Lakes in Central Asia, survey from satellite remote sensing.

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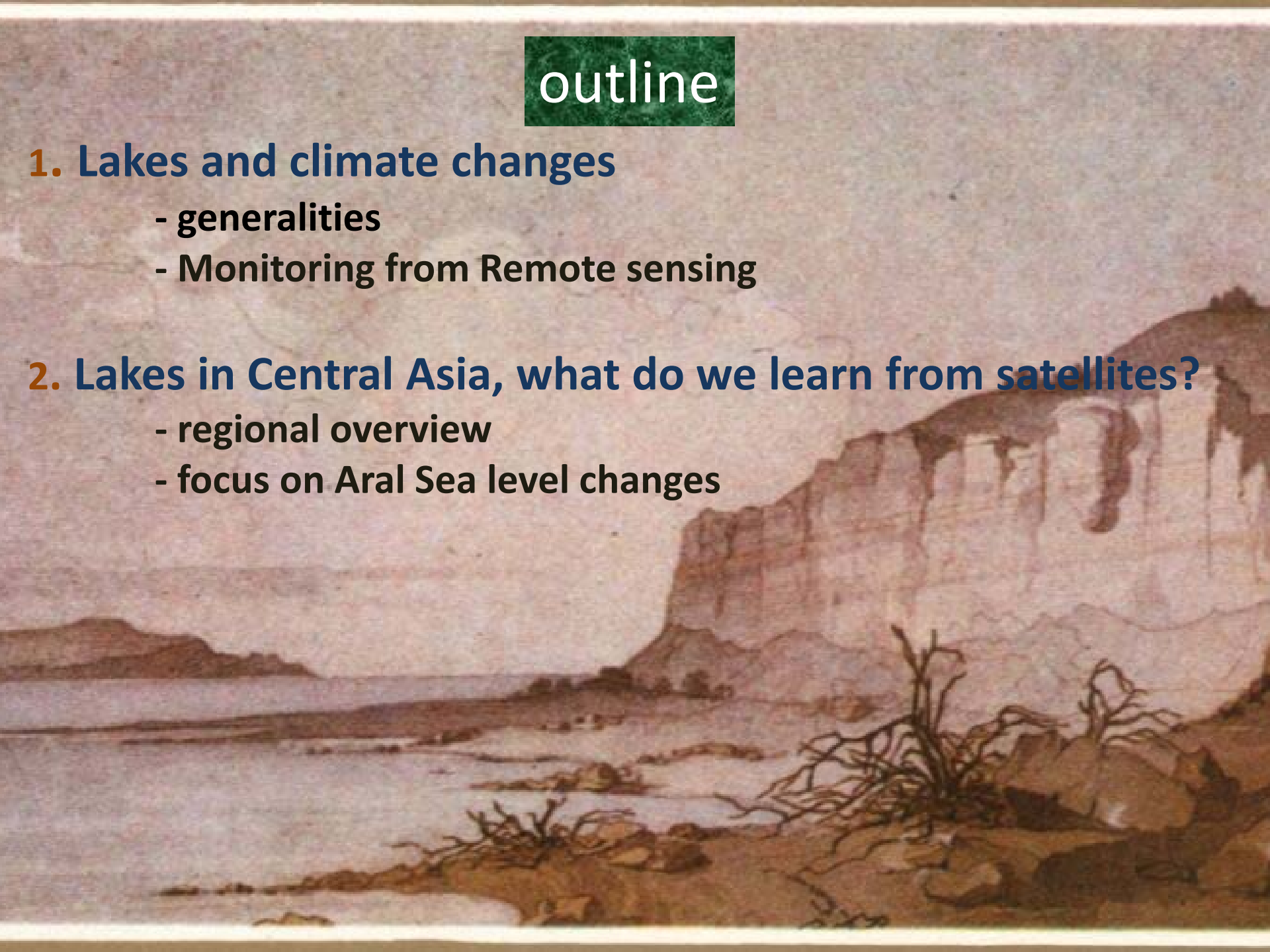
Muriel Bergé-Nguyen

St Petersburg, Nov 18, 2019

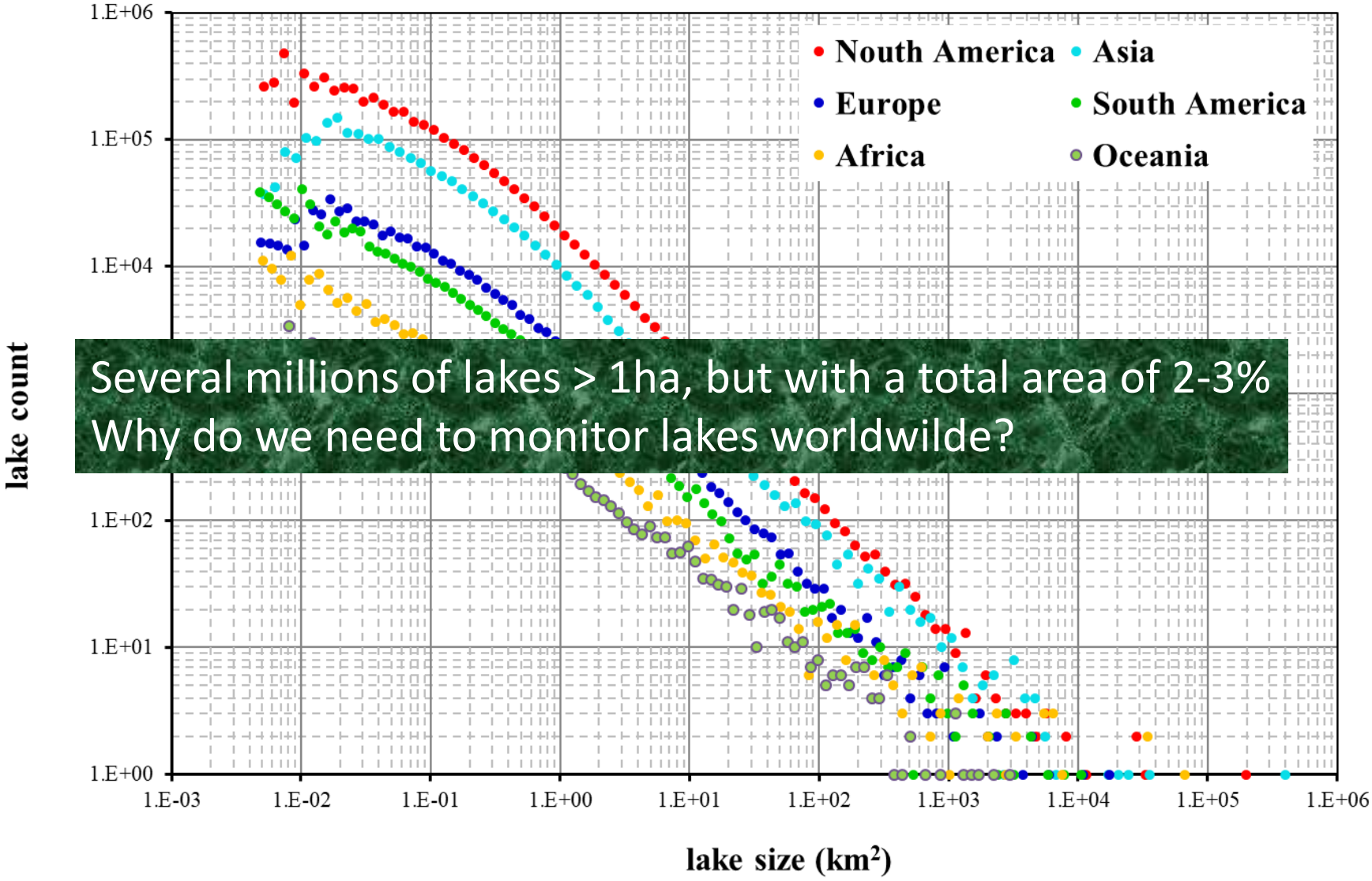
outline

1. **Lakes and climate changes**
   - generalities
   - Monitoring from Remote sensing

2. **Lakes in Central Asia, what do we learn from satellites?**
   - regional overview
   - focus on Aral Sea level changes



Continent-based Global Lake Size Distribution



Several millions of lakes > 1ha, but with a total area of 2-3%

Why do we need to monitor lakes worldwilde?

Courtesy of Y. Sheng

Because lakes are:

1) sentinels, regulators and integrators of climate change **(Williamson et al., 2009)**

FLAKE, VIC (Arclake, OLCI, ERA)

Lake Water Balance

$$\frac{dV_{(lac)}}{dt} = Sl_{(t)} * \left(P_{l(t)} - El(t)\right) + G + R - D$$

Alti+imagery
SWOT

imagery
NISAR, Venus, S2, SWOT

TRMM, APHRODITE, GPCP, CRU
GPM

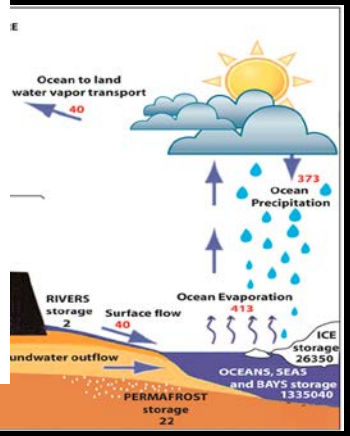
In Situ, models
SWOT

Watershed balance

$$\frac{dV_{(GW)}}{dt} + \frac{dV_{(sn)}}{dt} = \frac{dV(total)}{dt} - \frac{dV(lac)}{dt} - \frac{dV_{(SM)}}{dt}$$

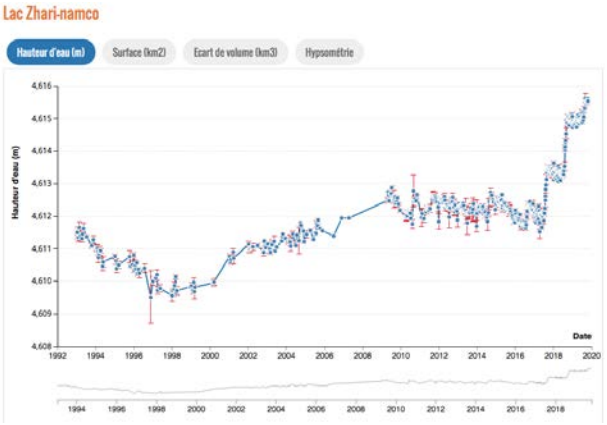
GRACE
GRACE-FO

SMOS, GLDAS ESA CCI
SMAP

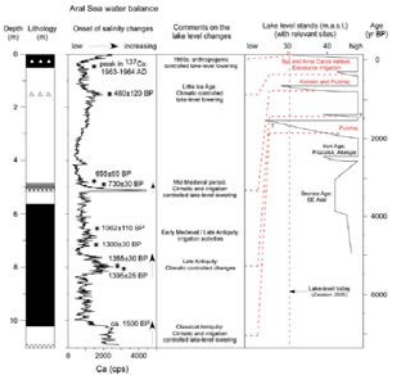


$$\Delta S = P - ET - Q = \Delta S_L + \Delta S_{sn} + \Delta S_{SM} + \Delta S_{GW}$$

