# LOW-LATITUDE CONJUGATE ULF OBSERVATION BY RULFMETERS

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***Abstract*:** In order to identify the HM wave modes for low-latitude Pc 3 pulsations, it is important to observe ULF waves with some standardized magnetometers simultaneously at low-latitude conjugate stations. Hence, an intercontinental ULF observation was carried out from November 1982 to June 1983 at the three low-latitude stations; Onagawa (ONW), Japan, Townsville (TSV), Northern Australia, and Beveridge (BVR), Southern Australia. New ring-core type ULF magnetometers (rulfmeters) were set at the three sites. ONW ($L$=1.30) and TSV ($L$=1.29) are nearly conjugated magnetically, while ONW (38°.4) and BVR (−37°.8) are nearly at the same geographic latitude.

Analyses were made to obtain various wave characteristics including polarization and orientation angle of Pc 3 ellipses, their diurnal behavior, etc. The results suggest a diurnal tendency that the low-latitude Pc 3 is due mainly to the compressional mode in 18–21 and 0–(8) UT, while the fundamental standing Alfvén mode in 21–24 UT in these meridians.

## 1. Introduction

The purpose of the present paper is to report some preliminary results of our low-latitude conjugate observation of ULF waves which was carried out by the use of rulfmeters in 1982. This observation was planned as a part of the project to study the structure of the heliomagnetosphere.

An example of the relation between the heliomagnetosphere and Pc 3 is shown in Fig. 1, where a 27-day recurrence time pattern of amplitudes of the Pc 3-type ULF wave observed at the Onagawa Magnetic Observatory in 1974 is displayed in the panel at the bottom. The panel shows two marvelous series of 27-day recurrence tendency of the Pc 3 on 2–6th days and 12–19th days, respectively, which correspond to the epochs of enhancement of the solar wind speed, which further corresponds to the

