Subseasonal to Seasonal Prediction of Extratropical Storm Track Activity over the U.S. using NMME data

Final Scientific/Technical Report

1. General Information

Project Title: Subseasonal to Seasonal Prediction of Extratropical Storm Track Activity over the U.S. using NMME data
PI name and institution: Edmund Kar-Man Chang (Stony Brook University)
Report Period: 8/1/2015-7/31/2017
Grant # DE-SC0014050

2. Main goals of the project, as outlined in the funded proposal

The goals of the project are:

- To develop and assess subseasonal to seasonal prediction products for storm track activity derived from NMME data
- Assess how much of the predictable signal can be associated with ENSO and other modes of large scale low frequency atmosphere-ocean variability
- Further explore the link between storm track variations and extreme weather statistics

3. Results and accomplishments

a) Further explore the link between storm track variations and extreme weather statistics

In this project, we have further explored the links between storm track and extratropical cyclones and extreme weather statistics, both for summer and winter. Since the results described in the following paragraphs have already appeared in two papers (see Section 5), they are only described briefly here.

Extratropical cyclones cause much of the high-impact weather over the midlatitudes. With increasing greenhouse gases, enhanced high-latitude warming are expected to lead to weaker cyclone activity. Our results show that between 1979 and 2014, the number of strong cyclones in Northern Hemisphere in summer has decreased at a rate of 4% per decade, with even larger decrease found near northeastern North America. Climate models project a decrease in summer cyclone activity, but the observed decreasing rate is near the fastest projected. Decrease in summer cyclone activity will lead to decrease in cloud cover, giving rise to higher maximum temperature, potentially enhancing the increase in maximum temperature by 0.5 K or more over some regions. Our results also show that climate models may have biases in simulating the positive correlation between cyclone activity and cloud cover, potentially underestimating the impacts of cyclone decrease on accentuating the future increase in maximum temperature. These results have been published in Chang et al. (2016, see section 5 below) and presented at the 28th Conference of Climate Variability and Change as well as the 2016 DOE RGCM PI Meeting (see section 6 below).

Extratropical cyclones are responsible for much of the high-impact weather events over the U.S. in winter, including extreme cold, extreme high wind and extreme heavy precipitation. In this study, impacts from the variations of the cyclone (or storm track) activity on these extreme events are examined through composites based on map-averaged cyclone activity. Increased cyclone activity enhances the frequency of extreme cold and high wind events over much of the U.S., and impacts extreme precipitation around the Ohio Valley. These impacts are largely due to the changing of the tail of the distribution rather than a shifting of the mean. To systematically study these impacts, three singular value decomposition (SVD) analyses have been conducted, each one between the cyclone activity and one kind of extreme event frequency. All three SVD leading modes represent a pattern of overall increase/decrease of storm track over the U.S. The average of the time series of these leading modes is highly correlated with the observed map-averaged storm track and strongly associated with the Pacific/North America pattern (PNA) and the El Niño Southern Oscillation (ENSO). However, composites based on either PNA or ENSO do not show as strong impacts as the map-averaged storm track. A second common SVD mode is found which correlates weakly with the North Pacific mode and is likely to be largely due to internal variability. Finally, the potential impacts of projected storm track change on the frequency of extreme events are examined, indicating that the projected storm track decrease over North America may give rise to some reduction in the frequency of extreme events. These results have been published in Ma and Chang (2017, see section 5 below), and presented at the 28th Conference of Climate Variability and Change as well as the 2016 DOE RGCM PI Meeting (see section 6 below).

b) Subseasonal to seasonal prediction of storm track activity using NMME data

The North American Multi-Model Ensemble (NMME) provides a novel opportunity for us to assess how well the current generation of climate prediction models can predict storm track variability in the subseasonal to seasonal time frame. Phase II of the NMME project provides daily reforecast data, initialized every month, at 00Z on the first day of the month, from 1982 to 2010. In this study, the assessment is based on storm track activity quantified by monthly (or seasonal) averaged variance of 24-h difference filtered sea level pressure (SLP) data, which is a metric that has been frequently used in storm track study and highlights synoptic time scale variability.

