Use of the GFDL Vortex Tracker

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WRF Tutorial for Hurricanes
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Outline

• History & description of the GFDL vortex tracker
• Inputs & Outputs
• ATCF-plot: GrADS-based track and intensity plotting script
GFDL Vortex Tracker: History

• Requirements:
  - A flexible tracking algorithm to work on a variety of models and resolutions.
  - Must run quickly
  - Must produce output in ATCF format

• Became operational at NCEP in 1998
Purpose of a vortex tracker

- **Operations**: Quick reporting of track and intensity forecast data to NHC, JTWC, others.

- **Research**: Quick evaluation of the track & intensity skill of a forecast
Why the need for an external tracker?

- Valuable CPU time is not wasted during model execution.
- Tracking analysis can be re-done without re-running model.
- Uniform tracking criteria can be applied to multiple models.
Why the need for an external tracker?

• Ike in HWRF: A well-defined storm with center locations collocated.

• So then... why the need for anything sophisticated?
Why the need for an external tracker?

- **Gustav in GFS**: For an observed 80-knot hurricane, the GFS was initialized with a poorly organized vorticity center.
Why the need for an external tracker?

- **Gustav in GFS**: The SLP center was found 188 km from the vorticity center. *What is the storm’s central position?*
Why the need for an external tracker?

- **Gustav in GFS**: The SLP center was found 188 km from the vorticity center.

**Also note**: The center locations for the parameters were not found exactly at a model gridpoint.
Tracker Design: Multiple Variables

• A weighted average of the positions of several low-level variables is used.

• 6 Primary parameters:
  ➢ 850 mb vorticity ➢ 850 mb gp height
  ➢ 700 mb vorticity ➢ 700 mb gp height
  ➢ Surface (10 m) vorticity ➢ Mean Sea-Level Pressure

• 3 Secondary parameters:
  ➢ 850 mb minimum in wind speed
  ➢ 700 mb minimum in wind speed
  ➢ Surface (10 m) minimum in wind speed
Tracker Design: Center-fixing algorithm

- Instead of interpolation, a Barnes Analysis is performed on an array of points surrounding a guess storm location:

The Barnes function, $B$, provides a Gaussian-weighted average value for a variable, $F(n)$, at a given gridpoint, $g$.

The weighting function, $w$, is dependent on the distance, $d_n$, of a point from the origin gridpoint, $g$, and the choice of the e-folding radius, $r_e$.

The center is found at the point where this Barnes function is maximized (e.g., NH vorticity) or minimized (e.g., MSLP).
Barnes analysis weighting

- Choosing $r_e$: A balance between including enough points to get a representative sample vs. too much smoothing.
- For most models, we use $r_e = 75$ km. For $dx < 0.1^\circ$, $r_e = 60$ km.
Barnes analysis: multiple search iterations

NHC observations indicate a storm initially located here
A grid of analysis points is set up, relative to the NHC observed position.

A Barnes analysis is performed for all points within a specified distance from the NHC position.
Barnes analysis: multiple search iterations

After the first iteration through all the points, suppose the Barnes analysis identifies the center as being here.
A second iteration through the Barnes analysis is performed after further limiting the domain and halving the grid spacing.
This process is repeated multiple times (up to 5), halving the grid spacing for the Barnes analysis each time, until a center position is fixed using a Barnes analysis grid spacing < 0.1°.
The Barnes analysis is repeated for all 6 primary parameters to produce fixes for each.

Parameters fixes that are within a specified error distance threshold of the current guess position are used to create a preliminary mean fix.
The Barnes analysis is repeated for the 3 secondary, wind-based parameters.

This analysis is performed over a small domain, centered on a position that is a mean of the 6 primary fixes and the guess position.
Parameters fixes that are beyond a specified error distance threshold of the current guess position are discarded.

- Error distance thresholds:
  - Initially 275 km
  - At later times, can be a function of spread in previous position fixes
The remaining parameter fixes are averaged to produce the mean position fix for each forecast hour.

- These additional parameters are computed once the center fix is made:
  - Max surface wind
  - $R_{\text{max}}$
  - Minimum MSLP
  - 34-, 50- and 64-kt wind radii
Tracking from one lead time to the next

Linear extrapolation

Barnes analysis & advection

A Barnes analysis with a large $r_e$ at 850, 700 & 500 mb is used to compute mean steering winds. A parcel is advected to a guess position at the next lead time.

