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**GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8742**

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global navigation satellite system monitoring technology
at Ripley Landslide and South Slide near Ashcroft,
British Columbia**

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¹Geological Survey of Canada, 1500 - 605 Robson Street, Vancouver, British Columbia

²Geological Survey of Canada, 9860 West Saanich Road, Sidney, British Columbia

³Ophelia Sensors, 19 boulevard Poissonnière, 75002 Paris, France

2020

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Installation, operation and evaluation of an innovative global navigation satellite system monitoring technology at Ripley Landslide and South Slide, near Ashcroft, British Columbia

David Huntley, Peter Bobrowsky, Robert Cocking, Jamel Joseph, Peter Neelands, Roger MacLeod, Drew Rotheram-Clarke, Remi Usquin and Frédéric Verluise

Introduction



Vital railway infrastructure and operations are at risk from landslides across much of Canada. A particularly vulnerable section of the Canadian National (CN) and Canadian Pacific (CP) railway corridors runs through the Thompson River valley between Ashcroft, Spences Bridge and Lytton in southern British Columbia (**Fig. 1**; Bobrowsky et al. 2014; 2017; 2018).

Rail is the dominant method to move Canada's export bulk commodities (coal, oil, grain, potash, forest products) to marine terminals in Vancouver. All CP and CN rail traffic into and out of the Port of Vancouver must pass through Fraser River Canyon and the Thompson River valley corridor. The Port of Vancouver is the third largest port in North America by tonnage and Canada's busiest container port. In 2017, the port handled 142 million tonnes of cargo, including 3.25 million twenty-foot equivalents, which enabled the trade of approximately \$200 billion in goods. The economic importance of Thompson River valley corridor, along with the need to understand and manage the safety risk related to the landslides that threaten this route, make this project a priority for Transport Canada (TC) and Natural Resources Canada (NRCan).

Landslide Research Activities in the Thompson River Valley

The Geological Survey of Canada (GSC) is leading innovative research and monitoring of landslides in this area with international and national partners as part of the Railway Ground Hazard Research Program (RGHRP) and the International Consortium on Landslides (ICL) International Programme on Landslides (IPL) Project 202. Research provides government agencies, university partners, national railway companies, and other stakeholders with vital information to understand geohazard risk, predict landslide movement, improve the safety, security and resilience of Canada's transportation infrastructure, and reduce such risks to the economy, environment, natural resources and public safety.

Landslides in the Thompson River valley serve as field-based laboratories to test and compare the reliability and effectiveness of different static, dynamic and real-time monitoring technologies. A number of GSC-led publications summarize project findings to date (e.g., Huntley and Bobrowsky 2014; Huntley et al. 2016; Huntley et al. 2017a; 2017b). GSC and partner-led publications meet Federal Department of Natural Resources requirements by providing new information in a timely manner to improve the safety and security of Canada's transportation infrastructure, economy, environment, communities and population (keyword search: Ripley Landslide, <http://geoscan.nrcan.gc.ca>).

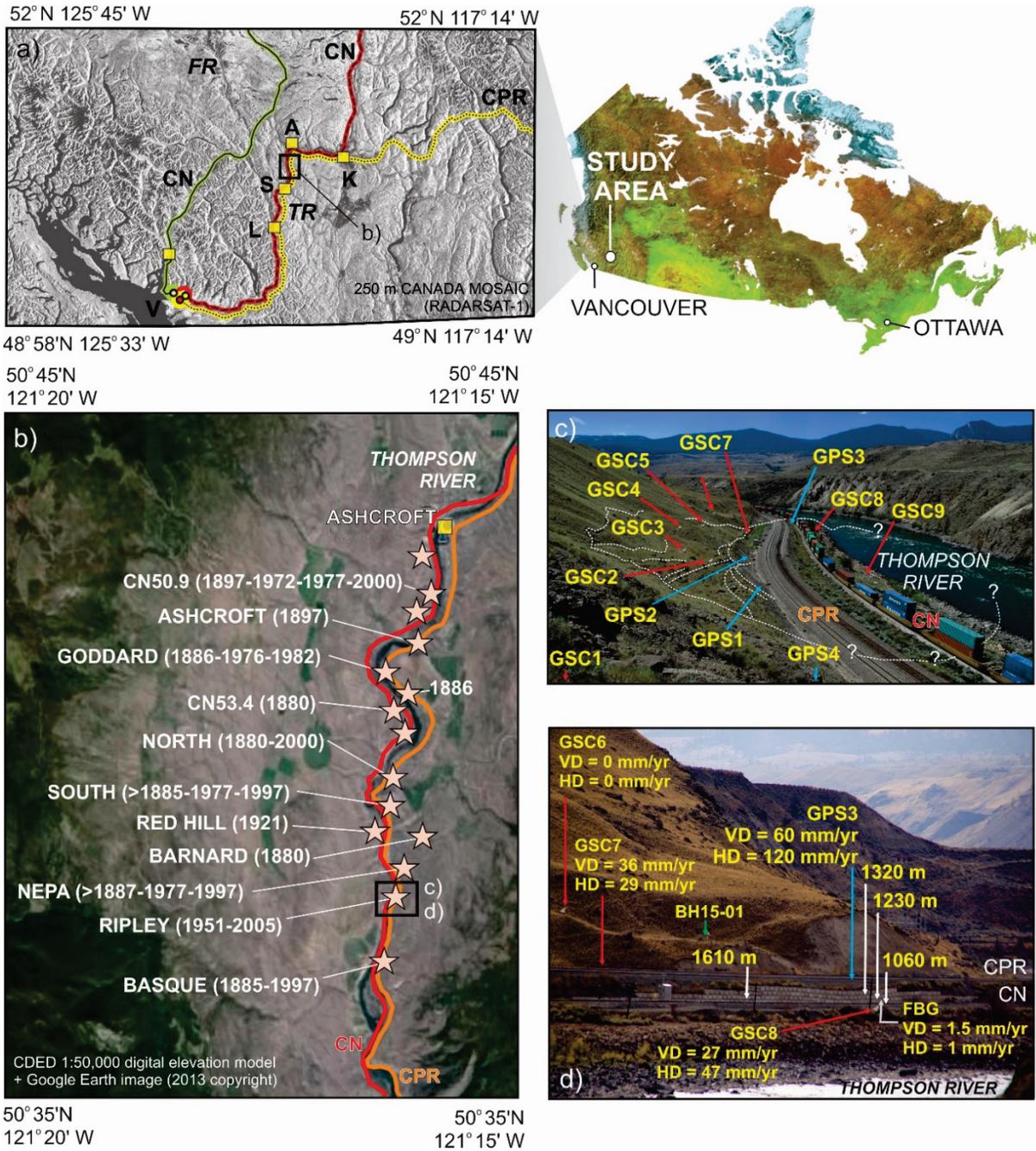


Fig. 1 The study area. a) Rail transportation corridors in southwestern British Columbia with location of the Thompson River valley area of interest: **A** – Ashcroft; **K** – Kamloops; **L** – Lytton; **S** – Spences Bridge; **V** – Vancouver; **FR** – Fraser River; **TR** – Thompson River. b) Landslides of the Thompson River valley, with location of Ashcroft, the railway transportation corridor and Ripley Landslide test site. c) Overview of the test site highlighting the location of global navigation satellite system (GNSS) monitoring stations (GPS1-4), InSAR corner reflectors (GSC1-9), and the monitored retaining wall dividing the CN and CPR tracks - view to south (NRCan photo 2020-290). d) South flank of landslide with sagging retaining wall separating CN and CPR tracks with displacement vectors for FBG, GNSS and InSAR stations; strain points detected by BOTDR (white arrows and distance in metres from datum); **VD** – vertical displacement; **HD** – horizontal displacement detected by FBG (grey arrow with displacement values expressed as mm/yr); and location of BH15-01 (green arrow) (NRCan photo 2020-291).

Ripley Landslide Test Site

Ripley Landslide is approximately 220 m wide (N-S) by 150 m long (E-W) with an estimated volume of 400,000 m³ (Fig. 1 c). The landslide has been active since at least the early 1950s, but displacement across the slide body increased after 2005 when a rail siding was constructed across its middle portion (Bunce and Chadwick 2012). During construction, embankments were extended upslope and a lock-block retaining wall separating the CN and CP tracks was installed (Fig. 1 d). Pronounced sagging and bulging of the retaining wall has occurred since 2005 (Huntley et al. 2016). To accommodate continual lateral and vertical displacement across the landslide, both rail companies periodically add ballast, in addition to lifting and re-aligning their tracks.

Landslide monitoring

Numerous conventional and experimental continuous monitoring technologies (Fig. 1 c, d) provide insight on the activity, deformation mechanisms, and potential acceleration triggers of Ripley Landslide. Each of these technologies records increased landslide activity in winter, when river and groundwater levels are lowest (Macciotta et al. 2014; Hendry et al. 2015; Schafer et al. 2015; Journault et al. 2018). Permanent global navigation satellite system (GNSS) markers record time-referenced coordinates that can be used to precisely characterize the timing, rate, and direction of landslide movement at a particular point in space (Bunce and Chadwick 2012; Macciotta et al. 2014). Four permanent GNSS monuments installed across the landslide in 2008 (Fig. 1 c) record cumulative annual displacement on the order of 100 mm/yr to 200 mm/yr, which peaks from autumn to winter (Bunce and Chadwick 2012; Macciotta et al. 2014; Hendry et al. 2015). Because GNSS displacement records capture full (i.e. three-dimensional) displacement vectors with high temporal resolution, they are complementary to remote sensing techniques, which provide spatially expansive records of motion but have generally lower accuracy (e.g. photogrammetric surveys) or are restricted to line-of-sight components (e.g. InSAR). Consequently, GNSS markers provide a baseline measure of landslide activity that can be used to assess other monitoring technologies.

Multi-year movement records now exist for the fixed GNSS system and InSAR at the landslide. GNSS and InSAR results from 2013 to 2015 indicate similar magnitudes and spatial-temporal patterns of displacement (Huntley et al. 2017b; Journault et al. 2018). Ground movement concentrated within the centre of the sliding mass averages 39 mm/year, with fastest displacements detected upslope from the railway tracks and on the southern flank. Average and maximum line of sight displacement rates (equivalent to the downslope direction for the west-facing test site) of InSAR corner reflectors (Fig. 1 c) and other coherent targets (e.g., buildings, large boulders) are 49 mm/year and 77 mm/year, respectively; with greater displacement from November to March (Huntley et al. 2017b; Journault et al. 2018). Fibre Bragg grating (FBG) and Brillouin optical time domain reflectometry (BOTDR) monitoring of the retaining wall from 2013 to 2015 detected ~ 2 mm of accumulated strain in the wall, including displacement of individual blocks at its southern end (Fig. 1 d), with peak activity occurring in the fall and winter months (Huntley et al. 2016; 2017c).

Subsurface borehole monitoring combining ShapeAccelArray (SAA) inclinometry with piezometer head levels indicate that the main slide body is failing along sub-horizontal, weak, basal shear surfaces in highly plastic clay beds (Macciotta et al. 2014; Hendry et al. 2015; Schafer et al. 2015). The central and northern parts of the slide are translating sub-horizontally (2.1° to 2.5°) whereas the southern portion near the lock-block retaining wall has a steeper (28°) slide surface.

Knowledge gap and Geocubes

A critical knowledge gap is our understanding of the spatial and temporal distribution of movement/displacement across the landslide from year to year. The innovative Geocube (GeoKylia) high-resolution (millimetric) GNSS is specifically designed to address this research problem. Geocubes are small, rugged GNSS receivers designed with directional antennas to relay GNSS data to Geocoordinator units. The Geocoordinator stores the GNSS data for multiple Geocubes and can be connected to a modem and an omnidirectional antenna to access a local 3G network to provide internet access to the GNSS data. Geocubes and Geocoordinators are developed and provided by *Ophelia Sensors*. If successful, the Geocube system will help to characterize the three-dimensional ground displacement patterns of discrete locations at Ripley Landslide and South Slide. These systems will help to improve characterization of slope activity by combining three-dimensional displacement measurements with more spatially detailed line-of-sight displacements measured by InSAR. In addition, Geocube data will help evaluate the utility of precipitation, ambient temperature, and soil moisture in predicting landslide activity based on comparison of three-dimensional displacement measurements with multi-dimensional electrical resistivity tomography datasets and meteorological records (Huntley et al. 2019).

