

# GROUND TILT OBSERVATIONS AT SYOWA STATION, ANTARCTICA

## PART 2. WATER-TUBE TILTMETER

Katsutada KAMINUMA

*National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

and

Toshiyasu NAGAO

*Faculty of Science, Chiba University, 33, Yayoi-cho 1-chome, Chiba 260*

**Abstract:** To observe the secular change of ground tilt in response to deglaciation in Antarctica, a water-tube tiltmeter was installed at Syowa Station, in the snow-free area without a vault. It was the first observation of ground tilt using a water-tube tiltmeter in Antarctica. The tiltmeter adopted is a moving float type using antifreeze as the fluid. The tiltmeter consists of four detectors which measure two tilt components. The detectors were covered with wooden boxes and the water-tubes were covered by airtight polyvinyl chloride tubes. Observations began in April 1981. The records were strongly affected by air temperature and solar radiation. In spite of these problems it was found that the ground tilt observations by means of water-tube tiltmeters was possible in the Antarctic region, even if there was no vault for installing the equipments.

### 1. Introduction

A set of water-tube tiltmeters was installed at Syowa Station to test a possibility of detecting secular change of ground tilt in response to deglaciation in Antarctica. Ground tilt was simultaneously observed with a bubble-type borehole tiltmeter discussed in Part 1 of this paper (KAMINUMA *et al.*, 1983).

This was the first attempt to observe ground tilt by means of a water-tube tiltmeter in Antarctica which has a severe environment.

### 2. Water-tube Tiltmeter and Its Installation

The detector of the water-tube tiltmeter installed at Syowa Station was of the same principle as model MF-N2 developed by SHICHI *et al.* (1980). The water-tube tiltmeter adopted is a moving float type using a 60% ethylene glycol antifreeze solution as the fluid. Prior to installation, the total system was tested in the low temperature laboratory of the National Institute of Polar Research in Japan.

The water-tube tiltmeter was installed directly on outcrops of granitic gneiss as shown in Fig. 1 of Part 1. Two components of tilt, *A-B* and *C-D*, were measured by connecting detectors *A* and *B*, and *C* and *D* with teflon tubes of 10 mm inside diameter. Each detector was mounted on a polished granite block which was set on top of a concrete block.

The detectors *A*, *B* and *C*, and *D* were covered with boxes made of 24 mm thick wood panels and sprayed with urethane foam to make the corners airtight. The three boxes were connected by polyvinyl chloride tube, 75 mm in diameter. The water-tube was installed in this polyvinyl chloride tube. Thus the entire system was airtight and was protected from both short-term atmospheric pressure fluctuation and variations in solar radiation. It was necessary to install the water-tubes close to the same level as the detectors to avoid noise caused by density change of the fluid due to temperature changes. Unfortunately, the topography of the observation site was not perfectly flat, which caused a rag in the water tubes for both components. The lowest points of the tube from the free surface of the fluid were about 200 cm for the *A-B* component and 50 cm for the *C-D* component.

The base lengths between detectors *A-B* and detectors *C-D* were 31.19 m and 32.15 m as shown in Fig. 1 of Part 1. The angle between *A-B* and *C-D* was  $95^{\circ}45.5'$ .

The block diagram of the observation system is shown in Fig. 3 of Part 1 of this paper.

Output signals from each detector and relative change between the two pairs of the float movements were recorded with a 12-channel chart recorder in the data processing hut, together with the signals from the borehole tiltmeters. The relative changes between the two pairs of floats were detected with a differential operational amplifier. The full scales of the *A-B* and *C-D* components on the chart were set so as to be 50 mV which corresponded to ground tilt of  $133 \mu\text{rad}$  and  $83 \mu\text{rad}$  respectively.

The temperature in the wooden box covering detectors *B* and *C* measured with a quartz thermometer was also recorded. A photo of the water-tube tiltmeter is shown in Fig. 1.

