Societal and Economic Research and Applications (SERA) for Adaptation to Atmospheric Hazards in Canada

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Abstract: Economics and other social science disciplines offer a wide range of methods and tools that can be applied to atmospheric hazards to determine the need for adaptation and the costs and benefits associated with various forms of planned response—including the provision of better weather, climate, and climate change information. Unfortunately the limited number of studies and applications that have been conducted in Canada are insufficient to adequately document the economic implications of atmospheric hazards and the costs and benefits of adaptation. The rationale and priorities for pursuing a renewed research agenda in Canada are examined based on deliberations that occurred during the *SERA North: Economics of Weather, Climate, and Climate Change* meeting held February 2008 in Waterloo, Ontario. While progress is being made towards the recommended activities, much remains to be done to fill research gaps and overcome methodological and practical challenges such as the aggregation and generalization of impacts across scales or regions and the valuation of environmental and social costs and benefits.

Keywords: atmospheric hazards, economic valuation, climate change, adaptation.

1. Introduction

This paper is based on material presented and discussed at a recent forum: the *SERA North: Economics of Weather, Climate, and Climate Change* meeting held February 2008 in Waterloo, Ontario (Mills, 2008). A rationale and priorities for pursuing a renewed research agenda in the area of weather and climate-related societal and economic research and applications (SERA) are introduced along two primary and interrelated lines of inquiry:

1) What is the value of weather, climate, and climate change information to Canadian society; and
2) What are the costs of impacts resulting from weather, climate, and climate change, with and without the adoption of adaptive and mitigative response measures?

The overriding context for the theme selection stems from the mandate and core functions of Environment Canada (EC) which are captured in the mission statement of the current and peer-reviewed EC Science Plan (2006a):

To deliver the high-quality knowledge, information and data that enable the Minister, the Government, the Department and other decision makers to enhance the health *and safety of Canadians, protect the quality of the natural environment, and advance Canada's long-term competitiveness.*

The mission and mandate imply that Environment Canada produces information to enable better decisions and provide clear indicators, if not well-defined thresholds, of societal value that extend beyond goods and services traded in markets. Although Environment Canada, partner organizations, and others in Canada have developed and disseminated substantive amounts of information concerning weather, climate and climate change, there is often a disconnect between the production of this information and the value it provides to Canadian society. SERA activities can help bridge this gap and the February 21-22 meeting in Waterloo was one step towards defining a path forward while building on past efforts (i.e., Morss *et al.*, 2008; Stratos Inc., 2004).

2. What is the value of weather, climate, and climate change information?

Hundreds of thousands of weather forecasts, severe weather warnings, and climate predictions are issued to the public each year in Canada. Along with billions of archived environmental observations, data from numerical weather and climate prediction models, and associated applications, this information is intended to encourage adaptive behaviour among the public and decision-makers in health, agriculture, energy, forestry, transportation, construction, insurance, and many other sectors. The production of this information is dependent on a federal public monitoring, computer, telecommunication, and research laboratory infrastructure valued at over $330 million and the efforts of about 2,000 meteorologists, scientists, technicians and support staff. Unquantified, yet significant (perhaps greater?), contributions are also made by international, provincial, local, or non-government agencies; and academia. Contributions by the private sector, which includes meteorological service providers, media and experts employed directly by large user businesses, institutions and organizations, are increasing.

