Horizontal GPS Positioning Accuracy During the 1999 Solar Eclipse

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Although GPS positioning errors are now well described, there are still some uncertainties regarding the impact of some rare space weather phenomena on GPS positioning accuracy. Solar eclipses have been considered as one source of such rare events, so the 1999 solar eclipse gave the opportunity to collect horizontal GPS positioning data for further analysis. The results of statistical analysis show no deterioration of horizontal GPS positioning accuracy. Space weather, ionospheric and geomagnetic conditions were also carefully analysed and showed no significant activity. In conclusion, the experiment confirmed negligible impact of the 1999 solar eclipse on horizontal GPS positioning accuracy, and opens discussion concerning application of satellite positioning systems in space and ionospheric weather monitoring.

KEY WORDS

1. GPS. 2. Solar eclipse. 3. Space weather.

1. INTRODUCTION. A very comprehensive analysis has been made of GPS positioning errors since the introduction of the system. However, there are still some uncertainties regarding the influence of several error sources, especially those with irregular or rare appearance, generated mainly by either space weather phenomena or ionospheric disturbances. Solar eclipses were expected to generate processes capable of impacting satellite positioning accuracy. Among the processes that solar eclipses may cause are:

(a) relativistic effects supposed to influence the accuracy of atomic clocks (Udem, 1999),
(b) ionospheric disturbances as the consequences of disturbed solar energy transfer (Davies, 1990, pp 310) and,
(c) changes in orbits of the GPS satellites due to modifications in resultant gravitational fields (Spilker Jr. & Parkinson, 1996, pp 36). The 1999 solar eclipse (that appeared on 11 August 1999) offered an opportunity to investigate these effects on GPS positioning accuracy.

2. EXPERIMENT DESCRIPTION. The 1999 solar eclipse was expected to be at least 95% visible in northern Croatia, so an experiment was designed to investigate possible special effects on horizontal GPS accuracy. A fixed experimental site was set up near Virje, Croatia. A Garmin GPS-38 8-channel, single-frequency receiver measured horizontal position continuously and stored the results with the rate of one sample per 10 seconds. The GPS receiver was installed at a fixed position

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well away from power lines. Approximately 15% of the satellite view was obstructed. Additional PC software was developed for post-processing and analysis of collected horizontal positioning data.

3. EXPERIMENTAL CONDITIONS.

3.1. *Atmospheric conditions.* The experiment was conducted in a relatively quiet atmosphere with a slight overcast (3/8), visibility of more than 10 km, air temperature of 26 °C and atmospheric pressure of 1012 hPa. A slight westerly breeze was observed.

3.2. *Space weather.* According to archive data (References 3 and 4), mild solar activity was observed before and during the experiment. The sunspot number was relatively low (SSN = 76). The remnants of a four-day old solar flare were observed (Udem, 1999 and Reference 3).

3.3. *Ionospheric conditions.* Iono-sounding data collected throughout Europe (Reference 4) showed no sign of any significant ionospheric disturbance. Ionospheric soundings made at the nearest site (Rome) show a usual daily distribution of critical F2 layer frequency (f_0F_2) (Reference 4). No auroral activity was reported over Croatia during the experiment.

3.4. *Geomagnetic activity.* Geomagnetic activity was also at quiet levels. The global 3-hours geomagnetic activity index $K_p = 2$ for 11 August 1999 (09:00–12:00 GMT) indicating quiet geomagnetic conditions. The same values for the K indices in the observed time interval were reported from USGS stations (over Croatia: 3). However, some of them reported increased A indices (Cape Chelyuskin: 135, Dixon Island: 102, Tiksi Bay: 52), but they were too distant to generate a significant impact on the experimental results. USGS stations nearest to our experimental site reported low-level A indices (over Croatia: 3).

4. DISCUSSION OF EXPERIMENTAL RESULTS.

439 horizontal positioning results were collected between 9:24:17 GMT and 10:55:23 GMT (approximately across the middle of the eclipse). The time series of collected latitudes and longitudes are presented at Figures 1 and 2, respectively.

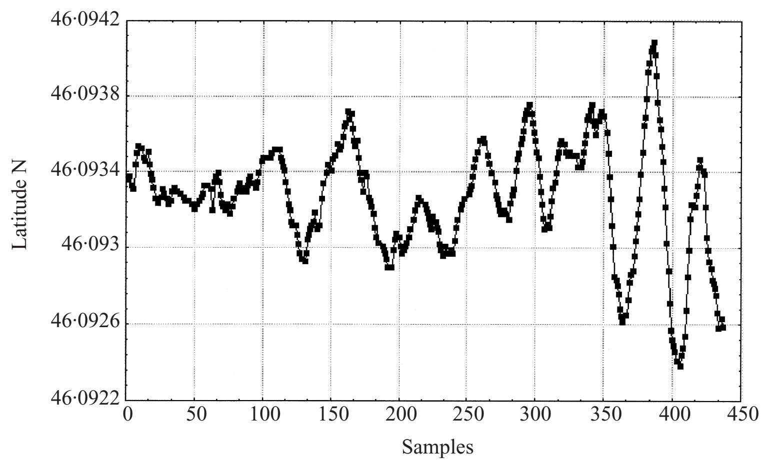

Figure 1. Time series of latitude measurements (sample 1 collected on 11 August 1999, 9:24:17 GMT).

