Signal outages during geomagnetic storms from the northern crest of the equatorial anomaly in the Indian longitude sector

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Degradation of performance of GNSS during geomagnetic storms is a topic which has been studied for almost two decades. The first storm reported to have affected GPS was the storm of 22 October 1999 [*Basu et al., J. Geophys. Res.*, 2001b], when the Wide Area Augmentation System (WAAS) parameter Grid Ionospheric Vertical Error (GIVE) exceeded a value of 6m. Later, during the superstorms of 29 and 30 October 2003, 20 November 2003 and 8 November 2004, the localizer performance with vertical guidance service level of WAAS were unavailable for the entire WAAS coverage region for varying periods of time, with full or partial coverage loss in excess of 10 h [*Doherty et al., GPS Solut.*, 2004; *Basu et al., J. Geophys. Res.*, 2008]. Most of the work available in literature addresses ionospheric response to superstorms. This paper presents performance of a dual frequency GPS receiver during four storms with Dst peak values in the range -100 and -150 nT.

The storms under study occurred during 29 September – 02 October, 2012, 07-11 October 2012, 14-17 July 2012 and 15-19 February 2014. During these storms, 50 Hz carrier phase data from GPS receiver located at Calcutta (22.58^{o}N, 88.38^{o}E, 32^{o}N magnetic dip) under the SCINDA program were analyzed. Cycle slips have been observed during the main phase of three storms, namely, 29 September – 02 October 2012, 07-11 October 2012 and 15-19 February 2014 and during the recovery phase of the storm of 14-17 July 2012. Out of the first three storms, cycle slips of duration in excess of 6s were observed during two storms. The first one occurred around local midnight hours of 30 September 2012, during the main phase of the storm of 29 September – 02 October 2012, while the second one in the local pre-midnight hours of 18 February 2014, during the main phase of the storm of 15-19 February 2014. It is important to note that Signal-In-Space (SIS) performance requirement for Approach with Vertical Guidance (APV) specified by the International Civil Aviation Organization (ICAO) stipulates a time-to-alert of 10 s for APV I and 6 s for APV II operations [International Civil Aviation Organization, 2006]. The observations have been explained in terms of storm time magnetospheric-ionospheric coupling leading to the development and intensification of the

eastward low latitude prompt penetration electric field in the dusk sector thereby raising the F-layer to great heights where recombination is negligible, and F-region irregularity generation is possible through Rayleigh-Taylor mechanism. The resulting amplitude and phase scintillations, which are more intense near the anomaly crest location, causes loss of lock and cycle slips, and degradation of position accuracy in GPS receivers.