Experiments of determining geopotential difference using two hydrogen atomic clocks based on TWSTFT technique

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Outline

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1.Introduction

Based on **general relativity theory**: A clock runs quicker at higher geopotential position （W_B） than at lower position （W_A）

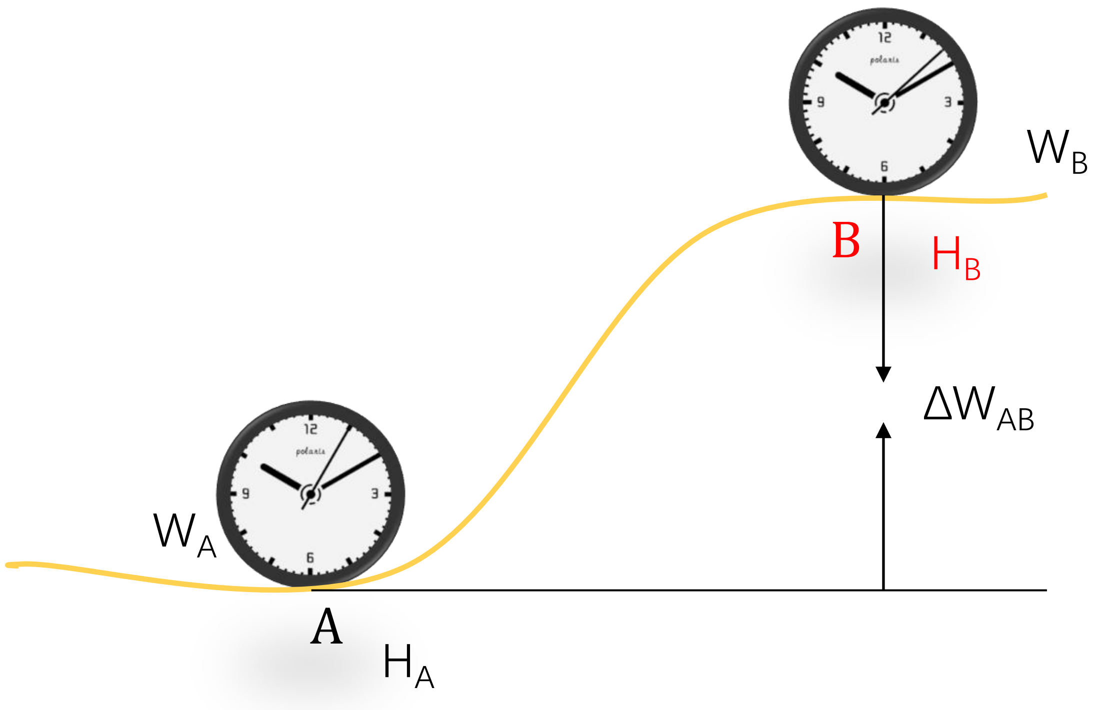

Fig. 1 Two clocks are located at A and B with geopotentials W_A and W_B , respectively

1.Introduction

To compare the time elapse between two remote atomic clocks, there are different ways, one of which is the **two-way satellite time and frequency transfer (TWSTFT)**.

Here we provide experimental results use the TWSTFT observations covering the period **from 7 December 2016 to 3 January 2017** at **China Aerospace Science & Industry Corporation (CASIC), Beijing**.

Fig. 2 Hydrogen clock used in the experiments

1. Abstract

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2.Method

•The geopotential difference of two arbitrary points can be expressed as

$$\Delta W_{AB} = W_B - W_A = (c^2 + W_A)(\frac{dT_B}{dT_A} - 1) \approx c^2 (\frac{dT_B - dT_A}{dT_A}) \quad (1)$$

•We determine the time elapse difference between two clocks located at stations A and B via **TWSTFT** technique, which is based on the exchange of timing signals through geostationary telecommunication satellites (see Fig. 1). Mathematical expressions are referred to Shen et al. (2019)

