

IVS2016

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Book of Abstracts

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Oral5: Geodetic and Astrometric Results / 1**Application of Kalman filtering for the determination of a VLBI terrestrial reference frame****Author:** Benedikt Soja¹**Co-authors:** Harald Schuh²; Kyriakos Balidakis³; Maria Karbon¹; Richard Gross⁴; Robert Heinkelmann¹; Susanne Glaser³; Tobias Nilsson¹¹ *GFZ German Research Centre for Geosciences*² *GFZ German Research Center for Geosciences*³ *Technische Universität Berlin*⁴ *Jet Propulsion Laboratory, California Institute of Technology***Corresponding Author:** bsoja@gfz-potsdam.de

Terrestrial reference frames (TRF) of high quality are indispensable for many geoscientific and geodetic applications including very long baseline interferometry (VLBI) data analysis. While secular station coordinate changes, e.g. due to tectonic plate motion, can be well represented by a linear model, current accuracy requirements also demand modeling of non-linear signals such as surface deformations due to mass loading or post-seismic deformations. The ITRF2014, for instance, includes coefficients for exponential and logarithmic functions after major earthquakes. Another approach, used for the determination of JTRF2014, is the application of Kalman filtering that allows post-seismic displacements to be accounted for in a non-parametric manner.

In this paper, we portray a TRF solution solely based on VLBI data, employing Kalman filtering and smoothing for the computation of session-wise coordinates of more than hundred VLBI radio telescopes over more than 30 years. By using a random walk process, non-linear coordinate changes are modeled stochastically. The noise model is derived from loading deformation time series that are not included in the model for the station motion (i.e., non-tidal atmosphere, non-tidal ocean, and continental water storage loading). This stochastic model alone is not able to adapt to the large coordinate variations that can happen after major earthquakes. Therefore, we additionally increase the process noise in the periods following earthquakes based on the amplitude of the estimated coordinate jumps, introducing the epochs of the seismic events as prior information.

We compare our Kalman filtered and smoothed VLBI-TRF to a classical least squares VLBI solution calculated by the VieVS@GFZ software, based on linear segments between episodic events. Additionally, multi-technique TRF, such as the ITRF2014 and JTRF2014, are included in the comparisons, especially for assessing the different approaches of modeling post-seismic deformations.

Oral5: Geodetic and Astrometric Results / 2**On the impact of different mapping functions on geodetic and tropospheric products from VLBI data analysis****Author:** Kyriakos Balidakis¹**Co-authors:** Florian Zus²; Harald Schuh²; Jan Douša³; Maria Karbon²; Robert Heinkelmann²; Soja Benedikt²; Susanne Glaser¹; Tobias Nilsson²¹ *Technische Universität Berlin, Institute of Geodesy and Geoinformation Science, Berlin, Germany*² *Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum GFZ, Department of Geodesy and Remote Sensing, Potsdam, Germany*³ *Geodetic Observatory Pecny of the Research Institute of Geodesy, Topography and Cartography, Czech Republic***Corresponding Author:** kyriakos.balidakis@tu-berlin.de

Due to the highly volatile character of the neutral atmosphere, the modeling of the related propagation delay is challenging. This poses the most prominent limitation in the precision and accuracy of the parameters estimated in very long baseline interferometry (VLBI) data analysis. Hence, it is of paramount importance that all parameters involved in the process to describe the atmosphere induced delay effects such as mapping functions or gradients are rigorously accounted for.

In this work, we assess the impact of different mapping functions (MFs) in the analysis of the 24-hour VLBI sessions from 2002 onwards. Besides the original Vienna mapping functions (VMF1), which are based on data from ECMWF operational analysis, we apply MFs based on this concept but utilizing data from ray tracing in CMC's GDPS (UNB-VMF1). In addition to these we test the concept of advanced mapping using ECMWF's ERA-Interim reanalysis based on rigorous ray-tracing approach. For the parameter estimation we use the VieVS@GFZ software applying the classical Gauß-Markov model.

The purpose of this study is twofold. We investigate the effect of these analysis options on the baseline length repeatability as well as on the time series of station, source coordinates and Earth orientation parameters. As far as the tropospheric products are concerned, estimated zenith wet delays and linear horizontal gradients are compared with the ray traced ones from the aforementioned models.

Poster4-6 - Board: S4P1 / 3

Refinement of Rapid UT1 Estimation Derived from Tsukuba VLBI Measurements after 2011 Earthquake

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The Tsukuba station in Japan is an essential station in the IVS Intensive series for rapid UT1 estimation. The use of this station in rapid UT1 estimation requires a set of best-predetermined station coordinates but the consequences of the Earthquake in Japan in March 2011 were such that the previously known velocity rates of the station Tsukuba were unusable.

Since 2012, the VLBI group at BKG uses a method, which solves this problem. This procedure was refined with respect to a newly developed extrapolation to get most probable station positions of Tsukuba for the epochs of the Intensive sessions. The procedure is explained and could be successfully integrated into the technological process of operational analysis of post-quake Intensive sessions with station Tsukuba.

Oral5: Geodetic and Astrometric Results / 4

Tidal atmospheric loading and VLBI

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This presentation is dedicated to the influence of diurnal atmosphere-ocean dynamics on Earth rotation and loading effects as observed by Very Long Baseline Interferometry. The first part focuses on the rotational signals associated with atmospheric tides, comprising small but non-negligible oscillations in the order 5 μ s. Here, we compare tidally analysed VLBI observations against estimates

from different providers of numerical weather models. We also discuss the complexity of the issue that must make allowance for indirect effects due to tidal pressure variations acting on the ocean. In the second part, we are investigating loading signals caused by atmospheric tides and the associated mass variations in the ocean. Different models of the effect are compared with respect to their performance in a VLBI analysis, and strategies how to apply consistent corrections for the atmosphere and the ocean are discussed. Moreover, we also show VLBI results for two gravitational ocean tide models, FES2004 and FES2012, where the latter benefits from a much finer horizontal resolution and an improved description of hydrodynamic processes.

Oral4: Data structures and Analysis Strategies in the VGOS Era / 5

Results from the VLBI Analysis Software Comparison Campaign 2015

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The IERS Conventions contain recommendations, definitions and models for space geodetic techniques including geodetic VLBI. In practice, different analysis software packages follow different estimation methods, use a variety of different correction models and sometimes adhere to conventions that might not be the latest. This may lead to differences in the results that should not appear among the software packages dealing with the same observational data-set. Consistency of geodetic VLBI analysis is especially important for the VLBI Global Observing System (VGOS), for which we need station position and velocity accuracies of 1 mm and 0.1 mm per year, respectively.

The aim of the VLBI Analysis Software Comparison Campaign 2015 (VASCC2015) was to compare different VLBI analysis software packages on the basis of computed theoretical delays. Two networks, one in the northern and one in the southern hemisphere, were scheduled in a way so that in each network a single source could be tracked continuously. In total fifteen consecutive 24 hour sessions with one minute observation resolution formed the base of this comparison campaign. More than eight research groups and institutes participated in this project, which allowed us to compare software packages that are used in operational VLBI analysis as well as those being currently under development.

We are going to present the first results and the outcomes of this project and we show how well the individual software packages agree. We will discuss discrepancies between analysis software packages and reveal where those differences are coming from. Moreover, we are going to evaluate whether these discrepancies are small enough to be neglected for reaching the VGOS goals.

Oral1: Advances in VGOS Stations and Technology / 6

<i>INVITED TALK:</i> An Overview of the Japanese GALA-V Wide-band VLBI System

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We are developing a new broadband VLBI system, named GALA-V with aim of frequency comparison between atomic time standards over intercontinental distances. The development of broadband GALA-V system is coordinated to be as compatible as possible with the VGOS system. Kashima 34m antenna that had modified Cassegrain optics was enabled to carry out broadband observation with originally developed two types of prototype broadband feeds named IGUANA-H and NINJA. Two ways of data acquisition modes; broad channel mode and narrow channel mode, are employed in the project. Narrow channel mode acquires multiple channels of 32MHz bandwidth, and this mode is compatible with the observation mode developed by MIT Haystack as the 'NASA proof of Concept' (PoC) system. Broad channel mode acquires four channels of 1 GHz bandwidth signal. RF Direct sampling technique is applied in this mode as a new approach for broadband observation by using high speed sampler K6/GALAS. This technique has several advantages in precision delay derivation by broadband bandwidth synthesis.

Ishioka 13m VGOS station has constructed by GSI in Japan, and the first broadband observation over 8 GHz bandwidth was successfully performed in early 2015 on Kashima 34m - Ishioka 13m baseline. We have achieved super broadband bandwidth synthesis over 8GHz bandwidth for the first time in the world. The theoretical delay precision has reached about 30 femto seconds in this experiment. This presentation will report about recent progress of the broadband GALA-V developments.

Poster1-3 - Board: S3P6 / 7

The Development of Hardware Correlator in SHAO

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The hardware correlator have been used in Chinese Chang'E missions. Recently, a hardware correlator based on uniboard has been developed. This article presents the development of hardware correlator at SHAO and some results.

Poster1-3 - Board: S3P7 / 8

High-speed data playback of VLBI hardware correlator

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VLBI(Very Long Baseline Interferometry) is an important radio astronomy technology, is widely used in deep-space probes high-precision measurement. The correlator as the core data pre-processing equipment of VLBI, its performance is very important. At present, China VLBI data acquisition system (CDAS) can collect data 2Gbps, and multiband combination can reach 16Gbps or 32Gbps. For ensure the requirements of high-speed and high-precision, there used Uniboard as the hardware platform, used 10G Ethernet as the data playback interface and 1G Ethernet as the control interface, research the VLBI data playback which speed up to 4Gbps for single CDAS, and design some pre-processing method just

like data correct and data decode specific to the VLBI data characteristic. Now we have finished the preliminary system, and there will show the design and some results.

Oral4: Data structures and Analysis Strategies in the VGOS Era / 9

Robust ambiguity estimation for automated analysis of Intensive sessions

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Robust and automatic estimation of ambiguities is one of the main requirements for a fully automated analysis of Intensive sessions. We apply the L1-norm minimization to ambiguity estimation and ionosphere calibration using the c5++ analysis software. This study includes IVS Intensive sessions on the Kokee-Wetzell baseline from 2001 to 2015 where Version-1 database are accessible. Version-1 corresponds to correlation output meaning the ambiguity elimination and the ionosphere calibration need to be performed prior to parameter estimation. In total we use 1778 databases in this study. The analysis is done in two steps. First the session is processed in automatic mode to resolve the ambiguities and estimate the ionospheric delays. Then, we estimate UT1-UTC using the ionosphere-free databases. In standard c5++ both steps use the well-known least-squares optimization (L2-norm minimization) to fit the model to the observations. We introduce the L1-norm minimization into the first step and then estimate UT1-UTC using the least-squares method. The results are compared with databases analysed using least-squares in both steps. The performance differences are assessed by investigating the session fit and the respective UT1-UTC estimates. Further details can be found in [1].

[1] Kareinen et al. (2015), Robust ambiguity estimation for automated analysis of Intensive sessions, manuscript submitted to Computers & Geosciences.

Oral3: Stations, Correlators and Operations Centres / 10

A Technical Overview of the EVN

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As chair of the Technical and Operations Group (TOG) of the European VLBI Network (EVN) I would like to present an overview of the technical aspects of the EVN. I will explain which institutes and telescopes constitute the EVN, and their main characteristics and observation frequencies. The scheduling process together with fringe tests, network monitor experiments, standard observations, e-VLBI observations and target of opportunity observations will be described. The EVN signed a MoU with JIVE and as result activities from both sides are deeply interleaved. I will present some of these activities with relevant impact in the EVN. I will also describe the calibration control process. Finally technical developments in the last year, including 2 Gbps recording in DDC mode, 2 Gbps recording in VDIF format supported by the FS for Mark5C, Mark6 and Flexbuff and the works to

get PFB mode will also be presented together with the tests performed. These developments are the result of collaboration works from different parties in the EVN and also NVI Inc with which the EVN signed a contract.

Poster4-6 - Board: S5P9 / 11

On the impact of inhomogeneities in meteorological data on VLBI data analysis

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In this study, the issue of the quality of meteorological data employed for VLBI data analysis is addressed. Traditionally, ambient barometric pressure and temperature values are used to model the hydrostatic component of the neutral atmospheric propagation delay and the thermal deformation of antennas, in VLBI data analysis. Unlike the other microwave-based space geodetic techniques currently contributing to the TRF, where the necessary meteorological data are customarily acquired by either empirical or numerical weather models, VLBI analysis has the advantage that the aforementioned nuisance effects can be potentially eliminated more effectively employing in situ meteorological data. Nevertheless, there are cases where erroneous meteorological records yield unacceptable products which have a dubious traceability. For instance, if the recorded pressure series at a certain site has a significant positive bias with respect to the actual one, negative zenith wet delays will indicate a serious problem. Should the bias be anything but like this, its detection will be challenging and it will contaminate the geodetic products of the site and potentially at other sites participating in the same session. In the long term, such biases will affect the scale of the estimated TRF.

We establish a service for the online detection and correction of inhomogeneities in recorded meteorological data at the VLBI sites. Employing the homogenized data set, the “IVS Rapid Tropospheric Combination Center” is re-launched providing zenith total and wet delays, as well as linear horizontal gradients.

Poster4-6 - Board: S5P4 / 12

The effects of quasar variability on astrometry

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Radio sources observed in global IVS sessions are mostly flat-spectrum radio-loud quasars. While some quasars appear almost point like, many have extended jet components in addition to compact cores. The structure of these jets often varies on timescales of months to years as the black hole at the centre of the quasar accretes new material and ejects components of radio-emitting plasma. These components expand adiabatically as they move away from the compact core, and eventually disappear. In this way, the structure and flux density of quasars are related.

We present an analysis of nine variable quasars frequently observed in global geodetic VLBI programs. We find a clear anti-correlation between source flux density and structure index, in the sense that the brightest sources are also the most compact. This anti-correlation is stronger on the rising side of the flare, consistent with astrophysical expectations. Consistent with previous findings, we show that bright, compact quasars also have more repeatable astrometric positions. We suggest that flux density time series may be a useful additional piece of information used in selecting quasars for geodetic VLBI observations.

