Refining the Mapping of Lakes in the Arctic: A Landsat Based Approach

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The Arctic: How many lakes are there?

Why this figure is important?

How did we come up with this figure?

Where are they?

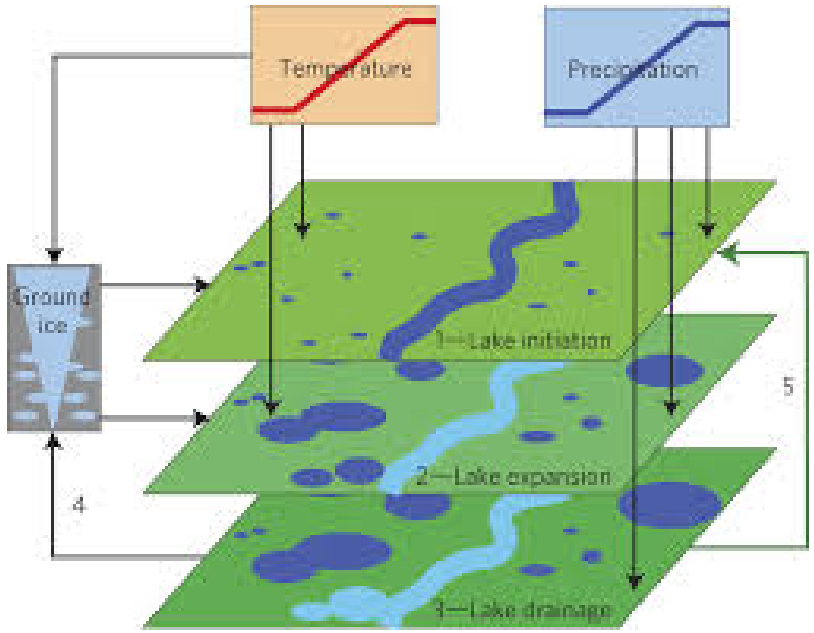
What's their typical size?

What are the implications of their distribution?

Can we monitor them in a pan-arctic scale? If so, how?

Why is it important to know where lakes are?

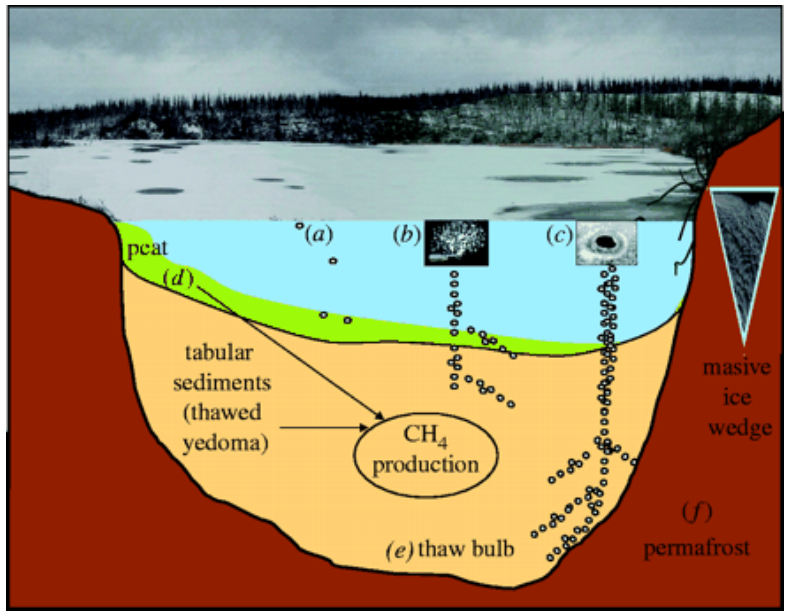
Local hydrology



(V. Huisssteden et al, 2001)

