Chapter 2
Exposure of Rural Communities to Climate Variability and Change: Case Studies from Argentina, Colombia and Canada

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Abstract This paper presents results from studies of exposure to climate change and extreme events in the Mendoza River Basin in western Argentina, the Chinchiná River basin in the Colombian Andes, and the Oldman River basin and Swift Current Creek watershed in the Canadian Prairies. These case studies are a major component of an international research project: “Vulnerability and Adaptation to Climate Extremes in the Americas” (VACEA). This project is very much interdisciplinary; with social and natural science providing context and direction for research in the other realm of scholarship, producing insights that very likely would not arise from a more narrow disciplinary perspective. A large number of interviews with local actors revealed that agricultural producers and local officials recognize their high degree of exposure and sensitivity to climate variability and extreme weather events, although they generally do not associate this with climate change. Case studies of exposure demonstrate that the perceptions of the local actors are consistent with the nature of the regional hydroclimatic regimes. In all four river basins, climate variability between years and decades masks any regional expression of global climate change. These modes of periodic variability dominate the paleoclimate of past centuries and the recorded hydroclimate of recent decades. The exposure variables examined in this paper, indices of stream flow, snowpack, water excess and deficit, vary in coherence with the characteristic frequencies of large-scale ocean–atmosphere circulation patterns, specifically the ENSO and PDO. Projections of the future states of these variables require the use of climate

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models that are able to simulate the internal variability of the climate system and the teleconnections between ocean–atmosphere oscillations and regional hydroclimate.

Keywords Rural agricultural communities • Exposure • Climate change • Climate variability • Canada • Colombia • Argentina

Introduction

Vulnerability and adaption to climate change, and the related concepts, are defined by the IPCC (Agard and Schipper 2014) in terms of the extent to which a social and natural system is or could be adversely or beneficially affected:

- **Adaptation**: "The process of adjustment to actual or expected climate and its *effects*."
- **Adaptive capacity**: "The ability of systems [etc.] to adjust to potential *damage*, to take advantage of opportunities, or to respond to consequences."
- **Exposure**: "The presence of people [etc.] in places that could be adversely *affected*."
- **Sensitivity**: "The degree to which a system or species is *affected*, either adversely or beneficially, by climate variability or change."
- **Vulnerability**: "The propensity or predisposition to be adversely *affected*."

These definitions imply that "a predisposition to be adversely affected" (i.e., vulnerability), requires, in the first place, "The presence of people . . . in places that could be adversely affected" (i.e., exposure). Secondarily, a necessary condition is that social or natural systems must have either some sensitivity or lack adaptive capacity, or both. In general, rural communities are among the most vulnerable places because they tend to be on the social and economic margins of society and the typical livelihood, agriculture, is highly exposed and sensitive to climate variability and extremes (Hales et al. 2014). Rural livelihoods and social structures are vulnerable to the impacts of climate change on natural resources, including shifts in supplies of water and ecological goods and services. Relative to urban areas, rural communities tend to have less capacity for responding to and preparing for climate changes, as a function of their physical isolation, lower economic diversity, aging population, and less access to formal institutions infrastructure, health care and emergency response systems (Hales et al. 2014).

This paper examines the exposure of rural agricultural communities in Argentina, Canada and Colombia to climate variability and change. These case studies are a key component of the major interdisciplinary research project "Vulnerability and Adaptation to Climate Extremes in the Americas" (VACEA).[1] The goal of the VACEA project is to improve the understanding of the vulnerability of rural agricultural and indigenous communities to shifts in climate variability and to the

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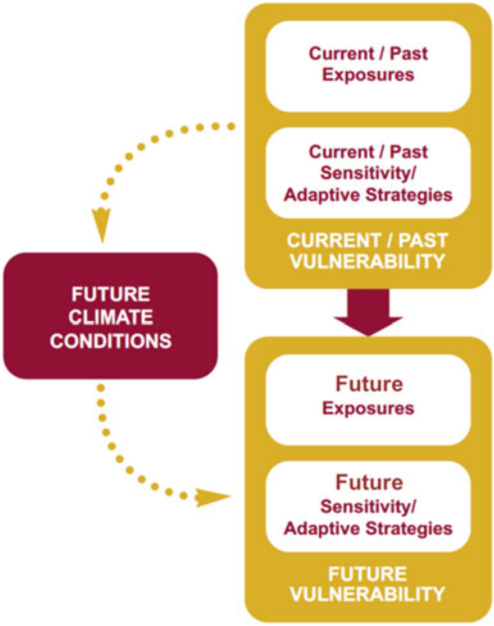
[1] http://www.parc.ca/vacea/

frequency and intensity of extreme climate events, and to engage governance institutions in enhancing the adaptive capacity of these communities. This paper presents results of our studies of exposure to climate change and extreme events in the Mendoza River Basin in western Argentina, the Chinchiná River basin in the Colombian Andes, and the Oldman Riverbasin and Swift Current Creek watershed in the Canadian Prairies. Elsewhere in this volume, related papers (Diaz, Mussetta et al. Hurlbert et al. Marchildon et al.) present the results of research on the sensitivity and adaptive capacity of rural communities in these river basins. Our evaluation of exposure in this paper is based on the statistical analysis of trends, variability and extremes in time series of climate and water variables. Whereas much of these data are instrumental observations from monitoring networks, we also analyze output from climate models and paleoclimate data inferred from climate proxies such as tree rings.

