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A 32-YEAR REANALYSIS INTERCOMPARISON OF TROPICAL CYCLONE STRUCTURE IN THE EASTERN NORTH PACIFIC AND NORTH ATLANTIC

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1. INTRODUCTION

Global reanalyses provide a complete depiction of the atmosphere in four dimensions using a single, consistent model and a wide variety of available observations, though the method by which the observations are assimilated varies. Ongoing model development and increased computing power have produced higher resolution datasets in recent years. However, past work has shown that reanalyses often struggle to properly resolve tropical cyclone (TC) intensity and structure (e.g., Schenkel and Hart 2012; Wood and Ritchie 2014).

In order to highlight the limitations of using reanalyses to investigate TCs, this study presents a comparison of datasets that include special treatment of TCs, such as wind profile retrievals and vortex relocation, and datasets that do not include any additional processing for TCs. The availability of reconnaissance data is also examined for potential improvements to TC representation within the reanalyses.

2. DATA & METHODS

The datasets included in this study are the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim Reanalysis (ERA-I; Dee et al. 2011); the 25-year Japanese Reanalysis (JRA-25; Onogi et al. 2007); the Climate Forecast System Reanalysis (CFSR; Saha et al. 2010); the 20th Century Reanalysis (20CR; Compo et al. 2011); the Modern Era Retrospective-Analysis for Research and Applications (MERRA; Rienecker et al. 2011); the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) Reanalysis (NNR; Kalnay et al. 1996); and the 55-year Japanese Reanalysis (JRA-55; Ebita et al. 2011).

All data are obtained at 6-hourly resolution. The FNL is the only non-reanalysis dataset explored, and it is used as a reference due to the vortex relocation method applied for TCs in the Global Forecast System (GFS) model. Note that the regular grid data discussed here tend to be coarser than the native model resolution (e.g., ~60 km for the JRA-55 and ~38 km for the CFSR).

Cyclone phase space (CPS; Hart 2003) parameters are calculated and compared for all TCs in the National Hurricane Center (NHC) best track for 1979-2010. The resulting dataset is comprised of 487 TCs in the eastern North Pacific (ENP) and 382 TCs in the North Atlantic (NATL). As a result of greater data assimilation since 2000, the subset of cases during 2000-2010 are explored in greater detail. Due to its high spatial resolution (0.225°) and its tropical focus, data from the Year of Tropical Convection (YOTC) project are examined in 2008.

3. COMPARING THE DATASETS

In general, the reanalyses examined here depict tropical structures (B < 10 m and $-V_T^L$ > 0 m s^{-1}; the lower right CPS quadrant) more consistently in the NATL than the ENP (Figs. 1, 2). Features of extratropical transition (B > 10 m and $-V_T^L$ < 0 m s^{-1}; the upper left CPS quadrant) are also more commonly found in the NATL, as expected. Increased variability between datasets is observed in the ENP compared to the NATL as shown by the distribution of positive and negative 900-600 hPa thermal wind values.

