Global Water Futures 2021 Operations Team Meeting – Project Reporting Template

Project Name:	Transformative sensor Technologies and Smart Watersheds for Canadian Water Futures (TTSW)

Our major accomplishments to date are:

Sensor and Sensor Network Activities:

- Development and deployment of ultrasonic sensor for multiple environmental measurements.
- Development and testing of drone-based CHIONE.
- Development of microwave sensor integrated microfluidic system for heavy metals/lead detection in water.
- Advancement in commercial development of interactive and fully programable iWT data logging system being produced by Solinst Canada.
- Characterization of soil dielectrics during freeze–thaw transitions using L-band coaxial and soil moisture probes.

Drone/Aircraft/Satellite Remote Sensing Activities (development of systems and algorithms):

- Development and deployment of ACRO drone over research basins to investigate hydrological processes with integrated lidar, RGB, multispectral and thermal remote sensing.
- Deployment and testing of UW GNSS-R (L-band) technology on drone for the estimation of soil moisture.
- Development of approaches/algorithms for estimating: 1) wind slab thickness of tundra snowpack using UW Ku-band radar system; 2) snow depth in tundra landscapes using wideband radar (1-18 GHz) airborne observations; and 3) ice thickness on sub-arctic lakes using GNSS-IR (L-band) technology.
- Demonstration of sensitivity of GNSS signals to lake ice thermodynamic processes at a mid-latitude lake site (surface melt, ice growth, snow ice formation).
- Deployment and testing of new WISE hyperspectral sensor built by Canadian industry on NRC aircraft over Lake Erie for mapping of algal blooms.
- Development of multilayer perceptron neural network (deep learning) for the estimation of phycocyanin from hyperspectral remote sensing data, showing potential for development of a globally applicable cyanobacteria measurement approach.

Our current activities are:

Sensor and Sensor Network Activities:

- Development of user interface and portable version of Chione acoustic snow measurement sensor (Winter 2021-2022).
- Development of enhanced Chione acoustic snow measurement signal processing using machine learning for robustness and speed of data analysis at deployment locations characterized by wind and motion.
- Machine learning methods initially developed for Chione – potential application to prediction and forecasting methods for toxicology.
- Further development and deployment of heat pulse probes for quantification of soil and plant transpiration processes.
- Deployment and testing of WaterWatcher sensor—an open-source hardware platform and IoT system for measurement of turbidity, total dissolved solids (TDS) and water temperature.
- Deployment and upkeep of Chione acoustic snow measurement sensors at various field sites across Canada.

- Use of microwave sensor integrated with a microfluidic platform for detection of lead in water. A Palm-sized Nano-VNA is being employed and investigated to realize portability and real-time detection.
- Exploring the application of the microwave sensor in heavy water (deuterium oxide) detection.
- New fabrication method for the microwave sensor, which will be less time-consuming and more cost-effective.
- Incorporation of AI-based hydrologic triggering algorithms into the iWT data logging system (coll. Solinst Canada).

Drone/Aircraft/Satellite Remote Sensing Activities (development of systems and algorithms):

- Preparation of novel airborne geophysical survey method utilizing a multi frequency electromagnetic system developed in Canada to be flown in the early summer of 2022 at one of the northern observatories to map discontinuous permafrost. Regular ACRO drone operations at Fortress Mountain Snow Lab during snow accumulation/melt periods to collect data on forest-snow interactions.
- Annual monitoring of Peyto Glacier to document glacial decline specifically regarding the lateral moraines and their contribution to the glacier meltwater discharge with drone based remote sensing.
- Regular ACRO operations in the Canadian Prairies (Livestock and Forage Centre for Excellence) to quantify spatial variability of crop growth and water usage. Contributing to the development of high-resolution evapotranspiration modelling with precision ag applications.
- Focused prairie snowmelt monitoring campaigns with ACRO drones to quantify the spatial variability of Canadian prairie depression focused hydrology (evaluating abilities to quantify snowmelt, runoff, depression storage and infiltration dynamics).
- Deploying and evaluating the ability of drone based passive gamma-ray spectroscopy to estimate spatial variability of prairie snow water equivalent and soil moisture.
- CryoSAR (Ku and L-band polarimetric) radar system airborne flights and correlative field experiments (snow, soil freeze-thaw, lake ice) are planned for February and March 2022 in Ontario. Flights are planned at Fortress Mountain in W2023.
- Use of a hyperspectral sensor on UAV to map vegetation growth over a weighing lysimeter facility near Elora Ontario UAV for evapotranspiration monitoring.
- Preparation for field experiment with coll. JPL (spring/summer 2022) for improved retrieval of soil moisture in the boreal forest from L-band radar system.
- Planning for deployment and operation of prototype L-Band radiometer designed for deployment on UAVs in development by coll. Skaha Remote Sensing.
- Development of algorithms for monitoring lake ice phenology using data from GNSS-R constellations of satellites (CYGNSS and coll. Spire).
- Development of machine/deep learning/AI algorithms for the detection of cyanobacteria from Canada/US hyperspectral sensors over Lake Erie (coll. NRC).

