



GEOLOGICAL SURVEY OF CANADA

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Permafrost research and monitoring stations in west Kitikmeot, Slave geological province, Nunavut

S.A. Wolfe

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monitoring stations in west Kitikmeot,
Slave geological province, Nunavut**

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TABLE OF CONTENTS

TABLE OF CONTENTS	i
LIST OF FIGURES	iii
LIST OF TABLES	iv
BACKGROUND	1
SUMMARY	3
INTRODUCTION	4
METHODS	4
REGIONAL SETTING	5
SURFICIAL SEDIMENTS AND PERMAFROST FEATURES	7
Till	7
Glaciofluvial Sediments	10
Glaciolacustrine Sediments	11
Alluvial Sediments	12
Organic Sediments	12
MASSIVE GROUND ICE POTENTIAL	12
TEMPERATURE MONITORING STATIONS	14
Station Locations and Installations	14
1996 and 1998 Station Observations and Servicing	17
Station GSC-0886	17
Station GSC-0887	20
Station GSC-0888	20
Station GSC-0889	21
Station GSC-0890	22
Station GSC-0891	23
Station GSC-001	23
Station GSC-002	25

THERMAL MONITORING RESULTS	29
Air and Near Surface Ground Temperatures	29
Ground Temperatures	36
Lake Bottom Temperatures	41
ACKNOWLEDGEMENTS	44
REFERENCES	45
APPENDIX I	48

LIST OF FIGURES

FIG. 1 Surficial and permafrost geology study areas in 1995, 1996 and 1998 (depicted by shaded area)	2
FIG. 2 Location of monitoring stations in the study area	6
FIG. 3 Location of eskers and stabilized thawslides in the Contwoyto Lake (NTS 76 E, north half) map sheet	9
FIG. 4 Comparison of air and ground temperatures for sites GSC-0886 and GSC-0887	31
FIG. 5 Comparison of air and ground temperatures for sites GSC-0888 and GSC-0889	32
FIG. 6 Comparison of air and ground temperatures for sites GSC-0890 and GSC-0891	33
FIG. 7 Ground temperature profiles for site GSC-001	39
FIG. 8 Ground temperature profiles for site GSC-002	40
FIG. 9 Lake bottom temperatures at sites GSC-001 and GSC-002	42

LIST OF TABLES

TABLE 1 Air temperature and near surface ground temperature station setups for 1995-96	15
TABLE 2 Ground temperature and lake bottom temperature station setups for 1995-96	16
TABLE 3 Air temperature and near surface ground temperature station setups for 1996-98	18
TABLE 4 Ground temperature station setups for 1996-98	19
TABLE 5 Ground temperature observations at site GSC-001, July 25, 1996	24
TABLE 6 Ground temperature observations at site GSC-002, July 25, 1996	25
TABLE 7 Monthly and annual summaries of air and near surface ground temperatures from monitoring stations, 1995-96	26
TABLE 8 Monthly and annual summaries of air and near surface ground temperatures from monitoring stations, 1996-97	27
TABLE 9 Monthly and annual summaries of air and near surface ground temperatures from monitoring stations, 1997-98	28

TABLE 10 Degree days and n-factors calculated from monitoring stations for the period Sept 01 1996 to Aug 31 1997	35
TABLE 11 Monthly ground temperature measurements at site GSC-001 and GSC-002	37
TABLE 12 Monthly lake water temperatures and degree days at sites GSC-001 and GSC-002	43

BACKGROUND

In the summer of 1995, a permafrost research project was initiated in Slave Geological Province, West Kitikmeot, Nunavut, through a cooperative agreement between DIAND, Land Administration and the GSC, Terrain Sciences Division. Utilizing an existing NATMAP project, a permafrost component was incorporated into the surficial geology program in the Coppermine (NTS 86O, east half) and Kikerk Lake (NTS 86P) map sheets (Figure 1). A Report of Activities, prepared for DIAND, summarized the activities of the 1995 field season. The report described preliminary observations on permafrost and geotechnical conditions based on initial field investigations, and also described the monitoring sites installed for permafrost and climate monitoring.

In 1996, permafrost field activities continued with the surficial mapping of the northern Contwoyto Lake (NTS 76E, north half) map sheet (Figure 1). At this time data from the monitoring stations were retrieved, and the stations were serviced. The interim report highlighted some of the permafrost related features and observations made in conjunction with surficial mapping in this area. The report further summarized the data from each of the monitoring sites over the previous year. An attached Appendix provided graphs of the mean daily and monthly temperatures and digital data from the monitoring sites were provided on diskette attached to the report (in Lotus 1-2-3 version 3.0 format).

In 1998, permafrost field activities were completed in co-operation with a DIAND esker inventory in the West Kitikmeot region and, specifically, with assistance from April Desjarlais and Patricia Fitzpatrick. At that time, data from the monitoring stations were retrieved, and the stations were removed. This final report summarizes the data collected from each of the monitoring sites during entire monitoring period from July 1995 to August 1998. An attached Appendix provides graphs of the mean daily and monthly temperatures for the entire period, while the digital data from the monitoring sites are provided on diskette (in Lotus 1-2-3 version 4.0 format).

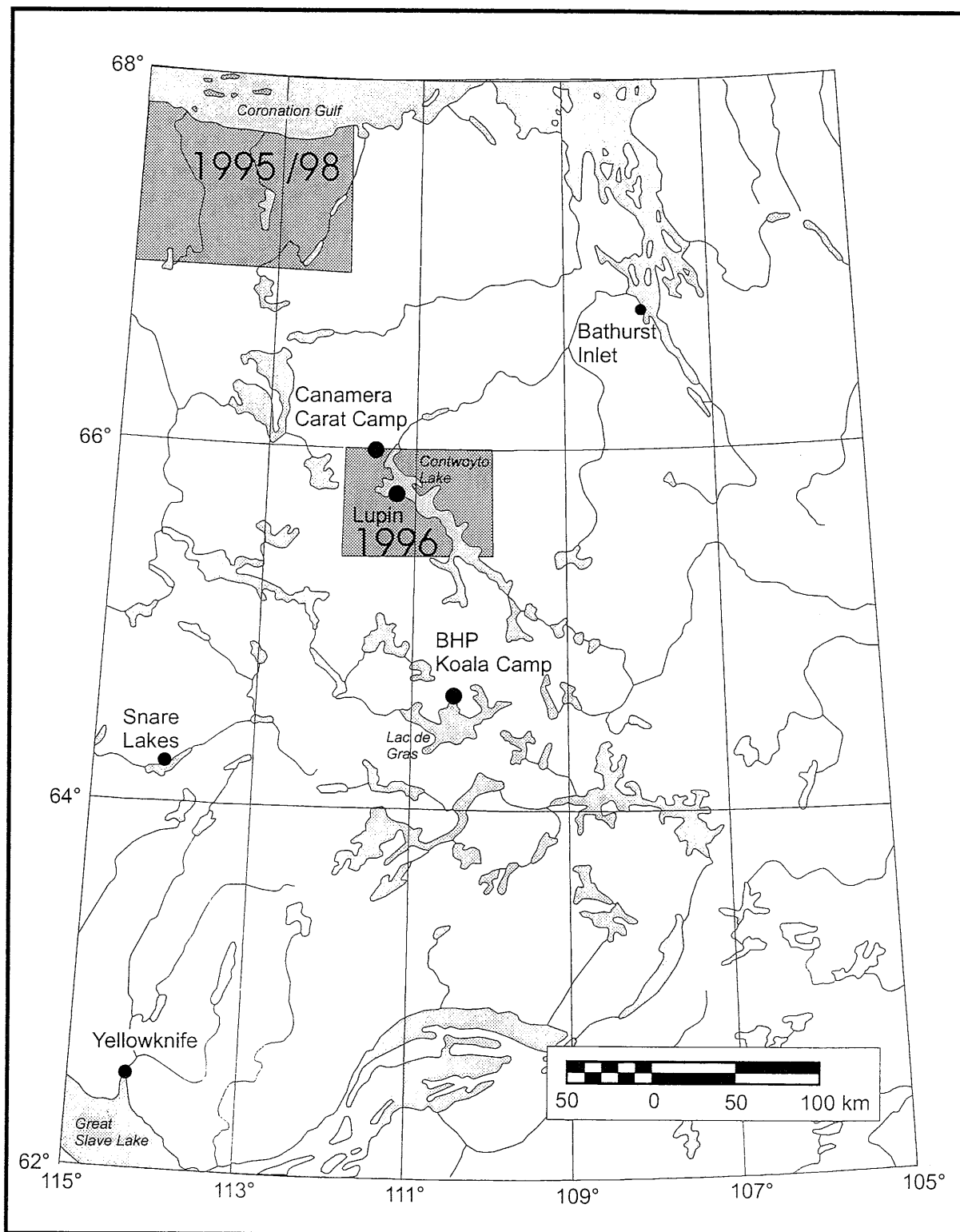


Figure 1. Surficial and permafrost geology study areas in 1995, 1996 and 1998 (depicted by shaded areas).

SUMMARY

Permafrost investigations were undertaken in conjunction with surficial geology mapping in the north-Slave region in 1995 and 1996 and were continued, in conjunction with DIAND, in 1998. Till blankets and veneers are the most widespread surficial sediments in the area, although hummocky till deposits also cover a considerable amount of the Contwoyto Lake area. There is evidence that some till and glaciofluvial deposits contain massive ice or ice-rich sediments. Locally, a few stabilized thawslide scars occur in hummocky till terrain east of Contwoyto Lake, suggesting that ice-rich sediments may be present. As well, there is growing general opinion that buried glacial ice may be present within most end moraine systems in the continuous permafrost regions of Canada (A.S. Dyke, pers. comm.). In addition, some glaciofluvial deposits, such as eskers and glaciolacustrine outwash, may also contain significant amounts of massive ground ice. These landscape elements are often considered as potential development sites and as sources of aggregate for construction. Due to the potential for massive ground ice within these deposits, geotechnical investigations should be conducted in all areas within the West Kitikmeot and Slave Geological Province prior to any major development.

Air and near surface ground temperatures at six stations, in addition to two permafrost and two lake bottom sites, were monitored for periods of one to three years during this study. Temperature data are summarized as mean daily, mean monthly and mean annual temperatures, along with associated degree day indices. Mean annual ground temperatures are on the order of -6.5°C to -7.5°C at permafrost monitoring sites near the Coronation Gulf coast. Mean air temperatures throughout the region ranged from -8.2°C to -10.7°C during the period from August 1996 to July 1997, with near surface ground temperatures ranging from -5.3°C to -9.7°C . While regional trends may be observed in air temperatures, near surface ground temperatures (which affect the underlying permafrost regime) commonly depend upon a number of site specific conditions and therefore show considerably more spatial variability at local scales. The use of degree day indices and n-factor values may provide an additional means of quantifying this variability. Finally,

annual lake bottom temperatures, below a depth of 2 m, were found to be continually above freezing, with an annual average temperature of approximately 4°C at one monitored lake. Degree day indices calculated from lake bottom temperatures and data from permafrost monitoring stations may also be used as input parameters to calculate permafrost and talik configurations.

The data presented in this report contribute to the general body of permafrost and climatic information required for making development decisions in this region.

INTRODUCTION

With ongoing geological exploration and development in Slave Geological Province, there is an essential need for baseline geoscience information. The cooperative permafrost research initiative instigated by Land Administration (DIAND) and Terrain Sciences Division (GSC) in 1995 represented a significant step towards filling some of the geoscience information gaps in the West Kitikmeot/Slave Region. A permafrost component was first incorporated into the 1995 surficial geology mapping program in the Kikerk Lake (NTS 86P) and Coppermine (NTS 86O, east half) region, in 1996 this was continued in the northern Contwoyto Lake region (NTS 76E, north half), and in 1998 the work was completed in co-operation with DIAND through the final retrieval of air and ground temperature data (Figure 1).

METHODS

Permafrost and terrain information was gathered in association with the surficial mapping project through helicopter-assisted traverses and interpretation of 1:60 000 airphotos. In addition, all of the monitoring stations installed in 1995 were revisited in 1996 and 1998 for the purpose of servicing and downloading of accumulated data.

Information from other studies such as drilling programs conducted by DIAND and the GSC during this period, are also referred to here for context and completeness, although they were not strictly a part of this study.

REGIONAL SETTING

The entire study area lies within the zone of continuous permafrost (Brown, 1967) and permafrost has been recorded to depths of approximately 500 m (Taylor et al., 1982). The region lies north of treeline and supports sparse clumps of low birch, willow, and tundra heath vegetation. In general, vegetation growth in the major river valleys terminating in the Coronation Gulf, (including the Coppermine, Kugaryuak and Tree rivers) is more lush than that of the surrounding terrain. Climatic data from an AES weather station operating at the Lupin minesite indicate an annual daily air temperature of -12°C (Atmospheric Environment Service, 1982). By comparison, climate data from Coppermine (Kugluktuk) indicate a comparable but slightly warmer mean annual air temperature of -11.6°C (Atmospheric Environment Service, 1982). The difference in temperature is possibly due to moderating effects of the Coronation Gulf.

The study area was entirely glaciated by the Laurentide Ice Sheet during the Late Wisconsinan. During deglaciation, coastal regions along the Coronation Gulf experienced rapid ice retreat and simultaneous marine incursion across isostatically-depressed terrain. The marine limit ranges from about 170 m a.s.l. near Coppermine to 210 m a.s.l. in the upper Tree River valley (Fig. 2) and was formed from approximately 11 to 10.2 ka BP respectively (Kerr, 1994). Wood from the base of a thermokarstic depression on a marine delta 32 km southwest of Coppermine suggests that vegetation development began by at least 9150 ± 100 BP (Geurts, 1985). This date is comparable to, but slightly younger than, the onset of the early Holocene warm period which initiated extensive mass wasting in the MacKenzie Delta region to the west between 9500 and 10 000 BP (MacKay and Dallimore, 1992). However, the timing and potential terrain impacts of an early Holocene

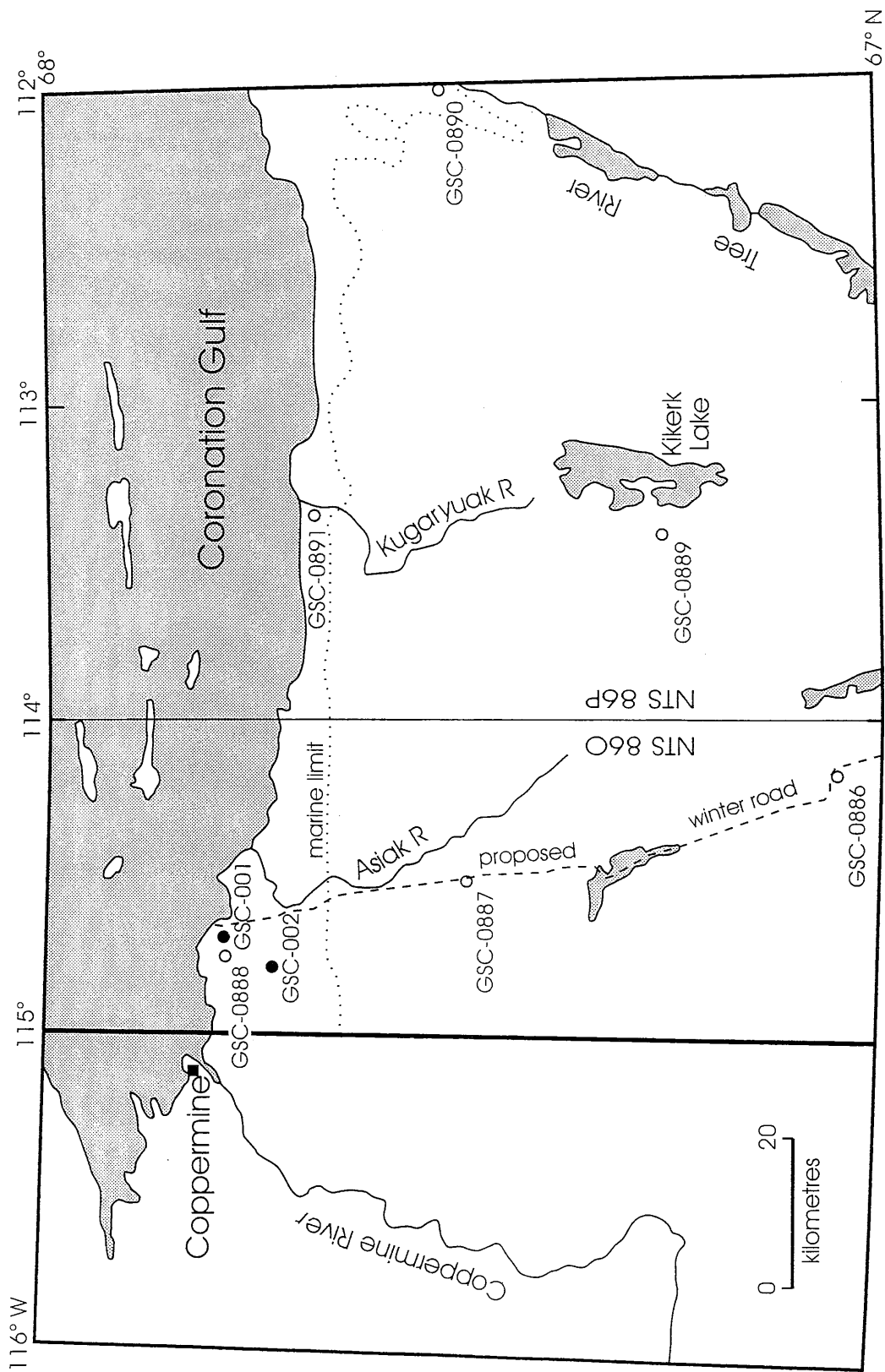


Figure 2. Location of monitoring stations in the study area. Black dots represent ground thermal profile and lakewater monitoring stations; white circles represent air and near surface ground temperature stations.

Warm period in the Coppermine-Kikerk Lake region are presently unknown.

In the Contwoyto lake area, elevations range from 445 m (Contwoyto Lake) to 580-640 m in the Peacock and Willingham Hills in the northernmost section of the area. The terrain northwest and east of Contwoyto Lake is generally between 480-520 m, whereas much of the area south of the lake lies below 500 m a.s.l. Local relief is variable, commonly between <10 m and 20 m in areas of outcrop and till cover, although relief in rocky areas of the Peacock and Willingham Hills may exceed 100m..

Contwoyto Lake is on the divide between two drainage systems; its southern outlet is the Contwoyto River which flows into the Back River. The northern outlet drains into Kathawachaga Lake and the Burnside River. Numerous small lakes occupy glacially scoured bedrock basins, as well as isolated depressions in till plains. Most drainage channels are shallow; few streams and rivers have cut into bedrock or surficial sediments, with the exception of a few unnamed streams which have incised glaciofluvial sediments.

SURFICIAL SEDIMENTS AND PERMAFROST FEATURES

As mentioned above, the region was entirely glaciated by the Laurentide Ice Sheet during the Late Wisconsinan and became ice-free by about 9000 BP (Dyke and Prest, 1987). Consequently, all glacial features in the study area relate to this most recent glaciation.

Till

In the Kikerk Lake and Coppermine areas, till blankets and veneers are the main surficial sediment south of the limit of marine submergence (Fig. 2). Till veneers, generally <2 m thick, cover large areas containing small bedrock outcrops, and conform to underlying bedrock morphology. Along the western margin of the Kikerk and eastern margin of the Coppermine map areas, lies an extensive area of large, parallel crag and tail

and drumlinoid features, some of which are up to 35 km long (Plate 1), separated by zones of bare bedrock, thin till veneer and glaciofluvial outwash deposits.

The tills consists of a matrix-supported diamicton, with a clayey silt to fine sand matrix, exhibiting low to high compaction. Clasts range in size from small pebbles to large boulders, with medium to large pebbles predominating. Subangular to subrounded clasts are most common but some exposures, notably those close to bedrock, may be dominated by angular blocks. Most exposures have between 10 and 30 percent clasts (Kerr et al., 1996). Matrix grain size varies according to bedrock source; till derived from sedimentary and volcanic rocks is silty whereas granitoid rocks produced a more sandy till.

Similarly, in the Contwoyto Lake region, till is the most extensive surficial sediment in the area. In this region, stagnant ice was responsible for large areas of hummocky till and moraine ridges (Kerr et al., 1997a). Non-oriented rim ridges (Prest, 1968) composed of till are also present in this area, and may reflect the position of former crevasses in the ice. Immediately east of the NTS 76 E map area is a large end moraine ridge (Aylsworth and Shilts, 1989) oriented north-south and associated with an extensive area of hummocky till.

Frost-action within the active layer results in the widespread occurrence of mudboils in all till units. Mudboils are best developed on till blankets (Plates 1 and 2), frequently occurring as stripes on inclined surfaces. Solifluction lobes are also common and are most pronounced near the base of slopes. Ice wedge polygons may be present within tills, but are seldomly visible on the surface perhaps due to cryoturbation activity within the active layer. However, ice wedges rooted in till occur in depressions where peat cover is on the order of 0.25 m thick or greater. Massive ground ice or icy sediments within till blankets may be present in the northeastern part of the Contwoyto Lake map sheet as evidenced by stabilized thawslides (Figure 3 and Plate 3).

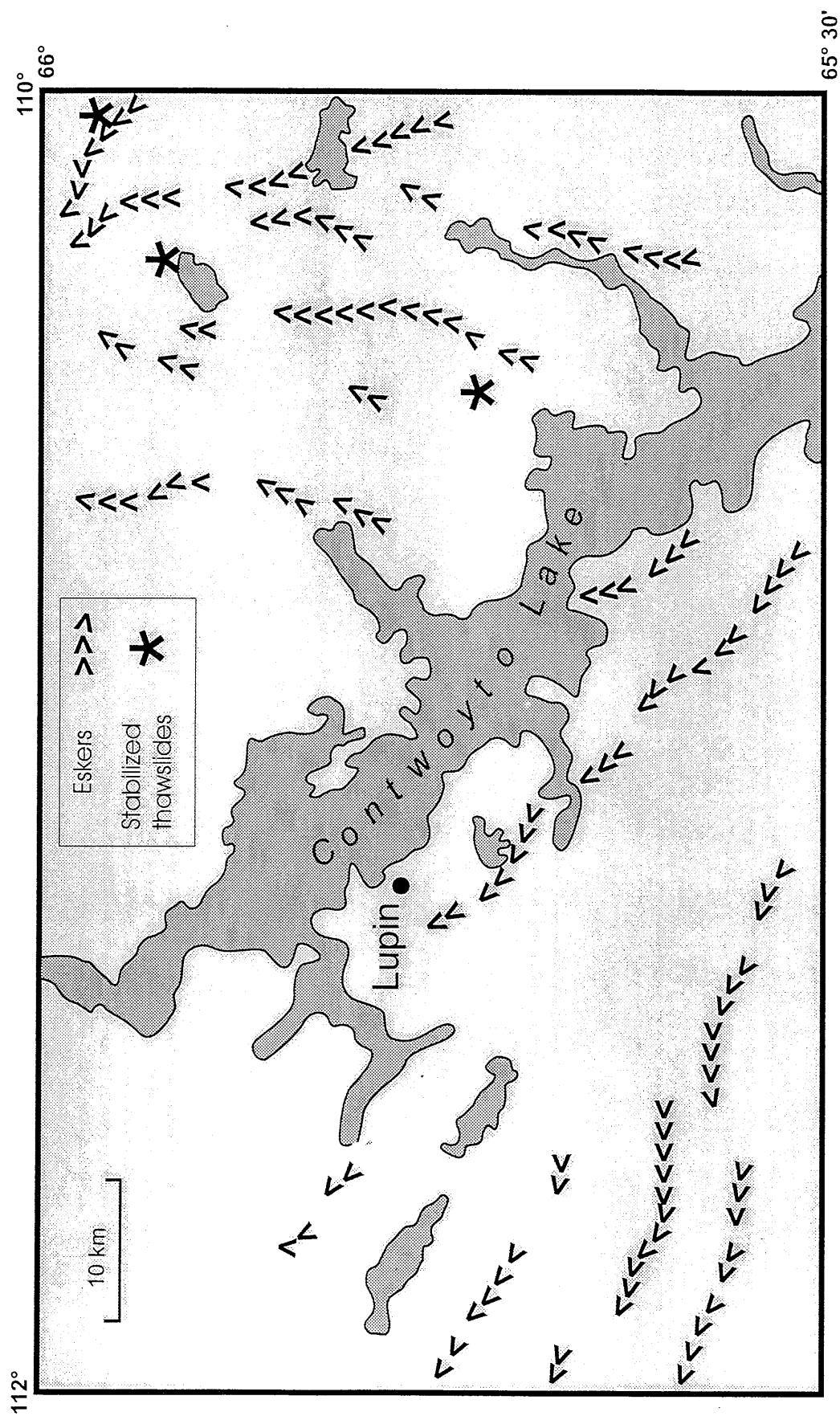


Figure 3. Location of eskers and stabilized thawslides in the Contwoyto Lake (NTS 76 E, north half) map sheet.

Glaciofluvial Sediments

Glaciofluvial sediments consist of fine sand to cobbles in the form of eskers, kames and proglacial outwash. Eskers have a linear to slightly sinuous form, and generally parallel the dominant and latest glacial flow direction. The eskers range from small ridges a few tens of metres long, to large complexes up to 32 km long and 20-30 m high. The locations of the major eskers and esker trends in the Contwoyto Lake area are presented in Figure 3. Outwash plains with braided channels and kettle lakes are sometimes associated with esker extremities, and may link longer esker segments together. Throughout much of the Kikerk Lake map area, outwash plains scarred by braided channels and kettle lakes are associated with the esker complexes. Some of these sand and gravel outwash plains cover areas of 8 square kilometres or more. As with eskers, their grain size is variable. Glaciofluvial deposits are potential resources for large volumes of granular materials, and can also serve as airstrips to facilitate development (Plate 4).

The presence of permafrost typically results in the formation of ice-wedge polygons in glaciofluvial sediments while mudboils are rarely present in these relatively coarse grained materials. In the Kikerk map area, ice-wedge polygons are exceptionally well developed on most flat-topped outwash deposits despite the thin (<0.2 m) organic cover. Polygons on the order of 30 to 100 m in diameter with troughs up to 2 m deep and raised rims up to 1 m high are common and some troughs reaching over 6 m wide (Plates 5 and 6). Smaller polygons, approximately 10 m in diameter with troughs on the order of 0.3 m deep, also occur on outwash sediments. In some areas, both sets of polygons occur together, possibly indicating multiple periods of ice-wedge growth. Ice-wedge polygons are seldomly visible on eskers in the map areas, perhaps due to the narrow and steep-sided nature of these features.

In addition, some eskers and outwash sediments have cores of massive ice in excess of 10 m thick (see Massive Ground Ice Potential below).

Glaciolacustrine Sediments

Raised glaciomarine and marine sediments occur along the coastal lowlands of Coronation Gulf and extend up to 40 km inland in the Tree River valley. These sediments consist primarily of four types: 1) undifferentiated, massive to well stratified silt and clay up to 30 m thick; 2) veneers of similar composition less than 2 m thick; 3) coarse sand, pebbles and cobbles of littoral origin (raised beaches) (Plate 7); and 4) sand to cobbles forming perched glaciomarine and marine deltas.

The presence of permafrost has extensively affected marine sediments in this region. Mudboils are widespread in marine silts and clays. In many areas along the coast, particularly within the Tree River valley, fine-grained marine blanket deposits are gullied and bare of vegetation cover (Plate 8). Retrogressive thaw flowslides are common along streams in these areas, with active slides typically greater than 10 m in diameter and headwalls 1-2 m high (Plate 9). As with till, ice wedge polygons are rarely visible on fine-grained marine deposits, probably due to mudboil and solifluction activity. It appears that ice wedges are absent in this terrain. Alternatively, they may be masked by near-surface cryoturbation processes. Ice-wedge polygons are common on most raised beach and sandy littoral sediments (Plate 7) while mudboils are rare. Where littoral sediments form laterally extensive veneers over marine silts or clays, tundra ponds and low centre polygons are common (Plate 10). As with the outwash plains, large ice-wedge polygons in excess of 30 m diameter with deeply incised troughs are found on the coarse glaciomarine/marine deltaic deposits.

In the Contwoyto Lake map area, a number of erosional and depositional shoreline landforms relate to a sequence of proglacial lakes that formed in the region surrounding Contwoyto Lake during deglaciation. Perched deltas, raised beaches, terraces and spits, from 1 to > 10 m thick, together with wave-cut benches and washed bouldery till surfaces occur up to 45 m above present lake level (Kerr et al., 1997). Depositional features consist of poorly to moderately sorted fine to coarse-grained sand with variable amounts of pebbles, cobbles and boulders.

Alluvial Sediments

Alluvial sediments consist of gravel to silt size sediment deposited by modern streams and rivers. They range from massive to well stratified and vary in thickness from 1 to 5 m. Alluvial sediments are associated with meandering and braided environments, as well as floodplains and alluvial fans, and undergo annual erosion and deposition. Alluvial sediments are more common in the Kikerk and Coppermine map areas, than in the Contwoyto Lake area.

