Report of Working Group: Enhancement of GNSS Performance, New Services and Capabilities

1. The Working Group on Enhancement of Global Navigation Satellite Systems (GNSS) Services Performance (WG-B), co-chaired by the European Space Agency (ESA) and the Indian Space Research Organization (ISRO), held its ninth annual meeting in Boulder, Colorado, United States of America, on 04 and 05 November 2015, preceded by a dedicated session on Space Service Volume (SSV) on 03 November 2015.

2. WG-B held a special meeting on the subject of establishing an interoperable GNSS Space Service Volume (SSV) on 03 November 2015. During this special meeting the completeness and coherency of the SSV characteristics provided by the different Service Providers was discussed. The way towards the generation of an SSV dedicated booklet to promote the interoperable GNSS SSV was addressed. An action group is formed to advance on the necessary simulations and the preparation of the SSV booklet. All Service Providers are willing to contribute to this effort.

3. At the ninth annual meeting of WG-B the following presentations were given and discussed:

   (a) The Application Subgroup, established within WG-B and co-chaired by China and Japan, presented its finding resulting in an GNSS Application Catalogue. This GNSS Application Catalogue is the result of four workshops conducted by the subgroup over the last years with user participation in order to identify future trends for GNSS applications. The accuracy needs for Personal Navigation, Transportation, Agriculture, Timing and Real-Time Monitoring are identified. Also accuracy needs for Space applications are derived. The Application Subgroup has established a questionnaire to identify further user needs which is available through the ICG WG-B website. Another Application Subgroup meeting will be held in the course of 2016 in conjunction with one of the major GNSS conferences to allow industry and user participation. The subgroup plans to release a report on its finding for ICG-11.

   (b) The China Academy of Space Technology (CAST) gives a presentation on the Space Service Volume of BeiDou. BeiDou is willing to participate in establishing an interoperable GNSS SSV for the benefit of space applications. The BeiDou SSV Booklet is presented, showing the system status, the SSV experience and the relevant SSV characteristics for BeiDou. Antenna gain characteristics are provided for operational satellites which base on pre-flight ground tests. Also for modernized BeiDou satellites, antenna parameters relevant to conduct SSV analyses are provided. GNSS space users could benefit from the hybrid BeiDou constellation that contains IGSO/GEO and MEO satellites. Chinese space missions already embark on GNSS space-receiver technology and the relevance of GNSS for space missions is expected to further grow.

   (c) The European Space Agency (ESA) presents the status of the Galileo SSV characterisation. The relevance of GNSS for space missions is underlined. The Galileo SSV characterisation was conducted following the conventions identified in past WG-B meetings. The SSV characteristics are provided for Galileo Full Operational Capability (FOC) class satellites. It is underlined that these characteristics cannot be interpreted as a commitment from the European Commission for the already launched or future satellites. Official information related to SSV characteristics of Galileo will be published through the Galileo Open Service (OS) Definition Document. It is also noted that the two Galileo satellites facing launch anomaly, leading this to eccentric orbits, offer the unique opportunity to characterize the SSV-relevant off-boresight range from ground. Finally ESA presents the capabilities and the applications of its latest multi-GNSS space receiver development.

   (d) The Institute of Space Device Engineering of the United Rocket Space Corporation provides the latest results on Russian Geodetic Class Navigation Equipment. The test objective is to check the receiver measurement accuracy and availability. The measurement errors for a base station are determined in different sessions showing very low Root Mean Square (RMS) errors in the sub-centimeter range between Russian-domestic hard- and software and other

commercial products. It is noted that the obtained measurement errors for both GLONASS and GPS are compliant to geodetic user needs.

(e) TOPCON provides its view on SBAS for commercial applications under the headline "Not all SBAS Are Equally Good" and derives recommendations how SBAS providers can assist to enhance Machine Control Applications. For Machine Control Applications an accuracy of 1-20 cm is required that can be achieved today by different means, including Real Time Kinematics(RTK), Dead Reckoning (DR) and Precise Point Positioning (PPP). Considering the operational environment for Machine Control Applications multi-GNSS is important, but also additional ranging sources as from SBAS are very beneficial. The usage of SBAS ranging data in RTK is covered by a patent. Also PPP does not offer an adequate solution as no precise ephemeris and clock data are available for SBAS satellites. The concept of DR with Carrier Phase Increments is outlined. The approach can also be extended to SBAS satellites, but requires sufficiently accurate ephemeris and clock data for the SBAS ranging sources. A user range accuracy for SBAS satellites up to 30 m is acceptable for this type of application, however is not supported by all SBAS systems. TOPCON recommends that all SBAS providers pay more attention to the accuracy of the ephemeris data for their SBAS satellites.

(f) Following an ICG-9 WG-B recommendation, NASA provides its assessment on the NeQuick-G Performance and Usability. A particular feature of the NeQuick-G model is its capability to model the electron density as a function of the height in addition to geographic latitude, longitude and solar activity. Therefore it is of particular interest for single frequency space users in Low Earth Orbit (LEO). It is of lower interest for dual frequency users as these can eliminate the first order ionospheric error by linear combination. As further work NASA recommends to perform analysis of NeQuick-G performance for space applications.

