16B.8 Extreme Vertical Winds Measured by Dropwindsondes in Hurricanes

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1. Introduction

Since the introduction of the GPS dropwindsonde into operations in 1997, literally thousands of sondes have been released into Atlantic and East Pacific tropical cyclones. The vast majority of these record relatively weak vertical motions of the air, and even eyewall sondes rarely record updrafts greater than 5m/s. This is consistent with the fact that the convection within hurricanes is far weaker than that within mid-latitude storms. However, relatively strong vertical motions do indeed occur within some tropical cyclones. Because the horizontal scale on which these occur is small relative to the size of the inner core, such motions do not appear in the azimuthal mean, nor are they likely to be well sampled by any given sonde. With a large enough database of sondes however, the occurrence of such updraft cores becomes evident. We herein present observations of 33 dropsondes which sampled updrafts which were strong enough to cause the sonde to temporarily rise upward for a period of time. Hence, we call them “upsondes”. This criterion for an extreme updraft is arbitrary, but is as useful as any other. For a sonde to rise, the vertical velocity of the air must be greater than the terminal fall speed of the sonde. While the terminal speed varies slightly with altitude, it is generally about 12-13 ms^{-1} at low levels, where sondes are dropped, and that is therefore the speed that the updraft must exceed.

2. Characteristics of the upsondes

Shown in Table 1 is a summary of relevant characteristics of the upsondes. There are 10 different storms that have produced at least one upsonde, although 21 are from just two hurricanes (8 from Isabel and 13 from Ivan). All 33 occurred in major hurricanes with sustained winds of 100kts or greater (as determined by the best track data closest in time to the drop), and central pressures ranged from 910mb to 954mb (median 920mb). While a few of the storms were rapidly deepening at the time (Bret, Charley), many were either near steady state (Isabel) or weakening (Ivan on the 13th and 15th). Most of the sondes measured extreme horizontal winds as well, and 17 had maximum winds greater than 90m/s. The height of maximum wind varies greatly, ranging from 103-2155m. This is partly a function of dropping sondes at different radii, into an outwardly sloping eyewall, but it likely also represents real mesoscale and convective scale variation, as well as variation between different storms. Unfortunately, there are only 4 upsondes which recorded a surface wind. However, there are 14 upsondes for which it is possible to estimate a surface wind from the lowest 150m of wind data. Of these, the windspeed varies from 50-67m/s, with a median of 61m/s.

3. Locations of the upsondes

Figure 1 shows the location of each upsonde relative to its respective storm center. Despite the fact that the dataset is dominated by a few storms, and that there are many upsondes which are dropped rather close to each other in time, there is a surprisingly variable distribution around the center. Upsondes are found in all quadrants, although only 2 are found in the SW. All of the upsondes are found within 50km of the center, which is where one would expect to find the most intense updrafts in a hurricane. All but 5 are found between 10 and 30km from the center. A preliminary examination of the radar and satellite data shows this radial distribution to be almost entirely a function of the size of the eye. The inner outliers (<10km) were from storms with exceptionally small eyes, and the outer outliers (>40km) were from storms with very large eyes. It appears that most (if not all) of the upsondes were dropped within a few kilometers of the eye/eyewall boundary.

Figure 2 is identical to Fig. 1, except “North” is now the direction of the storm motion vector, and the plot is divided into Right-Front, Right-Rear, Left-Front, and Left-Rear quadrants. There is perhaps a slight preference for the right-front quadrant, with 11 of the upsondes.

Figure 3 shows upsonde location relative to the direction of the shear vector (from SHIPS). “North” is now downshear, and the plot

