# Estimation of Integrity Support Message (ISM) of Precise Satellite Orbit and Clock Corrections Based On PPP-AR Phase Residuals

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## MOTIVATION

The quality monitoring of precise orbit and clock products is crucial for achieving high-precision Global Navigation Satellite System (GNSS) positioning. Traditional methods evaluate the quality of satellite precise orbit and clock products by calculating the Signal-in-Space Range Error (SISRE). However, the SISRE is not suitable for real-time quality monitoring. To address this, the carrier phase residuals of Precise Point Positioning with Ambiguity Resolution (PPP-AR) were used to estimate the Integrity Support Messages (ISM), which are then utilized to calculate the fault detection threshold.

## METHODOLOGY

### PPP-AR residuals equations

$$res_P = P_{IF}^{Si} - \left(\tilde{\rho}_r^{Si} + dt_{r,IF}^{S} + m_{W,r}^{Si} T_{W,r}\right)$$

$$= P_{IF}^{Si} - \left(\left\| X_{precise}^{Si} - X_r \right\| - dt_{precise}^{Si} + dt_{r,IF}^{S} + m_{W,r}^{Si} T_{W,r}\right)$$

$$res_L = L_{IF}^{Si} - \left(\tilde{\rho}_r^{Si} + dt_{r,IF}^{S} + m_{W,r}^{Si} T_{W,r} + \bar{N}_{r,IF}^{Si}\right)$$

$$= L_{IF}^{Si} - \left(\left\| X_{precise}^{Si} - X_r \right\| - dt_{precise}^{Si} + dt_{r,IF}^{S} + m_{W,r}^{Si} T_{W,r} + \bar{N}_{r,IF}^{Si}\right) \approx res_{orb+clk+phsbias}$$

$$res_{orb+clk+phsbias} < res_L$$

- The ambiguity-fixed ionosphere-free (IF) phase and code residuals are generated by calculating the difference between the ionosphere-free linear combination (IF LC) of the raw observations and the sum of the computed geometric distance and other parameters.
- After parameter estimation, the of the satellite-related corrections are the main components in the IF phase residuals, particularly in the presence of faults or biases in the corrections.

### Phase residuals characteristic analysis

#### ◆Sample moments

$$m_r = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - m_1\right)^r, \quad r \geq 2$$

- Sample moments are a method used to characterize the distribution of data in a statistical data set, including sample mean, sample standard deviation, sample skewness, and sample kurtosis;

#### ◆Allan Variance

$$\sigma^2(T) = \frac{1}{2\left(N_C - 1\right)}\sum_{k=1}^{N_C - 1}\left(\bar{y}_{k+1} - \bar{y}_k\right)^2$$

- Allan variance analysis has been widely used and is considered the preferred method for identifying quantization noise, white noise, correlated noise, sinusoidal noise, random walk, and flicker noise.

#### ◆Power Spectral Density (PSD)

$$PSD \propto \frac{1}{f^{\beta}}$$

- Power Spectral Density (PSD) is a method used to analyze noise in a signal and determine its type and characteristics.

### Integrity Support message estimation

#### ◆Paired overbound method

$$G_L(x) \geq G_a(x), \forall x,$$

$$G_R(x) \leq G_a(x), \forall x.$$

- The paired overbound method uses the left and right functions to realize the overbound purpose for a single random variable and the sum of random variables[4]. The Gaussian overbounding parameters (the mean b and the standard deviation σ) are obtained.

$$Th = b + C^{-1}\left(1 - \frac{P_{SAT}}{2}\right) * \delta$$

- Then, the fault detection threshold is determined using these parameters and the integrity monitoring of precise corrections can be performed by comparing the calculate phase residuals to specified thresholds ***Th***.

## RESULTS

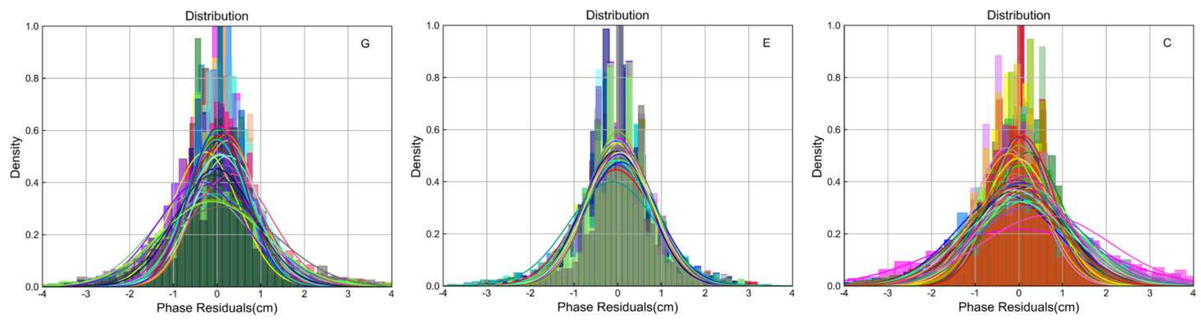


Figure 1 Histogram and fitted normal distribution curves of IF phase residuals

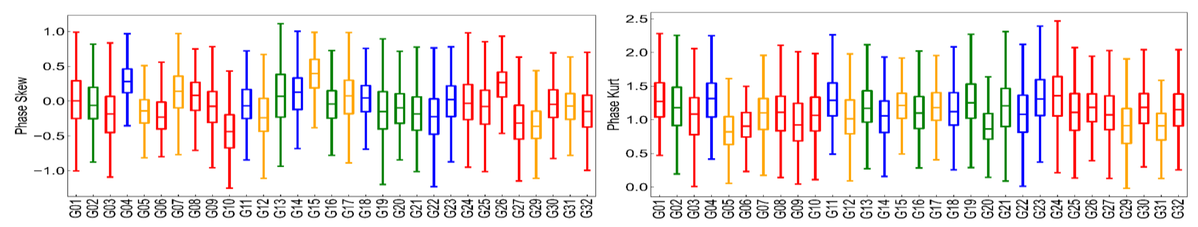


Figure 2 The daily sample Skewness and Kurtosis of GPS phase residuals

- The sample moments indicate that the phase residual deviates from the ideal zero-mean Gaussian distribution and presents a relatively symmetrical (single-peaked) super-Gaussian distribution;

