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Äspö Hard Rock Laboratory

Hydro monitoring program

Report for 1998

Göran Nyberg, Stig Jönsson, Joachim Onkenhout

GEOSIGMA, Uppsala

August 1999

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Äspö Hard Rock Laboratory

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Abstract

The Äspö island is situated close to the nuclear power plant of Simpevarp in south-eastern Sweden. As part of the pre-investigations preceding excavation of the so called Äspö Hard Rock Laboratory, registrations of the groundwater levels and electrical conductivity in packed off borehole sections and levels in open boreholes started in 1987. The investigations are still ongoing and are planned to be continued for a long period after the termination of the tunnel construction. As the tunnel excavation went on from the autumn 1990 and onwards, new boreholes were drilled in the tunnel and instrumented to enable groundwater pressure monitoring in packed off sections. Also other hydro-related measurements such as water flow in the tunnel, electrical conductivity of tunnel water and inflow and outflow of water through tunnel pipes has been performed. This report is a presentation of the monitoring during 1998 and of the instrumentation and measurement methods used.

In order to allow for comparison with factors that may influence the groundwater level/pressure and flow, meteorological data and measurements of the level of the Baltic Sea are presented in the report. In one chapter, attention is paid also to the earth tide effect.

From the end of 1991 the disturbances from the tunnel are the dominating factors influencing groundwater levels in the area. In one chapter activities that may have an influence on the ground water situation are listed and briefly discussed.

Executive Summary

The construction of the Äspö Hard Rock Laboratory started in October 1990. The laboratory is an extensive tunnel system excavated down to a depth of 460 m below the ground surface. Äspö island is situated close to Simpevarp in south-eastern Sweden. A 3.6 km long entrance tunnel to the laboratory, starting at the ground surface close to the nuclear power plant on the Simpevarp peninsula, has been excavated. Vertical shafts, which connects the laboratory with the ground surface of Äspö, were also drilled. When excavating the last part of the tunnel, between 3.2 and 3.6 km, the traditional blasting technique was replaced by full face TBM-technique.

Extensive preinvestigations have been performed in the area, e.g. aerial and ground geophysical surveys, mapping of solid rocks and borehole investigations. These activities have been carried out on Äspö and four adjacent areas: on the islands of Ävrö, Bockholmen and Mjälen east and south of Äspö and in the Laxemar area at the mainland west of Äspö. A large number of core and percussion boreholes, varying in length between 20 m and 1 700 m, have been drilled in these areas. One important part of the pre-investigations has been geohydrological borehole measurements, such as different types of hydraulic tests, hydrochemical investigations, tracer tests and groundwater level registrations.

Along with the excavation of the tunnel, a number of boreholes in the tunnel have been included in the hydro-monitoring program. In addition, other groundwater-related measurements, such as water flow in the tunnel and electrical conductivity of tunnel water, have been performed.

The objectives of the geohydrological investigations are 1) to document the groundwater conditions before, during and after excavating the laboratory tunnel system and 2) to obtain a data set of hydraulic, transport and chemical parameters. These parameters are essential in order to improve predictions of transient processes, e.g. predictions of groundwater level changes, which is one consequence of the tunnel excavation.

The groundwater level registrations were initiated in 1987, before the start of the tunnel excavation. The measurements are ongoing during the whole period of construction and will be continued after the completion of the tunnel system. The results of these registrations have consecutively been presented in annual reports. However, the first report in this publication series comprised groundwater level data from three years: 1987-89 (Nyberg et al 1991). Earlier reports only comprised data collected in surface boreholes but as from the annual report for 1995, also data collected from measurements in the tunnel were included. The following data are described:

1) groundwater level data in surface boreholes,

2) electrical conductivity registrations of the groundwater in surface boreholes,

3) groundwater pressure in tunnel boreholes,

4) water flow in tunnel,

5) water flow in tunnel pipes,

6) electrical conductivity of tunnel water,

7) humidity transport in the ventilation air in the tunnel (only in report for 1995)

8) level registrations of the Baltic Sea,

9) precipitation,

10) air temperature and

11) potential evaporation.

The meteorological data is collected at the meteorological stations situated as close as possible to the investigation area.

During 1998, there were 76 boreholes involved in the hydro-monitoring program within the five investigation areas and in the tunnel. The boreholes are either core drilled (39 in number) or percussion drilled. Most of the boreholes are equipped with one or several rubber packers, which isolate up to ten borehole sections often representing different hydraulic units of the bedrock. The groundwater levels in many of the surface boreholes are gauged by pressure transducers, one for each borehole section. The transducers are planted in tubes connecting the sections with the ground surface. In certain boreholes, the design of the instrumentation is slightly different and in some cases, the measurements are performed by manual levelling. In a number of boreholes on the Äspö island that were excluded from the measurement program during 1995 manual levelling was resumed during 1997. In the tunnel, many sections are hydraulically connected to a multiplexer, controlling magnetic valves that opens to a pressure transducer. Therefore, the same transducer is used to measure a number of borehole sections. For special reasons, a number sections are connected to individual transducers mounted on a panel.

Most core drilled surface boreholes on Äspö were initially equipped with two sensors to monitor electrical conductivity of the groundwater. One of the sensors is placed relatively close to the ground surface, the second rather deep in the borehole. During the course of time most of these sensors has ceased to work and in the end of 1998 only two sensors were still measuring.

In the tunnel 21 gauging boxes equipped with a v-notch weir are installed for flow measurements. Electrical conductivity of tunnel water has been measured at eleven locations. Water flow into and out of the tunnel in fresh water and discharge pipes are measured at 0/700 m tunnel length.

During the spring of 1991, the tunnel excavation began to affect the groundwater level in many boreholes. During 1992 and 1993 the effect of the tunnel is evident in all subareas except at Laxemar. In the central part of Äspö and on Bockholmen the drainage by the tunnel has caused dramatic effects in many boreholes. In some sections close to the latest excavated parts of the tunnel, the decline in level during 1994 is some ten metres.

During 1995 the levels continued to decline a few metres in a number of borehole sections at Äspö, but a stabilisation occurred in 1996 when the level change, seen over the year, in most boreholes was within one metre. The results for 1997 indicate a somewhat greater decline at one or a few meters in the vicinity of the Äspö tunnel but during 1998 there have been small changes. In the main part of the borehole sections the change over the year is within half a metre, increasing in some boreholes and decreasing in others.

In all tunnel boreholes, the pressure was still decreasing during 1997. During 1998 most boreholes down to a tunnel length of approximately 2000 metres shows a decreasing pressure between 10 and 40 kPa over the year, while further down in the tunnel the pressure in the main part of the boreholes is slightly increasing, or is relatively unchanged seen over the year.

A considerable drawdown in the pressure in most tunnel boreholes that is also seen in the levels in many surface boreholes, occurs on the 21th October and extends to the beginning of November. This is most certainly caused by the excavation, and the following grouting, of a niche in the assembly hall.

The flow changes in most gauging boxes are relatively small but at most locations a decline is observed when comparing mean flow for the period October – December for the latest four years. A few exceptions from this could be related to newly excavated parts of the tunnel and locations where fresh water, in connection to activities, has been added.

The flow in the pipe for incoming consumption water is somewhat lower during the period July – October than during the rest of the year.

The daily flow in the pipes as a mean during October - December 1998 is 9.2 m^3/24 h into the tunnel. During the same period 2268 m^3/24 h was pumped out from the tunnel, which is a decrease with approx. 125 m^3/24 h from 1997.

The total amount of precipitation during 1998 was approximately 626 mm, which is 73 mm more than mean for the comparison period 1961-90. Large amounts were measured in April and June whereas the precipitation figures were low in May and July.

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1 Introduction

Since October 1990 construction works for the Äspö Hard Rock Laboratory, situated a few kilometres north of the nuclear power plant of Simpevarp in south-eastern Sweden (Figure 1-1), are in progress. The laboratory is situated at a depth of maximum 460 m below the ground surface of the small island of Äspö (Figure 1-2). The entrance tunnel, starting at the ground surface on the mainland close to the nuclear power plant (1-2), has a length of about 3.6 km. Conventional blasting technique has been applied until about 3.2 km. Full face boring with TBM-technique was used to construct the remaining part of the main tunnel. The projection on the ground surface of the tunnel excavation is shown in Figures 1-2 and 2-1. Three vertical shafts (elevator shaft and two ventilation shafts), which connect the laboratory with the ground surface of Äspö, have been excavated.

Starting in 1987 extensive aerial and ground geophysical surveys, mapping of the rock outcrops and geohydrological investigations have been performed on Äspö, on the adjacent islands of Ävrö, Bockholmen and Mjälen and in the Laxemar area on the mainland west of Äspö (Figure 1-2). A large number of investigation boreholes have been drilled at these sites. The lengths of the boreholes vary between 22 m and 1 700 m and almost every borehole has, shortly after drilling, been instrumented with rubber packers, separating the borehole into two or more sections (maximum seven). The sections often represent different hydraulic units of the granitic bedrock. Most of the boreholes are also equipped with one or more pressure transducers, enabling groundwater pressure monitoring in the different borehole sections. In some sections the electrical conductivity of the groundwater is monitored. The deepest borehole in the investigated area, the 1 700 m long KLX02, is however not yet included in the groundwater monitoring program.

In March 1992 the first pressure measurements in tunnel boreholes were included in the hydro-monitoring program. Since then the tunnel measurements have been extended to comprise, except pressure measurements in several borehole sections, also flow measurements in the tunnel, measurements of electrical conductivity of tunnel water and flow in tunnel pipes. Most of the tunnel borehole sections are connected to hydraulic multiplexers that make it possible to measure up to 14 sections with the same pressure transducer. Water flow in the tunnel is measured with gauging boxes equipped with v-notch weirs and a pressure transducer to measure the water level in the box.

One important aim of the investigations has been to document the natural groundwater conditions regarding groundwater levels and groundwater chemistry, i.e. the prevailing conditions before excavation of the Äspö tunnel. Another purpose is to reveal hydraulic connections between different boreholes by analysing the pressure responses resulting from hydraulic disturbances of the aquifer (pumping or injection of water). Furthermore a goal has been to determine hydraulic, transport and chemical parameters in different units of the bedrock by analysing hydraulic tests, result from tracer tests and chemical sampling. With access to an extensive set of geological and geohydrological data, model predictions of different transient processes (e.g. pressure drawdown) which are a consequence of the tunnel excavation, have successively been tested and improved.

The groundwater level investigations from surface boreholes so far have been described in several progress reports. The groundwater level registrations are ongoing since 1987. The measurements have continued during the entire period of tunnel excavation and will go on for a long period afterwards. The registrations are successively presented in annual reports. The first report, however, contained groundwater level data from three years: 1987-89 (Nyberg et al 1991). Since the report for 1995, also tunnel data are included. The present paper is the annual report covering the year 1998. It contains:

1) groundwater level data in surface boreholes

2) electrical conductivity registrations of the groundwater in surface boreholes

3) groundwater pressure in tunnel boreholes

4) water flow in tunnel

5) water flow in tunnel pipes

6) electrical conductivity of tunnel water

Background data considered necessary for interpreting changes of groundwater levels are also presented in the report. This includes:

7) the water level of the Baltic Sea gauged by The Swedish Meteorological and Hydrological Institute (SMHI) at the harbour inlet of the city of Oskarshamn (Figure 1-2)

8) precipitation in Oskarshamn (SMHI)

9) air temperature in Oskarshamn (SMHI)

11) potential evapotranspiration calculated on data from the meteorological station at Gladhammar (southwest of Västervik), but with cloudiness (which is on of the input variables) from the Målilla station

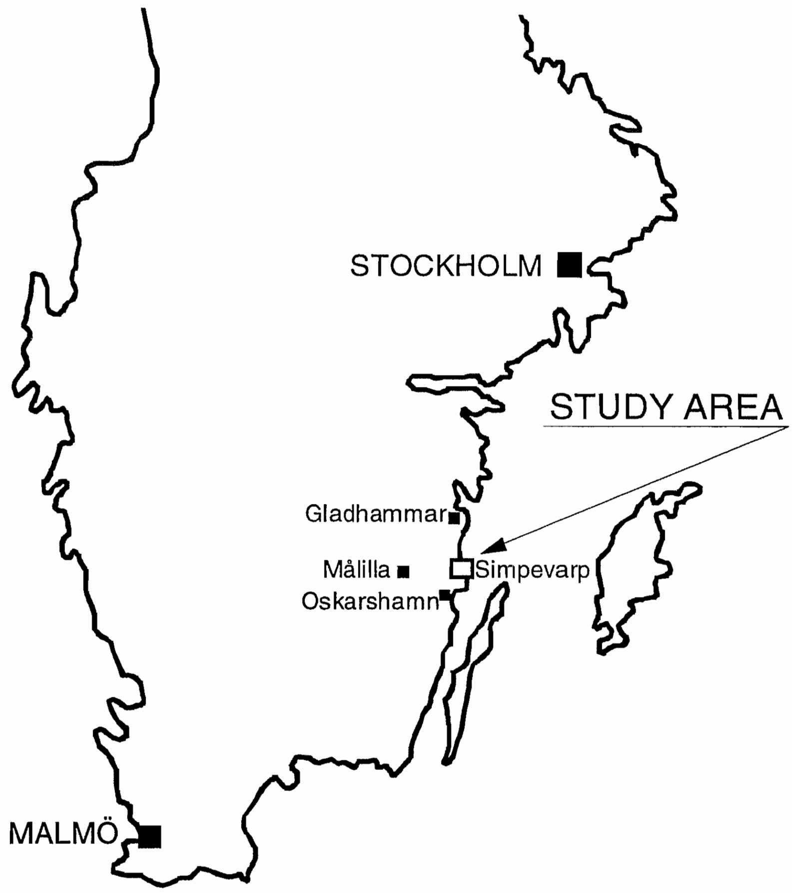


Figure 1-1 Location of the Äspö Hard Rock Laboratory area and of the stations used to collect background data.

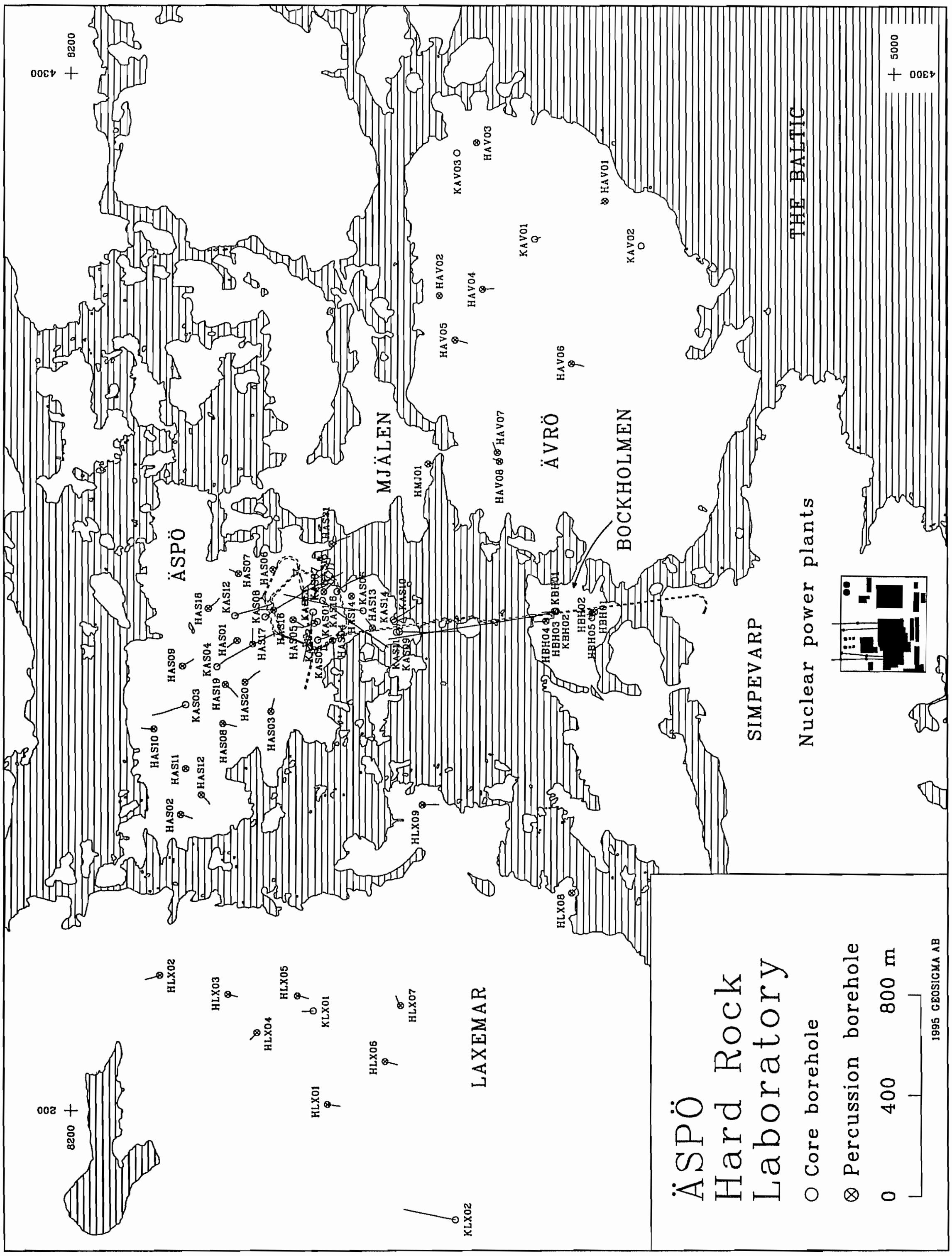


Figure 1-2 The investigation area with borehole locations

2 Geological and topographical overview of the investigation area

2.1 General

The near-coast areas of Äspö, Ävrö, Bockholmen, Mjälen and Laxemar (Figure 1-2) are characterised by small hills with an elevation range of a few meters or tens of meters, large areas of exposed crystalline bedrock and a thin and heavily abraded soil cover. Äspö, Ävrö, Bockholmen and Mjälen are islands, whereas Laxemar is part of the mainland. All five areas are forested, mainly with pine forest. However, especially on the islands of Äspö and Mjälen, the element of deciduous forest is apparent. The investigation area is almost uninhabitated.

The rocks in the investigation area, consisting of the five above mentioned sub-areas, belong to the extensive region of Småland-Värmland intrusions extending from south-eastern Sweden towards north and north-west to south-eastern Norway. Older, Sveco-carelian supracrustals and gneissic granites also occur as well as intrusions of anorogenic granites forming small massifs in the older bedrock, e.g. the Götemar granite. Datings of the Småland granites have yielded an age of > 1 700 Ma. The younger anorogenic granites range between 1 350 and 1 400 Ma in age (Kornfält, Wikman, 1988).

Concerning the structural conditions prevailing at the site of the Äspö Hard Rock Laboratory, much effort has been devoted to identification and characterisation of fractures and fracture zones. Since the fracture distribution governs the ground-water conditions of crystalline bedrock, the study of this subject is essential for implementation of reliable geohydrological predictions. To understand the variations with time of the ground-water levels studied in the present report, the spatial relation between the Äspö tunnel and the major fractures and fracture zones in the area is one of the key factors. Other important factors are climatic conditions, variations of the Baltic Sea level and the earth tide.

In sections 2.2-2.6 a brief description is given of the morphology, the petrography of the solid bedrock (based on mapping of outcrops) and of the structural conditions prevailing at the five subareas mentioned above. The structural model of the area is based on remote sensing, observation of outcrops as well as on tunnel and drill core mapping.

In earlier reports documenting the ground water level program at the Äspö Hard Rock Laboratory only boreholes drilled from the ground surface were accounted for. In the corresponding report from 1996 (Nyberg et al. 1996), data from boreholes drilled from the Äspö tunnel were included for the first time.

2.2 Äspö

The northern coastline of the triangular-shaped island of Äspö is rather straight (Figure 2-1), whereas the eastern and southwestern coasts are more irregular with several small islands and rocky islets at short distances from the coastline.

The bedrock of Äspö is dominated by so called Smålandsgranite: a finemedium-grained to medium-grained, reddish grey granitoid with megacrysts (1-3 cm) of red microcline. Dikes of fine-grained red to greyish granite intersect this older rock. At the southeastern part of the island, areas of Ävrö granite, a variety of the Smålandsgranite, are found. Minor intrusions of other rock types: greenstone, metavolcanics, aplite, pegmati-te, diabase and mylonite, are also scattered over the island (Kornfält, Wikman, 1988).

The altitude of the Äspö island exceeds 10 m.a.s.l. at the centre. Within a few small areas, e.g. close to the boreholes KAS04 and KAS08, small heights with an altitude of about 10 - 15 m.a.s.l. occur. The northern coastline is rather steep, especially in the central part.

Topographical maps and remote sensing reveal several more or less prominent lineaments intersecting the site of the Äspö Hard Rock Laboratory. The lineaments correspond to fracture zones of varying magnitude. In many cases, their existence at depth has been confirmed by borehole and tunnel observations.

Five major fracture zones have been identified by surface mapping of Äspö. One zone, denominated the mylonite zone and trending NE-SW, is approximately coinciding with a gully across the island between KAS04 and KAS12. In addition, a large number of minor fracture zones of various directions have been identified by surface mapping and confirmed by drilling.

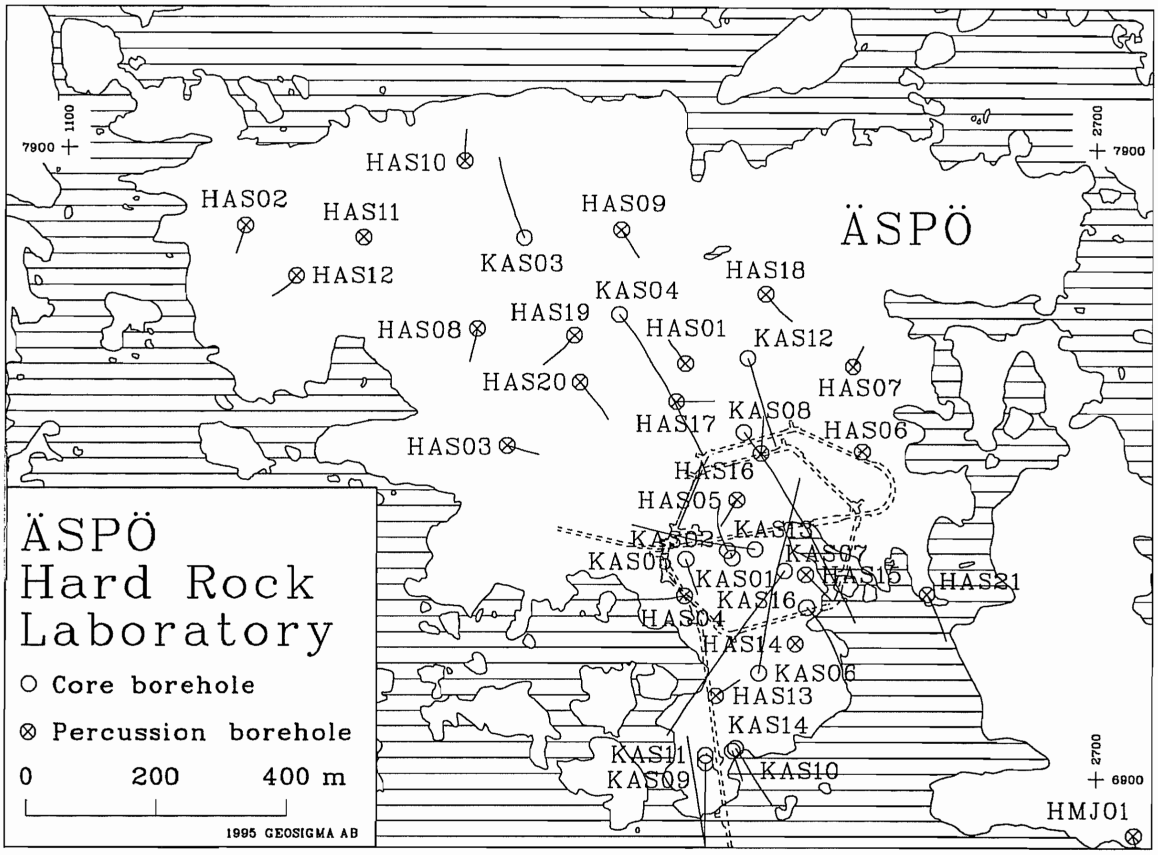


Figure 2-1 The Äspö area with borehole locations. Circles represent the intersection of the boreholes with the ground surface, the lines represent the projection on the ground surface of the respective boreholes. The tunnel is also shown in the figure.

2.3 Ävrö

The rectangular-like island of Ävrö (Figure 1-2) exhibits smoother coastlines than on Äspö. In addition, the topography of the Ävrö island is of different character. Ävrö consists of a plateau with a moderately undulating surface. The altitude varies between 6 and 15 m.a.s.l. A depression in the terrain, corresponding to a rock change, divides the plateau into a northwestern and a southeastern part. Most of the coastline is rather steep.

Granitic rocks dominate on Ävrö. The most frequent rocktype, denominated Ävrö granite, is greyish red and medium-grained. The above-mentioned NE-SW depression coincides with a fine-grained, grey metavolcanite (dacite to andecite) completely surrounded by the Ävrö granite (Kornfält, Wikman, 1987 a). Sparsely scattered remainders of other rock types also occur.

Two major fracture zones penetrated by the Äspö tunnel, a southern branch of zones found on the Äspö island, are trending ENE into the island of Ävrö at the northern part of its western coast (Gustafson et al., 1991 and Stanfors et al., 1994). A few other major fracture zones, however without contact with the Äspö tunnel, as well as several minor zones also intersect the island.

2.4 Bockholmen

Bockholmen is a small island (300 x 400 m) south of Äspö (Figure 1-2). Concerning geological character, Bockholmen can be described as a Southwest extension of the island of Ävrö, separated from the latter only by a narrow strait. Accordingly, the Ävrögranite is the dominating rock.

Only a few minor fracture zones have been identified at Bockholmen.

2.5 Mjälen

The postglacial land elevation has caused the Äspö, Mjälen and Ävrö islands to be almost connected to each other and to other islands further east (Figure 1-2). The long, narrow and curved island of Mjälen is situated between the Äspö and Ävrö islands and is geologically a part of both. The rocks of the major part of the island belong to the Småland granites. A minor part to the Southeast, close to Ävrö, is composed of the Ävrögranite. Only one investigation borehole has been drilled on Mjälen (Figure 1-2).

The island of Mjälen is in its southern part intersected by two major fracture zones, both penetrated by the Äspö tunnel. Further to the north, Mjälen is probably intersected by two other major fracture zones also found on the Äspö island.

2.6 Laxemar

The mainland to the west alongside the island of Äspö is called the Laxemar area. The coastline of Laxemar is somewhat irregular, especially to the south (Figure 1-2).

The predominant rocktype in the area is medium-grained, reddish grey, porphyritic granite with reddish augen (1-3 cm) of microcline. The granite is sometimes intruded by fine-grained, greyish red granite, both in smaller massifs and in dikes. Especially in the northeastern part of the area there exist xenoliths of mostly fine-grained, dark grey greenstone. The size of the xenoliths varies from a few meters to almost 50 meters (Kornfält, Wikman, 1987 b).

The Laxemar area exhibits a slightly more accentuated topography than the islands of Äspö, Ävrö, Mjälen and Bockholmen. In the southern and central parts the altitude exceeds 22 m.a.s.l.

During the autumn of 1992, a new borehole, KLX02, was drilled in the Laxemar area. The borehole, beeing the deepest core drilled borehole so far produced in Scandinavia, is almost vertical and has a length of 1 700 m. An extensive set of borehole loggings have been performed in KLX02. After this period of documentation, the borehole is planned to be included in the hydro-monitoring program described in this report. Three percussion boreholes were drilled in the vicinity of the core borehole KLX02, primarily for the production of cooling water. These boreholes are still not integrated into the official list of test boreholes.

Lineaments traversing the Laxemar area have been described by Munier, 1993. Munier correlates the most significant structure, here trending EW, to the mylonite zone at Äspö.

2.7 The Äspö tunnel

The extension of the Äspö HRL tunnel is illustrated in Figure 2-2. The geo-scientific conditions during excavation of the tunnel are described in a series of Progress Reports from the Äspö Hard Rock Laboratory: Stanfors et al., 1992, 1993, 1994a, 1994b and 1995 and Rhén ed., 1995. These reports, in which also evaluation of the geological predictions produced prior to the tunnel excavation is presented, cover the tunnel length 0/0-3/600 m.

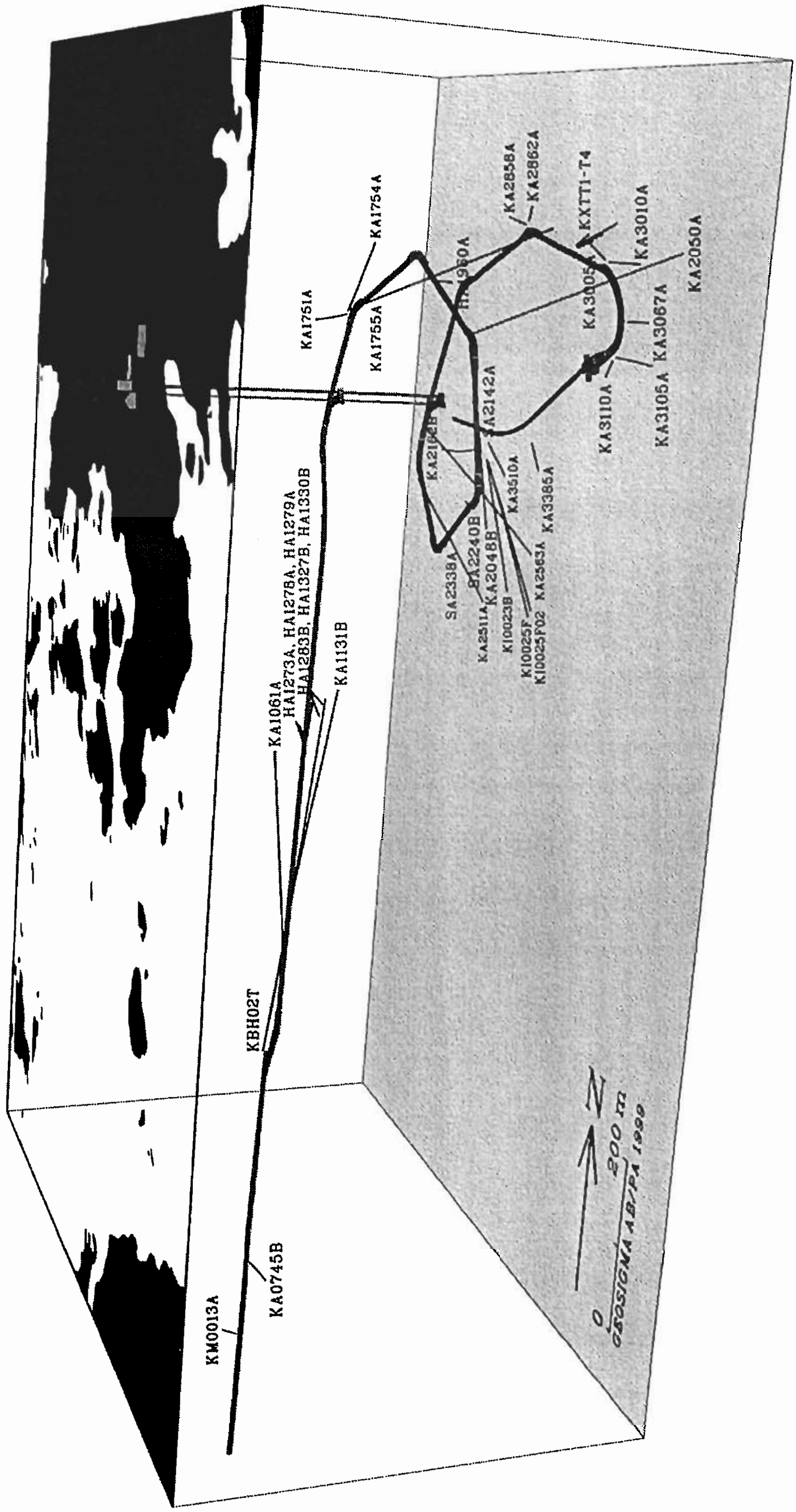


Figure 2-2 Outline of the Äspö Hard Rock Laboratory with a side-view of the access ramp, the tunnel spiral and boreholes.

3 Boreholes

3.1 Surface boreholes

The location of the boreholes is shown in Figure 1-2. Of the five subareas mentioned above, the island of Äspö has the largest number of boreholes. The location of the Äspö boreholes is illustrated also in Figure 2-1.

The following number of boreholes existed at the end of 1998:

In the Äspö area:	16 core drilled boreholes and
	21 percussion drilled boreholes
In the Ävrö area:	3 core drilled boreholes and
	8 percussion drilled boreholes
In the Bockholmen area:	2 core drilled boreholes
	5 percussion drilled boreholes
In the Laxemar area:	2 core drilled borehole and
	9 percussion drilled boreholes
In the Mjälen area:	1 percussion drilled borehole

In some boreholes on Äspö and in most boreholes on Ävrö, Bockholmen and Laxemar the measurements were terminated during 1995 – 1996. The extent of the monitoring program during 1998 is shown in Table 4-3.

The borehole deviation (inclination and declination), borehole length, the elevation of the top of casing, length of casing and finally the date for completion of drilling are presented in Table 3-1.

The height above ground for the top of casing is normally less than half a meter, typically about 30 cm.

Table 3-1 Borehole deviation, length, elevation of top of casing, length of casing and date for the completion of drilling.

Borehole	Inclination at ground (°)	Declination * at ground (°)	Borehole length (m)	Elevation** at top of casing (m a s l)	Length of casing (m)	Drilling completed
KAS01	≈ 85	≈ 318	101.00	8.18	1.00	871030
KAS02	84.0	318	924.04	7.68	1.05	880126
KAS03	82.9	326	1002.06	8.79	1.11	880407
KAS04	59.9	128	480.98	11.66(+0.21)	100.80	880501
KAS05	84.9	151	549.60	8.68(-0.06)	1.05	890227
KAS06	59.6	355	602.17	5.16(+0.01)	1.30	890129
KAS07	59.1	205	603.75	4.58(+0.02)	1.15	890131
KAS08	59.0	133	601.49	7.66	100.80	890219
KAS09	59.9	169	450.52	4.08	100.65	891122
KAS10	≈ 60	≈ 150	99.93	3.72	2.50	891023
KAS11	88.7	22	248.90	4.26	6.00	900221
KAS12	69.9	149	380.40	4.83	6.00	900320
KAS13	62.2	268	406.95	3.89	6.00	900314
KAS14	61.3	136	211.85	3.35	6.00	900511
KAS16	84.5	126	548.46	3.23	6.00	920903
HAS01	60.7	315	100.00	6.38(+0.09)	1.20	870807
HAS02	55.4	186	93.00	2.11(+0.07)	1.60	870801
HAS03	55.6	95	100.00	2.34(+0.21)	1.60	870803
HAS04	61.2	244	100			870804
			201.00	6.26(+0.07)	1.40	8904
HAS05	58.1	195	100.00	6.31(+0.13)	1.40	870806
HAS06	88.1	249	100.00	4.73	1.00	870806
HAS07	61.5	18	100.00	3.76(+0.15)	2.00	870801
HAS08	58.0	176	125.00	6.62(-0.01)	1.50	880319
HAS09	59.3	137	125.00	7.84(+0.38)	1.50	880320
HAS10	60.6	349	125.00	6.31(-0.04)	1.50	880322
HAS11	89.3	343	125.00	5.59(-0.01)	1.50	880323
HAS12	59.9	209	125.00	2.90(-0.01)	1.50	880325
HAS13	60.3	47	100.00	2.05(-0.01)	3.00	881212
HAS14	88.0	242	100.00	1.67	1.50	890118
HAS15	≈ 60	≈ 124	120	4.19		890420
HAS16	≈ 60	≈ 353	120	4.36		890416
HAS17	≈ 60	≈ 78	120	7.89		890418
HAS18	62.2	134	150	7.46	6.00	900303
HAS19	57.3	207	150	8.97	6.00	900313
HAS20	60.5	129	150	6.24	6.00	900319
HAS21	60.0	147	148	3.04	3.00	911106
KAV01	89.2	225	502			770516
			743.60	13.81	11.74	861113
KAV02	≈ 90	125	97.10	7.54	12.40	770531
KAV03	89.4	134	248.40	8.21	2.80	861005
HAV01	88.6	322	175.00	9.77		860813
HAV02	89.1	125	163.00	6.58		860821
HAV03	88.0	148	134.20	9.15		860824
HAV04	60.1	168	100.00	7.96	0.40	870724
HAV05	54.5	179	100.00	7.24	1.00	870728
HAV06	59.5	178	100.00	12.36	1.20	870730
HAV07	56.2	54	100.00	4.10	4.00	870728
HAV08	61.9	16	63.00	6.98		Before 1984

Borehole	Inclination at ground (°)	Declination * at ground (°)	Borehole length (m)	Elevation** at top of casing (m a s l)	Length of casing (m)	Drilling completed
KLX01	85.3	346	702.11		1.00	880205
			1077.99	16.81	≈ 101 + 1.00	900804
KLX02	85.0	357	1700.50	18.31	203 + 3.00	921129
HLX01	59.4	175	100.00	8.93	3.00	871021
HLX02	57.4	327	100			871027
			132.00	9.04	0.60	871110
HLX03	62.4	185	100.00	10.43	1.40	871104
HLX04	63.6	301	125.00	10.40	1.20	871106
HLX05	57.7	175	100.00	15.55	0.60	871105
HLX06	59.9	178	100.00	15.48	1.00	871030
HLX07	59.4	47	100.00	8.61	1.00	871103
HLX08	47.8	133	40	2.27	6.0	911114
HLX09	61.3	176	151	3.43	3.0	911121
HMJ01	60.0	185	46	1.45	6.0	911030
KBH02	45.0	335.5	706.35	5.50	5.50	900517
HBH01	58.5	339	50.6	4.71	3.0	910220
HBH02	47.5	333	32.4	4.68	3.0	910221
HBH03	58.2	343	100	5.92	1.2	910306
HBH04	59.7	343	90.4	5.52	5.1	910307
HBH05	≈45	≈335	22	2.97	6.7	9206(?)

≈ Deviation in borehole is not measured. Value is intended deviation at start of drilling.

* Degrees (0-360) measured clockwise from magnetic north. Values in local bearing is achieved by adding 12.1°.

** The values in parenthesis are changes due to new levellings valid from July 1990.

The borehole diameters are presented in Table 3-2. Most boreholes are enlarged in the uppermost part to allow for the installation of a casing. All core boreholes except six are "telescope drilled"; i.e. the diameter of the upper part is larger than below. The exceptions are KAS01, KAS10 and KBH01 where the drilling was not successful and therefore only the upper enlarged part was finished and the three core boreholes on Ävrö that were not telescope drilled. Normally this enlarged part has a length of approx. 100 m. All telescope drilled core boreholes also have an enlargement (approx. 1 m. long) where the diameter is changing to make room for a funnel-shaped pipe which gives a smooth connection between the two borehole diameters.

Table 3-2 Borehole diameters.

Borehole	Borehole diameter (mm)	Length of borehole from (m)	to (m)
KAS01	155		95.85
	56	0.00	101.00
KAS02	155	0.00	93.35
	56	93.35	924.04
KAS03	164	0.00	100.80
	56	100.80	1002.06
KAS04	155	0.00	100.70
	56	100.70	480.98
KAS05	164	0.00	150.00
	76	150.00	549.60
KAS06	164	0.00	100.00
	56	100.00	602.17
KAS07	164	0.00	100.00
	56	100.00	603.75
KAS08	164	0.00	100.00
	56	100.00	601.49
KAS09	167	0.00	100.65
	56	101.45	450.52
KAS10	56	0.00	99.93
KAS11	160	0.00	40.40
	56	40.40	248.90
KAS12	167	0.00	100.05
	56	101.00	380.40
KAS13	162	0.00	100.20
	56	102.28	406.95
KAS14	164	0.00	100.44
	56	101.40	211.85
KAS16	165	0.00	100.00
	56	100.00	548.46
HAS01	115	0.00	100.00
HAS02	115	0.00	93.00
HAS03	115	0.00	100.00
HAS04	115	0.00	201.00
HAS05	115	0.00	100.00
HAS06	115	0.00	100.00
HAS07	115	0.00	100.00
HAS08	115	0.00	125.00
HAS09	115	0.00	125.00
HAS10	115	0.00	125.00
HAS11	115	0.00	125.00
HAS12	115	0.00	125.00
HAS13	115	0.00	100.00
HAS14	115	0.00	100.00
HAS15	115	0.00	120.00
HAS16	115	0.00	120.00
HAS17	115	0.00	120.00
HAS18	162	0.00	150.00
HAS19	158	0.00	150.00
HAS20	152	0.00	150.00
HAS21	115	0.00	148
KAV01	56	0.00	743.60
KAV02	56	0.00	97.10
KAV03	56	0.00	248.40
HAV01	110	0.00	175.00

Borehole	Borehole diameter (mm)	Length of borehole from (m)	to (m)
HAV02	110	0.00	163.00
HAV03	110	0.00	134.20
HAV04	115	0.00	100.00
HAV05	115	0.00	100.00
HAV06	115	0.00	100.00
HAV07	115	0.00	100.00
HAV08	76	0.00	63.00
KLX01	155	0.00	101.30
	76	101.30	702.11
	56	702.88	1077.99
KLX02	304	0.00	3.00
	215	3.00	200.80
	165	200.80	201.00
	92	201.00	202.95
	76	202.95	1700.50
HLX01	115	0.00	100.00
HLX02	115	0.00	132.00
HLX03	115	0.00	100.00
HLX04	115	0.00	125.00
HLX05	115	0.00	100.00
HLX06	115	0.00	100.00
HLX07	115	0.00	100.00
HLX08	115	0.00	40
HLX09	115	0.00	151
HMJ01	115	0.00	46
KBH02	165	0.00	101.50
	56	101.50	706.35
HBH01	115	0.00	50.6
HBH02	115	0.00	32.4
HBH03	115	0.00	100
HBH04	115	0.00	90.4
HBH05	115	0.00	22

3.2 Tunnel Boreholes

A great number of boreholes are drilled in the tunnel. Pressure measurements from packed-off sections in 36 boreholes were connected to the monitoring system during 1997. The position of these boreholes in the tunnel is illustrated in Fig. 2-2.

The borehole deviation (inclination and declination), borehole length, borehole diameter, the elevation of the starting point at tunnel wall, length of casing and finally the date for completion of drilling are presented in Table 3-3. Only those boreholes that has been or is presently monitored within the HMS are listed.

Most boreholes are enlarged in the outermost 2 - 2.5 metres to enable installation of a casing. Except for HA1283B, which was lengthened with a smaller diameter, the diameter inside the casing enlargement is unchanged.

Table 3-3 Borehole deviation, length, diameter, elevation at tunnel wall, length of casing and date for the completion of drilling.

Borehole	Inclination at top of b.h. (°)	Declination at top of b.h. (°)	Borehole length (m)	Borehole diameter (mm)	Elevation at tunnel wall (m. a. s. l.)	Length of casing (m)	Drilling completed
HA1273A	10	332.7	30	57	-175.2	2.0	920312(920423?)
HA1278A	-1	307	29	57	-175.6	2.0	920910
HA1279A	-1	312	24	57	-175.6	2.0	920910
HA1283B	8	352.7	35.5	57	-176.5	2.0	920415
			40.2	51			
HA1327B	0.5	140	29.5	57	-182.8	2.0	920911
HA1330B	0.5	90	32.5	57	-183.0	No c.	920911
HA1960A	7	89	32	58	-263.7	No c.	930121
KA1061A	-0.57	349.6	208.5	56	-144.9	2.0	920123
KA1131B	12.9	0.51	203.1	56	-155.3	2.0	920212
KA1751A	-5.2	274.2	149.9	56	-237.5	2.0	930504
KA1754A	-26.2	299.9	159.9	56	-237.8	2.0	930519
KA1755A	19.9	69.0	320.6	56	-237.8	2.5	940406
KA2048B	10.6	190.9	184.5	56	-275.4	2.5	930216
KA2050A	53.5	55.3	211.6	56	-275.8	2.5	931102
KA2162B	15.2	272.2	288.1	56	-289.9	2.5	930401
KA2511A	33.35	234.73	293	56	-335.2	2.5	930905
KA2563A	41.1	237.09	362.43	56	-340.8	2.5	960924
KA2858A	4.29	287.0	59.7	56	-379.4	2.5	950115
KA2862A	7.99	15.95	16.0	56	-379.6	2.5	950125
KA3005A	4.50	299.11	58.1	56	-399.9	2.5	941205
KA3010A	4.70	99.52	60.7	56	-399.9	2.5	941208

Borehole	Inclination at top of b.h. (°)	Declination at top of b.h. (°)	Borehole length (m)	Borehole diameter (mm)	Elevation at tunnel wall (m. a. s. l.)	Length of casing (m)	Drilling completed
KA3067A	4.71	98.36	40.1	56	-408.6	2.5	941211
KA3105A	4.72	102.48	69.0	56	-413.7	2.5	941215
KA3110A	5.37	238.34	26.8	56	-413.7	2.5	941217
KA3385A	4.84	161.0	34.2	56	-446.0	No c.	950110
KA3510A	30.15	255.27	150.06	76	-448.70	2.65	980909
KF0051A01	-29.92	310.32	11.70	76	-451.38	2.5	980527
KI0023B	20.73	214.61	200.71	76	-447.69	2.65	971120
KI0025F	20.0	187.1	193.8	76	-448.2	2.3	970425
KI0025F02	25.63	200.0	204.18	76	-448.53	2.65	980825
KXTT1	46.79	61.16	28.8	56	-392.1	2.5	950518
KXTT2	45.22	61.42	18.3	56	-392.4	2.5	950928
KXTT3	36.66	51.41	17.4	56	-391.1	2.5	950606
KXTT4	36.48	61.45	49.3	56	-391.1	2.5	950616
SA2142A	9	174	20	57	-287.4	No c.	930223
SA2338A	7	234	20	57	-313.1	No c.	930414

4 Measurements methods

4.1 Data collection

4.1.1 Data collecting system

The data collecting system, which is a part of the Hydro Monitoring System (HMS) at Äspö HRL, consists of a number of measurement stations (computers) connected by a computer network. One station is a host station to which all data from the other measurement stations are collected once a week. Each measurement station, except for the host station, communicate with and collect data from a number of dataloggers or datascan units (in tunnel only). The host station is connected to the Ethernet LAN in the HRL, which in turn is connected to SKB corporate Ethernet in Stockholm. The host station and the measurement station collecting data from surface boreholes are situated at the site office, while three stations collecting data from tunnel measurements are located in the tunnel.

The on-line system is designed to handle breaks in the communication. Data can be stored in loggers and in measurement stations, in a logger for at least five days and in a measurement station for at least four weeks. However, data collected by the datascan unit, which is not a logger, is directly transferred to the measurement station. All data are finally stored on the host station. Backup of the host station is made on tape.

Data is transferred to the measurement stations in different ways:

Borre data network. Data from Borre loggers in the tunnel are transmitted via a logger network to the measurement stations in the tunnel.

Datascan network. Data from Datascan connected transducers are transmitted via a special network to the measurement stations in the tunnel.

Power line. Data from most surface boreholes at Äspö are transmitted via loggers and power line modems.

Radio. Data from some boreholes are collected via datalogger and radio to HMS.

Laptop. All loggers at the surface, not directly connected to HMS, are manually dumped into a portable PC and then transmitted to a measurement station

Manual. Manual readings are also entered into HMS. This is done either by editing a file directly or by using a portable PC with special written software, and then transferring the output to a measurement station.

All on-line dataloggers are frequently polled for new data by the measurement stations.

The surface part of the data collection system is illustrated in Figure 4-1.

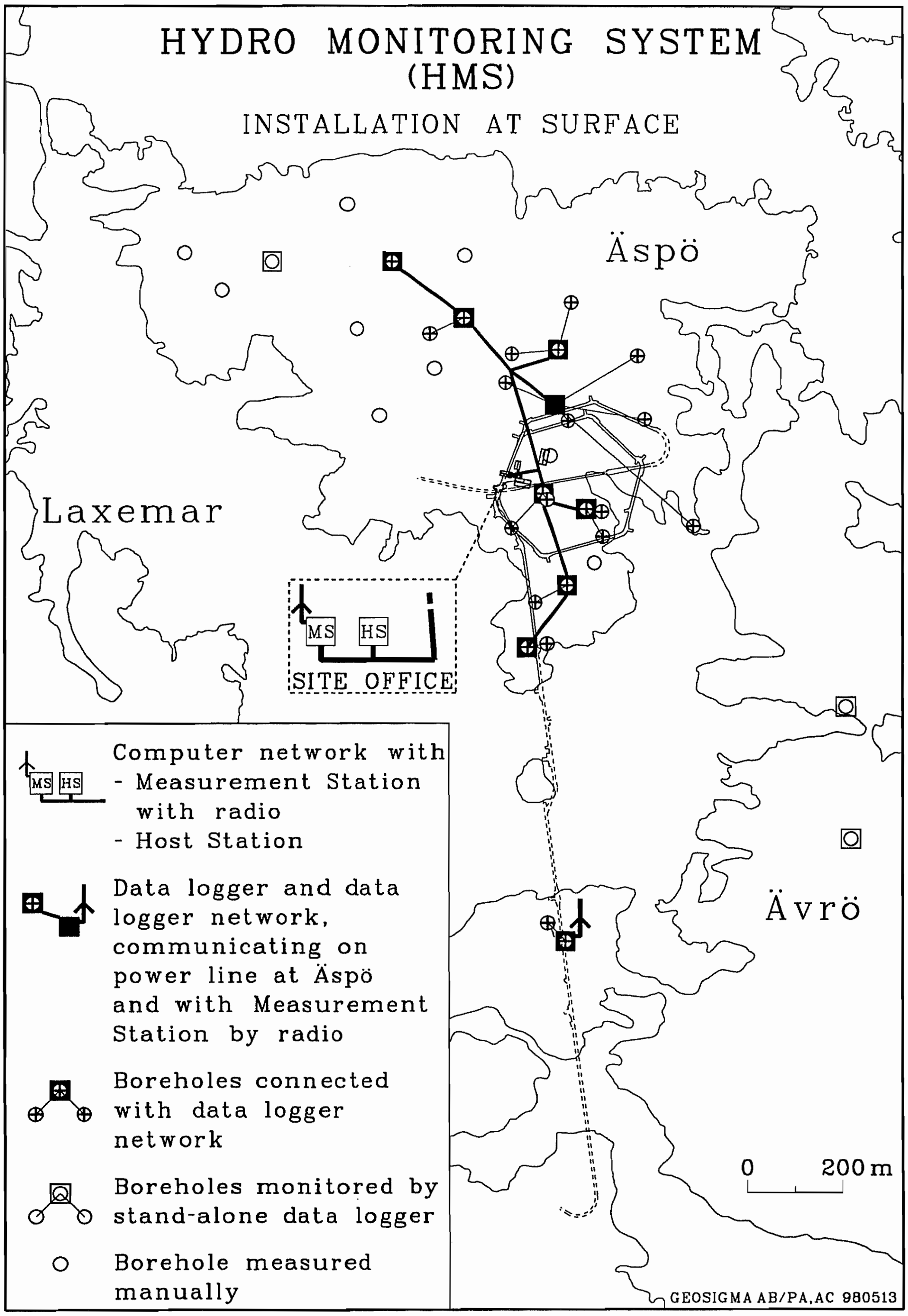


Figure 4-1 Surface part of the HMS showing the data logger network and radios.

4.1.2 Logger and Datascan units

Five different logger units are used to collect pressure data. The most important components of these units are a multiplexer (except in GRUND), an A/D converter, a data storing facility and a serial I/O port. They all have a battery power supply, either as the only supply or for safety.

The Datascan unit has a multiplexer, an A/D converter and a serial I/O port.

In the tunnel, pressure in borehole sections are measured either via a hydraulic multiplexer or by individual transducers for each section connected directly to a Borre logger or a Datascan unit. The hydraulic multiplexer holds a pressure transducer connected to a Borre logger of a type that can operate the magnetic valves on the multiplexer.

To sum up, the following units are used:

BorreF is a logger with a 16 bits A/D converter. This logger is a stand-alone type used at the surface only.

BorreR is a logger with a 16 bits A/D converter. This logger is communicating with a measurement station either by radio or via the power net. Used at the surface only.

BorreT is a logger with a 16 bits A/D converter communicating with a measurement station on a Borre data network. The logger, that can operate magnetic valves on a hydraulic multiplexer, is used in the tunnel only.

Grund is a single channel logger with a 13 bits A/D converter. This logger is a stand-alone type used at the surface only.

Datascan has a 16 bits A/D converter. This unit is connected directly to a measurement station and used in the tunnel only.

The logger types used for different boreholes on the surface are presented in Table 4-1.

Table 4-1 Monitoring equipment in surface boreholes.

Borehole	Section	Equipment	from	to
KAS01	1	BorreR	91-09	
KAS03	1-6	BorreR	91-09	
KAS04	1	Manually	970320	
KAS07	1	Manually	970220	
KAS09	1-5	BorreR	91-09	
KAS10	1	BorreR	91-09	
KAS11	1	Manually	970320	
KAS12	1-5	BorreR	971119	
KAS14	1	Manually	970320	
KAS16	1	Manually	92-10	
	2-4	BorreR	92-10	
HAS01	1	BorreR	91-09	
HAS02	1	Manually	970320	
HAS03	1	BorreF	970205	981018
	1	Manually	981018	
HAS04	1-2	BorreR	91-09	

Borehole	Section	Equipment	from	to
HAS05	1	Manually	970320	
HAS06	1-2	BorreR	91-09	
HAS07	1	BorreR	970218	
HAS08	1	Manually	970130	
HAS09	1	Manually	970320	
HAS10	1	Manually	970320	
HAS11	1-2	BorreF	91-09	981201
	2	Manually	981201	
HAS12	1	Manually	970320	
HAS13	1-2	BorreR	91-09	
HAS14	1	Manually	970320	
HAS15	1-2	BorreR	970522	
HAS16	1-2	BorreR	91-09	
HAS17	1-2	BorreR	91-09	
HAS18	1	Manually	970227	
HAS19	1-2	BorreR	91-09	

Borehole	Section	Equipment	from	to	Borehole	Section	Equipment	from	to
HAS20	1-2	Manually	970130		HLX05	1	BorreR	950901	
HAS21	1	BorreR	970130		KBH02	3-6	BorreR	91-09	
HAV02	1	Manually	970205		HBH04	1	BorreR	91-12	
HAV05	1	Grund	89-06			2	Manually	91-03	
HAV08	1	Grund	91-12		HMJ01	1	Grund	91-12	
KLX01	1-5	BorreR	950901			2	Manually	92-01	
HLX04	1	Manually	970129						

Note - Data not relevant for 1998 is to be found in earlier annual reports.

In Table 4-2, the data-collecting units used for pressure measurements in different borehole sections in the tunnel are presented.

Table 4-2 Monitoring equipment in tunnel boreholes.

Borehole	Sect. no	Equipment	Date from	Date to	Borehole	Sect. no	Equipment	Date from	Date to
HA1273A	1	HM*+BorreT			KA3105A	1-5	HM+BorreT	950310	980303
HA1278A	1	HM+BorreT				5	HM+BorreT	980303	
HA1279A	1	HM+BorreT				1-4	BorreT	950310	
HA1283B	1	HM+BorreT			KA3110A	1	BorreT	950310	
HA1327B	1	HM+BorreT				1-2	HM+BorreT	950310	980303
HA1330B	1	HM+BorreT				2	HM+BorreT	980303	
HA1960A	1	HM+BorreT			KA3385A	1-2	Datascan		
KA1061A	1	HM+BorreT			KA3510A	1-3	Datascan	981027	
KA1131B	1	HM+BorreT			KF0051A	1-4	Datascan	980612	
KA1751A	1-3	HM+BorreT	940426		KI0023B	1-9	Datascan	980216	
KA1754A	1-2	HM+BorreT	941025		KI0025F	1-6	Datascan	970710	
KA1755A	1-4	HM+BorreT	940503		KI0025F02	1-10	Datascan	981027	
KA2048B	1-4	HM+BorreT			KXTT1	1,4	HM+BorreT	950720	
KA2050A	1-3	HM+BorreT				2-3	BorreT	950720	
KA2162B	1-4	HM+BorreT			KXTT2	1,4	HM+BorreT	950720	
KA2511A	1-6	Datascan	970716	980210		2-3	BorreT	950720	
	1-5	Datascan	980218			5	HM+BorreT	951211	
KA2563A	1-7	Datascan	961120		KXTT3	1	HM+BorreT	950720	
KA2858A	2	HM+BorreT	950223			2-3	BorreT	950720	
KA2862A	1	HM+BorreT	960912			4	HM+BorreT	950720	
KA3005A	2-3	BorreT	951213		KXTT4	1-2,5	HM+BorreT	951212	
	4-5	HM+BorreT	951213			3-4	BorreT	951212	
KA3010A	2	BorreT	950720		SA2142A	1	HM+BorreT		
KA3067A	1-4	HM+BorreT	950310	980303	SA2338A	1	HM+BorreT		
	1	HM+BorreT	980303						
	2-4	BorreT	950310						

* HM=Hydraulic Multiplexer

4.2 Groundwater level measurements in surface boreholes

4.2.1 Mechanical equipment in boreholes

A detailed description on instrumentation is given in "Manual för HMS (del 3:4), 1994".

Most boreholes were initially divided into different sections by rubber packers. Successively the packers have been removed in many boreholes and during 1998 less than half the boreholes were equipped with packers (see Figure 4-2 -- 4-4 and Table 4-3).

Boreholes without packers are called "open boreholes". The uppermost section in boreholes with one or several packers is an "open section". The measurement principles are somewhat different between percussion and core boreholes due to the different borehole diameters.

Most open boreholes have no equipment except a pressure transducer connected to a BORRE logger or a GRUND logger. At the end of 1998 HAV05, HAV08 and HMJ01 were the only boreholes equipped with the datalogger GRUND.

The hydraulic packers in **core boreholes** are inflated by means of a gas tube (N_2) and a water-filled pressure vessel connected to the packer-system.

During 1998 five core boreholes on Äspö, KLX01 at Laxemar and KBH02 on Bockholmen were divided into 4-6 sections. Each section has a hydraulic connection to the ground surface via a bypass plastic tube through the packers. The tubes have an inner diameter of 4 or 6 mm at depth, connected to wider tubes with an inner diameter of 23 or 54 mm at the uppermost part (see Figure 4-3). In two sections in KLX01 the inner diameter of the wider tube is only 12 mm.

Until the summer 1991 the length of these wider tubes were 40 - 50 m. In order to allow measurements at greater depths the tubes has been lengthened to 90 - 100 m in most boreholes on Äspö. Only KAS08 and KAS09 are still equipped with the shorter tubes.

In this upper wide tube, a pressure transducer is installed. To achieve a rapid response to pressure changes in the actual borehole section, a small packer is installed in each tube, a short distance below the pressure transducer. The latter is connected to the borehole section via a thin tube through the small packer. Since the beginning of 1993, due to problems with collapsing PEM-tubes, this small packer had to be removed in many sections to enable manual levelling.

One or two sections in the packer-equipped core boreholes has a second tube between the section and the ground surface (sections P2 and P4 in Figure 4-2). This tube has an inner diameter of 6 mm all the way to the surface. In the enlarged part of the borehole the tube is branching, and a third tube (inner diameter 4 mm) leads up to the surface. The wide PEM-tube to these sections has a diameter of 54 mm followed in the narrow part of the borehole by a plastic tube of 6 mm inner diameter. The purpose of this special equipment in some sections is to make possible circulation of section water during tracer tests.

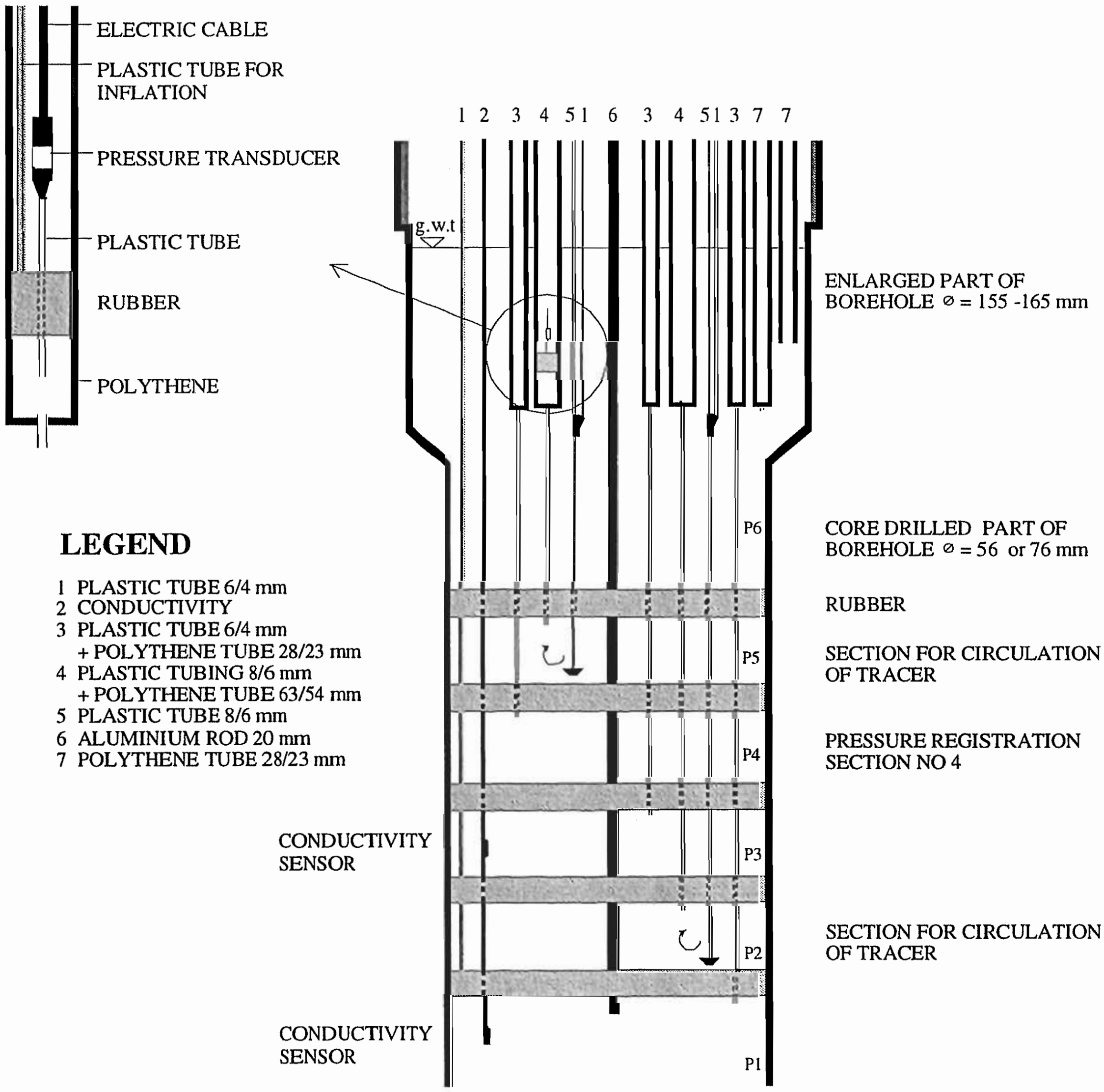


Figure 4-2 Instrumentation in core boreholes on Äspö.

Percussion boreholes are open or divided in two sections by rubber packers. See Figures 4-3 and 4-4.

Also the packed-off sections in the percussion boreholes have a hydraulic connection to the ground surface through tubes passing the packers. The tubes have an inner diameter of 4 mm at depth. The tubes in the uppermost 10 - 80 m of the borehole have an inner diameter of 23 or 28 mm. If the logger is of the BORRE type, only pressure transducers are installed in this wider part of the tubes. If on the other hand, the logger is of the GRUND type, the logger itself is installed in the borehole.

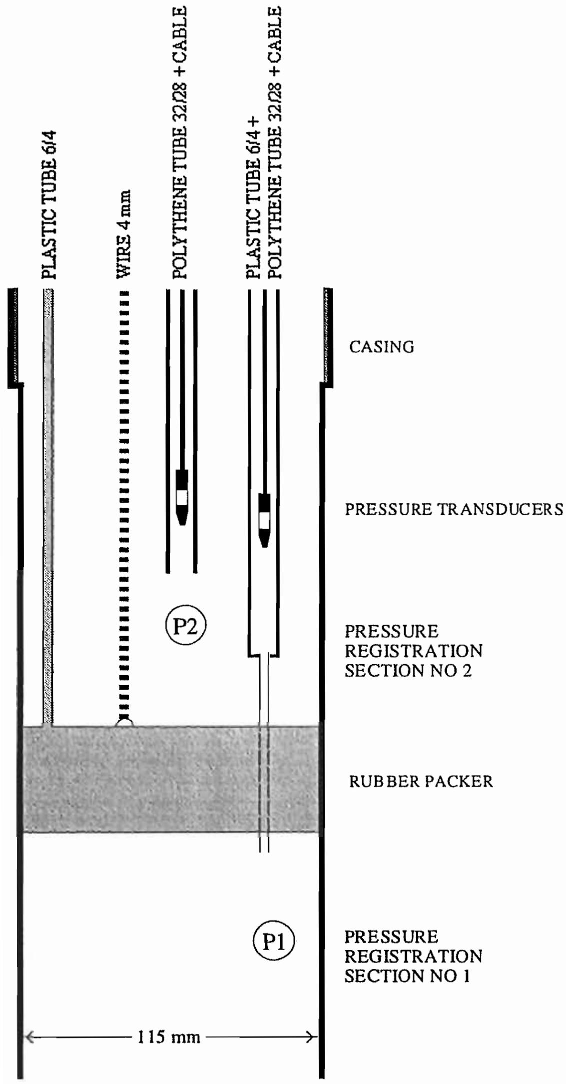


Figure 4-3 Instrumentation in percussion boreholes with the logger BORRE.

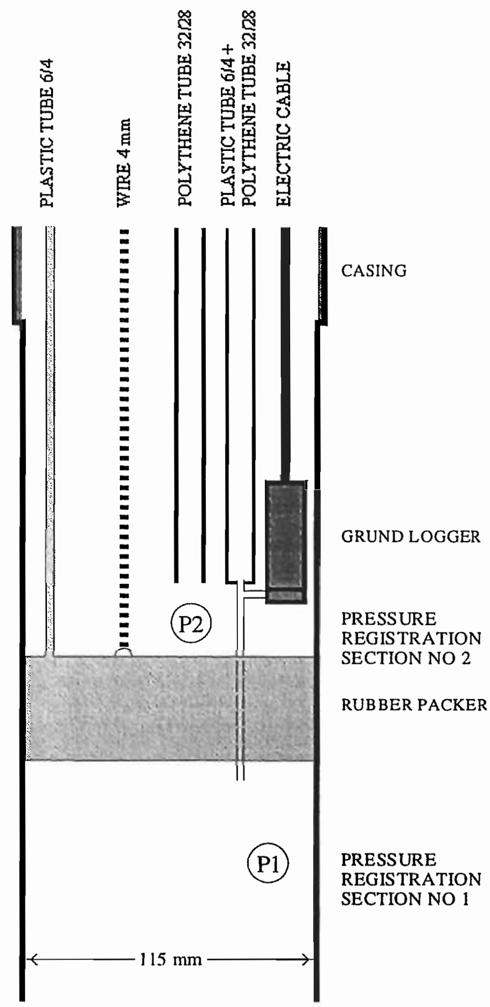


Figure 4-4 Instrumentation in percussion boreholes with the logger GRUND.

In Table 4-3 lengths along the borehole to top and bottom of each section as well as elevation of the top of section is presented. If no end date is given, the borehole is equipped in the same way at the end of 1998. However, the period when some of the boreholes were open to enable re-instrumentation (summer 1991) is not included in the table.

Table 4-3 Monitored sections in surface boreholes

Borehole	Section no	Borehole length from (m)		to (m)	Elevation at top of section (masl)	Date from	to
KAS01	1	0	-	101		871030	
KAS03	1	627	-	1002	-613.36	960427	
	2	533	-	626	-520.22		
	3	377	-	532	-365.45		
	4	253	-	376	-242.42		
	5	107	-	252	-97.47		
	6	0	-	106			
KAS04	1	0	-	481		930604	
KAS07	1	0	-	604		970220	
KAS09	1	261	-	450	-220.08	900409	
	2	241	-	260	-202.94		
	3	151	-	240	-125.97		
	4	116	-	150	-96.02		
	5	0	-	115			
KAS10	1	0	-	100		90	
KAS11	1	0	-	249		970320	
KAS12	1	0	-	380		960201	
	1	331	-	380	-300.75	971028	
	2	300	-	330	-272.40		
	3	271	-	299	-245.85		
	4	111	-	270	-98.58		
	5	0	-	110			
KAS14	1	0	-	212		970320	
KAS16	1	466	-	548	-453.34	921020	
	2	390	-	465	-380.02		
	3	121	-	389	-116.79		
	4	0	-	120			
HAS01	1	0	-	100		8808	
HAS02	1	0	-	93		970320	
HAS03	1	0	-	100		970225	
HAS04	1	101	-	201	-82.89	890512	
	2	0	-	100			
HAS05	1	0	-	100		970320	
HAS06	1	57	-	100	-52.18	960117	
	2	0	-	56			
HAS07	1	0	-	100		970218	
HAS08	1	0	-	125		970130	
HAS09	1	0	-	125		970320	
HAS10	1	0	-	125		970320	
HAS11	1	31	-	125	-25.88	880715	
	2	0	-	30			
HAS12	1	0	-	125		970320	
HAS13	1	51	-	100	-41.88	890512	981220
	2	0	-	50			981220
	1	0	-	100		981220	
HAS14	1	0	-	100		970320	
HAS15	1	48	-	120	-37.38	970522	
	2	0	-	47			
HAS16	1	41	-	120	-31.15	890512	
	2	0	-	40			
HAS17	1	88	-	120	-68.32	970529	981008
	2	0	-	87			981008
	1	0	-	120		981008	990224
	1	88	-	120	-68.32	990224	
	2	0	-	87			
HAS18	1	0	-	150		970227	

Borehole	Section no	Borehole length from (m)		to (m)	Elevation at top of section (masl)	Date from	to
HAS19	1	61	-	150	-43.30	900610	
	2	0	-	60			
HAS20	1	69	-	150	-52.66	901212	
	2	0	-	68			
HAS21	1	0	-	148		970130	
KLX01	1	856	-	1078	-837.63	920302	
	2	695	-	855	-676.85		
	3	272	-	694	-254.52		
	4	141	-	271	-123.81		
	5	0	-	140			
HAV02	1	0	-	163		970205	
HAV05	1	0	-	100		970218	
HAV08	1	0	-	63		870905	
HLX04	1	0	-	125		970129	
HLX05	1	0	-	100		970129	
KBH02	1	261	-	326	-110.16	910919	
	2	151	-	260	-80.35		
	3	106	-	150	-62.04		
	4	0	-	105			
HBH04	1	31	-	90.4	-21.27	910404	
	2	0	-	30			
HMJ01	1	33	-	46	-26.30	911213	
	2	0	-	32			

Note - Data not relevant for 1998 is to be found in earlier annual reports.

4.2.2 Pressure gauges

Until beginning of 1996 all BORRE loggers were equipped with a DRUCK PDCR 830 differential pressure transducer and/or with a DRUCK PTX 160/D differential pressure transducer. The pressure range has been 0-1, 0-3.5 or 0-10 bar. Sections 3 and 4 in KLX01 are equipped with a DRUCK PDCR 35 differential pressure transducer with the pressure range 0-10 bar.

Since there have been problems with moisture in the thin tube delivering air pressure to the differential pressure transducers, these has been successively replaced by absolute pressure transducers (DRUCK PDCR 35/D and PTX1830, 0-10 bar) from the beginning of 1996.

Air pressure, to enable subtraction from absolute pressure measurements, is measured with a DRUCK PDCR 930 with a pressure range of 0-1 bar.

The **GRUND** logger normally has a CRL951 differential pressure transducer with the pressure range 0-15 psi. In a few cases, a DRUCK PDCR 900 differential pressure transducer with a pressure range of 0-1.5 bar is used.

Accuracy for all **DRUCK** transducers is ±0.1% F.S. (B.S.L.) and for the CRL transducer ±2% F.S.

4.2.3 Absolute pressure in borehole sections

Sometimes it is of interest to determine the absolute pressure at the top of a packed off section. This value can be calculated if the vertical distance from top of section to the water table in the tube connecting the section with the ground surface and the density of water in the tube are known.

The altitude of the water table is presented in the diagrams in Appendix 2.

The altitude at top of section is to be found in Table 4-3.

Density

The density of the tube water is determined in the following way. When all packers in a core borehole are installed and inflated, water is flushed from all sections to the ground surface through the tubes. When at least the double tube volume has been discharged, a water sample from each tube is collected. The electrical conductivity of the sample is measured. On approximately 75 samples from 1988 and 1989 the density is laboratory-determined. The electrical conductivity of the density-determined samples range from 60 to 3400 mS/m. From these measurements a first degree equation is set up, by means of the least square method (by Ann-Chatrin Nilsson, KTH, 1990), which gives the density from the electrical conductivity (see note in Table 4-4). This equation is then used to calculate the density of any sample. The deviation from the straight line for a single value is at most 1.5 kg/m3, but normally less then 0.5 kg/m3.

A problem more difficult to handle is whether the water sample is representative for the water in the tube or not. For example, water with other density than the sample might have entered into a part of the tube when the flushing was interrupted. Considering even this possibility, the maximum error in the density is estimated at ±10 kg/m3, corresponding to ±1 m per 100 m water column.

Calculated density in the tubes and measured electrical conductivity is found in Table 4-4. Measurements of the electrical conductivity, from water samples, were performed only in the core boreholes on Äspö and in KLX01, beginning in 1988.

The values may differ from undisturbed values in the section. For example, if the sample was taken immediately after inflation of the packers, the electrical conductivity in the section may not have reached its natural value.

It can be mentioned that the electrical conductivity of the sea surface water east of Ävrö in august and september 1986 was 1180 and 1170 mS/m respectively.

Table 4-4 Electrical conductivity and calculated density (at 25° C) of water in tubes between section and ground.

Borehole	Sec.	Valid from	Electr. conduct. (mS/m)	Density (kg/m^3)
KAS02	1	910902	2650	1010
	3	"	1405	1004
	5	"	825	1001
	6	"	760	1001
	2	930907	2050	1007
	4	940407	79	998
KAS03	1	960522	940	1002
	3	"	480	1000
	4	"	350	999
	5	"	70	998
	6	"	50	998
	2	970313	1782	1006
	2	971002	1800	1006
	2	980331	1850	1006
	2	981001	1500	1004
	5	970313	465	999
	5	971003	772	1001
	5	980331	830	1001
	5	981005	645	1000
KAS09	1	900407	1600	1005
	2	"	1600	1005
	3	"	1600	1005
	5	"	1600	1005
	4	940906	890	1001
	4	970313	880	1001
	4	971008	970	1002
	4	980331	980	1002
	4	981001	767	1001
KAS12	1	971112	990	1002
	2	971113	725	1001
	3	971117	Dry	
	4	971114	208	998
	5	971117	112	998
KAS16	1	921020	1450	1004
	2	"	1350	1004
	3	"	800	1001
	4	"	750	1001
KBH02	3	920514	970	1002
	4	"	1090	1002
	5	"	870	1001
	6	"	530	1000
KLX01	1	930416	1838	1006
	2	"	349	999
	3	"	60	998
	4	"	91	998
	1	980617	1824	1006
	2	980617	503	1000
	3	980617	68	998
	4	980617	365	999
	5	930416	50	998

Density (kg/m^3) = 997.3 + 0.00467 · Electrical conductivity (mS/m).
Note - Data not relevant for 1998 is to be found in earlier annual reports.

4.2.4 Calibration method

To calibrate the registrations from the data loggers, manual levellings of all sections are made, normally once every month.

The logger data is converted to water levels by means of a linear calibration equation (if the pressure transducer is of the absolute type, subtracting the air pressure is also necessary). Converted logger data are compared with manual levellings, corrected to account for borehole deviation. If the two differs, calibration constants are changed and the procedure is repeated until an acceptable fit is achieved.

4.2.5 Recording interval

In some boreholes the recording interval is shortened during hydraulic test periods.

For loggers not directly connected to HMS the following recording intervals have normally been used:

Sections registered with a logger at Laxemar and on Ävrö 4 hours

Sections registered with a logger on Äspö and on Mjälen 2 hours

Most sections not connected to a logger are manually levelled once a month.

All directly connected boreholes have the following recording principle: Groundwater level is **measured** every 8th minute. The value is not stored unless it differs more than 0.2 m from the latest stored value. Regardless from this a value is stored every second hour.

4.2.6 Accuracy of groundwater level data

The results presented in the diagrams are the groundwater levels for each section expressed as metres above sea level. The total error in these values, consists of errors in the following measurements:

- Pressure gauge registrations
- Levelling of the borehole casing
- Levelling of the borehole groundwater surface
- Borehole deviation measurements
- Air pressure measurements (only sections with absolute pressure transducers)

(For more detailed information about the different errors see Ekman et al, 1989.)

When calculating the absolute pressure at the top of a packed off section, errors due to uncertainty in the density estimation of the water in the tube connecting the section with the ground surface must also be considered (see section 4.2.3).

The magnitude of the error in the groundwater level or pressure data is to a large degree varying with time, depending mainly on two factors, the frequency of manual levellings and the influence of activities in the boreholes. As the pressure gauges are calibrated against series of manually levelled values, the error due to erroneous levellings will in general be smaller than for a single measurement. During tests, however, disturbances in the instrumentation may cause discontinuities in the data series. Some of these can be eliminated in the calibration process, while others are more difficult to identify and may remain for shorter periods.

Errors in determination of the altitude of the borehole casing and the borehole deviation are systematic. Errors in pressure gauge registrations and in levelling of the groundwater table, on the other hand, have a certain amount of randomness, while errors due to uncertainties in the density estimation can be of both types. (Note: There are new values for elevation of top of casing in some boreholes from July 1990, due to corrections after renewed levellings; see Table 3-1. Corrections for the new levellings are not made on data collected before July 1990.)

When making a rough estimate of the errors mentioned above, the total error in groundwater level elevation under hydraulically undisturbed conditions has been estimated to ±0.06 m for percussion boreholes and top sections in core boreholes. For packed off sections in core boreholes ±0.15-1.2 m. is valid. The value 1.2 m stands for relatively short periods without manual levellings and with disturbances in the instrumentation.

During the autumn 1992, because of the tunnel excavation, substantial drawdowns were observed in many boreholes on Äspö. This was especially noticed when the first of two raice-drilled ventilation shafts was drilled at the end of October 1992. Therefore, the manual levellings were more difficult to carry out. Therefore, in these boreholes, the error due to manual levellings may be significantly larger from the end of October 1992.

Errors of a slightly different character are those caused by failure in the mechanical or electronic equipment in boreholes. To some extent data including these type of errors are eliminated from the diagrams, but sometimes (when data is trustworthy) they are difficult to recognise and may therefore decrease the reliability of data for shorter periods. Errors of this type are usually caused by one of the following failures:

- Leakage in the couplings connecting the hydraulic measurement system or in the system used to inflate the rubber packers.

- Uncertain communication between a section and the pressure transducer, due to clogging in the plastic tube.

- Failing pressure transducers.

4.3 Electrical conductivity in surface boreholes

4.3.1 Measurement equipment

To start with, electrical conductivity in two sections was measured in most core boreholes on Äspö. In course of time, many of the sensors have ceased to work and during 1998, electrical conductivity was measured only in three boreholes. Length along the borehole to the electrical conductivity sensors, as well as the pressure gauge section numbers are given in Table 4-5. The deeper sensor in each borehole is connected to a BORRE logger and the upper sensor is read manually once a month. Besides the sensors, the equipment consists of an electronic unit at ground and an electrical cable between the sensors and the logger. The sensors are of a two-electrode type, made of gold and with a cell constant of 2.0. The electronic unit is a commercial, type LX, made by Conducta GmbH & Co. The measurements are not temperature compensated.

Table 4-5 Electrical conductivity equipment

Borehole	Length along borehole (m)	Pressure gauge section
KAS02	500	3
	125	5
KAS03	950	1
	400	3
KAS09	249	2
	133	4

Note - Data not relevant for 1998 is to be found in earlier annual reports.

4.3.2 Accuracy of the electrical conductivity data

The electrical conductivity sensors are strongly non-linear and the conductivity at measurement depth is not known when the calibration is performed. The calibration is carried out at the surface, with the cables connected, before installation in the borehole. Mostly, a two point linear method is used. Conductivities for the two point calibration solutions are 666.8 and 5864 mS/m. Unfortunately this gives a poor result, since the calibration range is too wide in relation to the nonlinearity of the sensors. In KAS05 and KAS11 (from June 1992) a second degree polynomial is fitted to a four point calibration (127.4, 539, 1160 and 2231 mS/m), which gives a considerably better result.

4.4 Groundwater pressure in tunnel boreholes

4.4.1 Mechanical equipment in boreholes

For a detailed description on instrumentation, see "Manual för HMS (del 3:4), 1994".

Instrumentation in tunnel boreholes may be of different types. In boreholes with more than one section, the packers dividing the borehole are always of the hydraulic type. Single-section boreholes have either a valve mounted on the borehole casing or a mechanical packer. The hydraulic packers are inflated by means of a gas tube (N_2) and a water-filled pressure vessel connected to the packer-system. The packed off sections have a hydraulic connection to the tunnel via plastic bypass tubes through the packers (essentially the same type of packers as in the surface boreholes). These tubes have an inner diameter of 4 or 6 mm. To some sections, prepared for circulation of tracer during tracer tests, there is an extra tube with an inner diameter of 6 or 8 mm. The borehole instrumentation is anchored to the tunnel wall.

In two boreholes (KI0023B and KI0025F02) a different type of packer system is used. The packers are connected by a large-diameter central tubing through which the smaller tubes building up the packer-, pressure- and circulation lines are drawn. The inner diameters on these small tubes are 2 mm for the packer- and pressure lines and 4 mm for the circulation line.

4.4.2 Pressure measurements

The pressure in a borehole section is transmitted via a plastic tube, and a hydraulic multiplexer to a pressure transducer or directly to a pressure transducer. For many boreholes there is also a valve panel between the borehole and the pressure measuring equipment.

The multiplexer holds 16 magnetic valves that open to the pressure transducer one after another for all sections connected. Two of the inlets to the hydraulic multiplexer are reserved for reference pressure to enable in-situ calibrations of the pressure transducer. The data logger that collects data from the pressure transducer operates the valves.

The pressure reference system consists of calibration vessels at some carefully levelled locations and tubes connected to the hydraulic multiplexers. The system is filled with deionized water to give well-defined pressures. A tube connected on top of the calibration vessels, deliver air pressure from the surface.

A schematic outline of the pressure measurement system with a hydraulic multiplexer and the pressure reference system is shown in Figure 4-5.

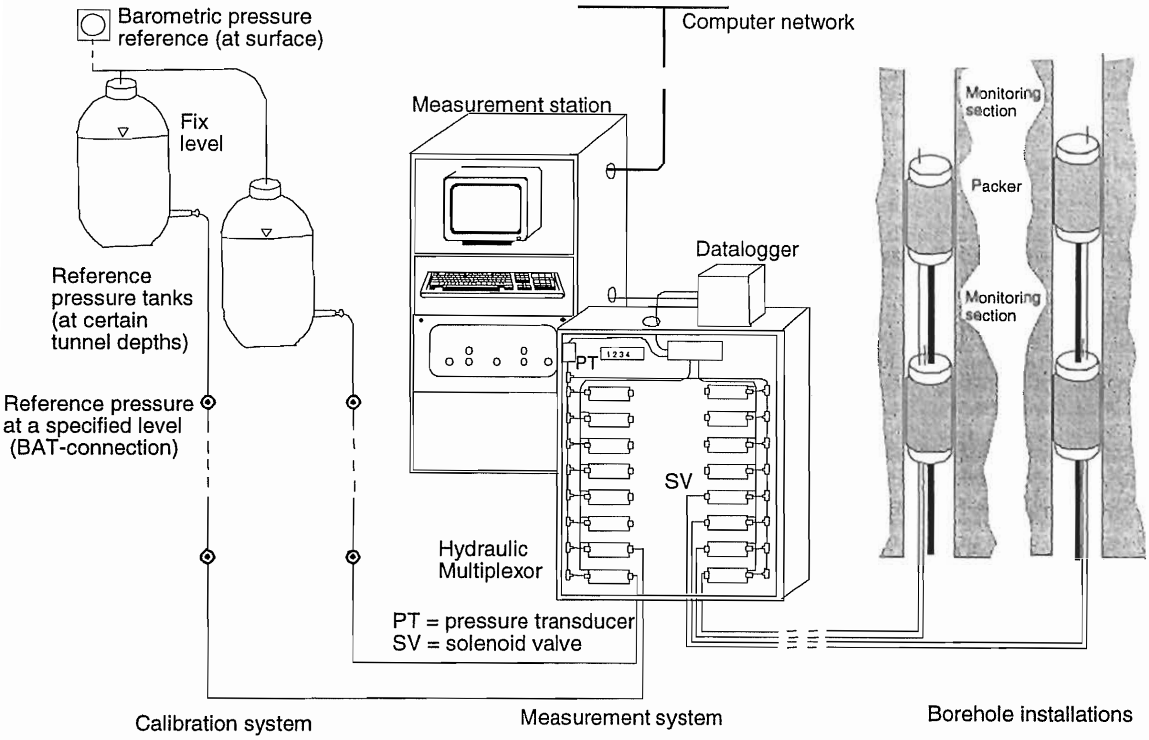


Figure 4-5 Equipment installations for groundwater pressure measurements with a hydraulic multiplexer.

The hydraulic multiplexers are equipped with a DRUCK PTX 610 absolute pressure transducer with a pressure range 0 - 40 or 0 - 50 bar.

A number of borehole sections are also (or only) connected to individual pressure transducers. In these cases, a number of transducers is mounted on a panel where tubes from the pressure reference system are available to enable in-situ calibrations. One reason for this arrangement was that the monitoring via the hydraulic multiplexer could not offer a measuring frequency that was high enough.

On the pressure transducer panels, DRUCK PTX 620 absolute pressure transducers with a pressure range of 0 - 50 bar are used.

Normally a pressure value is scanned once every fourth minute but stored only once every second hour, unless the change since latest stored value exceeds a "change value" of approximately two kPa.

In Table 4-6 the length along the boreholes to top and bottom of each section and the elevation at the middle of section is presented. To enable calculations of absolute pressure at the middle of section, also the level of the pressure transducer is given.

