Evaluation and diagnostics of ECMWF tropical cyclone forecasts in 2020

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UEF 2021, Online, 1 June 2021
2020: An extraordinary Atlantic hurricane season in extraordinary circumstances
Objectives

1. To provide guidance for research aircraft mission planning

2. To provide insights into forecasts and their errors
   a. Position (“track”)
   b. Formation (“genesis”)
   c. Intensity (central pressure; maximum wind speed)
1. Research mission planning: HRES and Ensemble Products

ECMWF HRES (square), CF (triangle), ENS (circle) TCs initialized 20201003 12. 72-hour forecast valid at 20201006 12. TCs/Invests: ['25L', '92L'].
Contour: 500 hPa Z (m), Shading: 700 hPa RH (%), Dots: 200-850 hPa Wind Shear (m/s).

This product is not to be disseminated without permission from ECMWF
Research and Operational missions: Hurricane Delta

Synoptic Surveillance: Dropwindsondes

Inner-Core Sampling: Airborne Doppler Radar; in-flight data; Dropwindsondes; SFMR

NOAA / U.S. Office of Naval Research
2a. Preliminary NHC Verification of Atlantic Tropical Cyclone Position Errors

- ECMWF
- US NOAA GFS
- UK Met Office
- US NOAA HWRF
- US NOAA HMON
- US NHC

Average Position Error (km)

Forecast Period (h)
2a. Remarks on Position Forecast Errors (Atlantic Basin)

• 1-3 day forecasts
  – ECMWF and NCEP GFS performed best

• 4-5 day forecasts
  – All models (including ERA5) produced higher average errors than in most recent years.
  – Errors associated with several Atlantic TCs gaining significant latitude as they moved into the extratropics

• Position errors of initially weak TCs are overall larger than those of strong TCs

• Overall, other NWP centres are catching up each year

• A blend of different operational model predictions is overall superior to the predictions from any individual model
2b. Probabilistic Prediction of Tropical Storm Formation

- **Straightforward cases**
- ECMWF >30% chance of TC 5 days prior to being a tropical storm
- Relatively **high** 700 hPa relative vorticity at this lead time
- Ensemble-based probability that a TC exists within 500 km of the actual location of the TC (or wave) at a given time, as a function of forecast lead time

![Pre-Marco graph](image1)

![Pre-Teddy graph](image2)
2b. Probabilistic Prediction of Tropical Storm Formation

• Difficult cases
  • ECMWF 0-10% chance of TC within 5 days
  • NHC 0-10% chance of TC within 5 days and 0-30% chance of TC within 2 days
  • Relatively low 700 hPa relative vorticity 5 days prior to being a tropical storm

Pre-Sally

Pre-Eta
2b. Remarks on Forecasts of Tropical Storm Formation (Atlantic Basin)

• Large waves are well-predicted – no obvious “misses”

• For weak and/or interacting waves, it is challenging to discriminate between developers and non-developers 2+ days prior to formation

• For non-developing waves, there do not seem to be falsely high probabilities of formation

• Some concerns with ensemble “jumpiness” (David Richardson)

• Initialization, modelling, and predictability challenges for a variety of multi-scale mechanisms:
  • Distinct, solitary waves with high vorticity
  • Distinct, solitary waves with low vorticity
  • Role of convection in organizing the vortex
  • Wave- Wave / Low Pressure / ITCZ interactions
  • Large-scale interactions
2c. HRES: Tropical Cyclone Intensity Forecasts (Pmin and Vmax)

Initially weak TCs have largest Pmin forecast errors at >36 h.
Initially weak (strong) TCs have high (low) Pmin biases.

Low Vmax biases
ECMWF Special Topics Paper (in preparation)

• August 15– September 20, 2020

• 30+ numerical research experiments
  – Modelling (e.g., resolution; coupling; physics; numerics; non-hydrostatic…)
  – Data Assimilation (e.g., microwave; all-sky; AMV; pressure; scatterometer; aircraft; GPS RO; Aeolus …)

• Illustration: One research experiment
  – 4 km, hydrostatic, New Physics for Cy47r3 (expid: hjfb, thanks to Peter Bechtold)
  – (Near) operational initial conditions
  – Hurricane Teddy, initialized 2020-09-16, 12 UTC
TEDDY. 48 h 0001 forecast initialized at 2020-09-16 12
MSLP and wnd. Vmax=91 kt, Pmin=943 hPa.
NHC Best Track: Vmax = 115 kt, Pmin = 947 hPa, RMW = 46 km.
47r3 physics 4 km ECMWF
47r3 physics 4 km ECMWF
Radial profiles of radially averaged surface winds

Black: absolute wind speed
Red: azimuthal wind component
Blue: radial wind component
Light blue: maximum wind speed per radius

Experimental 4 km ECMWF

NHC Vmax and RMW
Experimental
4 km ECMWF

r-p profile of azimuthally averaged wind speed
Azimuthally averaged azimuthal wind

Azimuthally averaged radial wind
2c. Remarks on Forecasts of Tropical Cyclone Intensity Change

• Large tropical cyclones (Teddy; several NW Pacific typhoons) can intensify well in predictions

• However, most predicted tropical cyclones do not intensify as much as in reality

• Accurate representation of convective-scale and mesoscale processes in the initial conditions is necessary

• Intensification is better caught at 4 km with assimilation and/or initialization on these scales
  – Including Rapid Intensification
  – Vmax predictions are less biased

• Large intensity errors exist for initially strong TCs – is the weakening process too slow?
Future Goals

• Complete Special Topics paper

• Deliverable evaluation and diagnostics code framework (Python)

• Additional publications: some ideas
  – Refined analysis of evaluations
  – Process-driven diagnostics of interesting research experiments
  – Future verification methods (e.g. structure; precipitation)