ANALYSIS OF A GRAVITY RECORD COLLECTED IN THE ACTIVE CALDERA OF CAMPI FLEGREI: A SEARCH FOR VOLCANIC SIGNALS

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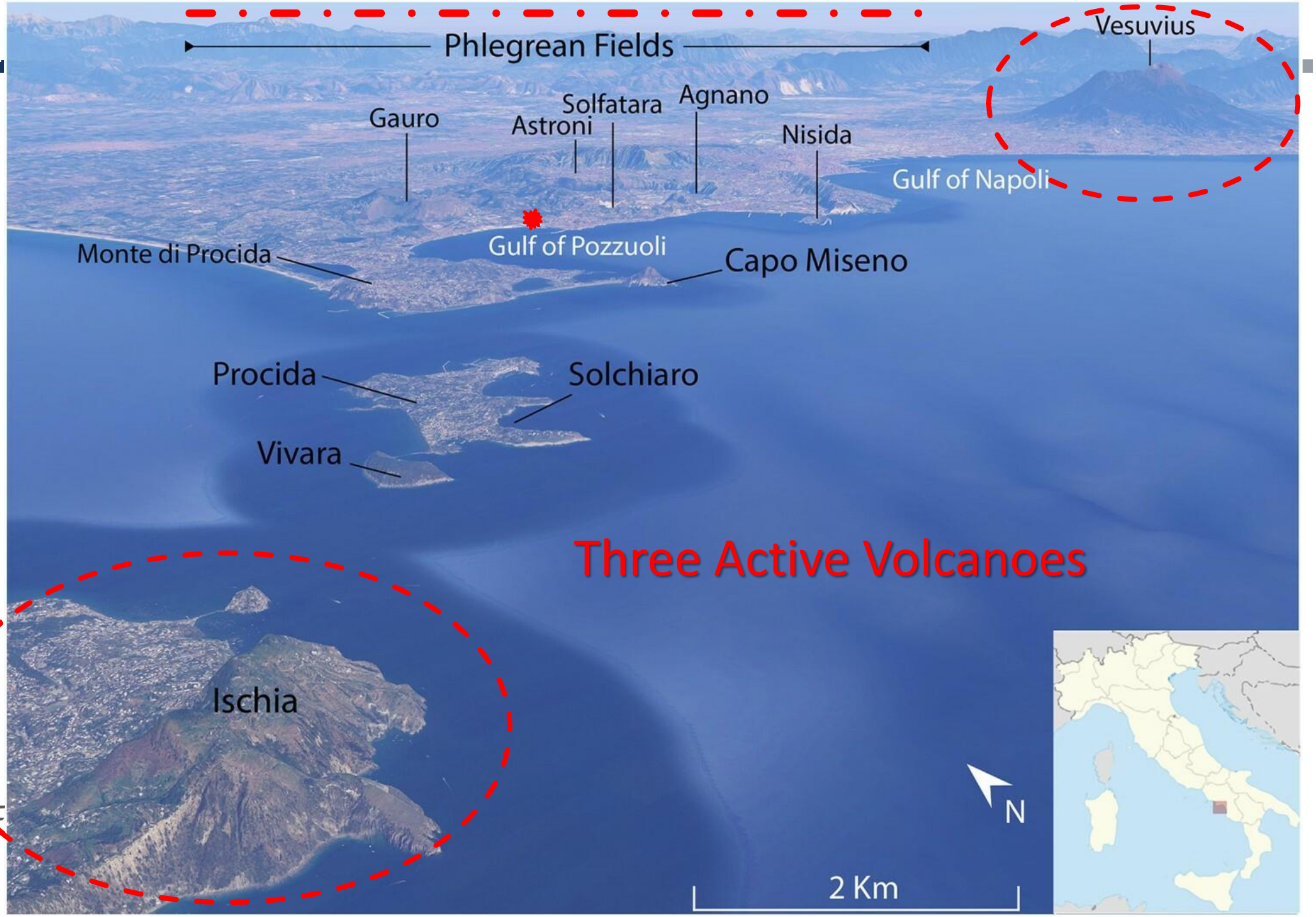

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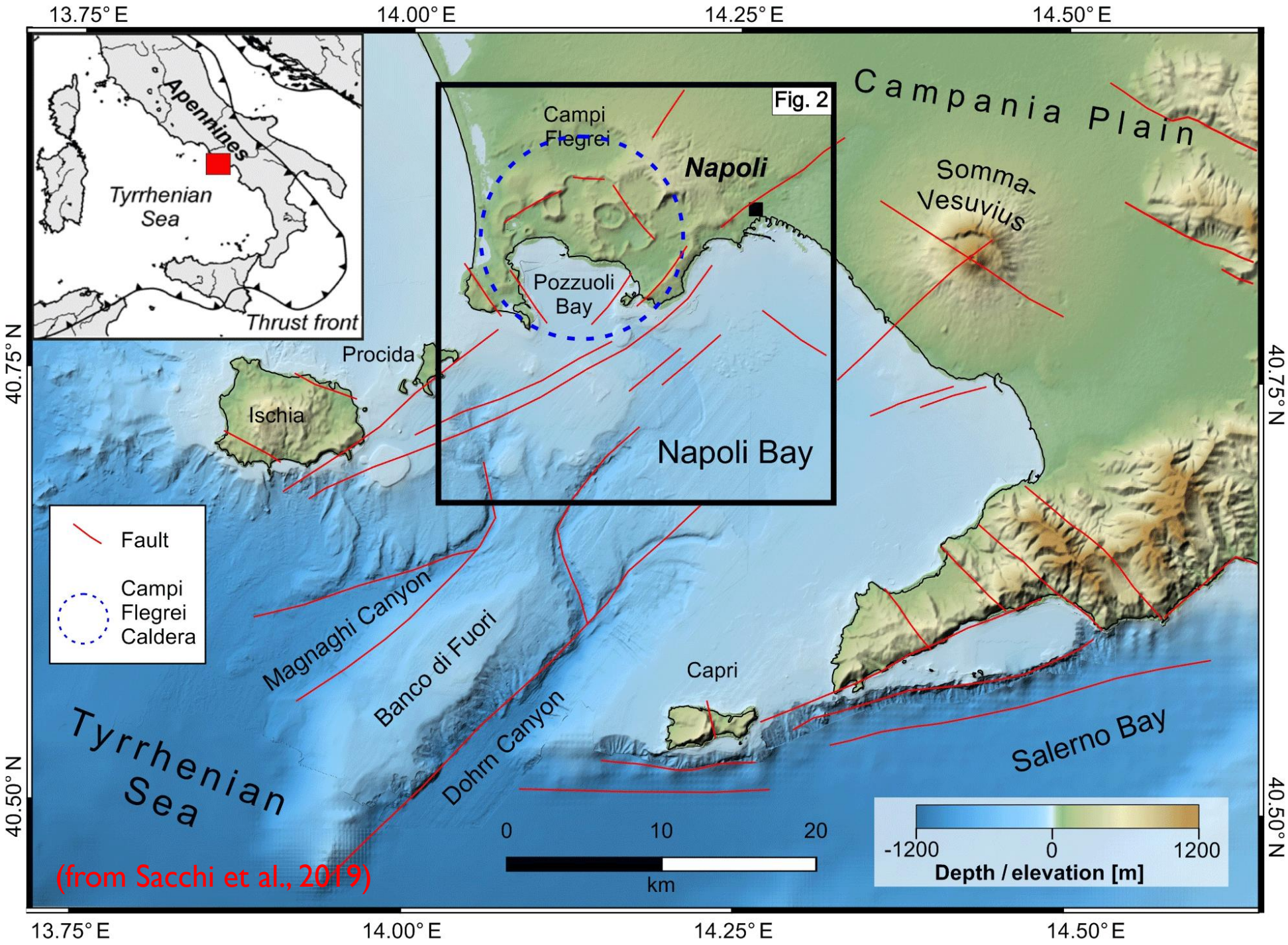
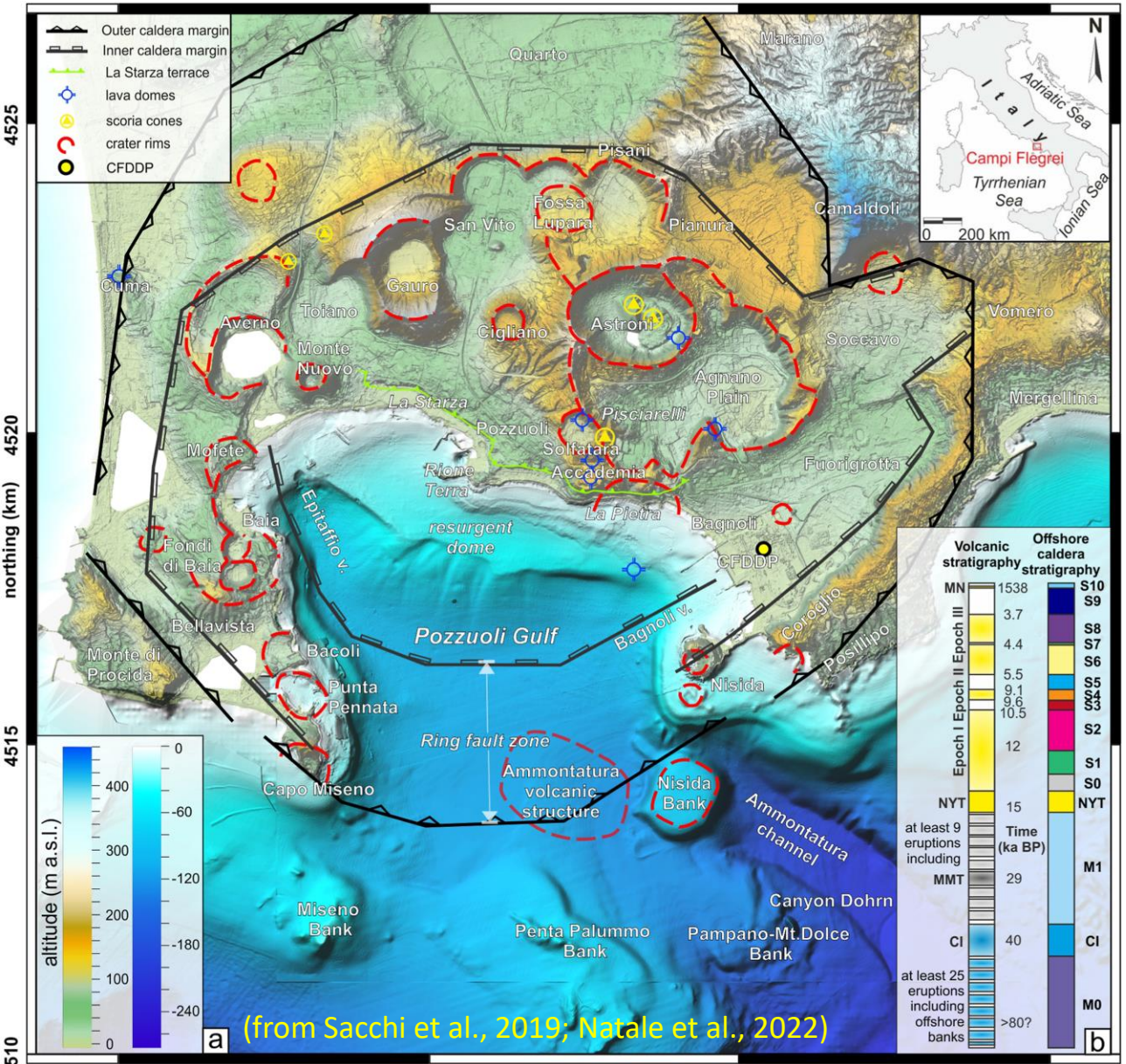
Tectonic sketch Campanian continental margin

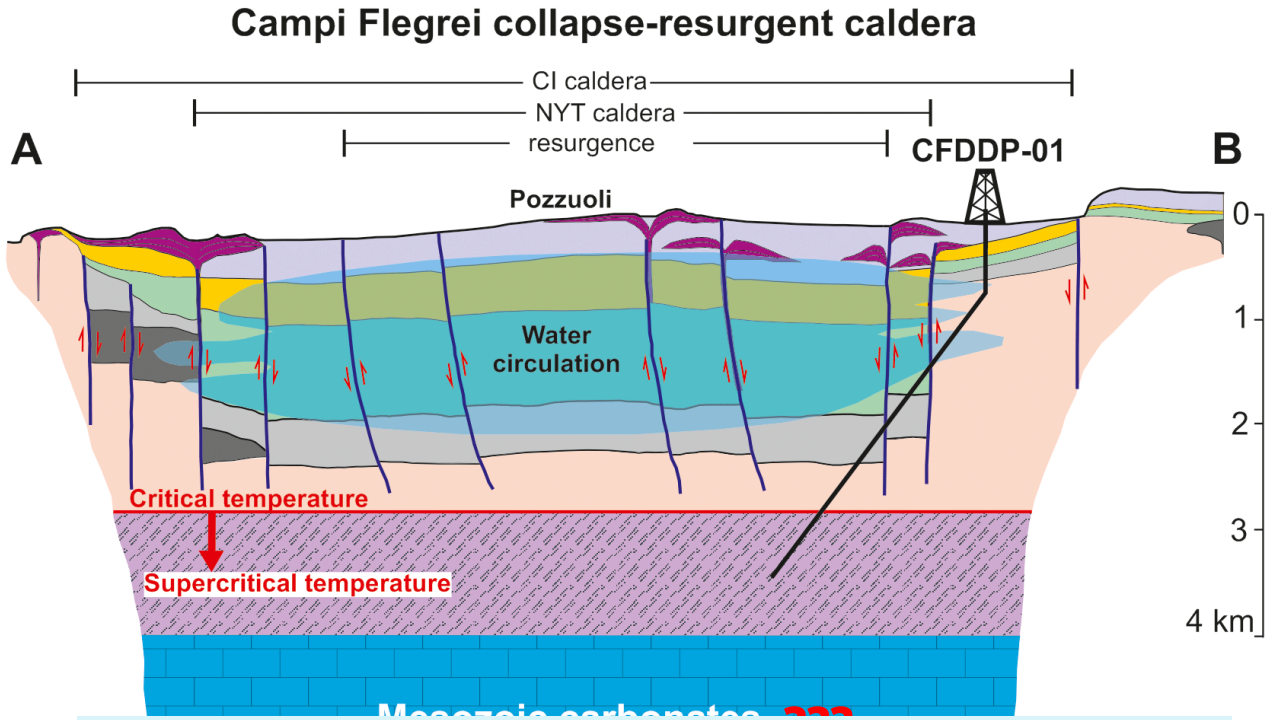


Campi Flegrei: a “nested” caldera

Ring-fault–resurgent-dome system caldera



(from Sacchi et al., 2019; Natale et al., 2022)



Magma or Geotherma fluids or both?

