Effects of Atmospheric Pressure Loading on the EUREF Network

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Abstract

Atmospheric pressure variations may cause vertical site displacements of tens of millimetres. This loading effect is presently not modelled in the GPS data processing although it might exceed the uncertainty of GPS height estimates. As the EUREF permanent network extends to very high northern latitudes and as large pressure variations occur mainly at high latitudes, this paper aims at demonstrating the pressure loading effects on the EUREF network. Therefore, the observations of a 17 stations sub-network during a 32 days period of high pressure variations in early 2000 are analyzed. During this period peak to peak pressure differences of up to 60 hPa occurred between northern Scandinavia and the Mediterranean. According to our results the corresponding vertical loading displacement is as large as 4 centimetres, equivalent to 0.7 mm per hPa pressure variation.

1. Introduction

The increasing performance of Global Positioning System (GPS) receiver and antenna systems as well as improvements in data modelling allow progresses in studying geophysical phenomena by analyzing time series of GPS position estimates. As regards the heights, phenomena to be addressed are post glacial rebound and sea level changes. Unfortunately, the vertical component is still the worst determined in GPS point positioning. The main contributing error sources are antenna phase centre variations, tropospheric path delay irregularities, and site displacements due to ocean tide as well as atmospheric pressure loading. Whereas some progress has been achieved regarding the first three modelling problems, pressure loading is probably the most poorly investigated effect, and most GPS software packages are presently not capable of modelling it. The reason is that the effect is strongly site dependent and hardly predictable.

Atmospheric pressure variations can cause radial loading displacements of the Earth's surface of tens of millimetres. The spatial extension of pressure anomalies may range from some hundred kilometres in the presence of tropical cyclones to a few thousand kilometres in case of continental anticyclones. Pressure highs and lows can have periods of some days but may also be stable for a few weeks.

The 1996 conventions of the International Earth Rotation Service (IERS) recommend to consider the pressure loading effect in the analysis of space geodetic observations. In the absence of dedicated local or regional models the standards suggest the application of the following relation for estimating the radial site displacement Δr (MC CARTHY 1996):
$$\Delta r \; [mm] \; = \; -0.35 \; \Delta p \; [hPa] \; - \; 0.55 \; \Delta p_0 \; [hPa]$$
Δp is the local pressure anomaly with respect to standard pressure, and Δp_0 stands for the pressure anomaly within a 2000 km region.

So far, only very few investigations analyzing GPS and VLBI positioning results with regard to atmospheric pressure loading have been performed. VAN DAM and HERRING (1994) proved a high correlation between pressure and VLBI intersite distance variations on long baselines provided the availability of a sufficient number of occupations. MAC MILLAN and GIPSON (1994) estimated vertical atmospheric loading terms for a number of sites directly from VLBI measurements and surface pressure data. Unlike VLBI, an analysis of GPS point positioning results could not demonstrate a high correlation between pressure and height estimates (VAN DAM et al. 1994).

The EUREF permanent network includes a number of sites at high northern latitudes exposed to much larger pressure variations than the central and southern European part. The objective of this paper is to assess the pressure loading effects on position estimates by analyzing the data collected by a EUREF sub-network of about 4000 km north-south extension during a 32 days period of high pressure variations.

2. Data Analysis

Considering the accuracy of between 5 and 10 mm achievable for daily station height estimates and the magnitude of the pressure loading effect in the order of 0.5 mm per hPa pressure variation, the proper selection of the network and the time period to be analyzed is important. As already indicated, a large north-south extension is essential because rapid pressure variations, anomalies and gradients occur mainly at high latitudes. In addition, the network should suffer gaps as little as possible in the time series of observations. As regards the time period, it should be characterized by large pressure variations within the network enabling to demonstrate the loading effects.

