The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

World Year of PHYSICS 2005

H4.SMR/1642-8

"IAG-IASPEI Joint Capacity Building Workshop on Deformation Measurements and Understanding Natural Hazards in Developing Countries"

17 - 23 January 2005

Integration of Space & Terrestrial Techniques to Study Crustal Deformation. Examples in North Eastern Italy

S. Zerbini

University of Bologna
Department of Physics
Bologna

Integration of space and terrestrial techniques to study crustal deformation. Examples in northeastern Italy

Susanna Zerbini
Dipartimento di Fisica, University of Bologna, Italy

Università di Bologna

IAG-IASPEI Joint Capacity Workshop on
“Deformation Measurements & Understanding Natural Hazards in Developing Countries
Trieste, 17-23 January, 2005

Fine-tuning in the knowledge of station motions has not yet been reached.

Detailed knowledge will allow

- Better understanding of geophysical processes responsible of horizontal and vertical deformation;
- Constraining the physical models describing the deformations of the Earth;
- Contributing to high-precision reference frame realizations.

Validation and crosschecking of techniques is necessary to understand the error sources and to fully exploit the potential of each single technique.

Integration allows to take advantage of the complementary strengths of the single techniques (GPS, VLBI, SLR, InSAR, gravimetry….).

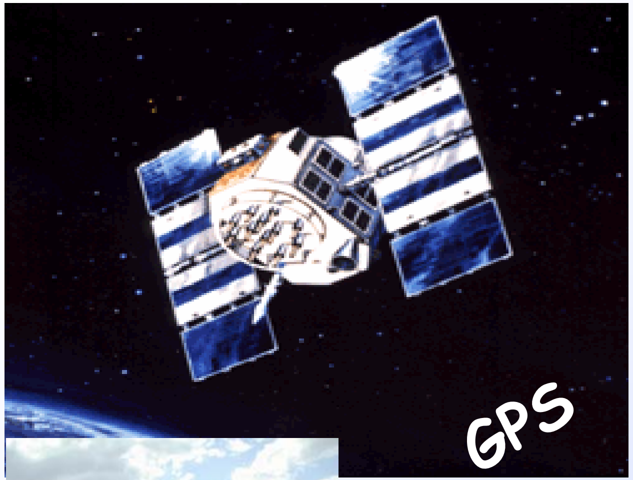
VLBI, SLR

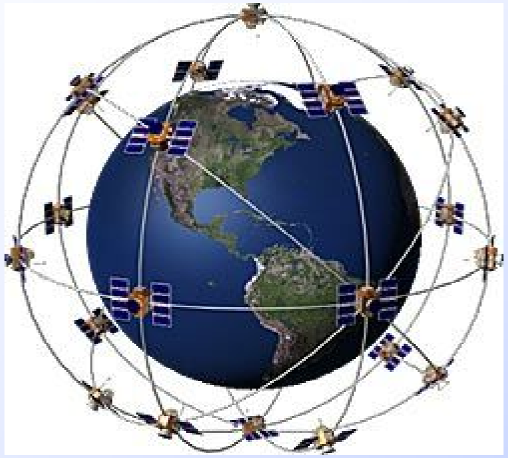
limited number of stations around the globe

major importance for global reference frame

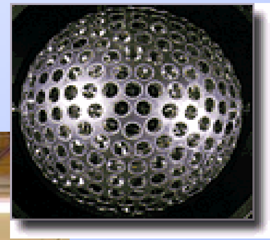
GPS networks, though dense, provide information, which is continuous in time, however, is not spatially continuous.

InSAR has proven capability to provide spatially continuous information, which, however, is limited in temporal coverage.

