IGS Stations: Station and Regional Issues

W. L. Combrinck[1] and M. Chin[2]

[1]Hartebeesthoek Radio Astronomy Observatory, Krugersdorp, South Africa
[2]NGS/NOAA, Silver Spring, MD, USA

Camera-ready Copy for

Physics and Chemistry of the Earth

Manuscript-No. I02

Offset requests to:
W. L. Combrinck
HartRAO
PO Box 443
Krugersdorp
1740
South Africa

Pergamon

Phys. Chem. Earth, Vol. 26, No. 6-8, pp. 539–544, 2001

IGS Stations: Station and Regional Issues

W. L. Combrinck[1] **and M. Chin**[2]

[1]Hartebeesthoek Radio Astronomy Observatory, Krugersdorp, South Africa
[2]NGS/NOAA, Silver Spring, MD, USA

Received: 30 July 2000; – Accepted: 16 February 2001

Abstract. This paper presents an overview of selected IGS station equipment and regional issues and was presented as the position paper for the session 'Regional operations and equipment issues'. Regional issues include IGS network densification of areas which are sparsely populated with IGS stations. Station specific issues include GPS and peripheral equipment, footprints, space geodetic and geophysical instrument collocation, data latency, integrity monitoring and station installation procedures. There are several issues pertinent to equipment and regional issues which are in the process of being addressed by various agencies, some issues such as global densification do however require more effort.

1 Introduction

The impact of station and regional specific issues on overall network performance is becoming more relevant as the quest for improved accuracy highlights problems which stem from these issues. These issues exhibit themselves in many forms and are separated here for the sake of convenience into station equipment issues and regional operations and responsibilities.

Station specific issues include GPS receivers, antennae, radomes, rf cables, computer and peripheral equipment, control and download software, data integrity monitoring, lightning protection, monument installation and local site integrity monitoring (footprint).

Regional issues include the responsibility of a region to actively support and promote the activities and objectives of the IGS. Regional issues could include all components of the station specific issues but are mainly higher level operations. Densification of regions which are sparsely populated with IGS stations could be seen to be a regional responsibility. Not all regions are financially, technically or politically able to accept this responsibility.

A prime example of regional densification is the Crustal Movement Observation Network of China (CMONOC), a major scientific project in China with earthquake prediction and geodetic research as objectives. CMONOC consist of 25 fiducial stations, 56 basic stations, 1000 regional stations and a data center for the network (Guohua et al., 2000). At least 11 of these stations are IGS stations. Here we present an overview of some station specific and regional issues with some examples which demonstrate the nature and magnitude of some of the problems.

Correspondence to: W. L. Combrinck

2 IGS Network Systems Workshop (Annapolis 1998) Recommendations

One recommendation (**R2**) and two action items (**A4, A12)** resulted from the 1998 IGS Network Systems workshop which have direct bearing on the topic of this paper:

– Regional Operations and Responsibilities (see 2.1)
  R2. *Implementation of additional stations in Africa, Asia, and oceanic regions should be actively pursued to improve the robustness and geographic distribution of the IGS network.*

– Equipment and Station Issues (see 2.2)
  A4. *An IGS working group should be formed to focus on issues of antenna calibration and radome effects.*

– Site Specifications (see 2.3)
  A12. *An official IGS document derived from the "Physical Site Specifications" document presented at the workshop should be generated and made available at the CBIS.*

2.1 Regional Operations and Responsibilities

There has been a gradual but slow improvement in the geographical distribution and density of IGS stations during the last two years. In some areas stations conforming to IGS standards are operational but data are not available to the

IGS community. For instance CMONOC has the potential to provide adequate densification of the China region and it is hoped that more data will be made available for IGS purposes in the near future. Members of the IGS community should actively encourage network operators to release at least subsets of the network as IGS stations. It has been mentioned before that the expanding IGS network is the single most important factor that has improved the IGS combined orbit over the years (Zumberg et al., 1999). In certain areas the density requires improvement as the robustness of the IGS network is compromised easily if equipment failure occurs. In addition, it is a requirement of the IGS Ionosphere Working Group (Feltens, 1999) that a well distributed and sufficiently dense network is in place. The equatorial region in particular requires more sites to meet the goals of the IGS Ionosphere Working Group. Africa has a problem in very weak coverage of its equatorial region.