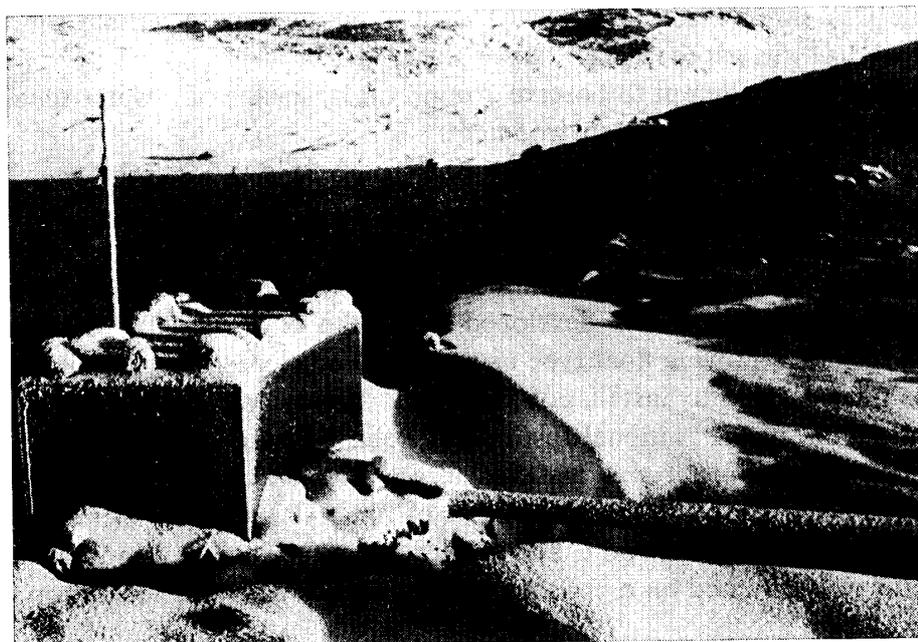


Fig. 1. A view of the water-tube tiltmeter in the winter season. Even in mid-winter the water-tube was not covered with snow.

### 3. Observations

The observations were started in April 1981. Figure 2 shows the raw data of relative change for the *A-B* and *C-D* components, and the air temperature from April 1

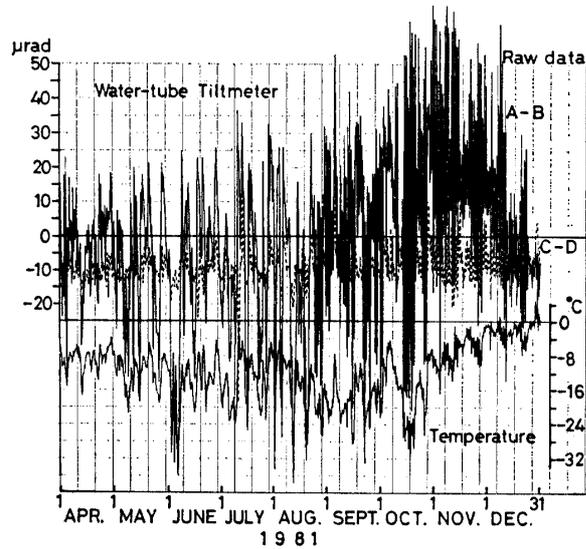


Fig. 2. Tiltmeter records of the *A-B* and *C-D* components and air temperature plotted every 6 hours.