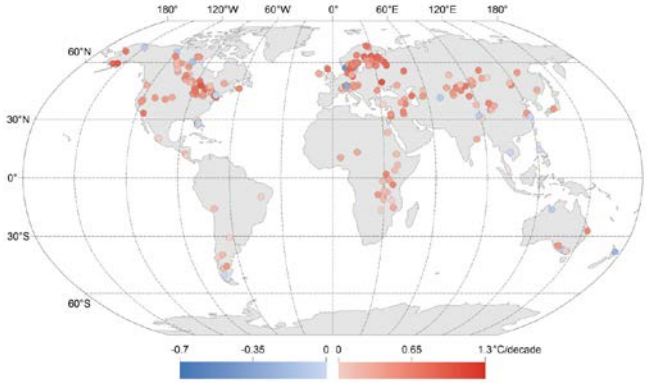
Water level and storage changes are reflecting regional and global climate changes

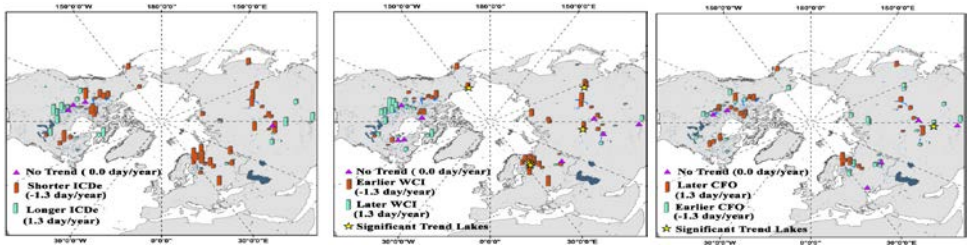


Lakes sediments contain archives of past climate

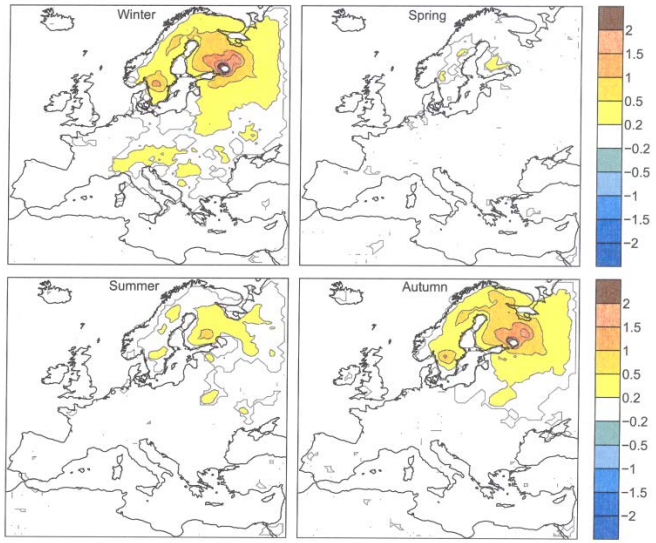


Lakes are warming at a global average of 0.34 C per decade





Under global warming the lake ice cover have diminished in time duration, depth and extent



Lakes regulate the regional climate

Courtesy, O Reilly, Duguay, Cretaux, Rose, Oberhansli

CCI+, ECVs lacs

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

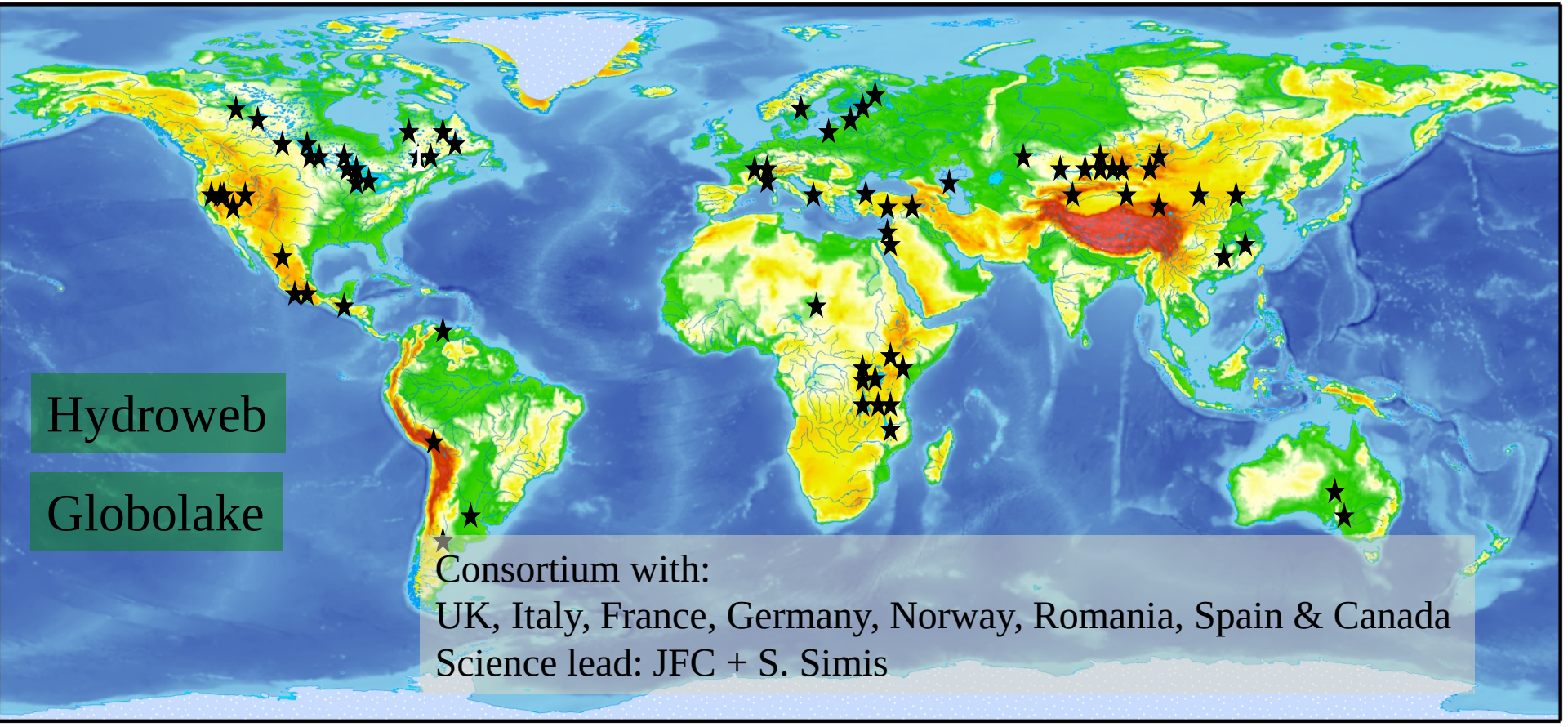
5 types of ECVs have been defined

- 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

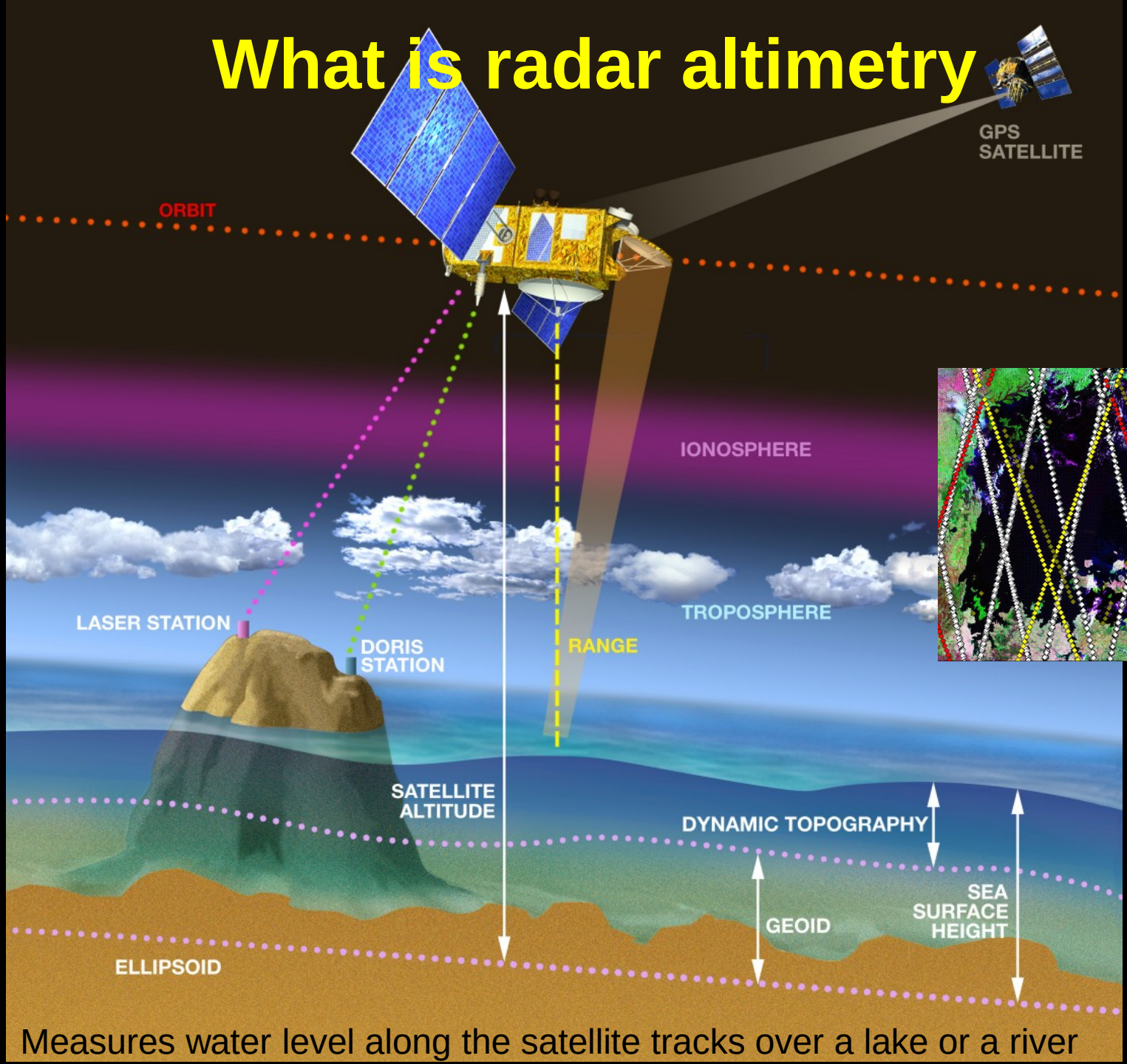
Are there measurable from remote sensing?

