Final Progress Report

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Title: Assessing the quality of synoptic scale variability derived from the Twentieth Century Reanalysis Project

Award Period: 1 September 2011 – 31 August 2013 (No cost extension)
Report Period: 1 September 2011 – 31 August 2013 (Final report)

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Institution: The Research Foundation of SUNY

Final Progress Report:

I. Personnel:

The P.I. worked part time on the project over the entire support period. Graduate students Minghua Zheng and Albert Yau worked either part-time or full time on the project during different periods.

II. Research activities:

The main research activities conducted under this project can be grouped into 4 main categories:

1. Acquisition of reanalysis data, including 20th Century Reanalysis (20CR) data and ERA-Interim Reanalysis data for comparison

2. Deriving synoptic time scale storm track activity from reanalysis data. These include deriving Eulerian variance statistics as well as Lagrangian cyclone tracking statistics.

3. Assessing the quality of synoptic time scale storm track variability and trend derived from 20th Century Reanalysis data by comparison with similar statistics derived using observations and other reanalysis data.

4. Conducting an integrated assessment of the trend in Northern Hemisphere storm track activity over the second half of the 20th Century using reanalysis data, observations, and storm track model experiments.

5. Assessing the quality of storm track activity derived from CMIP3 and CMIP5 model simulations.

III. Research results:

The main results based on research conducted under the support of this project are summarized below:

1. Assessing the quality of synoptic time scale storm track variability and trend derived from 20th Century Reanalysis data

Two different kinds of statistics have been widely used to indicate synoptic time scale storm track variability. In this study, we have made use of both types of statistics. Traditionally, storm track activity is indicated by Lagrangian cyclone track statistics, since the weather over most mid-latitude regions is closely associated to passages of cyclones and anticyclones over each region. With the development of many objective tracking algorithms within the last two decades, the use of cyclone track statistics has become quite popular recently. In this project, we make use of the objective tracking algorithm developed by Kevin Hodges of Reading University to derive cyclone track statistics (based on sea level pressure (SLP) data) from reanalysis datasets. Reanalysis data used in this study include the 20CR (1870-2010), NCEP-NCAR reanalysis (1948-2010), ERA-40 (1958-2002), and ERA-Interim reanalysis (1979-2010).

An alternative indicator of storm track activity is Eulerian temporal variance and covariance statistics. Variance/covariance statistics are widely used in the climate dynamics community since these statistics highlight the close relationship between the synoptic scale eddies and mean flow variations. Many different quantities have been used, including geopotential height and SLP variance statistics, eddy kinetic energy, variance of meridional veloicity (v'), northward heat flux and momentum flux. In this project, we examined monthly mean synoptic scale variance of SLP and meridional wind at the 300 hPa level, with each variable filtered by a temporal filter that highlights variability within the period between 1.2 and 6 days.

Variance of 300 hPa v' computed based on each reanalysis dataset is assessed by comparing with variance derived directly from radiosonde observations. Note that radiosonde observations only exist mostly over land, and only became abundant since the International Geophysical Year (IGY, 1957-58). Also note that 20CR only assimilates surface pressure observations and does not assimilate radiosonde wind observations, hence radiosonde observations of 300 hPa v' can be regarded as independent observations to assess the quality of 20CR data. The other reanalysis datasets examined all assimilate radiosonde observations.

One main reason for the development of the 20CR dataset is to use an advanced data assimilation system to assimilate a type of observation that has undergone less change over the 20th Century compared to most other observation systems. All other reanalysis projects make use of many different kinds of observations including surface, radiosonde, aircraft, and satellite observations, with radiosonde observations only becoming abundant after the IGY, aircraft observations increasing in number since the late 1960s, and satellite data becoming abundant after the late 1970s. Changes in the

observation system have been shown to contribute to spurious trends or jumps in climate statistics, and previous studies by the P.I. and other investigators have shown that some of the trends in storm track activity derived based on NCEP-NCAR and ERA40 data likely contain significant biases, especially over the Pacific. With 20CR assimilating only surface pressure observations, it is expected that synoptic scale storm track statistics derived based on 20CR data should contain less time dependent biases compared to those derived using the other reanalysis datasets.

