GULL LAKE GOES HIGH-TECH

By Gabriela Nuta and Georgia Fotopoulos

Since 1920, Gull Lake, Ontario (~44.9°N, 78.8°W) has served as an educational camp for University of Toronto surveying and civil engineering students to get hands-on land surveying experience. Today, 86 years later, a plan has been initiated to further enhance the student experience not to mention conduct cutting edge research by creating an Earth Observation Laboratory (EOL) at camp. This site will consist of a continuously operating Global Navigation Satellite Systems (GNSS) reference station and various co-located sensors including meteorological, water level gauge, and seismometer. A graphical depiction of the main EOL components is provided in Figure 1.

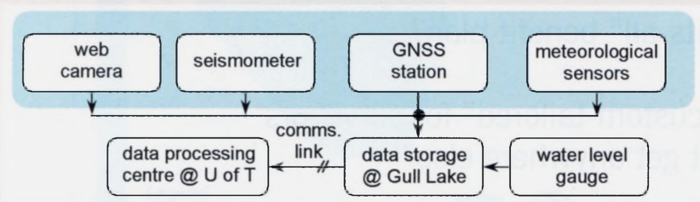

Figure 1: Main components of the proposed Earth Observation Laboratory

This article chronicles the technical and practical requirements for the development of the EOL. In particular, a pre-survey of the region was conducted in order to determine the most suitable location for the physical monumentation and laboratory equipment. Other key elements involved the type of monument, data issues and hardware/equipment configurations, which were investigated in detail.

GNSS Reference Station

The core of the EOL is the continuously operating permanent GNSS reference station, which on a fundamental level will provide GNSS observation data (GPS and GLONASS and in the near future Galileo) needed for relative positioning used for higher accuracy geodetic, geodynamic, surveying, and mapping applications. Permanent GNSS reference stations are also useful for the generation of precise satellite ephemerides and clock correction data, crustal motion monitoring (in particular with the proposed co-located seismometer), atmospheric and Earth rotation studies. Given a strategically distributed network of permanent reference stations situated over an area of interest key scientific issues such as (i) glacial-isostatic adjustment, land subsidence and land deformation and (ii) earthquake hazard, stress distribution and tectonics can be addressed. Along shorelines, GNSS reference stations co-located with tide gauges can provide critical data for studying sea level change, coastal erosion and climate change while a network focused in Arctic regions (such as northern Canada) can provide vital information for permafrost and Arctic ice studies.

The guidelines that will be used for installing, operating and maintaining the station are according to the standards outlined by the International GNSS Service (IGS), formerly the International GPS Service, which was founded in 1994 (Beutler et al., 1999). The IGS is a voluntary, civilian organization that collects data from 379 (at the time of this article) continuously operating reference stations from all over the world, of which 334 are currently active. To date, there are thirty-five IGS stations in Canada. Six of these are within 1000km of the proposed station. The fundamental products of the IGS are orbital/station positions and consistent Earth orientation parameters used to fulfill its primary objective of providing support and a reference system for the highest precision civilian GNSS community. Further details on IGS products and their impact on geoscientific applications can be found at the official website of the IGS (see references) and Kouba et al., 1999. Once the permanent station has been operational and proven to meet the standards set out by the IGS, a proposal will be made to include it in the list of potential sites.

GNSS Receiver

There are several manufacturers that produce high-quality geodetic-grade reference station equipment and systems. A survey of four GNSS receiver manufacturers was conducted to determine the best overall system based on the equipment and operational characteristics outlined in Table 1. As evidenced from the table it is clear that any one of the receivers evaluated would be sufficient. In view of the current GNSS modernization efforts and the potential improvement in reliability, availability, and accuracy achiev-

