Aral Sea level variations from satellite Remote sensing data

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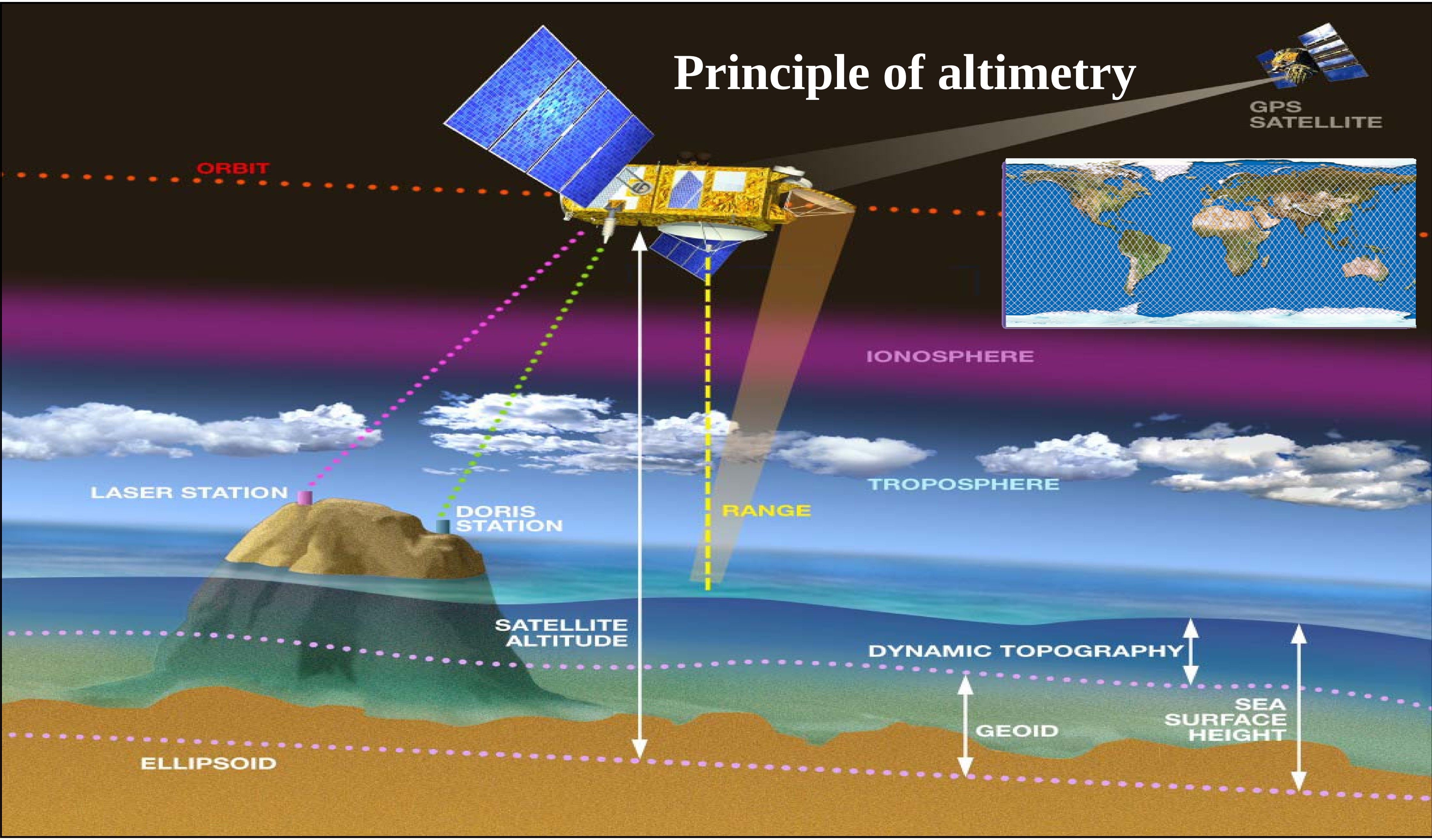
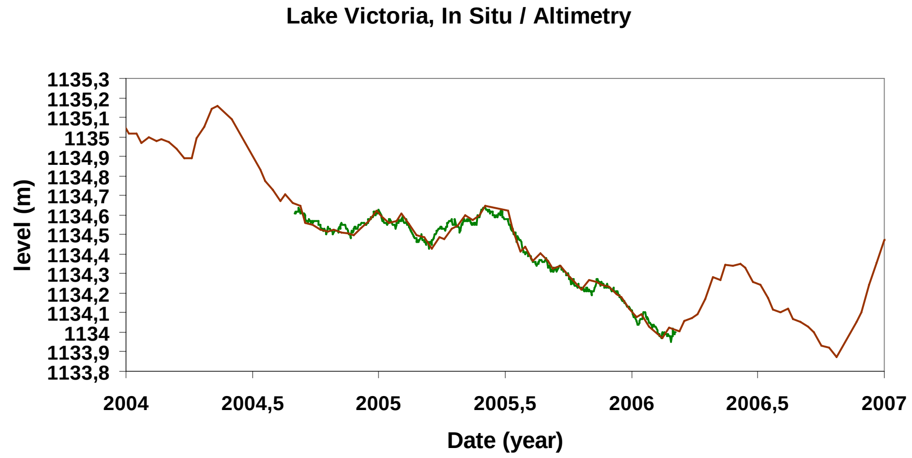
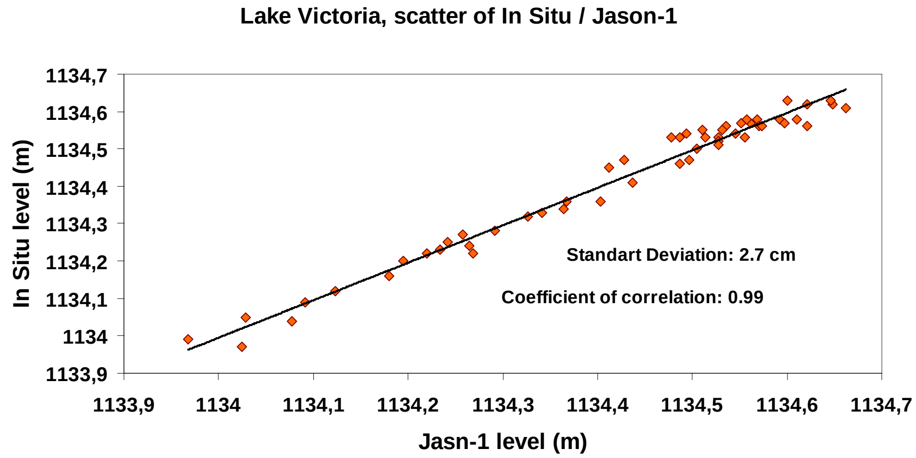
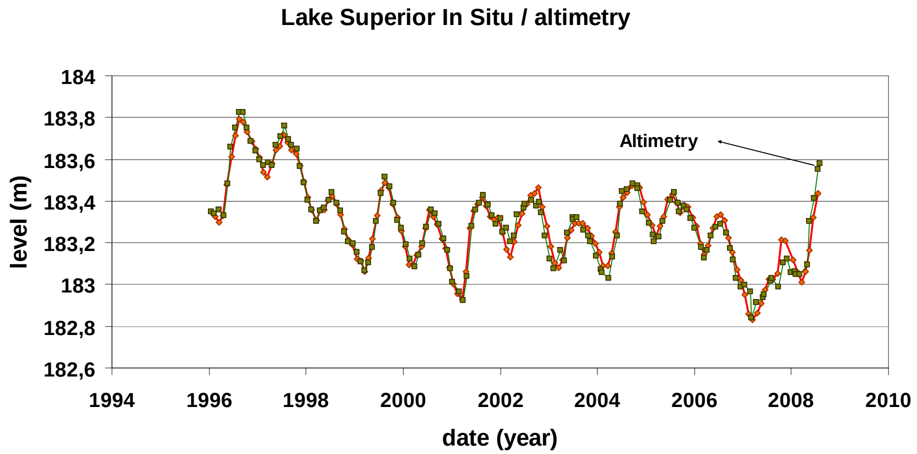
Aral Sea conference
St Petersburg, October, 13-15, 2009

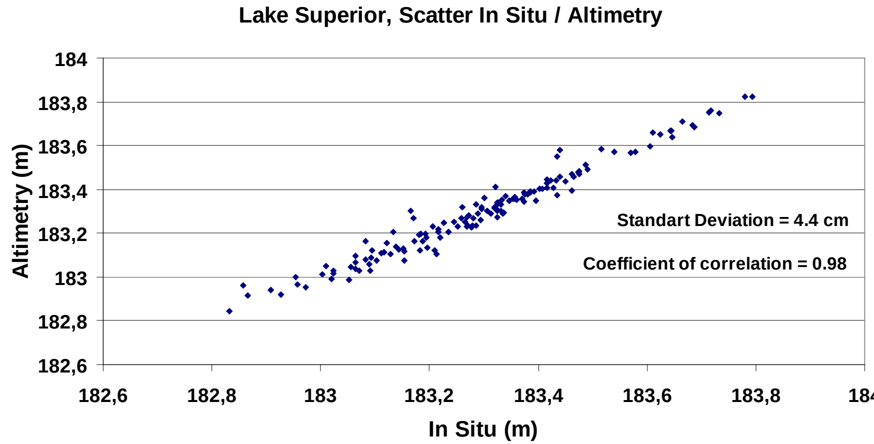

Principle of altimetry
GPS SATELLITE
ORBIT
IONOSPHERE
TROPOSPHERE
LASER STATION
DORIS STATION
RANGE
SATELLITE ALTITUDE
DYNAMIC TOPOGRAPHY
SEA SURFACE HEIGHT
GEOID
ELLIPSOID

Altimetry over lakes: comparison with In Situ data (1/2)