The research design of the VACEA project follows a vulnerability assessment model (Fig. 2.1) and its associated community-oriented, participatory methodologies. This model frames vulnerability as a function of exposure to climate hazards and their impacts, and the social conditions that determine sensitivity and adaptive capacity (Smit and Wandel 2006), providing a consistent basis for interdisciplinary and comparative research. This "bottom-up" approach incorporates the assessment of vulnerability according to how actors perceive their exposures, sensitivities, and adaptive capacity in the context of other stressors and changes (for example, drought will exaggerate vulnerability to falling international market prices). While the perspective of local actors is critical for evaluating the social variables,

Fig. 2.1 A conceptual model for the assessment of vulnerability to climate change



it also provides important context for the study of physical exposure to regional climate variability and extremes and to impacts on the agro-ecosystems and environmental services that support rural populations.

The Evaluation of Exposure in a Social Science Context

The VACEA project was designed to undertake climate change science in a social science context. The advantage of this bottom-up, community-based approach is a greater relevance, applicability and interdisciplinarity of the science. Alternatively, the historical and future hydroclimate of any study area could be characterized by processing climatic, ecological and hydrologic data, accessing observations and model outputs available from online repositories. Without a sampling of the human population, however, researchers run the risk of investigating environmental changes that are of little or no consequence from the perspective of the local actors; "relying on hazard/impact modelling alone can lead to entirely erroneous conclusions about the vulnerability of rural communities, with potential to significantly misdirect policy intervention" (Nelson et al. 2010: 18). Therefore, the case studies of exposure reported here were very much informed by community vulnerability assessments carried out during the initial stages (2011–13) of the VACEA project. Hundreds of local actors, mainly agricultural producers and local officials, were interviewed using a common methodology, a semi-structured questionnaire with mostly open-ended interview questions.

The social surveys have focused the VACEA project on the weather events and climate changes of greatest concern to the residents of the rural communities. As an example, in the Swift Current Creek watershed in southwestern Saskatchewan (Canada) survey participants identified

The stresses caused by periodic drought, including crop damage resulting from a lack of soil moisture, poor surface water quality, and a slow institutional response.

Heightened sensitivity to water deficits where there is less access to surface and groundwater or irrigation is underdeveloped, or because the impacts of drought are exacerbated by a growing cost/price squeeze, a shift in production to single commodities, and increasing farm size and dependence on technology, which tend to offset the benefits of traditional soil and water conservation practices.

The impacts of excess precipitation: damage to transportation and irrigation infrastructure, delayed seeding and harvest, and changes to water quality, which also are linked to the intensification and industrialization of agriculture and other industrial development (e.g., oil and gas).

Some of these impacts and sensitivities are unique to the physical geography and agricultural production in the Canadian prairies; but most are shared with the river basins in South America. For example, climate extremes impact water quality in the Chinchiná River basin. In the Mendoza River basin, access to water is an issue:

producers located upstream, or nearer to the sources of water, tend to be less sensitive to drought than those downstream of urban centers or at the far end of the irrigation network.

A common theme emerging from the community vulnerability assessments is that 'long-term' climate changes and their affects are not obvious to most agricultural producers. They experience weather not climate. Their adaptive capacity is tuned to seasonal and interannual variability. The main threat posed by climate change is from extreme and unexpected weather, which is more often viewed as natural climatic variability rather than an indication of climate change. This distinction between climate change, a monotonic trend, and climate variability, short-term periodicity, is somewhat arbitrary given that these concepts describe statistical properties of a single climate system. However, it is a meaningful distinction in terms of climate impacts and adaptation strategies (Sauchyn et al. 2015). Observable and projected trends in climate variables, notably the consistent rise in global mean surface temperature, can be attributed directly to the increased concentration of anthropogenic greenhouse gases (IPCC 2013). Furthermore, a large number of studies have documented changes in biological and physical systems that are consistent with global warming (IPCC 2014). Whereas, in absence of anthropogenic global warming, these trending changes may not exist, climate is inherently variable and extreme events occur even in the times of relatively stable climate, although there is substantial scientific evidence suggesting that shifts in amplitude and frequency are occurring in response to warming of the oceans and atmosphere (IPCC 2012; Trenberth 2012).