Table 4-6 Monitored sections in tunnel boreholes

Borehole	Section no	Borehole length from (m)	Borehole length to (m)	Elevation of middle of sec. (m.a.s.l)	Elevation of transducer (m.a.s.l)	Date from	Date to
HA1273A	1	0	23	-177.8	-163.3		
HA1278A	1	0	29	-175.4	-163.3		
HA1279A	1	0	29	-175.4	-163.3		
HA1283B	1	0	40.2	-179.3	-163.3		
HA1327B	1	0	29.5	-182.9	-163.3		
HA1330B	1	6	32.5	-183.0	-163.3		
HA1960A	1	4	32	-265.9	-289.2		
KA1061A	1	0	208.5	-144.0	-163.3		
KA1131B	1	0	203.1	-178.9	-163.3		
KA1751A	1	99	150	-248.2	-224.3	940426	
	2	56	98	-244.2	-224.3		
	3	6	55	-240.3	-224.3		
KA1754A	1	75	159.88	-284.0	-224.3	941025	
	2	6	74	-253.7	-224.3		
KA1755A	1	231	320.58	-329.0	-224.3	940503	
	2	161	230	-301.6	-224.3		
	3	88	160	-277.6	-224.3		
	4	6	87	-252.6	-224.3		
KA2048B	1	149.5	184.45	-304.9	-289.2	941212	-
	2	100	148.5	-297.6	-289.2		
	3	50.5	99	-288.9	-289.2		
	4	5	49.5	-280.4	-289.2		
KA2050A	1	155	211.57	-422.8	-289.2	940414	
	2	102	154	-378.7	-289.2		
	3	6	101	-318.8	-289.2		
KA2162B	1	201.5	288.1	-353.2	-289.2	940415	
	2	143	200.5	-334.9	-289.2		
	3	80.5	142	-319.2	-289.2		
	4	40	79.5	-305.7	-289.2		
KA2511A	1	231	293	-480.7	-334.6	970716	980210
	2	171	230	-446.7	-334.6		
	3	139	170	-421.2	-334.6		
	4	92	138	-399.3	-334.6		
	5	64	91	-378.4	-334.6		
	6	6	63	-354.4	-334.6		
	1	242	244	-470.2	-334.6	980218	
	2	217	241	-462.4	-334.6		
	3	110	216	-425.9	-334.6		
	4	92	109	-391.2	-334.6		
	5	52	53	-364.4	-334.6		

Borehole	Section no	Borehole length from (m)	to	Elevation of middle of sec. (m.a.s.l)	transducer	Date from	to
KA2563A	1	266.00	362.00	-547.4	-334.6	961120	980218
	2	197.00	265.00	-494.2	-334.6		
	3	187.00	196.00	-468.5	-334.6		
	4	146.00	186.00	-451.8	-334.6		
	5	113.00	145.00	-427.4	-334.6		
	6	76.00	112.00	-404.1	-334.6		
	7	6.00	75.00	-368.2	-334.6		
	1	262	362	-546.2	-334.6	980225	
	2	225	228	-491.3	-334.6		
	3	220	224	-488.4	-334.6		
	4	191	219	-477.3	-334.6		
	5	187	190	-466.5	-334.6		
	6	146	186	-451.8	-334.6		
	7	76	145	-415.1	-334.6		
KA2858A	2	39.77	40.77	-382.4	-399.1	950223	
KA2862A	1	6.82	6.92	-380.5	-399.1	960912	
KA3005A	2	46.78	50.03	-403.6	-399.1	951207	
	3	44.78	45.78	-403.4	-399.1		
	4	39.03	43.78	-403.1	-399.1		
	5	6.53	38.03	-401.6	-399.1		
KA3010A	2	8.56	15.06	-400.9	-399.1	950223	
KA3067A	1	34.55	40.05	-411.7	-413.1	950228	
	2	30.55	33.55	-411.3	-413.1		
	3	28.05	29.55	-411.0	-413.1		
	4	6.55	27.05	-410.0	-413.1		
KA3105A	1	53.01	68.95	-418.8	-413.1	950301	
	2	25.51	52.01	-416.9	-413.1		
	3	22.51	24.51	-415.6	-413.1		
	Blind	20.51	21.51				
	4	17.01	19.51	-415.2	-413.1		
	5	6.51	16.01	-414.6	-413.1		
KA3110A	1	20.05	28.63	-416.0	-413.1	950223	
	2	6.55	19.05	-414.9	-413.1		
KA3385A	1	32.05	34.18	-448.8		950302	
	2	7.05	31.05	-447.6			
KA3510A	1	122.02	150.06	-516.7	-448.0	981025	
	2	114.02	121.02	-507.5	-448.0		
	3	4.52	113.02	-478.2	-448.0		
KF0051A	1	10.55	11.80			980610	
	2	8.85	9.55				
	3	6.26	7.85				
	4	4.66	5.26				
KI0023B	1	113.70	200.71	-503.5	-448.2	980219	
	2	111.25	112.70	-487.7	-448.0		
	3	87.20	110.25	-482.9	-448.0		
	4	84.75	86.20	-478.2	-448.0		
	5	72.95	83.75	-475.6	-448.0		
	6	70.95	71.95	-473.2	-448.0		
	7	43.45	69.95	-467.9	-448.0		
	8	41.45	42.45	-462.6	-448.0		
	9	4.60	40.45	-455.7	-448.0		

Borehole	Section no	Borehole length from (m)	to	Elevation of middle of sec. (m.a.s.l)	transducer	Date from	to
KI0025F	1	169.0	193.8	-505.7	-448.2	970710	980225
	2	158.0	168.0	-500.3	-448.2		
	3	152.0	157.0	-497.7	-448.2		
	Blind	89.0	151.0	-487.3	-448.2		
	4	86.0	88.0	-477.0	-448.2		
	5	41.0	85.0	-469.4	-448.2		
	6	3.5	40.0	-455.7	-448.2		
	1	169.0	193.8	-505.7	-448.2	980305	
	2	164.0	168.0	-501.1	-448.2		
	3	89.0	163.0	-489.1	-448.2		
	4	86.0	88.0	-477.0	-448.2		
	5	41.0	85.0	-469.4	-448.2		
	6	3.5	40.0	-455.7	-448.2		
KI0025F02	1	135.15	204.18	-518.0	-447.4	981025	
	2	100.25	134.15	-497.3	-447.4		
	3	93.35	99.25	-488.8	-447.4		
	4	78.25	92.95	-484.3	-447.4		
	5	73.30	77.25	-480.1	-447.4		
	6	64.00	72.90	-477.2	-447.4		
	7	56.10	63.00	-473.6	-447.4		
	8	51.70	55.10	-471.0	-447.4		
	9	38.50	50.70	-467.4	-447.4		
	10	3.40	37.50	-457.3	-447.4		
KXTT1	1	17.00	28.76	-408.5	-399.1	951207	
	2	15.00	16.00	-403.2	-399.1		
	Blind	12.50	14.00				
	3	7.50	11.50	-398.9	-399.1		
	4	3.00	6.50	-395.5	-399.1		
KXTT2	1	16.55	18.30	-404.6	-399.1	951207	
	2	14.55	15.55	-403.0	-399.1		
	3	11.55	13.55	-401.2	-399.1		
	4	7.55	10.55	-398.8	-399.1		
	5	3.05	6.55	-395.8	-399.1		
KXTT3	1	15.42	17.43	-400.9	-399.1	951207	
	2	12.42	14.42	-399.1	-399.1		
	3	8.92	11.42	-397.2	-399.1		
	4	3.17	7.92	-394.4	-399.1		
KXTT4	1	24.42	49.31	-413.0	-399.1	951207	
	2	14.92	23.42	-402.5	-399.1		
	3	11.92	13.92	-398.8	-399.1		
	4	8.42	10.92	-396.8	-399.1		
	5	3.17	7.42	-394.2	-399.1		
SA2142A	1	6.00	20.00	-289.4	-289.2		
SA2338A	1	6.00	20.00	-314.6	-334.6		

Note - Data not relevant for 1998 is to be found in earlier annual reports.

4.4.3 Accuracy of pressure measurements

No systematic estimation of different errors in the pressure measurements has been performed.

One source of error is the determination of the calibration constants. This is related to the status of the pressure reference system, i.e. the accuracy of the estimated levels of the calibration vessels and pressure transducers, the density of the water in the tubes and occurrence of air in the system.

Another error is related to the measurement method itself when measuring via a hydraulic multiplexer. The main dilemma is the delay time in the hydraulic multiplexers. When a magnetic valve opens towards a new section it will take some time before a deviating pressure inside the multiplexer, resulting from the previously measured section, has decayed and a correct pressure from the new section is obtained. Therefore, a delay time of 30 seconds between valve opening and measurement is used (Before March 1998 a delay time of 10 seconds have been used). However, the needed delay time depends on a number of factors such as hydraulic transmissivity and length of section and the length of the tube between a section and the hydraulic multiplexer. Since the value used is a compromise between the wish to be able to measure with relatively high frequency and the need of a delay time long enough, a certain error will be involved. This is especially valid in sections with low hydraulic transmissivity.

If one wants to calculate absolute pressure at the section location, one must consider errors in density estimates of the water in the tubes between the section and the pressure transducer. The accuracy of the estimated levels of the section and the pressure transducer also has to be regarded.

4.5 Water flow in tunnel

4.5.1 Instrumentation

For a detailed description on instrumentation, see "Manual för HMS (del 3:4), 1994".

The water flow along the tunnel is collected at certain locations by concrete ditches across the tunnel and diverted to a gauging box equipped with a v-notch weir. The water level in the box is measured with either a pressure transducer or an ultrasonic transmitter, connected to the HMS, that are calibrated against a ruler mounted on the box. After passage through the gauging box, the flow is diverted to a discharge pipe common for a number of gauging boxes, which finally leads into one of the sumps in the tunnel. See Figure 4-6.

Before autumn 1998 the levels in all flow weirs were measured with DRUCK PTX 510, relative pressure transducers with a pressure range of 0 - 100 mbar.

Since there have been some problems with the pressure transducers (incomplete compensation for air pressure, drift in the offset and sudden jumps in the registration), a number of ultrasonic transmitters of the type EXAC- /STA-270 has replaced the pressure transducers during the autumn 1998. The ultrasonic transmitter is placed above the water surface in the box and measures the level by means of an ultrasonic signal.

The measuring range is 0.2 – 0.7 m. At the end of 1998 eleven ultrasonic level indicators were in use.

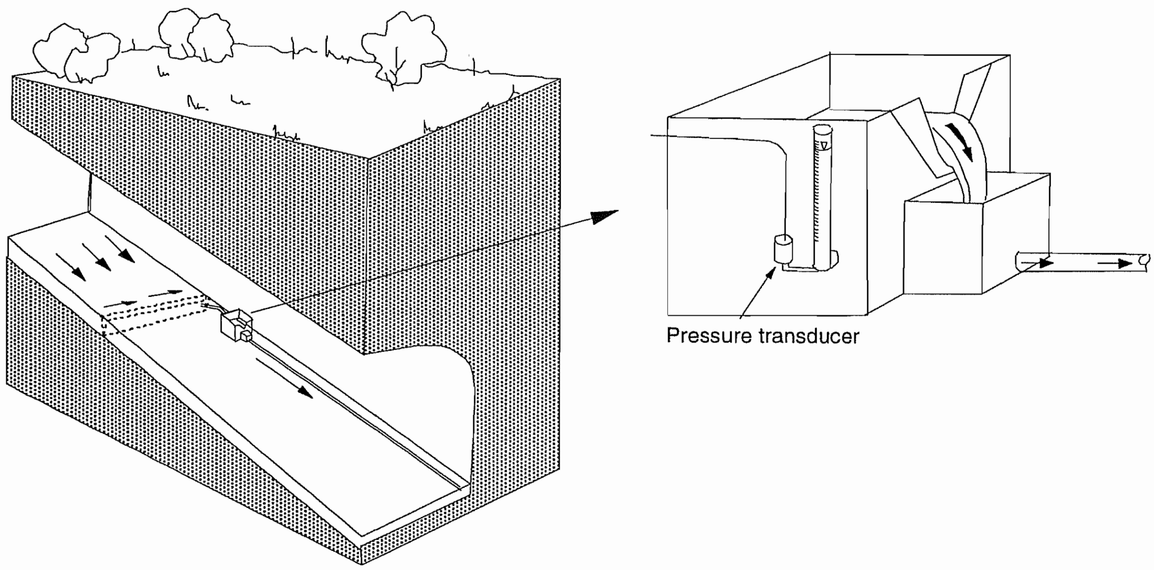


Figure 4-6 Water flow measurements in the tunnel.

The tunnel sections, in metres from tunnel entrance, between which water is drained to the different measuring ditches, are listed in Table 4-7. Normally the gauging box is placed some 10 metres downward from the measuring ditch crossing the tunnel. Special arrangements are used to collect the water from the side tunnels containing the elevator and the ventilation shafts.

Table 4-7 Water flow measurements in tunnel segments

Gauging box	Upper section (m)	Lower section (m)
MA0682G	0	682
MA1033G	682	1033
MA1232G	1033	1232
MA1372G	1232	1372
MA1584G	1372	1584
MA1659G	Water from the elevator shaft (TH: 0-213 m), from the ventilation shaft for incoming air (TV: 0-213 m) and from a sump inside the gate in the side tunnel.	
MA1745G	1584	1745
	Water from the side tunnel collected at MA1659G is not included.	
MA1883G	1745	1883
MA2028G	1883	2028
MA2178G	2028	2178
MA2357G	2178	2357

Gauging box	Upper section (m)	Lower section (m)
MA2496G	2357	2496
MA2587G	Water from the elevator shaft (TH: 220-333 m) and from a sump inside the gate in the side tunnel.	
MA2699G	2496	2699
	Water from the side tunnel collected at MA2587G is not included.	
MA2840G	2699	2840
MA2994G	2840	2994
MA3179G	2994	3179
MA3385G	Water from the elevator shaft (TH: 340-450 m), from the ventilation shaft for incoming air (TV: 220-450 m) and from the ventilation shaft for outgoing air (TW: 0-450 m)	
MA3411G	3179	3426
	Water from the side tunnel collected at MA3385G is not included.	
MA3426G	3426	3600
	Water from parts of tunnel J at approx. 3510 m is included	
MF0061G	Water from tunnel F 0-61 m, parts of tunnel J and tunnel G	

4.5.2 Methodology

Water levels in the gauging boxes are used on the HMS to calculate flow rates by means of a discharge equation expressing flow rate as a function of level. Normally the level is monitored every 10th second but stored only every 30th minute unless the change since latest stored value exceeds a predefined amount (change value). The change value is usually 1 mm, but due to oscillating levels in some gauging boxes it has been necessary to increase this value to avoid sampling too much data.

Initially the discharge equation for a weir is determined. The flow rate is measured at four different levels on the ruler. The level indicator is then calibrated against the ruler by altering the level in the box. This two-step procedure is used to avoid a new determination of the discharge equation every time a level indicator has to be replaced and to make the discharge equation independent to changes in the transducers calibration equation.

The levels in the gauging boxes are manually read ones every month to enable adjustments of the calibration constants for the level indicators. Once a year the discharge equation is checked through a field measurement of the existing flow rate and, if necessary, a new discharge equation is determined (see for example Jönsson et al. 1999).

4.5.3 Accuracy

If the flow rate does not differ too much from the interval where the measuring points were selected to determine the calibration equation, the error due to the equation is within a few percent.

However, the maintenance of the v-notch weir is important. If there are obstacles or coatings on the weir the relation between level and flow rate is disturbed.

4.6 Water flow in tunnel pipes

For a detailed description on instrumentation, see "Manual för HMS (del 3:4), 1994".

The flow in the pipes for incoming consumption water and pumped out drainage water is measured with an acoustic "clamp-on" type flow meter. The sensors are situated approx. 700 m from the tunnel entrance.

4.6.1 Methodology

It is not enough to use calibration constants given by the manufacturer. Using some material constants for different pipes is then necessary and the errors caused by using wrong constants are unknown. The pipes consist of different material layers, and can be coated at the inside. The flow meters are therefore calibrated using a "watch and bucket" method.

If the flow values are used as a part of the water balance for the tunnel one shall be aware that some of the incoming water is used for consumption at the Site office. However, this portion is a very small part of the total water balance of the tunnel.

The drainage water is pumped from one sump to the sump upward (there are five sumps in the tunnel). From the top sump the water is pumped out of the tunnel. The pump in every sump is working at max capacity until the sump is emptied and starts again when the sump is filled to a certain level. The flow is measured at one location only, some 10 metres upwards the top sump. This means that the flow rate is either zero or at the maximum capacity of the pump. The flow meter is calibrated by measuring the level changes per time in the sump. Since the area of the sump at different levels is known one can calculate the discharged water.

Both flowmeters measure very frequently, every ten seconds for incoming and every five seconds for discharged water, but the values are stored only if a certain change has taken place.

4.6.2 Accuracy

No systematic estimation of different errors has been performed.

Measurements of incoming consumption water have quite good accuracy, while calibrating the meter by the described method is quite easy.

The error in outpumped flow rate is probably larger because of the uncertainty in the area estimates of the sump.

4.7 Electrical conductivity of tunnel water

For a detailed description on instrumentation, see "Manual för HMS (del 3:4), 1994".

Electrical conductivity is measured with a 4-electrode conductivity meter, consisting of a housing with an electronic unit and an integrated sensor. The meter is mounted either in a gauging box for flow measurements or on the common discharge pipe leading water from the gauging boxes to the pumping sumps.

In Table 4-8 the tunnel parts from which water originates at the different measuring points are listed. Length to section is given in metres from the tunnel entrance.

Table 4-8 Electrical conductivity of water in tunnel segments

Mearuring point	Upper section (m)	Lower section (m)
EA0682G	0	682
EA1584T	1033	1584
EA1659B	Water from the elevator shaft, from the ventilation shaft for incoming air (TV: 0-220 m) and from a sump inside the gate in the side tunnel.	
EA2496T	Water between section 1584 m and section 2496 m, and from the gauging box MA2587G (see below).	
EA2587G	Water from the elevator shaft and from a sump inside the gate in the side tunnel at 2587 m.	
EA3179G	2994	3179
EA3384G	Water from the elevator shaft (TH: 340-450 m), from the ventilation shaft for incoming air (TV: 220-450 m) and from the ventilation shaft for outgoing air (TW: 0-450 m)	
EA3411G	3179	3426
EA3426G	3426	3600
	Water from parts of tunnel J at approx. 3510 m is included	
EF0061G	Water from tunnel F 0-61 m, parts of tunnel J and tunnel G	
EPG5	Water below section 2496 m, including the water from the gauging box MA3384G (see above)	

4.7.1 Methodology

The electric conductivity meter is connected to a logger on the HMS. A value is measured and stored once every hour. The four gauging boxes MA3384G, MA3411G, MA3426G and MF0061G are all situated near the sump PG5 in the bottom part of the tunnel, and the same electrical conductivity meter is used for periods in the different boxes and the sump.

Once a year the meters are calibrated by measuring on three buffer fluids having well-defined electrical conductivity.

4.7.2 Accuracy

No careful calculations on errors have been done, but a rough estimate gives a figure around some tens mS/m.

4.8 Earth tide

Depending on the tidal forces of the moon and the sun, the earth is periodically deformed. Because of this deformation, the earth's surface moves up and down with an amplitude of 15-30 centimetres every day. The tide effect also causes volume changes in compressible material in the earth's crust, an effect termed tidal volumetric dilatation. This phenomenon can be observed as a nearly semidiurnal sinusoidal fluctuation in some groundwater pressure registrations (see example in Figure 4-7). In fact, the tidal wave is composed of two longwave (half a month and half a year) and two shortwave (nearly half diurnal and half diurnal) oscillations.

Hourly values on earth tide, expressed as level above mean, have been calculated with an analytical model by Hans-Georg Scherneck at Chalmers University of Technology, Onsala Space Observatory, for the Äspö location. Since the earth tide mainly is a global phenomenon affecting the whole earth crust, local conditions are of minor importance and the relative error in the calculated values is less then a few percent.

At Äspö the effect can be seen in nearly all core boreholes and in many of the percussion boreholes. The groundwater pressure increases when the Earth crust is depressed and decreases when the crust rises. Therefore the oscillations in the pressure registration are almost an image of the Earth tide expressed as a level above mean (Figure 4-7). Furthermore, the amplitude is greater in sections not in direct contact with the groundwater surface, due to less relaxation than in the uppermost section.

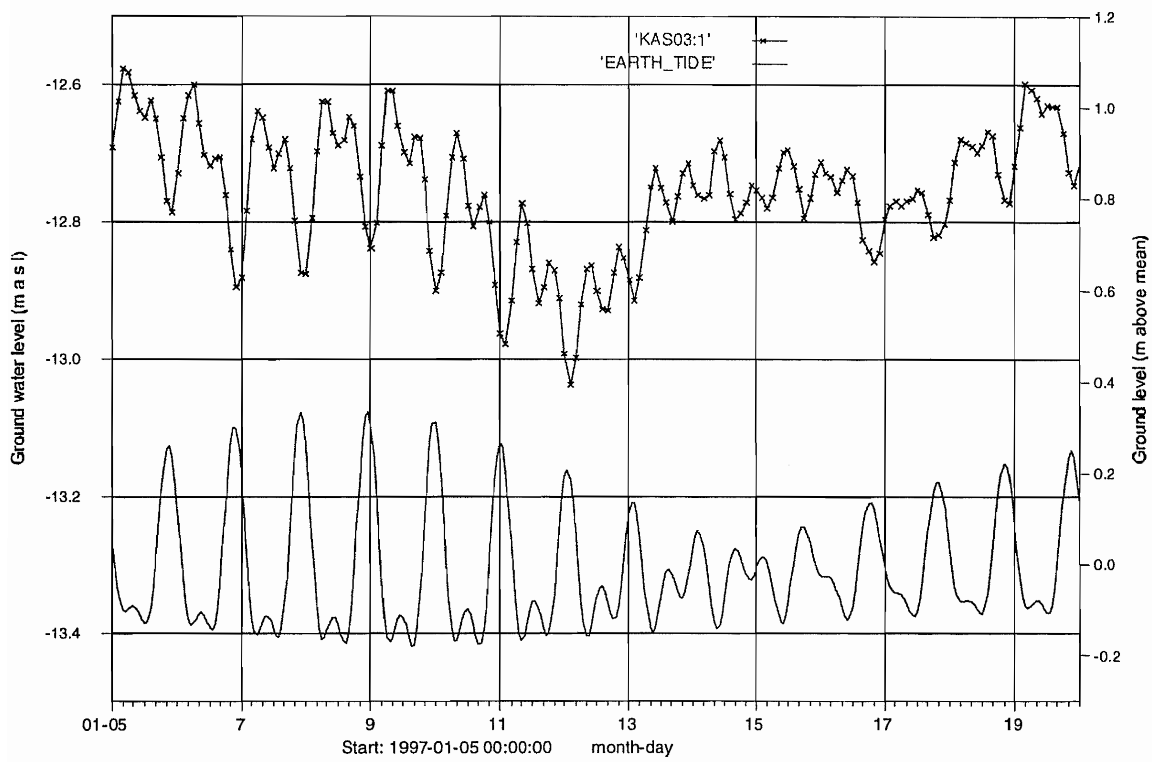


Figure 4-7 Earth tide (bottom curve, right axis) and groundwater level in KAS03:1 (top curve, left axis) during January 1997.

4.9 Level data from the Baltic Sea

The Swedish Meteorlogical and Hydrological Institute (SMHI) record the sea level at the city of Oskarshamn (some 25 km from the Simpevarp area). A writing recorder is connected to a float in a gauge well. Data is digitized and transferred to computer media (by SMHI) on an hourly basis. The influence of oscillations with short frequency (waves) is filtered, both by the gauge well and when digitizing data. Sea levels are adjusted to the national elevation system (RH70), which gives approximately 6 centimetres higher values than the local system on Äspö.

The errors in the data presented in the diagrams are, according to SMHI, less than one hour in time notation and less than a few centimetres in elevation.

For shorter periods, during quickly changing weather conditions, the difference in sea level between Oskarshamn and the Äspö area can be a few centimeters, but is normally much less.

4.10 Meteorological data

4.10.1 Precipitation

Precipitation is obtained from the Oskarshamn station (SMHI no 7616). The station is a regular SMHI-station, where a precipitation gauge with a wind shield (SMHI-type) is emptied at 0700 hours every day. Precipitation amounts are always referred to the day before emptying the gauge.

The most important error in point measurements of precipitation is due to the wind. The wind error varies with type of precipitation, wind speed and site, but always results in a deficiency of catch. The error due to evaporation from the gauge is largest during warm summer days with showers. The loss is estimated to some 1.5 mm/month (Gottschalk, 1980) as a mean, although much depending on meteorological factors. All types of errors cause precipitation to be underestimated. For the Oskarshamn station the total correction needed have been estimated at +18 % (Eriksson, 1980) for the annual precipitation amount. All precipitation values in this report are measured values, without any corrections.

A much more difficult problem when dealing with precipitation data is the poor areal representativeness of precipitation measurements, especially during showery conditions in the summer.

4.10.2 Temperature

Daily mean temperatures are obtained from the Oskarshamn station. These are, by SMHI, evaluated as a weighted mean of temperatures measured at 0700, 1300 and 1900 hours and the maximum and minimum temperatures.

Temperature is an easier variable to measure than precipitation, and the areal representativeness is normally much better. Therefore the Oskarshamn measurements some 25 km away can be regarded as good estimates of the temperature at Äspö, especially since both sites are near-coastal and at nearly the same altitude.

4.10.3 Potential Evapotranspiration

Potential evapotranspiration[1] is calculated with the Penman formula. This demands meteorological data available only at a few synoptical stations. Until 31 July 1995 , when the station at Ölands Norra Udde was closed, all presented values were means of potential evaporation calculated for Gladhammar and Ölands Norra Udde. Furthermore, the observation of cloudiness, which is used to obtain incoming short wave radiation in Penmans formula, was ended for Gladhammar 30 June 1995. Therefore, from 31 July 1995, the potential evaporation is calculated with data from Gladhammar but with cloudiness from Målilla some 50 km west from the Simpevarp area. Since the cloudiness at Målilla is greater than at the near coastal station in Gladhammar this will result in lower calculated potential evapotranspiration.

Ölands Norra Udde and Gladhammar are situated approx. 25 and 35 km respectively from the study site.

Although actual evapotranspiration can show a rather great aerial variation on the local scale, the potential evapotranspiration, depending mainly upon meteorological factors, does not vary that much. For long periods the actual evapotranspiration is almost the same as the potential, but during the summer months it does not reach the potential rate. The difference between the two very much depends upon vegetation, ground conditions and the wetness situation in an area.

[1] The theoretical evapotranspiration from a surface completely covered by a homogenous surface of green vegetation (crop) experiencing no lack of soil water.

5 Summary of activities influencing groundwater levels, pressure and flow

5.1 General

One main purpose of this report is to give an overview of the long-term effect of the tunnel excavations on the groundwater situation in the area. Therefore activities that might influence the groundwater pressure, groundwater levels and groundwater inflow to the tunnel are presented. The character and magnitude of the disturbances are different for different activities. Some might influence the groundwater pressure/level in many surrounding boreholes while others have influence only in the borehole where the activity takes place.

During the spring of 1991, the tunnel excavation began to have a visible effect on the groundwater level in many boreholes, especially on Äspö and Bockholmen. Later on most boreholes, except those on Laxemar, were influenced by the tunnel activities. From the late 1991, the disturbances from the tunnel had a dominating influence on the groundwater levels in the area. One single activity affecting the groundwater levels in many boreholes on Äspö was the drilling of the first of two raice-drilled ventilation shafts to the tunnel at the end of October 1992. After this event, the groundwater levels continued to decline in many borehole sections, but nothing as spectacular as in the late 1992 has occurred. Since 1996, the level/pressure in most boreholes seems to have stabilised and the changes during 1998 were within half a meter in nearly all surface borehole sections. During 1998 most boreholes down to a tunnel length of approximately 2000 metres shows a decreasing pressure between 10 and 40 kPa over the year, while further down in the tunnel the pressure in the main part of the boreholes is slightly increasing, or is relatively unchanged seen over the year.

A great number of activities, which may or may not have influenced the groundwater level/pressure and inflow to the tunnel, have been carried out during 1998. A total of more than 3500 entries during 1998 are to be found in the activity table in the SKB database. Certainly, there are activities that have influenced groundwater conditions that are not included in the database. Because of the great number of activities in the database, only a selection of activities is presented in the following tables.

The activities are listed in Tables 5-1 - 5-6. The dates stated in the tables are the dates for the actual activity. However, the influence on groundwater levels/pressures may last 5-10 times the length of the activity.

5.2 Tunnel excavation and permanent reinforcement

These activities, presented in Table 5-1, may have a substantial influence on ground water levels and pressures. The permanent reinforcements are carried out after the tunnel excavation and include (among other things) drilling and bolting, grouting and shot creating. (Additional scaling not performed in connection to the tunnel excavations is not included.)

Table 5-1 Tunnel excavation and permanent reinforcements

From	To	Tunnel	Activity
980119	980119	TASD	Tunnel excavation
980119	980119	TASO	Tunnel excavation
980120	980120	TASD	Tunnel excavation
980120	980120	TASO	Tunnel excavation
980121	980121	TASK	Tunnel excavation
980122	980122	TASO	Tunnel excavation
980128	980128	TASD	Tunnel excavation
980128	980128	TASO	Tunnel excavation
980129	980129	TASK	Tunnel excavation
980203	980203	TASD	Tunnel excavation
980203	980203	TASO	Tunnel excavation
980209	980209	TASD	Tunnel excavation
980211	980211	TASK	Tunnel excavation
980212	980212	TASD	Tunnel excavation
980212	980212	TASK	Tunnel excavation
980217	980217	TASD	Tunnel excavation
980318	980318	TASO	Permanent reinforcement
980522	980524	TASK	Tunnel excavation
980522	980524	TASK	Tunnel excavation
980526	980529	TASK	Tunnel excavation
980529	980603	TASK	Tunnel excavation
980603	980604	TASK	Tunnel excavation
980604	980605	TASK	Tunnel excavation
980608	980609	TASA	Tunnel excavation
980608	980609	TASA	Tunnel excavation
980617	980617	TASK	Tunnel excavation
980617	980617	TASA	Tunnel excavation
980617	980617	TASA	Tunnel excavation
980617	980617	TASK	Tunnel excavation
980617	980617	TASK	Tunnel excavation
981006	981008	TASK	Permanent reinforcement
981006	981008	TASK	Permanent reinforcement
981019	981025	TASK	Permanent reinforcement
981019	981025	TASK	Permanent reinforcement
981021	981022	TASK	Permanent reinforcement
981026	981102	TASK	Permanent reinforcement
981026	981102	TASK	Permanent reinforcement
981105	981108	TASK	Permanent reinforcement

981106	981107	TASK	Permanent reinforcement
981108	981109	TASK	Permanent reinforcement
981111	981117	TASK	Permanent reinforcement
981116	981122	TASK	Permanent reinforcement
981116	981122	TASK	Permanent reinforcement

5.3 Opening of valves in tunnel boreholes

The main reason for valve openings in boreholes is water sampling for chemical analyses. Usually, before water samples are taken from a tunnel borehole section, a certain amount of water is discharged to assure that the water is representative for that section. Typically for chemical sampling, a volume corresponding to five section volumes is discharged. When a valve is opened, the flow rate may vary a lot from section to section due to different transmissivities and pressures. Normally these type of valve openings have only a minor influence in other boreholes and therefore only borehole sections included in the monitoring program are listed in the table. Dates when valves have been open are to be found in Table 5-2. In some cases, due to missing data records, only start- or stop-date is noted. Since the opening and closing of a valve are uncoupled activities in the database is also possible, if two successive data records are missing, that the "from"- and "to"-dates are mismatching.

Table 5-2 Open valves in tunnel boreholes.

From	To	Borehole:sec
	980306	KA2563A
	980309	KA2563A
	981029	KA2862A
	980916	KA3510A
	980917	KA3510A
	980327	KI0023B:8
	980424	KI0023B:6
	980130	KI0023B
	980512	KI0023B
	980617	KI0023B
	981004	KI0025F02
970715	981210	KXTT3:2
980111	980117	KI0023B
980119	980120	KI0023B
980121	980123	KI0023B
980129	980129	KI0023B
980203		KI0023B
980210		KI0023B
980217	980313	KA2511A
980225	980225	KA3385A:1
980302	980304	KA1061A
980302	980304	KA1131B
980302	980305	KA1755A:3

From	To	Borehole:sec
980302	980302	KA3385A:1
980304	980304	KA2162B
980305	980306	KA2050A
980305	980305	KA2511A
980305	980305	KA2511A
980305	980305	KA2511A:5
980305	980305	KA2511A:4
980305	980305	KA2563A
980305	980305	KA2563A
980305	980305	KI0023B
980305	980305	KI0023B:8
980305	980305	KI0023B:6
980305	980305	KI0023B:4
980305	980305	KI0023B:2
980305	980305	KI0025F:4
980305	980305	KI0025F
980305	980305	KI0025F:2
980306	980306	KA2511A
980306	980306	KA2511A
980306	980306	KA2511A
980306	980306	KA3110A:1
980306	980306	KI0023B
980306	980306	KI0025F:4

From	To	Borehole:sec
980306	980306	KI0025F
980306	980306	KI0025F:1
980306	980306	KA2563A
980309	980312	KA2862A:2
980309	980312	KA2862A:1
980406	980406	KA2511A
980406	980406	KA2511A:5
980407	980407	KA2862A:1
980414	980415	KA2862A
980415	980415	KA2862A
980424	980424	KI0023B:4
980424	980424	KI0025F:4
980427	980427	KI0023B:4
980429	980429	KI0025F:4
980429	980429	KXTT2:2
980518	980518	KA2511A:4
980518	980518	KA2563A:4
980518	980518	KA2563A:1
980519	980519	KI0023B:7
980519	980519	KI0025F:5
980519	980519	KI0025F:3
980519	980519	KI0025F:2
980520	980520	KA3105A:2
980520	980520	KA3110A:1
980520	980520	KI0023B:5
980520	980520	KI0023B:2
980527	980527	KF0051A01
980528	980528	KF0051A01
980612		KF0051A01
980623	980623	KA2862A:1
980629	980629	KI0023B:4
980706	980706	KA2862A
980706	980706	KA2862A
980707	980707	KA2862A
980710		KI0023B:3
980721	980721	KA2862A:1
980722	980722	KA2862A:1
980722	980722	KA2862A:1
980814		KI0025F02
980909		KI0025F02
980913	980913	KI0025F02
980917	980917	KI0025F02
980920		KA3510A
980928	980930	KA1061A
980928	980930	KA1131B
980928	980929	KA1755A:3
980928	980928	KA2162B:1
980928	980928	KA2511A:5
980928	980928	KA2511A:4
980928	980928	KA2563A:5
980928	980928	KA3110A:1
980928	980928	KA3385A:1
980928	980928	KI0023B:8
980928	980928	KI0023B:6
980928	980928	KI0023B:4
980928	980928	KI0023B:2
980928	980928	KI0025F:4
980928	980928	KI0025F:2
980929	980929	KA1755A:3
980929	980930	KA2050A
981001	981001	KA1061A
981001	981001	KA1131B
981004	981004	KI0025F02
981005	981005	KA1061A
981005	981005	KA1131B
981018	981018	KI0025F02
981019	981023	KI0025F02
981020		KA3510A
981028	981029	KA3005A:2
981028	981029	KA3105A:1
981028	981029	KA3110A:1
981028	981028	KI0023B:6
981028	981030	KI0025F02
981029	981030	KI0023B:6
981109	981109	HA1273A
981109	981109	HA1278A
981109	981109	HA1279A
981109	981109	HA1283B
981109	981109	HA1327B
981109	981109	HA1330B
981109	981109	KA1061A
981109	981109	KA1131B
981116	981116	KA2511A:4
981123	981123	KA3385A:1
981213	981218	KI0023B

5.4 Packer expansion and release

Packers often isolate different fractures or fracture zones from each other in order to prevent flow along the borehole, which otherwise may act as a connection between fractures or zones. Therefore, release and expansion of packers may have an influence on the groundwater system. The dates for packer expansion/release in surface boreholes are listed in Table 5-3 (This refers to the large borehole packers and not the PEM - packers). Surface boreholes not included in the table have no packers.

In Table 5-4 packer expansion and release in tunnel boreholes are presented. This table only includes entries found in the database for 1998. In a few cases, data on expansion/release is missing in the database, which means that two entries on packer expansion or release may occur after one another.

Table 5-3 Packer expansion and release in surface boreholes.

Borehole	Expansion	Release
KAS02	910806	
KAS03	960427	
KAS05	911124	
KAS07	910707	970220
KAS08	890512	
KAS09	900405	
KAS12	910830	960201
	971028	
KAS16	921020	
HAS03	890512	970205
HAS04	890512	
HAS06	890512	
HAS07	890516	970218
HAS08	890512	970130
HAS11	890516	
HAS13	891123	981215
HAS15	890511	970218
	970522	
HAS16	890512	970129
HAS17	950812	970304

Borehole	Expansion	Release
	970529	981008
HAS18	930930	970227
HAS19	900609	
HAS20	901212	
HAS21	911210	970130
HAV02	890517	970205
HAV05	890517	970218
KLX01	920226	
HLX04	890517	970129
HLX05	890517	970129
KBH02	920507	
HBH04	911211	
HMJ01	911213	

Table 5-4 Packer expansion and release in tunnel boreholes.

Borehole	Expansion	Release
KA2048B		981013
	981020	
KA2511A		980210
	980218	
	981019	981019

Borehole	Expansion	Release
KA2512A	980217	980217
	980225	980304
	980305	980318
KA2563A		980219
	980225	

Borehole	Expansion	Release
	981222	981222
KA2598A	980304	
KA2861A		980325
	980326	
KA3510A	981020	
	981027	981123
	981123	
KA3544G01		980408
KA3548A01	980810	
	981124	981124
KA3548G01	980415	980415
KA3550G01	980416	980416
KA3572G01	980418	980417
KA3573A	980305	980305
KA3578G01	980418	980418
KA3584G01		980419
	980420	
KA3586G01	980420	980420
KA3588G01		980421
KA3600F	980305	
KF0051A01	980612	
KG0021A01	980811	980906
		980916
		981016
KG0048A01	980811	980906
	981124	
KI0023B	980101	980119
	980123	980126
	980203	
	980212	
	980216	980511
	980617	980617
KI0025F		980226
	980304	
KI0025F02		981004
	981019	
	981027	
KXP27BGR	980713	
KXZB3	981022	
KXZRD7H	981020	
KXZRD7HR	981020	
KXZSD8HL	981023	
KXZSD8HR	981009	
KZ0041A02	981007	
KZ0041B02	981007	
KZ0041G01	981001	
KZ0041I01	981015	
KZ0041I02	981007	
KZ0042A01	980929	

Borehole	Expansion	Release
KZ0042B01	981001	
KZ0043G01	980929	
KZ0043I01	981015	
KZ0044A01	980928	
KZ0044B01	980930	
KZ0046A01	980929	
KZ0046B01	980930	
KZ0046G01	980929	
KZ0046I01	981015	
KZ0048A01	980929	
KZ0048B01	980930	
KZ0048G01	980929	
KZ0048I01	981015	
KZ0050A01	980929	
KZ0050B01	980930	
KZ0050G01	981012	
KZ0050I01	981015	
KZ0052G01	980930	
KZ0052I01	981014	
KZ0053A01	980929	
KZ0053B01	980930	
KZ0054G01	980929	
KZ0054I01	981014	
KZ0055A01	980930	
KZ0055B01	980930	
KZ0057A01	980929	
KZ0057B01	980930	
KZ0057G01	981012	
KZ0057I01	981013	
KZ0059A01	980930	
KZ0059B01	980930	
KZ0059G01	981007	
KZ0059I01	981013	
KZ0061A01	980929	
KZ0061B01	980930	
KZ0061G01	980930	
KZ0061I01	981013	
KZ0063G01	980930	
KZ0063I01	981001	
KZ0064A01	980929	
KZ0064B01	980930	
KZ0065A02	981006	
KZ0065B02	981006	
KZ0065G01	980929	
KZ0065G02	981006	
KZ0065I01	981006	
KZ0065I02	981006	
KZ0066A01	980929	
KZ0066B01	980930	

5.5 Drilling

Only tunnel boreholes have been drilled during 1998.

During drilling water is injected into the borehole with high pressure, and the effect at different locations in the borehole may be either injection or removal of water. During drilling interruptions, water is flowing out of the borehole and the net result on pressure registrations mainly seems to be a pumping effect. In Table 5-5 dates when boreholes were drilled, borehole length and type of drilling are presented. Drilling before rounds and drilling for bolting are not included in the table.

Table 5-5 Drilling

Start	Stop	Borehole	Borehole length (m)	Type of drilling
980110	980111	KZ0082F01	25.09	Core drilling
980112	980112	KZ0065A02	5.05	Core drilling
980113	980113	KZ0041G02	5.06	Core drilling
980113	980113	KZ0065B02	5.05	Core drilling
980114	980114	KZ0065G02	5.26	Core drilling
980115	980115	KZ0041A02	5.05	Core drilling
980115	980115	KZ0041B02	5.1	Core drilling
980121	980121	KZ0041I02	5.05	Core drilling
980122	980123	KZ0055I01	25.05	Core drilling
980122	980123	KZ0061I02	25.05	Core drilling
980123	980123	KZ0065I02	5.14	Core drilling
980126	980206	NASA3384A		Core drilling
980126	980206	NASA3384A		Core drilling
980302	980310	NASA3384A		Core drilling
980302	980310	NASA3384A		Core drilling
980311	980312	KK0051G01	8	Core drilling
980312	980312	KK0037G01	8	Core drilling
980313	980316	KK0025G01	8	Core drilling
980316	980316	KA3588G01	8	Core drilling
980317	980318	KA3586G01	8	Core drilling
980317	980324	KK0045G01	8.5	Core drilling
980318	980319	KA3584G01	12	Core drilling
980319	980319	KA3578G01	12.58	Core drilling
980320	980320	KA3572G01	12	Core drilling
980321	980321	KA3552G01	12.01	Core drilling
980322	980322	KA3550G01	12.03	Core drilling
980323	980324	KA3546G01	12	Core drilling
980323	980323	KA3548G01	12.01	Core drilling
980324	980325	KA3544G01	12	Core drilling
980325	980325	KK0031G01	8	Core drilling
980330	980330	KD0092G01	8	Core drilling
980331	980331	KA2195A01	0.59	Core drilling
980331	980331	KD0086G01	8	Core drilling

Start	Stop	Borehole	Borehole length (m)	Type of drilling
980401	980401	KA2195A02	1.1	Core drilling
980401	980401	KA2195A03	1.61	Core drilling
980401	980401	KA2195A04	0.73	Core drilling
980401	980401	KA2195A05	1.66	Core drilling
980401	980401	KA3147G01	8	Core drilling
980402	980402	KA2195A06	1.01	Core drilling
980402	980402	KA2195A07	1.41	Core drilling
980402	980402	KA2195A08	1.34	Core drilling
980402	980402	KA3153G01		Core drilling
980403	980403	KA2195A09	1.11	Core drilling
980420	980513	HZ0043A01	26.5	Core drilling
980423	980513	HZ0045A01	28.6	Core drilling
980425	980513	HZ0047A01	29.3	Core drilling
980425	980426	KA3576G01	12.01	Core drilling
980426	980428	KA3574G01	12	Core drilling
980427	980513	HZ0049A01	30.1	Core drilling
980427	980513	HZ0051A01	31	Core drilling
980428	980513	HZ0053A01	31.6	Core drilling
980428	980428	KA2511TES	293	Core drilling
980429	980513	HZ0054A01	31.6	Core drilling
980502	980512	HZ0056A01	32.1	Core drilling
980503	980512	HZ0058A01	33.1	Core drilling
980504	980512	HZ0060A01	33.7	Core drilling
980504	980512	HZ0066A01	37.5	Core drilling
980504	980504	KA3593G	30.01	Core drilling
980505	980506	HZ0041A01	23.8	Core drilling
980506	980507	KA3563G	30	Core drilling
980508	980512	KA3557G	30.04	Core drilling
980512	980513	KA3539G	30.01	Core drilling
980526	980527	KF0051A01	11.7	Core drilling
980527	980603	KA3542G01	30.04	Core drilling
980604	980605	KA3542G02	30.01	Core drilling
980605	980606	KA3554G02	30.01	Core drilling
980607	980607	KA3554G01	30.01	Core drilling
980608	980609	KA3566G01	30.01	Core drilling
980610	980610	KA3566G02	30.01	Core drilling
980615	980616	KA3590G02	30.05	Core drilling
980616	980617	KXP25BGR	4.56	Core drilling
980617	980623	KA3590G01	30.06	Core drilling
980617	980617	KXP24BGR	4.45	Core drilling
980617	980618	KXP26BGR	8.45	Core drilling
980618	980622	KXP27BGR	8.7	Core drilling
980625	980628	KA3548A01	30	Core drilling
980702	980708	KG0021A01	48.82	Core drilling
980723	980804	KG0048A01	54.69	Core drilling
980804	980812	KK0045G01	65.06	Core drilling
980810	980825	KI0025F02	204.18	Core drilling
980902	980903	KD0089G01	10.01	Core drilling
980904	980905	KD0094G01	10.05	Core drilling
980905	980906	KD0092G02	10.06	Core drilling
980906	980907	KD0089G02	10.05	Core drilling
980907	980908	KD0084G01	10.03	Core drilling

Start	Stop	Borehole	Borehole length (m)	Type of drilling
980908	980909	KD0086G02	10.06	Core drilling
980908	980909	KD0086G02	10.06	Core drilling
980908	980909	KD0086G02	10.06	Core drilling
980909	980909	KD0089G03	10.05	Core drilling
980922	980922	KD0092G03	2.93	Core drilling
980922	980922	KD0093G01	5.5	Core drilling
980923	980923	KD0087G01	8.52	Core drilling
980923	980923	KD0091G01	3.08	Core drilling
980923	980923	KD0092G04	5.77	Core drilling
980924	980924	KD0085G01	4.53	Core drilling
980924	980924	KD0086G04	8.52	Core drilling
980925	980925	KD0086G03	4.56	Core drilling
981103	981103	KA3553G01	9.56	Core drilling
981104	981105	KA3551G01	9.58	Core drilling
981106	981106	KA3543G01	9.55	Core drilling
981108	981108	KA3545G02	9.55	Core drilling
981109	981109	KA3548G02	9.59	Core drilling
981110	981110	KA3548G03	9.57	Core drilling
981111	981111	KA3552G02	1.72	Core drilling
981112	981116	KA3546G02	1.71	Core drilling
981116	981116	KA3544G02	1.71	Core drilling
981117	981117	KA3550G02	1.71	Core drilling
981117	981117	KXP28GRS	5	Core drilling
981118	981118	KA3551G03	4.21	Core drilling
981118	981118	KA3551G04	8.3	Core drilling
981119	990117	DA3147G01	8.9	Core drilling
981119	981119	KA3545G04	5.29	Core drilling
981120	981120	KA3545G03	2.83	Core drilling
981120	981120	KA3552G03	8	Core drilling
981121	981123	KA3546G03	5.01	Core drilling
981121	981121	KA3550G03	3.99	Core drilling
981123	981125	KA3544G03	2.5	Core drilling
981202	981202	KA2195A10	0.32	Core drilling
981203	981203	KA2195A11	1.17	Core drilling
981204	981208	KA2195A12	2.71	Core drilling
981208	981208	KA2195A13	2.14	Core drilling
981208	981208	KA2195A14	2.74	Core drilling
981209	981209	KA2195A15	2.38	Core drilling
981209	981209	KA2195A16	0.59	Core drilling
981209	981209	KA2195A17	1.25	Core drilling
981209	981209	KA2195A18	1.43	Core drilling
981209	981209	KA2195A19	1.38	Core drilling
981210	981210	KA2195A20	1.14	Core drilling
981210	981211	KXP29GRS	0.67	Core drilling
981210	981211	KXP30GRS	0.81	Core drilling

5.6 Tests

All tests in Table 5-6 have been performed in tunnel boreholes.

Tracer tests are performed in a number of different ways:

Dilution test is a single hole test where the tracer is circulated in one section. No water is withdrawn or added to the circulation section (except for a small amount of tracer solution).

During *radially converging or dipole tests* water is pumped out of one section and tracer injected in another section. In radially converging tests there is usually no excess pressure in the injection section while during dipole tests a certain injection flow is maintained during the test. In Table 5-6 the sections that were pumped during the tests are listed.

Interference tests means that pumping or flowing is done in one section to induce and study a response in other sections. The length of such a test and the magnitude of flow may vary over a wide range.

Flow logging means that a single or a pair of packers is expanded at certain intervals in the borehole and the flow rate from inside/between the packers is measured.

Flow logging with the UCM probe. Water is pumped or flowed out of the borehole while the probe is moved along the borehole to measure the flow.

Pressure build up test. The borehole is discharged between 45 minutes and a few hours before the valve is closed and the pressure recovery is studied.

Outflow tests with constant flow or constant pressure are equivalent to pumping tests in surface borehole.

Flow logging with thermal probe. Water is pumped or flowed out of the borehole while the probe is moved along the borehole to measure the flow.

Pulse injection test is a type of water injection test where the test section is short (50 mm) and the injection under constatnt pressure is performed during a few minutes (a pulse).

Table 5-6 Tests

From	To	Borehole	Borehole length (m)		Type of test
			From	To	
970715	980306	KXTT3	12.42	14.42	Radially converging
971203	980306	KXTT1	15	16	Radially converging
980123	980126	KI0023B	41.45	42.45	Outflow test with constant pressure
980126	980126	KI0023B	41.45	42.45	Pressure Build Up Test
980126	980126	KI0023B	41.45	42.45	Outflow test with constant pressure
980126	980126	KI0023B	41.45	42.45	Pressure Build Up Test
980126	980126	KI0023B	42.4	43.4	Outflow test with constant pressure
980126	980126	KI0023B	42.4	43.4	Pressure Build Up Test

From	To	Borehole	Borehole length (m)		Type of test
			From	To	
980126	980126	KI0023B	43.4	44.4	Outflow test with constant pressure
980126	980126	KI0023B	43.4	44.4	Pressure Build Up Test
980126	980126	KI0023B	43.4	44.4	Outflow test with constant pressure
980126	980126	KI0023B	43.4	44.4	Pressure Build Up Test
980126	980126	KI0023B	50	51	Outflow test with constant pressure
980126	980126	KI0023B	50	51	Pressure Build Up Test
980126	980127	KI0023B	68.4	69.4	Outflow test with constant pressure
980127	980907	KI0023B	68.4	69.4	Outflow test with constant pressure
980127	980127	KI0023B	68.4	69.4	Pressure Build Up Test
980127	980127	KI0023B	69.4	70.4	Outflow test with constant pressure
980127	980127	KI0023B	69.4	70.4	Pressure Build Up Test
980127	980127	KI0023B	70.4	71.4	Outflow test with constant pressure
980127	980127	KI0023B	70.4	71.4	Pressure Build Up Test
980127	980127	KI0023B	70.4	71.4	Outflow test with constant pressure
980127	980127	KI0023B	75.1	76.1	Outflow test with constant pressure
980127	980128	KI0023B	75.1	76.1	Pressure Build Up Test
980128	980128	KI0023B	78.3	79.3	Outflow test with constant pressure
980128	980128	KI0023B	78.3	79.3	Pressure Build Up Test
980128	980128	KI0023B	78.6	79.6	Outflow test with constant pressure
980128	980128	KI0023B	78.6	79.6	Pressure Build Up Test
980128	980128	KI0023B	85	86	Outflow test with constant pressure
980128	980128	KI0023B	85	86	Pressure Build Up Test
980128	980128	KI0023B	87.1	88.1	Outflow test with constant pressure
980128	980128	KI0023B	87.1	88.1	Pressure Build Up Test
980128	980128	KI0023B	109.5	110.5	Outflow test with constant pressure
980128	990217	KI0023B	109.5	110.5	Pressure Build Up Test
980128	980128	KI0023B	111.45	112.45	Outflow test with constant pressure
980128	980129	KI0023B	111.45	112.45	Pressure Build Up Test
980129	980129	KI0023B	168.1	169.1	Outflow test with constant pressure
980129	980129	KI0023B	168.1	169.1	Pressure Build Up Test
980129	980129	KI0023B	170.2	171.2	Outflow test with constant pressure
980129	980129	KI0023B	170.2	171.2	Pressure Build Up Test
980130	980130	KI0023B	111.2	111.7	Outflow test with constant pressure
980130	980130	KI0023B	111.2	111.7	Pressure Build Up Test
980130	980130	KI0023B	111.7	112.2	Outflow test with constant pressure
980130	980130	KI0023B	111.7	112.2	Pressure Build Up Test
980130	980130	KI0023B	112.2	112.7	Outflow test with constant pressure
980130	980130	KI0023B	112.2	112.7	Pressure Build Up Test
980305	980305	KA2598A	5	300.77	Pressure Build Up Test
980309	980310	KA2598A	5	95	Pressure Build Up Test
980309	980310	KI0025F	158	168	Dilution test
980309	980310	KI0023B	84.75	86.2	Dilution test
980310	980310	KA2598A	5	95	Pressure Build Up Test
980310	980311	KA2598A	5	95	Pressure Build Up Test
980310	980312	KI0025F	89	151	Dilution test
980310	980312	KI0023B	41.45	42.45	Dilution test
980311	980313	KA2511A	52	54	Interference test
980311	980311	KA2598A	5	95	Pressure Build Up Test
980312	980312	KA2598A	5	185	Pressure Build Up Test
980312	980313	KI0025F	158	168	Dilution test
980312	980313	KI0023B	84.75	86.2	Dilution test
980312	980313	KA2598A	185	275	Pressure Build Up Test

From	To	Borehole	Borehole length (m)		Type of test
			From	To	
980316	980316	KA2598A	5	15	Pressure Build Up Test
980316	980316	KA2598A	15	25	Pressure Build Up Test
980316	980316	KA2598A	15	25	Pressure Build Up Test
980316	980317	KI0025F	89	151	Dilution test
980316	980316	KA2598A	15	25	Pressure Build Up Test
980316	980317	KI0023B	84.75	86.2	Dilution test
980316	980316	KA2598A	15	25	Pressure Build Up Test
980317	980317	KA2598A	15	25	Outflow test with constant pressure
980317	980319	KI0025F	89	151	Dilution test
980317	980319	KI0023B	70.95	71.95	Dilution test
980318	980320	KA3573A	4.5	17	Interference test
980318	980318	KA3573A	4.5	17	Interference test
980319	980320	KI0023B	84.75	86.2	Dilution test
980319	980320	KI0025F	89	151	Dilution test
980323	980324	KI0023B	70.95	71.95	Dilution test
980323	980324	KI0025F	41	85	Dilution test
980324	980326	KI0025F	89	151	Dilution test
980324	980326	KI0023B	84.75	86.2	Dilution test
980325	980327	KI0023B	41.45	42.45	Interference test
980326	980327	KI0023B	70.95	71.95	Dilution test
980326	980327	KI0025F	89	151	Dilution test
980330	980401	KI0025F	89	151	Dilution test
980330	980401	KI0023B	70.95	71.95	Dilution test
980331	980401	KA2563A	187	190	Interference test
980401	980401	KA3588G01	0	8	Pressure Build Up Test
980401	980401	KA3588G01	0.5	8	Interference test
980401	980402	KA3586G01	0	8	Pressure Build Up Test
980401	980402	KA3586G01	0.5	8	Pressure Build Up Test
980402	980402	KA3572G01	0	12	Pressure Build Up Test
980402	980402	KA3572G01	0.5	12	Pressure Build Up Test
980402	980404	KI0023B	70.95	71.95	Dilution test
980402	980404	KI0023B	84.75	86.2	Dilution test
980402	980403	KA3552G01			Pressure Build Up Test
980402	980403	KA3552G01	0.5	12.01	Interference test
980403	980403	KA3550G01			Pressure Build Up Test
980403	980403	KA3550G01	0.5	12.03	Interference test
980403	980404	KI0025F	86	88	Interference test
980403	980403	KA3544G01			Pressure Build Up Test
980403	980403	KA3544G01	0.5	12	Interference test
980403	980404	KA3548G01			Pressure Build Up Test
980403	980404	KA3548G01	0.5	12.01	Interference test
980404	980404	KA3546G01			Pressure Build Up Test
980404	980404	KA3546G01	0.5	12	Interference test
980404	980405	KA3578G01			Pressure Build Up Test
980404	980405	KA3578G01	0.5	12	Pressure Build Up Test
980405	980405	KA3584G01			Pressure Build Up Test
980405	980405	KA3584G01	1.21	12	Pressure Build Up Test
980406	980406	KA2512A	34	37.27	Interference test
980407	980407	KA3544G01	9.7	10.7	Pressure Build Up Test
980407	980407	KA3544G01	9.7	10.7	Pressure Build Up Test
980407	980409	KI0025F	86	88	Dilution test
980407	980409	KI0023B	72.95	83.75	Dilution test

From	To	Borehole	Borehole length (m) From	To	Type of test
980407	980407	KA3544G01	10.7	12	Flow logging
980407	980407	KA3544G01	0.5	12	Flow logging
980408	980408	KA3546G01	0.5	12	Flow logging
980408	980424	KI0023B	70.95	71.95	Interference test
980414	980415	KA3548G01	0.5	12.01	Flow logging
980414	980414	KA3548G01	5.7	6.7	Pressure Build Up Test
980414	980414	KA3548G01	5.7	6.7	Pressure Build Up Test
980415	980415	KA3548G01	10.7	12	Flow logging
980415	980416	KA3550G01	0.5	12.03	Flow logging
980415	980415	KA3550G01	5.7	6.7	Pressure Build Up Test
980415	980415	KA3550G01	5.7	6.7	Pressure Build Up Test
980416	980416	KA3550G01	10.7	12	Flow logging
980416	980416	KA3552G01	0.5	12.01	Flow logging
980416	980416	KA3552G01	4.7	5.7	Pressure Build Up Test
980417	980417	KA3552G01	10.7	12	Flow logging
980417	980417	KA3552G01	1	2	Flow logging
980417	980417	KA3572G01	0.5	12	Flow logging
980417	980417	KA3572G01	10.7	12	Flow logging
980418	980418	KA3578G01	0.5	12.58	Flow logging
980418	980418	KA3578G01	11.25	12	Flow logging
980419	980419	KA3584G01	1.21	12	Flow logging
980420	980420	KA3584G01	1	3.7	Flow logging
980420	980420	KA3584G01	10.7	12	Flow logging
980420	980420	KA3586G01	0.5	8	Flow logging
980420	980420	KA3586G01	6.7	8	Flow logging
980421	980421	KA3588G01	0.5	8	Flow logging
980421	980421	KA3588G01	4.7	5.7	Pressure Build Up Test
980421	980428	KXTT2	14.55	15.55	Radially converging
980421	980421	KA3588G01	6.7	8	Flow logging
980421	980421	KA3588G01	6.7	8	Flow logging
980427	980427	KI0023B	84.75	86.2	Interference test
980511	980514	KA3147G01	0.3	8	Interference test
980518	980518	KA2563A	262	362	Interference test
980518	980518	KA2563A	191	219	Interference test
980518	980518	KA2511A	92	109	Interference test
980519	980519	KI0025F	89	163	Interference test
980519	980519	KI0025F	41	85	Interference test
980519	980519	KI0025F	164	168	Interference test
980519	980519	KI0023B	43.45	69.95	Interference test
980520	980520	KI0023B	72.95	83.75	Interference test
980520	980520	KI0023B	111.25	112.7	Interference test
980520	980520	KA3573A	18	40	Interference test
980521	980521	KA3539G	1	29.5	Flow logging with UCM probe
980521	980521	KA3539G	1	29.5	Flow logging with UCM probe
980526	980528	KXTT4	11.92	13.92	Dilution test
980605	980605	KXTT3	12.42	14.42	Radially converging
980605	980605	KXTT4	11.92	13.92	Radially converging
980624	980625	KA3590G02	1	27	Flow logging
980625	980626	KA3590G02	12	30	Pressure Build Up Test
980626	980626	KA3590G02	27	30	Flow logging
980629	980707	KI0023B	84.75	86.2	Interference test
980629	980707	KI0023B	87.2	110.25	Interference test

From	To	Borehole	Borehole length (m) From	To	Type of test
980701	980701	KA3590G02	0.39	30.05	Interference test
980701	980701	KA3590G01	0.39	30.06	Interference test
980701	980701	KA3593G	0.39	30.02	Interference test
980701	980702	KA3566G02	0.39	30.01	Interference test
980702	980702	KA3566G01	0.39	30.01	Interference test
980702	980702	KA3554G01	0.39	30.01	Interference test
980702	980702	KA3554G02	0.39	30.01	Interference test
980703	980703	KA3542G02	0.39	30.01	Interference test
980703	980703	KA3542G01	0.39	30.04	Interference test
980703	980704	KA3539G	0.39	30.01	Interference test
980704	980704	KA3557G	0.39	30	Pressure Build Up Test
980704	980705	KA3574G01	0.39	12	Pressure Build Up Test
980705	980705	KA3576G01	0.39	12	Pressure Build Up Test
980705	980706	KA3548A01	0.39	30	Interference test
980706	980706	KA3563G	0.39	30	Pressure Build Up Test
980706	980709	KA3590G01	1	27	Flow logging
980706	980709	KA3590G01	1	24	Pressure Build Up Test
980707	980707	KA3542G01	2	30	Flow logging with UCM probe
980707	980707	KA3542G02	2	30	Flow logging with UCM probe
980708	980708	KA3548A01	2	30	Flow logging with UCM probe
980708	980708	KA3554G01	2	30	Flow logging with UCM probe
980708	980708	KA3554G02	2	30	Flow logging with UCM probe
980708	980708	KA3566G01	2	30	Flow logging with UCM probe
980708	980708	KA3566G02	2	30	Flow logging with UCM probe
980708	980708	KA3590G01	2	30	Flow logging with UCM probe
980708	980708	KA3590G02	2	30	Flow logging with UCM probe
980708	980709	KA3593G	8	27	Flow logging
980708	980709	KA3593G	11	12	Pressure Build Up Test
980709	980709	KA3593G	27	30	Flow logging
980709	980709	KA3590G01	27	30	Flow logging
980709	980710	KA3576G01	1	10	Flow logging
980710	980710	KA3576G01	10	12	Flow logging
980713	980713	KA3574G01	1	12	Flow logging
980713	980713	KA3574G01	6	12	Flow logging
980713	980715	KA3566G01	1	28	Flow logging
980714	980714	KA3566G01	13	22	Pressure Build Up Test
980715	980715	KA3566G01	12	13	Flow logging
980715	980716	KA3566G02	1	27	Flow logging
980716	980716	KA3566G02	15	24	Pressure Build Up Test
980716	980716	KA3566G02	27	30	Flow logging
980717	980720	KA3557G	8	27	Flow logging
980720	980720	KA3539G	1	30	Flow logging
980720	980720	KA3557G	27	30	Flow logging
980720	980721	KA3554G02	1	24	Flow logging
980720	980724	KA3554G02	8	30	Pressure Build Up Test
980722	980723	KA3554G01	1	18	Flow logging
980723	980724	KA3554G01	18	31	Pressure Build Up Test
980727	980729	KA3542G02	1	30	Flow logging
980727	980729	KA3542G02	3	27	Pressure Build Up Test
980729	980729	KA3542G01	1	27	Flow logging
980730	980731	KA3542G01	12	30	Pressure Build Up Test
980731	980731	KA3542G01	27	30	Flow logging

From	To	Borehole	Borehole length (m) From	To	Type of test
980801	980802	KA3539G	8	27	Flow logging
980801	980802	KA3539G	11	24	Pressure Build Up Test
980802	980802	KA3539G	27	30	Flow logging
980804	980808	KA3548A01	5	27	Pressure Build Up Test
980804	980808	KA3548A01	0	27	Flow logging
980808	980808	KA3548A01	27	30	Flow logging
980901	980901	KI0025F02	2	204	Flow logging with UCM probe
980903	980903	KA3557G	2	30	Flow logging with UCM probe
980904	980904	KA3563G	2	30	Flow logging with UCM probe
980904	980904	KA3593G	2	30	Flow logging with UCM probe
980904	980904	KK0045G01	2	65	Flow logging with UCM probe
980908	980908	KZ0041G01			Flow logging
980909	980909	KZ0044B01	0.43	1.08	Flow logging
980909	980909	KZ0048B01	0.43	1.07	Flow logging
980909	981125	KZ0053B01	0.43	0.95	Flow logging
980909	980909	KZ0048A01	0.43	1.01	Flow logging
980909	980909	KZ0053A01	0.43	0.87	Flow logging
980909	980910	KI0025F02	28	203	Flow logging with thermal probe
980910	980910	KZ0057B01	0.43	0.97	Flow logging
980910	980910	KZ0061B01	0.43	0.95	Flow logging
980910	980910	KZ0061A01	0.43	0.99	Flow logging
980910	980910	KZ0057A01	0.43	1.02	Flow logging
980910	980913	KI0025F02	32.5	200	Flow logging with thermal probe
980914	980914	KA3510A	5	105	Flow logging with thermal probe
980914	980915	KA3510A	49.5	125	Flow logging with thermal probe
980914	980914	KZ0065G02	1	5.94	Flow logging
980914	980914	KZ0065B02	1	5.02	Flow logging
980914	980914	KZ0065A02	1	5.1	Flow logging
980915	980915	KZ0065G02			Flow logging
980915	980915	KZ0065G02	3	5.24	Flow logging
980915	980915	KZ0041A02			Flow logging
980915	980921	KZ0041B02			Flow logging
980915	980915	KZ0041G02			Flow logging
980916	980920	KA3510A	75	119	Flow logging with thermal probe
980917	980919	KA2598A	75	119	Flow logging with thermal probe
980917	980919	KA2598A	6	179	Flow logging with thermal probe
980921	980921	KZ0041B02	1.5	5.12	Flow logging
980923	980923	KZ0041A02	1.75	5.06	Flow logging
980923	980923	KZ0041B02	3.5	5.12	Flow logging
980923	980923	KZ0044A01	0.43	1.1	Flow logging
980923	980923	KZ0048G01	0.48	1.01	Flow logging
980923	980923	KZ0054G01	0.43	0.88	Flow logging
980923	980923	KZ0057G01	0.43	1.05	Flow logging
980924	980924	KXZRD7HR	1.21	8.09	Flow logging
980925	980925	KXZRD7HR	1.21	8.18	Flow logging
980929	981003	KI0025F	86	88	Dilution test
980929	981003	KI0023B	70.95	71.95	Dilution test
980930	980930	KI0025F02	73.3	77.3	Outflow test with constant flow
980930	980930	KI0025F02	73.3	77.3	Outflow test with constant flow
980930	981001	KI0025F02	73.3	77.3	Outflow test with constant pressure
981001	981001	KI0025F02	73.7	77.7	Pressure Build Up Test
981001	981002	KI0025F02	64.2	68.2	Outflow test with constant pressure

From	To	Borehole	Borehole length (m)		Type of test
			From	To	
981002	981004	KI0025F02	64.2	68.2	Outflow test with constant pressure
981004	981004	KI0025F02	64.2	68.2	Pressure Build Up Test
981006	981006	KZ0065I01	0.43	1.02	Flow logging
981006	981008	KG0048A01	0	54.69	Interference test
981007	981007	KZ0059G01	0.43	0.86	Flow logging
981008	981008	KXZB3	3	8.36	Flow logging
981008	981015	KG0048A01	5	53	Flow logging
981008	981016	KG0048A01	5	54.69	Pressure Build Up Test
981013	981013	KZ0057I01	0.43	1.15	Flow logging
981013	981013	KZ0061I01	0.43	0.99	Flow logging
981014	981014	KZ0052I01	0.43	1.04	Flow logging
981015	981015	KZ0048I01	0.43	1.05	Flow logging
981020	981021	KA3563G	8	27	Flow logging
981021	981021	KA3563G	27	30	Flow logging
981028	981030	KI0025F02	93.35	99.25	Dilution test
981028	981030	KI0025F02	73.3	77.25	Dilution test
981028	981030	KI0025F02	51.7	55.1	Dilution test
981029	981029	KI0023B	70.95	71.95	Interference test
981113	981113	KXP26BGR	7.18	7.68	Flow measurement
981113	981113	KXP27BGR	6.15	6.65	Flow measurement
981113	981113	KXP26BGR	1.48	6.68	Flow measurement
981113	981113	KXP26BGR	8.18	8.35	Flow measurement
981113	981113	KXP27BGR	7.15	8.61	Flow measurement
981113	981113	KXP27BGR	1.65	5.65	Flow measurement
981113	981113	KXP24BGR			Flow measurement
981113	981113	KXP25BGR			Flow measurement
981113	981113	KXP26BGR			Outflow test with constant pressure
981114	981114	KXP26BGR	7.18	7.68	Flow measurement
981116	981116	KXP26BGR	6.15	6.65	Pulse injection test
981116	981116	KXP26BGR	6.2	6.6	Pulse injection test
981117	981117	KXP26BGR			Flow measurement
981117	981117	KXP26BGR			Pulse injection test
981118	981118	KXP26BGR			Flow measurement
981118	981118	KXP26BGR	4	4.5	Pulse injection test
981118	981118	KXP27BGR	1.45	5.65	Pulse injection test
981119	981119	KXP26BGR			Flow measurement
981119	981119	KXP25BGR	3.8	4.3	Pulse injection test
981119	981119	KXP25BGR	2.8	3.3	Pulse injection test
981120	981120	KXP25BGR	3.23	3.73	Pulse injection test
981120	981120	KXP24BGR	3.9	4.5	Pulse injection test
981123	981124	KXP24BGR	2.9	3.4	Pulse injection test
981124	981124	KXP24BGR	3.6	4.5	Pulse injection test
981125	981125	KXP24BGR	3.25	3.75	Pulse injection test
981126	981126	KXP24BGR	2.1	2.6	Pulse injection test
981130	981201	KG0021A01	0	54.69	Interference test
981202	981215	KG0021A01	4	47	Flow logging
981202	981215	KG0021A01	7	46	Pressure Build Up Test
981216	990218	KA3579G	0.7	22.65	Pressure Build Up Test
981216	990217	KA3579G	1	12	Flow logging
981216	981217	KR0013B	7.05	16.94	Flow measurement

6 Results

6.1 General

Results from the measurements in surface boreholes and in the tunnel are presented in annually based diagram Appendices. Brief descriptions of the different variables are given in the following chapters. In some cases comments are given when data is missing or if the registration has a deviating appearance. Meteorological background data (precipitation, temperature and potential evapotranspiration) are also summarised in monthly and yearly values.

Due to failures in the mechanical or electronic equipment, data sometimes is missing for longer or shorter periods. This is not specifically commented on below. In Appendix 1, statistics on missing registrations for different reasons are summarised for each measuring point.

6.2 Groundwater levels

In most surface boreholes, there have been small changes in groundwater levels during 1998. In the main part of the borehole sections, the change over the year is within half a metre. In some boreholes there is a pronounced drawdown during the second part of October (see for example KAS12 in Appendix 2). This is probably an effect of the excavation of a niche in the assembly hall in the tunnel and the same response can be seen also in many tunnel boreholes.

Annual diagrams of groundwater levels are presented in Appendix 2. All levels in the diagrams are given as meters above sea level (local system). The local system on Äspö results in approximately 6 centimetres lower values than the national elevation system (RH70). In these diagrams, at most one data point per day and section is displayed. When registration is missing, manually levelled data, if available, are inserted.

The levels from all sections in one borehole are presented in the same diagram. The symbols used in the diagrams are:

The lowest section = Section 1 o o o o o o o o o o o
Section 2 + + + + + + + + + +
Section 3 × × × × × × × × × × × ×
Section 4 □ □ □ □ □ □ □ □ □ □ □
Section 5 ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇
Section 6 △ △ △ △ △ △ △ △ △ △

In the diagrams there are vertical lines with a text indicating changes in packer configuration (for example "Packers removed").

Sometimes it is difficult to differentiate registrations from the individual sections in the diagrams, but since the main purpose with this report is to present an overall view of the long term level changes, it was not found to be advantageous to separate sections from one borehole into different diagrams. More detailed groundwater level diagrams during test periods are presented in reports from the different tests.

In Figures 6-1 to 6-5 an overview over the 5-year period 1994-1998 for some of the boreholes is presented. The diagrams are of the same type as the annual diagrams described above. (For the sake of continuity the same boreholes that were presented in earlier annual reports have been chosen, even if data is missing for shorter or longer periods.)

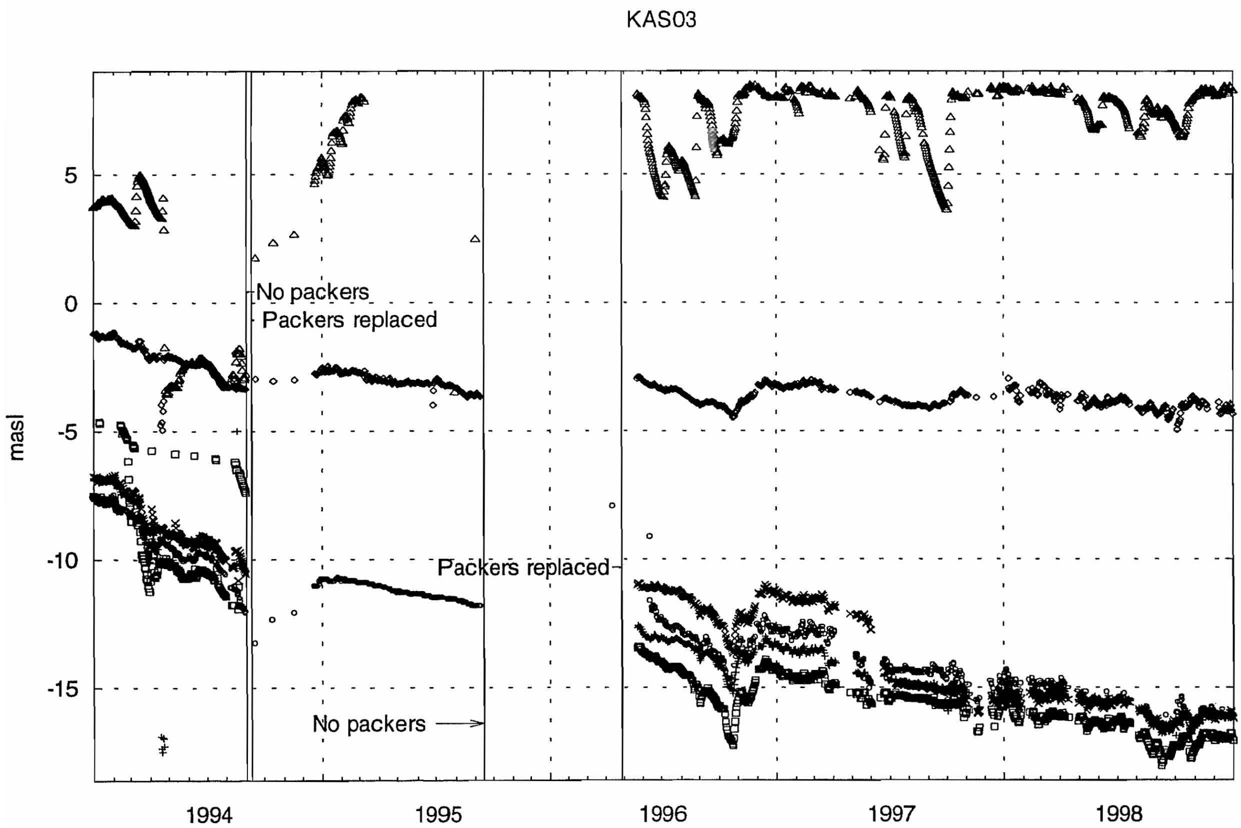


Figure 6-1 Groundwater levels in KAS03 on Äspö, 1994-1998.

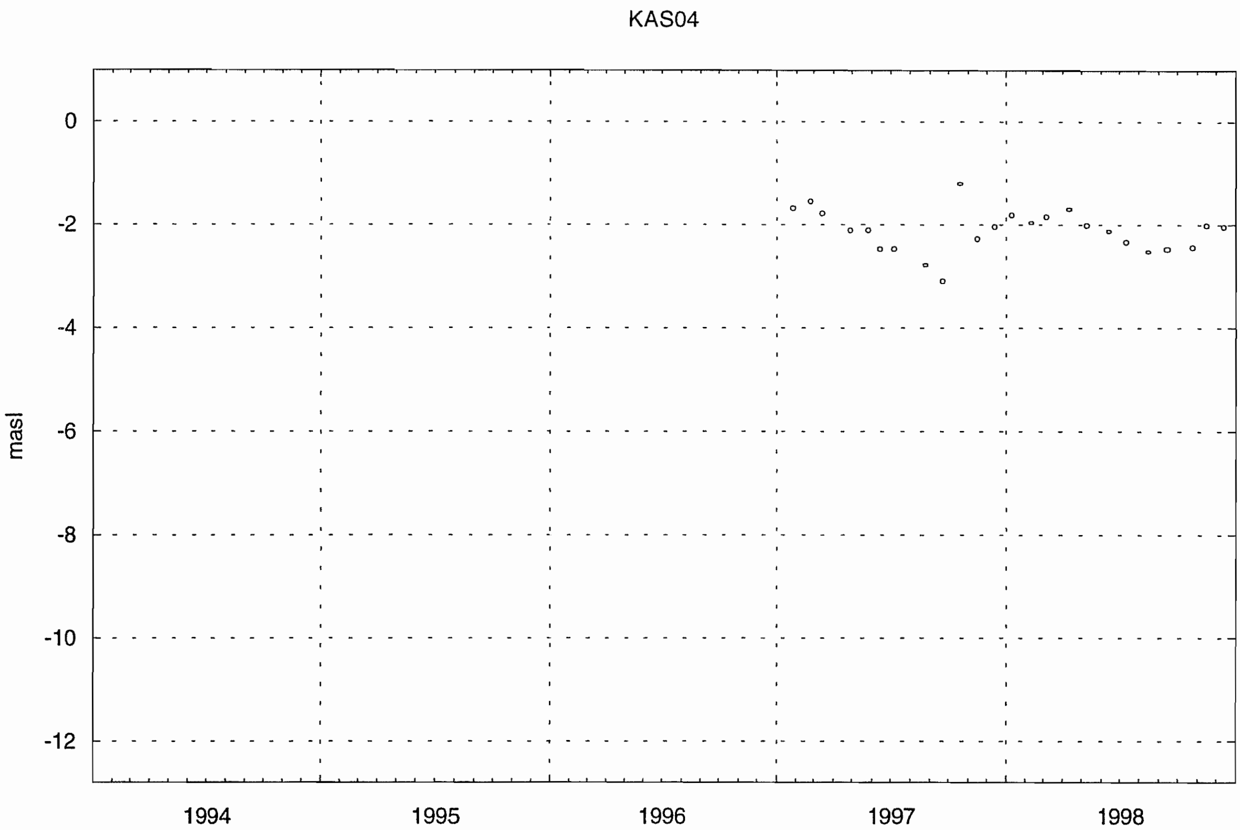


Figure 6-2 Groundwater levels in KAS04 on Äspö, 1994-1998.

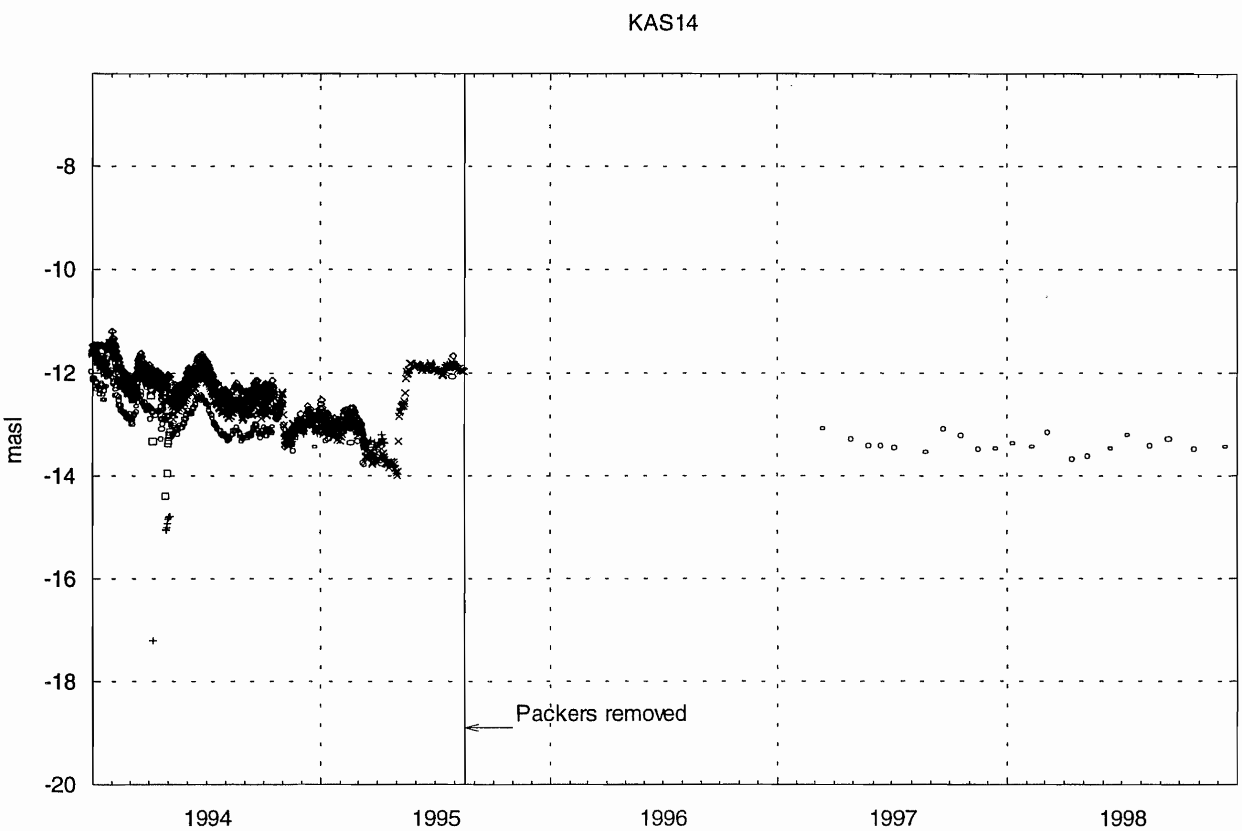


Figure 6-3 Groundwater levels in KAS14 on Äspö, 1994-1998.

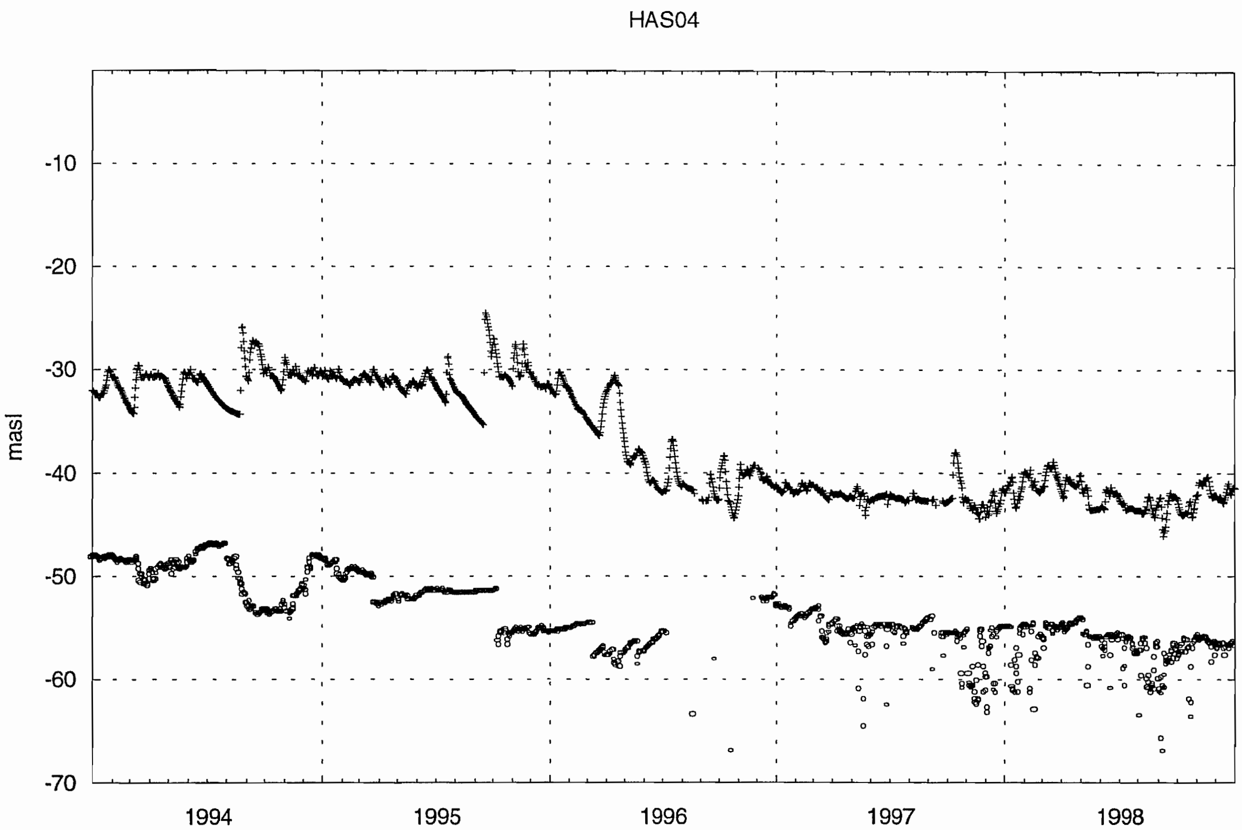


Figure 6-4 Groundwater levels in HAS04 on Äspö, 1994-1998.

