Tropical Cyclone Track Prediction

Richard J. Pasch and David A. Zelinsky
National Hurricane Center

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Outline

- Basic Dynamics
- Guidance Models
  - Statistical models
  - Beta and Advection Models
  - Dynamical models
  - Ensembles and consensus
- Synoptic Surveillance
- Track Forecasting at NHC
  - Practical considerations
  - Verification
Note that changes in inner core structure appear to have little influence on track.
Since inner-core variability does not have much influence on TC track, we can conclude that the dominant atmospheric motions are on the scale of the outer circulation of the TC.

Vorticity Equation

Scale Analysis of the Vorticity Equation

Use scales for tropical cyclone outer wind:

\( L \sim 500 \text{ km} \)

Rotational wind \( V \sim 10 \text{ m/s} \)

Divergent wind \( U \sim 1 \text{ m/s} \)

\( \Delta P \sim 10^5 \text{ Pa} \)

\( T \sim \frac{L}{V} \sim 5 \times 10^4 \text{ sec} \)

\( \zeta \sim \frac{V}{L} \sim 2 \times 10^{-5} \text{ sec}^{-1} \)

\( \delta \sim \frac{U}{L} \sim 2 \times 10^{-6} \text{ sec}^{-1} \)

\( \omega \sim \delta \Delta P \sim 0.2 \text{ Pa/sec} \)

\[
\frac{\partial \zeta}{\partial t} = -V \cdot \nabla \zeta - \omega \frac{\partial \zeta}{\partial P} - \beta v - (\zeta + f) \delta - k \cdot \nabla \omega \times \frac{\partial V}{\partial P}
\]

\[
\begin{array}{cccc}
(1) & (1) & (4) & (2) \\
4 \times 10^{-10} & 4 \times 10^{-10} & 4 \times 10^{-11} & 2 \times 10^{-10} & 1 \times 10^{-10} & 4 \times 10^{-11}
\end{array}
\]
To a first approximation, TC motion is governed by conservation of relative vorticity (vortex moves with the large-scale steering flow).

Second order includes the Beta term (conservation of absolute vorticity).

Divergence term (e.g., wavenumber 1 asymmetry in convection, interactions with orography, friction)

Vertical motions (e.g., twisting term) less important.

3-d dynamical model includes all of these terms.
Large-Scale Steering
The Beta Effect

- The circulation of a TC, combined with the North-South variation of the Coriolis parameter, induces asymmetries known as Beta Gyres.

- Beta Gyres produce a net steering current across the TC, generally toward the NW at a few knots. This motion is known as the Beta Drift.
Track Forecasting Exercise 1
Steering of Tropical Cyclones

- The concept of “steering” of a TC by the environmental winds is still a very useful one.
- Which level(s) to use?
- The best single pressure level appears to be typically around 500mb.
- Even Better: A pressure-weighted deep-layer (100-1000mb) mean wind field:

$$\int (\vec{V}) \, dp \quad / \quad \int dp$$
Exercise 1

- You are given deep-layer mean wind plots for 3 tropical cyclones (TCs) that were located in the vicinity of 24-25°N 67-70°W.

- Also shown are the subsequent 72-h tracks taken by the 3 TCs.

- Match up each deep-layer flow chart with the correct track.

- Bonus: What were the names/years of the 3 TCs?
Exercise 2

- You are given deep-layer mean wind plots for 3 tropical cyclones (TCs) that were located in the vicinity of 15°N 63°W.

- Also shown are the subsequent 72-h tracks taken by the 3 TCs.

- Match up each deep-layer flow chart with the correct track.

- What were the names/years of the 3 TCs?
Numerical Weather Prediction Models for TC Track Prediction
Atlantic Track Error Trends

NHC Official Track Error Trend
Atlantic Basin

Forecast error (n mi)

Year


24 h 48 h 72 h 96 h 120 h
Track Model Trends

48-h Track Forecast Guidance Trends
Atlantic Basin

Forecast Error (n mi)

Year


GFSI GFDI/HMNI EGRI NVGI HWFI EMXI
Hierarchy of TC Track Models

* **Statistical**
  - CLIPER: Forecasts based on established relationships between storm-specific information (i.e., location and time of year) and the behavior of previous storms

* **Simplified dynamical**
  - TABS, TABM, TABD: Forecasts based on simplified dynamic representation of interaction with vortex and prevailing flow (trajectory)

* **Dynamical**
  - GFS, ECMWF, UKMET, CTCX, HWRF, HMON: solve the three-dimensional physical equations of motion that govern the atmosphere.

