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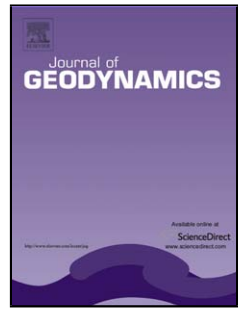

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PII: S0264-3707(09)00070-2
DOI: doi:10.1016/j.jog.2009.09.003
Reference: GEOD 897

To appear in: *Journal of Geodynamics*

Please cite this article as: Nordman, M., Mäkinen, J., Virtanen, H., Johansson, J.M., Bilker-Koivula, M., Virtanen, J., Crustal loading in vertical GPS time series in Fennoscandia, *Journal of Geodynamics* (2008), doi:10.1016/j.jog.2009.09.003

Crustal loading in vertical GPS time series in Fennoscandia

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Abstract

We compare time series of vertical position from GPS with modelled vertical deformation caused by variation in continental water storage, variation in the level of the Baltic Sea, and variation in atmospheric pressure. Monthly time series are used. The effect of continental water storage was calculated from three different global models. The effect of non-tidal variation in Baltic Sea level was calculated using tide gauge observations along the coasts. Atmospheric loading was computed from a numerical weather model. The loading time series are then compared with three different GPS time series at seven stations in Fennoscandia. A more detailed analysis is computed at three coastal stations. When the monthly GPS time series are corrected using the load models, their root-mean-square scatter shows an improvement between 40 and zero percent, depending on the site and on the GPS solution. The modelled load effect shows a markedly seasonal pattern of 15 mm peak-to-peak, of which the uncorrected GPS time series reproduce between 60 and zero percent.

Keywords: crustal loading, Baltic Sea, atmospheric pressure, continental water, GPS

Introduction

The geographical distribution of atmospheric, oceanic and hydrologic masses varies in time and this in turn loads and deforms the surface of the solid Earth. Such deformations can be detected by GPS. Height changes due to atmospheric loading were pointed out in global time series of GPS coordinates by van Dam et al. (1994). The deformation due to variable loading by continental water storage was found by van Dam et al (2001). Blewitt et al. (2001) demonstrated that a global mode of seasonal mass exchange between the Northern and Southern hemisphere is detectable in GPS data.

Many of the mass fluxes that produce the deformation follow a near-annual cycle. In fact, time series of GPS positions typically show a seasonal variation, which is tempting to associate with geophysical loads. However, Dong et al. (2002) estimated that only about 40% of the seasonal power of apparent vertical motion could be attributed to modelled mass redistribution. Similarly, e.g. van Dam et al (2007) found large discrepancies between seasonal vertical displacements estimated from GRACE and observed at European GPS sites. The discrepancies are believed to be due to technique errors and unmodelled or mismodelled factors in the GPS analysis. Candidates for producing spurious long-period signals in the GPS time series include the propagation of unmodelled short-period signals like tides to longer periods (Penna and Stewart, 2003, Stewart et al., 2005, Penna et al., 2007, King et al. 2008), mismodelling of troposphere delays (Munekane et al., 2008), the satellite repeat constellation (Ray et al., 2008), monument movements, variation in local multipath (Dong et al., 2002, Williams et al., 2004).

In this paper we investigate the agreement between GPS time series and independent loading models in Fennoscandia, and the subsequent application of the models to reducing GPS time series residuals. We compare time series of vertical positions from GPS with modelled vertical deformation from three geophysical loads. They are the atmospheric pressure variation, non-tidal variation in Baltic sea level, and continental hydrology. The loads are studied at seven continuous GPS stations, five in Sweden, one in Finland, and one in Norway (Figure 1a). We want to see whether the residuals in the GPS time series can be reduced by the model corrections. We also compare the seasonal pattern in GPS and in the load models. Our data on Baltic level is monthly, as are the hydrology models. Therefore the GPS and atmospheric loading time series are averaged to monthly means as well (see next chapter).

[Figure 1]

Data and methods

GPS

Figure 1a shows the positions of the 7 stations. We use three daily GPS time series of vertical positions. Two of them are by M.B. Heflin and were obtained from the Processing Centre of the International GNSS Service (IGS) at the Jet Propulsion Laboratory (JPL) (http://sideshow.jpl.nasa.gov/mbh/series.html). These solutions apply the no-fiducial strategy and GIPSY software. Daily solutions are aligned to the ITRF2005 in the least-squares sense using either a 6-parameter (translation, rotation) or 7-parameter (translation, rotation, scale) Helmert transformation. Hereafter we refer to them as MHp6 and MHp7, respectively. The starting years for these time series varies, from 1993 to 2004 depending on the station.