The guess positions from these 2 methods are averaged to compute a final guess position for the search at the next lead time.
“Quality Control”

A series of checks is applied to ensure that the tracker is following a storm that is the system of interest

**MSLP Gradient:** Gross check to ensure minimum gradient (~0.5 mb / 300 km) exists within 300 km of center. Set in script: “mslpthresh” variable

**$V_T(850 \text{ mb})$:** Mean $V_T$ within 225 km must be cyclonic and exceed threshold. Default (1.5 ms$^{-1}$) is set in script: “v850thresh” variable

**DIST$_{(\text{MSLP-Zeta850})}$:** This distance between the MSLP and Zeta$_{850}$ parameter fixes must not exceed a distance defined in source by “max_mslp_850” (usually set to 323 km).

**Translational speed:** Speed of storm movement must not exceed threshold, set by “maxspeed_tc” variable (usually set to 60 knots).
Outline

• History & description of the GFDL vortex tracker
• Inputs & Outputs
• ATCF-plot: GrADS-based track and intensity plotting script
Tracker inputs: Synoptic data

- Data must be in Gridded Binary (GRIB) Version 1 format.
- Data points must increment from northwest (1,1) to southeast (imax, jmax).
- Data must be on a lat/lon grid.
- \(dx\) does not need to equal \(dy\), but both must remain uniform over the domain.
- Data lead time intervals do not need to be evenly spaced.
Tracker inputs: Observed TC data

- Tracker searches for a vortex initially at a location specified by NHC or JTWC on a “TC Vitals record”:

  NHC 12L KATRINA 20050829 0000 272N 0891W 335 046 0904 1006 0649 72 037 0371 0334 0278 0334 D 0204 0185 0139 0185 72 410N 815W 0167 0167 0093

  - ATCF ID (12L = 12\textsuperscript{th} storm in the Atlantic).
  - E = Eastern Pacific
  - C = Central Pacific
  - W = Western Pacific

  - Report date and time
  - Observed storm latitude & longitude
  - Observed direction of storm motion in degrees from north (335 = ~NNW), and storm translation speed (046 = 4.6 ms\textsuperscript{-1})
Tracker inputs: Namelist options

```plaintext
# Generate the namelist
cat <<EOF > namelist
&datein
  inp$bcc=${CC},
inp$syy=${YY},
inp$bmm=${MM},
inp$bdd=${DD},
inp$hh=${HH},
inp%model=17,
inp%lt_units='minutes'
/
&atcfinfo
  atcfnum=83,
atcfname='${ATCFNAME}',
atcfymdh=${YYYY}${MM}${DD}${HH}
/
&trackerinfo
  trkrinfo%westbd=260.0,
  trkrinfo%eastbd=350.0,
  trkrinfo%northbd=40.0,
  trkrinfo%southbd=1.0,
  trkrinfo%type='tracker',
  trkrinfo%mslpthresh=0.0015,
  trkrinfo%v850thresh=1.5000,
  trkrinfo%gridtype='regional',
  trkrinfo%contint=100.0,
  trkrinfo%out_vit='n'
/
&phaseinfo
  phaseflag='n',
  phasescheme='both'
/
&structinfo
  structflag='n',
  ikeflag='n'
EOF
```

- **Starting date & time**
- **ID number for model in the executable. Leave as ‘17’**
- **Indicator for GRIB data lead time units**
- **Obsolete, leave as ‘83’**
- **ATCF model name: “HWRF”, “HAHW”, “TEST”, etc**
- **Starting yyyymmdhh for output ATCF record**
- **For genesis tracking use. Fill with any values, as shown.**
- **Thresholds for mslp gradient and V_{850}**
- **Model grid type: ‘regional’ or ‘global’**
- **Not yet supported. Leave values as they are…**
Tracker inputs: List of forecast hours

- The tracker can handle lead times that are stored in the GRIB file header either in units of minutes or hours.

- Explicitly detailing the forecast hours allows for irregularly spaced intervals.

