

Mid-Term Report IAG Section 1 "Positioning"

President's Report

The structure of Section I in the period 1999-2003, established during the IUGG General Assembly in Birmingham, is similar to that for the previous four-year period, in that it consists of one Commission, one Special Commission and four Special Study Groups. These are:

Commission X "Global and Regional Geodetic Networks"
Chair Claude Bocher

Special Commission 4 "Application of Geodesy to Engineering"
Chair Heribert Kahmen

SSG 1.179 "Wide Area Modelling for Precise Satellite Positioning"
Chair Shaowei Han

SSG 1.180 "GPS as an Atmospheric Remote Sensing Tool"
Chair Hans van der Marel
Co-Chair (ionosphere) Susan Skone

SSG 1.181 "Permanent Regional Arrays"
Chair Robert Weber

SSG 1.182 "Multipath Mitigation"
Chair Mike Stewart

The Commissions and SSGs have all been very productive during the period 1999-2001, and details of their activity are reported below. In particular, there has been substantial activity in the topic of SSG 1.180, where GPS is proving to be of significant importance in a number of atmospheric research and operational applications.

Section I has also played a major part in several scientific meetings during the last two years, of particular note perhaps were the Mobile Mapping Technology workshop in Cairo, Egypt in January 2001, and the symposium on Vertical Reference Systems in Cartagena, Colombia in February 2001. In addition the Section will be playing a full role in the forthcoming IAG Scientific Assembly in Budapest, and has several meetings planned for the period between then and the next IUGG General Assembly in 2003.

It is increasingly apparent that there has been growing interaction and overlap between the Sections of the IAG (Section I and Section II in particular) as well as between the Sections and the IAG services. This is no more apparent than in Section I with for example the subject of global and regional networks being of primary importance to both Commission X and the IGS.

The IAG review of its structure, which will be presented for discussion and approval at the forthcoming IAG Scientific Assembly in Budapest, in September 2001, addresses the growing importance of the IAG Services, whilst also redefining the Section/Commission structure in an attempt to recognise the changing geodetic scene. In the proposed structure the present five sections and their associated commissions and special commissions, will be abolished, to be replaced by four topic-related Commissions. Under this new structure it is proposed that a Commission on "Positioning and Applications" be established, largely taking on the role of the current Section I, but recognising the growing involvement of geodesists in the application of geodesy.

Previously this application role in the field of engineering has been addressed through SC4. Under the new proposal, applications in a much wider sense will in future have more substantial recognition in the work of the IAG. Furthermore the IAG Services, such as the IGS, will have a more explicit role in IAG activities, as together with the new Commissions, they will form the main components of the new IAG structure.

Alan Dodson, President
Chris Rizos, secretary

Special Study Group 1.179: "Wide Area Modelling for Precise Satellite Positioning"

Introduction

Precise satellite positioning requires that carrier phase data be used and that the integer ambiguities associated with the carrier phase measurements be resolved in some way. However, the distance from the user receiver to the nearest reference receiver may range from a few kilometres to hundreds of kilometres. As the receiver separation increases, the problems of accounting for distance-dependent biases increase, and reliable ambiguity resolution for carrier phase-based satellite positioning becomes an even greater challenge.

'Wide area modelling' for precise satellite positioning requires either long observation spans to estimate all biases in the functional model, or multiple reference stations. For the first approach, all error sources, such as orbit bias, atmospheric parameters, receiver inter-channel biases, along with the user's trajectory, should be estimated simultaneously. This is the approach used for geodetic static positioning (e.g., IGS-based site coordinate determination, and precise GPS orbit determination). The second approach provides more opportunities to either estimate the different biases individually and then apply interpolated biases (at the user location) to the measurements, *or* generate a so-called 'virtual reference station', by using the data from a multiple reference station network. Some of the concepts have been studied in the past by previous IAG SSGs, both separately and in combination, and with respect to various applications. In 1999 the IAG established SSG 1.179 to focus on investigations of the GPS functional model, the stochastic model, and ambiguity resolution procedures. The website of the Special Study Group 1.179 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1179.htm.

Objectives of the SSG 1.179

1. Error modelling through the improvement of functional models for medium-range, and long-range high precision satellite positioning using multiple reference stations, including:
 - multipath mitigation algorithms,
 - troposphere model refinement,
 - regional ionosphere modelling algorithms,
 - orbit bias modelling,
 - parametric modelling algorithms (for each error source), and
 - integer bias estimation and validation, e.g. cycle slip detection/repair and ambiguity resolution.
2. Error modelling through stochastic model refinement, including:
 - correlation analysis of carrier phase measurements from satellite positioning systems,
 - stochastic modelling algorithms suitable for post-processing applications, and
 - stochastic modelling algorithms suitable for real-time applications.
3. The continued study of ambiguity resolution techniques in order to develop:

- more efficient means of searching integer ambiguities, and
 - validation procedures for ambiguity resolution.
4. The application of these improvements to:
- short-range satellite positioning applications,
 - differential correction generation from multiple reference GNSS receiver network, in support of medium-range high precision navigation,
 - precise long-range GPS kinematic positioning, and
 - sub-centimetre engineering applications, e.g. construction deformation monitoring, volcano monitoring, etc.

Members and Corresponding Members

Members: Shaowei Han (Chair, USA), Oscar Colombo (USA), Paul Cross (UK), Paul de Jonge (U.S.A), Hans-Jürgen Euler (SWITZERLAND), Yanming Feng (AUSTRALIA), Yang Gao (CANADA), Yongil Kim (KOREA), Donghyun Kim (CANADA), Dennis Odijk (THE NETHERLANDS), Günter Seeber (GERMANY), Dariusz Lapucha (USA), Jingnan Liu (CHINA), Nigel Penna (AUSTRALIA), Rock Santerre (CANADA), Julia Talaya (SPAIN), Jinling Wang (AUSTRALIA), Xinhua Qin (USA), Peiliang Xu (JAPAN).

Corresponding Members: Changdon Kee (KOREA)

Activities of the SSG1.179

Error Modelling Through Improvement of Functional Models

Error modelling through the improvement of functional models for medium-range, and long-range high precision satellite positioning using multiple reference stations includes the study of topics such as multipath mitigation, troposphere modelling, regional ionosphere modelling, and orbit bias modelling. These biases could be estimated individually through some special approaches, or by setting different parameters in the functional model for the different error biases.

Absolute field calibration of GPS antennas is based on the controlled antenna motion of a robotic arm, and is now a mature calibration technique. The technique can be used to calibrate all antennas in a multiple reference station network. With (absolutely) calibrated antennas it is possible to separate phase centre variations and multipath. An approach for multipath calibration based on controlled antenna motion was proposed.