Long, stable time series are required for tectonic applications. The East African Rift problem necessitates a denser, permanent network of IGS stations in Africa. The extension and possible propagation of the rift in a south-west direction through Botswana is an important problem which, if solved, could lead to major changes in the way the African continent is viewed in a geodynamical sense. Better coverage of Africa is also crucial (Stein, 1998) in order to resolve plate motions where the geological models (such as NUVEL-1) are inadequate as a result of poor plate geometry (e.g. Caribbean, Nubia-Somalia and the East African Rift).

The ability of the space-geodetic community to integrate itself into a broader context to enable global and regional monitoring of changes in some of the parameters of the multivariable 'global change' problem has been recognised and discussed by Plag (1999). It has to be added that certain regions (Africa in particular), can only make a worthwhile and long term contribution if societal needs are embedded in any attempt to densify the IGS network in Africa. The *institutional network* (government/politicians/decisionmakers) identified by Plag (1999) which ensures political and financial support for the observing system often is the downfall of attempts to install equipment in Africa. There is normally a very small component that could qualify as a *virtual network* as societal and scientific requirements are often nonexistent or regarded as superfluous to requirements by the institutional network. The scientific requirements, more often than not, originate from outside the region.

In order to positively and constructively address this problem, HartRAO has accepted the responsibility to try and identify key role-players on the African continent. These role-players should be able to participate in a meaningful way by hosting equipment as well as take part in collaborative projects such as post-graduate programmes. This will ensure, or at least boost the scientific awareness of the multitude of IGS and GPS applications, supporting the concept of an African reference frame (AFREF). HartRAO has also taken the first steps towards the establishment of a Geodetic Institute for Africa. This Institute will unify, expand and develop geodesy in Africa.

Furthermore, the increased participation of role-players, even on the individual level, will create the framework for integration of 'global change' type parameters into general societal and governmental awareness. Several catastrophical natural events have occurred in the last year in certain parts of Africa (e.g. the devastating floods in the Mocambique lowlands) which could have been used to raise the awareness and demonstrate the importance of global monitoring to relevant government related agencies. General education and attitude towards IGS and other geodetic networks, geodetic technology and applications, will have to be addressed in an agressive manner via different approaches. In a sense, many parts of the 'institutional networks' in Africa need to be guided into science and technology and out of war and corruption. The final objective for Africa would be to fit into the *Network Triangle* concept as described by Plag (1999). Currently however, plane coordinate geometry would fail to describe our situation.

When one views the IGS network displayed on a world map, it is glaringly obvious that South America and especially, the African continent require more attention. HartRAO, in collaboration with JPL and CNES has installed one additional site at Richardsbay on the east coast of South Africa which has been collecting data since the 10th of May 2000. With the cooperation of the South African Navy, a station is to be installed at Simonstown, on the west coast of South Africa. Both these coastal stations will be collocated with operational tide gauges. An IGS station will be operational in Windhoek, Namibia before the end of the year and we are also in the process of negotiating a site in Zambia (Lusaka), another joint effort between HartRAO and JPL.

In addition, HartRAO is negotiating to install an IGS station in Madagascar at the Institute and Observatory of Geophysics at Antananarivo (I.O.G.A.), in a joint project with the University of the Witwatersrand and JPL. These two stations will be collocated with wide band seismometers. HartRAO is actively working on the densification of Africa and accepts its regional responsibility. Africa is however, a very large continent with many practical problems when it comes to GPS installations. We therefore would gratefully accept any support, in whatever form, from more affluent regions. For instance, met packages should be collocated with the IGS stations in Africa, currently only HRAO is equipped with a met package.

Europe is a region which has accepted responsibility for regional densification with success. Currently the EUREF network consists of approximately 100 permanent stations, of which 50 % are IGS stations. EUREF as RNAAC delivers regional network solutions to the IGS (Bruyninx et al., 2000).

The Australian region is served well by the Australian Regional GPS Network (ARGN) which consists of fifteen permanent GPS stations installed in Australia and its offshore Territories. The ARGN provides the fundamental framework for spatial data in Australia. It provides data for Australia's contribution to global geodesy programs and the study of earth processes such as crustal dynamics and sea level monitoring. Future developments and other contributions include high rate and rapid data products, network densification and participation in IGEX and sea level monitoring (paper this session by B Twilley, AUSLIG).

2.2 Equipment and Station Issues

The IGS working group on antenna calibration is currently being organized by the IGSCB and we would expect work on this to commence very soon. NGS (G Mader) is coordinating this working group and prospective participants are welcome to contact G Mader or the IGSCB (Angelyn Moore) for more information. A large amount of work has been done by T Clark and B Schupler at GSFC on amplitude and phase performance of different antennae, this should be taken into account by the IGS working group.

