Visco-elastic rebound of the lithosphere around Siling Co lake : an InSAR study

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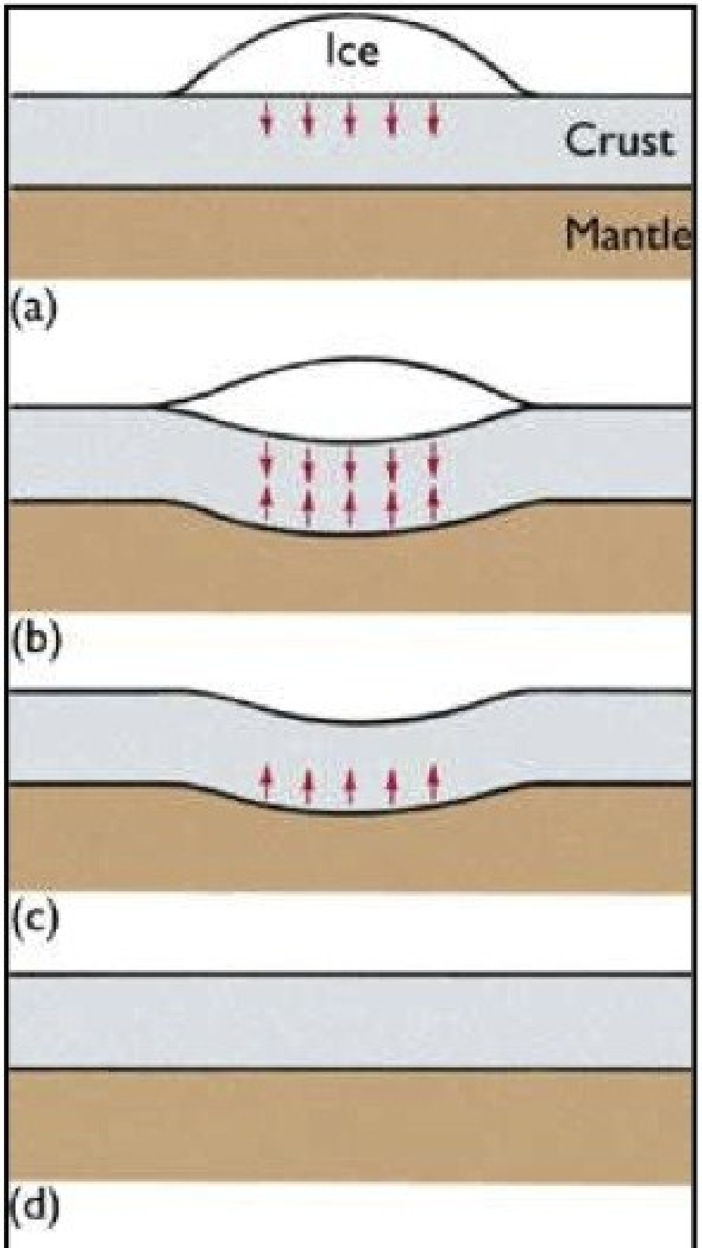
Why study the lithosphere response to earth surface loading (as post-glacial rebound studies) ?



-> Provide constraints on the mechanical behavior of the lithosphere and mantle.

Traditionally : loading response studied on a ~ 10 000 years time scale.

However : post-seismic response observed on a decade time scale !

--> large ductility or transient behavior ?

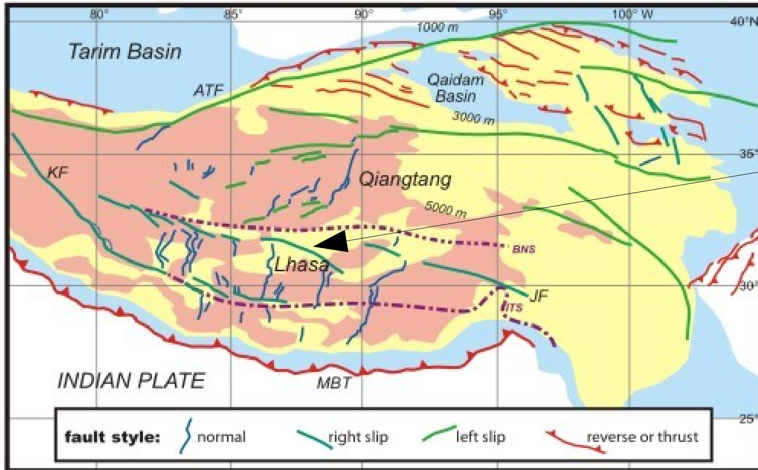
Why using lake water level variations and InSAR to study the lithosphere response to earth surface loading ?

-> A priori simple problem with known load geometry and fluctuations
-> Local constraint on the mechanical properties of the lithosphere and mantle.
-> Observation time scale of InSAR : 1992-2010 ==> too short ?

Advantages and drawbacks of Siling Co lake :

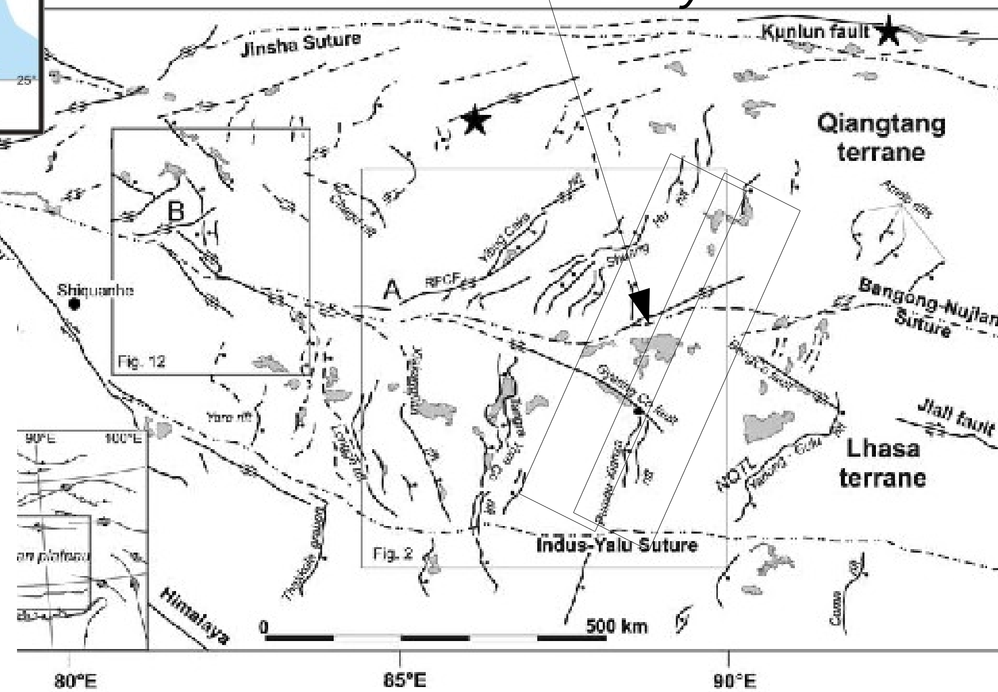
-> Tibet : thick crust, question of ductile channel flow in the crust
-> Very large lake, incredibly large lake level variations given its size
-> But : Little is known...

