2023 CMAR Sea Ice Mapping

Presented to

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Executive Summary

1. Introduction

The Nova Scotia Community College Applied Geomatics Research Group (NSCC-AGRG) was contracted by the Center for Marine Applied Research (CMAR) to generate sea ice map products to support CMAR's coastal exposure monitoring initiative.

The goal of the project was to map sea ice development around the province of Nova Scotia using historical (2006 to present) sea ice charts and derived data products. Historical data were available as weekly releases for an 18-year period (n = 936) that covered the Maritimes, with a focus on Nova Scotia, to a distance of at least 3 km offshore (Figure 1). NSCC-AGRG compiled the available data and developed a database of ice formation extents and characteristics at a 100 m by 100 m (1 ha) spatial resolution. AGRG developed logic to calculate ice observations over seasonal intervals for each spatial index by evaluating all database records.

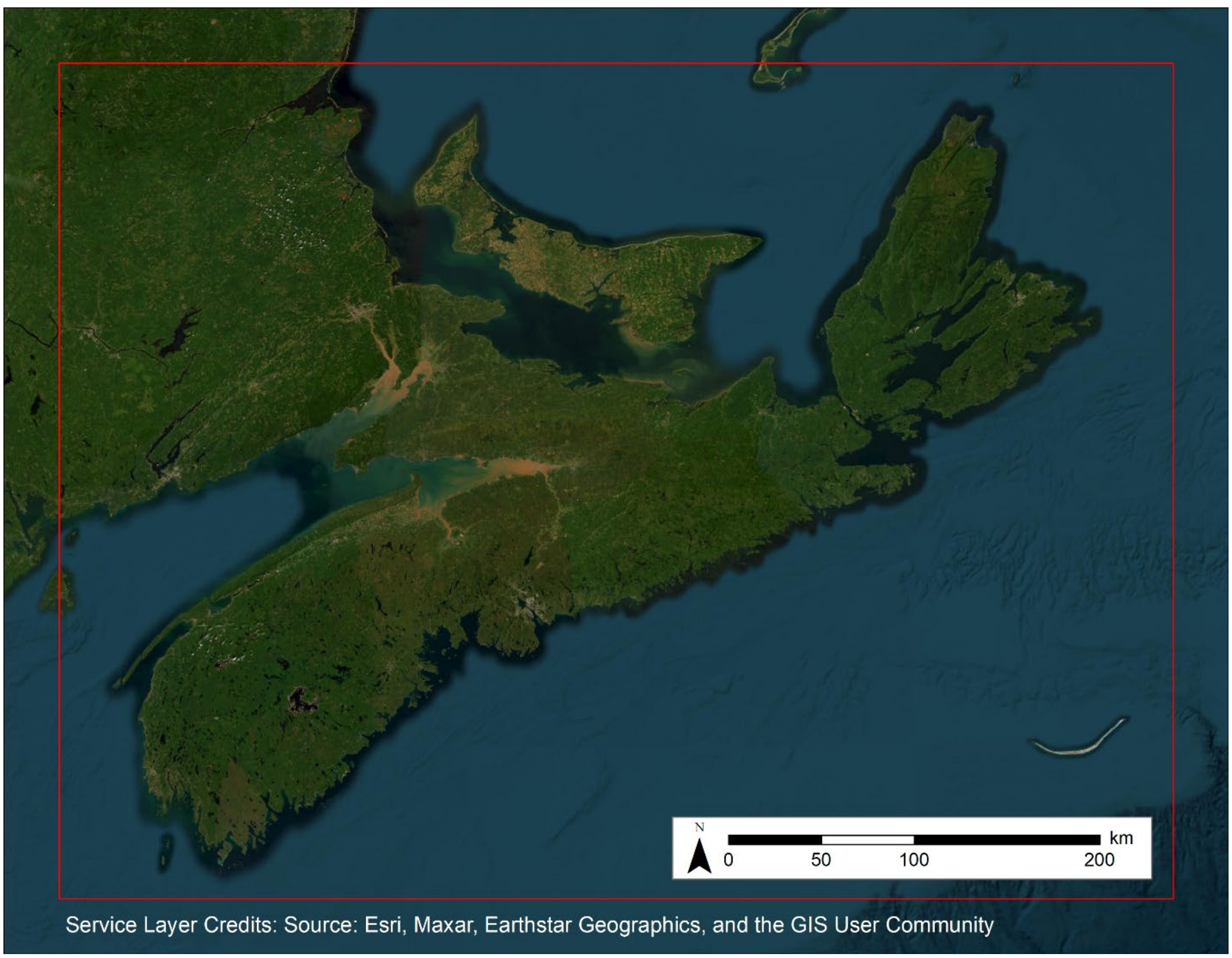


Figure 1. Mapping area of interest (delineated red box) focused on Nova Scotia to a distance of greater than 300 m offshore.

2. Methods

Data Acquisition and Format

Sea ice data were retrieved from the International Ice Charting Working Group for the World Meteorological Organization (IICWG) as vectorized Sea Ice Grid (SIGRID-3) layers which represented Canadian Ice Service (CIS) weekly maps 2006 – 2023 (n = 936). Ice layers were attributed with fields which closely resembled egg codes used by CIS (Figure 2; Figure 3).

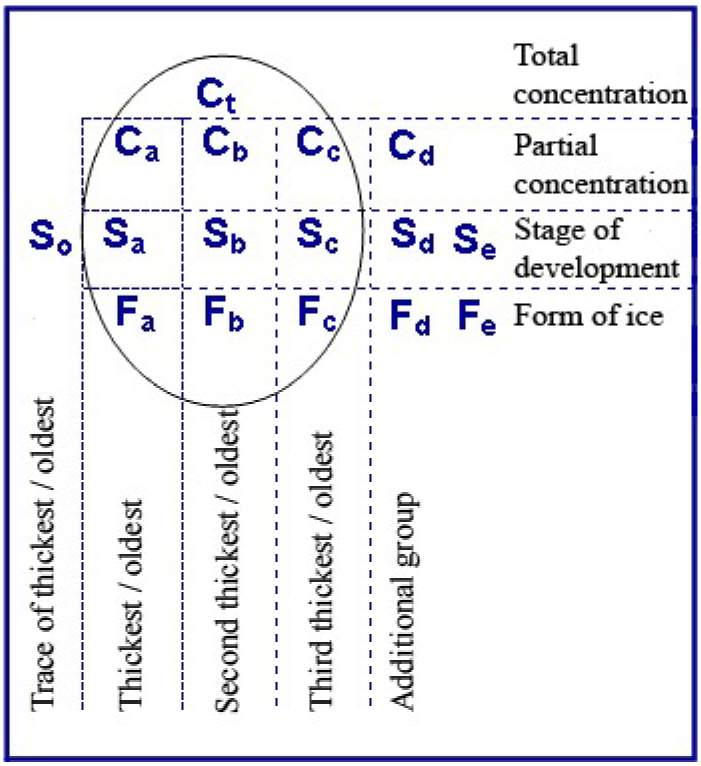


Figure 2. CIS egg code definitions for concentration, stage, and form.

3	CT	Text	2	42-43	Table 4.1	Total concentration
4	CA	Text	2	44-45	Table 4.1	Partial concentration of thickest ice
5	SA	Text	2	46-47	Table 4.2	Stage of development of thickest ice
6	FA	Text	2	48-49	Table 4.3	Form of thickest ice
7	CB	Text	2	50-51	Table 4.1	Partial concentration of second thickest ice
8	SB	Text	2	52-53	Table 4.2	Stage of development of second thickest Ice
9	FB	Text	2	54-55	Table 4.3	Form of second thickest ice
10	CC	Text	2	56-57	Table 4.1	Partial concentration of the third thickest ice
11	SC	Text	2	58-59	Table 4.2	Stage of development of third thickest ice
12	FC	Text	2	60-61	Table 4.3	Form of third thickest ice
13	CN	Text	2	62-63	Table 4.2	Stage of development of ice thicker than SA but with concentration less then 1/10
14	CD	Text	2	64-65	Table 4.2	Stage of development of any remaining class of ice
15	FP	Text	2	66-67	Table 4.3	Predominant form of ice
16	FS	Text	2	68-69	Table 4.3	Secondary form of ice
17	Poly_type	Text	1	70	Table 4.4	
18…56	Optional fields, see Appendix 4 Table 3.3.	Text			Tables 4.5 - 4.15	

Figure 3. SIGRID-3 layer fields which closely resemble CIS egg codes for concentration, stage, and form.

The CT, SA, and FA fields were selected for use during data analysis to define the concentration, stage, and form of ice respectively. While the additional fields contained useful information pertaining to the non-dominant ice, these fields often contained undefined values and were found to produce sporadic results when added to the data analysis.