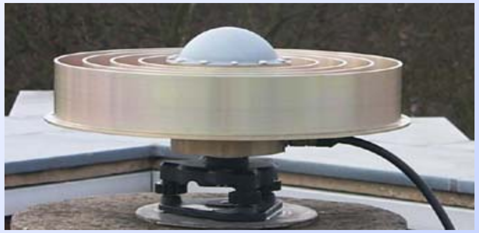




LAGEOS II



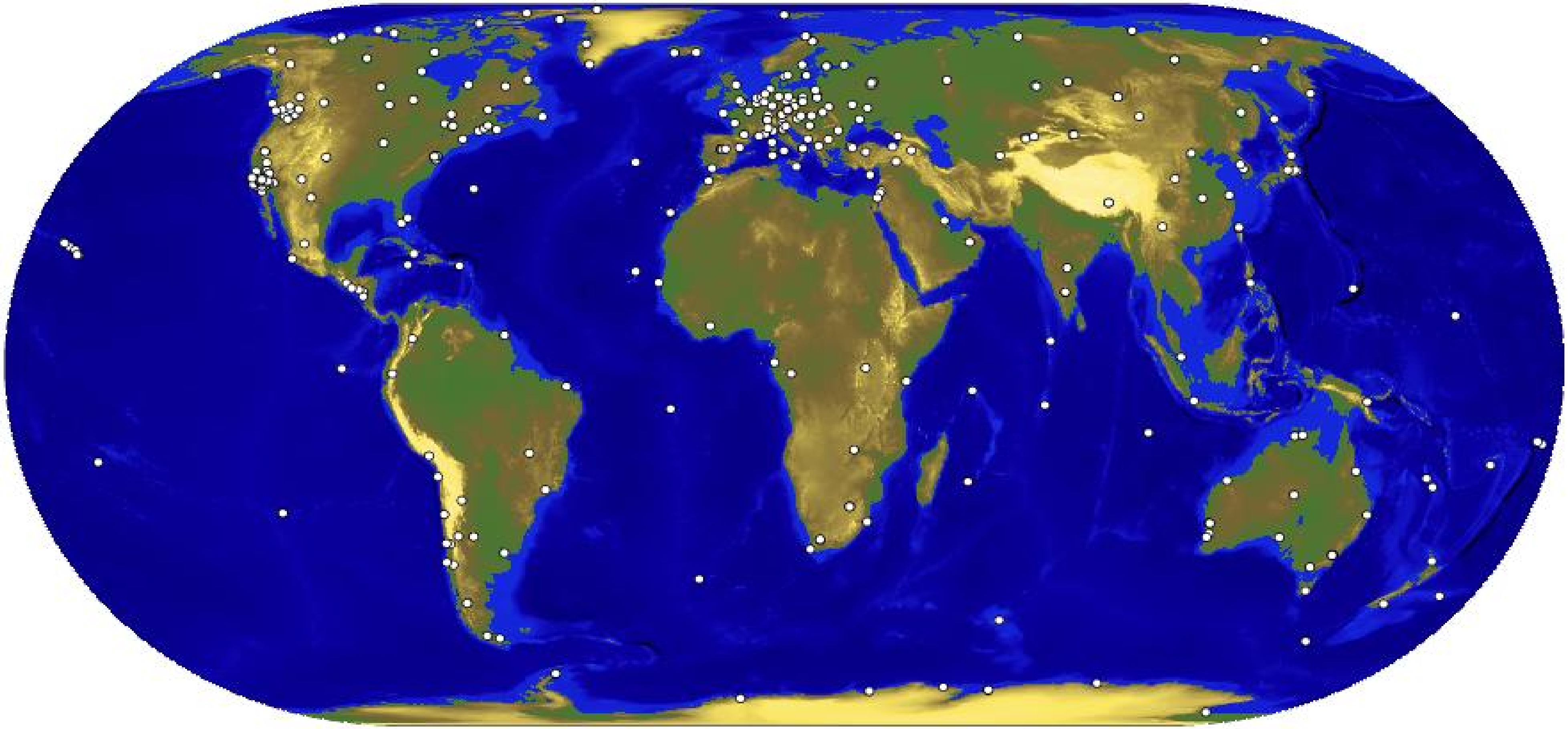
Satellite Laser Ranging



Absolute and relative gravimetry

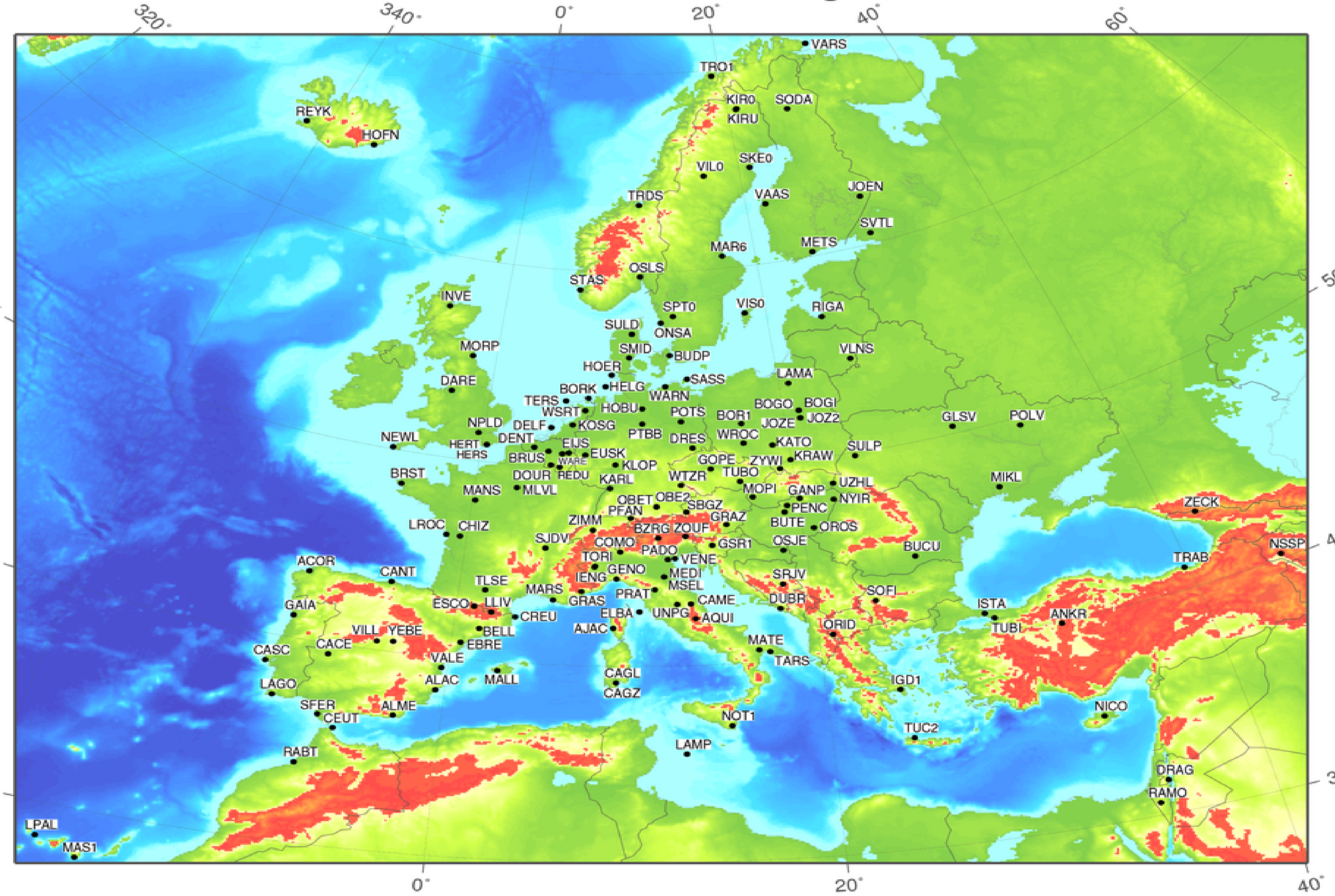
Università di Bologna

IGS GPS network

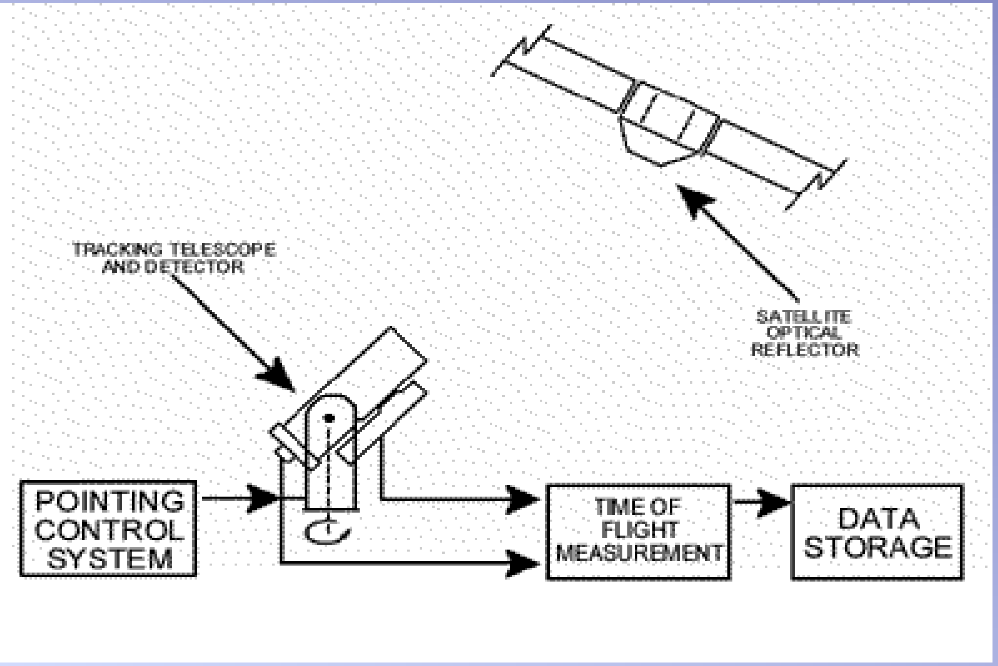


Università di Bologna

EUREF Permanent Tracking Network

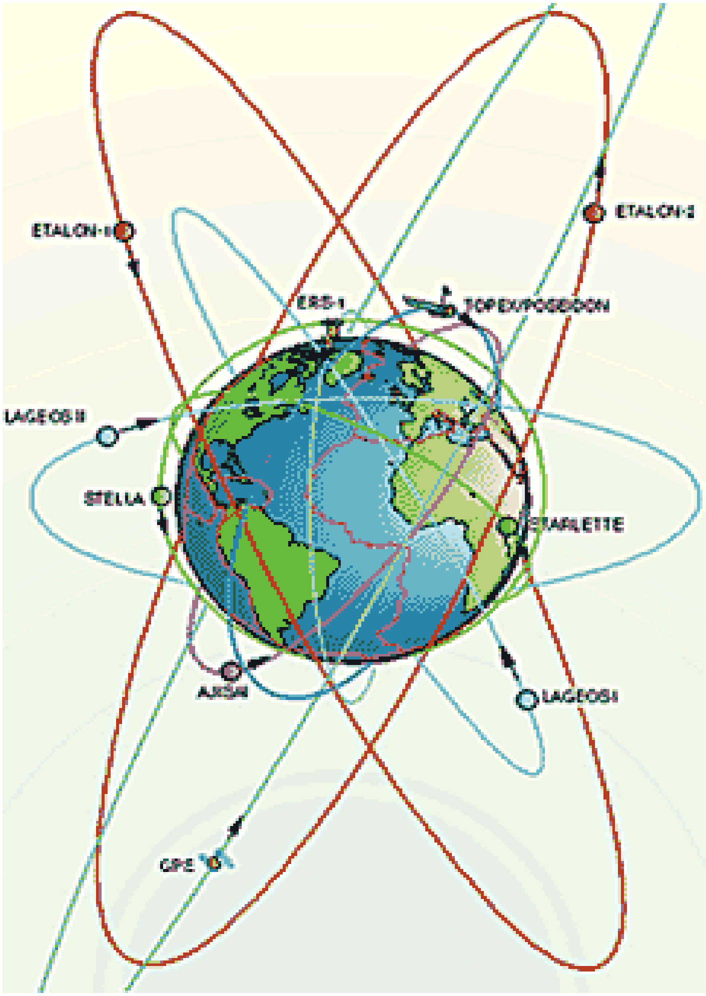


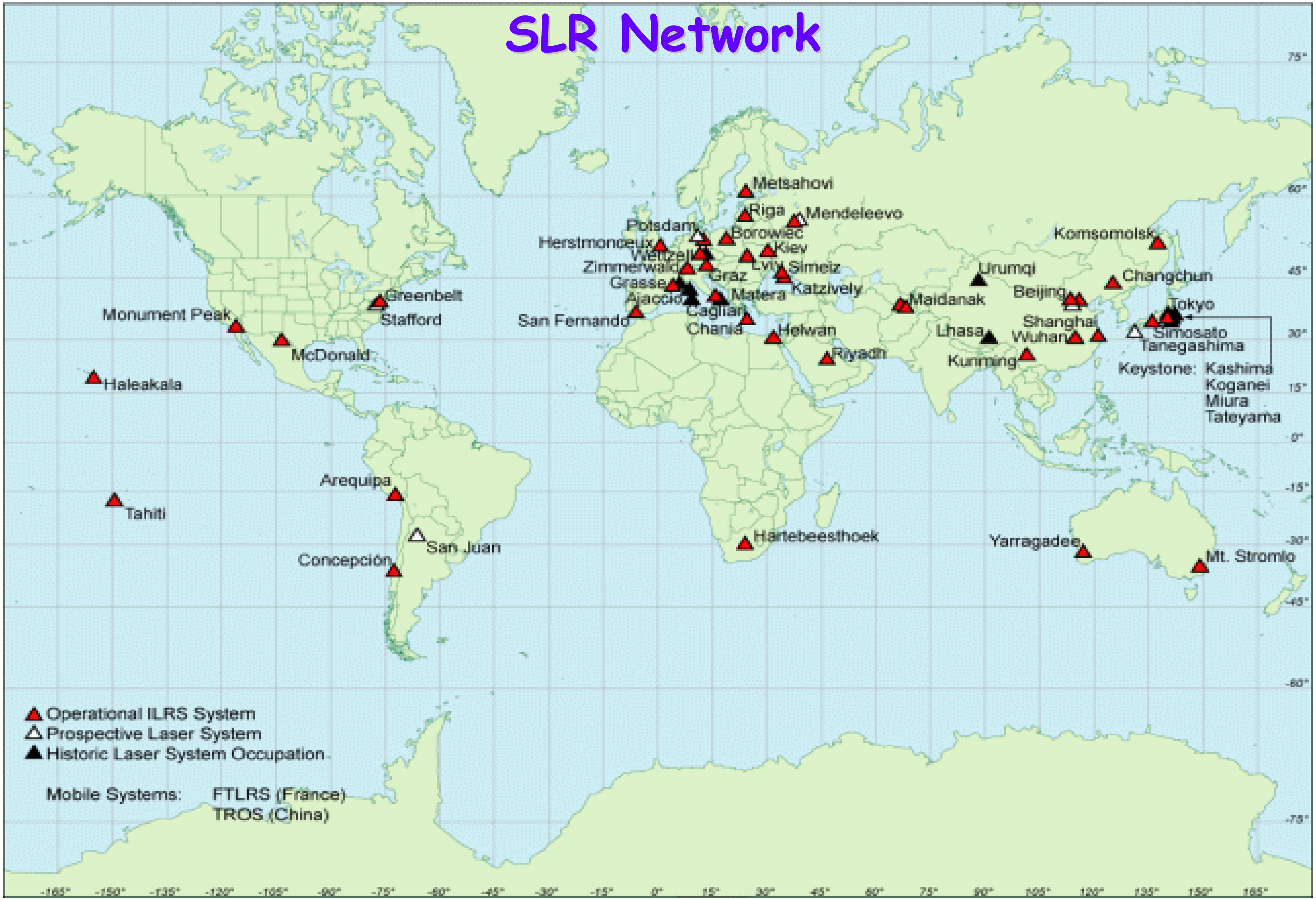
SLR concept



In Satellite Laser Ranging, a short pulse of coherent light generated by a laser (Light Amplification by Stimulated Emission of Radiation) is transmitted in a narrow beam to illuminate corner cube retroreflectors on the satellite. The return signal, typically a few photons, is collected by a telescope and the time-of-flight is measured. Using information about the satellite's orbit, the time-of-flight, and the speed of light, the location of the ranging station can be determined. Similar data acquired by another station, many kilometers distant from the first, or on a different continent, can be used to determine the distance between stations to precisions of a few mm. Repetitive measurements over months and years yield the change in distance, or the motion of the Earth's crust.

SLR satellites




SLR Network
Metsahovi
Riga
Mendeleevo
Potsdam
Borowiec
Herstmonceux
Wettzell
Kiev
Zimmerwald
Lviv
Simeiz
Graz
Grasse
Katzively
Matera
Ajaccio
Cagliari
San Fernando
Chania
Helwan
Riyadh
Maidanak
Urumqi
Komsomolsk
Changchun
Beijing
Tokyo
Shanghai
Wuhan
Lhasa
Simosato
Tanegashima
Kunming
Keystone: Kashima
Koganei
Miura
Tateyama
Greenbelt
Stafford
Monument Peak
McDonald
Haleakala
Arequipa
Tahiti
San Juan
Concepción
Hartebeesthoek
Yarragadee
Mt. Stromlo
Operational ILRS System
Prospective Laser System
Historic Laser System Occupation
Mobile Systems: FTLRS (France)
TROS (China)