The main accomplishments expected by the end of the project are:

Sensor and Sensor Network Activities:

- Increased accuracy and precision when quantifying snow resources and climate change.
- Enhanced bi-directional transfer of data between field sites used for testing of experimental sensors.
- An increase in the accuracy and precision of data collected to quantify flooding, drought and water quality.
- Improved accuracy characterization of soil processes and plant transpiration for precision agriculture applications and quantification of hydrological processes.

- Development of a smart water quality monitoring system based on the microwave technology integrated with microfluidic platforms. The system is expected to realize real-time detection and remote monitoring of heavy metal and other matters in water. The system should be affordable and portable.
- The iWT data logging system is anticipated to be available for commercial release through Solinst Canada.
- The multiscale data streams will be fully integrated into the next generation of numerical models for advanced modeling of permafrost degradation, land subsidence and solute transport.

<u>Drone/Aircraft/Satellite Remote Sensing Activities (development of systems and algorithms)</u>:

- New airborne geophysical survey techniques will be able to directly contribute to the mapping of permafrost continuity including the mapping of taliks at a regional scale.
- Demonstration of the ability to quantify the spatial variability of forest/vegetation-snow interactions, prairie crop growth, surface energy balance, shallow snow water equivalent with drone mounted lidar, thermal, RGB, multispectral and gamma ray -spectroscopy sensors.
- A validated high spatial resolution crop evapotranspiration modelling system to improve the water management capabilities of precision agriculture in the Canadian prairies.
- Deployment and acquisition of science analysis-ready data of the CryoSAR to Ontario, Alberta, Saskatchewan. These data will be the first dual frequency Ku and L-band observations in Canada.
- Creation of test science data sets in support of the TSMM satellite mission at ECCC. This dual frequency Ku-concept is novel and the first of its kind in Canada and will support retrieval science for radar observations of terrestrial and lake ice snow accumulation and soil moisture freeze/thaw and content estimates.
- Significant improvement to operational algorithms used to retrieve soil moisture, particularly over the Canadian boreal forest.
- Development of an approach for soil moisture retrieval from a UAV mounted L-Band radiometer. The proposed retrievals will be at high spatial resolution than what has been possible to date.
- Informing space agencies and partners from space industry, supported by research project findings: 1) optimal wavelengths needed from hyperspectral/multi-spectral instruments and ML/AI algorithms for the monitoring of cyanobacteria (blooms); and 2) optimal configurations/data acquisitions from GNSS-R constellations of satellites and algorithms for lake ice monitoring at the global scale.

Here is a key visual from the project (figure, photo, table, graph, etc.)

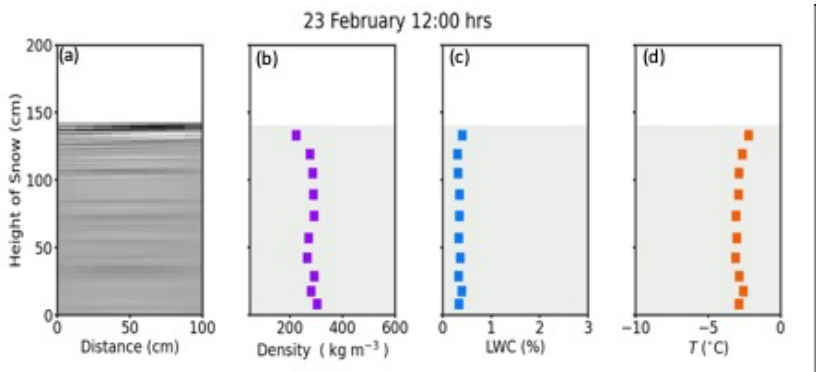

Figure 1. Cross-section of a virtual snowpit as an acoustic image observed, without disturbing the snowpack, by the Chione acoustic system (a), along with Chione estimates of vertical profiles of snow density (b), Liquid Water Content (c), and snow temperature (d).

