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# Multi-GNSS precise point positioning for precision marine

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The world of satellite navigation has been undergoing dramatic changes with the rapid development of multi-constellation Global Navigation Satellite System (GNSS). More than 80 GNSS satellites are now in orbit around the Earth, and about 120 satellites will be available once all the four GNSS systems (i.e. GPS, GLONASS, BeiDou and Galileo) are fully deployed in the near future, which will bring abundant opportunities and challenges for GNSS scientific and engineering applications. In precision marine, it is well recognized that GNSS is the major enabler of 'precision'. High precision GNSS (cm level) can be used for auto-steering systems on unmanned surface vehicle and self-propelled machines and for precision operations such as precision guidance, controlled marine surveying, and tide souding. Real Time Kinematic (RTK) GNSS is currently most commonly used for high precision GNSS applications in real time, producing typical errors of less than 2 cm with carrier phase measurements, but it requires at least one reference station. In contrast with RTK GNSS, precise point positioning (PPP) GNSS does not require access to observations or corrections from reference stations and it can provide an absolute positioning at the same accuracy level as RTK, with higher flexibility and potentially lower capital and running costs. In this paper, the feasibility of Multi-GNSS PPP for PA applications is demonstrated by assessing the improvement of satellite visibility, spatial geometry, dilution of precision, accuracy, continuity and reliability that a combining utilization of Multi-GNSS brings to precise positioning (against a single GNSS system). Our results in two sessions in Chinare Ship (one in the southern hemisphere and one in the northern hemisphere) suggested that the addition of the BeiDou, Galileo and GLONASS systems to the standard GPS-only processing improved the positioning stability, while the positioning accuracy was achieved in the 10-20 cm level in the horizontal direction with an improvement against the GPS-only PPP results. Some outliers in the GPS-only solutions disappeared when Multi-GNSS observations are processed simultaneously. In space constrained and harsh environments (e.g., farms surrounded with dense trees), the availability and reliability of precise positioning decreased dramatically for the GPS-only PPP results, but limited impacts were observed for Multi-GNSS PPP.