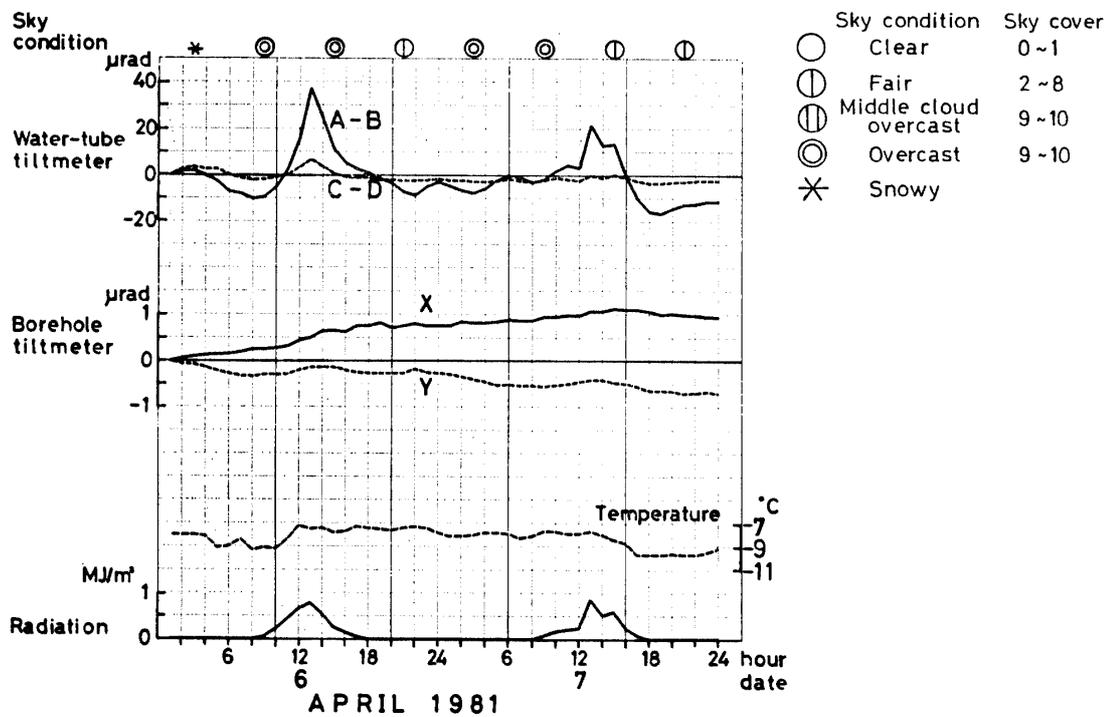


Fig. 3. Sky condition, hourly records of the water-tube and the borehole tiltmeters, air temperature and radiation on April 6-7, 1981.

to December 31, 1981. A distinct high-frequency diurnal fluctuation on the tiltgram is directly correlated with the variation of the solar radiation. The lower frequency fluctuations are mainly correlated with long-term temperature variations. The maximum amplitude of fluctuation on the *A-B* component reached  $100 \mu\text{rad}$ . This value is several times larger than the maximum amplitude seen on the *C-D* component. Main cause of this difference is attributed to the different vertical configurations of the connecting water-tubes as described above.

Solar radiation strongly affected the tilt data. The effects of solar radiation on the tilt data for different seasons of the year will be discussed in this section. Figure 3 is an example of data for autumn in Antarctica and compares the sky condition every 6 hours and hourly readings of tilts measured by both the water-tube and the borehole tiltmeters, the air temperature and the solar radiation during 48 hours of April 6–7. The duration of sunshine in early April is about 8 hours at Syowa Station. There is a clear correlation of large fluctuation in the tilt data with changes in radiation. However no such fluctuation was recorded with the borehole tiltmeter.

Figure 4 shows the same parameters as in Fig. 3 during 72 hours of June 6–8. In the winter season, radiation is unimportant because the sun is below the horizon at Syowa Station. The tilt data, especially that observed for the *A-B* component of the water-tube tiltmeter, is affected only by air temperature and not by radiation, because of the darkness.

Figure 5 shows the same parameters as in Figs. 3 and 4 during 48 hours of August 18–19. These days are at the end of winter in Antarctica and the sun shines 4–5 hours per day. Even on fine days radiation was very weak, less than  $0.1 \text{ MJ/m}^2$  as shown in

