# Strategies to counter scintillation in challenging GNSS PPK operational scenarios

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## INTRODUCTION

Global Navigation Satellite System (GNSS) signals propagating through ionospheric regions affected by electron density irregularities are subject to rapid fluctuations in amplitude and/or phase, known as ionospheric scintillation. These disturbances degrade signal quality, introducing uncertainties in observables, causing cycle slips, and potentially leading to loss of satellite tracking (loss of lock), thus compromising GNSS-based applications.

## OBJECTIVE

This study aims to develop and evaluate strategies to improve the modeling of GNSS observables under scintillation conditions, thus enhancing positioning accuracy in challenging ionospheric environments. More specifically, the work seeks to:

- Characterize the impact of ionospheric scintillation on phase observations within the positioning solution;
- Adapt the stochastic modeling of GNSS observables to better represent signal behavior under severe scintillation;
- Reduce the negative effects of data degradation, including gaps and loss of signal tracking;
- Improve the robustness of the estimation process by identifying and excluding unreliable measurements during filtering;
- Assess the effectiveness of the proposed strategies within a PPK framework and explore their potential applicability to real-time positioning.

## METHODS

The methodology was assessed using a Post-Processed Kinematic (PPK) approach, based on data collected at 2 Hz from a dedicated network of experimental GNSS stations located in the region of Presidente Prudente, São Paulo State, Brazil. The dataset corresponds to a period of strong scintillation activity, also influenced by a magnetic storm that temporarily inhibited scintillation. Implementation was carried out using a modified version of the RTKLib software named as RTKLib-ISMIT (ISMIT: ionospheric scintillation mitigation).

- In summary, RTKLib-ISMIT implements a stochastic model adapted for severe scintillation scenarios, which uses SNR observables or ROTI as input; criteria for optimally selecting the best base satellite for double differences; techniques to mitigate data gaps caused by signal degradation; criteria to better identify and exclude highly degraded observations from the Kalman Filter estimation process.

## RESULTS

The implementation of the proposed strategies resulted in substantial improvements in positioning performance under scintillation conditions, with accuracy gains reaching up to 90% compared to conventional processing approaches:

- The adaptive stochastic modeling allowed a better representation of the increased variability of phase observations, while the data screening and gap mitigation techniques reduced the impact of signal degradation.
- Additionally, the exclusion of highly degraded measurements contributed to a more stable and reliable estimation process within the Kalman Filter framework.
- The improvements were more pronounced in multi-constellation solutions and for short baselines, where increased satellite availability enhanced robustness against scintillation effects.
- Some limitations were observed, particularly in ambiguity resolution, where the effectiveness of the ratio test was reduced, and in the detection of cycle slips under severe scintillation conditions, indicating areas for further refinement.

*Base station CTAS were equipped with Septentrio PolaRx5s ISMR receiver providing scintillation levels.*