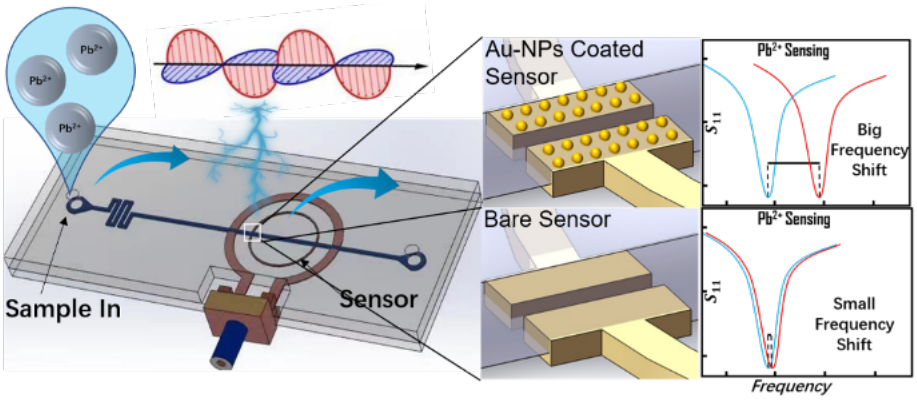

Figure 2. Schematic of lead detection using a microwave sensor integrated with a microfluidic platform.

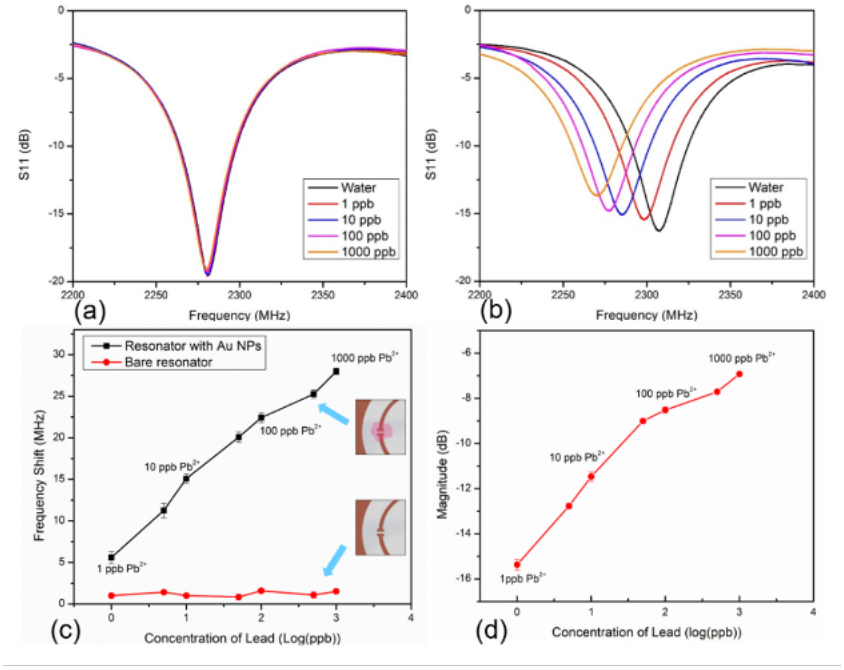

Figure 3. Lead detection: Signal sweep for the microwave sensor without Au-NPs coating (a) and for the microwave sensor with Au-NPs coating (b). Frequency shift for the microwave sensor with and without Au-NPs coating (c). S11 magnitude change for the microwave sensor with Au-NPs coating (d).

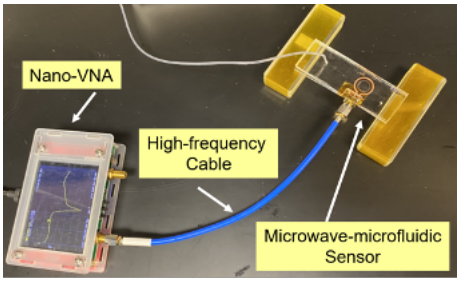

Figure 4. A portable system including a microwave sensor integrated on a microfluidic chip (2.5x7.5cm), high-frequency cable, and a Nano-VNA (about 10x10cm).

