International Civil Aviation Organization

MIDANPIRG Communication, Navigation and Surveillance Sub-Group

Ninth Meeting (CNS SG/9)
(Cairo, Egypt, 19 – 21 March 2019)

Agenda Item 4: CNS planning and implementation in the MID Region

GNSS ISSUES

(Presented by the Secretariat)

SUMMARY

This paper presents the Guidance on GNSS implementation in the MID Region, and the RSA on GNSS vulnerabilities. The aim of this paper is to highlight the importance of cooperation with relevant authorities to protect the GNSS Signal.

Action by the meeting is at paragraph 3.

REFERENCES

- ANC/13 Report
- MSG/6 Report
- RSC/6 Report

1. INTRODUCTION

1.1 The GNSS is a vital component to the Air Navigation and that has been increasingly used by many Aviation applications.

2. DISCUSSION

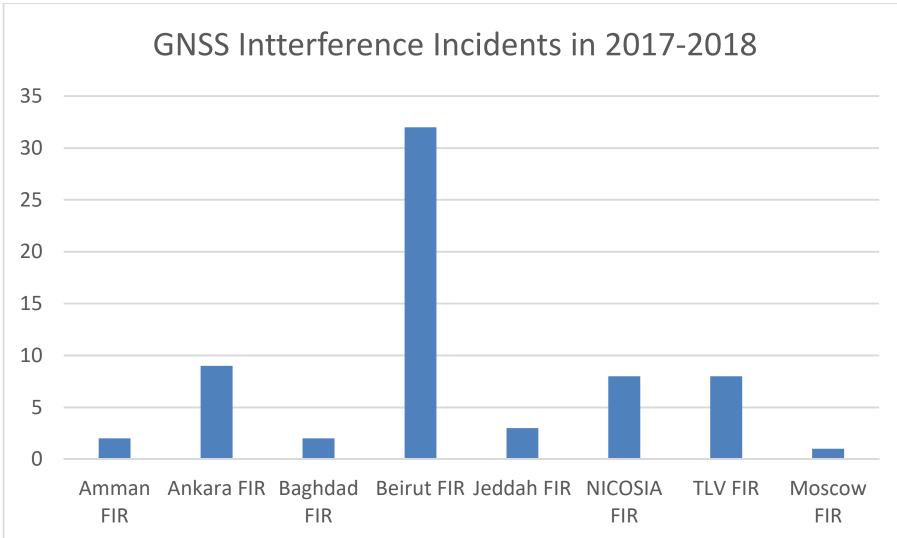
2.1 MSG/6 meeting through Conclusion 6/31 endorse the Guidance on GNSS Implementation in the MID Region, the document has been published as MID Doc 011.

MSG CONCLUSION 6/31: GUIDANCE ON GNSS IMPLEMENTATION

That, the Guidance on GNSS Implementation in the MID Region at ***Appendix A*** *is endorsed and be published as ICAO MID Doc 011.*

2.2 The meeting may wish to recall that MIDANPIRG/16 recognized the impact of the GNSS signal interference and vulnerabilities and agreed that as a first step it is needed to gather data on actual interference causes and users were also requested to collect data from pilots using the reporting form adopted by the meeting.

2.3 Sixty-five (65) interference incidents have been reported by users in 2017 and 2018 as depicted in the following Graph:



2.4 RASG-MID Safety Advisory (RSA) on GNSS vulnerabilities has been developed at **Appendix B**, and will be presented to the RASG-MID/7 meeting for endorsement.

2.5 The meeting may wish to note the following ANC/13 Recommendation 2.2/2 on GNSS evolution:

Recommendation 2.2/2 — Global navigation satellite system (GNSS) evolution

That States:

a) when defining their air navigation strategic plans, take advantage of the improved robustness and performance offered by dual-frequency, multi constellation (DFMC) global navigation satellite system (GNSS) to deliver incremental operational benefits and encourage related industry developments;

b) avoid, in principle, prohibiting the use of available GNSS elements if they perform according to ICAO Standards and Recommended Practices (SARPs) and can meet all safety and regulatory requirements for the intended operations;

c) avoid mandating equipage or use of any particular GNSS core constellation or augmentation system unless clear operational benefits are offered in return and appropriate consultations have been made with the relevant airspace users;

d) ensure implementation of ICAO provisions for publication of information related to the use of GNSS elements in aeronautical information publications (AIP); and

e) take timely action to meet the long-term goal whereby every State accepts for lateral navigation use all GNSS elements that are compliant with SARPs, thus creating a positive environment for DFMC GNSS.

That ICAO:

e) continue the development of SARPs and guidance material for existing and future GNSS elements in coordination with recognized standards-making organizations;

f) further develop provisions intended for States and organizations that provide GNSS services regarding publication of service performance standards, regular performance assessment and timely notification of events that may affect the service; and

h) develop additional guidance addressing technical and regulatory aspects to assist States in their acceptance and use of existing and future GNSS elements.

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) review and amend, as deemed necessary, the GNSS interference Reporting procedure in the RSA GNSS Vulnerabilities; and

b) urge States to strengthen cooperation with their National Telecommunication Authorities in protecting GNSS signal, timely identification and locating source of interference.

APPENDIX A

MID Doc 011

INTERNATIONAL CIVIL AVIATION ORGANIZATION

MIDDLE EAST AIR NAVIGATION PLANNING AND IMPLEMENTATION REGIONAL GROUP (MIDANPIRG)

GUIDANCE ON GNSS IMPLEMENTATION IN THE MID REGION

EDITION DECEMBER, 2018

AMENDMENTS

The GNSS Guidance in the MID Region should be reviewed and updated by the CNS Sub-Group. States shall submit their proposal for amendment to the Plan to the ICAO MID Regional Office, the changes can be coordinated by correspondence with main CNS focal points/ or State letters.

The table below provides a means to record all amendments. An up to date electronic version of the Plan will be available on the ICAO MID Regional Office website.

Edition	Date	Comment	Section affected
V0.1	11/2/2018		All
V0.2	1/4/2018	Add NDB IDs to the Appendix A	Page 26-28

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ACRONYMS

AO	Aircraft Operators
AAIM	Aircraft Autonomous Integrity Monitoring
ABAS	Aircraft Based Augmentation System
APCH	Approach
CAPEX	Capital Expenditure
DME	Distance Measuring Equipment
DOP	Dilution of Precision
EGNOSS	European Geostationary Navigation Overlay Service
FD	Fault Detection
FDE	Fault Detection and Exclusion
GAGAN	GPS Aided GEO Augmented Navigation
GBAS	Ground Based Augmentation System
GLONASS	Global Navigation Satellite System
GLS	GBAS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ILS	Instrument Landing System
INS	Inertial Navigation System
IRS	Inertial Reference System
LNAV	Lateral Navigation
MLS	Microwave Landing System
MSAS	MTSAT Satellite based Augmentation System
NDB	Non-Directional Beacon
NPA	Non-precision Approach
NSE	Navigation Sensor Error
OPEX	Operating Expense
PA	Precision Approach
PBN	Performance Based Navigation
RAIM	Receiver Autonomous Integrity Monitoring
RNAV	Area Navigation
RNP	Required Navigation Performance
SBAS	Satellite Based Augmentation
SDCM	System of Differential Correction and Monitoring
VOR	Very High Frequency Omni Directional Radio Range

THE OBJECTIVE AND SCOPE OF THE DOCUMENT

The objective of this document is to provide States in the Middle East Region with guidance for GNSS implementation based on the Global Air Navigation Plan and Regional Requirements.

The document outlines the status of Satellite constellations and Augmentation systems worldwide, with focus on the available Augmentation systems that can be implemented in the MID Region; the services provided, and requirements to exploit these Navigation services. Moreover, the document provides practical information on GBAS deployment, with reference to other Regions experience and factors to be considered in the process of cost estimation for the cost benefit analysis.

The GNSS application is out of scope of this document and addressed in the MID PBN implementation plan and the MID Region Surveillance Plan. As the GNSS is the key enabler for PBN implementation, this guidance document developed to complement the information in the MID PBN implementation Plan; ICAO MID DOC 007.

This document is divided into three parts; Part one includes information about the GNSS and Augmentation systems worldwide, and ICAO GANP Navigation Roadmap.

Part II identifies the current conventional Navigation aids infrastructure in the MID Region. And focuses on the SBAS Systems that may extends their services to the MID states.

Part III addresses the GNSS vulnerabilities due to intentional and unintentional sources of interference and to certain ionospheric effects. Also, it defines mitigation strategies to be deployed by States to reduce the likelihood and impact of the GNSS interference as defined by ICAO.

Part I: General Navigational Infrastructure

Navigation Aids Infrastructure refers to the ground and space-based NAVAIDs and provides positioning capability.

1- TERRESTRIAL NAVIGATIONS

Terrestrial Navigation Aids "conventional" refers to ground-based navigations such as NDB, ILS, VOR, TACAN, DME, …, etc.

The basic principle of all of these navigation facilities is the fact that aircraft in general navigate towards and away from the navigation aid itself, "point to point". This means that the location of the navigation aid must be in an optimized location. This optimized position is, in many cases, not achievable (due to being situated in high terrain, open seas, politically unacceptable areas, etc.). Therefore, the route structure must be aligned with the position of the navigation aid and not aligned in the ideal position for its purpose. This results in additional distances being flown by aircraft which has a number of disadvantages including economic, environmental and efficiency drawbacks.

In addition to the additional distance flown a number of other problem areas arise;

- High terrain. At airports located in high terrain with difficult accessibility arrival procedures, based upon conventional ground based navigation aids, may result in aircraft being unable to land at the airport safely during periods of low visibility.

- Lateral containment of tracks. With conventional ground based navigation aids the accuracy of the track to be flown is a factor of how close to the aid the aircraft is. The closer the aircraft is to the aid the more accurate the track keeping capability. As the aircraft gets further away from the aid the accuracy reduces. This requires that a maximum distance for the aid to be used must be published and that the route spacing requires to be established on the worst case scenario.

In the global context, GNSS based PBN procedures have been implemented, and several GLS (CAT I) procedures are in place.

2- GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

GNSS is a satellite-based navigation system utilizing satellite signals, for providing accurate and reliable position, navigation, and time services to airspace users. It provides location and time information anywhere on, or near, the earth in all weather conditions.

In 1996, the International Civil Aviation Organization (ICAO) endorsed the development and use of GNSS as a primary source of future navigation for civil aviation. ICAO noted the increased flight safety, route flexibility and operational efficiencies that could be realized from the move to space-based navigation. Today several GNSS systems are available in the world, the first system in operation was the Global Positioning System (GPS).

2-1 GPS

The Global Positioning System (GPS) is a space-based radio-navigation system consisting of a constellation of satellites and a network of ground stations used for monitoring and control. Currently 32 GPS satellites orbit the Earth at an altitude of approximately 11,000 miles providing users with accurate information on position, velocity, and time anywhere in the world and in all weather conditions.

GPS is operated and maintained by the Department of Defense (DoD).

2-2 GLONASS

The Russian Global Navigation Satellite System, which began operation in 1993. GLONASS network provides real-time positioning and speed data for surface, sea and airborne objects with an accuracy of one meter (three feet).