In the literature on climate change impacts, vulnerability and adaptation, climate variability and extremes generally are viewed as a bigger problem than changes in average conditions (Katz and Brown 1992), although referring to "organizations that specialize in hazard issues" Orlove (2009: 160) suggested "this emphasis directs attention towards short-term acute problems of moderate importance; and away from long-term chronic problems of greater importance, particularly water availability". The relative importance of "short-term acute" versus "long-term chronic" problems would depend very much on context, and specifically the severity of climate events relative to the local capacity to cope. The case study areas considered here are interior river basins characterized by large inter-annual and decadal climatic variability. Despite a history of adaptation to this variable climate, extreme events (floods, droughts and storms) in these river basins have been among the mostly damaging and costly natural events in their respective countries. In these regions, extreme weather has not been of "moderate importance". The problematic climatic changes in these rural watersheds are not a monotonic rise of temperature, or changes in the mean states of other climate variables; it is the prospect of climate variability and extremes that are outside the experience and adaptive capacity of the rural communities.

Case Studies of Exposure

Despite the tens of thousands of kilometres that separate the four case study river basins (Table 2.1), and a difference in agricultural commodities, there is much similarity in terms of exposure of the rural communities to hydroclimatic variability and extremes. Three of the four watersheds (Chinchiná, Mendoza, Oldman) have mountain headwaters shedding snowmelt and rainfall runoff. The fourth stream, Swift Current Creek, also is fed primarily with snowmelt waters although from a prairie upland (Cypress Hills) as opposed to the Cordillera. Droughts and floods are serious climate hazards in these basins, threatening water supply for human consumption and agricultural production. In all four regions, irrigation is an important agricultural practice and adaptation to permanently or seasonally dry conditions. The communities in the Mendoza River basin have been called "hydraulic societies" dependent entirely on the diversion of water from the Rio Mendoza; 98 % of the population of the Province of Mendoza resides in the oases that represent only 3 % of the total surface area. Southern Alberta has more than 60 % of Canada's irrigated area and most of this is located in the Oldman River Basin. These dry river basins also suffer from periodic inundation from the flooding of mountain rivers. Flooding and intense rain also is a serious hazard in the Chinchiná River Basin, and even though it is located in the tropical Colombian Andes, fruit crops are irrigated to overcome seasonal moisture deficits. Thus there are sufficient similarities among the chosen river basins to enable a multi-national comparative study of the human and environmental dimensions of the impacts and adaptive responses to short-term climate variability and extreme events.

Climate Change

Because anthropogenic climate change presents a new distribution of weather statistics, a shift in means and extremes, the regional consequences of change in the earth's energy balance can be understood only from the analysis of output from multiple runs of climate models and different greenhouse gas emission scenarios. In

Table 2.1 Geographical characteristics of the case study river basins

River Basin	Country	Region or province	Size (km^2)	Agricultural production
Chinchiná	Colombia	Caldas	1052	Coffee, fruits, maize, cattle
Mendoza	Argentina	Mendoza	17,821	Grapes, fruits, cattle, horticulture, goats
Oldman	Canada	Alberta	26,700	Grains, pulses, forage, vegetables, cattle
Swift Current	Canada	Saskatchewan	5592	Grains, pulses, forage, cattle

each country, climate change scenarios were derived from global and regional models that are able to simulate important aspects of the regional climate, including the spectral and geographic characteristics of teleconnection patterns (e.g., Lapp et al. 2011) and historical climatic variability. Thus a model that performs well for the Chinchiná River basin in Colombia is not the best model for projecting future climate in western Canada or west-central Argentina. Despite this difference in the source of model projections, there are important common tendencies, including rising minimum temperatures resulting in a decline of the extent of snow and glacier ice and an earlier onset of annual snowmelt.

The case of the Chinchiná River basin is used to illustrate the projection of climate changes and their impact on water supplies. The projections in Fig. 2.2 are expressed as anomalies; the difference in mean annual temperature (°C) and precipitation (%) between 2010–2039 and 1981–2010. The source of these data is six global climate models from the CMIP3 archive built for the IPCC Fourth Assessment Report (Meehl et al. 2007). The temperature anomalies are all positive with greater warming at mid elevations. There is a large range of precipitation anomalies, especially at higher elevations, but with a median projection of little change.

In Fig. 2.3, which illustrates the impact of the projected climate changes on the Chinchiná River, there is little change in mean monthly flows. The projected mean flow rates follow the historical bimodal distribution. On average streamflow is reduced by about 1 %. This compares to an estimated error of around 5 % in the hydrological model.

