

Hydrological Research in Hudson Bay, Canada

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[Abstract] Hudson Bay streamflow represents a major component of the streamflow in Canada, approximately 30% of all river discharge enters Hudson and James Bays. Three current hydrological research issues are examined for this region. First the relationship between streamflow and local climate change is reviewed. Second the impact of river discharge in James Bay is linked to sea level variations in Churchill, Manitoba and the implications of this on Hudson Bay recirculation are explored. Finally, the historical and projected sea level variations in the Bay are examined with particular emphasis on the Churchill, Manitoba record. The report is concluded by a discussion of future directions for hydrological research in the Hudson Bay region.

[Key words] Streamflow; sea level; Hudson Bay; Canada

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Introduction

Hudson Bay is a dominant feature of the North American continent, its largest inland sea (Figure 1). The surface area of Hudson Bay exceeds 1 000 000 km². The drainage basin spans from the Rockies in the west, the United States to the south and Quebec to the east totaling over 4 million km², much larger than the Great Lakes basin immediately to the south. The bay (which includes James Bay as a southern appendage), is relatively shallow with an average depth of 120 m and a maximum depth of 200 m.

The coasts along Hudson Bay, James Bay, and Foxe Basin to the north of Hudson Bay, are sparsely

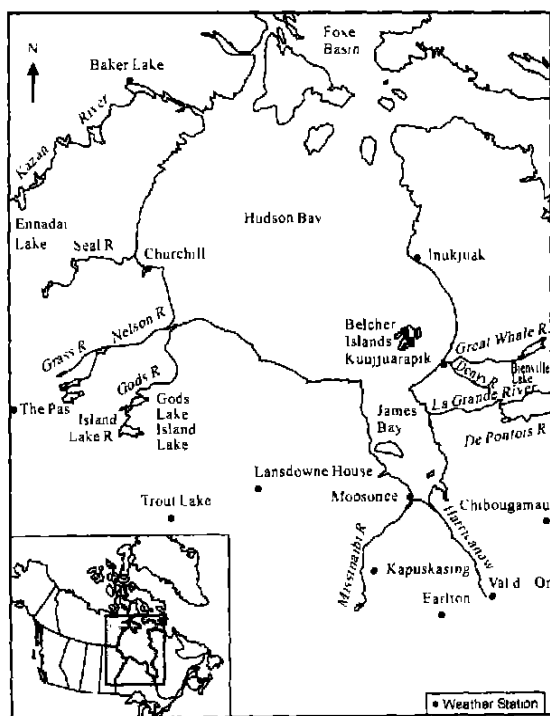


Fig. 1 Map of Hudson Bay, Canada
from Gagnon and Gough (2002)

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populated by some 7 500 Cree peoples in the south, and 10 500 Inuit peoples in the north, as well as 6 000 ~ 7 000 non-native people all comprised in thirty five small communities. The locations of present-day settlements correspond to historic fur trade posts, missions, summer gathering places of various nomadic groups, or more recent economic development/military activities (Berkes and Freeman, 1986, Laidler and Gough, 2003).

The Hudson Bay region experiences cold winters and cool summers. Much of the coastal region on the western and southern side of the Bay is underlain by permafrost a result, in part, of the cold climate and seasonal ice distribution (Gough and Leung, 2002, Ju and Gough, 2004). The Bay is typically ice covered from December to June. August and September are the only months it is completely free of ice (Wang et al., 1994b; Gagnon and Gough, 2004a, b). However there is strong interannual variability in sea ice extent (Gough et al., 2004a).

Circulation in Hudson Bay is both wind driven, density driven and forced by inflow from Hudson Strait. The main source of water flow into Hudson Bay is through Hudson Strait. Approximately 0.6 Sv ($1 \text{ Sv} = 1 \times 10^6 \text{ m}^3/\text{s}$) flows in at depth from the Labrador Sea and is relatively cold and salty. These waters enter Hudson Bay at intermediate depth. The deepest waters originate from Foxe Basin to the north where Arctic origin waters are conditioned by brine formation (Jones and Anderson, 1994). This input has been estimated at 0.06 Sv. The Bay has been traditionally viewed as characterized by surface cyclonic flow traveling south along the western side of the Bay and returning north along the eastern side (Prinsenberg, 1994; Ingram and Prinsenberg, 1998). This flow is dominated by strong coastal currents and a relatively quiescent interior flow. Exiting surface waters are relatively fresh due to the dominant river runoff which amounts to 0.03 Sv. Using the volume of Hudson Bay waters and the major contributor to the inflow (Hudson Strait inflow) a resi-

dence time of 5 years for Hudson Bay waters can be calculated.