* **Consensus**
  - TVCN, HCCA, FSSE, AEMI: Based on multi-model or single-model ensembles
Climatology and Persistence Model (CLIPER)

- Statistical model, developed in 1972, extended from 3 to 5 days in 1998, re-derived in 2005.
- Developmental sample is 1931-2004 (ATL), 1949-2004 (EPAC).
- Required inputs:
  - Current and 12-h old speed and direction of motion
  - Current latitude and longitude
  - Julian day, maximum wind
- No longer provides useful operational guidance, but is used as a benchmark for other models and the official forecast. If a model has lower mean errors than CLIPER it is said to be “skillful”.
- New version has been developed that can be extended to 7 days (or beyond).
**Simplified Dynamical Models**

*Trajectory and Beta*(TABS, TABM, TABD)

* Two-dimensional “trajectory” model. Uses steering determined from a global model (GFS), averaged over a 400km radius circle around the storm location at a given time.
* Adds a correction to simulate the Beta effect (about 0.7 m/s in 2016)
* Includes a small component of persistence
* Three versions, representing different depths of steering flow. The spread of these is a useful indicator of environmental vertical shear:
  * TABS (shallow): 850-700 mb
  * TABM (medium): 850-400 mb
  * TABD (deep): 850-200 mb
Three-Dimensional Dynamical Models

* Dynamical models
  - May be global or limited area.
  - May be grid point or spectral.
  - May employ a “bogussing” scheme to represent the TC vortex.

* Global models
  - Have inadequate resolution to define the TC inner core (eye and eyewall structure).
  - Are often useful for forecasting TC size and outer wind structure.
  - Have no lateral boundary conditions and therefore should have better performance at longer ranges than limited area models.

* Limited Area (Regional) models
  - Generally have higher horizontal resolution and are therefore more capable of representing core structure and intensity change.
  - Performance degrades at longer ranges.
Operational Global Models for TC Track Forecasting

* National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS)
* United Kingdom Met Office Model (UKMET)
* Navy Global Environmental Model (NAVGEM)
* European Centre for Medium Range Weather Forecasting Model (ECMWF)
* Canadian Global Deterministic Prediction System (CMC)