In order to accomplish these criteria, we have reviewed both the EUREF data holdings and pressure time series for the entire year 2000. The pressure data were daily averages for a global grid of 2.5° by 2.5° spacing, accessible from the National Center for Atmospheric Research (NCAR), Boulder, Colorado (USA). As a result of this review we selected the EUREF sub-network of 17 stations shown in Figure 1. Figure 2 displays the time series of daily pressure values during 2000 interpolated for some sites. The figure shows clearly the large pressure variations at the high latitude stations compared to those in southern Europe. As regards both data completeness and pressure variations the period covering days 23 to 54, 2000 was identified as almost optimal. The data processing was done with the Bernese software version 4.2 (HUGENTOBLER et al. 2001), and the main characteristics can be briefly summarized as follows:

- Satellite orbits, clock offsets and Earth orientation parameters fixed to combined IGS solutions referring to ITRF97;

- Quasi ionosphere free (QIF) strategy applied for resolving the L1 and L2 phase ambiguities;

- Periodic site displacements due to ocean tide loading modeled according to the GOT99.2 model (RAY 1999);

- Tropospheric delays predicted using the SAASTAMOINEN (1973) model and NIELL'S mapping function (NIELL 1996);

- Residual zenith delays estimated practically unconstrained for each 2 hours interval, again applying the NIELL mapping function;

- Antenna phase center variations modeled according to IGS recommendations, elevation angle cutoff set to 10°;

- Analysis of adjustment residuals for identifying unrepaired cycle slips.

Fig. 1: Analyzed EUREF sub-network
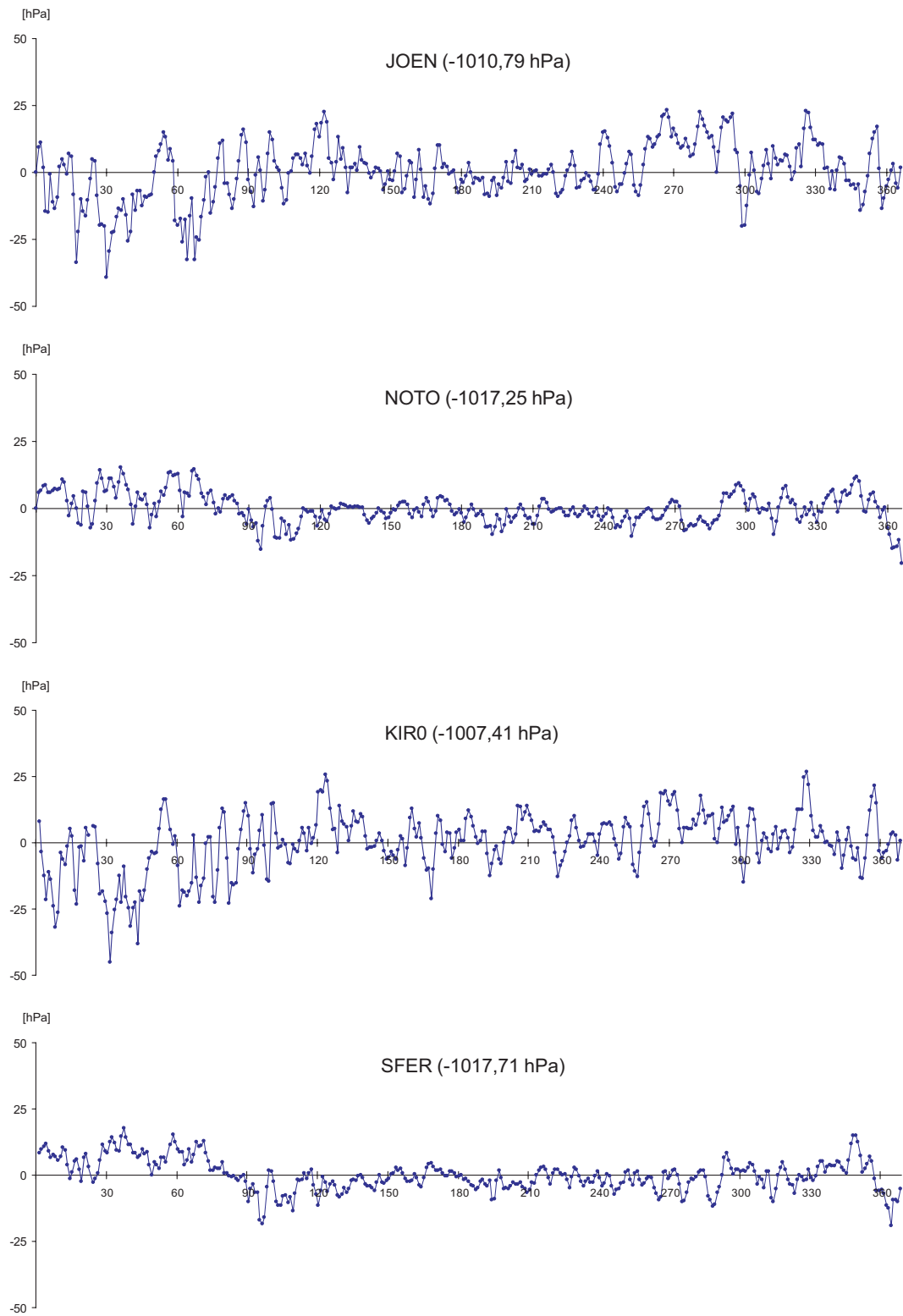
Fig.2: Daily pressure anomalies during 2000 with respect to the annual means, given in parenthesis, at the EUREF sites JOEN, KIRO, NOTO, and SFER.

