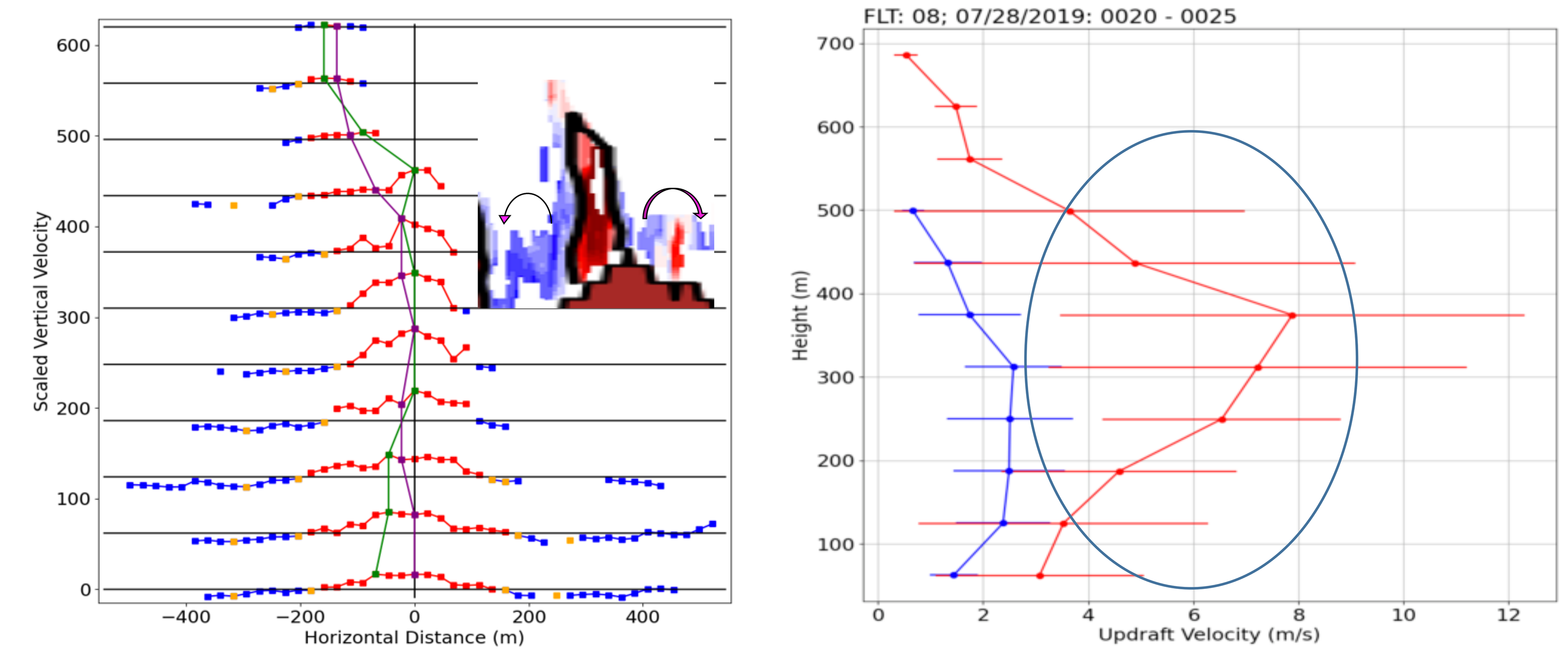

Figure 4: (left) Scaled vertical velocity of updraft profile that is circled on the right. Blue squares are outside of updraft and fall below horizontal lines (negative velocities) while red squares are within updraft region. Orange squares represent index of most distant local downdraft minimum identified. The green and purple lines represent max. wind and updraft center, respectively. Inset of the updraft slice is overlaid on left panel. (Right) represents the average vertical velocities of targeted updrafts and their horizontal variability.

