Convective Asymmetries Measured by XDD Dropsondes in Tropical Cyclones

Part I: Joaquin (2015)

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Goals of Analysis

- Examine the convective updrafts and downdrafts (UDs)
  - Joaquin (2 – 5 October)
- Derive vertical velocity using dropsonde fall speed and density correction
- Evaluate the spatial distribution of abnormally strong UDs (magnitude ≥ 5 m s^{-1})

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- Compute vertical velocity following similar to Hock and Franklin (1999); however, we use the near surface fall speed instead of drag coefficients:

$$w = V - V_f \quad (1)$$

$$V = (F_o^2) * \sqrt{\frac{\rho_o}{\rho}} \quad (2)$$

$$\rho = \frac{p}{(R_d * T_v)} \quad (3)$$

- Sonde derived vertical velocities were then filtered using a nine-point binomial filter
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- UDs were restricted to within 1500 km of the TC center and only considered data below 13.5 km
- Used a 'shear-relative' framework
  - DSL = downshear-left, DSR = downshear-right, USL = upshear-left, and USR = upshear-right
  - The environmental shear, TC intensity, and TC heading were obtained from the Statistical Hurricane Intensity Prediction Scheme (SHIPS) dataset (DeMaria and Kaplan 1994)
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Methodology

- A propensity parameter was calculated

$$\gamma = \frac{n_o}{\frac{H}{F_o} * N} \qquad (4)$$

- Spatial Analysis: Polar plots, contoured frequency diagrams by altitude (CFADs), shear-relative azimuth (CFAzDs), and radius (CFRDs)
- Each of the vertical velocity data points that a sonde records were originally assumed to be independent observations
  - One cannot *immediately* ascertain whether any of these data points belong to a single, coherent updraft or a collection of nearby updrafts

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Date	Storm	I [m s^{-1}]	N_t	|S| [m s^{-1}]	S_D [deg]
2 Oct	Joaquin	56.59	75	4.90	151
3 Oct	Joaquin	66.88	65	13.20	127
4 Oct	Joaquin	43.73	66	4.90	66
5 Oct	Joaquin	38.58	76	3.90	39
TOTAL	**----------**	**51.44 (avg)**	**28 2**	**6.73 (avg)**	**----------**

- 282 Sondes Total
- Previous studies of sonde calculated vertical velocities achieve this in many storms (e.g., Stern et al. 2016)
- With ~700 data points per sonde, that's approximately 197,000 data points

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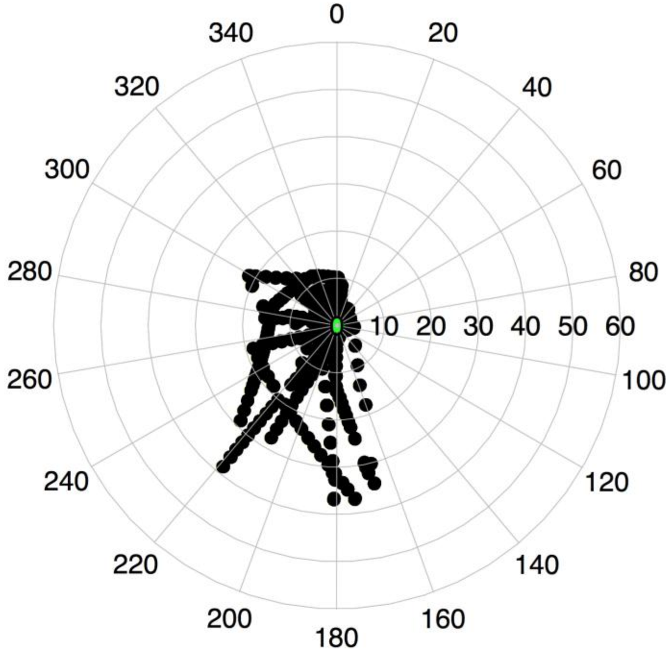
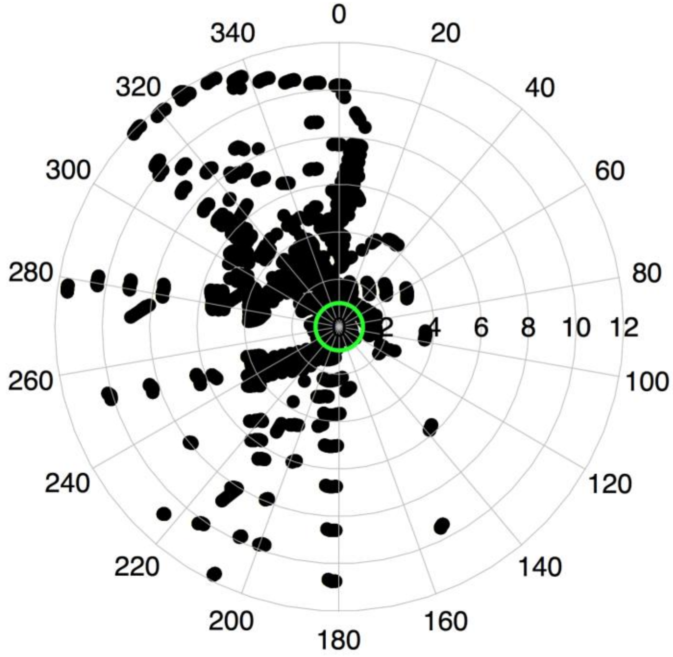
- Moderately sheared
- Maximum observed strength = Cat. 4
- Northwesterly to Southwesterly shear

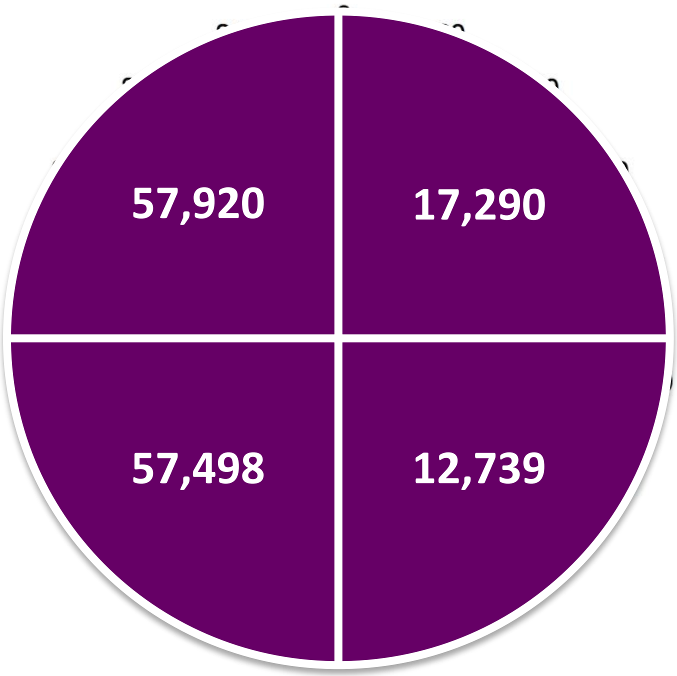
Spread of Data Points

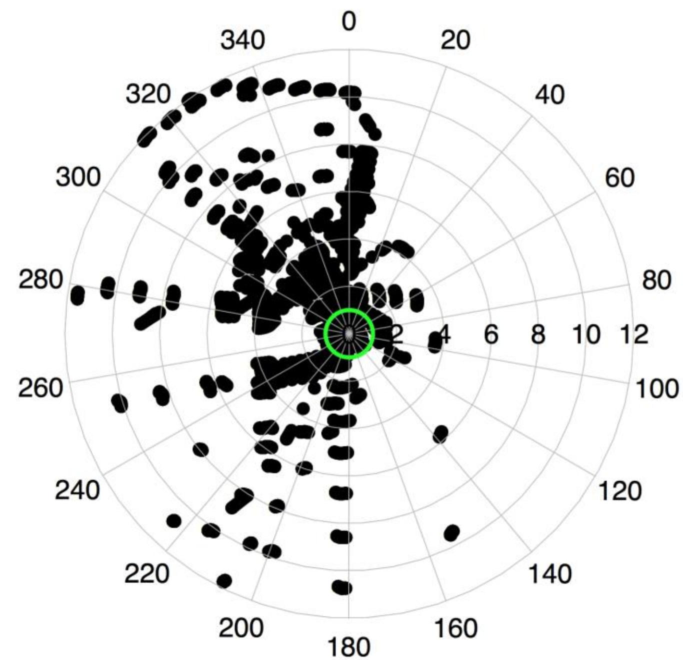




- Great coverage inside R* = 2
- Outside R* = 2, preference for DSL and USL quadrants
  - Void in outer R* values in DSR

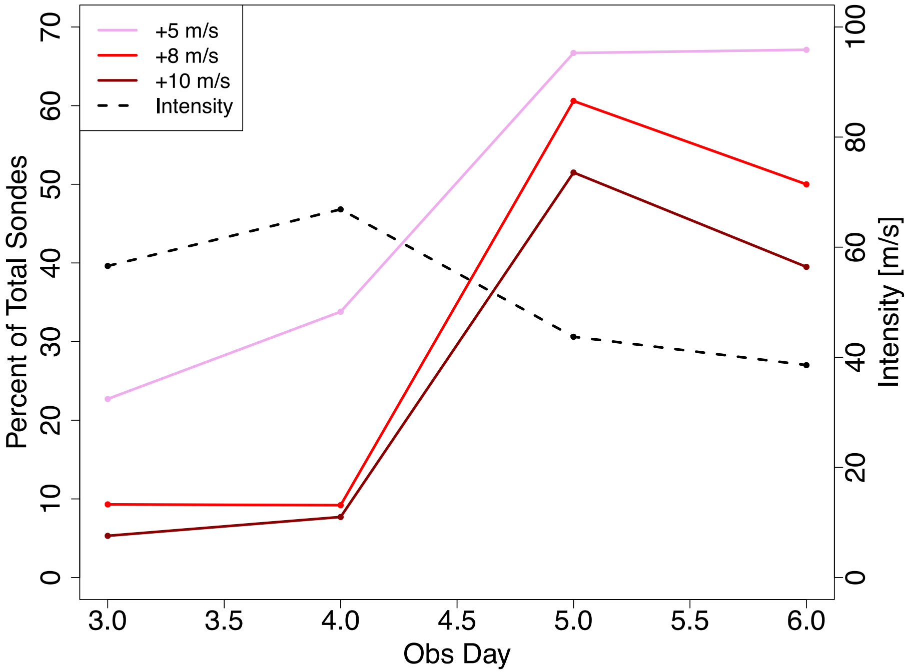
Spread of Data Points

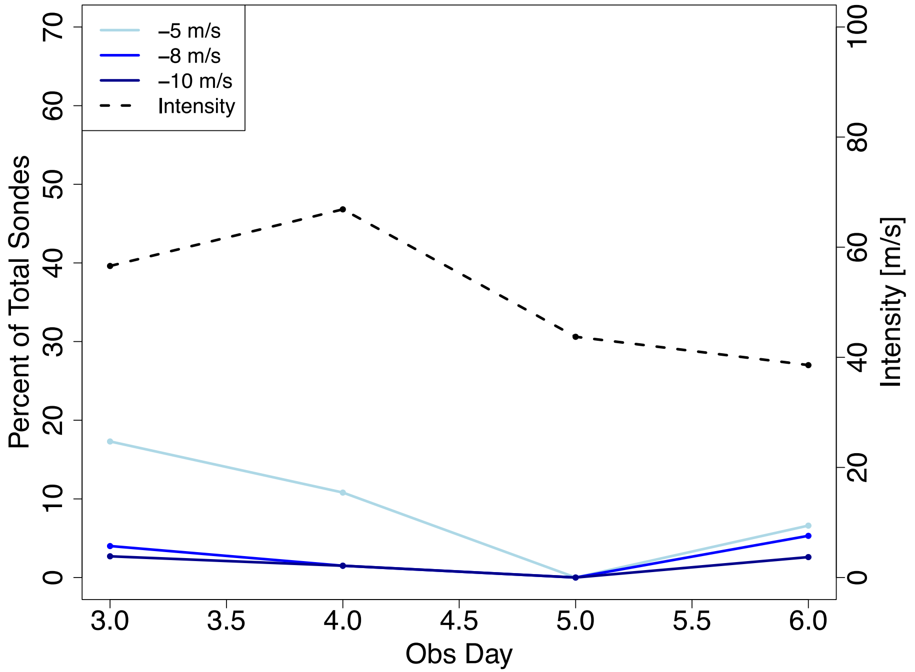




- Definite sampling shear asymmetry
- Will have to be taken into account

Percent of Total Sondes above Threshold





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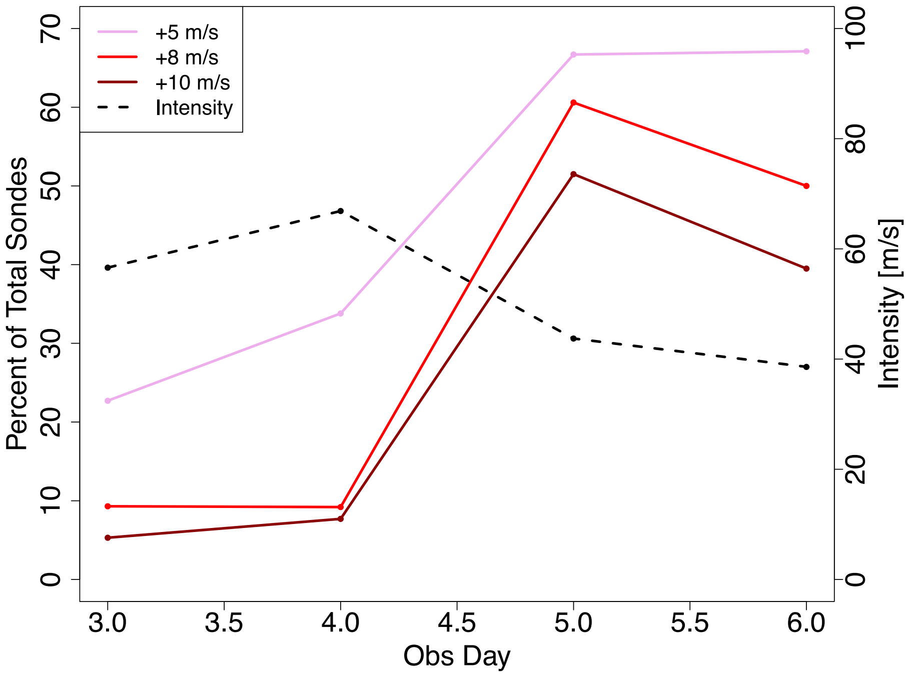

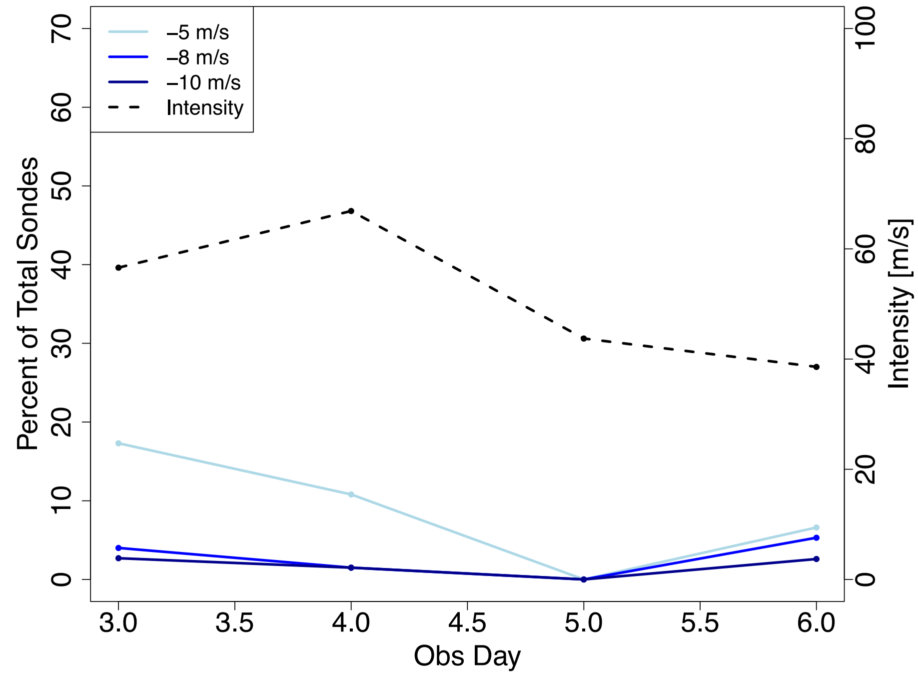

- Increase of percent of updraft sondes during decay
- Decrease of downdraft sondes after peak intensity
- Maximum Correlations: Positive: +8 m s^{-1} at -0.89

  Negative: - 5 m s^{-1} at 0.61

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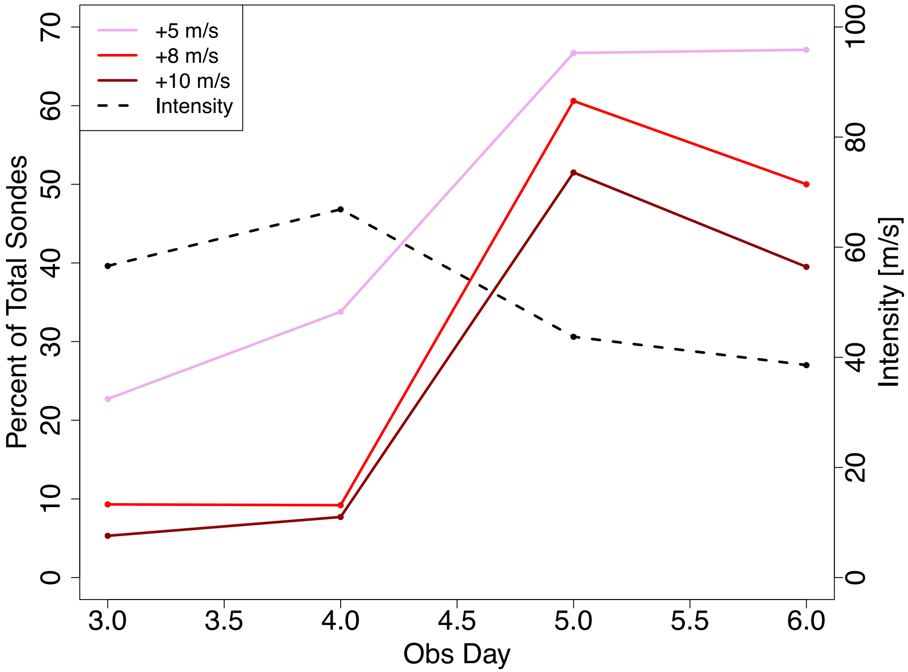

