EFFECTS OF SATELLITE-BASED POSITIONING EVOLUTION ON ABLOS ACTIVITIES

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ABSTRACT

Over the past two decades, the Global Positioning System (GPS) has become ubiquitous in outdoor positioning and navigation applications. For aspects of the Law of the Sea (LOS), applications include terrestrial and bathymetric surveys, and vessel navigation. Within the context of the LOS community, this paper has the overview goals of 1) describing the current state of GPS and the wider scope of satellite-based positioning systems – so-called Global Navigation Satellite Systems (GNSSs), that include Russia's GLONASS, Europe's Galileo, and China's Beidou / Compass constellations, and Regional Navigation Satellite Systems (RNSS), including Japan's QZSS; 2) addressing the future developments or "evolution" of these and similar systems; 3) providing insight into the future combined performance of these systems, taking into account hardware and processing algorithm advances; 4) predicting the effects of these performance improvements on maritime boundary delimitation, considering modern geodetic conventions (to be described in another paper at this conference); and 5) suggesting possible headwinds in these developments due to, e.g., political decisions, financial uncertainty, competing activities, and physical effects.

1 INTRODUCTION

The development of the U.S. Global Positioning System (GPS) has truly revolutionised outdoor positioning and navigation. Prior to GPS reaching Initial Operational Capability (IOC) in 1993, precise positioning relied on mostly short-distance electronic or laser length measurements and optical angular measurements, and navigation on a patchwork of local and regional systems. Not only has GPS replaced most of these technologies, it has harmonised positioning and navigation across many applications over the entire planet. These effects have been felt very strongly in maritime boundary delimitation activities, such as hydrographic surveying, coastal geodetic surveying, and, of course, marine navigation.

This paper discusses the impact of developments in current and near-term GPS and similar satellite navigation technology, typically referred to as Global Navigation Satellite Systems or GNSS, development on maritime boundary delimitation. To do so, a logical progression of information and synthesis is provided. The current state of the satellite navigation technology is presented and explained. The planned future developments or “evolution” of these and similar technologies are then given. Arising from these developments, the expected performance benefits will be considered, and potential effects on ABLOS activities will be discussed. Finally, possible delays or alterations to this future will be contemplated. This paper makes use of material presented in the new edition of the TALOS manual (TALOS, 2012) and is a companion to the paper from this conference on the topic of geodetic modernisation (Rizos and Bisnath, 2012).

2 CURRENT STATE OF GNSS

A GNSS is a one-way (passive) ranging system, using satellites at known positions continually transmitting time synchronised signals. They are 24 hour, global, all weather services, accessible to an unlimited number of military, civilian and commercial users with access to the open-sky. All GNSSs have a freely-available service and typically a military or commercial service. Fundamentally, a GNSS is a timing system: orbiting precise atomic clocks, at known positions, transmit known signals to user receivers to synchronise low-quality receiver clocks. This time synchronisation allows for the measuring of signal travel time from satellite to receiver, which is converted to range or distance. These satellite-to-receiver ranges are used in a variety of processing modes, providing few metre-level to mm-level point or relative positioning.

All GNSS receivers are capable of making pseudorange (also called code) measurements, and, in addition, receivers used for high accuracy (sub-metre) applications also make carrier-phase (also called phase) measurements. Both types of measurements are made on the tracked microwave L-band frequencies transmitted by the satellites. Position, navigation and timing (PNT) accuracy is dependent on such factors as measurement type, quality of antenna and receiver hardware, algorithm design, and mode of operation. For more details about GNSS, the reader is referred such texts as Hofmann-Wellenhof et al. (2008) and Leick (2004).

GNSSs are comprised of satellites, ground tracking stations and user equipment. The fundamental parameters under discussion here are the number and location of satellites within a GNSS constellation, the number of signal frequencies and modulations transmitted by each satellite, and the levels of service provided. It is further assumed that geodetic-grade receivers are used for surveys and navigation-grade user equipment for marine navigation.