2.3 Site Specifications

Action item A12 of the 1998 IGS Network Systems workshop specifies that an official IGS document on site specifications and monumentation be generated. A physical site specification website is being prepared by one of the authors (Combrinck) and will be available for evaluation by the IGSCB within the near future. The IGS community should forward any contributions to the author. The website will contain information on site preparation, selection, monumentation, footprints, lightning protection too mention but a few. A comprehensive link section will provide access to related sites. Ideas and information should be forwarded to the author. The contents of the website could also be prepared in booklet form and as PDF files.

3 Data Integrity Monitoring

Currently UNAVCO's TEQC, some additional QC scripts and post-processing feedback are used for data integrity checking, as well as GIMP and GPSPACE (Schmidt, 2000). It has been reported (Jamason, 2000) that QC will be re-evaluated soon, due to the occasional appearance of erroneous data on the SOPAC archive. IGS site changes, which are not properly documented in the log files, continue to result in incorrect processed values due to a mismatch in the log and rinex file header. This makes it very difficult to ensure consistent metadata between rinex headers and site logs. The frequency of these mismatches have been reduced since the IGS's use of official receiver and antenna naming conventions, but too many conflicts still occur. Data latency is monitored using an Oracle database. If data latency degrades for SCIGN stations, action is taken to remedy the problem (van Domselaar, 2000).

4 Station Equipment

Important work on the factors which may influence the performance of GPS antennae is being conducted at GSFC. A large number of antennae have been characterized in the anechoic chamber at GSFC in a variety of configurations. Details concerning how these factors affect amplitude and phase performance are available from B Schupler (see paper in this session).

The degrading of GPS receiver tracking performance during periods of enhanced ionospheric activity has been investigated by (Skone and deJong, 2000). Tracking performance can vary significantly between receivers under identical scintillation (phase and amplitude variations) conditions. Skone and deJong (2000) have investigated the frequency and magnitude of receiver tracking errors on a regional basis, as well as the global distribution of such effects.

Although the use of permanent monuments has reduced the error due to antenna reinstallation at a site, an error due to change of equipment (especially if model or receiver or antenna is changed) still remains. In order to evaluate the effect of changed GPS equipment, Niell (2000) investigated the efficiency of establishing an independent nearby reference system and making measurements before and after the equipment change.

Equipment problems experienced by SCIGN have included modem initialization strings being dropped by the receiver which precludes remote dial-up and requires travelling to the site to re-enter the initialization string. Water infiltration into the LNA has forced replacement of cast Dorne Margolin antennae with a milled design.

NRCan (Geological Survey) has been installing (Schmidt, 2000) inline lightning arrestors at their sites and all sites will be fully protected by the end of this year. Lightning remains one of the most damaging environmental hazards to IGS stations. Most stations do have some form of UPS backup which improves isolation from transients in the power lines. Some have additional backup in the form of generators.

Ambrus Kenyeres (FOMI Satellite Geodetic Observatory, Penc, Hungary) has commented that apart from the obvious physical components and specifications, the next most important factor is 'human competence'. Station managers have a huge responsibility to maintain homogeneous and repeatable circumstances for geodetic purposes. Sometimes changes are made (new antenna, radome etc.) without due consideration for the impact it will have on station coordinate continuity. In some instances the changes are only seen weeks later after data processing. The EUREF Permanent Network has established a so-called 'Special Project', which intends to set-up and maintain station quality monitoring activities, as well as evaluate and improve EUREF station monumentation. This project is headed by Ambrus Kenyeres. Activities will involve, firstly, an overview of EUREF stations monumentation and stability. Secondly, a time series 'stability' analysis will be made in order to derive more realistic products for geokinematic investigations. The group also wants to develop guidelines for the future to avoid problems (e.g. unnecessary jumps) in the coordinate time series.

5 Station Monumentation

Station monumentation remains one of the most important components of any geodetic installation and several factors (Combrinck and Schmidt, 1999); (Combrinck, 2000) such as monument type, interface between the monument and the Earth's crust, local variables (joints, fractures, shear zones, expansive clays, varying ground water levels, slope movement) affect the long term stability of the monument.

