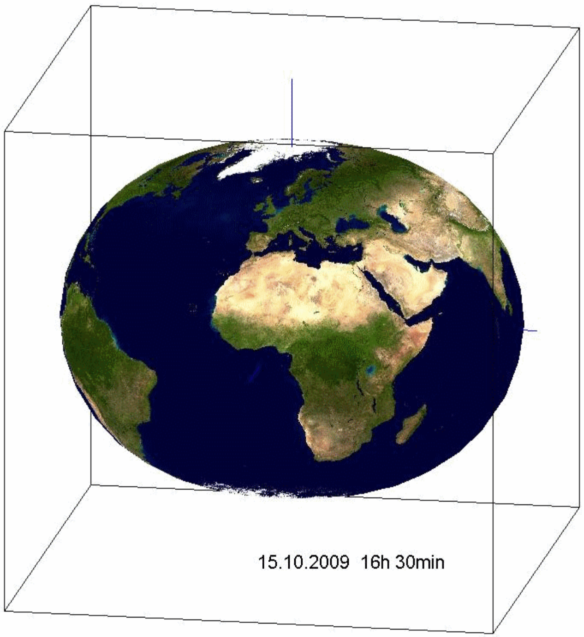
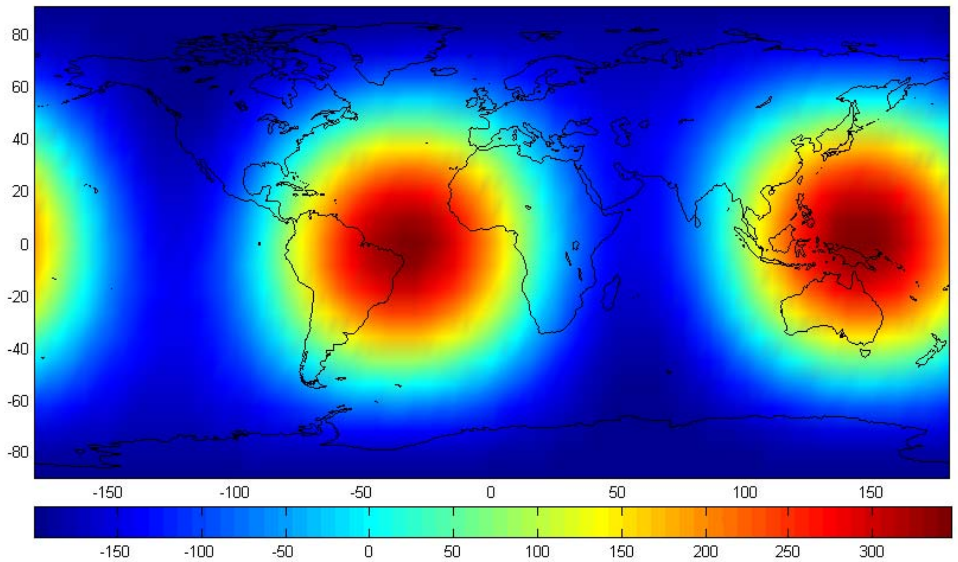
CERN BE/ABP

# How to Establish a **Straight Line** on the **Dynamic Curved** Surface of the **Earth** ?




J. Boerez, S. Guillaume, M. Jones

**CLIC09 Workshop** 15.10.2009

**CLIC Pre-alignment tolerence**

± 10 [µm] over a 200 [m] sliding window ($3\sigma$)

# Definition of "Straight Line" for CLIC Pre-Alignment?

# Trajectory of Photons in a vacuum Tube on the Earth

↓

Relativistic deflection on the Earth ~ 0.5 µm/200 m — **NEGLECTED**

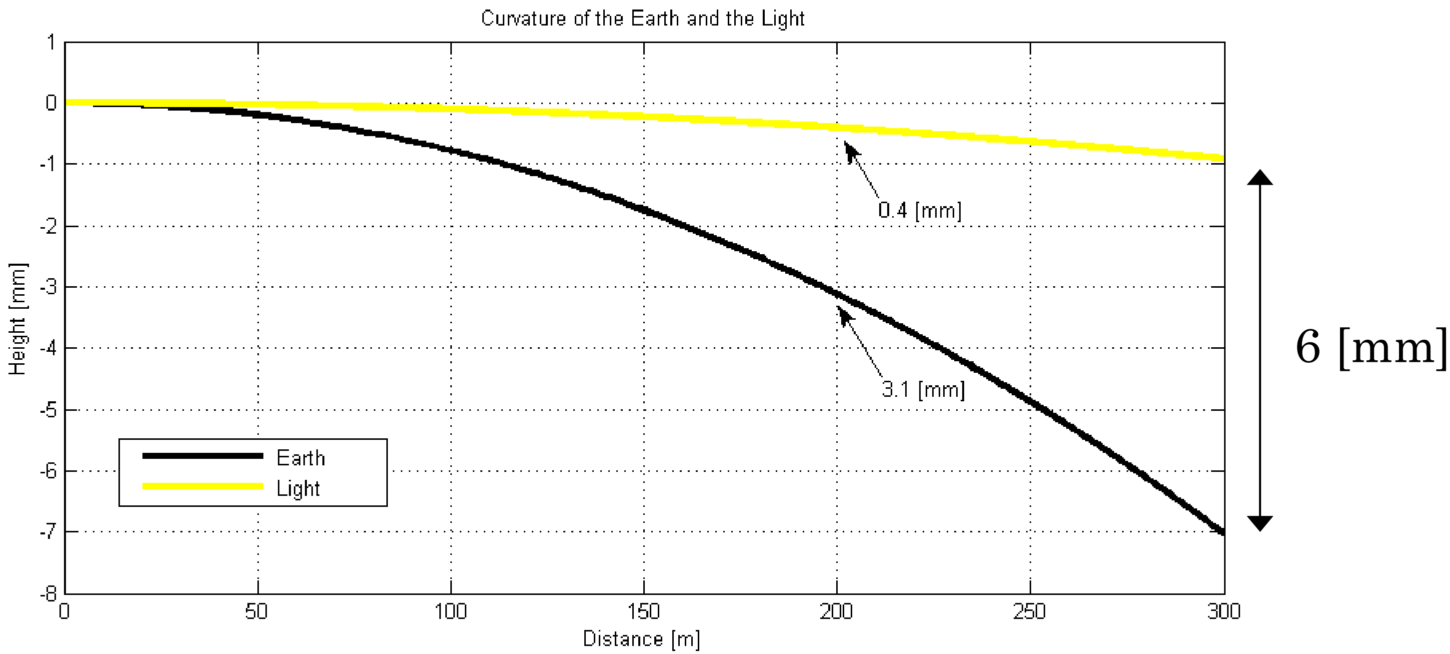
↓

Newton's approximation

↓

# Shortest Path between 2 Points in Euclidian Space

# **Trajectory** of the **Light** in Standard Atmosphere Refraction Field and **Shape** of the **Earth** in **Euclidian Space**



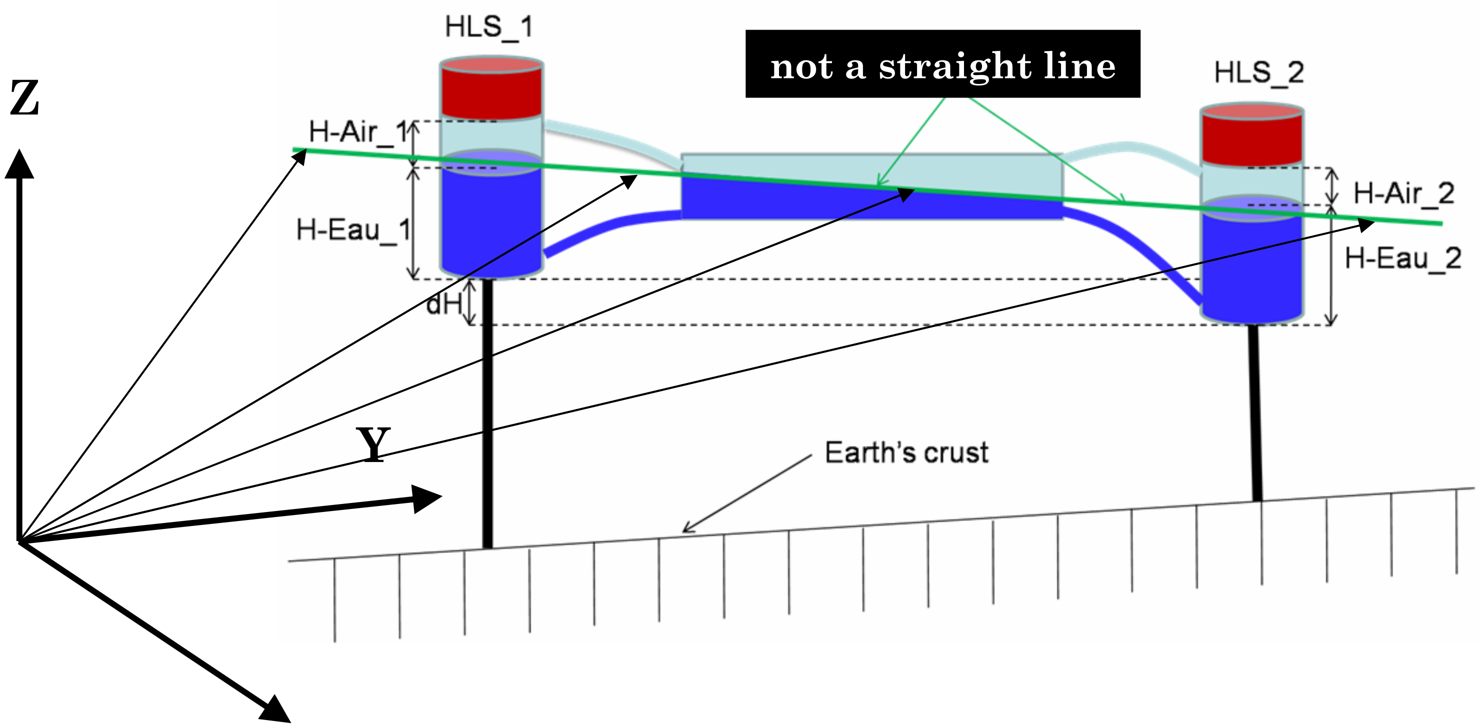
# References

Three **References** under study:

| | |
|---|---|
| • the static water (HLS) | vertical |
| • a stretched wire (WPS) | horizontal + vertical |
| • a laser beam under vacuum | ...ertical |