Methods of Enquiry

Research objective

The project activity aim was to install two arrays of Geocube sensors (developed by *Kylia/Ophelia Sensors*) to measure movement over the Ripley Landslide and South Slide, with central computers (Geocoordinators) located in the CP signals bungalows (**Fig. 2, Fig. 3**). Acquisition of GNSS data was quasi-continuous to enable measurement and real-time monitoring of very slow or sudden small movements over several years. The monitoring systems were run over the winter months of 2018 and into spring 2019 to evaluate the quality of data recovered, and to compare information with other change detection methods (e.g., InSAR, GNSS and UAV). GSC Open File 8742 discusses the effectiveness, usefulness and limitations of this system. The key research question addressed was whether the pattern of landslide activity captured by the Geocube system is similar to spatial and temporal patterns indicated by other monitoring data. For example: are changes in movement detected by the Geocube system related to groundwater levels monitored in boreholes across the landslide?

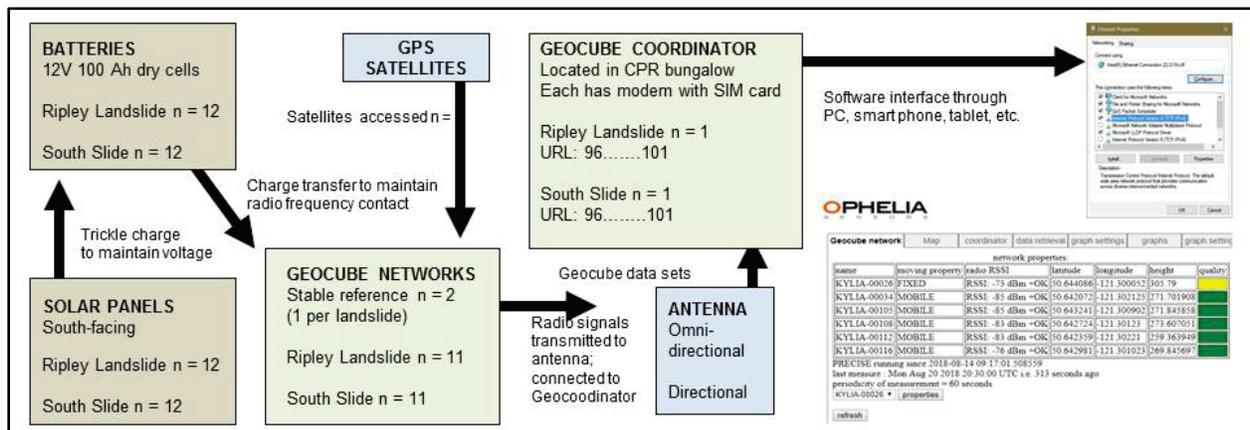


Fig. 2 Schematic of Geocube system.

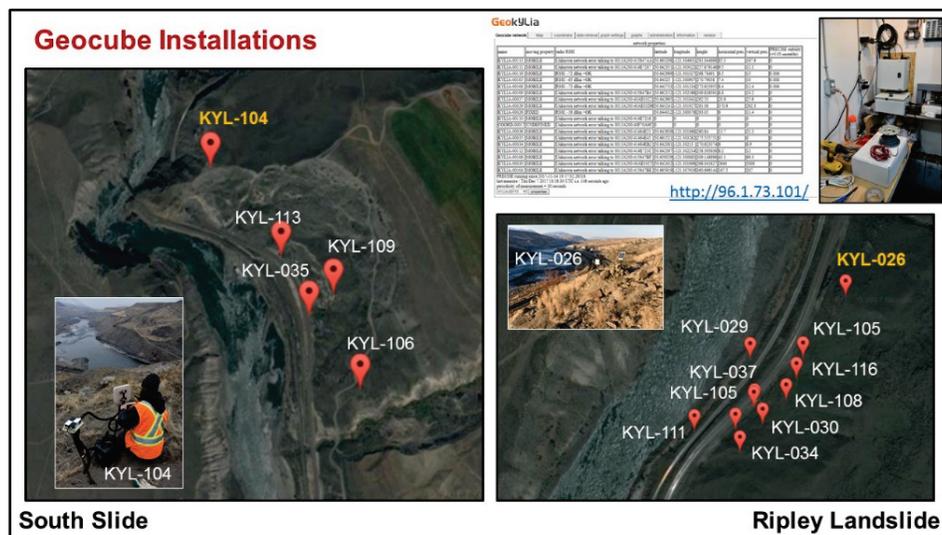


Fig. 3 Geocubes installed at South Slide and Ripley Landslide (yellow text labels are stable reference positions) (Geocube KYL 104, NRCan photo 2020-310; Geocube KYL 026, NRCan photo 2020-311), showing web-link to GeoKylia database and Geocoordinator located inside railway signals bungalow (NRCan photo GSC 2020-312).

Installation of Geocubes

At each monitoring location, a 1 m length of steel rebar was first driven into the soil to a maximum depth of 75 cm. A Geocube was mounted on an aluminum plate and attached to the rebar by means of pipe clamps and adhesive tape. An alternative mounting approach was to attach the plate and Geocube to a nearby InSAR corner reflector. The second method ensured Geocubes had a wide horizon to receive satellite signals. Geocubes were levelled by using spacing washers, a locking washer and nut, then oriented in the line-of-sight with the antenna side pointing toward the Geocoordinator. Care was taken to ensure that each GNSS antenna had their line-of-sight cleared of vegetation (**Fig. 4, Fig. 5**). A second, 1.5 m length of rebar was driven to a maximum depth of 75 cm to allow the mounting of a 50 cm² solar panel. The mount was angled to allow solar panels maximum exposure to the sun when oriented facing south (**Fig. 4, Fig. 5**).

Because of the remote location, a requirement for the Geocube system was low power consumption. The monitored slopes face west-north-west and were overshadowed by the surrounding hillsides, making solar panels unsuitable sole power sources for system components. Ruggedized, rechargeable 12V 100Ah lead-acid batteries were selected as a reliable power source to drive the monitoring systems, with recharging facilitated by the solar panels. Batteries were housed in either a weatherproof steel or high-impact plastic box with four-pin and two-pin electrical sockets for the attachment of a Geocube unit and solar panel (**Fig. 4, Fig. 5**). Battery voltages between 11 and 15 Volts were required for optimal performance.

Stable locations

For each landslide, one Geocube was installed on stable terrain. For Ripley Landslide, a stable location (i.e. reference location) was selected adjacent to stations GSC1 and GPS 4: a bedrock outcrop that confines the landslide in the northeast (**Fig. 1 c, Fig. 3**). There was excellent line-of-sight visibility across the landslide from this vantage point. Railway infrastructure (e.g., rolling stock, tracks and lock block retaining wall) were anthropogenic obstacles between the coordinator, reference site and Geocubes. The deployment plan required directional and omnidirectional antennae. For South Slide, the stable location (reference) was selected adjacent to station GSC10: a glaciofluvial terrace remnant at the northern limit of the landslide. There was again excellent line-of-sight visibility across the landslide from this vantage point. Railway infrastructure (e.g., rolling stock, tracks and earth embankments) were obstacles between the coordinator, reference site and Geocubes. The deployment plan also required directional and omnidirectional antennae.

Installation of Geocoordinators, Routers, Issues and Solutions

Geocoordinators, routers and modems were installed in CP bungalows: secure weatherproof aluminum huts, insulated and supplied with DC power (**Fig. 6**). Geocoordinators and routers were directly connected to power and an uninterruptable power supply (UPS) with wide ring terminals and secured by a double set of nuts. Geocoordinators, router and modem were on a UPS to maintain operation in case of loss of DC power. Omnidirectional and directional antennae were attached to the outside corners with cables running inside to connect with the wall-mounted Geocoordinators.

Geocube networks at Ripley Landslide and South Slide were initially configured with independent Geocoordinators, each with a router/modem and an antenna to reach cell networks (**Fig. 2, Fig. 3**). When initializing or rebooting the system at one slide, it was necessary to remove the visible Geocubes and Geocoordinators installed at the other slide to generate separate datasets.

Geocoordinators were connected via an Ethernet cable to wall-mounted modems containing SIM cards with static IP addresses (**Fig. 2, Fig. 3, and Fig. 5**). For Ripley Landslide and South Slide, the Geocoordinator was directly connected to the internet via a Red Lion Cellular Router (192.168.0.100, locally or <http://96.1.73.101:8000/>) (**Table 1**).

Connectivity issues with the South Slide Geocoordinator (COORD-00017) were resolved by running all Geocubes from the Geocoordinator at Ripley Landslide. Geocoordinator (COORD-00007).

Wildlife Issues and Solutions

Numerous instruments experienced damaged attributed to local wildlife (e.g., cattle, bears, deer, and rats). Within two months of initial installation at Ripley Landslide, cables were damaged on a number of units (**Fig. 7**). Wildlife cameras established the culprit to be a herd of deer grazing on the rangeland. After some experimentation, the most cost-effective and animal-proof approach was to cover exposed cable with a combination of tightly-woven fine wire mesh, 2 mm thick spiral-wound plastic tubing and rubberized adhesive electrical tape (**Fig. 4, Fig. 8**).

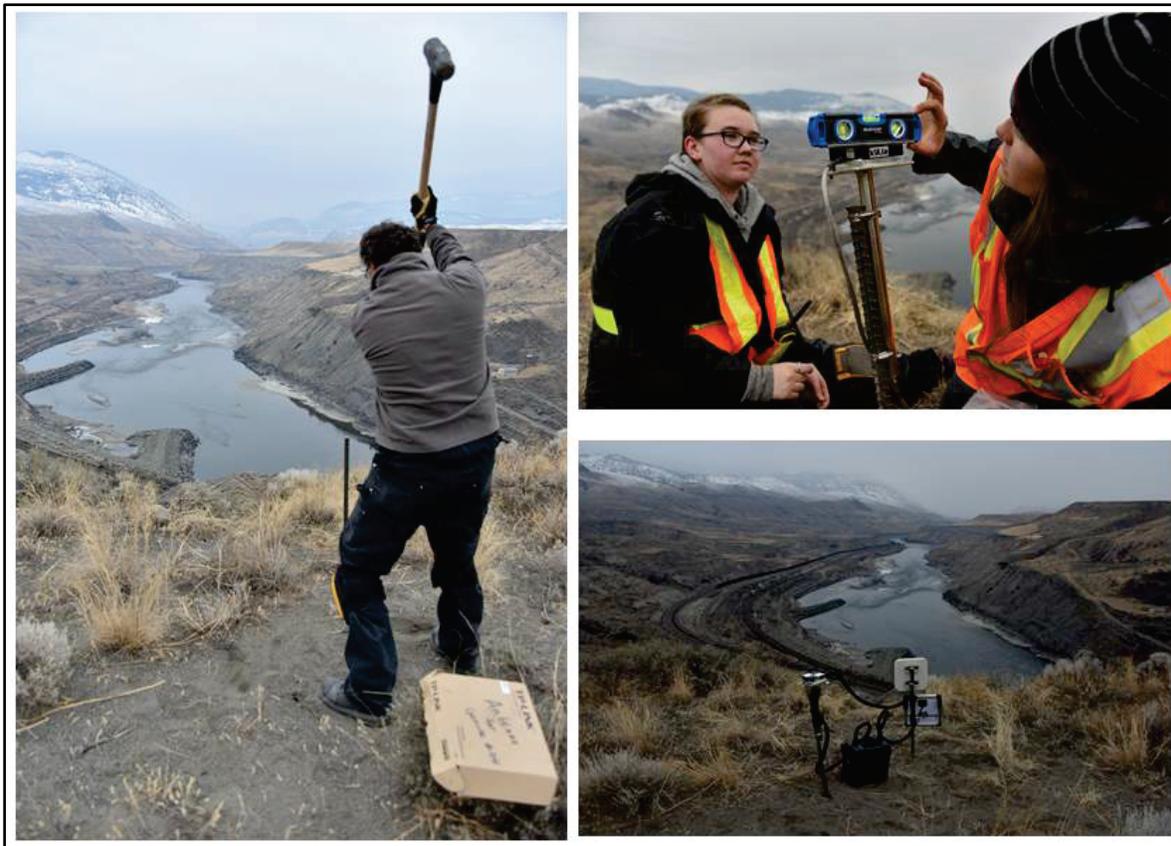


Fig. 4 Installation stages of stable Geocube (KYL-00104) at the South Slide. Rebar driven into surface materials to a depth of 0.7 m (left, NRCan photo 2020-313); leveling of Geocube platform attached to rebar (top right, NRCan photo 2020-314); completed installation with Geocube, battery in weatherproof box, south-facing solar panel and directional antenna to boost transmission and reception of radio signals (bottom left, NRCan photo 2020-315).

