# POLAR MOTION PROGRAM OF THE EARTH PHYSICS BRANCH

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## ABSTRACT

The Polar Motion Group was established in 1973 as part of the newly organized Geodynamics Section within the Gravity Division to carry on studies of polar motion, earth's rotation and crustal plate movements. This long term program includes the operation of the two Canadian PZT observatories located near Ottawa and Calgary which have been accumulating astronomical data on latitude and longitude variations since 1951 and 1968 respectively. Both PZT which appear to be capable of detecting secular motions greater than 10 cm, contribute data regularly to the international time (BIH) and polar motion (IPMS) services.

In 1974 two Doppler satellite tracking stations were collocated with the PZT observatories to compare polar motion as determined by the two independent techniques. It is hoped that the Doppler satellite method will increase the accuracy and time resolution of pole determinations to facilitate studies of short-term variations of polar motion. A mini-computer system is being used to automate the satellite data acquisition, processing and communication. As part of the world-wide TRANET satellite tracking network the Doppler stations contribute data to the Dahlgren Polar Monitoring Service.

## 1. INTRODUCTION

The Polar Motion Group was formed in 1973 as part of the newly organized Geodynamics Section within the Gravity Division to carry on studies of polar motion, earth's rotation and crustal plate movements. The group was organized around the well established PZT operations in Ottawa and Calgary which were attached to the geophysical divisions when the Earth Physics Branch was formed in 1970 after the dissolution of the Dominion Observatory. The Polar Motion Group was to continue the PZT work which still contributes much excellent data on the global dynamics of the earth, and at the same time it is supposed to investigate and experiment with newer techniques which could eventually supersede the optical astronomical observations. Since the Polar Motion group presently consists of only one research scientist and four technical officers, two in Ottawa and two in Calgary, automation of routine observing procedures and data processing is of necessity an important aspect of the polar motion program.

## 2. PZT PROGRAM

The PZT operation in Ottawa was set up in 1951 as part of the Positional Astronomy Division and has since been producing data nearly continuously (Thomson, 1955). During this period the PZT location was changed three times and the original instrument was replaced in 1968. Since 1970 the Ottawa PZT No. 2 has been located at Shirleys Bay approximately 16 km due west of its original site at the Dominion Observatory. With the exception of the first period between 1952 and 1955, when the scatter of observations was rather large due to changing operation procedures and the lack of an atomic standard for time comparisons, the Ottawa PZT observations of time and latitude provide excellent material for studies of polar motion and earth's rotation. Analyzing the PZT data accumulated between 1956 and 1970 Woolsey (1972) concluded that the observational noise in both coordinates is around 10 cm for averaging intervals of about 15 days. He clearly identified the Chandler term as the most prominent in the latitude observations with more than twice the amplitude of the annual term. For the time observations long-term variations prevail while the annual and semi-annual terms can be observed on the background of short-term variations.

Realizing the potential of precise PZT observations and in an attempt to eliminate biases between different PZT star catalogues which define the reference frame, the IAU strongly recommended in 1963 to locate new PZT sites on the latitudes of existing PZT observatories whenever possible. Following this recommendation a site for a new PZT was chosen at Priddis near Calgary on the same latitude as the Herstmonceux PZT of the Royal Greenwich Observatory in England. The regular observations at Calgary commenced in 1968 using the PZT No. 1 from Ottawa and the Hertsmonceux star catalogue. The data obtained at Calgary from 1968 to 1972 contributed to a major revision of the star catalogue and the new catalogue was introduced at the beginning of 1975.

The nightly operations of both PZT are fully automated using an electro-mechanical system which has to be manually reset once a day. Although the measurement of PZT plates requires manual setting on program star images the data are automatically punched on cards for computer processing. The PZT results from both stations are transmitted weekly to the BIH in Paris and monthly to the IPMS in Mizusawa in a form of average time and latitude observations for star groups. Both stations also participated in the so called rapid service during critical phases of the Mariner series interplanetary flights when UT1 and pole position were evaluated daily from observations of only fourteen BIH stations (Feissel, Guinot 1974).