(g) ESA summarizes two year global performance results for NeQuick-G. The NeQuick ionospheric correction model is recalled including the derived parameters that are provided through the Galileo navigation message. A specific document detailing the Ionospheric Correction Algorithm is available through the Galileo Service Center website. The two years performance assessment was conducted during the solar maximum in the years 2013-2015. Based on the measurement data obtained and evaluated, ESA concludes that the Galileo ionospheric single frequency correction algorithm with the current reduced Galileo infrastructure shows great performance for all stations around the globe. It shows a correction capability at a level of 70%. Further on ESA briefs on a recently launched scientific activity that has the objective to conduct general relativity tests exploiting the eccentric orbit of two Galileo satellites and the high accuracy on-board Hydrogen Maser clocks.

(h) Concluding the session on ionospheric modelling, ISRO presents its assessment on the NeQuick Model for Low Latitude Regions. The Total Electron Content (TEC) as derived from the Indian SBAS (GAGAN) is compared against the TEC values that result from the NeQuick model. A strong correlation is observed between the TEC obtained from two models.

(i) The European Commission (EC) addresses in its presentation the subject of Galileo Authentication. Over the last decade a strong demand for Position, Navigation and Timing resilience is observed in general and for GNSS authentication in particular. The Galileo Program studied Navigation Message Authentication (NMA) for its Open Service and Spreading Code Authentication for the encrypted Commercial Service. First prototypes are under development and will be tested in 2016.

The Moscow Technical University gives a presentation on GNSS Accuracy Improvements through Multipath Mitigation with New Signals. The provision of precise orbit and clock corrections at high rate will improve accuracy based on PPP. Common wide band signals across all GNSS in the E5 band (E5a/L5 + E5b/L3 band) and the L1 band will minimize the multipath error for high precision applications. Approaches to process these signals in low-cost receivers can be thought of that base on half-band processing.

4. Following the request of the ICG Provider Forum, WG-B reviews the adequacy of its Workplan. The discussion leads to an update of the Workplan in order to align it to current work areas of the group and to complement it by areas of interest to ICG. The future scope of WG-B is to
   - Promote and coordinate activities aimed at enhancing GNSS performance,
   - Recommend system enhancements that lead to New Services and Capabilities to better serve the different GNSS user communities.

   The updated Workplan covers the following top-level tasks:
   1. Future and novel integrity solutions
   2. Monitoring of techniques considered by application developers and external service providers
   3. Implementation of interoperable GNSS Space Service Volume and its evolution
   4. Examination of the performance of atmospheric models
   5. Establish a dialogue with Space Weather/Remote Sensing community

   The updated Workplan of WG-B is provided in Attachment 2 of this report. In order to reflect the revised scope of WG-B, its title is updated to WG-B on "Enhancement of GNSS Performance, New Services and Capabilities".

5. The group members recognize that WG-B has important tasks to carry out as identified in the updated Workplan of the Group. In addition the good implementation of endorsed ICG WG-B recommendations needs to be monitored in detail. These aspects will lead to an increase of workload for the co-chairs and additional support is considered beneficial in order to ensure a smooth operation of WG-B. As such, following Recommendation 2 (see Attachment 1.2) China is appointed as additional co-chair of WG-B. In the future WG-B will be co-chaired by ESA, ISRO and China.

6. The WG-B plans to organise at least one WG-B Interim Meeting in June 2016 in conjunction with the ICG-11 Preparing meeting in Vienna to examine the Workplan progress and identify Draft recommendations. The Application Sub-group plans to extend its questionnaire to an electronic version to support its work on an GNSS Application Catalogue report. The results will be made available through the ICG website.

7. The progress of ICG-9 recommendations is assessed. The work towards an interoperable GNSS SSV and its documentation in an SSV booklet is ongoing and has not yet been completed. It is important to note that after ICG-10 all six service providers have issued its SSV characteristics according to the template developed by WG-B. The ICG-9 recommendation in relation to NeQuick Ionospheric model was followed up during the WG-B session of ICG-10. Three recommendations were prepared by WG-B and were endoresed by the ICG Plenary. The endorsed recommendations of WG-B at ICG-10 are listed in Attachment 1.1, 1.2 and 1.3 of this report. The updated Workplan of WG-B as endorsed by the ICG plenary can be found in Attachment 2 of this report.

ATTACHMENT 1.1

WG-B Recommendation 1 Endorsed by Committee Decision

Prepared by: **Working Group B: Enhancement of GNSS Performance, New Services and Capabilities**

Date of Submission: 04/11/2015

Issue Title: WG-B Workplan Update

Background/Brief Description of the Issue:

The Workplan of WG-B was endorsed at ICG-6 in 2011. Since then important new areas of work were followed up by WG-B.

Discussion/Analyses:

WG-B reviewed its existing workplan taking into consideration the actual work conducted by the group and areas of interest to ICG. Based on this the group recommends an update of the workplan, that also allows to streamline the work and monitor its progress.