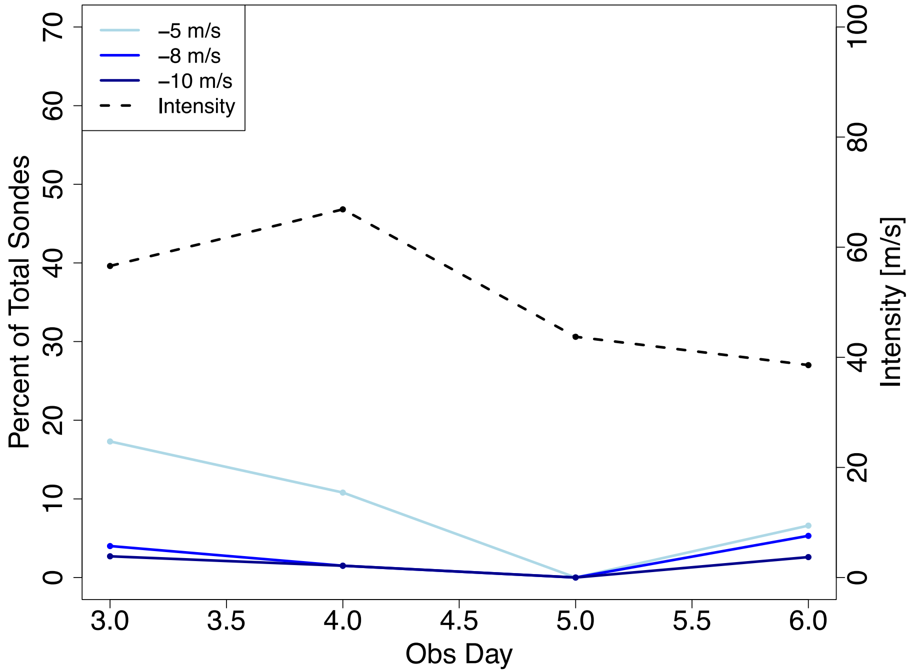

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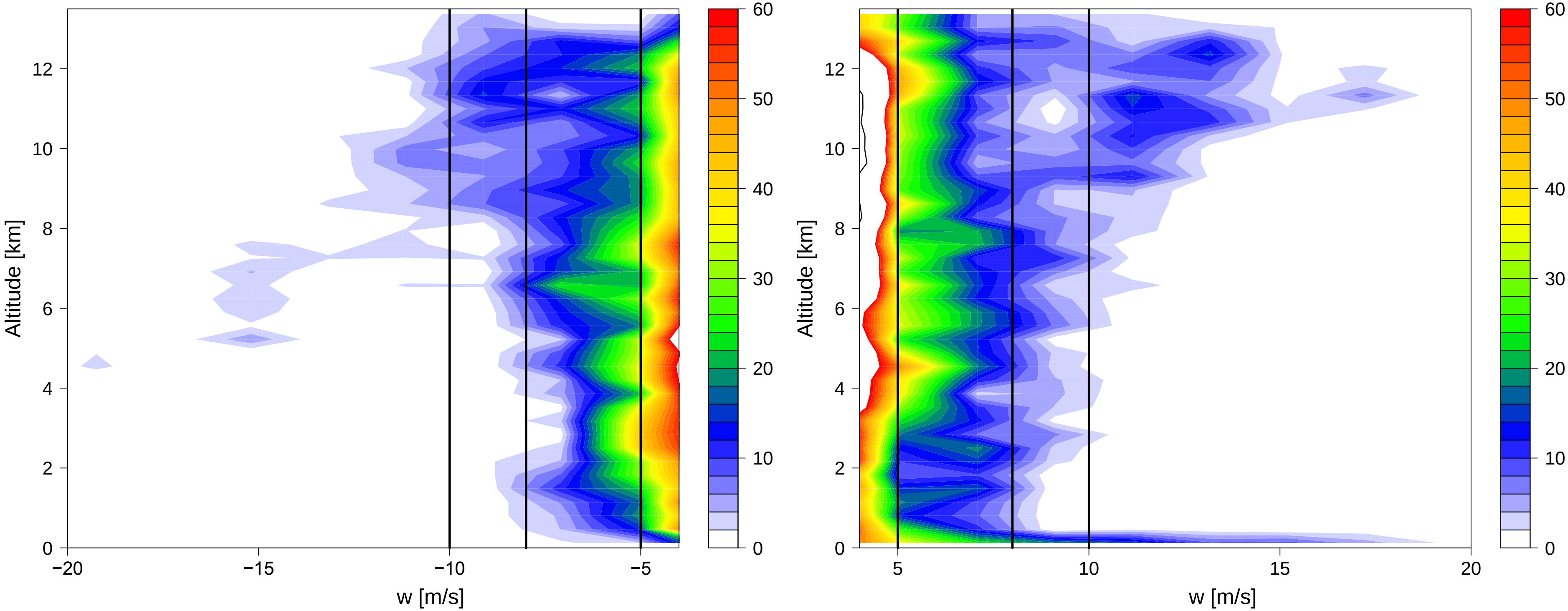
  Negative: - 5 m s^{-1} at 0.61
- Shear –percent correlations slightly weaker

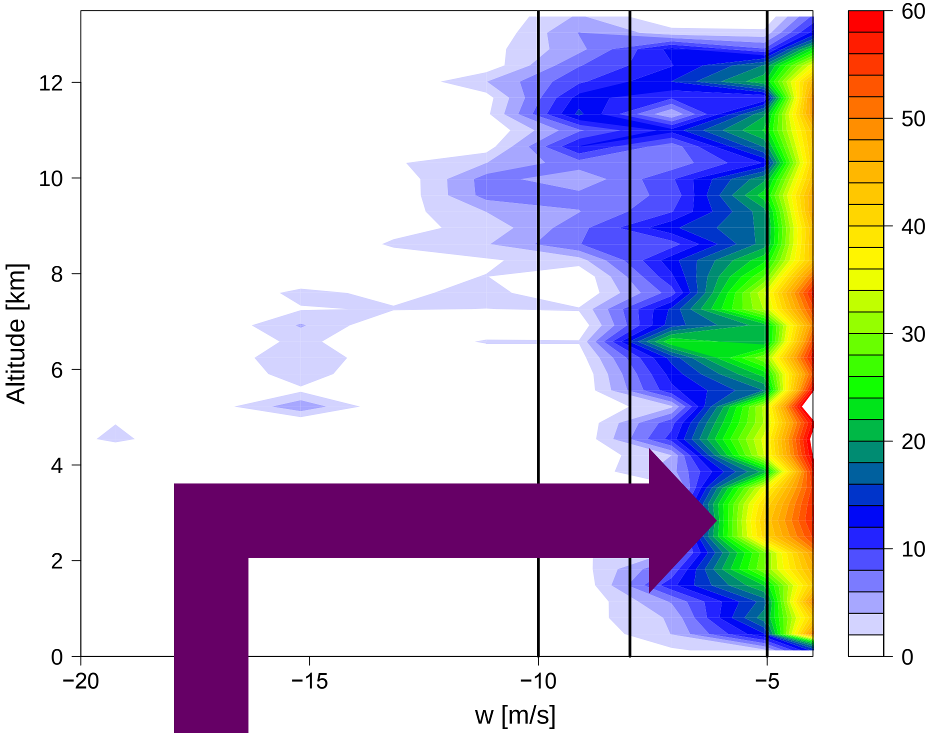
Results: CFADs

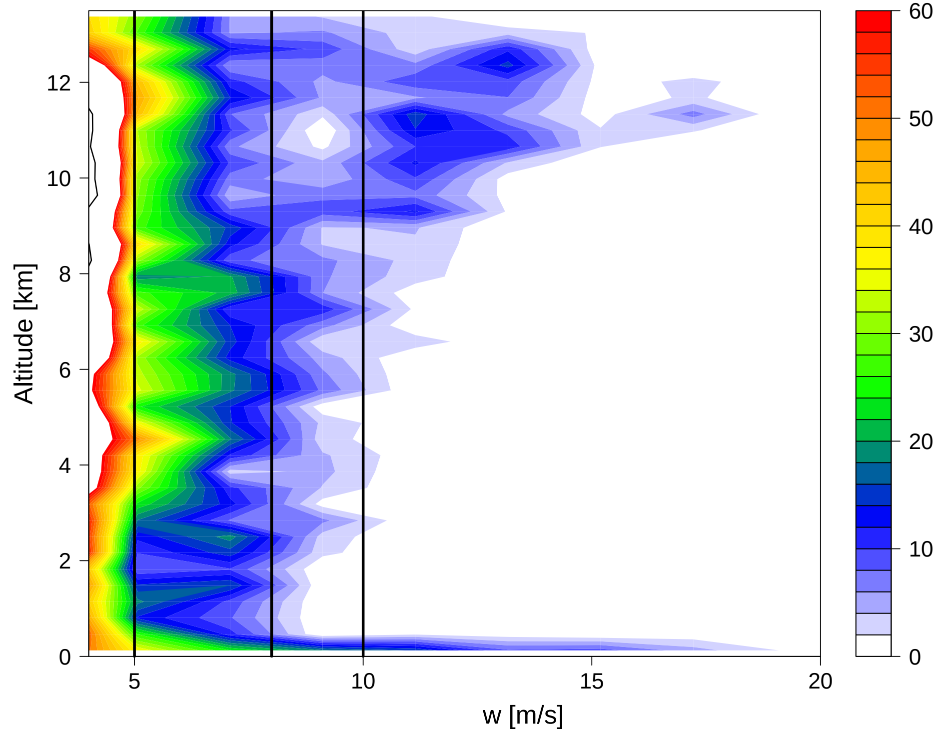
Joaquin (2 – 5 October 2015)



- Moderately sheared (~7 m s^{-1})
- Maximum intensity = 66.88 m s^{-1} (Cat. 4)

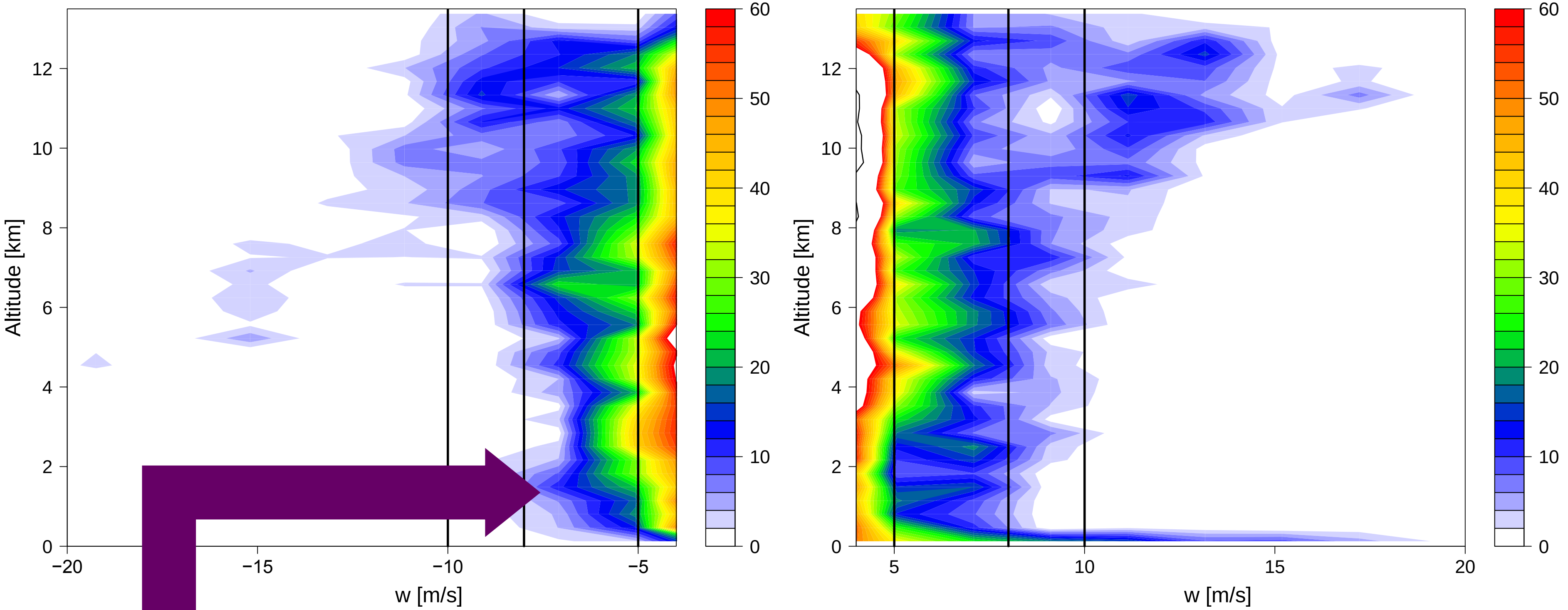
Joaquin (2 – 5 October 2015)





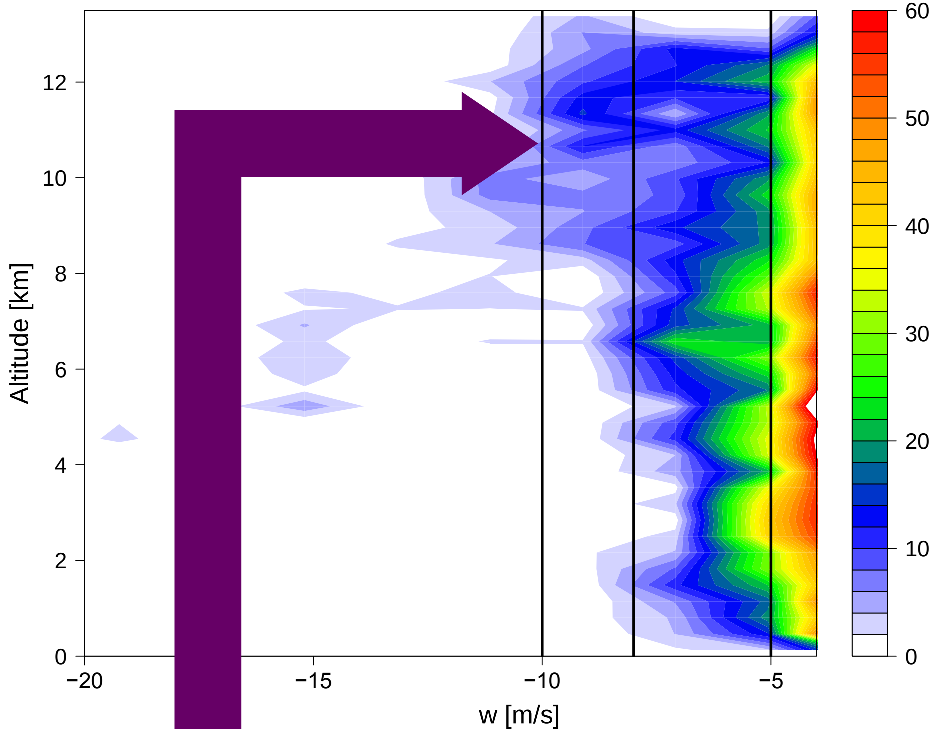
- > -5 m s^{-1} tended to occur in mid- and low-levels
- Moderate downdrafts had a single mode at 2.5 km altitude

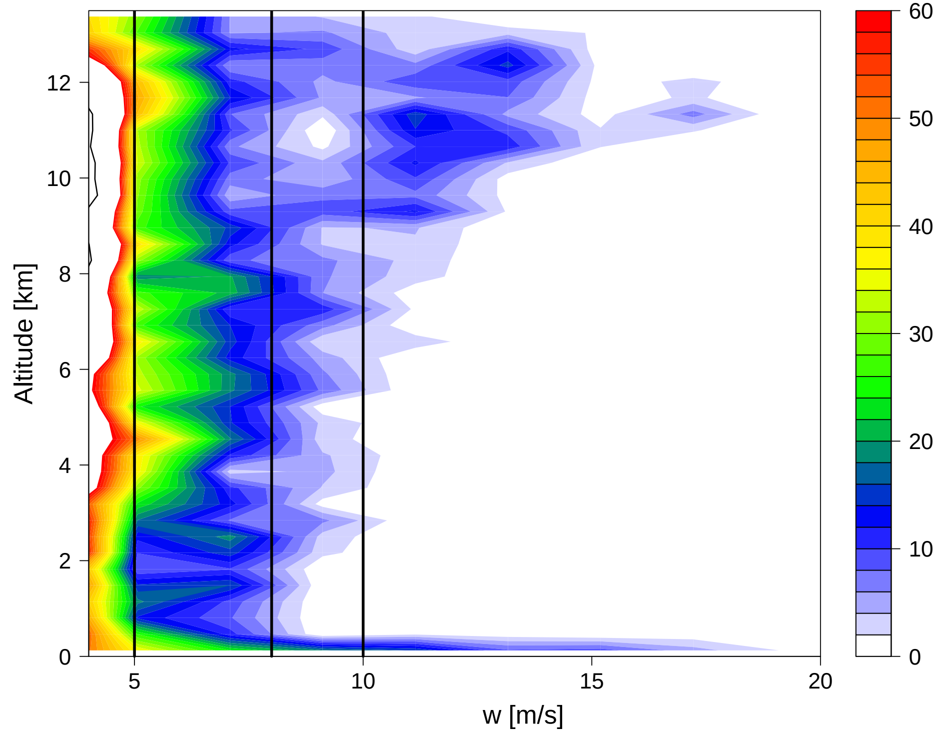
Joaquin (2 – 5 October 2015)