Poster4-6 - Board: S6P3 / 13

<i>INVITED POSTER:</i> APOD mission status and observe APOD by VLBI

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On Sept. 20, 2015, the Chinese CZ-6 test rocket was launched successfully from TaiYuan Satellite Launch Center, and 20 satellites was sent simultaneously into a circular, near-polar and 520 Km altitude orbit. Among these 20 satellites, four CubSats, named with APOD (Atmospheric density detection and Precise Orbit Determination), are projected for atmospheric density in-situ detection and derivation via precise orbit. The APOD satellites, manufactured by DFH Co., carries a number of instruments including density detector, dual-frequency GNSS (GPS/BD) receiver, SLR reflector and S/X band VLBI beacon. The mission aims to detect atmospheric density below 520 Km. The ground segment is run by BACC for payload operation as well as science data receiving, processing, archiving and distribution. Currently, one of the APOD satellites and payload validation had finished, and the preliminary results are presented as follows. The precision of orbit determination is about 10cm by both overlap method and by compared with SLR observation, and the derived atmospheric density from this precise orbit determination matches well with in-situ detection.

Since three space geodetic techniques (i.e. GNSS, SLR, and VLBI) are co-located on APOD satellite, the observations can be used for combination and validation in order to detect the systematic differences. Furthermore the observations of APOD satellite by VLBI radio telescope can be used in an ideal fashion to link the dynamical reference frames of the satellite with terrestrial and, most importantly, to the celestial reference frame as defined by the positions of quasars. From a VLBI observational point of view, APOD satellites rather challenging since mutual visibility depends on the altitude of APOD satellite and the separation of the radio telescopes. And the APOD satellite travel through the field of view very fast. The possibility of observing APOD satellite by IVS VLBI radio telescopes will be analyzed in the presentation, considering continental-size VLBI observing networks and the small telescopes with sufficient speed.

Poster4-6 - Board: S4P2 / 14

Improvement of the IVS-INT01 Sessions

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An on-going goal of the GSFC Analysis Center is the improvement of the UT1 formal error obtained from the IVS-INT01 sessions, as well as the improvement of related metrics, such as robustness against atmospheric turbulence. Improvement can be achieved by improving the scheduling and/or the analysis of these sessions. Here we report on our latest efforts to improve the performance of the IVS-INT01 sessions.

Oral2: VGOS Strategies and Expected Results / 15

Observing with sibling and twin telescopes

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With the transition to VGOS, co-located radio telescopes will be common at many sites. This can be as a sibling telescope, when a VGOS antenna is built next to a legacy one or as the concept of a twin telescope, with two identical VGOS antennas.

The co-location of two antennas offers new possibilities in both operation and analysis. The immediate question for observing with a sibling/twin telescope is the applied observing strategy and its realisation in the scheduling software.

In this contribution we report about our efforts implementing new scheduling modes for sibling and twin telescopes in the Vienna VLBI Software. On the example of the sibling telescope in Hobart, several types of sessions will be discussed: scheduling redundant observations observing in identical scans, improved troposphere solution through observations in different directions, improved antenna sensitivity through adding the legacy antenna for observations to weak sources, or sessions dedicated to determine the local baseline.

Results from sibling experiments, applying new analysis strategies combining common parameters, will further demonstrate the potential of twin telescopes for VGOS.

Oral1: Advances in VGOS Stations and Technology / 16

On your Marks ... Flex, Buff and VGOS, partly even in real-time

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Modern, VGOS and general purpose radio-astronomical digital back ends (DBEs), will produce enormous amounts of data, posing some challenges for the recorders. Fortunately, the availability of ever faster digital hardware has also meant that capturing these large data streams on - relatively speaking - general purpose hardware has become quite feasible.

Currently there are two models of ethernet packet recorders in use: MIT Haystack's Mark6 and the FlexBuff, developed in the European VLBI Network (EVN). As the hardware has become more and more commercial-off-the-shelf (COTS) so has grown the importance of software support; in fact, these newer recorders are full software recorders.

As such the usability and performance of such a recorder is completely defined by the functionality of the software running on it. In this talk I would like to introduce the capabilities of EVN's software jive5ab on this class of recorders and what extra benefits it may have for dealing with recorded ethernet data.

Besides these mundane recording aspects, I would like to present, on behalf of Stuart Weston (Warkworth, New Zealand) and Simone Bernhart (IGG Bonn), an application of the features of the jive5ab recording software for real-time recording of IVS R1 sessions.

In this test the scans were recorded on Warkworth's Mark5B+ but also, in parallel and in real-time, at the cluster in Bonn. This has proven to work and provides a measurable increase in turn-around time for correlation with a minimum of hassle if more stations [w/c]ould do this.

Poster1-3 - Board: S3P5 / 17

From CONT to VGOS: The Evolution of the CONT Campaigns

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Continuous VLBI Campaigns (CONT) started in 1994 with the goal of demonstrating state of the art VLBI over a continuous period of time. The first CONT was followed by campaigns in 1995 and 1996. After a six year hiatus, CONT campaigns were organized approximately every three years from 2002 through 2014. In this presentation we primarily focus on the cornerstones of each CONT campaign. Specifically, we review the developments in networks, scheduling techniques, recording media, correlation, and other resources used. A timeline of the history of the CONTs and the goals for future campaigns will be presented. The CONTs used a significant amount of IVS resources to produce a large volume of high quality data and demonstrated the advantages of continuous observing which will soon be realized with VGOS.

Oral1: Advances in VGOS Stations and Technology / 18

BRAND EVN

Author: Gino Tuccari¹

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Multi-band concurrent observation capability for the frequencies bands commonly used in EVN greatly could improve the VLBI scientific opportunities, even enabling important simplification in the radiotelescope operations.

The project for a 1.5 - 15.5 GHz fully digital receiver is presented with the

possible solutions for a smooth introduction in the different from each other EVN radiotelescopes.

Oral1: Advances in VGOS Stations and Technology / 19

IVS Retreat 2015

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On October 7 and 8, 2015, the IVS Directing Board held an IVS Retreat at the Dominion Radio Astrophysical Observatory, Penticton, BC, Canada, to discuss current implications and future challenges of the IVS's existence and operations. In order to benefit from outside views, six external advisors had been invited as well. The group spent two days discussing correlation, product lines, institutional relations, and operations details with concepts for the future. Critical items included the aging of the experienced workforce of the IVS, the preparation of the correlators for the large increase in data throughput for VGOS, an emphasis on the service aspect of the IVS, and the need for increased public relations work, among other items. In this presentation, the chair of the IVS will inform the participants about the retreat and its consequences.

Conference Dinner / 20

***DINNER TALK:* Half a century of geodetic VLBI analysis – a personal retrospect and future outlook**

Author: Harald Schuh¹

¹ *GFZ German Research Center for Geosciences*

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Through the analysis of geodetic VLBI data a multitude of scientific topics in geodesy, geophysics, and astronomy can be covered. Starting from astrometry, relativity, and the essential contribution of VLBI to the terrestrial reference frames, geophysical effects like loading and deformation of the Earth's crust, variations of the Earth orientation parameters, and changes of the troposphere and ionosphere can be investigated. Examples of some results achieved in the last decades will be given, and a future outlook of VLBI analysis will be provided.

Poster1-3 - Board: S2P1 / 21

The UN-GGIM Roadmap for the Global Geodetic Reference Frame

Author: Halfdan Pascal Kierulf¹

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In February 2015 the UN General Assembly adopted the resolution “A Global Geodetic Reference Frame for Sustainable Development” - the first resolution recognizing the importance of a globally-coordinated approach to geodesy. The GGRF Working Group is working on the development of a roadmap that will describe how governments can contribute to the sustainability and enhancement of the Global Geodetic Reference Frame. The ambition is that UN-GGIM 6th session endorses the GGRF Roadmap in New York in August 2016.

We will address the ongoing work with the roadmap and future plans. We will also discuss the opportunities and benefits of the UN resolution and roadmap for the development of geodesy and geodetic networks like VGOS.

Oral1: Advances in VGOS Stations and Technology / 22

Building a new core station in Ny-Ålesund

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The existing 20 m telescope in Ny-Ålesund was set in operation in 1994. The telescope is more than 20 years now and is ready for retirement.

We decided to build a VGOS core site with twin telescopes. The existing telescope is just 70 meters away from the runway and the CAA did not allow us to build anything more so close.

The new site is about 1500 meters northwest of the old telescope and we had to build a road with a bridge. This was finished summer 2014 and the construction work started in October 2014. It is a bit challenging to do construction work during wintertime at 79 degree north with permafrost. During the winter, the VLBI fundamentals came up. Station, SLR and gravity buildings are built too.

This presentation will show what is done until now and different solutions for the telescopes. The telescopes shall arrive, April 2016

Oral2: VGOS Strategies and Expected Results / 23

Next Generation Global Geodetic Networks for GGOS

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We simulated future networks of VLBI+SLR sites to assess their performance. The objective is to build a global network of geographically well distributed collocated next generation sites from each of the space geodetic techniques. The network is being designed to meet the GGOS terrestrial reference frame goals of 1 mm in accuracy and 0.1 mm/yr in stability. We simulated the next generation networks that should be available in 5 years and in 10 years to assess the likelihood that these networks will meet the reference frame goals. Simulations were based on the expectation that 17 broadband VLBI stations will be available in 5 years and 27 stations in 10 years. We also consider the improvement resulting from expanding the network by 6 additional VLBI sites to improve the global distribution of the network. In the simulations, the networks will operate continuously, but we account for station downtime for maintenance or because of bad weather. We assess the agreement

between the estimated SLR and VLBI coordinate differences and the survey ties by doing combination TRF solutions that tie the networks together only through the estimation of EOP. The strengths of VLBI and SLR allows them to provide the necessary reference frame accuracy in scale, geocenter, and orientation. Even with just the +5 year network operating for 10 years, simulations indicate that accuracies will be at the level of 0.03 ppb, 0.3mm, and 10 μ as. Combining the +5 year and +10 network realization will provide better estimates of accuracy.

Oral5: Geodetic and Astrometric Results / 24

About the extension of the coordinate parametrization of radio sources in VLBI

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Usually celestial radio sources in the celestial reference frame (CRF) catalog are divided in three categories: defining, special handling, and others. The defining sources are those used for the datum realization of the celestial reference frame, i.e. they are included in the No-Net-Rotation (NNR) constraints to maintain the axis orientation of the CRF, and are modeled with one set of totally constant coordinates. At the current level of precision, the choice of the defining sources has a significant effect on the coordinates. For the ICRF2 295 sources were chosen as defining sources, based on their geometrical distribution, statistical properties, and stability. The number of defining sources is a compromise between the reliability of the datum, which increases with the number of sources, and the noise which is introduced by each source. Thus, the optimal number of defining sources is a trade-off between reliability, geometry, and precision.

In the ICRF2 only 39 of sources were sorted into the special handling group as they show large fluctuations in their position, therefore they are excluded from the NNR conditions and their positions are normally estimated for each VLBI session instead of as global parameters. All the remaining sources are classified as others. However, a large fraction of these unstable sources show other favorable characteristics, e.g. large flux density (brightness) and a long history of observations. Thus, it would prove advantageous including these sources into the NNR condition. However, the instability of these objects inhibit this. If the coordinate model of these sources would be extended, it would be possible to use these sources for the NNR condition as well. All other sources are placed in the “others” group. This is the largest group of sources, containing those which have not shown any very problematic behavior, but still do not fulfill the requirements for defining sources.

Studies show that the behavior of the sources can vary dramatically in time. Hence, each source should be modeled individually. Considering this, the sheer amount of sources, in our study more than 900 are included, sets practical limitations.

We decided to use the multivariate adaptive regression splines (MARS) procedure to parametrize the source coordinates, as they allow a great deal of automation as it combines recursive partitioning and spline fitting in an optimal way. The algorithm finds the ideal knot positions for the splines and thus the best number of polynomial pieces to fit the data. We investigate linear and cubic splines determined by MARS to “human” determined linear splines and their impact on the CRF.

Within this work we try to answer the following questions: Do we still need the categorizations in stable, special handling and other sources? If yes, how can we find optimal criteria for the definition of these categories? Whats the best approach to find the best fitting polynomials? And finally, what can we gain by introducing this type of parametrization within the CRF determination?

Oral5: Geodetic and Astrometric Results / 25**Aspects of ICRF-3****Author:** Chopo Ma¹**Co-authors:** Daniel MacMillan²; David Gordon³; Karine Le Bail⁴¹ *NASA Goddard Space Flight Center*² *NVI, Inc./NASA GSFC*³ *NVI Inc./GSFC*⁴ *NVI, Inc./GSFC***Corresponding Author:** chopo.ma@nasa.gov

The Second Realization of the International Celestial Reference Frame (ICRF) used dual-frequency VLBI data acquired for geodetic and astrometric purposes from 1979-2009 by organizations coordinated by the IVS and various precursor networks. Since 2009 the data set has been significantly broadened, especially by observations in the Southern Hemisphere, and modeling of astronomical, geophysical and tropospheric effects has progressed. While the new southern data have ameliorated the north/south imbalance of observations, they appear to cause a systematic zonal declination change in the catalog positions. Over the three decades of the ICRF data set the effect of galactic aberration may be significant. Geophysical and tropospheric models also may affect the source positions. All these effects need to be addressed in preparation for ICRF-3.

Oral3: Stations, Correlators and Operations Centres / 27**Report on the current activities of GSI VLBI****Author:** Ryoji Kawabata¹**Co-authors:** Kojin Wada¹; Masayoshi Ishimoto¹; Takahiro Wakasugi¹; Yoshihiro Fukuzaki¹¹ *Geospatial Information Authority of Japan***Corresponding Author:** kawabata-r96aq@mlit.go.jp

The Geospatial Information Authority of Japan (GSI) has been operating Network Stations such as Tsukuba 32-m antenna, Tsukuba Correlator, and Tsukuba Analysis Center. Recently we started to operate a new VGOS antenna, Ishioka 13-m antenna, which will take over the role of Tsukuba 32-m antenna and, on the other side, stopped operation of the three regional antennas in Japan. GSI is now being actively involved in the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) by using Tsukuba 32-m and Ishioka 13-m antenna and by correlating regular AOV sessions. We will talk on the current activities of GSI VLBI.