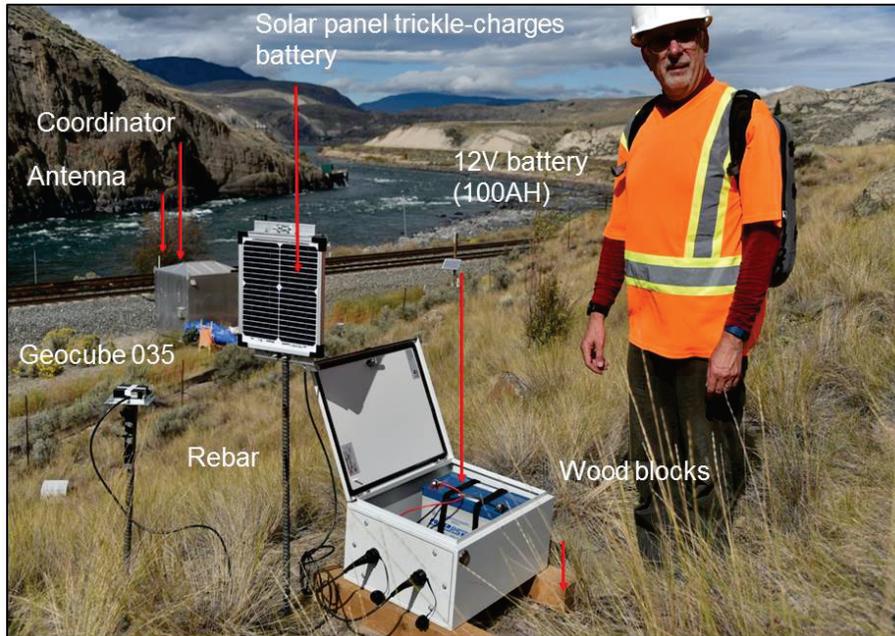


Fig. 5 Geocube system (KYL-035) installed at Ripley Landslide (NRCan photo 2020-307).



Fig. 6 Geocoordinators, routers and modems in bungalows: ring terminals used for attachment to power sources (centre left); Ripley Landslide COORD-00007 (top left, NRCan photo 2020-316); Red Lion Router at Ripley Landslide (top right, NRCan photo 2020-317); D Link Router at South Slide (bottom right, NRCan photo 2020-318); ACE management software on laptop (bottom left, NRCan photo 2020-319).

Table 1 Geocoordinators, routers and modems for Ripley Landslide and South Slide

Landslide	Geocoordinator	Firmware	MAC Address	Static IP
Ripley Landslide and South Slide	COORD-00007	Version 82	MAC: d0:50:99:74:52:a2	192.168.0.100 locally or http://96.1.73.101:8000/ via the web



Fig. 7 Cables to Geocubes and battery boxes are at risk from damage by wildlife: damage to Geocube KYL 028 (top left, NRCan photo 2020-320); damage to Geocube KYL 037 (top right, NRCan photo 2020-321); damage to Geocube KYL 034 (bottom left, NRCan photo 2020-322); detail of damage to Geocube KYL 034 cable (bottom right, NRCan photo 2020-323). Cameras were installed in 2017 to monitor instruments on the landslide and determine which animals were damaging wires and other components.



Fig. 8 Deer appear to be the dominant animal crossing the landslide and damaging cables, either by chewing or rutting with antlers. Wiring is now protected with a combination of steel meshing, plastic wrapping and rubberized adhesive electrical tape (NRCan photo 2020-324). Time will tell whether this approach is effective.

Geocube Instrument Management

With Geocube networks on the slopes and Geocoordinators in the bungalow installed (**Fig. 9**), an outline of the data management protocols used at Ripley Landslide and South Slide is presented in this section. The order of sub-headings presented below follows the procedural steps to be followed in connecting to the system with laptop computer, configuring system elements, and downloading data from the Geocoordinator (**Fig. 10**).

Connecting a Laptop

1. Connect to PC via network cable (see **Fig. 9**)
2. Go to Network Settings
3. IP must be static, not dynamic
4. Connect network cable
5. Click on the Local Area Connection button
6. Click on the Properties button
7. Click on Internet Protocol Version 4
8. Click on the Properties button
9. Select Automatic
10. OK
11. Close
12. Should show activity

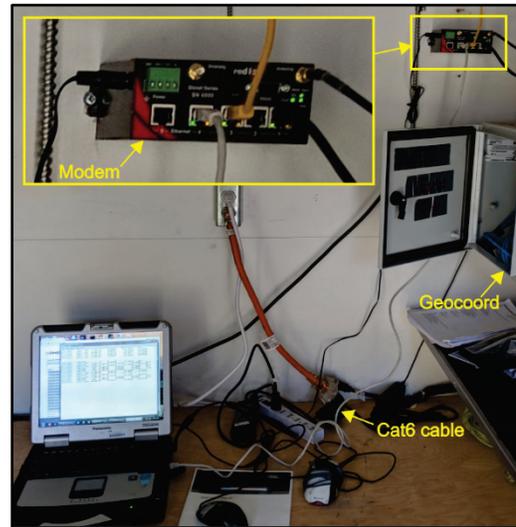


Fig. 9 Laptop connected to the modem via a Cat6 cable (NRCan photo 2020-325).

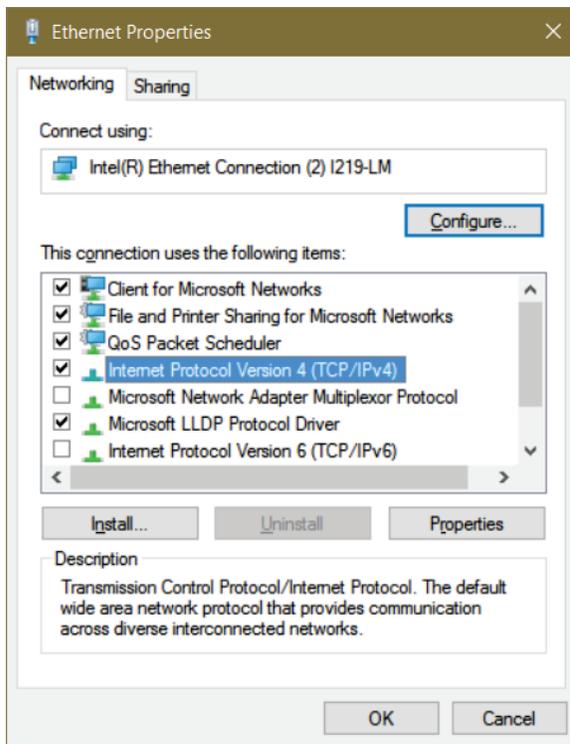


Fig. 10 Ethernet properties

In the command window, “ipconfig” is typed: IP address, <http://96.1.73.101:8000/>

Geocube Network tab

The Geocube Network tab shows the status and coordinates of the connected Geocubes. The properties of an individual Geocube can be queried here. Radio RSSI (Received Signal Strength Indication) indicated the power level received after any possible loss at the antenna and cable level. RSSI is expressed in decibels from 0 (zero) to -120db: the closer to zero, the stronger the signal. Practically speaking an RSSI signal of -60 dBm is nearly perfect, and -112 dBm is call-droppingly bad. For the Thompson River valley, a good range was -70 to -90 dBm (**Fig. 11**).



Geocube network | Map | coordinator | data retrieval | graph settings | graphs | graph settings

network properties:

name	moving property	radio RSSI	latitude	longitude	height	quality
KYLIA-00026	FIXED	RSSI: -73 dBm +OK	50.644086	-121.300052	305.79	
KYLIA-00034	MOBILE	RSSI: -85 dBm +OK	50.642072	-121.302125	271.701908	
KYLIA-00105	MOBILE	RSSI: -85 dBm +OK	50.643241	-121.300902	271.845858	
KYLIA-00108	MOBILE	RSSI: -83 dBm +OK	50.642724	-121.30123	273.607051	
KYLIA-00112	MOBILE	RSSI: -83 dBm +OK	50.642359	-121.30221	259.363949	
KYLIA-00116	MOBILE	RSSI: -76 dBm +OK	50.642981	-121.301023	269.845697	

PRECISE running since 2018-08-14 09:17:01.508559

last measure : Mon Aug 20 2018 20:30:00 UTC i.e. 313 seconds ago

periodicity of measurement = 60 seconds

KYLIA-00026 ▾ properties

refresh

Fig. 11 Geocube network tab.

Geocube properties tab

1. Select a Geocube at the bottom of the Geocube Network tab (**Fig. 12**).
2. Click on the Properties button to produce a detailed summary of the Geocube, including firmware version.
3. It is good practice to watch battery voltages in order to diagnose which batteries are prone to failure. Similar information is located in the Sensor Logging sub-tab under the Administration tab.

Geocube network	Map	coordinator	data retrieval	graph settings
------------------------	-----	-------------	----------------	----------------

KYLIA-00026

RF :
RSSI: -73 dBm

GPS :
Satellites verouilles: 8

BATTERY :
Voltage: 13.960 V

TEMPERATURE :
Temperature: 39.9 C

GEO3 firmware :
.....A 21/04/2017 09:02:58 0 v15A 05/10/2017 22:32:20 0 v17 +OK

RF range test

Fig. 12 Geocube properties tab.

Map tab

The Map tab (Fig. 13) shows almost real-time GNSS data with a Google Maps backdrop. By default, the interface uses the satellite background rather than the map background. The map always centres in on the fixed Geocube for the slide (e.g., KYLIA-00026 for Ripley Landslide), so it is necessary to zoom out to see the other Geocube locations. To display the name of the Geocube, hover over a Geocube location. Note: the map does not work with a mouse scroll wheel: the + and – buttons must be used to zoom in and out.

The screenshot shows the OPHELIA interface with the 'Map' tab selected. The main display area shows a satellite view of a landslide area. Several red location pins are visible, indicating the positions of selected functioning Geocubes. The interface includes a navigation bar at the top with tabs for 'Geocube network', 'Map', 'coordinator', 'data retrieval', 'graph settings', 'graphs', and 'graph settings-'. A sub-menu at the top left of the map area shows 'Map' and 'Satellite' options, with 'Satellite' currently selected. The Google logo is visible in the bottom left corner of the map area.

Fig. 13 Map tab for Ripley Landslide, showing selected functioning Geocubes.

Coordinator tab

The Coordinator tab displays the status of the Geocoordinator used on the site (**Fig. 14**).

OPHELIA
S E N S O R S

Geocube network | Map | **coordinator** | data retrieval | graph settings

name : COORD-00007
ON LINE : OK

System Up time:
00:05:27 up 319 days, 1 min, 0 users, load average: 0.06, 0.03, 0.05

disk use :
used out of 226G

temperature :
Core 0: +50.0 C (high = +105.0 C, crit = +105.0 C)
Core 1: +50.0 C (high = +105.0 C, crit = +105.0 C)
Core 2: +53.0 C (high = +105.0 C, crit = +105.0 C)
Core 3: +53.0 C (high = +105.0 C, crit = +105.0 C)
User mail is: jamel.joseph@canada.ca
Admin mail is : jamel.joseph@canada.ca

Fig. 14 Coordinator tab.

Data Retrieval tab

The Data Retrieval tab contains a number of sub-tabs (**Fig. 15**).

