# Commission 1 – Reference Frames

President: **Christopher Kotsakis** (Greece)
Vice President: **Jean-Paul Boy** (France)

*http://www.com1.iag-aig.org*

## Terms of Reference

Reference systems and frames are of primary importance for Earth science based research and applications, satellite navigation and orbit determination as well as for practical applications in positioning, mapping and geo-information related fields. A precisely defined reference frame is needed for an improved understanding of the Earth system, including its rotation and gravity field, sea level change with time, tectonic plate motion and deformation, glacial isostatic adjustment, geocentre motion, deformation due to earthquakes, local subsidence, and other crustal displacements. Commission 1 activities and objectives deal with the theoretical and operational aspects of how best to define reference systems and how reference systems can be used for practical and scientific applications at different spatio-temporal scales on the deformable Earth. Commission 1 will closely interact with the other IAG Commissions and Services, the ICCT, the newly established ICCC, and the GGOS components where reference system aspects are of concern, to address related problems for the realization of celestial and terrestrial reference systems in conformity with present and future accuracy needs. Commission 1 is also linked with the IUGG/COSPAR joint Sub-Commission B2 (International Coordination of Space Techniques for Geodesy) under the aim to develop links and coordinate the work between various groups engaged in the field of space geodesy and geodynamics.

## Objectives

The main objectives of Commission 1 are as listed in the IAG by-laws:

- Definition, establishment, maintenance and improvement of the geodetic reference frames;
- Advanced terrestrial and space observation technique development for the above purposes;
- International collaboration for the definition and deployment of networks of terrestrially-based space geodetic observatories;
- Theory and coordination of astrometric observation for reference frame purposes;
- Collaboration with space geodesy/reference frame related international services, agencies and organizations;
- Promote the definition and establishment of vertical reference systems at global level, considering the advances in the regional sub-commissions;
- Work to maintain a reference frame that is valuable for global change studies.

## Structure

### Sub-Commissions

SC 1.1: Coordination of Space Techniques
Chair: *Urs Hugentobler* (Germany)
SC 1.2: Global Reference Frames
Chair: *Xavier Collilieux* (France)
SC 1.3: Regional Reference Frames
Chair: *Carine Bruyninx* (Belgium)
SC 1.3a: Europe
Chair: *Martin Lidberg* (Sweden)
SC 1.3b: South and Central America
Chair: *Sonia Maria Alves Costa* (Brazil)
SC 1.3c: North America
Co-Chairs: *Michael Craymer* (Canada) and *Dan Roman* (USA)
SC 1.3d: Africa
Chair: *Elifuraha Saria* (Tanzania)

SC 1.3e: Asia-Pacific
Chair: *Basara Miyahara* (Japan)
SC 1.3f: Antarctica
Chair: *Martin Horwath* (Germany)
SC 1.4: Interaction of Celestial and Terrestrial Reference Frames
Chair: *Zinovy Malkin* (Russia)

### Joint Study Groups

JSG T.32: High-rate GNSS (joint with ICCT, Commissions 3 and 4, GGOS; see description under ICCT)
Chair: *Mattia Crespi* (Italy)
JSG T.24: Integration and co-location of space geodetic observations (joint with ICCT, Commissions 3 and 4, GGOS; see description under ICCT)
Chair: *Krzysztof Sośnica* (Poland)
JSG T.31: Multi-GNSS theory and algorithms (joint with ICCT, Commission 4, GGOS; see description under ICCT)
Chair: *Amir Khodabandeh* (Australia)
JSG T.33: Time series analysis in geodesy (joint with ICCT, Commission 3, GGOS; see description under ICCT)
Chair: *Wieslaw Kosek* (Poland)
JSG T.29: Machine learning in geodesy (joint with ICCT, Commissions 2, 3 and 4, GGOS; see description under ICCT)
Chair: *Benedikt Soja* (USA)
JSG T.37: Theory and methods related to high-resolution digital topographic and bathymetric models (joint with ICCT, Commissions 2 and 3, GGOS; see description under ICCT)
Chair: *D.Carrion* (Italy)
JSG 3.1: Geodetic, seismic and geodynamic constraints on GIA (joint with Commissions 2 and 3, IASPEI; see description under Commission 3)
Chair: *Rebekka Steffen* (Sweden)
Vice-Chair: *Erik R. Ivins* (USA)

### Joint Working Groups

JWG C.4: Regional sea level and vertical land motion (joint with ICCC, Commissions 2 and 4, GGOS; see description under ICCC)
Chair: *Roelof Rietbroek* (Germany)
GGOS Working Group: Towards a consistent set of parameters for a new GRS (joint with Commission 2, GGOS; see description under GGOS)
Chair: *Urs Marti* (Switzerland)

## Program of Activities

Commission 1 fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing symposia, either independently or at major conferences in geodesy, geophysics and geodynamics. Some events will be focused narrowly on the interests of the sub- commissions and other entities listed above, and others will have a broader commission-wide focus.

More specifically, the program of activities for Commission 1 includes:

- Theoretical and applied research activities related to reference frames;
- Research and development activities that impact the reference frame determination and its accuracy, as well as, the best and optimal usage of reference frames in Earth Science applications;
- Interaction with all established IAG Services: IVS, IGS, ILRS, IDS and the IERS, including their Combination Centres and Working Groups;
- Development in the theory of the transformation between Celestial and Terrestrial Reference Systems and application of the theory to improve the consistency between ICRF, ITRF and EOPs, in cooperation with IVS and IERS;
- Exploration of advanced methodologies for the combination of products and raw observations of space geodetic techniques;
- Investigation of systematic error sources and factors limiting the precision of space geodetic techniques and their combination;
- Encouraging and assisting regional sub-commission countries to re-define and modernize their national geodetic systems so that they are compatible with the ITRF;

The status of Commission 1, including its structure and membership, as well as links to the internet sites of its sub-entities and parent and sister organizations and services, will be updated regularly and can be viewed on the Commission's webpage.

## Steering Committee

| | |
|---|---|
| President Commission 1: | *Christopher Kotsakis* (Greece) |
| Vice President Comm. 1: | *Jean-Paul Boy* (France) |
| Chair Sub-Comm. 1.1: | *Urs Hugentobler* (Germany) |
| Chair Sub-Comm. 1.2: | *Xavier Collilieux* (France) |
| Chair Sub-Comm. 1.3: | *Carine Bruyninx* (Belgium) |
| Chair Sub-Comm. 1.4: | *Zinovy Malkin* (Russia) |
| Representative of IGS: | *Paul Rebischung* (France) |
| Representative of IERS: | *Detlef Angermann* (Germany) |
| Member-at-Large: | *Guangli Wang* (China) |

# Sub-Commissions

## SC 1.1: Coordination of Space Techniques

Chair: *Urs Hugentobler* (Germany)

### Terms of Reference

Space techniques play a fundamental role for the realization and dissemination of highly accurate and long term stable terrestrial and celestial reference frames as well as for accurate monitoring of the Earth orientation parameters linking the two fundamental frames. The current space geodetic techniques contributing to ITRF and ICRF, i.e., Very Long Baseline Interferometry (VLBI), Satellite and Lunar Laser Ranging (SLR/LLR), Global Navigation Satellite Systems (GNSS) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) have particular strengths and technique-specific weaknesses.

Strengths of the techniques are exploited by combining them making use of fundamental sites co-locating more than one technique. Sub-commission 1.1 focusses on the coordination of research related to the geodetic space techniques with emphasis on co-location aspects at fundamental geodetic observatories as well as on co- location targets in space, considering common parameters such as coordinates of stations and satellites, troposphere parameters, and clock parameters.

### Objectives

- Coordinate research on co-location using common parameters in space;
- Coordinate research on co-location using common parameters at fundamental geodetic observatories;
- Explore the use of new techniques and technologies;
- Interface with IERS WG on Site Survey and Co- location;
- Interface with the GGOS Committee on Performance Simulations and Architectural Trade-Offs (PLATO);
- Interface with Joint WG on Tropospheric Ties.