The third GPS time series is the one used for BIFROST studies (Johansson et al., 2002). This is also calculated using the no-fiducial strategy and GIPSY. Satellite orbits were referred to various releases of the International Terrestral Reference Frame ITRF. The geodetic positions were then transformed to a frame provided by M. Heflin, using a core subset of the BIFROST stations; for description see Johansson et al. (2002). We refer to this time series as JJ and the data span is 1993–2006 at all our stations.

All time series use the same strategy, cut-off angle of 15° and IERS conventions for the solid Earth tide and ocean tidal loading. The models of ocean tidal loading used in GPS processing do not include Baltic tides. They are a few centimetres only, and thus negligible in the terms of the load. The effect of non-tidal ocean loading for our stations is small, 1.5-2 mm peak-to-peak from the ECCO-model (Takiguchi et al. 2006), and is neglected. At the (seasonal) timescales of interest here, the GPS time series approximately refer to the CF (Center of Figure) frame (Dong et al., 2002).

Since the GPS time series show larger scatter in the beginning, we left the first years out and chose a time period 1997-2006 (10 years) for all the stations, when available. All daily series were decimated to monthly series taking the simple average over a calendar month. The time series of all the stations are plotted in Figure 1b.

Baltic Sea

We used monthly tide gauge (TG) data from all around the Baltic, provided by the Permanent Service for Mean Sea Level (Woodworth and Player, 2003). The reference for the sea level was determined by regression of the whole lengths of the TG records and by fixing the epoch to 2000.5. Monthly series of a sea surface model were created using the minimum-curvature-surface interpolation scheme with splines (Smith and Wessel, 1990). The number of available TG stations varies monthly, between 22 and 26, but the interpolation scheme is not sensitive to missing support points. The loading deformation was calculated from these sea-surface models by convolving them with the Green's function from the Gutenberg-Bullen Earth model (Farrell, 1972). The degree one Love numbers applied by Farrell (1972) imply that the frame is CE (Center of mass of the solid Earth). For our purposes, the difference from CF frame is negligible (Dong et al., 2002). Steric effects were neglected, i.e. sea heights were equated with sea mass. For more details see Virtanen et al. (2008). An example of a monthly Baltic Sea load deformation can be seen in Figure 1a.

Atmospheric loading

We use the atmospheric pressure loading time series provided by the Goddard VLBI group, available on the Web at http://gemini.gsfc.nasa.gov/aplo/. They were computed by convolving the Green's function from the Preliminary Earth Model (PREM) with a surface pressure field (Petrov and Boy, 2004). The surface pressure field comes from the NCEP/NCAR Reanalysis numerical weather model and has a 2.5 x 2.5 degree spatial resolution and 6-hour temporal resolution. We averaged the 6-hour values to monthly means. In this time series, oceans are assumed to have the inverse barometer (IB) response, but semi-enclosed seas like the Baltic Sea are taken to be "dry land", which is consistent with the Baltic Sea load computation. The frame of the time series is CM, i.e., Centre of Mass of the entire solid Earth plus load.

Continental water storage

We used three monthly models of continental water storage. The model of the Climate Prediction Centre (CPC, Fan and van den Dool, 2004) only contains soil moisture, but its leaky-bucket model can hold 0.76 m of water and therefore is capable of partly accounting for groundwater, too. Snowfall is modelled as liquid water and thus it may exit from the model too fast. The WaterGAP Global Hydrology Model (WGHM; Döll et al. 2003) and the LaDWorld Gascoyne (Milly and Shmakin, 2002) account for all aspects of water storage: snow, soil moisture, groundwater. We have used each model in the whole area where it is released. WGHM excludes the polar ice sheets but LaDWorld and CPC cover them.

To compensate for the change in total continental water storage, we add or subtract a uniform layer of water to/from the oceans. Thus the global water mass is conserved but gravitational consistency (Clarke et al., 2005) is not implemented. The time series of deformation are then calculated by convolving the global loads with the Green's function from the Gutenberg-Bullen Earth model by Farrell (1972). The frame is CE (cf. the Baltic Sea above).

Results and discussion

Time series plots

In the following figures all loads are relative to a mean value and time series plots have been detrended. An example of a monthly Baltic Sea load can be seen in Figure 1a. The deformation decreases rapidly with growing distance from the sea.