Organic Sediments

Organic sediments, up to 1 m thick, consist of peat formed by the accumulation of fibrous, woody and mossy vegetative matter, locally overlain by a dense grass or shrub cover. In all areas, these occur predominantly in topographic depressions and poorly defined water courses with imperfect drainage. In the Coronation Gulf area, peat accumulations are most noticeable below the marine limit, where they overlie fine-grained marine sediments. Organic sediments are also present in areas once submerged by glacial lakes relating to Contwoyto Lake, where they may overlie fine-grained glaciolacustrine and lacustrine sediments. Ice-wedge polygons are often associated with organic sediments.

MASSIVE GROUND ICE POTENTIAL

The presence of ground ice in surficial sediments is a function of depositional conditions (resulting in specific terrain types, thickness and sediment texture), and post-depositional climatic and geomorphic events. Two main types of massive ice found in permafrost are buried surface ice and intrasedimental ice. Intrasedimental ice, formed by the in-situ freezing of water within sediments, includes segregation ice and intrusive ice (Mackay and Dallimore, 1992), ice-wedges and pingo ice. Massive tabular bodies of

intrasedimental ice may form by the downward aggradation of permafrost into surficial sediments, provided a source of unfrozen water is available. Buried ice includes glacier ice, snowbank ice, aufeis (river icings) and other forms of ground ice subsequently buried by sediment. In the Contwoyto Lake region, massive ground ice (ranging from 3 to 7 m thick) has been identified in eskers (EBA Engineering Consultants Ltd., 1993) and in outwash sediments (Wolfe et al., 1997a and b). If engineered structures, transportation right-of-ways, or borrow pits are developed in the region, then engineering constraints or hazards could exist, stemming from the presence of massive ground ice in various terrain units.

At the Canamera Geological Ltd. Carat Lake exploration site, located approximately 4 km west of northern Contwoyto Lake (just north of the 76E map sheet), surface evidence exists for the presence of large tabular bodies of massive ground ice. On the surface of the outwash terrace north of Carat Lake, several 1-2 m high raised irregular-surfaces occur, which have been found to be underlain by massive ground ice (Plate 11). Geotechnical drilling conducted in the summer of 1996 encountered massive ice in excess of 15 m thick beneath the largest of these surface features. Presently, an airstrip, tank farm and quarry site are located on the outwash terrace. While much of the terrace appears devoid of massive ground ice, the area identified above and similar areas on the outwash terrace, should be avoided. The ice contained within this outwash terrace has been interpreted as buried ground ice by Wolfe (1998).

Additional evidence for the presence of massive ice, or ice-rich sediments exists for the north-half of the 76E map sheet. Several thawslides in the hummocky till terrain in the northeast (Figure 3 and Plate 3) appear to be well-stabilized, and may possibly have been active soon after deglaciation, although no chronological evidence was found to establish the timing of activity. The presence of stabilized thawslides in hummocky till is evidence for ice-rich terrain in this area. Clearly, geotechnical investigations should be conducted in these areas prior to any major development.

TEMPERATURE MONITORING STATIONS

Station Locations and Installations

Several temperature monitoring stations were installed in the Kikerk Lake and Coppermine map area in 1995 in order to obtain baseline temperature data on permafrost and climatic controls in the region. The location of these stations are shown in Figure 2.

Six air temperature and near-surface ground temperature monitoring stations were installed in the Kikerk Lake and Coppermine map area in 1995 to monitor climatic controls on the active layer and permafrost (sites GSC-0886;0887;0888;0889;0890;0891 in Figure 2). Thermistors recording near-surface temperatures were placed 25 mm below the ground. In addition, programmed thermistors recording air temperatures were placed within Gill-type radiation shields at heights of 1.5 m using masts similar to those described by Nixon and Taylor (1994). Table 1 summarizes the locations and specifications of each station as set up in 1995.

Two ground temperature profile stations, each with seven thermistors, were installed using the jet-drilling method to depths of 30 and 19 m, respectively, within marine sediments near the Coronation Gulf (sites GSC-001 and GSC-002 in Figure 2). Temperatures from these stations are continuously recorded on programmable data loggers. The ground temperature sites are adjacent to small lakes, each of which was thermally monitored with submersible data loggers. Table 2 summarizes the locations and specifications of each station as set up in 1995.



Plate 1. Large drumlinoid feature consisting of till blanket (right) with solifluction lobes advancing over washed till veneer (foreground).



Plate 2. Till blanket with unvegetated mudboils (stripes) on surface and small outcrop in distance.



Plate 3. Stabilized thawslide in till, NTS 76E N1/2.



Plate 4. Airstrip on glaciofluvial outwash, Canamera Carat Camp.



Plate 5. Glaciofluvial outwash complex near the Kugaryuak River. Note deeply incised ice wedge polygons and kettled (hummocky) outwash plain in centre and relatively featureless plain to the right.



Plate 6. Deeply incised ice-wedge trough in glaciofluvial outwash.

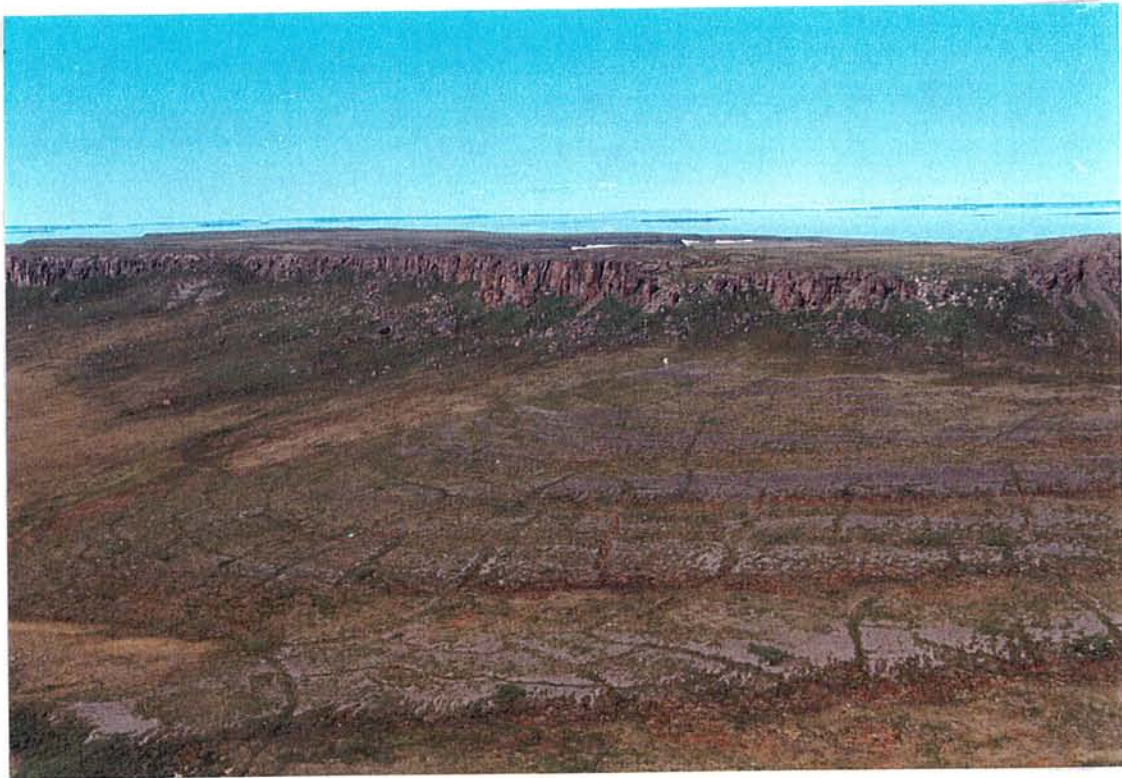


Plate 7. Raised marine beaches 7 km east of the mouth of the Kugaryuak River, Coronation Gulf. Note ice-wedge polygons cross cutting beach ridges.



Plate 8. Silty clay marine sediments in the Tree River valley. Slope processes keep surface bare of vegetation.

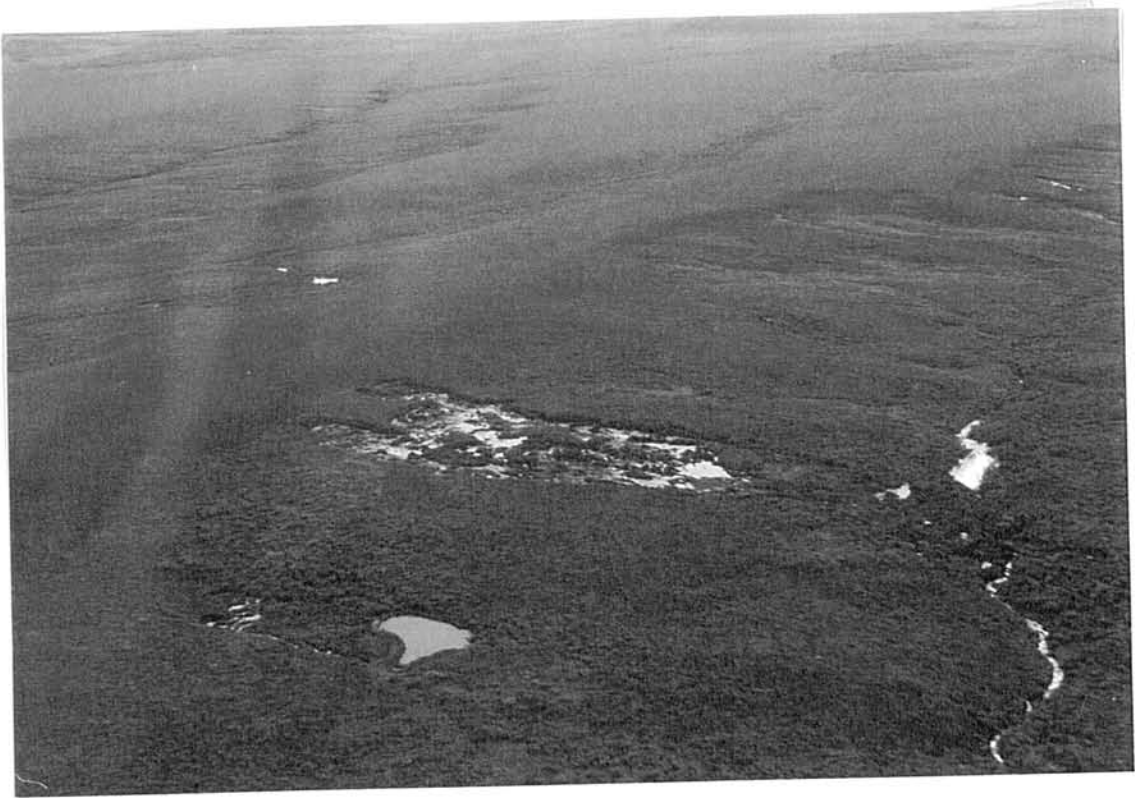


Plate 9. Small thawslide east of Coppermine on silty-clayey marine sediments.

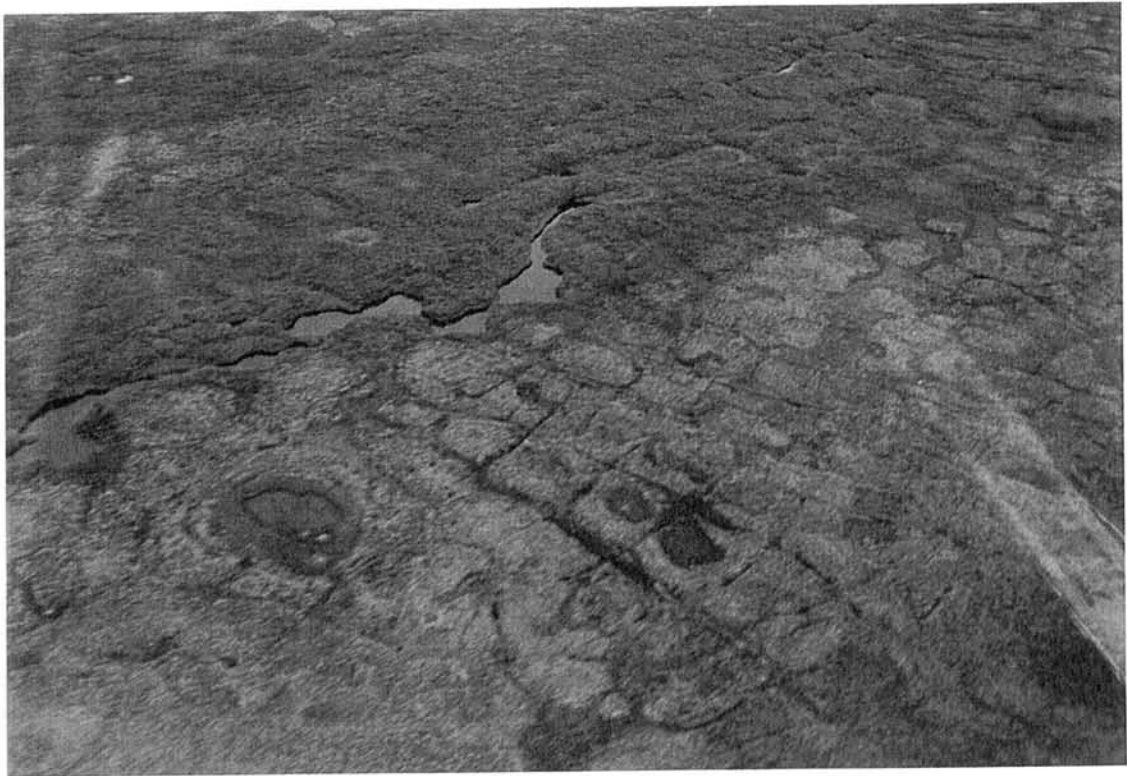


Plate 10. Checkerboard pattern of ice-wedge polygons on littoral sediments near mouth of the Asiatic River.



Plate 11. Ice-cored glaciofluvial terrain (centre), Canamera Carat Camp.



Plate 12. Site GSC-0886 on glaciofluvial sediment near Izok proposed winter road.



Plate 13. Site GSC-0887 on till blanket near Izok proposed winter road.



Plate 14. Site GSC-0888 on littoral and marine sediments south of the Coronation Gulf coast.

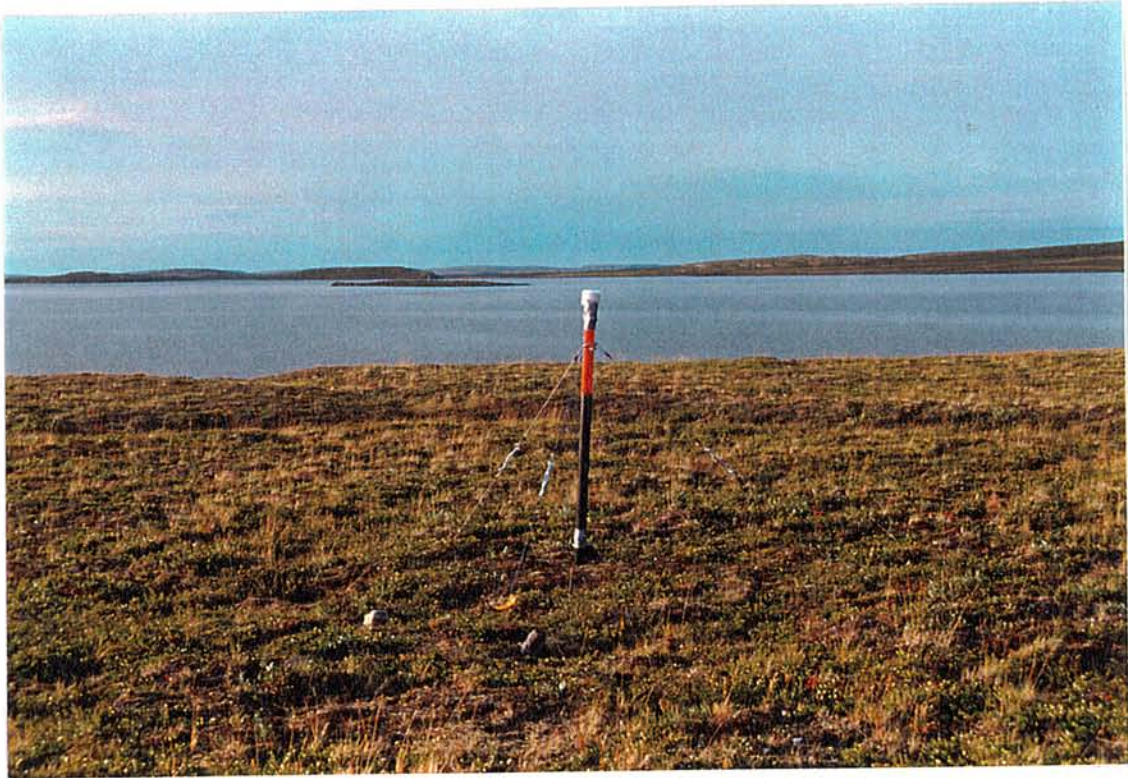


Plate 15. Site GSC-0889 on glaciofluvial outwash west of Kikerk Lake.



Plate 16. Site GSC-0890 on marine sediments in the Tree River valley.



Plate 17. Site GSC-0891 alluvial sediments at the mouth of the Kugaryuak River.



Plate 18. Site GSC-001 on littoral and marine sediments south of the Coronation Gulf coast (same location as GSC-0888).



Plate 19. Site GSC-002 on marine sediments south of GSC-001.

Station ID	Site Location	UTM coordinates	Initiation date	Specifications	Logger ID and Program
GSC-0886	SE section of 86O/1; gf outwash with polygons near Izok road	622130 E 7439689 N Zone 11	25-07-95	Air temp. 1.5 m.	#0886; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#17575; 4.8 hr int; 360 days
GSC-0887	NE corner of 86O/7; till blanket on Izok road	606600 E 7487863 N Zone 11	31-07-95	Air temp. 1.5 m.	#0887; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#17593; 4.8 hr int; 360 days
				Ground temp. 3.0 m S of tower; -2.5 cm.	#17492; 4.8 hr int; 360 days
GSC-0888	E of Napaktoktok R; littoral veneer adjacent to small lake	595147 E 7521150 N Zone 11	31-07-95	Air temp. 1.5 m.	#0888; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#17597; 4.8 hr int; 360 days
GSC-0889	W of Kikerk Lake; gf outwash with polygons	394596 E 7459378 N Zone 12	25-07-95	Air temp. 1.5 m.	#0889; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#17520; 4.8 hr int; 360 days
GSC-0890	Tree River Valley; marine clay with willow	457453 E 7491248 N Zone 12	27-07-95	Air temp. 1.5 m	#0890; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm	#17592; 4.8 hr int; 360 days
GSC-0891	Mouth of Kugaryuak R; alluvial delta with polygons	402688 E 7510722 N Zone 12	27-07-95	Air temp. 1.5 m	#0891; 6:00 hr int.; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm	#17595; 4.8 hr int; 360 days

Table 1. Air temperature and near surface ground temperature station setups for 1995-96.

Station ID	Site Location	UTM coordinates	Initiation date	Specifications	Logger ID and Program
GSC-001	E of Napaktoktok R; littoral veneer adjacent to small lake and GSC-0888	595143 E 7521155 N Zone 11	10-08-95	HT278: 0.5, 2.0, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0 m	RBR XL-800 #2572; 6:00 hr int; 366 days
			11-08-95	Submerged in ~2.5 m of water	RBR XL-100 #3190; 6:00 hr int; 366 days
GSC-002	E of Napaktoktok R; marine silts adjacent to small lake GSC-0888	592116 E 7513697 N Zone 11	11-08-95	HT288: 0; 0.3; 3.3; 8.3; 11.8; 15.3; 18.3 m	RBR XL-800 #3449; 6:00 hr int; 366 days
			12-08-95	Submerged in ~2.0 m of water	RBR XL-100 #3453; 6:00 hr int; 366 days

Table 2. Ground temperature and lake bottom temperature station setups for 1995-96.

1996 and 1998 Station Observations and Servicing

In July, 1996 all of the monitoring stations were visited in order to retrieve the stored data and to service the instruments. At all of the air temperature and near-surface ground temperature sites, the existing data loggers were removed and replaced with new (VEMCO-type) loggers. At the two ground temperature sites (GSC-001 and 002), the data were retrieved from the existing loggers, the batteries replaced and the loggers reprogrammed. All of the loggers were programmed to retrieve temperature data every 6:00:00 hours. The initiation date for the VEMCO loggers was set for August 5, 1996 while the initiation date for the two ground temperature sites were set for July 26, 1996. All of the loggers were programmed to collect data for a minimum of two years. At the two lake temperature monitoring sites, the loggers were retrieved but not replaced. Tables 3 and 4 summarize the setups at each of the monitoring stations following data retrieval and servicing in July, 1996. In addition to the above servicing and reprogramming, field observations were made at all locations.

In July, 1998 all of the air temperature and near surface ground temperature sites were revisited in order to retrieve the stored data and the instruments.

Station GSC-0886

This site is located in the southeast corner of map sheet NTS 86O, along the proposed winter road for the Izok port facility (Figure 2). The site is situated on a glaciofluvial outwash deposit adjacent to a lake towards the west and a north-south trending esker system to the east. The surface is flat and covered by moss, lichen, sedge and grass, with a good organic cover to a depth of approximately 10 cm. The site is about 25 m from the edge of the lake, and is elevated approximately 8-10 m above the lake level. Ice wedge polygons have developed in the local vicinity, the nearest ice wedge is located approximately 10 m from the monitoring site.

Station ID	Site Location	UTM coordinates	Initiation date	Specifications	Logger ID and Program
GSC-0886	SE section of 86O/1; gf outwash with polygons near Izok road	622130 E 7439689 N Zone 11	05-08-96 12:00:00	Air temp. 1.5 m.	#1444; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#1432; 6:00 hr int; 2016 days
GSC-0887	NE corner of 86O/7; till blanket on Izok road	606600 E 7487863 N Zone 11	05-08-96 12:00:00	Air temp. 1.5 m.	#1439; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#1446; 6:00 hr int; 2016 days
				Ground temp. 3.0 m S of tower; -2.5 cm.	#1427; 6:00 hr int; 2016 days
GSC-0888	E of Napaktoktok R; littoral veneer adjacent to small lake	595147 E 7521150 N Zone 11	05-08-96 12:00:00	Air temp. 1.5 m.	#1436; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#1434; 6:00 hr int; 2016 days
GSC-0889	W of Kikerk Lake; gf outwash with polygons	394596 E 7459378 N Zone 12	05-08-96 12:00:00	Air temp. 1.5 m.	#1440; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm.	#1438; 6:00 hr int; 2016 days
GSC-0890	Tree River Valley; marine clay with willow	457453 E 7491248 N Zone 12	05-08-96 12:00:00	Air temp. 1.5 m	#1445; 6:00 hr int; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm	#1428; 6:00 hr int; 2016 days
GSC-0891	Mouth of Kugaryuak R; alluvial delta with polygons	402688 E 7510722 N Zone 12	05-08-96 12:00:00	Air temp. 1.5 m	#1435; 6:00 hr int.; 2016 days
				Ground temp. 2.5 m S of tower; -2.5 cm	#1437; 6:00 hr int; 2016 days

Table 3. Air temperature and near surface ground temperature station setups for 1996-98.

Station ID	Site Location	UTM coordinates	Initiation date	Specifications	Logger ID and Program
GSC-001	E of Napaktoktok R; littoral veneer adjacent to small lake and GSC-0888	595143 E 7521155 N Zone 11	26-07-96 12:00:00	HT278: 0.5, 2.0, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0 m	RBR XL-800 #2572; 6:00 hr int; 765 days
GSC-002	E of Napaktoktok R; marine silts adjacent to small lake	592116 E 7513697 N Zone 11	26-07-96 12:00:00	HT288: 0; 0.3; 3.3; 8.3; 11.8; 15.3; 18.3 m	RBR XL-800 #3449; 6:00 hr int; 765 days

Table 4. Ground temperature station setups for 1996-98.

The station was visited on July 23, 1996. The mast had fallen over and broken into two parts. The Gill screen was torn off and moved approximately 15 m away from the original site. The air temperature cable was torn into pieces. Apparently the mast had been knocked down by a large animal, possibly a bear. The air temperature logger (#0886) was not found and the data could not be retrieved. The near surface ground temperature logger (#17575) was retrieved and found to be fully functional.

The station was serviced. The air temperature logger was replaced with VEMCO logger #1444. The near surface ground temperature logger was replaced with VEMCO logger #1432. Plate 12 depicts the condition of the site after servicing.

The station was revisited on July 6, 1998. Although the mast had fallen over, both the air temperature logger (VEMCO #1444) and the near surface ground temperature logger (VEMCO #1432) were fully functional. The data were retrieved and the station was removed.

Station GSC-0887

This site is located north-northwest of site GSC-0886 in the centre of the eastern half of map sheet NTS 86O (Figure 2). The site is also adjacent to the proposed winter road for the Izok port facility and is situated on a till blanket, locally vegetated with grass, cotton grass, sedge, lichen and moss. There are abundant mudboils in the vicinity ranging from 0.7 to 1.3 m in diameter and spaced 1.5 to 3 m apart. The mudboils are comprised of a moderately compact silty sand till with pebbles and cobbles at the surface. The monitoring site is open and exposed to winds from all directions. One near-surface ground temperature sensor (#17593) was placed beneath the vegetation cover and a second sensor (#17492) was placed within an unvegetated mudboil.

The station was visited on July 25, 1996. The mast had fallen over but was in good condition. The air temperature logger (#0887) and the two near surface ground temperature loggers #17593 and #17492) were retrieved. One of the near surface ground temperature loggers (# 17593) was found to be non-functional.

The station was serviced. The air temperature logger was replaced with VEMCO logger #1439. The near surface ground temperature loggers were replaced with VEMCO loggers #1446 and #1427, respectively. Plate 13 depicts the condition of the site after servicing.

The station was revisited on July 6, 1998. The mast had fallen over, but the air temperature logger (VEMCO #1439) and both near surface ground temperature loggers (VEMCO #1446 and #1427) were fully functional. The data were retrieved and the station was removed.

Station GSC-0888

This site is located approximately 2 km from the Coronation Gulf coast east of the Napaktoktok River and is north of site GSC-0887 in the NTS 86O map sheet (Figure 2). The site is located west of the proposed Izok port facility, and is situated on littoral beach

sands underlain by more than 30 m of marine silts. The site is approximately 100 m west of a small lake, and the surface is gently sloping, with occasional sandy knobs (used as siccus dens) in the local area. The site is locally vegetated with moss and willow shrubs. The organic cover is approximately 10-15 cm thick.

The station was visited on July 25, 1996. The mast had fallen over and the cable to the air temperature logger had been torn apart. The air temperature logger and near surface ground temperature loggers were retrieved. The near surface ground temperature logger (#17597) was fully functional while the air temperature logger (#0888) only had temperature data for the first 20 days prior to being damaged (possibly by a bear).

The station was serviced. The air temperature logger was replaced with VEMCO logger #1436. The near surface ground temperature logger was replaced with VEMCO logger #1434. Plate 14 depicts the condition of the site after servicing.

The station was revisited on July 6, 1998. The mast had fallen down, but the air temperature logger (VEMCO #1436) and the near surface ground temperature logger (VEMCO #1434) were fully functional. The data were retrieved and the station was removed.

Station GSC-0889

This site is located west of Kikerk Lake in the NTS 86P map sheet (Figure 2). The site is located on a glaciofluvial outwash deposit adjacent to a lake towards the west. The site forms a small peninsula on the west side of a north-south trending lake system. Consequently, the area is exposed to winds from these direction and is likely to be wind swept in winter. The surface is flat and covered by dwarf birch, occasional willow shrub, lichen and moss. It appears well-drained with a sandy subsoil and a surface organic cover of 2 to 5 cm. Ice wedge polygons occur in the local vicinity, with troughs 30 to 50 cm deep and approximately 1 m wide. The ice wedge troughs are spaced roughly 20 to 30 m apart.

The station was visited on July 23, 1996. The mast had fallen over but was in good condition. The air temperature logger (#8889) and near surface ground temperature logger

(#17520) were retrieved and found to be fully functional.

The station was serviced. The air temperature logger was replaced with VEMCO logger #1440. The near surface ground temperature logger was replaced with VEMCO logger #1438. Plate 15 depicts the condition of the site after servicing.

The site was revisited on July 7, 1998. At that time, the site had been disturbed and the mast had fallen over. The air temperature logger (VEMCO # 1440) was not found. The wires to the logger had been chewed by an animal, and the logger removed. The ground temperature logger (VEMCO #1438) was found exposed on top of the ground, apparently dug up by an animal. The logger was fully functional. The data from the logger were retrieved and the station was removed.