# Working Groups of Sub-Commission 1.1

## JWG 1.1.1: Intra- and Inter-Technique Atmospheric Ties (joint with SC 4.3 and GGOS)

Chair: *Kyriakos Balidakis* (Germany)
Vice-Chair: *Daniela Thaller* (Germany)

### Terms of Reference

The differences between atmospheric parameters (mainly zenith delays and gradients) at co-located stations that observe nearly simultaneously, and stem from external systems (e.g., meteorological sensors or weather models) are understood as atmospheric ties. Atmospheric ties mainly exist because of differences in (i) the observing frequency, (ii) the relative position, and (iii) the observing system setup.

The acquisition of accurate atmospheric delay corrections is of paramount importance for mm-level positioning employing space geodetic techniques. Atmospheric delay corrections may stem from dedicated instruments such as water vapor radiometers, meteorological sensors, numerical weather models, or from the geodetic data itself. While the latter is fairly common for modern GNSS and VLBI, observation geometry and accuracy limitations inherent to other systems such as SLR and DORIS impede the accurate atmospheric parameter estimation, thus hindering among else positioning. To this end, it might be useful to compare and combine atmospheric parameters at co-located sites, in a manner similar to the combination of station and satellite coordinates, as well as Earth rotation parameters (via local, space, and global ties, respectively). The multi-technique combination is indispensable to the distinction between real signals and undesired technique-specific artefacts. Nowadays, the multi-technique combination is facilitated by the increasing investments in state-of-the-art geodetic infrastructure at co-located sites. However, a host of systematic and random errors render the combination via atmospheric ties a difficult task. Moreover, since atmospheric delays are dependent upon essential climate variables (pressure, temperature, and water vapor), differences in long-term atmospheric delay time derivatives at co-located stations might offer an insight into local climate change.

### Objectives

The purpose of this working group is to answer the following questions:

- How can one relate atmospheric (electrically neutral) parameter estimates and the time derivatives thereof that refer to different place, time, and observing system?

What are the limits in distance, time lag, and observing system?
- What is the optimal way to combine atmospheric parameters?
- What is the benefit from including atmospheric ties in a multi-technique terrestrial reference frame combination?

### Proposed activities

- Comparison of atmospheric (electrically neutral) delay estimates from single-technique geodetic analysis (GNSS, SLR, VLBI, and DORIS).
- Comparison of atmospheric delays from state-of-the-art meso-β scale weather models (e.g., ERA5 and MERRA2), and high-resolution runs utilizing the Weather Research and Forecasting (WRF) Model.
- Assessment of spatial and temporal correlation between atmospheric parameters.
- Assessment of multi-technique combination employing atmospheric ties on the single site and global TRF level.

### List of members

*Balidakis, Kyriakos* (Germany), Chair
*Boisits, Janina* (Austria)
*Coulot, David* (France)
*Drożdżewski, Mateusz* (Poland)
*He, Changyong* (France)
*Heinkelmann, Robert* (Germany)
*Kitpracha, Chaiyaporn* (Germany)
*Lemoine, Frank* (USA)
*Lengert, Lisa* (Germany)
*Nilsson, Tobias* (Sweden)
*Pollet, Arnaud* (France)
*Santos, Marcelo* (Canada)
*Soja, Benedikt* (USA)
*Sośnica, Krzysztof* (Poland)
*Thaller, Daniela* (Germany), Vice-Chair
*Wang, Xiaoya* (China)
*Wijaya, Dudy* (Indonesia)
*Zus, Florian* (Germany)

## SC 1.2: Global Reference Frames

Chair: *Xavier Collilieux* (France)

### Terms of Reference

Sub-commission 1.2 focuses its activity on the definition and realization of the terrestrial reference system (TRS). The TRS realization, named Terrestrial Reference Frame (TRF), is fundamental to study and locate global phenomena or objects at the Earth's surface, in the ocean or in space. It is used as the basis of several operational observation system processing chains such as sea level determination from space and Earth's rotation monitoring but is also used for most regional and national TRFs. Thus, TRF specifications in terms of origin, scale and orientation have to be optimally realized to satisfy user needs. That's why sub-commission 1.2 shall study either fundamental questions or more practical aspects that could improve current TRF determinations.

Thanks to the accumulation of space geodesy observations and progress in modeling and analysis, non-stationary Earth surface displacements are nowadays clearly evidenced. The next generation of TRF should be able to explicitly model them or should be constructed in such a way that those displacements are accurately modelled. There are currently two different approaches to represent the TRF: Long-term linear and nonlinear TRFs. Time series of quasi-instantaneous frames are proposed but practical implementations still need to be investigated so that the implicit reference frame definition reach the required accuracy. Augmented parametric TRF, coupled with enhanced forward displacement models is an alternative to TRF time series. This approach is in agreement with past modeling of the International Terrestrial Reference Frame (ITRF) but still require progress in forward models (e.g. loading and post-seismic deformations). The dominant non-steady displacement signal is the geocenter motion which is related to the origin definition of the frame. While its main contribution is included in non-tidal loading forward models and while it can be observed by space geodesy, there are still open questions regarding its annual variation.

Technique systematic errors still exist in space geodesy products, which impact the TRF definition, especially the scale parameter. Dedicated satellite missions with onboard multi-technique sensors could improve further our understanding of technique systematic errors thanks to solving parameters common to multiple techniques. However, a set of accurate tie vectors that relate position of various technique instruments at co-location sites will still be of outmost importance to validate those new space-ties and monitor their long-term variations. In parallel, due to the high cost of local tie surveys, it is worth investigating supplementary ways to monitor reference point variations with time. Here, the potential of PSInSAR technique to investigate ground/monument deformation is proposed.

A step forward could be established by investigating relativistic reference frames based on a network of clocks in space linked with time transfer technologies. Such realized frame would be entirely decoupled from ground fixed stations and could be used to reference any point on the Earth's surface. The relativistic frequency shift between clocks in space and on the ground would be a direct measurement of the Earth gravity potential. This technology can be used to realize a world height system based on a network of ground clocks.

While this ultimate goal still requires intensive research works, TRF and future World Height Systems need to be studied in closer partnership in order to connect reference benchmarks, gravimeters or clocks to the TRF but also to provide consistent coordinate and height time-variations.

The work of this sub-commission will be done in partnership with the International Earth Rotation and Reference Systems Service (IERS) as well as IAG Global Geodetic Observing System (GGOS).

### Objectives

The main objectives of sub-commission 1.2 are the following:

- Definition of the global terrestrial reference frame (origin, scale and orientation, time evolution, standards, conventions, models);
- Methods to determine local tie vectors and to relate instrument reference points to surveyed ground markers;
- Investigate new methods to determine relative motions at co-location sites;
- Evaluation of technique systematic errors by focusing on errors at co-location sites;
- Enhanced forward modeling of the Earth's surface deformation;
- Modeling of the reference frame in general relativity;
- Linking global height reference frames with the terrestrial reference frame;
- Pursue studies and investigation related to multi-technique satellites (space ties) and concepts of novel dedicated missions with onboard multi-technique sensors.

### Link to Services

Sub-Commission 1.2 will establish close links to relevant services for geodetic reference frames, namely the IERS, GGOS and IAG technique services: International GPS Service (IGS), International Laser Ranging Service (ILRS), International VLBI Service for Geodesy and Astrometry (IVS), and International DORIS Service (IDS). A close link with the IERS Conventions Center will be also maintained, especially for chapter 4 (“Terrestrial Reference Systems and Frames”) updates.

## Working Groups of Sub-Commission 1.2

## WG 1.2.1: Assessing impacts of loading on Reference Frame realizations

Chair: *Anthony Mémin* (France)

### Terms of Reference

Non-tidal loading (NTL) deforms the Earth's surface adding variability to the coordinates of geodetic sites. The effects of NTL are already observed in geodetic time series from VLBI, SLR, DORIS and GNSS techniques. They occur in a wide range of period, from sub-daily to centennial time scale. They also have an impact on crustal velocity estimates and as a consequence on the realization of the terrestrial reference frame.