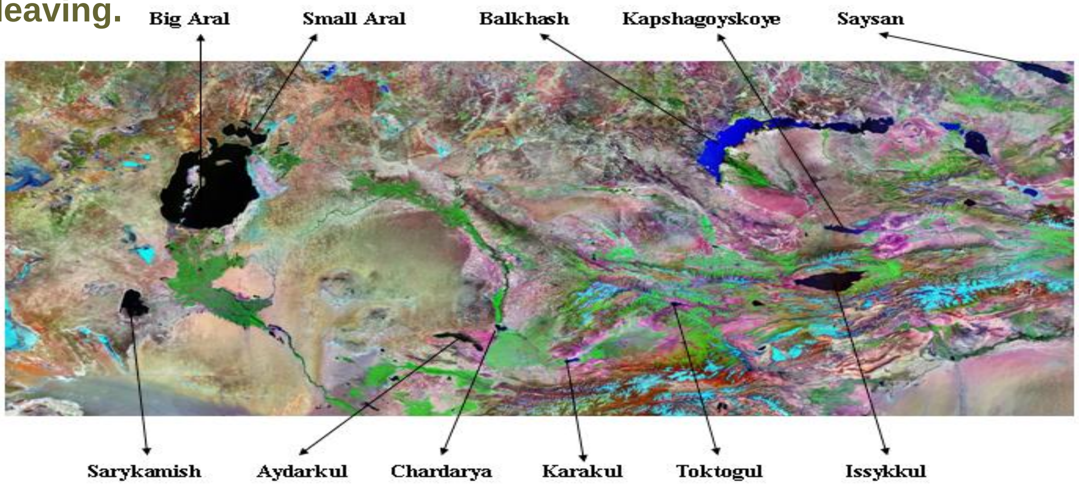
Altimetry over lakes: comparison with In Situ data (2/2)

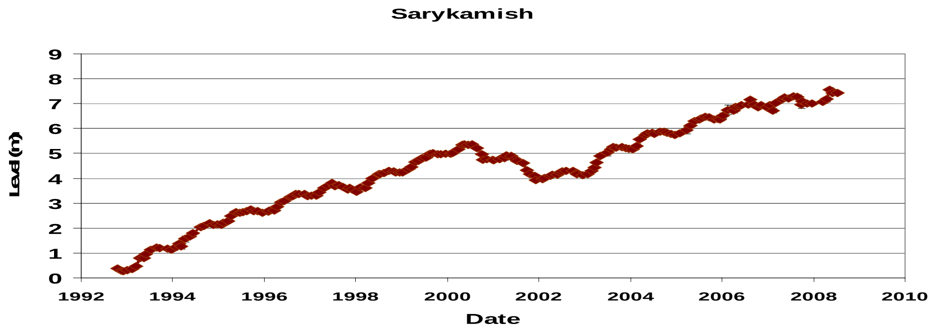
Lake name	*Country*	*Size of the lake (km2)*	*RMS of the differences In Situ / altimetry level (cm)*
Erie	**USA, Canada**	**25821**	**5**
Issykkul	**Kyrgyzstan**	**6236**	**4**
Kariba	**Zambia, Zimbabwe**	**5400**	**24**
Mar de Chiquita	**Argentina**	**6000**	**13**
Powell	**USA**	**380**	**80**
Superior	**USA, Canada**	**82367**	**4**
Titicaca	**Peru, Bolivia**	**8372**	**17**
Victoria	**Tanzania, Uganda, Kenya**	**68800**	**3**

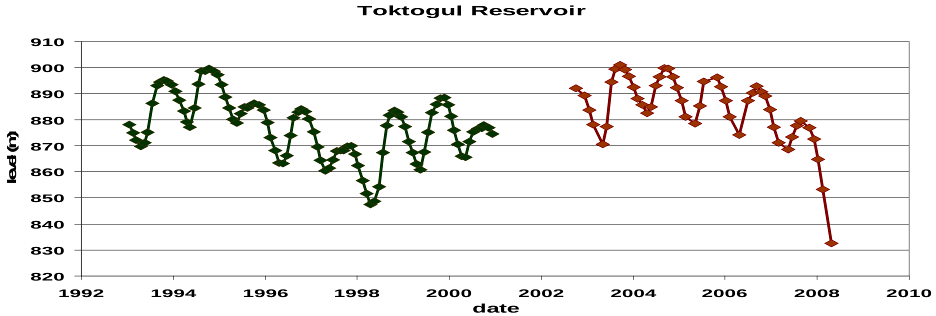
For the biggest lakes (Victoria, Superior and Erie) the accuracy is better than 10 cm, the intermediate (Kariba, Mar de Chiquita, and Titicaca) the accuracy is at the decimetre level, while for some small water bodies, as Lake Powel it is closer to 1 meter, particularly due to the fact that this lake is long but very thin. The Lake Issykkul which is an intermediated lake in size, presents surprisingly very accurate results.

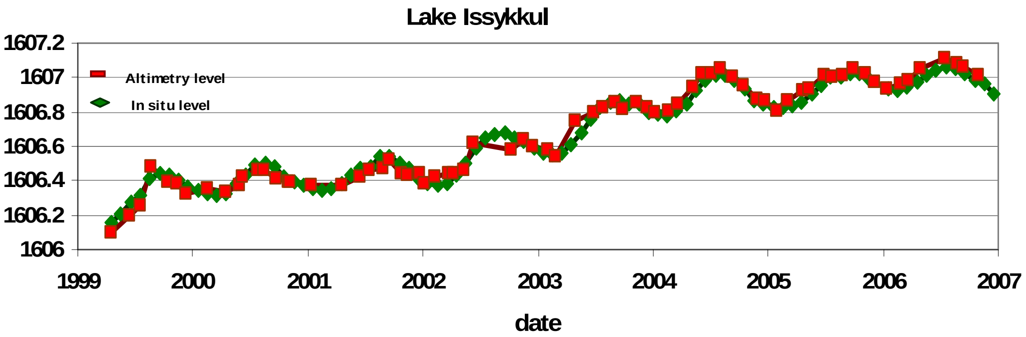
Interest for scientific community and others

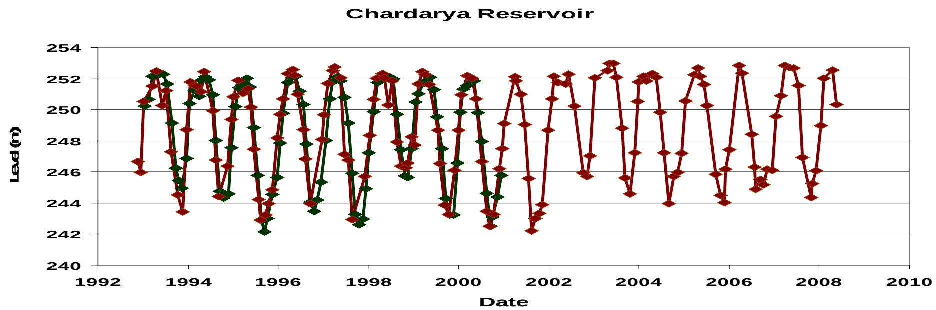
Central Asian river's flow is changed by acceleration of glaciers melting, variability in rain regime, irrigation and artificial reservoirs regulation under interstate agreements. Complex system, hard political framework, and lack of ground network for free water information delivery and sharing. 5 countries with around 50 million of people leaving.