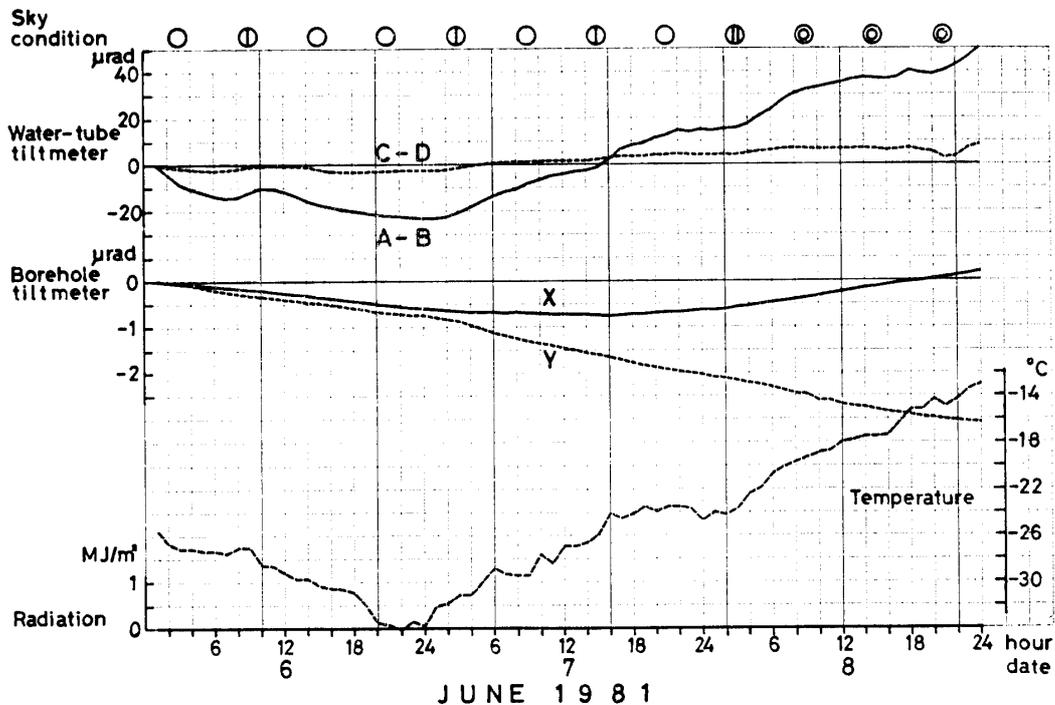


Fig. 4. Sky condition, hourly records of the water-tube and the borehole tiltmeters, air temperature and radiation on June 6–8, 1981.

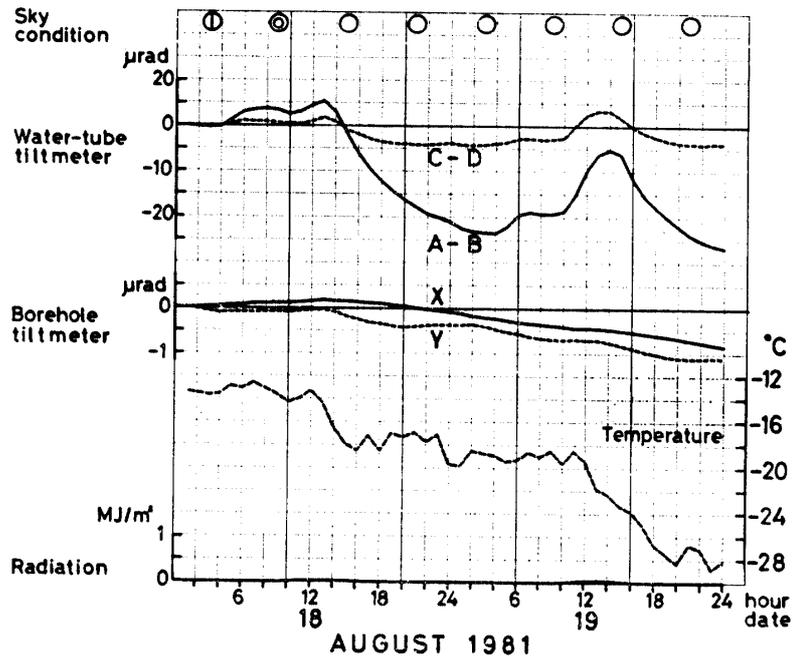


Fig. 5. Sky condition, hourly records of the water-tube and the borehole tiltmeters, air temperature and radiation on August 18-19, 1981.