3 French SLR systems at Grasse

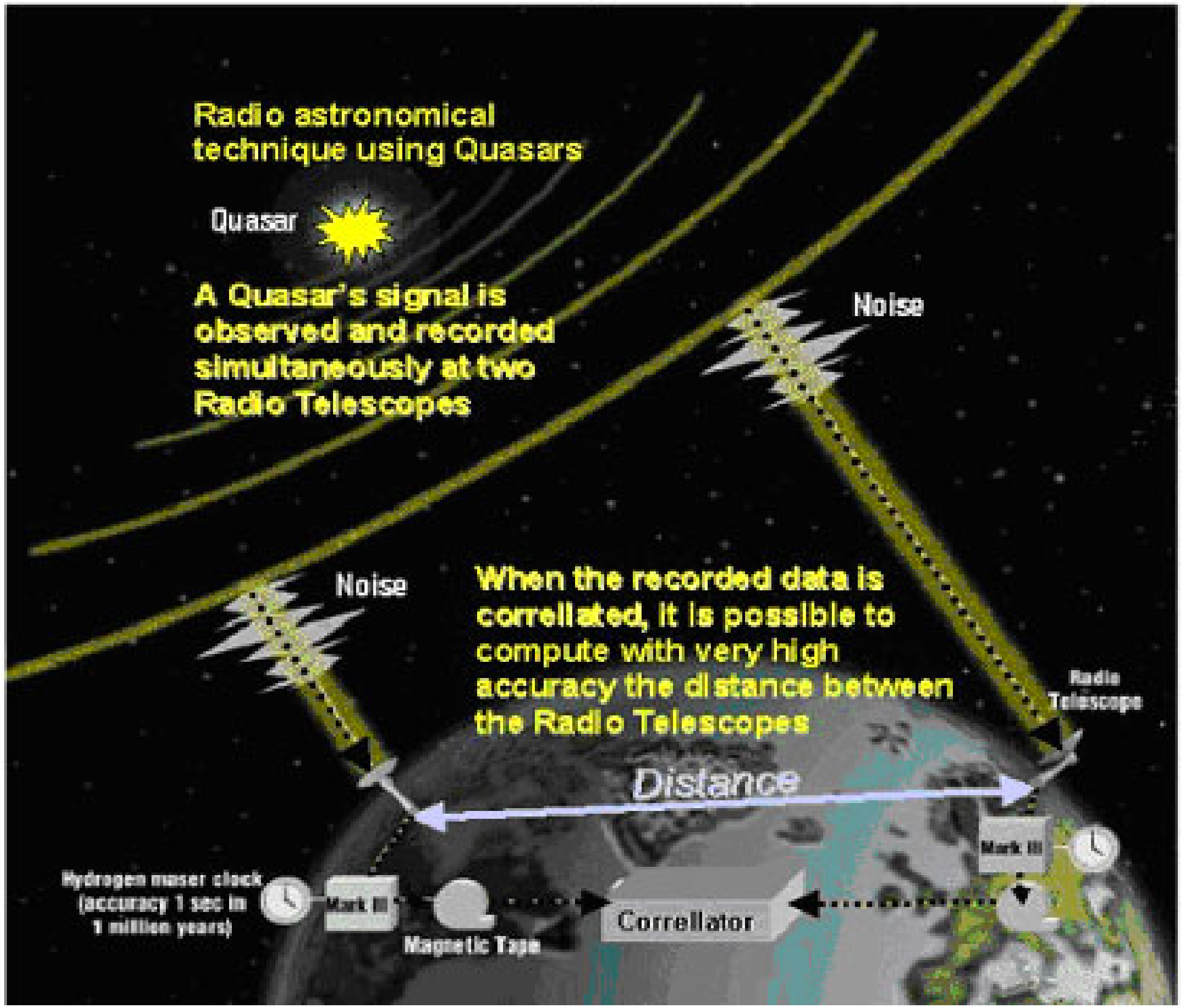
Riyadh SLR system

Matera LRO

Università di Bologna

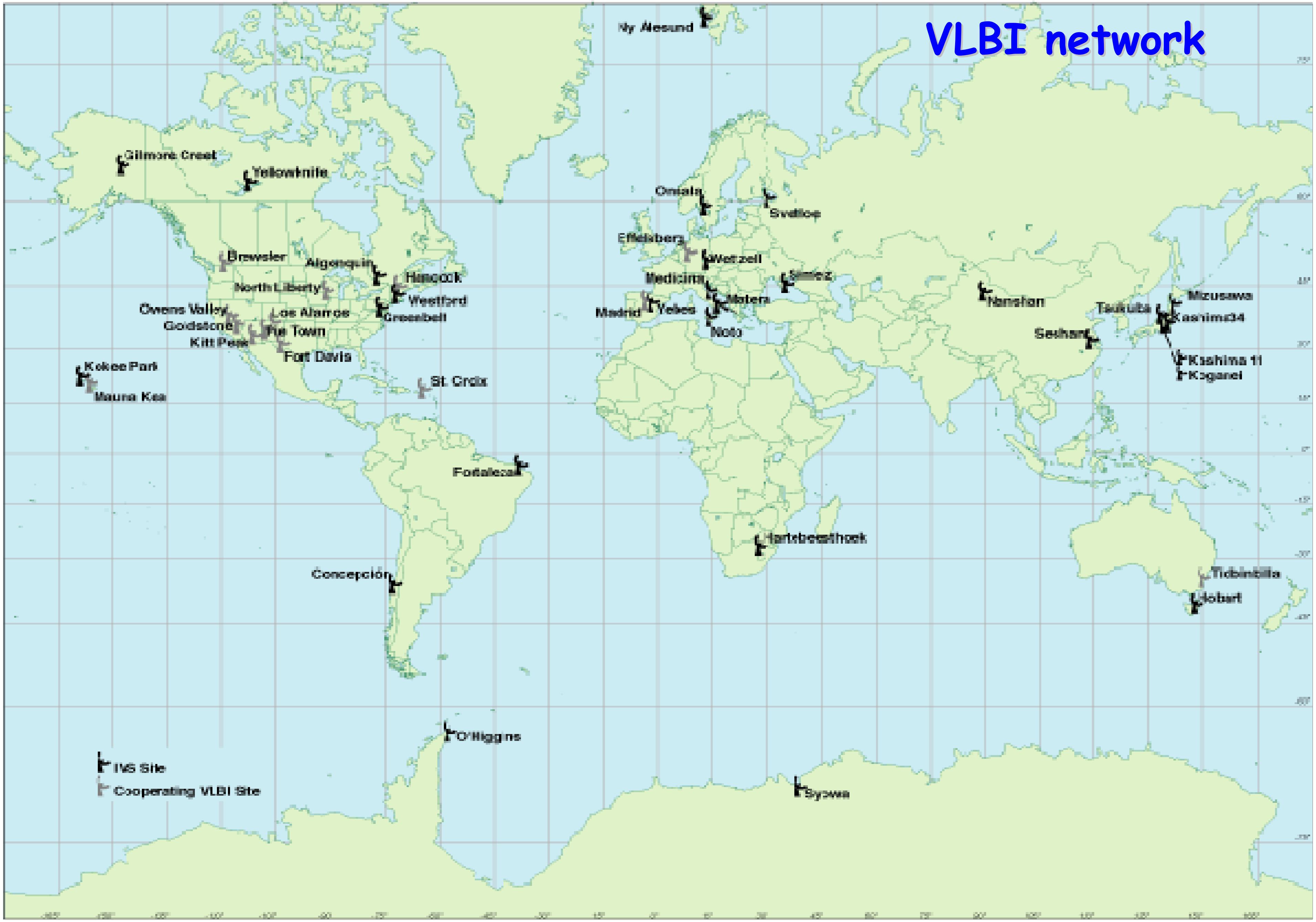
VLBI concept

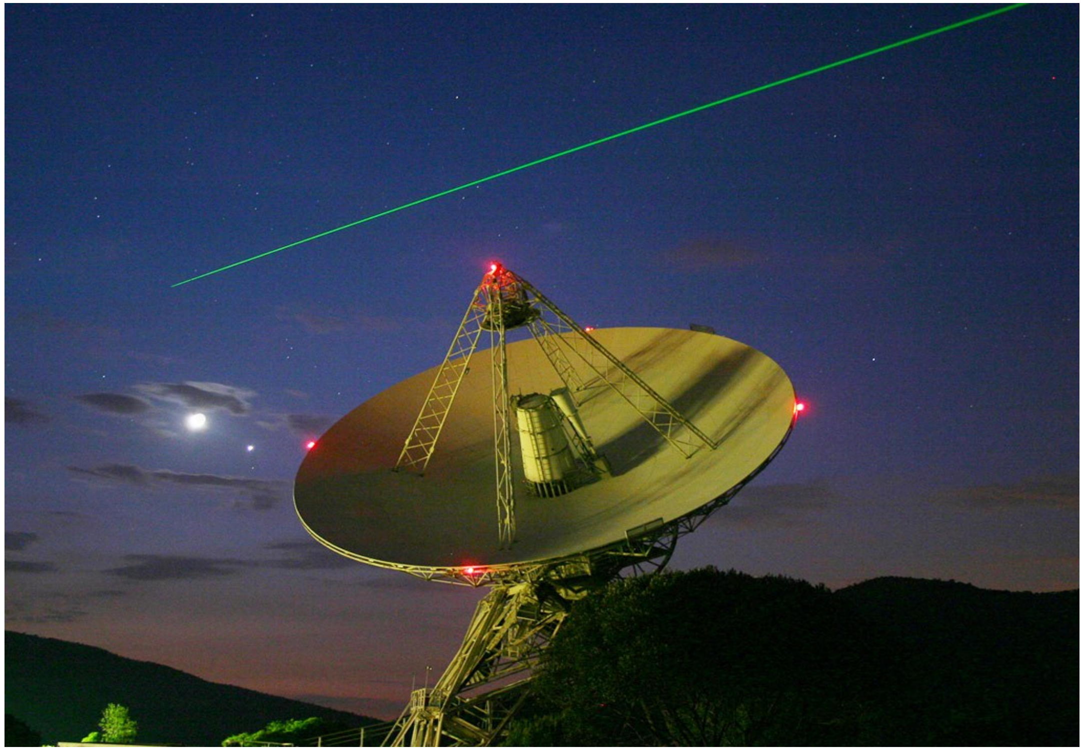
VLBI is a geometric technique: it measures the time difference between the arrival at two Earth-based antennas of a radio wavefront emitted by a distant quasar.



Because the time difference measurements are precise to a few picoseconds, VLBI determines the relative positions of the antennas to a few millimeters

Università di Bologna


VLBI network
Ny Alesund
Gilmore Creek
Yellowknife
Onsala
Svetloe
Effelsberg
Wettzell
Brewster
Algonquin
Hancock
North Liberty
Westford
Medicina
Simeiz
Nanshan
Mizusawa
Owens Valley
Los Alamos
Greenbelt
Madrid
Yebes
Matera
Tsukuba
Kashima34
Goldstone
Pie Town
Kitt Peak
Noto
Seshan
Fort Davis
Kashima 11
Koganei
Kokee Park
Mauna Kea
St Croix
Fortaleza
Hartebeesthoek
Concepción
Tidbinbilla
Hobart
O'Higgins
IVS Site
Cooperating VLBI Site
Syowa



Hartebeesthoek, South Africa, 26 m

Medicina, Italy, 32 m

TIGO

Conception, Chile, VLBI 6m

InSAR Permanent Scatters (PS) technique

Stable natural reflectors (PS) can be identified from long temporal series of interferometric data.

PS are parts of buildings, metallic structures etc.

PS constitute a sort of “natural geodetic network”, a monitoring tool with very high spatial density of measurements.

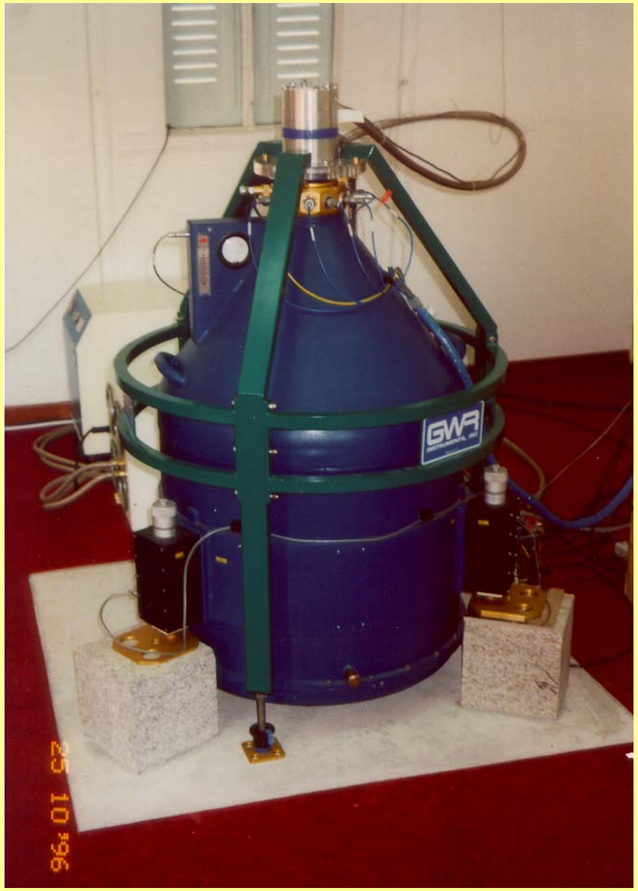
The combination of GPS and InSAR provides the ability to observe time and space continuous deformation by taking advantage of the complementary strengths of the two techniques.

GPS provides absolute positions and is, at present, the only technique contributing time continuous information, however, limited to the station location.

InSAR results are relative to a reference point. The technique provides spatially continuous information, which, however, is limited in temporal coverage.

Gravimetry

Among the terrestrial observation techniques used for the estimate of vertical land movements, gravimetry is a completely independent method with respect to space techniques.



