Hurricane Structure: Theory and Application

John Cangialosi
National Hurricane Center

World Meteorological Organization Workshop
Is this Tropical, Subtropical, or Extratropical?

Subtropical  Tropical  Extratropical

(a) Tropical
(b) Subtropical
(c) Extratropical
Is this Tropical, Subtropical, or Extratropical?

(Tropical) (b) Subtropical (c) Extratropical

“Tropical Storm” Cindy
Outline for this presentation

* Background
* Application and Predictions
* Verification
* Exercise
Intensity and Structure Parameters that NHC analyzes and predicts

- Maximum Wind Speed
- Radius of 34-, 50-, 64-kt winds
- Minimum Pressure
- Radius of Maximum Wind
- Radius of the Outermost Closed Isobar
Hurricane Structure
Structure of a Hurricane

NOAA P-3 Flies into the Eyewall of Hurricane Katrina at Landfall Aug. 29, 2005
Notice the symmetric, inward spiraling flow.
Primary Circulation
Wind speeds are close to symmetric – only after subtracting the forward motion.
THE WARM CORE IS A CONSEQUENCE OF BOTH LATENT HEAT RELEASE AND WARMING BY SUBSIDENCE.
INTENSE WARM CORE: CAN BE 16 K WARMER THAN NORMAL TROPICAL VALUES
DEEP-LAYER CYCLONIC CIRCULATION
NOTE: CYCLONIC CIRCULATION AT UPPER-TROPOSPHERIC LEVEL, WITHIN A FEW DEGREES RADIUS OF THE CENTER!

Fig. 4. Analysis of wind (streamlines and isotachs) on meshes 1–3 for (a) 850, (b) 500, and (c) 200 mb. Isotachs are at 5 m s⁻¹ intervals. Shading indicates wind speeds greater than 60 m s⁻¹.
BEYOND A FEW DEGREES RADIUS FROM THE CENTER, THE UPPER-TROPOSPHERIC FLOW TURNS ANTICYCLONIC.
The Effects of Wind Shear

Effects of Vertical Wind Shear ($V_z$) on Tropical Cyclones

WEAK SHEAR = FAVORABLE

STRONG SHEAR = UNFAVORABLE

UPPER-LEVEL WINDS

LOWER-LEVEL WINDS

Neal Dorst/Stan Goldenberg
Hurricane Research Division
AOML/NOAA
Fig. 2.17 Differences between the outflow and upper-level asymmetries of intensifying and nonintensifying hurricanes (Merrill 1988b).
Well-established outflow
Restricted outflow
The Extremes: Tropical vs. Extratropical Cyclones

Hurricane Katrina (2005)  Superstorm Blizzard of March 1993
Life Cycle of a Cape Verde Hurricane
Cyclone Phase Space for Bill

0.5º NCEP GFS (12Z19AUG2009 run) Cyclone #3 (Existing cyclone)

Start (A): 06Z12AUG2009 (Wed) (−174h)
Current (C): 12Z19AUG2009 (Wed) (0h)
End (Z): 00Z27AUG2009 (Thu) (+180h)

NOTE: A 24hr running mean smoother is applied to the GPS trajectory.
Hurricane Size Variability

Hurricane Floyd
September 14, 1999 @ 1244 UTC

Hurricane Andrew
August 23, 1992 @ 1231 UTC

Size Matters!
The Extremes: Tip vs. Tracy
Hurricane Sandy

- 75 kt, 971 mb
- ~ 110 n mi
- 70 kt, 956 mb
- ~ 390 n mi
- 75 kt, 943 mb
- ~ 450 n mi
Radius of Tropical Storm Force Winds versus Location

Kimball and Mulekar (2004)
Size versus Intensity

Kimball and Mulekar (2004)
\[ \Delta P = 5.962 - 0.267 V_{srm} - \left[ \frac{V_{srm}}{18.26} \right]^2 - 6.8S \]

\[ \Delta P = 23.286 - 0.483 V_{srm} - \left[ \frac{V_{srm}}{24.254} \right]^2 - 12.587S - 0.483\varphi \]

Knaff, Zehr, and Courtney
(2009)
Knaff-Zehr-Courtney technique accounts for the following:

* Maximum wind speed
* 34-kt wind radii
* Latitude
* Environmental Pressure
* Forward Speed

Knaff and Zehr (2007)
Sometimes we stick with it...