Oral3: Stations, Correlators and Operations Centres / 28**VERA K-band Geodetic VLBI experiment using newly developed high speed sampler and recorder****Author:** Takaaki Jike¹¹ *National Astronomical Observatory of Japan*

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According to increasing the number of observations by 1-Gbps recording, geodetic VLBI solutions of VERA improve the accuracy. This is for guaranteeing the accuracy of VERA astrometry. However, much more increase in the number of observations is already difficult by the limit of the driving performance of the VERA antenna. OCTAVE series is a candidate of a next-generation data processing system in VERA. Sampling/recording rate of the system is 8-Gbps and corresponds by 8 times the present recording rate of VERA. Broadening of the recording bandwidth leads to improve delay estimation accuracy, and improving accuracy of geodetic solution is expected. We performed experimental geodetic VLBI observation which used the high-speed sampler and recorder. In connection with it, we optimized selection of observed radio sources.

Poster4-6 - Board: S6P4 / 29

Preliminary Results of VLBI observations of the Chang'E-3 Lunar Lander

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The successful deployment of the Chang'E-3 Lander on the Moon on Dec 14th, 2013 has opened a new window for VLBI observations of the Moon. Following proposals to the IVS Observing Program Committee, a global IVS R&D network augmented with two China Deep Space Stations was configured for joint observations of the lander in a project called OCEL (Observing the Chang'E-3 Lander with VLBI). From July 2014 to December 2015, the Chang'E-3 Lander was observed successfully during several 24-hour sessions. More than 10 stations distributed all around the world participated in each observing session. In this paper, correlation results of the Beijing Aerospace Control Center (BACC) for sessions in 2014 are presented, concentrating on the software correlator, key algorithms and observable accuracy analysis.

BSCS(BACC Software Correlator System) is designed to run on Beowulf clusters consisting of commodity machines with parallel processing algorithms adopted in the software.

For the OCEL observations, the DeltaDOR mode was adopted, which means a sequence of "Quasar - Chang'E-3 - Quasar". Here, quasars with small separation angles are preferred to eliminate common errors as much as possible. The Chang'E-3 Lander is equipped with an X-band transponder which transfers an X-band carrier and four DOR tones at +/-19.25 MHz and +/-3.85 MHz in coherent modes. With a spanned bandwidth of 38.5 MHz, DOR tones are recorded in five different channels. Phase calibration (PCAL) is used to remove any offset in phase due to the BBCs electronics of different channels. When the phases of the PCAL tones are too noisy, a strong calibrator is used to manually specify the phase of each channel. The group delay is computed by bandwidth synthesis. The preliminary accuracy analysis shows that the delay observables of Chang'E-3 are better than 1 ns, depending on the signal-to-noise ratio of the different baselines.

Poster4-6 - Board: S4P4 / 31

VieVS 2.3 - status of the Vienna VLBI Software and plans for the future

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The Vienna VLBI Software (VieVS) is a VLBI analysis software developed and maintained at Technische Universität Wien (TU Wien) since 2008 with contributions from groups all over the world. It is used for both academic purposes in university courses as well as for providing VLBI analysis results to the geodetic community. Written in a modular structure in Matlab, VieVS offers easy access to the source code and the possibility to adapt the programs for particular purposes.

The new version 2.3, released in December 2015, includes several new parameters to be estimated in the global solution, such as tidal ERP variation coefficients. The graphical user interface was slightly modified for an improved user functionality and, e.g., the possibility of deriving baseline length repeatabilities. The scheduling of satellite observations was refined, the simulator newly includes the effect of source structure which can also be corrected for in the analysis.

This poster gives an overview of all VLBI-related activities in Vienna and provides an outlook to future plans concerning the Vienna VLBI Software.

Oral5: Geodetic and Astrometric Results / 32

ICRF sources: How good is the 'deep' southern sky

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The International Celestial Reference Frame (ICRF) are constructed using catalogs of extragalactic radio source (mainly quasars) positions measured at 2.3 and 8.4 GHz with the Very Long Baseline Interferometry (VLBI) technique. Most extragalactic radio sources exhibit spatially extended structures on milliarcsecond and sub-milliarcsecond scales which are variable in both time and frequency. These extended structures may contribute significant errors in the VLBI measurements that will introduce uncertainty in the source position measurements. Therefore, in order to define and maintain the celestial reference frame with the highest accuracy, efforts are required to map sources and to study their suitability as reference frame source on VLBI scales.

We will present multi-epoch imaging results of the ICRF sources in the southern sky from the Celestial Reference Frame Deep South (CRDS) observing campaign from the IVS. Source morphology as well as source quality aspects will be discussed in the presentation which will give a better understanding of source behavior at 2.3 and 8.4 GHz observing frequencies with the VLBI technique.

Poster4-6 - Board: S5P10 / 33

Application and development of VieVS at BACC

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BACC(Beijing Aerospace Control Center), as the command center for the Chinese space program, got access to VieVS in 2011. Since 2013, IVS VLBI data has been downloaded and analyzed automatically with VieVS at BACC and the geodetic products will be provided firstly in the presentation. VieVS was also used to estimate the coordinates of new Chinese VLBI telescopes with domestic VLBI network in the past two years, the preliminary results will be presented secondly. Furthermore, Chinese lander on the moon has been observed by IVS VLBI telescopes with success already and the APOD (Atmospheric density detection and Precise Orbit Determination) satellite provides great possibility since it carries dual-frequency GNSS (GPS/BD) receiver, SLR reflector and S/X band VLBI beacon. VieVS was developed at BACC to meet the requirements of satellite observations. Lastly EOP prediction has been interpolated to VieVS and the comparisons of EOP prediction will also be presented.

Poster4-6 - Board: S4P3 / 34

Hard- and software tools for the education of Geodetic VLBI

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Onsala Space Observatory hosts two 2.3 m radio telescopes called SALSA ("Such a lovely small antenna") which are utilised to bring front-line interactive astronomy to the classroom. Until now SALSA has been used for astronomical educational purposes solely, in particular demonstrating the concept of single dish measurements. However, it is possible to combine both SALSAs to an interferometer by making use of hardware which has been developed for software-defined radio. In doing so, one can utilise the SALSA antenna pair as a student demonstrator for geodetic Very Long Baseline Interferometry. We will discuss the COTS hardware components that are necessary to turn the SALSA installation into an interferometer. Moreover, we will show how a simple correlator has been used to detect fringes and provide single-band delays. Such delays were then processed with our analysis software c5++. We are going to discuss how it is possible to mimic the complete processing chain of geodetic VLBI and how this can be used for training of students and other interested parties.

Oral2: VGOS Strategies and Expected Results / 35

Progress on the United Nations Global Geospatial Information Management initiative on the Global Geodetic Reference Frame and the Norwegian Mapping Authority's core station project at 79° North

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February 26th 2015 the United Nations General assembly adopted the resolution on the Global Geodetic Reference Frame (GGRF). Presently major effort under a UN mandate is entered into developing a road map giving guidance to how the GGRF shall become sustainable. This work will influence the geodetic framework conditions in the years to come. As a contribution to global geodesy, Norway is building a core station at Ny-Ålesund, Spitsbergen. Presently the station buildings and fundamentals are finished and waiting for the new twin VLBI telescopes to be installed.

Oral5: Geodetic and Astrometric Results / 36

The XKa Celestial Reference Frame: Assessing Accuracy

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Observations at X/Ka-band are motivated by their ability to access more compact source morphology and reduced core shift relative to observations at the historically standard S/X-band. In addition, the factor of four increase in interferometer resolution at Ka-band should resolve out some wide binary black holes which are a topic of concern for AGN centroid stability.

Given these motivations, an X/Ka-band (8.4/32 GHz) celestial reference frame has been constructed using a combined NASA and ESA Deep Space Network. In 124 observing sessions we detected 673 sources covering the full 24 hours of right ascension and the full range of declinations. The resulting XKa median precision is now better than the ICRF-2 precision thereby raising the question of which frame is more accurate.

Comparison of over 500 X/Ka sources in common with the S/X-band (2.3/8.4 GHz) ICRF2 produced wRMS agreement of about 200 microasec. There is evidence for systematic errors above the 100 microasec level. Known errors include limited SNR, lack of phase calibration, troposphere mismodelling, and terrestrial frame distortions. Actions are underway to reduce all of these errors. In particular, a collaboration between NASA and the ESA deep space antenna in Malargüe, Argentina is quickly reducing weaknesses in the southern hemisphere. By looking at the best observed sources, we probe the accuracy limits of current celestial frames in an effort to understand the advantages of each frame.

Poster4-6 - Board: S5P3 / 37

Vienna contribution to ITRF2014

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The next realisation of the International Terrestrial Reference System, the ITRF2014, is currently in preparation or under evaluation, respectively. The VLBI input to ITRF2014 is provided by the International VLBI Service for Geodesy and Astrometry (IVS) and consists of a combination of all analysis center contributions. One of these single solutions is contributed by the Vienna special analysis center of the Department of Geodesy and Geoinformation at TU Wien. In this presentation we describe the characteristics of the Vienna contribution (calculated using the Vienna VLBI Software VieVS) to ITRF2014 or VTRF2014, respectively. We give a documentation of the included sessions and stations as well as some statistical information which show the performance of the Vienna contribution compared to the other contributions to the IVS combination. In addition to that, a single solution TRF, VieTRF2014, which is based on the Vienna input to ITRF2014, is presented and compared to previous TRF solutions.

Poster1-3 - Board: S3P8 / 38

DOR Local-correlation Delay Model Calculation Experiment in CE-3 Mission

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The beacon of CE-3 satellite have several tones for communication and VLBI tracking. In order to improve data transferring and processing efficiency, we tried the local-correlation method which was different from the one used in CE-3 project. The Time delay model used in local-correlation experiment also differed from normal time delay model. The result shows that there are a few dozen meters of discrepancy between orbit determination result and reference orbit. The equivalent delay difference is less than 1 ns.

Poster4-6 - Board: S4P5 / 39

ivg::ASCOT: The Development of a new VLBI Software Package

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Although several fully developed VLBI software packages exist already, the VLBI group of the Institute of Geodesy and Geoinformations of Bonn University (ivg) started implementing a new analysis toolbox. The main reason is the need for a flexible environment, which allows for straightforward implementations of new scientific and software-related ideas for VLBI data analysis. Furthermore, we wanted to be able to control and understand the whole processing chain and, last but not least, the developments, which have been performed in Bonn in recent years, should be accumulated under a unified software installation.

The software is implemented in C++ and should finally be able to perform schedules of VLBI sessions, simulation of VLBI observations as well as geodetic data analysis and intra-technique combination. Thus, it is named: Analysis, Scheduling and Combination Toolbox of the Institute of Geodesy and Geoinformations VLBI group (ivg::ASCOT). Currently, we are able to perform single-session data analysis in line with the IERS2010 Conventions, at a stage where the ambiguities have been resolved. The VGOS-DB data format is used as input. Furthermore, global solutions to derive celestial and terrestrial reference frames can be performed on the normal equation level. This can be done based on our single session analysis as well as with SINEX input from other analysis centers. Intra-technique combinations of several solutions complete the initial functionality of the software package. In this paper, we present the modelling of our toolbox as well as some key ideas of our processing and some first results.

Oral4: Data structures and Analysis Strategies in the VGOS Era / 40

Constraining Least Squares VLBI Solutions

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In a traditional least squares adjustment of parameters to the VLBI observation, typically tropospheric as well as clock parameters are determined in form of continuous piece-wise linear functions (CPWLF) with a given temporal resolution. As the VLBI observations are not equidistant, and on the contrary, exhibit gaps of sometimes several hours, singularities arise due to unresolvable parameters inside these gaps. This issue as well as the geometric datum deficiency require additional information to determine the VLBI target parameters, e.g. Earth orientation parameters, as well as the celestial and terrestrial reference frames. For this reason, it is necessary to constrain the respective parameters in the solution.

In this paper we analyze the singularities which arise within the geodetic VLBI data analysis and show the ramifications of traditional constraining. Furthermore, we give suggestions to optimize the least squares solution with regard to constraining the VLBI solution. The effects of various approaches are validated by the analysis of continuous VLBI campaigns.

Oral5: Geodetic and Astrometric Results / 41

An Inequality Constrained Least-Squares approach as an alternative estimation procedure for atmospheric parameters from VLBI observations

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On its way through the atmosphere, the signals of space-geodetic techniques, such as GNSS or VLBI, are delayed and affected by bending and attenuation effects relative to a theoretical path in vacuum. Changing atmospheric conditions contribute considerably to the error budget of the observations. At the same time, space-geodetic techniques play a crucial role in the understanding of the Earth's atmosphere, because atmospheric parameters can be linked to the water vapor content in the atmosphere.

In the VLBI data analysis, the tropospheric delay is usually taken into account by applying an adequate model for the hydrostatic component and by additionally estimating zenith wet delays for the highly variable wet component. Unfortunately, the standard Least-Squares approach sometimes leads to negative estimates, which would be equivalent to negative water vapor in the atmosphere and does of course not reflect the meteorological and physical conditions in a plausible way.

To cope with this phenomenon, we introduce an Inequality Constrained Least-Squares (ICLS) method from the field of convex optimization and use inequality constraints to force the tropospheric parameters to be non-negative allowing for a more realistic tropospheric parameter estimation in a meteorological sense. The impact of the ICLS approach will be validated with regard to station positions. Since deficiencies in the a priori hydrostatic modeling are almost fully compensated by the tropospheric estimates, the ICLS approach urgently requires suitable a priori hydrostatic delays. Thus, we present strategies to deal with missing or incorrect a priori model data.

Oral5: Geodetic and Astrometric Results / 42

<i>INVITED TALK:</i> IVS contribution to the ITRF2014

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Generating the contribution of the International VLBI Service for Geodesy and Astrometry (IVS) to the ITRF2014 was the main task of the IVS Combination Center at the Federal Agency for Cartography and Geodesy (BKG, Germany) in 2015. Starting with the ITRF2005, the IVS contribution to the ITRF is an intra-technique combined solution using multiple individual contributions from different institutions.

