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Recent Advances in Wide Area Real-Time Precise Positioning

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ABSTRACT: This paper describes briefly new high precision wide area real time positioning systems, discusses their evolution, implementation and presents recent results. In the latter part the paper is primarily focused on discussing the benefits of GLONASS augmented high precision positioning.

1 INTRODUCTION

Differential GPS (DGPS) has been an established technique that provides meter level positioning in real time over wide area typically using single frequency Global Navigation Satellite System (GNSS) receivers. DGPS systems may utilize single reference station based corrections, such as IALA maritime stations, or orbit and clock corrections derived from wide area network, such as US WAAS and European EGNOS. The accuracy of DGPS technique is limited to about one meter level because of inherent pseudorange noise. Also, single frequency based DGPS accuracy may deteriorate during ionospheric storms.

Real Time Kinematic (RTK) positioning technique can potentially provide centimeter-level positioning accuracy. However, RTK requires the distance to the closest reference station to be within several tens of kilometers. Because of its fundamental distance limitations RTK is not well suited for wide area and offshore positioning.

To address the needs of higher accuracy users Fugro has pioneered over the last ten years several decimeter level wide area real time positioning systems, called HP, XP, and the most recent G2. The XP and HP systems are based on the use of GPS satellites only, while G2 is augmented with GLONASS satellites. G2 is the first real-time positioning system combining observations from GPS and GLONASS that has wide area coverage. The addition of GLONASS satellites in G2 positioning solutions results in improved availability and robustness of high precision positioning compared to HP and XP, GPS only systems.

These real-time systems developed by Fugro achieve decimeter accuracy by using dual frequency carrier phase observations to eliminate ionospheric effects and provide high accuracy positioning. By offering decimeter level accuracy over wide area, Fugro high accuracy systems have bridged the accuracy and coverage gaps between a confined area centimeter level RTK and a wide area meter level DGPS.

Fugro high precision services use wide footprint area geostationary satellites to transmit corrections determined from global reference networks to the GNSS users, conceptually shown in Figure 1. Fugro developed HP, XP and G2 solutions are embedded in virtually thousands of GNSS receivers. These receivers may be enabled to receive the corrections broadcast via geostationary satellites. The receivers with Fugro enabled HP, XP and G2 high precision solutions are used in various applications such as Dynamic Positioning of drill ships/supply vessels, airborne lidar surveys, hydrographic surveys, tidal control and precision agriculture.

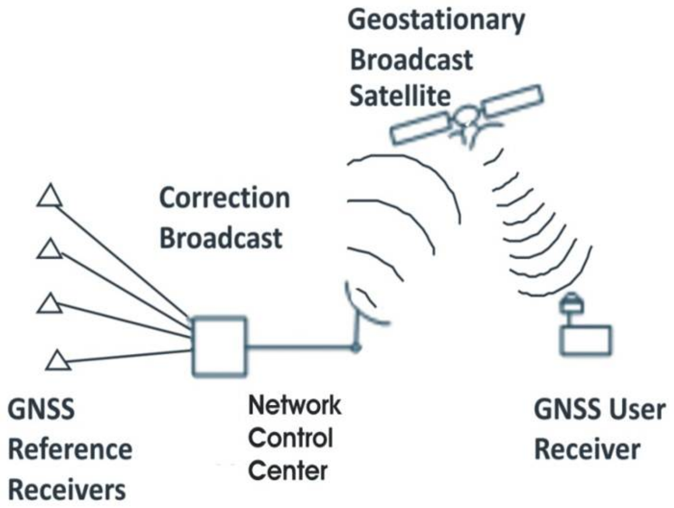

Figure 1. Geostationary Satellite Correction Broadcast

This paper describes briefly Fugro high precision systems, discusses their evolution, implementation and presents recent results. In the latter part the paper is primarily focused on discussing the benefits of combined GPS and GLONASS positioning as offered by G2 system.

2 CARRIER PHASE POSITIONING

Unlike standard DGPS systems that use lower precision pseudorange observations Fugro high accuracy systems use higher precision dual frequency carrier phase data as primary observations in a positioning solution. The use of dual frequency carrier phase observations enables virtual eliminating of ionospheric delays, one of the major error sources of GNSS positioning. The carrier phase observations are adjusted with the respective HP, XP or G2 correction information before entering the user positioning filter. Carrier phase observations are also corrected for various disturbing effects using high fidelity error modeling.