In light of such investments, Environment Canada and many other public National Meteorological and Hydrometeorological Agencies (NMHAs) have become increasingly interested in identifying, tracking and evaluating the costs and benefits of providing timely, precise and accurate information about the past, current and future states of the atmosphere. This desire is also driven by broader globalization pressures that have encouraged the proliferation of international quality control, quality assurance and other standard-setting and performance-measuring practices. Clearly there is a need to justify the cost of *current* operations and this objective has underpinned public agency support for societal and economic valuation research. A small but growing literature has emerged over the past 40 years that documents and estimates the use and value of weather and climate information. Katz and Murphy (1997) provide one of the most critical and comprehensive collections of referenced work, critiquing a wide spectrum of methods available to determine economic value (e.g., contingent valuation, market-based cost-loss functions, cost-benefit analysis, etc.). Rubas *et al.* (2006) review a selection of both applied and theoretical modeling approaches to value climate information (e.g., decision theory, general equilibrium modeling, game theory). Elsewhere, recent examples of sector-specific studies on aspects of agriculture (Johec *et al.*, 2001; Fox *et al.*, 1999), energy (Gurtuna and Davison, 2007; Roulston *et al.*, 2002), human health (Ebi *et al.*, 2004), forestry/fire management (Gunasekera *et al.*, 2005), transportation (Keith, 2003; Smith and Vick, 1994; Stewart *et al.,* 2004), and water resources management (Hamlet *et al.*, 2002) are complemented by broader evaluations of multiple sectors and public or household willingness-to-pay for weather services (Rollins and Shaykewich, 2003; Lazo and Chestnut, 2002; Brown, 2003) and public satisfaction surveys (e.g., Ekos Research Associates, 2007). Such studies most often examine the value of information that is currently received or that could be obtained with some specified level of improvement in quality (i.e., precision, accuracy, delivery frequency or medium). Other researchers have examined a particular component of the monitoring and forecast system, such as the impact of an expanded network of Doppler radar infrastructure in Canada (Vodden and Smith, 2003) or *Weatheradio* (Cavlovic *et al.*, 1997).

These analyses serve as a useful base and, in most cases, provide suitably large numbers to more than justify past NMHA expenditures. For example, the research by Vodden and Smith (2003) found that the discounted benefits of the improved national radar program in Canada would amount to $433M relative to costs of $88M over a ten-year horizon. Overall though, the cost-benefit research in Canada remains ad hoc, fragmented, under-funded, inconsistently peer-reviewed, and underutilized. A more systematic, strategic, and long-term approach to funding, designing, conducting and applying societal and economic valuation research could yield much greater benefit. For public agencies, better understanding of the value of providing meteorological, hydrometeorological and climatological information could be fundamental inputs to measuring and improving products and services. This knowledge would also inform

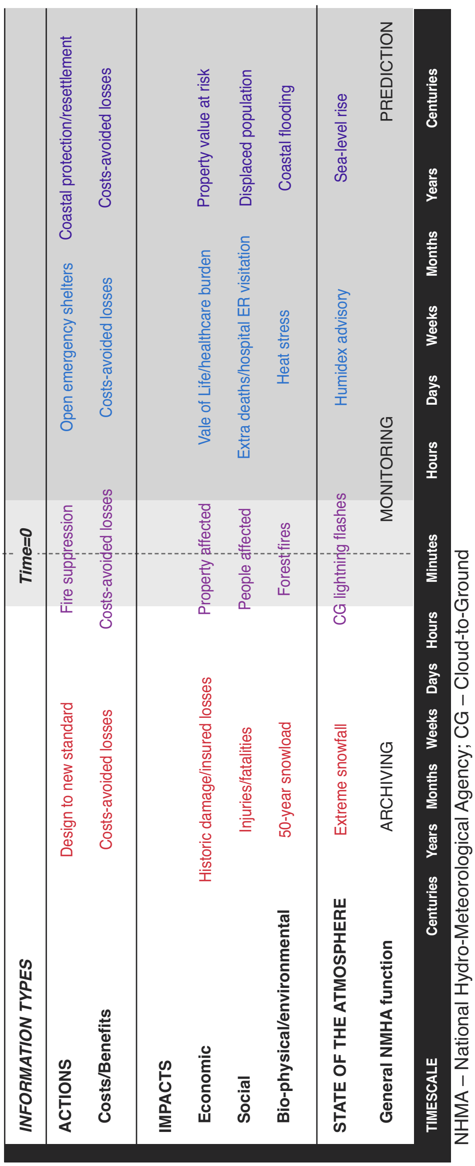

Figure 1 | Types of information potentially provided by National Meteorological and Hydrometeorological Agencies at different timescales.

critical decisions with respect to the application of new technologies and changes to existing monitoring networks, observation strategies, communications, computer infrastructure, human resource management, and priorities for research and development—or the most appropriate mix of adjustments.

