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Removal of GPS Selective Availability - Consequences for DP Applications

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Abstract

This paper presents a summary of expected GPS and DGPS performance after the removal of GPS Selective Availability (SA). Performance is reviewed in terms of accuracy, availability and integrity. Special focus is given on the ionospheric effects on GPS and DGPS. The benefits of using dual frequency (L1/L2) GPS receivers are presented. GLONASS satellites can be used together with GPS in order to mitigate special availability and accuracy problems introduced by the ionosphere in equatorial waters. Therefore the current status of the Russian GLONASS system is also presented. Several examples of achievable accuracy GPS and DGPS are included.

A short review of available GPS and DGPS systems for DP and their potential application areas are presented, and it is proposed that GPS can be utilised as a standalone system with no differential corrections for some DP applications. Modifications to the DP control system in order to cater for the different performance levels that might be experienced are proposed.

Introduction

The removal of SA on 1st May 2000 implied that the accuracy of GPS was improved from a “guaranteed” horizontal accuracy of 100 m (95% probability) to approximately 15 m (95% probability). An official statement on the accuracy with SA removed is not yet released from the US Government. The ionospheric signal delay is the dominant error source after SA is turned off. This implies that the actual accuracy will vary with geographic location, the 11-year sunspot cycle, time of year and time of day. For latitudes higher than approximately 30 degrees horizontal accuracy better than 10 m can be expected most of the time.

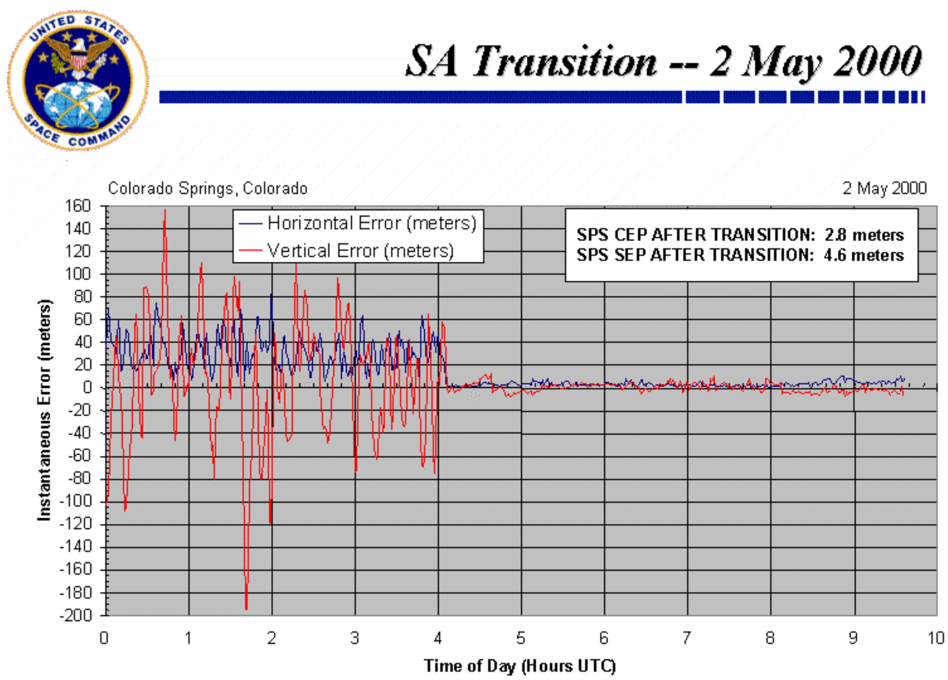

Figure 1. SA Transition: Accuracy Improvement in Colorado Springs.
(CEP: 50% horizontal accuracy. SEP: 50% 3-dimensional accuracy)

Return to Session Directory ►

Differential GPS (DGPS) has been used for offshore DP applications in order to compensate for systematic and periodic errors in the GPS signals. This has improved the accuracy to 1-10 m (95% probability) dependent on type of GPS receiver, processing algorithms, distance to reference stations etc. Due to the nature of Selective Availability (see Figure 1) it was dangerous to use standalone GPS for any DP applications and therefore such data was automatically rejected by the DP system. The removal of SA means that standalone GPS now can be used for some DP applications.

GPS and DGPS Accuracy

The expected accuracy level from GPS and DGPS is listed in the following table. The total error pr. satellite is computed as the Root Sum Squared of the statistically independent individual errors. Multiplying the total error per satellite with an average HDOP (here set to 1.6) gives the resulting position accuracy. It should be noted that the maximum HDOP can be significantly higher, especially when some satellites are lost. (See chapter on Availability). The table shows typical accuracy levels, meaning that the 95% accuracy generally will be worse than the figures presented in the table.