The average night observations at Ottawa and Calgary together with reduced smoothed values of latitude and time are summarized in annual reports published in the Geodynamics Series Bulletins. The 1974 Ottawa PZT time results are shown in Fig. 1 where the standard deviation of the average night UT2 from the smoothed curve is about 4 ms. Fig. 2 shows the average night latitude variations at Ottawa in 1974; the standard deviation from the smoothed curve is about 0".035. The scatter for the Calgary observations is about 40% larger due to the shorter focal length of the telescope built to match the Hertsmonceux PZT and its higher latitude which affects the time observations (Fig.3). The smoothing is performed using the graduation method generalized by Vondrak (1969) for uneven data distribution with different weights. For this method different degrees of smoothing can be achieved by changing a single parameter, the so called coefficient of roughness, from one extreme when the smoothed curve is a least squares parabola, to the other when the smoothed curve passes through each observation while minimizing the sum of third differences. The coefficient of roughness can be varied to produce a smoothed curve with a certain standard deviation. Fig. 4 shows the same time observations at Calgary with a standard deviation from the smoothed curve reduced by 1 ms (from 6 to 5 ms). How much of the variations are due to observing conditions (meteorological or instrumental) and what is due to short term variations in the earth's rotation and polar motion remains to be determined. However, it has been generally accepted that short term variations as well as major changes particularly in the rate of rotation do exist although their causes are not fully understood. A significant change in the earth's rate of rotation occurred at the end of 1973 as shown in Fig. 5; the change in the slope of UT2 against UTC amounts to about 0.5 ms per day. A similar change but in the opposite direction took place between 1964 and 1966. (Woolsey, 1972).

## 3. RECENT DEVELOPMENTS IN POLAR MOTION STUDIES

Greater interest particularly in irregular changes in polar motion was stimulated by the hypothesis put forward by Smylie and Mansinha (1967) relating such changes to major earthquakes. Disadvantages of the optical astronomical observations to detect positively abrupt changes in the polar motion are obvious: only night observations under favourable weather conditions are possible and data from a number of observatories are necessary to determine the pole position; the processing itself tends to suppress any abrupt fluctuations. In 1969 Anderle and Beuglass (1970) found that polar motion could be determined by analysis of Doppler satellite observations. A difference between the true and assumed pole position produces a systematic effect on along track residuals of satellites in polar orbit. The period of this systematic effect is 24 hours with maxima occurring at the times when the meridian plane containing the true and assumed poles coincides with the satellite orbital plane and nulls when these planes are perpendicular to each other. This effect can be evaluated from data of a single station providing the distribution of satellites is favourable. Smith et.al. (1972) reported on a method using laser satellite tracking to determine polar motion effect on station latitude by measuring the apparent variations in the inclination of the satellite orbit. At the same time very promising results for polar motion and UT1 determinations were reported using radio astronomical methods, VLBI in particular (Gold, 1967; Shapiro et al., 1974).

## 4. DOPPLER SATELLITE TRACKING PROGRAM

These developments led in 1971 to the formation of a committee consisting of R.W.Tanner and R.I.Walcott to study possibilities of using some of the new methods for geodynamic studies and complement the existing PZT operations of the Earth Physics Branch. After extensive consultations the committee found Doppler satellite tracking as the best immediate prospect for a satellite geodynamics program. This was supported by the resolution of the IAU Symposium on Earth's Rotation in 1971 which strongly recommended collocation of Doppler satellite tracking equipment with existing observatories participating in the international time and polar motion services. Such collocations were negotiated for other sites, Misuzawa and Brussels, and Ottawa and Calgary were considered as important additions because of their locations and rather prominent position in the BIH and IPMS systems. More important support came from the NWL which was responsible for data processing and pole determinations for the world-wide TRANET satellite tracking network. The Doppler satellite tracking equipment, personnel training as well as close co-operation in data processing and evaluation have been offered in exchange for data. This was rather important considering the high costs of equipment and operation. The agreement covering the loan, operation and maintenance of Doppler satellite tracking stations between the U.S.Defense Mapping Agency Topographic Center and the Earth Physics Branch was reached in January 1974. In April 1974 a Geoceiver was set up at Calgary and a TRANET van was brought to Ottawa and installed in September.