**PhD Thomas Touzé**

# HLS Hydrostatic Leveling System



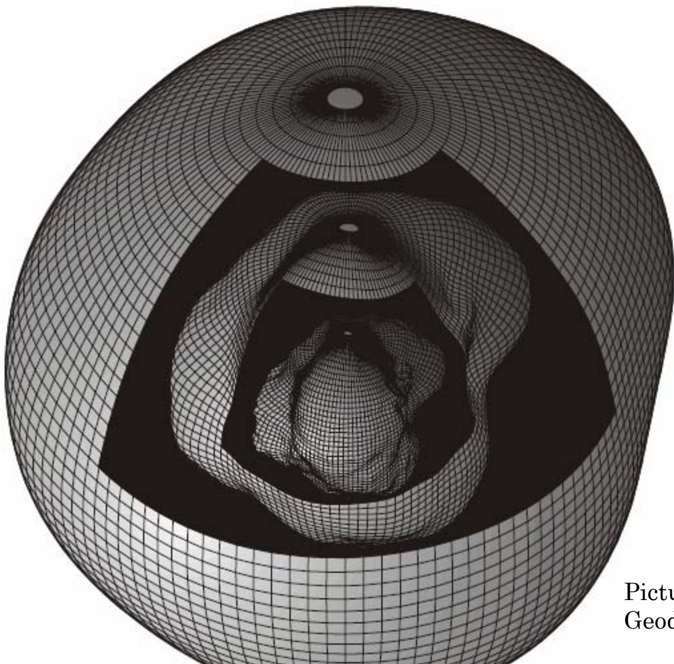

Euclidian Reference System

# Definition of Gravity Potential

Potential **W(P)** at point **P** is the **Work** needed to bring a unit mass from infinity to **P**

# Definition of Gravity Potential

$$\mathbf{W}(x,y,z) = \underbrace{\mathbf{V}(x,y,z)+\mathbf{\Phi}(x,y,z)}_{\text{Time independent}}+\underbrace{\mathbf{Tide}(x,y,z)}_{\text{Time dependent}}$$



Picture from the Physikalische Geodäsie Skriptum Universität Bonn

Equipotential Surfaces of the Earth's Gravity Field at different Levels

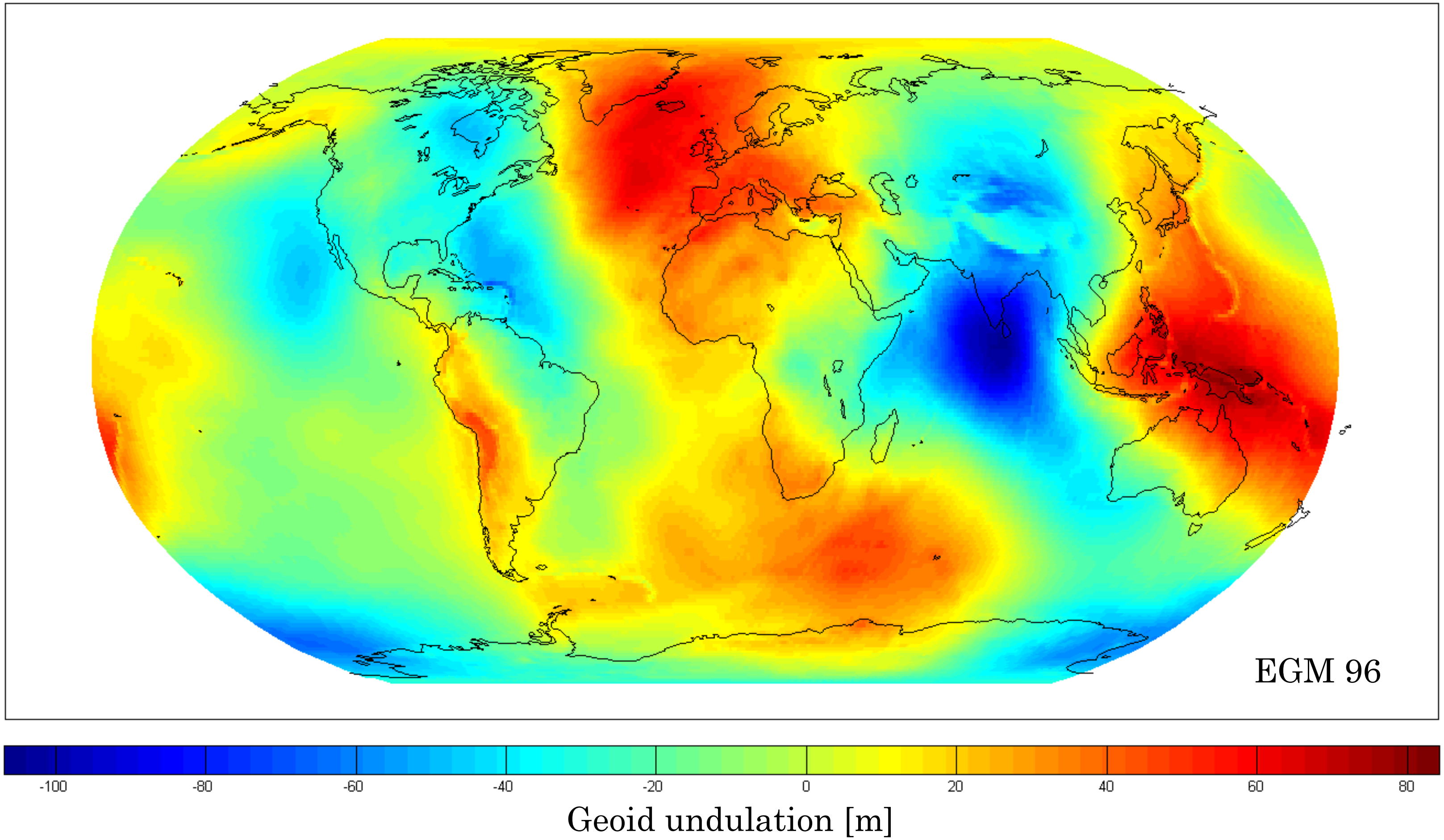
$$\text{surface of static water} \equiv \mathbf{W}(x,y,z) = \mathbf{const}$$

# First Part

$$\mathbf{W}(x,y,z) = \underbrace{\mathbf{V}(x,y,z) + \mathbf{\Phi}(x,y,z)}_{\text{Time independent}} + \underbrace{\mathbf{Tide}(x,y,z)}_{\text{Time dependent}}$$

$$\boxed{\text{surface of static water} \equiv \mathbf{W}(x,y,z) = \mathbf{const}}$$

# Time Independent Geometry of the Gravity Equipotentials (Geoid)



# Time Independent Geometry of the Gravity Equipotentials (Geoid)

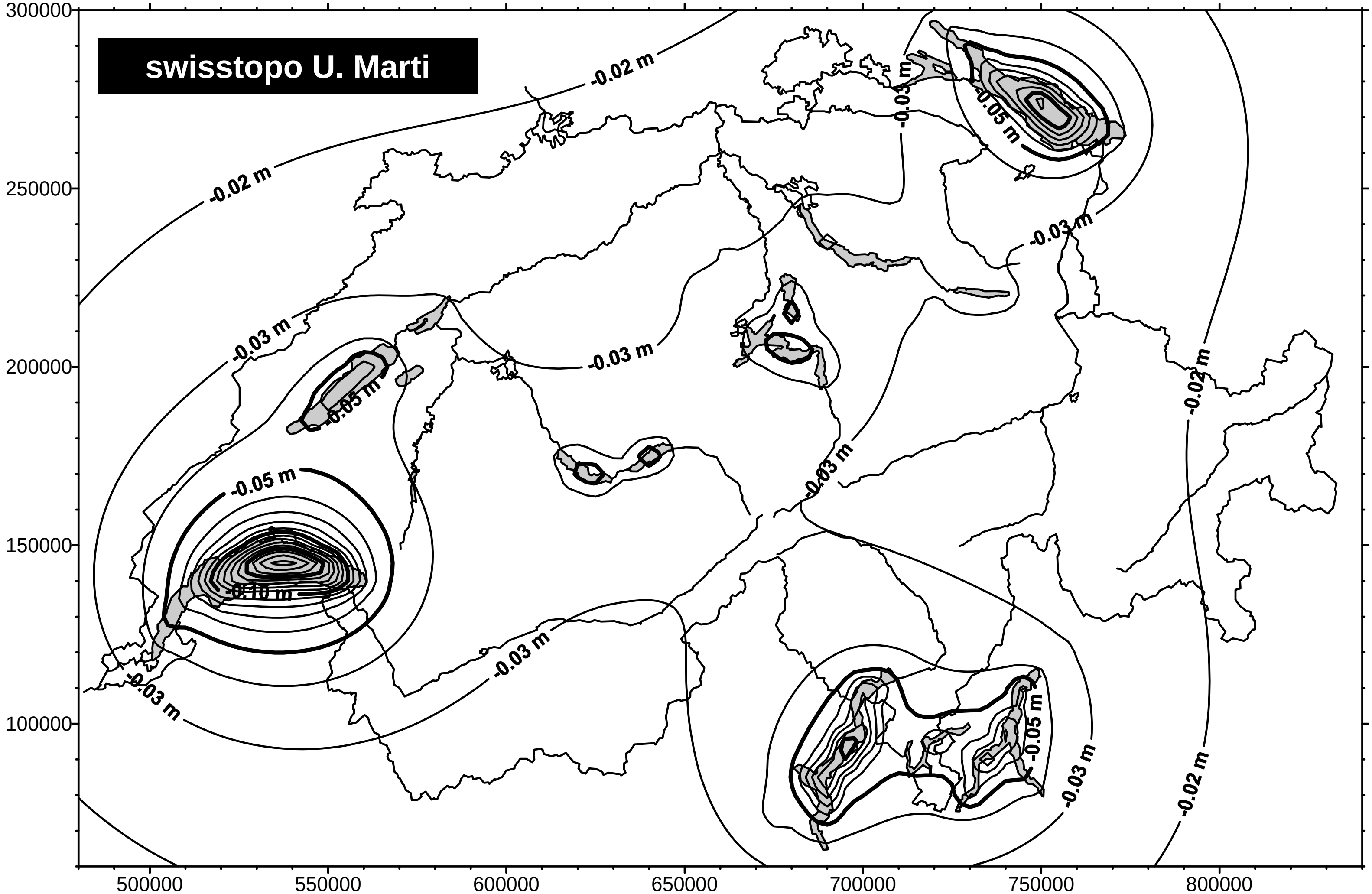
$$\mathbf{V}(x, y, z) + \mathbf{\Phi}(x, y, z) \quad =$$

$$G \cdot \iiint_{Earth} \frac{1}{r} \rho \cdot dV + \frac{1}{2} \omega^2 r^2 \sin^2 \phi$$