Six models provided daily re-forecast data. However, the NOAA GFDL model did not provide daily SLP data, and thus we could not compare its results to those from the other models. NCAR CESM provided reforecast data which were not initialized to the observed state. As we will see below, much of the predicted signal depends on the correct initial conditions, thus CESM data are not included in the final assessment. This leaves data from 4 models: CanCM3 and CanCM4 from Environment Canada, CCSM4 from the University of Miami, and GEOS-5 from NASA GSFC. Each of these 4 models provided 10 ensemble members, making a large 40-member multi-model ensemble, predicting the coupled evolution of the atmosphere and ocean for nine months or longer at the beginning of each month.

Here, we will only briefly highlight the main results. A manuscript that will contain more details about the results described in this and the next subsection is being prepared and will be submitted for publication in the near future.

First we examine how well the models do in subseasonal (monthly) prediction of winter storm track variability. Fig. 1a shows the lead 0 (i.e. December storm track activity predicted based on 00Z December 1 initial conditions, etc.) point-by-ponit anomaly correlation between the multi-model ensemble mean predicted storm track anomaly and the observed anomaly based on ERA-Interim reanalysis data. The highest skill (anomaly correlation > 0.5) is found over northeastern Asia and northern Europe, but the skill is also relatively high over much of the US and Canada. For lead 1 (i.e. December storm track activity predicted based on 00Z November 1 initial conditions, etc.; Fig. 1b), the skill has decreased substantially, with the highest skill (correlation > 0.4) over central US. For leads over 1 month, the skill is not very different from that shown in Fig. 1b out to at least a lead of 5 months (not shown). As we will show in the next subsection, this extended skill is largely related to the influence of ENSO. Fig. 1 shows that monthly storm track forecasts with leads of 1 month or longer are not very skillful, but lead 0 forecasts are quite skillful and can be potentially useful (see discussions below).

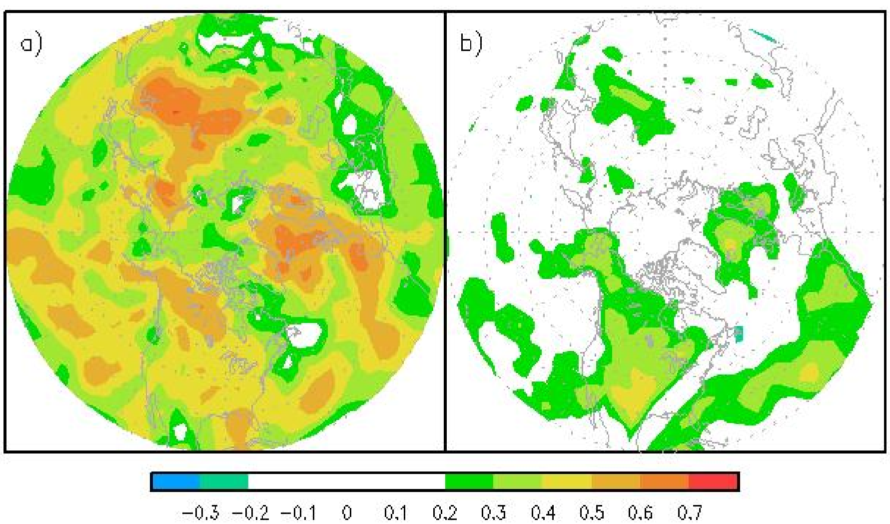

Fig. 1: Anomaly correlation between model predicted and observed monthly (December, January, and February) storm track activity. Correlations of 0.2 or above are significant at the 90% level. a) Lead 0; b) Lead 1 month.

Next we examine how the models perform in seasonal storm track prediction. Fig. 2a shows the anomaly correlation for lead 0 forecasts (i.e. DJF storm track activity predicted based on 00Z December 1 initial conditions). It can be seen that close to North America, the seasonal prediction skill is much higher than that of the monthly prediction skill shown in Fig. 1. This is mainly because the amplitude of the unpredictable "noise" due to internal variability of the coupled ocean-atmosphere system is reduced with the 3-month averaging.

For lead 1 (DJF storm track activity predicted based on 00Z November 1 initial conditions; Fig. 2b), while the overall skill has decreased, the skill is still relatively high over central US, Canada, and Alaska. For leads longer than 1 month, again the skill stays close to that shown in Fig. 2b, largely related to the influence of ENSO.