The Doppler satellite tracking is a 24 hour all weather operation producing a large amount of raw data. It has been apparent from the very beginning that without proper automation of the Doppler stations one man can never acquire and manually process the satellite data to meet daily transmissions to the Satellite Control Center (SCC) at the John Hopkins University in Maryland. Moreover, any independent data processing and analysis would be impossible. The Doppler satellite operations were therefore carefully analysed and after surveying the market of automatic measurement instruments, a real-time data acquisition processing and communication system was procured toward the end of 1974.

The system as presently constituted (Fig. 6) is based on a Hewlett-Packard distributed mini-computer system with a central unit in Ottawa and a terminal in Calgary. The central unit consists of a 24K HP2100 mini-computer operating under multiprogramming real-time executive with file manager, paper tape reader, 5 megabyte cartridge disc drive, 30 cps console printer and card reader. The distributed system package provides on-line communication between the terminal and central computers giving the terminal full access to all the resources of the central system such as data storage and file manipulation on the central disc, program scheduling on the central computer and terminal program development and storage. The terminal system which consists of an 8K HP2100 mini-computer, paper tape reader, console printer and card reader, operates under terminal communication executive as a sophisticated input-output device with its own programing capability. Both mini-computers are equipped with interface cards to enable direct real-time data input from the satellite tracking stations and eventually basic computer control of the stations. The latter will probably be limited to a simple switching function for the Geoceiver whereas the modular design of the TRANET station is more suitable for implementation of additional control functions. The mini-computers will eventually be directly interfaced with automatic weather stations so that meteorological parameters (temperature, pressure and humidity) can be automatically recorded during satellite passes.

Immediately after a satellite pass the data will be checked for internal consistency and identified by comparison with satellite predictions before being temporarily stored on the central disc. Another program will prepare a uniform observation file for permanent storage and select passes for transmission to the SCC as requested.

The HP Remote Data Transmission System in connection with a 2000 bps data phone enables the central system to emulate an IBM 2780 terminal to any large computer installation supporting a dial-up port using the 2780 protocol. This system is operational and will be used to transfer the observation file onto high density magnetic tapes for permanent storage as well as for batch job processing.

Since the SCC supports only teletype communication a buffered telex interface has to be used for the daily data transmissions of requested passes from the central computer disc to the SCC.

At the present time most of the hardware has been assembled with the exception of the weather stations. A concrete pier has been built for the geoceiver antennae on the PZT observatory grounds at Calgary and the TRANET antennae is presently mounted on the roof of the Geophysical Building at the old Dominion Observatory grounds in Ottawa. The software for the real-time data acquisition and processing is being developed and it is hoped that the basic system will be operational in a few months. In the meantime the Doppler satellite tracking is limited to manual or unattended modes of operation for the highest priority satellites.

## 5. CONCLUSIONS

The primary objectives of the Polar Motion Group of the Earth Physics Branch can be summarized as follows:

1. Continuous observation of variations of the station coordinates at Ottawa and Calgary using the astronomical and Doppler satellite methods to study polar motion and analyse differences between the two systems; since the error sources in PZT and Doppler results are largely independent any common changes in polar motion can be considered to be due to physical rather than computational sources:
2. To use the Doppler satellite method to increase the accuracy and time resolution of pole determinations in order to facilitate studies of short-term variations of polar motion:
3. To study variations in the rate of rotation of the earth:
4. To provide permanent reference points for satellite and astronomical observations and for long term studies of crustal plate movements.

The program is intended to generate high quality data which would help to preserve the continuity of polar motion studies and enhance the understanding of global geodynamics phenomena.

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## CAPTIONS

Fig. 1 Individual night observations of time with the Ottawa PZT in 1974 and the smoothed curve for UT2 - UTC + 2.7 ms/day (STD 4.1 ms; UTC step adjustments removed).

Fig. 2 Individual night observations of latitude with the Ottawa PZT in 1974 and the smoothed curve for PHI 1 (latitude corrected for the 1974 BIH pole positions; STD 0."035).