Siling Co lake location



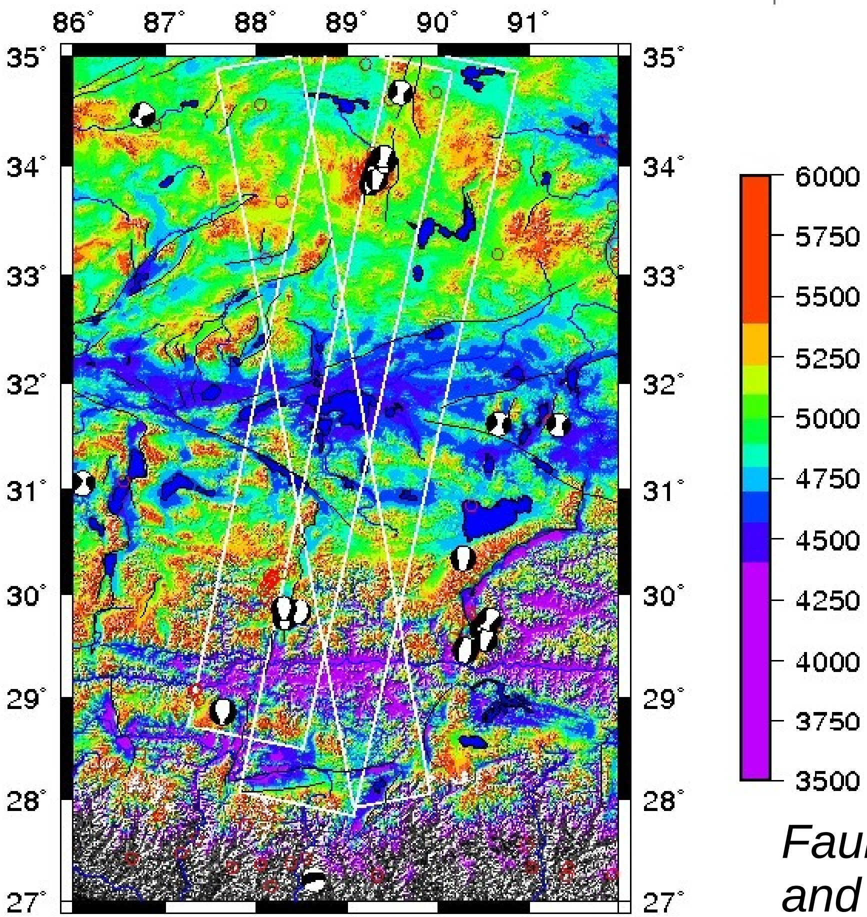
Siling Co location

Taylor and Peltzer



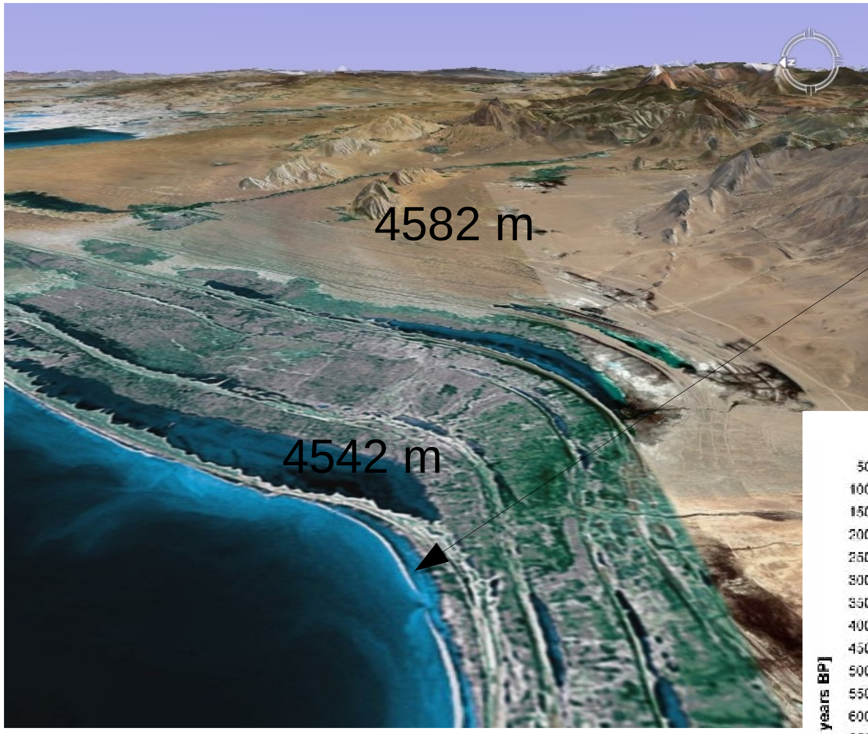
T491

T219

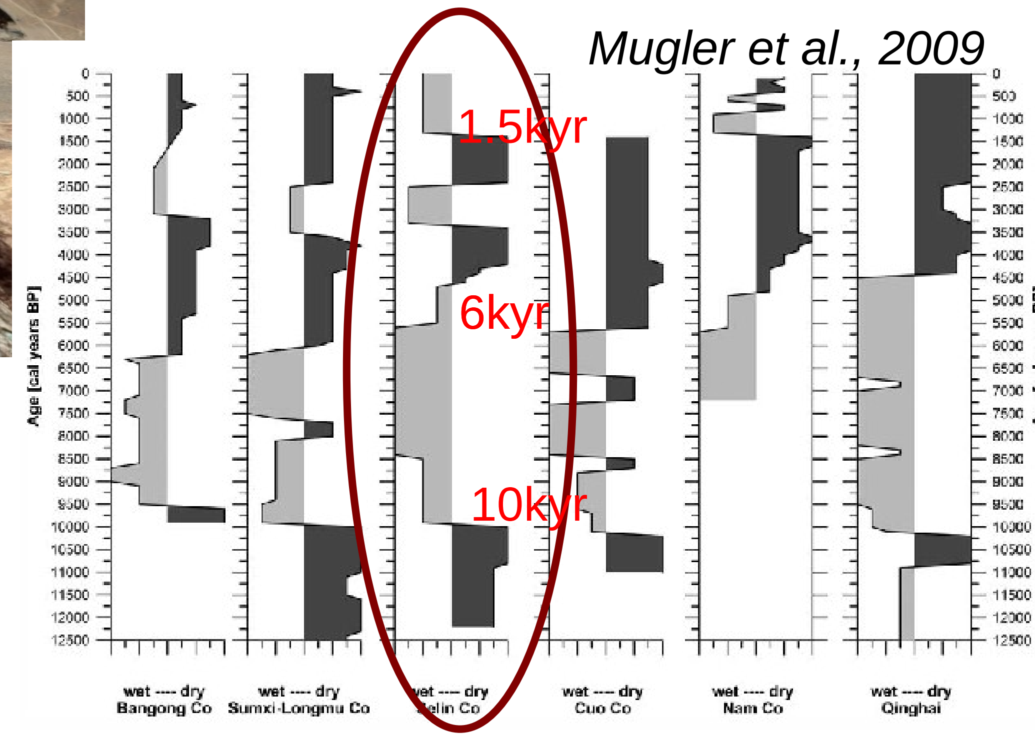


Faults from Taylor and Yin, 2009

Holocene lake level variations

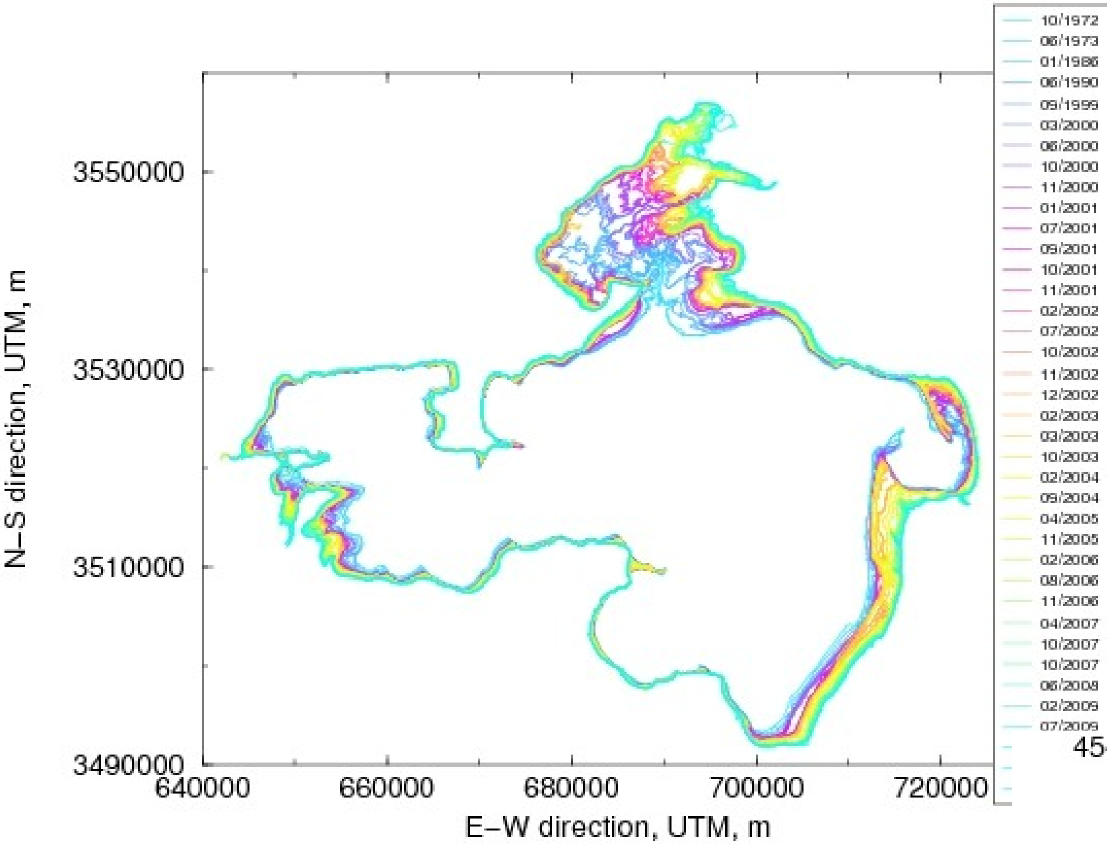


Old shorelines are being submerged



Palaeo-shorelines :
Latest highest stand at 6000 yr ?
Latest lowest stand at 1500 yr
(below present day lake level) ?