For the ITRF2014 nine international institutions were used for a combined solution. The data files contain 24h VLBI sessions from the late 1970s until the end of 2014 in SINEX file format containing datum free normal equations with station coordinates and Earth orientation parameters (EOP). All contributions have to meet the IVS standards for ITRF contribution in order to guarantee a consistent combined solution.

In the course of the generation of the intra-technique combined solution, station coordinate time series for each station as well as a terrestrial reference frame based on the contributed VLBI data (VTRF) were generated and analyzed.

The data analysis, the combination procedure and results of the combined solution for station coordinates and EOP will be presented.

Oral5: Geodetic and Astrometric Results / 43

The structure of the radio source 0642+449 detected from CONT14 observations

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The CONT14 campaign features state-of-art VLBI data. Therein, the radio source 0642+449 was observed with about one thousand observables each day during the continuous observing period of fifteen days, providing tens of thousands of closure delays, the sum of the delays around a closed loop of baselines. The closure delay is independent of the instrumental and propagation delays and provides valuable additional information about the source structure. An example of the use of this new “observable” for the determination of source structure is given for the radio source 0642+449. This source, as one of the defining sources in the second realization of the International Celestial Reference Frame (ICRF2), is found to have two point-like components with separation of 425 milliarcseconds in right ascension and 47 milliarcseconds in declination. The two components are almost equally bright with the flux-density ratio up to 0.92. With the help of recent space VLBI observations at 1.6 GHz, the morphology of 0642+449 could be identified to some extent. The closure delays larger than 1 ns are found to be caused by the source structure as well, demonstrating the structure effect of a source with this simple structure could reach up to tens of nanoseconds, at least one magnitude larger than expected. We anticipate our study to be a starting point for more effective determination of the structure effect in VLBI observations without the involvement of radio source images.

Poster1-3 - Board: S3P9 / 44

Plans and progress of the Vienna Correlator

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The VLBI group at Technische Universität Wien (TU Wien) is going to run a VLBI software correlator for scientific purposes. For that reason, DiFX is installed on the Vienna Scientific Cluster 3 (VSC-3) consisting of 2020 nodes, each equipped with 2 processors (Intel Xeon E5-2650v2, 2.6 GHz, 8 cores). Of course, only a fraction of the total number of cores will be available for VLBI correlation. The VSC-3 is connected to the scientific Geant network with 10 Gbps, thus providing a high bandwidth for downloading data via e-transfer. In this presentation, we provide information about the current status of that project and future plans.

Oral4: Data structures and Analysis Strategies in the VGOS Era / 45

Simulations of near real-time EOP estimation from a future VGOS network

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The VLBI Global Observing System (VGOS) will present a number of challenges for VLBI data analysis. For example, there will be an increase in the number of observations per day by a factor of 10-30 or even more. Furthermore, another goal of VGOS is to reduce the latency between observation and availability of the results, like the Earth Orientation Parameters (EOP) to less than one day. Ideally, the results should be available in near real-time. Thus, every part of the VLBI processing chain, e.g. observation, data transfer, correlation, and data analysis, needs to be able to operate autonomously in real-time.

To meet the challenges that VGOS will put on the data analysis part, we have implemented a Kalman filter module in our software, VieVS@GFZ, which is able to analyze VLBI data fully automated in near real-time. In this contribution, we present this module, in particular the setup for real-time analysis, and we test its performance through simulation of a real-time estimation scenario from a potential future 30 station VGOS network. We focus on the precision obtained for the EOP, which is the most interesting VLBI product in terms of near real-time availability. Furthermore, we study how well the Kalman filter is able to autonomously cope with potential problems in the VLBI data, such as clock breaks.

Poster1-3 - Board: S3P2 / 46

Metsähovi Geodetic Fundamental Station in Finland - new VGOS site, plans, and current status

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The Metsähovi Geodetic Fundamental Station is a key infrastructure of the Finnish Geospatial Research Institute (FGI). It is a Global Geodetic Observing System (GGOS) core site, i.e., member of global network of geodetic stations which is used in maintaining global terrestrial and celestial reference frames, computing precise orbits of satellites, and for geophysical studies. Metsähovi is one of the few geodetic stations that has all major geodetic observing instrumentations co-located. These include satellite laser ranging (SLR), very long baseline interferometry (VLBI), global navigation satellite system (GNSS), superconducting and absolute gravimeters, and the DORIS beacon. The station has been operational since 1978, it contributes several global services of the International Association of Geodesy (IAG), and due to its long existence it helps to retain sustainability in the maintenance of global reference frames.

In the autumn 2015 FGI obtained financial support to build new VGOS compatible radio telescope. This project is funded by Finnish Ministry of Agriculture and Forestry and the National Land Survey. The site chosen for a new telescope is within 100 m from other facilities of the Metsähovi geodetic station. We aim for a 12-13 m telescope and expect to complete the procurement process during the first half of 2016. The plan is to be operational by the end of 2018.

Poster4-6 - Board: S4P7 / 47

IVS Combiation Center at BKG: Options and functions of the revised website

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The International VLBI Service for Geodesy and Astrometry (IVS) Combination Center at the Federal Agency for Cartography and Geodesy (BKG, Germany) is responsible for generating combined Earth orientation parameter (EOP) products. Additionally, results of combined station coordinates and a terrestrial reference frame based on VLBI observations are generated. For providing information on the combination, the Combination Center maintains the CCIVS website where results, activities and new products are presented. Due to the implementation of a new content management system, the website was revised and new functions were added. A new search function was realized to find individual terms of the page content. A glossary, a sitemap and simplified standardized contact forms improve and enhance the handling of the website. The new design is clear, color matched and fills up the text content with informative graphics and pictures. Information about the results on the IVS contribution to the ITRF2014 were introduced and all existing data is regularly updated. The website is reachable over the Internet link ccivs.bkg.bund.de or www.ccivs.bkg.bund.de. In the future all users may get in contact with the Combination Center via the simplified contact forms or the new central email address ccivs@bkg.bund.de. The revised website with old and new options, functions and features is presented.

Poster4-6 - Board: S5P2 / 48

Application of Kalman filtering for the analysis of Intensive sessions

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The VLBI Intensive sessions are one-hour long, usually single-baseline VLBI sessions performed every day in order to estimate UT1-UTC. Due to the small number of observations in these sessions, the latency between observation and results is relatively short, normally a few days. However, the accuracy of the UT1-UTC estimates is significantly lower than expected based on their formal errors. Although the reason for this is not completely understood, it indicates that the results could get better if improved modeling or estimation procedures are applied.

In this contribution, we analyze the Intensive sessions with the newly developed Kalman filter module of our software, VieVS@GFZ, and investigate whether results improve compared to those obtained when applying the classical least squares method for the data analysis. The accuracy is evaluated by comparing the results for UT1-UTC as well as the tropospheric delays with the estimates from 24-hour VLBI sessions on the same days as the Intensives. We study the impact of different stochastic modelling of the estimated parameters, e.g. of the tropospheric delays. Furthermore, we test whether the results could be improved by including tropospheric parameters estimated from GNSS as additional observations in the Kalman filter.

Oral5: Geodetic and Astrometric Results / 49**Images of VLBI calibrators from the BeSSeL survey****Author:** Bo Zhang¹¹ *Shanghai Astronomical Observatory***Corresponding Author:** zb@shao.ac.cn

The BeSSeL Survey (Bar and Spiral Structure Legacy Survey) is a VLBA Key Science project. The primary goal of the survey is to study the spiral structure and kinematics of the Milky Way, by measuring distances and proper motions to masers in regions of massive star formation across large portions of the Milky Way. To measure the distances of masers via trigonometric parallaxes, the relative positions between the masers and extragalactic VLBI calibrators are determined with phase-referencing VLBI at different epochs spanning at least 1 year.

The Masers are usually served as phase reference since they are much stronger than the calibrators, allowing several hours' integration times for the weak calibrators. In addition, the calibrators are often observed through the whole observing program, providing excellent uv-coverage for imaging. From the BeSSeL survey, there will be about ~5000 high quality images of ~400 VLBI calibrators distributed near the Galactic plane. For each calibrator, there are at least 4 images obtained from different epochs spanning at least 1 year. In this talk, I will introduce the construction of the image database of these calibrators, and discuss the potential application on VLBI astrometry using this image database.

Oral5: Geodetic and Astrometric Results / 50**VLBI processing at ESOC, the last piece for generating an independent reference frame****Author:** Claudia Flohrer¹**Co-authors:** Erik Schönemann¹; René Zandbergen¹; Tim Springer¹; Werner Enderle¹¹ *ESOC - Navigation Support Office, Darmstadt, Germany***Corresponding Author:** claudia.flohrer@esa.int

ESOC's Navigation Support Office is providing the geodetic reference for ESA missions and as leader of the Galileo Geodetic Service Provider (GGSP) consortium, also for Galileo. The Navigation Support Office has demonstrated its expertise in the processing of various space-geodetic techniques, such as GNSS, SLR and DORIS and their combination on the observation level. Nevertheless, the last and vital piece missing for the generation of an independent reference frame is VLBI, which is required to define the Earth's orientation.

ESOC's Navigation Support Office is currently extending its expertise to VLBI processing and analysis. We are enhancing the processing capabilities of our work horse software package NAPEOS for VLBI tracking data.

This capability will put us in the position to combine all space-geodetic techniques with one single software package at the observation level. The combination of the different techniques brings together the strengths of the individual techniques. The satellite techniques GNSS, SLR and DORIS are able to determine the Earth's centre of mass, the X- and Y-pole offsets and rates and the Length of Day. However, VLBI is the only technique able to accurately determine universal time (UT1-UTC) and the celestial pole offsets.

The processing of VLBI tracking data will complete ESOC's capabilities in generating an independent reference frame for ESA missions. It will allow us to contribute to the IERS service for UT1-UTC and for the celestial pole offset, whilst at the same time to reduce our dependency on this service. And last but not least our software NAPEOS would become the first software combining all four geodetic techniques on the observation level and thus supporting GGOS, the Global Geodetic Observing System, to get a better understanding of our living planet.

We will present an overview of the current status of the VLBI processing at ESOC and will give an outlook on our future plans.

Oral5: Geodetic and Astrometric Results / 51

Vienna contribution to the ICRF3

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The current realisation of the celestial reference frame, the ICRF2, was published 2009. Since then the VLBI technique evolved. New stations were implemented and the amount of data from the Southern Hemisphere increased dramatically. The demands on accuracy of the celestial reference frame are higher than ever, with the GAIA mission providing a catalogue in the visible spectrum with comparable accuracy. These advances in the VLBI technique and new demands on accuracy entail the necessity of a new version of the celestial reference frame which will be called ICRF3. We will report on the progress and plans of the Vienna group to estimate such a reference frame. Furthermore, we will discuss issues which arise during the estimation process such as a declination bias.

Oral3: Stations, Correlators and Operations Centres / 52

Optimizing the African VLBI Network for Astronomy and Geodesy

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Currently SKA-SA and HartRAO are converting the redundant 34-m telecommunications antenna in Ghana to a radio telescope. The Ghanaian radio telescope will be the second element, HartRAO the first, of what will become the African VLBI Network (AVN). There are 29 documented 30-m class telecommunications antennas in 19 African countries (though some have been destroyed). It is proposed that more of these can be converted and added to the AVN. Each addition will improve the present global VLBI networks; some will have greater impact than others. Currently there are plans, and limited funding, to convert two more antennas in Kenya and Zambia. It is presently proposed that each of these new AVN stations will be equipped with the same receivers as Ghana, a 5 and 6.7 GHz receivers and later a 1.4 - 1.7 GHz receiver. New radio telescopes may also be built. However, no significant evaluation of the optimization of the AVN has been completed. Such an analysis will inform which to convert first, where to build new stations and what next-generation instruments and receivers they should have.

In this presentation we re-visit the scientific justifications for the AVN including both astronomical and geodetic science. We analyse weather station, GPS and satellite weather data for each telecommunications antenna in Africa to determine the frequency limitations at each. A Google-based assessment of the possible radio frequency interference environment is made. We also generate UV-coverage plots for existing VLBI networks together with potential AVN locations to get an idea of the density and distribution of the UV tracks and the imaging quality that may be obtained. In addition we simulate some geodetic observations to assess the contribution of AVN antennas to geodetic VLBI products in current and future networks. With this data we attempt to optimize the AVN for each science case, both astronomical and geodetic. We discuss the potential contributions the AVN might make to current global geodetic and astronomical experiments, as well as what a stand-alone AVN can do. We also discuss possible stations of interest for high-frequency radio astronomy and astrometry, possible sites for future VGOS antennas and where collocation of other geodetic instruments can be implemented.

Poster4-6 - Board: S5P5 / 53

Completing the K-band Celestial Reference Frame in the North.

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K-band (22 GHz) radio observations have the potential to form the basis for the most accurate celestial reference frame ever constructed. Relative to the standard S/X (2.3/8.4 GHz) observing bands, K-band is expected to exhibit a reduction in extended source morphology and core-shift. This reduction in astrophysical systematics should allow for a more stable celestial reference frame at K-band and should also be advantageous in tying the VLBI radio frame to the Gaia optical frame. The current K-band catalogue consists of only 274 sources from a few VLBA sessions and uncertainties in source positions at the ~100 micro-arcsecond level. Modern 2 Gbps data rates are 16 times better than previous observations, yielding a four fold increase in sensitivity. Southern observations to reduce astrometric systematics and to complete the sky coverage at K-band are under way. However, new astrometric and imaging observations are also required in the North to improve K-band precision and spatial coverage, and to map the intrinsic source structure so that their astrometric quality can be evaluated. A proposal for astrometric and imaging observations using the Very Long Baseline Array (VLBA) at K-band have been approved. We discuss some of our first results from our K-band VLBA campaign.

Oral3: Stations, Correlators and Operations Centres / 54

The progress of VLBI digital backend in SHAO

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Abstract: Shanghai Astronomical Observatory(SHAO) has started to development VLBI digital back-end in 2004. And since 2010, the first generation of digital backends named CDAS(Chinese VLBI Data Acquisition System) have been installed in CVN VLBI stations and applied in several projects. This presentation will introduce the history, the current status and the future of the VLBI digital backends developed by SHAO.