Table 1: GNSS Receiver Characteristics and Comparison

Receiver characteristics	Rx. A	Rx. B	Rx. C	Rx. D
Track code and phase on L1 and L2	✓	✓	✓	✓
At least 8 channels	✓	✓	✓	✓
Sampling interval $\leq$ 30 seconds	✓	✓	✓	✓
Cutoff angle $\leq$ 10°	✓	✓	✓	✓
Operating temperature	-40°C to 65°C	-40°C to 65°C	-30°C to 50°C	-40°C to 55°C
Operating humidity	up to 100%	up to 100%		
Power consumption (Watts)	3.5	3.6	3.7	6.6 (inc. antenna)
Memory (up to)	950MB	1GB	1GB	128MB
Communication options	RS232, ethernet	RS232, ethernet	RS232, USB, ethernet	RS232, ethernet
Accuracy – horizontal (mm)	5 + 1ppm	3 + 0.5ppm		
Accuracy – vertical (mm)	5 + 1ppm	6 + 0.5ppm		

able by combining observables from GPS, GLONASS and Galileo, the receiver selection will also be based on the potential for future upgrades and multi-satellite system tracking capabilities.

GNSS Antenna

The GNSS reference station antenna must be of the highest quality (e.g., dual frequency chokering) and carefully installed such that it is leveled and oriented to true North, rigidly attached with no more than 0.1mm motion with respect to the mounting point and also be represented accurately in the phase center variation file (including the radome if applicable). All of the receiver manufactures compared above have compatible antennas capable of meeting these requirements. Due to the site location (see next section), a radome must also be considered. Although this is discouraged for IGS stations when possible, eight of the 35 Canadian IGS permanent stations use SCIS radomes for snow protection. Radomes can increase errors in measurements (vertical offsets of at the mm-level for hemispheric and at the cm-level for conical), but when they are hemispheric with a constant wall thickness and properly calibrated, these errors can be minimized and/or modeled. The weather statistics for the proposed site for the past 30 years were assembled to assess the tradeoffs between using a radome and possible snow accumulation. It was found that a radome would most likely be necessary as average cumulative snow cover in the region is over 57 cm (during the months of October to April) with a maximum snow cover of up to 82 cm. Even with a radome snow may accumulate and therefore additional measures such as installing a web camera for staff at the University of Toronto laboratory to monitor and potentially remotely activate an infrared heater or, when possible, site visits to clear the snow cover. Radomes also provide protection from vandals (animal or human) that might tamper with the antenna. This is a valid consideration since there is some wildlife present in the proposed area.

Site Selection and Monument

Several monument options exist. A summary of three common configurations assessed for the purposes of the proposed station include reinforced concrete, short drilled, and deep drilled. A summary of the main characteristics of each is provided in Table 2.

Table 2: Summary of Monument Characteristics

Characteristics	Reinforced Concrete Pillar	Short Drilled	Deep Drilled
Cost	low to medium	medium	High
Ease of construction/install	easy to moderate	labour intensive	labour intensive
Type of soil/rock required	bedrock or unconsolidated material	bedrock within 0.5 m of surface	bedrock or unconsolidated material
Degradation issues	freeze-thaw action	N/A	N/A
Settling	can settle if not in bedrock	N/A	N/A
Stability	high	high	high
Longevity	long term	long term	long term
Environmental impact	moderate	moderate	Significant

Based on the above comparison, and keeping in mind the other sensors for the EOL (i.e., seismometer), it was determined to install the monument in bedrock using a reinforced concrete pillar. However, due to potential negative effects of metal within close proximity to the antenna it is recommended to use a C-bar, which is a brand of fiber-reinforced polymer (typical of National Geodetic Survey sites). For installation, it is important to select an appropriate height for the monument to reduce the amount of multipath, which increases if the monument is either too tall or alternately too short. A tall monument could experience quickly changing multipath, while a short monument could cause multipath to change very slowly resulting in systematic errors in the computed position. In addition, the width of the monument should be smaller than the antenna ground plane in order to minimize signal reflections from the top of the monument. Given the selected antennas evaluated, this would imply a monument width of less than 38 cm. Furthermore, the space between the top of the monument and the base of the antenna should be as small as possible reducing the resonance cavity which could cause signal degradation and increased multipath.

A detailed investigation of three feasible locations at the Gull Lake survey camp were reviewed as potential sites for the EOL. The site that met most of the criteria is depicted in Figure 2.

