Energy Budget-Based Simulation of Evapotranspiration from Land in the Great Lakes Basin

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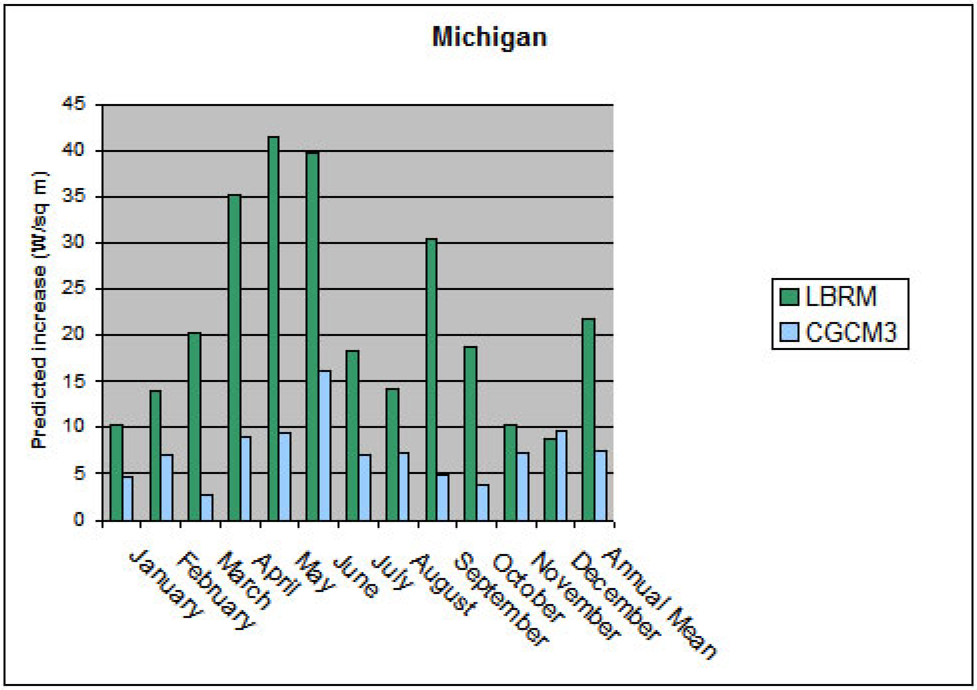
Overview

Estimates of future changes in evapotranspiration (ET) from land surrounding the Great Lakes, based on GLERL's Large Basin Runoff Model (LBRM) may show an excessive increase in ET. This is based on a comparison between the change in ET and the relatively newly-available data for change in net radiative energy for land surfaces in the same region in the same general circulation models. Direct comparisons shows that the increase in latent heat of evaporation from the land throughout the Great Lakes Basin exceeds the amount of additional ET as well as additional net radiative energy available in this region according to the corresponding GCM. Thus there is a mismatch: While air temperature and ET are intimately linked within the GCM, the LBRM believes the GCM's projected changes in air temperature while ignoring its projected changes in ET. The reason for the disagreement appears to be that LBRM uses a definition of potential ET that is constrained to have an annual total that equals the incident solar radiation in the calibration time period, while this constraint is relaxed for the future time periods, allowing the potential ET to increase by very large amounts. Thus the empirical relationship are likely not valid in a future regime with enhanced greenhouse gas concentrations, higher overall temperatures, and higher absolute humidity.

This project has already shown this, and will proceed to attempt to use the general framework of the LBRM to create a model that is more consistent with an overall energy budget.