Station GSC-0890

The site is located in the Tree River valley, and is situated in the centre of the westernmost edge of map sheet NTS 86P (Figure 2). The site is situated on a high ridge near a dolomite outcrop, between the Tree River (to the east) and a tributary (to the west). The underlying surface material is comprised of marine silts and clays, which locally form raised mounds approximately 15 cm high and 1 m in diameter. The surface is generally clayey, with dense willow shrubs standing 30 to 35 cm high and some moss cover in furrows between the mounds. Of all the sites monitored, the vegetation cover is highest at this location, however, a significant proportion of the surface is unvegetated

The station was visited on July 24, 1996. The mast had fallen over but was in good condition. The air temperature logger (#8890) and near surface ground temperature logger (#17592) were retrieved and found to be fully functional.

The station was serviced. The air temperature logger was replaced with VEMCO logger #1445. The near surface ground temperature logger was replaced with VEMCO logger #1428. Plate 16 depicts the condition of the site after servicing.

On July 7, 1998, the station was revisited. The mast had fallen down, but the air temperature logger (VEMCO #1445) and the near surface ground temperature logger

(VEMCO #1428) were fully functional. The data were retrieved and the station was removed.

Station GSC-0891

The site is located on the Coronation gulf coast at the mouth of the Kugaryuak River in the NTS 86P map sheet (Figure 2). The site is located on an alluvial (deltaic) deposit approximately 150 m from the beach (to the north) and 150 m from the river (to the south). The site is on a slight terrace, with ice wedge polygons visible on the flat-topped surfaces. The surface is vegetated by lupin, moss, lichen and willow shrub, standing 35 to 100 cm tall in a few areas. The area is frequented by local inhabitants of the Hamlet of Kugluktuk (Coppermine), who travel to the area for hunting and fishing.

The station was visited on July 24, 1996. The mast was standing and in good condition. The air temperature logger (#0891) and near surface ground temperature logger (#17595) were retrieved and found to be fully functional.

The station was serviced. The air temperature logger was replaced with VEMCO logger #1435. The near surface ground temperature logger was replaced with VEMCO logger #1437. Plate 17 depicts the condition of the site after servicing.

The site was revisited on July 7, 1998. At that time, the site had been disturbed. The wires to the air temperature logger (VEMCO # 1440) had been chewed by an animal. However, the logger was found and data for part of the record were retrieved. The ground temperature logger (VEMCO #1438) was undisturbed and fully functional. The data from the logger were also retrieved and the station was removed.

Station GSC-001

The site is located at station GSC-0888 and was visited on July 25, 1996. The eight-channel logger (#2572) was found to be fully functional, and was tested manually at approximately 12:00:00. The readings were as follows:

Channel	Depth (m)	Resistance (Ohm)	Temperature (°C)
1	0.5	5925	4.29
2	2	8940	-3.78
3	5	10885	-7.49
4	10	10490	-6.81
5	15	10430	-6.7
6	20	10380	-6.61
7	25	10315	-6.49
8	30	10260	-6.39

Table 5. Ground temperature observations at site GSC-001, July 25, 1996.

The station was serviced, with the batteries replaced and the logger reprogrammed. In addition, the lake bottom temperature logger (#3190) was retrieved and found to be fully functional. Plate 18 depicts the condition of the ground temperature monitoring site after servicing.

On July 8, 1998 the site was revisited. Unfortunately, the thermistors cable to the logger had been severed (probably by a bear), and no additional ground temperature data were retrieved. Nevertheless, the data collected previously are felt to provide an adequate representation of the ground thermal regime at this site.

Station GSC-002

The site is located south of stations GSC-0888 and GSC-001, and is located approximately 10 km from the Coronation Gulf coast east of the Napaktoktok River in the NTS 86O map sheet (Figure 2). The site is underlain by more than 20 m of marine silts and the surface contains numerous mudboils at surface, similar to the Tree River site (GSC-0890). The site is approximately 100 m south and west of two small lakes and the surface is gently sloping towards the lake to the north. The site is locally vegetated with moss and dwarf birch and willow shrubs to 60 cm high. The organic cover is variable, being non-existent on the surface of the mudboils, to more than 30 cm thick in troughs between the mounds.

The station was visited on July 25, 1996. The eight-channel logger (#3449) was found to be fully functional and was tested manually at approximately 13:00:00. The readings were as follows:

Channel	Depth (m)	Resistance (Ohm)	Temperature (°C)
1	(air)	1885	28.5
2	0.3	4680	9.1
3	3.3	10200	-6.28
4	8.3	10160	-6.2
5	11.8	10090	-6.07
6	15.3	9990	-5.89
7	18.3	10020	-5.99

Table 6. Ground temperature observations at site GSC-002, July 25, 1996.

The station was serviced, with the batteries replaced and the logger reprogrammed. In addition, the lake bottom temperature logger (#3453) was retrieved and found to

Site	Logger	Aug 95	Sep 95	Oct 95	Nov 95	Dec 95	Jan 96	Feb 96	Mar 96	Apr 96	May 96	Jun 96	Jul 96	Avg	Annual
0886	Air	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	Ground 17575	6.53	0.39	-2.55	-13.47	-23.87	-24.70	-24.00	-21.81	-15.73	-4.59	7.49	11.72	-9.40	na
0887	Air	7.16	1.04	-9.73	-19.19	-30.28	-29.79	-25.27	-24.52	-16.81	-5.91	10.88	14.23	-11.00	na
	Ground 17593	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	Ground 17492	7.26	1.32	-0.24	-2.11	-6.33	-8.92	-11.74	-12.47	-11.37	-5.83	9.10	13.18	-2.60	na
0888	Air	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	Ground 17597	4.98	1.04	-0.66	-6.85	-17.34	-20.84	-20.19	-19.38	-14.98	-6.94	2.97	8.33	-7.74	na
0889	Air	7.97	1.28	-4.45	-12.58	-21.53	-23.69	-22.59	-20.93	-14.38	-3.31	10.36	14.61	-7.87	na
	Ground 17520	7.17	0.85	-3.35	-11.59	-20.39	-22.15	-21.94	-19.87	-13.99	-3.39	8.70	13.30	-7.94	na
0890	Air	8.84	2.28	-4.46	-12.09	-19.64	-23.34	-19.97	-19.55	-12.80	-1.97	12.96	15.75	-6.56	na
	Ground 17592	5.25	1.18	-1.46	-6.10	-12.57	-15.57	-15.94	-15.72	-12.29	-4.67	6.20	9.87	-5.57	na
0891	Air	8.50	2.87	-5.86	-15.83	-28.95	-25.60	-23.30	-21.54	-14.96	-3.17	11.16	14.22	-8.95	na
	Ground 17595	6.05	1.34	-1.19	-10.11	-21.46	-22.08	-21.31	-19.87	-15.18	-5.82	5.68	9.81	-8.32	na

Table 7. Monthly and annual summaries of air and near surface ground temperatures from monitoring stations, 1995-96.

Site	Logger	Aug 96	Sep 96	Oct 96	Nov 96	Dec 96	Jan 97	Feb 97	Mar 97	Apr 97	May 97	Jun 97	Jul 97	Avg	Annual
0886	Air	1444	5.80	3.20	-8.70	-19.40	-24.70	-29.80	-27.50	-27.10	-14.90	-5.20	7.20	13.70	-10.70
	Ground	1432	5.70	3.60	-3.50	-15.20	-21.20	-26.80	-25.20	-25.40	-16.60	-6.20	4.30	11.00	-9.72
0887	Air	1439	5.29	2.68	-6.47	-12.66	-17.62	-22.61	-22.02	-22.39	-16.48	-7.40	6.85	13.33	-8.30
	Ground	1446	5.50	3.40	-0.70	-4.70	-9.80	-16.30	-17.30	-18.40	-14.80	-7.50	3.80	10.20	-5.60
	Ground	1427	5.80	3.38	-1.18	-5.62	-10.49	-16.65	-17.48	-18.82	-14.80	-8.14	4.66	11.72	-5.71
0888	Air	1436	7.78	4.24	-4.81	-16.78	-23.60	-28.02	-25.43	-24.76	-16.26	-5.71	8.47	13.97	-9.37
	Ground	1434	4.68	2.75	-1.49	-9.73	-17.25	-22.04	-21.39	-21.18	-16.82	-7.72	1.74	6.92	-8.55
0889	Air	1440	na	na	na	na	na	na	na	na	na	na	na	na	na
	Ground	1438	7.10	4.40	-4.70	-15.50	-21.40	-25.70	-25.30	-25.40	-15.50	-4.60	8.00	14.20	-8.82
0890	Air	1445	7.04	4.88	-8.24	-17.79	-24.27	-26.20	-24.99	-25.09	-14.89	-5.05	7.51	14.11	-9.54
	Ground	1428	4.76	3.54	-1.01	-6.95	-11.35	-15.34	-16.16	-16.83	-12.88	-4.67	4.53	9.06	-5.34
0891	Air	1435	7.67	5.00	-3.66	-14.21	-20.61	-24.50	-23.92	-24.20	-15.64	-4.33	8.20	13.19	-8.19
	Ground	1437	5.88	3.85	-3.17	-13.45	-19.96	-24.15	-23.34	-24.19	-16.30	-4.88	4.30	9.54	-8.92

Table 8. Monthly and annual summaries of air and near surface ground temperatures from monitoring stations, 1996-97.

Site	Logger	Aug 97	Sep 97	Oct 97	Nov 97	Dec 97	Jan 98	Feb 98	Mar 98	Apr 98	May 98	Jun 98	Jul 98	Avg	Annual	
0886	Air	1444	9.70	3.80	-8.50	-12.70	-21.10	-32.50	-25.10	-20.30	-10.00	0.90	8.10	16.40	-9.32	na
	Ground	1432	8.20	3.70	-3.20	-10.20	-17.70	-28.40	-23.70	-19.50	-9.50	0.50	6.40	12.20	-8.10	na
0887	Air	1439	9.27	3.02	-5.96	-6.85	-13.63	-23.23	-20.34	-17.25	-9.46	-0.40	8.51	16.47	-6.51	na
	Ground	1446	7.90	3.10	-0.50	-2.20	-5.60	-13.70	-15.30	-14.10	-10.10	-1.30	6.00	11.60	-3.85	na
	Ground	1427	8.46	3.10	0.56	-3.11	-7.33	-16.85	-16.43	-15.05	-9.24	-0.66	7.66	14.06	-4.19	na
0888	Air	1436	9.66	3.70	-4.31	-8.51	-15.96	-28.47	-23.32	-19.39	-11.51	1.40	8.62	na	-8.60	na
	Ground	1434	5.99	2.60	-0.89	-4.32	-12.27	-22.90	-20.96	-17.73	-12.16	-1.78	2.70	7.71	-7.12	na
0889	Air	1440	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	Ground	1438	9.70	3.90	-8.10	-14.30	-22.60	-32.10	-24.80	-20.30	-9.70	0.50	8.60	17.80	-9.35	na
0890	Air	1445	9.83	4.51	-7.22	-10.56	-18.52	-28.85	-23.07	-18.73	-7.98	2.27	10.49	18.24	-7.42	na
	Ground	1428	6.43	3.01	-0.86	-3.56	-8.55	-15.39	-14.74	-13.55	-6.90	0.41	5.96	10.29	-4.02	na
0891	Air	1435	9.27	4.09	-2.72	na	na	na	na	na	na	na	na	na	na	na
	Ground	1437	7.33	3.26	-2.42	-8.26	-15.75	-26.76	-23.53	-18.15	-9.50	-0.50	5.71	11.08	-7.51	na

Table 9. Monthly and annual summaries of air and near surface ground temperatures from monitoring stations, 1997-98.

contain data up to January 20, 1997. The reason for the loss of temperature data after this date is unknown. Plate 19 depicts the condition of the ground temperature monitoring site after servicing.

On July 8, 1998 the station was revisited. At that time, the cable between the logger and the thermistors had been severed (possibly by a bear) and no additional data were retrieved from the logger.

THERMAL MONITORING RESULTS

Air and near surface ground temperatures

Air and near surface ground temperatures have been monitored for a period of up to three years at six locations (described above) east of Coppermine and south of the Coronation Gulf coast (Figure 2). The results of the air and near surface ground temperature monitoring are summarized on Tables 7, 8 and 9 which display the monthly and annual average temperatures. In Tables 7 and 9, the temperature data was short of a full year record, ranging from 3 to 21 days of a complete record. The missing period of the record is the last few days of July, 1996 and July, 1998. For these years the average values of the available data are shown, but an annual average is not shown (although extrapolation methods can be used to compensate for the missing data if necessary). The temperature records are generally complete for the period of August 1996 to July 1997 and, therefore, both average values and annual values are shown in Table 8.

Based on the mean annual air temperatures shown in Table 8, the coldest site was GSC-0886 (-10.7°C) which is the most southerly site along the Izok proposed winter road, whereas the warmest site was the site situated along the Coronation Gulf coast at the mouth of the Kugaryuak River (GSC-0891; -8.2°C). In other years, the location of the warmest and coldest sites vary. For example, in the previous year the site situated in the Tree River valley (GSC-0890; -6.33°C) farthest to the east was warmest, while the site GSC-0887, also along the Izok proposed winter road, was the coldest (-11.0°C).

Figure 4, 5 and 6 present the air and near surface ground temperature trends for all of the sites containing both records. The most obvious comparison is the considerable difference in ground temperatures at each site. This is also observed in Table 8 which shows that the mean annual near surface ground temperatures range from -5.34°C at site GSC-0890 to -9.72°C at site GSC-0886. The reasons for the extreme differences in near surface ground temperatures are probably due to local site conditions including local air temperatures (described above), soil type and moisture content, organic matter thickness and winter snowfall (acting as insulators) and vegetation cover (acting to trap snow and further insulate the ground).

As seen in Figure 6, the near surface ground temperatures at site GSC-0890 are much warmer in winter than the corresponding air temperatures. This site, along the Tree River valley, has a dense cover of willow shrub and likely traps more snow in winter than the other monitored sites. A reasonable explanation for the warm ground temperatures in winter is that the surface is well insulated by snow in the winter. In other instances it is also possible that moisture in the soil may produce a strong latent heat effect, thereby keeping the local ground temperatures relatively warm during the months of October and November until the moisture freezes. By comparison, there is much less of a difference between the air and ground temperatures at sites GSC-0886 and GSC-0891 which, presumably are more wind-swept as well as being drier sites. Finally, it is significant to note that, in all cases the ground temperatures remained warmer than the air temperatures in winter, and cooler than the air temperatures in summer, indicating the insulating effects of the overlying ground, vegetation and/or snow cover.

An important aspect of thermal monitoring procedures, is the calculation of degree days, including freezing degree days, thawing degree days and total degree days. Freezing degree days are defined as the sum of the mean daily temperatures below 0°C for the period of one year. By comparison, thawing degree days represent the sum of the mean daily temperatures above 0°C for the same period. Total degree days represent the total annual sum of degree days above and below 0°C . Below the active layer (ie within the

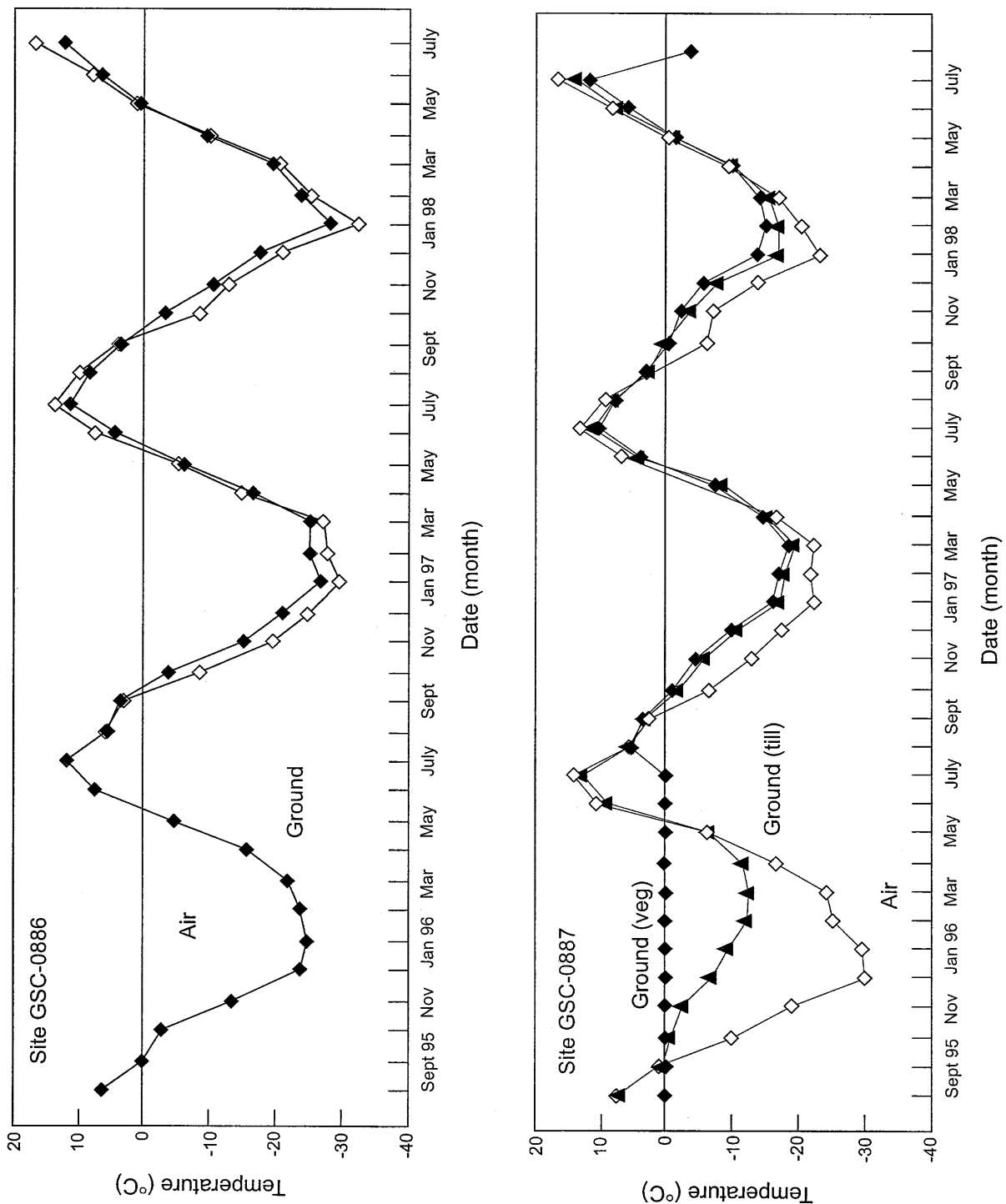


Fig 4. Comparison of air and ground temperatures for sites GSC-0886 and GSC-0887.

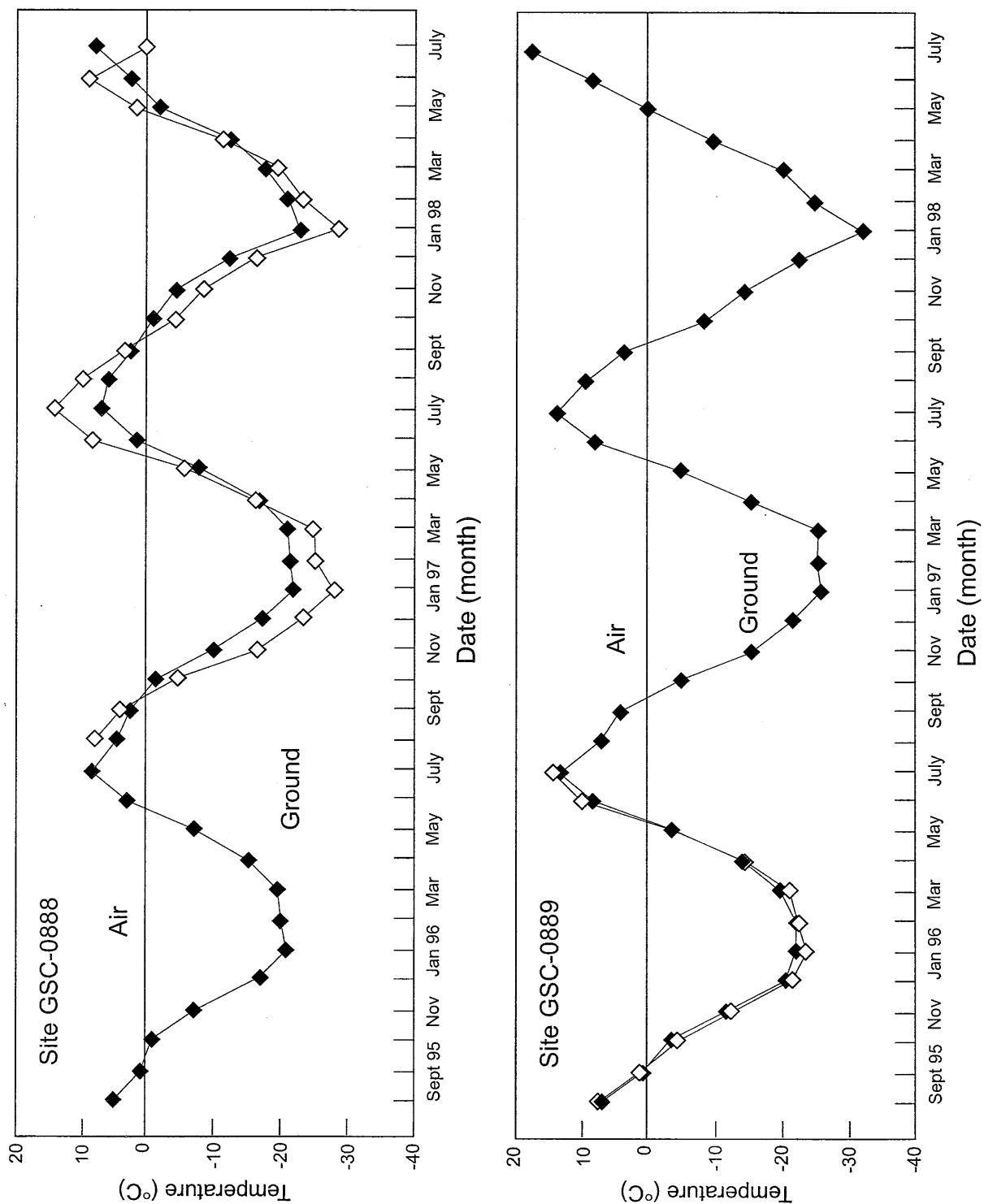


Fig 5. Comparison of air and ground temperatures for sites GSC-0888 and GSC-0889.

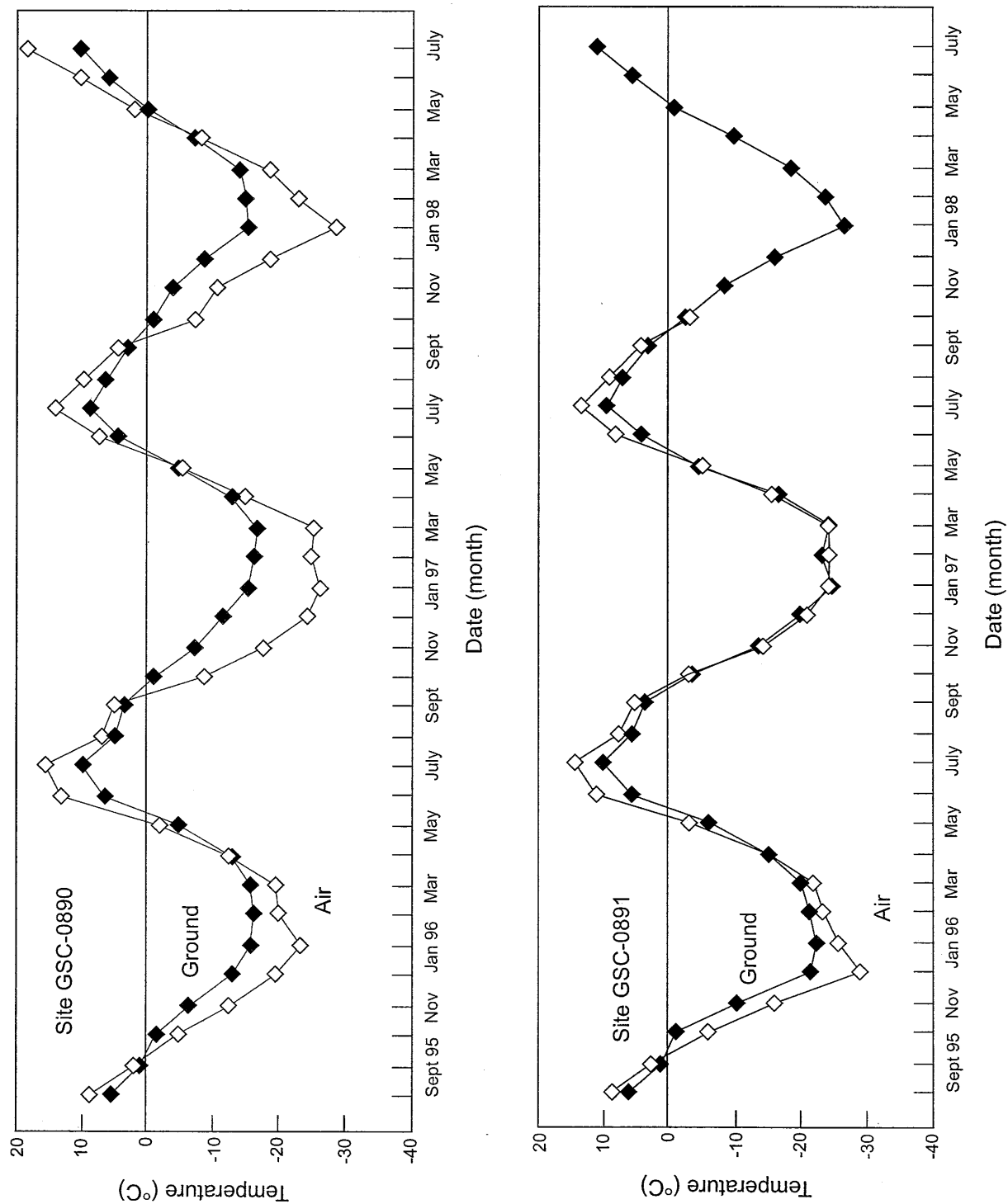


Fig 6. Comparison of air and ground temperatures for sites GSC-0890 and GSC-0891.

permafrost), all of the degree days will be freezing degree days, as the ground is perennially frozen. Within the active layer and in the air, the degree days will consist of both freezing degree days (days below 0°C) and thawing degree days (days above 0°C). However, because mean annual temperatures are below freezing, there will always be more freezing degree-days than thawing degree-days on an annual basis. Finally, it should be noted that in freshwater lakes and in water bodies that do not freeze to the bottom, the bottom temperatures will also be thawing degree days (ie the temperature at the bottom is always above 0°C). Degree days are used extensively in thermal calculations, both for climatic and engineering purposes. Consequently, degree days have been calculated for all of the monitoring sites.

Table 10 presents the total thawing degree days and freezing degree days for both the air temperature and near surface ground temperature sites from the period of September 01 1996 to August 31 1997. Also included in Table 10 are the “n-factors”, which represent the ratio of degree days in the ground to the degree days in the air. An “n-factor” is an expression of the modulation of heat flow between the air and ground due to “buffer-layer” effects of vegetation cover and snow accumulation (Taylor, 1995). For example, the n-factor value of 0.72 for thawing degree days at site GSC-0887 represents the ratio of the thawing degree days at the near surface ground temperature station to the thawing degree days for the air temperature station at the same site. The n-factors were calculated for these sites because they have been used extensively in the Mackenzie Valley region of the Northwest Territories as a part of the ongoing climate monitoring in that area (Taylor, 1995).

In general, the n-factors calculated for the Coppermine region, are higher than those for the Mackenzie Valley because the sites are typically less well insulated than the Mackenzie Valley sites. For example, the Coppermine region sites typically contain less organic matter, less vegetation cover and less snow accumulation than the Mackenzie Valley.

Site	Degree Days				n-factors	
	Air		Ground		n-thaw	n-freeze
	Thawing	Freezing	Thawing	Freezing		
0886	1085	4808	782	4237	0.72	0.88
0887	1015	3860	782 875	2703 2824	0.77 0.86	0.70 0.73
0888	1129	4412	539	3559	0.48	0.81
0889	na	na	1129	4481	na	na
0890	1161	4481	723	2573	0.62	0.57
0891	1128	3997	773	3919	0.69	0.98

Table 10. Degree Days and n-factors calculated from monitoring sites.

Ground Temperatures

Ground temperatures were collected from two monitoring sites (GSC-001 and GSC-002) east of Coppermine along the Coronation Gulf coast (Figure 2). At site GSC-001 ground temperature measurements extend to a depth of 30 m, whereas at site GSC-002 temperature measurements extend to a depth of 18.3. Both sites are underlain by marine silts which are quite uniform in texture. At site GSC-001, the marine silts are capped by approximately 2 m of littoral sands. Vegetation cover at the two sites are similar, both dominated by willow shrubs and mosses. However, as depicted in Plates 18 and 19, site GSC-002 is more densely vegetated with willow, and contains a thicker organic mat of moss at the surface.