Figure 5. GNSS antenna and receiver setup on the lake ice surface for the estimation of ice thickness from L-band reflected signals.

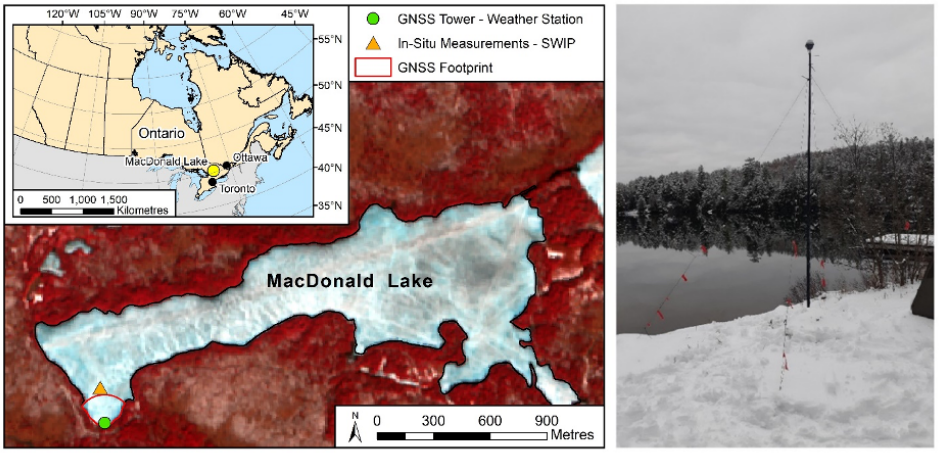

Figure 6. Location of MacDonald Lake, GNSS tower and auxiliary sensors (left). The background image is from the Sentinel-2 satellite (acquired on 6 April 2020) displayed as a false color composite. GNSS tower installation on the shore of MacDonald Lake on 19 November 2019 (right) for the study of lake ice thermodynamics.

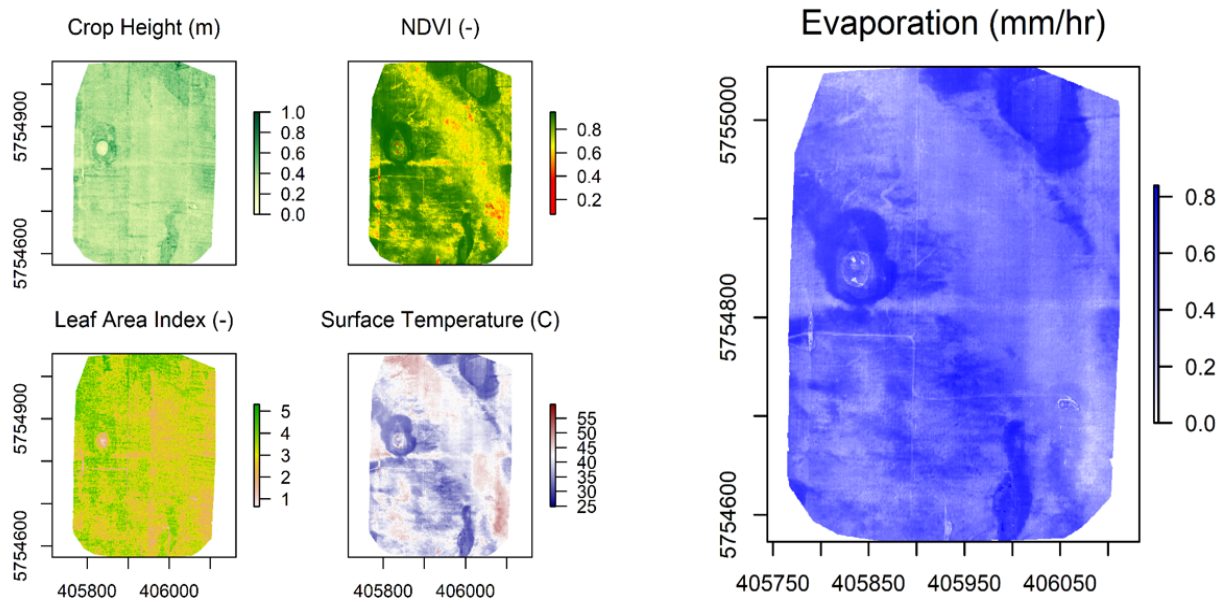

Figure 7. Field-scale high resolution estimates of Prairie crop evapotranspiration (output on right) based upon drone remote sensing observations and estimates on the left and energy balance modelling to quantify the spatial variability of crop water usage and vegetation health. This technique will improve the precision management of agricultural production on the Canadian Prairies.