Geocube network | Map | coordinator | **data retrieval** | graph settings | graphs | graph settings-old | graphs

Kyليا Cloud Service | e-mail | download | DataBase | FTP server | FTP client | post-processing

use this service for synchronizing the coordinator with Kyليا Cloud Service
Service is OFF

Fig. 15 Data retrieval tab.

Email sub-tab

This allows the set-up of a daily or hourly email service from the Geocoordinator (**Fig. 16**).



Fig. 16 Email sub-tab.

Download sub-tab

The Download tab allows you to download data from the Geocoordinator based on start and end dates (Fig. 17).

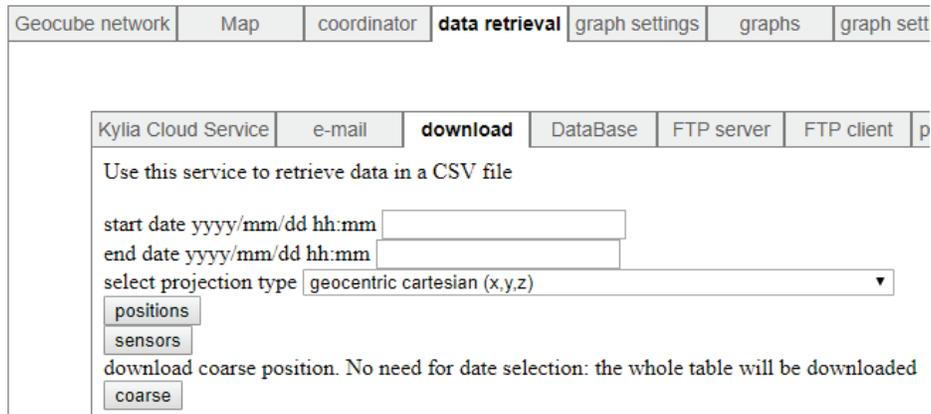


Fig. 17 Download sub-tab.

There are three download options, 'positions', 'sensors', and 'coarse.' To download the entire dataset, date fields blank should be left blank.

Positions button

This button will download the positional data for each Geocube as a .CSV file (Fig. 18).

	A	B	C	D	E	F	G	H	I	J	
1	name	time	x	y	z	pdop	rms	sig_x	sig_y	sig_z	
2	KYLIA-00034	2017-08-03 2:11	-2105775.748	-3463103.184	4908600.297						
3	KYLIA-00034	2017-08-03 2:49	-2105775.748	-3463103.184	4908600.297	-1		-1		-1	
4	KYLIA-00105	2017-08-03 2:49	-2105650.248	-3463062.011	4908683.568	0		0	0.277841452	0.391291722	0.269043851
5	KYLIA-00112	2017-08-03 2:49	-2105764.115	-3463072.463	4908610.864	0		0	0.215038158	0.367348893	0.164229903
6	KYLIA-00116	2017-08-03 2:49	-2105667.624	-3463078.823	4908663.003	0		0	0.216962493	0.670914215	0.140495952
7	KYLIA-00108	2017-08-03 2:49	-2105692.759	-3463092.168	4908648.015	0		0	0.228370223	0.672050697	0.158194553
8	KYLIA-00034	2017-08-03 3:04	-2105775.748	-3463103.184	4908600.297	-1		-1		-1	-1
9	KYLIA-00105	2017-08-03 3:04	-2105649.89	-3463062.377	4908683.176	0		0	0.149801025	0.296031937	0.112655024
10	KYLIA-00112	2017-08-03 3:04	-2105764.088	-3463072.426	4908610.923	0		0	0.149865977	0.296841741	0.113768648
11	KYLIA-00116	2017-08-03 3:04	-2105667.729	-3463078.15	4908663.095	0		0	0.144398914	0.418850217	0.097049553
12	KYLIA-00108	2017-08-03 3:04	-2105692.872	-3463091.488	4908648.073	0		0	0.147352346	0.418849676	0.102015896

Fig. 18 CSV file of positional data.

Sensors button

This button will download the full set of user-specified parameters as set under Administration and Sensors Logging (Fig. 19).

	A	B	C	D	E
1	name	time	sensor	description	result
2	KYLIA-00034	2018-09-15 0:00	ADC	Temperature	25.9
3	KYLIA-00026	2018-09-15 0:00	ADC	Temperature	22
4	KYLIA-00105	00:00.0	ADC	Temperature	19.6
5	KYLIA-00112	2018-09-15 0:00	ADC	Voltage (Vcc)	2.942
6	KYLIA-00034	00:00.1	GPS	Date (UTC)	14/09/2018
7	KYLIA-00112	00:00.2	MON	Voltage	13.212
8	KYLIA-00116	2018-09-15 0:00	ADC	Temperature	23.9
9	KYLIA-00108	2018-09-15 0:00	ADC	Temperature	26.8
10	KYLIA-00034	00:00.4	GPS	Heure (UTC)	23:59:42
11	KYLIA-00112	00:00.5	GPS	Date (UTC)	14/09/2018

Fig. 19 User-specified parameters set under Sensor Logging.

Coarse button

This downloads the entire table.

Caveat 1: the service only supports geocentric Cartesian coordinates despite seeming to support other projections. Caveat 2: the service may not work from the GSC due to latency issues in the office network when downloading large amounts of data. One year of data retrieved on a home fibre-optic network resulted in a 79.4MB CSV file with almost 26,000 records.

DataBase sub-tab

This sub-tab cannot be implemented due to GSC firewall restrictions (Fig. 20).

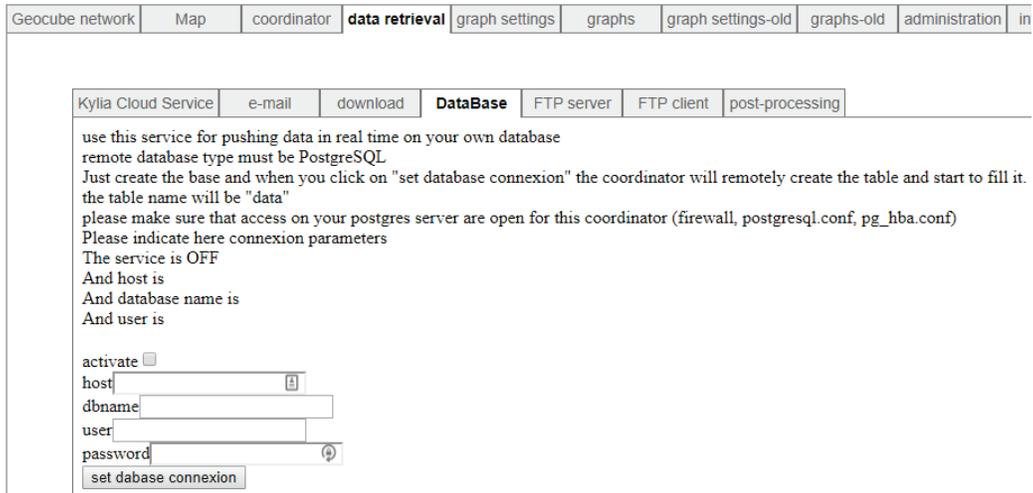


Fig. 20 DataBase sub-tab.

FTP Server sub-tab

This is not functioning.

FTP Client sub-tab

This is not functioning (Fig. 21).

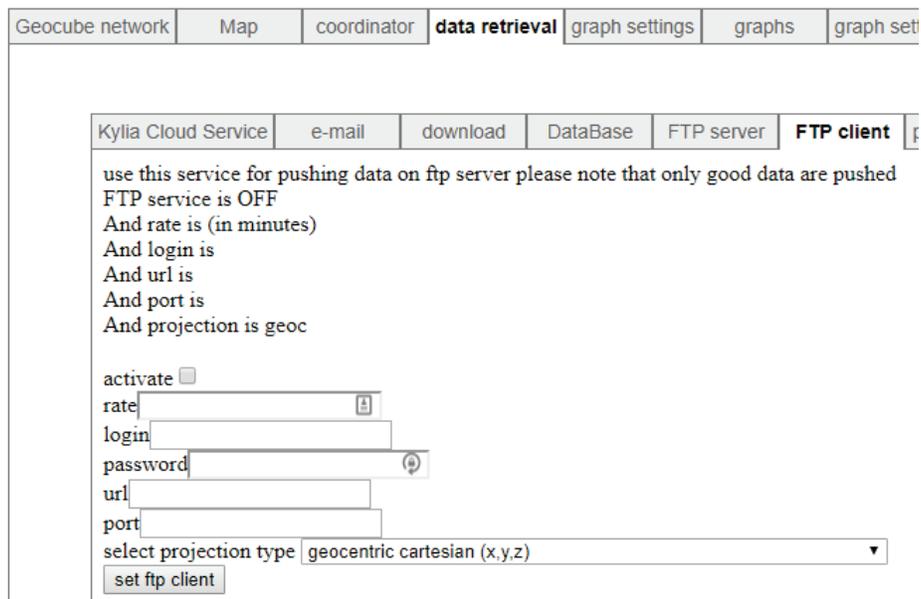


Fig. 21 FTP Client sub-tab.

Post-processing sub-tab

The Post-processing sub-tab (Fig. 22) allows raw data to be grabbed directly from the Geocoordinator as a .KYL file. This data will be binary and therefore unreadable without conversion.

Geocube network	Map	coordinator	data retrieval	graph settings	graphs	graph settings-old	graphs-
-----------------	-----	-------------	-----------------------	----------------	--------	--------------------	---------

Kylia Cloud Service	e-mail	download	DataBase	FTP server	FTP client	post-processing
---------------------	--------	----------	----------	------------	------------	------------------------

Use this service to retrieve raw data in a .kyl file
Once downloaded you can post process the results on <http://geokylia.fr/postprocessing/>
there you will get the post processed files in a .csv file.

start date yyyy-mm-dd

end date yyyy-mm-dd

file name (no space etc.)

Fig. 22 Post-processing sub-tab.

Further post-processing must be done on the associated website at <http://geokylia.fr/postprocessing/> returning a .CSV file. As of August 21, 2018, the post-processing website is blocked by NRCAN Internet security because it is interpreted as a ‘personal storage’ website.

Graph Settings tab

This tab allows the user to set up the parameters in the Graphs tab (**Fig. 23**). The projection type is constrainable and the number of days graphed, or the range of days with a start and end date can be selected. Last, the spacing between points in seconds can be controlled.

OPHELIA
S E N S O R S

Geocube network	Map	coordinator	data retrieval	graph settings	graphs
-----------------	-----	-------------	----------------	-----------------------	--------

review here graph settings:
the fixed cube is: KYLIA-00026
the altitude difference with height is:
the local coordinate system is turned with (degrees):
the local coordinate translations are (Te, Tn, Th in meter): , ,
the scale factor is (10e-6):
the moving avearge is done over 1 day.

redefine settings:
select projection type

display graph since (in days):

or choose a start & end dates:
start date yyyy/mm/dd hh:mm

end date yyyy/mm/dd hh:mm

spacing between points in seconds:

Fig. 23 Graph Settings tab (default projection is geocentric Cartesian).

Upon clicking on the SET button, the webpage will return a number which does not seem to have any particular meaning.

Graphs tab

Each Geocube in the network will have a separate graph tab. Each graph shows positional data in the X, Y, and Z (**Fig. 24**); hence there are three graphs per Geocube. **Fig. 25** shows X and Y positions; the user must scroll down to view the third graph, showing the Z-axis (not shown in figure). The vertical units are displayed as metres or radians.

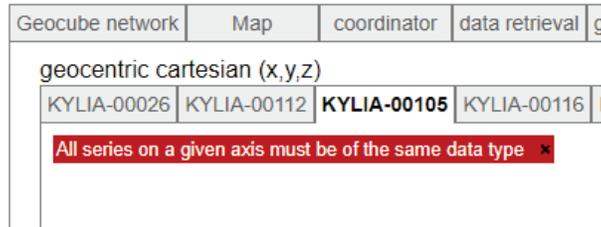


Fig. 24 Graphs tab.