A panoramic view of the area surrounding this site is shown in Figure 3. The main criteria for site selection include

Figure 2: Proposed future site of the Earth Observation Laboratory

bedrock, clear horizon with minimum obstructions above 5° elevation, low multipath environment and low radio frequency interference. This must also be balanced with an accessible location (for installation and maintenance), but remote from heavy traffic from passersby (for security purposes) and power availability for equipment. The selected site meets all of these criteria with minor exceptions. An abandoned water tank nearby must be removed before the station and all equipment are installed. The only remaining obstructions to the satellite-antenna line-of-sight are trees (coniferous and deciduous) in the North and Northwest directions. A precise survey will be conducted to determine the effects (if any) on the total satellites in view. Past studies indicate that trees are not as detrimental to the signals when using a high-end geodetic grade reference station receiver/antenna configuration. The site is also ideal as power can be drawn from a small cottage that is approximately 60 metres away, thereby reducing construction costs.

stored on-site (with data from the GNSS station and meteorological instrument) and then uploaded to the main processing center located at the University of Toronto (U of T) St. George campus.

Water Level Meter

Gull Lake is just south of the proposed EOL location, which presents the opportunity of integrating a water level meter and data logger that can be used to communicate water level fluctuation measurements over time to the main processing centre. This *controlled* environment is particularly useful for

Figure 3: Panoramic view from proposed site

Meteorological Sensors

Meteorological sensors can provide invaluable information both for improved parameters in atmospheric models used for high accuracy 3D positioning as well as for studies on weather monitoring and forecasting. The main sensors investigated for the proposed site include temperature, humidity, barometric pressure and wind speed and direction. Numerous manufacturers for each sensor are currently available on the market, however the study limited the options by looking into only those that met the specifications of the IGS. Of the 35 Canadian IGS stations, 17 include some meteorological sensors. In particular data should be provided in RINEX format, minimum observation interval of 60 minutes (optimal being 10 minutes), and accuracy requirements (1°C for temperature and 0.5 hPa for pressure). The selected instrument incorporates all four sensors in one system and is also operational at temperatures as low as -40°C (which has occurred although rarely) and as high as 60°C (maximum recorded temperature is 35°C). The instrument height must be accurately surveyed with respect to the GNSS antenna and periodically calibrated.

Seismometer

A seismometer measuring and recording seismic events in co-location with a GNSS station is important for geodynamic research and studies involving crustal deformation (i.e., land subsidence or uplift). The main criteria used in selecting an appropriate seismometer for the EOL were frequency range, operating temperature, power consumption and cost. In addition a seismic recorder with four channels for recording a wide range of frequencies was selected. The digitized data from the seismic recorder will be temporarily

educational purposes to demonstrate the seasonal effect on the lake and subsequent dam operation. A completely submersible pressure sensor with an operational range as deep as 76 metres was selected for use in Gull Lake.

Data Storage and Processing Issues

The EOL will be hosted at two locations, namely at Gull Lake where the monument, equipment and sensors are installed and at the University of Toronto, St. George campus, where the main processing centre will be located. A visual connection between the two locations will be achieved via an outdoor web camera (and housing) specially designed to function under harsh environmental conditions. At the site the equipment and power supplies (back up) will be protected in a secure heated enclosure that is also surge and lightening protected.

Wherever possible all data will be collected in RINEX format, which is a universal standard and facilitates information sharing. On-site data will be stored for a minimum of seven days, which can be satisfied by any modern workstation computer. Various internet-based alternatives for continuously transmitting data from the EOL Gull Lake to U of T were evaluated including high-speed DSL and cable Internet, telephone line dial-up modem, ISDN and T1 digital phone lines and satellite Internet. A dial-up modem connection is the most economical option with estimated data transfer times of a maximum of 3 minutes for daily files and less than 4 minutes for hourly files (both meet IGS standards). However, the connection would be quite slow for the web camera images. Therefore, efforts will be made towards installing a high-speed digital phone line connection.

What's next?

We have briefly described the first phase of this project designed to assess the feasibility, technical and practical requirements of an Earth Observation Laboratory at Gull Lake. Our next step is to secure funding for the proposed infrastructure and begin implementation. During the entire process, undergraduate and graduate students in the Department of Civil Engineering will be involved as it is an excellent opportunity to get hands-on experience in surveying, equipment installation and operation. A website tracking this process will also become available for teaching purposes and later used as a data access point for teaching and research. Students in the years following the laboratory development will benefit from complete access to real-time data from the multiple sensors of the EOL.

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