Fig. 3 Individual night observations of time with the Calgary PZT in 1974 and the smoothed curve for UT2 - UTC + 2.7 ms/day (STD 6.1 ms; UTC step adjustments removed).

Fig. 4 Individual night observations of time with the Calgary PZT in 1974 and the smoothed curve for UT2 - UTC + 2.7 ms/day using an increased coefficient of roughness (STD 5.1 ms; UTC step adjustments removed).

Fig. 5 Individual night observations of time with the Ottawa PZT in 1973 and 1974.

Fig. 6 Mini-computer system for satellite data acquisition, processing and communication.

Fig. 1 Individual night observations of time with the Ottawa PZT in 1974 and the smoothed curve for UT2 - UTC + 2.7 ms/day (STD 4.1 ms; UTC step adjustments removed).

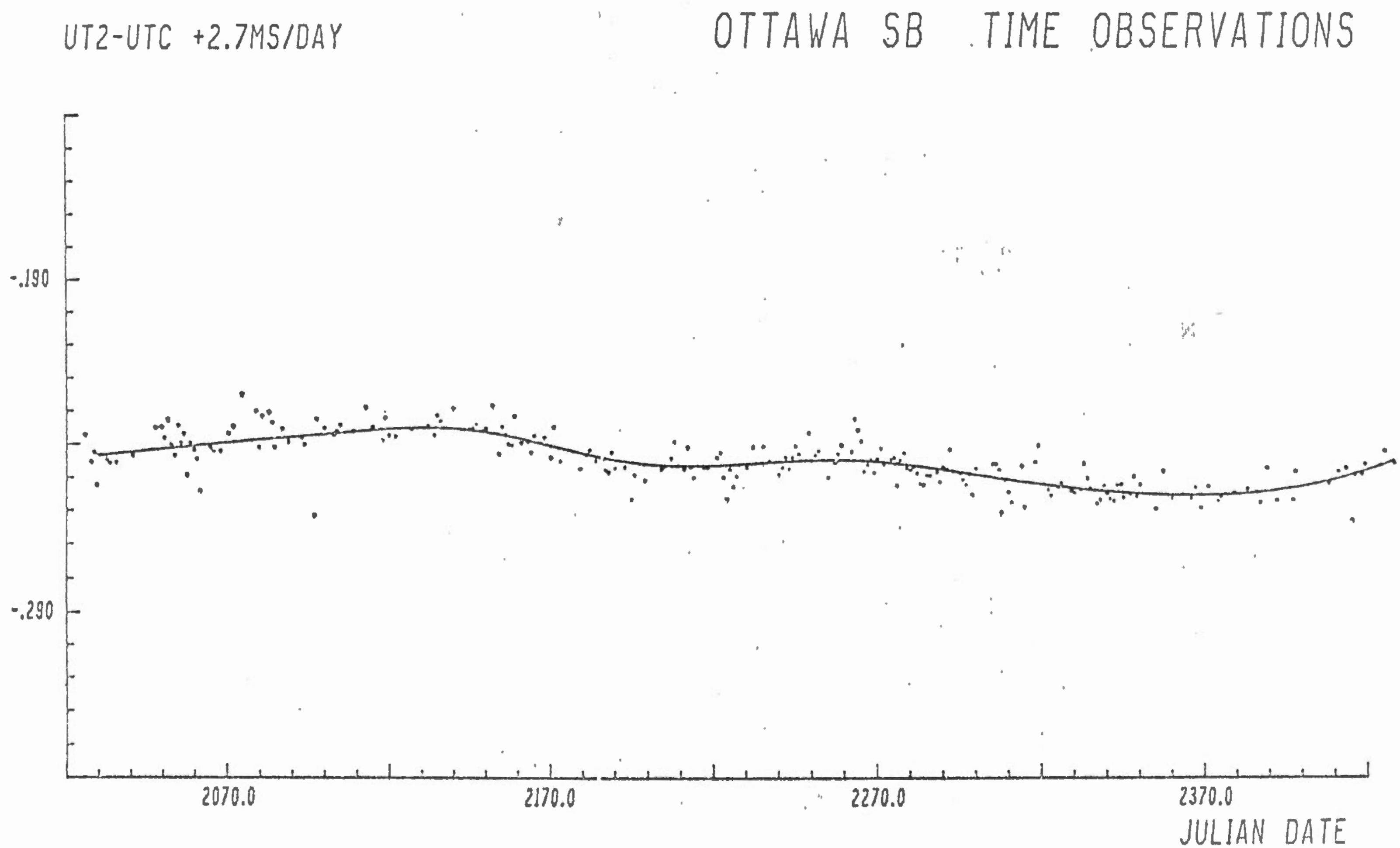


Fig. 2 Individual night observations of latitude with the Ottawa PZT in 1974 and the smoothed curve for PHI 1 (latitude corrected for the 1974 BIH pole positions; STD 0."035).

