Properties of updrafts observed in situ during NASA IMPACTS

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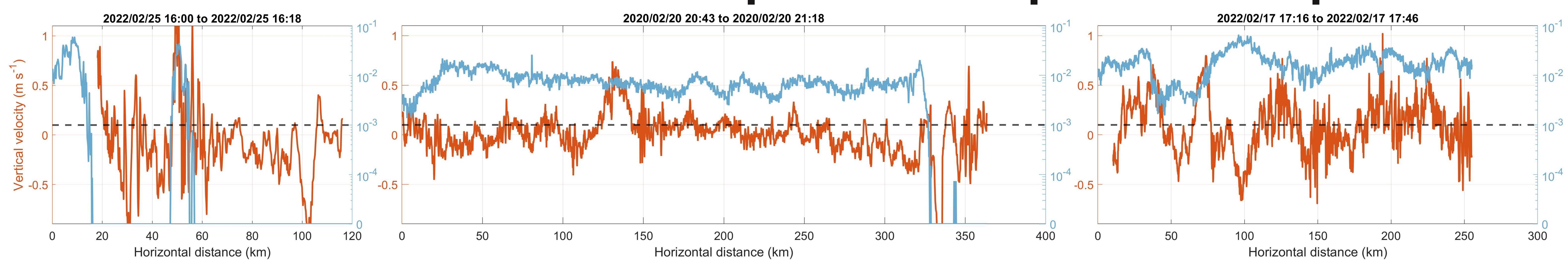
IMPACTS data: dx.doi.org/10.5067/IMPACTS/DATA101
PLOWS data: doi.org/10.5065/D6HX1B1V

Motivation

Vertical motions in winter storms are important to ice growth via vapor deposition and riming as well as the transport of particles. As parcels are lifted, their temperature decreases and relative humidity increases. If RH_{ice} > 100% deposition occurs and if RH_{water} > 100% condensation occurs. Analyses of aircraft in situ vertical velocity observations, including updraft strength, breadth, and structure, in winter storm environments are lacking.

Definition of updraft envelope with examples

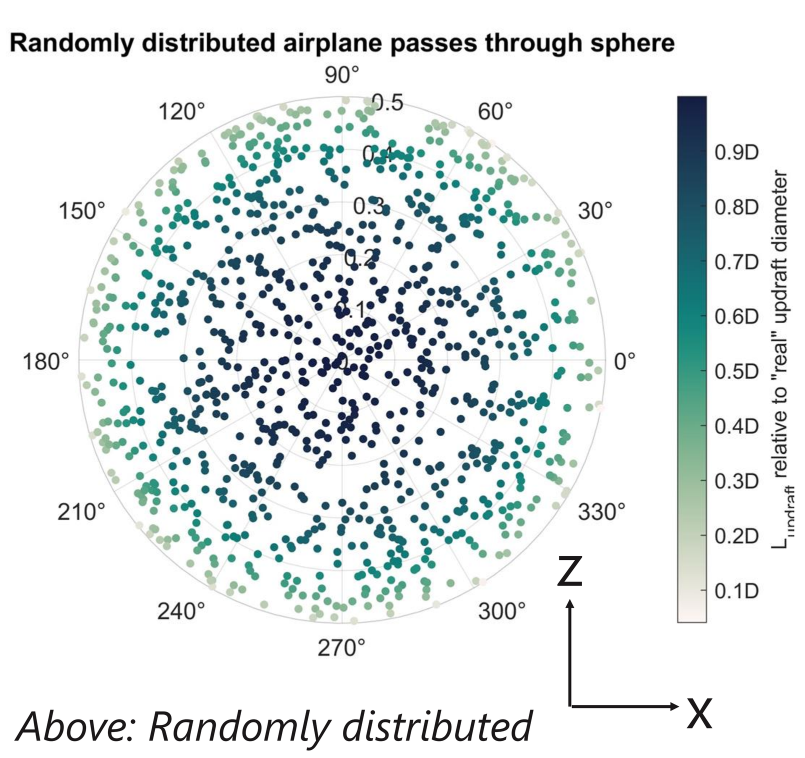


Vertical velocity (orange) and 2D-S total number concentration (blue) for example level flight legs during IMPACTS flights. Horizontal dashed line is at 0.1 m s^{-1}, the threshold for updraft envelopes. Time is converted to distance traveled by the airplane on the ordinate.