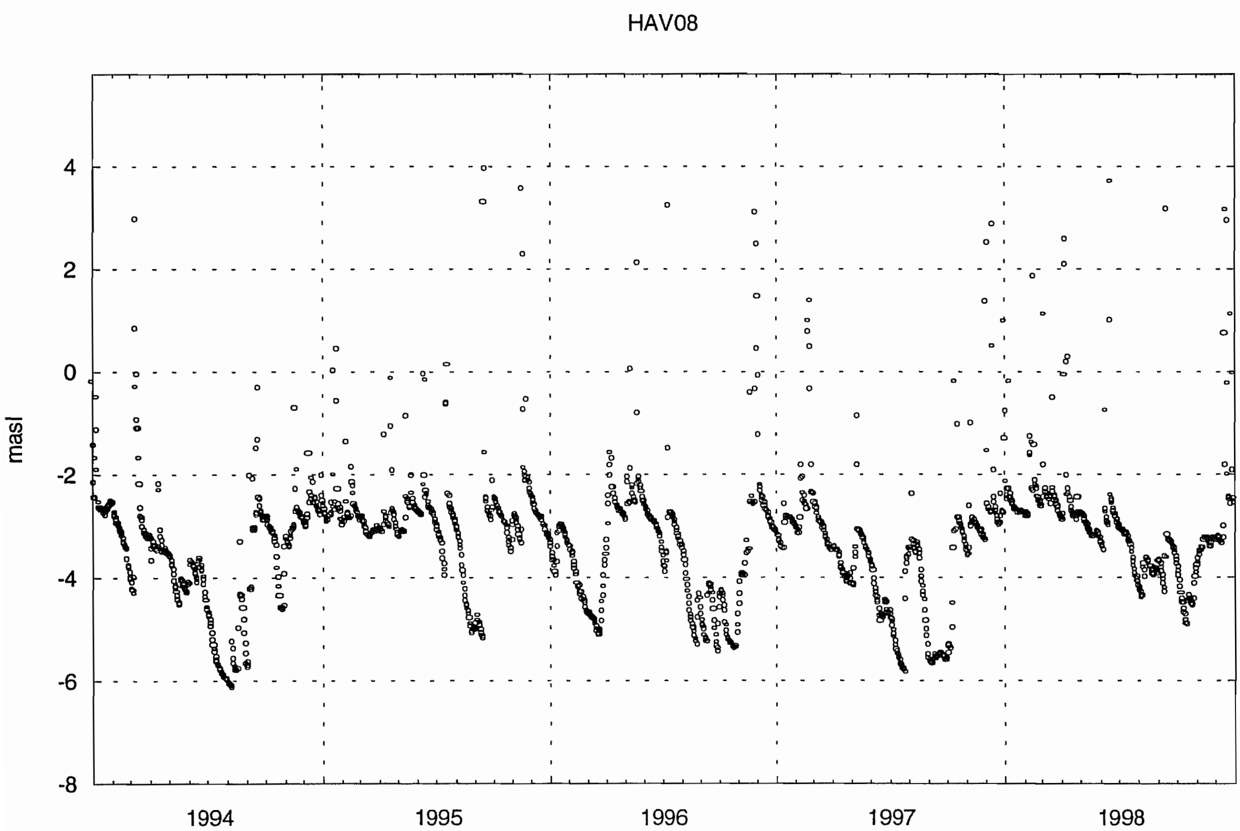


Figure 6-5 Groundwater levels in HAV08 on Ävrö, 1994-1998.

6.2.1 Comments on some of the diagrams

Remarks are given when the registration for some reason has a deviating appearance. When registration is missing manually levelled data, if available, are inserted.

Packers may deflate, due to leakage in the packer system, which can be difficult to discover. If one section in a borehole suddenly shows a pressure that is close to the pressure in a neighbouring section, the reason might be deflated packers.

Considerable draw-downs have complicated the manual levellings in many sections in boreholes at Äspö. Some sections have not been possible to level at all, while others have been difficult to level. In other sections, the actual groundwater level for some periods is uncertain while relative changes during short periods are fairly certain even during these periods.

To facilitate/enable manual levellings the PEM-packers has been removed in some sections. At the end of 1998 PEM-packers were installed in the following sections: KAS03 (1-5), KAS09 (1-4), KAS12 (1-4), KBH02 (3-5) and KLX01 (1,2).

The removal or deflation of a PEM-packer will dampen pressure changes due to water transport between the PEM-tube and the section. In sections with low hydraulic transmissivity this may cause the response to pressure changes to be very slow.

HAS13: After the considerable drawdown in June 1992 the groundwater level in section 2 responds quickly to rain. The reason for this is probably that the effective porosity in the aquifer communicating with the borehole is considerably lower below some meter above sea level than above. This means that a small amount of rain may cause a great and quick increase in the groundwater level.

HAV08: The groundwater level in this borehole responds quickly to rain.

KAS12: The pronounced drawdown in October is probably a result of the excavation of a niche in the assembly hall in the tunnel (this effect may also be seen in some other surface boreholes and in most tunnel boreholes).

KLX01: Since there were suspicions that some of the tubes connecting the borehole sections to the ground were clogged, airlift pumping was performed in the PEM-tubes on the 17^{th} of June. As a result the groundwater levels in sections 1 and 2 increased with 4 and 1 metre respectively. It can not be excluded that this increase is an effect of changed density in the tubes and therefore data before the pumping is preserved.

6.3 Electrical conductivity of the groundwater

Because of the poor calibration and other problems with the electrical conductivity sensors, one must be very careful when interpreting the diagrams in Appendix 3. The values are in most sections very uncertain. It is not advised to compare values from different sections.

The data from both sections in one borehole are presented in the same diagram. The symbols used in the diagrams are:

The lower section o o o o o o o o o o

The upper section + + + + + + + + +

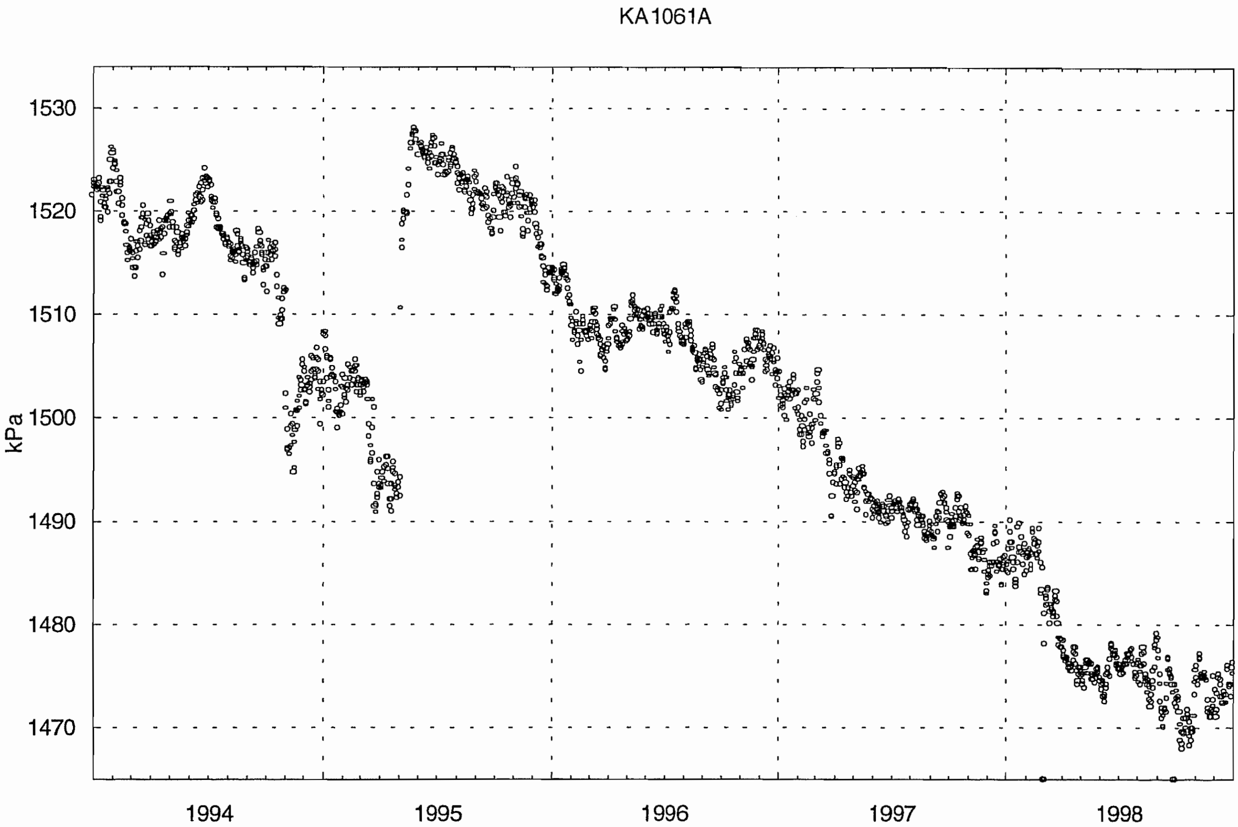
6.4 Ground water pressure in tunnel boreholes

In most boreholes down to a tunnel length of approximately 2000 metres, the pressure decreases between 10 and 40 kPa during 1998. Exceptions are HA1283B and HA1327B where the pressure drop is 70 and 80 kPa respectively and HA1960A where no pressure changes is observed over the year. Further down in the tunnel the main part of the boreholes shows slightly increasing pressures, or very small pressure changes. However, in boreholes KA2162B, KA3385A and SA2338 there are sections where the pressure has decreased 70-80 kPa.

A tracer test started in June 1997 (pumping in KXTT3:2) has influenced the pressure in a number of sections in boreholes KA3005A, KXTT1, KXTT2, KXTT3 and KXTT4. The test was terminated the 10th of December 1998 and a changed pump flow has caused a pronounced jump in the registrations in the end of May 1998.

Groundwater pressures from tunnel borehole sections are presented in Appendix 4. The same symbol convention as for surface boreholes is used (see section 6.2). If a borehole has more than 6 sections the symbols are repeated from section 7, meaning that section 7 has a ring, section 8 a plus and so on. In these cases sections 7 and greater (in number) are presented in a separate diagram. An exception is a 7th section in borehole KA2563A that is presented in the same diagram as sections 1 – 6; however, this is especially noted in the diagram. For tunnel boreholes, as for surface boreholes, section 1 means the innermost section, section 2 the next section towards the tunnel/surface and so on.

In Figures 6-6 to 6-8 an overview over the 5-year period 1994-1998 for some of the boreholes is presented. The diagrams are of the same type as the annual diagrams described above.



Figur 6-6 Groundwater pressure in tunnel borehole KA1061A, 1994-1998.

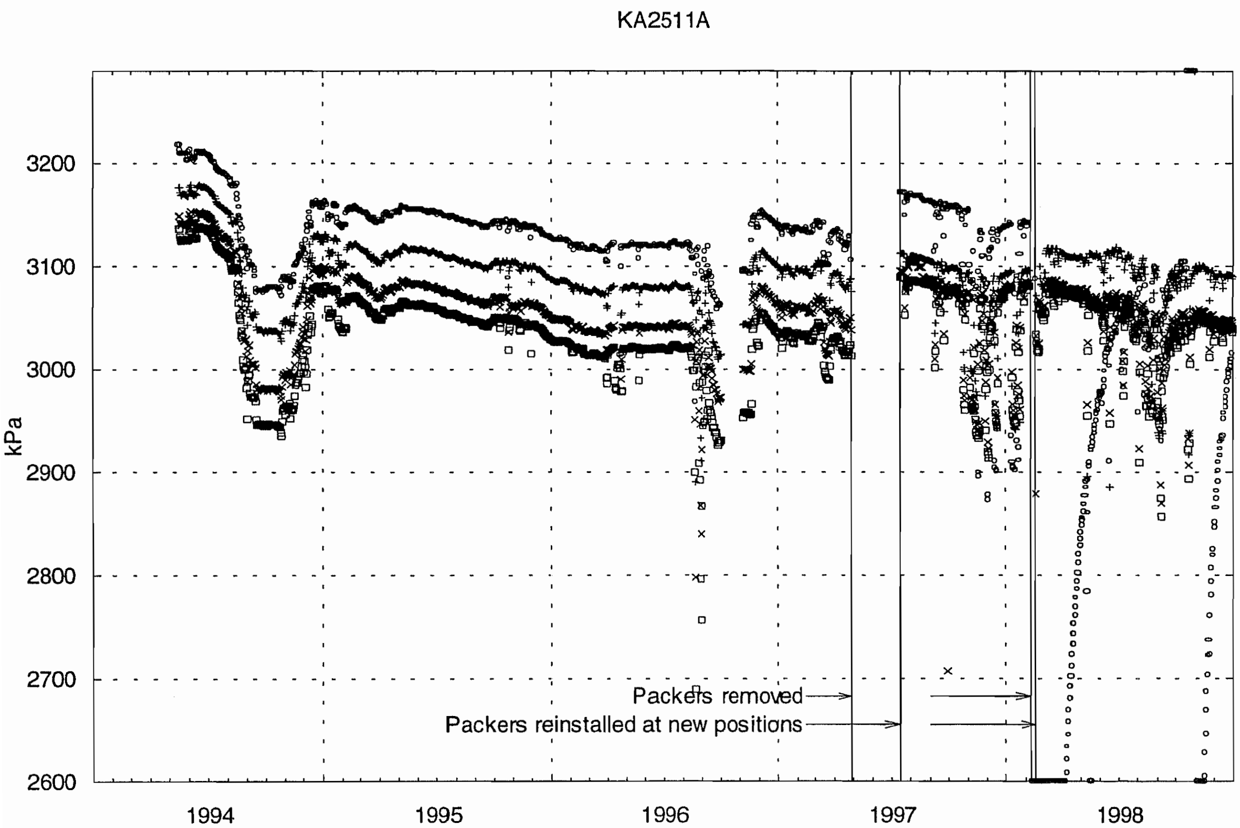


Figure 6-7 Groundwater pressure in tunnel borehole KA2511A, 1994-1998.

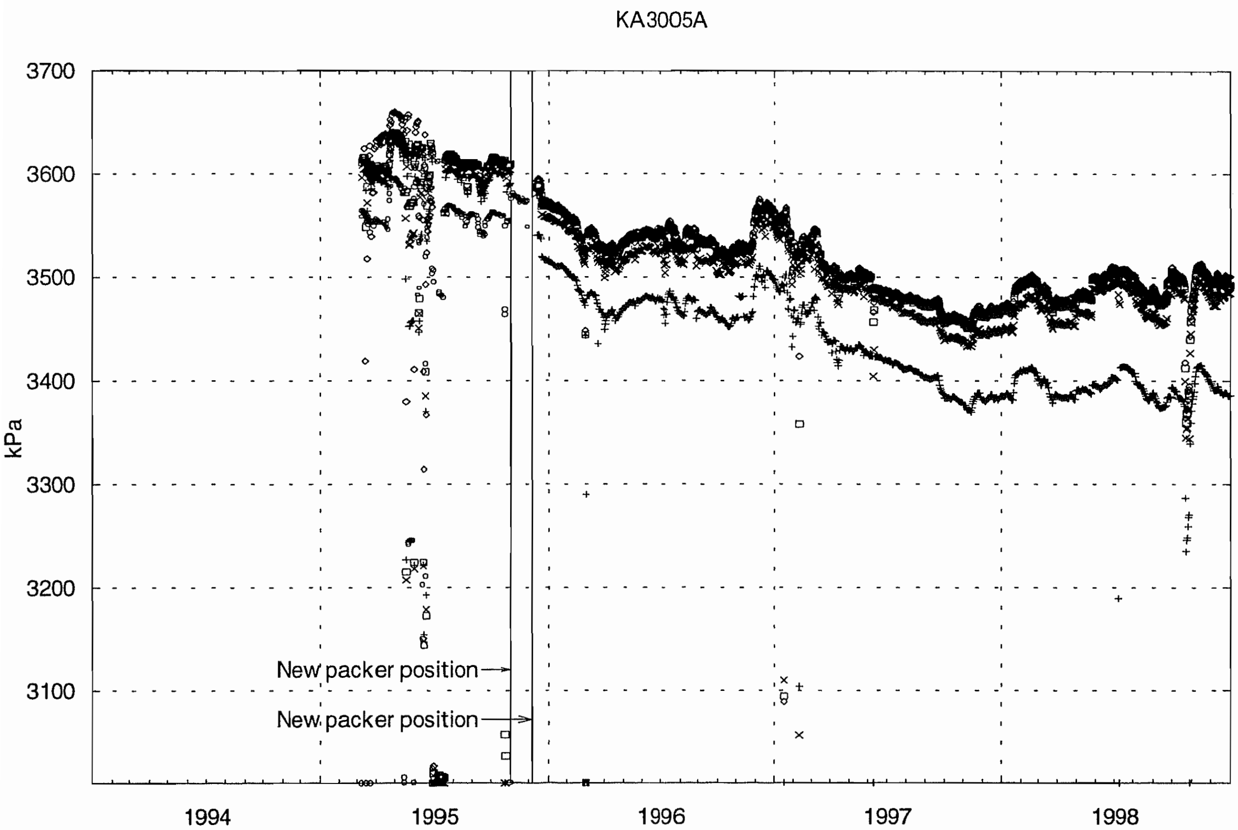


Figure 6-8 Groundwater pressure in tunnel borehole KA3005A, 1994-1998.

6.4.1 Comments on some of the diagrams

In most boreholes below approximately 1700 m tunnel length, a distinct drawdown occurs on the 21st October. A related recovery extends to the beginning of November. This is most certainly caused by the excavation, and the following grouting, of a niche in the assembly hall at approx. 3170 m tunnel length (also mentioned in section 6.2).

KA1754A: In August 1999, it was found that a valve on the packer line that should have been open was closed. Therefore, the packer between the two sections seems to have been deflated (at least partially) since beginning of May 1997. This has mainly affected the pressure in section two, which has been approximately ten kPa too low during the period.

KA2511A: Due to low transmissivity the pressure build-up in section 1 is very slow after the re-instrumentation in February and after the drawdown in October.

KA2563A: Due to low transmissivity the pressure build-up in sections 2 and 3 is slow after the re-instrumentation in February.

KA3067A: A prolonged delay time between valve opening and measurement in the hydraulic multiplexer in the beginning of March has caused a jump in the registration in section 1. This means that the pressure was influenced (more influenced) by a deviating pressure in the multiplexer before this date. (See section 4.4.3)

KA3385A: The packers were deflated between November 30 and December 15.

KA3385A: Data is missing from the end of February until the beginning of July due to a failing datalogger.

KA3510A: Due to low transmissivity the pressure build-up in section 1 is very slow after the instrumentation in October.

KI0023B: For periods the pressure in some sections is incorrect because of problems with the instrumentation.

KI0025F02: Due to low transmissivity the pressure build-up in section 4 is very slow after the instrumentation in October.

6.5 Water flow in tunnel

Water flow in the tunnel, measured at the gauging boxes at different tunnel lengths is presented in Appendix 5. The flow is integrated to daily values given as m^3/24 hours. The flow changes in most boxes are small over the year 1997.

For periods, the flow at some gauging boxes increases as a result of water added in connection to work using water in the tunnel, especially in the deepest part of the tunnel system, from the assembly hall and downward. Water from the assembly hall is collected by the gauging box MA3179G.

Data is missing for a period in April – May for MA1033G, depending on a leakage in the dam collecting the water to the gauging box, and for a period from April to September for MF0061 where the pressure transducer was out of order.

The flow in all gauging boxes is shown in Figure 6-9 as a mean during October - December 1998. For comparison purposes, also data for the corresponding period in 1995, 1996 and 1997 is illustrated. Although data is missing in some boxes for certain periods (especially during 1995 and 1996), the diagram gives realistic values because the flow has been fairly constant during the period presented. During 1998, the data for the period was complete for all the gauging boxes except for MA2699G where data was missing for three days in October.

Figure 6-9 shows that the mean flow for the comparison period October – December decreases from year to year at most locations. One exception is MA1033G and some measuring locations in the deeper parts of the tunnel system. The latter may be a result of new excavations of side tunnels plus the addition of fresh water in connection to these and other activities.

The gauging box MA1033G has been moved during the summer 1997 and placed in the same way as most other gauging boxes (described in chapter 4.5.1). Earlier the water was pumped from a sump beside the ditch crossing the tunnel to the box located on top of the sump at approx. 700 m. tunnel length. Leakage from sump beside the ditch can not be excluded. Furthermore, the value for 1996 is uncertain since data was missing for the period October – December. Because of the changed installation and the uncertainty due to missing data for 1996, one should be careful when interpreting the flow changes observed in MA1033G.

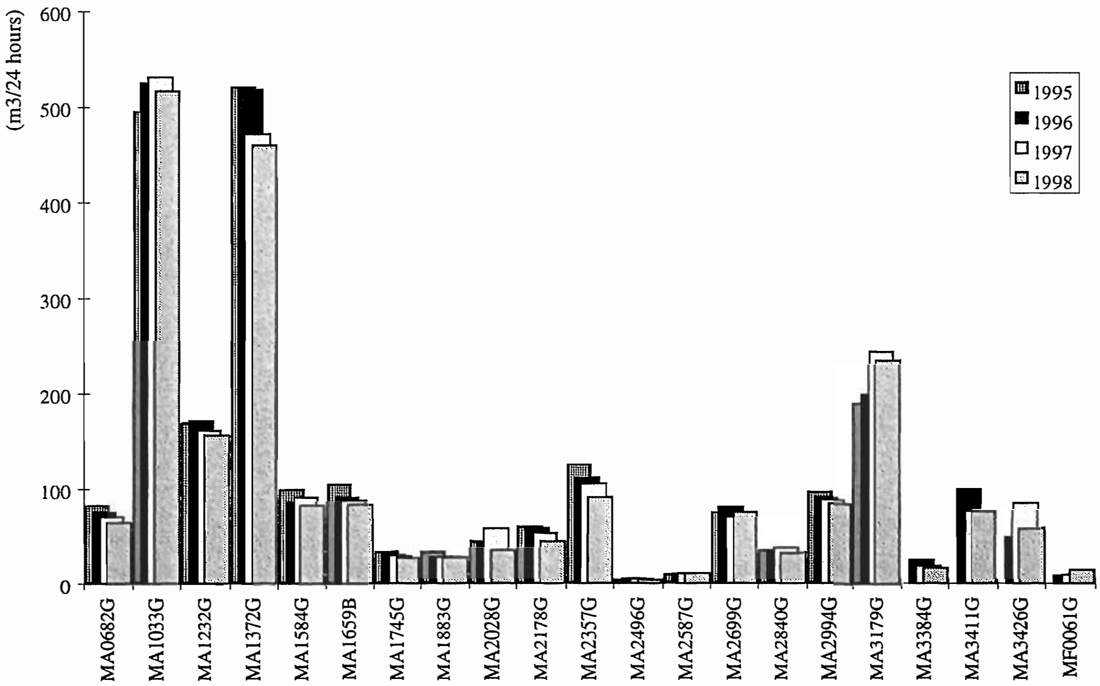


Figure 6-9 Water flow in all gauging boxes as a mean during October - December.

6.6 Water flow in tunnel pipes

The pumped flow out from the tunnel is very stable during 1998.

The mean daily flow of water in the pipes during October - December 1997 was 9.2 m^3 into the tunnel and 2268 m^3 pumped out from the tunnel. The figures for the last four years are found in Table 6-1

Table 6-1 Water flow in tunnel pipes, October - December.

Year	Water in (m^3/24 hours)	Water out (m^3/24 hours)
1995	4.4	2479
1996	9.6	2438
1997	11.0	2393
1998	9.2	2268

The flow of water pumped out from the tunnel and water flow in pipes into the tunnel are presented in Appendix 6 as integrated daily values given in m^3/24 hours. Data on pumped out water is missing in August 4 – 18, depending on a defect transmitter. For four days in the end of August a malfunctioning logger caused a drop out of data for both incoming and pumped out water.

6.7 Electrical conductivity of tunnel water

Electrical conductivity of tunnel water has been measured in eight gauging boxes for flow measurements, at one locations on the discharge pipe leading water from the gauging boxes to one of the sumps, and in two of the sumps (see section 4.7).

The same electrical conductivity meter is used for periods in the four gauging boxes MA3384G, MA3411G, MA3426G, MF0061G and in the sump PG5, all in the deepest part of the tunnel system.

The results, one data point per day, are presented in Appendix 7.

6.8 Levels of the Baltic Sea

The sea level varies in the approximate range -0.5 - +0.5 m.a.s.l. during the year. Sea levels are adjusted to the national elevation system (RH70), which gives approximately 6 centimetres higher values than the local system on Äspö.

On some occasions, there are very fast level changes. This happens when weather conditions, i.e. wind direction and air pressure, changes rapidly.

Hourly values of the sea level in Oskarshamn are presented in a diagram in Appendix 8.

6.9 Precipitation

Monthly precipitation at the SMHI-station in Oskarshamn (see section 4.10.1) for 1998, as well as monthly mean for the period 1961-1990 and yearly values are presented in Figures 6-10 and 6-11. All precipitation values are measured values without any corrections. A diagram of daily totals is shown in Appendix 9.

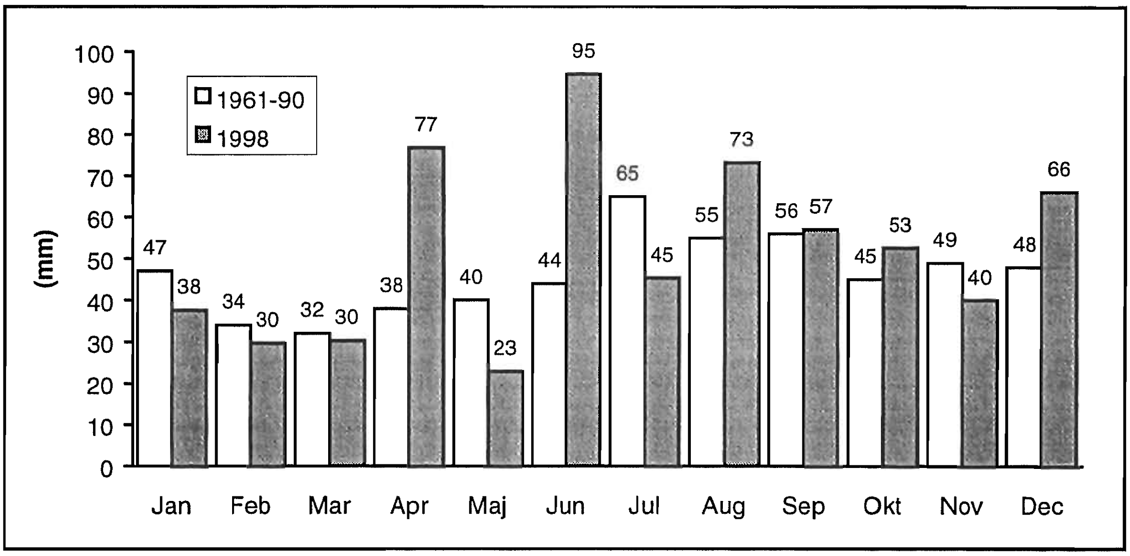


Figure 6-10 Precipitation at Oskarshamn. Monthly values 1998 and monthly means 1961 – 1990.

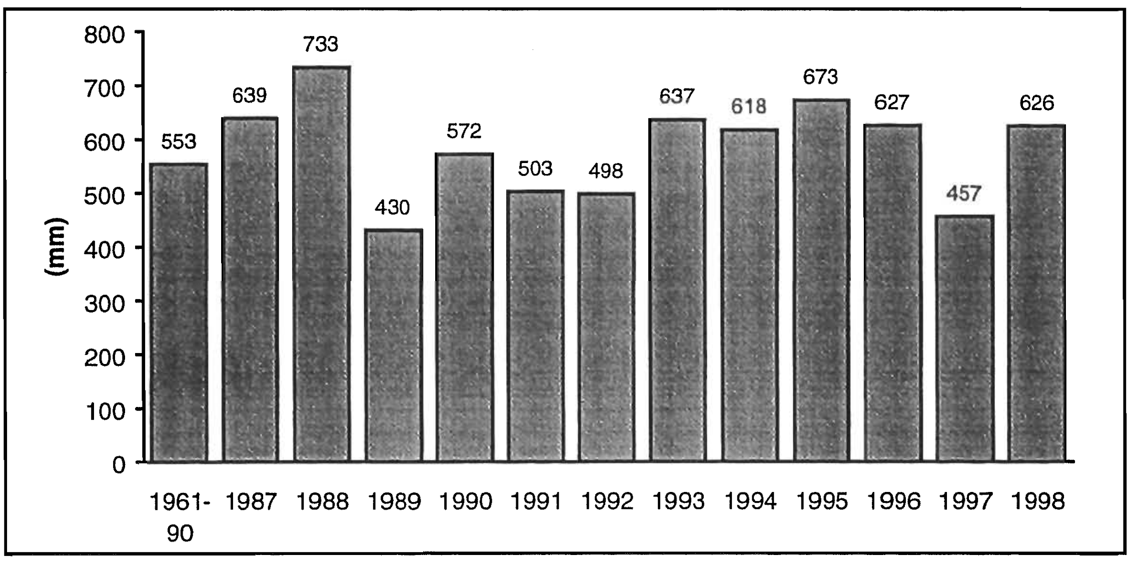


Figure 6-11 Precipitation at Oskarshamn. Yearly values 1987 - 1998 and yearly mean for the period 1961 - 1990.

6.10 Air temperature

Monthly mean temperature at the SMHI-station in Oskarshamn (see section 4.10.2) for 1998, as well as monthly mean for the period 1961-1990 and yearly values are presented in Figures 6-12 and 6-13. The daily mean temperatures during 1998 is demonstrated in Appendix 10.

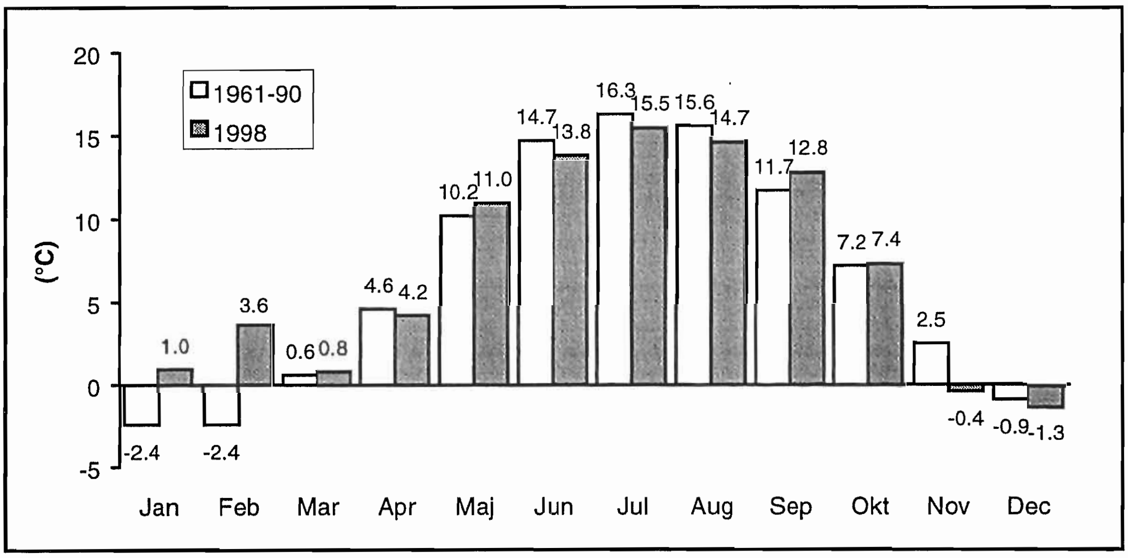


Figure 6-12 Temperature at Oskarshamn. Monthly values 1998 and monthly means 1961 – 1990

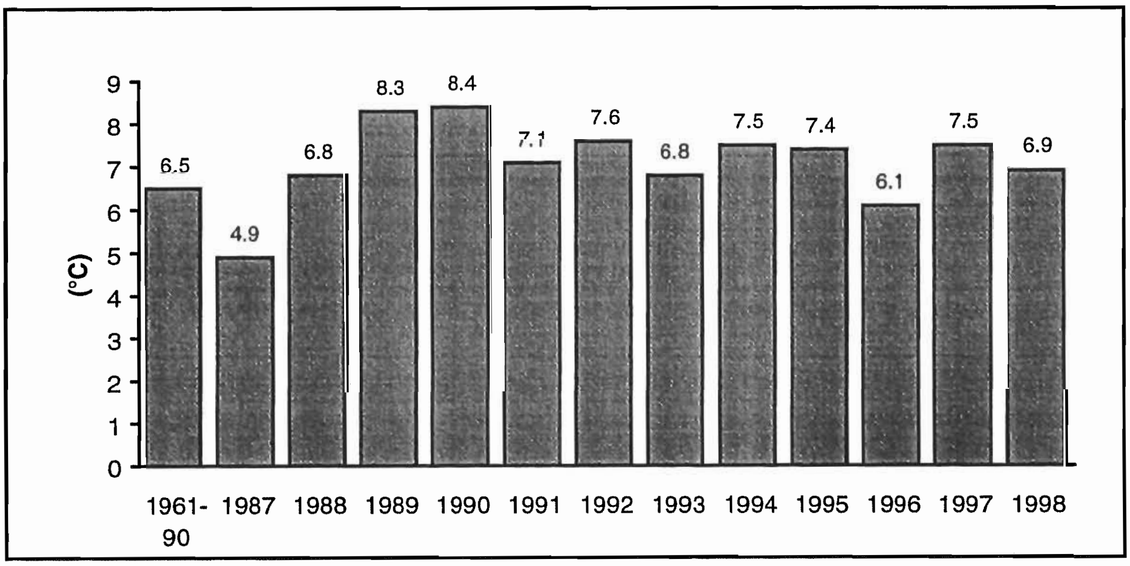


Figure 6-13 Temperature at Oskarshamn. Yearly values 1987 - 1998 and yearly mean for the period 1961 - 1990.

6.11 Potential evapotranspiration

The daily amount of potential evapotranspiration (see section 4.10.3) is presented in diagrams in Appendix 11. Monthly and yearly amounts are presented in Figures 6-14 and 6-15. Since evaporation is not normally calculated by the SMHI, there are no mean values for the period 1931-1990 available. Due to changes of the origin of the involved variables (see section 4.10.3), the calculated potential evapotranspiration seems to be considerably lower from August 1995 and onwards.

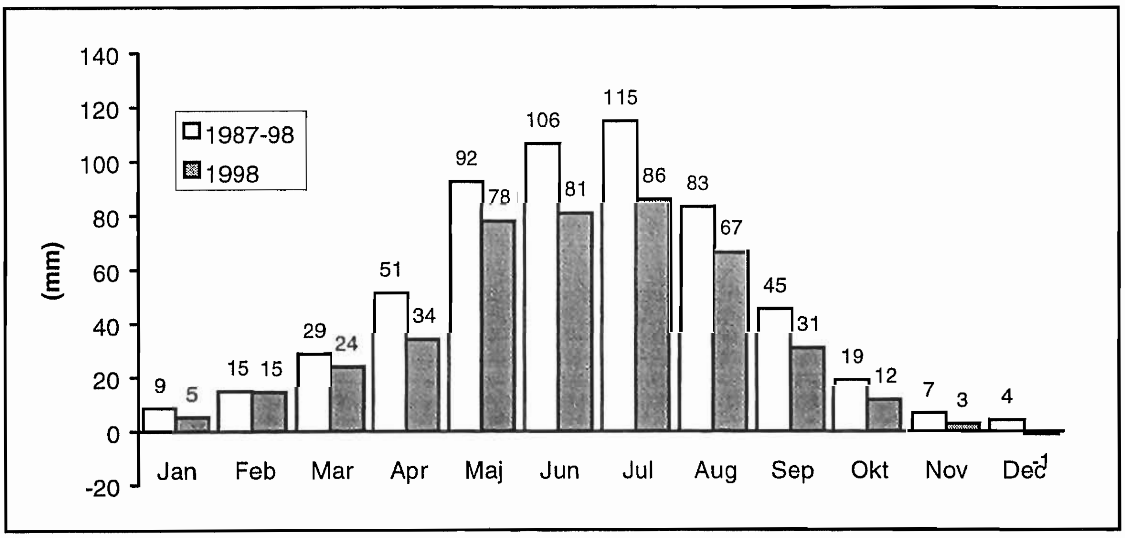


Figure 6-14 Potential evapotranspiration. Monthly values for Gladhammar 1998 and monthly means 1987 - 1998 (an average from Gladhammar and Ölands Norra Udde is used before 1 of August 1995).

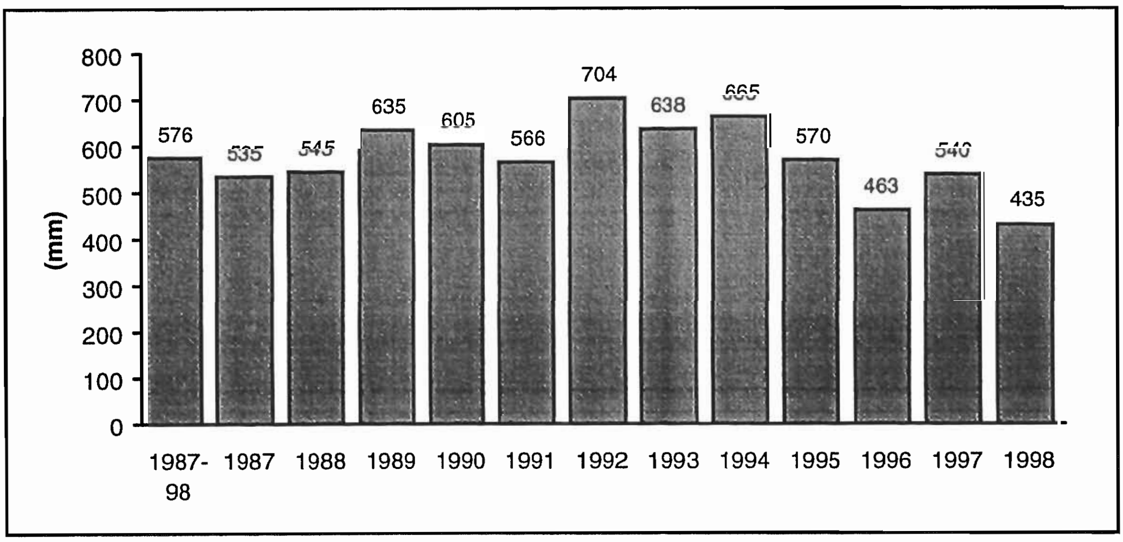


Figure 6-15 Potential evapotranspiration as average from Gladhammar and Ölands Norra Udde (only Gladhammar from 1 of August 1995). Yearly values 1987 - 1998 and yearly mean for the period 1987 - 1998.

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Appendices

Appendix 1: Statistics on missing data

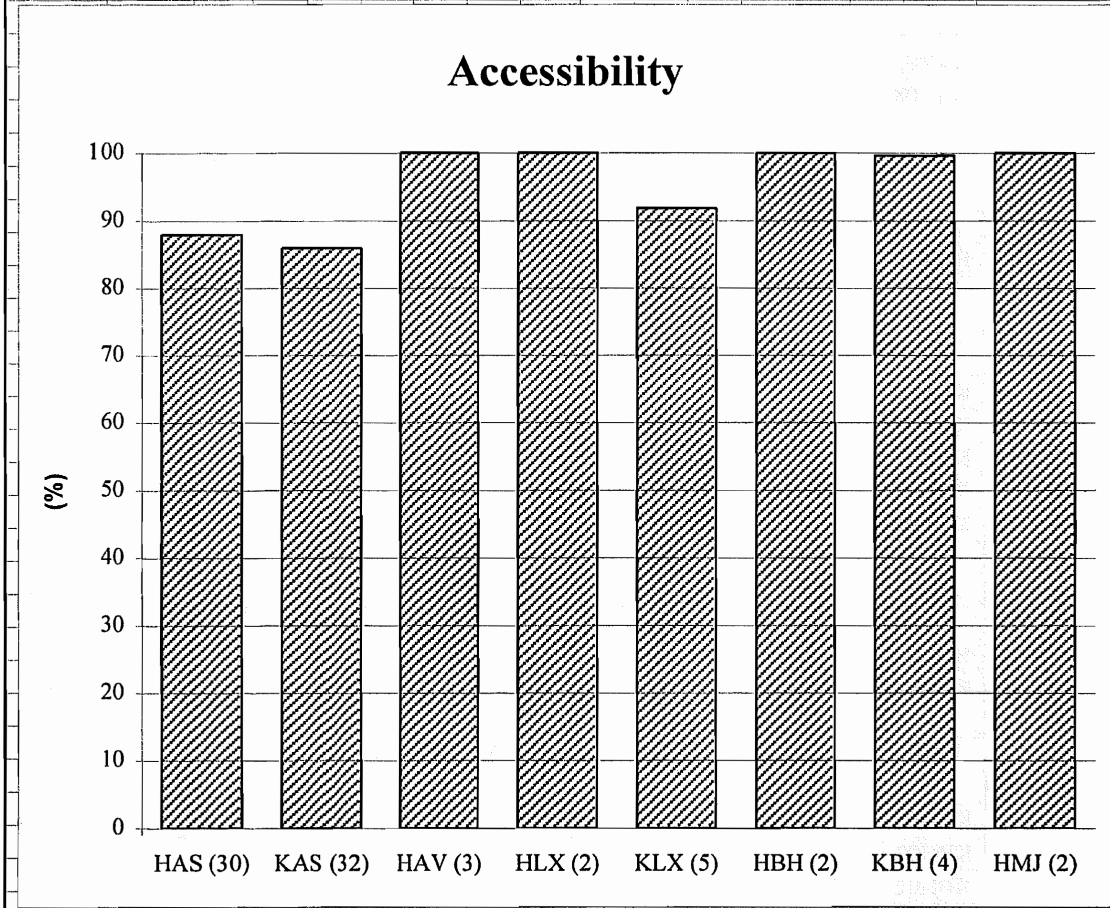
Äspö Hard Rock Laboratory	First date for statistics:	1998-01-01
Groundwater Level Program	Last date for statistics:	1998-12-31
Error statistics	Latest calibration date:	1999-05-17
	No of days in period:	365

Borehole	Section	Duration of error (days)														Accessibility
		TG	**M**	**KOM**	**I**	**U**	**B**	**L**	**Å**	**ML**	**OP**	**G**	**K**	**?**	Sum	(%)
HAS01	1														0	100
HAS02	1														0	100
HAS03	1						258								258	29
HAS04	1														0	100
HAS04	2														0	100
HAS05	1														0	100
HAS06	1														0	100
HAS06	2														0	100
HAS07	1	176													176	52
HAS08	1														0	100
HAS09	1														0	100
HAS10	1														0	100
HAS11	1						297								297	19
HAS11	2						143								143	61
HAS12	1														0	100
HAS13	1			10											10	97
HAS13	2			10						17					27	93
HAS14	1														0	100
HAS15	1			7											7	98
HAS15	2			7											7	98
HAS16	1													6	6	98
HAS16	2	11													11	97
HAS17	1	81													81	78
HAS17	2	191								84					275	25
HAS18	1														0	100
HAS19	1			9											9	98
HAS19	2			9											9	98
HAS20	1														0	100
HAS20	2														0	100
HAS21	1														0	100
HAS		459	0	52	0	0	698	0	0	101	0	0	0	6	1316	88

Borehole	Section	Duration of error (days)														Accessibility
		TG	**M**	**KOM**	**I**	**U**	**B**	**L**	**Å**	**ML**	**OP**	**G**	**K**	**?**	Sum	(%)
KAS01	1														0	100
KAS02	1							365							365	0
KAS02	2							365							365	0
KAS02	3														0	100
KAS02	4							365							365	0
KAS02	5														0	100
KAS02	6														0	100
KAS03	1	62		58											120	67
KAS03	2			58											58	84
KAS03	3			58											58	84
KAS03	4			58											58	84
KAS03	5	8		58											66	82
KAS03	6			58											58	84
KAS04	1														0	100
KAS07	1														0	100
KAS09	1			15										5	20	95
KAS09	2			15											15	96
KAS09	3			15											15	96
KAS09	4			15											15	96
KAS09	5			15											15	96
KAS10	1			15											15	96
KAS11	1														0	100
KAS12	1														0	100
KAS12	2														0	100
KAS12	3														0	100
KAS12	4														0	100
KAS12	5														0	100
KAS14	1														0	100
KAS16	1														0	100
KAS16	2			7										4	11	97
KAS16	3			7										4	11	97
KAS16	4			7										4	11	97
KAS		70	0	459	0	0	0	1095	0	0	0	0	0	17	1641	86

Borehole	Section	Duration of error (days)														Accessibility
		TG	M	KOM	I	U	B	L	Å	ML	OP	G	K	?	Sum	(%)
HAV02	1														0	100
HAV05	1														0	100
HAV08	1														0	100
HAV		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
HLX04	1														0	100
HLX05	1														0	100
HLX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
KLX01	1														0	100
KLX01	2	76													76	79
KLX01	3										36				36	90
KLX01	4										36				36	90
KLX01	5														0	100
KLX		76	0	0	0	0	0	0	0	0	72	0	0	0	148	92
HBH04	1														0	100
HBH04	2														0	100
HBH		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
KBH02	3														0	100
KBH02	4														0	100
KBH02	5														0	100
KBH02	6	5													5	99
KBH		5	0	0	0	0	0	0	0	0	0	0	0	0	5	100
HMJ01	1														0	100
HMJ01	2														0	100
HMJ		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
							SUMMARY									
HAS (30)		459	0	52	0	0	698	0	0	101	0	0	0	6	1316	88
KAS (32)		70	0	459	0	0	0	1095	0	0	0	0	0	17	1641	86
HAV (3)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
HLX (2)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
KLX (5)		76	0	0	0	0	0	0	0	0	72	0	0	0	148	92
HBH (2)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
KBH (4)		5	0	0	0	0	0	0	0	0	0	0	0	0	5	100
HMJ (2)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
TOTAL (80)		20%	0%	16%	0%	0%	22%	35%	0%	3%	2%	0%	0%	1%	100%	89

Borehole	Section	Duration of error (days)													Accessibility
		TG	M	KOM	I	U	B	L	Å	ML	OP	G	K	?	Sum	(%)



ERROR CODES

TG:	Failing pressure transducer
M:	Leakage in the PEM-packer system leading to wrong level registration
KOM:	Failure in the communication with on-line loggers
I:	Communication tube clogged
U:	Ground water level below pressure transducer
B:	Failure in datalogger Borre
L:	Levellings were not possible to perform
Å:	Failure in lightning protector
ML:	Leakage in the packer system
OP:	Mistake by the operator leading to a break in registration
O:	Reinstrumentation
K:	Broken signal cable
?:	Unknown error
G:	Failure in datalogger Grund
V:	Failure in power supply
Ö:	Misc. errors
TST:	Registration broken due to other tests

Äspö Hard Rock Laboratory
Monitoring in tunnel
Error statistics

First date for statistics:	98-01-01
Last date for statistics:	98-12-31
Latest calibration date:	99-08-20
No of days in period:	365

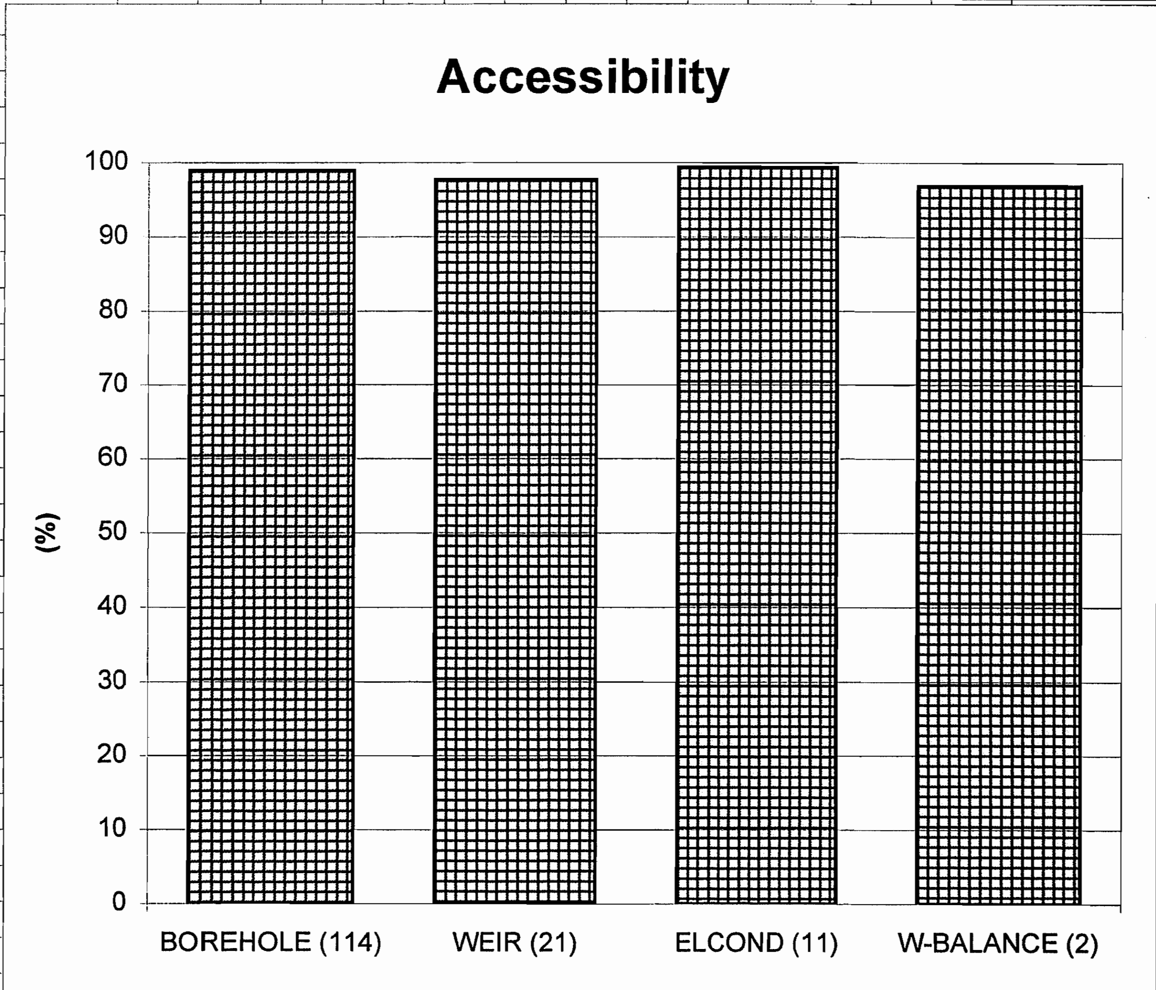
Idcode	Sec.	Duration of error (days)													Accessibility
		G	K	OP	TST	V	O	L	B	ML	S	W	?	Sum	(%)
HA1273A	1													0	100
HA1278A	1													0	100
HA1279A	1													0	100
HA1283B	1													0	100
HA1327B	1													0	100
HA1330B	1													0	100
HA1960A	1													0	100
KA1061A	1													0	100
KA1131B	1													0	100
KA1751A	1													0	100
KA1751A	2													0	100
KA1751A	3													0	100
KA1754A	1													0	100
KA1754A	2													0	100
KA1755A	1													0	100
KA1755A	2													0	100
KA1755A	3													0	100
KA1755A	4													0	100
KA2048B	1					53				8				61	83
KA2048B	2					32				8				40	89
KA2048B	3					32				8				40	89
KA2048B	4					53				8				61	83
KA2050A	1													0	100
KA2050A	2													0	100
KA2050A	3													0	100
KA2162B	1													0	100
KA2162B	2													0	100
KA2162B	3													0	100
KA2162B	4													0	100
KA2511A	1						9							9	98
KA2511A	2						9							9	98
KA2511A	3						9							9	98
KA2511A	4						9							9	98
KA2511A	5						9							9	98
KA2511A	6													0	100
KA2563A	1						7							7	98
KA2563A	2						7							7	98
KA2563A	3						7							7	98
KA2563A	4						7							7	98
KA2563A	5						7							7	98
KA2563A	6						7							7	98
KA2563A	7						7							7	98
KA2858A	2					8								8	98
KA2862A	1													0	100
KA3005A	2													0	100
KA3005A	3													0	100
KA3005A	4													0	100
KA3005A	5													0	100
KA3010A	2													0	100

Idcode	Sec.	Duration of error (days)													Accessibility
		G	K	OP	TST	V	O	L	B	ML	S	W	?	Sum	(%)
KA3067A	1													0	100
KA3067A	2													0	100
KA3067A	3													0	100
KA3067A	4													0	100
KA3105A	1													0	100
KA3105A	2													0	100
KA3105A	3													0	100
KA3105A	4													0	100
KA3105A	5													0	100
KA3110A	1													0	100
KA3110A	2													0	100
KA3385A	1	15												15	96
KA3385A	2													0	100
KA3510A	1													0	100
KA3510A	2													0	100
KA3510A	3													0	100
KF0051A	1												15	15	96
KF0051A	2												15	15	96
KF0051A	3												15	15	96
KF0051A	4												15	15	96
KI0023B	1													0	100
KI0023B	2													0	100
KI0023B	3													0	100
KI0023B	4													0	100
KI0023B	5													0	100
KI0023B	6													0	100
KI0023B	7													0	100
KI0023B	8													0	100
KI0023B	9													0	100
KI0025F	1						8							8	98
KI0025F	2						8							8	98
KI0025F	3						8							8	98
KI0025F	4						8							8	98
KI0025F	5						8							8	98
KI0025F	6						8							8	98
KI25F2	1													0	100
KI25F2	2													0	100
KI25F2	3													0	100
KI25F2	4													0	100
KI25F2	5													0	100
KI25F2	6													0	100
KI25F2	7													0	100
KI25F2	8													0	100
KI25F2	9													0	100
KI25F2	10													0	100
KXTT1	1													0	100
KXTT1	2													0	100
KXTT1	3													0	100
KXTT1	4					11								11	97
KXTT2	1													0	100
KXTT2	2													0	100
KXTT2	3													0	100
KXTT2	4													0	100

Idcode	Sec.	Duration of error (days)													Accessibility
		G	K	OP	TST	V	O	L	B	ML	S	W	?	Sum	(%)
KXTT2	5													0	100
KXTT3	1													0	100
KXTT3	2													0	100
KXTT3	3													0	100
KXTT3	4													0	100
KXTT4	1													0	100
KXTT4	2													0	100
KXTT4	3													0	100
KXTT4	4													0	100
KXTT4	5													0	100
SA2142A	1													0	100
SA2338A	1												11	11	97
BOREHOLE		**15**	**0**	**0**	**0**	**189**	**142**	**0**	**0**	**32**	**0**	**0**	**71**	**449**	**99**

Idcode	Sec.	Duration of error (days)													Accessibility
		G	K	OP	TST	V	O	L	B	ML	S	W	?	Sum	(%)
MA0682G									4					4	99
MA1033G								27						27	93
MA1232G														0	100
MA1372G														0	100
MA1584G														0	100
MA1659G														0	100
MA1745G														0	100
MA1883G														0	100
MA2028G														0	100
MA2178G														0	100
MA2357G														0	100
MA2496G														0	100
MA2587G														0	100
MA2699G													4	4	99
MA2840G														0	100
MA2994G														0	100
MA3179G														0	100
MA3384G														0	100
MA3411G														0	100
MA3426G														0	100
MF0061G		146												146	60
Weir		**146**	**0**	**0**	**0**	**0**	**0**	**27**	**4**	**0**	**0**	**0**	**4**	**181**	**98**
EA0682G									4					4	99
EA1584T														0	100
EA1659B														0	100
EA2496T														0	100
EA2587G			8											8	98
EA3179G														0	100
EA3384G														0	100
EA3411G														0	100
EA3426G														0	100
EF0061G									12					12	97
EPG5														0	100
ELCOND		**0**	**8**	**0**	**0**	**0**	**0**	**0**	**16**	**0**	**0**	**0**	**0**	**24**	**99**
QA0690I									4					4	99
QA0687O		15							4					19	95
W-BALANCE		**15**	**0**	**0**	**0**	**0**	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**23**	**97**

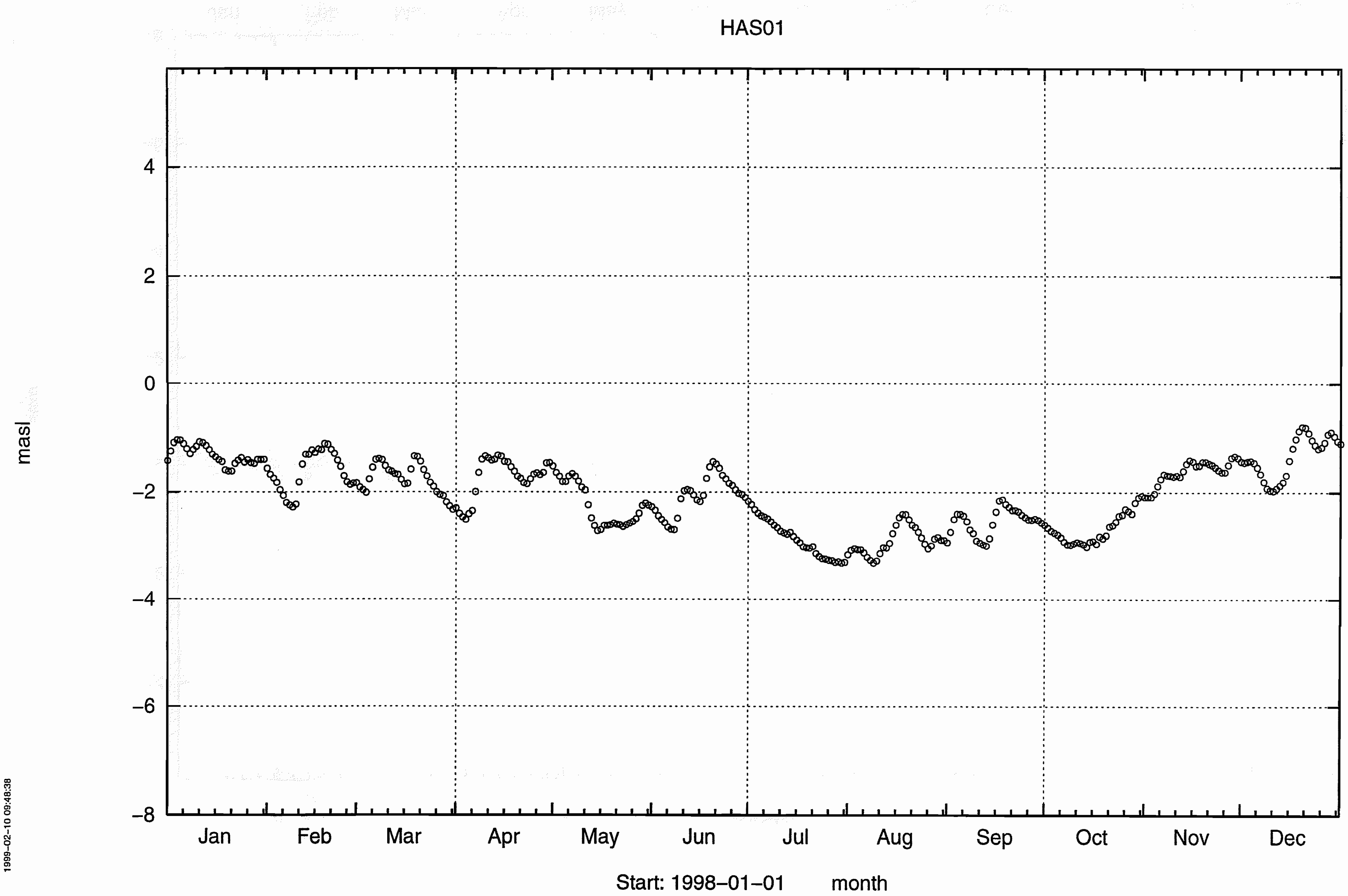
Idcode	Sec.	Duration of error (days)													Accessibility
		G	K	OP	TST	V	O	L	B	ML	S	W	?	Sum	(%)
							SUMMARY								
BOREHOLE (114)		15	0	0	0	189	142	0	0	32	0	0	71	449	99
WEIR (21)		146	0	0	0	0	0	27	4	0	0	0	4	181	98
ELCOND (11)		0	8	0	0	0	0	0	16	0	0	0	0	24	99
W-BALANCE (2)		15	0	0	0	0	0	0	8	0	0	0	0	23	97
TOTAL		26%	1%	0%	0%	28%	21%	4%	4%	5%	0%	0%	11%	100%	99

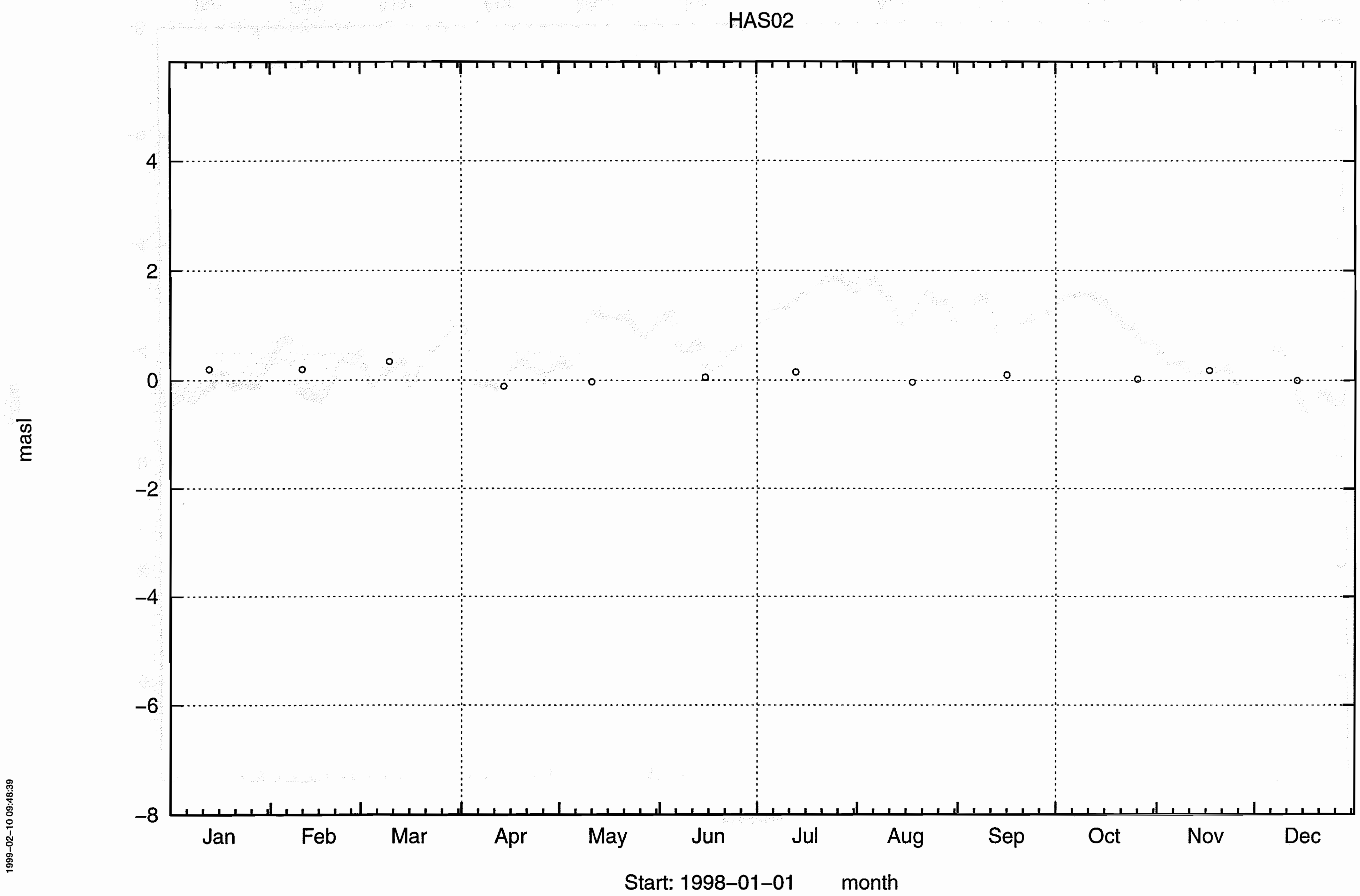


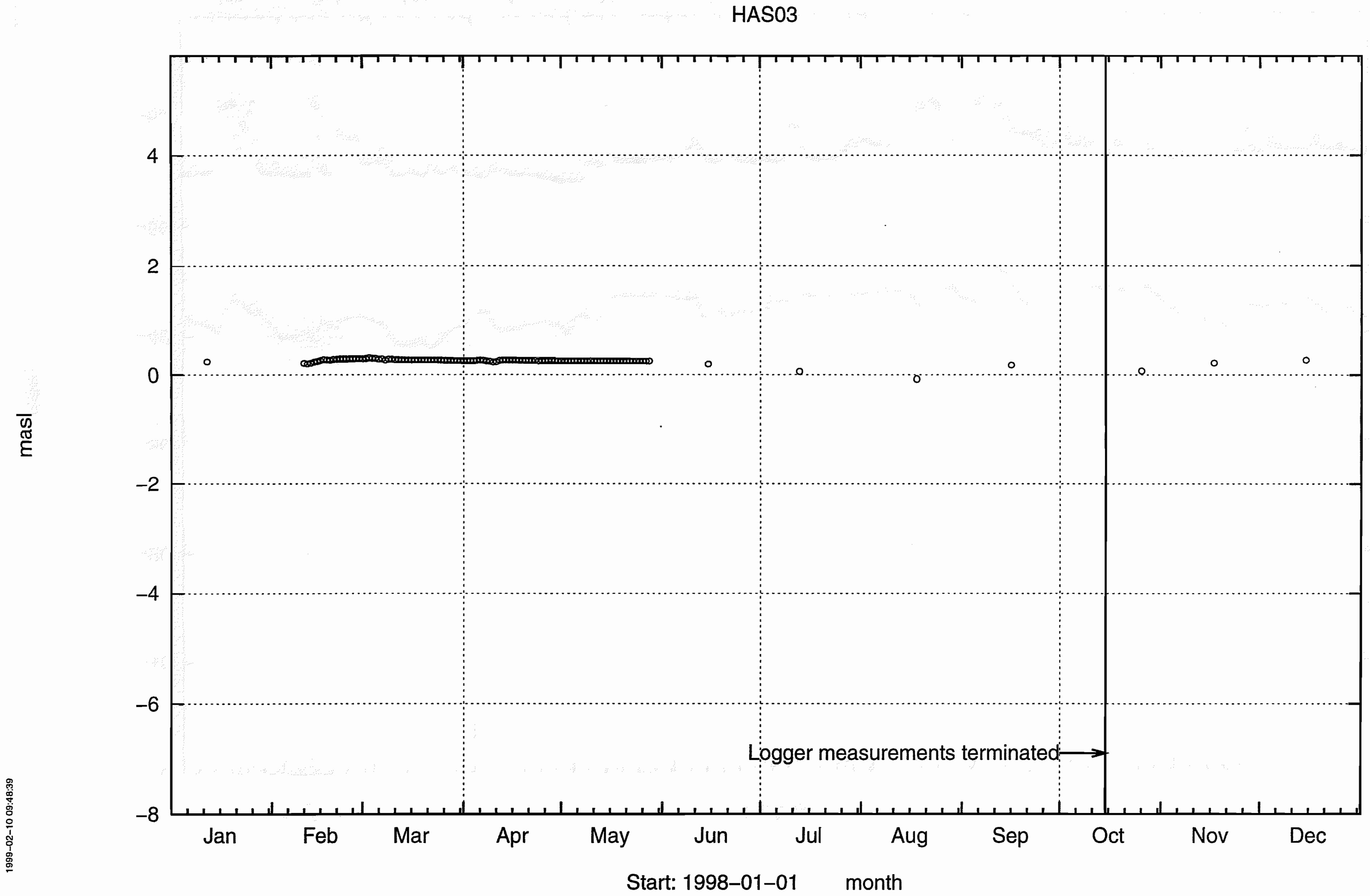
ERROR CODES

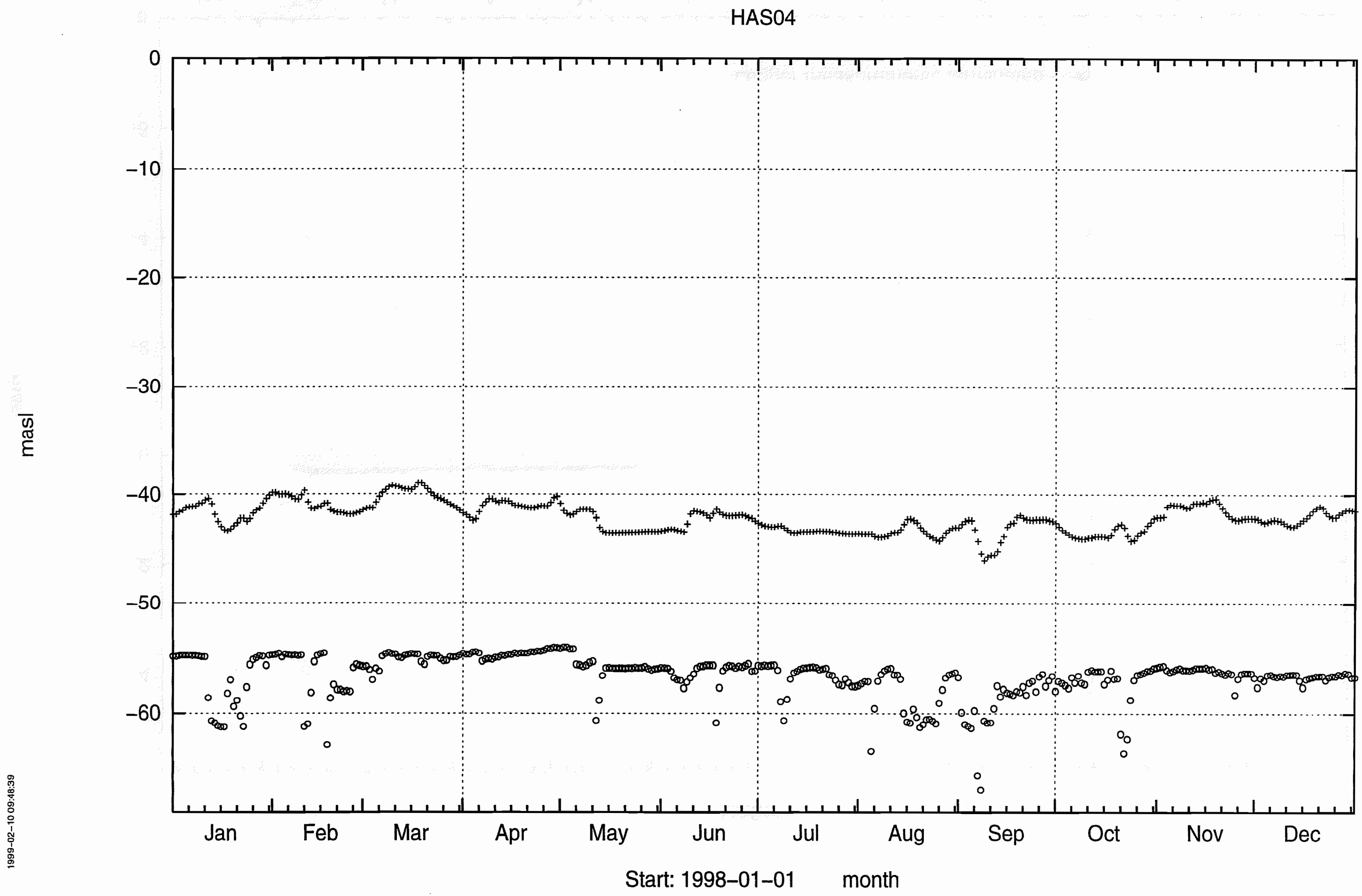
W:	Missing data due to work in vicinity
G:	Failing transducer
TST:	Registration broken due to other tests
K:	Broken signal cable
O:	Reinstrumentation
OP:	Mistake by the operator leading to a break in registration
V:	Failure in Hydraulic Multiplexer: jammed magnetic valve or clogged tubes
L:	Leakage or broken communicating tubes
B:	Failure in datalogger Borre
S:	Ditch and/or gauging box filled with sediment
D:	Computer error that leads to a break in registration
ML:	Leakage in the packer system
?:	Unknown error

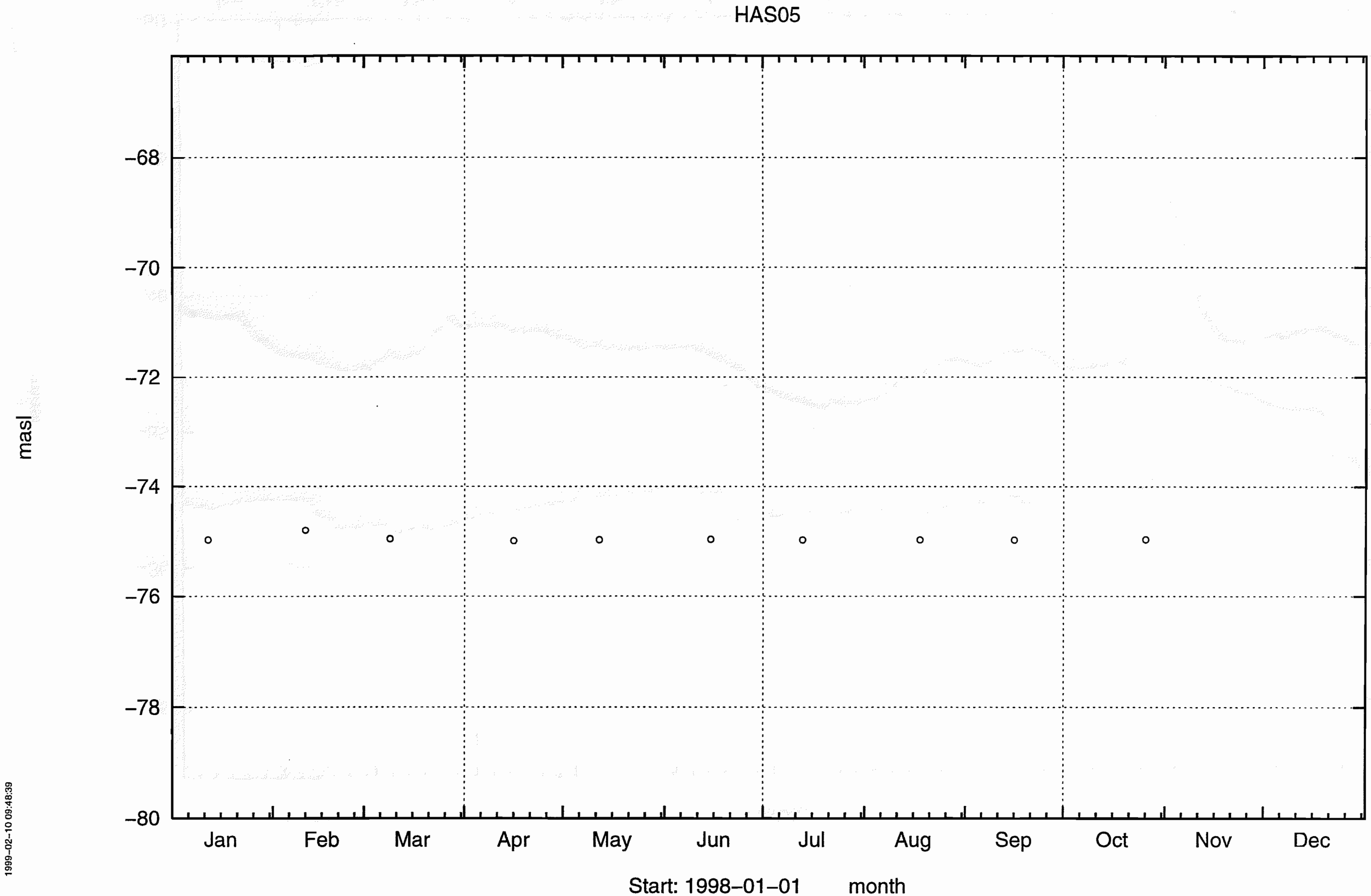
Appendix 2: Groundwater level

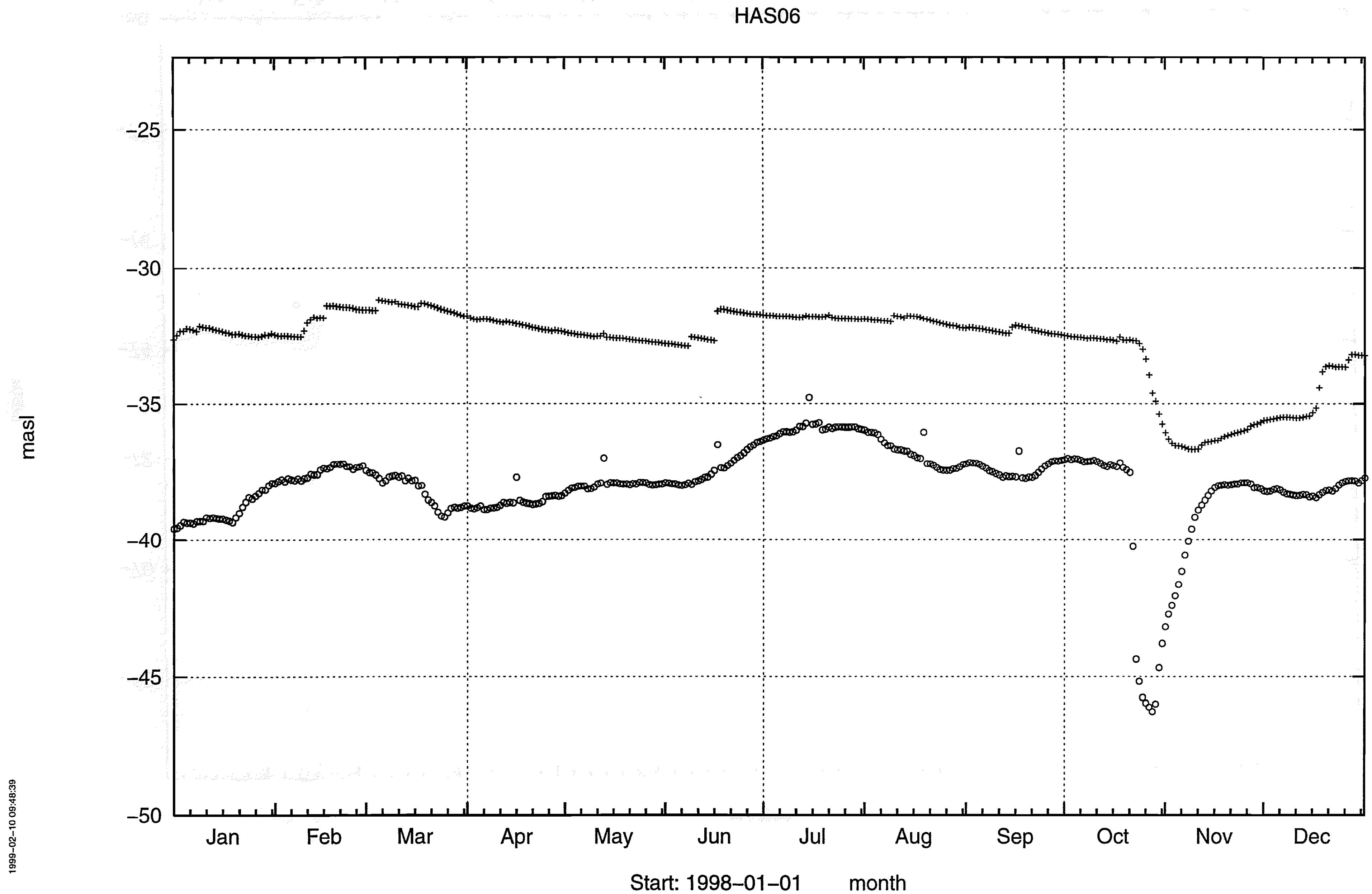

HAS01
masl
4
2
0
-2
-4
-6
-8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:38

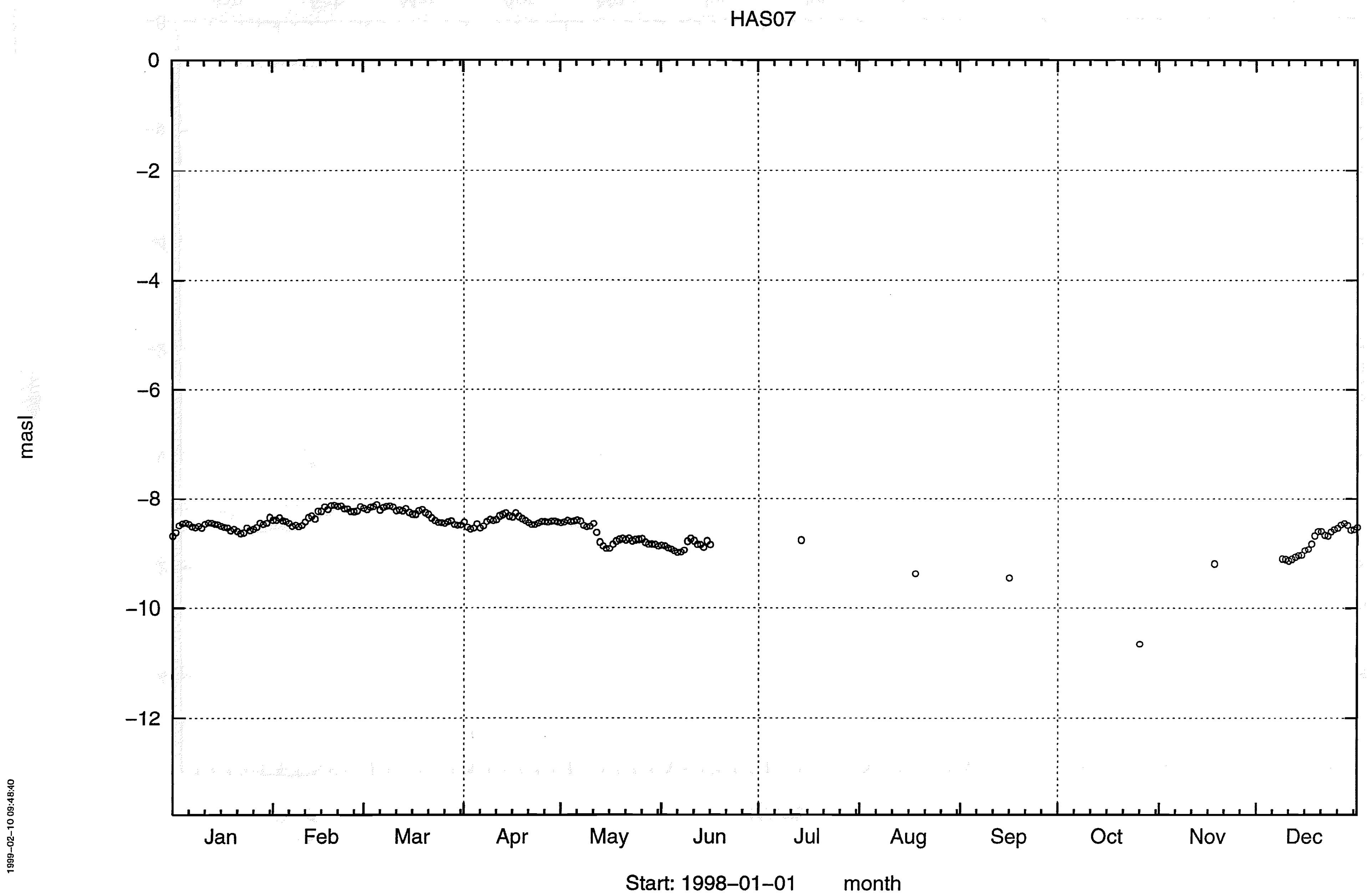

HAS02
masl
4
2
0
-2
-4
-6
-8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:39

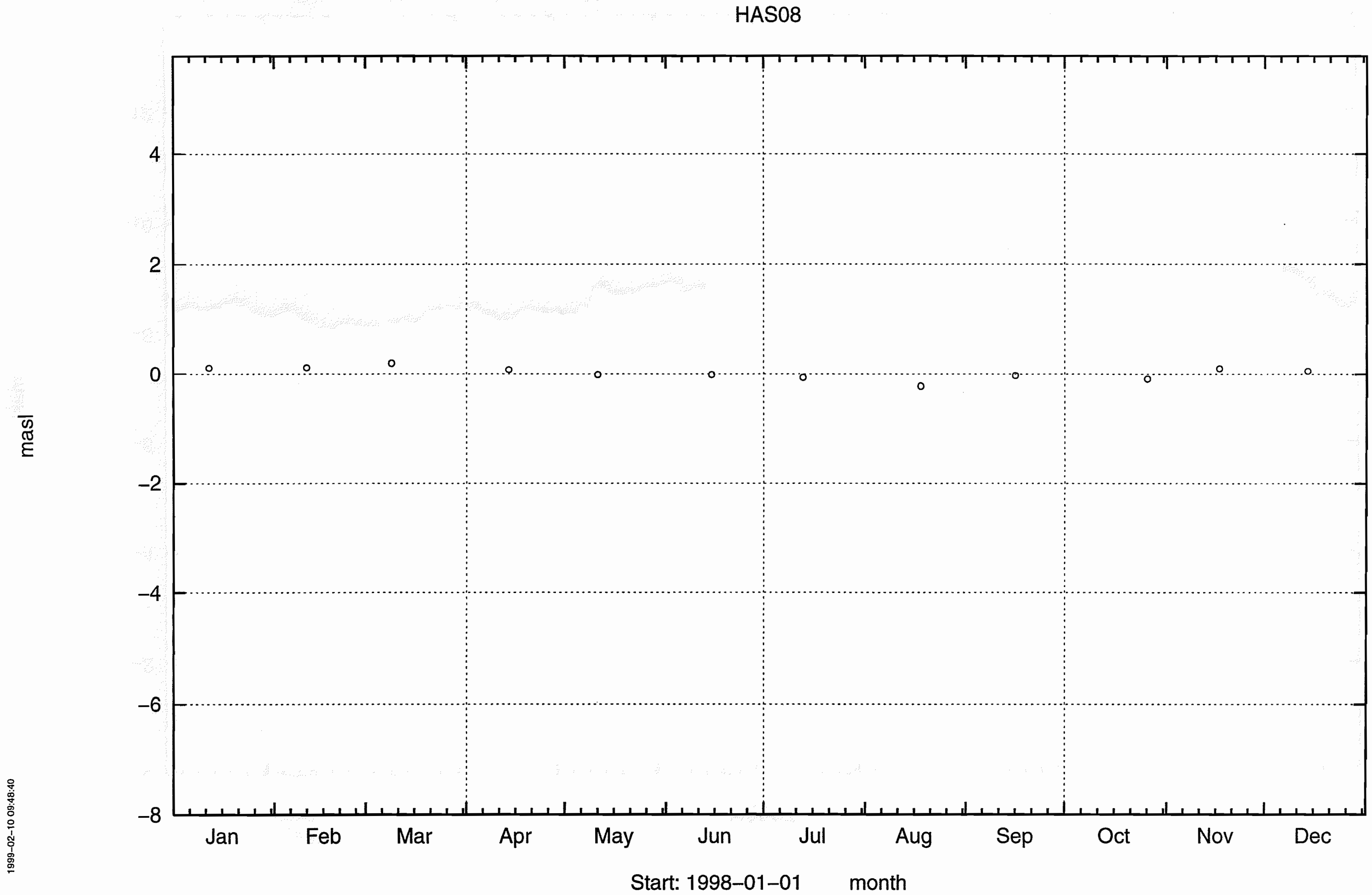

HAS03
masl
4
2
0
−2
−4
−6
−8
Logger measurements terminated
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01
month
1999−02−10 09:48:39


