International Civil Aviation Organization
CAR/SAM REGIONAL PLANNING IMPLEMENTATION GROUP (GREPECAS)
Fifth Meeting of the CNS Committee of the GREPECAS ATM/CNS Subgroup (CNS/COMM/5)
Lima, Peru, 13 to 17 November 2006

Agenda Item 2: Navigation systems developments
2.1 Review of the results of the SBAS augmentation projects carried out in the CAR/SAM Regions.

STATUS OF SBAS AUGMENTATION TRIALS ACCORDING TO PROJECT RLA/00/009

(Presented by the Secretariat)

SUMMARY

This working paper contains information concerning the preliminary final report of project RLA/00/009, highlighting the availability of data collected by the project, as well as GNSS implementation options for NPA procedures in the CAR/SAM Regions.

References:

- Report of the Fifth Coordination Meeting on GNSS augmentation trials of project RLA/00/009 (Lima, Peru, 25 September 2006).
- Preliminary final report of project RLA/00/009.

1. Introduction

1.1 In order to establish a test bed for the development of a WAAS-type SBAS system in the CAR/SAM Regions, a Memorandum of Understanding (MoU) was signed between ICAO and the FAA on 4 June 2001.

1.2 As a result, a UNDP/ICAO technical co-operation project (RLA/00/009) was implemented, with the participation of the following States and International Organisations: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Panama, Peru, United States, Venezuela and COCESNA.

1.3 The CAR/SAM Regional Satellite Test Bed implemented through project RLA/00/009 was named CAR/SAM Satellite Test Bed (CSTB). It was designed on the basis of the NSTB. The CSTB and the NTSB are connected through a dedicated circuit.

1.4 The CSTB was established to facilitate the collection, development, acquisition, and implementation of an operational air navigation system based on GPS and WAAS-type SBAS technologies.

1.5 The test bed was implemented to reduce operational implementation costs, through the development of a test infrastructure that could be applied to the operational environment (i.e., site selection, preparation and securing of ground communication links, development of operational procedures, aircraft certification, training, etc.).

1.6 Initially, the project envisaged the implementation of a flight test plan using the CSTB to verify, among other parameters, the precision and non precision procedures, terminal area manoeuvres in selected airports, as well as SID and STAR tests in some locations, in order to demonstrate an overall capability from take-off to landing.

1.7 The first flight tests carried out in Brazil beginning in 2002 and, later on, in Argentina, Bolivia, Peru, and Chile in 2003, revealed that the ionosphere effect on the GPS signal did not guarantee NPAs with vertical precision requirements. Consequently, many of the aforementioned flight tests that had been foreseen were not carried out.

1.8 The CSTB included the implementation of a satellite earth station that would broadcast the augmentation of the GPS signal. It was to be implemented by the aeronautical administration of Brazil, but due to its high cost and flight test limitations due to the ionosphere effect on the GPS signal over the Equator, it was not implemented and the augmentation trials that were conducted were broadcast through a VHF transceiver.

1.9 In view of the above, project RLA/00/009 shifted its focus to the collection of data by reference stations, to be used in the study of the ionosphere effect on GPS signals.

1.10 Since the beginning of project activities, five coordination meetings have been held. The fifth coordination meeting was held on 25 September 2006, in which the preliminary final report of the project was submitted, together with the scheduled dates for the last course foreseen and for the termination of the Memorandum of Understanding between ICAO and the FAA for the lending of five reference stations (TRS).

2 Analysis

2.1 The preliminary final report of project RLA/00/009, shown in the **Appendix** to this working paper, analyses the operational navigation requirements in the CAR/SAM Regions, the technical aspects related to the WAAS-type SBAS test bed and the equipment involved, and the data collected by the reference stations, and finally, presents implementation alternatives of GNSS systems for NPA procedures.

Collected data available

2.2 The CAR/SAM test bed was mainly configured for data collection. The test bed reference stations (TRS) were configured for either sending data to the Master Test Bed Station or for collecting data locally. Measurements consisted mainly on the measurements made by the GPS receiver satellite and the collection of ephemeris messages. The TRS containing the Millennium receiver also collected data on WAAS GEO measurements.

2.3 Data collection started in 2002 and was completed in November 2005. All of the data collected during this period is stored in DVDs at the FAA technological centre in Atlantic City.

2.4 Raw data from the TRS and recorded in the Atlantic City database are available for the RLA/00/009 Project participating States/Organization as well as other participants from the GREPECAS Mechanism at their request.

2.5 Chapter 3 of the preliminary final report, which appears in the Appendix to this working paper, shows in figures 24 to 29 the amount of data received at the FAA technological centre in Atlantic City from each CSTB TRS during the 2002 -2005 period.

GNSS implementation options for NPA procedures in the CAR/SAM Regions

2.6 In its final report, Project RLA/00/009 analysed three GNSS options to cover NPA operations in the CAR/SAM Regions in the short term:

- Use of GPS with receiver autonomous integrity monitoring, or RAIM (ABAS)
- Use of the United States' WAAS system
- Development and use of an independent SBAS system for the CAR/SAM Regions

2.7 Chapter 4 of the final report contains feasibility studies of the aforementioned alternatives, as well as some estimated implementation costs.

2.8 The project analysed several configuration options for independent SBAS systems with a view to identifying the most economical option for the CAR/SAM Regions. SBAS configurations consisting of 13 reference stations (currently implemented in the CSTB), and configurations based on 8 and 6 reference stations were analysed. For each of these configurations, service volume availability models for LNAV operations were run, as shown in chapter 4 of the final report of the project (Appendix to this working paper).

2.9 The analysis shows that a configuration with 13 reference stations does not offer much more availability than a configuration based on 8 and 6 reference stations. There are very slight differences between the configurations with 6 and 8 stations, and probably they do not warrant the cost of a configuration with more reference stations. Based on the service volume model that was run, a configuration with 6 reference stations provides a good LNAV availability in the CAR/SAM Regions, and is the most economical. Service volume models could be run with less reference stations, which could result in similar availability values.

2.10 The implementation of an independent SBAS in the CAR/SAM Regions represents a very expensive endeavour. This is due not only to the cost of the TRS (reference stations) and the WMS (master station), but also to the cost of the satellite earth station, the recurring annual costs of the communication platform that will support the SBAS, and the cost of the space segment.

2.11 Costs would be drastically reduced if the United States WAAS services were used for LNAV (NPA) procedures in the CAR/SAM Regions. In order to use this service, a system with monitoring capability for generating NOTAMs would be required. LNAV availability is very good in the CAR/SAM Regions.

2.12 Likewise, the use of the basic GPS with RAIM also provides a very good availability for LNAV procedures in the CAR/SAM Regions. To use this service, it is required to have a system with monitoring capability to generate NOTAMs. Implementation costs are practically inexistent.

2.13 In conclusion, given the cost of the space segment in an SBAS system and the uncertainty of ionosphere conditions in the geomagnetic Equator, the CAR/SAM Regions must make a prompt decision regarding:

a) The implementation of a simple SBAS system for LNAV service capable of providing a precision service once the second protected civil frequency is available; or

b) The use of existing technologies (basic GPS with RAIM, basic GPS with baro-VNAV, or the United States WAAS) to provide LNAV and a limited support for precision approaches. The precision approach capability will be based on a CAT-1 GBAS system or on the use of the second civil frequency.

3. Suggested Actions

3.1 The meeting is invited to:

a) take note of the information presented in this working paper;

b) take note of Appendix, which contains the preliminary final report of project RLA/00/009;

c) review the section on data collection (paragraphs 2.2 to 2.5) and consider that the collected data are available whenever required for its corresponding analysis;

d) review the section on the GNSS implementation options for NPA procedures in the CAR/SAM Regions described in paragraphs 2.6 to 2.13 of this working paper; and

e) analyse and recommend other actions that the Meeting deems appropriate.

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RLA/00/009

INTERNATIONAL CIVIL AVIATION ORGANIZATION

RLA/00/009 PROJECT – GNSS AUGMENTATION TESTS

FINAL REPORT

June 2006

INDEX

SUMMARY

Satellite-based Global Navigation Satellite System (GNSS) technologies are being developed for use in civil aviation operations. A key feature of GNSS is that accurate navigation can be provided globally.

The United States Federal Aviation Administration (FAA), for example, developed the Wide Area Augmentation System (WAAS) which enhances the Global Positioning System (GPS) by improving system accuracy, integrity, and availability to meet requirements for en route through precision approach navigation.

To provide a platform for WAAS development, the FAA established the National Satellite Test Bed (NSTB). The NSTB is a prototype WAAS with ground infrastructure located throughout the United States and internationally.

With the aim of establishing a trial platform for the development of a WAAS type SBAS system in the CAR/SAM Regions, a Memorandum of Understanding (MOU) was established between ICAO and the FAA. The memorandum was signed on 2 June 2001.

As a consequence, the RLA/00/009 UNDP/ICAO technical cooperation project was created, to which the following States and International Organizations adhered to: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Panama, Peru, United States, Venezuela and COCESNA.

The CAR/SAM satellite platform test bed, implemented through RLA/00/009 project was named CAR/SAM Test Bed (CSTB). It was designed on the basis of the NSTB. Both CSTB and NTSB are connected through a dedicated communications circuit.

This communications circuit, initially implemented between Santiago, Chile (CSTB) and Atlantic City, United States (FAA Technical Center (NSTB)), consists in a link between Rio de Janeiro (CSTB) and the Atlantic City FAA Technical Center (NSTB).

The regional approach to demonstrate the objectives of this plan was carried out to help in illustrating the manner in which this regional system could benefit the whole region, and not only those actively participating in it.

The CSTB was established to facilitate the efforts destined towards the collection, development, purchase and implementation of an air navigation operational system based on GPS and WAAS type SBAS technologies.

The CSTB was implemented to support a standardized GPS implementation along the CAR/SAM Regions, create a regional cadre of technical experts and include an initial wide area augmentation system test platform, to be later complemented with an augmentation area capacity specific to each country.

The testing platform was implemented to reduce operational implementation costs through the development of a trial infrastructure that could be applied to the operational environment (i.e., site selection and preparation, safe ground communications links, operational procedures development, aircraft certification, training, etc.).

Initially, the Project had considered the execution of a flight test plan using the CSTB.

The objective of the regional flight trials included:

a) Demonstrate efforts toward seamless GNSS operation.
b) Demonstrate expansion of service volume through international participation.
c) Demonstrate that international GNSS compatibility is technically achievable.
d) Demonstrate that, with vertical guidance, precision approaches can be performed in Caribbean and South America using GPS-augmented signals broadcast from a wide area augmentation system.
e) Measure the system accuracy and message performance via ground and flight tests in each participating State, for the following applications, as appropriate:
    i. Long term performance data at local reference stations
    ii. Precision approaches at selected airport
    iii. Vertical guidance precision and non-precision approaches
    iv. Category I approaches
    v. Category I approaches at a country where there is no reference station (closed curve test)
    vi. Terminal area maneuvers at selected airports
    vii. En route land areas
    viii. En route oceanic areas.
f) Test SIDS and STARS at some selected locations to demonstrate a seamless takeoff to landing capability.
g) Increase international understanding for sharing information between independent GPS augmentation systems, and the shared use of communication satellites.
h) Promote international acceptance and use of augmented GPS in civil aviation applications.
i) Collect and analyze operational performance of the wide area augmentation system with focus on feasibility of using a Wide Area Differential GPS System in the CAR/SAM region.
j) Foster international cooperation and contribute to the safety of the global transportation system through sharing of information, technologies, data, technical assistance, and training between countries and non-governmental agencies.
k) Encourage future Satellite-Based Augmentation System (SBAS) flight tests.

As result of the first flight trials carried out in 2002 in Brazil, and later in Argentina, Bolivia, Chile and Peru, it was proven that the ionosphere effect over the GPS signal did not guarantee NPA approaches with vertical precision requirements, therefore, many of the afore mentioned scheduled flight trials were not carried out.

The CSTB platform included the implementation of a ground satellite station in charge of transmitting the GPS signal’s augmentation, its implementation had been planned by Brazil, but due to its high cost and the flight trial limitations caused by the effect of the ionosphere over the GPS signal in the Equatorial zone, this was never carried out, and the augmentation trials that were carried out were irradiated through a VHF transceiver.

Due to the above, project RLA/00/009 was re-oriented towards data collection from the reference stations, plus their respective processing. Chapter 3 shows the analysis of the data collected.

This report includes in **Chapter 1**, an analysis of operational navigation requirements in the CAR/SAM Regions, in **Chapter 2**, the technical aspects related with the WAAS type SBAS trial platform, as well as the equipment it is composed of. **Chapter 3** analyzes the data collected from the reference stations, describing the software tools used for data processing, the ionosphere problems and its influence over GPS signals, and **Chapter 4** presents GNSS systems implementation alternatives, their costs, and their benefits.

CHAPTER 1

ANALYSIS OF NAVIGATION REQUIREMENTS IN THE CAR/SAM REGIONS

Current navigation systems planning in accordance with CAR/SAM air navigation plan

Conventional navigation equipment

1.1 Currently, air navigation requriements in the CAR/SAM Regions are defined in Fasid Table CNS 3, which is shown in **Appendix A** to this Chapter.

1.2 Table CNS 3 indicates conventional navigation systems requirements (NDB, VOR, DME, ILS) to guarantee air navigation operations in all phases (route, non-precision approaches, precision approaches). In addition, as a result of an initial Global Navigation Satellite System (GNSS) implementation analysis, FASID Table CNS 3 indicates GNSS requirements (SBAS GBAS) in support of air navigation operations.

1.3 This Table indicates that, for Category I, II and III precision approaches, the Ground Based Augmentation System (GBAS) of the Global Positioning System (GPS) will be used, whilst for non-precision approaches (NPA), the GPS Satellite Based Augmentation System (SBAS) will be used.

1.4 In accordance with Table CNS 3, VOR/DME represents the backbone of the air navigation systems. This system will continue providing navigation phases from the en-route phase up to the non-precision approach, during the entire transition period to satellite navigation.

1.5 Table CNS 3 does not specify a target date for the transition towards the GNSS system, but it is expected that gradual elimination of VHF Omnidirectional Range (VOR)/Distance Measuring Equipment (DME) start on the second decade of this Century, alter which it will be necessary to keep some basic conventional systems for any contingencies.

1.6 The Instrument Landing System (ILS) is the main system in support of CAR/SAM precision approaches and landings. Most ILS requirements are in Categories I and II, very few airports in the region have Category III requirements. The use of ILS systems will decrease as performance and availability of GNSS based systems improve. Gradual ILS elimination in favor of GBAS is expected to also start in the second half of the 21st Century. Again, some basic conventional approach and landing systems will be kept for contingency measures.

1.7 Non-directional Radio Beacon (NDB) is used at small aerodromes as an autonomous aid for non-precision approaches, and as a compass beacon localizer, generally located near an ILS exterior radio beacon, to help pilots enter the ILS course in a non-radar environment.

1.8 NDB elimination is being gradually made. At the moment, CAR/SAM policy is that once the equipment's lifespan is over, it is not replaced.

GNSS systems

1.9 GNSS is the generic term that includes all the elements used in the provision and use of satellite navigation systems. Following is a brief description of the elements composing the GNSS system, as well as considerations on implementation plans in the CAR/SAM Regions.

Aircraft Based Augmentation Systems (ABAS)

1.10 The purpose of ABAS is to augment and/or integrate information obtained from the space segment of GNSS with onboard information. This information or integration is required to ensure that technical performance meets the requirements of Annex 10, Volume I, Chapter 3, Table 3.7.2.4-1. **Appendix B** to this chapter presents the characteristics that GPS signals must have in space for various operations in accordance with Annex 10, Volume I, Chapter 3, Table 3.7.2.4-1.

1.11 In addition, Annex 10, Volume I, Chapter 3, Section 3.7.3.3 and Attachment D, Section 5, has information and guidelines for the application of standards and recommended practices (SARPS) regarding the ABAS system.

1.12 ABAS requires the use of one of the following two processing schemes to meet aviation operational requirements and it is either:

a) The use of Receiver Autonomous Integrity Monitoring (RAIM) which uses GNSS information exclusively; or
b) Aircraft Autonomous Integrity Monitoring (AAIM) which uses information from additional onboard sensors such as barometric altimeter, multi-sensor RNAV, inertial navigation and/or a precise clock plus the GNSS information.

Receiver Autonomous Integrity Monitoring (RAIM)

1.13 Avionics certification standards require the RAIM function to detect faulty satellite signals and warn the pilot. The availability of RAIM is determined by the number of satellites in view and their geometry, receiver mask angle, phase of flight and particular algorithm used. To accomplish this task, more than five satellites must be visible allowing at least four good computations. The use of barometric altimeter aiding will improve RAIM availability.