PRESENT-DAY TEMPORAL VARIATIONS IN WATER LOAD

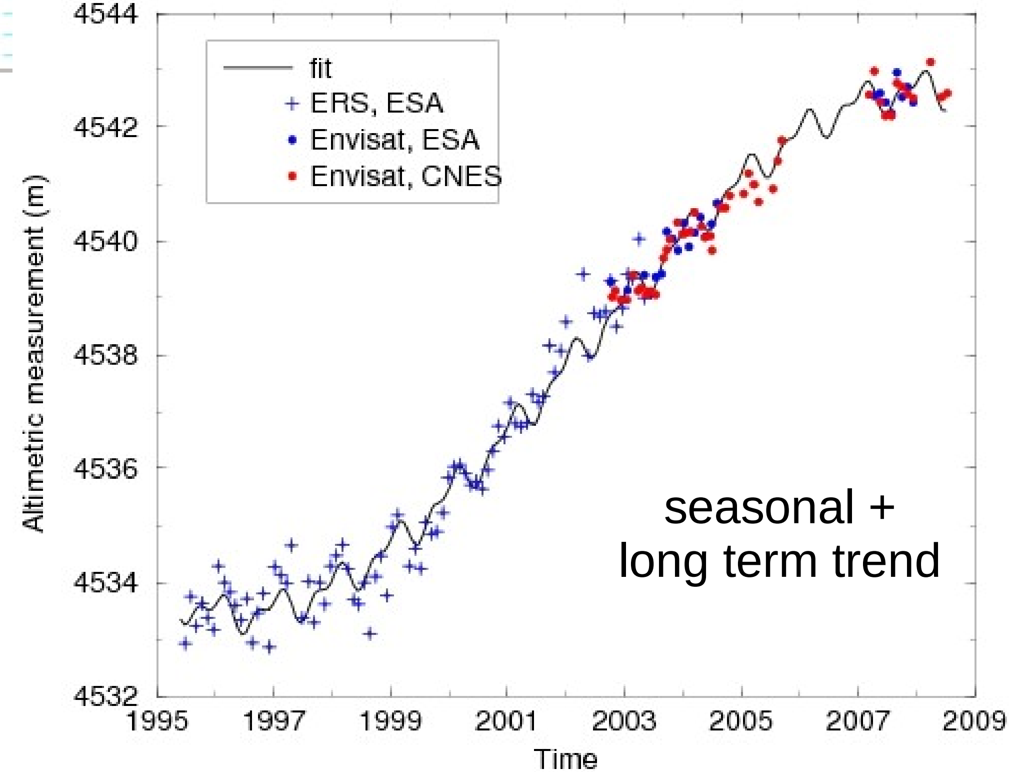


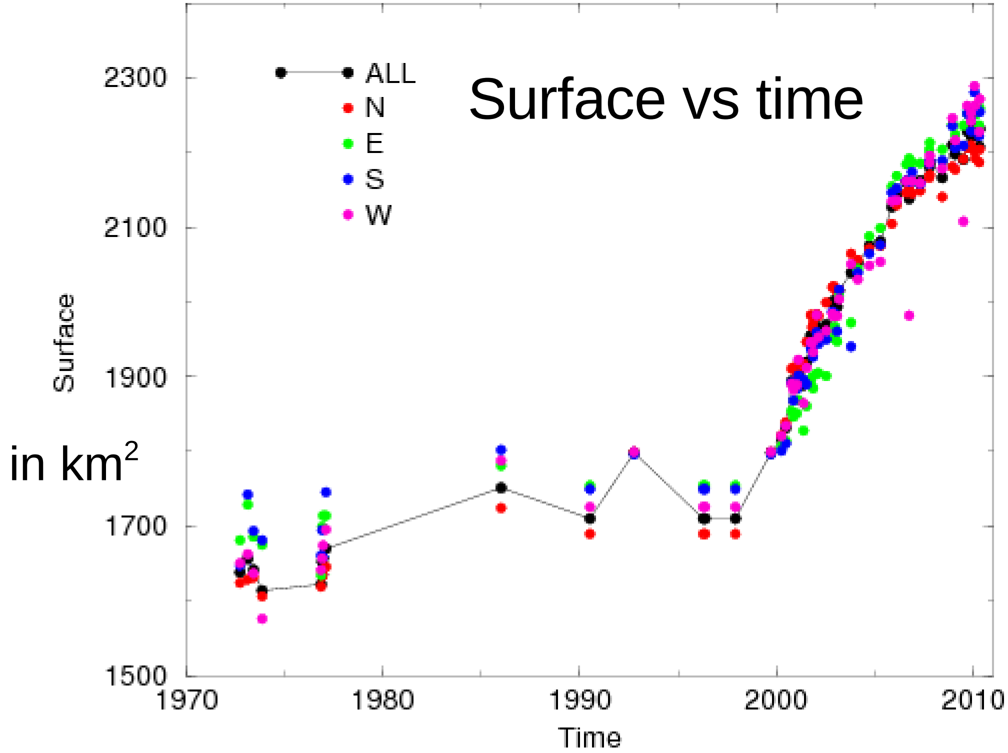
Lake surface

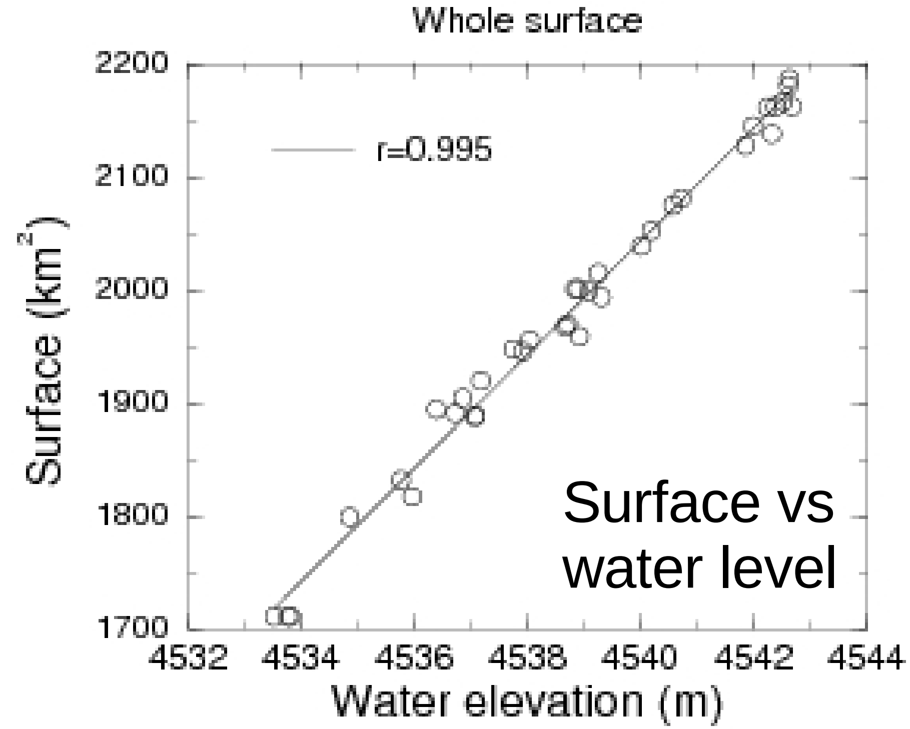
Lake contour variations from LANDSAT images : 1972 to 2010

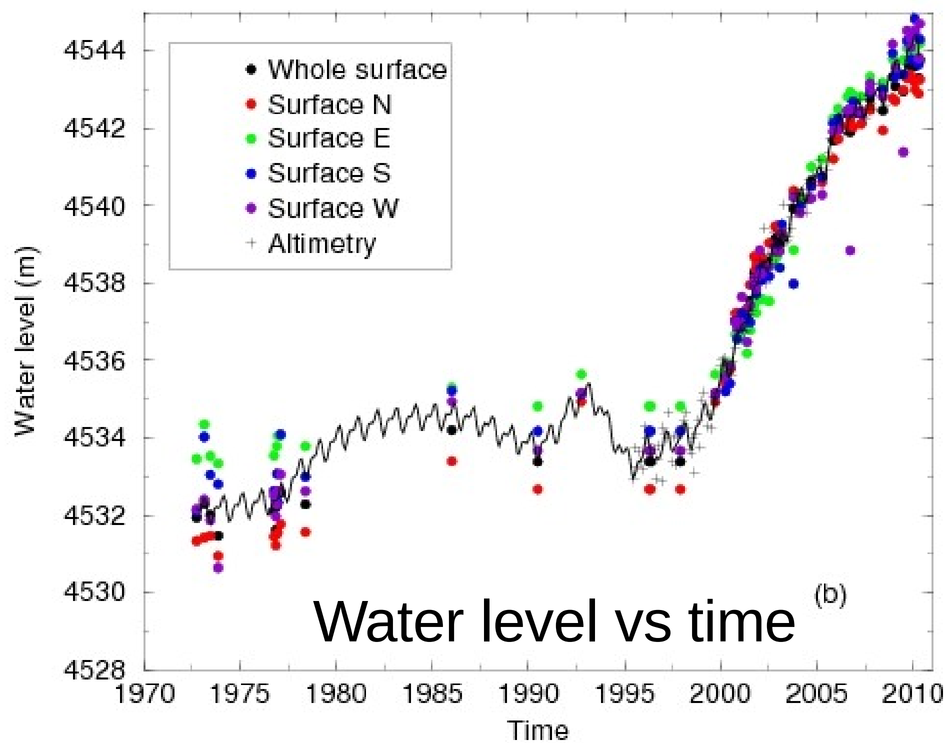
Lake level

Altimetry *(ESA and Hydroweb, Legos, CNES, Cretaux et al.),*
Envisat + ERS. 1995-2008