Table 11 summarizes the mean monthly and the mean annual temperatures at each depth for sites GSC-001 and GSC-002. It is important to note that, for the first two months, ground temperatures were generally elevated above the background equilibrium temperatures because of the thermal disturbance caused by drilling. An example of this effect can be seen in Table 11 at 20 m depth, where mean temperatures for the months of August and September are -4.81°C and -5.94°C , respectively, compared to colder temperatures for the remainder of the year and to the mean annual temperature of -6.29°C at this depth. Because of this effect, the mean annual ground temperatures in Table 11 are likely somewhat warmer than the equilibrium temperatures. However, as the thermal disturbance has since dissipated, the later monitored temperatures better reflected the undisturbed conditions.

Figures 7 and 8 present the mean monthly temperatures at depth for the period after the thermal disturbance had dissipated (ie the months of August and September are excluded). The figures indicate that, below a depth of approximately 8 m, the ground temperatures are very nearly constant; varying with depth by less than 0.2°C and monthly by 0.6°C or less. At both sites, there appears to be a slight warming at the base of the profiles, by about 0.1°C .

Site GSC-001		0.5 m	2.0 m	5.0 m	10.0 m	15.0 m	20.0 m	25.0 m	30.0 m
DATE									
Aug-95	3.79	-0.19	-6.32	-2.03	-2.32	-4.81	-5.03	-5.91	
Sep-95	0.92	-1.82	-6.38	-5.09	-5.37	-5.94	-6.19	-6.18	
Oct-95	-0.08	-2.27	-6.39	-6.11	-6.06	-6.23	-6.28	-6.21	
Nov-95	-0.30	-2.36	-6.23	-6.44	-6.29	-6.36	-6.34	-6.26	
Dec-95	-8.98	-4.75	-6.07	-6.63	-6.44	-6.47	-6.41	-6.31	
Jan-96	-13.43	-8.35	-5.98	-6.71	-6.52	-6.52	-6.45	-6.34	
Feb-96	-15.23	-10.50	-6.13	-6.75	-6.56	-6.53	-6.46	-6.35	
Mar-96	-15.24	-11.40	-6.54	-6.75	-6.57	-6.53	-6.46	-6.35	
Apr-96	-13.45	-11.52	-7.06	-6.73	-6.57	-6.53	-6.44	-6.32	
May-96	-8.43	-10.04	-7.45	-6.66	-6.54	-6.49	-6.39	-6.28	
Jun-96	0.14	-6.27	-7.45	-6.22	-6.31	-6.22	-6.29	-6.13	
Jul-96	4.27	-4.26	-7.43	-6.64	-6.50	-6.46	-6.35	-6.23	
ANNUAL MEAN	-5.92	-6.33	-6.61	-6.16	-6.09	-6.29	-6.29	-6.25	

Site GSC-002		0 m	0.3 m	3.3 m	8.3 m	11.8 m	15.3 m	18.3 m
DATE								
Aug-95	5.1	1.9	-1.5	-4.2	-4.3	-5.2	-5.7	
Sep-95	2.3	1.0	-4.0	-5.8	-5.8	-5.9	-5.9	
Oct-95	-0.5	-0.3	-4.4	-6.2	-6.0	-5.9	-5.9	
Nov-95	-2.2	-1.7	-4.4	-6.2	-6.1	-6.0	-5.9	
Dec-95	-9.2	-8.3	-4.3	-6.2	-6.1	-6.0	-5.9	
Jan-96	-12.5	-11.5	-4.4	-6.2	-6.1	-6.0	-5.9	
Feb-96	-13.5	-12.9	-5.1	-6.2	-6.2	-6.0	-5.9	
Mar-96	-14.2	-13.4	-6.1	-6.1	-6.2	-6.0	-5.9	
Apr-96	-12.3	-12.1	-7.1	-6.1	-6.2	-6.0	-5.9	
May-96	-5.3	-6.2	-7.6	-6.1	-6.1	-6.0	-5.9	
Jun-96	13.1	3.9	-7.1	-6.1	-6.0	-5.8	-5.7	
Jul-96	16.8	7.1	-6.4	-6.1	-5.9	-5.8	-5.7	
ANNUAL MEAN	-3.3	-4.8	-5.3	-6.0	-6.0	-5.9	-5.9	

Table 11. Monthly ground temperature measurements at site GSC-001 and GSC-002.

The mean annual ground temperature at a depth of approximately 15 m, after the thermal disturbance had dissipated, is approximately -6.4°C at site GSC-001 and -6.0°C at site GSC-002. Extrapolating the ground temperature trends with depth below 10 m to the surface, results in approximate mean annual ground temperatures of -7.1°C at site GSC-001 and -6.5°C at site GSC-002. The warmer ground temperatures at site GSC-002 may be associated with greater snow accumulation/insulation in winter, trapped by the more abundant willow shrubs at this site.

Unfortunately, because a complete annual record of equilibrium ground temperatures is not available, it is not possible to determine actual degree days at these sites. However, at a depth of 15 m, the total degree days are likely to be about -2335 at site GSC-001 (the negative sign indicates that the net degree days are freezing) and -2190 at site GSC-002, based on the ground temperature data collected. These values are likely to be accurate estimates of the true number of total degree days, as no thawing occurs at these depths and the temperatures do not vary significantly. By extrapolating ground temperatures to the surface, the estimated total degree days just below the surface of the ground may be on the order of -2590 at site GSC-001 and -2370 at site GSC-002. These estimates, however, are subject to substantial uncertainty since ground temperatures vary considerably near the surface, and the total degree days are comprised of both freezing and thawing degree days.

Finally, the extrapolated mean annual ground temperature and total degree days at site GSC-001 can be compared to the mean annual near surface ground temperature at site GSC-0888, which is located at the same site. The mean annual ground temperature of -7.1°C and degree days of -2590 at site GSC-001 is colder than the average near surface ground temperatures of -7.7°C and -8.6°C obtained during the first two years of temperature monitoring. The difference in temperatures obtained between the extrapolated and monitored data is mostly due to the very rapid dissipation of heat experienced in the upper layers of ground soil, making extrapolation to the near surface difficult. Under the circumstances, the two methods compare favourably.

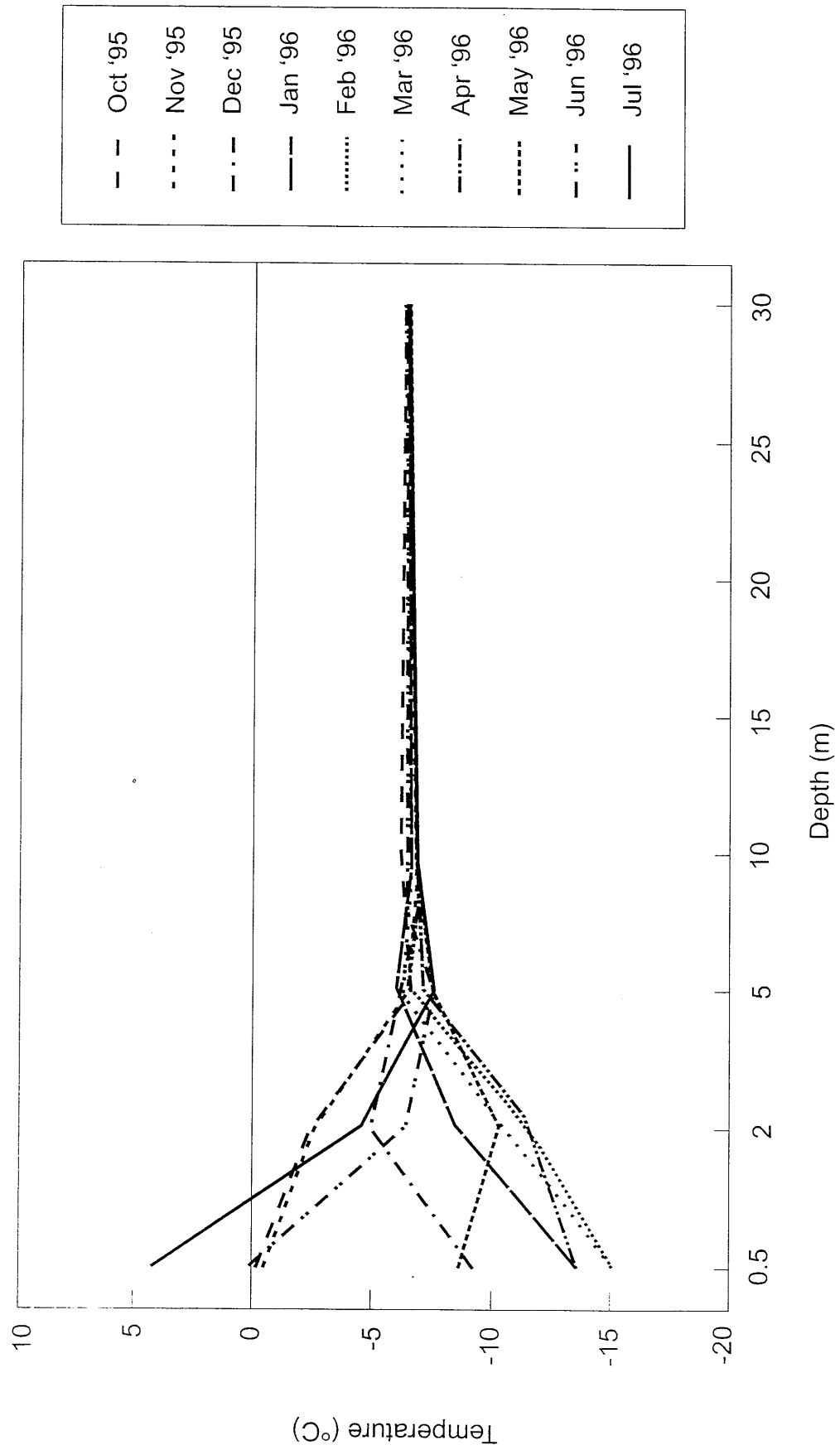


Fig 7. Ground temperature profiles for site GSC-001.

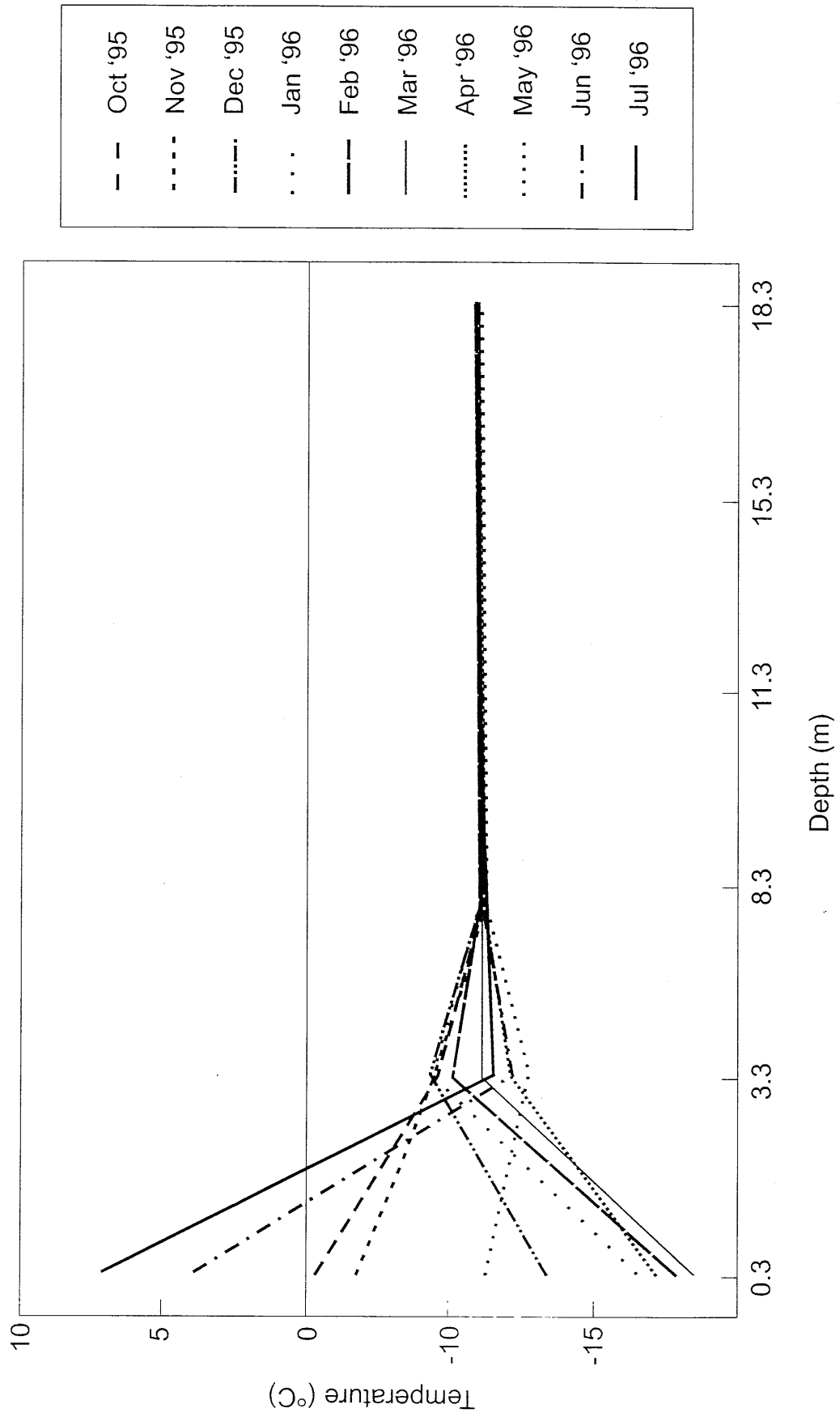


Fig 8. Ground temperature profiles for site GSC-002.

Lake Bottom Temperatures

Lake bottom temperatures were collected from two small lakes east of Coppermine along the Coronation Gulf coast (Figure 2). Each lake was between 2 and 3 metres deep and was underlain by at least 20 to 30 m of marine silts and thin littoral sands. As depicted by the ground temperatures (Figures 7 and 8) permafrost is present in the terrain surrounding the lakes.

Figure 9 depicts the lake bottom temperatures obtained from sites GSC-001 and GSC-002. Although the logger at site GSC-002 stopped functioning on January 20, 1996 the lake water temperatures obtained indicate slightly higher water temperatures (approximately 1.1°C warmer) during the winter months, than at site GSC-001.

The lake water temperatures obtained from site GSC-001 over the year are very interesting, as the extreme differences between summer and winter months are well depicted. The lake reached a minimum water temperature of 0.2°C at 2.5 m depth on October 3, 1995 and maximum water temperature of 19.5°C on July 8, 1996. It is also interesting to note the increase in lake water temperature at 2.5 m depth that occurred after the minimum temperature was reached on October 3, 1995. This is likely attributable to lake water freezing at the surface, resulting in density changes in the water. After freeze-up, the bottom temperatures warmed to 2.5°C by October 30, 1995 and subsequently reached a secondary minimum of 0.9°C on between March 27 and April 8, 1996.

The mean monthly lake bottom temperatures for both sites are shown in Table 12. The mean annual lake bottom temperature at site GSC-002 is approximately 3.9°C. In addition, the total number of degree days (1364) and the estimated annual degree days (1565) are also provided. Because the temperature record is 17 days short of a complete annual record, the temperature trend at the beginning of the record was extended by 10 days and at the end of the record by 7 days, to determine the estimated annual degree days. Using this method, the estimated mean annual lake bottom temperature for the entire year is approximately 4.3°C.

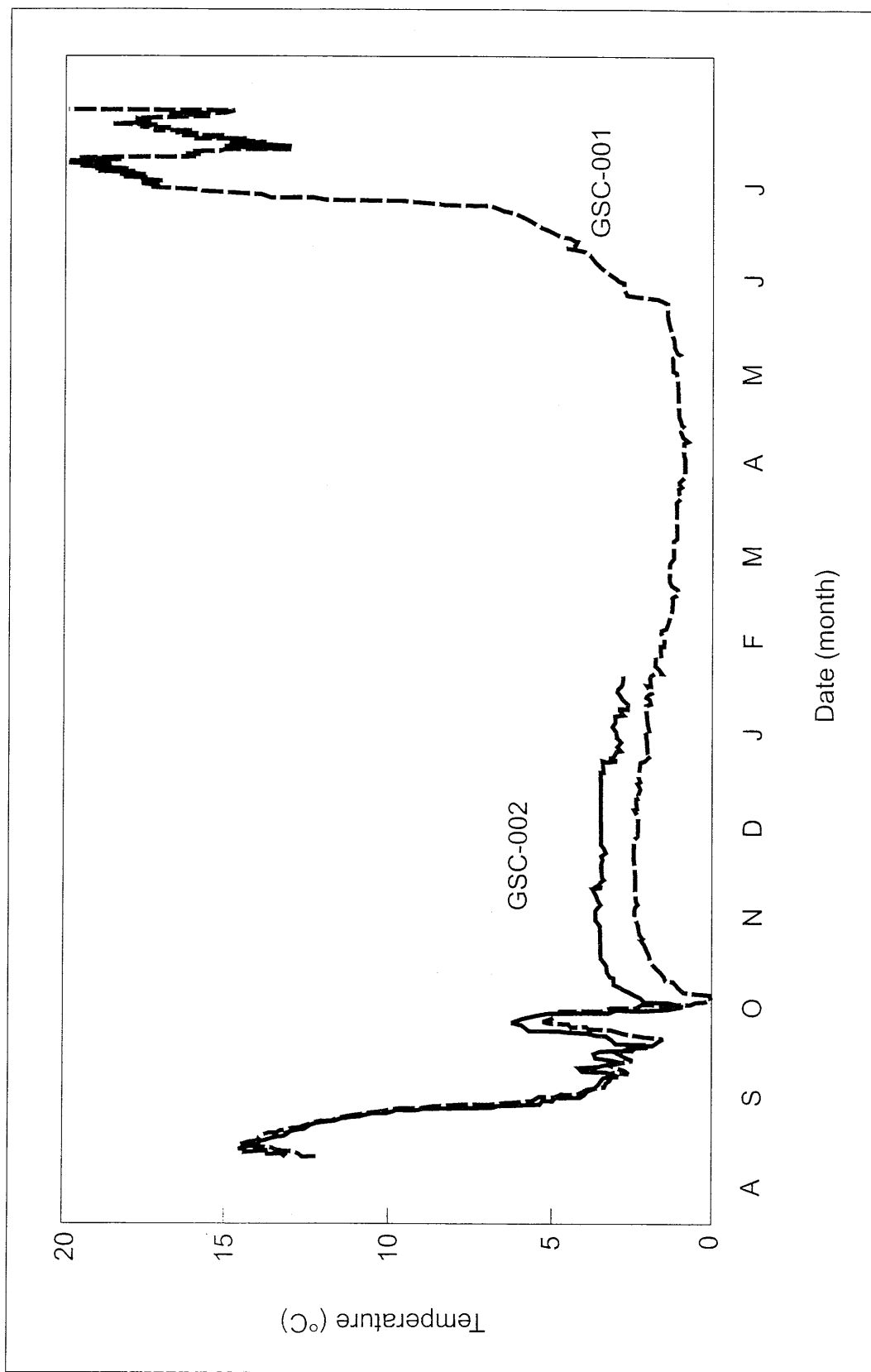


Fig 9. Lake bottom temperatures at sites GSC-001 and GSC-002.

DATE	GSC-001	GSC-002
Aug-95	11.25	11.40
Sep-95	3.35	3.80
Oct-95	1.76	3.20
Nov-95	2.47	3.60
Dec-95	2.27	3.40
Jan-96	1.92	na
Feb-96	1.37	na
Mar-96	1.14	na
Apr-96	1.09	na
May-96	1.70	na
Jun-96	6.74	na
Jul-96	16.89	na
ANNUAL MEAN	3.90	na
TOTAL DEGREE DAYS	1364.00	na
ESTIMATED ANN. D. D.	1565.00	na

Table 12. Monthly lake water temperatures and degree days at sites GSC-001 and GSC-002

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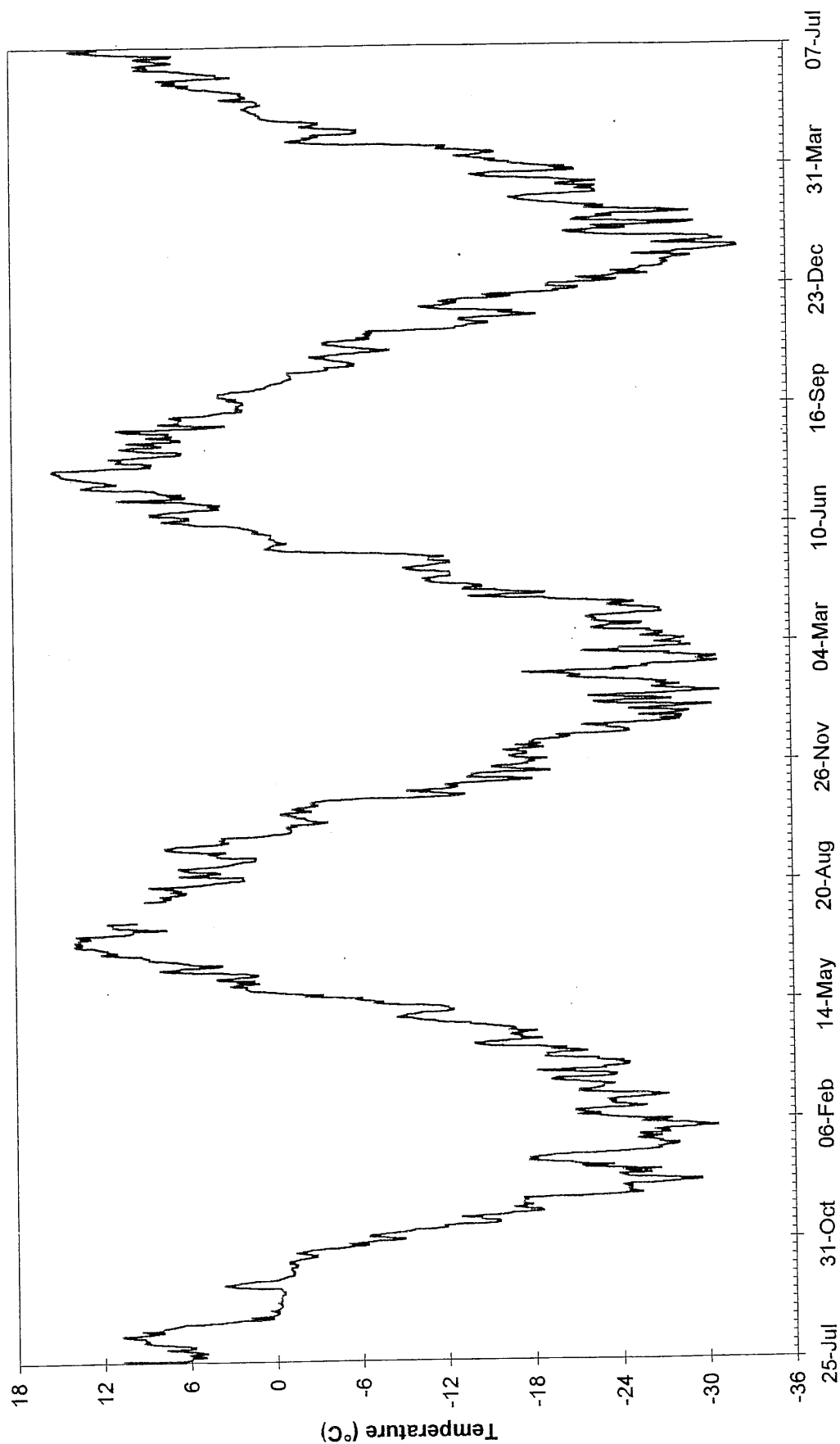
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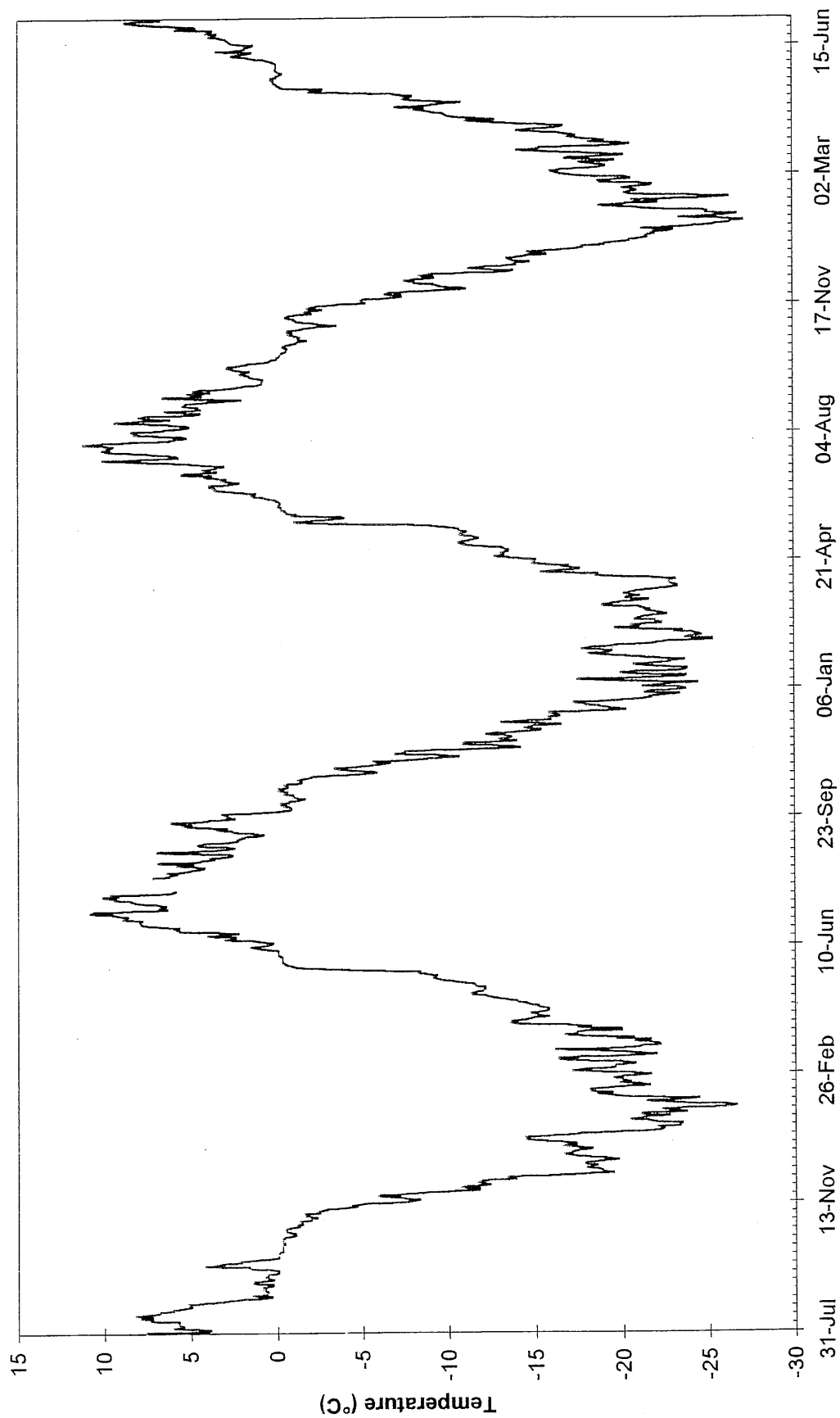
APPENDIX I

