Presentations by Michigan Tech (MTU and MTRI) Researchers

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Observed Dynamics of Surface pCO₂ in Lake Superior.
Carbon fluxes from large water bodies may be important to understanding regional and continental carbon budgets. The Laurentian Great Lakes, with a surface area that comprises 3% of the continental United States may play an important role in the continental carbon budget, particularly in the upper Mid West, a region of focus by the North American Carbon Program (NACP). We examine mechanisms of carbon fluxes from Lake Superior at small and large spatial and temporal scales using available data. In the western arm, we consider the relationship between temperature, biological activity and pCO₂ at daily to monthly time scales during the summer of 2001. We find that springtime pCO₂ is determined predominantly by temperature, but after the Lake warms and stratifies, biological activity can draw down CO₂ and rapidly decrease near-surface pCO₂. The magnitude of the lake-wide flux is considered using a reanalysis of biannual lake-wide surveys from the USEPA and is coupled with an assessment of our current understanding of terrestrial carbon inputs. We link our analysis to a coupled physicalbiogeochemical model of the Lake to improve our understanding of the lake carbon budget, its spatial and temporal variability, and to quantitatively improve the carbon budget.

Keywords: Carbon cycle, Lake Superior.
Coupling the Great Lakes *Cladophora* Model (GLCM) with a Whole Lake Eutrophication Model (AEM3D).

The recent reoccurrence of *Cladophora* and other nearshore nuisance algal blooms throughout much of the Great Lakes has generated renewed interest in modeling the phenomenon. A revised version of the GLCM has been used to quantify the relationship between the supply of available phosphorus and *Cladophora* production as well as how that relationship changes as a function of light availability. This model can be used to inform phosphorus control decisions only if it can be coupled to a model that provides the supply of available phosphorus and light to a given shoreline area as a function of lakewide nutrient loadings and the processing of those nutrients in the rest of the lake. We have accomplished this nearshore – offshore coupling by incorporating the GLCM into our linked 3D hydrodynamic – nutrient - lower food web – dreissenid model (AEM3D). This presentation will describe how this coupling has been accomplished and will provide several examples of how the full model framework can provide a quantitative relationship between phosphorus loading and *Cladophora* production.

*Keywords: Cladophora, Eutrophication, Nutrients.*


Two algorithms used to produce depth maps from multi-spectral remote sensing satellite imagery were adapted and evaluated for use in the clear, shallow lakes found on the North Slope of Alaska, also applicable to lakes in the Great Lakes basin. The low turbidity and shallow depth of these lakes are ideal properties for these algorithms. The algorithms were adapted from the so-called “linear” approach developed by Lyzenga (1978) and the “ratio” approach developed by Stumpf, Holderied, and Sinclair (2003). The linear approach derives water depth from a linear combination of the log-transformed radiance at different bands, while the ratio approach derives water depth by scaling and offsetting the ratio of the natural log of two bands. In-situ bathymetry data was collected with BathyBoat, a remote controlled robot buoy that collects depth data along with GPS location data. The in-situ data was used to determine the algorithm coefficients for a given lake. The variability of the coefficients between lakes was compared in order to estimate the ability to use the algorithm in lakes without collecting in-situ data. Correlations between insitu and satellite depth were high when in-situ data was used to calculate the algorithm coefficients for that specific lake, and accuracy decreased when coefficients from another lake were used.

*Keywords: Remote sensing, Risk assessment, Assessments.*
Remote Sensing-Based Object-Oriented Approach to Determine Frozen Lake Condition.

The North Slope of Alaska encompasses 89,000 square miles. Lakes are a dominate feature on the North Slope, but due to the vast geographic area and remote location, ground surveys are not feasible and little data currently exists on these lakes. Building upon previous research, we have developed a remote sensing-based approach to distinguish between lakes on the North Slope that are completely frozen to the lakebed with lakes that have some liquid water. An object-orientated approach has been used to map freeze condition that utilizes the specific advantages of electro-optical and radar data to extract lake boundaries and areas of frozen water in a more accurate and efficient manner. Identification of freeze condition is useful for determining the feasibility of winter water withdrawal for oil and gas development activities and for assessing which lakes are capable of supporting diverse biota. Data outputs have also been used to enhance remote sensing based bathymetry algorithms. Our work on the North Slope could also be applicable to other shallow lakes in the Great Lakes basin and any other applicable cold regions of the world.

Keywords: Remote sensing, Ice, Satellite technology.

Update on Modeling and Analyzing the Use, Efficiency, Value, and Governance of Water in the Great Lakes Region through an Integrated Approach.

