Monitoring crustal vertical deformation by optical clocks network

Anh The Hoang [1,2], WenBin Shen [1,3]

[1] Time and Frequency Geodesy Center, Department of Geophysics, School of Geodesy and Geomatics, Wuhan University, China

[2] School of Agriculture and Natural Resource, Vinh University, Vietnam

[3] State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, China

(Correspondence: wbshen@sgg.whu.edu.cn)

EGU General Assembly 2022 - Session G4.1, 23-27 May 2022

https://doi.org/10.5194/egusphere-egu22-2016

Contents

1 Introduction

Basic principle: According to GRT, the vibration frequency of a clock at a position with higher potential is larger than that an identical clock at a position with lower potential.

Application: Comparing clocks set at two different points, we can determine geopotential difference as well as orthometric height difference between those two points.

$$\frac{f_Q - f_P}{f} = \frac{\Delta f_{PQ}}{f} = -\frac{W_Q - W_P}{c^2} \qquad (1)$$

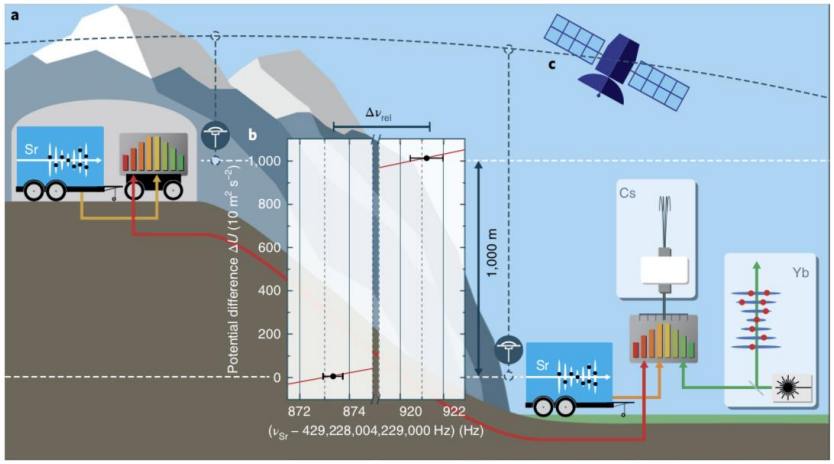


Fig 1. Comparing clocks to determine geopotential difference (Grotti et al. 2018)

2. Optical fiber frequency transfer

- Gravity frequency shift equation

$$\Delta W_{PQ} = -\frac{\Delta f_{PQ}}{f} c^2 + O(c^{-4}) \tag{2}$$

- The orthometric height of point B:

$$H_Q = \frac{H_P(g_P + 0.0424 \times H_P)}{g_P + 0.0424 \times H_Q^0} + \frac{\Delta f_{PQ}}{f} c^2 + O(c^{-4}) \tag{3}$$

