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CONTAMINANT TRANSPORT IN WATER-FILLED MINE-PITS

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Abstract:

Water-filled decommissioned mine-pits are likely to contain deleterious concentrations of various dissolved metals and salts. It is apparent that any given property of interest is not evenly distributed throughout the water column; the pit-lake is stratified. Thermal and chemical stratification are the controlling factors influencing the density of water and it is density that controls the overall stratification as heavy fluid cannot sit on top of light fluid. It is important to determine how concentrations of these properties might change over time.

This paper describes some unique field data collected in the Brenda Mines pit-lake near Peachland, BC. The data illustrates the dynamics that should be expected before and after ice-on. Modelling based on this data indicates the sensitivity of the system to wind at the time of fall over-turn. The generality of the modelling is discussed, along with required input information.

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Introduction

Two major motivating factors drive the need to understand transport of deleterious material in water-filled mine-pits. Firstly, due to the nature of the mine-site, at certain depths the stratified pit-lake often contains material at concentrations above regulatory thresholds. Consequently, in the event of surface or groundwater outflow from the pit-lake, the concentration of deleterious material in the outflow must be quantified. Secondly, if a pit-lake is deemed hydrodynamically stable, it provides a disposal site whereby a tailings slurry may be placed at the base of the water column. In an ideal situation this material would be considered removed from the local environment. However, natural processes create situations whereby there might be slow ᵛ leakage' of this material - or even a catastrophic overturning of the pit-lake.

There are few studies available with sufficient data to provide a basis for understanding of the problem (see Davis and Ashenberg 1982 and Tones 1982 for exceptions). As described in the 1994 Mine Reclamation Symposium (Stevens *et. al* 1994a), pit-lakes differ from the majority of natural lakes in a number of ways. They are deep relative to their surface area, they have high concentrations of dissolved material and they have a relatively 'new' benthic zone (Fig. 1). Consequently, while they can be assumed to physically behave as a lake, direct implementation of quantitative results from physical limnology is unlikely to provide useful results.

After estimating the basic physical parameters for the stratified water column (see Imberger and Patterson 1990, Stevens *et. al* 1994a,b) the next step is to collect relevant field data. The Environmental Fluid Mechanics Group in Civil Engineering at the University of British Columbia conducted a detailed field program from September 1994 to May 1995 with additional, less detailed, data recorded outside of this period. This paper describes the important features of the data-set and how they relate to computer modelling and also to other mine pit-lakes in the region.

Instrumentation

The Environmental Fluid Mechanics Group in The Department of Civil Engineering at the University of British Columbia, Canada, deployed a suite of instruments in the pit-lake over a total period running from March 1994 through to the present time. Instrumentation included meteorological stations, conductivity-temperature-depth profilers (hereinafter CTD profilers), dissolved oxygen (DO) sensors, a transmissometer, a 3D anemometer and temperature loggers.

The critical information that comes from this equipment can be summarized as follows.

(i) *temperature and conductivity profiles.* The CTD is rapidly (~ Im/s) profiled through the water column recording data on-the-fly and providing information on the vertical structure with a resolution of 10's of centimetres. Information on 5 or 10 metre spacing, while useful for a general picture of the stratification, gives little indication of the structural subtleties in the variations necessary for identification of mixing processes. Thermoclines and chemoclines might often be less than a metre thick. In addition, these properties must be sampled as unobtrusively as possible. A mine pit-lake is not like the ocean where one can assume the effects of sampling are rapidly carried away by currents.

(ii) *meteorological data* from near, or on, the water/ice surface. This group of instruments recorded wind speed & direction, solar radiation, air temperature and other properties. Due to the nature of the pit geometry it is possible that wind velocities outside the pit show little resemblance to those in the pit at the water/ice surface. The wind strength plays a large role in the development of the stratification.

(iii) *temperature time series data.* A collection of temperature loggers spaced out on a rope that has one end moored on the pit-lake-bed and the other held at the water surface by a buoy is called a thermistor chain. The loggers are set to record temperatures every few minutes. This rapidity of sampling might appear unnecessary - however slower sampling can alias data or filter out short, but highly active, events.

Observations

There is a paradigm for the seasonal behaviour of a lake that most limnological textbooks describe (e.g. Wetzel 1983). Here we shall concentrate on how our observations in the Brenda pit-lake differ from this.