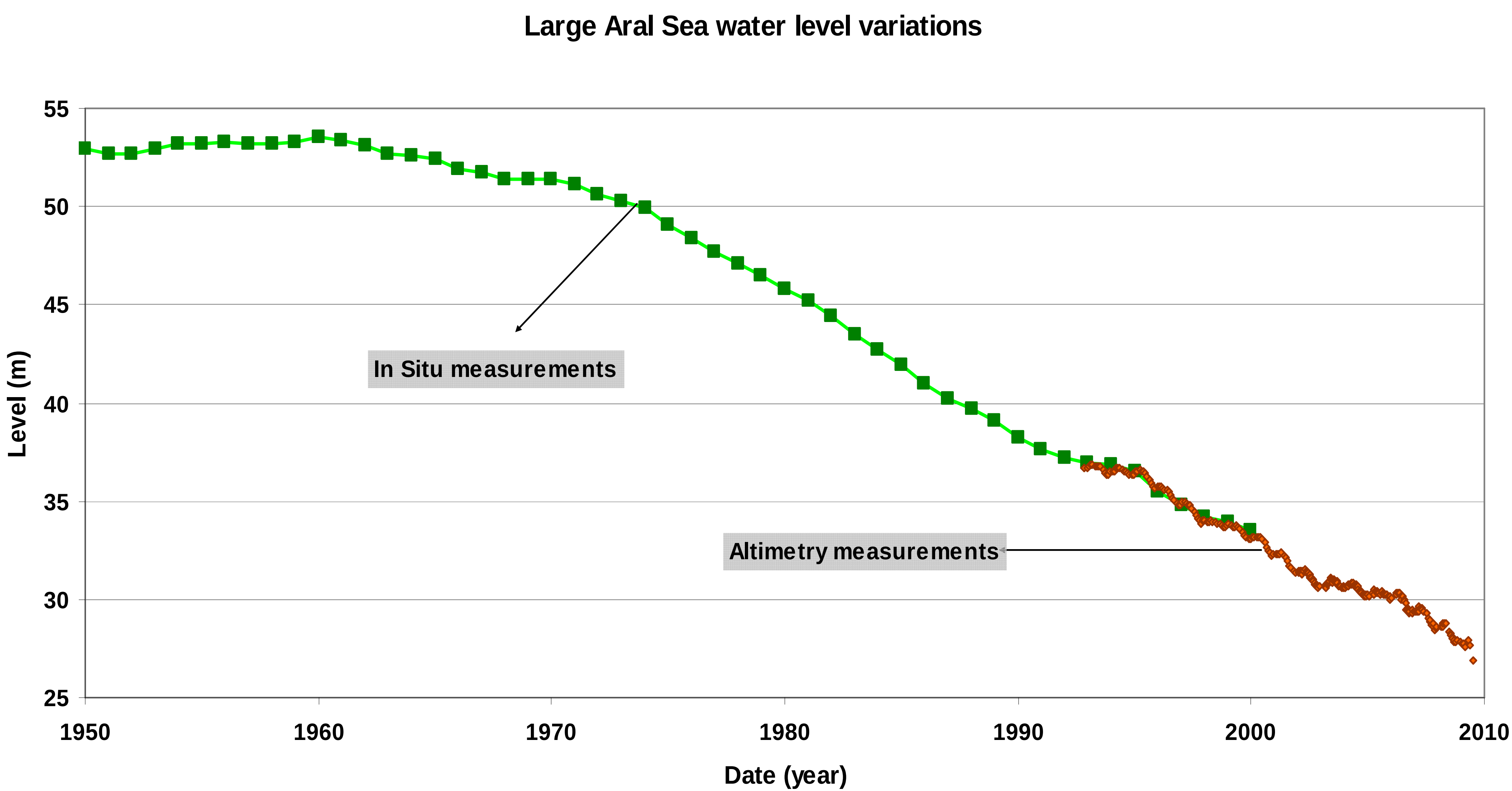






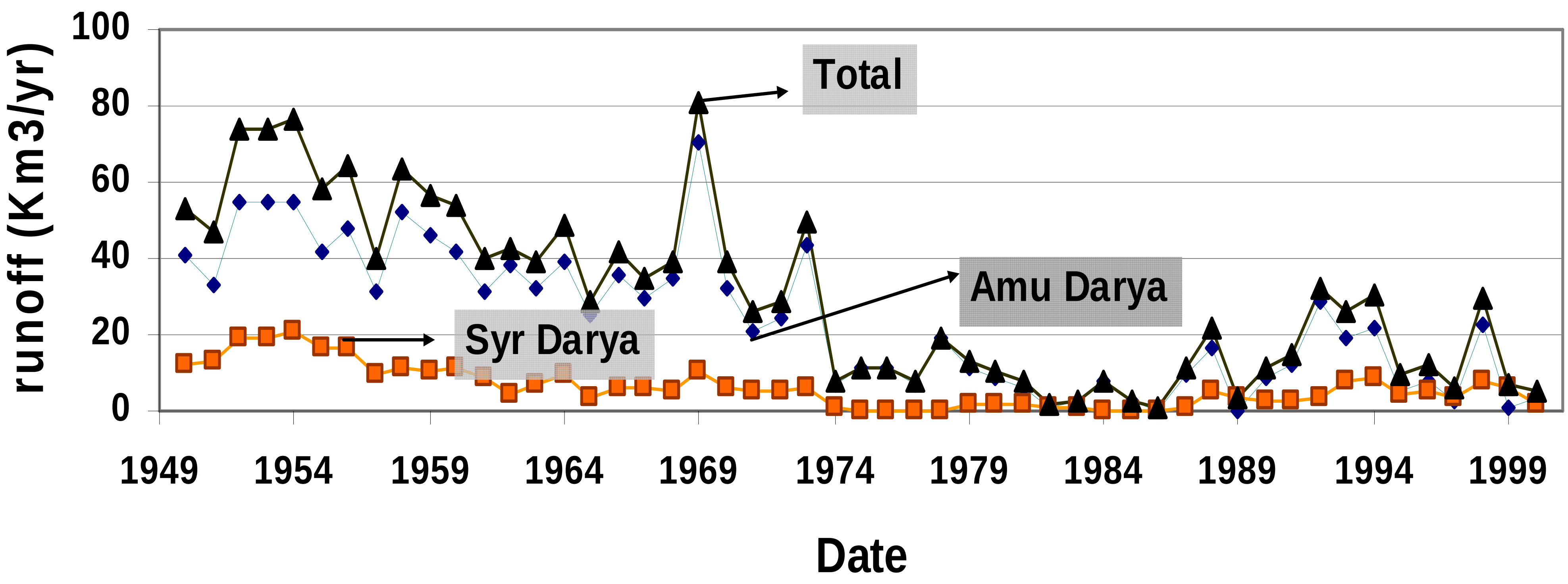


Continuous , accurate, monitoring of large number of lakes and reservoirs where no in situ gauges are available



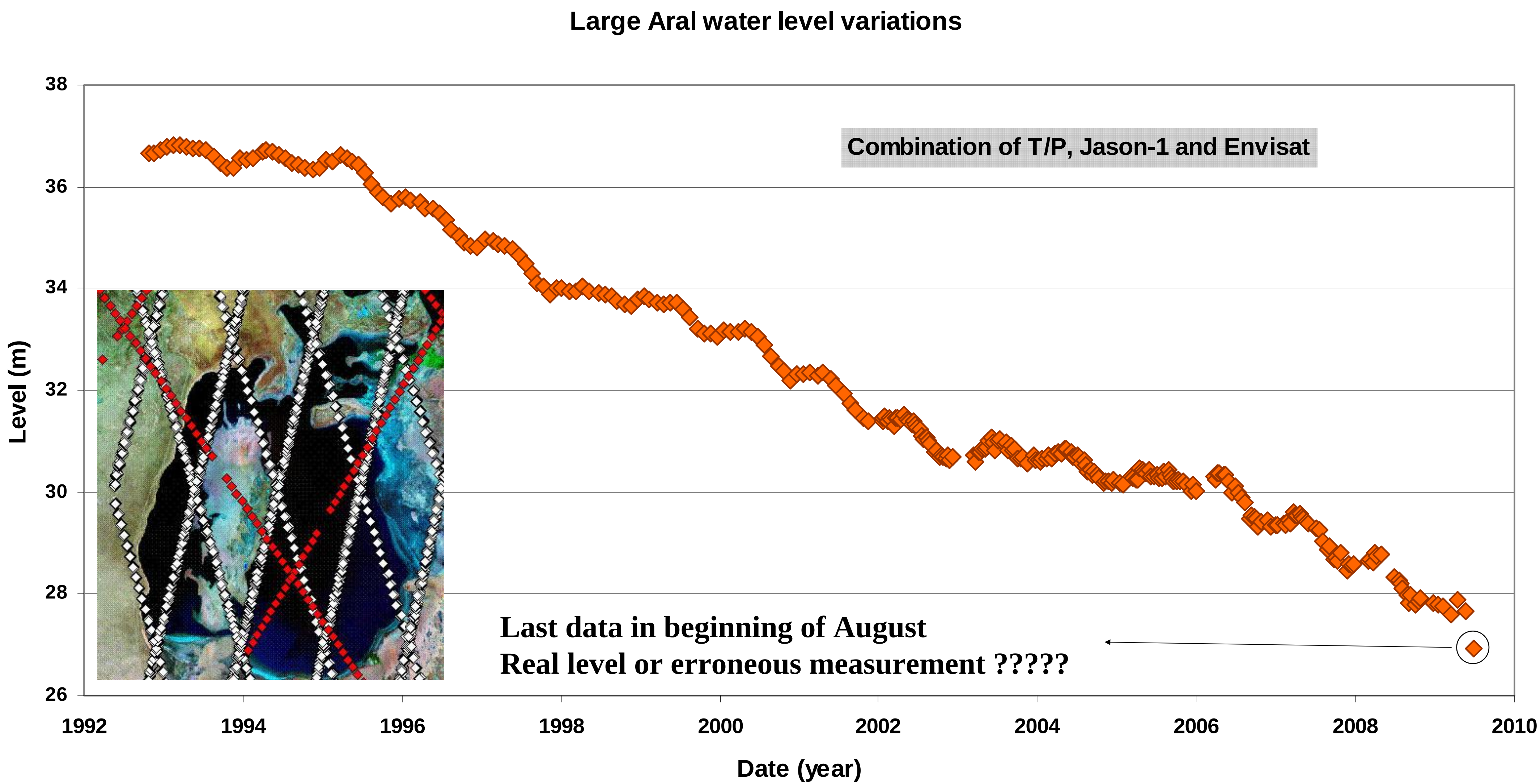
- Good coherence between In Situ and altimetry
- Altimetry is a realistic alternative when in situ gauge are missing

Inflow To Aral Sea

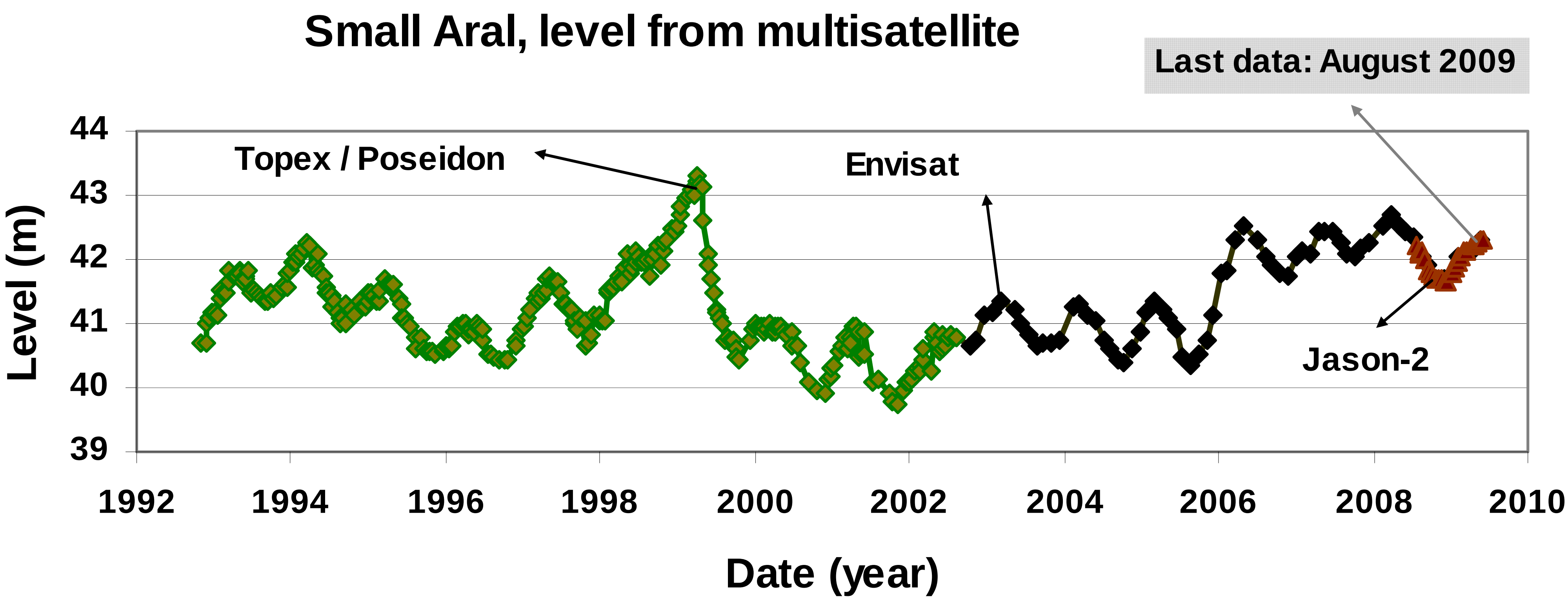


➢Slight decrease of inflow from Syr Darya and Amu Darya until 1974 followed by high drop down and high interannual variability over the last 30 years