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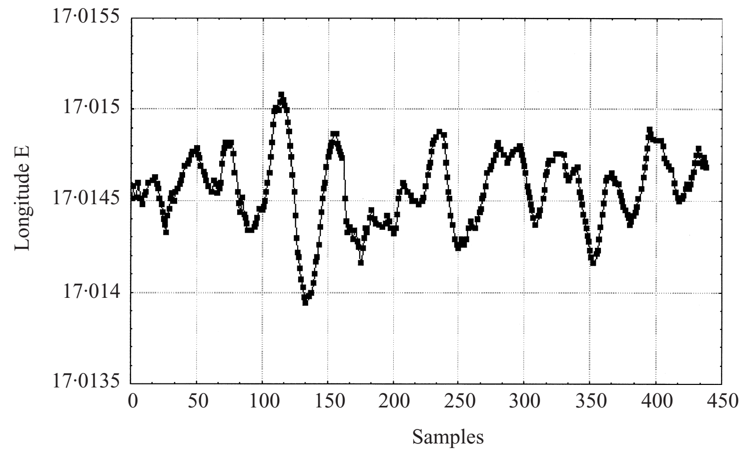

Figure 2. Time series of longitude measurements (sample 1 collected on 11 August 1999, 9:24:17 GMT).

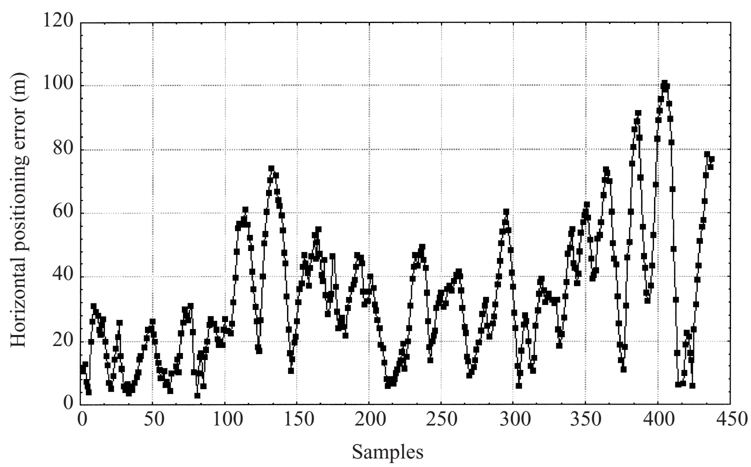

Figure 3. Time series of horizontal positioning errors related to the mean position (sample 1 collected on 11 August 1999, 9:24:17 GMT).

The mean values of measured positioning data are:

Latitude: $\varphi = \text{N}46 \cdot 09327°$ with standard deviation $\sigma_\varphi = 0 \cdot 000292°$,

Longitude: $\lambda = \text{E}017 \cdot 01456°$ with standard deviation $\sigma_\lambda = 0 \cdot 000207°$.

Equivalent horizontal positioning error ε(n) in metres for the n-th positioning result (φ(n), λ(n)) is defined as:

$$\varepsilon(n) = \sqrt{\{k[(\varphi(n) - \varphi)^2 + (\lambda(n) - \lambda)^2]\}}, \quad (1)$$

where: k is degrees-to-metres conversion factor, and φ and λ are average latitude and longitude, respectively. The time series of the equivalent horizontal positioning errors ε(n) is shown at Figure 3. The average positioning error during the experiment is 33·91652 m ($\sigma_\varepsilon = 20 \cdot 77897$ m). Data analysis shows that only one of 439 samples exceeds a positioning error of 100 m (relative to the mean position).

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5. CONCLUSION. Archive data shows a lack of any significant ionospheric and geomagnetic activity during the 1999 solar eclipse. Other teams (Udem, 1999) reported no significant problems with atomic clocks during the same event. Experimental results presented here are consistent with other reports and show no dilution of horizontal GPS positioning accuracy. In addition, the control experiment carried out later in similar atmospheric, ionospheric and geomagnetic conditions yields very similar average horizontal positioning error and standard deviations of measured latitude and longitude (Filjar *et al*., 2000). Therefore, our experiment confirmed that the 1999 solar eclipse made no significant impact on horizontal GPS positioning accuracy. Further research will yield more data for the generalised conclusion about the effects of solar eclipses on GPS positioning accuracy. Moreover, the experiment sheds a new light on the GPS applications in space and ionospheric weather monitoring.

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