Profile data

The important features are illustrated in Fig. 2, a compilation of salinity and temperature profiles derived from the CTD data. The data captures, firstly, the development and depression of the surface layer and, secondly, the deep, warm, salty layer. A cross-lake transect indicates that the surface layer appears to have some transverse structure even in winter. Furthermore the warm pool at the bottom must have some supply to maintain its temperature. In fact, the warm salty pool at the bottom of the pit would be expected to exhibit only minor variations as the heat slowly diffuses out; instead it is significantly different in almost every profile.

Meteorological data

Figs. 3a & b compare wind and temperature data collected on the rim of the pit with that collected inside at the pit surface. Air turbulence, generated as the air flows into the pit cavity, creates a very complex and variable wind field. The resultant effect is that, the wind forcing is reduced moderately in magnitude, and is less directionally systematic than if there were no high walls surrounding the pit. Thus, the pit-walls cannot be assumed to generate significant sheltering but wind-forcing models whereby the wind acts everywhere in the same direction with the same magnitude are inappropriate. Snow/ice cover data is poorly resolved in this data set, however, it is of secondary importance in relation to improved residence times of introduced material.

Temperature loggers

Fig. 4 shows a short segment of data recorded in September 1994 from a temperature logger placed to one side of the pit-lake at a depth of 10m. It shows rapid temperature fluctuations that, when compared with temperature profiles of around the same time, indicate that wind forcing (presumably, see later) can drive vertical excursions in the temperature structure of up to several metres. This translates to lesser but still significant motion deeper in the water column. These motions help to spread any introduced material.

Data, recorded under ice cover in February 1995, show an interesting and highly dynamic picture during a period when the paradigm suggests little activity. Fig. 5 shows a temperature logger placed at 130 m in almost the deepest part of the pit-lake (max. depth Feb. 1995 138m). Upon recovery it yielded data indicating temperature fluctuations of almost 0.1C. This may appear minimal but the neighbouring thermistor, at a depth of 80m, showed fluctuations of the order of the resolution of the instrument, around 0.002C. Some process generates a large transient at the bottom of the pit-lake but has no impact in the centre (in volumetric sense) of the water mass.

Modelling

The model presently being developed by the authors is mechanistic in its approach to describing changes in the vertical stratification. It is one-dimensional and essentially adds or removes heat to the upper-most of a series of layers. By checking for stability in a recursive fashion these energy changes can penetrate vertically through the water column. The effect of wind is also simply parametrized. Furthermore there is a link between wind at the surface and mixing at depth. This parametrization is made through consideration of overall stability and geometry to figure in events such as illustrated by Fig. 4. The type of mechanism captured in Fig. 5 is beyond the scope of this work as there is insufficient data to satisfactorily explain it beyond the level of speculation.

Discussion

The data builds a picture of the development of the pit-lake stratification and it suggests emphasis on inflows, both natural and artificial. It clearly identifies the need for better ways of recording and understanding ice-cover at these latitudes. Finally the impact of subsidence is of significance as these events must impact on the system at various levels.

Modelling at this level does not have a sufficient data base to form a reliable prognostic tool. This is especially true given the variability of stratification in different mine pit-lakes within the same general region. Our input data, when applied to each situation, would be little different, yet the vertical temperature structure at two other mine pit-lakes (SIMILCO-Ingerbelle & Highland Valley Copper-Highmont West) close (i.e. <200 km) to the Brenda Pit are completely different from each other and the structure found at the Brenda mine site.

The implications for Sub-Aqueous Disposal - Under ideal conditions, a region of very heavy deleterious fluid placed at the bottom of the water column will remain intact. However molecular diffusion, which although slow, will be sufficient to broaden the chemocline separating the introduced material from the rest of the water column. This serves to weaken the density gradient so that it is more susceptible to the mixing occurring during fall and spring when temperature stratification is reduced. A time scale for emergence of trace, or greater, levels of the disposed material must then be set at 6 months. Determination of a more quantitative estimate is ongoing as part of the present study.

However, if groundwater fluxes and/or subsidence events transport heat to the bottom of the water column, as is apparent in this data set, then this ultimately de-stabilizing process has the potential to quickly transport high levels of 'disposed' material to the surface.

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Figure Captions

Fig. 1 Schematic of processes affecting a pit-lake.