➢This amount of water release does not allow the Aral Sea to keep in equilibrium



Interannual to seasonnal Aral Sea level change is possible

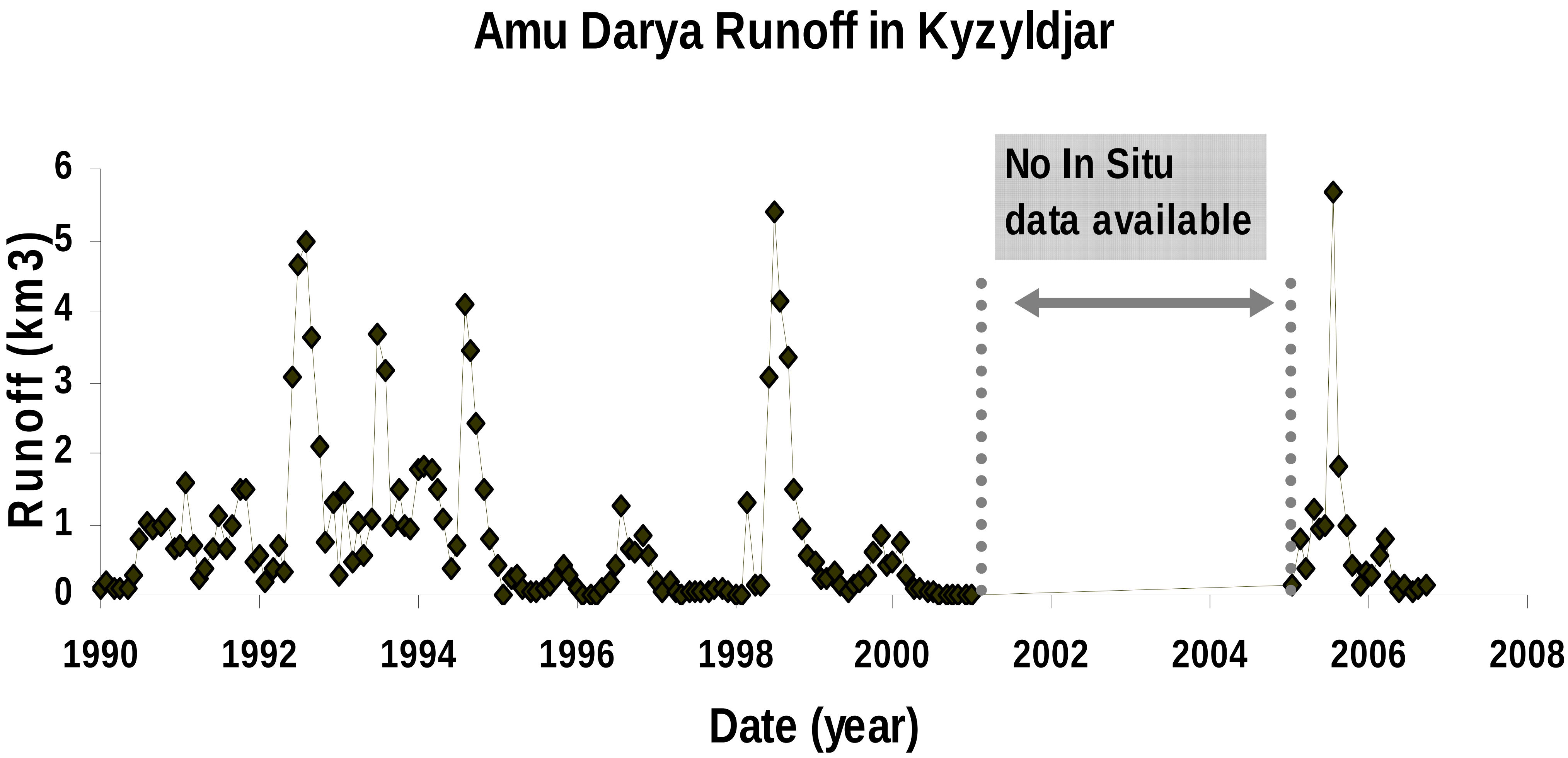


Continuity of Small Aral Sea level monitoring is made possible with multisatellite altimetry mission over the last 16 years every 10 days with T/P and Jason2 and 35 days with Envisat. Coherence between satellites is excellent

Altimetry in some case can be used to improve water balance

$$\frac{dV}{dt} = [R + P + Gi] - [D + E + Go]$$

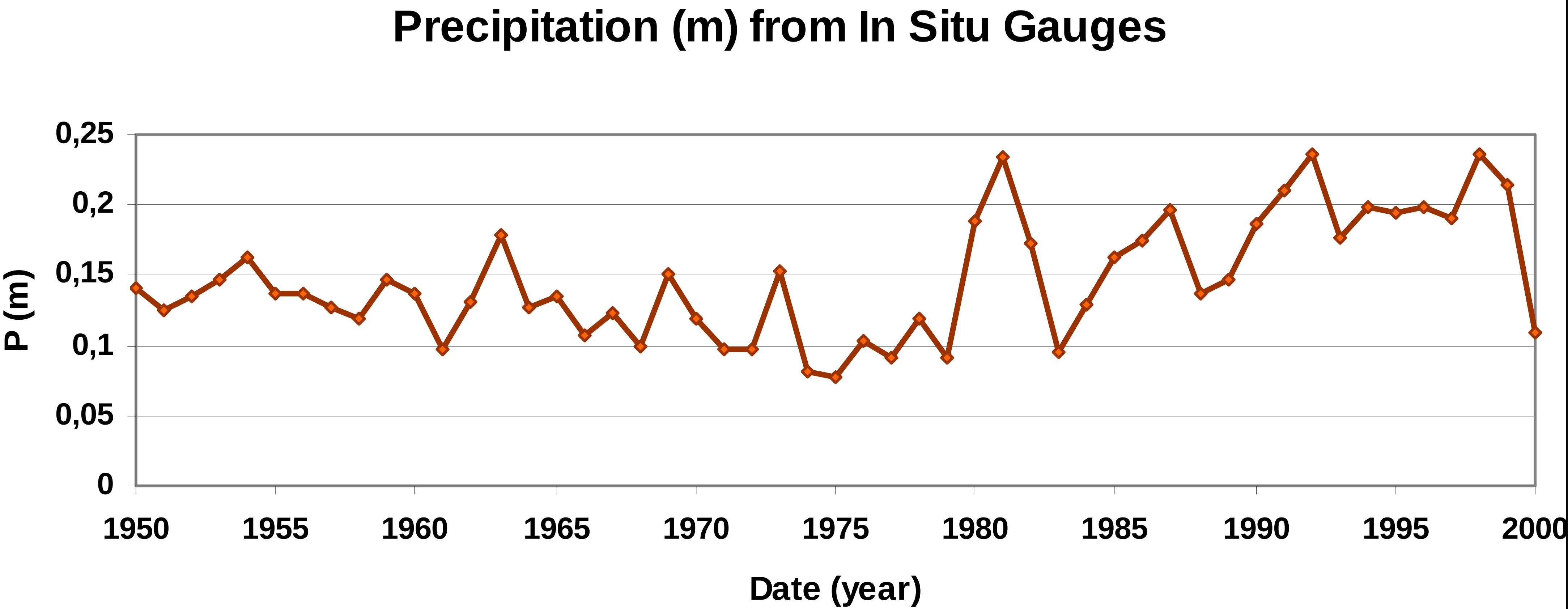
- R = river runoff → **In-Situ data**
- P = precipitation → **In-situ and/or Remote sensing data**
- GI/GO = underground transport of water → **Gauges or model Or supposed to be 0**
- E = evaporation → **Data and model**
- D = outflow water → **0 for Big Aral Unknown for Small Aral**
- DV/dt = variation of volume → **Need dh/dt and bathymetry or dh/dv**



➢Significant inter-annual variability of Amu Darya runoff

➢This explains the large Aral water level slope differences, ranging from -20 cm/yr in the middle of the 90ties and around 2004-2005 to -80 cm/year for period 1995-1998

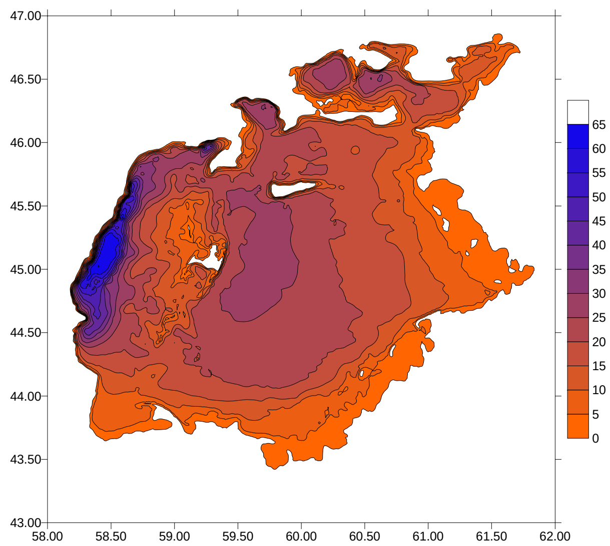
➢Missing data avoid good continuous water balance estimation



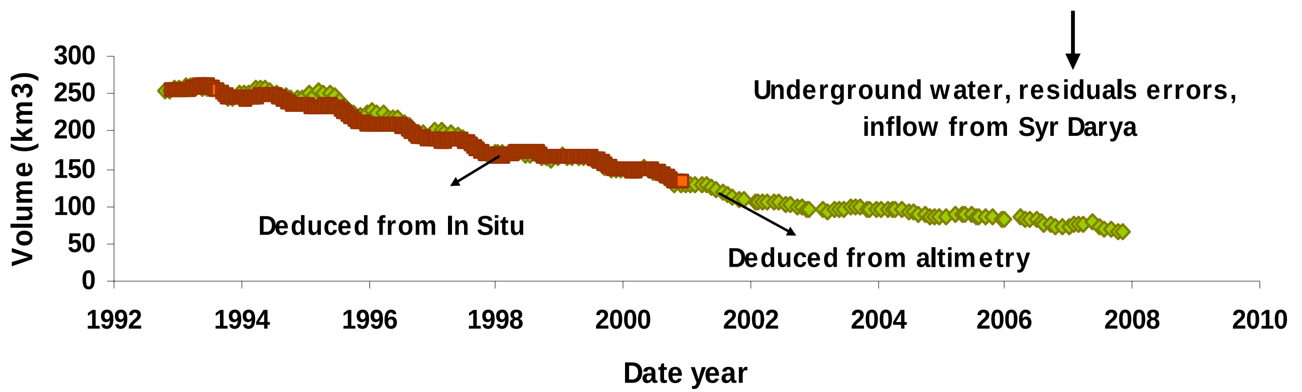
Different data sources for precipitation gave different averaged values, ranging from 10 to 25 cm
Satellite data from TRMM has been tested but they clearly overestimated the rain over the Aral Sea (more than 40 cm/yr) while GPCP provided averaged precipitation of around 20 cm/yr