2.Method

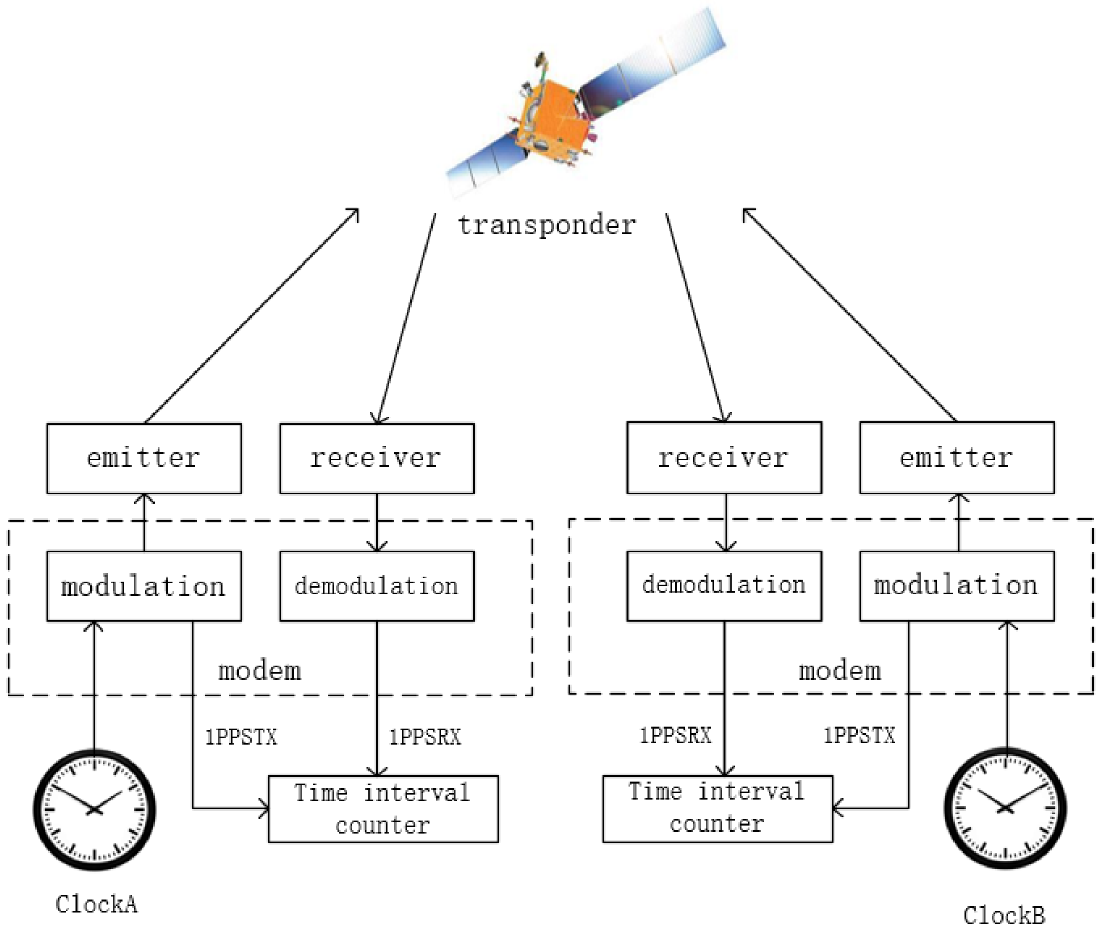

Fig. 3 The scheme of TWSTFT. Station A sends a time signal to a communication satellite (CS), the latter transponds it to station B, which receives this signal. At the same time, station B sends a time signal to the CS, the latter transponds it to station A, which receives this signal. By exchange the two signals, one can determine the time elapse difference between the two clocks located at A and B

2.Method

The **TIC (time interval counter)** reading of station A is

$$R_{BA} = \tau_{A\to B} + \Delta T_{AB} = \tau_A^U + \tau_B^D + \tau_A^T + \tau_B^R + \tau_S^{AB} + \Delta\tau_{Sag}^{AB} + \Delta T_{AB} \quad (2)$$

The **TIC** reading of station B is

$$R_{AB} = \tau_{B\to A} - \Delta T_{AB} = \tau_B^U + \tau_A^D + \tau_B^T + \tau_A^R + \tau_S^{BA} + \Delta\tau_{Sag}^{BA} - \Delta T_{AB} \quad (3)$$

τ_i^U and τ_i^D（i=A or B） are the uplink and downlink signal delay of ground station

τ_i^T and τ_i^R are transmitting and receiving delay for ground station

τ_S^{AB} and τ_S^{BA} are satellite transponder delay for two links

$\Delta\tau_{Sag}^{BA}$ and $\Delta\tau_{Sag}^{AB}$ are Sagnac effect error caused by two links

2.Method

•The Modified Allan Deviation is applied to evaluate the frequency stability of experiment results, expressed as

$$\sigma_y^M(\tau)=\sqrt{\frac{1}{2\tau^2 n^2(N-3n+1)}\sum_{j=1}^{N-3n+1}\left(\sum_{i=j}^{n+j-1}(x_{i+2n}-2x_{i+n}+x_i)\right)^2} \qquad (3)$$

3. Experiment Setup and Data Processing

- The data used in our experiments are measured by atomic clocks based on the TWSTFT approach.

