SWOT HR
LAKE FIELD DATA COLLECTION

Roger Fjørtoft, Nicolas Picot
on behalf of the Cal/Val Team

SWOT VALIDATION MEETING, CHAPEL HILL, NC
18 JUNE 2024

OUTLINE

LAKE VALIDATION APPROACH

General features

- Collection of reference data mainly for Water Surface Elevation (WSE) and area

- Dedicated in situ measurements and acquisition of high-resolution satellite images
  - Mainly during Cal/Val period (1-day orbit, March 30th – July 10th 2023)
  - Heterogeneous in situ equipment and preprocessing

- Extensive use of existing gauges and publicly available satellite data
  - Additional leveling activities and preprocessing

- Comparison with SWOT LakeSP data on a large number of PLD lakes worldwide
  - No strong distinction made between Tier 1 and Tier 2 sites (similar accuracy)

- The reference data are targeted to be more accurate than SWOT requirements, but they are not perfect
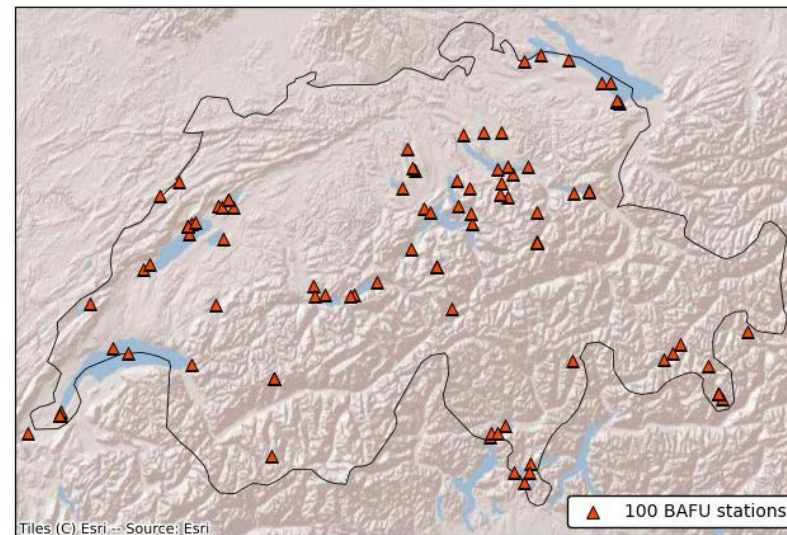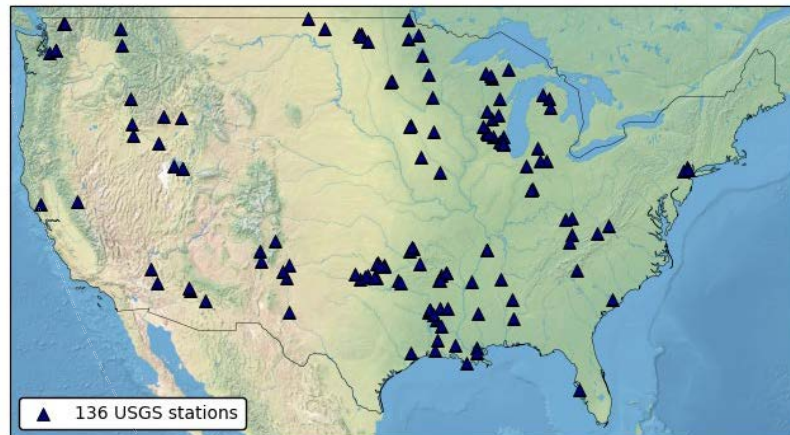
LAKE WSE REFERENCE DATA

Overview

- Sites and data sources used for lake WSE mission validation:
  - Gauge networks in USA and Europe : USGS, BAFU, NVE, SMHI...
  - Canadian lakes
  - US lake sites
  - Lakes in Eastern France
  - Lakes in the Pyrenees, France (OECS/LOCSS)
  - Lakes in Ceara, Brazil
  - Lakes in Western Africa
  - Issykkul, Kyrgyzstan (for specific studies on slope, geoid variations, not addressed here)
- Assignment of gauges based on intersection with Prior Lake Database (PLD) polygons
- Conversion to WSE w.r.t. EGM2008 geoid for gauges with precise native leveling
  - Use of IceSat-2 data to level all other gauges

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USE OF EXISTING GAUGE NETWORKS COVERING LAKES IN USA AND EUROPE

- The bulk of the reference WSE data for validation of SWOT lake WSE comes from existing gauge networks, including the following ones in USA and Europe:
  - USGS (USA)
  - BAFU (Switzerland)
  - NVE (Norway)
  - SMHI (Sweden)

136 USGS stations

Tiles (C) Esri -- Source: Esri

100 BAFU stations

Cal/Val and Science phases

243 NVE stations   16 SMHI stations

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# USE OF EXISTING GAUGE NETWORKS COVERING LAKES IN USA AND EUROPE

- Such gauge networks typically provide WSE measurements at least hourly (down to every few minutes).

- The relative precision is generally very good (cm-level or below).

- For validation of SWOT LakeSP WSE, we need absolute reference WSE w.r.t. to the EGM2008 geoid, with a targeted accuracy well below the WSE science requirement (10 cm).

- The four networks are, at least for part of the gauges, natively leveled in a national or regional reference system.
  - BAFU gauges are all very precisely leveled, so the native leveling was used.
    - Conversion to EGM2008 (with WGS84 as an intermediate step)
  - For USGS, NVE and SMHI this approach was less successful, with also many unleveled gauges.
    - Leveling based on IceSat-2 was therefore performed (next slide) .
      - IceSat-2 was also used to quality-check natively leveled gauges (identify invalid gauges).

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Credits: Maxime Vayre and Julien Renou

USE OF EXISTING GAUGE NETWORKS COVERING LAKES IN USA AND EUROPE

- Example: Leveling of USGS gauge using IceSat-2
  - Identification of ICESat-2 acquisitions over the lake (may be anterior to SWOT)
  - Comparison of ICESat-2 WSE measurements (converted from WGS84 to EGM2008) with matching dates of in-situ WSE time series.
  - Estimation of the median bias and median absolute deviation (MAD) for leveling and uncertainty assessment

- The accuracy of the absolute leveling based on IceSat-2 is expected to be << 10 cm.