Investigations into the use of 'semi-parametric least squares' for the mitigation of systematic errors in GPS processing have been conducted. Current focus is the lumping together of all systematic errors as a single smoothing function, estimated over the processing session. Initial results from a 'short' 30km baseline are encouraging, and tests have commenced on more data sets.

An adaptive Finite-duration Impulse Response filter, based on a least-mean-squares algorithm, has been developed to derive a relatively noise-free time series from continuous GPS results. This algorithm is suitable for real time applications. Numerical simulation studies indicate that the adaptive filter is a powerful signal decomposer, which can significantly mitigate multipath effects.

Increased use has been made of ionospheric regional modelling to improvement on-the-fly ambiguity resolution over long distances, as part of initiatives within the GEOIDE project (website: www.scg.ulaval.ca/gps-rs/). Ionospheric tomography has also been used to help resolve GPS ambiguities on-the-fly at distances of hundreds of kilometres during increased geomagnetic activity. An approach, referred to as the "grand solution", which estimates orbit, refraction, and local bias error states, along with the user's trajectory, was proposed. The modelling and estimation of the tropospheric zenith delay, both for more accurate real time and post-processed navigation, and for rapid and precise meteorological updates, has been implemented.

With respect to Real-Time Kinematic (RTK) positioning using multiple reference stations, the results of a survey conducted by Dr. Euler, Chair of the RTCM SC104 Working Group "Network RTK", of working group members found:

- The expected RTK accuracy could be at sub-decimetre to centimetre level (one sigma).
- The reference station distances should be of the order of 50-70 km for centimetre accuracy, or about 200 km and above for decimetre accuracy.
- The size of a reference station area should be of the order of 500 km x 500 km. However, target could be nationwide to continentwide coverage.
- The medium for distribution of data could be unidirectional techniques (Broadcast like UHF, VHF, TV, DARC, etc) or bi-directional techniques (GSM, UTMS, etc.).
- The baud rates for transmission are from 2400 Baud upwards, including 1Hz observation data.
- The tolerated latency is up to 10 seconds without SA, or up to 2 seconds with SA. However, the orbit information can be delayed by up to 120 seconds, ionosphere by up to 10 to 60 seconds, troposphere by up to 30 seconds. The real-time positioning output is expected within 100 milliseconds.
- The requirement for reference station equipment is dual-frequency receivers with clear sky view.

With regards to GPS/Glonass surveying and navigation applications using multiple reference stations, a new method was proposed, in which the distance-dependent biases have been separated into the frequency-dependent errors (ionospheric bias) and frequency-independent errors (e.g. troposphere bias and orbit bias). The separate estimates of the two types of errors, which are generated from the carrier phase measurements using the multiple reference stations, can be used to model the user distance-dependent biases for L1, L2 carrier phase and pseudo-range measurements in different ways.

Error Modelling Through Stochastic Model Refinement

High quality estimation results using least squares require the correct selection of the functional *and* stochastic models. The stochastic model should represent the statistical characteristics of the modelling errors. It is dependent on the choice of observation functional model, hence for a different choice of functional model, a different stochastic model may be needed. For example, if the ionospheric delay is considered an unknown parameter in the functional model, the modelling errors will not include the residual (double-differenced) ionospheric bias, and hence they will more likely have random properties.

The SIGMA- Δ model has been developed for stochastic modelling of GPS signal diffraction errors in high precision GPS surveys. The basic information used in the SIGMA- Δ model is the measured carrier-to-noise power-density ratio (C/N0). Using the C/N0 data and a template technique, the proper variances are derived for all phase observations. Thus the quality of the measured phase is automatically assessed and if phase observations are suspected of being contaminated by diffraction effects they are downweighted in the least-squares adjustment. An extended weight model for GPS phase observations was also proposed.

Mathematical and statistical modelling has also been investigated. Using a multipath estimation method based on the signal-to-noise ratio and an elevation-dependent stochastic model, the height accuracy of a typical RTK session has been improved by approximately 44% and the fidelity of quality measures has been increased.

A stochastic assessment procedure has been developed to take into account the heteroscedastic, space- and time-correlated error structure of the GPS measurements. Test results indicate that by applying the stochastic assessment procedure developed, the reliability of the estimated positioning results is improved. In addition, the quality of ambiguity resolution can be more realistically evaluated.

Magellan's new product Instant-RTKTM has reportedly overcome the functional and stochastic modelling problem through empirical knowledge and a real-time learning procedure which can be used to adapt the model when the environment is changing.

On the other hand, the stochastic modelling approach has been applied to the parameters in the functional model. For example, the residual ionospheric delay after applying ionospheric delay corrections could be accounted for through processing the residual ionospheric delay correction as stochastic observables. The stochastic model to be applied for the corrections could be provided by multiple reference stations. First results show indeed an enormous improvement in the success rate of ambiguity resolution.

Continued Study of Ambiguity Resolution Techniques

GPS ambiguity resolution (AR) techniques have been intensively investigated. The integer ambiguity searching techniques have been dramatically improved over the last

decade, especially by the contribution of the LAMBDA method. However, it has to be recognised that all search algorithms are likely to result in identical integer ambiguity candidates under comparable setups, e.g. using like search windows/volumes and similar parameters. Continued study is now focused on AR in integrated systems: GPS, Glonass, pseudolite or other systems, and more powerful validation criteria to ensure correct ambiguity resolution.

For example, Magellan's new product Instant-RTKTM appears to have successfully addressed the functional and stochastic modelling problem through empirical knowledge and a real-time learning procedure. A series of validation criteria have been implemented, in addition to the commonly used ratio test, which can be adapted based on the reliability requirements, number of satellites, observation time and baseline length. The Instant-RTK validation criteria have successfully traded off the requirements of observation span on the one hand, and RTK solution reliability on the other. Moreover, the algorithm to detect, identify and adapt the outliers to guard against incorrect integer ambiguity determination has been implemented, and the success rate of AR has been increased significantly.

Leica Geosystems' System 500 has implemented a repeated search processing technique to shorten ambiguity initialisation time and to improve AR reliability, especially in difficult environments. This method repeats its internal determination of the integer ambiguity using significantly shorter observation times. Once the AR algorithm has verified that they are identical, the system can output its coordinates.

On the theoretical side, a method was proposed to evaluate the probabilities of correct integer estimation based on the variance matrix of the (real-valued) least-squares ambiguities. These success rates are given for the ambiguity estimator that follows from integer bootstrapping. Although less optimal than integer least-squares, integer bootstrapping provides useful and easy-to-compute approximations to the integer least-squares solution. In a similar manner, the bootstrapped success rates provide bounds for the probability of correct integer least-squares estimation.