Each of the SIGRID-3 fields were coded with variable definitions that categorized ice concentration (Figure 4), stage (Figure 5), and form (Figure 6). These variable definitions were used to identify the minimum threshold for an ice observation which presented a risk. An observation was only counted if all minimum concentration, stage, and form requirements were met.

Definition	Code Figure
Ice Free	55
Less than 1/10 (open water)	01
Bergy Water	02
1/10	10
2/10	20
3/10	30
4/10	40
5/10	50
6/10	60
7/10	70
8/10	80
9/10	90
10/10	92

Concentration intervals (lowest concentration in interval followed by highest concentration in interval)	
9/10 –10/10 or 9+/10	91
8/10 – 9/10	89
8/10 – 10/10	81
7/10 – 9/10	79
7/10 – 8 /10	78
6/10 – 8/10	68
6/10 – 7/10	67
5/10 – 7/10	57
5/10 – 6/10	56
4/10 – 6/10	46
4/10 – 5/10	45
3/10 – 5/10	35
3/10 – 4/10	34
2/10 – 4/10	24
2/10 – 3/10	23
1/10 – 3/10	13
1/10 – 2/10	12
Undetermined / Unknown	99

Figure 4. SIGRID-3 ice concentration definitions with threshold values highlighted.

Stage of Development	Thickness	Code Figure
Ice Free		55
Brash Ice	Given by AV, AT, AM, AT in Table 3.3	70
No Stage of Development		80
New Ice	< 10 cm	81
Nilas, Ice Rind	< 10 cm	82
Young Ice	10 - <30 cm	83
Grey Ice	10 - <15 cm	84
Grey - White Ice	15 - <30 cm	85
First Year Ice	≥30 - 200 cm	86
Thin First Year Ice	30 - <70 cm	87
Thin First Year Stage 1	30 - <50 cm	88
Thin First Year Stage 2	50 - <70 cm	89
For Later Use		90
Medium First Year Ice	70 - <120 cm	91
For Later Use		92
Thick First Year Ice	≥120 cm	93
For Later Use		94
Old Ice		95
Second Year Ice		96
Multi-Year Ice		97
Glacier Ice		98
Undetermined/Unknown		99

Figure 5. SIGRID-3 ice stage definitions with threshold values highlighted.

Form	Size/Concentration	Code Figure
Pancake Ice	30 cm - 3 m	22
Shuga/Small Ice Cake, Brash Ice	< 2 m across	01
Ice Cake	< 20 m across	02
Small Floe	20 m - 100 m across	03
Medium Floe	100 m - 500 m across	04
Big Floe	500 m - 2 km across	05
Vast Floe	2 km - 10 km across	06
Giant Floe	> 10 km across	07
Fast Ice		08
Growlers, Floebergs or Floebiits		09
Icebergs		10
Strips and Patches	concentrations 1/10	11
Strips and Patches	concentrations 2/10	12
Strips and Patches	concentrations 3/10	13
Strips and Patches	concentrations 4/10	14
Strips and Patches	concentrations 5/10	15
Strips and Patches	concentrations 6/10	16
Strips and Patches	concentrations 7/10	17
Strips and Patches	concentrations 8/10	18
Strips and Patches	concentrations 9/10	19
Strips and Patches	concentrations 9+/10	91
Strips and Patches	concentrations 10/10	20
Level Ice		21
Undetermined/Unknown		99

Figure 6. SIGRID-3 ice form definitions with threshold values highlighted.

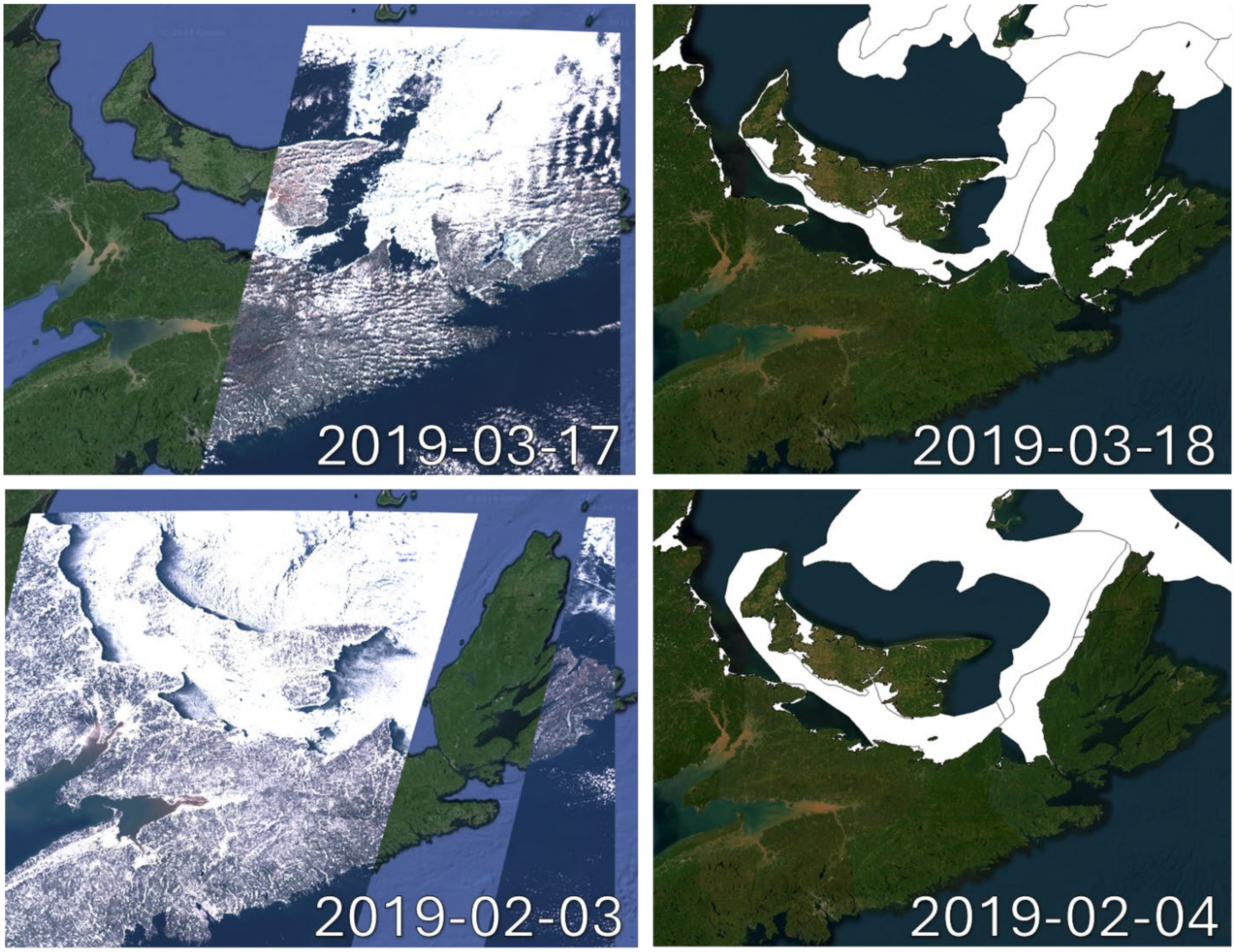
Data Processing

NSCC-AGRG developed Python code to apply the selected concentration, stage, and form threshold values to the acquired SIGRID-3 data and generate map products. The developed logic thresholds the weekly ice chart data from 2006 to 2024 and produces products in under 10 minutes. Concentration, stage, and form thresholds can be adjusted by the user to fine-tune the results. NSCC-AGRG have presented best estimates for reasonable threshold definitions and have generated preliminary results based on these values.

Validation

Satellite observations were acquired from the Copernicus SENTINEL-2 system to validate ice map extents generated using the preliminary threshold values. Predominantly cloud free images were obtained between 2016 and 2024 and were cataloged online to facilitate future comparisons.