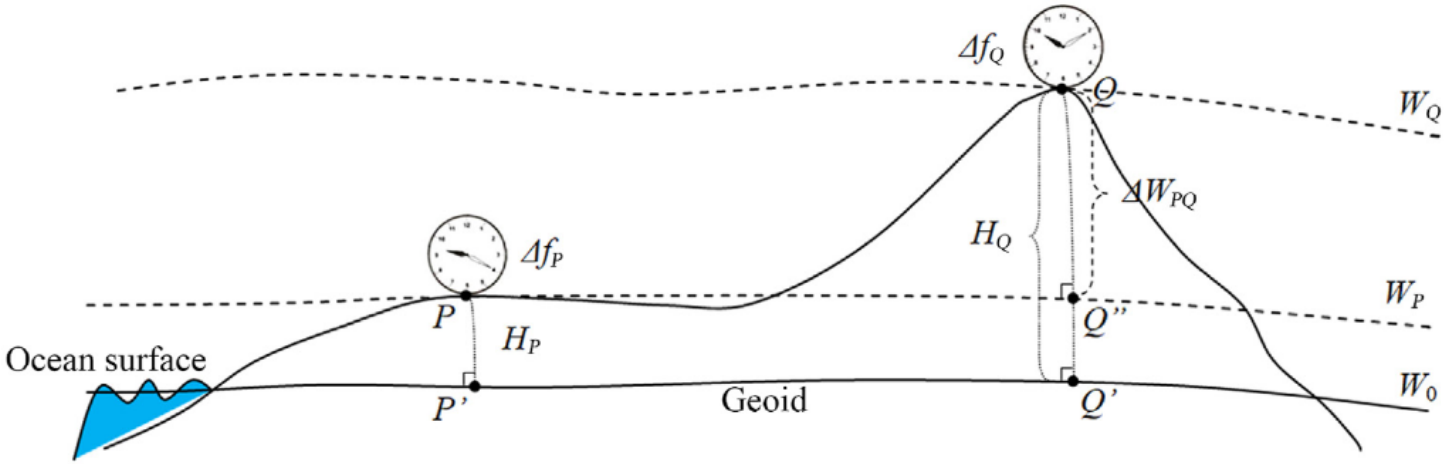


Fig 2. Determining the orthometric height by comparing frequency method (Hoang et al. 2021)

2. Optical fiber frequency transfer

- **Optical fiber frequency transfer (OFFT) method** (Shen et al 2019)

$$\Delta f = \frac{\Delta f_{PQ} + \Delta f_{QP}}{2} \qquad (4)$$

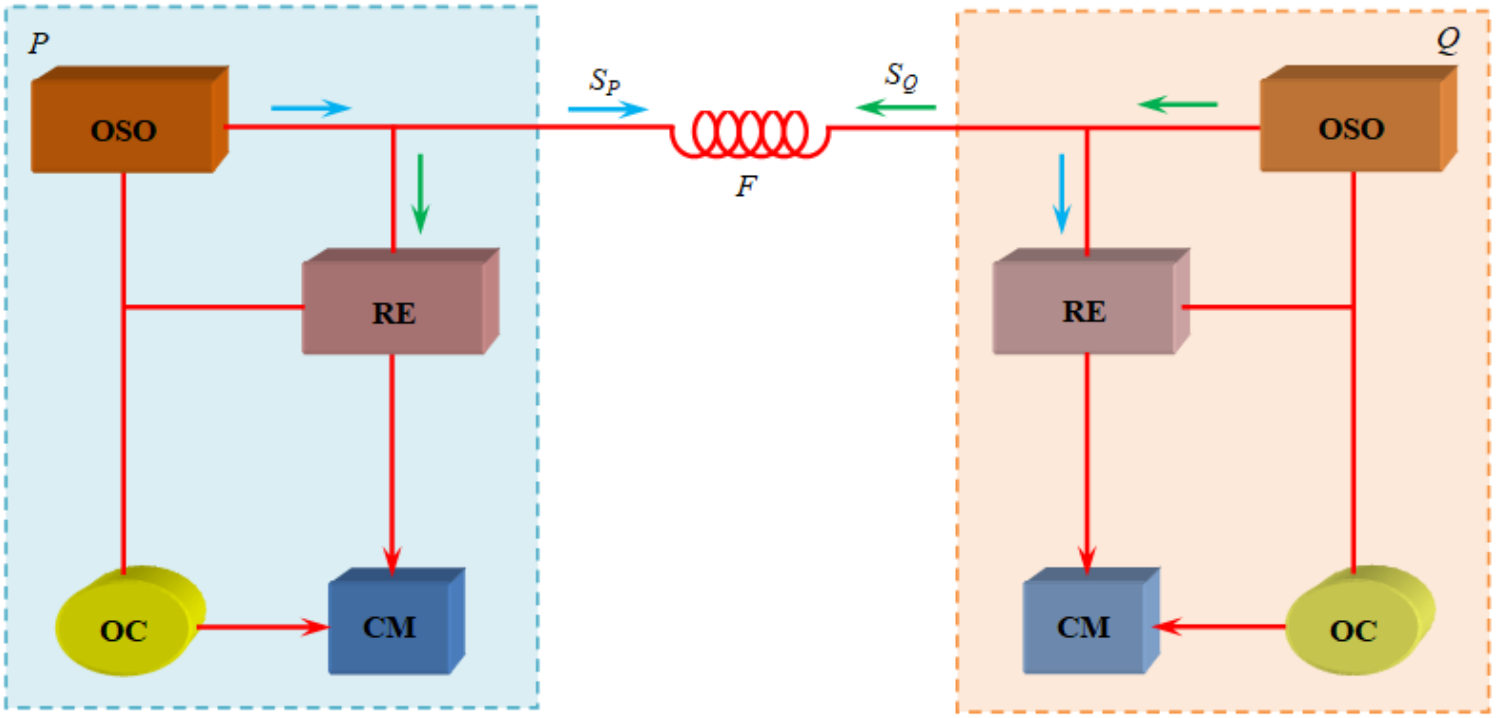
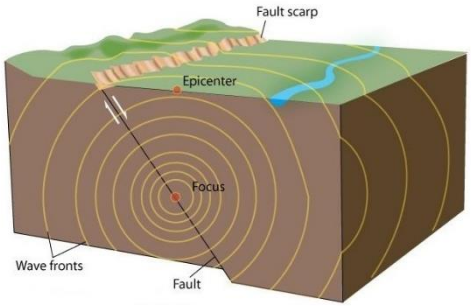