- First, we placed two clocks in ground floor B1, obtained TWSTFT observations from Dec 15 to 25, 2016. Then we moved one clock to the fifth floor with a height 22 m above B1 (see Fig.5) and obtained TWSTFT observations from Dec 28 to Jan 3, 2017.

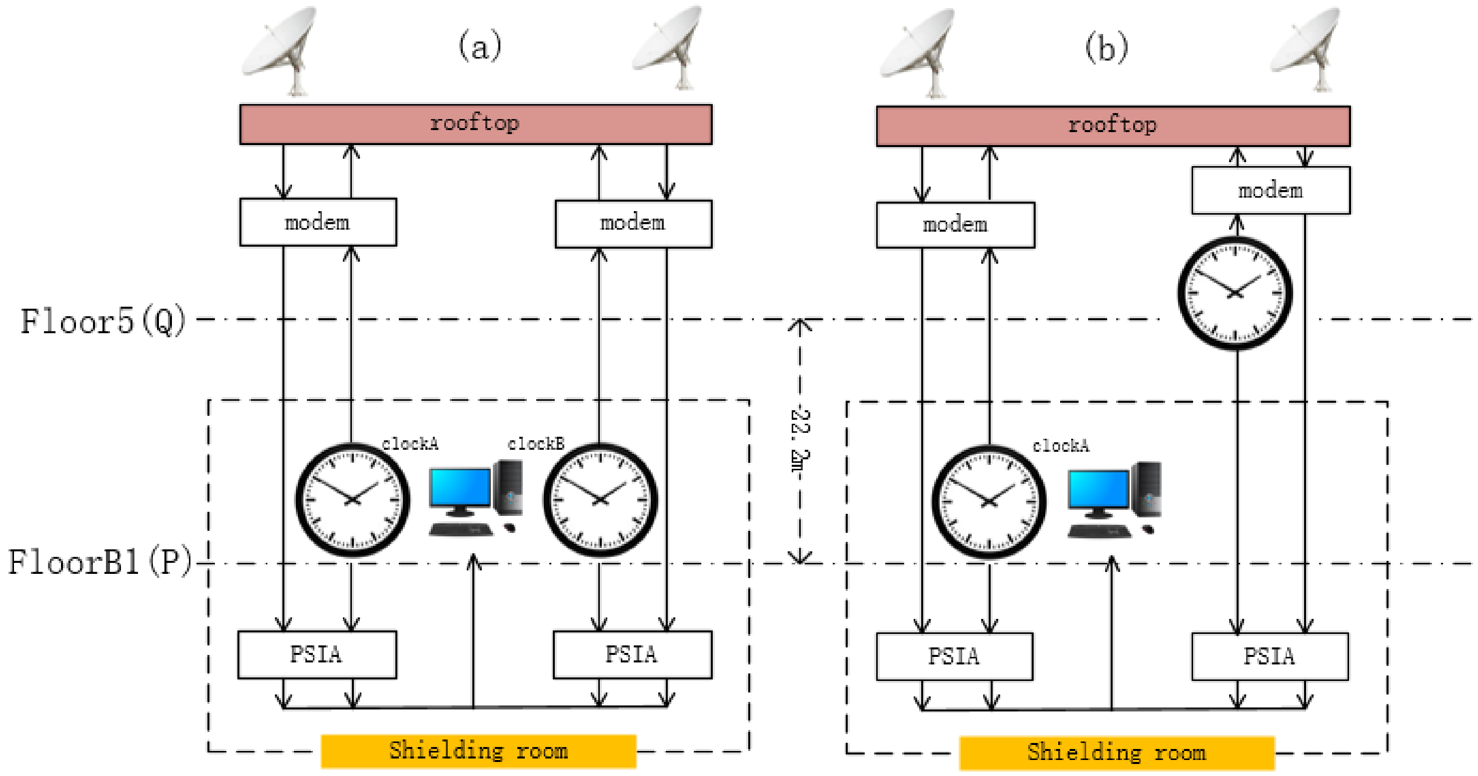

Fig. 4. (a) Zero-baseline experience and (b) geopotential difference experience. In zero-baseline experience two clocks are placed on the same floor B1 (at position P). Then clock B is carried to fifth floor at position Q. Two clocks were connected with a satellite antenna through connection cables, modems, and a PSIA (Modified after Shen et al. 2019)