Climate Variability

Earlier in this paper, we reported that the agricultural producers interviewed in the four case study areas made little or no reference to the threats or opportunities presented by long-term trends in climate variables. Rather their focus and concerns

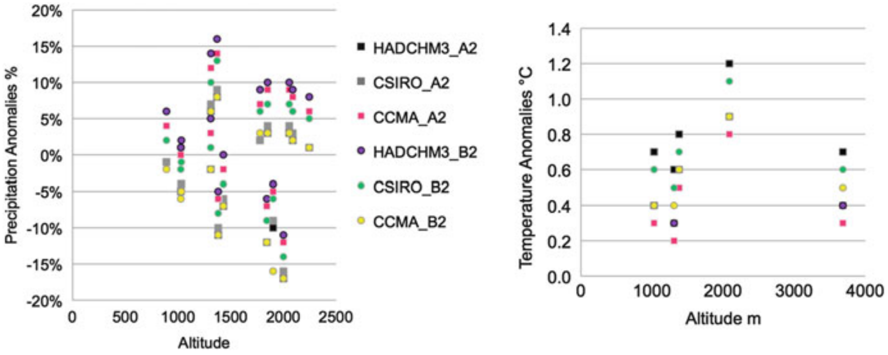


Fig. 2.2 CMIP3 (IPCC AR4) climate change scenarios for the Chinchiná River basin: precipitation (%) and temperature (°C) anomalies, 2010–2039 versus 1981–2010 (Colour figure online)

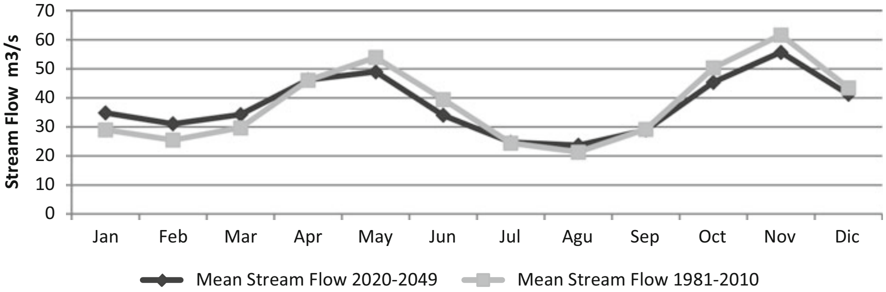


Fig. 2.3 A projection of the future flow of the Chinchiná River based on a historical run (1981–2010) of the Tetis hydrological model and a future (2020–2049) simulation, created by driving the Tetis model with output from the climate model NCC_NORESM1 (RCP 8.5)

relate to recent weather events, which they perceive as unusually severe, but not necessarily an indication of climate change. They tend to regard extreme weather events as typical of their variable climate but nonetheless stressful. The clear message for the natural scientists on the VACEA project was that, if our research is to have relevance for the local administrations and agricultural economy, we should address this dominant concern: exposure and sensitivity to climate variability and extreme events. At the same time, adaptation planning and policy making at higher levels would benefit from new climate change projections and research on how weather is changing as a consequence of the anthropogenic warming of the oceans and atmosphere.

The histories of the studied communities and local economies are punctuated by the impacts of flooding and drought. Therefore considerable scientific effort was applied to characterizing and analyzing these hydrologic extremes, mostly by deriving, from instrumental weather and water records, maps and time series of commonly used indices of drought and excess water, such as the Palmer Drought Severity Index, Climate Moisture Index and Standardized Evapotranspiration Precipitation Index (SPEI). For example, in Canada we found that that the SPEI is an effective index of moisture variability in terms of the impact on agricultural production as illustrated in Fig. 2.4, a plot of growing season (May to August) SPEI and spring wheat yields for the Swift Current Creek watershed over the period 1956–2012 (From Wittrock et al. 2014). Both variables are dimensionless. The crop yield data were processed to remove a positive trend that reflects technological innovation and better farming practices over the past six decades, and in general progressive adaptation to a dry climate and relatively short growing season. In Fig. 2.4, negative departures in wheat yields occur in years with a negative water balance; they are lowest in the second of two or more dry years (i.e., 1961 and 1985). Higher yields (positive departures from the long-term trend) are associated with a positive SPEI, however, excessive moisture can suppress yields, such as in the most recent 4 years, by delaying the seeding and germination of annual crops.

The risks and impacts associated with extreme water levels and sustained dry spells, as illustrated in Fig. 2.4 and reported by the local actors, focused our research