For evaporation several studies based on model (Penman and others) provided averaged yearly value ranging from 100 to 120 cm/yr.
Averaged seasonnal variations of precipitation and evaporation were also included in the computation

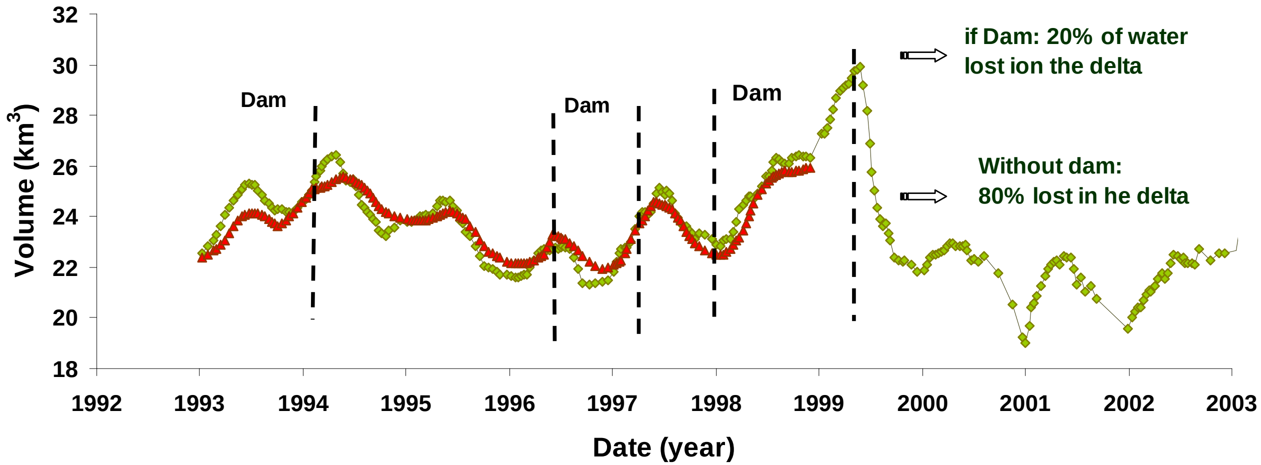
Bathymetry of the Aral Sea:
0 on the map is +53 m above the 0 Baltic sea
(Shoreline of Aral in 1962)



Large Aral, volume variations



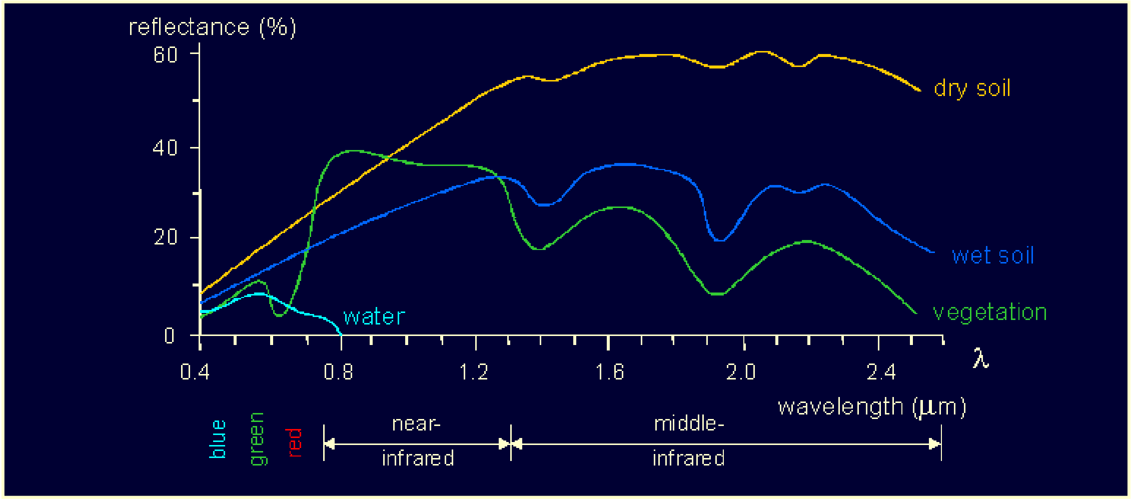
Small Aral, volume variations



Combination of bathymetry and altimetry allow to calculate the water balance of Small and Large Aral

Monitoring of Aral Sea from Modis optical multispectral imagery

What do we measure ?



MODIS

Band 1 (620 – 670 nm)

Band 2 (841 – 876 nm)

Band 3 (459 – 479 nm)

Band 4 (545 – 565 nm)

Band 5 (1230 – 1250 nm)

Band 6 (1628 – 1652 nm)

Band 7 (2107 – 2155 nm)

Surface classification from Combination of band

Classification of surface with Modis

Classical methodology:

B2 (NEAR IR)<1000 or NDVI< 0 ⇔ open water

NDVI>0.3/0.4 ⇔vegetation

0<NDVI<0.3/0.4 ⇔ dry land

Not valid for: shallow water bodies

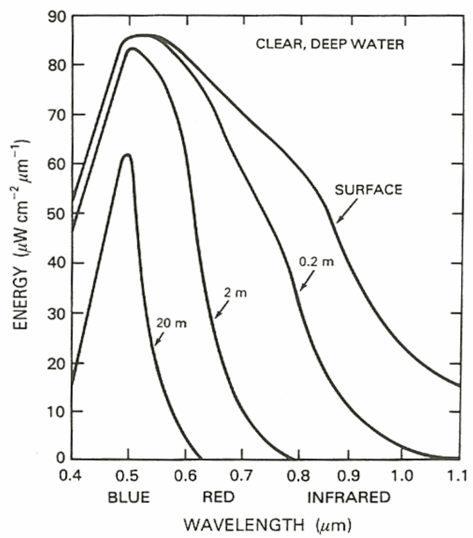
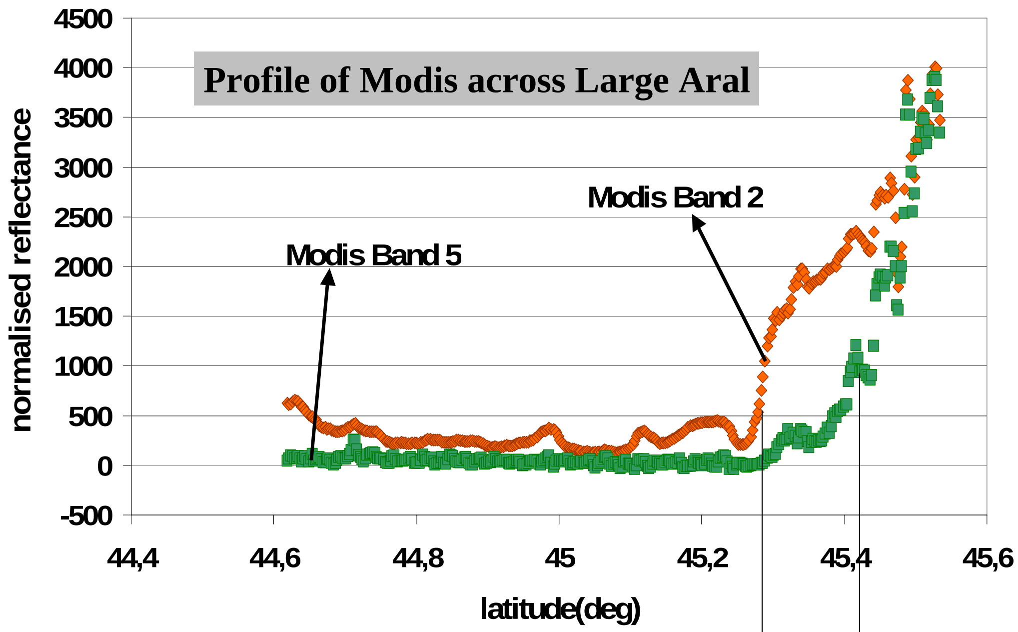


Figure 9.1 An illustration of how light is attenuated by clear water. Note that in the infrared region there is very little penetration into the water.



NDVI = (B2-B1)/(B2+B1)
NDS = (B2-B7)/(B7+B2)

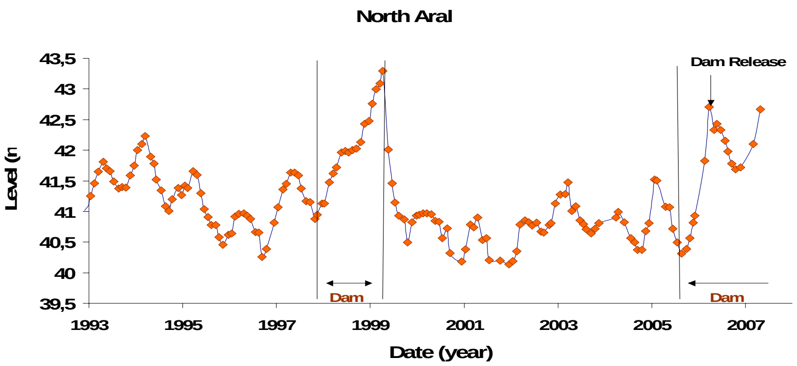
~10 km are missing that Correspond to shallow water

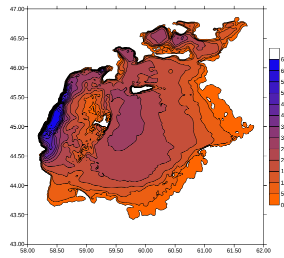
	Modis Band5	NDVI	NDS
Open water	< 1000	No test	No test
Mixed water/dry land	> 1000 & < 2700	< 0.3	No test
Aquatic vegetation	> 1000 & < 2700	> 0.3	No test
Vegetation	> 2700	> 0.3	No test
Dry land	> 2700	< 0.3	No test
Salt Crust	> 2700	< 0.3	> 0.4

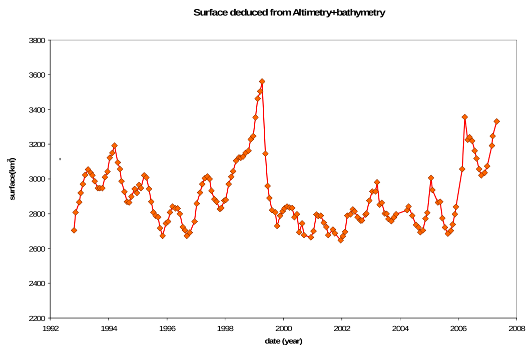
Classification Developped for Shallow water in Arid zone