(https://ee-thomallagrg.projects.earthengine.app/view/s2-iceseason-ns). Ice map products were selected based on nearest date for comparison and qualitative validation for 2019 (), 2020 (), 2021 (), 2022 (), and 2023 ().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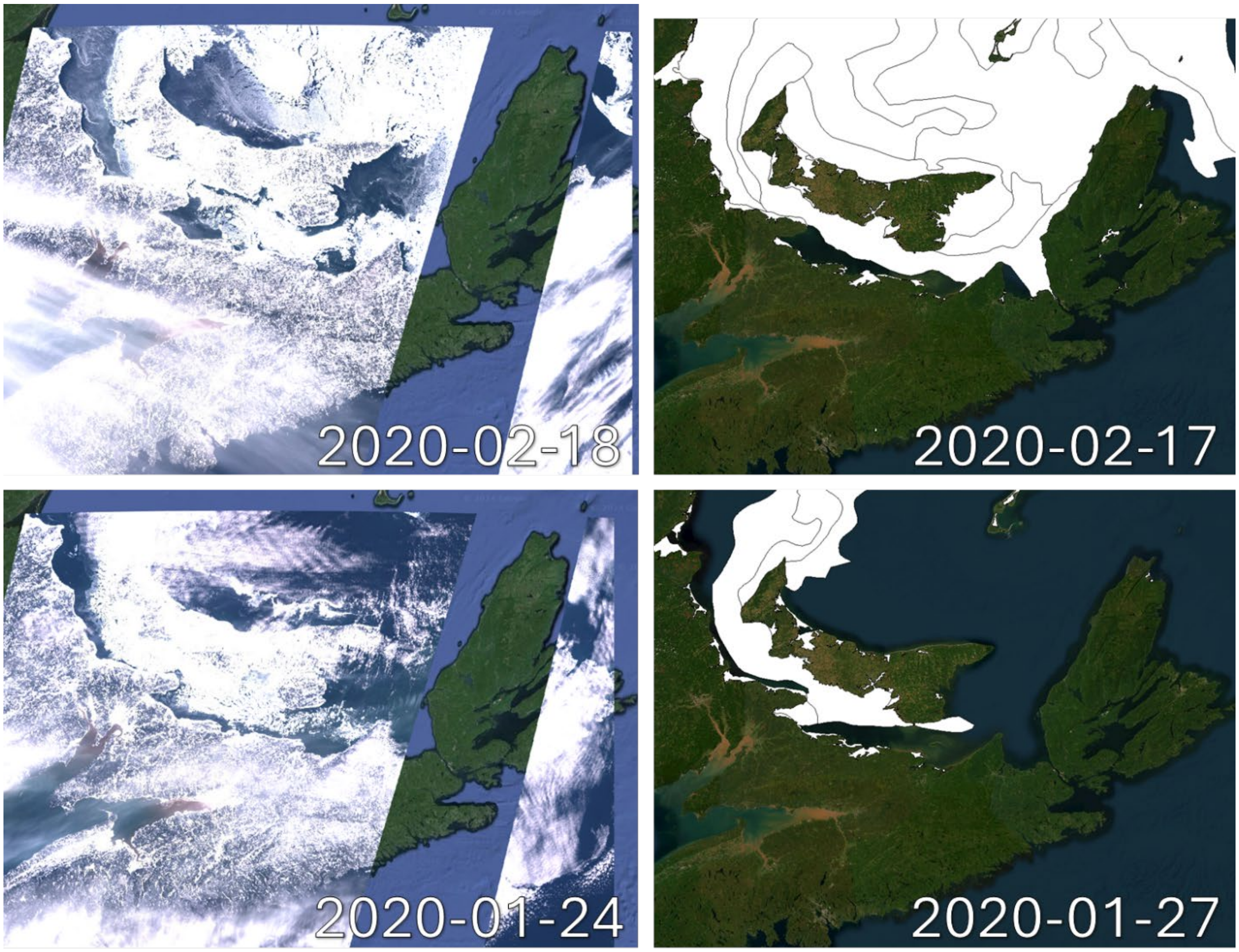
2019-02-04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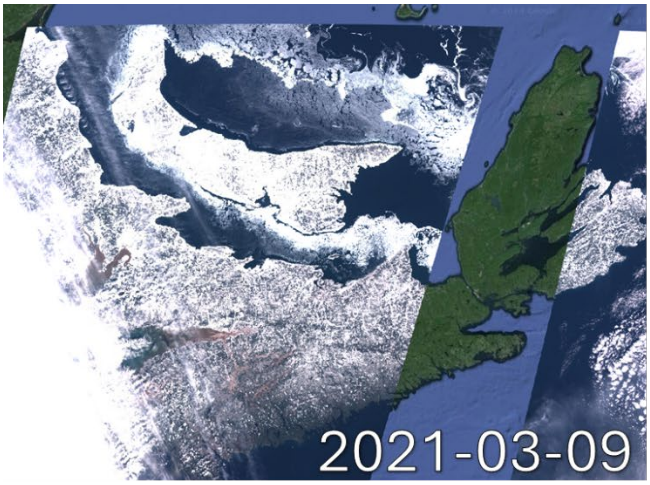
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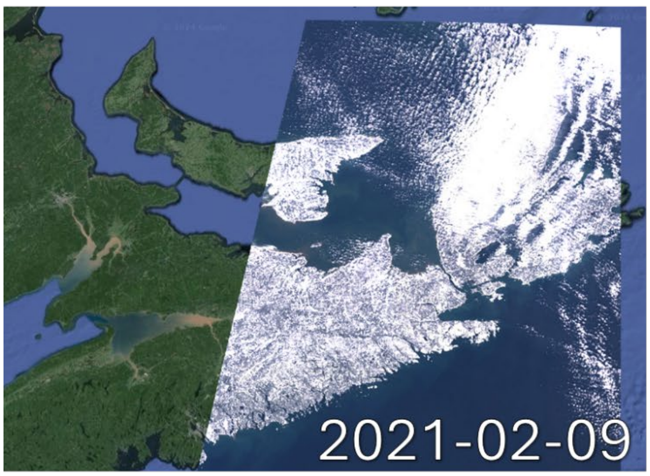
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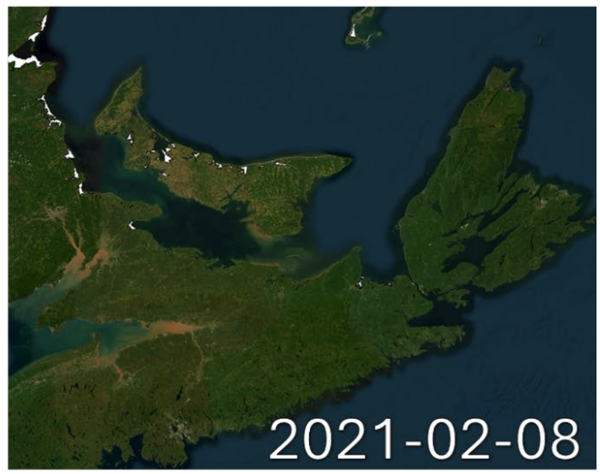
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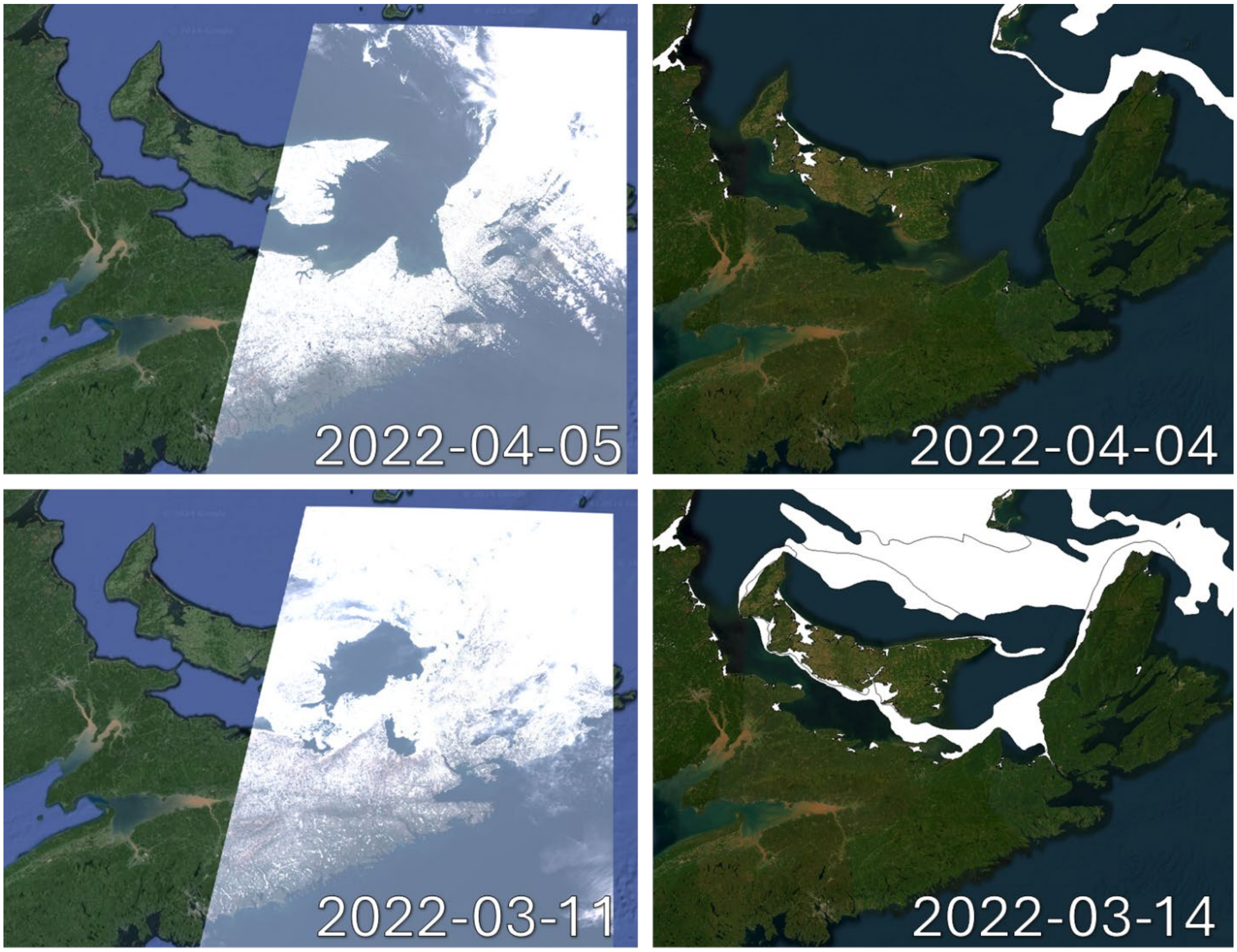
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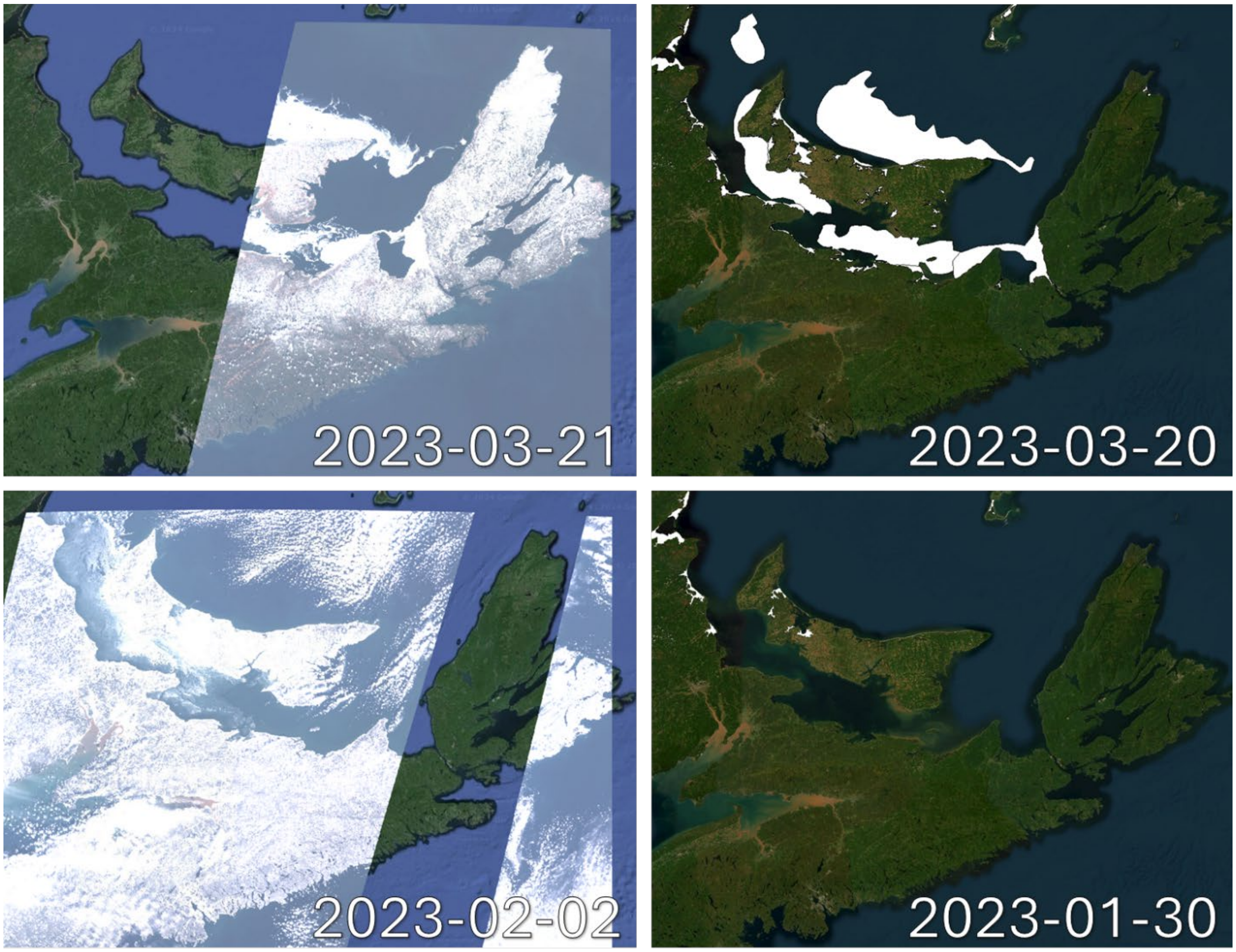
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2023-03-20
2023-02-02
2023-01-30