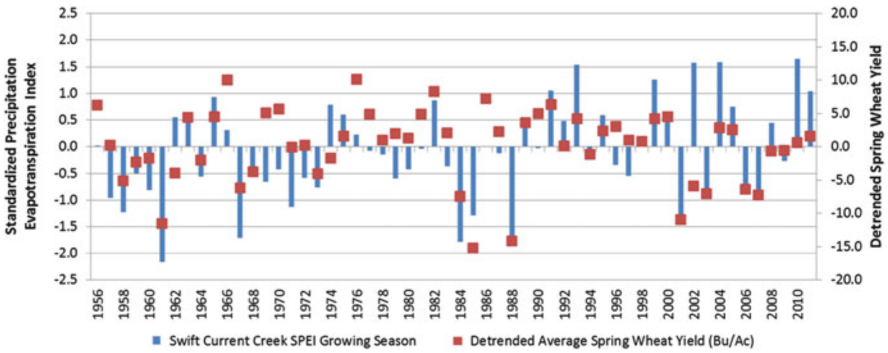


Fig. 2.4 Time series (1956–2011) of dimensionless growing season SPEI and detrended spring wheat yields, Swift Current Creek watershed, Saskatchewan, Canada. From: Wittrock et al. (2014) (Colour figure online)

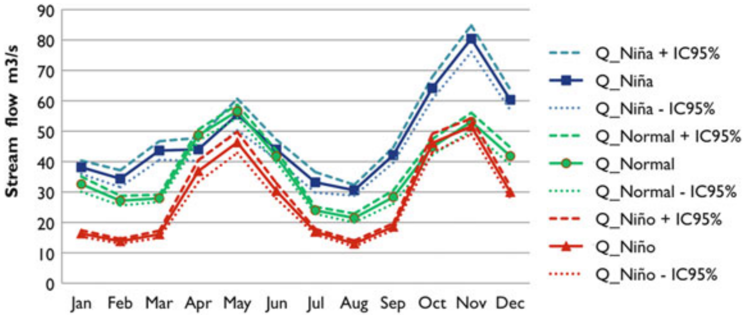


Fig. 2.5 The annual water balance (1981–2010) of the Chinchiná River Basin for La Niña (*blue*), El Niño (*red*) and normal (*green*) weather conditions. The three simulations, plotted with 95 % confidence intervals (IC), were run using a lumped hydrological model (Colour figure online)

activity on the causes, frequency, severity and duration of excessive moisture and water scarcity, and particularly variability at annual and decadal time scales. Furthermore, climate model projections (e.g., Kharin et al. 2007; Tebaldi et al. 2006; IPCC 2013) converge on a scenario of amplified hydroclimatic variability with twenty-first century greenhouse warming. In all four of our case study watersheds, the hydroclimatic variability is linked to the correlation over space and time between the regional hydroclimatic regimes and large-scale patterns of coupled ocean–atmosphere circulation, specifically the El Niño-Southern Oscillation (ENSO), and Pacific Decadal Oscillation (PDO) Masiokas et al. 2006, 2010; Poveda and Mesa 1997; Shabbar et al. 2011; Villalba et al. 2011).

The strong influence of the ENSO is observed across the Colombian Andes (Poveda et al. 2011) including the Chinchiná River basin. Figure 2.5 shows the results of a simulation of the annual water balance (1981–2010) using a lumped hydrological model driven with monthly weather conditions during El Niño, La Niña and normal years. While flows are similar during the early wet season (AMJ) in La Niña and normal years, and during the later wet season (ON) in normal and El Niño years, there is otherwise a significant difference according to the ENSO phase. El Niño produces abnormally low flows during the two dry seasons (JFM and JAS), and there are large positive anomalies under La Niña weather conditions, especially during the late wet season (OND). Overall, El Niño is associated with a 25 % reduction in river discharge, while there is an increase of 27 % in La Niña years.

The influence of Pacific Ocean sea surface temperature (SST) is also very evident in the hydroclimate of the Andes of west-central Argentina (location of the Mendoza River basin), as demonstrated by the plots in Fig. 2.6 of regional snowpack and stream flow records for the period 1909–2010 (Masiokas et al. 2010, 2012). A slightly negative but non-significant trend in regional river discharges is obscured by the large inter-annual and decadal scale variability. Using an objective and relatively simple method of detecting the driest and wettest intervals in these time series, Masiokas et al. (2012) identified statistically significant regime shifts in 1945, when mean water levels dropped 32 %, and in 1977, when they increased by 29 %. Also plotted in Fig. 2.6 is the July–June PDO index of sea surface