What are the climate issues adressed?

- Water cycle
- GhG cycle
- Biophysical processes



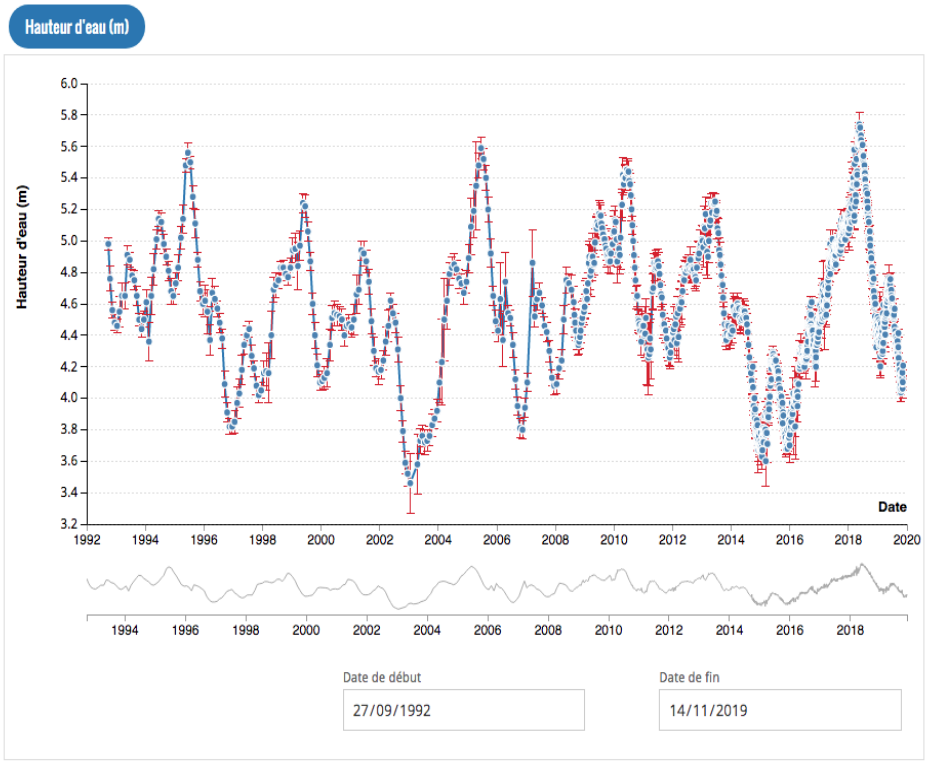
What is radar altimetry



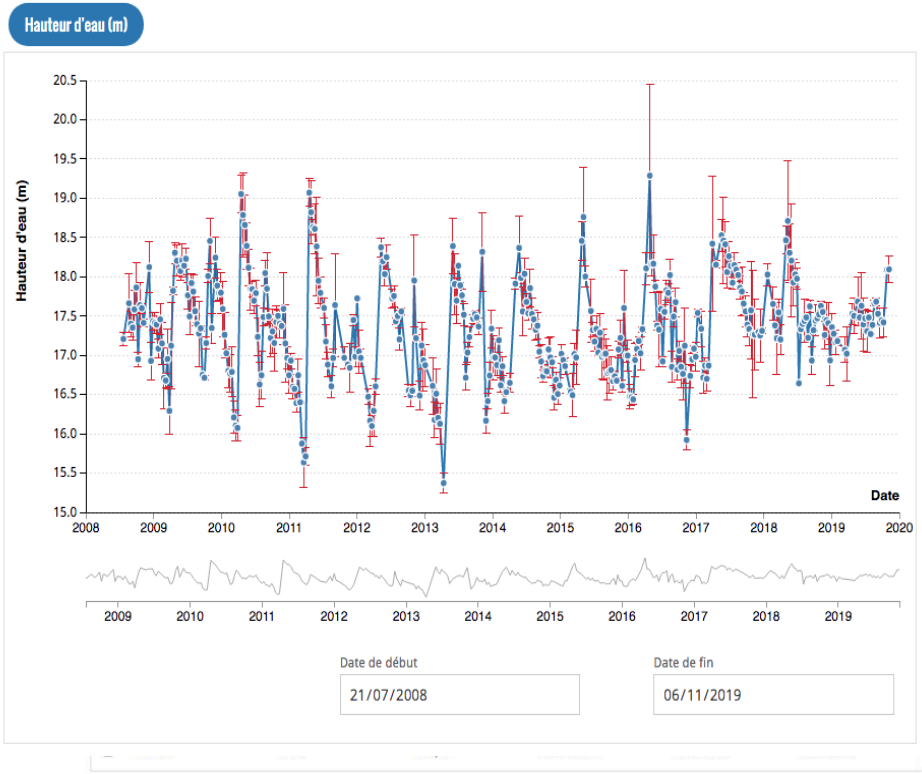
Measures water level along the satellite tracks over a lake or a river

Hydroweb services for lakes and rivers worldwide

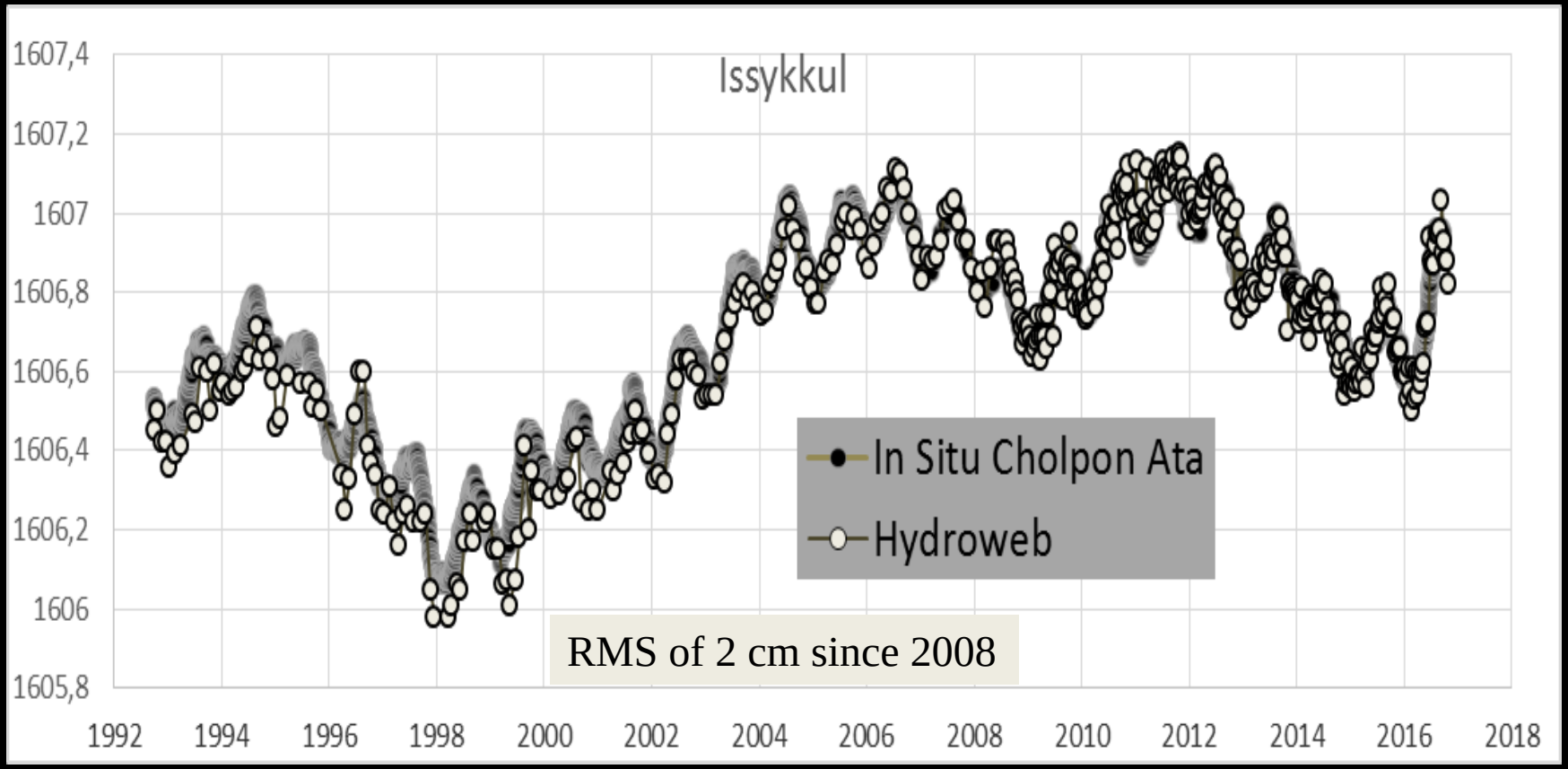
Lac Ladoga



Rivière Volkhov



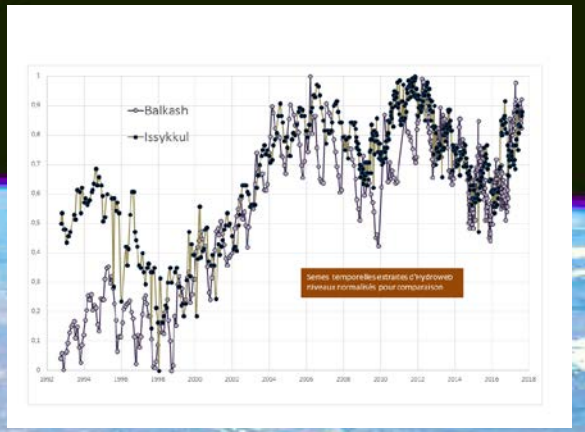
Lakes and rivers operationnaly processed