A group of 28 GLONASS satellites was in orbit as of April 2014, with 24 in operation, three spares, and one in the test-flight phase.

2-3 Galileo

Galileo is Europe's Global Satellite Navigation System (GNSS), providing improved positioning and timing information with significant positive implications for many European services and users. The system is still under deployment.

2-4 BeiDou

The BeiDou Navigation Satellite System (BDS) built and operated by China with a three-step strategy of development: to complete the construction of the BDS-1 and provide services to the whole country by the end of 2000; to complete the construction of the BDS-2 and provide services to the Asia-Pacific region by the end of 2012; and to complete the construction of the BDS and provide services worldwide around 2020.

2-5 RNSS

Regional Navigation Satellite System (RNSS) like NAVIC and QZSS. The Indian Regional Navigation Satellite System (IRNSS) with an operational name of NAVIC. QZSS is a system especially for usage in the Asia-Oceania regions, with a focus on Japan.

3- AUGMENTATION

Augmentation System provides additional data to users of GNSS equipment to improve accuracy, integrity, availability, or any other improvement to positioning, navigation, and timing. A wide range of different augmentation systems have been developed.

3-1 Space Based Augmentation System (SBAS)

SBAS systems are designed to augment the navigation system constellations by broadcasting additional signals from geostationary (GEO) satellites. The basic scheme is to use a set of monitoring stations (at very well-known position) to receive GNSS signals that will be processed in order to obtain some estimations of these errors that are also applicable to the users (i.e. ionospheric errors, satellite position/clock errors, etc.). Once these estimations have been computed, they are transmitted in the form of "differential corrections" by means of a GEO satellite.

Wide range of SBAS systems, designed according to the same standard have already been commissioned by the US (Wide Area Augmentation System WAAS) and Japan (MTSAT Satellite based Augmentation System MSAS).

Other systems are under commissioning or deployment in other regions of the world (e.g. GPS Aided GEO Augmented Navigation GAGAN in India and System of Differential Correction and Monitoring SDCM in Russia).

The current and planned SBAS systems coverage depicted in the figure (1-1)

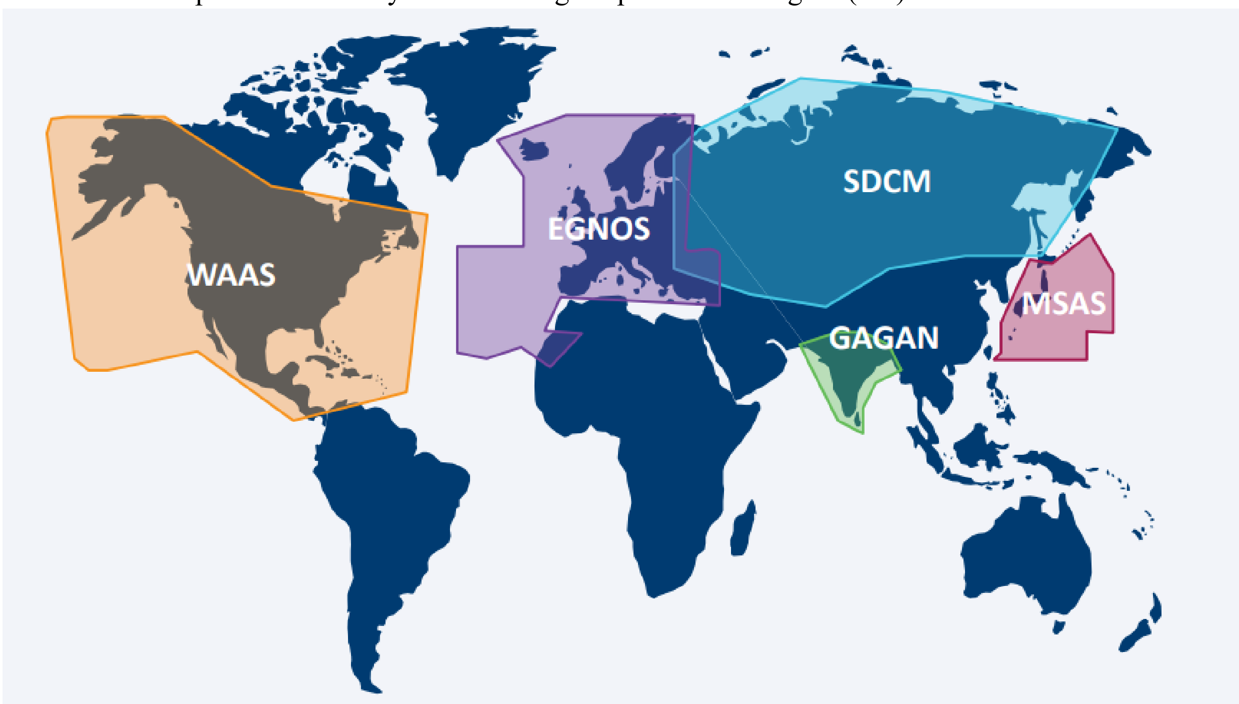

Figure (1-1)

3-1-1 WAAS

The Wide Area Augmentation System (WAAS) is an Air navigation aid developed by the Federal Aviation Administration to augment the Global Positioning System (GPS), with the goal of improving its accuracy, integrity, and availability.

3-1-2 EGNOS

The European Geostationary Navigation Overlay Service Navigation (EGNOS) is the European implementation of SBAS. Originally it was planned to augment GPS and GLONASS. Today, EGNOS augments GPS signals. EGNOS provides corrections and integrity information to GPS signals over a broad area centered over Europe and it is fully interoperable with other existing SBAS systems.

EGNOS provides three services:

- Open Service (OS), freely available to any user;
- Safety of Life (SoL) Service, that provides the most stringent level of signal-in-space performance to all Safety of Life user communities;
- EGNOS Data Access Service (EDAS) for users who require enhanced performance for commercial and professional use.

The main objective of the EGNOS SoL service is to support civil aviation operations down to Localizer Performance with Vertical Guidance (LPV) minima. In order to provide the SoL Service, the EGNOS system has been designed so that the EGNOS Signal-In-Space (SIS) is compliant to the ICAO SARPs for SBAS.

The Services provided by EGNOS:

- Non-Precision Approach operations and other flight operations supporting PBN navigation specifications other than RNP APCH, not only for approaches but also for other phases of flight.
- Approach operations with Vertical Guidance supporting RNP APCH PBN navigation specification down to LPV minima as low as 250 ft.
- Category I precision approach with a Vertical Alert Limit (VAL) equal to 35m and supporting RNP APCH PBN navigation specification down to LPV minima as low as 200 ft.

A NOTAM (Notice to Airmen) is a notice issued to alert pilots of potential hazards along a flight route that could affect the safety of the flight. The objective of the EGNOS NOTAM proposal generation is to:

• Predict APV-I and LPV-200 services outages at given airports.
• Create and format the corresponding NOTAM proposals into an ICAO format and according to the European Concept for GNSS NOTAM to ease the validation process to be performed by the NOF (NOTAM Offices).
• Distribute the NOTAM proposals to the concerned NOFs through the AFTN network.

3-1-3 GAGAN

GAGAN is the acronym for GPS Aided GEO Augmented Navigation. The GAGAN uses a system of ground stations to provide necessary augmentations to the GPS standard positioning service (SPS) navigation signal. A network of precisely surveyed ground reference stations (INdian Reference Stations INRES) is strategically positioned across the country to collect GPS satellite data. Using this information, the master control center (Indian Master Control Centre INMCC) generates messages to correct any signal errors. These correction messages are then uplinked through (Indian Land Uplink Station INLUS) and broadcast through communication satellites (Geostationary) to receivers onboard aircraft using the same frequency as GPS.

The Indian Space Research Organization (ISRO) and Airports Authority of India (AAI) have implemented the GPS Aided Geo Augmented Navigation-GAGAN project as a Satellite Based Augmentation System (SBAS) for the Indian Airspace. The objective of GAGAN to establish, deploy and certify satellite based augmentation system for safety-of-life civil aviation applications in India has been successfully completed. The system is inter-operable with other international SBAS systems like US-WAAS, European EGNOS, and Japanese MSAS etc. GAGAN GEO footprint extends from Africa to Australia and has expansion capability for seamless navigation services across the region. GAGAN provides the additional accuracy, availability, and integrity necessary for all phases of flight, from enroute through approach for all qualified airports within the GAGAN service volume.

The services provided by GAGAN are the following:

- RNP 0.1 within India FIR
- APV-1 in the landmass of Indian FIR.

Due to impact of ionosphere behavior over the equatorial regions, availability of GAGAN APV -1 service is better than 76% of landmass on nominal iono days.

3-1-4 SDCM
The System for Differential Corrections and Monitoring (SDCM) is the SBAS currently being developed in the Russian Federation as a component of GLONASS.

3-1-5 MSAS
MTSAT Satellite Based Augmentation System (MSAS) is the Japanese SBAS, the system in operation since September 27, 2007.

MSAS provide GPS Augmentation Information for RNAV, from En-route through NPA (RNP 0.3) within Fukuoka FIR. Due to ionosphere horizontal navigation information only provided.

MSAS provide users with NOTAM when required, including alert for Service Interruption or Predicted Service Outage.

3-2 GROUND BASED AUGMENTATION SYSTEM (GBAS)
GBAS is an augmentation system in which the user receives augmentation information directly from a ground-based transmitter. GBAS support precision approach, landing, departure and surface movement.

GBAS cat I is now operational at many Airports, GBAS classified based on approach service type as following:

- GAST-A : APV I Performance
- GAST-B : APV II Performance
- GAST-C : CAT I Performance
- GAST-D : CAT III Performance (amendment 91 to Annex 10 Vol I)
- GAST-F : CAT III Performance (multiconstellation, multifrequency, ICAO Standards will be available 2025-2028)

The cost of a single certified GBAS ground station is from SESAR studies and deployment in Europe 1,5 to 2 M€ per airport, which is equal roughly to the cost of three ILSs.

3-3 AIRCRAFT BASED AUGMENTATION SYSTEM (ABAS)
ABAS is achieved by features of the onboard equipment designed to overcome the performance limitations of the GNSS constellations. The two systems currently in use are Receiver Autonomous Integrity Monitoring (RAIM) and the Aircraft Autonomous Integrity Monitor (AAIM). ABAS considered low cost integrity supervision.

3-3-1 Receiver autonomous integrity monitoring (RAIM)
RAIM is a technology developed to assess the integrity of the GPS in a GPS receiver system and can predict areas in which the GPS signal may be compromised. RAIM requires no data from outside the satellite receiver, only from GPS.

Fault detection and Exclusion (FDE) mechanism is used in RAIM, minimum five (5) satellite is needed for ‘fault detection’ and six (6) for ‘fault exclusion’.

3-3-2 Aircraft Autonomous Integrity monitoring (AAIM)

AAIM uses the redundancy of position estimates from multiple sensors, including GNSS, to provide integrity performance that is at least equivalent to RAIM. An example is the use of an inertial navigation system or other navigation sensors as an integrity check on GPS data when RAIM is unavailable but GPS positioning information continues to be valid. AAIM requires data from GPS and other sensor (INS).

AAIM uses GNSS signal plus onboard Inertial (INS) to achieve primary means for enroute though non-precision approach.