Example: Lake Atoka, Oklahoma

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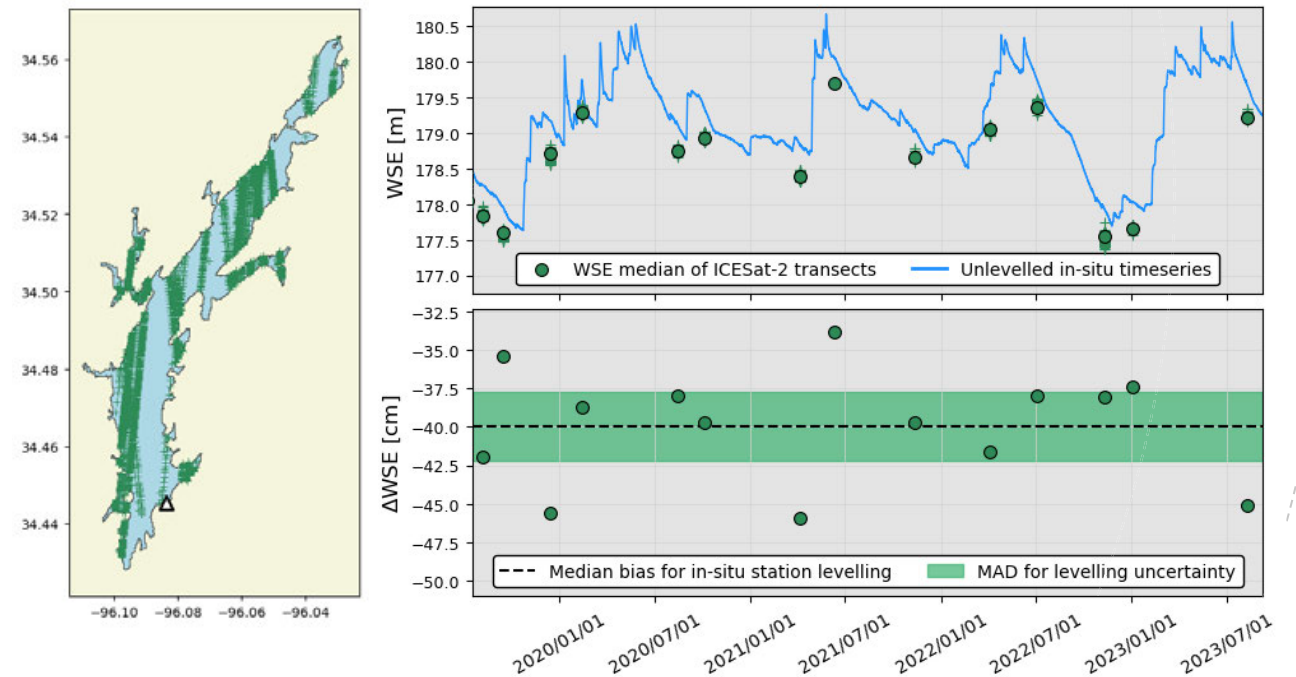
WSE REFERENCE DATA FOR SWOT VALIDATION OVER CANADIAN LAKES
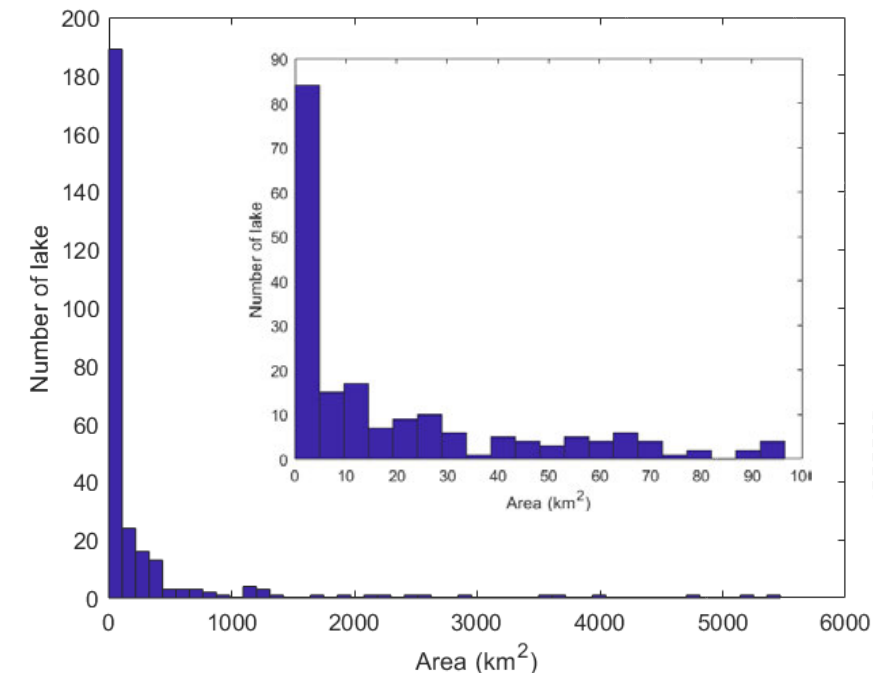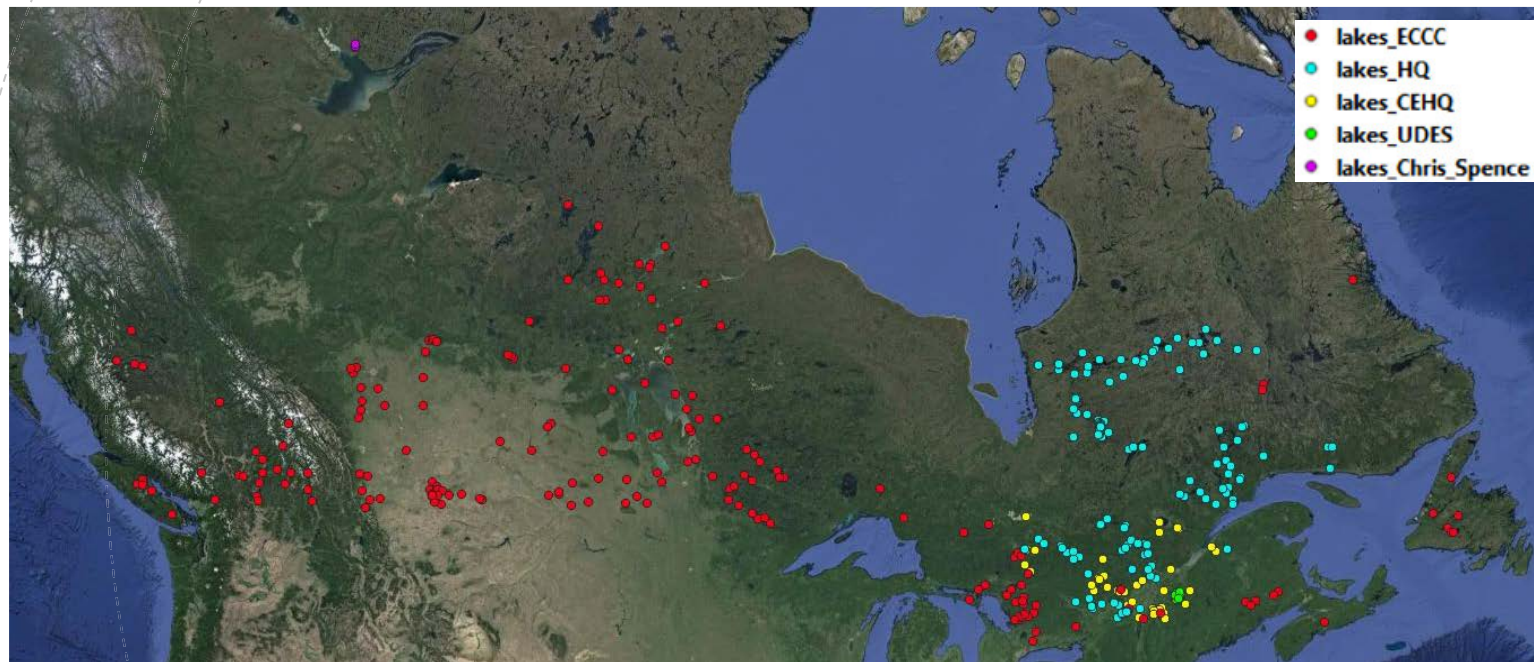
Data source (short name)	Cal/Val phase		Science phase		Min size [km²]	Max size [km2]	Leveling	Description
	# of gauges	# of PLD lakes	# of gauges	# of PLD lakes				
UdeS	6	6	6	6	0.42	1.76	GNSS	PTs installed by University of Sherbrooke for SWOT Cal/Val + camera to monitor ice and roughness
CEHQ	4	3	42	35	0.1	1114	GNSS	CEHQ long term gauge network, mostly reservoirs managed by Quebec government
SPENCE	4	4	4	4	0.16	5.93	GNSS	PTs installed by Chris Spence (ECCC) to study artic lakes (initially for another project)
HQ	30	18	142	67	1.25	4037	GNSS	HydroQuebec long term network for hydropower production, mostly very large reservoirs
ECCC_GNSS	16	14	45	42	0.05	5469	GNSS	ECCC long term gauge network for lake monitoring
ECCC_ICESAT	9	10	125	85			IceSat-2	
Total	72	55	364	239				

US LAKE VALIDATION SITES
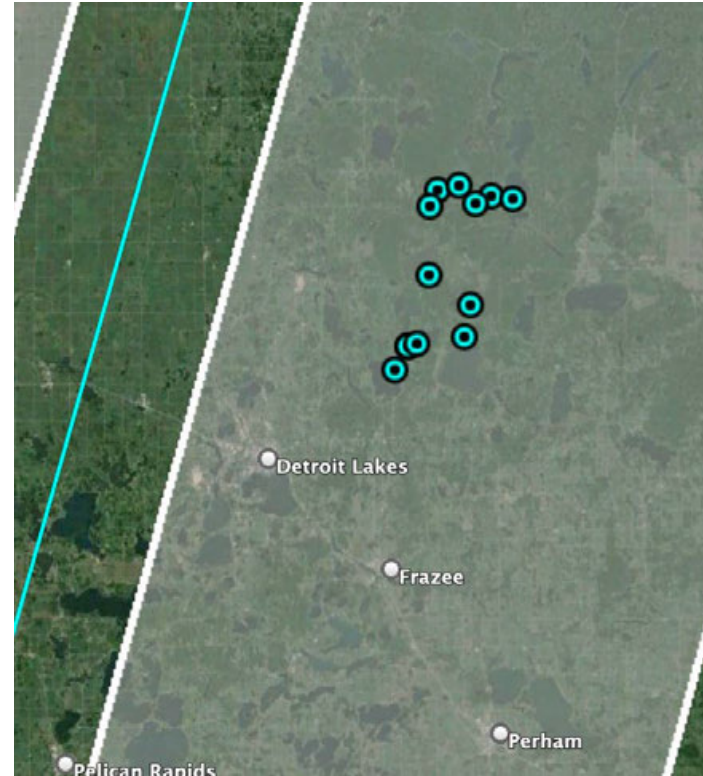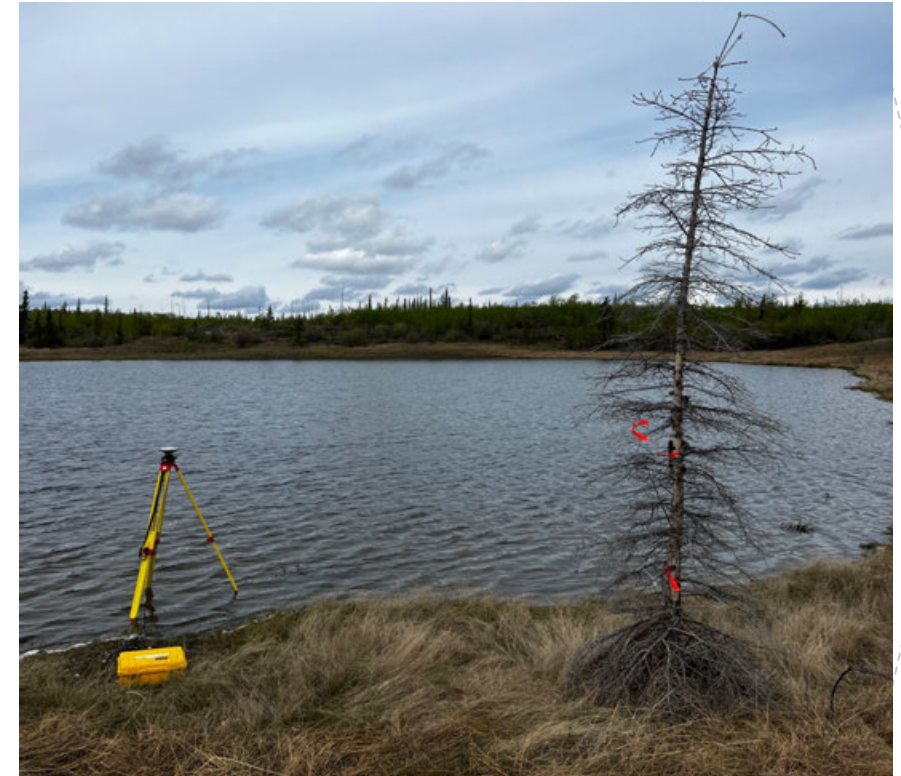
Pacific North West
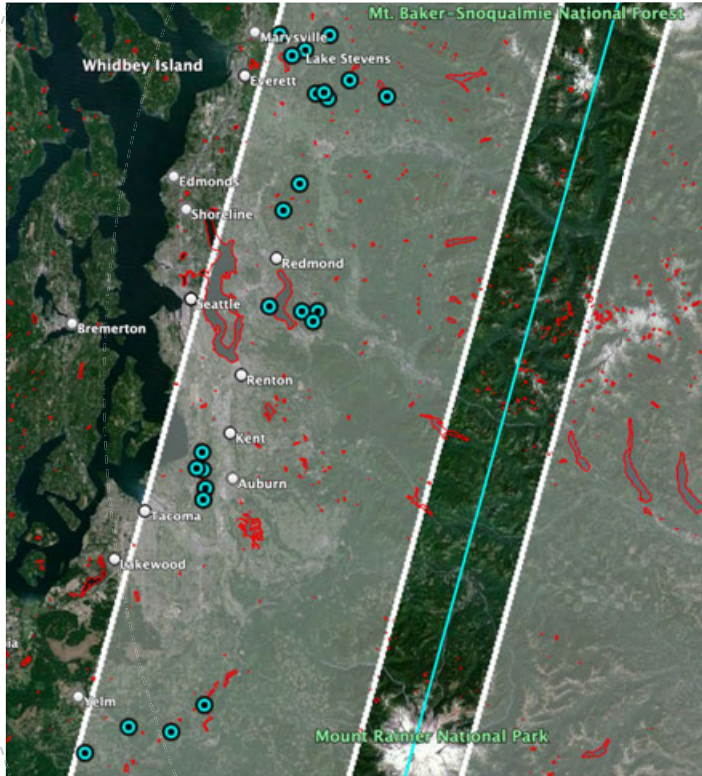
- Near Seattle, WA
- 24 lakes installed, 21 retrieved
- Mar 14, 2023 – July 19, 2023