2.1 GPS

As of September 2012, there are 31 active U.S. GPS satellite in six orbital planes, with an orbital period of approximately 12 hours, at an inclination of about 55° with respect to the Equator. This constellation exceeds the specified 24 satellites necessary in such a configuration to provide complete 24 hour global coverage, or what is known as Full Operational Capability (FOC).

The majority of the GPS satellites broadcast two signals in the L1 (1575.42 MHz) and L2 (1227.60 MHz) frequency bands. GPS signals are of the type known as Code Division Multiple Access (CDMA), where each satellite is distinguished by a special ranging code that is modulated on the L-band carrier waves. The phase measurements are approximately one thousand times more precise than the code measurements. Simultaneous measurements of code or phase made on two frequencies permit the ionospheric measurement bias to be determined and subsequently removed, hence improving positioning accuracy.

Civilian navigation receivers currently only can make code or phase measurements directly on the L1 signal using the C/A-codes. This means that such receivers are unable to correct for delays to the signal as it passes through the ionosphere, which is now one of the two dominant causes of error for such users, the other being multipath. High-quality geodetic receivers make code and phase measurements on both the L1 and L2 frequencies, and are comparatively expensive due to: (a) their dual-frequency, phase-tracking capability, (b) high-quality antennas, and (c) sophisticated measurement processing software. Military receivers can access the ranging codes on both the L1 and L2 frequencies, which enable them to correct for ionospheric errors and achieve higher accuracy and reliability of PNT results.

GPS positioning performance ranges from ~10 m horizontal error and ~20 m vertical error (95% confidence) for civilian navigation receivers, to dm-cm-level 3D positioning for hydrographic applications using processing techniques such as Real-Time Kinematic (RTK) and Precise Point Positioning (PPP), to cm-mm-level 3D positioning for static terrestrial applications using static relative positioning and PPP (see, e.g., Hofmann-Wellenhof et al., 2008; Leick, 2004).

2.2 GLONASS

The Russian GLONASS or *Global'naya Navigatsionaya Sputnikovaya Sistema* has re-emerged, and as of September 2012, 24 active satellites are in orbit in three planes, each with a nominal period of 11 hours and 15 minutes, and an inclination of approximately 64.5°. Therefore GLONASS now has FOC, providing 24 hour, full global coverage.

Unlike GPS, GLONASS uses Frequency Division Multiple Access (FDMA) to differentiate between satellites – each satellite transmits different frequencies rather than different codes. The two base frequencies are L1 (1.602 MHz) and L2 (1.246 MHz). Like GPS, GLONASS satellites transmit code modulations for restricted military users and global civilian users. Similar grades of GLONASS receiver exist, providing similar performance; however, there are relatively few of these GLONASS-only receivers in use outside of the Russian Federation. With the re-population of the constellation, most new geodetic-quality receivers being produced by instrument manufacturers have the capability to track both GPS and GLONASS satellite signals.

2.3 Other Satellite Navigation Systems

Other navigation satellites exist, but they are in the development stages with the intention they evolve to global systems, or are planned to be regional systems or regional augmentation systems of exiting GNSSs. The user impact of a particular system will depend on that system's geographic coverage.

2.3.1 Beidou-2/Compass

Beidou-2 or "Compass" is the second step in China's satellite navigation plan, and will consist of a constellation of passive satellites providing global PNT coverage. A constellation of nine satellites in various orbits produced a service capability in late 2011 in Southeast Asia: 55°S to 55°N by 90°E to 150°E, and by the end of 2012 Initial Operational Capability will be reached spanning a slightly larger region: 55°E to 180°E (Lu, 2011). Currently there are eleven active Compass satellites, with freely-available navigation accuracy of ~25 m. Compass will have more signals and modulations than the current GPS and GLONASS satellites. More discussion of Compass will be provided in Section 3.

2.3.2 Galileo

There are currently two operational European Union "Galileo" satellites in orbit for testing and validation. When fully developed with 30 satellites, Galileo will represent the fourth GNSS. Galileo is a passive system, with similar signals as GPS and Compass, along with next-generation code modulations. Many aspects of its operation and performance will be similar to that of the other GNSSs. More discussion of Galileo is given in the Section 3.