	GPS	DGPS
Error in Meters (per satellite)		
Orbit and Satellite clocks	2.0-3.0	0
Ionosphere	1.5-7.0	0.1-5.0
Troposphere	0.5-1.5	0.2-0.5
Receiver Noise, MultiPath	0.5-0.8	0.5-1.1
Selective Availability	30.0	0-2.0
Total (SA, Single Frequency)	30.3-31.0	0.5-5.5
Total (No SA, Single Frequency)	3.3-7.8	0.5-5.1
Total (No SA, Dual frequency)	2.1-3.4	0.7-1.9
Horizontal Position Accuracy (HDOP*Total)		
SA present, single frequency	~50	1-8
No SA, single frequency	5-12	1-7
No SA, dual frequency	3.5-5.5	1-2

Table 1. GPS and DGPS Accuracy

The table clearly shows the accuracy improvement after Selective Availability was removed. The most significant error source after removal of SA is the signal delay in the ionosphere. The effect of the ionosphere is discussed in more detail below. The actual accuracy for GPS will be lower near equator than at higher latitudes. The same applies for DGPS where significant accuracy degradation with distance to the DGPS reference station(s) is experienced in equatorial areas.

The signal delay in the ionosphere can however be removed by utilizing a dual frequency GPS receiver. This is the same principle as utilized in military GPS receivers, but can also be exploited by some civilian GPS receivers with “code-less” tracking techniques. Code-less tracking implies that the GPS receiver utilize known characteristics of the L2 code and carrier for tracking of the L2 signal in contrast to locking directly on to the encrypted military code on the signal. The code-less tracking gives decreased S/No ratio compared to the standard code and carrier locked tracking loops.

The table also shows the interesting fact that a dual frequency GPS receiver without DGPS corrections in some cases will give better accuracy than a single frequency receiver with corrections. The accuracy figures presented above are confirmed by several sources, and some example data are provided in this paper. Please note that, due to natural variations, these example data cannot be used to derive the exact accuracy from standalone GPS or DGPS at any location or time

Return to Session Directory ►

Ionospheric Activity

The accuracy figures presented above illustrate that the signal delay in the ionosphere generally is the worst remaining error source after SA was removed. The ionospheric activity will vary with:

- Geographic location. (Highest activity within ± 25° from geomagnetic equator)
- 11 year sunspot cycle (Peak during 1999 to 2001)
- Seasonal variations (Most activity during the period November to March)
- Daily variations (irregularities worst during evening/night, absolute level highest during day)

The ionospheric activity has **two** effects on GPS and DGPS:

1. Degradation of absolute accuracy that will be seen all over the earth, but the largest magnitude is in equatorial areas. Absolute accuracy is degraded because of the signal delay through the ionosphere. The signal delay is directly correlated with the number of free electrons in the atmosphere. (Total Electron Content, TEC is the measurement unit).
2. Ionospheric noise (scintillation) might lead to data outages (loss of positioning or significantly degraded positioning) due to loss of lock on one or more satellites.

Both the absolute accuracy degradation as well as the number of occurrences of ionospheric irregularities will vary with the 11-year sunspot cycle. The figure below shows historic data. A new peak somewhat smaller than the preceding ones is expected in mid 2000. This implies that the coming two winters will give more or less the same level of activity as the two previous.

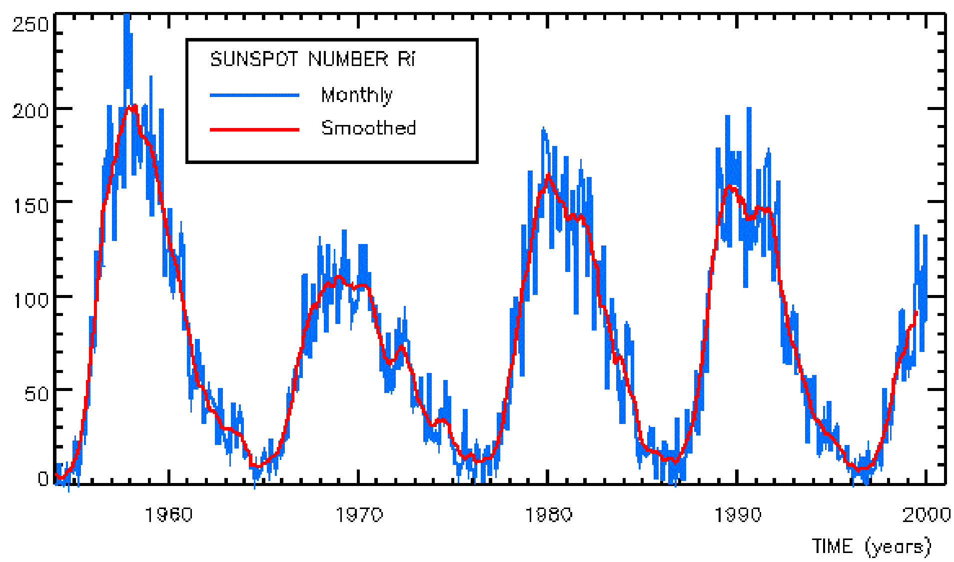

Figure 2. Historic Sunspot data

Ionospheric Accuracy Degradation (Systematic Errors)

The TEC (Total Electron Content) is directly correlated with ionospheric delay and hence with accuracy for single frequency GPS. The figure below shows the actual TEC for one given time and day. The area with large TEC will move during the day and that the magnitude. Also the extent of the red area can be signifcantly larger for other days. At times of high sunspot activity, the areas with high TEC values might be extended; up to latitudes of 40 to 50° compared to 20 to 30° for this particular figure.