- Small nose below 2 km for strong downdrafts

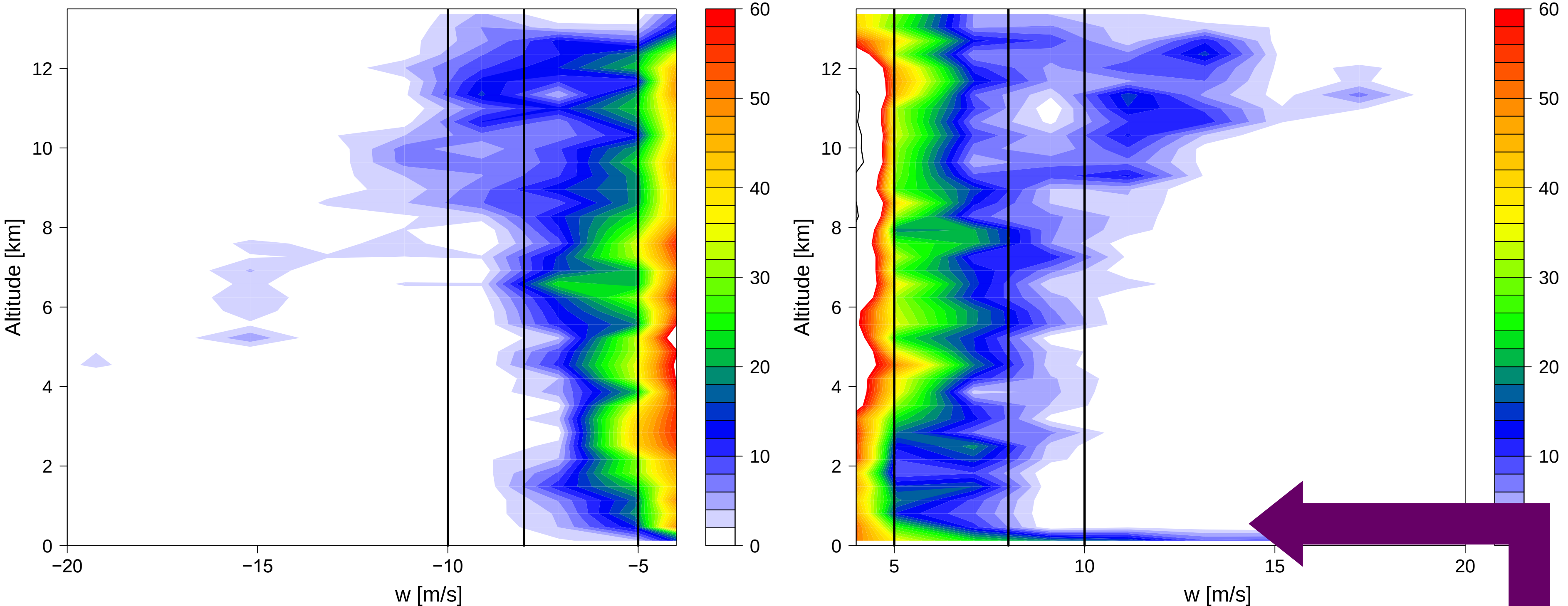
Joaquin (2 – 5 October 2015)





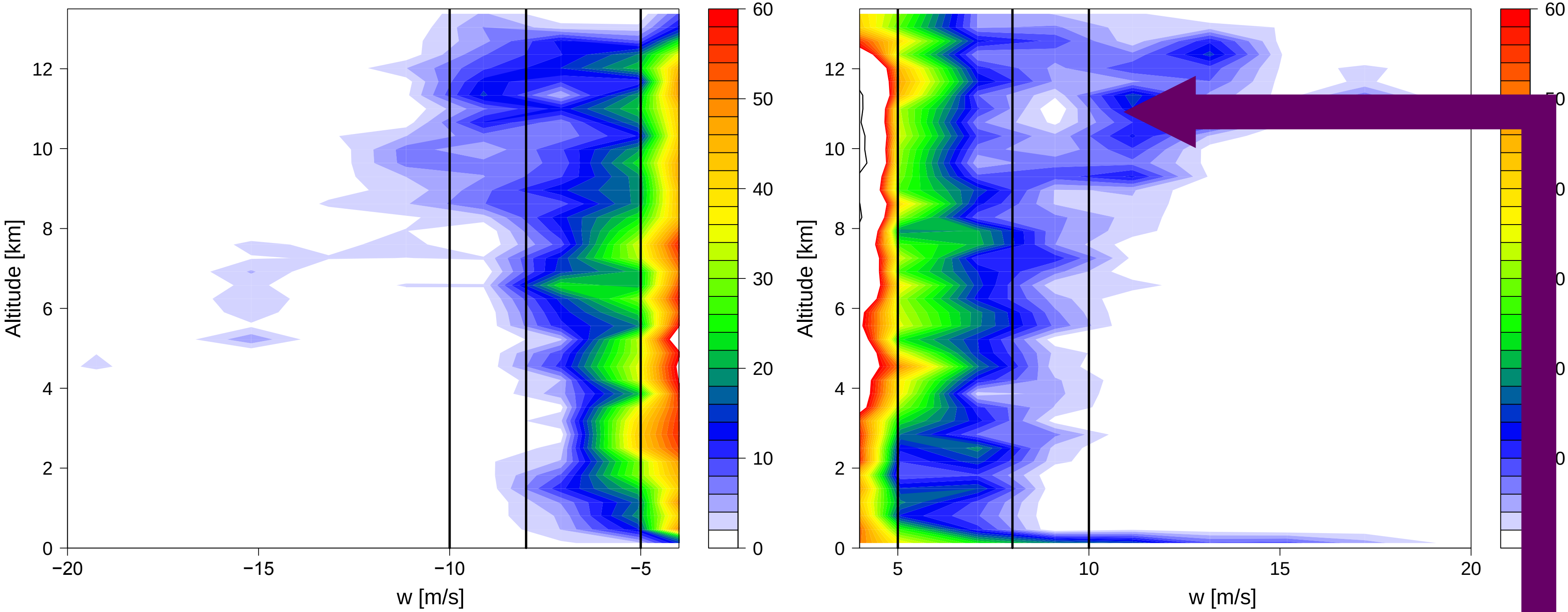
- Strong downdrafts tended to occur aloft up to -11 m s^{-1}
- < -11 m s^{-1} altitude decrease

Joaquin (2 – 5 October 2015)



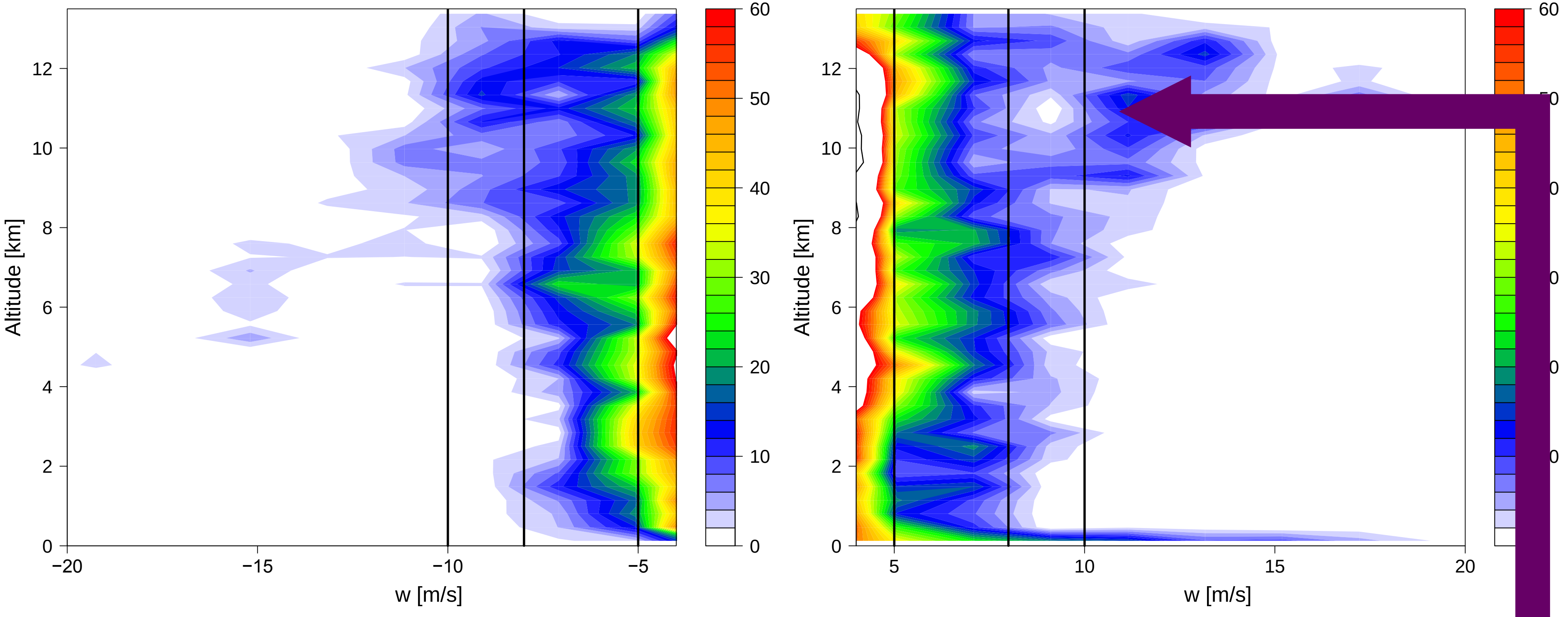
- Presence of near-surface vertical velocity maxima (Stern et al. 2016)

Joaquin (2 – 5 October 2015)



- Higher frequencies for updrafts, stronger
- Above the surface, frequency of updrafts above strong threshold increased with altitude

Joaquin (2 – 5 October 2015)

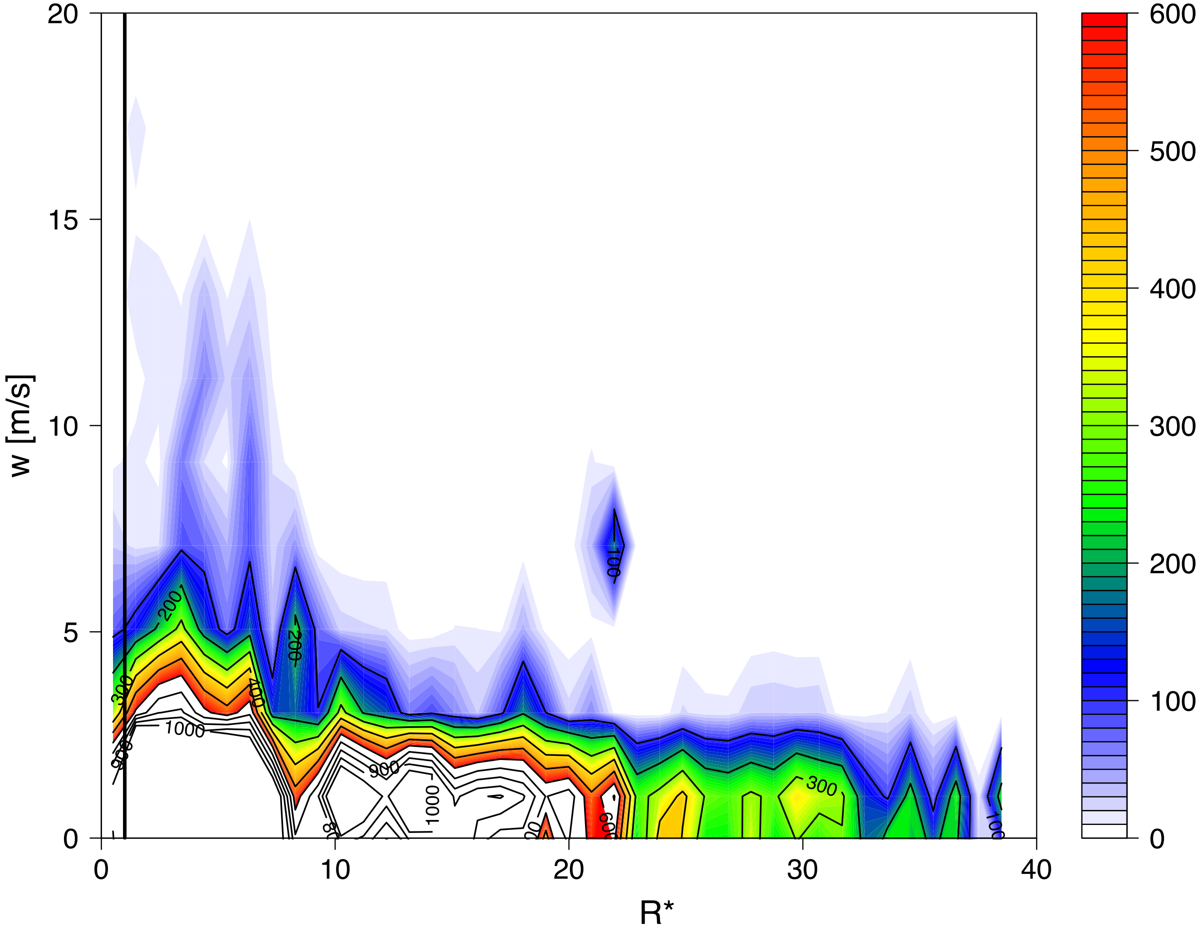


- Extreme updrafts peaked in frequency aloft
- Mid-level maxima for strong updrafts
- Bimodal for moderate updrafts
    - Also, below 5 m s^{-1}

Results: CFRDs*

* For updrafts only

Joaquin (2 – 5 October 2015)



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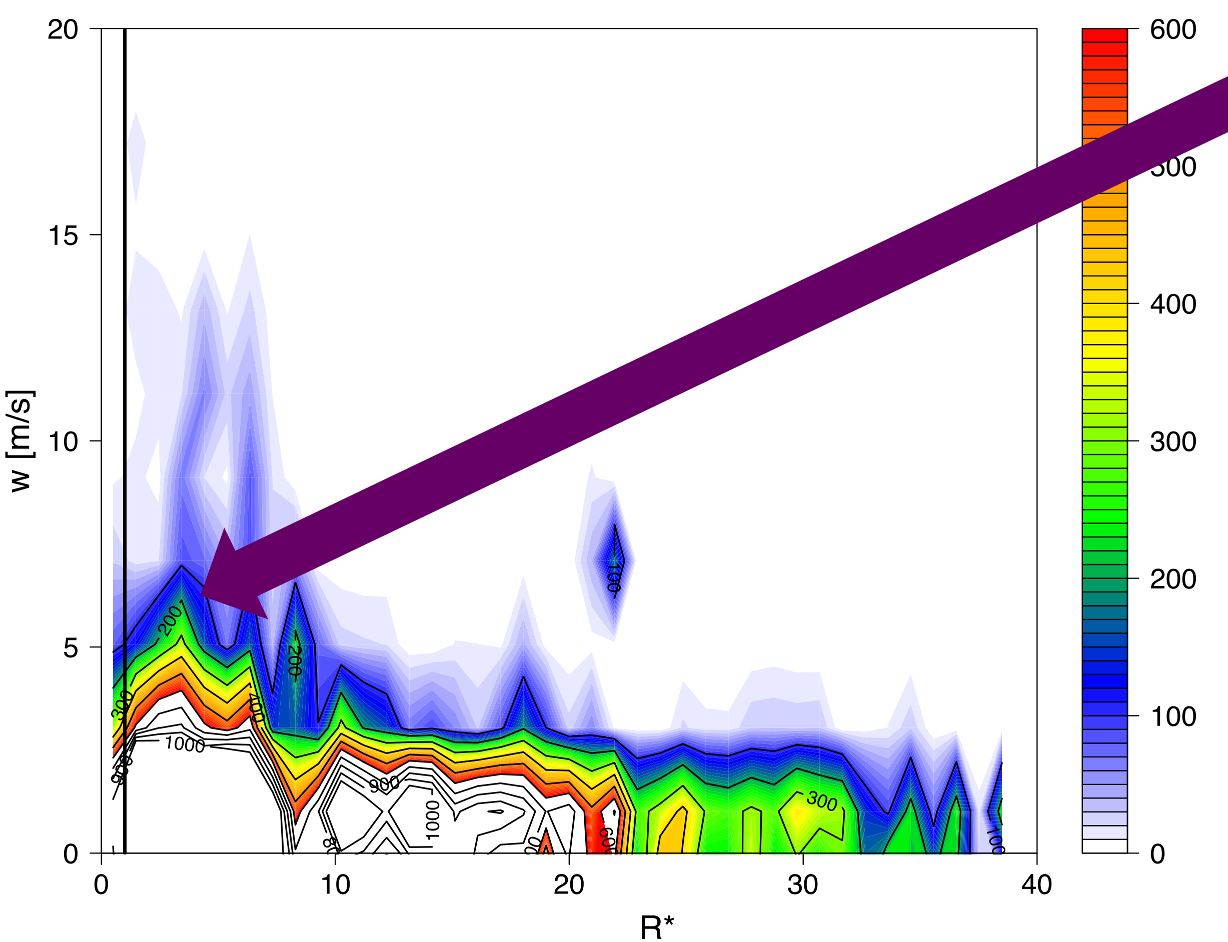
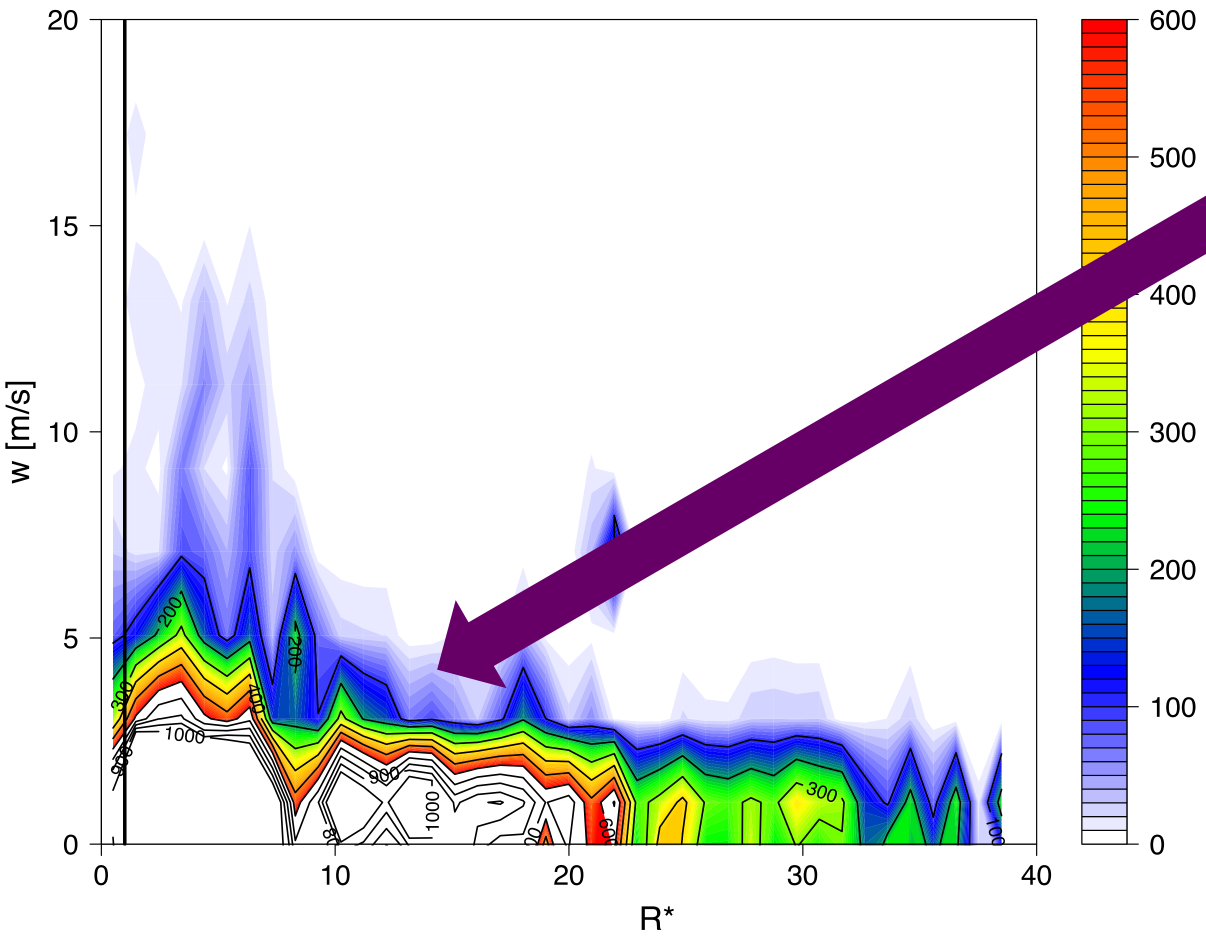