Figure 2a shows the monthly time series at Metsähovi: GPS, loading, and GPS residuals after removing all loads. Figures 2b, 2c and 2d show the same time series at Kiruna, Mårtsbo and Onsala, but with Metsähovi subtracted. Obviously, at closeby stations the loading signals are very similar. However, at longer distances clear differences already emerge, e.g. in the hydrological loading between Kiruna and Metsähovi. Noteworthy are also the relatively large discrepancies between the different hydrological models. The plots for Borås (not shown) are rather similar to Onsala and Tromsö (not shown) resembles Kiruna.

As we are particularly interested in loading by the Baltic Sea, we have chosen three stations for closer analysis: Metsähovi, Mårtsbo, and Visby. At the other stations its loading is small.

[Figure 2]

Load time series as corrections to GPS

Here we look at the load time series as corrections to GPS. We have computed the standard deviations of the three GPS time series before and after the load effects in various combinations have been corrected for. The standard deviations of the individual load effects are given, too. This is done for the Visby station in Table 1, for Mårtsbo in Table 2, and for Metsähovi in Table 3. We have then calculated the reduction in the standard deviation with respect to the original GPS time series. The change is expressed in percent and is negative if the standard deviation decreases, i.e. improves. Note that for Visby and Mårtsbo the GPS time series MHp6 and MHp7 have only three years of data and for comparison also three-year period has been computed for JJ solution (JJS). All the other GPS time series cover the period January

1997 to December 2006. Tables 1, 2 and 3 show that the performance of the corrections depends on the site and on the GPS time series in question, both on its length and on the solution (JJ or MH).

[Table 1]

[Table 2]

[Table 3]

At Visby the Baltic Sea correction reduces the standard deviation in all time series, for MH time series also the hydrology correction helps. For the three-year time series at Mårtsbo the hydrology models and Baltic Sea correction reduce the standard deviation using almost every combination, whereas the ten-year time series (JJ) for the same stations hardly improve. At Metsähovi the highest reductions are achieved in MHp6 using hydrology correction only.

The ten-year series MHp7 and JJ at Metsähovi respond almost identically to the corrections, similarly the three-year series MHp7 and JJS at Mårtsbo. In fact this could be expected as the GPS time series themselves (Fig 1a) are very similar. At Visby the three-year series MHp7 and JJS differ appreciably in the winter 2006 (Fig 1a) and so does their response to the load corrections.

In nearly all instances, the hydrological time series improve MHp7 less than they do MHp6. The difference between the MHp6 and MHp7 is that in the latter series a scale parameter is included in the alignment to ITRF2005. Possibly the global fit for scale couples into the global seasonal deformation cycle due to hydrology. The ten-year series JJ show hardly any improvement from corrections, anyplace. Scherneck et al. (2003) have discussed in detail the low admittance of load series into the GPS observations in the shorter daily version of the series (Johansson et al., 2002), using a much larger set of stations.

The relative performance of the different hydrological models depends on the station and on the time series, no clear pattern emerges. The correction for the Baltic level ("bs") only works at Visby, which is situated in the middle of the Baltic Sea and also near the coast. This is baffling as it is relatively large at all three stations. The poor performance of the atmospheric correction ("aplo") may be in part related to the fact that our correction is in CM frame while the other time series are approximately in the CF frame. We thus neglect the geocenter motion (motion of the CM relative to CF) due to the atmosphere, which is at the monthly timescale is of the order 3 mm (e.g., Feissel-Vernier et al., 2006) which in turn is as large as our atmospheric correction in the CM frame. On the other hand, Tregoning and van Dam (2005) show that there are several sites where the correction for atmospheric loading does not improve GPS daily series even when both are in the same frame.

The largest reductions in the GPS residuals are 20–40%, for the MHp7 and MHp6 series. This is similar to the results by Tervo et al. (2006) but the difference is that they reached best results by removing all the loading factors.

Influence of load corrections on trend determination

All our stations are in the area of the Fennoscandian postglacial rebound and it is of interest to see how the load corrections influence the trend determination from the GPS time series. Obviously, the formal uncertainty of the trend fitted using least squares will decrease in the same way as the residual standard deviation in Tables 1, 2, and 3. But what about the trend itself? Table 4 gives the results of trend determination for the three stations. There is the GPS time series name and the time period for which the trend was computed, the trend from daily values and the trend from monthly values. As could be expected, the values are quite similar, since the same data set is used. The rest of the columns show the trends computed for the different loading signals. The last three columns show the sum of the trends using different hydrological models. The figures give the opposite number of the change in the trend of the GPS time series, if it were corrected for the corresponding load(s). Most of the trends are small as expected

[Table 4]

The hydrological models are not constructed for determination of hydrological long-term trends but rather for the annual cycle and for short-term inter-annual phenomena. They could perhaps be trusted only over a few years. However, we see that in Visby and Mårtsbo, where the uncertain trends from the short 3-year GPS time series deviate appreciably from the 10-year GPS trend, the inclusion of the hydrological load would only make the discrepancy worse. On the contrary, the modelled loads with the exception of the CPC seem near trend-free over the 10-year period.

