When estimating the orbits of artificial Earth satellites using observations from terrestrial sites, one may solve for the coordinates of the Earth’s center of mass—the geocenter. The relation between the geocenter coordinates, $x$, $y$, and $z$, and the first-degree coefficients $C_i$, $S_i$, and $D_i$, of the spherical harmonics of the geopotential is given by:

$$C_i = \frac{\Delta C_i}{a^2}, \quad S_i = \frac{\Delta S_i}{a^3}, \quad D_i = \frac{\Delta D_i}{a^4},$$

where $a$ is the equatorial radius of the Earth.

One may directly determine the geocenter by solving for the geopotential coefficients. On the other hand one may also set the coefficients $C_i = S_i = D_i = 0$, i.e., use a truly geocentric coordinate system for orbits and stations and solve for a common translation of the entire system of reference stations. The two approaches give identical results. In our analysis we actually estimated the common offsets but follow common practice and speak of geocenter offsets. All our experiments are based on observation data from a network of 92 globally distributed GPS/GLONASS combined tracking stations (see Fig. 1). The data was continuously recorded for the years 2008 through 2011.

Special care was taken to keep the GPS and GLONASS solutions on a comparable level, in particular concerning the selection of the tracking sites. All stations for which a pronounced imbalance between the available GPS and GLONASS observations could be identified, were excluded from processing. Figure 2 (left) shows the number of available stations during the four years. After an almost linear increase from 30 to about 80 stations in 2008, a stable level was reached. The number of GPS satellites ranges between 30 and 32. The numerous “drop-outs” of single satellites are caused by repositioning events. The number of GLONASS satellites increases from initially 18 in 2008 to 24 in 2011. In 2008, the GLONASS constellation was still very weak. Figure 2 (right) shows the development of the number of satellites.

We have computed high-quality GPS-only, GLONASS-only, and combined GPS/GLONASS solutions. Up-to-date models were used and the processing closely followed the processing scheme used by CODE, the Center for Orbit Determination in Europe.

In our analysis each orbit is parameterized with six osculating orbital elements. The orbit of each satellite plane w.r.t. the inertial equatorial plane, right ascension of the ascending node $\Omega$, argument of perigee $\omega$, and periapsis passage time $T_\text{p}$.

In addition, three constant forces in the $x_\text{e}$, $y_\text{e}$, and $z_\text{e}$-direction are set up together with two once-per-revolution parameters in the $x_\text{e}$ and $y_\text{e}$-direction. These parameters are estimated for each orbital arc. The unit vector $\mathbf{e}_\text{c}$ points from the satellite to the Sun, $\mathbf{e}_\text{c}$ coincides with the solar panel axis, and $\mathbf{e}_\text{c} = \mathbf{e}_\text{s} \times \mathbf{e}_\text{r}$.

When interested in the correlations between geocenter Z-offset and one of the solar panel axis, and $

$$\delta Z = \sum_{i=1}^{k} D_i \sin \beta_i,$$

where $D_i$ and $\beta_i$ are mean values over all satellites of the particular orbital plane-$k$ (assuming identical satellites).

No problem arises as long as only the D-component of the empirical force model, but no geocenter coordinates are estimated in the GNSS analysis. A problem appears, however, as soon as geocenter coordinates are estimated in addition to constant radiation pressure parameters for all satellites of the constellation. The estimate of the Z-component of the geocenter might just compensate the shift of the orbital plane caused by an additional D-component, introduced by the simultaneous estimation of the geocenter and the D-parameters.

Figure 5 shows the X-, Y-, and Z-components of the estimated geocenter coordinates by year (in red). The data was continuously recorded for the years 2008 (red) and 2011 (blue). The GLONASS-derived results show a pure GLONASS than for the GPS solution—in particular in 2009, when the GLONASS observation geometry was rather weak due to the small number of satellites (see Fig. 2, right).

The X- and Y-coordinates of the geocenter estimated from GPS and GLONASS are highly correlated. Apart from the noise, the two solutions are comparable. The combined solution is very close to the GPS-only solution. The picture is completely different, however, for the Z-component (top right). The GLONASS-derived geocenter coordinates are much larger (peak-to-peak variations of about 30 cm) than those emerging from GPS. The GLONASS variations are spurious and cannot be explained by geophysical means. Note that the combined solution is close to the GPS solution, indicating that the GPS-derived geocenter coordinates are much stronger than the GLONASS-derived results. Nevertheless, the combined solution also contains traces of the GLONASS excursions—an effect which is not wanted.

The middle and bottom row of Fig. 3 give the GPS- and GLONASS-only results (blue) together with the elevation $\beta_0$ (green) of the Sun above the single orbital planes. There is an eye-catching correlation between the large GLONASS-derived excursions of the Z-component and the maximum values of $\beta_0$.

This is a strong indication that these extreme excursions are artifacts and caused by the correlation of the geocenter Z-coordinate and one or a linear combination of orbital parameters.

The most important part of the empirical orbit model causing a force in W-direction is the perturbing force along the X-component of the orbit model $F_X = \vec{F}_X$. This force is dominated by the direct radiation pressure w.r.t. the solar panels. The force in W-direction caused by the direct radiation pressure is given by $\vec{F}_W = \vec{D}_W \sin \beta$. Projecting the parallel orbit shift $\Delta \mathbf{r}$ on the Z-direction of the geocenter, the Z-coordinate is correlated with the direct solar radiation pressure parameter for all $k = 1,\ldots, n_\text{orbital planes}$ is then given by

$$\delta Z = \sum_{i=1}^{k} D_i \sin \beta_i.$$