1.14 The equipment performance standards developed by the RTCA and EUROCAE indicate that in order to perform GNSS-based NPAs the aircraft must be equipped with avionics that include Aircraft Based Augmentation system (ABAS) and meeting Technical Standard Order (TSO) 129A Levels 1 or 3.

1.15 Fault detection and exclusion (FDE) goes beyond RAIM by excluding a failed satellite and permitting interrupted GNSS navigation. FDE requires 6 or more satellite in view.

Aircraft Integrity Monitoring (AAIM)

1.16 AAIM uses the redundancy of position estimates from multiple sensors including GNSS. The integrity performance of AAIM must be at least equivalent to RAIM. AAIM avionics must meet TSO C-115A standards.

Basic GNSS receivers

1.17 Basic GNSS receivers must comply to TSO C-119 (Ed 72A) and provide 100m (95 %) horizontal accuracy supported by GPS/SPS.

Satellite Based Augmentation System. (SBAS)

1.18 Satellite based augmentation systems are composed of numerous ground reference stations monitoring the ranging signals received from the navigation satellites and master stations that not only process the data received from the reference stations but also computes the necessary corrections and prepares appropriate correction message to be up-linked to the geostationary satellite for subsequent broadcast to aircraft (users). The channel used for the broadcast of integrity information also includes a ranging signal and as such, higher availability of SBAS and associated corrections, can support approaches with vertical guidance (APV) and possibly Category I precision approaches to aircraft equipped with SBAS avionics.

1.19 Information and orientation text for the application of SARPS son the SBAS system are found in Annex 10, Volume I, Chapter 3, Section 3.7.3.4, and in Attachment D, Section 6.

SBAS avionics

1.20 The Minimum Operational Performance Standards for GPS and WAAS are described in RTCA DO-229B and thee avionics certification standards in TSO C-145. SBAS will include FDE and support en-route applications, Non-Precision Approach, Approach with Vertical Guidance (APV) and possibly Cat I precision approach.

1.21 There are two APV categories (APV1 and APV2). APV 1 can be flown using either SBAS or Barometric VNAV for vertical guidance. APV 2 has lower minima and requires SBAS.

1.22 SBAS availability levels will allow operators to take advantage of SBAS instrument approach minima when designating an alternate airport since an SBAS approach does not require an SBAS infrastructure at an airport therefore, improving airport usability at minimal cost.

1.23 En-route SBAS can also support en-route RNAV operations therefore supporting the present RNAV program in the CAR/SAM regions and permit the gradual retirement/reduction of ground navaids used for en-route operations.

1.24 Even though the SBAS program is still in development phase, the inclusion of this augmentation option is indeed found in the CAR/SAM Regions implementation plans, as mentioned before.

1.25 The coverage area of the SBAS system is determined by the footprint of the geostationary broadcasting satellite, which unfortunately does not cover very well high latitude polar regions. Considering the above, States can define service areas where approved SBAS-based operations are approved or supported.

1.26 Recognizing that the State is responsible for the services provided within a service area, appropriate institutional arrangements, while still maintaining a certain level of control, could significantly increase service areas at minimal cost through the sharing of resources. Furthermore, with appropriate arrangements the cost can also be shared with other user community such as marine, ground transportation community such as trucking, railway, ambulance etc. This arrangement will likely require the provision of notices to all concern relating the availability and quality of the augmentation signals.

Ground Based Augmentation Systems (GBAS)

1.27 Information and guideline material for the application of GNSS Standards and Recommended Practices (SARPs) are found in Annex 10, Volume I, Chapter 3, Section 3.7.3.5.1 and in Attachment D, Section 7.

1.28 The Ground Based Augmentation System (GBAS) is a system composed of ground and aircraft elements. A ground subsystem (ground station) can provide support to all aircraft subsystems within its coverage, providing the aircraft with approach, corrective and seamless information data for in sight GNSS satellite, through VHF data dissemination (VDB).

1.29 The GBAS ground subsystems provide two services: precision approach and GBAS position determination. The precision approach service provides a deviation guideline for final approach segments, while the GBAS position determination service provides information on the horizontal position to provide support to RNAV operations at terminal areas.

Analysis of GNSS system implementation as support to air navigation operations in the CAR/SAM Regions

Analysis of GNSS systems to support en route, approach, landing and take-off operations

1.30 In the CAR/SAM Regions, where operation efficiency improvement is being taken under consideration, an immediate advantage of GNSS would represent an optimization of en route operations, upon permitting pilots direct flights to their destinies, at preferred altitudes, without having to follow routes that depend on ground based navigation aids. Again, the use of GNSS will greatly simplify the development of parallel routes to satisfy traffic demands. In addition, GNSS will ease NPA introduction at many airports, where costs of traffic volume would not justify a big investment. The low cost associated with the GNSS/WAAS receivers makes this innovation accessible and encourages the use of a navigation reference.

1.31 The lack of conventional navigation and surveillance aids in the oceanic airspace has forced the establishment of higher separation minima, with the aim of satisfying the desired safety level. With GNSS, greater navigation accuracy and better data link availability can be achieved to transmit position reports, so as to reduce the separation minima and carry out a greater number of optimum altitude flights.

1.32 The CAR/SAM Regions have great oceanic areas of low traffic density, where it World be impossible or too costly to offer appropriate navigation and surveillance capability. Again, important operational improvements can be obtained through the use of GNSS and the gradual elimination of conventional navigation aids.

1.33 To use GNSS as primary means of navigation in en-route and oceanic areas, the avionics must have the ability to identify and exclude a faulty satellite signal and continue to provide guidance. This is called “Fault Detection and Exclusion” (FDE). Under this approval, aircraft must carry dual systems and operators must perform pre-flight predictions to ensure that there will be enough satellites in view to support the planned flight. This approval allows operators to use aircraft without costly inertial navigation systems in oceanic and remote airspace.

1.34 Annex 15 requires that Notice to Airmen (NOTAM) service be provided for navigation systems in order to inform users about forecasted satellite outages. Considerations should be given to the establishment of a regional NOTAM advisory systems to inform pilots when the RAIM function is or will not be available.

1.35 As an additional value, many operators use GPS as an aid to VFR navigation. As long as pilots rely on map reading and visual contact with the ground. This use of GPS can increase efficiency and safety. In some States, aircraft must be equipped with IFR-certified GPS avionics for night VFR and VFR on top.

GNSS for terminal area applications

1.36 While there will be some economic and operational advantages associated with the non-replacement of VOR/DME en-route, the bulk of the savings and operational improvements for States could come from the elimination of VOR/DMEs used for terminal area operations. Considering the more complex environment and the need for improved accuracy, integrity, continuity and availability, satellite-based and or ground-based augmentation systems will be required. As a result of recent events, there will likely be a need for backup for contingency measures. This will significantly affect the expected savings for States since, in addition to the retention of a minimum operational network of conventional navaids, facilities for maintenance and calibration of those navaids will need to be maintained. Considering the reduced number of installations, some reduction in cost could be achieved through the sharing of, for example, flight inspection and calibration units.

GNSS for Non-Precision and Precision approach and landings

1.37 The use of GNSS with appropriate augmentation will provide non-precision and precision approach and landing capability especially at airports that either because of siting problems or where the installation of an ILS could not be financially justified. . GNSS-based precision approach and landing systems is an important consideration since it would have the advantage of providing these capabilities to all runway ends of one airport. In the case of GBAS, distance and terrain permitting, precision approach can also be provided to other airport in the vicinity (Within approximately 20 nautical miles).

GNSS considerations and comments related to the use of GNSS for NPA operations

1.38 While GNSS has the potential to support better approaches to more runway ends at relatively low cost, approach minima also depend on aerodrome physical characteristics and on infrastructure such as lighting. States must therefore, consider the cost of meeting aerodrome standards when planning new approaches.

1.39 Technical Standard Order 129 (TSO C129), which defines the conditions under which GNSS can be used as a “supplemental means” of navigation for en-route and non-precision approach, has been available since 1992. The availability of low cost TSO C129 GNSS receivers, and procedures makes possible the immediate implementation of GNSS-based NPA.

1.40 Safe GNSS navigation also depends on the accuracy of airborne navigation databases. Therefore, States must ensure data integrity when creating new procedures. Additionally, data management procedures and systems must be in place to ensure the integrity of the data as they are processed for use by the avionics.

1.41 GNSS technology and operation are not as simple to operate as traditional avionics. States therefore, need to mandate pilot training programs to ensure the safety of GNSS operation.

1.42 The bulk of the work related to the introduction of GNSS-based NPA will be focus on:

a) An accurate survey of each airport.
b) The development of a systematic approach to the development and maintenance of related databases.
c) The development of procedures and ways to monitor their compliance.
d) The development of an approval process.

Planning for the implementation of Performance Based Navigation (PBN)

PBN concept

1.43 Performance based navigation specifies performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in an airspace. Information on performance based navigation is found in ICAO Document 9613 – *Manual on Required Navigation Performance (RNP).*

1.44 Performance requirements are defined in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept. Performance requirements are identified in navigation specifications, which also identify which navigation sensors, and equipment may be used to meet the performance requirement.

1.45 There are both RNP specifications and RNAV specifications. A RNP specification includes a requirement for onboard performance monitoring and alerting and is designated as a RNP X. An RNAV specification does not have such requirements and is designated as RNAV X. Performance based navigation therefore depends on:

a) The RNAV system and installation on the aircraft being approved to meet the performance and functional requirements of the navigation specification prescribed for RNAV operations in an airspace;

b) Air crew satisfying the operating requirements set out by the regulator for RNAV operations;

c) A defined airspace concept which includes RNAV operations; and

d) An available navigation aid infrastructure.

Benefit of the performance based navigation

1.46 To avoid unnecessary constraints upon the airspace users it is necessary to avoid specifying how the navigation requirements are to be met but only what Navigation Performance and Functionality is required from the RNAV system. Under PBN, generic navigation requirements are defined based on the operational requirements. Operators are then able to evaluate options in respect of available technologies and navigation services that could allow these requirements to be met. The chosen solution would be the most cost effective for the operator rather than a solution being imposed as part of the operational requirements. Technologies can evolve over time without requiring the operation itself to be revisited as long as the requisite performance is provided by the RNAV system.

1.47 Thus, PBN offers a number of advantages over the sensor-specific method of developing airspace and obstacle clearance criteria:

1.48 The cost of maintaining sensor-specific routes and procedures can be significant. For example, moving or reassigning a single VOR ground facility can impact dozens of procedures, as that VOR can be used on routes, VOR approaches, as part of missed approaches, etc. Adding new sensor-specific procedures will compound this cost, and the rapid growth in available navigation systems (see below) would soon make system-specific routes and procedures unaffordable.

1.49 Aircraft and avionics manufacturers have adopted on-board performance monitoring and alerting capabilities to manage multi-sensor RNAV systems. In these systems, the achieved performance varies depending on the navigation sensors in use, the supporting navigation (Navaid) infrastructure, and whether or not there are any failures.

1.50 The expansion of satellite navigation services is expected to contribute to the continued diversity of RNAV systems in different aircraft. The original Basic GNSS equipment is evolving due to the augmentations of SBAS, GBAS and GNSS Regional Augmentation System (GRAS), while the expected introduction of Galileo and planned modernization of GPS and GLONASS will further improve performance. The use of GNSS/inertial integration is expanding. Developing system-specific operations with each new evolution would be cost-prohibitive.

1.51 Within an airspace concept, PBN requirements will be affected by the communication, surveillance and ATM environment as well as the Navaid infrastructure and what the functional and operational capabilities are needed to meet the ATM application. PBN performance requirements will also depend on what reversionary, non-RNAV means of navigation are available and hence what degree of redundancy is required to ensure an adequate continuity of function.

1.52 The development of the Performance Based Navigation Concept recognizes that advanced aircraft RNAV systems are achieving a predictable level of navigation performance accuracy, which together with an appropriate level of functionality, allows a more efficient use of available airspace to be realized. It also takes account of the fact that RNAV systems have developed over a 40-year period and as a result there are a large variety of implementations. Identifying navigation requirements rather than on the means of meeting the requirements will allow use of all RNAV systems meeting these requirements irrespective of the means by which these are met.

Considerations on the implementation of performance based navigation

Short term (up to 2010)

En route operations

1.53 Taking into account air traffic low density in oceanic airspaces, no significant changes are expected in the present airspace structure that will demand changes in applied RNAV values. The only exception will be RNP-10 application in the WATRS Region, which will demand a significant change in the CAR Region airspace structure. In airspaces where RNP-10 is applied (EUR/SAM Corridor, Lima-Santiago de Chile Routes and South Atlantic Random Routes System), no short-term changes are expected.

1.54 In the continental airspace, RNAV-5 implementation in selected airspaces is expected, where possible to obtain operational benefits and available CNS infrastructure is able to support it.

TMA operations (SIDs and STARs)

1.55 The application of RNAV-1 in State-selected TMAs, in radar environments, with ground navigation infrastructure is expected, which permits DME/DME and DME/DME/INS operations. In this phase mixed operations (equipped and non-equipped) will be admitted, and RNAV-1 operations shall be initiated when an adequate percentage of air operations are approved.

1.56 In non-radar environments and/or in environments that do not count with adequate ground navigation infrastructure, the application of RNP-1 is expected in State-selected TMAs with exclusive application of GNSS, whenever an adequate percentage of air operations are approved. In this TMA will also be admitted approved and non-approved aircrafts. The application of overlay procedures or exclusive RNP procedures will depend on air traffic complexity and density.

IFR approaches

1.56.1.1 The application of RNP 0,3 approach procedures (basic GNSS) is expected in the maximum possible of State-selected airports, principally in international airports, maintaining conventional approach procedures for non-equipped aircraft.

1.56.1.2 The application of RNP AR approach procedures is expected in State-selected airports, where obvious operational benefits can be obtained, based on the existence of significant obstacles.

Short Term (until 2010)	
Airspace	**RNAV or RNP Value**
Route (Oceanic o Remote)	RNP 10 Corridor EUR/SAM and Santiago/Lima/AORRA/WATRS
Route (Continental)	RNAV 5 in selected airspaces
TMA	RNAV-1 in radar environment and with adequate ground navigation infrastructure.
	RNP 1 – No radar environment and/or without appropriate DME coverage.
Approach	RNP 0,3 in most possible airports and in all international airports. RNP AR in airport where there are obvious operational benefits.
• Non compulsory installation of RNAV equipment on board of non equipped aircraft in TMA and APP • Mixed Operations (equipped and non equipped aircraft) in TMA and APP • Required RNAV 2 equipment above FL350 for flights to/from United States.	

Medium term (2011-2015)

En-route operations

1.57 The application of RNP 4 in the oceanic airspace in EUR/SAM corridor is expected, with utilization of ADS/CPDLC, in order to permit the use of lateral and longitudinal separation of 30 NM. This application will depend on the evolution of the aircraft fleet flying in the airspace.

1.58 In this phase, the application of RNP-2 is expected in selected areas of the continental airspace, with high air traffic density and exclusive application of GNSS, depending on the analysis of ground infrastructure, which will indicate whether it is possible to use RNAV applications. The establishment of a backup system will be necessary as well as the development of contingency procedures in the event of GNSS failure. The application of RNP-2 will facilitate the PBN application is non surveillance airspace. With the exclusive application of GNSS more control of the GNSS signal is needed, through GPS Monitoring Systems that include NOTAM, FDE, etc.

TMA operations

1.59 In this phase, it is expected to extend the application of RNAV (RNP) 2/1 in State-selected TMAs, depending of ground infrastructure and of aircrafts navigation capacity. In TMAs of high air traffic complexity and movement (excluding airspaces), the use of RNAV or RNP 1 equipments will be mandatory. In TMAs of less air traffic complexity, mixed operations will be admitted (equipped or non-equipped).

IFR approaches

1.60 In this phase the extended application of procedures RNP 0.3 and RNP AR in selected airports is expected. Also, the initiation of application of GLS procedure is expected to guarantee a smooth transition between TMA phase and the approximation ´has, basically using GNSS for the two phases.

Medium Term (2011-2015)	
Airspace	**RNAV or RNP Value**
Route (Oceanic or Remote)	RNP 4 in EUR/SAM Corridor and Santiago/Lima
Route (Continental)	RNP 2 in selected airspaces
TMA (SID/STAR)	Expansion of RNAV-1 or RNP-1 application Compulsory RNAV 1 or RNP 1 approval for aircraft operating in greater air traffic density TMAs (exclusionary airspace)
Approach	Expansion of RNP 0,3 and RNP AR application Application of GLS procedures
• RNP2 required equipment over FL290 for flights to/from United States.	

