Summary of IVS 2015 Retreat
„IVS Strategy for the next decade (IVS2020)”

October 7 and 8, 2015 Penticton, BC, Canada

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Summary

On October 7 and 8, 2015, the IVS Directing Board and six invited guests discussed the current and future challenges of developing the IVS to meet the needs and take advantage of the opportunities of the next decade. In a series of SWOT analyses (Strength, Weaknesses, Opportunities, and Threats) the current state was evaluated. It was concluded that the relationships of the IVS with some of the space agencies, research institutions and surveying and mapping agencies should be improved. A business plan was discussed indicating that if the IVS were to be established from scratch it would cost an initial investment of $200 million for a network of 30 observatories plus $70 million per year operating costs for daily UT1-UTC determinations. The findings of this document are intended to be the basis for a separate document “IVS Strategic Plan 2015”.

Introduction

On October 7 and 8, 2015, the IVS Directing Board and six invited guests met in Penticton, BC, Canada, for the IVS Retreat 2015, which was organized to discuss the “IVS Strategy for the next decade (IVS2020)”. The Directing Board invited the guests to broaden the basis of views and backgrounds. Their in-depth knowledge and overall experience in the field of space-geodetic techniques—both in the technical and administrative domains—were an essential factor for the success of the retreat. We were fortunate to have them as independent consultants providing many useful suggestions.

The need for this structured discussion arose because the IVS is preparing for transition to VGOS operations and requires a strategic plan for the IVS for the next decade. In this context, the organizational relationships of the IVS, external as well as internal, and the administration of the IVS stood in the foreground of the retreat. In several rounds of discussions, either with the whole group or in separate smaller groups, the current status and expectations for the future were analyzed. A useful tool for the introduction to the individual topics was the SWOT analysis (Strengths, Weaknesses, Opportunities and Threats), which helped to identify shortcomings in the current concept of the IVS. Another important aspect for the discussions was the identification of discrepancies between maximum demands naturally arising and what is actually feasible under the current economic and organizational circumstances.

The basis for the discussions was the key statement that the IVS is essential for the monitoring of the Earth orientation parameters and the maintenance of the celestial and terrestrial reference frames. At the same time the IVS acts as an entity consisting of hardware, an organizational structure and the associated personnel for organizing and administering the IVS on a best-effort basis. Furthermore, many experienced colleagues have reached or are close to retirement age. Hence, an active recruiting philosophy is needed to replace them. Because of this, an increased awareness is needed within the IVS components up to the highest level of their administrations.

Another *a priori* key statement is that there are only a few countries that would be able to run their own VLBI organization from taking observations with their telescopes to creating final products. However, the full potential of geodetic and astrometric VLBI can only be exploited if baselines beyond a length of about 6000 km are employed for EOP and for celestial reference frame determinations, because only then does the technique unfold to its full sensitivity. The same also applies to any terrestrial reference frame application.

Under these premises the retreat had the following goals: a) planning for the future (vision vs. realistic possibilities), b) informing stakeholders, c) raising awareness of the threats (operational and financial), d) identifying user demands, and e) triggering more marketing. The main areas of discussion were correlation, product lines, institutional relations, a business plan, and operations details with concepts for the future. The output of the retreat was planned to be a series of documents with various levels of detail and meant for different groups of readers. This is the full-size document with detailed content.

Correlation

Since correlation of the observed data is a central prerequisite of VLBI and the situation with funding and operating the correlators is very fragile, this topic was considered so important that it was assigned to a special session and was discussed first.

Correlation is currently carried out for IVS primarily by

1. the Bonn Correlator operated and funded by BKG, MPIfR and IGG of Bonn University
2. the Haystack Correlator (funded by NASA/GSFC)
3. the Tsukuba Correlator (funded by GSI)
4. the Washington Correlator (funded by USNO, NOAA and NASA/GSFC (NEOS))
5. the Shanghai Correlator (funded by SHAO).

It is expected that HartRAO (Johannesburg, South Africa) and the University of Tasmania (Hobart, Australia) for the AuScope network will take up some of the IVS correlation in the future.