For KyLIA-00105, using a setting of 1 day and 3600 seconds, the following graph is generated (**Fig. 25**):

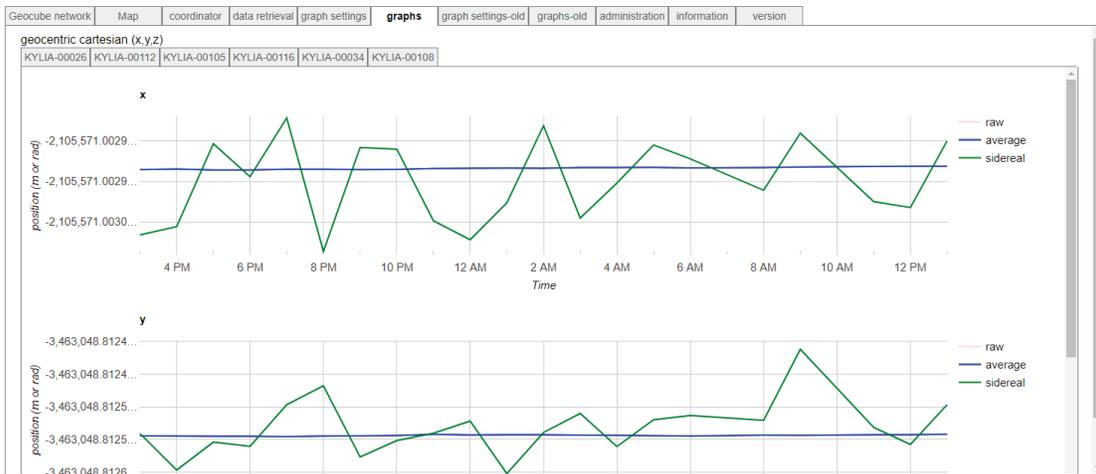


Fig. 25 X and Y values for KyLIA-00105 on Ripley Landslide (Z- value hidden in screen-shot).

Using a setting of 7 days and 60 seconds, the following graph is generated (**Fig. 26**):

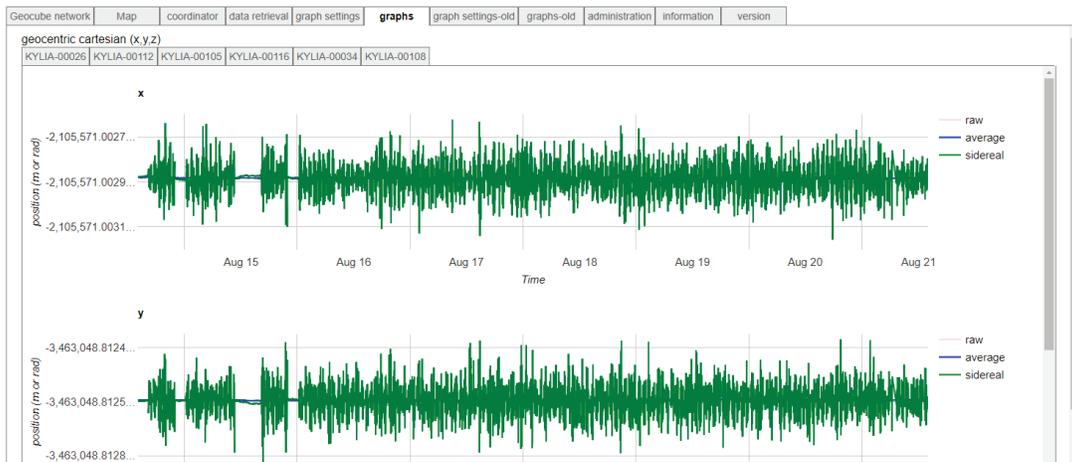


Fig. 26 X and Y values for KyLIA-00105 on Ripley Landslide (Z- value hidden in screen-shot).

Graph Settings-old tab

This tab allows you to return to a previously used graph setting (Fig. 27).

The screenshot shows the OPHELIA interface with the 'graph settings-old' tab selected. The page content includes:

- review here graph settings:
- since (in seconds) 604800
- number of points displayed: 60
- the fixed cube is: KYLIA-00026
- the altitude difference with height is:
- the local coordinate system is turned with (degrees):
- the local coordinate translations are (Te,Tn,Th in meter): , ,
- the scale factor is (10e-6):
- the moving avearge is done over (in seconds):
- redefine settings:
- select projection type: geocentric cartesian (x,y,z)
- display graph since (in days): 7
- or choose a start & end dates:
- start date yyyy/mm/dd hh:mm
- end date yyyy/mm/dd hh:mm
- spacing between points in seconds: 60
- moving average in seconds : 86400
- SET button

Fig. 27 Graph Settings-old tab.

Administration

Set process sub-tab

This tab (Fig. 28) allows you to ping Geocubes in range and add them to the network using either of the Update Network buttons; this tab also calculates first positions. The 'non-fast' button can take several minutes to execute. Updating the Network takes several minutes and will slow down at 60% and 80% completion, so be patient.

The screenshot shows the OPHELIA interface with the 'administration' tab selected and the 'set process' sub-tab active. The sub-tab contains the following options:

- 1- discover the geocube network:
 - complete (with position detection)
 - update network (takes a while...)
 - fast (without position detection)
 - update network (fast)
- 2-If desired set positions manually in /administration/set parameter table
- 3- Define process:
 - (re-)Define process
- 4- run processes
 - STOP

Fig. 28 Set process sub-tab.

Define Process button

Under sub-heading 3 (the Define Process button) the Geocubes can be set to fixed (i.e. stable position) or mobile (**Fig. 29**). Note: **KYLIA-00026** at Ripley Slide and **KYLIA-00104** at South Slide are the fixed Geocubes. Each network must have one fixed Geocube that is anchored in bedrock or stable surficial sediments and unlikely to move.

1. Set the fixed Geocube to 'fixed'
2. Set all other Geocubes to 'mobile'
3. Set the delay to '60' (seconds)
4. Click on the *set process* button

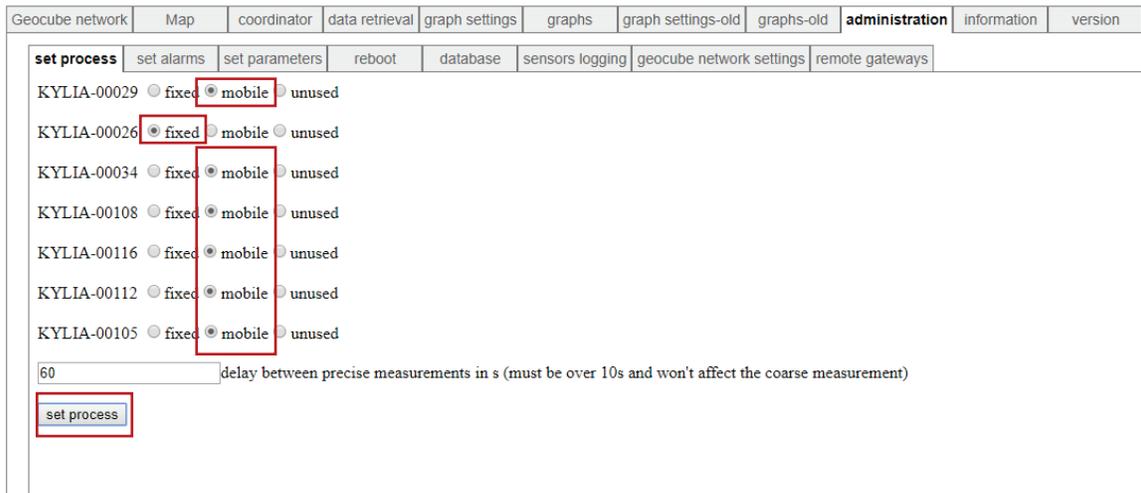


Fig. 29 Set process button is used to establish fixed and mobile Geocube units.

Run Processes button

Lastly, sub-heading 4 (Run Processes) will alternately Stop or Start (RUN-TD) all processes for all Geocubes (**Fig. 28**). Note that the button will appear as Stop if the processes are currently running, or as RUN-TD if the processes are currently stopped.

Set alarms sub-tab

This tab allows you to set up email alarms to either the registered user or the administrator (in both cases this is currently Jamel Joseph).

Users and Administrators are set up in the Administration > Set Parameters sub-tab (**Fig. 30**).

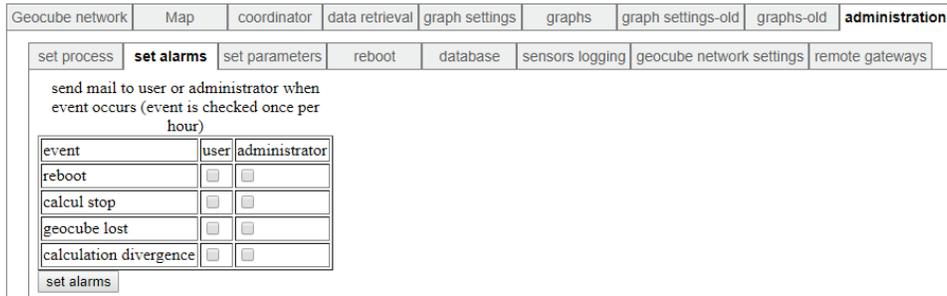


Fig. 30 Set alarms tab.

Set parameters sub-tab

This sub-tab (**Fig. 31**) allows the user to:

- set up and maintain User and Administrator accounts
- define coordinate system parameters
- set fixed Geocube coordinates in longitude/latitude/height
- set the web page that appears on the Information tab

User login

Username: Kyla

Password: Kyla

Administrator login

Username: jameljoseph

Password: 40Jianhua

The positions of the fixed Geocubes are considered motionless. Movements of other Geocubes are calculated in relation to these stable references. In order for movements to be monitored precisely, fixed Geocube(s) have been installed on ground known to be stable and within a 3 km radius of moving Geocubes.

Precise positioning of fixed point(s) is not required for precise monitoring of moving Geocubes. In a default mode, the system will roughly position the fixed Geocube and monitor movements from there. If a precise position of the fixed Geocube is required/available, it can be entered using the “Optional manual exact position setting”. Simply enter the coordinates (latitude, longitude, height) and press “set position”.

Fig. 31 Set parameters sub-tab.

Reboot sub-tab

Firmware versions are controlled by *administration > reboot*

- Note: all processes must be stopped on the Geocube that is being updated
- Set Upgrade/reflash Geocube to the Geocube to be updated
- Click *flash Geocube firmware* button (**Fig. 32**)

Individual Geocube information from Geocube network will be seen at the bottom of the page.

- Set Geocube # and click properties

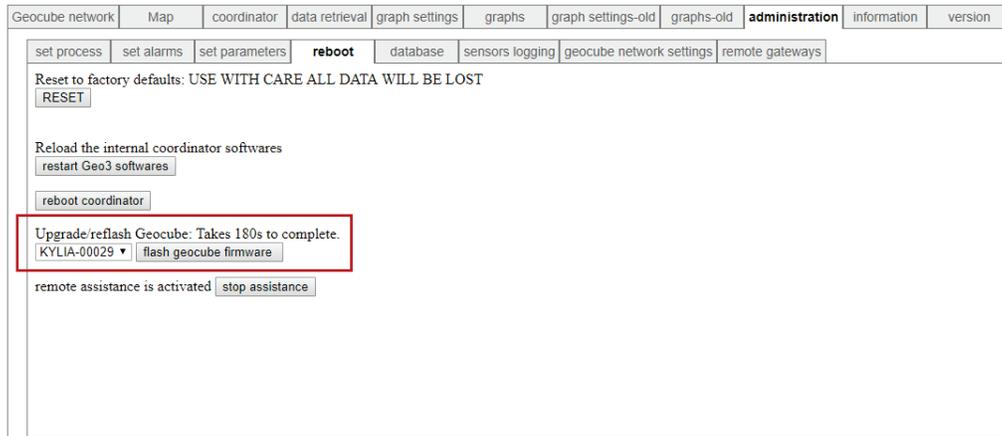


Fig. 32 Reboot sub-tab.

Database sub-tab

The database tab allows the user to monitor the size of the current database on the Geocoordinator and to reset or clear the Coarse, Precise and Sensor tables on the Geocoordinator (**Fig. 33**).