Fig 3. Schematics of the system for comparing frequencies transmitted via optical fiber (Hoang et al. 2021)

3. Monitoring vertical deformation

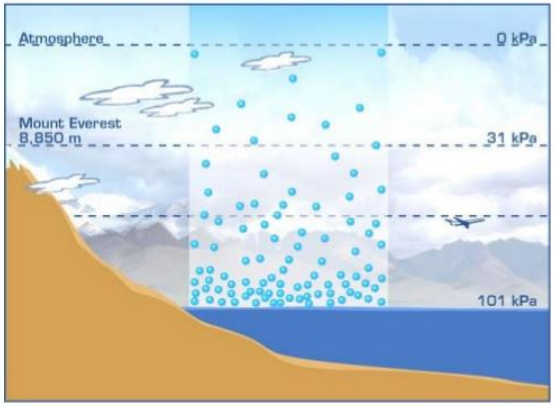
➢ Earth's crustal variations

Tides



Earthquakes

Ice mass changes



Atmospheric pressure

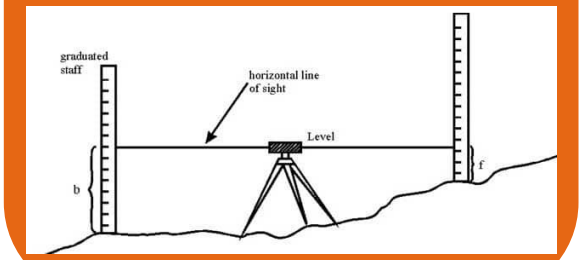
- Continental water
- Non-tidal ocean bottom pressure (OBP)
- Long-term viscoelastic responses of the mantle to deglaciation

3. Monitoring vertical deformation

➢ Measuring vertical crustal motions

Geodetic leveling

An uncertainty > 1cm when two points > 100 km

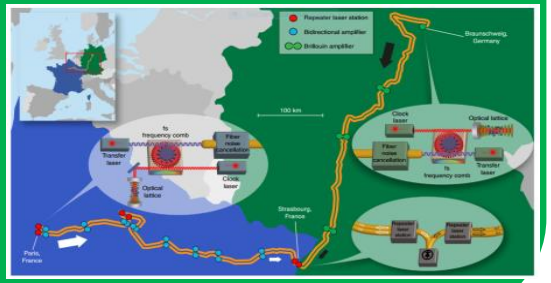


GNSS leveling

An uncertainty > 1cm in 24h average (from Wiki)

OFFT method

An uncertainty of several mm in several hours
No limit in distance
(Lisdat et al. 2016)