New Development and Future Trends

In the next few years, more commercial system will be developed to generate corrections from multiple reference stations for surveying and precise navigation applications. RTCM SC104 Working Group "Network RTK" will propose a new format to transmit correction information from multiple reference station networks. This is not only beneficial to RTK systems, but also to single-frequency, low-cost GPS systems. Moreover, once the additional civilian frequency is transmitted by Block IIF satellites, the wide area error modelling for precise satellite positioning will be significantly improved.

Special Study Group 1.180: "GPS as an Atmospheric Remote Sensing Tool"

Introduction

Using networks of ground-based GPS receivers it is possible to observe the integrated water vapour (IWV) and the total electron content (TEC) of the Earth's atmosphere. While at first these parameters were considered a mere nuisance, it is nowadays considered to be an important signal for atmospheric sciences.

Water vapour is one of the most important constituents of the atmosphere. It plays a crucial role in many atmospheric processes covering a wide range of temporal and spatial scales. Furthermore, it is also the most important greenhouse gas and highly variable. Climate research and monitoring, as well as operational weather forecasting, need accurate and sufficiently dense and frequent sampling of the water vapour, to which existing GPS networks could contribute significantly. In order to be of any use for operational weather forecasting, firstly GPS networks must be able to provide integrated water vapour in near real-time (NRT) (with a typical delay of one hour), and secondly GPS observations must be assimilated into Numerical Weather Prediction (NWP) models.

Dual-frequency GPS receivers enable the estimation of total electron content (TEC) along a given satellite-receiver signal path. By combining observations from regional and global networks of continuously operating dual-frequency receivers, parameters describing the spatial and temporal distribution of total electron content can be derived. Such observations of TEC, available globally on a near real-time basis, allow an excellent opportunity for monitoring ionospheric signatures associated with space weather. For example, the development of ionospheric storms can be observed in global patterns of TEC, while small-scale irregularities in electron density (associated with scintillation) can be observed in short-term variations of TEC and/or spectral analysis of GPS phase observations. The website of the Special Study Group 1.180 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1180.htm.

Objectives of the SSG 1.180

The focus of the SSG is to explore the issues related to the derivation of water vapour and TEC in NRT using GPS, the assimilation of GPS water vapour data into weather forecasting models, use of GPS water vapour data for climate applications and the integration of GPS-derived TEC estimates and scintillation indices into space weather applications. The main objectives of the special study group are:

1. Identify key signatures observed in GPS-derived estimates of TEC, as associated with phenomena such as ionospheric and geomagnetic storms, scintillation, travelling ionospheric disturbances, magnetospheric substorms and auroral activity.
2. Assess methods to quantify the level and nature of ionospheric activity, based on TEC estimates.

3. Explore key issues related to the feasibility of integrating TEC estimates, and TEC-based indices, into space weather forecasting and nowcasting - such issues include real-time requirements, and the temporal and spatial resolution necessary for reliable detection and prediction of ionospheric phenomena.
4. Identify key problems in GPS-derived integrated water vapour, as associated with phenomena related to the near field of the antenna, such as multipath and phase centre variations, and local weather (gradients, mapping to the vertical), reprocessing and archiving of data, in relation to climate applications.
5. Explore key issues related to the assimilation of GPS-derived integrated water vapour observations into NWP models - such issues include real-time requirements, temporal and spatial resolution, slant or vertical delays, temporal and spatial correlation and quality insurance issues.
6. Assess the potential impact of tropospheric tomography using GPS-estimated slant delays.

The activities of the SSG consist of compiling a database of relevant literature and research groups, and to facilitate discussions of key issues through email between members, and describe the products of the research through periodic progress reports. Due to the large number of meetings, sessions and symposia in relation to the work of the SSG it was not necessary to organise a special working group meeting.

Members

Hans van der Marel (Co-chair, THE NETHERLANDS), Susan Skone (Co-chair, CANADA), Helen Baker (UK), Michael Bevis (USA), Steven Businger (USA), Galina Dick (GERMANY), Mark Falvey (NEW ZEALAND), Manuel Hernandez-Pajares (SPAIN), Per Hoeg (DENMARK), Tetsuya Iwabuchi (JAPAN), Mark Knight (AUSTRALIA), Tony Mannucci (USA), Christian Rocken (USA), Akinori Saito (JAPAN), Peter Stewart (CANADA), Rene Warnant (BELGIUM).

Activities of the SSG1.180

TEC Estimation and Monitoring

Networks of permanent GPS receivers are an excellent tool to compute the Total Electron Content (TEC) of the ionosphere. The International GPS Service (IGS) has set up an Ionospheric Pilot Project in June 1998, involving several International Associate Analysis Centers (CODE, EMR (NRCAN), ESA, JPL, UPC). Estimates of TEC are available on a daily basis in the form of IONEX files. Special campaigns were organised during the solar eclipse in August 2000 and during the solar maximum in 2001 involving high-rate (1ssec) observations of many GPS receivers.

The precise determination of TEC in real-time is important for DGPS and GPS-RTK applications with the closest reference station at several hundred kilometres. Several improvements of ionospheric models with GPS have been made involving tomographic and adaptive approaches.

A real-time ionospheric TEC model for the Australian region, based on a network of semi-codeless receivers extending from Northern Australia to the Antarctic, has been developed by the Ionospheric Prediction Services (IPS) in Australia. The purpose of this work is to provide broadcast corrections for single-frequency users as part of a proposed Wide Area DGPS system. More recent work has involved the use of GPS to monitor ionospheric disturbances during magnetic storm events, for ionospheric TEC and scintillation monitoring in low, mid and high (Southern) latitudes, including the Antarctic, and the use of GPS to measure the Earth's plasmasphere.

In Canada an ionospheric warning and alert system for Canadian Coast Guard DGPS users was developed.

Ionospheric Scintillation Monitoring and Effects of Scintillations on GPS

The Australian Defence Science & Technology Organisation (DSTO) has been developing models of the effects of ionospheric scintillations on GPS with the intention of quantifying losses in navigational accuracy and acquisition performance. The scintillation model they use is essentially a stochastic model in which the amplitude and phase distribution functions are assumed to be Nakagami-m and Gaussian respectively, and the power spectral densities are assumed to follow an inverse power-law relationship. This is based on measurements taken from numerous sources, in particular the Defense Nuclear Agency Wideband satellite experiment from the 1970s. It is also consistent with the Wide Band Scintillation Model, WBMOD, which was developed by Northwest Research Associates and enables key scintillation parameters such S_4 and σ_f to be predicted. By linking WBMOD with the receiver performance models, predictions can be made about the likely impact of scintillations on a GPS receiver at a given time and location under a specified set of solar and geomagnetic conditions. In parallel with this work it has been attempted to validate the WBMOD model for the Northern Australia / South East Asia region using a network of Ionospheric Scintillation Monitoring receivers (ISMs which provide S_4 and σ_f measurements etc.) and semi-codeless NovAtel Millennium receivers (used to measure TEC). These receivers have been in place for several years in locations close to both the magnetic equator and the crests of the equatorial anomaly in Indonesia, Malaysia and Papua New Guinea. This work has compared WBMOD predictions with regional measurements of the diurnal, seasonal and solar cycle variations in S_4 and σ_f . Various groups within these countries have been actively involved with DSTO in this effort.