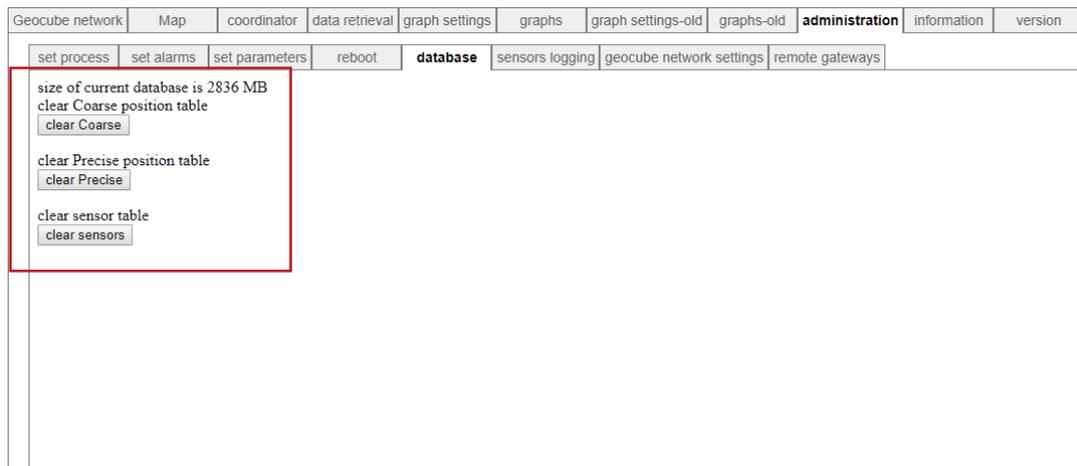


Fig. 33 Database sub-tab.

Sensors logging sub-tab

This tab (**Fig. 34**) allows the addition of a variety of sensor information, although many are not active. We have been recording the following standard parameters since the start of the project and have added a few others in 2018.

- GNSS Date (UTC)
- GNSS Heure (UTC)
- GNSS Longitude deg
- GNSS Latitude deg
- GNSS Altitude mm
- GNSS hzPrec mm
- GNSS vtPrec m

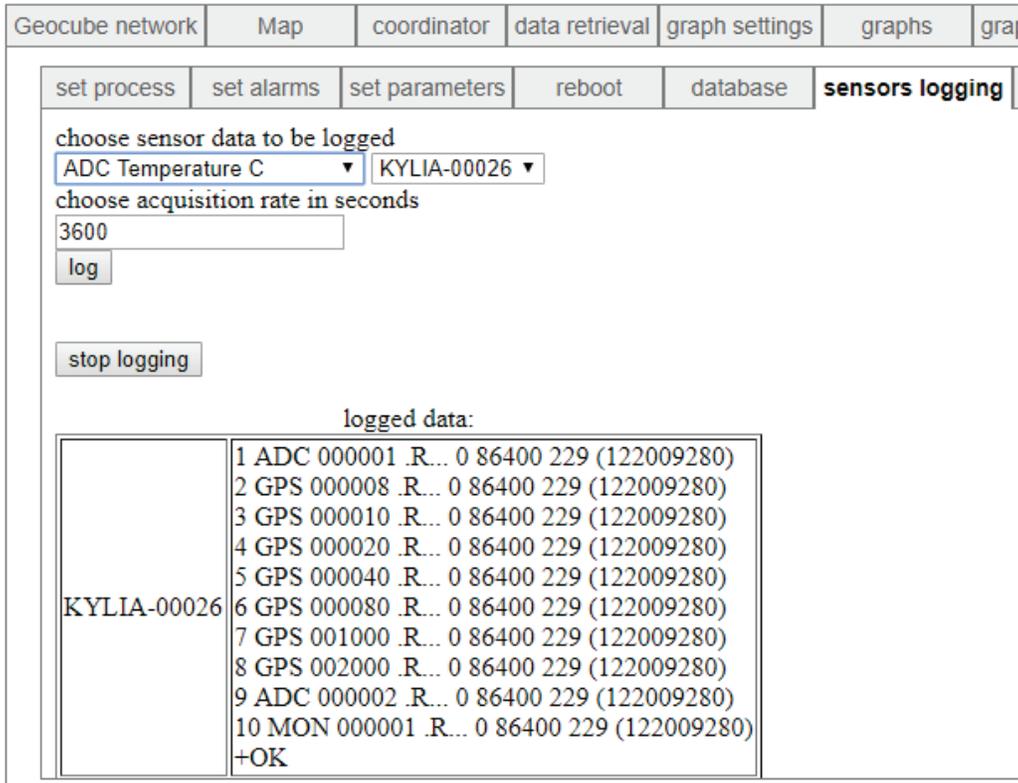


Fig. 34 Sensors logging sub-tab.

Note that most sensors are not active, so it is important to make sure to test only those wanted. At the Ripley Landslide and South Slide, an acquisition rate of 86400 seconds is being used, equal to 24 hours or once per day.

- After setting a sensor on a Geocube, the tab will go blank
- Click on the Sensors Logging tab to refresh

Broad sensor categories

ADC: voltage and temperature inside Geocube

G3: OS information

GNSS: GNSS information

MON: power supply information

RF: radio information

RTC: real-time clock information

EXT: extensometer measures

WEA: weather station measures

In June 2018 *ADC Temperature °C* was added to the logging profile; in September 2018, *ADC Voltage (Vcc) V* and *MON Voltage V* were added (*MON Voltage V* seems to be the better indicator of the two).

Note: all regular parameters were added to KYLIA-00112, which had memory issues and had not previously been accepting parameters.

Geocube Network Settings sub-tab

This tab (Fig. 35) allows you to remove a Geocube from the network. To return the Geocube to the network you must go to the Administration > Set Process tab and click either of the Update Network buttons.

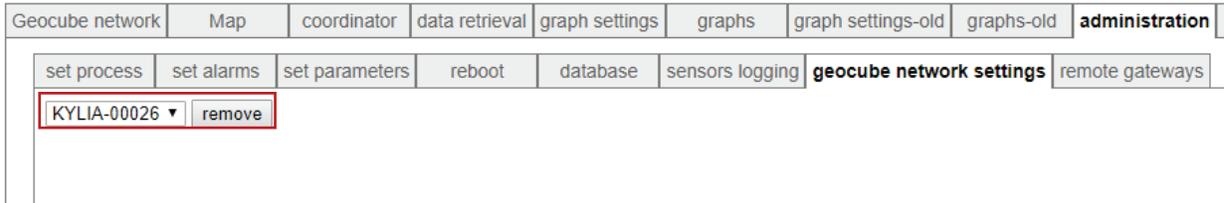


Fig. 35 Geocube Network Settings sub-tab.

Remote Gateways sub-tab

This sub-tab (Fig. 35) is currently non-functional and not covered in Kyliia documentation.

Information tab

This tab shows the *Kyliia/Ophelia* website, including products, customization options, optical assembly information, company details and points of contact (Fig. 36).



Fig. 36 Information tab.

Version tab

This tab (Fig. 37) provides a list of the changes that occurred in each version of the software.



Geocube network	Map	coordinator	data retrieval	graph settings	graphs	graph settings-old	graphs-old	administration	information	version
v82 : - switch to Ophelia-Sensors v81 : - bug correction ORIGIN is now the first FIXED. RMS disappear on front page replaced by a coloured quality indicator v80 : - graphs can now be toggled on/off v79 : - cosmetic changes : geocube in alphabetic order and progression bar during start/stop process v78 : - old and new graph version are available v77 : - correction of bug in updating process that could cause web server to stop v76 : - the coordinator now does not require internet to compute positions. This requires fixed devices SN > KYLIA-00130 - implementation of sidereal graph, graph settings are made easier v75 : - list of connected gateways is available - made possible to choose projection for ftp push v74 : - implementation of remote assistance: this assistance enables Kyliya team to monitor health of coordinator - indication of switching process evolution v73 : - adding one more heartbeat listening test v72 : - bug coorrected in coarse calculation, if old epehemeris existed v71 : - new firmware for geocubes preparing the future update of software enabling the systeme to work without internet access v70 : - faster web interface v69 : - bug raw data corrected v68 : - fast network update										

Fig. 37 Version tab.

Flashing Firmware

1. Go to the Administration tab and log in as administrator (Fig. 38).



Geocube network	Map	coordinator	data retrieval	graph settings	graphs	graph settings-old	graphs-old	administration	information	version
-----------------	-----	-------------	----------------	----------------	--------	--------------------	------------	----------------	-------------	---------

Fig. 38 Administration tab.

2. Go to the Set Process tab (Fig. 39).

Geocube network	Map	coordinator	data retrieval	graph settings	graphs	graph settings-old	graphs-old	administration
set process	set alarms	set parameters	reboot	database	sensors logging	geocube network settings	remote gateways	

Fig. 39 Set process tab.

3. Click on the STOP button. The interface will report 'done', but displays 83.333% despite being 'done' (Fig. 40).

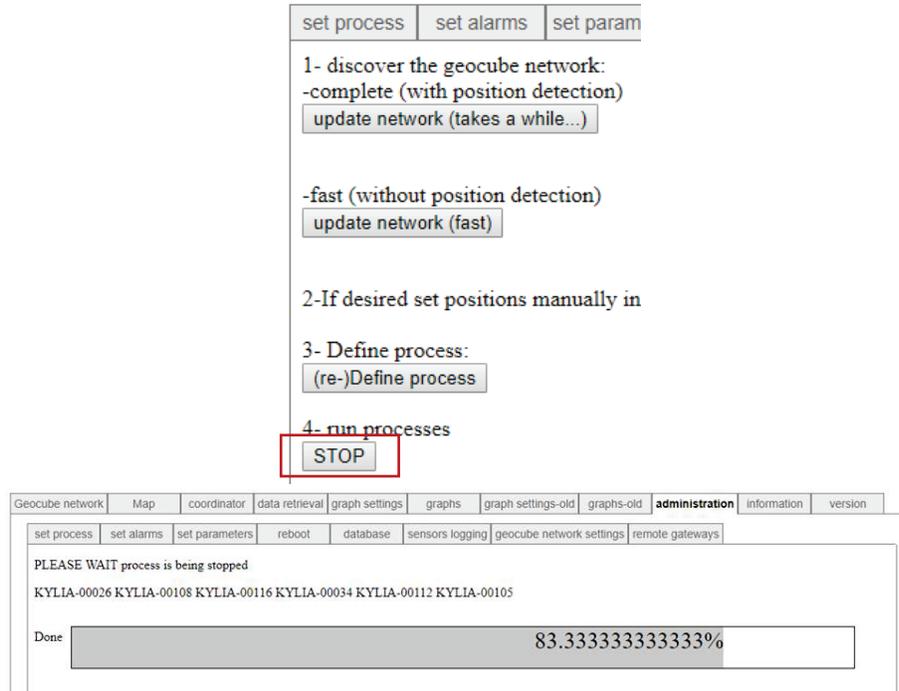


Fig. 40 Clicking on STOP button.

4. Go to the Reboot tab.
5. Select a Geocube (**Fig. 41**)

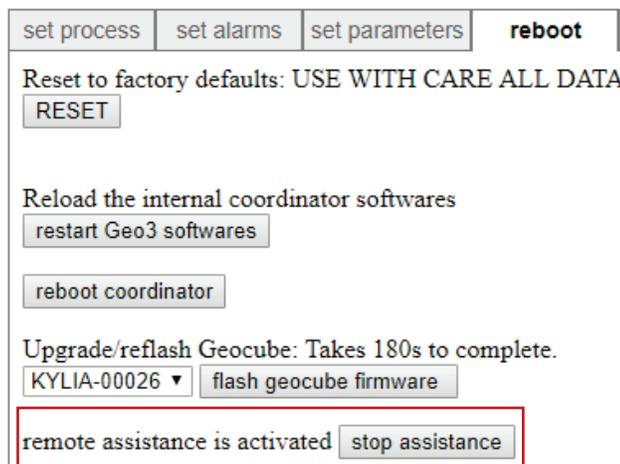


Fig. 41 Reboot tab.

6. Click on the *Flash Geocube Firmware* button.
7. You will never receive a system message telling you that the firmware was updated.
8. After waiting, restart the processes from Set Process > Run TD.
9. Check the Geocube properties from the Geocube Network tab to see the current firmware version (**Table 2**).

This setting allows the user to set up which parameters are logged at each Geocube.

Table 2 Geocube firmware table.