- Regardless of whether your GRIB data lead time units are in minutes or hours, you must supply a text file as input that has the lead times listed in minutes (code will convert to hours).
Tracker output: Standard ATCF file

- Text format. Minimum of 1 record per lead time (↓), maximum of 3.
  - 1st record contains track & intensity info, plus radii for 34-knots winds
  - 2nd record: Same track & intensity info, plus radii for 50-knot winds, if present.
  - 3rd record: Same track & intensity info, plus radii for 64-knot winds, if present.
<table>
<thead>
<tr>
<th>Model ID (3 or 4 char)</th>
<th>Tracker output: Standard ATCF file</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin (AL, EP, WP, etc)</td>
<td>Forecast Initial DTG</td>
</tr>
<tr>
<td>Storm number in basin</td>
<td>Max sfc wind (knots)</td>
</tr>
<tr>
<td>Forecast latitude * 10</td>
<td>Minimum MSLP (mb)</td>
</tr>
<tr>
<td>Forecast longitude * 10</td>
<td>NE Quad radii (n mi)</td>
</tr>
<tr>
<td>Wind radii threshold (Ks)</td>
<td>SE Quad radii (n mi)</td>
</tr>
<tr>
<td>Begin radii in NE Quad</td>
<td>NW Quad radii (n mi)</td>
</tr>
</tbody>
</table>

| AL, 09, 2008091012, 03, HWRF, 000, 239N, 855W, 68, 969, XX, 34, NEQ, 0163, 0146, 0086, 0124, 0, 0, 064 |
| AL, 09, 2008091012, 03, HWRF, 000, 239N, 855W, 68, 969, XX, 50, NEQ, 0090, 0088, 0063, 0070, 0, 0, 064 |
| AL, 09, 2008091012, 03, HWRF, 000, 239N, 855W, 68, 969, XX, 64, NEQ, 0067, 0060, 0060, 0048, 0, 0, 064 |
| AL, 09, 2008091012, 03, HWRF, 006, 240N, 861W, 95, 960, XX, 34, NEQ, 0262, 0283, 0168, 0214, 0, 0, 052 |
| AL, 09, 2008091012, 03, HWRF, 006, 240N, 861W, 95, 960, XX, 50, NEQ, 0114, 0122, 0092, 0095, 0, 0, 052 |
| AL, 09, 2008091012, 03, HWRF, 006, 240N, 861W, 95, 960, XX, 64, NEQ, 0084, 0087, 0049, 0073, 0, 0, 052 |
| AL, 09, 2008091012, 03, HWRF, 012, 244N, 866W, 97, 958, XX, 34, NEQ, 0255, 0239, 0136, 0159, 0, 0, 046 |
| AL, 09, 2008091012, 03, HWRF, 012, 244N, 866W, 97, 958, XX, 64, NEQ, 0160, 0122, 0090, 0091, 0, 0, 046 |
| AL, 09, 2008091012, 03, HWRF, 012, 244N, 866W, 97, 958, XX, 64, NEQ, 0094, 0095, 0049, 0078, 0, 0, 035 |
| AL, 09, 2008091012, 03, HWRF, 018, 249N, 872W, 99, 954, XX, 34, NEQ, 0263, 0245, 0182, 0241, 0, 0, 035 |
Tracker output: Modified ATCF file

- Nearly same format as standard ATCF file, except the lead time (↓) has 2 extra places for fraction of an hour, allowing for ATCF-style output at non-hourly times.
  - Example: “04825” would be 48.25 hours, or 48 hours, 15 minutes.
Tracker output: Standard out

- A table is printed out that lists the tracker-derived fixes for each parameter and distance from the guess.

<table>
<thead>
<tr>
<th>Guess location for this lead time</th>
<th>Distance of parameter fix from guess location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max or min barnes-averaged value found by tracker</td>
<td></td>
</tr>
<tr>
<td>Storm &amp; lead time info</td>
<td></td>
</tr>
<tr>
<td>Maximum allowable distance that a parameter fix can be from the guess location in order to be included</td>
<td></td>
</tr>
</tbody>
</table>

| Flag to indicate if parameter fix is within errmax distance and will be included in fix average for this lead time |

