EFFECTS OF SATELLITE-BASED POSITIONING EVOLUTION ON ABLOS ACTIVITIES

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INTRODUCTION

- Development of U.S. Global Positioning System (GPS) has truly revolutionised outdoor positioning and navigation
- GPS has replaced most previous technologies and has harmonised positioning and navigation across many applications over the entire planet

- Paper discusses impact of current and near-term developments in GPS and similar satellite navigation technology (Global Navigation Satellite Systems – GNSS) on maritime boundary delimitation

OVERVIEW

- Describe current state of GPS and GNSSs
- Address future developments or “evolution” of GNSS
- Provide insight into future combined performance of these systems
- Predict effects of these performance improvements on maritime boundary delimitation
- Consider possible delays or alterations to this future

CURRENT STATE OF GPS AND GNSS

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GNSS PRINCIPLES OF OPERATION

- One-way (passive) ranging system using satellites at known positions continually transmitting time synchronised signals
- 24 hour, global, all weather service, accessible to an unlimited number of users with access to open sky
- Military, civilian and commercial services

- Orbiting precise atomic clocks, at known positions, transmit known signals to user receivers to synchronise low-quality receiver clocks
- Time sychronisation allows for measuring of signal travel time from satellite to receiver, which is converted to range
- Satellite-to-receiver ranges used in a variety of processing modes, providing m to mm level point or relative positioning

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GNSS MEASUREMENTS

- All GNSS receivers can make pseudorange (code) measurements
- High accuracy (sub-metre) receivers make carrier-phase (phase) measurements on more than one frequency
- All measurements are made on tracked microwave L-band frequencies transmitted by GNSS satellites

- Position, navigation and timing (PNT) accuracy dependent on: measurement type, quality of antenna and receiver hardware, processing algorithm, and mode of operation

- Fundamental parameters consider here: number and location of satellites, number of signal frequencies and modulations transmitted, levels of service provided

GPS OVERVIEW

- As of September 2012, 31 active U.S. GPS satellites in six orbital planes; ~12 hour orbital period; ~55° inclination with respect to Equator

- GPS satellites broadcast signals on (at least) two frequencies
- Code Division Multiple Access (CDMA) signal type

- Phase measurements are approximately 1,000x more precise than m-level codes
- Measurements on two frequencies allows removal of ionospheric bias

- Civilian navigation receivers usually make code measurements on one frequency
- High-quality geodetic receivers make code and phase measurements on both frequencies

GPS PERFORMANCE

- Large range, due to hardware and processing algorithm
- ~10 m horizontal and ~20 m vertical point positioning accuracy (95% confidence)
- dm-cm-level 3D positioning for hydrographic applications using processing techniques such as Real-Time Kinematic (RTK) and Precise Point Positioning (PPP)
- cm-mm-level 3D positioning for static terrestrial applications using static relative positioning and PPP

GLONASS

- Russian GLONASS has re-emerged and, as of September 2012, 24 active satellites are in orbit in three planes; period of ~11.25 hours; inclination of ~64.5°
- Now provides 24 hour, full global coverage

- Uses Frequency Division Multiple Access (FDMA) to differentiate between satellites
- Like GPS, transmits code modulations for restricted military users an global civilian users

- Similar grades of GLONASS receivers exist, but very few outside of Russian Federation
- Most new geodetic-quality receivers now have GPS and GLONASS tracking capability

GLOBAL SATELLITE NAVIGATION SYSTEMS IN DEVELOPMENT

- Beidou-2 / Compass:
  - Second phase in China's satellite navigation plan
  - Passive satellite constellation providing global PNT coverage
  - Constellation of 9 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 end of 2012: 55°E to 180°E

- Galileo:
  - Passive, global system
  - Currently 2 validation satellites in orbit

- *Operation of all GNSSs similar*
- *All provide a free service component*

REGIONAL SATELLITE NAVIGATION SYSTEMS

- Beidou-1:
  - Two-way ranging system
  - Has communications function as well
  - 3 satellites in near geostationary orbits covering: 5°N to 55°N by 70°E to 140°E
  -
- Quasi-Zenith Satellite System (QZSS):
  - Passive system
  - 1 satellite over Asia-Pacific augmenting existing GNSS, rather a standalone
  - Improves satellite availability and viewing geometry resulting in higher positioning precision in constrained sky view

GNSS MODES OF OPERATION: SPP; DGNSS

- Single Point Positioning (SPP):
  - Mode for which GNSS was originally designed
  - For GPS, standard civilian receivers deliver real-time, horizontal, absolute accuracy performance of ~5-10 m
  - Vertical accuracy is typically 2-3 times worse
  - Vast majority of GNSS receivers use this mode, include marine navigation