The satellite ambiguities, inherent in carrier phase observations, are recomputed for the rising satellites that are brought in a solution. The carrier phase ambiguities and residual atmospheric effects are then estimated, along with a position, primary parameter of interest in a user solution.

Achieving high accuracy after the cold start requires some initial convergence time, typically 10 to 30 minutes. The convergence time is a function of satellite geometry and tracking environment. Generally, shorter convergence time is achieved with better satellite geometry.

3 MULTI REFERENCE HP

Fugro introduced the first commercial decimeter level wide area real time positioning system in 2001. This service named HP, is based on the application of virtual station corrections optimized for the user location (Lapucha et al, 2001). The virtual corrections are computed using the corrections from the region of the multiple reference stations typically close to or surrounding the user. The virtual base station corrections are applied to the rover observations to mitigate satellite clock and orbit errors.

Fugro operates a worldwide network of about a hundred HP reference stations providing high precision coverage for major land masses and coastal areas. The HP solution approaches RTK accuracy if the user is within the reference network and the closest station is generally less than 1000 km. However, HP positioning accuracy gradually deteriorates if the user is outside of the network and the distance to the closest station is more than 1000 km. Thus the HP system is not suitable to provide high accuracy positioning in truly remote areas from reference stations such as in the middle of the oceans.

Typical 24 hour monitoring results from the HP system operating in dynamic mode at Lafayette, USA, on the Gulf of Mexico coast, using four reference stations with the distances ranging from 350 km to more than 1000 km, observed on January 23, 2011 are shown in Figure 2. The position accuracy given in terms of standard deviation is 3, 3 and 5 cm, for longitude, latitude and height, respectively.

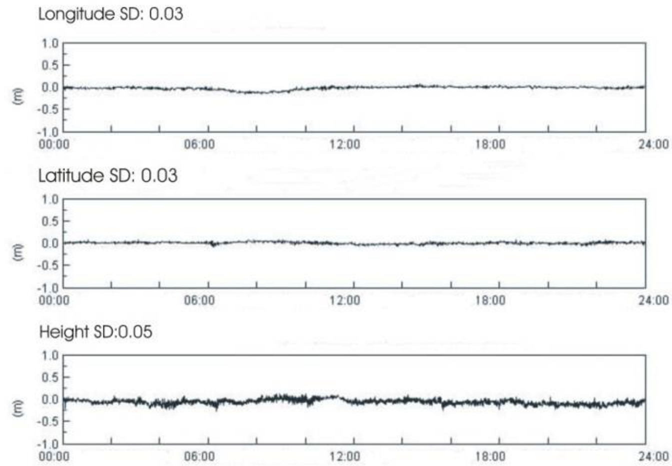

Figure 2. HP Position Results, Lafayette, January 23, 2011

HP solution was also extensively tested at various locations and over an extended time. The results of these tests showed that HP solution provides 10 cm horizontal, 15 cm vertical accuracies 95% at distances up to 500 km and 15 cm horizontal, 30 cm vertical accuracies 95% at distances up to 1000 km from the closest reference station.

4 PRECISE POINT POSITIONING XP

The XP system, based on the Precise Point Positioning (PPP) method, was introduced by Fugro in 2003.

The precise orbit and clock corrections used in the XP system are determined in cooperation with National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) based on NASA's worldwide network of reference stations.

The PPP method used in the XP system involves using the satellite specific precise orbit and clock corrections instead of virtual reference station range corrections. These corrections represent the most accurate estimate of the errors of the GNSS satellites broadcast orbit and clocks. Unlike the corrections used in the multiple reference station HP method, which are reference station and satellite specific, the orbit and clock corrections used in the PPP XP method are satellite specific only and not location dependent. The positioning accuracy is no longer limited by the distance from the reference stations. Therefore, application of these corrections leads to virtually homogeneous high positioning accuracy worldwide.

Typical 24 hour monitoring results from the XP system operating in dynamic mode at Lafayette, USA, on the Gulf of Mexico coast, as observed on January 23, 2011 are shown in Figure 3. The position accuracy given in terms of standard deviation is 4, 3, and 8 cm, for longitude, latitude and height, respectively.

