

Installation and operation of PRARE tracking antenna at  
Syowa Station, AntarcticaKazuo Shibuya<sup>1</sup>, Masaki Kanao<sup>1</sup>, Toshihiro Higashi<sup>2</sup> and Shigeru Aoki<sup>1</sup>

## PRARE 追跡アンテナの昭和基地設置と運用

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**要旨:** PRARE とは Precise Range and Range-rate Equipment の略称である。その地上局アンテナが 1997 年 3 月、第 38 次日本南極地域観測隊 (第 38 次隊) によって昭和基地に設置された。アンテナ支柱と国際 GPS 観測局網 (IGS 網) の昭和基地アンテナ基準点との間は GPS 受信機による相対測位によって結ばれ、1994 年国際測地基準座標系 (ITRF94) における座標値は元期 1997.0 において  $X_P=1766500.399$  m,  $Y_P=1460251.211$  m,  $Z_P=-5932214.446$  m と求められた。15 秒間隔で得られる ERS-2 衛星までの測距データは 1997 年 3 月から 9 月末まではほぼ 100% (1 週あたり約 2500 分) 得られたが、その後受信数は急激に減少した。これは、レドーム内が低温になり、X バンドの受信ケーブルが劣化したためと思われる。測距データに対してリアルタイムの対流圏補正は出来なかったが、地上気象観測データを用いた後処理によると、標準誤差が補正なしの 50 cm に対して、補正ありだと 30 cm まで改善されることがわかった。PRARE 精密軌道解を用いた、レーダー高度計や合成開口レーダーデータの応用研究については別途報告する。

**Abstract:** A PRARE (Precise Range and Range-rate Equipment) tracking antenna was installed by the 38th Japanese Antarctic Research Expedition (JARE-38) at Syowa Station (69.0° S, 39.6° E), Antarctica in March 1997. The antenna pillar pin of the PRARE tracking antenna was tied to the International GPS Service for Geodynamics (IGS) antenna reference point by relative GPS positioning, and its International Terrestrial Reference Frame 1994 (ITRF94) coordinates were estimated as  $X_P=1766500.399$  m,  $Y_P=1460251.211$  m, and  $Z_P=-5932214.446$  m at the epoch of 1997.0. The total number of normal point data for range measurements attained almost 100% (around 2500 min per week) from March to September, 1997; however, the number of received data decreased significantly thereafter. This may be due to a degraded X-band RF-cable under the cold temperature condition in the radome. Although an on-site tropospheric correction could not be made, post-processing with the surface synoptic data showed improvements of the overall root mean square (rms) range errors from about 50 cm to 30 cm. Application of the PRARE obtained precise orbits to radar altimeter and synthetic aperture radar studies will be discussed in a separate report.

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## 1. Introduction

The European Remote Sensing Satellites 1 and 2 (ERS-1/-2) were launched by the European Space Agency (ESA) in 1991 and 1995, respectively. The satellites had the same characteristics for the onboard radar sensors; synthetic aperture radar (SAR) in the C-band (5.3 GHz) and a radar altimeter (RA) in the Ku-band (13.8 GHz). They are expected to play important roles in monitoring the land ice mass budget and change of sea ice extent in the Antarctic region, because their footprints cover most of the continent, north of 82°S. In order to map the precise surface topography by RA and perform successful SAR interferometry, precise determination of their orbits is very important, and specially dedicated instruments called PRARE have been designed.

Precise Range and Range-rate Equipment (PRARE) was developed by German institutions. It consists of a satellite unit and a ground tracking antenna. Although the satellite unit onboard ERS-1 malfunctioned due to X-ray interference when ERS-1 flew over the Brazilian magnetic anomaly at its commissioning phase (December 1991), that on ERS-2 has successfully operated since January 1996 after a 7-month commissioning phase.

The National Institute of Polar Research (NIPR) had planned to install a PRARE tracking antenna at Syowa Station (69.0°S, 39.6°E) from an early stage of the ERS-1 launch, but the above malfunctioning delayed installation until March 1996 by the 38th Japanese Antarctic Research Expedition (JARE-38), after confirmation of the successful operation of the ERS-2 onboard unit.