The SWOT analysis yielded the following assessment:

Strengths

- The correlators guarantee an intrinsic value of their products
- Expertise in multiple correlation centers
- Capability to shift loads if needed
- Decades of experience of the community
- Sharing of information

Weaknesses

- Lack of young successors to experienced staff
- Often no permanent positions of staff
- Cost burden shouldered by only a few institutions
- Lack of visibility of output
- Deficiencies in the cooperation with astronomy groups
- No redundancy in personnel
- Lack of coding and functional standardization

Opportunities

- Seek the support of computer scientists
- Funding opportunities of „big data“ (companies, government institutions)
- Seek contact to SKA/ALMA correlation specialists
- Leverage the UN resolution on Global Geodetic Reference Frame (UN-GGRF)
- Development of broad bandwidth brings other groups into the VLBI community
- Outreach
- Advancing technology (cloud and green computing, network capacity)

Threats

- Funding cuts
- Retirement/quitting of experienced colleagues
- Too few young experts
- The current correlators may not be able to handle the anticipated data from VGOS
- Bandwidth limitations of data lines
- Lack of network security (hacking)

The discussions yielded the insight that the load needs to be distributed on more correlators and that, where possible, a firm commitment of the funding agencies is needed to maintain the current level of correlator throughput and even more so for any increases originating from the upgrades to VGOS operations.

In order to exploit synergies across multiple correlator development activities in various fields including astronomy and to benefit from modern computational and data transport improvements, Alessandra Bertarini is charged with setting up an IVS Working Group on the concept of next generation/VGOS correlations. Participation will be organized by invitation to be implemented by the Directing Board.

Product lines

The discussion of current and future product lines took place in two separate groups, one dealing with the EOP and the other one with reference frame and troposphere issues.

EOP

The EOP group identified the following:

Strengths

- Geodetic and astrometric VLBI is the only technique for UT1-UTC
- Only technique for nutation
- Can do all 5 EOP parameters at once
- Capability to determine UT1-UTC in near real-time
- Long stable history for all EOP
- Capability for high-frequency resolution
- Only technique for GNSS polar motion validation

Weaknesses

- Results depend on network (bias and precision)
- No redundancy
- Unequal, non-continuous sampling
- Latency still too high (also depends on external factors)
- Dependency on station stability (position/equipment)
- Low visibility of IVS results
- IVS UT1 *Intensives* are not combined rigorously
- Dependencies on same correlation/fringing program
- Dependencies on only a few data analysis programs
- Legacy program code and languages

Opportunities

- Combination with other techniques
- VGOS network will improve almost everything
- Better station network
- Higher precision
- Lower latency
- Continuous sampling (tunable time resolution)
- Increased robustness
- Less vulnerable to station-specific events

Threats

- Financial limitations
- Risk of drop-out of key institutions
- Fading interest in VLBI
- Development of alternative approaches for high-resolution EOP

The need for high-accuracy EOP was identified to arise in particular from space navigation and from global navigation satellite systems as well as from all other geodetic satellites. The latency requirement for IERS UT1-UTC prediction is near real-time. For validation of time series it is necessary that the update interval be at least every 6 hours. For the rapid product, the IERS RS/PC needs UT1-UTC with one day latency, and for the final products all 5 components after 1–2 weeks.

If the IVS products are not provided, the UT1-UTC time series accuracies of the IERS predictions are degraded, the IERS C04 long term stability suffers, and the GNSS EOP and all satellite precise orbit determinations will degrade.

We determined that only the sister services IERS, IGS, ILRS and IDS as well as very few people in military and government institutions actually know that the IVS is behind these products. For increasing this knowledge, we need more targeted public relations and outreach.

Reference frames

For the reference frames the following items of the SWOT analysis emerged:

Strengths

- Long time history, longer than GPS
- CRF is a unique product, essential to many applications
- Important contributor to scale of TRF

Weaknesses

- TRF
  - Sites not well distributed
  - Precision is uneven
  - Poor temporal distribution
- CRF
  - Uneven sky coverage
  - Systematic deviations in Southern Hemisphere

Opportunities

- VGOS will lead to higher accuracies and new users
- High precision astrometry for astronomers and for spacecraft navigation
- More observatories in southern hemisphere
- Political support through UN-GGRF resolution

Threats

- Financial limitations
- Risk of drop-out of key institutions
- Fading interest in VLBI

In parallel to the EOP, the current product lines comprise the CRF, TRF, troposphere parameters, and baseline length time series (as a deduced product). Other internal products are ionosphere information, radio source correlated flux density time history, radio source maps, station SEFDs (System equivalent flux densities), station system noise temperatures, and local weather data.

CRF

A good CRF is needed for astronomy and for spacecraft navigation as well as for geodetic applications. The latency requirement is low and an update interval of about 5 years is considered sufficient but we should investigate whether a yearly update is needed. The lack of a good CRF limits the quality of the astrometry which is critical for space missions and EOP determinations. Currently, the only people, who know of the leading role of the IVS in the CRF maintenance activities, are those who are involved in this work themselves. The IAU in general seems to be unaware of this. The participants of the retreat consider it useful that regular official extensions of the CRF with revised source positions, new source positions, and position stability information be released by the IVS. Concerning the ICRF work, the link between IAU and IAG needs to be strengthened through the IVS.