Each model consists of its own independent dynamical core, long- and short-wave radiation, cumulus convection, large-scale precipitation, surface fluxes, turbulent transports, and cloud microphysics.
<table>
<thead>
<tr>
<th>ATCF ID Tracker</th>
<th>Global/Regional Model Name</th>
<th>Horizontal Resolution</th>
<th>Vertical Levels and Coordinates</th>
<th>Data Assimilation</th>
<th>Convective Scheme</th>
<th>Cycle/Run Frequency</th>
<th>2017 TVCN INCLUSION</th>
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<tbody>
<tr>
<td>NVGM/NVGI</td>
<td>Navy Global Environmental Model</td>
<td>Spectral ~31km</td>
<td>60 Hybrid Sigma-pressure</td>
<td>NAVDAS-AR 4D-VAR</td>
<td>Simplified Arakawa-Schubert (SAS)</td>
<td>6 hr (144 hr) 00/06/12/18 UTC</td>
<td>NO</td>
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<td>AVNO/AVNI</td>
<td>Global Forecast system</td>
<td>Spectral ~13km</td>
<td>64 Hybrid Sigma-pressure</td>
<td>GSI/4D-VAR EnKF hybrid, including TC central pressure</td>
<td>Simplified Arakawa-Schubert [Arakawa and Schubert (1974) / Pan and Wu (1994)]</td>
<td>6 hr (180 hr) 00/06/12/18 UTC</td>
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<td>European Centre for Medium-Range Weather Forecasts</td>
<td>Spectral ~9km</td>
<td>137 Hybrid Sigma-Pressure</td>
<td>4D-VAR</td>
<td>Tiedke mass flux [Tiedke (1989)]</td>
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<td>EGRR/EGRI EGRZ</td>
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<td>Grid Point ~10 km</td>
<td>70 Hybrid Sigma-Pressure</td>
<td>4D-VAR</td>
<td>UKMET [Gregory and Rowntree (1990)]</td>
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<td>CMC/CMCI</td>
<td>Canadian Deterministic Prediction System</td>
<td>Grid Point ~25km</td>
<td>80 Hybrid Sigma-Pressure</td>
<td>4D-VAR ensemble Hybrid</td>
<td>Kain -Fritsch [Kain and Fritsch (1990, 1993)]</td>
<td>12 hr (240 hr) 00/12 UTC</td>
<td>NO</td>
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<td>HWRF/HWFI</td>
<td>Hurricane Weather Research and Forecast System</td>
<td>Grid Configuration 3 nests 18-6-2 km</td>
<td>61 Hybrid Sigma-Pressure</td>
<td>4D-VAR Hybrid GDAS GFS IC/BC</td>
<td>SAS mom. mix. + GFS shallow convection (6km and 18km) 2km nest – none</td>
<td>6 hr (126 hr) 00/06/12/18 UTC Runs commence on NHC/JTWC request</td>
<td>YES</td>
</tr>
<tr>
<td>HMON/HMNI</td>
<td>Hurricane Multi-scale Ocean-coupled Non-hydrostatic model</td>
<td>Grid Configuration 3 nests 18-6-2 km</td>
<td>42 Hybrid Sigma-Pressure</td>
<td>None for this season</td>
<td>SAS mom. mix. + GFS shallow convection (6km and 18km) 2km nest – none</td>
<td>6 hr (126 hr) 00/06/12/18 UTC Runs commence on NHC/JTWC request</td>
<td>NO</td>
</tr>
<tr>
<td>CTCX/CTCI</td>
<td>NRL COAMPS-TC (using GFS for IC and BC)</td>
<td>Grid Configuration 3 nests 45-15-5 km</td>
<td>42 Hybrid Sigma-Pressure</td>
<td>3D-VAR (NAVDAS) EnKF DART</td>
<td>Kain-Fritsch [Kain and Fritsch (1990, 1993)]</td>
<td>6 hr (126 hr) 00/06/12/18 UTC Runs commence on 1st NHC/JTWC advisory</td>
<td>YES (Possibly removed in 2018)</td>
</tr>
</tbody>
</table>
Data Assimilation and Model Initialization for Tropical Cyclones

* All operational dynamical models assimilates large quantities of remotely-sensed observations, including microwave data from polar-orbiting satellites, ASCAT vectors, cloud-drift winds, etc.

* Generally, global models do not use any observations from the inner core

* Bogussing is used by some models to ensure that an appropriate representation of the vortex is present in the model initial condition. Examples include:
  * Creating artificial (synthetic) data points to the model’s data assimilation process (NAVGEM, GFS).
  * Relocation of model-analyzed vortex to the correct location in first guess field (GFS, HWRF), followed by real data assimilation.
Operational Regional Models for TC Track Forecasting

- **Hurricane Weather Research and Forecasting model** *(HWRF)*
  - HWRF is the only model that assimilates some inner-core or near-inner-core data, i.e. airborne Doppler velocities flight-level reconnaissance wind data

- **Hurricane Multi-scale Ocean-coupled Non-hydrostatic model** *(HMON)*
  - Replacement for GFDL model, first ran operationally in 2017
  - Shares many parameterization schemes with HWRF, but no data assimilation

- **Coupled Ocean-Atmosphere Mesoscale Prediction System for Tropical Cyclones** *(COAMPS-TC)*
  - 2 versions: one runs using initial and boundary conditions off of NAVGEM and the other off of GFS; the latter produces superior forecasts and is used by NHC
Regional Modeling: Nesting and Storm Structure

Three telescopic domains: 18km: 75x75°; 6km ~11x10°; 2km inner-most nest 6x5.5°
Tracker Design

- Need to determine a point location of a storm in model output to use while making a track (or intensity) forecast
- An external tracker is applied to the model fields *after* the model run is complete
- A weighted average of the centroid positions of several low-level variables is used:
  - 850 mb vorticity
  - 700 mb vorticity
  - Surface/10m vorticity
  - 850 mb geopotential height
  - 700 mb geopotential height
  - Mean Sea Level Pressure
  - 3 secondary parameters (850 mb/700 mb/10m wind speed minimum)
Why the need for a multi-variate external tracker?