Figure 7. H20T 120 meter AGL calibration curve.

3. Results

3-1 Raster Datasets

All three rivers were collected in their entirety in the month of September 2023. Round Hill was completed across three days, yielding 19 thermal rasters. Gold River was completed across four days, yielding 18 thermal rasters. Lastly, Skye River was completed in one day, yielding 8 thermal rasters. Further information can be found in *Table 1*. For each thermal orthomosaic raster, there is a corresponding RGB orthomosaic generated from the RGB imagery that was collected during the same flight. The RGB orthomosaics cover a slightly larger area than the thermal rasters because of the size of the individual RGB image frame and camera field of view. Thermal imagery and orthomosaic data products cover the entirety of the river AOIs as the flight planning was done with this taken into consideration.

Table 1. Data products by river and day.

River/Collection Area	Date	Rasters
Round Hill	September 7th, 2023	5 thermal, 5 RGB
	September 8th, 2023	9 thermal, 9 RGB
	September 21st, 2023	5 thermal, 5 RGB
Gold River	September 12th, 2023	5 thermal, 5 RGB
	September 13th, 2023	3 thermal, 3 RGB
	September 22nd, 2023	9 thermal, 9 RGB

	September 26th, 2023	1 thermal, 1 RGB
Skye River	September 27th, 2023	8 thermal, 8 RGB