TRF

The value of the TRF provided by the IVS consists of two components: the strong internal global geometrical stability and the reliability of the global scale which is consistent over decades since it does not depend on the distribution of observatories. The availability of a stable TRF from the IVS is an integral part of IAG's GGOS (Global Geodetic Observing System) and is needed for applications in land management, mapping, GIS, and high accuracy navigation. At its highest accuracy level, the TRF from IVS is fundamental for detecting and quantifying global sea level rise through its scale accuracy and stability. The update frequency of the IVS TRF is every three months, but a new ITRF, in which the IVS TRF is of fundamental importance, is computed only every few years. The latency of IVS TRF products can be as long as a year but more frequent data are needed in case of earthquake displacements. If an IVS TRF were not provided to the ITRF computations, the scale consistency over time would deteriorate at a non-negligible level. The IVS TRF (VTRF) is hardly known outside of IVS. Although the IVS TRF products are essential for the generation of the ITRF, they are overshadowed by the dominant perception of the ITRF. Here, better marketing is needed. The scale stability of VLBI needs to be demonstrated in a more convincing way than simply plotting session-wise residuals which tend to be rather noisy. The use of DOI numbers for IVS data sets would be another means of raising awareness of IVS products.

Troposphere

Troposphere products are used in validating GNSS troposphere results and may also serve as a benchmark for long-term stable climate change assessments. The latency should be not more than three months. IVS products have the advantage that in many cases they are made up of decade-long time series, which will be consistent if the pressure sensors are maintained with sufficient accuracy over the whole period or if replacements of the barometers are accompanied by proper calibrations. A much higher data volume is expected when VGOS is in full operation. The tracking of usage of these products is a problem (as it is for the other products as well).

Future products

Source structure maps are important information to be introduced into the analysis to create better VLBI solutions. Also, regularly generated maps would provide insight into whether a source is changing in such a way as to preclude its use in standard R1/R4 or intensive observations. For this reason, more endeavors should be taken up to regularly produce source structure maps.

In addition, several other products were discussed, which are, however, often of purely scientific interest. Galactic aberration, core shift parameters, relativity parameters, or satellite observations for orbit determination and time transfer (GNSS, GRASP), just to name a few. The requirements and available resources will always depend on the circumstances and it needs to be decided whether these activities justify the use of a service.

Institutional relations

The discussions under this topic concerned questions such as: What relationships exist with IVS? Where could we strengthen them? How can we improve them? Which agency needs what? How could we establish new relationships?

The existing links of the IVS to institutions and organizations document the strong relationships of the IVS to many activities in various fields. Some of them are very close due to mutual dependencies, others are weak, and some are non-existent even though there seems to be an obvious need for close cooperation. Below, we summarize the current status of the institutional relationships.

NASA is an essential contributor to the IVS. At GSFC are located the IVS Coordinating Center, the Analysis Coordinator, the Network Coordinator, a key Operation Center, and an Analysis Center that reviews all IVS data and provides UT1-UTC products. The GSFC group is a major participant in the advancement of the ICRF. NASA also funds the KPGO station (with USNO) and the Fortaleza station. JPL, another NASA center, is an IVS Associate Analysis Center. It is responsible for solar system missions and is a user of IVS UT1-UTC data, desiring an accuracy better than 5 µs on a daily basis.

European Space Agency (ESA): No direct links exist between the IVS and ESA. They run a small correlator and otherwise take the EOP information from IERS. Loose contacts exist through J. Böhm and J. Gipson. ESA cooperates with C. Jacobs (JPL) on Ka band observations.

Russian Space Agency: Organizations subordinate to the Russian Federal Space Agency (Roscosmos), to the Federal Agency for Technical Regulation and Metrology (Rosstandart), and to the Federal Agency for Scientific Organizations (FASO) are involved in the activities of estimating Earth Orientation Parameters including Universal Time. For Roscosmos these studies are performed by the Federal state unitary enterprise "Central Scientific and Research Institute of Machine Building" (TsNIImash), for Rosstandart the Federal state unitary enterprise "National Scientific and Research Institute of Physical-Technical and Radio Technical Measurements" (VNIIFTRI), and for FASO the "Institute of Applied Astronomy of the Russian Academy of Sciences" (IAA RAS). The distributed Center for Processing and Analysis of Space Geodesy Data has been created on the basis of these organizations. Official data such as the national time scale of Russian Federation UTC(SU) and the Earth Orientation Parameters EOP(SU), namely Xp(SU) and Yp(SU), are obtained, maintained and provided to the users by the "Russian national service of time, frequency and Earth orientation parameters", which is the part of the VNIIFTRI."