3. Monitoring vertical deformation

Measuring vertical crustal motions

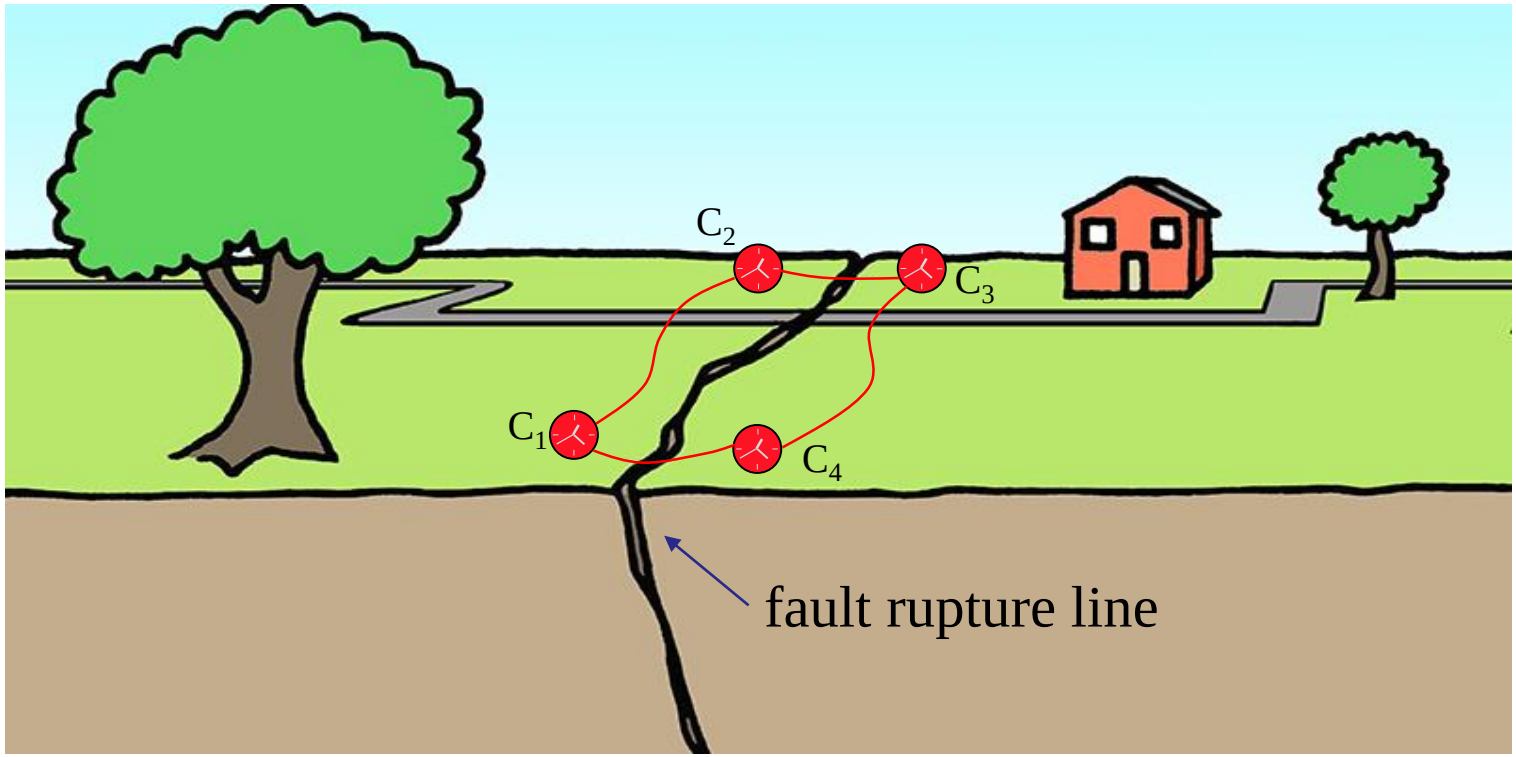


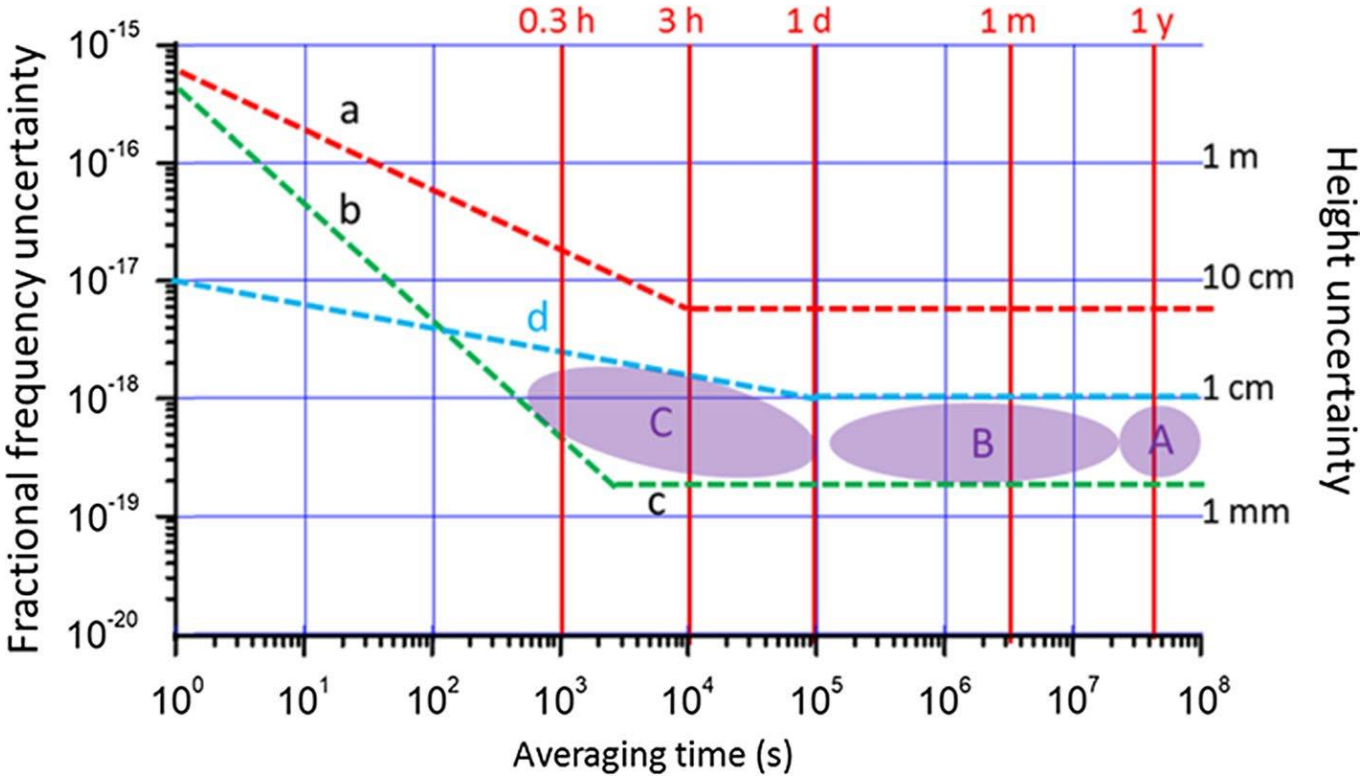
Fig 4. Schematics of optical clock network to monitor vertical motions