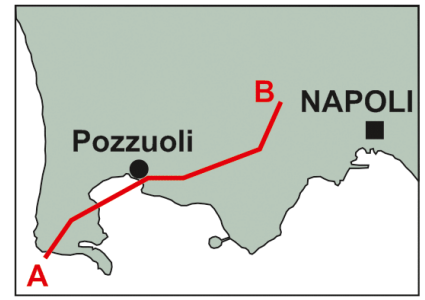
Volcaniclastic and marine siliciclastic deposits (<15 ka)

Neapolitan Yellow Tuff (NYT) (15 ka)

Volcaniclastic and marine siliciclastic deposits (39-15 ka)

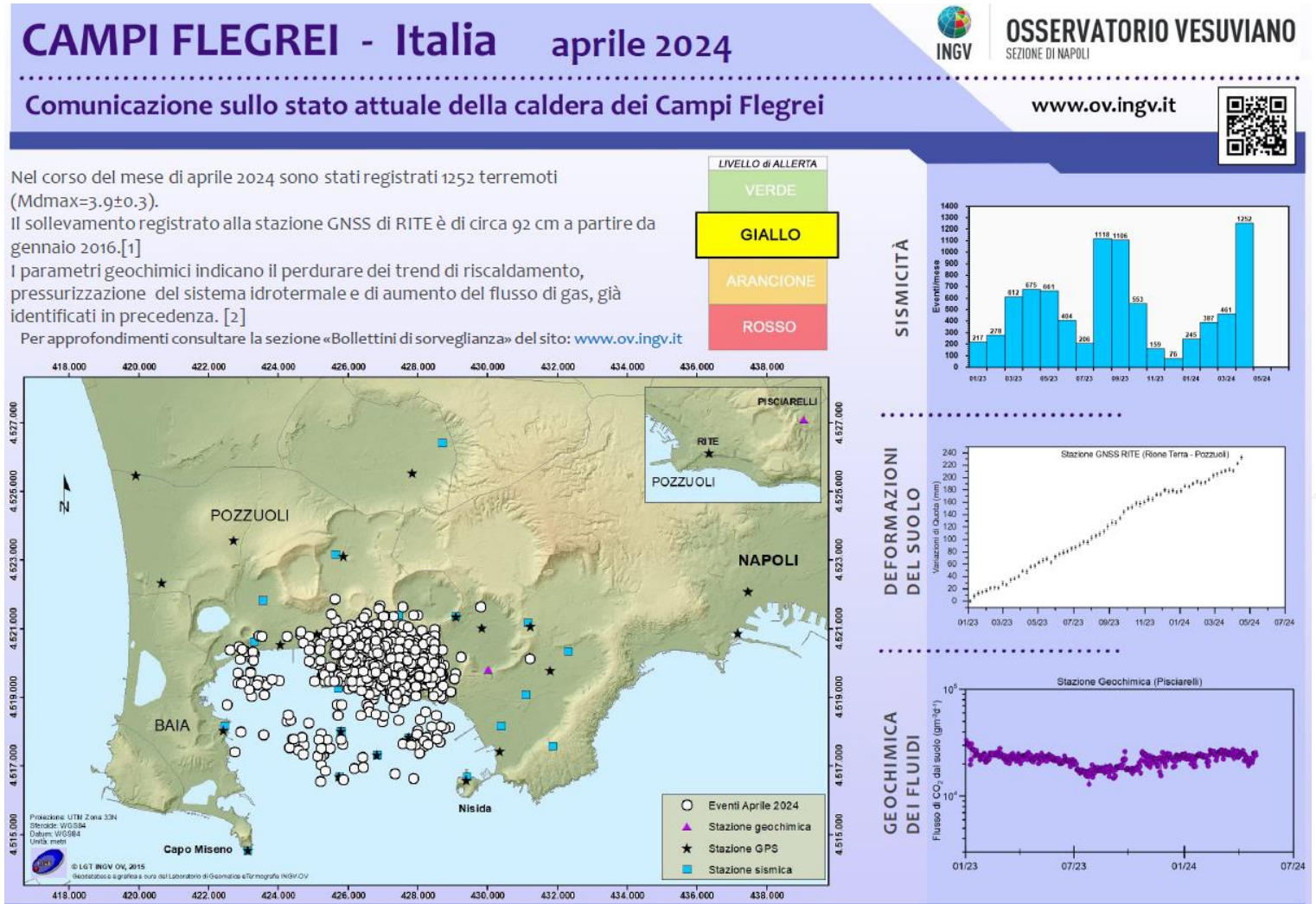
Campania Ignimbrite (CI) (39 ka)

a b Volcanic rocks (>39 ka); a: pyroclastics; b: lavas



(From Sacchi et al., 2019)

PRESENT-DAY DYNAMICS & MONITORING



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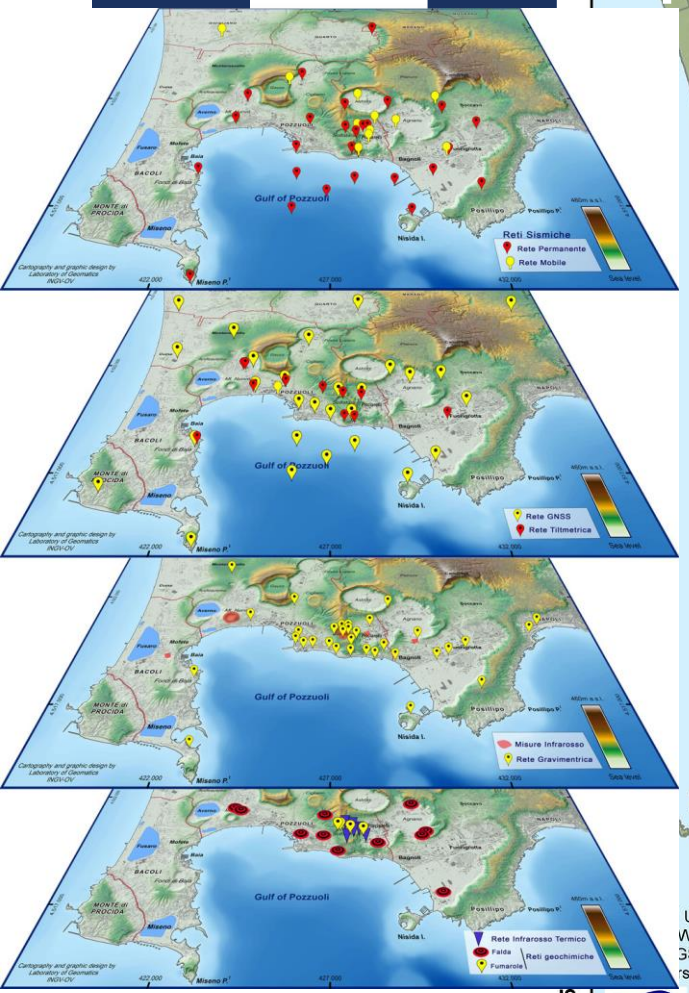
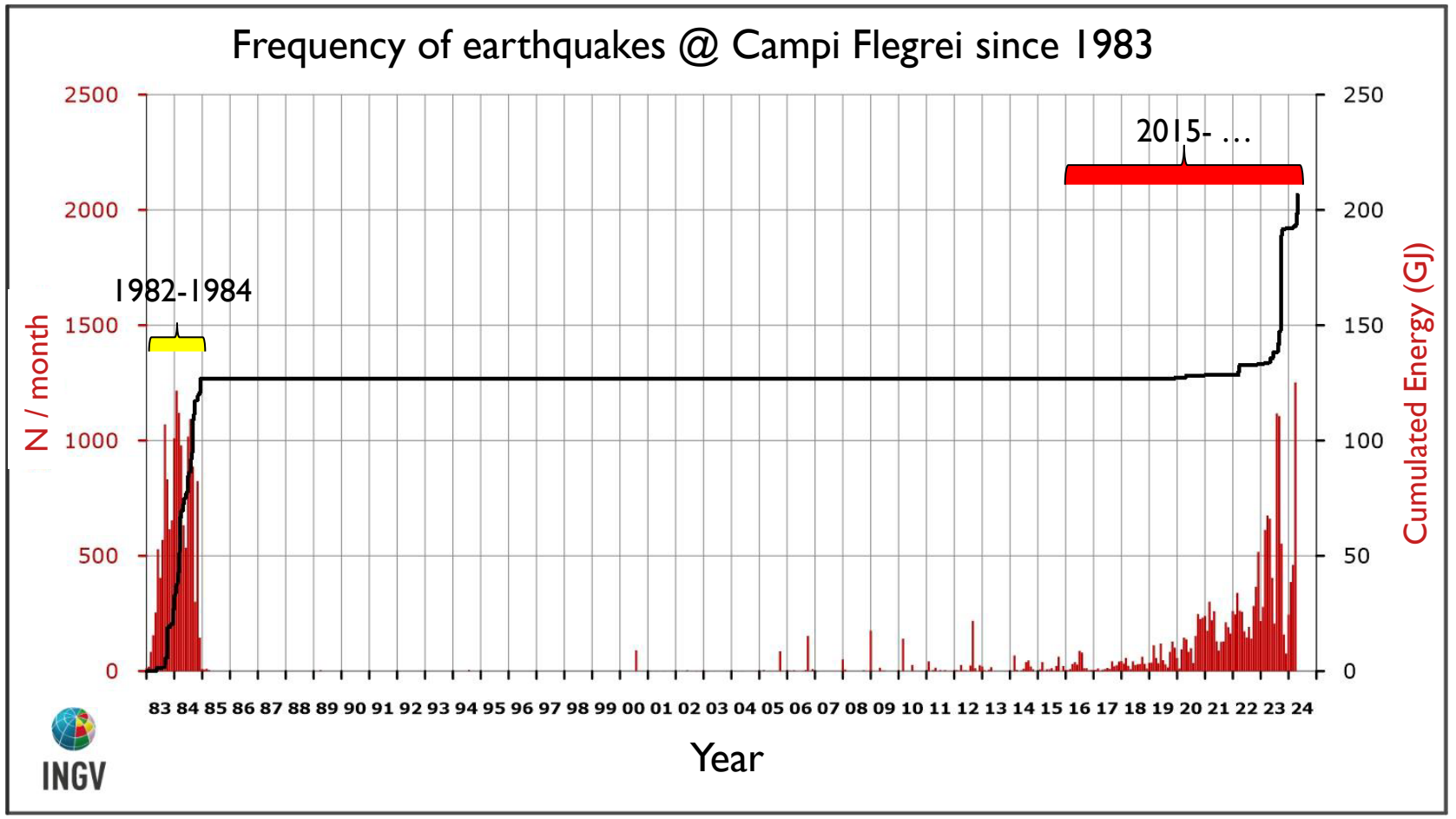
INGV

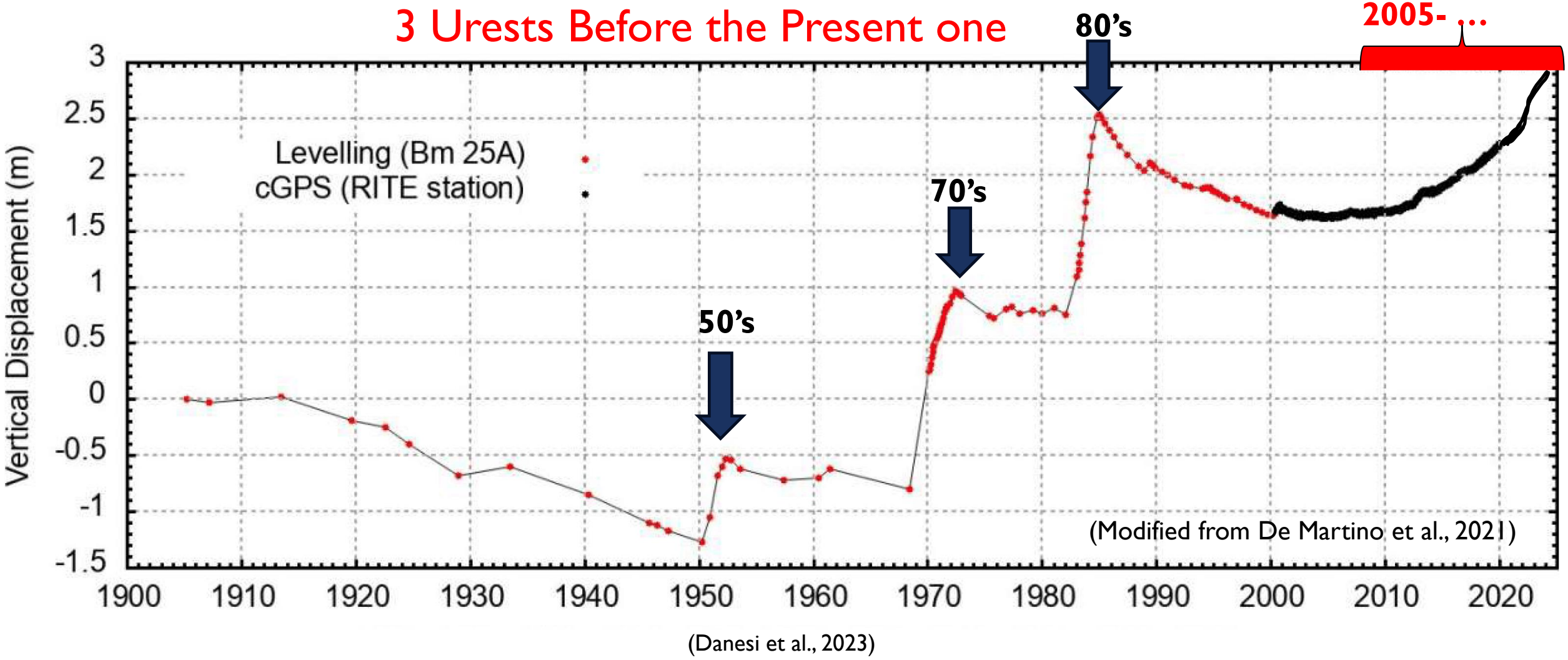
MULTI-PARAMETRIC MONITORING NETWORK



The 2 Last Unrests 1982—1984; 2005-Present-days



GROUND DEFORMATION (VERTICAL COMP.)
«BRADYSEISM»