3. Experiment Setup and Data Processing

- EEMD is used to eliminate from the original observations the periodic signals, which are useless for our present purpose. EEMD results are shown in Fig.4, and data after filtering are shown in Fig.5

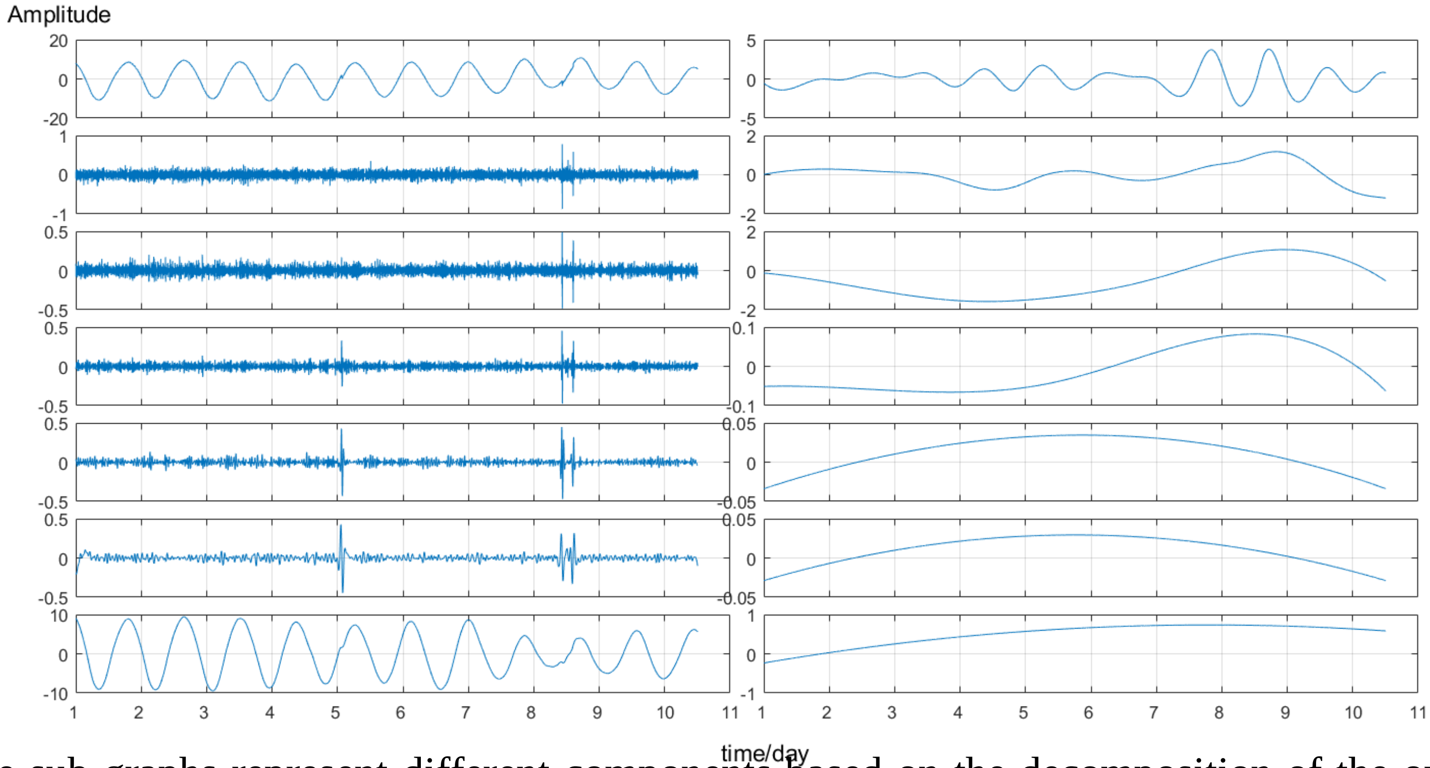

Fig. 5 EEMD processing. The sub-graphs represent different components based on the decomposition of the original data. We can find some of the sub-graphs don’t contribute to the time difference. So we removed them away from the raw data.

