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The use of atmospheric analogues to predict Alberta Clipper storm trajectories in a changing global climate

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ABSTRACT

Alberta Clippers are extratropical cyclones that form in Alberta, Canada and move east-southeastward over the Great Plains and Midwest regions. With the onset of global climate change and the potential shifts in atmospheric circulation patterns, however, this defined storm trajectory could be modified. Since the affected regions support much of the national population and agricultural activity, the presence of the Alberta Clipper storm track influences regional climatological patterns.

In this study, atmospheric analogues defined by global temperature and El Niño-Southern Oscillation (ENSO) characteristics are used to compare the trajectories of past Alberta Clipper storms to hypothesize how these could change with global warming. The results indicate that, although the trajectory azimuths from $t = 0$ to $t = 60$ are similar between the analogues, starting latitude and longitude results show that, on average, Warm analogue storms form further to the north and east than La Niña analogue Clippers.

Introduction

Extratropical cyclones are low pressure, large-scaled (synoptic) phenomena that serve as one of the primary means of energy and moisture transport poleward from the equatorial region. Because certain regions consistently exhibit conditions preferable for mid-latitude cyclone formation, these source regions generally account for a majority of extratropical cyclone formation activity. In North America, one of the main source regions is located in Alberta, Canada, downwind of the Rocky Mountains (Whittaker and Horn, 1982). Referred to as Alberta Clippers, these storms move east-southeastward over the Great Plains and Midwest regions and are most prevalent during the winter months. Since the affected regions support much of the national population and agricultural activity, the presence of the Alberta Clipper storm track influences regional climatological patterns. With the onset of global climate change and the potential shifts in atmospheric circulation patterns, however, this defined storm trajectory could be modified.

Global climate change is normally a natural process brought about by variances in Earth System-based phenomena at varying time scales. However, the warming now taking place is largely being influenced by anthropogenic-based activity, such as the combustion of fossil fuels (IPCC, 2013). As a result of changing global temperature characteristics, circulation patterns could also be modified. In the midlatitudes, warming of the atmosphere could potentially lead to reduced lower-level baroclinicity, or changing atmospheric pressure with changing location, and subsequent changes in circulation patterns (Lunkeit, Fraedrich, & Bauer, 1998). Another concern related to global climate change in the midlatitudes is how regional teleconnection patterns could be altered with increasing temperature. Local to North America, the El Niño-Southern Oscillation (ENSO) pattern is a component of the climate system that affects regional weather patterns of varying spatial scales. Although the reaction of ENSO to increasing global temperature has not been ascertained, it is hypothesized that the El Niño phase will become increasingly more prevalent because of increasing global temperature (Lenton et al., 2008; Tsonis, Hunt, & Elsner, 2003). Despite the potential importance of climate change on midlatitude storm systems, as well as how subsequent changes in ENSO could potentially affect extratropical cyclones, researchers have only analysed the characteristics of present-day Alberta Clippers (Hutchinson, 1995; Thomas & Martin, 2007).

In this study, atmospheric analogues defined by global temperature and El Niño-Southern Oscillation (ENSO) characteristics are used to compare the trajectories of past Alberta Clipper storms to hypothesize how these could change with global warming.

Methods

In order to determine the potential effects of global climate change on Alberta Clipper trajectories, past events are divided into

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four defined analogues and analysed qualitatively and statistically. These analogues, referred to as “Cold”, “Warm”, “El Niño”, and “La Niña”, are defined based on the average temperature deviation and Multivariate ENSO Index (MEI) characteristics of October through March for the years between 1950 and 2012. Temperature deviations, which are provided by the National Climate Data Center (NCDC) on a monthly basis and are calculated using the average global temperature from 1900 to 1999, are averaged together for each cool season (October through March) (NCDC, 2012; Wolter & Timlin, 2011). The cool seasons with negative global temperature deviations are possible Cold analogue years, while those with positive deviations are potential Warm analogue years. Similarly, the bimonthly MEI rankings are averaged together in each cool season; those with an overall MEI ranking greater than one standard deviation above the mean MEI ranking for 1950–2012 are potential El Niño years, while those with values less than one standard deviation below the mean are possible La Niña years (NOAA, 2013). Taking all of these factors into account, the ten years included in each analogue are listed in Table 1.