Counter Vortices, Length-Scales, and Downdrafts

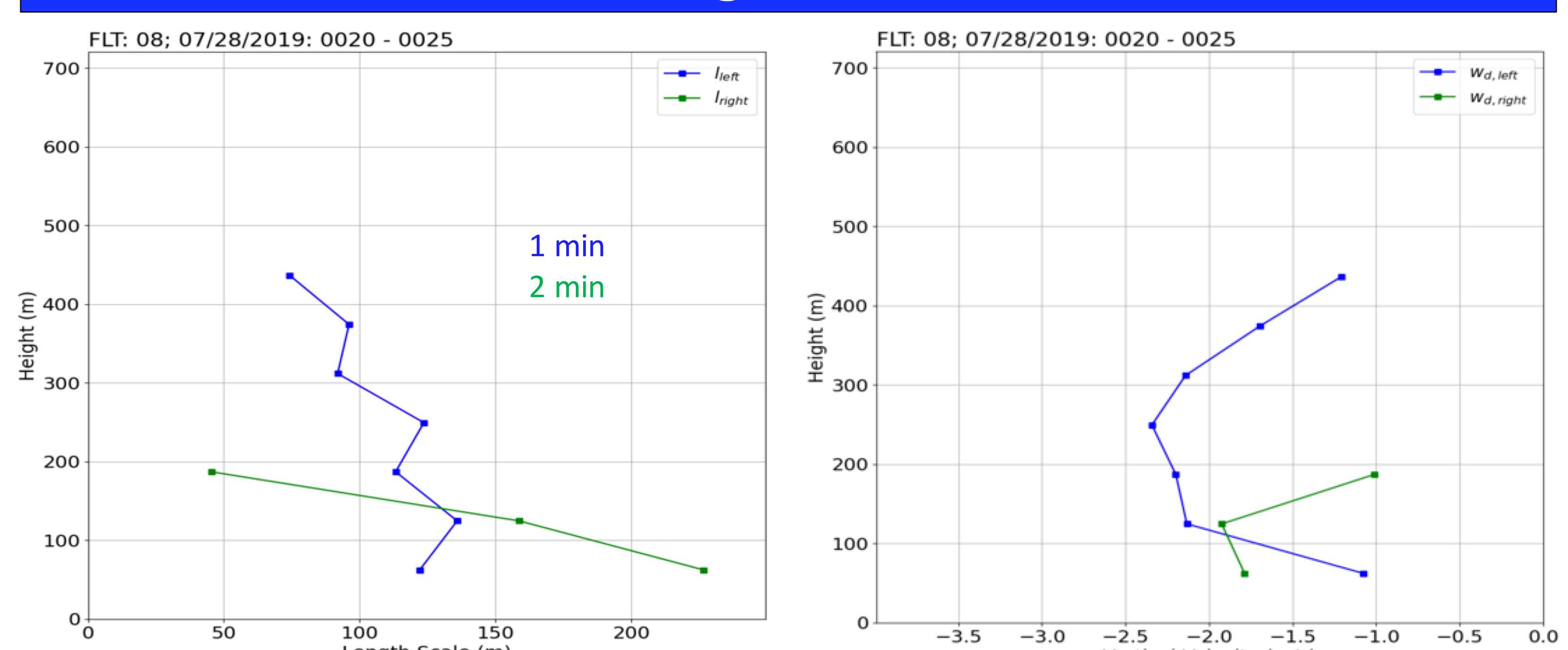

Figure 5: Estimates of the (left) horizontal length-scale and (right) downdraft structure to the left and right of updraft for the profile circled in Figure 4. Time-scales on left are derived from $\frac{l_{max}}{max(\langle w_d(z)\rangle)}$