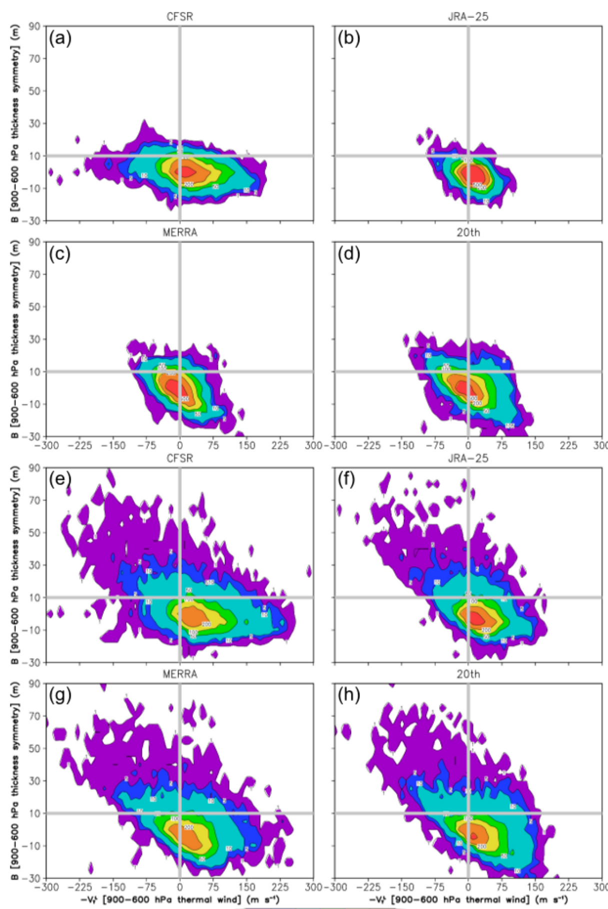

Figure 1. Accumulated CPS frequency for CFSR, JRA-25, MERRA, and 20CR for (a)-(d) the ENP and (e)-(h) the NATL over the period 1979-2010.

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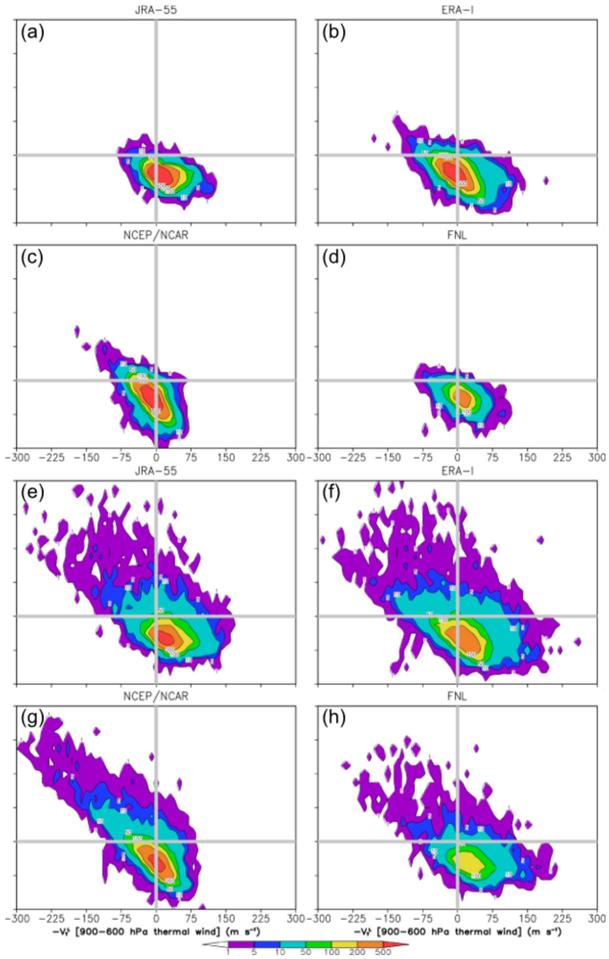

Figure 2. Same as Fig. 1 except for JRA-55, ERA-I, and NNR. Note that the FNL time period is restricted to 2000-2010.

Mature, intense TCs, here defined as an intensity of at least 115 kt (minimal category 4 hurricane), are expected to have the strongest warm cores and thus the most negative geopotential height anomalies. Figure 3 shows the average zonal geopotential height anomalies composited using the center of the TC as the reference point for 103 observations of 115+ kt in the ENP and 219 observations in the NATL over the period 2000-2010. The FNL is also shown for comparison. The expected structure is depicted more consistently in the NATL, with the most negative values existing near the surface and decreasing upward. This compares well with the structure shown in NOGAPS data for Hurricane Floyd in 1999 at 115 kt (Hart 2003).

Conversely, the anomaly structure is far weaker in the ENP despite the strong intensities of the TCs in the composite. The weakest signatures are found in the NNR, ERA-I, and MERRA. The NNR has the coarsest spatial resolution, while the ERA-I and MERRA datasets do not include special treatment for TCs. Alarmingly, the composite anomaly from the ERA-I has its minimum centered in the lower troposphere rather than near the surface, which affects the computation of the thermal wind in CPS for the 900-600 hPa layer. This may contribute to the skewed distribution of CPS values in the lower left quadrant (e.g., Fig. 2b).