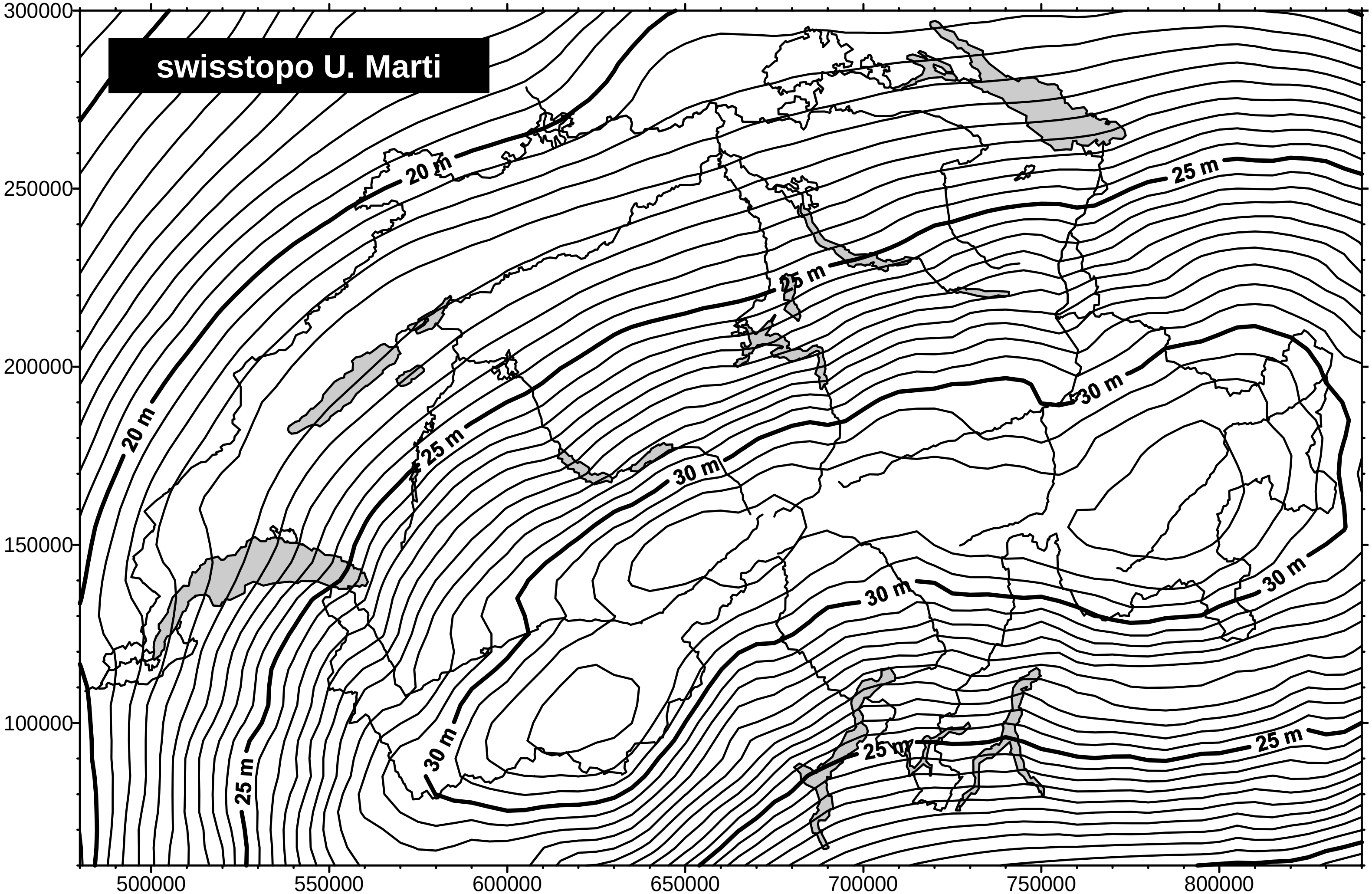
density, approx. known

well known

# Effect of the Swiss Lakes on Geoid



# Effect of Topography on Geoid



# Accuracy of the Best Available Geoids

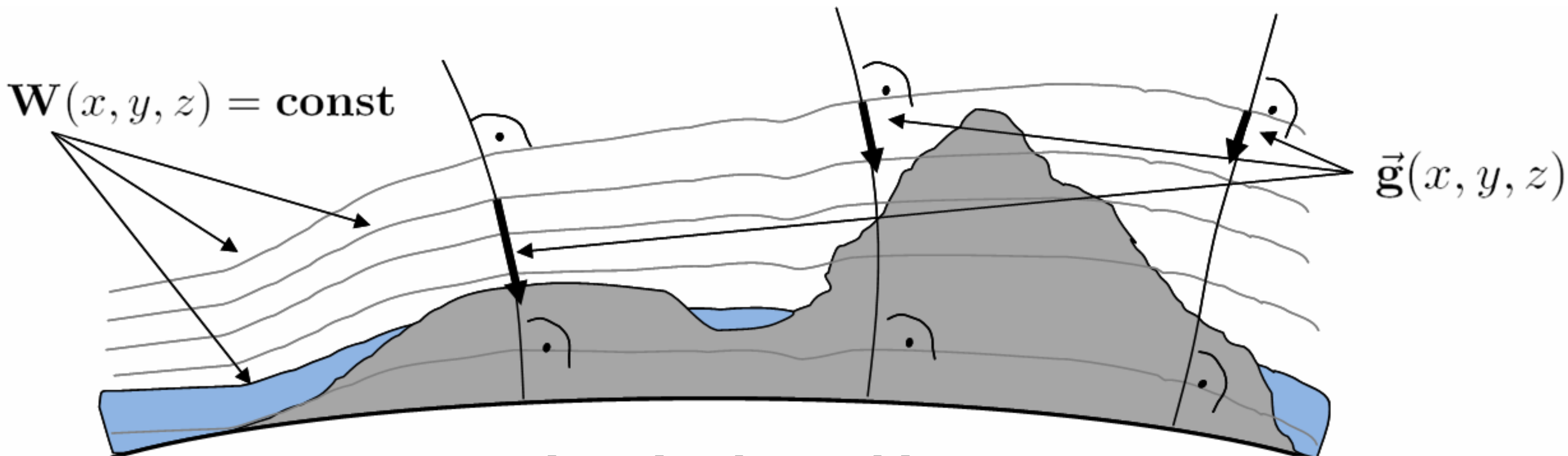
- 1-2 [cm] for wavelengths of 10-100 [km]
- 1-10 [mm] for wavelengths 1-10 [km]

**For wavelengths < 1 [km], some questions to be answered :**

- Spectrum for very shorts wavelengths ?
- Time Variation ?
- Detection of dangerous anomalies (ampl. > 1-2 μm for λ < 200 [m])

**Measurement process ?**

# Gravity Field's Observables on the Earth




$\mathbf{W}(x, y, z)$ → not directly observable

$$\mathbf{grad}\ \mathbf{W}(x, y, z) = \vec{\mathbf{g}}(x, y, z) = g \cdot \vec{\mathbf{e}}_{\mathbf{g}}$$

$g$ → gravimeter; $\vec{\mathbf{e}}_{\mathbf{g}}$ → astro-geodetic instrument

$$\mathbf{grad}\ \vec{\mathbf{g}}(x, y, z) = \begin{pmatrix} \mathbf{W}_{xx} & \mathbf{W}_{xy} & \mathbf{W}_{xz} \\ \mathbf{W}_{yx} & \mathbf{W}_{yy} & \mathbf{W}_{yz} \\ \mathbf{W}_{zx} & \mathbf{W}_{zy} & \mathbf{W}_{zz} \end{pmatrix}$$

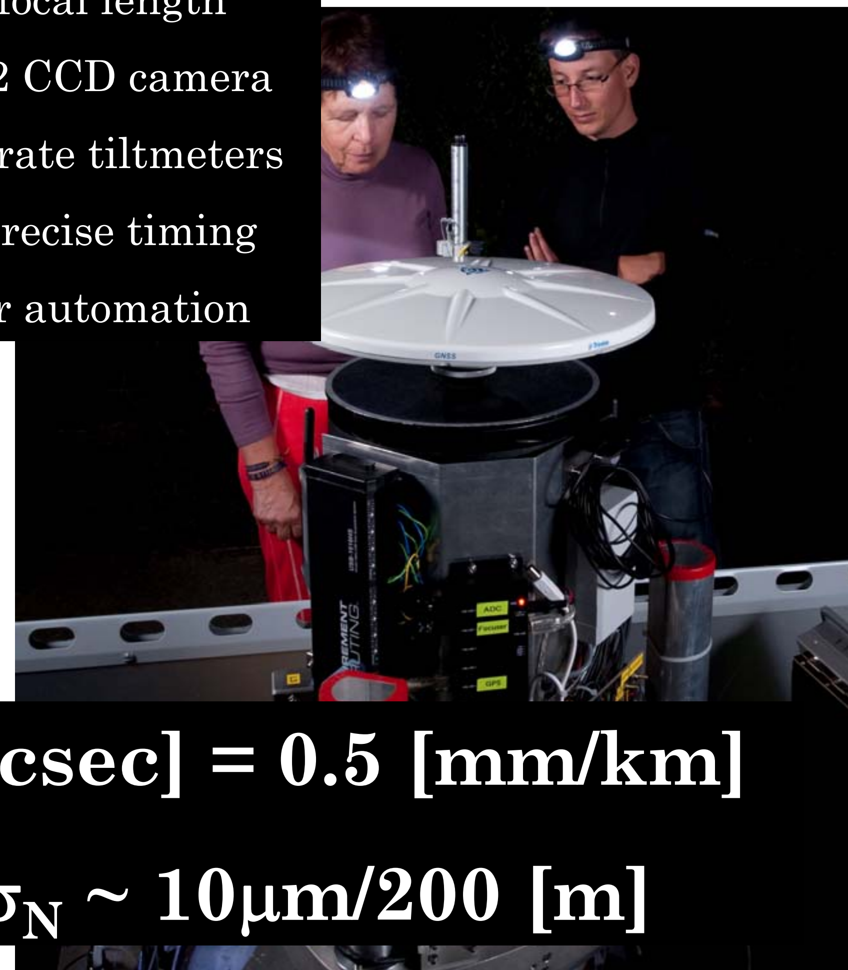
gravimeter

torsion balance

Autocollimator in vacuum coupled with inclinometers (to be developed)

# Astro-Geodetic Measurements

- 1000 [mm] focal length
- 2184 x 1472 CCD camera
- 6 very accurate tiltmeters
- 1 GPS for precise timing
- 8 motors for automation



