



GNSS receiver for long-term installation

D. H. Jones et al.

A new high-precision and low-power GNSS receiver for long-term installations in remote areas

D. H. Jones, C. Robinson, and G. H. Gudmundsson

British Antarctic Survey, High Cross, Madingley Road, Cambridge, UK

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Correspondence to: G. H. Gudmundsson (ghg@bas.ac.uk)

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[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Abstract

We have developed a new high-precision GNSS receiver specifically designed for long-term unattended deployments in remote areas. The receiver reports its status, and can be reprogrammed remotely, through an integrated satellite data link. It uses less power than commercially available alternatives while being equally, if not more, accurate. Data is saved locally on dual SD card slots for increased reliability. Deployments of a number of those receivers in several different locations on the Antarctic Ice Sheet have shown them to be robust and able to operate flawlessly at low temperatures down to -40°C .

1 Introduction

Long-term monitoring using permanently installed GNSS receivers is a powerful tool for geophysics research, and this technique is now commonly used in various different settings. Applications are too numerous to list but include measurements of glacier flow, tectonic movements, ground subsidence, and isostatic uplift, to name a few. In such applications the reliability of the system is of utmost concern as the GNSS units are often left unattended for prolonged periods of time.

Here we discuss the development and testing of a new simple-to-use, reliable, low-power and low-cost GNSS unit, for use in remote areas. We describe the design and performance of a new GNSS unit that fits all those criteria. Although we believe our new GNSS receiver to be of general use for the wider geophysical sciences community, we will specifically focus on its application to remote polar areas. This is because our own primary application of GNSS receivers is to monitor the temporal variation in glacier flow in Antarctica.

1.1 The need for a new GNSS receiver

Field installations of GNSS receivers in remote areas require a reliable and sustainable power source. A common solution is the use of batteries with supplementary solar

GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



panels. In polar areas, where there is insufficient sunlight for much of the winter, wind turbines or often employed as well together with large battery packs to ensure continuous power over period of low winds (Rose et al., 2009; Bauguitte et al., 2011). Figures 1 and 2 shows a typical polar GNSS installation used by the British Antarctic Survey for over-winter deployment of GNSS units. As the figure shows the power-system is fairly large and the weight of these batteries, wind turbines, solar panels and their necessary scaffolding is not insignificant, and often determines the upper limit of the scope of any polar installation. The power consumption of a GNSS receiver therefore puts significant constraints on their applicability in remote areas.

Although commercial off-the-shelf (COTS) GNSS receivers can, and have been used, for long-term deployments in Antarctica (e.g. Dach et al., 2008; King et al., 2011; Anderson et al., 2013; Tregoning et al., 1999), they are not primarily designed for such applications. As a consequence, and as we will show below, the power consumption of such devices is higher than it needs to be. Furthermore, the numerous features of commercial GNSS receivers, many of which tend to be irrelevant for long-term static deployments, actually make such units less reliable and complicate their use.

Based on our experience in the use of commercial GNSS monitoring systems in polar areas acquired over more than a decade, common sources of failure in long-term GNSS monitoring systems are due to corruption of the memory card, mechanical failure of the power supply, or user error whilst navigating their myriad configuration menus. The memory card failure rate is particularly problematic in polar installations: a survey of 30 memory cards retrieved from a variety of year long polar monitoring stations found that 4 had suffered a complete hardware failure whilst 3 were corrupted with partial loss of data.

Commercially available systems benefit from regular services, repairs and firmware updates. Although generally beneficial, for long-term deployments in remote areas such regular services and updates bring with them their own problems. Installing critical firmware updates on GNSS units that are only visited once a year may not always be possible. As an example, for a one brand of commercial GNSS units a number of ob-

servational GNSS campaigns by the British Antarctic Survey have, in the recent past, been severely compromised as the GNSS units all stopped recording simultaneously due to a firmware error. Although the error was detected by the supplier well ahead of time, installing the firmware patch on all affected remote GNSS units was not possible.