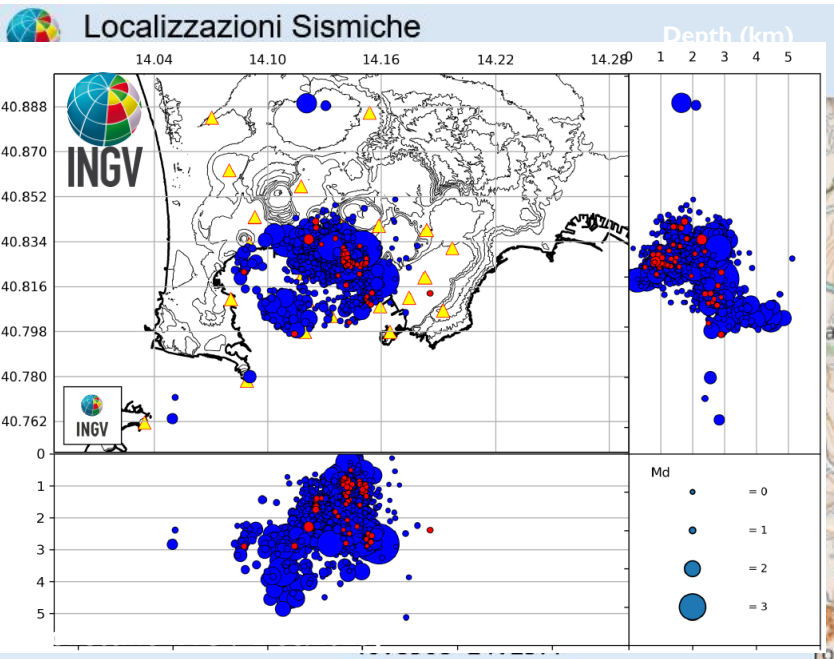
(Danesi et al., 2023)

Campi Flegrei 2023-2024 (Last 16 month)

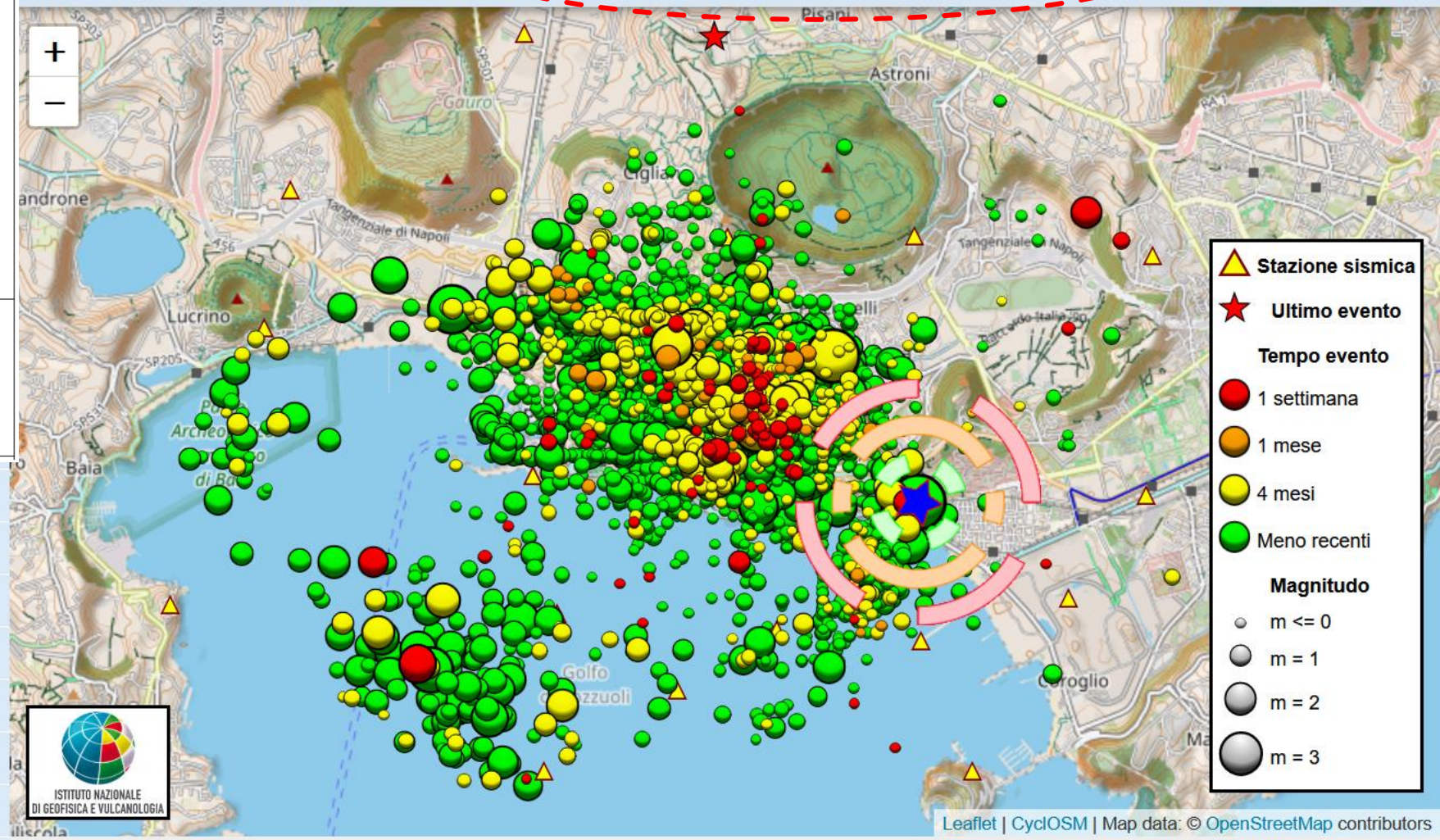
Gravity record

N° Eventi 5741

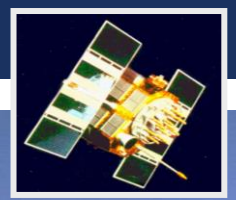
Max Magnitude : 4.4 (20/05/2024)

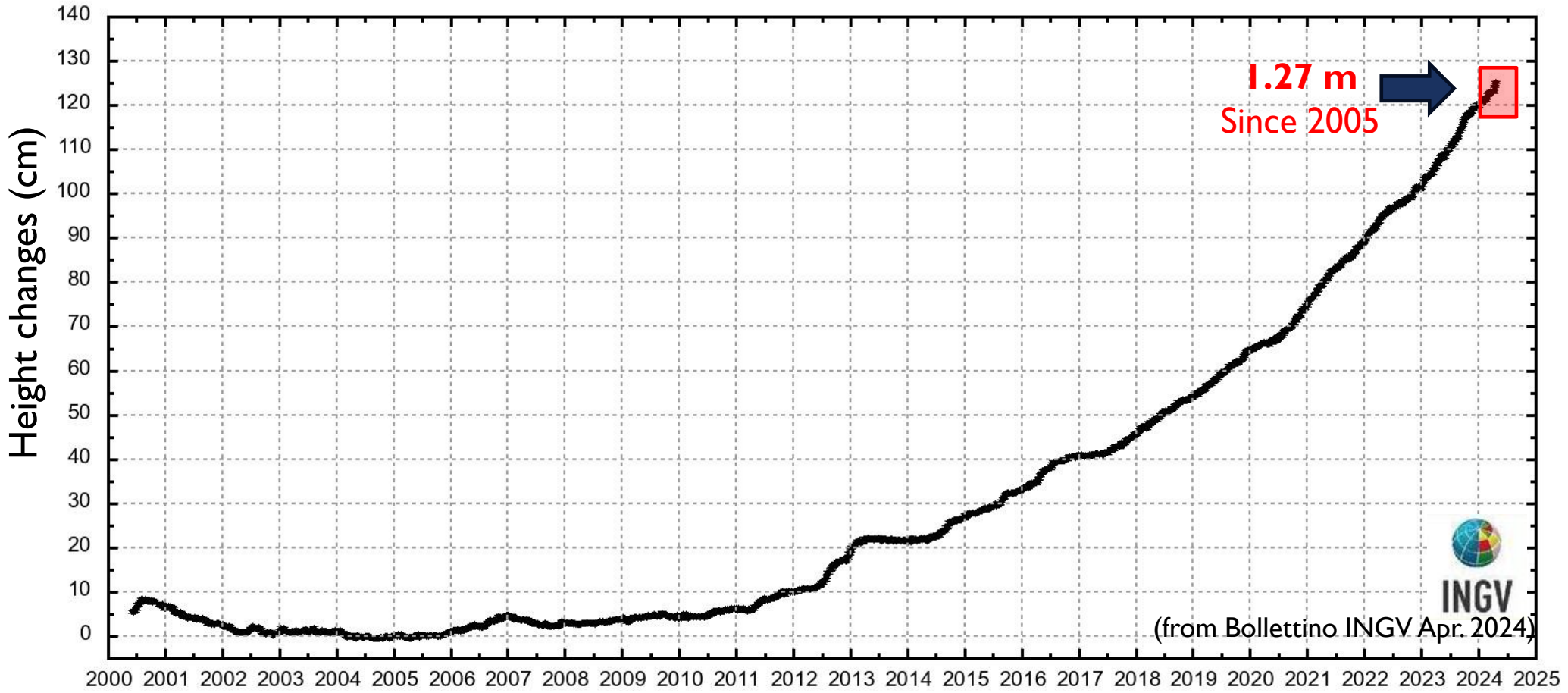


m_d 1.4 ± 0.3	2023/09/26 22:30:21 40.8182 14.1553	2.8
m_d 0.6 ± 0.3	2023/09/26 21:46:27 40.8400 14.1380	1.2
m_d 2.1 ± 0.3	2023/09/26 21:36:38 40.8185 14.1560	2.7
m_d 0.7 ± 0.3	2023/09/26 20:53:13 40.8337 14.1297	1.8
m_d 1.8 ± 0.3	2023/09/26 20:49:15 40.8197 14.1448	0.3
m_d 1.1 ± 0.3	2023/09/26 20:07:30 40.8203 14.1472	0.6
m_d 0.6 ± 0.3	2023/09/26 19:37:05 40.8175 14.1548	2.8



GROUND DEFORMATION (VERTICAL COMP.)
«BRADYSEISM»