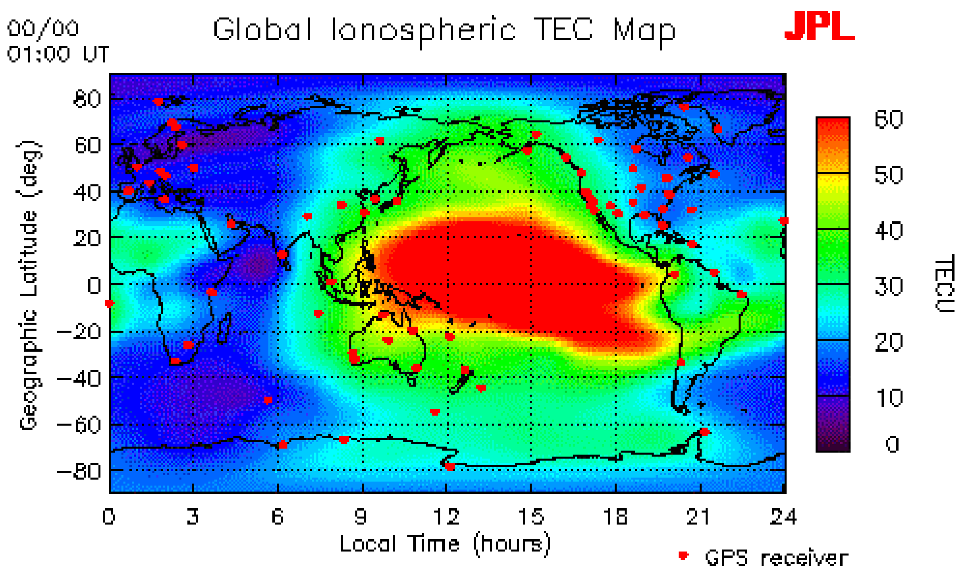

Figure 3. Ionospheric TEC Map

The GPS system includes a model of the TEC as a function of geographic location and time in order to compensate for this error. However, due to "unpredictable" variations this model will on average not correct for more than approximately 50% of the actual delay, and the remaining error may be as large as 15 m for some satellites.

On very short distances between reference station and mobile user, the signal path through the ionosphere will be strongly correlated, and the differential correction will totally eliminate the ionospheric delay. As the distance between reference station and mobile user grows the correction data becomes less correlated with the actual data on the vessel. With reference to Figure 3, the mobile user may be in the red area (high ionospheric delay) and the reference station may in the blue area (low ionospheric activity).

The military GPS signal (Precise Positioning Service) was designed with two L-band frequencies in order to eliminate the ionospheric delay. The same method is employed in some civilian receivers through "code-less" tracking of the L2-signal. This will give weaker signal strength and more measurement noise on the L2 frequency compared to PPS. The L2 data can however be utilised to correct for ionospheric delay. A dual frequency DGPS system requires L1/L2 receivers both at the reference station and at the mobile user.

Single versus Dual Frequency DGPS; August 22nd 1999

The following two figures shows the accuracy with single and dual frequency DGPS on the baseline from Douala to Luanda in West Africa (distance 1467 km). It can be seen that utilisation of dual frequency DGPS gives a major accuracy improvement; from 13.2 m to 2.2 m (95 % horizontal accuracy). These graphs also illustrate the daily accuracy variations, with a very quiet period from 2 to 9 UTC and significantly reduced performance for the rest of the day.