**Precision : < 0.1 [arcsec] = 0.5 [mm/km]**

**1 point/10[m] → $\sigma_N$ ~ 10μm/200 [m]**

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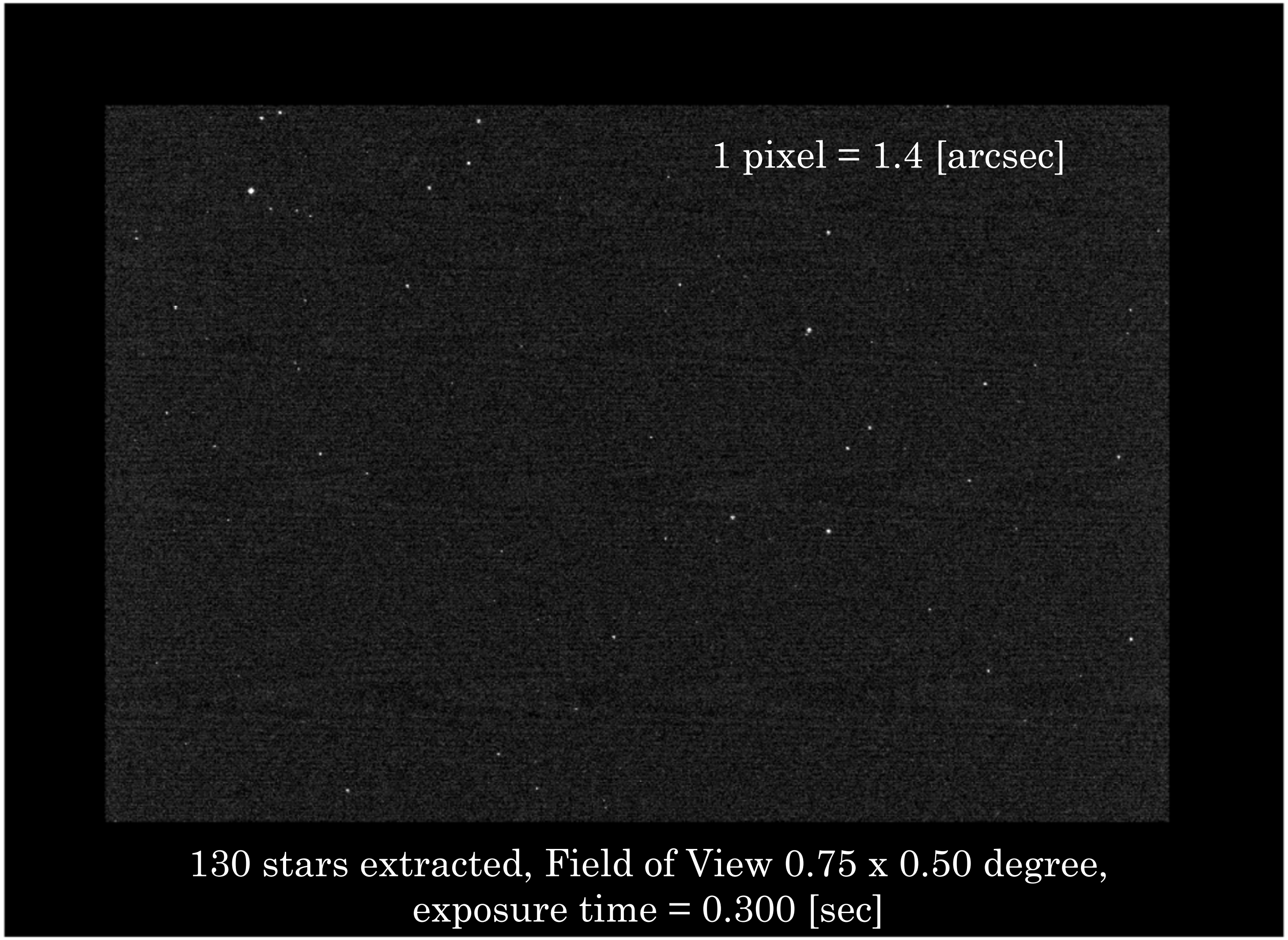
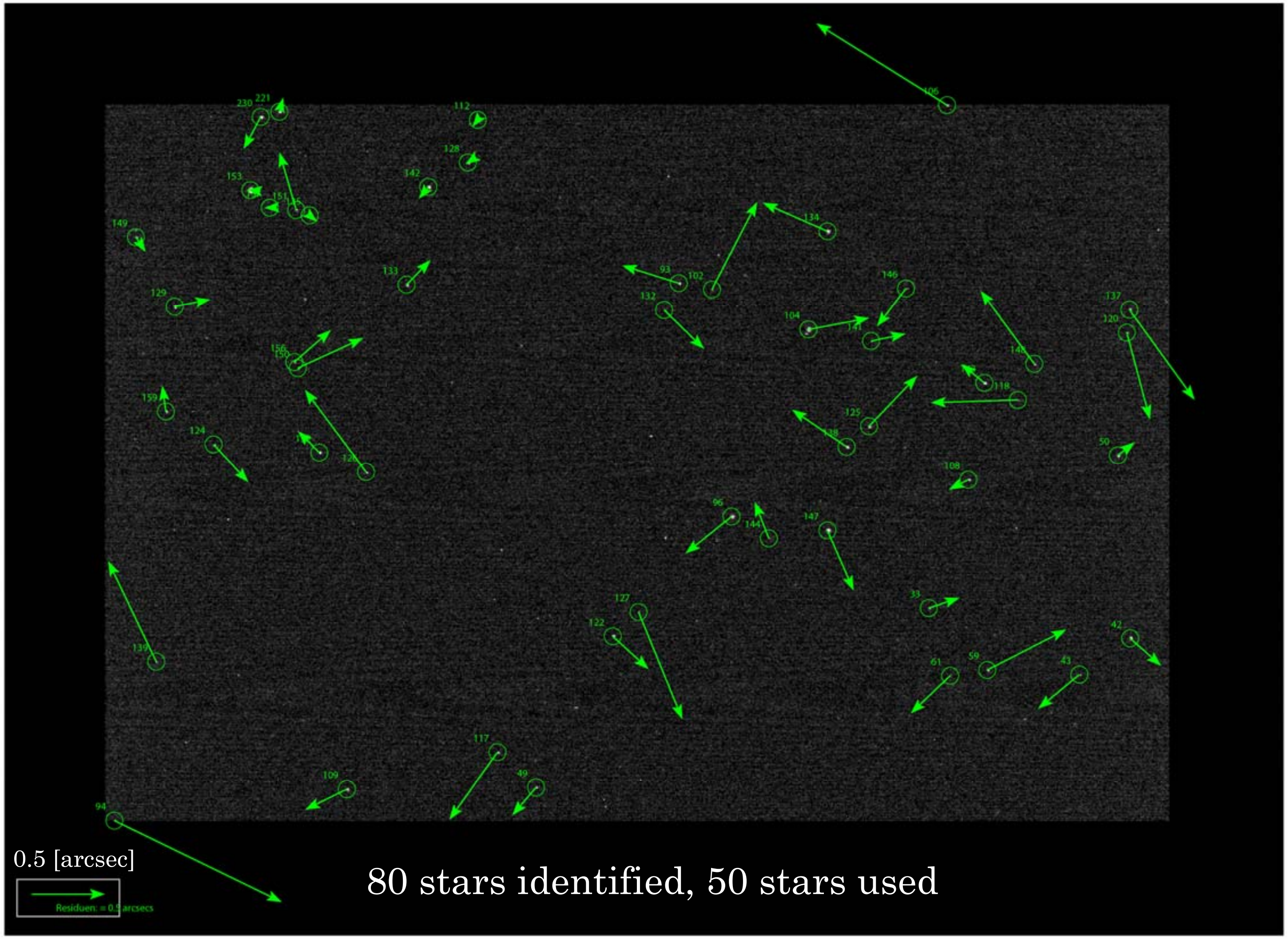
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