HAS04
0
-10
-20
-30
-40
-50
-60
masl
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:39

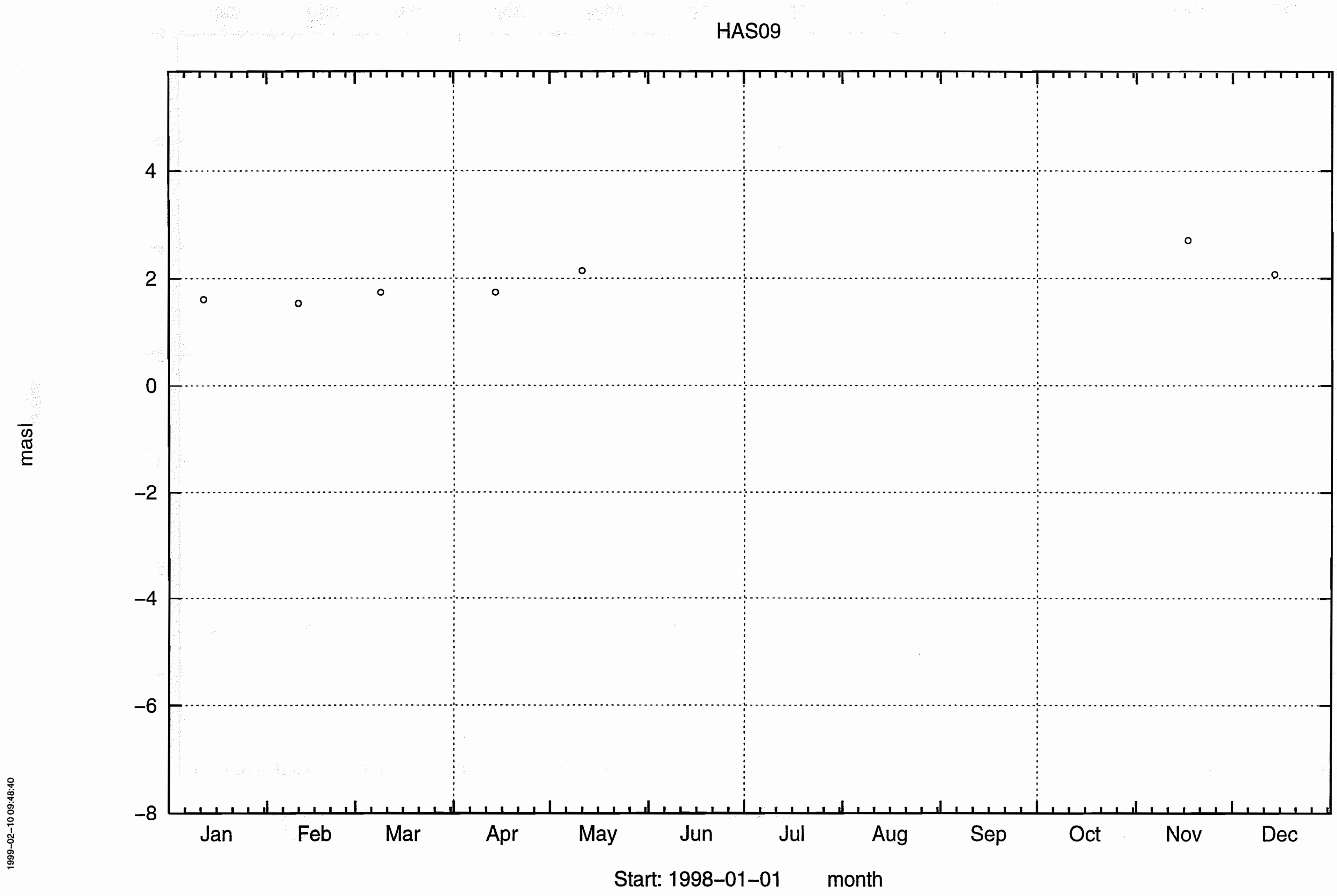

HAS05
masl
-68
-70
-72
-74
-76
-78
-80
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:39

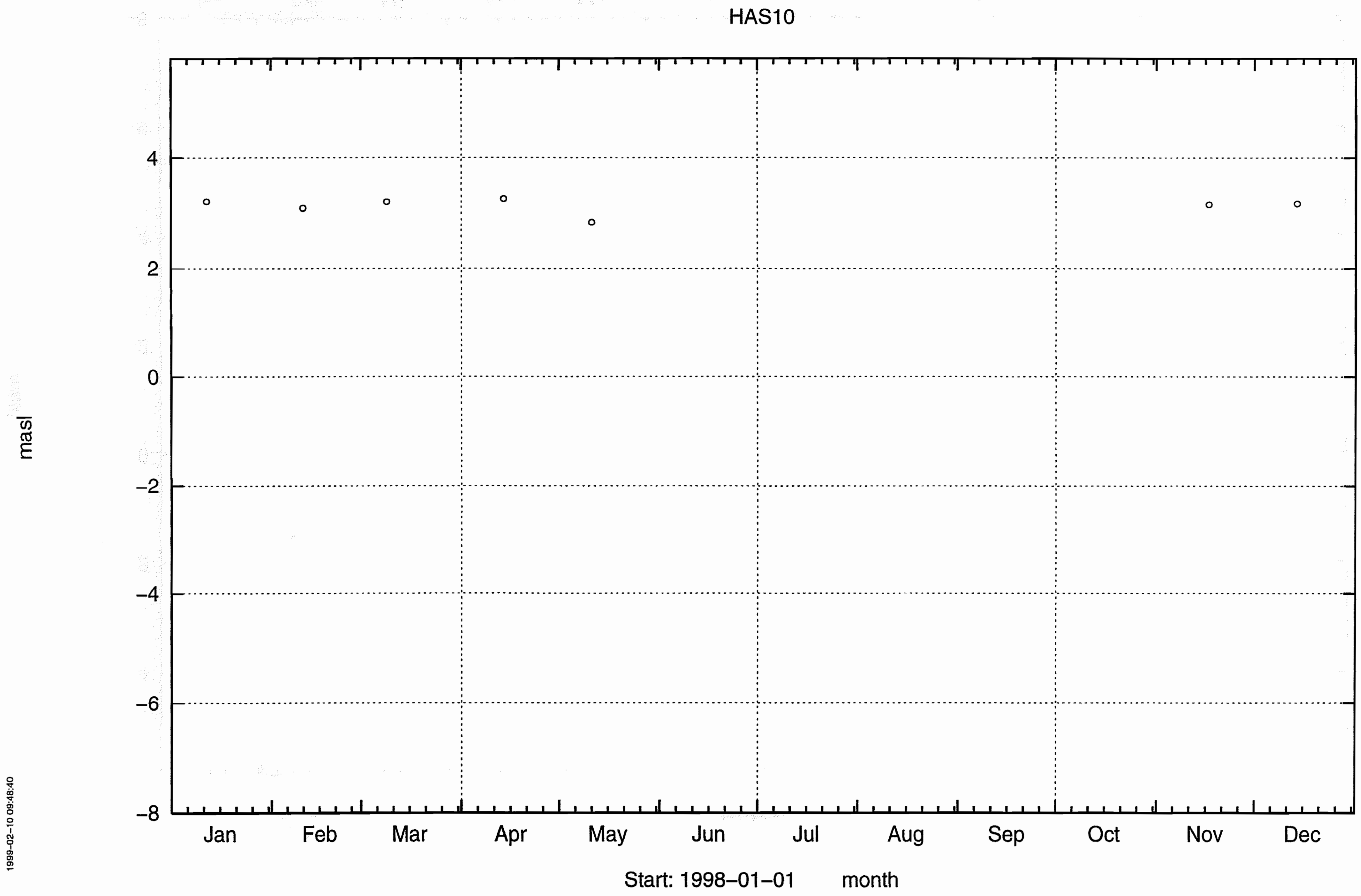

HAS06
masl
-25
-30
-35
-40
-45
-50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:39

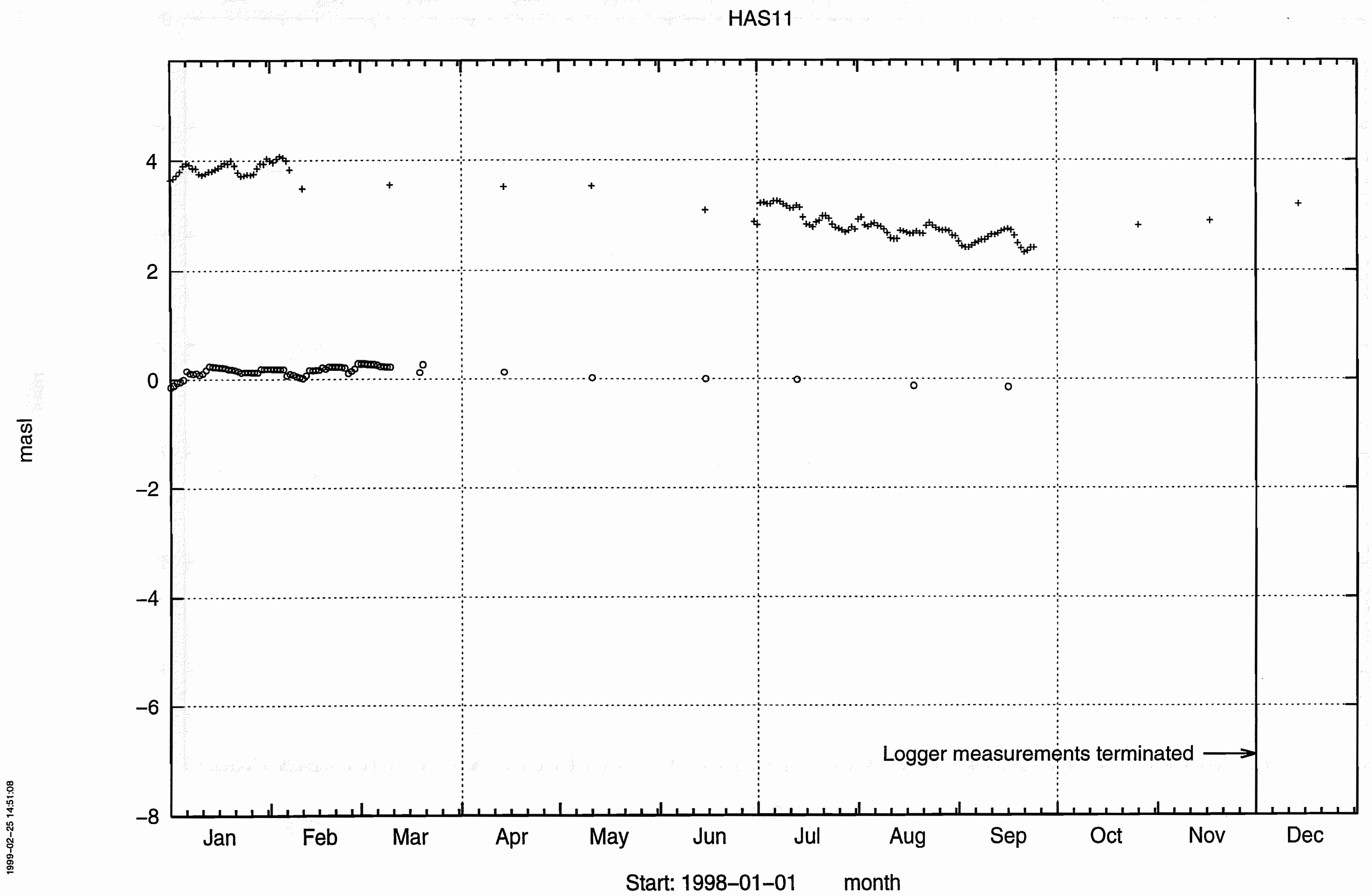

HAS07
0
-2
-4
-6
-8
-10
-12
masl
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:40

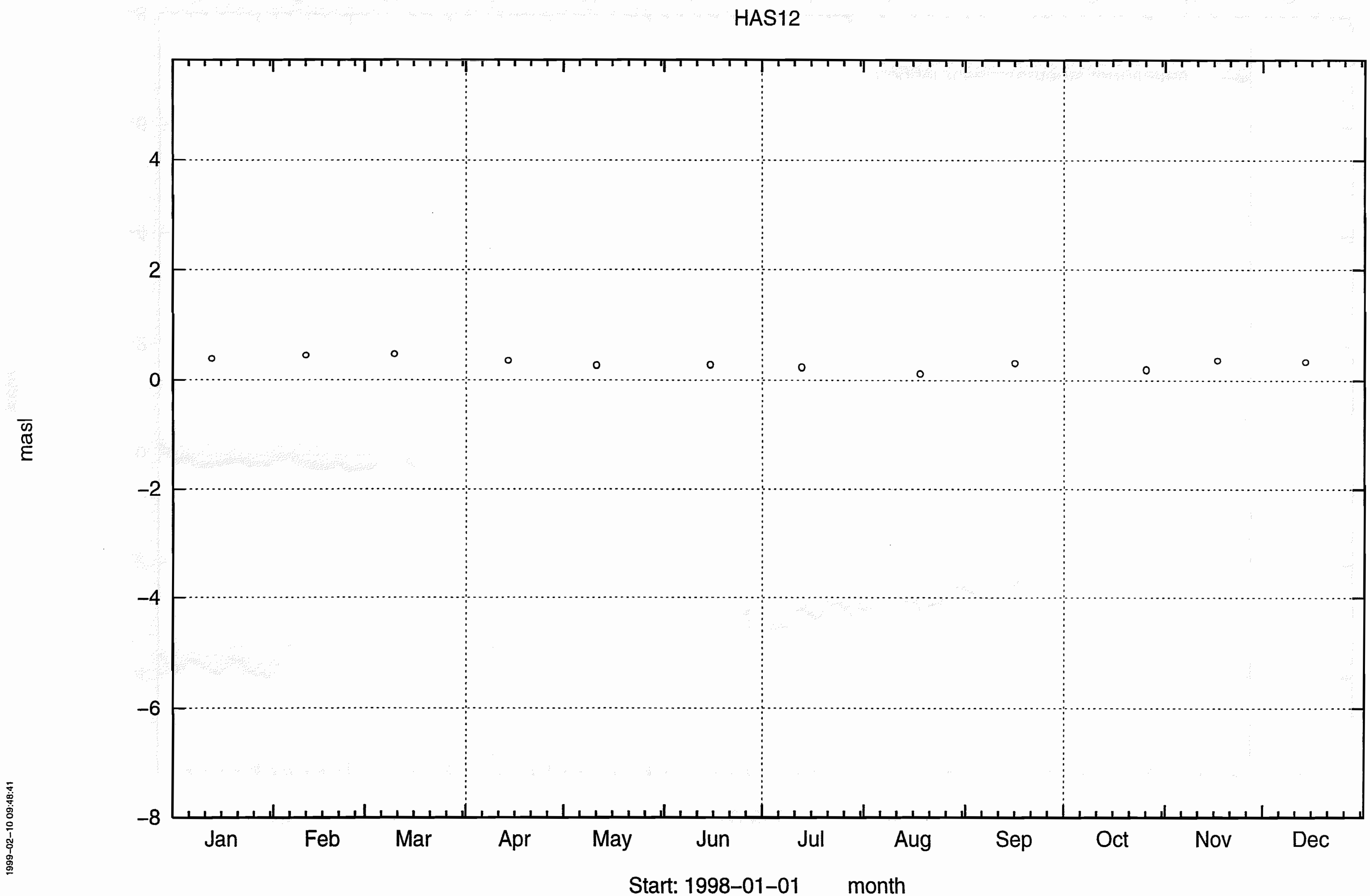


HAS08
masl
4
2
0
-2
-4
-6
-8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:40

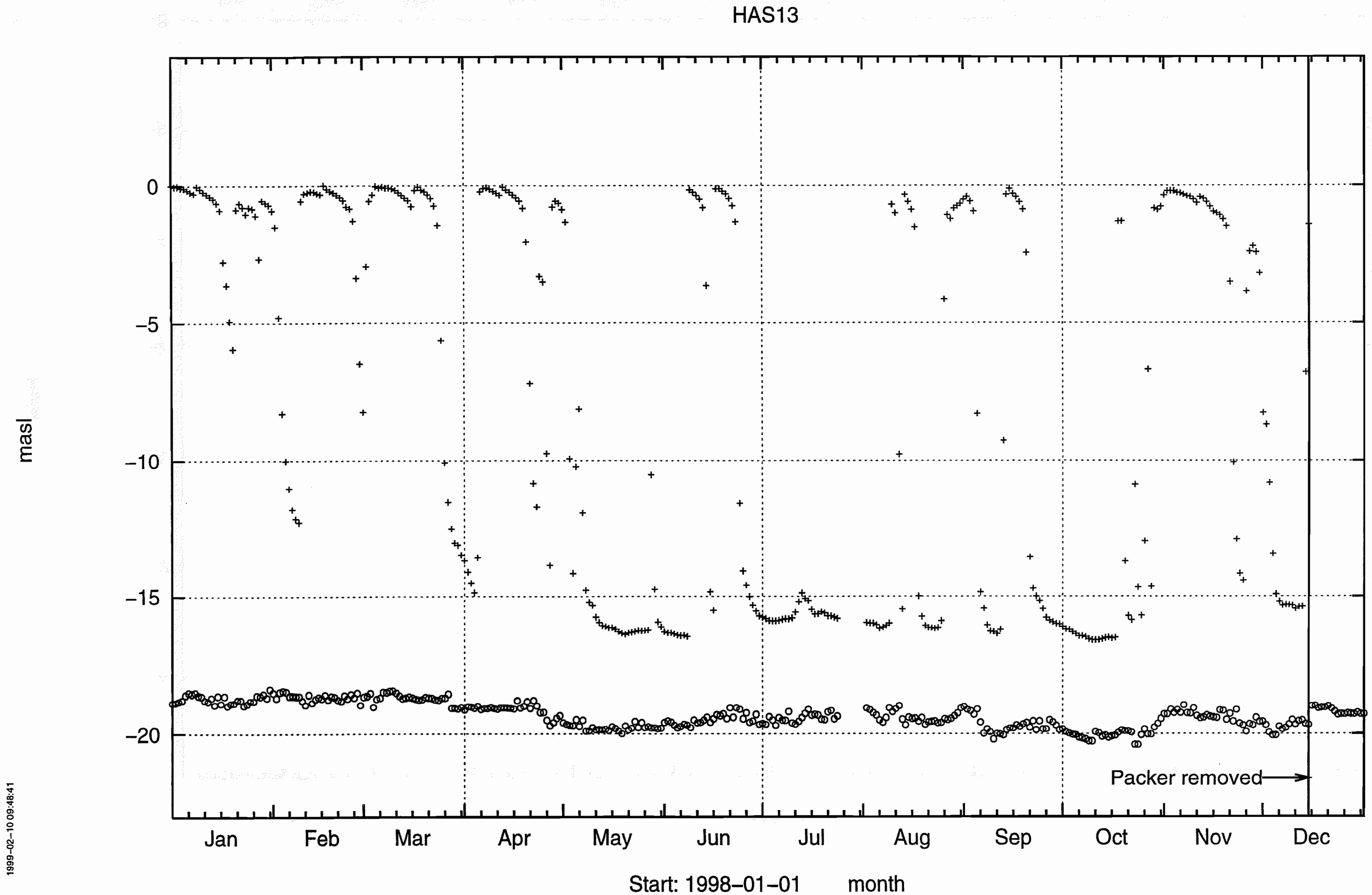

HAS09
masl
4
2
0
−2
−4
−6
−8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01 month
1999−02−10 09:48:40


HAS10
masl
4
2
0
−2
−4
−6
−8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01
month
1999-02-10 09:48:40

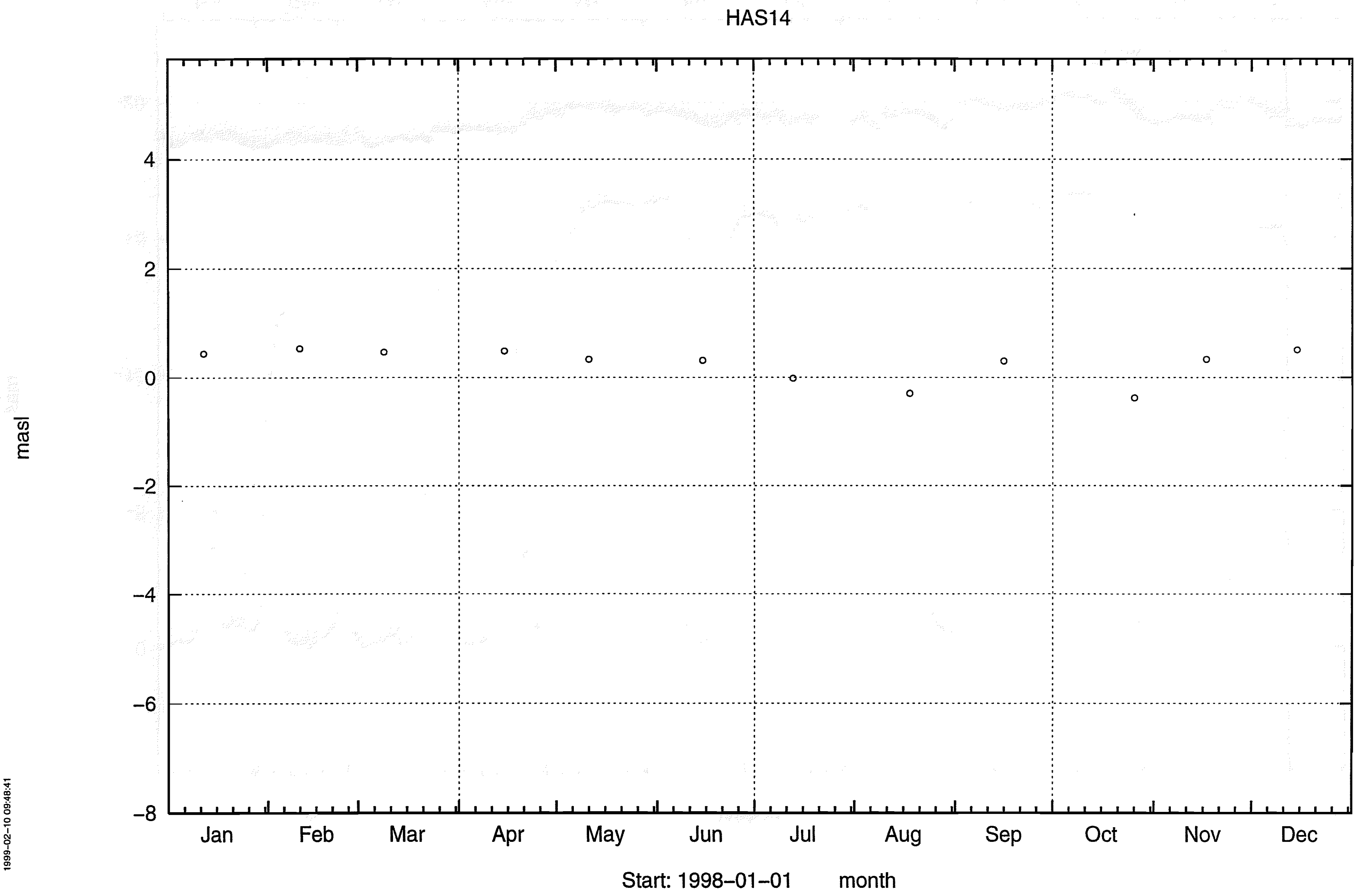

HAS11
masl
4
2
0
−2
−4
−6
−8
Logger measurements terminated
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01 month
1999−02−25 14:51:08

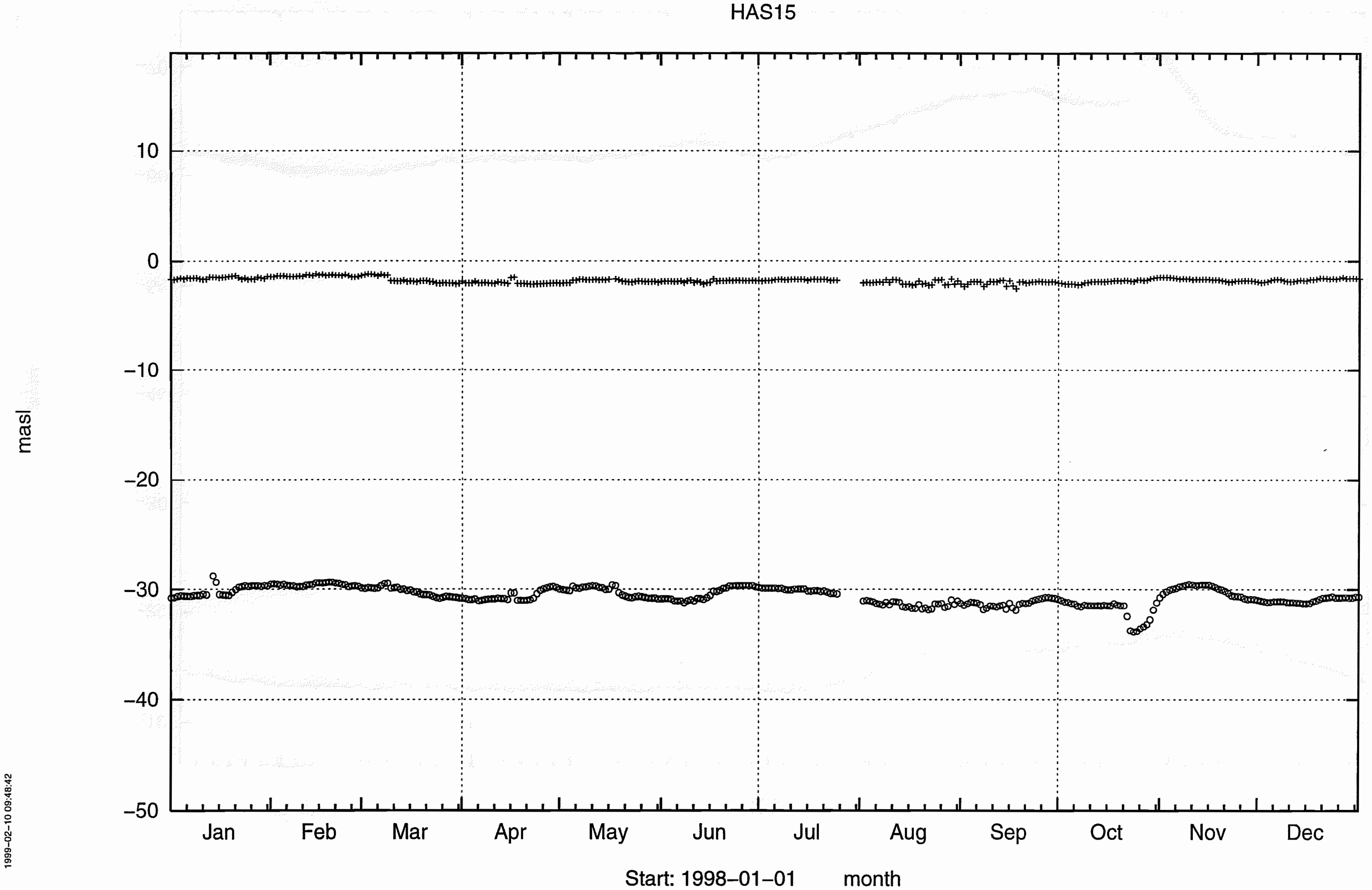


HAS12
masl
4
2
0
−2
−4
−6
−8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01 month
1999−02−10 09:48:41

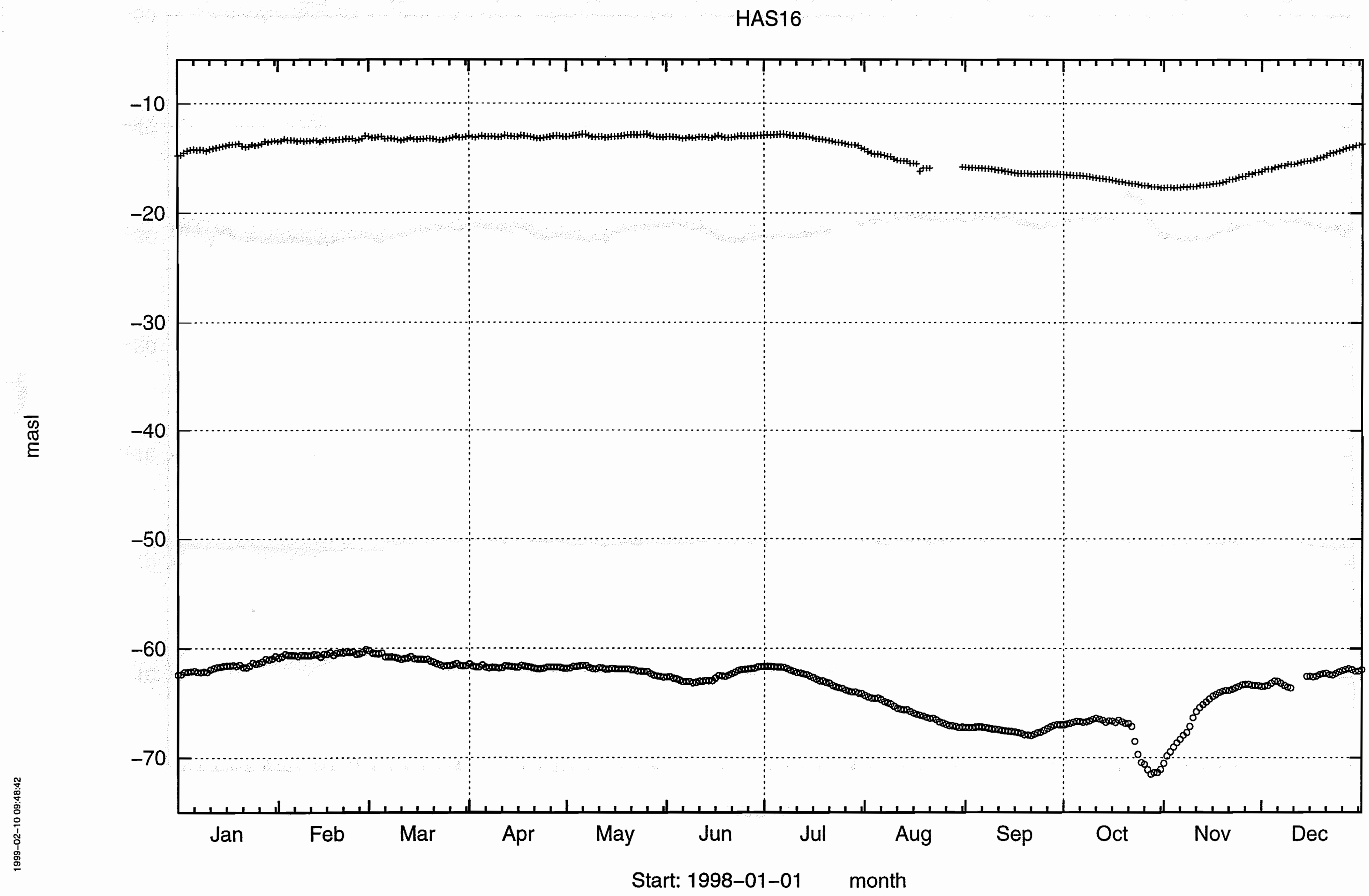


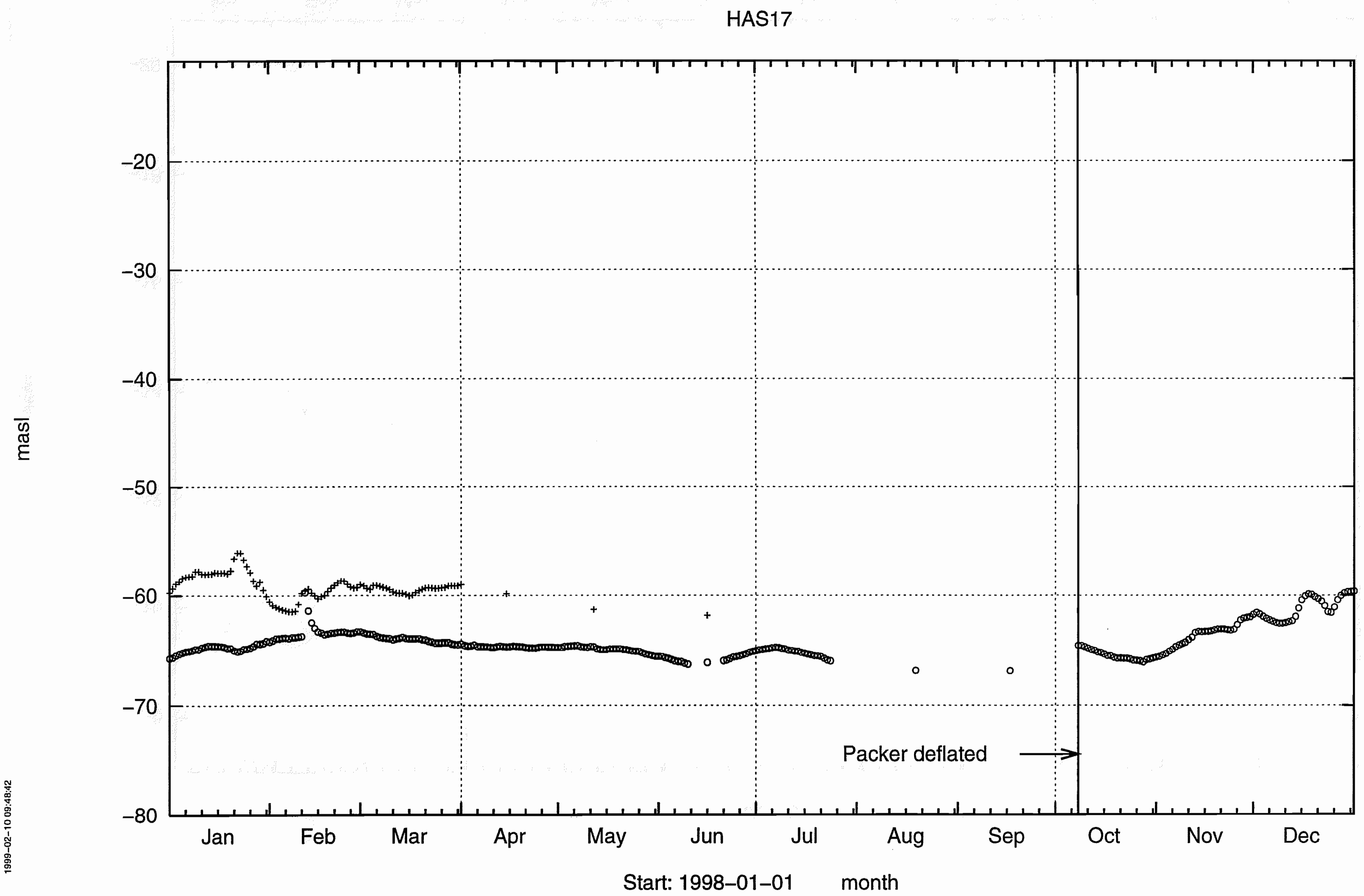
HAS13
masl
0
−5
−10
−15
−20
Packer removed
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01 month
1999−02−10 09:48:41


HAS14
masl
4
2
0
-2
-4
-6
-8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:41

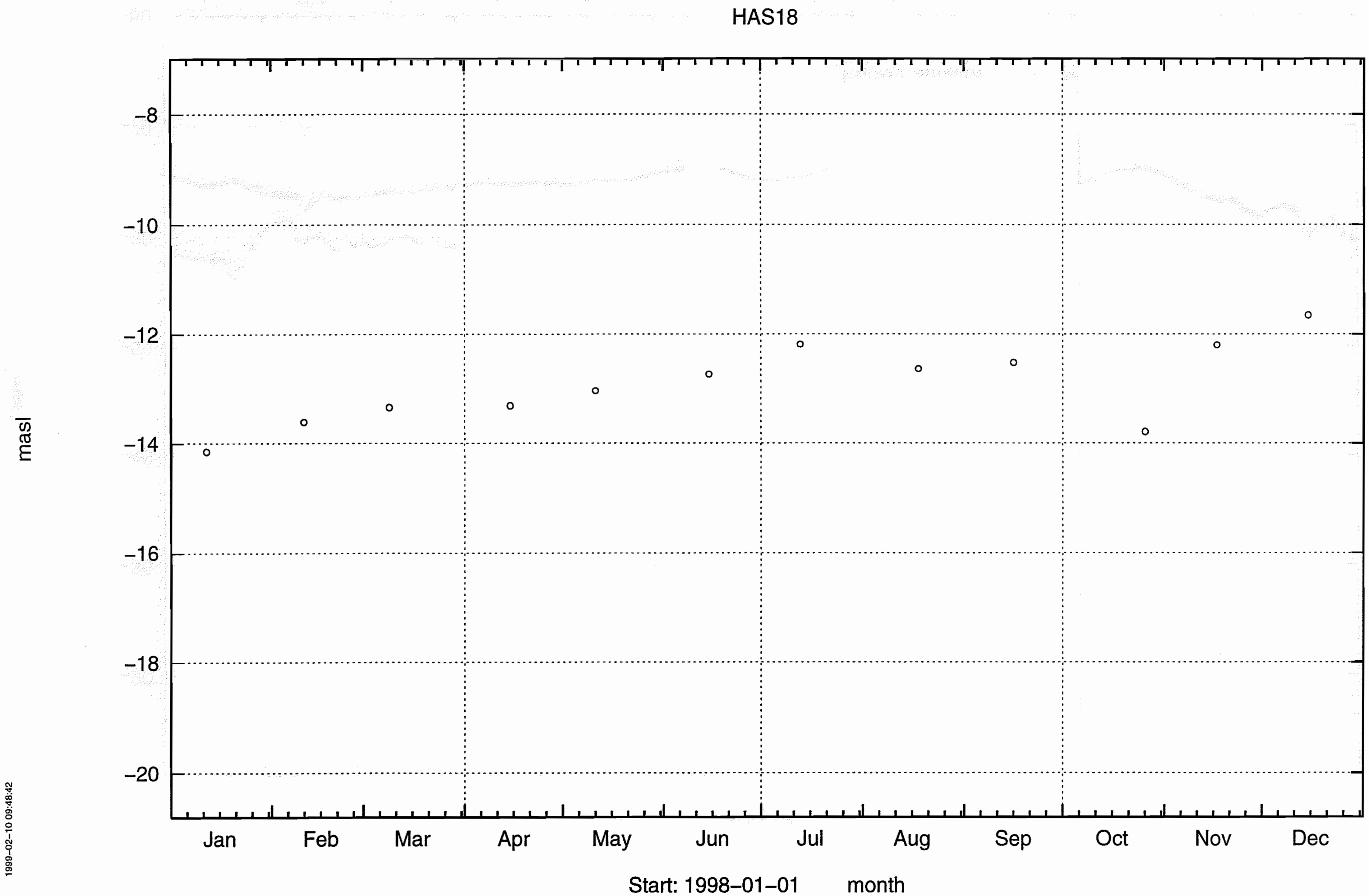


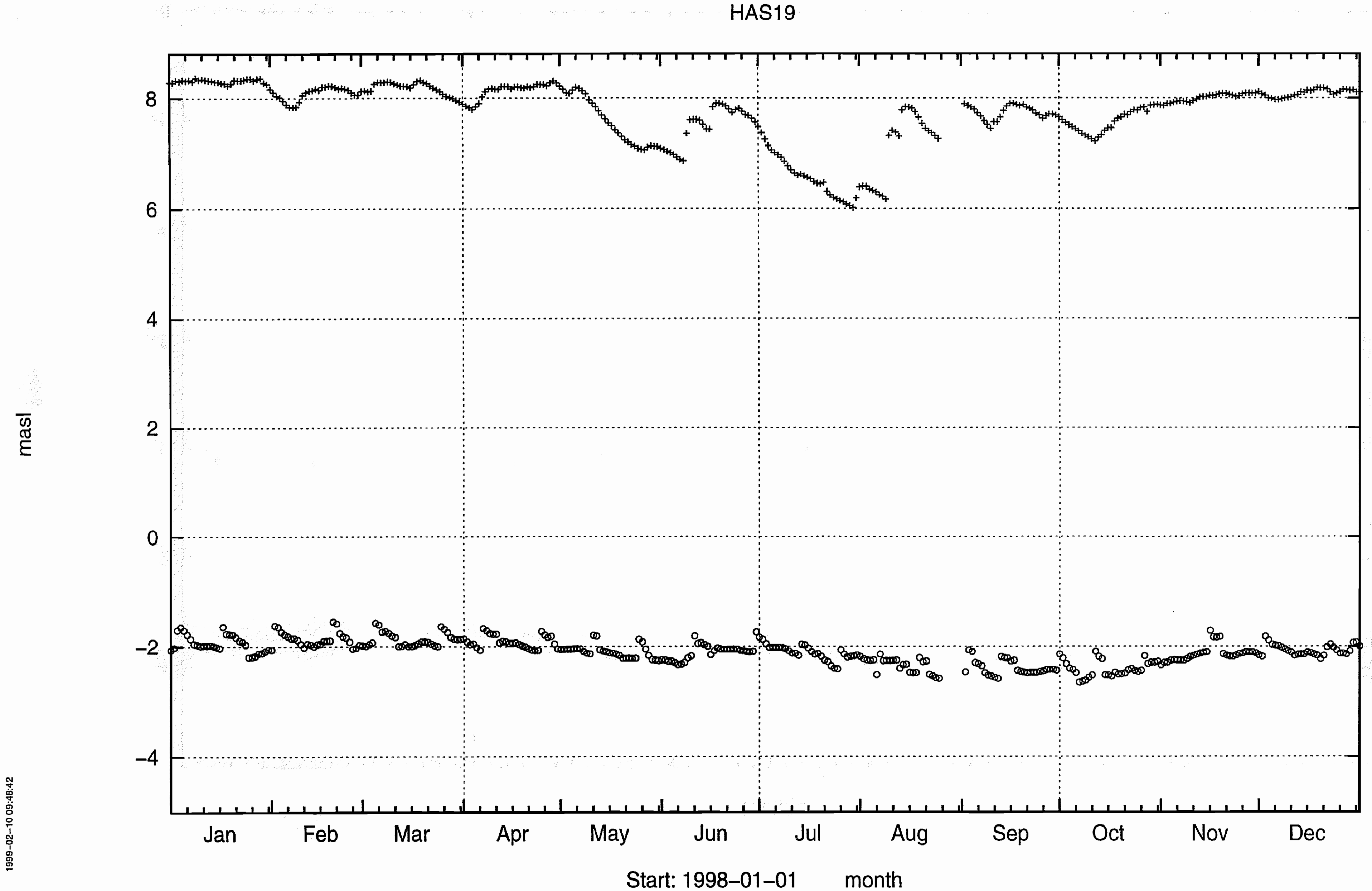
HAS15
masl
10
0
−10
−20
−30
−40
−50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01
month
1999−02−10 09:48:42

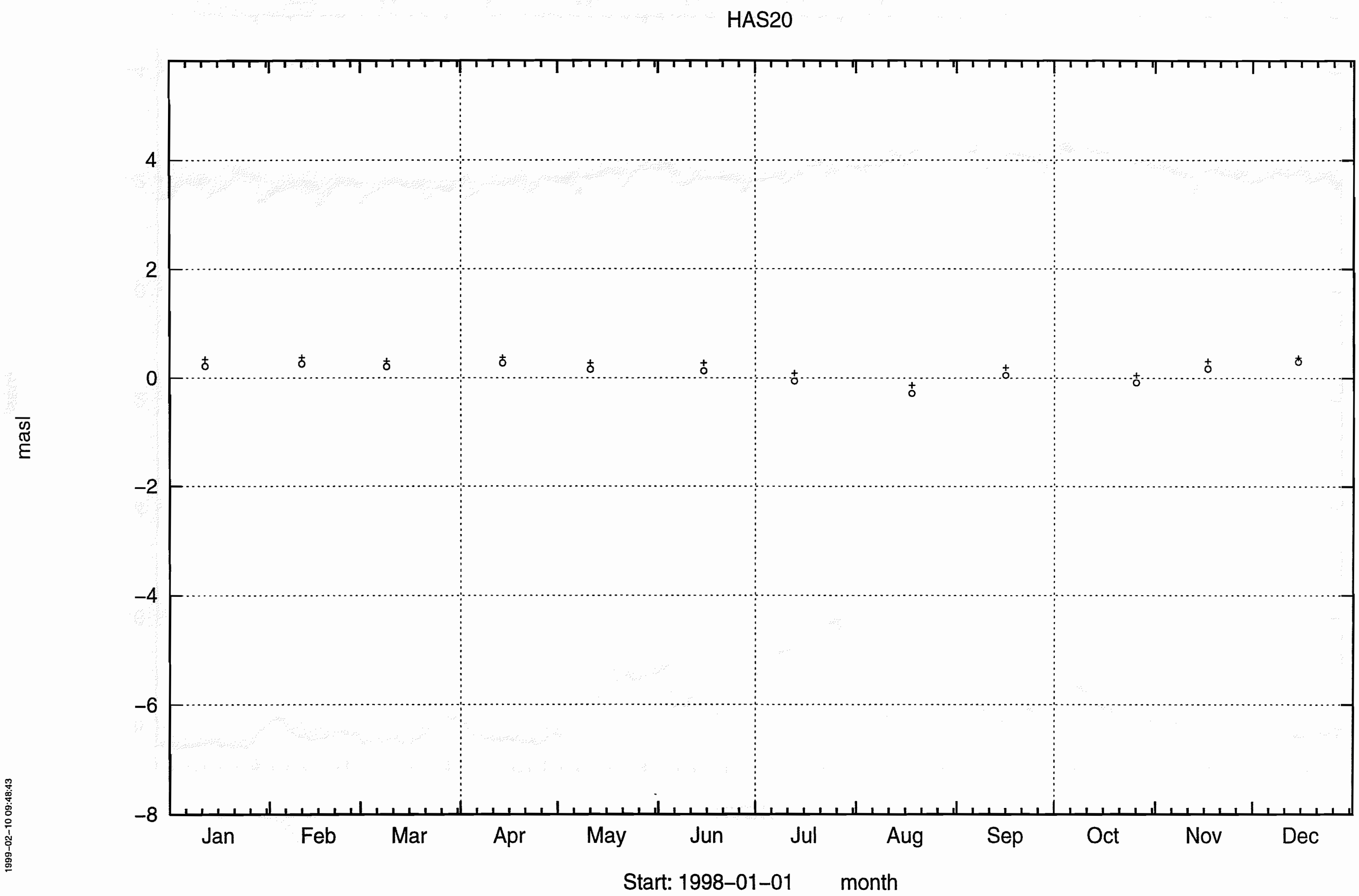

HAS16
masl
-10
-20
-30
-40
-50
-60
-70
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-10 09:48:42



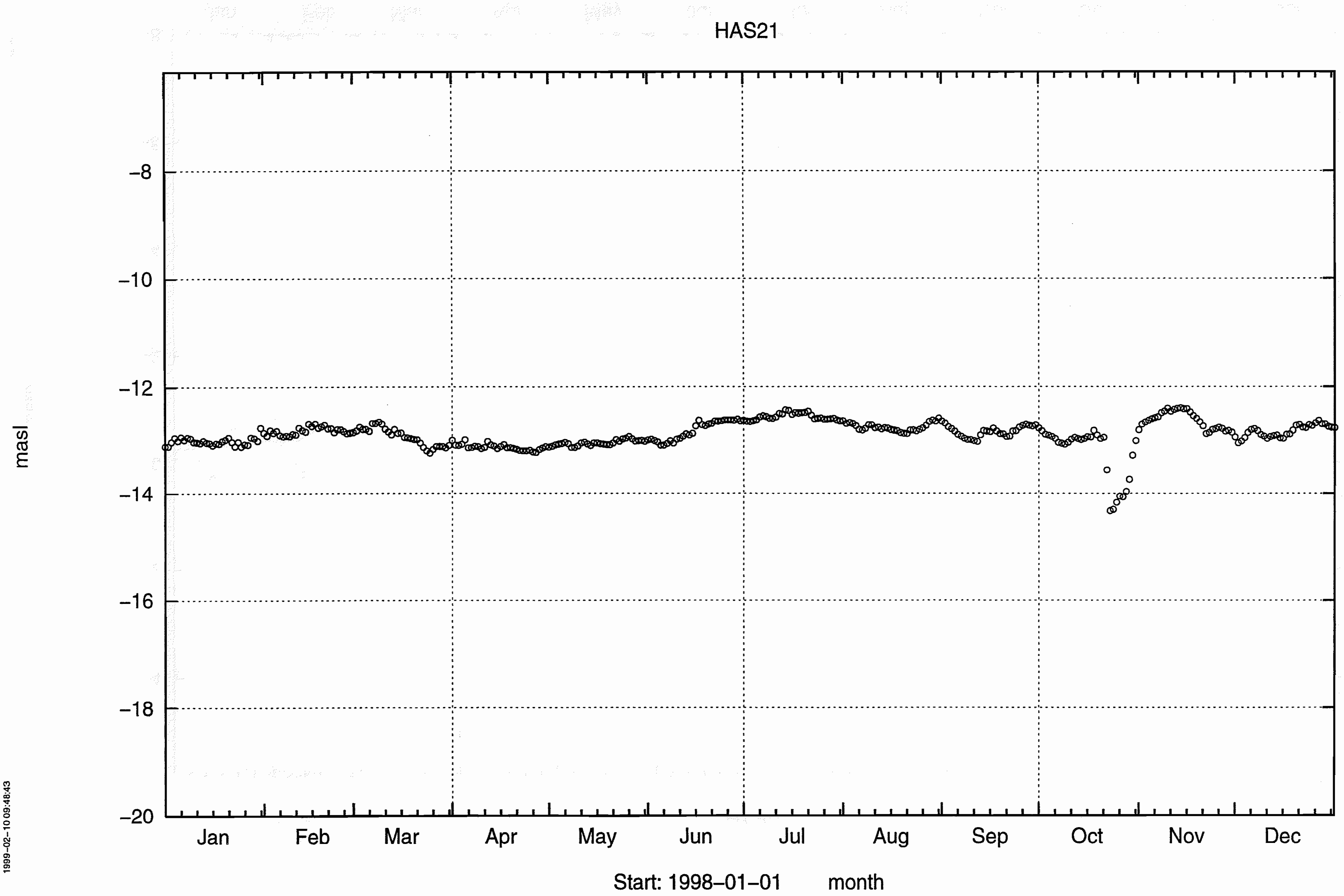
HAS17
masl
-20
-30
-40
-50
-60
-70
-80
Packer deflated
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:42


HAS18
masl
-8
-10
-12
-14
-16
-18
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:42

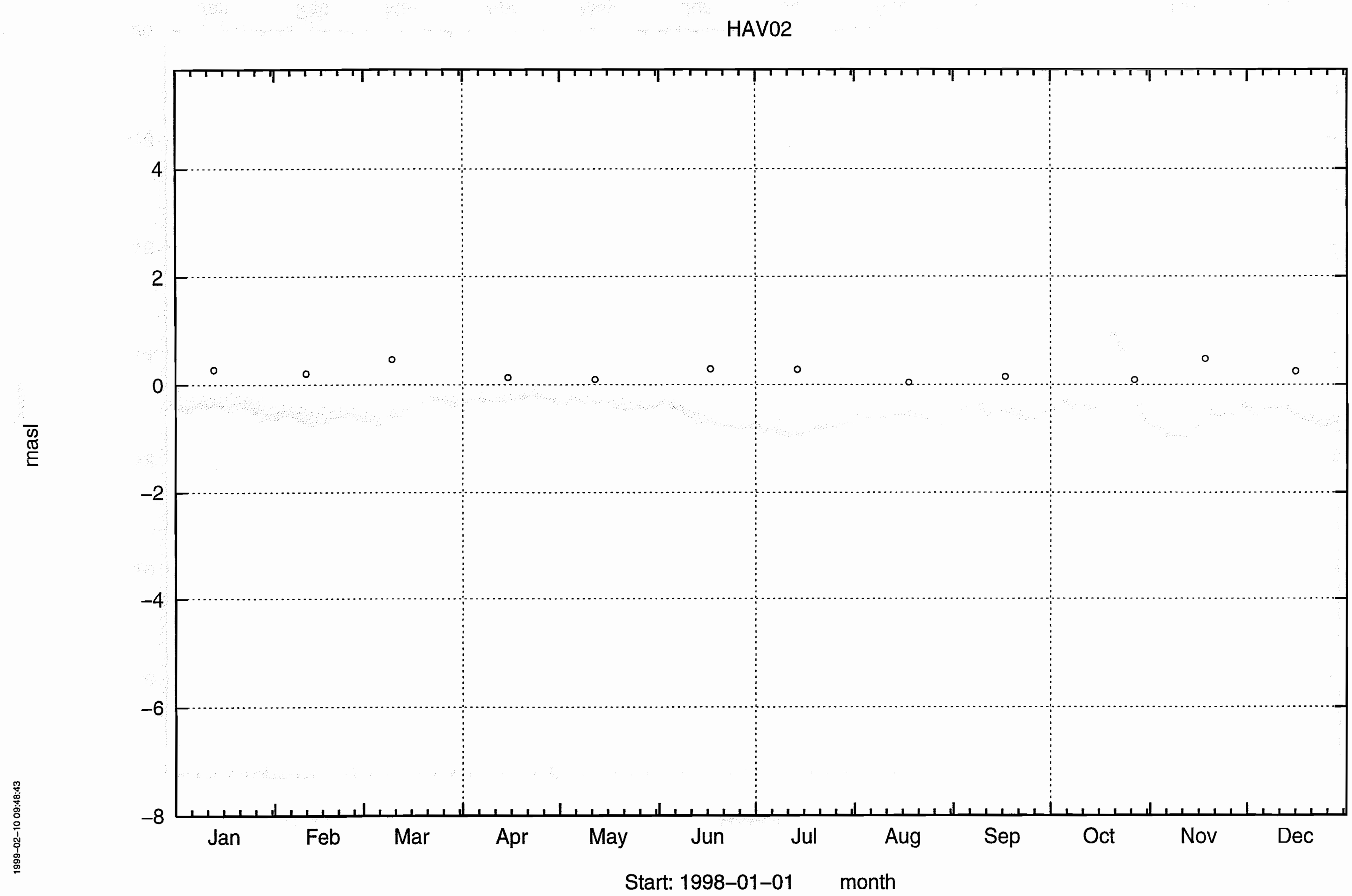

HAS19
masl
8
6
4
2
0
-2
-4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:42

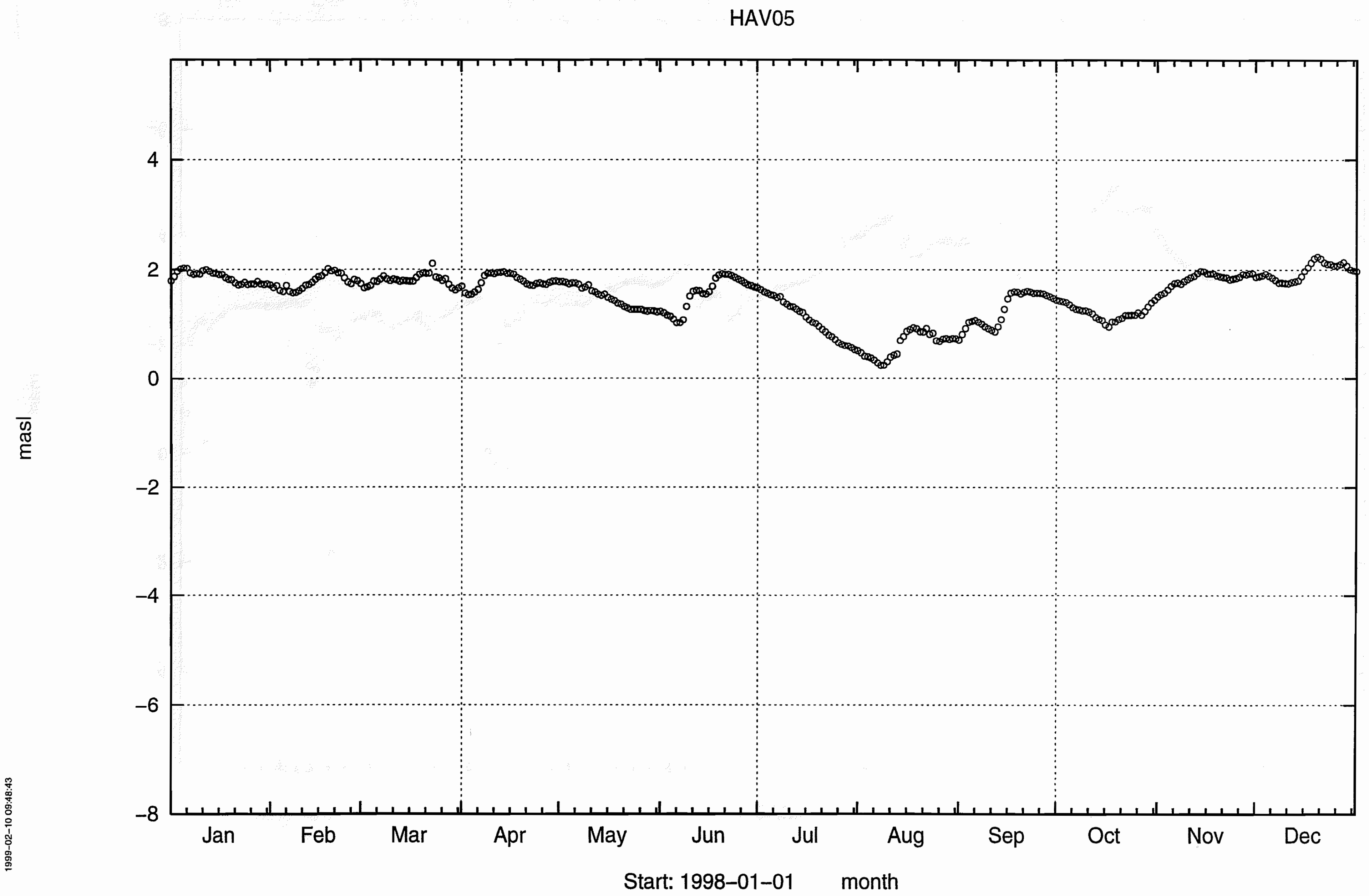


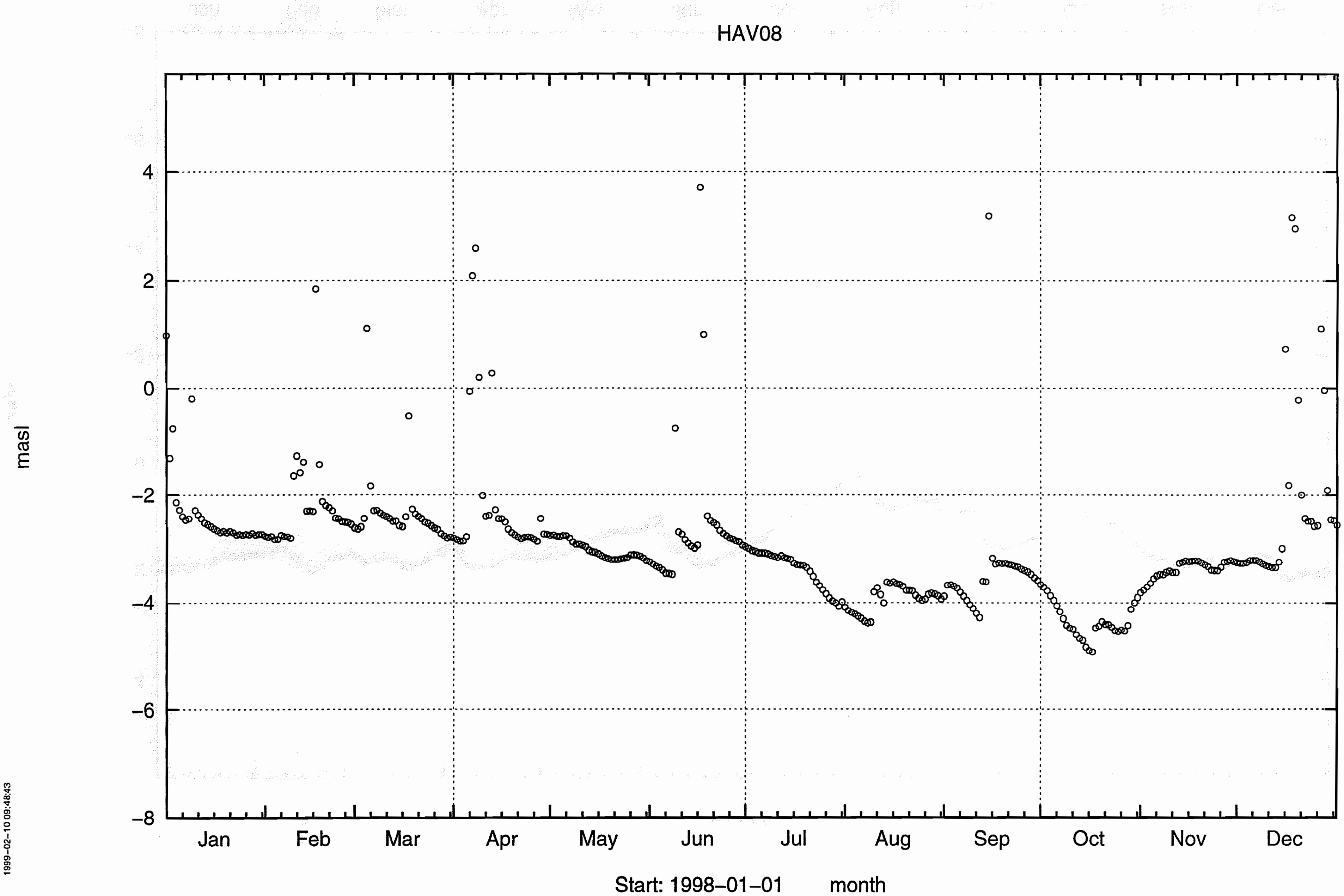
HAS20
masl
4
2
0
-2
-4
-6
-8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-10 09:48:43



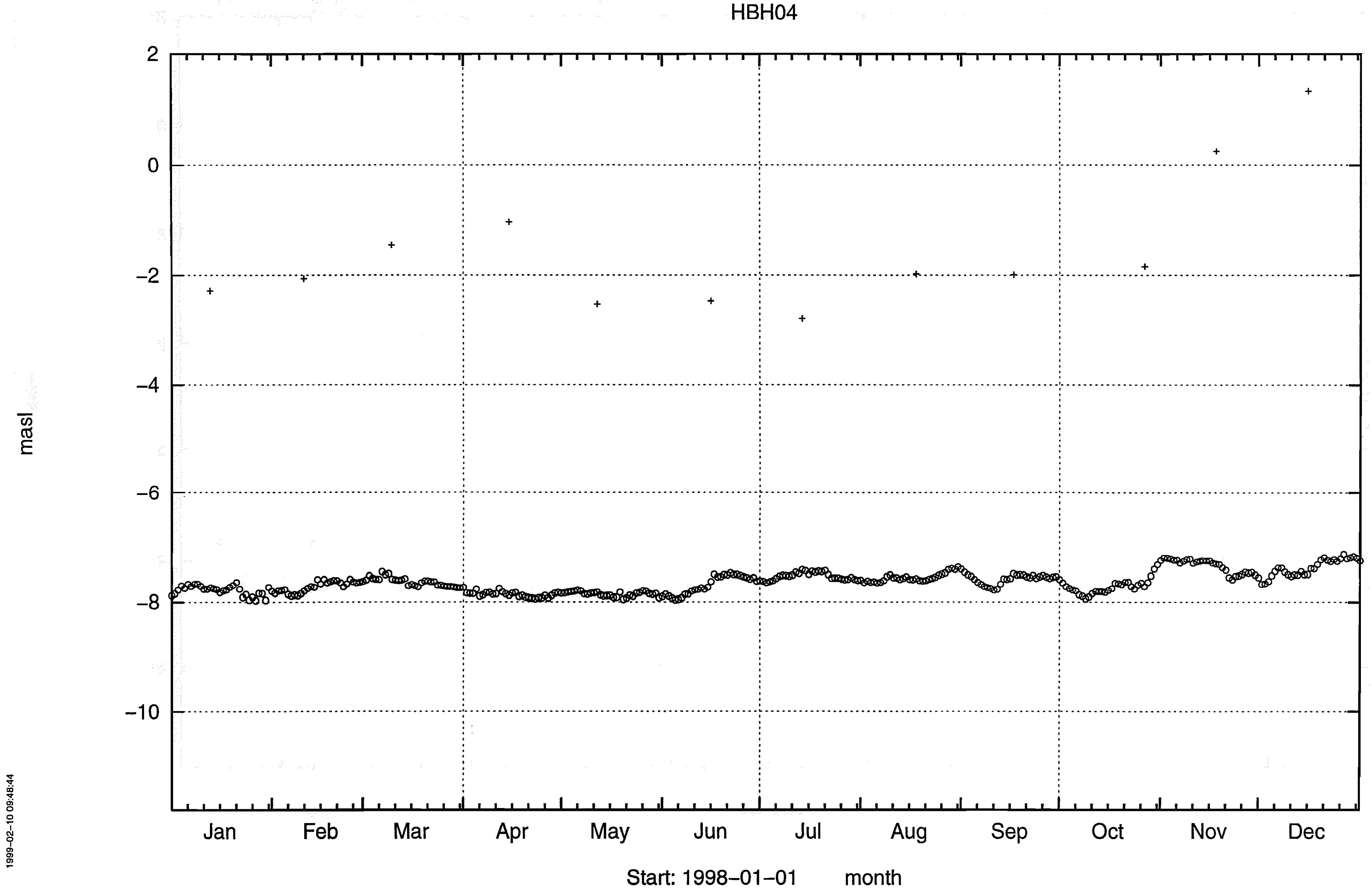
1999–02–10 09:48:43


HAV02
masl
4
2
0
−2
−4
−6
−8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01
month
1999−02−10 09:48:43

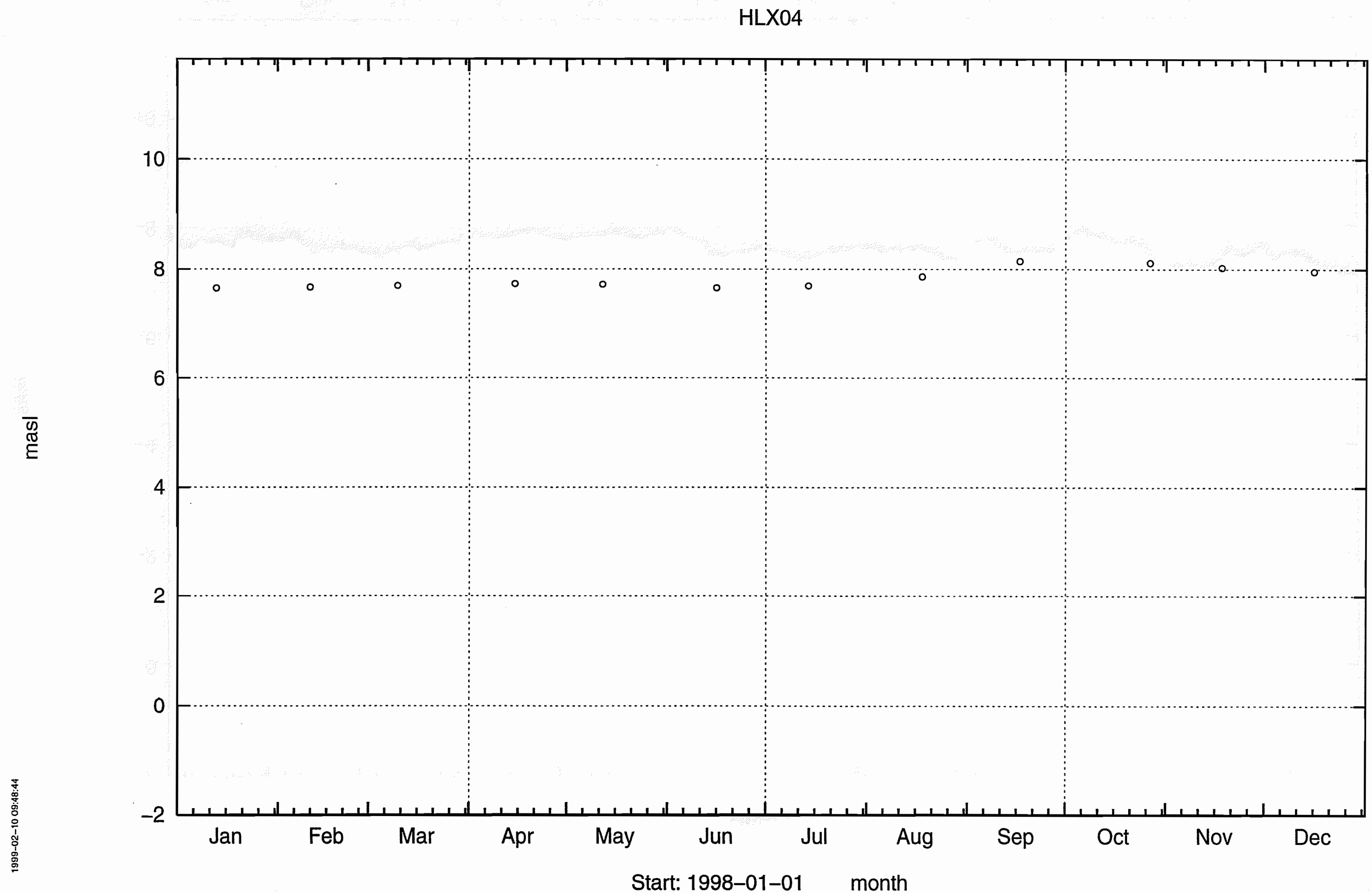

HAV05
4
2
0
−2
−4
−6
−8
masl
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01
month
1999−02−10 09:48:43

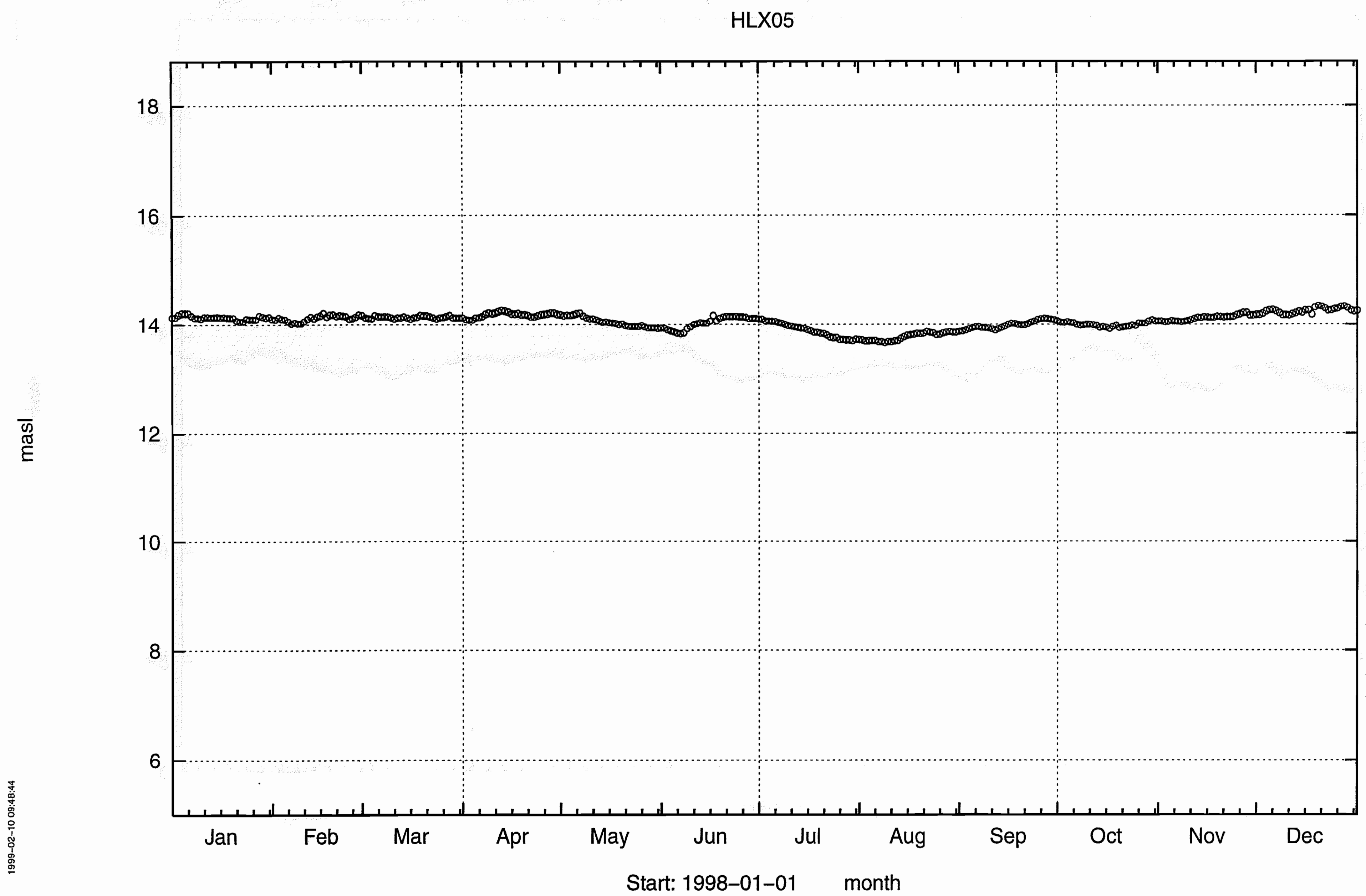


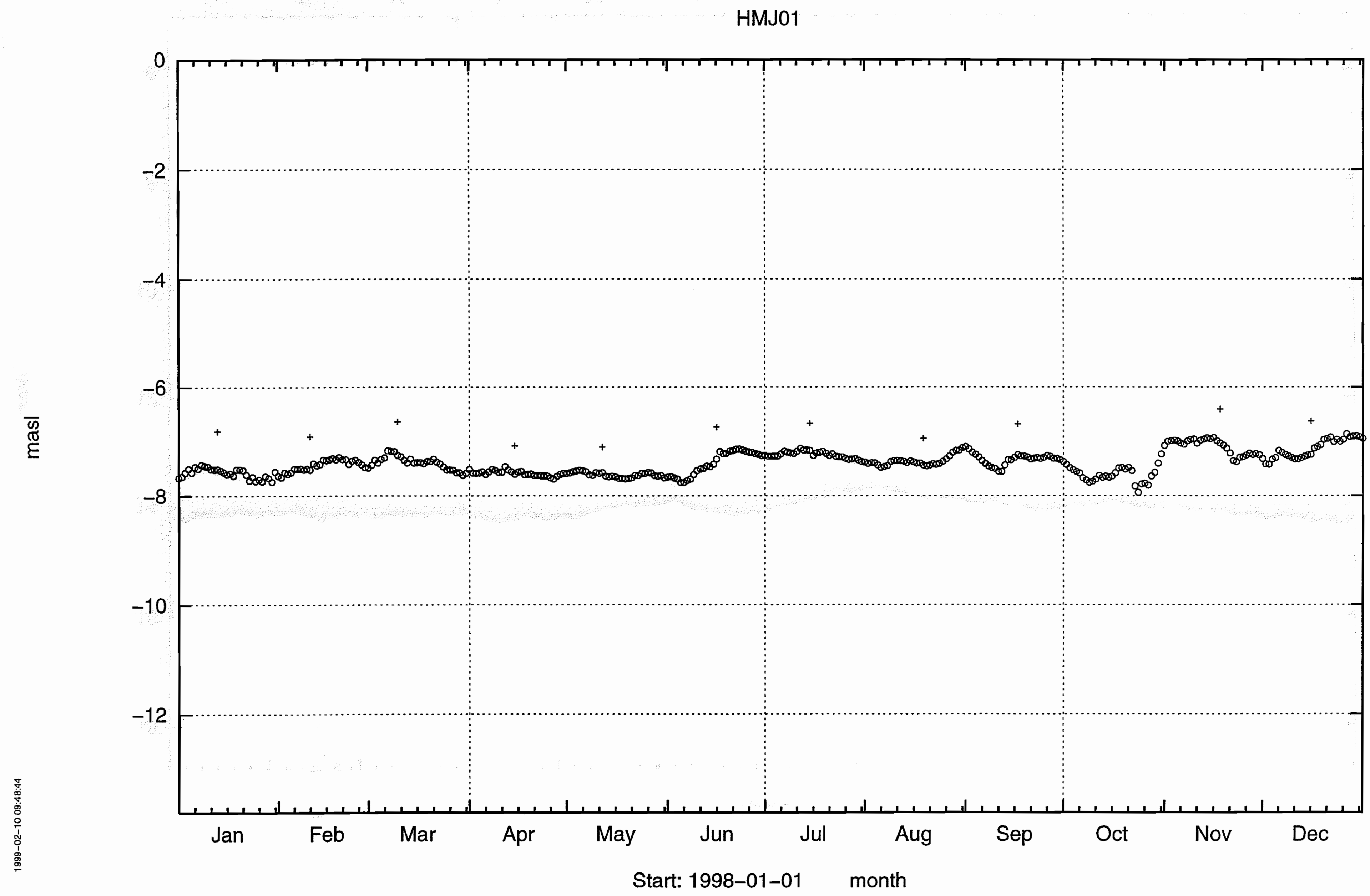
1999-02-10 09:48:43

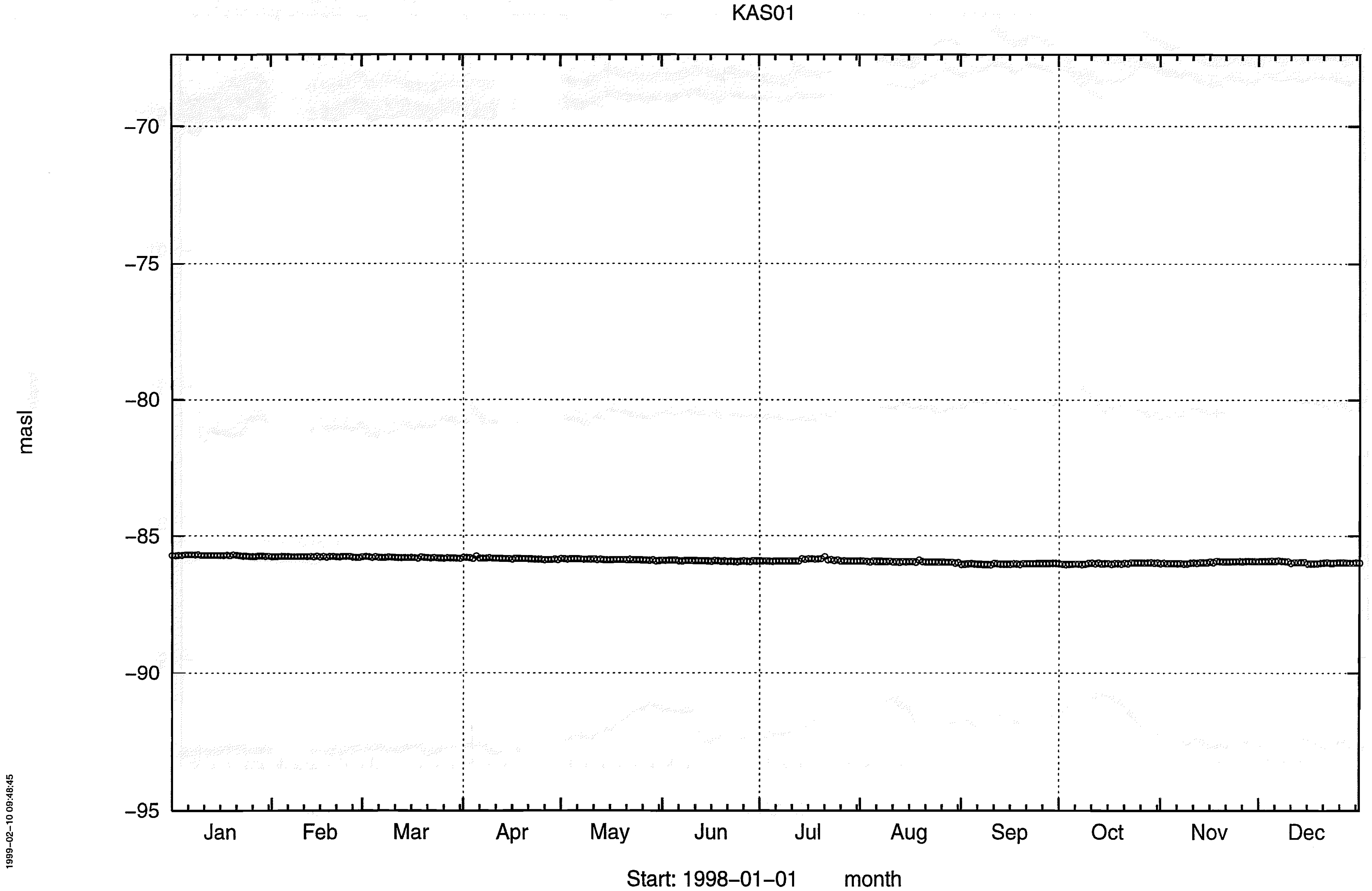


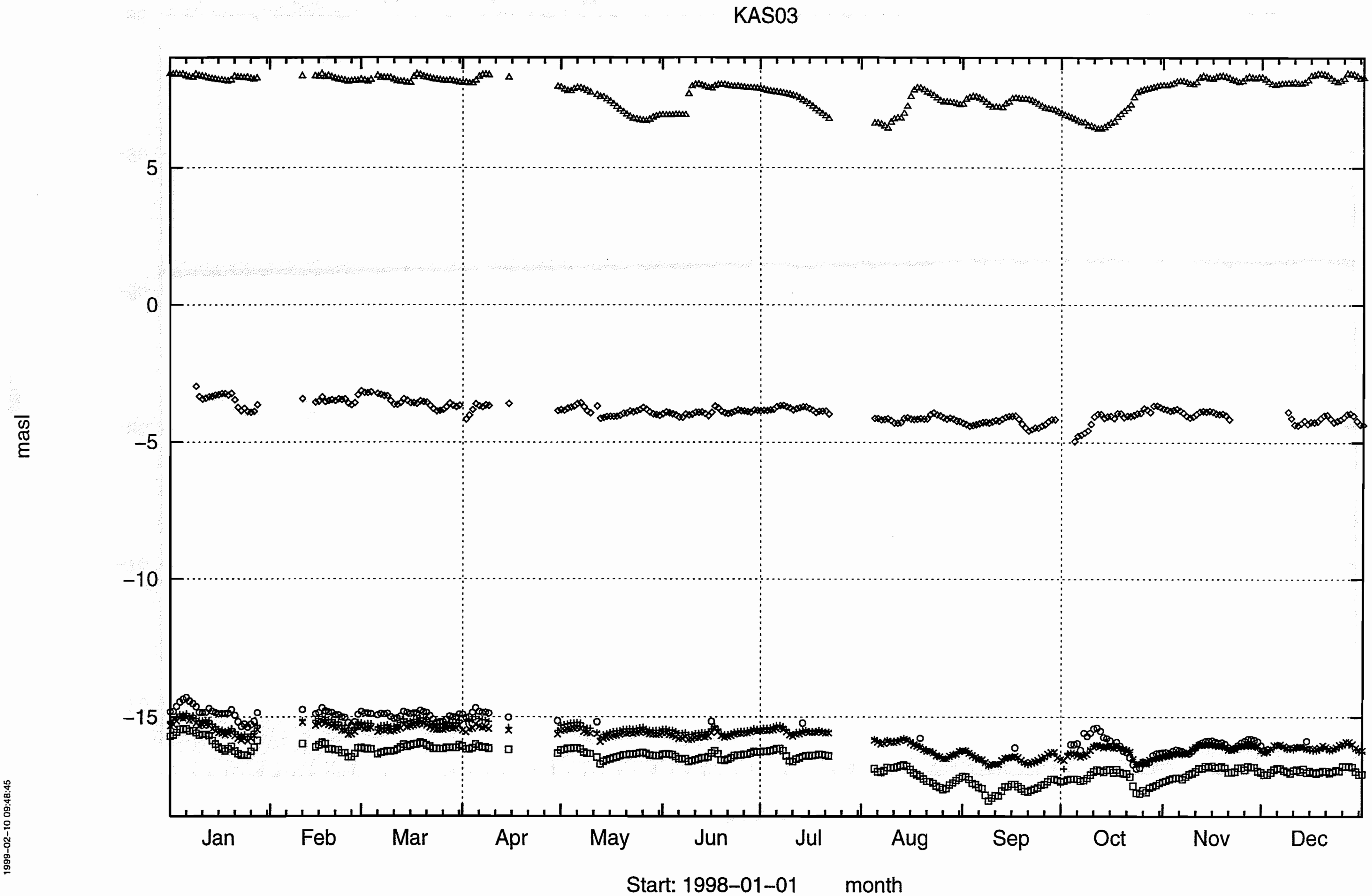
HBH04
masl
2
0
−2
−4
−6
−8
−10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01 month
1999−02−10 09:48:44

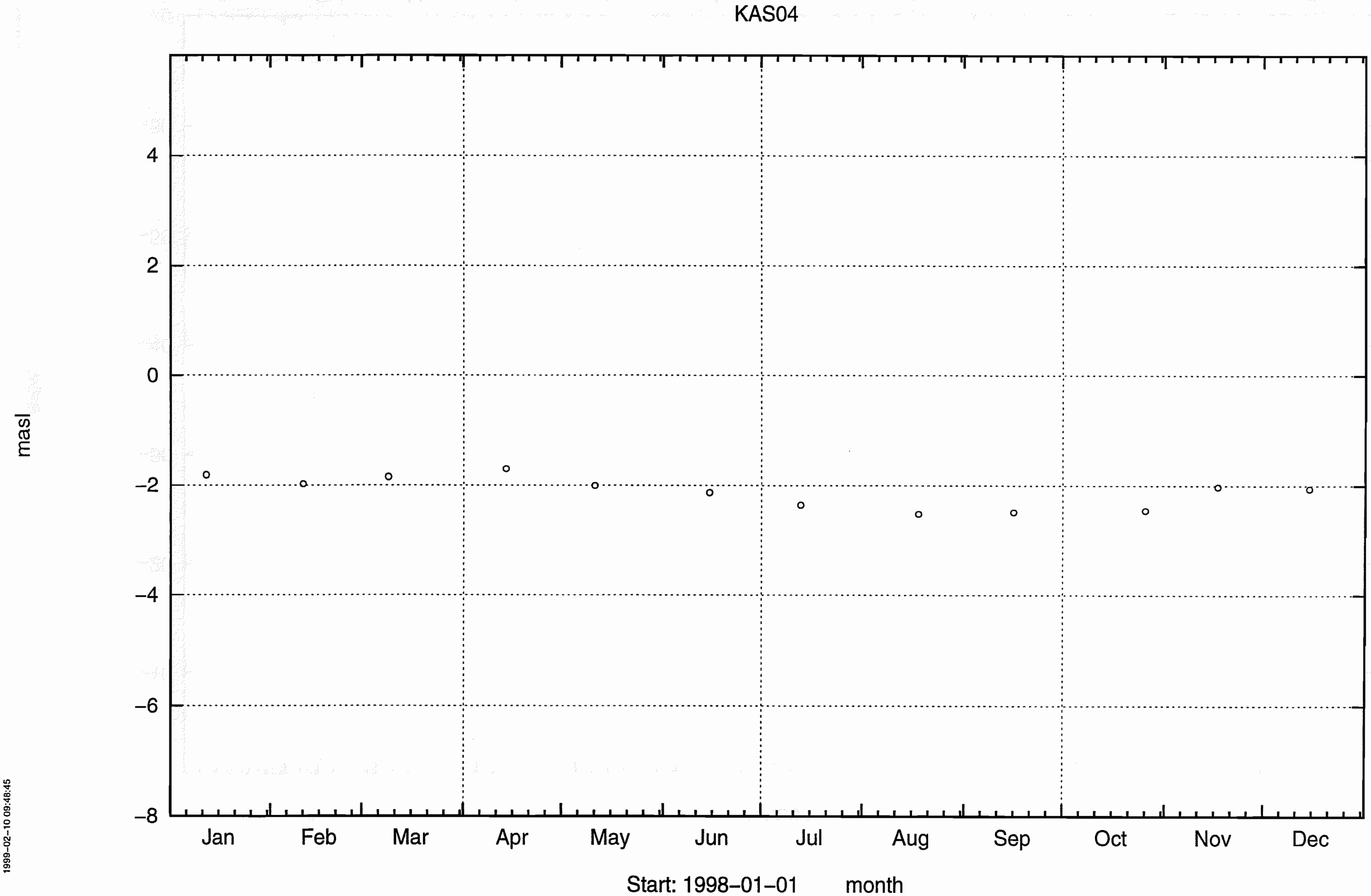

HLX04
masl
10
8
6
4
2
0
−2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01 month
1999−02−10 09:48:44