APPENDIX A / APENDICE A

TABLE CNS 3 - TABLA CNS 3

TABLE OF RADIO NAVIGATION AIDS - TABLA DE AYUDAS PARA LA RADIONAVEGACIÓN

EXPLANATION OF THE TABLE

Column

1 Name of the country, city and aerodrome and, for route aids, the location of the installation.

2 The designator number and runway type:

NINST C Visual flight runway
NPA C Non precision approach runway
PA1 C Precision approach runway, Category I
PA2 C Precision approach runway, Category II
PA3 C Precision approach runway, Category III

3 The functions carried out by the aids appear in columns 4 to 8 and 10 to 12.

A/L C Approach and landing
T C Terminal
E C En route

4 ILS CInstrument landing system. Roman numerals I, II and III indicate the acting category of the ILS I, II or III. (I) indicates that the facility is implemented.

The letter AD@ indicates a DME requirement to serve as a substitute for a marker beacon component of an ILS.

Note.C Indication of the category refers to the performance standard to be achieved and maintained, in accordance with pertinent specifications in ICAO Annex 10, and not to specifications of the ILS equipment, since both specifications are not necessarily the same.

An asterisk (*) indicates that the ILS requires a Category II signal, but without the reliability and availability which redundant equipment and automatic switching provide.

5 Radio beacon localizer, be it associated with an ILS or to be used as an approach aid at an aerodrome.

6 Radiotelemetrical equipment. When an AX@ appears in column 6 in line with the VOR in column 7, this indicates the need that the DME be installed at a common site with the VOR.

7 VOR C VHF omnidirectional radio range.

8 NDB C Non-directional radio beacon.

9 The distances and altitude to which the VOR or VOR/DME signals are required, indicated in nautical miles (NM) or thousands of feet, or the nominal coverage recommended of the NDB, indicated in nautical miles.

10, 11 GNSS C global navigation satellite system (includes GBAS and SBAS).

GBAS (ground-based augmentation system) implementation planned to be used in precision approach and landing CAT I, CAT II, CAT III.

SBAS (satellite-based augmentation system) implementation planned to be used for route navigation, for terminal, for non precision approach and landing. An AX@ indicates service availability; exact location of installation will be determined.

Note. C GPS receiver is under standard rules and ABAS (aircraft-based augmentation system).

12 Remarks

Note.C Columns 5 to 12 use the following symbols:

D C DME required but not implemented.
DI C DME required and implemented.
X C Required but not implemented.
XI C Required and implemented.

EXPLICACIÓN DE LA TABLA

Columna

1 Nombre del país, ciudad y aeródromo y, para las ayudas en ruta, el emplazamiento de la instalación.

2 Número de designador y tipo de pista:

NINST C Pista de vuelo visual
NPA C Pista de aproximación que no es de precisión
PA1 C Pista de aproximación de precisión, Categoría I
PA2 C Pista de aproximación de precisión, Categoría II
PA3 C Pista de aproximación de precisión, Categoría III

3 La función efectuada por las ayudas figura en las Columnas 4 a 8 y 10 a 12.

A/L C Aproximación y aterrizaje
T C Terminal
E C En ruta

4 ILS C Sistema de aterrizaje por instrumentos. Los números romanos I, II y III indican la categoría de actuación del ILS, I, II o III. (I) indican que la instalación está en servicio.

La letra AD@ indica que se requiere un DME para sustituir a un componente de radiobaliza de un ILS.

Nota.C La indicación de la categoría se refiere a la norma de performance que ha de alcanzarse y mantenerse, de conformidad con las especificaciones pertinentes del Anexo 10 de la OACI, y no con las especificaciones del equipo ILS, ya que ambas especificaciones no son necesariamente las mismas.

Un asterisco (*) indica que el ILS requiere una señal de Categoría II, pero sin la fiabilidad y disponibilidad que proporcionan el equipo de reserva y la conmutación automática.

5 Localizador de radiofaro, asociado a un ILS o para utilizarlo como ayuda de aproximación en un aeródromo.

6 Equipo radiotelemétrico. Cuando figura una AX@ en la Columna 6 junto con el VOR de la Columna 7, quiere decir que el DME debe instalarse en un sitio común con el VOR.

7 VOR C Radiofaro omnidireccional en VHF.

8 NDB C Radiofaro no direccional.

9 Las distancias y altitud a las cuales se requieren señales VOR o VOR/DME indicadas en millas marinas (NM) o miles de pies, o la cobertura nominal recomendada del NDB indicada en millas marinas.

10, 11 GNSS C sistema mundial de navegación por satélite (incluye GBAS y SBAS).

GBAS (sistema de aumentación basado en tierra) según lo previsto se utilizará en las aproximaciones y aterrizajes de precisión de CAT I, CAT II y CAT III.

SBAS (sistema de aumentación basado en satélites) según lo previsto, se utilizará en navegación en ruta, terminal, y aproximaciones y aterrizajes que no son de precisión. La AX@ indica disponibilidad de servicio; se determinará el emplazamiento exacto de la instalación.

Nota.C El receptor GPS se ajusta a reglas uniformes y ABAS (sistema de aumentación basado en la aeronave).

12 Observaciones

Nota.C En las Columnas 5 a 12 se utilizan los símbolos siguientes:

D C DME requerido pero no en servicio.
DI C DME requerido y en servicio.
X C Requerido pero no en servicio.
XI C Requerido y en servicio.

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
ANGUILLA (United Kingdom)											
THE VALLEY WALL BLAKE, Anguilla I.	10 NPA	A/L					XI			X	
ANTIGUA AND BARBUDA											
SAINT JOHNS/V.C. Bird, Antigua I.	07 PA1	A/L	II* D		XI	XI	XI		X		
	25 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E					XI	400		X	
ARGENTINA											
BUENOS AIRES/Aeroparque	13 PA1	A/L	II D (I)		XI	XI			X		
Jorge Newbery											
BUENOS AIRES/Ezeiza	11 PA3	A/L	III D (I)		XI	XI			X		
Ministro Pistarini											
	35 PA1	A/L	II (I)		XI	XI			X		
		T			XI	XI				X	
		E			XI	XI		160/45		X	
BUENOS AIRES/San Fernando	23 NPA	A/L			XI	XI					
		T			XI	XI					
CATARATAS DEL IGUAZU/My. D.	31 PA1	A/L	I D (I)		X	XI			X		
Carlos Eduardo Krause											
	13 NPA	A/L				XI					
		T/E			X	XI		190/45		X	
CERES		E			XI	XI		200/45		X	
COMODORO RIVADAVIA/Gral.	25 PA1	A/L	I (I)		X	XI			X		
Mosconi											
	07 NINST										
		E			XI	XI		200/45		X	
		E					XI				
CORDOBA/Ing. Aer. A. L. Taravella	18 PA1	A/L	II* D (I)		XI	XI	XI		X		
	36 NINST										
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	90		X	
FORMOSA/Formosa	03 NPA	A/L			XI	XI	XI	200/45		X	
	21 PA1	A/L	I D (I)		XI	XI	XI		X		
		T			XI	XI	XI			X	
		E			XI	XI				X	
GENERAL PICO		E				XI		160/45		X	
GUALEGUAYCHU		E						190/45		X	
JUJUY/Jujuy	33 PA1	A/L	I (I) D		XI	XI	XI		X		
	15 NINST										
		T/E			XI	XI		200/45		X	
		E					XI	200		X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
JUNIN		E				XI		200/45		X	
		E					XI	100		X	
LABOULAYE		E			X	XI		200/45		X	
LA PLATA		E				XI		230/45		X	
		E					XI	110		X	
LAS LOMITAS		E				XI		200/45		X	
MALARGUE		E			XI	XI		250/45		X	
		E					XI			X	
MAR DE PLATA/Brig. Gral. B. de la Colina	13 PA1	A/L	II D (I)		XI	XI	XI		X	X	
	31 NINST										
		T			XI	XI	XI			X	
		E			XI	XI		250/45		X	
		E					XI	110		X	
MARCOS JUAREZ		E			X	XI		200/45		X	
MENDOZA/El Plumerillo	18 NPA	A/L			XI	XI	XI			X	
	36 PA1	A/L	II (I) D		XI	XI	XI			X	
		T			XI	XI	XI			X	
		E			XI	XI		210/45		X	
MONTE CASEROS		E			X	XI		210/45		X	
NEUQUEN/Presidente Peron	08 PA1	A/L	I (I)		XI	XI			X		
	26 NINST										
		T/E			XI	XI		200/45		X	
		E					XI			X	
ORAN		E					XI	70		X	
POSADAS/Libertador Gral. D. José de San Martín	01 NPA	A/L			XI	XI	XI			X	
	19 PA1	A/L	II D (I)		XI	XI	XI		X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
RECONQUISTA		E			XI	XI		200/45		X	
RESISTENCIA/Resistencia	21 PA1	A/L	II (I)		XI	XI	XI		X		
	03 NINST										
		T/E			XI	XI		200/45		X	
		E					XI	200		X	
RIO GALLEGOS/Piloto Civil N. Fernández	25 PA1	A/L	II (I) D		XI	XI	XI		X		
	07 NPA	A/L			XI	XI	XI			X	
		T/E			XI	XI		200/45		X	
		E					XI	80		X	
RIO GRANDE/Rio Grande	25 PA1	A/L	I D (I)		X	XI			X		
		T/E			X	XI	XI	200/45		X	
		E					XI	200		X	
ROSARIO/Rosario	19 PA1	A/L	I (I)		XI	XI			X		
	01 NINST										

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
		T/E			XI	XI		200/45		X	
SALTA/Salta	01 PA1	A/L	I (I) D		XI	XI	XI		X		
	19 NINST										
		T/E			XI	XI		200/45		x	
SAN ANTONIO DE ARECO		E			X	XI		200/45		X	
		E					XI	150		X	
SAN CARLOS DE BARILOCHE/San Carlos de Bariloche	11 NPA	A/L			XI	XI				X	
	29 PA1	A/L	I D (I)		XI	XI	XI		X		
		T/E			XI	XI		200/45		X	
		E					XI	150		X	
SAN JUAN		E			XI	XI		230/45		X	
		E					XI			X	
SAN RAFAEL		E				XI		180/45		X	
TANDIL		E			XI	XI		210/45		X	
TRELEW		E			XI	XI		200/45		X	
TUCUMAN/Tte. Benjamín Matienzo	01 PA1	A/L	I (I)		XI	XI	X		X		
	19 NINST										
		T/E			X	XI		290/45		X	
USHUAIA/Malvinas Argentinas	25 PA1	A/L	I D (I)			XI			X		
	07 NPA	A/L				XI			X		
		E				XI		200/45		X	
ARUBA (Netherlands)											
ORANJESTAD/Reina Beatrix, Aruba I.	11 PA1	A/L	II* D (I)		XI	XI			X		
	29 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
										X	
BAHAMAS											
ALICE TOWN/South Bimini, Bimini I.	NINST									X	
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E					XI	285		X	
CAPE ELEUTHERA/Cape Eleuthera, Eleuthera I.	NINST									X	
FREEPORT/Intl, Grand Bahama I.	06 PA1	A/L	II* D		XI	XI	XI		X		
	24 NPA	A/L							X		
		T			XI	XI				X	
GEORGE TOWN/EXUMA Intl, Exuma I.		A/L			XI	XI	XI		X		
GOVERNOR=S HARBOUR/Governor=s Harbour, Eleuthera I.	15 NPA				XI	XI			X		

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
		T			XI	XI				X	
		E			XI	XI				X	
MARSH HARBOUR/Marsh Harbour, Abaco I.	NINST									X	
NASSAU/Intl, New Providence I.	14 PA1	A/L	II* D		XI	XI			X		
	32 NPA								X		
	09 NPA								X		
	27 NPA								X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E					XI	400		X	
NORTH ELEUTHERA/North Eleuthera, Eleuthera I.	NINST										
TREASURE CAY/Treasure Cay, Abaco I.	14 NPA				XI	XI				X	
	32 NPA									X	
		T			XI	XI				X	
		E			XI	XI				X	
WEST END/West End, Grand Bahama I.	11 NPA				X	X				X	
BARBADOS											
BRIDGETOWN/Grantley Adams Intl.	09 PA1	A/L	II* D		XI	XI	XI		X		
	27 NPA									X	
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	355		X	
BELIZE											
BELIZE/Intl.	07 PA1	A/L	II* D (I)		XI	XI	XI		X		
	25 NPA									X	
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	275		X	
BOLIVIA											
CHARAÑA		E					XI	60		X	
COCHABAMBA/Jorge Wilsterman	31 PA1	A/L	I D	XI	XI	XI			X		
		E			XI	XI		100/45		X	
		E					XI	100		X	
LA PAZ/El Atlo Intl.	10R PA1	A/L	II* D (I)	XI	XI	XI	XI		X		
		T			XI	XI	XI			X	
		E			XI	XI	XI	100/45		X	
		E					X	275		X	
CALAMARCA		T			XI	XI			X		
		E			XI	XI		100/45		X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
RIBERALTA		E				XI		100/45		X	
		E					XI	100		X	
ROBORE		E				XI		100/45		X	
		E					X	100		X	
SANTA ANA		E					X	100		X	
SANTA CRUZ/Viru Viru	15 NPA	A/L	I	XI	XI	XI			X		
	33 PA1	A/L	I				XI		X		
		T			XI	XI					
		E			XI	XI		200/45		X	
		E					X	200		X	
SUCRE		E			XI	XI		125/45		X	
		E					XI	125		X	
TARIJA/Oriel Lea Plaza	13 NPA	A/L			XI	XI	XI			X	
		E				XI		100		X	
		E					XI	80			
TRINIDAD/Tte. Av. Jorge Henrich Arauz	14 PA1	A/L	II		XI	XI			X		
	32 NPA	A/L					XI		X		
		E				XI		180/45		X	
		E					X	80		X	
YACUIBA		E					XI	100		X	
BRAZIL											
ABROLHOS		E					XI	90			
ALDEIA		T					XI	30			
		E					XI				
ALTA FLORESTA		E			XI	XI		200/45			
		E					XI	200			
AMAPA		E					XI	180			
ARACAJU		E			XI	XI		120/45			
		E					XI	100			
BAGE		E				XI		100/45			
		E					XI	100			
BARREIRAS		E				XI		200/45			
		E					XI	200			
BAURU		E			X	X		200/45			
		E					XI	200			
BELEM/Val De Caes	06 PA1	A/L	ID	XI	XI	XI					
	24 NPA	A/L			XI	XI	XI				
		T/E			XI	XI		200/45			
		E			XI	XI	XI	150			

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
BELO HORIZONTE/Tancredo Neves Intl.	16 PA1	A/L	I	XI	XI	XI					
	34 NPA	A/L			XI	XI	XI				
		T/E			XI	XI	XI	200/45			
							XI	100			
BOA VISTA/Boa Vista Intl.	07 PA1	A/L	I		XI	XI	XI				
	25 NPA	A/L			XI	XI	XI				
		E			XI	XI		200/45			
		E					XI	200			
BONSUCESSO		E/T			XI	XI		200/45			
BRAGANCA		T			XI	XI		100/25			
		E			XI	XI		200/45			
BRASILIA/Brasilia Intl.	11 PA1	A/L	ID	XI	XI	XI					
	29 PA1	A/L	ID		XI	XI					
		T			XI	XI	XI				
		E			XI	XI		200/45			
		E					XI	200			
CAMPINAS/Viracopos	15 PA1	A/L	I	XI	XI	XI					
	33 NPA	A/L			XI	XI					
		T			XI	XI	XI				
		E			XI	XI		200/45			
CAMPO GRANDE/Campo Grande Intl.	06 PA1	A/L	ID	XI	XI	XI					
	24 NPA	A/L			XI	XI	XI				
		T			XI	XI	XI				
		E			XI	XI		200/45			
		E					XI	200			
CAMPOS		E					XI	120			
CARAJÁS		E			XI	XI		200/45			
							XI	200			
CARAUARI		E					XI	120			
CARAVELAS		E				XI		200/66			
		E					XI	130			
CAROLINA		E			X	XI		130/45			
		E					XI	130			
CAXIAS		T			XI	XI	XI				
		E			XI	XI		200			
CONGONHAS		E			XI	XI		200/45			
CORUMBÁ/Corumbá Intl.	09 PA1	A/L	II* D		X	X	XI				
	27 NPA	A/L			X	X	XI	200/45			
		T			X	X	XI				
		E			X	X					
		E					XI	100			
CRUZEIRO DO SUL/Cruzeiro do Sul Intl.	09 NPA	A/L			XI	XI	XI				