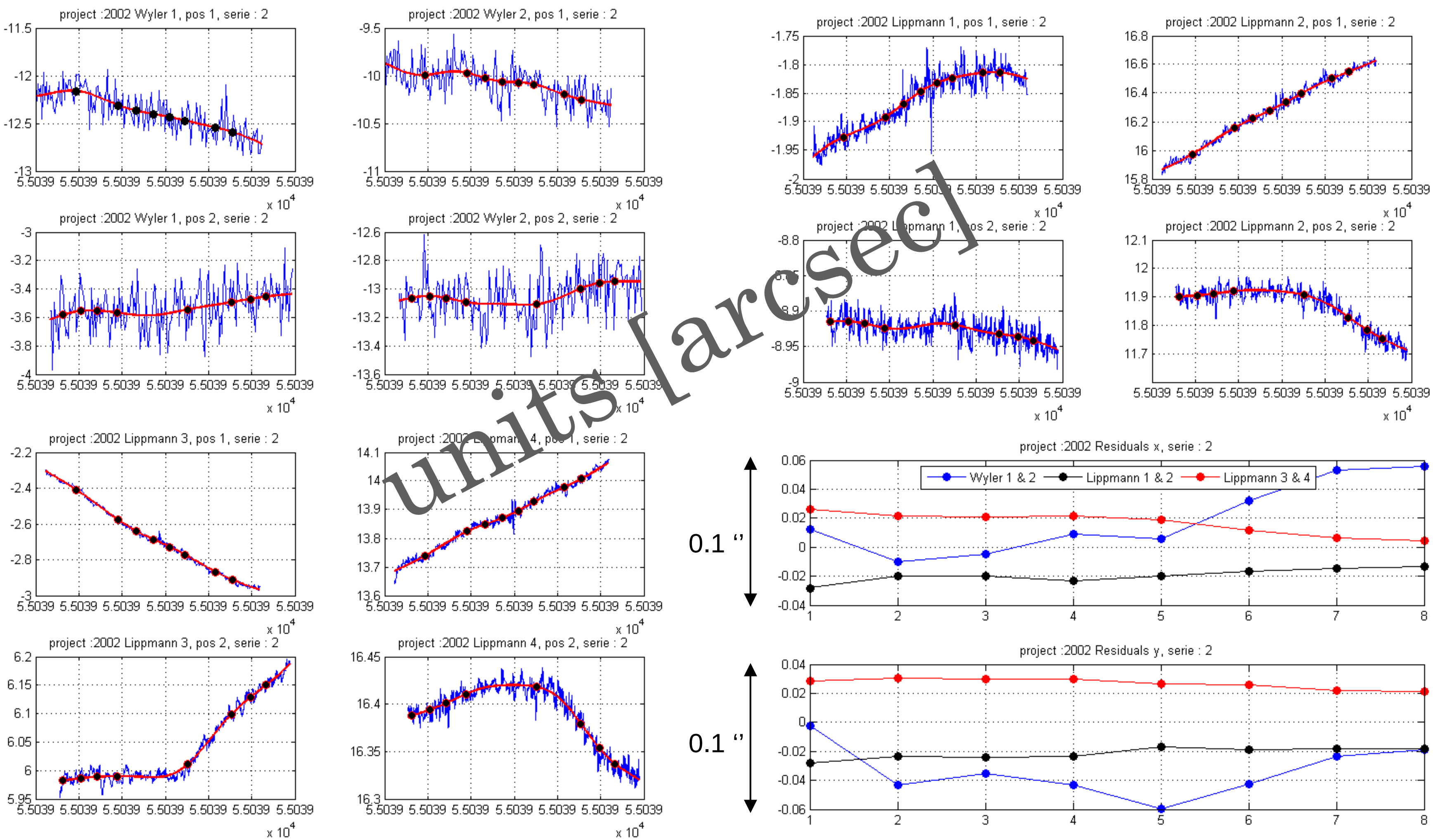
# Astro-Geodetic Measurements



# Astro-Geodetic Measurements

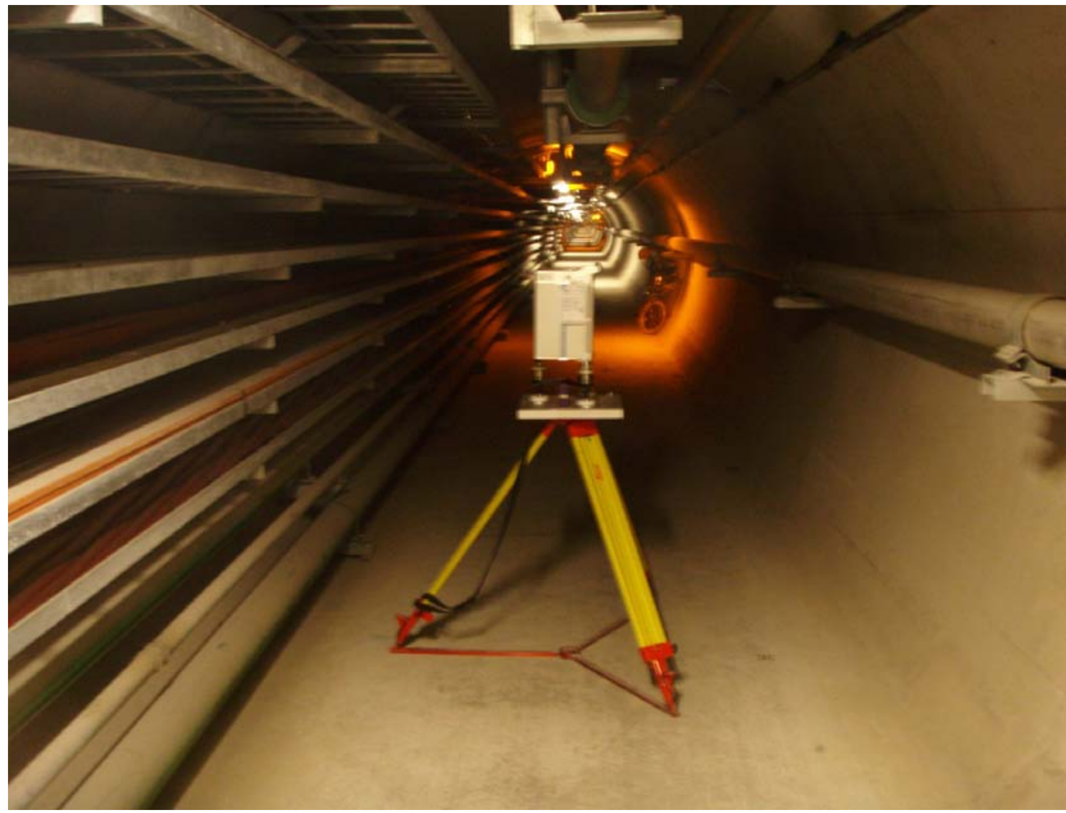


# Astro-Geodetic Measurements



# Gravimetric Measurements

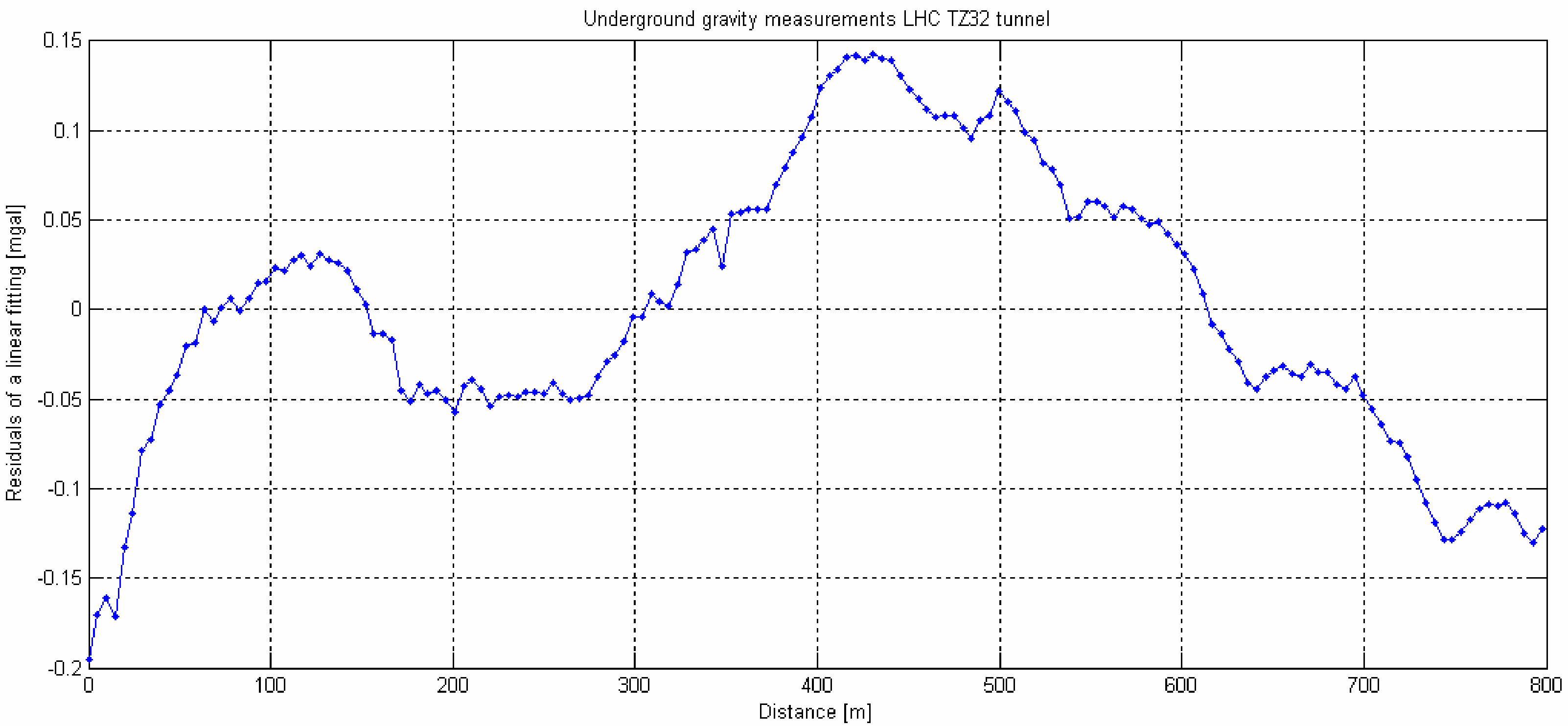
Absolute



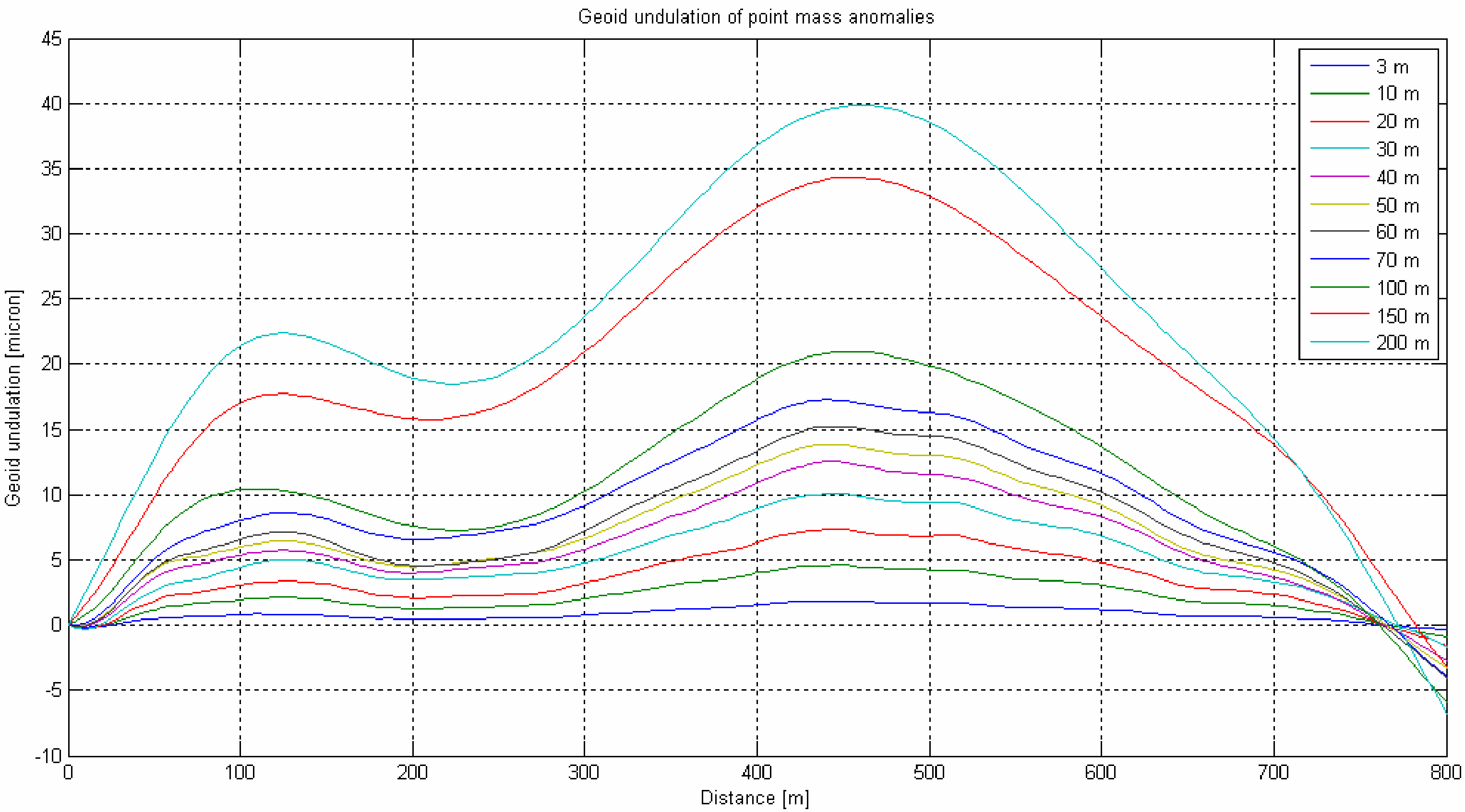
Relative

# Test Measurements

# Gravimetric Measurements



# Gravimetric Measurements

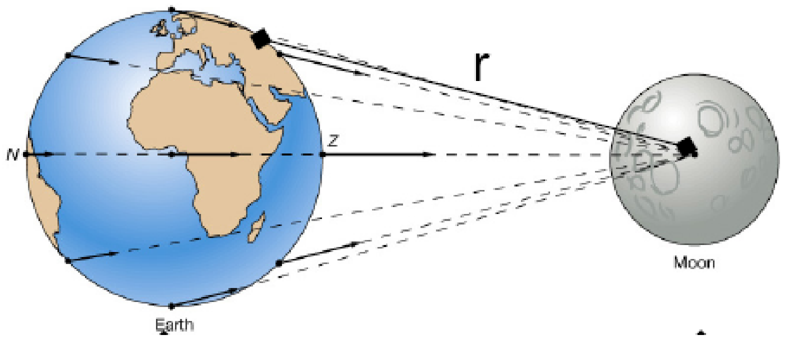


# Second Part

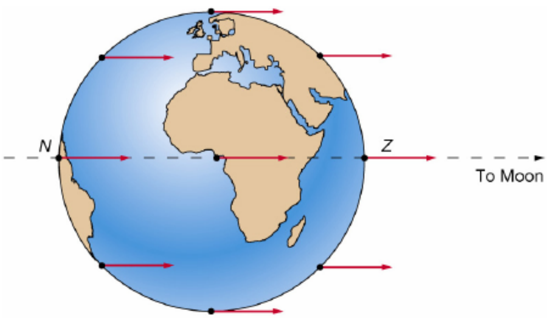