Chinese Space Agency by itself is only an umbrella organization and has several institutes. Presentations at conferences indicate activities towards establishing a Chinese Earth Rotation Service (CERS).

Japan Aerospace Exploration Agency (JAXA): GSI has collaborative relationship with the VLBI group of JAXA. They carry out geodetic VLBI observations with GSI once a year in order to determine the position of their own antenna which will be utilized for space missions. The VLBI group members of JAXA know well the importance of VLBI as the contributor to

EOP determination. Kawabata will advertise the importance of VLBI to other groups of JAXA which are also using EOPs.

Centre National d'Études Spatiales (CNES): P. Charlot has links to CNES (GINS software)

Agenzia Spaziale Italiana (ASI): Needs and contacts to be investigated.

Instituto Nacional de Pesquisas Espaciais (INPE), Brazil: Needs and contacts to be investigated.

Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany: EOPs are primarily used at the German Space Operations Center (in the context of flight dynamics and GNSS related research). Polar motion used originates from IGS while UT1-UTC comes from the IVS Contact by L. Combrinck with Oliver Montenbruck.

Bundesamt für Kartographie und Geodäsie (BKG) has the mandate to maintain reference frames through a special BKG Law. VLBI is considered part of this mandate.

Geoscience Australia (GA): VLBI is part of GA and its observing network.

Geospatial Information Authority of Japan (GSI): The Japanese Datum has to be consistent with ITRF, therefore VLBI is part of reference frame activities.

Kartverket (Norwegian Mapping Authority): National reference frame needs to be connected to global reference frame; therefore, VLBI is part of reference frame activities.

Canada may reenter VLBI; the first step has been taken through Director/Surveyor General.

IAG is a parent organization of IVS and should be well aware of IVS. The same applies to GGOS and GIAC. IAG Service Assessment was very successful.

IAU: The relationship needs to be strengthened because not many people in the IAU know about the existence of IVS and its products. On the other side, some persons in IAU have become aware that IAU needs stronger links to IVS as evidenced by the Vice President of IAU contacting P. Charlot.

EVN: Reporting between IVS and EVN is regularly done by P. Charlot. Other links exist through technical developments such as the Field System, recording systems and data transfer formats; new chair of EVN, Rene Vermeulen, ASTRON, seeks contact to IVS.

VLBA: The VLBA has a strong relationship with IVS via NASA/GSFC and USNO through CRF and VCS work. USNO may fund part of VLBA operations, e.g., for CRF observations and backup EOP determinations.

A strong relationship needs to exist with the IERS in Paris because here the EOP are combined with those of the other IAG services. C. Bizouard is the new director of the IERS EOP group at OBSPM. Contacts between IVS and the IERS EOP Product Center need to be strengthened. The IERS International Celestial Reference System Centre, hosted jointly at OBSPM and USNO, is another important component of the IERS. Here, communication with IVS seems to be at a good level, mainly driven by the activities for ICRF-3.

USNO IERS RS/PC: One of the most important customers for EOP and particularly UT1-UTC are the navigation satellite systems. While for GPS, it is rather clear that their UT1-UTC information originates from the IVS, this is less clear for the other systems. In addition, all satellite solutions of IGS, IDS, and ILRS need precise UT1-UTC. For their combination and prediction service, USNO likes to have UT1-UTC every 6 hours.

UN-GGIM /UN-GGRF: The key issue is the sustainability of the terrestrial reference frame for geospatial information applications and for monitoring global change. The UN initiative consists of 2 levels: UN-GGIM (Global Geospatial Information Management) is a community of experts to find ways forward and to make decisions; members are nominated by foreign ministries of each participating country. UN-GGRF (Global Geodetic Reference Frame) is a working group where geodesists are needed (R. Neilan (USA), Z. Altamimi (France), H. Kutterer (Germany), P.E. Opseth (Norway), G. Johnston (Australia)…, H. Schuh (Germany as IAG President) are members already). Members must be suggested by national representatives.