3. Results

The reference frame of the network adjustments is in principle defined by fixing the satellite orbits, satellite clock offsets and Earth orientation parameters. Nevertheless, when adjusting double difference phase observations, one has to apply any further constraint in order to avoid a shift of the network primarily in radial direction. Therefore, the station GRAZ was loosely constrained to its ITRF97 position in each daily solution. It is not of great relevance which of the sites is constrained, because we are analyzing differences between position estimates, and we compare their variations with pressure difference variations.

Looking at the pressure time series displayed in Figure 2, it is obvious that one can expect loading effects mainly between sites in northern Scandinavia and sites in the Mediterranean area or on the Iberian peninsula. Thus, we show in the sequel the results for the same stations as in Figure 2. The Figures 3 and 4 display the time series of daily ellipsoidal height difference estimates versus the daily mean pressure differences. It is to be mentioned that there might be a small arbitrary offset between the height and pressure difference time series because the daily pressure values were reduced to the annual means, whereas the height estimates could not. Thus, only the similarity of both series should be interpreted.

Looking at these results, being representative for the whole network, and considering also the uncertainty of the daily GPS height determinations, one can state that the pressure loading effects are clearly reflected in the height estimates. A very rough estimate of the vertical loading displacement in this network is 0.7 mm/hPa pressure variation.

