Vertical wind profiles in hurricanes

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VIRGINIA KEY, MIAMI FL (ABOUT 20 MILES EAST OF THE NATIONAL HURRICANE CENTER)

30 SCIENTISTS AND SUPPORT STAFF FROM NOAA AND UNIVERSITY OF MIAMI COOPERATIVE
INSTITUTE FOR MARINE AND ATMOSPHERIC STUDIES, REGIONAL LAB WITH OCEANOGRAPHIC
EXPERTISE
• STRATEGIC GOALS
• IMPROVE INTENSITY FORECASTS
• DIAGNOSE AND PREDICT HURRICANE IMPACTS
Outline

- How do hurricanes impact commercial multi-story buildings?
- Vertical wind profile needed for wind loads
- What does the profile look like in a hurricane?
- How does it vary between open ocean, coast, and inland?
- Low-level jets
Impacts: Hurricane Wilma 2005

- Fort Lauderdale
- Broward County School Board building
Impacts: Hurricane Wilma 2005

- downtown miami adjacent to Biscayne Bay
HURRICANE IKE 2008

EXAMPLE OF OPEN TERRAIN WIND CHANGE WITH HEIGHT IF SURFACE WINDS WERE HURRICANE FORCE

WIND LOADS ON CHASE TOWER INCREASE MORE THAN A FACTOR OF THREE FROM THE GROUND TO TOP FLOOR

118 MPH SS CAT 3

110 MPH SS CAT 2

100 MPH SS CAT 2

64 MPH SS CAT 1

LOOKING NORTH

300 M

200 M

100 M

10 M
Coastal structures are susceptible
10-12 m/s fall speed

2 Hz Samples P, T, RH, Position

Accuracy 0.5-2m/s, 2 m height

Filtered to remove undersampled scales and noise from satellite switching

Corrected for acceleration bias

Wind errors large below 5-8 m
STORM RELATIVE DISTRIBUTION OF GPS SONDES 1997-2005

42 STORMS
550 FLIGHTS

2340 POST PROCESSED

1270 AT RADII OF 2-200 KM
NUMBER OF WIND PROFILES BY MEAN BOUNDARY LAYER (LOWEST 500 M) MEAN WIND

<table>
<thead>
<tr>
<th>MPH</th>
<th>5</th>
<th>15</th>
<th>25</th>
<th>35</th>
<th>45</th>
<th>55</th>
<th>65</th>
<th>75</th>
<th>85</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBL_Group (m/s)</td>
<td>65</td>
<td>90</td>
<td>135</td>
<td>180</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bar chart showing the number of wind profiles by mean boundary layer (lowest 500 m) mean wind.
Fig. 4. Dropwindsonde profiles from the eyewall of (a) Hurricane Bonnie on 25 Sep 1998 and (b) Hurricane Mitch on 27 Oct 1998. The times of the profiles in (a) are 0015 (solid), 0017 (short dashes), and 0021 (long dashes) UTC. The times of the profiles in (b) are 2337 (solid) and 2343 (dashed) UTC.
INDIVIDUAL PROFILE

HEIGHT-BINNED SAMPLES AND MEAN

Gust Factor Scale (U / U10)

U / MBL

1.0  1.25  1.50  1.75
MEAN WIND PROFILES BY MBL GROUP
MEAN PROFILES ARE LINEAR ON A LOG SCALE
INTERCEPT IS A MEASURE OF ROUGHNESS
2003: Powell-Vickery-Reinhold first profile-method measurements in tropical cyclones

330 profiles were distributed into four MBL groups of 40-100 sondes per group

Cd was shown to level off and decrease after an initial increase with increasing wind speed

2004: Donelan et al. similar results from flume experiments
Open ocean

Roughness relatively smooth compared to land
1521 UTC
800 FT 105 MPH

2 MIN LATER
UTC 1500 FT 125 MPH

SEA STATE PHOTOS HURRICANE ELLA 1978
Continuous breaking hypothesis

Donelan et al., 2004, Reul 1998
VAD profile over land

Slidell LA  Hurricane Katrina  at 1354 UTC 29 Aug.
SHALLOW WATER (< 50 M) PROFILES WERE ORGANIZED INTO ONSHORE, OFFSHORE, INLAND, AND ALONGSHORE FLOW REGIMES
# Wind Profile sample counts

<table>
<thead>
<tr>
<th>MBL group (m/s)</th>
<th>Sonde profiles in deep water</th>
<th>Shallow water profiles</th>
<th>Onshore / Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>224</td>
<td>32</td>
<td>19</td>
</tr>
<tr>
<td>30-39</td>
<td>252</td>
<td>65</td>
<td>42</td>
</tr>
<tr>
<td>40-49</td>
<td>307</td>
<td>30</td>
<td>19</td>
</tr>
<tr>
<td>50-59</td>
<td>187</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>60-69</td>
<td>118</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>70-79</td>
<td>94</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>80-89</td>
<td>26</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Note: excludes post-2000 A/F sondes, post-2006 NOAA and Wilma sondes
Drag coefficient in Shallow and deep water

Shallow water and deep water roughness are similar
No significant differences between shallow and deep water Cd

Shallow and deep water roughness is smoother than open terrain

ASCE 7 roughness underestimates winds and loads
STARTING WITH SAME WIND AT 70TH FLOOR
WHAT IS SURFACE WIND FOR OPEN TERRAIN AND OCEAN
ROUGHNESS?
low-level jet

