THE GREAT LAKES / ST. LAWRENCE PROJECT: INVESTIGATION OF THE IMPACTS OF CLIMATE CHANGE ON THE GREAT LAKES HYDROCLIMATIC CONDITIONS

Scientific Note

Prepared by

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Preface

The purpose of this document is to provide an overview of the current state of climate change research activities on the Great Lakes/St. Lawrence basin, to present the analyses performed and planned at Ouranos, and to put our expertise in perspective with those with whom we could collaborate.

1 INTRODUCTION

Great Lakes water supply components and their changes have been investigated in many studies through a series of models known as Advanced Hydrologic Prediction System (AHPS) developed by NOAA's Great Lakes Environmental Research Laboratory (GLERL; Croley 1990; Croley et al. 1998; Lofgren et al. 2002, Angel and Kunkel 2010). The traditional "delta change method" is used in these studies, where the projected changes from different Global Climate Model (GCM) projections are applied to a reference climate (i.e., observations) to provide meteorological input for future climate, which are required by the AHPS. This technique, based on a cascade of (non-coupled) models, does not allow two-way exchange of energy, water and momentum across the land-atmosphere and the lake-atmosphere interfaces, and therefore does not capture important feedback processes occurring between these components. In addition, surface energy budget constraints in traditional hydrological models are not necessarily enforced. Several recent studies suggest that the hydrological models that typically use air temperature as a proxy for potential evapotranspiration across all time scales and climate regimes project an exaggerated evapotranspiration increase in future climate due to global warming (Lofgren et al. 2011, Milly and Dunne 2011). As a consequence, applying the delta change method to a traditional hydrological model in general leads to projections of a significant runoff reduction in the Great Lakes Basin, which implies an overall decline in future Great Lakes water levels.

2 EXPLORING OUTPUTS FROM CLIMATE MODELS

A promising alternate method to explore Great Lakes water supply components consists in direct use of global and regional climate model outputs, which ensures internal consistency between simulated variables, together with energy and water budget conservation. Even though GCM simulations are available at a relatively coarse resolution (a few hundreds of kilometers), limiting somewhat their use to the entire Great Lakes region, their advantage remains in the large number of simulations available, which can be very useful in defining the uncertainty (help in "boxing the uncertainty") of future projections. At Ouranos, we have performed an analysis based on the ensemble of GCMs from the CMIP3 (Meehl et al. 2007), looking into projected changes of the surface air temperature and precipitation over the entire Great Lakes Basin. It can be envisaged to explore also the projected changes in evaporation and runoff from the GCMs (for those who have provided the information); this would help in getting a more complete picture from all components of the hydrologic cycle. In order to differentiate each of the Great Lakes and investigate future conditions over these lakes and their associated watersheds, Regional Climate Model (RCM) simulations produced at a finer resolution (a few tens of kilometers) are required, where GCM climate is dynamically downscaled over the region of interest. Due to their higher computational cost, a limited number of RCM simulations are available. Currently, only a few studies based on dynamically downscaled Great Lakes hydroclimatic conditions have been reported in scientific literature (Lofgren and Hunter 2011; MacKay and Seglenieks 2010). Although projected changes based on RCMs with GCM-driven boundaries may lie in the range of those obtained using traditional delta change approach, they still have an added value for providing insights into the dynamics (inter-relations or feedbacks) of the Great Lakes Basin's hydroclimatic conditions, which are unavailable with statistical downscaling. Furthermore, an appropriate lake model is essential to produce a reliable simulation of the Great Lakes conditions. Hence, further investigations relying on state-of-the-art RCMs that include an interactively coupled lake model are needed to better understand the dynamics of the Great Lakes hydroclimatic system in different climate conditions.