This report briefly summarizes installation, maintenance and current status of the Syowa PRARE tracking antenna.

## 2. PRARE tracking antenna

The PRARE is a kind of ranging and Doppler measurement system which was developed by the University of Stuttgart and the Deutsches Geodätisches Forschungsinstitut (DGFI) (*e.g.*, Reigber *et al.*, 1988). The ground tracking antenna was manufactured by Dornier GmbH (later transferred to Nortel Dasa Network Systems GmbH). The satellite unit onboard ERS-2 transmits pseudo-noise (PN)-coded signals on X-band (8489 MHz) radio waves for pseudo-range and Doppler shift measurements by the PRARE tracking antenna. The S-band (2248 MHz) PN-code signals are also used to measure the delay relative to the X-band signals to correct for refraction in the ionosphere. The PRARE tracking antenna receives the above signals and transmits these measurement data back to ERS-2 on another X-band (7225 MHz). These data are stored in the ERS-2 memory and downloaded to the German processing and archiving facility (D-PAF) located at Oberpfaffenhofen (near Munich) when the ERS-2 flies over it.

The PRARE tracking antenna basically consists of 60 cm diameter main-reflector and Cassegranian feed system, gearing unit on the supporting pillar, and receiver electronics unit, as schematically illustrated in Fig. 1. All outdoor units are stored within a 2.1 m diameter radome. The main characteristics of the PRARE tracking antenna are summarized in Table 1.

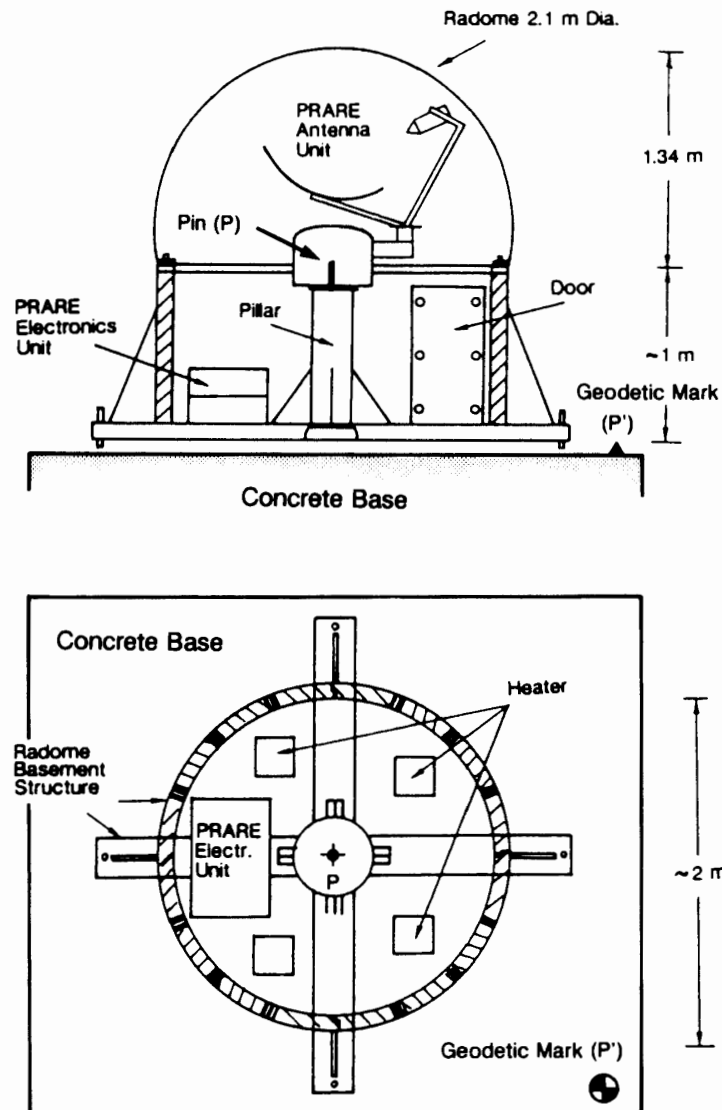


Fig. 1. Schematic design of the PRARE tracking antenna at Syowa Station.  $P$  indicates the pillar pin (reference point of PRARE) for the local tie to the SCAR GPS point, while  $P'$  indicates a nearby geodetic mark installed after the radome covering. Geometry between  $P$  and  $P'$  has not been measured yet.