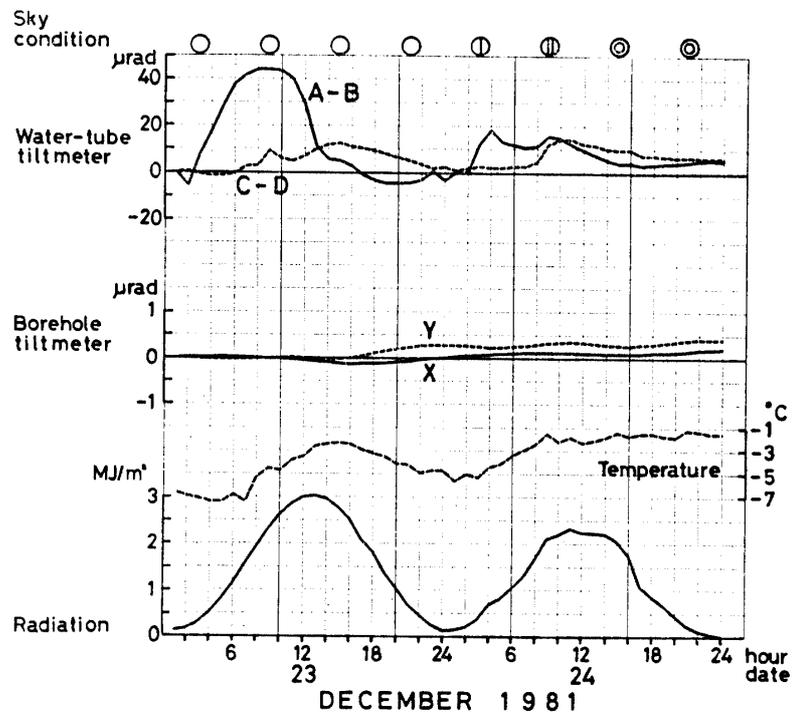


Fig. 6. Sky condition, hourly records of the water-tube and the borehole tiltmeters, air temperature and radiation on December 23-24, 1981.

Fig. 5. The tilt change measured by the water-tube tiltmeter was also affected by air temperature.

Figure 6 shows the same parameters as in the previous three figures during 48 hours of December 23–24. This is an example of data for the mid-summer season in Antarctica. The sun shines all day long and radiation reaches a yearly maximum. The tilt data observed with the water-tube tiltmeter shows a complicated pattern: 1) on December 23, which was a clear day, the variation of the water-tube  $A-B$  component was affected significantly by radiation, 2) on December 24, which was an overcast day, the variation of  $A-B$  was not affected by radiation as much as on the previous day, 3) the overall variation of  $A-B$  was similar to that of the radiation, but the maximum value of  $A-B$  appears 4–5 hours earlier than that of the radiation, and 4) the variation pattern of  $C-D$  is less affected by radiation and principally reflects variations of air temperature.

#### 4. Correction for Air Temperature Effects

To remove the high frequency fluctuations of the raw data, running means for both components and the air temperature were calculated. Figures 7 and 8 show 7- and 28-day running means of the tilt data and the air temperature. For the 7-day running mean the trends of the water-tube tilt changes generally follow the variation of air temperature. For the 28-day running mean a correlation with air temperature is not obvious. There are particularly significant departures of the tilt and air temperature trends from mid-November to December. The maximum variations of the  $A-B$  and  $C-D$  components shown in Fig. 8 reach  $40 \mu\text{rad}$  and  $5 \mu\text{rad}$ .

The value of cumulative tilt data of the  $C-D$  component is too small to be explained by the annual variation.