One of the main objectives of this project is to improve our scientific understanding of hydroclimatic processes taking place in the Great Lakes Basin, to help in the evaluation of the impacts of climate change. For this purpose, time series (annual, monthly and eventually bi-weekly) of the so-called Net Basin Supply (NBS) of water to each of the Great Lakes under the present and future climate conditions will be constructed and analysed using outputs from different RCMs. The NBS describes the net available water to the basin, and is derived from overlake precipitation (P), overlake evaporation (E), and runoff (R) from the watershed associated with each lake (i.e., $NBS=P-E+R$). The RCMs simulate all components needed to construct NBS time series and usually provide all the data to users.

We have recently undertaken an analysis of NBS (Music et al. 2012) based on raw outputs from an ensemble of climate change simulations generated with the Canadian RCM Version 4 (CRCM4) developed at Ouranos. In this model version, the CRCM atmospheric module is interactively coupled with the Canadian Land Surface Scheme (CLASS 2.7; Verseghy et al. 1993) over the ground, while a simple one-dimensional (1-D) mixed-layer/thermodynamic-ice lake model (Goyette et al. 2000) provides surface boundary conditions over the Great Lakes. Interactive coupling between the land and lake surfaces with the atmosphere ensures that these surfaces receive precipitation and radiation inputs and return appropriate turbulent (momentum, sensible and latent heat) and radiative fluxes back to the atmosphere at each time step. Since Ouranos' Climate Simulation Team has produced an ensemble of CRCM4 simulations driven by several Global Climate Models (CGCM2, CGCM3, ECHAM5, CNRM), we were able to investigate the effects of lateral boundary conditions on simulated NBS for each of the Great Lakes. Furthermore, by comparing CRCM4 simulations driven by different members[1] of the same global model, an estimate of natural climate variability is obtained and illustrates the uncertainty in the NBS projections, which cannot be reduced.

In order to optimize credibility, projections of future Net Basin Supply of water to the Great Lakes should be based on a consensus between different RCMs. Construction of NBS time series using regional climate simulations generated within the framework of the North American Regional Climate Change Assessment Program (NARCCAP; Mearns et al. 2009) will allow us to evaluate how well different RCMs can reproduce actual NBS statistics based on observations. It should be noted here that uncertainty related to observed NBS is important and will be included in the analysis. The GLERL has developed two ways of obtaining historical NBS estimates (by components and by residuals), but uncertainty associated with these estimates remains large and needs to be quantified. Therefore, data from both approaches will be explored in our study. Since different RCMs are coupled to different land surface and lake models, an evaluation and comparison of surface fluxes will also be undertaken. Ice fraction over the lakes will be compared to the observed climatology as well, as evaporation from the lakes is greatly influenced by ice presence. It is expected that

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[1] GCM simulations differing only in initial conditions

the analysis based on NARCCAP regional climate model simulations combined with the Ouranos in-house simulations, will help point out the main weaknesses of current models and provide valuable insight for improving representation of key processes of the Great Lakes water balance dynamics.

For a better understanding of the potential impacts of climate change in the Great Lakes region, it is very important to improve our knowledge of Great Lakes hydroclimate variability across different time scales. The dynamics of the Great Lakes system on inter-annual and decadal timescales is presently very poorly understood. Historical NBS records are marked by strong inter-annual and decadal variability (i.e., years of high levels followed by years of low levels). This strong "natural variability" is likely to mask any forcing due to anthropogenic greenhouse gas emissions in the near term, i.e. 30 years (IUGLS, 2012). Continued efforts are needed to improve our understanding of this important issue. An appropriate analysis of precipitation, evaporation, runoff, and NBS variability for each of the Great Lakes will be undertaken using available simulations and data based on observations.

Regarding the climate change modelling capacity in the Great Lakes Region, it is important to recognize the need for more comprehensive climate models in which the atmosphere is fully coupled with a three-dimensional lake modelling system containing an explicit lake-ice module; this would allow the inclusion of important physical and dynamical processes taking place in the Great Lakes (that are not well simulated by the simple 1-D models) and affecting the surrounding atmosphere. To our knowledge, no RCM has yet been developed with such an advanced coupled system to provide future climate projections. In Canada, some coupling development efforts have been initiated at Environment Canada's RPN (Recherche en prévision numérique), and an organized effort is just starting under one of the recently established Networks of Centers of Excellence: "Marine Environmental Observation, Prediction And Response Network (MEOPAR)" based at Dalhousie University. Over the next five years, MEOPAR will bring together many Canadian researchers to address critical issues related to human activity in the marine environment. One of the challenging tasks, involving among others the researchers from the Centre ESCER at UQAM, Environment Canada and Ouranos, will be the interactive coupling of the Global Environment Multiscale (GEM) model used for weather forecasting at Environment Canada