A high latitude scintillation monitoring network has also been established for Northern Canada.

GPS Radio Occultation Measurements

GPS and LEO satellites are used to carry out radio occultation studies of the ionosphere and for ionospheric tomography to reveal vertical density profiles.

The GeoForschungsZentrum (GFZ) has commenced, together with other research centres of German Helmholtz Society, a new strategic project GASP ("GPS Atmosphere Sounding") using ground-based and space-based GPS techniques for applications in numerical weather predictions, climate research and space weather monitoring. One of the two sub-projects of GASP focuses on water vapour estimation, and temperature and pressure profiles from radio occultation measurements.

Development of a 6-satellite constellation for GPS occultation and space weather measurements (COSMIC) has commenced. An occultation data analysis centre is being developed at UCAR (COSMIC Data Analysis and Archive Center), for the processing of data from COSMIC and other occultation missions.

Use of Ground-Based GPS for Numerical Weather Prediction (NWP) and Climate Research Applications

Requirements for the use of ground-based GPS for Numerical Weather Prediction (NWP) have been formulated by the European COST-716 project "Exploitation of Ground Based GPS for NWP and Climate Applications". The upper limit for the latency of the GPS data is 1h 45m. Also, it has been established that it is best to use Zenith Total Delays in NWP applications, without converting to Integrated Water Vapour first. It is expected that GPS may improve the forecast of precipitation under certain conditions.

To gather experience with a NRT system, and to assess the quality of tropospheric estimates in the framework of the GASP project, a small test network of ten GPS receivers was installed by the GFZ at the synoptic sites of the DWD in 1999. The NRT network established for the test campaign has been expanded by existing German DGPS sites (SAPOS network) and by an additional 12 GFZ GPS receivers installed at the synoptic sites of the DWD during the year 2000. The total number of sites in the analysis is presently 70, with an expected increase to about 90 sites. A new analysis strategy has been developed to make possible the automatic operation of 100 and more stations, a ZTD estimation interval of 15 minutes, as well as the estimation of gradients.

New Zealand has an operational system in which estimates of PW are obtained with a delay of 1-3 hours (<http://www.gns.cri.nz/earthact/crustal/precip/gpspw.html>). The website also shows radiosonde and global weather model PW for comparison. The use of GPS PW in mesoscale models was found to positively influence rainfall simulation during a storm observed during SALPEX'96 (Southern ALPS EXperiment).

Several groups have started investigating true real-time water vapour determination. A network of over 100 GPS stations, and the real-time analysis facility for these data to generate PW, called the SuomiNet, is currently being established.

GPS Water Vapour Tomography and Slant-Delay Estimation

UCAR has initiated the development of ground-based GPS slant measurement techniques to obtain refractivity profile and signal bending information from a mobile platform. In

Oklahoma a dense 25-site GPS network for water vapour tomography is operating (ARM-Tomography).

List of Meetings Relevant to the SSG 1.180

XXII General Assembly IUGG, July 18-30, 1999 Birmingham, UK (HM, GD)
COST 716 Workshop, Soria Moria, Oslo, 10-12 July 2000. (HM)
COST 716 Management Committee and Working Group Meetings. (HM, GD)
ION-GPS'99, Nashville, USA, September 1999. (HP, MK)
GPS'99, Tsukuba, Japan, October 1999. (HP)
PLANS 2000, San Diego, USA, March 2000. (HP)
EGS'2000, Nice, France, April 2000. (HP)
IRI workshop 2000, Warsaw, Poland, July 2000. (HP)
ION-GPS'2000, Salt Lake, USA, September 2000. (HP)
AMS meeting Albuquerque Jan 2001 (CR). Special session on GPS slant and Special session on SuomiNet
COSPAR meeting, Green Bay, Taiwan, Sept. 27-29 2001 (CR). Special meeting on COSMIC mission.
URSI meeting Boulder, CO, Jan 2001 (CR). Special Session on GPS remote sensing.
IAIN World congress, San Diego, June 2000. (MK)
ION National Technical Meeting, Anaheim, USA, January 2000.
URSI National Radio Science Meeting, Boulder, USA, January, 2000.
S-RAMP Conference (Solar-Terrestrial Energy Program for Space Weather), Sapporo, Japan, October, 2000.
Fall Meeting of the American Geophysical Union, San Francisco, California, December, 2000.
EGS'2001, Nice, France, March 2001. (HM,HP) Special session on GPS Meteorology.
GNSS'2001, Seville, Spain, May 2001.
Beacon Satellite Symposium 2001, Boston, USA, June 2001.
IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting, Boston, Massachusetts, July 8-13, 2001.
ION meeting SLC, Sept. 2001 (Session on GPS meteorology).
IAG Scientific Meeting, September 2001

Special Study Group 1.181: "Regional Permanent Arrays"

Introduction

In recent years an increasing number of GPS reference stations have been established on both global and regional scales. Ideally, the latter should represent local densifications of the International Terrestrial Reference Frame (ITRF) polyhedron. While at the outset these stations were built up in most cases to monitor active tectonic regions, recently the augmentation of real-time surveying and probing of the atmosphere have become important applications. The website of the Special Study Group 1.181 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1181.htm.

Objectives of the SSG 1.181

The work of this SSG aims at the tie of regional GPS networks to the International Terrestrial Reference Frame (ITRF), as well as to study the ambiguity resolution within a network of multiple reference stations at baselines with lengths of up to several tens of kilometres. In particular, the appropriate modelling of ionosphere and troposphere path delays as the limiting factors for ambiguity resolution, and the influence of antenna phase centre variations, will be studied. Concepts and realisations of "virtual reference stations" will be compared. Real-time kinematic (RTK) solutions within active reference station networks, the benefits of using combined GPS/Glonass receivers, as well as the use of predicted IGS orbits will also be subjects of investigation. Last, but not least, in cooperation with SSG 1.179, reliable error models of the baseline solutions have to be formulated. To achieve these goals the SSG will focus on:

1. Studying the atmospheric modelling part within a network of multiple reference stations.
2. Maintaining a website providing SSG related information.
3. Studying in-depth the concept of "virtual reference stations".
4. Providing test data sets from regional GPS/Glonass arrays for case studies.
5. Investigating the influence of antenna phase centre variations.
6. Encouraging participation in related symposia.
7. Reporting achievements at the IAG Conference in Budapest in 2001, and the next IUGG General Meeting in 2003.
8. Preparing recommendations and a final report on the SSG's activities.