HLX05
masl
18
16
14
12
10
8
6
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01 month
1999-02-10 09:48:44

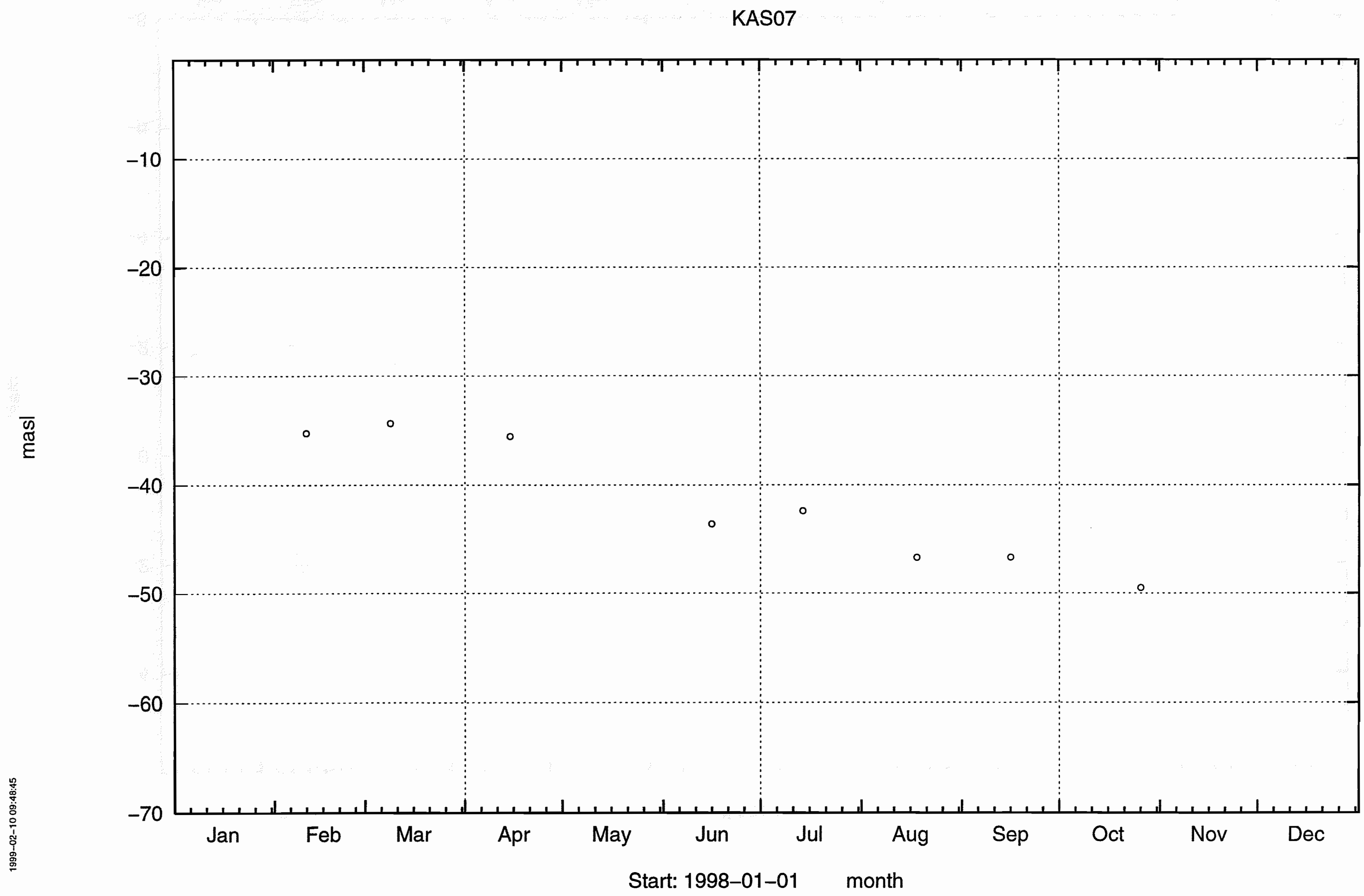

HMJ01
0
-2
-4
-6
-8
-10
-12
masl
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:44

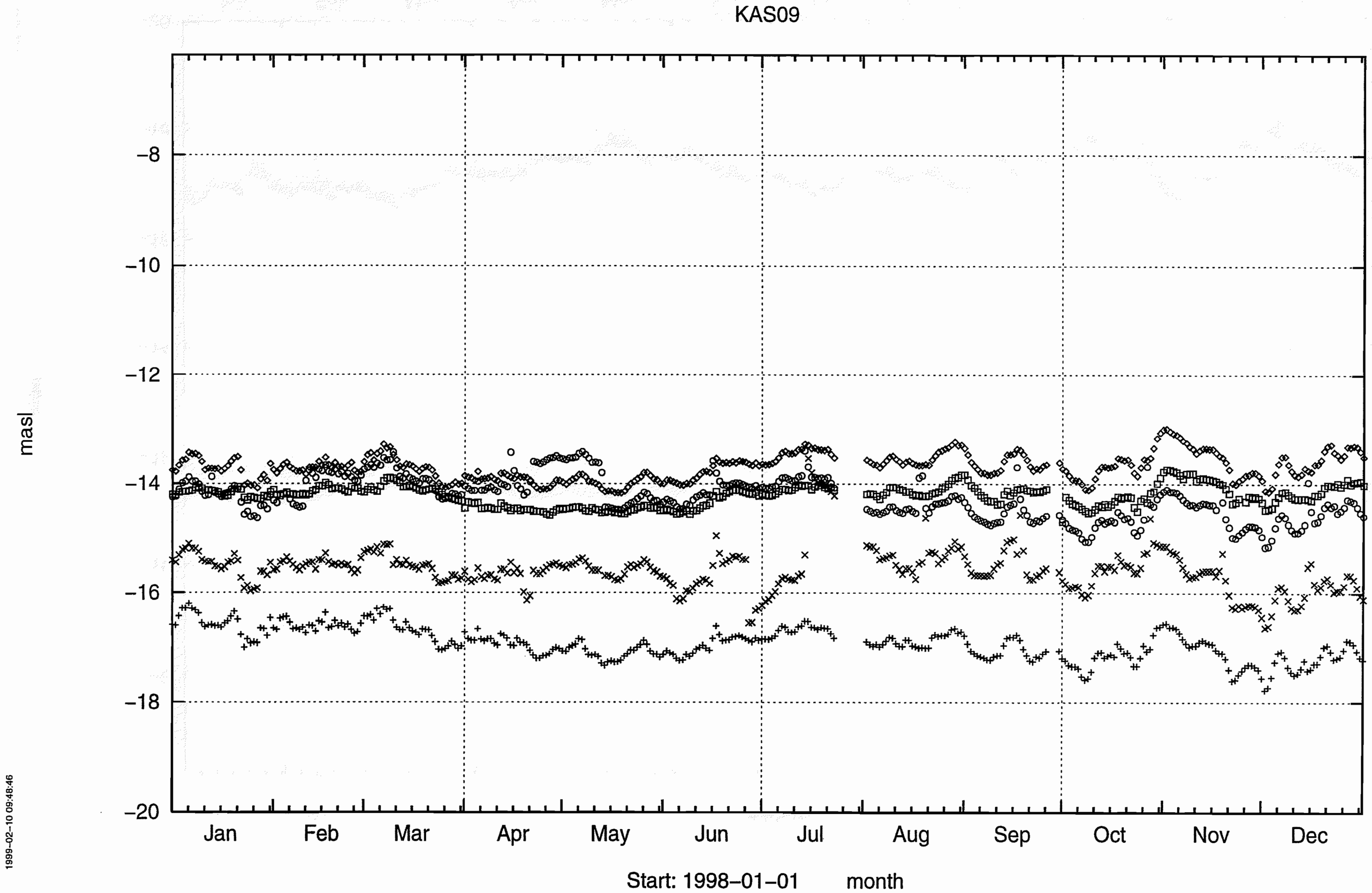

KAS01
masl
-70
-75
-80
-85
-90
-95
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:45

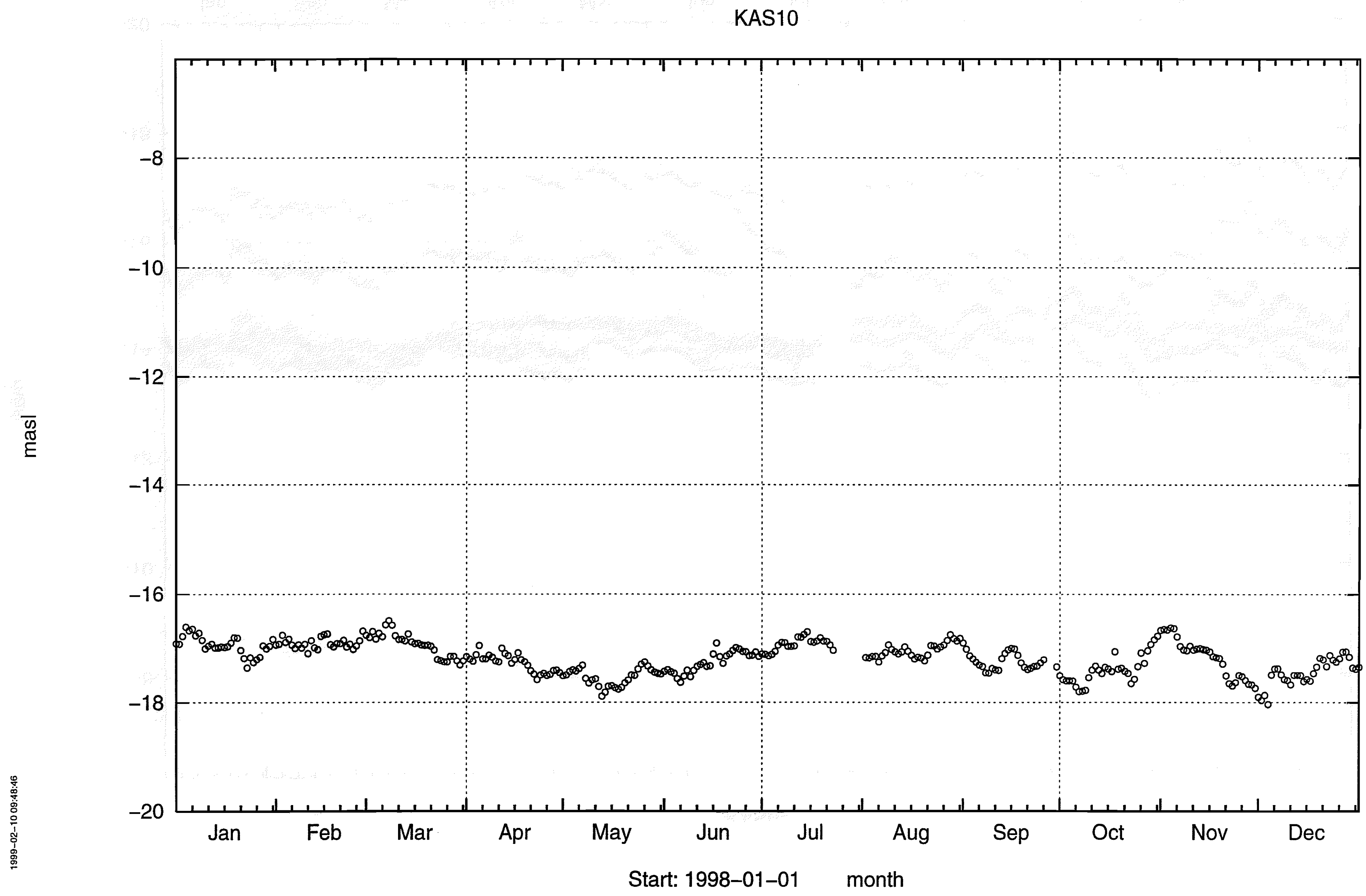

KAS03
masl
5
0
-5
-10
-15
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:45

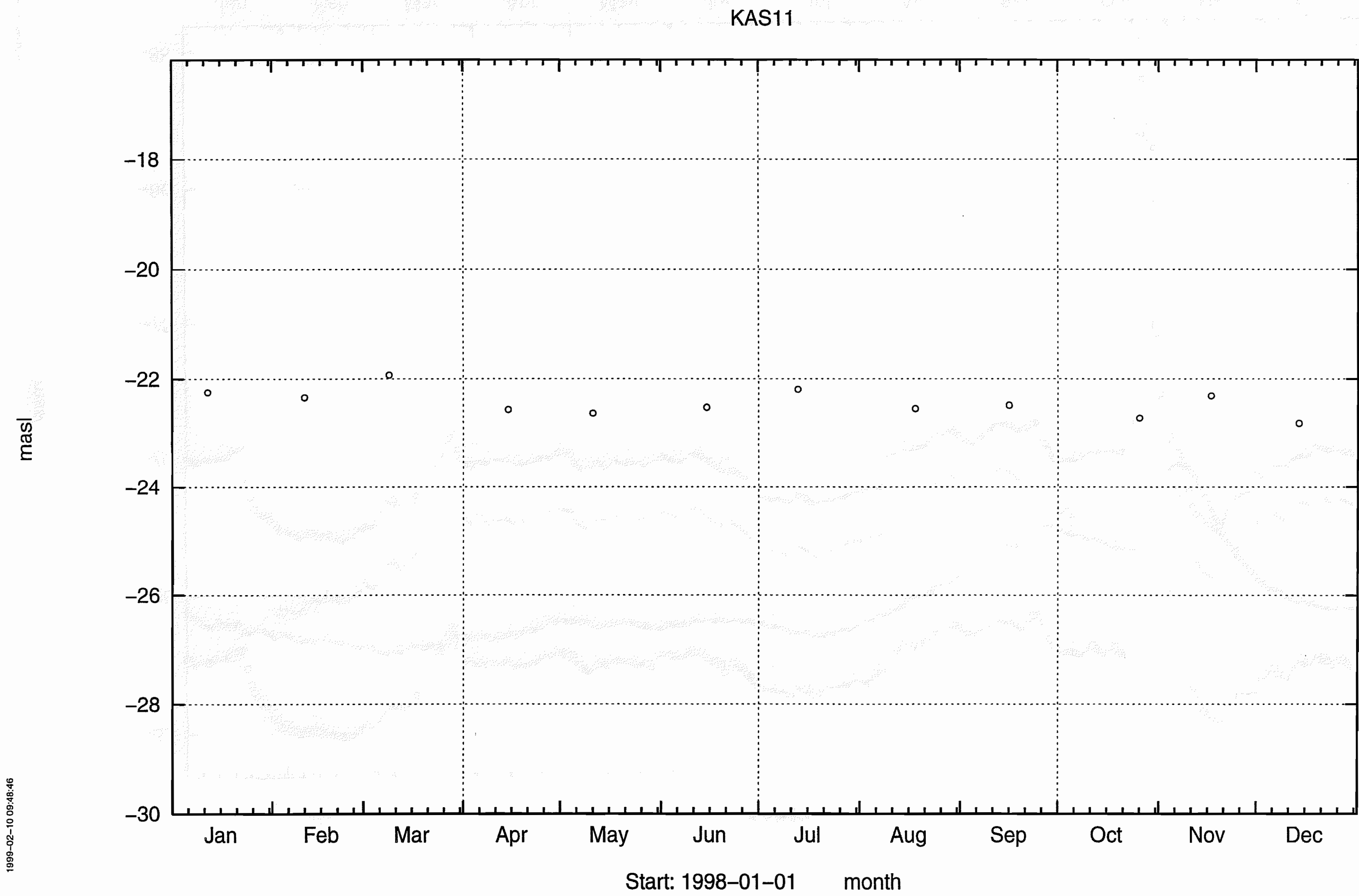


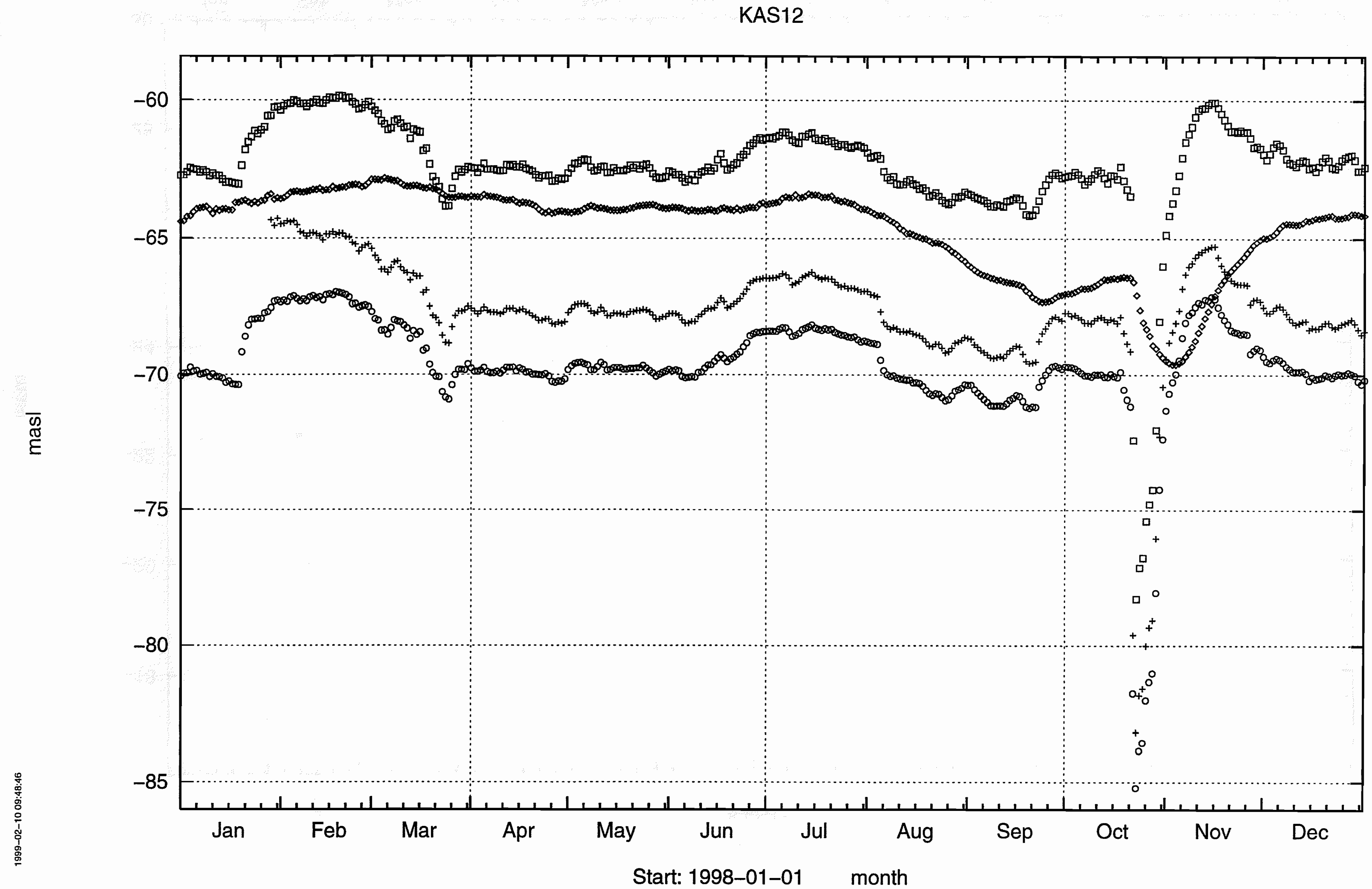
KAS04
masl
4
2
0
-2
-4
-6
-8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:45

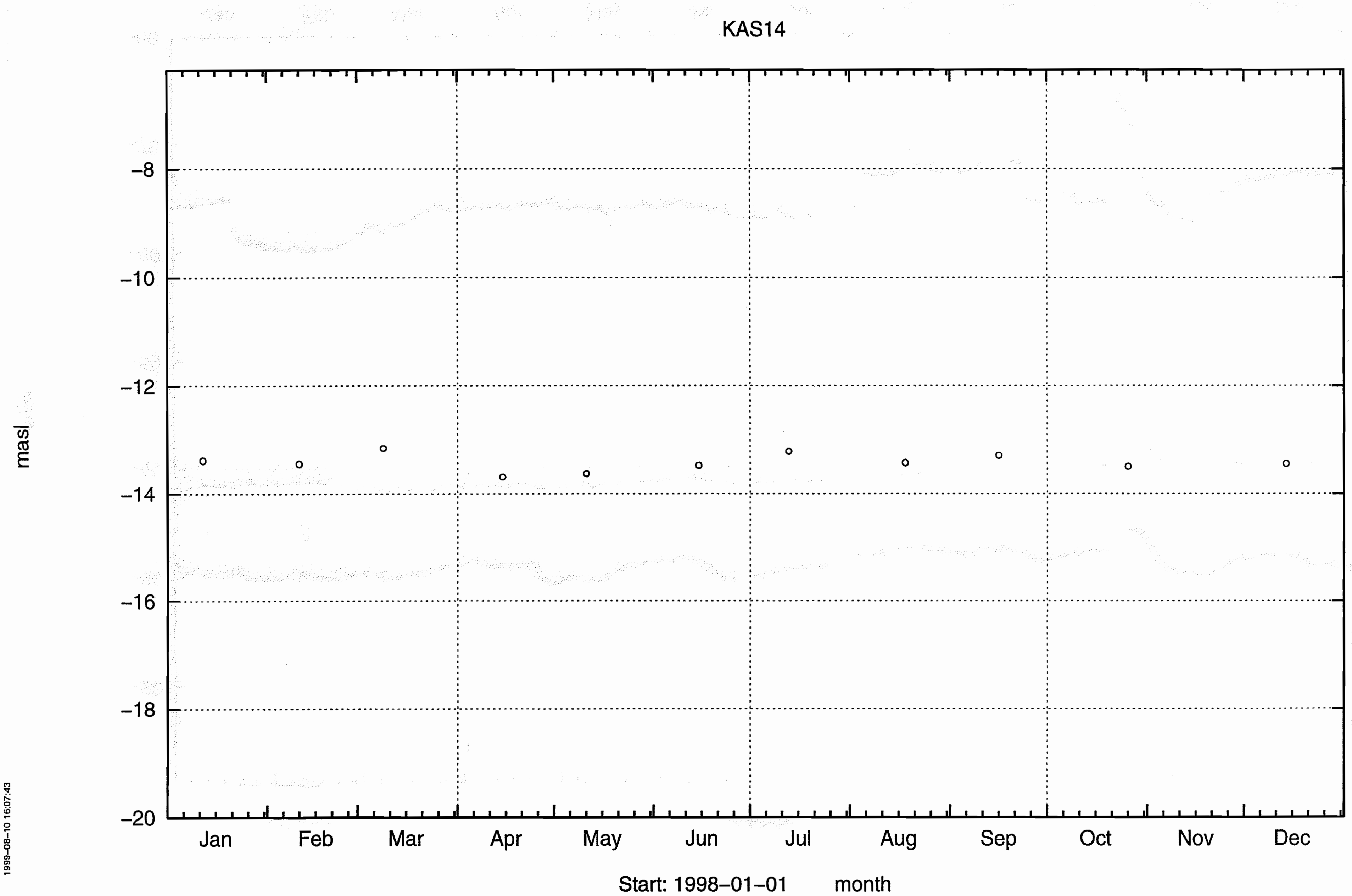

KAS07
masl
-10
-20
-30
-40
-50
-60
-70
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:45


KAS09
masl
-8
-10
-12
-14
-16
-18
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-10 09:48:46

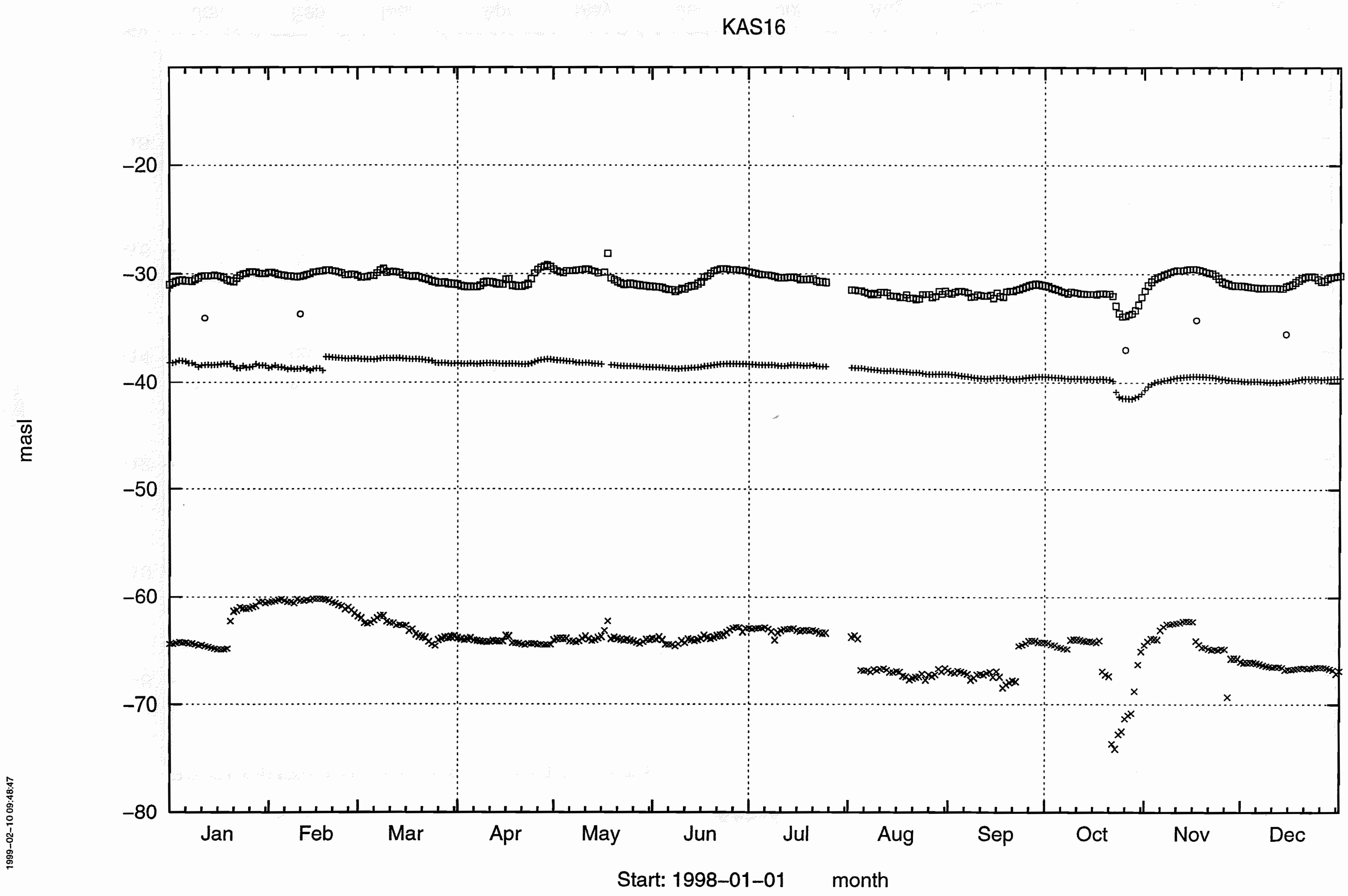

KAS10
masl
-8
-10
-12
-14
-16
-18
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:46


KAS11
masl
-18
-20
-22
-24
-26
-28
-30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:46

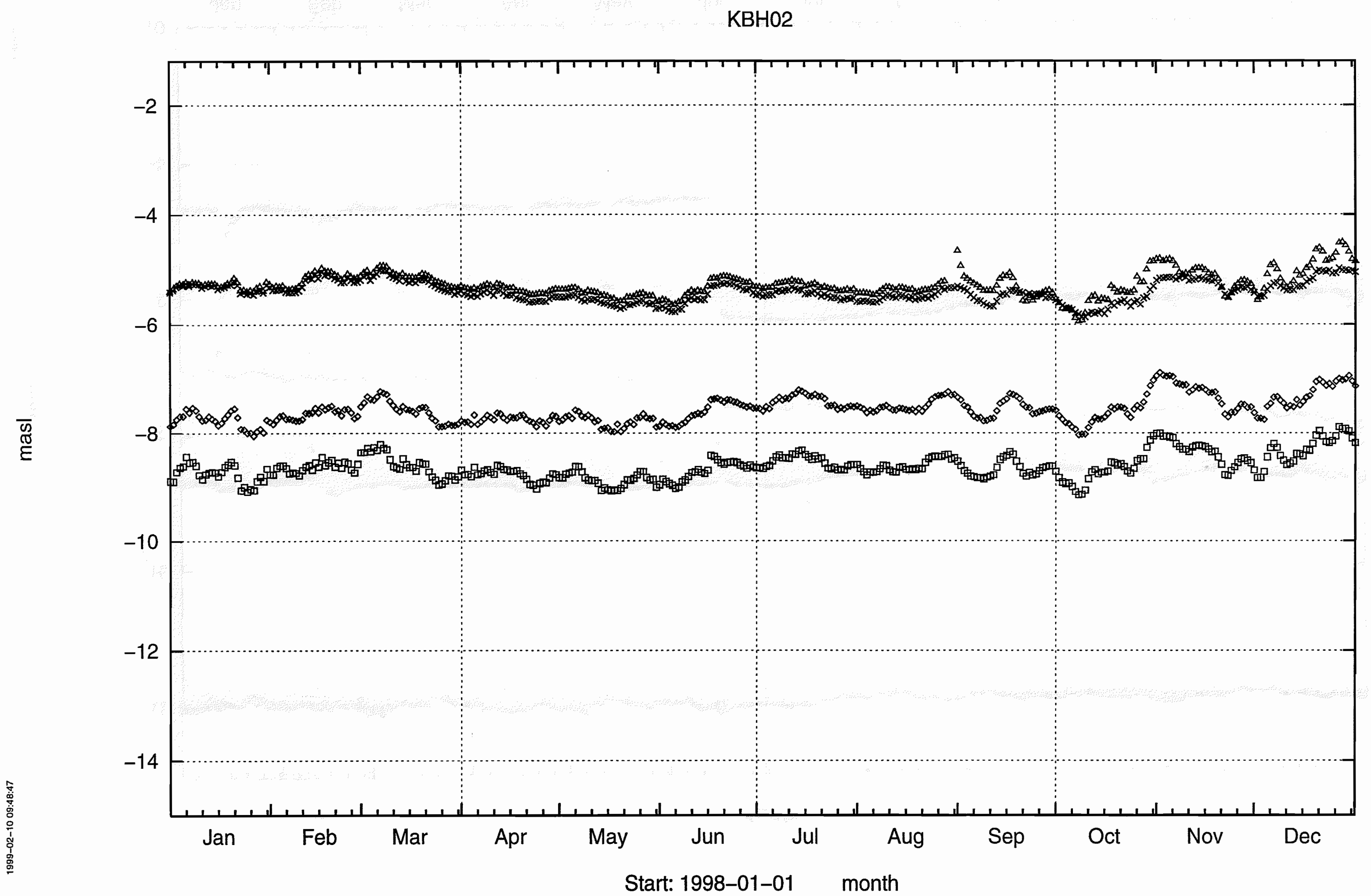

KAS12
masl
-60
-65
-70
-75
-80
-85
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-10 09:48:46

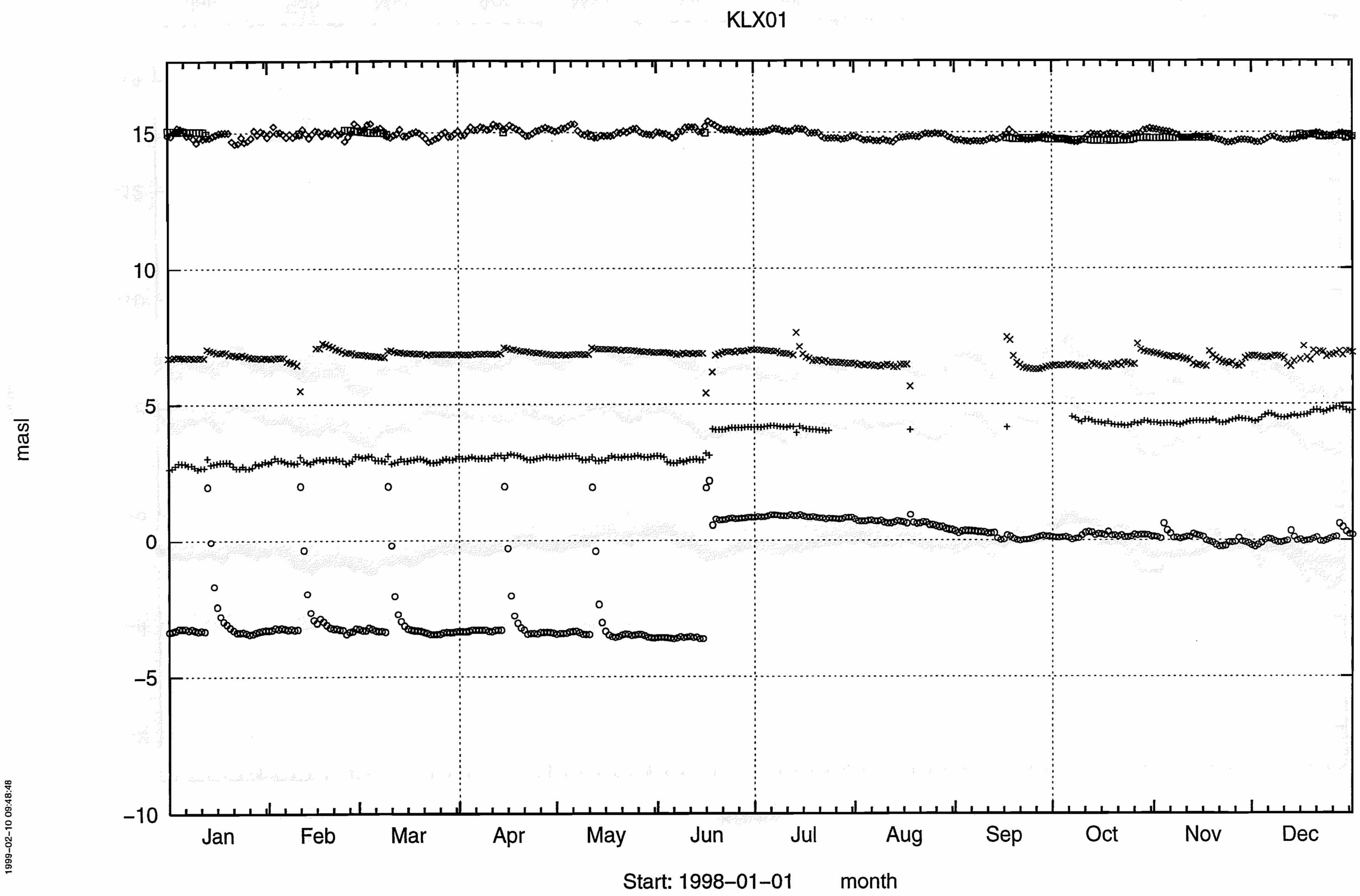


1999-08-10 16:07:43



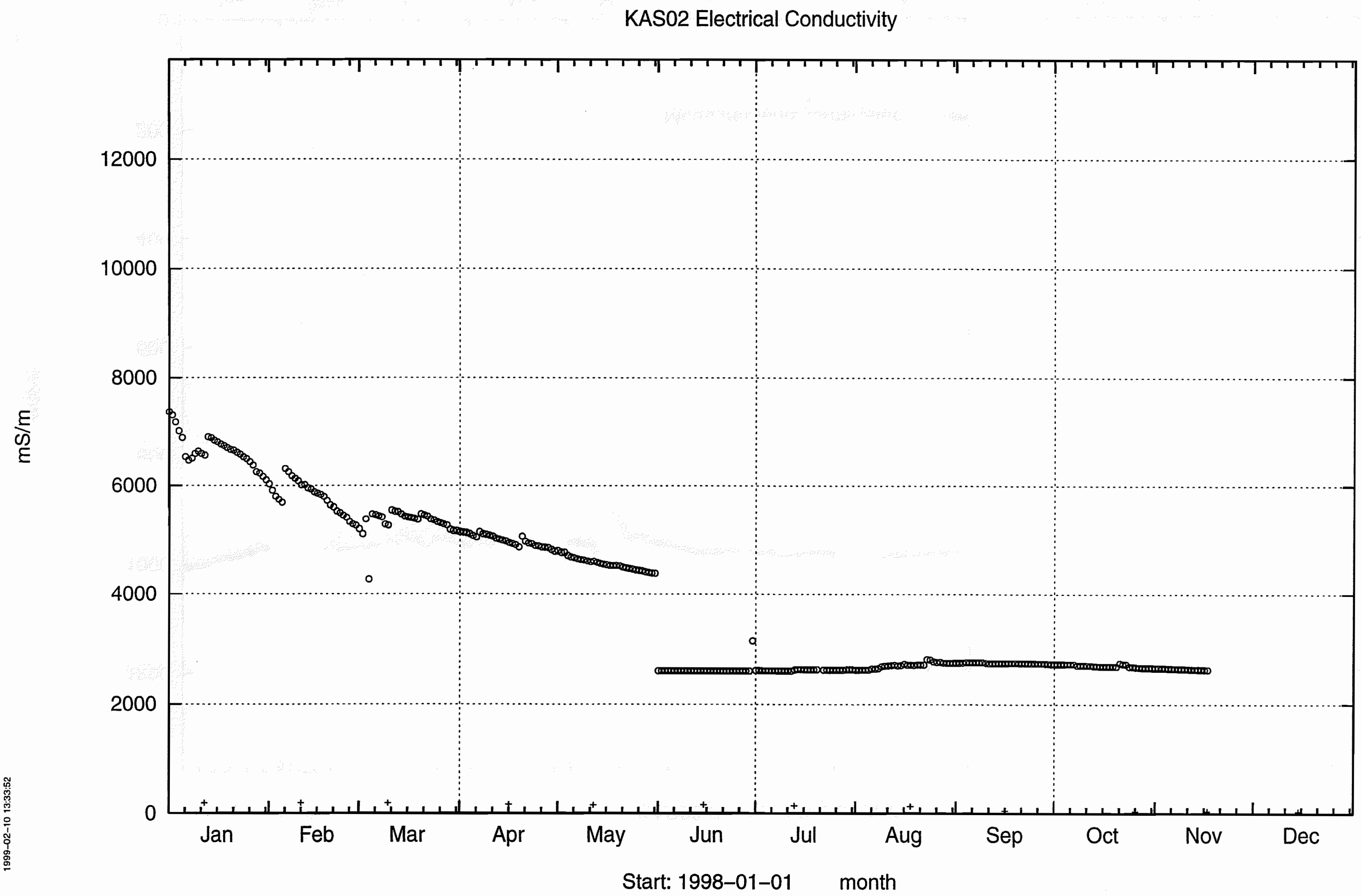
KAS16
masl
-20
-30
-40
-50
-60
-70
-80
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:47


KBH02
-2
-4
-6
-8
-10
-12
-14
masl
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 09:48:47

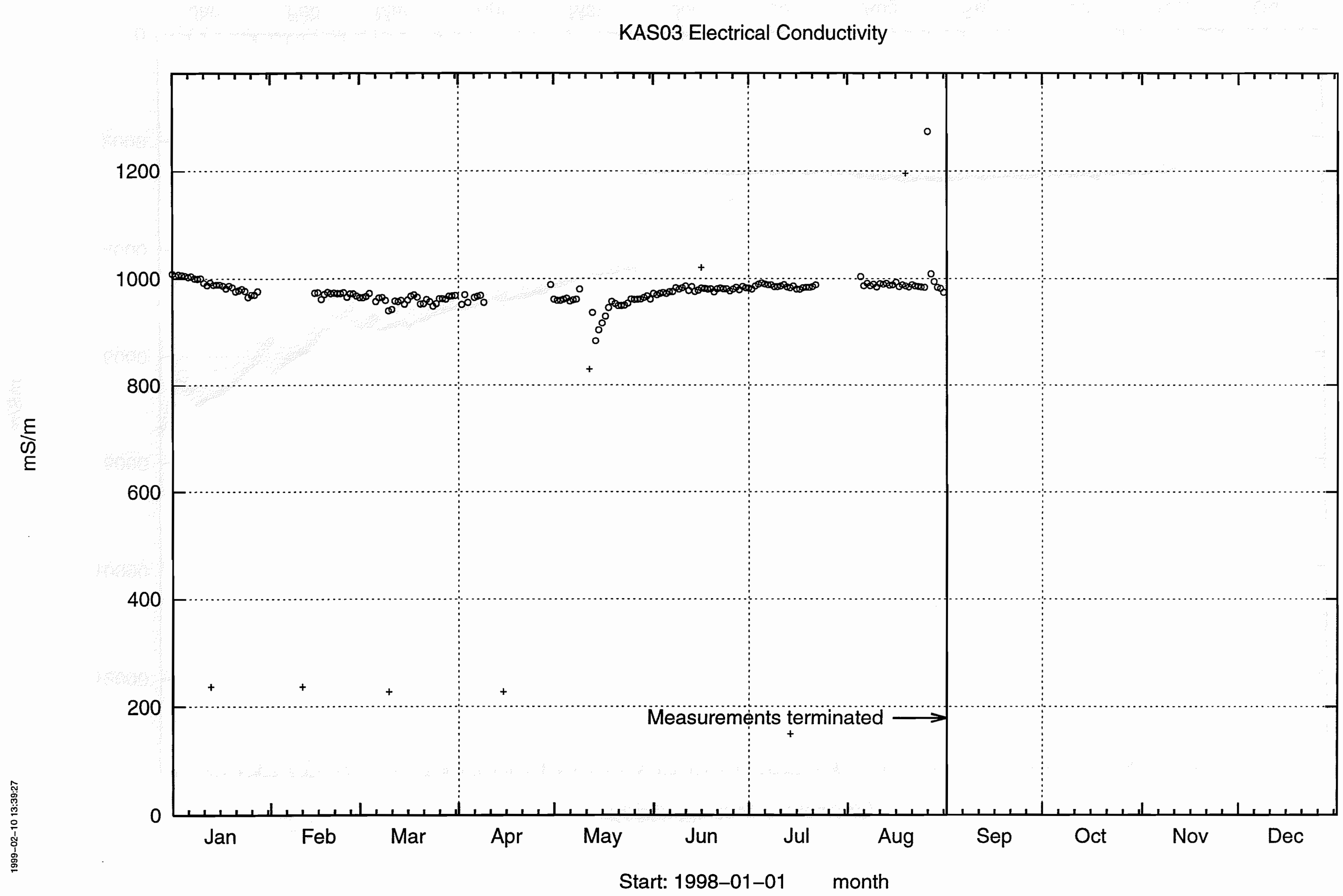


KLX01
masl
15
10
5
0
−5
−10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01 month
1999−02−10 09:48:48

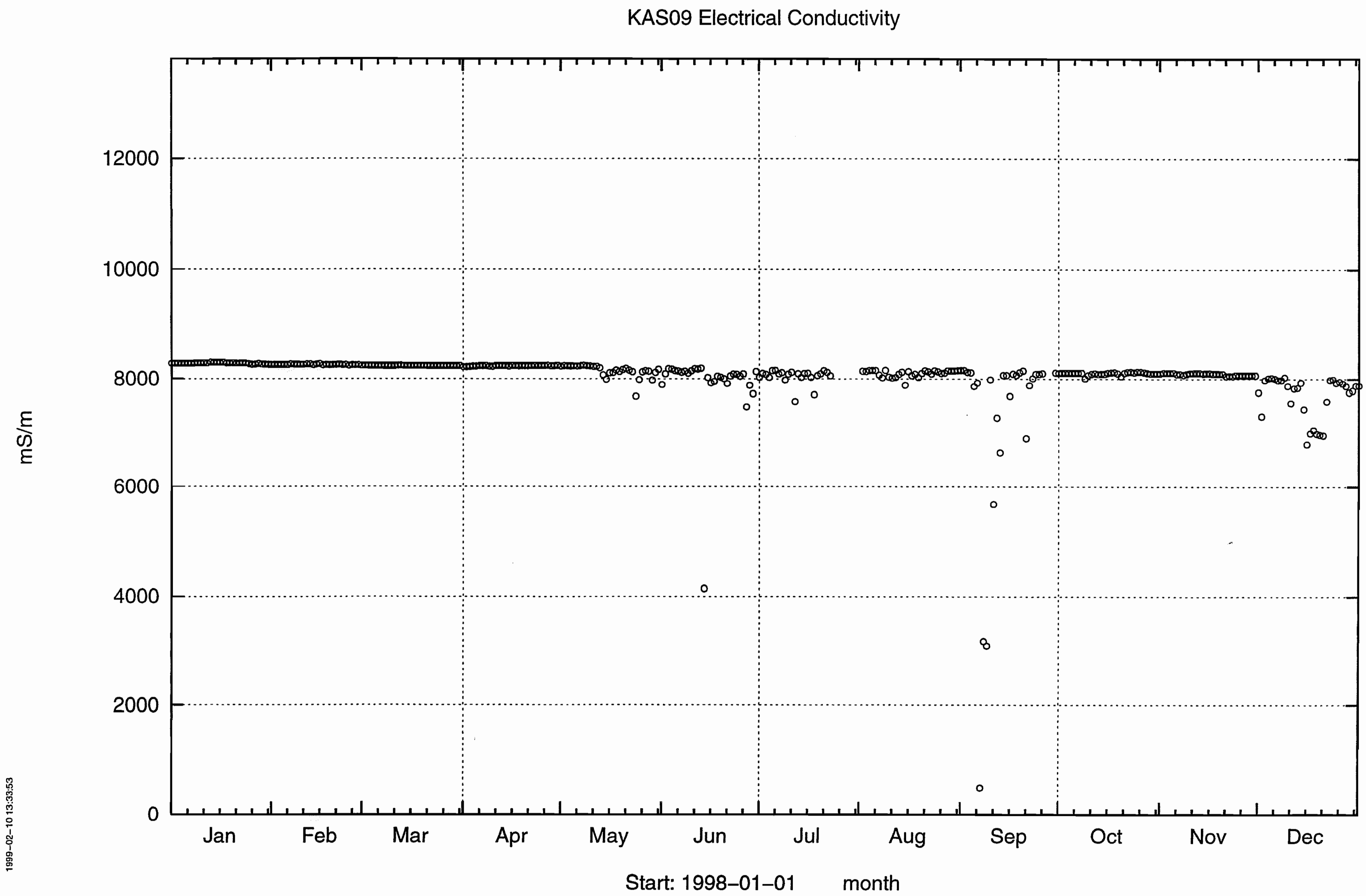
Appendix 3: Electrical conductivity in surface boreholes



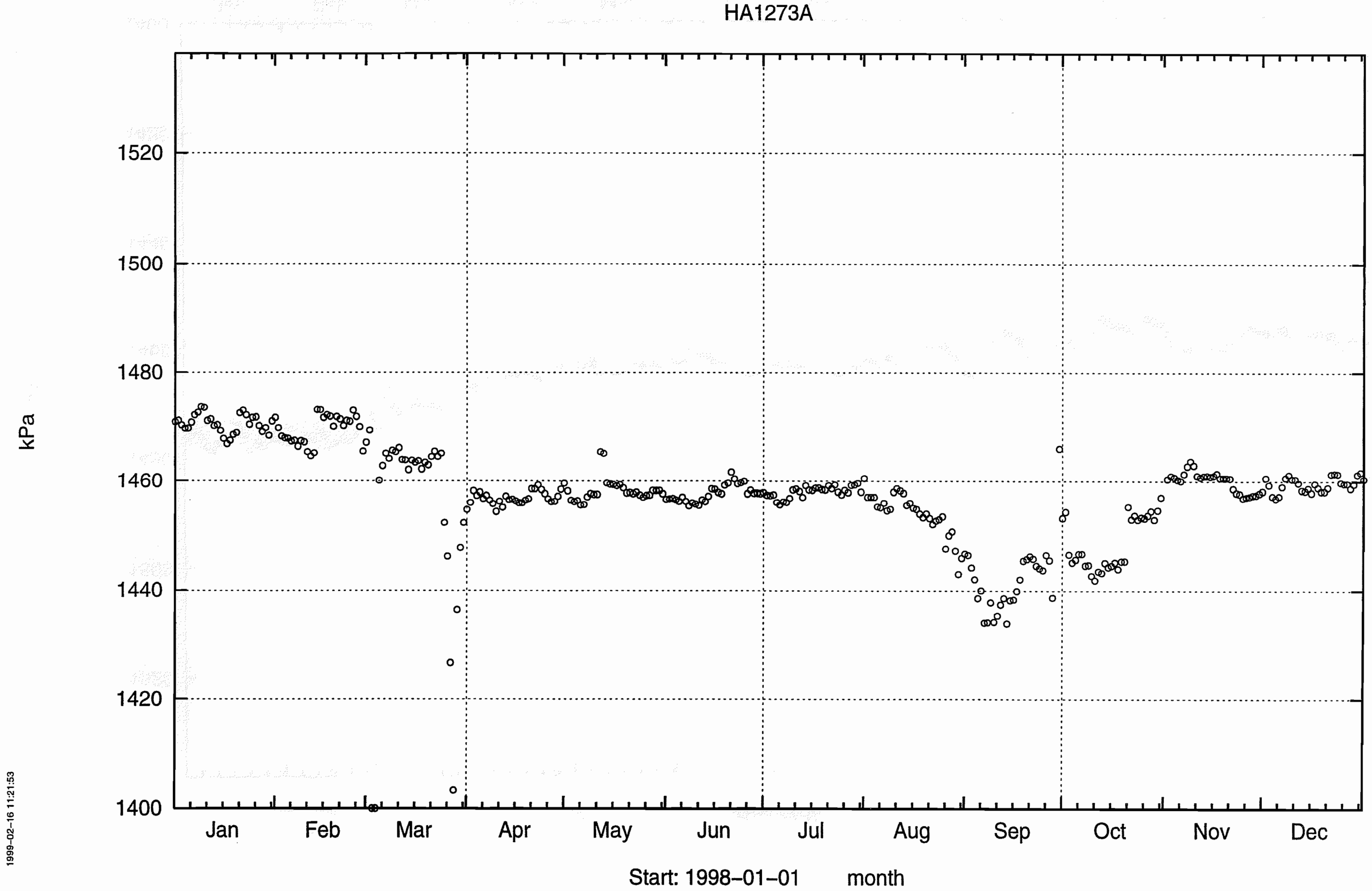
KAS02 Electrical Conductivity
mS/m
12000
10000
8000
6000
4000
2000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-10 13:33:52

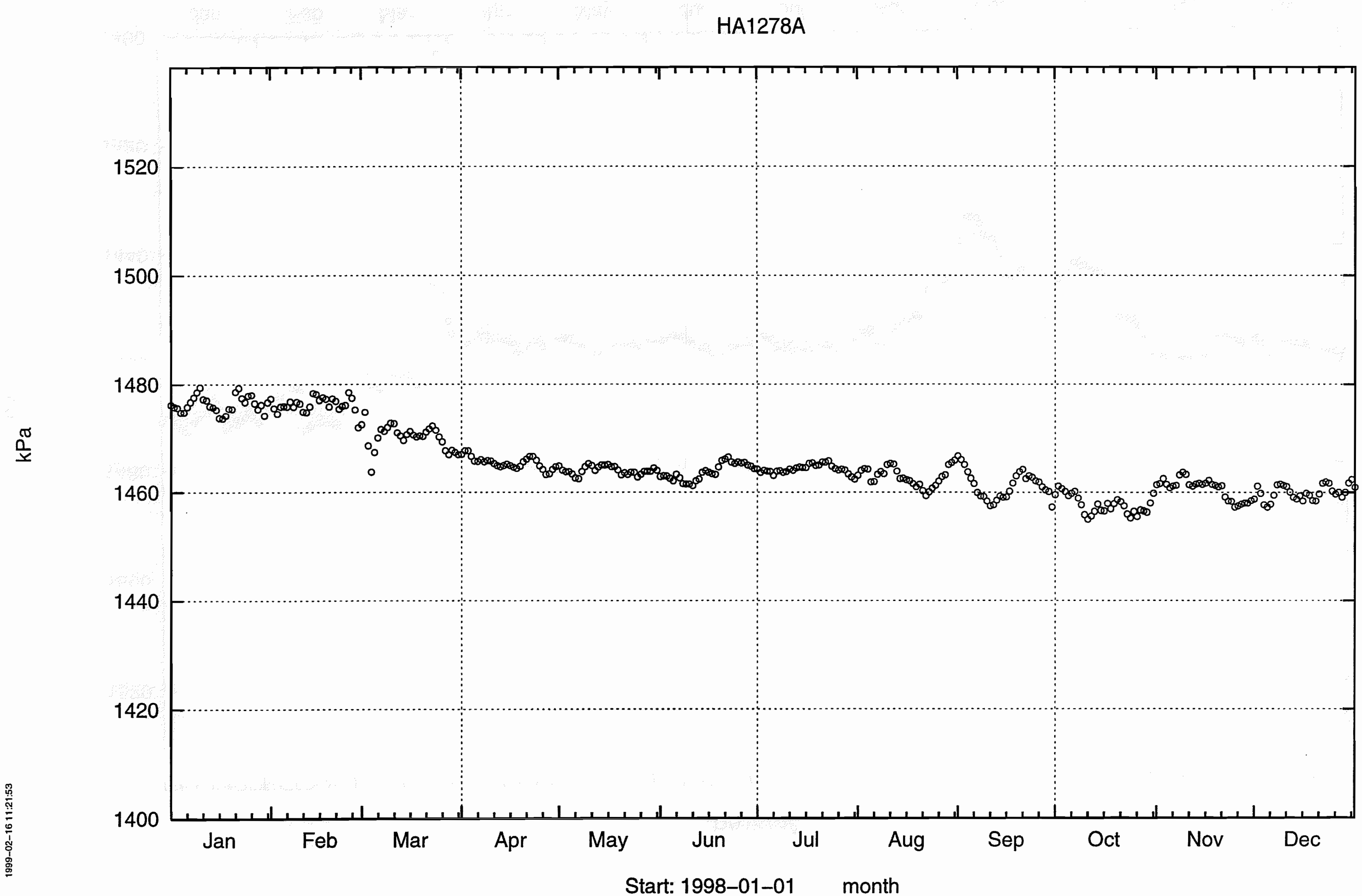


KAS03 Electrical Conductivity
mS/m
1200
1000
800
600
400
200
0
Measurements terminated
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–02–10 13:39:27

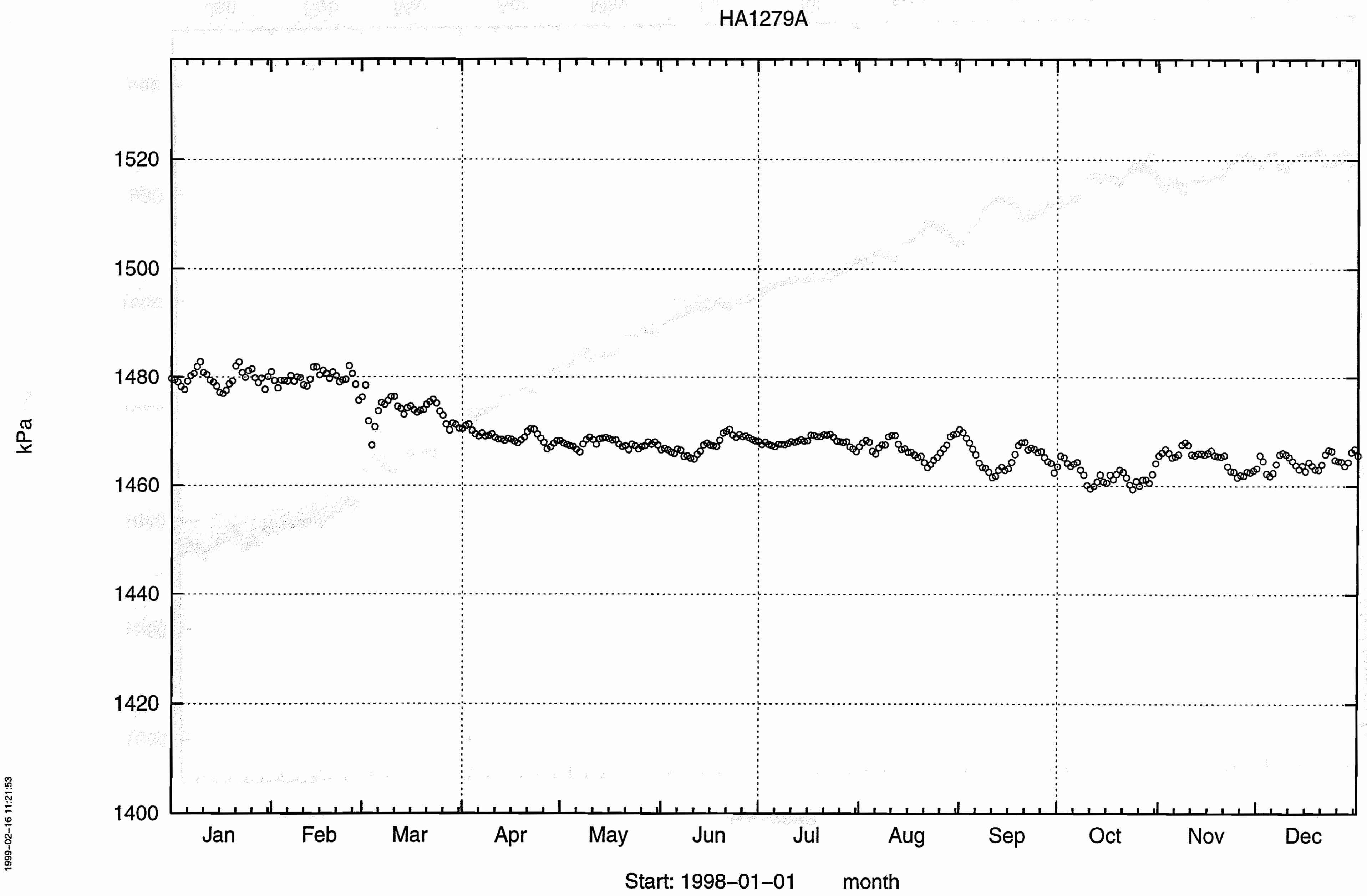

KAS09 Electrical Conductivity
mS/m
12000
10000
8000
6000
4000
2000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-10 13:33:53

Appendix 4: Groundwater pressure in tunnel boreholes

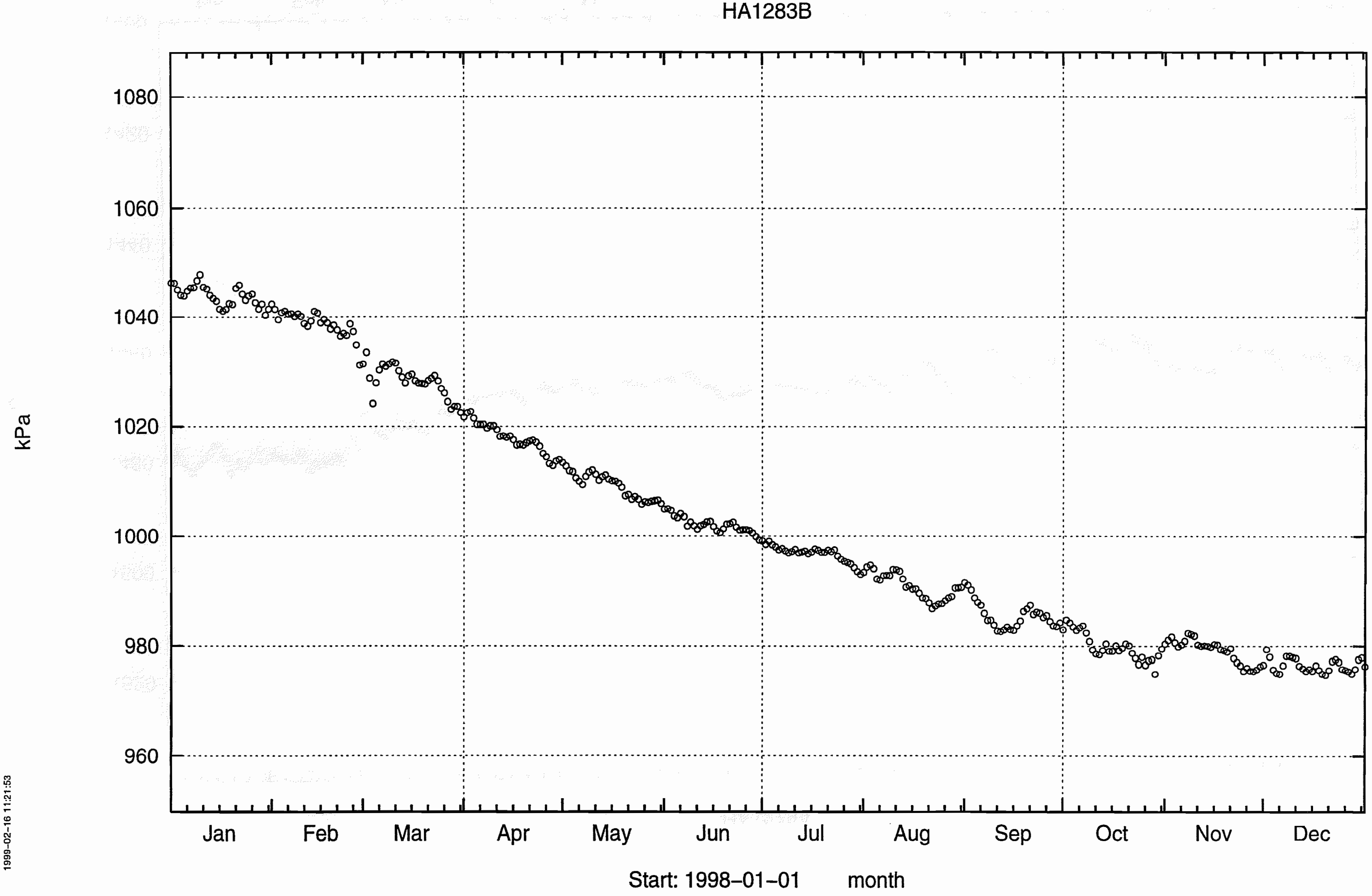

HA1273A
kPa
1520
1500
1480
1460
1440
1420
1400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:53



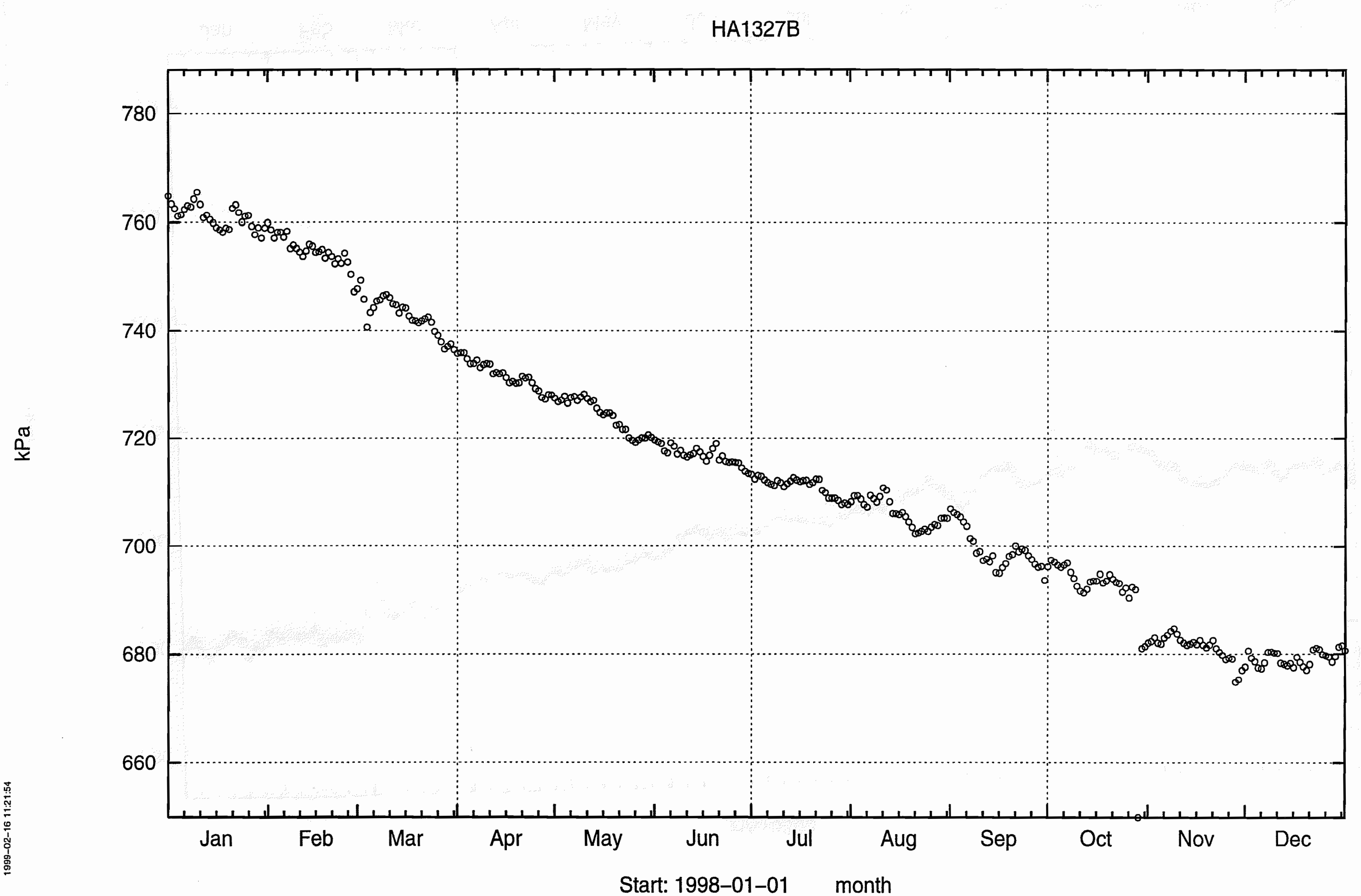
HA1278A
kPa
1520
1500
1480
1460
1440
1420
1400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:53

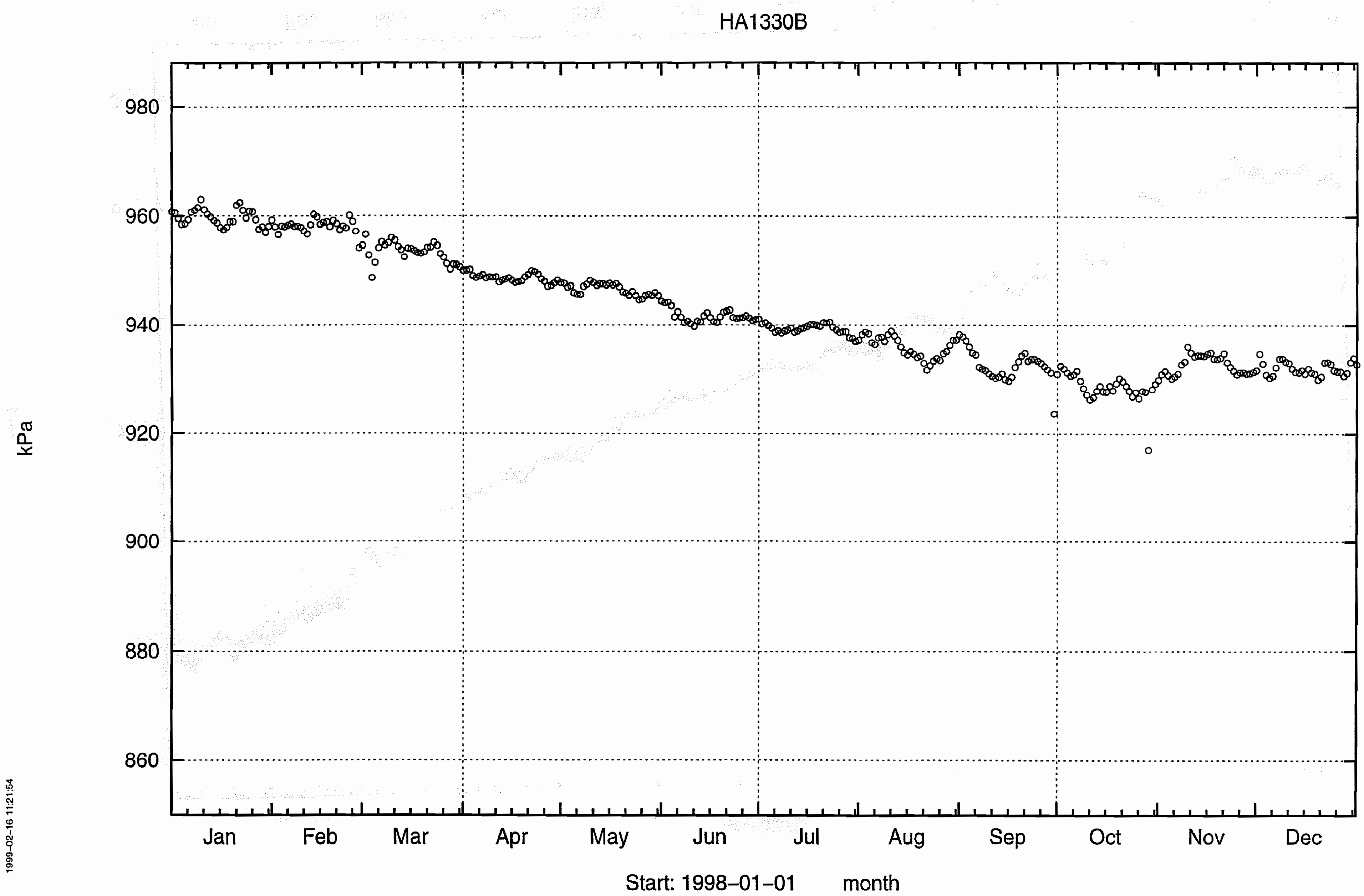


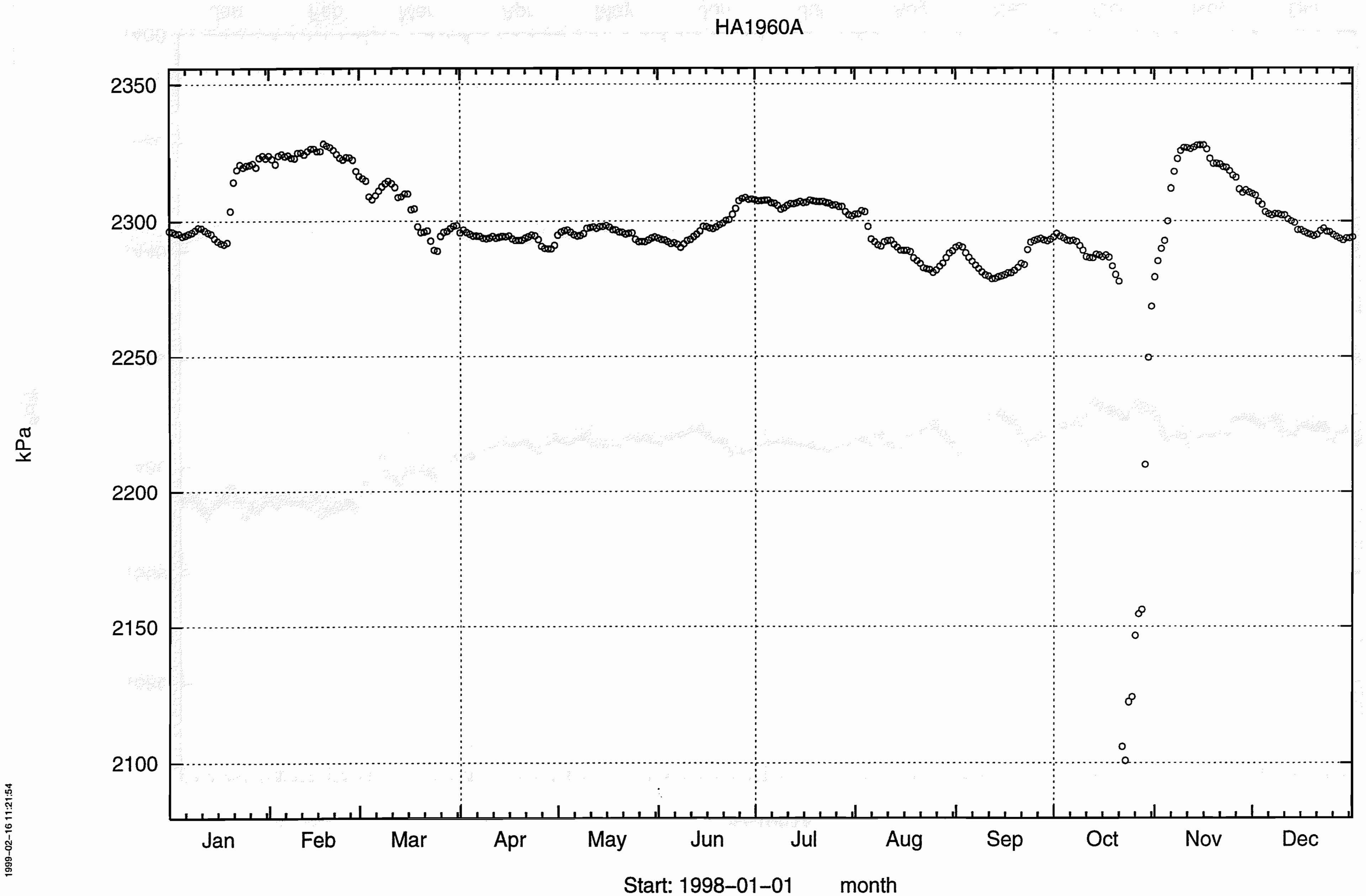
HA1279A
kPa
1520
1500
1480
1460
1440
1420
1400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:53



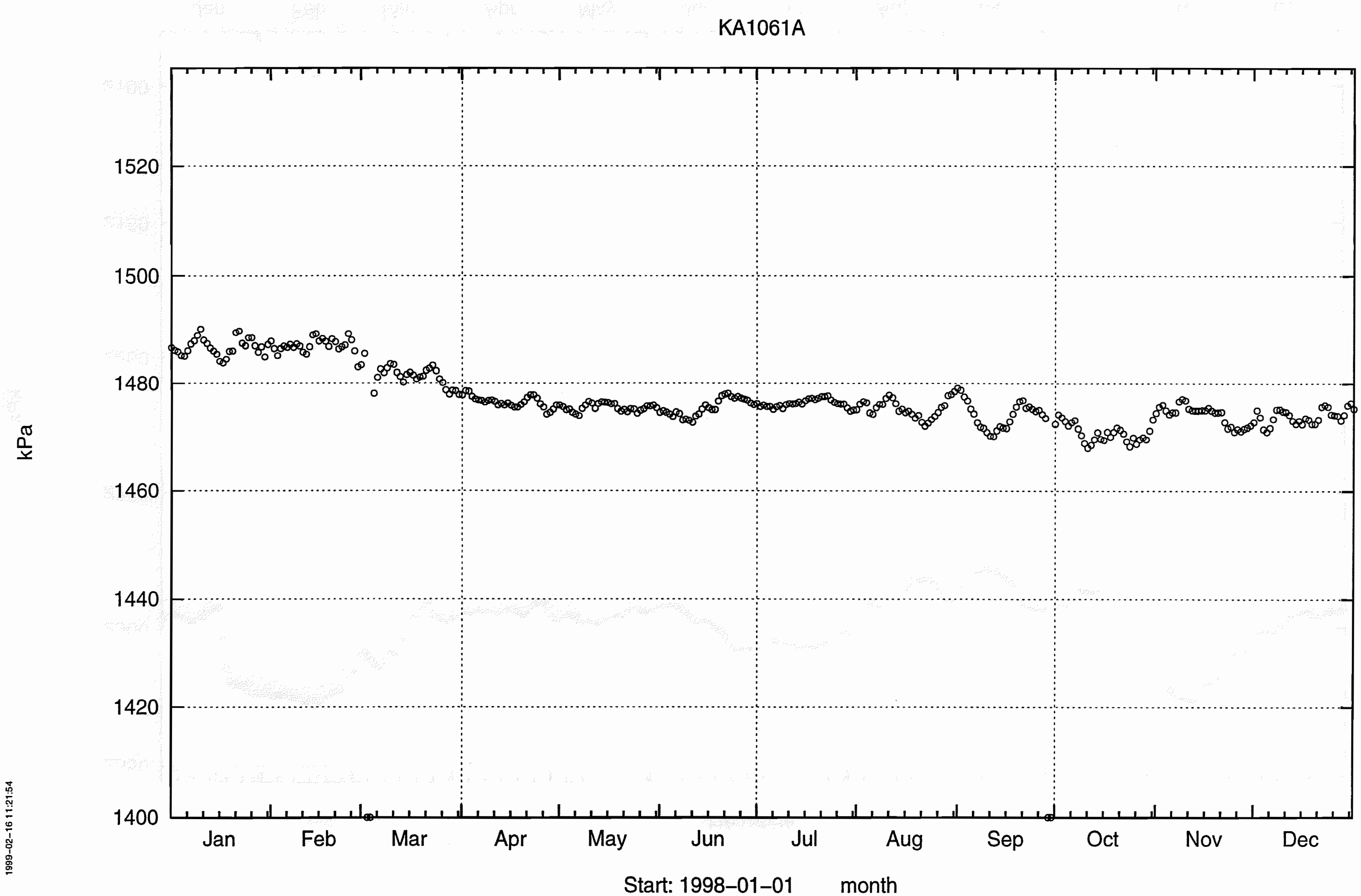
1999–02–16 11:21:53

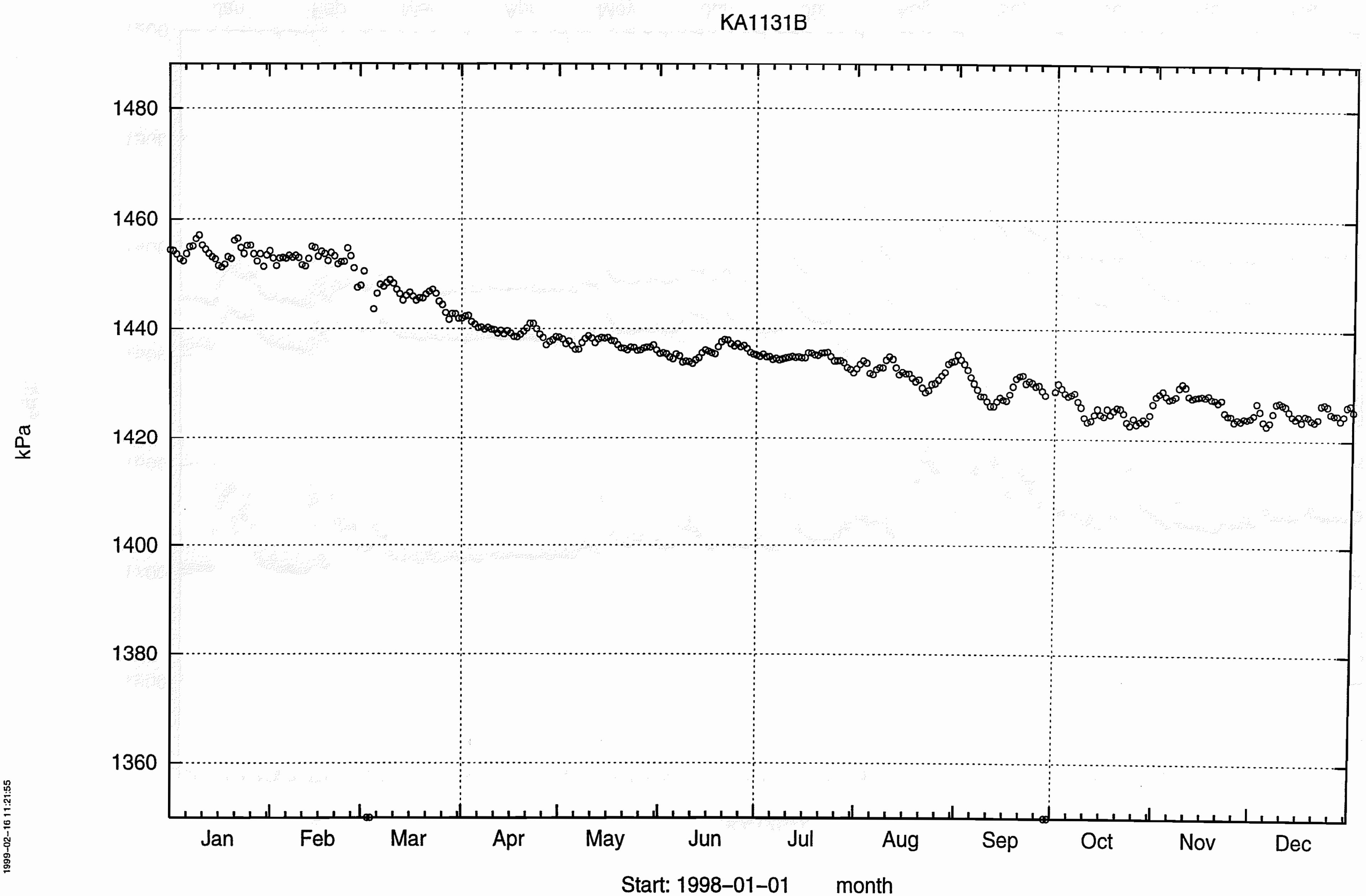

HA1327B
kPa
780
760
740
720
700
680
660
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:54


HA1330B
kPa
980
960
940
920
900
880
860
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–02–16 11:21:54

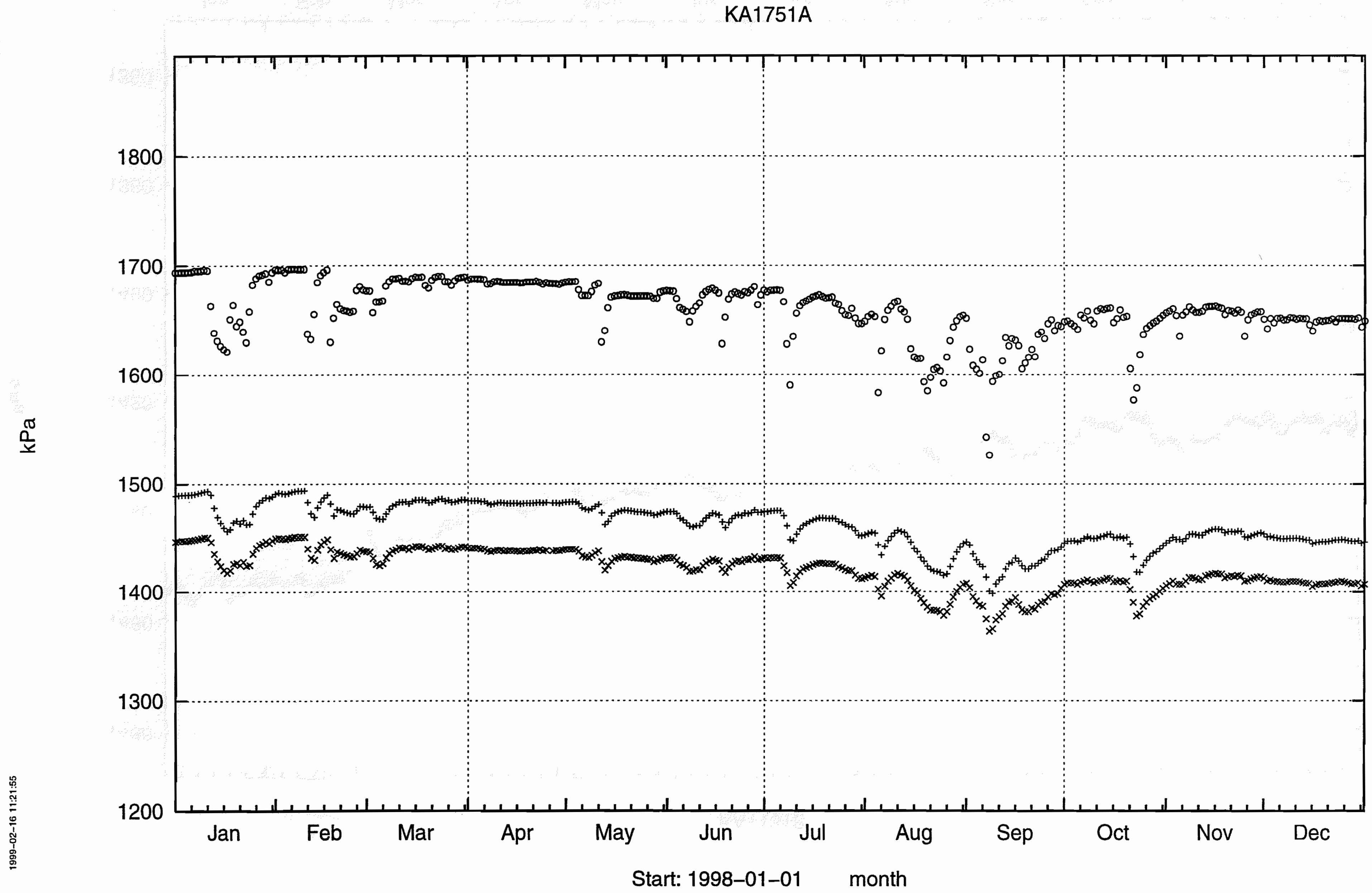


HA1960A
kPa
2350
2300
2250
2200
2150
2100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-16 11:21:54