(Côté et al. 1998) with the NEMO (Nucleus for European Modelling of Ocean) ocean model; the aim is to make it portable so that the coupled model can be applied not only to the oceans adjacent to Canada but also to the Great Lakes and St. Lawrence Estuary and Gulf.

3 FROM CLIMATE MODEL OUTPUT TO LEVELS AND FLOWS FOR THE ST. LAWRENCE

In order to simulate levels over the lakes and flows in the connecting channels, the NBS series produced by the climate models can be used as an input to a routing and regulation model. The Coordinated Great Lakes Routing and Regulation Model (CGLRRM) was developed in the 1998-2003 period under the auspices of the Coordinating Committee on Great Lakes Basic Hydrology and Hydraulic Data, and used in the recent International Joint Commission's (IJC) International Upper Great Lakes Study (IUGLS). It is based on a hydrologic response model for the middle Great Lakes (Clites & Lee 1998) and on lake regulation rules (for Lake Superior), and includes water diversions and water consumption information (International Great Lakes Diversions and Consumptive Uses Study Board 1981). This provides inflow to Lake Ontario. Then, to obtain levels and flows for Lake Ontario, the CGLRRM requires Ottawa River outflows, because regulation at Cornwall is strongly influenced by the Ottawa River (particularly during the spring freshet). Expertise in the use of CGLRRM is very specific and seems to be concentrated at Environment Canada's, Great Lakes/St. Lawrence Regulation Office in Cornwall, while the expertise with regards to the Ottawa River seems to reside at Hydro-Quebec and the Quebec Ministry of Environment (CEHQ). The Ottawa River is managed through the Ottawa River Regulating Committee to ensure integrated management of the principal reservoirs of the Ottawa River Basin, which are owned by federal and provincial institutions from Ontario and Quebec, and private interests.

Since climate models have biases in the hydroclimatic components they simulate, some type of post-processing ("bias correction") needs to be applied to their NBS outputs to ensure that the routing and regulation model will generate a realistic portrait of levels and flows. Bias correction work on monthly NBS from CRCM output was performed within the recent

IUGLS (2012) by Seglenieks and MacKay, but some aspects still need to be worked out to refine the technique.

In summary, generating levels and flows for the St. Lawrence is a very complex issue that needs a team of specialists from various institutions with knowledge, not only in climate change, hydrology and hydraulics but also with operational experience with the Great Lakes and the Ottawa River regulation rules. In the past, Great Lakes projects were successful because they spanned from specific initiatives of the IJC, providing budgets that allowed scientists and specialists from different institutions to be dedicated to the project and to work together. This momentum is lost when these projects are completed, and the specialists go back to their respective institutions to pursue their own work. It is interesting to note that in the most recent IJC study, a recommendation was made to maintain a continuous and coordinated bi-national effort in order to strengthen climate change modelling capacity in the Great Lakes basin (IUGLS 2012, p. ix Study Board Recommendations). Trying to move from the climate model components to levels and flows for the St. Lawrence represents a great challenge for an institution such as Ouranos. However, with its recognized expertise in climate modelling and its recent experience in providing CRCM data for IUGLS (to EC and GLERL researchers), Ouranos is well positioned to develop knowledge of the hydroclimatic processes taking place in the Great Lakes basin and to explore the impacts of climate change on the water supply components, including the NBS; the evaluation of changes in the net available water to the Great Lakes basin (NBS) remains quite relevant. Ouranos will contribute by keeping up to date on the IJC projects, staying in contact with some of the Great Lakes experts (particularly those at EC and at GLERL), and follow on the reports and results published on the subject.