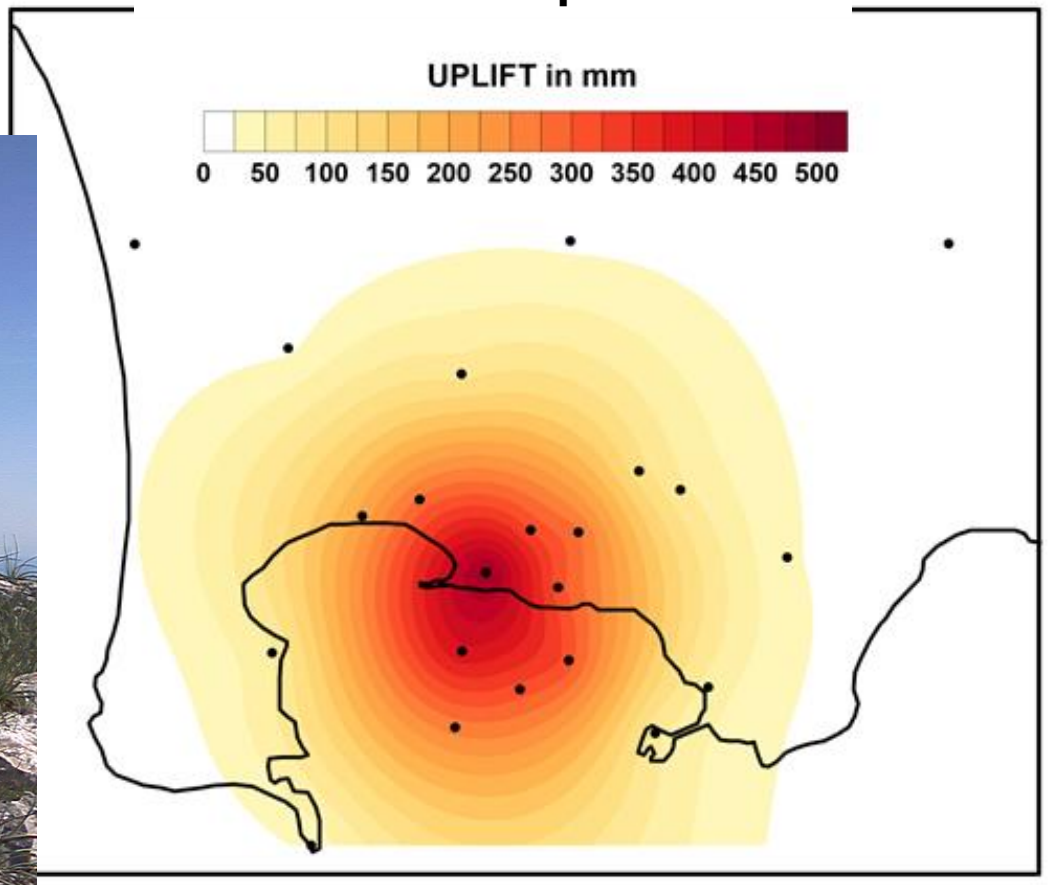




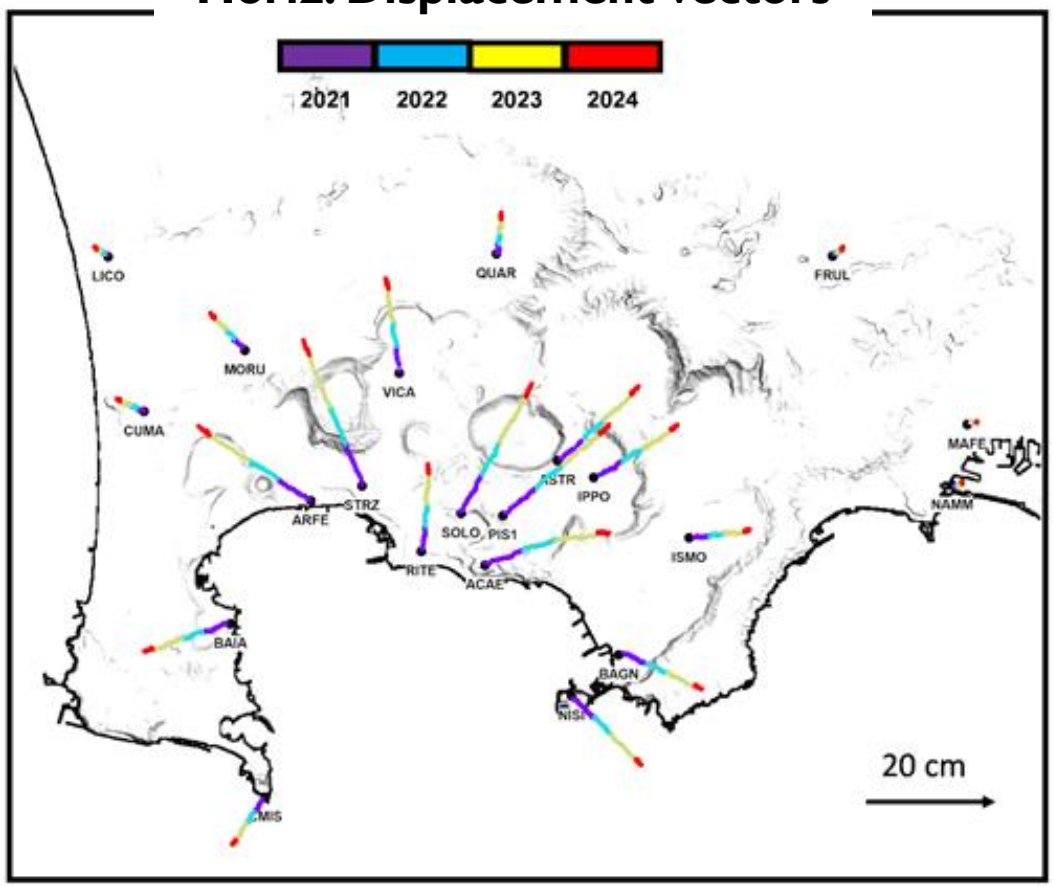
Ground deformation Jan. 2021-Apr. 2024

INGV

Vertical component



Horiz. Displacement vectors

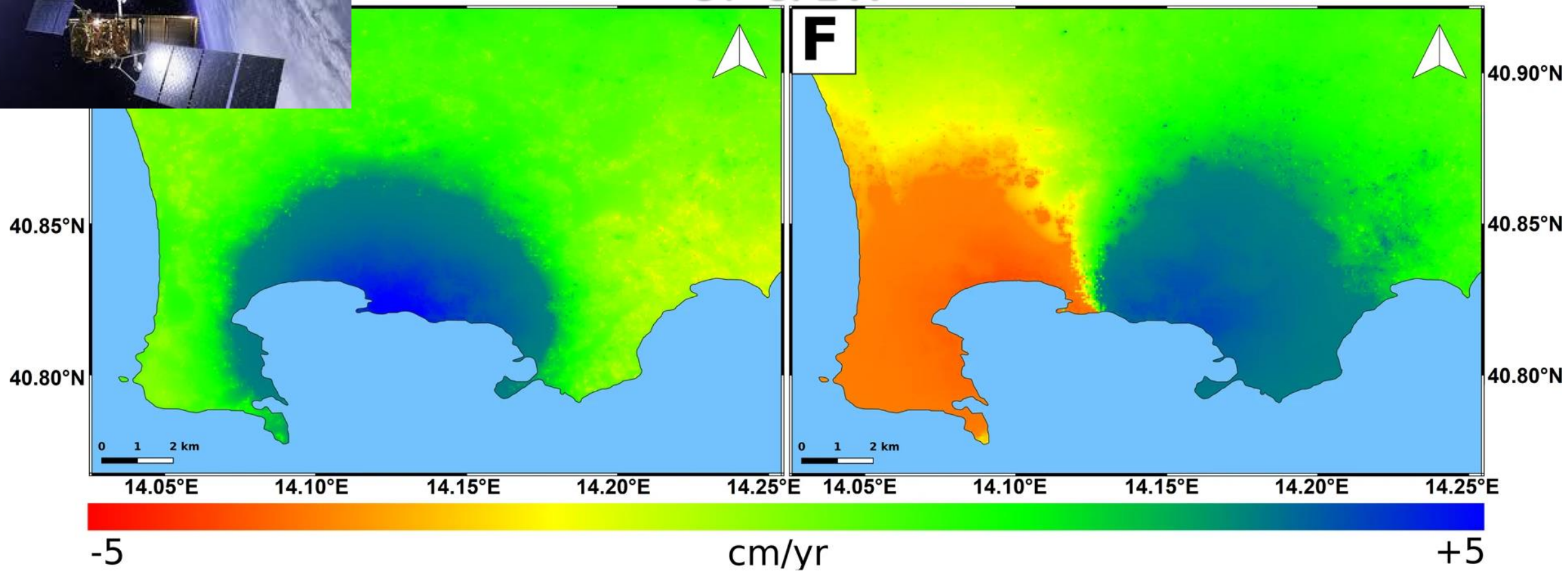


(from Bollettino INGV Apr. 2024)

Radial shape of the deformation field with its characteristic "*bell*" shape

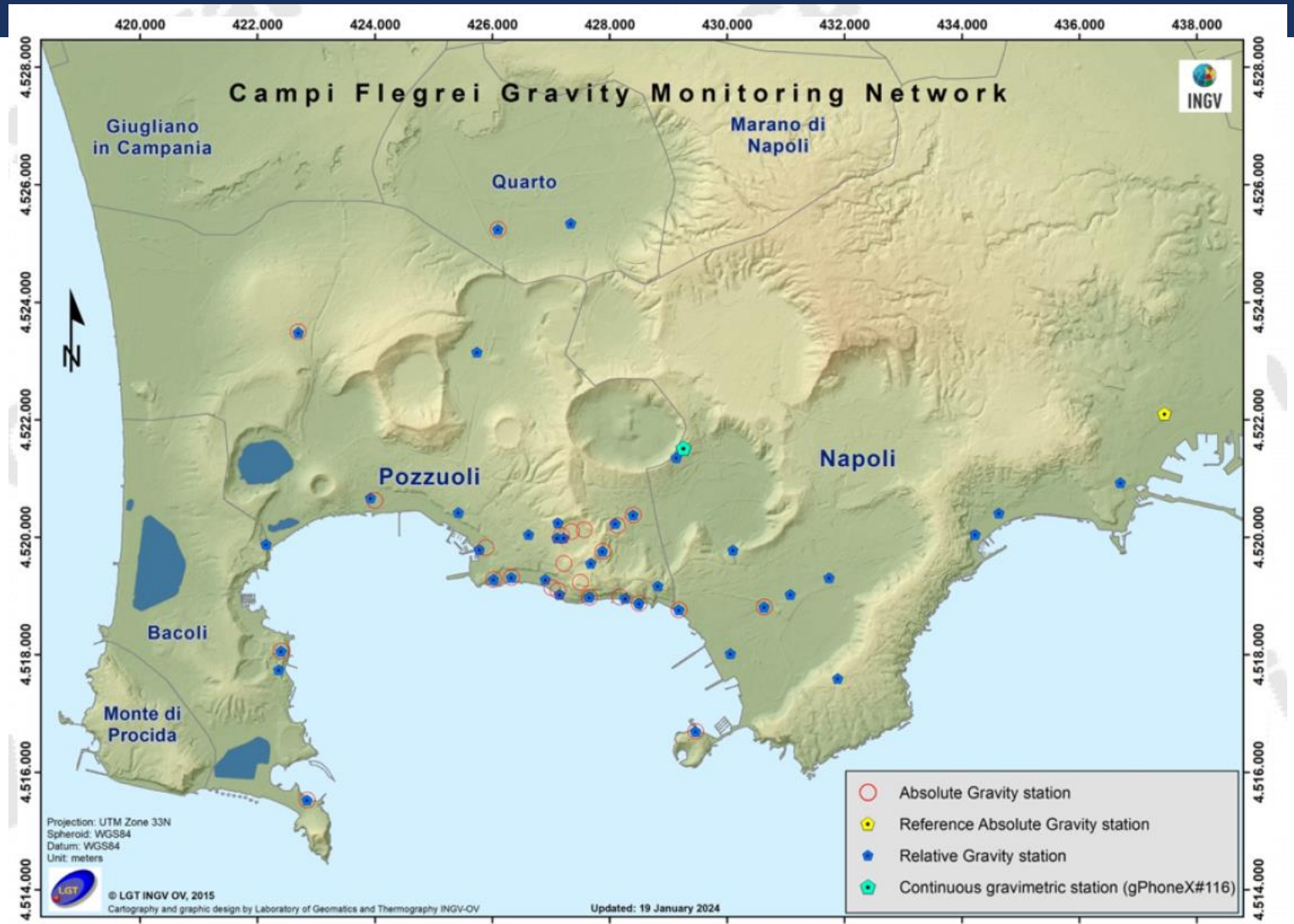
InSAR: Deformation rate (2011-2021)

UP & EW

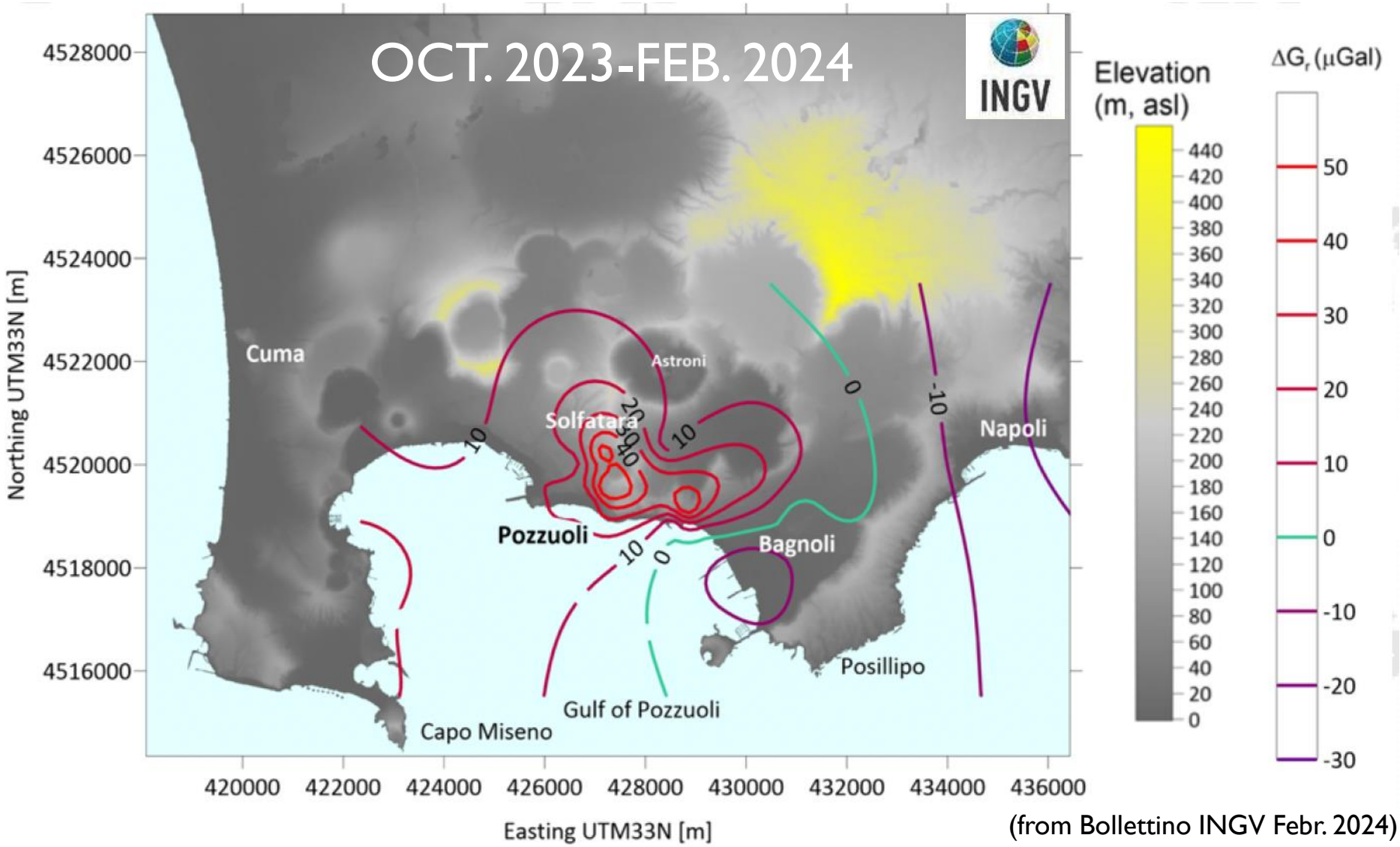


(Polcari et al., 2022)