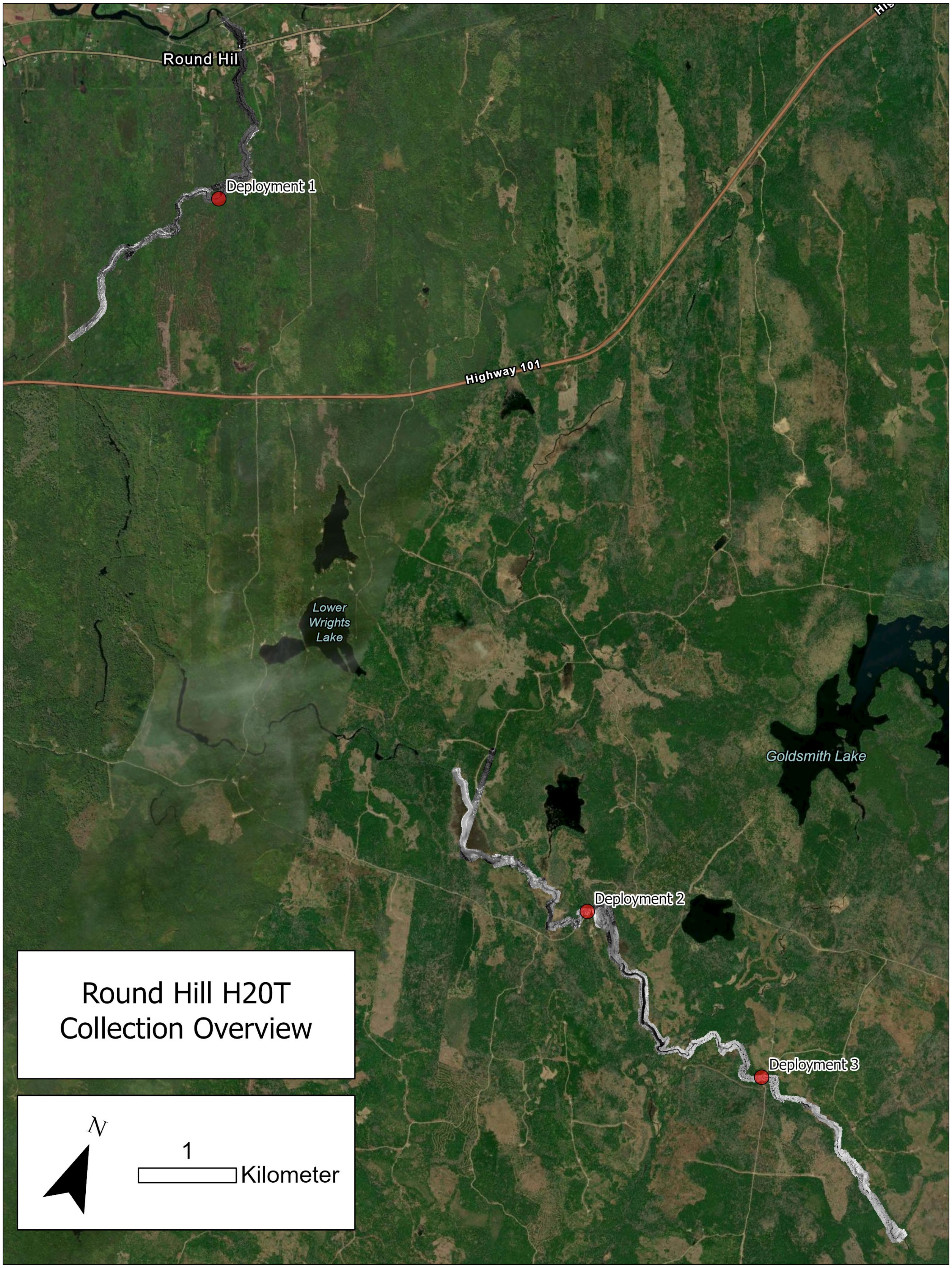

Figure 8. Round Hill collection data overview. CMAR's temperature sensor deployments marked.

Figure 9. Round Hill downriver data overview. CMAR's temperature sensor deployments marked.

Figure 10. Round Hill upriver data overview. CMAR's temperature sensor deployments marked.

Figure 11. Gold River data collection overview. CMAR's temperature sensor deployments marked.

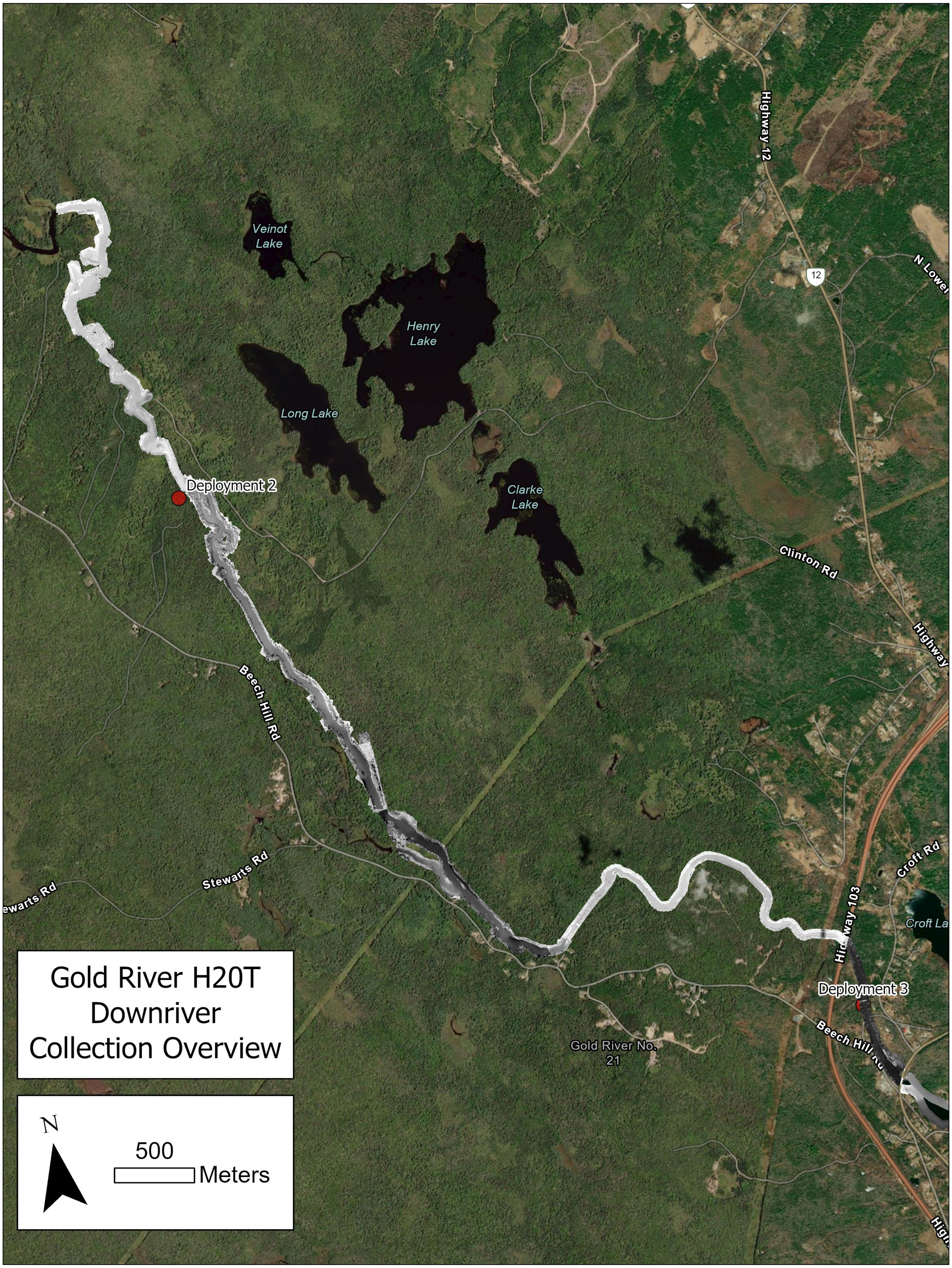

Figure 12. Gold River downriver data collection overview. CMAR's temperature sensor deployments marked.

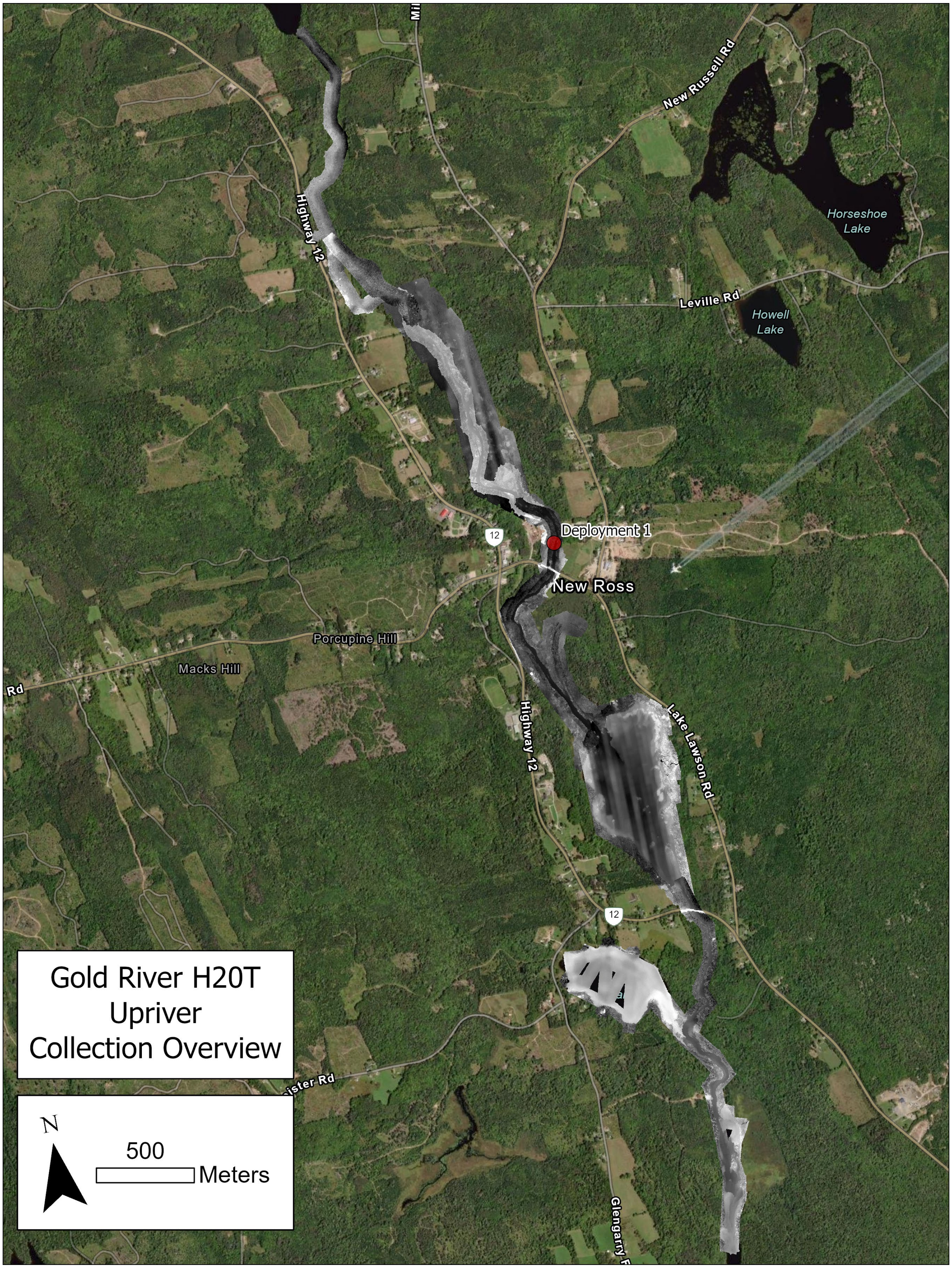

Figure 13. Gold River upriver data collection overview. CM'R's temperature sensor deployment location marked.