4- Global Air Navigation Plan

The GANP and ASBUs recognize the Global Navigation Satellite System (GNSS) as a technical enabler supporting improved services. Roadmaps in the GANP outline timeframes for the availability of GNSS elements, the implementation of related services and the rationalization of conventional infrastructure. The ICAO Navigation roadmap depicted in figure (1-2)

Figure (1-2)

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Part II: GNSS in ICAO Middle East Region

1- The Conventional Ground Based Navigation systems in the MID

States Should introduce rationalizing terrestrial navigation aids, retaining a minimum network of terrestrial aids necessary to maintain safety of aircraft operations; in accordance with AN-Conf/12 recommendations 6/10. Some ILSs may be retained to support precision approach and to mitigate GNSS outage.

Removal of conventional ground infrastructure should be planned carefully to ensure that safety is not compromised, such as by performance of safety assessment, consultation with users through regional air navigation planning.

The NDB should be rationalized based on need and equipage, MIDANPIRG/12 urged states to plan for complete decommissioning of NDBs by 2012 and to terminate the use of NDB for approach operations not later than 2012. The list of current NDBs and purpose of use in the MID Region is at Appendix A.

Furthermore, table (2-1) shows the current conventional infrastructure in the MID Region.

System	Frequency	Ground Stations	Status
NDB	200 – 1600 MHz	150 NDBs in (Egypt, Iraq, Iran, Jordan, Libya, Qatar, Syria, UAE, and Yemen)	States should plan for Complete decommissioning of NDBs by 2012 unless its operational justified.
ILS	108 – 112 MHz 329 – 335 MHz		-
VOR	108 – 118 MHz		-
TACAN	960 – 1215 MHz	38 TACANs	TACAN used in Egypt, Iran, Iraq, Qatar and Saudi Arabia
DME	960 – 1215 MHz		
MLS	5031 – 5091 MHz	MLS is not implemented in the MID Region	-

Table (2-1)

2) SBAS

The implementation of GNSS and augmentations systems in the MID Region should be in full compliance with ICAO Standards and Recommended Practices and PANS; due to geographic location of some MID States, taking advantages of adjacent SBAS services (EGNOS and GAGAN) is possible.

SBAS-based procedure does not require any infrastructure at the Airport served, but SBAS elements (e.g. reference stations, master station, satellites) must be in place to support required service level*

2-1 EGNOS

Some of MID Region States who are member in the EUROMED* can exploit the use of EGNOS in various applications, mainly in the transport sectors. As of the time of developing this document; five (5) States have officially notified their interest in EGNOS implementation (Algeria, Jordan, Lebanon, Libya, and Tunisia).

**Euromed countries (Algeria, Egypt, Jordan, Lebanon, Libya, Morocco, Palestine, Syria and Tunisia)*

The requirements to use EGNOS services are as follow:

a) Installation of additional RIMS, three RIMS Stations are sufficient to extend the service to EURCOMED States.
b) Air Navigation Service Providers should sign an EGNOS Working Agreement (EWA) with the ESSP (Certified provider of Safety of Life service in aviation in EU) to be able to activate use of EGNOS SoL.
c) International bilateral agreements should be signed between EU and each State to define liability in case of EGNOS failure which results in death/injury/loss/damage to equipment.

EGNOS Service Maps

The current service maps shown in the figures (2-1, 2-2, 2-3 and 2-4), the current availability and continuity for APV-I and LPV service level in the MID Region are less than the minimum required signal-in-space performance specified in Annex 10 Vol. I., the requirements are shown in table (2-2)

a) APV-I Service Level

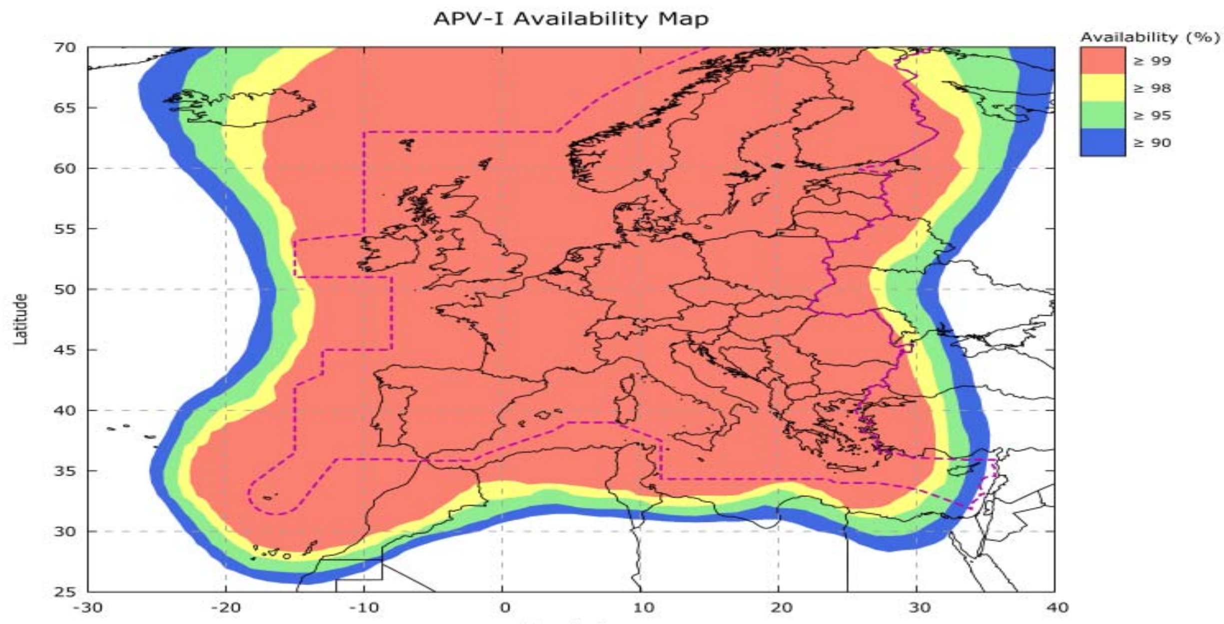

Figure (2-1)

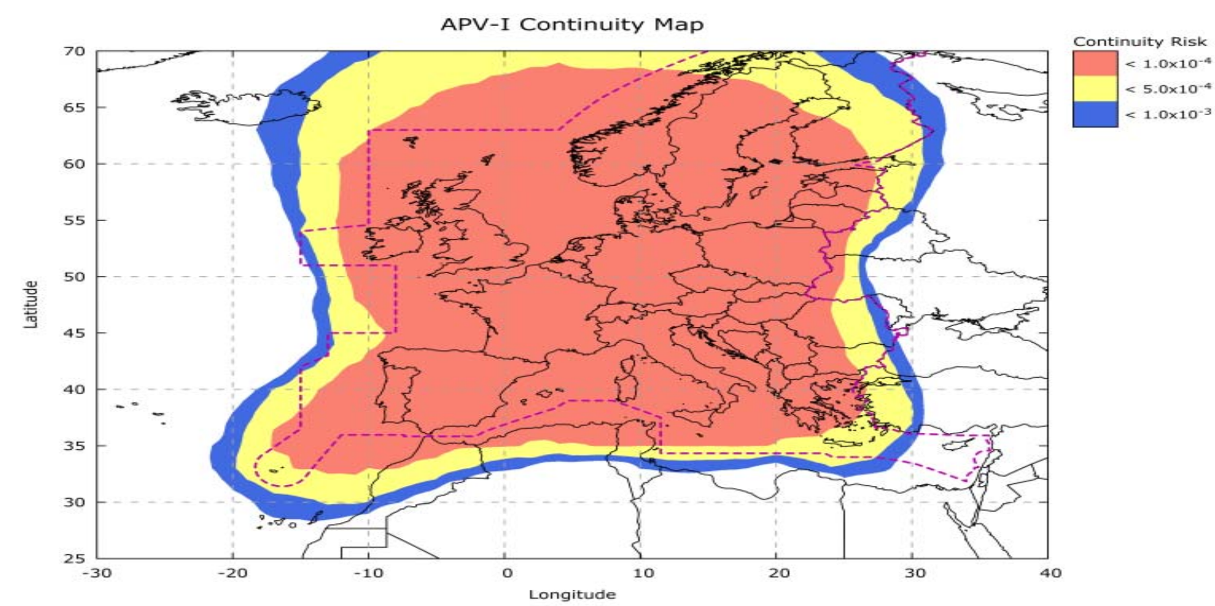

Figure (2-2)

b) LPV200 Service Level

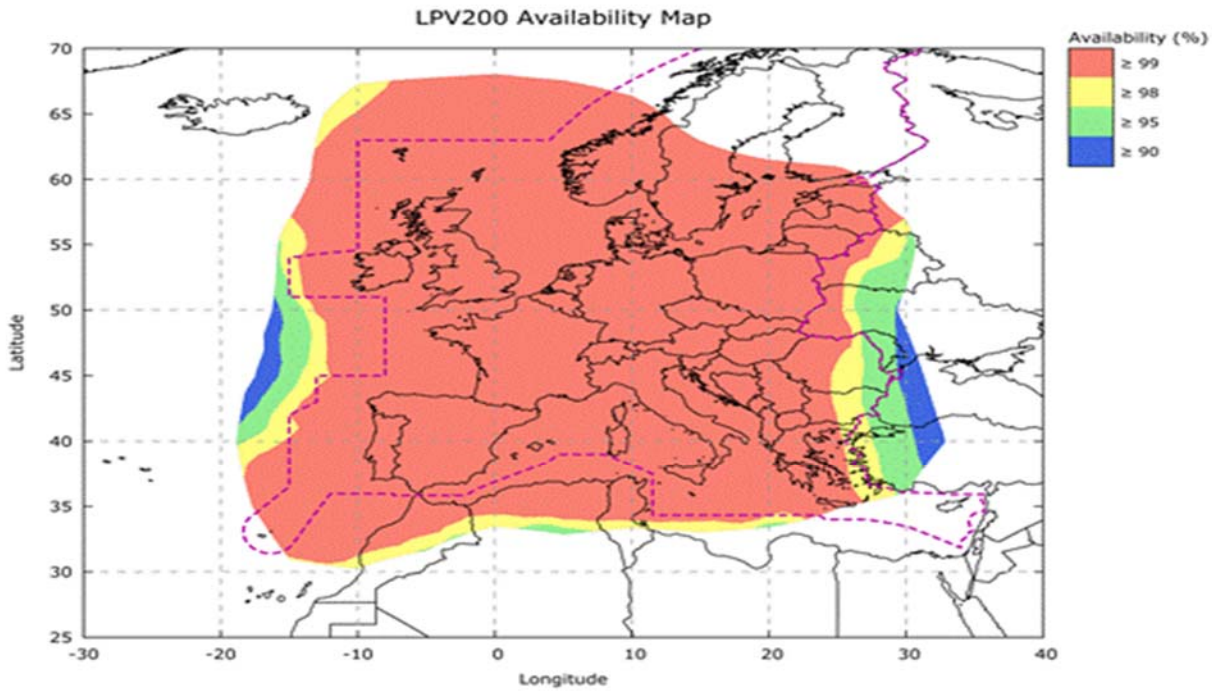

Figure (2-3)