3. Experiment Setup and Data Processing

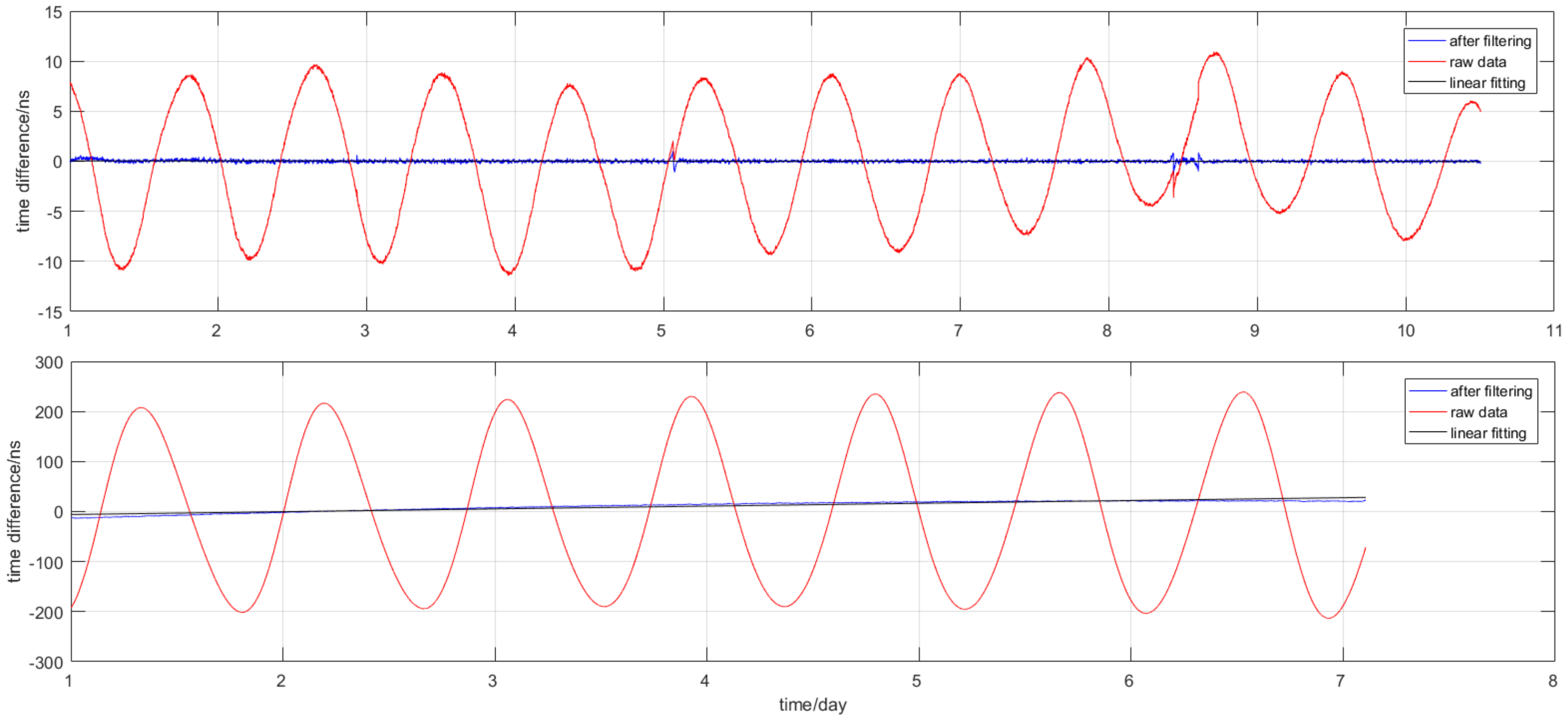

Fig. 6 Red curves are raw data. Blue curves denote the residuals after removing periodic signals from the raw data. Black curves are linear fitting of the residuals. The slope rate of fitting line denotes the time elapse difference which is used to determine the geopotential difference. Top slot denotes experiment with height difference, and bottom slot denotes experiment in zero-baseline.