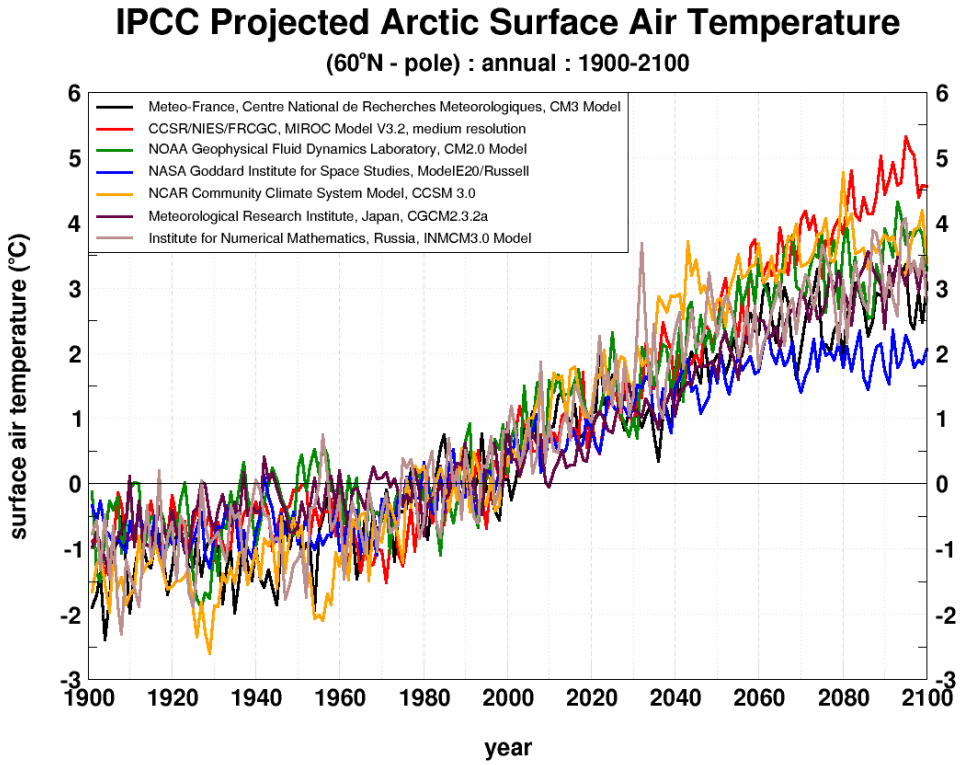
Why is it important to know where lakes are?

Lakes and the biogeochemical cycle. → location of thermokarst lakes



(Diagram from Walter et al 2007)

What do we know so far about distribution of Arctic lakes?



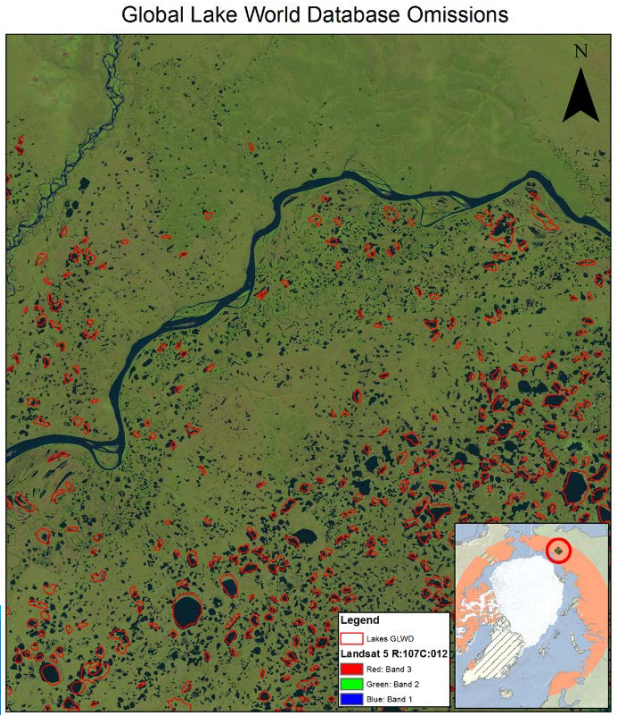
Acceleration of physical, biogeochemical and limnological changes in Arctic landscapes!

How well understood is the pan-Arctic lake distribution?