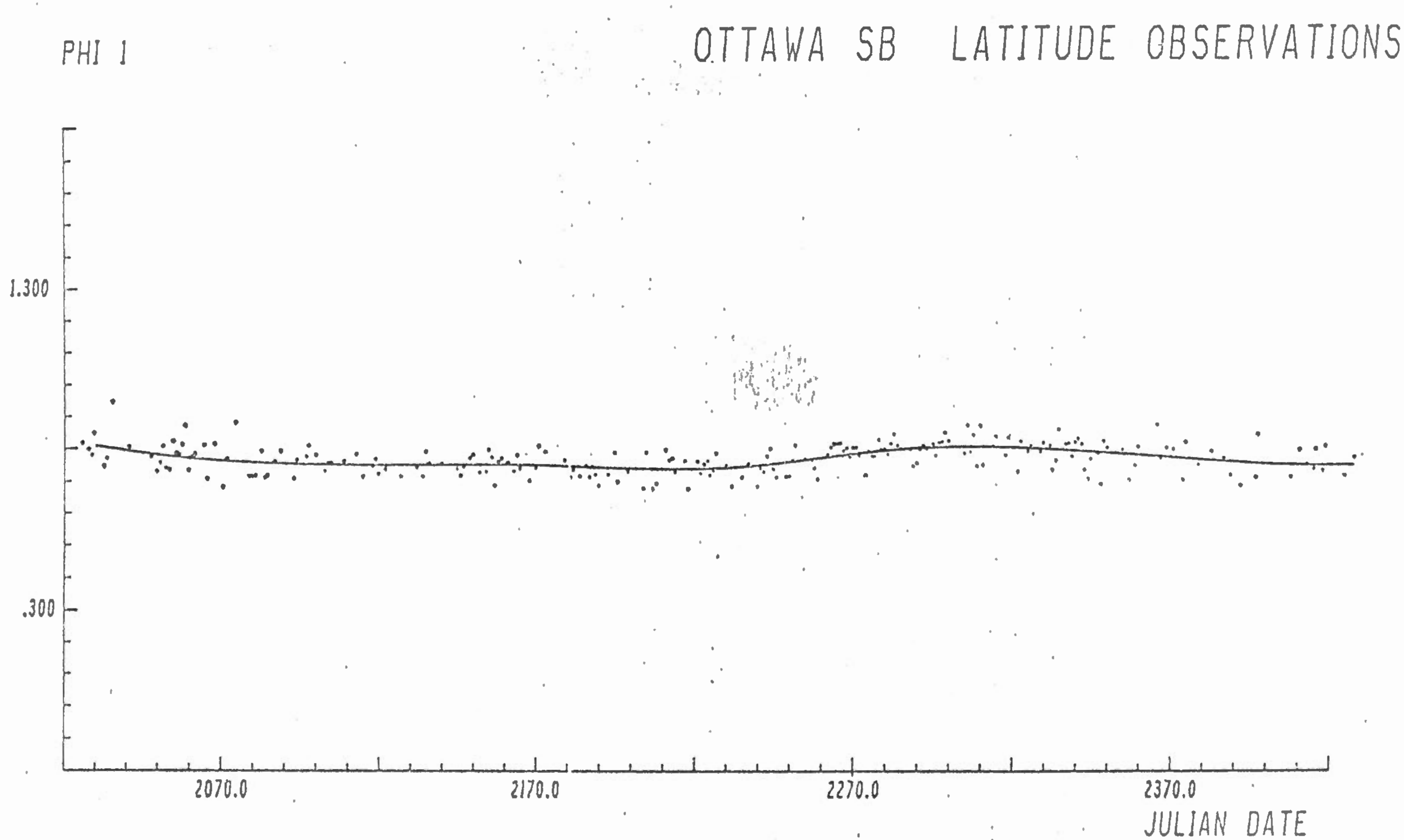


Fig. 3 Individual night observations of time with the Calgary PZT in 1974 and the smoothed curve for UT2 - UTC + 2.7 ms/day (STD 6.1 ms; UTC step adjustments removed).