Recommendation of Committee Action:

WG-B recommends ICG to endorse its updated workplan, which centers around the following tasks:

1. Examine the problem of user position integrity and possible novel solutions to it.
2. Monitor techniques considered by application developers and external service providers for enhancement of GNSS performance.
3. Follow up the implementation of an interoperable GNSS Space Service Volume and its evolution.
4. Examine the performance of atmospheric models to correct single frequency measurements.
5. Establish a dialogue with Space Weather/Remote Sensing community.

All tasks shall eventually lead to the identification of recommendations for GNSS Service Providers in order to enhance the GNSS performance for users, enable new services and capabilities. In addition the results of WG-B shall provide guidance to the GNSS user community to better exploit GNSS services and capabilities.

WG-B recommends to update its title to “WG-B on Enhancement of GNSS Performance, New Services and Capabilities” to better reflect its objective and scope of work.

While tasks 1,2 and 4 are maintained from the WG-B workplan endorsed in 2011, the tasks 3 and 5 are new elements. As such WG-B enlarges its scope.

ATTACHMENT 1.2

WG-B Recommendation 2 Endorsed by Committee Decision

Prepared by: **Working Group B: Enhancement of GNSS Performance, New Services and Capabilities**

Date of Submission: 04/11/2015

Issue Title: Additional Co-Chair for Working Group

Background/Brief Description of the Issue:

Working Group has important tasks to be carried out that are identified in the updated Workplan of the Group.

Discussion/Analyses:

A rising number of aspects shall be covered and addressed by Working Group. The implementation of endorsed ICG Working Group recommendations needs to be monitored. These aspects will lead to an increase of workload for the co-chairs and additional support is considered beneficial in order to ensure a smooth operation of Working Group.

Recommendation of Committee Action:

Working Group recommends to introduce a Third Co-chair in order to ensure a timely and successful follow up of the updated Workplan. A Third Co-chair will also help to ensure to conduct the necessary interim meetings of Working Group. Given the good work of the Working Group Application Subgroup and the active role of China in this Application Subgroup, Working Group recommends to appoint China as a Third Co-Chair of Working Group.

ATTACHMENT 1.3

WG-B Recommendation 3 Endorsed by Committee Decision

Prepared by: **Working Group B: Enhancement of GNSS Performance, New Services and Capabilities**

Date of Submission: 04/11/2015

Issue Title: Utilization of GNSS satellites in Eccentric, Non-Nominal MEO Orbits

Background/Brief Description of the Issue:

Following the launch anomaly in August 2014 of two Galileo satellites, actions were put in place to stabilize the orbit and the satellites. The satellites are now occupying an eccentric orbit, which differs from the nominal orbits of GNSS Medium Earth Orbit (MEO) satellites. The satellites are transmitting Ranging Signals with good quality.

Discussion/Analyses:

Satellites in eccentric, non-nominal MEO orbits offer particular opportunities, that can be exploited e.g. for scientific studies of relativity, fast ambiguity fixing for Precise Point Positioning (PPP) users and enhancement of the interoperable GNSS Space Service Volume (SSV).

Recommendation of Committee Action:

ICG participants and scientific organizations are welcome to report to the Working Group on their experience utilizing satellites that are in eccentric, non-nominal MEO orbits in order to build a survey of these satellites for scientific research and Position, Velocity and Time (PVT) applications.

ATTACHMENT 2

REVISED WORK PLAN
WORKING GROUP B - Enhancement of GNSS Performance, New Services and Capabilities

As a unique combination of GNSS service providers and major user groups, the Working Group B (WG-B) of ICG will work to promote and coordinate activities aimed at enhancing GNSS performance, recommending system enhancements that shall eventually lead to New Services and Capabilities at System Level to better serve the different GNSS user communities.
Specifically, the following actions will be taken by WG-B:

Task 1: Examine the problem of user position integrity and possible novel solutions to it. Recommend any required system enhancements or actions that contribute or are required for the implementation of novel integrity solutions to Service Providers.

Task 2: Monitor on a regular basis the techniques considered by application developers and external service providers for enhancement of GNSS performance in order to recommend any required system enhancements or actions that may support the realization of such techniques to Service Providers.

Task 3: Follow up the implementation of an interoperable GNSS Space Service Volume and provide recommendations to Service Providers regarding possible evolution needs arising from users/application developers.

Task 4: Examine the performance of atmospheric models to correct single frequency measurements and recommend models for implementation to Service Providers.

Task 5: Establish a dialogue with Space Weather/Remote Sensing community in order to identify how GNSS can better support the advancement of Space Weather/Remote Sensing products and vice versa.

In the execution of its tasks, WG-B shall also provide guidance to the GNSS user community to better exploit GNSS services and capabilities.

In addition to its annual WG-B session, at least one interim WG-B session (preferably in conjunction with an ICG Provider Forum Meeting) will be called for in order to ensure progress on the different WG-B tasks. Additional interim WG-B sessions may be organized as needed.

The work in relation to Task 2 on the regular monitoring of application developer techniques and related needs is supported by the “WG-B Application Subgroup”. The “WG-B Application Subgroup” objectives, tasks and procedures of work are specified in its Terms of Reference.

In the execution of its work, WG-B will coordinate its activities with all other Working Groups of the ICG.