GLWD (Lehner & Döll, 2004): Identify about 70.000 Arctic lakes

Main patterns driving lake distributions: climate, geomorphology, substrate permeability, glaciation history and, permafrost. (Smith, Sheng, and MacDonald 2007).

However.. GLWD → **omits** a large number of water bodies – specially small lakes (<10 ha or 0.1 km^2)



Objectives of our study

Main goal. Our goal is the improvement of estimates of regional lake abundance and patterns of distribution

- To test of Landsat capability **(temporal resolution, spatial resolution and availability of imagery**) as a basis for detecting and monitoring lakes in the Arctic
- to develop a database of lakes for the Arctic region with high spatial resolution.
- To improve our understanding of Arctic lakes spatial distribution

Methods – what images did we use?

Developing a New Arctic Lakes Geodatabase.

617 cloud free Landsat 5 TM+ imagery: 2006 – 2011 (98% of them).

Temporality of the scenes used in this study

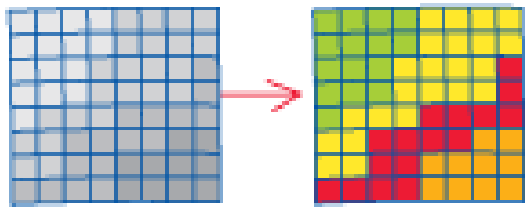
	2004	2005	2006	2007	2008	2009	2010	2011
Number Scenes	4	8	59	172	9	281	40	46
% Total	0.6	1.3	9.5	27.7	1.4	45.2	6.4	7.4

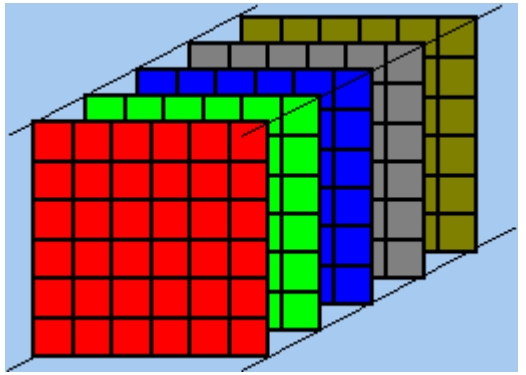
*Yet some areas in Greenland and north Taimyr (Russia) are under-represented because images for those areas could not be acquired.

Methods – how did we extract water bodies out of Landsat imagery?

What Technique? Density Slicing as proposed by Frazier (2000)

What band? Band 5 discriminates better water vs land (Roach, Griffith, and Verbyla, 2012)

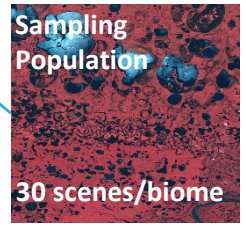




How efficient these techniques are in **a regional scale**?

Methods – Water vs non-water pixels: How to define a suitable threshold for the density slicing for the Arctic? Defining a **regional water pixel threshold**

Stratified Random Sampling.



ANOVA

Source of variation	*SS*	*df*	*MS*	*F*	*p value*	*F critic*
Between Groups	14.9259091	5	2.985181818	**1.377549593**	0.23207157	**2.24007639**
Within Groups	749.79	346	2.167023121			
Total	764.715909	351				

Recording **maximum DN** water value of every lake in a transect (over 500 lakes were sampled)