The objective of this project is to determine, through integrated physical and economic models and under various scenarios of population growth, climate change, land use, and emissions, the impact of direct and indirect drivers on water quality, quantity, and availability in the Great Lakes region. The project will emphasize quantifying the stocks and flows of fresh water, analyzing the underlying factors affecting water use and allocation decisions, and developing cost frameworks for capturing the value of having a specific amount of water available at a given purity, time, and location. This project will result in several advances in the analysis of water management issues, including (1) development of new, physically-based modeling approaches to simulate quantity and quality in the Great Lakes region; (2) creation and testing new, empirical models of the energy embodied in water delivery and treatment for the Great Lakes context; and (3) selection of relevant future climate, population, land use, and emissions scenarios to use as input to water quantity and quality predictions and in analyses of uncertainty in those predictions. We will report on recent progress, including the development of watershed models, water quality models, water treatment cost and energy models, and water demand models.

Keywords: Watersheds, Regional analysis, Hydrologic cycle.
Kinetic Modeling of the Nitrogen Cycle in Lake Superior.
Increasing nitrate concentrations in Lake Superior are well-documented (Bennett 1986, Sterner et al. 2007) Recent studies suggest that atmospheric deposition alone cannot account for the observed increases in nitrate concentrations, and that biological transformation of reduced forms of nitrogen may be responsible (Finlay et al. 2007). Quantifying the rate at which this biological cycle operates is requisite to understanding the N cycle in the lake as well as other biologically-mediated processes (e.g., C cycling, residence time of toxic substances). While direct measurements of N uptake rates have been made (Kumar et al. 2008), the rates at which mineralization and excretion occur remain unknown. We have compiled a historical record of N inputs, and developed a mechanistic model to estimate the rates of biological processes associated with N cycling in the lake. The model was used to explore the response of the lake to reductions in N loading. Results indicate that despite the long hydraulic residence time, this large lake can respond to changes in loadings on the timescale of a decade because of the magnitude of the internal biological pump. The model also helps to constrain the magnitude of primary production in the lake to be at the upper end of the range reported in the literature.

Keywords: Nutrients, Lake Superior, Biogeochemistry.

The Magnitude and Mechanisms of the CO2 Flux from Lake Superior.
The Laurentian Great Lakes cover 25% of the land area of the 8 Great Lakes states, and seasonal CO2 emissions from them may be comparable to local terrestrial ecosystems. Lake Superior is of particular interest because its fluxes directly influence nearby observations of the terrestrial carbon cycle. The ongoing CyCLeS (Cycling of Carbon in Lake Superior) project is working to quantify carbon fluxes from the Lake and to place them in the context of regional carbon budgeting efforts by the North American Carbon Program (NACP). As part of CyCLeS, we have configured a three-dimensional hydrodynamic model (MITgcm, Marshall et al. 1997) with an ecosystem-carbon module for the Lake. The model allows us to study the seasonal cycle of pCO2 and the air-lake
fluxes of CO2 and to assess sensitivity to variable physical and biogeochemical forcings. We find that, without external inputs, the model is able to capture observations of pCO2, net primary productivity (NPP), and other biogeochemical quantities within reasonable error estimates. This suggests that, for the long-term, lake-wide average, the Lake is not respiring significant amounts of terrestrial carbon, in contrast to findings by previous authors (Cole et al., 1994, Alin and Johnson, 2007).

Keywords: Carbon cycle, Atmosphere-lake interaction, Hydrodynamic model.

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Eddy Covariance Measurements of CO2 Fluxes above Lake Superior.
Lake Superior has been reported to be seasonally supersaturated with respect to atmospheric CO2, and fluxes estimated from measured pCO2 are regionally significant. An empirical gas exchange model predicted that the CO2 flux out of the lake is 0.1-0.4 g C m2d-1 for an annual flux of ~140 g C m2d-1. Nearby terrestrial fluxes are -8 to +4 g C m2d-1, with an annual range of -120 to -300 g C m2d-1. Eddy covariance measurements conducted in summer 2007 and 2008 at eight stations yielded 25 10-minute mean CO2 fluxes in the range of -166 to +56 g Cm2d-1. The median flux among these values was +3.4 g C m2d-1. Fluxes at near shore stations were larger and more variable than those further from shore. Statistical analysis of data resulted in a mean ±95% confidence interval of 2.1 + 5.6 g C m2d-1. Quality control of data, comparison with independent empirical estimates, and fluxes from other sites will be presented. These preliminary results suggest that short-term fluxes are much larger and more variable than previously estimated. The variability in space and time may make estimation of the lake-wide flux difficult.

Keywords: Lake Superior, Atmosphere-lake interaction, Carbon cycle.