Prairie Potholes

- Near Detroit Lakes, MN
- 13 lakes installed, 13 retrieved
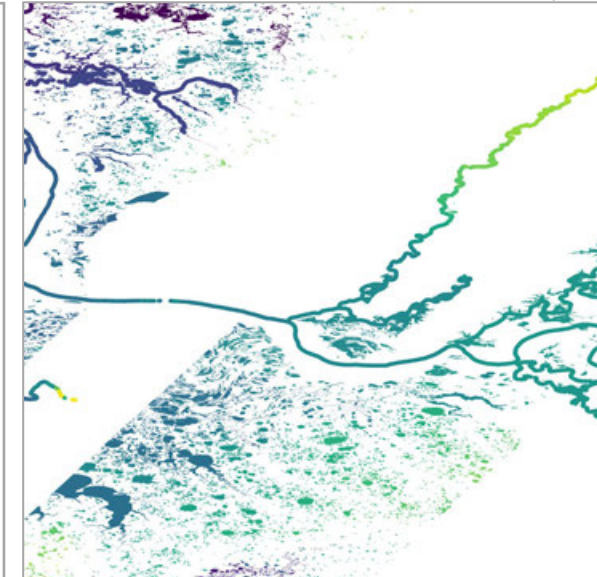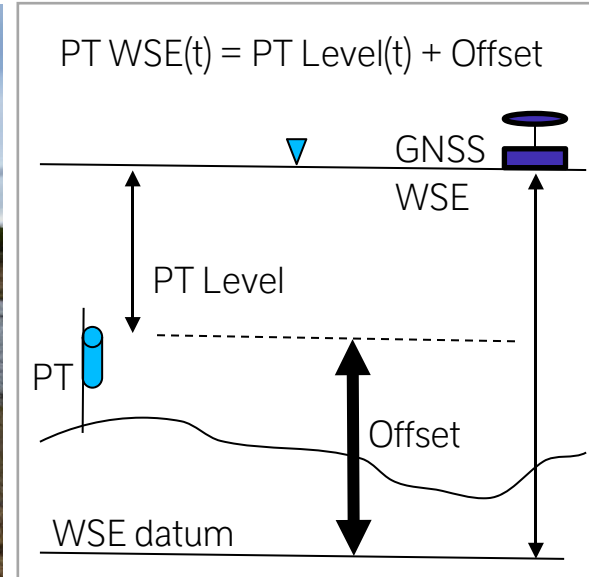- May 15, 2023 – June 27, 2023

- Baro loggers and in-water pressure transducers
- 1+ hour GNSS record, with measurements to water surface for both install and retrieval

Courtesy: Toby Minear, Taylor Rowley, Colin Gleason

US LAKE VALIDATION SITES

Lake processing chain

$$\text{PT WSE(t)} = \text{PT Level(t)} + \text{Offset}$$

Collect field data

- Pressure Transducer (PT) install for 15 minute data
- 1 hour GNSS survey for PT install and uninstall

GNSS PPP processing

- Resolve ellipsoid, geoid, earth tides, atmospheric interference
- Filter to <5cm uncertainty in vertical

Processing

- Field water level ➜ WSE
- Calculate offset from antenna to water surface to obtain WSE at PT location
- QA/QC (i.e., look for shifts in the time series)

Validation

- Assess SWOT performance

Courtesy: Toby Minear, Taylor Rowley, Colin Gleason

LAKES IN EASTERN FRANCE

OECS network in the Grand-Est Region (France)

OECS installation on Gerardmer Lake

Leveling of Kruth Lake

5 Vosges
2 Bas Rhin
3 Haut Rhin
3 Ardennes

2 bas Rhin
5 Vosges
4 Champagne Ardennes

WSE from Gerardmer Lake OECS station
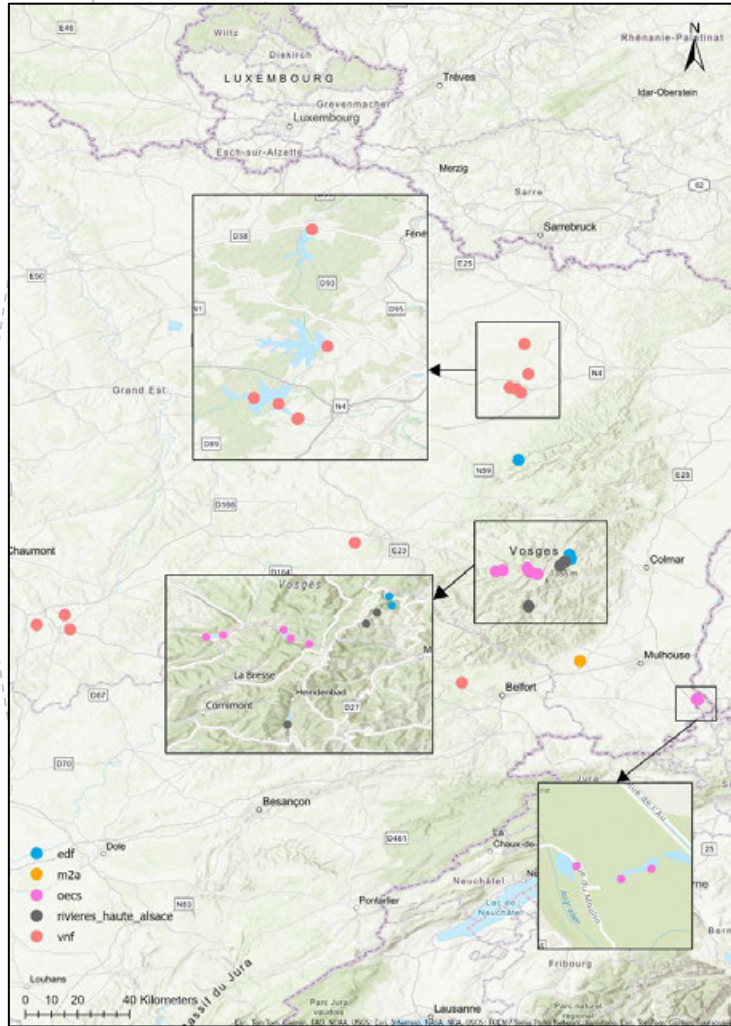
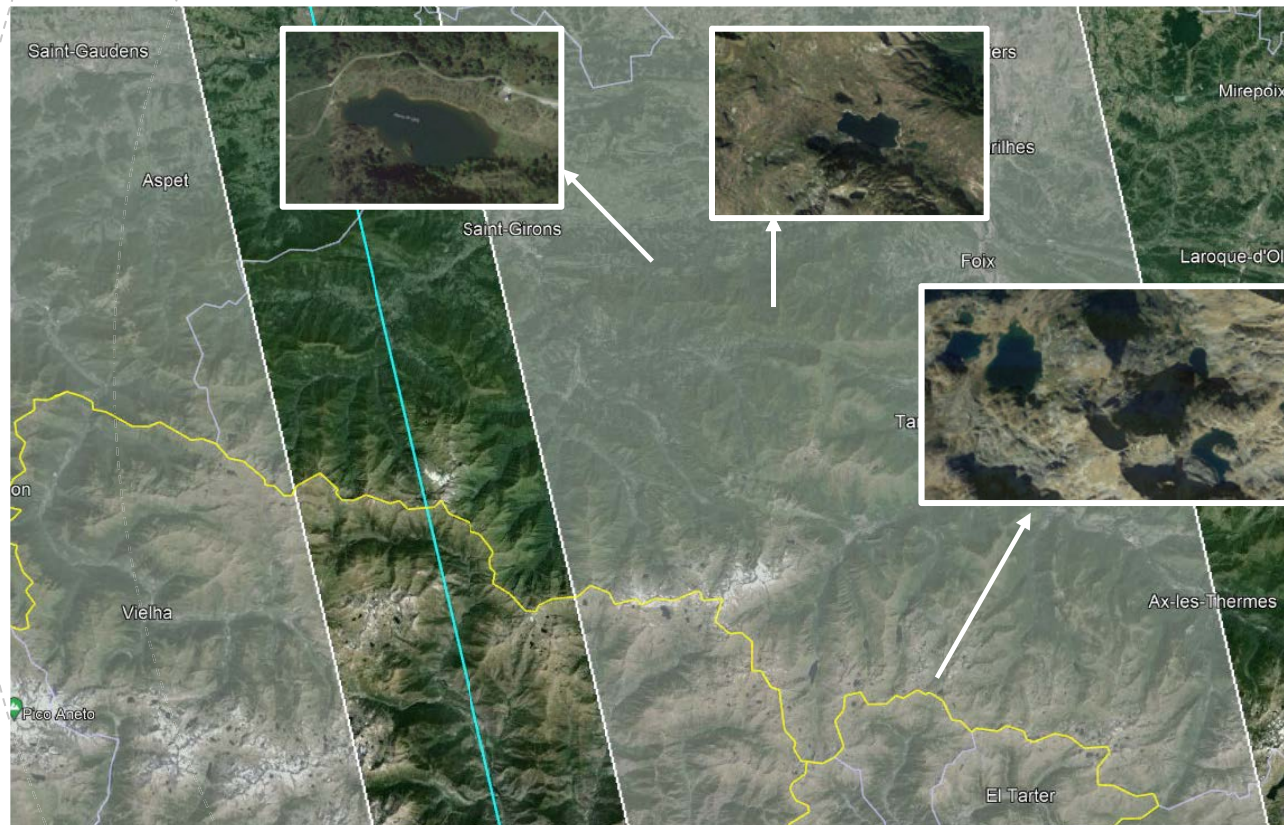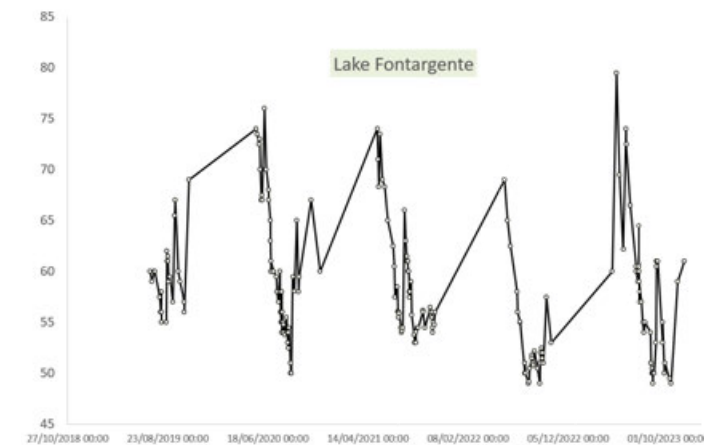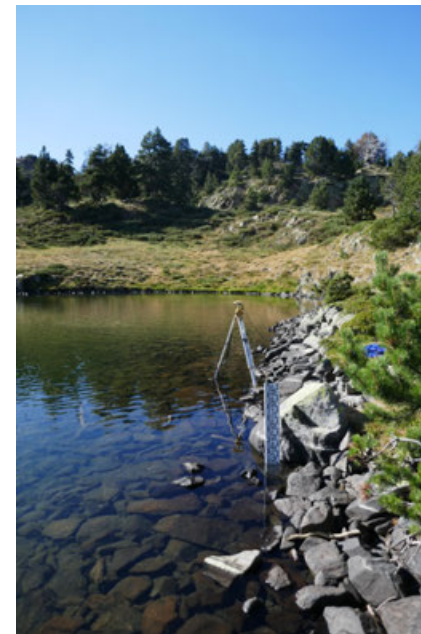21 stations in the Alsace and Lorraine regions (France) used for SWOT Cal/Val
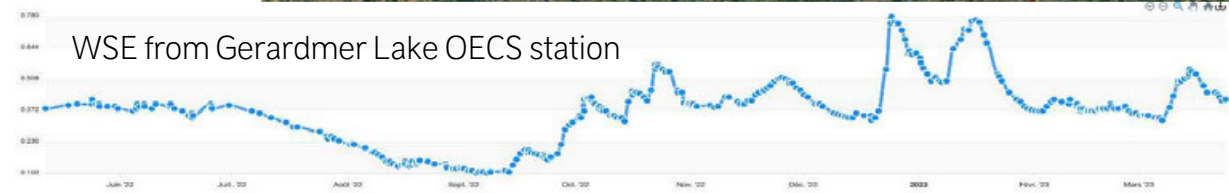
LAKES IN THE PYRENEES, FRANCE