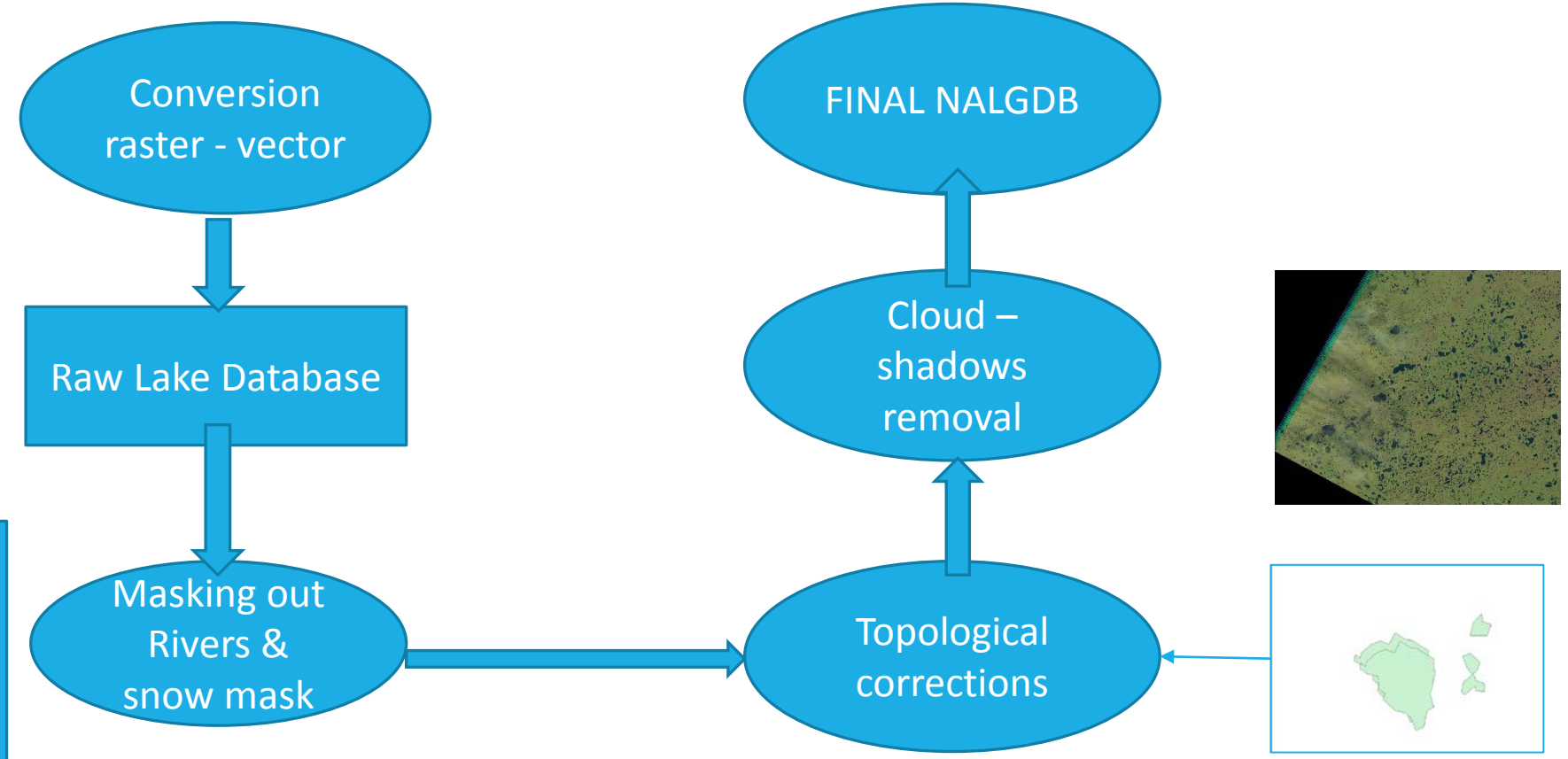
Are the Biome means different between each other? **ANOVA test**!

Use a single DN value

95% Confidence, F<Fcritic: **Means are similar**. Regional DN: 24

Analyse further regional differences

Methods – vectorization:



Compactness (McKeown and Denlinger, 1984). $= \frac{4\,\pi Area}{Perimeter^2}$ features with < 0.1 are considered rivers

Results – how many lakes are in the Arctic? What's their size?