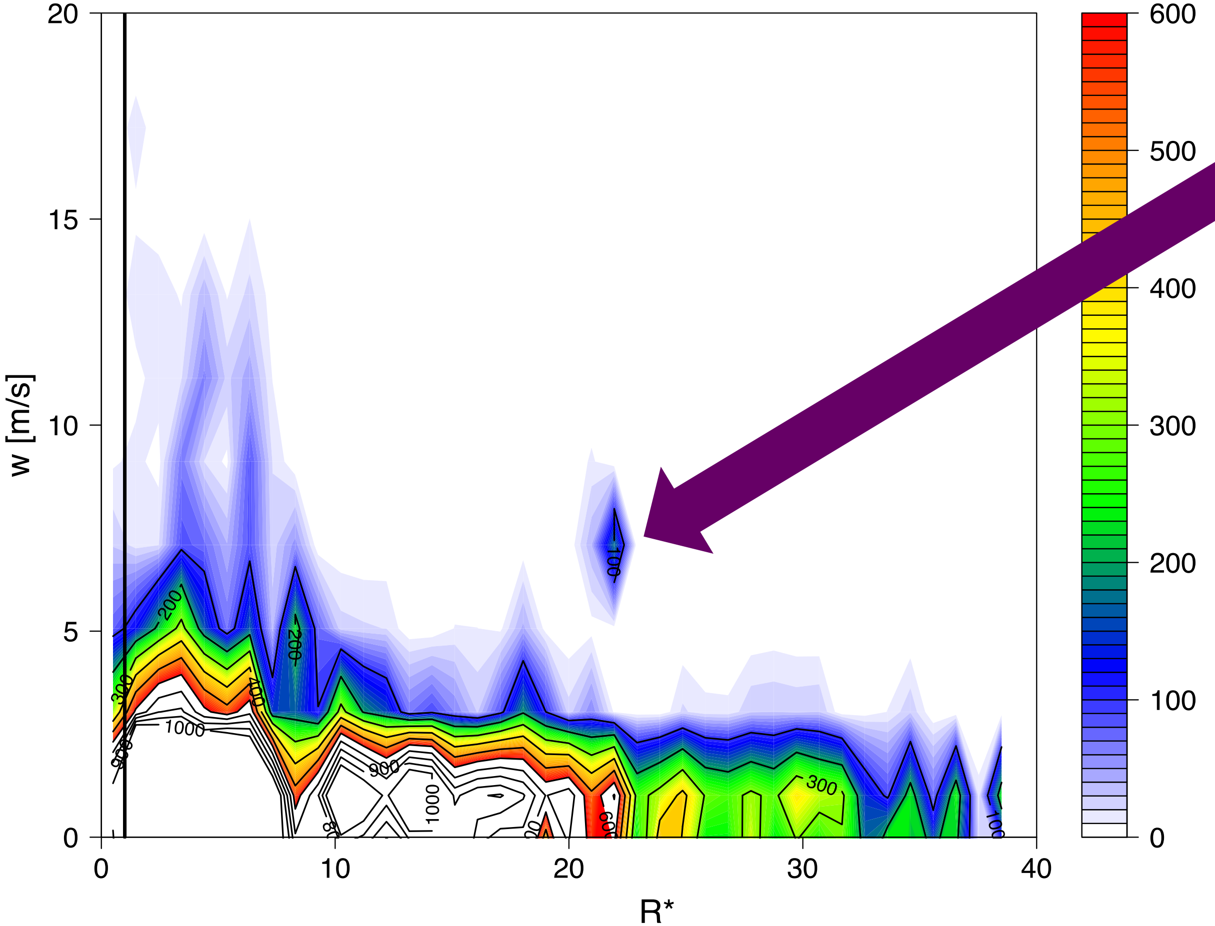
- Sharp increase at the average RMW
- Maximum vertical velocity tended to decrease with radius
- Broad maximum below 5 m s^{-1} over the inner core
- Most updrafts stronger than 5 m s^{-1} were outside the RMW at R* = 3

Joaquin (2 – 5 October 2015)



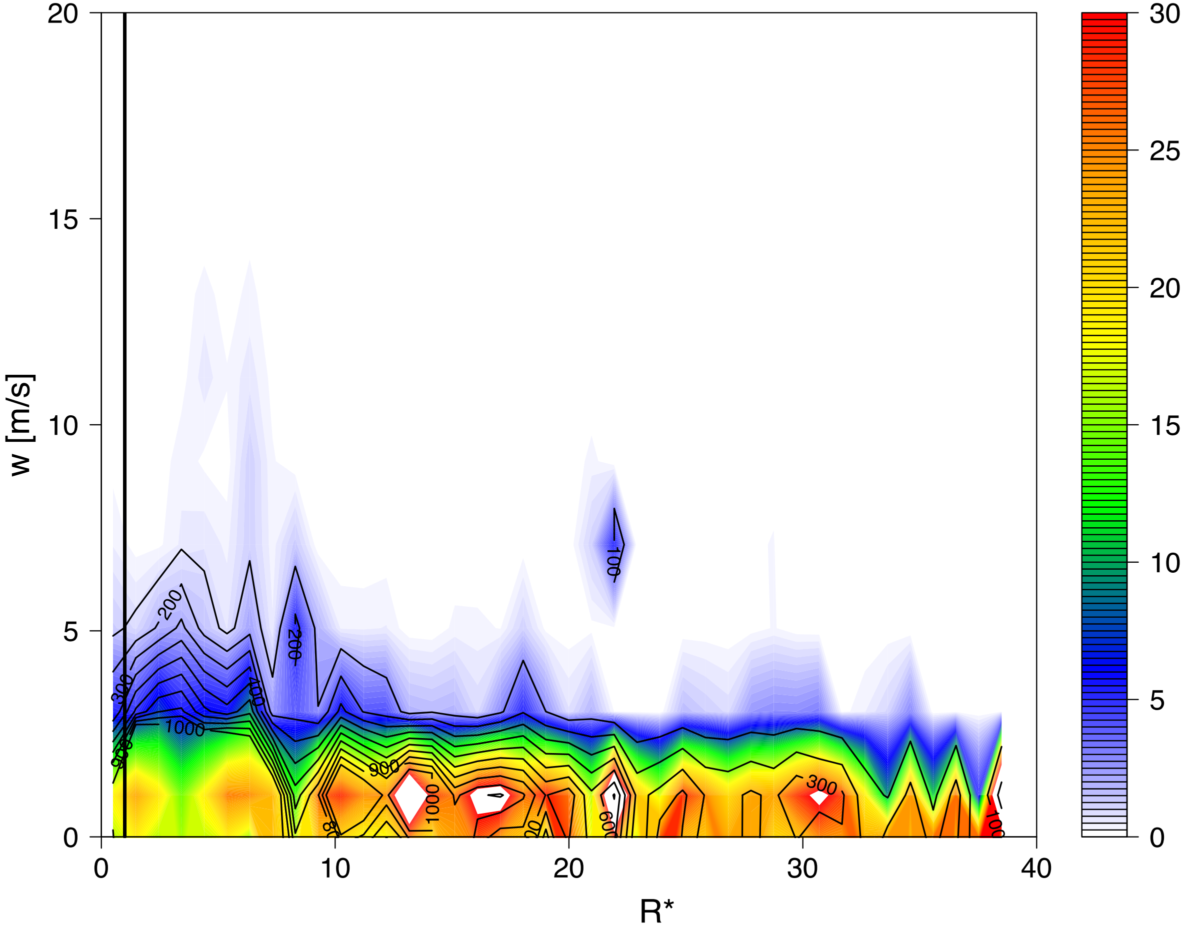
- Banded features evident with higher frequency lobes out to R*=30
- Updrafts in rainbands much weaker

Joaquin (2 – 5 October 2015)



- Unusual isolated lobe of high vertical velocity at R* = 22
    - Corresponds to 800 km peak

Joaquin (2 – 5 October 2015) Percentages



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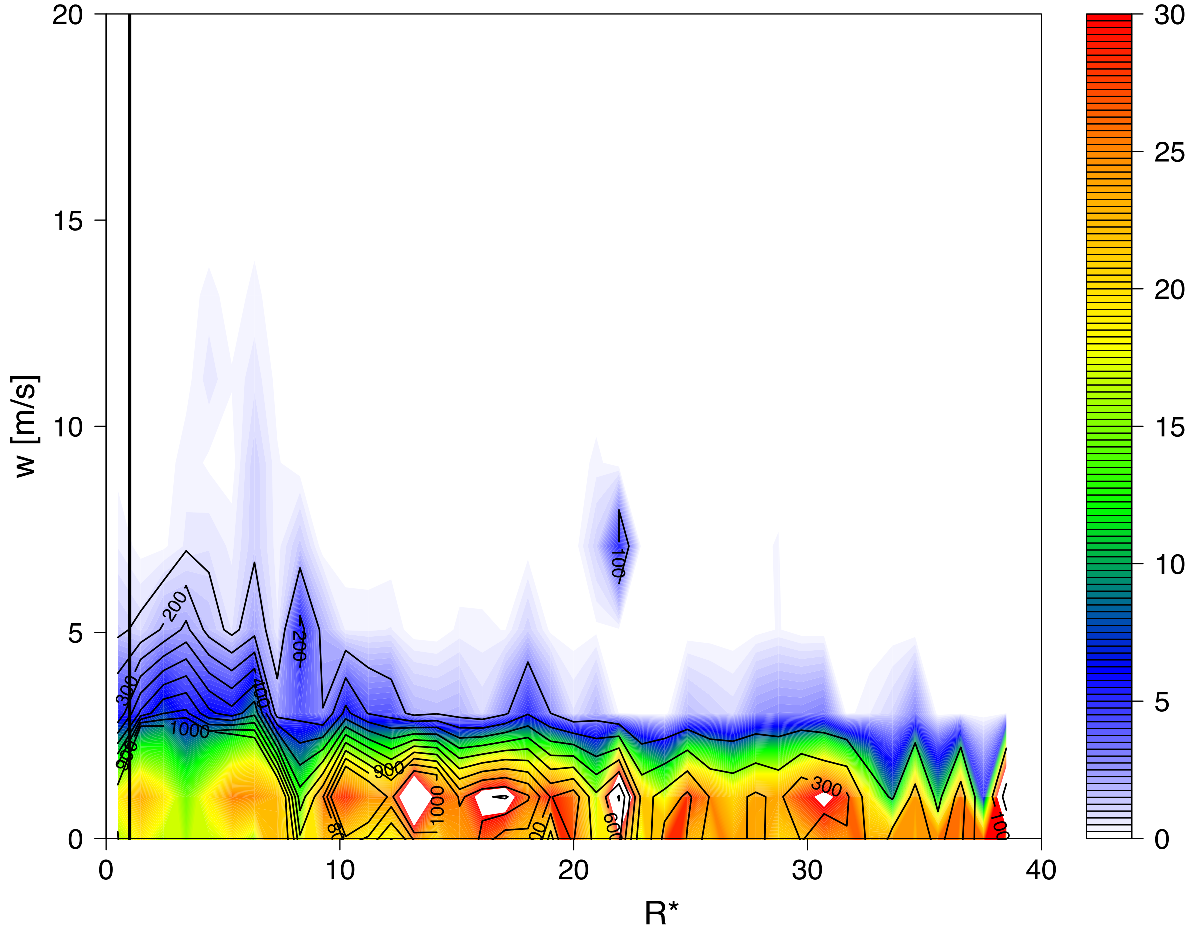
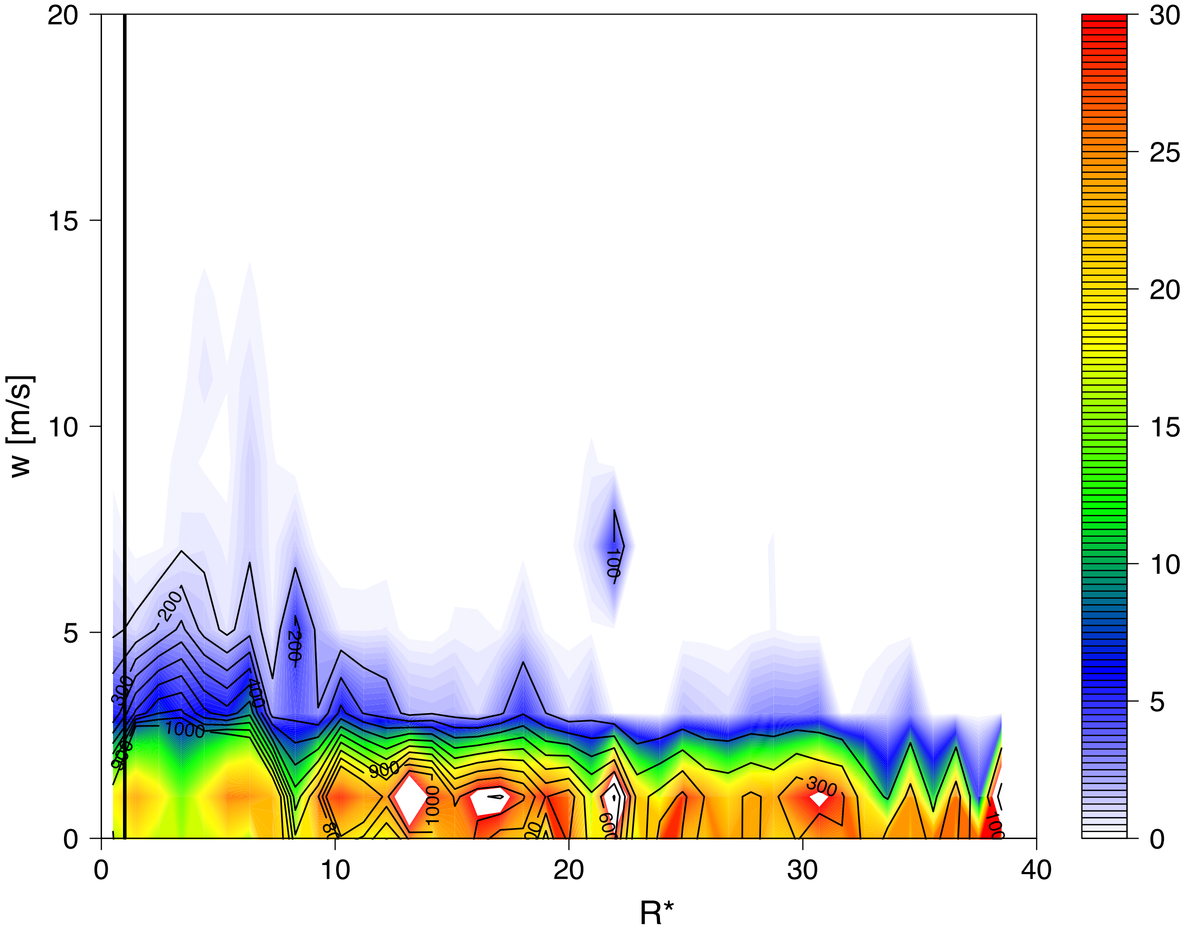


- Divide the number of data points in each vertical velocity and radial bin by the total number of data points in each radial bin
  - Sums up to 100% for vertical velocities from -20 m s^{-1} to +20 m s^{-1}
- Black contours are frequency in intervals of 100 from previous slide

Joaquin (2 – 5 October 2015) Percentages

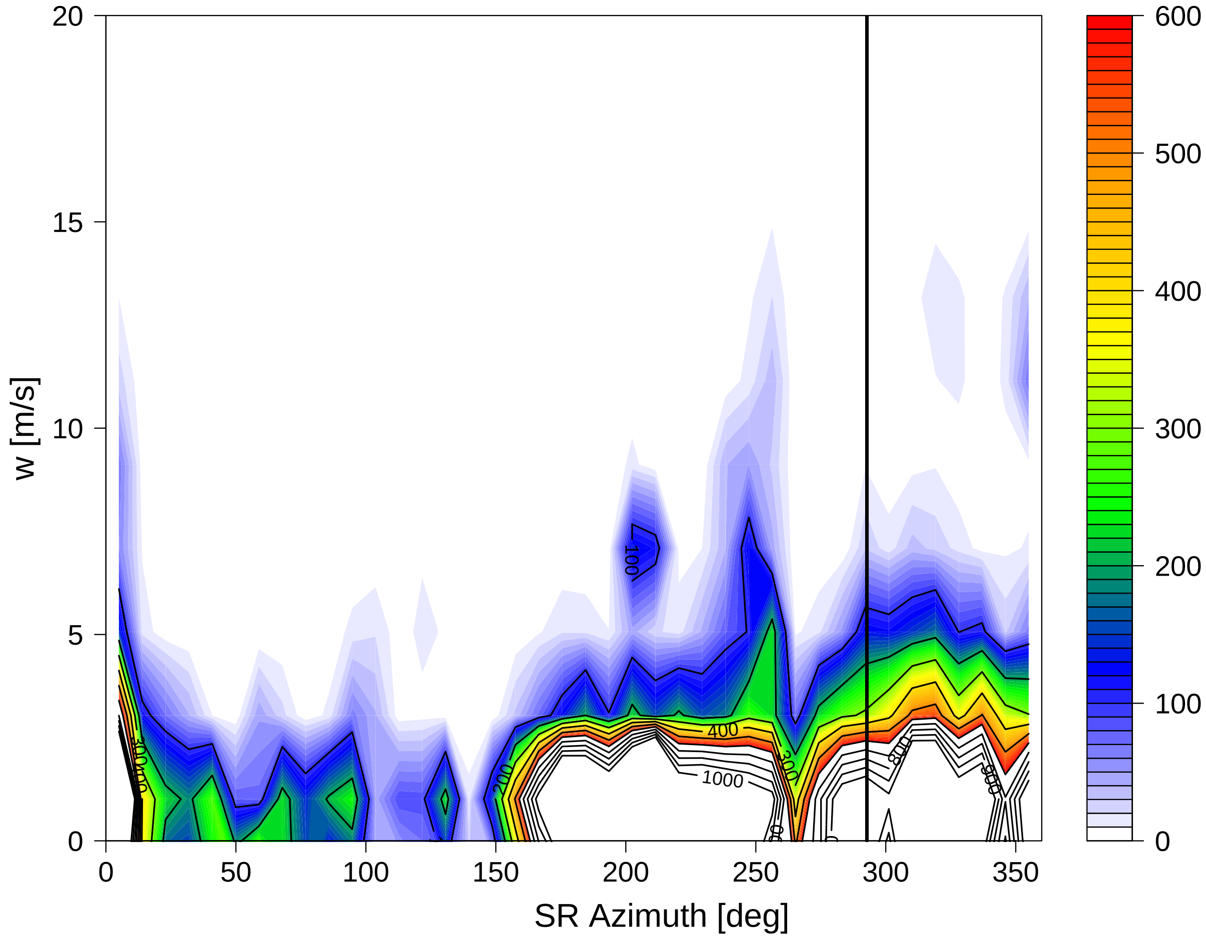


- Still see a decrease in vertical velocity maxima with increasing radius outside of the inner core
- Unexpected point at R* = 22 still there