<table>
<thead>
<tr>
<th>para#</th>
<th>param</th>
<th>Max/Min</th>
<th>Lon_fix(E)</th>
<th>Lon_fix(W)</th>
<th>Lat_fix</th>
<th>Max/Min_value</th>
<th>calcparm</th>
<th>errdist(km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>zeta 850</td>
<td>Max</td>
<td>267.73</td>
<td>92.27</td>
<td>37.94</td>
<td>59.82</td>
<td>T</td>
<td>122.74</td>
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<tr>
<td>2</td>
<td>zeta 700</td>
<td>Max</td>
<td>267.99</td>
<td>92.01</td>
<td>38.05</td>
<td>43.82</td>
<td>T</td>
<td>148.76</td>
</tr>
<tr>
<td>3</td>
<td>vagn 850</td>
<td>Min</td>
<td>267.40</td>
<td>92.60</td>
<td>38.15</td>
<td>12.30</td>
<td>T</td>
<td>110.81</td>
</tr>
<tr>
<td>4</td>
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<td>NOT USED</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>F</td>
<td>.00</td>
</tr>
<tr>
<td>5</td>
<td>vagn 700</td>
<td>Min</td>
<td>267.40</td>
<td>92.60</td>
<td>38.69</td>
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<tr>
<td>6</td>
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<td>NOT USED</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>F</td>
<td>.00</td>
</tr>
<tr>
<td>7</td>
<td>gph 850</td>
<td>Min</td>
<td>267.75</td>
<td>92.25</td>
<td>37.60</td>
<td>1253.22</td>
<td>T</td>
<td>114.48</td>
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<tr>
<td>8</td>
<td>gph 700</td>
<td>Min</td>
<td>267.78</td>
<td>92.22</td>
<td>37.67</td>
<td>2917.31</td>
<td>T</td>
<td>118.31</td>
</tr>
<tr>
<td>9</td>
<td>MSLP</td>
<td>Min</td>
<td>267.72</td>
<td>92.28</td>
<td>37.53</td>
<td>98153.14</td>
<td>T</td>
<td>111.22</td>
</tr>
<tr>
<td>10</td>
<td>vagn sfc</td>
<td>Min</td>
<td>267.40</td>
<td>92.60</td>
<td>37.65</td>
<td>6.58</td>
<td>T</td>
<td>84.76</td>
</tr>
<tr>
<td>11</td>
<td>zeta sfc</td>
<td>Max</td>
<td>267.34</td>
<td>92.66</td>
<td>37.65</td>
<td>19.72</td>
<td>T</td>
<td>80.13</td>
</tr>
</tbody>
</table>
• History & description of the GFDL vortex tracker
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• ATCF-plot: GrADS-based track and intensity plotting script
ATCF_plot: GrADS-based plotting tool

- Interactive GrADS tool for plotting both track and intensity.
ATCF_plot: How it works

User-input selections for models, storm, date, etc, are passed to unix scripts.

The unix scripts pull only the requested ATCF records from the ATCF file for the user-selected storm...

...and dumps those ATCF records into text files.

The ATCF records from those flist and vlist text files are read by atcfplot.gs, and the track and intensity plots are created.
ATCF_plot: Script setup

- Edit path names to replace $USER with your username in your version of atcfplot.gs:

  _rundir="/wrfclass/users/$USER/HWRF/src/gfdl-vortextracker/trk_plot/plottrak/
  _netdir="/wrfclass/users/$USER/HWRF/src/gfdl-vortextracker/trk_plot/plottrak/tracks/"

- For all atcfplot unix scripts here at the tutorial, all paths are defined using environmental variables $HOME and $USER. Back at home, be sure to change the path names accordingly.
• atcf_plot reads in standard ATCF format records, but it needs the *operational* ATCF files, since it keys off of the observational “CARQ” records and uses that data to plot the observed track and intensity (note: Real-time data used, not Best Track).

• Be sure to insert your ATCF records in the ATCF file specifically named $a\{\text{basin}\}b\{\text{storm ID}\}^{\{\text{YYYY}\}}.dat$ after the CARQ records for the correct DTG:
ATCF_plot: Input data

- atcf_plot opens up a GrADS ctl file (plottrak.ctl) that points to a meaningless data set with a global domain. By opening this ctl file and plotting a variable, GrADS now has global dimensions over which we can plot tracks for TCs anywhere on the globe.

- Be sure to also have the plottrak.grib file, then from your unix prompt run the command “gribmap –v –i plottrak.ctl”. In the output, you should see one line that says “MATCH”.

- To run, enter this command from your unix prompt:
  atcfplot.sh YYYY basin
  where basin = al, ep, wp, etc....
ATCF_plot: Some features

- Plot tracks alone, intensity alone, or tracks with an intensity inset window.
- Plot tracks that span from the current DTG through the end of the storm’s lifecycle.
- The ability to click & drag to zoom in on a particular track segment.