Maritime & Coastguard Agency

MARINE INFORMATION NOTE

MIN 453 (M+F)

Navigation: Global Navigation Satellite Systems (GNSS) - Availability During Increased Sunspot Activity

Notice to all Owners, Masters, Skippers, Officers and Crews of Merchant Ships and Fishing Vessels

This MIN expires 31/03/2014

Summary

This MIN addresses several factors that may coincide over the next 5 years and produce an adverse impact on the availability of GNSS, and consequent effect on maritime navigation. The maximum of the solar cycle is predicted around May 2013, with increased frequency of GNSS performance degradation likely during the period 2012 to 2015 due to increased ionospheric scintillation and signal propagation delays.

1. Introduction/ Background

1.1 The use of Position, Navigation and Timing (PNT) information derived from Global Navigation Satellite Systems (GNSS) is widespread within many vessels' navigation systems and underpins situational awareness for many mariners. GNSS provides the positions of the ship and surrounding vessels and of Aids to Navigation (AtoN) for the Electronic Chart Display and Information System (ECDIS) and hence is the basis of relative positions displayed to the mariner. GNSS is also used in applications such as the correction of gyro compass drift, precise manoeuvring of ships (such as during the navigation of tight channels and docking), the position information within the Automatic Identification System (AIS), and vessel location reports in emergency situations.

1.2 Delivery of reliable, efficient and cost effective AtoN services for shipping has led to the establishment of coastal beacon differential GPS (DGPS), complementing traditional AtoN (lights and buoys), to provide GPS augmentation services for littoral navigation and harbour approach. The DGPS service safeguards navigation performance for shipping, to the standards required by the International Maritime Organisation (IMO), which require < 10m accuracy in coastal waters with an availability > 99.8%, as per IMO resolution A.1046.

1.3 The impact of the ionosphere on GNSS performance can be significant due to the propagation effects on the GNSS signals-in-space as they pass through the ionized ionosphere at altitudes above 50km from the earth's surface. GNSS signal propagation is affected to a greater extent during periods of higher solar activity (e.g. sun spots and solar

flares), when the effect of ionizing solar radiation creates more free electrons in the ionosphere. Solar activity is cyclical, peaking at a maximum approximately every 11 years, during which periods GNSS performance can be severely degraded, especially at equatorial, auroral and polar latitudes. The next solar maximum is predicted to occur during 2013, and this might be expected to lead to a period of reduced GPS constellation.

1.4 Galileo is unlikely to provide sufficient satellites to fill the gap left by a reduced GPS constellation. The Galileo schedule and associated regulatory activities will bring only limited benefit for maritime GNSS availability within the 2014 timeframe. However the GLONASS constellation is fully populated and providing global coverage and we would expect to see the full benefit of using GPS and GLONASS combined, once the whole GLONASS constellation has been updated to provide CDMA signals.

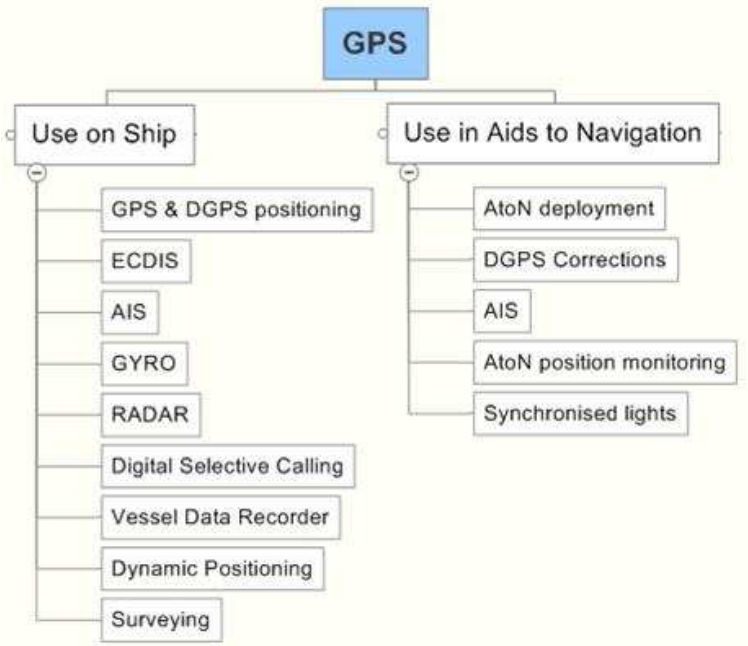
2. Impact of reduced GPS constellation

2.1 The General Lighthouse Authorities (GLA) of UK and Ireland studied the impact of a reduced GPS constellation, with the support of modelling and analysis by the GNSS Research and Applications Centre of Excellence (GRACE) at Nottingham.

2.2 With a 21-satellite constellation, simulation results have highlighted GPS coverage 'windows' (with only 3 satellites in view) that could last for several minutes at a time. During these periods, position accuracy is degraded with horizontal position errors typically increased by 50% and with occasional error spikes of the order of many tens of metres.