Results: CFAzDs*

* For updrafts only

Joaquin (2 – 5 October 2015)



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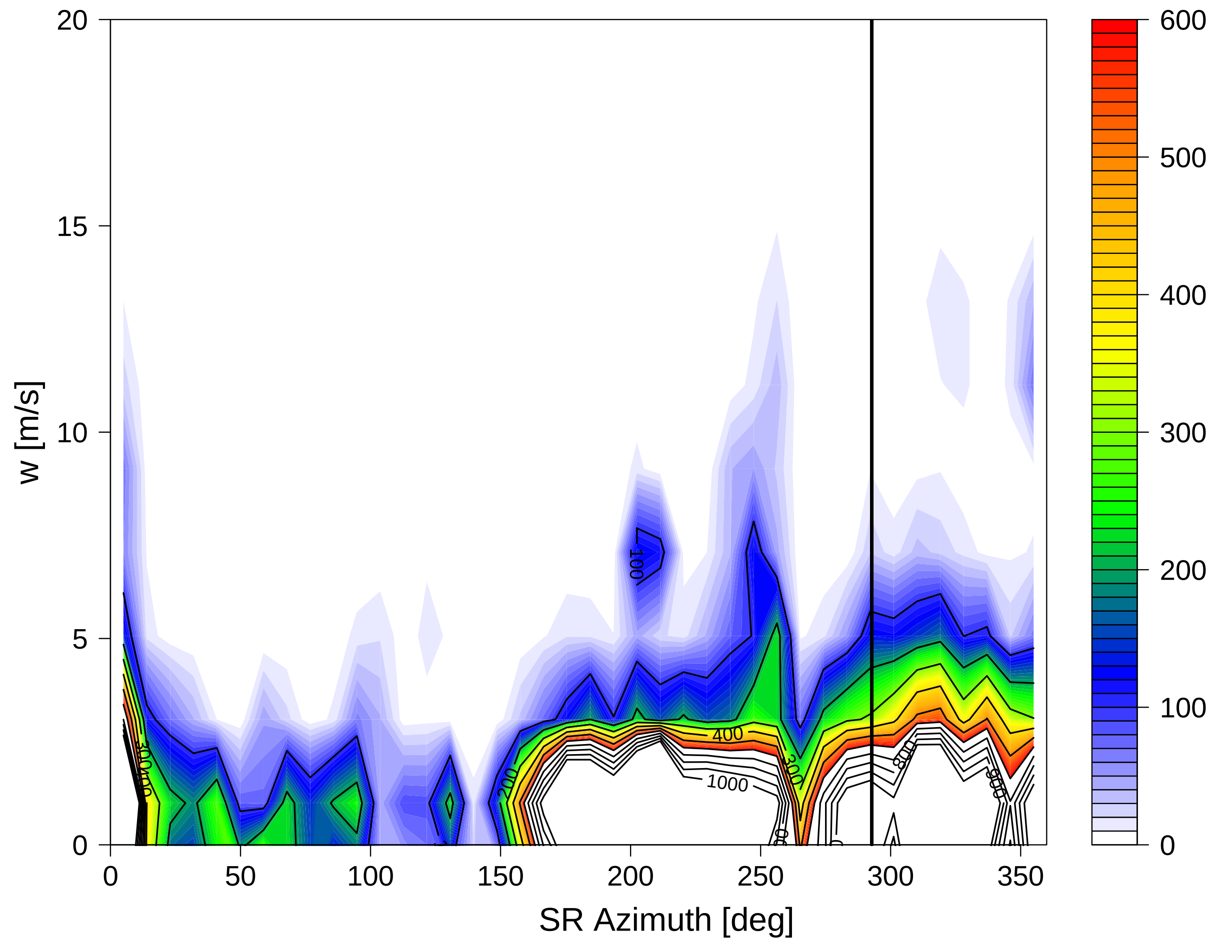
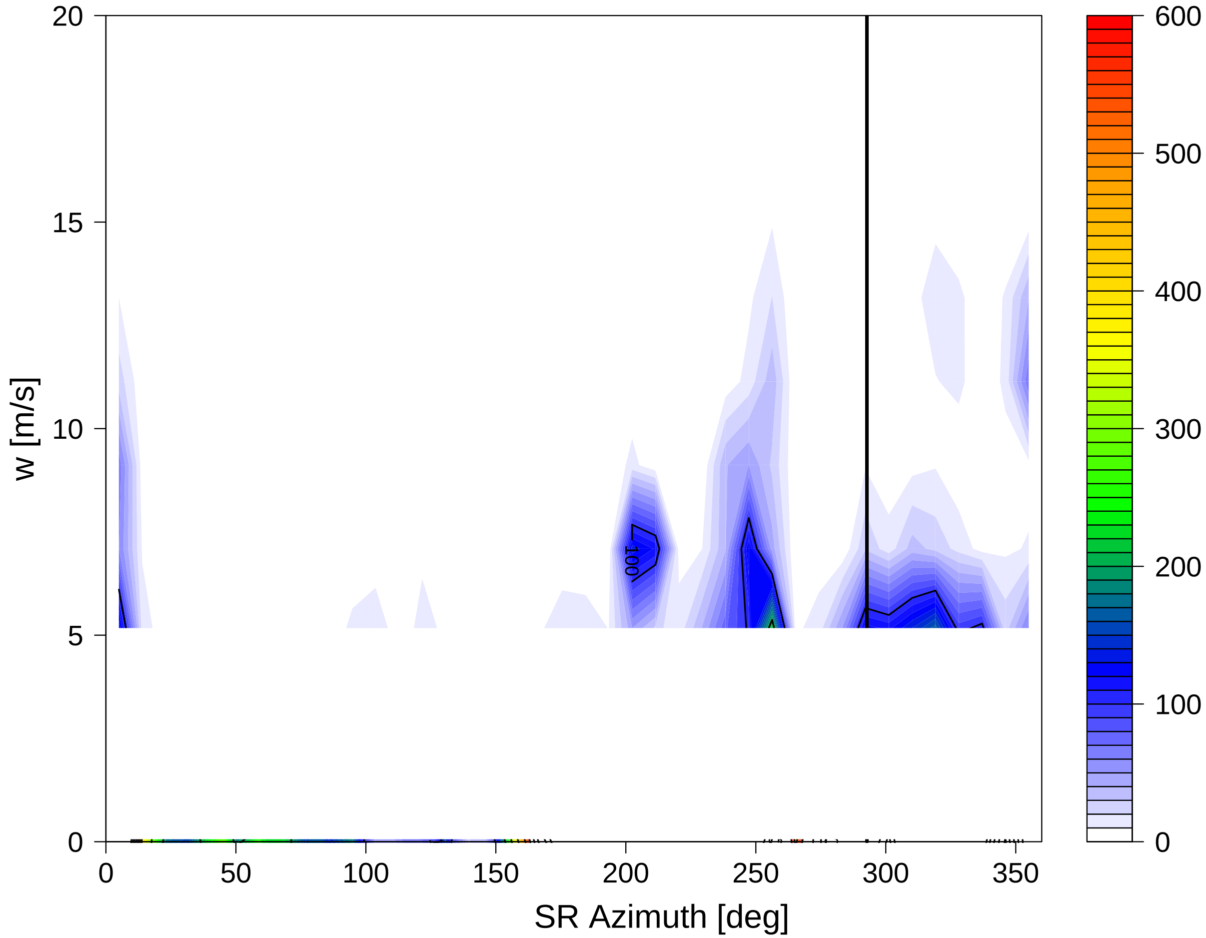


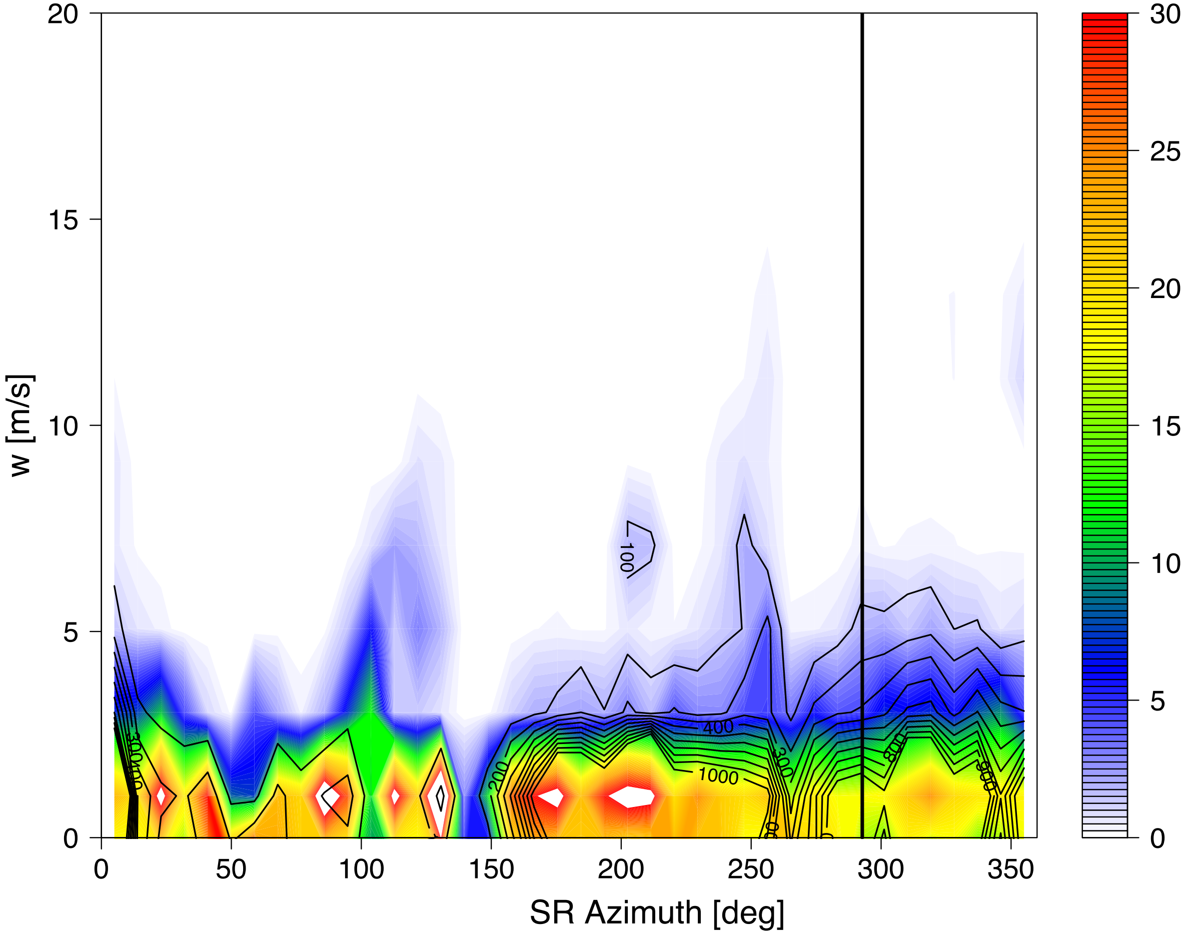
- Frequency maxima in left of shear
- Updrafts stronger than moderate threshold mainly between 200 and 360°
- Suppressed convection in USR (?)

Joaquin (2 – 5 October 2015)

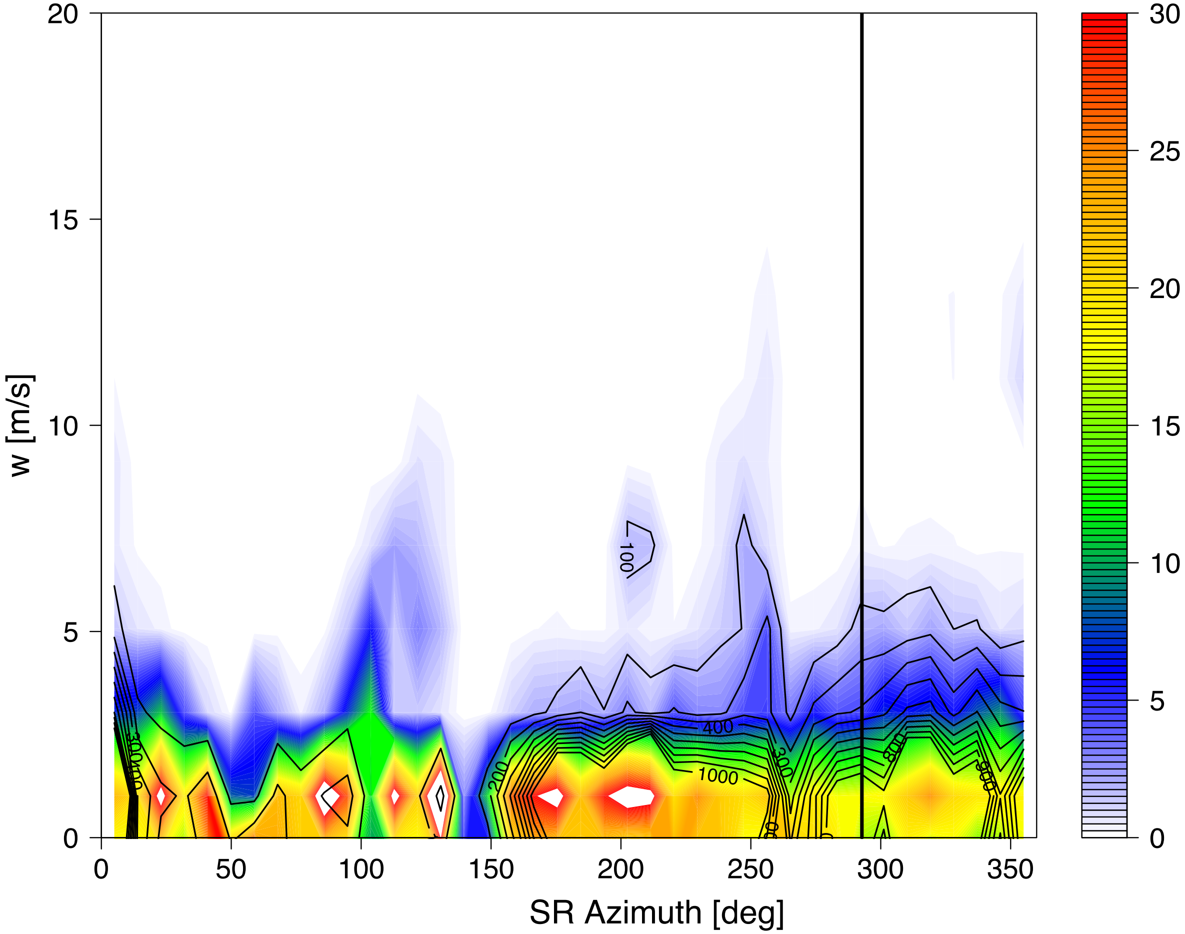


- Looking at just above the moderate threshold:
  - Convective suppression in DSR and USR
  - Convective maxima in downshear

Joaquin (2 – 5 October 2015)
Percentages

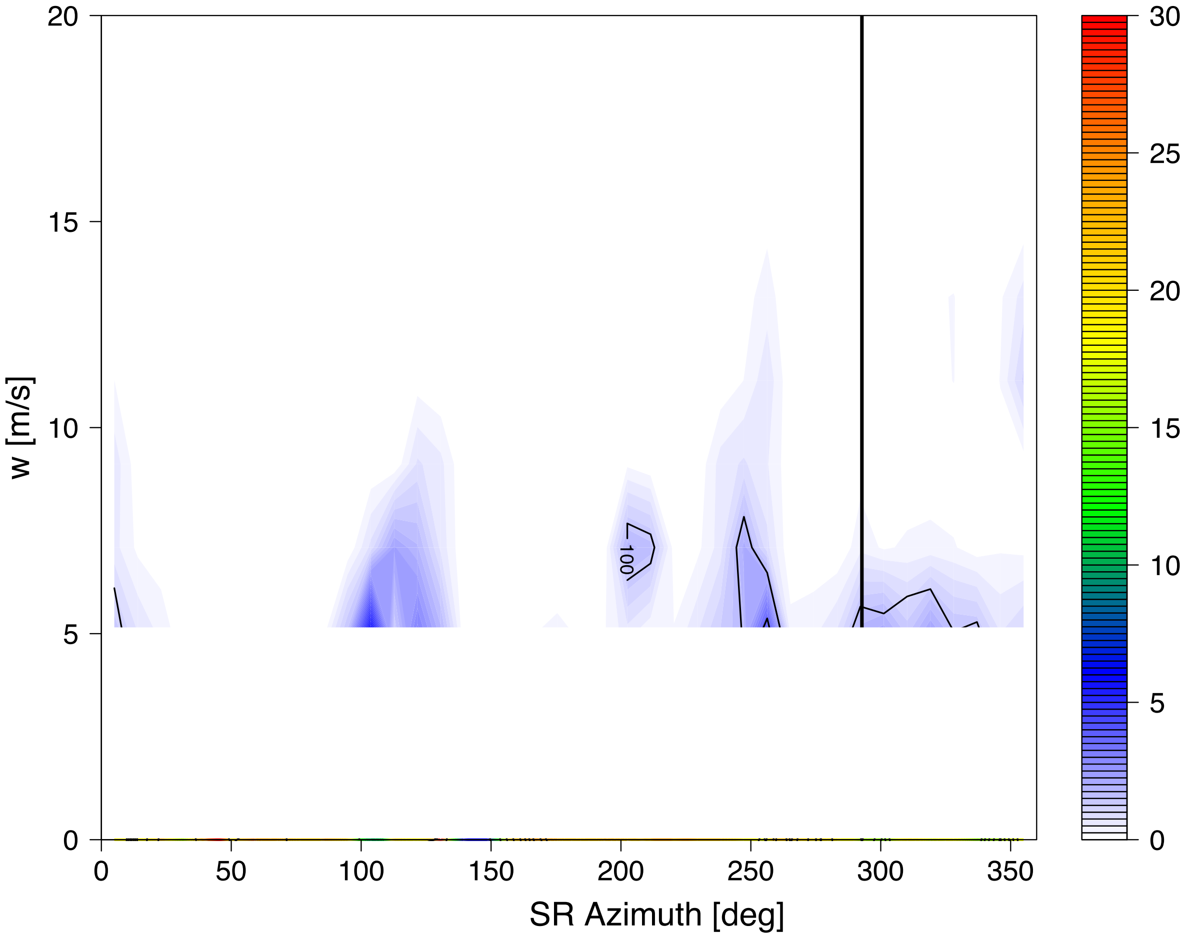


Joaquin (2 – 5 October 2015) Percentages



- Broad nose of stronger updrafts in the DSL
- Sharp peaks of stronger updrafts in the USL and USR
- Convective suppression near 50 and 150°