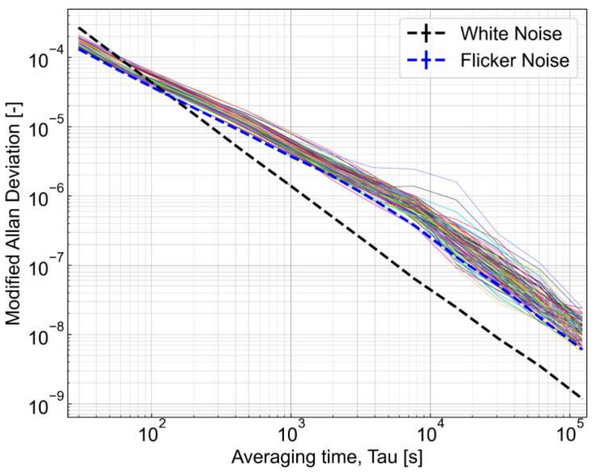


Figure 3 MDEV of the analyzed phase residuals for all observed satellites

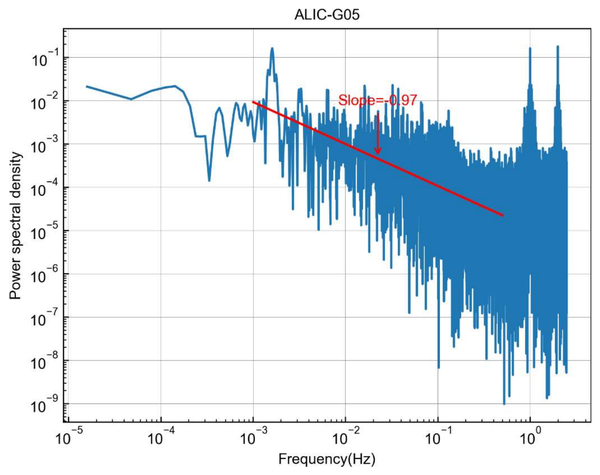


Figure 4 PSD of the analyzed phase residuals for G05

- The Allan Variance and PSD results show that the noise amplitudes for all satellites are at the same order of magnitude and the flicker noise is the dominant noise in phase residuals;

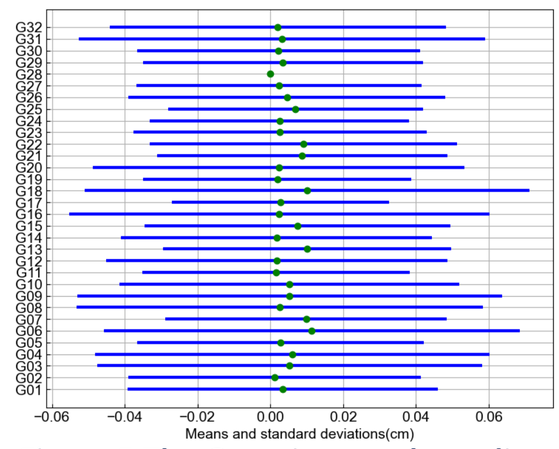


Figure 5 The Gaussian overbounding mean and standard deviation value of IF phase residuals

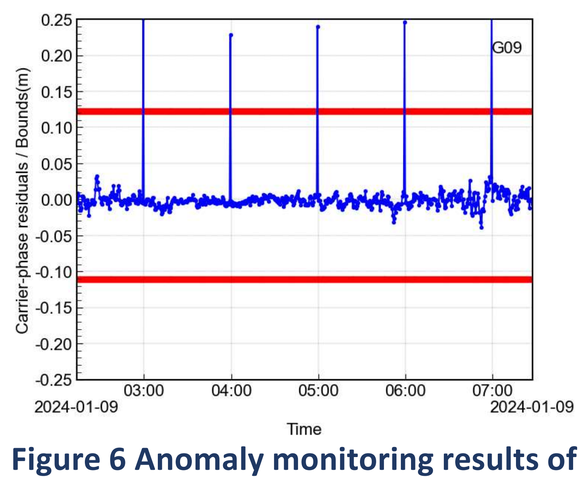


Figure 6 Anomaly monitoring results of step fault for G09 in the clock products (red: Threshold, blue: Phase residuals)

- The ISM parameters of each satellite were successfully calculated using the Paried method;
- Simulated step faults were inserted to clock produsts and experimental results indicate that the monitoring threshold effectively identifies anomalies in precise satellite

## CONCLUSION and OUTLOOK

The IF PPP-AR phase residual were first extracted to characterize the residuals of the precise clock and orbit corrections. Based the residual characteristic, the paired overbounding method successfully estimates the bias and standard deviation. Experiments demonstrated that the phase residual can capture anomalies in the precise corrections and these anomalies can be detected using the threshold calculated from the ISM. Future work will focus on utilizing more data to obtain more universal results and applying these ISMs to PPP protection level (PL) calculations.