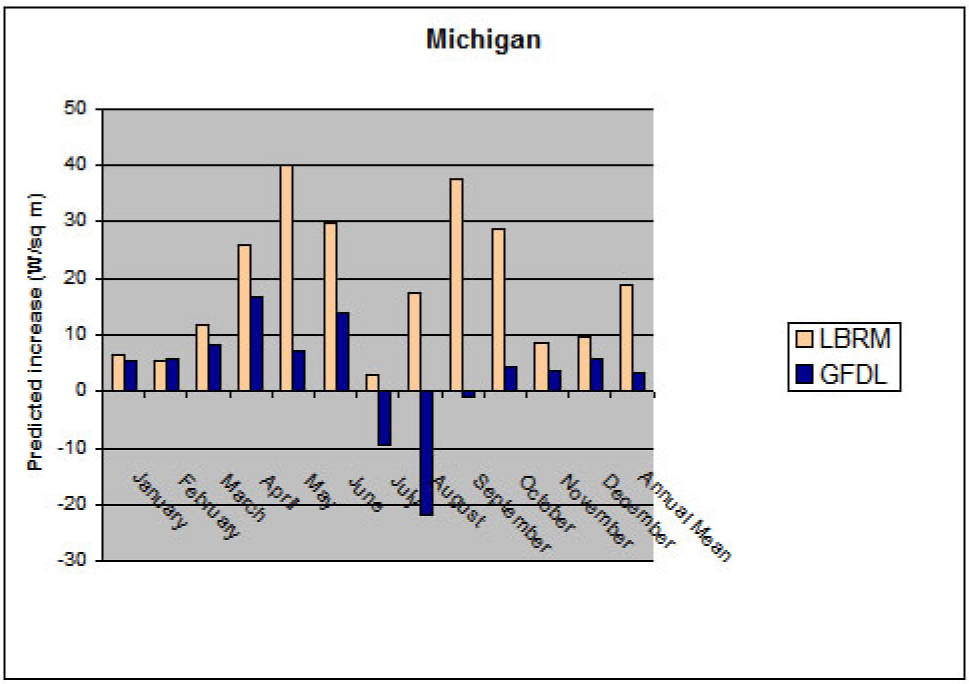


Figure 1: *Change in latent heat of evapotranspiration averaged over the Lake Michigan basin between the 2070s and the 1990s as predicted by (top) the LBRM driven by the Canadian Centre for Climate Modeling and Analysis Coupled General Circulation Model version 3 (CGCM3) and directly by CGCM3, and (bottom) the LBRM driven by the Geophysical Fluid Dynamics Laboratory Climate Model version 2.0 (indicated by "GFDL") and directly by the GFDL model.*

Proposed Work

To follow up on last year's work, we would like to consider ways to create a scheme for calculating ET using a paradigm that more closely reflects that ordinarily used in climate models: that evapotranspiration is constrained by the available energy. Here are two ways to try:

1. Calculate the ratio of net radiative energy available in GCM's future time period to that of the recent past, and multiply the potential ET in the current version of LBRM by this ratio, rather than determining it based on the change in air temperature.
2. Simply increase ET in LBRM by the amount predicted by the GCM. This scheme would fit within the general framework of the Large Basin Runoff Model (LBRM) and parameters could be calibrated as before, but PET would be determined by the net radiative energy rather than air temperature.

Scientific Rationale

Many previous estimates of evapotranspiration (ET) in the land portions of the Great Lakes basin have used the paradigm that potential evapotranspiration (PET) is a linear function of air temperature, and that ET is the product of PET, the amount of water stored in a soil moisture storage zone, and an empirical parameter calibrated for each sub-basin. This usage was necessitated by the availability of temperature as an output from climate models, but not a full suite of surface energy terms. However, the Canadian Centre for Climate Modeling and Analysis (CCCma) has currently made available the downward shortwave radiation, upward shortwave radiation, downward longwave radiation, upward longwave radiation, sensible heat flux, and latent heat flux as simulated by their Coupled General Circulation Model version 3 (CGCM3), on a daily basis.

The basic equation for conservation of conservation of heat energy at the land surface in any weather or climate model that couples the land and atmosphere (this includes all modern GCMs and RCMs) is:

$$S = (1-\alpha)\,SW + LW\downarrow - LW\uparrow - SH - LE \qquad (1)$$

Where S is the heat storage in the soil, α is the surface albedo, SW is the downward incident shortwave radiation (sunlight), $LW\downarrow$ is the downward longwave radiation emitted by the atmosphere that is incident on the surface, $LW\uparrow$ is the upward longwave radiation emitted by the surface according to the Stefan-Boltzmann law, SH is the sensible heat flux from the surface, L is the latent heat of evaporation per unit mass, and E is the evapotranspiration rate. For land surfaces, S is taken as being very close to zero when averaged over time periods of a day or longer.

A rough estimate of the overall change in evaporation shown in Fig. 16 of Croley (2003), produced as part of the IJC Lake Ontario-St. Lawrence River Study, indicates an increase of evapotranspiration of at least 120 mm/year, which is equivalent to an average change in latent heat flux of 9.6 watts per square meter. The various scenarios shown there have different exact values, but among those scenarios are two that used the CCCma's previous model, CGCM2. As an incompletely matched comparison, the mean change in net radiation (downward components of both shortwave and longwave radiation minus the upward components of each) in the CGCM3 between the decade of the 1990s and the 2060s is only 4.5 watts per square meter. First, according to (1), this would necessitate a highly unexpected change in sensible heat flux of opposite sign to the change in latent heat flux in order to maintain a neutral surface energy budget. Second, such a change in sensible heat flux would produce a drop in air temperature, creating a paradoxical situation, since an increase in air temperature was already assumed. It is likely that moving to a different climate regime due to warming and moistening of the atmosphere makes the previously derived relationship between air temperature and ET invalid.

Governmental/Societal Relevance

Results based on the Large Basin Runoff Model have led to a conventional wisdom that global warming will lead to a drop in Great Lakes levels. However, preliminary calculations that compare the changes in evapotranspiration projected by LBRM with energy budgets of the GCMs that were used to drive it show significant discrepancies. Hence, LBRM is likely to be overestimating the evapotranspiration in future scenarios. Making efforts to straighten out such a discrepancy will result in enhanced value to the many government and private groups that have an interest in the results of projections of the Great Lakes basin water budget over the next century.

Relevance to Ecosystem Forecasting

This project will lead toward an improved version of the LBRM and should aid in convergence with other methods of forecasting runoff, such as a regional climate/hydrologic model like CHARM. For all ecosystem issues that are influenced by tributary flow and lake levels, this project should help enhance a sense of accuracy in long-term projections.