Experiences with atmospheric pressure loading and GPS vertical estimates

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ABSTRACT

Vertical displacements due to atmospheric loading effects can be detected in GPS height estimates. Even weekly solutions of GPS determined vertical coordinates are correlated with atmospheric loading in more than 70% of the stations investigated. When correcting the GPS coordinates resulting from the different GPS processing centers for atmospheric loading, different variance reductions or augmentations for the same station are found. However, stations in Central and Southern Asia show high variance reductions, whereas nearly all coastal stations and island stations show a small augmentation in the variance, due to the small variances of the loading signal itself.

INTRODUCTION

Atmospheric pressure loading can be described as the vertical displacement of the earth's crust due to changing atmospheric pressure.
The effects of atmospheric pressure loading are computed by convoluting Farrel's elastic Green's functions (Farrell, 1972) with 6-hourly global surface pressure values (1° x 1° grid) provided by the European Center for Medium Range Weather Forecasts (ECMWF) operational analyses. The ECMWF pressure fields are derived from a Global Objective Analysis (GANL) using global satellite data, global free-atmosphere data, oceanic data and land data as input. Since we are using surface pressure values, variations in pressure due to the effects of surface topography are already taken care of.
The maximal variation of the atmospheric pressure at a station can amount up to 60-80 hPa. Horizontal displacements due to atmospheric loading effects are, however, limited to a few millimeter and thus smaller than the magnitude of the noise in the GPS measurements. Vertical displacements can amount up to 3 cm (for the station Brussels in Belgium) and 3.5 cm for the station Zwenigorod in Russia. Continental, mid-latitude station show the highest atmospheric pressure loading effects. Atmospheric pressure systems are known to have large spatial extensions, so that the differential effects ,for stations with more or less the same latitude, are much smaller. When processing a worldwide network, the differential effects amount up to a few centimeter.

CORRELATION BETWEEN ATMOSPHERIC PRESSURE LOADING AND GPS-DETERMINED HEIGHTS

Figure 1 and Figure 2 represent time series for the vertical component of the atmospheric pressure loading effect and the GPS determined coordinates for different stations and for the IGS weekly processing strategy. Juxtaposing the two time series reveals the degree to which the GPS residuals track temporal variations in atmospheric pressure loading. For some stations, the two time series are highly correlated (e.g. the station KOSG (Kootwijk) in the Netherlands).

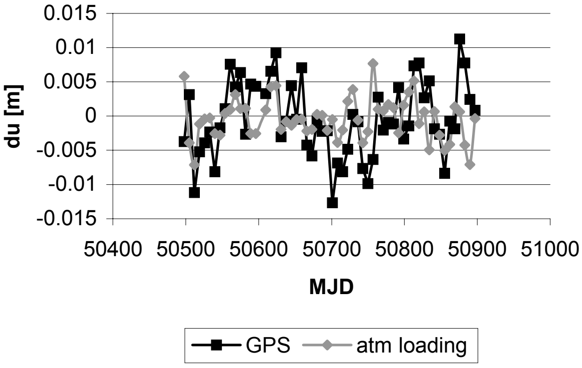

Fig. 1. Time series of the vertical displacement of the atmospheric loading together with the vertical coordinate determined by GPS for the station KOSG

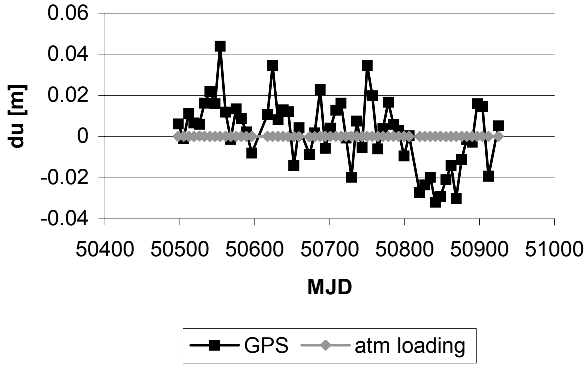

Fig. 2. Time series of the vertical displacement of the atmospheric loading together with the vertical coordinate determined by GPS for the station ASC1

Other stations, island or coastal equatorial stations like FORT (Fortalesa) in Brasil or ASC1 (Ascension Island) show very small variances in the atmospheric loading due to very small atmospheric ground pressure variances. However, for these stations the ocean tide loading effects are generally large, so that the remaining variance of the GPS height signal after correcting for atmospheric loading is most likely due to remaining ocean tide loading effects. Most continental stations in Central and East-Europe, Northern America and Asia show high positive correlations. All island and most coastal stations have small negative correlations.