Surface vs time
in km2
Surface
Time
ALL
N
E
S
W
2300
2100
1900
1700
1500
1970
1980
1990
2000
2010

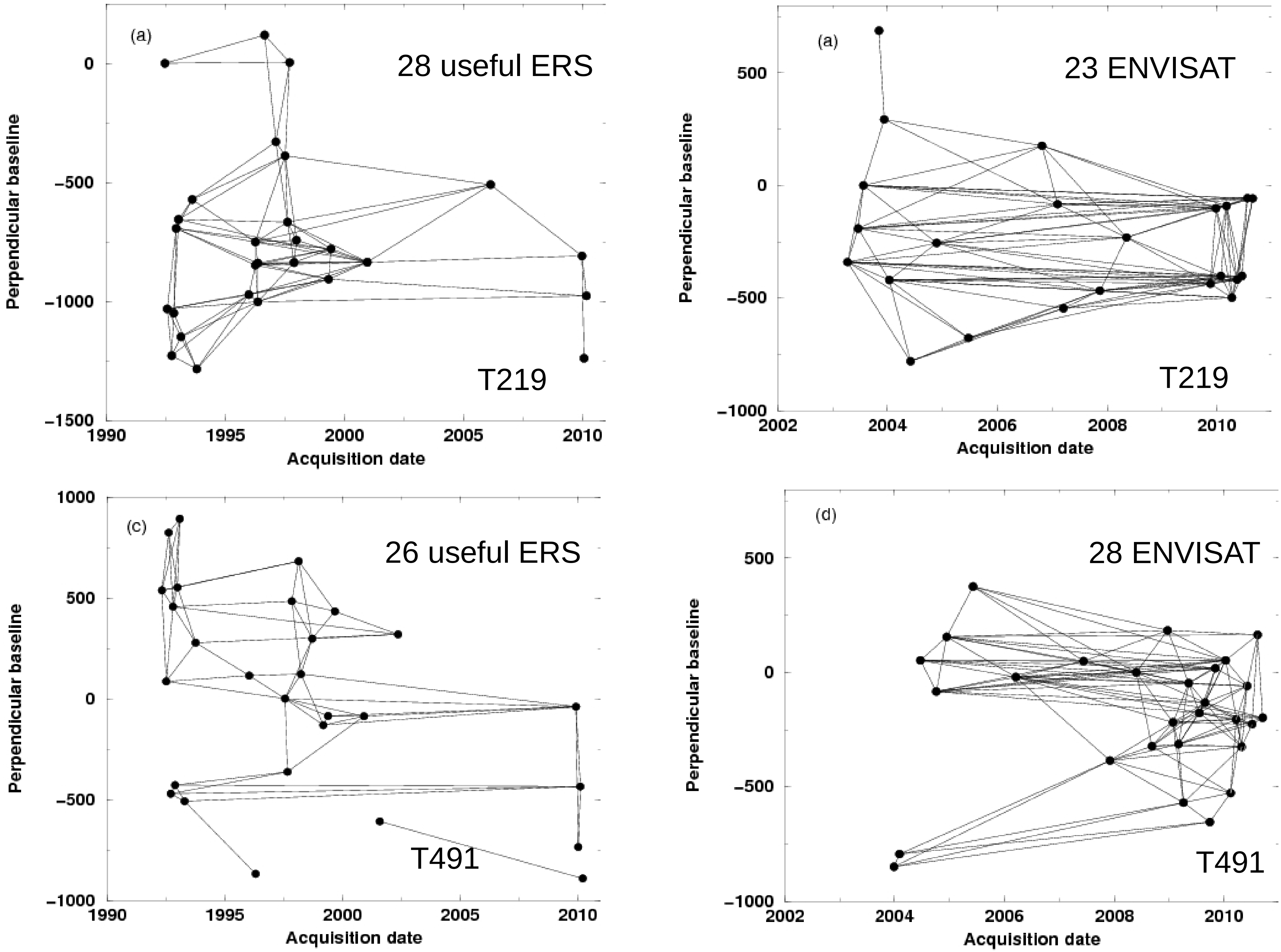

Whole surface
r=0.995
Surface (km2)
Water elevation (m)
Surface vs water level
2200
2100
2000
1900
1800
1700
4532
4534
4536
4538
4540
4542
4544

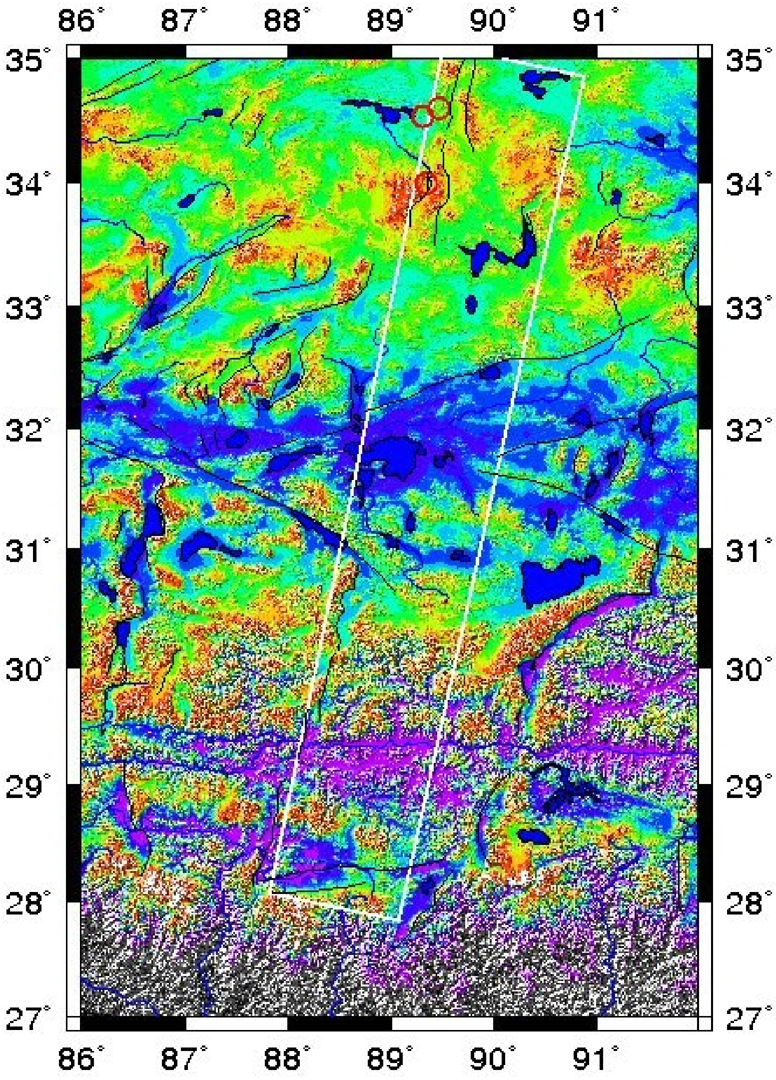

Water level vs time
(b)
Water level (m)
Time
Whole surface
Surface N
Surface E
Surface S
Surface W
Altimetry
4544
4542
4540
4538
4536
4534
4532
4530
4528
1970
1975
1980
1985
1990
1995
2000
2005
2010

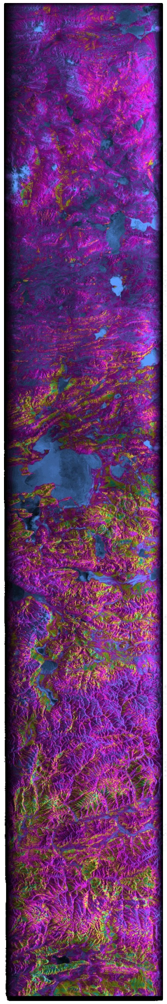
- Measure of surface displacement around Siling Co lake using InSAR technique based on all available ERS and Envisat SAR data
  - ✓ T219 : 28 ERS, 1992-2010
    23 Envisat, 2003-2010
  - ✓ T491 : 26 ERS, 1992-2010
    28 Envisat, 2004-2010

- For a given mechanical structure of lithosphere and the water load history, model the expected surface displacement

- Comparison data/model : ==> test possible mechanical structures for the lithosphere


(a)
28 useful ERS
T219
Perpendicular baseline
Acquisition date
(a)
23 ENVISAT
T219
Perpendicular baseline
Acquisition date
(c)
26 useful ERS
T491
Perpendicular baseline
Acquisition date
(d)
28 ENVISAT
T491
Perpendicular baseline
Acquisition date





Very long track (~750 km) :
assess orbital trends and stratified atmospheric delays far away from the lake.