Return to Session Directory ►

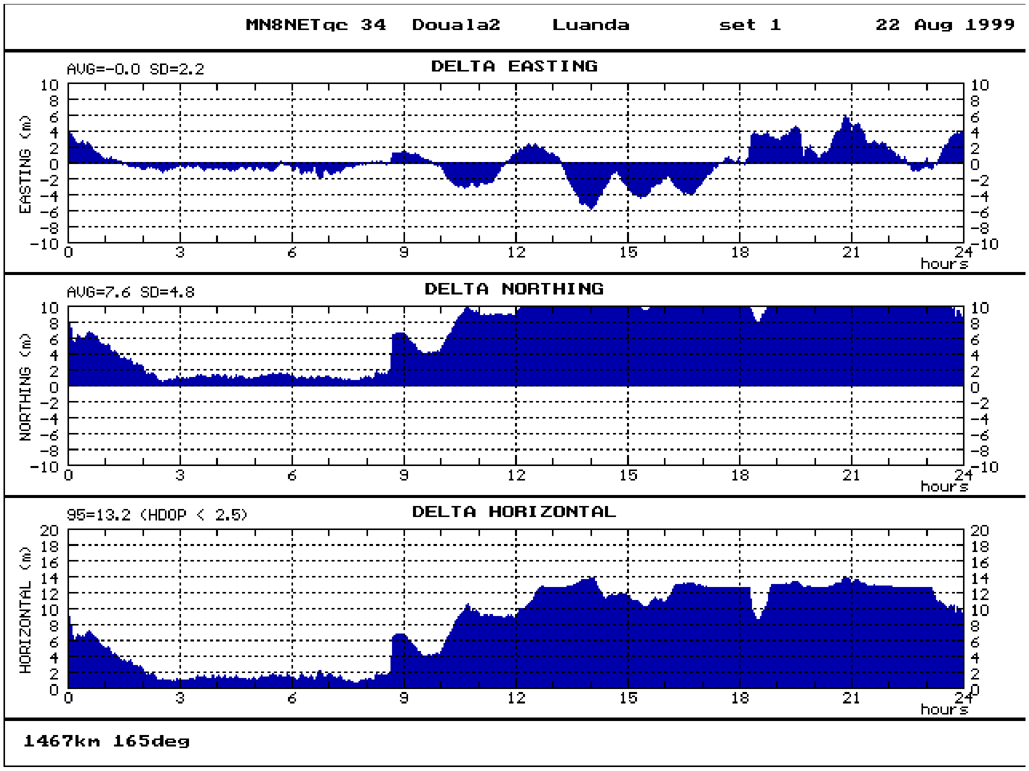

Figure 4. Single Frequency DGPS. Douala/Luanda 22.08.99

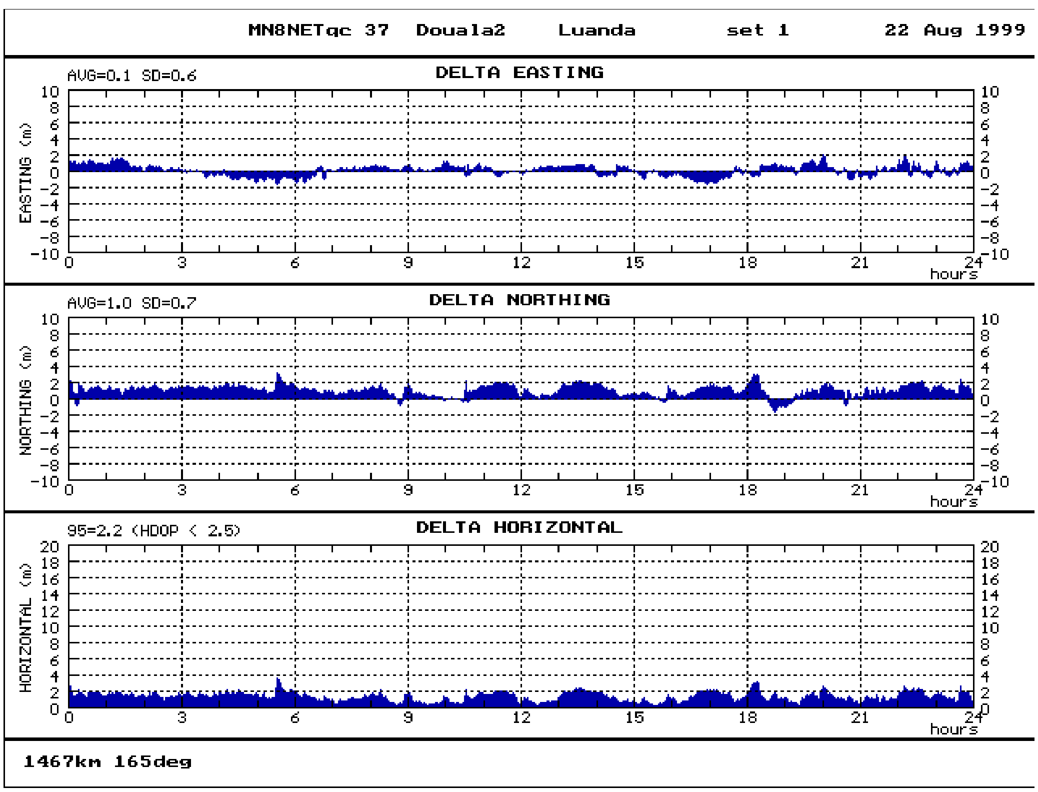

Figure 5. Dual frequency DGPS. Douala / Luanda, 22.08.99

Return to Session Directory ►

GPS and DGPS Availability

GPS Constellation Availability

The availability of the GPS satellite constellation cannot be seen isolated from the accuracy requirements. One approach might be to look at the time-periods where the satellite geometry exceeds a defined threshold. A PDOP value up to 6 is typically used as a limit for acceptable geometry. Simulations can be run in order to assess the availability both for certain areas as well as for predicting global availability. Such data are presented daily on the USAF GPS Control Centre web site. Global availability as a function of number of active (healthy) satellites is illustrated in the figure below. The figure clearly illustrates that, despite a constellation of 27 to 28 satellites, some areas of the world will experience short periods of degraded performance when one or two satellites are withdrawn from service due to maintenance.