Joaquin (2 – 5 October 2015) Percentages



- Looking at just above the moderate threshold:
  - Convective suppression in DSR and USR (only 140—180°)
  - Sharp peak in USR dominates

Updrafts + Downdrafts

> |5 m s^{-1}|

3219	542
2194	556

> |8 m s^{-1}|

794	287
797	124

> |10 m s^{-1}|

487	116
488	35

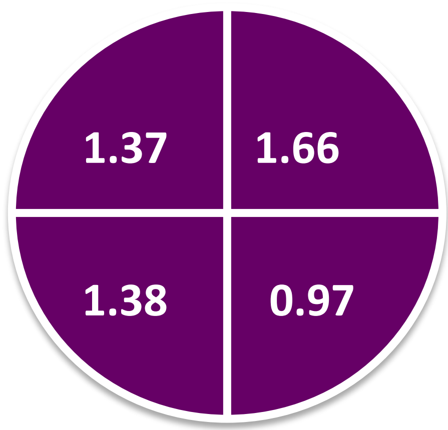
- Moderate convection occurred mainly in the DSL quadrant with a secondary maxima in the USL. Strong and extreme convection maximized in the USL quadrant with a secondary maxima in the DSL

Updrafts + Downdrafts Normalized

*In percent

> |5 m s^{-1}|

> |8 m s^{-1}|

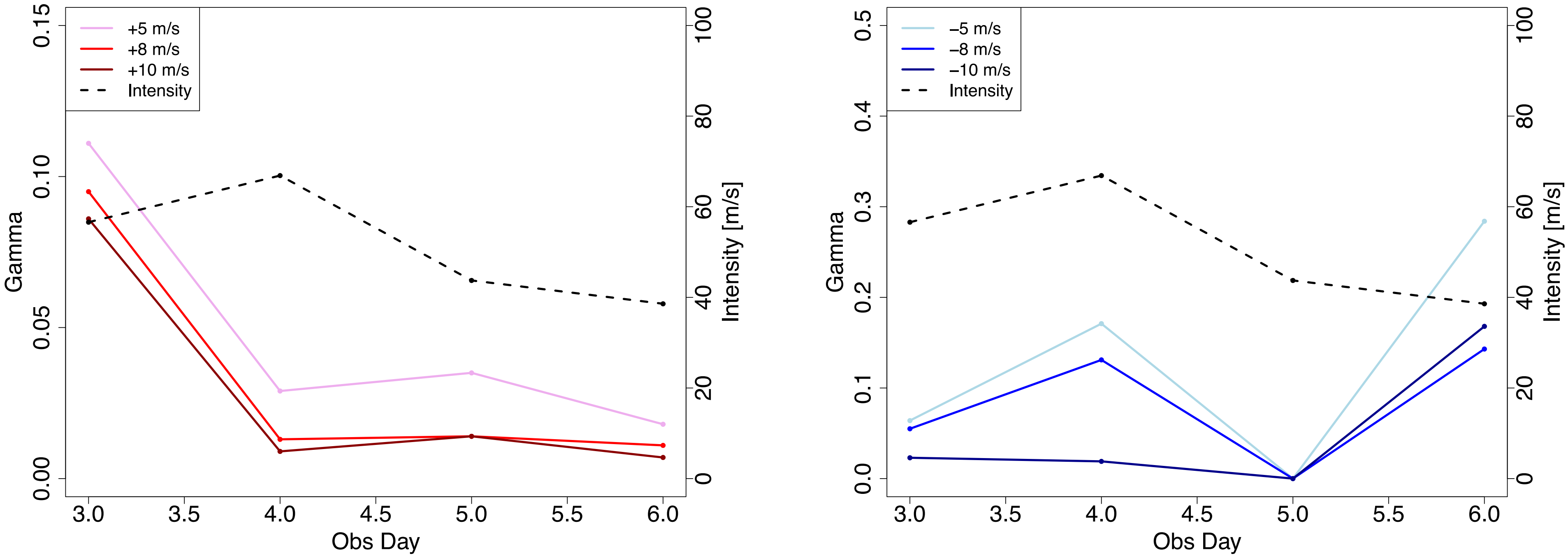


> |10 m s^{-1}|

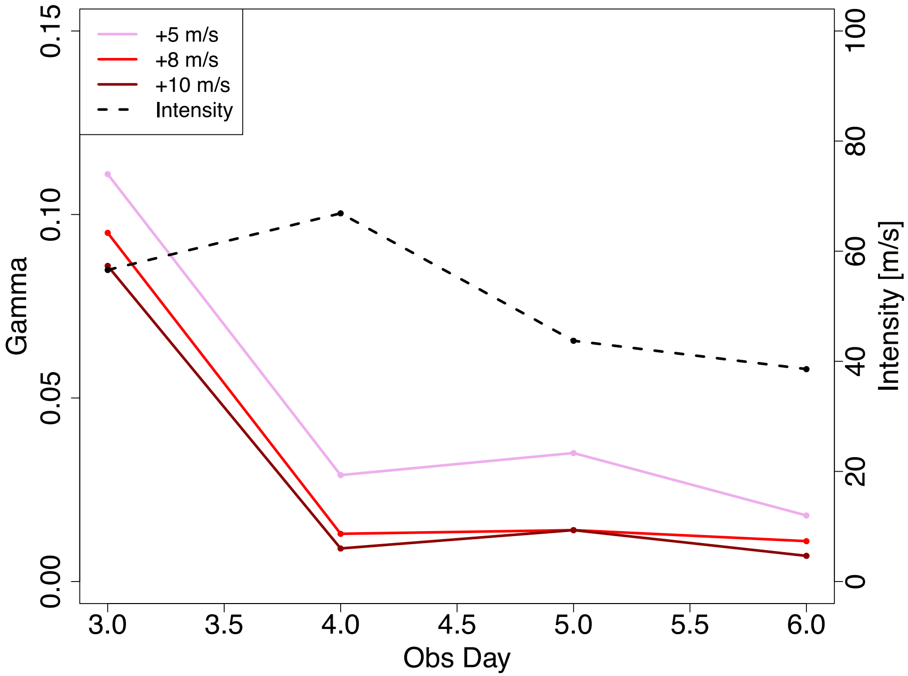
- Most convection in down-shear and left quadrants
  - Preference for DSR in strong UDs…BUT, not what it seems….
  - DSL had more data points further out radially and strength tends to decrease with increasing radii
  - Could also explain peak in percentage CFAzD for USR

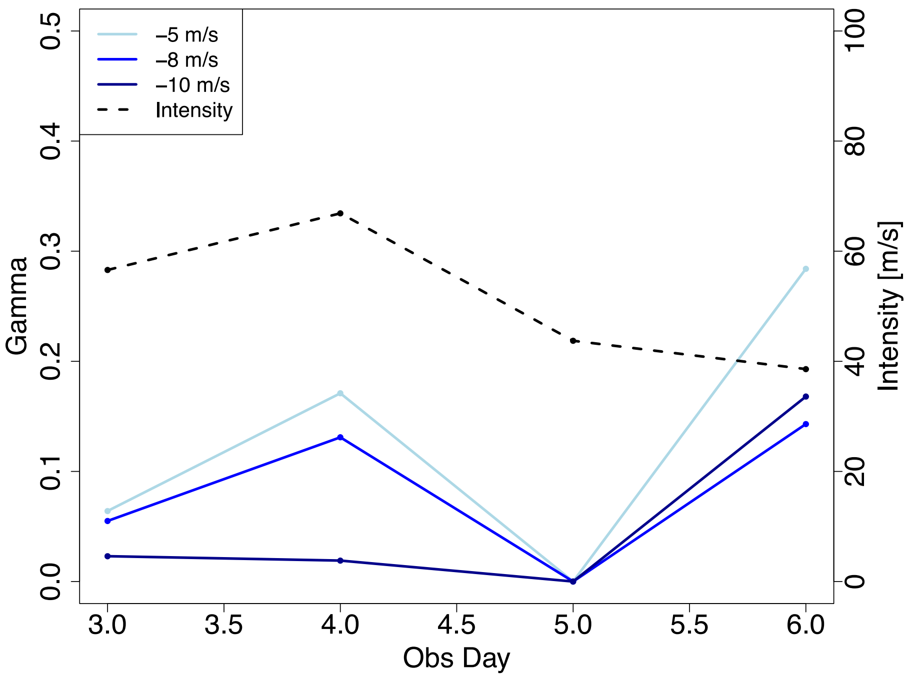
Results: Gamma and RMW

Gamma Values



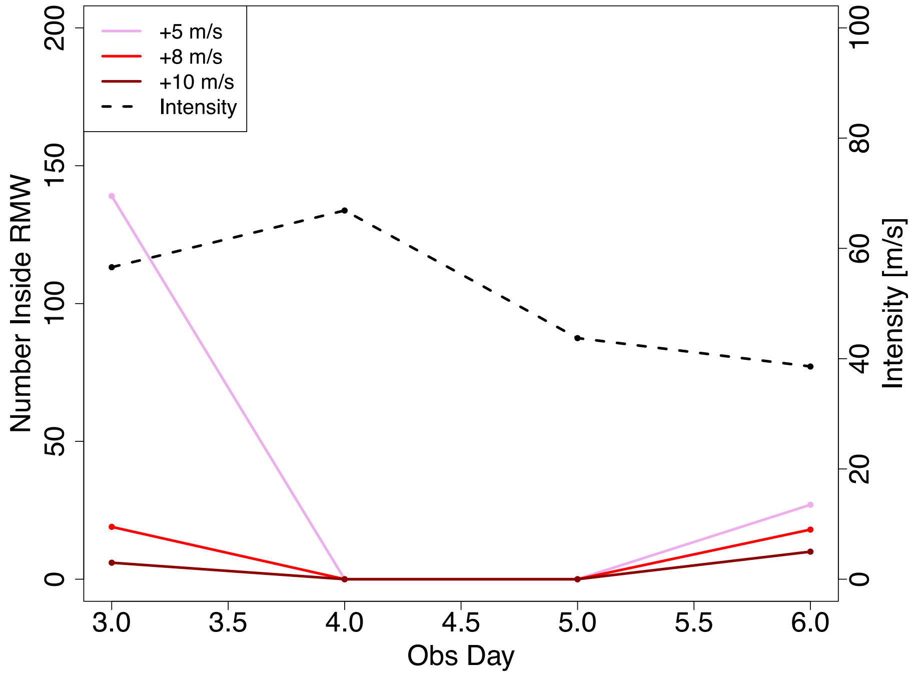
Gamma Values

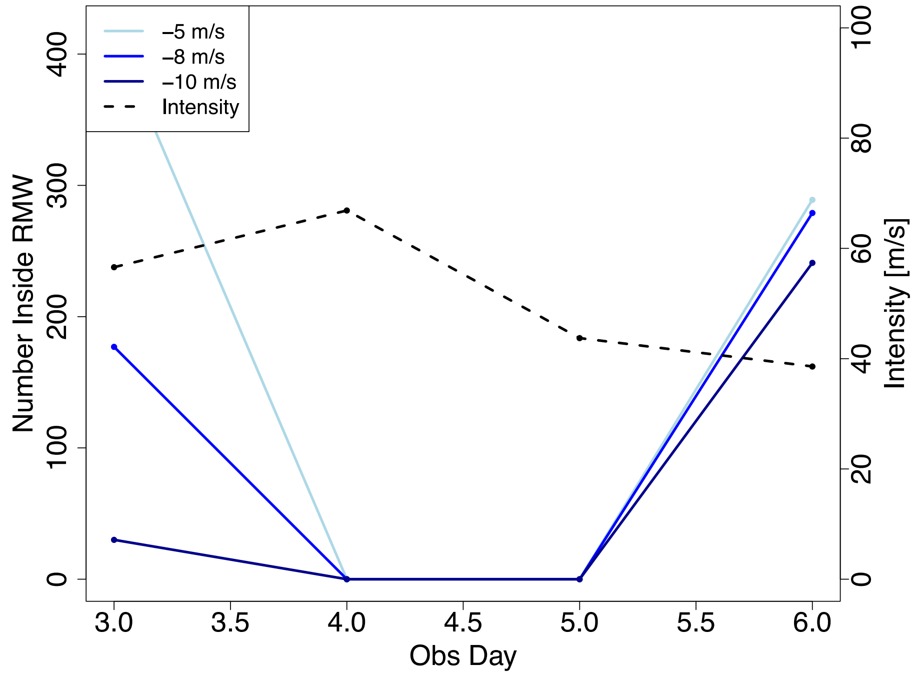




- Gamma tended to maximize for positive thresholds just before intensification
- Gamma tended to maximize for negative thresholds once a TC has hit its peak and begins to decay

Number of UD Data Points Inside RMW





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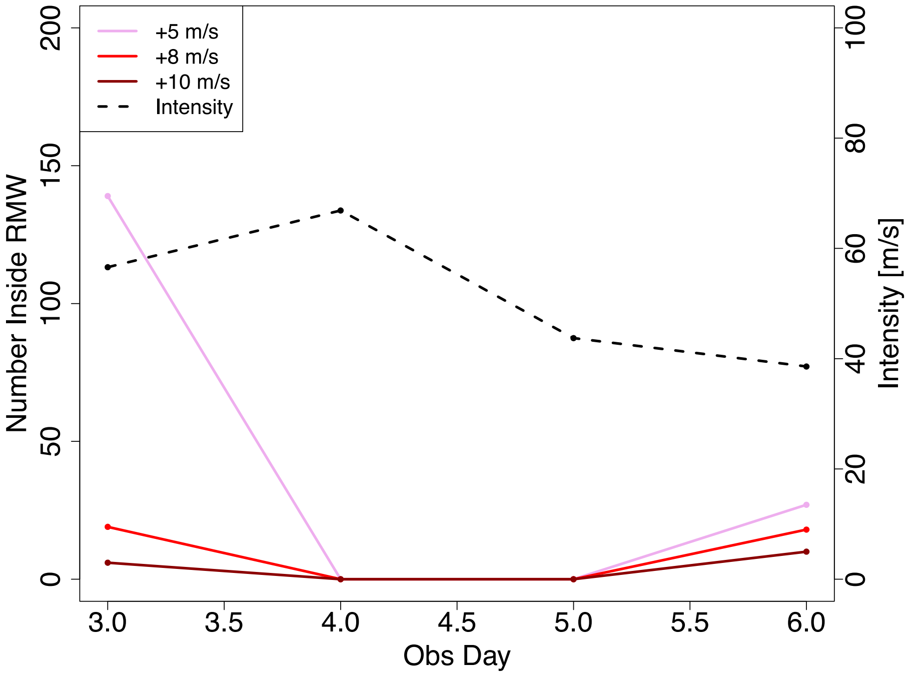
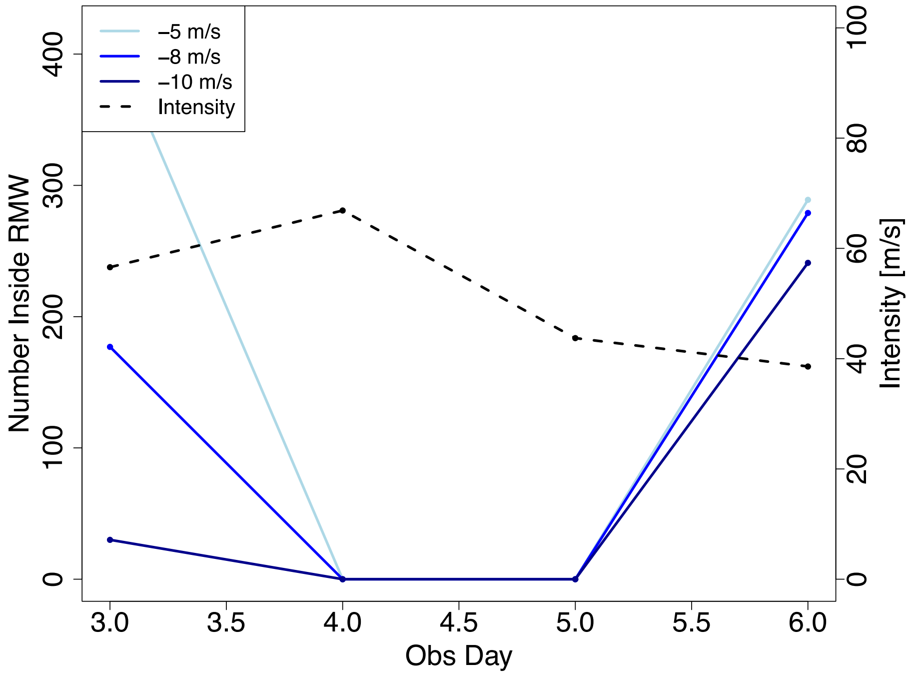
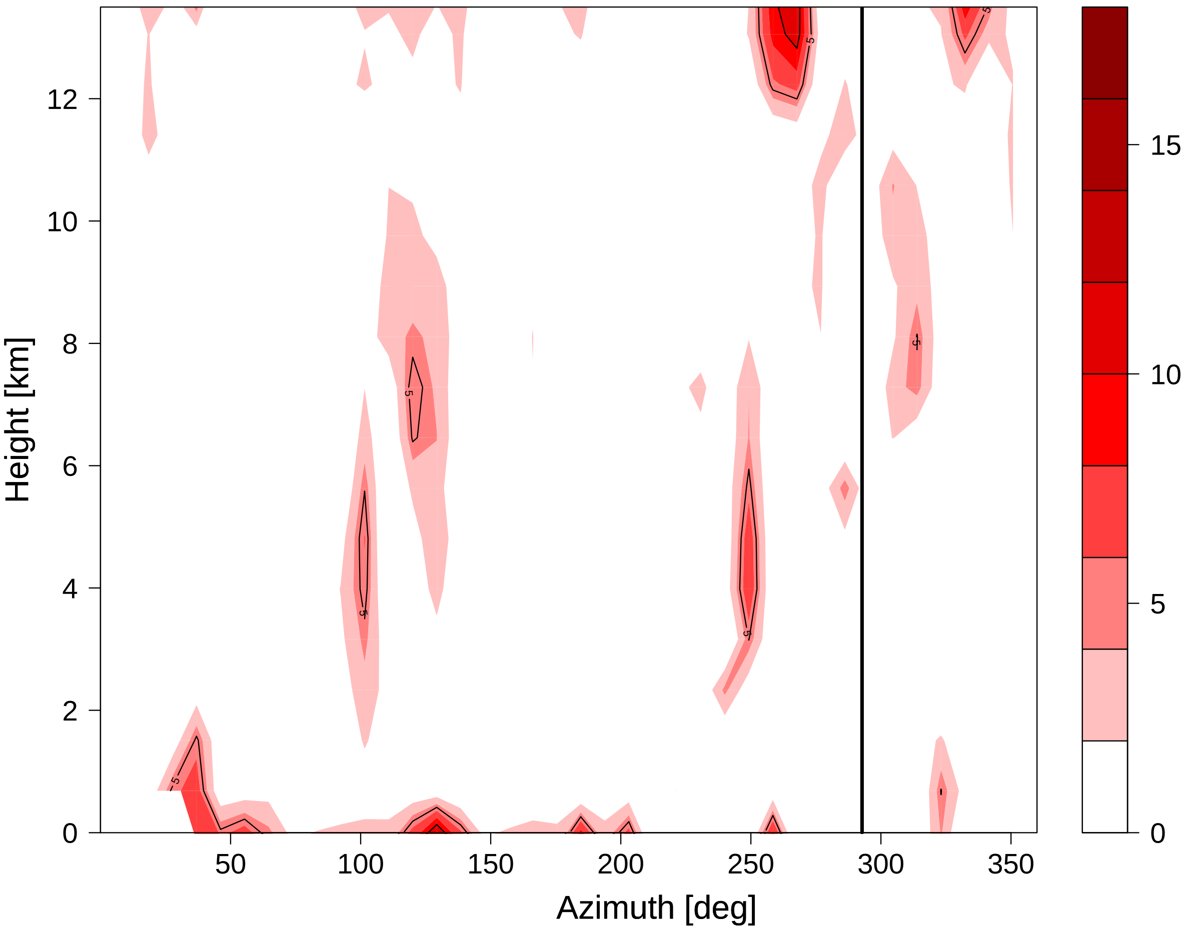




