Chapter 4

Variability of Cold-Season Temperatures in the Mackenzie Basin

Kit K. Szeto

Abstract The Mackenzie River Basin exhibits extremely large interannual variability in its cold-season atmospheric temperatures while some of the strongest warming signals in the Northern Hemisphere have also been observed over the Basin. To understand these observed thermal characteristics and behavior of the region, the atmospheric enthalpy budget for the Basin during 1970–99 was studied using the NCEP reanalysis dataset. Adiabatic warming associated with mean subsidence was found to be more important than net horizontal temperature advection in governing the heat budget during the cold-season. Processes responsible for the development of extreme warm/cold winters were investigated in conjunction with the composite atmospheric heat budget and large-scale atmospheric conditions that prevailed during the anomalous winters. The large temperature variability is linked to the interactions between the North Pacific airflow and the regional environment, notably the Western Cordillera. Understanding the mechanisms responsible for winter temperature variability facilitates the interpretation of temperature trends and offers an explanation of the cold-season temperature bias found in some climate modeling results.

1 Introduction

The Mackenzie River Basin (MRB) has an extremely variable climate (Stewart et al. 2002). In particular, it has the largest intra- and inter-annual variability of winter temperatures in the world (Fig. 19 in Kistler et al. 2001; Fig. 3 in Szeto et al. 2007a), suggesting that its cold-season climate is highly sensitive to variations in the large-scale circulation on both intra-seasonal and interannual time scales. These characteristics make predicting the climate for the region a particularly challenging task. For example, simulating the hydroclimate for the MRB is particularly problematic among the several major arctic basins considered in a study by Finnis (2005). Recent climate simulations for the MRB have also produced a persistent cold bias with attendant negative effects (MacKay et al. 2007, Szeto et al. 2007b). Improving our physical understanding and modeling capabil-
ity of climate variability for this northern region is a pressing issue because most Global Climate Models have predicted an amplified polar response to the increase in atmospheric greenhouse gas content (Houghton et al. 2001). Indeed, some of the strongest warming signals have been observed in high-latitude continental regions, including the MRB (e.g., Zhang et al. 2000).

A first step in improving climate predictions is to examine the underlying mechanisms that cause extreme winter temperature variability in this region. The purpose of the present study is to better understand these mechanisms through an assessment of the mean and anomalous atmospheric enthalpy budgets, and relate the temperature response of the MRB to variations in the large-scale circulation over the North Pacific. Implications of the results for the understanding and prediction of climate change in the region will also be discussed.

2 Methodology and Datasets

Consider the atmospheric energy budgets for the MRB. Neglecting the kinetic energy which accounts for only a small faction of total energy in the atmosphere, energy conservation in a hydrostatic vertical air column is given by the temperature equation:

\[ \frac{1}{g} \int \frac{\partial H}{\partial t} dp = \frac{1}{g} \int \left( -u \frac{\partial H}{\partial x} - v \frac{\partial H}{\partial y} - \omega \frac{\partial H}{\partial p} + \alpha \omega + \dot{Q} \right) dp \]

(1)

where the atmospheric specific enthalpy \( H \) is defined by \( H = Cp \ T \), with \( Cp \) and \( T \) representing the specific heat capacity for dry air and atmospheric temperature, respectively; \( u, v, \omega \) are \( x-, y-, \) and pressure velocities, \( \alpha \) is specific volume, and \( p \) is atmospheric pressure. The advective form of the temperature equation is used to illustrate the relative importance of the atmospheric transport terms in affecting the \( H \)-budgets. The first two terms within the integral on the RHS represent horizontal temperature advection, the third term is vertical advection, the fourth term gives the heating/cooling effects associated with adiabatic compression/expansion in descending/ascending air, and the fifth term represents net diabatic effects such as radiative and latent heating in the atmosphere. The vertical advection and adiabatic heating terms are combined into a single term, called the “vertical” term in the following discussion.

The 3-D wind velocities and air temperatures from the 6-hourly and 2.5° resolution NCEP/NCAR reanalysis dataset (Kalnay et al. 1996; Kistler et