- Differential GNSS (DGNSS):
  - Applies corrections to SPP via a second (reference) receiver used to calibrate error sources
  - m-dm performance, depending on hardware and distance between receivers
  - One use is for coastal marine navigation

GNSS MODES OF OPERATION: RELATIVE GNSS; RTK; PPP

- Relative GNSS:
  - Most accurate mode
  - Combine phase measurements from two geodetic receivers
  - mm-level performance over hundreds to thousands of kms
  - Used for terrestrial geodetic surveys and therefore in definition of ITRF
- Real-Time Kinematic (RTK):
  - Relative GNSS over 10s kms for mobile geodetic receivers
  - Widespread establishment of continuously operating reference stations (CORS) – some institutional, other commercial
  - Few cm-level accuracy in real-time
  - Used for hydrography, and near-shore construction
- Precise Point Positioning (PPP):
  - Recently developed mode
  - Single geodetic receiver can produce dm-cm level accuracy without any baseline constraint
  - Used for hydrography, and near-shore construction

GNSS “EVOLUTION”

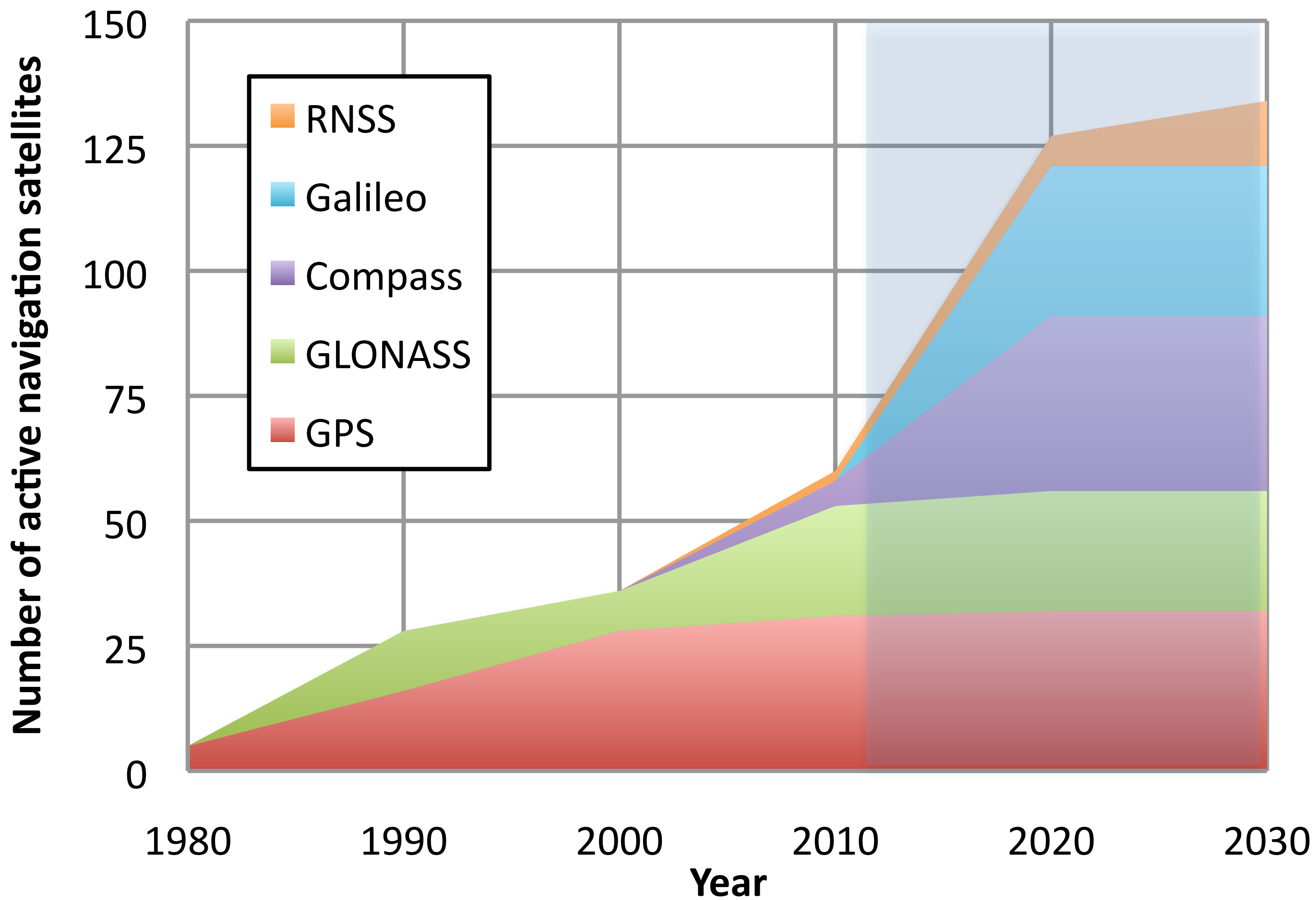
FUTURE GPS

- GPS Modernization:
  - Underway
  - Additional civilian and military modulations
  - Additional frequency
  - Improvements in signal acquisition and positioning performance
  - Freely available component
- GPS III:
  - Next generation of GPS satellites and architecture
  - Additional modulations
  - Added signal power
  - Improved anti-jamming capabilities
  - Possible alternations to constellation design
  - Freely available component