To address the above listed problems we have developed a new GNSS receiver around the requirements of a long-term polar installation. The receiver uses less power than all commercial available alternatives known to us, while at the same time being more reliable, and at least equally, if not more, accurate. Henceforth this receiver design is referred to as Ubi the Latin word for “where”.

1.2 Design requirements

The four principle design requirements that we set out to meet with our new GNSS receiver, Ubi are that it should (1) be at least as accurate as equivalent COTS GNSS receivers, (2) reliable, (3) use as little power as possible, and (4) be simple to configure.

Discussions with operations managers and relevant scientists at UNAVCO, US, the British Antarctic Survey (BAS), UK, and at the Alfred-Wegener-Institute (AWI), Germany, furthermore highlighted the importance of the individual user being able to quickly assess the status of the unit. Therefore it was decided that the Ubi should have a status display indicating if the unit is logging, if the power supply is performing correctly, and whether the GNSS antenna is connected and working. For easier retrieval, and for planning repair and service visits, the Ubi should furthermore report its status and location periodically via a remote communications link. Finally, it should be possible to remotely reconfigure the Ubi. Thus, if the power supply is failing, or the battery supply is not sufficient for 24 h operation over the winter period, the receiver can be re-configured to log for a fraction of the day instead, entering a low power sleep mode for the remaining period.

GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



2 Ubi instrument design

The Ubi is mostly assembled from a number of off-the-shelf components. These include a GNSS receiver module, a micro-controller, and Iridium modem and antenna, a power management unit, and GNSS antenna. An overview of the principal components is given in Figs. 3 and 4 shows the internal hardware.

There are number of precision GNSS receiver units (i.e. dual frequency receivers) available, in the form of daughter boards, that can be integrated into a larger system. Table 1 compares the accuracy (in Differential GNSS (DGNSS) and on-board Real-Time Kinematic (RTK) position modes) and power consumption of five OEM receivers (values from their respective datasheets).

After having evaluated available GNSS receiver boards, we decided to build the Ubi around the Ashtech MB100 L1/L2 GNSS receiver board. The MB100 was chosen over others for its low power consumption and low cost, while at the same time having similar accuracy as other boards (see Table 1).

The Ubi is build around a micro-controller (Micro-robotics VM2) which is responsible for configuring the GNSS receiver, managing its power supplies, monitoring its performance and logging the raw, unprocessed, GNSS data on to an SD card. The micro-controller is also responsible for organising the transmission of the Ubi status messages and processing reconfiguration commands via an Iridium 9602 modem.

As past experience has shown SD cards to be a significant source of unreliability, dual SD card slots are provided for increased reliability. At any given time data is written to only one of those cards. If data-write failure is detected, the system automatically switches to the other memory card.

2.1 Configuration options

The Ubi is configured by storing a simple, text-based configuration file on the SD card. Without such a file, the Ubi will use default configuration values. We have deliberately kept the programming of the units as simple as possible without limiting their intended

GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



use. As our system is intended for long-term recording of GNSS data and subsequent post-processing only, there is no need for any programming options related to any other uses. This greatly simplifies the use and the programming of the system. At present there are only three configuration variables that need to be set:

1. The duration within each 24 h period (synchronised at midnight) over which the Ubi records GNSS data (0–24 h, default 24). It will spend the rest of the time in a low-power idle mode.
2. The frequency of status update transmissions via the Iridium link, back to the user (1–365 days between messages, default 1 day).
3. The raw GNSS sample rate (1–300 s).

The raw GNSS data is stored in a compressed ATOM format (Artushkin et al., 2008) which is simple to convert to standard RINEX formatted files.

2.2 Remote interface

An Iridium modem provides a two-way datalink between the Ubi and the user at a remote location. This is a low bandwidth link that is not intended for transferring the large GNSS datasets but for supervision and reconfiguration purposes only. Regular updates from the Ubi describe its configuration, location, power supply voltage and available file-space, details which are displayed or plotted through a website (see Fig. 5). The user can reconfigure the logging period, status update frequency and GNSS sample rate of the Ubi via this same website.

