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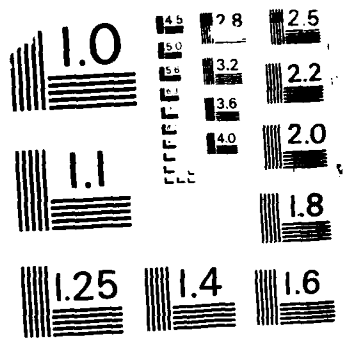
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Naval Ocean Research and Development Activity
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A Technique for Processing Noisy AXBT Data

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Foreword

The U.S. Navy routinely conducts airborne expendable bathythermograph (AXBT) surveys of oceanic regions. Hundreds of AXBTs are expended during these regional surveys and, naturally, some of the profiles contain considerable noise. Because it was costly to obtain this data, it is unwise to discard profiles because of noise contamination. Therefore, it is desirable to develop a cost-effective method for processing noisy data. This report describes a technique for processing noisy AXBT data that is being used at the Naval Ocean Research and Development Activity.

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Commanding Officer, NORDA

Executive summary

Noise or spikes beyond acceptable levels often occur in data, even from the most carefully planned and executed experiments. A method is described here for processing noisy temperature profiles obtained from airborne expendable bathythermograph surveys to a level in which useful information can be gained. The technique is simple to apply and can be adapted to a wide range of noisy data.

Acknowledgments

Discussions with Z. Hallock of NORDA were instrumental in the development of this processing technique. This procedure was applied and critiqued by J. Dastugue of Planning Systems Incorporated. This work was supported by the Office of Naval Research under Program Element 61153N, Dr. H. C. Eppert, Jr., Program Manager, as part of Project GEOSAT.

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A technique for processing noisy AXBT data

Introduction

Extensive airborne expendable bathythermograph (AXBT) surveys are routinely conducted by the U.S. Navy. These surveys are often used to describe mesoscale variability, western boundary currents, or eddies. Quasi-synoptic coverage of an oceanic region is possible with a single P-3 aircraft dropping AXBTs over a period of three to five full flight days. Temperature structure is attainable down to 400 m by using shallow probes and down to 800 m by using deep probes.

Regional AXBT surveys often expend hundreds of AXBTs, and some of the profiles commonly contain considerable noise. Noise can originate from equipment malfunctions, electrical problems, radio interference, rough sea state, or weak radio signals (due to transmission range). Noisy profiles are often discarded or truncated because editing seems impossible or very costly. Much data, which were taken at considerable expense, are not processed.

A procedure for processing such AXBT data is described. The technique is simple to apply. Very little user input control is required. Data editing is automatic and produces consistent editing, which is well defined. The technique is flexible and can be adapted to most AXBT data (whether or not the data are noisy).

Method

Basically, the main elements of the procedure described here consisted of automatically editing the data, filtering the data to two resolutions (high and low), and then combining the appropriate portions of the low-resolution profile where raw data were very noisy with the high resolution profile where raw data quality was good. Subsampling occurred at equal intervals in the resulting profile. This method was developed at the Naval Ocean Research and Development Activity (NORDA) on a VAX 11/750 digital computer, and was first applied to a data set consisting of about 500 AXBT profiles collected during two aircraft operations. All routines used in the processing scheme were developed earlier as general utility programs for application on a standard file format, which incorporates all the physical oceanographic profile data holdings of the Physical Oceanography Branch at NORDA. Thus, the runstreams were both modular and flexible. After transferring the raw data from digital cassette to VAX disk files, these steps were followed for processing the raw AXBT data.

1. Plot raw temperature data versus depth.
2.* Auto edit the raw data; insert bad data flags.
3.* Plot edited raw data.
4.* Interpolate bad data records.
5. Filter raw (edited) data to desired resolution.
6.* Filter raw (edited) data to a degraded (lower) resolution.
7. Interpolate higher resolution data (Step 5) to appropriate levels.
8.* Interpolate lower resolution data (Step 6) to same levels as Step 7.
9.* Merge appropriate sections of the interpolated high resolution and the interpolated low resolution files for the final profile.
10. Plot the final profile.

Note: * indicates optional.

Each step of the processing is now explained in detail. The example AXBT raw, unedited profile shown in Figure 1 is used for illustrative purposes. Data for this profile were collected at 8 Hz, which corresponded to about 0.2 m sampling.

Raw, unedited temperature data are plotted versus depth in Step 1. This step is used as an editing guide and as a means of intercomparison with a final plot of processed data (Step 10).