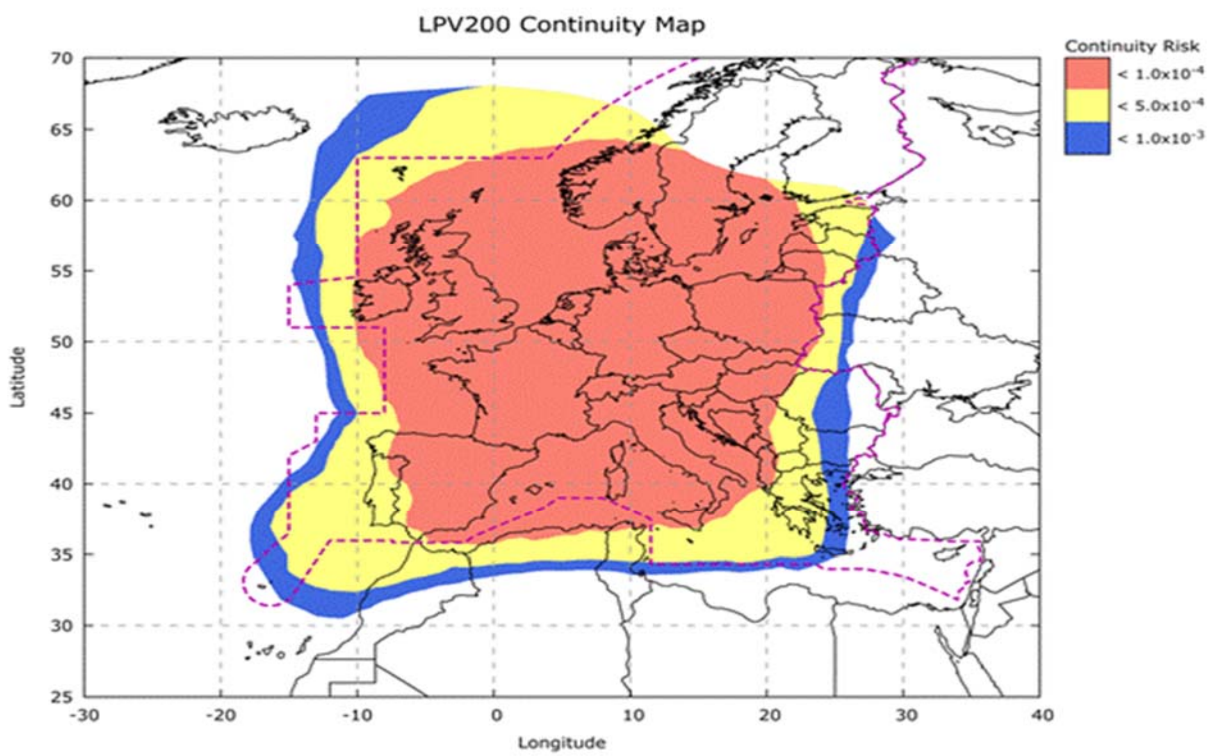

Figure (2-4)

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}$/h	5 min	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}$/h	15 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}$/h	10 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1 - 2 \times 10^{-7}$ in any approach	10 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Category I precision approach (Note 7)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 6)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

NOTES.—

1. The 95th percentile values for GNSS position errors are those required for the intended operation at the lowest height above threshold (HAT), if applicable. Detailed requirements are specified in Appendix B and guidance material is given in Attachment D, 3.2.
2. The definition of the integrity requirement includes an alert limit against which the requirement can be assessed. For Category I precision approach, a vertical alert limit (VAL) greater than 10 m for a specific system design may only be used if a system-specific safety analysis has been completed. Further guidance on the alert limits is provided in Attachment D, 3.3.6 to 3.3.10. These alert limits are:

Table (2-2)

2-2 GAGAN

Gulf region falls within the GAGAN GEO footprint as shown in figure (2-5), GCC States can take advantage of GAGAN infrastructure to implement the RNP 0.1 and APV 1 service in the respective states without having the full SBAS infrastructure in their country.

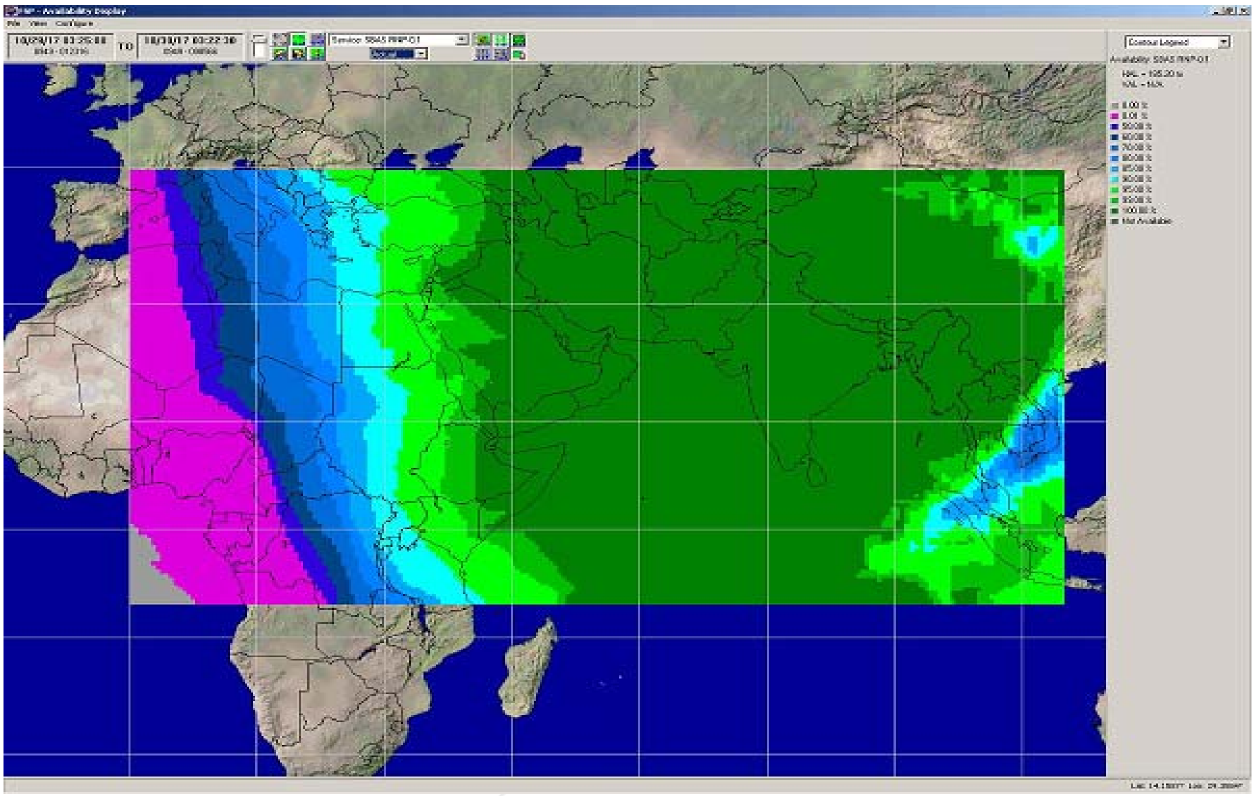

figure (2-5)

India and Gulf regions are on equatorial anomaly region. Ionosphere Scintillation is most intense and most frequent in that equatorial region. It can severely affects the performance of SBAS, Therefore, An MLDF (Multi-Layer Data Fusion) iono model suitable to serve the equatorial anomaly region was implemented in GAGAN system .

The Requirements to use GAGAN as follow:

1- Installing additional reference stations at strategic locations in gulf region and forward the measurements data to GAGAN-INMCC, RNP 0.1/APV 1 services can be extended to gulf region.
2- States to notify Indian Airport Authority (IAA) about their interest to use GAGAN

3-GNSS Application in the MID Region

The GNSS is the foundation for the Regional implementation of PBN, Automatic dependent surveillance (ADS-B), the Multilateration System (MLAT), in addition to many other aircraft and ground applications that require position or time information.

4-GBAS

Transition from ILS to GBAS should be based on an economic assessment, an operational assessment and from a safety and security perspective. Cost benefits analysis should be conducted taking on consideration that one GBAS can be used for several runways ends and even in some cases more than one Airports.

5- Cost Benefits Analysis

The use of GNSS in PBN applications reduces the overall running cost of Navigation infrastructure. Also deploying GBAS reduces the cost for ground infrastructure since a single GBAS ground station can provide approach guidance to all runways at an airport. GBAS can increase the Airport capacity, because it does not have sensitive areas that must be protected. However, the CBA is very dependent on specific operational and airport infrastructure aspects.

States may consider the following factors during the process of estimating the cost associated with competing alternative in CBA:

a) CAPEX
   a.1 Installation Cost;
   - One GBAS costs around 1.5 -2 M euro (equal to the cost of 3 ILSs).
   - ILS(s) must be retained to ensure the service continuity during the GNSS/GBAS outage.

   a.2 Training for operational and technical staff.

b) OPEX
   c.1 Cost of Flight Check (Calibration).
   c.2 Maintenance costs (Preventive, Reactive, maintenance Contract, less Spare parts).

It has been reported by several CBA studies, that GBAS initial investment is higher than for ILS, and lower OPEX. However, Net Present Cost need to be calculated based on Airport infrastructure and operational requirements.

6- GBAS Implementation in the MID Region

Currently GBAS is not implemented in the MID Region.

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PART III: GNSS VULNERABILITIES

1- Introduction

GNSS signals are very weak at the receiver antenna therefore the signal is vulnerable, and also susceptible to ionosphere effects. Current GNSS use a single frequency band common to GPS, GLONASS and SBAS. This makes it easier to intentionally jam GNSS signals.

2- Unintentional Interference Sources

There are a number of sources of potential interference to GNSS, including mobile and fixed VHF communications, Solar effect and other sources. The likelihood and operational effect of interference vary with the environment.

Unintentional interference is not considered a significant threat provided that States exercise proper control and protection over the electromagnetic spectrum for both existing and new frequency allocations.

2-1 Solar Effect

GNSS signals are delayed by varying amounts of time depending on the density of ionized particles (ionosphere) which itself depends on the intensity of solar radiation and other solar energy bursts. The solar activity can cause GNSS service to be degraded or temporarily lost.

The type and severity of ionospheric effects vary with the level of solar activity, the region of the world and other factors such as time of year and time of day. Rare solar storms can affect GNSS service over a wide area. The Solar activity peaks happens every eleven years.

The availability of a second frequency will allow avionics to calculate ionospheric delay in real time, effectively eliminating a major error source.

2-2 Radio Frequency Interference

Harmonics of television stations, certain radars, mobile satellite communications and military systems can cause interference with GNSS signals.

2-3 On-board systems

Many reported instances of GNSS interference have been traced to on-board systems; such interference can be prevented by installing advanced avionics.

3-Intentional Interference Sources

3-1 Jamming

Personal privacy devices (PPDs) have been recognized as being responsible for causing interference to GPS receivers in many occurrences. The intention of PPDs is to protect the privacy of the user so that the user's location is not revealed, therefore the user will not be tracked or monitored. PPDs are low-cost jammers to mask GPS signal.