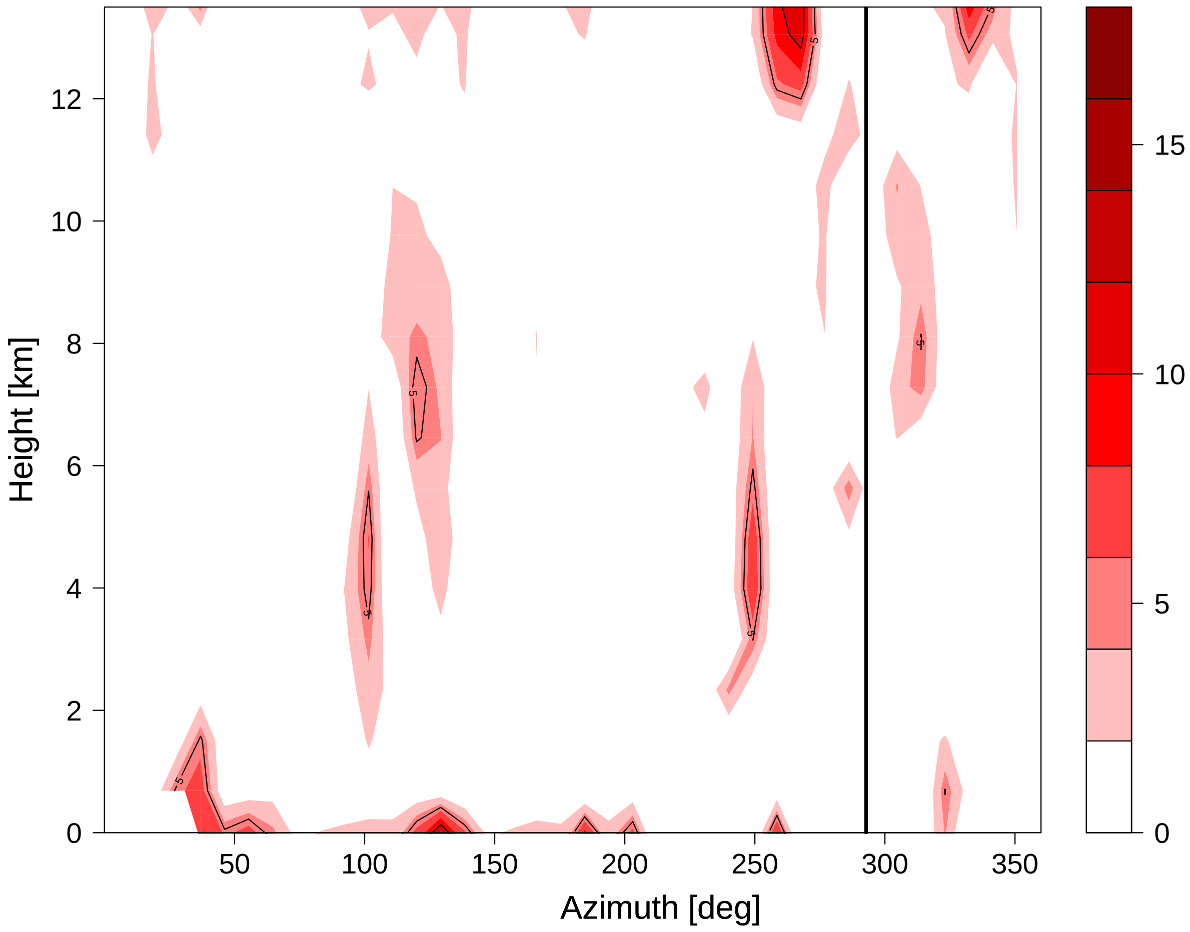
- For both positive and negative thresholds, it appears that there was an increase in convective activity inside the RMW before intensification and it minimized inside the RMW at maximum intensity

Results: Azimuthal and Radial Composites

Azimuthal Composite

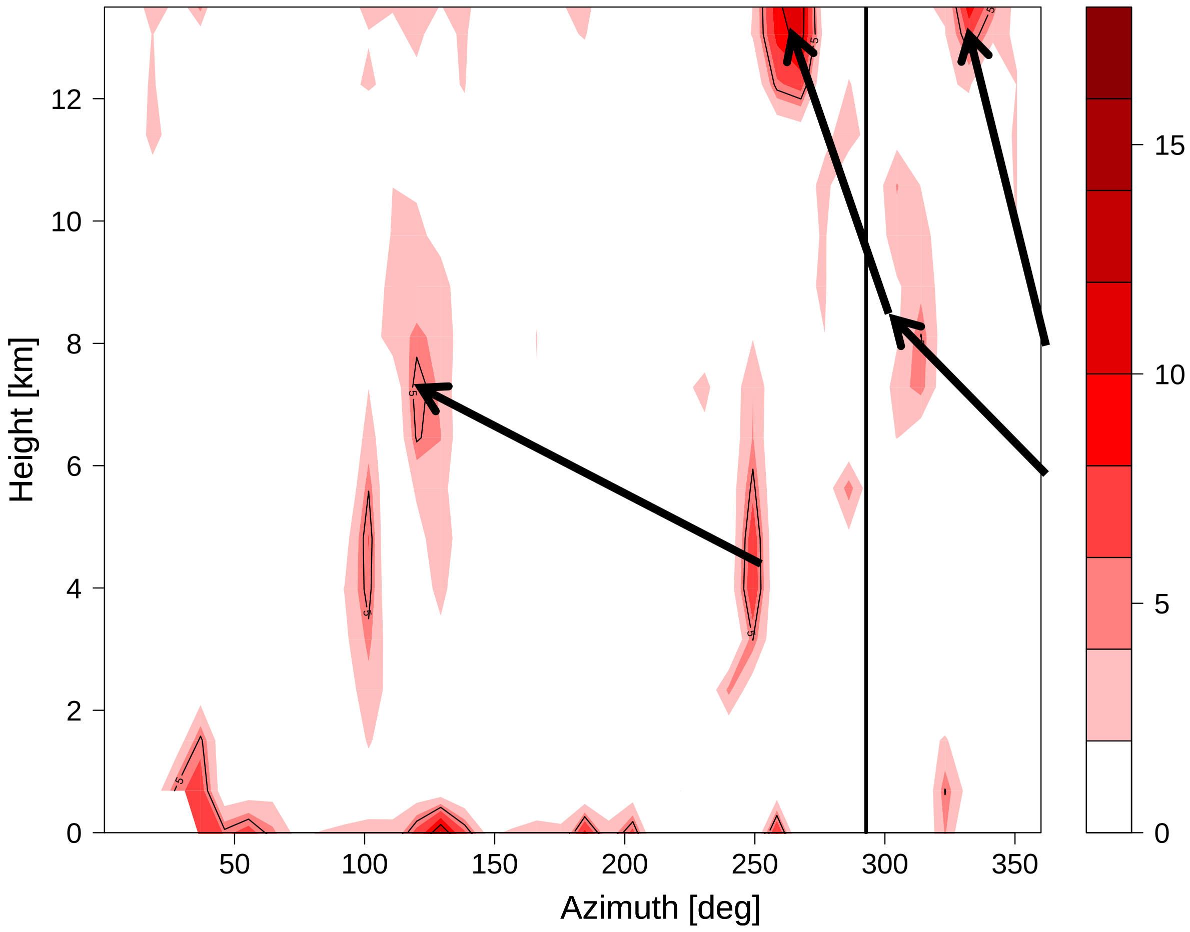


Azimuthal Composite



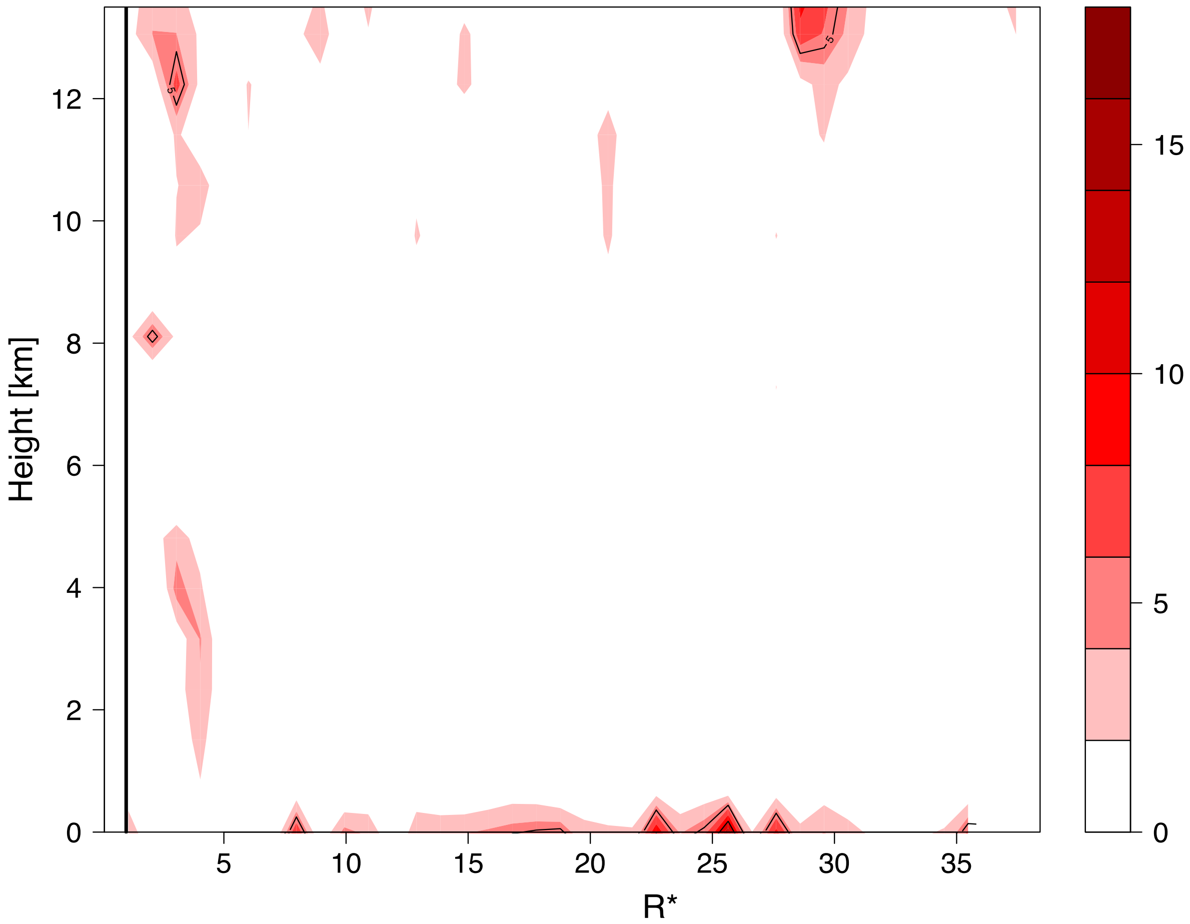
- Evidence of helical rise in updrafts:
  - Initiate in DSR and USR between 50 and 200° **AND** DSL near 325°
  - Rise and maximize in mid-levels and aloft in the downshear

Azimuthal Composite



- Evidence of helical rise in updrafts:
  - Initiate in DSR and USR between 50 and 200° **AND** DSL near 325°
  - Rise and maximize in mid-levels and aloft in the downshear left
  - Unclear as to which surface updrafts rise
    - Need

Radial Composite



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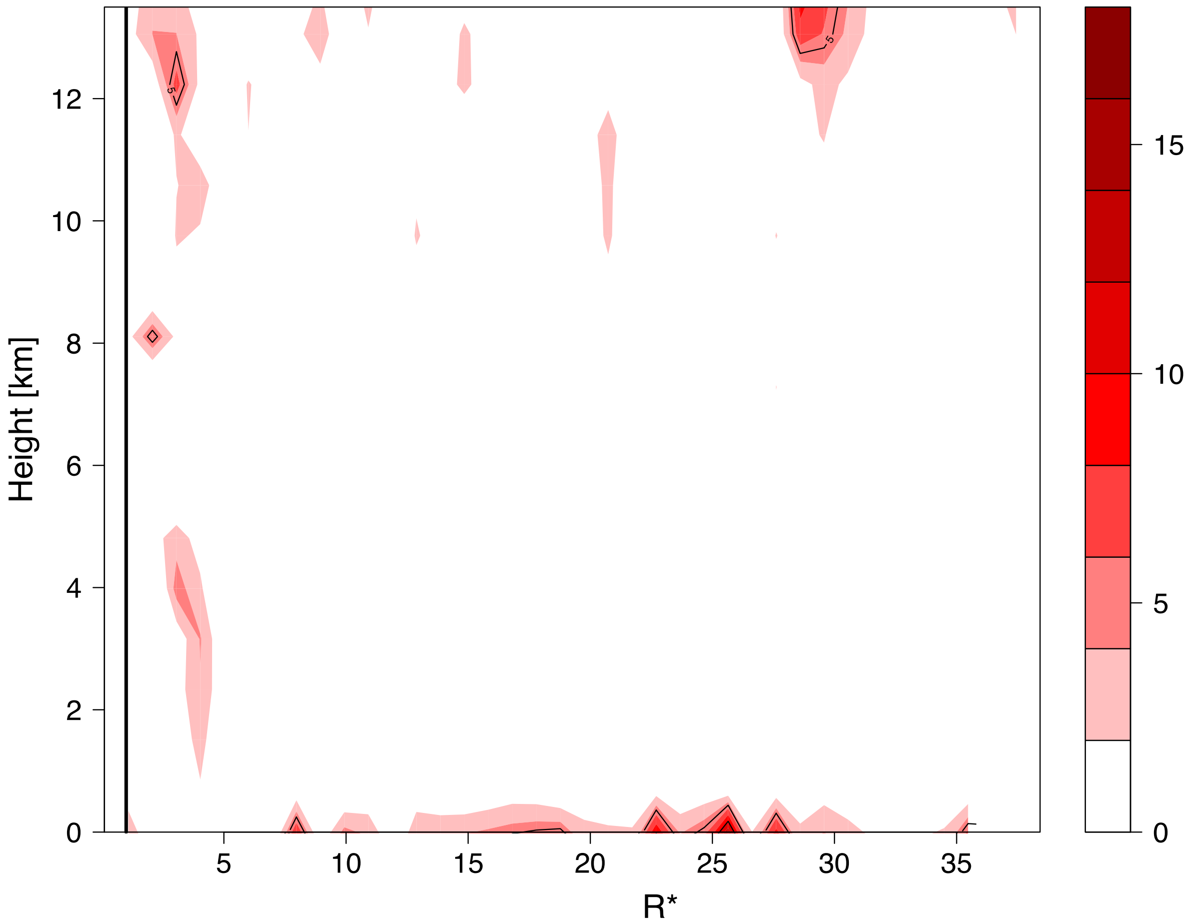

- Inner core updrafts were above 10 km and below 5 km
- Surface based strong updrafts beyond R*= 8
- Upper level updrafts further outward radially at R*= 30
- All outside of RMW

Discussion

- Distinguishing the altitudinal, azimuthal, and radial tendencies for moderate, strong, and extreme UDs plays a crucial role in:
  - Understanding how shear interacts with TCs
  - TC intensity changes
- Conducted using XDD Dropsondes in Joaquin (2015)
- Extension of Stern et al. (2016) and Stern and Aberson (2006), which only had data in lowest 2 – 3 km
  - Most comparable studies to this current work

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TC Intensity

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  - Some correlation between convection (via gamma parameter) and intensity
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UD Locations

- Occurred both inside and outside the RMW, but decreased in strength outside of “inner core”
  - Collectively, majority of UDs were outside of RMW
- Outside of inner core, oscillatory pattern of convection of rainbands
- Vertical velocities maximized:
  - Aloft near 12 km (Jorgensen et al. 1985; Marks et al. 2008; Rogers et al. 2012)
  - Just above the surface (Stern et al. 2016)
- Convection tended to maximize **BROADLY** in the DSL quadrant for UDs (Black et al. 2002; Corbosiero and Molinari 2002, 2003; Stern and Aberson 2006; Guimond et al. 2010; Reasor et al. 2013)
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Composite Plots

- Radial composite plot showed evidence of inner core convection maximizing aloft
- Outside of the inner core, surface updrafts increased in strength
- Azimuthal composite plots show strong surface updrafts rising helically
  - Location of initiation variable
    - DSR/USR and DSL
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Future Work

