CLIMATE CHANGE AND NORTH AMERICAN WATERS – an OVERVIEW

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INFLUENCES ON CLIMATE:

The global climate system, and its changing decadal manifestations over North America, is driven by a number of forcing factors “external” to the system. Year to year variations are driven by internal factors. Among the dominant internal factors are the natural modes of climate variability, El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO), and the Arctic Oscillation (AO).

It has been shown that until the mid 1960s, natural external factors, especially changes in the amount of solar energy reaching earth and volcanic emissions, were important in driving changes in global and North American mean air temperatures and sea temperatures. However, by that time, (mid 1960s), greenhouse gas concentrations had increased, due to human activities, to the point where they effectively overwhelmed the natural factors. Since about 1970, the relatively rapid warming has been driven mainly by greenhouse gas concentrations and this is expected to continue and accelerate. (IPCC-WG1, 2007, G.A. Meehl, 2004) (See Fig. 1) Thus the overall trend in climatic factors observed since the mid 1960s should be good indicators of trends in coming decades, in most cases.

At the same time, shorter term variations in climate conditions have continued to occur, accompanying the natural internal modes of the climate system noted above. These shorter term fluctuations at times augment the greenhouse gas driven trends and sometimes reduce the effects of longer term change. These variations, and the fact that only the past 35 to 40 years contain the unequivocal anthropogenic climate signal, make statistical significance tests of trends difficult to obtain. A physical understanding and climate model projections to the future can provide physical reasoning to combine with the relatively short term trend analyses. Where observed trends, on the one hand, and projections by Global Climate Models (GCMs) and Regional Climate Models (RCMs) on the other, are in good agreement, confidence can be placed in estimated future effects for coming decades.

It has also been shown, recently, that the global patterns of precipitation bear the imprint of greenhouse gas forcing (Zhang, X., et al., 2007) with, in general, greater amounts north of 50ºN, lesser average amounts south of 30ºN and mixed results in between.

CLIMATE CHANGE TRENDS AND PROJECTIONS:

Annual mean temperature increases during the last century averaged 0.9ºC over Canada although the northeast cooled slightly, and 0.56ºC over U.S.A., but with accelerated warming in the Arctic and sub-Arctic. The increase in frost free period ranged from 4.1 to 5.4 days in western U.S.A. to only 0.3 days in the southeast and an average of 2 to 3 days in Canada. Most warming has occurred in spring and winter, resulting in some winter precipitation falling as rain and earlier melt of snow pack (IPCC-WG2, 2007). Both of these factors contribute to reduced snowpack water storage by April 1 especially in the western cordillera and foothills (Mote, et al., 2005). Changes in the Palmer Drought Severity Index (a function of temperature and precipitation) from 1972 to 2002 are distinctly negative (i.e. dryer) over most of Canada except extreme North and North East, slightly negative over much of U.S.A. but positive (wetter) in the Dakotas and northwestern Alaska (Dai, et al., 2004). Increases in heavy one-day precipitation amounts and frequency were observed over much of coterminous U.S.A. and parts of southern Canada (Groisman, 2005) (Fig. 2). Lake ice thaw-dates in Canada averaged 6 days earlier in spring by 2005 compared to 1950, but with little change in date from 1900 to mid-60s. Greatest changes were in central, western and northwestern regions, with least in Labrador and Newfoundland (EC 2007). Snow cover disappearance shows similar earlier date trends over most of western half of North America, the Great Lakes basin and mid-western U.S.A., as well as Alaska and the Canadian Arctic Islands.

These observed trends since the mid sixties are projected by models to continue. Warming in the time period 2010-2039 (2025) is projected to be in the range of 1 to 3ºC over various parts of North America. By 2040-2069 (mid-point 2055) winter warming in northern regions is expected to be 2 to 6ºC, twice the expected warming in summer. Projections for temperate areas for mid century are for an increase ranging from 1 to 5ºC in all seasons (IPCC 2007, WGII Ch.14). For time slices later in the century, projected changes become highly dependent on future emission scenarios assumed. While annual precipitation north of 50ºN is expected to continue increasing, precipitation changes over North America south of 50ºN are expected to vary both temporally and spatially. However, with higher winter and spring temperatures more precipitation in these seasons will be rain rather than snow. IPCC (2007) projects that continued increase in frequency and intensity of high intensity rains is “very likely” in many regions and this has been based in part on the work of Kharin and Zwiers, 2007.