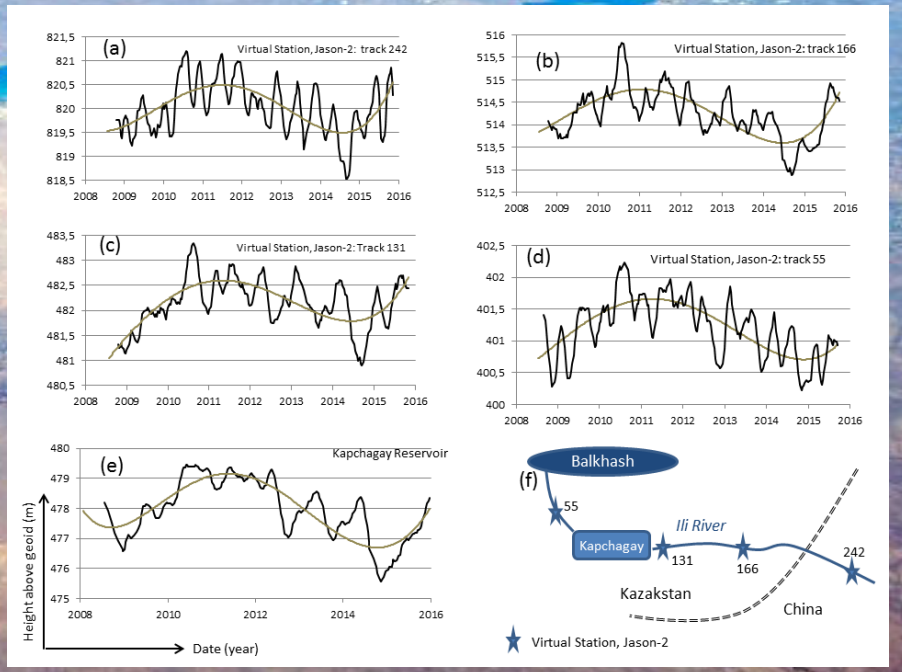

Issykkul
1607,4
1607,2
1607
1606,8
1606,6
1606,4
1606,2
1606
1605,8
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
In Situ Cholpon Ata
Hydroweb
RMS of 2 cm since 2008

Central Asian basins, transboundary issues

- Desert
- steppe
- Three big rivers
- Reservoirs
- High mountains
- 9 countries

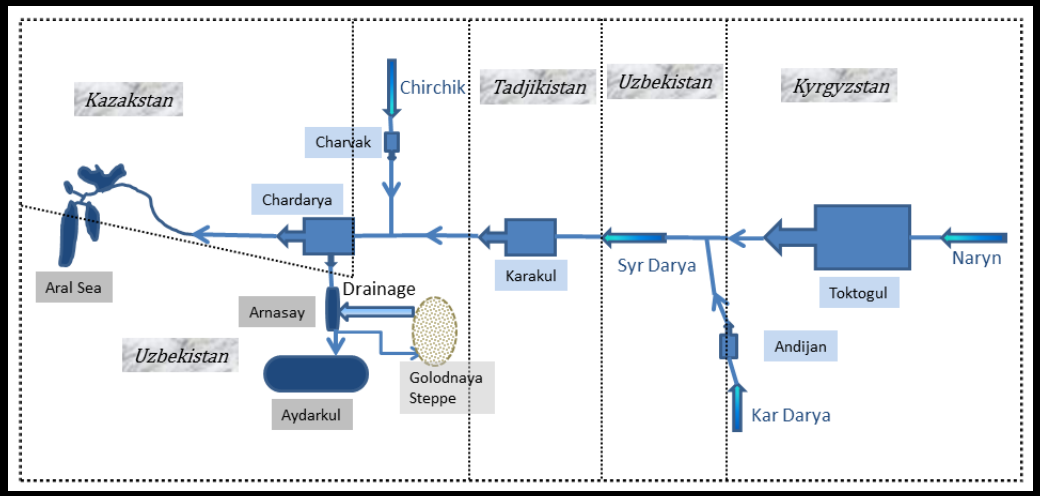
Satellite altimetry over Balkhash lake basin