2.3.3 Regional Navigation Satellite Systems (RNSSs)

Aside from GNSSs, there are a few Regional Navigation Satellite Systems or RNSSs. The goal of such systems is to cost-effectively provide additional or dedicated satellite navigation signal coverage over a specific portion of the Earth.

Beidou-1 is one such system. Unlike GPS and GLONASS, Beidou-1 is a two-way ranging system, in which signals are sent from a ground control centre to the satellites, from the satellites to user equipment, back to the satellites, then on the ground control centre for processing and position estimation, before rebroadcast to the user. This method limits the number of simultaneous users, but requires only a few satellites and allows for a communications functionality. The three Beidou-1 satellites are in near geostationary orbits, allowing for a coverage area of 5°N to 55°N by 70°E to 140°E – most of Asia. It is a dual-frequency L-band system, for military and commercial applications, with augmented positioning performance in the 5 m range (Hofmann-Wellenhof et al., 2008).

Japan's Quasi-Zenith Satellite System (QZSS) is the other currently available RNSS, with one satellite in orbit over the Asia-Pacific region providing augmentation to existing GNSS, as opposed to being a stand-alone system. QZSS transmits GPS-like signals, simplifying user equipment requirements and therefore cost. The augmentation of GPS with the single QZSS satellite provides enough enhancement in satellite availability and viewing geometry that positioning and navigation performance in sky-blocked areas shows improvement over a range of position processing modes.

2.4 GNSS Positioning and Navigation Modes of Operation

At its most basic level, a GNSS positioning / navigation mode or technique is classified according to whether it provides point or relative positioning results, and along with the grade of user equipment, dictates obtainable accuracy. These are each briefly discussed below, and while the long established GPS is mostly referred to, the concepts apply to all GNSS.

2.4.1 Single Point Positioning (SPP)

SPP is the operational mode for which GNSS was originally designed. For GPS, standard civilian receivers currently deliver real-time, horizontal, absolute accuracy performance of the order of 5-10 m in the GPS reference frame. Vertical accuracy is typically 2-3 times worse than horizontal accuracy. The civilian users achieve such an accuracy using the GPS Standard Positioning Service (SPS), whether the user is stationary or moving. Code measurements made on only the L1 frequency are the basis of the SPS, and, as the name of the service implies, the vast majority of GPS user equipment falls in this category, including receivers installed on ships to support marine navigation.

2.4.2 Differential GNSS (DGNSS)

DGNSS can overcome some of the limitations of SPP by applying corrections to the basic code measurements at the user receiver to mitigate or eliminate some of the more serious satellite system and atmospheric biases, based on a second receiver, a base or reference station, making similar measurements at a known point. The relative positioning accuracy achievable can range from the metre-level down to a few decimetres, depending on the quality of the receivers, distance between the user receiver and the reference receiver generating the correction data, and the particular DGNSS technique, and perhaps the DGNSS correction service, that is used. DGPS has been used extensively for coastal marine navigation.

2.4.3 Relative GNSS

Relative GNSS refers to the most accurate of the positioning modes, using the DGNSS principles with one or more reference stations relative to which receiver coordinates are computed from phase measurements as opposed to the noisier code measurements. Geodetic applications have been using relative GPS extensively since the 1980s to address regional and global reference frame applications that do not require real-time results, nor need to account for the user receiver being in motion. Relative GNSS has therefore mainly supported national renovated geocentric datums and global datum definition, such as the International Terrestrial Reference Frame (ITRF) realisations and maintenance (see Rizos and Bisnath, 2012), as well as Earth science users, but at ever increasing levels of accuracy. Currently, relative positioning accuracies are typically at the few parts per billion level of the inter-receiver distance or a few millimetres of error over a one thousand kilometre baseline, i.e., the 3D vector connecting the reference station to the user receiver (see, e.g., Rizos, 2010). Hence GNSS geodesy underpins the definition of modern geocentric datums, permits control surveys to be conducted to extend or densify a State's geodetic control network, and is used to monitor the stability of tide gauge sites or datums.