Auto-editing in Step 2 consisted of removing impossible data values and then straight line fitting segments of the data using a least squares method. Data that differed by more than a specified tolerance with the fitted data were replaced with bad data flags. Data shown in Figure 1 were fitted in 10-m segments, beginning at a depth of 150 m, and were replaced with bad data flags if they differed by more than 0.5°C from the straight line fit. The resulting profile is shown in Figure 2 (Step 3). The fitting was begun at 150 m to avoid removing good data in regions containing strong gradients. The 10 m segment and 0.5°C tolerances were determined after some experimentation. Segment length and temperature tolerance might need adjustment for application in regions containing strong gradients; for particularly noisy profiles, different segment lengths and tolerances could be required within the same profile. Step 2 would be skipped if inspection of the profile shown in Figure 1 (Step 1) indicated that no editing was necessary. Then only Steps 5, 7, and 10 would be required. This editing technique also worked well in removing isolated data spikes and was found to be suitable for general editing of AXBT data.

For quality control, it was important that the edited data were plotted in Step 3 before missing data records were interpolated. Gaps evident in the profile shown in Figure 2 resulted from consecutive bad data records. If the gaps were too large or too numerous, the profile would have been cut short prior to the gaps. In Step 4, the gaps in the edited profile were interpolated. This step was required prior to filtering the data.

Data in the lower noise regions (0–300 m for the profile in Fig. 2) were considered good to at least 4-m resolution. In Step 5, the profile was low-pass filtered to 4-m resolution using a filter with a half-width of 21 points, a Bartlett taper, and a cutoff frequency of 0.25 c/m (Fig. 3). Data in the higher noise regions were considered good to, at best, 20–40 m resolution. Fortunately, the higher noise areas usually occurred only below the thermocline regions; vertical structure here could be adequately described with lower resolution data. Therefore, the profile was filtered to a 40-m resolution in Step 6 by using a filter with a half-width of 201 points, a Bartlett taper, and a cutoff frequency of 0.025 c/m (Fig. 4). This filter effectively constructed the temperature profile through the center of the high noise region.

It was advantageous to have the final processed data at integral multiples of 1 m in depth. For the filtered profiles, 2-m depth intervals corresponded to the Nyquist sampling interval for the 4-m resolution data. In Steps 7 and 8 the 4-m resolution profile and the 40-m resolution profile were subsampled at 2-m levels. In Step 9 the first 300 m of the 4-m resolution profile were merged with the data from the 40-m resolution profile below 300 m. Oversampling of the profile occurred below 300 m. The resulting profile is shown in Figure 5 (Step 10).

Discussion

Goals of the scientific project would not have been accomplished if large numbers of profiles had been rejected or truncated. Without a technique similar to the one described here, approximately 10–15% of the profiles would have been rejected. The data were far too noisy for techniques based on manual editing or on first differences to work.

Manual editing of the profiles would have been nearly impossible due to the time and labor required for such editing. In many cases good data were not visually distinguishable from bad data. In fact, the true temperature seemed to be the mean of the noise. This characteristic is probably essential if the method is to work; otherwise, the data could be biased by the bias in the noise.

The severity of the noise problem was further illustrated by the spectrum (Fig. 6) of the auto-edited profile with missing data interpolated and the spectrum (Fig. 7) of the final combined profile, both at raw resolution. The spectrum for the edited profile was unacceptable. Here, spectral energy was confined to one energy decade for all frequencies. For the final profile the spectrum was typical. Energy was down by more than five decades at 1 Hz.

Subsets of this technique were used on all the profiles. Manual labor was approximately the same for processing clean raw data as for very noisy raw data. A little more computer time was needed for the messy data. Manual editing of data spikes was not required for any profile. Processing progressed quickly and smoothly, and was easy to document. User input control was minimal.

Filter parameters (Steps 5 and 6) and edit parameters (Step 2) were determined for the entire data set after all raw data had been plotted. When the processing of a profile required all 10 steps, as determined from the raw profile plot in Step 1, the only parameters to be determined were the depth range over which to apply the auto editor (Step 2) and the depth at which to recombine the higher and lower resolution profiles (Step 9). If the profiles required **spike editing (Step 2) but did not require degrading the** resolution (Step 6), then Steps 6, 8, and 9 could be skipped. Then, only where to apply the editor needed to be determined. If the profiles did not require editing, then Steps 2, 3, 4, 6, 8, and 9 could be skipped. Parameters required for processing clean profiles were the same.

Summary and conclusion

Complete processing consisted of three phases. First, the AXBT data were transferred from digital cassettes to the VAX 11/750 computer, depth and temperature were computed, and the data were written in the standard tape format. Then, raw data were plotted for all profiles. Finally, based on the information gained from the raw plots, all (for noisy raw data) or part (for clean raw data) of Steps 2–10 were executed in a single computer job. These steps included auto-editing, filtering, interpolating, and plotting of the data. A different filtering procedure was applied to the noisier portions of the profiles. If this filtering procedure was applied, final processed profiles were at a lower resolution over the depth range where noise was a problem than over the depth range where noise was not a problem. Often, noisy areas were limited to portions of the profile that could be adequately described at lower resolution.