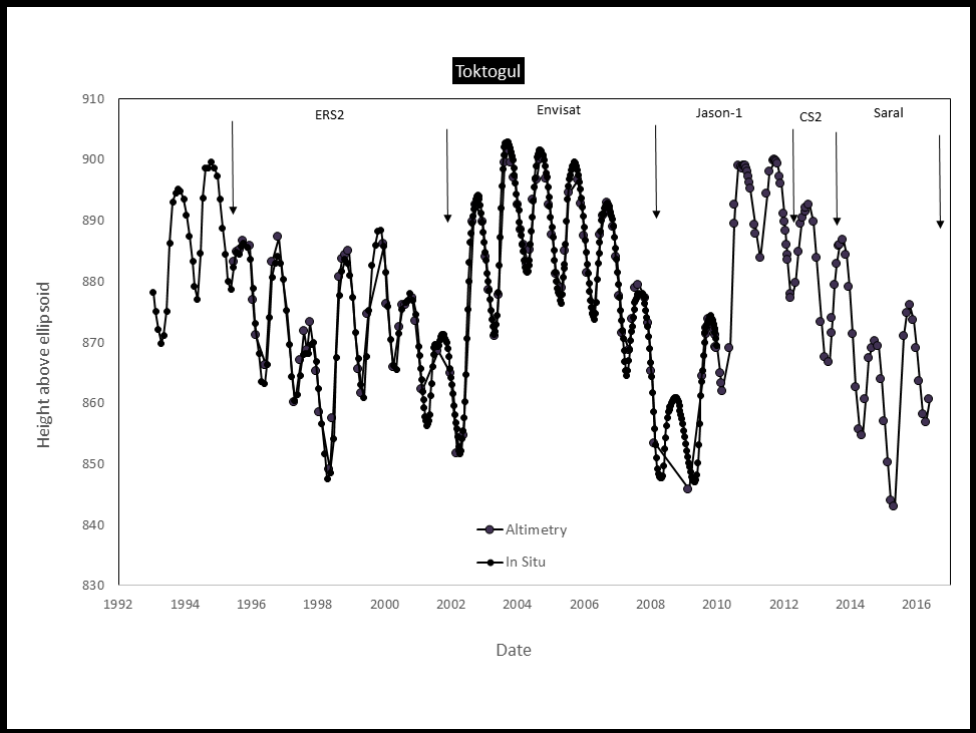




Isbekov et al., 2018

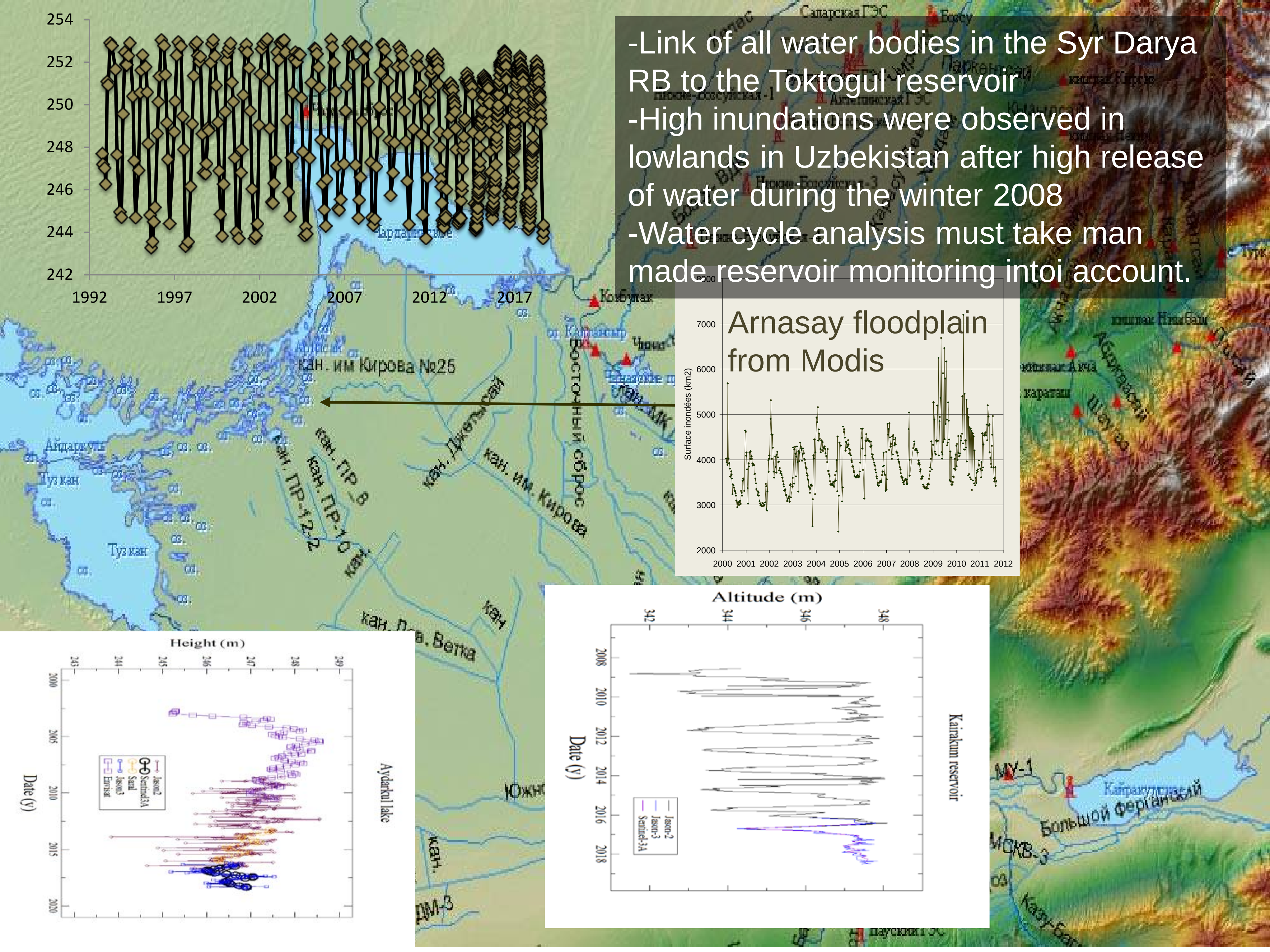
Transboundary Syr Darya monitoring



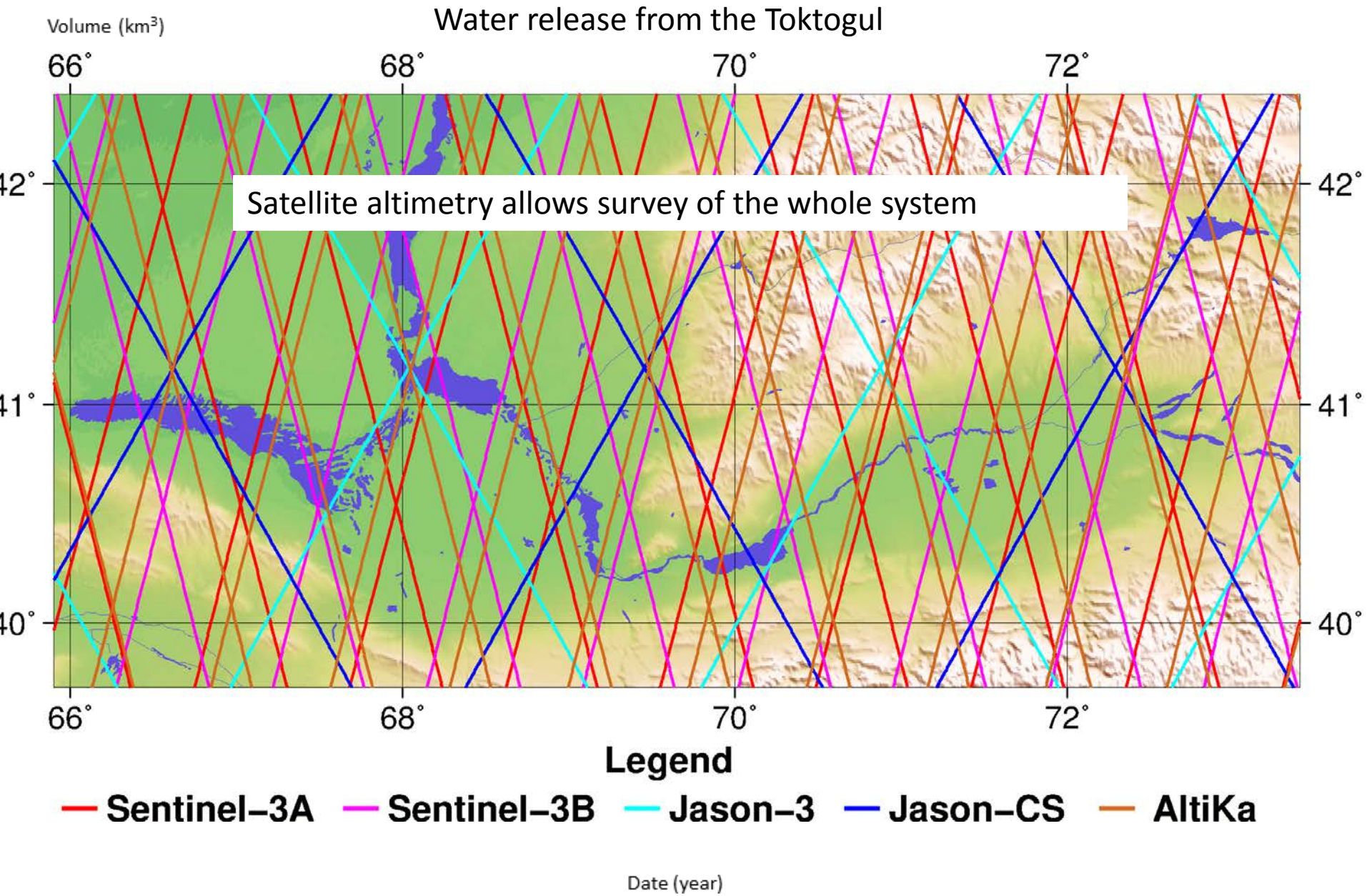


The hydrologic connectivity of rivers, lakes, reservoirs, floodplains, and wetlands is hugely important for hydrology, biogeochemistry, and ecology but is very hard to assess using current technology. Satellite altimetry & imagery allow us to track hydrologic connectivity among water bodies.

Cretaux et al., Erl,, 2015

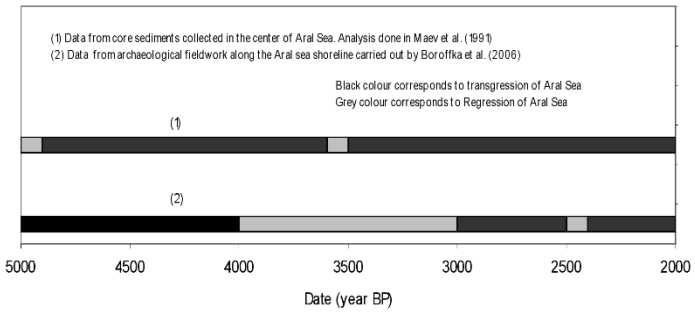

-Link of all water bodies in the Syr Darya RB to the Toktogul reservoir
-High inundations were observed in lowlands in Uzbekistan after high release of water during the winter 2008
-Water cycle analysis must take man made reservoir monitoring intoi account.
254
252
250
248
246
244
242
1992
1997
2002
2007
2012
2017
Arnasay floodplain from Modis
Surface inondées (km2)
7000
6000
5000
4000
3000
2000
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Height (m)
Date (y)
Aydarkul lake
Jason2
Sentinel3A
Saral
Jason3
Envisat
Altitude (m)
342
344
346
348
Date (y)
Kairakum reservoir
Jason-2
Jason-3
Sentinel-3A
кан. им Кирова №25
кан. им. Кирова
Восточный сброс
Айдаркуль
Тузкан
Кайраккумское
Большой Ферганский
кан. Лев. Ветка

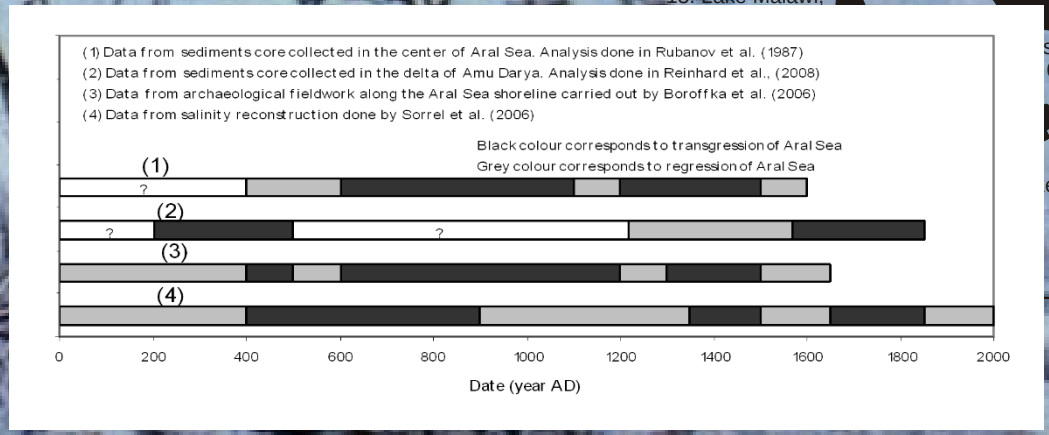
Water management of the Toktogul is strenghly driving the Syr Darya reservoirs water management

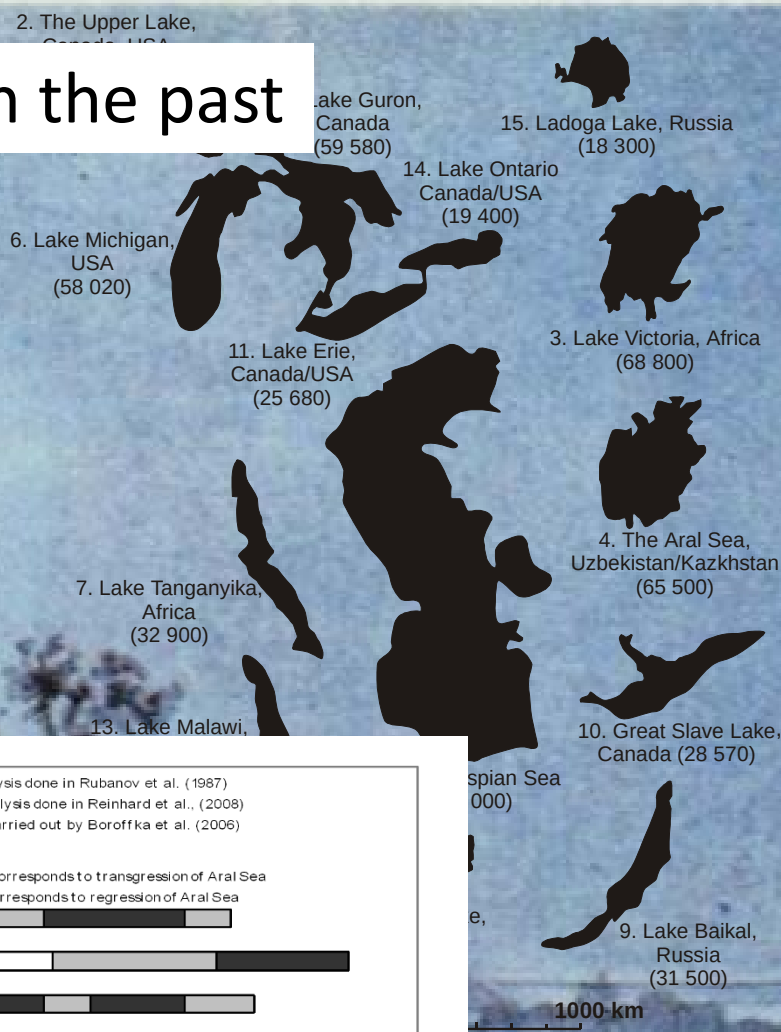


The Aral Sea in the past

Past phases of regression & transgression







4th biggest lake in the world in 1960

Cretaux et al., Global Planetary Change, 2013

How past of Aral Sea is reconstituted?

Temples of Kerdery close to ancient river bed of Syr Darya

Archaeological investigation

Old settlement locations

Historical chronical

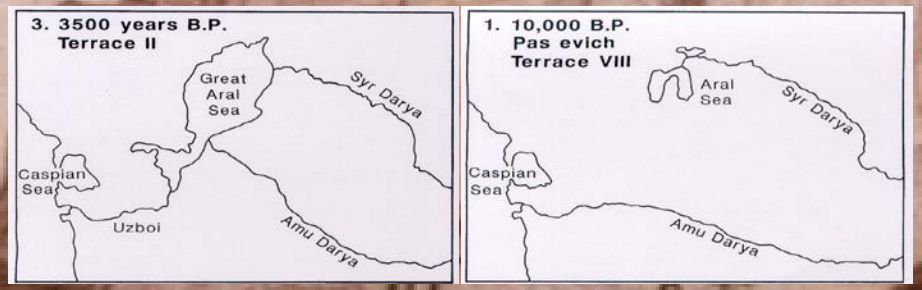
Memories (Babur, others), works of scholars of the middle Age

Report from travellers of the past (European, Arabs, Persian, Chinese)

Sediment core analysis

-Pollens studies

-stratification/datation/classification of different salt minerals



Géomorphology

-Mapping of old river beds, channels (Uzboy)