Fig. 2 (a) Temperature, (b) salinity and (c) Sigma-T (density - 1000 kg/m^) profiles from March, May, September, October and December 1994 and January 1995.

Fig. 3 Data from the pit-lake observation area and the meteorological station on the ice-surface; from February 1995. (a) wind speed (observation area offset by 4 units) and (b) air temperature.

Fig. 4 Water temperature data from a side chain, from October 1994, at a depth of 10 m.

Fig. 5 Water temperature data from a depth of 130 m, recorded in February 1995.

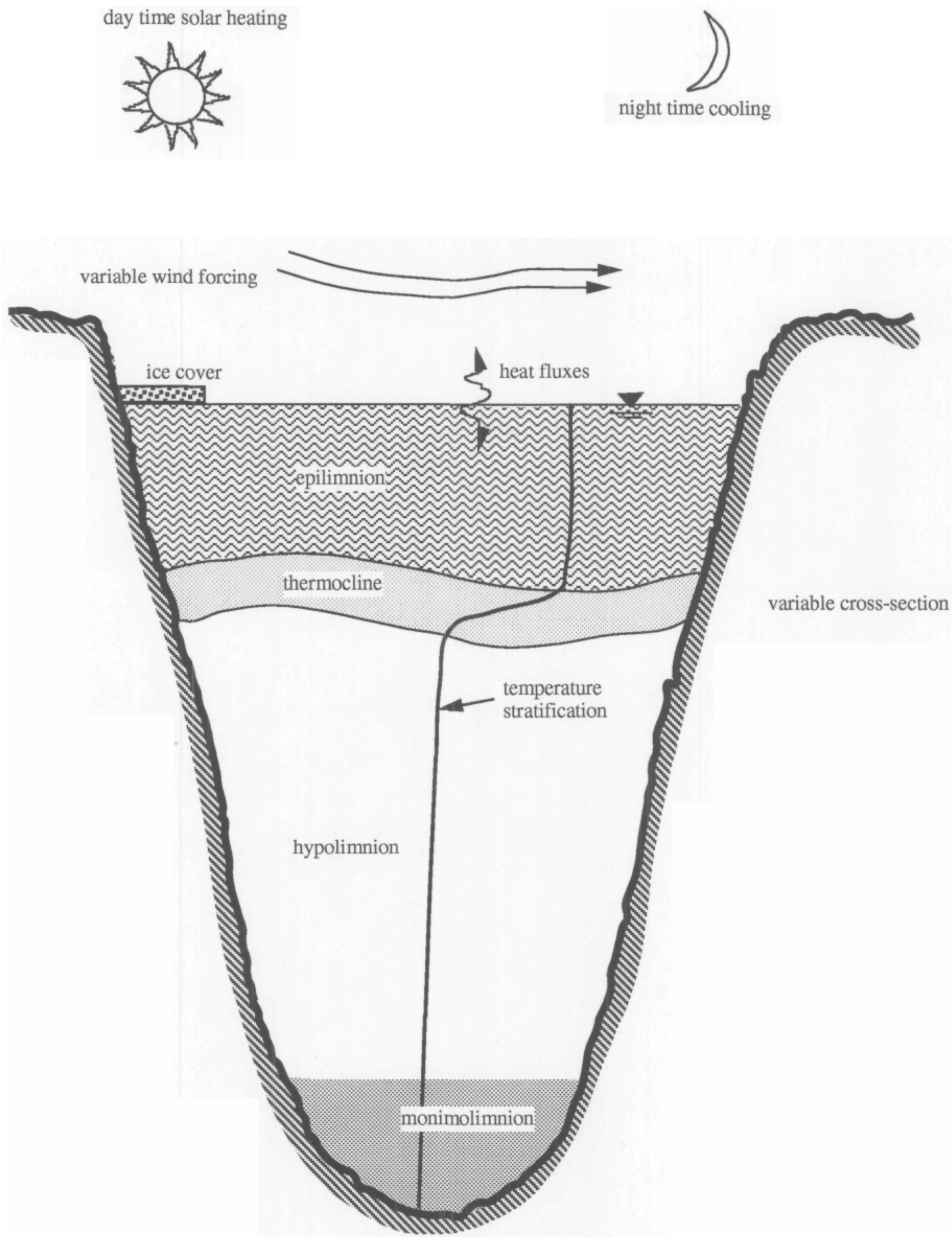

day time solar heating
night time cooling
variable wind forcing
ice cover
heat fluxes
epilimnion
thermocline
variable cross-section
temperature
stratification
hypolimnion
monimolimnion