HYDROLOGIC EFFECTS:

On average, total streamflow has increased in southeastern U.S.A. and decreased in the west (IPCC, 2007, WGII Ch. 14) In Canada, streamflow in southern regions has in general declined since the 1960s, except for the Red River rising in the Dakotas. In the north flow has increased (Zhang, et al., 2000). These findings are generally consistent in temperate and southern areas with Palmer Drought Severity Index trends (Dai, et al., 2004) and with increasing frequency of fair weather conditions in southern Canada and decreasing in the north (Wang, X., 2006).

In boundary and transboundary waters, some difficult bilateral management choices may be needed. For example, on the Laurentian Great

Lakes, Superior is currently at or near its lowest recorded level, and Michigan-Huron well below (56 cm) normal and most models project a long term lowering. The IJC Upper Great Lakes Study (IUGLS) is investigating the extent to which these lower lake levels are due to climate change or to natural variability of the system (Assel, R.A., et al., 2004), or other factors such as increased Lake Huron outflow due to dredging in the St. Clair River. Indications of a climate change signal include rising surface water temperatures, declining ice cover and hence increased evaporation, and greater lake effect snowfalls (Burnett, A.W., et al., 2003). Water temperatures are rising at a more rapid rate than air temperatures (Austin, J. and S. Coleman, 2007). This is likely due to the lakes absorbing more solar energy in winter with declining ice cover which itself leads to more evaporation in the cold season.

On the Great Plains, some bilateral agreements concerning the sharing of transboundary river waters are under stress. For example, on the combined Milk-St. Mary River system, declining contributions from Glacier National Park and increased evaporation from reservoirs and the basin have resulted in lower flows at border crossings (both ways). Between 1 April and 31 October irrigation season, U.S.A. can appropriate 500 c.f.s. or ¾ of the "natural" flow of the Milk River and Canada has similar rights on the St. Mary River. Declining flows of the past 3 decades have been hopelessly inadequate to meet the 500 c.f.s. target at some border locations. Montana has requested a new deal and studies are underway (Bruce, et al., 2003).

A common phenomenon in basins with significant snowmelt and glacier contributions has been an increase in winter and early spring flows, and earlier peak flows by 1 to 4 weeks but with reduced flows in the later dry season (Stewart, et al., 2005.) . This change in seasonality of flows is causing problems in basins fed from the western cordillera, especially where irrigation water is at a premium in summer (Barnett, T.P., et al., 2004 and 2005).

The frequency of intense tropical storms (hurricanes category 4 and 5) has been rising in recent decades although total numbers have not changed much (Emmanuel, 2005, Webster, 2005). There is a lively debate as to whether this is due to rising sea temperatures in a warming climate or to internal modes of the climate system such as the North Atlantic Oscillation. It is likely that both were at work over the past 30 years but more than half of the change appears to be due to large scale ocean warming (Munich Re 2005). Severe flooding, but at times helpful, recharge of aquifers often accompany these storms, especially in southeastern U.S.A. and the Gulf Coast but increasingly in Atlantic Canada.

HYDROLOGIC PROJECTIONS

These changes are expected to be exacerbated as the climate continues to warm. Projections of precipitation by GCMs while not nearly as reliable as those for temperature, suggest that drying of much of the west is likely to continue since any small increases in precipitation would be offset by greater increases in evaportranspiration. There has, however, been some controversy over the latter, since higher atmospheric CO2 concentrations tend to make plants in a river basin more water efficient. Some authors suggest that this may account for increased flow in some basins, but others strongly disagree (see IPCC, 2007, WGII, Ch.3 for this controversy).. To consider an example of a transboundary river, for the Columbia River, GCMs and hydrologic models project by 2050, declines in annual flows at The Dalles by 3% to 16% (Bruce, J.P. et al., 2003). Changes in seasonality are already being observed in this mainly snow and glacier fed river which rises in Canada and northwest U.S.A. Conflicts are arising in meeting needs of important fisheries, irrigation and hydro-power developments and will be exacerbated as the climate warms, with increasing winter melt (Cohen, et al., 2000).