Hudson Bay waters can be characterized by three distinct water masses (Jones and Anderson, 1994). The Hudson Bay Surface Water (HBSW) is conditioned by the seasonal cycle of surface temperatures, precipitation and streamflow. Thus the salinity of this water mass ranges from 15 to 30 ppt with a mean temperature of 5°C . This layer extends approximately to 30 m depth. Below this is the Labrador Sea Water (LSW) which enters at an intermediate depth from Hudson Strait. This water mass is characterized by salinity ranging from 31 to 32 ppt and a temperature of 2°C to 3°C . Beneath this is the Hudson Bay Deep Water (HBDW) with a salinity of 33 ppt and a temperature of -1.8°C to -1°C . This water mass originates in the Foxe Basin and is created during ice formation.

In this paper I will review three current issues in Hudson Bay research related to the hydrology of the Bay. The first is the examination of variations in streamflow in undammed rivers in Hudson Bay relating this to changes in climate in the region. The second is the linking of streamflow variations in James Bay with sea level variations at Churchill, Manitoba and linking this to our understanding of the circulation of the Bay. Finally sea level variations in the past and projections for the future are examined.

Streamflow Variation in Hudson Bay

This section is largely based on the work of Gagnon and Gough (2002). Long-term streamflow time series were analysed to examine evidence of climate change in the Hudson Bay region. Ten rivers representing all areas of Hudson Bay were selected. Undammed rivers were used to avoid the complication of streamflow regulation. In addition, relationships between streamflow and proximal temperature and precipitation time series were investigated. The Mann-Kendall test for trend reveals an earlier occurrence of the spring peak flow in three rivers located

in southern Hudson Bay with a corresponding statistically significant warming trend in spring temperature. In northwestern Hudson Bay, precipitation has significantly increased in all seasons, resulting in increasing trends in the discharge. In contrast, a decrease in river discharge was detected in central Manitoba, because of warmer temperatures and less abundant rainfall. On the east side of Hudson Bay, statistically significant streamflow trends were detected for individual months, but temporally and spatially coherent patterns could not be identified. This study of the Hudson Bay streamflow provides evidence of climate change using streamflow and climate data in the Hudson Bay region over the past century. The climate change signal is not spatially uniform and is obscured when the Bay is treated as a single large region.

These results indicate that Hudson Bay cannot be treated as one coherent region for climate change detection and impact assessment. The question of why there is both spatial and temporal heterogeneity in the climate change signal is an interesting and important issue to pursue. One possibility is the changing populations of synoptic meteorological conditions that characterize a given location. As this distribution shifts with a changing climate it may manifest in non-linear changes allowing certain months to warm preferentially and certain regions to have an exaggerated warming and others to have no warming and possibly a cooling. An analysis of synoptic meteorological conditions may prove fruitful, perhaps following the classification system of Kalkstein et al. (1998).

Streamflow and Sea Level

This section is largely based on Gough et al. (2004b) and explores the impact of streamflow into James Bay (which represents 42% of the streamflow into both Hudson and James Bays) and its impact on sea level at Churchill, Manitoba, the only continuously operating sea level recording station in Hudson Bay. The impact of James Bay spring runoff on sea

level variation at Churchill, Manitoba is assessed. James Bay discharge data for 1963 to 1983 is used with corresponding sea level data recorded at Churchill. A significant correlation between spring (May and June) discharge from James Bay and a secondary peak in sea level in October and November at Churchill was found. The coefficient of determination (R^2) increased substantially from 26% to 47% when an outlier year, 1963, was removed from the analysis. This is justified due to the limited data available for approximating discharge for that year. A lower limit of 5 cm/s advection speed is estimated for propagation of discharge from James Bay to Churchill consistent with previous estimates. Using the difference in sea level arising from high and low discharge years it was estimated that 35% to 50% of the discharge from James Bay does not exit directly out of Hudson Bay but recirculates in western Hudson Bay. This is contrary to a classic view of the Hudson Bay circulation which has James Bay streamflow largely exiting Hudson Bay as a coastal current along the eastern coast of Hudson Bay directly to Hudson Strait. However, Wang et al. (1994a) suggested that the flow was more structured than this traditional picture with closed gyres within the Bay. The strength of the cyclonic flow was estimated to be 0.55 Sv (1 Sv = $10^6 \text{ m}^3/\text{s}$). This modeled circulation appears to be substantiated by the sea level variation analysis.