Validation of the method with Aral Sea

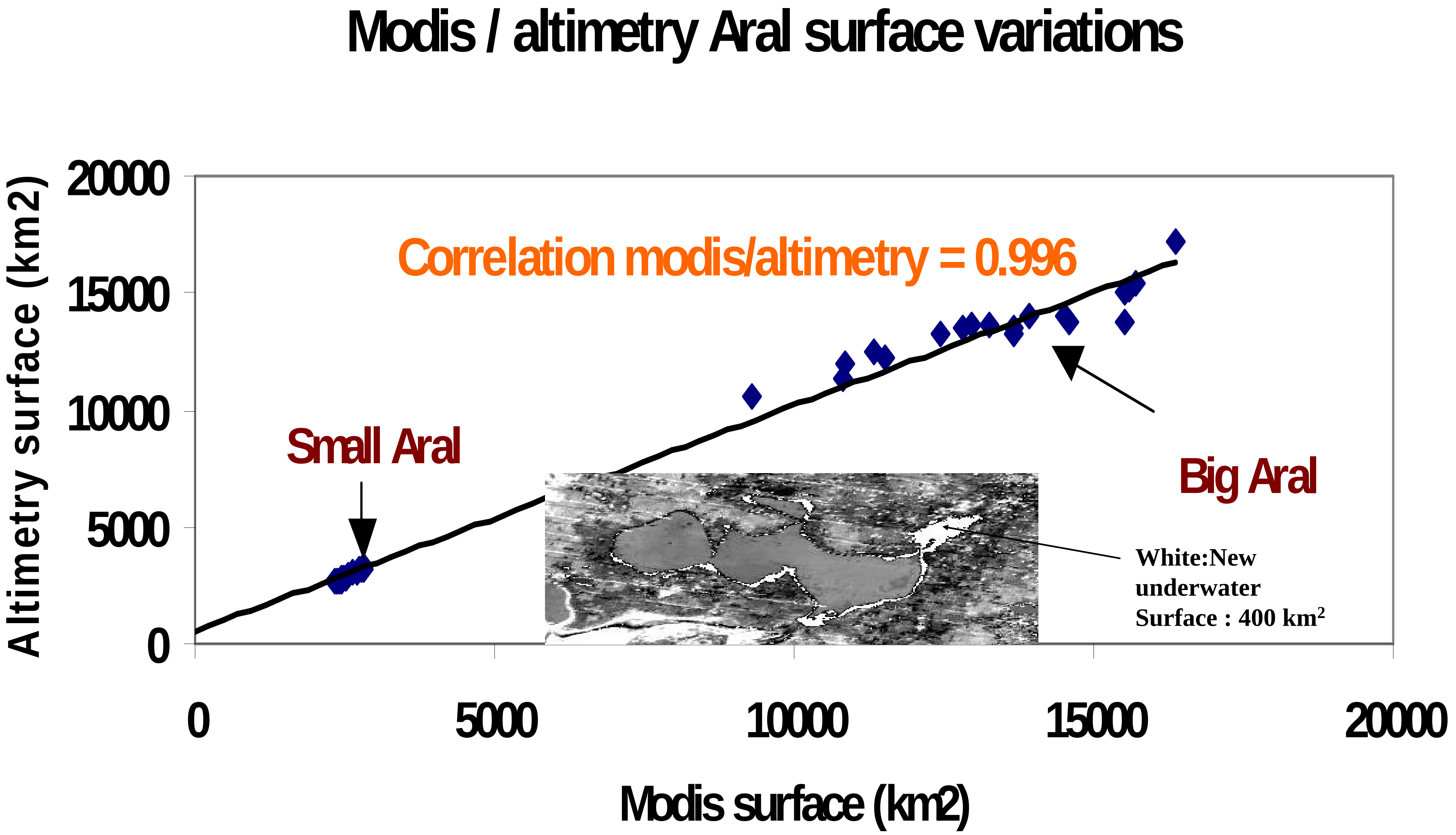
From altimetry + bathymetry = > variation of surface



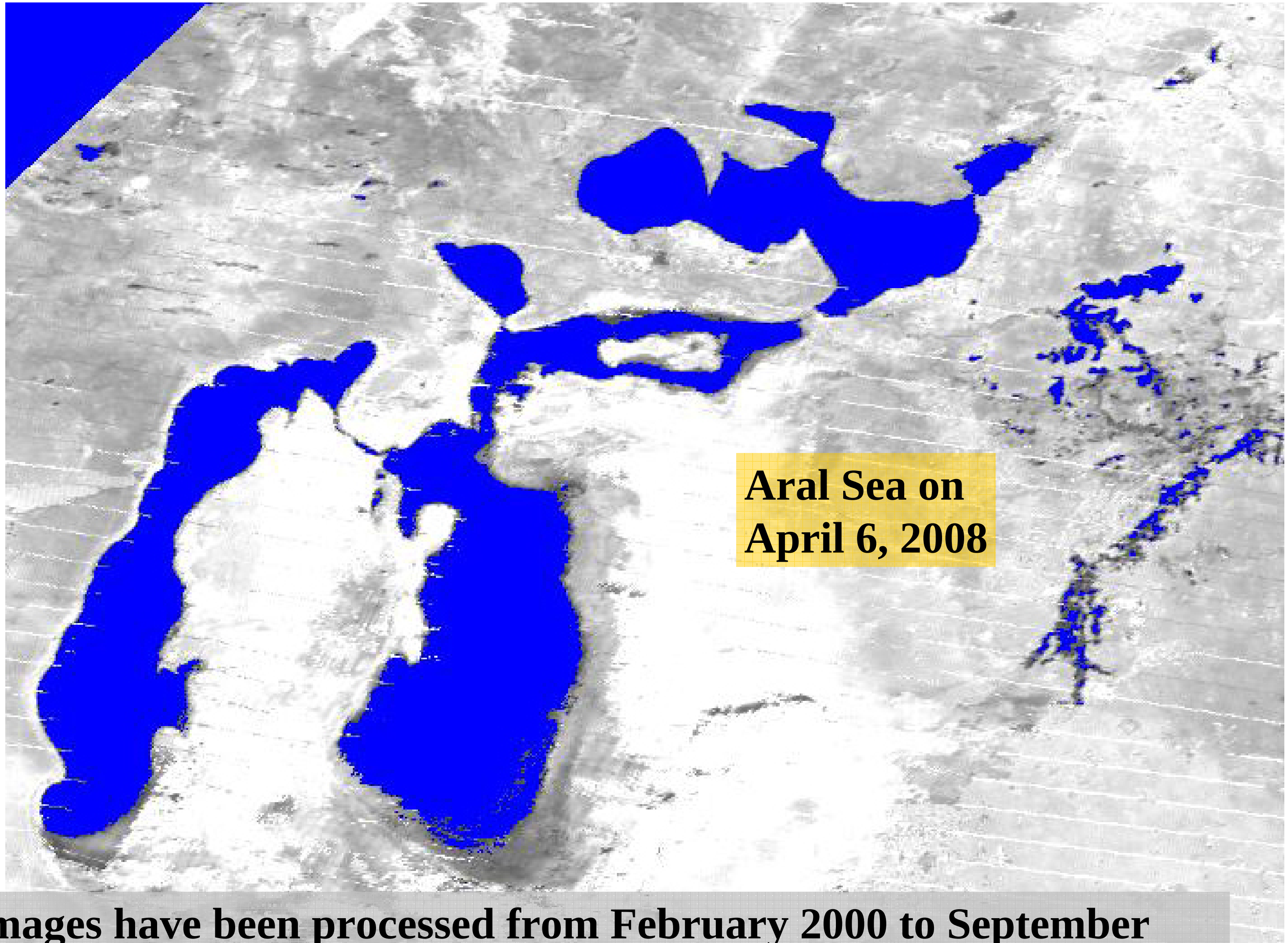




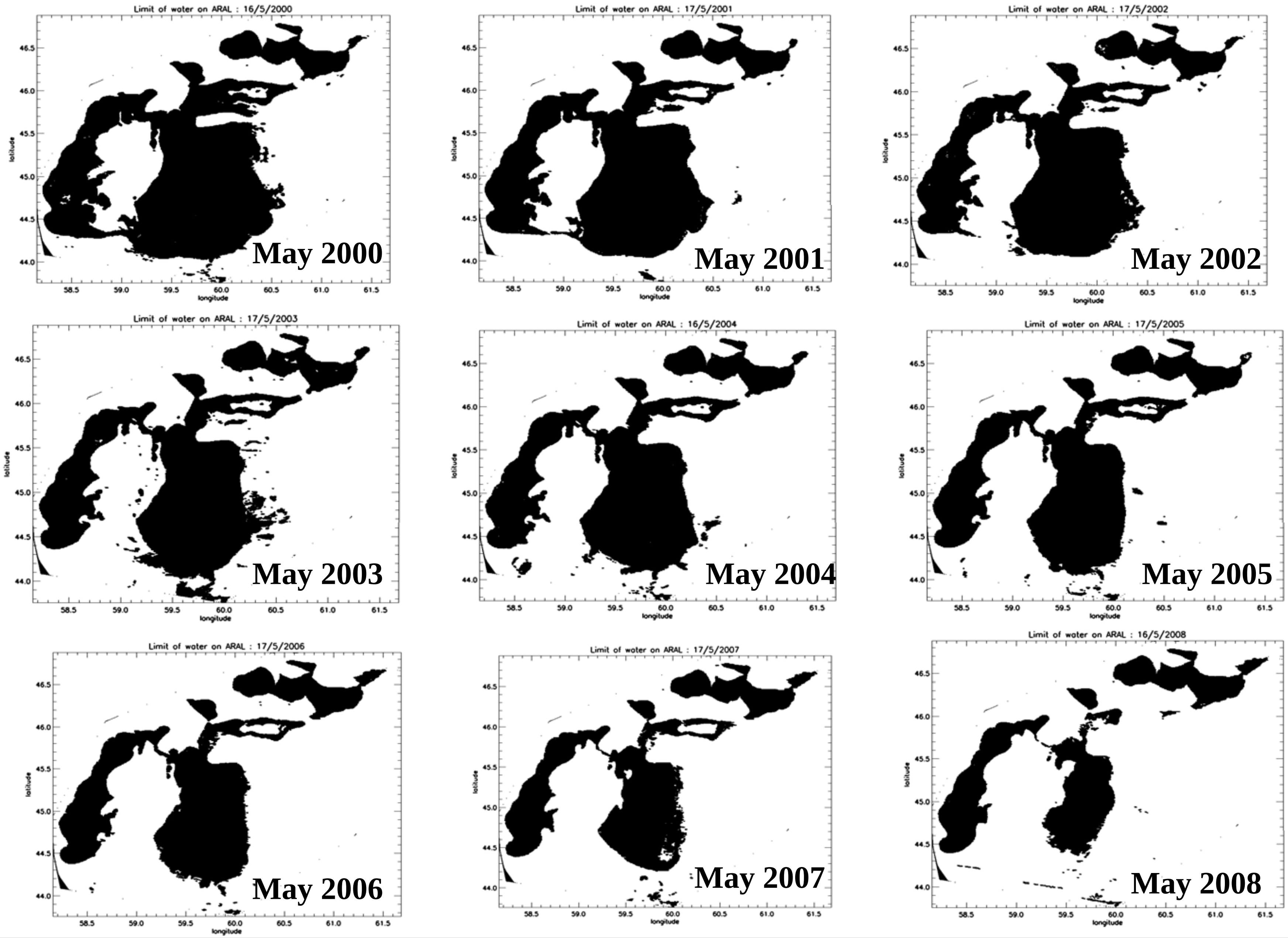
Direct measurement from analysis of the Modis images