HEAVY RAINS, GROUNDWATER

Climate models also project that increasing frequency and intensity of high intensity rainfalls are likely to continue over much of the continent (IPCC, WGI, 2007). This has implications for flood frequencies on small watersheds and urban drainage systems for which adaptation measures, such as enlarged storm water systems, are already being undertaken in some regions and cities. Water quality implications are considered in the next section.

While not much work has been published on climate change impacts on groundwater, this has been studied mainly through assessment of potential changes in base flow, in rivers interacting with groundwater (Moin, S., et al., 2000). This work suggests significant decrease in groundwater-fed base flow in the Grand River, the largest Canadian tributary to Lake Erie (Piggott, A., et al., 2001).

On the other hand, for an unconfined aquifer in north east U.S.A., groundwater effects from GCM projections to 2030 and 2100 were uncertain and highly model dependent. (IPCC, 2007, WGII, Ch.3)

WATER QUALITY AND AQUATIC ECOSYSTEM ISSUES:

Salt water intrusion in coastal aquifers in eastern North America, the Gulf Coast, California and British Columbia has been observed (IPCC, WGII, Ch. 14). This is expected to become more serious as sea level rises, perhaps more rapidly in future (IPCC, WGI, 2007), especially when storm-surge flooding occurs. Inland, a saline aquifer is projected to gradually replace fresh water in southern Manitoba, in the warming climate (Chen, et al., 2004).

The Soil and Water Conservation Society has examined the influence of more frequent and intense rainfalls, especially in Spring, on soil erosion from cropland, especially in the Great lakes basin, but with more general applicability. Increases in erosion losses in upland soils are expected to be 2 to 3 times the increases in heavy rain frequencies, resulting in increasing sediment loads, with attached phosphorus, nitrogen and contaminants carried into waterways. Renewed efforts at erosion prevention are warranted (Soil and Water Conservation Society, 2007).

It has been noted that some 68% of incidents of waterborne disease in U.S.A. (and probably Canada) occur after heavy rain events (Patz, J., 2001).

The International Joint Commission's Great lakes Water Quality Board examined the ways in which a warming climate will affect Great Lakes Water Quality. In their 2003 report, among other issues, they identified:

- Higher surface water temperatures stimulating nuisance algal growth
- Earlier seasonal stratification of the lakes, with dissolved oxygen in the hypolinmion being depleted for longer periods
- The above noted increased sediment and pollutant transport due to heavy rain events in both urban and agricultural parts of the basin.

In short, the IJC Board concluded that climate change will make it increasingly difficult to meet the shared objectives of the Great Lakes Water Quality Agreement (1972, 1978 and 1986).

Rises in river water temperatures in the Fraser River are expected to adversely affect salmon runs (Morrison, G., et al., 2002). Schindler has assessed adverse aquatic ecosystem effects with climate change, in lake and river systems more broadly in North America (Schindler, 1997).

SUMMARY AND ADAPTATION OPTIONS:

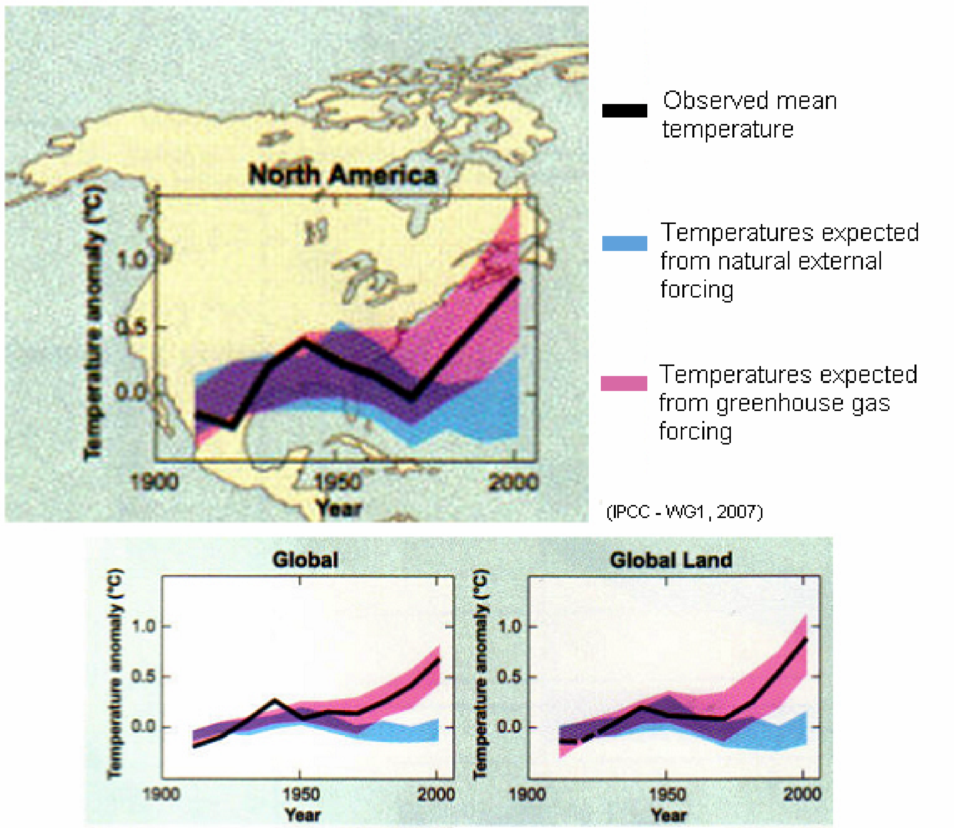
The changing climate is already affecting seasonality of river flows, evaporation and thermal structure of lakes, ecosystems sensitive to lake and river temperatures, salinity of groundwater and ability to fulfill obligations between U.S.A. and Canada under the Boundary Waters Treaty and Agreements pursuant to it. Projections with global and regional climate models indicate continuation and perhaps intensification of most observed trends in coming decades.