Members and Corresponding Members

Members: Robert Weber (Chair, AUSTRIA), Richard Bindley (UK), Heike Bock (SWITZERLAND), Carine Bruyninx (BELGIUM), Peter CLARKE (UK), Herb Dragert (CANADA), Galera Monico (BRAZIL), Tom Herring (USA), Horst Hartinger (AUSTRIA), Paul de Jonge (USA), Ambrus Kenyeres (HUNGARY), Jan Johnsson (SWEDEN), Lambert Wanninger (GERMANY), Teriyuki Kato (JAPAN), Elena Ostrovsky (ISRAEL).

Corresponding Members: Manuel Hernandez-Pajares (SPAIN), Helmut Titz (AUSTRIA), Leos Mervart (CZECH REPUBLIC)

Activities of the SSG1.181

A Work Program has been proposed by the Chair. Topics of this WP are:

1. Reference Frame Issues - how to tie the regional network to the ITRF.
2. Impact of the Atmosphere - a priori models / height correlation.
3. Satellite Orbits - errors in satellite orbits, differences Broadcast and IGS precise/rapid/ultra-rapid orbits.
4. Parametrisation of Error Sources within a GNSS Real-Time Network.
5. Concept of 'Virtual Reference Stations'.
6. GPS/Glonass integration.
7. Signal Diffraction and Multipath.

Currently substantial contributions to this Working Program (including manuscripts and presentations) cover the topics 1, 3, 4, 5 and 6. The Impact of the Atmosphere, and Multipath (as well as Signal Diffraction) have not been dealt with due to a only moderate response of the members to these issues. This might change within the next two years at least for the atmosphere modelling because of the upcoming 'COST Action 716 Demonstration Experiment (troposphere wet delay) and the 'Solar Max Campaign (ionosphere). (Although other SSGs are also active in these areas.)

Test data sets are available from the Chair and several WG members covering small regional networks in Austria, Switzerland and parts of the EUREF network. Data sets contain GPS as well as combined GPS/Glonass data.

A SSG web page has been established primarily for communication and information of the WG members (for details see <http://luna.tuwien.ac.at/ssg1181/ssg1181.htm>).

A meeting of the SSG members will take place at the next IAG Scientific Assembly in Budapest, as well as one meeting in the USA (AGU Fall Meeting 2001).

Future plans comprise include the detailed study of the quality of quasi real-time orbits, as well as their influence on ambiguity resolution and troposphere modelling. Synergy effects of using data from dual system (GPS/Glonass) / dual-frequency receivers are also under investigation.

The final goal over the next two years is to prepare recommendations and a comprehensive final report on the SSG's activities.

Special Study Group 1.182: "Multipath Mitigation"

Introduction

The precision of raw carrier phase observations recorded by modern GNSS receivers is generally at the sub-millimetre level. However, in all but the most benign environments, the achievable resolution of GNSS positioning is one or more orders of magnitude worse. This discrepancy between the theoretical hardware-dependent precision of the raw observations and the practical accuracy of GNSS position solutions can, in part, be attributed to the effects of site-dependent electromagnetic scattering of incoming GNSS signals. If millimetre level (or better) GNSS accuracies are to be routinely achieved in the future, these electromagnetic scattering effects (commonly referred to as multipath and diffraction) must be eliminated. The website of the Special Study Group 1.182 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1182.htm.

Objectives of the SSG 1.182

The goal of the SSG 1.182 is to study GNSS multipath detection and mitigation techniques with the aim of improving existing high precision positioning accuracies. In the context of this SSG, multipath is loosely defined as the systematic errors in raw GNSS observations that are due to any signal scattering effect caused by the local environment surrounding an antenna. Furthermore, this SSG will focus on carrier phase and code-based multipath in terms of effects on receiver operation for high precision applications. Finally, within the scope of the group, the term GNSS is defined to encompass any type of global positioning system (for example, GPS, Glonass-GPS and Galileo-GPS), or systems simulating GNSS signals (such as in the case of pseudolites). The objectives of the group can be summarised as:

1. Evaluate and compare existing and developing algorithms and techniques for multipath detection and mitigation.
2. Quantify and document the effectiveness of commercial receiver-based multipath mitigation techniques for high precision positioning.
3. Investigate and document the properties of multipath in a variety of environments (particularly high risk environments).
4. Provide information and guidelines for multipath detection and elimination for high precision applications.

Members and Corresponding Members

Members: Mike Stewart (Chair, AUSTRALIA), Penina Axelrad (USA), David Betaille (UK), Mike Braasch (USA), Luisella Giulicchi (THE NETHERLANDS), Cythia Junqueira (BRAZIL), Guillermo Ortega (THE NETHERLANDS), Jayanta Ray (CANADA), Angela Reichert (USA), Rodney Walker (AUSTRALIA), Andreas Weiser (AUSTRIA).

Corresponding Members: Joao Batista (BRAZIL), Paul Cross (UK), Xiali Ding (HONG KONG), Minghai Jia (AUSTRALIA), Domenico Sguerso (ITALY).

Activities of the SSG 1.182

The primary activities of the group since its inception in January 2000 have been:

- a. Define the terms of reference and objectives.
- b. Compile review of relevant and available literature. A list of some 120 multipath related papers is located at:
<http://www.cage.curtin.edu.au/~mike/ssg1.182/biblio.htm>.
- c. Compile review of relevant web sites. A set of links to relevant web sites can be found at: <http://www.cage.curtin.edu.au/~mike/ssg1.182/links.htm>.
- d. Compilation of data archive for multipath data. The SSG is in the process of compiling a data archive to provide multipath researchers with easy access to a variety of different data types from different environments. The archive will also provide reference to the multipath analysis performed by the group who supplied the data, enabling direct comparison between different techniques and different research groups. The archive should be on-line by late 2001.
- e. Define core research areas within the SSG's terms of reference. As the terms of reference are rather broad, a number of core research sub-sections have been defined. Individual group members have been encouraged to monitor developments in the sub-sections relevant to their personal fields of expertise. These include:
 - multipath characterisation and attitude determination;
 - multipath mitigation developments in receiver hardware;
 - semiparametric and parametric multipath modelling techniques;
 - weighting and SIGMA models for multipath mitigation;
 - multipath in space-based applications;
 - multipath mitigation using multi-antenna arrays, time stacking and crossing points; and
 - electromagnetic propagation modelling for multipath analysis.

