5D.2 ## ANALYSIS AND FORECASTS OF TROPICAL CYCLONES IN THE ECMWF 40-YEAR REANALYSIS (ERA-40)

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1. INTRODUCTION

One of the more attractive aspects of global reanalysis is the potential for more insightful and accurate studies of the relationship between tropical cyclones (TCs) and lower-frequency components of the tropical atmosphere. Conversely, the quality of the reanalysis model precipitation physics and the analysis of the large-scale flow is strongly related to the analysis and track forecasts of TCs. Thus, the evaluation of TC performance in reanalysis serves to quantify the quality of reanalysis for tropical applications.

Perhaps the most remarkable result from the first European Centre for Medium-range Weather Forecasts (ECMWF) reanalysis (ERA-15) was the very high probability of detection (POD) for TCs through the 1979-93 period compared to operations as shown in Fig. 1 (Serrano 1997). Note the jump in operational model POD in 1989. This improvement was a consequence of changes to the model physics (i.e., cumulus parameterization) and followed a concomitant improvement in tropical wind score as seen in Fig. 2.

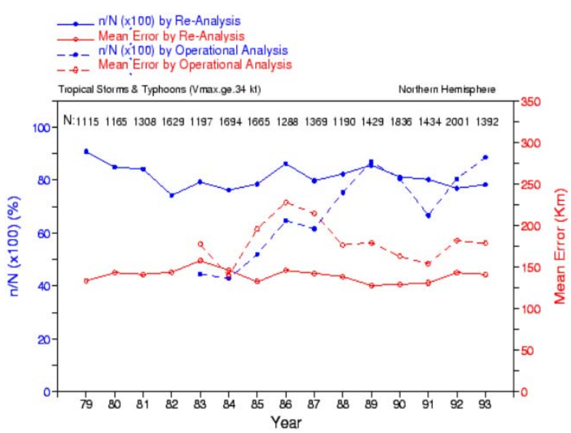

Figure 1. ERA-15 (dark solid line) v ECMWF (dark dash line) operations POD 1979-1993.

This difference suggests that observational content (the observations for ERA-15 and ECMWF operations were largely the same) is not a sufficient condition for quality in the tropical analysis and that TC analysis is strongly dependent on the modeling of tropical physics.

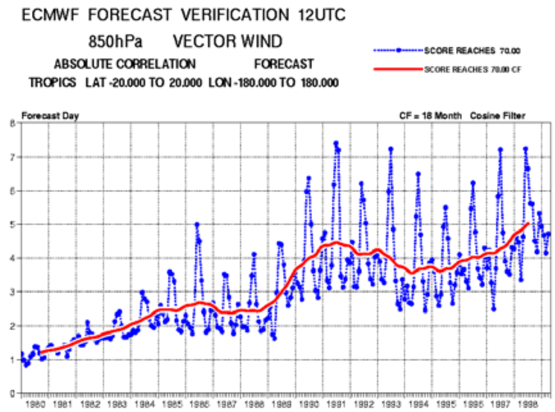

Figure 2. ECMWF tropical wind score 1982-2000 defined as the time when the correlation between the verifying wind anlaysis and and the forecast drops below 0.7.

2. ERA-40 SYSTEM & 2001 RESULTS

The next ECMWF reanalysis (ERA-40) project is now in its production phase and will reanalyze the period 1957-present using a higher resolution global assimilation model (T159 or 80 km and 60 layers to 0.1 hPa) than was used in previous global reanalyses. A comprehensive description of ERA-40, with status and preliminary results, is available at `http://owms.ecmwf.int/research/era/index.html`. A key feature of the ERA-40 model is that its resolution is comparable to that of the U.S. operational global model (T170L42 for National Center for Environmental Prediction (NCEP) and T159L34 for Fleet Numerical Meteorology and Oceanography Center (FNMOC)) circa 2001.

Fig. 3 compares the mean forecast error (FE = great circle distance between forecast and observed TC position) of the NCEP(AVN) and ECMWF (IFS-Integrated Forecast System) models for the 2001 Northern hemisphere season. This verification was conducted independently using the same resolution gridded model fields. Note the very low mean FE at t=72 h for both models. This mean FE represents a 30-40% improvement over the no-skill track model CLImatology and PERisistence (CLIPER, ~330 nm, not shown).