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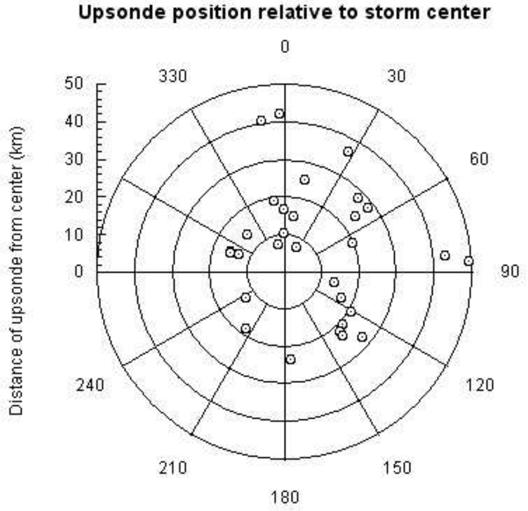
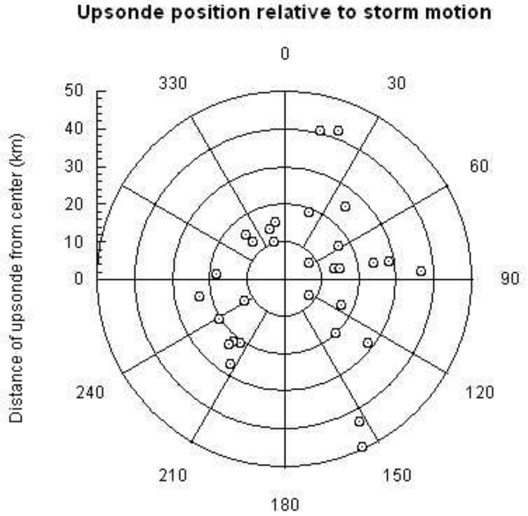
Storm	Date	Time	Maximum Upward Displacement (m)	Maximum Wind Speed (ms^{-1})	Sustained Wind Speed (kts)	MSLP (hPa)	Shear Magnitude (kts)
Mitch	981028	082216	9	53.18	130	938	17.7
Bret	990821	224913	1	76.80	120	954	12.9
Keith	001001	193519	11	65.26	110	950	14.5
Iris	011008	180628	85	46.06	115	950	8.2
Lili	021002	095133	22	*	100	954	8.4
Lili	021002	193249	11	*	120	941	9.2
Lili	021002	201212	*	73.97	120	941	9.2
Lili	021002	214205	12	*	125	940	13.6
Kenna	021024	185726	*	98.77	140	917	11.2
Isabel	030912	165948	2	90.53	140	920	11.9
Isabel	030912	172432	1	86.79	140	920	11.9
Isabel	030912	190346	28	90.28	140	920	11.9
Isabel	030912	190353	1	91.56	140	920	11.9
Isabel	030912	190405	16	93.17	140	920	11.9
Isabel	030912	190451	3	89.21	140	920	11.9
Isabel	030913	175248	136	107.00	140	932	8.1
Isabel	030913	175436	10	91.41	140	932	8.1
Charley	040813	152121	*	58.54	125	954	5.3
Ivan	040909	101320	2	92.27	140	919	8.7
Ivan	040910	065340	9	77.91	125	930	12.3
Ivan	040910	065857	5	81.98	125	930	12.3
Ivan	040911	222231	20	90.63	145	910	10.4
Ivan	040913	013658	5	92.88	140	916	22.9
Ivan	040913	185206	2	95.69	140	912	18.3
Ivan	040913	185238	2	86.69	140	912	18.3
Ivan	040913	194319	2	91.05	140	912	18.3
Ivan	040913	214710	12	95.47	140	914	17.8
Ivan	040913	235423	49	91.26	140	914	17.8
Ivan	040913	235439	15	91.96	140	914	17.8
Ivan	040915	003954	16	89.42	120	928	23.6
Ivan	040915	004004	9	90.96	120	928	23.6
Rita	050921	191231	6	96.85	145	920	3.0
Rita	050922	195638	3	73.25	125	914	12.0

Table 1: Dropwindsonde profiles used in this study.

is divided into Downshear-Right, Upshear-Right, Upshear-Left, and Downshear-Left. There is a striking left of shear preference, with 27 (90%) of the sondes found left of shear. There also seems to be a particular preference for the Downshear-Left quadrant, where 19 (63%) of the upsondes are found. This is generally consistent with previous theoretical and observational studies, and appears to be the first study of dropwindsondes that demonstrates a downshear-left preference for strong updrafts.


Upsonde position relative to storm center


Upsonde position relative to storm motion

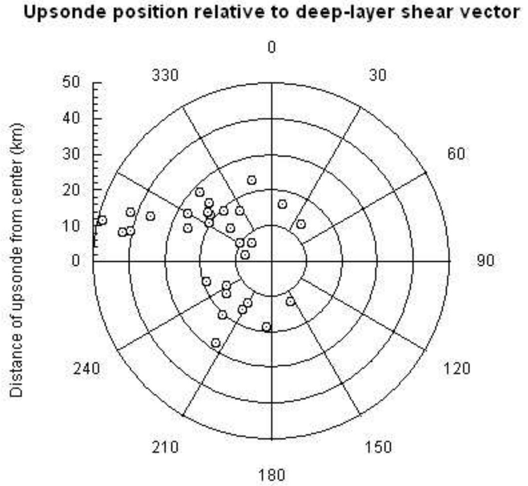

Upsonde position relative to deep-layer shear vector

Figure 1: Location of each upsonde relative to its respective storm center in earth-relative (left), storm-motion-relative (below left), and shear-relative (above) coordinates.