Below is a brief summary of the technical developments being covered by this SSG. Full reports from group members can be found at the SSG 1.182 own website: http://www.cage.curtin.edu.au/~mike/ssg1.182/recent_reports.htm.

Multipath Mitigation Developments in Receiver Hardware

A variety of so-called multipath-mitigating receiver architectures have been developed over the past decade.

Narrow-correlator (NovAtel); Edge correlator (Ashtech) - The narrow-correlator concept involves moving the traditional 'early' and 'late' correlators closer together. The peak of the pseudo-range multipath error envelope is reduced in direct proportion to the correlator spacing. Ultimately the finite bandwidth of the GPS signal places a practical lower bound on the correlator spacing. Correlator spacings of 0.1 and 0.05 chips are

commercially available, thus providing approximately a factor of 10 to 20 reduction in the peak of the error envelope.

Multipath-Estimating Delay-Lock Loop (MEDLL) (NovAtel)- The MEDLL uses multiple correlators (6 – 10) per channel in order to determine the shape of the multipath-corrupted correlation function. The MEDLL software determines the best combination of direct and multipath signals (that is, amplitudes, delays, and phases) which could have produced the measured correlation function.

Strobe correlator (Ashtech) - The strobe correlator was developed by Ashtech in 1996 and involves a linear combination of two narrow correlator discriminator functions. The result is a discriminator function which is very narrow and thus is significantly less susceptible to medium and long delay multipath.

Enhanced strobe correlator (Ashtech); Pulse-Aperture Correlator (NovAtel) - For most practical purposes the Enhanced Strobe Correlator exhibits true P-code-like multipath characteristics. Specifically, it is virtually insensitive to multipath with delays longer than 50 metres. More recently, NovAtel has released the Pulse Aperture Correlator which has very similar performance. Other manufacturers (Leica, Navcomm) have similar architecture.

Multipath mitigation through modified antenna design is also an important field of research. The most recent developments include adaptive array techniques in which two classes of solutions have been proposed. A first is based on the joint utilisation of a direction-of-arrival (DOA) estimation technique together with a constrained adaptive algorithm. A second approach uses a self-adaptive constant modulus technique, eliminating the need of a pilot signal and DOA estimator.

Multipath Mitigation Using Functional and Stochastic Modelling

One of the most important developments to date in this field are the SIGMA models which were developed to overcome artificially introduced periods of weak satellite geometry by proper weighting of phase observations (SIGMA- ϵ model) and to reduce signal diffraction effects of the phase observations (SIGMA- Δ model). The main parameter of these models is the ratio of the power of the GPS carrier wave C [dBW] to the noise power density N_0 [dBW-Hz], in short C/N_0 [dB-Hz]. Usually, geodetic receivers provide the C/N_0 measurement in the receiver internal binary format or in the NMEA \$GPGSV message. There are currently discussions in progress to standardise and include the C/N_0 observation in a future RINEX format of the GPS observation files. Recently, researchers from Leica Geosystems have proposed a self-calibrating SIGMA- Δ weight model.

A different approach to the SIGMA models also uses signal quality indicators such as signal-to-noise ratio (SNR) to reduce the errors due to multipath. Work is concentrating on direct estimation of the size and sign of multipath errors and subsequent correction of the raw phase measurements, and the estimation of the elements of a full covariance

matrix for the raw GPS phase data according to the likely size of the multipath contamination and the amount of correlation of errors between satellites.

An alternative to traditional least squares modelling of systematic errors in GPS data has also been proposed. The semiparametric model and penalised least squares method describe multipath by a complex but smoothly varying function with time. The functions, and estimated parameters such as station coordinates and ambiguities, are decomposed using the penalised least squares method. Multipath mitigation using the repeatability of SNR ratios over the sidereal day at permanent GPS receivers is based on using a residual stacking algorithm. Others separate multipath from the carrier phase observations. The University of Colorado has developed an algorithm to utilise the spatially-correlated characteristics of multipath to reduce multipath in ground and space-based applications. This algorithm will be used to mitigate multipath in ground-based GPS reference stations.

Electromagnetic Propagation Modelling for Multipath Analysis

The European Space Agency (ESA) is using a software tool "Multipath Virtual Laboratory" (MVL) to compute multipath effects on the GPS observables having satellite constellation location, receiver antenna location, positioning of surrounding structures and antenna information as input parameters. The computation of signal propagation uses a ray-tracing angular Z-buffer algorithm, followed by an electromagnetic field computation using the Geometric Theory of Diffraction (GTD). The MVL tool was used to pre-compute the presence of multipath for the rendezvous of the shuttle Atlantis with the Russian space station MIR.

Work on modelling the multipath environment of the International Space Station is currently underway at the Jet Propulsion Laboratory (JPL) using a multipath simulator previously developed in 1990. In this recent application of the simulation model, the measurement error due to multipath has been computed for a number of different antenna locations. Once the multipath error for each antenna is computed, the corresponding orbit error due to multipath is determined using JPL's GIPSY-OASIS II orbit determination software.

A relatively new technique that involves a numerical solution to the Parabolic Equation (PE) has been used to solve for two-dimensional propagation over any type of terrain. The PE provides a direct solution of Maxwell's wave equations by approximating the Helmholtz scalar wave equation. This technique does not rely on the study of individual ray paths as used in the GTD. Propagation simulations from the model accurately provide the amplitude and phase of the propagated plane wave at all points within the model domain. The PE model was used to study the effects of diffraction and multipath caused by various types of terrain commonly found in an open cut mining environment.

Multipath Characterisation and Attitude Determination

Both ESA and the NASA Johnson Space Center group have been studying multipath

effects on attitude determination in the particularly severe environment of the International Space Station (ISS). NASA has compared space shuttle GPS flight data to predicted results from geometrical diffraction prediction. ESA has analysed data from on-ground experiments and in-flight demonstrations for the rendezvous and docking of ESA's Automatic Transfer Vehicle with the ISS. Researchers at ESA have also studied the design of a modified patch antenna that provides low elevation and LHCP signal rejection. Size, weight, and other characteristics are designed for space applications with the goal of improving attitude accuracy below 1° .