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
	27 NPA	A/L			XI	XI	XI				
		E			XI	XI		200/45			
		E			XI		XI	150			
CUIABÁ/Marechal Rondom	17 PA1	A/L	ID		XI	XI	XI				
	35 NPA	A/L			XI	XI	XI				
		T			XI	XI	XI				
		E			XI	XI		200/45			
		E					XI				
CURITIBA/Afonso Pena Intl.	15 PA3	A/L	III		XI	XI	XI				
	33 NPA	A/L			XI	XI	XI				
		T			XI	XI	XI				
		E			XI	XI		200/45			
		E					XI				
FLORIANÓPOLIS/ Hercílio Luz Intl.	14 PA1	A/L	I		XI	XI	XI				
	32 NPA	A/L			XI	XI	XI				
		T			XI	XI					
		E			XI	XI		200/45			
		E					XI	150			
FORTALEZA/ Pinto Martins	13 NPA	A/L			XI	XI	XI				
	31 NPA	A/L			XI	XI	XI				
		T			XI	XI					
		E			XI	XI		200/45			
		E					XI				
FOZ DO IGUACU/Cataratas Intl.	14 PA1	A/L	I		XI	XI	XI				
	32 NPA	A/L			XI	XI	XI				
		T			XI	XI					
		E			XI	XI		200/45			
GABRIEL		E			XI	XI		200/45			
		E					XI	200			
GUAJARÁ		E					XI	50			
ILHEUS		E			X	X		150/45		X	
		E					XI	95		X	
IMPERATRIZ		E			XI	XI		200/45		X	
ITACOATIARA		E					XI	125		X	
JACAREACANGA		E			XI	XI		135/45		X	
		E					XI	75			
LAGES		E					XI	120		X	
LAPA		E				XI		200/45			
		E					XI	200			
LONDRINA		E			XI	XI		200/45			
LUZIANIA		T			X	X					
		T					XI				
MACAE		E			XI	XI		120/25			

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
MACAPA/Macapa Intl.	08 PA1	A/L	I		XI	XI	XI				
	26 NPA	A/L			XI	XI	XI				
		E			XI	XI		90/25			
		E					XI	50			
MACEIO		E			XI	XI		150/45			
		E					XI	70			
MANAUS/Eduardo Gomes Intl.	10 PA1	A/L	I		XI	XI	XI				
	28 NPA	A/L			XI	XI	XI				
		T			XI	XI	XI				
		E			XI	XI		200/45			
MARICA		T			XI	XI					
		E			XI	XI		230/45			
MONTES CLAROS		E					XI	100			
MOSSORO		E			XI	XI		200/45			
		E					XI	90			
MOZ		E					XI	90			
NANUQUE		E			XI	XI		200/45			
NATAL/Augusto Severo Intl.	16 L PA1	A/L	I		XI	XI	XI				
	34 R NPA	A/L			XI	XI	XI				
		T			XI	XI					
		E			XI	XI		200/45			
		E					XI				
PALMAS		E			XI	XI		200/45			
		E					XI	150			
PARANAGUA		E					XI	70			
PARNAIBA		E					XI	30			
PAULO AFONSO		E				XI		200/45			
		E					XI	120			
PELOTAS		E				XI		130/45			
		E					XI	130			
PETROLINA		E			XI	XI		200/45			
		E					XI	150			
PIRAI		E			XI	XI		200/45			
		E					XI	150			
POCOS		E					XI	90			
PONTA PORA/Ponta Pora Intl.	03 NPA	A/L					XI				
	21 NPA	A/L					XI				
		E					XI	70			
PORTO ALEGRE/Salgado Filho Intl.	11 PA1	A/L	I	XI	XI	XI					
	29 NPA	A/L		XI	XI	XI					
		T			XI	XI	XI				
		E			XI	XI		160/45			

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
		E					XI	160			
PORTO		T			XI	XI		100			
		E			XI	XI		200/45			
PORTO VELHO		E			XI	XI		200/45			
RECIFE /Guararapes	18 PA1	A/L	I		XI	XI	XI				
	36 NPA	A/L			XI	XI	XI				
		T			XI	XI					
		E			XI	XI		200/45			
		E					XI	200			
REDE		T			XI	XI					
		E			XI	XI		200/45			
RIO BRANCO		E			XI	XI		200/45			
		E					XI	100			
RIO DE JANEIRO/Galeão Antônio Carlos Jobim Intl.	10 PA2	A/L	II	XI	XI	XI					
	28 PA1	A/L	I	XI	XI	XI					
	15 PA1	A/L	I	XI	XI	XI					
	33 NINST										
RONDONIA		E					XI	50			
SALVADOR/Deputado Luis Eduardo Magalhaes	10 PA1	A/L	I	XI	XI	XI					
	28 NPA	A/L									
		T			XI	XI	XI				
		E			XI	XI		200			
SANTA CRUZ		T			XI	XI					
		E			XI	XI		125/45			
SANTANA		T			XI	XI					
		E			XI	XI		100/45			
SANTAREM/Santarem Intl.	10 NPA	A/L			XI	XI	XI				
	28 NPA	A/L			XI	XI	XI				
		T			XI	XI	XI				
		E			XI	XI	XI	200/45			
SAO LUIS/ Marechal Cunha Machado	06 PA1	A/L	I	XI	XI	XI	XI				
	24 NPA	A/L			XI	XI	XI				
		T/E			XI	XI	XI	150/30			
SAO PAULO/Guarulhos Intl.	09R PA2	A/L	II	XI	XI	XI					
	27L PA1	A/L	I	XI	XI	XI					
	09L PA1	A/L	I	XI	XI	XI					
	27R PA1	A/L	I	XI	XI	XI					
SOROCABA		T			XI	XI					
		E			XI	XI		200/45			
TABATINGA/Tabatinga Intl.	12 NPA	A/L					XI				
	30 NPA	A/L					XI				
		T					XI	200			

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
TEFE		E			XI	XI		200/45			
		E					XI	50			
TRES MARIAS		E			XI	XI		115/20			
UBERABA		E					XI	130			
URUBUPUNGA		E			XI	XI		200/45			
		E					XI	100			
URUBURETAMA		E					XI	80			
URUGUAIANA/ Rubem Berta Intl.	09 NPA	A/L					XI				
	27 NPA	A/L					XI				
		T					XI	80			
VITORIA		E			XI	XI		200/45			
CAYMAN ISLANDS (United Kingdom)											
CAYMAN BRAC/Gerrard Smith Intl.	09 NPA	A/L					XI	200/45		X	
GEORGETOWN/Owen Roberts Intl.	08 PA1	A/L			XI	XI	XI		X		
	26 NPA	A/L								X	
		E			XI	XI		200/45		X	
		E					XI	350		X	
CHILE											
ANTOFAGASTA/Cerro Moreno	18 NPA	A/L			XI	XI				X	
	36 NPA	A/L		XI						X	
		T/E			XI	XI		100/25		X	
ARICA/Chaculluta	02 NPA	A/L		XI	XI	XI	XI				
	20 NPA	A/L								X	
		T			XI	XI				X	
		E			XI	XI		185/45		X	
		E				X				X	
BALMACEDA		E			XI	XI		200/45		X	
		E					XI	200		X	
CALAMA		E			XI	XI		70/250		X	
							X	160			
CALDERA		E			XI	XI		200/45		X	
		E					X	350		X	
CHAITEN		E					XI	100		X	
CHILLAN		E			XI	XI		160/45		X	
		E					XI				
CONCEPCION/Carriel Sur	02 PA1	A/L	I	XI	XI	XI			X		
	20 NPA									X	
		T			XI	XI	XI			X	
		E			XI	XI		95/45		X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
		E					XI			X	
CURICO		E			XI	XI		60/45		X	
		E					XI			X	
ISLA REY JORGE		E			XI	XI		200/45		X	
		E					XI	200		X	
IQUIQUE/Gral. Diego Aracena	18 NPA	A/L		XI	XI	XI				X	
		E					XI			X	
PUERTO AGUIRRE		E			XI	XI		130/25		X	
		E					XI			X	
PUERTO MONTT/El Tepual	17 NPA	A/L							X		
	35 PA1	A/L	II*	XI	XI	XI			X		
		T			XI	XI				X	
		E			XI	XI		155/45		X	
		E					XI			X	
PUERTO NATALES		E			XI	XI		100/25		X	
PUNTA ARENAS/Presidente Cabo Ibañez del Campo	07 NPA	A/L							X		
	25 PA1	A/L	I D (I)	XI	XI	XI			X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	350		X	
QUINTERO		E			XI	XI		85/45		X	
SANTIAGO/Arturo Merino Benitez	17 PA3	A/L	III		XI	XI			X		
	35 NPA	A/L							X		
		E					XI			X	
SANTO DOMINGO		E			X	XI		200/45		X	
		E					XI			X	
TABON		E					X	90		X	
TEMUCO/Manquehue	06 NPA	A/L			XI	XI				X	
	24 NPA	A/L			XI	XI				X	
		E			XI	XI		90/45		X	
TONGOY		E			XI	XI		200/45		X	
		E					XI	350		X	
VALDIVIA		E			XI	XI		95/45		X	
COLOMBIA											
ARAUCA		E			XI	XI		200/45		X	
ABEJORRAL		E					XI	150		X	
AMBALEMA		E					XI	150		X	
BARRANCA BERMEJA		E			XI	XI		200/45		X	
		E					XI	150		X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
BARRANQUILLA/Ernesto Cortissoz	04 PA1	A/L	I (I)	XI	XI	XI	XI	200/45	X	X	
	22 NPA	A/L			XI	XI					
		T/E			XI	XI					
		E					XI	150		X	
SANTAFE DE BOGOTA/Eldorado	13 RPA2	A/L	II (I)	XI	XI	XI	XI	200/45	X	X	
	31 LNINST							180			
	13 LPA2	A/L	II	XI	XI	XI	XI		X		
	31 RNINST										
		T			XI	XI	XI	200/45			
		E			XI	XI	XI	180		X	
BUCARAMANGA		E			XI	XI		200/45		X	
		E					XI	150			
BUENAVENTURA		E			XI	XI		200/45		X	
							XI	150			
BUVIS		E			XI	XI		200/45		X	
CALI/Alfonso Bonilla Aragón	01 PA1	A/L	I (I)	XI	XI	XI		200/45	X	X	
	19 NPA	A/L			XI	XI					
		T/E			XI	XI	XI	100		X	
CARTAGENA/Rafael Nuñez	36 NPA	A/L			XI	XI	XI	200/45			
	18 NINST										
		T/E			XI	XI					
CUCUTA/Camilo Daza	15 PA1	A/L	I (I)	XI	XI	XI		200/45	X	X	
	33 NINST										
	02 NINST										
	20 NINST										
		T/E			XI	XI					
EL BANCO		E			XI	XI		200/45		X	
GIRARDOT		E			XI	XI		240/45		X	
LA MINA		E			XI	XI		200/45		X	
LETICIA/Alfredo Vasquez Cobo	02 NPA	A/L			XI	XI	XI	200/45		X	
	20 NPA	A/L			XI	XI	XI	300		X	
		T/E			XI	XI					
		E					XI			X	
LOS CEDROS		E			XI	XI		200/45		X	
MAGANGUE		E			XI	XI		200/45		X	
MARIQUITA		E			XI	XI		200/45			
MERCADERES		E			XI	XI		200/45		X	
		E					XI	150		X	
MITU		E			XI	XI		200/45		X	
		E					XI	200		X	
MONTERIA		E			XI	XI		200/45		X	
OTU		E			XI	XI		200/45			

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS GBAS	 SBAS	Remarks Remarques Observaciones
1	2	3	4	5	6	7	8	9	10	11	12
PEREIRA		E			XI	XI		200/45		X	
		E					XI	100		X	
PUERTO LEGUIZAMO		E			XI	XI		200/45		X	
RIO HACHA		E					XI	150		X	
RIO NEGRO/Jose Maria Cordova	36 PA2	A/L	II	XI	XI	XI		200/45	X	X	
	18 NINST									X	
		T/E			XI	XI					
SAN ANDRES /Gustavo Rojas Pinilla	06 NPA	A/L			XI	XI	XI	200/45		X	
	24 NINST										
		T/E			XI	XI	XI				
		E					XI	200		X	
SAN JOSE DEL GUAVIARE		E			XI	XI		200/45		X	
		E					XI	160		X	
SANTA MARTHA		E			XI	XI		200/45		X	
TECHO		E					XI	150		X	
TULUA		E				XI	XI	200/45		X	
TUMACO		E			XI	XI		200/45		X	
		E					XI	150		X	
VILLAVICENCIO		E			XI	XI		200/45		X	
		E					XI	150		X	
ZIPAQUIRA		E					XI	150		X	
COSTA RICA											
ALAJUELA/Juan Santamaria Intl.	07 PA1	A/L	II*	X	XI	XI			X		
		T			XI	XI				X	
		E			X	X		95/45		X	
COTO		E					XI	100		X	
CHILES		E					XI	100		X	
HORCONES		E					XI	100		X	
LIBERIA/Daniel Oduber Intl.	07 PA1	A/L	II*		XI	XI			X		
	25 NPA	A/L							X		
		T			XI	XI				X	
		E			X	X		200/45		X	
LIMON/Limón Intl.	NINST										
		T			XI	XI				X	
		E			XI	XI		125/45		X	
PARRITA		E					XI	100		X	
PAVAS/Tobias Bolaños Intl.	NINST									X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
CUBA											
CAMAGUEY/Ignacio Agramonte Intl.	07 PA1	A/L	II*	XI	XI	XI			X		
	25 NPA	A/L							X		
		T			XI	XI		170/45		X	
CAYABO		E					XI	100		X	
CAYO LARGO DEL SUR/Vilo Acuña Intl.	12 NPA	A/L			XI	XI				X	
		E			XI	XI		170/45		X	
		E					XI	170		X	
CIEGO DE AVILA/Maximo Gomez Intl.	07 NPA	A/L/T/E			XI	XI	XI	190/45		X	
HABANA/Jose Martí Intl.	06 PA1	A/L	II*	XI	XI	XI			X		
	24 NPA	A/L							X		
		T			XI	XI		170/45		X	
HOLGUIN/Frank Pais Intl.	05 NPA	A/L			X	XI	XI			X	
MANZANILLO		E			XI	XI		85/45		X	
NUEVA GERONA		E					XI	170			
NUEVAS		E			X	XI		190/45		X	
SANTIAGO DE CUBA/Antonio Maceo Intl.	09 NPA	A/L		XI	XI	XI				X	
	27 NPA	A/L								X	
		T			XI	XI		170/45		X	
		E					XI	70		X	
VARADERO/Juan Gualberto Gomez Intl.	06 PA1	A/L	I	X	XI	XI			X		
	24 NPA									X	
		T			XI	XI				X	
		E			XI	XI		160/45		X	
DOMINICA											
MELVILLE HALL/Dominica	NINST									X	
ROSEAU/Canefield	NINST									X	
DOMINICAN REPUBLIC											
BARAHONA/María Montés Intl.	12 NPA	A/L			XI	XI	XI			X	
CABO ROJO		E			XI	XI		200/45		X	
		E						210		X	
HERRERA/Herrera Intl.	01 NPA	A/L				XI	XI			X	
	19 NPA	A/L								X	
LA ROMANA/La Romana Intl.	NINST						XI			X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS GBAS	 SBAS	Remarks Remarques Observaciones
1	2	3	4	5	6	7	8	9	10	11	12
PUERTO PLATA/Gregorio Luperon Intl.	08 NPA	A/L							X		
	26 NPA	A/L			XI	XI	XI		X		
		T				XI				X	
		E				XI		65/45		X	
PUNTA CANA/Punta Cana Intl.	09 NPA	A/L			X	XI	XI			X	
PUNTA CAUCEDO		T			XI	XI	X			X	
		E			XI	XI		200/45		X	
		E					X	365		X	
SANTIAGO/Cibao Intl.	NINST									X	
SANTO DOMINGO/De las Américas Intl.	17 PA1	A/L	II* D (I)		XI	XI	XI		X		
	35 NPA								X		
ECUADOR											
AZCAZUBI		T					XI	40		X	
CHONGON		T					XI	40		X	
CONDORCOCHA		T			XI	XI				X	
		E			XI	XI		200/45		X	
CUENCA		E			XI	XI		200/45		X	
		E					XI	50		X	
ESMERALDAS		E			XI	XI		200/45		X	
		E					XI	350		X	
GUAYAQUIL/Simon Bolivar Intl	03 NPA	A/L							X		
	21 PA1	A/L	II*	XI	XI	XI			X		
		T			XI	XI				X	
		E			XI	XI		130/45		X	
LATACUNGA/Cotopaxi Intl	18 PA1	A/L	I		XI	XI	XI	30	X		
MACHALA		E			XI	XI		140/25		X	
MANTA/Eloy Alfaro Intl	23 PA1	A/L	I D		XI	XI			X		
		T			XI	XI		60/25			
PALMA		T					XI	40		X	
QUITO/Mariscal Sucre Intl	17 NPA	A/L							X		
	35 PA1	A/L	II*	XI	XI	XI			X		
SALINAS		E			XI	XI		100/250			
EL SALVADOR											
SAN SALVADOR/El Salvador Intl.	07 PA1	A/L	II*	X	XI	XI			X		
	25 NPA								X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E					X	235		X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
SAN SALVADOR/Ilopango Intl.	15 NPA	A/L		XI	XI	XI			X		
		T					XI			X	
							X				
		E			XI	XI		200/45		X	
FRENCH ANTILLES (France)											
FORT-DE-FRANCE/Le Lamentin, Martinique	09 PA1	A/L	II* D		XI	XI			X		
	27 NPA	A/L							X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
POINTE-A-PITRE/Le Raizet, Guadeloupe	11 PA1	A/L	II* D		XI	XI			X		
	29 NPA								X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	250		X	
SAINT-BARTHELEMY/ Saint-Barthelemy, Guadeloupe	NINST									X	
SAINT-MARTIN/Grand Case, Guadeloupe	NINST									X	
FRENCH GUIANA (France)											
CAYENNE/Rochambeau	08 PA1	A/L	II* D (I)		XI	XI	XI		X		
	26 NPA	A/L			XI	XI			X		
		E			XI	XI		200/45		X	
		E					XI	300		X	
GRENADA											
CARRIACOU/Lauriston Intl.	NINST									X	
SAINT GEORGES/Point Salines	10 PA1	A/L	II*		XI	XI	XI		X		
	28 NPA								X		
		T				XI				X	
		E				XI		200/45		X	
GUATEMALA											
CHINAUTLA		T			X	X				X	
		E			X	X		100/45		X	
FLORES/Flores Intl.	10 PA1	A/L	I D		XI	XI	X		X		
		E			XI	XI		75/45		X	
GUATEMALA/La Aurora	01 NPA	A/L							X		
	19 PA1	A/L	II* D	X	XI	XI			X		
		T				XI	XI			X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
		E				XI		110/45		X	
		E					XI	200		X	
IZTAPA		E					X	100		X	
PUERTO BARRIOS/Puerto Barrios	NINST									X	
		E					XI	70		X	
RABINAL		E					X	200		X	
SAN JOSE/San Jose	15 NPA	A/L			XI	XI				X	
		T			XI	XI					
		E			XI	XI				X	
GUYANA											
TIMEHRI/Cheddi Japan Intl.	06 PA1	A/L	II*		XI	XI	XI		X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					X	300		X	
KATA		T					X			X	
		E					X	50		X	
HAITI											
CAP HAITIEN/Cap. Haitien Intl.	NINST				XI	XI				X	
PORT-AU-PRINCE/Port-au-Prince Intl.	09 PA1	A/L	II* D		XI	XI			X		
	27 NPA	A/L							X		
		T			XI	XI				X	
OBLEON		E			XI	XI		200/45		X	
HONDURAS											
. COPAN RUINAS		E					X	55		X	
LA CEIBA/Golosón Intl.	06 NPA	A/L			XI	XI	XI	200/45	X		
		E			XI	XI				X	
		E					XI	110			
ROATAN		T			XI	XI		60	X		
		E			XI		XI	180/25		X	
SAN PEDRO SULA/La Mesa Intl.	03 NPA	A/L							X		
	21 PA1	A/L	I D		XI	XI	XI		X		
		T				XI				X	
		E				XI		200/45		X	
		E					XI	300			
TEGUCIGALPA/Toncontín Intl.	01 PA1	A/L	I		X	X	XI		X		
	19 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI				X	
		E					XI	300			