The advantage of this remote reconfiguration capability is the flexibility to respond to changing environmental conditions. For instance, if installing large battery packs and wind turbines is impractical, the Ubi can be configured to record for 24 h a day when there is sufficient solar power, or for shorter periods when there is not.

The transmitted updates from the Ubi will also give an insight into any failures. For instance, if the power supply is failing this will be evident in the reported battery voltage.

GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



If the GNSS antenna or Ashtec modem have failed this will be evident in the use of file-space. Finally if the Ubi stops transmitting updates the end-user can conclude there has been a complete system failure. Based on this information the end-user is better equipped to plan for the next site visit.

2.3 External hardware

Ubi is housed in a weather-proof IP67 case (see Fig. 6). Three ports protrude from one end, an SMA connection for the Iridium antenna port, a TNC connection for the GNSS antenna port and a four pin Lemo connector for power and serial communication.

The other end of the case features 4 leds visible behind an enclosed window. These enable the end user to quickly validate the correct operation of the power supply, the file system, the GNSS antenna and the Iridium antenna, as well as the Ubi itself. This end is fastened in place with four thumb screws so as to make accessing the SD cards simple.

3 Test results

3.1 Power consumption

Table 2 compares the power consumption of the Ubi with two commonly used COTS GNSS receivers. The power consumption values listed include the power needed to supply an active GNSS antenna. The lifetime figures are an estimate of how long the receiver will operate on 2 100 Ah batteries at -30°C .

From Table 2 it can be seen that the Ubi receiver uses less power than currently available COTS receivers when recording GPS data. Thus the Ubi will run for longer when deployed with a battery power supply.

GNSS receiver for long-term installation

D. H. Jones et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



3.2 Kinematic tracking accuracy

A network of Ubi receivers has been installed next to a Trimble R7 receiver from a different project (Anderson et al., 2013) on the Brunt Ice Shelf, Antarctica. This ice shelf has a typical daily vertical tidal movement of 1 m, and the GNSS data was processed with the kinematic precise point positioning (kPPP) technique. We use the GIPSY/OASIS (Zumberge et al., 1997) GNSS data processing package to perform the kPPP analysis. Figure 7 shows the recorded horizontal movements of three of these receivers, each 20 m apart, from 24 h of data. Two of these receivers were Ubi units (Ubi(1) and Ubi(2)) and one was a Trimble R7 receiver. All were equipped with the same type of GNSS antenna (Leica AS10).

The receivers were all attached to a fixed infrastructure, so their relative position did not change. For ease of comparison between these three receivers, the mean position of each receiver has been subtracted from the displacement curves shown in Fig. 7. As the figure shows, these three displacement curves overlap almost perfectly. Hence, the horizontal displacements as determined by these three receivers are almost identical, and their accuracy therefore comparable.

A further insight into the performance and the accuracy of the receivers is gained by calculating the temporal variation in the distances between the receivers (see Figs. 8 and 9). As mentioned above all three receivers were attached to the same platform and the distance between them did therefore not change with time. Calculating the pair-wise distance at each 30 s interval between all the three receivers gives three time series of baseline lengths. We analysed the scatter in those three time series, i.e. the fluctuations in calculated baseline lengths around their respective mean values. Doing so revealed that that the scatter was smallest for the Ubi(1) to Ubi(2) baseline, and somewhat larger for the two Ubi(1) to Trimble R7 and the Ubi(2) to Trimble R7, baselines (see Fig. 9). Possibly the smaller scatter in the Ubi(1) to Ubi(2) baseline is simply related to the two Ubi receivers having similar error characteristics resulting in cancellation of errors as

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



the baseline length is calculated, but nevertheless this experiment shows that the Ubi is at least comparable in accuracy to the Trimble R7 GNSS receiver.

3.3 Static position analysis accuracy

This trial was conducted at the British Antarctic Survey headquarters in Cambridge. An Ubi receiver and a Trimble R7 receiver are installed on the roof with a largely unobstructed view of the sky. Both receivers shared a common choke-ring antenna (Novatel ANT-533) via a two-way powered splitter. The GIPSY/OASIS software was used to generate position estimates and double difference phase residuals. Seven 24 h, 10 s interval files were collected from each receiver. The only change to the default configuration of each receiver was to set the minimum satellite track elevation to be zero degrees.