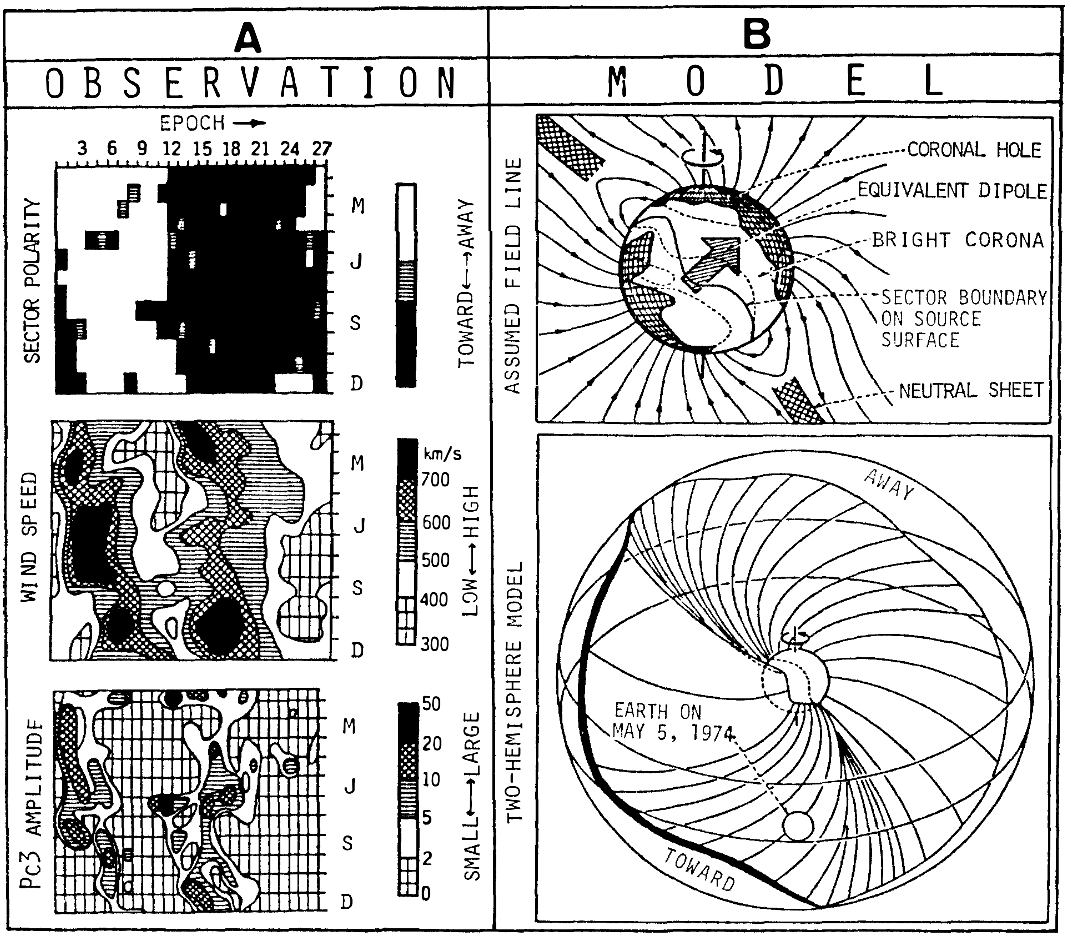


*Fig. 1. (A) Observed 27-day recurrence time pattern of IMF sector polarity, solar wind speed, and Pc 3 amplitude. (B) Two-hemisphere model on the structure of the heliomagnetosphere to interpret (A).*

solar wind magnetic field, namely, the crossing of the two interplanetary sectors as shown in Fig. 1A. The recurrence tendency of these events was considered by SAITO (1982) to be due to the structure of the heliomagnetosphere as shown in Fig. 1B. It was concluded in this sense that Pc 3 is a useful phenomenon to study the heliomagnetosphere as if Pc 3 is a very sensitive anemometer to feel the solar wind. Nevertheless, the constitution of the anemometer, namely, the mechanism of transmission from the solar wind to Pc 3 observed on the low-latitude ground is not always minutely clarified yet, since the HM wave propagation is complicatedly related to all the magnetic and plasma structures from the magnetopause to the low-latitude ground.

In order to study the characteristics of ULF waves, we carried out, prior to the present observation, the First Oversea ULF Observation Project, which was called Circum Northern Pacific ULF Observation Project. In this project, we put four sets of rulfmeter at four sites surrounding the Northern Pacific Ocean; Ewa (Hawaii), San Gabriel Canyon (California), College (Alaska), and Onagawa (Japan) as shown in Fig. 2A. Although the main purpose of this first project is to clarify the Pi 2-substrom relation and the study of Pc 3 is a by-product in this project, it was revealed that the averaged

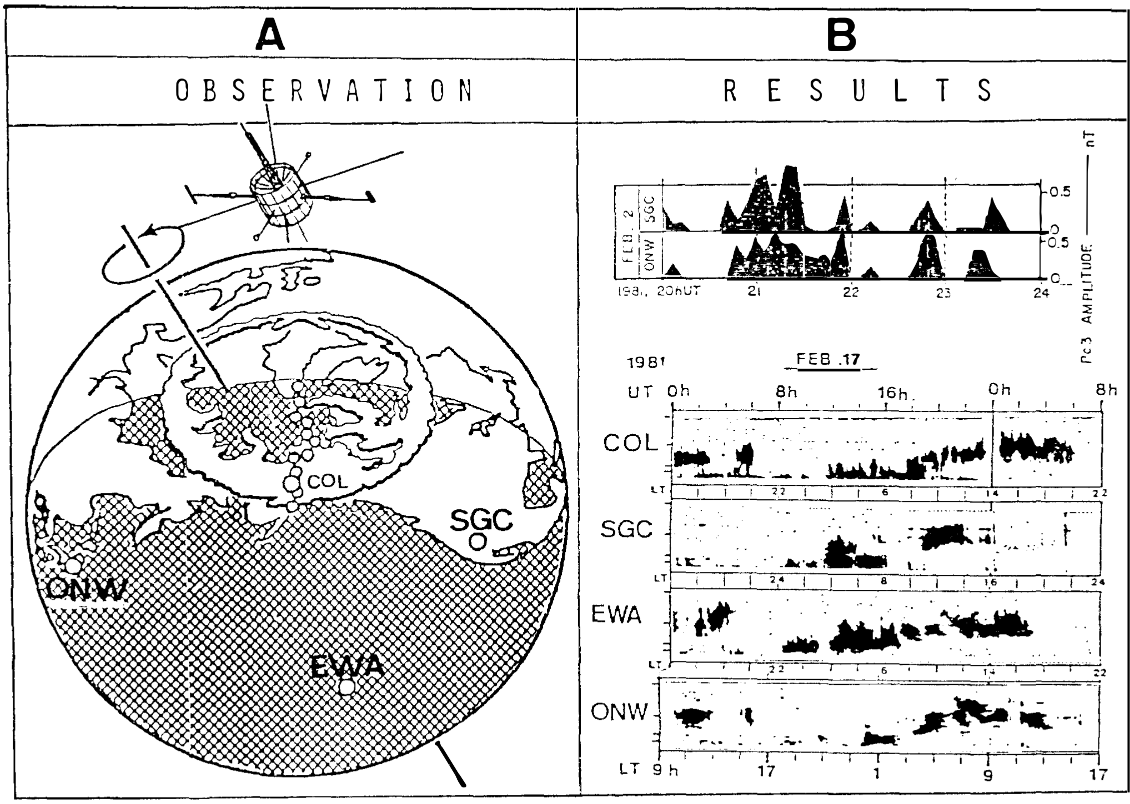


*Fig. 2. The First Oversea ULF Observation Project carried out in 1981. (A) Four ULF stations and ISEE-3. (B) A part of the analyzed results.*