This technique salvaged many questionable profiles. The processing was quite flexible, simple, and easy to use. In general, it can be used in processing a wide variety of AXBT data. Similar techniques can be applied to other data types.

Six general, nondata-specific utility programs were used in Steps 2–10. Conceivably, these steps could be combined into a single program (or two, if plotting programs were separate). However, such a program could be quite large, complicated, and data specific. Fully automating this procedure is possible. Decisions concerning where to apply the editor and where to recombine the profiles can be made via programming logic. More work is required in this area.

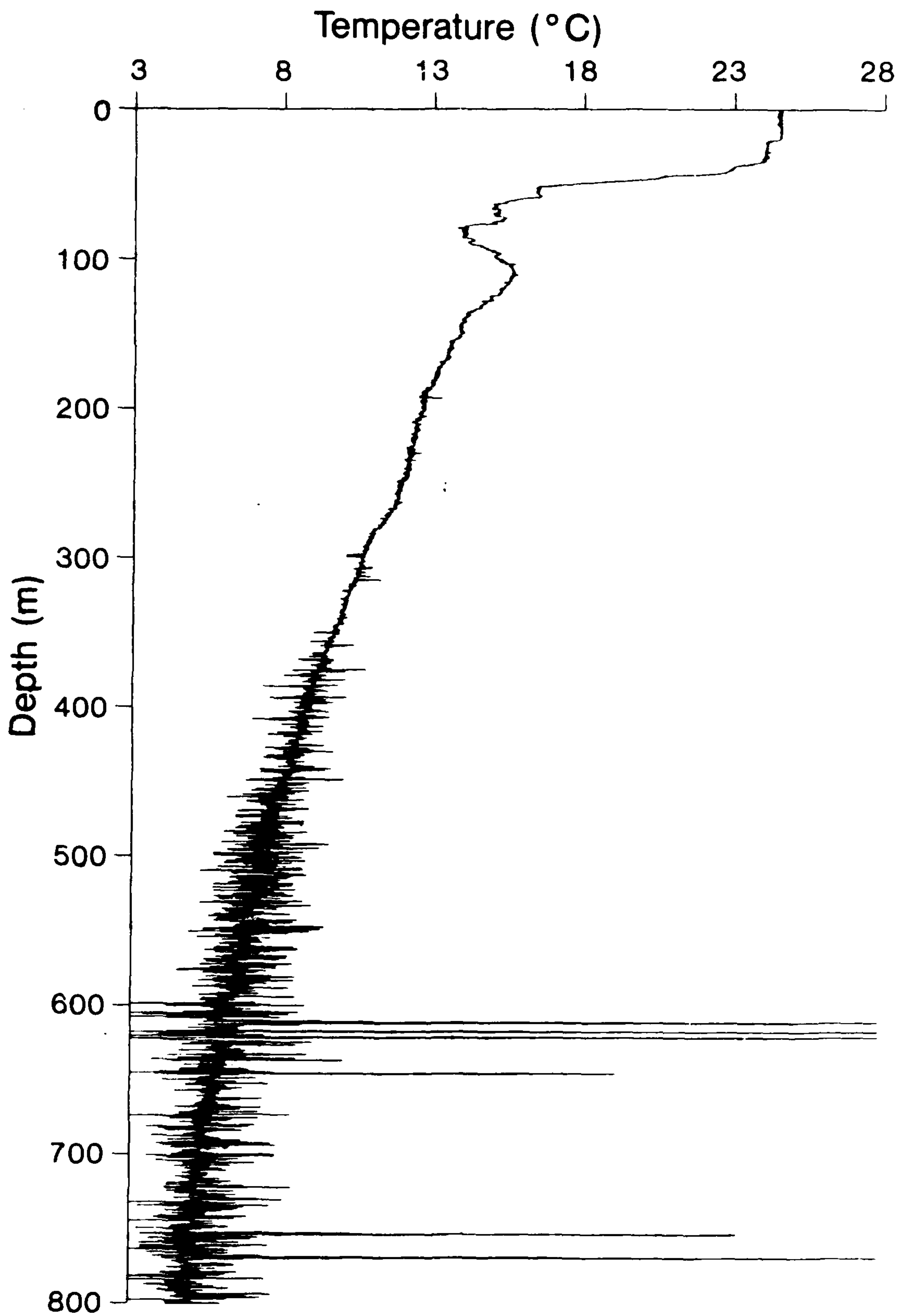

Figure 1. Example of a very noisy unedited AXBT profile.