Figure 9 shows 14-day running mean of the water-tube tilt change and the air

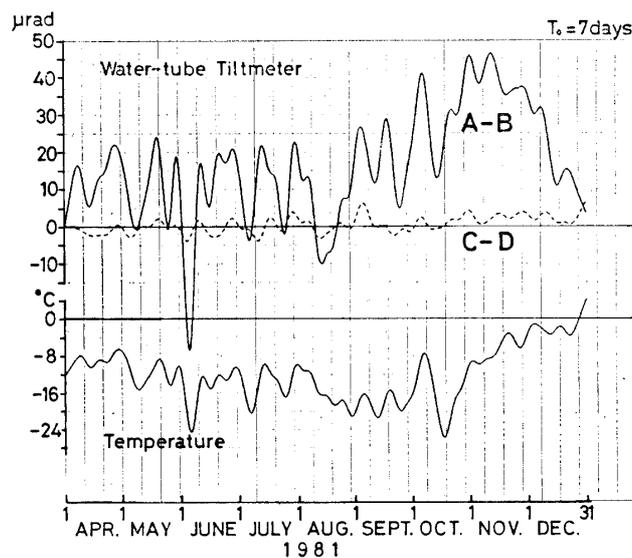


Fig. 7. 7-day running mean of tilts of the  $A-B$  and  $C-D$  components and air temperature.

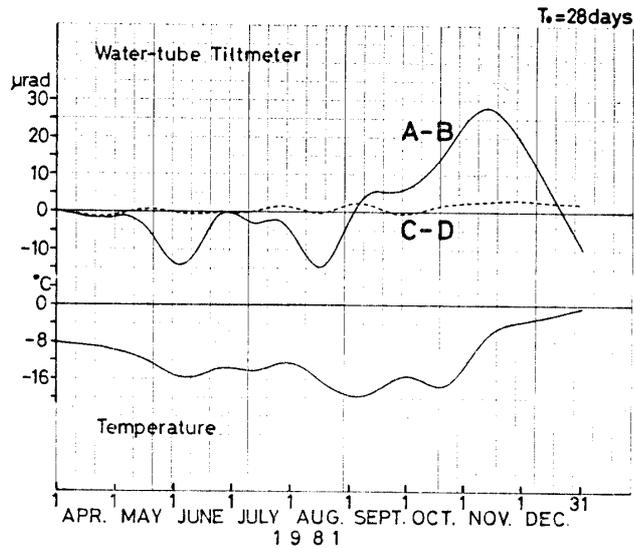


Fig. 8. 28-day running mean of tilts of the A-B and C-D components and air temperature.

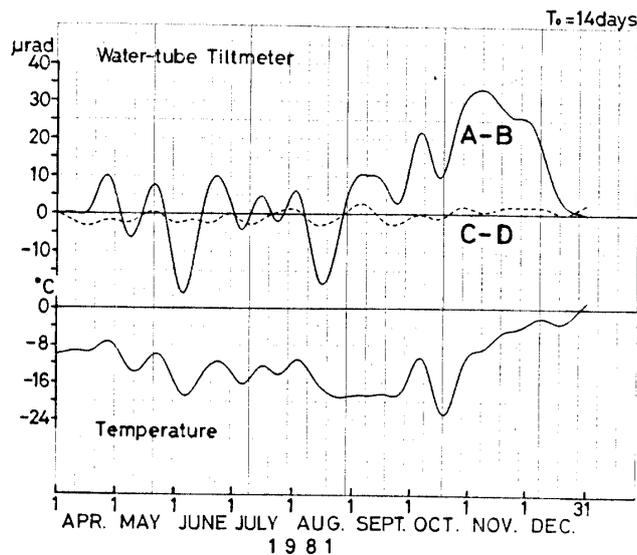


Fig. 9. 14-day running mean of tilts of the A-B and C-D components and air temperature.

temperature. From the early stage of the observations to mid-November, the tilt record seems to correlate with air temperature. Using the same method as discussed in Part 1 of this paper, the observed tilt data were corrected for temperature variations on the assumption that there was a linear relation between tilt and air temperature. Corrected values are given in Figs. 10 and 11.