amplitudes of Pc 3 waves increase and decrease almost simultaneously in the wide area of the sunlit side of the earth as shown in Fig. 2B, having been controlled by both the cone angle of IMF and the solar wind speed. Based on this result of the longitudinally wide coherence, the present observation was planned as the Second Oversea ULF Observation Project.

Actually, the plan was proposed about 15 years ago as one of our IASY projects in the 1960's (KATO *et al.*, 1968) as shown in Fig. 3A. Unfortunately our plan was not granted as the IASY project, but a part (chain-station) of our plan was executed by many other research groups in the 1970's as shown in Fig. 3B. However, the rest of our plan (SAITO, 1979), that is the low-latitude conjugate study, was still not realized. As we pointed out, an appropriate low-latitude conjugate pair is taken almost only with the Japan-Australia pair in the world.

*Table 1. Geographic and geomagnetic location of the three stations.*

| Station | Geographic | | Geomagnetic | | *L* |
|---|---|---|---|---|---|
| | Lat. | Long. | Lat. | Long. | |
| Onagawa | 38.43N | 141.47E | 28.55 | 208.14 | 1.30 |
| Conjugate P. | 18.55S | 135.45E | −28.55 | 208.14 | 1.30 |
| Townsville | 19.27S | 146.78E | −28.10 | 220.63 | 1.29 |
| Beveridge | 37.77S | 145.08E | −46.61 | 222.28 | 2.12 |