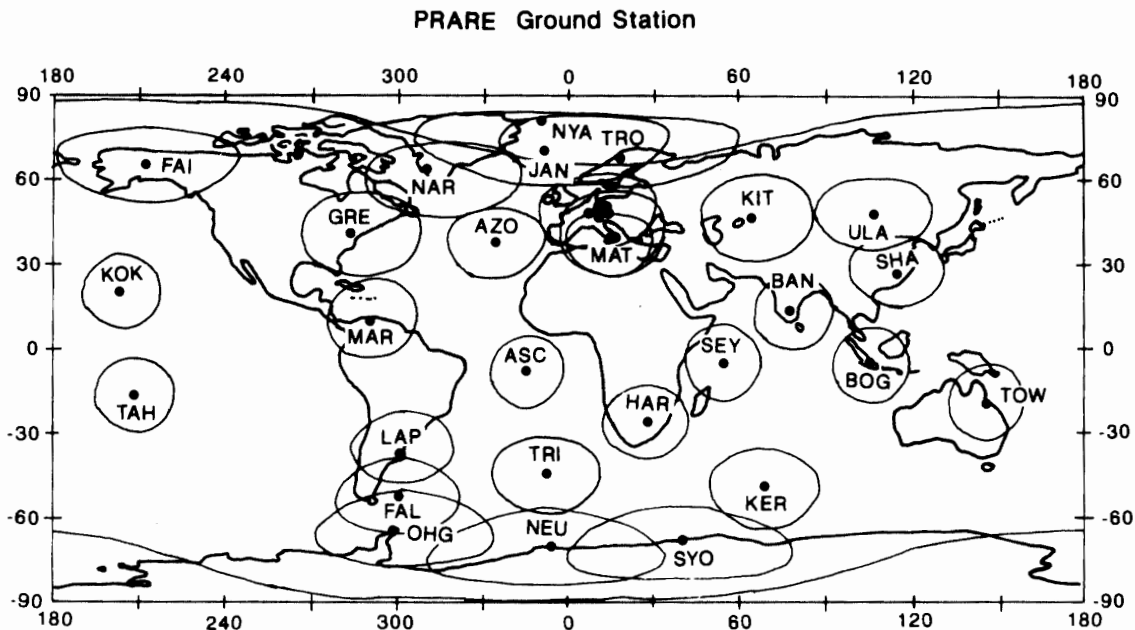
Figure 2 illustrates the PRARE global network which has been organized by the GeoForschungs Zentrum Potsdam (GFZ Potsdam). Because there are no laser tracking stations in southern high latitudes, PRARE tracking antennas at Kerguelen Island (KER), Syowa Station (SYO), Neumeyer Station (NEU) and Bernardo O'Higgins Station (OHG) are important for global orbit determination of the ERS-2 and for accurate calibration of the radar altimeter data.

### 3. Space geodesy reference points at Syowa Station

Figure 3 illustrates locations of reference points by several space geodetic techniques

Table 1. Main characteristics of PRARE tracking antenna, after Dornier GmbH.

Offset antenna with X- and S-band feed	0.6 m diameter
Tracking accuracy	$\pm 1$ deg
Receiver chain	
Antenna gain S-band ( $f = 2248$ MHz)	19.7 dB
X-band ( $f = 8489$ MHz)	32.0 dB
S/X-band Pseudo-Noise-code for range measurement	1 and 10 Mchips/s
Phase-Shift-Keying modulated data	1 and 2 kbits/s
Measurement function	
Difference of S/X-band delay	30 ps resolution
Internal station delay (test transponder)	30 ps resolution
Transmitter chain	
Antenna gain X-band ( $f = 7225$ MHz)	30.8 dB
Transmitter power	5 W peak
Pseudo-Noise-code	10 Mchips/s
Phase-Shift-Keying modulated data	1 and 2 kbit/s