Total lakes vs GLWD

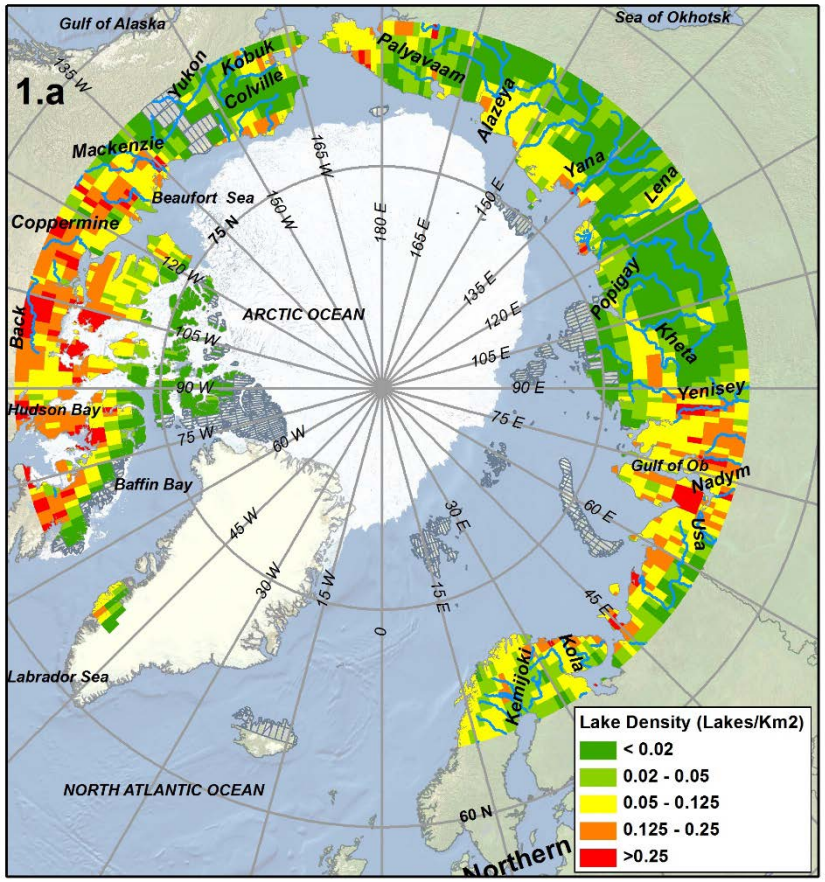
Table 1. Size Classes of lakes in the Arctic

Size Class (km2)	Number of lakes	% of the total	Total lake area (km2)	Mean Size (Km2)	Median Size (Km2)	Lake fraction (%)
0.0036 - 0.01	**1,130,262**	**32.116**	7,252.59	0.006417	0.009024	0.10
0.01-0.1	**1,875,177**	**53.282**	46,159.78	0.02462	0.024708	0.62
0.1-1	467,886	13.295	126,899.33	0.27122	0.196615	1.70
1-10	43,931	1.248	98,935.00	2.25205	1.644046	1.33
10-100	1,916	0.054	43,224.03	22.55951	15.362864	0.58
>100	142	0.004	72,506.85	510.61162	169.72507	0.97
Total	**3,519,314**		**394,978**	-	-	**5.30**

