Temporal Analysis of MSTID Impact on GNSS Positioning in Japan for 2022-2023

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Purpose of this study

This study aims to conduct a comprehensive statistical analysis of the impact of Medium-scale traveling ionospheric disturbances (MSTIDs) on Global Navigation Satellite Systems (GNSS) positioning, utilizing observations from ground based GNSS receivers. The specific objective is to investigate the statistical distribution of MSTID-induced ranging errors and their impact on GNSS positioning accuracy under different ionospheric conditions over Japan.

Methods

This study investigates the effects of MSTIDs on the accuracy of GNSS positioning across the Japanese islands. To achieve this dual-frequency GPS datasets were collected from a vast network (GPS Earth Observation Network (GEONET)) of over ~1300 GNSS receivers in Japan. These datasets, sampled at a high temporal resolution of 30 seconds, provided the necessary foundation for identifying MSTIDs through their characteristic signatures in TEC observations. The rate of TEC index (ROTI) was computed to quantify the associated ionospheric disturbances, providing a crucial metric for subsequent analysis. The positioning errors induced by MSTIDs were evaluated using the open-source software RTKLIB. At its core, RTKLIB leverages the raw data obtained from various GNSS constellations, including GPS, GLONASS, Galileo, BeiDou, SBAS, and QZSS. One of the key strengths of RTKLIB lies in its support for a wide range of positioning modes. These modes include Single, DGPS/DGNSS, Kinematic, Static, Moving-Baseline, Fixed, PPP-Kinematic, PPP-Static, and PPP-Fixed. However, for the purposes of this study, the highly accurate kinematic relative positioning approach was selected. To facilitate a systematic regional examination, the Japanese islands were divided into five distinct latitudinal regions (Figure 1). To execute the relative positioning calculations, pairs of stations within close proximity (ranging from 5 to 15 km apart) were carefully identified within each region. These regions are represented by the green rectangles in Figure 1. From each station pair, one station was designated as the base station (marked by red triangles), while the other served as the rover station (green triangles), facilitating the relative positioning computations.

Results

This study investigated the impact of MSTIDs on GNSS positioning accuracy in Japan, focusing on events occurring on July 3, 2022, and July 2, 2023. Utilizing 2D detrended TEC maps sourced from GEONET, MSTID fronts were identified, characterized by northwesterly to southeasterly orientations propagating from the northeast to the southwest during summer nighttime hours. The study assessed potential GNSS positioning errors induced by MSTIDs across different latitudinal extents of Japan. Observation files from base and rover stations were processed to derive relative positioning, revealing variations in ROTI values and positioning errors across different regions. Notably, regions closer to the northernmost part of Japan exhibited minimal MSTID-induced positioning errors, while southern regions experienced escalating ROTI (~0.2-0.5 TECU/min) and positioning error values (~0.1-1 m), with region 3 being particularly susceptible to MSTID influence (Figure 2). Furthermore, regions 4 and 5, situated even further south, demonstrated heightened errors

attributed to equatorial and low-latitude phenomena, overshadowing the influence of MSTIDs.