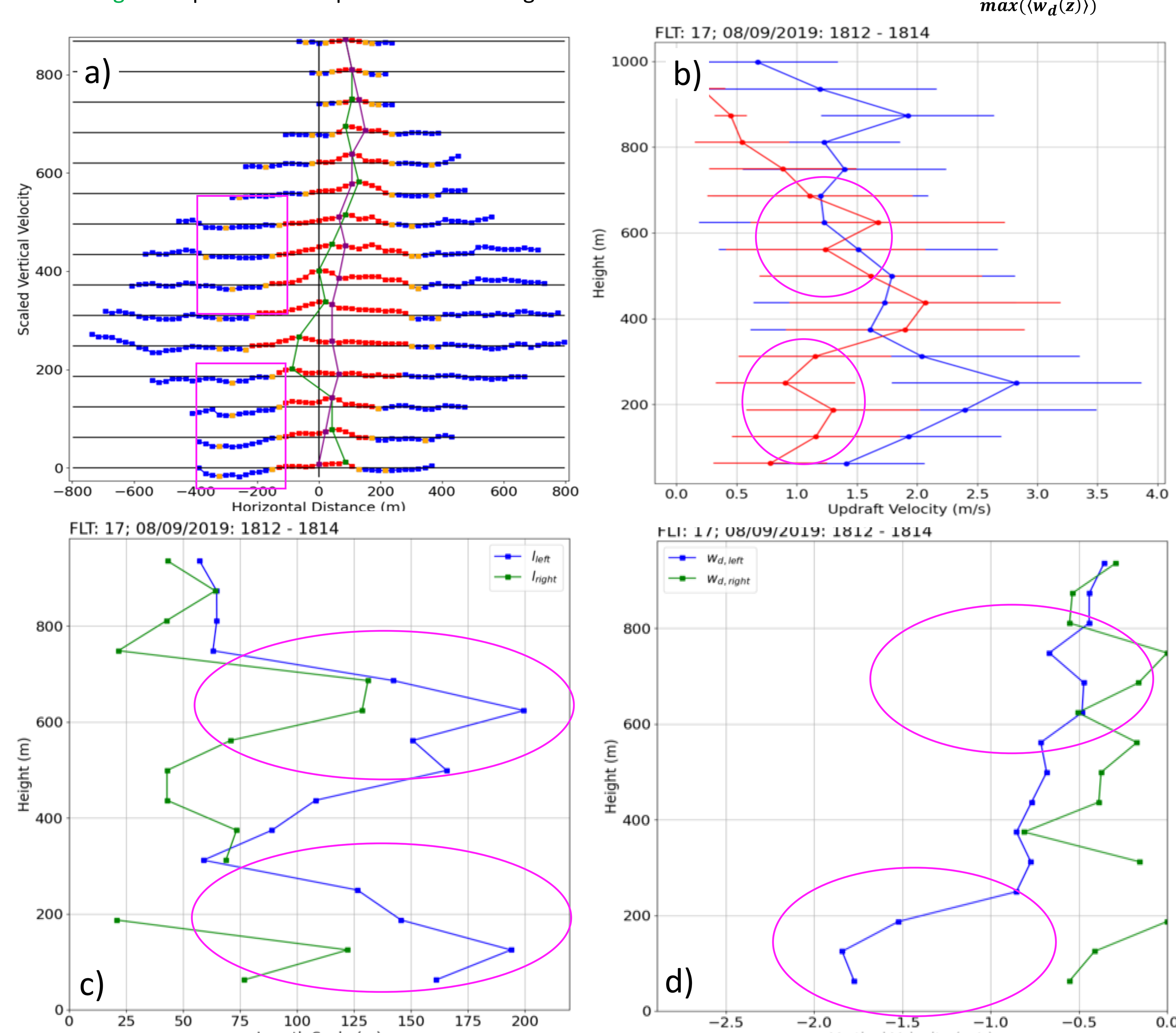

Figure 6: a) Scaled vertical velocity, b) updraft profiles identified during a leg of flight 17 overlaid with horizontal variability across updraft (we are interested in the red profile example), c) derived length-scales and d) downdraft profiles to the left and right side of updraft. Magenta annotations highlight changes in fine structure which impacts updraft structure. Refer to Figure 4 for plot details about a).

Introducing a Fire Whirl Diagnostic

- Key assumptions:
  - Meandering of maximum wind has a transversal component
  - The horizontal displacement can be modeled by sinusoid as a function of height.
  - The behavior is assumed as to be that of an ideal helix
- Essential conditions:
  - Whirling parameter can be assessed ‘along’ helical trajectory between layers
  - Horizontal and vertical winds increase/decrease proportionately to one another (i.e., angle between horizontal and vertical wind remains constant)
  - Vertical structure changes minimally within the following timescale: $T = \sum_k (z_{k+1} - z_k)/\langle w \rangle_{k+1}$
- Steps
  1. Re-center the vertical line such that the maximum displacement on left is equal to right. Call this R_{max}. Works better if max. displacement occurs at inflection points
  2. Model displacement as a sinusoid: $r(z) = R_{max}\cos(mz + \delta)$; where $\varphi(z) = mz + \delta$.
  3. Approximate the time it takes for the parcel to travel upwards by average core updraft between layers: $\tau = (z_{k+1} - z_k)/\langle w \rangle$.
  4. Combine the phase, $\varphi(z)$, and time-scale defined across each layer, τ, to estimate a whirling parameter, $\varsigma = {}^{(\varphi_{k+1} - \varphi_k)}/_{\tau}$
  5. Calculate the whirling strength, $\Lambda(z) = w\varsigma$;