We define updraft envelopes to be the periods of time in which vertical velocity (measured by the P-3 TAMMS) exceeded 0.1 m s^{-1}. We analyzed in situ data from flight missions during IMPACTS in 2020 and 2022 and during the Profiling of Winter Storms (PLOWS) field project in 2009-10. Points where the 2D-S and CDP total number concentration were less than 10^{-3} cm^{-1} were excluded from the analysis.

Thought experiment: how does measured updraft length compare to the real updraft diameter?

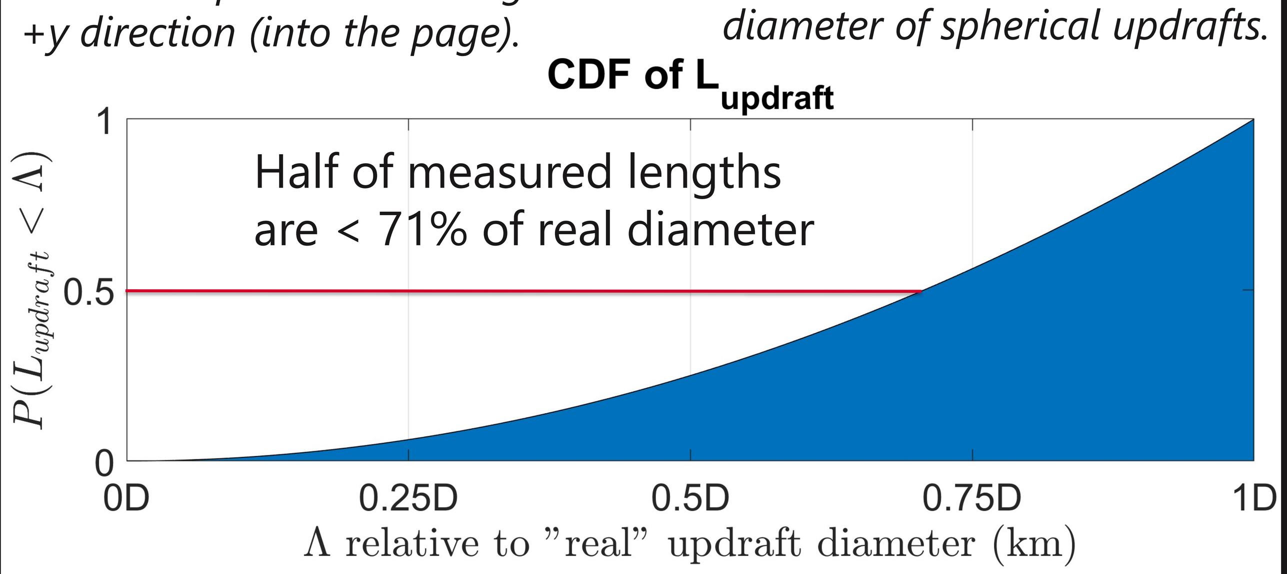
Suppose the "real" region with vertical velocity w exceeding some threshold $w_{threshold}$ is spherical with diameter D. If the airplane misses the center of the sphere by some distance h, then the measured updraft length is: $L_{updraft} = \sqrt{D^2 - 4h^2}$.



Above: Randomly distributed airplane passes through a spherical updraft such that they are area-uniform in the cross-section. Airplane is traveling in +y direction (into the page).