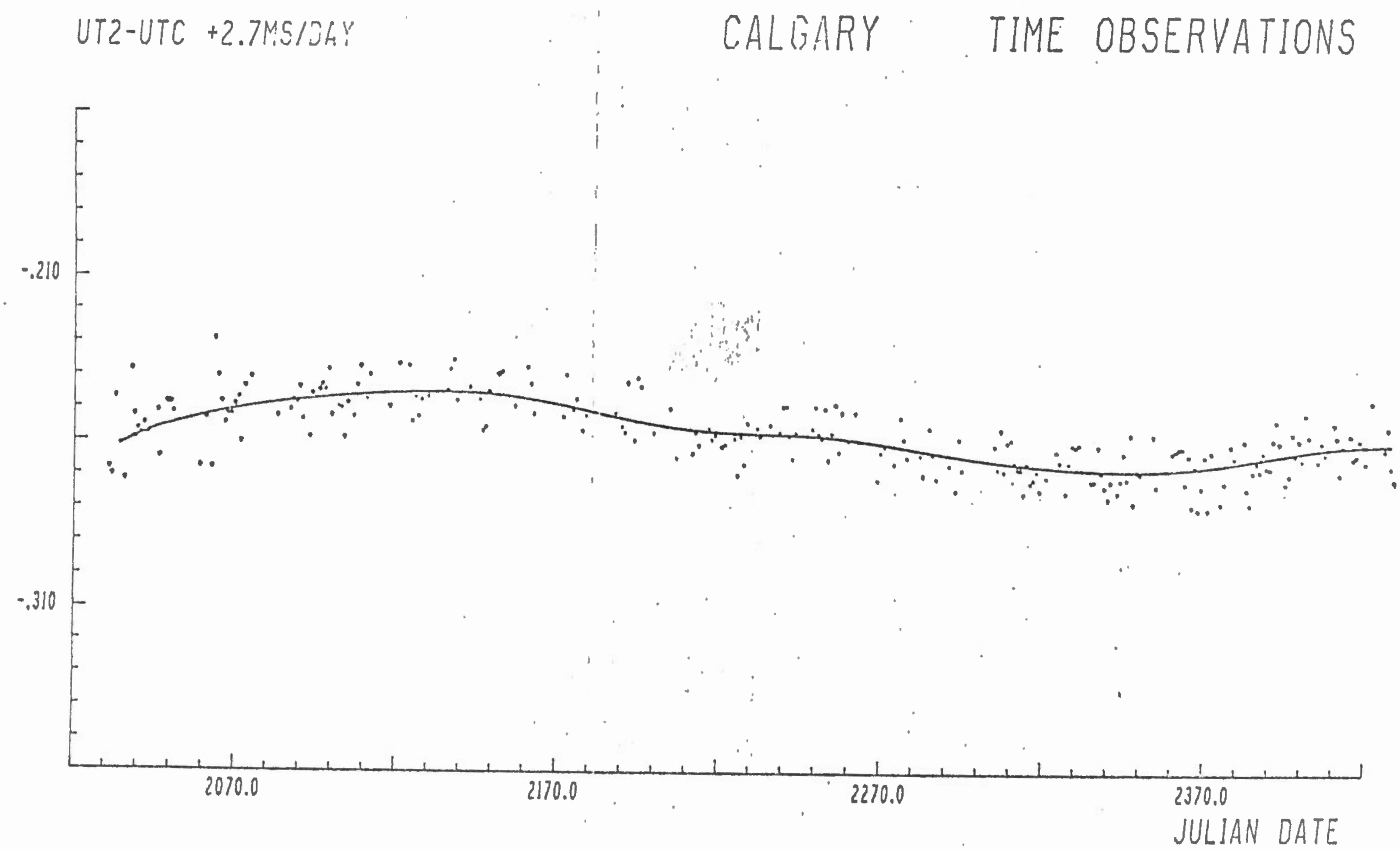


Fig. 4 Individual night observations of time with the Calgary PZT in 1974 and the smoothed curve for UT2 - UTC + 2.7 ms/day using an increased coefficient of roughness (STD 5.1 ms; UTC step adjustments removed).