Università di Bologna

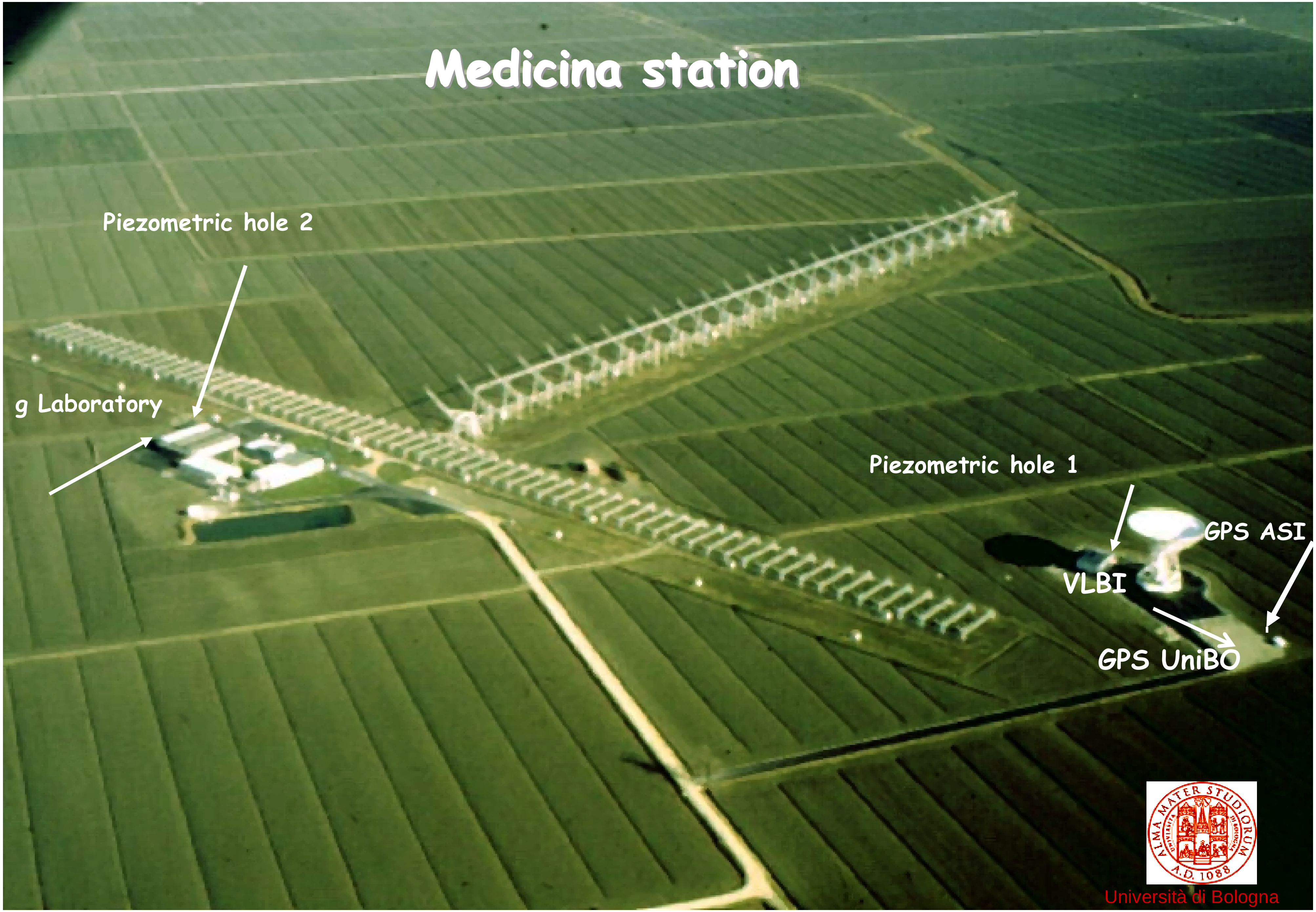
Examples of comparisons of techniques

GPS network of Dept.of Physics, Univ. Bologna

Medicina and Bologna are EPN/ECGN stations

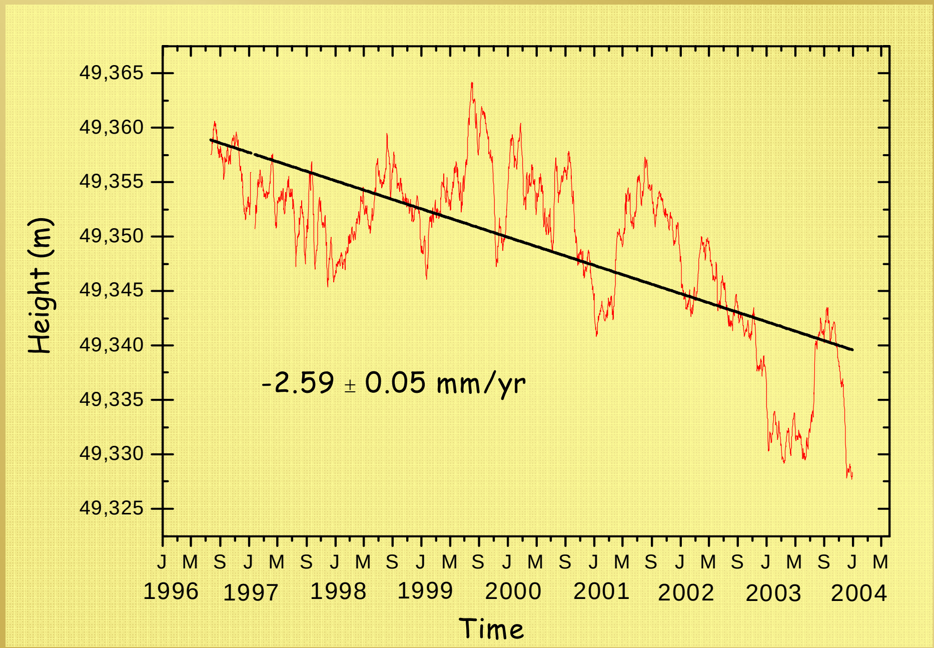
InSAR data available for Bologna, Medicina and Marina di Ravenna