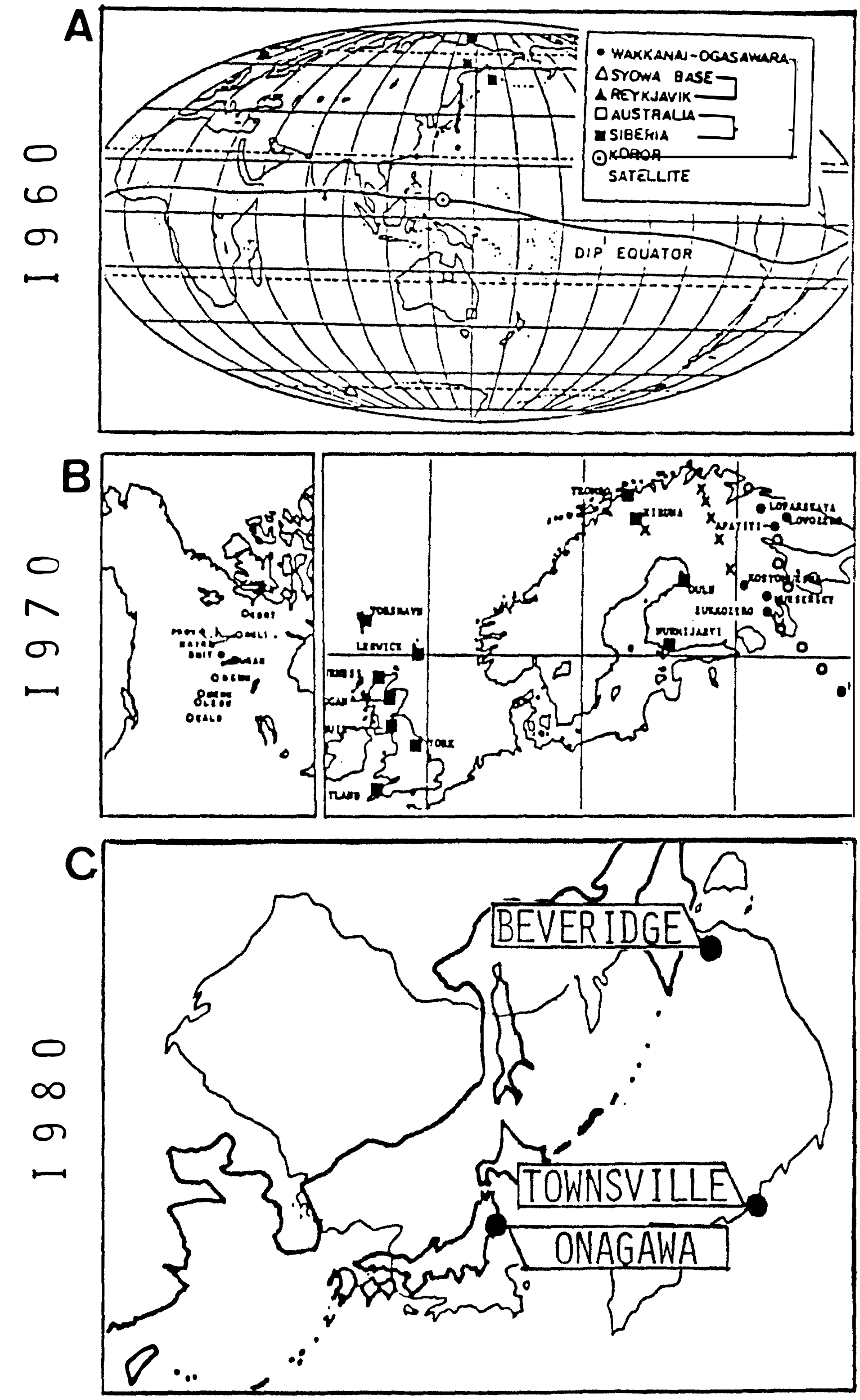


*Fig. 3. Various projects on simultaneous ULF observation at multi-stations. (A) IASY project proposed in the 1960's by the Onagawa research group. (B) IMS project carried out in the 1970's. (C) Low-latitude conjugate ULF observation project carried out in the present study.*

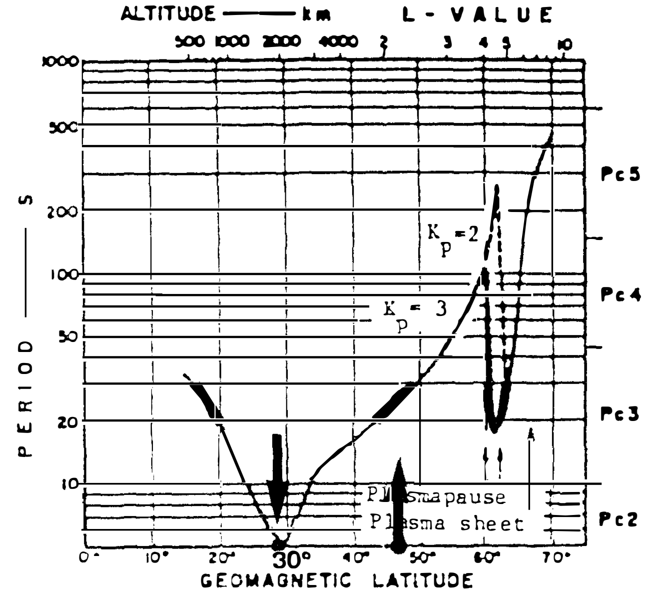


*Fig. 4. Theoretical expectation on the relation between the geomagnetic latitude and the period of the torsional HM oscillation.*

Our initial intention was an exactly conjugated observation, but we found it very difficult to observe at the exact conjugate point of Onagawa, because of a deep and hot desert. Then, Townsville, Queensland, is taken since its geomagnetic latitude is almost the same as that of Onagawa. Besides the Onagawa-Townsville pair, Beveridge, Victoria, is chosen since the period of the torsional oscillation of the field line anchoring there is theoretically in the Pc 3 range as shown in Fig. 4. The geographic and geomagnetic locations of the three stations are listed in Table 1.

## 2. New Ring-Core ULF Magnetometer

Our ULF observation is characterized by the use of a new type magnetometer which has been developed by our research group. Very small triaxial ring-cores with diameter of 25 mm are used as the ULF sensors instead of the traditional induction coils. It is very important in the study of ULF waves to analyze always in relation to the magnetosphere condition that is inferred from substorm, sc, si, sfe, initial phase, main phase, last phase, etc. In order to do so for field survey, we had to bring traditionally both triaxial induction coils ($\dot{H}$, $\dot{D}$, $\dot{Z}$) and triaxial fluxgate ($H$, $D$, $Z$). Since a ring-core is much more sensitive than the traditional 2-core type fluxgate sensor, only one small triaxial ring-core sensor can provide all the six components, $H$, $D$, $Z$, $\dot{H}$, $\dot{D}$, and $\dot{Z}$ by taking output of ordinary $H$, $D$, $Z$ as fluxgate, and the other set of output, $\dot{H}$, $\dot{D}$, and $\dot{Z}$, through appropriate filters (SAITO *et al.*, 1981). Since the new ULF magnetoMETER is characterized by the use of a Ring-core, this is called RULFMETER. Both the size and the weight of our rulfmeter is only $\sim 1/25$ of the traditional induction and fluxgate in the sensor part as shown in Fig. 5A. The small size and weight mean not only a handy type for field observation, but also saving of all the packages, carriages, man power, supplies, etc. These are immeasurably great