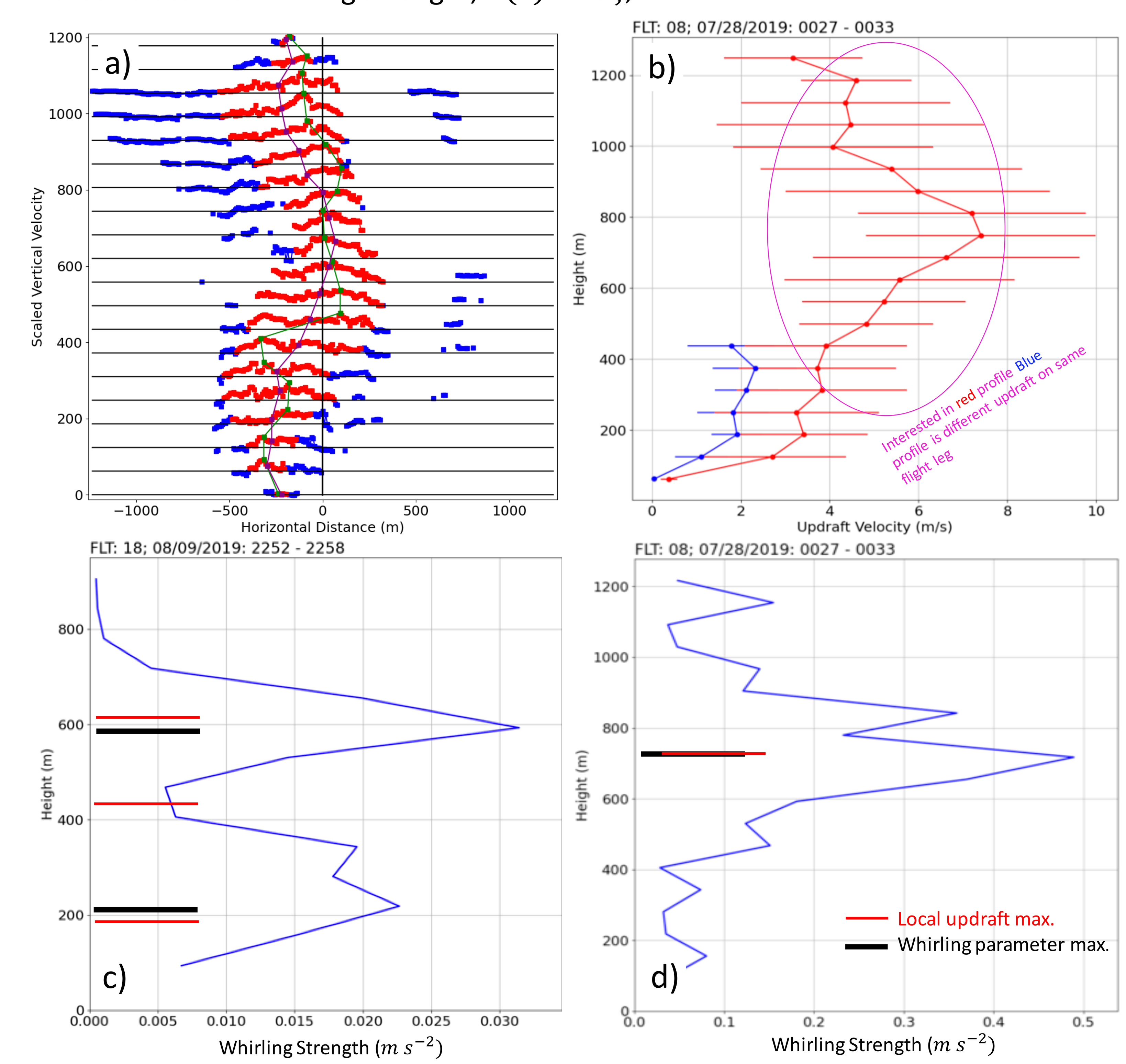

Figure 7: a) Scaled vertical velocity, b) updraft profiles overlaid with horizontal variability across updraft, and estimated whirling strength for updraft in c) Fig. 6 and d) Fig. 7a-b. Annotations in c) and d) delineate updraft maximum from a maximum in the whirling parameter, both of which are used to derive whirling strength

Conclusions

A technique was developed to isolate updrafts over wildfire source points. A relationship between plume depth and width from updraft samples was determined; and variability across updraft appears related to updraft core structure. Length-scales and downdrafts were derived for more than half of updrafts and revealed linkages with updraft profile structure. A fire whirl diagnostic was developed following key assumptions outlined above. The collocation of the whirling parameter max. with updraft max. *appears* related to a lack of turbulent mixing across updraft interface.