figure 1

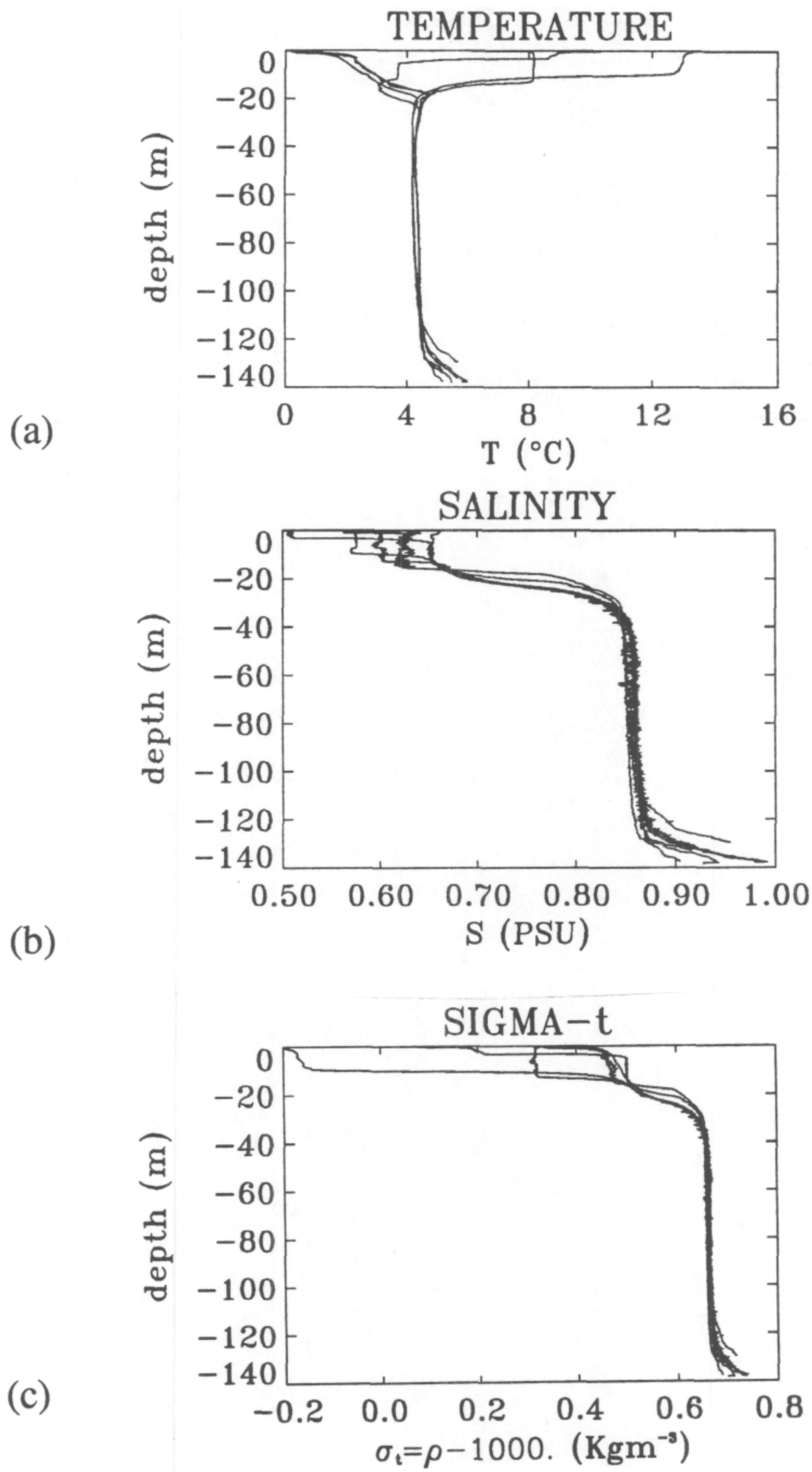