Mean Daily and Monthly Temperatures From Monitoring Stations

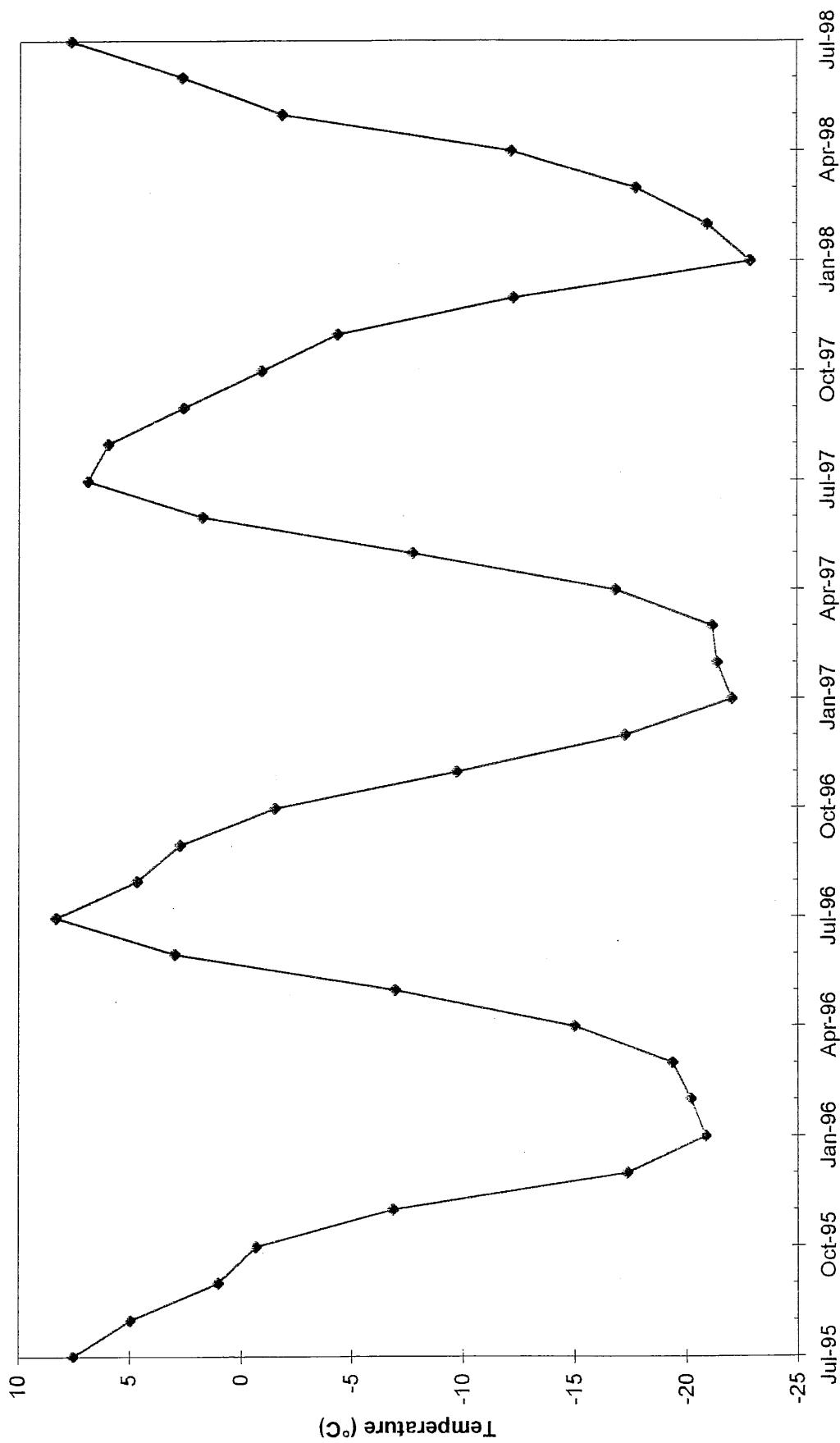
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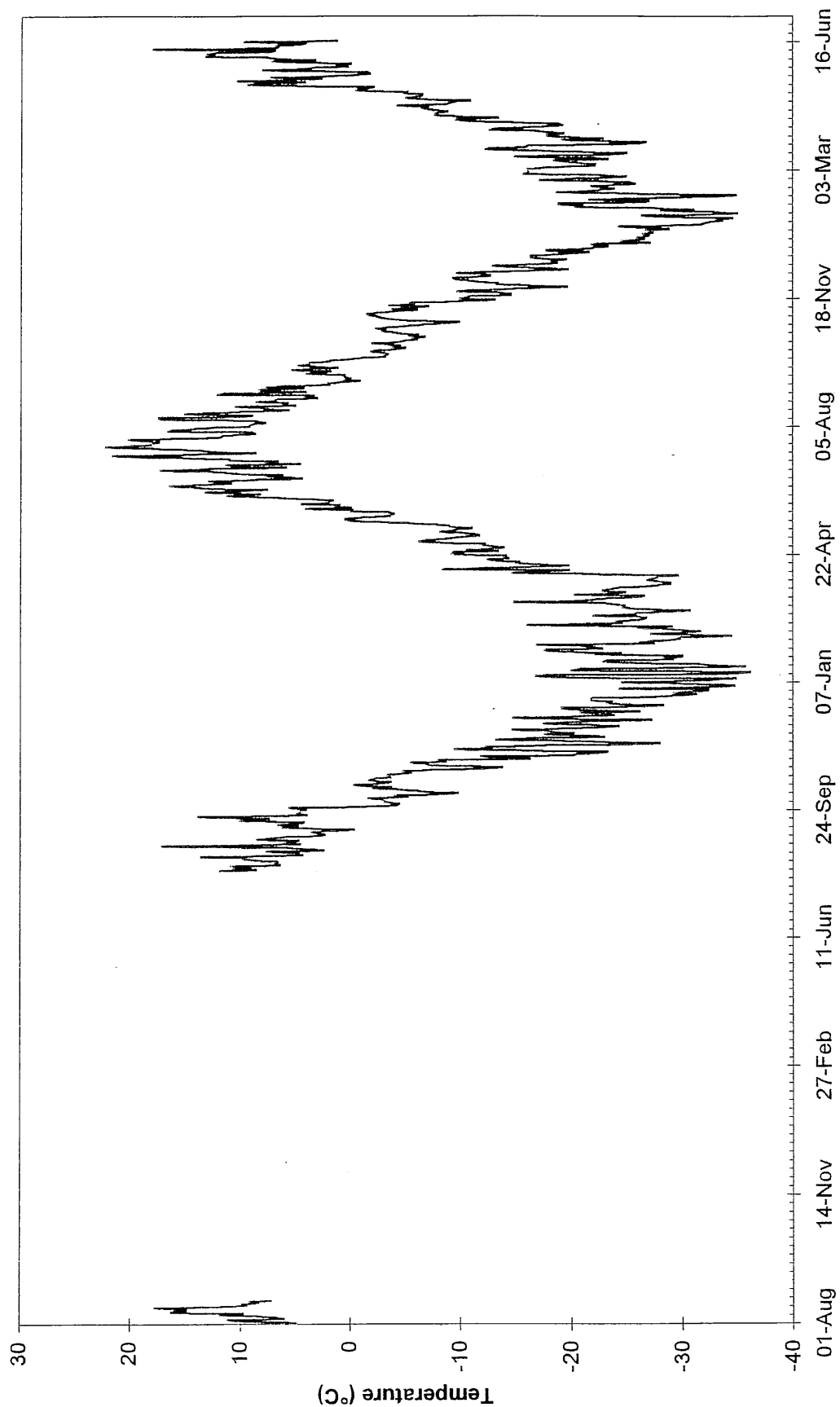
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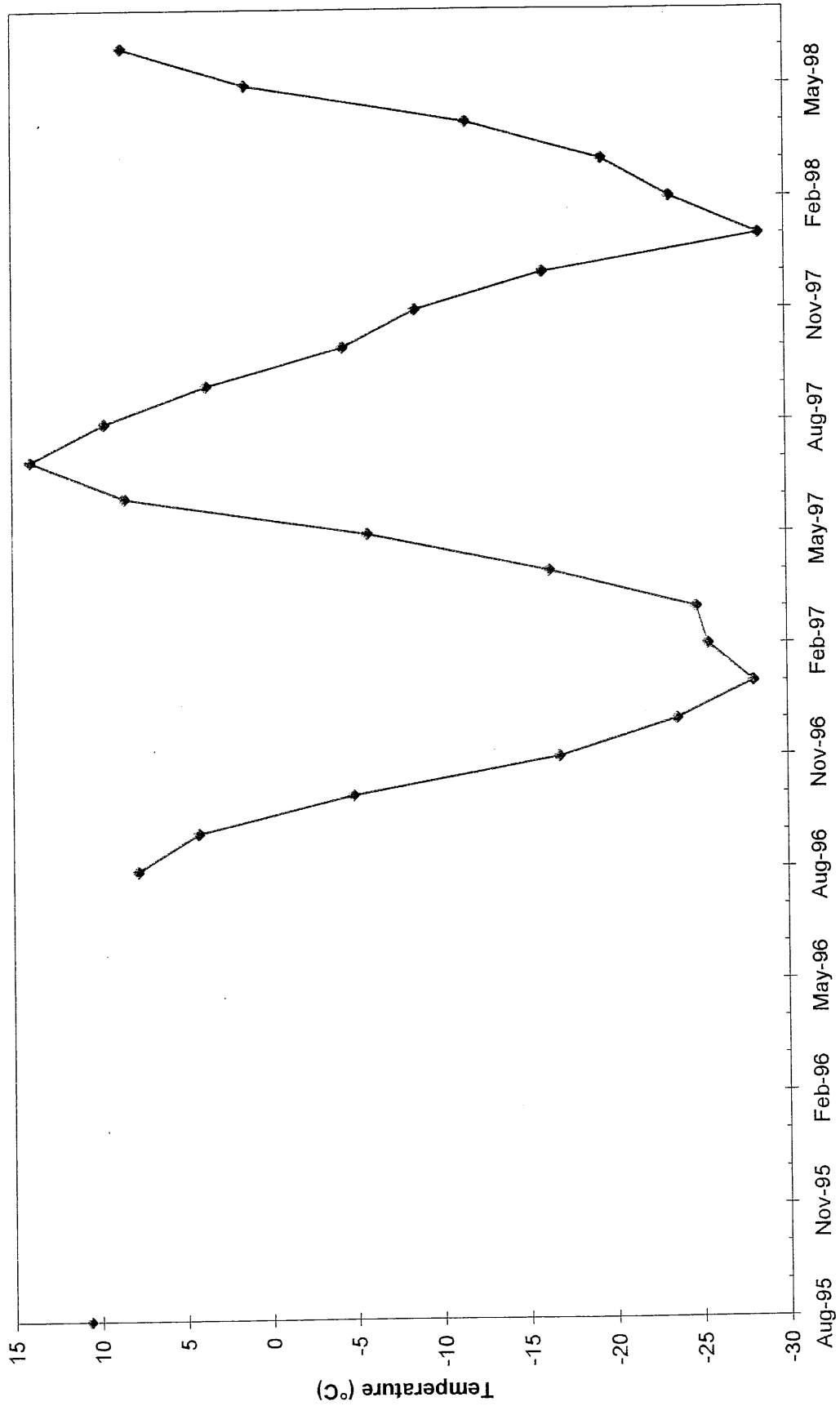
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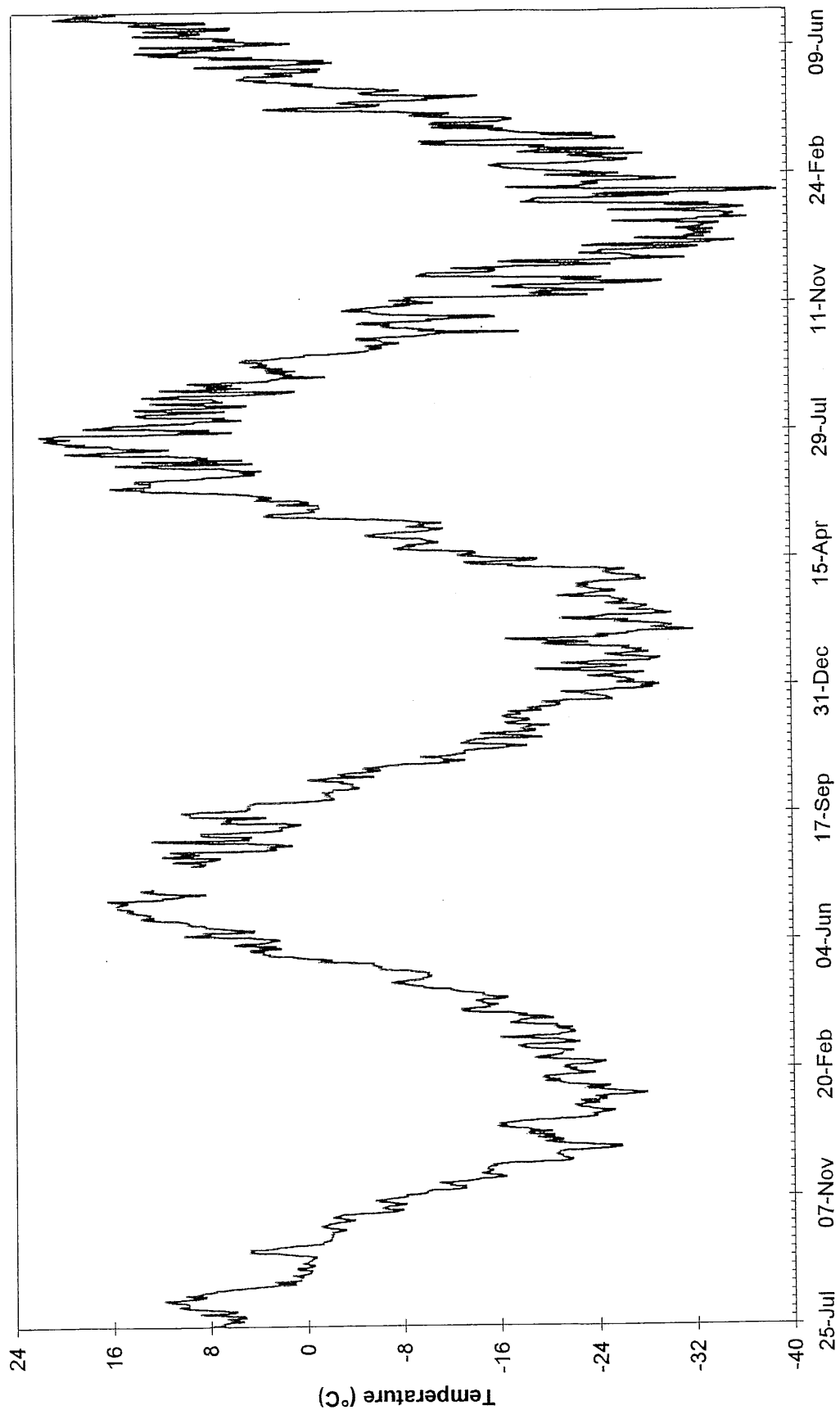
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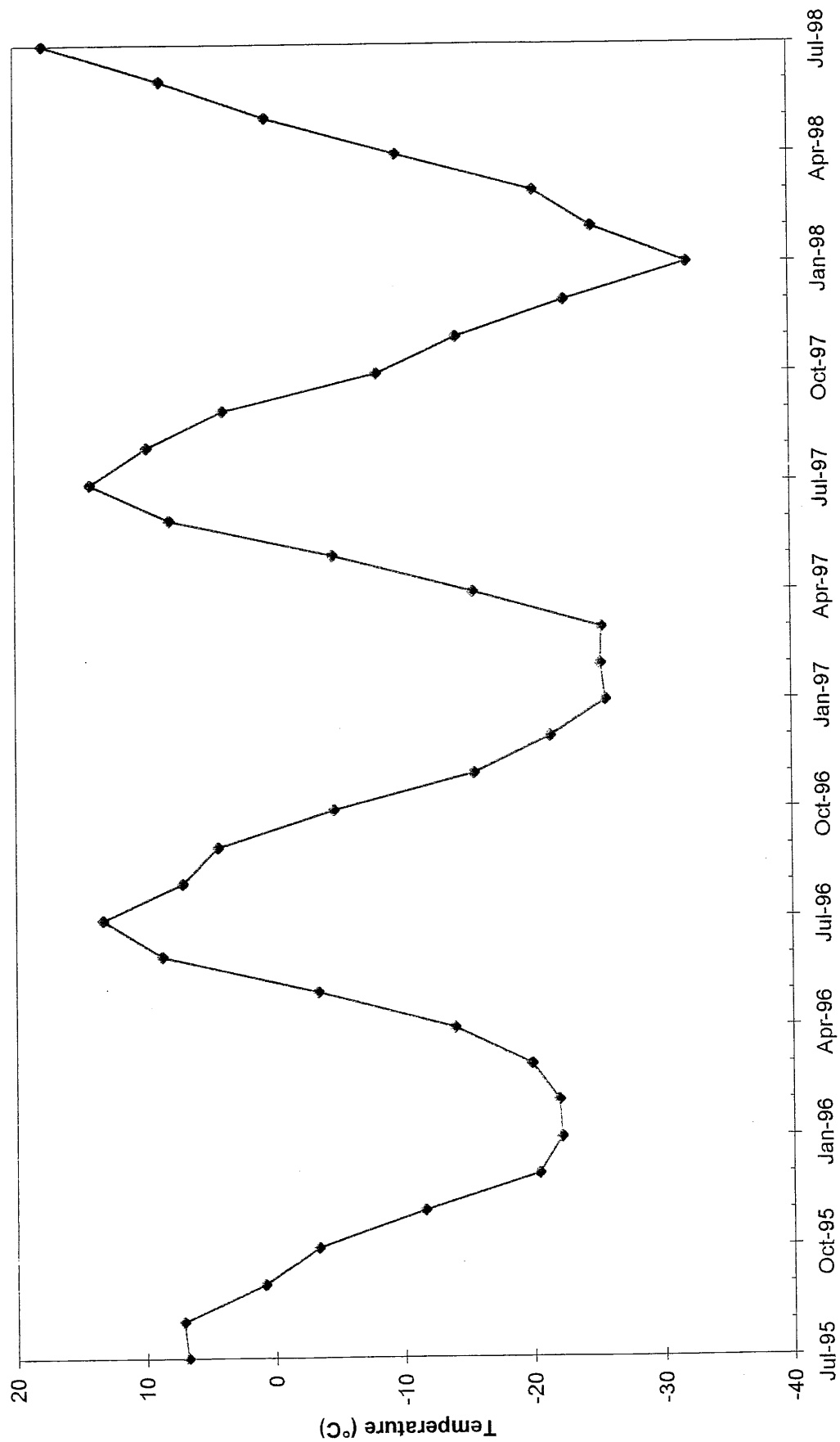
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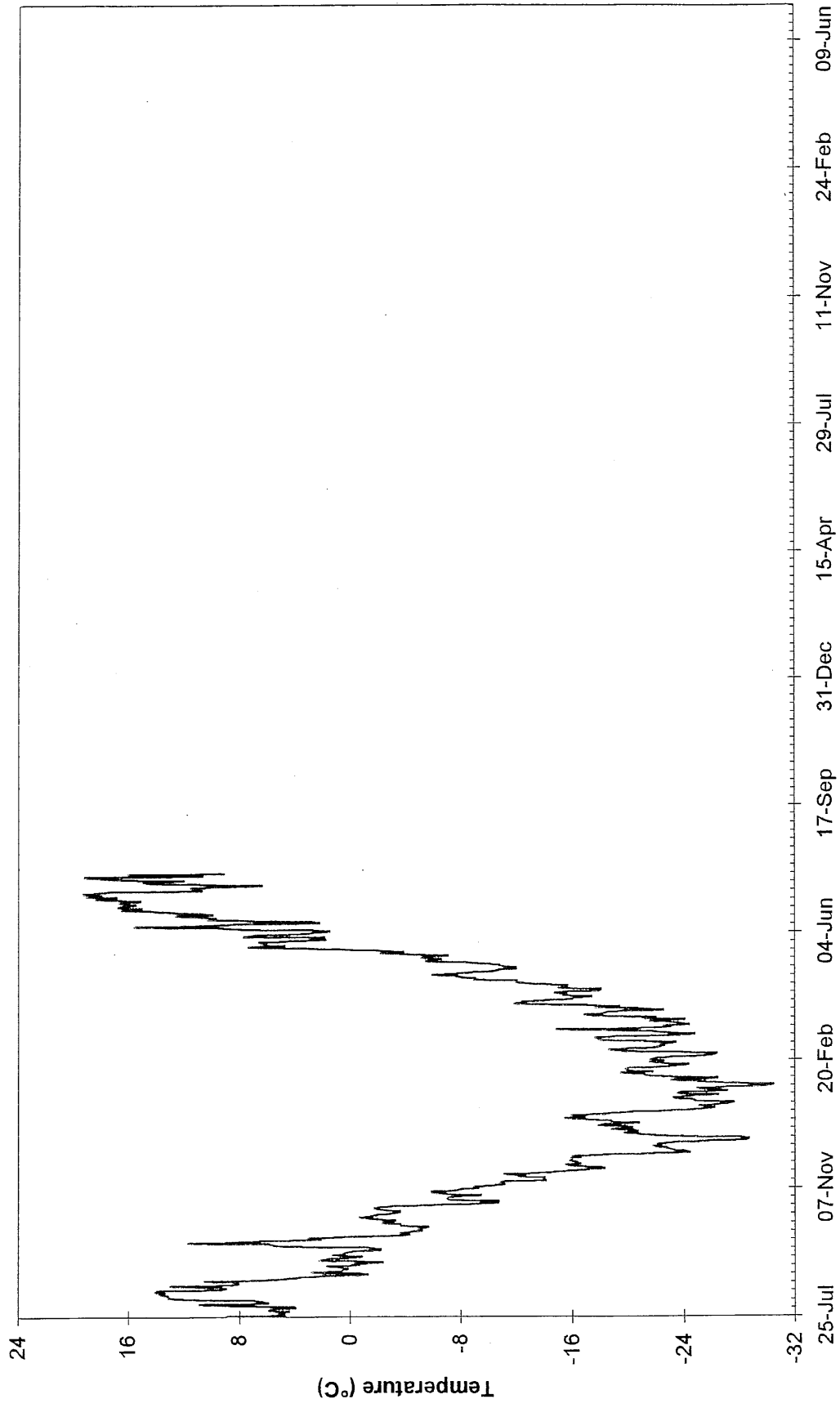
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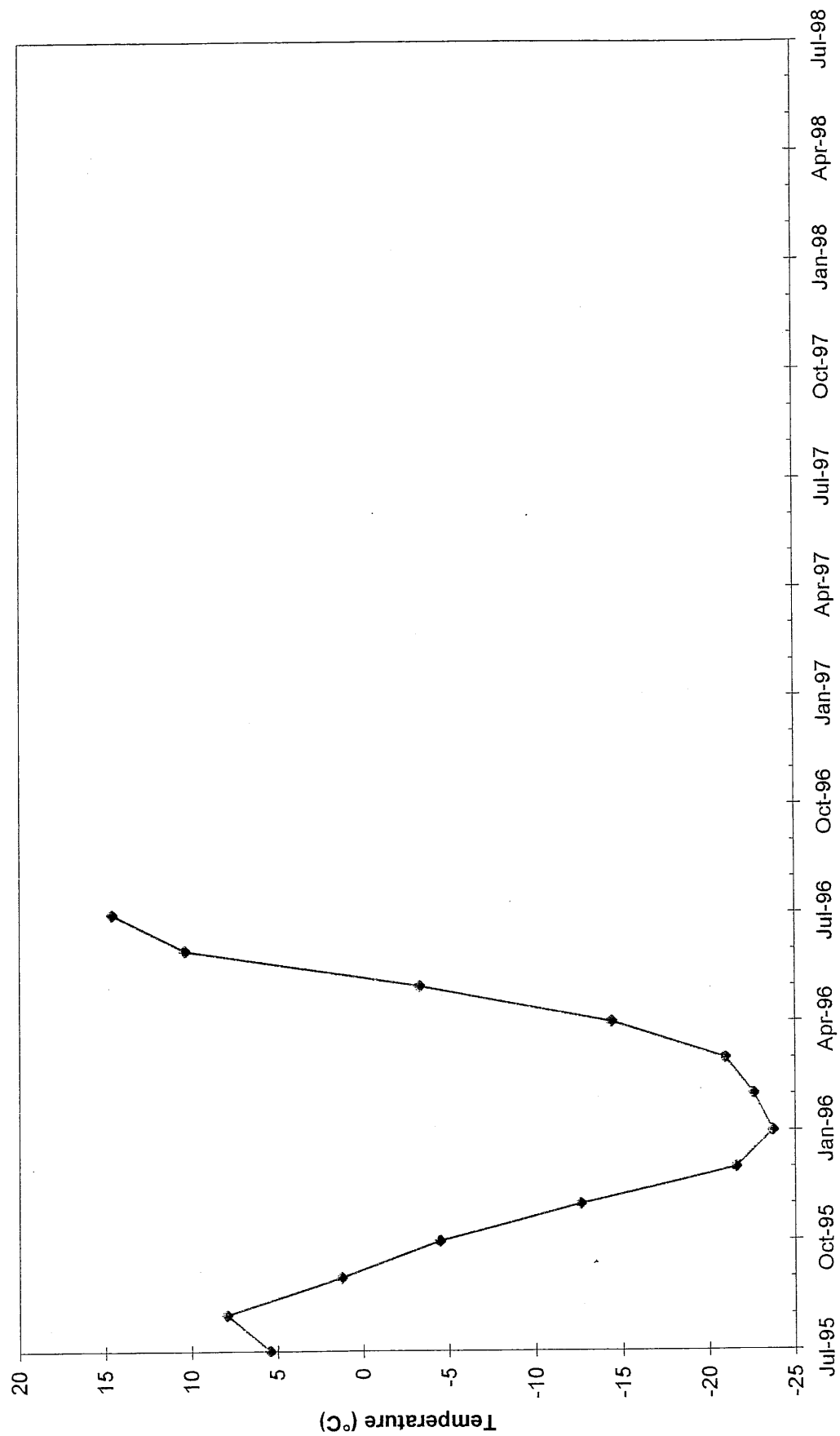
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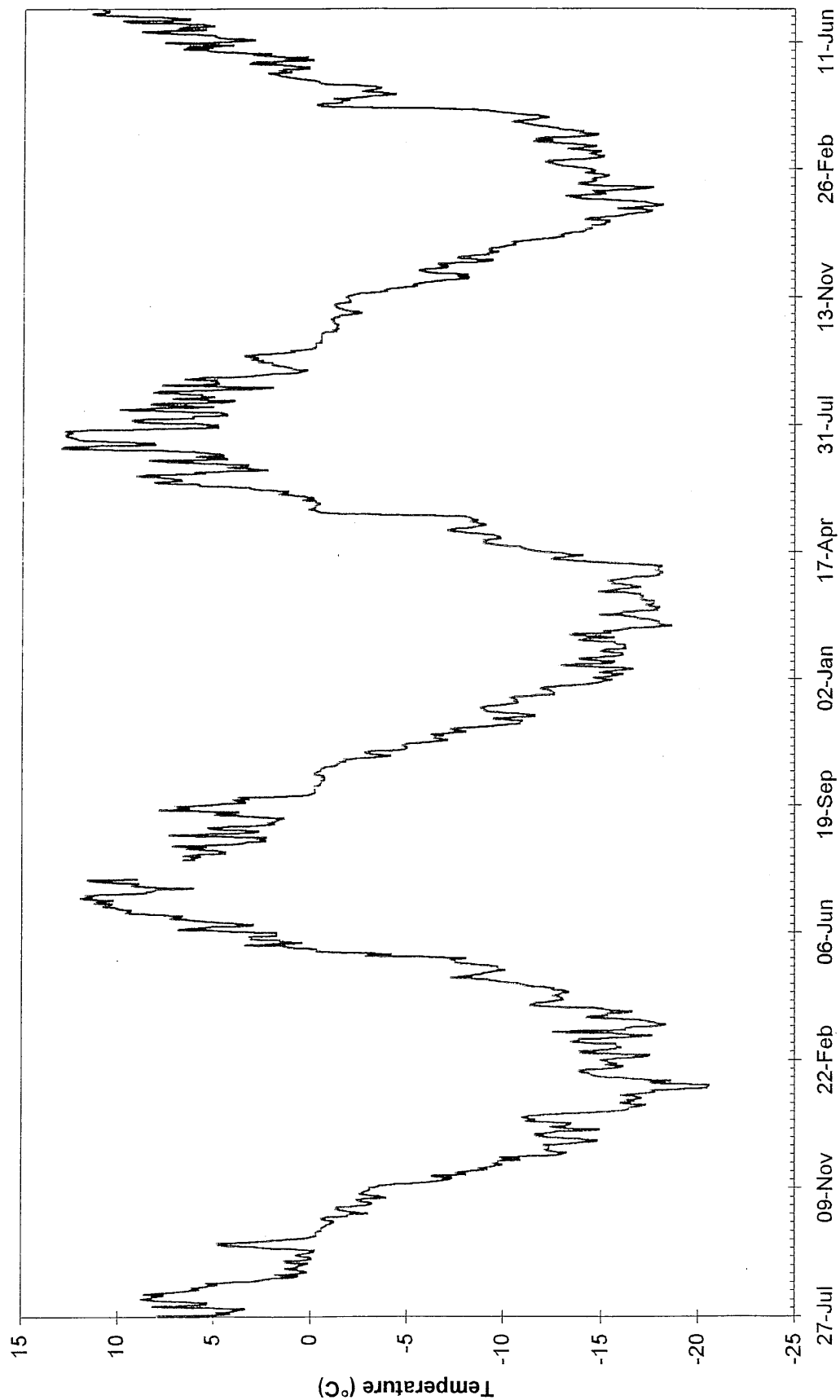