Date (Month/Day) vs Pressure (mb) chart showing the pressure changes of Hurricane Hilary from 21-30 July 2017.
And sometimes we don’t...
CONCENTRIC EYEWALLS

5:15 pm EDT
San Juan, PR Radar
Hurricane Matthew Radar Loop
Bertha (2008) Eyewall Replacement
Concentric Eyewall Cycle – Tangential winds (Gilbert)

Black & Willoughby (1992)
Fig. 3. Hurricane Allen: graph of minimum sea level pressure as a function of time, based on 44 aircraft observations.
What I know about eyewall replacement cycles

• We have a sense of when they could occur
• We can observe them
• Intensity changes are coming
• Big errors are likely going to happen too...
NHC estimates cyclone “size” via wind radii in four quadrants leads to an inherent over-estimate of radii, especially near land

Wind radius = **Largest distance from the center** of the tropical cyclone of a particular sustained surface wind speed threshold (e.g., 34, 50, 64 kt) somewhere in a particular quadrant (NE, SE, SW, NW) surrounding the center and associated with the circulation at a given point in time
“Overestimate” of the NE quadrant of 34-kt winds
Data to Determine Tropical Cyclone Size

* Satellite Imagery
  - Geostationary
  - Polar Orbiting – scatterometer
* Reconnaissance Data
  - Dropsondes
  - SFMR (Stepped Frequency Microwave Radiometer)
* Surface Observations
A typical day of marine data that is available around 12 UTC
Katrina - August 24

The Dvorak Technique is very skillful at estimating intensity, but does not help with TC size.
Geostationary satellite – Low-level cloud drift winds

Satellite winds for nearby environment and TC size
Low-Earth-Orbit Satellites

- Carry microwave imagers and sounders that can see through cloud tops and reveal the structures underneath.
- Gaps in instrument coverage between orbits, which causes irregular sampling of cyclones.

Microwave location, structure, intensity, rainfall.
Advanced Microwave Sounding Unit
ASCAT (Advanced Scatterometer) – Surface Winds from a Polar-orbiting satellite
Hurricane Reconnaissance and Surveillance Aircraft
(10 Air Force C-130s, 2 NOAA P3s, 1 NOAA G-IV)
Primary Aircraft Data

- Winds (along the aircraft track and dropsondes)
- Surface pressures (extrapolated and dropsonde)
- Surface winds from the Stepped Frequency Microwave Radiometer
- Aircraft Doppler Radar winds (from the P-3’s)
But nobody lives at 10,000 ft. How can we use flight-level data to estimate surface winds?
GPS Dropsondes

Measures the wind around and in hurricanes from the aircraft to the ocean’s surface

Franklin and Black (1999)
A large sample of GPS dropsondes in the inner core of TCs provides a way to determine surface wind radii from flight level winds via the mean wind profile.

Table 2. Reduction factors and flight-level wind thresholds for determining wind radii from 700 mb data.

<table>
<thead>
<tr>
<th>Sample</th>
<th>RF10m</th>
<th>FLW64 (kt)</th>
<th>FLW50 (kt)</th>
<th>FLW34 (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyewall</td>
<td>0.90</td>
<td>70</td>
<td>55</td>
<td>-</td>
</tr>
<tr>
<td>Outer vortex</td>
<td>0.85</td>
<td>75</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Outer vortex / Right quad</td>
<td>0.75</td>
<td>85</td>
<td>65</td>
<td>45</td>
</tr>
<tr>
<td>Outer vortex / Left quad</td>
<td>0.90</td>
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<td>40</td>
</tr>
</tbody>
</table>

Franklin (2001)
Remotely Sensed Surface Winds

C-Band Scatterometer (5.6 GHz) and Stepped-Frequency Radiometer (4-7 GHz)

“SMRF”
Automated Surface Wind Field in Tropical Cyclones

Multiplatform Satellite Surface Wind Analysis – CIRA

QUA  NE  SE  SW  NW
R34  305  305  165  175
R50  95   95   70   90   VMAX = 91 kt  MSLP = 957.9 hPa
R64  50   50   40   50   RMW = 25 nmi  BEARING = 10 degrees
And after using all of that data, we come up with this...
Surface Wind Field

Surface Wind Field of Hurricane Ike
Sustained Winds as of 1000 AM CDT Thu Sep 11, 2008 Advisory Number 42

Watches:
- Pink: Hurricane Watch
- Yellow: Tropical Storm Watch

Warnings:
- Red: Hurricane Warning
- Blue: Tropical Storm Warning

Sustained Winds:
- Maroon: Hurricane Force
- Orange: Tropical Storm Force

Position:
- Diamond: Center as of 1000 AM CDT
- Dash: Past Track

Map showing the surface wind field of Hurricane Ike with watches, warnings, and sustained winds indicated on a map of the Caribbean and Gulf of Mexico.
Wind Radii Forecast “Guidance”

• Empirical ideas
  – Is the storm strengthening or weakening?
  – Is persistence appropriate, or are conditions changing?
  – Is the storm becoming extratropical, causing wind field to expand?
  – Will all or part of the circulation be passing over land, such that radii could decrease?
  – Is the system accelerating, such that the storm could become more asymmetric?
Yes, the NHC wind radii forecasts are skillful. Skill declines over time.

34 kt skill: ranges from 30-35%
50 kt skill: ranges from 20-35%
64 kt skill: ranges from 5-35%

How good is the guidance?
The Models - 34 kt Verification

The guidance is not very good. OFCL is considerably better than all of the dynamical guidance shown here. GFSI and EMXI have some skill (errors are lower than DRCL) at 48 and 72 h.
OFCL is considerably better than the dynamical guidance. Among the guidance, only the GFSI had skill at 72 h.
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