Fig. 2. PRARE global network, after Reigber *et al.* (1988).

at Syowa Station, where P indicates the PRARE tracking antenna which was installed in March 1997 by JARE-38. In Fig. 3, R indicates the 11 m S-/X-band paraboloid antenna which receives SAR data from the ERS-1/-2, as well as the Japanese Earth Resources Satellite 1 (JERS-1) which was launched by the National Space Development Agency (NASDA) of Japan in February 1992. The coordinates of the reference point (cross point of the elevation and the azimuth axes) of this 11 m antenna were determined by the Very Long Baseline Interferometry (VLBI) technique in February 1990 during a test campaign (*e.g.*, Takahashi *et al.*, 1997).

As for other reference points, A indicates the astronomical point where satellite Doppler positioning was done in 1980 using a JMR-1 dual-frequency Navy Navigation

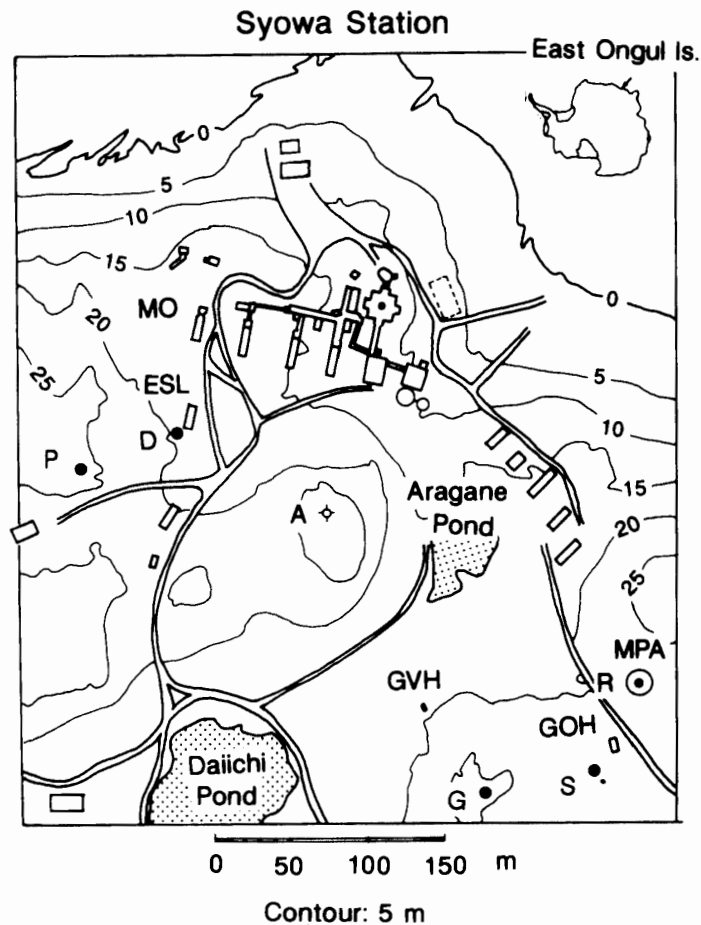


Fig. 3. Space geodesy reference marks at Syowa Station ( $69.0^{\circ}\text{S}$ ,  $39.6^{\circ}\text{E}$ ). "P" indicates the location of the PRARE tracking antenna, about 70 m distant from the Earth Science Laboratory. Other reference marks are explained in the text.

Satellite System (NNSS) receiver (Shibuya, 1985). G indicates the continuous Global Positioning System (GPS) receiver site registered as the station for the International GPS Service for Geodynamics (IGS) network (e.g. Yamada *et al.*, 1998). S indicates the geodetic mark for the Scientific Committee on Antarctic Research (SCAR) GPS campaign (e.g. Dietrich, 1996), and D indicates the beacon point for the Doppler Orbitography for Radiopositioning Integrated by Satellites (DORIS) (e.g. Shibuya *et al.*, 1999).

Local geodetic ties among several reference points are summarized in Kanao *et al.* (1995).

