An Intercomparison of Tropical Cyclone Position and Intensity Among Atmospheric Reanalysis Datasets

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Introduction

The emergence of reanalyses has provided tools of great utility for studying interactions between tropical cyclones (TCs) and their larger scale environment. In spite of the increasing usage of reanalyses in studying TCs, there has been no comprehensive examination of TC representation within these datasets. The implications of the accurate depiction of TCs within reanalyses may have far reaching consequences including potentially impacting the representation of the general circulation on short time scales. The following study seeks to quantitatively compare reanalysis TC position, intensity, and intensity life cycle with the best-track and examine how these parameters vary among reanalyses.

Methodology

In this study, the fidelity of TC position, intensity, and intensity life cycle is examined within five reanalysis datasets: the ECMWF ERA-40 (Uppala et al. 2005), ECMWF ERA-I (Dee et al. 2011), JMA JRA-25 (Onogi et al. 2007), NASA MERRA (Rienecker et al. 2011), and NCEP CFSR (Saha et al. 2010). TCs within the NHC best-track dataset (Jarvinen et al. 1984; Neumann et al. 1993) and JTWC best-track dataset (Chu et al. 2002) in the Eastern North Pacific, North Atlantic, and Western North Pacific from 1979–2001 are chosen for study. Each best-track TC within the reanalyses is manually tracked using minimum mean sea-level pressure and maximum 925 hPa relative vorticity. Reanalysis TC position and intensity are then compared to those found in the best-track. TC position is examined by calculating TC position difference which is defined as the difference between the position of the best-track TC and corresponding reanalysis TC. TC intensity life cycle is defined as the temporal evolution of TC intensity since the time at which the best-track TC intensity first reached or exceeded 34 kt. To facilitate the comparison of reanalysis and best-track TC intensity life cycle, the intensity within each dataset is normalized by subtracting the mean intensity and then dividing by the standard deviation of intensity for the specific dataset.

Spatial Variation of Tropical Cyclone Position Difference

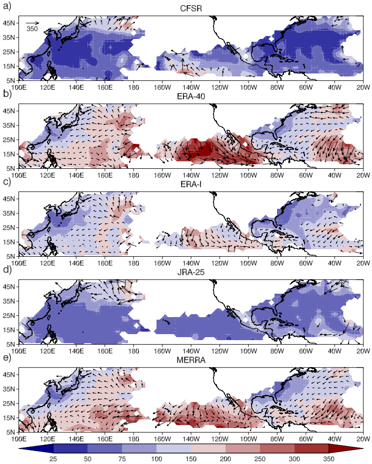

Fig. 1: Plan view of the magnitude (shaded) and vector (arrow) mean position differences (km) for the (a) CFSR, (b) ERA-40, (c) ERA-I, (d) JRA-25, and (e) MERRA for TCs passing within 250 km of each gridpoint in the Eastern North Pacific, North Atlantic, and Western North Pacific. Position difference is defined as the difference between the best-track and reanalysis TC position. Vectors point from the best-track to the reanalysis TC position from tail to head and are not drawn for mean position difference magnitudes less than 100 km. Position difference is interpolated to a 2° latitude by 2° longitude grid with each gridpoint representing the average of the position difference weighted by its distance from the gridpoint. The grid is smoothed once with a nine-point smoother.

Spatial Variation of Tropical Cyclone Maximum 10 m Winds

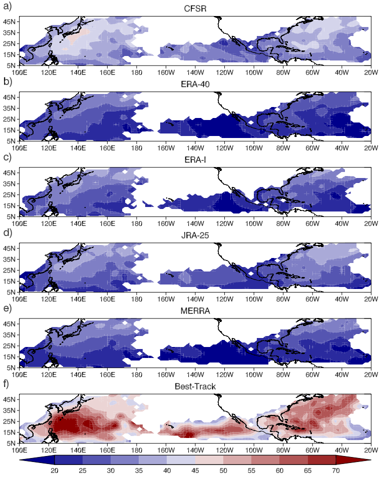

Fig. 2: Plan view of mean maximum 10 m winds (kt) from the (a) CFSR, (b) ERA-40, (c) ERA-I, (d) JRA-25, (e) MERRA, and (f) best-track for TCs passing within 250 km of each gridpoint in the Eastern North Pacific, North Atlantic, and Western North Pacific. Reanalysis maximum 10 m winds are determined by computing the maximum value in a 7° latitude by 7° longitude box centered on each TC. Maximum 10 m winds are interpolated to a 2° latitude by 2° longitude grid with each gridpoint representing the average of maximum 10 m winds weighted by its distance from the gridpoint. The grid is smoothed once with a nine-point smoother.