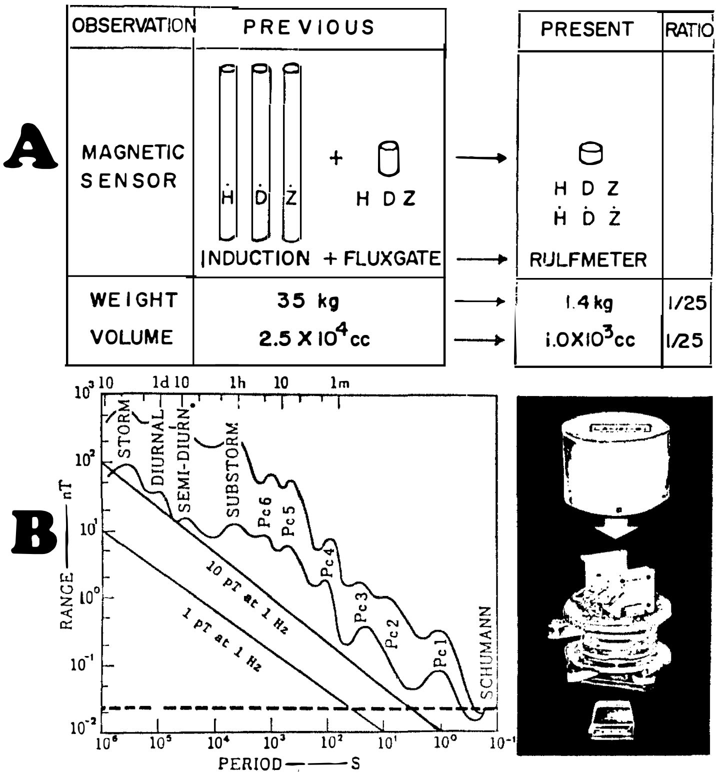


*Fig. 5. (A) Comparison of the rulfmeter with the previous induction and fluxgate magnetometers. (B) Spectrum of geomagnetic perturbations and a picture of the rulfmeter sensor.*

merits especially in carrying out oversea ULF observation.

Besides the merits in size and weight, we found and concluded in this observation that the rulfmeter is much free from artificial noises. Usually we have been bothered by the noises with frequencies of 1 Hz or higher, which are amplified time-derivatively by an induction sensor and frequently provide a very bad signal-to-noise ratio as shown in Fig. 5B. In our case, the rulfmeter has a good constant response for a very wide frequency range from DC to 30 Hz. Hence, the noises can be under the threshold of the rulfmeter. The present observation, therefore, makes confirmation of our previous prediction (SAITO *et al.*, 1981) that in the very near future rulfmeters will be currently used for the study of ULF waves instead of induction magnetometers which have been used for about one century.

## 3. Outline of Observation

One set of the rulfmeter was installed at the Beveridge field station of La Trobe University, Melbourne on November 3, 1982. A sensor case and a fence against sheep were constructed in the open area and the recording part was set in the observatory house as shown in Fig. 6. A distinct Pc 3 event was promptly registered within the same day as shown on the rulfgram in Fig. 7, where the marvelous fluctuations are not artificial, but Pc 3 waves.