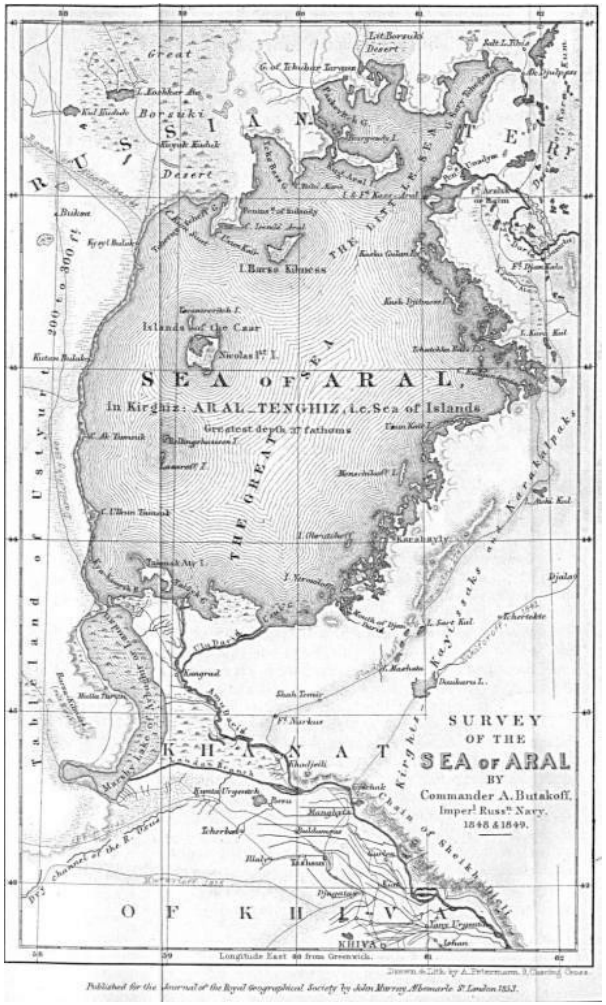
-Datation of west coast terraces


Panoramic view of ancient Gonurdepe

Parameters of the Aral Sea in the beginning of 20th century

Between the middle of the 19th century and 1961 shape and salinity of the Aral Sea practically didn't change.

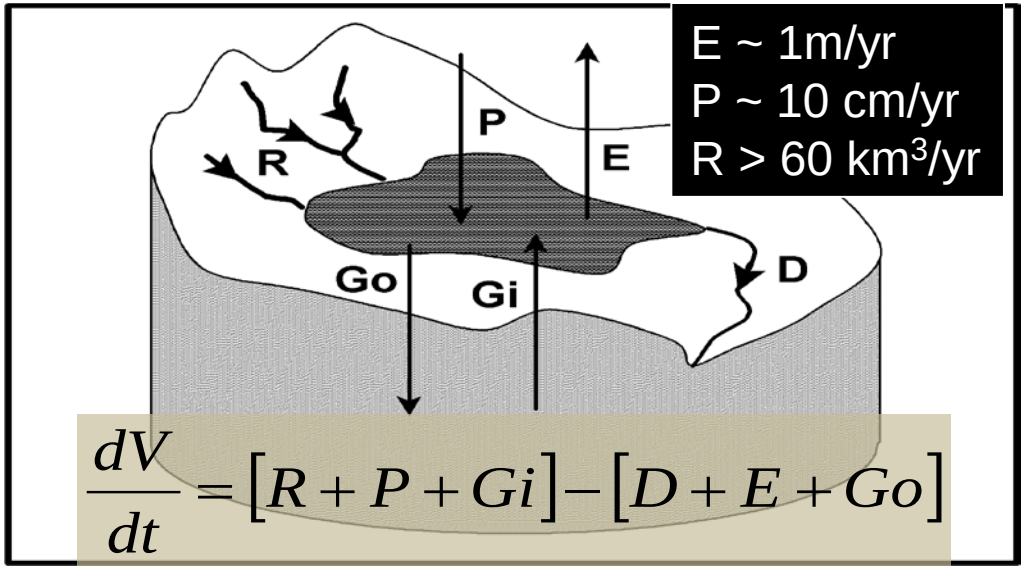
- Area 67499 km^2
  - Large Aral 61381 km^2
  - Small Aral 6118 km^2
- Volume 1089 km^3
  - Large Aral 1007 km^3
  - Small Aral 82 km^3
- Level +53.4 m
- Maximal depth 69 m
- Salinity about 10 g/l
- inhabited by about 20 species of fishes and about 200 species of free-living Invertebrates-
- 4 millions of Ha of irrigated land

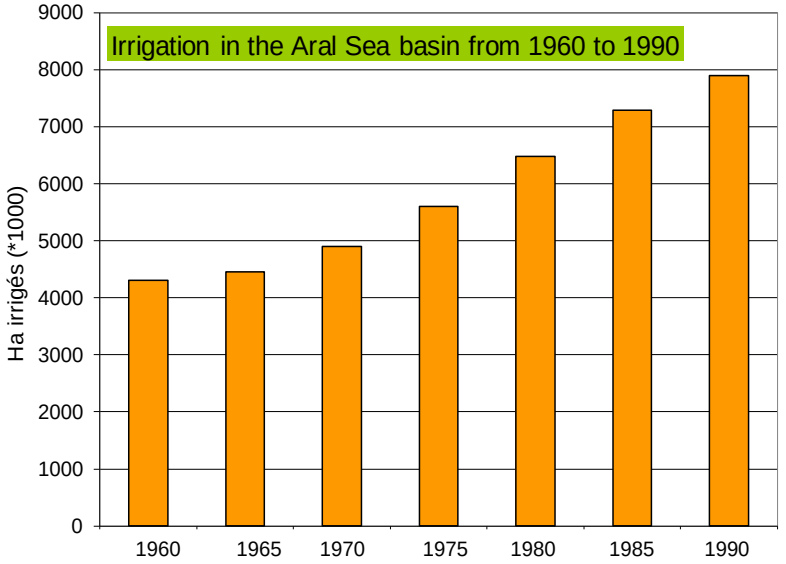


The Aral Sea map made by A.I. Butakov expedition materials in 1848-1849

Courtesy of N. Aladin

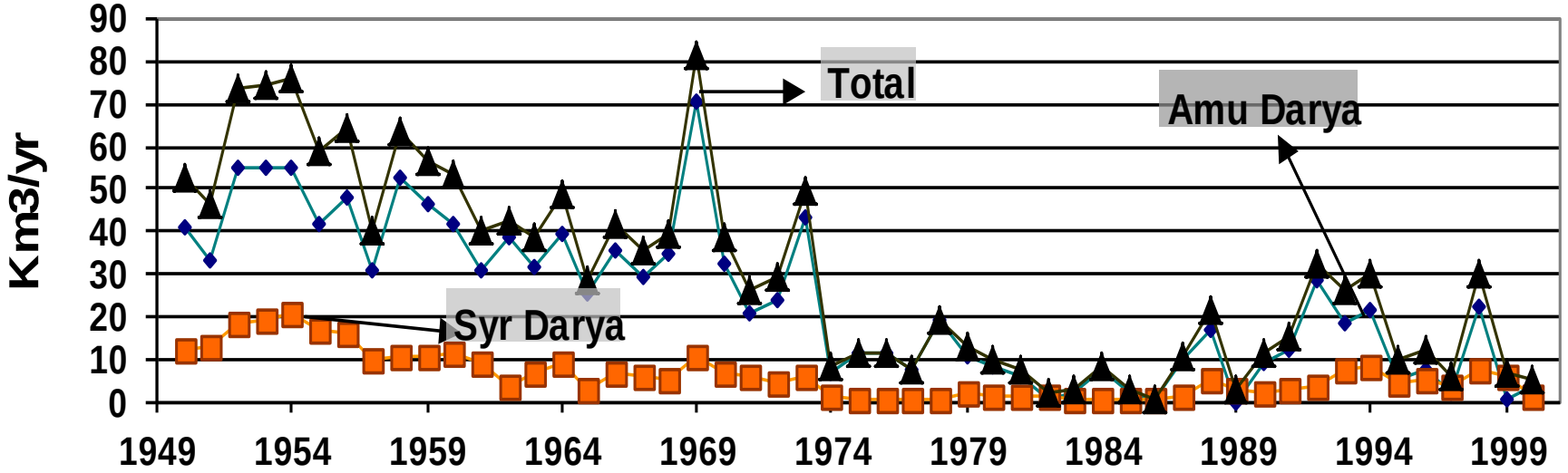
What happened after 1960?





Discharge into the Aral Sea

Cretaux et al., JGLR, 2005



A lake is an integrator of climate change: it always tend towards equilibrium
=> After severe decrease of river runoff the Aral Sea shrank dramatically

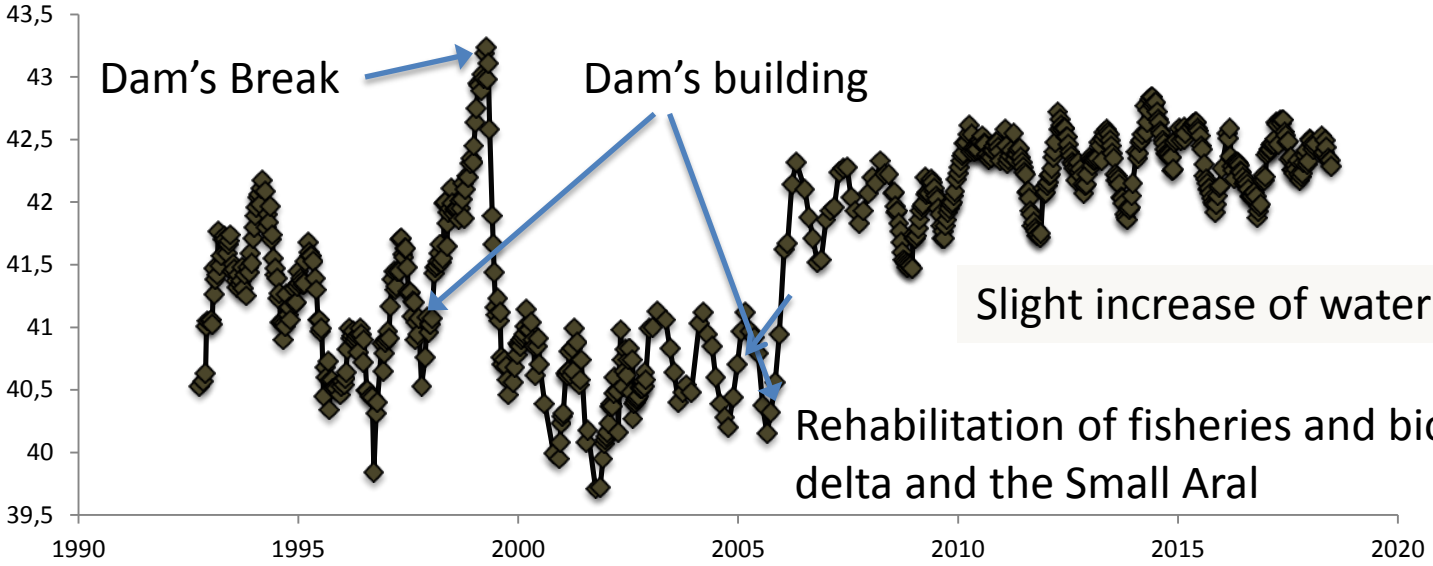
Aral Sea level and salinity variation from 1960 to 2005

Courtesy of N. Aladin

What happened over the last 25 years on Small Aral?