- kepert 2006
- radial pressure profile -> radial profile of wind speed determines jet which is more marked and lower on left side of storm
- For a “peaked” eyewall wind maximum the low level jet can be supergradient by 20%
- Kepert’s (2001) linear theory models this behavior
1) OUTWARD TILT OF WIND MAX (RMAX) WITH HEIGHT
2) SFC WIND ON LEFT SIDE CLOSER TO FL WIND
Examples of low level jets in Hurricane Georges and Kepert’s model solution
Research on the low level jet by Ian Giamannco, TTU grad student and IGERT Fellow at HRD in 2007

Height of low-level jet max decreases with wind speed, ~11 % of all profiles show a jet < 200 m

<table>
<thead>
<tr>
<th>GPS Sonde MBL Group (ms⁻¹)</th>
<th>Total GPS sondes</th>
<th>Mean height of maximum $W_s$ (m)</th>
<th>Standard deviation of maximum $W_s$ height (m)</th>
<th>% of sondes with maximum below 500 m AGL</th>
<th>% of sondes with maximum below 200 m AGL</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 – 19.999</td>
<td>49</td>
<td>1703.0</td>
<td>2308.0</td>
<td>27%</td>
<td>8%</td>
</tr>
<tr>
<td>20 – 29.999</td>
<td>180</td>
<td>1403.2</td>
<td>1521.1</td>
<td>27%</td>
<td>7%</td>
</tr>
<tr>
<td>30 – 39.999</td>
<td>290</td>
<td>867.4</td>
<td>778.4</td>
<td>37%</td>
<td>11%</td>
</tr>
<tr>
<td>40 – 49.999</td>
<td>237</td>
<td>758.4</td>
<td>568.2</td>
<td>41%</td>
<td>11%</td>
</tr>
<tr>
<td>50 – 59.999</td>
<td>152</td>
<td>550.3</td>
<td>436.7</td>
<td>58%</td>
<td>13%</td>
</tr>
<tr>
<td>60 – 69.999</td>
<td>113</td>
<td>526.9</td>
<td>400.3</td>
<td>61%</td>
<td>11%</td>
</tr>
<tr>
<td>70 – 79.999</td>
<td>84</td>
<td>453.3</td>
<td>300.8</td>
<td>92%</td>
<td>11%</td>
</tr>
<tr>
<td>80 – 89.999</td>
<td>26</td>
<td>488.7</td>
<td>293.2</td>
<td>61%</td>
<td>7%</td>
</tr>
<tr>
<td><strong>All MBL Groups</strong></td>
<td><strong>1131</strong></td>
<td><strong>924.6</strong></td>
<td><strong>1206.1</strong></td>
<td><strong>41%</strong></td>
<td><strong>11%</strong></td>
</tr>
</tbody>
</table>
Research by Ian Giamannco, TTU grad student and IGERT Fellow at HRD in 2007

The height of the maximum wind speed is nearly always above the structures being considered for the commercial model, most of which are < 100 m in height.

In very strong winds the low-level eyewall jet can reach below 100 m

<table>
<thead>
<tr>
<th>MBL Group</th>
<th>Number of wind profiles</th>
<th>Height of max wind 10% Quantile (m)</th>
<th>Height of max wind 2.5% Quantile</th>
<th>Height of max wind 0.5% Quantile</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>277</td>
<td>300</td>
<td>127</td>
<td>32</td>
</tr>
<tr>
<td>30-39</td>
<td>290</td>
<td>192</td>
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<td>41</td>
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<td>182</td>
<td>58</td>
<td>-----</td>
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<td>112</td>
<td>173</td>
<td>64</td>
<td>28</td>
</tr>
<tr>
<td>70-79</td>
<td>80</td>
<td>171</td>
<td>87</td>
<td>83</td>
</tr>
<tr>
<td>80-89</td>
<td>26</td>
<td>198</td>
<td>68</td>
<td>68</td>
</tr>
</tbody>
</table>
summary: Vertical Wind Profile in Hurricanes

- Mean winds follow an exponential increase with height.
- Roughness in open ocean and shallow water decreases with increasing wind, much smoother than open terrain.
- ASCE-7 underpredicts onshore hurricane winds and loads.
- In extreme winds, a low-level jet is present < 200 m in 11% of the cases (< 100 m in 2.5% of cases).
- Kepert linear theory describes jet behavior.
the end

questions?
M-4CR Hurricane Vertical Wind Profile*
(*New Standard)

The model shall represent the vertical profile of damaging winds for commercial structures.

Purpose: This Standard requires that the windfield model be implemented consistently with the vertical distribution of the hurricane boundary layer windfield.

The methodology for treating both historical and stochastic storm sets is to be documented, including any variations between these storm sets.

Disclosures

1. Provide a plot of the maximum 1-minute windspeed (x-axis) versus height above the ground (y-axis) at the radius of maximum wind as measured at the surface.

2. Justify the choice of the vertical wind profile as used in the model.

3. Identify all non-meteorological variables that affect vertical variation of windspeed.

4. Describe any variations in the treatment of the model windfield for stochastic versus historical storms and justify this variation.

5. Provide a list of any published references used in the development of the vertical wind profile.

Audit

1. Provide any modeler-specific research performed to develop the vertical windfield distributions used in the model. Identify all databases used.

2. The vertical distribution of the winds as used in the model will be reviewed.