As an example, one of the many critical decisions currently being debated relates to the type of information being generated and communicated to the public by NMHAs. Figure 1 is a simplified attempt to map a generic set of information types. Different classes of information are indicated along the left-hand column while timescales, centred on the Time=0 line, are defined along the bottom of the figure. In general, user-relevance and presumably value increases as one moves from *state of the atmosphere* through *impacts* and up to *action*-oriented information types. Four sample "information chains" are indicated in like-coloured text above the applicable time period. Three general functions common to most NMHAs are identified above the appropriate timescale: *monitoring* of current atmospheric and related environmental conditions; the *archiving* and analysis of this data; and *prediction* of future states of the atmosphere.

Typical NMHA products include current weather conditions, forecasts and warnings that are disseminated via the Internet and various media to the public in an array of text, audio and graphic formats. Much of the information that is distributed relates to observations, analyses and predictions of physical or bio-physical quantities such as temperature and precipitation amounts. Historically, the users of this information have implicitly been assumed by NMHAs to follow a linear model of decision-making whereby the provision of more accurate information at higher spatial and temporal resolution leads directly to improved safety, environmental protection, and economic productivity. SERA activities can be used to explore the validity of this and other assumptions prior to committing to costly, long-term, and inflexible investments. For instance, it may be more effective to change the message or the medium rather than invest in a new monitoring technology or supercomputer. Often this involves greater consideration of users and the decisions they face. Along this line of thought, recent efforts by Environment Canada and other NMHAs to move towards broader environmental prediction—where atmospheric data and simulation tools are coupled with biophysical and eventually socio-economic impact models—are effectively attempting to move up the information chain presented in Figure 1. Heat alert systems (e.g., Sheridan, 2007) and the development of air quality health index forecasts (e.g., Environment Canada, 2009) are encouraging examples of this shift. However, like the traditional information products that they are replacing or augmenting, they are being constructed in isolation, and often without the benefit of SERA valuation work and underlying monitoring of key indicators from which progress towards societal objectives can be verified.

3. Costs of weather, climate, and climate change

At the extreme right side of Figure 1, one is confronted with information concerning atmospheric-related phenomena and predictions that won't be verifiable for decades or centuries. The centre-piece at this end of the timescale is anthropogenic climate change, an issue that has emerged over the past 25 years as one of the most significant challenges facing humanity. Citizens, non-government organizations and decision-makers at all levels of government and throughout industry are grappling with ways to manage greenhouse gases (mitigation) and adjust to the implications of a changing climate for society's welfare (adaptation). Many decisions must be taken now in the face of considerable uncertainty about the extent and nature of future global and regional climate and, more importantly, societal vulnerability and adaptability (i.e., related to values, geo-political stability, trade and wealth distribution, natural resource availability, technology, etc.).

In Canada, a significant amount of research has been conducted to provide information about possible future states of climate under various emission growth scenarios (e.g., CCCma[1], CCCSN[2]). Scientists have directly or indirectly used this information to analyze potential impacts and evaluate the efficacy of measures to manage risks and opportunities. Much of this effort has focused on defining biophysical and first-order socio-economic impacts of weather, climate, and climate change within specific regions (e.g., Cohen, 1997; Mortsch *et al.*, 1998, 2000), sectors (Auld and MacIver, 2005; Mirza, 2004; Mills *et al.*, 2006; Ogden *et al.*, 2006; Scott and Suffling, 2000), issues (MacIver, 1998 – biodiversity) or for particular hazards and events (e.g., Koshida *et al.,* 1999; Etkin and Myers, 2000; Cheng *et al.*, 2007; Auld *et al.*, 2004). In many cases adaptive responses or strategies have been identified, modeled and evaluated using criteria and methods drawn from natural hazard and climate adaptation frameworks (e.g., Burton *et al.*, 1993; MacIver and Wheaton, 2005; Fenech *et al.*, 2004) and the intense engagement/involvement of regional or sectoral decision-makers

1 Canadian Centre for Climate Modelling and Analysis **http://www.cccma.bc.ec.gc.ca/**
2 Canadian Climate Change Scenarios Network **http://www.cccsn.ca/index-e.html**

or stakeholders (e.g., Cohen *et al.*, 2006). More recently, studies have been proposed and undertaken to integrate climate change research within a broader sustainable development framework that encompasses mitigation and adaptation responses (e.g., Bizikova *et al.*, 2008; Swart and Raes, 2008).