Oral6: VLBI observations of Space Vehicles / 55

VLBI observations of GNSS signals on the baseline Hobart-Ceduna – First results

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The observation of GNSS satellites with the geodetic VLBI system is an interesting approach which offers a variety of new possibilities. Promising applications can be found, among others, in the field of inter technique ties. Such observations provide possibilities to directly connect the dynamic GNSS and the kinematic VLBI reference frame, which may result in improved future ITRF realizations. In our research we are trying to apply observation strategies, which are commonly used in geodetic VLBI, i.e. the main observables are group delay values derived from direct observations and the subsequent correlations of GNSS satellite signals. However, data acquisition schemes for VLBI satellite observations are still at an experimental stage. Further research is required to establish an operational process chain, similar to that applied for standard observations of natural radio sources.

We successfully carried out several experiments in 2015 on the Australian baseline Ceduna-Hobart. During these sessions, with a few hours duration each, GNSS satellites (GLONASS and GPS) were observed in the L1 and L2 band along with natural radio sources for calibrations. All experiments were based on VEX-formatted schedule files created with the satellite scheduling module in the Vienna VLBI Software (VieVS). These control files implement a satellite tracking scheme which is based on stepwise antenna repositioning using sequences of discrete celestial coordinates. The recorded data were successfully correlated with the DiFX correlator software in combination with a suitable input model for near field targets. A preliminary analysis of the group delay measurements derived with the AIPS software suite was carried out with VieVS.

Within this contribution we will give an insight into the applied data acquisition schemes, from scheduling, over correlation to data analysis, and we will present latest results.

Oral6: VLBI observations of Space Vehicles / 56

E-GRIP: A Highly Elliptical Orbit Satellite Mission for Co-location in Space

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In recent years much effort has been undertaken to combine space geodetic observations on-board satellites, known as co-location in space. Whereas for SLR and GNSS, co-locations on-board satellites already exist (LEO, GNSS), no such satellites are allowing at present for VLBI observations. In order to cure this situation new satellite missions like GRASP are considered, new observation concepts like tracking of GNSS L-band signals were implemented, and at some telescopes receiver chains were modified. However, evaluating today's situation, only a few experimental GNSS L-band observations were conducted, whereas the majority of radio telescopes participating in the IVS cannot observe these. Future VLBI observations to the proposed GRASP mission will be possible for nearly all radio telescopes but, due to the low orbit, only for short baselines.

In this presentation we will introduce a new mission: the Einstein Gravitational Red-shift Probe (E-GRIP). The scientific objectives of E-GRIP are the measurement of the space-time curvature around the Earth and the performance of multiple tests of general relativity. Therefore, E-GRIP will fly in a highly eccentric orbit ($e > 0.6$, apogee > 35000 km) and will carry a narrow- and a wide-angle microwave link (both at X- and K-band), two GNSS antennas, an SLR retro-reflector array, and a space hydrogen maser. Consequently, E-GRIP could act as a co-location satellite with optimal observation conditions for VLBI. Beyond a mission overview, we will present results from extended VLBI simulations concerning link budget, visibilities, and achievable station coordinate results. We will also discuss the benefits for VLBI compared to co-location on GRASP and on GNSS satellites in terms of visibility and station coordinate accuracy. In addition, we will show the feasibility of co-located GNSS and SLR observations for this highly elliptical orbit.

Oral1: Advances in VGOS Stations and Technology / 57

Operating Experience of Broadband Acquisition System on RT-13 Radio Telescopes

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Broadband Acquisition System (BRAS) was designed to digitize wideband signals from receivers of radio telescopes, pack the digital samples into VDIF frames and transmit them through 10G Ethernet interface. The system has been installed in Badary and Zelenchukskaya observatories on the recently constructed 13-meters RT-13 radio telescopes in February–March 2015. Since November 2016, IAA RAS performs regular observations with RT-13 equipped with BRAS. Besides, BRAS has been used in several international observations. The talk will describe both the structure and performance of BRAS as well as the operation results.

Oral5: Geodetic and Astrometric Results / 58

Status of the X/S Source Catalog

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The current state of the X/S source catalog is presented and compared to ICRF2. There are currently ~60% more observations and ~30% more sessions than were used for ICRF2. An ICRF made today would have ~20% more sources than ICRF2 and the average inflated formal errors would be ~2.4 times better than ICRF2. Much of this improvement has come from the VCS-II campaign on the VLBA, in which the average inflated formal errors of 2062 sources were reduced by a factor of 3.7 and 324 new sources were added. Additional new sources have come from the RDV/RV, CRF, AUST, AUA, and AOV sessions. In addition to the current status, we will present some of the additional goals for the X/S catalog before ICRF3 in 2018. This includes improving the positions of a limited number of sources for Gaia alignment and for X/Ka comparisons.

Poster1-3 - Board: S3P10 / 59

Difxcalc: Calc11 for the DiFX Correlator

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Difxcalc is a version of calc11 modified specifically for the DiFX correlator. It is a replacement for the calc9.1 'calserver' currently in use. To create difxcalc, all of the Mark3 database handler calls were removed from calc11 and new input, output and initialization modules were written and the flow of the program was modified for correlator usage. Difxcalc takes as its input the .calc files that are created in the difx processing stream and directly outputs the .im correlator model files. It can handle jobs with multiple scans and multiple phase centers. Difxcalc also contains near-field models, which will allow easier correlation of spacecraft or other objects in the solar system. We will outline the structure of difxcalc and list the differences from the calc9.1 'calserver' and from the calc11 database version. Results of various tests and comparisons will also be presented.

Poster4-6 - Board: S4P6 / 60

Transition to the vgosDb data format.

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The IVS Working Group 4 developed the new format to store and exchange data obtained from geodetic VLBI observations. The new data format, vgosDb, will replace existing Mk4 databases this year. At the GSFC NASA we developed software that will implement vgosDb format and will be used routinely to convert correlator output to the new data storage format. On this poster we present the vgosDb capable utilities that will replace the legacy software and our plans for switching to vgosDb format in the routine VLBI data analysis.

Oral5: Geodetic and Astrometric Results / 61

Estimating the Celestial Reference Frame via Intra-Technique Combination

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One of the primary goals of VLBI is the determination of a CRF. Currently the third realization of the internationally adopted CRF, the ICRF3, is under preparation. In this process, various optimizations are planned to realize a CRF which does not only benefit from the increased number of observations. For instance, various campaigns have been performed to sample the southern hemisphere with a better density. Furthermore, the VLBI Calibrator Surveys have been redone. Further optimizations of the ICRF3 with respect to the prior versions will be obtained on the analysis side. The new ICRF will benefit also from an intra-technique combination as it is also done for the TRF. Following IUGG Resolution No. 3 (2011) this approach can then easily be extended to a consistent estimation of CRF, TRF and the EOPs, based on the observations of different geodetic space techniques.

Here, we aim at estimating an optimized CRF by means of an intra-technique combination. The solutions are based on the input to the official combined product of the International VLBI Service for Geodesy and Astrometry (IVS), also providing the radio source parameters. We discuss the differences in the setup between the classical TRF-EOP combination and an extended CRF-TRF-EOP combination. Furthermore, we investigate the differences between the combined CRF and the CRFs for the individual ACs. Finally, the impact on the TRF and the EOPs are analyzed to demonstrate the benefits of our enhanced combination procedure.

Poster1-3 - Board: S2P2 / 62

Implementation of the VGOS Trials

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In February 2014, the VGOS Project Executive Group (VPEG) presented the so-called VGOS Observing Plan, which outlined possible steps on how to go from initial VGOS broadband tests to intermediate observing scenarios to the fully operational VGOS system. The document introduced VGOS trial campaigns as the initial means to accustom the VGOS stations as well as the subsequent component types to the VGOS processing load: scheduling, data taking, data transport, correlation, and analysis. Three different trial campaigns of 6-8 weeks each were envisioned. The Coordinating Center in conjunction with the Observing Program Committee (OPC) was tasked with their implementation. In this presentation we will discuss the progress made on implementing the trial campaigns.

Oral3: Stations, Correlators and Operations Centres / 63

New DiFX software correlator cluster at Bonn

Authors: Alessandra Bertarini¹; Arno Mueskens²; Helge Rottmann³; Laura La Porta²; Schueler Torben⁴; Simone Bernhart²; Walter Alef⁵; Walter Briskén⁶

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We present the status of the Bonn Correlator Center (2015/2016) for astronomical and geodetic correlation. The correlator center is being operated jointly by the Max Planck Institute for Radio Astronomy (MPIfR) in Bonn, the Federal Agency for Cartography and Geodesy (BKG) in Frankfurt with support from the Institute of Geodesy and Geoinformation (IGG) in Bonn for more than 20 years.

We will give a brief summary of the first experience with correlating on our new DiFX correlator cluster, which was planned to be compatible with the VGSO requirements.

We will also report on new features implemented for instance to handle Mark 6 recordings and some benchmarking of the correlation of VGOS observations, and on planned further software improvements.

Oral5: Geodetic and Astrometric Results / 64

The IVS Contribution to JTRF2014

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KALREF, JPL's KALman filter and smoother for REference Frames, has been used to produce JTRF2014, a combined terrestrial reference frame determined from the input SINEX files submitted by the IVS, IGS, ILRS, and IDS for ITRF2014. Using a Kalman filter and smoother allows the reference frame to be determined sequentially as a time series. Incorporating process noise, determined from geophysical fluid loading models, allows the observed station positions to be smoothed between discontinuities caused by earthquakes and equipment changes. Non-linear and non-seasonal changes in station positions, such as postseismic displacements, are automatically included in the smoothed time series. The creation of JTRF2014 will be discussed with an emphasis on the contribution that the VLBI observations made to it.

Poster1-3 - Board: S1P3 / 65

First 2 Gbps observations between KVAZAR VGOS antennas and Yebes RAEGE antenna

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A series of joint test observations using three 13-m VGOS antennas were carried on between September and November, 2015. These were include 256 Mbps experiments as well as first 2 Gbps observations. Different working setups of DBBC were tested at Yebes, data recorded, and transferred to IAA Correlator Center. Combined correlation of mixed bandwidth data from KVAZAR antennas and Yebes were performed with DiFX 2.4.1 and some results were obtained.

Oral5: Geodetic and Astrometric Results / 66

Selecting sources that define a stable celestial reference frame with the Allan variance

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ICRF2 was adopted by the IAU in 2009 and was based on the position of 3414 radio sources determined by VLBI. Discussions on the next realization of the ICRF (ICRF3) have been underway within the IAU and IVS since 2012. VLBI has made significant advances since ICRF2. From the latest GSFC solution, we extract a set of sources that defines a stable celestial reference frame, as shown by M. Feissel-Vernier 2003 (A&A) using tools such as the Allan variance and the drift of the position time series. This method also allows us to highlight a set of the least "stable" sources that may need special handling.

Oral2: VGOS Strategies and Expected Results / 67**Prototyping automation and dynamic observing with the AuS-cope array****Author:** Jim Lovell¹**Co-authors:** David Mayer²; Jamie McCallum¹; Lucia Plank¹; Stanislav Shabala¹¹ *University of Tasmania*² *Technische Universität Wien***Corresponding Author:** jim.lovell@utas.edu.au

The continuous observing mode envisioned for the new array of VGOS stations would benefit greatly from a high level of automation, from scheduling through to analysis. The centrally-operated AuS-cope VLBI array of three 12m antennas in Australia is serving as a testbed for these automation techniques. Here we describe the challenges we are addressing, how we are using simulations to understand where the most beneficial improvements can be obtained (in dynamic scheduling for example) and present the progress we have already made.

Poster4-6 - Board: S6P5 / 68**Connected-element interferometry and error analysis of Beidou GEO navigation satellites****Author:** Tianpeng REN¹**Co-authors:** Fengchun Shu²; Geshi TANG¹; Jing SUN¹; Lue CHEN¹; Mei WANG¹; Songtao HAN³; Zhenwei SHI⁴¹ *Beijing Aerospace Control Center*² *Shanghai Astronomical Observatory*³ *National Key Laboratory of Science and Technology on Aerospace Flight Dynamics, Beijing Aerospace Control Center*⁴ *Beijing University of Posts and Telecommunications***Corresponding Authors:** tpren@nudt.edu.cn, sfc@shao.ac.cn

Using the same frequency standard, a high-precision phase delay can be obtained in a connected element interferometry (CEI) system. Beidou GEO navigation satellite C02 is tracked from a CEI observations, where the CEI of the two stations at hangtiancheng and shahe linked by a phase stabilization system is built by Beijing Aerospace Control Center (BACC). And Beidou GEO navigation satellite C03 is applied as calibration to conduct a differential measurement. After introducing group-delay-aided phase delay, the measure noise of the interferometry delay is about 9.4ps (root mean square of the linear fitting residuals in each 300 seconds). Following a differential observation as “2 hours calibration-13 hours tracking -2 hours calibration”, the accuracy of the interferometry delay for C02 is better than 0.4ns. Results show that using a GEO satellite with high-accuracy ephemeris as the calibration, a high-accuracy interferometry can be achieved for the target satellite using small aperture antennas.

Oral3: Stations, Correlators and Operations Centres / 69**First Local Ties from Data of the Wettzell Triple Radiotelescope Array**

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The Geodetic Observatory Wettzell features a 20 m radiotelescope (RTW) as well as two new 13.2 m TWIN telescopes. Whilst RTW performs routine operations since 1984, the first of the TWIN telescopes, TTW1, has entered its productive phase in mid 2014, and TTW2 has just been equipped with an Elevenfeed broadband receiving system.

The triple telescope array at Wettzell establishes a geodetic very short baseline interferometry network. Local correlation yields group delay observations for baseline estimation from VLBI data alone without any immediate augmentation by terrestrial measurements. Apart from relative positioning of the telescopes, these are versatile capabilities for an end-to-end quality control of the VLBI data.

Results from local VLBI data analysis will be portrayed in this contribution and compared to the latest local ties from precision terrestrial surveying. Moreover, monitoring results of the TTW2 reference point will be presented and an initial concept for continuous surveillance of the TWIN reference points is discussed.

