



Lakes are sentinels, regulators and integrators of climate change (Williamson et al;, 2009)



Some key variables: water level, water temperature, ice over lakes, water color ...

Lakes and models: some examples, how lakes are linked to climate changes?

a constellation of satellites in 2021 for multi-variable survey of lakes: towards integrated approach

What are the main outcome of the lake's workshop of June 2017? what is the place of SWOT in more general lakes studies?

Definition of ECVs: 79 lakes were selected by GCOS organisation in a first step to caracterise Climate Changes related to lakes

#### Sentinel of CC

### 5 types of ECVs have been defined

- Daily/Weekly/Monthly water level changes
- Daily/Weekly/Monthly water extent changes
- Daily/Weekly/Monthly water temperature
- Date of Freez-up and break-up of lake ice, ice extent & depth
- Water color

Are there measurable from remote sensing? What are the climate issues adressed?

- Water cycle
- GhG cycle
- Biophysical processes





Date (years)

# **Response of Lake Water Temperature to climate (1/2)**



### Lakes are warming at a global average of 0.34 C per decade

there are lakes warming up rapidly adjacent to lakes that might even be cooling!

- Are model like Flake able to reconstruct these behavior?
- Are there feedbacks on climate itself?

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# **Response of Lake Water Temperature to climate (2/2)**





#### Seasonal (732 lakes; ARC-Lake)





- Lake temperature varies with depth and in time from daily to millennial time scales.
- The temperature structure is one of the most fundamental characteristics of a lake
- Trends may be observed only during winter

Courtesy of Woolway

### Response of Lake ice to climate (1/2)



Freeze-up/break-up, (ice duration) are robust indicators of climate variability and changes

Ice cover extent/concentration has an important impact of lake-atmosphere interactions

Manual measurements of ice dates (freeze-up/break-up) and ice thickness have drastically decreased at many national networks over the last three decades

Courtesy of C. Duguay

# Response of Lake ice to climate (2/2)

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20 years of SAR data on ERS1/2, S1A/B, Radarsat constellation (April; 1992 to 2011)

400 lakes studies in the Barrow region in Alaska



This result suggests that the general diminution of ground ice could be due to a general Courtesy of C. Duguay diminution of depth's ice but:

It does not take into account yearly dynamic of lake level when the ice is formed in winter.

Definitive conclusion on impact of global warming is therefore not possible

Ground cover of the classical nadir altimeters does not allow to determine the lake level of each of the small lakes in the area of study, and this is not possible to obtain this information from in situ measurements. => Would SWOT be able to solve this issue?

# Lakes as Regulator of climate change (1/2)

1- Lakes receive from the surface runoff, store and re-emit GhG to the atmosphere depending on biomass quantities in their vicinity

2- Lakes may change the regional climate through evaporation and cloud formation

Shrinkage of the Aral Sea reinforced the gradient of temperature between winter and summer and the intensity of wind (Micklin 1980)

Permafrost thawing due to climate change enhanced the global warming in the boreal regions through the emission of GhG in shallow lakes

3- The stock of carbon into lake sediments is much higher than the total contained in the ocean (Tranvik et al., 2009)

4- Shrinkage due to warming or rainfall decrease amplifies the carbon re-émission

DIC: Dissolved Inorganic Carbon DOC: Dissolved Organic Carbon POC: Particulate Organic Carbon TOC: Total Organic Carbon



# Lakes as Regulator of climate change (2/2)

### Simulation by Flake of the impact of lakes on the air température and précipitations in Europe

#### Temperature changes by season



Rouse et al., 2005

2 simulated cases : lakes taken into account and lakes erased from a 30 years simulation

Increasing air temperature in summer, autumn and winter up to 1/1.5°C Deep lakes like the Ladoga provoke a slight cooling in spring

It also has an impact on rainfall but in a lower amplitude

There is a high sensitivity of the Flake model to the depth of lake, often unknown for small lakes Impact also of ice duration over the lakes and of water temperature.

Can we assimilate satellite data on those parameters to improve the models outputs and consequently the climate change prediction?

### Impact of climate change on the water cycle



When changes occurs on the hydrological parameters of a lake, it always tends towards a new equilibrium



Mason et al., 1994, Cretaux et al., 2016

# Why do we need a satellite constellation? Models?



Yesou, Fruteau, Cretaux

# Outcome from the workshop on lakes, remote sensing, and climate (1/3)

The quantity of CO2 stored in a lake is modified by the duration of ice period in winter (Catalan et al., 2009)

The salt lakes contribute two times more to the emission of CO2 than freshwater lakes (Duarte et al., 2008)

Shallow & small lakes are more active in GhG re-emission

Studying lakes water balance and their interaction with CC depends on the morphology of lakes

Due to the high role of lakes as source and sink of CO2 & CH4, & the sensitivity to their geographycal distribution (number, type of surrounding ecosystem), their morphology (size, depth) and their type (salt/fresh)

=> their is a fundamental need to not only defining ECVs and system (Remote Sensing, In situ) to measure them, and model (Flake, GCM) to assimilate them but also to develop:



Tranvik et al., 2009

An inventory of lakes under different criteria and platforms to store and release these fundamental caracteristics



# SWOT determination of level, area and volume changes will enable to classify shallow and deep lakes

=> together with models will allow determining GhG emission
=> will allow selecting group of lakes for which area or level needs to be analysed
=> together with other RS will allow closing lake water balance at regional & global scale
=> will allow better take into account lakes into GCM



Classification and inventory of lakes by water occurrence from multi-spectral satellite images SWOT in 2021 will make a survey for the first time of lakes and reservoirs globally but only for 3 variables:

Height, area and storage changes

In 2021 many new sensors will allow measuring other variables in an unprecendent accuracy and exhaustivity:

Water temperature, water color, biomass, precipitation, gravity field, soil moisture, high resolution mapping

We examined what are the current situation in lake studies from the linkage with climate change's point of view, what are the questions to adress and what are the first suggestions to propose?

# Some key questions

What are the most needed satellite data sets in limnology, are current sensors adequate, do we need new sensors?

How to organize international community of remote sensing data providers to make data useful for lakes more accessible to the science communities, and what recommandations for short term funding & long-term observation plans related to lakes?

Can we understand climate change impacts on lake ice, lake temperature, lake hydrology, and lake biogeochemistry independently, or are changes only understandable through coupled analysis, with integrated data analysis?

Is there a need to revise the definition of the ECVs defined by GCOS?

Is there a joint field (including airborne) & remote sensing campaign that we could plan that would address key questions related to lakes?

It is needed to develop global ecological Lake Network with in situ instrumentation on a high range of variables to measure, for:

- satellite data calibration and validation
- assimilation into models
- comprehension of the long term changes in a multi variable point of view

There is a lack of global classification of lakes under different criteria (morphological, climatic, physical, biogeochemical).

Set up a network of lakes with adequate and pertinent classification, is therefore a necessity together with an integrated database of inter-calibrated various climate records

Constitute a working group on Lakes, Remote Sensing and Climate with regular worshop and prepare a white paper for the end of the year