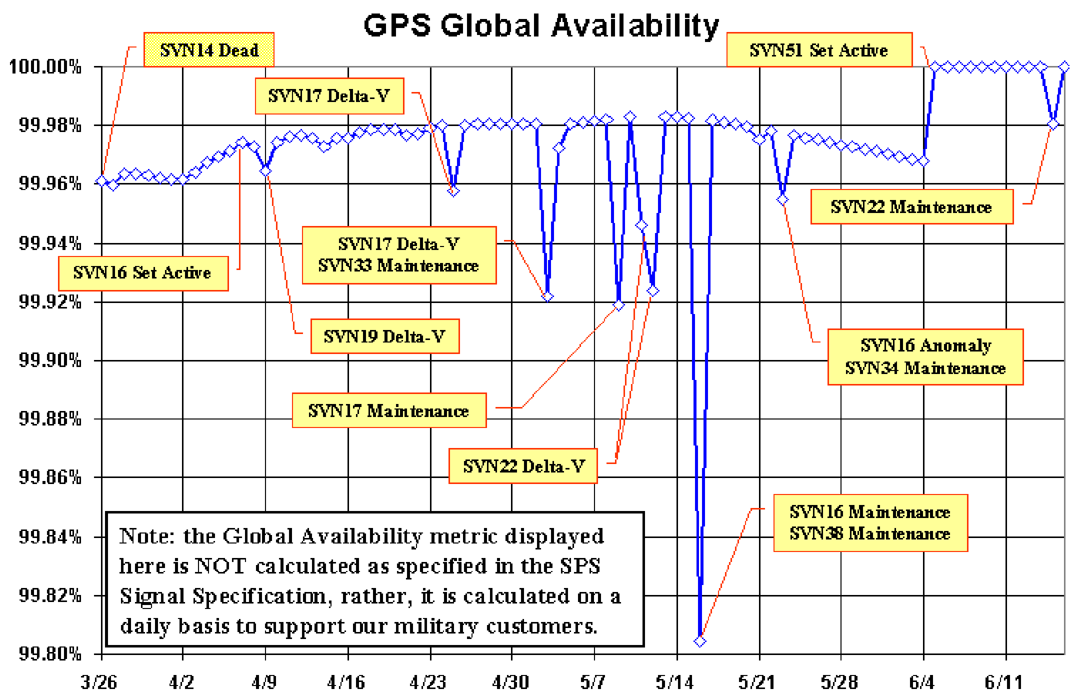

Figure 6. Global GPS Availability (March 26 to June 16 2000)

Correction Update Rate

The nature of Selective Availability meant that frequent correction updates (less than 10 seconds) was needed in order to compensate for the position error. The SA also implied large velocity errors for standalone GPS. With the removal of SA, the velocity error will be much smaller and correction updates is typically not needed at update periods faster than 60 to 120 seconds. This means that DGPS now will be less influenced by short time correction failures on the correction links and that the overall availability of the DGPS system will be improved.

Geometry degradation for DGPS

The basic principle for DGPS is to correct satellite data at the mobile user with correction data from the reference station. This means that only satellites in common view from the mobile user and reference station will be used for computing a position fix. At long distance from reference station to mobile user this will give a slight degradation of the experienced satellite geometry. I.e. the number of available satellites is reduced and the PDOP value is increased.

Example data from Brazil (7 hr of data on 8th July 2000) is included below. Number of satellites and PDOP in Rio is compared for the stand-alone situation and using correction data from Recife at a distance of 1870 km. The figure illustrates that a DGPS system is slightly more vulnerable to loss of satellites than a stand-alone GPS system. Even though PDOP is improved for standalone GPS, the positioning accuracy might be worse due to larger errors in the measurements. (See Table 1).

