**PROJECT TITLE: Temperature and Ice Phenology Information for Lake Management**

**I. PROJECT STATEMENT**

This project will enhance fisheries and water quality management by implementing and validating automated approaches using Google’s Earth Engine (GEE) cloud-based infrastructure to provide lake temperature and ice phenology assessments from satellite observations. Ice phenology, including ice cover onset, snow cover and ice disappearance, are important since it sets up the thermal structure of lakes and is needed for reliable modeling of lake temperature, which in turn is needed for fish habitat, algal growth, and harmful algal bloom (HAB) occurrence modeling. Lake surface temperature is important since it can be used as a measure of lake temperature on a regional basis and to calibrate and validate lake temperature models.

This project is a compelling opportunity as it leverages the archive of publicly available optical and radar data from current operational Earth observation satellites and the no-cost high performance computing and storage resources of GEE. **Radar data has the advantage of not being affected by cloud cover**, which can be persistent especially during the winter. The Sentinel 1 C-band Synthetic Aperture Radar (SAR) collects data at 3 to 6-day intervals. Meanwhile, Landsat-8 and Sentinel-2 provide multispectral data every 3 to 5 days and should allow for ice phenology validation when combined with concurrent SAR measurements. Further, the Landsat satellites have the unique feature of measuring thermal radiance of the surface and will allow for mapping lake surface temperatures. With the launch of Landsat 9 scheduled for December 2020, the combined use of these sensors can produce data every 8 days.

**Ice phenology and surface temperature of inland lakes are new applications that will require significant research and development.** For this project, we will conduct exploratory research to understand the potential for a multi-sensor (optical and radar) approach to map ice phenology (including snow, ice cover onset and disappearance, and water retrievals), potentially ice thickness and lake surface temperature. We will use GEE to conduct preliminary evaluation by querying all available Landsat and Sentinel 2 optical imagery and Sentinel-1 SAR data over several sub-regions throughout Minnesota. These sub-regions will span from southern to northern portions of the state and include lakes with varying levels of phytoplankton and color as well as variations in size and depth. From a multi-sensor approach, spectral and optical observations from Landsat-8 and Sentinel-2 multi-spectral data will be used in combination with the SAR imagery to discern snow and ice characteristics. The ability to manipulate all these datasets in a single GEE environment will be explored to extrapolate developed models to a regional scale and ultimately to over 10,000 Minnesota lakes.

During the winter 2018 we conducted two field campaign to measure optical properties and collect lake ice and snow measurements. For the second trip, we collaborated with under ice Limnologists from NRRI and LLO at the University of Minnesota Duluth who collected limnological parameters from six lakes with varying levels of phytoplankton and color. For these trips, we used GEE to process all available SAR imagery throughout Minnesota to target areas where the backscatter signal was different than other lakes in the area, so we could get data from a range of lake ice conditions. Those trips made it clear that there is some important information that can be identified with this data such as differences in ice thickness, areas with thin ice and water due to springs, clusters of fish houses and ice road to name a few. Since the SAR data is collected at an angle there are some systemic differences across the imagery that need to be corrected. These corrections to normalize the imagery will be a part of our preprocessing steps that will allow for consistent ice thickness measurements over large regions. The optical and radar data time series allows us to visualize ice onset, thickening, melting and disappearance. For this project, we are planning to collect field data each year of the project during February and early March for lakes within the sub-regions discussed above. Snow/ice surface sampling will consist of in situ frozen lake surface reflectance using field spectrometers and ice thickness using an auger and measuring stick. Snow pits and ice cores will be collected at a subset of locations to determine snow and ice structure. The field data will be supplemented with ice thickness and snow data collected by state and local agencies and will be used to calibrate and validate different approaches to identify open water, ice, ice thickness and snow using clear Landsat 8, 9 and Sentinel 2 imagery and Sentinel 1 SAR data implemented in GEE. This proposal was developed in cooperation with staff from state water management agencies and is designed to support their management needs.

Our project goals are to: 1) **develop remote sensing methods to permit routine measurement of lake ice/snow phenology and lake surface temperature in Minnesota’s waters**; 2) **apply methods to our 10,000 lakes and large rivers to create a database and corresponding maps**.

**II. PROJECT ACTIVITIES AND OUTCOMES**

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| **Activity 1: Build advanced methods for measuring lake ice/snow phenology and lake Budget: $154,704 surface temperature in surface waters of Minnesota**Physically-based predictive relationships will be developed to measure lake ice/snow phenology and lake surface temperature using available remote sensing data from satellites. Methods will be established and validated with field data collected from lakes within sub-regions distributed throughout the state. Applications of the methods will be used to gain information for all lakes and large rivers. |  |
| **Outcome** | **Completion Date** |
| *1. Measure ice thickness and snow depth at multiple lakes and locations within sub-regions throughout the state to obtain a data set for developing predictive relationships* | *March 2023* |
| *2. Gather field ice and snow measurement data from state and local agencies* | *June 2022* |
| *3. Analysis of field and satellite data to develop predictive relationships to permit routine**monitoring ice/snow phenology and lake surface temperature in the state’s waters* | *January 2023* |
| *4.* *A method for ice/snow phenology and lake surface temperature for Minnesota’s 10,000 Lakes* | *January 2023* |

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| **Activity 2: Dissemination in web-accessible mapping tool and application for lake and Budget: $40,000****fisheries management**Information gained in Activity 1 will be used to construct a web‐accessible statewide database of lake ice onset, snow cover and ice disappearance and lake surface temperature during the late summer that will be available to the public, researchers and state agencies. This information will also be used to create animations from select areas of ice phenology and lake temperature to illustrate seasonal changes. Results will be disseminated to water resource managers, and stakeholders via presentations at local meetings. |  |
| **Outcome** | **Completion Date** |
| *1. Integrate project results into a publicly accessible web accessed database/mapping tool* | *June 2023* |
| *2. Two peer reviewed publications, and numerous presentations on methods & applications* | *June 2023* |

**III. PROJECT PARTNERS AND COLLABORATORS:**

The project team consists of the Principal Investigator (PI) Leif Olmanson and Co-I Benjamin Page who are based at the University of Minnesota and unfunded collaborator Christopher Crawford from the U.S. Geological Survey Earth Resources Observation and Science (EROS) Center.

**IV. LONG-TERM IMPLEMENTATION AND FUNDING:**

This project directly addresses LCCMR funding priorities in Water Resources and Foundational Natural Resource

Data and Information. In collaboration with University of Minnesota Duluth and USGS scientists, we are seeking funding from the NSF for a complementary project exploring the effects of snow/ice phenology on under ice limnology in different optical water types. The results from this project will be of immediate use to the DNR for fish habitat modeling and prioritization of resources and could be implemented in a HABs occurrence model.