#### 4. Installation and maintenance of the PRARE ground station

A concrete base for the PRARE tracking antenna was constructed in January 1997 in the north-western part of Syowa Station (P in Fig. 3). Set-up of the antenna and cabling to the receiver electronics were done in February. A terminal computer to control the antenna pointing to the satellite and to monitor system diagnostics was placed in the Earth Science Laboratory (ESL in Fig. 3), about 70 m distant. Coarse adjustment of the

antenna direction had to be done before covering the radome. Fine tuning of the alignment was conducted in mid-March just before the start of normal tracking. Continuous operational tracking of the ERS-2 satellite was initiated from the beginning of April 1997.

The tracking successfully continued for five months; however, the number of receiving passes decreased from the end of September 1997. It was suspected that the X-band RF-cable had been degraded by being twisted/tensioned under low temperature conditions. Temperature control within the radome was very difficult because the prepared heaters could not moderately warm up the instruments, but raised the environmental temperature too high. Thus we decided not to use the heaters; as a result, air temperature dropped below  $-20^{\circ}\text{C}$  in September.

In January 1998, the suspect high frequency RF-cable was replaced by a new one which was supplied by JARE-39, but stable reception of the passes was not recovered. There might have been other damage to the receiver system. Then the receiver electronics unit was brought back to Japan/Germany for troubleshooting as a whole system; however, the troubleshooting did not reveal exactly what was wrong. After standard maintenance by the manufacturer, the electronics unit was brought down again to Syowa Station in January 1999 to be integrated to the antenna. It is not active yet (as of December 1999) in spite of efforts by the JARE-40/-41 wintering members.

### 5. Local tie of the PRARE pillar to the IGS site

GPS relative positioning between the SCAR GPS point, (S in Fig. 3, see also Fig. 4a) and the pillar pin (P in Fig. 1) of the PRARE tracking antenna (Fig. 4b) was done in February 23, 1997 before covering the radome (see Fig. 4c). A pair of Trimble 4000 SST GPS receivers were used; 12 hours of data at sampling intervals of 30 s were recorded. The data were analyzed using the Bernese software version 4.0 (Rothacher and Mervart, 1996), and the offset vector from the SCAR GPS point to the PRARE pillar pin was estimated as

$$dx_P = 317.7708 \pm 0.0003 \text{ m}, \quad dy_P = -85.5627 \pm 0.0003 \text{ m}, \quad dz_P = 71.1219 \pm 0.0008 \text{ m}, \quad (1)$$

after correcting for the height offsets between the GPS antenna phase centers and the marks.