Next, we flew to Townsville, Queensland and installed another set of rulfmeter

*Fig. 6. The rulfmeter sensor at the Beveridge field station.*

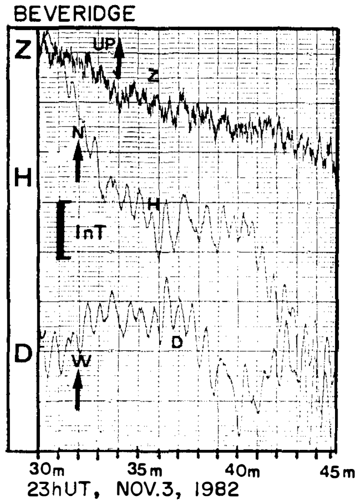


*Fig. 7. An example of rulfgrams of Pc 3 events observed at Beveridge.*

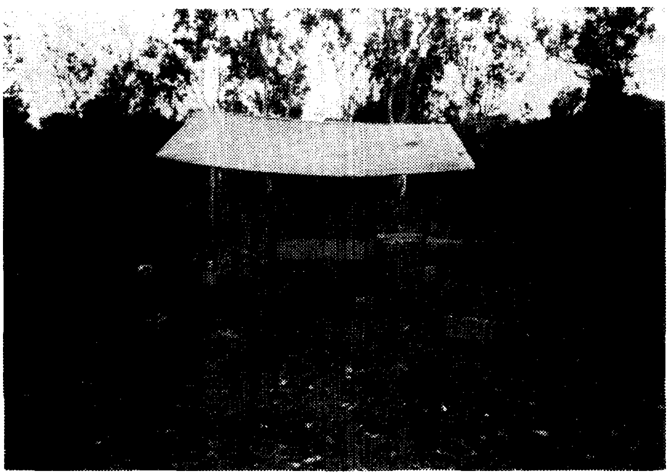

*Fig. 8. The recording part of the rulfmeter at the Townsville field station.*

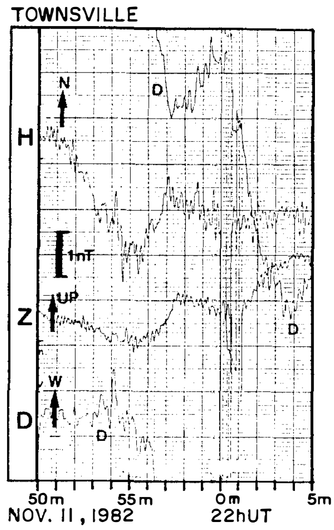


*Fig. 9. An example of rulfgrams of Pc 3 events observed at Townsville.*

by the physics building in the James Cook University campus. The cables were buried in the ground to protect them from kangaroos and wild fires. The amplifier, timer, recorder, etc. were set in a small aluminum case which was prepared by the University. The solar heat was shielded by a tent, aluminum painting, and ventilator (Fig. 8). A part of the first record in Townsville is exhibited in Fig. 9, where a Pc 3 event is registered.

The small cassette MT's and chart records obtained at the two sites are punctually sent to the Onagawa Magnetic Observatory in good cooperation with La Trobe University and James Cook University.

## 4. Analysis of ULF Waves

### *4.1. Polarization*

There are two main rules of polarization at the stations in the opposite hemispheres: opposite sense and coherent sense. A typical case of the opposite sense is displayed in Fig. 10, where the Pc 3 polarization is left-handed at ONW, while right-

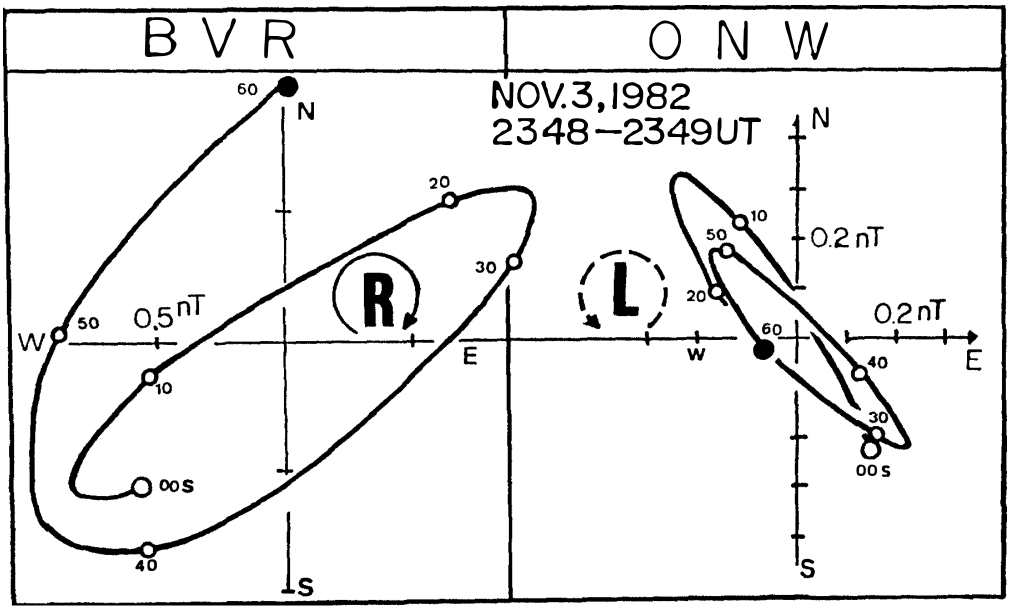


*Fig. 10. Polarization of the Pc 3 event at Beveridge and Onagawa on November 3, 1982.*