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS GBAS	 SBAS	Remarks Remarques Observaciones
1	2	3	4	5	6	7	8	9	10	11	12
JAMAICA											
KINGSTON/Norman Manley Intl.	12 PA1	A/L	II* D		XI	XI			X		
	30 NPA								X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	400		X	
MONTEGO BAY/Sangster Intl.	07 PA1	A/L	II* D		XI	XI	XI		X		
	25 NPA								X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	325		X	
MEXICO											
ACAPULCO/Gral. Juan N. Alvarez Intl.	10 PA1	A/L	II*	X	XI	XI			X		
	28 PA1	A/L	II*						X		
		T		X	XI	XI				X	
		E			XI	XI		200/45		X	
		E					X			X	
AGUASCALIENTES	NPA	A/L									
		E			XI	XI				X	
APAN OTUMBA		T								X	
		E								X	
		T			XI	XI					
		E			XI	XI					
BAHIAS DE HUATULCO/Bahias de Huatulco	07 NPA	A/L			XI	XI				X	
	25 NPA									X	
		E			XI	XI				X	
CAMPECHE/Ing. Alberto Acuña Ongay	16 NPA	A/L			XI	XI				X	
	24 NPA	A/L									
					XI	XI				X	
CANCUN/Cancun Intl.	12 PA1	A/L	II* D (I)		XI	XI			X		
	30 NPA								X		
		T			XI	XI				X	
		E			XI	XI		135/45		X	
CHETUMAL/Chetumal Intl.	10 NPA	A/L			XI	XI	XI			X	
	28 NPA									X	
		E			XI	XI	XI			X	
CHIHUAHUA/Gral. Roberto Fierro Villalobos Intl.	18L NP	A/L			XI	XI	XI		X		
	36R PA1	A/L	II* D						X		
		T			XI	XI	XI			X	
		E			XI	XI	XI			X	
CHOIX		E					XI			X	
CIUDAD JUAREZ/Abraham González Intl.	03 NPA	A/L			XI	XI				X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
	21 NPA	A/L								X	
		T			XI	XI				X	
		E			XI	XI				X	
CIUDAD OBREGON	NPA	A/L									
		E			XI	XI		70/45		X	
CIUDAD VICTORIA	NPA	A/L									
		E			XI	XI		80/45		X	
COLIMA	NPA	A/L									
		E			XI	XI				X	
CONCEPCION DEL ORO		E			XI	XI				X	
COZUMEL/Cozumel Intl.	11 PA1	A/L	II*		XI	XI	XI		X		
	29 NPA	A/L							X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	230		X	
CUAUTLA		T			XI	XI				X	
		E			XI	XI				X	
CULIACAN/Fidel Bachigualato	NPA	A/L									
		E			XI	XI				X	
DELICIAS		T									
		E			XI	XI				X	
DURANGO/Pte. Guadalupe Victoria Intl.	03 NPA	A/L			XI	XI				X	
		E			XI	XI		145/45		X	
GUADALAJARA/Miguel Hidalgo Costilla Intl.	10 PA1	A/L	II*	XI	XI	XI			X		
	28 PA1	A/L	II*						X		
		T			XI	XI				X	
		E			XI	XI		125/45		X	
GUAYMAS/Gral. José Maria Yañez Intl.	20 NPA	A/L					XI			X	
HERMOSILLO/Gral. I. Pesqueira Garcia Intl.	05 NPA	A/L			XI	XI				X	
	23 NPA	A/L								X	
		T			XI	XI				X	
		E			XI	XI		105/45		X	
IXTAPA -ZIHUATANEJO/ Ixtapa-Zihuatanejo Intl.	NPA	A/L									
		E			XI	XI		105/45		X	
LA PAZ/Gral. Manuel Marquesde de León Intl.	18 PA1	A/L	II*		XI	XI			X		
	36 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		135/45		X	
LEON	NPA	A/L									
		t									
		E								X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
LORETO/Loreto Intl.	34 NPA	A/L			XI	XI				X	
		E			XI	XI				X	
LOS MOCHIS	NPA	A/L			XI	XI				X	
		E			XI	XI		120/45		X	
		E					X	120		X	
MANZANILLO/Playa de Oro Intl.	10 NPA	A/L			XI	XI				X	
		E			X	X				X	
MATAMOROS/Intl.	15 NPA	A/L			XI	XI				X	
	33 NPA	A/L								X	
		T			XI	XI				X	
		E			XI	XI				X	
MAZATLAN/Gral. Rafael Buelna Intl.	08 NPA	A/L							X		
	26 PA1	A/L	II* D		XI	XI			X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
MERIDA/Lic. Manuel Crescencio Rejón Intl.	10 PA1	A/L	II*		XI	XI	XI		X		
	28 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E				XI		200		X	
MEXICALI/Gral. Rodolfo Sanchez Taboada Intl.	28 NPA	A/L			XI	XI				X	
		T			XI	XI				X	
		E			XI	XI		70/45		X	
MEXICO/Lic. Benito Juárez Intl.	05R PA1	A/L	II* D		XI	XI	XI		X		
	23L PA1	A/L	II* D						X		
		T			XI	XI				X	
		E			XI	XI		60/45		X	
MINATITLAN	NPA	A/L			XI	XI				X	
		E			XI	XI		70/45		X	
MONCLOVA	NPA	A/L									
		E			XI	XI				X	
MONTERREY/Aeropuerto Del Norte Intl.	20 NPA	A/L			XI	XI				X	
		T			XI	XI				X	
		E									
MONTERREY/Gral. Mariano Escobedo Intl.	11 NPA	A/L			XI	XI			X		
	29 PA1	A/L	II* D						X		
		T			XI	XI				X	
		E			XI	XI		80/45		X	
MORELIA/Gral. Francisco J. Mujica Intl.	05 NPA	A/L			XI	XI				X	
		E			XI	XI				X	
NAUTLA		E			XI	XI		200/45		X	
		E						400		X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
NUEVO LAREDO/Quetzatlcoatl Intl.	14 NPA	A/L			XI	XI				X	
	32 NPA	A/L								X	
		T			XI	XI				X	
		E			XI	XI		60/45		X	
OAXACA	NPA	A/L									
		T			XI	XI				X	
		E			XI	XI		110/45		X	
								100		X	
OTUMBA		T			XI	XI				X	
		E			XI	XI				X	
PACHUCA		T			XI	XI				X	
		E			XI	XI		70/45		X	
POZA RICA	NPA	A/L									
		E			XI	XI		200/45		X	
PUEBLA	NPA	A/L									
		E			XI	XI				X	
		T									
PUERTO ESCONDIDO	NPA	A/L									
		E			XI	XI				X	
PUERTO PEÑASCO		E			XI	XI		105/45		X	
PUERTO VALLARTA/Lic. Gustavo Díaz Ordaz Intl.	04 PA1	A/L	II* D		XI	XI			X		
	22 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		135/45		X	
QUERETARO	NPA	A/L									
		E			XI	XI		200/45		X	
REYNOSA/Gral. Lucio Blanco Intl.	31 NPA	A/L			XI	XI				X	
		T			XI	XI				X	
		E			XI	XI		135/45		X	
SALTILLO	PA1	A/L									
		E			XI	XI				X	
SAN JOSE DEL CABO/San Jose del Cabo Intl.	16 NPA	A/L			XI	XI				X	
	34 NPA	A/L								X	
		E			XI	XI				X	
SAN LUIS POTOSI	NPA	A/L									
		E			XI	XI				X	
SAN MARCOS		T					XI			X	
		E								X	
SAN MATEO		T			XI	XI				X	
SAN QUINTIN		E			XI	XI				X	
SANTA ANITA		T					X			X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
SANTA LUCIA		T			XI	XI					
		E									
SANTA ROSALIA		E			XI	XI		135/45		X	
TAMPICO/Gral. Francisco Javier Mina Intl.	13 PA1	A/L	II* D (I)		XI	XI	XI		X		
	31 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E					XI	265		X	
TAMUIN		E				XI		75/45		X	
TAPACHULA/Tapachula Intl.	05 NPA	A/L			XI	XI				X	
		E			XI	XI		185/45		X	
TEPIC		E					X			X	
TEQUESQUITENGO		T			XI	XI				X	
		E			XI	XI		100/45		X	
TIJUANA/Gral. Abelardo L. Rodriguez Intl.	09 PA1	A/L	II* D (I)		XI	XI			X		
	27 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		50/45		X	
TOLUCA/Lic. Adolfo Lopez Matos	15 PA1	A/L	II D (I)		XI	XI				X	
	33 NPA	A/L								X	
		E			XI	XI				X	
TORREON/Torreon Intl.	12 NPA	A/L			XI	XI				X	
	30 NPA	A/L								X	
		T			XI	XI				X	
		E			XI	XI					
TUXTLA GUTIERREZ	PA1	A/L	II* D (1)								
		E			XI	XI				X	
		T									
VERACRUZ/Gral. Heriberto Jara Intl.	18 NPA	A/L			XI	XI				X	
	36 NPA	A/L								X	
		T			XI	XI				X	
		E			XI	XI		70/45		X	
VILLAHERMOSA/C.P.A. Carlos Rovirosa Intl.	08 NPA	A/L			XI	XI				X	
		T			XI	XI				X	
		E			XI	XI				X	
ZACATECAS/Gral. Leobardo C. Ruiz Intl.	02 NPA	A/L			XI	XI				X	
		E			XI	XI				X	
MONTSERRAT (United Kingdom)											
PLYMOUTH/W.H. Bramble,	NINST	A/L					XI			X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
Montserrat I.											
NETHERLANDS ANTILLES (Netherlands)											
KRALENDIJK/Flamingo, Bonaire	10 NPA	A/L								X	
	28 NPA	A/L		XI	X	XI				X	
		E			XI	XI				X	
ORANJESTAD/F.D. Roosevelt, Saint Eustatius I.	NINST									X	
PHILIPSBURG/Prinses Juliana, St. Maarten I.	09 PA1	A/L	II* D		XI	XI	XI		X		
	27 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E				XI		255		X	
WILLEMSTAD/Hato, Curacao I.	11 PA1	A/L	II* D		XI	XI	XI		X		
	29 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E					XI	225		X	
NICARAGUA											
MANAGUA/Augusto César Sandino Intl.	09 NPA	A/L							X		
	27 PA1	A/L	II*		XI	XI	XI		X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E					XI	280		X	
PUERTO CABEZAS/Puerto Cabezas	09 NPA	A/L			XI	XI				X	
		T			XI	XI				X	
		E			XI	XI		180/45		X	
PANAMA											
PANAMA/Marco A. Gelabert	NINST									X	
BOCAS DEL TORO/Bocas Del Toro	08 NPA	A/L			XI	XI				X	
	26 NPA	A/L								X	
		E			XI	XI		90/45		X	
CHANGUINOLA/Cap. Manuel Niño	NINST									X	
DAVID/Enrique Malek	04 NPA	A/L			XI	XI	XI			X	
		E			XI	XI		100/45		X	
		E			XI	XI		100		X	
FRANCE/Enrique Jimnez		T			XI	XI				X	
LA PALMA		E				XI		180/45		X	
PANAMA/Tocumen Intl.	03R PA1	A/L	II*		XI	XI	XI		X		
	21L NPA	A/L							X		
	03L NPA	A/L							X		

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
		T			XI	XI				X	
TABOGA		E			XI	XI	XI	200/45		X	
		E					XI			X	
WANNKANDI		E					XI			X	
PARAGUAY											
ASUNCION/Silvio Pettirossi	02 NPA	A/L							X		
	20 PA1	A/L	II* D (I)		XI	XI	XI		X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	300		X	
CIUDAD DEL ESTE/Guaraní	23 PA1	A/L	II		XI	XI			X		
	05 NPA	A/L			XI	XI			X		
CONCEPCION		E					XI	65		X	
ESTIGARRIBIA		E				X		200/45		X	
		E					XI	300		X	
FILADELFIA		E					X	180		X	
PERU											
ANDAHUAYLAS		E				XI		150/250		X	
AREQUIPA/Rodríguez Ballón Intl.	09 PA1	A/L	I D		XI	XI			X		
	NINST									X	
		T			XI	XI		165		X	
		E			XI	XI					
ASIA		E			XI	XI		85/45		X	
AYACUCHO		E					XI	200		X	
CAJAMARCA		E					XI	140		X	
CHACHAPOYAS		E				XI		200/45		X	
CHICLAYO/Cap. José Quiñones González	18 PA1	A/L	I D (I)		XI	XI			X		
		E			XI	XI		90/25		X	
		T			XI	XI				X	
CHIMBOTE		E			X	XI		120/25		X	
CUZCO/Velasco Astete	NINST									X	LLZ associated with the approach procedure/ LLZ associé à la procédure d=approche/ LLZ asociado con el procedimiento de aproximación
	27 NPA	A/L			X	X				X	
		T			X	X					