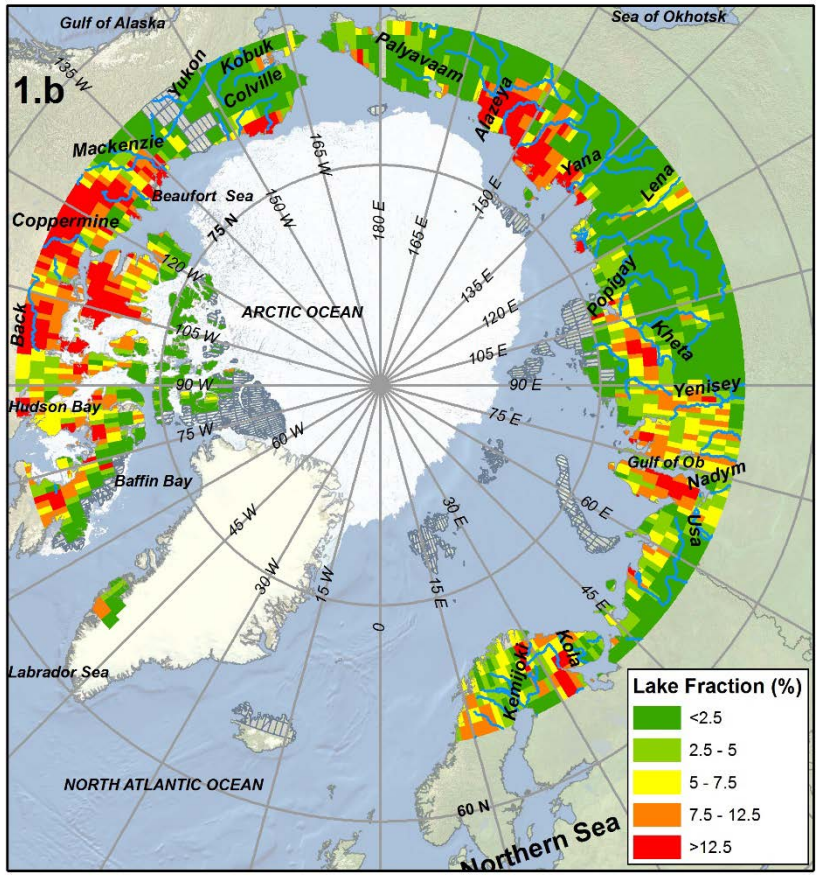
3.500.000(This study) vs 70.000 (GLWD)

Results – Where are they?

Lake Density

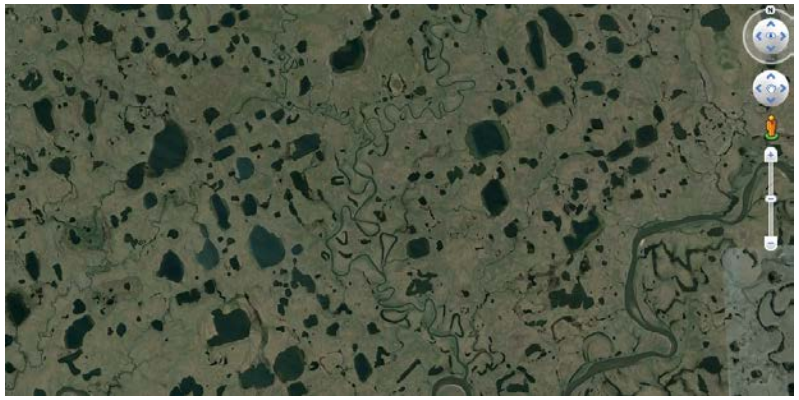


Lake Fraction



Results – Accuracy Assessment

Comparison of the dataset against **High Resolution Imagery → Google Earth**



Error matrix was built up.

Overall Accurracy: 80%

Results – What are the landscape implications?

Supplementary thematic data:

i) **Vegetation** - Kaplan et al. (2003)

ii) **Permafrost** - Brown et al. 2011)

iii) **Topography** - USGS GTOPO 30 DEM

iv) **Surface geology:**

- **glaciated or unglaciated** - Peltier (2004)
- **yedoma or non-yedoma** - Siberian extent from Walter et al. (2007) and for North America using Kanevskiy et al. (2011)

Results – What are the landscape implications?

Tundra and Permafrost: Higher lake density and fraction: (density > 0.125 lakes/ km^2 and lake fractions >12.5% of land area.

Erect dwarf-shrub tundra vegetation and the low -and high- shrub tundra biome units: Greatest number of lakes:

Yedoma areas:

- **Siberia about 400 000** lakes were identified, covering nearly **67.000 km^2:** 7% of the total yedoma land surface. Most of them are **small (80%)**
- **North America: 17.000 lakes**; **255 Km^2** (<1% of the area)

Areas where the last glacial reached its maximum are also rich in lakes.