- Examine the sources of these moderate, strong and extreme UDs
  - 37 GHz polarization correction temperature microwave data and satellite data (Naval Research Laboratory)
  - Moisture and buoyancy
  - Bulk Richardson number
  - CAPE
  - Sea surface temperature
  - Potentially, modeling initialized on soundings
- Differentiating between inner core convection and inner rainband convection
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Conclusions

- UDs occurred in throughout Joaquin regardless of intensity or shear strength
- Occurred both inside and outside RMW
  - Inside RMW maximum before intensification
- DSL convective preference
- Suppression in parts of the USR and DSR
- UD strength maximized aloft
- Helically rising updrafts

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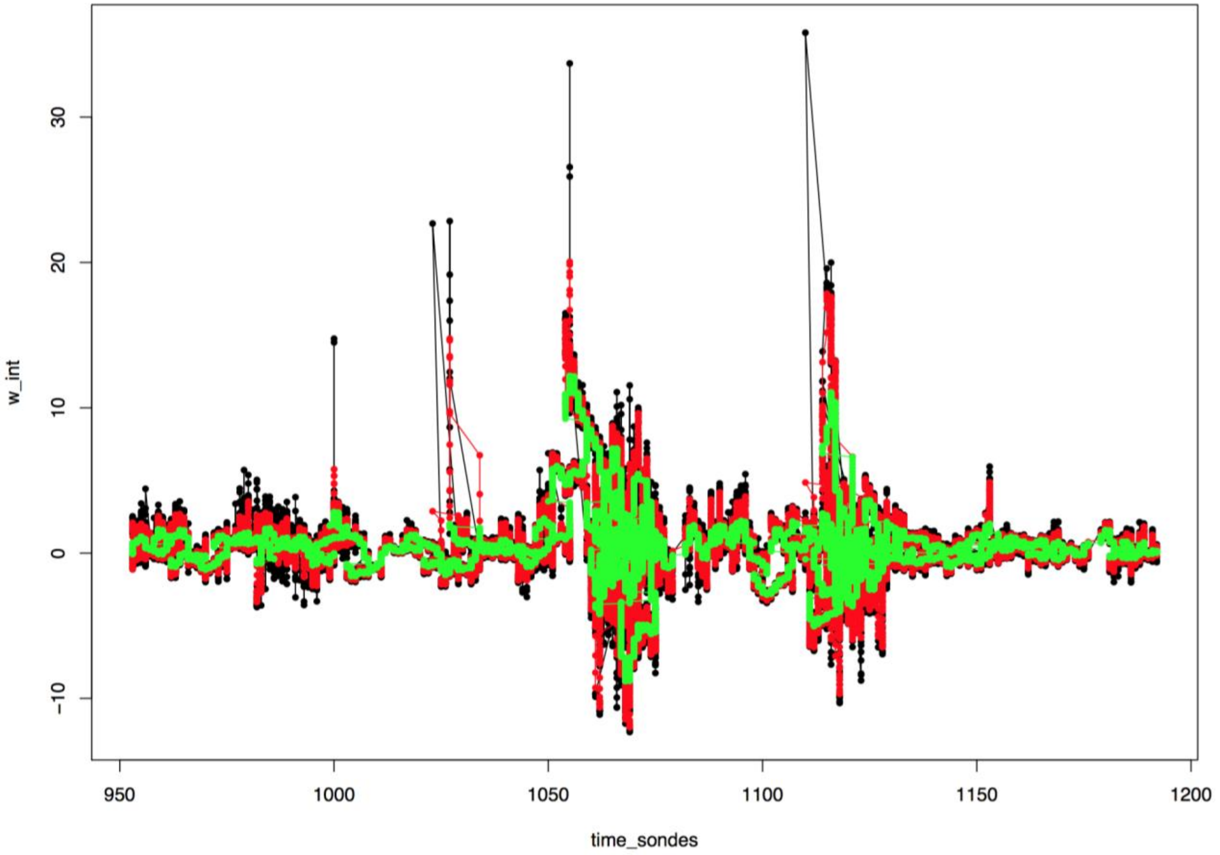
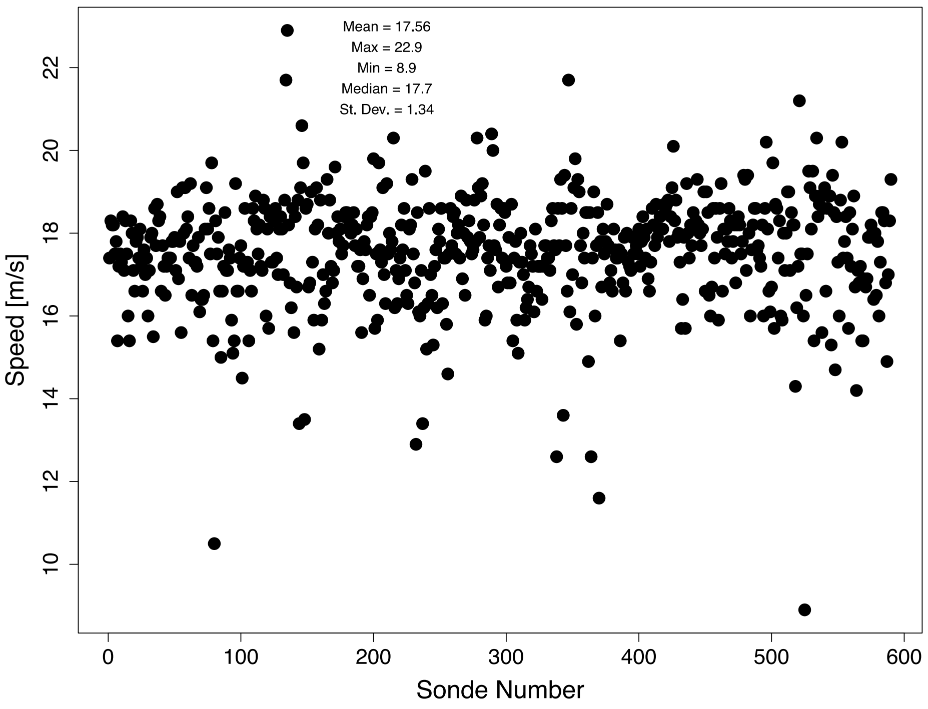
Bonus Slides

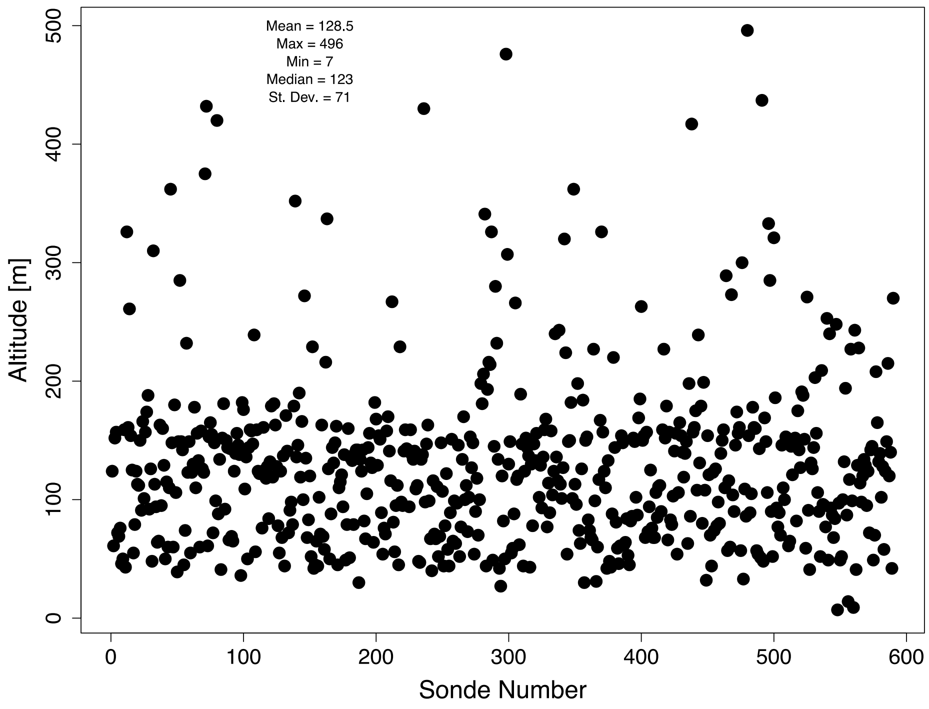
Filtered Data Example



- Example of filtering of data: Joaquin on 02 Oct. 2015
- Black is raw data
- Red is nine-point binomial filter
- Green is 100 Hz Butter filter that has been corrected for phase shift

Surface Fall Speed Factor





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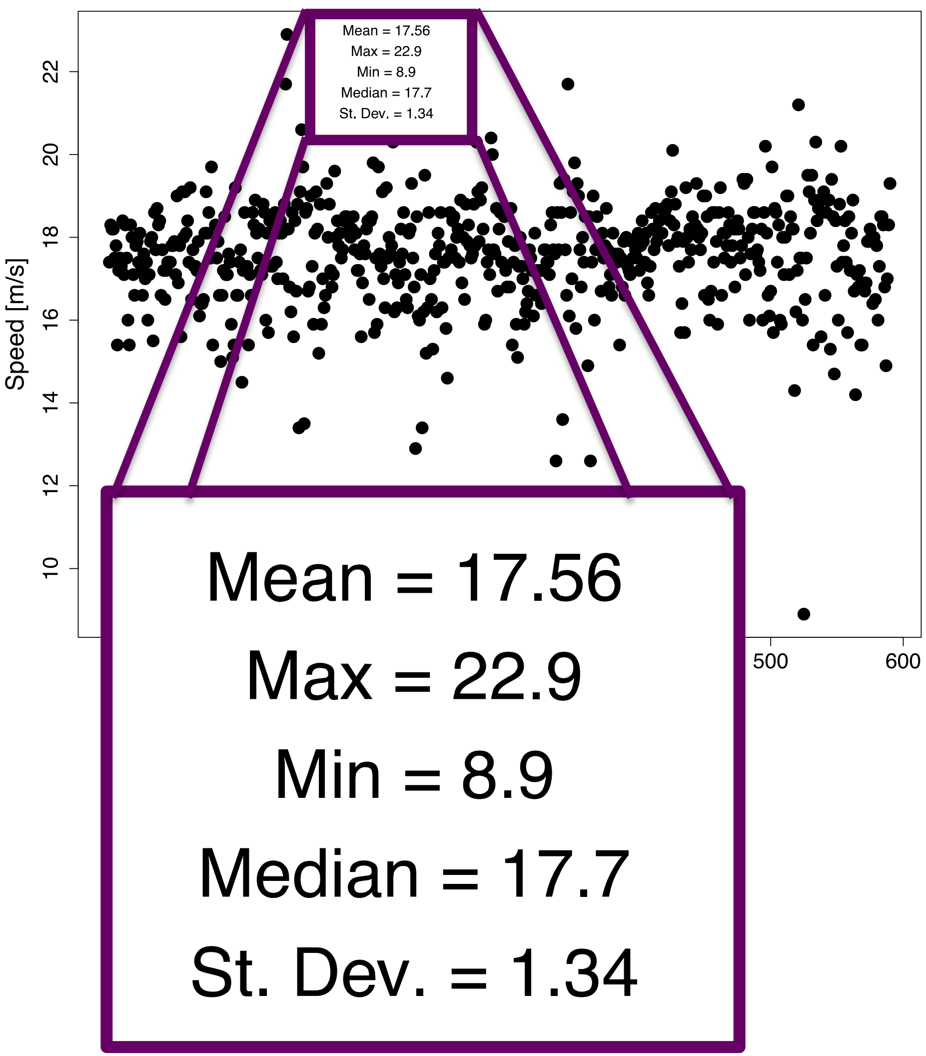

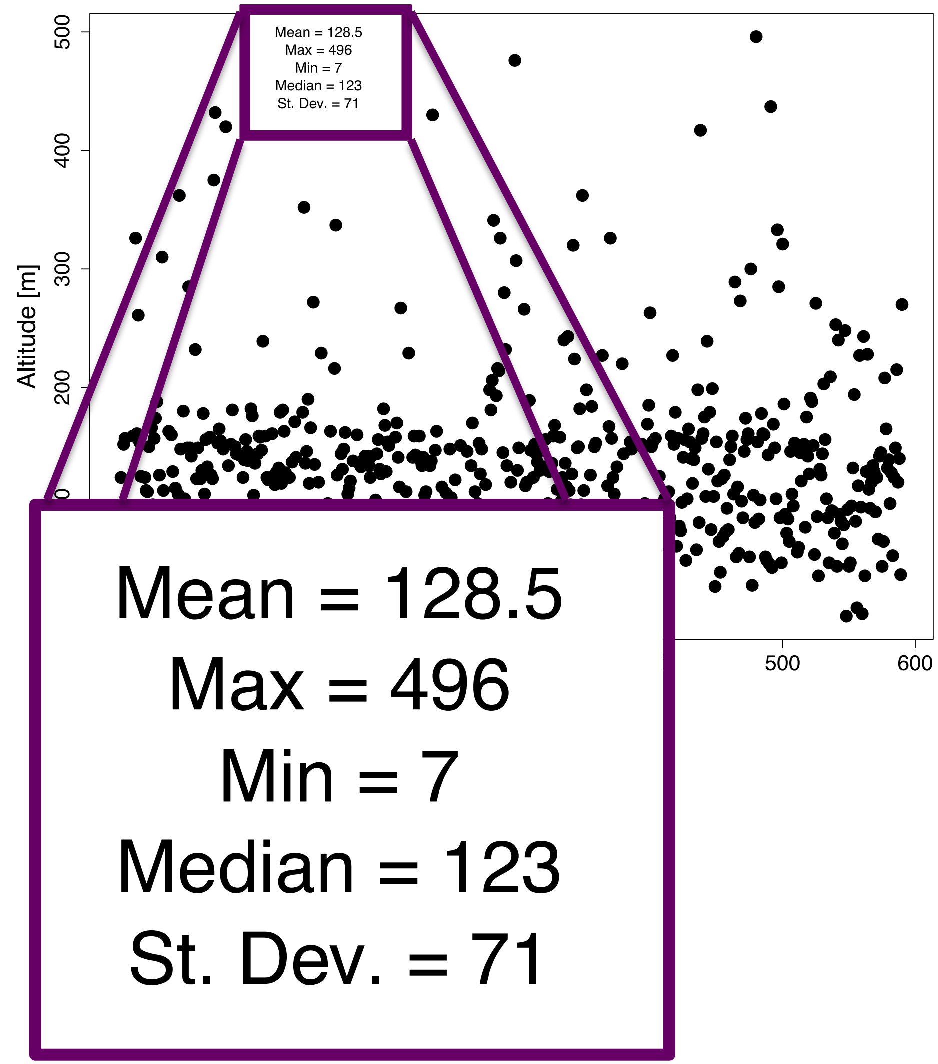

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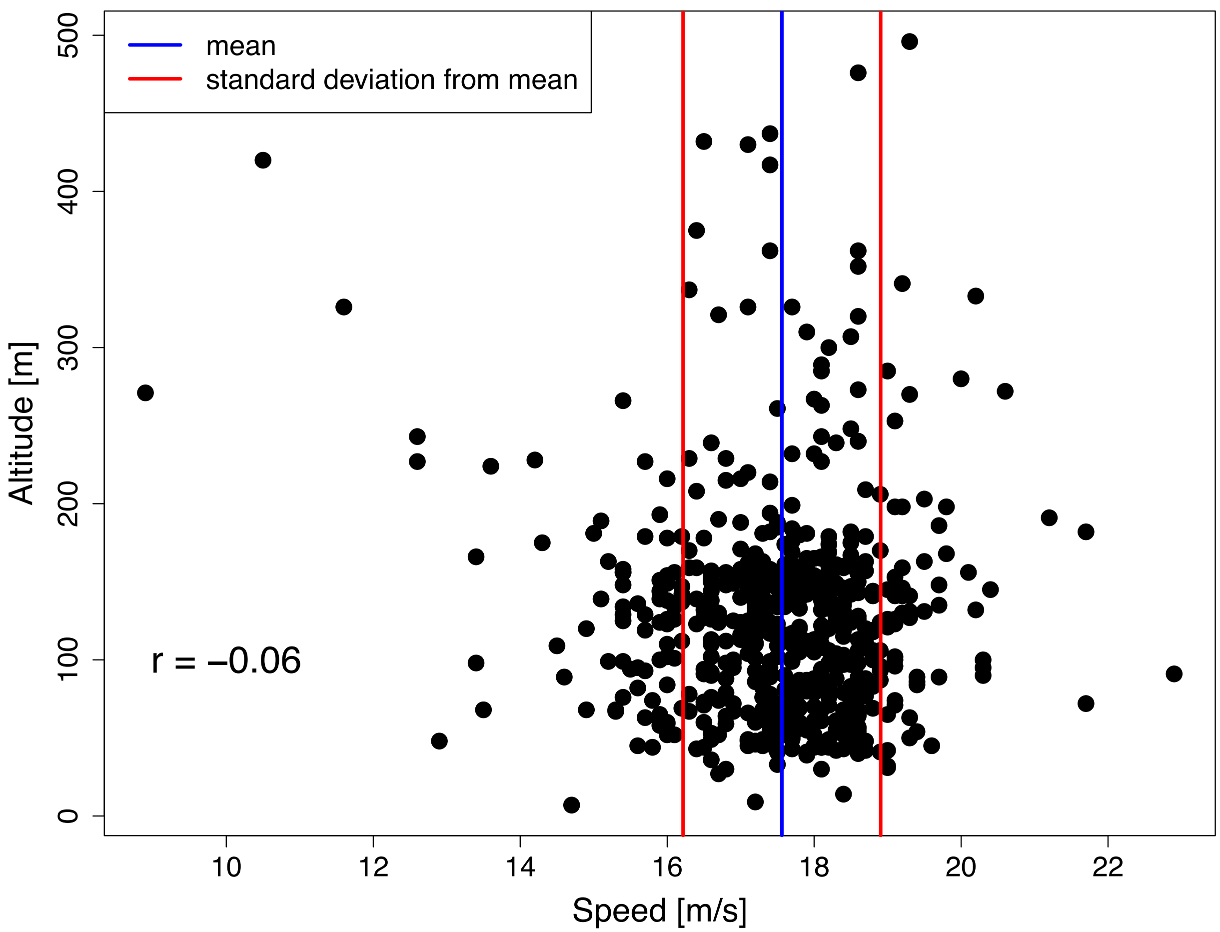

- Very weak (and negative) correlation between height of "surface" and the fall speed
- Most data within 1 standard deviation of mean fall speed
- Outside of 1 standard deviation not affected by altitude
- Close to the 18 m s^{-1} surface fall speed reported by Black et al. (2016)