Modis / altimetry Aral surface variations
Correlation modis/altimetry = 0.996
Small Aral
Big Aral
White:New
underwater
Surface : 400 km²
Altimetry surface (km2)
Modis surface (km2)
0
5000
10000
15000
20000

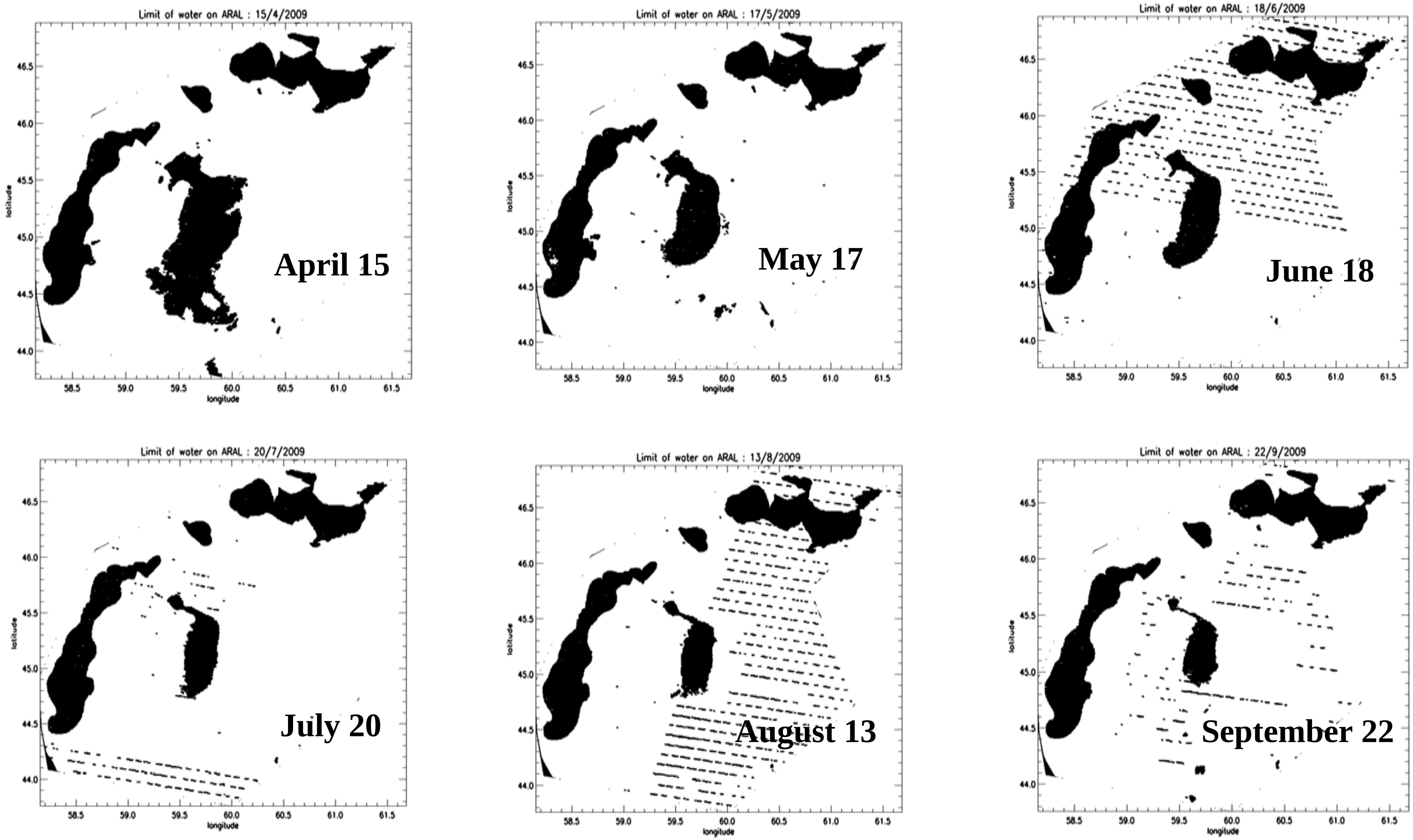
With a resolution of 500 meters many details are missing, particularly in straits and river banks (Syr Darya is not visible) but general tendancy of Aral Sea desiccation is possible

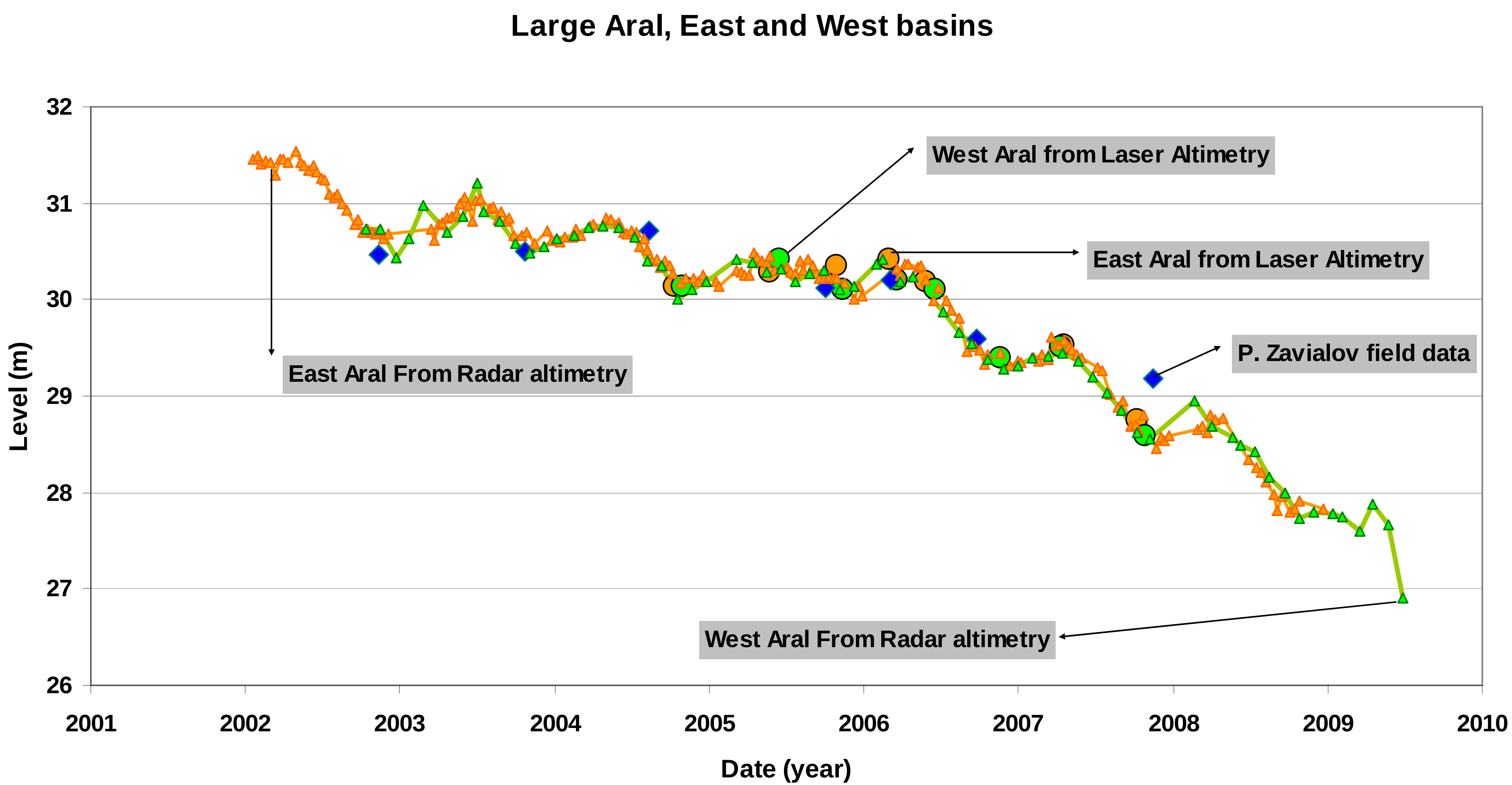


More than 400 Modis images have been processed from February 2000 to September 2009


Limit of water on ARAL : 16/5/2000
May 2000
Limit of water on ARAL : 17/5/2001
May 2001
Limit of water on ARAL : 17/5/2002
May 2002
Limit of water on ARAL : 17/5/2003
May 2003
Limit of water on ARAL : 16/5/2004
May 2004
Limit of water on ARAL : 17/5/2005
May 2005
Limit of water on ARAL : 17/5/2006
May 2006
Limit of water on ARAL : 17/5/2007
May 2007
Limit of water on ARAL : 16/5/2008
May 2008
latitude
longitude