Only a few studies, however, have explicitly been designed to include an evaluation of the economic impacts of weather, climate, or climate change in Canada—or the costs and benefits of adaptation. Specific weather and climate events, generally those that are severe or extreme and have led to substantial media coverage, have been the focus of several detailed investigations. Canadian examples include assessments of heavy snowfall in the B.C. Lower Mainland (Pan Pacific Communications, 1997), 1997 Red River flood in Manitoba (Haque, 2000), Ice Storm 1998 (Lecomte *et al.,* 1998), January 1999 Toronto snow emergency (Mills *et al.*, 2003), and 2001-02 drought (Wheaton *et al.*, 2008). Such studies normally provide a chronological account of the specific physical hazard, often set within the bounds of local experience, and then proceed to document social and economic impacts and responses. The latter are assembled using a broad range of data sources of varying quality (e.g., media accounts; interviews or focus groups with stakeholders, segments of the public, and key officials; statistics collected/reported by insurance and government agencies). Wheaton *et al.* (2008) likely provide the most comprehensive and sophisticated assessment completed to date in Canada, employing a multitude of data sources and analytical methods, including input-output modeling to ascertain direct, indirect and induced effects on the economy.

Event-based analyses provide great detail for a unique situation but results may not be transferable to other locations, may not provide much information on changes through time, and are not easily aggregated. Although a few studies have estimated composite impact costs for particular hazards at the national scale (e.g., lightning, Mills *et al.*, 2010), there is no national Canadian economic study examining the sensitivity of sectors and regions to climate that is comparable to efforts in other countries (e.g., U.S., Lazo *et al.*, 2008). A modest effort by Herbert and Burton (1994) to define the costs of climate adaptation across multiple economic sectors and activities in Canada (Table 1) remains the most commonly cited effort to establish an aggregate national estimate.

Table 1: Estimates of the Cost of Adaptation to Current Climate in Canada and Possible Trends Under Climate Change				
Sector/Activity	**Total Cost ($ million)**	**% Attributable to Climate Adaptation**	**Cost of Climate Adaptation ($ million)**	**Possible Trend under Climate Change**
Transport:	7,367.5		1,657.3	decrease
Air	83.5	100	83.5	decrease
Marine	258.8	55	143.8	decrease
Rail	702.0	29	203.2	uncertain
Roads	6,323.1	19	1,226.5	decrease
Construction	2,000.0	100	2,000.0	uncertain
Agriculture	1,887.3	70	1,329.6	increase
Forestry	556.3	72	402.6	increase
Water:	1,058.0	73	767.3	increase
Flood Control	4.7	80	3.8	
Household Expenditure	6,023.0	88	5,296.4	decrease
Emergency Planning	14.4	75	10.8	increase
Weather Information	189.4	100	189.4	increase
TOTAL	19,095.9	61	11,653.0.4	
Source: Adapted from Herbert and Burton (1994)				

Source: Rothman *et al.,* 1998:18

Despite the significant attention afforded to the issue, Canadian studies focused on the economic impacts of future climate change, or costs of associated adaptation, are also limited in number (e.g., Buttle *et al.*, 2004; Environment Canada, 2006; Hauer *et al.*, 2003; Hrasko and McNeill, 2006; Maoh *et al.*, 2008; Mendelsohn and Reinsborough, 2007; Millerd, 2005; Reinsborough, 2003; Dore and Burton, 2001; Watt *et al.*, 2003; Yevdokimov, 2005). The scope of most of the individual studies is constrained to one sector (i.e., agriculture or transportation), region (i.e., New Brunswick, Great Lakes, Okanagan watershed), or issue (sea-level rise, water management). Methods range from relatively straightforward direct loss (e.g., Millerd, 2005) and adaptation cost (e.g., Watt *et al.,* 2003) estimations to more intricate statistical models relating climate factors to the value of land (e.g., Ricardian approach used by Mendelsohn and Reinsborough, 2007). In most cases the cost estimations are static comparisons between a baseline and some future period. Assumptions concerning the degree of climate change and adaptation vary significantly.