Figure 14. Overview of the data collected for the Skye River AOI. CMAR's temperature sensor deployments marked.

4. Discussion

4-1 Challenges

Throughout the duration of the project, AGRG was met with various challenges to adapt and respond to. The weather proved to be a challenge, and determining when to fly came with the need to prioritize risks. Due to the timing on when the project was approved and signed off on, AGRG was left without much summer weather to heat up the river water across all the sites. Multiple days of rain across September also left AGRG waiting days at a time for water levels to drop back down to what they were on previous days of collection. Towards the end of September, Skye had to be flown when it was relatively cold, as waiting any longer would have risked it being even colder, or having it rain again and further delay the collection.

Poor cell network coverage in rural areas limited the use of RTK for the duration of the trip. For the M300 or GS14 to receive their real time corrections, they need access to the internet. Being mobile devices meant for use in the field, the M300 and GS14 each have their own SIM cards and subscription to cell network data plans that provide them with internet wherever there is coverage. As mentioned, many of the areas flown early in the project were very rural and had no or extremely limited network reception. This meant that RTK was not available to the field crew. Post-processing procedures were developed early in the project to assure RTK availability was not a limiting factor.

Perhaps the most challenging aspect of the fieldwork portion of the project was finding locations to take off to fly a given section of the river. When choosing where to take off and land, the RPAS operator needs to consider where there's enough space to takeoff and land safely. For the section of the river being flown, the RPAS needs to be visible to the operator and the visual observer, restricting how far can be flown from the point of takeoff. Round Hill proved to be the most challenging of all the areas by far. There were few roads near the river, even fewer of which were paved the further you travel upriver, with some of the "roads" marked on Google Maps being completely overgrown by trees. Two examples of these conditions can be seen in *Figure 24* and *Figure 25*. Closely related to this issue is the issue of access to the rivers themselves. Areas that were both suitable for RPAS operations and had access to the river to collect ground truth data often did not overlap, leaving fewer than desired ground truth points to work with.

Figure 15. Trees blocking a path in Round Hill.

Figure 16. Example of the "roads" used for river access seen around Round Hill.

4-2 River Conditions

With the exception of Skye River, which was collected all in one day, effort was made to fly each river at roughly the same water level based on the gauge being monitored. However, due to reasons discussed in the previous section, flying at the same water level each time was not possible. As we can see in *Figure 26, Figure 27*, and *Figure 28*. Water levels for the Middle River Cape Breton gauge monitored for Skye River with the day flown indicated. AGRG managed to collect data while avoiding peaks in water level.

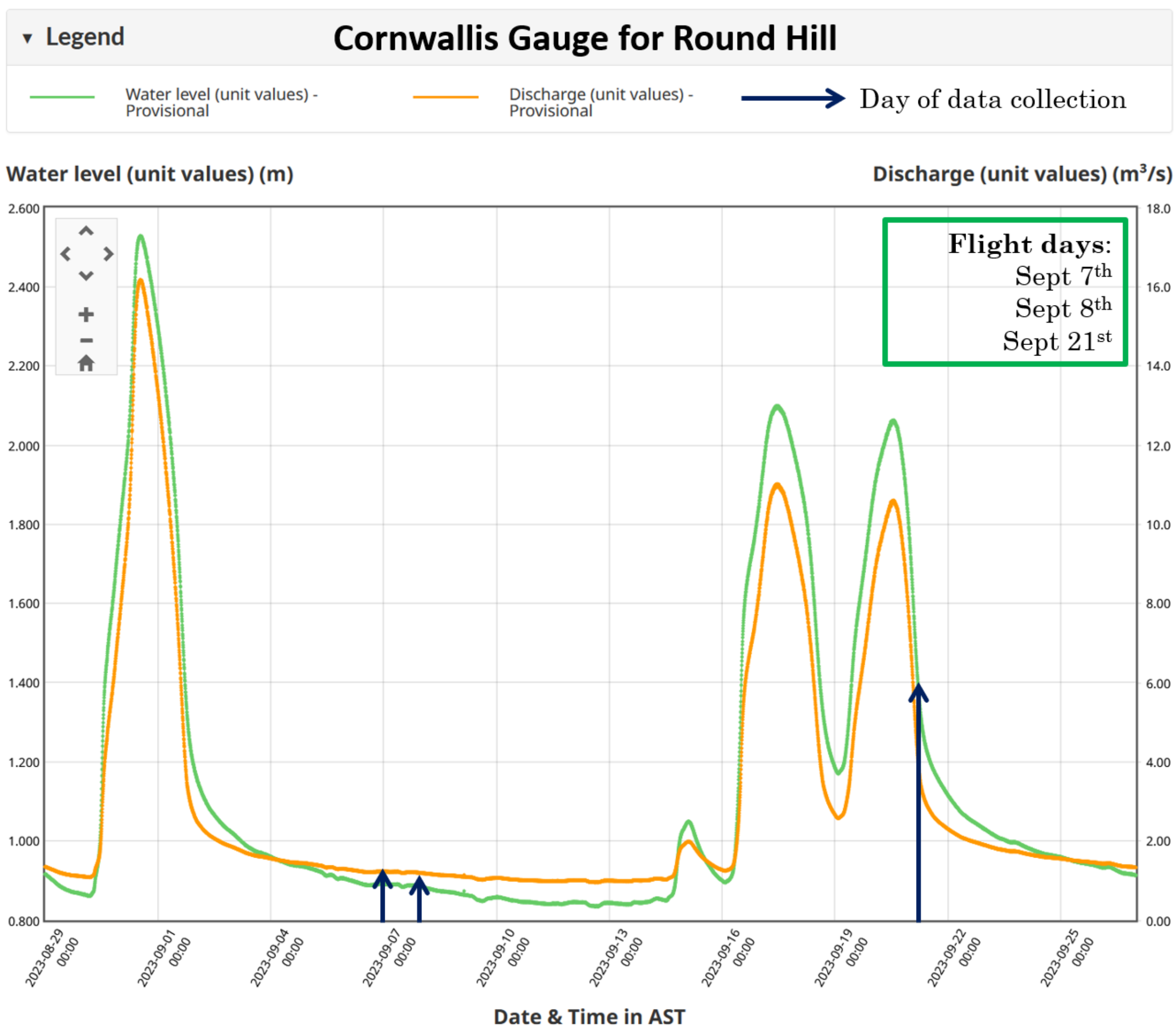

Figure 17. Water levels for the Cornwallis gauge monitored for Round Hill with days flown indicated.