2.4.4 Real-Time Kinematic (RTK)

RTK is a relative positioning technique that can achieve centimetre-level accuracy in real-time, using pairs of receivers, even if the user receiver is moving, i.e., in kinematic mode. Operational efficiencies and high accuracy are assured when both code and phase measurements are made on both L1 and L2. Hence RTK techniques require expensive, compared to single-frequency SPP/DGNSS receivers, dual-frequency instrumentation and specialised phase baseline processing algorithms (see, e.g., Rizos, 2010).

A critical enabler for the RTK technique is the widespread establishment of permanent, continuously operating reference stations (CORS) at the necessary density. Depending upon whether single-base RTK or so-called network RTK techniques are used, the separation of CORS ranges from about 30 to 100 km. Most CORS providing RTK services are commercial operations, and a user must be a subscriber to the service. The RTK technique is commonly used for precision hydrographic, harbour and offshore engineering applications, including precision navigation of large vessels when there is little keel clearance, for dredging operations, and various engineering and construction tasks. For such near-shore, or even internal waters applications it is not difficult to ensure CORS deployment satisfies the baseline length constraints for efficient and reliable RTK. However, RTK techniques cannot be used when operating more than a few tens of kilometres offshore. As with DGNSS techniques, the datum of the resulting coordinates is that on which the CORS coordinates are defined.

2.4.5 Precise Point Positioning (PPP)

PPP is a more recently developed processing mode, which applies very accurate GPS (and increasingly GPS plus GLONASS) satellite orbit and clock information computed separately from global CORS networks to a single high-quality receiver via specialised processing algorithms, in order to produce decimetre to centimetre-level coordinates without any baseline constraints. The technique is now an industry standard for hydrographic surveys and marine construction, given its accuracy and performance near and far from shore. Coordinates are computed in the datum of the satellite orbit and clock products, typically ITRF. Efforts to further improve this technique are ongoing (see, e.g., Bisnath and Gao, 2009).

3 EVOLUTION OF GNSS

As important as the developed GNSS technology and its impact on our work, is the myriad of continued developments in these systems mentioned in the previous section. This section will very briefly describe these activities for individual systems and as a whole, the results of latter that we refer to as “GNSS evolution”.

3.1 Future GPS

There are two components of GPS advancement: so-called “GPS Modernization” and “GPS III”. Modernization is underway, with the introduction of an additional civilian modulation L2C on the L2 frequency, as well as the introduction of the L5 frequency and associated modulations on newly launched satellites. The result can be summarised as improvements in signal tracking, reduction in user equipment costs, and overall improvements in position accuracy, availability, integrity, reliability, and interoperability (more in Section 4).

GPS III refers to the next generation of GPS satellites and GPS architecture. Improvements will come in the form of added signal modulations (L1C on the L1 frequency), added signal power, improved anti-jamming capabilities, improved accuracy and reliability, and possible alterations to the constellation design.

3.2 Future GLONASS

The future of GLONASS appears much more stable that its past, with predicable Russian government funding and more cooperation with other GNSS and RNSS governmental organisations. Transitioning from FDMA to CDMA is proposed, which will enhance GNSS interoperability (further described in Section 4).

3.3 Future Galileo

The Galileo signals and services have been clearly defined. Most new geodetic-quality receivers have Galileo tracking capability. Additional validation satellites are scheduled for launch before the end of 2012 with IOC by mid-decade and FOC towards the end of the decade.

3.4 Future Compass

Compass user equipment development has been limited outside of China, but as the system has reached IOC over the Asia-Pacific region, commercial and academic interest has grown. It is expected that as FOC as a GNSS will be reached at the end of the decade, the freely-available portion of the system will become widely adopted by the global community.

3.5 Future RNSSs

The three satellite BeiDou-1 system is expected to continue as is, with China placing its focus in the near-term on completing the Compass RNSS before deploying a full GNSS. Japan's QZSS was intended to be a three satellite constellation, though no launch dates have been given for the remaining two satellites. However, the Japanese government has approved the pathway to a 5-7 satellite RNSS, but provided no firm timeline. Recent information about development of the seven satellite Indian RNSS (IRNSS) constellation is very limited. No launch schedule has been disseminated.