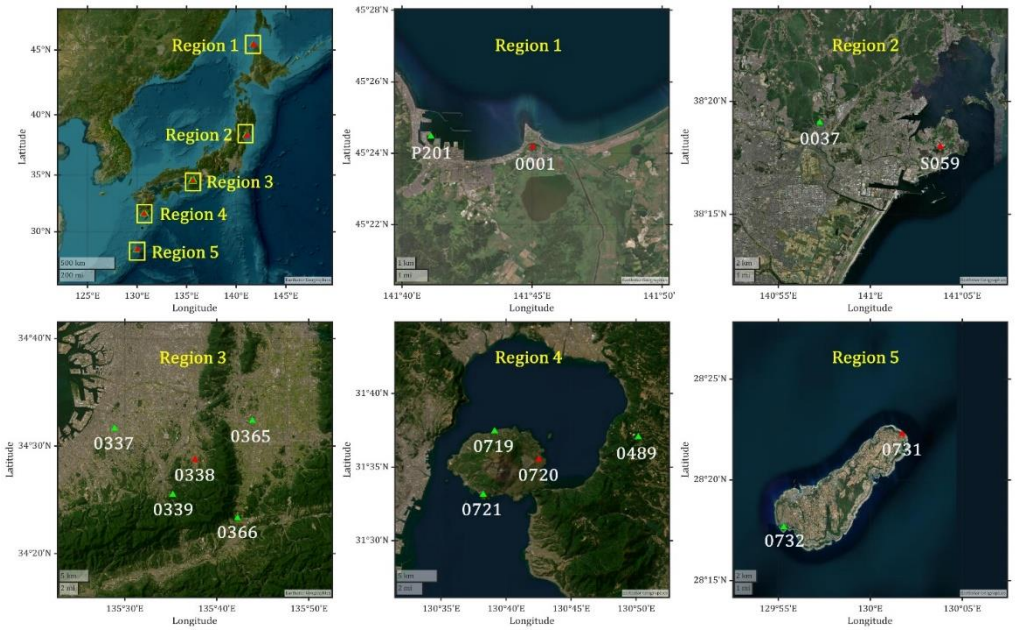

Figure 1: Spatial distribution of base and rover stations across various regions of the Japanese islands.

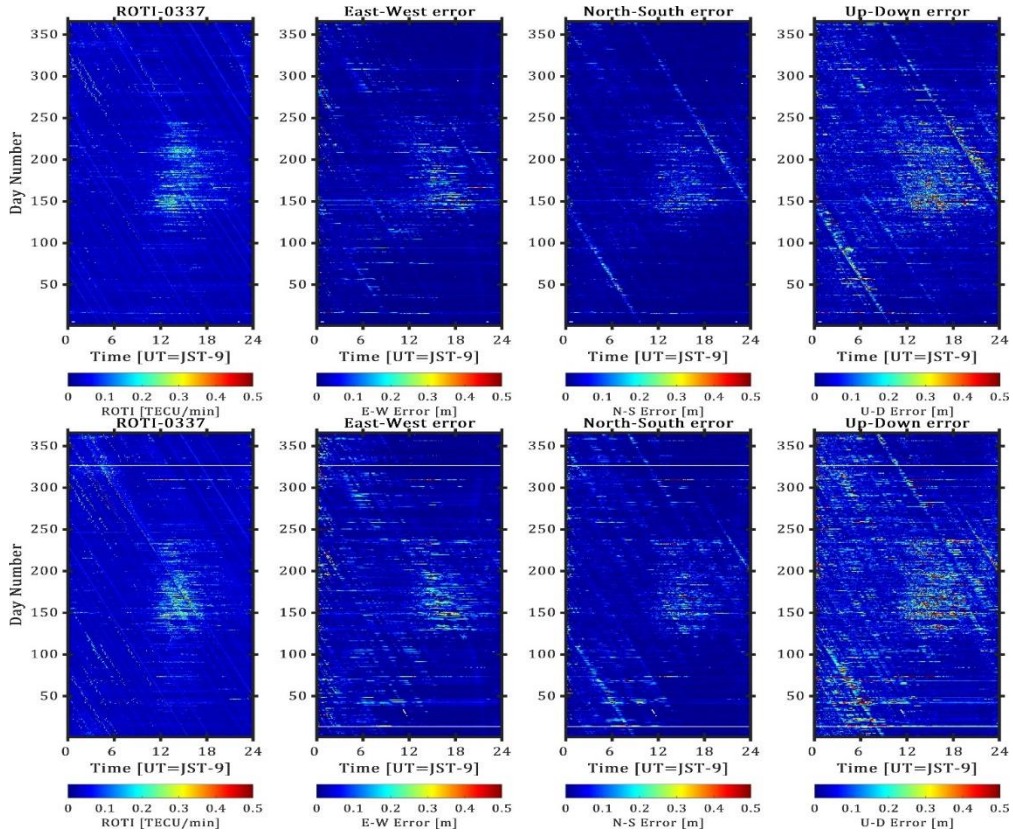

Figure 2: Day-to-day variation of ROTI and associated positioning errors observed at station 0337 in region 3 during the period spanning 2022 to 2023.

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