Seasonal variation in the GPS and in the loading time series

As discussed in the Introduction, GPS time series often show seasonal variation; in apparent positions load phenomena like hydrology are also seasonal in nature. Inspection of Figure 2 shows a clear seasonal signal in the hydrological time series, and in the Metsähovi GPS series. For better visualization, we stack the GPS and load time series for each site by averaging over each month separately. This simple method has the advantage that no functional form (e.g. sinusoidal) is assumed for the phenomena. The results are depicted in Figure 3. It shows the total load effect (in which hydrology is represented by WGHM) and the three different GPS time series for each station,

[Figure 3]

First note is that the load stacks are very similar at all stations and over both 10 and 3 years. In Metsähovi all time series are stacked over 10 years. The phases of the GPS stack agree and are rather close to the phases of the load stack. The GPS amplitudes are 40–80% of the load amplitude. JJ and MHp7 are near-identical as previously noted. For Mårtsbo and Visby we use load stacks over 3 years and 10 years. GPS stacks MHp6 and MHp7 are over 3 years and JJ over 3 and over 10 years. At Mårtsbo the 3-year GPS stacks agree quite well. The amplitude of the JJ solution is not as clear as for MHp6 and MHp7 but they all agree with the load. The 10-year JJ stack deviates considerably from the load and shows only a very subdued annual cycle. At Visby, the (3-year) MHp6 and MHp7 reproduce the phases of the load stack but have about 70 percent of its amplitude. The 3-year JJ stack is bimodal due to the data of the winter 2006. The 10-year JJ stack does not show any seasonal pattern at all.

While at some stations the similarity of the annual cycle from GPS and from the load models is obvious, it should be remembered that even at them the GPS seasonal component explains only a part of the variation in the monthly GPS time series. E.g. at Metsähovi subtracting the monthly means from the MHp6, MHp7, and JJ time series decreases their standard deviation by 24, 11, and 5 percent, respectively. For the 3-year series at Mårtsbo the figures are 39, 5, and 5 percent. At Visby we have 13, –18 and –18 percent, i.e. partly a deterioration. This is because we have taken into account that in eliminating the monthly means the degrees of freedom decrease by 11.

Conclusions and outlook

We have studied the effect of the atmospheric pressure loading, the effect of the non-tidal Baltic Sea loading and the effect of continental water loading at seven GPS stations in Fennoscandia. Despite this being a limited region, the loading signals are far from identical: the Baltic loading is limited to the vicinity of the sea and across the region differences appear also in the continental water loading. At three sites close to the Baltic the loading time series were compared with apparent vertical movements derived from GPS. Removing the computed loading from the GPS time series reduce the standard deviation, but not for all series nor for all combinations of loads. The maximum reduction was found to be 23% at Metsähovi, 43% at Mårtsbo and 34% at Visby. This is of the same size as in our previous results (Tervo et al., 2006).

The three GPS time series studied use the same processing strategy but different alignment to the reference frame. This is reflected in their relationship to the load time series. The MHp6 does not use a scale parameter in the alignment and after correcting for the loads performs better than the MHp7 that does. The 10-year JJ and MHp7 series are not significantly improved by the loading corrections on any of the stations, but the corresponding 3-year series at Mårtsbo are. For control we computed the 3-year series at Metsähovi and found the same results (not shown) as at Mårtsbo. This could be related to the piecewise transformations used in the alignment to the frame.

The three time series of hydrological loads differ appreciably but the GPS series do not show clear preference for any of them. Obviously, there is considerable uncertainty the models involved. No such uncertainty should appear in our Baltic load model and therefore it is baffling that it does not perform better for the GPS. We will improve the atmospheric load series by including the corresponding geocentre motion.

At the three stations analyzed, removing the seasonal variation decreases the standard deviation of the monthly GPS solutions by maximally 40 percent. The seasonal variation in GPS tends to underestimate the seasonal variation in modelled load.