Oral5: Geodetic and Astrometric Results / 70

Effects on Earth Orientation Parameters caused by different analysis options

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The Earth Orientation Parameters (EOP) are arguments of the time-dependent rotation matrices describing the difference in orientation between the Earth crust-fixed reference system, ITRS, and the space-fixed reference system, ICRS. Very Long Baseline Interferometry (VLBI) is the technique that connects the realizations of ITRS and ICRS in terms of orientation directly on the observation level. Many applications in spacecraft navigation, fundamental astronomy, astrometry, and geosciences depend on the provision of the Earth Orientation Parameters (EOP). Currently, under the IAG/IAU Joint Working Group on the Theory of Earth Rotation, activities are supported that foster the advance on the theory of Earth rotation. Some components of the Earth rotation, such as the Free Core Nutation (FCN), are not well predictable but rely entirely on empirical determination through VLBI. In our paper we step-by-step alternate different analysis options, such as a priori data and models, and quantify the resulting effects on the EOP. Our approach is purely empirical: we will alternate certain analysis options and assess the differences with respect to the reference solution that adheres to IERS Conventions (2010) and applies the parameterization that was used in our contribution to ITRF2014, the next realization of the ITRS. For demonstration we analyze current regular

International VLBI Service for Geodesy and Astrometry (IVS) sessions: IVS-R1 and -R4. The IAG flagship component GGOS (Global Geodetic Observing System) aims to realize EOP with an accuracy of 1 mm, i.e. about 30 microarcseconds. This accuracy will be used as a threshold to interpret the significance of the effects.

Oral5: Geodetic and Astrometric Results / 71

Ultra-rapid earth rotation determination with VLBI during CONT11 and CONT14

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In 2007 the Geospatial Information Authority of Japan (GSI) and the Onsala Space Observatory (OSO) started a collaboration project aiming at determining the earth rotation angle, usually expressed as UT1-UTC, in near real-time. In the beginning of this project dedicated one hour long one-baseline experiments were observed periodically using the VLBI stations Onsala (Sweden) and Tsukuba (Japan). The strategy is that the observed VLBI data are sent in real-time via the international optical fibre backbone to the correlator at Tsukuba where the data are correlated with a software correlator and analyzed in near-real time with the c5++ VLBI data analysis software, thus producing UT1-UTC results with very low latency. The latency between the observation at the stations and the determination of UT1-UTC is on the order of a few minutes, thus we can talk about an ultra-rapid determination of UT1-UTC. An offline version of this strategy was adopted in 2009 for the regular VLBI intensive series INT-2, organized by the International VLBI Service for Geodesy and Astrometry (IVS), that involves Wettzell (Germany) and Tsukuba. Since March 2010 the INT-2 is using real-time e-transfer, too, and since June 2010 also automated analysis. Starting in 2009 the ultra-rapid approach was applied to regular 24 hour long IVS VLBI-sessions that involve Tsukuba and Onsala, so that ultra-rapid UT1-UTC results can be produced already during ongoing VLBI-sessions. This strategy was successfully operated during the 15 days long continuous VLBI campaigns CONT11 and CONT14. In this presentation we give an overview of the ultra-rapid concept, present the results derived during CONT11 and CONT14, and compare these ultra-rapid results to results derived from post-processing.

Oral1: Advances in VGOS Stations and Technology / 72

VGOS observations with GGAO12M, Westford, and the new Kokee 12m antenna

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The GGAO 12m and Westford 18m antennas are instrumented with the broadband signal chain to provide VGOS capability. These antennas have been making VGOS geodetic observations for more than a year. Approximately seventeen one- to twenty-four-hour VGOS sessions were conducted in 2015 to develop and test many of the procedures needed for an operational program, including

scheduling, unattended observing, correlation, and preliminary data analysis through geodetic estimation. Currently, after the creation of a schedule, the session can be run unattended following checkout of the antenna sensitivity and pointing. The Field System controls the Backend, including the four UpDownConverters (for band frequency selection), the four RDBE-G digital backends in polyphase filter bank (PFB) mode, and the Mark6 recorder. For correlation direct playback from the Mark6 is being tested. The broadband delay observable is derived by combining the four linear polarization cross-products in all four RF bands and simultaneously estimating the phase dispersion due primarily to the ionosphere. With some slight modifications of the database creation and editing programs it has been possible to do geodetic analysis of most of the sessions using nuSolve. Preliminary analysis of the first eleven sessions gives a weighted RMS deviation of 2 mm from the mean baseline length (600 km) for those one-hour sessions.

The Kokee 12m VGOS antenna, designed and manufactured by InterTronics Solutions, has been completed, and the broadband signal chain, built by Haystack, will be installed in early 2016. It is expected that Kokee12m will be added to the GGAO-Westford observations by February, and the procedures developed for the GGAO-Westford sessions will form the basis for observations with the three-station network.

Results for both the GGAO-Westford series and for observations with all three antennas will be reported.

Oral5: Geodetic and Astrometric Results / 73

Combination of the two radio space geodetic techniques with VieVS during CONT14

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Unlike CONT11, CONT14 does not have official information on common frequency standards for co-location sites. Nevertheless, according to Kwak et al. (2015), we have a possibility to find the co-located sites, which used the same clocks, through comparing clock rates from single technique solutions. Moreover, CONT14 includes co-located VLBI radio telescopes, i.e. HOBART26 and HOBART12. Therefore, it is a good test bed to develop the analysis strategy for future twin/sibling telescopes.

In this study, we compute GNSS single differences between the ranges from two stations to a satellite, using phase measurements with most of the errors corrected by the c5++ software. We estimate station coordinates and site common parameters, i.e. zenith wet delays, troposphere gradients and clock parameters, with the Vienna VLBI Software. Common clock parameters are limited to the sites that are sharing the same frequency standard during CONT14. Local tie vectors are introduced as fictitious observations for co-located instruments, GNSS-VLBI and even VLBI-VLBI, i.e. at Hobart. In this presentation, we show the comparison results between the combination solutions and the single technique solutions in terms of station position repeatability during 15 days.

Oral2: VGOS Strategies and Expected Results / 74

<i>INVITED TALK:</i> Delay & Phase Calibration in VGOS Post-processing

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Now that significant amounts of data have begun to flow through the VGOS pipeline, we are encountering real-world issues in the fringe-fitting process. In order to create a high-quality geodetic observable one wants to minimize the sensitivity of group delay to instrumental parameters that may change over time, while at the same time maximizing the amount of information that is extracted. This talk will address a number of topics relevant to those goals, such as matching of delays in polarization products and receiving bands, and coherent phasing of the four polarization products. Software that automates the somewhat tedious determination of the calibration parameters will be described. The accurate removal of the effect of the ionosphere is central to a precision observable, and our procedures and experience in doing so will be discussed.

Oral6: VLBI observations of Space Vehicles / 75

Accurate spacecraft positioning by VLBI imaging

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VLBI is a radio astronomy tool with very high space angle resolution and Chinese VLBI Network has played a important roles in the Chang'E series lunar mission. In the upcoming Chinese lunar and deep space missions, higher angular position ability is needed. For these reasons, we carried out research on accurate spacecraft positioning and conducted several space vehicles phase-referencing positioning experiments using the Chinese VLBI network and other VLBI antennas. The near-field target uvw prediction method is adopted. This paper shows the VLBI spacecraft imaging position experiment results of several ChangE lunar probes, the Mars Express probe and the Rosetta probe. The results validate VLBI with the mill-arcsecond level position ability for deep space probes.

Oral1: Advances in VGOS Stations and Technology / 76

Plan for a VLBI antenna in Tahiti from 2018

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It is known that the VLBI Global Observing System (VGOS) network suffers from a lack of implementation in the South Pacific area. It is why GRGS was considering setting up a VLBI antenna in Tahiti in cooperation with NASA.

There is an existing geodetic observatory (OGT) in the campus of the French Polynesian University (UPF) which was created in 1998 in a tripartite cooperation between UPF, NASA and CNES. It gathers several geodetic instruments such as the NASA's MOBLAS-8 station, a DORIS master beacon and several GNSS receivers. But there is not enough room to install a VLBI antenna, moreover in an environment surrounded by many buildings or houses.

That is why we explored other hosting possibilities for a NASA's VLBI2010 antenna and other new

geodetic instruments (SLR-NG, Regina GNSS, DORIS). Finally, we could find an adequate ground on the site of the Tahiti Nui Telecom (TNT) company. The project was submitted then to the French involved organisms: CNES, INSU-CNRS, OCA... and to NASA for further implementing studies.

We propose to describe the state-of-the-art of this project for a possible realization from 2018 in addition to the core space geodetic network. Some simulation results will be presented as well in support to this project.

Oral3: Stations, Correlators and Operations Centres / 77

Real-time e-VLBI in the EVN and software correlation at JIVE

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Real-time e-VLBI continues to form an integral element of the European VLBI Network (EVN), accounting for about a quarter of all EVN hours and providing unique rapid-response capabilities to transient events as well as the opportunity for higher-cadence observations compared to the standard EVN sessions that fall three times per year. The EVN software correlator at JIVE (SFXC) can currently process real-time correlation for a 14-station array at 1 Gbps with cross-polarizations. Tests show that 8-9 stations at 2 Gbps can also be sustained.

The classes of e-EVN proposals has grown to include two new types of triggered observations. “Generic triggers” allow a set of potential targets that can not be defined explicitly at proposal time, which opens e-EVN observations to newly discovered transient sources. “Automatic triggers” can receive and adjudicate trigger requests without human intervention (e.g., by a program listening for specified VO events), and can similarly create and distribute an appropriately modified schedule to override the currently running observations (for stations permitting such remote interventions). This can provide significantly faster response – down to 10 minutes, as compared to the 29 hr for traditional triggers. Running *jive5ab* at the correlator and the stations enables simultaneous real-time e-VLBI correlation and recording (at the correlator and/or at the stations). This permits, among other applications, commensal searches for transients via analysis of the real-time autocorrelations, the result of which could trigger a wide-field correlation of the baselines for the corresponding time-range, detached from the on-going real-time correlation.

SFXC has processed all EVN disk-based observations correlated at JIVE since the May/June 2012 session, and all e-EVN observations since December 2012. It removes the physical limitations to the number of stations, the channel & total bit-rates, and the number of frequency points. It also applies a purely station-based fringe rotation, decouples the correlation and delay-tracking FFT sizes, and permits choice of the spectral-windowing function. It can correlate observations containing a mixed number of channels, mixed channel bandwidths, and mis-matched side-bands – accelerating developments in various digital back-ends has led to this being a quite routine situation. SFXC opens up new astronomical areas for correlation at JIVE via pulsar gating/binning (including coherent de-dispersion), multiple phase-center output within a wider field, spectral zooming, space VLBI (comprising both antennas in orbit such as RadioAstron, and near-field targets in the solar-system), and a phased-up mode. Each of these has been exploited by proposal-driven user experiments over the past couple years.

Oral2: VGOS Strategies and Expected Results / 78

Current status of an implementation of a system monitoring for seamless auxiliary data at the Geodetic Observatory Wettzell

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A first test implementation of an auxiliary data archive is tested at the Geodetic Observatory Wettzell. It is software which follows-on the Wettzell SysMon, extending the database and data sensors with the functionalities of a professional monitoring environment, named Zabbix. Some extensions to the remote control server on the NASA Field System PC enable the inclusion of data from external antennas. The presentation demonstrates the implementation and discusses the current possibilities to encourage other antennas to join the auxiliary archive.

Poster1-3 - Board: S2P4 / 80

First results of the FAST-S/X-sessions with new VGOS antennas

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The organization of first fast slewing observations with new VGOS antennas was decided during the VTC meeting at Ponta Delgada. The goal was to observe S/X-schedules regularly, using the fast slewing capabilities of the antennas as long as they are equipped with classic S/X-capabilities. The poster/presentation discusses and shows first results of these observations.

Poster1-3 - Board: S3P3 / 81

The German Antarctic Receiving Station O'Higgins and its VLBI-capabilities

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The German Antarctic Receiving Station (GARS) O'Higgins started in the early 1990th with regular VLBI operations. Because of its remote position on the Antarctic Peninsula, the VLBI observation was mostly restricted to the Antarctic summer month. New equipment, a continuous operation by the German Aerospace Center (DLR), and new realizations of observation schedules may open the door for regular observations over the whole year. The poster shows the upgrades carried out in hard- and software and the latest results.

Poster1-3 - Board: S3P11 / 82

First implementations of new monitoring capabilities as extension to the e-RemoteCtrl software

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A new release of the telescope control software e-RemoteCtrl, which is designed to run VLBI observations remotely, has been extended with new monitoring capabilities.

The software extension is a test for further monitoring and control infrastructures for complete VLBI networks. The poster shows Ideas and already implemented elements.

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Near-field VLBI for Planetary Science

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Near-field VLBI is a radio astronomical technique that, when applied to observations of spacecraft, provides unique insights into those areas of a space mission's scientific programme requiring precise determination of the spacecraft's lateral position on the celestial sphere and its radial velocity. This technique was pioneered 30 years ago with the tracking of VEGA balloons to determine the wind field in the atmosphere of Venus.

The Planetary Radio Interferometry and Doppler Experiment (PRIDE) exploits near-field VLBI for accurate estimation of the state-vector of a spacecraft using arrays of Earth-based radio telescopes. PRIDE has proven to be very efficient in a number of recent VLBI experiments, starting with tracking the descent and landing of the Huygens Probe in the atmosphere of Saturn's moon Titan. PRIDE

has conducted several observations of ESA's Venus Express mission for investigations ranging from its aero-braking maneuvers through the Venusian atmosphere to the scintillation structure in the interplanetary medium. On 28-29 December 2013, a global VLBI campaign including over 30 stations was conducted to observe Mars Express during its close fly-by of Phobos. PRIDE provided measurements of the spacecraft's differential lateral position relative to the ICRF background extragalactic radio sources with an accuracy of 100 to 10 μas (1 σ ; RMS) over integration times from 60 to 1000 s.

With such accuracy, PRIDE can address scientific objectives spanning the improvement of satellite ephemerides, ultra-precise celestial mechanics, the study of planetary atmospheres via occultations, and the characterization solar-wind and ionospheric effects on spacecraft transmissions. Improved satellite ephemerides would in turn allow a planetary system to be tied more firmly into the extragalactic reference frame, providing a major contribution to planetary geodesy and the definition of the Solar System reference system.