3-2 Spoofing

Spoofing is the broadcast of GNSS-like signals that cause avionics to calculate erroneous positions and provide false guidance. It is considered that the spoofing of GNSS is less likely than the spoofing of traditional aids because it is technically much more complex.

Spoofing of the GBAS data broadcast is virtually impossible, because of an authentication scheme that has been developed.

4-Reducing the Likelihood of Interferences

The likelihood of interference depends on such factors as population density and the motivation of individuals or groups in an area to disrupt aviation and non-aviation services

a) Effective spectrum management, this comprises creating and enforcing regulations/laws that control the use of spectrum and carefully assessing applications for new spectrum allocations.

b) The introduction of GNSS signals on new frequencies will ensure that unintentional interference does not cause the complete loss of GNSS service (outage) although enhanced services depending upon the availability of both frequencies might be degraded by such interference

c) State should develop and enforce a strong regulatory framework governing the use of intentional radiators, including GNSS repeaters, pseudolites, spoofers and jammers, should forbid the use of jamming and spoofing devices and regulate their importation, exportation, manufacture, sale, purchase, ownership and use.

d) Multi-constellation GNSS would allow the receiver to track more satellites, reducing the likelihood of service disruption.

5- Mitigation Strategies

The disruption of GNSS signals will require the application of realistic and effective mitigation strategies to both ensure the safety and regularity of air services and discourage those who would consider disrupting aircraft operations.

There are three principal methods which can be applied in combination:

a) taking advantage of on-board equipment, such as IRS;
b) taking advantage of conventional navigation aids and radar; and
c) employing procedural (aircrew and/or ATC) methods.

Mitigation of GNSS vulnerabilities needs to be balanced in the context of the overall threats to communications, navigation, and surveillance/air traffic management (CNS/ATM) operations to ensure that the applied effort is neither too small (leading to potentially unacceptable risks and/or preventing realization of GNSS enabled benefits) nor too large (in comparison with the effort expended on mitigating other risks).

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9- FAA, AC 20-138C, AC90 105A, AC90 101A.
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APPENDIX A

LIST OF NDBs IN THE MID REGION AND PURPOSE OF RETAIN

NO.	State	NDB ID	Purpose of retain	Plan to remove
1.	EGYPT	MB	Used at local airport for homing	Until the end of lifetime
2.	EGYPT	NWB	Used for enroute	Until the end of lifetime
3.	EGYPT	OCT	Used at local airport for homing	Until the end of lifetime
4.	IRAN	ABD		
5.	IRAN	ABM		
6.	IRAN	AJ		
7.	IRAN	ARB		
8.	IRAN	ARK		
9.	IRAN	AWZ		
10.	IRAN	BAM		
11.	IRAN	BND		
12.	IRAN	BRD		
13.	IRAN	BRG		
14.	IRAN	BRN		
15.	IRAN	BUZ		
16.	IRAN	DNZ		
17.	IRAN	DZF		
18.	IRAN	ESH		
19.	IRAN	FSA		
20.	IRAN	GGN		
21.	IRAN	GSN		
22.	IRAN	HAB		
23.	IRAN	HAM		
24.	IRAN	HAS		
25.	IRAN	IFN		
26.	IRAN	IKA		
27.	IRAN	ILM		
28.	IRAN	ISR		
29.	IRAN	JAM		
30.	IRAN	JIR		
31.	IRAN	JRM		
32.	IRAN	JSK		
33.	IRAN	KAZ		
34.	IRAN	KER		
35.	IRAN	KHG		
36.	IRAN	KHM		
37.	IRAN	KHY		
38.	IRAN	KIH		
39.	IRAN	KLH		
40.	IRAN	KMS		
41.	IRAN	KRD		
42.	IRAN	LAM		
43.	IRAN	LAR		
44.	IRAN	LEN		

45.	IRAN	LVA		
46.	IRAN	MSD		
47.	IRAN	NSR		
48.	IRAN	OMD		
49.	IRAN	PAD		
50.	IRAN	PIM		
51.	IRAN	PRG		
52.	IRAN	PSR		
53.	IRAN	RAF		
54.	IRAN	RST		
55.	IRAN	SAV		
56.	IRAN	SBZ		
57.	IRAN	SHD		
58.	IRAN	SHR		
59.	IRAN	SIR		
60.	IRAN	SKD		
61.	IRAN	SMN		
62.	IRAN	SNJ		
63.	IRAN	SR		
64.	IRAN	SRN		
65.	IRAN	SRS		
66.	IRAN	TBS		
67.	IRAN	TBZ		
68.	IRAN	UMH		
69.	IRAN	VR		
70.	IRAN	YSJ		
71.	IRAN	YZD		
72.	IRAN	ZAJ		
73.	IRAN	ZAL		
74.	IRAN	ZD		
75.	IRAQ	ALI		
76.	JORDAN	AQC		
77.	JORDAN	MDB		
78.	JORDAN	QA		
79.	Lebanon	BOD	Used by Helicopters and light aircraft	Not Determined
80.	LIBYA	BNA		
81.	LIBYA	CW		
82.	LIBYA	GAD		
83.	LIBYA	GAL		
84.	LIBYA	GHT		
85.	LIBYA	GRT		
86.	LIBYA	GS		
87.	LIBYA	HON		
88.	LIBYA	IZD		
89.	LIBYA	JFR		
90.	LIBYA	KDR		
91.	LIBYA	KFR		
92.	LIBYA	KH		
93.	LIBYA	LAB		

94.	LIBYA	MB		
95.	LIBYA	OA		
96.	LIBYA	OB		
97.	LIBYA	OJ		
98.	LIBYA	OR		
99.	LIBYA	OV		
100.	LIBYA	OXY		
101.	LIBYA	PRB		
102.	LIBYA	PRC		
103.	LIBYA	RAG		
104.	LIBYA	ROO		
105.	LIBYA	SAH		
106.	LIBYA	SEB		
107.	LIBYA	SRT		
108.	LIBYA	STF		
109.	LIBYA	TRO		
110.	LIBYA	TZR		
111.	LIBYA	UBR		
112.	LIBYA	VA		
113.	LIBYA	VG		
114.	LIBYA	VH		
115.	LIBYA	VO		
116.	LIBYA	VR		
117.	LIBYA	WF		
118.	LIBYA	WLD		
119.	LIBYA	XS		
120.	LIBYA	XY		
121.	LIBYA	ZAR		
122.	LIBYA	ZEL		
123.	LIBYA	ZT		
124.	LIBYA	ZUE		
125.	QATAR	AK		
126.	QATAR	QPC	Used for Qatar Petroleum Company	-
127.	SYRIA	ABD		
128.	SYRIA	ALE		
129.	SYRIA	DAL		
130.	SYRIA	DAN		
131.	SYRIA	DRZ		
132.	SYRIA	HAS		
133.	SYRIA	KAM		
134.	SYRIA	KAR		
135.	SYRIA	LTK		
136.	SYRIA	MER		
137.	SYRIA	MEZ		
138.	SYRIA	PAL		
139.	UAE	BH		
140.	UAE	JD		
141.	UAE	RNZ		

142.	UAE	ZKU		
143.	YEMEN	BDE		
144.	YEMEN	GDA		
145.	YEMEN	HD		
146.	YEMEN	MRB		
147.	YEMEN	SCT		
148.	YEMEN	SYE		
149.	YEMEN	SYN		
150.	YEMEN	TZ		

NUMBER OF RETAINED NDBs PER STATES

STATE	NUMBER OF NDBs
EGYPT	**3**
IRAN	**71**
IRAQ	**1**
JORDAN	**3**
LEBANON	**1**
LIBYA	**45**
QATAR	**2**
SYRIA	**12**
UAE	**4**
YEMEN	**8**
TOTAL	**150**

APPENDIX B

RASG-MID SAFETY ADVISORY – 14

(RSA-14)

June 2018

MID-Region

GUIDANCE MATERIAL REALTED TO GNSS VULNRABILTIES

Date of Issue:	June 2018
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Disclaimer

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ACRONYMS

ABAS	AIRCRAFT BASED AUGMENTATION SYSTEM
ADS-B	AUTOMATIC DEPENDENT SURVEILLANCE-BROADCAST
AHRS	ATTITUDE AND HEADING REFERENCE SYSTEMS
ANS	AIR NAVIGATION SERVICES
ATC	AIR TRAFFIC CONTROLLER
DME	DISTANCE MEASURING EQUIPMENT
EGPWS	ENHANCED GROUND PROXIMITY WARNING SYSTEM
FIR	FLIGHT INFORMATION REGION
FMS	FLIGHT MANAGEMENT SYSTEM
GBAS	GROUND BASED AUGMENTATION SYSTEM
GLONASS	GLOBAL NAVIGATION SATELLITE SYSTEM
GNSS	GLOBAL NAVOGATION SATELLITE SYSTEM
GPS	GLOBAL POSITION SYSTEM
HAL	HORIZONTAL ALERT LIMIT
ILS	INSTRUMENT LANDING SYSTEM
IRS	INERTIAL REFERENCE SYSTEM
ITU	INTERATIONAL TELECOMMUNICATION UNION
MIDANPIRG	MID AIR NAVIGATION PLANNING AND IMPLEMENTATION GROUP
NAV	NAVIGATION
NOTAM	NOTICE TO AIRMEN
PBN	PERFORMANCE BASED NAVIGATION
POS	POSITION
RAIM	RECEIVER AUTONOMOUS INTEGRITY MONITORING
RF	RADIO FREQUENCY
RNAV	AREA NAVIGATION
RNP	REQUIRED NAVIGATION PERFORMANCE
SBAS	SPACE BASED AUGMENTATION SYSTEM
TAWS	TERRAIN AVOIDANCE WARNING SYSTEM
TSO	TECHNICAL STANDARD ORDER
VHF	VERY HIGH FREQYENCY
VNAV	VERTICAL NAVIGATION
VOR	VERY HIGH OMNI DIRECTIONAL RADIO RANGE
WAAS	WIDE AREA AUGMENTATION SYSTEM

GNSS VULNERABILITIES

1. INTRODUCTION

GNSS supports positioning, navigation and timing (PNT) applications. GNSS is the foundation of Performance Based Navigation (PBN), automatic dependent surveillance – broadcast (ADS-B) and automatic dependent surveillance – contract (ADS-C). GNSS also provides a common time reference used to synchronize systems, avionics, communication networks and operations, and supports a wide range of non-aviation applications.

GNSS Vulnerability has been identified as a safety issue and one of the main challenges impeding the implementation of PBN in the MID Region. The sixteenth meeting of the MID Air Navigation planning and Implementation Regional Group (MIDANPIRG/16Kuwait, 13-16 February 2017) recognized the impact of the GNSS signal interference and vulnerabilities and agreed that the subject should be addressed by the Regional Aviation Safety Group-Middle East (RASG-MID) in order to agree on measures to ensure effective reporting of GNSS interferences, which could be mandated by the States' regulatory authorities. The meeting invited the RASG-MID to consider the development of a RASG-MID Safety Advisory (RSA) related to GNSS vulnerabilities, highlighting the Standard Operating Procedures (SOP) for pilots, including the reporting procedures.

The RASG-MID/6 (Bahrain, 26 – 28 September 2017) agreed that IATA and ICAO MID Office should develop a RSA on GNSS vulnerabilities.