Acknowledgments. The calculations were done using programs NLOADF (soil moisture and Baltic Sea loading, Agnew, 1997), Generic Mapping Tools version 3.4.2. (maps, Wessel and Smith, 1998) and R version 2.4.1 (analysis and figures, R Development Core Team, 2006). This work was partly funded by the Academy of Finland (decision number 117094).

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Figure and table captions

Figure 1. a) Loading caused by the Baltic Sea in March 2006 and the positions of the GPS stations. The scale is in millimetres. b) The GPS time series of all the stations, scale is in millimetres. TROM=Tromsö, KIRU=Kiruna, MART=Mårtsbo, METS=Metsähovi, VISB=Visby, BORA= Borås, ONSA=Onsala. Solid black line = JJ, gray line = MHp6, dashed black line = MHp7.The peaks in Kiruna ja Tromsö time series are likely due to snow accumulation on top of the antenna.

Figure 2. Time series. a) Metsähovi b) difference Kiruna – Metsähovi (distance 880 km) c) difference Mårtsbo – Metsähovi (distance 410 km) d) difference Onsala – Metsähovi (distance 790 km). The top panel (gps) is the GPS time series (or the difference) after trend removal: solid black line = JJ, gray line = MHp6, dashed black line = MHp7. The second panel from top (bs) is the Baltic Sea loading and the third panel (ap) the atmospheric pressure loading. The fourth panel (cw) shows three different continental water model loads: solid black line = CPC, gray line = WGHM, dashed black line = LadWorld. The fifth panel shows the sum of the loads i.e. panels 2, 3 and 4. The bottom panel (resid) shows the GPS time series residual after the loading time series are subtracted. The WGHM was used for water load. The different lines are the same as for the top panel. The peaks in the Kiruna GPS time series are due to snow accumulation on top of the antenna. The scale is in millimetres.

Figure 3. Stacked time series for stations Metsähovi, Mårtsbo and Visby. The monthly mean for the whole time series has been computed and plotted. The circles show the sum of the loading factors, the triangles show the JJ time series and the grey symbols

show the MH time series, plusses the 6-parameter transformation and crosses the 7-parameter transformation. The dashed line is for 10-year time series of JJ and solid line for 3-year in Mårtsbo and Visby.

Table 1. The results for station Visby, standard deviations in mm of the different time series and their reduction with respect to the original time series. MH p6 = MH time series with 6-parameter transformation, MH p7 = the same, but with 7 parameters, JJ = BIFROST time series, JJS = JJ time series for 3 years, red % = reduction percentage of the standard deviation, gps = GPS time series after trend removal, aplo = atmospheric pressure loading, bs = Baltic Sea loading, wghm = continental water loading from model WGHM, cpc = continental water loading from model CPC, ladw = continental water loading from model LadWorld. The standard deviations of the load time series (aplo, bs, wghm, cpc, ladw) are 2.73, 2.01, 3.91, 2.01, 0.80 mm (10 years) and 2.81, 2.19, 3.77, 1.70, 0.83 mm (3 years).

Table 2. The results for the station Mårtsbo. The abbreviations are the same as in Table 1. The standards deviations of the load time series (aplo, bs, wghm, cpc, ladw) are 2.72, 1.24, 4.23, 2.18, 1.68 mm (10 years) and 2.68, 1.34, 3.96, 1.82, 1.68 (3 years).

Table 3. The results for the station Metsähovi. The abbreviations are the same as in Table 1. The standards deviations of the load time series (aplo, bs, wghm, cpc, ladw) are 3.07, 1.38, 4.75, 2.27, 2.35 mm.

Table 4. The determined trends (mm/year) from different time series. The first column gives the name of the GPS time series, MHp6 = MH time series with 6-parameter transformation, MHp7 = the same, but with 7 parameters, JJ = BIFROST time series, and their length (10 or 3 years). gps/d = trend determined from daily GPS time series, gps /m = trend from the monthly time series, aplo = atmospheric pressure loading, bs = Baltic Sea loading, wghm = continental water loading from model WGHM, cpc = continental water loading from model CPC, ladw = continental water loading from model LadWorld, sum (A) = the trend of the sum of the loadings using different water models A.