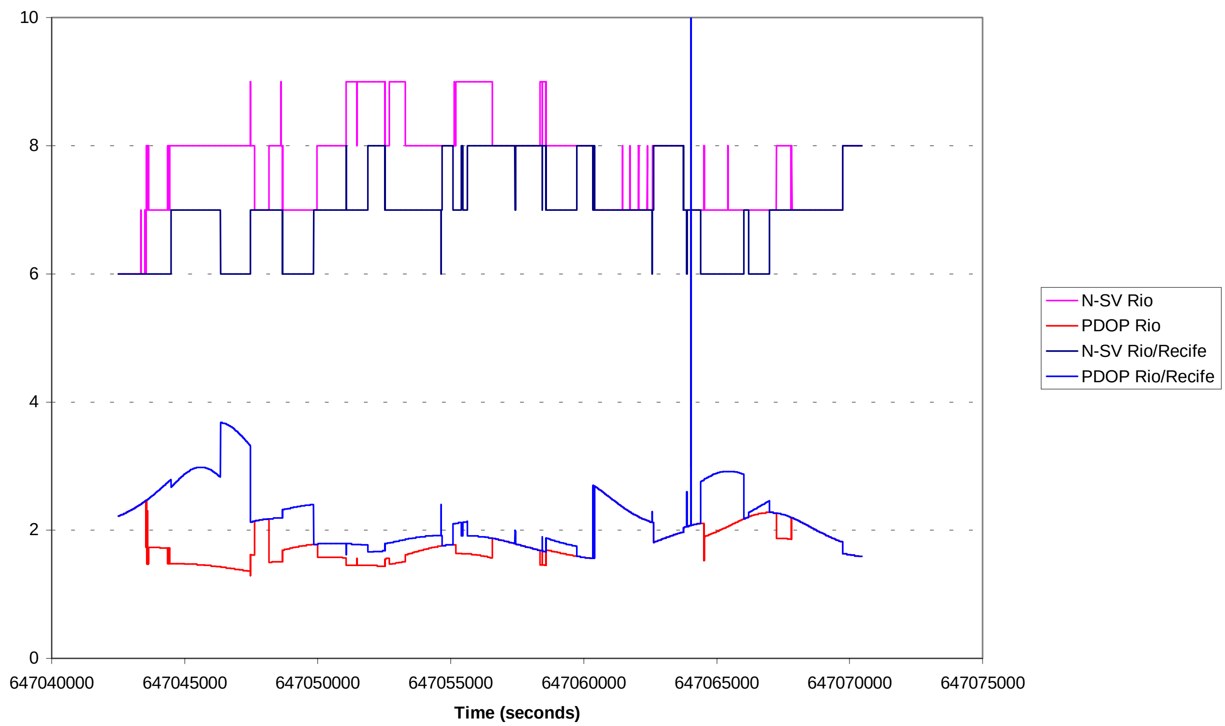

Figure 7. Satellite Geometry for Rio and Rio/Recife

Ionospheric Irregularities (Noise / Loss of DGPS position)

As mentioned above, ionospheric activity might also lead to loss of lock on some of the satellite signals. This occurs when the TEC level changes very rapidly and the GPS receivers bandwidth is too narrow to follow the variation. Rapid change in TEC level is called scintillation and affects satellite telecommunication as well as GPS. Scintillation will very seldom lead to loss of lock on all satellites at the same time. Scintillation strong enough to completely loose lock on the satellite signal is reported most frequently from equatorial areas, but it might be a problem in the auroral oval as well. The auroral oval is the area where aurora borealis or northern light is seen. In the winter 1999-2000 there were several periods where GPS was reported useless for more than 1 hour each night in Brazil due to scintillations combined with severe accuracy degradation.

The figure below is a model of the frequency of ionospheric irregularities (scintillation) for one particular day and time. The affected area will move within the dashed lines as a function of time of day, and the frequency of occurrences will vary from day to day. The figure illustrates where loss of satellites might occur, and it can be seen that this area is more distinctly related to the area ±20° from **geomagnetic** equator (±30° geographic latitude). Please note that a GPS-receiver north or south of this area will receive satellite signals that have passed through the affected part of the atmosphere.

Return to Session Directory ►

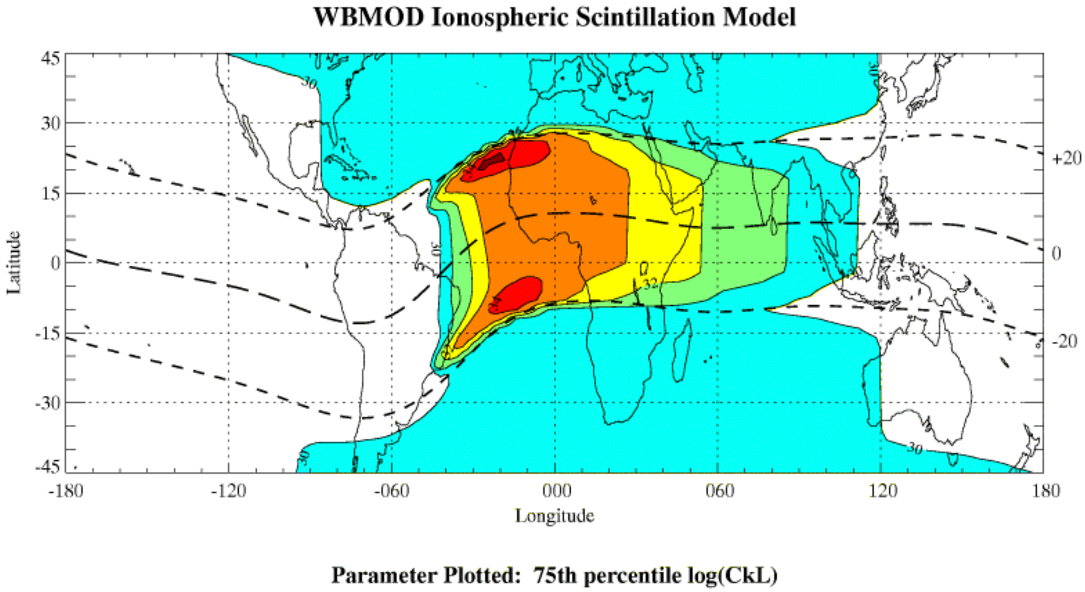

Figure 8. Ionoshperic Irregularities (scintillations)

Utilization of dual frequency GPS does not improve the situation in terms of availability. The general accuracy level is improved, but the reduced signal level on L2 means that these data are even more suspect to loss of lock than the L1 signal.