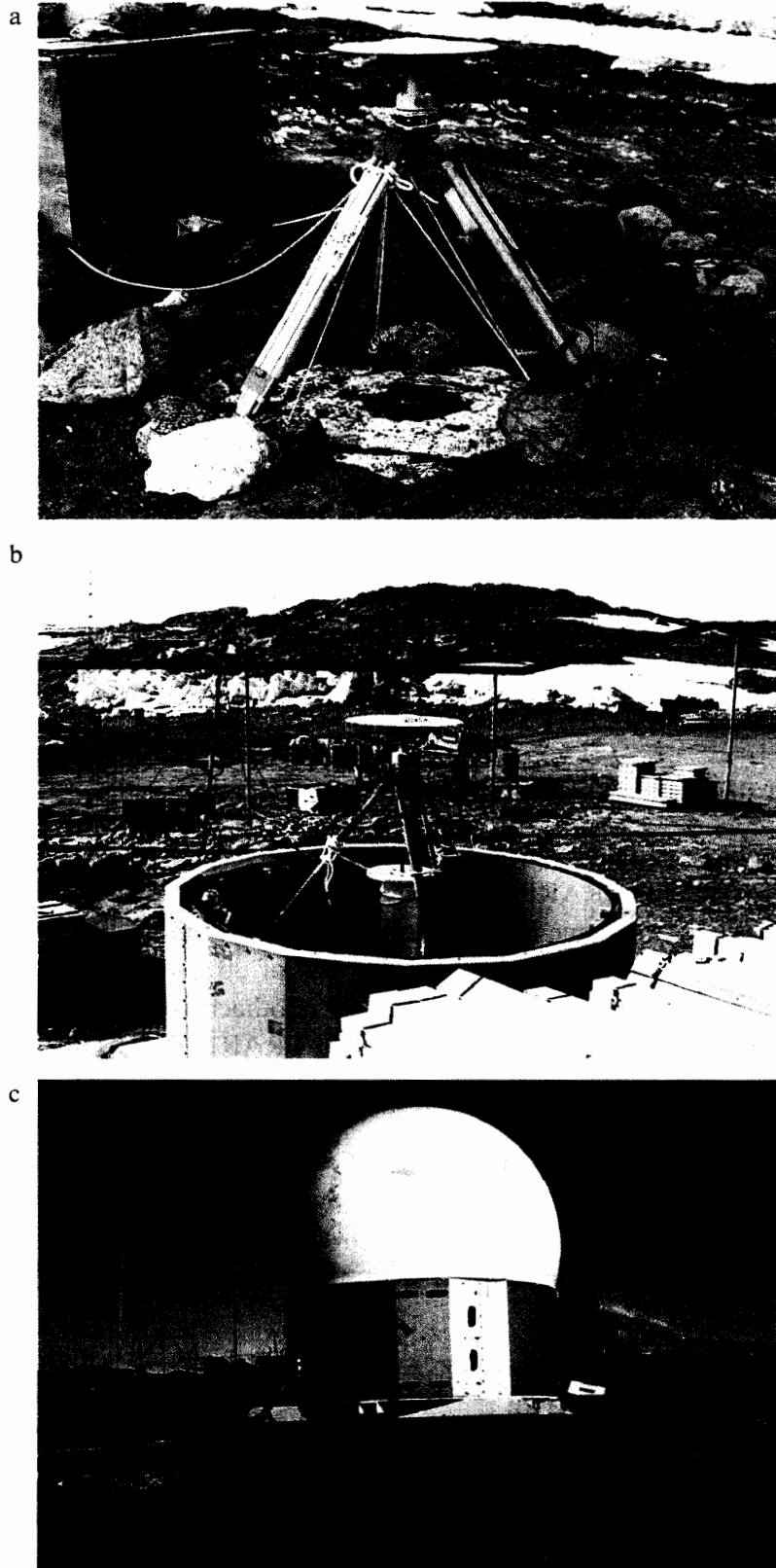
The coordinates of the antenna reference point of the Syowa IGS TurboRogue Dorne Margolin T receiver (G in Fig. 3) in the International Terrestrial Reference Frame 1994 (ITRF94) are estimated as

$$X_G = 1766207.8686 \text{ m}, \quad Y_G = 1460290.3801 \text{ m}, \quad Z_G = -5932297.7652 \text{ m}, \quad (2)$$

at the epoch of 1997.0 by Yamada *et al.* (1998), and the offset vector of the SCAR GPS point from the IGS antenna reference point (ARP) is estimated as

$$dx_S = -25.240 \text{ m}, \quad dy_S = 46.394 \text{ m}, \quad dz_S = 12.197 \text{ m}. \quad (3)$$

By combining eqs. (1), (2), and (3), the ITRF94 coordinates of the PRARE pillar pin can finally be obtained as



*Fig. 4. Snap shots of the relative GPS positioning between the SCAR GPS point (Fig. 4a) and the pillar pin of the PRARE antenna (Fig. 4b). The local geodetic tie was made on February 23, 1997. The radome (Fig. 4c) was covered just after the geodetic tie and coarse adjustment of the antenna alignment.*

$$X_p = 1766500.399 \text{ m}, Y_p = 1460251.211 \text{ m}, Z_p = -5932214.446 \text{ m}, \quad (4)$$

or

$$\phi = 69^\circ 00' 18.0418'' \text{S}, \lambda = 39^\circ 34' 41.9873'' \text{E}, H = 44.136 \text{ m} \quad (5)$$

at the epoch of 1997.0 on the Geodetic Reference System 1980 (GRS80) ellipsoid.