CORRECTING FOR ATMOSPHERIC PRESSURE LOADING IN GPS TIME SERIES

In a worldwide network, 8 GPS timeseries (IGSW, SIOD, SIOW, CODW, JPLW, GFZW, NEWW, COMW) of more than 80 stations were investigated. Of these timeseries the variance after correcting for the atmospheric pressure loading effect was calculated. Per processing center approximatelly 55% of the stations show a variance reduction (see Table 1). Keeping in mind the central limit theorem of statistics, a variance reduction is quite rare to observe when substracting two independent signals. Having variance reductions for more than 50% of the stations investigated is an indication of the two signals not being independent. However huge discrepancies between the different processing centers can be detected (see table 1)

Table 1. Order of magnitude of the variance reduction of GPS heights after correcting for atmospheric loading; comparison between different processing centers

Var reduction	CODW	JPLW	SIOW	IGSW
>20 mm²	8 %	6 %	5 %	4 %
10 mm² < x < 20 mm²	12 %	8 %	5 %	11 %
5 mm² < x < 10 mm²	9 %	8 %	8 %	3 %
0 mm² < x < 5 mm²	30 %	37 %	32 %	34 %
-5 mm² < x < 0 mm²	23 %	25 %	25 %	28 %
-10 mm² < x < -5 mm²	6 %	8 %	11 %	8 %
-20 mm² < x < -10 mm²	4 %	0 %	6 %	9 %
< -20 mm²	8 %	8 %	8 %	3 %

Regional Distribution of the Variance Reduction

Different processing centers show different distributions for the variance reduction. In global, one cannot depict a station or a region where correcting for atmospheric loading will surely lead to a variance reduction in the GPS heights. However, stations in Central and Southern

Asia show high variance reductions whereas stations in Northern Europe mostly have to deal with variance augmentations.

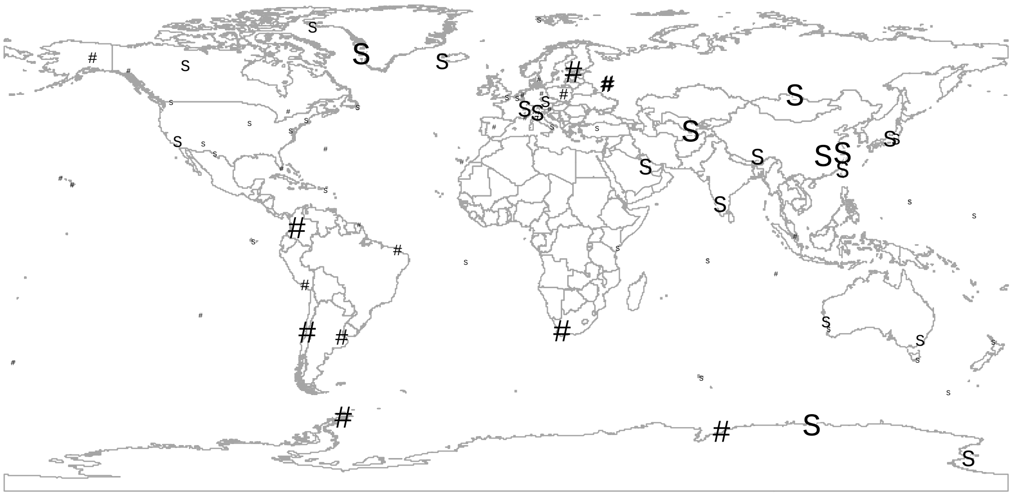

Fig. 3. Distribution of the variance reduction [mm²] for the processing centers CODW

Because the computations were made with the same stations and the same time span for every processing center, the reason for different distributions has to be searched in the different processing techniques of the GPS data. Noise in the pressure data or erroneous calculation of the atmospheric loading effects would propagate for different processing centers in the same way. A possible cause for the different distributions could be the definition of the reference frame by the choice of the fixed or heavily constrained stations or the way troposphere effects, ocean loading effects etc. are treated. Further investigation in the different processing centers will be imperative.

CONCLUSIONS

Our analysis clearly shows that GPS height results are affected by atmospheric pressure loading effects. Time series of more than 80 stations and 8 different processing centers were investigated. For coastal or island sites, the variance of the atmospheric loading effect is too small to have an influence on the GPS heights. However, for almost 55% of the stations investigated a variance reduction of the GPS heights can be found after correcting the GPS results with the atmospheric loading signal.

Different processing centers lead to different distribution patterns of the variance reduction. However, nearly all coastal stations and island stations show an augmentation in the variance, due to the small variances of the loading signal itself. Stations in Central and South Asia mostly show high variance reductions whereas stations in Northern Europe show variance augmentations. The distribution for the stations in America and Central Europe differs in different processing centers. The reason for this is not clear at this time but has to be searched in the different processing methods and the different definition of the reference frame. When determining station velocities this effect should be kept in mind.