The only factor that significantly improves positioning availability is tracking of more satellite signals. Signals will not be blocked in all directions simultaneously. This means that a 12-channel "All-In-View" receiver should be mandatory in these areas. A 6 or 8 channel receiver might waste time looking for a satellite that is blocked due to scintillation, while an other satellite could be tracked with slightly degraded geometry compared to the optimum constellation. Another way to improve satellite availability is to utilise a combined GPS/GLONASS receiver.

GLONASS Constellation Status

The current status of the GLONASS system is that only 8 satellites are operational. The last launch of new satellites was on 30.12.98 and since then the active constellation has dropped from 12-13 operational satellites down to the current number of 7-8. This means that GLONASS has reduced impact in situations where some or more GPS satellites are lost. We need to have at least 2 GLONASS satellites above the horizon in order to get any additional information from the combination of GPS and GLONASS.

Unless new GLONASS satellites are launched, the GLONASS constellation will probably be reduced to 5 to 6 operational satellites before the end of this year. (Four of the remaining satellites have exceeded trhe design lifetime of four years). This again implies that a combined GPS/GLONASS receiver will have a limited advantage compared to a GPS receiver.

Return to Session Directory ►

The geographic areas where combined GPS/GLONASS has shown benefits compared to standalone GPS have been limited to areas with GLONASS reference stations, i.e. North Sea, Caribbean, Florida and Brazil. Application areas have been:

1. North Sea: Platform Support Vessels; increased availability of positioning near platforms where many satellites might be obstructed by the platform.
2. Brazil: General GPS positioning; increased availability of positioning in periods with large ionospheric disturbances (scintillation).

Single/Dual Frequency DGPS + DGLONASS, Rio–Macae; March 21st 2000

The first graph clearly shows the effect of ionospheric delay and disturbances even with a short distance to the reference station. The disturbances can cause loss of lock on one or more satellites and is the reason for the “spikes” in the data series. The second graph shows improved accuracy because of **three** factors: dual frequency corrections, multiple reference stations and utilisation of differential GLONASS together with the DGPS solution. (I.e. this figure cannot be used to derive the additional benefit of using GLONASS alone). The GLONASS satellites provide increased robustness towards loss of satellites due to ionospheric noise (scintillation). At the time of these tests there were 11 operational GLONASS satellites compared to the current 7.

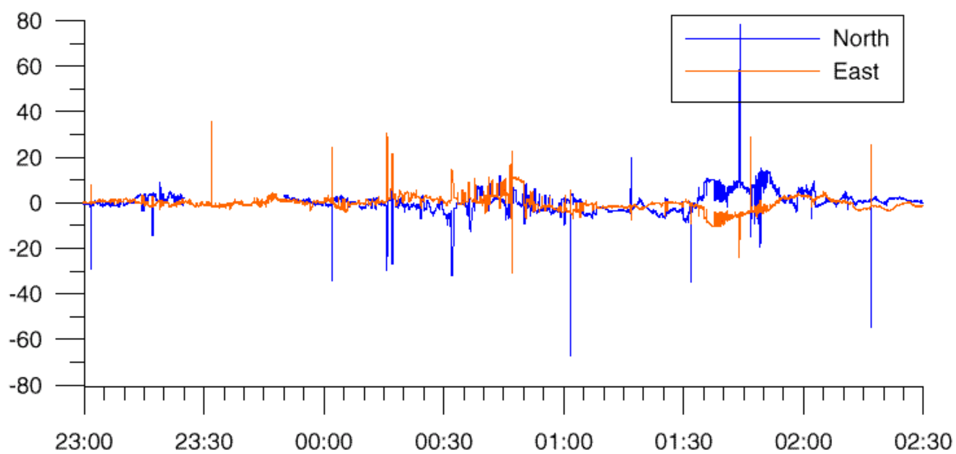

Figure 9. Single Frequency DGPS, Macae – Rio (80 km)