Citizen science projects (LOCSS&OECS) for small lakes

Limnimetric ruler leveled using GNSS, with user instructions panel, placed well visible, near a trail. Data by picture or QRC.

A network of 24 lakes in the Pyrenees equipped with a ruler and/or a pressure transducer, 7 of them covered by SWOT during the Cal/Val phase (1-day orbit)

LAKES IN CEARA, BRAZIL

Cal/Val Orbit
Monitored reservoirs
Not Monitored reservoirs
Ceará's Watershed
Cities
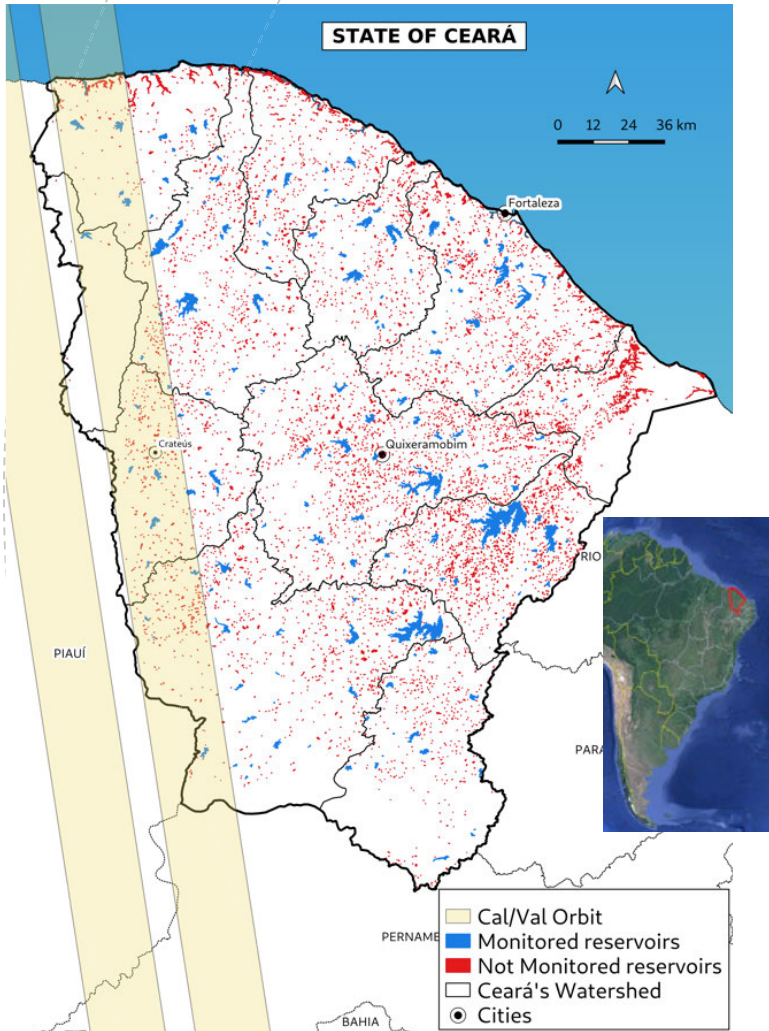
More than 100 000 small reservoirs

- Water resource management

- Risks (dam failures...)

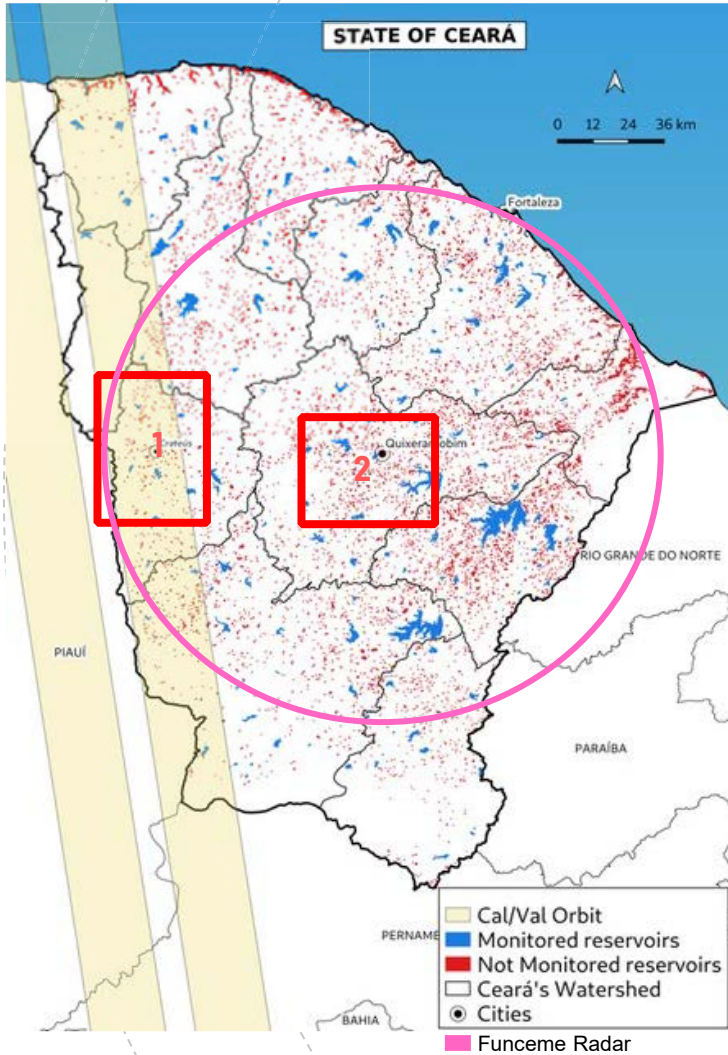- Short rainy season

- Rapid dynamics

- Very often cloudy

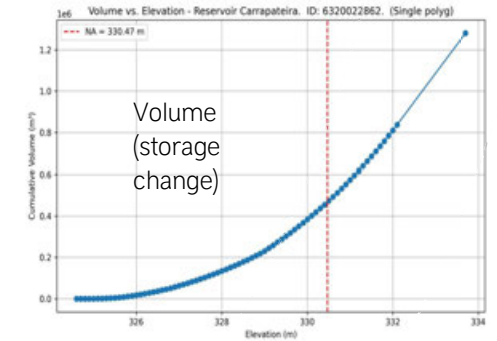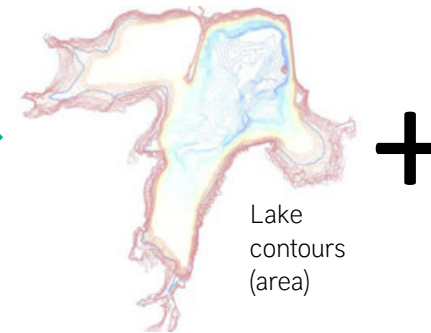A joint Brazil-France effort for SWOT Cal/Val!

Example:

Insitu site = Violete (id=ceara_wse:6330149942)

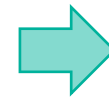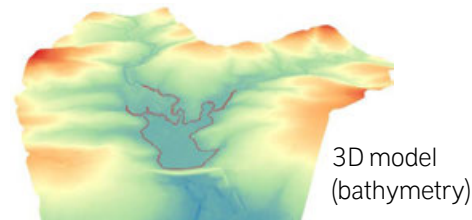Courtesy: Marielle Gosset, Raphael Reis, and many others.