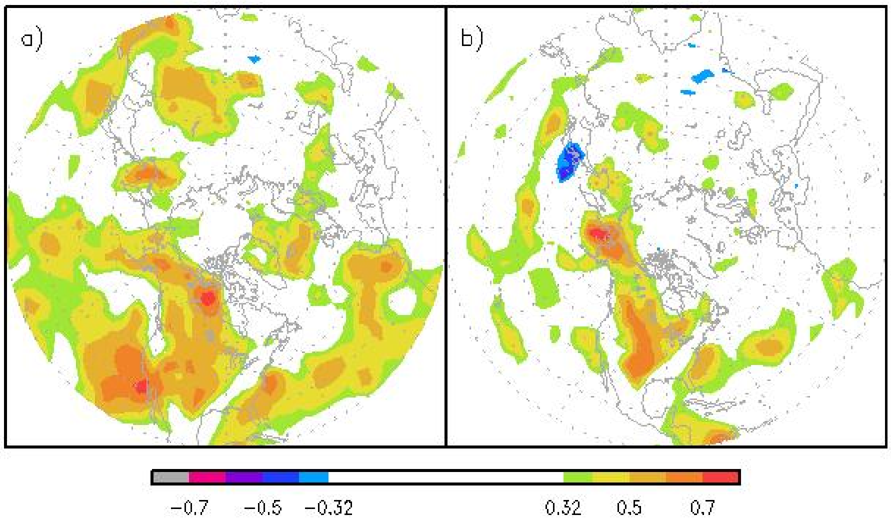

Fig. 2: Anomaly correlation between model predicted and observed seasonal (December, January, and February averaged) storm track activity. Correlations of 0.32 or above are significant at the 90% level. a) Lead 0; b) Lead 1 month.

Fig. 2 shows that the winter mean storm track variability over central US and Canada can be quite well predicted by the NMME models out to 1 month (or more) in advance. This has important practical implications, as we have shown in section 3a above that the frequency of extreme events, including extreme cold, extreme wind, and extreme precipitation over many regions of the continental US, is modulated by the average storm track activity over this region (Ma and Chang, 2017). In addition, a previous study by our group has also shown that winter precipitation over California and parts of the southwestern US is highly modulated by storm track activity over the eastern Pacific off the California coast, which can be well predicted at lead 0 (Fig. 2a). Further analyses also show that precipitation over Alaska and along the east coast of the US is also highly modulated by storm track activity over these regions (not shown), which can be quite well predicted (Fig. 2). Thus skillful prediction of storm track activity over the vicinity of North America can provide useful information about how precipitation and extreme weather may change over multiple regions of the US and assist forecasters in the formulation of seasonal outlooks. Given that lead 0 monthly storm track predictions are also quite skillful (Fig. 1a), these also have potential applications to week 3-4 outlooks.

As mentioned above, these results are being written up into a paper and will be submitted for publication in the near future. Some of these results have been presented at the NMME/SubX Workshop (see section 6 below).

c) Storm track predictability associated with ENSO

In section 3b, we mentioned that the skill of model prediction of storm track activity, both monthly and seasonal, does not change much after a lead of one month. To show that this is mainly due to the influence of ENSO, we developed a statistical-dynamical model to predict storm track anomalies given model predicted sea surface temperature (SST) anomalies. A statistical regression model relating observed storm track anomalies to the leading EOFs of SST anomalies is first developed. This model is then applied to the model predicted SST anomalies. The cross validation results, based only on the leading EOF of tropical SST variability (ENSO), is shown in Fig. 3. The results show that in both monthly and seasonal prediction, using the model predicted ENSO variability can explain a significant amount of storm track predictability, especially over the vicinity of North America. Results for leads of 1 to 5 months are very similar, due to the high degree of predictability of the winter ENSO SST signal through the preceding summer and fall. Comparing Fig. 3 to Fig. 1b and 2b, it is clear that much of the skill of storm track prediction exhibited by the models at leads of 1 month or longer near North America is related to the influence of ENSO.