Provided the network extension is at least some thousand kilometres, the loading effects should show up also in the baseline lengths. This is confirmed by Figure 5 which presents the baseline length changes of four long baselines during a 13 days period of particularly large pressure variations.
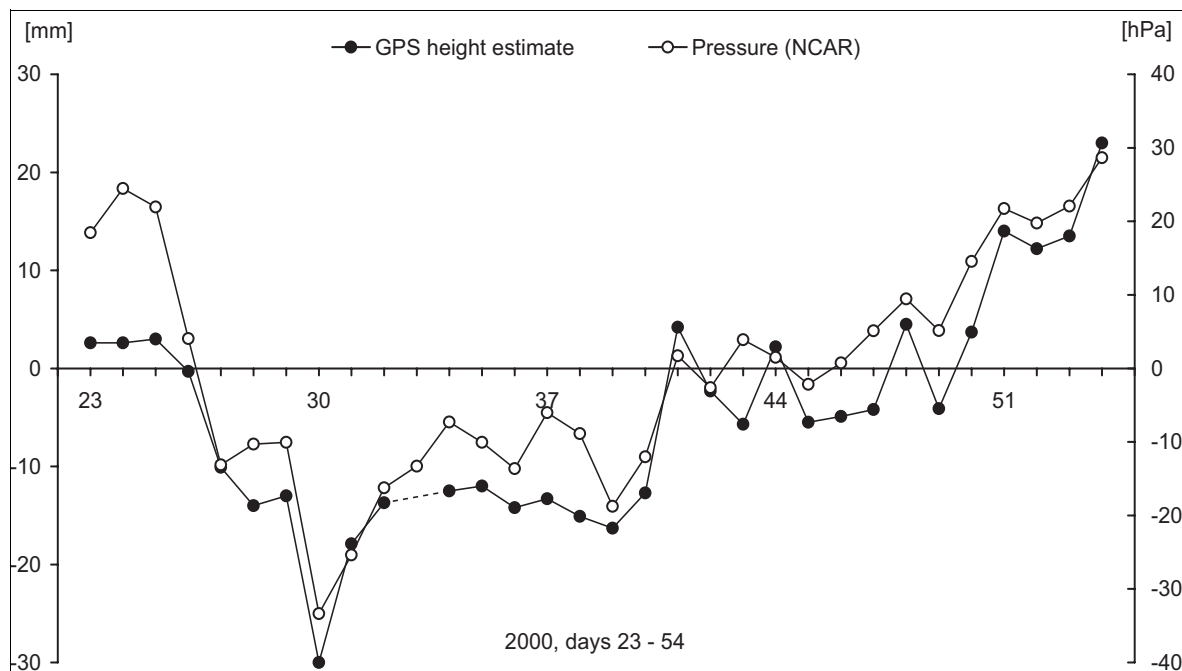
Fig. 3: Ellipsoidal height difference vs. pressure difference on baseline JOEN – SFER.