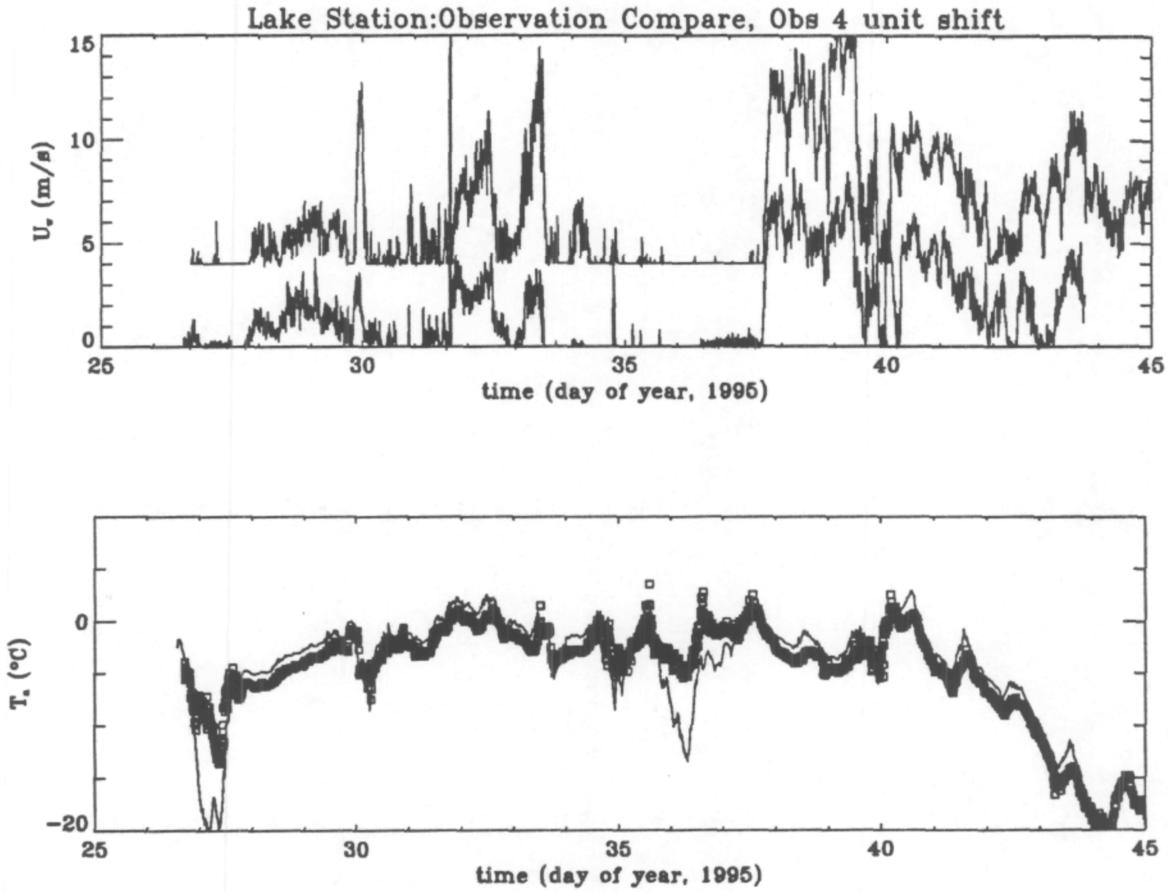