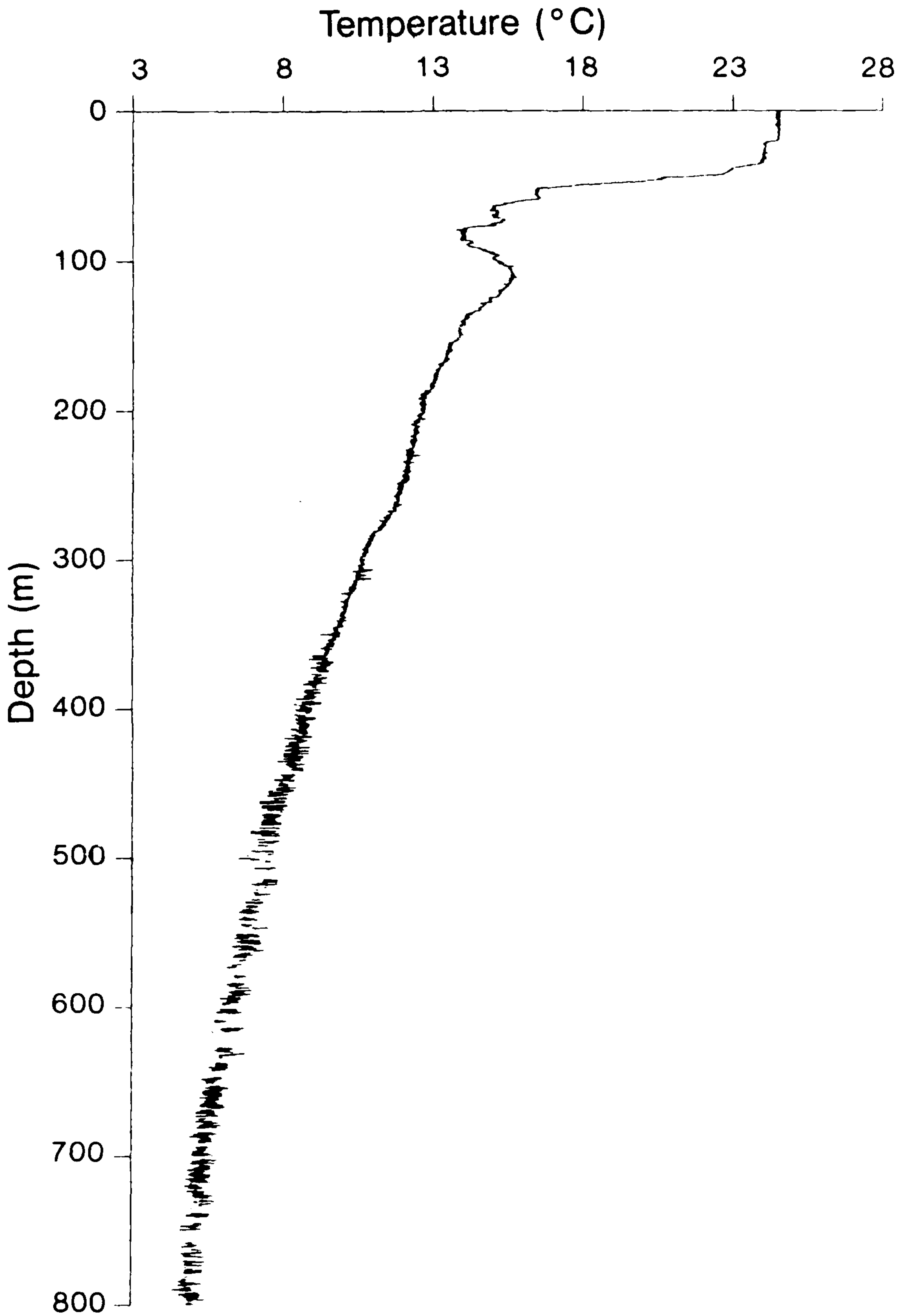

Figure 2. Results of automatic editing of the profile shown in Figure 1

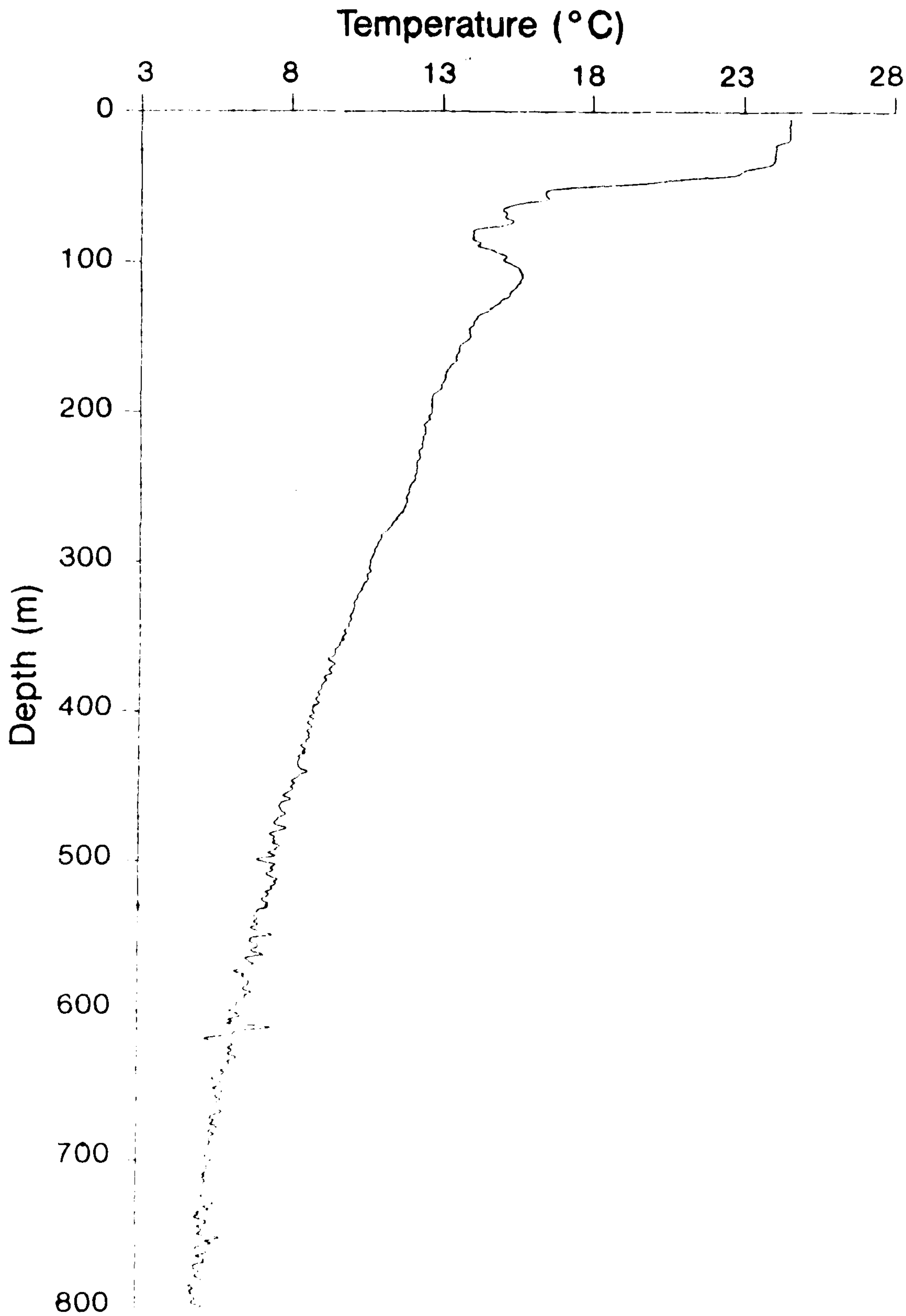

Figure 3. Profile shown in Figure 2 filtered to a 4 m resolution.