REFERENCES

Angel, J.R., Kunkel, K.E., 2010. The response of Great Lakes water levels to future climate scenarios with an emphasis on Lake Michigan-Huron. J. Great Lakes Res. 36(2), 51–58.

Clites, A.H., Lee, D.H., 1998. MIDLAKES: A Coordinated Hydrologic Response Middle Great Lakes. NOAA Technical Memorandum ERL GLERL-109.

Croley, T., 1990. Laurentian Great Lakes double-CO2 climate change hydrological impacts. Clim. Chang. 17(1), 27–47.

Croley, T., Quinn, F., Kunkel, K., Changnon, S., 1998. Great Lakes hydrology under transposed climates. Clim. Change 38, 405–433.

Côté, J., Gravel, S., Méthot, A., Patoine, A., Roch, M. and coauthors. 1998. The Operational CMC-MRB Global Environmental Multiscale (GEM) Model. Part I: design considerations and formulation. Mon. Weather Rev. 126, 1373_1395.

Goyette, S., McFarlane, G.M., 2000. Application of the Canadian Regional Climate to the Laurentian Great Lakes Region: Implementation of a Lake Model. – Atmos.-Ocean. 38, 481–503.

International Great Lakes Diversions and Consumptive Uses Study Board, 1981. Great Lakes diversions and consumptive uses. International Joint Commission, Washington, D.C.

IUGLS (International Upper Great Lakes Study, 2012. Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels. Final Report to the International Joint Commission.

Lofgren, B., and Hunter, T., 2011. NOAA Great Lakes Environmental Research Laboratory’s Contributions to the Activity “Comparative Analyses of Net Basin Supply Components and Climate Change Impacts on the Upper Great Lakes”. Prepared for the International Upper Great Lakes Study.

Lofgren, B.M., Hunter, T.S., Wilbarger, J., 2011. Effects of using air temperature as a proxy for potential evapotranspiration in climate change scenarios of Great Lakes basin hydrology. J. Great Lakes Res. 37(4), 744-752.

Lofgren, B.M., Quinn, F.H., Clites, A.H., Assel, R.A., Eberhardt, A.J., Luukkonen, C.L., 2002. Evaluation of potential impacts on Great Lakes water resources based on climate scenarios of two GCMs. J. Great Lakes Res. 28, 537–554.

MacKay, M. and Seglenieks, F. 2010. Simulating Net Basin Supply and Lake Levels for the Upper Great Lakes Part II: Climate Change Analysis. Report for the Hydroclimatic Technical Work Group. December 7, 2010. Available at http://www.iugls.org/sup-Hydroclimate.aspx. This report is included as section 2.3 in Climate Change Analysis Peer Review Submission. Hydroclimate Work Group. June 10, 2011.

Mearns, L. O., W. J. Gutowski, R. Jones, L.-Y. Leung, S. McGinnis, A. M. B. Nunes, and Y. Qian, 2009. A regional climate change assessment program for North America. EOS 90(36), 311-312.

Meehl, G. A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J. F. B. Mitchell, R.J. Stouffer and K. E. Taylor, 2007. The WCRP CMIP3 multimodel dataset: A new era in climate change research. Bulletin of the American Meteorological Society, 88(9), 1383-1394.

Milly, P.C.D., Dunne, K.A., 2011. On the hydrologic adjustment of climate-model projections: the potential pitfall of potential evapotranspiration. Earth Interactions 15. doi:10.1175/2010EI363.1.

Music B., Frigon A., Slivitzky M., 2012. Great Lakes/St-Lawrence hydrological conditions as projected by an ensemble of RCM simulations. IAGLR's 55th Annual Conference on Great Lakes Research, Cornwall, ON, CA, May 13-17, 2012;

Verseghy, D. L., N. A. McFarlane, N. A., Lazare M., 1993. CLASS—A Canadian land surface scheme for GCMs. Part II: Vegetation model and coupled runs. Int. J. Climatol. 13, 347–370.