LAKES IN CEARA, BRAZIL

8 (Cal/Val phase) + 3 (Science phase) reservoirs instrumented

- WSE (every 30 minutes)
- GNSS leveling
- 3D model (drone/bathymetry)

Example: Reservatório Carrapateira

STATE OF CEARÁ

3D model (bathymetry)

WSE

Lake contours (area)

Volume (storage change)

Cal/Val Orbit
Monitored reservoirs
Not Monitored reservoirs
Ceará's Watershed
Cities
Funceme Radar

LAKES IN WEST AFRICA

Tracking level changes of shallow lakes in West Africa
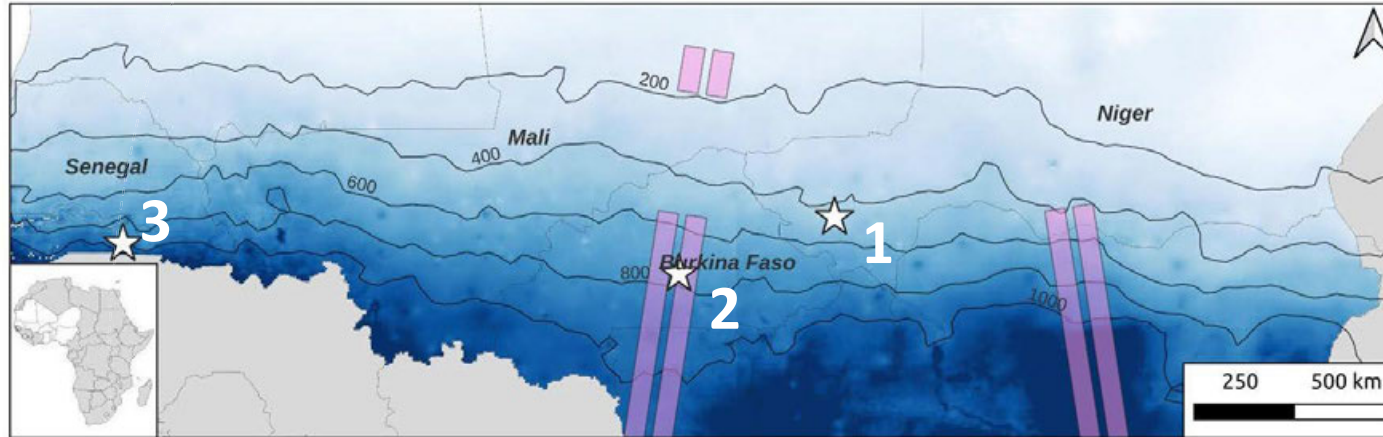
1. Bangou Kirey lake (~0.2 km²)

2. Arzuma reservoir (~1.5 km²)

3. Niandouba reservoir (~25 km²)
Instrumentation planned late June 2024

Courtesy: F. Girard, L. Kergoat, M. Grippa, H. Nikiema, M. Wubda, A. Touré, I. Mainassara, C. Faye, B. Fati

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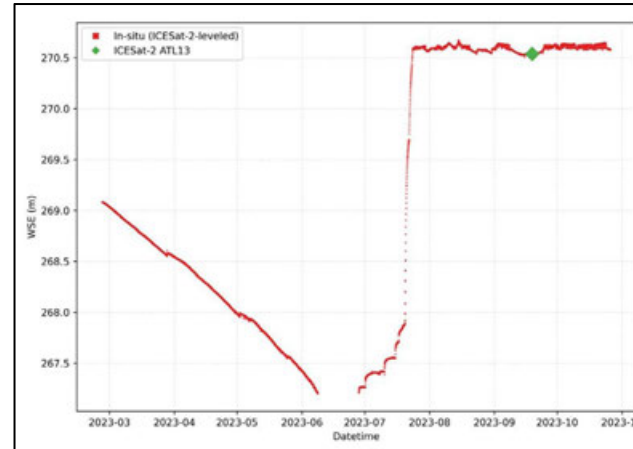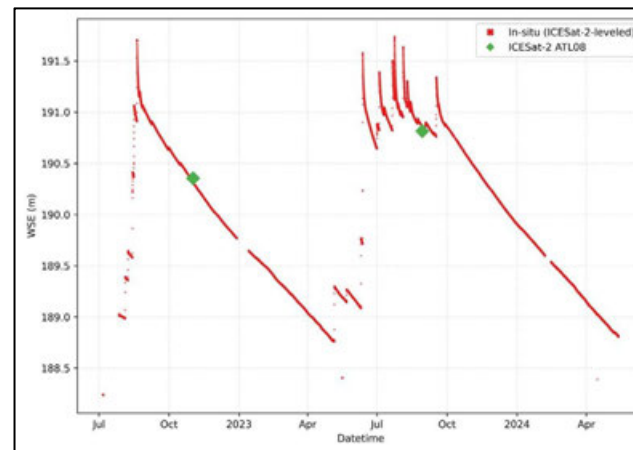
LAKES IN WEST AFRICA

In-situ: Pressure transducers, absolute leveling using ICESat-2

OTT Ecolog1000 pressure transducer with 30 min time step and live transmission.

Arzuma

- Time period: Mar. 2023 – Nov. 2023
- Leveled using ICESat-2 ATL13 (1 synchronous overpass)
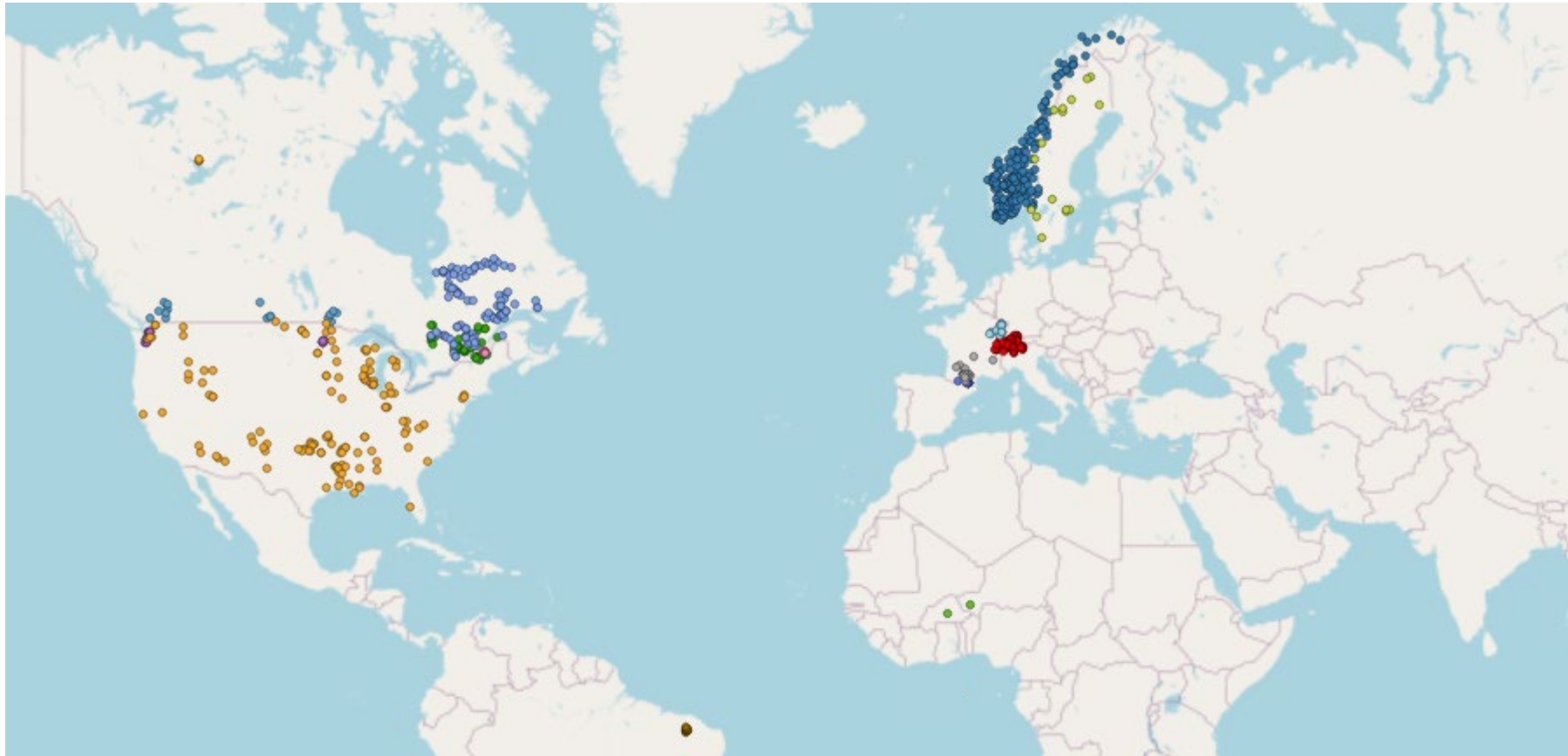
Bangou Kirey

- Time period: July 2022 - present
- Leveled using ICESat-2 ATL08 (2 synchronous overpasses)

Courtesy: F. Girard, L. Kergoat, M. Grippa, H. Nikiema, M. Wubda, A. Touré, I. Mainassara, C. Faye, B. Fati