Within each of these years, Alberta Clipper events are identified from December through February. To do this, data from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis dataset is used in this study (Kalnay et al., 1996). The data provided are all recorded at 6 h intervals over a gridded dataset with two-and-a-half degree by two-and-a-half degree latitude–longitude spacing (Kalnay et al., 1996). Although the surficial spatial resolution of the dataset might seem somewhat coarse, it suffices in the determination of the storm center location at any given time step because a normal Alberta Clipper low pressure center is approximately fifteen degrees in diameter (Thomas & Martin, 2007). To be classified as an Alberta Clipper, the cyclone must form within, or in close proximity to, the political boundaries of Alberta. Once identified as a potential Clipper, the storm is examined at 12 h increments through 60 h after formation (herafter referred to as the time of cyclolysis, or dissipation); in order to be an Alberta Clipper, the cyclone must maintain a minimum of one closed isobar (4 mb increments) for at least 24 h. Based on these criteria, a total of five hundred fifty-four Alberta Clippers are identified; one hundred fifty-five are in the Warm analogue, one hundred thirty-three are in the El Niño analogue, one hundred twenty are identified in the La Niña years, and one hundred forty-six are found in the Cold analogue.

To measure individual Alberta Clipper trajectories, ArcMap 10.1 is used to identify the storm locations based on the geographic center of the Clipper at both cyclogenesis ($t = 0$) and cyclolysis ($t = 60$). Using four separate maps for each of the analogues, the trajectories are plotted using lines from $t = 0$ to $t = 60$. All of the cyclogenesis and cyclolysis locations are then spatially averaged by analogue to determine the average trajectories. These are all plotted on a single map to compare the azimuthal and locational characteristics of the analogues.

Table 1
Analogue years.

	Cold	El Niño	La Niña	Warm
1	1952–53	1957–58	1950–51	1980–81
2	1953–54	1965–66	1955–56	1989–90
3	1956–57	1972–73	1970–71	1990–91
4	1959–60	1982–83	1973–74	2001–02
5	1964–65	1986–87	1975–76	2003–04
6	1966–67	1987–88	1988–89	2004–05
7	1968–69	1991–92	1998–99	2005–06
8	1971–72	1994–95	1999–00	2006–07
9	1976–77	1997–98	2007–08	2008–09
10	1984–85	2009–10	2010–11	2011–12

Quantitatively, the latitude and longitude values at $t = 0$, as well as azimuths determined from $t = 0$ to $t = 60$ of the individual trajectories are analysed using one-way ANOVA analyses with a ninety-five percent confidence level. In the case that the analogue-based distributions are determined as being non-normal by the Shapiro–Wilk test, a Kruskal–Wallis test is also performed to verify the one-way ANOVA results. If the findings are significant, a Tukey Honestly Significantly Different (HSD) test is performed to determine which of the analogues differ from the others (Abdi & Williams, 2010). These findings, along with the maps, provide a basis for conjecture of the effects of global climate change on Alberta Clipper Trajectories.

Results and discussion

Individual and average trajectory maps

The individual Alberta Clipper trajectories from $t = 0$ to $t = 60$ for the Cold, El Niño, La Niña, and Warm analogues are shown in Figs. 1–4, respectively.

Based on these trajectory maps, most of the Alberta Clippers in each analogue trekked in a west-northwesterly direction. Trajectories that moved further to the south or north of the main grouping were also present in all of the analogues. However, in the case of the Cold analogue, the Alberta Clipper trajectories that extended to the south tended to reach lower latitudes than like Clipper events in the other three analogues. Furthermore, although the azimuths typically ranged from zero to one hundred eighty degrees (where zero degrees is north), the Warm analogue contained one case that had an azimuth of 341.07°, moving from north–central Alberta into the Beaufort Sea, just north of the Yukon Territories. This was most likely caused by an interruption in the westerly airflow through the process of blocking, or the presence of a persistent anticyclone to the east of the Clipper (Renwick & Wallace, 1996). The distributions of trajectory azimuths for each analogue are shown in Fig. 5.

The average trajectories that resulted from the individual Alberta Clipper trajectory output are shown in Fig. 6.

Fig. 6 showed that the Warm analogue cyclogenesis location was the furthest north, while the La Niña trajectory started the further south and west than all of the other analogues. Of all of the analogues, the location of cyclogenesis for the El Niño analogue was the furthest east. As expected, the composite trajectories of all of the analogues exhibit west-northwesterly motion; however, the southerly component of the Cold analogue shown to be larger than that of the others. The starting latitude of the Warm analogue average trajectory relative to the others indicates the predicted northward shift of baroclinicity associated with Alberta Clipper formation in a global warming scenario (Raible, Yoshimori, Stocker, & Casty, 2007). However, whether this shift is significant is statistically determined in the following section.

Quantitative results

The Shapiro–Wilk test results used to determine the normality of the distributions for each analogue and variable are shown in Table 2 as significance (p) values.

Because the results indicate that all but the El Niño latitude ($t = 0$) and the La Niña azimuth distributions are non-normal, one-way ANOVA and Kruskal–Wallis tests are both performed on each of the variables to determine how the values differ between analogue. The results are shown in Table 3.

These significance values indicated that, despite the non-normal distributions indicated by the Shapiro–Wilk tests, the significance values agree between the one-way ANOVA and Kruskal–Wallis