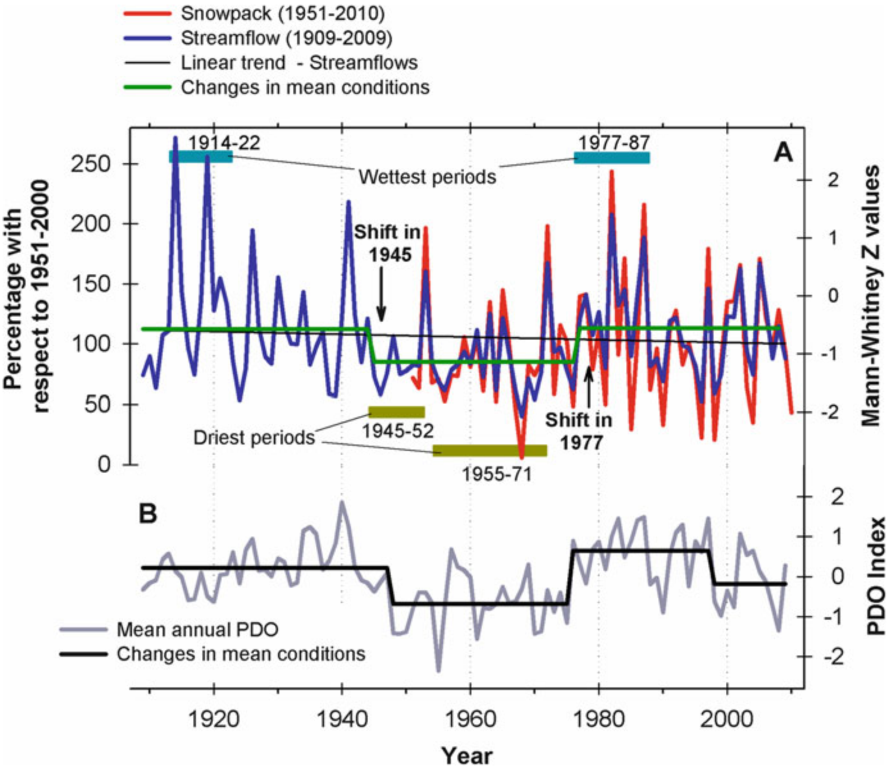


Fig. 2.6 (**a**) Regional snowpack (*red*) and streamflow (*blue*) records from west-central Argentina and adjacent Chilean Andes. Statistically significant shifts in mean flow conditions (*green line*) occurred in 1945 and 1977; (**b**) a 1909–2009 time series of the mean July to June PDO index (*gray*) and shifts in mean levels (*black*). *Source*: Masiokas et al. (2010, 2012) (Colour figure online)

temperatures in the extra-tropical, northern hemisphere Pacific Ocean. Decadal-scale variability dominates the PDO index, with definite shifts in the mean value every few decades. Clearly evident in Fig. 2.6 are the coinciding patterns of decadal-scale variations in regional streamflow and snowpack and the temporal pattern of the PDO.

The teleconnections between Pacific Ocean climate oscillations and regional hydroclimate, demonstrated above for the Andes, extend throughout the Cordillera of the western Americas (Villalba et al. 2011). Whereas a 30-year record of hydroclimate, such as in Fig. 2.5, is sufficient to capture the short-term affects of ENSO, the detection of lower-frequency (decadal) periodicity requires longer hydroclimatic time series, such as in Fig. 2.6. Even longer records of annual hydroclimate, inferred from the growth of long-lived trees, are available from the central and southern Andes of Argentina and the Canadian Rocky Mountains. In these temperate mid-latitudes (30–60°), tree growth is confined to a distinct growing season and tends to be limited by available soil moisture because at these latitudes the eastern slopes of the cordillera are dry. Using moisture-sensitive tree-ring chronologies, and the well-established methods and principles of dendrochronology (Hughes et al. 2011), researchers associated with the VACEA project have reconstructed annual streamflow for the past six to eight centuries.

The time series in Fig. 2.7, from west-central Argentina and the adjacent Chilean Andes, includes snowpack reconstructed back to 1866 using rainfall data, and