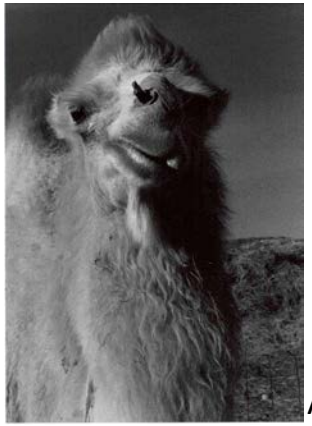
What do we learn from satellite altimetry?

North Aral Sea level from satellite altimetry

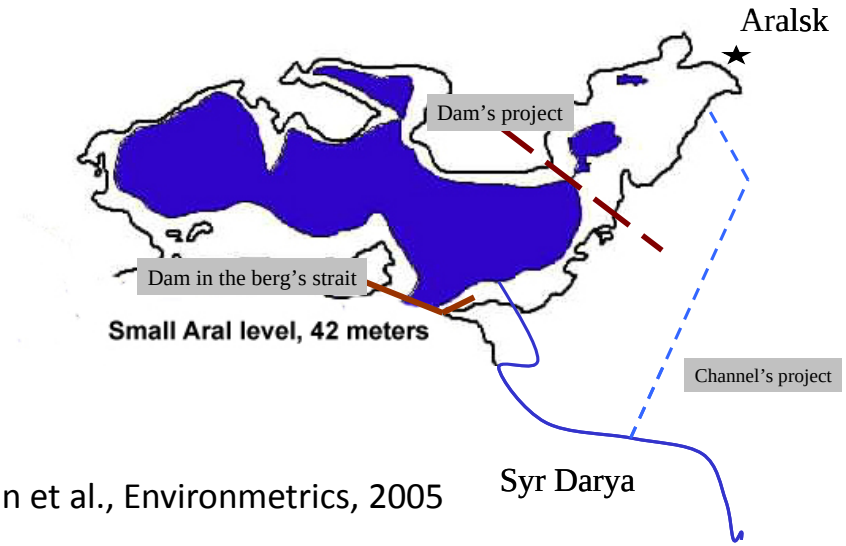


Slight increase of water level

Rehabilitation of fisheries and biodiversity in the delta and the Small Aral



Aladin et al., Environmetrics, 2005



Current desiccation of the Aral Sea : What about Large Aral?

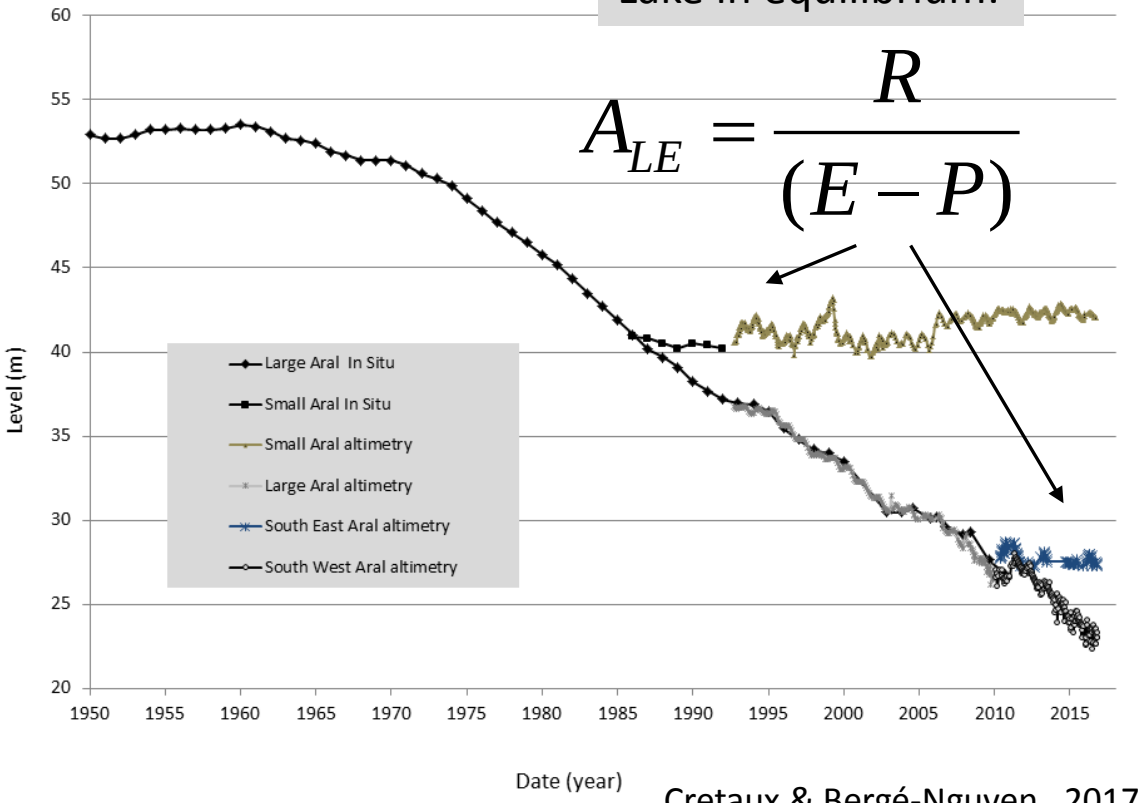
No operationnal in situ observations after 2000=> Altimetry offers a continuous operationnal survey monitoring of all individual water bodies

Separation of Aral Sea in 1989 into small (North) and big (South) Aral Sea=> Small Aral at long term equilibrium

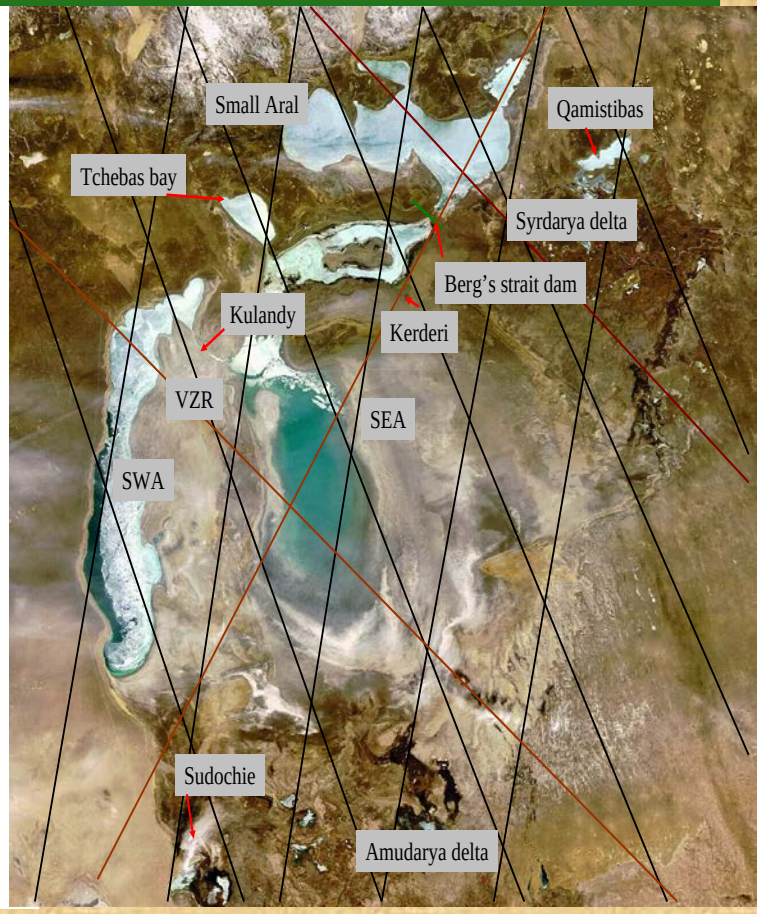
Separation of Big Aral after 2010-2012 into SW and SE Aral Sea => SE Aral in relatively stable equilibrium since SW Aral continues to shrink

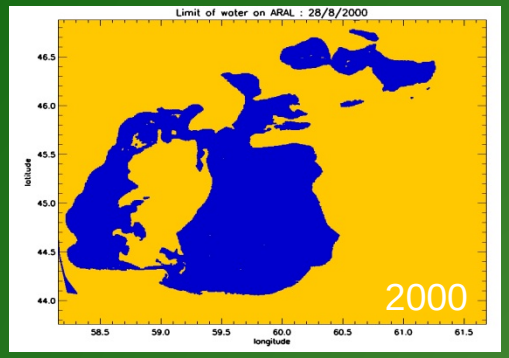
Lake in equilibrium:

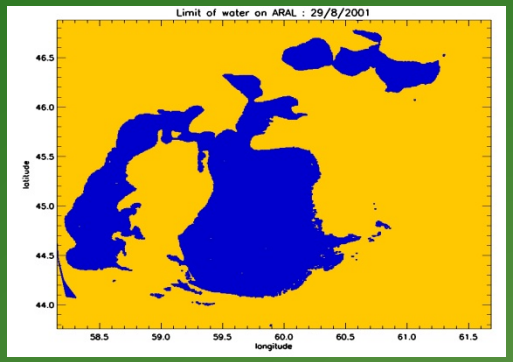
$$A_{LE} = \frac{R}{(E-P)}$$

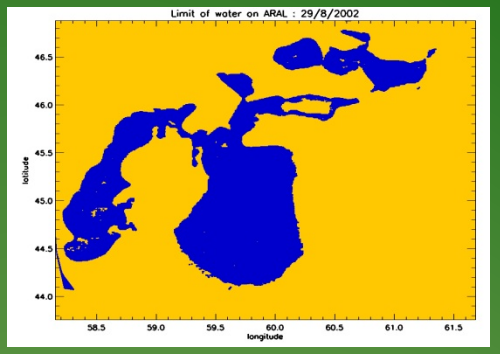


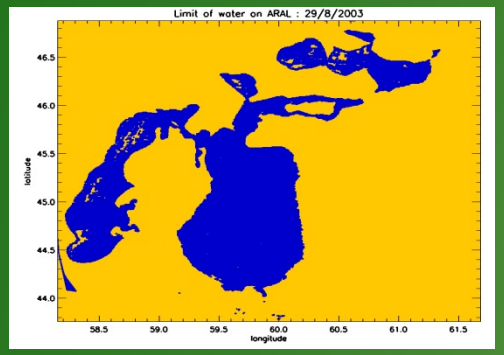
Cretaux & Bergé-Nguyen , 2017

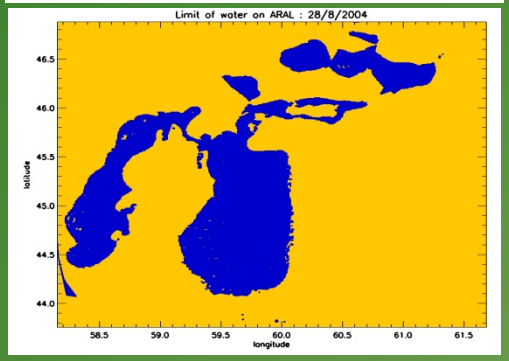


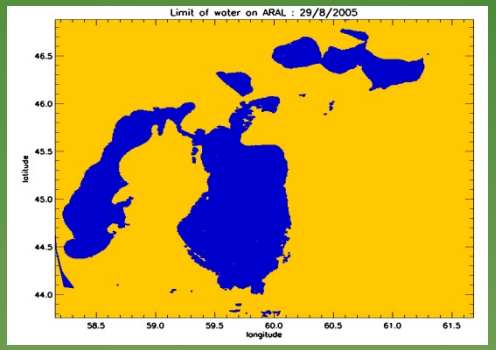

Limit of water on ARAL : 28/8/2000
2000
latitude
longitude

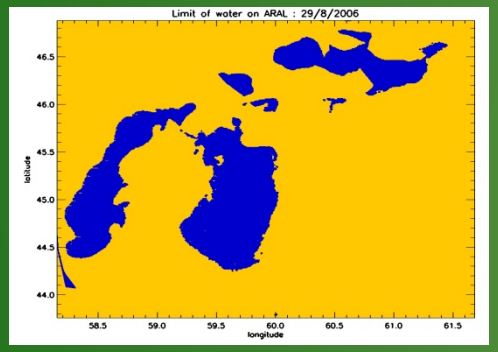

Limit of water on ARAL : 29/8/2001
latitude
longitude

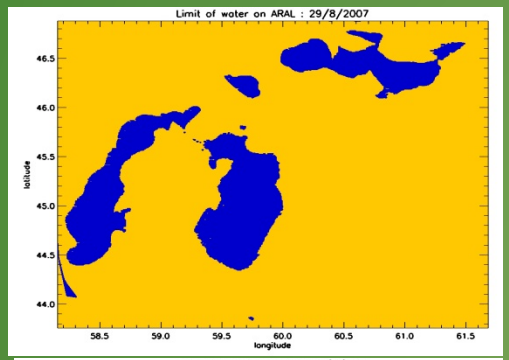

Limit of water on ARAL : 29/8/2002
latitude
longitude

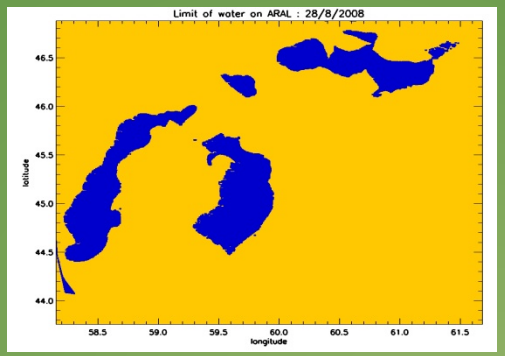

Limit of water on ARAL : 29/8/2003
latitude
longitude

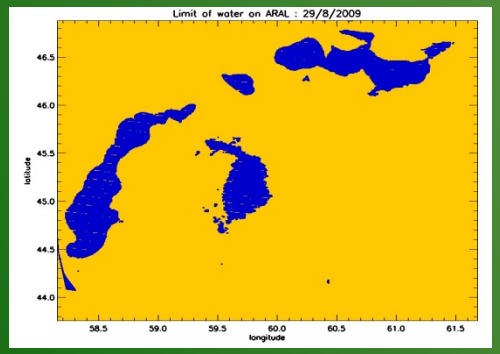

Limit of water on ARAL : 28/8/2004
latitude
longitude

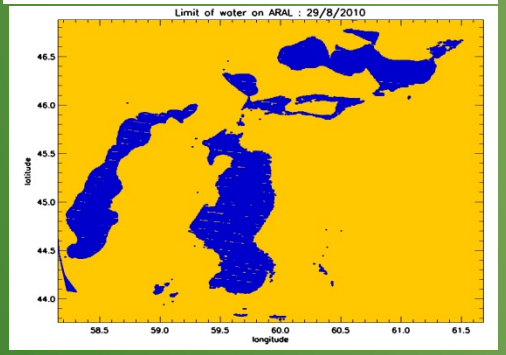

Limit of water on ARAL : 29/8/2005
latitude
longitude

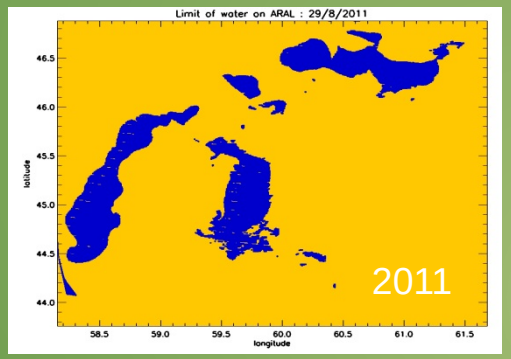

Limit of water on ARAL : 29/8/2006
latitude
longitude


Limit of water on ARAL : 29/8/2007
latitude
longitude

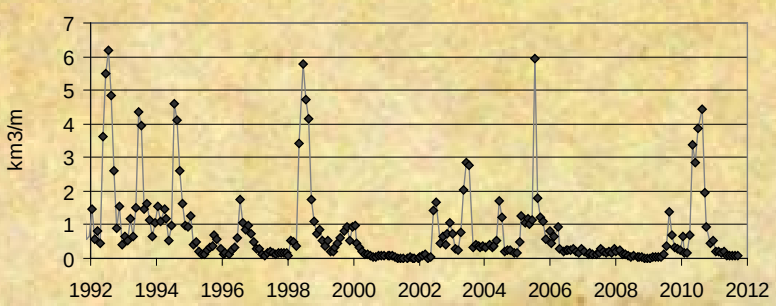

Limit of water on ARAL : 28/8/2008
latitude
longitude

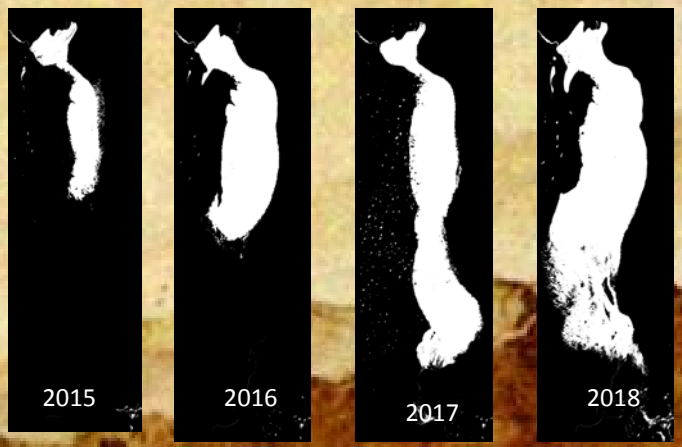

Limit of water on ARAL : 29/8/2009
latitude
longitude

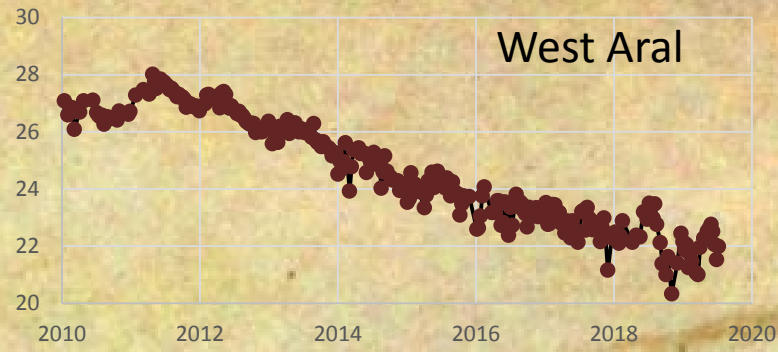

Limit of water on ARAL : 29/8/2010
latitude
longitude

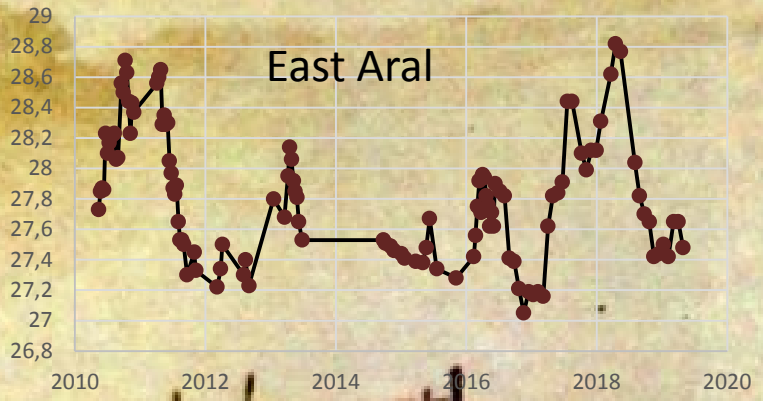

Limit of water on ARAL : 29/8/2011
2011
latitude
longitude

Discharge of Amu Darya

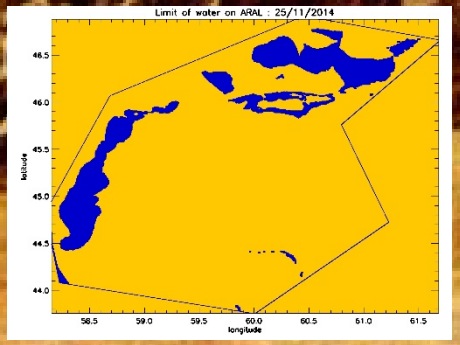








November 2014, 2019



Separation

Conclusions

Aral Sea has desiccated since 1960 but this is not the first time in geological & historical time

Using satellite altimetry and imagery operationnal systems it is possible to fully and continuously :

- monitor Aral Sea water level, areal extent and volume
- Understand the process of desiccation and separation into several small water bodies
- Monitor reservoir level, areal extent and volume of all reservoirs along the Amu and Syr Darya, as well as other basins like the Balkhash/Kapchagay/Illi system

Future altimetry missions are now planed for the next 20-30 years => they will maybe allow to see a future re-habilitation of the Aral Sea, but this is another history

Thank you for attention