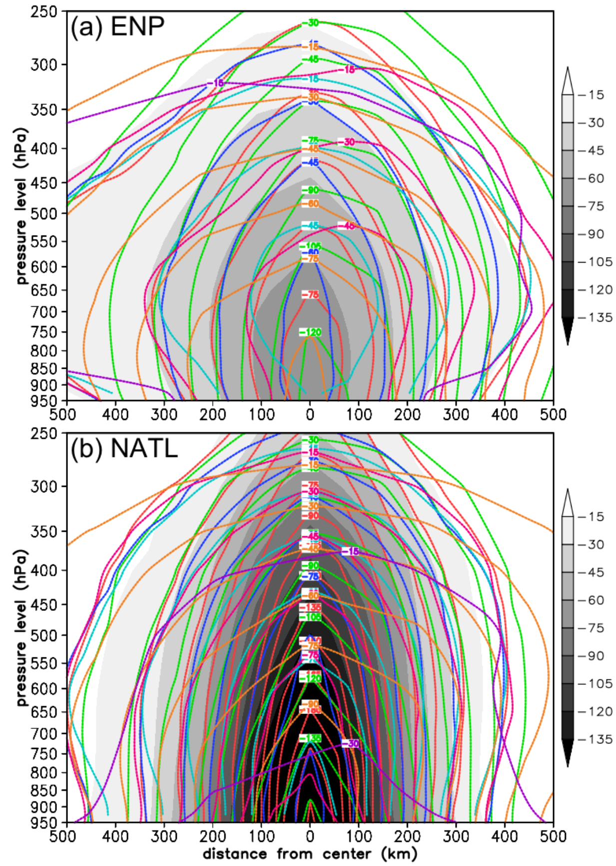

Figure 3. Average zonal geopotential height anomalies (m) centered on the TC best track position from 2000-2010 for synoptic times with intensities at or greater than 115 kt from the FNL (shaded), CFSR (red), JRA-25 (green), JRA-55 (dark blue), ERA-I (magenta), 20CR (orange), and NNR (purple).

In order to further examine the impact of these anomalies in the different reanalyses on their CPS results, the percentage frequency of warm core ($-V_T^L > 0$ m s^{-1}) and cold core ($-V_T^L <= 0$ m s^{-1}) structures for both basins are shown in Fig. 4. Though this subset is restricted to the period of increased data assimilation for some datasets (such as the CFSR) from 2000-2010, it does include TCs of all intensities.

There is a marked increase in frequency of cold core (and corresponding decrease in frequency of warm core) conditions in the ENP compared with the NATL. However, this is not consistent across all reanalysis datasets, as the CFSR, JRA-25, and JRA-55 all reach at least 75% warm core frequency in both basins. Note that the FNL, which is an analysis and not a reanalysis, exhibits similar behavior to these three reanalyses. All four of these datasets are derived from assimilation schemes that include special treatment for TCs. The CFSR utilizes a vortex relocation scheme similar to that applied in the GFS model (and thus the FNL), while the JRA-25 and its successor, the JRA-55, use a wind profile retrieval method that improves TC representation in data-sparse areas (Hatsushika et al. 2006). As the ENP is marked by few *in situ* observations, it is encouraging to see positive impacts from these methods on reanalysis TC structure in this basin.

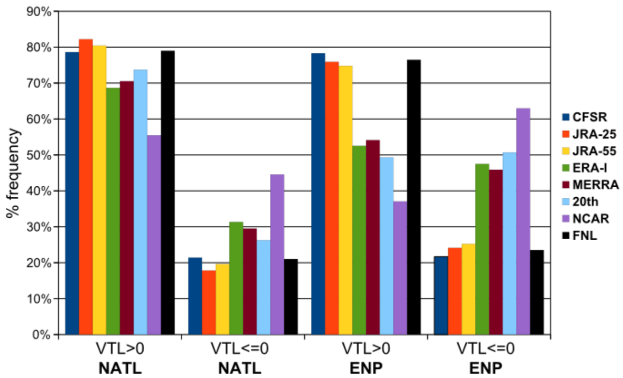

Figure 4. Frequency of positive and negative 900-600 hPa thermal wind values in the NATL and ENP

To focus on the “best” available data, synoptic times within 3 h of aircraft reconnaissance during 2000-2010 are used to compare the relative strength of the 900-600 hPa thermal wind and the geopotential height anomalies for intensities of at least 65 kt (category 1 hurricane). Given the dearth of aircraft observations in the ENP, this portion of the analysis is restricted to the NATL.