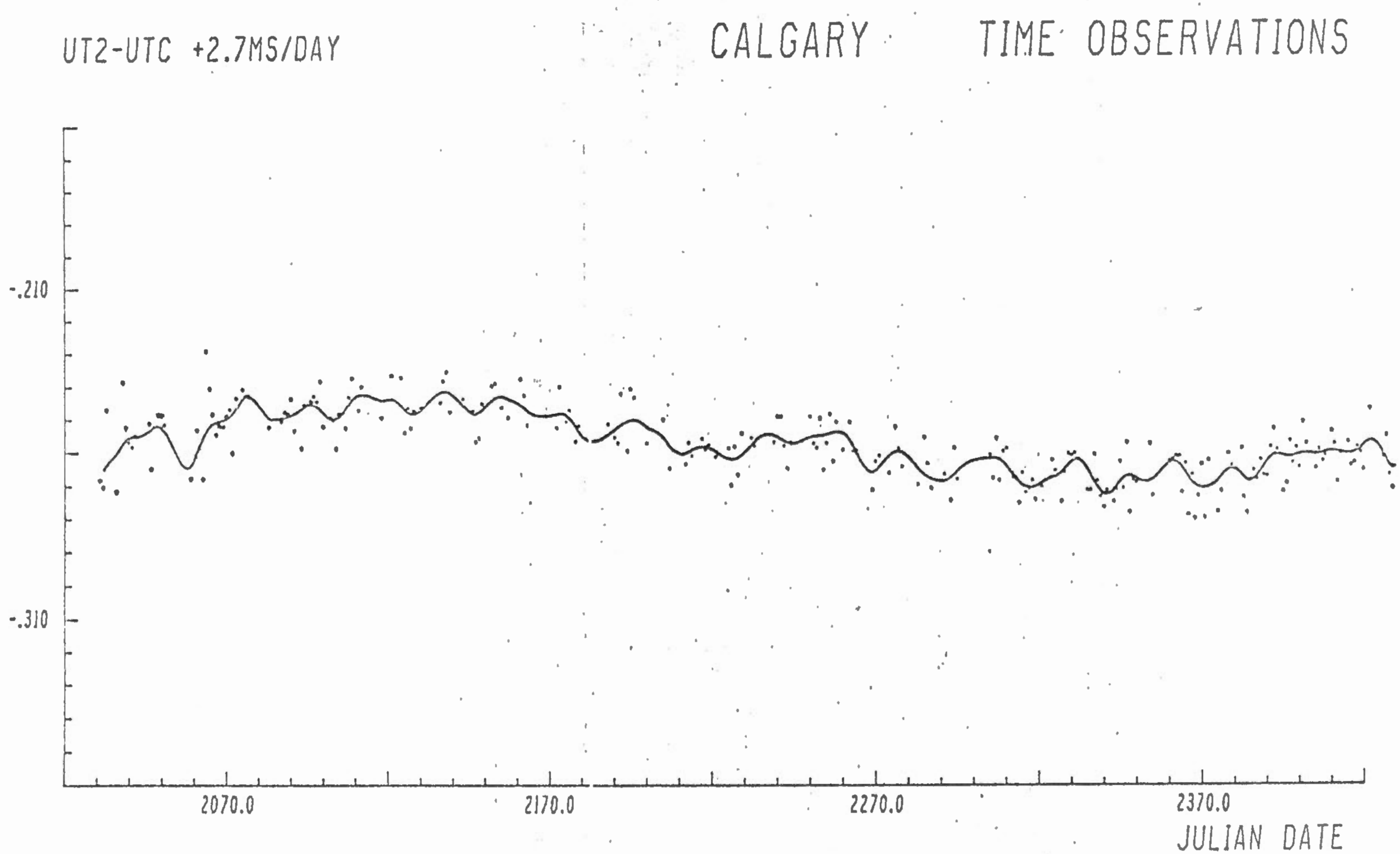
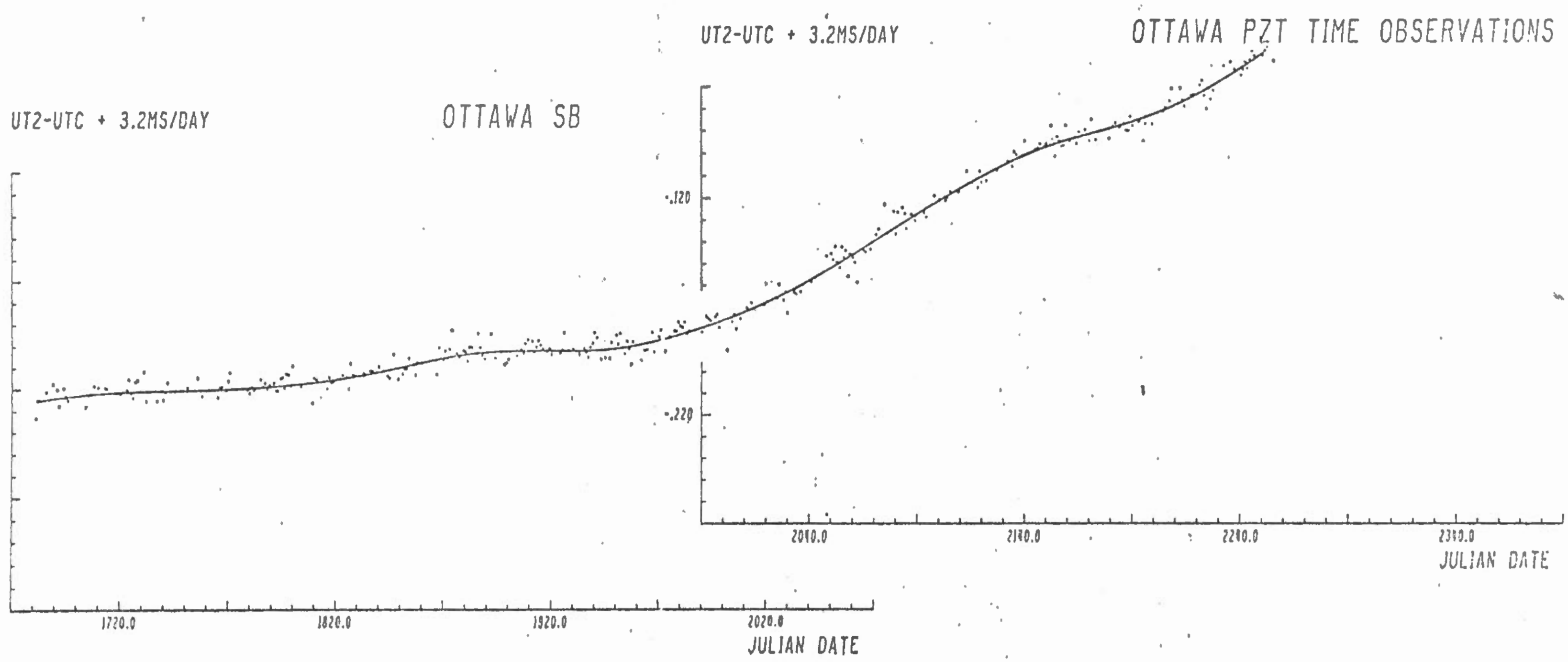


Fig. 5 Individual night observations of time with the Ottawa PZT in 1973 and 1974.



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