As an adaptation to the decline in winter snowpack water storage, especially in the mountainous west, some jurisdictions may want to consider construction of additional upstream storage to meet water needs in low flow seasons. Careful environmental assessments would be required, and, in particular, assessments should be required of improving water use efficiency and water conservation measures, as an alternative to additional storage.

Greater efforts in erosion loss prevention and dealing more effectively with pollution due to urban and agricultural runoff with heavier rain events will be needed in most regions and drainage design criteria need to be revisited.

To address projected declining water availability in much of southern Canada and south western U.S.A. some may be tempted to consider large scale diversions of water from one region to another. Past experience shows that such diversions result in ecosystem disruption in donor basins, often devastating invasive species in receiving waters and a limitation on development opportunities in donor regions. Water conservation measures, within a basin, are much more effective, and less costly. Nationally and internationally we should aim to keep water in its natural basins, that is, practise “basin water security”.

Global and Contintental Temperature Changes



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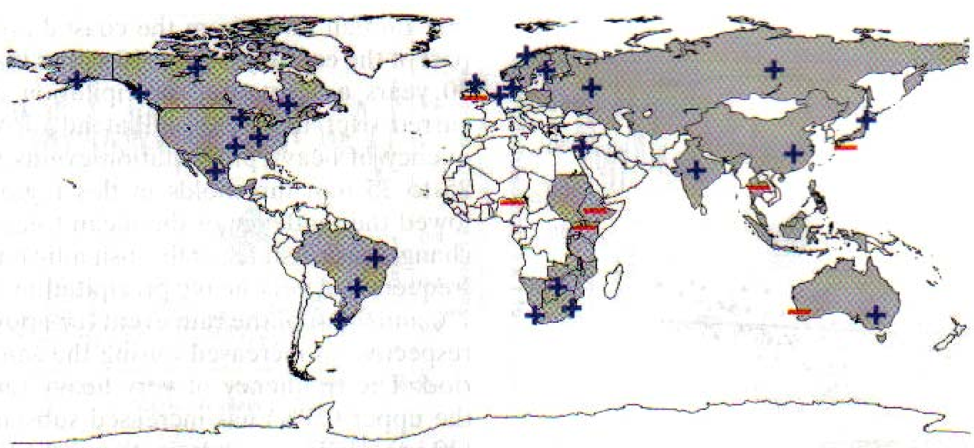

FIG. 11. Regions where disproportionate changes in heavy and very heavy precipitation during the past decades were documented compared to the change in the annual and/or seasonal precipitation (Easterling et al. 2000c, substantially updated). Thresholds used to define heavy and very heavy precipitation vary by season and region. However, changes in heavy precipitation frequencies are always higher than changes in precipitation totals and, in some regions, an increase in heavy and/or very heavy precipitation occurred while no change or even a decrease in precipitation totals was observed.

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