Coherence :

+ Moderate spatial decorrelation up to Bp = 400 m

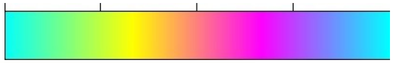
+ Large temporal decorrelation in the lake area

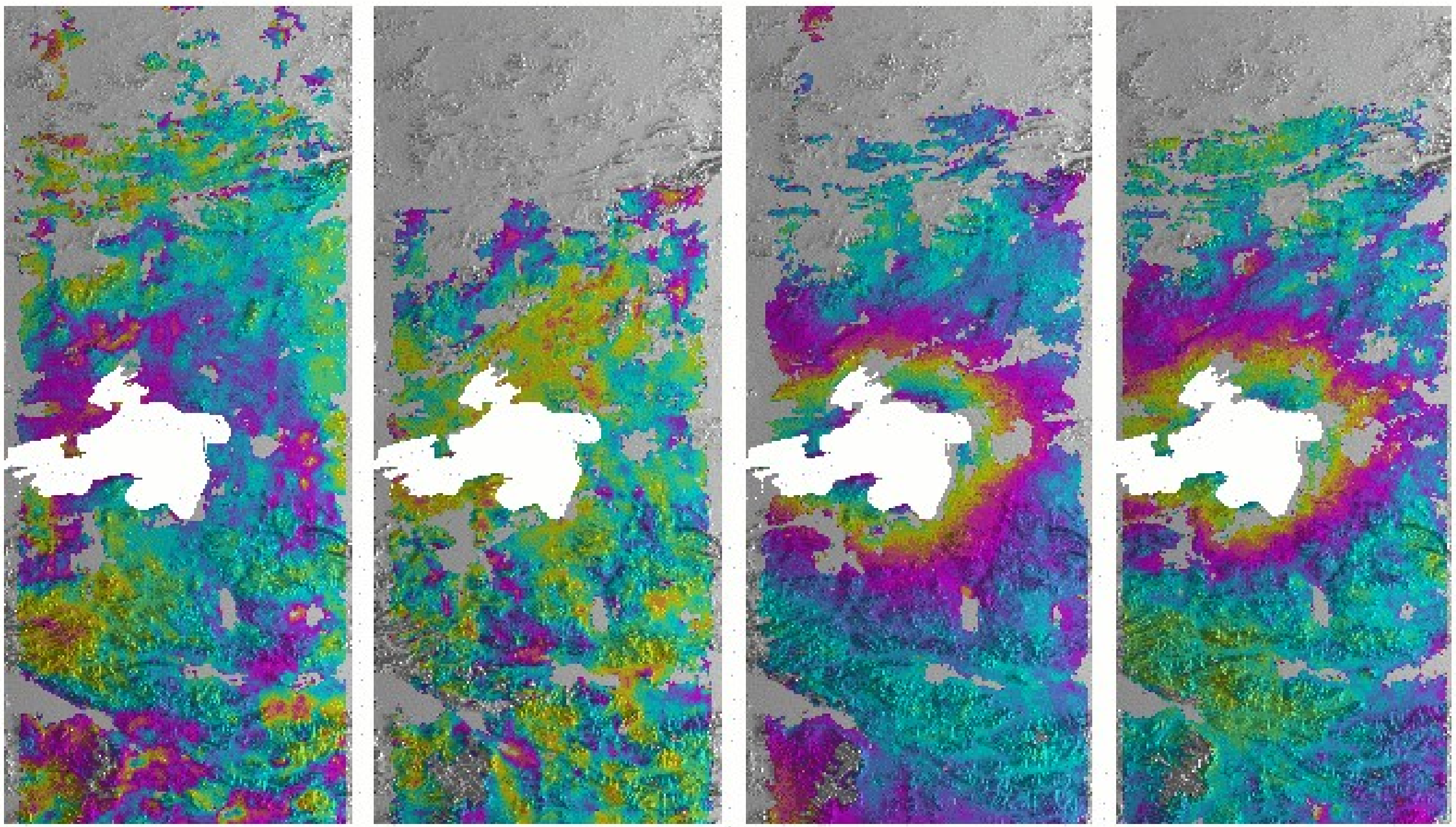
+ Extreme temporal decorrelation in the northern part of the track

==> Need strong spatial filtering (equivalent to at least 16 looks)

Examples of processed interferograms

- after corrections of orbital ramps + stratified atmospheric contributions
- after strong spatial filtering



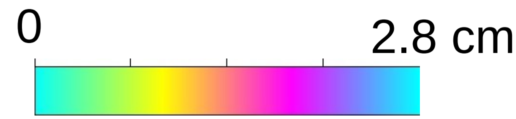


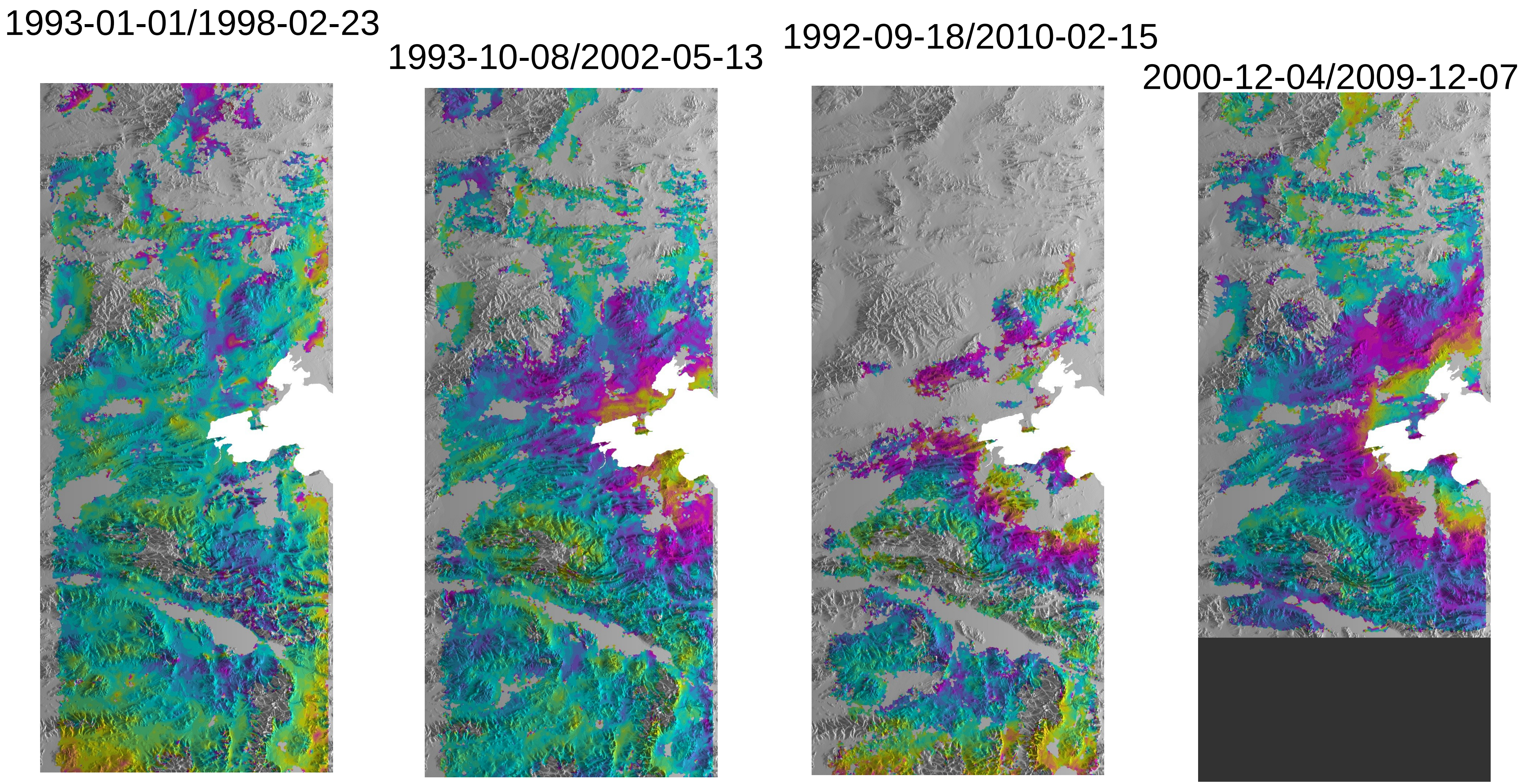
(a) 1992/06/21-1997/09/17 (b) 1993/01/17-1997/07/09 (c) 2000/01/20-2009/12/23 (d) 2003/04/09-2009/11/18

Figure 5. Examples of ERS and Envisat interferograms, centered in the lake area. The acquisition dates are displayed below the interferograms. One color cycle corresponds to a delay of 2.8 cm. Note that the trends in range and azimuth have been removed from these interferograms.