In collaboration with other on-board radio science experiments of a planetary mission, PRIDE enhances the overall mission's science return. We will review the technique of PRIDE and illustrate its capabilities in multi-disciplinary applications for planetary science missions.

Poster4-6 - Board: S5P6 / 84

VLBI sources in optical and radio

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Until now, the main criteria for selecting geodetic sources were based on astrometric stability and structure at 8 GHz [Fey et al., 2015]. Other physical characteristics, especially at other wave-lengths, including the optical, should also enter the selection procedure. To this aim, we propose to summarize all known physical characteristics, thanks to the use of three different catalogs : the Large Quasar Astrometric Catalogue [Souchay et. al., 2015], the Radio Fundamental Catalogue (Petrov, <http://astroteo.org/rfc/>) and the Optical Characteristics of Astrometric Radio Sources [Malkin, 2013]. We also bring radio stability criteria derived from our own VLBI analysis. With such a compilation, we may identify new criterion for geodetic VLBI targets.

Poster4-6 - Board: S5P7 / 85

The variable Earth annual retrograde nutation

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Very Long Baseline Interferometry is the only technique that can estimate Earth nutations with an accuracy under the milliarcsecond level. With 35 years of geodetic VLBI observations, the principal nutation terms caused by luni-solar tides and geophysical response have been estimated. We focus on the variability. Two of them present very significant amplitude and phase variations : the retrograde Free Core Nutation (FCN) at around 430 days period and the Annual Retrograde Nutation (ARN). Despite progresses achieved in global circulation models, the atmospheric and

ocean excitation cannot account for that. In particular the ARN shows an amplitude modulation of approximately 6 years, reminding the 6-year geomagnetic oscillation in Length of Day (LOD). Therefore we investigate possible correlation of this modulation with the 6-year wave observed in LOD. More generally, we suggest that the nutation term variability may have deep Earth causes, and cannot be integrally attributed to surface mass redistribution.

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Defining Sources Selection and Celestial Reference Frame Stability

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In a previous study, we characterized radio sources observed by Very Long Baseline Interferometry by different criteria in both radio and optical domains (see the abstract “VLBI sources in optical and radio”). On the basis of the data derived from this study, we constructed several celestial reference frames by choosing a set of defining sources and studied their stability by two ways, statistically and temporally, inspired by Lambert [2013]. In parallel, a re-analysis of the ICRF2 was made, in the perspective of ICRF3 (expected date : 2018), to estimate its current stability and if it has changed since 2009, as it was the case for ICRF1 [Gontier et al. 2001, Feissel-Vernier 2003, Lambert et al. 2008, Lambert & Gontier 2009] . Finally, an ambitious goal will be to develop by those works an automatic tool that will regularly analyse new VLBI observation sessions and will be able to alert the community on defining sources becoming potentially unstable.

Poster4-6 - Board: S5P8 / 87

Progress on VLBI Ecliptic Plane Survey

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The goal of VLBI Ecliptic Plane Survey (VEPS) is to increase the number of calibrator radio sources within 7.5 degree of the ecliptic plane by surveying a complete sample of sources with single dish flux densities at 5 GHz greater than 50 mJy. A dense grid of calibrators along ecliptic plane with very accurate coordinates is required for many applications, including observations of spacecrafts in the phase referencing mode. Such observations are used for spacecraft navigation, improvement of planet ephemerides and determination of the Moon's libration. The VEPS observing program is underway with participation of 3 core Chinese VLBI stations: Seshan25, Kunming and Urumqi, and several international stations that join on ad hoc basis. We will present the current status of the VEPS observing program and show preliminary results.

Poster4-6 - Board: S4P8 / 88

IVS Primary Data Center and Analysis Center at BKG

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The BKG (Federal Agency for Cartography and Geodesy) Data Center is one of the three IVS Primary Data Centers. It archives all VLBI related data of IVS components and provides public access for the community.

The VLBI Analysis Group of BKG is part of the jointly operated IVS Analysis Center of BKG and the Institute for Geodesy and Geoinformation of the University of Bonn. The BKG is responsible for the computation of time series of earth orientation parameters and tropospheric parameters, the generation of SINEX files for 24 hours VLBI sessions and Intensive sessions, and quarterly updated global solutions for terrestrial reference frame and celestial reference frame realizations.

Oral3: Stations, Correlators and Operations Centres / 89

The Italian VLBI network: first results and future perspectives

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A first 24-h Italian VLBI geodetic experiment, involving the Medicina, Noto and Matera antennas, shaped as an IVS standard EUROPE, was successfully performed. Starting from the correlator output, a geodetic database was created and a typical solution of a small network was achieved, here presented. From this promising result, we have planned new observations in 2016, involving the three Italian geodetic antennas, that should be the beginning of a possible routine activity, creating a data set that can be combined with GNSS observations to contribute to the National Geodetic Reference Datum. Particular care should be taken in the scheduling of the new experiments in order to optimize the number of the usable observations. These observations can be used to study and plan future experiments in which the time and frequency standards can be given by an optical fiber link, so having a common clock at different VLBI stations.

Poster1-3 - Board: S1P2 / 90

Preparations for a new VGOS radio telescope at HartRAO

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Very long baseline interferometry (VLBI) is used in geodesy to determine a telescope's position relative to the galactic centre. A modern, fast slewing radio telescope measuring approximately 13 metres in diameter have been chosen to be used in the VLBI Global Observing System (VGOS), which will help improve the accuracy across global baselines from around 1 cm down to 1 mm. In 2014 HartRAO started the process of obtaining the new radio telescope which will be used within the VGOS network. Specifying the telescope requirements, Radio Frequency Interference (RFI) measurements, core drilling and logging, and an Environmental Impact Assessment (EIA) are part of the prerequisite actions that need to take place before construction can commence.

Oral1: Advances in VGOS Stations and Technology / 91

Status and first results from the VGOS-compatible antenna Ws with an Elevenfeed at Wettzell

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The VGOS antenna Ws at Wettzell is equipped with an Elevenfeed, having a continuous frequency range from 2 GHz - 14 GHz. The receiving system with eight parallel intermediate frequency channels enables the use of four bands at different polarizations. A DBBC in combination with a FILA10G and a Mark6 System is used as backend. The presentation gives an overview about the current status of the broadband development and the recording systems installed at the Wettzell antenna Ws.

Poster1-3 - Board: S3P4 / 92

Update on the Spanish-Portuguese RAEGE project

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An update of the deployment and activities at the Spanish/Portuguese RAEGE project ("Atlantic Network of Geodynamical and Space Stations") is presented. Regular observations with Yebes radio telescope are ongoing. Commissioning of the radio telescope at Santa Maria is advanced, and site works for a new station in Tenerife (Canary Islands) have started. Technological developments on receivers for VGOS are progressing at Yebes laboratories, as well as works on local-ties.

Oral3: Stations, Correlators and Operations Centres / 93**Current Status of Shanghai VLBI Correlator****Author:** Wu Jiang¹**Co-authors:** Fengchun Shu ¹; Tianyu Jiang ²; Zhiqiang Shen ²; Zhong Chen ²¹ *SHAO,CAS*² *SHAO, CAS***Corresponding Author:** jiangwu@shao.ac.cn

Shanghai Astronomical Observatory has upgraded its DiFX cluster to a 420 cpu cores and a 432 TB storage system at the end of 2014. An international network connection for the raw data transfer has also been established. The routine operations for IVS sessions including CRF, AOV, and APSG series began from the early 2015. Some X/Ka fringe search experiments were conducted with Tianma 65-m radio telescope in order to check its performance. In addition to the IVS observations, the correlator is also dedicated to astrophysical and astrometric observations with Chinese VLBI network, the east Asian VLBI network and some international joint VLBI observations. Meanwhile, comparisons to the domestic software correlator and the SFXC correlator are to be made with DiFX. Shanghai correlator is also planning a more powerful platform for the future correlation tasks.

Oral1: Advances in VGOS Stations and Technology / 95**The progress of Seshan VGOS station construction****Author:** Guangli Wang¹¹ *Shanghai Astronomical Observatory***Corresponding Author:** wgl@shao.ac.cn

The Seshan VGOS station is now in building. It is a very-fast-slewing 13.2m antenna, with QRFH wideband feed, and a realtime 3D measurement system of reference point variation is planing to install. And it locates in the yard of Tianma 65m radio telescope. Its recent progress will be introduced in this report.

Poster4-6 - Board: S6P1 / 96**VLBI Delay Reduced from S/C Observation and its Calibration in Chang'E Mission****Author:** Guangli Wang¹**Co-authors:** Jiulong Liu ¹; Zhibin Zhang ¹¹ *Shanghai Astronomical Observatory***Corresponding Author:** wgl@shao.ac.cn

VLBI technique was used in China's Lunar Exploration Project Since the Chang'E-1 launched in the year of 2007, after then VLBI was played an important role in the series of Chang'E missions, CE-2, CE-3 and CE-5T1, and will be continued in the future space mission. The observation network consists of Shanghai 25m&65m, Beijing 50m, Kunming 40m and Urumqi 25m radio telescopes. Up to now it still works in the traditional astronomy-compatible S/X station systems, both quasar and

S/C are observed in the same Frequency setup. In CE-1 & CE-2 the quasar and S/C switching rules are 15min quasar and 45min S/C, in CE-3 and thereafter are <5min switching.

Poster1-3 - Board: S2P5 / 97

How to register a VGOS-radio telescope at ITU and why it is important

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A number of new VGOS-radio telescopes are built or under construction, partly at new locations. VGOS radio telescopes enable observations in the range of 2-14 GHz. For this reason VGOS radio telescopes are much more receptive for unwanted radio frequency interference. RFI originates from local transmitting devices as well as from space based transmitting systems. Some space-borne devices may cause detrimental radiation to VGOS receivers. It is important to register the new sites at ITU in order to obtain administrative protection for the radio telescope sites and to avoid direct illuminations by strong radars. This contributions explains how to achieve the registration.

Oral3: Stations, Correlators and Operations Centres / 98

Activities of Sejong station and toward the GGOS

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The Sejong station is a part of SGOC(Space Geodetic Observation Center) which belongs to NGII(National Geographic Information Institute). We will present conventional S/X system issues that we need to improve, establishment of sever cluster for S/W correlation(Storage about 100TB), local tying results for collocation, installation of the ARGO(Mobile SLR system, 40cm diameter) which developed by KASI(Korea Astronomy & Space Science Institute) at the SGOC site, current progress of construction KVNG(Korea VLBI Network for Geodesy) and development of wide-band feed horn for VGOS.

Poster1-3 - Board: S1P1 / 99

Current Status of Ishioka VGOS antenna

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The Geospatial Information Authority of Japan (GSI) is constructing a new VGOS station in Ishioka. The construction of the 13-m antenna has been finished, and a new operation building will be completed by February 2016. Ishioka 13-m antenna is observing legacy S/X-band VLBI observation with Tsukuba 32-m antenna by using tri-band feed system. We have also carried out some broadband experiments collaborating with the National Institute of Information and Communications Technology (NICT). The paper reports current situation of Ishioka VGOS antenna including recent geodetic result of VLBI observation.

Oral5: Geodetic and Astrometric Results / 100

The Statistic Analysis of Atmospheric Effects of Differential VLBI

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During the Chinese Lunar Mission hundreds of VLBI observations have been carried, we re-analysis all the quasar observations which used to calibrate the satellite observables. In each observation there are two quasar scans lasting about one hour, we use these data by splitting them into different time intervals and doing self-calibration each other in phase-referencing style to investigate the relationship of differential atmospheric delay and different "time-switching". In this report we will present our primary result.

Poster1-3 - Board: S3P1 / 101

Automated simultaneous local ties with GNSS and robot tachymeter

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We have used GPS-based local-tie measurements simultaneously with geo VLBI observations since 2008 during every geodetic VLBI session at Metsähovi. This system uses gimbal-mounted GNSS-antennas that are mounted on the reflector of the Metsähovi 14 m radio telescope. A similar system

has been installed in 2013 at the Onsala 20 m radio telescope and been used for a large number of VLBI sessions, including e.g. the 15 day long CONT14 campaign. In order to verify the results of the two systems, we performed a dedicated measurement campaign in the framework of the SIB60 project, involving both Metsähovi and Onsala. During this campaign the local ties at the two stations were measured simultaneously during two VLBI sessions in August and September 2015 where both stations participated. The robot tachymeter monitoring system HEIMDALL was used for the automated classical monitoring of the telescopes at both stations. Moreover, additional local terrestrial measurements were performed several times to derive the full IVS-IGS local ties at both sites. The kinematic GPS measurement at the two stations were analyzed with two individually developed analysis programs.

We present here the preparations of the campaign, the measurement process, and preliminary results.

Oral4: Data structures and Analysis Strategies in the VGOS Era / 102

Status Report Norwegian Mapping Authority Analysis Center

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The Norwegian Mapping Authority has been using GEOSAT to analyze 24-hour VLBI sessions. GEOSAT was originally developed by Per Helge Andersen at the Norwegian Research Defense Establishment, but is now owned by Norwegian Mapping Authority. GEOSAT is a multi-technique geodetic analysis software that aims to process observations from VLBI, SLR, GNSS and DORIS to improve the global geodetic reference frame.

To validate the VLBI model in GEOSAT the Norwegian Mapping Authority tried to contribute to the next ITRF solution but encountered some major problems too close the final deadline. However, the Norwegian Mapping Authority successfully participated the VLBI Software Comparison Campaign 2015. A quick overview of the recent activities, challenges, priorities, status and future plans for the GEOSAT project at the Norwegian Mapping Authority will be presented.

Poster4-6 - Board: S4P9 / 103

The new Geodetic Research Data Management System at HartRAO

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The Hartebeesthoek Radio Astronomy Observatory (HartRAO) participates in astronomic, astrometric and geodetic Very Long Baseline Interferometry (VLBI) observations using both 26- and 15-m diameter radio telescopes. These as well as additional geodetic data from a Satellite Laser Ranger (SLR), Global Navigation Satellite System (GNSS), Met4 weather stations, a new seismic network must be stored at HartRAO and made available to the scientific community. Some data are e-transferred to correlators, analysis centres and space geodesy data providers, while others are processed locally to produce basic data products. The African VLBI Network (AVN) data storage and correlation will occur at HartRAO as well.