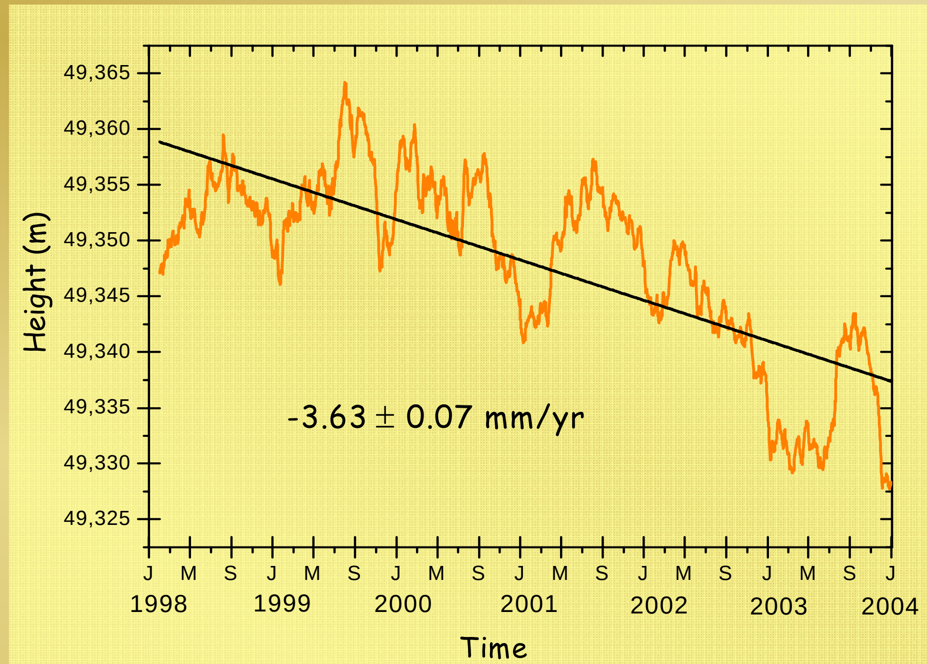
Università di Bologna

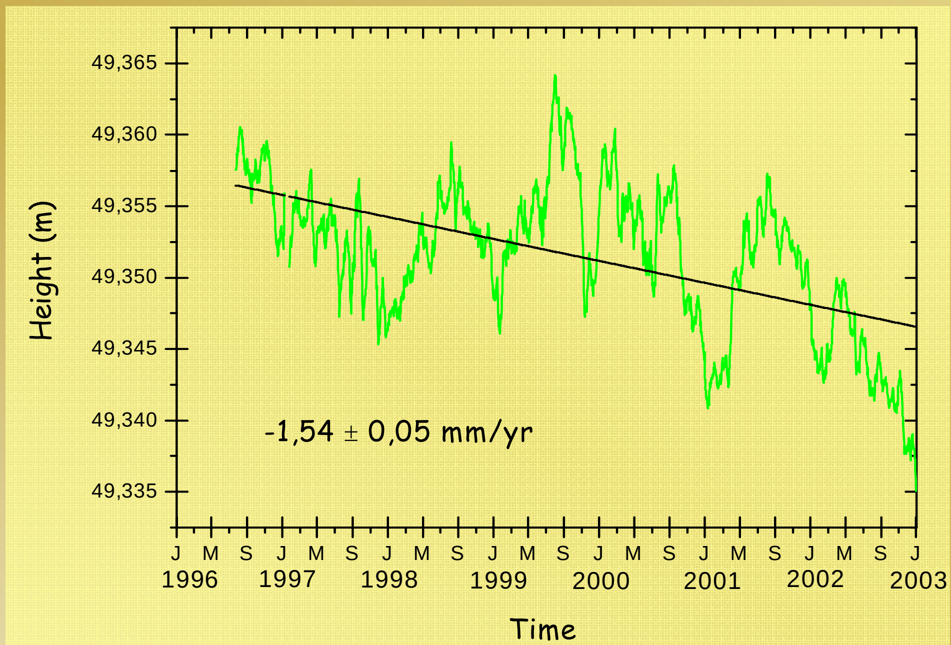


Università di Bologna

Medicina GPS Height



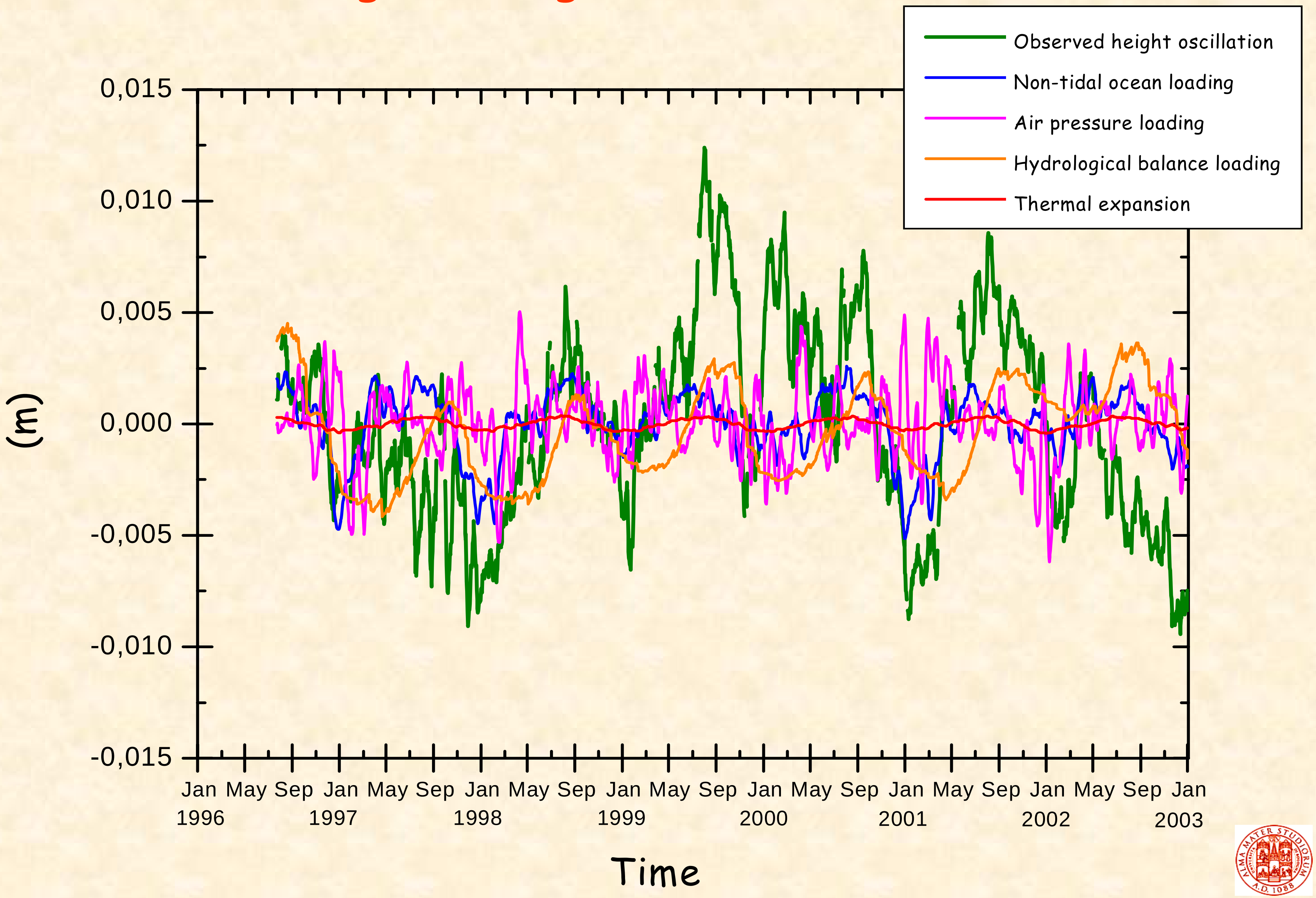




Differences due to length of time series but also to data treatment

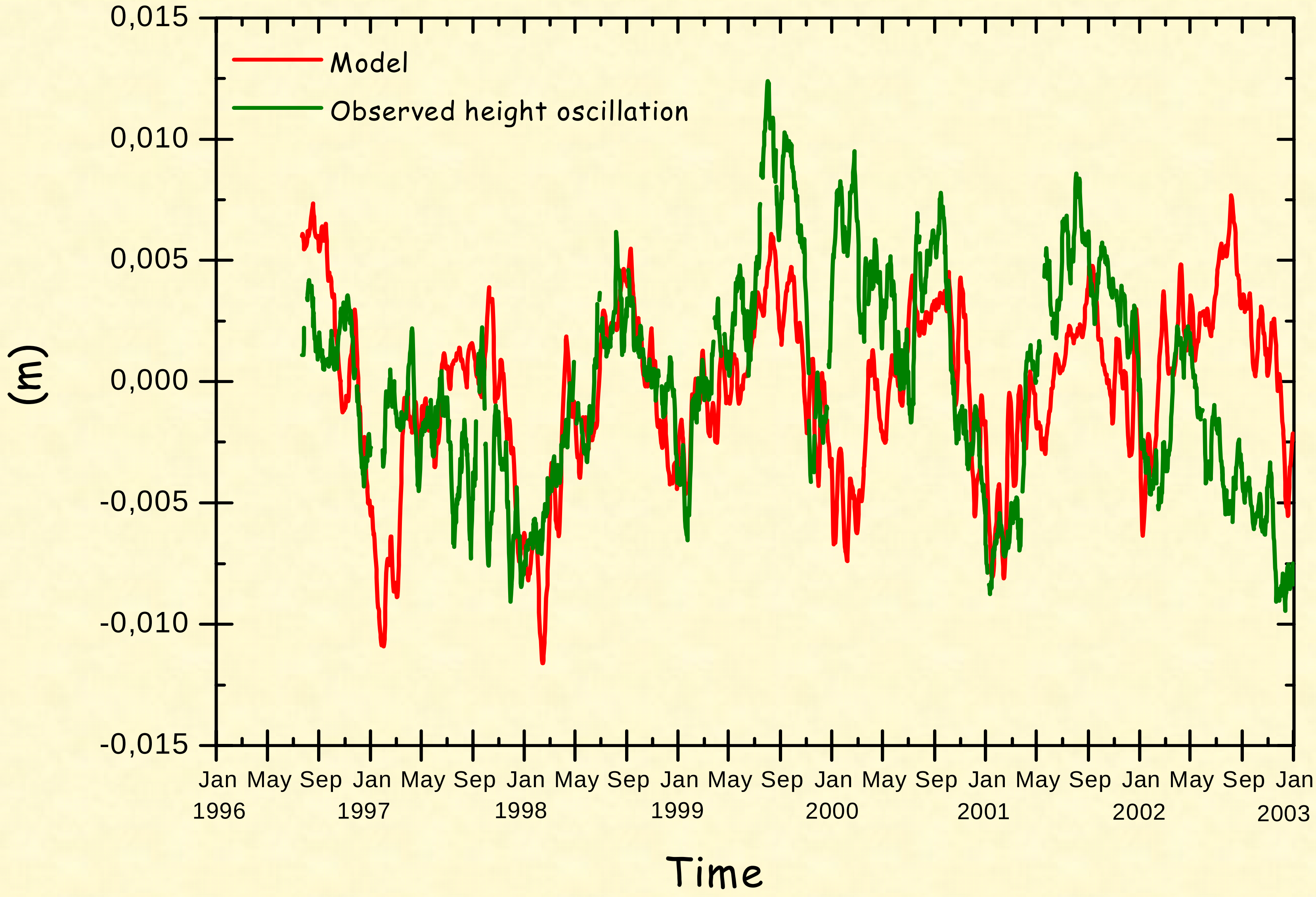
Università di Bologna

Modeling the height seasonal oscillations

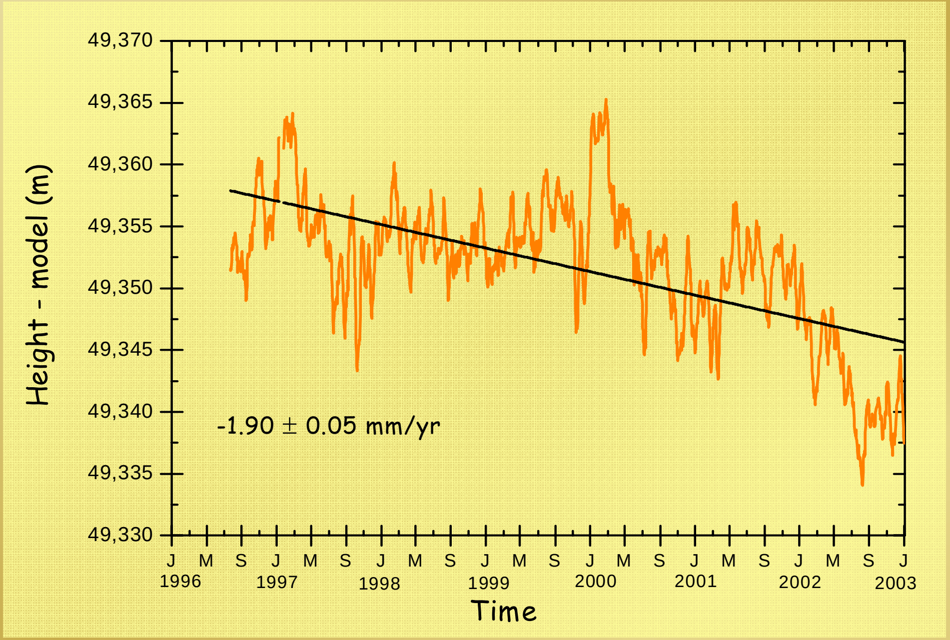


Università di Bologna

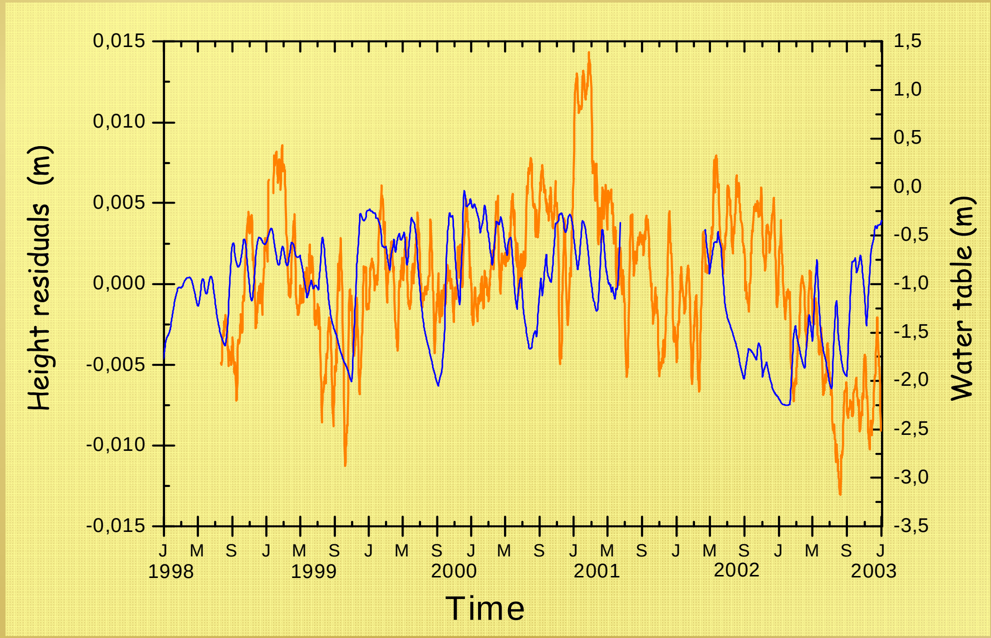
Model of the seasonal oscillations



Long-term trend



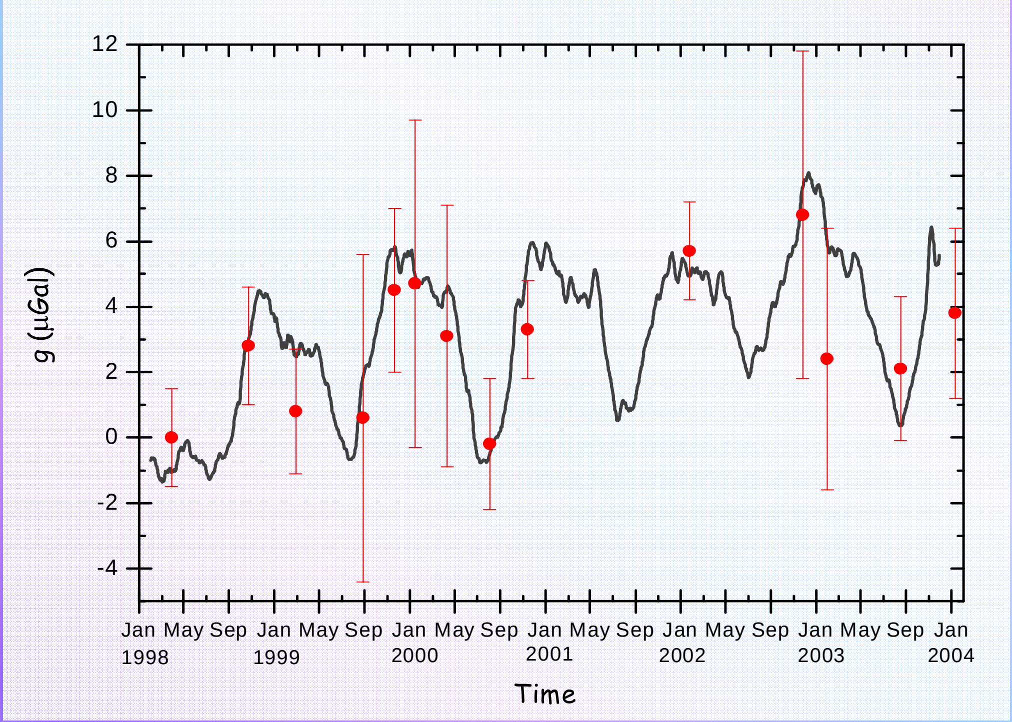
Height residuals

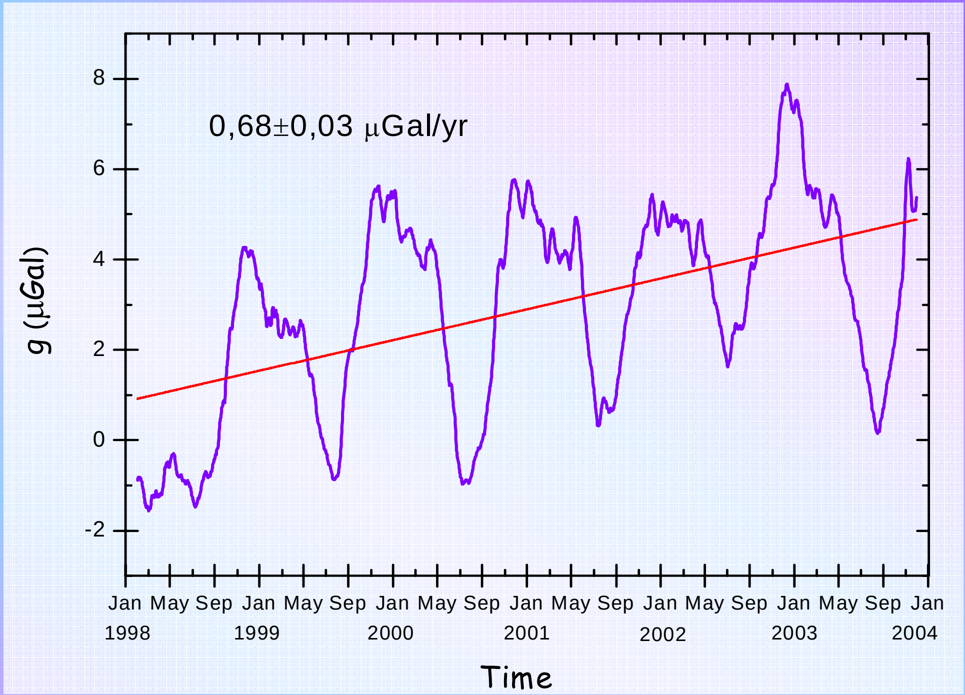


Improved modeling of the seasonal oscillations needed for reliable estimates of long-term trends