The carrier-phase residuals from each satellite are a measure of the uncertainty of a position calculation. Figure 10 shows the root-mean-square average of the phase residuals, binned by the calculated angle of elevation of each satellite relative to the receiver in 5-degree intervals. The y axis is the residual in millimetres. Each bin is a seven-day average of the computed L2 band residual. At all elevations the residuals of the Trimble were the highest. This is an indication that the Ubi is the more precise receiver.

Figure 11 shows the scattering of the positions calculated by GYPSY/OASIS over the same seven-day period. The data is split into both 7×24 h segments, and 84×2 h segments prior to processing. The scattering of the positions calculated from 24 h data segments is similar for both receivers, however the outliers from the positions calculated from 2 h segments are all from the Trimble receiver.

3.4 Reliability

As mentioned above, the mail functioning of memory cards is a common reason for data loss. For that reason, our system uses two memory cards and switches from one

GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



be used. When deploying system using aircrafts, where total weight of the system is often the limiting factor affecting the design of a GNSS network, the resulting weight reduction can have important consequences.

As an example, in January 2013 we set out to install three commercial GNSS receivers on Institute glacier (81° S, 76° W), Antarctica, in a single flight from a Twin Otter aircraft. Two power systems were designed for this installation, a summer only system weighing 140 kg, and a full year system weighing 410 kg. Under BAS safety criteria our aircraft can take off from and land on snow runways with a maximum payload of 2200 kg. Of this payload 250 kg were passengers, and as the nearest fuel depot was 245 km away we needed 1250 kg of fuel, allowing for a potential 700 kg of cargo. Thus we were able to install no more than one full year system and two summer only systems. Had we instead of using commercial GNSS systems, used the Ubi receiver, we could have installed a greater number of such units under the same logistical constraints. Furthermore, the remote programming capability of the Ubi system would have allowed us to make better use of the available power. For example, using the same summer-only power system, Ubi could have be programmed to log an estimated eight hours of each day during the winter (derived from Table 2), and then to switch to a 24 h logging mode during the summer. If this setup had been available in 2013 we would have had the payload capacity necessary to install four Ubi receivers instead of three, still allowing for the extra fuel needed for a fourth site visit.

4 Conclusions

We have developed, tried and tested a new GNSS receiver specifically designed for long-term deployments in polar areas under harsh conditions. Our GNSS receiver, Ubi uses less power than existing commercial GNSS receivers, reducing the necessary batteries, solar panels and wind turbines needed for long-term GNSS monitoring.

The system allows for a two-way communication via an Iridium link. The status of the Ubi receiver is broadcast, and the unit can be reprogrammed remotely. The ability to

GNSS receiver for long-term installation

D. H. Jones et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



remotely reconfigure the Ubi logging period in response to the availability of solar power creates further opportunities to reduce the size and weight of these power system components.

The Ubi receiver is at least as accurate as commercial GNSS receivers commonly used for long-term monitoring. It is easy to configure and has improved status reporting features. We have made the Ubi software open-source and available at <https://github.com/antarctica/UBI>. This will allow other polar scientists to evaluate, use, adapt and improve upon the design for the benefit of all in the community.

Acknowledgements. This study is part of the British Antarctic Survey Polar Science for Planet Earth Programme. It was funded by The Natural Environment Research Council (NE/1007156/1).

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GID

5, 285–310, 2015

GNSS receiver for long-term installation

D. H. Jones et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



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GNSS receiver for long-term installationD. H. Jones et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

GID

5, 285–310, 2015

GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Table 2. Comparison of GNSS receiver power consumption.

GNSS receiver	Power consumption	Predicted lifetime
Leica GS10	3.25 W	18.5 days
Trimble R7	2.5 W	25 days
Ubi	2.0 W	29.5 days



Figure 1. GNSS station installed on the Institute Ice Stream showing the two wind turbines and solar panels required to power the GNSS receiver.