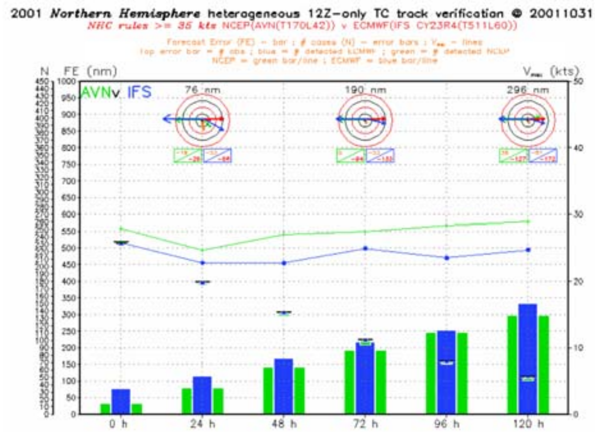

Figure 3. 2001 NHEM TC forecast error NCEP(AVN) v ECMWF (IFS) for forecast time t=0, 24, …, 120 h. The circles with arrows indicates cross track and along track error.

Thus, from a technical perspective, the ERA-40 system should be capable of performing as well as the 2001 U.S. models with modern-era observations if the TC is well-analyzed, particularly in the 3-7º annulus around the cyclone where the critical dynamical motion processes occur (e.g., Fiorino and Elsberry 1989).

3. TC OBSERVATIONS

Mr. Charlie Neumann (formerly of the National Hurricane Center) has conducted a continuing global reanalysis of operational best track data from the warning centers (data extends back to the 1850s in the Atlantic). The final product is a global 6-h (synoptic times 00/06/12/18 UTC) position, motion and intensity (max wind speed), including positions during formation (i.e., winds < 30 kts). These data are used for both verification and in a wind profile retrieval scheme developed for TC data assimilation experiments. We denote the Neumann data as "TC observations" because they are seldom based wholly on meteorological observations (e.g., typically derived from an interpretation of satellite imagery) and are quasi-independent of other observations used in reanalysis.

Fig. 4 gives a global view of TC activity 1956 — 2001 in which we see a noticeable *decrease* in activity from 1993 — 2001 when the TC observing system was fairly constant. Some of the low-frequency variability, before the era of global satellite reconnaissance (~1970), comes from observing system variability and operational practices. The Neumann data set has been an invaluable resource for this and other studies of TCs.

4. TC DETECTION IN ERA-40 & NCEP REANALYSES

We have adapted the operational tracking scheme of FNMOC to find TC-like circulations in the model output. This system requires an initial, *a priori* TC position and then locates model TCs based on surface wind shifts and 850 hPa relative vorticity. While such features may be operationally significant (e.g., are visibly high amplitude on a map), they are not necessarily meteorological. For the purpose of first-order TC verification, detection is defined as the existence of an operationally trackable circulation. The more meteorological tracking scheme of Vitart et al. (1997) has also been implemented to define meteorological quality, but results are not presented here.

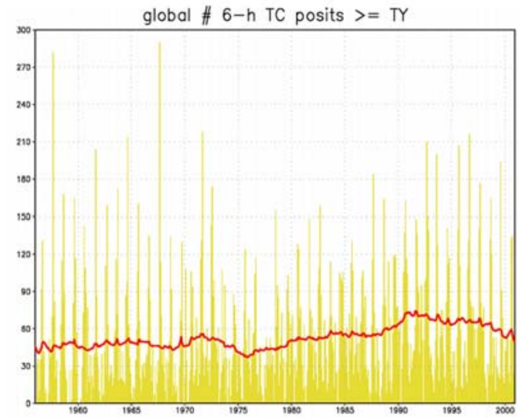

Figure 4. TC activity -- # 6-h positions / month with max wind ≥ 65 kts. The dark line is a 2-y running average.

In Fig. 5, we compare TC detection rates between ERA-40 and the first NCEP/National Center for Atmospheric Research (NCAR) reanalysis (NCEP/R1; Kistler et al. 2001) for the years 1957-, 1973- and 1989-94. Despite large variation in the observing system, both reanalyses achieve detection rates of 80% with ERA-40 substantially higher at 90%. Part of the better detection in ERA-40 is because the NCEP/R1 model had lower resolution (T64L28). However, initial position and maximum wind speed errors are considerably higher than found in the 2001 operational models implying a large analysis error in the vicinity of TCs.

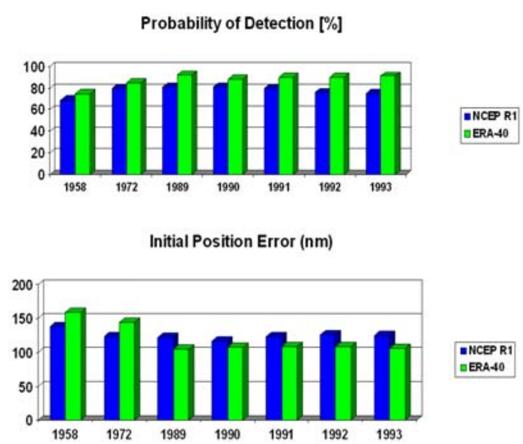

Figure 5. NCEP R1 v ERA-40 POD and initial position error (nm) for all TCs in 1958, 1972, and 1989-1993.