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

⋆ An ensemble is a collection of forecasts all valid at the same forecast time.

⋆ Often formed by making multiple runs of a given model (e.g. the GFS) with slightly different initial conditions and/or randomly varying physics.

⋆ At some forecast time, the average of all the ensemble member’s forecasts is the ensemble mean or consensus. The average distance of each member’s forecast from the ensemble mean is the ensemble spread.
Ensembles and Consensus

- In the case of a single model ensemble, the perturbed initial conditions represent uncertainty in the initial analysis. The model physics may also vary for each ensemble member.

- Single model ensembles are typically run with a lower resolution version of a model that is also used for the “deterministic” (regular) run.

- **AEMN** is the average of the GFS ensemble members (**AEMI** is the interpolated version of the ensemble mean).
GFS Ensemble example

HURRICANE IKE BEST TRACK & GFS
9/8/08 12Z
GFS Ensemble example

HURRICANE IKE BEST TRACK, GFS, & GFS ENSEMBLE 9/8/08 12Z
GFS Ensemble example

HURRICANE IKE BEST TRACK, GFS, GFS ENSEMBLE, & ENSEMBLE MEAN 9/8/08 12Z
Another way to form a consensus is to use an ensemble of different prediction models from the same initial time. This is called a multi-model ensemble.

In a multi-model ensemble, the forecasts from the various member models differ due to differences in model initialization, dynamical cores, and model physics.

- **TVCN** is the average of at least two of GFSI, EGRI, HWFI, CTCI, and EMXI (a “simple” average or consensus).
- **FSSE and HCCA** are weighted averages of several models (and OFCI in FSSE). They include bias correctors to account for model error tendencies (a “smart” consensus).
HFIP Corrected Consensus Approach (HCCA) for Tropical Cyclone Track and Intensity Forecasts

- “in-house” unequally weighted consensus for TC track and intensity forecasts
- Weighting coefficients chosen based on input model performance during a set of training forecasts
- 2017 input models for track: AVNI, CTCI, EGRI/2, EMN2/3, EMXI/2, HWFI
- 2017 input models for intensity:
  - Atlantic: AVNI, CTCI, DSHP, HWFI
  - East Pacific: AVNI, CTCI, DSHP, HWFI, LGEM
Ensembles and Consensus

* Often, the most successful consensus models are those formed from an ensemble of good performing models with a high degree of independence.

* Recently, some single-model consensus models (especially the GFS ensemble) have performed as well as the deterministic version of the same model especially at longer ranges (day 5 and beyond).

* Inclusion of the single-model consensus mean into a multi-model corrected consensus (such as HCCA) may add more value than the inclusion of the corresponding deterministic model.
Excellent example of a TVCN consensus: Hurricane Isaac, 0000 UTC 24 Aug 2012

120-hr observed center location of Isaac

120-hr TVCA Forecast
Of course, the consensus approach doesn’t always work! Sometimes the forecaster might want to exclude certain models and form a “selective consensus”, if the discrepancies among the models can be resolved. Resolving these discrepancies is often more difficult than some may have you believe!
Early vs. Late Models

- Forecast cycle begins at synoptic time (e.g., 12Z), and forecast is released at t+3 h (15Z).

- The 12Z runs of the dynamical models (HWRF, GFS, etc.), are not available until 16Z-19Z, well after forecast is made and released.

- These models are known as “late models”

- Forecasts that are available in time for forecast deadlines are called “early” models (TABs, CLIPER).

- For the 12Z forecast cycle, the latest available run of each model is taken (from the 06Z or even 00Z cycle), and adjusted to apply at 12Z. These modified forecasts are known as “interpolated” models (HWFI, GFSI, etc.).
Interpolated models are created by adjusting a smoothed version of the previous model run such that its 6 h forecast position exactly agrees with the current storm position. Then the rest of the forecast is adjusted by the same vector.
Interpolated models are created by adjusting the previous model run such that its 6 h forecast position exactly agrees with the current storm position. Then the rest of the forecast is adjusted by the same vector.

The "early" version of the model is what the forecasters actually have available to them when making a forecast.