The AVN correlation and seismic network will generate large volumes of raw data to be stored and archived at HartRAO. The current data storage systems are distributed and outdated, and management systems currently being used will not be able to handle the additional large data volumes. This necessitates the design and implementation of a new, next-generation research data management system which combines all the datasets into one database, as well as cater for current and future data volume requirements.

In terms of processing, HartRAO is collaborating with the CSIR Centre for High Performance Computing and we will operate a Dell Westmere cluster containing 2880 CPU cores (61.5 TFlops)

Professionals from different disciplines will be working together in designing and implementation of the new data and processing systems. A short overview of the project as well as a progress report will be presented.

Poster1-3 - Board: S1P4 / 105

The impact of the broadband VLBI on the next decade

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The Kashima 34 m radio telescope, the cassegrain optics is currently realized 3.2GHz to 14 GHz receiver system by installing the NINJA feed. Furthermore a direct sampler GALAS easily connect four 1GHz bandwidth without any analogue frequency converter and phase-cal. VGOS, EHT and other astronomy VLBI highly demand broadband system for better delay determination, shorter integration time and better SNR.

We will report our progress of developing broadband system and recent results.

Oral1: Advances in VGOS Stations and Technology / 106

Current status of the development and performance of OCTAVE-DAS and Correlator System

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The new VLBI observing system (OCTAVE-DAS) have been developed based on the VSI-H and VDIF specifications at NAOJ (National Astronomical Observatory of Japan). It consists of 1) a high speed 1-20 Gbps 3-10 bit RF direct ADC (OCTAD) enable us to acquire not only wide intermediate frequency but also radio frequency up to 50 GHz and have DBBC functions for VGOS (VLBI Global Observing System), 2) a converter (OCTAVIA and OCTAVIA2) between one 10 GigE port and four 2 Gbps input and output ports conformable to VSI-H, and 3) new recorders (OCTADISK, OCTADISK2 and VSREC) have functions of both recording and playing at a maximum rate of 32 Gbps and 4) Gbit

realtime correlator (OCTACOR) and software correlator system (OCTACOR2) using GICO3 was developed by NICT. We have been upgrading the software correlator using GPGPU technology. These OCTAVE-DAS are connected via >10 Gige network with VDIF and VSI specifications. These components have been used for VERA, JVN (Japanese VLBI network) and Daejeon Correlator. We will report on a installation plan and a 4-year progress since the 7th IVS general meeting and results of test and scientific broad-band(>8 Gbps) VLBI observations using the OCTAVE-DAS.

Oral3: Stations, Correlators and Operations Centres / 107

The first geodetic VLBI field-test of LIFT: a 550Km long optical fiber link for remote antenna synchronization

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We present the first field-test of the implementation of a coherent optical fiber link for remote antenna synchronization realized in Italy between the Italian Metrological Institute (INRIM) and the Medicina radio observatory. The Medicina VLBI antenna participated to the Eur137 experiment carried out in September 2015, in tag along mode, using, as reference systems, both the local H maser and a remote H maser hosted at the INRIM labs in Turin, 550km far from Medicina. In order to assess the quality of the remote clock, the observed sources were split in two sets, each one has been observed with the associated H maser (local or remote). A system to switch automatically between the two references was integrated in the antenna field system. The observations were correlated in Bonn and preliminary results are encouraging since fringes have been detected with both time references along all the 24 hours of the session. The experimental set-up, the results and the perspectives for future radio astronomical and geodetic experiments will be presented.

Oral1: Advances in VGOS Stations and Technology / 108

KPGO 12m Signal Chain Update, First Light and Beyond

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The Kokee Park Geophysical Observatory's 12m is expected to see First Light early 2016. A description of the integration and testing that was performed at MIT Haystack Observatory before shipping the signal chain is described. This is followed by a summary of the teams work that had to occur before first light and the initial results.

Beyond KPGO first light focuses on the commissioning summary followed by the road to the second installation at McDonald Texas. Here the focus shifts to the expected enhancements to the signal chain and retrofit plans for KPGO.

Poster4-6 - Board: S6P2 / 109

Venus and Mars Express spacecraft observations with Wettzell radio telescopes

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The ESA Venus and Mars Express spacecrafts were observed at X-band with the Wettzell radio telescopes Wn and Wz in a framework of the assessment study of the possible contribution of the European VLBI network to the upcoming ESA deep space missions and further projects. These observations were extended to regular weekly sessions to routinely run the processing and analysis pipeline. Recorded data were transferred from Wettzell to the JIVE cooperation partners for correlation and analysis. A high dynamic range of the detections allowed us to achieve a milliHz level of the spectral resolution accuracy and extract the phase of the spacecraft signal carrier line. Several physical parameters can be determined from these observational results with more observational data collected. Apart from other results, the measured phase fluctuations of the carrier line at different time scales can assess to determine the influence of the Solar wind plasma density fluctuations on the accuracy of the astrometric VLBI observations.

Oral3: Stations, Correlators and Operations Centres / 110

<i>INVITED TALK:</i> Activities of the IERS Working Group on Site Survey and Co-location

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The combination of space geodetic solutions is critically reliant on the availability of local tie vectors, which are the relative positions of the reference points of co-located space geodetic instruments determined by some survey technique. Tie vectors enter the combination of space geodetic solutions effectively as a fifth technique and are not only necessary for rigorous terrestrial reference frame realization but also serve to highlight the presence of technique- and/or site-specific

biases.

With the ultimate objective of improving the accuracy of tie vectors as well as the consistency of space geodetic solutions, the Working Group (WG) provides an authoritative source of surveying methodology advice, promotes technical discussion, provides a forum for the evaluation of existing and new procedures and analysis strategies, and supports the exchange of relevant information across GGOS and between the IAG technique services.

The working group also acts as an entity of the GGOS Bureau of Networks and Observations under the IERS name, as well as of the IAG Subcommission 1.2 as WG 1.2.1.

In the presentation, we give examples of recent and current work on

- adequate terminology when discussing site surveying and local ties
- automatic reference point determination
- telescope deformation
- observations of common baseline components
- insights to DORIS, GNSS, and SLR work related to local ties

Poster1-3 - Board: S2P3 / 111

Operational VGOS Scheduling

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The VLBI Global Observing System (VGOS) has been designed to take advantage of advances in data bandwidths, allowing for smaller and faster antennas, wider bandwidths, and shorter observation durations. Here, schedules for a “realistic” VGOS network, frequency sequences, and expanded source lists are presented using a new source-based scheduling algorithm. VGOS aims for continuous observations which presents new operational challenges. As the source-based strategy is independent of the observing network, there are operational advantages which allows for more flexible scheduling of continuous VLBI observations. Using VieVs, Monte Carlo simulations of several schedules are presented and compared with previous VGOS studies.

Poster4-6 - Board: S5P1 / 112

Aspects of relativistic geodesy within the framework of VLBI and VGOS

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Relativistic geodesy is typically seen as a new type of gravity potential measurement technique using very high accuracy clocks; these clocks are more stable (by a factor of 100 or 1000) than the hydrogen masers currently used at VLBI stations. In modern terms however, geodesy entails much more than just geodesy of the Earth, therefore the term relativistic geodesy is re-assessed. The possible contributions of VLBI stations in the framework of GGOS using VGOS antennas and modernized geophysical and timing equipment are described. Time transfer using VLBI and GNSS, integrated geodetic systems, future space based missions and Lunar missions all have a roll to play in a relativistic geodesy which extends to the solar system and beyond. Instrumental and network requirements are considered, error sources and error budgets are discussed.

Oral2: VGOS Strategies and Expected Results / 113**VGOS Source Selection Criteria****Author:** Bill Petrachenko¹**Co-authors:** Anthony Searle¹; Arnaud Collioud²; Patrick Charlot²¹ *Natural Resources Canada*² *Laboratoire d'Astrophysique de Bordeaux*

Source structure has long been recognized as a significant risk factor for the broadband method. The issue of greatest concern is that structure related phases and delays will lead to cycle slips during broadband phase connection. These errors will be difficult to handle since they are both subtle to detect and almost certainly impossible to correct after the fact.

As the advent of VGOS operations draws near, criteria will be needed to generate lists of candidate VGOS sources that are at the same time strong enough to be detected and simple enough not to cause broadband phase connection errors.

The purpose of this study is to propose useful VGOS source selection criteria and to understand their relation to broadband frequency sequences, source lists, and geodetic/astrometric performance. In order to increase the number of available sources, an attempt will be made to find frequency sequences that operate reliably below the typical VGOS flux cut-off of 250 mJ. Candidate source lists will be generated using the Bordeaux VLBI Image Data Base (BVID) as input and geodetic/astrometric performance will be predicted using the VieVS Monte Carlo simulator.

Oral1: Advances in VGOS Stations and Technology / 114**Unveiling the VGOS Signal Chain at the Kokee Park Geophysical Observatory****Author:** Ganesan Rajagopalan¹¹ *MIT Haystack Observatory***Corresponding Author:** ganesh@haystack.mit.edu

MIT Haystack Observatory, as part of the NASA Space Geodesy Program, is delivering the first VGOS-compliant Signal Chain to the Kokee Park Geophysical Observatory (KPGO), Hawaii, and will soon be integrating and commissioning the KPGO 12-m station.

We will describe the Signal Chain subsystems and highlight the design and performance of the cryogenically cooled frontend. This incorporates a broadband Quad Ridge Flared Horn (QRFH) feed and Indium Phosphide low-noise amplifiers, both developed by the California Institute of Technology. The talk will also cover the design and performance of a Cable Delay Measurement System (CMDMS) and the salient features of a Calibrator module that enables phase and noise calibration as well as the cable delay measurements.

We expect to present some early results from the commissioning phase of KPGO including aperture efficiency, SEFD across the band, and delay stability. We will also discuss possible approaches towards RFI mitigation, enhanced receiver sensitivity and dynamic range, and other forward-looking technologies.

Oral5: Geodetic and Astrometric Results / 115

El Nino and VLBI measured LOD

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Short term (daily to annual) variations in LOD are highly correlated with Atmospheric Angular Momentum. It has been known since the late 1980s and early 1990s that you could detect the effect of El Nino in the Length of Day (LOD). I review these results, paying particular attention to the current El Nino which is still developing, and is one of the strongest ever recorded. I look at correlation with Modified Enso Index and VLBI measured LOD. I also discuss the cumulative effect of the El Nino on UT1.

Oral2: VGOS Strategies and Expected Results / 116

New generation VLBI: Intraday UT1 estimations

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IAA finished work on creation of new generation radio interferometer with two VGOS antennas at the Badary and Zelenchukskaya co-location stations. The series of 48 one base 1 hour VLBI sessions (up to four sessions per day) were performed from 04 Nov to 18 Nov 2015. Observations were carried out using wideband S/X receivers, 3 X-band and 1 S-band 512 MHz channels at one or two circular polarizations. Sessions consisted of about 60 scans with 22 seconds minimum scan duration. Stations broadband acquisition systems generate 1.5-3 TB data per session which are transferred via Internet to the IAA FX correlator. Accuracy of group delay in single channel was 10-20 ps what allows to use every single channel observations for geodetic analysis without synthesis. 156 single channel NGS-cards were obtained in total. UT1-UTC estimations give 19 μ s RMS of differences when comparing with the IERS finals.

Oral5: Geodetic and Astrometric Results / 117

<i>INVITED TALK:</i> Status of the ICRF3 and Gaia activities

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The ICRF3, the next realization of the International Celestial Reference Frame, is going to be built within the next two years for approval at the IAU 2018 General Assembly. This timescale is driven by the forthcoming optical reference frame to be built by the Gaia mission and aligned at best with the ICRF3. The ICRF3 work is carried out by an IAU Working Group set up in 2012. While the work so far was primarily focused on increasing the pool of observations, it must now concentrate on the

analysis. The Gaia mission is operational since September 2014, observing 30-40 million sources per day. It is performing largely nominally despite a few problems which slightly degrade the accuracy. A first release of the Gaia data is planned for mid-2016 while a second release is expected by mid-2017.

Oral1: Advances in VGOS Stations and Technology / 118

<i>INVITED TALK:</i> Current Trends and Challenges in Satellite Laser Ranging

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Satellite Laser Ranging (SLR) is used to measure accurately the distance from ground stations to retro-reflectors on satellites and on the Moon. SLR is one of the fundamental space geodetic techniques that define the International Terrestrial Reference Frame (ITRF), which is the basis upon which many aspects of global change over space, time, and evolving technology are measured; with VLBI the two techniques define the scale of the ITRF; alone the SLR technique defines its origin (geocentre). The importance of the reference frame has recently been recognized at inter-governmental level through the United Nations, which adopted in February 2015 the Resolution 'Global Geodetic Reference Frame for Sustainable Development.'

Laser Ranging provides precision orbit determination and instrument calibration/validation for satellite-borne altimeters for the better understanding of sea level change, ocean dynamics, ice mass-balance, and terrestrial topography. It is also a tool to study the dynamics of the Moon and fundamental constants and theories. With the exception of the currently in-orbit GPS constellation, all GNSS satellites now carry retro-reflectors for improved orbit determination, harmonization of reference frames, and in-orbit co-location and system performance validation; the next generation of GPS satellites due for launch from 2019 onwards will also carry retro-reflectors. The ILRS delivers weekly realizations that are accumulated sequentially to extend the ITRF and the Earth Orientation Parameter series with a daily resolution. SLR technology continues to evolve toward the next generation laser ranging systems and it is expected to successfully meet the challenges of the GGOS2020 program for a future Global Space Geodetic Network. Ranging precision is improving as higher repetition rate, narrower pulse lasers and faster detectors are implemented within the network. Automation and pass interleaving at some stations is expanding temporal coverage and greatly enhancing efficiency. Discussions are ongoing with some missions that will allow the SLR network stations to provide crucial, but energy-safe, range measurements to optically vulnerable satellites. New retroreflector designs are improving the signal link and enable daylight ranging that is now the norm for many stations. We will discuss many of these laser ranging activities and some of the tough challenges that the SLR network currently faces.

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Closing Remarks**Author:** Axel Nothnagel¹

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