Figures

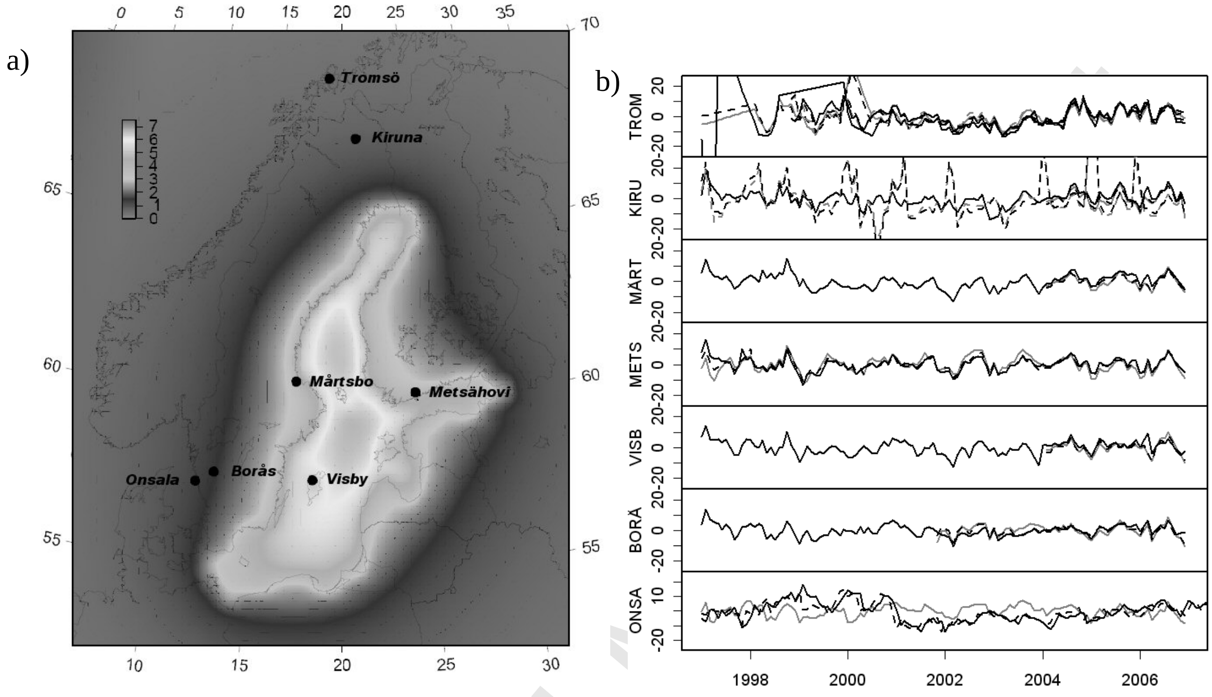

Figure 1. a) Station positions and loading in millimetres for March 2006. b) GPS time series.