OFCL is verified against the early models.
<table>
<thead>
<tr>
<th>Model</th>
<th>Late ID</th>
<th>Early ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamical Track Multimodel Consensus</td>
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<td>TVCN</td>
</tr>
<tr>
<td>HFIP Corrected Consensus</td>
<td>(none)</td>
<td>HCCA</td>
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<tr>
<td>FSU Superensemble</td>
<td>(none)</td>
<td>FSSE</td>
</tr>
<tr>
<td>GFS</td>
<td>AVNO/GFSO</td>
<td>AVNI/GFSI</td>
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<tr>
<td>GFS Ensemble</td>
<td>AEMN/GEMO</td>
<td>AEMI/GEMI</td>
</tr>
<tr>
<td>ECMWF global model</td>
<td>EMX/ECMO</td>
<td>EMX1/ECOI/EMX2</td>
</tr>
<tr>
<td>ECMWF Ensemble</td>
<td>ECMN</td>
<td>ECM2/ECM3</td>
</tr>
<tr>
<td>UKMET global model</td>
<td>EGRRR</td>
<td>EGR1/EGR2</td>
</tr>
<tr>
<td>Canadian GDPS</td>
<td>CMC</td>
<td>CMCI/CMC2</td>
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<td>U.S. Navy NAVGEM</td>
<td>NVGM</td>
<td>NVGI</td>
</tr>
<tr>
<td>HWRF</td>
<td>HWRF</td>
<td>HWFI</td>
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<td>Trajectory and Beta Models</td>
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<td>TABS/TABM/TABD</td>
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<td>Climatolgy and Persistence</td>
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<td>CLP5/OCD5/TCLP</td>
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<tr>
<td>NHC Previous Forecast</td>
<td>(none)</td>
<td>OFCI</td>
</tr>
</tbody>
</table>
Official forecasts were very skillful and were near best performing models, the consensus aids (FSSE, HCCA, TVCA).

EMXI best individual model, but not as good as the NHC forecasts or consensus models.

EGRI and UEMI were next best models.

GFSI, HWFI, AEMI, CMCI were fair performers (near the middle of the pack).

NVGI, HMNI, and CTCI trailed in 2017.
Official forecasts were very skillful, near or better than the consensus aids. EMXI best individual model, beating even the official forecast at 72h and beyond. GFSI, EGRI, AEMI, HWFI make up the middle tier of models. NVGI and CMCI trailed.
Additional Tools and Considerations for TC Track Forecasting
The magnitude of the consensus (TVCN) error can be statistically predicted based on:
- Model spread
- Initial and forecast intensity
- Forecast latitude and longitude displacements.

Adjust the regression line upward so that 75% of the time the actual error is smaller than the predicted error.

Adjusted regression gives you 75% “confidence circles” around TVCN.
72 h 75% GPCE circle, Hurricane Emily
1200 UTC 13 July 2005

48 h 75% GPCE circle, Hurricane Rita
0600 UTC 22 September 2005
NOAA G-IV AIRCRAFT: A SYNOPTIC SURVEILLANCE PLATFORM
Rita: 500 mb Dropsonde Observations
1800 UTC 21 Sept – 0300 UTC 22 Sept 2005
Rita Dropsonde Impact Example

NCEP GFS FORECAST

HURRICANE RITA
0000 UTC 22 SEP 2005

- Best Track
- With Sondes
- Without Sondes
1999-2005 Dropsonde Impact

Impact of Synoptic Surveillance
Dropwindsondes on GFS Track Forecasts
1999-2005

[Graph showing the impact of synoptic surveillance using dropwindsondes on GFS track forecasts from 1999 to 2005. The graph plots improvement (%) against the forecast period (h) with a decrease in improvement over time and a decrease in the number of forecasts.]
Track Forecasting at the NHC: Importance of Initial Motion

- Accurate estimate of initial motion is extremely important.
- Has dramatic impact on accuracy of the CLIPER model at shorter ranges.
- Initial motion vector is also used in some vortex bogussing schemes.
- 12-h NHC forecast is heavily weighted by the initial motion estimate.
- Not always easy to determine, particularly for systems with ill-defined centers.