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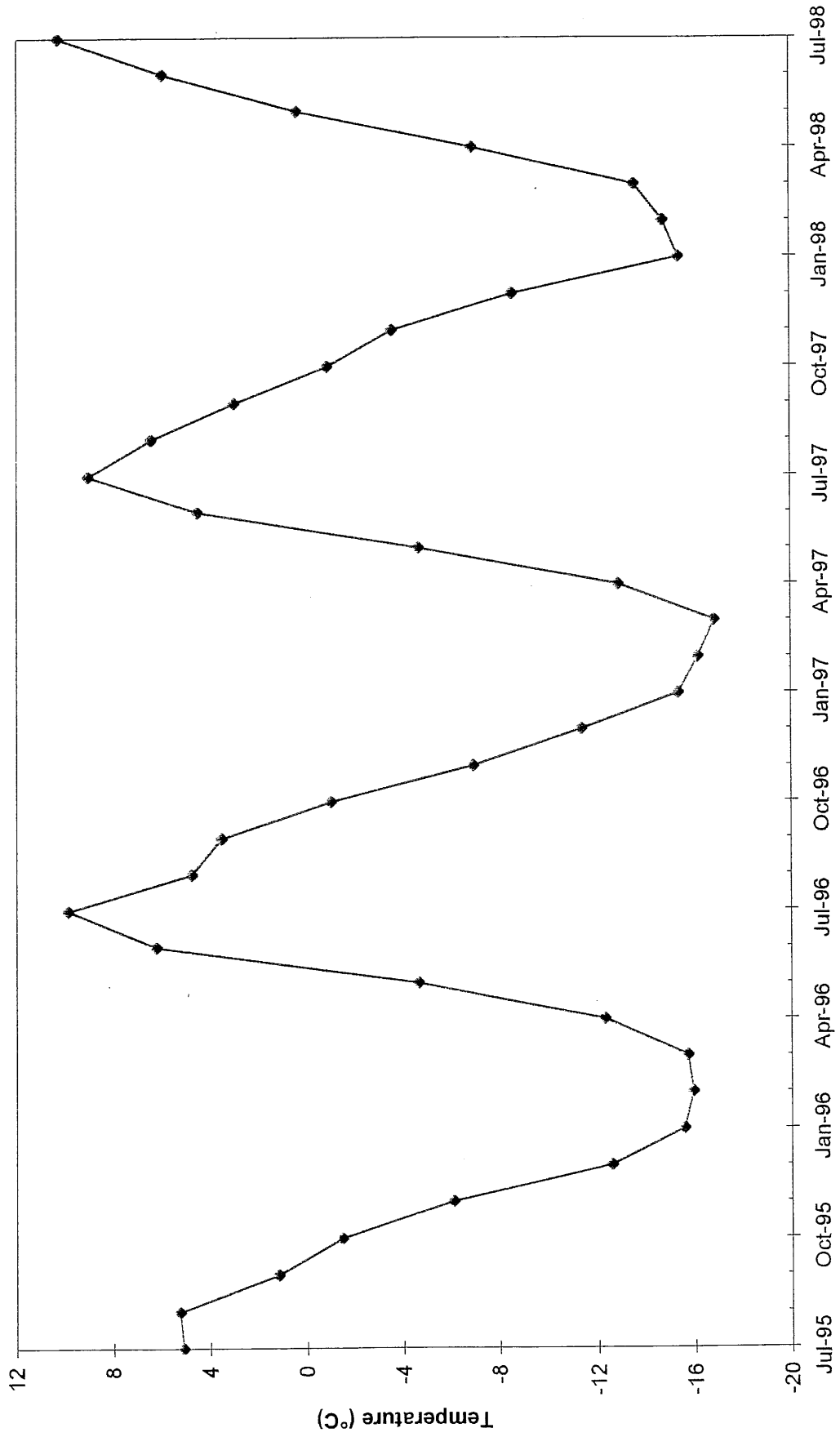