After canvassing the opinion of the IGS community, it seems that the availability of a small booklet on IGS site installation and selection would be very useful. The avoidance of several pitfalls would benefit the IGS and would ensure higher quality data and minimum data loss. NRCan (Geodetic survey) has such a guide which could be used as preliminary material and expanded to meet IGS requirements. The physical site specification website which is currently under development could contain this booklet as a file in suitable format for download. However, if there is sufficient interest, a number of booklets could be printed and bound in a manner which would facilitate field use. Several institutions have indicated that they would support and contribute to such a booklet. It has been suggested that the booklet be made available as a PDF document to ensure widest possible distribution.

6 IGS Stations and Some Local Factors which Influence Monument Stability

There are numerous factors which affect the short and long term stability of the geodetic monument such as local subsidence, slope movement, varying water content and thermal effects to name just a few. All monument types are affected one way or another, this necessitates the evaluation of each monument on its own. As an example, consider a monument fixed to exposed bedrock. This monument has an optimized interface to the Earth's crust. It is better than a building type monument or one located on unstable soil. Unfortunately, we have to face the fact that no monument is immune to external factors and processes which will continuously influence its stability by varying local stress levels.

6.1 Sources of Stress Near the Surface

There are four major sources of stress in rock close to the surface which might affect geodetic monument stability. The components of the in situ stress field which leads to deviation from a reference state due to natural processes include near-surface thermal stresses induced by the diurnal thermal cycle, as well as residual, tectonic and gravitational stresses.

- **Residual stresses**
  In a rock body, a metastable stress condition in absence of external stresses is created during plastic deformation resulting from overburden weight, original crystallisation, thermal gradients and tectonic pressures. These residual stresses may cause instability, buckling and fracture propagation when the metastable state is disturbed by removal of overburden or confining stresses.

- **Gravitational stresses**
  The weight of a column of rock above a specific point in the rock induces gravitational stress at that point. Vertical stresses due to gravity could lead to horizontal stresses as rock expands in directions perpendicular in response to applied compressive stress, as described by Poisson's ratio.

- **Tectonic stresses**
  Tectonic stress in general consists of the horizontal components of the in situ stress field which are a deviation from a reference state due to natural processes from local to platewide scales. The literature seems to have different approaches to what exactly should be regarded as tectonic stress. The near-surface thermal stress, stress due to topographic loading and unloading due to erosion, as well as thermoelastic loading processes resulting in local stresses, are not tectonic and tectonic stresses should probably be seen as those stresses which result from plate-scale boundary tractions. Tectonic stresses are important in areas of converging and diverging lithospheric plates.

- **Thermally induced stresses** The rocks near the surface undergo large variations in thermal stress due to the diurnal and annual temperature cycles. The temperature and therefore the thermal stresses are periodic and are related to surface temperature by the function (Carslaw and Jaeger, 1959)

  $$T_z = T_s \exp(-\frac{z\sqrt{\pi}}{kt}) \qquad (1)$$

  where T_z is the temperature variation ($^\circ C$) at depth z (cm), T_s is the total temperature variation about the mean at the surface ($^\circ C$), k is the diffusivity constant (cm^2/sec) and t is the period in seconds.

In work recently done at HartRAO, we investigated the effect of local Earth surface expansion on geodetic monument instability using GPS measurements and distinct element numerical modelling (W. L. Combrinck, Geodetic monument instability: The effect of localised Earth surface expansion as determined by GPS and numerical modelling, JGR solid Earth, submitted, 2000). The monument under investigation was fixed to exposed bedrock. The questions to be answered were:

- Whether the thermal variations of the Earth's surface are of a large enough magnitude to influence both the short and long term stability of a geodetic monument. Here the approach has been for a monument located on a large (1000 m) diameter rocky outcrop.
- What the magnitude of possible monument movement would be for a given temperature range.

– Whether permanent geodetic monument position changes are possible due to extreme temperature variations.

– Can these monument positional changes be measured using GPS ?

– What are the implications for footprint and campaign type surveys where individual sessions are of the order of hours, or perhaps several days ?

It was found that thermal expansion of the hill resulted in a diurnal positional variation at the several millimetre level using GPS as measuring technique. Longer term, such as seasonal cycles, will also be present. A complete error analysis had to be done to ensure that ionospheric, tropospheric and satellite geometry changes were not responsible for the thermal signature. This single thermal expansion factor affects global results and is embedded in all final results. Campaign type measurements and shorter occupation type measurements (such as footprints) which do not have the benefit of integration and averaging of the diurnal cycles will be most seriously affected.

It is clear that in the quest for millimetre and submillimetre global accuracy, possible thermal induced local effects will have to be taken into account.