2003-7 Atlantic Basin Track Errors
Operational vs Best Track CLIPER

- 43% improvement w/BT motion
- 25%
- 16%
- 11%
Track Forecasting at the NHC: Determination of Initial Motion

- Initial motion typically computed using the average motion over the previous 6, 12, or 18 h.
- Shorter when known changes in track are occurring, longer when center location is uncertain.
- Initial motion estimate should not reflect short-term track wobbles (e.g., trochoidal oscillations) that will not persist.

- NHC philosophy is that it is better to lag events a little bit than to be going back and forth with analyses or forecasts. We will usually wait several hours before “calling” a change in track.
Trochoidal Motion

- Substantial oscillation (wobble) of the center of a TC about its mean motion vector
- Primarily a side effect of convective asymmetries in the inner core
- Amplitude of motions varies but higher-frequency “wobbles” lost in ‘best track’ smoothing process
- Virtually impossible to forecast!
Previous official forecast exerts a strong constraint on the current forecast.

Credibility can be damaged by making big changes from one forecast to the next, and then having to go back to the original (flip-flop, windshield-wiper).

Consequently, changes to the previous forecast are normally made in small increments.

We strive for continuity within a given forecast (e.g., gradual changes in direction or speed from 12 to 24 to 36 h, etc.)
Official forecast near model consensus in extreme western FL panhandle.
Guidance shifts sharply westward toward New Orleans. Official forecast nudged westward into AL.
Little overall change to guidance, but NGPI shifts slightly eastward. Little change in official forecast.
Rest of the guidance shifts sharply eastward, leaving official forecast near the center of the guidance envelope (and very close to the actual track of Dennis.)
Track Forecasting at the NHC: Using Models

- Dynamical model consensus is an excellent first guess for the forecast (and often a good final guess!). Continuity dictates that it must be considered in view of the previous official forecast.

- Evaluate the large-scale environment using conventional data and satellite imagery (e.g., water vapor)
  - Try to assess steering influences so that you understand and perhaps evaluate the model solutions

- Compare the models’ forecast of the environmental features, not just the TC tracks.
  - Evaluate the initialization of the TC in the model fields. Unrealistic TC can affect the likelihood of a successful forecast.
  - Consider the recent performance of the various models, both in terms of accuracy and consistency.
  - Spread of models can dictate forecaster confidence.
Allow the forecaster to see features in the storm environment that could affect the future track and intensity of the cyclone.
Bad Initialization for Tropical Storm Gordon
1200 UTC 11 September 2006
How to resolve the difference between guidance models?
Poor organization (esp. lack of deep convection in the core) would argue against Jeanne being carried eastward by upper-level westerlies.

This reasoning allowed the forecasters to largely disregard the GFS and form a “selective consensus” of the remaining models.
Lack of consistency in GFDL forecasts for Wilma 19 October 2005

00Z

06Z

12Z

18Z
AGREEMENT AMONG THE TRACK GUIDANCE MODELS...WHICH HAD BEEN VERY GOOD OVER THE PAST COUPLE OF DAYS...HAS COMpletely COLLAPSED TODAY. THE 06Z RUNS OF THE GFS...GFDL...AND NOGAPS MODELS ACCELERATED WILMA RAPIDLY TOWARD NEW ENGLAND UNDER THE INFLUENCE OF A LARGE LOW PRESSURE SYSTEM IN THE GREAT LAKES REGION. ALL THREE OF THESE MODELS HAVE BACKED OFF OF THIS SOLUTION...WITH THE GFDL SHOWING AN EXTREME CHANGE...WITH ITS 5-DAY POSITION SHIFTING A MERE 1650 NMI FROM ITS PREVIOUS POSITION IN MAINE TO THE WESTERN TIP OF CUBA. THERE IS ALMOST AS MUCH SPREAD IN THE 5-DAY POSITIONS OF THE 12Z GFS ENSEMBLE MEMBERS...WHICH RANGE FROM THE YUCATAN TO WELL EAST OF THE DELMARVA PENINSULA. WHAT THIS ILLUSTRATES IS THE EXTREME SENSITIVITY OF WILMA'S FUTURE TRACK TO ITS INTERACTION WITH THE GREAT LAKES LOW. OVER THE PAST COUPLE OF DAYS...WILMA HAS BEEN MOVING SLIGHTLY TO THE LEFT OR SOUTH OF THE MODEL GUIDANCE...AND THE LEFT-MOST OF THE GUIDANCE SOLUTIONS ARE NOW SHOWING WILMA DELAYING OR MISSING THE CONNECTION WITH THE LOW. I HAVE SLOWED THE OFFICIAL FORECAST JUST A LITTLE BIT AT THIS TIME...BUT IF WILMA CONTINUES TO MOVE MORE TO THE LEFT THAN EXPECTED...SUBSTANTIAL CHANGES TO THE OFFICIAL FORECAST MAY HAVE TO BE MADE DOWN THE LINE. NEEDLESS TO SAY...CONFIDENCE IN THE FORECAST TRACK...ESPECIALLY THE TIMING...HAS DECREASED CONSIDERABLY.