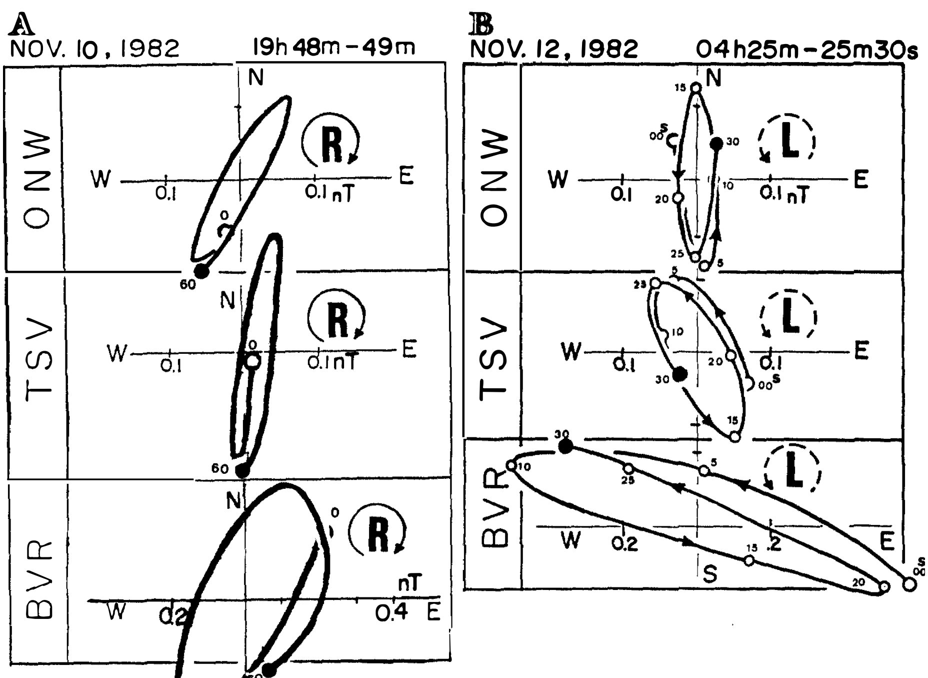


*Fig. 11. Polarization of the Pc 3 event at Onagawa, Townsville, Beveridge on November 10 and 12, 1982.*

handed at BVR. This case implies a possibility that some part of the low-latitude ground Pc 3 is due to a fundamental standing Alfvén mode and that the mode is transmitted from the conjugate points near Beveridge to Onagawa and Townsville via the ionosphere. In contrast to the opposite sense, two typical cases of the coherent sense are exhibited in Fig. 11, where R-mode is coherently detected in both hemispheres (Fig. 11A) while L-mode is recorded coherently (Fig. 11B). The coherent polarizations imply a possibility that a compressional mode of HM waves propagates downwards coherently in both hemispheres. The coherent case is ~30% of the total Pc 3 events from November 11 to December 3, 1982.

### 4.2. *Orientation of the major axis of Pc 3*

There are two main cases again in the orientation angle in the *H-D* plane of the major axis of Pc 3 polarization ellipse in the two hemispheres: opposite orientation and coherent orientation. Let us define the clockwise orientation angle $\alpha$ of the major axis from the geographic north. Figure 10 indicates a typical example of the opposite orientation; $\alpha<0$ at ONW while $\alpha>0$ at BVR. This relation implies again a possibility of the standing Alfvén wave.

On the other hand, Fig. 11 shows the cases of the coherent orientation; $\alpha>0$ and $\alpha<0$ at all the three stations in Figs. 11A and B, respectively. This relation supports the model of the compressive mode occurring on a global scale.

### 4.3. *Diurnal variation of conjugacy in orientation angle*

Figure 12 indicates a diurnal variation of the conjugate orientation angle at the three stations as expressed against UT. The following three stages seem to exist during a day:

(1) 18–21 UT; coherent orientation.
$\alpha>0$ at all the stations in this stage.

(2) 21–24 UT; opposite orientation.
$\alpha>0$ still at the two southern stations, while $\alpha<0$ at ONW in this stage.

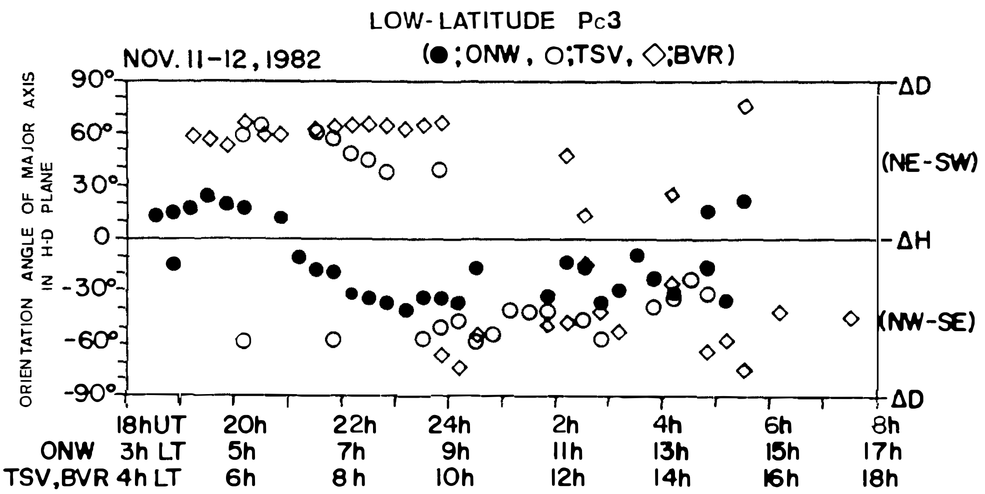


*Fig. 12. Orientation angle of the major axis of the Pc 3 event on the H-D plane at the three stations on November 11–12, 1982.*

(3) 0–(8) UT; coherent orientation.