$$\mathbf{W}(x,y,z) = \underbrace{\mathbf{V}(x,y,z)+\mathbf{\Phi}(x,y,z)}_{\text{Time independent}}+\underbrace{\mathbf{Tide}(x,y,z)}_{\text{Time dependent}}$$

$$\text{surface of static water} \equiv \mathbf{W}(x,y,z) = \mathbf{const}$$

# Earth Tides



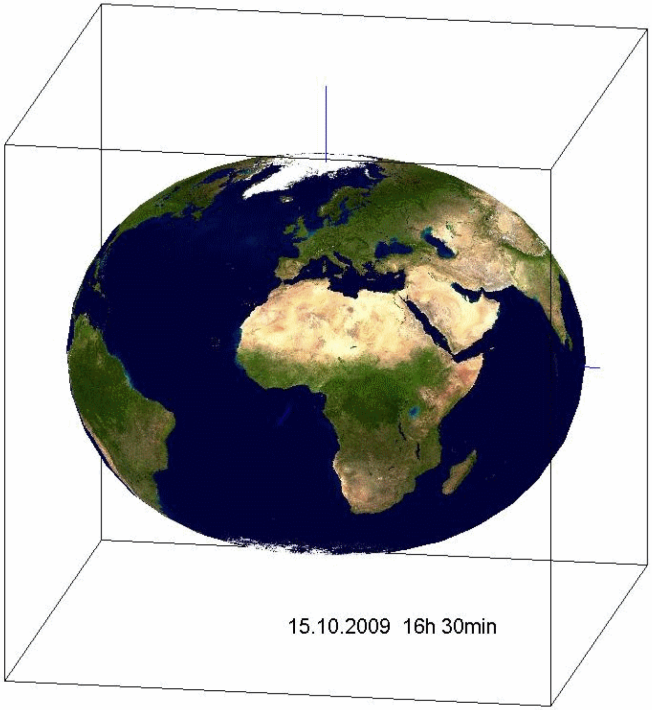

Gravitational Forces

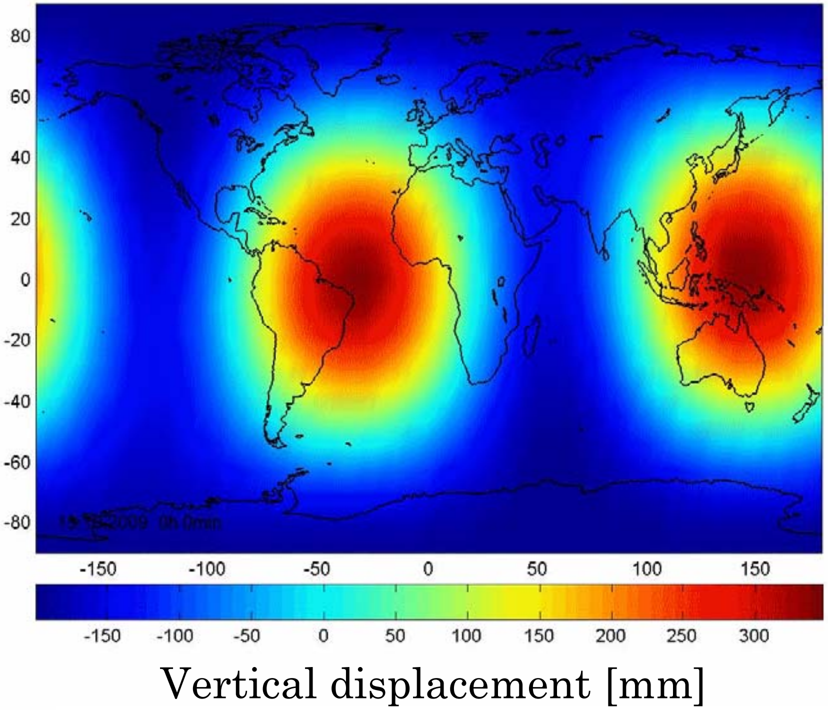



Centripetal Force

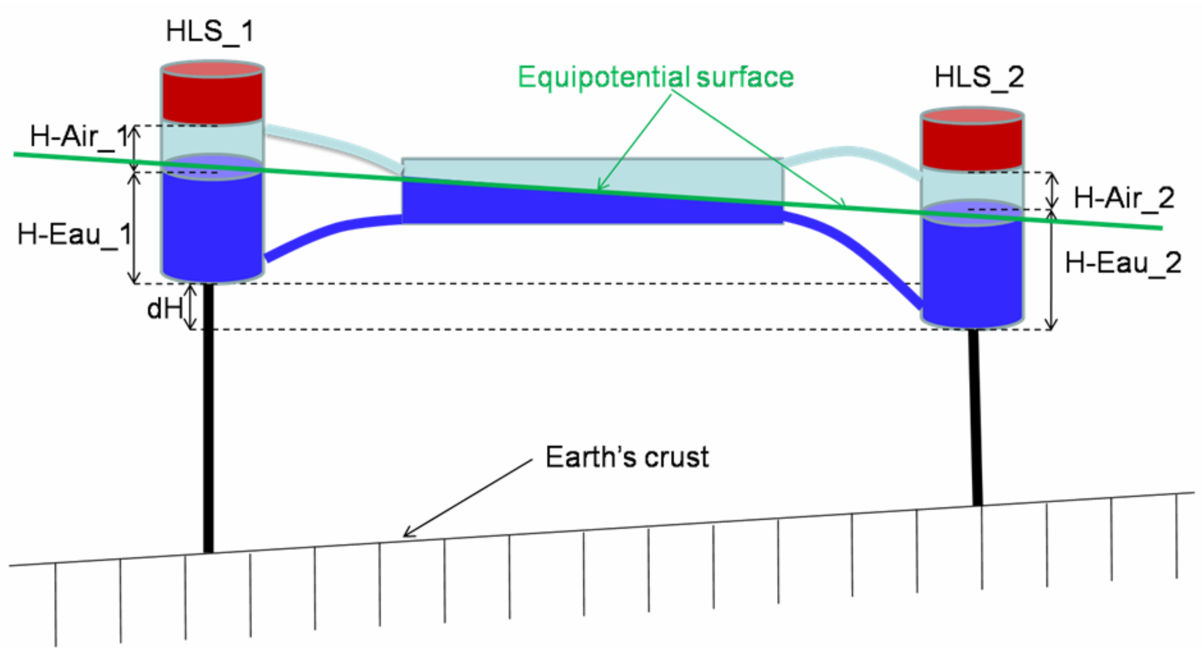
$$\vec{\mathbf{F}}_{Tide} = \vec{\mathbf{F}}_{Moon,Sun,\ldots} - \vec{\mathbf{F}}_{centripetal}$$