This subset produces positive thermal wind values (warm cores) at much higher rates in all datasets, including the NNR. Only the NNR and MERRA do not exceed 90% frequency (Table 1), though the average thermal wind value is much lower in the NNR compared to all other datasets. This result implies that reanalysis TCs more closely resemble their real world counterparts when observed by aircraft, either through direct assimilation of the reconnaissance data from the storm itself or improved representation of the surrounding environment.

	-VTL > 0	-VTL <= 0	average
CFSR	98.4%	1.6%	105.3
JRA-25	98.7%	1.3%	75.9
JRA-55	97.2%	2.9%	58.2
ERA-I	93.0%	7.0%	66.4
MERRA	89.9%	10.1%	60.1
20th	94.5%	5.6%	56.8
NNR	84.6%	15.4%	17.2
FNL	97.2%	2.9%	86.0

Table 1. Frequency of positive and negative 900-600 hPa thermal wind values in the NATL for synoptic times within 3 h of reconnaissance during 2000-2010. All TC intensities are at least 65 kt.

Due to its extremely high spatial resolution and focus on atmospheric properties in the tropics, data from YOTC during 2008 is also examined (Fig. 5). Within this subset, the CFSR shows the greatest similarity in the distribution and magnitude of geopotential height anomaly values. Despite its coarser resolution, the JRA-25 also closely resembles the structure depicted in the YOTC data. The weaker signature in the JRA-55 is likely due to the coarse data currently available from the Research Data Archive (RDA) at UCAR (1.25°) despite the original model data being produced at ~60 km.

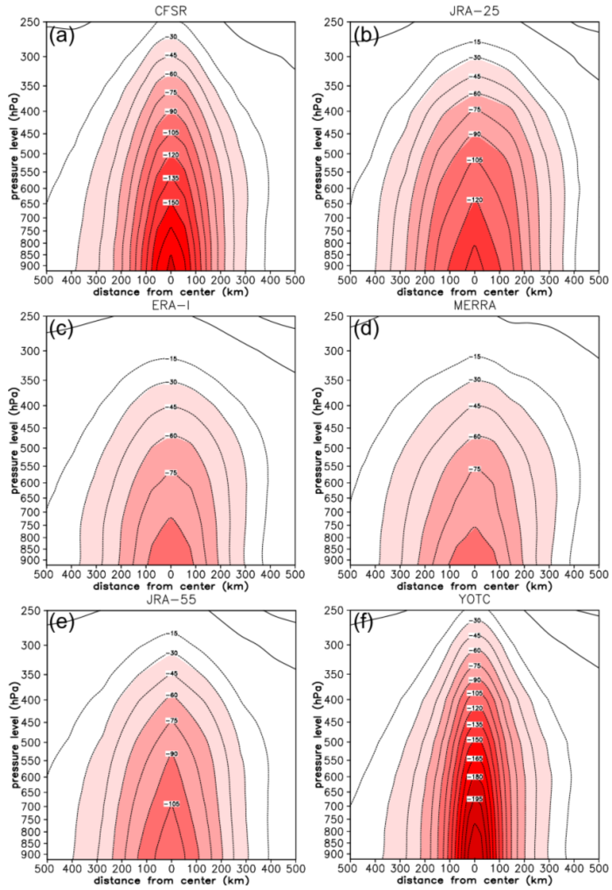

Figure 5. Average TC-centered zonal geopotential height anomalies (m) for all synoptic times at or greater than 65 kt during 2008 for six different reanalyses, including YOTC. The NNR and 20CR, which have the coarsest resolution, are excluded from this figure.