3. Experiment Setup and Data Processing

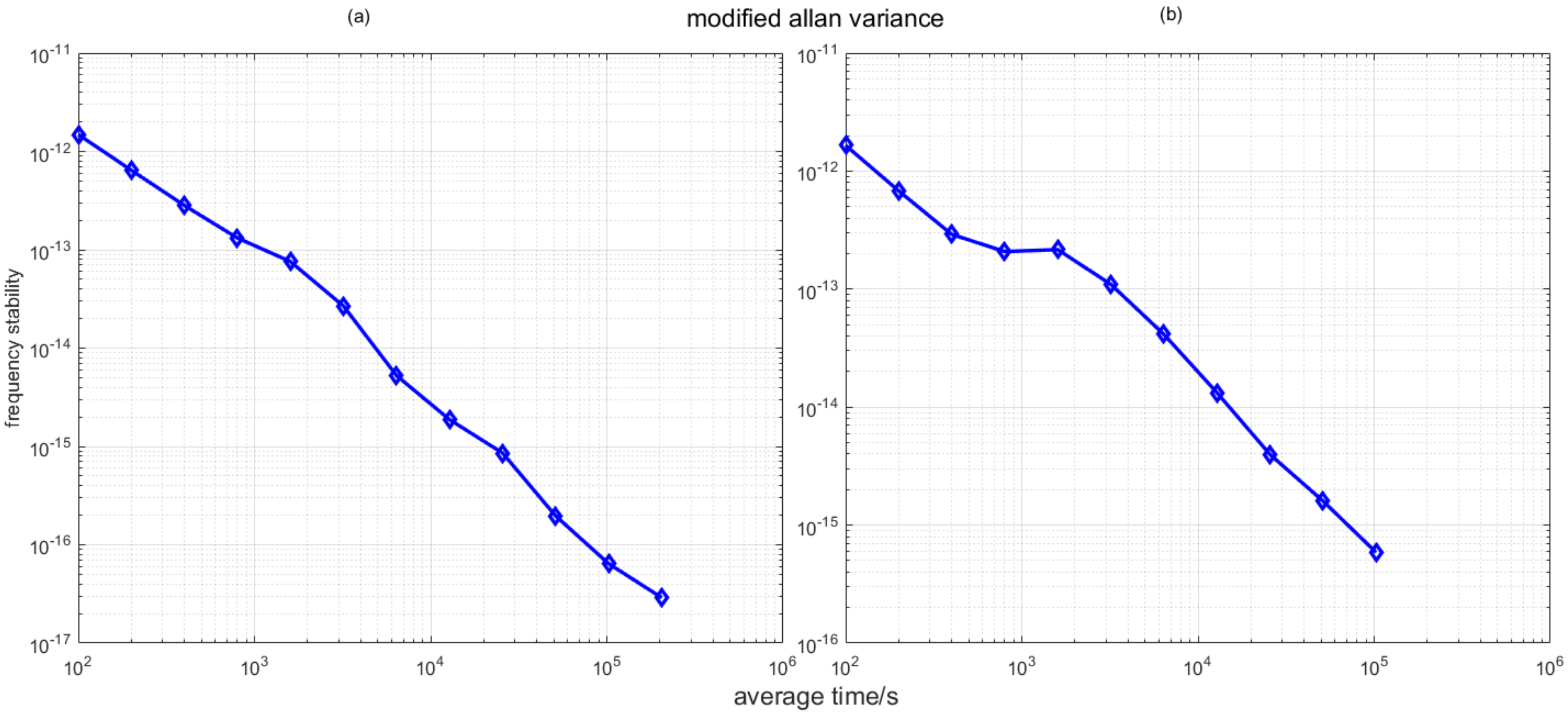

Fig. 7 Frequency stabilities of the clocks during two experiments periods are described by modified Allan variance. (a) Experiment with height difference; (b) experiment in zero-baseline.

1. **Abstract**

2. **Method**

3. **Experiment Setup and Data Processing**

4. **Results**

4.Results

Table 1 parameters and results in experiments in this study

Parameters	**Values**
Slope rate of time difference	7.8765×10^{-16}
Slope rate of zero-baseline	1.1768×10^{-14}
True value of height difference	22.2 m
calculated by time difference	100.8 m
Difference between true and calculate value	78.6 m
Long term clock frequency stability in height measurement	6.42×10^{-17}
Long term clock frequency stability in zero-baseline	5.87×10^{-16}
Accuracy level	54.3 m

- Parameters and results are listed in Table 1
- The result of our experiments show the height difference is 100.8 m and the true value is 22.2 m. The difference is 78.6 with uncertainty of 54.3 m
- **In conclusion, TWSTFT is a potential approach for determining geopotential difference, and the accuracy depends mainly on the stability of the clocks used.**

Thanks for your attention！