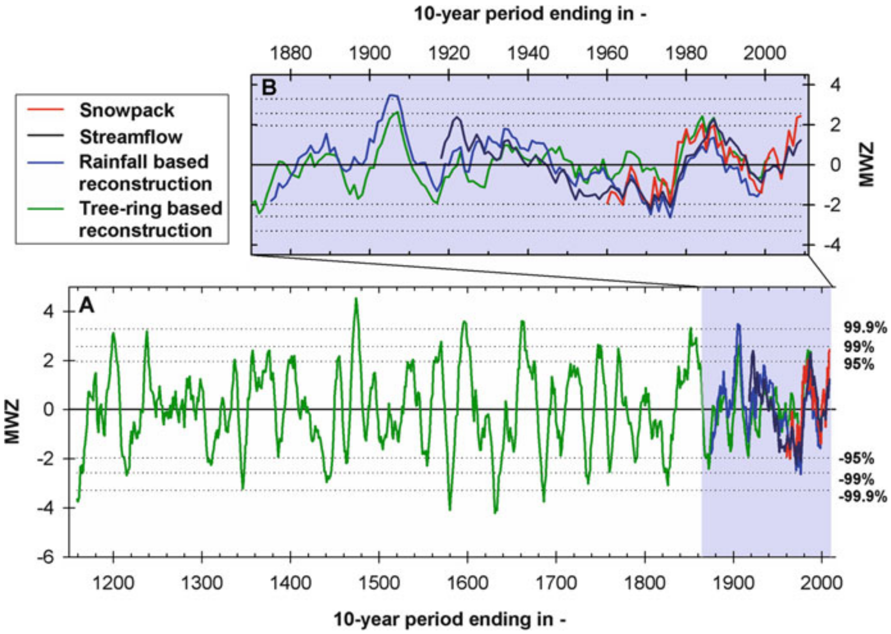


Fig. 2.7 Records of measured snowpack (*red*) and streamflow (*dark blue*) and reconstructed from rainfall data (since 1866, *light blue*) and from tree-rings (1150–2001, *green*). The data were standardized using Mann–Whitney Z statistics (MWZ) for 10-year intervals. All four curves display coherent patterns of decadal variation. *Horizontal dotted lines* indicate statistically wetter or drier conditions (Masiokas et al. 2012) (Colour figure online)

annual streamflow extended back to 1150 using tree rings. All data were standardized and averaged over 10-year intervals (Masiokas et al. 2012). These instrumental and proxy time series display coherent patterns of decadal variation, providing important context for the interpretation of trends and variability in recent observations of climate and water variables, and model projections of future hydroclimate.

A similar tree-ring reconstruction of annual streamflow for the Oldman River in western Canada was developed for this paper using methods described in Sauchyn et al. (2014). This proxy hydrometric time series, spanning 1377–2010, is plotted in Fig. 2.8. It reveals strong decadal-scale variability linked to SST oscillations in the northern Pacific Ocean, the primary source of precipitation over northwestern North America, particularly in winter. Figure 2.9 gives the results of a spectral analysis of this proxy streamflow record. The dominant modes of variability correspond to periodicities of approximately 2–4, 13 and 60 years. The highest and lowest of these frequencies are characteristic of the ENSO and PDO, providing further evidence of the strong teleconnections between these ocean–atmosphere oscillations and the hydroclimate of the case study river basins.

This teleconnection between the PDO and regional hydroclimate has important implications for the timing and intensity of extreme events, as highlighted by Fig. 2.10. Gurrapu et al. (2016) stratified the peak annual flow series for the Crowsnest River, a tributary of the Oldman River, into years of negative versus positive PDO. The corresponding flood frequency curves show a distinct separation; flood risk is relatively higher in the cool (negative) phase. At very high flows, with a return period of 10–50 years, there is some overlap but only in the 95 % confidence limits. Thus the probability of exposure to excess water (and conversely

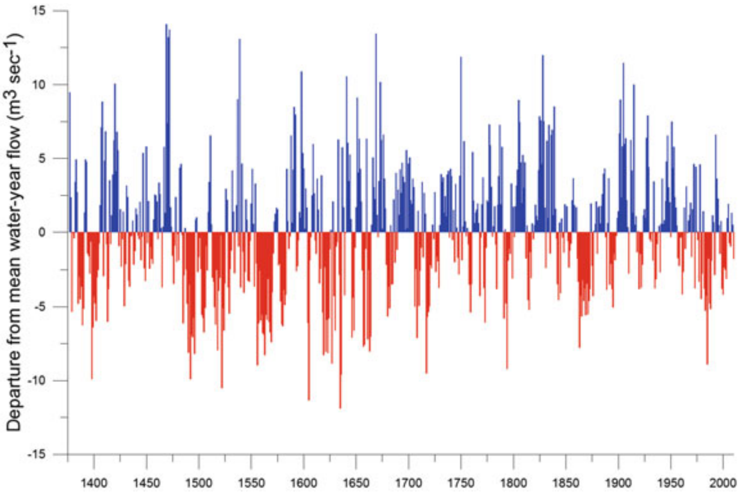


Fig. 2.8 A tree-ring reconstruction of the water-year (October–September) flow of the Oldman River from 1377 to 2010. These 12-month inferred flows are plotted as positive (*blue*) and negative (*red*) departures from the mean water-year flow for the reconstruction period. See Sauchyn et al. (2014) for a description of the methodology (Colour figure online)

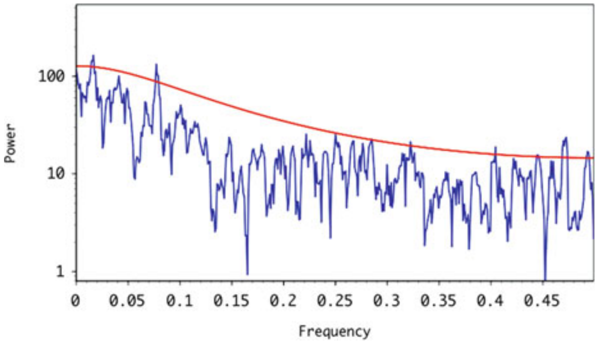


Fig. 2.9 The results of a multi-taper method (MTM) spectral analysis of the Oldman River reconstruction shown in Fig. 2.8. The most powerful frequencies, exceeding a significant level of 95 % (*red curve*), represent periodicity at approximately 2–4, 13 and 60 years (Colour figure online)