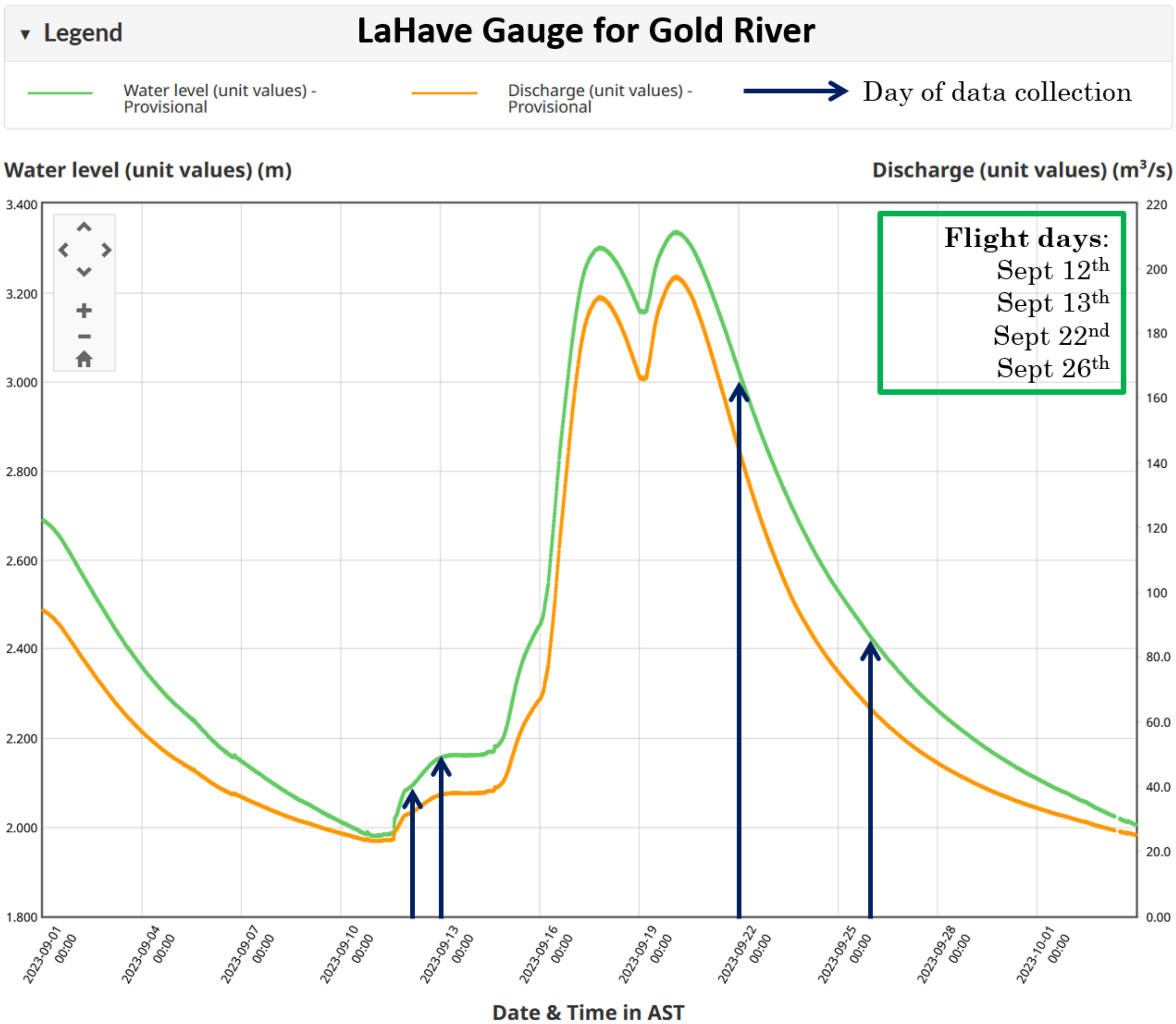

Figure 18. Water levels for the LaHave gauge monitored for Gold River with days flown indicated.

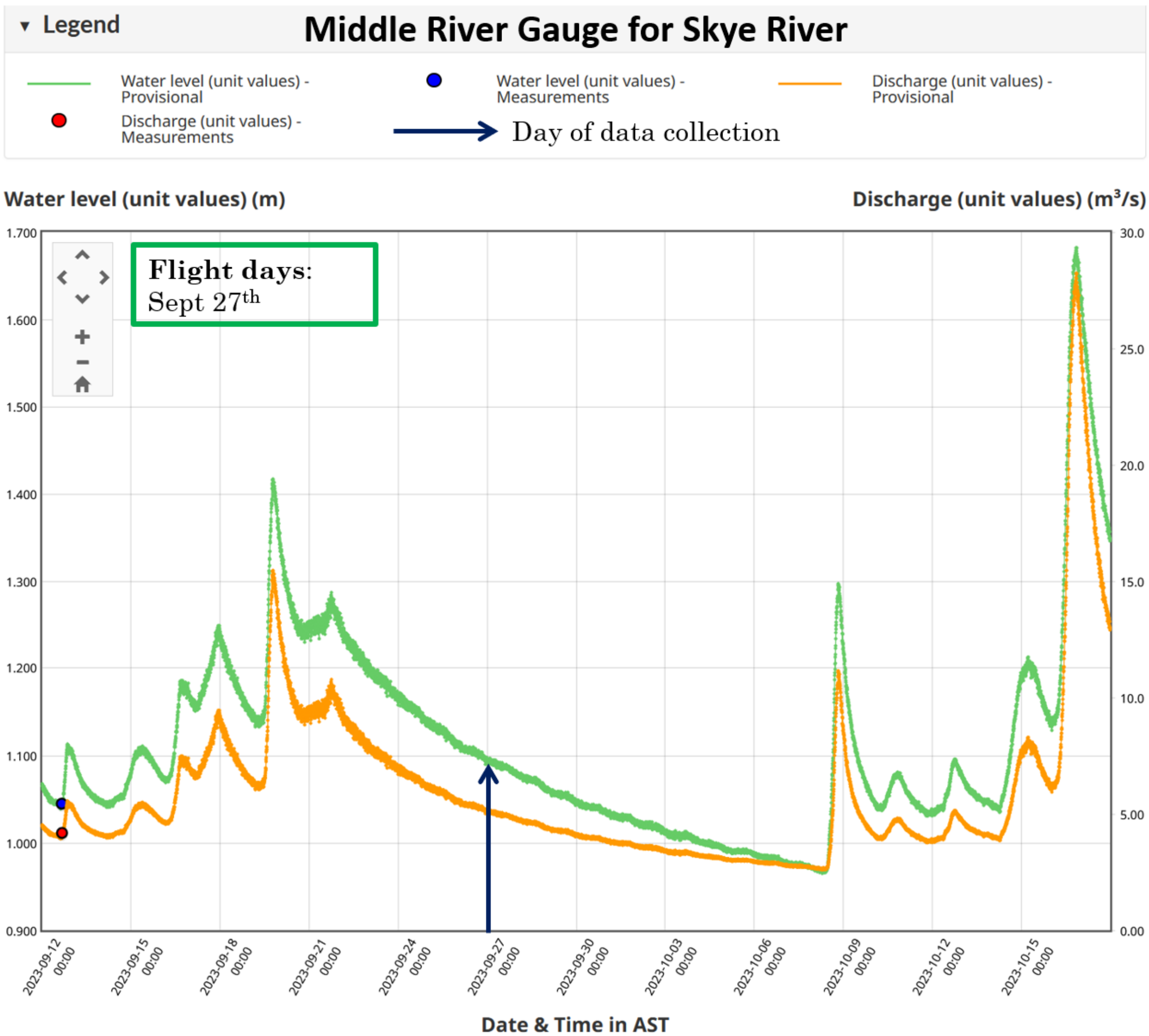

Figure 19. Water levels for the Middle River Cape Breton gauge monitored for Skye River with the day flown indicated.

4-3 Ground Truth

Across all rivers, a total of 16 ground truth points were collected. The majority of these were gathered in Gold River (9), with 5 in Round Hill, and two in Skye. Additionally, AGRG was provided with data from CMAR's U22 sensors deployed in the rivers flown to use for ground truth. Unfortunately, many sensors were lost over the field season, leaving only one sensor from Gold River, and three in Round Hill. None were retrieved from Skye River.

Comparison of in-situ temperature observations to H20T measurements yielded variable results (*Table 2*, *Figure 29*). Several factors were identified as having an impact on the H20T measured values including cloud cover, ambient temperature, local humidity, sun angle, wind, and image orientation. Unfortunately, the impact of these variables on H20T values were ambiguous and could not be resolved to systematically improve results. While we are confident that local frames can be adjusted to better match the in-situ measurement points, too few points exist to extend this confidence to the larger flight areas. It is advised that: additional care be taken to record pertinent environmental data during the thermal flights, additional in-situ measurements are taken to better represent a larger ranges of temperature values, the H20T locked in a fixed, or sun-facing orientation for all flights.

Table 2. In-situ U22 temperature logger measurements versus H20T pixel temperature values showing a tendency to underestimate remotely sensed values.