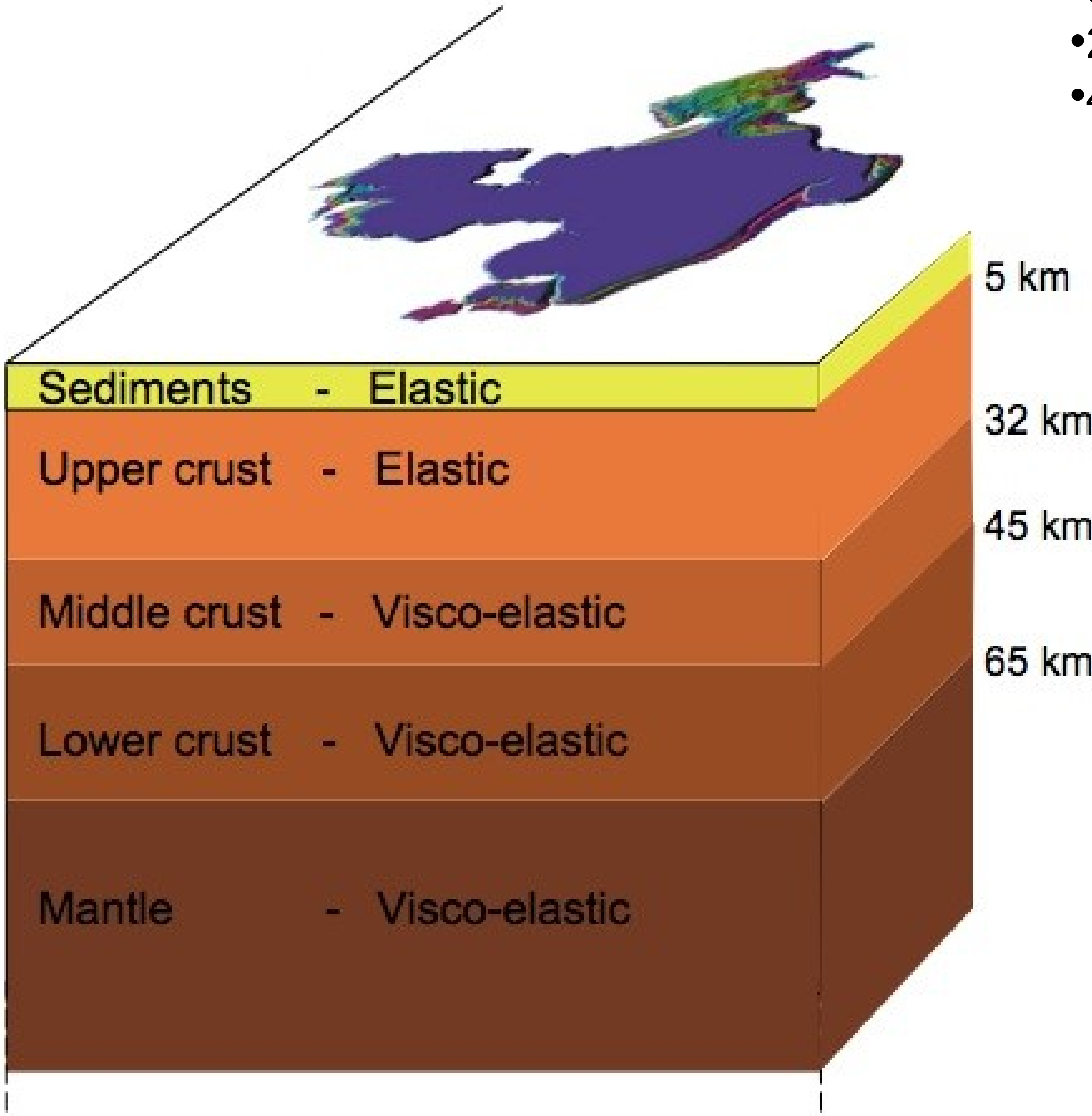
Examples of processed interferograms

- after corrections of orbital ramps + stratified atmospheric contributions
- after strong spatial filtering





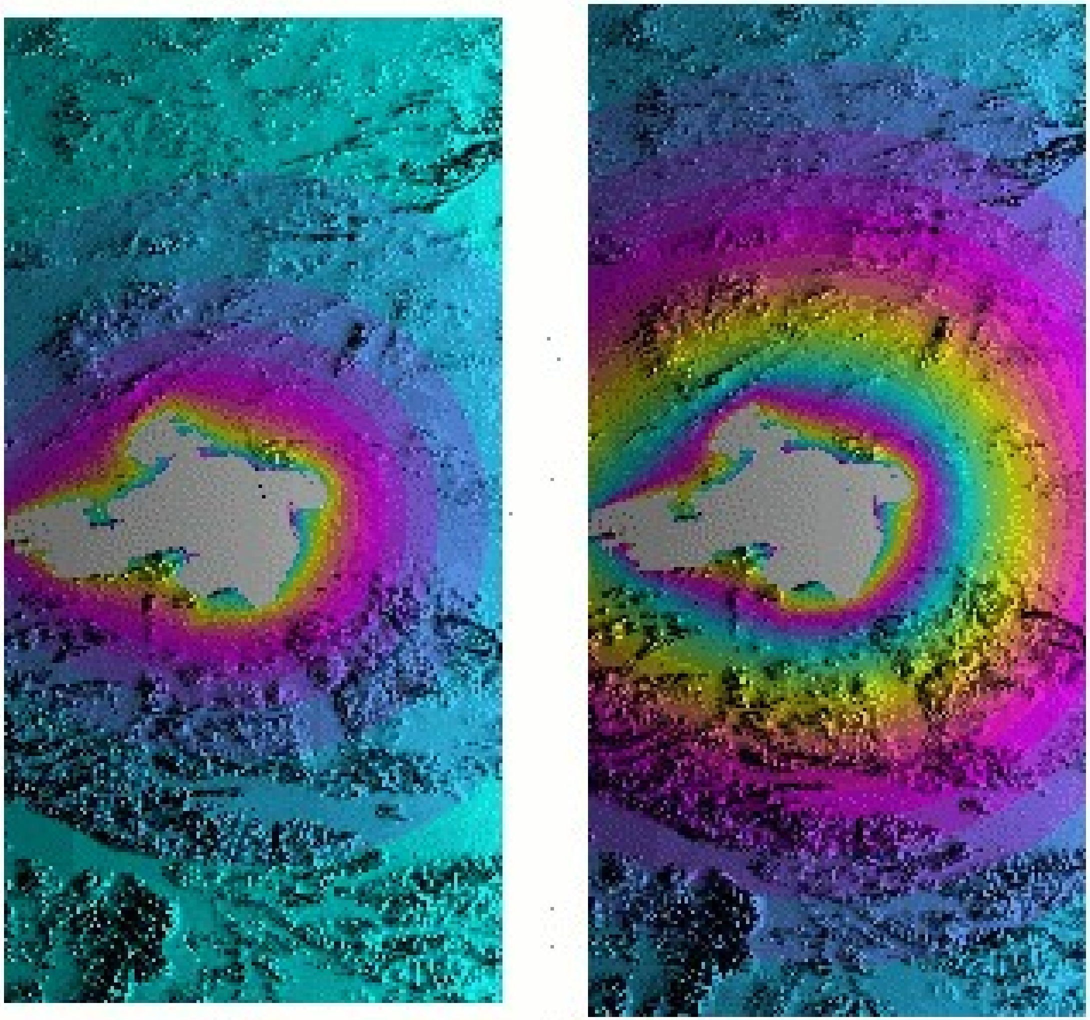
Elastic and visco-elastic models



- Spectral code
- 2-D surface load varying with time
- 400 km x 400 km x 400 km

- ✓ Elastic parameters from INDEPTH III profile seismic experiment (1982)
- ✓ If visco-elastic, viscosity set to 5×10^{18} Pa.s