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GEOGRAPHICAL DISTRIBUTION
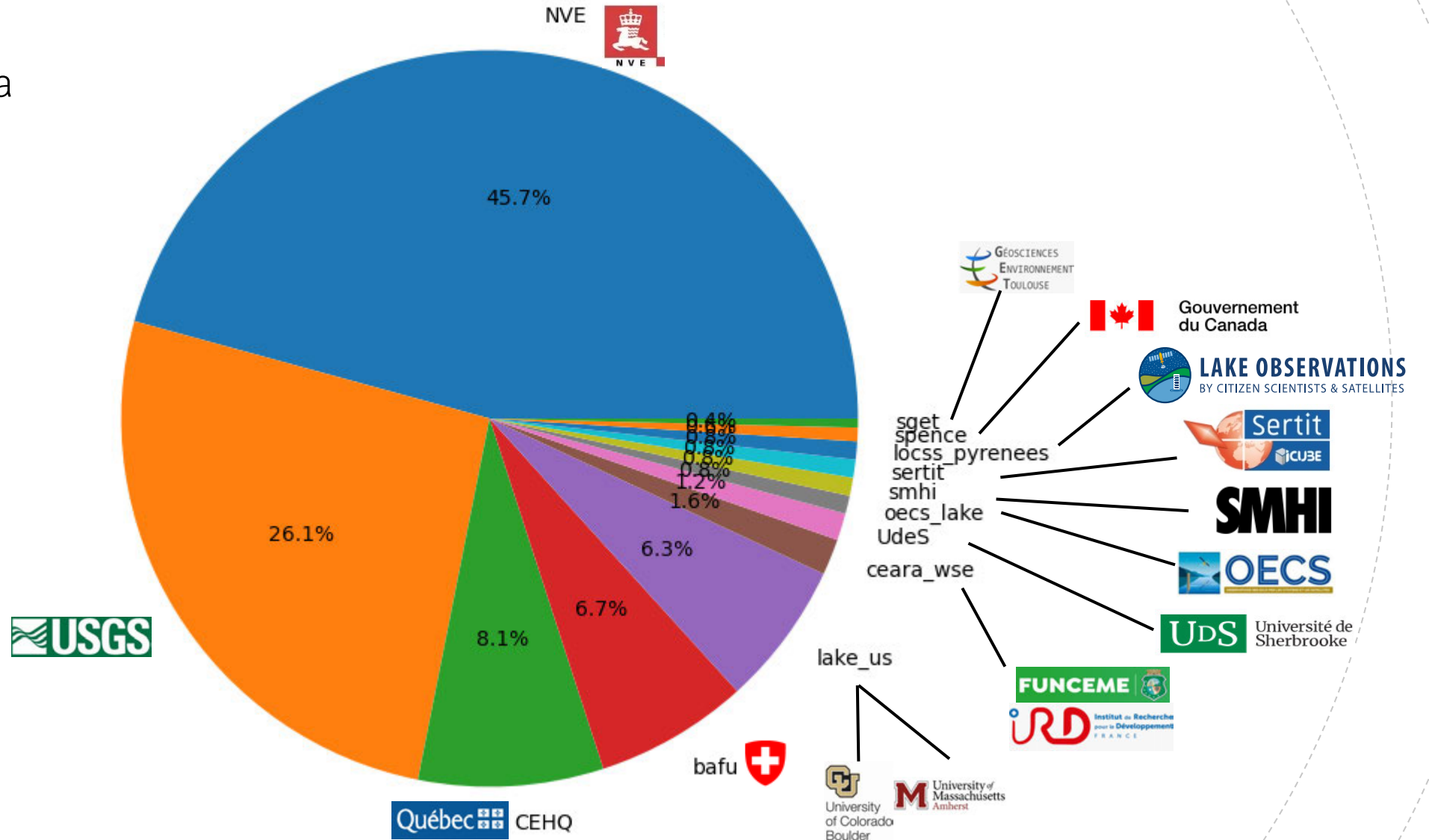
PLD lakes with ground truth available for WSE validation (leveled gauges only)
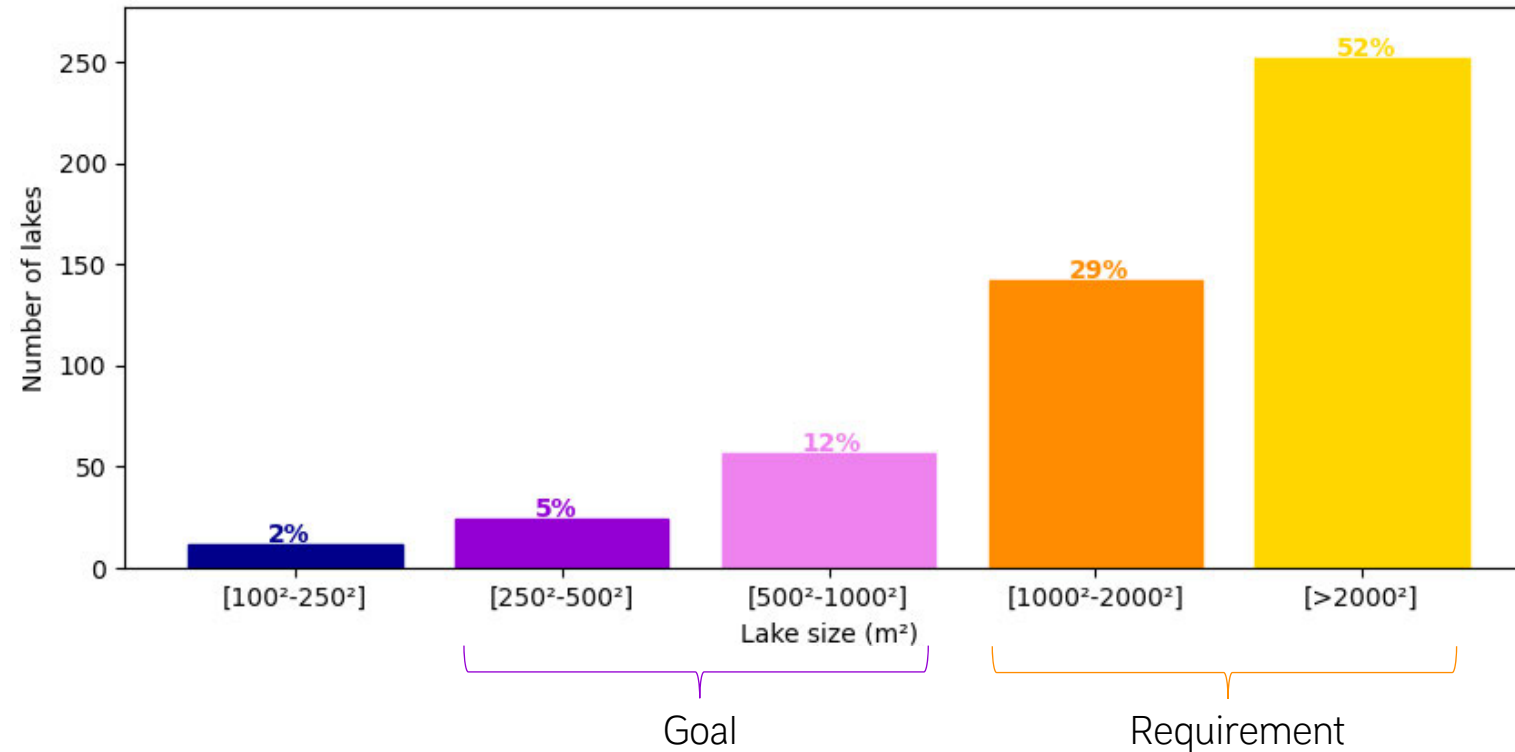
DATA SOURCE DISTRIBUTION

Leveled gauge data
used for LakeSP
WSE validation

SIZE DISTRIBUTION

487 PLD lakes with WSE ground truth available for validation of matching LakeSP data

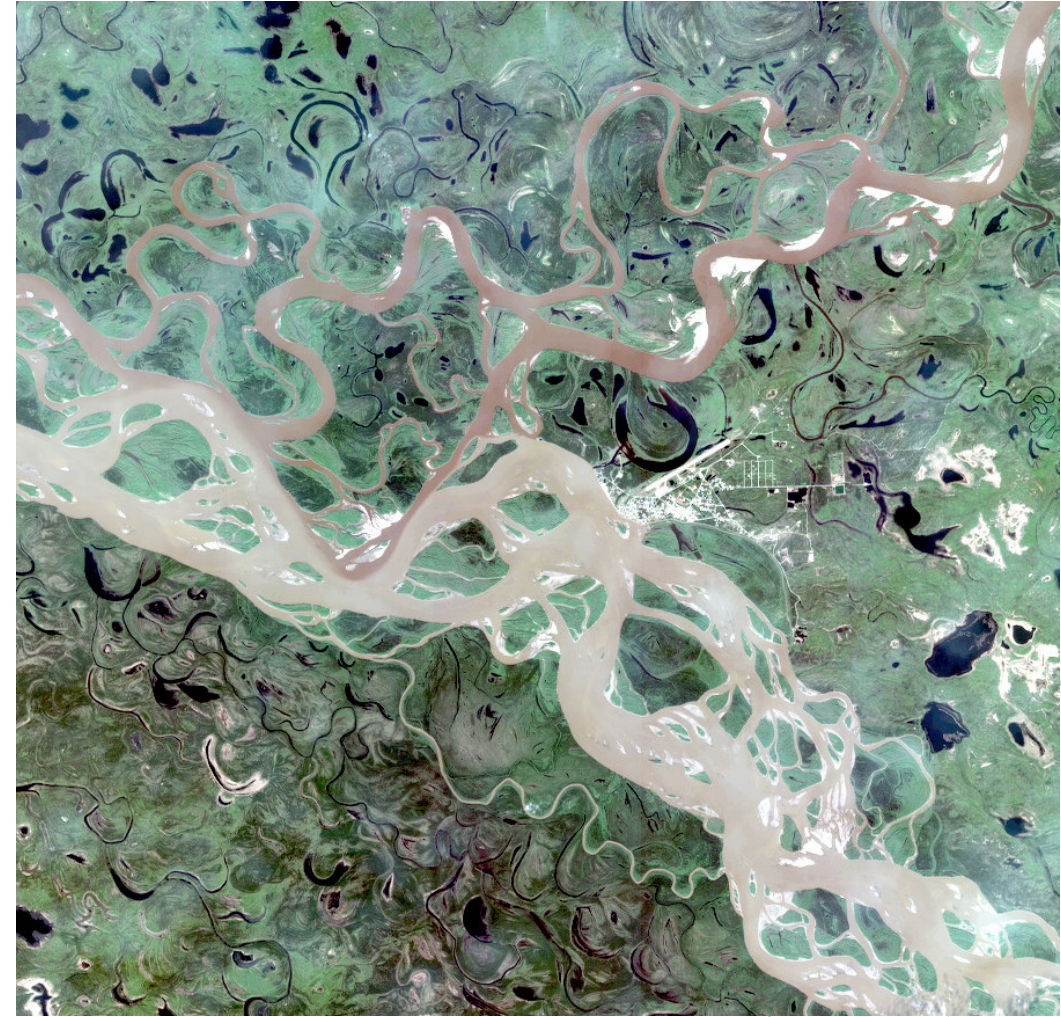- 89 in Cal/Val phase
- 431 in Science phase

- Inverse of expected global distribution: increasing number of lakes with increasing size

AREA REFERENCE DATA

Lake area reference data are based on water masks derived from high-resolution optical and radar satellite images.