FUTURE GLONASS, GALILEO, COMPASS

- GLONASS:
  - Future funding appears stable
  - More cooperation with other GNSSs and RNSSs
  - Proposed transition from FDMA to CDMA
  - Freely available component
- Galileo:
  - Signals and services clearly defined
  - Most new geodetic receivers have Galileo tracking capability
  - Initial Operational Capability (IOC) by mid-decade
  - Full Operational Capability (FOC) towards end of decade
  - Freely available component
- Compass:
  - Receiver development in China and now growing outside of China
  - FOC expected at end of decade
  - Freely available component

PAST, CURRENT AND FUTURE PREDICTION OF NUMBER OF ACTIVE GNSS AND RNSS SATELLITES



CURRENT AND FUTURE FULLY IMPLEMENTED SIGNALS AND MODULATIONS FOR FULLY OPERATIONAL GNSSs

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

FUTURE COMBINED GNSS PERFORMANCE

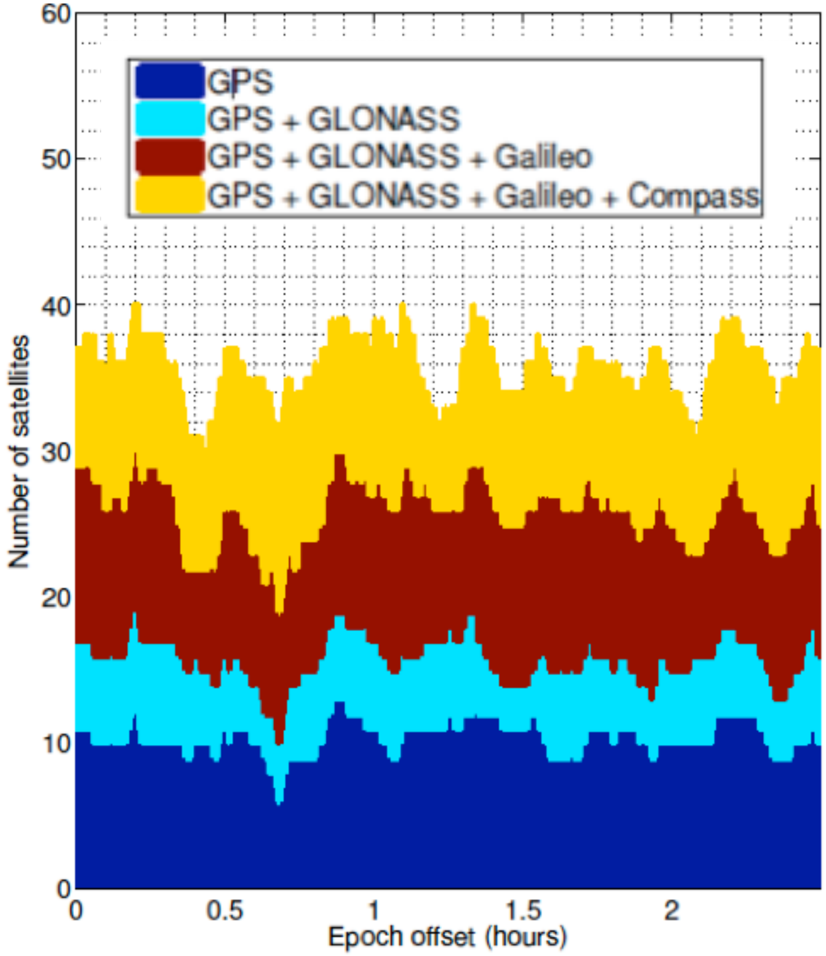
IMPROVED PERFORMANCE: AVAILABILITY; ACCURACY

- Additional GNSS satellites, signals and constellations will undoubtedly improve GNSS PNT performance – but how?
- Availability:
  - Increased signal availability at limited open-sky locations
  - Not a serious issue for maritime users
- Accuracy:
  - Improved accuracy
  - Given level of accuracy achieved faster
  - Positioning accuracy less susceptible to satellite geometry
  - Vertical accuracy approaching horizontal accuracy
  - Improved mitigation of interference and jamming
  - Each GNSS positioning mode should undergo incremental accuracy improvements
  - Law of diminishing returns takes effect at some point