It has been shown that unconsidered NTL effects can bias estimates of geodetic vertical velocity by 0.5 mm/yr over the continent to more than 1 mm/yr in the southern tropical regions between 1993 and 2014 (Santamaría-Gómez and Mémin 2015). It is five to more than ten times larger than the requirement of the Global Geodetic Observing System on interannual to secular time scales and about one-third of the current rate of sea level rise.

Geodetic techniques require accurate global circulation models to allow precise estimation of the Earth's surface displacements to reduce the variability of position time series, in addition to the corresponding time-variable gravity field affecting the orbits of artificial satellites. Correcting for NTL at the observation level reduced for example the variability of GNSS time series by up to 7 mm (Männel et al. 2019).

According to the 2010 IERS conventions, there are currently no recommended surface-mass change models (atmosphere, ocean circulation, ocean response to atmospheric changes, hydrology, past- and present-day ice-mass, sea level) nor Earth models (1D vs 3D, elastic, visco-elastic, rheology, coastline definition) to account for NTL deformation in geodetic position time series. Hence, a better understanding of NTL contribution to geodetic time series is required. Also, several studies have already shown that a posteriori corrections slightly decrease the variance factor of a Terrestrial Reference Frame (TRF) multi-technique combination but the improvement at some sites was also counterbalanced by degradation at others. The accuracy and precision of current space geodetic techniques are such that several scientific studies have already considered atmospheric loading corrections at the observation level. However, there still exist open questions regarding the application of loading corrections for the generation of operational geodetic products, either a priori or a posteriori.

### References

Santamaría-Gómez A, Mémin A (2015) Geodetic secular velocity errors due to interannual surface loading deformation. Geophys J Int Exp Lett 202 (2):763–767, doi:10.1093/gji/ggv190.

Männel B, Dobslaw H, Dill R, Glaser S, Balidakis K, Thomas M, Schuh H (2019) Correcting surface loading at the observation level: impact on global GNSS and VLBI station networks, J Geod, doi.org/10.1007/s00190-019-01298-y.

### Objective

The principal objectives of the scientific work are to assess the effects of load and Earth models and their applications for TRF utilization and to assemble specific recommendations for users and future IERS conventions.

### Program of Activities

- Create and maintain an updated list of loading studies: models and observations.
- Compare and assess differences between existing load models.
- Assess ice and sea level change loading deformation.
- Assess the propagation of loading model errors and differences in using several Earth models into the site coordinates, TRF parameters and the ITRF.
- Determine whether load models should be applied a priori or a posteriori.
- Organize meetings during international conferences (EGU, AGU…).
- Suggest recommendations for IERS conventions.

### List of members

*Jean-Paul Boy* (France)
*Kristel Chanard* (France)
*Benjamin Maennel* (Germany)
*Anthony Mémin* (France), Chair
*Laurent Métivier* (France)
*Manuela Seitz* (Germany)
*Giorgio Spada* (Italy)
*Daniela Thaller* (Germany)
*Wouter van der Wal* (The Netherlands)

**Corresponding members**
*Christopher Kotsakis* (Greece)

## JWG 1.2.2: Methodology for surveying geodetic instrument reference points

(joint with IERS)

Chair: *Ryan Hippenstiel* (USA)
Vice-Chair: *Sten Bergstrand* (France)

### Terms of Reference

The International Terrestrial Reference System is built upon multiple geodetic techniques; Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Doppler Orbitography and Radiopositioning Integrated by satellite (DORIS), and Global Navigation Satellite Systems (GNSS). At locations where these techniques are co-located, it is vital to determine and understand the vectors between the reference points of each technique. These vectors are determined by local tie surveys conducted terrestrially with various procedures and geodetic instruments. The reference points should be collected and properly aligned to a global reference frame in order to produce relative and absolute coordinates.

As the science of local tie surveys has developed, so has technology and the expectation of higher precision and improved protocols. It is the desire of this working group to investigate the current and expected best practices available, along with documenting past efforts, both in the field and researched. This working group will share methodology of existing tie surveys, continued to develop and document recommended procedures, and also archive surveys completed by all agencies represented.

In addition, efforts will be made to isolate systematic errors of the space geodetic techniques using surveying methods and investigate field procedures that could be completed during the course of a tie survey in order to provide the operator valuable feedback on potential physical errors found onsite. One critical example of this is quantifying thermal and gravitational deformation in VLBI sensors. It is the overall goal of the working group to encourage consistent field practice, terminology, and documentation throughout the community, with a continued eye on the future of tie surveys.

### Objective

Enhance and improve knowledge of local tie surveys through applied field practice, research, and dissemination of materials developed.

### Activities

- Investigate thermal and gravitational deformation.
- Consider importance and inclusion of DoV observations.

- Discuss overall error budget and precision (achieved/necessary) considering the above.
- Continue to enhance guidelines on procedures (and subsequent feedback for improvement).
- Archive reports, tie vectors and raw data of all agencies conducting tie surveys.
- Gather, distribute, and maintain publications on related matters.
- Coordinate with and solicit feedback from all geodetic techniques on developments.

### Expectations

- Participation in local tie surveys and/or testing of new methodologies.
- Attendance of meetings or participation in remote/virtual discussions.
- Reporting of survey results and/or research efforts towards the objectives of the WG.
- Develop and maintain a depository of past and future reference materials.

### List of members

*Zuheir Altamimi* (France)
*Sten Bergstrand* (France), Vice-Chair
*Steven Breidenbach* (USA)
*Benjamin Erickson* (USA)
*Kendall Fancher* (USA)
*Charles Geoghegan* (USA)
*Ryan Hippenstiel* (USA), Chair
*Kevin Jordan* (USA)
*Jack McCubbine* (Australia)
*Damien Pesce* (France)
*Jerome Saunier* (France)

**Corresponding members**
*Xavier Collilieux* (France)
*Mike Pearlman* (USA)

## JWG 1.2.3: Toward reconciling Geocenter Motion estimates

(joint with IERS)

Chair: *Kristel Chanard* (France)
Vice-Chair: *Alexandre Couhert* (France)

### Terms of Reference

The International Terrestrial Reference Frame (ITRF) origin is realized through Satellite Laser Ranging (SLR) orbit dynamics determining the Center of Mass (CM) of the Earth system, e.g. the solid Earth and its fluid envelops. The ITRF origin is considered, over secular time scales, to be the mean Earth CM, averaged over the time span of SLR observations (IERS Conventions 2010). Over shorter time scales, the ITRF origin behaves as an approximated Center of Figure (CF) of the solid Earth surface. The motion of CM with respect to CF is commonly called geocenter motion.

For number of operational and scientific applications, such as improving the ITRF accuracy or refining estimates of sea level variations, the ITRF origin should coincide with CM at any time. Thus, accessing true geocentric positions requires, to this day, to adopt a model for geocenter motion. However, due to discrepancies in models derived from various techniques and methods, no conventional model for geocenter motion has not been conventionally accepted yet. It is therefore the focus of this working group to identify scientific and technical obstacles leading to inconsistencies in geocenter motion estimates obtained from various geodetic techniques or forward geophysical models. Consequently, the working group will first gather geocenter motion time series derived from geodetic products, along with detailed information on methods of estimation, compare estimates and closely investigate discrepancies. We seek to identify potential sources of geodetic systematic errors and/or inconsistencies in methodologies used to retrieve geocenter motion (network effect, etc.), at both the annual and interannual time periods. A special attention will then be given to improving and/or developing new methods, less sensitive to errors in geodetic products and provide refined geocenter motion estimates.

### Objectives

- To review all methods to estimate geocenter motion, both from geodetic data and forward geophysical modelling, and systematically compare results.
- To focus on discrepancies in geocenter motion estimates and investigate potential biases in methods and/or systematic errors in geodetic products.
- To study the relative merit of geocenter motion data types (SLR, DORIS, GNSS, GNSS+LEOs). Special

emphasis should be placed in evaluating the network-effect biases.
- To evaluate consistencies in methods used to retrieve geocenter motion (translational and inverse approaches, forward modelling).
- To assess the impact of errors in geocenter motion through variability in estimates for operational and scientific users.