Small lakes - implications

The prevalence of small lakes likely reflects the peculiarities of permafrost hydrology:

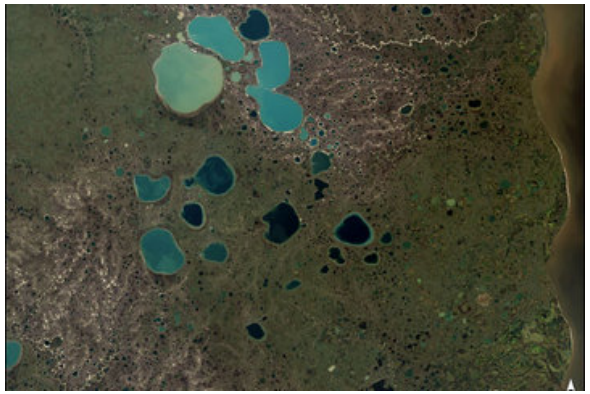
Small water bodies are known to **form via a range of permafrost-related processes**:

- Anastomosing polygonal ponds
- Thermokarst
- Degradation of partially frozen peat
- Thaw lakes can form rapidly after landscape disturbance.

Small lakes - implications

Small water bodies are a **dynamic component** of Arctic landscape!

- They are susceptible to drainage
- They disappear when continuous permafrost fragments → subsurface drainage



Is Landsat mission useful to map lakes in the Arctic?

With an 80% certainty estimate our results appear robust → a similar methodology, using Landsat products, would serve **to monitor lake in a multi-year basis**

As 97% of our images correspond to the period 2007-2011. **We can assess lakes in a multi-annual year basis. There is enough availability of scenes!**

Landsat imagery **can successfully be used to detect water bodies in the Arctic at a continental and regional scale**

To **monitor small lakes dynamism** → it is requires a flexible database → our method can provide this functionality!

What's next?

An immediate step is to **validate – compare simulated wetland extent** products against this dataset.

Test applicability at **other LANDSAT products** (including Landsat shortwave infrared band 6: 1.57 - 1.65 µm – similar to L5-B6)

In some zones errors were caused by relief → implement a topographic/DEM correction

Test other **time periods**

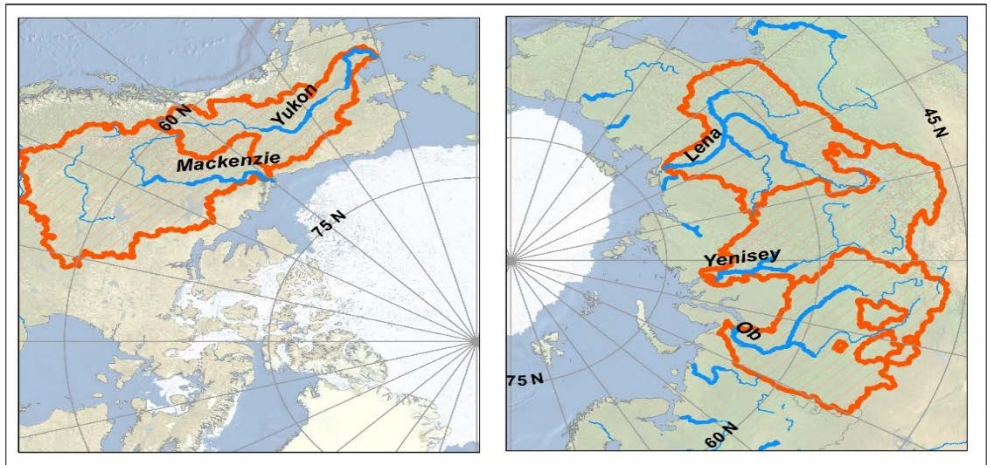
Incorporate **Google Earth Engine** to the process

Obtain **lake morphometrics** (area-circumference ratios are crucial in the quantification of gas-exchange properties)