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
IQUITOS/Coronel FAP Francisco Secada Vignetta	06 PA1	A/L	I D (I)	XI	XI	XI			X		
		E			XI	XI		200/45		X	
JULIACA		E			XI	XI		120/250		X	
LIMA CALLAO/Jorge Chavez Intl.	15 PA2	A/L	I	X	XI	XI			X		
	33 NPA									X	
		T			XI	XI				X	
		E			XI	XI		200/45		X	
PISCO/Pisco	21 NPA	A/L			XI	XI				X	
		T			XI	XI	XI			X	
		E			XI	XI		120/45		X	
PUCALLPA		E			XI	XI		160/45		X	
SALINAS		E			XI	XI		200/45		X	
SAN JUAN		E			X	XI		200/45		X	
SIHUAS		E				XI		160/45		X	
TACNA/CORONEL FAP Carlos Ciriani Santa Rosa	02 PA1	A/L	I D (I)		XI	XI			X		
		T/E			XI	XI				X	
TARAPOTO		E			XI	XI		160/45		X	
TRUJILLO/Cap. Carlos Martinez de Pinillos	01PA1	A/L	I D (I)						X		
	T/E				XI	XI		160/45		X	
URCOS		E			XI	XI		200/45		X	
PUERTO RICO (United States)											
AGUADILLA/Rafael Hernandez Intl.	08 PA1	A/L	I		X	X			X		
	26 NPA	A/L								X	
BORINQUEN		E			XI (Tacan)	XI				X	
DORADO		E					XI	400		X	
MAYAQUEZ/Mayaquez	09 NPA	A/L				XI	XI			X	
		E				XI		145/45		X	
POINT TUNA		E					XI	45		X	
PONCE/Ponce - Mercedita	30 NPA	A/L			XI	XI				X	
		T			XI	XI				X	
		E			XI	XI		110/45		X	
ROOSEVELT ROADS		T					XI			X	
SAN JUAN DE PUERTO RICO/Luis Muñoz Marín Intl.	08 PA1	A/L	II*		XI (Tacan)	XI	XI		X		
	26 NPA	A/L							X		

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
	10 PA1	A/L	II*		XI (Tacan)	XI			X		
	28 NPA	A/L							X		
		T			XI (Tacan)	XI				X	
		E			XI (Tacan)	XI		200/45		X	
SAN PAT		T					XI			X	
SAINT KITTS AND NEVIS											
BASSETERRE/Robert L. Bradshaw, Saint Kitts I.	07 NPA	A/L		XI	X	X				X	
	25 NPA	A/L								X	
CHARLESTOWN/Newcastle, Nevis I.	NINST									X	
SAINT LUCIA											
CASTRIES/Vigie	NINST			X						X	
		E					XI	65		X	
VIEUX-FORT/Hewanorra Intl.	10 PA1	A/L	I		XI	XI	XI		X		
	28 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		65/45		X	
SAINT VINCENT AND THE GRENADINES											
CANOVAN/Canovan	13/31 NPA						XI				
KINGSTOWN/E.T. Joshua	07 NPA	A/L		XI						X	
		E					XI	400		X	
MUSTIQUE	18 NPA	A/L					X			X	
UNION ISLAND/Union Island	NINST									X	
SURINAME											
NEW NICKERIE/Maj. Fernandes	NINST									X	
PARAMARIBO/Zorg En Hoop	NINST									X	
		T					X			X	
ZANDERY/Johan Adolfo Pengel Intl.	11 PA1	A/L	II*		XI	XI	XI		X		
	29 NPA	A/L							X		
		T				XI				X	
		E			XI			200/45		X	
		E					X	300		X	
TRINIDAD AND TOBAGO											
PORT OF SPAIN/Piarco Intl. Trinidad I.	10 PA1	A/L	II*			XI	X		X		

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS GBAS	 SBAS	Remarks Remarques Observaciones
1	2	3	4	5	6	7	8	9	10	11	12
	28 NPA	A/L							X		
		T			XI	XI		200/45		X	
		E					XI	400		X	
SCARBOROUGH/Crown Point, Tobago I.	11 NPA	A/L					XI			X	
		E					XI	150		X	
TURKS AND CAICOS ISLANDS (United Kingdom)											
GRAND TURK/Grand Turk Intl.	11 NPA	A/L		X	XI (Tacan)	X				X	
		E			XI (Tacan)	X	XI	200/45		X	
PROVIDENCIALES/Providenciales Intl.	10 NPA	A/L					XI			X	
	28 NPA	A/L								X	
SOUTH CAICOS/South Caicos Intl.	NINST									X	
URUGUAY											
COLONIA/Internacional de Colonia	12 NPA	A/L					XI			X	
	30 NPA	A/L								X	
DURAZNO		E				XI		110/45		X	
MALDONADO/Intl C/C Calos A. Curbelo Laguna del Sauce	08 PA1	A/L	I D		XI	XI	XI		X		
	26 NPA	A/L							X		
		E			XI	XI		200/45		X	
MELO		E				XI		200/45		X	
MONTEVIDEO/Aeropuerto Angel S. Adami Intl.	18 NPA						X			X	
	NINST									X	
MONTEVIDEO/Carrasco Intl.	06 NPA	A/L							X		
	24 PA1	A/L	II*		XI	XI	XI		X		
		T			XI	XI	XI			X	
		E			XI	XI		200/45		X	
		E					XI	200		X	
RIVERA/Cerro Chapeu Intl.	04 NPA	A/L					XI			X	
SALTO/Nueva Hesperides Intl.	04 NPA	A/L				XI	XI			X	
	22 NPA	A/L								X	
		E				XI	XI			X	
VENEZUELA											
BARCELONA/Gral. José Antonio Anzoategui Intl.	15 PA1	A/L	II*		XI (Tacan)	XI			X		
		E			XI (Tacan)	XI		55/25		X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS GBAS	 SBAS	Remarks Remarques Observaciones
1	2	3	4	5	6	7	8	9	10	11	12
BARINAS		E			XI	XI		100/25		X	
BARQUISIMETO		E			XI	XI		190/35		X	
CABO CODERA		E			XI	XI		200/45		X	
		E					X	300		X	
CAICARA DEL ORINOCO		E			XI	XI				X	
CANAIMA		E			XI	XI				X	
CARACAS/Simon Bolivar Intl., Maiquetia	09 PA1	A/L	II* D (I)		XI	XI	XI		X		
	27 NPA	A/L							X		
		T			XI	XI				X	
		E			XI	XI		200/45		X	
		E					XI	300		X	
CARORA		E			XI	XI				X	
CARUPANO		E					X	70		X	
CIUDAD BOLIVAR		E			XI	XI		100/45		X	
CORO		E			XI	XI		110/45		X	
CUMANA		T				XI				X	
EL CANTON		E			XI	XI		200/45		X	
ELORZA		E					XI	165		X	
GRAND ROQUE		T				XI				X	
		E			XI	XI		200/45		X	
		E					X	220		X	
GUYANA		E			XI (Tacan)	XI		200/45		X	
LA DIVINA PASTORA		E			XI	XI		200/45		X	
		E					XI	280		X	
MARACAIBO/La Chinita Intl.	02L PA1	A/L	II*		XI (Tacan)	XI	X		X		
	20R NP	A/L							X		
		T			XI (Tacan)	XI				X	
		E			XI (Tacan)	XI		200/45		X	
		E					X	280		X	
MARACAY		E				X				X	
MARGARITA I./ Intl. Del Caribe, Gral. Santiago Marino	09 PA1	A/L	II*		XI	XI	XI		X		
		T			XI	XI					
		E			XI	XI		200/45		X	
		E					X	300		X	
MATURIN		T			XI	XI				X	

Station/Territory Station/Territoire Estación/Territorio	Rwy type Type de piste Tipo de pista	Function Fonction Función	ILS	L	DME	VOR	NDB	Coverage Couverture Cobertura	GNSS		Remarks Remarques Observaciones
									GBAS	SBAS	
1	2	3	4	5	6	7	8	9	10	11	12
		E			XI	XI		190/45		X	
		E					XI	190		X	
MENE MAUROA		E				XI		190/45		X	
ÑO LEON		E			XI	XI				X	
PARAGUANA/Josefa Camejo Intl.	09 NPA	A/L			XI	XI				X	
	NINST									X	
		E			XI	XI		200/45		X	
PUERTO CABELLO		T				XI				X	
		E			XI	XI		200/45		X	
PUERTO AYACUCHO		E			XI (Tacan)	XI				X	
PUNTA SAN JUAN		T				XI				X	
		E			XI	XI		70/45		X	
SAN ANTONIO DEL TACHIRA/San Antonio del Tachira Intl.	16 NPA				X	X				X	
	NINST									X	
SANTA BARBARA DEL ZULIA		E			XI	XI		150/45		X	
SAN TOME		E				XI		80/45		X	
TUCUPITA		E					XI	150		X	
TUY		E			XI	XI				X	
		T			XI	XI					
VALENCIA/Zim Valencia Intl.	28 NPA	A/L			X	X	XI			X	
VIRGIN ISLANDS (United Kingdom)											
ROADTOWN/Beef Island	07 NPA	A/L					XI			X	
VIRGIN GORDA/Virgin Gorda	NINST									X	
VIRGIN ISLANDS (United States)											
CHRISTIANSTED/Henry E. Rohlsen, St. Croix	09 PA1	A/L	II*		XI	XI	XI			X	
	27 NPA	A/L								X	
		E			XI	XI		155/45		X	
SAINT THOMAS/Cyril E. King	10 PA1	A/L	I		XI	XI			X		
	28 NPA	A/L								X	
		T			XI	XI				X	

APPENDIX B

ICAO ANNEX 10, VOLUME I, CHAPTER 3, TABLE 3.7.2.4-1 SIGNAL-IN-SPACE PERFORMANCE REQUIREMENTS

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)**
Enroute	3.7 km (2.0 NM) (Note 6)	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
Enroute, 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, Nonprecision 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 (APVI)	16.0 m (52 ft)	20 m (66 ft)	$1 - 2 \times 10^{-7}$ per approach	10 s	$1 - 8 \times 10^{-6}$ in any 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ per approach	6 s	$1 - 8 \times 10^{-6}$ in any 15 s	0.99 to 0.99999
Category I precision approach (Note 8)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 7)	$1 - 2 \times 10^{-7}$ per approach	6 s	$1 - 8 \times 10^{-6}$ in any 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. These alert limits are:

Typical operation	Horizontal alert limit	Vertical alert limit
En-route (oceanic/continental low density)	7.4 km (4 NM)	N/A
En-route (continental)	3.7 km (2 NM)	N/A
En-route, Terminal	1.85 km (1 NM)	N/A
NPA	556 m (0.3 NM)	N/A
APVI	40 m (130 ft)	50 m (164 ft)
APV- II	40.0 m (130 ft)	20.0 m (66 ft)

Category I precision approach	40.0 m (130 ft)	15.0 m to 10.0 m (50 ft to 33 ft)

A range of vertical limits for Category I precision approach relates to the range of vertical accuracy requirements.

3. The accuracy and time-to-alert requirements include the nominal performance of a fault-free receiver.
4. Ranges of values are given for the continuity requirement for en-route, terminal, initial approach, NPA and departure operations, as this requirement is dependent upon several factors including the intended operation, traffic density, complexity of airspace and availability of alternative navigation aids. The lower value given is the minimum requirement for areas with low traffic density and airspace complexity. The higher value given is appropriate for areas with high traffic density and airspace complexity (see Attachment D, 3.4).
5. A range of values is given for the availability requirements as these requirements are dependent upon the operational need which is based upon several factors including the frequency of operations, weather environments, the size and duration of the outages, availability of alternate navigation aids, radar coverage, traffic density and reversionary operational procedures. The lower values given are the minimum availabilities for which a system is considered to be practical but are not adequate to replace non-GNSS navigation aids. For en-route navigation, the higher values given are adequate for GNSS to be the only navigation aid provided in an area. For approach and departure, the higher values given are based upon the availability requirements at airports with a large amount of traffic assuming that operations to or from multiple runways are affected but reversionary operational procedures ensure the safety of the operation (see Attachment D, 3.5).
6. This requirement is more stringent than the accuracy needed for the associated RNP types but it is well within the accuracy performance achievable by GNSS.
7. A range of values is specified for Category I precision approach. The 4.0 metres (13 feet) requirement is based upon ILS specifications and represents a conservative derivation from these specifications (see Attachment D, 3.2.7).
8. GNSS performance requirements for Category II and III precision approach operations are under review and will be included at a later date.
9. The terms APV-I and APV-II refer to two levels of GNSS approach and landing operations with vertical guidance (APV) and these terms are not necessarily intended to be used operationally.

CHAPTER 2

SBAS AUGMENTATION TEST BED (CSTB) BASED ON WAAS

Introduction to SBAS Augmentation Test Bed based on WAAS

SBAS operation concept

2.1 A SBAS augmentation system based on WAAS disseminates clock (synchronism), events, and ionosphere corrections. Aeronautical user equipment apply corrections to Global Positioning System (GPS) satellites measured and also convert the error margins in position domains.

2.2 Operations through a SBAS system may only be carried out when horizontal and vertical position errors are contained within some margins, which values depend on the flight phase.

2.3 A SBAS system would be supporting en-route operations, terminal, non-precision approach (NPA) and non-precision approaches with vertical guidance (APV).

2.4 A SBAS augmentation system based on WAAS provides the following functions using signal radio broadcastings through a geo-stationary communications satellite.

a) GPS signal additional to the constellation of existing GPS;

b) Correction vector to GPS signals in the space including components for ionosphere, clock and error events; and

c) Integrity monitoring function to inform users on tolerance condition in time terms.

2.5 The operation concept of a SBAS system based on WAAS is briefly described hereunder:

2.6 Wide area reference stations (WRS) are installed along a territory in order to measure pseudo-ranges and carrier phase to frequency L1 (1575.42 Mhz) and L2 (1227.2Mhz) from all visible GPS satellites.

2.7 Wide area reference stations send these measures to wide area master stations (WMS), which calculate clock and event corrections for each GPS satellite, event information of each geo-stationary communications satellite (GEO) and vertical delays in a grid. A grid consists in fixed ionospheric grid points (IGP – ionospheric grid points) located at a height of 350 Km over the earth surface. The space of a grid is 5º x 5º.

2.8 In addition to the corrections, wide area master stations calculate error limits for ionosphere corrections, corrections named GIVE (Grid Ionosphere Vertical Errors) to each fixed ionosphere grid point (IGP) and the error limits combined for clock corrections and events for each visible GPS satellite (UDRE – User Differential Rate Error).

2.9 The master station sends these corrections and error limits to users (Aircraft) through a geo-stationary communications satellite (For example, Inmarsat III) at a 250 bits/sec. speed.

2.10 Avionic receptors (WAAS) apply these corrections to pseudo distances measured in order to improve precision of estimated position. Also, they use UDREs and GIVEs and other information to calculate error limits in position errors named HPL (horizontal protection level) and VPL (vertical protection level).

2.11 For the integrity of the system, these protection levels have to limit position errors with a probability of ≥0.9999999 in one hour for an en-route navigation operation and NPA for an operation of NPA approach with vertical guidance.

2.12 The WAAS architecture has 25 WRS stations installed over the territory of the United States of America (including Hawaii and Puerto Rico), two wide area master stations (WMS), three ground earth stations (GES), two geo-stationary communications satellites (GEO), and a communications ground network.

Requirements of a SBAS system WAAS type

2.13 **Table 1** indicates a summary of the requirements of a WAAS system for the different flight phases:

Flight phase	Integrity	Availability	Alert limits
Oceanic en-route	$1\text{-}10^{-7}$ / hour	0.999 -0.99999	HAL = 7.4Km
Ground en-route	$1\text{-}10^{-7}$/ hour	0.999-0.99999	HAL = 3.7Km
Terminal	$1\text{-}10^{-7}$/ hour	0.999-0.99999	HAL = 1.852Km
Non-precision approach (NPA)	$1\text{-}10^{-7}$/ hour	0.999-0.99999	HAL = 556 m
NPA with vertical guidance (APV1)	$1\text{-}10^{-7}$/per approach	0.999-0.99999	HAL = 556m VAL= 50 m

Table 1: WAAS requirement for different flight phases

2.14 Integrity is the ability of the SBAS WAAS augmentation system to provide timely warning when the system could not be used for navigation.

2.15 Specifically, integrity requirements are indicated in terms of probability of false information in a flight operation.

2.16 The navigation information is false or non-usable when the horizontal position error (HPE) is greater than the value of the horizontal protection level (HPL) for en-route operations, terminal and non-precision approach. For non-precision approach with vertical guidance (APV), the vertical position error (VPE) needs to be less than the vertical protection level (VPL).