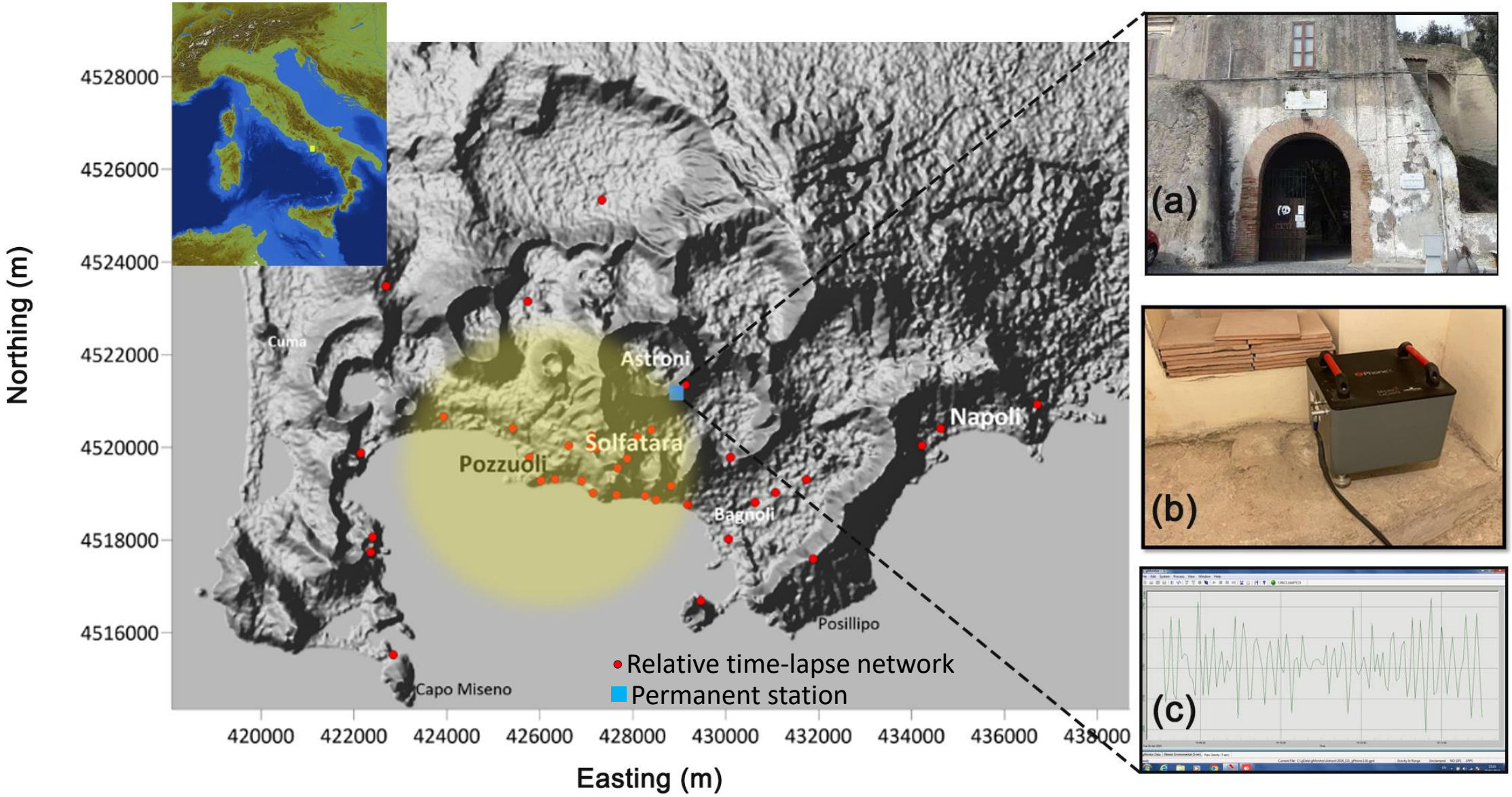
TIME-LAPSE RELATIVE GRAVITY MONITORING



Δg_{res}«RESIDUAL GRAVITY»

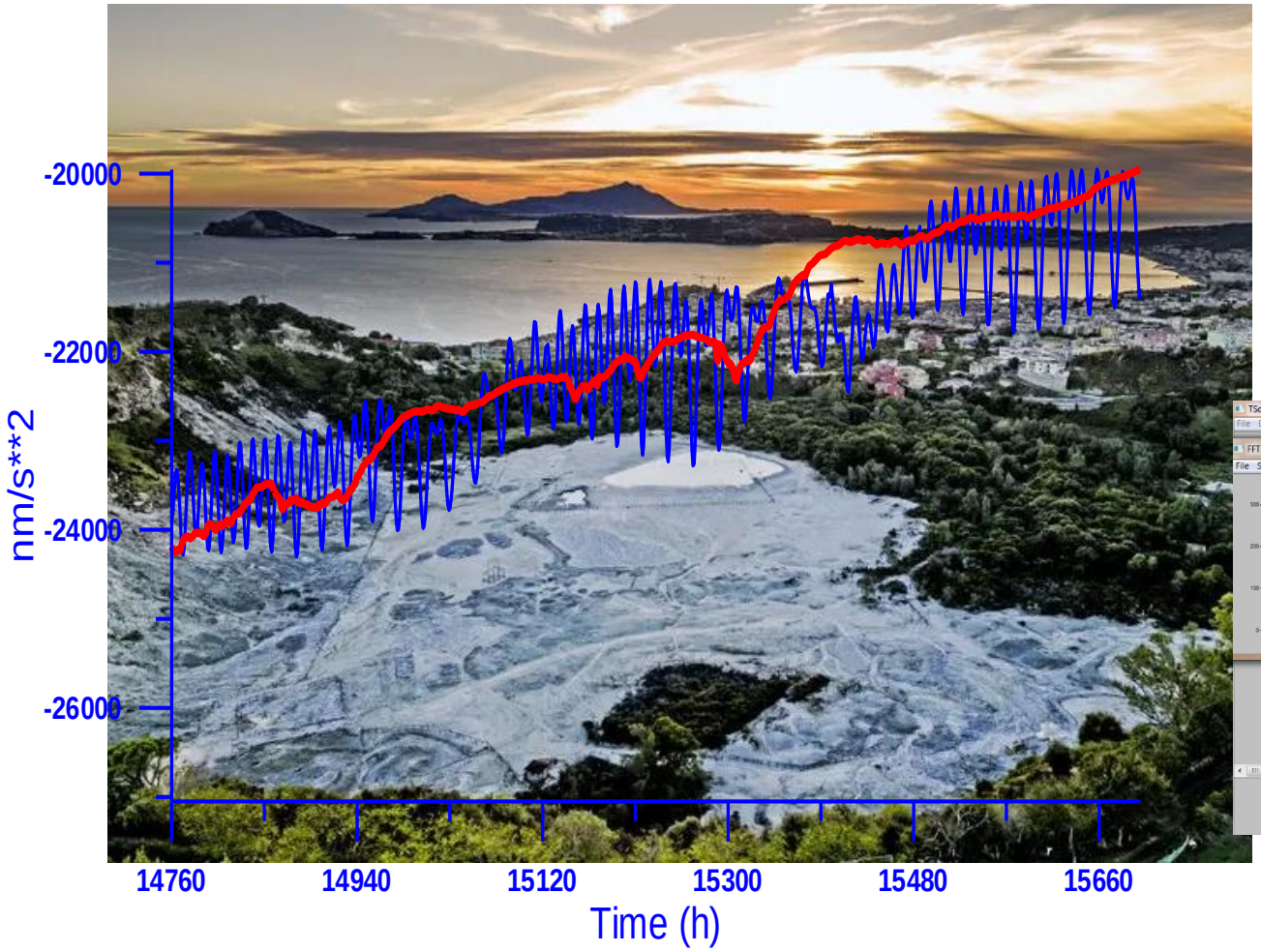


(from Bollettino INGV Febr. 2024)



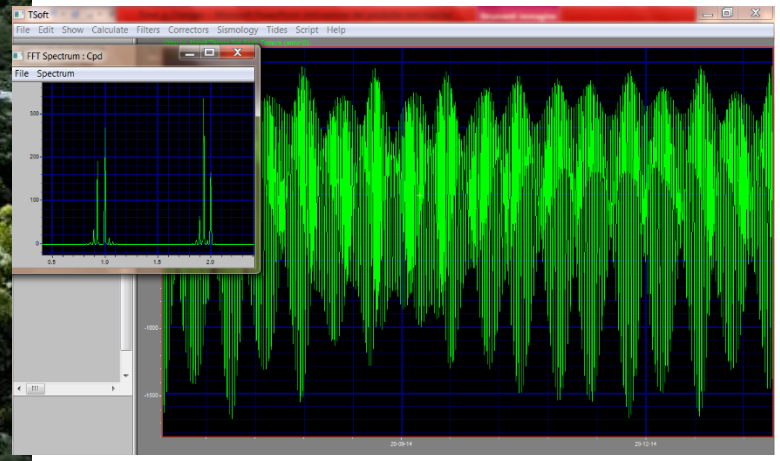
ASTRONI PERMANENT GRAVITY STATION

Principles of Analysis of a gravity record



«Decimation»

MATLAB ⟷ TSoft



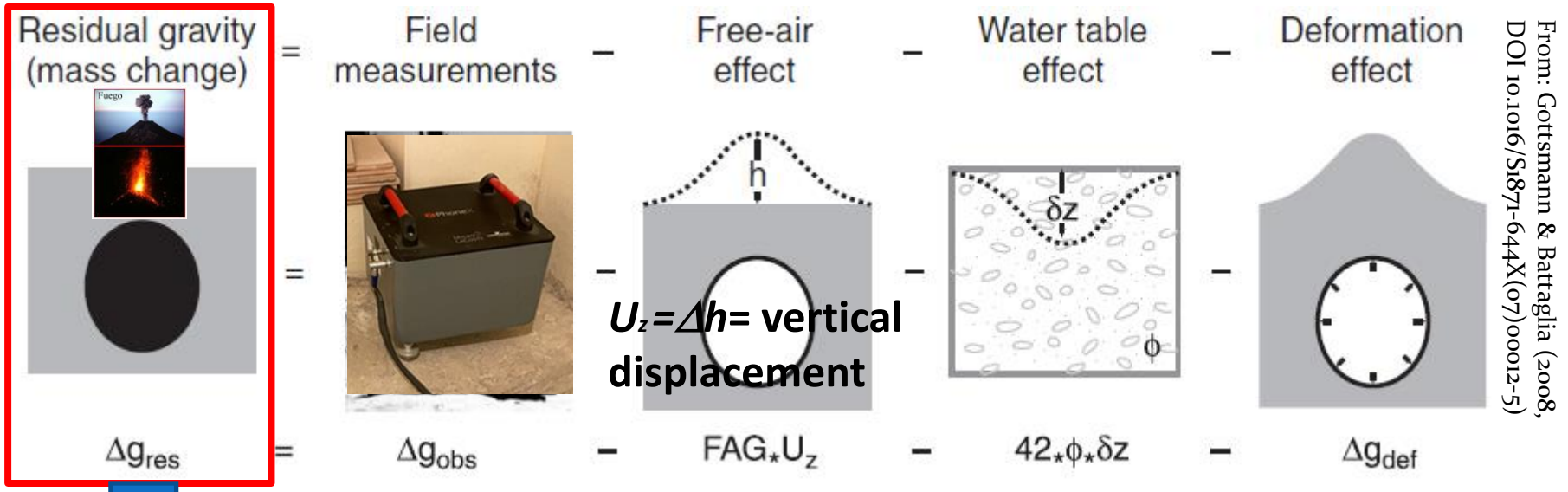
Conceptualization: Volcano g Monitoring

Extracting the gravity signal (Δg_{res}) induced by a subsurface mass and/or density change…

Observed gravity changes → Underground mass redistribution

$$\Delta g_{res} = \Delta g_{obs} - FAG_{obs} * U_z - \Delta g_{wt} - \Delta g_{def}$$

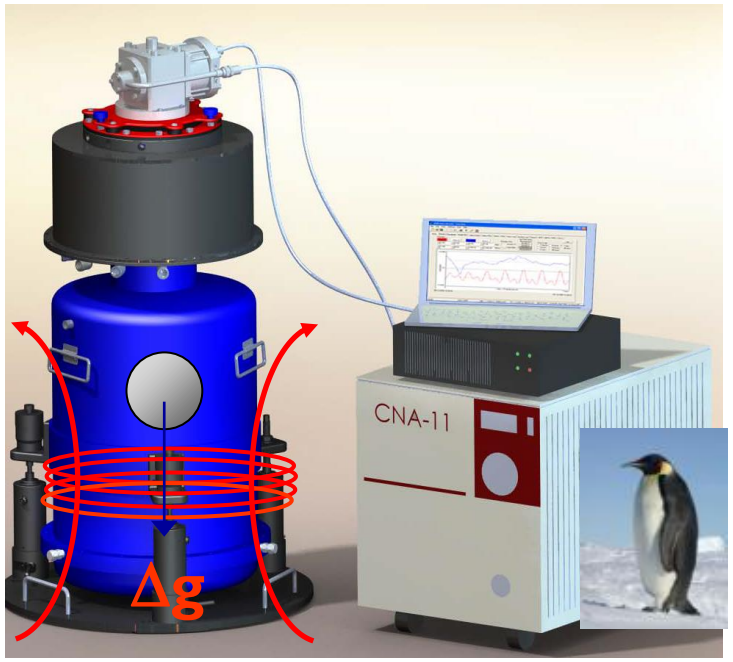
«Residualization»



From: Gottsmann & Battaglia (2008, DOI 10.1016/S1871-644X(07)00012-5)

$U_z = \Delta h$= vertical displacement

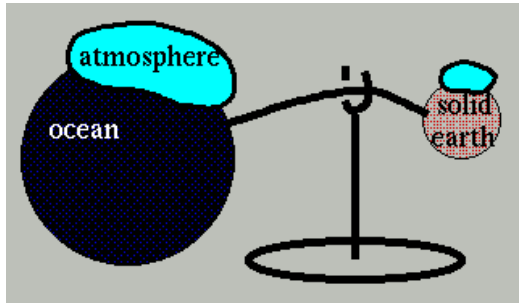
What is recorded when a gravimeter is in a continuous-mode configuration?



TIME GRAVITY CHANGES "Recordable"

1) «Exogenous» Sources:

G. Interactions Earth-Celestial Bodies (tides):

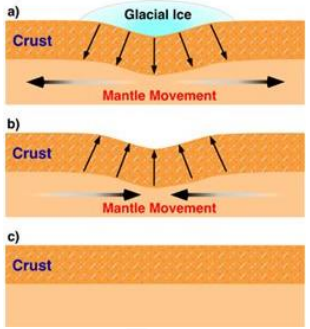


Atmosphere;

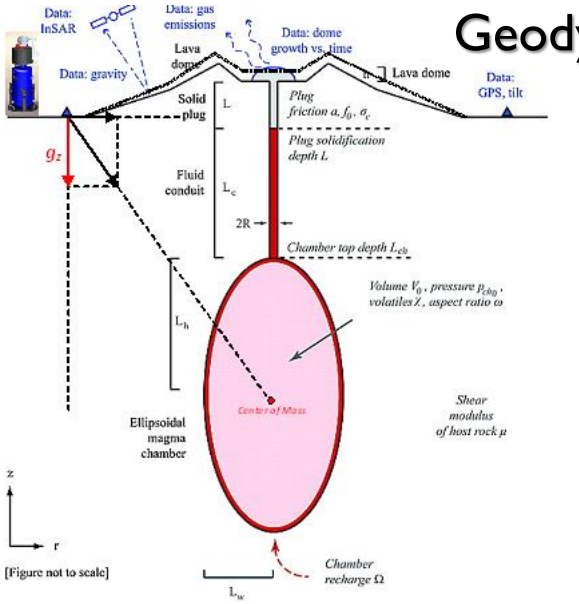
Oceans;

"Post-Glacial Rebound";

Variable EOP [1, 2].