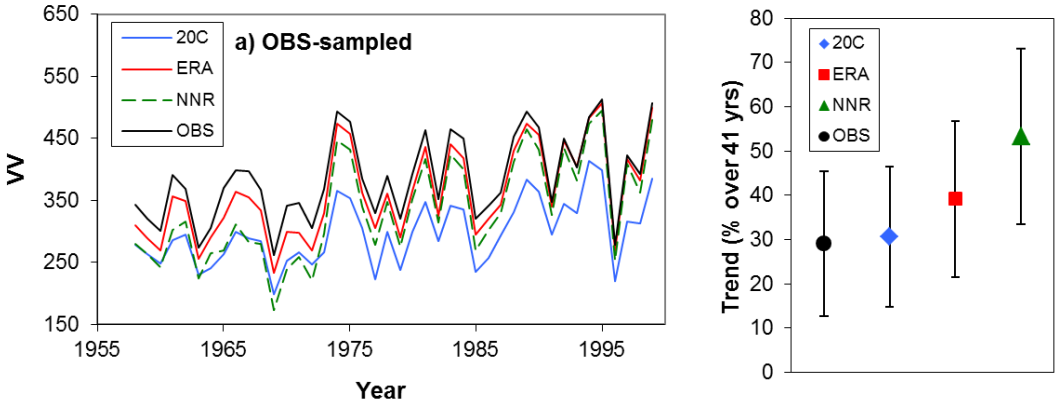

Fig. 1: Left: Variance of 300 hPa v', averaged over Europe, over grid boxes where there are radiosonde observations. Results based on radiosonde observations are shown in black, 20CR shown in blue, ERA-40 in red, and NCEP-NCAR reanalysis in green. Right: Trends of the time series shown in the left panel.

An example of the comparison between storm track activity derived based on the different reanalysis data sets and radiosonde observations is shown in Fig. 1, which shows a comparison over Europe (10 °W – 60 °E, 30 – 65 °N), for winters (December-January-February) of 1957/59 to 1998/99. It is clear that the year-to-year variability of storm track activity derived based on all 3 reanalysis datasets is highly correlated with that derived directly from observations. This is the case for 20CR even though radiosonde wind observations are not assimilated by 20CR. Storm track activity based on 20CR shows a consistent low bias, which is not surprising considering that upper tropospheric storm track activity in 20CR is projected by the assimilation system entirely from surface observations. Storm track activity based on ERA40 is closest to that derived from observations, but is biased low in the early years, with the bias decreasing with time. This time-dependent bias is more significant for storm track activity derived from NCEP-NCAR reanalysis data. Thus it is not surprising that the trend derived from ERA-40 is biased high compared to that derived based on observations, while that derived from NCEP-NCAR reanalysis shows an even larger bias, with the trend derived based on 20CR being most consistent with that derived based on observations. Again, this occur despite 20CR not assimilating the radiosonde observations while NCEP-NCAR and ERA40 both assimilate the data. Thus the results support those from previous studies that show that changes in observing system strongly impact storm track statistics derived from NCEP-NCAR and ERA40 data. Similar results are obtained over other regions examined,

including east Asia and North America where there are sufficient radiosonde observations.

Overall, our assessment shows that despite the fact that 20CR does not assimilate any upper air data, month-to-month variations in synoptic scale storm track activity in the upper troposphere derived from 20CR data is highly correlated with those derived based on the other reanalysis datasets and radiosonde observations. In addition, the trend in storm track activity between 1958 and 1999 derived based on 20CR data is more consistent with that derived based on radiosonde observations than those derived from NCEP-NCAR and ERA40 data that are significantly biased high. In particular, the largest bias occur over the Pacific, where the trend derived based on the NCEP-NCAR reanalysis dataset is much higher than that derived from observations and 20CR. Thus our assessment support the hypothesis that synoptic scale variability derived based on 20CR is of high quality, and that these statistics contain less time-dependent biases compared to NCEP-NCAR and ERA-40 data because 20CR only assimilates observations from a system (surface pressure observations) that has undergone less changes compared to other observing systems.