### Program of Activities

- Organize a group meeting to discuss the above objectives.
- Gather estimates of geocenter motion from working group members and proceed to systematic comparison highlighting discrepancies.
- Publishing a report on the current status of geocenter motion and associated error budget (and possibly provide common components to all estimates as a mean geocenter motion model).
- Contribution to international meetings and conferences (AGU, EGU, IUGG).
- Managing a website with all geocenter motion models and detailed information on estimates.
- Common publications by working group members.

### List of members

*Kristel Chanard* (France), Chair
*Xavier Collilieux* (France)
*Alexandre Couhert* (France), Vice-Chair
*Robert Dill* (Germany)
*Suzanne Glaser* (Germany)
*Christopher Kotsakis* (Greece)
*Flavien Mercier* (France)
*Laurent Métivier* (France)
*Paul Rebischung* (France)
*John Ries* (USA)
*Ricardo Riva* (Nehterlands)
*Krystof Sosnica* (Poland)
*Dariusz Strugarek* (Poland)
*Xiaoping Wu* (USA)
*Radoslaw Zajdel* (Poland)

# Study Groups of Sub-Commission 1.2

## SG 1.2.1: Relevance of PSInSAR analyses at ITRF co-location sites

Chair: *Xavier Collilieux* (France)
Vice-Chair: *Thomas Fuhrmann* (Australia)

### Terms of Reference

The scientific community has recognized the need for a highly accurate terrestrial reference frame (TRF) for Earth Science applications. Current determination of the International Terrestrial Reference System is made by combining data from space geodetic techniques, namely Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Doppler Orbitography and Radiopositioning Integrated by satellite (DORIS), Global Navigation Satellite Systems (GNSS), but also terrestrial measurements from local tie survey at co-location sites. For most of the sites, such local tie surveys are not performed on a regular basis. Thus, it is not possible to test the assumption of no relative motion between instrument reference points which is currently done almost exclusively by analyzing space geodetic data themselves.
The PSInSAR (Persistent Scatterer Interferometric Synthetic Aperture Radar) technique allows for determining deformation maps over large areas with various spatial resolutions as function of the satellite missions. Due to the availability of freely available SAR data for a significant period of time at many sites, it is relevant to ask if such data could supplement local tie measurements for those sites where sufficiently repeated terrestrial surveys do not exist. There are however some limitations that need to be addressed such as the size of a co-location site which is between 100 m and 1 km or the reference points themselves that are not accessible from the SAR satellites. Artificial corner reflectors or active transponders might however be used to add a PSInSAR measurement point in this context. Studying PSInSAR results in C- and X-band at some co-location sites is worth investigating to assess the potential use of this technique in reference frame determination in the future.

### Objective

The main objective is to investigate if the PSInSAR technique can be used to supplement local tie surveys at ITRF multi-technique sites.

### Proposed activities

- List strength and weakness of the PSInSAR technique for this application.
- Collect all studies related to INSAR and more particularly PSInSAR at co-location sites.
- If relevant, make an inventory of SAR images (for all missions) available at ITRF co-location sites.
- If relevant, identify multi-technique co-location sites where PSInSAR processing should be performed and compare InSAR results from various software packages. Compare results of free, but low-resolution, Sentinel-1 data with commercial high-resolution data (e.g. TerraSAR-X) where available; investigate whether a request for a supersite could be used to obtain additional high-resolution data (https://www.earthobservations.org/documents/gsnl/20120918_GSNL_CEOSSelectionProcess.pdf).
- Investigate the relevance of installing corner reflectors or transponders at co-location sites.
- Report conclusions and recommendations in IAG 2021 and/or IUGG2023 proceedings.

### List of members

*Xavier Collilieux* (France), Chair
*Francesco DeZan* (Germany)
*Stefan Friedländer* (Germany)
*Thomas Fuhrmann* (Australia)
*Christoph Gisinger* (Germany)
*Thomas Gruber* (Germany)
*Amy Parker* (Australia)

**Corresponding members**
*Ann Chen* (USA)
*Clément Courde* (France)

## SC 1.3: Regional Reference Frames

Chair: *Carine Bruyninx* (Belgium)

### Terms of Reference

Sub-commission 1.3 deals with the definitions and realizations of regional reference frames and their connection to the global International Terrestrial Reference Frame (ITRF) and International Height Reference Frame (IHRF). It offers a home for service-like activities addressing theoretical and technical key common issues of interest to regional organisations.

### Objectives

In addition to the specific objectives of each regional Sub-commission, the main objectives of SC1.3 as a whole are to:

- Coordinate the activities of the regional Sub-commissions focusing on exchange of data, competences and results;
- Promote operation of permanent GNSS stations, in connection with IGS whenever appropriate, as the basis for the long-term maintenance of regional reference frames;
- Promote open access to the GNSS data from permanent GNSS stations used for the maintenance of regional reference frames and scientific applications;
- Develop specifications for the definition and realization of regional reference frames, including the vertical component;
- Encourage and stimulate the development of the AFREF project in close cooperation with IGS and other interested organizations;
- Encourage and assist countries, within each regional Sub-commission, to re-define and modernize their national geodetic systems, compatible with the ITRF;
- Support the efforts of the United Nations Initiative on Global Geospatial Information Management (UN-GGIM) towards a sustainable Global Geodetic Reference Frame (GGRF).

### Program of Activities

- Provide a forum for addressing activities, results and key issues of common interest to the regional Sub-commissions;
- Develop analysis strategies and compare methods for the implementation of the regional reference frames and their expression in the ITRF, in full interaction with the IGS;
- Consider developing tectonic deformation models that will enable transformation of locations within a defined reference frame between different epochs;

## SC 1.3a: Europe (EUREF)

Chair: *Martin Lidberg* (Sweden)
Secretary: *Karin Kollo* (Estonia)

### Terms of Reference

EUREF, the Regional Reference Frame Sub-commission for Europe, deals with the definition, realization and maintenance of the European Reference Frames. EUREF is focusing on both the spatial and the vertical components in close cooperation with the pertinent IAG components (Services, Commissions, and Inter-commission projects). For more information, see www.euref.eu.

### Objectives

- The definition, realization and maintenance of the European Geodetic Reference Systems;
- The promotion and assistance of the adoption and use of European Terrestrial Reference System (ETRS89) and European Vertical Reference System (EVRS) in our partner countries;
- The development and maintenance of the EUREF GNSS Permanent Network (EPN) which is the ground based GNSS infrastructure for scientific and practical applications in positioning and navigation (Global Geodetic Observing System - GGOS, IGS Real-time Service);
- The development of strategies and technologies for the realization of geodetic reference systems.

### Structure

EUREF is composed of representatives from European IAG member countries. The Governing Board (GB) is composed of members elected by the EUREF plenary, members in charge of special tasks and ex-officio members. The current Chair of GB is *Wolfgang Söhne* (Germany).

In addition, several Working Groups have been set up:

- Working group on "European Dense Velocities"
  Chair: *Elmar Brockmann* (Switzerland)
- Working group on "EPN Densification"
  Chair: *Ambrus Kenyeres* (Hungary)
- Working group on "Deformation models"
  Chair: *Martin Lidberg* (Sweden)
- Working Group on "Multi GNSS"
  Chair: *Elmar Brockmann* (Switzerland)
- Working group on "EPN Reprocessing"
  Chair: *Christof Völksen* (Germany)

### Program of Activities

- Continue to develop the EPN in close cooperation with IGS (International GNSS Service), for the maintenance of the European Terrestrial Reference Frame (ETRF), as a contribution to the ITRF and as an infrastructure to support practical applications for precise positioning and referencing geo-information;
- Extend the Unified European Levelling Network (UELN) in order to include as many countries as possible in the current realization of the European Vertical Reference System (EVRS), and further continue the long-term maintenance of the European Vertical Reference Frame (EVRF) applying a kinematic approach;
- Closely follow and contribute to the developments regarding the International Height Reference System (IHRS) and its realizations in International Height Reference Frames (IHRF), and when appropriate establish the precise relation between IHRF and EVRF;
- Promote efforts on regional geoid models in Europe as the link between the ETRF and the EVRF;
- Support new developments in reference frame realization and applications by introducing new technologies like real-time GNSS data transfer and products, as well as Galileo for precise positioning;
- Realize a dense and homogeneous position and velocity product for Europe;
- Establish a dense velocity field model in Europe for the long-term maintenance of the European reference frame;
- Provide GNSS tropospheric estimates at the EPN stations in support of climate research;
- Contribute to the IAG Programme GGOS using the installed infrastructures managed by the EUREF members;
- Promote the adoption of the reference systems defined by EUREF (ETRS89 - European Terrestrial Reference System 1989 and EVRS - European Vertical Reference System) in the European countries and European-wide initiatives related to geo-referencing activities like INSPIRE;
- Cooperate with European political and scientific organisations and projects, e.g. EuroGeographics, EUMETNET, CEGRN (Central European GPS Geodynamic Reference Network), EPOS (European Plate Observing System), UN-GGIM: Europe, etc.;
- Organize annual symposia addressing activities carried out at national and Europe-wide levels related to the global work and objectives of EUREF.