A nearby geodetic mark was installed in January 1998 at the PRARE concrete base (P' in Fig. 1) by M. Iwata of JARE-39, and its offset vector from the IGS ARP was determined as

$$dx = 292.963 \text{ m}, dy = -38.164 \text{ m}, dz = 84.822 \text{ m}, \quad (6)$$

to an accuracy of 2–3 mm for each component. The point P' will be used for monitoring the stability of the PRARE pillar.

## 6. Data

### 6.1. Pre-processing

The pre-processing of the Syowa PRARE data was done by D-PAF for passes with enough record length of decoded range data. The original 91 range measurements per second were bias-corrected to form 1 s interval data; the corrections include ground station internal calibration correction (X/X-delays), ground station mechanical center correction, satellite internal calibration correction, etc. Then these “range full rate” data were compressed to so-called “normal point” data at intervals of 15 s.

The PRARE system time was calibrated to coordinated universal time (UTC) by comparing with the GPS time standard and by modeling the associated error characteristics. The accuracy of the time base for the normal point has been estimated to better than  $2 \mu\text{s}$ .

### 6.2. Weekly report

The processed Syowa PRARE data at D-PAF came back to NIPR and Syowa Station by e-mail weekly report, together with data from other global network stations. The passes were eliminated when (1) pass length was shorter than 30 s, (2) more than 95% were multipath observations, (3) transponder error was detected, (4) ionospheric or antenna internal delay was detected, or (5) noise of internal delay data was greater than 5 cm, etc.

The normal points within each pass were determined under the conditions that (1) range residuals were smaller than 5 m, (2) Doppler residuals were smaller than 10 mm/s, (3) pass time bias was smaller than 1 ms, and (4) pass noise was smaller than 12 cm for range and 0.4 mm/s for range-rate, respectively.

### 6.3. Summary of Syowa data

The total numbers of received “range full rate” data and “normal point” data are illustrated as a function of week number by solid and dotted curves respectively in Fig. 5a. The decrease in number of “normal points” from September (week 37) may correspond to the suspected X-band RF-cable degradation described in Section 4. Figure 5b illustrates