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Mean Tropical Cyclone Position Difference and Intensity

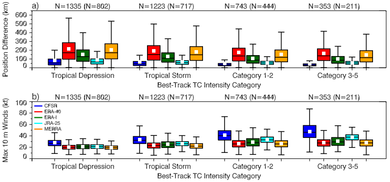

Fig. 3: Box and whiskers plots of (a) position difference (km) and (b) maximum 10 m winds (kt) for TCs in the Eastern North Pacific, North Atlantic, and Western North Pacific for each of the five reanalyses stratified by the four best-track intensity categories used in this study. The CFSR, ERA-40, ERA-I, JRA-25, and MERRA correspond with color coding of blue, red, green, cyan, and orange, respectively. The mean of the sample is denoted by a white square printed within each box. The number of distinctly named TCs for the CFSR, ERA-40, JRA-25, and MERRA is denoted at the top of the figure for each intensity category while the number of distinctly named TCs for the ERA-I is given in parentheses.

Unexpected Underestimation of Tropical Cyclone Intensity

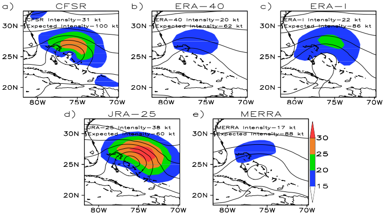

Fig. 4: Plan view of 10 m surface winds (kt; shaded) and mean sea-level pressure (hPa; contoured) for NATL TC Andrew at 1800 UTC 23 August 1992 (best-track intensity = 150 kt) in the (a) CFSR, (b) ERA-40, (c) ERA-I, (d) JRA-25, and (e) MERRA. The first intensity listed is the reanalysis maximum 10 m winds. The second intensity is obtained from Walsh et al. (2007) who coarsened a radial profile of 10 m winds for TC Andrew to the reanalysis resolution to provide a benchmark for determining whether intensity is underestimated beyond what can be expected due to the coarse reanalysis grid.

Life Cycle of Tropical Cyclone Intensity

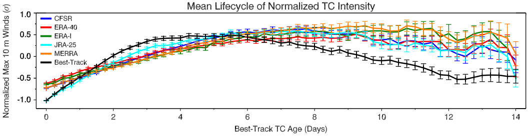

Fig. 5: Mean lifecycle of normalized maximum 10 m winds (σ, or standard deviation) for NATL and WPAC TCs within the best-track and five reanalyses. TC age is defined as the time since the maximum 10 m winds of the TC first reached or exceeded 34 kt in the best-track. TC intensity is normalized by subtracting the mean intensity and dividing by the standard deviation of intensity for a given dataset. The error bars denote the standard error of the mean.

Nonphysical Reanalysis Tropical Cyclone Structure

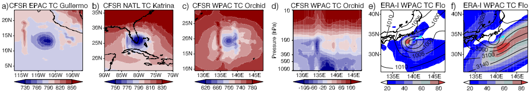

Fig. 6: Plan view of 925 hPa geopotential height (gpm) in the CFSR for (a) EPAC TC Guillermo at 1800 UTC 2 August 1997 (best-track intensity = 105 kt), (b) NATL TC Katrina at 0000 UTC 26 August 2005 (best-track intensity = 70 kt), and (c) WPAC TC Orchid at 1200 UTC 4 October 1991 (best-track intensity = 40 kt) in the CFSR. (d) Vertical cross-section of geopotential height anomalies (gpm) in the CFSR through the line of latitude (19.5°N) intersecting the center of WPAC TC Orchid in (c). Plan view of (e) 10 m surface winds (kt; shaded) and mean sea-level pressure (hPa; contoured) and (f) 700 hPa wind speed (kt; shaded) and geopotential height (gpm; contoured) in the ERA-I for WPAC TC Flo at 1200 UTC 8 October 1993 (best-track intensity = 60 kt). TC Flo is traveling at a speed of 43 kt in the direction of motion indicated by the cyan arrow in the best-track in (e) and (f).

Discussion

The results of this study show an underestimation of TC intensity beyond that expected from the coarse resolution of reanalyses (Walsh et al. 2007) as exemplified in Fig. 4. Further, reanalyses struggle to replicate the life cycle of best-track TCs underrepresenting pre-peak TC intensification rates and exhibiting a delay in peak intensity relative to the best-track (Fig. 5). Deficiencies are also observed for TC position differences with mean values of several hundred kilometers found depending upon the location and the dataset (Fig. 1). The ERA-40, ERA-I, and MERRA exhibit position differences that generally decrease as the TC approaches the most observation dense portions of the North Atlantic and Western North Pacific. In contrast, not only does the use of vortex relocation and TC wind profile retrievals in the CFSR and JRA-25, respectively, prevent the observation density from degrading track, but it also yields more intense TCs (Figs. 2 and 3). Of the three basins examined, the Eastern North Pacific is found to have the largest position differences and weakest TC intensities primarily due to the relative dearth of observations in this basin (e.g., Hatsushika et al. 2006). Moreover, the occurrence of nonphysical TC structure in the CFSR and ERA-I argues that further work is needed to improve reanalysis TC representation (Fig. 6). These results suggest that caution should be exercised when using reanalyses to study TCs for work that strongly depends on replicating TC position or intensity.

Acknowledgments and References

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