6.2 Building a Monument ?

Building a monument is not a popular undertaking, it requires funding, proper location, and the project could be complicated with accessibility, security and other problems. Using an existing building as monument (i.e. the building type monument) is quite often an option and alleviates some of the problems. What is of concern however, is that the building is hardly ever evaluated in terms of suitability as a geodetic monument. What are the foundations like, the depth to bedrock, long term settlement ? There are no evidence which proves that all building type monuments are implicitly weak monuments, some could in fact be very good monuments. Considering all the variables however, a building type monument has several long and short term disadvantages, which may prove it to be unsuitable. Buildings are in general not durable, their design has the objective to house people and their associated cultural goods, they change ownership, burn down and are never designed to be an interface to the Earth's crust.

Figure 1 describes the settlement of two buildings Feda (1992) where building No. 1 is located in Dudince (Slovakia) and No. 2 in Prague (Bohemia). Two totally different time scales are applicable, five years in the first case and forty years in the second. Both are within the timeframe of a geodetic monument. The adverse effect on data analysis and interpretation of results if a GPS antenna had been located on either of these buildings are easy to see. All buildings will show some settlement, the best will be those which have had pilings done to bedrock. It is probably good practice to avoid using buildings as monuments. When a building is constructed, its foundations may or may not be fixed to bedrock. The load imposed by the structure at the foundation level will always be accompanied by strain which results in settlement of structures.

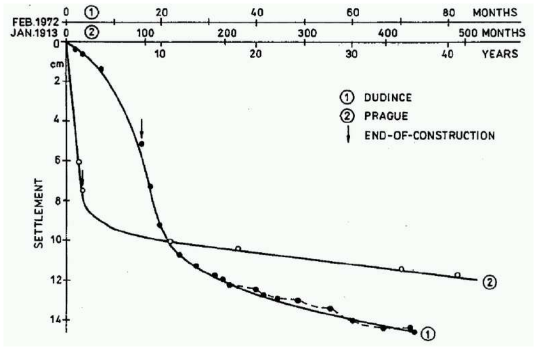

Fig. 1. Time-settlement relation of two buildings with shallow foundations (Feda, 1992)

7 NGS CORS Monument

The National Geodetic Survey (NGS) is developing a CORS geodetic monument which would be suitable for installation at most sites. The NGS monument is described here as an example of a well designed monument. It is not suggested that other types would be inferior or better as a critical evaluation of different monument types is beyond the scope of this paper. The antenna mount is unique in that it is constructed of Delrin. Delrin is a crystalline plastic which has a high tensile strength, low moisture absorption and good dimensional stability. It is machineable and can be treated as a material which is neither metal nor plastic. It should also minimize possible antenna interaction with the GPS antenna by avoiding the existence of a resonating cavity created by the gap between the antenna and the mounting plate. Although not final, complete design and installation documentation is available (Hoar, 2000). The design documentation is adequate to such detail that anyone with access to a machine shop would be able to construct this type of monument. Figure 2 depicts the basic design.

8 Conclusions

In the strive towards millimeter and submillimeter accuracy, station and network specific questions are placing more demands on how we install, operate, maintain, upgrade and treat IGS stations. Local factors such as thermal expansion can no longer be ignored. Local factors add to the noise in GPS position timeseries and will prevent the IGS network from obtaining the highest accuracy possible. Several institutions are actively involved in finding solutions or improving current solutions to these problems. This co-operation at different levels is one of the strongest attributes of the IGS and

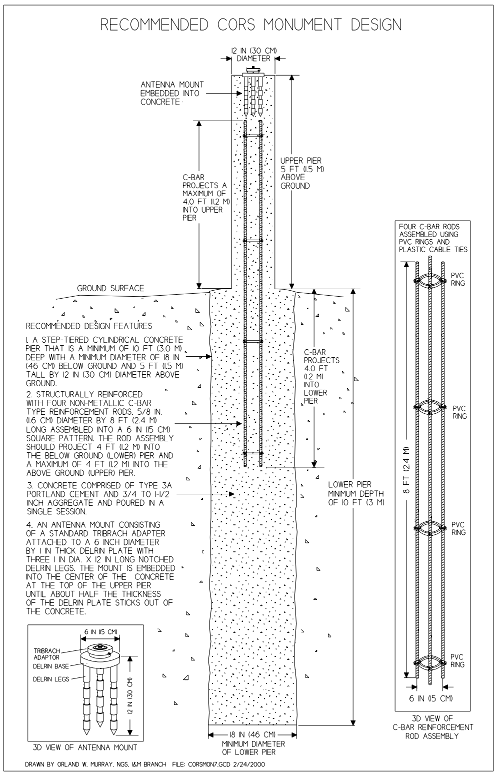

Fig. 2. Preliminary NGS CORS monument design.