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A two-dimensional Lagrangian internal boundary layer transport exchange (IBLTE) model was developed to predict the modification of temperature, humidity, and trace gas concentration and flux as a function of fetch in offshore flow. The model was designed to complement over-water flux measurements. The model incorporates the NOAA COARE gas transfer model to calculate turbulence scaling parameters and gas
transfer velocity. The model was applied to HCB flux measurements performed along a transect in Lake Superior in July, 2006. Measurements were taken at 16, 28, and 59 km fetch under off-shore flow conditions. Modification of concentration, air temperature, and flux with fetch resulted from fetch-dependent equilibration, growth of the IBL, and variation of lake surface temperature during the transect experiment. Good agreement was obtained between modeled and measured fetch-dependent concentration modification. Modeled HCB fluxes were greater than measured fluxes at the 16- and 28-km stations but nearly equal at the 59-km station. Error analysis indicated that the measured flux at the 59-km station was significantly different from zero and had a smaller uncertainty than flux calculated by the two-film model.

**Keywords:** Air-water interfaces, Atmosphere-lake interaction, Toxic substances.

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**Synergistic Approach to Measuring Lake Properties using Satellite and In-Situ Remote Sensing.**
Radar and electro-optical remote sensing data have been combined with in situ measurements of lakes on the North Slope of Alaska to obtain a baseline characterization of these lakes, determine change detection, document salt water intrusion, and investigate yellow billed loon habitat preference. This multi-faceted program, which also has applicability to the Great Lakes basin, has been aimed at using cost-effective technologies to investigate the remote lakes. In-situ data collected includes measurements using our autonomous water quality and bathymetry mapping robot instruments. ALWAS and BathyBoat robotic data have been used to provide baseline data as well as control and algorithm validation points for satellite remote sensing applications. Specifically, water depths from ALWAS and BathyBoat have been used in electro-optical and radar based water depth algorithms to produce bathymetry and volume of lakes on the North Slope. Additionally, in-situ data from the ALWAS buoys have been used to tune and validate satellite methods to then extend estimates of turbidity, chlorophyll, and salinity (expressed in alterations of aquatic vegetation and shoreline communities) to lakes that have not been directly sampled. These observations can then be linked to trophic index, saltwater intrusion, vegetation, and habitat.

**Keywords:** Remote sensing, GIS, Water quality.

The MTRI/NIERSC algorithm retrieves concentrations of chlorophyll (CHL), dissolved organic carbon (DOC), and suspended minerals (SM). The algorithm was validated (Pozdnyakov2005), applied in a seven-year inter-annual analysis of SeaWiFS data in Lake Michigan (Shuchman 2006), and recently also applied to all available SeaWiFS/MODIS Lake Michigan data. The algorithm uses a hydro-optical (HO) model that consists of the absorption and backscattering coefficients for CHL, DOC, and SM at each satellite band. During the initial validation of the algorithm, a proxy HO-model from Lake Ontario was used due to a lack of insitu data in the other Great Lakes needed to create an HO-model for those lakes. Since 2004, GLERL and MTRI have been collecting optical data using a Satlantic multi-spectral profiler, with coincident laboratory measured CHL, DOC, and SM data. Using this data, new HO-models will be created for each Laurentian Great Lake. The new results will be compared with historical in-situ and seasonal phenomena for validation. Also, the differences between the old and new Ontario HO-models will be compared and analyzed. Inter-annual analyses will be performed for each lake after validation.

Keywords: Biogeochemistry, Sediment resuspension, Carbon cycle.

Field Measurements of CO2 in and above the Great Lakes: the Case for Net Emission of CO2.

Mass balance studies, stable isotope measurements, and rates of respiration and photosynthesis indicate that Lake Superior is a net source of CO2 to the atmosphere. Recent modeling of carbon cycling suggests that the lake is a net sink for atmospheric CO2 in summer and only a weak source for the remainder of the year. In this talk, we review evidence for net emissions and try to reconcile the disagreement with the modeling study. All Laurentian Great Lakes are supersaturated with respect to atmospheric CO2, but supersaturation is least for Lake Superior. Previous mass balance studies have overestimated the degree of supersaturation and gas-exchange fluxes. Recent measurements show elevated CO2 above the lake relative to over land. Spatial and temporal variability in the difference between air and water pCO2 are not
well known, although this difference is essential for all estimates of air-water exchange. Short-term CO2 fluxes estimated from simultaneous measurements of pCO2 in and above the lake and eddy covariance measurements are 10-fold higher than current model predictions. CO2 emissions are also compared with rates of photosynthesis and microbial growth to assess the controls on emission rates. While not all differences can yet be explained, this comparison shows the need for both modeling and other approaches.

**Keywords:** Carbon cycle, Air-water interfaces, Biogeochemistry.