With the increasing dependence on GNSS, it is important that GNSS vulnerabilities be properly addressed. This Safety Advisory provides guidance on set of mitigation measures that States would deploy to minimize the GNSS vulnerabilities impact on safety and air operation. The RSA also includes the regional reporting and monitoring procedures of GNSS anomaly with the aim to analyze the threat and its impact on performance, and assess the effectiveness of the mitigation measures in place.

2. DESCRIPTION

Dependence on GNSS is increasing as GNSS is used for an ever-expanding range of safety, security, business and policy critical applications. GNSS functionality is being embedded into many parts of critical infrastructures. Aviation is now dependent on uninterrupted access to GNSS positioning, navigation and timing (PNT) services.

Aviation relies heavily on GNSS for area navigation and precision approach. Aircraft avionics such as the Flight Management Systems (FMS) require GNSS timing for a large number of onboard functions including Terrain Avoidance Warning System (TAWS) or Enhanced Ground Proximity Warning Systems (EGPWS). Onboard avionics are highly integrated on commercial aircraft and are very dependent on GNSS timing data. At the same time, GNSS vulnerabilities are being exposed and threats to denial of GNSS services are increasing.

There are several types of threat that can interfere with a GNSS receiver's ability to receive and process GNSS signals, giving rise to inaccurate readings, or no reading at all, such as radio frequency interference, space weather induced ionospheric interference, solar storm, jamming and spoofing. The disruption of GNSS, either performance degradation in terms of accuracy, availability and integrity or a complete shutdown of the system, has a big consequence in critical infrastructure. For example, local interference in

an airport could degrade position accuracy or lead to a total loss of the GNSS based services, which could put safety of passengers in jeopardy.
There are two types of GNSS Interference Sources; Intentional and Unintentional sources, the latter is not considered a significant threat provided that States exercise proper control and protection over the electromagnetic spectrum for both existing and new frequency allocations. Solar Effect, Radio Frequency Interference and On-board systems are examples of Unintentional GNSS interference sources. However, the Intentional sources such as Jamming and spoofing are considered as serious threats to the continued safety of air transport.

GNSS Jamming occurs when broadcasting a strong signal that overrides or obscures the signal being jammed. The GNSS jamming might occur deliberately by a military activity or by Personal Privacy Devices (PPDs). GNSS jamming has caused several GNSS outages in the MID Region.

In some States, military authorities test the capabilities of their equipment and systems occasionally by transmitting jamming signals that deny GNSS service in a specific area. This activity should be coordinated with State spectrum offices, Civil Aviation Authorities and ANS providers. Military and other authorities operating jamming devices should coordinate with State/ANS providers to enable them to determine the airspace affected, advise aircraft operators and develop any required procedures.

Spoofing is another source of intentional GNSS Interference, which is a deliberate interference that aims to mislead GNSS receivers into general false positioning solution.

Detailed information about the GNSS Implementation and Vulnerabilities can be found in MID DOC 010 – The Guidance on GNSS implementation in the MID Region.

3. RISK ASSESSMENT

The risk assessment covers affected operations during en-routre, terminal, and approach phase of flights. In addition, the aircraft impact at table (1), which presents an overview of different potential impacts from GNSS interference, needs to be considered for risk assessment.

Understanding the different types of threat and how likely they are to occur is key to conducting an accurate risk assessment. Broadly, the threat types break down as follows:

Threat Source	Threat Type	Description	Impact on the User
Solar Storms	Unintentional	Electromagnetic interference from solar flares and other solar activity “drowns out” the satellite signals in space.	Loss of signal, or range errors affecting the accuracy of the location or timing information.
Jamming	Intentional	Locally-generated RF interference is used to “drown out” satellite signals.	Loss of signal (if the jammer is blocking out all satellite signals) or range errors affecting the accuracy of the location or timing information

Spoofing	Intentional	Fake satellite signals are broadcast to the device to fool it into believing it is somewhere else, or at a different point in time.	False location and time readings, with potentially severe impacts on automated and autonomous devices and devices that rely on precise GNSS timing.
RF Interference	Unintentional	Noise from nearby RF transmitters (inside or outside the device) obscures the satellite signals.	Loss of signal (if the transmitter is blocking out all satellite signals) or range errors affecting the accuracy of the location reading (if the receiver is at the edge of the transmitter's range).
Signal Reflection	Unintentional	Reflection due objects such as buildings	GNSS signals can reflect off relatively due to distant objects, such as buildings, which would cause gross errors in position accuracy if the receiver falsely locks onto the reflected signal instead of the direct signal
User Error	Unintentional	Users over-rely on the GNSS data they are presented with, ignoring evidence from other systems or what they can see.	Can lead to poor decision-making in a range of scenarios

Table 1: Threats types

Depending on the nature of the interference and the nature of the application, a user may be affected in several ways; the impact may range from a small nuisance to an economic, operational or a safety impact. The detailed risk assessment methodology is addressed at **Appendix B**.

4. MITIGATION STRATEGIES

To minimize the risks associated with GNSS vulnerabilities, several mitigation strategies can be deployed to reduce the likelihood and impact of the threat.

4.1 REDUCING THE LIKELIHOOD OF GNSS INTERFERENCES

The likelihood of interference depends on many factors such as population density and the motivation of individuals or groups in an area to disrupt aviation and non-aviation services. To reduce the likelihood of GNSS interference, the following measures may be applied:

a) Effective spectrum management; this comprises creating and enforcing regulations/laws that control the use of spectrum and carefully assessing applications for new spectrum allocations.

b) The introduction of GNSS signals on new frequencies will ensure that unintentional interference does not cause the complete loss of GNSS service (outage) although enhanced services depending upon the availability of both frequencies might be degraded by such interference.

c) State should forbid the use of jamming and spoofing devices and regulate their importation, exportation, manufacture, sale, purchase, ownership and use; they should develop and enforce a strong regulatory framework governing the use of intentional radiators, including GNSS repeaters, pseudolites, spoofers and jammers. The enforcement measures include:

- detection and removal of jammers / interference sources; and
- direct or indirect detection (e.g. use of dedicated interference detection equipment).

d) Education activities to raise awareness about legislation and to point out that 'personal' jammers can have unintended consequences.

e) Multi-constellation GNSS would allow the receiver to track more satellites, reducing the likelihood of service disruption.

4.2 REDUCING THE IMPACT OF THE GNSS VULNERABILITIES

The GNSS signal disruption cannot be ruled out completely and States/ANSPs must be prepared to deal with loss of GNSS signals, and that States conduct risk assessment and implement mitigation strategies. The risk and impacts from these threats can be managed by evaluating the growing threat of GNSS interference, jamming and spoofing.

The disruption of GNSS signals will require the application of realistic and effective mitigation strategies to both ensure the safety and regularity of air services and discourage those who would consider disrupting aircraft operations. There are three principal methods, which can be applied in combination:

a) taking advantage of on-board equipment, such as Inertial Reference System (IRS);

IRS provides a short-term area navigation capability after the loss of GNSS updating. Many air transport aircraft are equipped with IRS and these systems are becoming more affordable and accessible to operators with smaller, regional aircraft. Most of these systems are also updated by DME.

b) Development of contingency procedures and processes to enable operations in a fallback mode in case of loss of GNSS (aircrew and/or ATC).

Procedural (aircrew or ATC) methods can provide effective mitigation in combination with those described above, taking due consideration of:

- ➢ the airspace classification;
- ➢ the available ATC services (radar or procedural);
- ➢ the avionics onboard
- ➢ aircrew and air traffic controller workload implications;
- ➢ the impact that the loss of GNSS will have on other functions, such as ADS-B based surveillance; and
- ➢ the potential for providing the necessary increase in separation between aircraft in the affected airspace.

c) taking advantage of conventional navigation aids and radar, conventional aids can provide alternative sources of guidance.

The regulator should conduct safety oversight of the service provider's GNSS based Services and validate the safety aspects of mitigation strategies, considering the impact on ATM operations. Details on Risk assessment process including some examples are at **Appendix B.**

The data analysis of the reported GNSS vulnerabilities for the period January 2015to June 2018, showed that the impact of the GNSS interference on Aircraft Operations in the MID Region were as follows:

1. Loss of GPS1 (fault)/ Loss of GPS2 (fault)
2. Observation of "Map shift" on Navigation display
3. Switching to an alternative navigation mode (IRS displayed, VOR/DME)
4. Degraded PBN Capability (NAV Unable RNP)
5. GPS POS Disagree
6. EGPWS warning
7. ADS-B Traffic triggered

5. MONITORING

The success of many of countermeasures is dependent on having a detailed understanding of the threats. In order to establish this understanding and to maintain an up-to-date knowledge of the threats - in terms of both types and number of threats – it is necessary to States to monitor the threat environment and the impact on performance.

Monitoring and reporting is required to inform stakeholders of the threats that exist. This would helps directly with enforcement (detecting and removing sources of interference) as well as monitoring the response to changes in legislation or education activities.

Receiver autonomous integrity Monitoring (RAIM) provides integrity monitoring by detecting the failure of a GNSS satellite. It is a software function incorporated into GNSS receivers.

In the event of GNSS performance degrading to the point where an alert is raised, or other cause to doubt the integrity of GNSS information exists, the pilot in command must discontinue its use and carry out appropriate navigation aid failure procedures. Should RAIM detect an out-of-tolerance situation, an immediate warning will be provided. When data integrity or RAIM is lost, aircraft tracking must be closely monitored against other available navigation systems.

States may consider the deployment of GNSS threat monitoring system, which allows monitoring of local GNSS interference environment; signal recording and monitoring for situational awareness of any drop in signal quality or signal outage and ground validation of GNSS-based flight procedures. The detection equipment may include localization utilities.

With reference to ICAO Doc 9849:

Given the variety of avionics designs, one service status model cannot meet all operators' requirements. A conservative model would produce false alarms for some aircraft. A less conservative model would lead to missed detection of a service outage for some and false alarms for others. Regardless, only the aircrew, not ATC, is in a position to determine whether, for example, it is possible to continue an ABAS-based instrument approach. In contrast, ATC has access to ILS monitor data and can deny an ILS approach clearance based *on a failure indication. The real time monitor concept is neither practical nor required for GNSS ABAS operations. It may be practical for SBAS and GBAS, but implementation would depend on a valid operational requirement.*

Aircraft operators with access to prediction software specific to their particular ABAS/RAIM avionics will find it advantageous to employ that software rather than use the general notification service. In the case of SBAS and GBAS, operators will rely on service status notifications.

6. REPORTING

ANSP must be prepared to act when anomaly reports from aircraft or ground-based units suggest signal interference. If an analysis concludes that interference is present, ANS providers must identify the area affected and issue an appropriate NOTAM.

From the perspective of the aircrew, a GNSS anomaly occurs when navigation guidance is lost or when it is not possible to trust GNSS guidance. In this respect, an anomaly is similar to a service outage. An anomaly may be associated with a receiver or antenna malfunction, insufficient satellites in view, poor satellite geometry or masking of signals by the airframe. The perceived anomaly may also be due to signal interference, but such a determination requires detailed analysis based on all available information.