While the POD is quite good in both reanalyses, the forecast error compared to CLIPER for ERA-40 is at best disappointing as shown in Fig. 6.

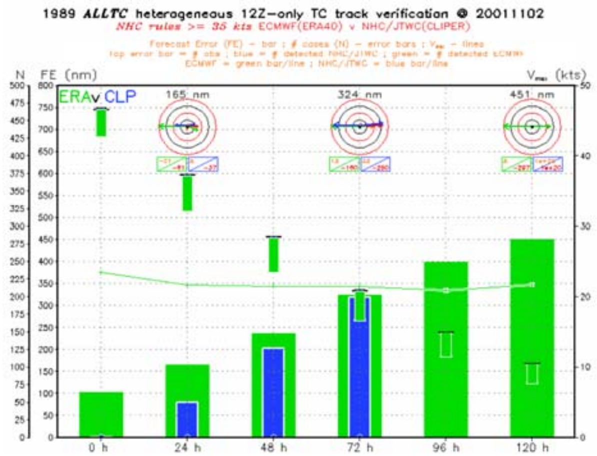

Figure 6. As in Fig. 2 except for ERA-40 (light bar) v CLIPER (dark bar) for all 1989 TCs.

Note that the 72-h mean ERA-40 FE is nearly the same as CLIPER whereas modern global models, of comparable resolution, achieve improvements of 30-40%. This despite direct assimilation of radiances and an observational coverage comparable to that in 2001. Nonetheless, many ERA-40 forecasts were excellent and better than CLIPER as shown in Fig. 7 for Hurricane Hugo.

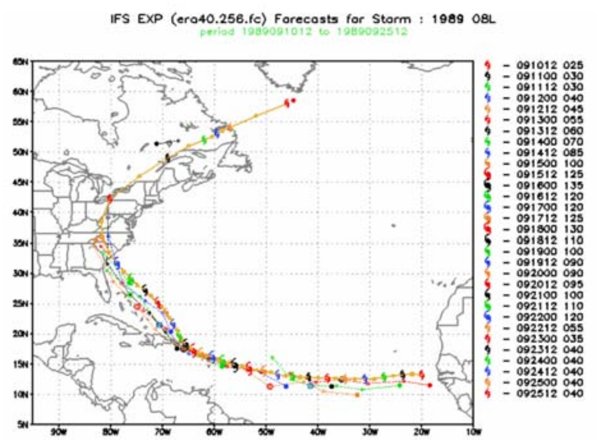

Figure 7. ERA-40 forecasts for Hurricane HUGO 1989. The hurricane symbols and the dark line is the best track.

5. TC ASSIMILATION EXPERIMENTS

While the ECMWF operational forecast system has been able to detect and forecast TCs with good skill in the current observing system *without* the assimilation of TC observations, the results shown in Fig. 5 and from the forecast in Fig. 6 suggest large analysis errors in the 3-7º annular region, i.e., in the region of dominant TC motion processes.

To test the impact of an improved TC analysis on the reanalyses, an assimilation scheme was developed in which the Neumann TC observations were used to construct synthetic wind soundings similar to the "bogussing" techniques used by many operational global models (e.g., Heming et al. 1995). The preferred and more accurate description is to *retrieve* wind profiles from the TC information and then to add these retrievals to the mix of observations being analyzed.

The input to the scheme is position, max winds speed (TC intensity), radius of 30 kt winds (from a climatology developed from operational warnings) and 12-h motion. The output consists of vertical wind profiles from 1000 – 300 hPa at the TC center and at 2, 4 and 6º latitude along four radial spokes in the ordinal directions North, East, South and West. This is the FNMOC 13-point stencil (Goerss and Jeffries 1994). The retrieved winds come from a weighted sum of three wind models: 1) a symmetric TC wind profile (modified Rankine) based on intensity and the 30 kt radius with boundary inflow at 1000 and 925 hPa; 2) storm motion; and 3) a T20 (smoothed) background (first guess) assimilation model winds.

In addition to this traditional 13-point retrieval we tested a reduced or "minimalist" scheme where only the inner five points of the 13-point stencil are retrieved (0 and 2º) with no contribution from the T20 model background wind field. The observation modeling assumption of the minimalist scheme is that the flow in the inertially stiff inner core of a TC is predominately motion and the symmetric component (plus inflow in the boundary layer). The accuracy of this observation model is undoubtedly higher than in the 13-point stencil model as the flow in the 3-7º annular region is asymmetric (e.g., beta gyres) and complicated by the large scale steering and thus more difficult to model.

For assimilation purposes the retrievals are treated as dropwindsondes (in terms of confidence factors and error). No special change was necessary to the pre-analysis quality control checking to prevent rejection and nearly 98% of all retrievals were assimilated.