PointID	u22 Observation (°C)	H20T Pixel (°C)	Residual (°C)
SR002	10.93	9.60	-1.33
GR001	22.49	18.31	-4.18
GR002	23.04	16.54	-6.50
GR003	23.23	16.90	-6.33
GR004	22.61	20.30	-2.31
GR005	16.88	13.88	-3.00
GR006	17.06	11.52	-5.54
GR007	16.99	12.70	-4.29
GR008	16.96	12.77	-4.19
GR009	12.34	7.46	-4.88
RH001	21.68	19.34	-2.34
RH002	21.15	15.06	-6.09
RH003	21.1	16.54	-4.56
RH004	20.89	17.05	-3.84
RH005	23.16	17.72	-5.44
GRC01	15.581	12.26	-3.32
RHC01	20.412	15.50	-4.91
RHC02	21.079	15.58	-5.50
RHC03	20.222	16.54	-3.69

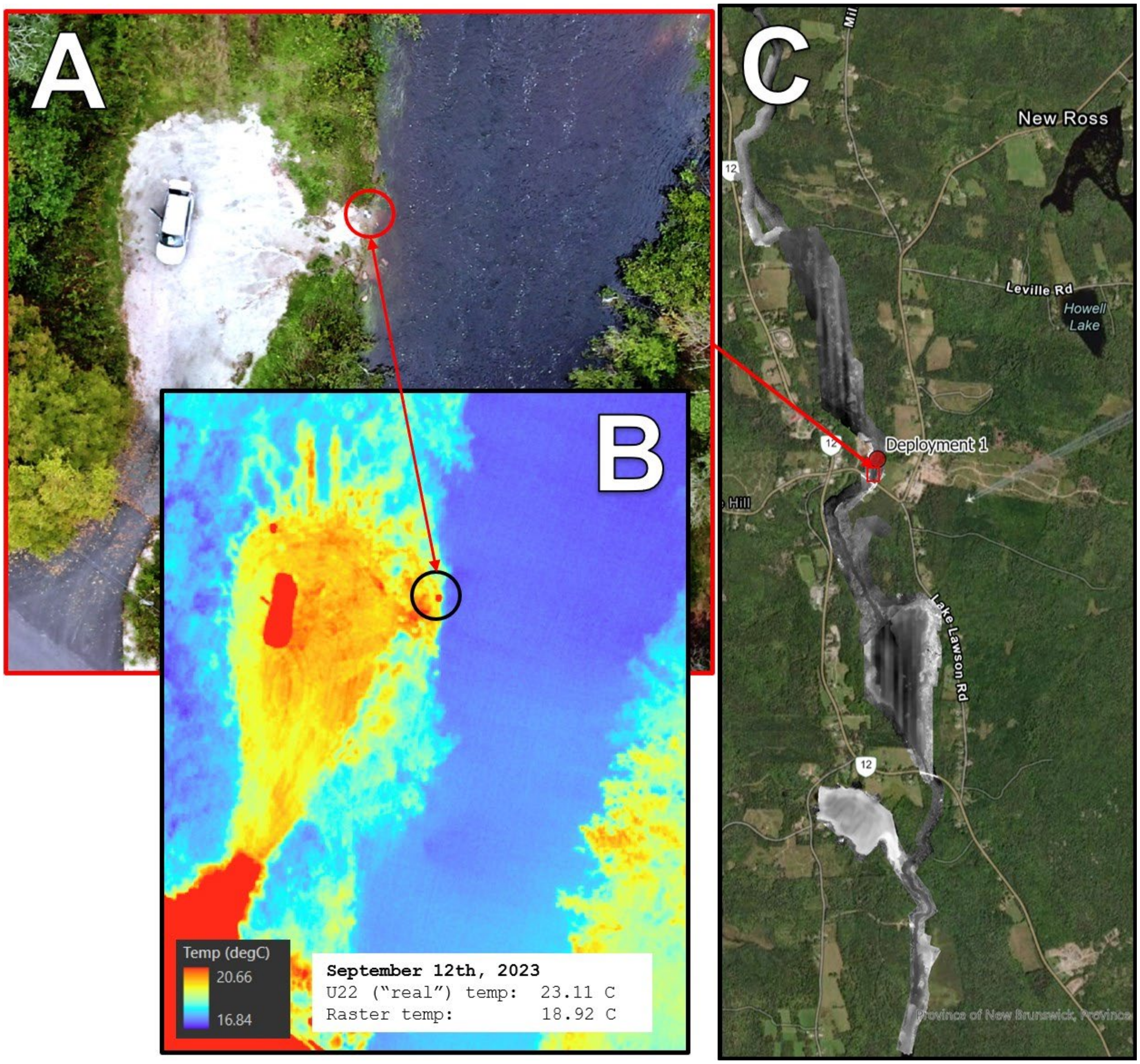

Figure 20. Example ground truth site from Gold River on September 12th, 2023. **A** – RGB orthomosaic for the data seen in B. **B** – Thermal image for the corresponding frame in A. Note the difference between the "real" temperature from the ground truth sensor and the temperature value from the adjusted H20T data (correction has been applied). **C** – Location of data in an overview of the upriver section of Gold River.

It should be noted that relative temperature fluctuations are well represented in the data despite poor absolute recordings. These relative differences are important in identifying warmwater intrusion (*Figure 30*) and cool water pools (*Figure 31*).

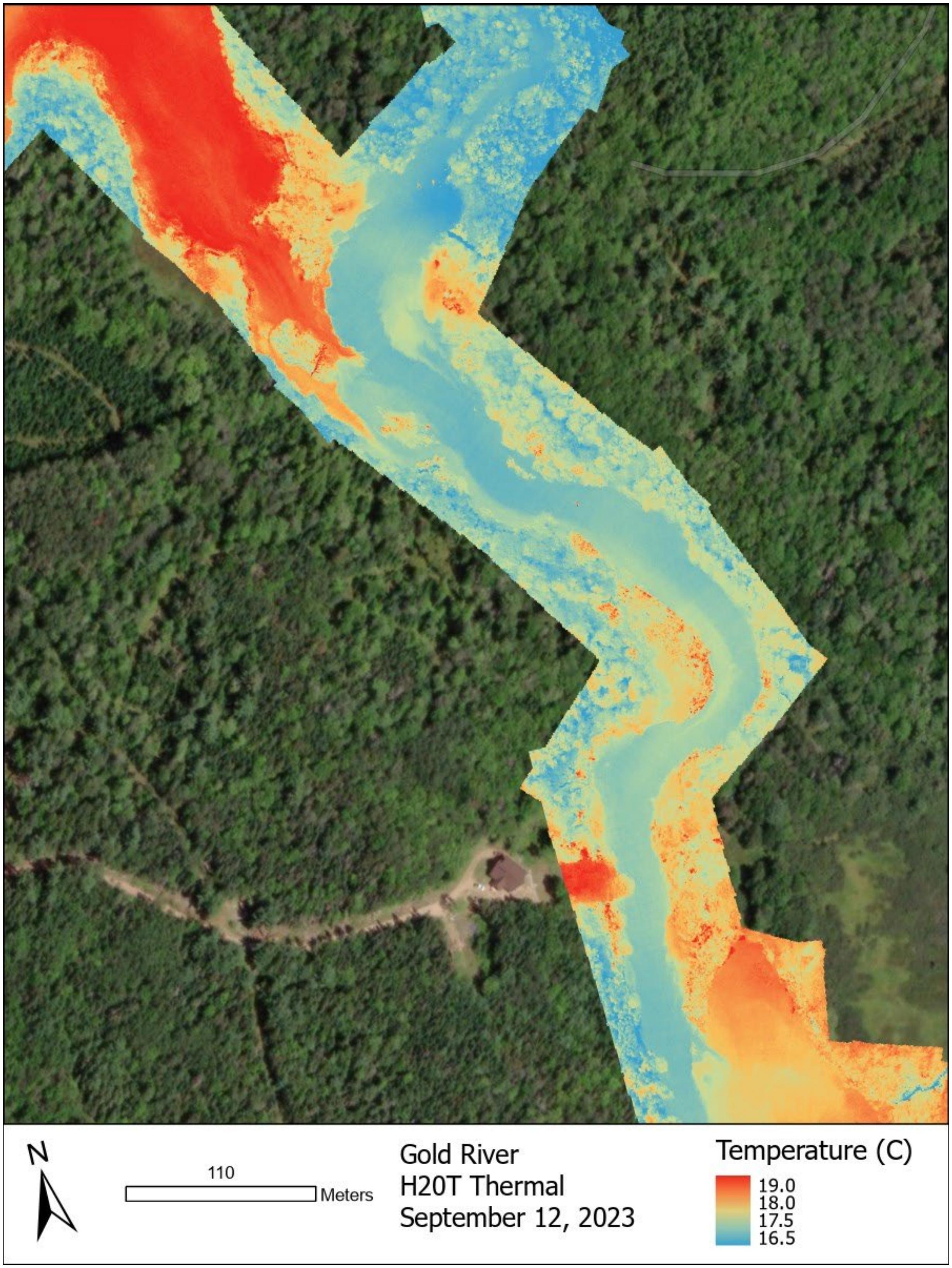

Figure 21. H20T imagery showing a warm western body of water mixing with the cooler main branch of Gold River.

Figure 22. H20T thermal imagery showing a cool pool and reach of water separated by warmer bend.

International Ice Charting Working Group | National Snow and Ice Data Center (nsidc.org)

https://nsidc.org/home