In case of GNSS anomaly detected by aircrew, **Pilot** action(s) should include:

a) reporting the situation to ATC as soon as practicable and requesting special handling as required;
b) filing a GNSS Interference Report using the Template at **Appendix A**, and forwarding information to the IATA MENA (sfomena@iata.org) and ICAO MID Office (icaomid@icao.int) as soon as possible, including a description of the event (e.g. how the avionics failed/reacted during the anomaly).

Controller action(s) should include:

a) recording minimum information, including aircraft call sign, location, altitude and time of occurrence;
b) cross check with other aircraft in the vicinity;
c) broadcasting the anomaly report to other aircraft, as necessary;
d) notify the AIS Office in case NOTAM issuance is required; andenable the fallback mode and implement related procedure and process (contingency measures).

ANSP action(s) should include:

a) ensuring the issuance of appropriate advisories and NOTAM, as necessary;
b) attempting to locate/determine the source of the interference, if possible;
c) notifying the agency responsible for frequency management (the Telecommunication Regulatory Authority);
d) locate and eliminate source in cooperation with local regulatory & enforcement Authorities;
e) tracking and reporting all activities relating to the anomaly until it is resolved; and
f) review the effectiveness of the mitigation measures for improvement.

ICAO MID Office action(s) should include:

a) collect anomaly related information and determine the course of action required to resolve reported anomalies;
b) follow-up with State having interference incident to ensure implementation of required corrective actions;
c) coordinate with concerned adjacent ICAO Regional Office(s) to follow-up with States under their accreditation areas, when needed; and
d) Communicate with ITU Arab Office and Arab Spectrum Management Group to resolve frequent interference incidents, when needed.

7. REFERENCES:

- Annex 10 Aeronautical Telecommunications, Volume I ─ Radio Navigation Aids
- Annex 11 Air Traffic Services
- PANS-ATM, ICAO doc 4444
- ICAO Doc 9613 PBN Manual
- ICAO Electronic Bulletin 2011/56, Interference to Global Navigation Satellite System (GNSS) Signals.
- GNSS Manual, ICAO Doc 9849
- Standardization of GNSS Threat reporting and Receiver testing through International Knowledge Exchange, Experimentation and Exploitation, STRIKE3 EUROPEAN Initiative, Paper 74
- The report of Vulnerabilities Assessment of the Transportation Infrastructure relying on the Global Position System, US Department of Transportation.
- Operational Impacts of Intentional GPS Interference. (A Report of the Tactical Operations Committee in Response to Tasking from the Federal Aviation Administration. March 2018.
- CANSO Cyber security and Risk Assessment guide.
- ICAO GNSS RFI Mitigation Plan and associated EUROCONTROL Efforts, 8 Nov 2016
- European Global Satellite Agency System, GNSS Market Report issue 4, March 2015

Appendix A

1. **GNSS interference reporting form to be used by pilots**
   ** Mandatory field*

Originator of this Report:	
Organisation:	
Department:	
Street / No.:	
Zip-Code / Town:	
Name / Surname:	
Phone No.:	
E-Mail:	
Date and time of report	
Description of Interference	
*Affected GNSS Element	[ ] GPS [ ] GLONASS [ ] other constellation [ ] EGNOS [ ] WAAS [ ] other SBAS [ ] GBAS (VHF data-link for GBAS)
Aircraft Type and Registration:	
Flight Number:	
*Airway/route flown:	

Coordinates of the first point of occurrence / Time (UTC):	UTC: Lat: Long:
Coordinates of the last point of occurrence / Time (UTC):	UTC: Lat: Long:
*Flight level or Altitude at which it was detected and phase of flight:	
Affected ground station (if applicable)	Name/Indicator; [e.g. GBAS]
*Degradation of GNSS performance:	[ ] Large position errors (details): [ ] Loss of integrity (RAIM warning/alert): [ ] Complete outage (Both GPSs), [ ] Loss of GPS1 or Loss of GPS 2 [ ] Loss of satellites in view/details: [ ] Lateral indicated performance level changed from:___to ___ [ ]Vertical indicated performance level changed from: __ to __ [ ] Indicated Dilution of Precision changed from __ to__ [ ] information on PRN of affected satellites (if applicable) [ ] Low Signal-to-Noise (Density) ratio [ ] Others
*Problem duration:	[ ] continuous for 20 minutes [ ] intermittent

Note: Only applicable fields need to be filled!

Appendix B
Risk Assessment

Threats and vulnerabilities

A threat assessment should be performed to determine the best approaches to securing a GNSS against a particular threat. Penetration testing exercises should be conducted to assess threat profiles and help develop effective countermeasures.

Table (B1) presents an overview of different potential impacts from GNSS interference. This is a snapshot of impacts based on input from two manufacturers and not intended to be a comprehensive list of all impacts:

Effect	Affected Operation	Impact
Loss of GNSS-based navigation	Enroute/ Terminal/ Approach	Aircraft with Inertial Reference Unit (IRU) or Distance Measuring Equipment (DME)/DME may have degraded RNP/RNAV. Aircraft may deviate from the nominal track May increase workload on aircrew and ATC May result in missed approach or diverting to other runway in case the aerodrome operating minima cannot be met through conventional precision or visual approaches. Conventional ATS routes, SIDs and STARs would be used.
Larger than normal GNSS position errors prior to loss of GNSS	Enroute/ Terminal/ Approach	Interference could cause the GNSS position to be pulled off but not exceed the HAL (2NM , 1NM, 0.3NM for enroute, terminal and approach phases, respectively).
Loss of EGPWS/ TAWS	Enroute/ Terminal/ Approach	Reduced situational awareness and safety for equipped aircraft. Terrain Awareness and Warning System (TAWS) is required equipment for turbine-powered airplanes > 6 passengers. Loss of GPS results in loss of terrain/obstacle alerting. Position errors as GPS degrades can result in false or missed alerts.
Loss of GPS aiding to AHRS	Flight Control	Can result in degradation of AHRS pitch and roll accuracy with potential downstream effects such as was experienced by a Phenom 300 flight.

Loss of GNSS to PFD/MFD	All flight phases	Can result in: -Loss of synthetic vision display and flight path marker on PFD -Loss of airplane icon on lateral and vertical electronic map displays, georeferenced charts, and airport surface maps without DME-DME or IRU -Loss of airspace alerting and nearest waypoint information without DME-DME or IRU Overall loss of situational awareness to flight crew and increased workload.
No GNSS position for ELT	Search and Rescue	Loss of GNSS signal could result in larger search areas for the Emergency Locator Transmitters (ELTs)

Table B1: Potential Impact from GNSS

Consequence/Impact of risk occurring

Category	Effect on Aircrew and Passengers	Overall ATM System effect
Catastrophic 1	Multiple fatalities due to collision with other aircraft, obstacles or terrain	Sustained inability to provide any service.
Major 2	Large reduction in safety margin; serious or fatal injury to small number; serious physical distress to air crew.	Inability to provide any degree of service (including contingency measures) within one or more airspace sectors for a significant time.
Moderate 3	Significant reduction in safety margin.	The ability to provide a service is severely compromised within one or more airspace sectors without warning for a significant time.
Minor 4	Slight reduction in safety margin.	The ability to provide a service is impaired within one or more airspace sectors without warning for a significant time
Negligible 5	Potential for some inconvenience.	No effect on the ability to provide a service in the short term, but the situation needs to be monitored and reviewed for the need to apply some form of contingency measures if the condition prevails.

Table B2: Impact of Risk Occurring

Likelihood of risk occurring

The definitions in the table (B3) were adopted for estimating the likelihood of an identified risk occurring, for this purpose, five situations are considered:

Event is expected to occur	
1	More frequently than hourly
2	Between hourly and daily
3	Between daily and yearly
4	Between yearly and 5 yearly
5	Between 5 and 50 years
6	Less frequently than once every 50 years

Table B3: Likelihood of risk occurring

Assessment of the level of risk and risk tolerance

All identified risks were reviewed and provided for each an overall risk ranking which is a combination of the two characteristics of consequence and likelihood. For example, a risk with a major consequence but a "5" likelihood would be described as having a "A" or "unacceptable" risk rating. The conversion of the combination of consequence and likelihood into a risk rating has been achieved by use of the following matrix.

Likelihood Criteria		**Consequence Criteria**				
Event expected to occur:		**Catastrophic 1**	**Major 2**	**Moderate 3**	**Minor 4**	**Insignificant 5**
1	**More frequently than hourly**	**A**	**A**	**A**	**A**	**C**
2	**Between hourly and daily**	**A**	**A**	**A**	**B**	**D**
3	**Between daily and yearly**	**A**	**A**	**B**	**C**	**D**
4	**Between yearly and 5 yearly**	**A**	**B**	**C**	**C**	**D**
5	**Between 5 and 50 years**	**A**	**B**	**C**	**D**	**D**
6	**Less frequently than once every 50 years**	**B**	**C**	**D**	**D**	**D**

Table B4: Risk Assessment Table

The previous matrix provides a guide to determine which risks are the highest priorities from the perspective of the timeliness of the corrective action required. The following table outlines the position in more definitive terms.

Safety tolerability risk matrix

Risk Index Range	Description	Recommended Action
A	Unacceptable	Stop or cut back operation promptly if necessary. Perform priority/immediate risk mitigation to ensure that additional or enhanced preventive controls are put in place to bring down the risk index to the moderate or low range
B	High Risk	Urgent action. Perform priority/immediate risk mitigation to ensure that additional or enhanced preventive controls are put in place to bring down the risk index to the moderate or low range
C	Moderate Risk	Countermeasures actions to mitigate these risks should be implemented.
D	Low Risk	Acceptable as is. No further risk mitigation required

Table B5: Risk Tolerability Matrix

Sample risk assessment

The risk assessment table (B6) could be used to identify and capture the threats, select the risk rating based on the risk matrix above considering the existing controls. In addition, recommended actions could be selected to minimize the risk.