**GNSS receiver for
long-term installation**

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)





Figure 2. 6 100 Ah batteries in 3 battery enclosures, for the field installation of Fig. 1. In total, the batteries and enclosures weighed 300 kg, nearly half of the aircraft payload available for the site installation.

**GNSS receiver for
long-term installation**

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



**GNSS receiver for
long-term installation**

D. H. Jones et al.

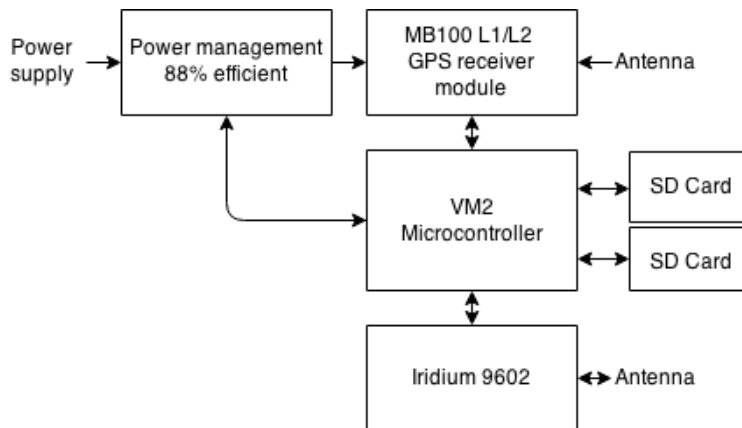
**Figure 3.** Diagram of receiver principle components.[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)



Figure 4. Internal hardware of Ubi.

GID

5, 285–310, 2015

GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)





Figure 6. Ubi case design.

GID

5, 285–310, 2015

GNSS receiver for long-term installation

D. H. Jones et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[I◀](#)

[▶I](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

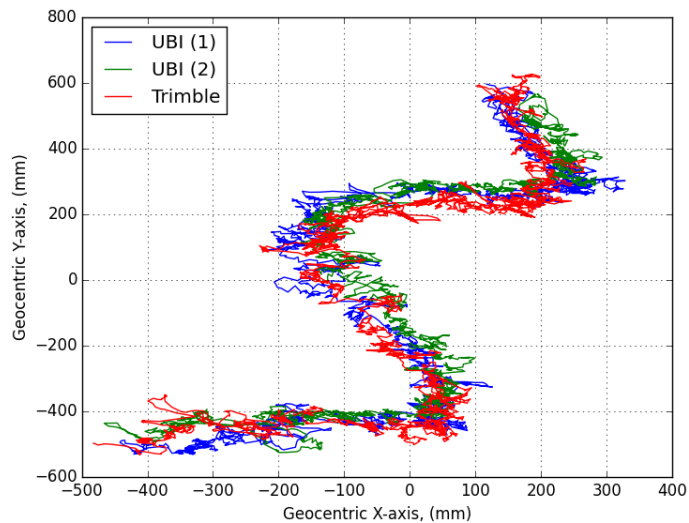
[Printer-friendly Version](#)

[Interactive Discussion](#)



**GNSS receiver for
long-term installation**

D. H. Jones et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[I◀](#)[▶I](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)**Figure 7.** Kinetic tracking of the Brunt ice shelf over the period of 24 h.