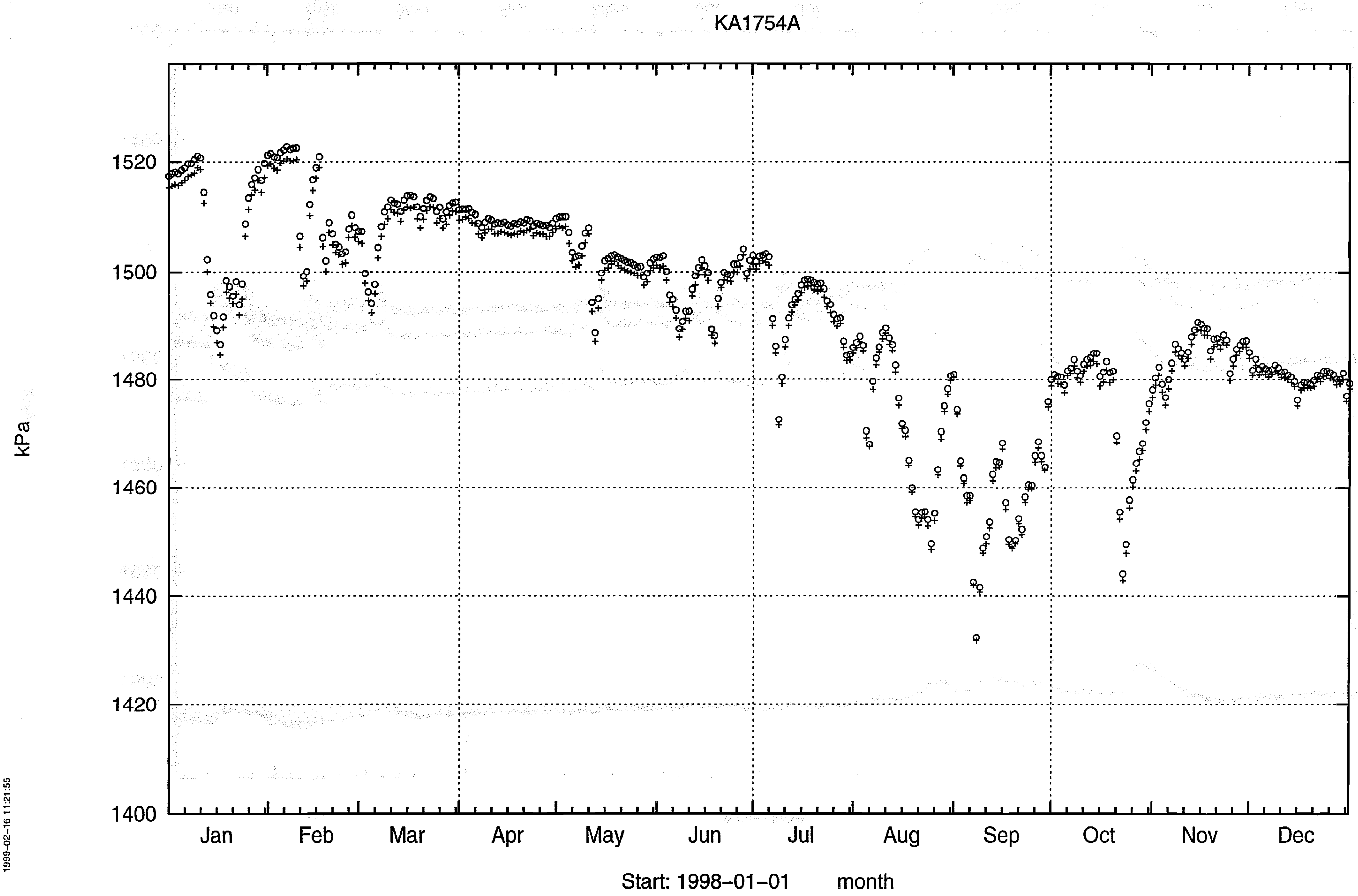

KA1061A
kPa
1520
1500
1480
1460
1440
1420
1400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-16 11:21:54



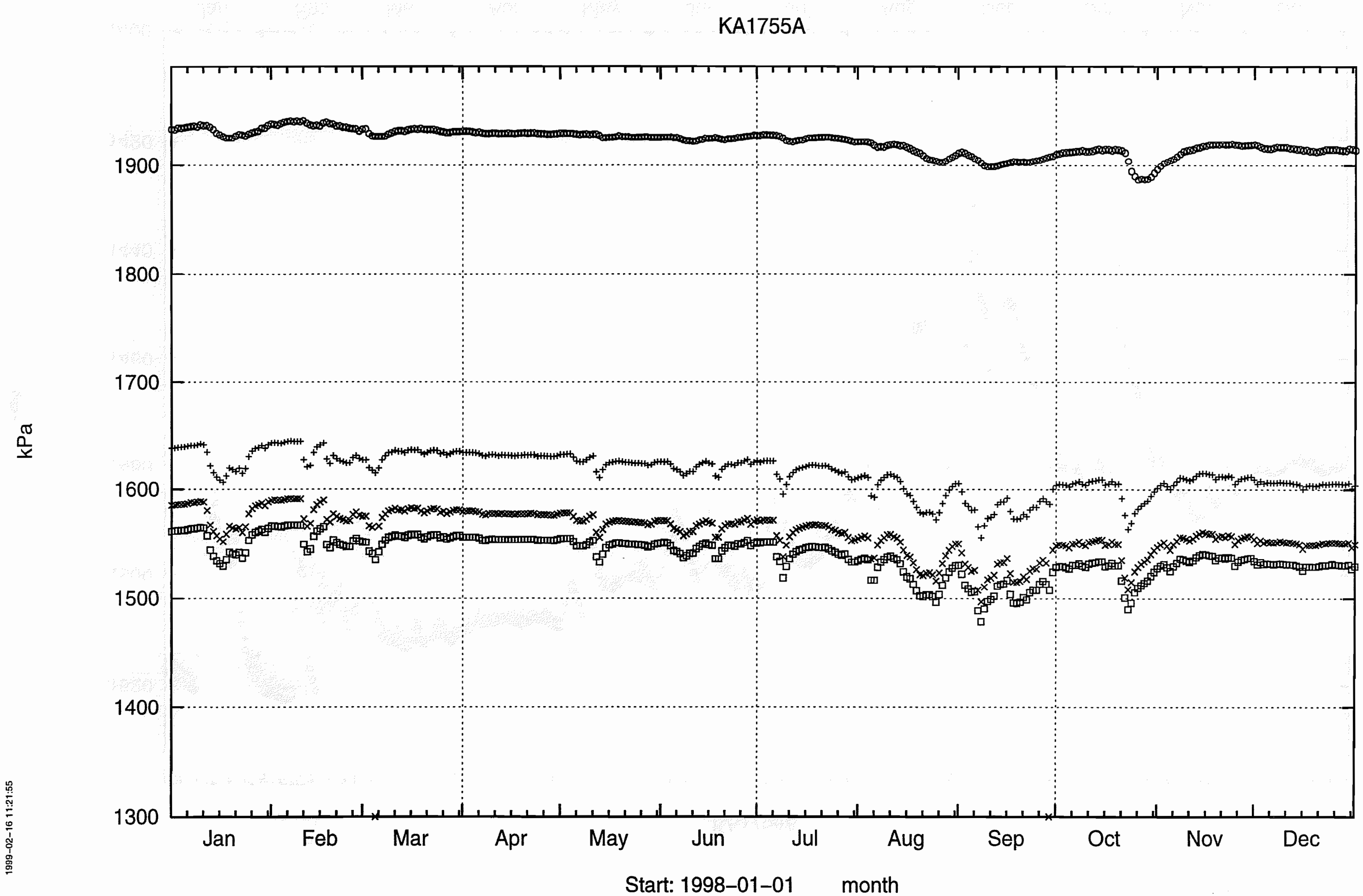
KA1131B
1480
1460
1440
1420
1400
1380
1360
kPa
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-16 11:21:55



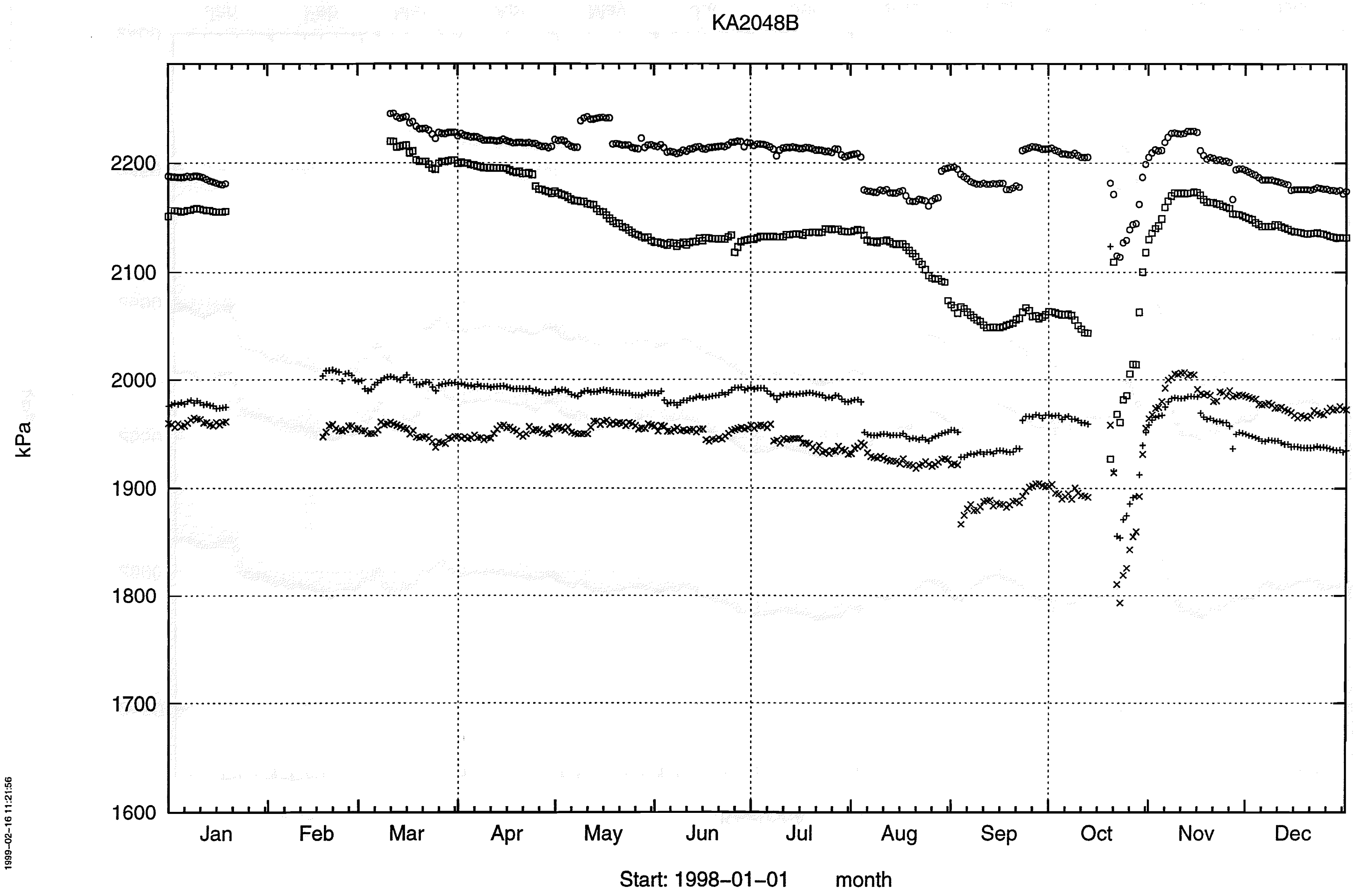
KA1751A
kPa
1800
1700
1600
1500
1400
1300
1200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-16 11:21:55



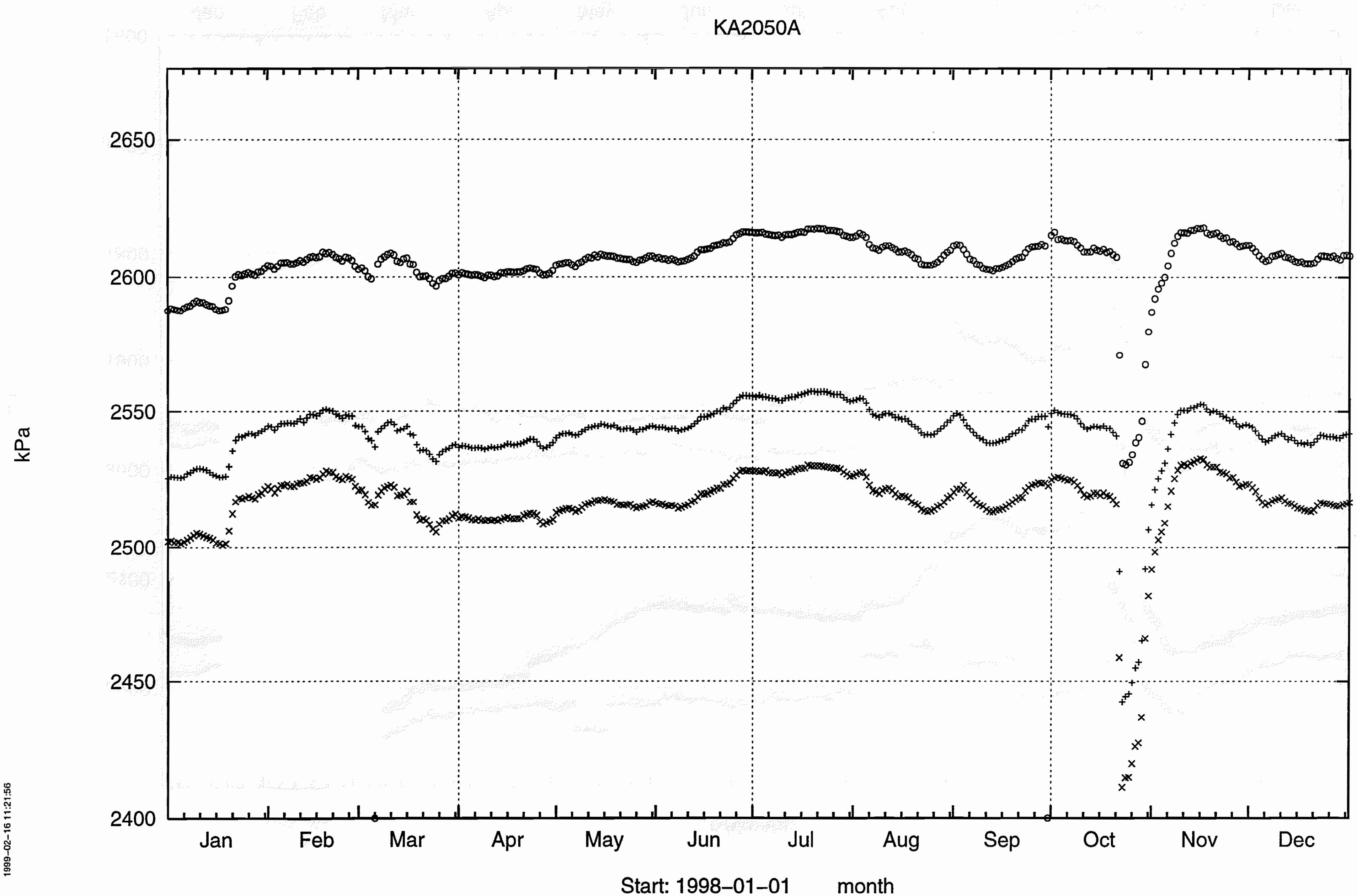
KA1754A
kPa
1520
1500
1480
1460
1440
1420
1400
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:55



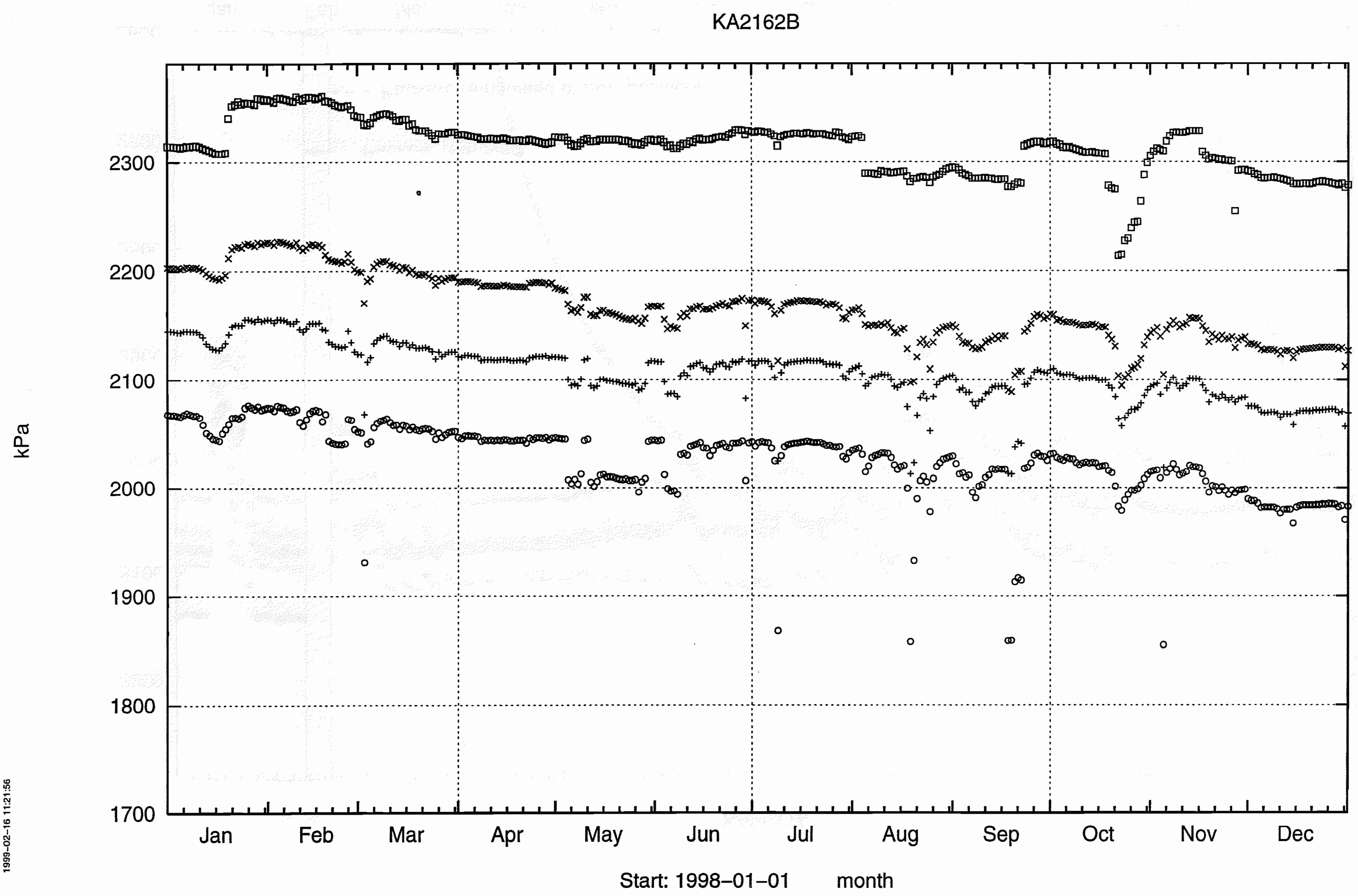
1999-02-16 11:21:55



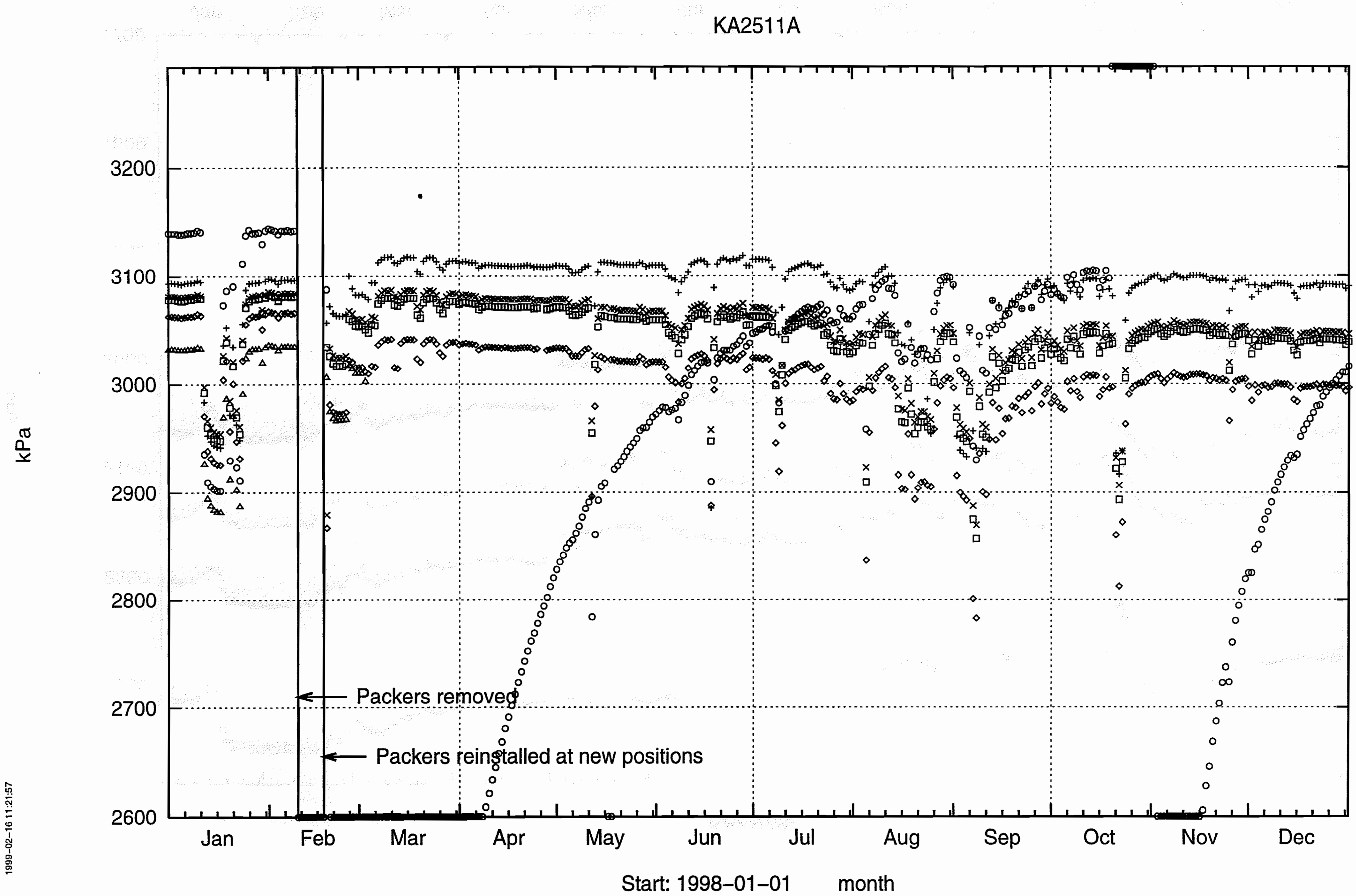
KA2048B
kPa
2200
2100
2000
1900
1800
1700
1600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:56

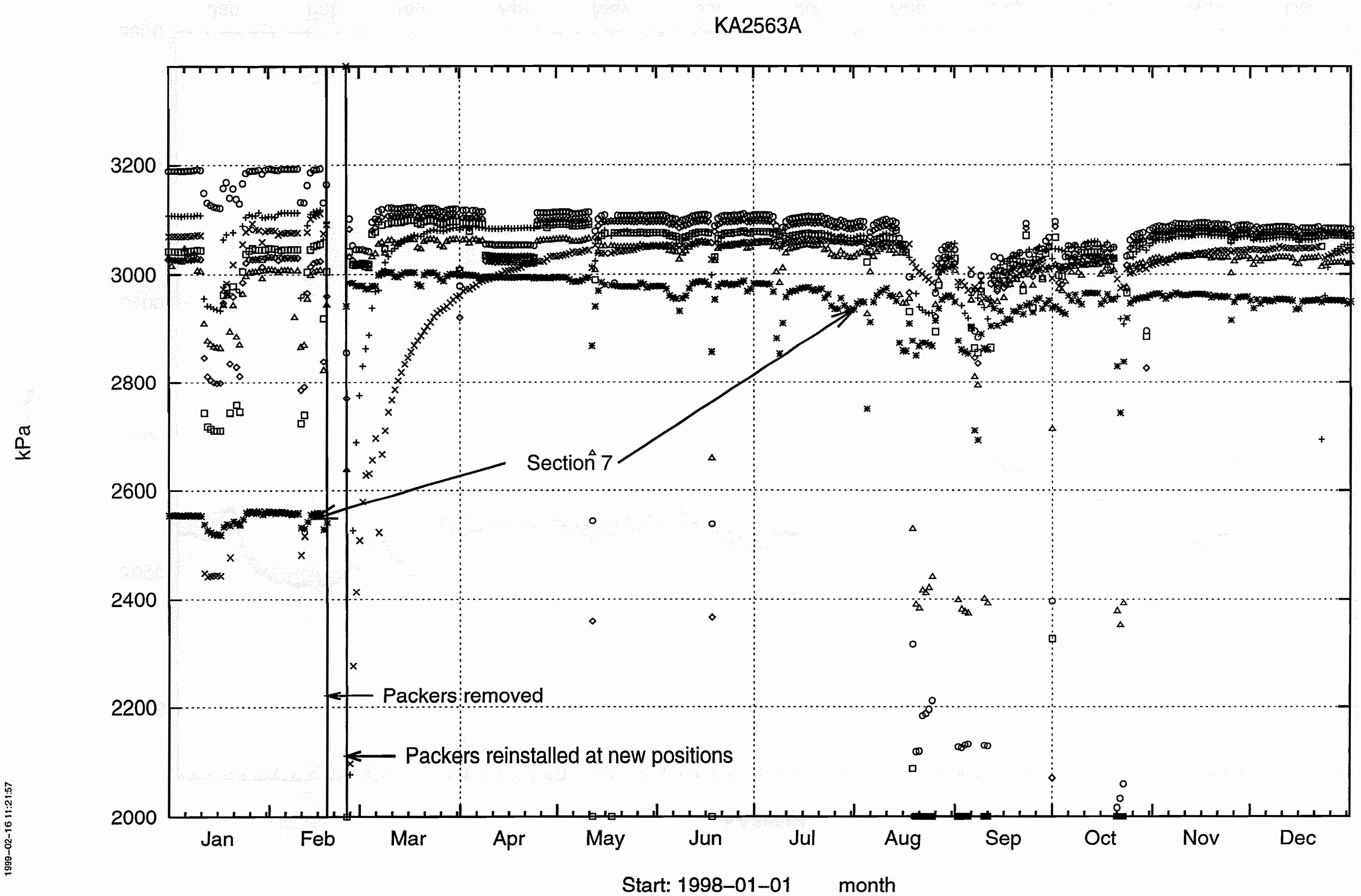


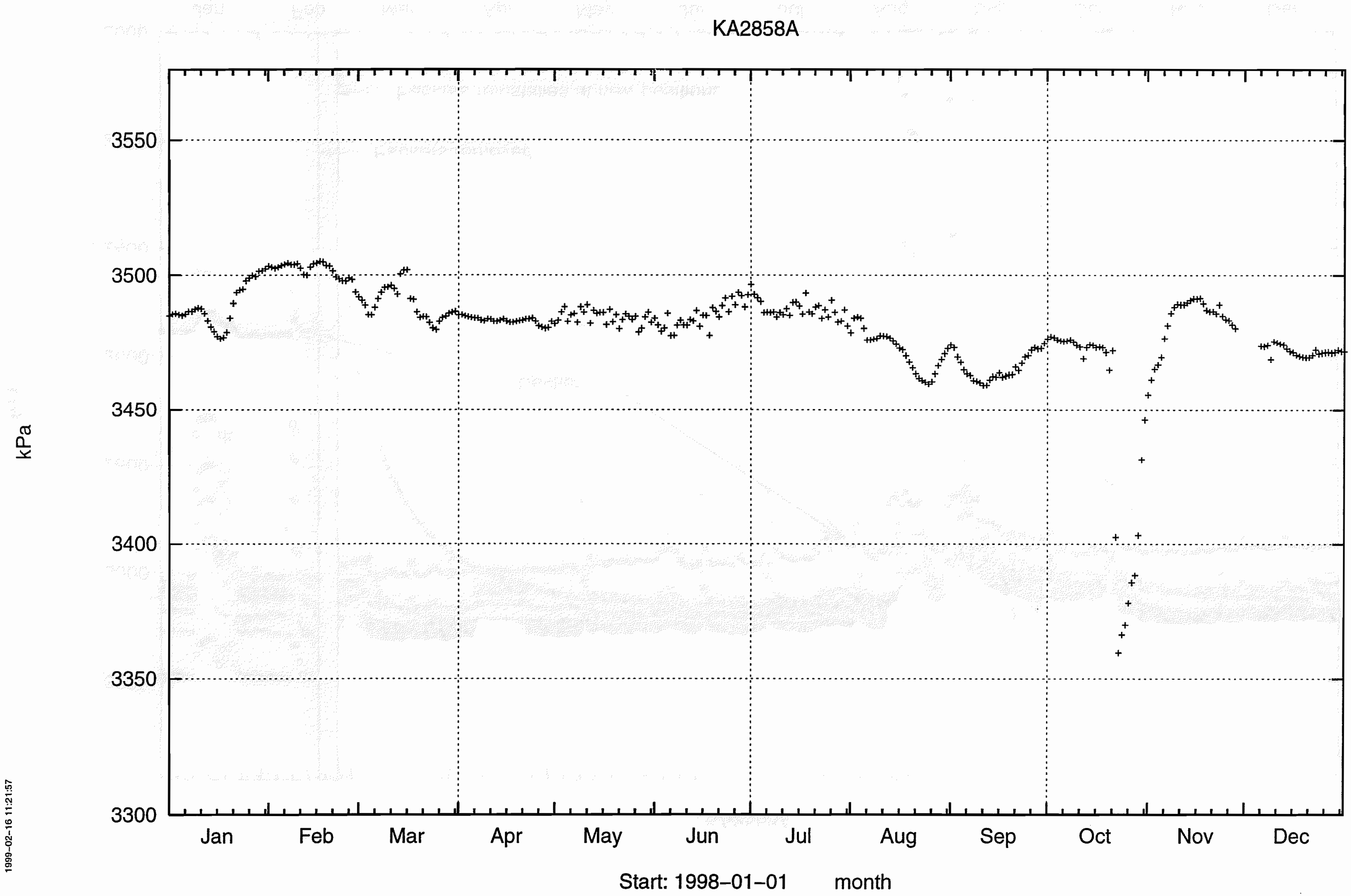
1999-02-16 11:21:56



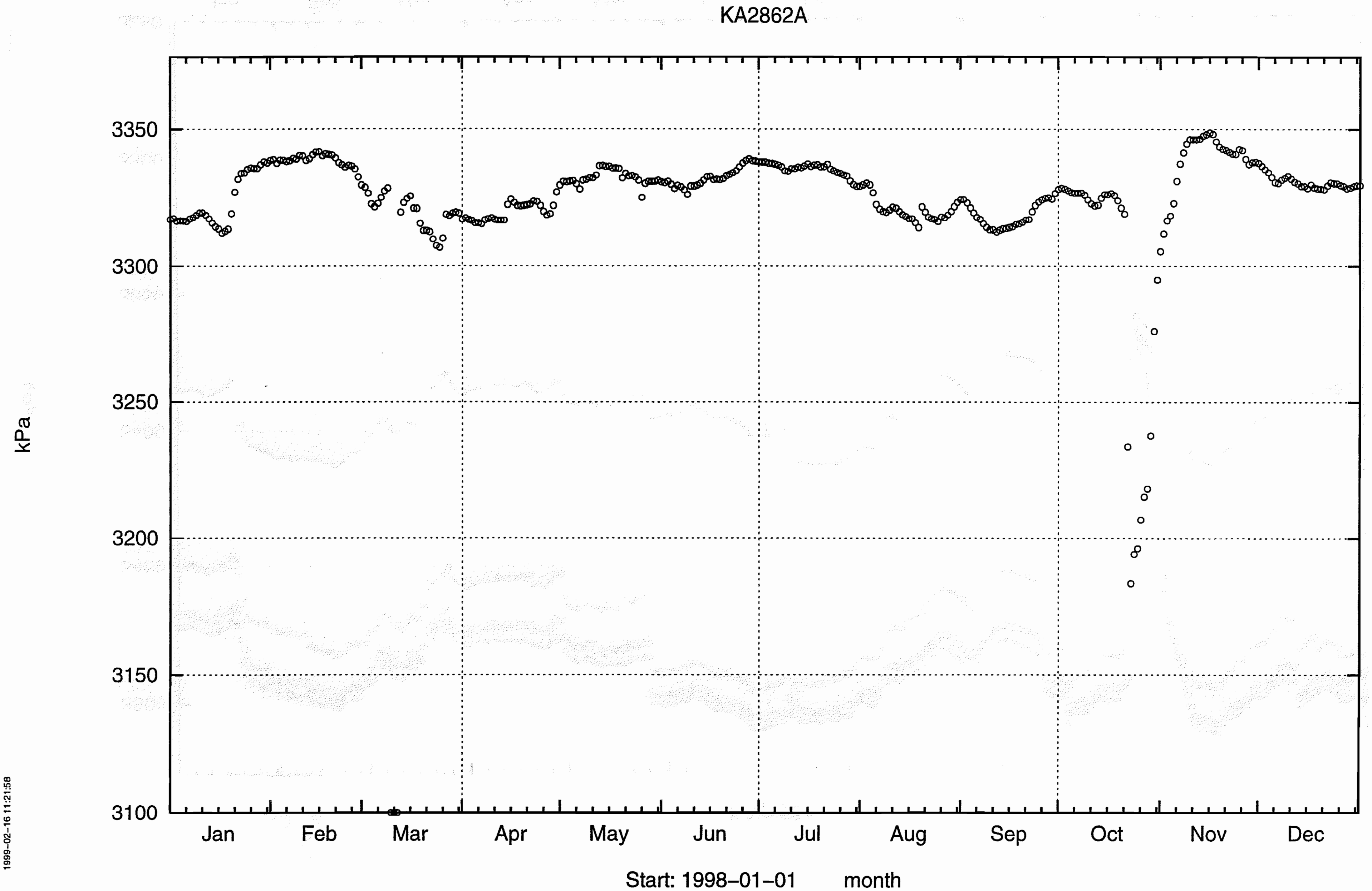
KA2162B
kPa
2300
2200
2100
2000
1900
1800
1700
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:56


KA2511A
3200
3100
3000
2900
2800
2700
2600
kPa
Packers removed
Packers reinstalled at new positions
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:57

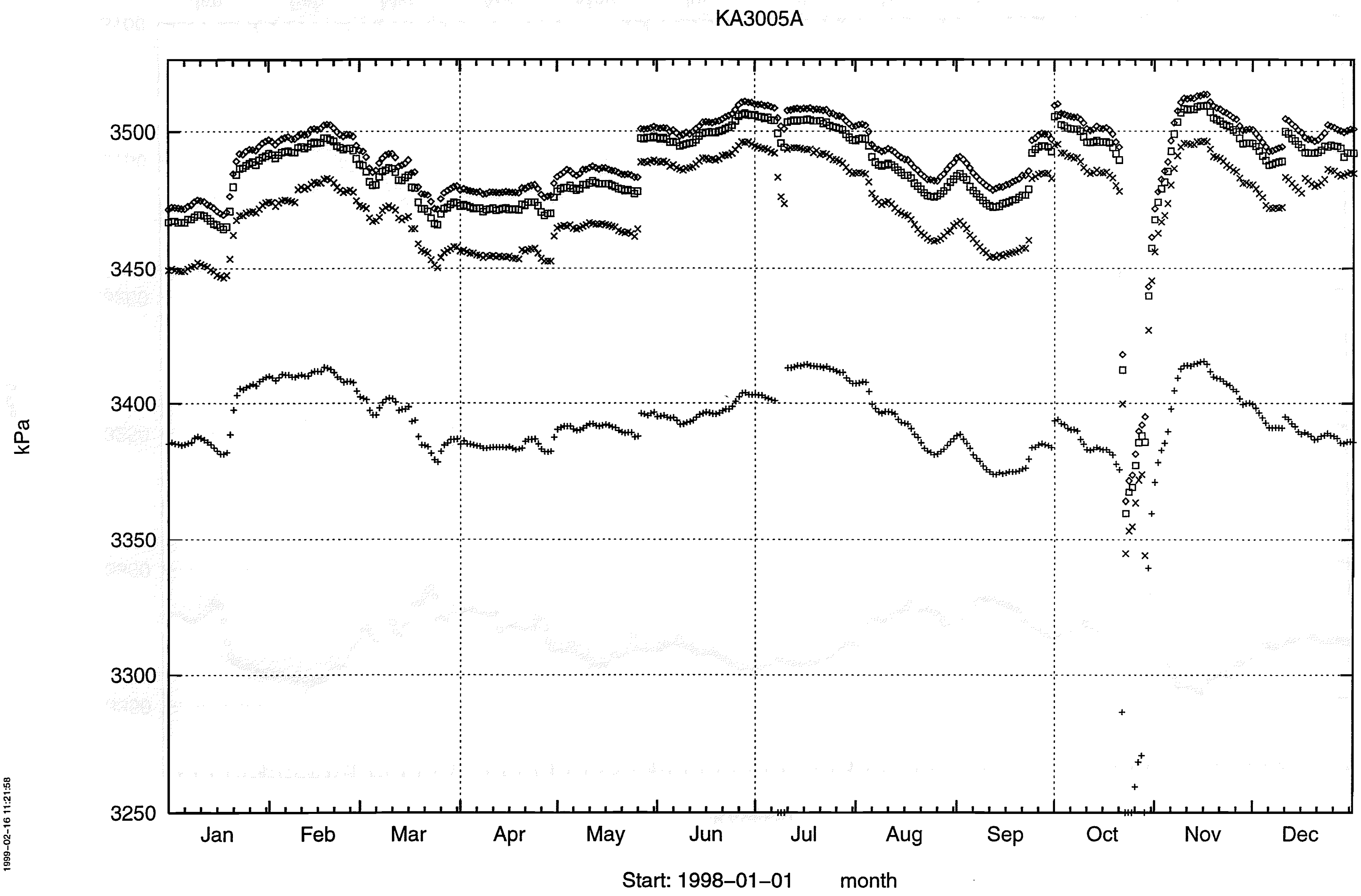

KA2563A
kPa
3200
3000
2800
2600
2400
2200
2000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
Section 7
Packers removed
Packers reinstalled at new positions
1999-02-16 11:21:57

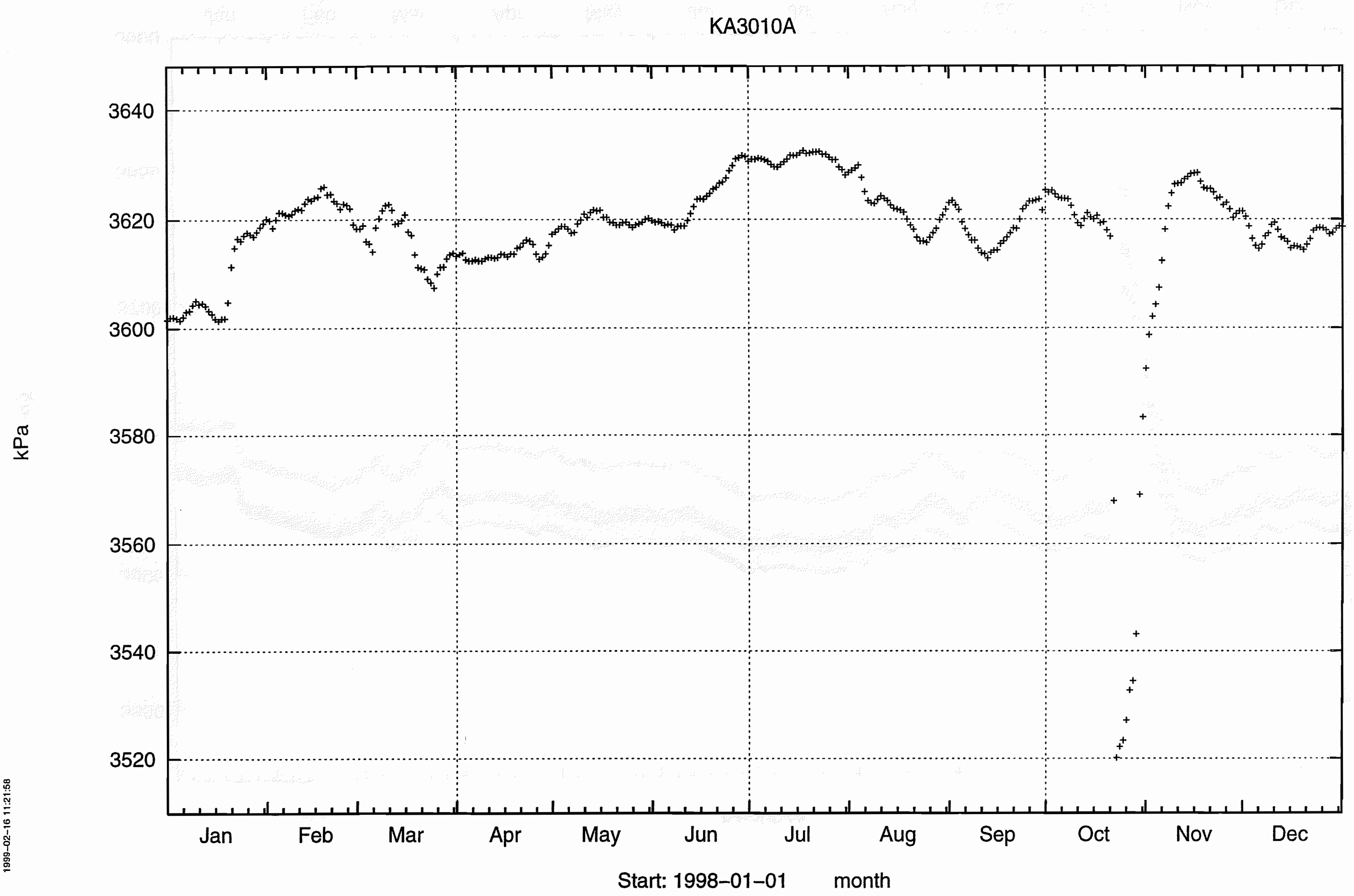


KA2858A
kPa
3550
3500
3450
3400
3350
3300
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:57



KA2862A
kPa
3350
3300
3250
3200
3150
3100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–02–16 11:21:58


KA3005A
kPa
3500
3450
3400
3350
3300
3250
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:58



KA3010A
3640
3620
3600
3580
3560
3540
3520
kPa
Jan
Feb
Mar
Apr
May
Jun
Jul
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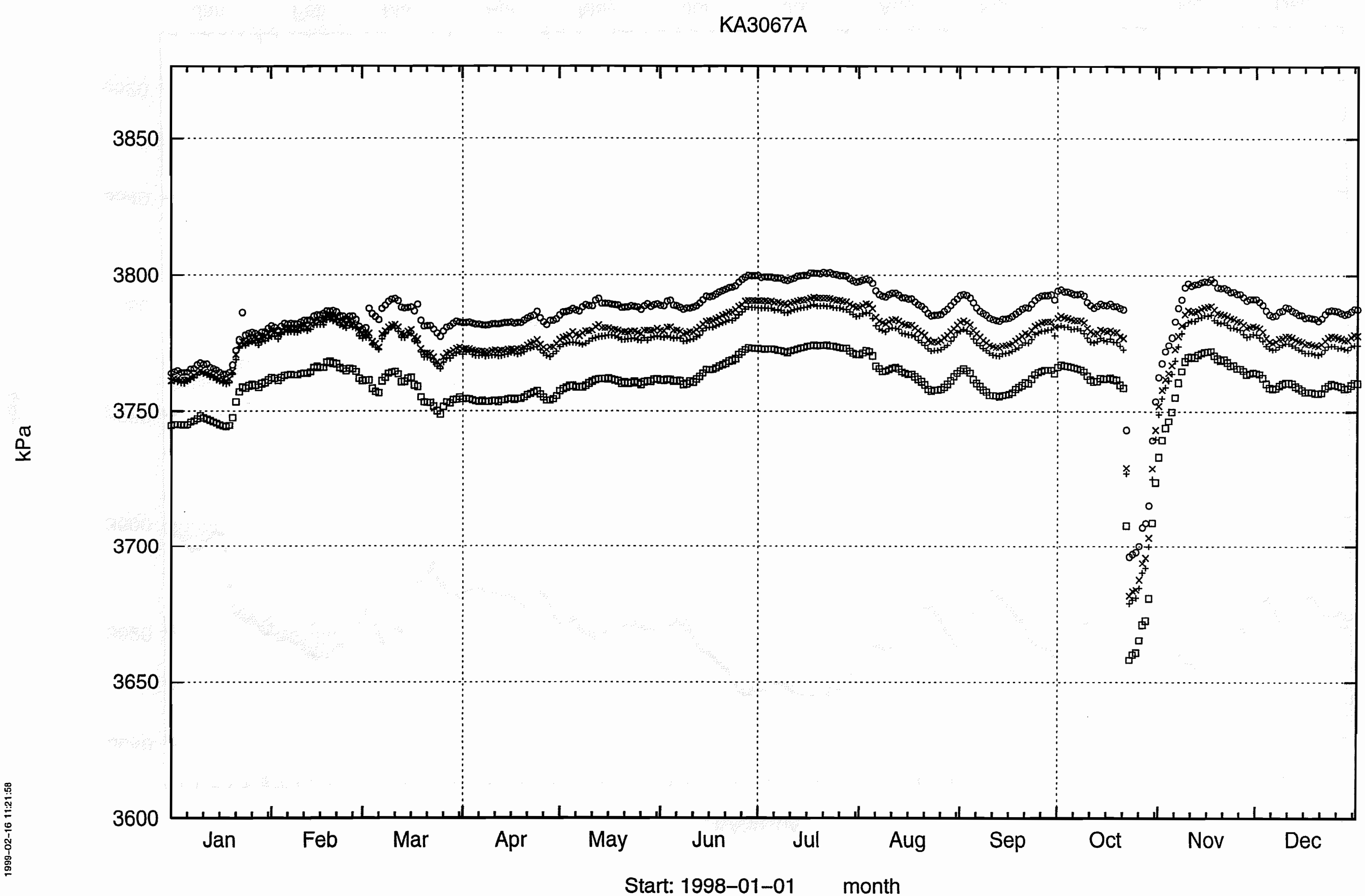
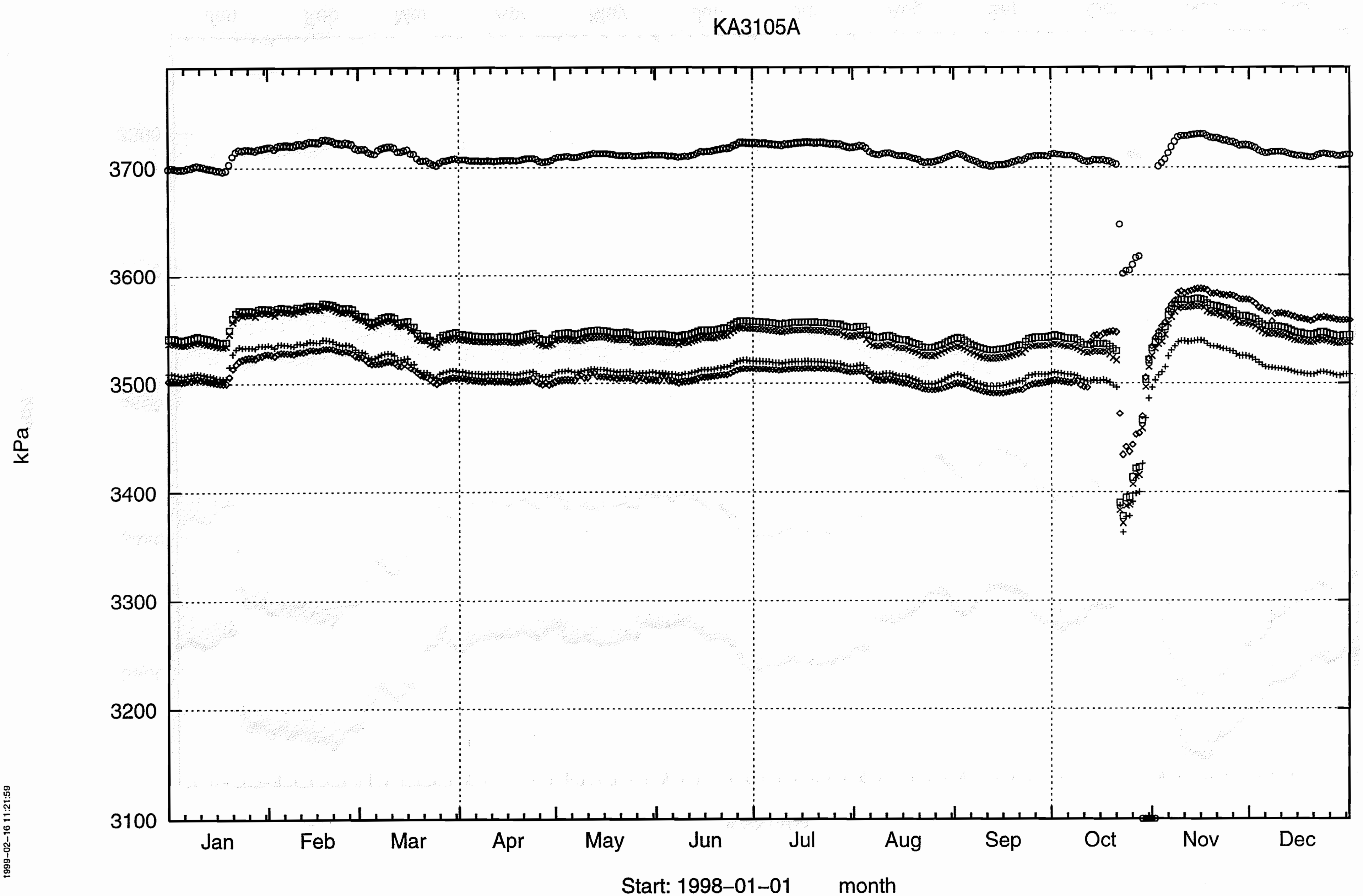
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:58



KA3067A
3850
3800
3750
3700
3650
3600
kPa
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:58



KA3105A
kPa
3700
3600
3500
3400
3300
3200
3100
Jan
Feb
Mar
Apr
May
Jun
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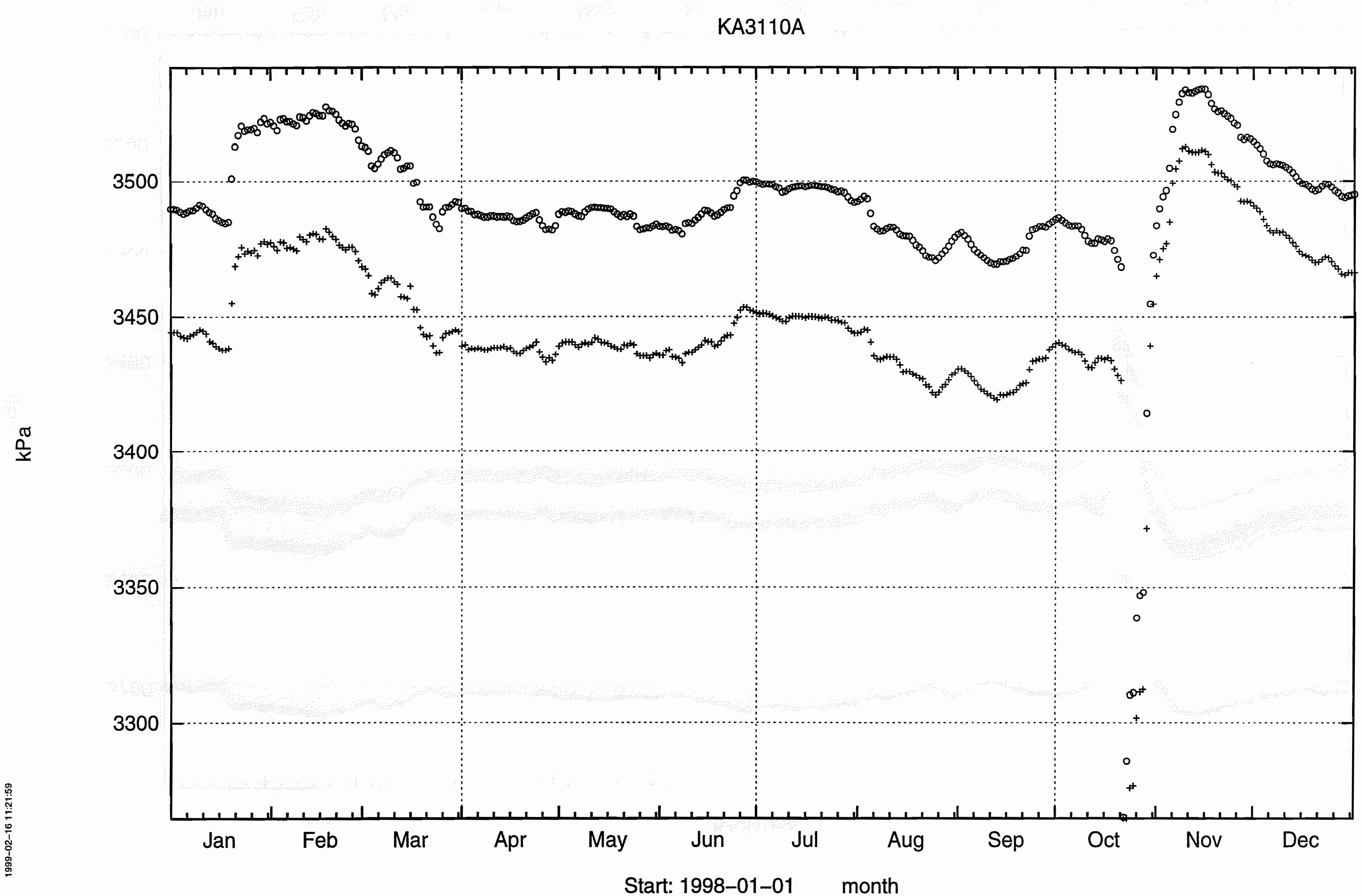
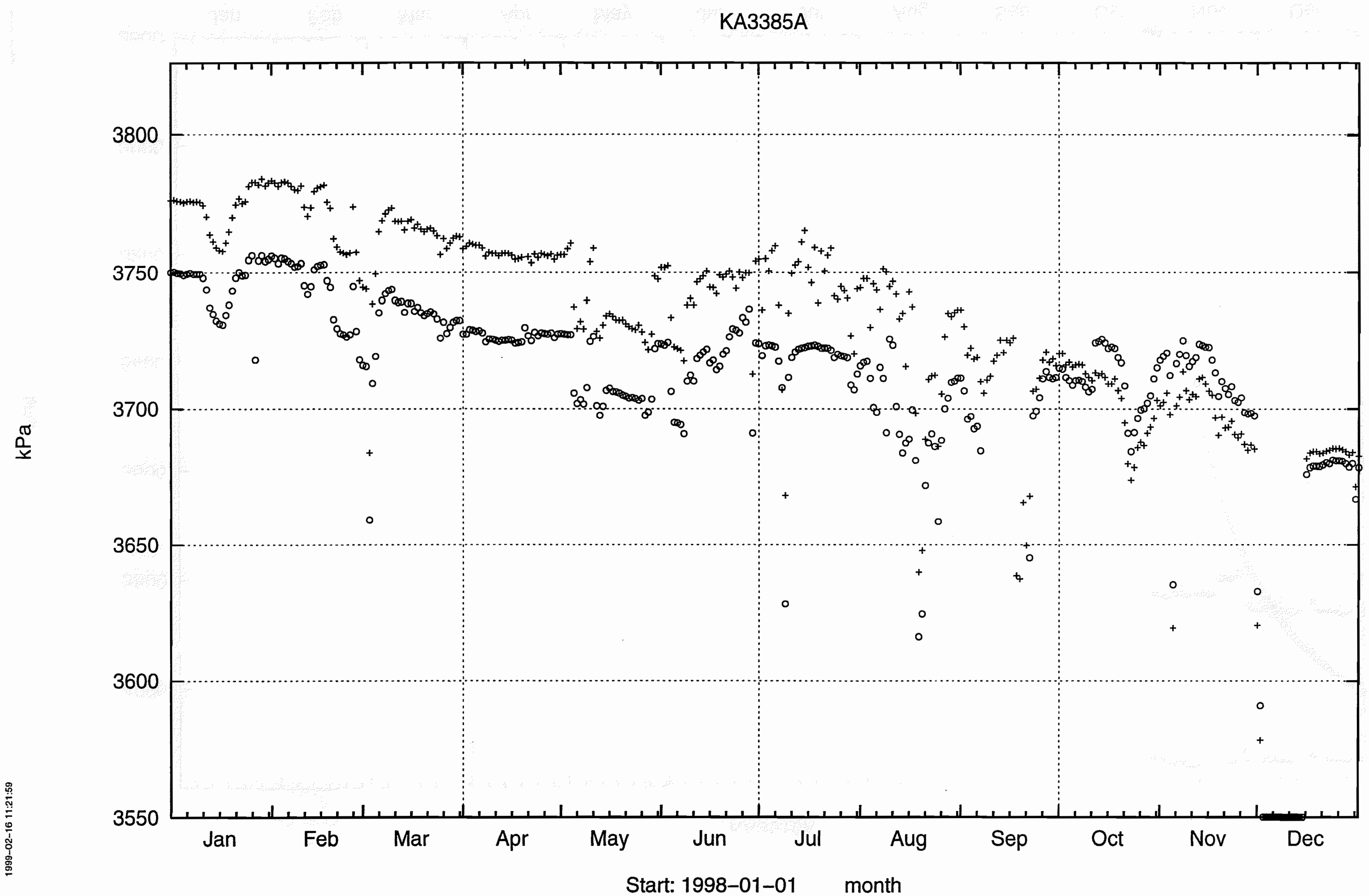
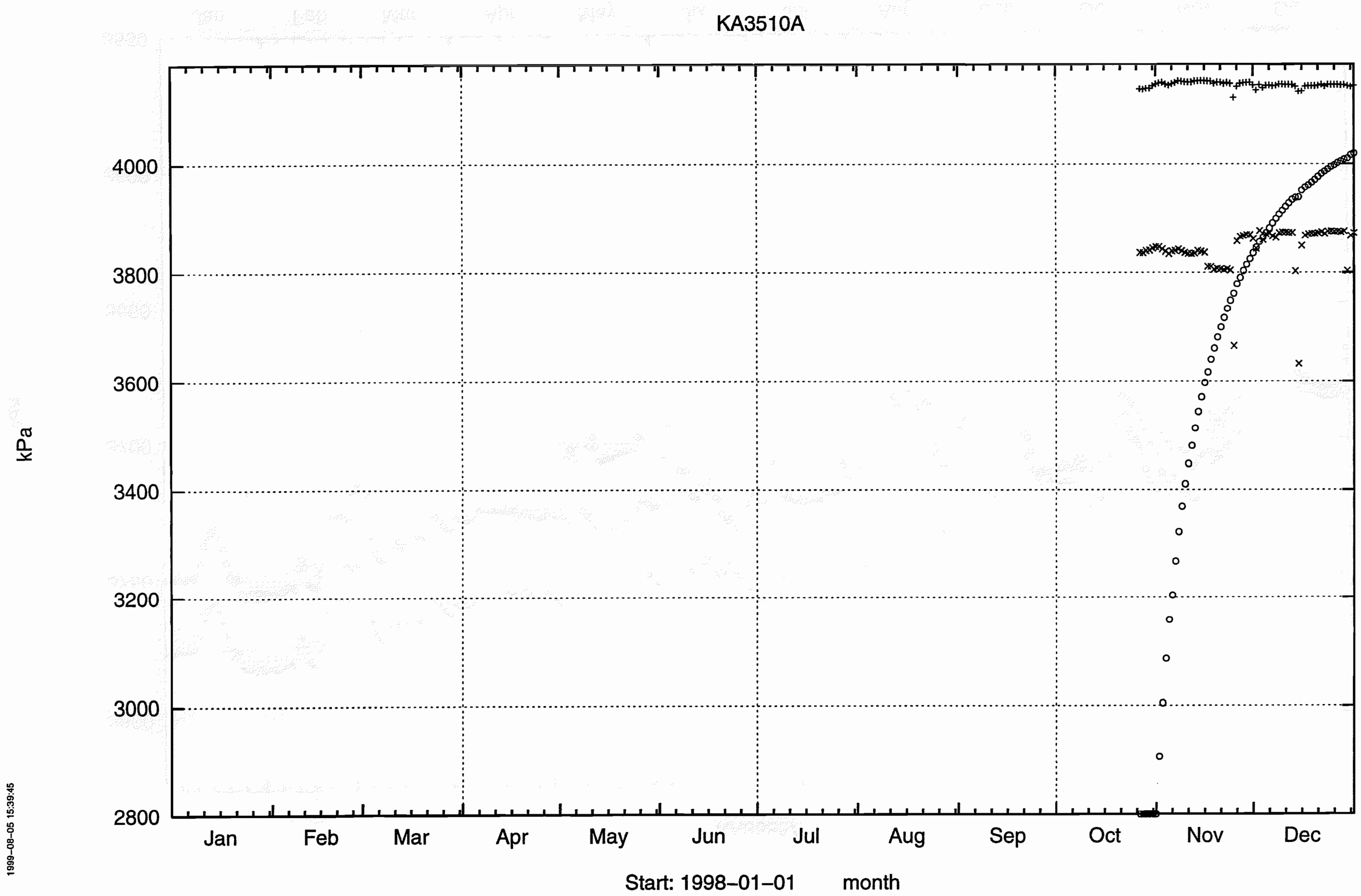
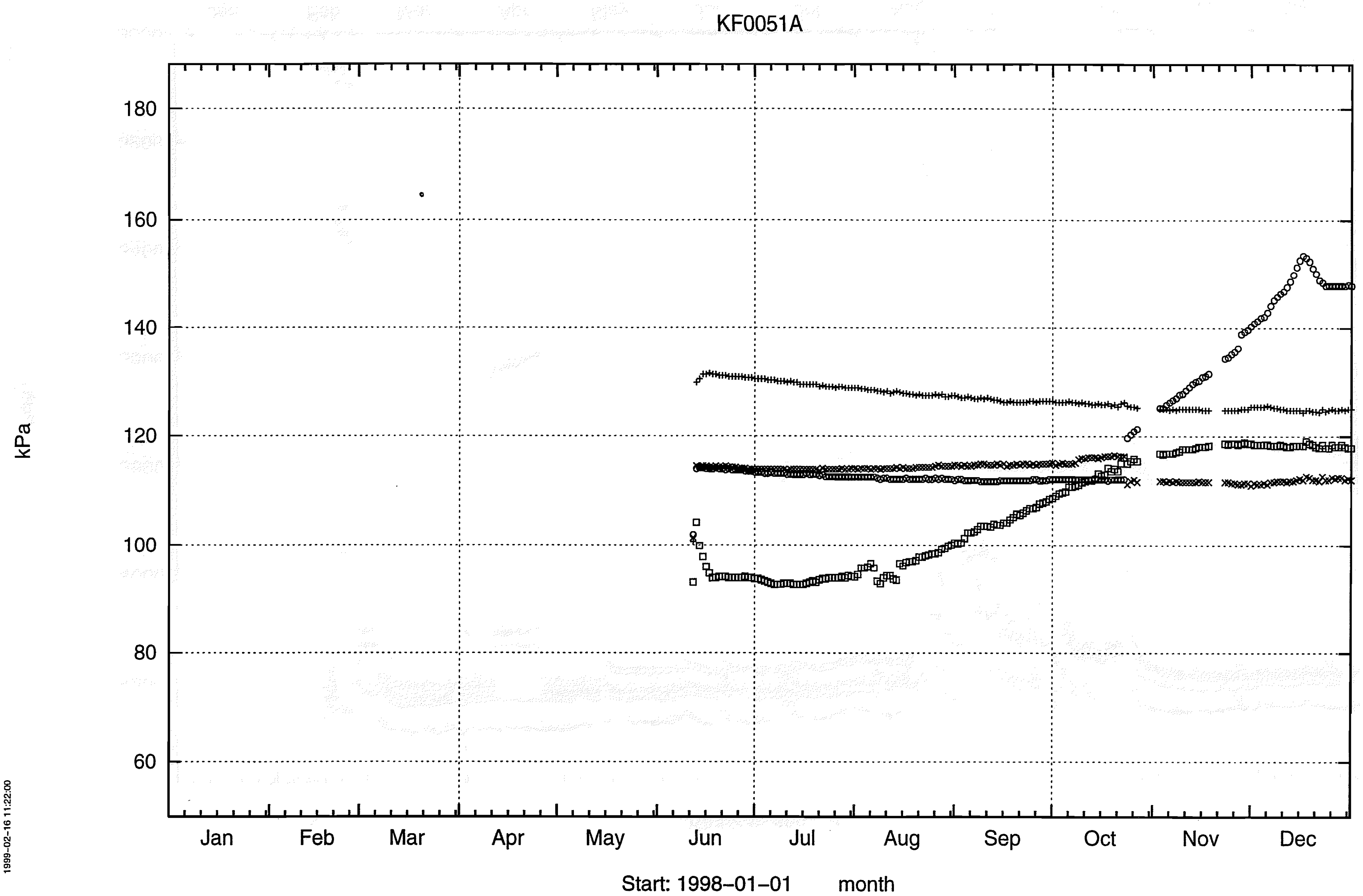
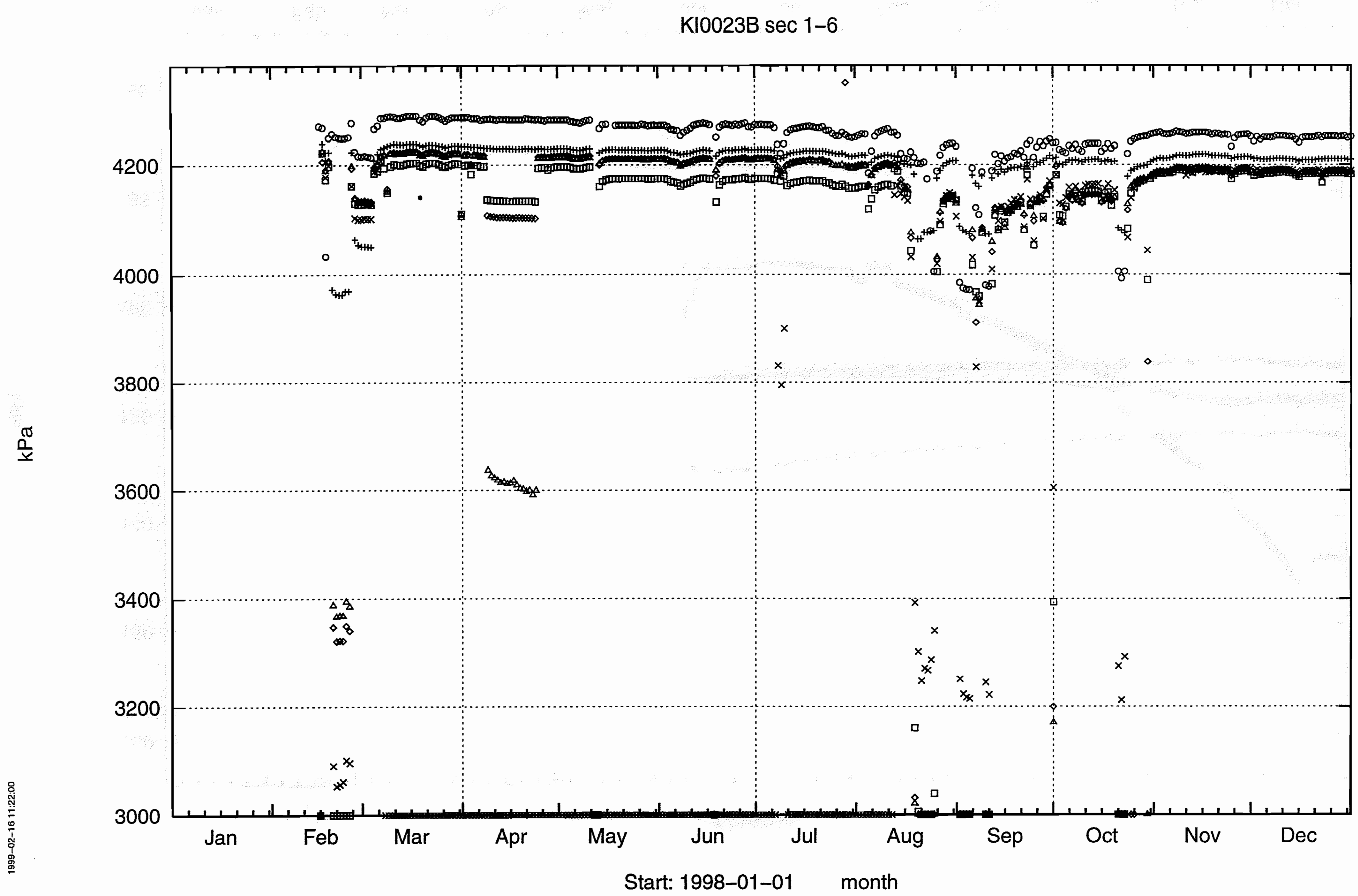
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:59

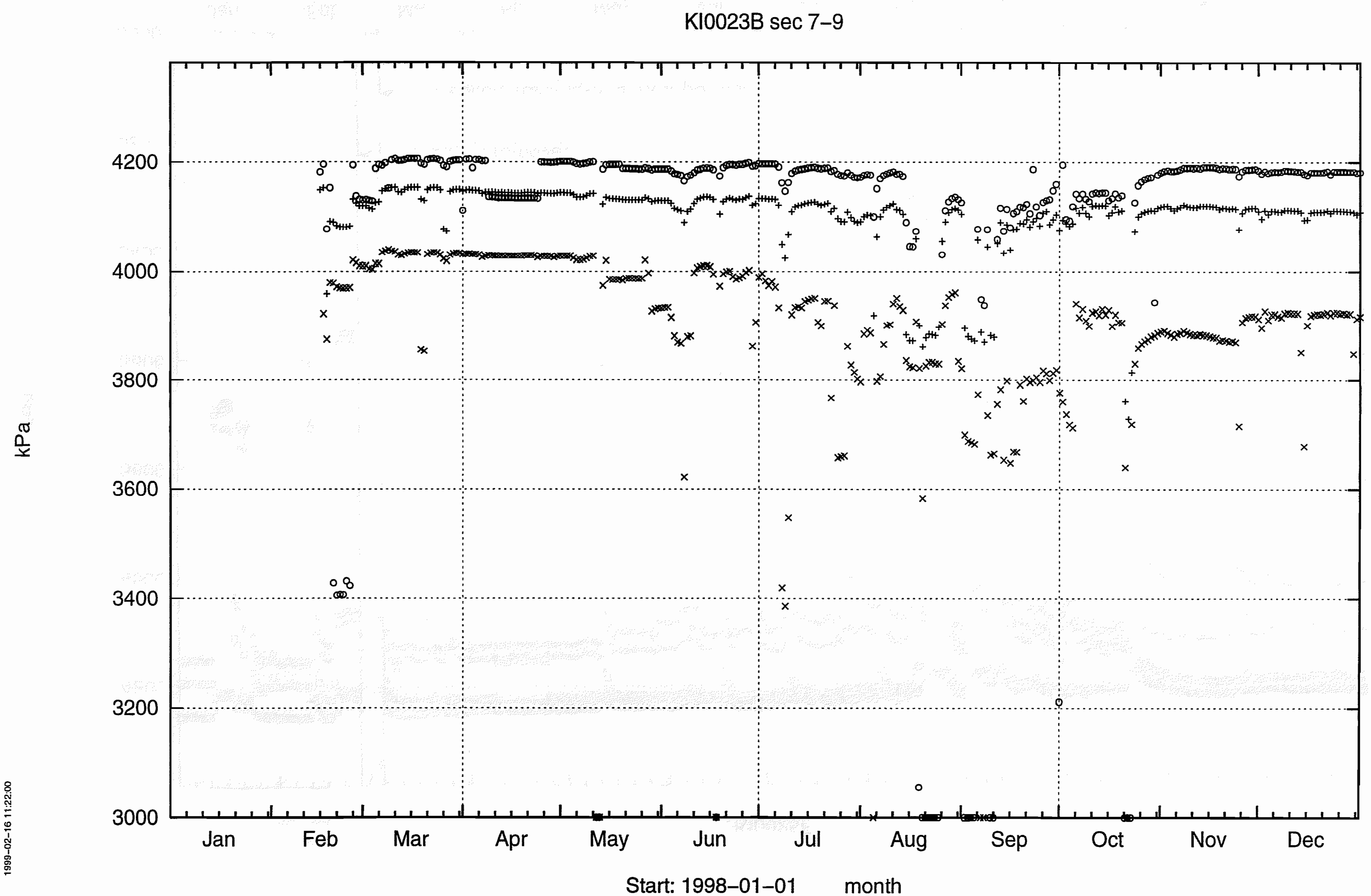

KA3110A
kPa
3500
3450
3400
3350
3300
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:59

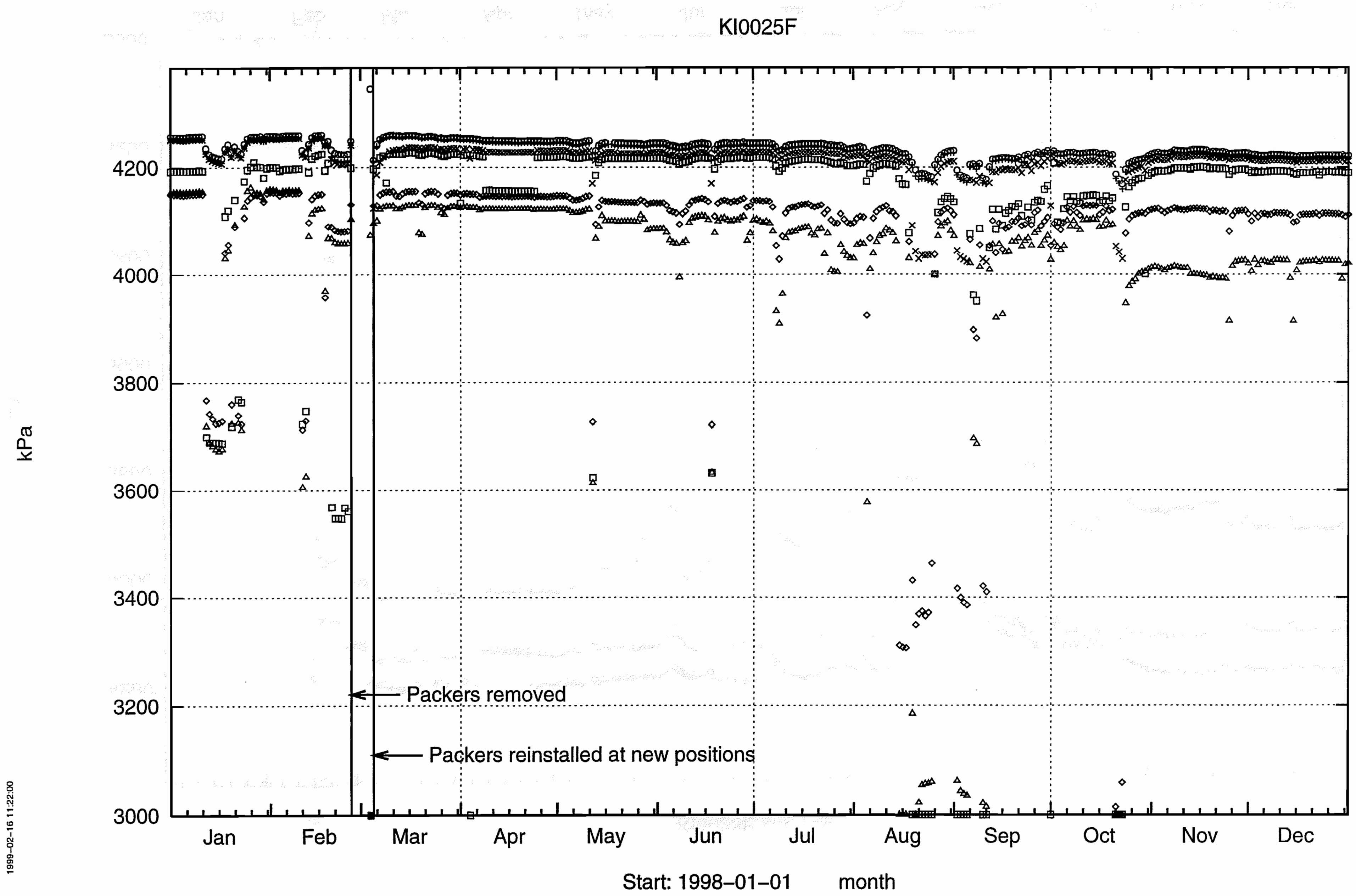

KA3385A
kPa
3800
3750
3700
3650
3600
3550
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:21:59

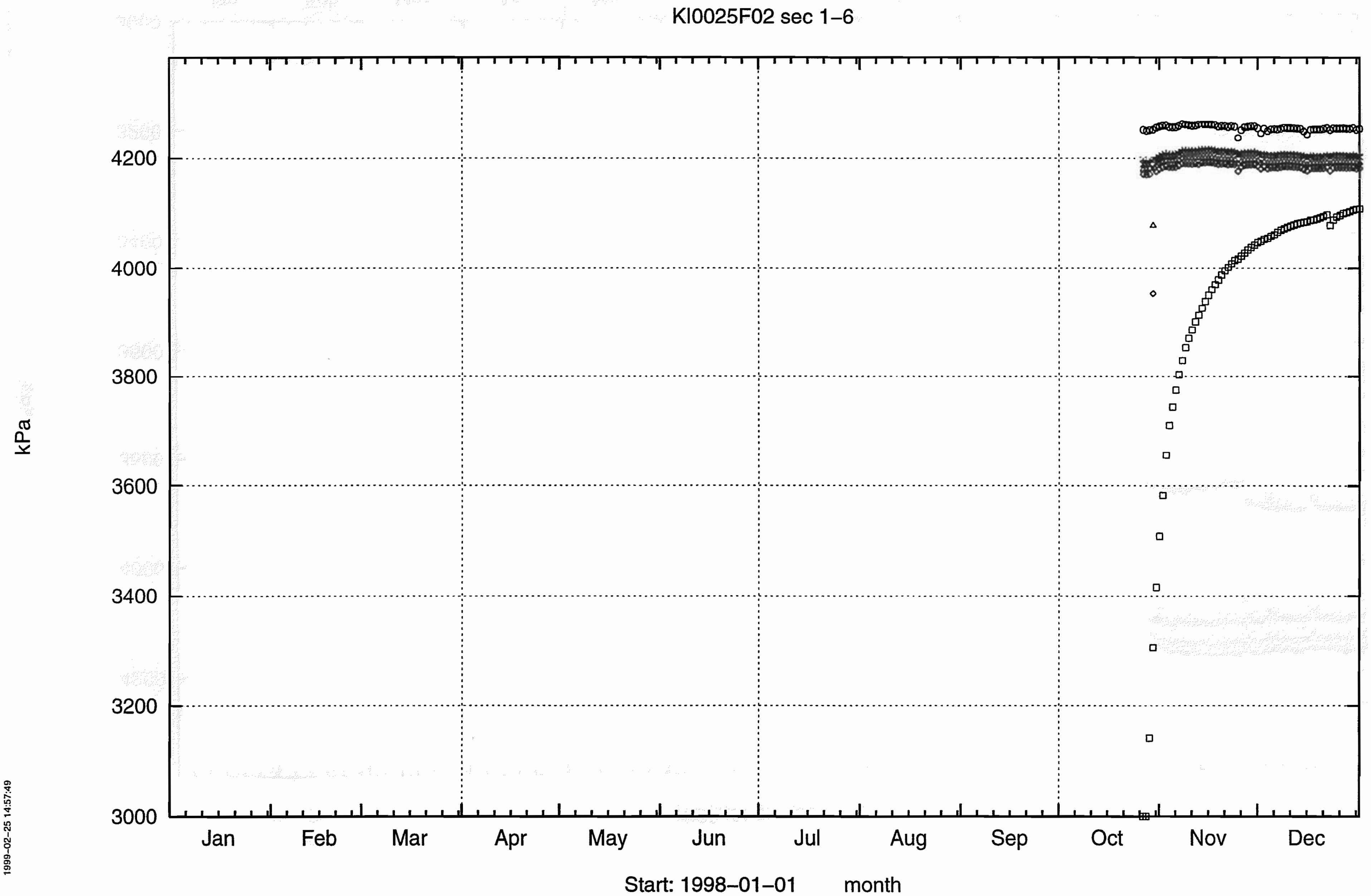

KA3510A
kPa
4000
3800
3600
3400
3200
3000
2800
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-08-05 15:39:45


KF0051A
180
160
140
120
100
80
60
kPa
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:22:00

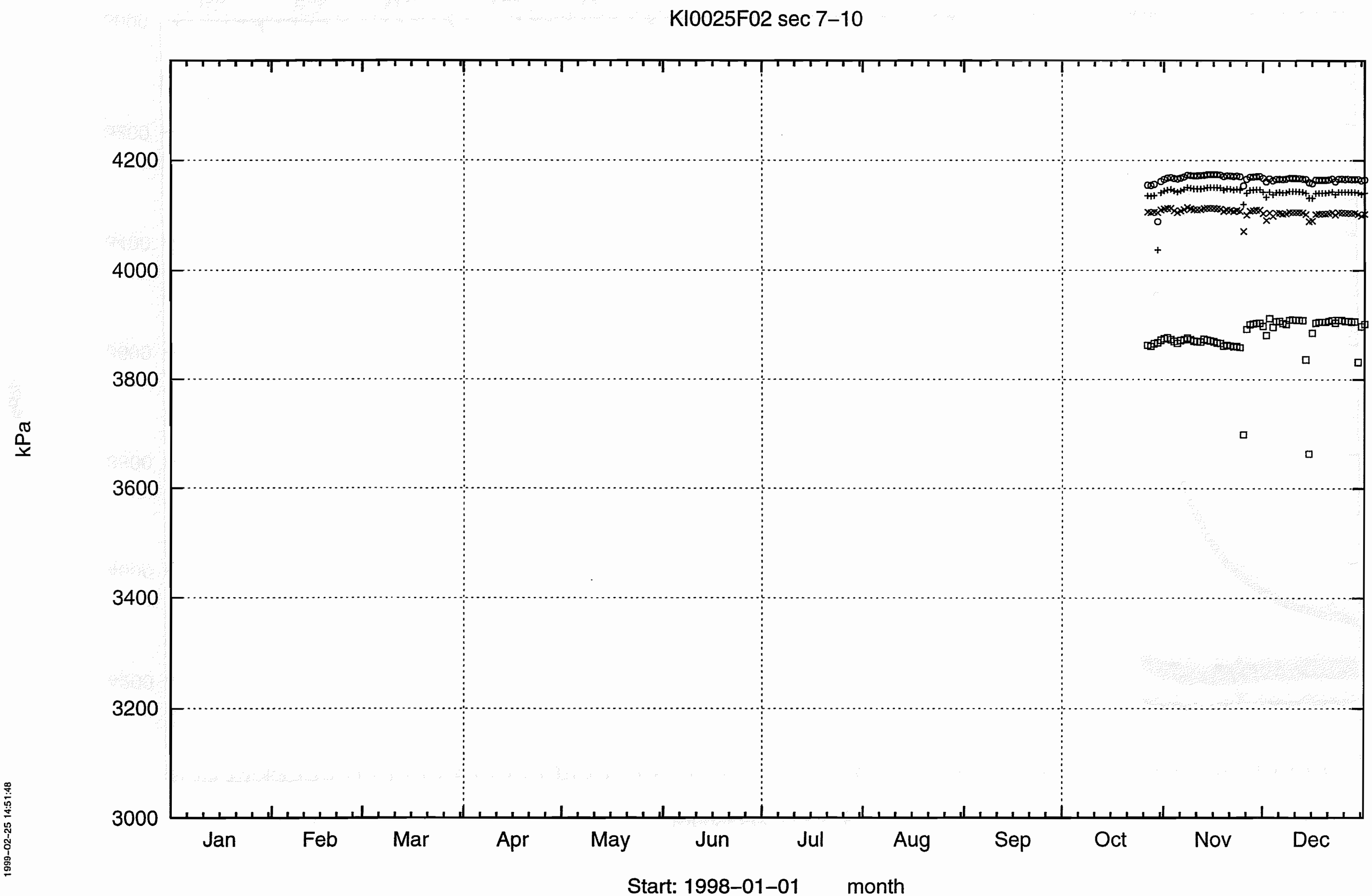

KI0023B sec 1-6
kPa
4200
4000
3800
3600
3400
3200
3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:22:00


KI0023B sec 7-9
kPa
4200
4000
3800
3600
3400
3200
3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:22:00