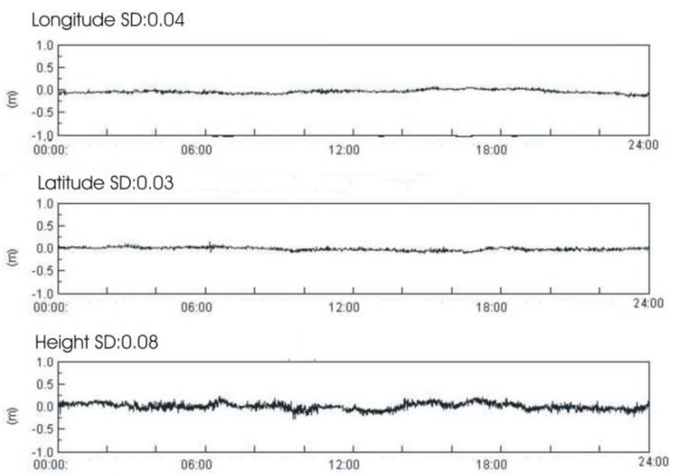

Figure 3. XP Position Results, Lafayette, January 23, 2011

XP solution was also extensively tested at various locations and over an extended time. The results of these tests showed that the XP solution provides 10 cm horizontal, 20 cm vertical accuracies in terms of 95% statistics. Unlike HP, the accuracy of XP is not dependent on location and distance from the reference stations.

5 GLONASS AUGMENTED PRECISE POINT POSITIONING G2

Fugro introduced in 2009 truly the next generation multi constellation real-time PPP system, based on the use of precise GPS and GLONASS orbit and clock corrections, called G2 (Melgard et al, 2009). The development has benefited from the close cooperation between Fugro and the European Space Operation Centre (ESOC), an establishment of the European Space Agency (ESA). ESOC has contributed with their expertise on precise orbit and clock processing techniques while Fugro built an operational real time system.

G2 position solution uses the PPP method with fine tuned statistical models to process GPS and GLONASS satellite observations and precise orbits and clock corrections determined from the global G2 network. These corrections are satellite specific only and not location dependent, similarly to XP. Therefore, the application of these corrections in a G2 user solution leads to virtually homogeneous high positioning accuracy worldwide

The G2 service utilizes Fugro's network of dual system GNSS reference stations to calculate precise orbits and clocks on a satellite by satellite basis for all 50 plus satellites of the two global navigation satellite systems. The system comprises about 40 dual-frequency GPS and GLONASS reference stations, operated independently of HP and JPL networks, evenly distributed around the world.

Successful integration of GLONASS carrier phase observations in G2 solution required accounting for incompatibilities between GPS and GLONASS systems. GLONASS satellites, unlike GPS, use different satellite specific frequencies. Also, GLONASS observations refer to different time system than GPS. However, after accounting for these differences GLONASS satellites act like additional GPS satellites in G2 solution.

Including GLONASS together with GPS satellites improves redundancy, geometry and availability of a positioning solution. Because of the greater number of satellites and improved geometry, integrated GPS and GLONASS G2 solution offers faster convergence than GPS only solution (Melgard et.al, 2009). Additional GLONASS satellites offer the potential to enable a positioning solution that may not be possible with GPS only, especially in challenging tracking environments with line of sight obstructions such as depicted in Figure 4.

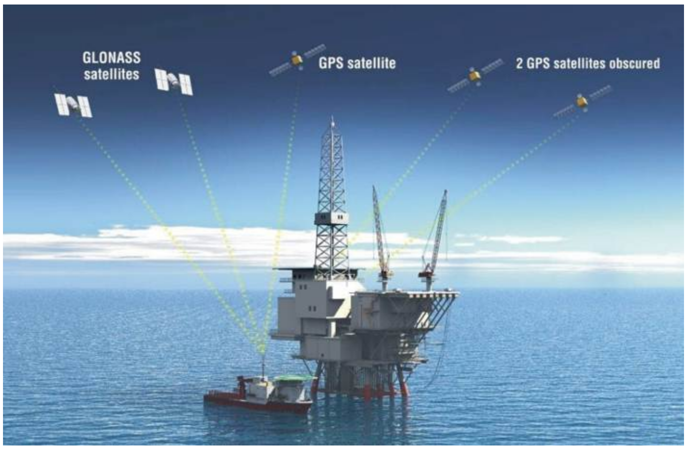

Figure 4. Challenging GNSS Tracking Environment

6 G2 POSITION ACCURACY ANALYSIS

In the following, G2 positioning results are presented from different locations and times to assess the representative G2 accuracy figures. These results were achieved with the systems operating in dynamic mode. It should be noted, the daily positioning accuracy can vary from day to day and with location depending on GNSS receiver, antenna and antenna cable and local environment. It is therefore important to note the following results represent examples observed at the monitor stations.