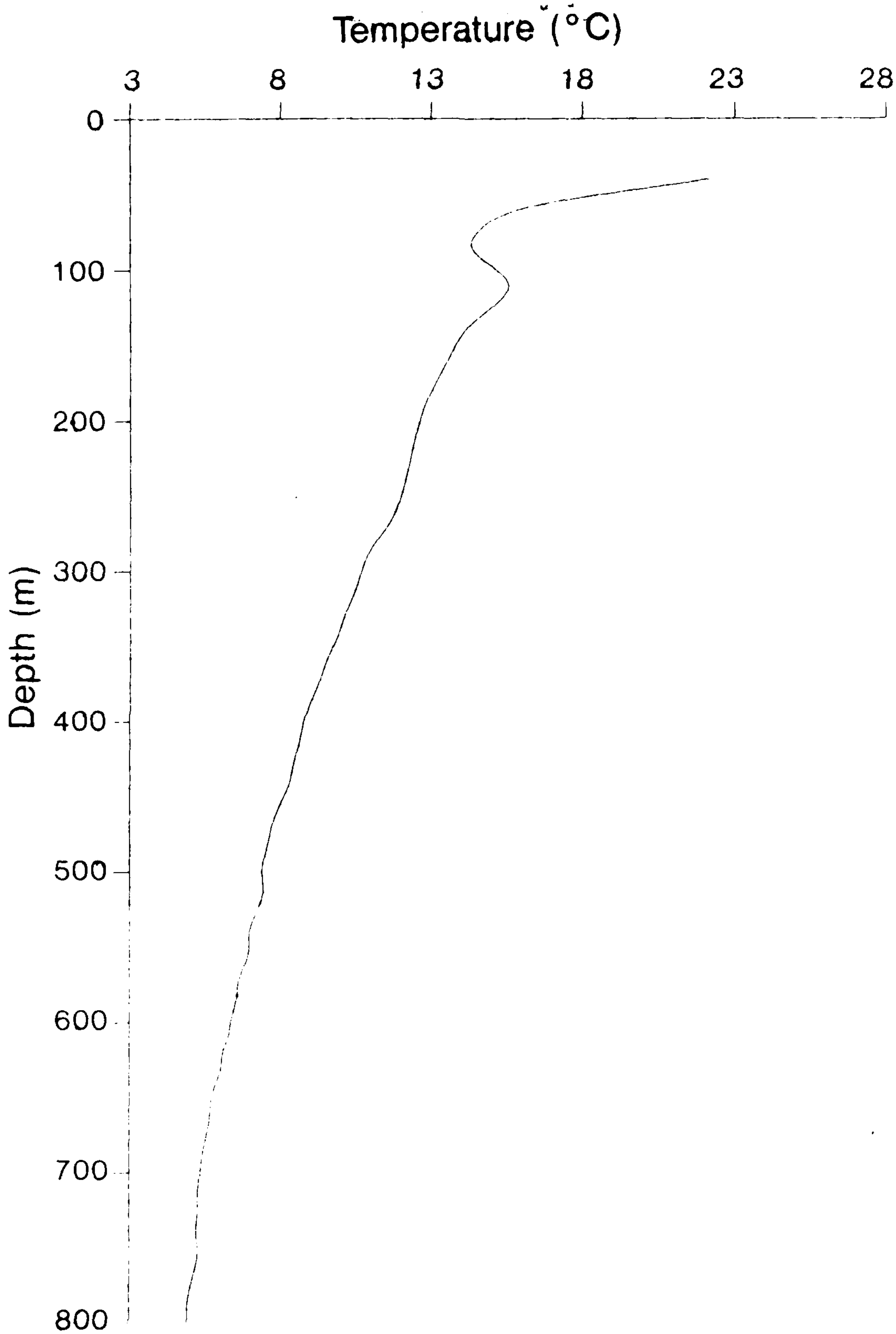

Figure 4. Profile shown in Figure 2 filtered to a 40 m resolution.