Geocube	GEO3 firmware
Ripley Slide	
KYLIA-00026(f)A 21/04/2017 09:02:58 0 v15..A 05/10/2017 22:32:20 0 v17 +OK
KYLIA-00029	+NAK DIR OR FILE NOT FOUND
KYLIA-00034A 19/09/2016 16:57:12 0 v13..A 21/04/2017 09:02:58 0 v15.....A 05/10/2017 22:32:20 0 v17 +OK
KYLIA-00105A 30/08/2016 07:26:42 0 v15.....A 05/10/2017 22:32:20 0 v17 +OK
KYLIA-00108A 05/10/2017 22:32:20 0 v17 +OK
KYLIA-00112	+NAK DIR OR FILE NOT FOUND
KYLIA-00116A 30/08/2016 07:26:42 0 v15 +OK
South Slide	
KYLIA-00104(f)	A 30/08/2016 07:26:42 0 v15... A15/11/2017 09:31:58 0 v17
KYLIA-00109	NAK DIR OR FILE NOT FOUND
KYLIA-00035	OK
KYLIA-00113	A 30/08/2016 07:26:42 0 v15 +OK
KYLIA-00115	A 30/08/2016 07:26:42 0 v15 +OK
KYLIA-00031	NAK DIR OR FILE NOT FOUND
KYLIA-00027	A 19/09/2016 16:57:12 0 v13... A 17/11/2017 15:11:08 0 v17 +OK
KYLIA-00038	A 19/09/2016 16:57:12 0 v13... A 17/11/2017 15 :11:08 0 v17 +OK

Potential issue: some Geocubes have internal memory issues and are unable to store data internally. Consequently they are unable to flash the firmware. Versions 16 and 17 only relate to fixed Geocubes, but should be addressed in the future. At Ripley Landslide and South Slide, the following parameters are logged (**Fig. 42**):

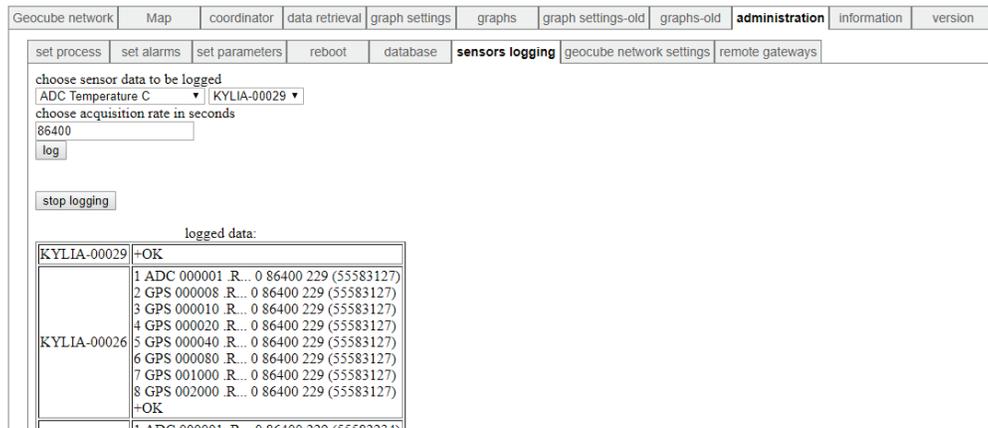


Fig. 42 Logged parameters in the Thompson River valley.

- Services > DHCP server
- Default lease time:14400
- The Kylia device shows up at the bottom of this page
- Add more PCS with the Add button
- Network > Firewall > Port allow/forwarding rules

- Note that the PRIME ERT system is on port 8080 (**Fig. 43**)
- This is also where email is enabled

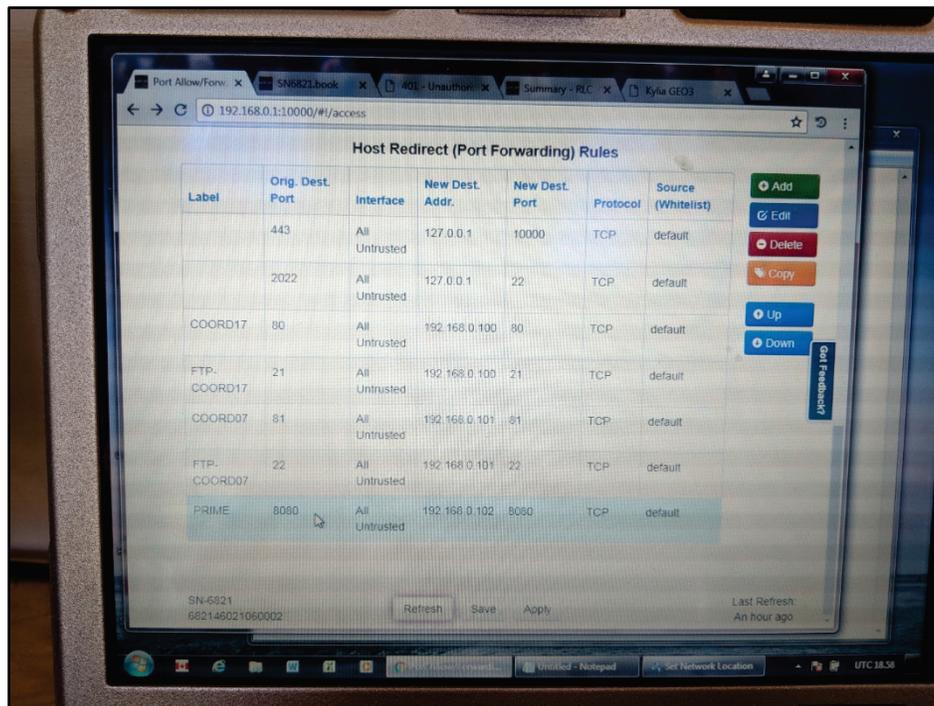


Fig. 43 Host redirection rules (NRCan photo 2020-326).

COORD17 is 192.168.0.101: although it works as .100, the user must always subtract 1.

- Open a CMD window (search for CMD under the Windows Start button)
- Check connectivity to the Geocoordinator by typing: ping 192.168.0.100
- See firmware table for Geocubes (**Tab. 2**)

Summary evaluation: applications of Geocube data

Geocube spatial data will be used to help understand the behaviour and drivers of slope instabilities affecting rail transport in the Thompson River valley. Detailed examination of Geocube records will provide insight on the rates and spatial pattern of creep as well as the timing, and possibly precursors of changes in creep behaviour. The resulting knowledge will help to characterize landslide hazard, and ultimately reduce landslide risk. The locations of highest creep rates as indicated by the Geocube networks will help identify where track damage can be expected if creep continues across Ripley Landslide and South Slide. Spatial variability in landslide motion will help inform the mechanism of the monitored landslides, such as whether failure involves complex interactions between structurally separate blocks, thus improving landslide characterization and mitigation efforts. Comparing displacement trends with proxy records of possible landslide drivers (including temperature, precipitation, river level, and irrigation) will help establish landslide warning threshold based on environmental conditions. Such comparisons will include detailed analysis of Geocube displacement histories spanning acceleration periods, indicated by CP's GNSS markers, in an effort to identify possible environmental triggers. If gradual acceleration is found to precede failure events, future Geocube-measured accelerated creep can be used to forecast impending failures.

Differential GNSS monitoring with Geocubes

Geocube displacement results from November 2018 to June 2019 are discussed here. Eight units installed across Ripley Landslide were active to some degree, and recorded 3D displacement during this time interval (**Fig. 44**). Three units were not active due to wildlife damage or low battery charge (KYL029, KYL030, KYL111). Geocube location data (X - longitude, Y - latitude, Z – height above sea level) collected over the eight month-long observation trial were imported into an ArcGIS Geodatabase. Geocube tracks are plotted as points, grey-shaded from light to dark according to date (per month) from exported individual Shape files (**Fig. 44**).

Immediately apparent is the generally NW displacement trend for all working Geocubes, with each unit's unfiltered data charting a helical orbital drift over the months of observation (**Fig. 45**). The most reliable units (KYL105, KYL108, KYL112, and KYL116) are the focus of discussion. Relative location data (X, Y, Z) averaged every 15 days over the eight month long observation trial are plotted as points overlying precipitation and temperature data (**Fig. 9**). The NW displacement trends are consistent with the displacement vectors derived from change detection analysis of the RTK survey, and UAV imagery using the SfM and Cosis-Corr software (**Fig. 46**).

Geocubes in the northern sector of the landslide capture movement at varying rates from November 2018 to June 2019, suggesting displacement of multiple slide blocks along moderately steep-dipping back scarps. The unit on the most northerly block moved horizontally NW 5.55 cm while dropping 1.8 cm in elevation (KYL105). A second unit, in a graben block, moved NW 4.5 cm with a 1.7 cm drop in elevation (KYL116). The third unit, on the central block, moved horizontally NW 5.0 cm, dropping 1.5 cm (KYL108) over the eight-month trial (**Fig. 44, Fig. 45**).

In the southern sector, generally slower horizontal, but greater vertical displacements are recorded over the eight month observation period. KYL037 captured 3.2 cm horizontal movement to the NW, with a drop of 3.0 cm on the slide block near the CP tracks and signals bungalow. Similar to KYL116 in the northern sector of the slide body, KYL031 and KYL112 are located in a graben toward the southern margin of the

slide. KYL031 moved horizontally NW 0.1 cm prior to power failure during the winter. While experiencing only 3.4 cm of horizontal movement NW, KYL112 dropped 1.8 cm in elevation. On the lock-block retaining wall, KYL028 recorded 3.9 cm of horizontal movement NW, and experienced 3.2 cm vertical downward displacement - the greatest vertical downward displacement across the slide body – before power failure in early May 2019 (Fig. 44). Above the southern head scarp, KYL034 captured 1.2 cm of horizontal movement to W, while dropping in height by 0.08 cm. These small displacement values may be an indication of developing (i.e. retrogressive) instability upslope of the active headscarp.

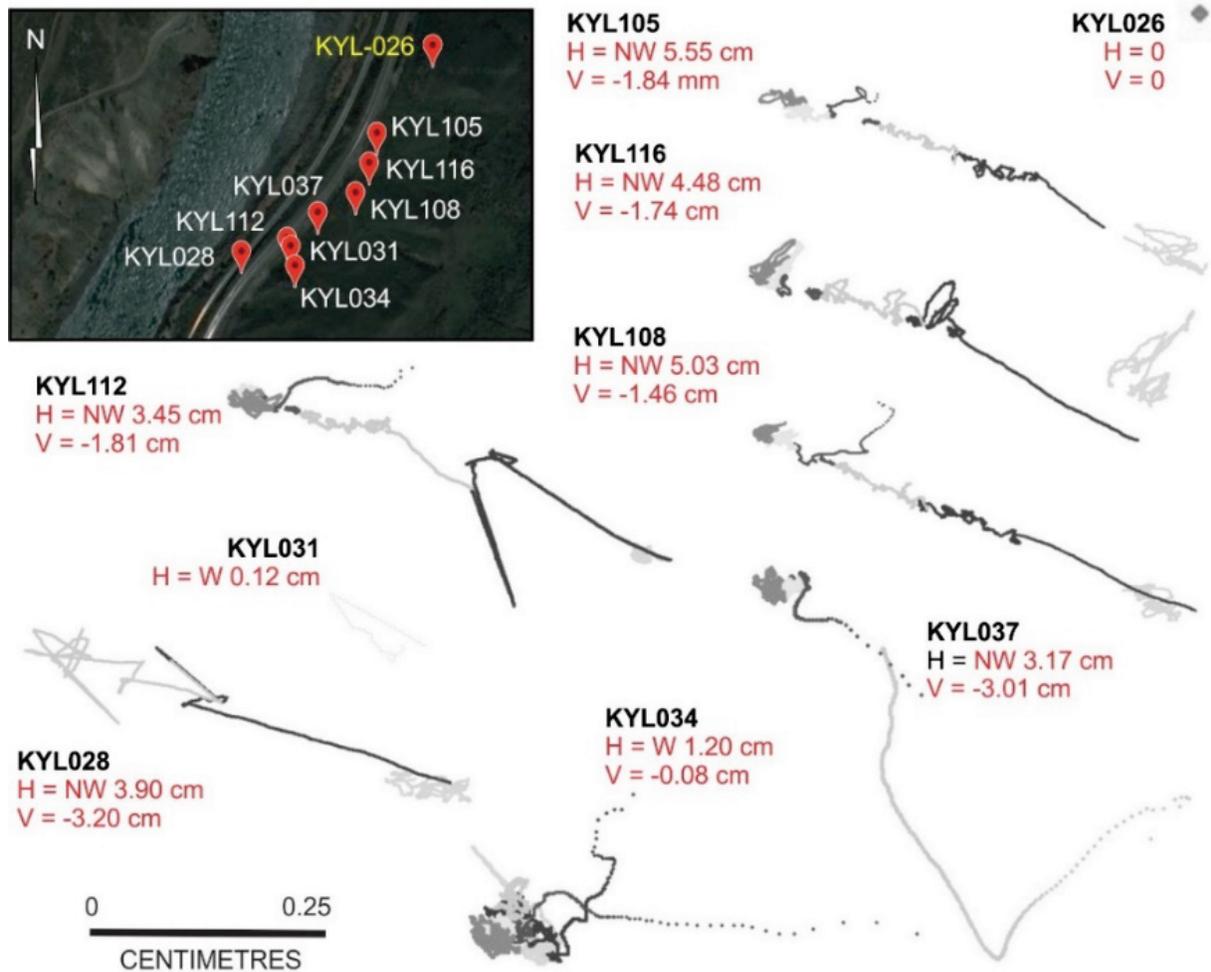


Fig. 44 Unfiltered displacement trends of Ripley Landslide Geocube network. Google Earth image showing active units from December 2018 and provisional results for the November 2018 to June 2019 observation period.