3.6 Future Combined Navigation Satellite Systems Environment

Over the last decade, users have grown use to, and now rely very heavily on, an approximately 30 satellite GPS constellation. Users are currently getting accustom to an approximately 50 satellite environment provided by independent GPS and GLONASS constellations. Combined system user equipment and services is becoming the norm, resulting in slightly improved positioning and navigation under constrained environments, and perhaps more importantly, improved solution integrity provided by two independent solutions.

Over the next decade, we will transition from the relatively new 50 satellite, two constellation world to the over 125 satellite, four constellation world – a truly breath taking advance. Figure 1 attempts to count the number of active GNSS and RNSS satellites from 1980 through 2030. These developments represent a very dramatic increase in the number of satellites, but also in the number of independent systems, and number of signals and modulations on those signals. Figure 2 summarises the current signals and modulations available on fully operational GNSSs, and the same for GNSSs into the next decade. Without delving into unnecessary detail, with more signals and modulations comes the ability to provide different levels of navigation services and measurement processing to further increase user performance. The potential impact of these changes are the subject of the next section.

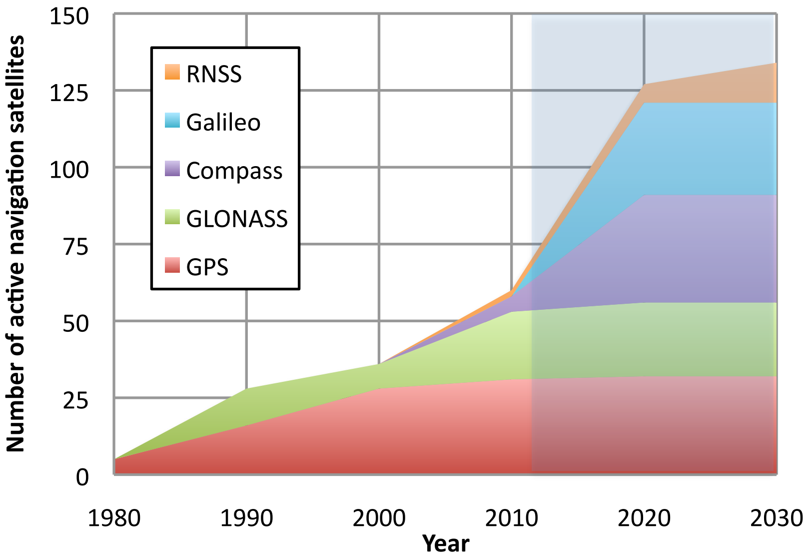

Figure 1: Past, current and future prediction of number of active GNSS and RNSS satellites. (Based on a wide number of sources.) (Gray area represents prediction.)

GNSS	**CURRENT STATUS**			**SPECIFIED FUTURE**		
	Signal	Frequency (MHz)	Modulations	Signal	Frequency (MHz)	Modulations
GPS	L1	1575.42	C/A, P	L1	1575.42	C/A, P, L1C, M
	L2	1227.6	P	L2	1227.6	P, L2C, M
				L5	1176.45	L5C
GLONASS	G1	1602	C/A, P	G1	1602	C/A, P
	G2	1246	C/A, P	G2	1246	C/A, P
				G3	1204.704	C/A_2, P_2
Galileo				E1	1575.42	E1A, E1B, E1C
				E6	1278.75	E6A, E6B, E6C
				E5	1191.795	
				E5a	1176.45	E5a-I, E5a-Q
				E5b	1207.14	E5b-I, E5b-Q
BeiDou-2 / Compass				B1	1561.098	B1(I), B1(Q)
				B2	1207.14	B2(I)
				B3	1268.52	B2(Q), B3

Figure 2: Current and future fully implemented signals and modulations for fully operational GNSSs. (Compiled from multiple sources.)