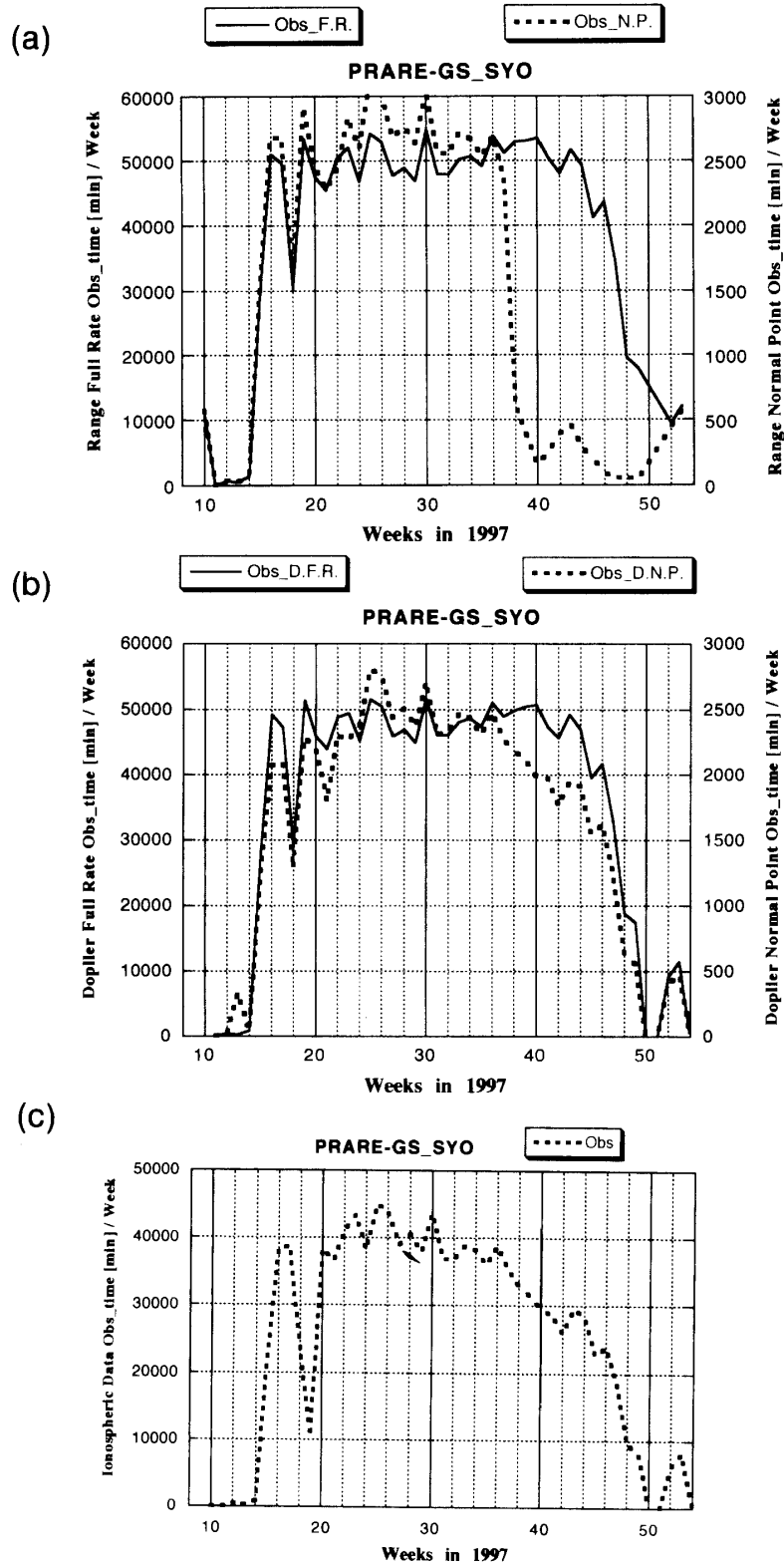


Fig. 5. Number of the received data as a function of week number; (a) 1 s interval “range full rate” data (solid curve) and 15 s interval “normal point” data (dotted curve), (b) similar “Doppler full rate” data (solid curve) and “Doppler normal point” data (dotted curve), and (c) “ionospheric data” (dotted curve).

the total number of similar “Doppler full rate” data (solid curve) and “Doppler normal point” data (dotted curve) as a function of week number. The degradation effect of the X-band RF-cable may be less pronounced than the corresponding decrease of the ranging data. Figure 5c illustrates a similar number of “ionospheric data”, where the decrease in weeks 18–19 is considered to be strongly affected by misalignment of the antenna.

In the pre-processed weekly reports, tropospheric correction was not included, because the PRARE standard meteo-sensor was not integrated. With the request from D-PAF, Syowa surface synoptic data (temperature, pressure and relative humidity) at intervals of 1 hour, which had been recorded at the Meteorological Observatory (MO in Fig. 3), were sent; these meteorological data were included in the post-processing procedure at D-PAF. The raw root mean square (rms) residuals including all systematic errors such as range bias, station coordinates and orbit errors, decreased from about 50 cm to 30 cm.

## 7. Concluding remarks

The PRARE tracking antenna was installed by JARE-38 at Syowa Station in March 1997. The coordinates of the pillar pin were estimated as  $X_P = 1766500.399$  m,  $Y_P = 1460251.211$  m, and  $Z_P = -5932214.446$  m at the epoch of 1997.0 in the ITRF94 system by a local tie from the IGS ARP using GPS receivers. The uncertainty for each component of the offset vector is estimated as within 1 mm. The total number of received “normal point” data was about 60,000 from April to September in 1997, but from October it decreased significantly to zero at the end of November 1997. This may be due to the degraded X-band RF-cable under the cold temperature condition. The PRARE tracking antenna has not been active since then. The raw rms residuals including all systematic errors improved from 50 cm to 30 cm by taking into account the surface synoptic data for tropospheric correction. Application of PRARE derived precise orbits to RA and SAR interferometry studies will be discussed in a separate report.

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