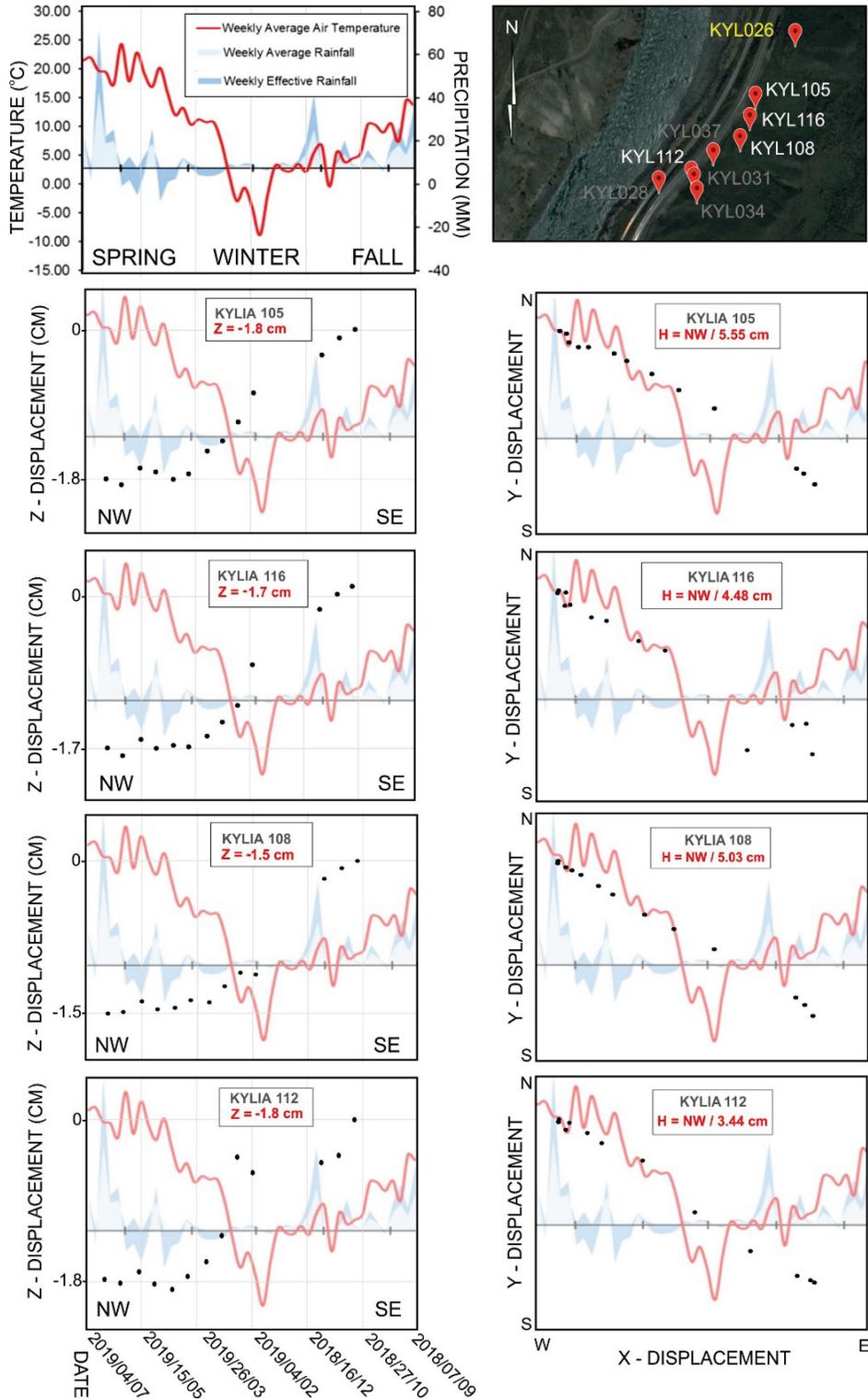


Fig. 45 Geocube displacement results: Z - vertical amounts (cm) and X,Y - horizontal displacements trends for the period September 07, 2018 to June 04, 2019; superimposed are rainfall and temperature data from Thompson Valley weather station (data provided by J. Holmes). Note that these graphical representations read right to left to represent the displacement trends across Ripley Landslide.

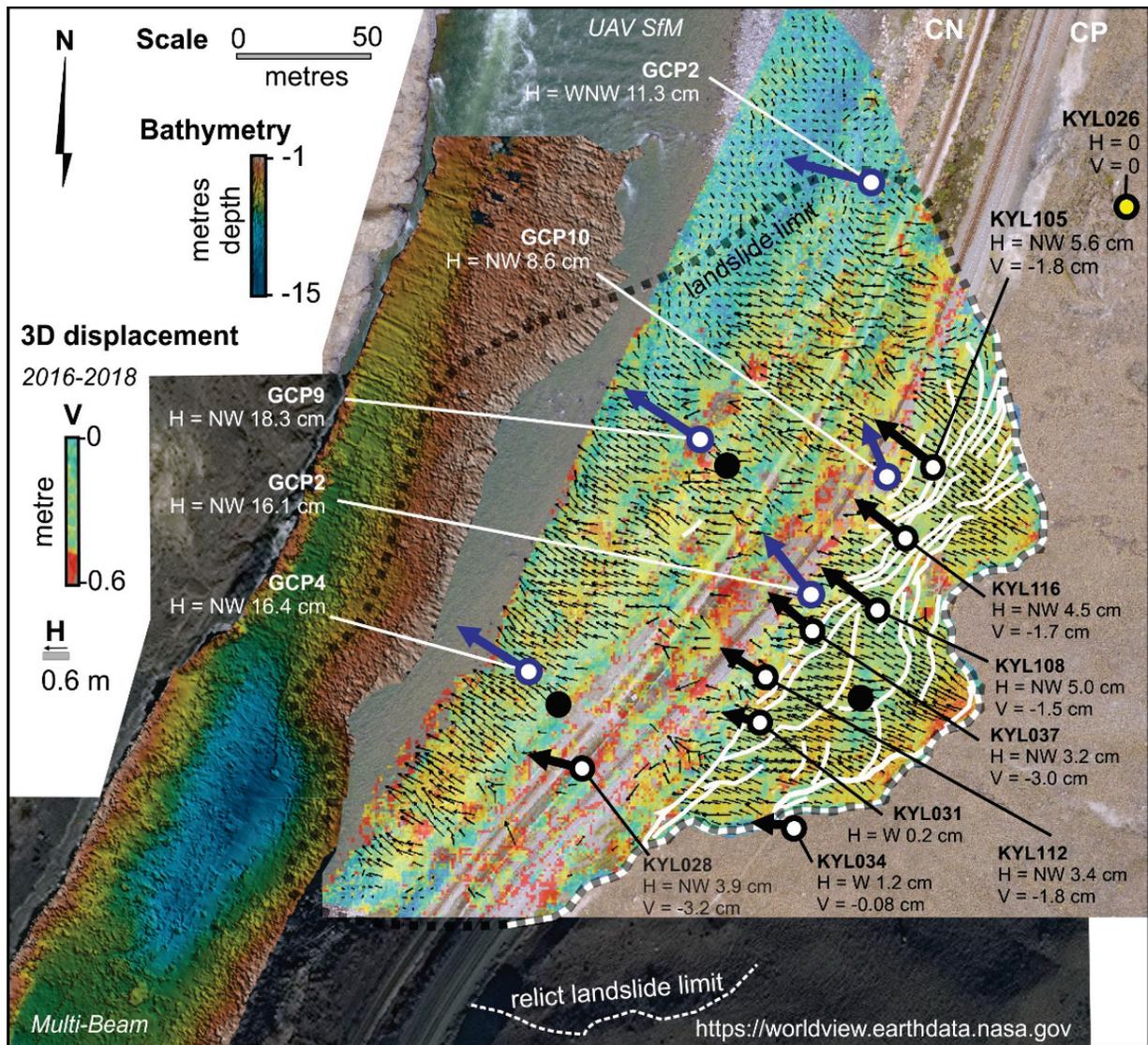


Fig. 46 Surface displacement data derived from UAV overflights in 2016 and 2018 and multi-beam bathymetry data collected in 2018; plotted with Geocube displacement data (November 2018 to June 2019). Figure also merges multi-beam bathymetry data of Thompson River with an outline of Ripley Landslide mapped from a WorldView-2 image of the study site. Stable Geocube – yellow dot; active Geocube – black and white dot; inactive Geocube – black dot. Active GCP - blue dot.

Evaluation of Geocubes

Together with RTK and UAV surveys, Geocube spatial data are helping landslide researchers understand the behaviour and drivers of slope instabilities affecting rail transport in the Thompson River valley. Detailed examination of Geocube records is providing new insight on the rates and spatial pattern of creep, and also on the timing and possibly precursors of changes in creep behaviour. The locations of highest displacement rates as indicated by the Geocube network can be used to identify where track damage will be expected if creep continues across Ripley Landslide. The spatial variability in landslide motion is a surface expression slope failure involving complex interactions between structurally separate blocks.

Comparing displacement trends with temperature, precipitation, river level, and ground resistivity will help establish landslide warning thresholds based on environmental conditions.

The way ahead

A number of issues are contributing to lengthy installation and evaluation periods, including personnel, wildlife, technical and environmental concerns. *Personnel issues*: other GSC project commitments limit access time to the technical support required to install and maintain the networks, and process data. *Wildlife issues*: several units have been damaged by deer, rodents and other large mammals, requiring innovative methods to protect cables and hardware. Cable damage by wildlife and lack of battery power prevented the system from functioning throughout the greater parts of 2015, 2016 and 2017. These issues were addressed between November 2017 and October 2018 through the addition of protective wrappings to cables and through the adjustment of Geocube and solar panel positions, and installation of upgraded batteries and battery boxes. *Technical issues*: as an experimental system, software updates and changes in product designs require frequent re-installation and re-calibration of Geocube networks in the Thompson River valley. *Environmental issues*: the Thompson River valley is an extremely harsh environment for electronic systems, so additional time has been spent making hardware more rugged and weatherproof. By November 2018, the Geocube networks at Ripley Landslide and South Slide were fully “ruggedized” and linked via remote internet connections to updated data processing software.

A future research goal will be to develop a Geocube monitoring protocol and tools that capture patterns and rates of movement, and changes in landslide activity. Comparing displacement trends with temperature, precipitation, river level, and ground resistivity will help establish landslide warning thresholds based on environmental conditions, and will be used to forecast pending failures.

Acknowledgements

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