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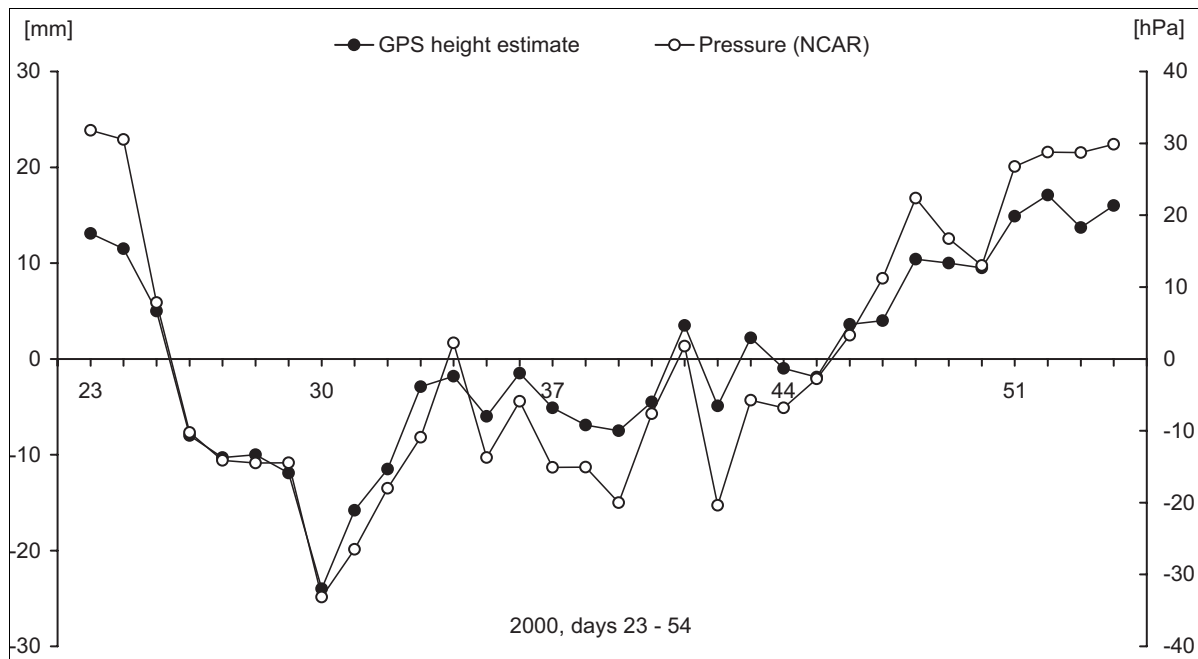
Fig. 4: Ellipsoidal height difference vs. pressure difference on baseline KIRØ – NOTO
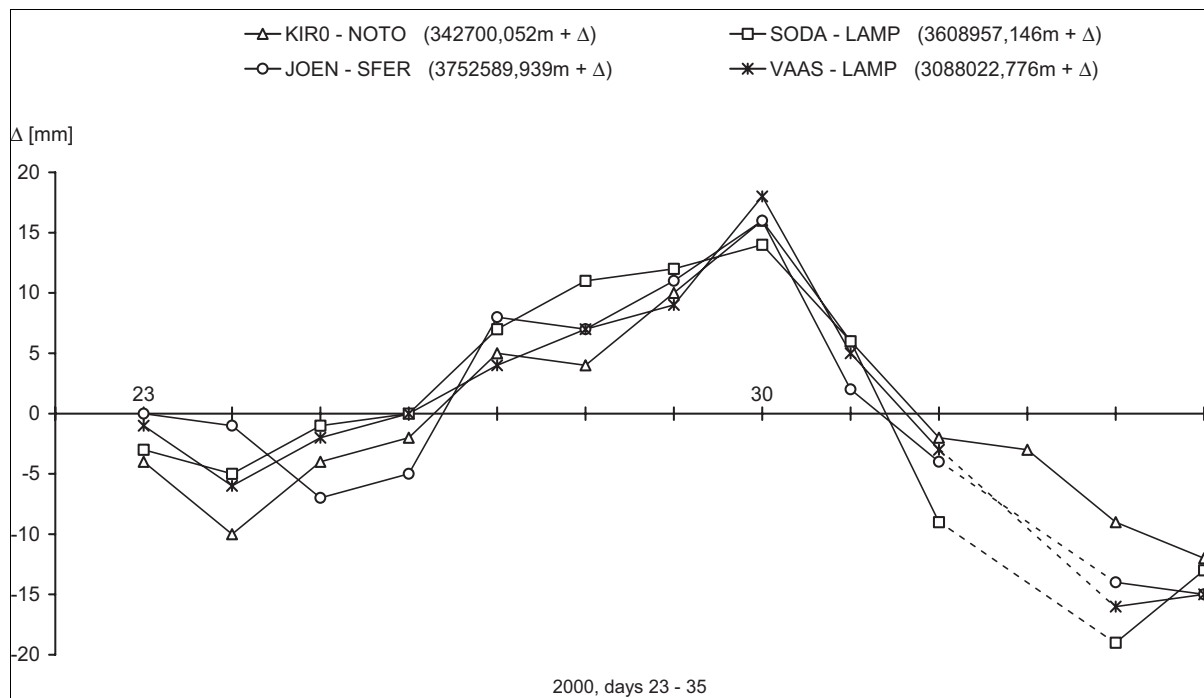
Fig. 5: Baseline length variations during 13 days of large pressure variations

4. Conclusion

Due to its extension to very high northern latitudes the EUREF permanent GPS network is exposed to large atmospheric pressure variations. During the 32 days period analyzed in this paper peak to peak pressure changes of 60 hPa occurred. This loading leads to vertical site displacements as large as 4 cm, equivalent to 0.7 mm per hPa pressure variation. This value is slightly larger than the prediction according to IERS standards. Consequently, it must be recommended to consider the pressure loading phenomenon in the future monitoring of EUREF. Finally, one should note that unmodelled pressure loading may in particular affect height results from episodic GPS measurements.

References

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