TEMPERATURE
depth (m)
0
−20
−40
−60
−80
−100
−120
−140
0
4
8
12
16
T (°C)
(a)
SALINITY
depth (m)
0
−20
−40
−60
−80
−100
−120
−140
0.50
0.60
0.70
0.80
0.90
1.00
S (PSU)
(b)
SIGMA-t
depth (m)
0
−20
−40
−60
−80
−100
−120
−140
−0.2
0.0
0.2
0.4
0.6
0.8
σt=ρ−1000. (Kgm⁻³)
(c)

figure 2


Lake Station:Observation Compare, Obs 4 unit shift
U* (m/s)
0
5
10
15
25
30
35
40
45
time (day of year, 1995)
T* (°C)
-20
0
25
30
35
40
45
time (day of year, 1995)

(a)

(b)

figure 3

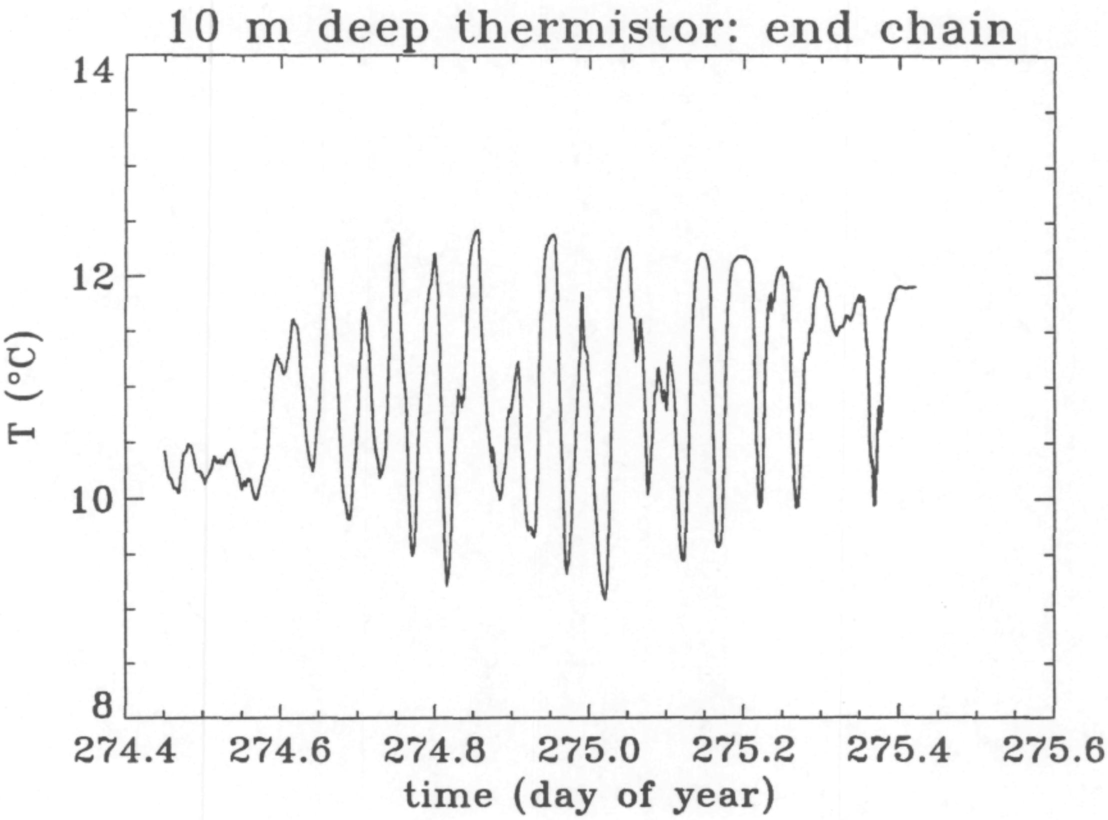


figure 4

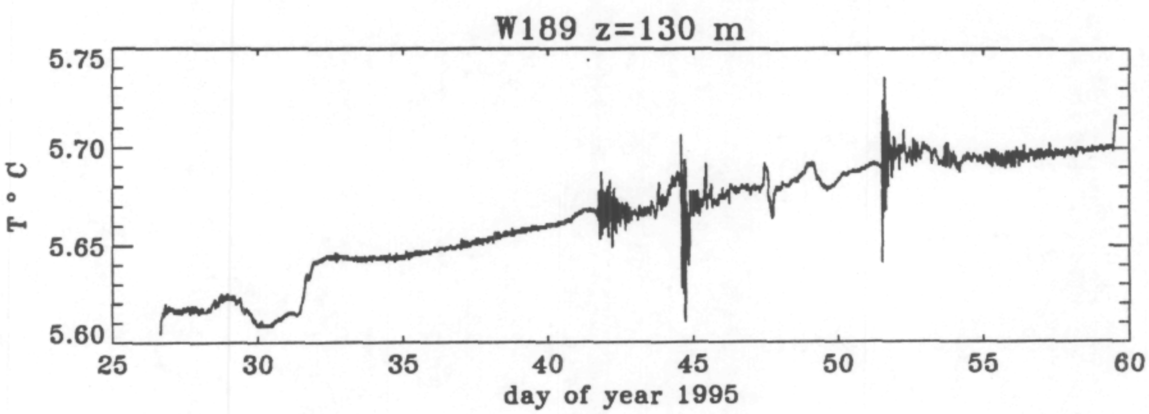


figure 5