# Tidal Deformation of the Earth's Crust



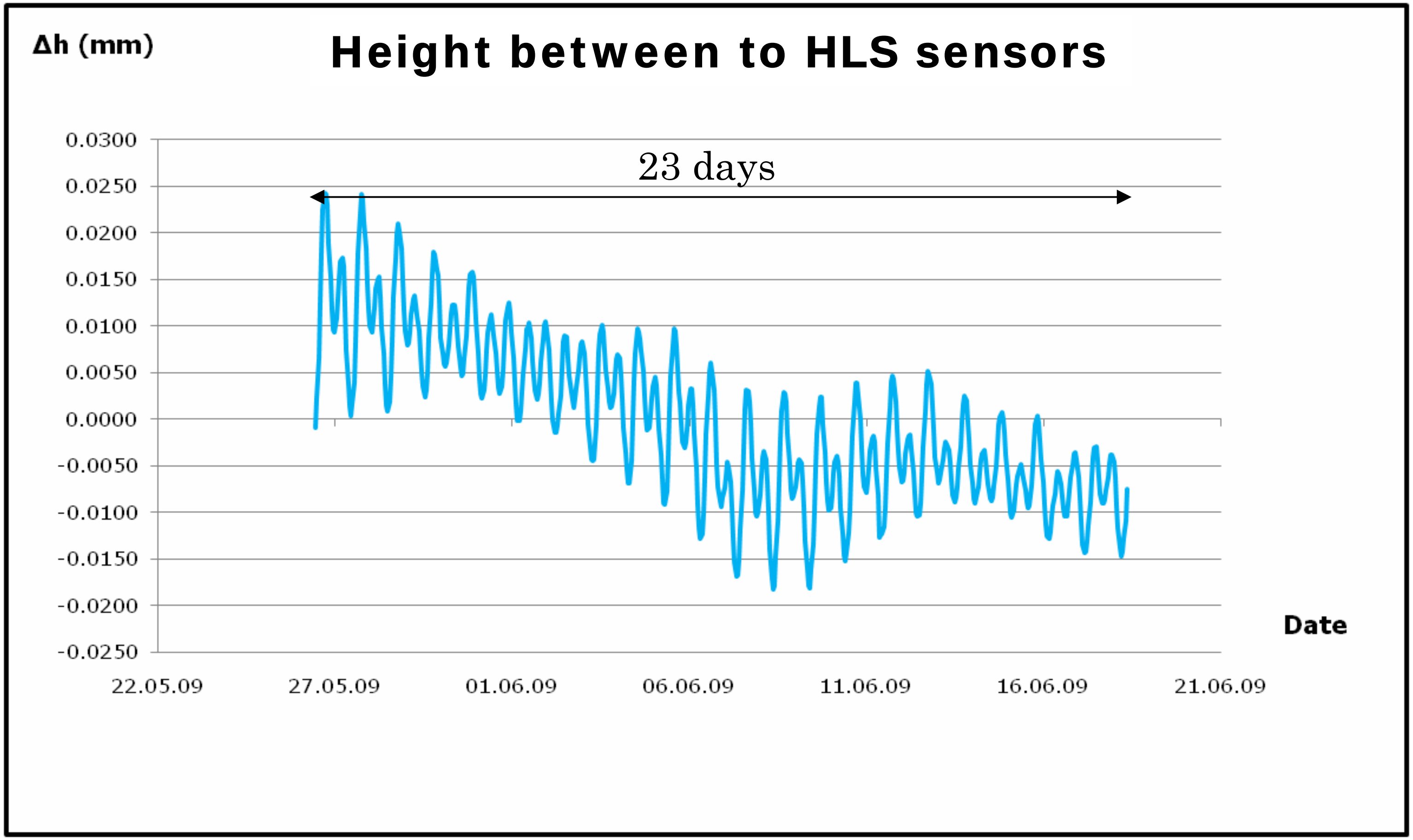

- Cyclical signal
- Mainly caused by Moon and Sun
- Maximum amplitude : 0.80 [m] !
- Long period, diurnal and semi-diurnal periods.



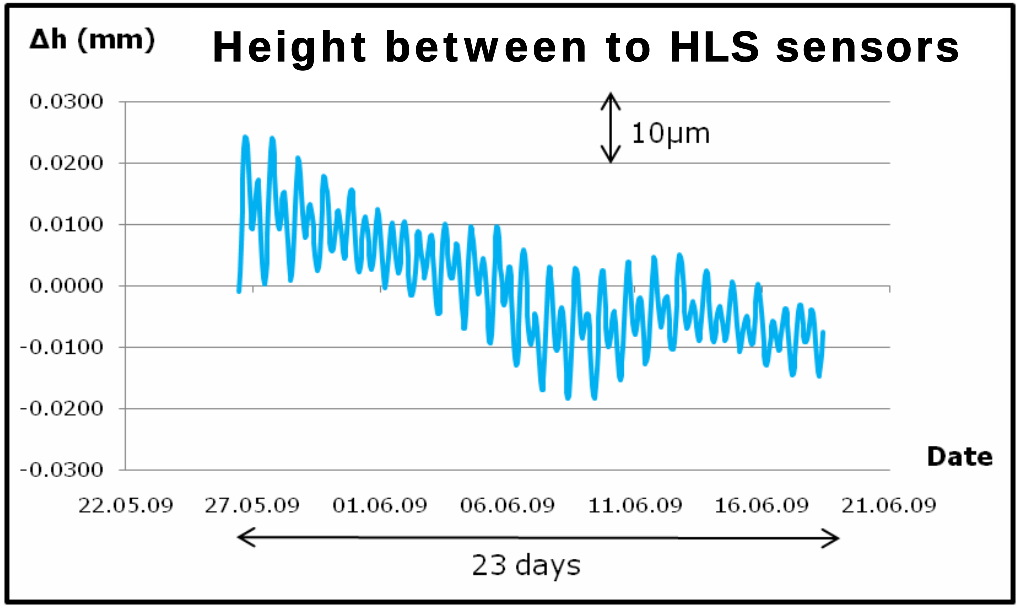

**The HLS measures** :

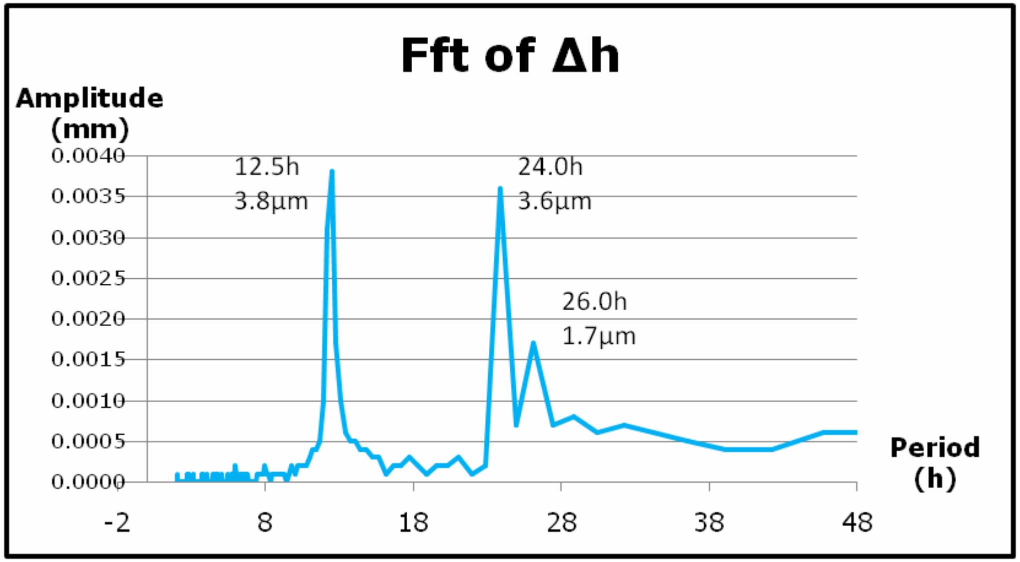
- The real height difference
- The movement of the earth's crust
- The tidal variation in gravity potential
- Others phenomenon…?

→ We want to measure the real height difference, so we must remove all factors that can be anticipated

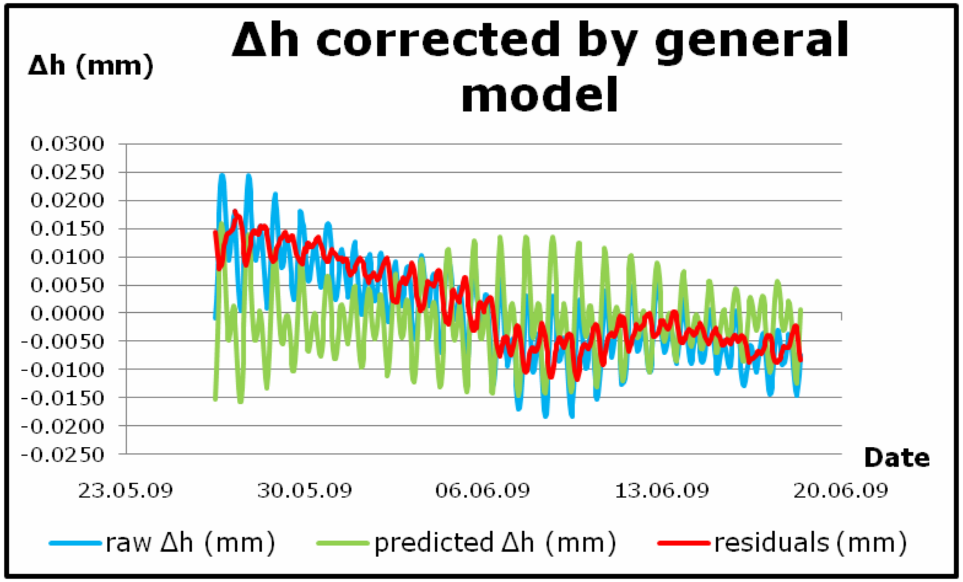


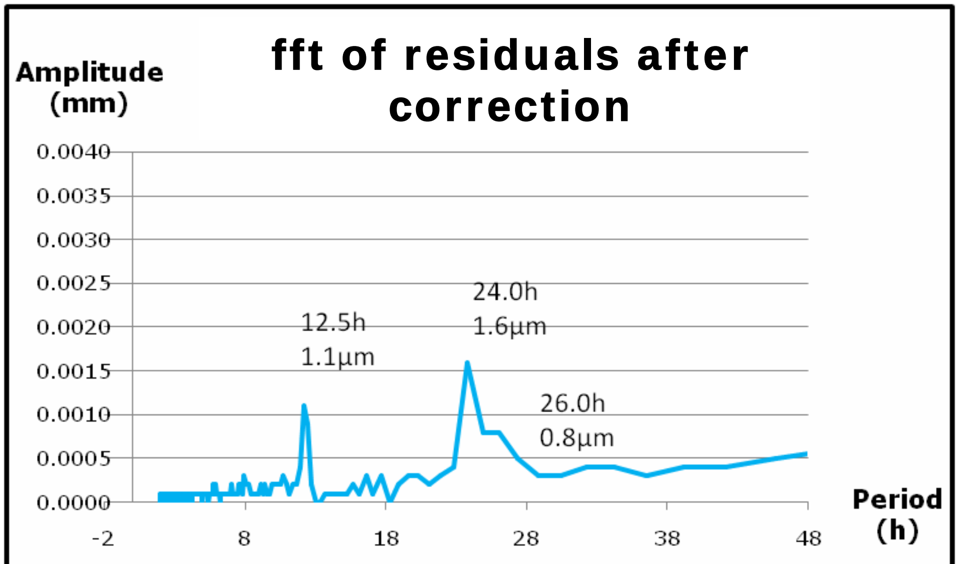

- Cyclical signal measured by a **H**ydrostatic **L**eveling **S**ystem
- In this example the 2 HLS sensors are separated from 115m




- 26/05/2009 → 18/06/2009 : **23 days**
- Sampling **1h**
- Distance between the 2 sensors : **115.438m**
- The Fast Fourier Transform shows **1 semi-diurnal** tide and **2 diurnal** tides