L = Likelihood
C = Consequence
R = Risk

Threat	Initial Risk			Existing controls	Accept/Reduce	Recommended controls	Residual Risk		
	L	C	R				L	C	R

Table B6: Sample Risk Assessment tables

The table (B7) below is an example of risk assessment for approach phase of flight, the detailed Risk assessment process is at Appendix B

L = Likelihood
C = Consequence
R = Risk

Threat	Initial Risk			Existing controls	Accept/ Reduce	Recommended controls	Residual Risk		
	L	C	R				L	C	R
Between daily and yearly	**3**	**2**	A	-Error message notification by avionic	Reduce	1)using of on-board equipment (IRS); 2)Interference detector by ANSPs 3) executing miss-approach	3	4	C

Table B7: Example Risk Assessment for Approach phase of flight

Another example risk assessment for en-route phase of flight at table (B8)

L = Likelihood
C = Consequence
R = Risk

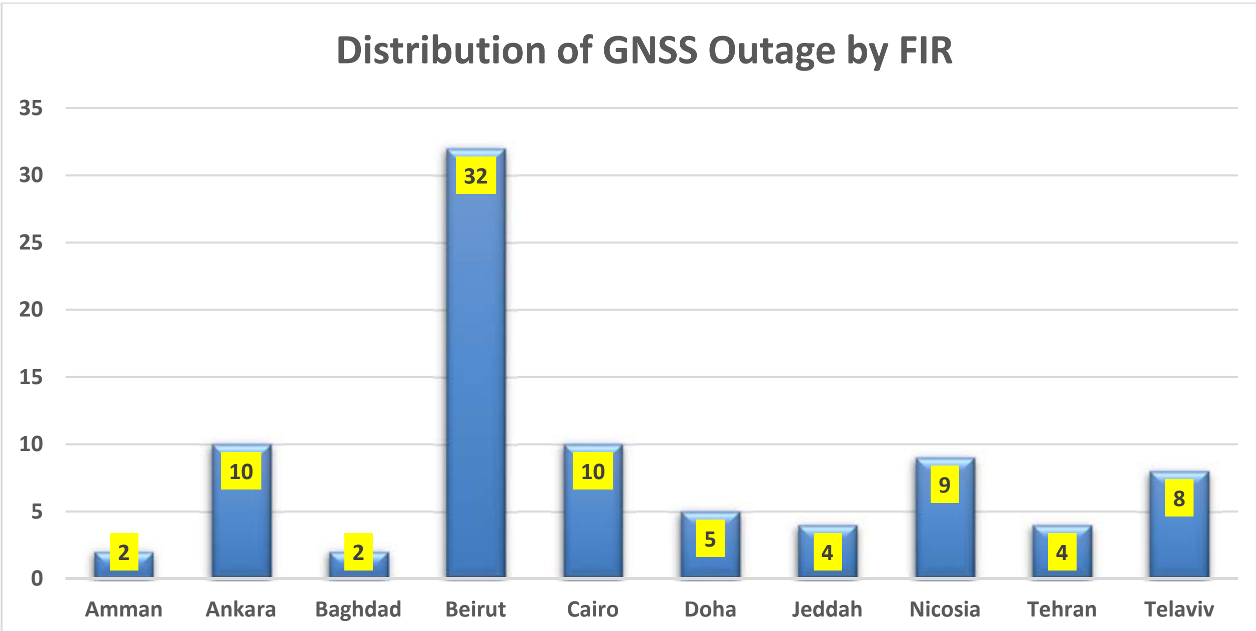
Threat	Initial Risk			Existing controls	Accept/Reduce	Recommended controls	Residual Risk		
	L	C	R				L	C	R
Between 5 and 50 years (short time GNSS Outage)	5	5	D	-Error message notification by avionic -Regulations/ law to protect the GNSS signal	Accept	-			

Table B8: Example risk assessment for enroute phase of flight

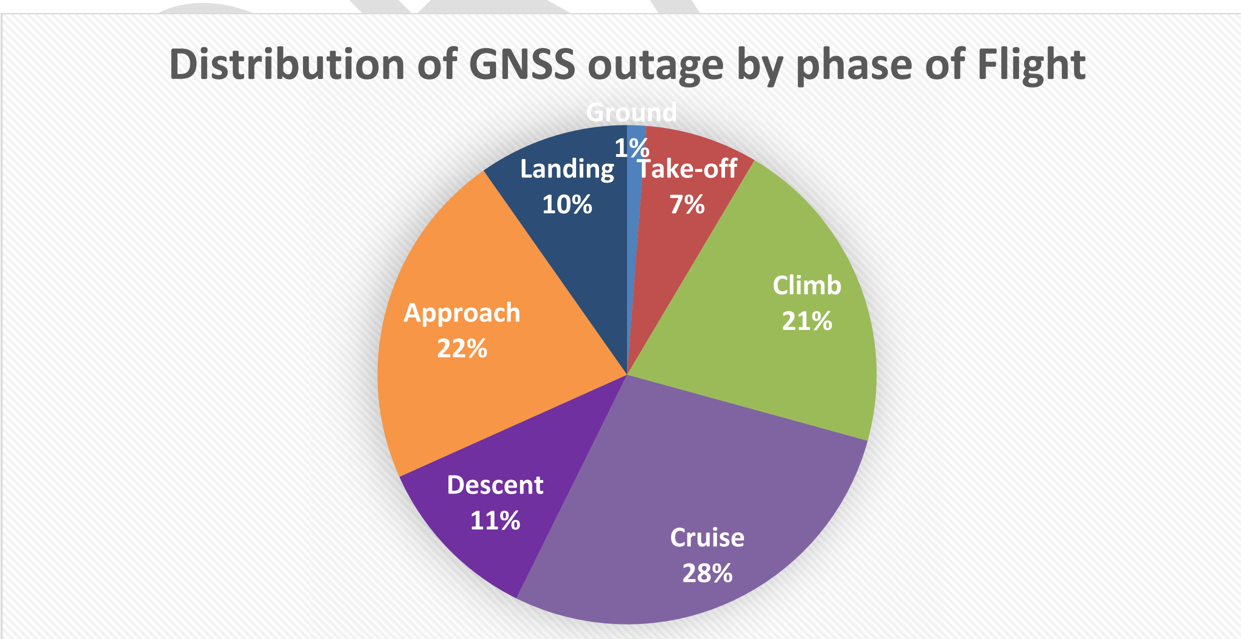
Appendix C

GNSS Anomaly for the Period January 2015- June2018

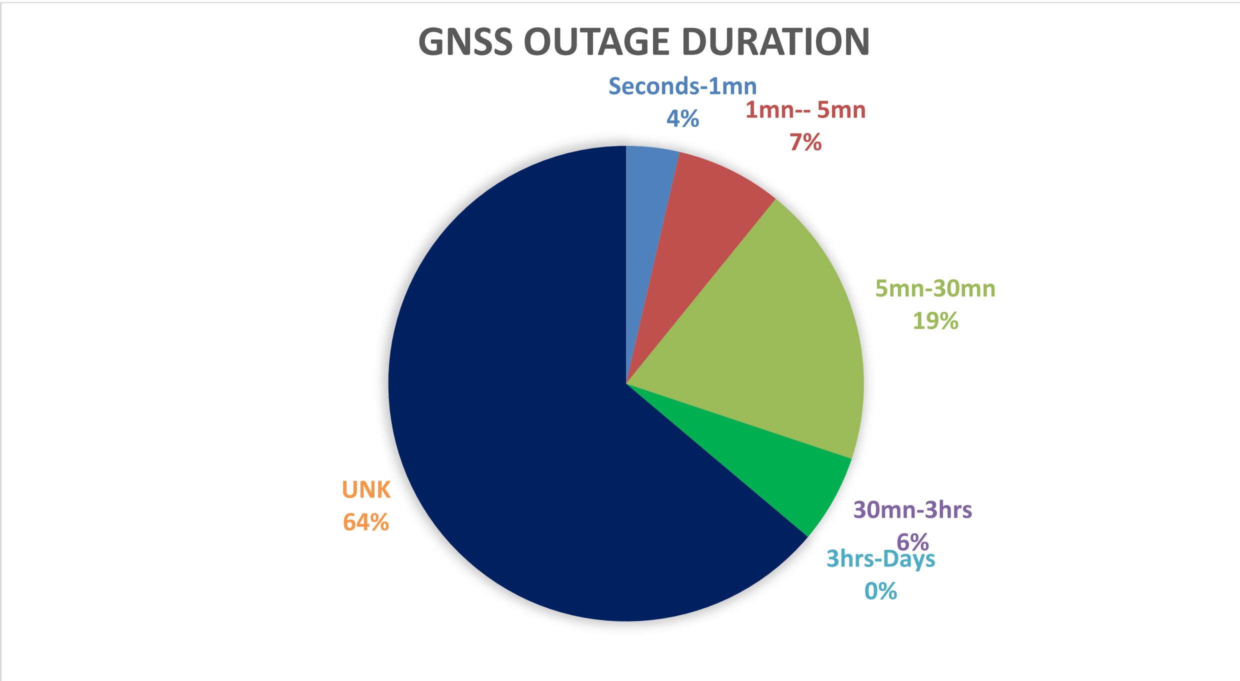
Brief data analysis of the incidents reported during Brief data analysis of the incidents reported by Air Operator are as follows:



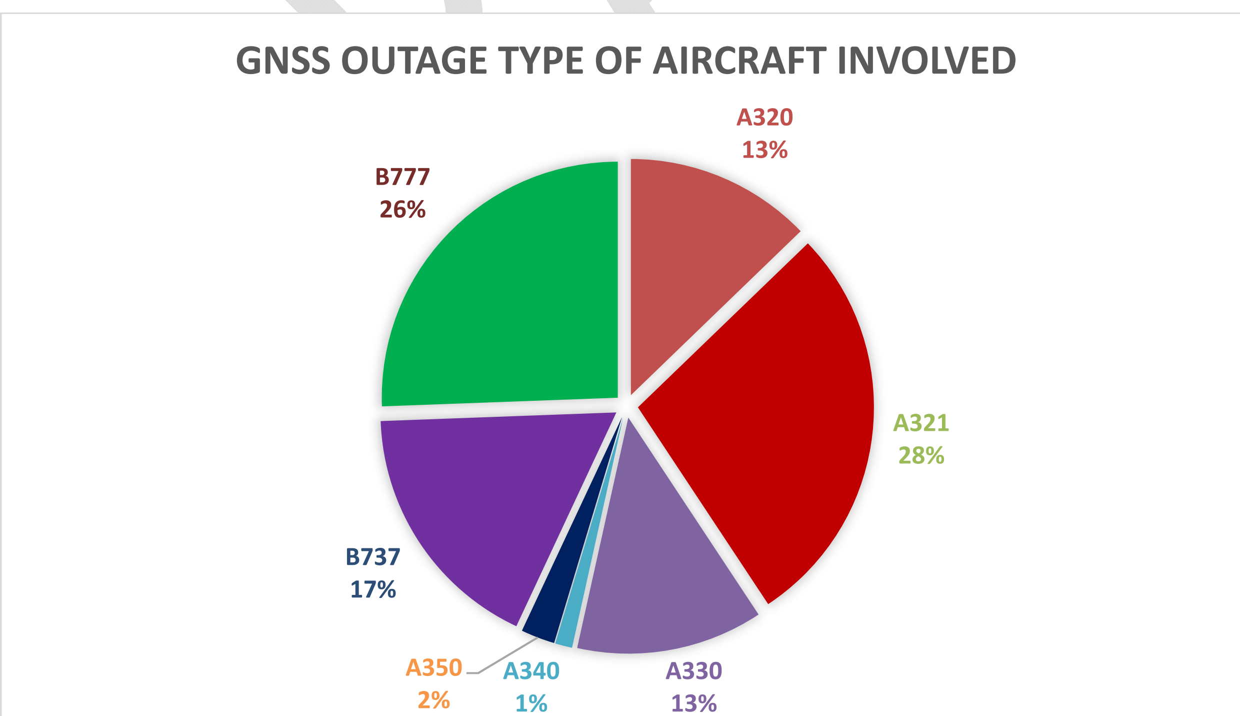
The data revealed that the most significant Flight Information Regions (FIRs) affected Beirut, followed by Cairo, Ankara, and Nicosia.



The data shows that the highest GNSS Outage occurred during the phase of flights cruise, approach, climb, and descent.



The data shows the highest GNSS outage duration was between 5 minutes- 30 minutes. Regarding the Unknown (UNK) it could not be determined as the data was not provided.



The A321, B777, and B737 were most flown aircraft type in areas most affected.