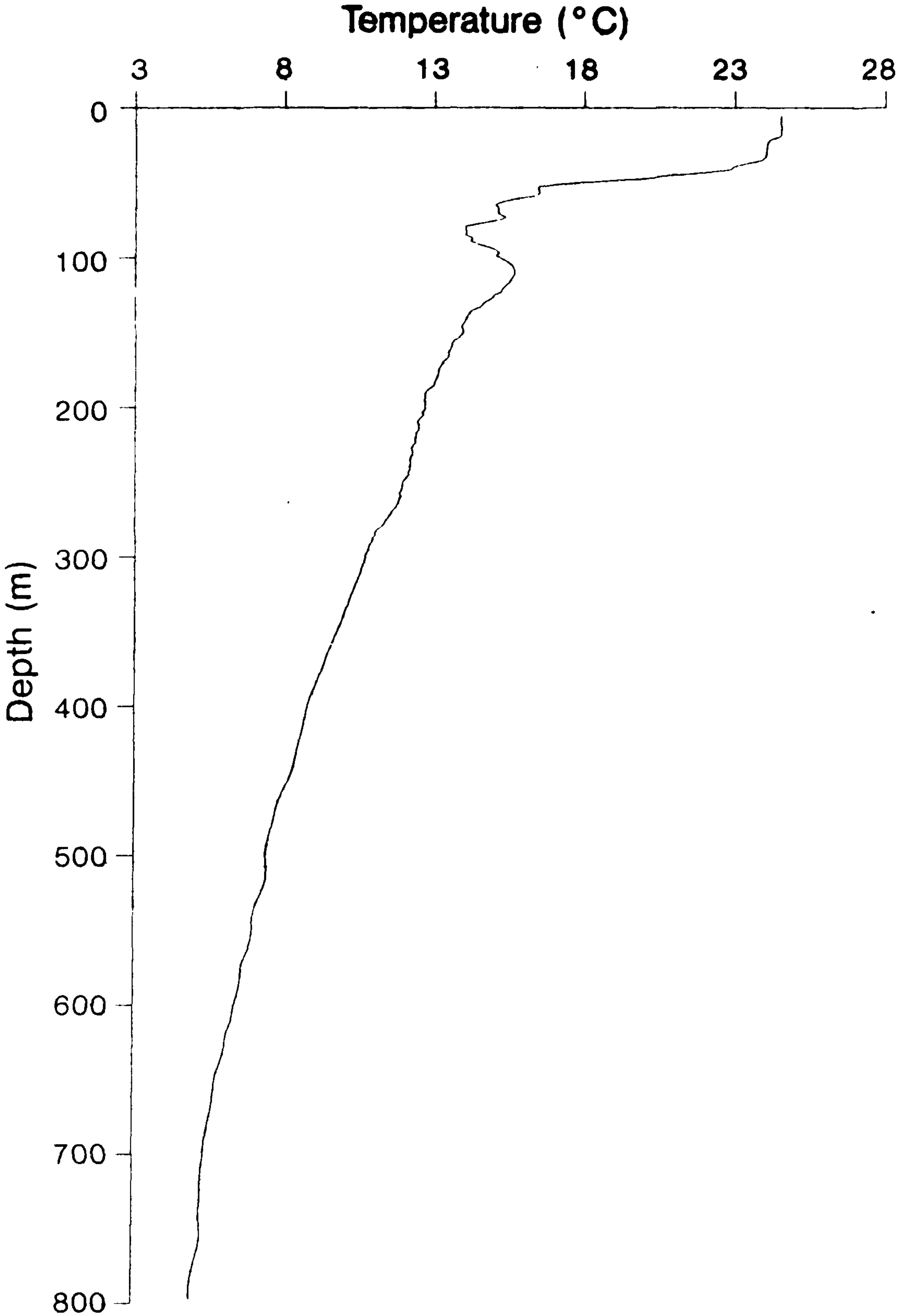

Figure 5. Results of merging the upper 300 m of the profile shown in Figure 3 with the portion of the profile below 300 m shown in Figure 4.