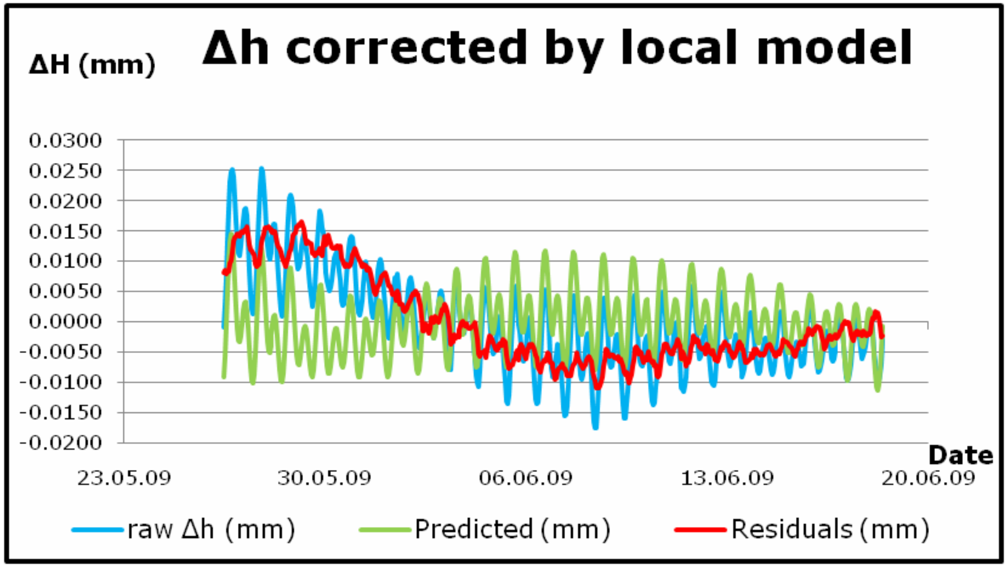


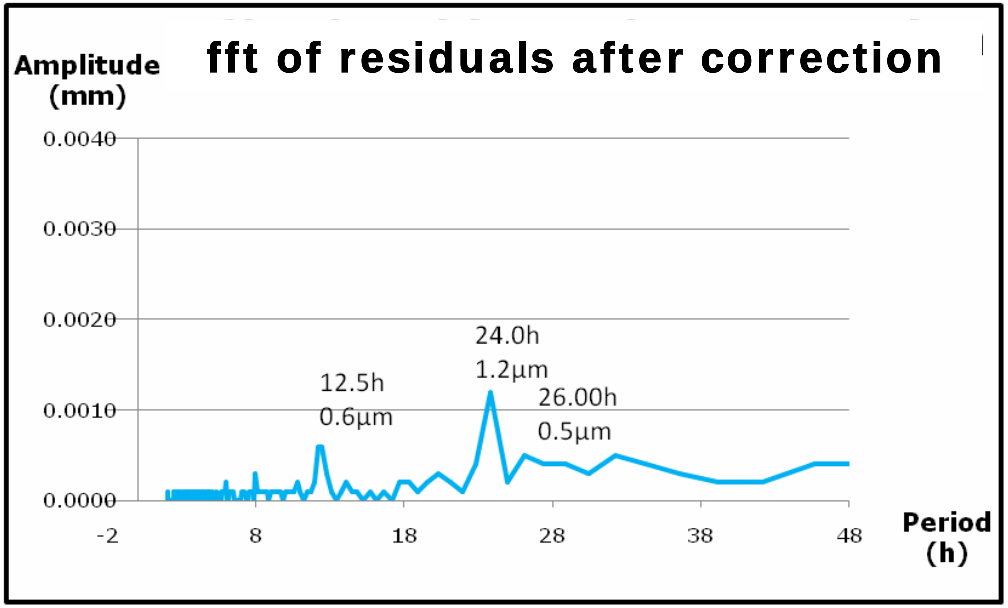




- Corrected by the **general model** of **ETERNA** (reference software to predict tides).

This model uses general parameters for tidal waves.

- Amplitudes reduced :
  - Diurnal divided by **3.5**
  - Semi-diurnal divided by **2**




- Corrected by a **local model** with **ETERNA.**

- This **local model** is obtained after an **analysis** of **another sample** of data.

It allows to have a better tidal model (specific parameters for tidal waves).

- Amplitudes reduced :
  - Diurnal divided by **6**;
  - Semi-diurnal divided by **3**

# How to Establish a Straight Line on the Dynamic Curved Surface of the Earth ?

(for the vertical component with HLS)

## Instrumentation :

- resolution and internal accuracy : **now :** 0.1, 1-2 [µm] resp. → **ok**
- stability with time (drifts) : **now :** < 5 [µm/month] → **objective :** < 1 [µm/month]
- absolute calibration : **now :** 10 [µm] → **objective :** 1 [µm]

## Reference System (time variable hydro-static shape) :

- **static part (geoid) :**
  - improvement and development of appropriate instruments (Zenith Camera, Autocollimator …)
  - measurement and data processing concept to get the geoid at [µm] accuracy level
  - determination of the spectrum for wavelengths < 1 [km]
  - determination of the impact of the time variable densities (underground water…)

- **time dependent part (earth tides)**
  - modelization of cyclical and systematical effects
  - better estimation of tidal parameters with longer time series of data
  - comparison with precise tiltmeters times series

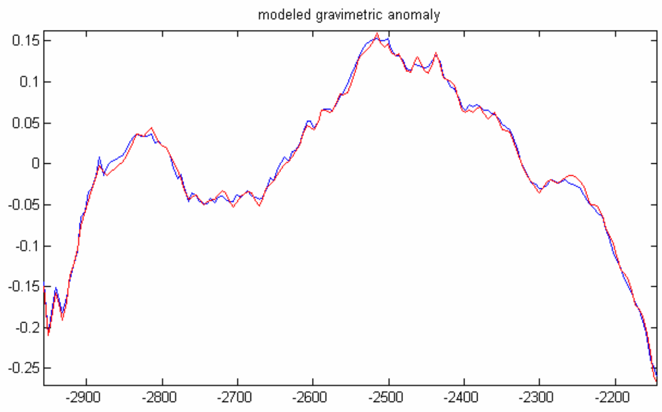
# Thanks' for your attention

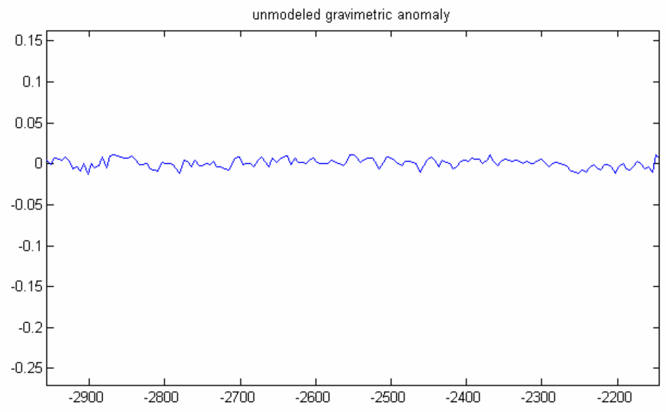
Julien Boerez

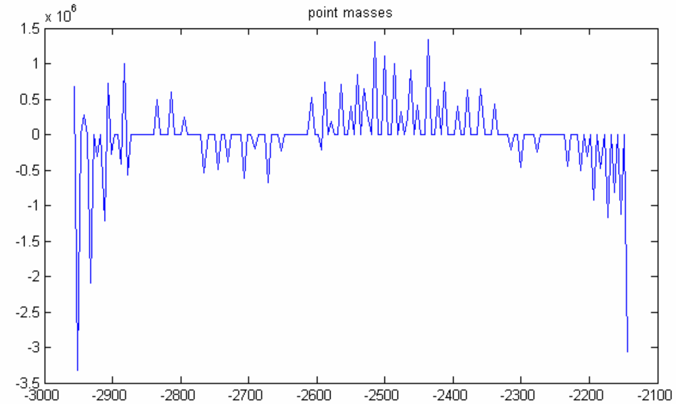
Sébastien Guillaume

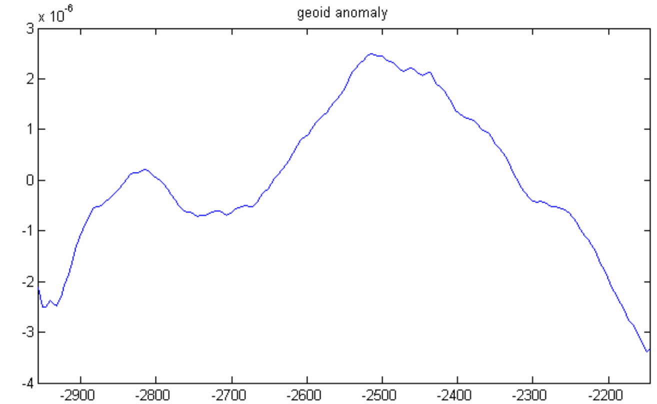
Mark Jones

# Gravimetric Measurements



# Summary

• The Global model of ETERNA has almost the same phases and amplitudes as the raw signal :

- o The cyclical signal measured by the HLS are the earth tides.
- o The residuals still have a cyclical component…

• After an harmonic analysis of a different sample, specific coefficients (for phases and amplitudes) for each wave can be used to predict tides

- o The residues are smaller than with global model
- o The residuals still have a cyclical component…

# Conclusion

- The harmonic analysis allows us to consider some of the effects of the environment over the theoretical tidal model :
  - Cavity forces
    (uneven forces acting on a tunnel's wall)
  - geological anomalies
    (local changes in the rock density)
  - response of the hydrostatic network
    (waves in the HLS water pipe, orientation of water pipe)

- We know that to obtain a very precise correction for the earth tides, we must analyze a long period of sample data.

- We need a long stable sample (several months) of data from the TT1 or other networks, with little noise and accurate measurements of temperature, humidity and pressure

# Conclusion

- This data sample needs to be analyzed to see if it is possible to completely remove the cyclical signal from the measurement data
- Once this analysis is completed it will be possible to determine if the HLS is well modeled solely by the earth tides or not
- If the residual signal after correction is too large to be ignored, another independent measurement is required to provide a control of the real changes in tilt in the TT1 tunnel
- Any discrepancy between the two will indicate if other environmental effects need to be considered in order to completely model an HLS, such as:
    - Underground water table levels
    - Changes in atmospheric pressure

# Next Steps

- Modification of the TT1 network :
  - To have long period data
  - Install a very accurate inclinometer to compare with HLS results
- Installation of another HLS network on TZ32 :
  - More stable than TT1 (less parasite noise)
  - Access to TT1 can be denied because of SPL project