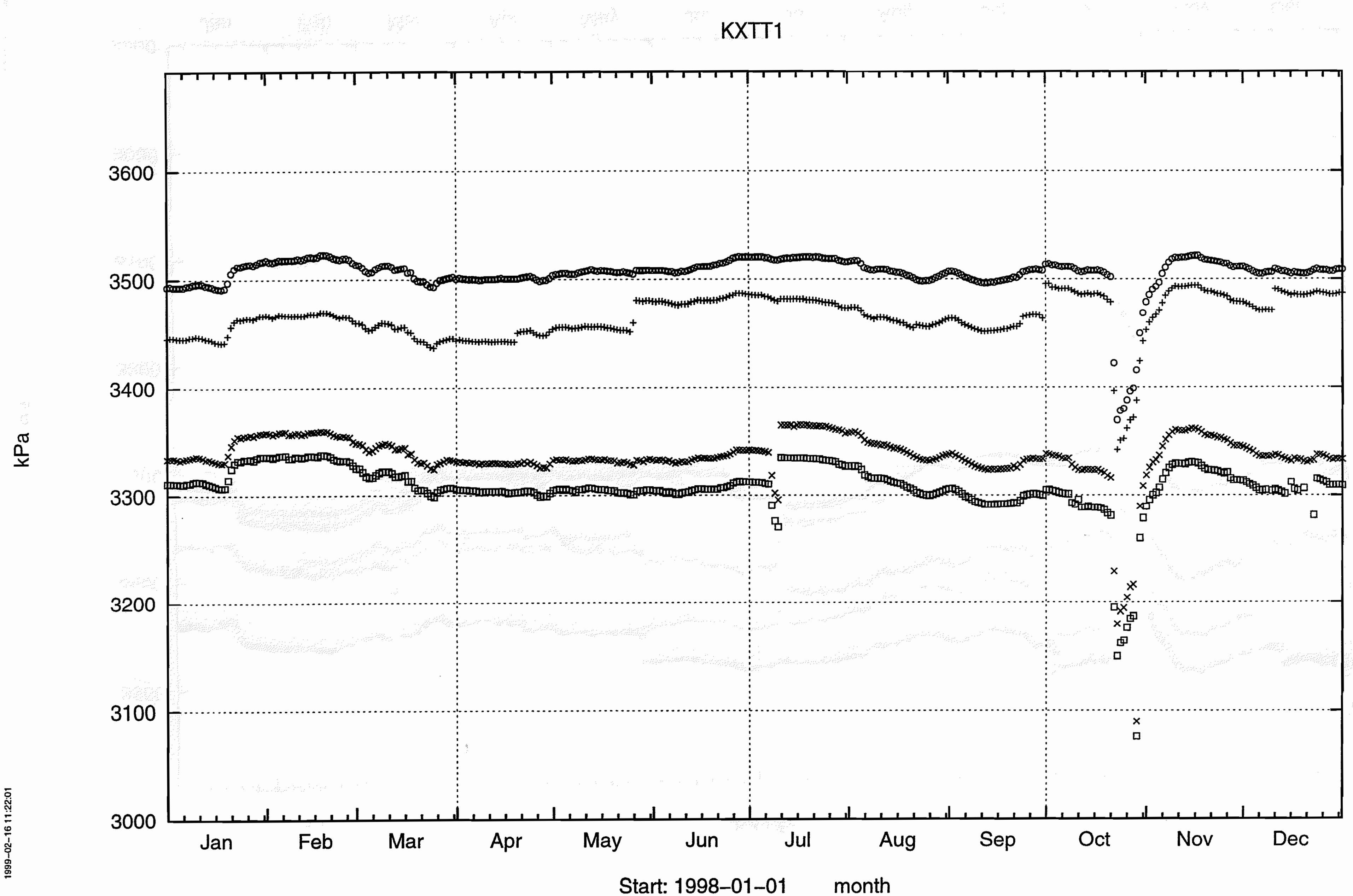

KI0025F
kPa
4200
4000
3800
3600
3400
3200
3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Packers removed
Packers reinstalled at new positions
Start: 1998-01-01 month
1999-02-16 11:22:00

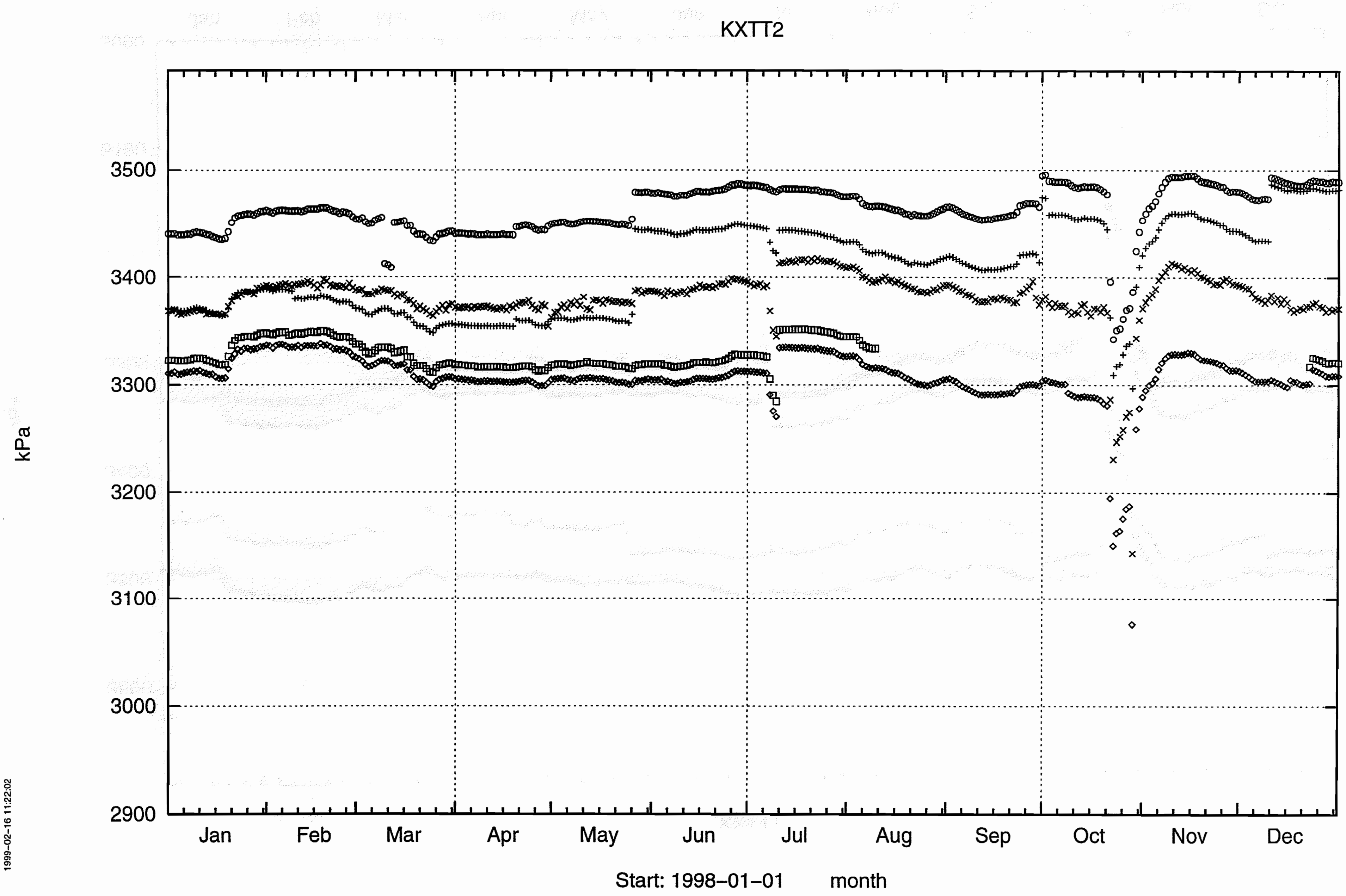


KI0025F02 sec 1–6
kPa
4200
4000
3800
3600
3400
3200
3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–02–25 14:57:49

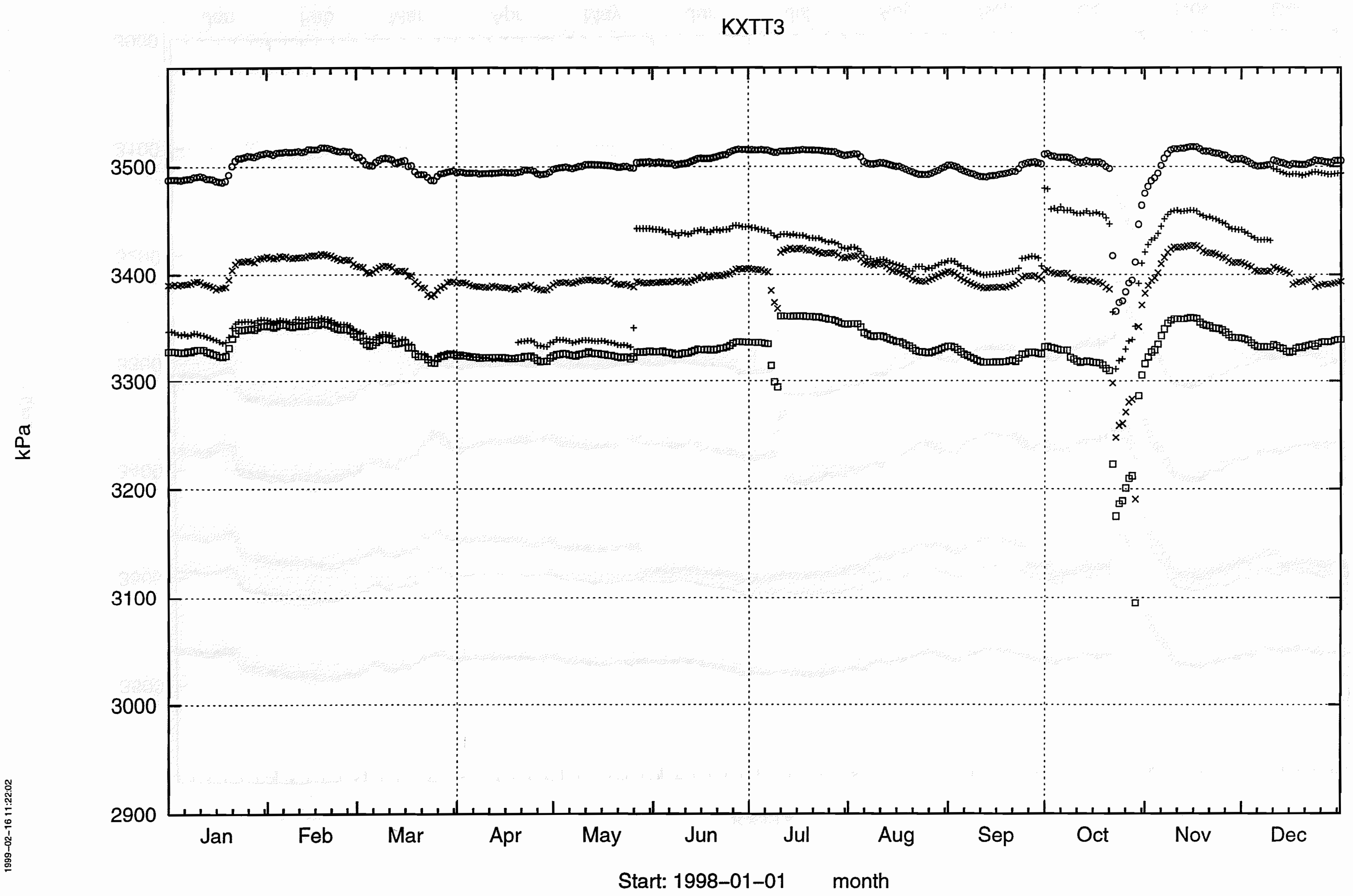


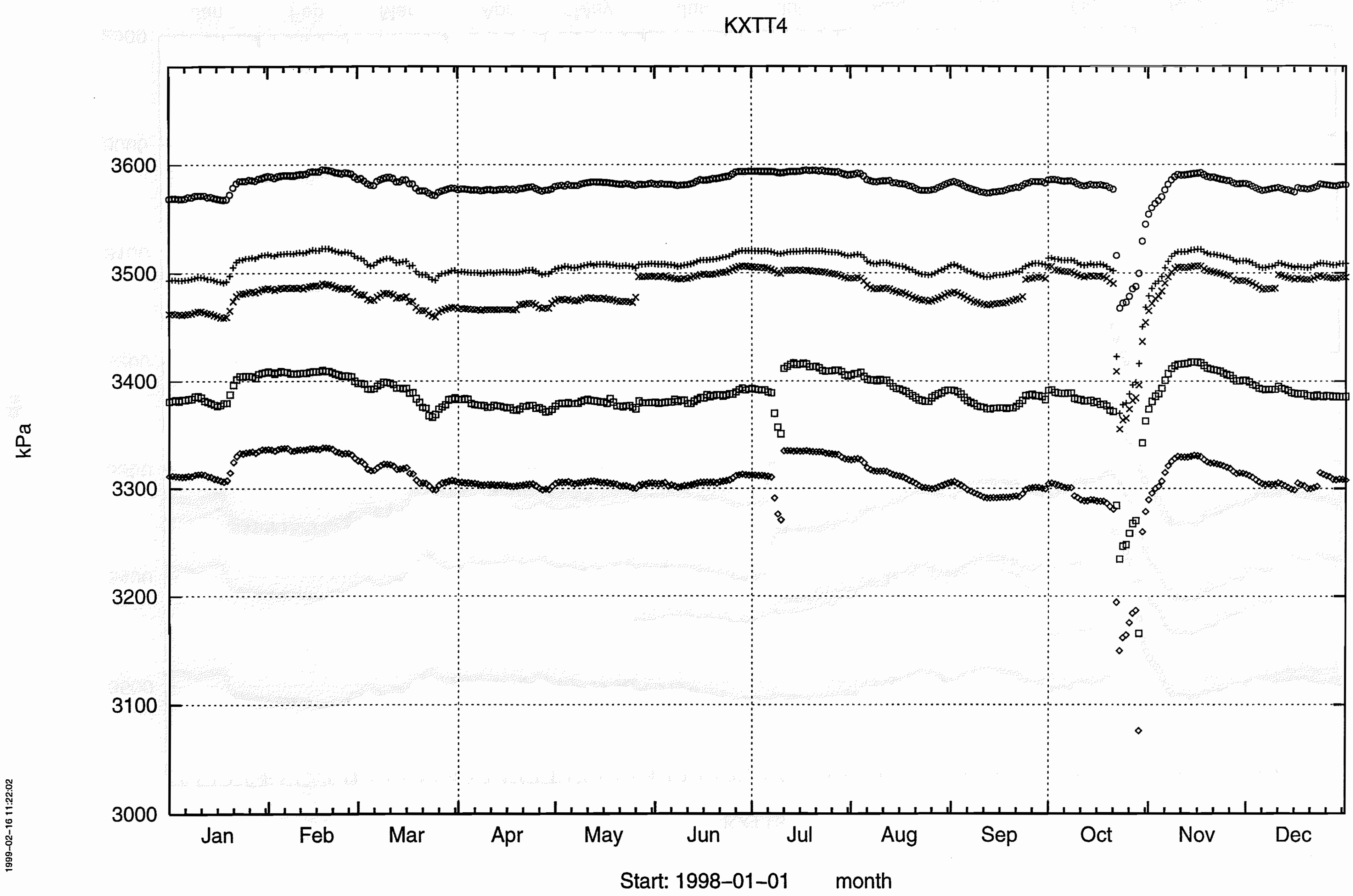
KI0025F02 sec 7–10
kPa
4200
4000
3800
3600
3400
3200
3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–02–25 14:51:48

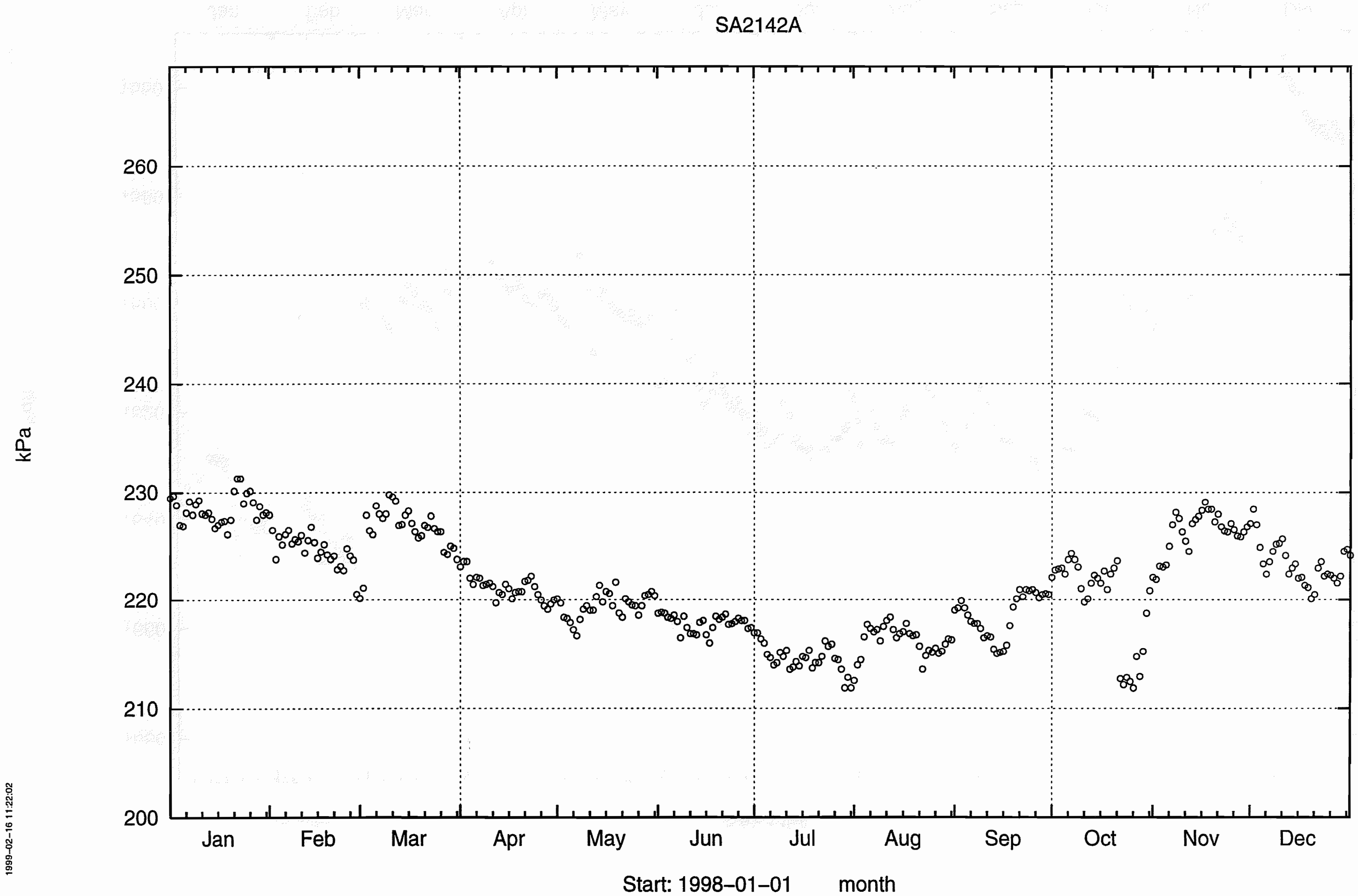

KXTT1
kPa
3600
3500
3400
3300
3200
3100
3000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:22:01



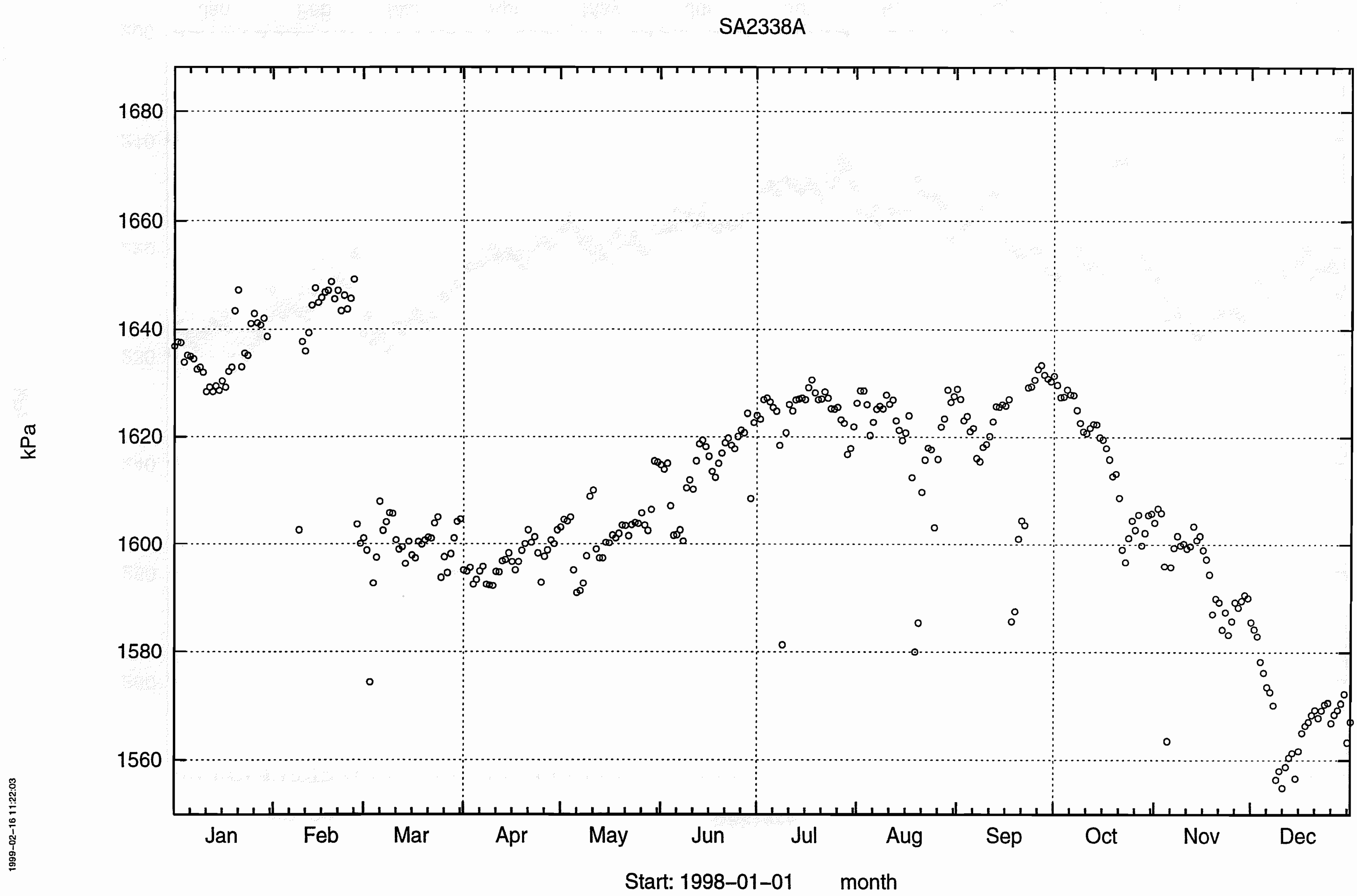
1999−02−16 11:22:02


KXTT3
kPa
3500
3400
3300
3200
3100
3000
2900
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:22:02

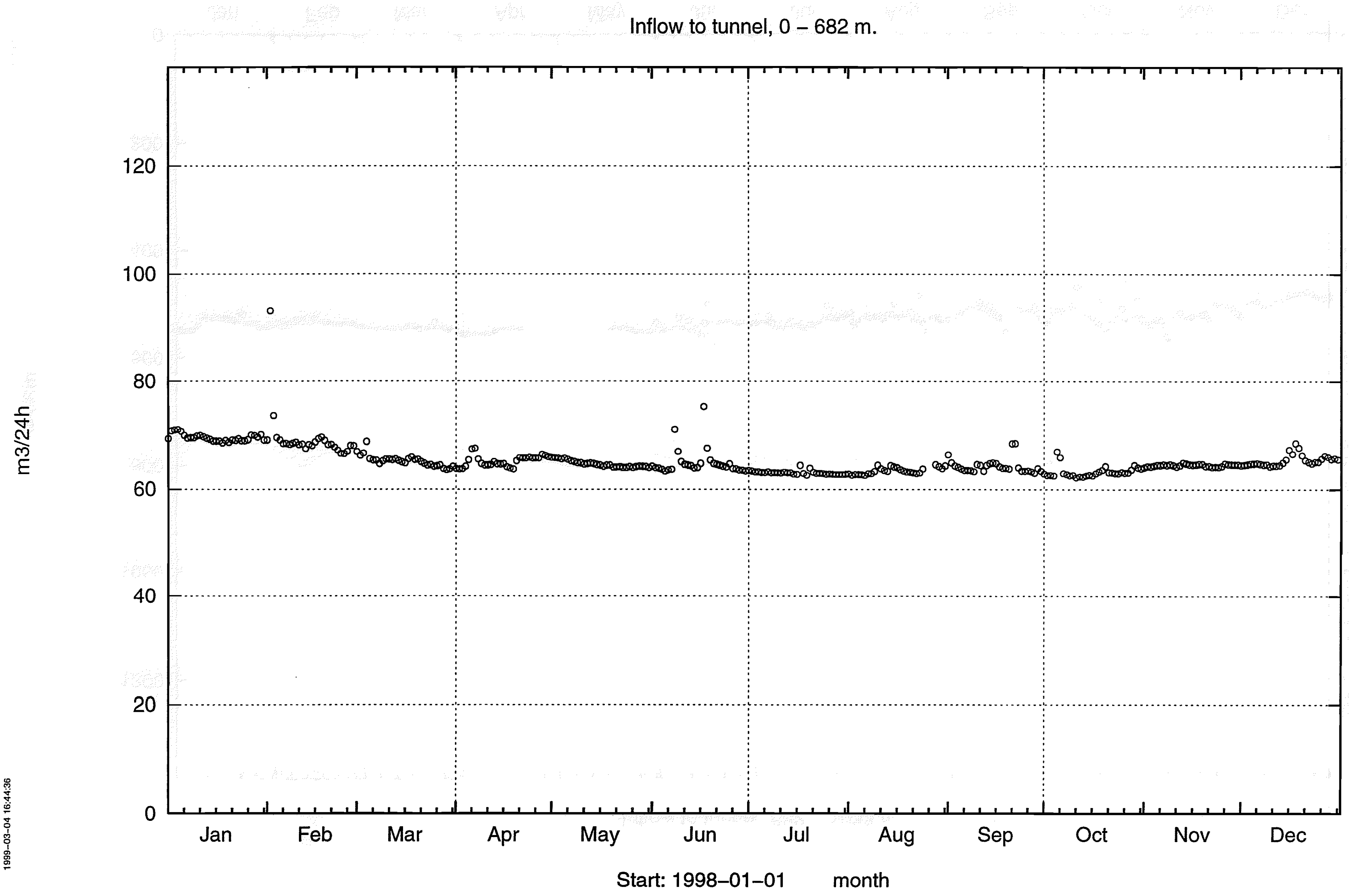

KXTT4
3600
3500
3400
3300
3200
3100
3000
kPa
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-02-16 11:22:02



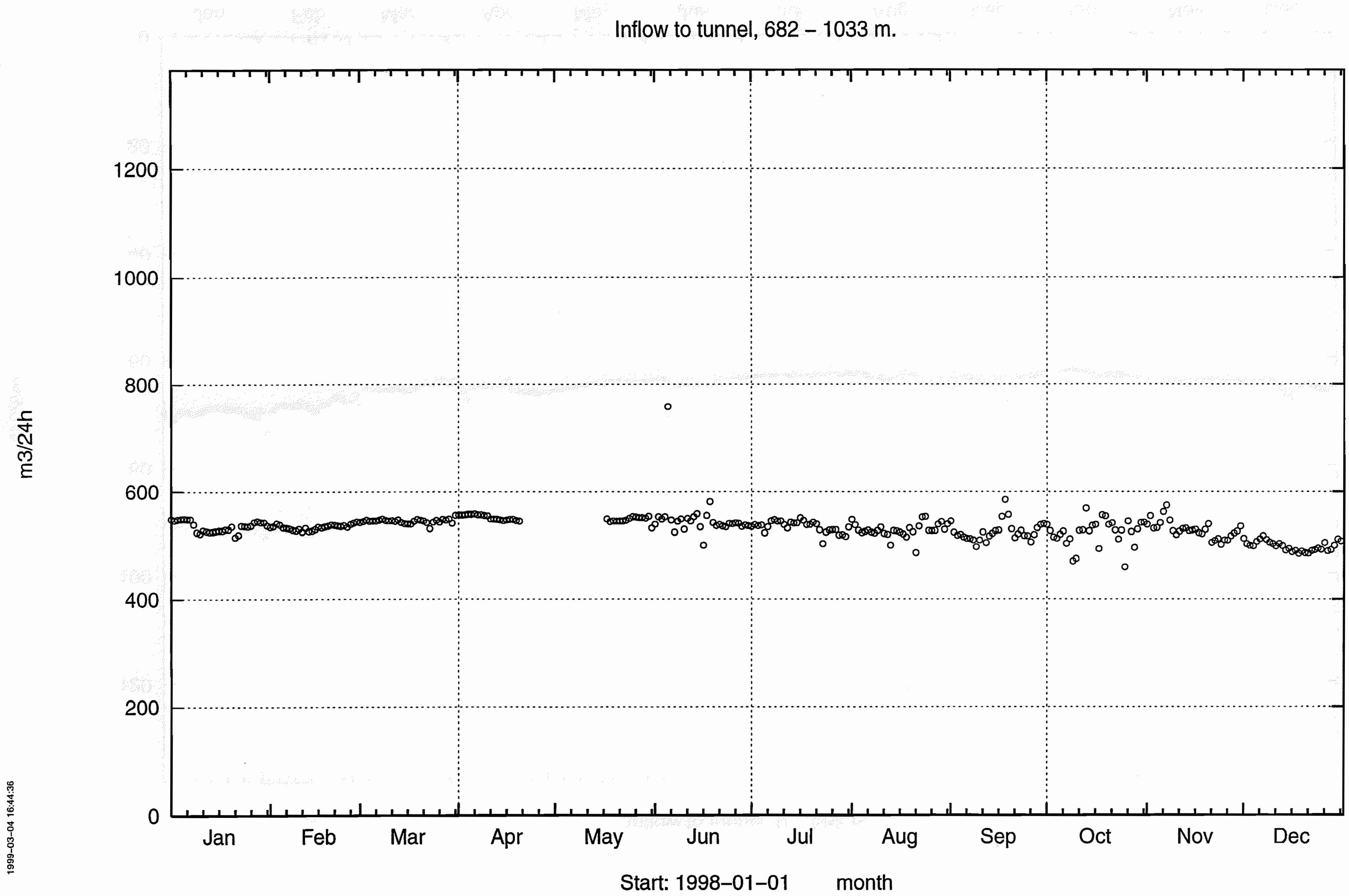
SA2142A
kPa
260
250
240
230
220
210
200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:22:02

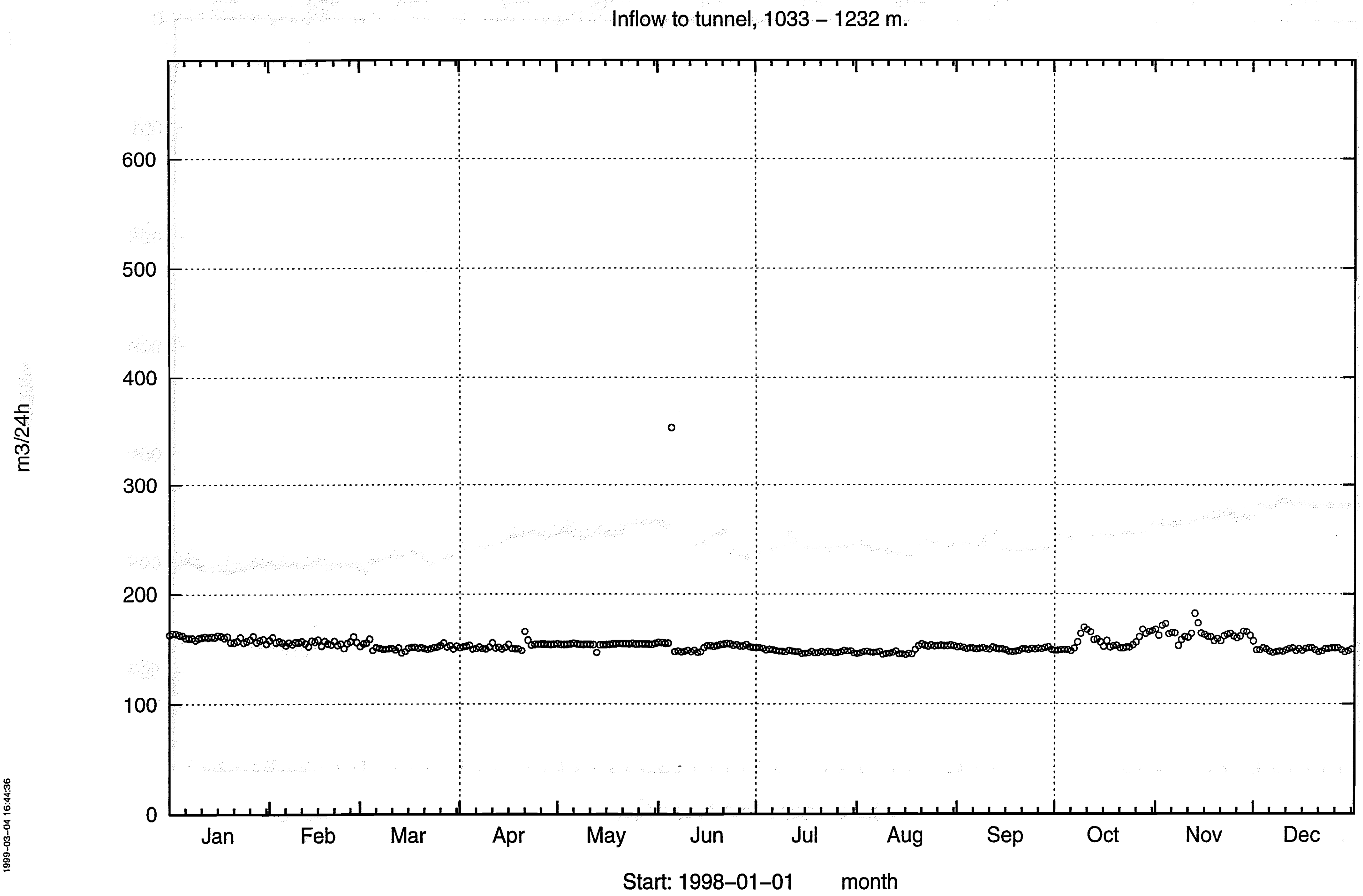

SA2338A
kPa
1680
1660
1640
1620
1600
1580
1560
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-02-16 11:22:03

Appendix 5: Water flow in tunnel

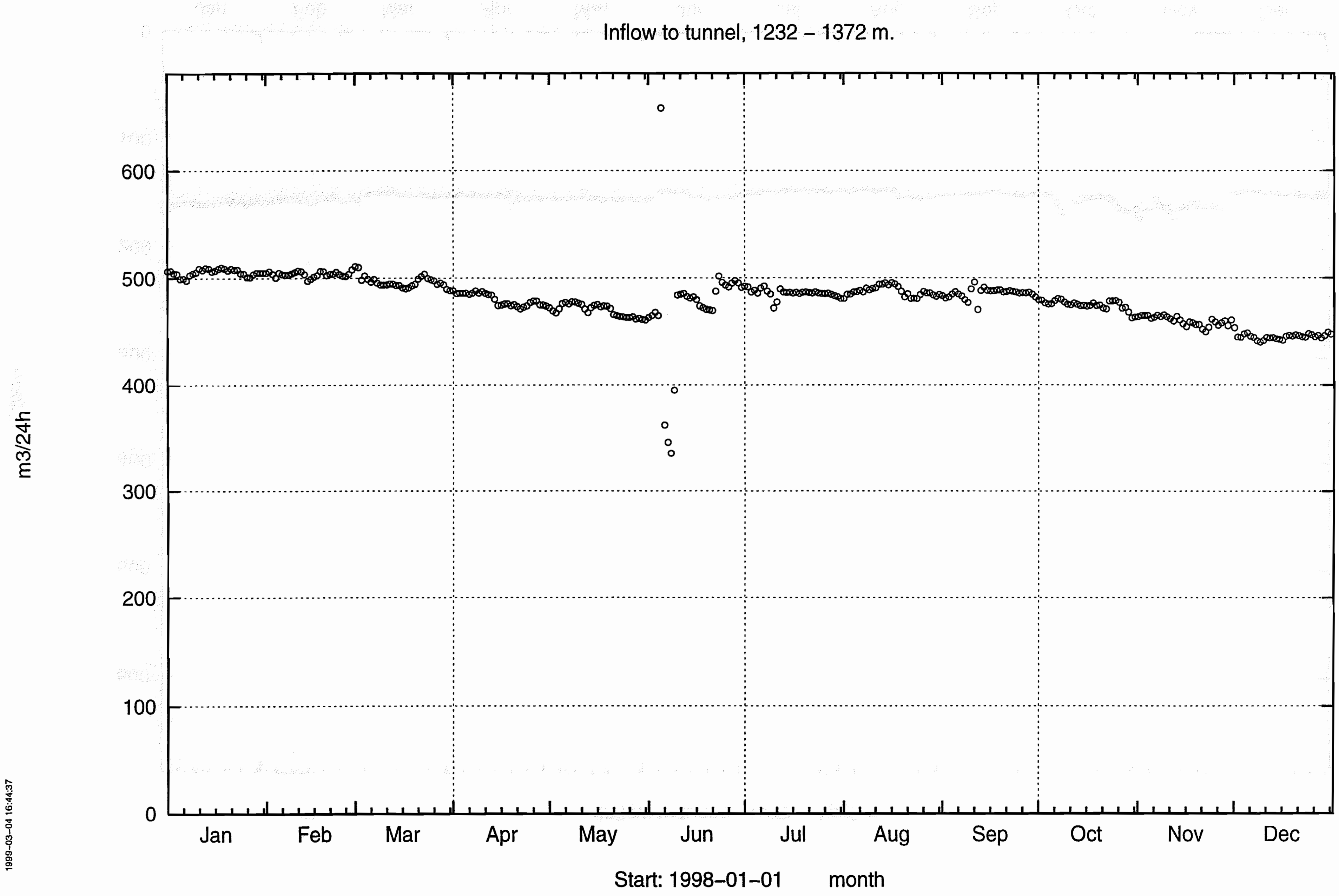


Inflow to tunnel, 0 – 682 m.
m3/24h
0
20
40
60
80
100
120
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–03–04 16:44:36

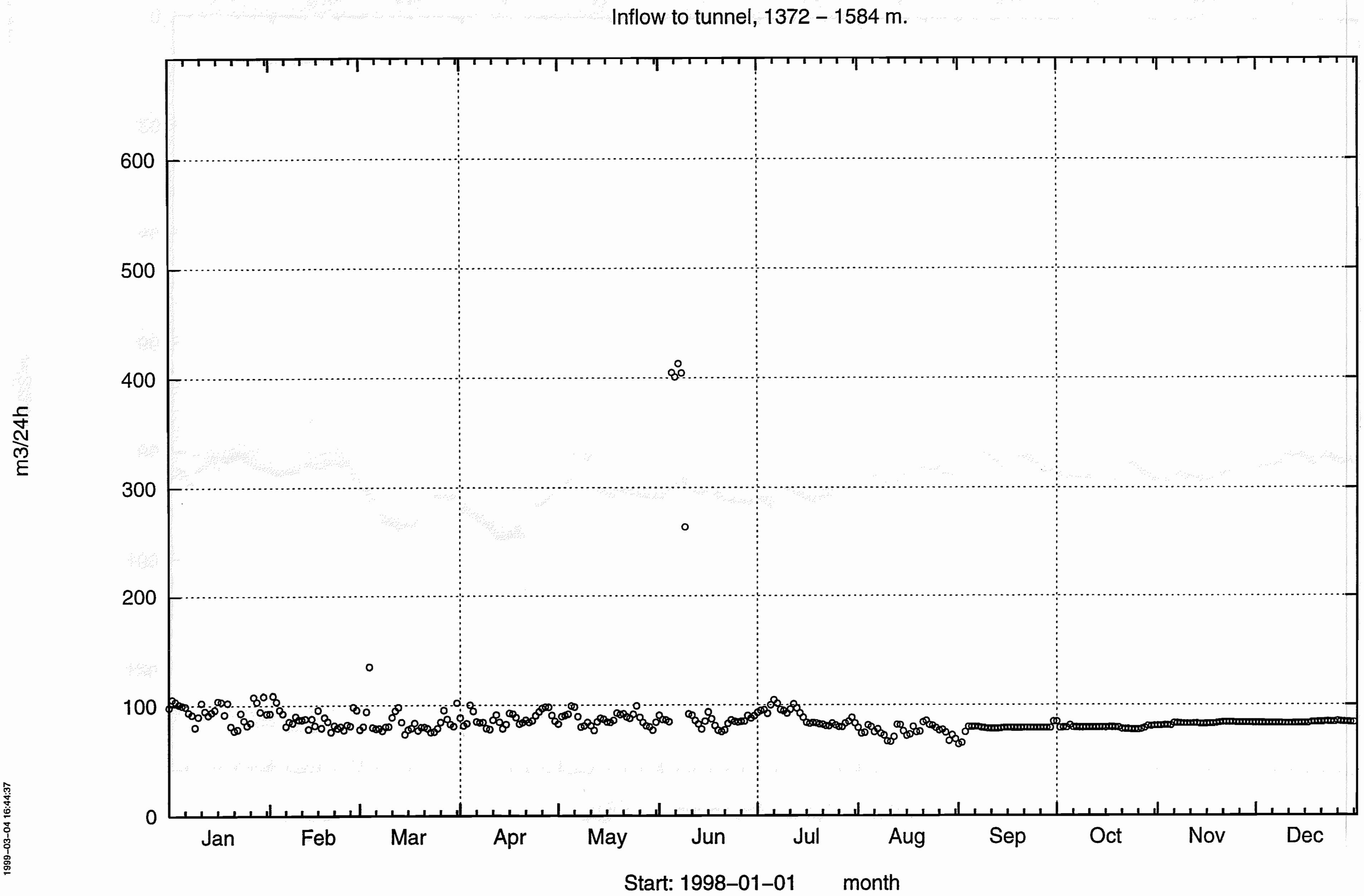

Inflow to tunnel, 682 – 1033 m.
m3/24h
0
200
400
600
800
1000
1200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999-03-04 16:44:36



1999–03–04 16:44:36

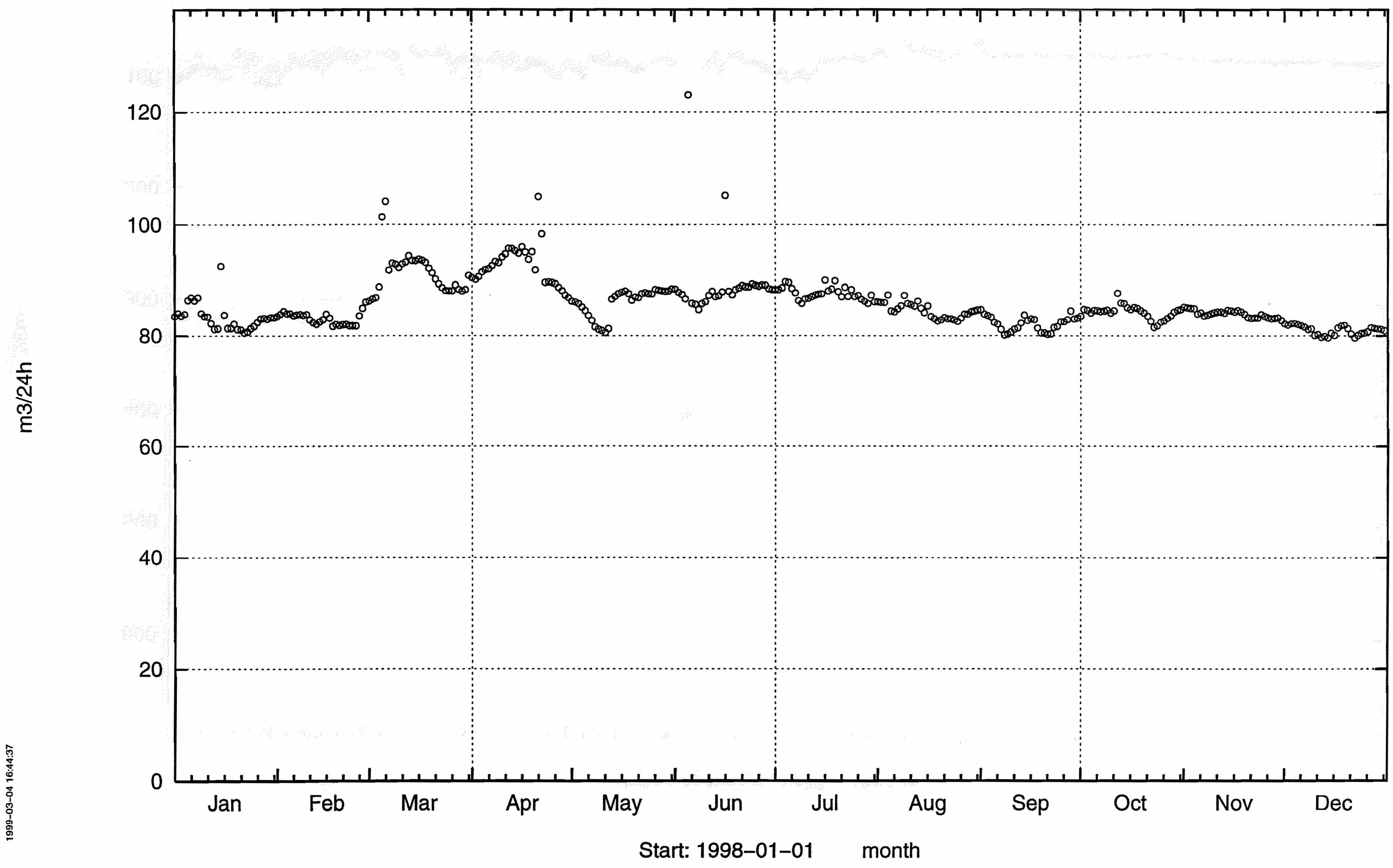


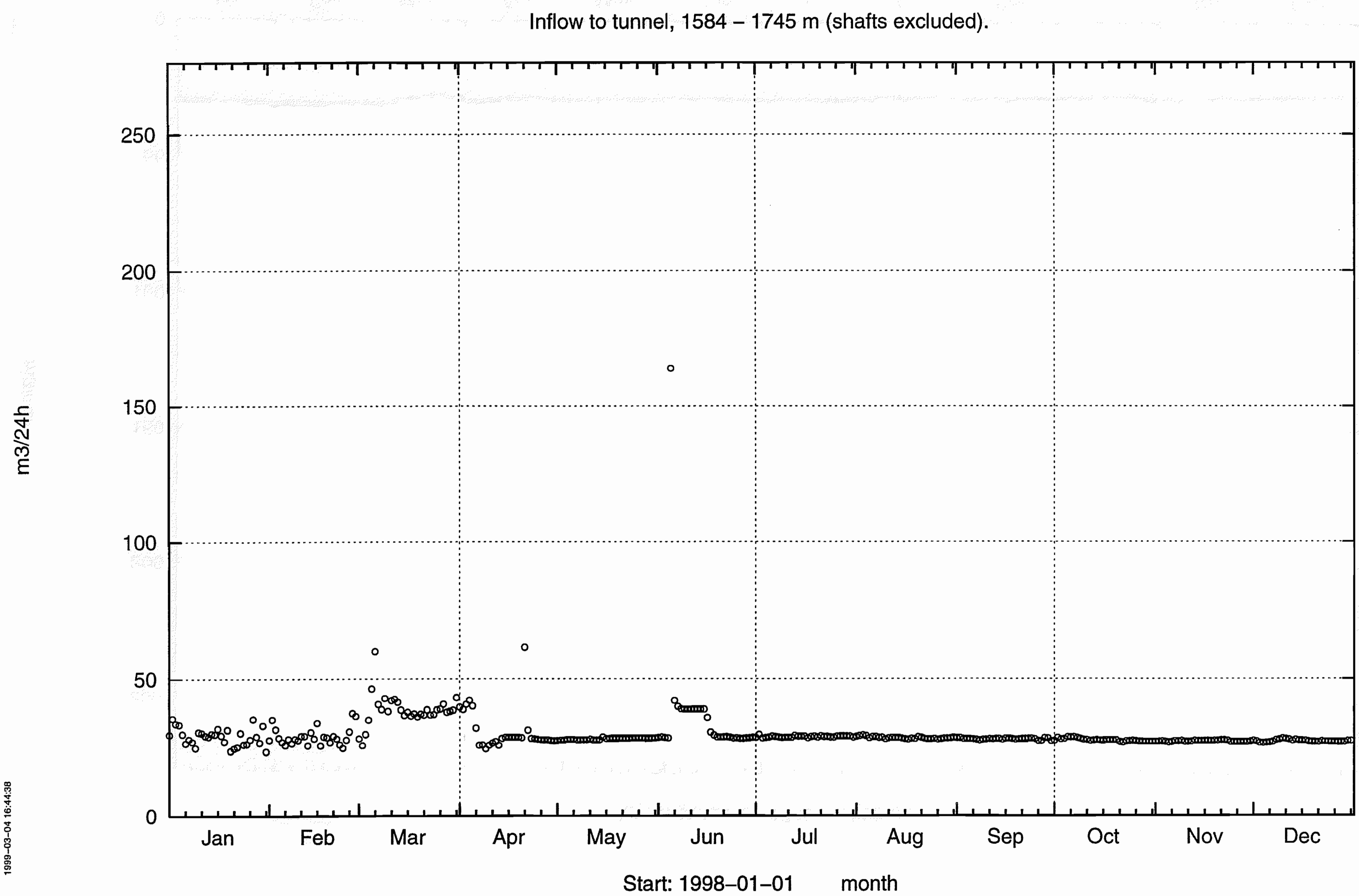
Inflow to tunnel, 1232 – 1372 m.
m3/24h
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–03–04 16:44:37



1999–03–04 16:44:37

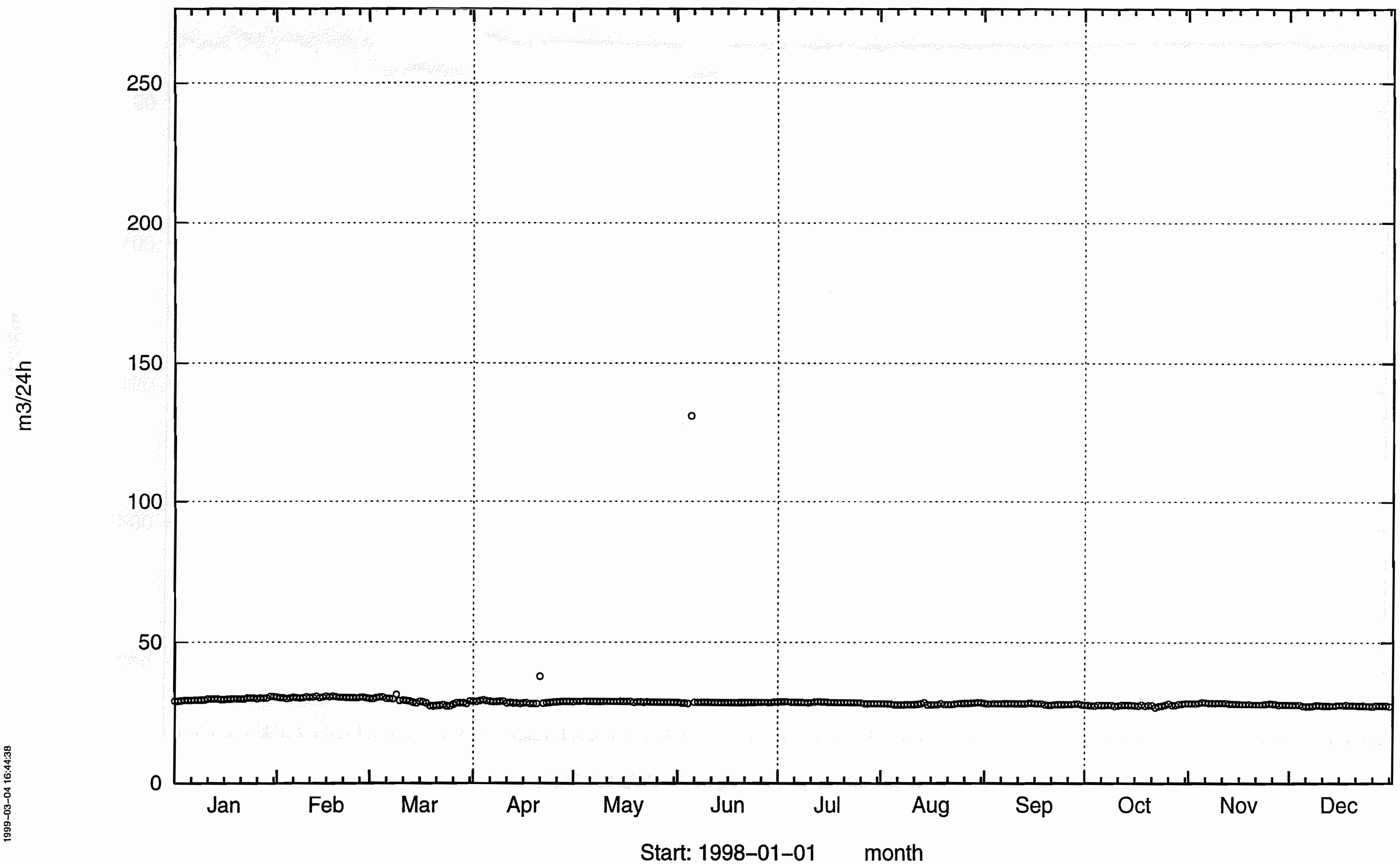
Inflow to tunnel, from shafts at 1659 m.





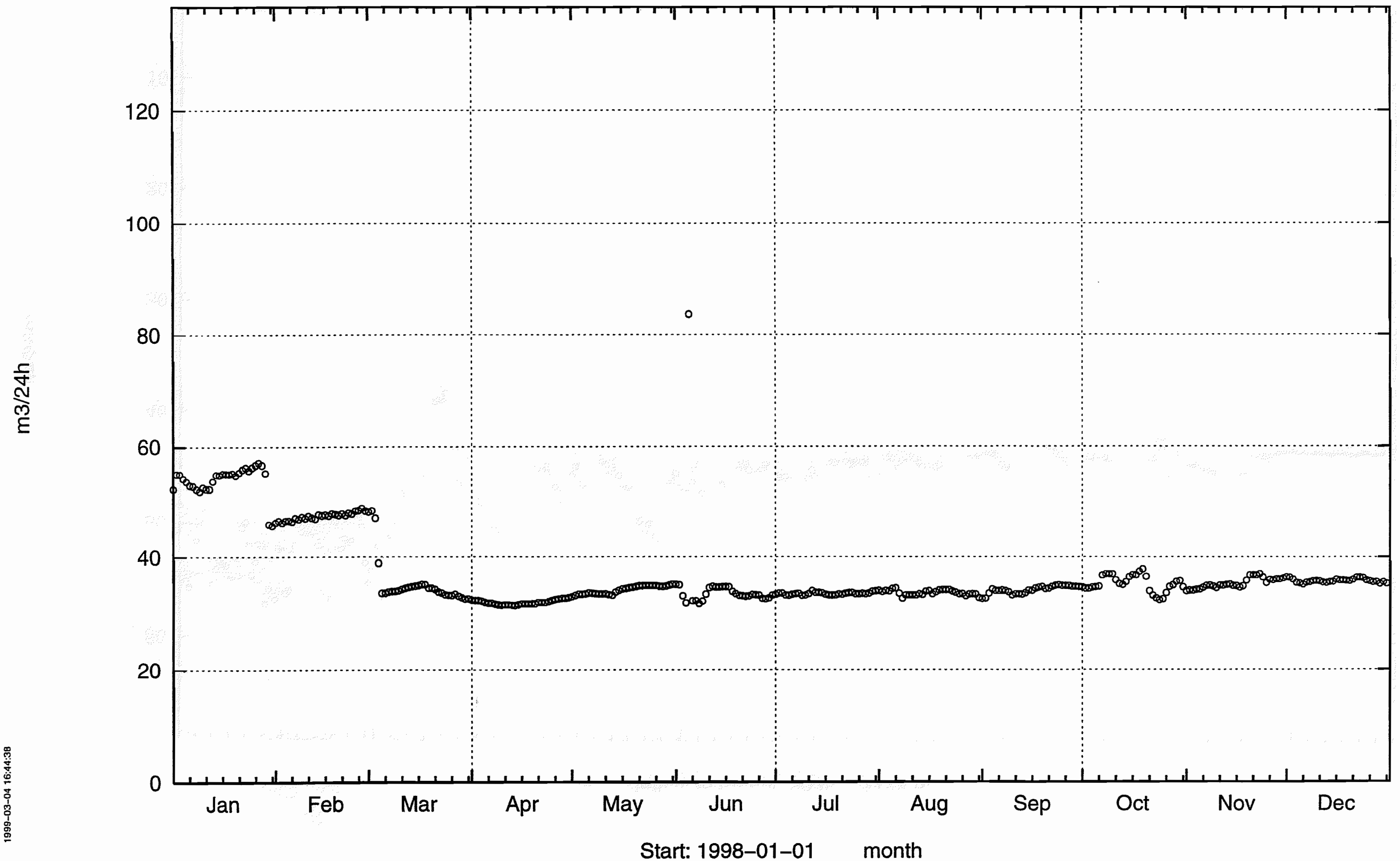
Inflow to tunnel, 1584 – 1745 m (shafts excluded).
m3/24h
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–03–04 16:44:38

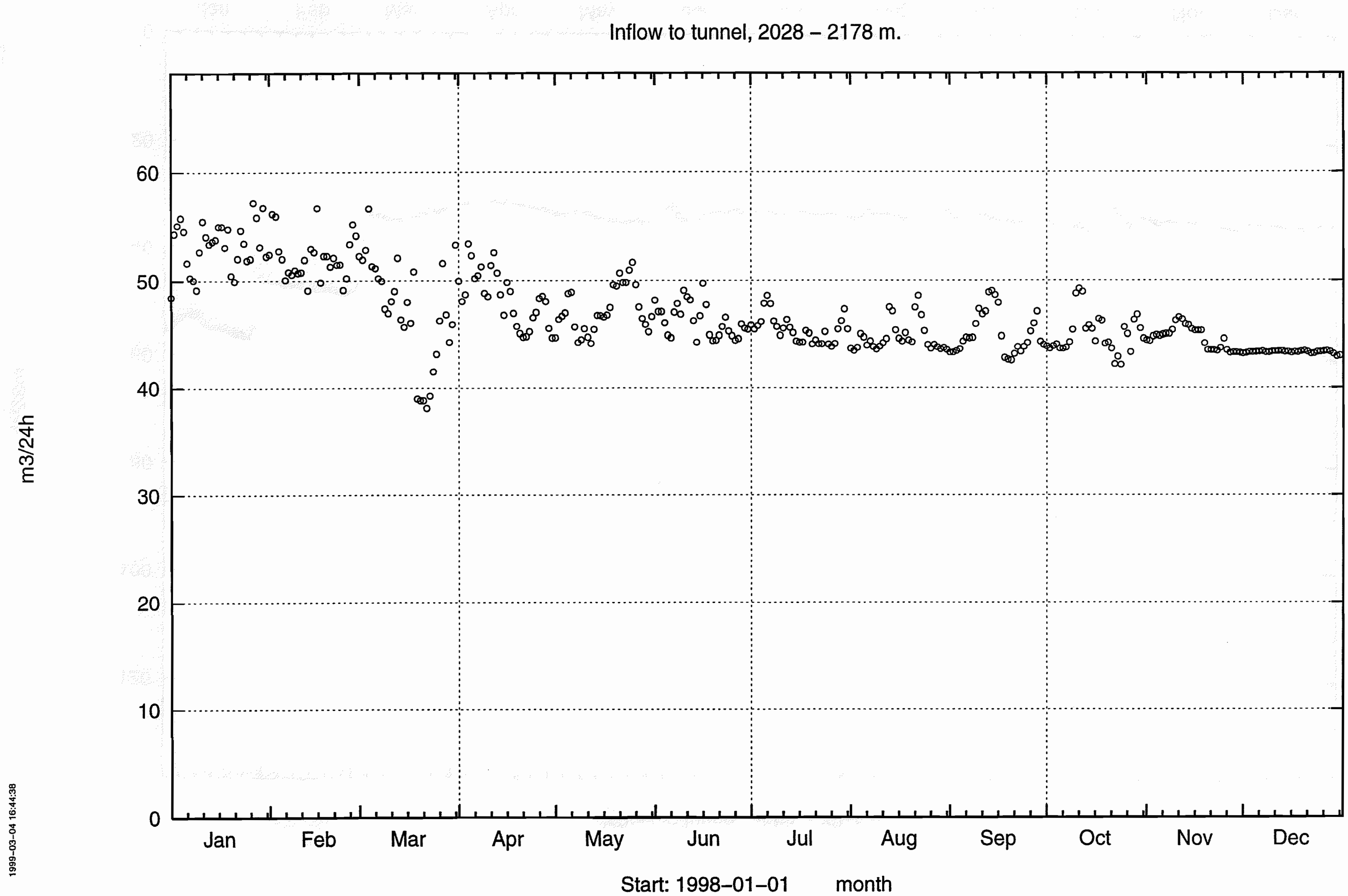
Inflow to tunnel, 1745 – 1883 m.



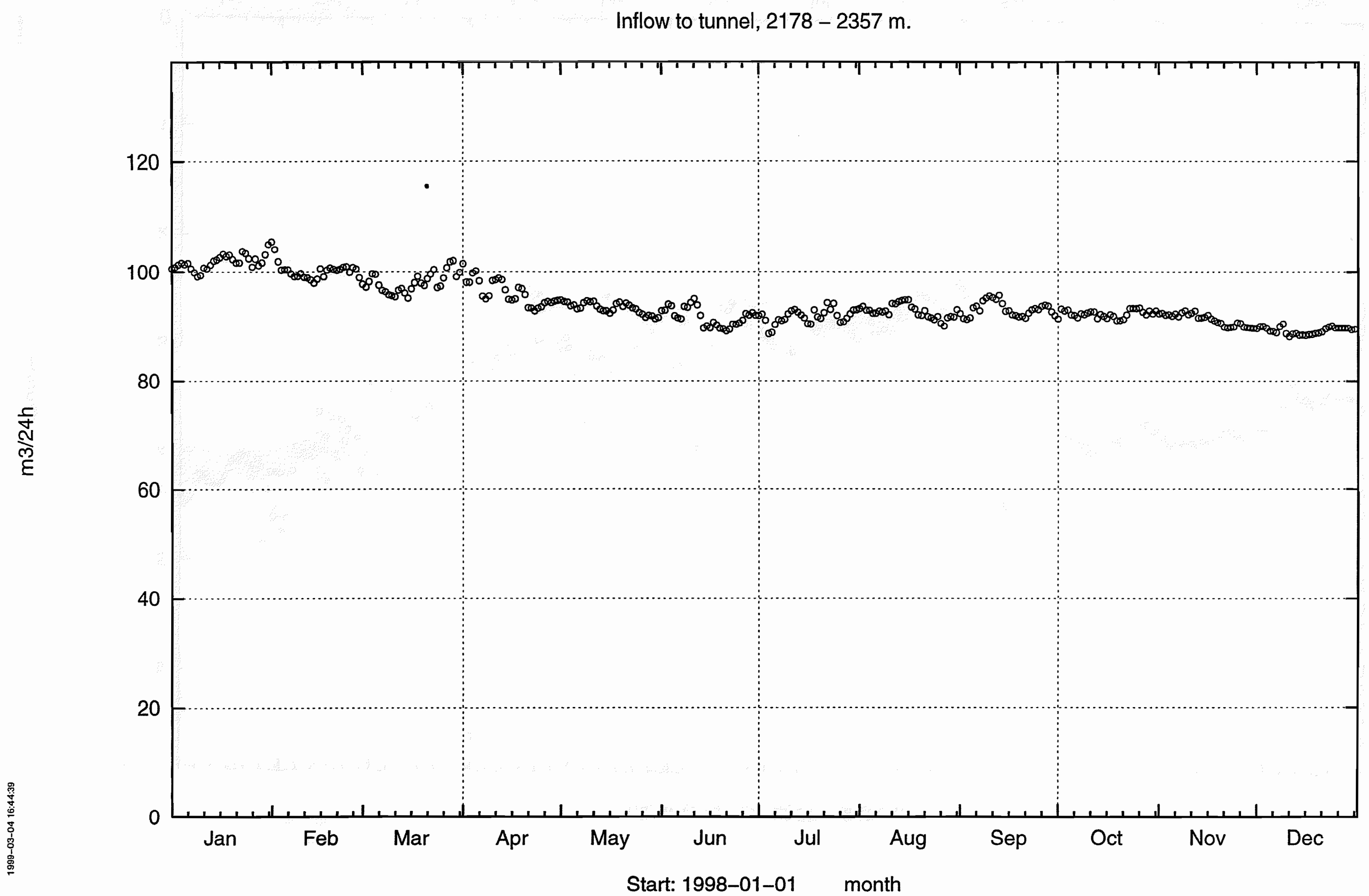
1999–03–04 16:44:38

Inflow to tunnel, 1883 – 2028 m.

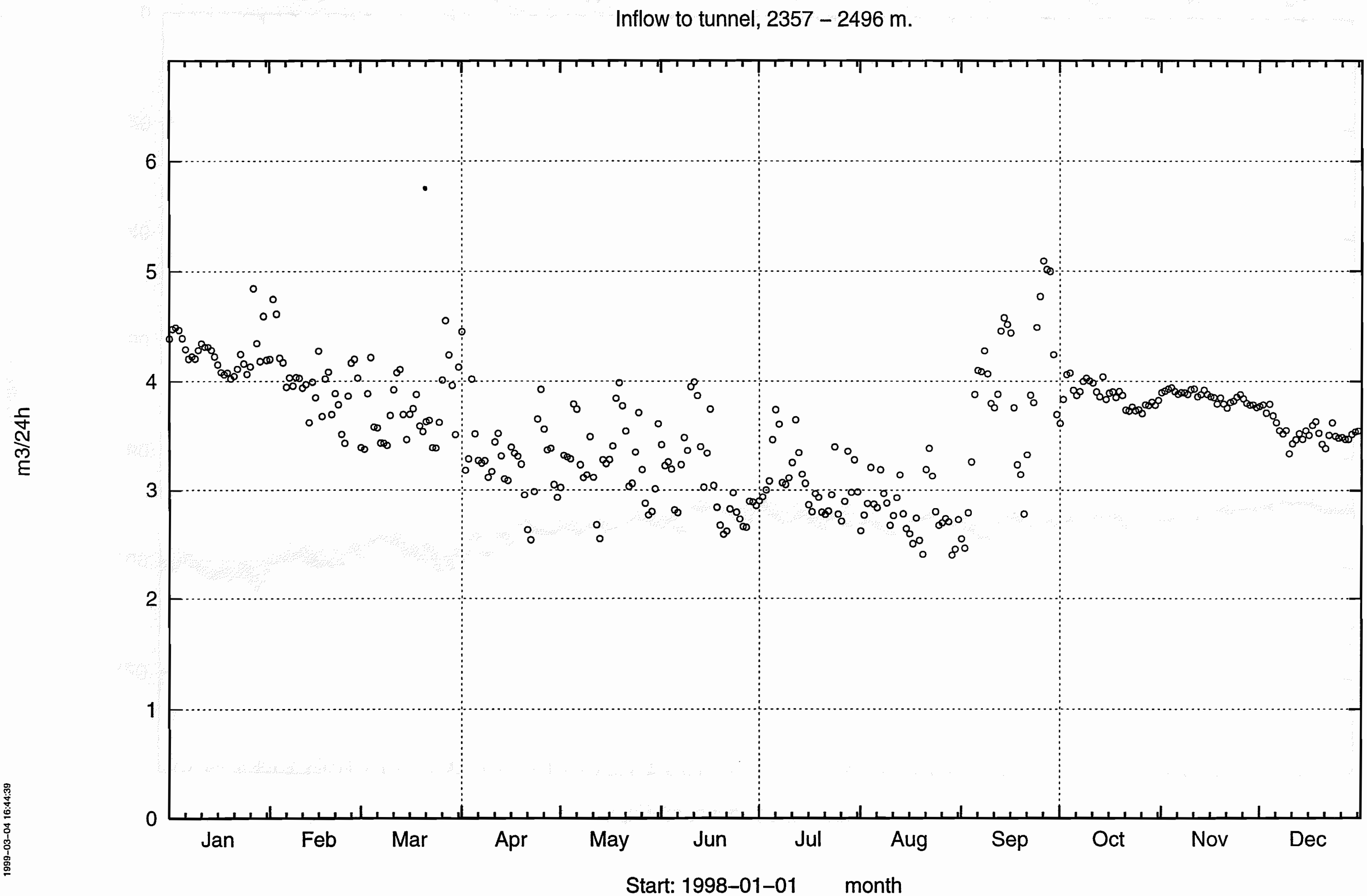




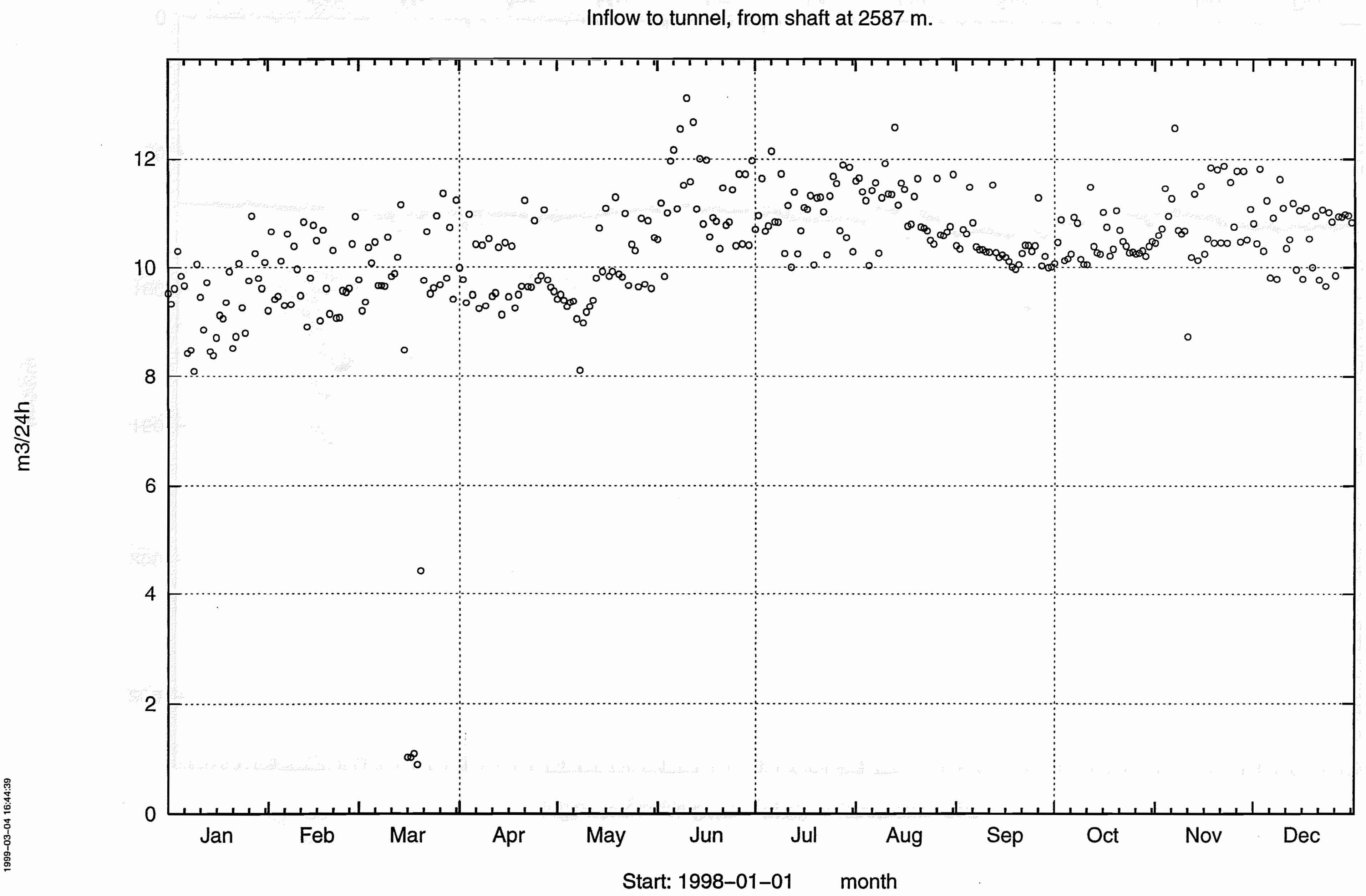
Inflow to tunnel, 2028 – 2178 m.
m3/24h
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–03–04 16:44:38



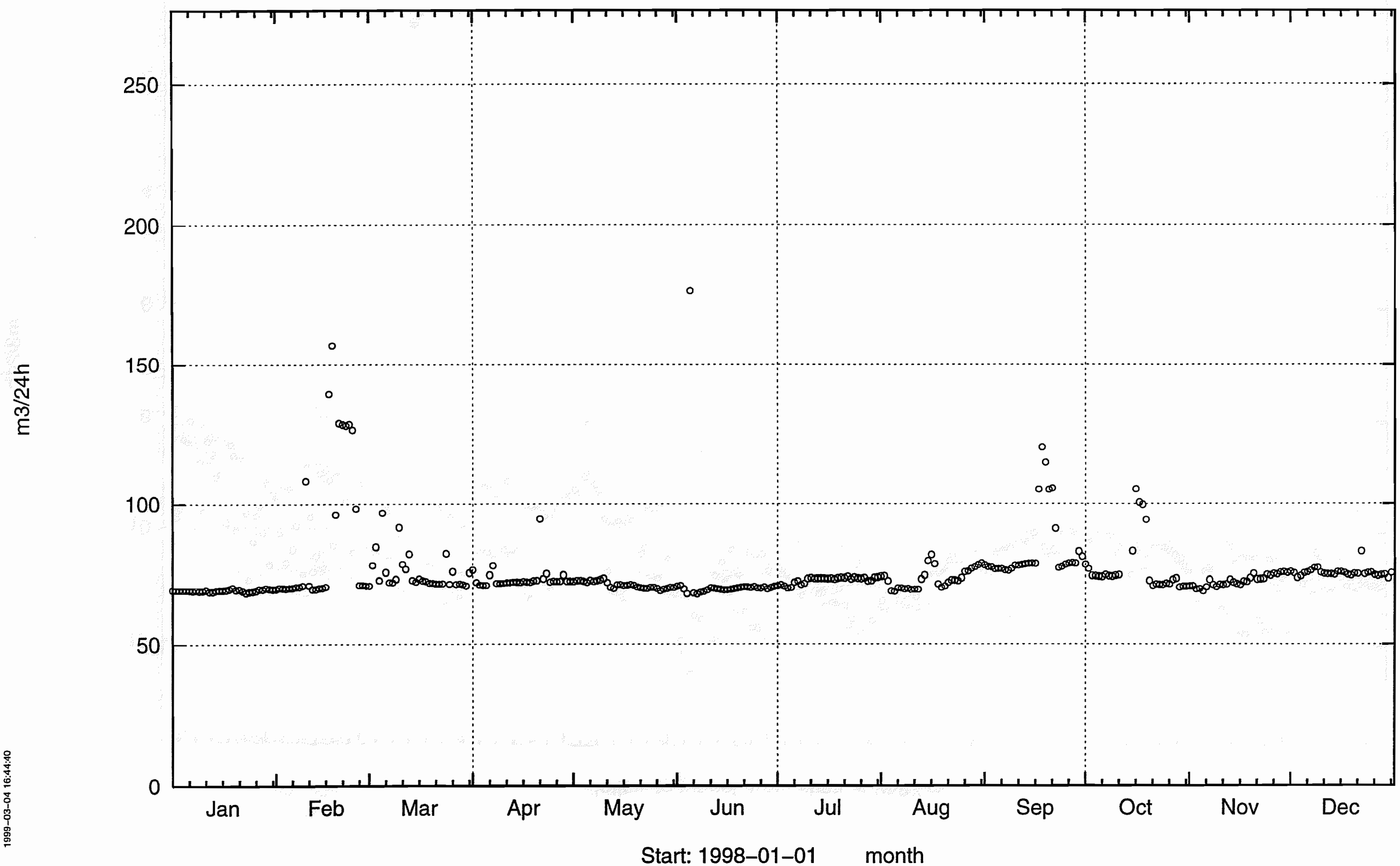
Inflow to tunnel, 2178 – 2357 m.
m3/24h
0
20
40
60
80
100
120
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-03-04 16:44:39



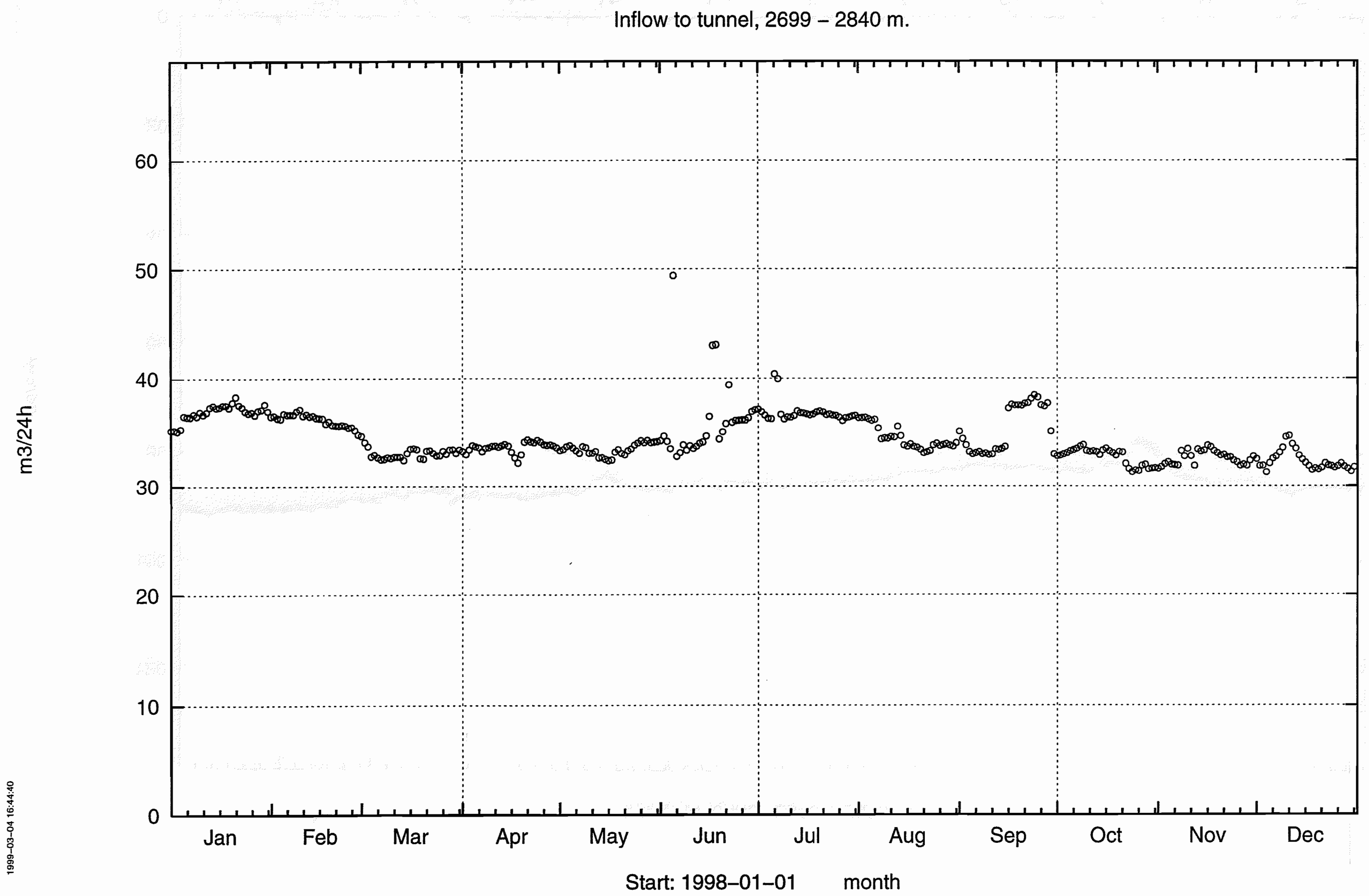
Inflow to tunnel, 2357 – 2496 m.
m3/24h
0
1
2
3
4
5
6
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–03–04 16:44:39

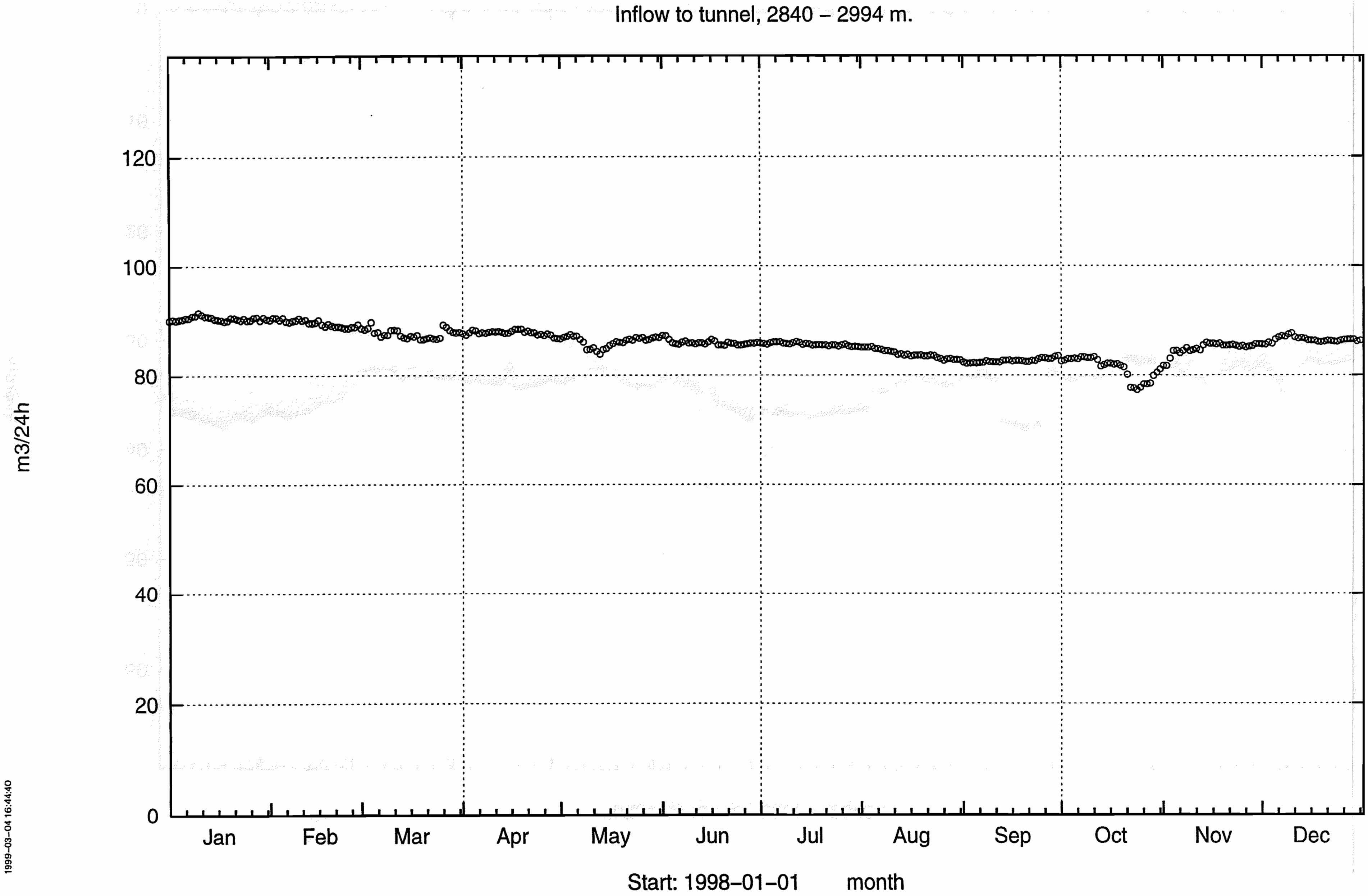

Inflow to tunnel, from shaft at 2587 m.
m3/24h
0
2
4
6
8
10
12
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-03-04 16:44:39

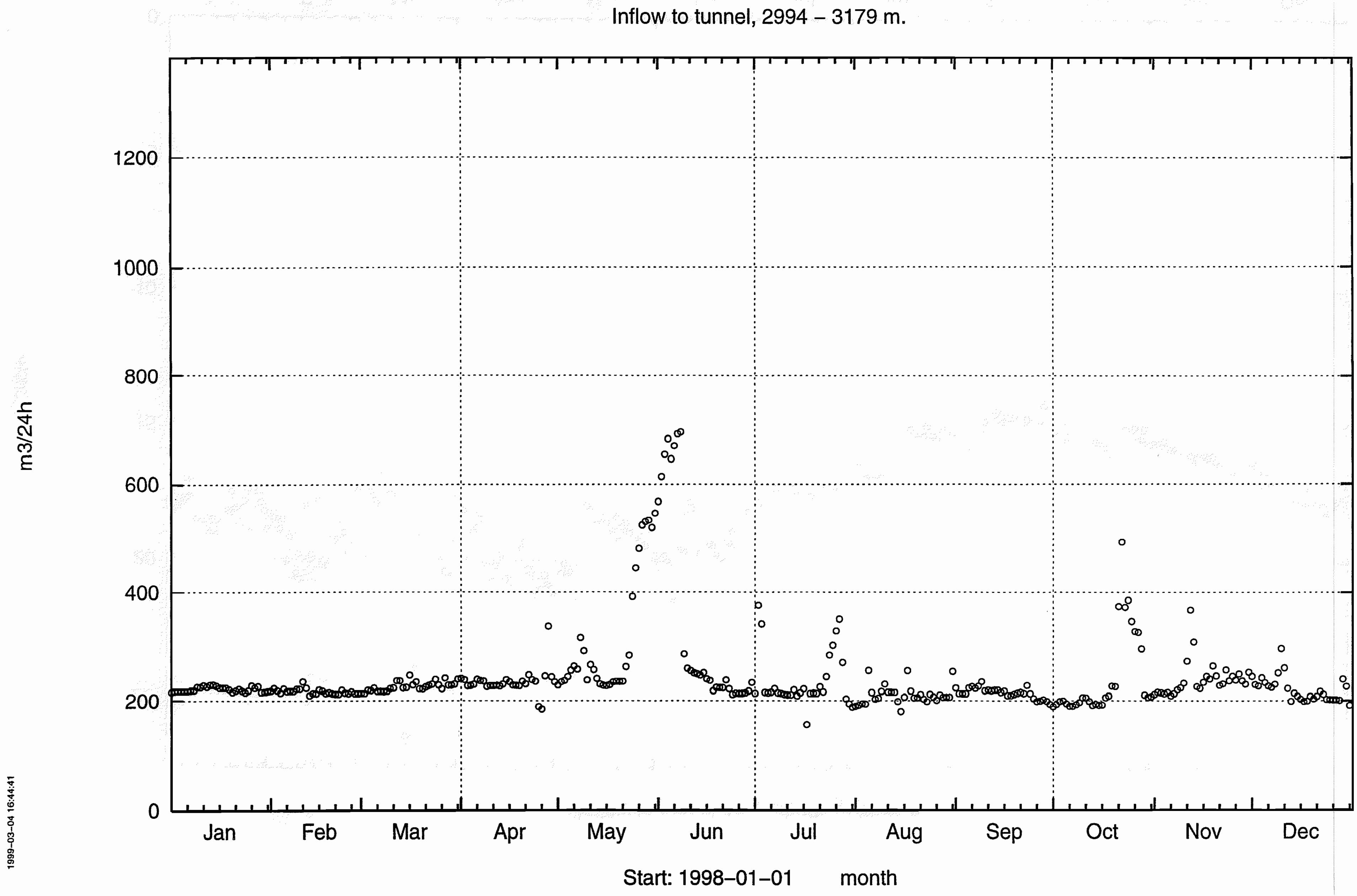
Inflow to tunnel, 2496 – 2699 m (shaft excluded).