2.17 Therefore, the integrity for en-route, terminal and NPA operations is defined as HPE ≤ HPL and it may be presented in case it is not complied in $1*10^7$.

2.18 In the same manner as in NPA operations with vertical guidance (APV1), the vertical position error VPE should be less than or equal to the vertical protection level, VPL value, as well as HPE ≤ HPL. For both cases, a case may be presented in which VPE and HPE are above the value of the VPL and the HPL in $1*10^7$ cases.

2.19 The availability is the time percentage in which the service is usable. The service is usable when HPL ≤ HAL (HAL represents the radio of a circle in a horizontal plane, with center in the real position that describes the region to which it is required to contain the indicated horizontal position with a probability of $1*0^{-7}$ per flight hour) for en-route operations, terminal and NPA.

2.20 For NPA operations with vertical guidance, the service is usable when HPL ≤ HAL and VPL ≤ VAL (VAL is half the length of a segment in the vertical axe, which center is the real position which describes the region to which it is required to contain the indicated vertical position with a probability of $1*0^{-7}$ per NPA approaches with vertical guidance (APV).

Elements composing the SBAS augmentation test bed based on WAAS in the CAR/SAM Regions (CSTB)

2.21 Before implementing a SBAS augmentation system, a trial platform or testbed is generally implemented. In the case of WAAS, the testbed is called the National Satellite Test Bed, or NSTB. The trial platform for the SBAS Augmentation testbed in the CAR/SAM Region is called CSTB (CAR/SAM Test Bed). Both are composed by testbed reference stations (TRS), testbed master stations (TMS), avionic segment, and a communications segment.

Testbed Reference Station (TRS)

2.22 A reference station is composed by the following equipment:

a) Novatel Novatel Millennium or Trimble Receptor series 4000 and antenna sub-system
b) Rubidium Oscilator Efratom PRFS;
c) RISC base IBM processor
d) Remote power supply Sentry R 1000
e) CISCO 2516 Router
f) Remote power administrador
g) UPS Smart Universal;
h) Hub; and
i) Digiboard.

GPS Novatel Millenium Receptor

2.23 It tracks from 1 to 10 satellites in frequency L1 (1575.42 MHz) and L2 (1227.2 MHz) and tracks GEO satellites fitted out for WAAS in a solution position. It also responds to user commands already determined. The receptor is equipped with a GPS 600 antenna.

GPS-600 Antenna

2.24 Designed for a variety of cinematic positioning applications. The radome (superior part of the antenna) permits it to be used in several marine and weather applications, and adverse means. It is portable and light. It operates in frequencies L1 and L2. The reception elements are connected to a low noise amplifier (LNA). Optimized to receive polarized signals in circles clockwise.

Trimble 4000 receptor

2.25 Tracks 9 or more satellites in frequency L1 1575.42 MHz) or L1/L2 (1227.2Mhz). Fitted for WAAS in a solution position. Responds to already determined user commands. The receptor is equipped with a Trimble antenna model 23903-00.

Rubidium Oscillator

2.26 Provides an extremely stable and pure signal to the receptor. It improves the GPS signal performance. The oscillator optimizes the operation of the system because it has a very stable clock signal, achieving a better synchronization of the system clock with the GPS satellites clocks. The equipment installed is model Efratom PRFS.

Processing Central Unit: Alpha DEC

2.27 Is the system's CPU operating with UNIX operative system. It processes the data from the receptor creating a binary type file automatically and daily for its further analysis.

Sentry Remote power administrator (Source)

2.28 Located in the reference station. It has 8 connection modules. Through Telnet it has the capacity to be turned off or reinitiated. It is the feeding source of the reference station.

Router: Cisco 2501

2.29 Requests primary access from and to the TRS. It delivers and relieves data from two synchronic serial ports (DB60). Central access port to the system (RJ45). Auxiliary port for remote access to the system using MODEM. Great variety of commands to be able to be configured.

UPS Smart Universa

2.30 Maximum load of 950 Watts. Transference time from 2 to 4 milliseconds. Six plugs.

Hub

2.31 Network repeater. Provides local access point to the network. May provide a data Chain for their collection processing.

Digi Board

2.32 Four (4) to eight (8) communication expansive ports of asynchronic serial interphase. Is the interphase between the GPS receptor and the CPU DEC Alpha.

2.33 **Figure 1** shows the block diagram of a typical reference station of the CSTB.

Installation requirements in a reference station

2.34 All equipment in each one of the reference stations were installed in each one of the stations and connected keeping in mind the following requirements

Installation GPS antenna

2.35 The antenna should be located as far as possible from lakes, puddles, buildings, trees and surrounding vehicles. The antenna position should be indicated in WGS-84 format (World Geodetic System 1984) with a precision better than 10 cm. in the three axes. That is to say, it should not move more than 10 cm in any of their positions (x, y, z). The antenna must be located as far as possible from any reflecting plane bigger than one square meter. The presence of any other physical object with a flat surface bigger than 0.1 m^2 should be avoided in 20 m^2 a radius of 10 m 1 m below the choke-ring plane. If there are many antennas presents in a 5 m radius, the antenna must be installed in such a way that the distance between antennas be an odd multiple of 5 cm ($\lambda/4$). The length of the antenna cable to the reference station receptor should be less than 30 m due to RG58 cable losses, which joins the antenna with the receptor.

2.36 The variations of the antenna positions should be smaller, of 1 cm for winds with speeds of less than 200 km/h. The connection between the antenna and the cable must be isolated against water penetration, preferably using impermeable vulcanized tape. The antenna and its LNA should be isolated from the antenna post. The location of the antenna should provide a mask angle not greater than 5° of elevation; that is to say, no obstruction should exist above 5°. For the installation of the TRS GPS antenna all protection should be available regarding security of equipment. **Figure 2** shows photos of antennas in some CSTB TRS stations. **Figure 3** shows photos of equipment in CSTB TRS stations.

Installation of reference station

2.37 The GPS antenna is connected to the receptor through a 50 Ohms RG58 impedance cable connected to the antenna is TNC type (thread) and the metal part exposed to the environment is isolated with tape so that water and other factors do not alter the most important characteristics of the antenna. The receptor port COM1 is connected to the Digiboard port COM1, which is an extensor to ports connecting the GPS receptor to the CPU. COM2 is a serial port used to access the receptor through a laptop. When connecting the laptop, the receptor is configured with software named *Winsat*, which also serves to observe within space in real time (SIS, Signal in Space). The rubidium oscillator is connected to the entrance *ExtRef* of the receptor. The oscillator has several exists if required or more receptor must be connected.

2.38 The Digiboard ports extensor has 8 ports, from which COM1 port is connected to the GPS receptor (COM1 port) to serve as link between Rx and the CPU. The DEC Alpha (CPU) is connected to the Digiboard EBI port. It has a network point exit to the hub in order to carry out entelnet in a remote manner from other office (with network point). Another Alpha (connector RJ45) DEC exit is connected to the Cisco router AUI0 port. The COM1 is connected to the source and has another additional port, which communicates with the RS232 of the source to shut down the equipment through telnet. The router AUI1 port is connected to a hub port and the AUX port with the RS232 of the source. The router is used for the REDDIG links through VSAT.

2.39 The hub is the network connector. It has eight ports, one used to join itself with the network point located in the site and the rest, to link the equipment necessary with the network. The Sentry feeding source provides 110V (AC) to the devices. Nevertheless, a port has a voltage adaptor of 14.7 volts DC to 2,25 Amp. at the entry of the 10-36 V DC receiver. The source is connected to the UPS, and some devices go connected directly to the UPS. This also has a voltage adapter going to the hub and, finally, it is connected to the building's main AC power (110V AC).

Testbed Master Station (TMS)

2.40 A master station is composed of the following equipment:

a) Alpha DEC processor;
b) Operation and maintenance monitor;
c) WAAS information dissemination server (WIB);
d) Recording device; and
e) CISCO router.

Avionics segment

2.41 The aircraft can be self-owned or rented for flight trials, but an important requirement is that a GPS/WAAS antenna be installed in the aircraft, and that arrival signals can be fed to three subsystems within the aerotransported avionics.

2.42 The three aerotransported subsystems are:

a) CSTB User Platform (CUP)
   - GPS/WAAS receiver,
   - Processor,
   - Fixed and removable storage devices,
   - Software for the collection of data and their remittance to other subsystems within the aerotransported avionics.

b) CSTB Real Reference (CTR)
   - Two differential GPS (DGPS) receivers, one in the aircraft, the other in the ground.

c) CSTB navigation platform and data purchasing (NAVDAC)
   - Regulation source,
   - Processor,
   - Fixed and removable storage devices,
   - Processing and integration software,
   - Interfaces towards aircraft data bases.

Communications segments

2.43 The communications platform permitting information transportation from the trial reference stations to the master stations is mainly carried out on a VSAT digital network named REDDIG (South American Digital Network). Segments from the Brazilian and Colombian VSAT networks complete the communications platform.

REDDIG VSAT digital communications network

2.44 The REDDIG has fifteen (15) nodes established in thirteen (13) SAM status and one (1) CAR State. The locations and coordinates where REDDIG nodes are found are described in **Table 2**.

STATE	NODE		LATITUDE	LONGITUDE
Argentina	Ezeiza	SAEZ	34° 49' 25" S	58° 31' 43" W
Bolivia	La Paz	SLLP	16° 30' 22" S	68° 11' 09" W
Brazil	Manaus	SBMN	03° 01' 52" S	60° 02' 29.9" W
	Recife	SBRF	08° 08' 15" S	34° 55' 29" W
	Curitiba	SBCT	25° 24' 06" S	49° 14' 07" W
Chile	Santiago	SCEL	33° 23' 27" S	70° 44' 18" W
Colombia	Bogotá	SKED	04° 42' 05" N	74° 08' 48" W
Ecuador	Guayaquil	SEGU	02° 09' 29" S	79° 53' 02" W
Guyana	Georgetown	SYGC	06° 25' 55" N	58° 15' 14" W
French Guiana	Cayenne	SOCA	04° 49' 11" N	52° 21' 38" W
Paraguay	Asunción	SGAS	25° 14' 24" S	57° 31' 09" W
Perú	Lima	SPIM	12° 01' 27" S	77° 06' 20" W
Surinam	Paramaribo	SMPM	05° 27' 10" N	55° 11' 16" W
Trinidad & Tobago	Piarco			
Uruguay	Montevideo	SUMU	34° 50' 15" S	56° 01' 49" W
Venezuela	Maiquetía	SVMI	10° 36' 12" N	66° 59' 26" W

Table 2: Localidades y coordenadas nodos REDDIG

2.45 REDDIG is a private digital communications network, with an estimated 10-year useful life, of open architecture and state of the art technology; it has a totally meshed topology; flexible and scalable to facilitate network changes and growth; it is of high availability; with distributed intelligence at its nodes and without common failure point; with traffic prioritization; dynamic administration and band width demand; with automatic alternate traffic routing in the event of; with a common, integrated and global network management system (NMS); "future-proof" to permit migration to other network Technologies and for continuous and uninterrupted use and unattended operation.

2.46 REDDIG architecture is distributed and established in a multi-service platform at each node (voice and data) / multi-protocol (switching and multiplexed system), based on frame-relay or ATM, with a dynamic band width management to provide access functions, circuit multi-plexation and switching and packages for the CAA equipment; a VSAT terminal (VSAT system) through which main internodal links should be established through a satellite repeater; connection to the backup network to the multi-service platform; the NMS system and a work station; and an uninterrupted energy system (SDEI) of continuous electrical power that feeds all REDDIG node's equipment.

Structure of the SBAS Augmentation Testbed based on WAAS in the CAR/SAM Regions (CSTB)

2.47 The CSTB is composed of 13 reference stations (TRS) and two master stations (TMS). The TRS are installed at the following locations:

Argentina	Ezeiza	International airport
Bolivia	El Alto	International airport
Brazil	Río de Janeiro	International airport
	Recife	Airport
	Brasilia	Airport
	Curitiba	Airport
	Manaus	Airport
Colombia	Bogota	CEA (Centro de Entrenamiento Aeronáutico)
Chile	Santiago	Cerro Colorado (Santiago ACC)
	Balmaceda	Airport
	Antofagasta	Airport
Peru	Lima	International airport
Honduras	Tegucigalpa	International airport

2.48 The TMS are installed in:

Brazil	Río de Janeiro	International airport
Chile	Santiago	Cerro Colorado (Santiago ACC)

2.49 The Ezeiza, El Alto and Lima reference stations (TRS) are connected to the router of the Santiago master station (TMS) through REDDIG frame relay permanent virtual circuits. From Santiago, the afore mentioned reference stations circuits, together with information from the Santiago, Balmaceda and Antofagasta reference stations, are connected to the Rio de Janeiro master station (TMS). The connection between Santiago and Río de Janeiro is composed of a segment (Santiago-Curitiba) through a REDDIG frame relay virtual permanent circuit, followed by a Brazilian VSAT network virtual permanent circuit between Curitiba and Río de Janeiro. In addition, the information of the Curitiba TRS is connected to the Rio TMS router through the Brazilian VSAT virtual permanent circuit.

2.50 On the other hand, the Tegucigalpa (Honduras–COCESNA) TRS station router is connected to the Bogota (Colombia) reference station router through the Colombian VSAT network. In Bogota, the information from the Bogota reference station is connected with information from the Tegucigalpa TRS to the Bogota TRS router, from here, the information from both stations is connected to the Bogota REDDIG node with a frame relay virtual permanent circuit connected to the Curitiba REDDIG node. From Curitiba, the information from the Bogota and Tegucigalpa TRS are connected to Rio through the Brazilian VSAT.

2.51 The Brasilia, Recife and Manaos TRS stations arrive to Rio through the Brazilian VSAT network.

2.52 The information between the TRS and the TMS is transmitted at 19.2 kbits/sec; between TMS stations, it is transmitted at 64 kbits/seg.

2.53 A 64 Kbits/sec. digital dedicated circuit was established between Rio de Janeiro and the FAA technological centre in Atlantic City. This circuit's purpose is to carry all data collected from each of the reference stations to the technological centre for their storage and processing.

2.54 **Figure 4** shows the configuration of the communications platform supported by the CSTB.

CSTB navigation messages

2.55 Even though the most important task carried out by RLA/00/009 project was data collection from each of the reference stations, the CSTB sends NAV DATA messages.

2.56 These messages were transmitted during the flight trials carried out in May 2002 in Argentina, Bolivia, Chile and Peru. Augmentation messages were sent through a portable VHF digital transmitter. Following is a description of the main CSTB navigation messages.

Message Type 1 – Satellite tracking data

2.57 The receivers get information in simple or dual frequency for satellite tracking data. This data is taken by the TRS software and formatted into a message type 1. The type 1 message will only be sent when satellite tracking data are available. The message includes a heading, a block of bytes for each satellite tracked, and a CCITT CRC checksum. The fields in the heading provide the number of satellites tracked in dual or simple frequency channels. In addition they include a header block that is a "TRS Epoch Counter", or programme sequence number. This epoch counter is a 16 bit whole number that increases with the transmission and creation of each type 1 message; the sequence number is renewed alter the maximum value, which is 65535.

2.58 Following is an explanation of a message type 1 and how it is constituted:

2.59 In all messages, the order of the byte for multi-byte fields is "little indian" (first the least significant bytes). The field pertaining to satellite status is the same for a dual frequency channel, a simple GPS channel or a simple GEO frequency channel. The distinction between a GPS and a GEO is made in accordance with its PRN number.

2.60 The total length of the message depends of the number of tracked satellite, Overhead (header + checksum) = 15 bytes. Average length (8 dual frequency channels) = 407 bytes. **Table 3** describes the message type 1 format.

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
1	Message type = 1	1	U Char
2-3	Receiver ID	2	U Short
4-5	Time of validity – GPS week	2	U Short
6-9	Time of validity - miliseconds	4	U Long
10-11	TRS Epoch Counter	2	U Short
12	Number of dual frecuency channels	1	U Char
13	Number of single frecuency channels	1	U Char
	Dual frecuency channels data: 49 bytes/channel		
	Repeated for each dual frecuency channel		
14	Satellite PRN number	1	U Char

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
15-18	Satellite status flags (see bit field table next page)	4	U Long
19-26	L1 Pseudo-range (PR1)(meters)	8	Double
27-34	L1 carrier range (meters)	8	Double
35-42	L2 carrier range (meters)	8	Double
43-46	L1/L2 differential group delay (PR2-PR1) (meters)	4	Float
47-50	L1 Doppler (DL1) (m/s)	4	Float
51-54		4	Float

Table 3: Type 1 message format

Message Type 5 - GEO/WAAS message

2.61 This critical time message carries the WAAS message that has been disseminated by the GEO. The message includes a header, 1 or more GEO satellite data blocks and a CCITT CRC checksum. Message type 5 will only be send when information from the GEO is available. The header includes a field defining the number of GEO satellites tracked. The time of validity is obtained from the receiver's ITRAME message. 32 bytes are reserved to store the 250 bit decoded WAAS FEC message. The last 6 bytes are not used. The total length of the message depends on the number of tracked satellites. Overhead (header + checksum) = 12 bytes. Average length (1 GEO satellite) = 45 bytes. **Table 4** describes the message type 5 format.