...DELETED DISCUSSION TEXT...

FORECASTER FRANKLIN

FORECAST POSITIONS AND MAX WINDS

<table>
<thead>
<tr>
<th>Time</th>
<th>Position</th>
<th>Max Wind</th>
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<tbody>
<tr>
<td>INITIAL</td>
<td>19/2100Z</td>
<td>17.7N 83.7W 140 KT</td>
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<tr>
<td>12HR VT</td>
<td>20/0600Z</td>
<td>18.0N 84.6W 135 KT</td>
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<td>20/1800Z</td>
<td>19.2N 85.6W 145 KT</td>
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<td>23/1800Z</td>
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<td>36.0N 70.0W 65 KT</td>
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</tbody>
</table>
The size of the NHC forecast uncertainty cone is now determined by the 67th percentiles of the NHC official forecast errors over the previous 5 year period. The cone is formed by connecting circles at 12, 24, 36 h, etc., where the radius of each circle is given by the 67th percentile. The circles are reevaluated each season, and they are tending to get smaller as years go by.

**Forecast Verification**

**OFCL Error Distributions and Cone Radii**

Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.
2017 Atlantic Cone

<table>
<thead>
<tr>
<th>Forecast period (h)</th>
<th>Circle radii (n mi)</th>
<th>Percent change from 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>29</td>
<td>- 3%</td>
</tr>
<tr>
<td>24</td>
<td>45</td>
<td>- 8%</td>
</tr>
<tr>
<td>36</td>
<td>63</td>
<td>- 5%</td>
</tr>
<tr>
<td>48</td>
<td>78</td>
<td>- 7%</td>
</tr>
<tr>
<td>72</td>
<td>107</td>
<td>- 7%</td>
</tr>
<tr>
<td>96</td>
<td>159</td>
<td>- 4%</td>
</tr>
<tr>
<td>120</td>
<td>211</td>
<td>- 11%</td>
</tr>
</tbody>
</table>

It is anticipated that the cone in 2018 will be slightly smaller, but the 2017 verification is not yet complete. NHC considering changing definition to increase the size of the cone.
What is the most important factor for tropical cyclone track?

a) Large-scale steering flow
b) Internal dynamics of the eyewall
c) Beta effect
d) Storm intensity
Track Forecasting Review

Which of the following is typically the best type of model to use for track forecasting?

a) Statistical-dynamical model (SHIPS/LGEM)
b) High-resolution global model (ECMWF/GFS)
c) Multi-model consensus (TVCN/HCCA)
d) Regional hurricane model (HWRF/HMON)
Track Forecasting Review

What is the difference between AEMN and AEMI?

a) AEMI is the 6-hour old version of AEMN, interpolated to match the current position of the storm.
b) AEMI is the GFS ensemble control, and AEMN is the GFS ensemble mean.
c) AEMN and AEMI are both GFS ensemble means, but only AEMI uses the NCEP tracker.
d) There is no difference.
Concluding Remarks

* Multi-level dynamical models are the most skillful individual models for TC track prediction. Among these models, the ECMWF and GFS have provided the best guidance overall in recent years, but performance does vary significantly from year to year (or storm to storm).

* A consensus formed from an ensemble of dynamical models is typically more skillful than the best dynamical model.

* Single-model ensembles appear to most useful for longer-range (4-5 days and beyond).

* NHC forecasters have philosophical constraints on the official forecast that results in a certain amount of response lag (and may contribute to our errors lagging the consensus).

* While it is possible to beat the models from time to time, model performance has improved significantly over the years, and they are very difficult to beat on a consistent basis.