Mesoscale Temperature Patterns in Southern Alberta

R. Cullen[1] and S. Marshall[2]
1 Ecosystem and Public Health, University of Calgary, rmcullen@ucalgary.ca
2 Department of Geography, University of Calgary, shawn.marshall@ucalgary.ca

Abstract

Near-surface air temperatures were monitored from May 2005 to the present in a landscape scale network of 280 sites in the foothills of the Rocky Mountains in southwestern Alberta, Canada. The monitoring network covers a range of elevations, topographic conditions, and surface environments and provides a high-density array that is uncommon in meteorological observations, allowing for detailed analysis of surface influences. Here we report on the seasonal structure of temperature patterns and near-surface lapse rates in the region for the period 2005-2009. Regression models identified the influence of synoptic weather systems on regional temperature patterns and prevailing lapse rates. To explore this further, we examined daily temperature patterns when the region is under the influence of two common weather systems that impact the region: cold (continental polar) air masses and chinooks.

Background and Relevance

Spatial-temporal patterns of temperature variability are relevant to a broad range of Earth surface processes, and many scientific disciplines confront the need to estimate local- or regional-scale surface temperatures based on point measurements or atmospheric models. Temperature is considered to be a relatively straightforward meteorological variable to interpolate on climatic scales, because temperature fields are continuous and horizontal temperature gradients are typically low when averaged over many years, over which time the effects of individual weather systems average out.

This generalization breaks down in regions with complex terrain, such as mountain environments, where varying topography can lead to processes such as cold air drainage and pooling in valley bottoms (Rolland, 2002), and variations in solar heating occur as a function of slope, aspect, and topographic shading (Barry, 2008). Contrasting surface conditions (e.g., snow vs. rock vs. forest environments) also lead to gradients in the surface energy balance processes that govern near-surface air temperature. These complications are rarely addressed, as meteorological data is generally unavailable to evaluate their importance. Instead, temperatures in complex terrain are typically estimated based on low-elevation (e.g., valley-bottom) data along with vertical temperature gradients based on typical values of the free-air atmospheric lapse rate, –6 to –7°C km^{-1} (e.g., Legates and Willmott, 1990; Walland and Simmonds, 1996; Dodson and Marks, 1997).

Standard atmospheric lapse rates may not represent near-surface temperature when interpolating temperature observations over shorter time periods or in areas of variable terrain. Surface environment, terrain features, and atmospheric conditions play a complicated role in dictating spatial and temporal patterns of surface temperature (McCutchan and Fox, 1986; Bolstad et al., 1998; Pepin et al., 1999). Large scale weather systems and local to regional air mass movements, such as the chinook winds that descend in the lee slope of the Rocky Mountains, also alter surface temperatures in ways that cannot be estimated as a simple function of elevation. Several studies have examined the seasonal and spatial variation in near-surface temperature patterns and lapse rates (*i.e.* Pepin et al., 1999; Pepin and Losleben, 2002). Many of these studies found influences of terrain variables, surface environment and synoptic weather systems; however, they have not been examined in detail.

Methods and Data

Data for this study were collected as part of the University of Calgary Foothills Climate Array (FCA), which has been in operation since the summer of 2004 and has a spatial coverage of approximately 24,000 km^{2}, with a station density of one station per 86 km^{2}. The weather stations that make up the FCA are deployed in a grid extending from the continental divide, across the eastern slopes of the Canadian Rocky Mountains to the agricultural prairie lands east of Calgary, Alberta. Stations were located 5 to 10 km apart along twelve west-east running transects located between 116°21’W and 113°21’W. North-south transect spacing was approximately 10 km, ranging from 51°32’N to 50°18’N. Stations collect and store instantaneous measurements of temperature and humidity at the top of every hour and are visited yearly to download the collected data.