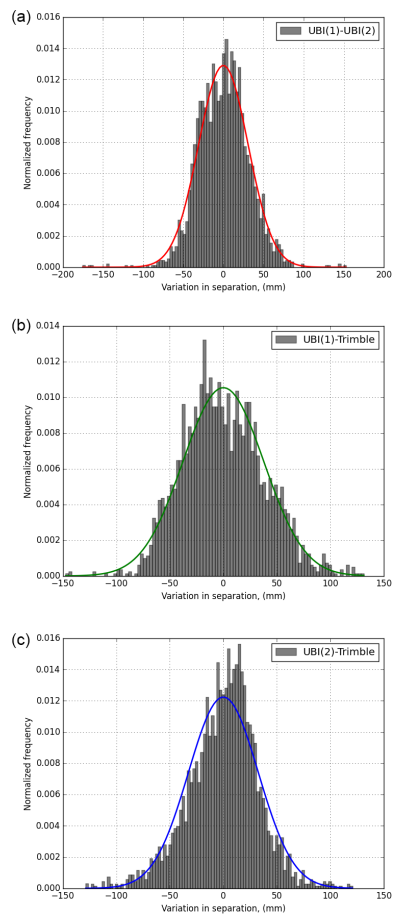


Figure 8. Histogram of variation in separation between receivers **(a)** Ubi(1) and Ubi(2), **(b)** Ubi(1) and the Trimble R7, **(c)** Ubi(2) and the Trimble R7.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

GNSS receiver for long-term installation

D. H. Jones et al.

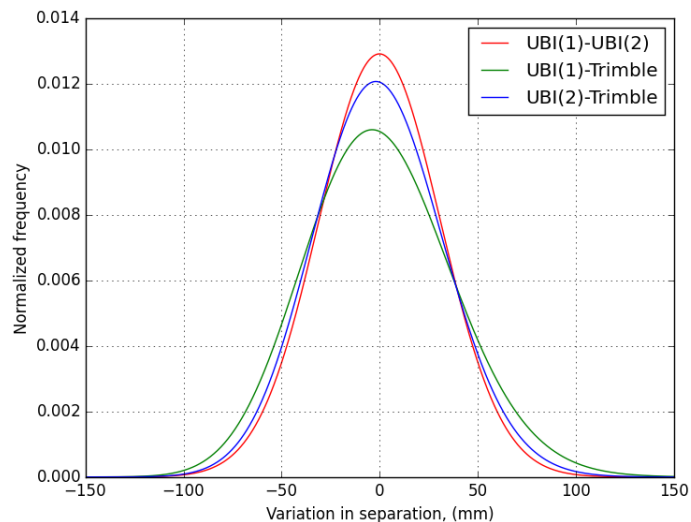


Figure 9. Gaussian fit to temporal variations in pair-wise distances between two Ubi receivers and a third Trimble R7 receiver. The GNSS data from each receiver was processed independently of the data from the other receivers using a kinematic precise point processing technique (kPPP). All receivers were attached to the same platform (with approximately 20 m separations), and the widths of the Gaussian curves therefore directly reflect baseline errors. As can be seen, the baseline errors are on the order of about 5 cm, an accuracy expected for short term kPPP occupation and similar for each receiver pair.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

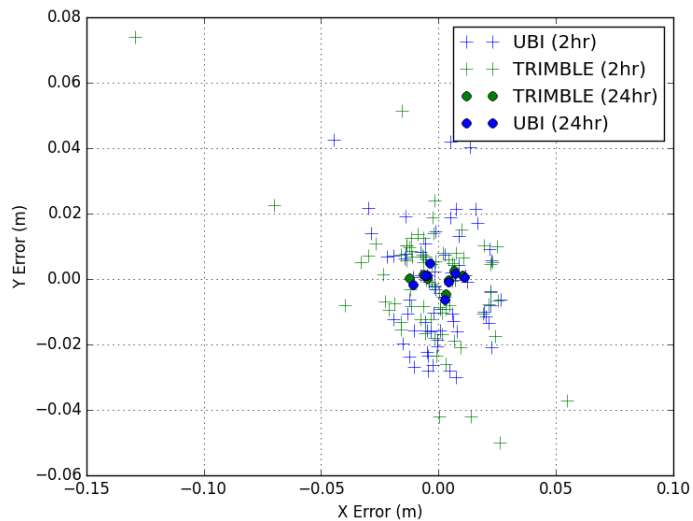
Printer-friendly Version

Interactive Discussion



**GNSS receiver for
long-term installation**

D. H. Jones et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[I◀](#)[▶I](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)**Figure 11.** Comparison of accuracy of Ubi and Trimble receivers in Static mode.