The maximum amplitude of the corrected records of the C-D component was 7  $\mu\text{rad}$ . This value is the same order as the records of the borehole tiltmeter described in Part 1 of this paper. In Japan, annual variations of a water-tube tiltmeter installed in a vault ranged from  $10^{-6.5}$  to  $10^{-4.5}$  rad (SHICHI and OKADA, 1979). The maximum amplitude of the corrected record of the A-B component was 60  $\mu\text{rad}$ , which was within the annual range of tilt observed in Japan.

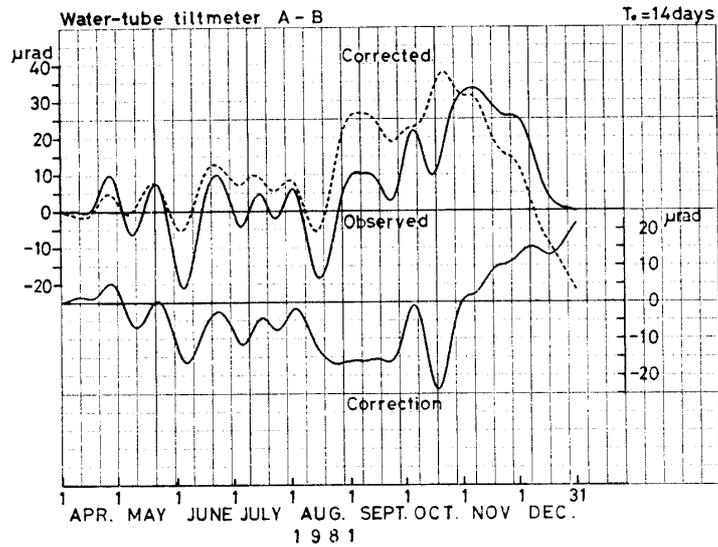


Fig. 10. Observed tilt data, correction for temperature, and the corrected tilt data for the A-B component. "Observed" is the tilt record of the A-B component, "correction" is the correction term and "corrected" is the value of "observed" minus "correction".

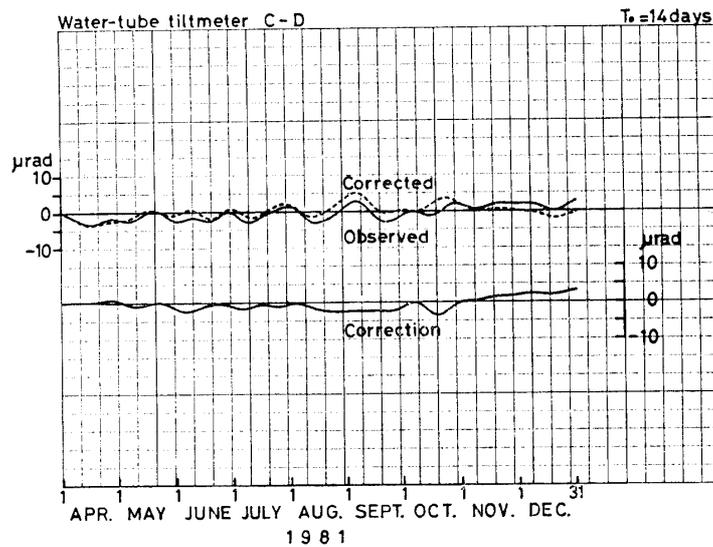


Fig 11. Observed tilt data, correction for temperature, and the corrected tilt data of the C-D component.

## 5. Conclusion

The tilt observations with the water-tube tiltmeter described in this paper were carried out for only nine months. The following preliminary results have been obtained from the observations presented here:

- 1) It is possible to observe ground tilt using a water-tube tiltmeter in Antarctica, even if there is no vault for installing the equipments.
- 2) Tilt records, observed with a water-tube tiltmeter installed on the surface,

were affected significantly by air temperature and radiation. However, the secular change of ground tilt in response to deglaciation will be detected.

3) In addition to the observations of the borehole and water-tube tiltmeters, a leveling route was established on East Ongul Island including the observation site in 1982. The measurements of the leveling and the observations of the tiltmeters will be continued at Syowa Station.

After the water-tube of the *A-B* component has to be replaced at nearly the same level as the detector, it should be continued over the next few years.

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