- 34 x Pleiades [0.5 m]

- 204 x Radarsat Constellation Mission (RCM) [5 m]

- 283 x Sentinel-2 (S2) [10 m]

- Mainly over Cal/Val sites and during Cal/Val phase

- Pre-processed to obtain reference areas [m^2]
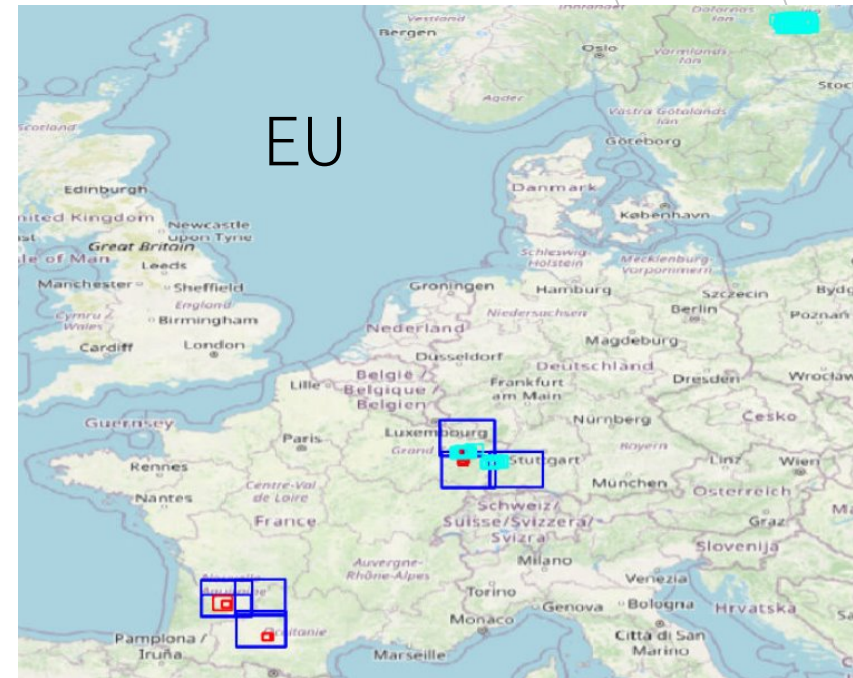 for all PLD lakes covered by the images (>10 000)

Pleiades image, Yukon Flats, Alaska, June 6, 2023

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GEOGRAPHICAL DISTRIBUTION OF SATELLITE IMAGES

NA

SA

EU

AF

283 x S2 [10 m]
204 x RCM [5 m]
34 x Pleiades [0.5 m]

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ES
GROUP

SIZE DISTRIBUTION OF PLD LAKES WITH MATCHING AREA REFERENCE DATA

Number of lakes as a function of lake size (11581 in total)
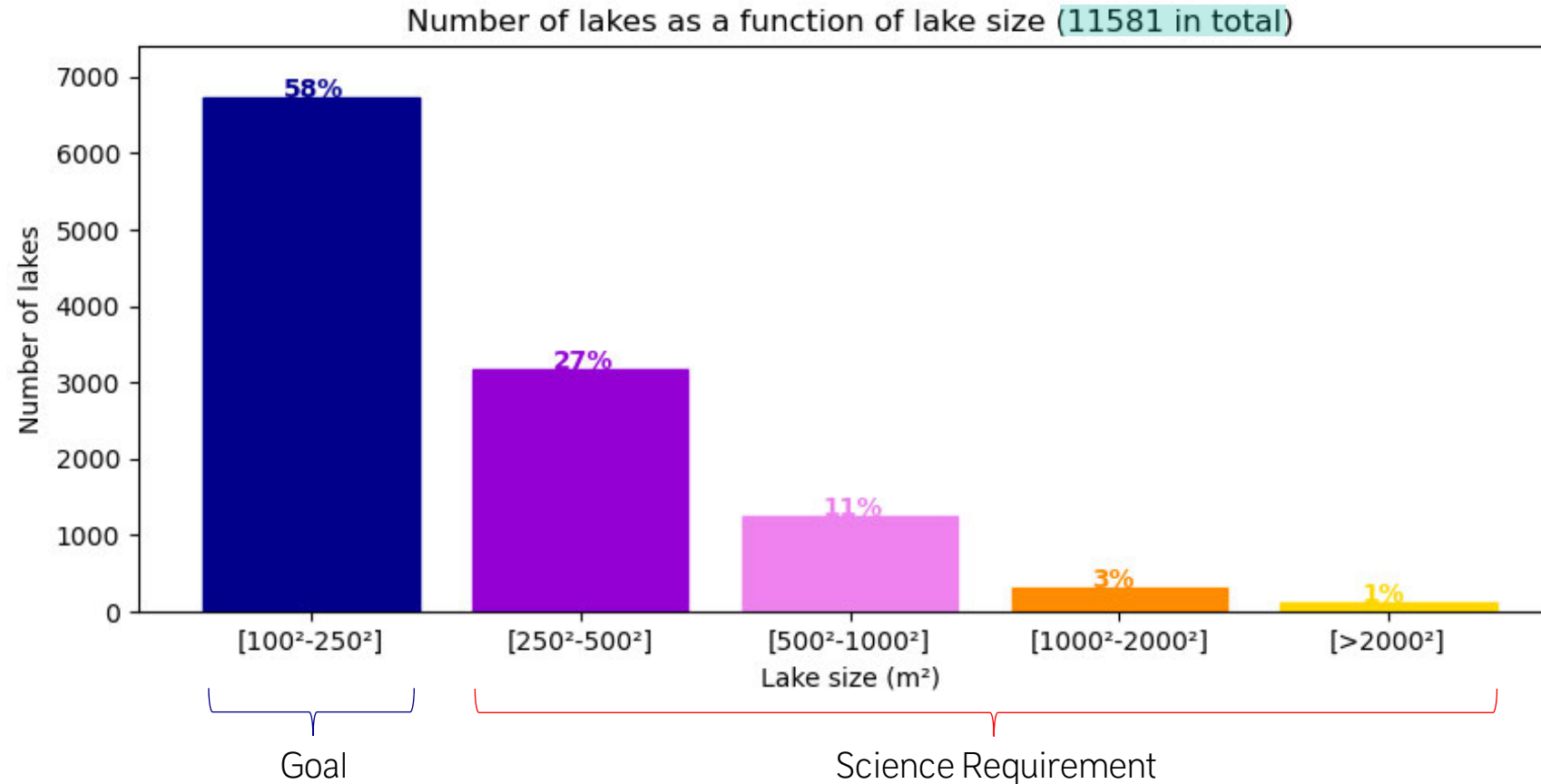
- Corresponds roughly to expected global distribution: decreasing number of lakes with increasing size

COMPUTATION OF WATER MASKS

0=land, 1=water, 255=NoData (e.g. clouds)

- Pleiades: Thresholding of NDWI
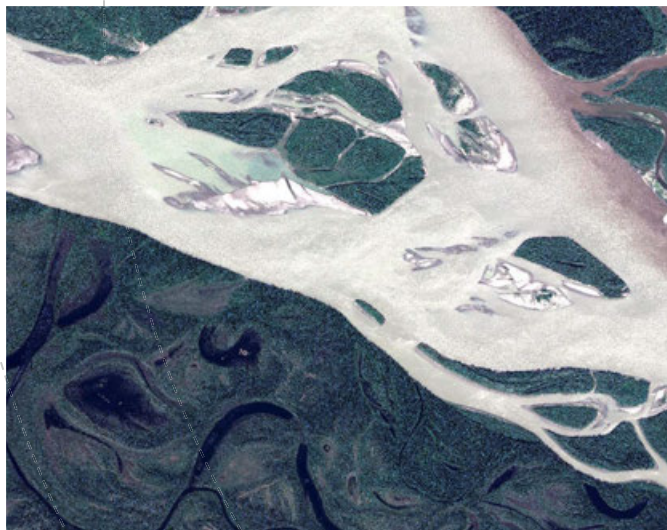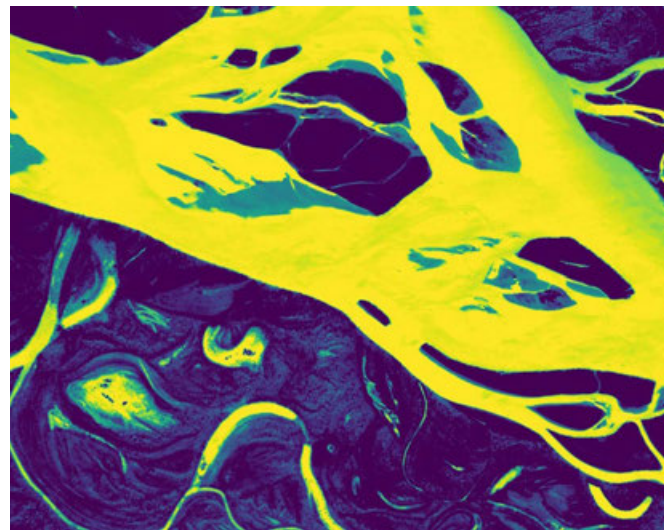- RCM: Polarimetric MRF classifier
- S2: ExtractEO (Random Forest classifier)

- Example:

Extract of Pleiades image, Yukon Flats, Alaska

NDWI

Reference water mask

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TRUTH PROCESSING

From water mask to (river and) lake areas

- Assignment of water pixels to SWORD river reaches and nodes based on RiverObs (~RiverSP processing)
    - Computation of area etc. per reach and node (RiverSP-like truth product)
- Assignment of water pixels to PLD lakes based on LOCNES (~LakeSP processing)
    - Computation of area etc. per lake (LakeSP-like truth product)
- Example:

Truth processing of
SLUM water mask
(Garonne downstream
site, May 30, 2023)

— SWORD centerline (v16)
□ PLD polygon (v1.05)
— Truth RiverSP reach
• Truth RiverSP node
■ Truth LakeSP lake
■ Reference watermask