### Members of the EUREF Governing Board

The members of the Governing Board in the fall of 2019 are as follows. However, some new members are foreseen to be elected at the symposium in May 2021. An up to date list is available at www.euref.eu.

*Carine Bruyninx* (Belgium)
*Elmar Brockmann* (Switzerland)
*Rolf Dach* (Switzerland)
*Ambrus Kenyeres* (Hungary)
*Karin Kollo* (Estonia)
*Juliette Legrand* (Belgium)
*Martin Lidberg* (Sweden)
*Tomasz Liwosz* (Poland)
*Rosa Pacione* (Italy)
*Martina Sacher* (Germany)
*Wolfgang Söhne* (Germany, Chair of GB)
*Christof Völksen* (Germany)

**Active honorary members:**
*Zuheir Altamimi* (France)
*Alessandro Caporali* (Italy)
*Markku Poutanen* (Finland)
*João Agria Torres* (Portugal)

## SC 1.3b: South and Central America (SIRGAS)

Chair: *José Antonio Tarrio* (SIRGAS WG I Chair)
Vice-Chair: *Demián Gomez* (SIRGAS WG II Chair)

### Terms of Reference

Sub-commission 1.3b (South and Central America) encompasses the activities developed by the "Geocentric Reference System for the Americas" (SIRGAS). As such, it is concerned with the definition, realization and maintenance of a modern geodetic reference infrastructure for South and Central America and the Caribbean. This includes a geometric reference frame consistent with ITRS/ITRF and a gravity field-related vertical reference system, defined and realized globally.

### Objectives

- To determine, maintain and make available a geocentric reference frame (a set of stations with high-precise geocentric positions and their variation with time) as a regional densification of the global ITRF;
- To support the SIRGAS countries in the establishment and maintenance of national geodetic reference networks as local densifications of SIRGAS in order to guarantee accessibility to the global ITRF at national and local levels;
- To establish a unified vertical reference system supporting the determination and precise combination of physical and geometric heights as well as their variations with time;
- To contribute to the GGOS program by developing and implementing state-of-the-art products based on the SIRGAS observational infrastructure;
- To promote, support, and coordinate the efforts of the Latin American and Caribbean countries to achieve these objectives.

### Structure

The structure of the Sub-commission 1.3b is based on the functioning SIRGAS Working Group I - Reference System and Working Group II - National Level. SIRGAS WG I coordinates the functioning and analysis of the SIRGAS Continuously Operating Network (SIRGAS-CON). SIRGAS WGI also promotes the installation of the of analysis centres for SIRGAS, under the responsibility of American institutions and the use of SIRGAS observations for atmospheric (ionosphere and troposphere) studies. SIRGAS WGII is responsible for promoting and supporting the adoption of SIRGAS realization through continuous operating GNSS stations.

- SC1.3b-WG 1: Reference System
  Chair: José Antonio Tarrio (Chile)
- SC1.3b-WG 2: SIRGAS at National Level
  Chair: Demián Gomez (US)

The SIRGAS Executive Committee (as it is named in the SIRGAS statutes) is composed of:
- Chair: *Sonia María Alves Costa* (Brasil).
- Vice-Chair: *Diego Alejandro Piñón* (Argentina)
- WG1 Chair: *José Antonio Tarrio* (Chile)
- WG2 Chair: *Demián Gomez* (US)
- WG3 Chair: *Gabriel do Nascimento Guimarães* (Brazil)

### Program of Activities

Since the SIRGAS countries are improving their national reference frames by installing an increasing number of continuously operating GNSS stations, it is necessary to outline the best strategy for the appropriate integration of those frames into the continental frame. This includes:
- Promotion of the IGS and IERS standards within the SIRGAS countries to ensure the adequate installation, maintenance, and analysis of continuously operating GNSS stations;
- Establishment of a SIRGAS National Processing Centre in all the member countries;
- Refinement of the SIRGAS station hierarchy. At present, two classes are considered: core and densification stations (the establishment of other categories is under consideration);
- Promotion of the adequate usage of SIRGAS as a reference frame by means of capacity building activities. This comprises SIRGAS schools on reference frames, scientific processing of GNSS data, atmospheric analysis based on the SIRGAS infrastructure, etc.;
- Promotion and implementation of real-time services based on the SIRGAS infrastructure to make available the reference frame to more users;
- The kinematics of the SIRGAS frame, up to now, have been represented by linear station movements (i.e. constant velocities). This representation is not sufficiently precise due to existing seasonal variations in the station position time series and due to discontinuities caused by the frequent occurrence of seismic events in the SIRGAS region.

According to this, it is necessary:

- To model non-linear station movements within the reference frame computation;
- To implement a methodology aiming at a precise transformation between different epochs and, in general, between pre-seismic and post-seismic reference frame realizations in particular;
- To evaluate the feasibility of computing and using near-real time reference frames instead of those based on epoch station positions and constant velocities.

The establishment of a unified vertical reference system continues to be a big challenge of SIRGAS. The related activities concentrate on:

- Continental adjustment of the national vertical networks in terms of geo-potential numbers;
- Combined analysis of tide gauge registrations, GNSS positioning and satellite altimetry observations to determine the dynamic ocean topography at the classical vertical datums;
- Determination of potential differences between the reference tide gauges and the global reference surface;
- Stronger cooperation with the Sub-Commission 2.4b (Gravity and Geoid in South and Central America - GGSCA) to promote national initiatives regarding the modernization of the gravity reference networks and the computation of geoid models of high resolution.

Hourly SIRGAS ionospheric models (vTEC) based on the GNSS SIRGAS stations have been generated since 2003 to 2015. The SIRGAS ionospheric model is being upgraded to include a better distribution of the electron density based on the assimilation of ground- and space-based GNSS observations. In addition, SIRGAS is developing a service for estimate hourly tropospheric Zenith Total Delay (ZTD) based on the operational SIRGAS processing. The ZTD estimates allow inferring Integrated Water Vapour (IWV) values with high accuracy.

### Members

**SIRGAS Executive committee**

*Sonia María Alves Costa*, Chair (Brasil)
*Diego Alejandro Piñón*, Vice-Chair (Argentina)
*José Antonio Tarrio* SIRGAS-WG1 Chair (Chile)
*Demián Gomez* SIRGAS-WG2 Chair (US)
*Gabriel do Nascimento Guimarães* SIRGAS-WG3 Chair (Brazil)