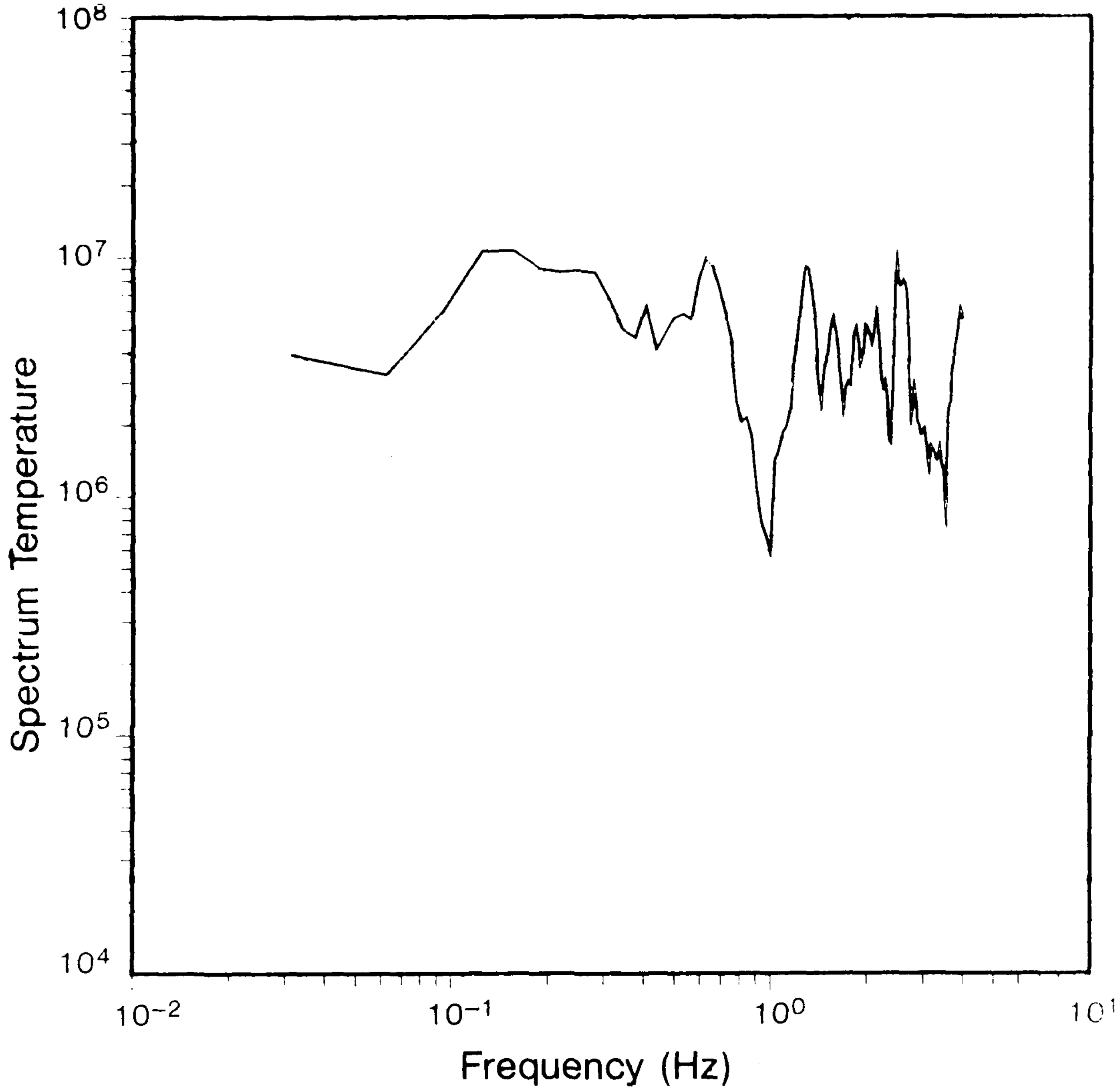

Figure 6. Spectrum of the edited profile shown in Figure 2 with missing data interpolated