Example, 24 hour monitoring results time series from G2 system operating at Gulf of Mexico, Lafayette location are shown in Figure 5. The position accuracy given in terms of standard deviation is 2, 2 and 6 cm, for longitude, latitude and height, respectively.

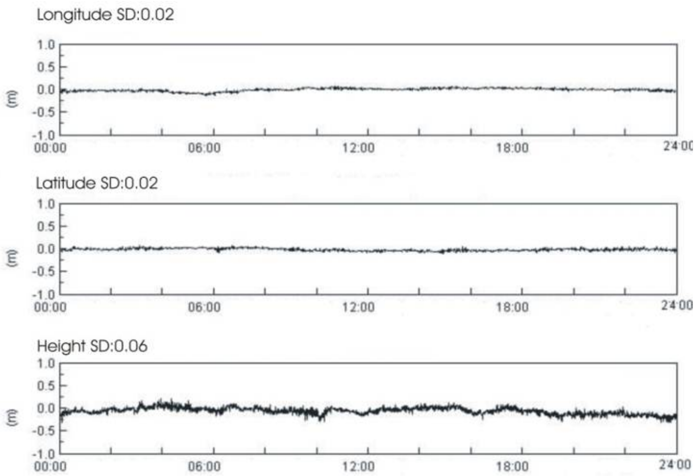

Figure 5. G2 Position Results, Lafayette, January 23, 2011

Example, monitoring results from the G2 system operating in Oslo, Norway are shown in Figure 6. The position accuracy given in terms of standard deviation is 2, 2 and 4 cm, for longitude, latitude and height, respectively.

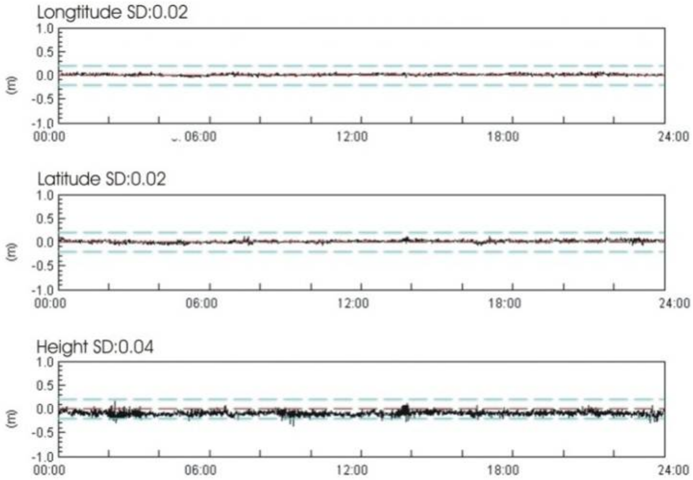

Figure 6. G2 Position Results, Oslo, January 2, 2011

Similar data were also collected in different locations around the world. Composite G2 accuracy figures given in terms of 95% statistics from some locations on January 23, 2011 are summarized in Figure 7. These results demonstrate that the G2 solution provides consistently, even with incomplete GLONASS constellation, 10 cm horizontal and 15 cm vertical accuracies in terms of 95% statistics.

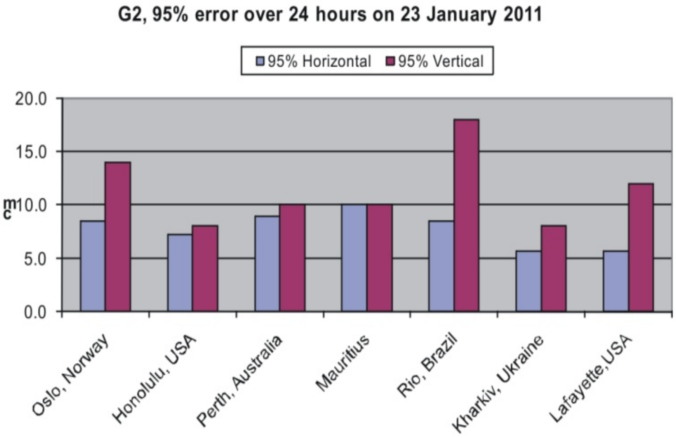

Figure 7. G2 Position Accuracy Summary, January 23, 2011

7 BLOCKAGE SIMULATION

Combining GPS and GLONASS observations in the integrated G2 solution offers potential to expand availability of high precision solution when single satellite system solution is not possible, as shown earlier at Figure 4. Generally, at least four satellites are necessary for single satellite system three dimensional user position determination.