### SIRGAS Directing council

*Hermann Drewes*, Representative of IAG
*Hector Carlos Rovera Di Landro*, Representative of PAIGH
*Juan Francisco* Moirano (Argentina)
*Demian Gómez* (Argentina)
*Arturo Echalar Rivera* (Bolivia)
*Mario Sandoval Nava* (Bolivia)
*Luiz Paulo Souto Fortes* (Brazil)
*Sonia Maria Alves Costa* (Brazil)
*Emilio Aleuy Schwerter* (Chile)
*Sergio Rozas Bornes* (Chile)
*Jose Ricardo Guevara Lima* (Colombia)
*Francisco Javier Mora Torres* (Colombia)
*Max Lobo Hernández* (Costa Rica)
*Álvaro Álvarez Calderón* (Costa Rica)
*Bolívar Troncoso Morales* (Dominican Republic)
*José Leandro Santos* (Dominican Republic)
*Edgar Fernando Parra Cárdenas* (Ecuador)
*Jose Luis Carrión* (Ecuador)
*Carlos Enrique Figueroa* (El Salvador)
*Wilfredo Amaya Zelaya* (El Salvador)
*Óscar Cruz Ramos* (Guatemala)
*Fernando Oroxan* Sandoval (Guatemala)
*Rene Duesbury* (Guyana)
*Hilton Cheong* (Guyana)
*Bruno Garayt* (French Guyana)
*Alain Harmel* (French Guyana)
*Luis Alberto Cruz* (Honduras)
*Enrique Muñoz Goncen* (Mexico)
*Francisco Medina* (Mexico)
*Wilmer Medrano Silva* (Nicaragua)
*Ramón Aviles Aburto* (Nicaragua)
*Javier Cornejo* (Panama)
*Melquiades Dominguez* (Panama)
*Daniel Arias* (Paraguay)
*Joel Roque Trinidad* (Paraguay)
*Julio Enrique Llanos Alberca* (Peru)
*Julio Sáenz Acuña* (Peru)
*Daniel Piriz* (Uruguay)
*Gustavo Cauberrere* (Uruguay)
*Dana J. Caccamise* II (USA)
*Daniel R. Roman* (USA)
*Jose Napoleón Hernández* (Venezuela)
*Melvin Jesús Hoyer Romero* (Venezuela)

### SIRGAS Scientific Council

*Hermann Drewes* (Germany)
*Luiz Paulo Souto Fortes* (Brazil)
*Laura Sanchez* (Germany)
*Claudio Brunini* (Argentina)
*María Virginia Mackern* (Argentina)

## SC1.3c: North America (NAREF)

Co-Chairs: *Michael Craymer* (Canada)
*Dan Roman* (USA)

### Terms of Reference

To provide international focus and cooperation for issues involving the horizontal, vertical, and three-dimensional geodetic control networks of North America, including Central America, the Caribbean and Greenland (Denmark). For more information, see www.naref.org.

### Objectives

In collaboration with the IAG community, its service organisations, and the national geodetic organizations of North America, the aims and objectives of this regional Sub-commission are to provide international focus and cooperation for issues involving the horizontal, vertical and three dimensional geodetic control networks of North America. Some of these issues include:

- Densification of the ITRF reference frame in North America and the promotion of its use;
- Definition, maintenance and future evolution of plate-fixed geometric reference frames for North America, including the North American Datum of 1983 (NAD83) and the forthcoming North American Terrestrial Reference Frame of 2022 (NATRF2022).
- Effects of crustal motion, including post-glacial rebound and tectonic motions along, e.g., the western coast of North America and in the Caribbean;
- Standards for the accuracy of geodetic positions;
- Coordination of efforts with neighbouring SC1.3b South America (SIRGAS) to ensure strong ties between each other's reference frames;
- Outreach to the general public through focused symposia, articles, workshops and lectures, and technology transfer to other groups.

### Steering committee

*Michael Craymer* (Canada)
*Dan Roman* (USA)
*Finn Bo Madsen* (Denmark)

## Working Groups of Sub-Commission 1.3c

## WG 1.3c.1: North American Reference Frame Densification (NAREF)

Chair: *Michael Craymer* (Canada)

### Programme of Activities

To densify the ITRF reference frame in the North American region by organizing the computation of weekly coordinate solutions and associated accuracy information for continuously operating GPS stations that are not part of the current IGS global network. A cumulative solution of coordinate and velocities will also be determined on a weekly basis. The working group will organize, collect, analyse and combine solutions from individual agencies, and archive and disseminate the weekly and cumulative solutions.

### Members

*Michael Craymer* (Canada), Chair
*Mike Piraszewski* (Canada)
*Remi Ferland* (Canada)
*Daniel Roman* (USA)
*Theresa Damiami* (USA)
*Sungpil Yoon* (USA)
*Jarir Saleh* (USA)
*Finn Bo Madsen* (Denmark)

## WG 1.3c.2: Plate-Fixed North American Terrestrial Reference Frame of 2022 (NATRF2022)

Chair: *Dan Roman* (USA)

### Programme of Activities

To establish a high-accuracy, geocentric reference frame, including velocity models, procedures and transformations, tied to the stable part of the North American tectonic plate which would replace NAD83 and serve the broad scientific and geomatics communities by providing a consistent, mm-accuracy, stable reference with which scientific and geomatics results (e.g., positioning in tectonically active areas) can be produced and compared.

### Members

*Daniel Roman* (USA), Chair
*Michael Craymer* (Canada)
*Joe Henton* (Canada)
*Dru Smith* (USA)

*Theresa Damiami* (USA)
*Michael Bevis* (USA)
*Geoff Blewitt* (USA)
*Tom Herring* (USA)
*Jeff Freymueller* (USA)
*Corné Kreemer* (USA)
*Richard Snay* (USA)

## WG 1.3c.3: Reference Frame Transformations in North America

Chair: *Michael Craymer* (Canada)

### Programme of Activities

To determine consistent relationships between international, regional and national reference frames in North America, to maintain (update) these relationships as needed and to provide tools for implementing these relationships.

### Members

*Michael Craymer* (Canada), Chair
*Daniel Roman* (USA)
*Dru Smith* (USA)

## SC 1.3d: Africa (AFREF)

Chair: *Elifuraha Saria* (Tanzania)

### Terms of Reference

Sub-commission 1.3d (Africa) is concerned with the definition and realization of a unified continental reference frame (AFREF) for Africa, which will be consistent and homogeneous with the global International Terrestrial Reference Frame (ITRF).

### Objectives

In collaboration with the IAG community and its services, regional organisations, and the National and Regional Mapping Organizations of Africa, the objectives of Sub-commission 1.3d (Africa) are:

- Coordinate the activities of the regional organisations focusing on exchange of data, competences and results;
- Promote operation of permanent GNSS stations, in connection with IGS whenever appropriate, as the basis for the long-term maintenance of regional reference frames;
- Promote open access to the GNSS data from permanent GNSS stations used for the maintenance of regional reference frames and scientific applications;
- Develop specifications for the definition and realization of regional reference frames, including the vertical component;
- Encourage and stimulate the development of the AFREF project in close cooperation with IGS and other interested organizations;
- Encourage and assist countries, within each regional organisation, to re-define and modernize their national geodetic systems, compatible with the ITRF;
- Support the efforts of the United Nations Initiative on Global Geospatial Information Management (UN-GGIM) towards a sustainable Global Geodetic Reference Frame (GGRF).

### Structure

- Chair: *Elifuraha Saria* (Tanzania)
- Governing Board (see list of members below)

### Programme of Activities

- Provide a forum for addressing activities, results and key issues of common interest to the regional organisations;
- Develop analysis strategies and compare methods for the implementation of the regional reference frames and their expression in the ITRF, in full interaction with the IGS;
- Consider developing tectonic deformation models that will enable transformation of locations within a defined reference frame between different epochs.

### Members

*Elifuraha Saria* (Tanzania), Chair
*Emanuel Nkurunziza* (Kenya)
*Joseph Dodo* (Nigeria)
*Salah Mahmud* (Egypt)
*Cesare Mbaria* (Kenya)
*Prosper Ulotu* (Tanzania)
*Andre Nonguierma* (Burkina Faso)
*Akingbade O* (Nigeria)
*Moha El-Ayachi* (Morocco)
*Elias Lewi* (Ethiopia)
*Patrick Vorster* (South Africa)
Prof. *Kamal Labbassi* (Morocco)
**Active honorary members**:
*Richard Wonnacott* (South Africa)
*Hussein Farah* (Kenya)
*Olajide Kufoniyi* (Nigeria)

Some additional members are foreseen to be elected at the AFREF meeting in 2020.

## SC 1.3e: Asia-Pacific (APREF)

Chair: *Basara Miyahara* (Japan)

### Terms of Reference

Sub-commission 1.3e aims to improve regional cooperation that supports the realization and densification of the ITRF. This activity will be carried out in close collaboration with the Geodetic Reference Framework for Sustainable Development Working Group of the United Nations Global Geospatial Information Management for Asia and the Pacific (UN-GGIM-AP). For more details about UN-GGIM-AP WG1 http://www.un-ggim-ap.org/workinggroups/geodetic.