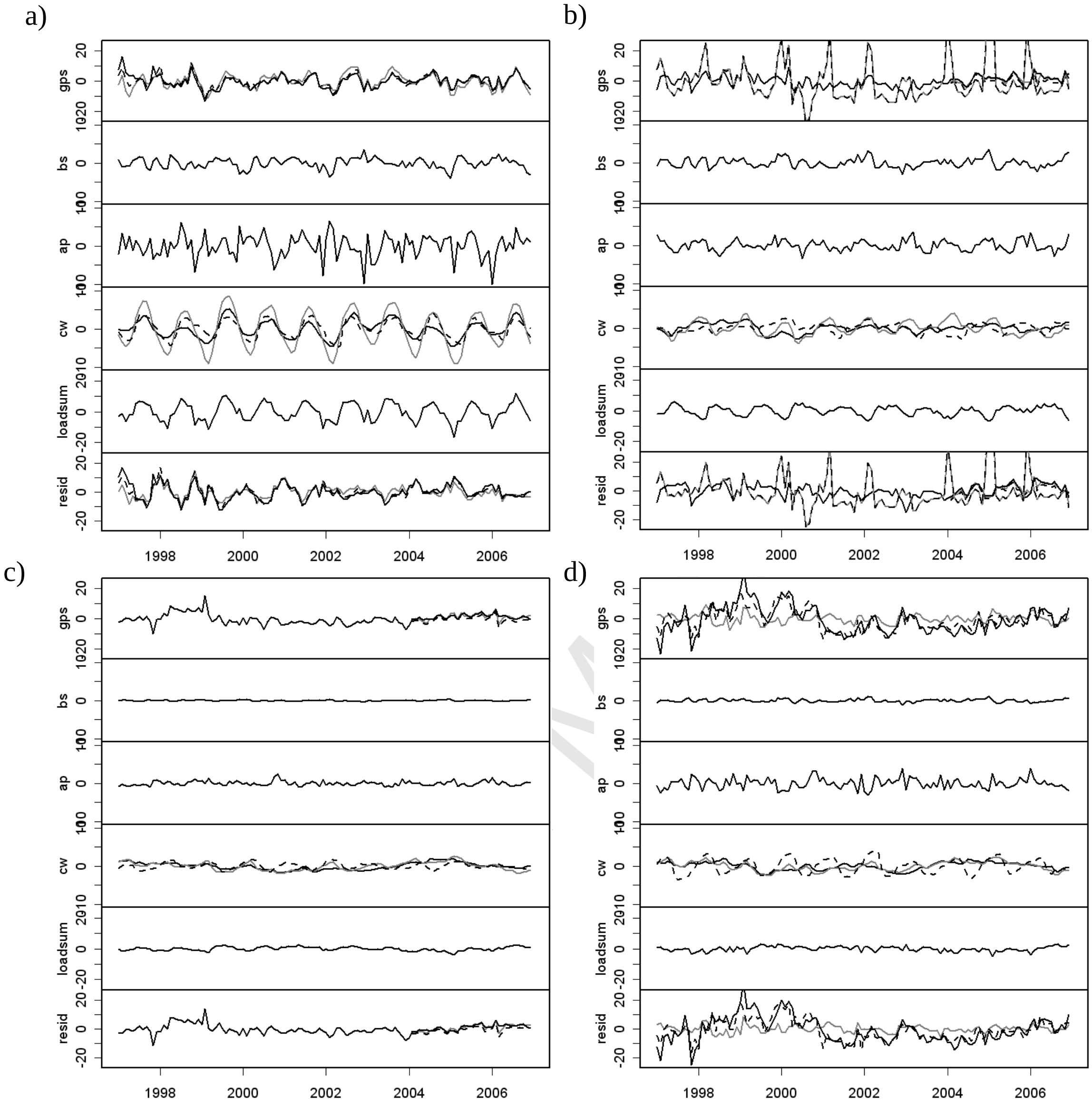

Figure 2. Time series. a) Metsähovi b) difference Kiruna – Metsähovi c) difference Mårtsbo – Metsähovi d) difference Onsala – Metsähovi.

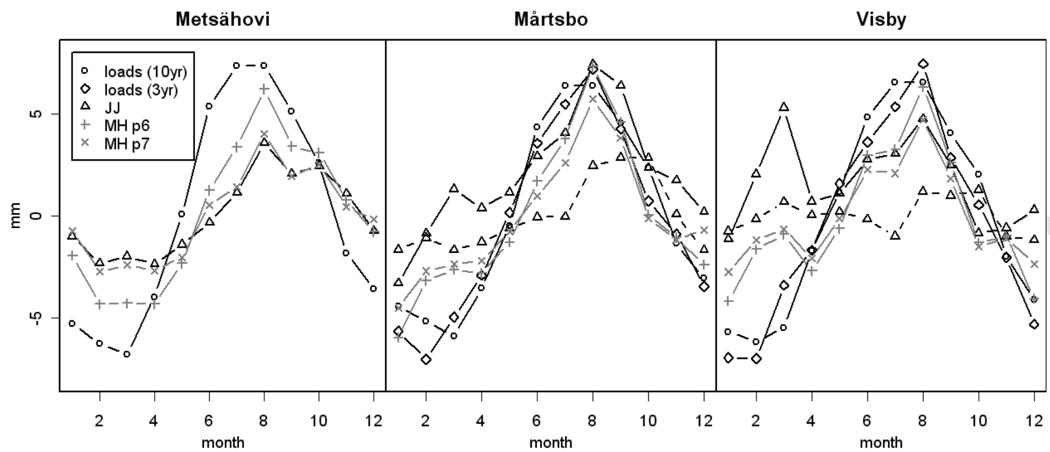

Figure 3. Stacked time series for all three stations.