Develop a **lake classification system** – key to upscale key carbon processes

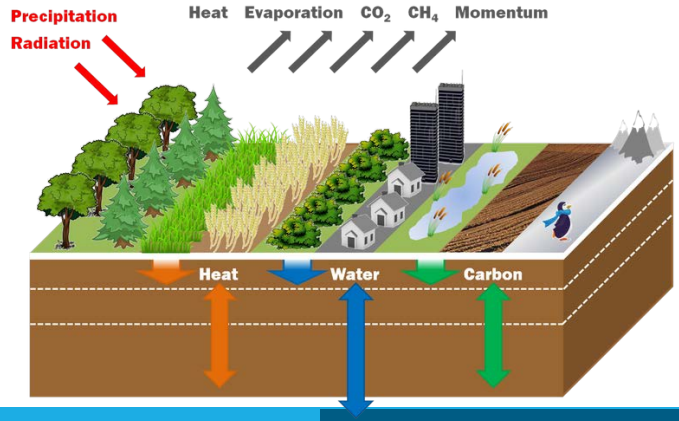
Current Research

Currently I am studying cold region's hydrology: how **climate variability affects links between runoff generation and downstream processes**



Approach: **Land Surface & Climate Modelling**

Running JULES (the Joint UK Land Environment Simulator).



Current Research

What is the runoff response to climate variability?

What is the wetland response to runoff variability?

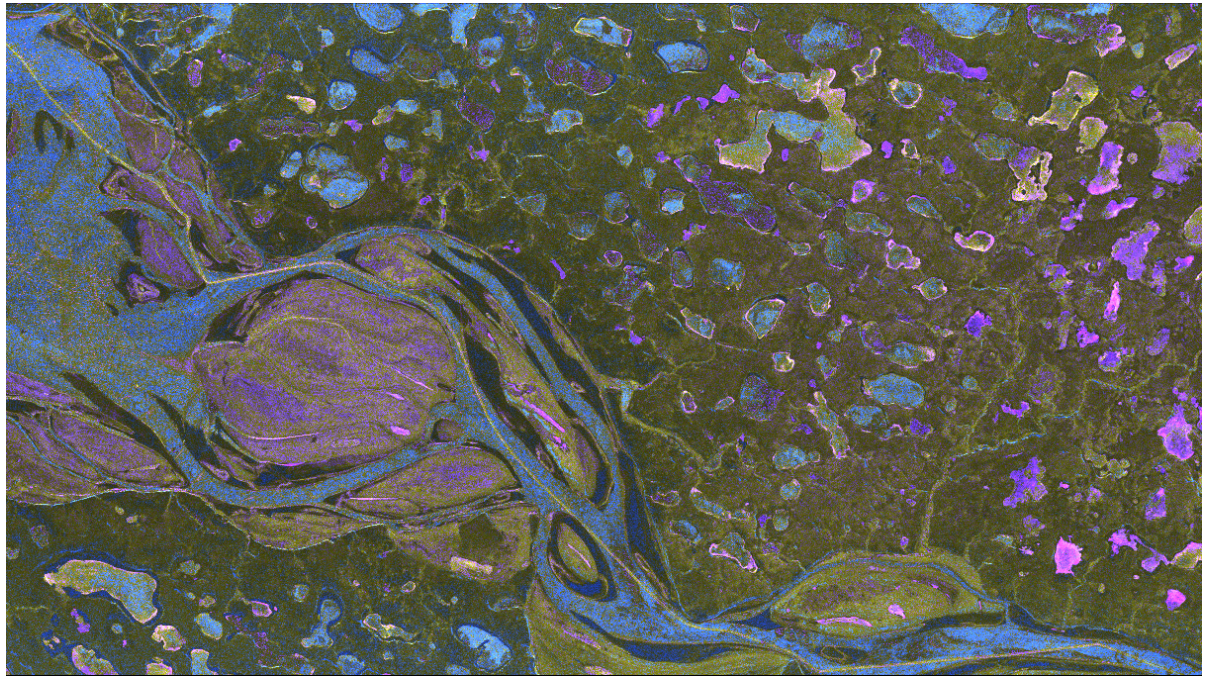
How well JULES Land Surface Model capture such variability?

How sensitive is the Arctic hydrological system to different set ups of the parameters? How well remote sensing helps tackling such uncertainties?

Thanks!

Questions?

Feel free to contact me: homero.paltanlopez@ouce.ox.ac.uk



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