4. Case Study: Isabel on the 12th

Many of the upsondes are found in clusters of multiple sondes, dropped closely together in time and space. One particularly well sampled case is a group of 8 sondes which were dropped in a radial line as the plane flew outward through the southeastern eyewall of Hurricane Isabel at around 1904 UTC on the 12th. Shown in Fig. 4 are horizontal trajectories of the sondes, overlaid with a reflectivity image from 1902 UTC. Moving outward from the center, the first 3 are upsondes, as is the 6th. Figure 5 shows profiles of horizontal and vertical winds as well as theta-e for all 8 sondes. Note how the first 2 trajectories cross each other, as do the 3rd with the 4th. Although they cross each other on a horizontal projection, sonde 3 is 500m vertically above sonde 4 at the point at which they cross. This is due to its history of being embedded within substantially stronger updrafts. Sonde 3, at ~1230m, has winds of 81m/s while sonde 4, at ~730m, has winds of 91m/s, with a direction that is backed by 10 degrees. At 730m, the air is saturated, while further up, RH is ~94%. This contributes to a decrease of theta-e with height from 360K to 357K through the layer, which is evidence of convective instability within the eyewall. Almost all eyewall sondes experience a sharp increase in theta-e as they fall through the lowest few hundred meters, where superadiabatic layers are often found. At the time that the trajectories cross however, both these sondes are well above that layer. At the crossing point, sonde 3 is experiencing an updraft of 5.7m/s (the extreme vertical velocities occured ~200m above) while sonde 4 is in an updraft of 3.0m/s. The sondes have been converging towards each other at about 15m/s, based on the difference in their radial velocities. The windspeed of sonde 3 increased to ~90m/s as it fell through 1000-900m, and remained ~85-92m/s until rapidly decreasing after falling below 300m. It is also interesting to compare the sondes when they are at the same height. At 1230m, sonde 4 has about the same windspeed that sonde 3 had at that level, but its theta-e is 1.5K lower. A hundred meters lower it reached a theta-e minimum of 350.7K. This implies a strong horizontal (and vertical) gradient in theta-e. Combined with the crossing of trajectories (albeit at different heights), this provides evidence for mixing of high theta-e air from the eye with lower theta-e air within the eyewall, which supports the superintensity theory of Persing and Montgomery (2003). Moving inward towards the eye, at similar altitudes, sonde 2 has theta-e of ~359K and sonde 1 has theta-e of 362-365K. Theta-e of a nearby eye sonde is actually lower (357K) at the same altitude, but that is because this is above the inversion level. The air below the inversion (which is the airmass which may be mixing with the eyewall) has theta-e which is ~5K warmer than the inner eyewall.

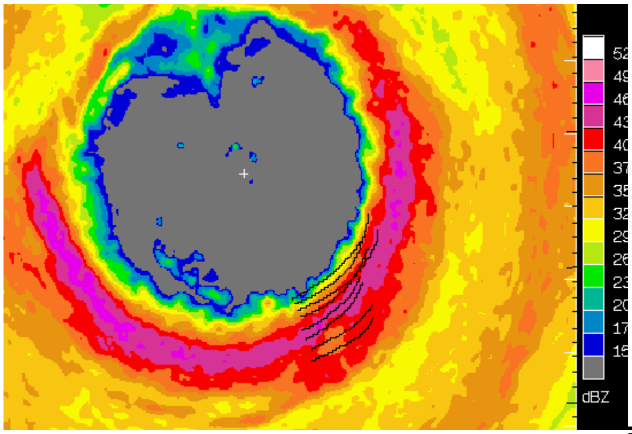


Figure 4: Horizontal dropwindsonde trajectories and reflectivity from Hurricane Isabel on the 12th. The radar image is from 1900:32 UTC.