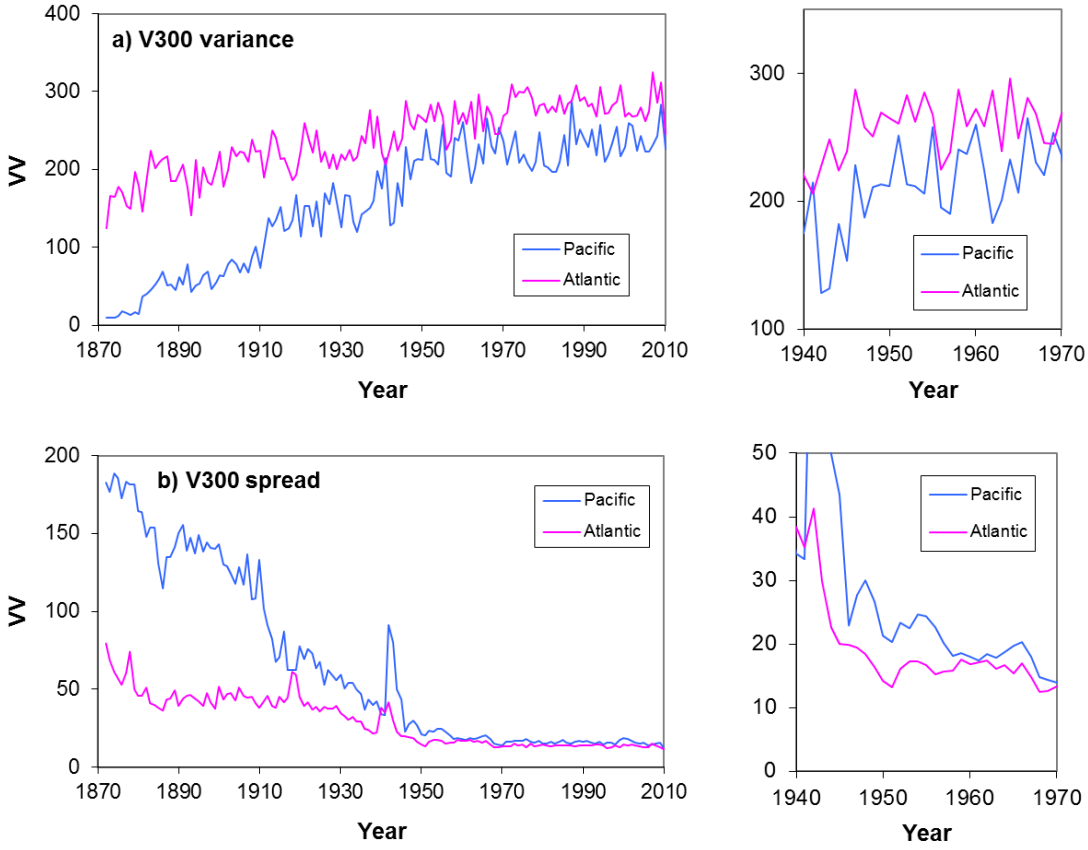

Fig. 2: a) Variance of 300 hPa v' for winter, averaged over the Pacific (blue) and Atlantic (magenta). b) Ensemble spread (as indicated by mean squared variance) in 300 hPa v' averaged over the same regions.

20CR provided data from 1870 to present, hence it is also of use to assess whether synoptic scale variability of consistent quality can be derived all the way back to the

beginning of the 20th Century or beyond (Fig. 2a). Unfortunately, comparisons with radiosonde observations are not of great use before the IGY since the number of such observations are insufficient to provide accurate quantitative estimates of storm track activity. To assess the quality of the 20CR data, we examined the ensemble spread, which is shown in Fig. 2b. Our results suggest that the ensemble spread in the Pacific is quite large over the Pacific during the late 1800's, and has been decreasing continuously until around 1960, after which the ensemble spread has stayed consistent. This suggests that over the Pacific, the quality of the 20CR data has been consistent since 1960. Over the Atlantic, the spread has been more or less constant since 1950, suggesting that the quality of 20CR data has been consistent over the Atlantic since 1950. Over the Atlantic, while the spread was larger prior to 1950, the magnitude is still not too large since 1890, suggesting that perhaps a reanalysis based on the observation density of 1890 may provide useful information on century long trend in Atlantic synoptic scale storm track activity from 1890 to present. These results also suggest that the weak storm tracks found before 1950 (Fig. 2a) are mainly due to the impact of significantly fewer surface observations before 1950, giving rise to larger spread in the ensemble, which leads to smoother fields in the final analyses and hence weaker variances.

Apart from variance statistics, we have also derived cyclone track statistics from 20CR. To assess the quality of these data, we have compared these statistics with those derived based on ERA-Interim data during the satellite epoch (1979-2010). Using ERA-Interim as reference, our results suggest that the quality of cyclone track statistics are not significantly different from those derived based on NCEP-NCAR and ERA40 reanalysis data. Given our analyses of variance statistics suggesting that 20CR data are of consistent quality back to 1950 over the Atlantic and 1960 over the Pacific, we expect that cyclone statistics over these two basins derived based on 20CR data should be of high quality back to these respective years over these two basins.