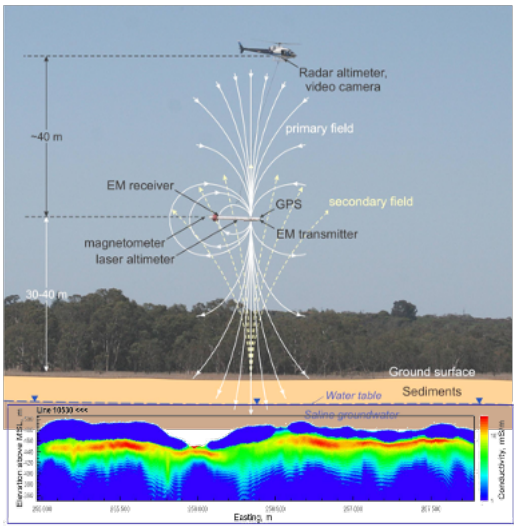

Figure 8. Airborne geophysical survey utilizing a multi frequency electromagnetic system.

Figure 9. Open door deployment configuration on aircraft of UW CryoSAR systems.

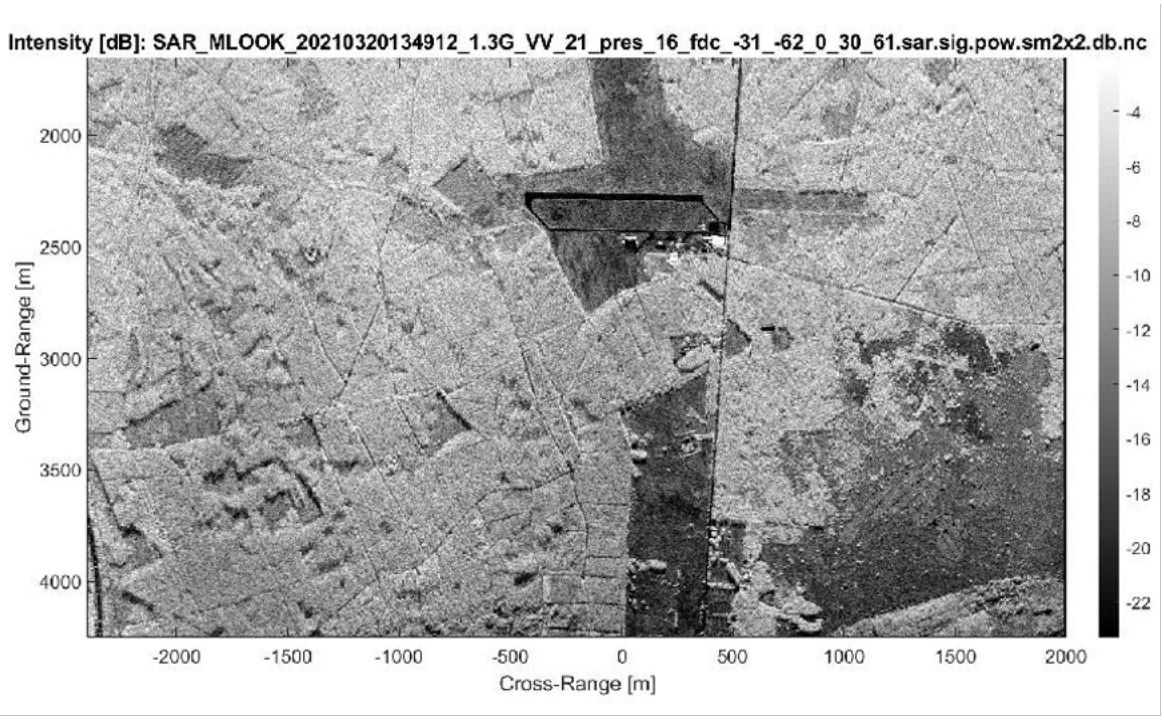

Figure 10. Calibrated L-band (VV) image data of a site near Spa, Belgium on 20 March 2021.