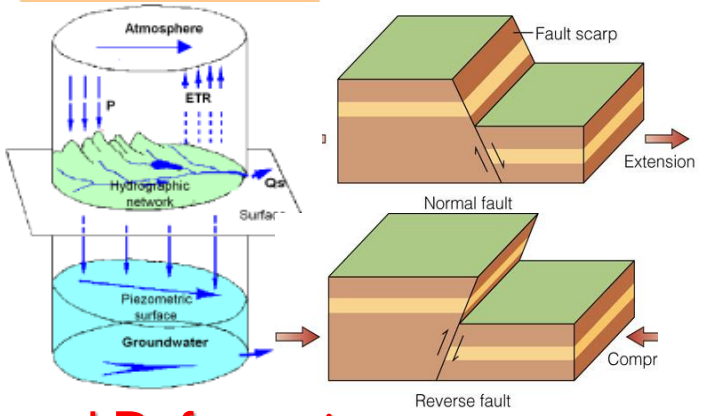
2) «Endogenous» Sources:



Geodynamics;

Hydrology;

Coseismic effects;

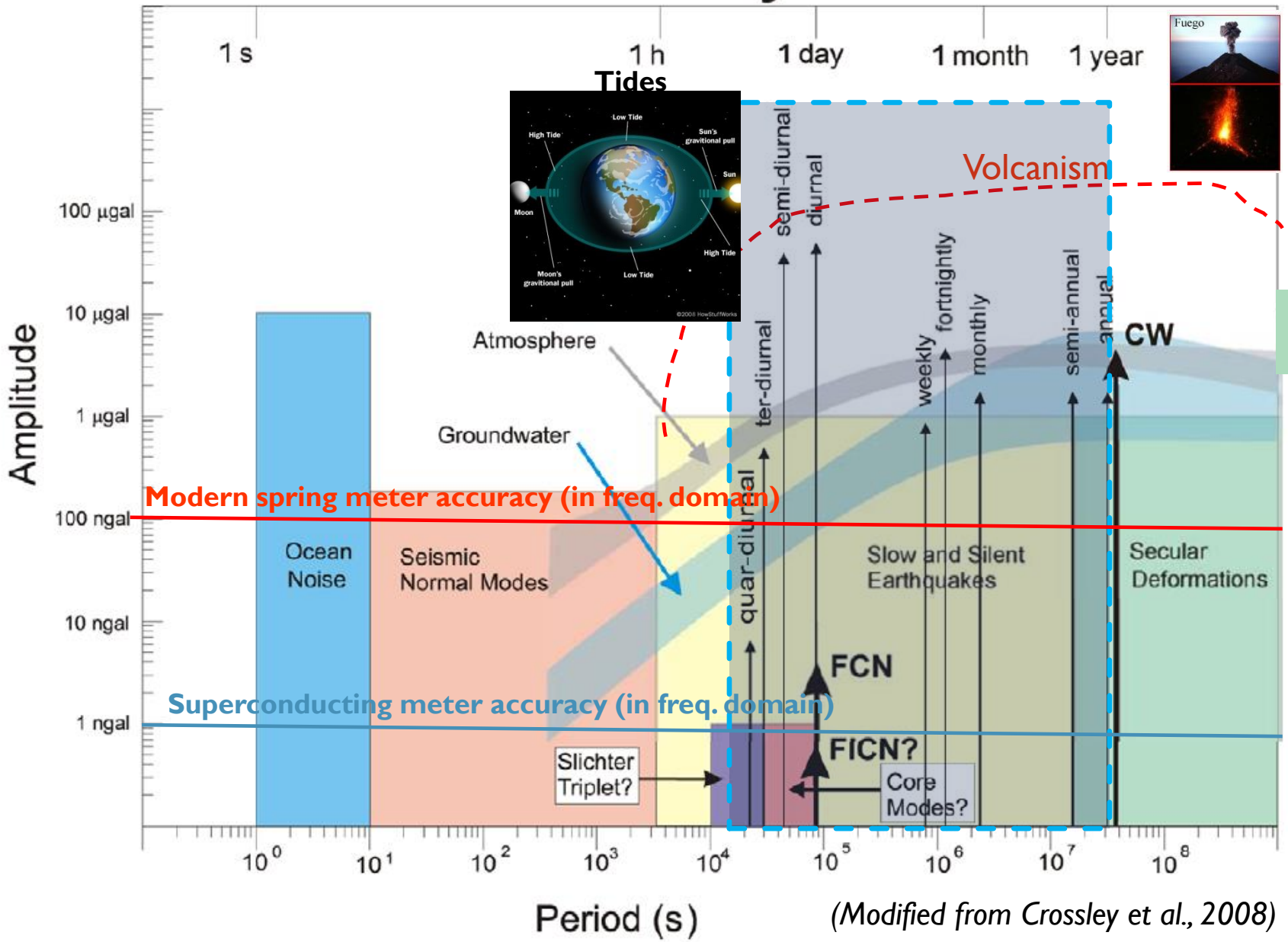


Volcanism: Ground Deformation;

Magma migration;

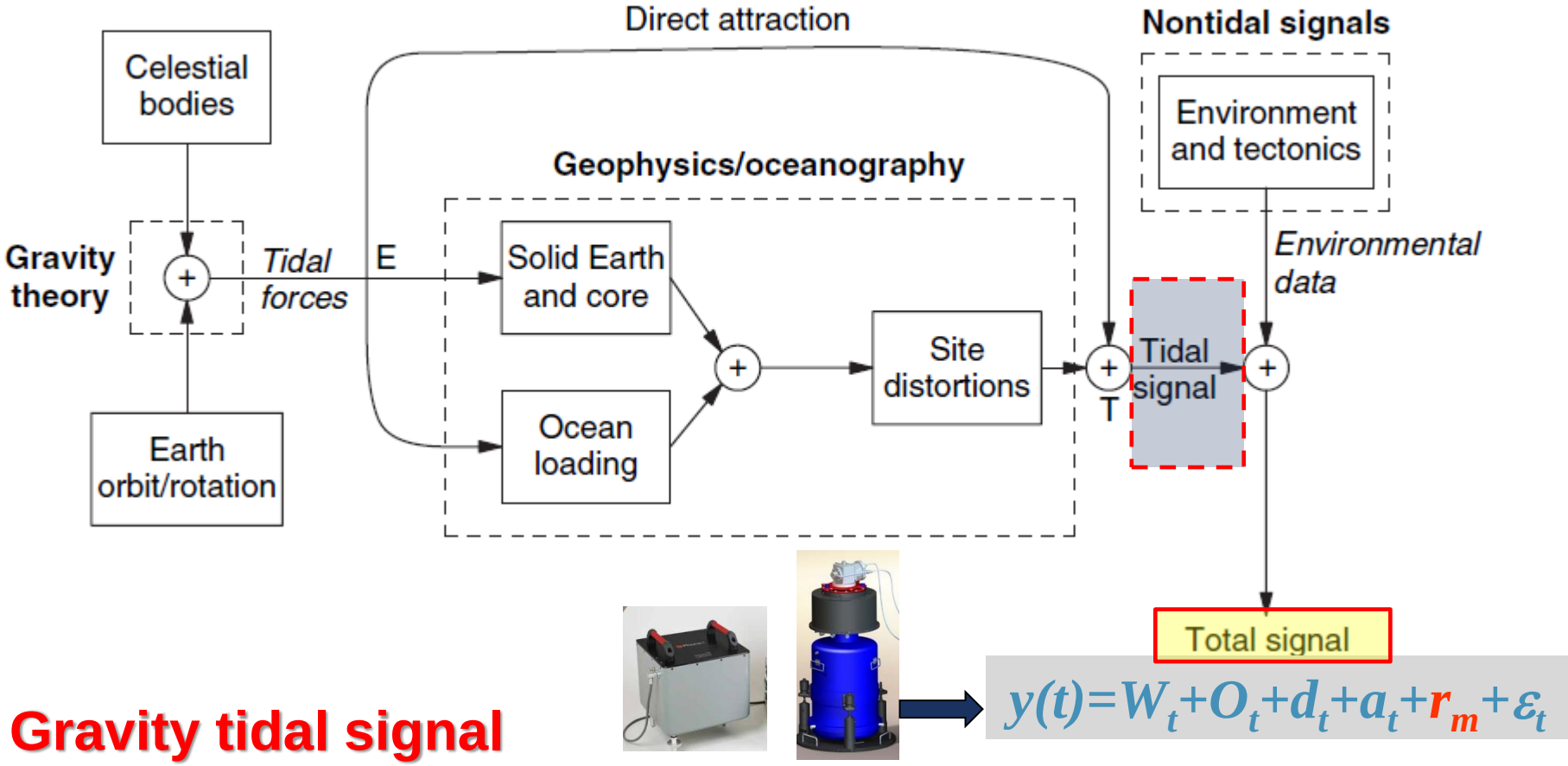
Geothermal Reservoir dynamics

Surface Gravity Effect



Drift matters!

(Modified from Crossley et al., 2008)



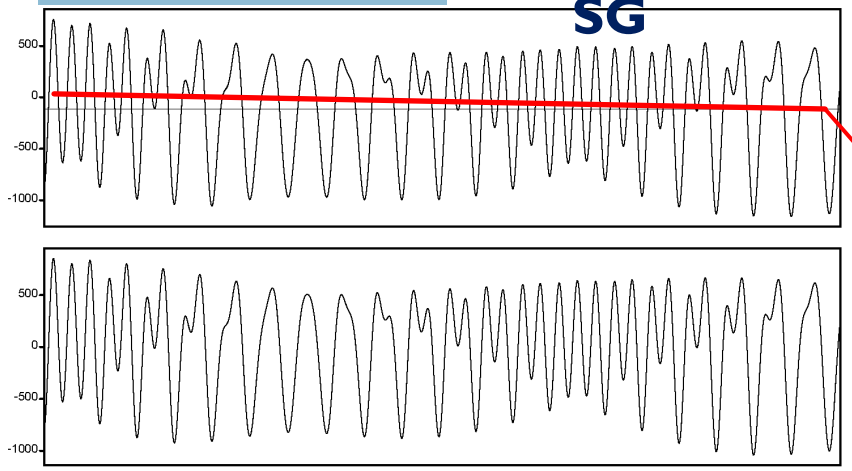
Gravity tidal signal

($g \sim 10\ m/s^2$)

$g_{tide} = 10^{-7} g = 10^{-6}\ m/s^2 = 10^2\ \mu Gal = 10^3\ nm/s^2$

Gravity Record

SG



Gravity Record y(t)

$$y(t) = W_t + O_t + d_t + a_t + r_m + \varepsilon_t$$

d_t **Instr. Drift**

$W_t + O_t$

W_t

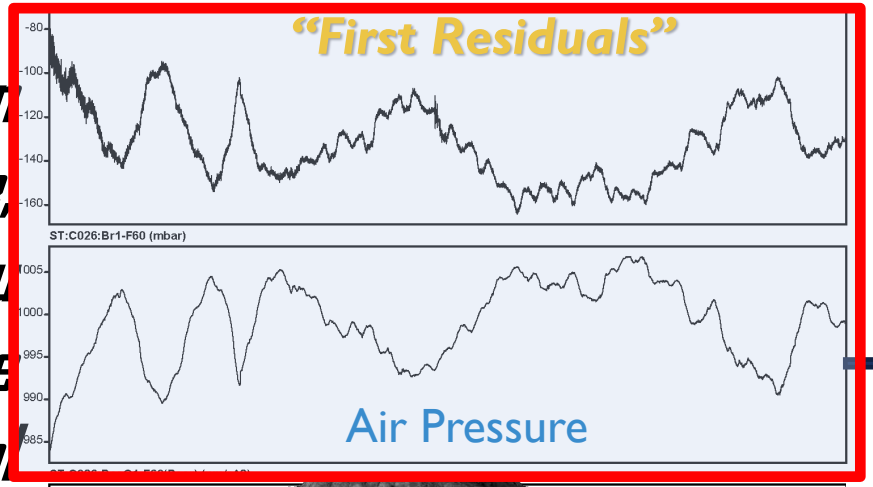
Body Tide

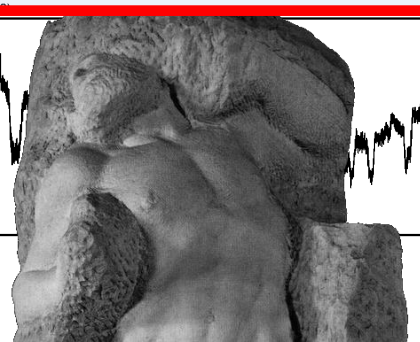
O_t

Ocean Loading

I mean sculpture, the kind you do by force of removal

(Michelangelo Buonarroti: Letter to Messer Benedetto Varchi; XVI Cent.)