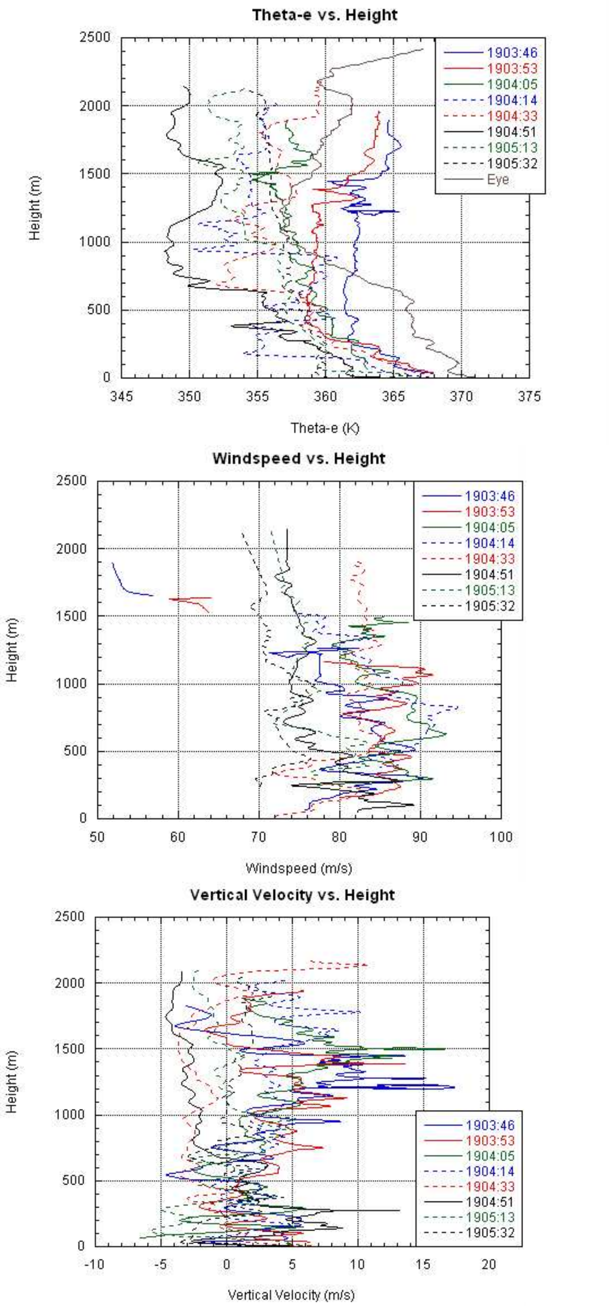


Figure 5: Theta-e (top), windspeed (middle), and vertical velocity (bottom) vs. height. The time each sonde was dropped is indicated in the legend. Upsondes are plotted with solid lines and non-upsondes are dashed. In the theta-e plot, an eye sonde dropped at 1902 UTC is plotted with a solid grey line.

5. Summary and Conclusions

We have presented a dataset of extreme updrafts sampled by GPS dropwindsondes. There are a limited number of samples (33) thus far and analysis of this data is still in the preliminary stage, so it is too early to draw broad conclusions. Still, there are some aspects of this data that clearly stand out. Firstly, every upsonde was found in a major hurricane, including 2 in category 3, 12 in category 4, and 19 in category 5. These extreme updrafts are therefore a phenomenon of the most intense hurricanes. Almost all of the upsondes were dropped within a few km of the radar eye/eyewall boundary. Falling into a presumably outward sloping eyewall, the upsondes generally encounter the extreme updrafts slightly to the eyewall side of the boundary. This appears to hold true over a wide range of eye sizes. There doesn't appear to be a relationship between upsonde locations and the direction of storm motion. There is a strong relationship between location and the shear vector however. Upsondes are almost all left of shear, with the majority in the downshear-left quadrant. Thus, it appears that shear plays a large role in determining the location of strong updrafts, despite the fact that all of these storms were very intense and apparently symmetric.

Many of the upsondes also experienced extreme horizontal windspeeds, either concurrently with the extreme updrafts, or elsewhere in their trajectories. More than half of these experience windspeeds greater than 90m/s, and they represent about a third of all sondes with such strong horizontal winds.

Preliminarily, it appears that these extreme updrafts may be associated with convective instability. One mechanism that could produce such instability is the transport of high theta-e air from the eye into the lower theta-e eyewall. This mixing appears to be occurring in Isabel on the 12th. In turn, this mixing could be driven by mesovortices along the eye/eyewall interface. Further analysis of the data (including the sondes, flight level data, and radar) will help to determine if such mesovortices and mixing are present here. If so, this would support the theory that hurricanes may in some cases exceed their potential intensity. In the presence of substantial shear (as in many of these cases), it may allow hurricanes to remain more intense than they otherwise would be.

It is anticipated that there will likely be additional upsondes present in storms from 2005 flown by the Air Force, whose data is not yet available as of this writing. Furthermore, this currently small dataset is expected to grow as intense storms continue to be sampled in the future.

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