4 FUTURE GNSS PERFORMANCE

GNSS evolution means that the future is very exciting: new satellites, signals, and whole new constellations. So how will all of these enhancements affect GNSS performance from the user perspective? As is explained below, there will be improvements in performance: availability, accuracy, efficiency, reliability and integrity, as well as improvements in system interoperability and compatibility.

4.1 Improved Performance

Performance can be a qualitative term; additional GNSS satellites, signals and constellations will undoubtedly improve GNSS PNT performance. But how and why? To be more quantitative, without unnecessary detail, performance is defined by the following metrics.

4.1.1 Availability

Extra satellites and signals will enhance signal availability at a particular location, crucial for users wanting PNT solutions in areas that do not satisfy the open-sky conditions, though this is not as serious an issue for maritime users. But to get a sense of the dramatic increase in the number of tracked satellites, consider a non-GNSS satellite in low Earth orbit equipped with a GNSS receiver. This satellite would orbit the Earth twice in approximately three hours. Figure 3 illustrates, through a computer simulation, the number of GPS, GLONASS, Galileo and Compass satellites such a receiver / platform combination would track. The average number of available satellites increases from ~10 with GPS to ~16 with GPS+GLONASS, and up to ~36 GNSS tracked with all four GNSSs are considered – an incredible bounty.

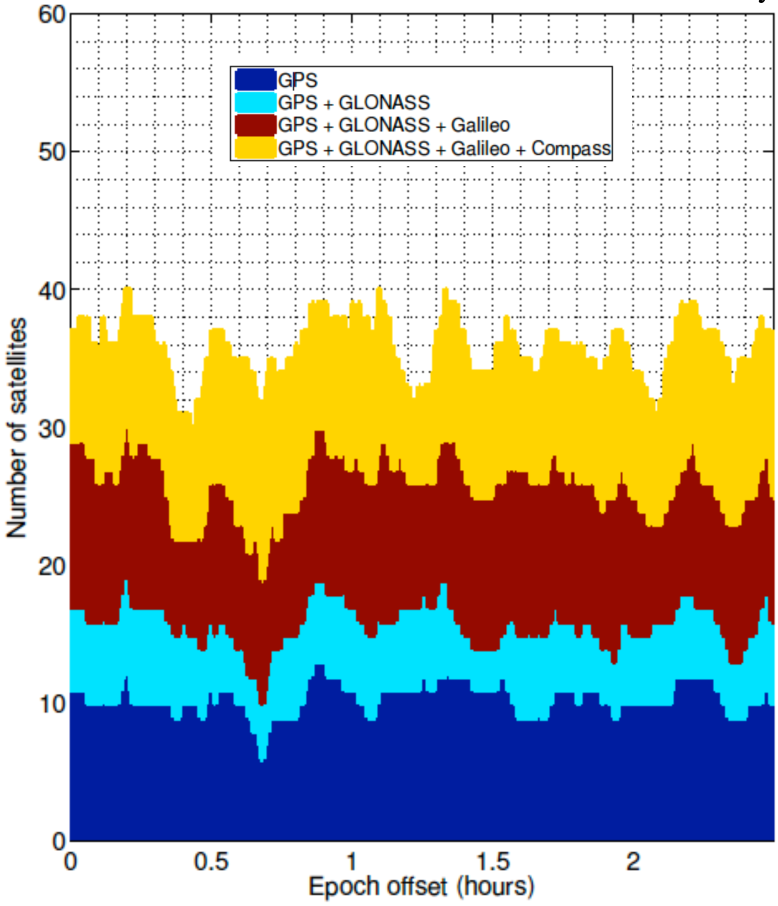

Figure 3: Simulated number of visible GPS, GLONASS, Galileo and Compass satellites from a multi-GNSS receiver aboard a low Earth orbiting satellite (Dolgansky, 2010).

4.1.2 Accuracy

Additional satellites and signals will improve accuracy. More satellites being observe means a given level of accuracy can be achieved faster. More signals means more measurements can be processed by the receiver's positioning algorithm. Position accuracy is less susceptible to the influence of satellite geometry. Vertical accuracy will more closely approach the performance of horizontal positioning. The effects of multipath and interference/jamming would be better mitigated through implementation of receiver autonomous integrity monitoring (RAIM) type satellite signal selection algorithms, ensuring that only measurements of high quality are processed.