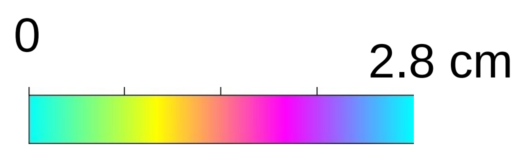
Elastic model **Visco-elastic model**

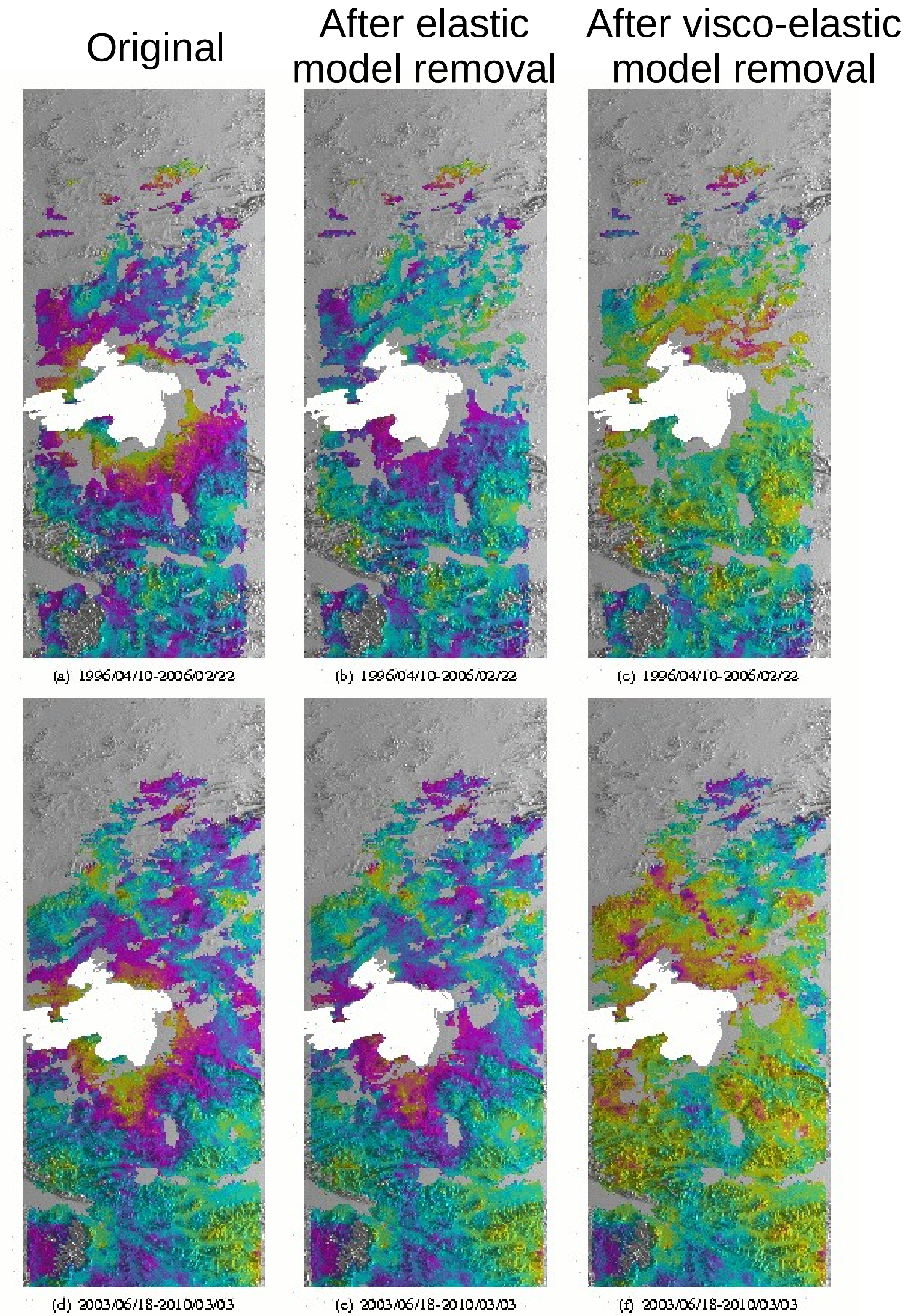


(a) (b)

Figure 6. LOS displacement models for the period 1992-2010. The lake is masked. One color fringe for 2.8 cm displacement. (a) Elastic. (b) Visco-elastic with a viscosity of 5×10^{18} *Pa.s.*