Università di Bologna

Gravity at Medicina

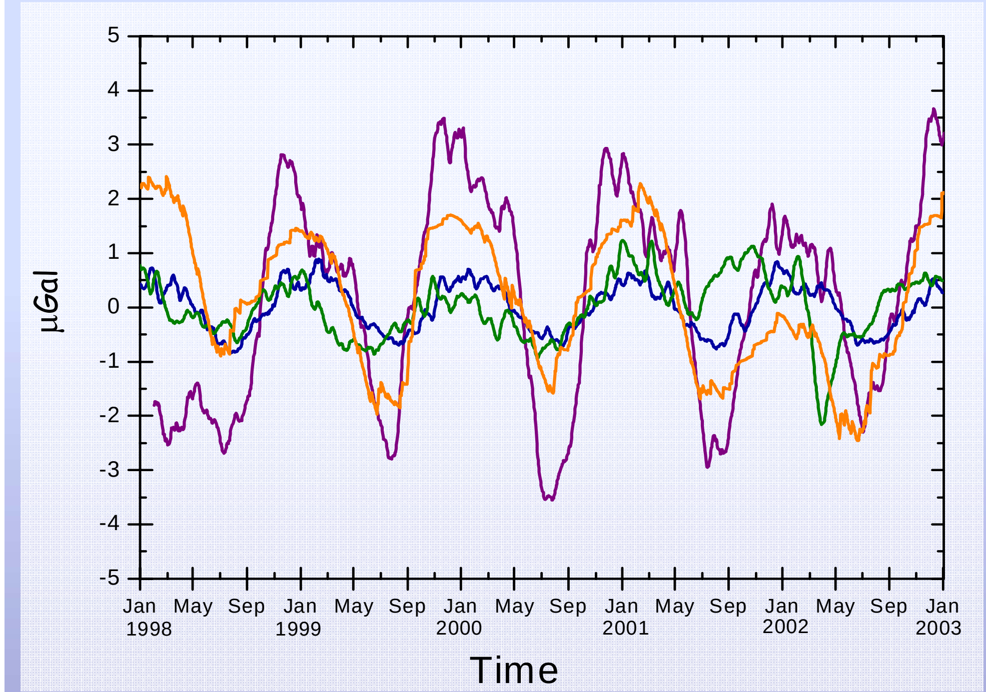




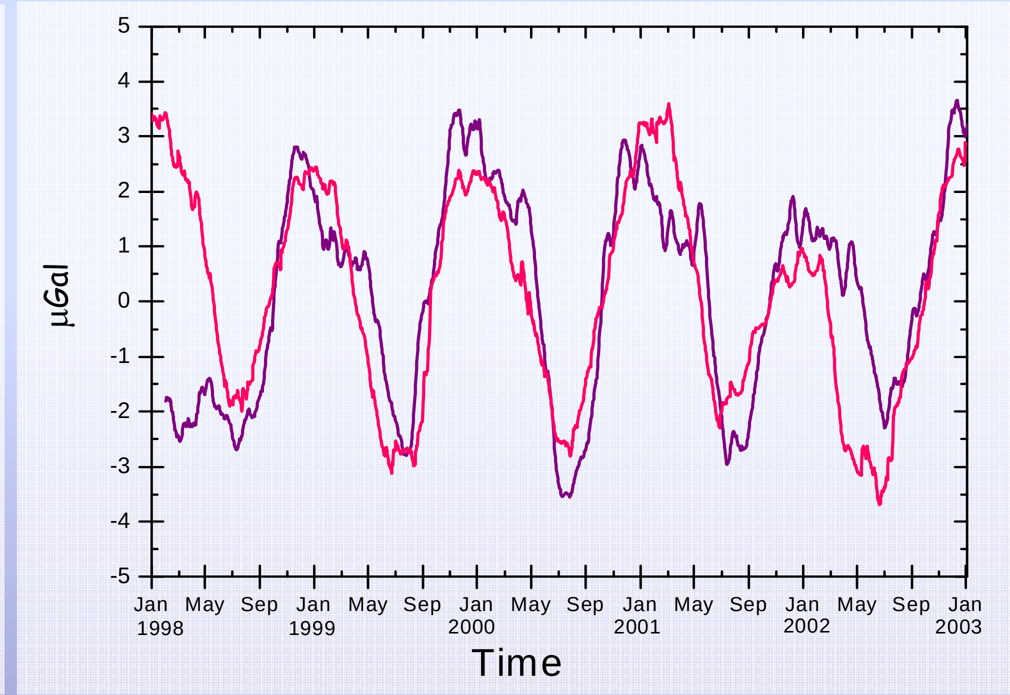
Università di Bologna

Modeling the seasonal oscillations

—observed gravity oscillation
—vertical air mass
—non-tidal ocean
— hydrological balance

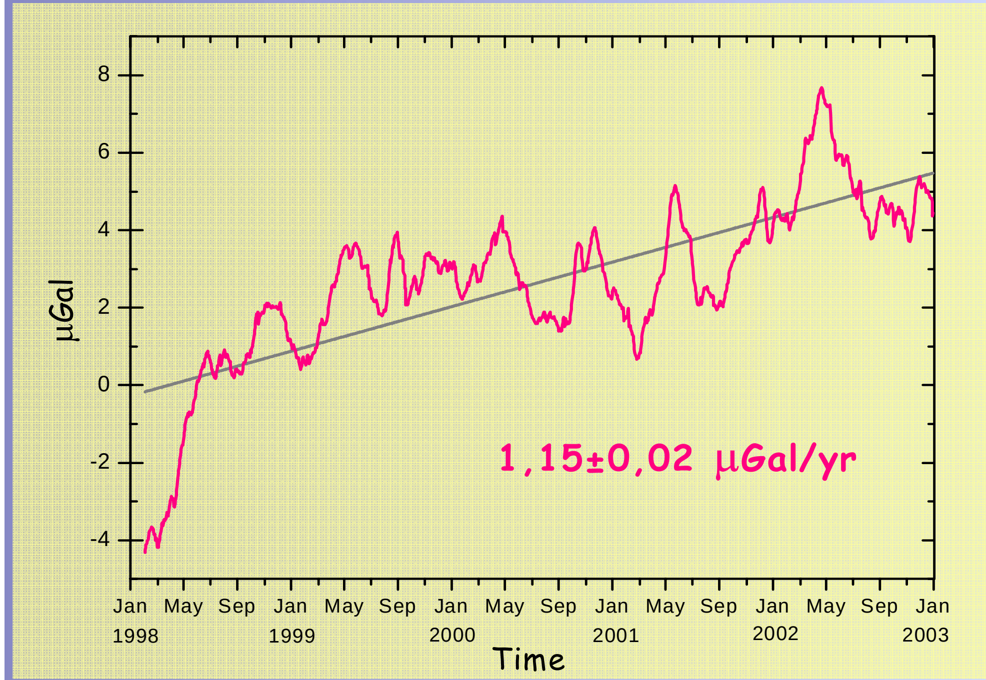


—Model
—observed gravity oscillations

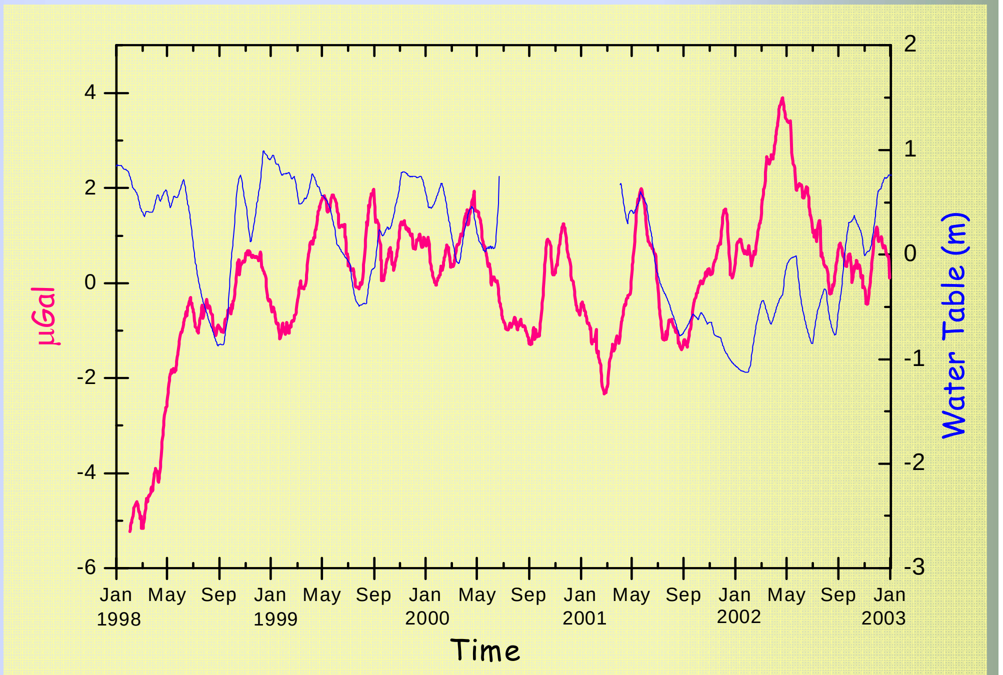


Università di Bologna

Long-term trend



Gravity residuals



Università di Bologna

Medicina height variations from different techniques and solutions

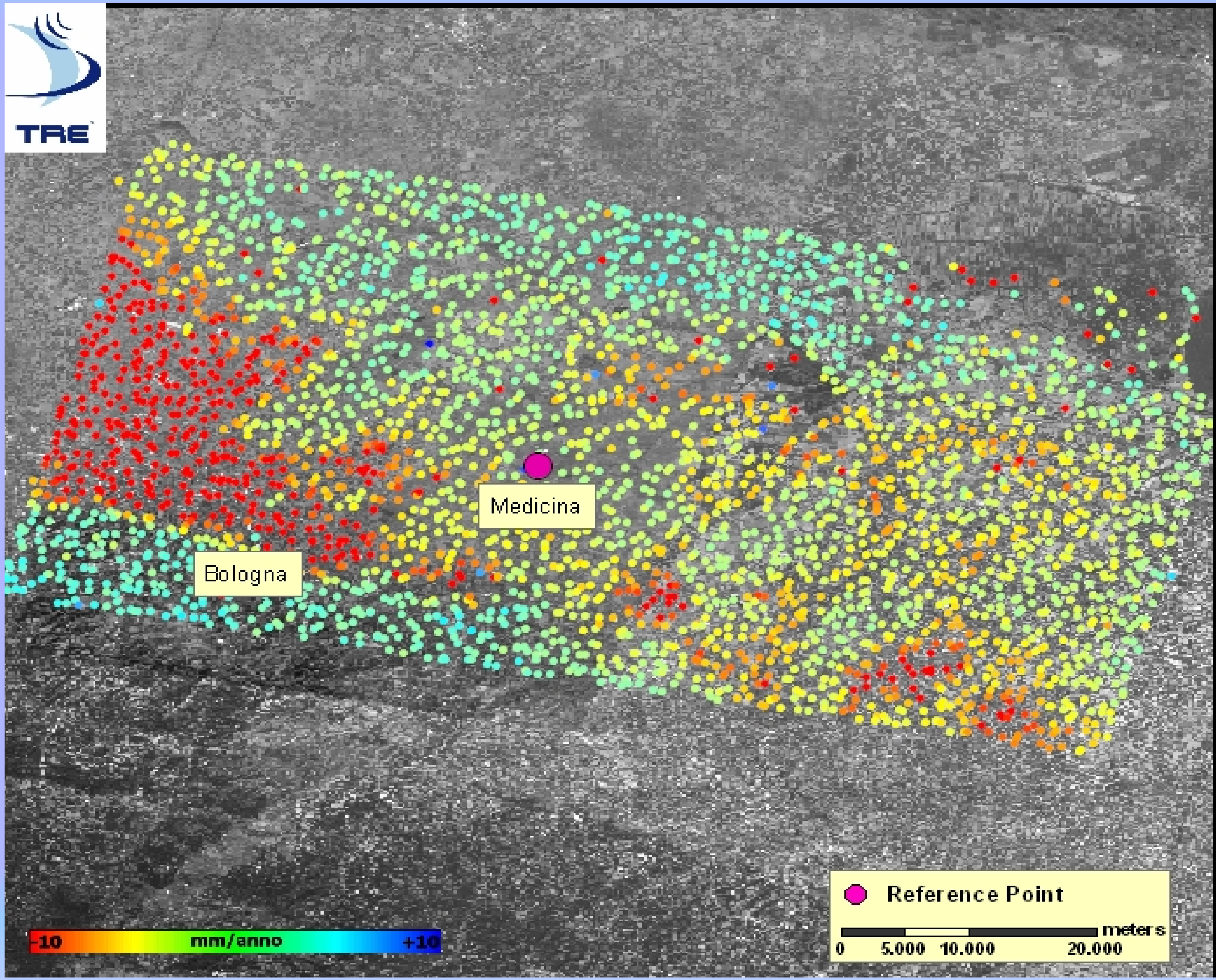
1998-2003

-3.63 ± 0.07 mm/yr CGPS UNIBO
-4.24 ± 0.15 mm/yr VLBI NASA solution (courtesy of D. McMillan)
+1.15 ± 0.02 μGal/yr ~ -3.8 mm/yr SG data