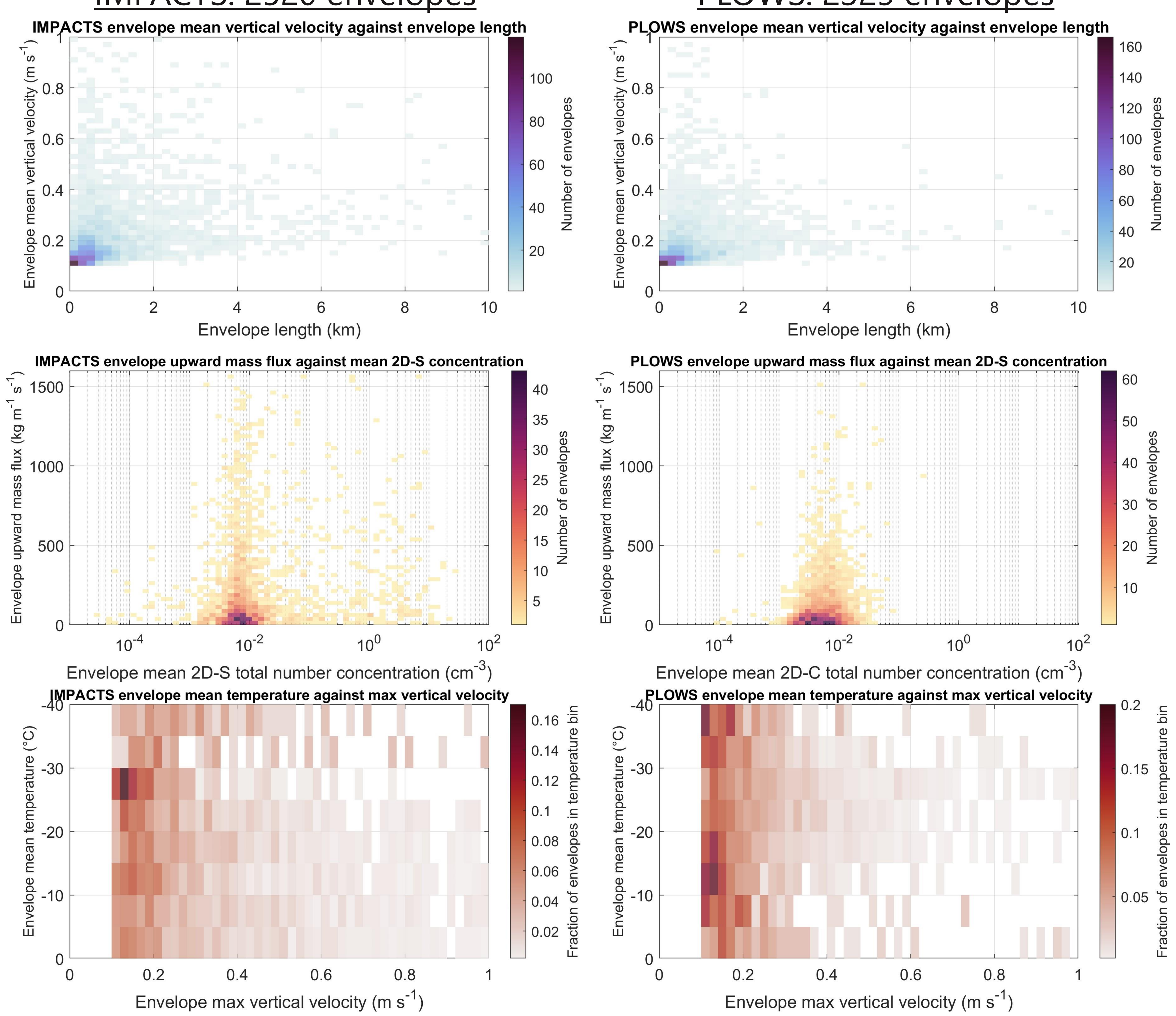
Assuming that h is area-uniform (i.e., h^2 is uniformly distributed), then the resulting CDF of $L_{updraft}$ is $P(L_{updraft} < \Lambda) = \frac{\Lambda^2}{D^2}$ where Λ is any value in (0, D). The PDF of $L_{updraft}$ is given by $\frac{2\Lambda}{D^2}$.

Below: CDF for randomly sampled measured updraft lengths relative to the real diameter of spherical updrafts.