$\alpha<0$ at all the stations.

Since the orientation angle changes its sense at $\sim$10 LT in the southern hemisphere and at $\sim$6 LT in the northern hemisphere, the change is not concluded to be due to the sunrise effect.

### *4.4. Coherence of the wavepacket*

As described in Section 1, Pc 3 shows activity-wisely coherent variation with time interval of >5 min over a wide area on the sunlit side of the earth. However, the Pc 3 amplitude is not always concurrent, if we take a time interval of <4 min. This situation is easily understood in Fig. 13, where wavepackets with $\sim$3–4 min duration appear inconcurrently among the components and the stations. This tendency is generally seen in the daytime to afternoon time sectors.

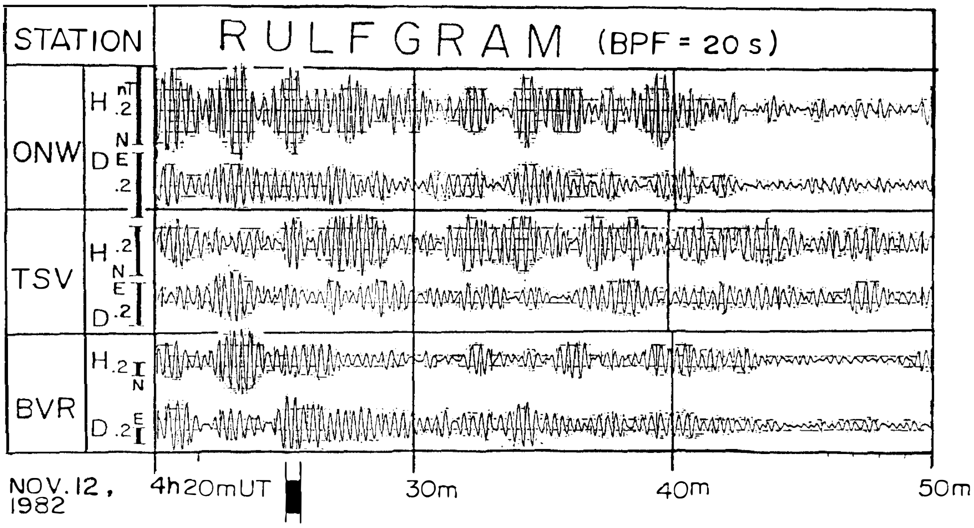


*Fig. 13. Rulfgram of the Pc 3 event observed at the three stations on November 12, 1982.*

## 5. Discussion and Conclusion

The present study based mainly on the sequential analyses will be summarized as follows:

(1) A simultaneous ULF observation started from November 1982 to date at three stations, Onagawa (ONW, Japan), Townsville (TSV, Australia), and Beveridge (BVR, Australia), where ONW and TSV are nearly conjugate point to each other.

(2) Instead of the traditional induction magnetometer and fluxgate, a new magnetometer, rulfmeter, is used to observe all the six components, $\Delta H$, $\Delta D$, $\Delta Z$, $\Delta\dot{H}$, $\Delta\dot{D}$, and $\Delta\dot{Z}$.

(3) The rulfmeter is found not only to be light and small, but also to be very stable against artificial noises.

(4) There are two main kinds of conjugacy in Pc 3 polarization; opposite sense and coherent sense.

(5) There are two main kinds of conjugacy in orientation angle of Pc 3 ellipses; opposite and coherent orientations.

(6) There are three stages in the diurnal variation of conjugacy in orientation angle; 18–21 UT (coherent), 21–24 UT (opposite), and 0–(8) UT (coherent) were found for the present data set.

(7) Incoherent wavepackets tend to be observed in daytime-afternoon sectors.

(8) These results imply a possibility that low-latitude Pc 3 is partly due to the fundamental standing Alfvén wave and partly due to the compressional HM wave.

Since the low-latitude Pc 3 is affected by all the complex magnetospheric and ionospheric structures, various effects on the ground Pc 3 must be taken into consideration. The further statistical analysis based on more conjugate data would reveal a more detailed mechanism of the low-latitude Pc 3.

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