IMPROVED PERFORMANCE: EFFICIENCY; RELIABILITY; INTEGRITY

- Efficiency:
  - Improved efficiency
  - Reduced time required for phase-based cm-level positioning
- Reliability and integrity:
  - Improved reliability
  - Increased data redundancy
  - Reduced signal denial
  - Improved continuity
  - Four independent GNSSs mean very remote chance of errors from all systems

SIMULATED NUMBER OF VISIBLE GNSS SATELLITES FROM RECEIVER ABOARD A LOW EARTH ORBITING SATELLITE



IMPROVED INTEROPERABILITY AND COMPATIBILITY

- Mixing different satellite signals in a receiver raises issues

- Interoperability:
  - Ability of GNSS services to be used together to provide user better capabilities than by using just one service
  - Implies same or very similar transmitted frequencies
- Compatibility:
  - Ability of GNSS to be used separately or together without interfering with each individual service or signal

- Degree of interoperability and compatibility that will be achieved is still unclear

EFFECTS OF GNSS PERFORMANCE IMPROVEMENTS ON MARITIME BOUNDARY DELIMITATION

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MARINE NAVIGATION

- GNSS evolution will not provide a “disruptive technology” as was the case with the introduction of GPS
- Higher navigation accuracy will be available, but not necessarily needed
- Additional integrity will be welcomed and will probably be adopted into standard navigation practices
- e.g., multi-GNSS navigation, and one GNSS as a back-up to another GNSS

HYDROGRAPHY

- Increased accuracy and integrity, improving mapping products, especially in vertical positioning component

- Current GPS positioning modes allow for products to meet IHO standards
- One consequence may be calls for higher mapping specifications given significantly improved performance of GNSS, inertial navigation, and sonar technologies

COASTAL TERRESTRIAL POSITIONING

- Expected that GNSS evolution will have greatest impact on coordination of coastal reference points
- More efficient and accurate relative, RTK and PPP GNSS positioning may mean further reduction in number of actual survey monuments and ability to confidently establish and re-establish coordinates at cm-level of accuracy in real-time

- Differences in datums and time scales between individual GNSSs must be rigorously accounted for
- Metre-level differences of little consequence in marine navigation
- 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

POTENTIAL DELAYS OR ALTERATIONS TO GNSS EVOLUTION

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POLITICAL DECISIONS

- 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 global powers
- Geopolitics has and mostly like will be crucial in plans being followed with action
- e.g., political (and economic) collapse of U.S.S.R. depleted GLONASS constellation, which was built as Soviet response to U.S. GPS during Cold War
- e.g., rise of Russian Federation has brought back GLONASS to full operation this year, due to it being seen as of primary strategic importance by Russian government
- e.g., a major justification for development of Galileo by EU was to remove reliance of such an important tool on close ally U.S.
- e.g., focus on Iraq and Afghanistan wars have required U.S. military to slow GPS Modernization and GPS III plans

FINANCIAL UNCERTAINTY

- Naturally linked to government policy is availability of funds to support these large, national programs
- At some point, political decisions and choices must be based on financial realities
- e.g., combination of political gridlock, but more importantly limited private support for development of Galileo, has delayed its implementation
- e.g., current economic situation in Europe may further slow satellite launch schedules and 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 coming years will unfold politically and financially, GNSSs continue to receive significant support from governments, and reliance on them continues to grow

COMPETING ACTIVITIES

- GNSS can be seen as a premier technology, but there are other technologies that have wider appeal to governments and people
- e.g., in U.S., frequency spectrum was initially allocated to company Light-Squared for development of a terrestrial, high-bandwidth wireless communications system in continental U.S
- It is possible that more such competing spectrum users will present themselves in coming years around world

INTEROPERABILITY AND COMPATIBILITY

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

OVER-RELIANCE

- GNSS evolution can only increase our dependency on satellite-based PNT
- Multiple, independent systems increases integrity and therefore limits over-reliance concerns
- However, these systems can all be negatively affected in same ways, such as via intentional and unintentional signal jamming
- Temptation to solely rely on GNSS, e.g., deactivation of U.S. Loran-C coast marine navigation system

PHYSICAL EFFECTS

- GNSS is an open-sky technology
- Physical blockage of GNSS signals will always be of concern in coastal areas, particular on shore
- Combination of GNSS with other sensors, such as inertial is a continued active research area

CONCLUSIONS

- GPS has revolutionised outdoor positioning
- We now live in a world of approximately 50 GNSS satellites of the GPS and GLONASS constellations
- By end of decade number will grow to over 125 satellites in four GNSS constellations
- Along with new satellites will come new signals and system architectures
- Expect more accurate positioning, navigation and timing, as well as increased availability, integrity and reliability
- 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 realities that political, economical and technical issues may slow or otherwise impact on this remarkable progress