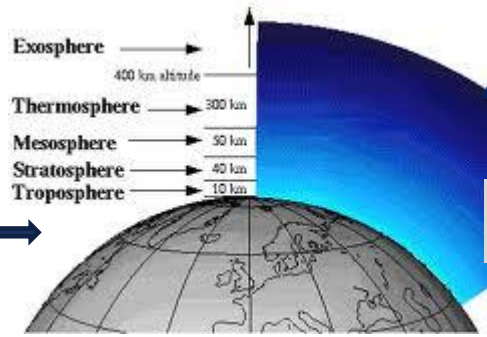




"Final Residuals"

$r_m + \varepsilon_t$

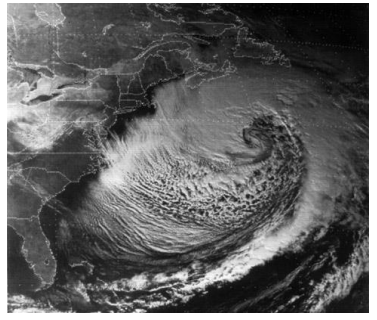
a_t



Atmospheric gravity Effect

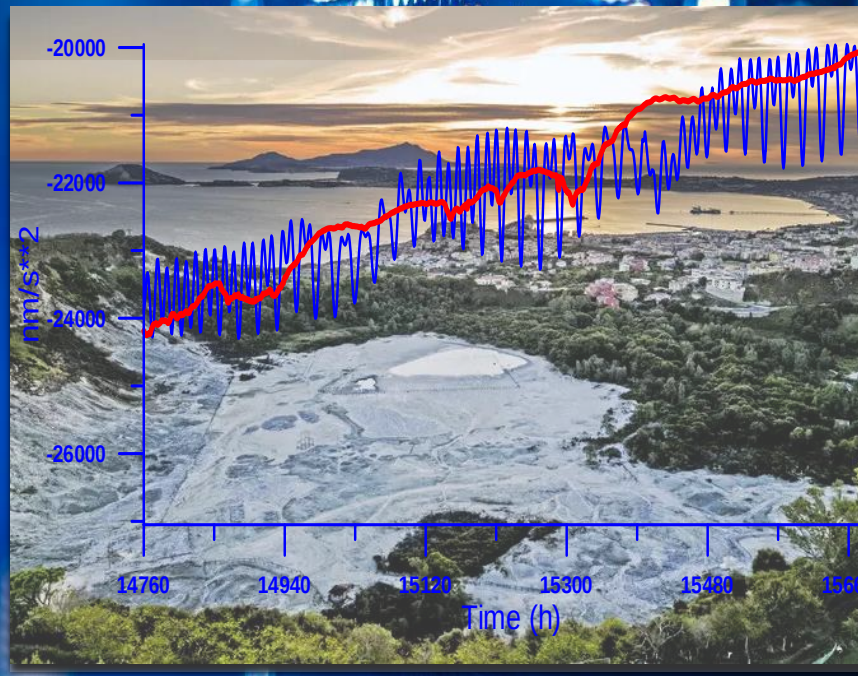
-3.0 nm s^{-2}/hPa

ΔP= 80 - 100 mbar



PRIMARY REDUCTIONS
MOST ENERGETIC SIGNALS

- Instrumental Drift
- Body & Ocean Tides
- Atmosph. Pres. Correction



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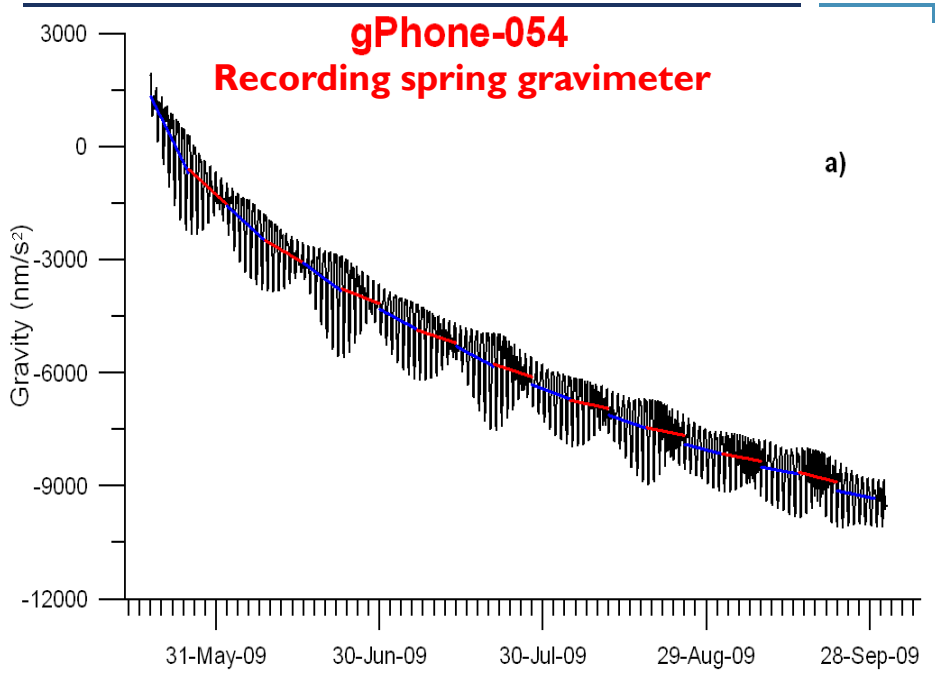
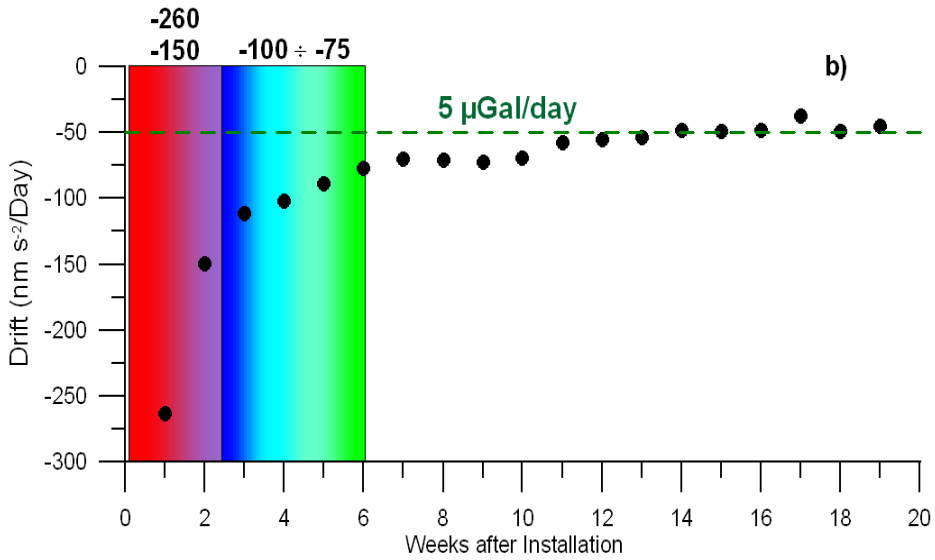
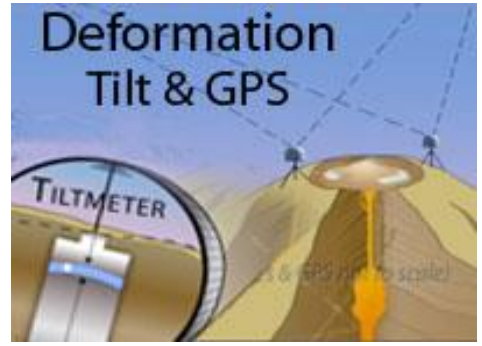
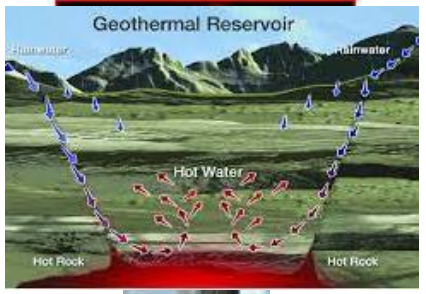
Instrumental drift can hide/mask a number of geophysical signals!

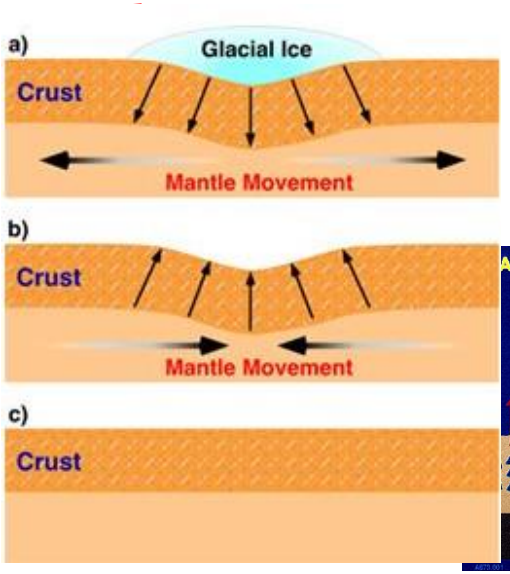


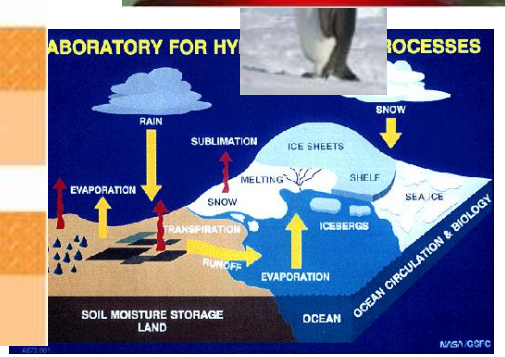


- Magma chamber refilling;
- Geoth. Reservoirs dynamics
- Low-rate ground deformation
- Elastic rebound
- Hydrodynamics







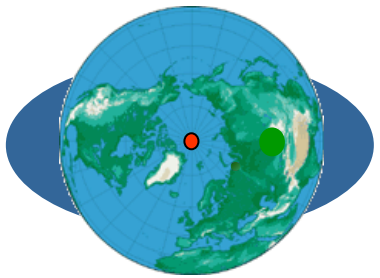


TIDES ARE PERIODIC PHENOMENA (WITH CHARACTERISTIC FREQUENCY)

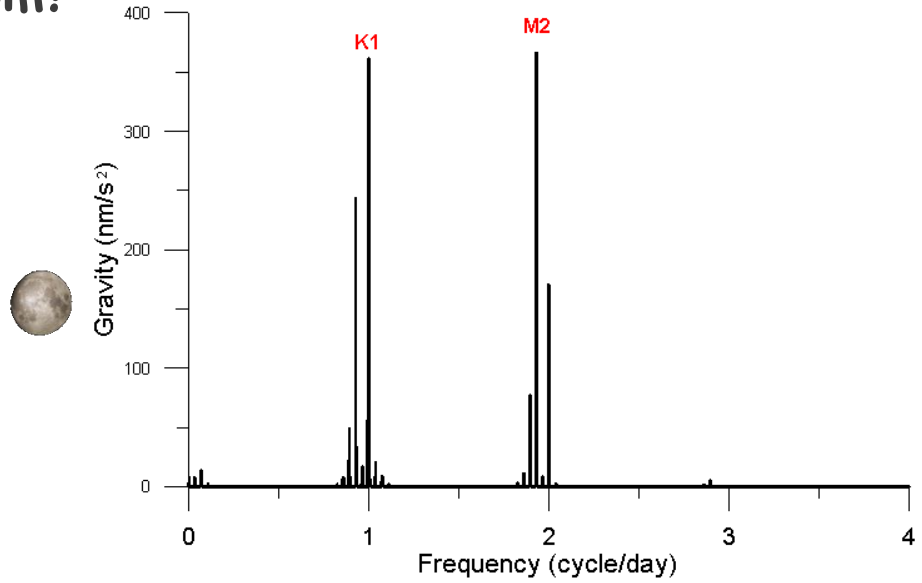
Tides occur at **fixed frequencies** given by the **combined** **spin** and **orbital dynamics** of the **Moon** about the Earth, and the Earth and the other planets around the **Sun**.
The largest components are at **semi-diurnal** and **diurnal** periods, but there are also **long-period** components (**fortnightly**, **monthly**, **half-yearly**, **yearly**, and an **18.6 year** nutation, corresponding to the "lunar nodal cycle").

Where does it come from?

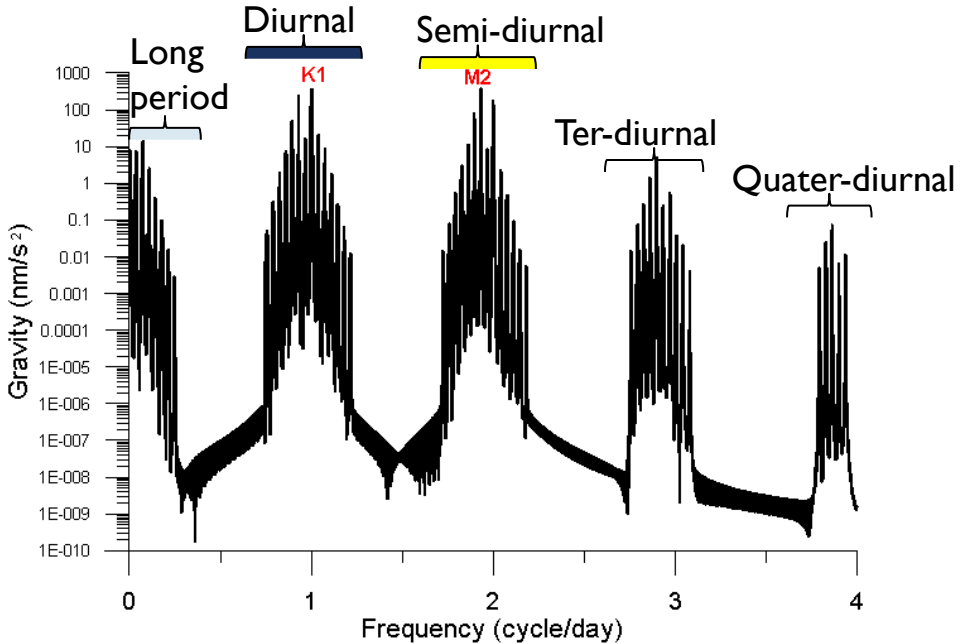
"Revolution without rotation"



1 month-long Record



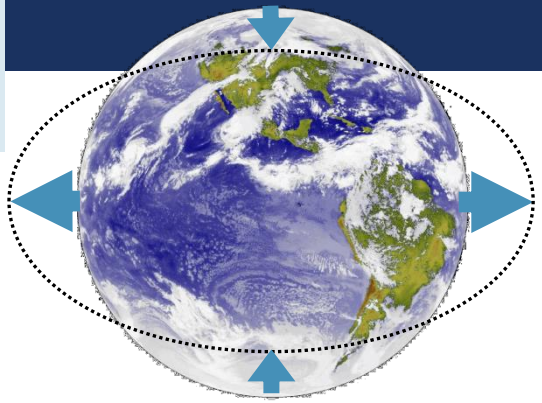
1 year-long Record

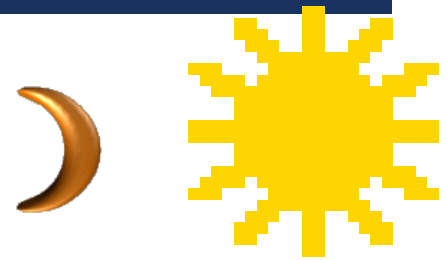


Earth is not a rigid body!!!

SOLID EARTH TIDES (BODY TIDES): DEFORMATION OF THE EARTH

Tides are not merely a water effect! The **Earth's** surface also has **tidal bulges**, about **10^{-1} m** in height. And the **moon** has an even greater tidal bulge **≈ 20 m** high.





The earth's body tides is the periodic deformation of the earth due to the tidal forces caused by the Moon and the Sun (Amplitude range 40 cm typically at low latitude).

Newtonian Effect	1.00+
Free Air Effect	0.60 -
Bouguer Effect	0.44 =

	1.16

To calculate Δg induced by Earth tides:

⇨ we need a *tidal potential*, which takes into account the relative position of the Earth, the Moon, the Sun and the planets.

⇨ But also a ***tidal parameter*** *set (δ, ϕ)*, which contains:

- The gravimetric factor $\delta \approx 1.16 = \Delta g_{Observed} / \Delta g_{Rigid\ Earth}$

  = Direct attraction (1.0) + Earth's deformation (0.6) - Mass redistribution inside the Earth (0.44).