### Objectives

- The densification of the ITRF and promotion of its use in the Asia Pacific region;
- To encourage the sharing of GNSS data from Continuously Operating Reference Stations (CORS) in the region;
- To develop a better understanding of crustal motion in the region;
- To promote the collocation of different measurement techniques, such as GNSS, VLBI, SLR, DORIS and tide gauges, and the maintenance of precise local geodetic ties at these sites; and
- To outreach to developing countries through symposia, workshops, training courses, and technology transfer activities.

### Program of Activities

The activities of Asia-Pacific Sub-commission will principally be those of the Asia-Pacific Reference Frame (APREF) project. The APREF project consists of a Central Bureau, Network operators, Data centers, and Analysis centers. The Central Bureau, within Geoscience Australia, functions as the 'day-to-day' APREF coordinating body. Specifically, the Central Bureau ensures that APREF products are made available to the global geodetic community. Furthermore, they are the combination center responsible for analyzing, combining and validating the individual solutions of the contributing Analysis Centers, and for expressing the combined solution in the ITRF. Following APREF data and products are provided with an open access data policy via the internet following the practice of the IGS. They consist of daily GNSS RINEX data, station log files, weekly coordinate estimates in SINEX format, and APREF network and time-series plots. For more details, see http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/asia-pacific-reference-frame.

### Members

The members of the Asia-Pacific Sub-commission are national geodetic representatives from the UN-GGIM-AP member nations and APREF participating organisations.

**UN-GGIM-AP WG1 (Geodetic Reference Frame)**
*Basara Miyahara* (Japan), Chair
*John Dawson* (Australia), vice-Chair
*Yamin Dang* (China)
*S. K. Singh* (India)
*Mohd Yunus* (Malaysia)
*Dalkhaa Munkhtsetseg* (Mongolia)
*Graeme Blick* (New Zealand)
*Sangoh Yi* (South Korea)

**APREF Analysis Group**
*Guorong Hu* (Australia)
*Alex Woods* (Australia)
*Yunbin Yuan* (China)
*Basara Miyahara* (Japan)

## SC 1.3f: Antarctica

Chair: *Martin Horwath* (Germany)

### Terms of Reference

Sub-commission 1.3f focuses on the realization and densification of a unified reference frame for Antarctica, which will be consistent with the global International Terrestrial Reference Frame (ITRF). The Sub-commission shares objectives and activities of the Scientific Committee on Antarctic Research (SCAR), namely of the SCAR Expert Group Geodetic Infrastructure of Antarctica (GIANT). The Sub-commission closely links IAG and SCAR activities by embedding identical activities, with identical persons where indicated, into the two complementary organisational structures.

### Objectives

- Maintenance and densification of the precise geodetic reference network in Antarctica by permanent observations and GNSS campaigns;
- Realization of a unified vertical datum including GNSS ties of tide gauges;
- Providing unified reference for further GNSS applications like airborne gravimetry, ground truthing for satellite missions, geodynamics and glaciology;
- Develop technologies for remote geodetic observatories;

- Stimulate and coordinate international collaboration on the above fields, under the unique political conditions of Antarctic research given by the Antarctic Treaty, in order to make optimum use of logistics and infrastructure.

### Program of Activities

- Organization of GNSS campaigns in Antarctica;
- Extend activities for the operation of remote permanent GNSS stations;
- Maintenance of the data archive (SCAR GNSS data base) to collect Antarctic GNSS data and provide them to the scientific community;
- Data analysis and determination of the Antarctic GNSS network as a regional densification of ITRF;
- Provide homogeneous site velocities for e.g. glacial isostatic adjustment determination;
- Support airborne surveys and satellite missions with precise terrestrial reference;
- Collaborate with IAG Sub-Commission 3.4 (Cryospheric Deformation) and the SCAR Scientific Research Programme Solid Earth Response and Influence on Cryosphere Evolution (SERCE) and subsequent programmes, respectively
- Organize special workshop(s) on the consistent analysis of GNSS data and realization of ITRF
- Organize meetings/sessions at conferences like IAG, IUGG, SCAR Open Science Conference.

### Members

*Martin Horwath* (Germany), Chair
*Alessandro Capra* (Italy)
*Mirko Scheinert* (Germany)
*Manuel Berrocoso* (Spain)
*Graeme Blick* (New Zealand)
*Koishiro Doi* (Japan)
*Rene Forsberg* (Denmark)
*Thomas James* (Canada)
*Aspurah Kamburov* (Bulgaria)
*Matt King* (Australia)
*Kenichi Matsuoka* (Norway)
*Alexey Matveev* (Russia)
*Gennadi Milinevsky* (Ukraine)
*Elizabeth Petrie* (United Kingdom)
*Markku Poutanen* (Finland)
*Goncalo Prates* (Portugal)
*Lars Sjoberg* (Sweden)
*Norbertino Suarez* (Uruguay)
*Terry Wilson* (USA)
*Andres Zakrajsek* (Argentina)

## Working Groups of Sub-Commission 1.3

## WG 1.3.1: Time-dependent transformations between reference frames in deforming regions

Chair: *Richard Stanaway* (Australia)

**Terms of Reference**

This WG will review different approaches used to enable transformation between reference frames within plate boundary zones and regions affected by glacial isostatic adjustment. These transformations are necessarily time-dependent to account for interseismic strain and also episodic seismic deformation. In these instances conformal transformations do not adequately model the complexity of the deformation field and other approaches are required to enable high precision transformations at different epochs of the source and target reference frames.

Deformation models and other time-dependent transformation models provide linkages between global reference frames such as ITRF, regional reference frames and local reference frames commonly used for positioning, land surveying, mapping and GIS.

The WG will collaborate with other regional reference frame working groups to develop a global deformation and transformation model schema. This will require development of a standardized deformation model format that can be accessed from international registries of geodetic parameters such as those hosted by ISO/TC 211 and IOGP/EPSG. WG 1.3.1 will work closely with FIG Commission 5 (Positioning and Measurement), specifically FIG Working Group 5.2 (Reference Frames). WG members comprise of a wide spectrum of researchers from different fields of geophysics, geodesy, land surveying and GIS.

### List of members

*Richard Stanaway* (Australia), Chair
*Wan Anom Wan Aris* (Malaysia)
*Elmar Brockmann* (Switzerland)
*Miltiadis Chatzinikos* (Greece)
*Yingyang Cheng* (China)
*Michael Craymer* (Canada)
*Chris Crook* (New Zealand)
*Nic Donnelly* (New Zealand)
*Kristian Evers* (Denmark)
*Jeff Freymueller* (USA)
*Pasi Häkli* (Finland)
*Muzaffer Kahveci* (Turkey)
*Kevin Kelly* (USA)
*Martin Lidberg* (Sweden)

*Niraj Manandhar* (Nepal)
*Basara Miyahara* (Japan)
*José Antonio Tarrío Mosquera* (Chile)
*Chris Pearson* (New Zealand)
*Susilo Sarimun* (Indonesia)

**Corresponding members**:
*Graeme Blick* (New Zealand)
*Carine Bruyninx* (Belgium)
*Xavier Collilieux* (France)
*Paul Denys* (New Zealand)
*Craig Roberts* (Australia)
*Yoshiyuki Tanaka* (Japan)
*Norman Teferle* (G.-D. Luxembourg)

## SC 1.4: Interaction of Celestial and Terrestrial Reference Frames

Chair: *Zinovy Malkin* (Russia)

### Terms of Reference

International terrestrial and celestial reference frames, ITRF and ICRF, respectively, as well as the tie between them expressed by the Earth Orientation parameters (EOP) are key products of geodesy and astrometry. The requirements to all the components of this triad grow steadily and the mm/μas level of accuracy is the current goal of the astronomic and geodetic community.