This work illustrates the dearth of direct knowledge of the Hudson Bay circulation. A comprehensive field study with the systematic collection of hydrographic data (temperature and salinity) and current measurements is highly desirable. In addition expanding the number of sea level recording stations would further substantiate the conceptual framework presented. This work also suggests that there may be some long range predictive ability in seasonal sea level variations at Churchill, Manitoba. This is particularly important as Churchill hosts the only commercial port in Hudson Bay.

Sea Level: Past, Present and Future

Annual sea level variations are the results of three mechanisms, the change in volume of water due to glacier and ice sheet melt, the change in volume due to thermal expansion and contraction, and changes in the earth's crust. In the Hudson Bay region, variations in the crust take the form of isostatic rebound which has been estimated to be as much as 10 mm per year (Gough, 1998; Gough and Robinson, 2000).

As mentioned above, Churchill, Manitoba is the only continuous record for sea level in the Hudson Bay area. Thus this record provides the only means to directly assess sea level in Hudson Bay. Gough and Robinson (2000) examined sea-level variation in Hudson Bay using tide-gauge data from Churchill, Manitoba. Statistical analysis shows that 43% of the variation in this record is the result of variation in the local Churchill River discharge. Evidence is also found for the delayed effect of advective lag of discharge from James Bay on Churchill sea level, a point explored in detail in the previous section (Gough et al., 2004b). Increase in the seasonal amplitude of sea level after 1975 is the result of anthropogenically induced river diversion. Long-term changes, particularly an increase in the rate of sea-level drop from 1970 to 1985, is not likely the result of changes in local discharge but possibly the result of thermal contraction of the world ocean due to short-term cooling from 1960 to 1975, an idea first put forward by Gough et al. (1997).

In Gough (1998) projections of sea level change in Hudson Bay due to climate warming suggested that the historically dominant sea level decreases due to isostatic rebound may cease due to thermal expansion of the world ocean and land-based ice melt. The thermally expanded sea water would propagate from other parts of the world ocean through Hudson Strait into Hudson Bay, likely with a temporal lag of 5 or 10 years. Gough and Robinson (2000) found some historical evidence to support this theory.

Future Directions

The results of the streamflow research indicate that Hudson Bay cannot be treated as one coherent region for climate change detection and impact assessment. The question of why there is both spatial and temporal heterogeneity in the climate change signal is an interesting and important research issue to pursue. One hypothesis is the changing populations of synoptic meteorological conditions that characterize a given location. An analysis of synoptic meteorological conditions may prove fruitful.

The other two research areas of Hudson Bay hydrological research discussed in this paper illustrate the dearth of knowledge on the direct measurement of Hudson Bay circulation. Using the scarce data available a sketch of Hudson Bay circulation does emerge. This needs to be developed further by a major effort to collect hydrographic, current, and sea level data in the Bay. This needs to be done in concert with higher resolution modeling of the dynamics of the flow in Hudson Bay. Only with this baseline information can climate change effects be reasonably assessed as well as other anthropogenic influences such as the damming of rivers for the generation of hydro-electric energy.

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加拿大 Hudson 海湾地区的水文研究

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摘要 Hudson 海湾的河川径流量在整个加拿大河川径流量中占有很大的比例, 所有河流排泄量约 30% 流入了 Hudson 和 James 海湾。研究了该地区河川径流与当地气候变化之间的关系; 把河川向 James 海湾的排泄与曼尼托巴省 Churchill 地区海水位的变化联系起来, 讨论了其对 Hudson 海湾再循环的影响; 根据曼尼托巴省 Churchill 地区海水位的观测资料重点讨论了该地区海水位在历史时期的变化及未来的预测变化等三个重要水文问题。最后指出了今后在 Hudson 海湾地区进行水文研究的方向。

关键词 河川径流; 海水位; Hudson 海湾; 加拿大

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