A two-month boreal summer period was chosen for testing (July/August, 1987) and the ERA-40 data assimilation system was run with conventional observations (i.e., no satellite radiances but satellite winds) only, and with and without TC retrievals. The first runs the 13-point FNMOC scheme resulted in improved track forecasts in the 0-72 h range but poorer forecasts at 120 h compared to the runs initialized without the TC retrievals. This result was counter to what the experience at the UK Met. Officer where positive impacts were found at all forecast times (Heming et al. 1995).

Examination of the fields showed the outer radii retrievals were substantially different than the background and resulted, on occasion, in unrealistic TC wind structure. The implication was that the outer radii retrievals were of poorer quality than the analysis coming from the non-TC observations. This suggests that the quality of the FNMOC observation model that converts the non-meteorological data to observations that can be assimilated (i.e., a retrieval scheme) lacked sufficient accuracy, whereas the retrievals near the center were of relatively higher quality. The conclusion is that the TC modeling in the retrieval scheme failed, or more positively, that the ERA-40 data assimilation was more correct for the larger scale components of the TC circulation.

Fig. 8 below demonstrates the 5-point stencil of this "minimalist" approach with obvious positive impacts on the analysis.

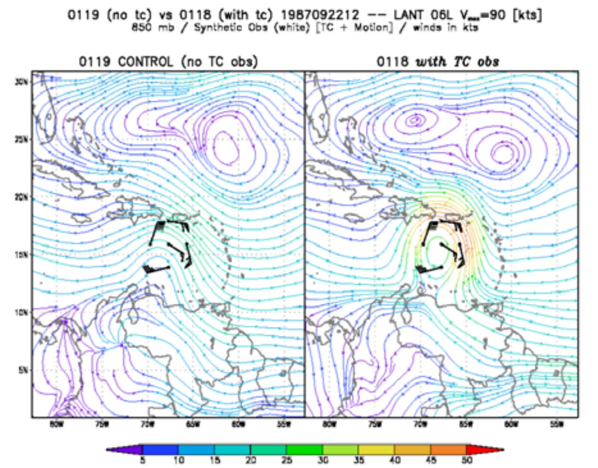

Figure 8. TC wind retrievals for a near hurricane strength system (wind barbs). The panel on the left is the no TC obs run and the right with TC obs.

Forecasts were also made to see the impact not only on POD, but also on track skill with the assumption that a better TC analysis should produce better forecasts. The results in Fig. 9 show much better forecasts at all forecast times including t=120 h. Thus, the minimalist approach yielded at better analysis of TCs.

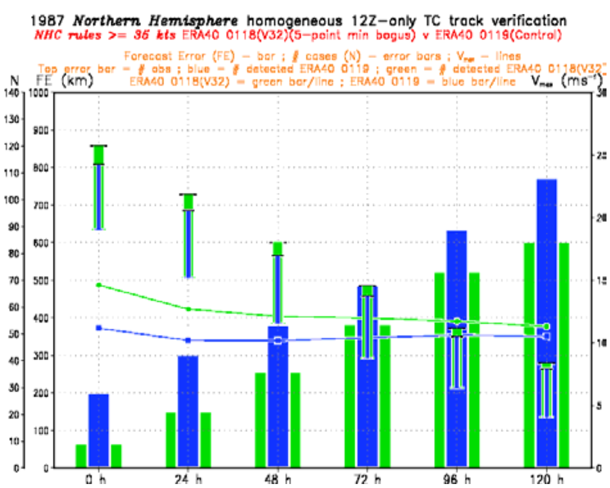

Figure 9. Mean forecast error (km) at t=0, 24, ..., 120 h with (light bar) and without the TC retrievals (dark bar).

Despite these positive impacts, ECMWF chose not to use the retrievals in ERA-40 because of a lack of confidence in the observation model and because the operational system produced good TC track forecasts without TC retrievals when satellite radiances were assimilated. However, the results from 1989 in Fig. 6 showed that the radiance observations did not correct apparently large TC analysis errors in the critical 3-7º annular region.

6. SUMMARY

The most basic conclusion from: 1) the TC assimilation experiments; 2) the 1989 ERA-40 and the 2001 ECMWF operational TC track forecasts is that the analysis of TCs in ERA-40 is not what it could be and quite a bit less than had been expected. While the large-scale and low-frequency components of the tropical circulation may still be well analyzed in ERA-40, application to TC studies may be problematic. Clearly, further experiments with the minimalist TC retrieval scheme are needed to understand the impact of a more accurate analysis of TCs on the larger-scales and on other aspects of the general circulation.

Regardless of the known deficiencies in the ERA-40 TCs, the availability of 40+ years of once-daily, 10-d forecasts starting in 1958 will be certainly provide many interesting cases for future studies.

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8. ACKNOWLEDGEMENTS

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