Evaluation of Extreme Severe Weather Environments in CCSM3

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The ability of climate models to predict extremes is determined by its ability to adequately simulate certain environmental conditions both spatially and temporally. Some of the conditions conducive to the occurrence of extreme weather can be quantified from the convective available potential energy (hereafter referred to as CAPE) and vertical shear of the horizontal wind from 0-6 kilometer (hereafter referred to as shear) [Holton, 2004]. CAPE is a measure of the buoyancy of an air parcel, which indicates atmospheric instability. It has an annual cycle, which increases up to a maximum in summer (JJA) [Brooks et al., 2003]. Shear is at its maximum during the winter (DJF) and at a minimum during the late summer (JAS) [Aiyyer and Thorncroft, 2006]. A combination of CAPE and shear are has been shown to be an effective predictor of severe thunderstorms [e.g. Brooks et al., 1994, Rasmussen and Blanchard, 1998, Brooks et al., 2003, Rasmussen, 2003, Trapp et al., 2007] In particular, high CAPE and high shear values generally indicate the occurrence of significant severe thunderstorms, producing hail, strong wind gusts, and those producing significant tornados [Brooks et al., 2003]. However, high CAPE and high shear rarely occur simultaneously and just one of CAPE and shear being extreme can still cause severe weather.

Since any projections of the future probability of extreme severe thunderstorms depend on the ability to model high values of CAPE and shear, there is a need to evaluate climate models in terms of these parameters. This study makes use of the statistical approach of extreme value theory to determine the ability of the Community Climate System Model Version 3 (CCSM3, Collins et al. [2006]) model output to simulate extremes in CAPE, shear, and CAPE*shear in comparison to the NCEP/NCAR reanalysis data.
Positive biases have been found in other studies for the mean annual and seasonal distribution of CAPE in CCSM3. However, the CCSM3 performs well at modeling the data spatially and the distribution is similar [Marsh et al., 2007]. Surface wind speeds are found to be overestimated in CCSM3, which leads to both a positive bias in the shear and a northward shift of shear values [Large and Danabasoglu, 2006]. In this study, before applying the extreme value statistical method, a simple analysis of the CCSM3 biases in mean, maximum and variance of CAPE, shear and CAPE*shear is performed and is found to be consistent with the known biases. Analyses of extremes of CAPE and shear have been performed in previous studies to determine how effective CCSM3 is at reproducing the spatial and magnitudinal patterns of the median annual maximum CAPE*shear. While the spatial patterns were found to be similar, there were discrepancies in the intensity.

Whereas previous studies mainly focused on point-to-point comparisons, this study uses the method of spatial pooling, after the application of a cluster analysis to determine regions, which feature similarities in the parameters of the Generalized Extreme Value Distribution (GEV). This approach is expected to achieve better estimates, due to an increase in the number of data points used. The domain of interest is North America, east of the Rocky Mountains, since large parts of this region are known to be frequently devastated by severe weather such as strong tornadoes and thunderstorms.

As a first step, the GEV distribution is fitted to seasonal maxima of the CCSM3 and NNRP data at each grid point. The statistical model is validated using model diagnostics. Thereafter a cluster analysis is performed based on the grid-point based shape parameters and the 100-year return levels of the distribution. The clusters are displayed in figure 1. Two clusters which are spatially consistent across the CCSM3 data and the NNRP reanalysis are chosen and are highlighted in figure 1 with a light blue frame (cluster 1) and a light yellow frame (cluster2). Cluster 1 is a composite of 3 separate clusters for CCSM3 and 2 for NNRP which are embedded into each other. Although the clusters show some discrepancies between CCSM3 and the NNRP reanalysis, there is confidence that the chosen clusters possess similar physical properties in both datasets.

Spatial pooling of summer seasonal maxima is performed for these regions. The GEV parameters are estimated for the pooled data of both datasets and compared quantitatively. Figure 2 shows the return level plots from the GEV distribution for the clusters. Whereas for cluster 1 there is good confidence
that the GCM and the reanalyses possess the same distribution of extremes in CAPE*shear, different trajectories are found for cluster 2. Table 1 shows the ratio between the 100-year return value and the 10-year return value. Whereas the ratio is similar for the GCM and the reanalyses for cluster 1, it differs more strongly for cluster 2, which confirms the observations from figure 2.

This issue might be caused by the pooling of a relatively large domain. An extreme value approach which models the spatial dependence across the region would probably give more reasonable results and is planned to be applied in the future. Apart from that the GCM largely overestimates the return level for CAPE*shear. It needs to be clarified whether this bias is real or only an offset in the data.

Table 1: Ratio between the 100-year return value and the 10-year return value of CAPE*shear for CCSM3 and NNRP.

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<tr>
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<th>Cluster 1</th>
<th>Cluster 2</th>
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<tbody>
<tr>
<td>NNRP</td>
<td>1.31</td>
<td>1.64</td>
</tr>
<tr>
<td>CCSM3</td>
<td>1.19</td>
<td>1.18</td>
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This study is going to be continued in the future. It is planned to apply the method to an ensemble of climate model simulations, possibly taking into account regional climate models as well. Since one model simulation represents only one realization of a set of random variables, an ensemble approach is expected to give better estimates for the parameters of the GEV. In order to tackle the issue of spatial pooling, it is planned to perform a pooled modal approach and bootstrapping of data at each site. Furthermore, the model could be adjusted for temporal and spatial dependence at the sites. An improved version of this method is expected to be a powerful tool for comparing extreme value distributions in different datasets.

References


Figure 1: Clusters after applying a cluster analysis based on the shape parameter and the 100-year return level for CAPE*shear for CCSM3 (a) and NNRP (b).
Figure 2: 100 year return levels of the GEV fitted to the pooled seasonal maxima of CAPE*shear for cluster 1 ((a),(b)) and cluster 2 ((c),(d)) for CCSM3 (left) and NNRP (right).