The Business Plan

The participants discussed the financial requirements which would be needed if the IVS and its operationwere to be set up from scratch for daily precise UT1-UTC determinations. For this assessment, it was assumed that thirty globally distributed observatories, one coordinating center, four operations centers, four data repositories, four correlator centers, and ten analysis centers are needed. For maintaining a sufficient level of robustness against failures, this is the minimum number of components for a CRF/EOP/TRF service provided that all work on a 100% basis. The number of thirty stations arises from the concept that at any time a twenty-station network can observe and ten stations are off for maintenance and, at a later stage, repairs. This scheme produces a 66% duty load for each telescope.

From a detailed accounting of all components and their specific costs, the global one-time investment for such a service was estimated to be approximately $200 million, while the annual operations and maintenance costs amount to approximately $70 million. It should be noted that this is for VLBI alone and does not take into account that many stations should be GGOS compliant and should, therefore, also accommodate the components of the other space-geodetic techniques (SLR, GNSS, DORIS).

Operations details and concepts for the future

In the last session of the retreat, a few open issues of operations were discussed in view of future concepts. Some key insights were addressed. For example, tit is expected that in the VGOS era the station selection for the daily network configuration should be automatic and driven by availability. All other scheduling activities, possibly also including dynamic scheduling, should also be automatic. Network size and the number of available stations determine whether dynamic scheduling is needed. It is not deemed necessary when many stations participate. A proper layout of the IVS process flow needs to be developed and exercised. VGOS will start with the same organization as is currently established for the legacy telescope network.

The possibility of carrying out observations with distributed monitoring and control via, for example, eRemoteControl will depend on the willingness and the needs of the individual stations. Security, safety and political issues will be the main obstacles to realize reductions in operations costs by handing over control to another observatory.

Concerning data transport and intermediate storage, it was discussed whether the current practice of the telescopes sending their data to the correlators is the right way to operate. For computer safety reasons and also for operational optimization (e.g., overflow of storage at correlators), the procedures may be changed so that the data are actually pulled from the telescopes by the correlator staff. For this reason, stations will be required to have playback capabilities which are independent of the recording terminal.

In the interim, current problems with the Web page for monitoring network traffic will have to be solved by increasing the update cycle from currently every 15 minutes to as frequently as the system permits.

Another option for alleviating the bottleneck of the last mile problem of the correlators is to establish centralized large-volume data storage at points where network capacity is high. Each correlator can then download the data from there at the very time when needed. This would also allow other correlators to access the data at the same time.

With respect to future correlator developments, an imminent question is whether DiFX can handle the expected full-scale VGOS data volume and rates. This will be investigated at Bonn and Haystack.

Conclusions

The retreat brought up a number of issues which need to be addressed sooner rather than later. In the list below, the sequence of items does not reflect priorities.

- The correlators are central elements of the IVS's operation and they are not prepared for the increase in data throughput that will be required for VGOS observing. The same applies to the network connectivity of the correlators.
- The IVS workforce is aging and needs active replacement with young enthusiasts.
- Many institutions rely on our results but do not care where they come from. Therefore, stronger institutional ties between the IVS and different groups are needed.
- Many people use our products but don't know where they come from. The public uses our products indirectly, but has no idea about IVS. For this reason, better PR is required.
- The IVS consists of many efficient components and motivated individuals. Besides all the scientific endeavors, it needs to be emphasized that the IVS is a service and that the service aspects require additional efforts.
- The actual value and importance of IVS products are currently undervalued and poorly understood. A database of users, the specific products (including parameters such as frequency of use, purpose, expected latency etc.) need to be established and maintained.

As a consequence of the retreat and this summary, an IVS Strategic Plan will be developed.

Action items/to-do list

(to be excluded from version to be published)

Do EOP have an effect in time transfer with GPS?

How sensitive are altimetry measurements to UT1?

Look for documentation of importance of CRF for space navigation (provide to Stephen)

Produce targeted public relations and outreach (in simple terms) for agencies and institutions

Contact sister techniques for collaboration on PR

Increase outreach to IVS-under-represented areas of the world (southern hemisphere)

Initiate guest talks of IERS, ILRS, IGS and IDS at IVS GM

Verify with IGS, ILRS and IDS how they use UT1-UTC and what accuracy is actually needed.

A. Bertarini: Establish WG on correlator/network architecture for 2020 including computer scientists

A.N. write one page for IAU via P. Charlot

PE Opseth writes short article for IVS Newsletter

S. Merkowitz will provide contact addresses of INPE

A.N. Check with Wolfgang and Daniela for Web access frequency of, e.g., UT1-UTC

L Combrinck will ask DLR who uses IVS products and establish a contact person or group.

Write up documents and summaries, in particular **write an IVS Strategic Plan as a consequence of this document**