- The phase lag ϕ = φ (observed wave) - φ (astronomic wave)

Main Goal of tidal Analysis

Earth's transfer function (δ, ϕ)

Correcting tidal effects using observed tides

Earth tide observations include the effect of the *ocean tides*

Advantage: take into account all the local effects e.g. ocean loading

➔ Very useful in coastal stations (problematic OTL models)

Disadvantage: a gravimeter must record continuously for 1 month, at least

***This effect is composed* of:**

1) the direct attraction (Newtonian)

2) the loading effect (Elastic) of the water masses

Amplitude

Close to the coast, it may assume up to **10%** in the **gravimetric tidal signal**, **several 10%** in **strain**, and **100%** and more in **tilt**, with corresponding **phase shifts**.

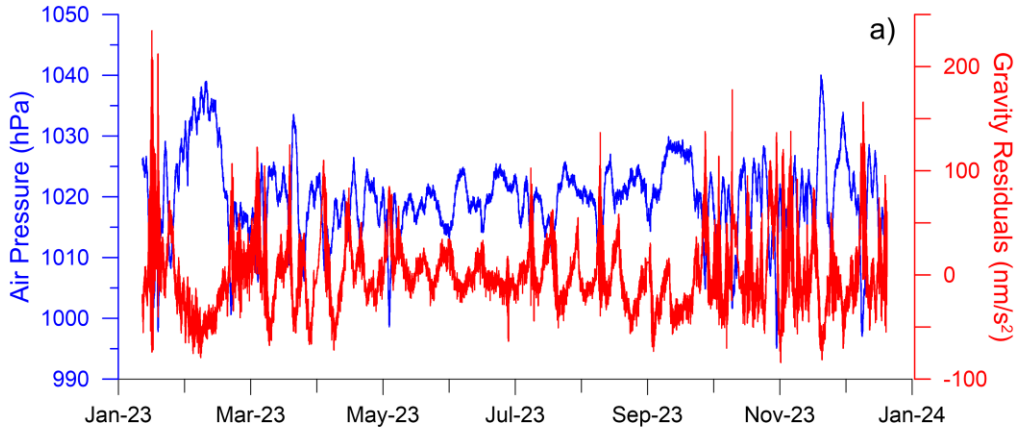
δ= 1.18 instead of 1.16

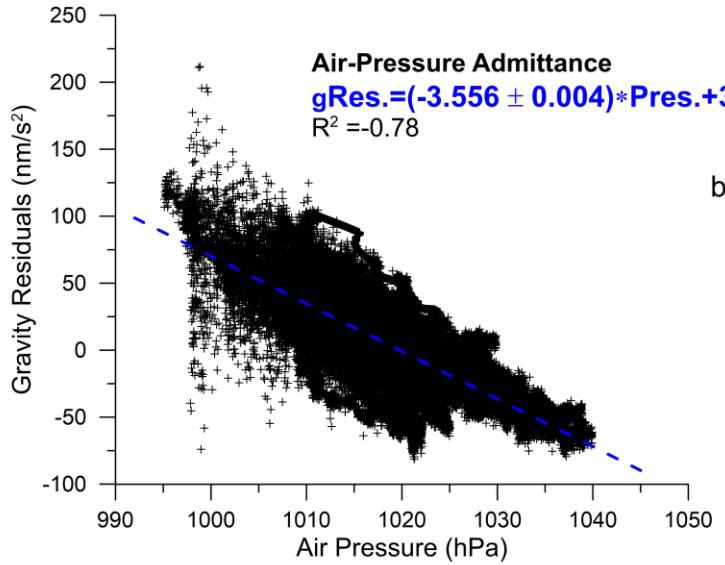
ϕ ~ 1 instead of 0

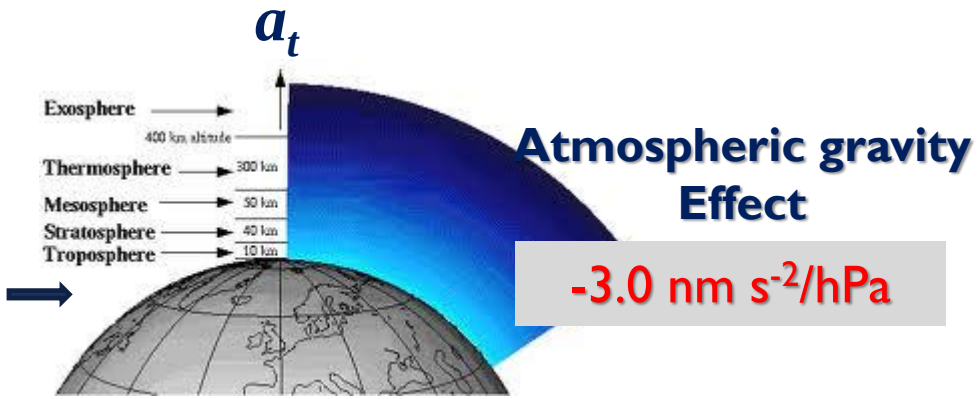
Observed tidal parameter set (Astroni 1year record):

Frequency (cpd)		δ	ϕ	Wave
0.000000	0.249951	1.16000	0.0000	MF
0.721500	0.906315	1.14660	-0.3219	Q1
0.915001	0.933200	1.14852	0.2990	O1
0.958085	0.974188	1.15776	0.2951	M1
0.989049	0.998028	1.15100	0.2101	P1
1.002334	1.004200	1.13507	0.1640	K1
1.013689	1.044800	1.16053	0.1085	J1
1.064841	1.216397	1.15964	-0.0457	OO1
1.719381	1.872142	1.16050	3.6084	2N2
1.888387	1.906462	1.17730	3.1945	N2
1.915115	1.950419	1.17772	0.8920	M2
1.958233	1.976926	1.18465	1.0527	L2
1.984283	2.004380	1.17069	0.4420	S2
2.003032	2.182843	1.19451	0.9437	K2
2.753244	3.081254	1.06239	0.3105	M3

ATMOSPHERIC PRESSURE CORRECTION







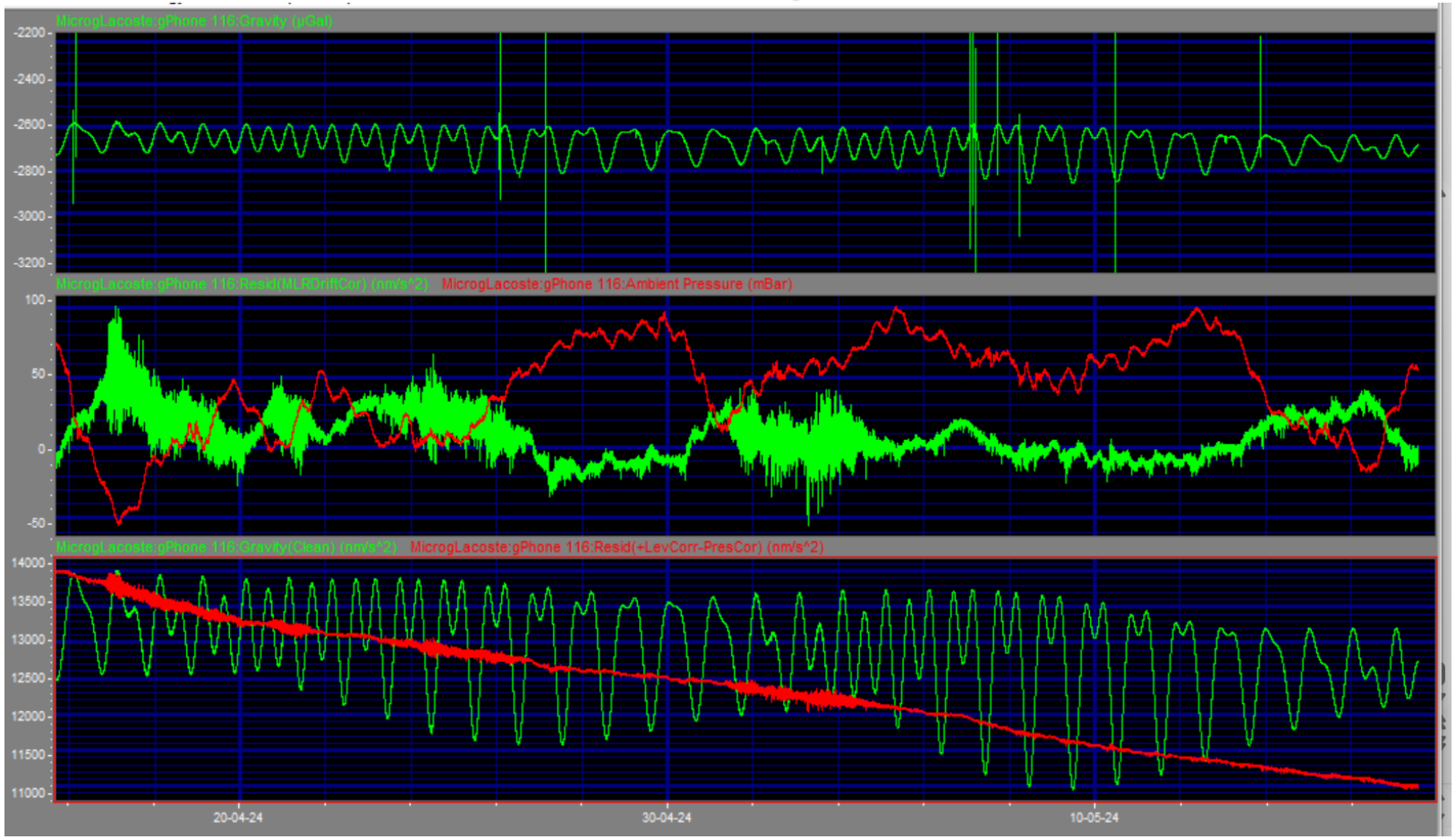
Atmospheric gravity Effect

-3.0 nm s^{-2}/hPa

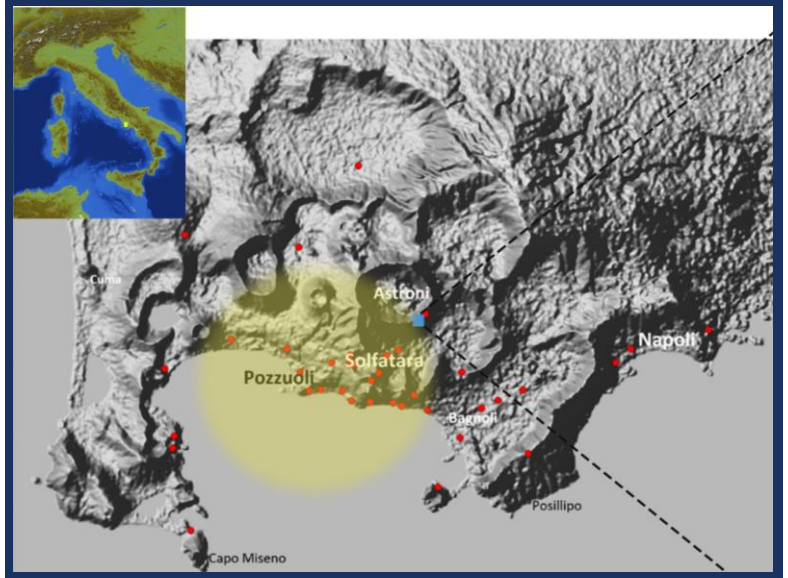
Analysis of a gravity record

15th April - 21st May 2024

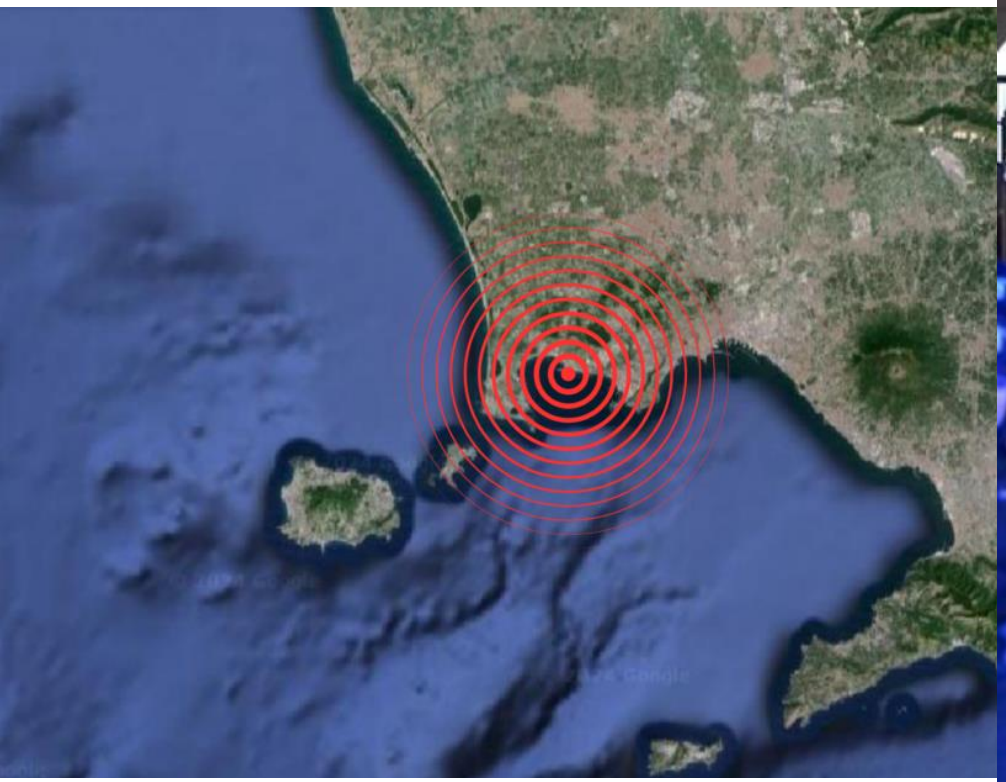
~37 days



THANKS



SEISMIC SWARM 20 MAY 2024



Terremoto oggi Campi Flegrei, scossa di M 3.6/ Ingv: record degli ultimi 40 anni di 4.4 alle ore 20:10

Pubblicazione: 20.05.2024 Ultimo aggiornamento: 23:45 - **Niccolò Magnani**

Terremoto oggi ai Campi Flegrei: l'Ingv rileva 20 differenti scosse, con il picco più alto degli ultimi 40 anni alle ore 20: 4.4 sulla scala Richter