The lack of economic research presents a major gap—past workshops and national assessments of potential impacts and adaptation repeatedly draw attention to the dearth of economic analyses (Stratos Inc., 2004; Maxwell *et al.*, 1997; Rothman *et al.*, 1998; Lemmen and Warren, 2006). To the author's knowledge, nobody has attempted to even qualitatively assess the full costs of climate change in Canada—costs of mitigation plus costs of adaptation plus residual costs (benefits of mitigation and adaptation subtracted from the costs of inaction). It may be possible to infer or generate Canadian economic impacts from the results of international research (e.g., Mendelsohn *et al.*, 2000; Tol, 2002). However, a recent review and synthesis of climate change damage functions for a variety of sectors (e.g., agriculture, energy, tourism) and issues (e.g., extreme or catastrophic events, sea-level rise) suggests that significant effort is required to modify and apply them to the Canadian context (Marbek Resource Consultants, 2009). It is important that generalized findings and assumptions be examined from a Canadian perspective, informed by regional and sectoral research, and contested using alternative economic/value frameworks. As has been demonstrated by the Stern Review report (Stern, 2007) and interpretations of its methods and results (Pielke, 2007; Yohe *et al.*, 2007; Neumayer, 2007; Dietz *et al.*, 2007), assumptions concerning levels of adaptation, mitigation, climate sensitivity, discounting, treatment of non-market costs, substitutability of natural capital, equity weighting and incorporation of low probability risks with catastrophic implications can dramatically affect the social costs of climate change.

4. Moving Forward

Clearly there is a need to improve our understanding of the value of weather, climate, and climate change information and the costs and benefits of a range of impacts and adaptations in Canada. Exactly where to start, how to prioritize, and what is required to support a renewed research agenda were subjects discussed at the *SERA North meeting* (Mills, 2008). For the valuation of information theme of inquiry, the following activities were suggested:

1. An improved (consistent, systematic, long-term, accessible) collection and management system for weather- or climate-related impact/damage/response data. Such an open-access web-based database, perhaps modeled from the best qualities of similar resources (e.g., NOAA Storm database, SHELDUS[3], EM-DAT[4]) would make it easier for new researchers to become engaged. Common data would facilitate comparisons across methods;

3 **http://webra.cas.sc.edu/hvri/products/sheldus.aspx**
4 **http://www.cred.be/**

2. A national household valuation study to assess the public benefits of weather forecasts;
3. Micro- or bottom-up studies focused on community-level decisions that can be influenced by weather, climate, and climate change information; and
4. A national econometric study to evaluate the sensitivity of Canadian economic sectors and regions to weather and climate.

Priorities to advance our knowledge of the economic impacts of climate change and the costs and benefits of adaptation included:

1. A resource document explaining what has and what needs to be done in Canada in terms of costing climate change impacts and adaptation. Such a report would ideally be constructed from a working inventory or database that references the scope, methods, data, and key results for all studies across Canada;
2. A national "expert-based" sectoral analysis of the economic impacts of climate change and potential costs and benefits of adaptation;
3. Development of a series of sector-specific empirical studies. Infrastructure, water, and food security were identified as being especially important; and
4. Establishment of a common suite of national climate change and socio-economic scenarios that ideally include some interpretation of reliability and uncertainty. Such a resource will enable comparison of results across methods, regions and sectors.

Progress is being made to implement a number of these suggested priorities. For example, the *SERA North meeting* web site[5] is in the process of being revamped to become a resources site for valuation and costing research. Preliminary studies led by Environment Canada and its university partners are underway to develop the initial elements of a damage database, household valuation instrument, and a methodology to determine the benefits of incorporating better climate and new climate change information into infrastructure design. A review of climate change economic damage functions has been completed (Marbek Consultants, 2009) and other organizations, such as the National Round Table on the Environment and Economy[6], are scoping and initiating a series of bottom-up studies. Catalyzing these somewhat disparate elements of progress into meaningful results and decision support will require a sustained and collaborative multi-year effort that reaches across jurisdictions,

5 **http://www.fes.uwaterloo.ca/research/aird/sera/index.html**

6 **http://www.nrtee-trnee.com/eng/issues/programs/economics-climate-change/economics-climate-change-eng.php**

disciplines, and institutional boundaries—the challenge is great but the rewards promise to be even greater.

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