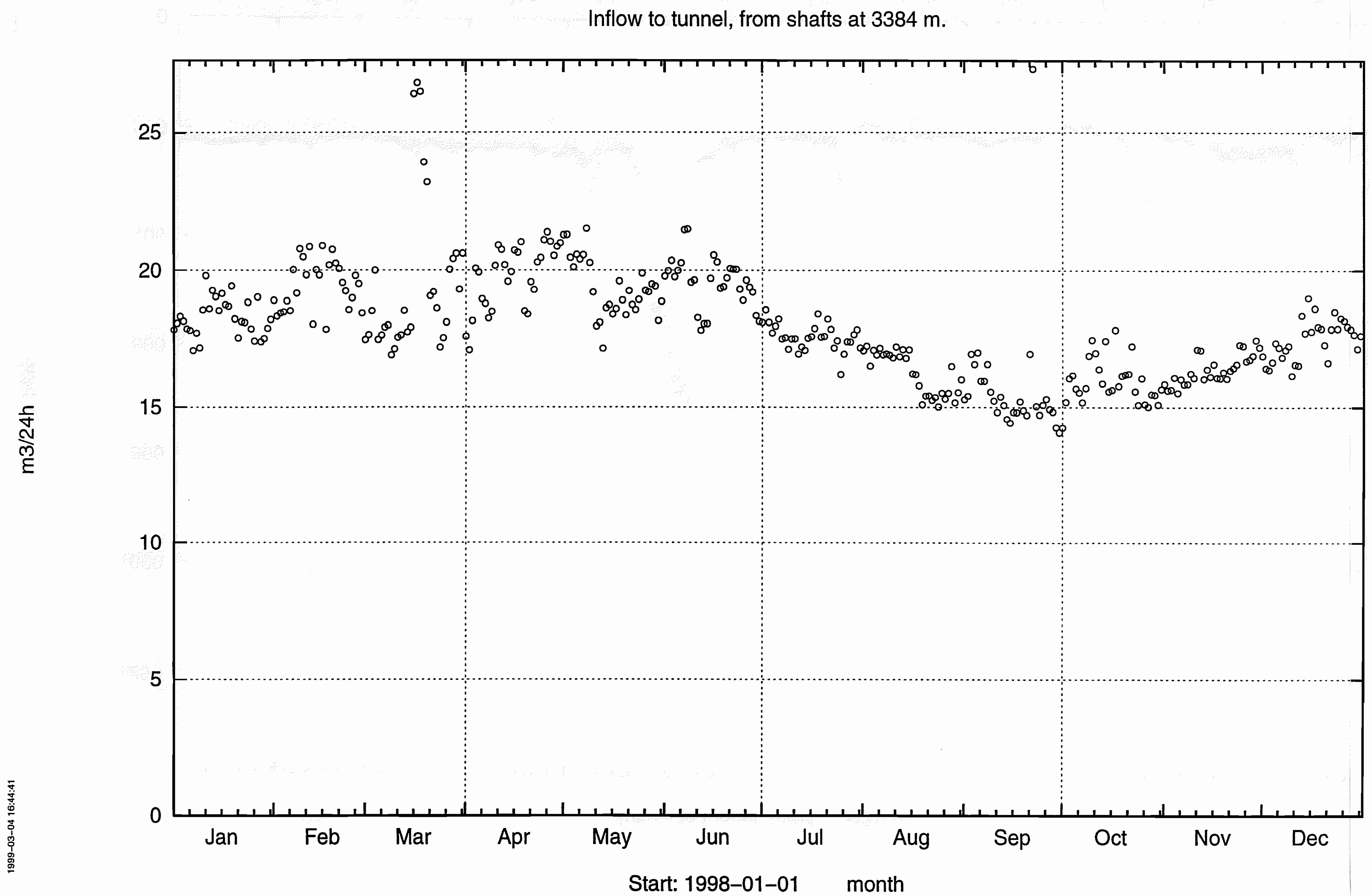


1999–03–04 16:44:40

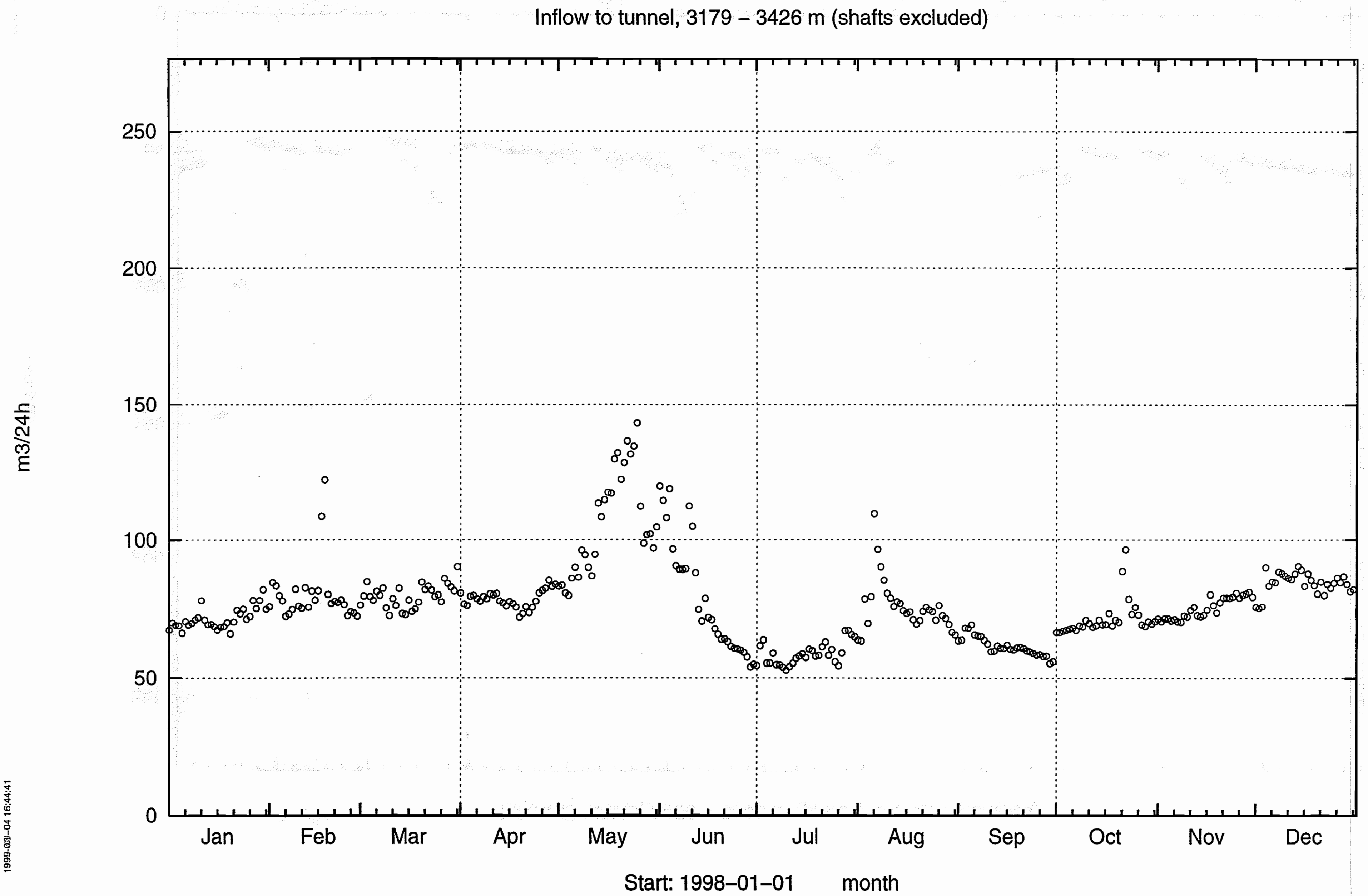

Inflow to tunnel, 2699 – 2840 m.
m3/24h
0
10
20
30
40
50
60
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–03–04 16:44:40


Inflow to tunnel, 2840 – 2994 m.
m3/24h
0
20
40
60
80
100
120
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-03-04 16:44:40

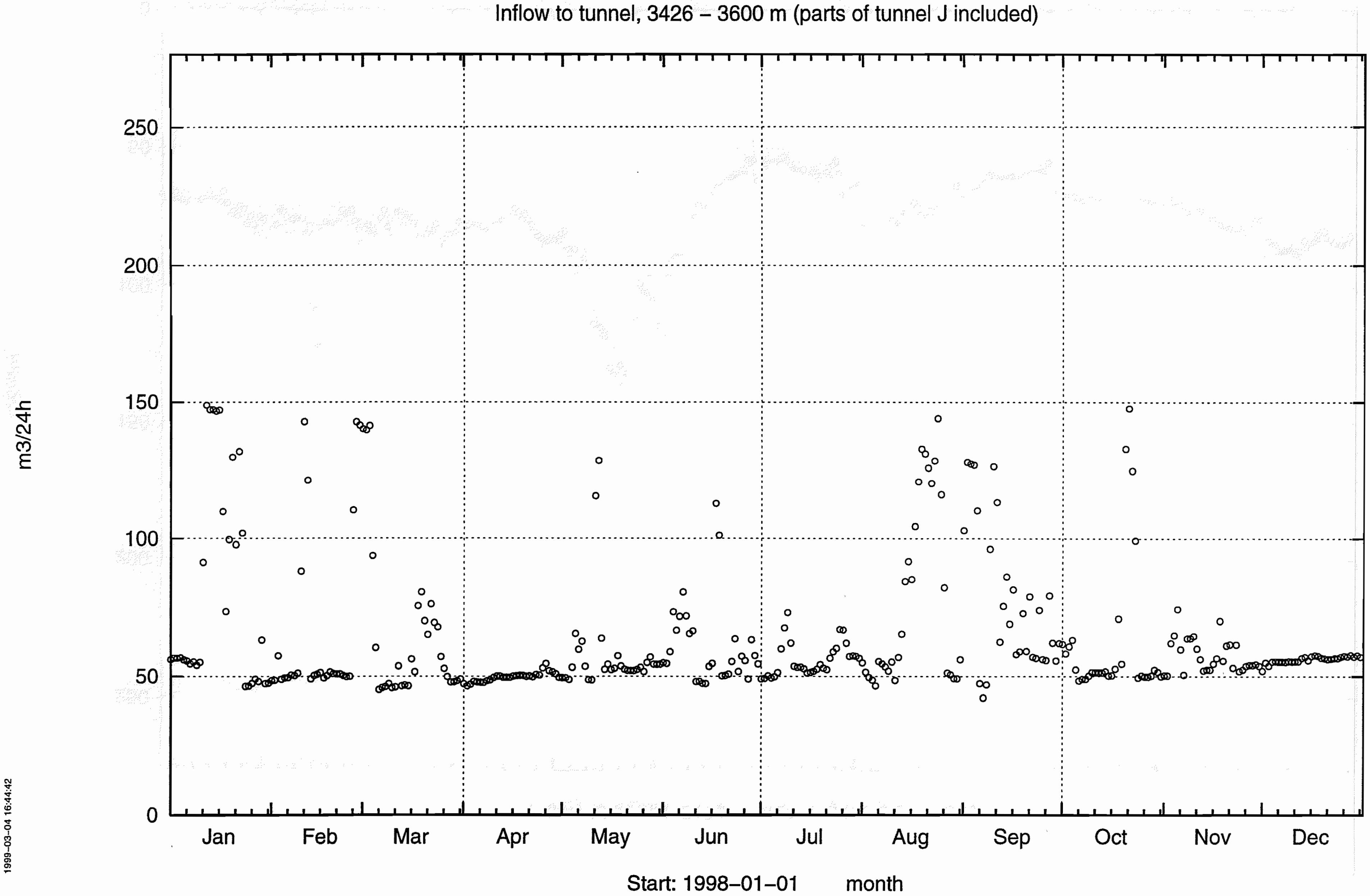

Inflow to tunnel, 2994 – 3179 m.
m3/24h
1200
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-03-04 16:44:41

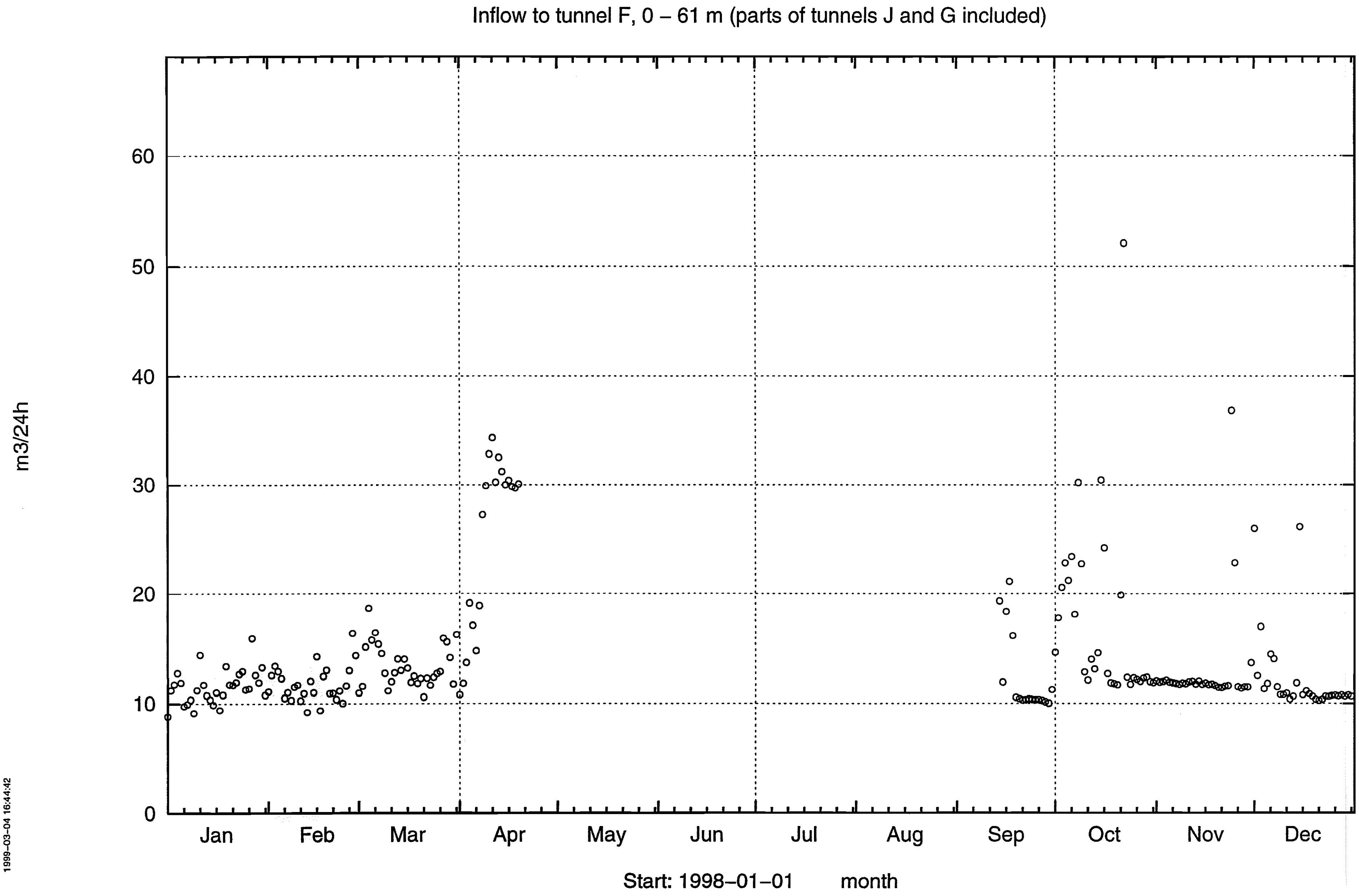


Inflow to tunnel, from shafts at 3384 m.
m3/24h
0
5
10
15
20
25
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-03-04 16:44:41



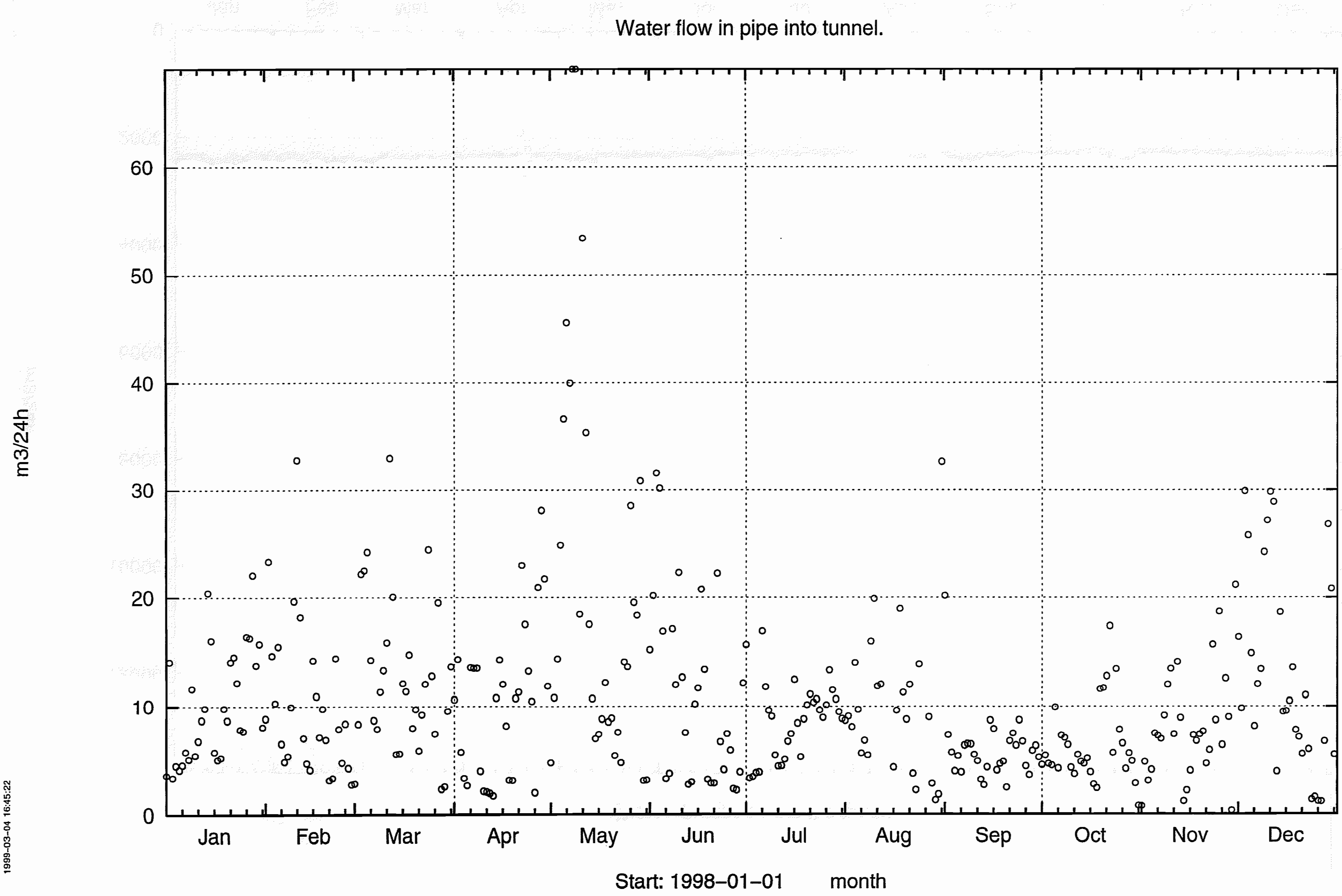
Inflow to tunnel, 3179 – 3426 m (shafts excluded)
m3/24h
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-03-04 16:44:41


Inflow to tunnel, 3426 – 3600 m (parts of tunnel J included)
m3/24h
0
50
100
150
200
250
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-03-04 16:44:42

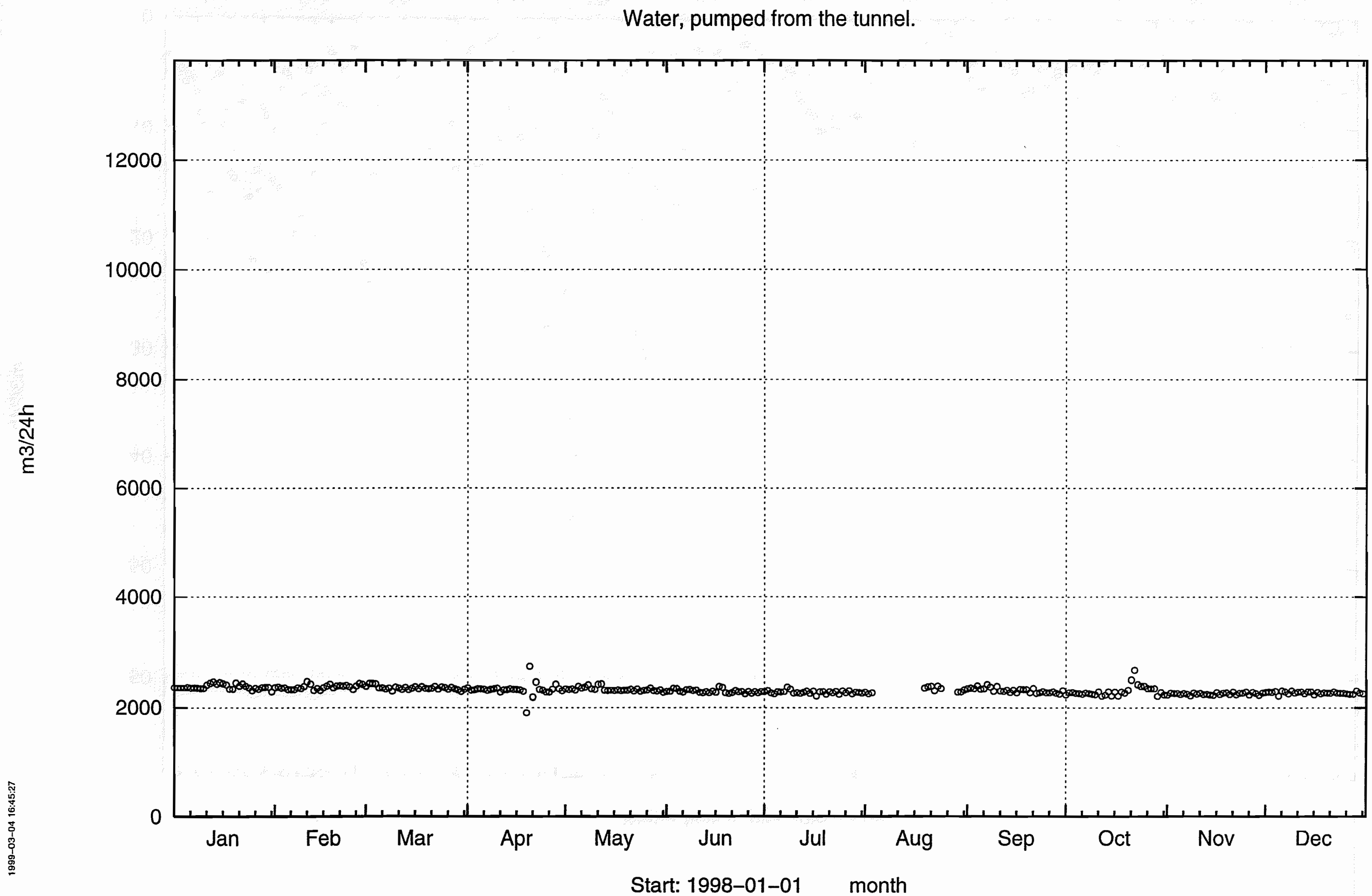


Inflow to tunnel F, 0 – 61 m (parts of tunnels J and G included)
m3/24h
0
10
20
30
40
50
60
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–03–04 16:44:42

Appendix 6: Water flow in tunnel pipes

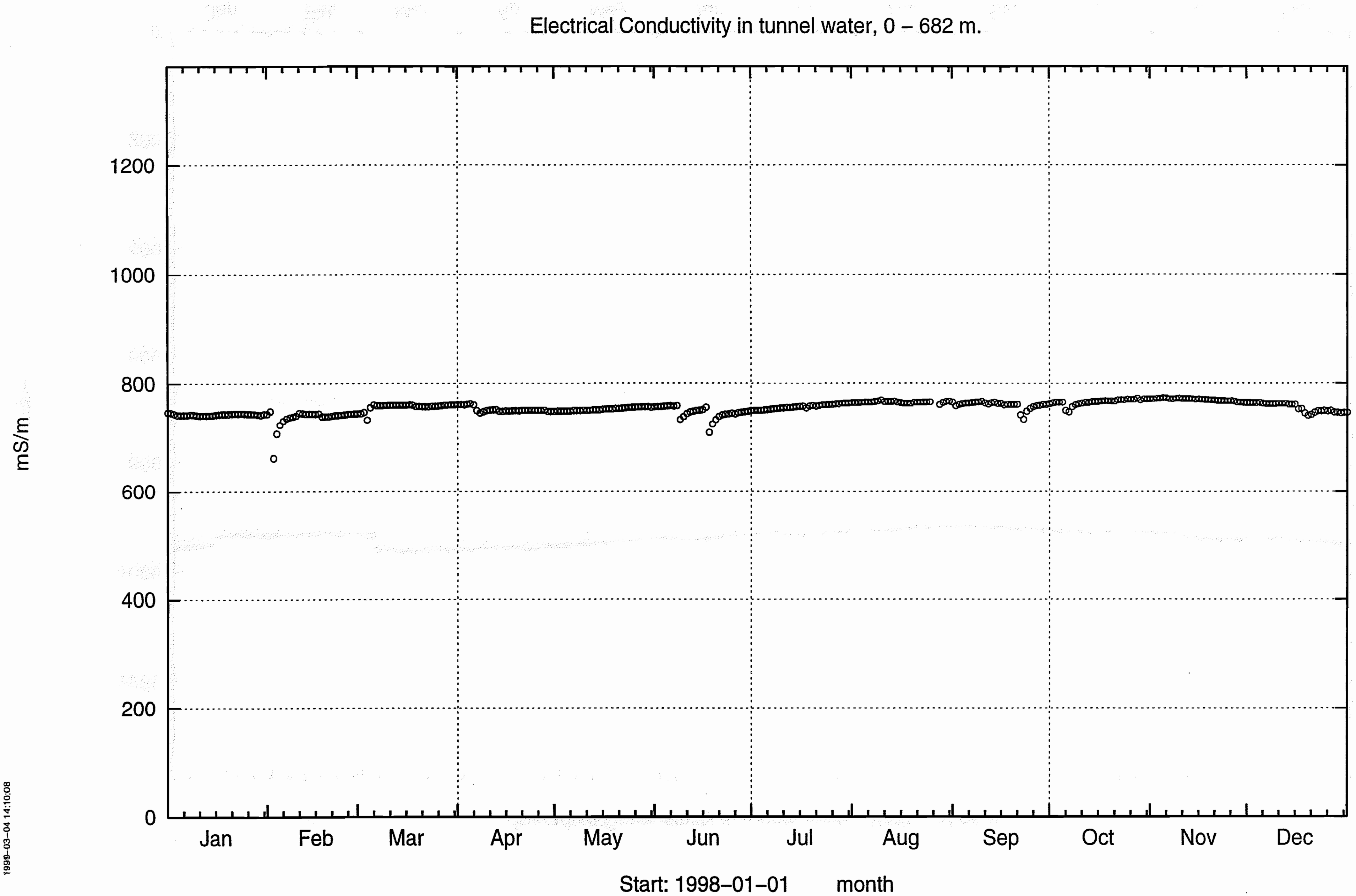


1999–03–04 16:45:22

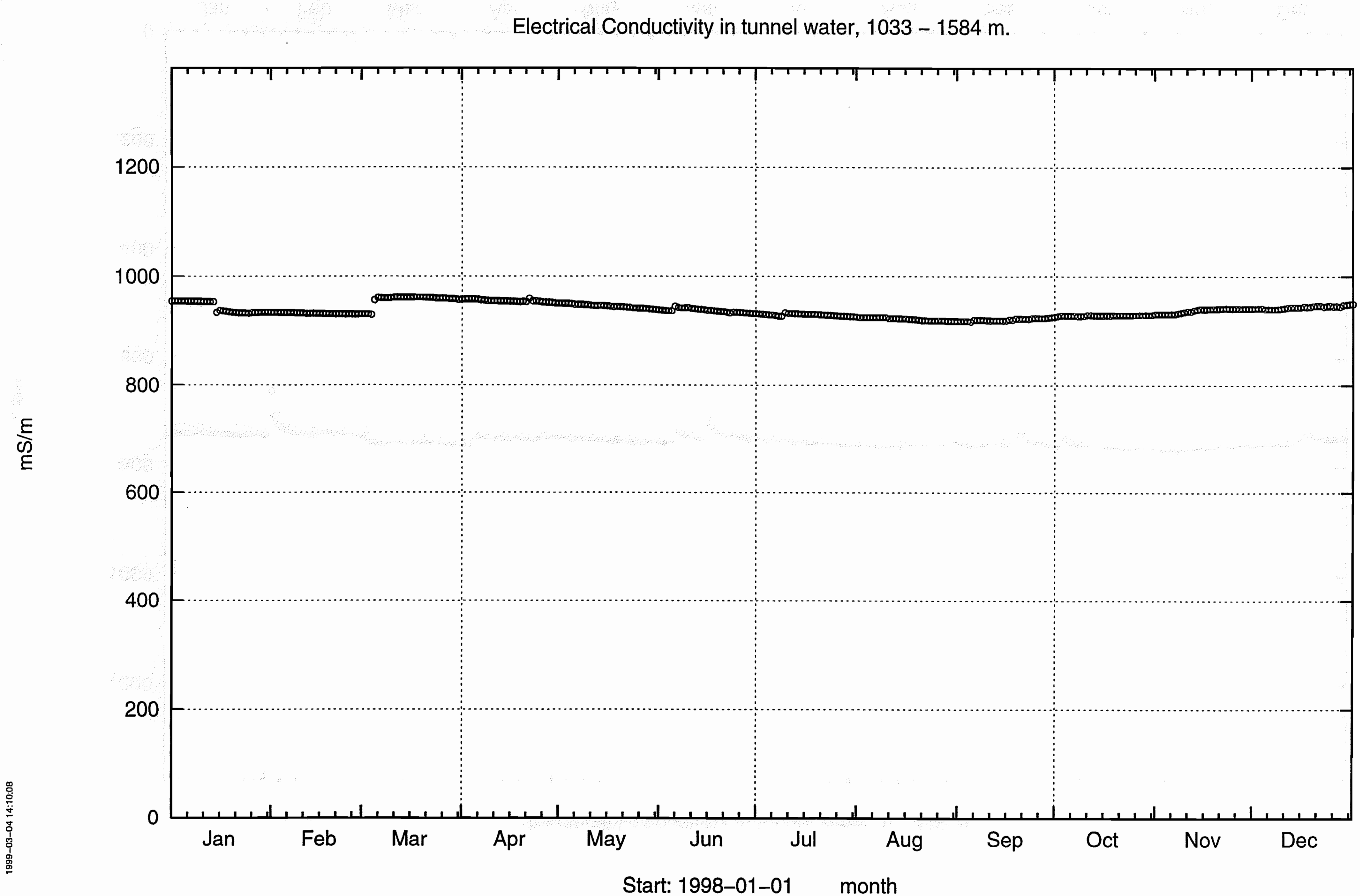


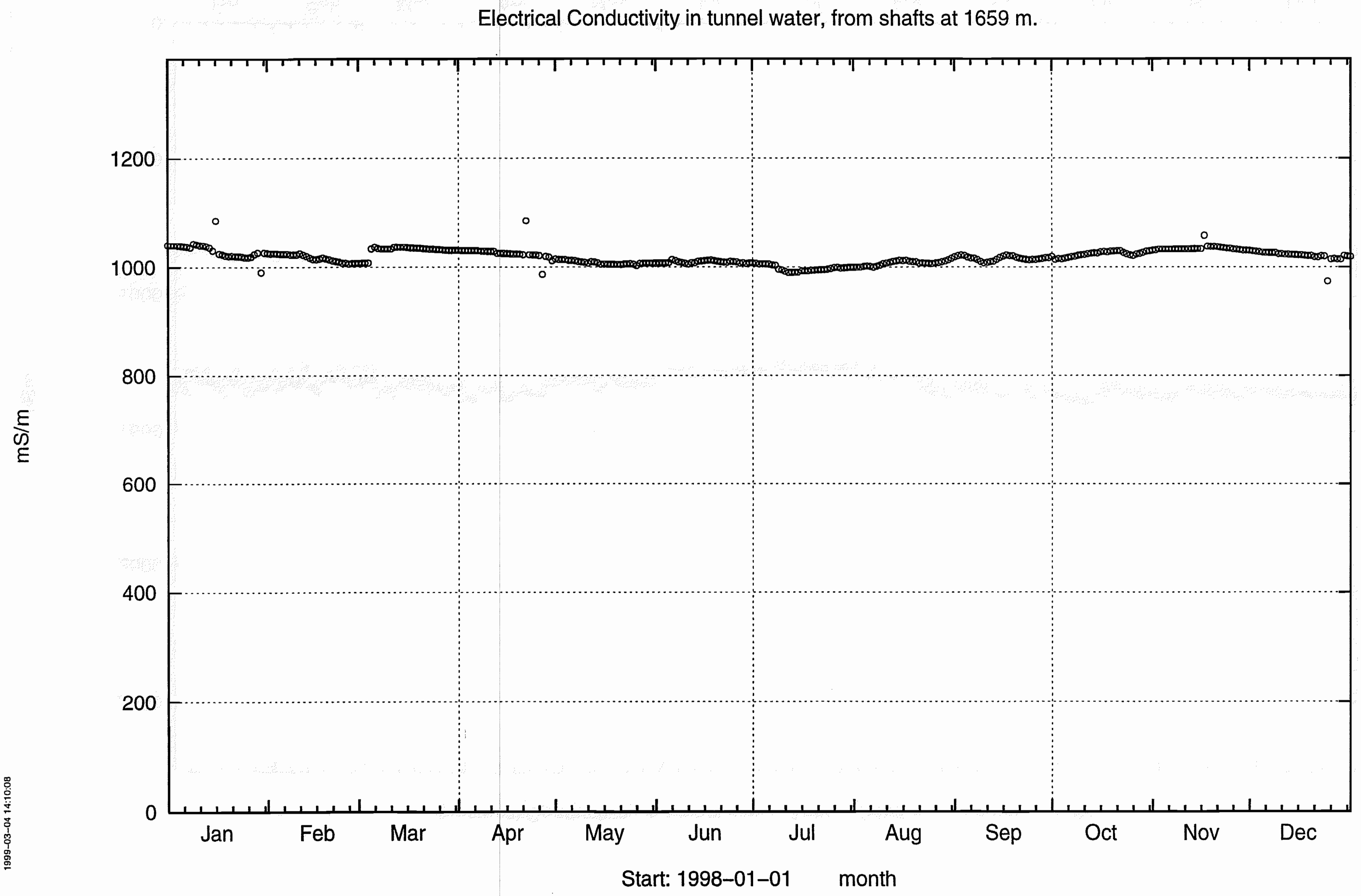
Water, pumped from the tunnel.
m3/24h
12000
10000
8000
6000
4000
2000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-03-04 16:45:27

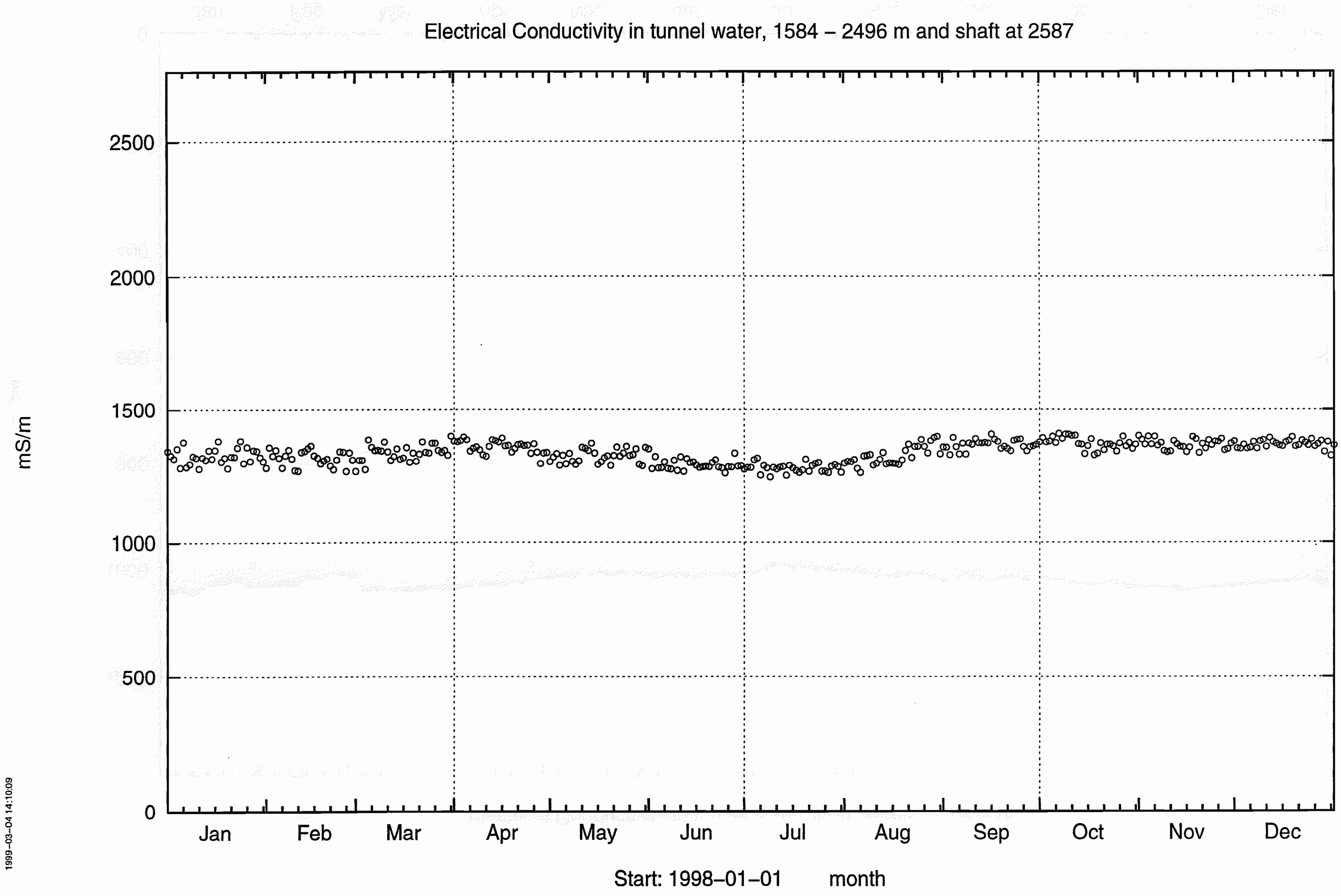
Appendix 7: Electrical conductivity of tunnel water



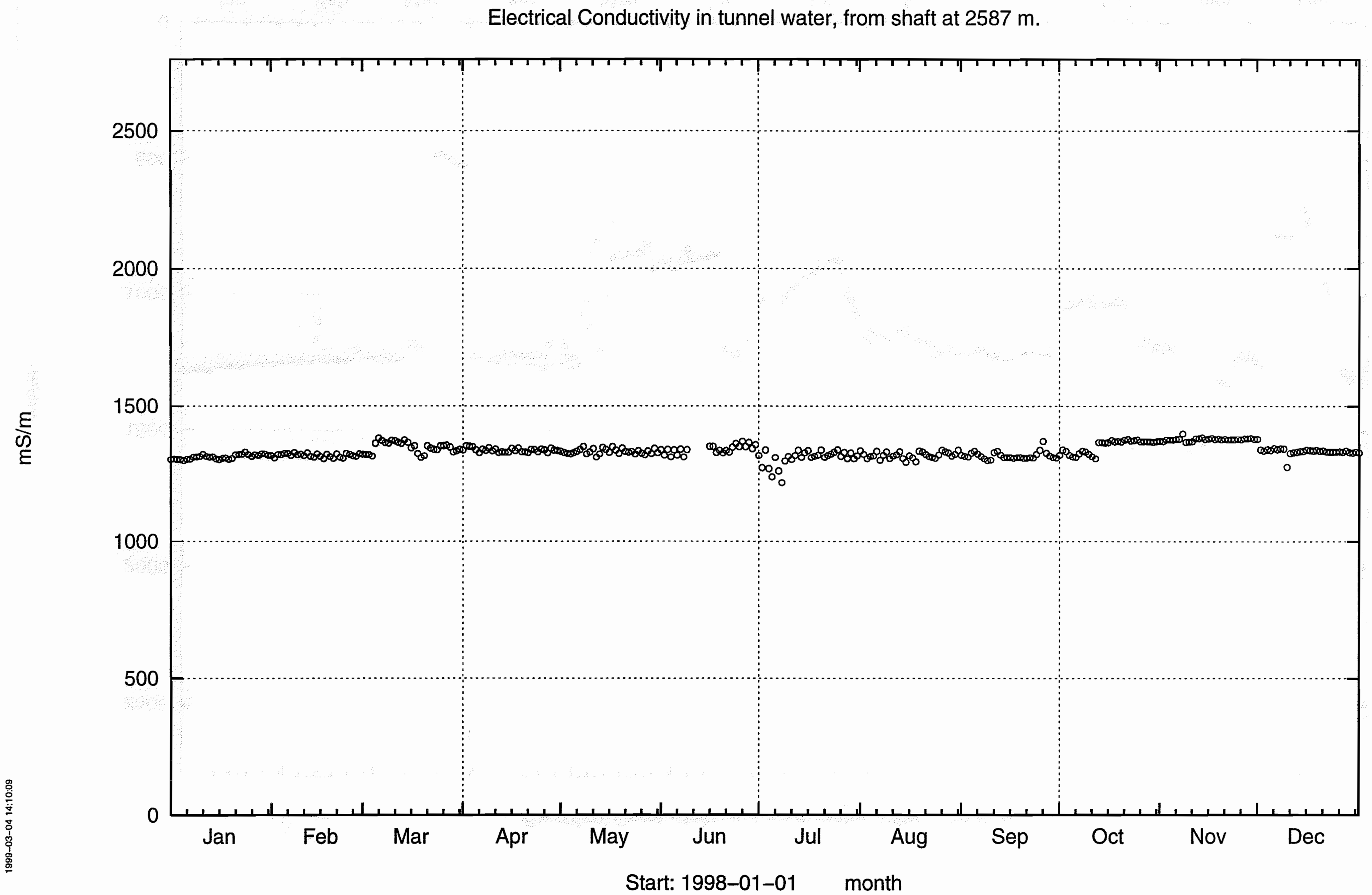
Electrical Conductivity in tunnel water, 0 – 682 m.
1200
1000
800
600
400
200
0
mS/m
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-03-04 14:10:08

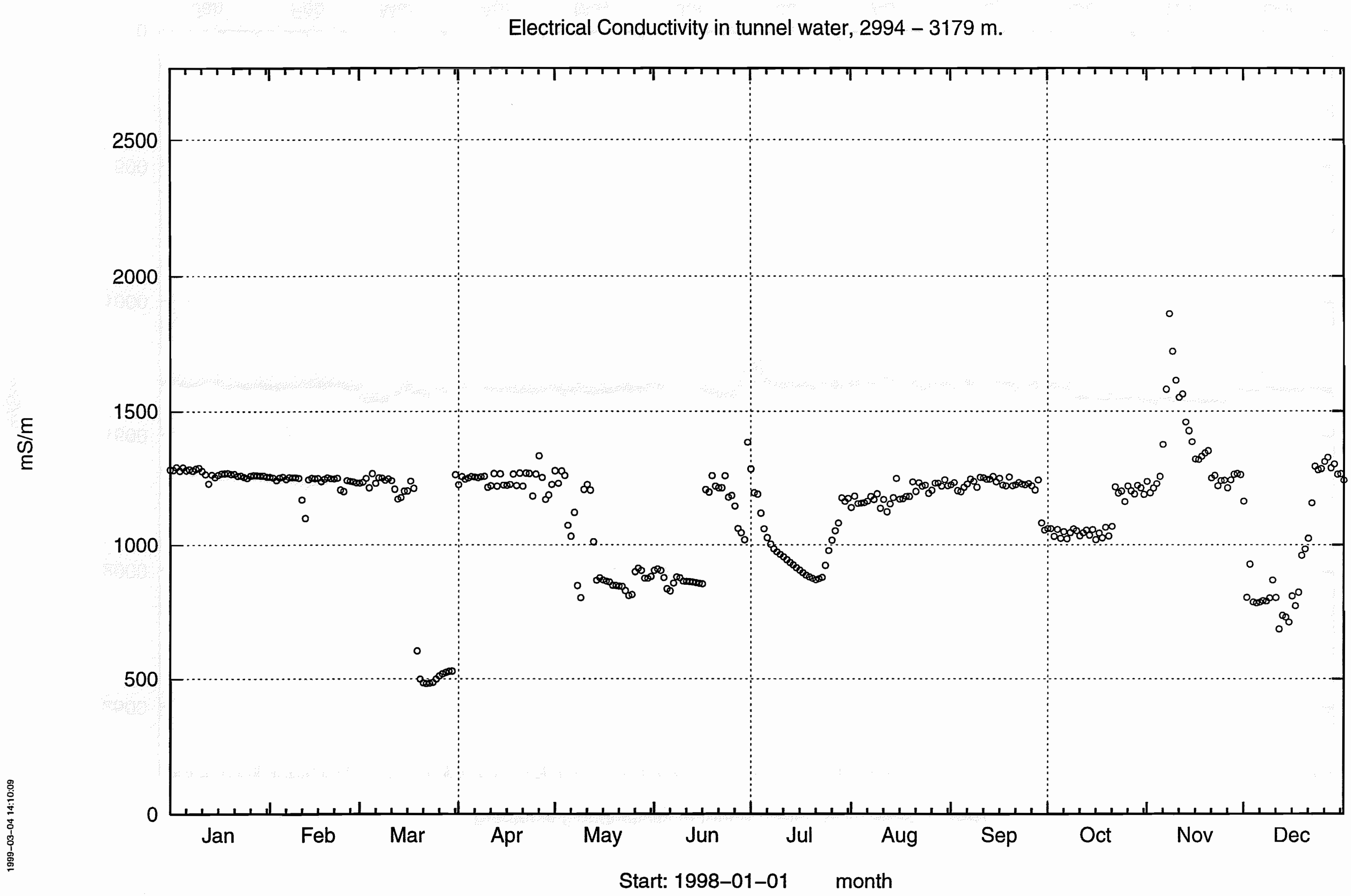

Electrical Conductivity in tunnel water, 1033 – 1584 m.
mS/m
1200
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–03–04 14:10:08


Electrical Conductivity in tunnel water, from shafts at 1659 m.
mS/m
1200
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-03-04 14:10:08

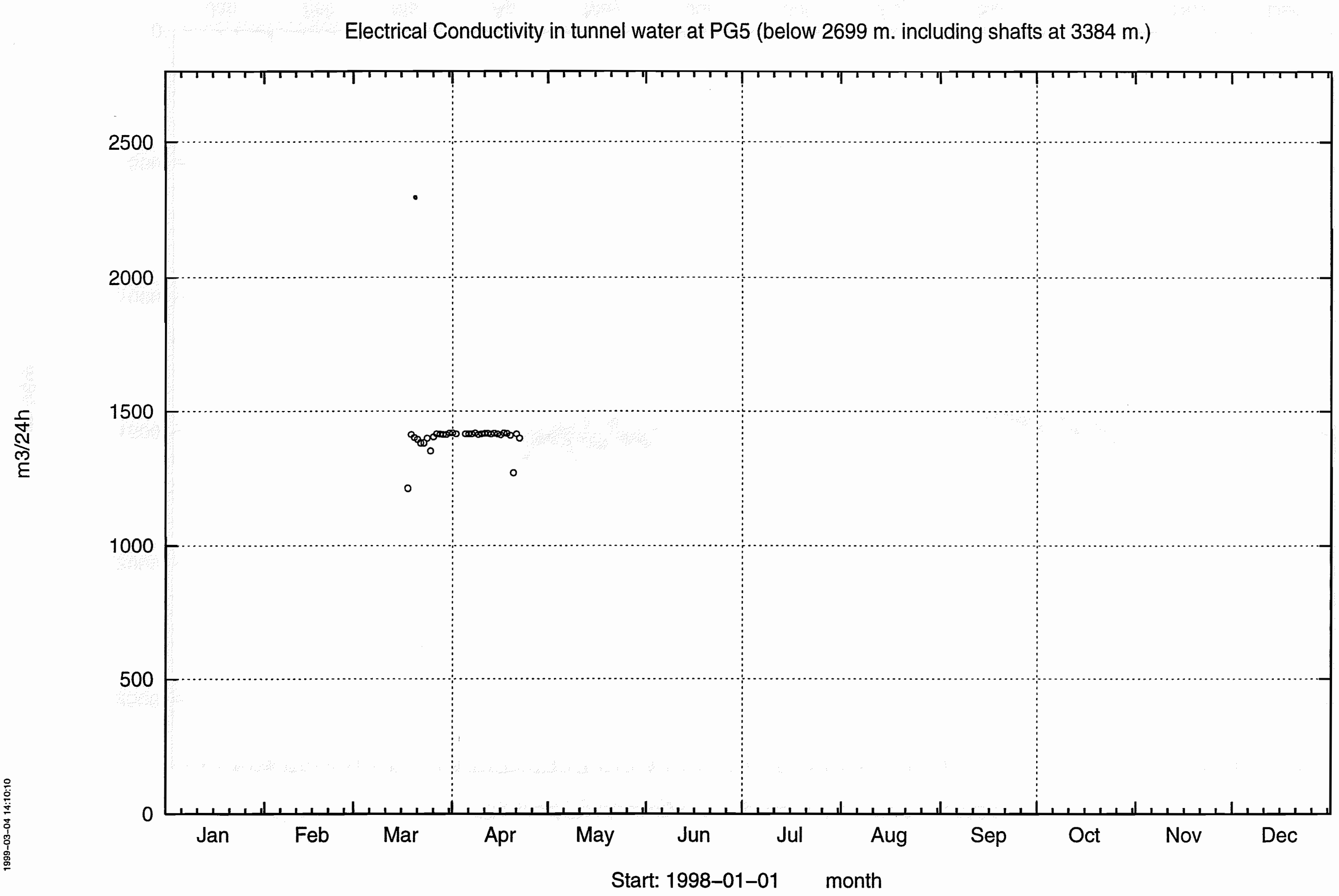


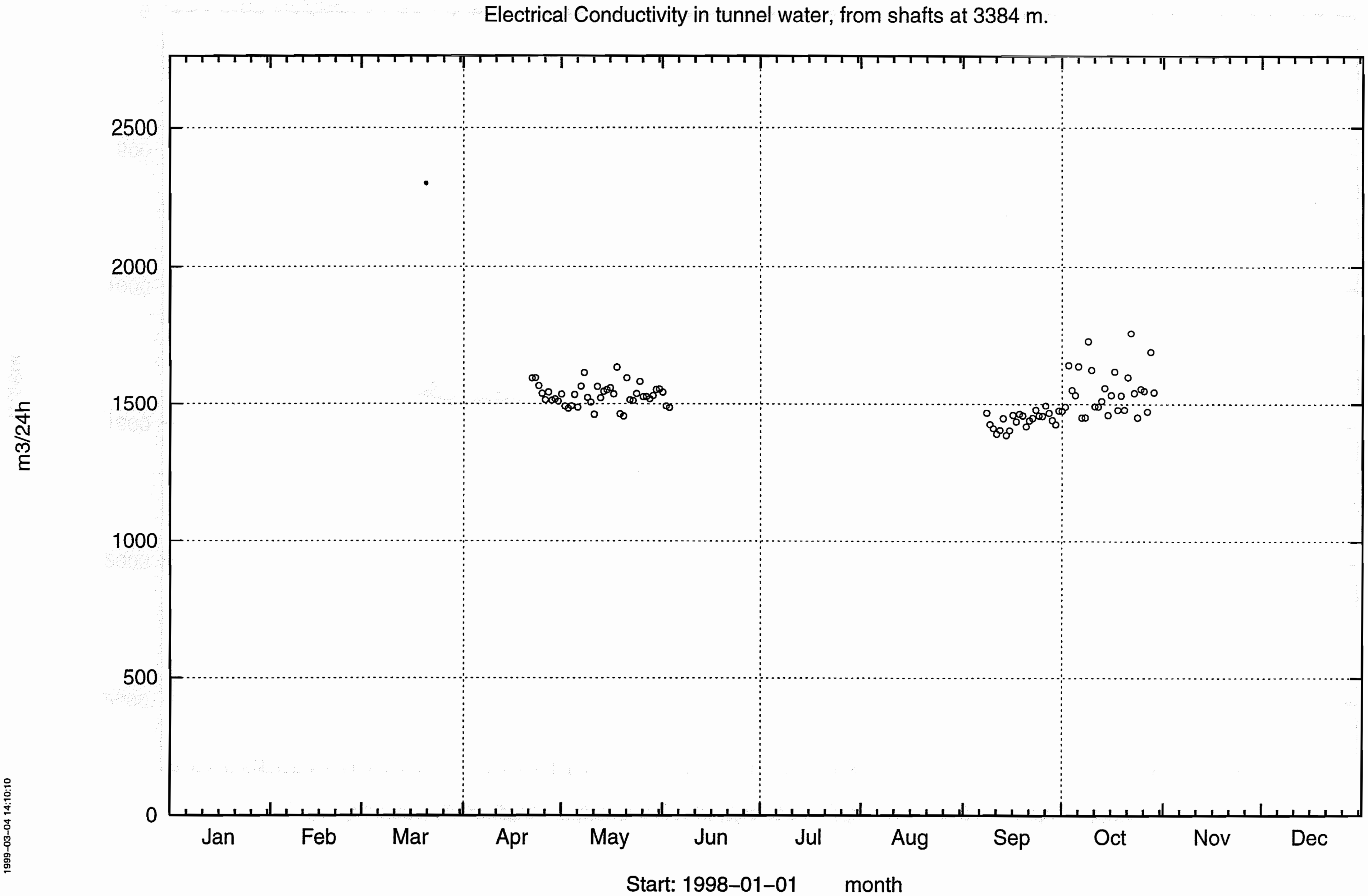
Electrical Conductivity in tunnel water, 1584 – 2496 m and shaft at 2587
mS/m
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–03–04 14:10:09


Electrical Conductivity in tunnel water, from shaft at 2587 m.
mS/m
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–03–04 14:10:09

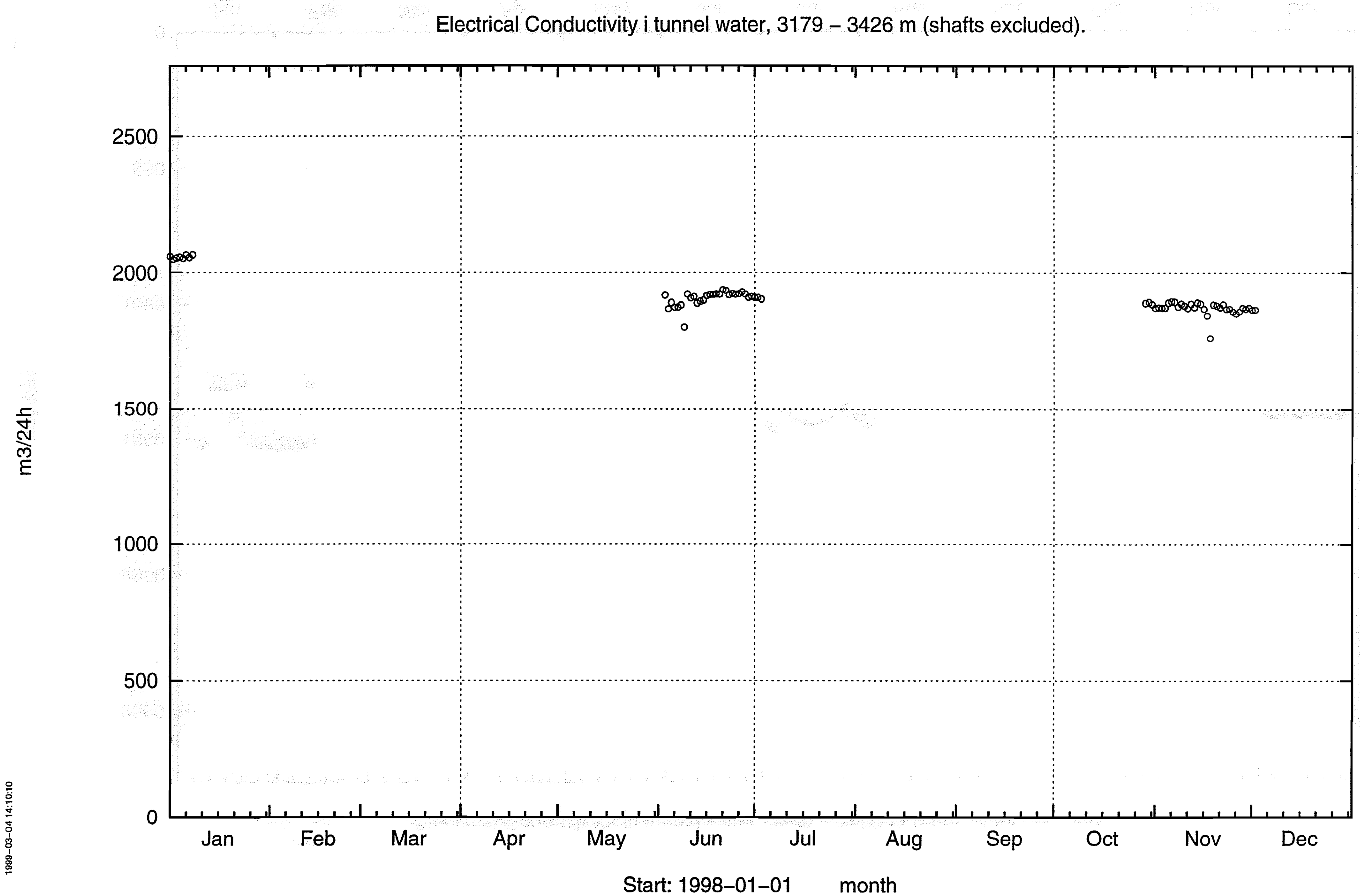


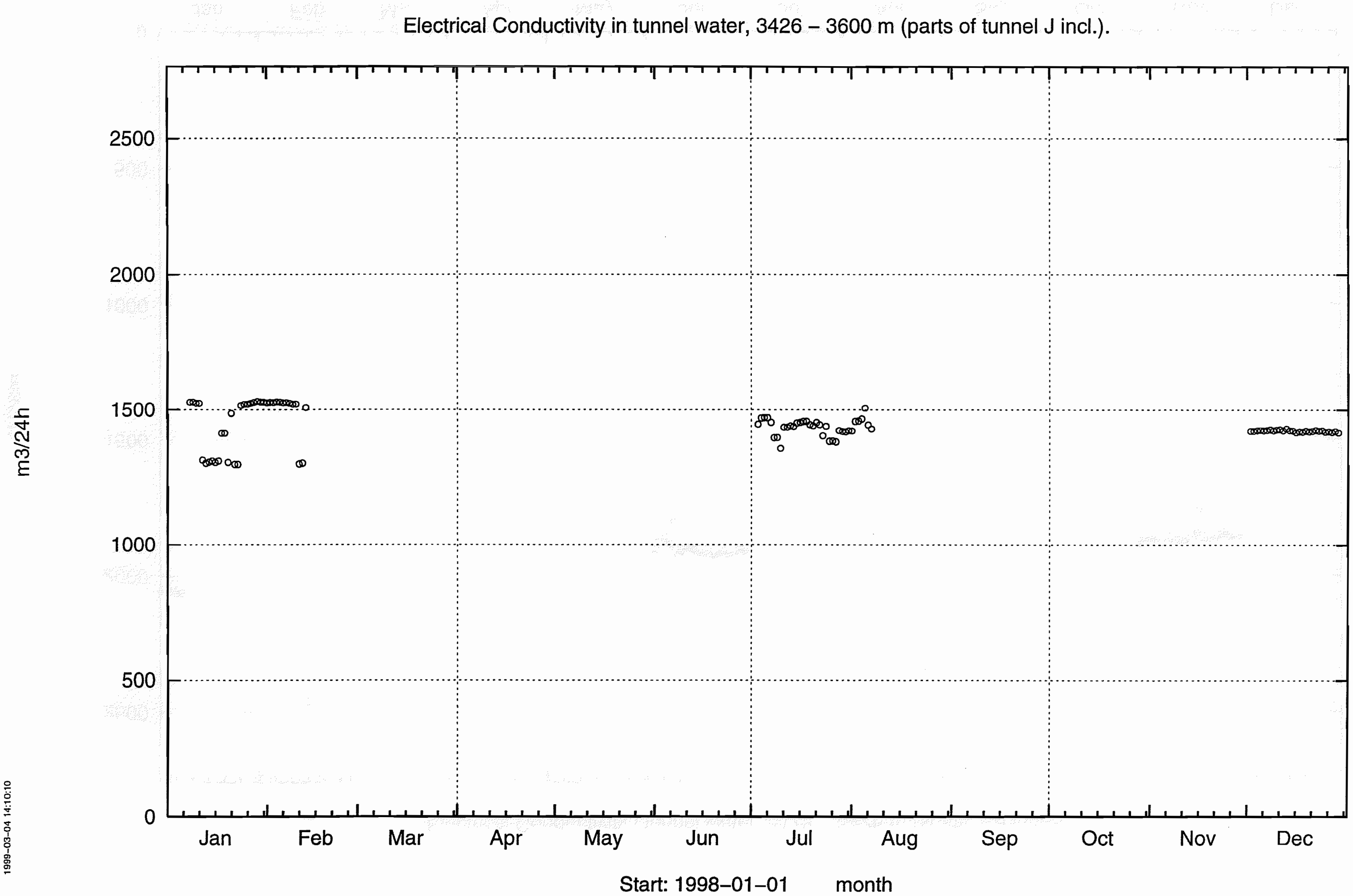
Electrical Conductivity in tunnel water, 2994 – 3179 m.
2500
2000
1500
1000
500
0
mS/m
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01 month
1999-03-04 14:10:09


Electrical Conductivity in tunnel water at PG5 (below 2699 m. including shafts at 3384 m.)
m3/24h
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–03–04 14:10:10

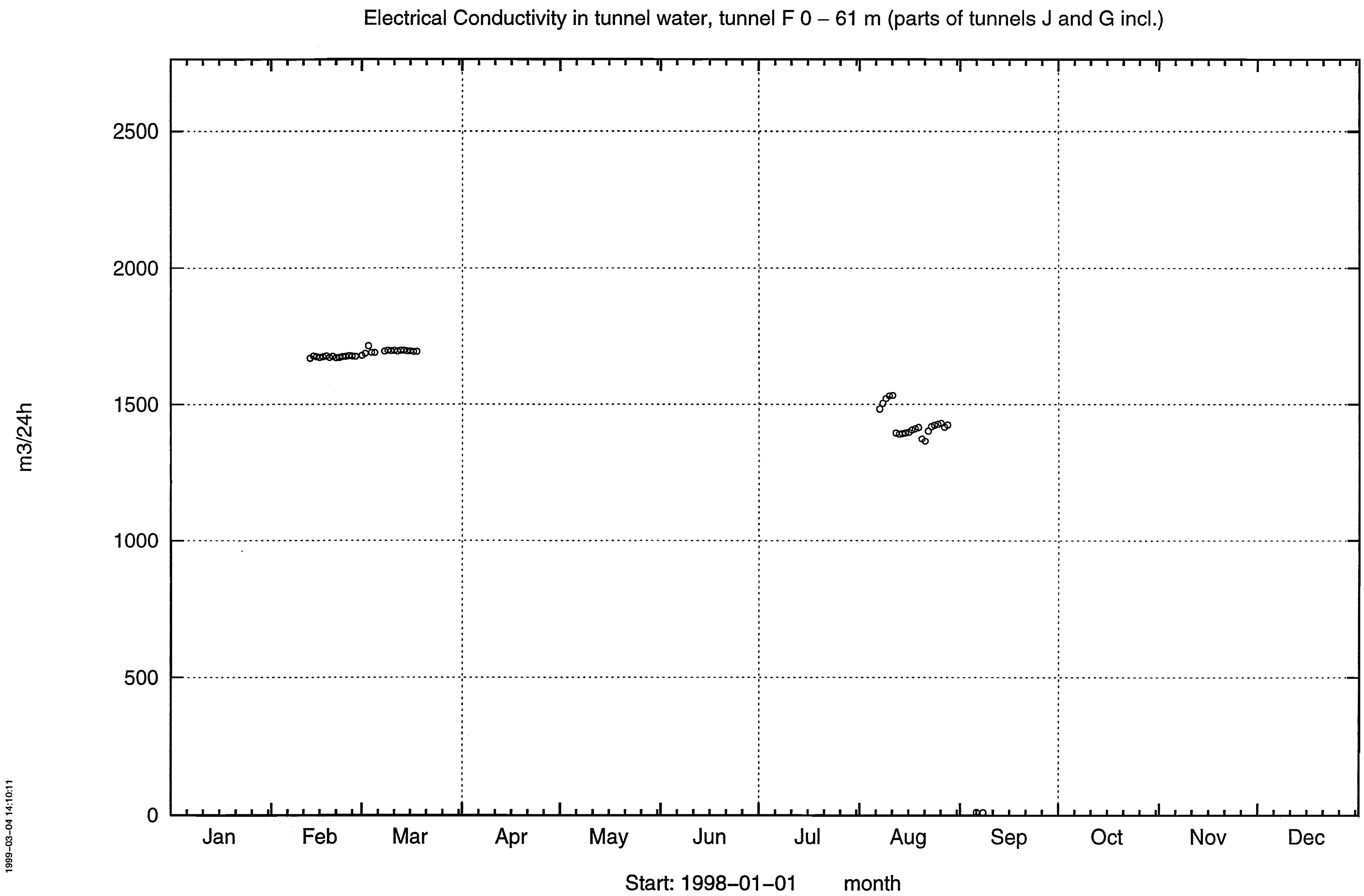


Electrical Conductivity in tunnel water, from shafts at 3384 m.
m3/24h
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–03–04 14:10:10

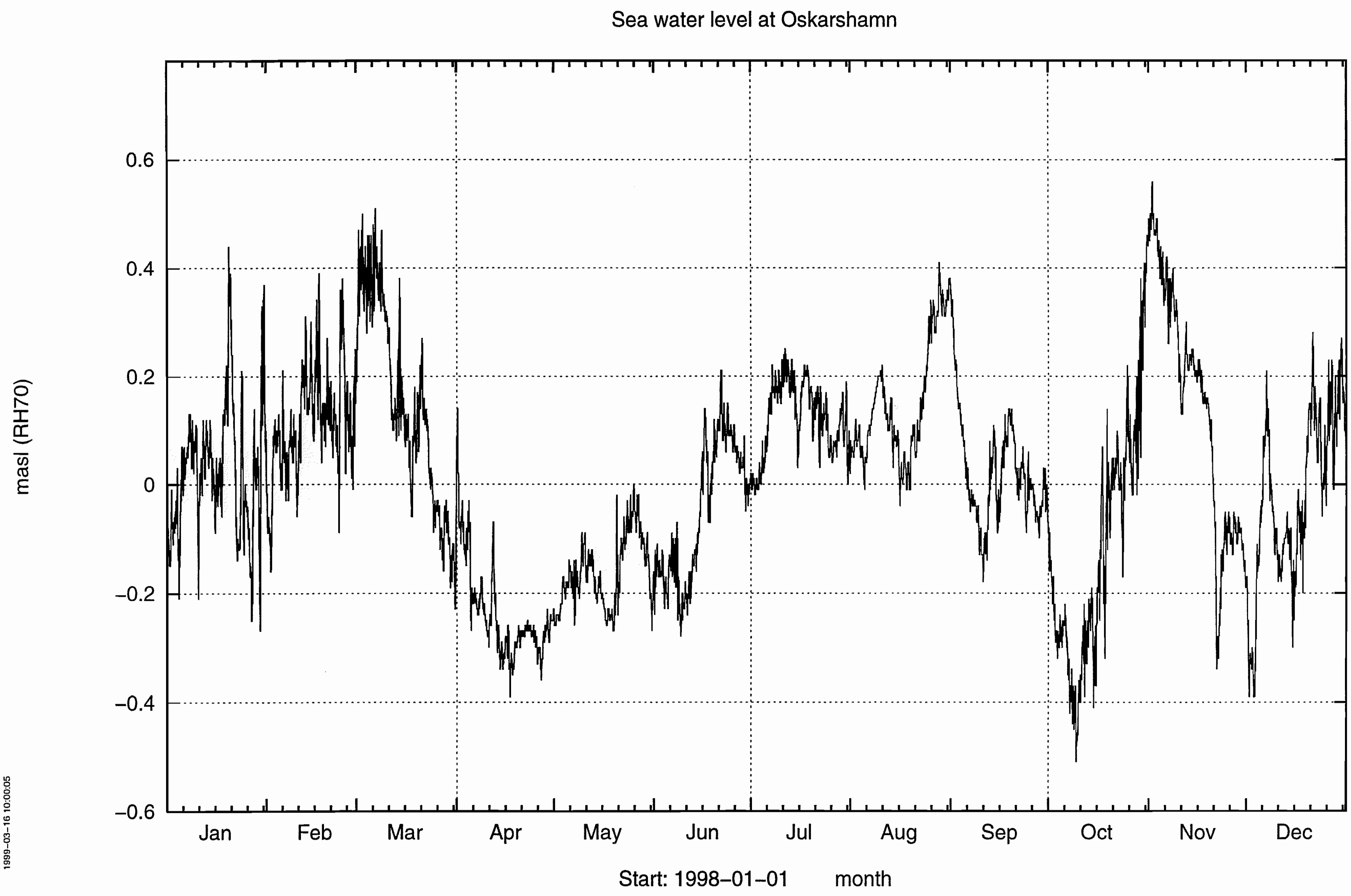

Electrical Conductivity i tunnel water, 3179 – 3426 m (shafts excluded).
m3/24h
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-03-04 14:10:10



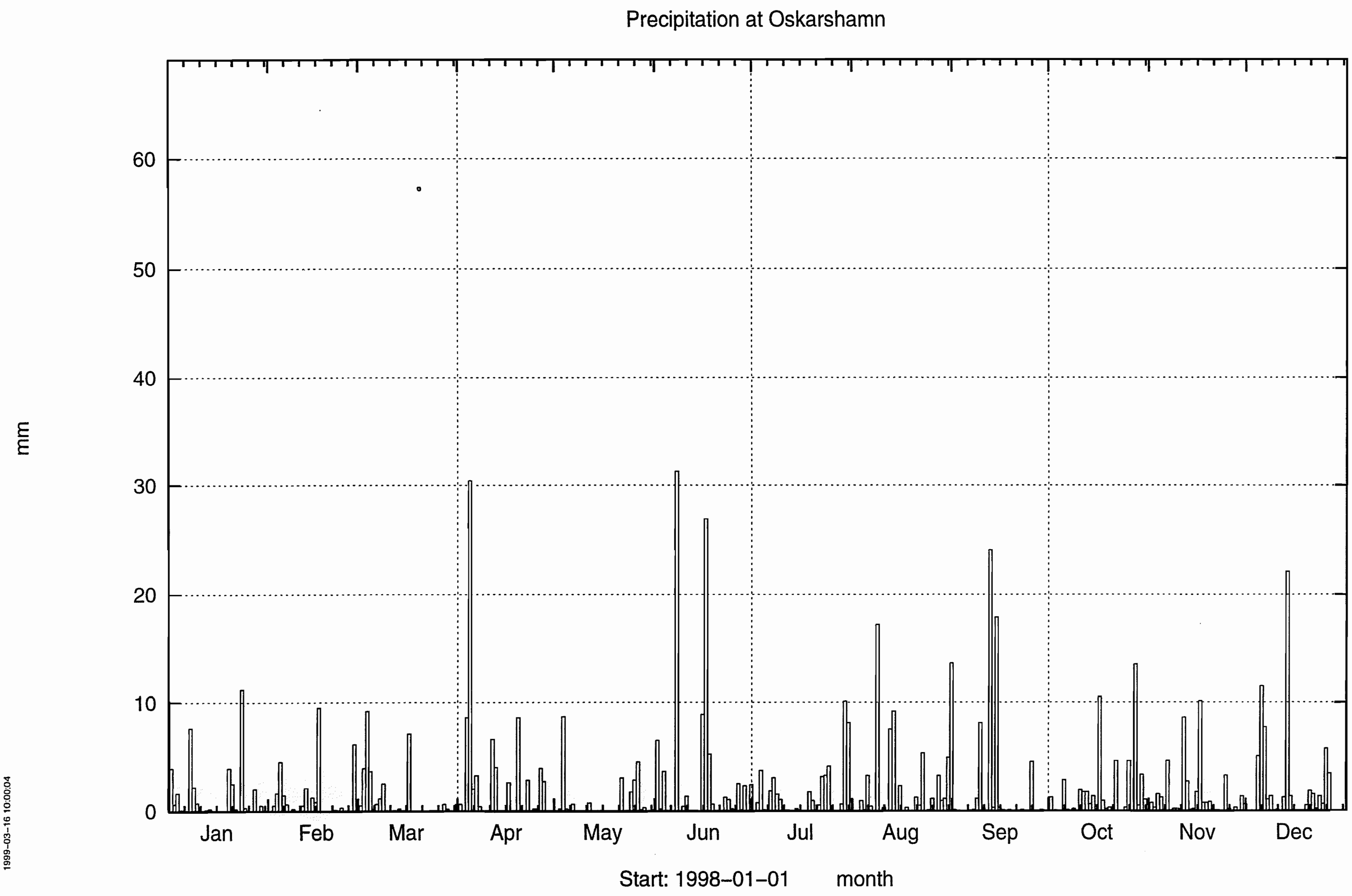
Electrical Conductivity in tunnel water, 3426 – 3600 m (parts of tunnel J incl.).
m3/24h
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01
month
1999–03–04 14:10:10


Electrical Conductivity in tunnel water, tunnel F 0 – 61 m (parts of tunnels J and G incl.)
m3/24h
2500
2000
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998–01–01 month
1999–03–04 14:10:11

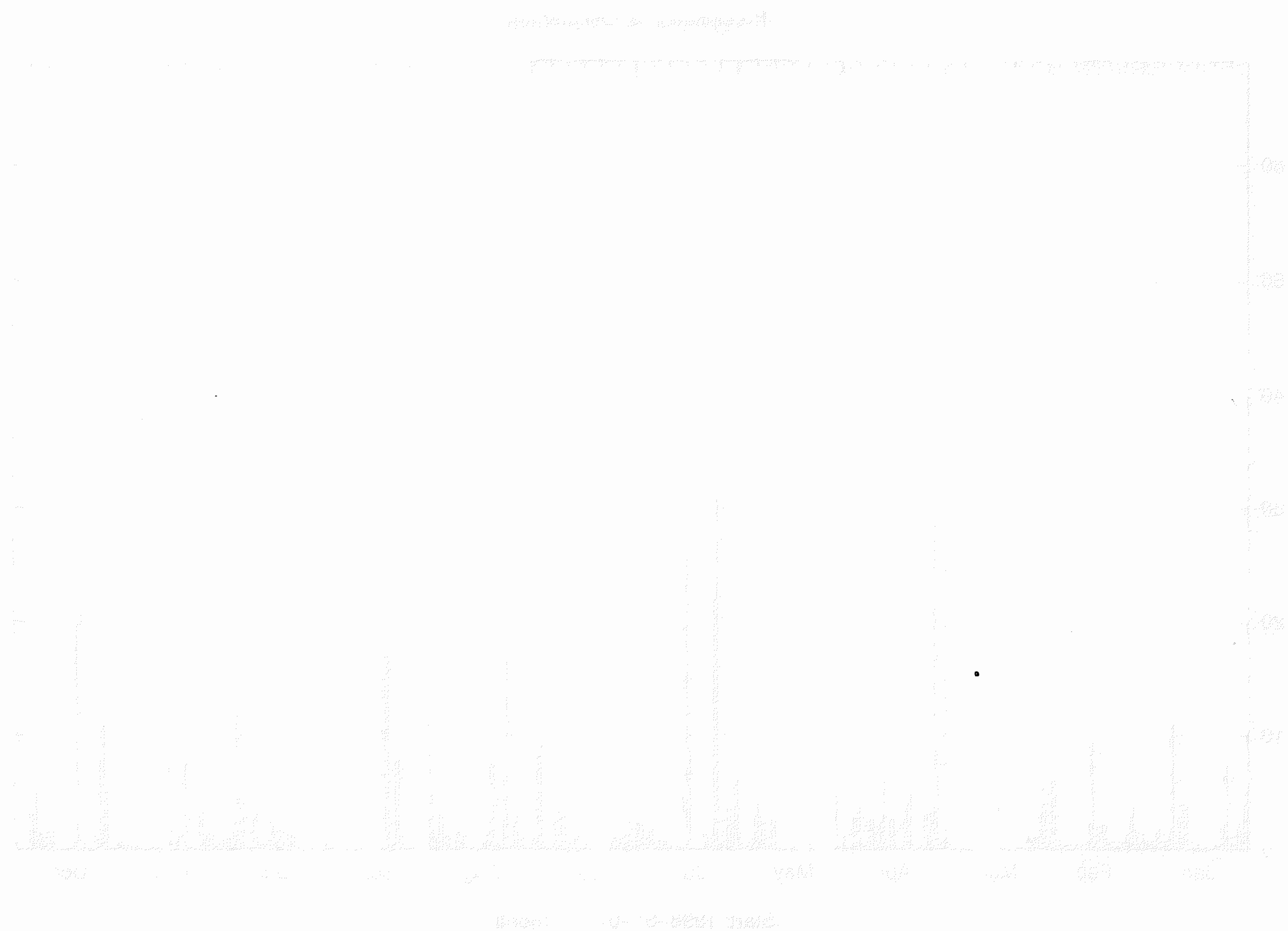
Appendix 8: Level of the Baltic Sea


Sea water level at Oskarshamn
masl (RH70)
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01
month
1999−03−16 10:00:05

Appendix 9: Precipitation

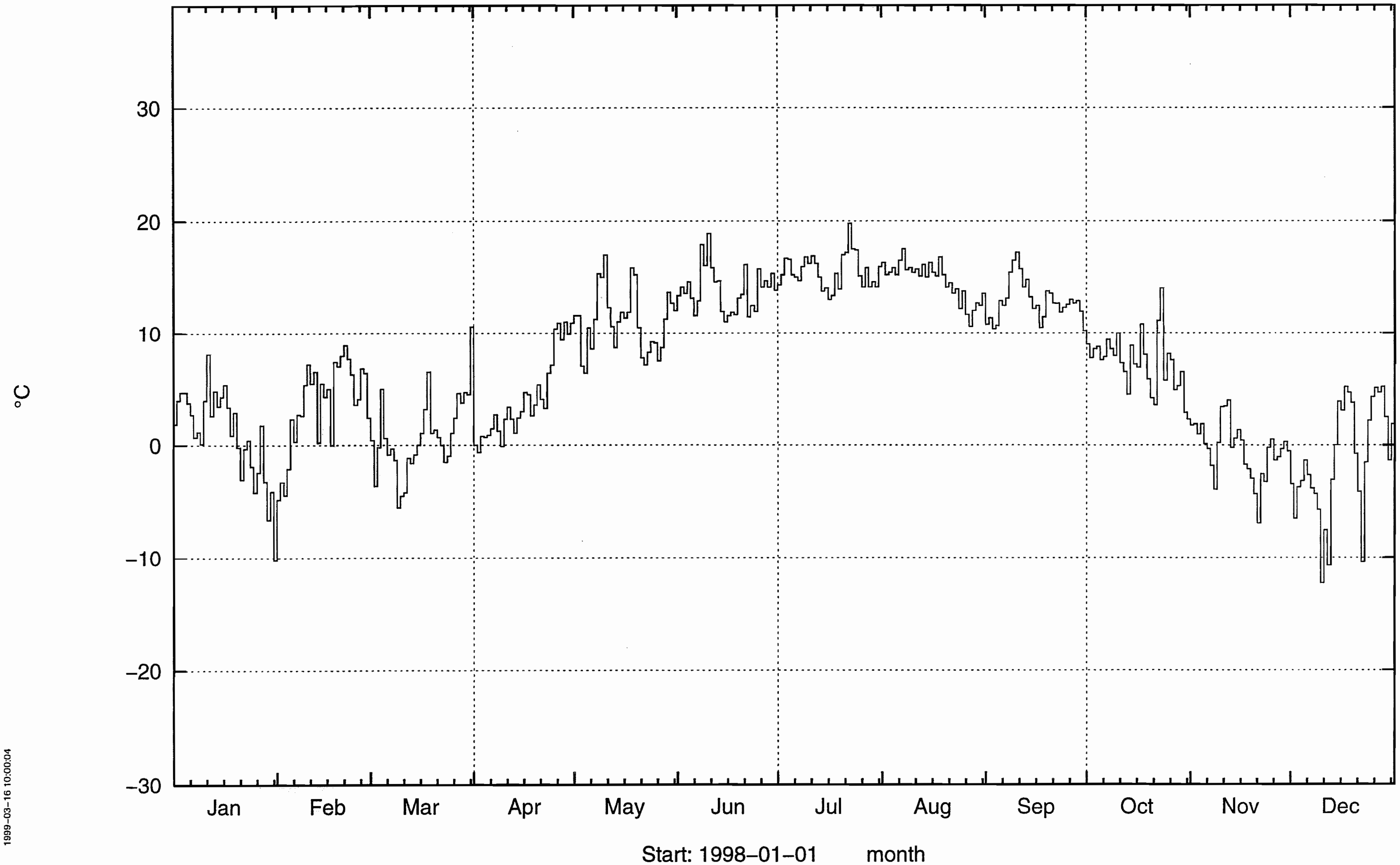


Precipitation at Oskarshamn
mm
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998-01-01
month
1999-03-16 10:00:04

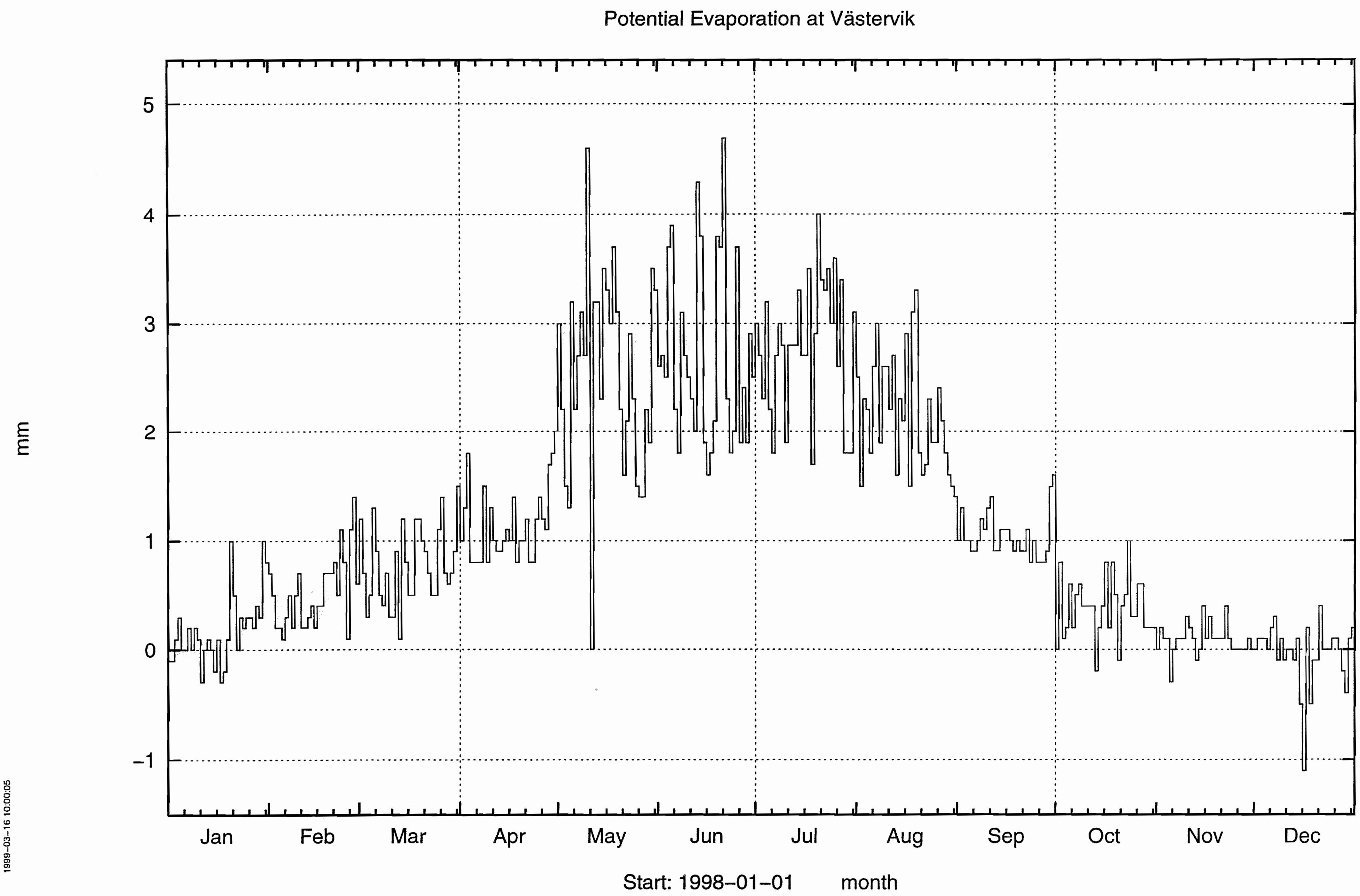


Appendix 10: Air temperature

Temperature at Oskarshamn



Appendix 11: Potential evapotranspiration



Potential Evaporation at Västervik
mm
5
4
3
2
1
0
−1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start: 1998−01−01
month
1999−03−16 10:00:05