However, it must be noted that occasional errors are observed in the CFSR in association with fields near TCs (e.g., Fig. 6). These errors do not appear to propagate in time, as they can exist at one time but not the prior nor subsequent times. Unfortunately, the presence of these errors significantly affects the calculation of both the thickness symmetry (*B*) as well as the thermal wind parameter in CPS. These errors are not observed in the composite geopotential height anomalies calculated from the CFSR (e.g., Figs. 3, 5a) due to being smoothed out during the averaging process. The existence of this bug is known to NCEP, the producers of the CFSR, but no announcement of a fix for this bug has been made. As a result, caution must be exercised when using the CFSR to analyze TCs.

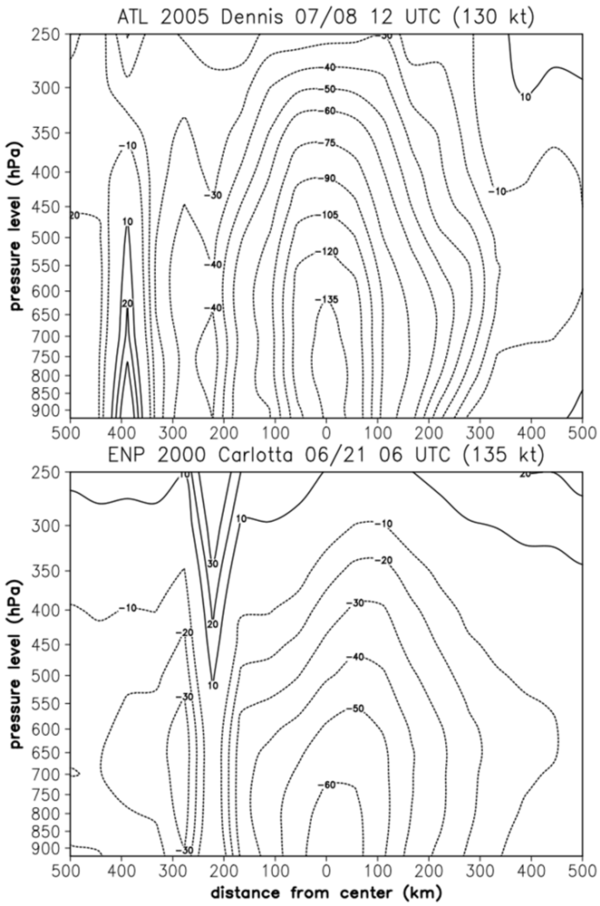

Figure 6. Geopotential height anomalies (m) from the CFSR for NATL Hurricane Dennis (2005; 130 kt) and ENP Hurricane Carlotta (2000; 135 kt) that depict the errors often observed within 500 km of a TC center.

4. DISCUSSION

The NNR tends to produce the lowest thermal wind values of all the reanalyses examined, likely a combination of its coarse resolution and the older model used to generate the dataset. YOTC produces consistently stronger thermal wind values in the 900-600 hPa layer than all but the CFSR, and it also has the finest spatial resolution. The weaker geopotential height anomalies found in the JRA-55 compared to the JRA-25 may be a result of the coarse resolution data available from the UCAR RDA. The data will be explored further once the higher resolution dataset (~0.5625°) is released.

The ERA-I often exhibits a maximum geopotential height anomaly above rather than at the surface, unlike structures generally found for TCs in other reanalyses and analyses (e.g., Hart 2003). In addition, the CFSR often has anomalous features and discontinuities in the atmospheric fields near TCs, leading to erroneous depictions of TC structure. Extremely negative thermal wind values are computed when these irregularities appear, up to an order of magnitude greater than those found from the other datasets.

These results corroborate the stronger positive temperature anomalies found for the CFSR and JRA-25 datasets for category 3-5 TCs in the NATL (Schenkel and Hart 2011), both of which include additional data processing for TCs. They also confirm the necessity of cautiously interpreting TC intensity and structure results derived from the reanalyses. Increased spatial resolution and greater density of observations appear to result in better TC representation in these datasets.

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