To assess G2 performance under blockage conditions G2 data was reprocessed with simulated virtual wall to the south blocking GNSS satellite observations, as shown in Figure 8.

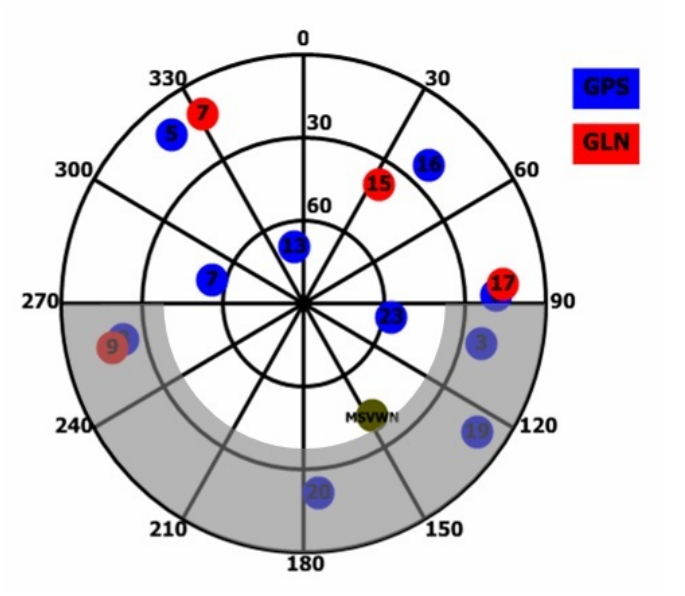

Figure 8. Satellite Blockage Skyplot

During the simulated blockage times, when a number of GPS satellites drops below the required four, GPS only solution fails to provide position, as shown in Figure 9. Moreover, positioning accuracy deteriorates after outage because of reconvergence in poor satellite geometry conditions.

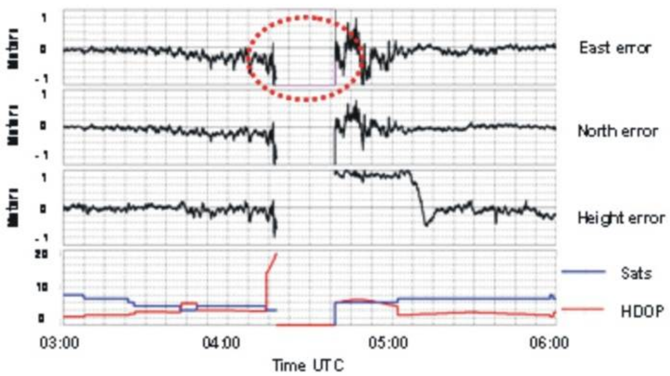

Figure 9. GPS only PPP Results Under Blockage Conditions

However, during time when GPS solution was not available, G2 solution provided seamlessly decimeter level positioning with only slightly degraded accuracy during blockage time, as can be in Figure 10. These results demonstrate improved resiliency of G2 solution in challenging tracking environment.

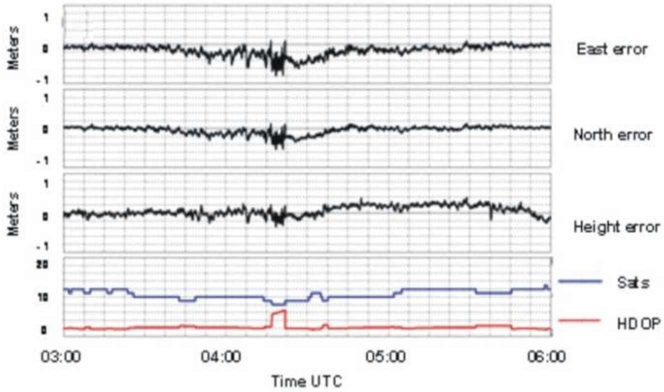

Figure 10. G2 Results Under Blockage Conditions

8 GLONASS ONLY PPP RESULTS

Expanding GLONASS constellation offers potential for PPP solution independent on GPS. As of beginning of 2011, GLONASS constellation does not offer 24 hour worldwide coverage. However it provides virtually 24 hour coverage of Northern Europe.