Each GNSS positioning mode (see Section 2.4) should undergo incremental accuracy improvements from the increased quality and quantity of measurements being applied to new processing algorithms. However, at some point, the law of diminishing returns takes effect, and more satellites will not provide any additional significant improvements to PNT accuracy.

4.1.3 Efficiency

Additional satellites and signals will improve efficiency. For phase-based positioning at the centimetre-level of accuracy, extra satellites and signals will significantly reduce the time required to resolve carrier-phase ambiguities.

4.1.4 Reliability and integrity

Extra satellites and signals will improve reliability. Extra measurements will increase data redundancy, aiding in the identification of measurement outliers. For example, the current GPS L2 measurements are more noisy and less continuous than those that will be made on either of the new GPS L2C or L5 signals, hence dual-frequency operation will be enhanced in future. More signals means that service is not as easily denied due to interference or jamming of one frequency or set of signals, that may prevent the making of critical pseudorange and/or carrier-phase measurements on one or more GNSS.

Extra satellites will improve continuity. GPS, GLONASS, Galileo and Compass being independent systems mean major system problems, unlikely as they are, have a very remote possibility of occurring simultaneously for all constellations. Some users may be content in using just a single system, others may require the improved performance afforded by a combination of systems, and yet others the necessity of multiple solutions from independent systems.

4.2 Interoperability and Compatibility

Finally, any discussion of mixing different satellite navigation signals so that users can improve the performance of their receivers invariably raises the issues of interoperability and compatibility. Interoperability is defined as the ability of GNSS services to be used together to provide the user better capabilities than would be achieved by relying solely on one service or signal. At the very least, this term would imply the same or very similar transmitted frequencies, but ideally the broadcast of the family of spreading codes by all GNSS. Compatibility is defined as the ability of GNSS to be used separately or together without interfering with each individual service or signal. The degree of interoperability and compatibility that will be achieved in a multi-GNSS world is still unclear, though a topic of great importance to the U.N.'s International Committee on GNSS (ICG, 2012).

5 EFFECTS ON MARITIME BOUNDARY DELIMATION

There are three distinct activity areas to consider when discussing the impact of GNSS evolution on maritime boundary delimitation and ABLOS concerns: marine navigation, hydrography, and terrestrial positioning.

5.1 Marine Navigation

GNSS evolution will not provide a "disruptive technology", as was the case with the introduction of <100 metre accuracy GPS navigation in the 1980s that placed pressure on existing less precise nautical charts. The marine community is now accustom to <10 metre navigation technology, and the improvement of that resolution by a few metres with additional satellites and signals will not have a significant effect. Likely, higher accuracy will be available, but it will not be needed for marine navigation.

Beyond accuracy, the additional integrity in individual systems and from independent solutions will be welcomed, and will probably be adopted into standard navigation practices. Having one GNSS as a back-up to another GNSS may become the norm.

5.2 Hydrography

Future GNSS developments will provide increased accuracy and integrity, improving mapping products, especially in the vertical positioning component. However, the current use of GPS positioning modes allow for these products to meet IHO standards. One consequence may be calls for higher mapping specifications given the significantly improved performance of GNSS, inertial navigation, and sonar technologies.

5.3 Coastal Terrestrial Positioning

It is expected that GNSS evolution will have the greatest impact on the coordination of coastal reference points. As the foundation of baseline determination, coordination must be performed at the centimetre-level. Additional satellites and signals will make this task more straightforward. More efficient and accurate relative, RTK and PPP GNSS positioning may mean the further reduction in the number of actual survey monuments and the ability to confidently establish and re-establish coordinates at the centimetre-level of accuracy in real-time whenever required.

Given the high precision necessary for such geodetic surveys, differences in datums and time scales between individual GNSSs must be rigorously accounted for. Note that metre-level differences are of little consequence in marine navigation. There should be no confusion of datums and time scales, so long as GNSS authorities clearly publicise these details, and manufacturers, software providers, and users are cognisant of these issues and take them into account in their PNT calculations. This is one of the goals of a working group within the ICG.