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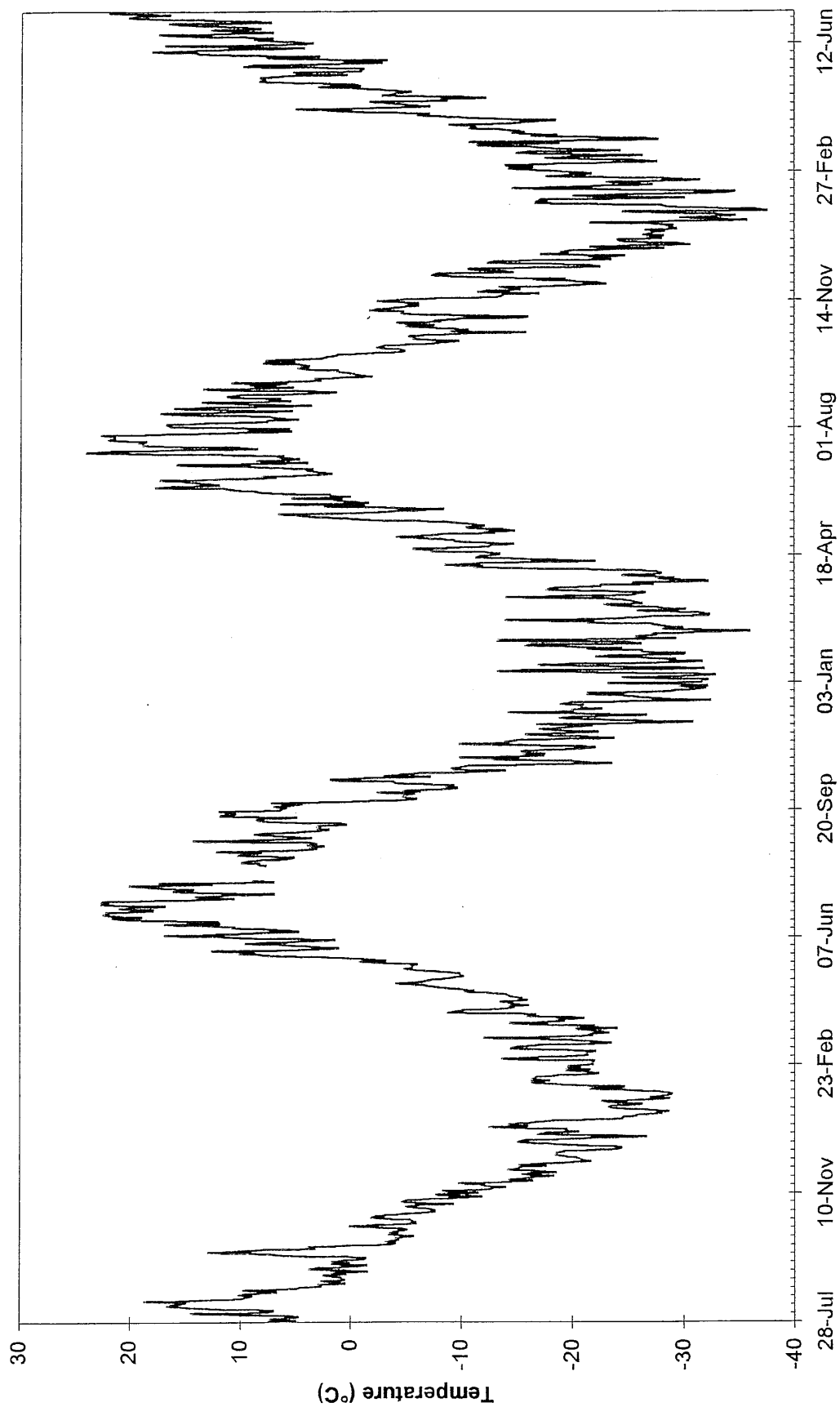
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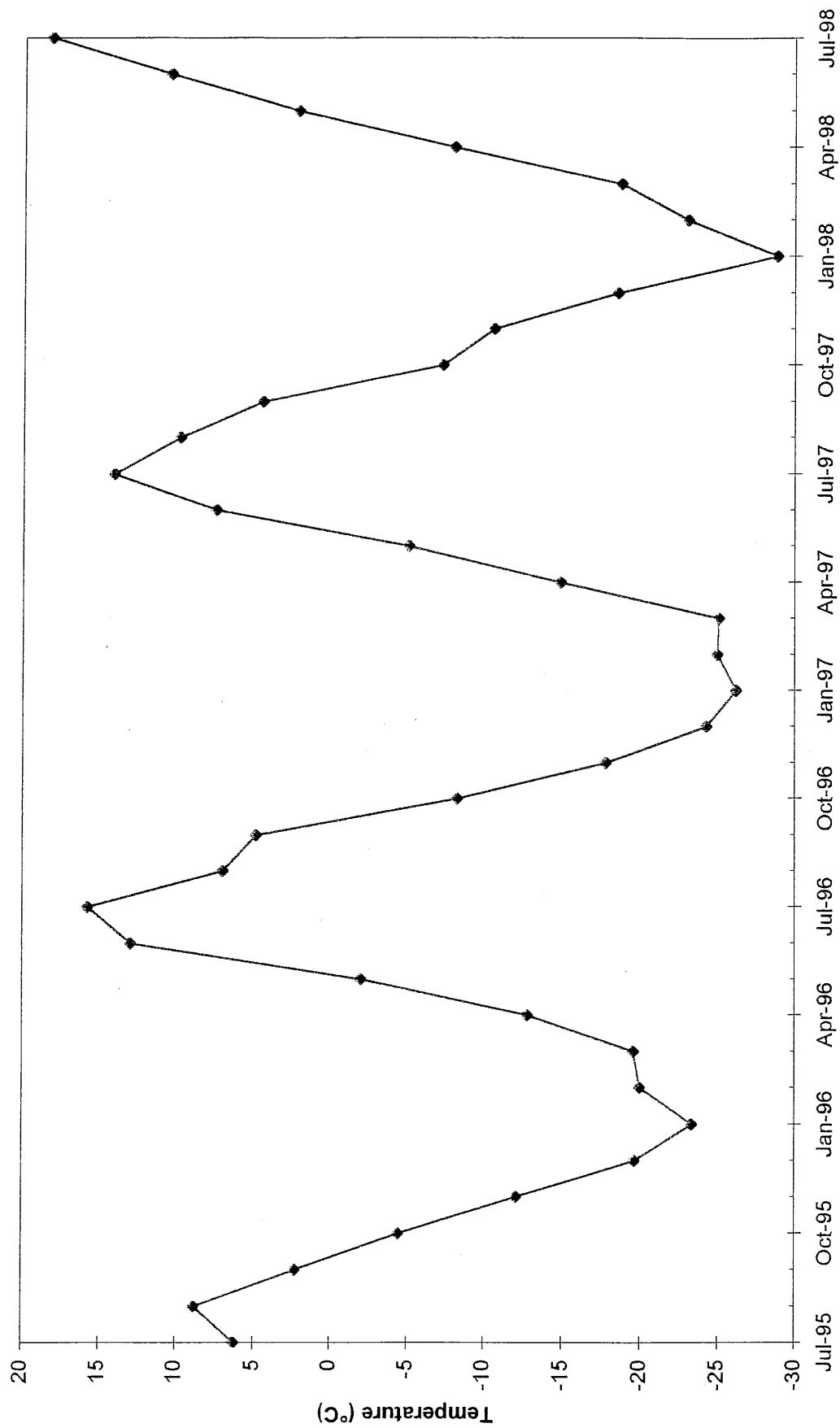
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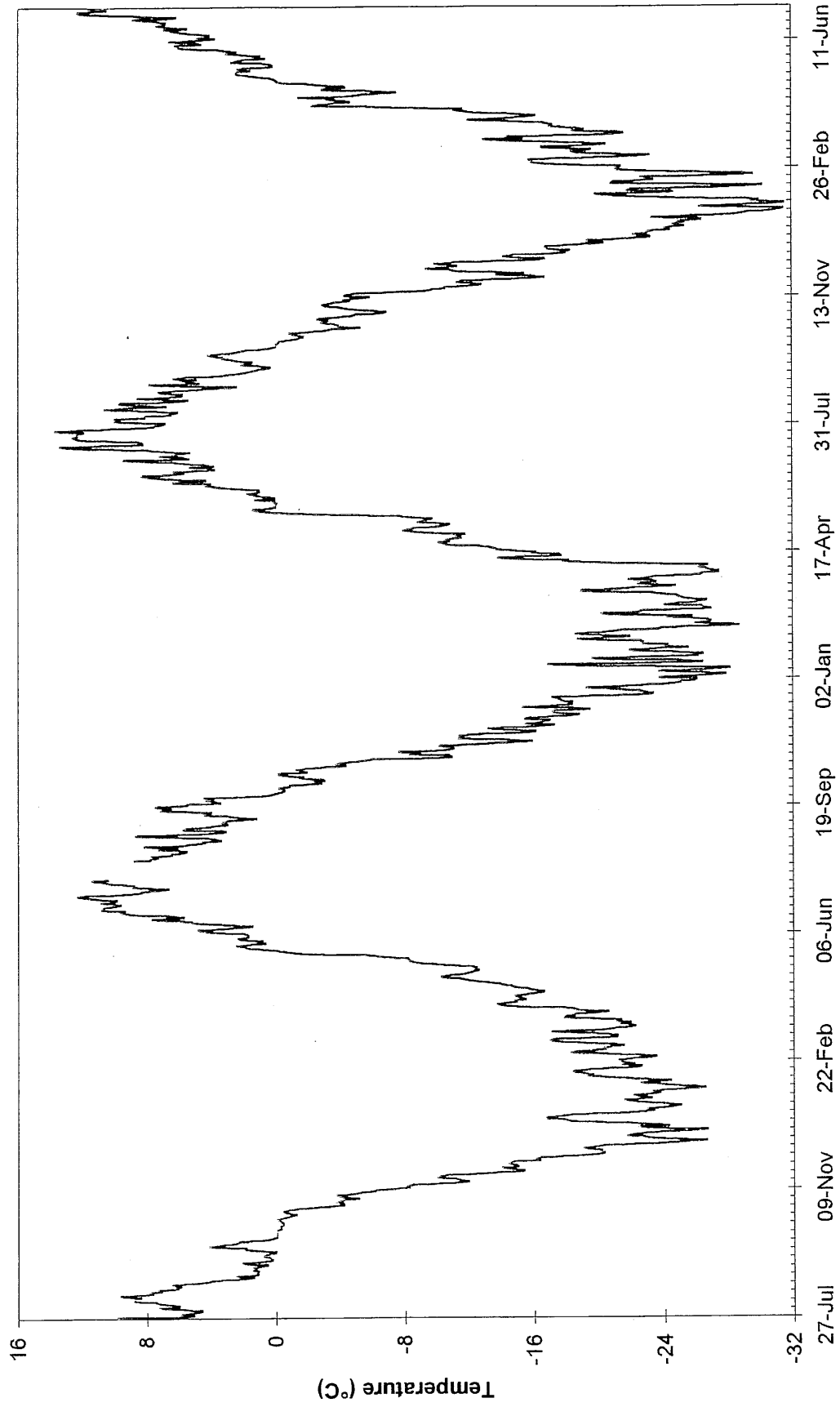
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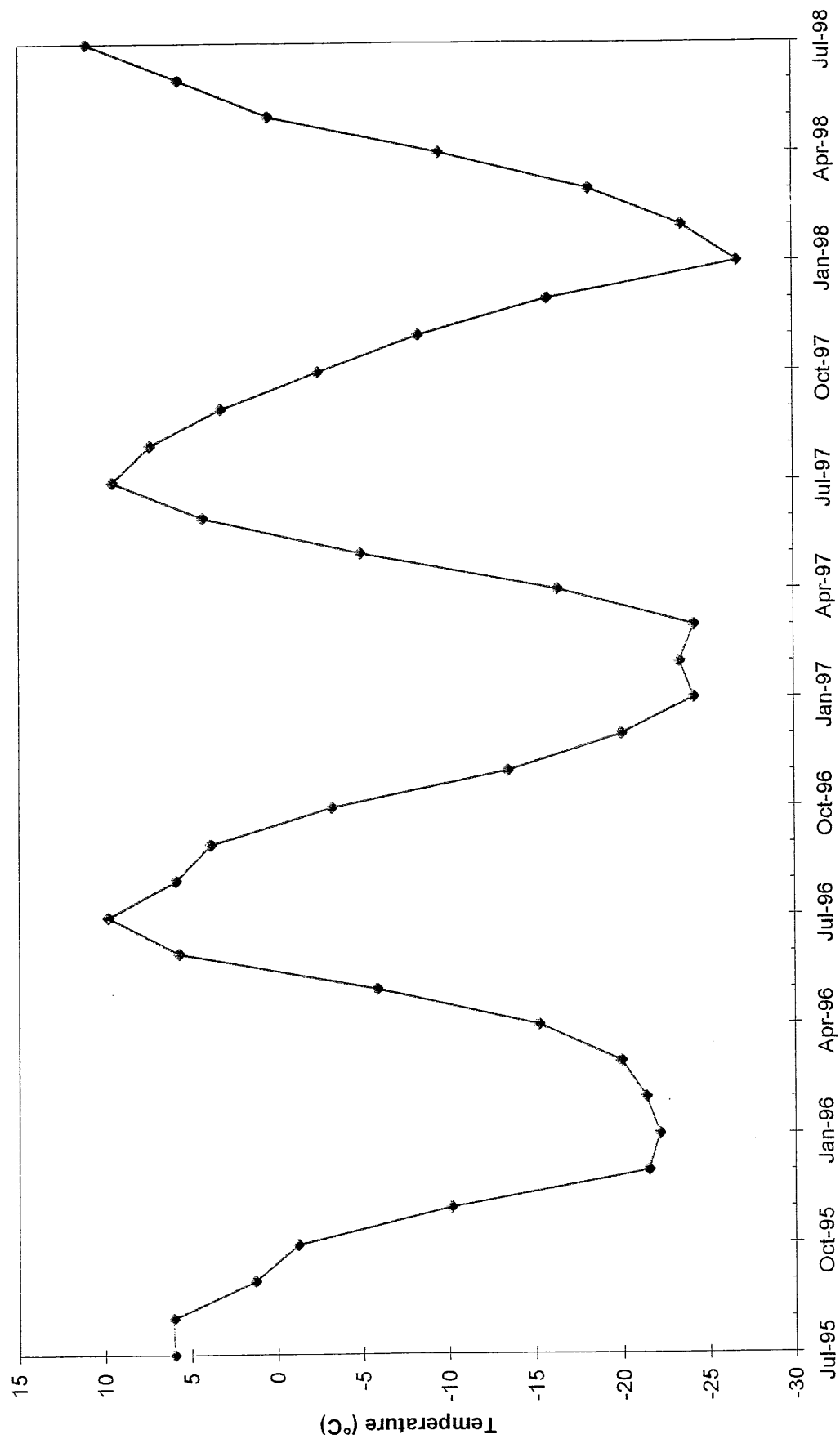
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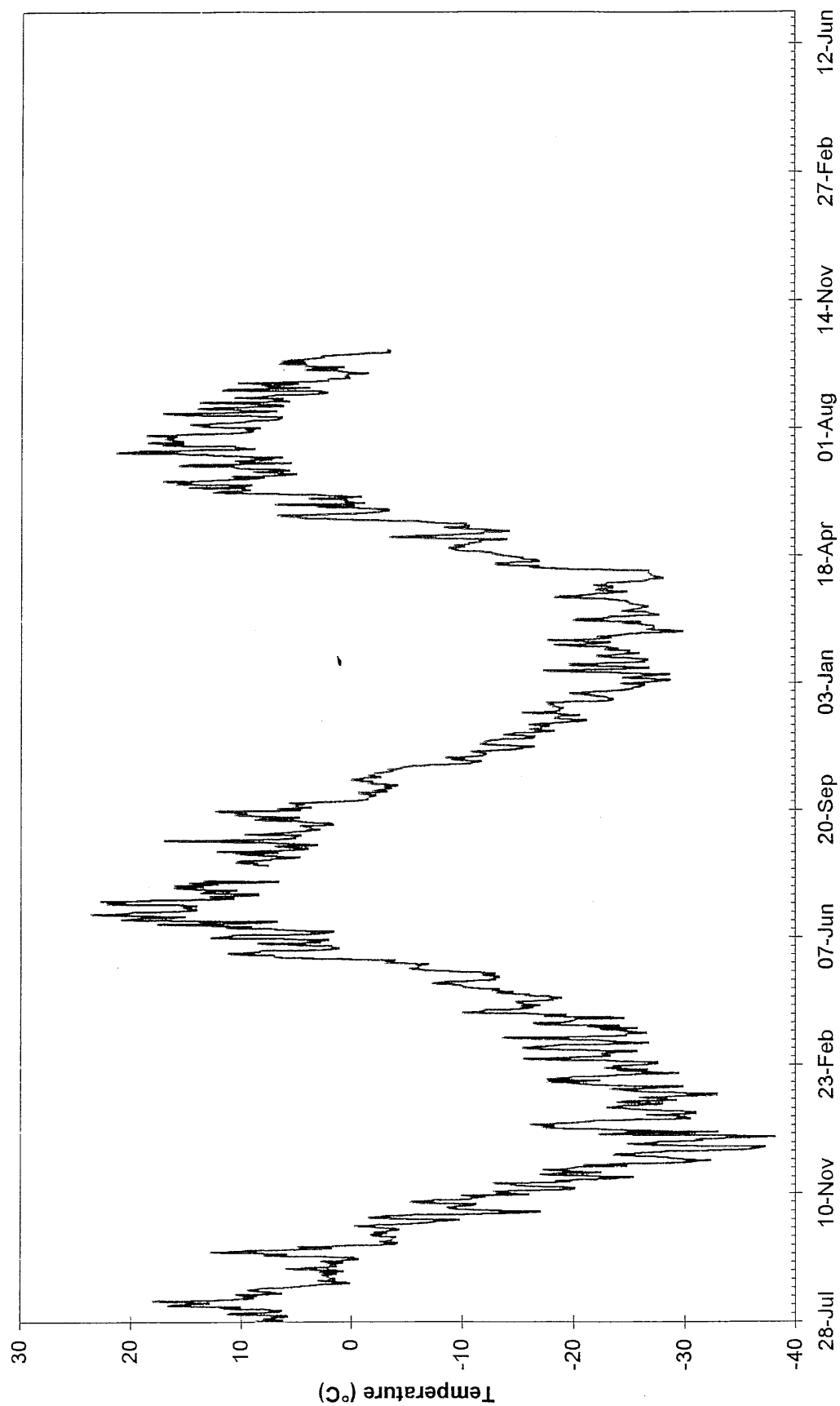
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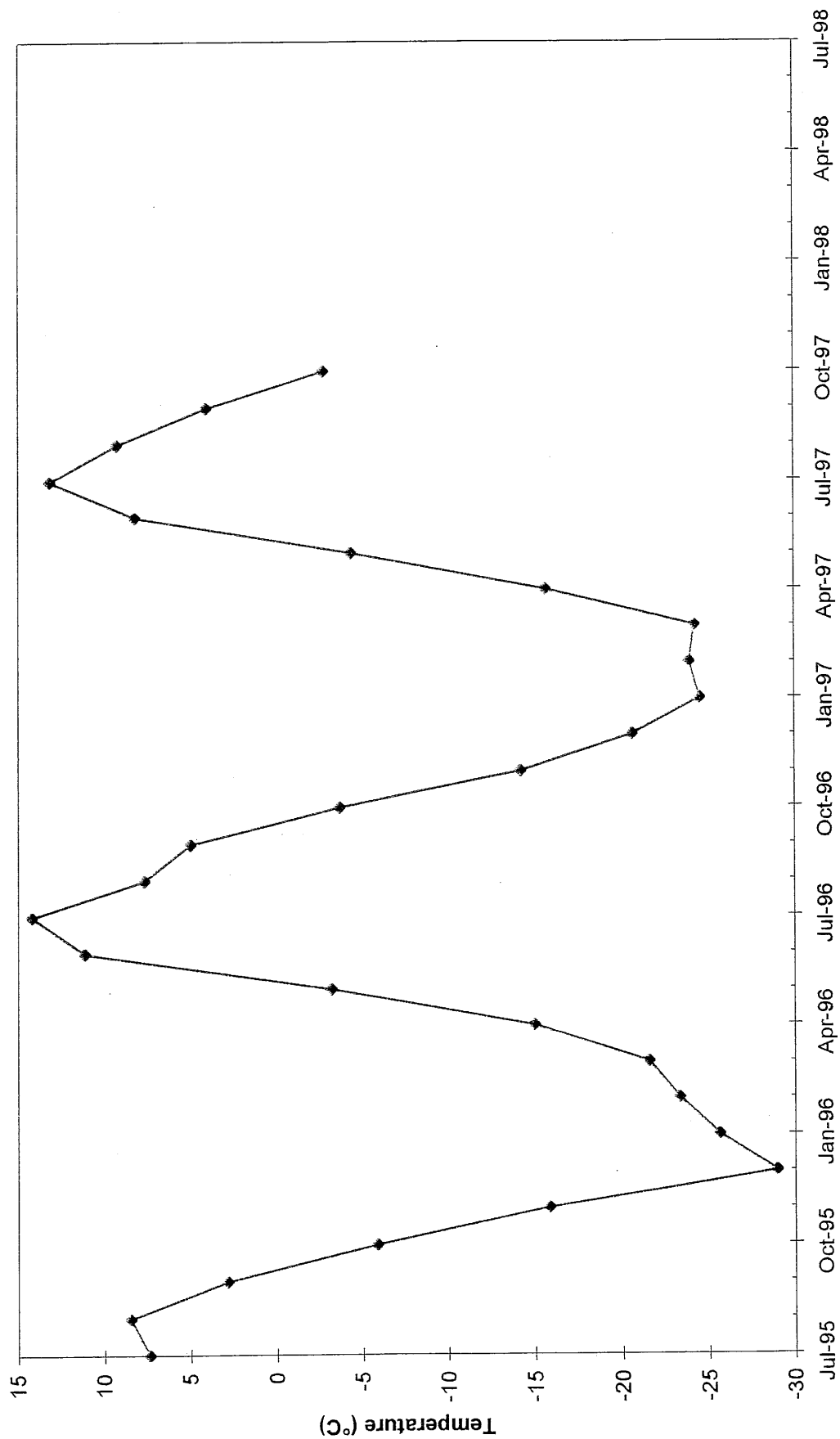
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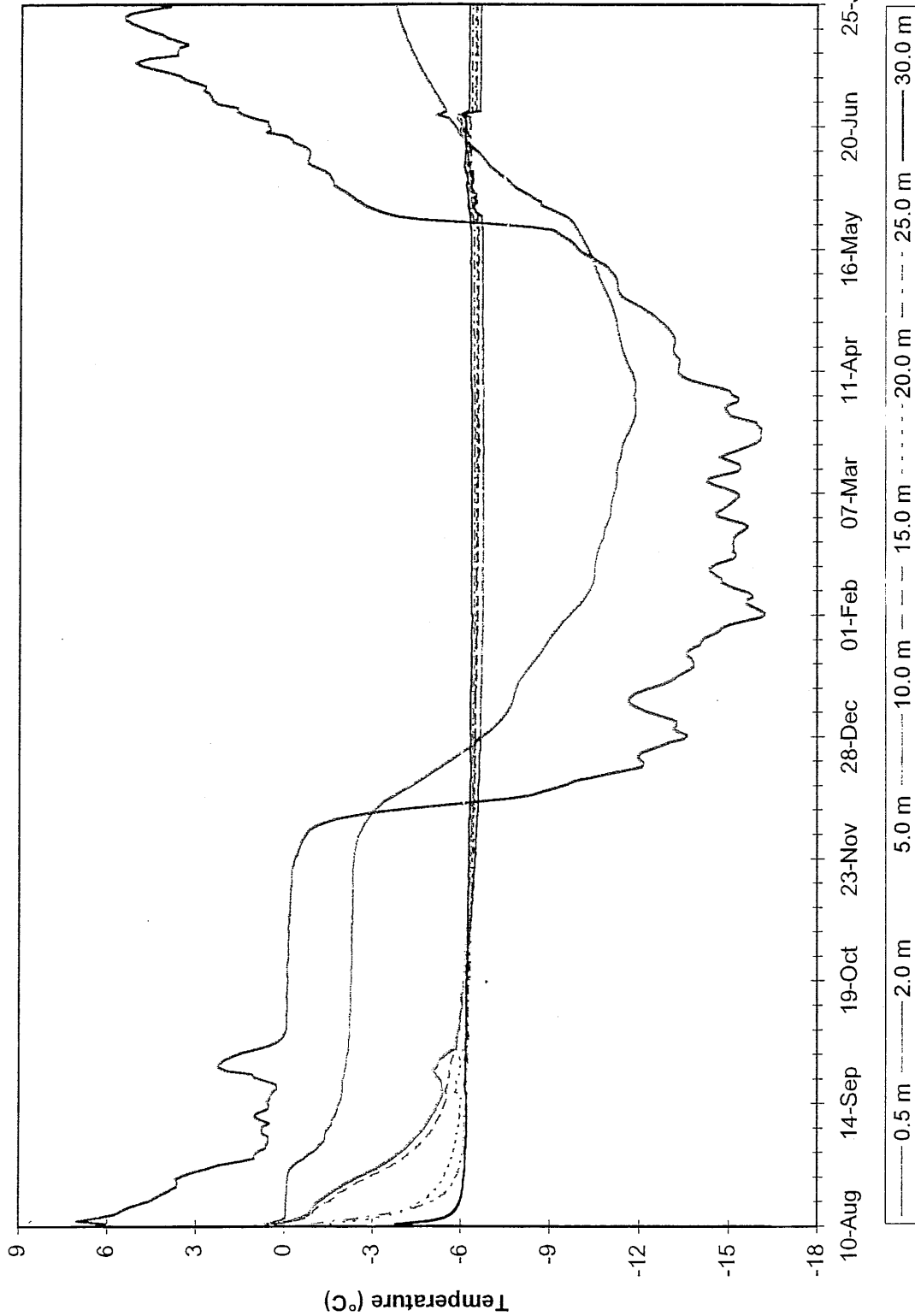
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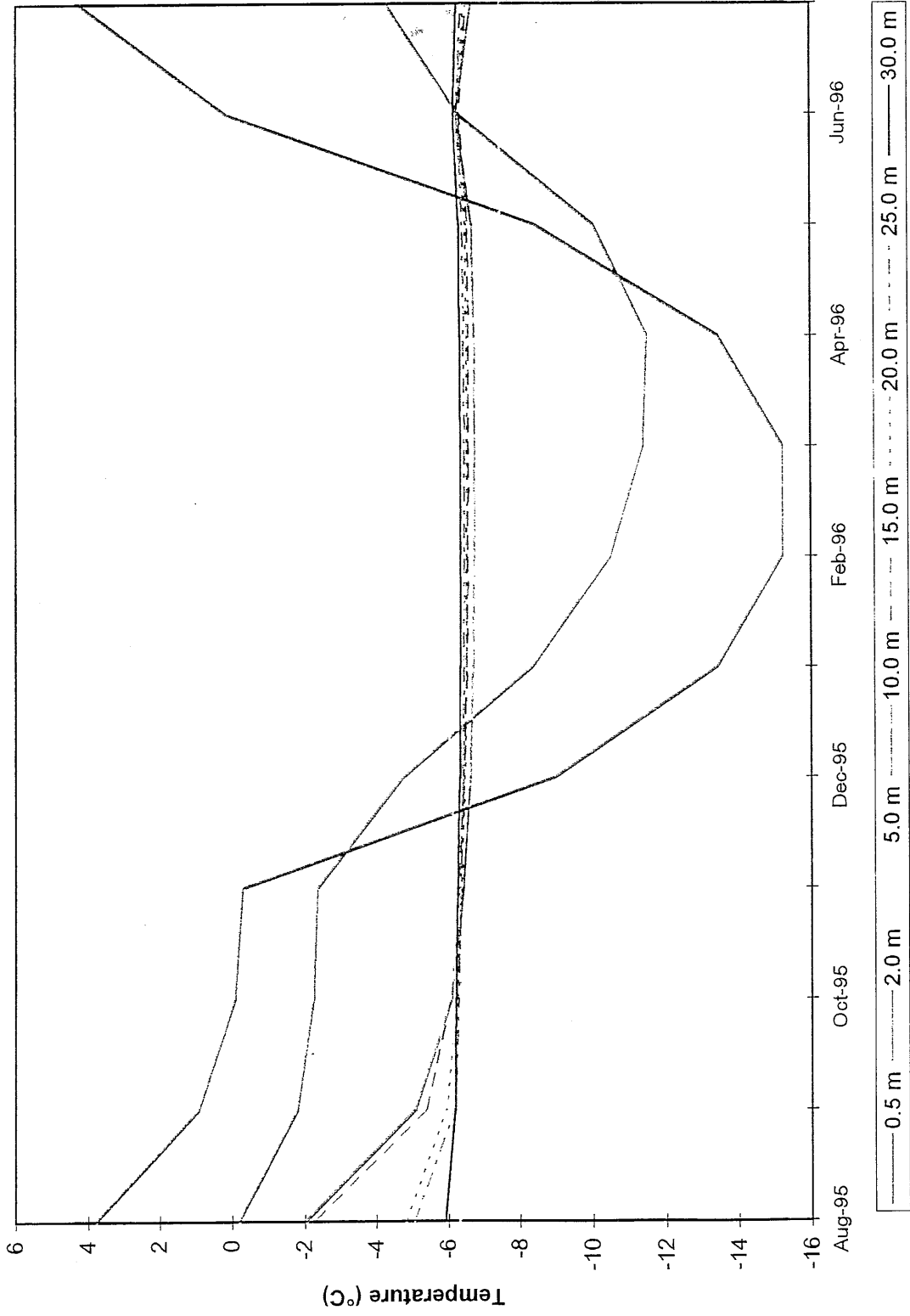
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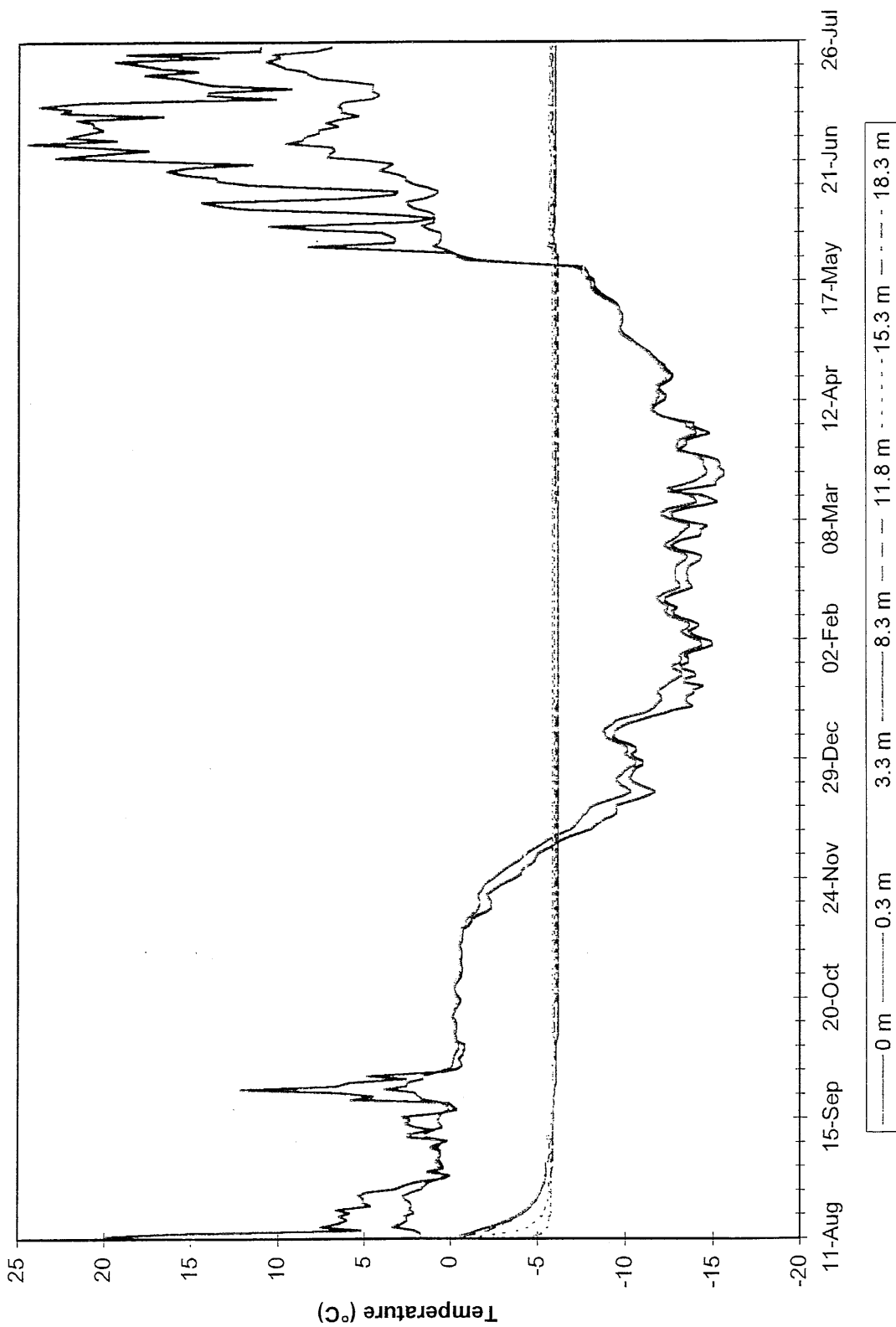
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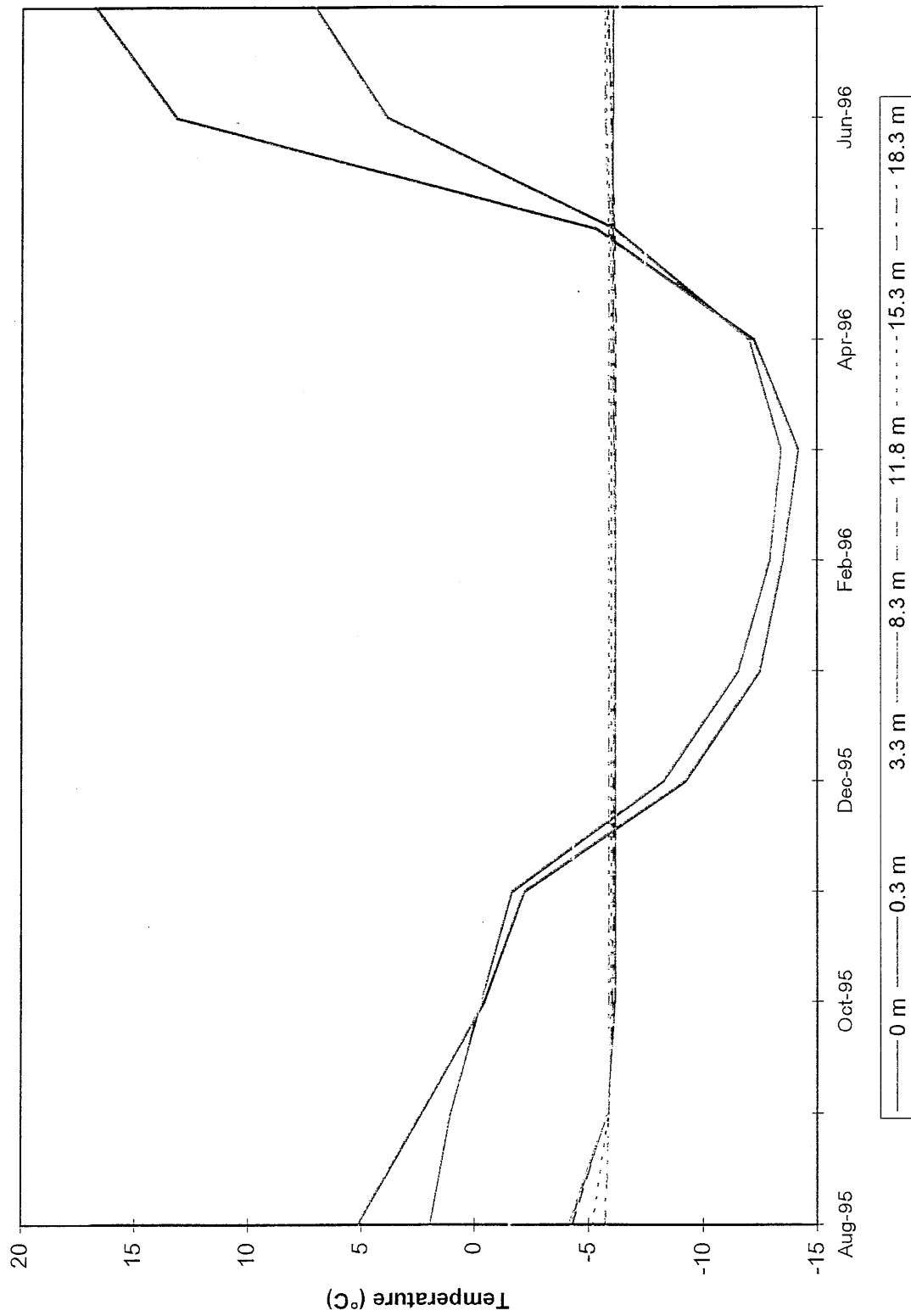
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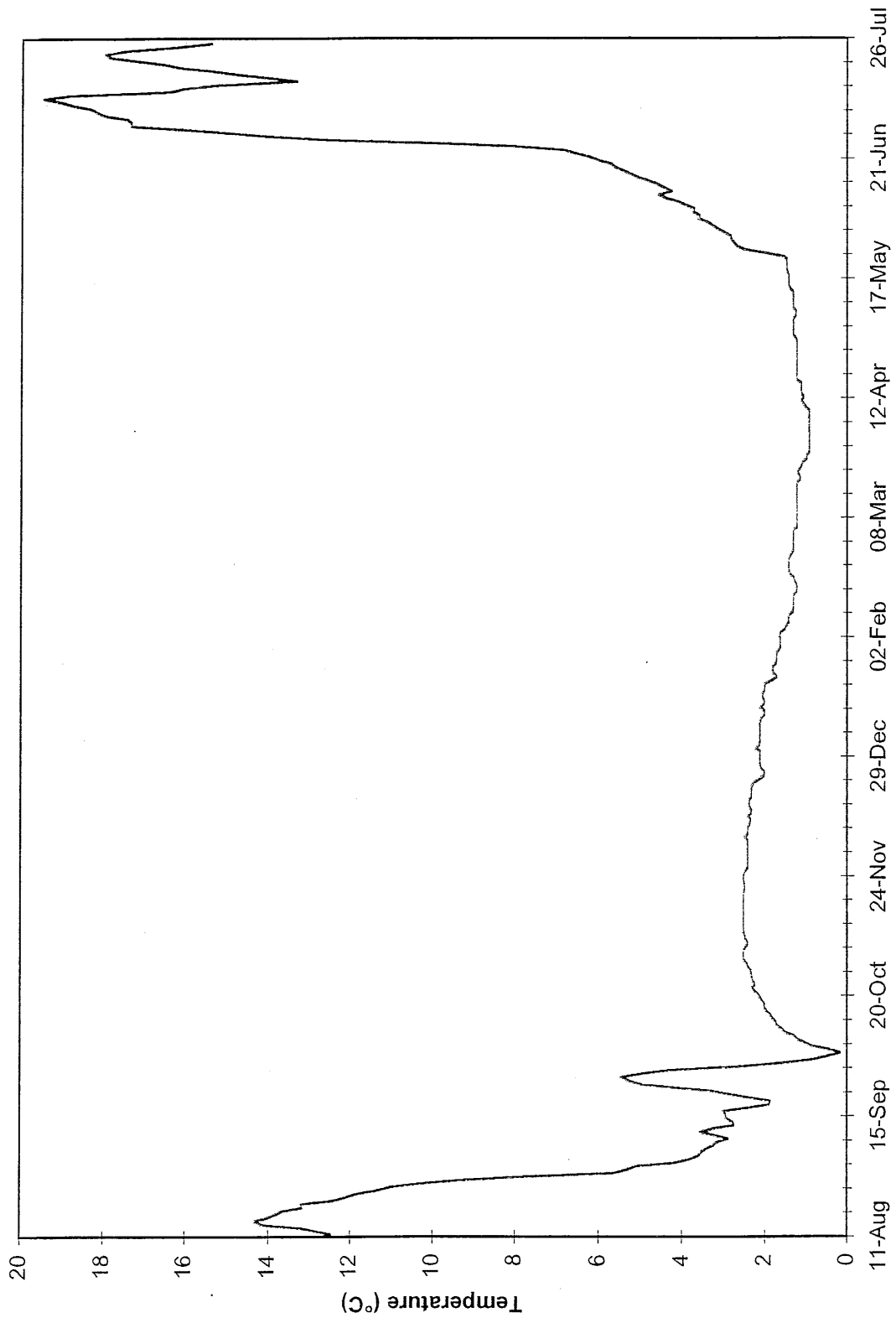
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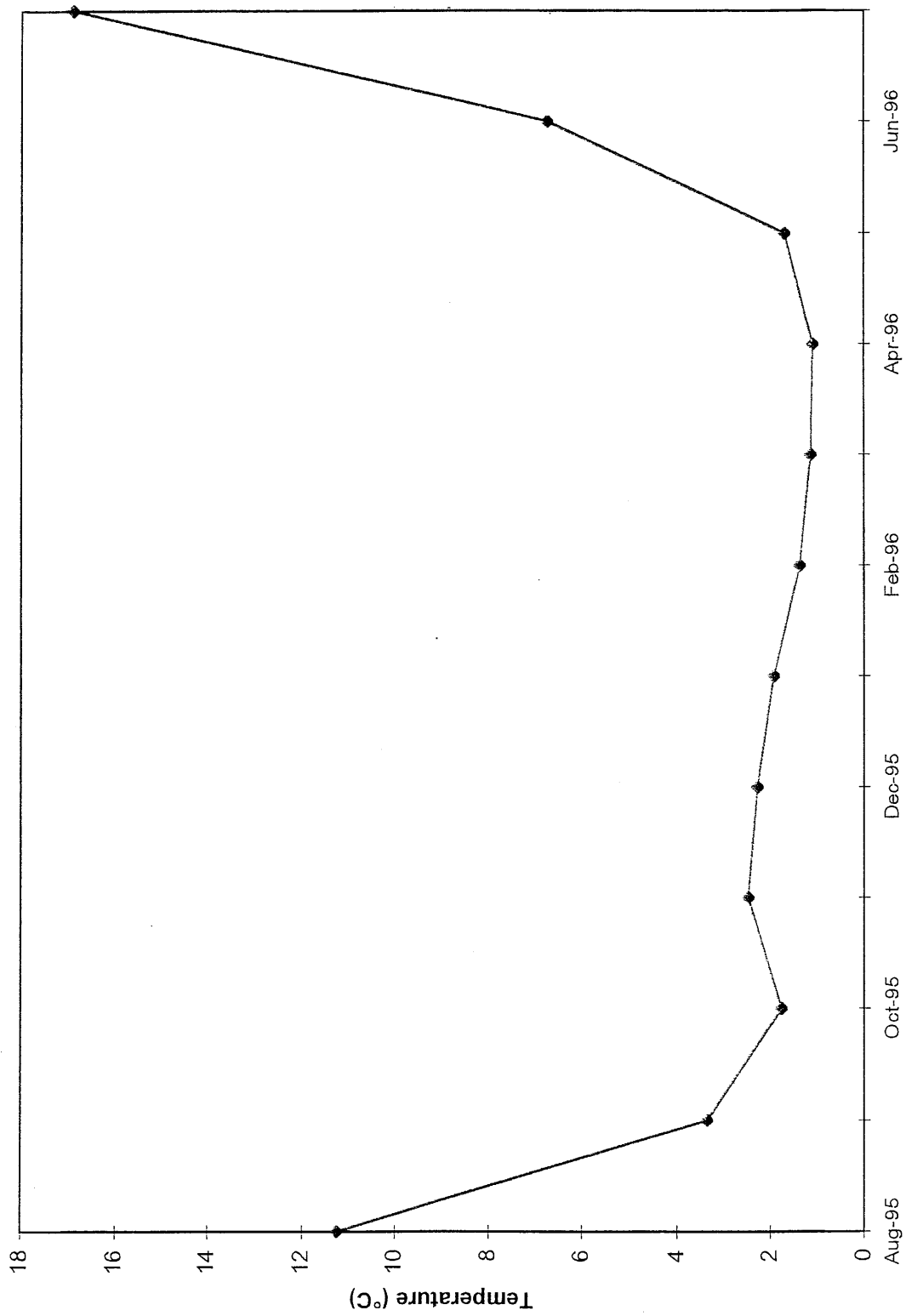
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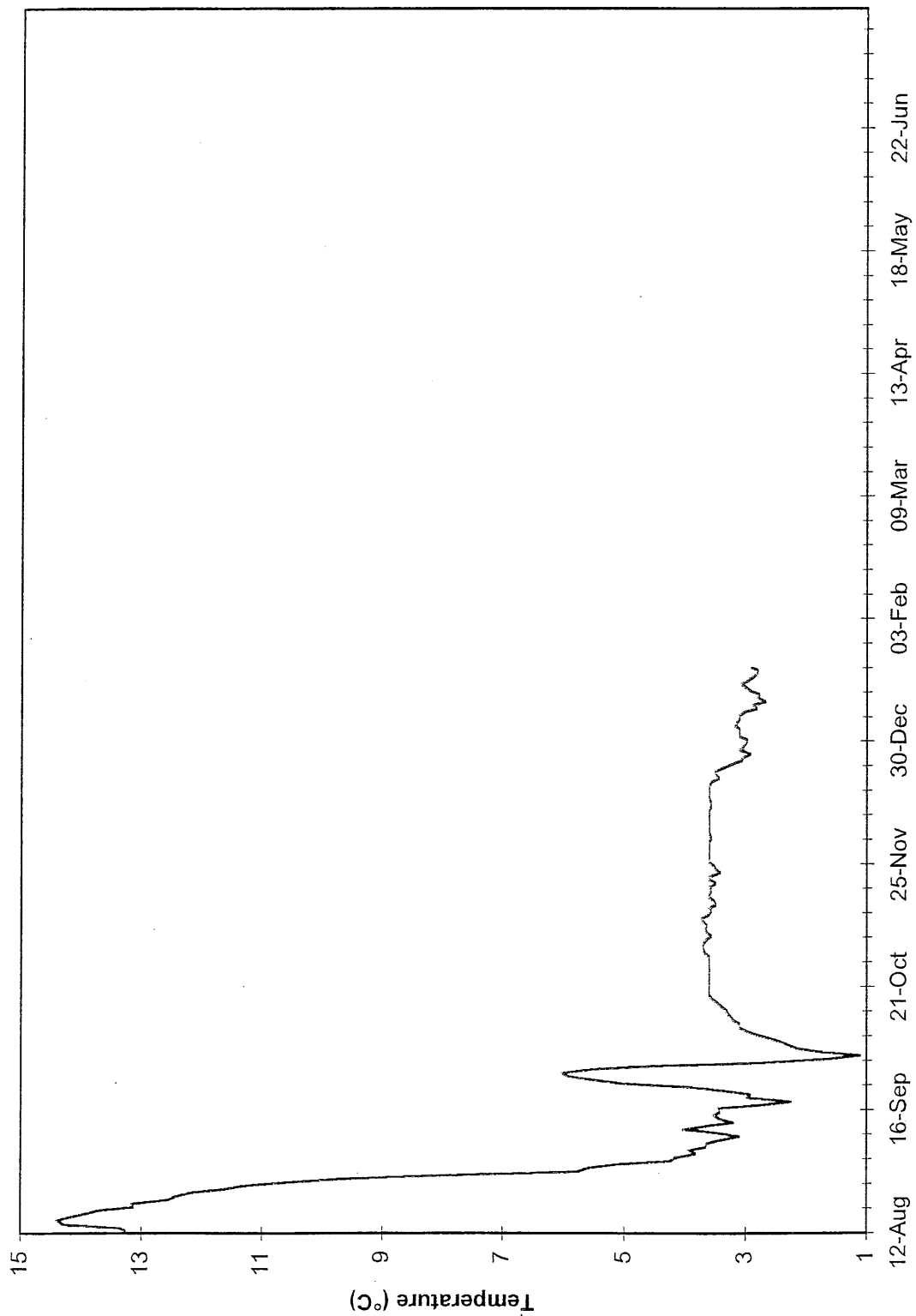
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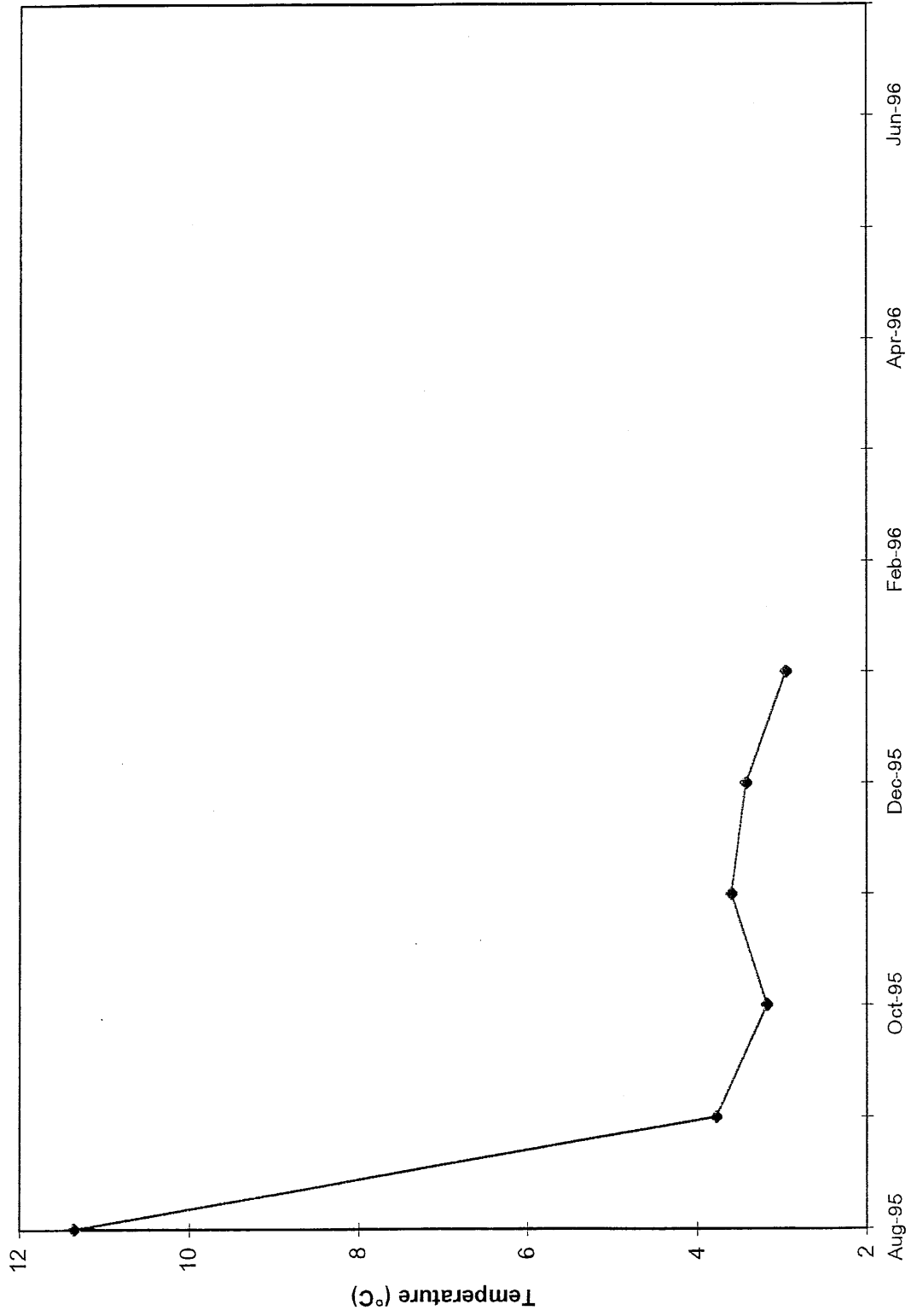
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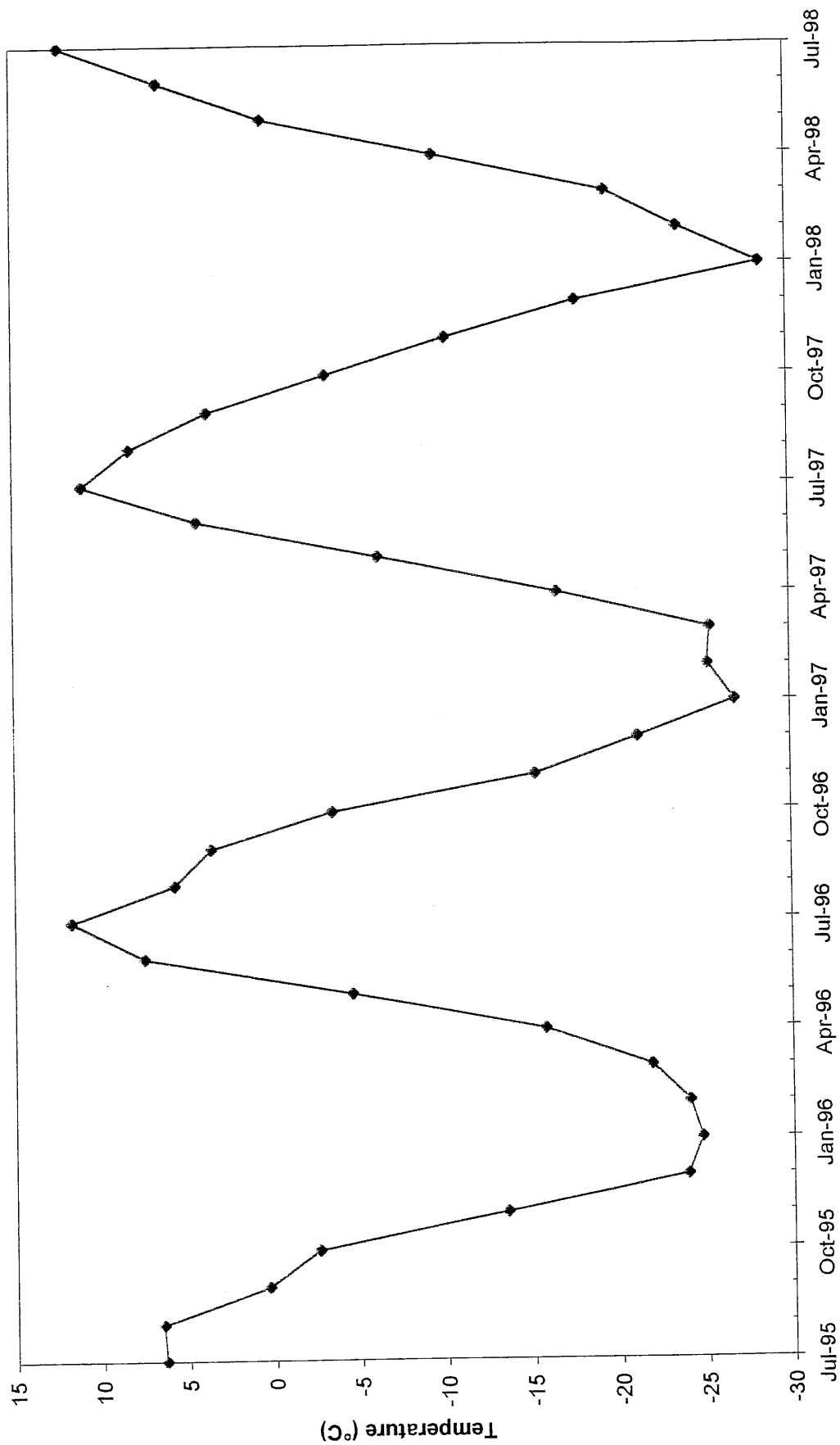
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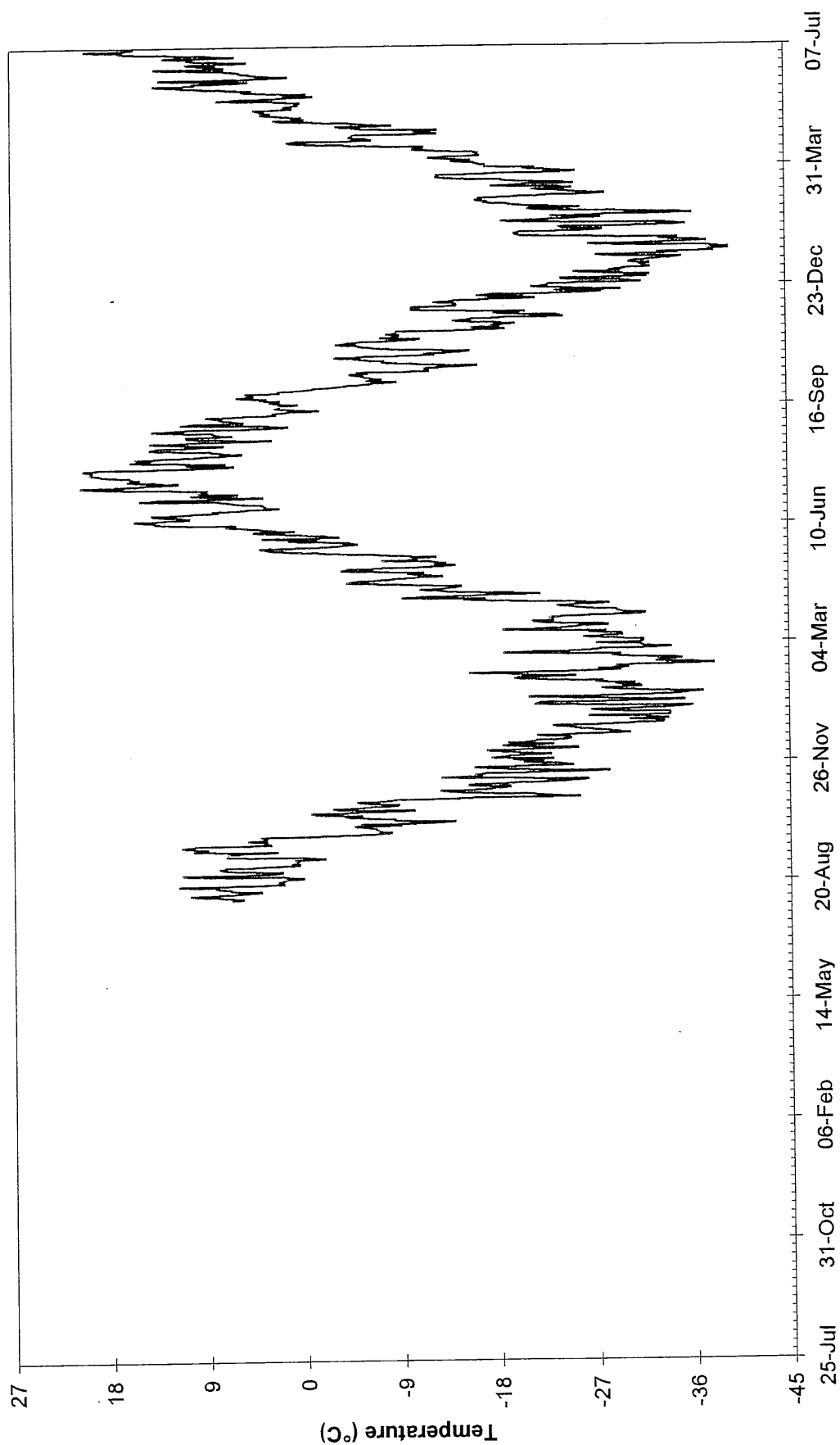
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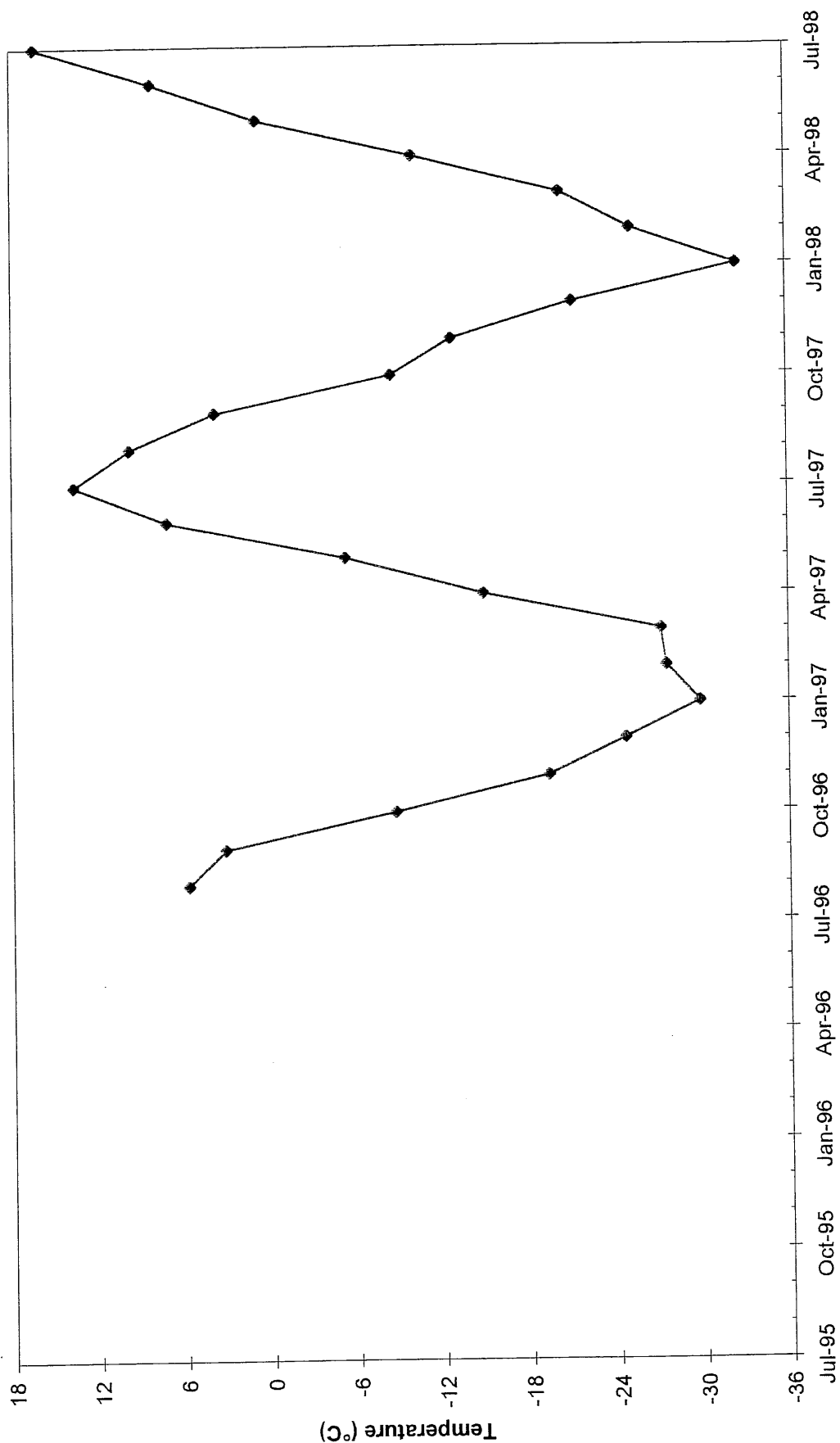
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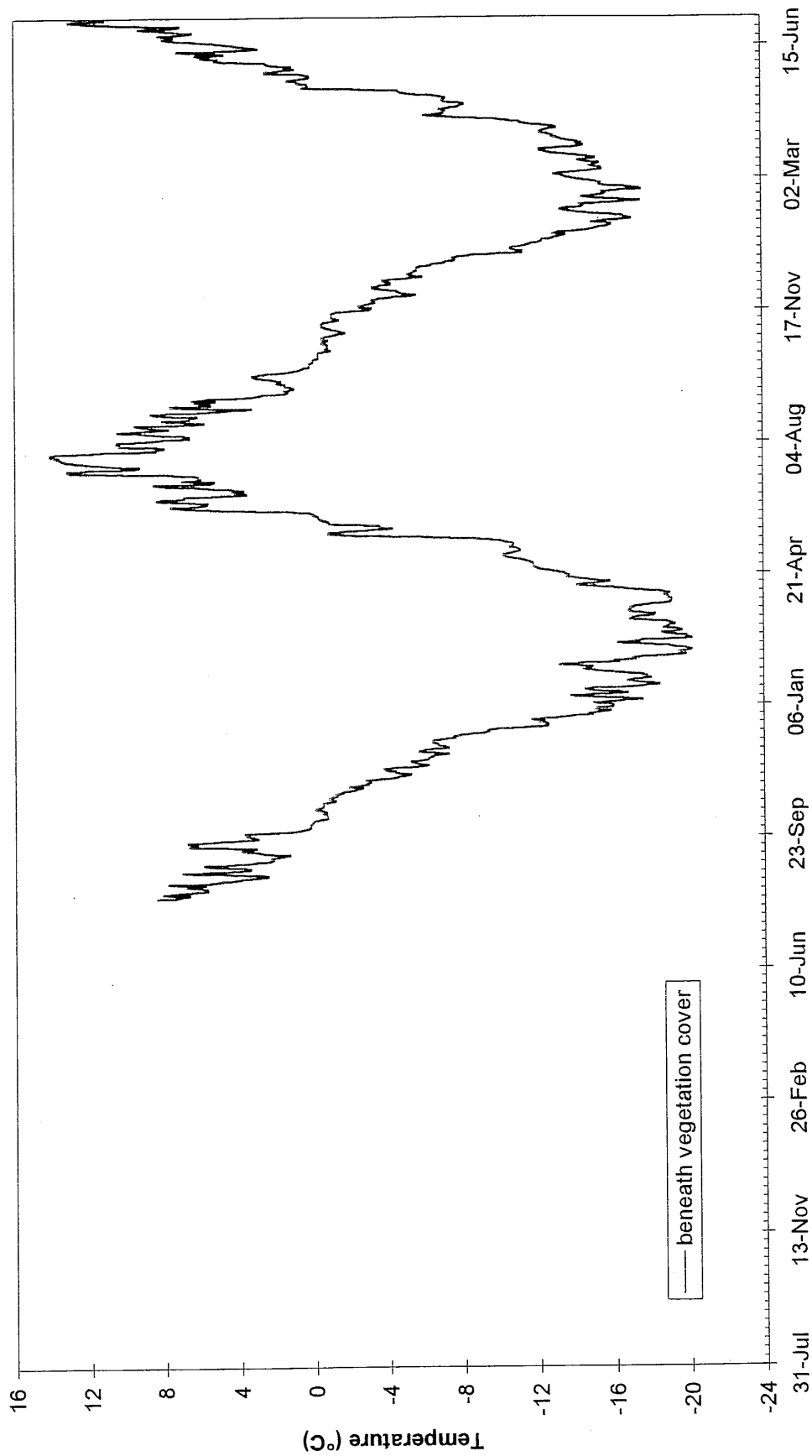
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JUL 95-JUL 98 Daily Mean Air Temperatures