Hourly station data was processed for daily mean, minimum and maximum temperatures. Initial quality control algorithms were developed to flag and omit suspect data, based on several known problems. Data that was retained were then compiled into daily, monthly, seasonal, and annual means. Seasonal means were calculated for each site based on the conventional meteorological seasons (DJF, MAM, JJA and SON). We then aggregated all available seasonal and annual data from each site to derive nominal five-year (2005-2009) mean values, although means were calculated from fewer years for sites with missing data.

36 multivariate statistical models of monthly temperature patterns were developed, with independent variables measured at each station location that were hypothesized to impact local temperature. These included elevation (measured with a GPS), aspect and slope (estimated), and surface vegetation (categorized in the field as urban, prairie, shrub, forest and rock). Daily temperature patterns were also explored for ensembles of two prominent weather systems that influence winter weather in the region: chinook and continental polar (cP) air mass incursions.

Results

We found an east-west gradient of mean seasonal temperatures in all seasons, reflecting the increase in elevation to the west. Temperature decrease with elevation (lapse rate) was –5.3°C km^{-1} and –4.8°C km^{-1}. Mean seasonal lapse rates were found to be steepest in spring and summer, ca. –6°C km^{-1}, with weakening in the fall and winter seasons as reported in previous studies (e.g., Shea et al., 2004). Winter lapse rate estimates differed markedly for the complete ensemble of FCA sites and the regression with stations aggregated into 100-m elevation bands. There was a large degree of variability in the winter season, giving a weak regression result with the complete set of data. Binning by elevation provided a stronger statistical result, so the associated winter lapse rate, ca. −4°C km^{-1}, may provide a good estimate.

The best temperature models were daytime and monthly models, with better explanatory power for the multivariate models observed in the summer months (April to September). There was high variation in the elevation coefficients, ranging from −1.0°C to −9.3°C km^{-1} with a mean of −4.3°C km^{-1}. Elevation coefficients could not be directly compared with the seasonal lapse rates calculated above, as other independent variables modified the predicted temperature in the multivariate model. They were nevertheless indicative of lapse rates, with diurnal and seasonal variability that is similar to what has been reported elsewhere (e.g., Shea et al., 2004; Pepin and Losleben, 2002).

One hundred and two chinook days and cP air mass days from 2005-2009 were compiled for this analysis. For the ensemble of chinook events, the mean temperature at all FCA sites was 0.0°C, with a between-site standard deviation of 2.6°C. Corresponding values under the influence of cP air masses were −16.9 ± 1.4°C. On chinook days, all sites were warmer than their mean DJF temperatures, with anomalies from 3.1 to 9.3°C. The mean site winter temperature anomaly was 7.1°C. The highest anomalies were in the eastern part of the study area. All sites were colder under the influence of cP air masses, with mean temperature anomalies from −13.0 to −3.9°C for the ensemble of cP days. The average temperature anomaly across all of the FCA sites was −9.8°C. Anomalies were again strongest in the eastern, prairie portion of the study area and were more muted in the foothills. Hence, both chinooks and cP air masses introduced high variability in the eastern part of the region.

Conclusions

The three phases to the analysis presented here paint a coherent picture of the patterns and controls of mesoscale temperature variability in the foothills region of southern Alberta. Our analysis shows the eastern, prairie sites within the study area experience more continental conditions, with a greater influence from cP air masses in winter and a greater degree of seasonal and annual temperature variability. The western edge of the study area has several high-elevation sites along or near to the continental divide. Both these sites and transitional sites in the foothills are colder overall but they experience less variability and less frequent influences from cP air masses; Pacific air masses are more influential here.

The chinook signal in the region introduces a notable exception to this. Anomalous seasonal warmth associated with chinooks is strongest at intermediate altitudes in the foothills region, with lesser warming along the western and eastern edges of the study area. This pattern explains some of the spatial and altitudinal temperature structure observed in the region in the winter season, but it largely opposes the spatial structure induced by cP air masses. The average winter temperature patterns are a complex composite that reflects the relative frequency of these two influences, amongst other weather systems.

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