Two academic research groups specialise in multipath mitigation for attitude determination. One group have looked at phase map corrections for using simulations and satellite data from the CRISTA-SPAS Experiment. Another group proposes the use of non-dedicated receivers for attitude determination, including using a group of closely spaced antennas for multipath correction in RTK. Attitude accuracy is quite poor because antenna separation is very small. Multipath reduction with the multi-antenna array has been studied in various environments, such as in urban canyons and under foliage. Improvement due to multipath corrections is reported to be approximately 50%.

Special Commission 4: "Application of Geodesy to Engineering"

Introduction

Rapid developments in engineering, microelectronics and the computer sciences have greatly changed both the instrumentation and methodology in Engineering Geodesy. The objectives of the Special Commission are on the one hand to document the body of knowledge in this field, and on the other hand to encourage new developments and present them in a consistent framework. Symposia and workshops are planned to document the current state of development in engineering applications of geodesy. Working Groups were established in areas of current research interest which will have specific goals to ensure that their research work can be accomplished in a four year period. In addition, there is considerable collaboration with other international organisations such as the ISPRS, FIG, and the ION.

SC4 WG 1: “Real-Time Mobile Multi-sensor Systems and Their Applications in GIS and Mapping”

To fulfil the need for up-to-date inventory and geometric data along transportation routes (e.g. roads, railways, rivers, pipelines, etc.) Mobile Multi-sensor Systems (MMS) are being operated. In general, MMS have in common that they integrate a set of sensors mounted on a single platform, and synchronized to a common time base. They are typically operated in kinematic mode. In principle, they are capable of operating only with the data measured on the platform, that is, no other information (such as external ground control) is needed, although it may be included as redundant information. Systems of this type:

- Can be immediately deployed anywhere on the Earth without the need for identifying existing ground control.
- Employ a task-oriented system design through integration at the measurement level, and hence data flow optimisation can be a built-in feature.
- Can be equipped with real-time quality control features by including data redundancies in the system design, and by using a combination of real-time data processing and Expert Knowledge to generate homogeneous results.
- Generally use software geo-referencing to transform the time-dependent measurement process into a sequence of geo-referenced images, which can be considered as independent geometric units in post-mission processing.

The objectives of the Working Group are:

1. Identify and promote new developments in MMS.
2. Identify and promoted new applications for MMS.
3. Encourage and document emerging processing techniques for MMS.

Chairman: [Naser El-Sheimy](#) (Canada)

Co-chairman: [Jan Skaloud](#) (Switzerland)

(18 members)

SC4 WG 2: “Dynamic Monitoring of Buildings and System Analysis”

The world records for bridge span and building height have increased more than tenfold in the second millennium. In the 20th century alone, the record height for a building has increased from 118m to 452m, while the record for a bridge span has increased from 521m to 1991m.

As can be seen from these records, quality control of these structures is a challenging task. The goals of the monitoring methods are: assessment of the structural behaviour (safety inspection) and improvement of maintenance (optimization of repair, early detection of damage, etc.). The input for the monitoring methods can be forced or ambient vibrations. Then "Forced Vibration Testing" (FVT) and "Ambient Vibration Testing" (AVT) can be applied.

Instruments, used to monitor the motions, are often fixed to the object under motion. That means that their dynamic parameters change depending on the frequencies of the motions. The goal of this Working Group is, to study dynamic monitoring methods, sensor systems and system analysis models for quality control of large manmade structures. Interdisciplinary collaboration will be necessary.

Chairman: Wolfgang Niemeier (Germany)

Co-Chairman: Rainer Flesch (Austria)

(8 members)

SC 4 WG 3: “Monitoring of Local Geodynamic Processes and System Analysis”

Monitoring and system analysis of landslides, mudflows and rockslides has become of great importance, since the population of the world is increasing dramatically and, as in many cases, housing estates and industrial sites were erected without taking these geodynamic processes into consideration.

In mountainous areas, for instance, as in the European Alps, it is estimated that about 6% of the country is affected by landslides. Along the Yangtze River in China, in the vicinity of the Three Gorges Dam Reservoir, for instance, about 100 landslide sites have to be monitored. Their average velocities can vary from 1 to 200mm/year, and in general the movements are fairly regular, especially on large slopes. In some cases there are reactions according to the climate conditions. However, sometimes instabilities are possible, which cause the velocities to be multiplied by a factor 100 and greater, sometimes resulting a disaster failure.

The main goals of the Working Group are to study:

1. Computer-controlled MMS recording geodetic, geophysical and meteorological data.
2. Different models of system analysis.
3. Models for disaster/failure prediction.

Chairman: [Gyula Mentés](#) (Hungary)

Co-Chairman: Ewald Brückl (Austria)

(14 members)

SC 4 WG 4: “Geodesy on Large Construction Sites”

The growing world population and the globalization of the economy demands improved traffic systems, power stations and construction of dwellings and bureau centres. Therefore in the future large construction sites will have to be managed. Geodetic methods and techniques can contribute to do this management in a most economical way. There will be large construction sites for high speed railway lines, tunnels, bridges, power dams, airports, and so on.

The main goals of the Working Group will be to study:

1. The design of networks based on permanent GPS stations.
2. The navigation of construction machines.
3. High precision alignment methods.
4. Information systems based on geodetic-geotechnical-geological data.

Chairman: A new chairman will be nominated within two months.

SC 4 WG 5: “Pseudolite Application in Engineering Geodesy”

In satellite-based precise positioning, the dominant factors are the number *and* geometric distribution of the satellites tracked by the receivers. In the case of global navigation satellite systems (GNSS) such as GPS, Glonass, and the planned Galileo system, four visible satellites are the minimum requirement for precise three-dimensional positioning. In general, the more satellites that are tracked, the more reliable the positioning solutions. However, in some situations, such as in downtown urban canyons, engineering construction sites, and in deep open-cut pits and mines, the number of visible satellites may not be sufficient. In the worst situations, such as in underground tunnels and inside buildings, the satellite signals may be completely lost. Such problems with existing GNSS systems can be addressed by the inclusion of additional ranging signals transmitted from ground-based "pseudo-satellites" (pseudolites). Pseudolites are an exciting technology that can be used for a wide range of positioning and navigation applications, either as a substantial augmentation tool of spaceborne systems, or as an independent system for indoor positioning applications.

The goal of this proposed Working Group is to study new concepts of pseudolite-related positioning and, in particular, applications of pseudolites in engineering geodesy. Major objectives of the research activities are to study:

1. Pseudolite augmentation of GPS system.
2. Pseudolite-only positioning scenarios.
3. Integration of pseudolites with other sensors, such as INS.

These objectives will be achieved by:

- Promoting discussions between Working Group members.

- Setting up a Working Group website providing a focus for pseudolite research and applications with the relevant links. The web site is located at: <http://129.94.250.108/iag-sc4-wg5/index.html>.
- Developing a comprehensive bibliography dealing with pseudolite research and applications.