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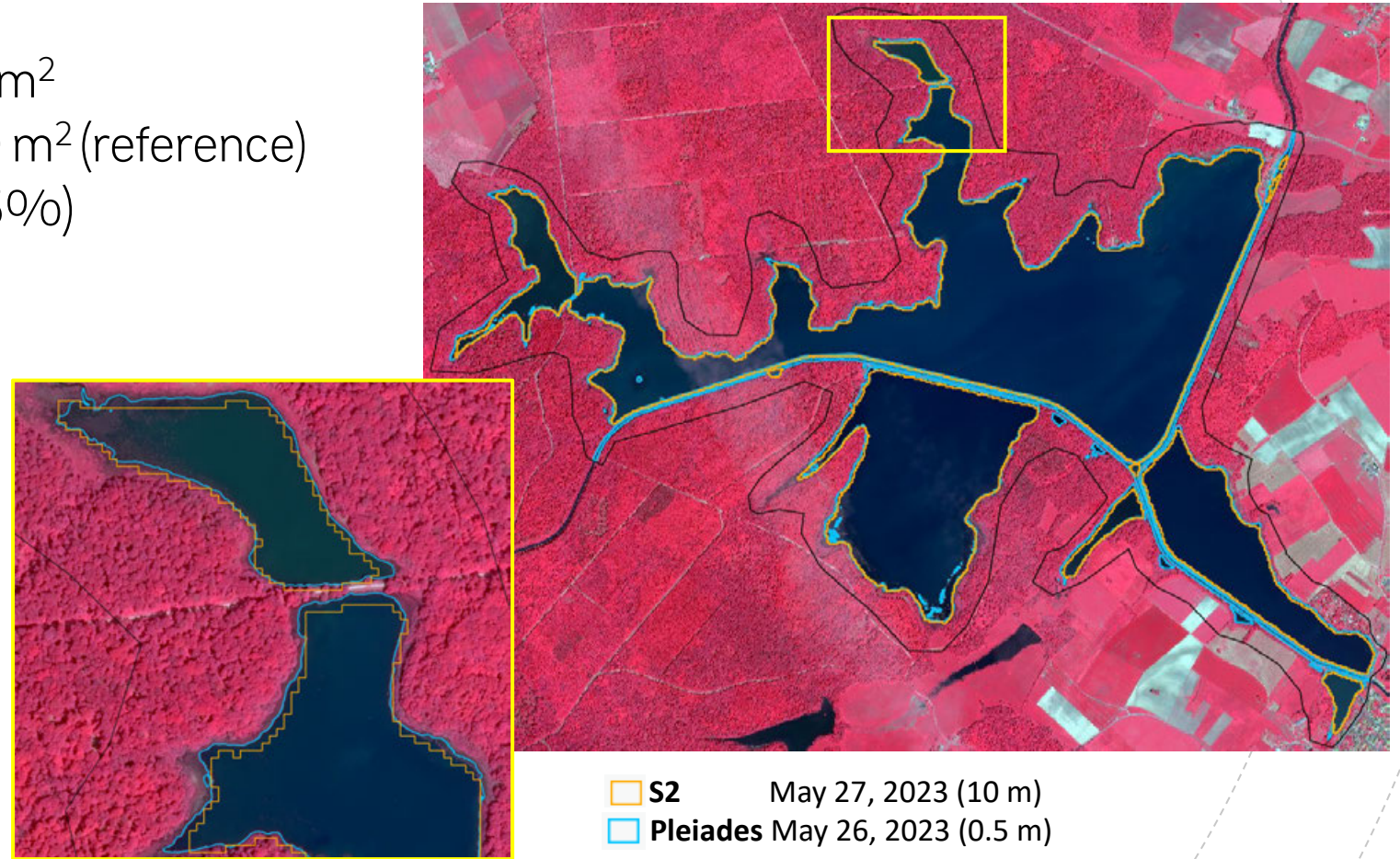*Liberté*
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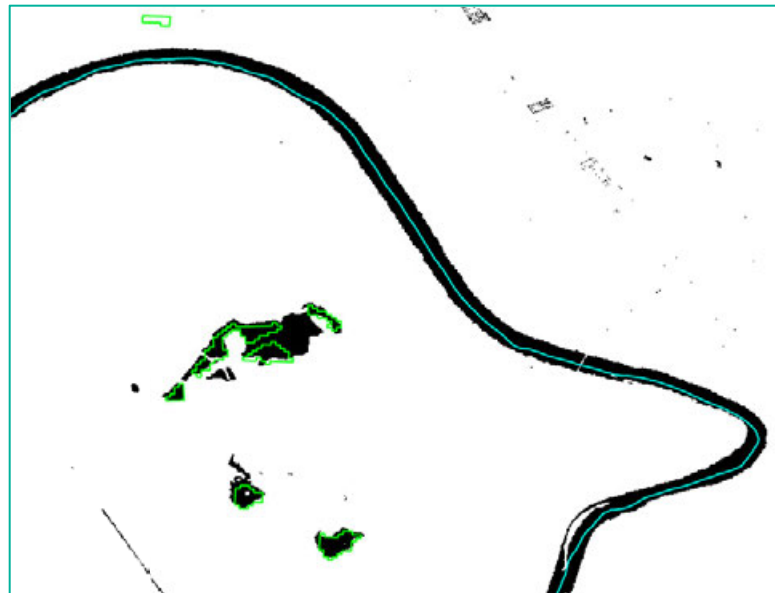
ACCURACY OF REFERENCE AREAS

Example: S2 vs. Pleiades water mask

- Gondrexange Lake, France, ~5.5 km^2
  - Pleiades water mask: 5460560 m^2 (reference)
  - S2 water mask: 5161300 m^2 (-5%)

Indicator	Score
Precision	0.98
Recall	0.93
Fscore	0.96
CSI	0.92

- Reference water areas are not perfect.
  - S2 water masks tend to underestimate area.

☐ **S2**   May 27, 2023 (10 m)
☐ **Pleiades** May 26, 2023 (0.5 m)

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SUMMARY

Huge collaborative effort to collect and process lake reference data for WSE and area!

- Lake WSE
  - Dedicated in situ measurements
  - Extensive use of existing gauge networks
  - Native leveling, or GNSS leveling, or leveling based on IceSat-2
  - Leveled WSE reference data for almost 500 PLD lakes (Cal/Val and Science phase)
  - Good geographical spread, but more large than small lakes covered

- Lake area
  - Based on water masks extracted from high-resolution optical and radar satellite images
  - Split into (rivers and) lakes similar to how SWOT HR data are processed
  - Reference area available for more than 10 000 PLD lakes (mainly Cal/Val phase)
  - Good geographical spread and size distribution (more small than big lakes)

- Reference data are not perfect and are at the origin of a fraction of the measured errors (differences)

Surface Water and Ocean Topography (SWOT) Mission
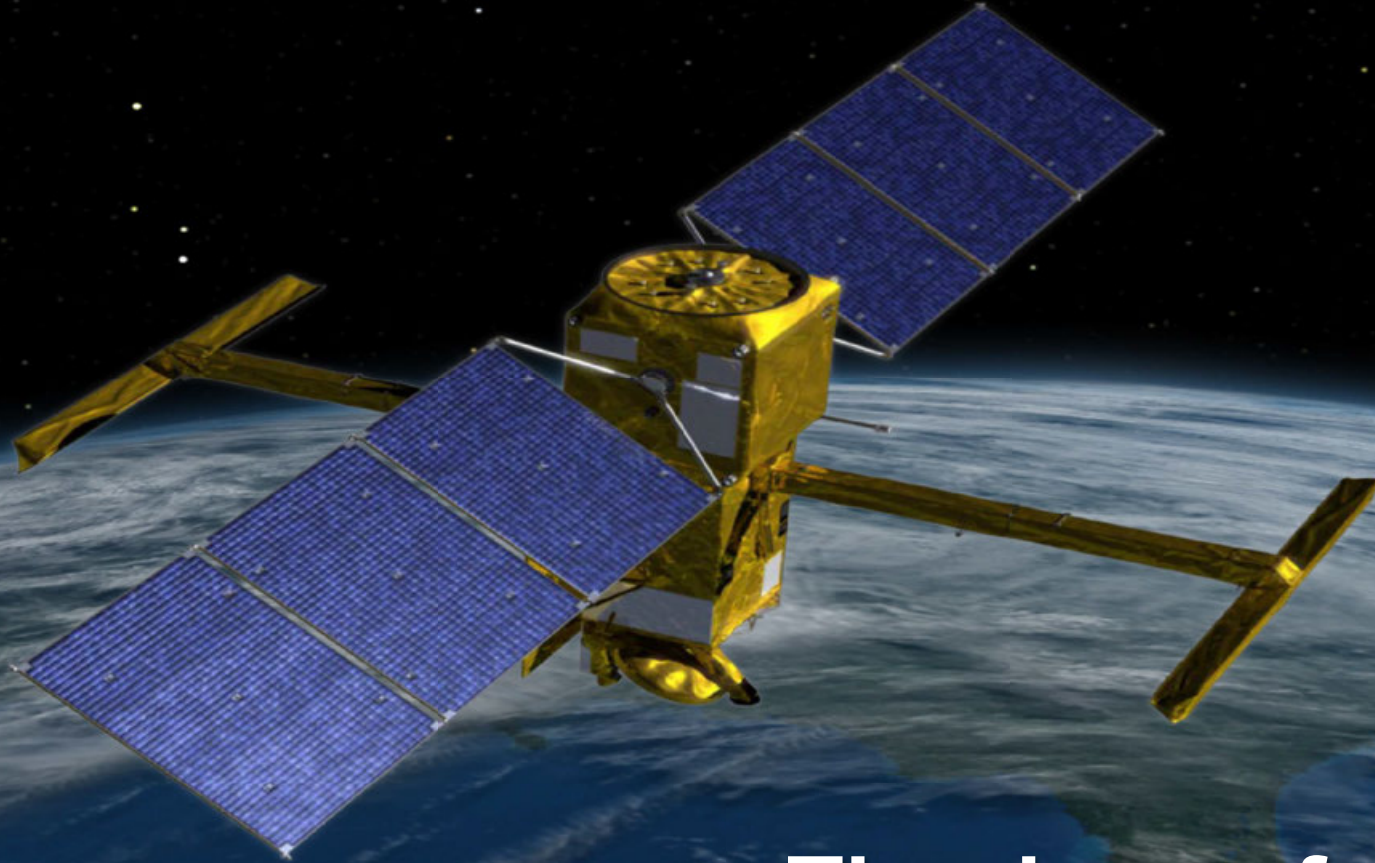
Thank you for your attention!

BACK-UP

OTHER LAKE WSE REFERENCE DATA

Collected, but not used for WSE mission validation w.r.t. requirements

- Issykkul, Kyrgyzstan (for specific studies on slope, geoid variations)

Collected, but not yet used (remaining work to level or preprocess data)

- EDF and CNR gauges in France
- Hydroweb data (based on nadir altimetry)
- Citec gauges in Panama