Spring / Summer 2009: Highlight on desiccation of Large Aral from MODIS





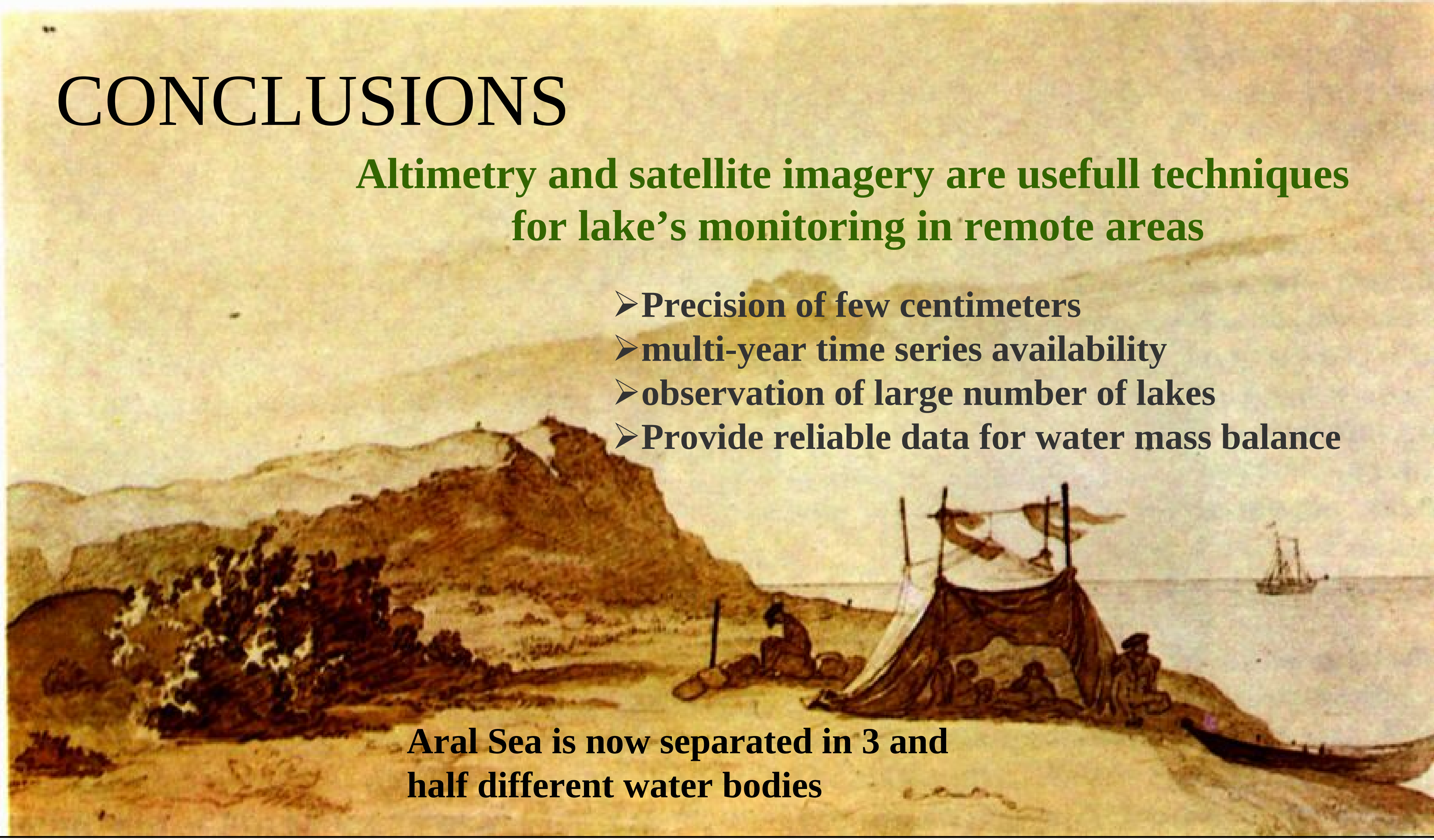
- ➢Altimetry is not capable to detect differences of West and East level variations.
- ➢After the beginning of 2009, there is no data on East Basin

CONCLUSIONS

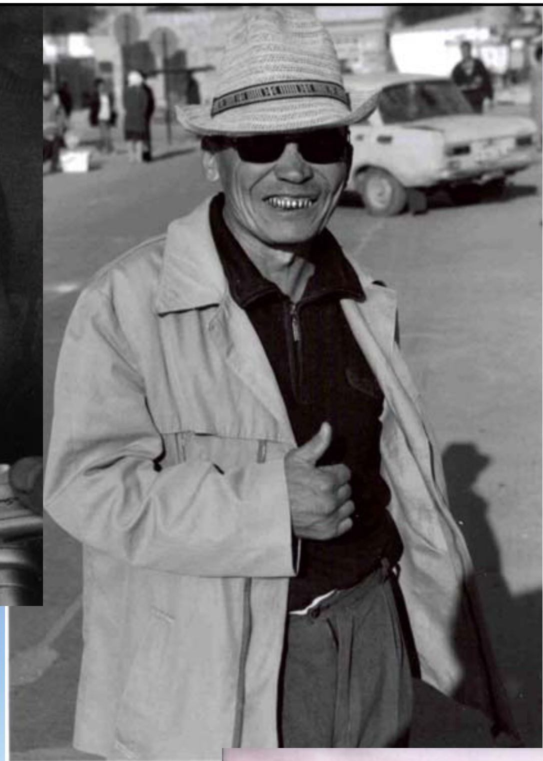
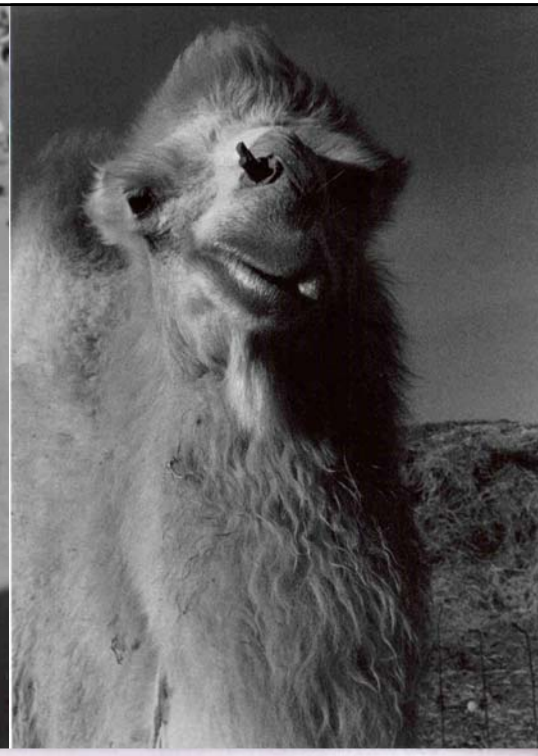
Altimetry and satellite imagery are usefull techniques for lake's monitoring in remote areas

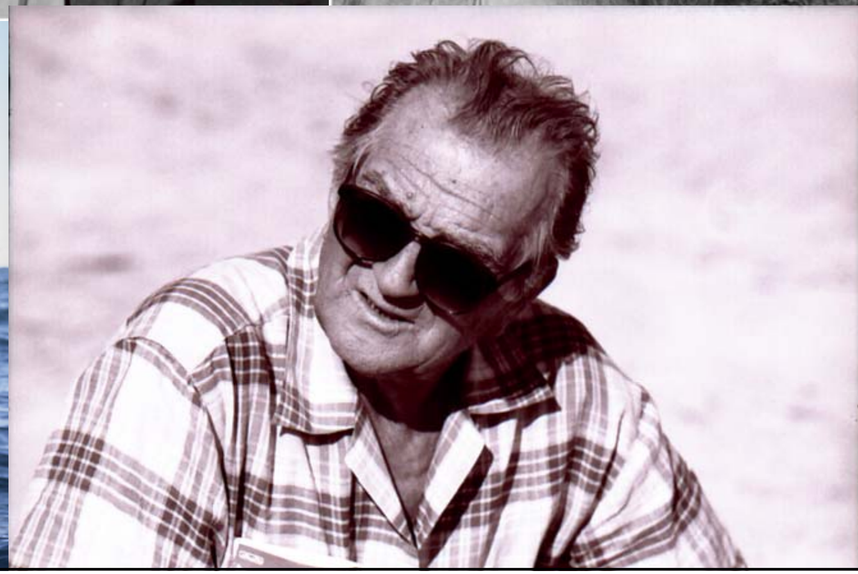
- **Precision of few centimeters**
- **multi-year time series availability**
- **observation of large number of lakes**
- **Provide reliable data for water mass balance**

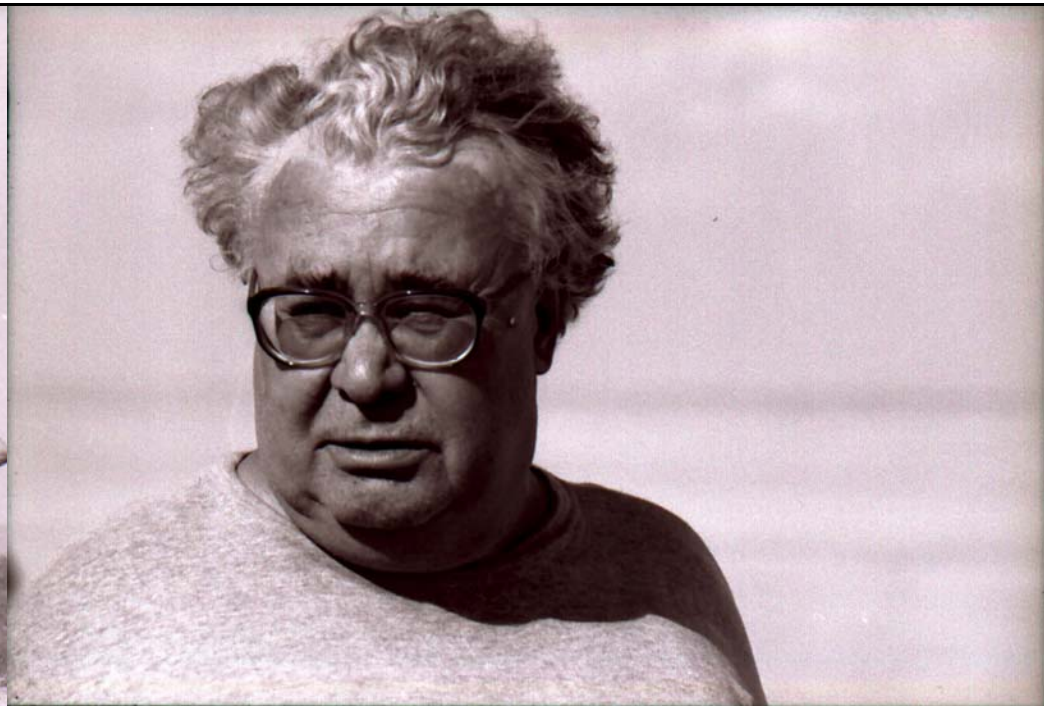
Aral Sea is now separated in 3 and half different water bodies







In all circumstances around the Aral Sea, keep zen and smiling.