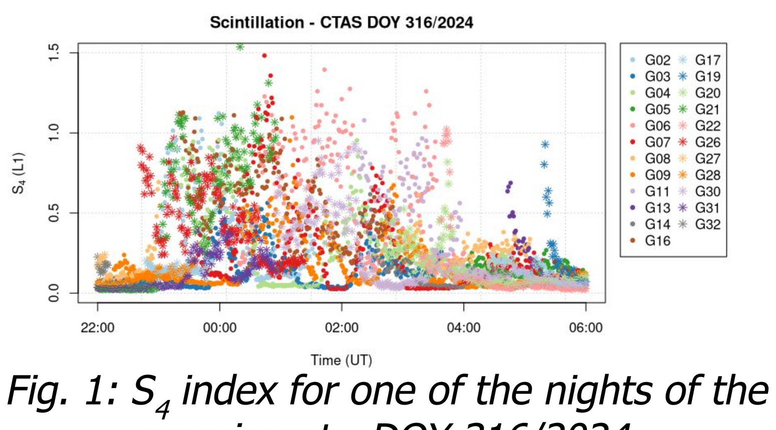


*Fig. 1: $S_4$ index for one of the nights of the experiment - DOY 316/2024.*

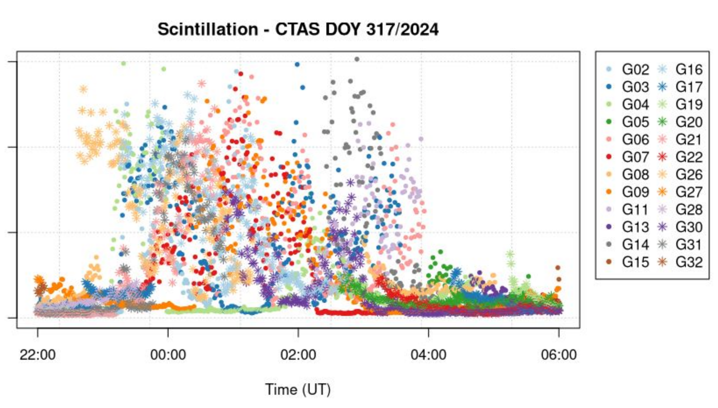


*Fig. 2: $S_4$ index for another night of the experiment - DOY 317/2024.*

*Fig. 3 shows a sample PPK comparison for a short baseline: default solution (a) and mitigated (b). The plots show horizontal (δH) and vertical (δV) errors, as well as fix/float indicators.*