The current computation procedures for ITRF and ICRF are based on multi-stage processing of observations made with several space geodetic techniques: VLBI, SLR, GNSS, and DORIS. Not all of them provide equal contributions to the final products. The latest ITRF realizations have been derived from combination of normal equations obtained from all four techniques, whereas the ICRF is a result of a single global VLBI solution. The latter is tied to the ITRF using an arbitrary set of reference stations. But VLBI relies on the ITRF origin provided by satellite techniques and shares responsibility with SLR for the ITRF scale. And all the techniques contribute to positions and velocities of ITRF stations.

This situation causes complicated mutual impact of ITRF and ICRF, which should be carefully investigated in order to improve the accuracy of both reference systems and the consistency between each other and EOP. The subject becomes more and more complicated when moving to millimeter accuracy in all components of this fundamental triad. As a consequence, we face systematic errors involving the connection between the ICRF and ITRF realizations, which cannot be fixed by datum correction during the current solution.

### Objectives

Several issues are currently preventing the realization of the terrestrial and celestial reference systems (TRF and CRF, respectively) at the mm/μas level of accuracy, such as: (a) insufficient number and non-optimal distribution of active and stable (systematically and physically) stations (VLBI and SLR in the first place) and radio sources, (b) technological (precision) limitations of existing techniques, (c) incompleteness of the theory and models, and (d) not fully understood and agreed-upon details of the processing strategy. These issues are the subject of research of the IAG Sub-Commission 1.4.

## Working Groups of Sub-Commission 1.4

## WG 1.4.1: Improving and unification of geophysical and astronomical modeling for better consistency of reference frames

Chair: *Daniel MacMillan* (USA)

### Terms of Reference

WG 1.4.1 is aimed to promote and coordinate investigations of the impact of geophysical and astronomical modeling on the terrestrial and celestial reference frames (TRF and CRF) and the consistency between CRF, TRF, and Earth orientation parameters (EOP), the latter serving as the transformation parameters between TRF and CRF. The primary attention will be given to VLBI as the only technique nowadays that can provide highly consistent global solutions for TRF, CRF, and EOP.

### Objectives

- Encourage and develop cooperation and collaboration in theoretical studies, simulations, and processing of real data aimed at a better understanding of the impact of geophysical and astronomical modeling on TRF, CRF, and EOP derived from VLBI observations.
- Advance means of comparing models as well as TRF, CRF, and EOP realizations.
- Compare different theoretical models and their realizations used by VLBI analysis centers. Study the propagation of differences in those models to differences in geodetic and astrometric products.
- Develop practical recommendations for VLBI analysis centers and the IERS Conventions Center on the optimal models to be used during processing of VLBI observations.

### List of members

*Robert Heinkelmann* (Germany)
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## WG 1.4.2: Improving VLBI-based ICRF and comparison with Gaia-CRF

Chair: *Sébastien Lambert* (France)

### Terms of Reference

WG 1.4.2 is aimed to review the current CRF status, to identify deficiencies and to make proposals for improvements. The WG will pay a particular attention to the next ICRF VLBI realization, ICRF3 extension or ICRF4, which should be a significant improvement over ICRF3 in respect of number of core and supplement radio sources, uncertainty and accuracy of the source position, and uniform distribution over the sky. Moreover, the Gaia mission is expected to improve an optical realization of the CRF with precision similar to the ICRF and with 1–2 order of magnitude more objects. However, as the set of extragalactic objects suitable for both optical and radio observation is limited, one goal of the WG is to identify such objects, oversee the relevant observations, and to analyze the data to permit the best possible connection between the radio and optical CRF realizations.

### Objectives

- Analyze the ICRS/ICRF definition in view of the latest developments in astrometry and space geodesy.
- Study systematic errors in the current individual CRF and ICRF realizations.
- Review systematic differences between CRF realizations at different wavelengths due to, e.g., core-shift or host galaxies.
- Analyze different modeling options and analysis strategies of computation of the next ICRF realization.
- Develop optimal procedures to align GCRF to ICRF.

### List of members

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*Jacques Roland* (France)
*Manuela Seitz* (Germany)

## JWG 1.4.3: Consistent realization of TRF, CRF, and EOP (joint with IAU Commission A2 and IERS)

Chair: *Robert Heinkelmann* (Germany)
Vice-Chair: *Manuela Seitz* (Germany)

### Terms of Reference

Many applications, e.g. in geodesy, astronomy, or navigation, rely on the consistency between terrestrial (TRF) and celestial (CRF) reference frames and Earth Orientation Parameters (EOP). The EOP connect the CRF and TRF in terms of their orientation and rotation differences. The EOP can only be considered as physically meaningful when determined consistently with the reference frames. The quality requirements for the applications including societal contributions were quantified through the IAG GGOS as 1 mm accuracy and 0.1 mm/yr stability, i.e. about 33 μas and 3.3 μas/yr in terms of EOP. For Earth system science based on EOP the consistency is a crucial characteristic. Today, the quality requirements for reference frames and EOP are not met.

*Data and model inconsistency*. Currently, TRF and CRF are determined independently of each other. Individual Working Groups (CRF) or Combination Centers (TRF) compute the frames through reprocessing/combination efforts every five to ten years. The releases of the terrestrial and celestial frames do not happen at the same time. In this way, the frames are computed based on different input data and on different analysis models in case of updates of the conventional models. Following independent approaches, the consistency of a new release of one of the frames can only be quantified and thus ensured to the last release of the respective other frame. If the frames are not fully consistent, the EOP based on these frames cannot be consistent.

*Multi-technique vs. single technique analysis*. DORIS, GNSS, SLR and VLBI observations are combined with local tie vectors at co-location sites for the TRF computation, whereas the CRF is directly connected to the TRF through VLBI alone. This situation does not change when applying alternative data analysis procedures. Nevertheless, as VLBI networks are sparse in comparison to multi-technique networks, it has been shown that the terrestrial part of the Earth orientation significantly improves through the combination with satellite-based data. The celestial parts of Earth orientation, dUT1 (UT1 ~ ERA) and CPO, determined by VLBI observations only – and possibly by LLR data –, can in turn improve due to correlations between the EOP within the VLBI data analysis. CRF realizations in other wavelengths are aligned to the X/S VLBI CRF and thus, do not contribute to the CRF orientation for ICRF3. Nevertheless, they allow for an independent validation. Apart from the rotation and spin, catalogues based on Gaia (optical) data releases can provide independent insight into deformations and other technique-dependent systematic errors and thus present another independent validation for the VLBI-based CRF.

*Prediction problem*. The reference frames and the EOP are customarily applied in prediction mode, e.g. for geodetic and astrometric data analyses. Accordingly, values have to be given beyond the data time span considered for the reference frame realization. As long as no significant non-linearity occurs, the global coordinates can be used very well for predicting the position into the future. For most of the applications, predicted EOP have to be available as well. The predicted EOP require consistency to the frames and to the reprocessed EOP at the same time. It is impossible to fulfill both requirements when new reference frame releases become available.

## Objectives

Addressing the abovementioned issues, the working group will:

- compute multi-technique CRF-TRF solutions together with EOP in one step, which will serve as a basis to quantify the consistency of the current conventional reference frames and EOP as well as the consistency of reprocessed and predicted EOP;
- investigate the impact of different analysis options, model choices and combination strategies on the consistency between TRF, CRF, and EOP;
- study the differences between multi-technique and VLBI-only solutions;
- study the differences between VLBI solutions at different radio wavelengths;
- study the differences between Gaia (optical) and VLBI (radio) reference frames;
- study the effects on the results, when different data time spans are considered;
- compare the practically achievable consistency with the quality requirements theoretically addressed by IAG GGOS; and
- derive conclusions about future observing systems or analysis procedures in case the quality requirements cannot be met with the current infrastructure and approaches.

## List of members

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*Florian Seitz* (Germany), representative of IAU Comm. A2
*Jean Souchay* (France)
*Daniela Thaller* (Germany), Director of IERS Central Bureau

## Proposed cycle

Classical cycles: IAG WG (4 year cycle), IAU WG (3 year cycle), IERS WG (2 year cycle). A 4-year cycle is proposed in order to be compliant with IAG bylaws as the initiative and thus the primary affiliation of this JWG is with IAG.