Figure 11 presents recent position results from the PPP system in Oslo utilizing only GLONASS observations and precise corrections in a user solution. Moreover, GLONASS precise orbit and clock corrections used in a solution were determined in the process that also used GLONASS observations only, completely independent on GPS.

The GLONASS PPP position accuracy from this test given in terms of standard deviation is 5, 5 and 8 cm, for longitude, latitude and height, respectively. Even with incomplete GLONASS constellation, these results demonstrate that GLONASS PPP method can potentially provide decimeter accuracy positioning independent on GPS.

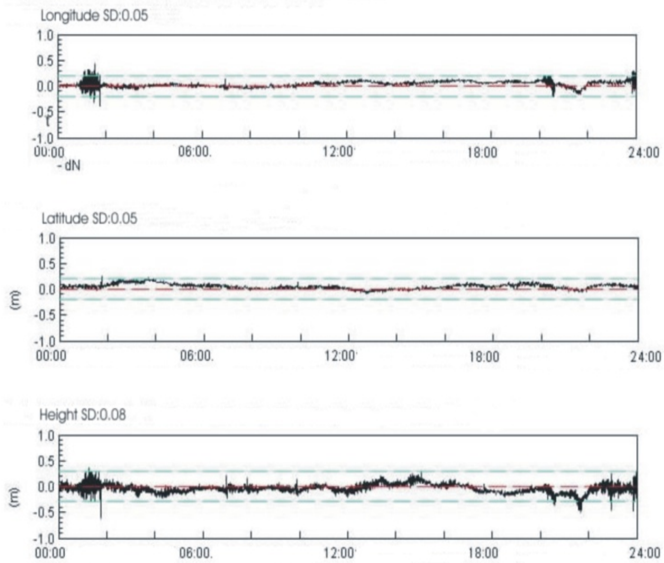

Figure 11. GLONASS PPP Results, Oslo, January 26, 2011

9 OPERATIONAL SERVICES

Fugro HP, XP and G2 services and networks are operated independently and redundantly to provide the highest level of positioning integrity. All Fugro positioning services use geostationary satellites transmitting data within L band, the same frequency band as used by GPS and GLONASS satellites. Use of L band has the advantage that user receivers can utilize the same antenna for reception of GNSS and geostationary satellite signals. The geostationary satellites used by Fugro provide virtually worldwide coverage, with the exception of polar regions, as can be seen in Figure 12.

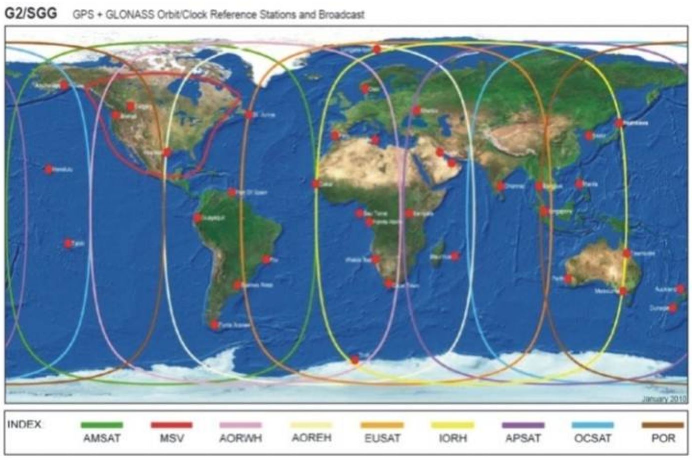

Figure 12. Geostationary Satellite Worldwide Coverage

Fugro developed HP, XP and G2 solutions are embedded in major brand GNSS receivers. The respective solutions can be activated with a subscription. These receivers employ the Fugro software library that decodes subscription and correction data and carries out high precision positioning computations. HP, XP and G2 enabled GNSS receivers are used for numerous applications requiring high precision positioning on land, sea and in the air.

10 CONCLUSIONS

The real time positioning systems developed by Fugro provide decimeter accuracy by using dual frequency carrier phase observations. These systems and services provide independently high accuracy worldwide positioning using geostationary satellites for correction broadcast.

Recently introduced G2 system is the first system offering combined GPS and GLONASS PPP positioning. Including GLONASS together with GPS satellites improves redundancy, geometry and availability of a positioning solution. It even opens for the possibility to use GLONASS as a positioning system completely independent of GPS also for higher precision positioning adding a new dimension to the redundancy.

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