Chairman: Jinling Wang (12 members)

SC 4 WG 6: “Application of Knowledge-Based Systems in Engineering Geodesy”

For many geo-(but also non-geo-)disciplines the results of geodetic measurements (coordinates, displacements, etc.) serve as a basis for solving problems such as interpretation, documentation, recognition, control, design, prediction, diagnose, alarming, simulation, and so on. Examples are the (intelligent) control of measurement or guidance systems, the detection of outliers, or the early recognition of noticeable patterns in the displacement data of tunnels under construction, etc. For these tasks geodetic data often must be considered incomplete and uncertain, and in most cases additional knowledge from experts of the specific application field is needed.

Nowadays there is a growing demand for geodesists to work in interdisciplinary teams and to contribute to the development of appropriate systems and techniques that help to solve these problems in a more 'intelligent' and 'automatic' manner. The application of AI-methods, such as Knowledge-based Systems, seems to be a promising approach, hence this research for, and applicability in, Engineering Geodesy will be the main objective of the Working Group.

Chairman: Klaus Chmelina (5 members)

Conference Activities

WG 1 was organiser of the conference "3rd International Workshop on Mobile Mapping Technology", 3-5 January, 2001 in Cairo, Egypt. A report on the conference can be downloaded from the SC4 websites.

Websites: http://info.tuwien.ac.at/ingeo/sc4/sc4_99-03.htm
<http://www.sc4.de.vu/>

Working Groups WG 2 and WG 3 have organised a workshop on "Monitoring of Constructions and Local Geodynamic Processes", held in Wuhan, P.R. China, from 22-24 May, 2001.

Websites: <http://info.tuwien.ac.at/ingeo/sc4/wuhan01.htm>
<http://www.wtusm.edu.cn/wuhan01.htm>

The Special Commission is co-sponsor of the "5th Conference on Optical 3-D Measurement Techniques", which will be held in Vienna, Austria, 1-4 October, 2001.

Websites: <http://info.tuwien.ac.at/ingeo/optical3d/o3d.htm>
<http://www.optical3d.de.vu/>

The Special Commission is organising the "2nd Conference on Geodesy for Geotechnical and Structural Engineering", which will be held in Berlin, Germany, 21-24 May, 2002. This will be the meeting where all the WGs will come together to present their scientific programs and report on their current research work.

Websites: <http://info.tuwien.ac.at/ingeo/sc4/berlin.html>
<http://www.sc4-berlin2002.de.vu/>

Commission X: "Global and Regional Geodetic Networks"

Introduction

The goal of the Commission is to focus on the variety of existing control networks (horizontal or vertical, national or continental, global from space techniques) as well as their connections and evolutions.

The Commission has two types of subdivisions: Sub-Commissions and Working Groups:

- 1) Sub-Commissions for large geographic areas: Europe, North America, South America, Africa, South East Asia and Pacific. Such Sub-Commissions will deal with all types of networks (horizontal, vertical and three-dimensional), and all related projects which belong to that geographical area.
- 2) Working Groups for specific technical topics which would be relevant to the Commission's activities. Such Working Groups are not substitutes for a SSG of the IAG, but rather look at technical and practical problems, in particular by establishing specifications for the countries, and also possibly sponsoring training seminars.

In addition, Commission X has a Steering Committee (SC) consisting of:

- President of the Commission
- Presidents of the Sub-commissions
- Chairs of the Working Groups

Each country member of the IAG is permitted to appoint one representative to Commission X. If the country belongs to an area where a Sub-Commission has been already established, the representative will be a de facto member of that Sub-Commission. Each country not yet a full member of the IAG is welcomed to appoint an observer to the Commission. Members of Working Groups will be selected by the Chairs, and approved by the SC after consultation with relevant people and representatives of countries. The web site for the Commission is at: <http://lareg.ensg.ign.fr/GRGN/>.

Objectives of the Commission

1. To expand the present GRGN web site in order to give a proper source of information of relevant activities, including Sub-Commissions and Working Groups, but also related activities at national or international level, such as survey agencies, international programs or projects, services such as IGS, IERS or others. This site should also provide informations on standards and terminology, catalogue of datums and cartographic coordinate systems.
2. To expand the list of national representatives and involve them more in the Commission activities (for instance updates of the web system).
3. To stimulate the formation of new Sub-Commissions.
4. To update the list and charters of the Working Groups.
5. To stimulate the development of a modern geodetic framework for Africa (AFREF).

6. To stimulate the organisation of a training school related to the GRGN field (modern networks, ITRF, GPS, etc.).
7. To promote ITRF as the international framework, and to realise its densification for all type of uses, help to remove misunderstandings with respect to WGS84, and promote ITRF for the new global navigation satellite systems such as the European Galileo program.

Organisation of Sub-Commissions and Working Groups

Sub-Commission for Europe (EUREF)

President: Jose Agria Torres (PORTUGAL)

Sub-Commission for North America

President: Dennis Milbert (USA)

Sub-Commission for South America

President: Luiz Paolo Souto Fortes (BRAZIL)

Sub-Commission for Antarctica

President (co-chairs): John Manning (AUSTRALIA), Reinhard Dietrich (GERMANY)

Sub-Commission for South East Asia and Pacific

President(co-chairs): John Manning (AUSTRALIA), Jun Yong Chen (CHINA)

Working Group on Datums and Coordinate Systems (WG1)

Chairman: Bjorn Geir Harrson (NORWAY)

Working Group on the Worldwide Unification of Vertical Datums (WG3)

Chairman:William Kearsley (AUSTRALIA)

National Representatives

Australia: John Manning

Austria: E Erker

Belgium: Carine Bruyninx

Brazil: Sonia Maria Alves Costa

Canada: Michael Craeymer

China: Yan Ping Zhang

Croatia: Damir Medak

Czech Republic: Jan Kostelecky

Egypt: A Tealeb

Estonia: Artu Ellmann

Finland: Matti Ollikainen

France: Michel Kasser

Germany: Ewald Reinhart

Hungary: Jozsef Adam

Israel: Yossi Melzer
Italy: Maurizio Barbarella
Japan: Hiromichi Tsuji
Luxembourg: Andre Majerus
Malaysia: Samad Bin Haji Abu
New Zealand: Graeme Blick
Norway: Oddgeir Kristiansen
Poland: L W Baran
Portugal: Luisa Bastos
Russia: G Demyanov
South Africa: Richard T Wonnacott
Switzerland: D Schneider
United Kingdom: Peter Dare
USA: Dennis Milbert
Yugoslavia: Dragan Blagojevic