6 GNSS DEVELOPMENT CONCERNS

While the future of GNSS is very bright, there are substantial headwinds. Governmental plans can change for a variety of reasons, and such change has marked the history of GNSS, so will undoubtedly affect its future. The major concerns are discussed here.

6.1 Political Decisions

The objectives of national governments change as sentiment within those governments and nations change. GNSS (and RNSS) capability and independence has been seen as a military and, perhaps equally or more importantly, as an economic necessity for the global powers. Geopolitics has and mostly like will play a crucial role in GNSS plans being followed with action.

For example, the political (and economic) collapse of the U.S.S.R. depleted the initial GLONASS constellation, which was built as the Soviet response to the U.S. GPS during the Cold War. The rise of the Russian Federation has brought back GLONASS to full operation this year, due to it being seen as of primary strategic importance by the Russian government. A major justification for the development of Galileo by the EU was to remove reliance of such an important tool on close ally the U.S. Focus on the Iraq and Afghanistan wars have required the U.S. military to slow GPS Modernization and GPS III plans.

6.2 Financial Uncertainty

Naturally linked to government policy is the availability of funds to support these large, national programs. At some point, political decisions and choices must be based on financial realities. A combination of political gridlock, but more importantly the limited private support for the development of Galileo, has delayed its implementation. The current economic situation in Europe may further slow satellite launch schedules and the attainment of IOC and FOC. Conversely, Compass is being implemented quickly by a Chinese government in good financial shape.

While it is difficult to predict precisely how the coming years will unfold politically and financially, GNSSs continue to receive significant support from governments, and reliance on them continues to grow.

6.3 Competing Activities

GNSS can be seen as a premier technology, but there are other technologies that have wider appeal to governments and people. Of concern is when other technologies progress at the expense of GNSS. An interesting recent example is that of the Light-Squared case in the U.S. Frequency spectrum was initially allocated to this company for the development of a terrestrial, high-bandwidth wireless communications system in the continental U.S. Real fears arose, supported by user equipment testing, that the transmitted signals would degrade GPS signal tracking in and near the continental U.S. The spectrum allocation was recently revoked, though not without political implications. It is a real possibility that more such competing spectrum users will present themselves in the coming years.

6.4 Interoperability and Compatibility

While GNSS interoperability and compatibility will improve multi-GNSS performance for users, these goals are not in themselves necessary for individual systems and the governments that support them. Therefore, as secondary system development objectives, plans may change if enthusiasm is weakened by political or financial concerns.

6.5 Over-reliance

GNSS evolution can only increase our dependency on satellite-based PNT. While it can be argued that having multiple, independent systems increases integrity and therefore limits over-reliance concerns, these systems can all be negatively affected in the same ways, such as via intentional and unintentional signal jamming – a very serious concern for military and safety of life applications. Also, there will be the temptation to solely rely on GNSS. The example of the deactivation of the U.S. Loran-C coast marine navigation system comes to mind.

6.6 Physical Effects

Not to be lost in this discussion is the fact that GNSS is an open-sky technology. While this fact does not negatively affect most maritime users, physical blockage of GNSS signals will always be of concern in coastal areas, particular on shore. The combination of GNSS with other sensors, such as inertial is a continued active research area.

7 CONCLUSIONS

GPS has revolutionised outdoor positioning. We now live in a world of approximately 50 GNSS satellites of the GPS and GLONASS constellations. By the end of this decade this number will grow to over 125 satellites in four GNSS constellations, representing a significant evolution of the technology. Along with new satellites will come new signals and system architectures. The result is expected to be more accurate positioning, navigation and timing, as well as increased availability, integrity and reliability; the latter of which may be of considerable importance for some users. In terms of ABLOS-related activities this evolution will impact marine navigation, hydrographic surveying and coastal terrestrial geodetic surveying, with the last area being most positively affected due to its high accuracy requirements. Associated with these GNSS developments are the realities that political, economical and technical issues may slow or otherwise impact on this remarkable progress.

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