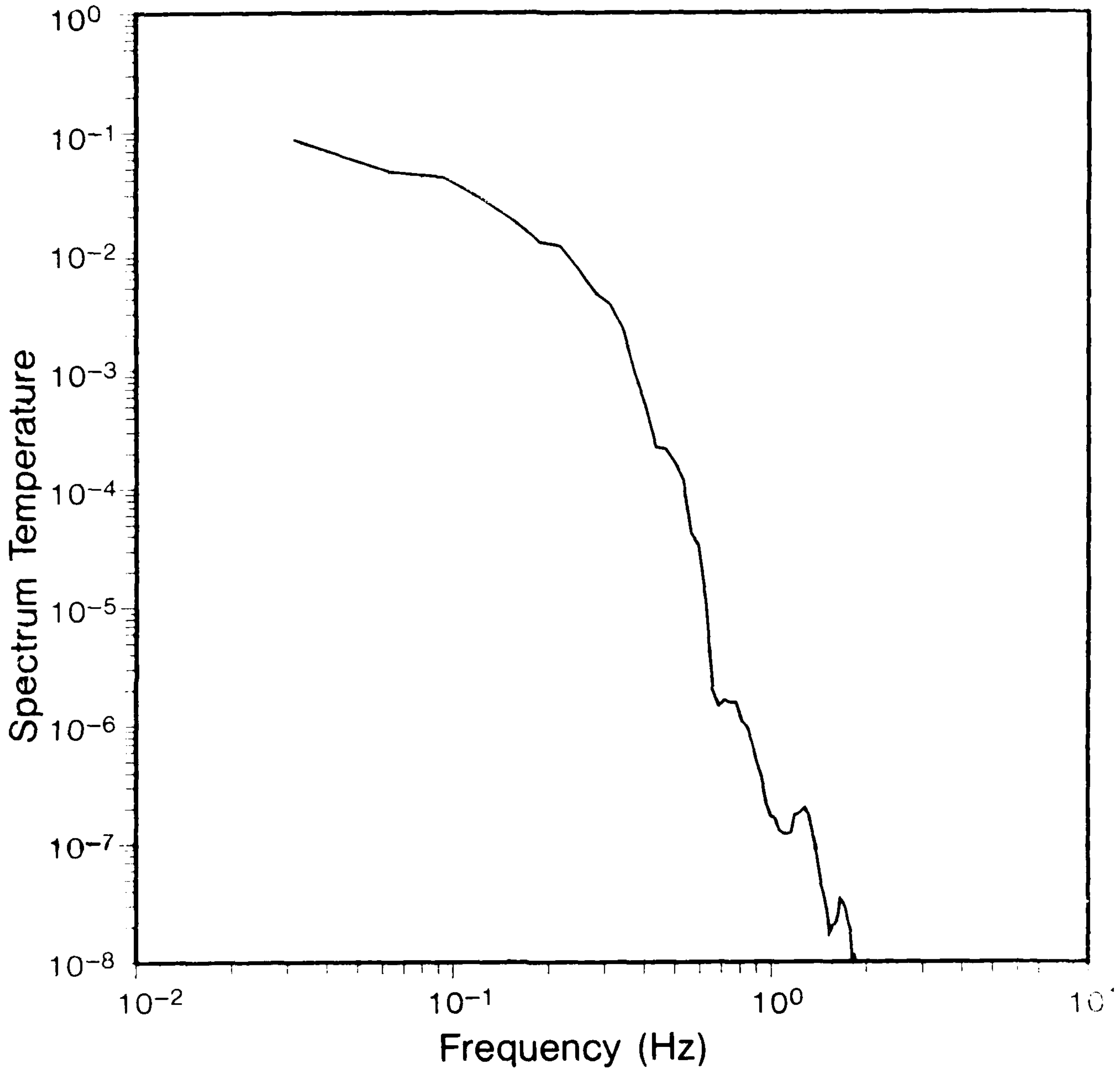

Figure 7. Spectrum of the final profile shown in Figure 5.

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