Updraft envelope statistics

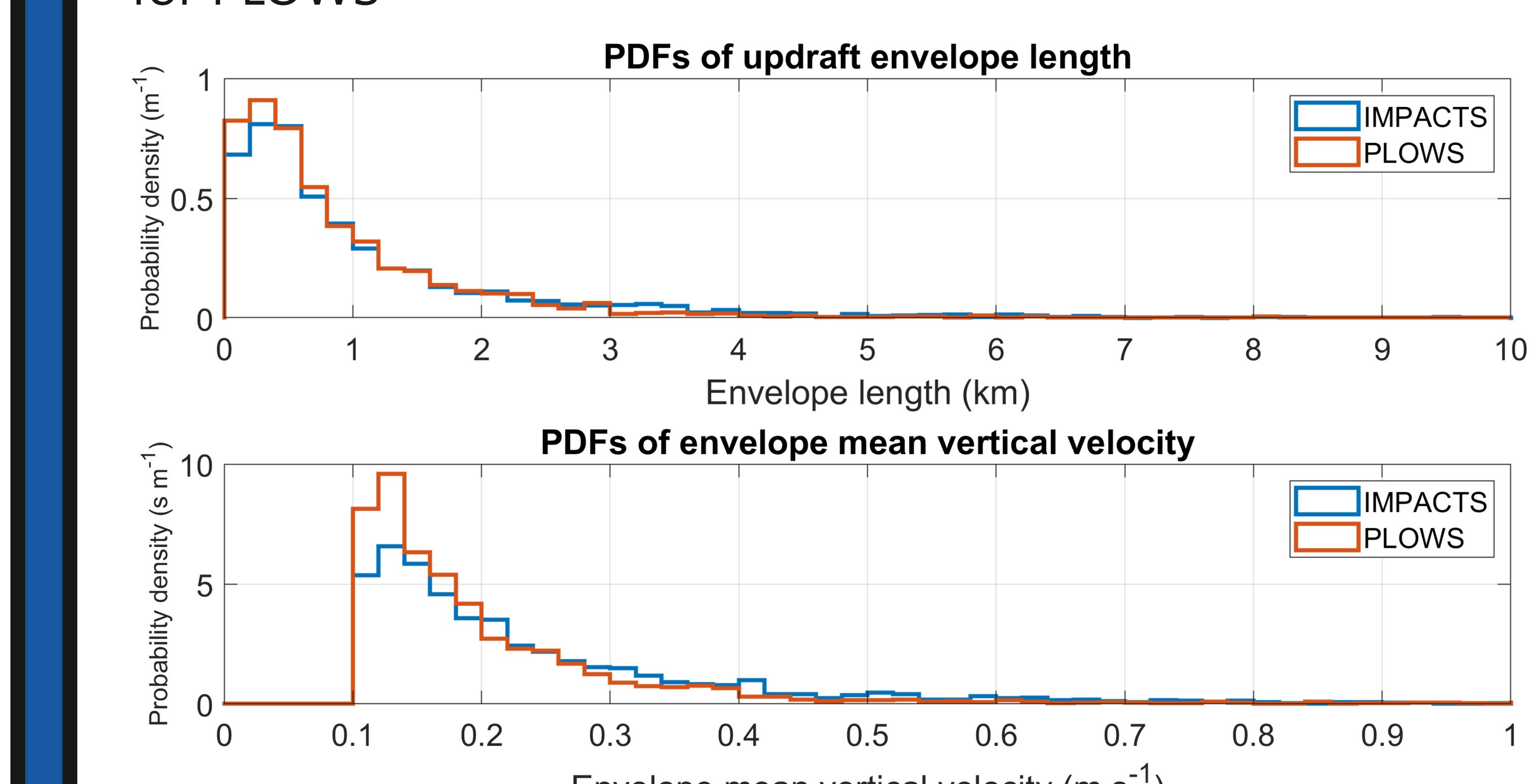
IMPACTS: 2520 envelopes | PLOWS: 2325 envelopes



Joint distribution plots of updraft envelope properties for (left) NASA IMPACTS Jan-Feb 2020 and Jan-Feb 2022 and (right) NSF PLOWS Nov 2009-Mar 2010. Since aircraft sampling by temperature varied between the two projects, values in bottom row of plots are normalized by number in each 5°C temperature bin.

Key findings

- The distributions of updraft size and strength are similar between IMPACTS and PLOWS. Most updrafts are too weak (< 0.5 m s^{-1}) to loft precipitation-size particles. Using 0.1 m s^{-1} as the updraft threshold:
  - 66% of updrafts were shorter than 1 km
  - 59% of updrafts had mean vertical velocity below 0.2 m s^{-1}
  - 85% of updrafts had peak vertical velocity below 0.5 m s^{-1}
  - 63% of updrafts had an envelope-integrated mass flux below 150 kg m^{-1} s^{-1}
- Mean total number concentrations measured by the 2D-S or 2D-C were below 10^{-2} cm^{-3} for most updrafts sampled by IMPACTS and PLOWS, though some higher concentrations were measured during IMPACTS
- Of the time spent in cloud during level flight legs, 26% was spent in updraft envelopes for IMPACTS, compared to 17% for PLOWS



Probability density function of (top) updraft envelope length and (bottom) envelope mean vertical velocity for IMPACTS and PLOWS.