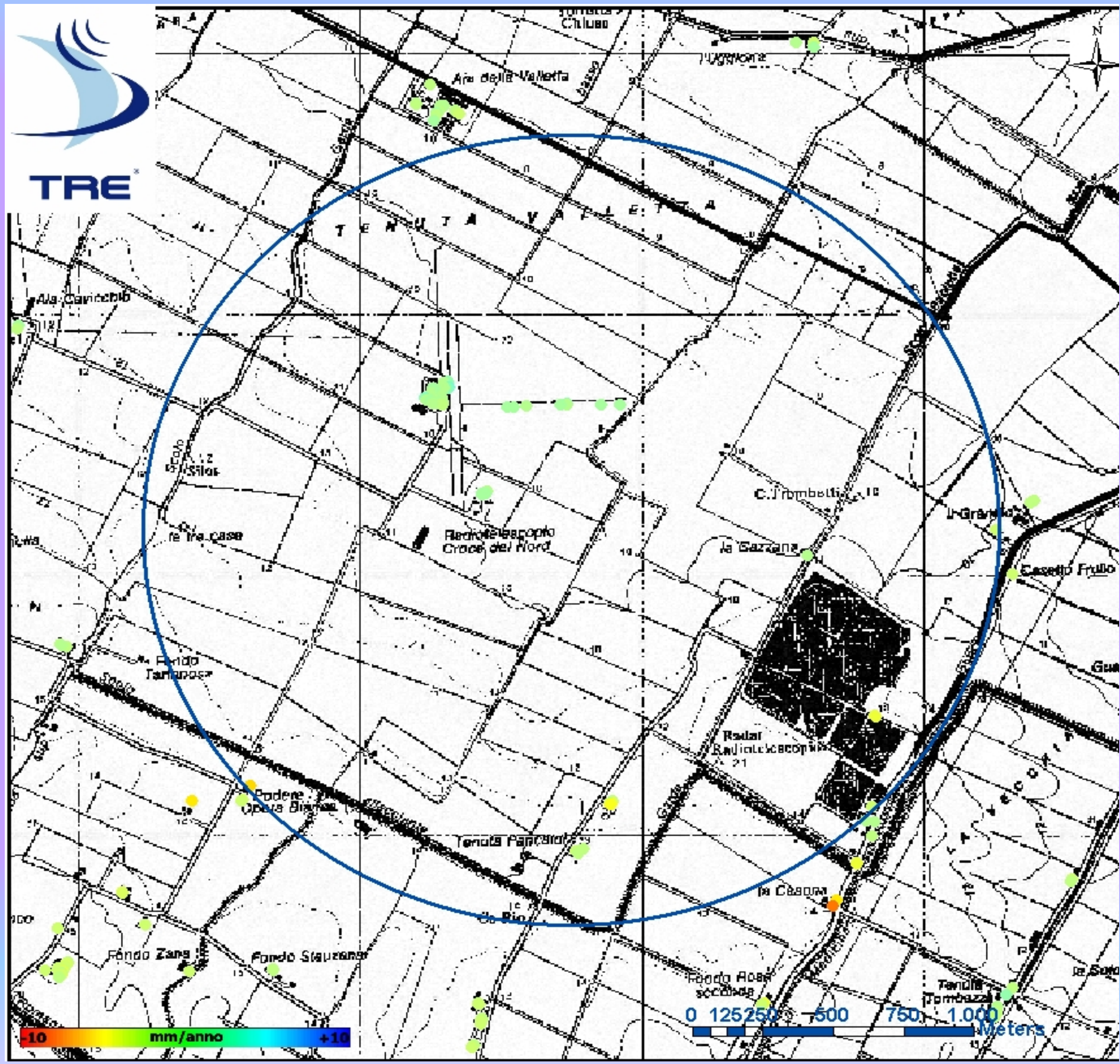
1996-2004

-3.06 ± 0.06 mm/yr CGPS UNIBO
-2.6 ± 0.5 mm/yr CGPS ASI SOPAC solution
-3.29 ± 0.14 mm/yr VLBI NASA solution (courtesy of D. McMillan)
-3.38 ± 0.30 mm/yr VLBI DGFI solution (courtesy of V. Tessmar)
-2.73 ± 0.26 mm/yr VLBI BKG solution

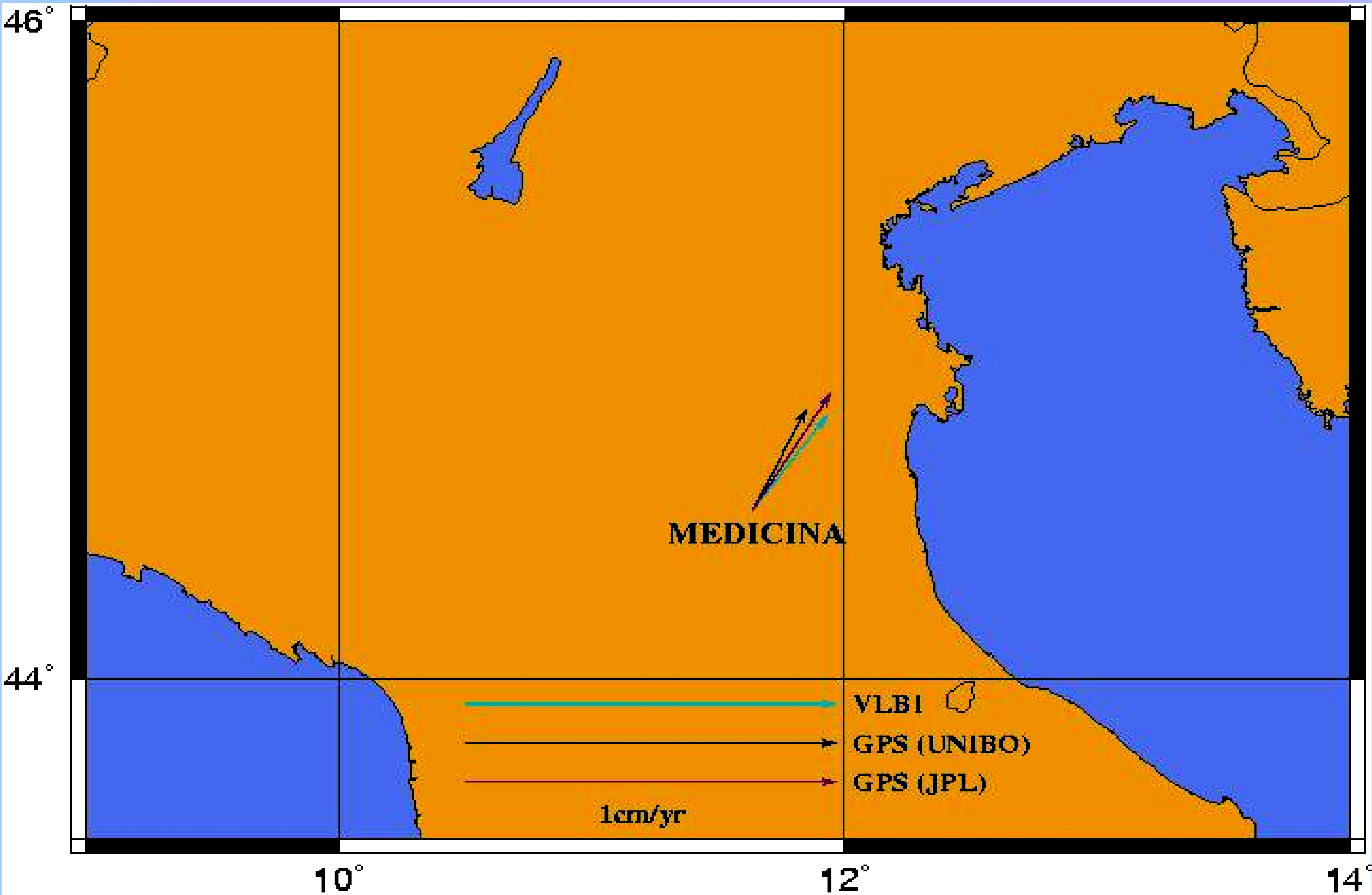
InSAR PS Medicina and Bologna



InSAR PS Medicina station

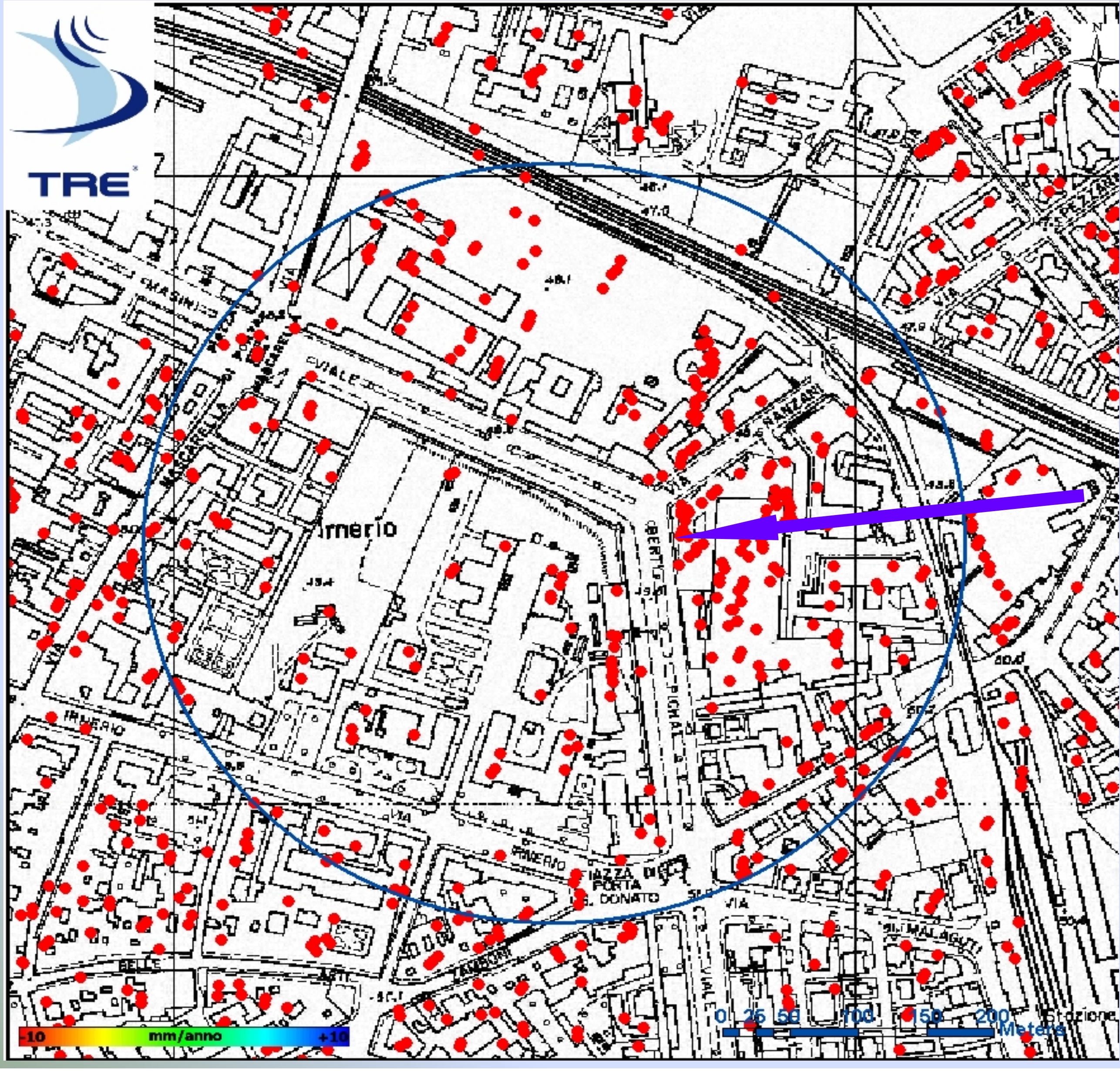


Horizontal motions
Comparison at Medicina



Università di Bologna

Bologna InSAR PS



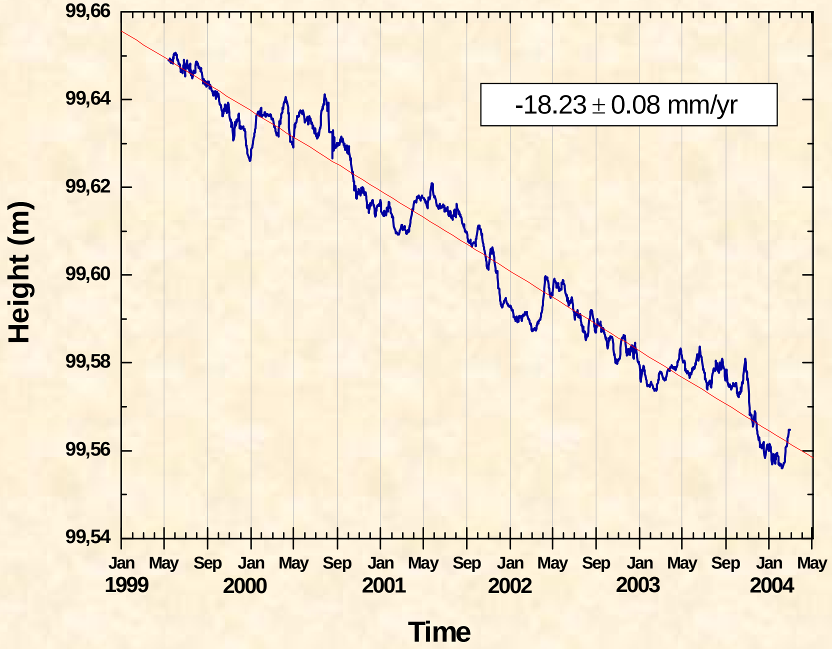
-16,0 mm/yr relative to the reference point in the Medicina area