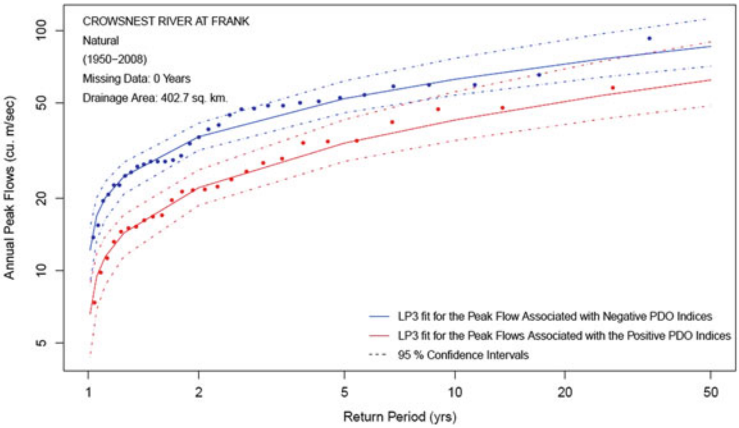


Fig. 2.10 Exceedence curves for the peak annual flow of the Crowsnest River, Alberta (Canada), during negative and positive phases of the PDO (From: Gurrapu et al. 2016) (Colour figure online)

drought) varies between decades, depending on the phase of the PDO and the state of ENSO (Fig. 2.5).

Conclusions

Climate change will increasingly impact the livelihoods of rural people, who are often disproportionately more vulnerable, given their dependency on natural resources and exposure to other stressors. The way that residents of agricultural communities perceive climate change was a key element and driver of research on the VACEA international research project. This critical information was the basis for not only an evaluation of sensitivity and adaptive capacity, but also, as reported in this paper, case studies of exposure to the most locally-relevant aspects of climate variability and change. The VACEA approach to interdisciplinary climate change research, whereby social and natural science provide context and direction for research in the other academic realm, has produced insights that very likely would not arise from a more narrow disciplinary perspective. The community vulnerability assessments (CVA) revealed that local actors were either not cognizant or not concerned about 'long-term' trends in climate variables. From the perspective of the science and impacts of global warming, as reported by the IPCC (2014), it would be easy to conclude that these rural farmers and administrators are naïve or in denial. However, five years of study of the weather, climate, hydrology, economy and sociology of communities in four watersheds suggests otherwise. Local agricultural producers observe and experience short-term variability, in relation to their seasonal to annual planning horizon and the impacts of wet/dry cycles and extremes. Given the degree of variability in the hydroclimate of the case study river basins, and the sensitivity of the rural livelihoods to this variability and weather extremes, the perception of the local actors conforms to their experiences and the nature of the regional hydroclimate.

In the case study river basins, climate variability between years and decades dominates the paleoclimate of past centuries, and the recorded hydroclimate of recent decades, masking the regional expression of global climate change. Exposure variables examined in this paper, indices of stream flow, snowpack, water excess and deficit, vary in coherence with the characteristic frequencies of ocean–atmosphere circulation patterns, specifically the ENSO and PDO. This finding suggests that future projections of these variables should be derived from climate models that are able to simulate the internal variability of the climate system and the teleconnections between ocean–atmosphere oscillations and regional hydroclimate. Recent climate modelling studies of the detection and predictability of anthropogenic climate change have concluded that much of the discrepancy among climate projections at regional scales is irreducible owing to the internal variability of the climate system (Knutti and Sedláček 2012), and therefore natural climate variability poses inherent limits to climate predictability (Deser et al. 2012).

Our findings, on the spatial and temporal patterns of stream flow and related variables, provide important perspective for understanding of vulnerabilities to climate variability and change in rural agricultural communities. They place the hydrologic extremes experienced by the communities in a long-term and natural science context. For example, the relative magnitude of extreme weather, such as the droughts of 1999–2002 and 2004–2005 in the Oldman and Mendoza River basins, respectively, locally perceived as severe, can be revaluated in the light of the regional variability and forcing of climate and hydrology over the past decades and centuries. Extreme dry years are not as uncommon as believed by local actors, especially as they become removed in time or space from the impacts of drought. Raising awareness of the possibility of severe and prolonged drought, and conversely high water levels that exceed recent extremes, should encourage appropriate adaptation measures. The important implication of our case studies of rural communities in three countries is that evidence-based adaptation policy and planning requires deep interdisciplinarity whereby research in the natural sciences depends on social science for the key variables and relevant scales and the resulting studies of exposure inform the evaluation of community adaptive capacity and governance. These lessons are transferrable to regions where rural comminutes are exposed and sensitive to a range of environmental fluctuations and stresses from extreme weather events to inter-annual and -decadal variability and long-term changes.

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