guarantees constant improvement in its activities. A globally distributed, sufficiently dense IGS network capable of long time series, high stability and reliability is an immediate requirement. Regional responsibilities throughout the world must be addressed vigorously from within the regions. The international community should recognize that certain areas are more problematic than others and be willing to assist in whatever way they can.

References

Bruyninx, C., Becker, M., and Stangl, G., Regional Densification of the IGS in Europe Using the EUREF Permanent GPS Network (EPN), paper presented during the session 'Regional operations and equipment issues', IGS Network Workshop 2000, 12-14 July, 2000, Oslo, Norway.

Carslaw, H. S. and J. C. Jaeger. *Conduction of Heat in Solids,* 496 pp., Second Edition, Oxford University Press, Oxford, UK, 1959.

Combrinck, W. L., and M. Schmidt., Physical site specifications: Geodetic site monumentation, *Proceedings of the IGS Network Systems Workshop, Nov 2-5, 1998,* 91-107, edited by C. E. Noll, K.T. Gowey, R.E. Neilan, IGS Central Bureau, JPL, Pasadena, USA, 1999.

Combrinck, W. L., Local surveys of VLBI telescopes, *Proceedings of the International VLBI Service for Geodesy and Astrometry 2000 General Meeting, February 21-24, 2000,* 118–127 edited by N. R. Vandenberg and K. D. Baver, NASA/CP-2000-209893, MD, USA, 2000.

Guohua, G., Hongye, N., Guojie, M., Hanrong, S., Yongjiang, X., Guiming, Z., Ying, F., and Shiying, S., Progress in the Crustal Movement Observation Network of China, paper presented during the session 'Regional operations and equipment issues', IGS Network Workshop 2000, 12-14 July, 2000, Oslo, Norway.

Hoar, D., Personal communications. National Geodetic Survey, National Oceanic and Atmospheric Administration, Washington DC, 2000.

van Domselaar, M., Personal communications. Scripps Orbit and Permanent Array Center, University of California, San Diego, 2000.

Feda, J., *Creep of Soils and Related Phenomena,* Elsevier, Amsterdam, 1992.

Feltens, J., Important Aspects for Ionospheric Applications in Future IGS Network Performance, *Proceedings of the IGS Network Systems Workshop, Nov 2-5, 1998,* 53–55, edited by C. E. Noll, K.T. Gowey, R.E. Neilan, IGS Central Bureau, JPL, Pasadena, USA, 1999.

Jamason, M., Personal communications. Scripps Orbit and Permanent Array Center, University of California, San Diego, 2000.

Niell, A. E., GPS Site Continuity, paper presented during the session 'Regional operations and equipment issues', IGS Network Workshop 2000, 12-14 July, 2000, Oslo, Norway.

Plag, H-P., Network Implications for Global Change Monitoring,*Proceedings of the IGS Network Systems Workshop, Nov 2-5, 1998,* 91–107, edited by C. E. Noll, K.T. Gowey, R.E. Neilan, IGS Central Bureau, JPL, Pasadena, USA, 1999.

Schmidt, M., Personal communications. Natural Resources Canada, Pacific Geoscience Centre, Sydney, British Columbia, 2000.

Skone, S., and deJong, M., Limitations in GPS receiver tracking performance under ionospheric scintillations, paper presented during the session 'Regional operations and equipment issues' IGS Network Workshop 2000, 12-14 July, 2000, Oslo, Norway.

Stein, S., and UNAVCO, IGS Data From a Tectonic User's Perspective, *Proceedings of the IGS Network Systems Workshop, Nov 2-5, 1998,* 61–66, edited by C. E. Noll, K.T. Gowey, R.E. Neilan, IGS Central Bureau, JPL, Pasadena, USA, 1999.

Zumberg, J., Gurtner, W., Kouba, J., and Springer, T., Current Performance of the IGS Network, *Proceedings of the IGS Network Systems Workshop, Nov 2-5, 1998,* 19–34, edited by C. E. Noll, K.T. Gowey, R.E. Neilan, IGS Central Bureau, JPL, Pasadena, USA, 1999.