2. <u>An integrated assessment of the trend in Northern Hemisphere storm track activity over the second half of the 20th Century</u>

Previous studies, mainly using NCEP-NCAR reanalysis data, have suggested that activity of the Northern Hemisphere storm tracks has increased over the second half of the twentieth century. Several studies, including those by the P.I., have suggested that at least part of this increasing trend could be due to biases in the reanalysis datasets due to changes in observing systems over the years, including increasing number of aircraft and satellite observations. In this project, we make use of a combination of reanalysis data, observations, and dynamical storm track model simulations (see Chang, 2006, J. Atmos. Sci., 63, 1818 for more information about the model), to conduct an integrated assessment of the trend in Northern Hemisphere storm track activity over the second half of the 20th Century.

Our results suggest that over the Atlantic, storm track activity has likely increased between 1958 and 1999. This increase is found in all reanalysis datasets including 20CR, and is prominent over Europe in radiosonde data. This increase is also dynamically consistent with the upward trend of the North Atlantic Oscillation observed during that period, as a storm track model forced with the observed mean flow change resulted in a significant increase in storm track activity over that region. However, since the late

1990's, both the NAO and the Atlantic storm track activity have been trending downward, resulting in no significant trend in storm track activity over the period 1958-2010.

Over the Pacific, our results suggest that the large increase in upper tropospheric storm track activity (>30% increase) found in NCEP-NCAR reanalysis between 1958 and 1999 is likely spurious. Over that period, 20CR data show only a small and not statistically significant trend over that period, and radiosonde observations over the Pacific storm track entrance and exit regions show much lower trends than those found in NCEP-NCAR reanalysis data. However, when the time period is extended to 2010, even 20CR data shows a statistically significant trend. Our storm track model results suggest that some of the increase in Pacific storm track activity may be related to an increase in the meridional temperature gradient in the lower stratosphere. What gives rise to such an increase is of interest and should be further investigated. These results are presented in Chang and Yau (2013).

3. Assessing the quality of storm track activity derived from CMIP3 and CMIP5 simulations

The storm track activity derived from the various reanalysis products under the support of this project has been applied to assess the fidelity of storm track activity simulated in the Coupled Model Intercomparison Project Phase 3 (CMIP3) and Phase 5 (CMIP5) simulations. Our results suggest that nearly half of the 17 CMIP3 models we examined show significant biases in storm track amplitude, and that the storm tracks in most CMIP3 models exhibit an equatorward bias in both hemispheres. CMIP5 models display slightly less biases, but there is still a large spread in storm track amplitude among the models. Our results also indicate that model biases may impact model projection of storm track changes. Under global warming, for the Northern Hemisphere, models with weak storm tracks tend to project larger percentage changes in storm track amplitude. For the Southern Hemisphere, models with large equatorward biases in storm tack latitude tend to project larger poleward shift. Thus it is important to further assess model biases as well as what gives rise to these biases. These results have been presented in Chang et al. (2012, 2013).

IV. Research Products:

Publications:

The following publication is entirely based on research supported by this grant. Full support from this grant has been acknowledged in the paper.

Chang, E.K.M., and A.M.W. Yau, 2013: Northern Hemisphere winter storm track trend during the second half of the twentieth century. Submitted to Climate Dynamics.

Activities conducted under this grant contributed to the following publications. Storm track activity (both Eulerian eddy variance and Lagrangian cyclone track statistics) derived based on the various reanalysis datasets under this project was used to assess

storm track activity derived from CMIP3 and CMIP5 model simulations. Partial support from this grant has been acknowledged in these publications.

Chang, E.K.M., Y. Guo, and X. Xia, 2012: CMIP5 multimodel ensemble projection of storm track change under global warming. J. Geophys. Research, 117, D23118.

Chang, E.K.M., Y. Guo, X. Xia, and M. Zheng, 2013: Storm track activity in IPCC AR4/CMIP3 model simulations. J. Climate, 26, 246-260.

Conference presentation made based on the results of this project:

Chang, E.K.M., Y. Guo, X. Xia, and M. Zheng, 2011: Assessing how well climate models simulate storm track activity. AGU Fall Meeting, San Francisco, CA, December 2011.

Chang, E.K.M., and A.M.W. Yau, 2012: Using 20th Century Reanalysis data to examine Northern Hemisphere storm track trend in the 20th century. AGU Fall Meeting, San Francisco, CA, December 2012.

Presentations in NOAA webinars

"Using 20th Century reanalysis data to examine Northern Hemisphere storm track trend in the 20th Century". NOAA CPO MAPP Webinar, February 14, 2012.

"Northern Hemisphere cyclone trends in reanalysis data". NOAA CPO MAPP Webinar, September 25, 2012.