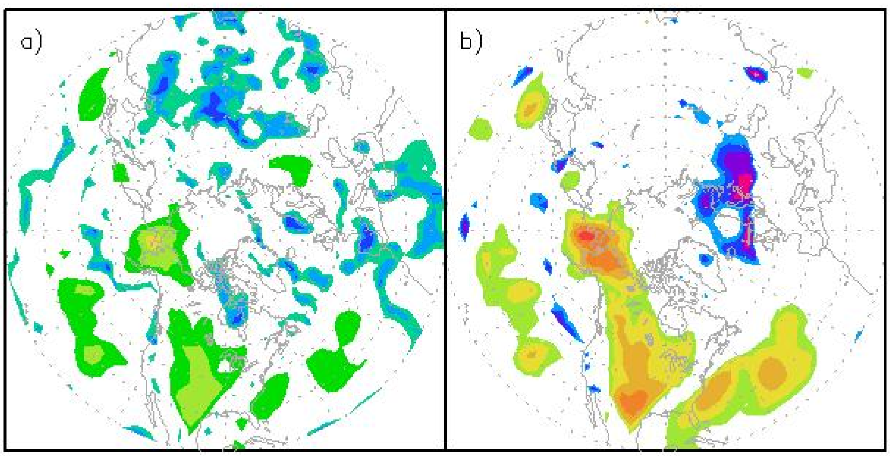

Fig. 3: Anomaly correlation between observed storm track activity and those predicted using the statistical-dynamical model based on the leading EOF of tropical SST at lead 0. a) Monthly; b) Seasonal. Color scale for panel a) same as that for Fig. 1, and for panel b) same as that for Fig. 2.

Nevertheless, comparison of Fig. 3 to Fig. 1a and 2a shows that the lead 0 NMME model prediction is significantly more skillful than the storm track signal linearly related to ENSO, suggesting that there is subseasonal predictability of storm track variability related to the initial conditions on top of the signal forced by ENSO.

We have also tested an extension of the statistical-dynamical model to include additional modes of SST variability, but did not find any overall improvements in the skill. Thus these results suggest that ENSO is likely the main predictable forcing at the monthly to seasonal time scale.

These results have been presented at the NMME/SubX Workshop, and is being written up for publication shortly.

4. Highlights of Accomplishments

- Our assessment of NMME reforecasts of storm track variability has demonstrated that NMME models have substantial skill in predicting storm track activity in the vicinity of North America
    - Subseasonal skill is high only for leads of less than 1 month. However, seasonal (winter) prediction skill near North America is high even out to 4 to 5 months lead
    - Much of the skill for leads of 1 month or longer is related to the influence of ENSO
    - Nevertheless, lead 0 NMME predictions are significantly more skillful than those based on ENSO influence
- Our results have demonstrated that storm track variations highly modulate the frequency of occurrence of weather extremes
    - Extreme cold, high wind, and extreme precipitation events in winter
    - Extreme heat events in summer
    - These results suggest that NMME storm track predictions can be developed to serve as a useful guidance to assist the formulation of monthly/seasonal outlooks
- Results of this project have been broadly disseminated
    - Two papers have already been published to date. One more paper will be submitted shortly
    - Four presentations have been made at major conferences and workshops

5. Publications from the Project

Chang, E.K.M., C.-G. Ma, C. Zheng, and A.M.W. Yau, 2016: Observed and projected decrease in Northern Hemisphere extratropical cyclone activity in summer and its impacts on maximum temperature. Geophys. Res. Lett., 43, 2200-2208. Doi:10.1002/2016GL068172.

Ma, C.-G., and E.K.M. Chang, 2017: Impacts of storm track variations on winter time extreme weather events over the continental U.S. J. Climate, 30, 4601-4624. Doi:10.1175/JCLI-D-16-0560.1.

The above two papers have been uploaded to the DOE E-link site. One other paper based on the results described above in sections 3b-c is being prepared and will be submitted for publication in the near future. This paper will be uploaded to the DOE E-link site after it has been accepted for publication.

6. Conference/Workshop Presentations from the Project

Chang, E.K.M., and C.-G. Ma: "Observed and projected decrease in extratropical cyclone activity in Northern Hemisphere summer and its impacts on extreme weather". January 2016, American Meteorological Society 28th Conference on Climate Variability and Change. New Orleans, LA.

Ma, C.-G., and E.K.M. Chang: "Impacts of storm track variations on winter time extreme weather events over the US". January 2016, American Meteorological Society 28th Conference on Climate Variability and Change. New Orleans, LA.

Chang, E.K.M., and C.-G. Ma: "Modulation of the frequency of weather and climate extremes by extratropical cyclone activity". November 2016, DOE RGCM PI Meeting. Rockville, MD.

Chang, E.K.M.: "Assessing S2S prediction of extratropical cyclone activity (ECA) using NMME daily hindcast data". September 2017, NMME/SubX Science Workshop, College Park, MD.

7. PI Contact Information

Edmund Kar-Man Chang:
Email: kar.chang@stonybrook.edu
Phone: 631-632-6170