3. Reliance of shipping on GNSS

3.1 Satellite navigation is now essential to the efficiency and safety of shipping. GPS is at the heart of today's integrated bridges, with chart displays driven by GPS receivers that also control the auto-pilot. Separation from other vessels is ensured by radar used in combination with the Automatic Identification System (AIS), but on many vessels, these are not independent of GPS and they specifically alarm when GPS is lost; GPS stabilises the radar display and the ship's gyro-compass. It also provides the ship's coordinates transmitted by AIS to the displays on other vessels in the vicinity and to the Vessel Traffic Services (VTS) ashore. GPS even guides rescuers to the vessel in an emergency. The figure below shows the full uses of GPS.



3.2 During 2012 to 2015, the combination of solar maximum with the possible reduction in operational GPS satellites, compounded by the limitations of the Galileo and GLONASS constellations, may pose a real impact on maritime navigation.

4. Ionospheric effects on GNSS

4.1 During quiescent periods of solar activity, ionospheric effects on GNSS can be managed such that the residual errors caused by the ionosphere do not generally pose a problem to maritime navigation performance. The use of embedded models (such as the Klobuchar model) within a standalone GPS receiver is effective at reducing the pseudorange measurement error induced by the ionosphere propagation delay. Where DGPS corrections are available, over baseline separations up to several hundred kilometres, the DGPS corrections significantly reduce the common mode errors, including the effects of the ionosphere. However, at the peak of the solar cycle with high levels of sunspot activity, solar storms and flares, the application of ionospheric models and differential corrections may be less effective and this could increase the integrity risk to maritime navigation. Studies have indicated that amplitude scintillation has been observed to cause substantial errors in GPS pseudorange measurements. Standalone range errors of up to 60 metres have been reported.

5. Impact on marine navigation

5.1 Maritime navigation systems and services that rely on GNSS are at greatest risk of disruption from the ionosphere during the period from 2012 to 2015. The intensity of the radio flux during the solar peak may be less than in previous peaks and the impact on GNSS may on average be less severe. However, even during a quieter solar maximum, the occurrence of individual sun spots could give rise to significant effects for discrete events. The effects vary with latitude, season and time of day (the hours soon after sunset being most affected). It is also worth noting that during the last solar maximum the level of dependence on GNSS was quite low, whereas it is now very high.

5.2 The most significant errors experienced by GNSS are due to the effect of solar activity on the ionosphere. The magnitude of the effect of the ionosphere varies in both time and spatial extent. The effect is much greater during the day than during the night.

5.3 The effects of the ionosphere, if not mitigated, can introduce measurement errors of greater than 10 m (even for DGPS users) and in severe conditions, the receiver can lose lock on the signal. Users of dual and multiple frequency GNSS receivers will be less affected. Adverse conditions can persist for several hours, presenting a significant issue for navigation. The Space Weather Prediction Center (SWPC) in the United States of America provides alerts and warnings on their website at www.swpc.noaa.gov/index.html to show GNSS users where problems may occur and the potential effects on their operations.

5.4 The UK Hydrographic Office (UKHO) will issue navigation warnings on the basis of information provided to them by the SWPC or the UK Met Office. An example of the type of warning is as follows;

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NAVAREA ?? ??/13

SPACE WEATHER.
 1. STRONG SOLAR RADIATION STORM IN PROGRESS UNTIL 081000 UTC JAN. RADIO
 AND SATELLITE NAVIGATION SERVICES MAY BE AFFECTED.
 2. CANCEL THIS MSG 081100 UTC JAN.
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6. Conclusion

6.1 Ionospheric events during solar maximum, or the occurrence of coverage 'windows' caused by a reduced GPS constellation, could result in GPS outages of several minutes. Beacon DGPS (over baselines in coastal waters) should be resilient during outages, continuing to provide integrity by invalidating (by not transmitting corrections) GPS satellites that are not in view and by providing integrity monitoring and corrections for those that are visible. However, some configurations of ships' navigation systems may react to the GPS receiver's indication of 'no position solution' by causing bridge systems to alarm, impairing the mariner's situational awareness and forcing reversion to fallback navigation techniques (visual references, chart and compass).

6.2 A vessel equipped with Gyro and Log (measuring heading and speed respectively) should be able to maintain the vessel's navigation position through short periods of GPS outage, but accuracy would be expected to degrade gradually over a few minutes. At the end of the outage, when a GPS position is restored, some onboard systems may require manual intervention to reinitialise.

6.3 Where DGPS is not utilised, or a beacon has declared itself unhealthy, ionospheric events and reduced satellite availability may increase standalone GPS horizontal position errors with occasional large spikes in the errors. This may present a problem to the mariner, as the systems may not alarm and the increased uncertainty in position may not be adequately accounted by all onboard systems. In the worst case, the increased error may go unnoticed by the mariner and his situational awareness could be impaired and incorrect navigational decisions could be taken.

6.4 For further information, please refer to the Admiralty Publication NP100 The Mariner's Handbook 9th Edition, published by the UK Hydrographic Office.

More Information

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