GPS and Absolute gravity

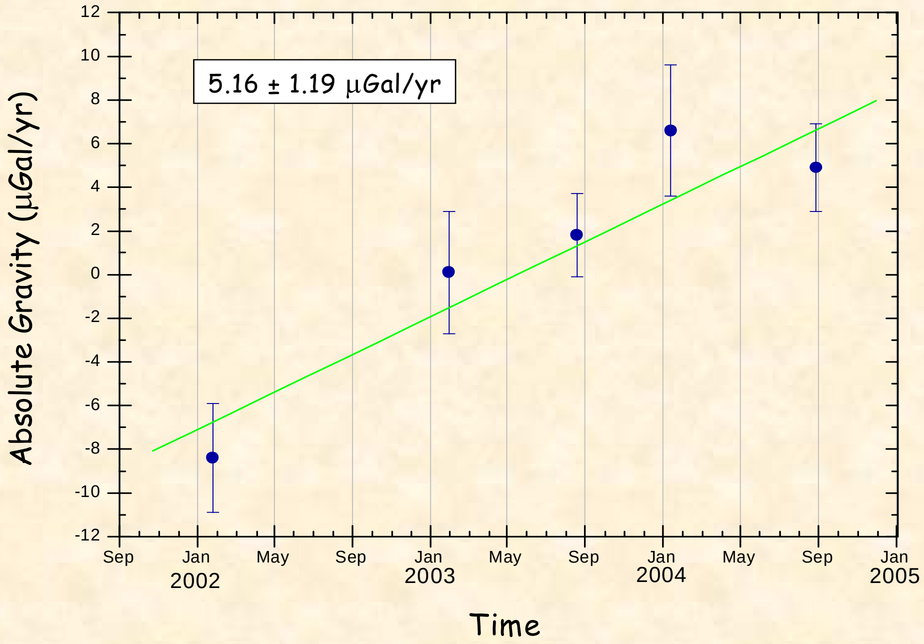
Università di Bologna

Bologna

GPS



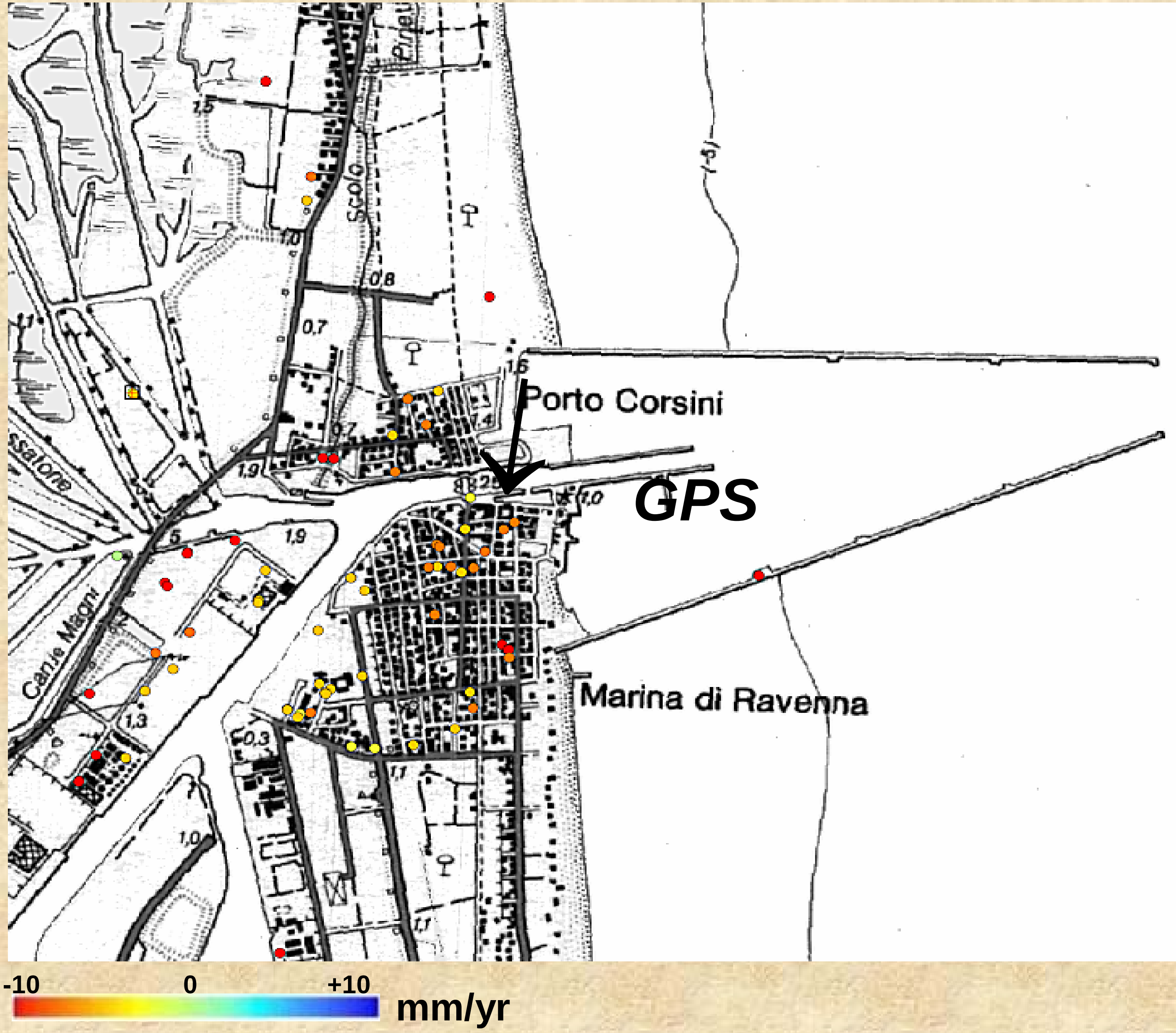
Gravity



~-17 mm/yr

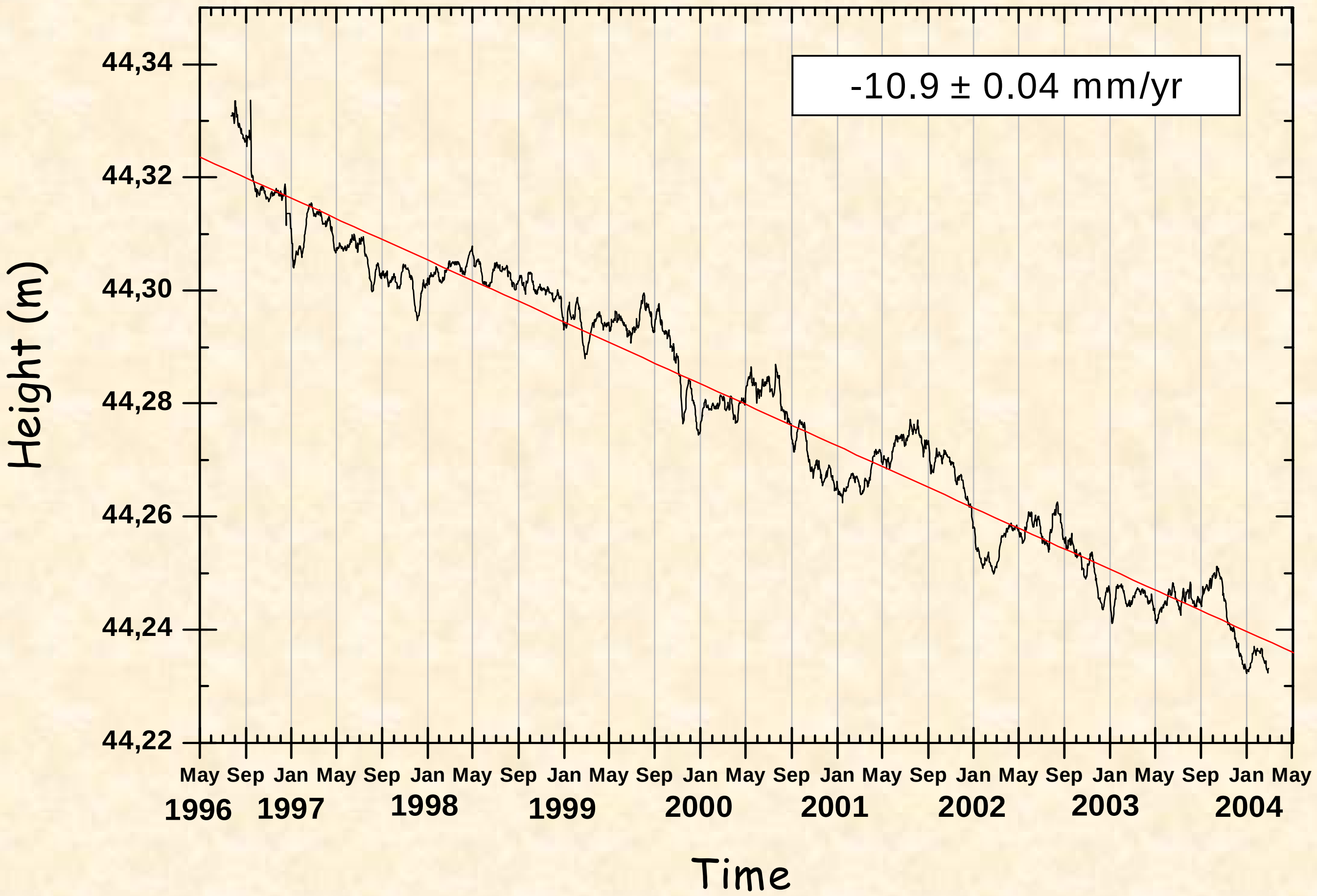
Università di Bologna

InSAR PS Marina di Ravenna



Università di Bologna

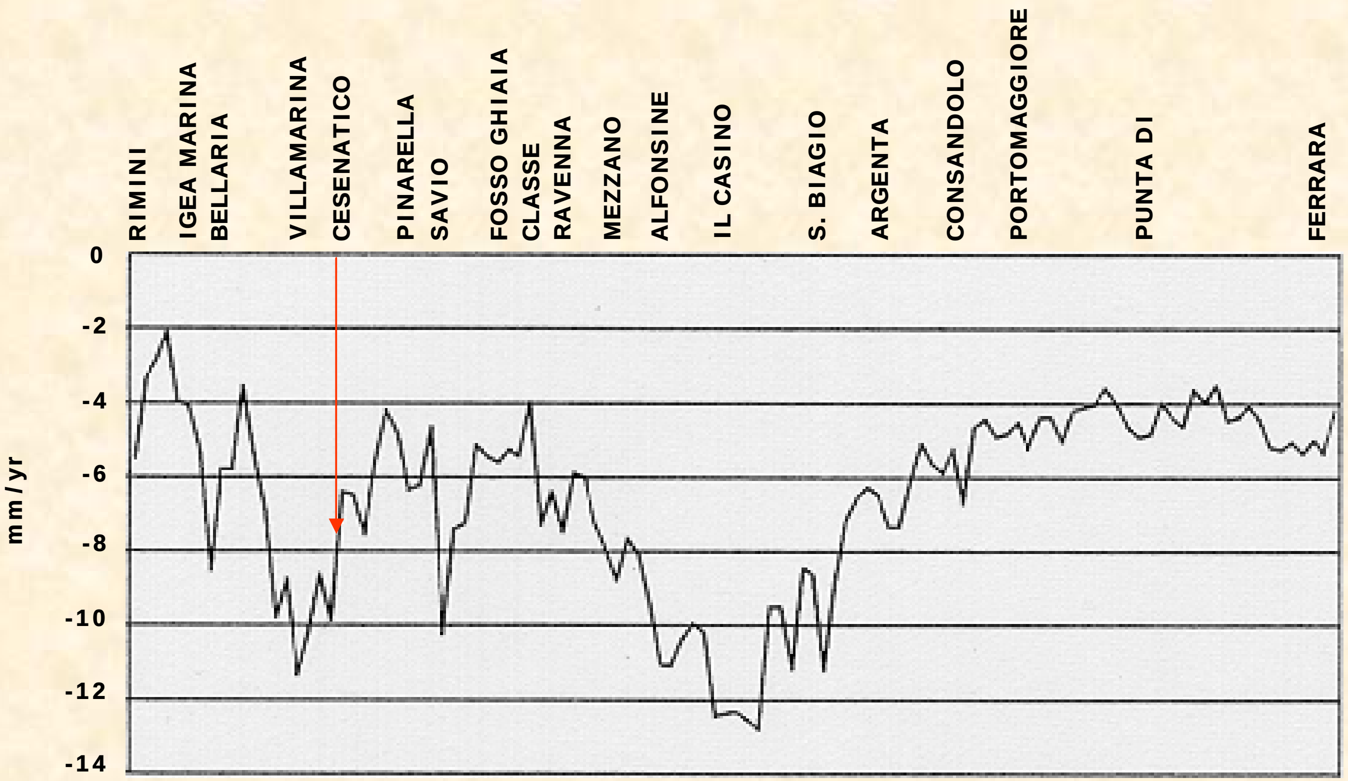
GPS Marina di Ravenna



Università di Bologna

Marina di Ravenna

High-precision leveling 1990-1999



Cesenatico
7-8 mm/yr
subsidence

Subsidence rate from Rimini to Ferrara. From Benedetti et al., Proc. 6th Int. Symposium on Land Subsidence, Ravenna, Sept. 2000.

Università di Bologna

Conclusions

A first comparison of the long-term height variations derived from space and terrestrial techniques yields satisfactory results;

However, there are still differences to be interpreted.

A thorough comparison between GPS and InSAR requires accurate knowledge of the motion of the InSAR reference PS and/or realization of a reliable "geodetic" PS near the GPS antenna;

Conclusions (cont.)

Both the GPS and gravity time series exhibit significant seasonal oscillations of similar amplitude (peak-to-peak 1.5 cm for GPS and about 2 cm for gravity);

They have been modeled.
Improved understanding/modeling of the local hydrology is necessary.

Removal of the seasonal oscillation reduces the sd of the residual series (ex. from 2 to 1 μGal for gravity at Medicina) and changes the estimate of the long-term trend