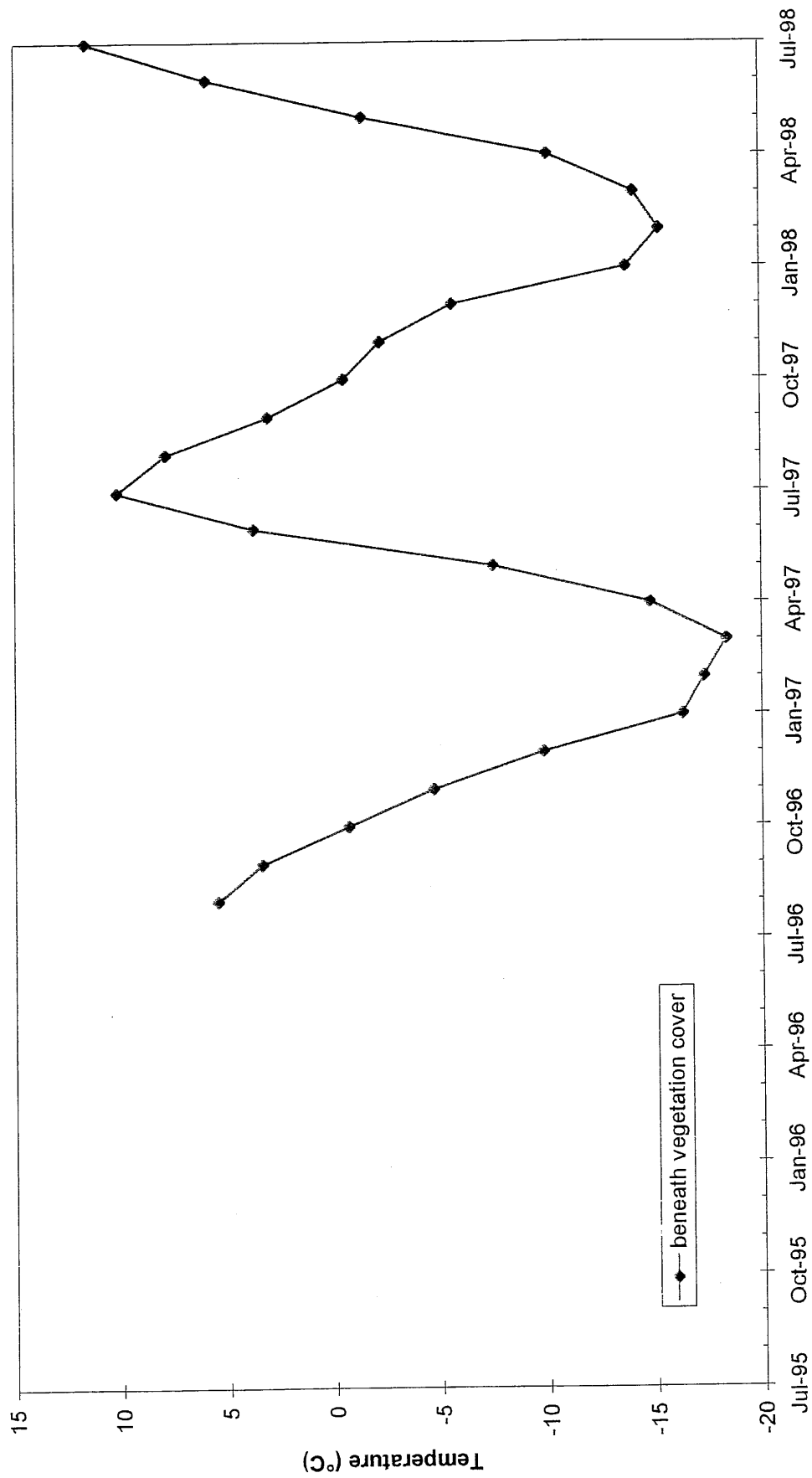
STATION GSC-0886
JUL 95-JUL 98 Monthly Mean Air Temperatures



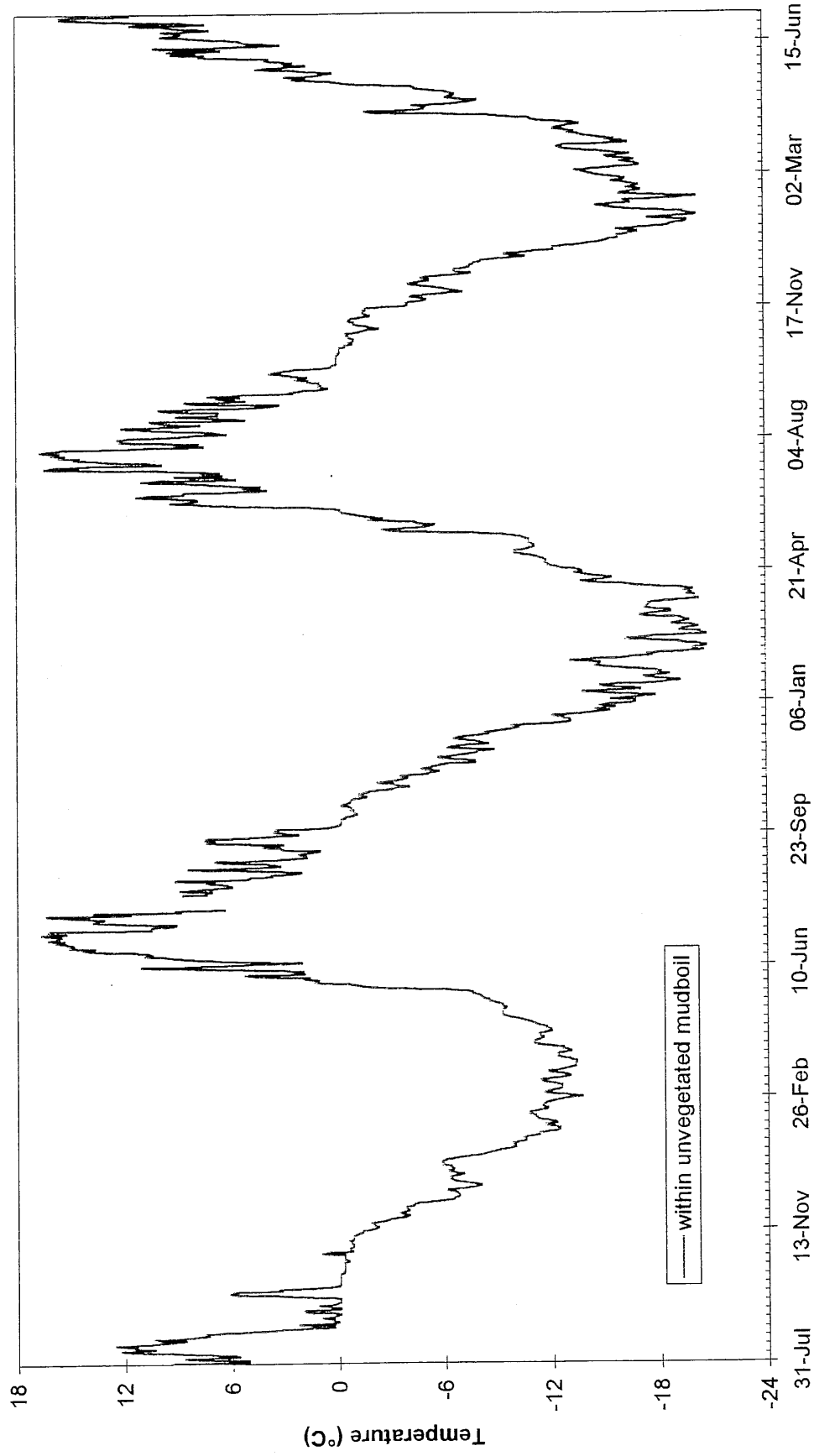
STATION GSC-0887
JUL 95-JUL 98 Daily Mean Near Surface Ground Temperatures



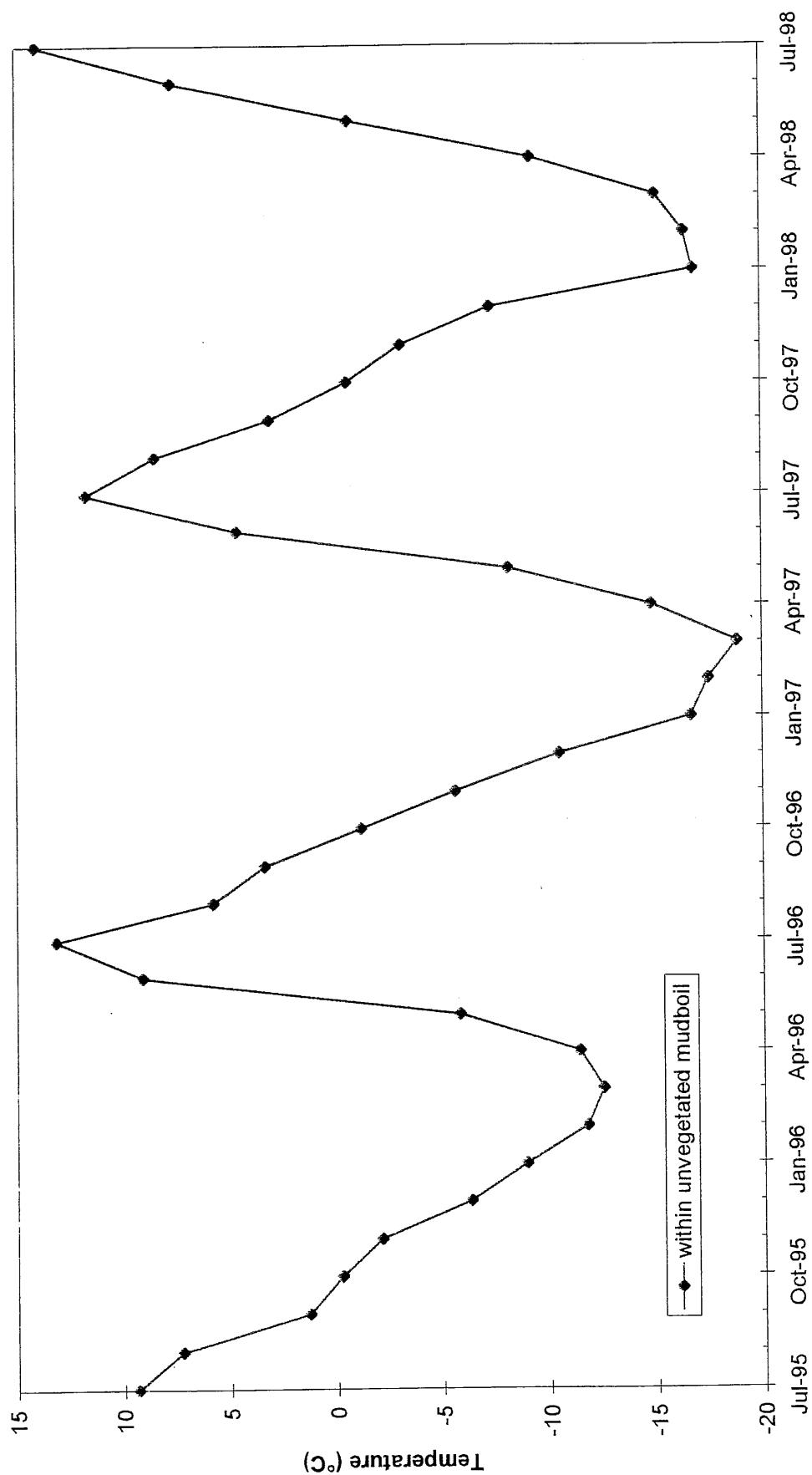
STATION GSC-0887
JUL 95-JUL 98 Monthly Mean Near Surface Ground Temperatures



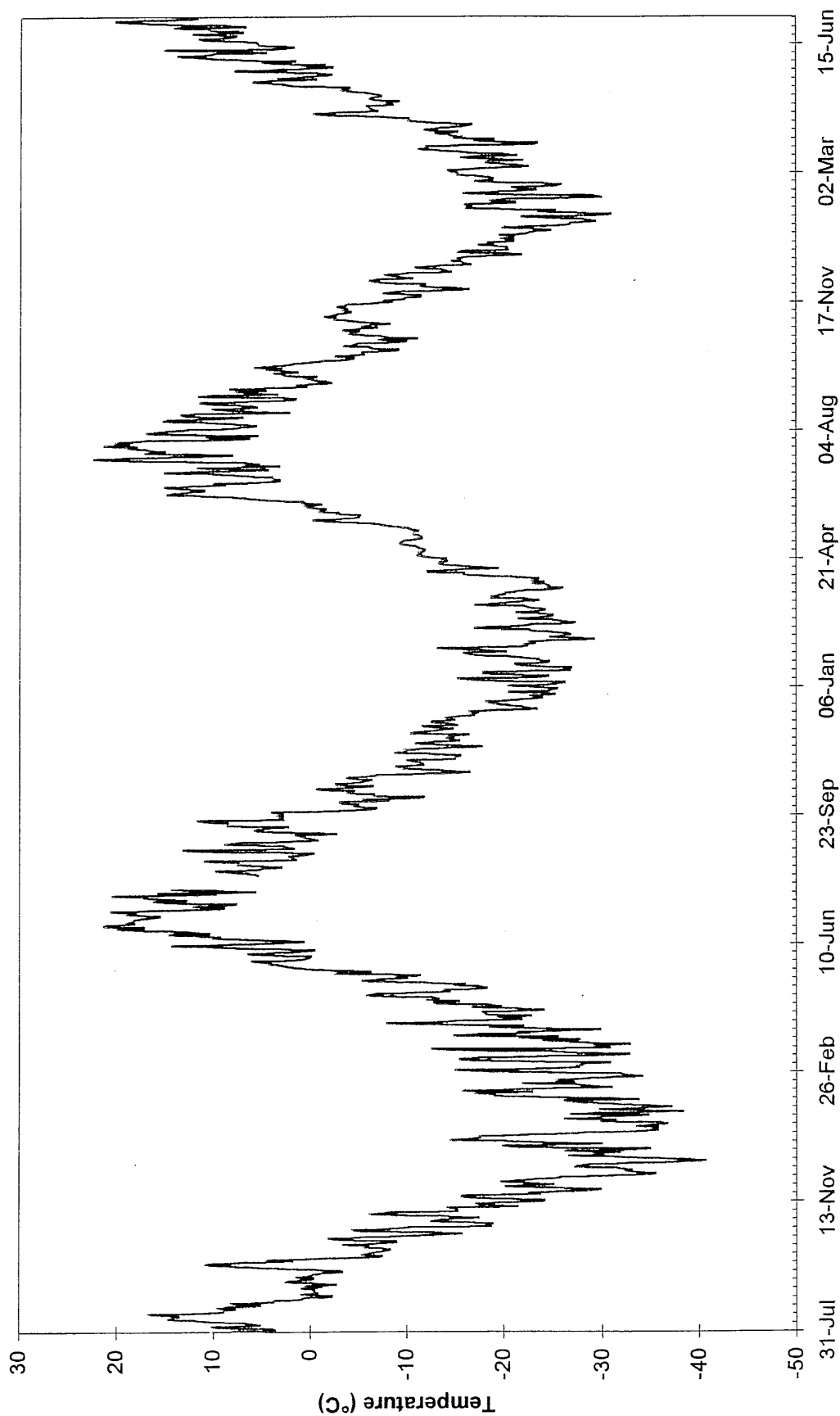
STATION GSC-0887
JUL 95-JUL 98 Daily Mean Near Surface Ground Temperatures



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STATION GSC-0887
JUL 95-JUL 98 Daily Mean Air Temperatures



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