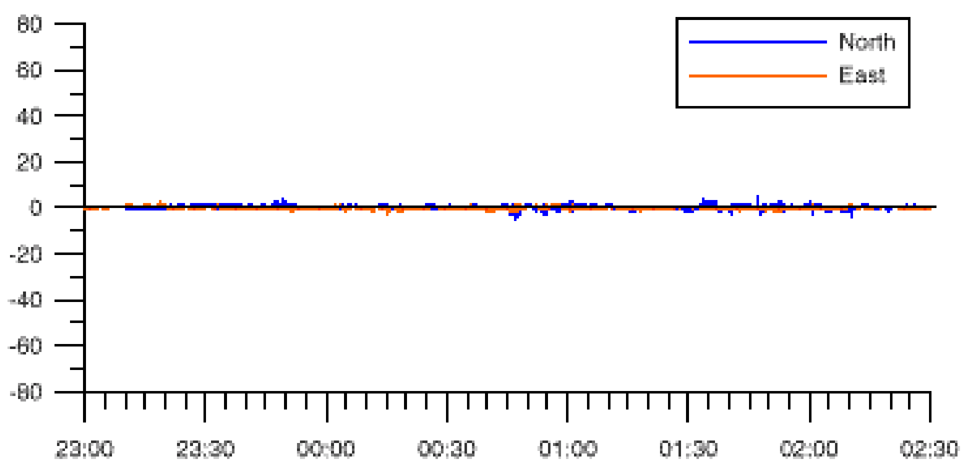

Figure 10. Dual frequency DGPS+DGLONASS Multiref, Macae – 2*Rio (80 km) / Recife (1870 km)

GPS and DGPS Integrity

In addition to the improved accuracy, DGPS also provides **integrity** monitoring of the GPS signals. This means that any failure in GPS satellite signals will be corrected or rejected by the reference station and that the mobile user not will apply erroneous signals. The integrity monitoring (differential corrections) will however not correct for local errors on the vessel such as multipath, GPS receiver errors or failure in the reference station itself. From the DP classification society, there is no requirement or condition that reference systems shall have built-in integrity. This is one of the reasons that class II and class III DP applications have requirements to independent position reference systems.

For standalone GPS the receiver should have built in Receiver Autonomous Integrity Monitoring (RAIM) in order to compensate for the lost integrity monitoring information from the reference station. Most GPS receivers used for DP purposes already have such algorithms (according to UKOOA QC standards), which are utilised in differential mode. The algorithms are designed to detect and reject failures when possible, and a by-product of the algorithms is an estimate of the accuracy of the position fix. Utilisation of the same algorithms for stand-alone GPS implies that the failure detection threshold normally will be raised compared to a DGPS system.

GPS Products and Application Areas

The following table gives a summary of the different application areas for different types of GPS equipment. In addition to the system types listed in the table, it should be mentioned that DGPS service providers, such as Racal and Fugro, now are offering solutions with dm-accuracy (Long Range or Wide Area Kinematic GPS) for some offshore areas.

The table is divided into “Relaxed Accuracy” and “High Accuracy” requirements. “Relaxed Accuracy” can typically be Deep-Water drilling, standby vessels, cable lay far from shore and some manoeuvring applications. “High Accuracy” typically will be heavy lift, construction work, dredging, pipe lay etc. From the table it can be seen that dual frequency GPS in standalone mode meets relaxed accuracy requirements for all geographic areas, whereas GPS and GPS/GLONASS only meets these requirements in differential mode. As discussed in the preceding chapters, a combination of dual frequency GPS and GPS/GLONASS (subject to GLONASS satellite availability) might be a benefit in equatorial areas in order to mitigate both the ionospheric accuracy degradation and the ionospheric scintillation effects.

	GPS		**Dual frequency GPS**		**GPS/GLONASS**	
	Standalone	Diff.	Standalone	Diff.	Standalone	Diff.
Relaxed Accuracy; Equator	—	XX	XX	XX	—	XX
Relaxed Accuracy; High Latitude	X	XX	XX	XX	X	XX
High Accuracy, Equator	—	X	—	XX	—	X
High Accuracy; High Latitude	—	XX	—	XX	—	XX
Legend: — Not suited for the application / area X Suited for the application / area XX Well suited for the application / area						

Table 2. Application Areas for different GPS systems

Return to Session Directory ►

Proposed Modifications to DP System

Single frequency DGPS at some distance from the reference station as well as stand-alone GPS will lead to a systematic and long-periodic nature of the resulting position errors. The reason for the systematic and long-periodic nature is slow variation in atmospheric and orbital errors combined with variations in satellite geometry as the satellites move. Position jumps of some meters might be experienced on satellite changes. (The same tendency with long-periodic errors is evident for all DGPS systems, but amplitudes and periods might be larger for stand-alone GPS or DGPS with long distance to the reference station).

This gives new challenges to the integration of the position reference systems in the DP. Expected accuracy derived from the RAIM algorithms in the GPS receiver should be passed on to the DP system in order to facilitate proper relative weighting between the available position reference systems and for adjustment of the failure detection algorithms in the DP. Also the DP estimator gains should be adapted to the actual accuracy level.

Dependent on the application the DP operator should be allowed to define what performance level that is needed for the application by defining performance level from the GPS/DGPS system. Such performance parameters could be:

- Reject stand-alone GPS in contrast to only issue a warning when corrections are lost and still keep on using the data
- Define maximum acceptable HDOP for utilisation of data (or issue of warning for extra precaution from operator)
- Define maximum acceptable accuracy level for utilisation of data (or issue of warning for extra precaution from operator)

Acknowledgements

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