Tables

Table 1. Results for Visby

VISBY	MHp6	red %	MHp7	red %	JJS (3-yr)	red %	JJ(10-yr)	red %
gps	4.22	0.0	3.61	0.0	3.22	0.0	4.38	0.0
- aplo	4.66	10.4	4.33	20.0	4.02	24.7	5.38	22.6
- bs	3.96	-6.3	3.34	-7.4	2.49	-22.7	4.05	-7.7
- wghm	3.47	-17.9	3.62	0.5	4.31	33.6	5.53	26.1
- cpc	3.28	-22.3	3.00	-16.9	3.13	-2.8	4.41	0.5
- ladw	3.85	-8.9	3.36	-6.8	3.10	-3.9	4.47	2.0
- aplo-bs	4.18	-1.1	3.85	6.6	3.14	-2.5	4.74	8.2
- aplo-wghm	4.60	9.0	4.91	36.1	5.44	68.7	6.54	49.2
- bs-wghm	2.78	-34.1	3.03	-16.0	3.50	8.7	5.36	22.2
- aplo-bs-wghm	3.85	-8.9	4.25	17.8	4.60	42.9	6.11	39.4
- aplo-bs-cpc	3.64	-13.7	3.70	2.4	3.50	8.5	4.95	12.9
- aplo-bs-ladw	3.81	-9.9	3.63	0.6	3.03	-6.0	4.82	9.9

Table 2. Results for Mårtsbo

MÅRTSBO	MHp6	red %	MHp7	red %	JJS (3-yr)	red %	JJ(10-yr)	red %
gps	4.05	0.0	3.29	0.0	3.41	0.0	4.65	0.0
- aplo	4.08	0.8	3.53	7.3	3.76	10.2	5.31	14.3
- bs	4.21	4.1	3.51	6.6	3.42	0.2	4.68	0.8
- wghm	2.29	-43.4	2.48	-24.5	2.61	-23.6	5.10	9.9
- cpc	2.58	-36.2	2.15	-34.8	2.35	-31.1	4.31	-7.3
- ladw	2.94	-27.3	2.40	-27.2	2.66	-22.1	4.61	-0.8
- aplo-bs	3.88	-4.1	3.32	0.8	3.35	-1.7	5.01	7.9
- aplo-wghm	3.22	-20.4	3.56	8.2	3.76	10.4	5.77	24.2
- bs-wghm	2.29	-43.3	2.51	-23.8	2.34	-31.3	5.19	11.6
- aplo-bs-wghm	2.73	-32.6	3.14	-4.7	3.15	-7.7	5.54	19.2
- aplo-bs-cpc	2.89	-28.7	2.79	-15.4	2.85	-16.5	4.79	3.1
- aplo-bs-ladw	2.89	-28.7	2.63	-20.1	2.77	-18.8	4.99	7.4

Table 3. Results for Metsähovi

METSÄHOVI	MHp6	red %	MHp7	red %	JJ	red %
gps	4.98	0.0	4.05	0.0	4.47	0.0
- aplo	5.50	10.6	4.76	17.4	5.15	15.1
- bs	5.01	0.6	4.19	3.4	4.58	2.4
- wghm	3.82	-23.2	4.45	10.0	4.95	10.7
- cpc	3.97	-20.3	3.65	-9.8	4.11	-8.1
- ladw	3.94	-20.8	3.68	-9.1	4.24	-5.2
- aplo-bs	5.17	3.8	4.46	10.0	4.85	8.5
- aplo-wghm	4.69	-5.7	5.28	30.5	5.74	28.2
- bs-wghm	4.01	-19.4	4.71	16.2	5.17	15.5
- aplo-bs-wghm	4.43	-11.1	5.13	26.7	5.58	24.8
- aplo-bs-cpc	4.40	-11.6	4.30	6.1	4.70	5.1
- aplo-bs-ladw	4.22	-15.2	4.17	2.9	4.68	4.7

Table 4. Trend determination

	mm/year	gps/d	gps/m	aplo	bs	wghm	cpc	ladw	sum (wghm)	sum (cpc)	sum (ladw)
METS	MHp6 (10yr)	5.48	5.43	-0.19	0.04	0.20	0.42	0.08	0.04	0.27	-0.07
	MHp7 (10yr)	5.61	5.58								
	JJ (10 yr)	5.48	5.45								
MART	MHp6 (3yr)	7.51	7.19	-0.17	0.06	0.58	0.80	0.27	0.48	0.70	0.17
	MHp7 (3yr)	7.85	7.68								
	JJ (3yr)	8.20	7.82								
	JJ (10 yr)	8.12	7.90	-0.17	0.03	0.17	0.50	0.01	0.03	0.36	-0.13
VISB	MHp6 (3yr)	2.03	1.46	-0.23	0.05	0.96	1.08	0.18	0.78	0.89	0.00
	MHp7 (3yr)	2.38	1.95								
	JJ (3yr)	3.33	3.14								
	JJ (10 yr)	3.56	3.78	-0.16	0.05	0.10	0.43	0.04	-0.01	0.31	-0.08