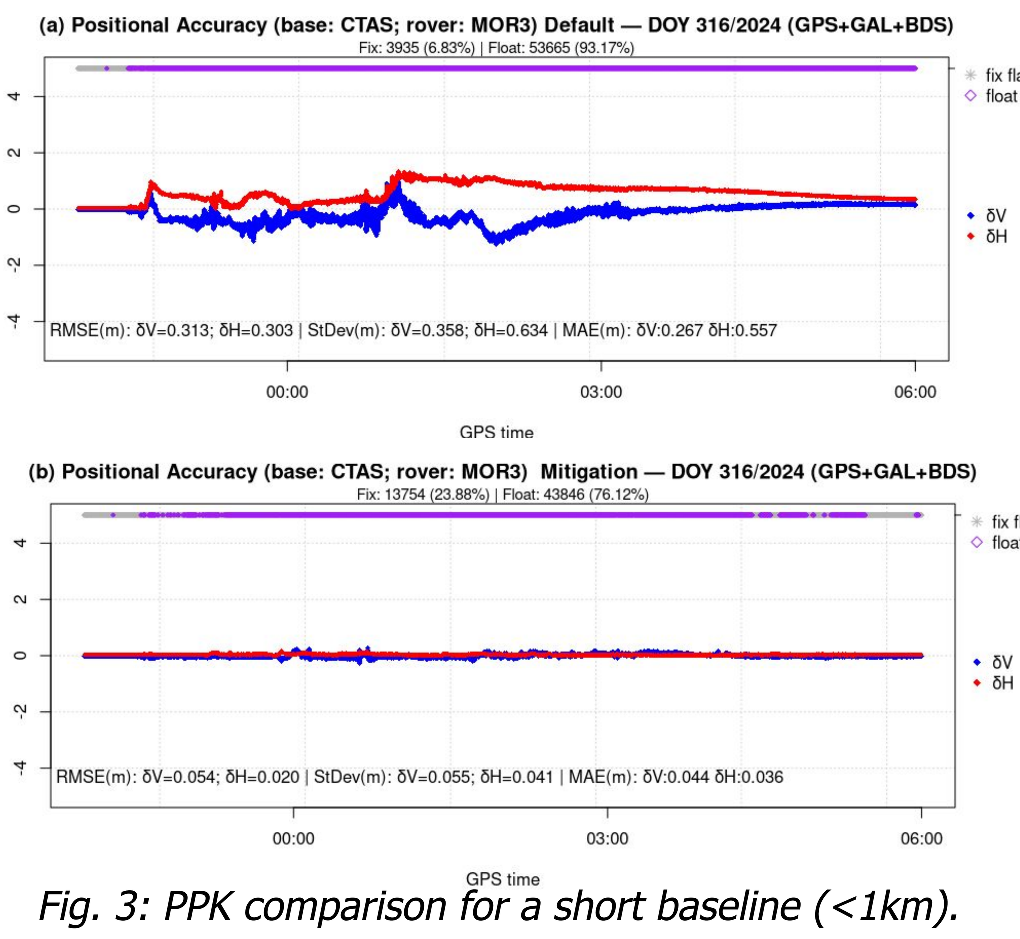


*Fig. 3: PPK comparison for a short baseline (<1km).*

*Fig. 4 shows the overall Root Mean Squared Error (RMSE) for both horizontal (δH) and vertical (δV) components for default (.def) and mitigated (.mit) solutions, demonstrating the effectiveness of the proposed method within different constellation setup.*

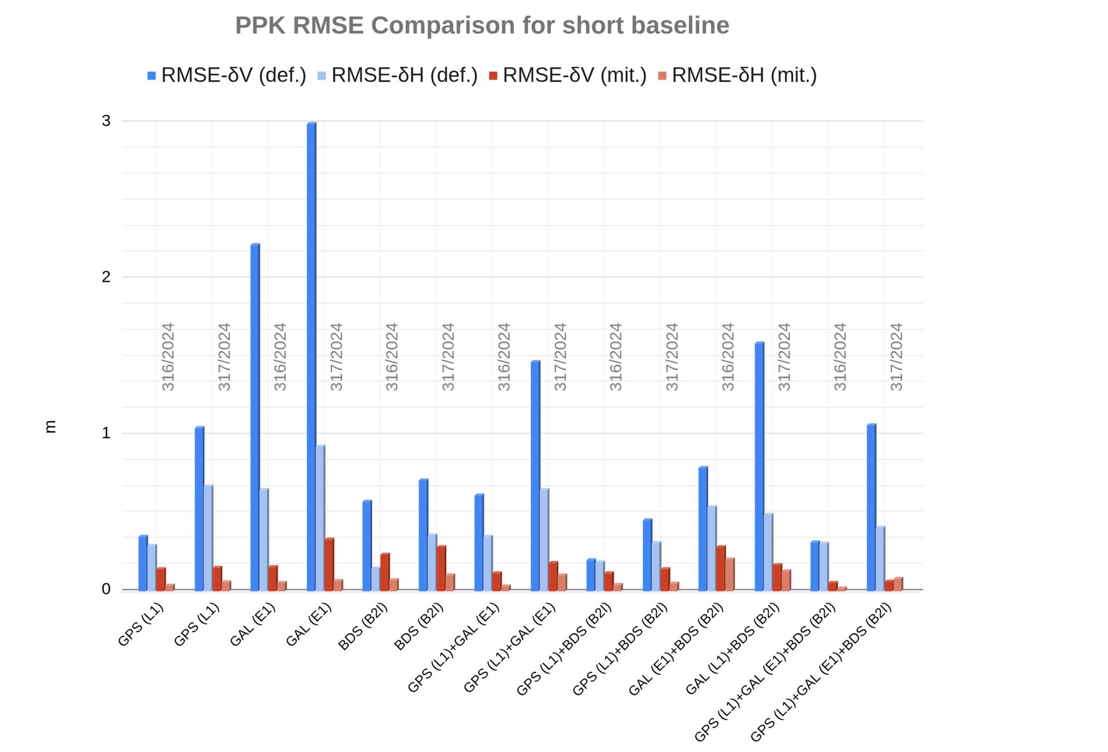


*Fig. 4: RMSE comparison between default and mitigated solutions with different constellation setup.*

## CONCLUSIONS

The proposed strategies proved effective in mitigating the impact of ionospheric scintillation on GNSS, leading to substantial improvements in positioning accuracy within a PPK framework.

- The adoption of an adaptive stochastic model, combined with data screening and gap mitigation techniques, enhanced the robustness of the estimation process under challenging ionospheric conditions;
- The results also revealed limitations, particularly related to ambiguity resolution reliability and cycle slip detection, indicating the need for further refinement of quality control procedures;
- Overall, the findings demonstrate strong potential for extending these approaches to real-time GNSS positioning, contributing to more reliable performance in critical high-precision applications operating under adverse ionospheric environments;
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