3. Monitoring vertical deformation

➢ Accuracy

a Takano et al. (2016)

b-c Near-future optical clocks



Accuracy:
1 mm ÷ 1cm level

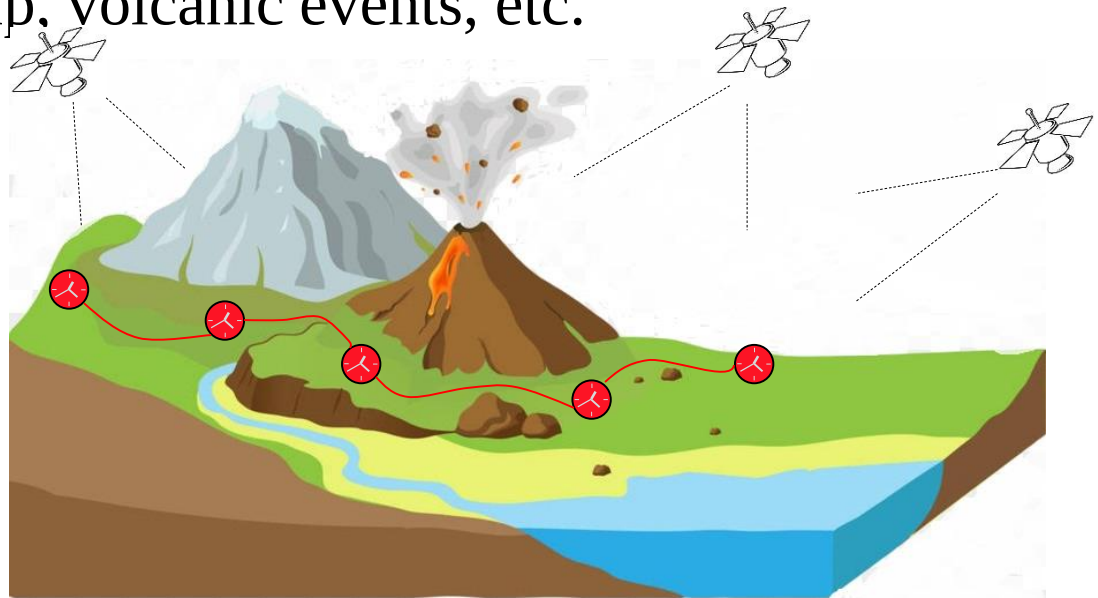
A-C Events which are expected

d GNSS (PPP) uncertainty

Fig 5. Fractional frequency uncertainties for fiber-linked optical lattice clocks as a function of an averaging time τ (Tanaka and Katori 2021)

4. Conclusion

- Fiber-linked optical clocks can precisely sense vertical motion
- Optical clock network can faster and more effectively monitor vertical deformation than GNSS/leveling
- In the future, optical clock network can be applied extensively, including vertical deformation, earthquake precurso, landslides, fault slip, volcanic events, etc.



EGU General Assembly 2022

Thank you for your attention !