Between 1992 and 2010

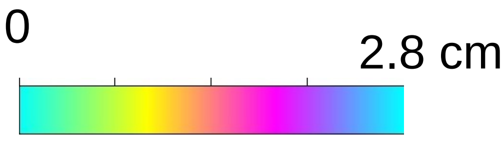


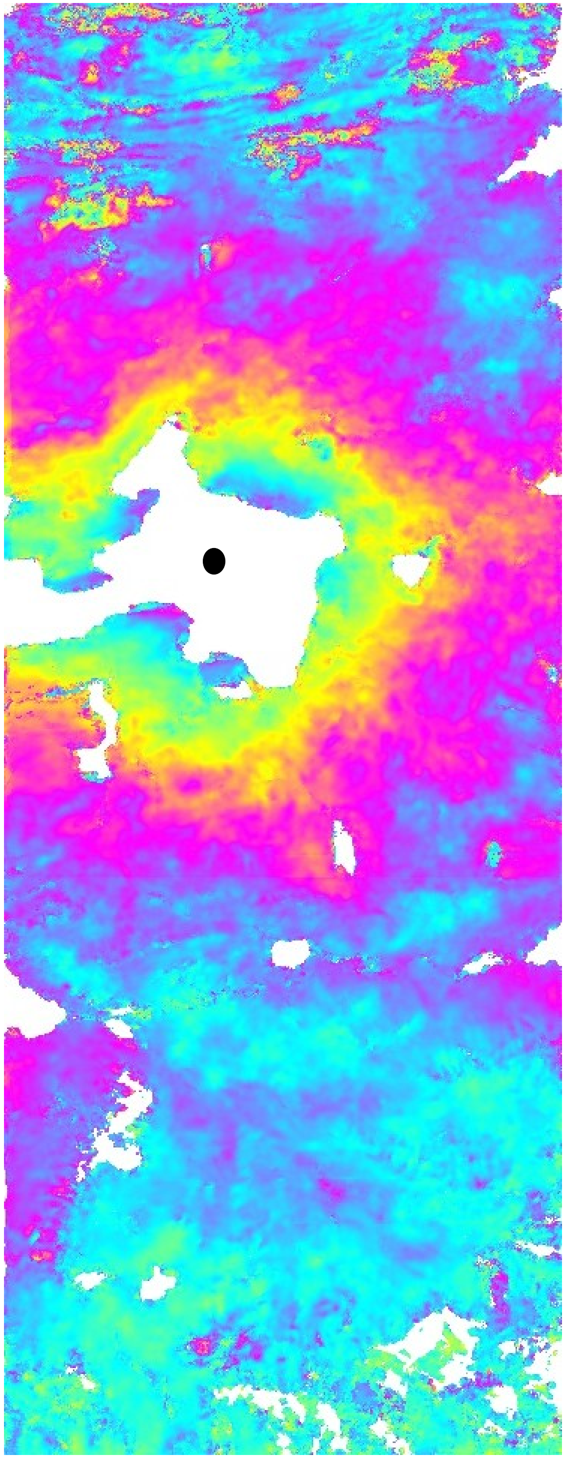


Comparison

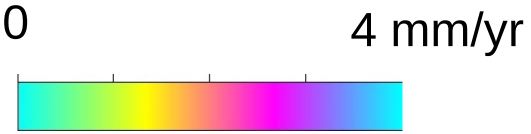
Interferograms

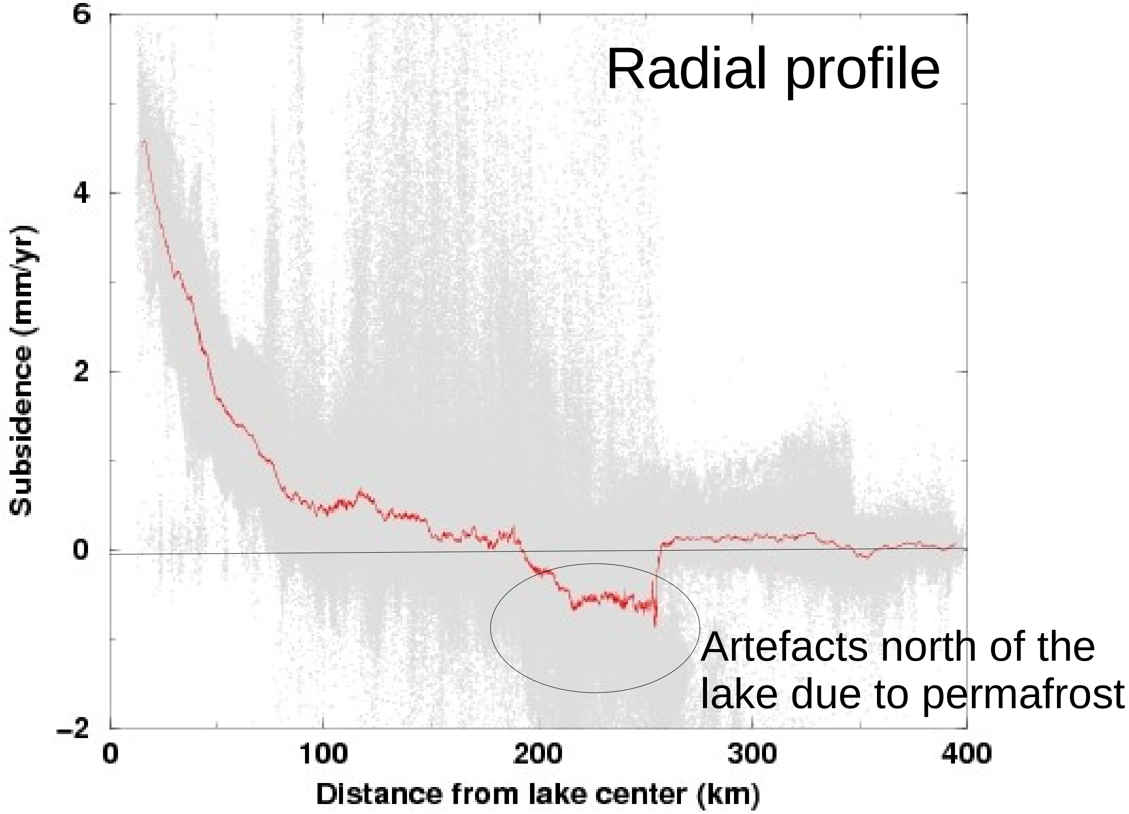
Elastic / visco-elastic models





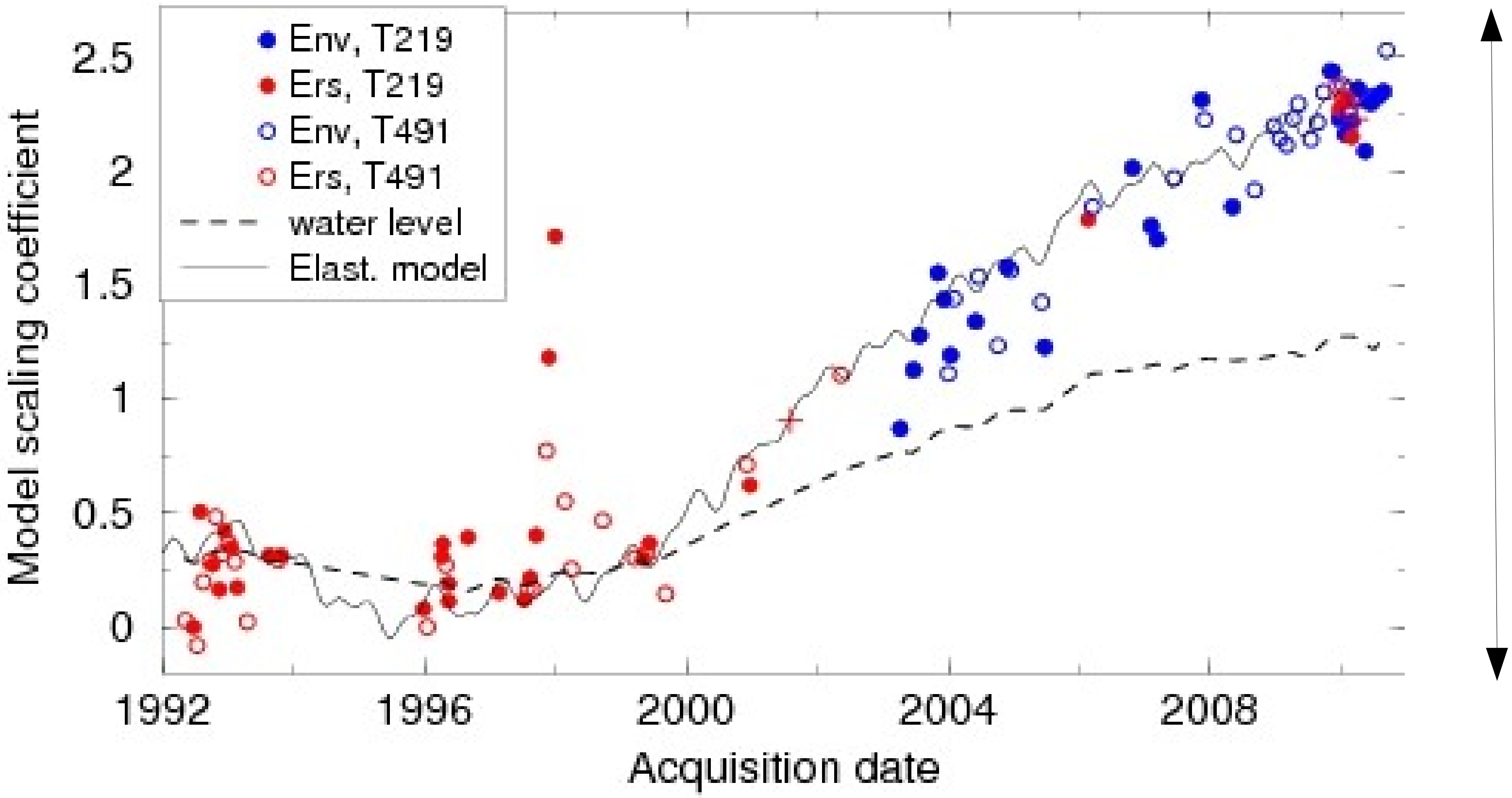
Average velocity map for the 2003-2010 period :
--> subsidence of 4.5 mm/yr centered on Siling Co lake





Proportionality coefficient, **a**, between the **purely elastic model** and the interferometric phase, inverted into temporal series

$$\Phi = \mathbf{a}\ \text{model} + b\,x + c\,y + d\,xy + e\,y{*}y + k\,z$$

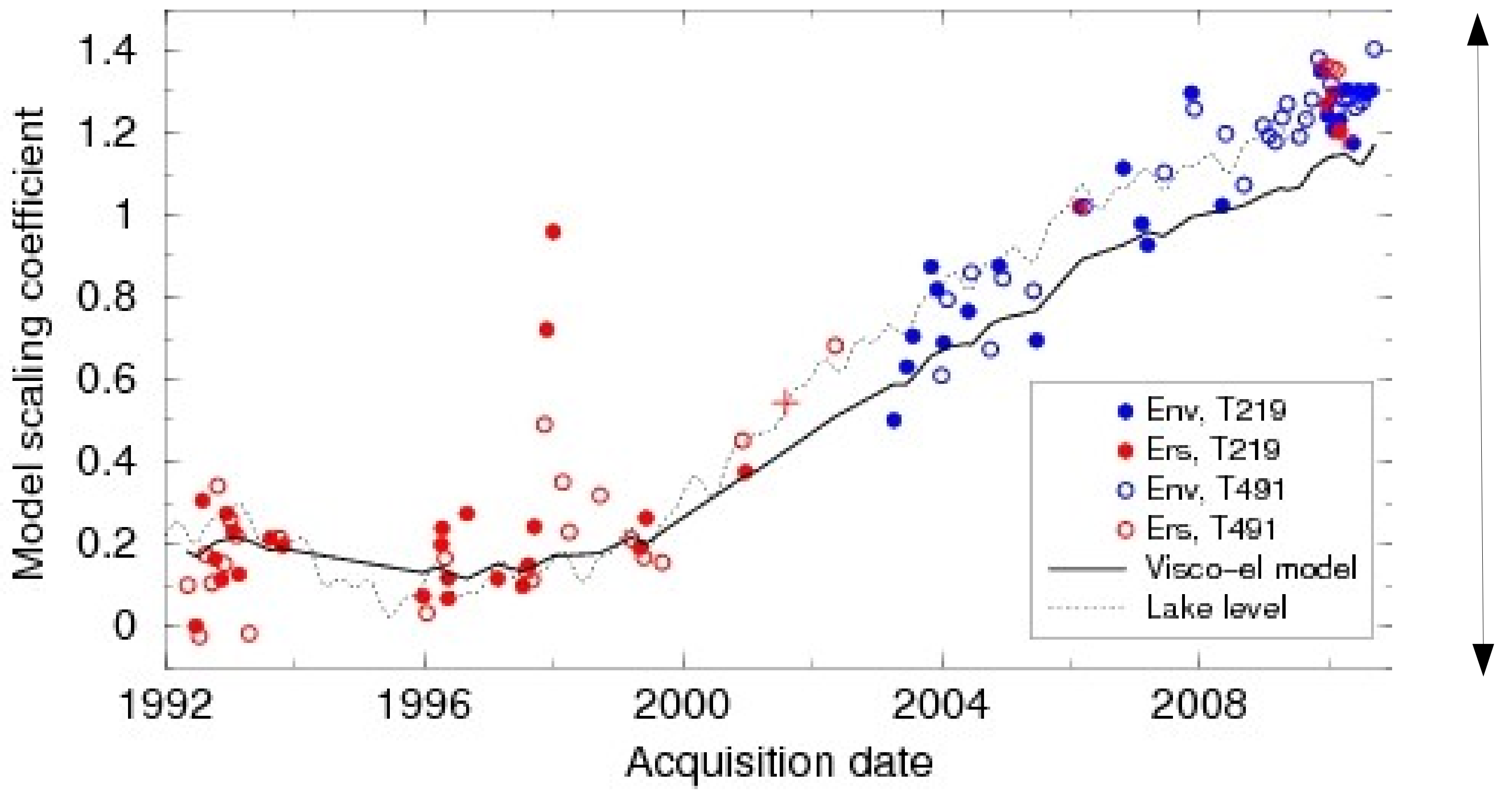


~6 cm close to the lake

Deformation amplitude too small for a purely elastic model

Proportionality coefficient, **a**, between the **visco-elastic model** and the interferometric phase, inverted into temporal series

$$\Phi = \mathbf{a} \text{ model} + b\,x + c\,y + d\,xy + e\,y*y + k\,z$$



~6 cm close to the lake

Deformation amplitude in favor of a viscoelastic model with large lower crust ductility.

Conclusions :

- ERS and Envisat altimetry combined with Landsat image analysis shows that the Siling Co lake level was stable from 1972 to 1999 and steadily increased afterwards by 0.8 m/yr

-origin : permafrost melting, increased precipitation, glacier melting ?

- SAR archive exploitation by InSAR time series analysis reveals a subsident bowl shape pattern centered on lake Siling Co, due to increased lake loading

- Mechanical models including a soft lower crust better explain the subsidence amplitude than a purely elastic model