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
1	Message type = 1	1	U Char
2-3	Receiver ID	2	U Short
4-5	Time of validity – GPS week	2	U Short
6-9	Time of validity - milliseconds	4	U Long
10	Number of GEO Satellites tracked (max. 2)	1	U Char
	First GEO satellite: 33 bytes		
	GEO PRN Number	1	U Char
	WAAS FEC Decoded bits (250 bits)	32	Char.32
	Second GEO satellite (if tracked): 33 bytes		
	GEO PRN Number	1	U Char
	WAAS FEC Decoded bits (250 bits)	32	Char.32
2 last	Checksum calculated on previous bytes – CCITT CRC	2	Short

Table 4: Message type 5 format

Message Type 20 - GPS ephemeris data

2.62 GPS receivers provide ephemeris data to the TRS processor, for their formatting into a message type 20. This message contains ephemeris data from only one tracked satellite. In addition, the TRS processes one message per second, until all ephemeris data are sent. This message is sent every 30 seconds for each tracked satellite. If the satellite is in “bad health”, data from the next message type 20 is taken. The message includes a header, a block of ephemeris data and a CCITT CRC checksum. The time of validity fields have the same values as the time of validity of the last message type 1 sent. Overhead (header + checksum) = 11 bytes. Length of message type 20 = 77 bytes. **Table 5** shows the format of message type 20.

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
1	Message type = 1	1	U Char
2-3	Receiver ID	2	U Short
4-5	Time of validity – GPS week	2	U Short
6-9	Time of validity - milliseconds	4	U Long
	Ephemeris data for one satellite:		
10	Satellite PRN Number	1	U Char
11-14	Time navigation message was received (Absolute GPS time in seconds of week)	4	U Long
15	URA User range accuracy	1	U Char
16	SV Health Satellite health (discrete)	1	U Char
17-18	IODC Issue of Data, Clock	2	U Short
19	TGD Estimated group delay differential (sec)	1	Char
20-21	Clock data reference time (sec)	2	U Short
22	Clock data coefficient (sec/sec2)	1	Char
23-24	Clock data coefficient (sec/sec)	2	Short
25-28	Clock data coefficient (sec)	4	Long
29-32	Mean anomaly at reference time (semi-circles)/sec)	4	Long
33-34	Mean motion difference from computed value (semi-circles)/sec)	2	Short
35-38	Eccentricity (dimensionless)	4	U Long
39-42	(A)1/2Square root of semi-major axis (meters1/2)	4	U Long
43-46	Longitude of ascending node of orbit plane at weekly epoch (semi-circles)	4	Long
47-50	Inclination angle at reference time (semi-circles)	4	Long
51-54	ω e	4	
55-58	IDOT rate of right ascension (semi-circles/sec)	4	Long
59-60	IDOT rate of inclination angle (semi-circles/sec)	2	Short
61-62	Cuc Amplitude of cosine harmonic correction term to argument of latitude (rad)	2	Short

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
63-64	Cus Amplitude of sine harmonic correction term to argument of latitude (rad)	2	Short
65-66	Crc Amplitude of cosine harmonic correction term to orbit radius (meters)	2	Short
67-68	Crs Amplitude of sine harmonic correction term to orbit radius (meters)	2	Short
69-70	Cic Amplitude of cosine harmonic correction term to angle of inclination (rad)	2	Short
71-72	Cis Amplitude of sine harmonic correction term to angle of inclination (rad)	2	Short
73-74	toe Reference time ephemeris (sec)	2	U Short
75	IODE Issue of Data Ephemeris	1	U Char
76-77	Checksum CCITT CRC	2	Short

Table 5: Message type 20 format

Message type 30- Klobuchar data

2.63 The TRS will provide Klobuchar ionosphere model parameters to the TMS. This message contains parameters of the Klobuchar model common to all GPS satellites. Therefore, the TRS sends this message to the TMS on a timed manner, who also processes it in the same manner. The message includes a header, a block of Klobuchar dada and a CCITT CRC checksum. The time of validity fields contain the same time of validity values as the last sent message type 1. The Klobuchar ionosphere model is in this table. Overhead (header + checksum) = 11 bytes. Length of the message type 30 = 23 bytes. **Table 6** shows the message type 30 format.

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
1	Message type = 1	1	U Char
2-3	Receiver ID	2	U Short
4-5	Time of validity – GPS week	2	U Short
6-9	Time of validity - milliseconds	4	U Long
	Klobuchar data		
10-13	Time Klobuchar data was received (Absolute GPS time in seconds)		U Long
14	Alpha 0 Amplitude coefficient (sec)		Char
15			Char
16	Alpha 2 Amplitude coefficient (sec/semi-circle)		Char
17	Alpha 3 Amplitude coefficient (sec/semi-circle3)		Char
18	Beta 0 period coefficient (sec)		Char
19	Beta 1 period coefficient (sec/semi-circle)		Char

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
20	Beta 2 period coefficient (sec/semi-circle2)		Char
21	Beta 3 period coefficient (sec/semi-circle3)		Char
22-23	CITT CRC		Short

Table 6: Message type 30 format

Message type 31 - UTC data

2.64 The TRS will provide UTC offsets to the TMS. This data is formatted into a message type 31. It contains the UTC GPS time offset common to all satellites. Therefore, the TRS sends this message to the TMS for its timed processing. This message includes a header, a block of UTC data and a CCITT CRC checksum. The time of validity fields contain the same values as the time of validity of the last message type 1 sent. Overhead (header + checksum) = 11 bytes. Length of message type 31 = 23 bytes. **Table 7** shows a message type 31.

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
1	Message type = 1	1	U Char
2-3	Receiver ID	2	U Short
4-5	Time of validity – GPS week	2	U Short
6-9	Time of validity - milliseconds	4	U Long
	UTC data		
10-13	A0 UTC offset coefficient (sec)	4	Long
14-17	A1 UTC offset coefficient (sec/sec)	4	Long
18	DtLSDelta time due to leap seconds (sec)	1	U Char
19	tot Reference time for UTC data (sec)	1	U Char
20	WNt UTC reference week number (weeks)	1	U Char
21	WNlsf Effectivity reference week number (weeks)	1	U Char
22	DN Effectivity reference days number (days)	1	U Char
23	DtVLSFdelta time at leap second event (sec)	1	Char
24-25	Checksum CCITT CRC	2	Short

Table 7: Message type 31 format

Message type 32- Calendar data

2.65 Data is formatted in a message type 32. This message contains calendar data for all GPS satellites. Therefore, the TRS sends this message to the TMS in a timed manner and the TMS processes it in the same manner. This message includes a header, a block of calendar data and a CCITT CRC checksum. The time of validity fields have the same values as the time of validity of the last message type 1 sent. **Table 8** shows the format of the message type 32.

BYTE	DESCRIPTION	SIZE BYTES	DATA TYPE
1	Message type = 1	1	U Char
2-3	Receiver ID	2	U Short
4-5	Time of validity – GPS week	2	U Short
6-9	Time of validity - milliseconds	4	U Long
10	DWN Difference between GPS GPS week and week of almanac	1	Char
11	toa Time of almanac	1	U Char
12	Number of satellites in the record	1	U Char
	Almanac data: 28 bytes*number of SVs		
	Block repeated for each satellite in the record		
N+			
1	Satellite PRN Number	1	U Char
2-3	E eccentricity	2	U Short
4-5	di Delta inclination from 0,3 (semi-circles)	2	Short
6-7	ΩDOTrate of right ascension (semi-circles/sec)	2	Short
8-11	A1/2Square root of sei-major axis (meters1/2)	4	U Long
12-15	Ω0 Longitude of ascension node (semi-circles)	4	Long
16-19	W Argument of perigee (semi-circles)	4	Long
20-23	M0 Mean anomaly at reference time (semi-circles)	4	Long
24-25	af0 Clock data coefficient (sec)	2	Short
26-27	af1 Clock data coefficient (sec/sec)	2	Short
28	Health	1	U Char
2 last	Checksum CCITT CRC	2	Short

Table 8: Message type 32 format

FIGURE 1

TRS STATION BLOCK DIAGRAMME

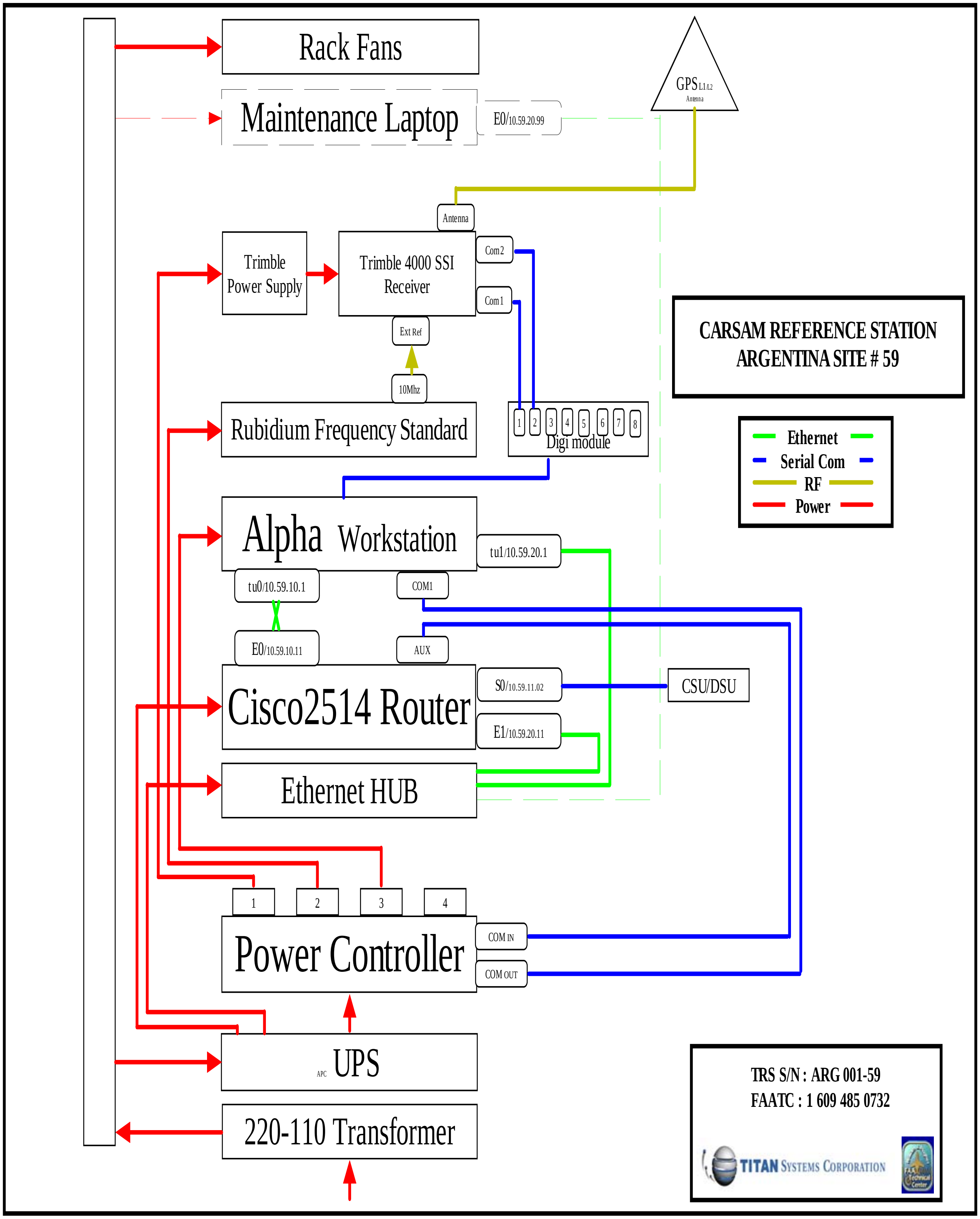


FIGURE 2

TRS GPS ANTENNA INSTALLATION LOCATIONS

TRS Bogotá (Colombia) Antenna

TRS La Paz (Bolivia) Antenna

Ezeiza (Argentina) GPS Antenna

GPS Antenna Tegucigalpa Honduras

FIGURE 3

PHOTOGRAPHS OF CSTB TRS EQUIPMENT

GPS Trimble Receiver

GPS Millenium Receiver

TRS Processor

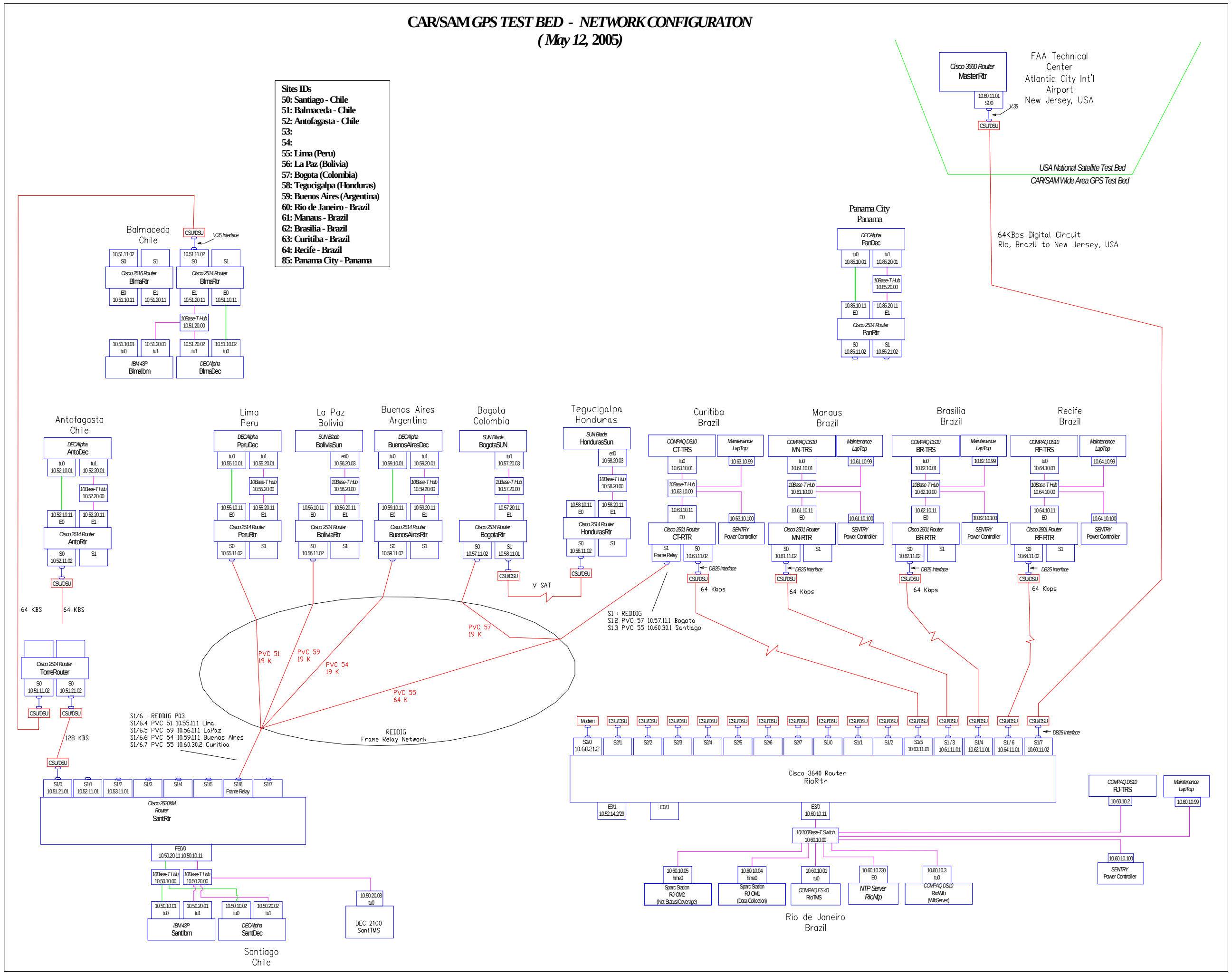
Power Manager System

Rubidium Oscillator

Digibord

FIGURE 4 / FIGURA 4

CAR/SAM TEST BED (CSTB) TRIAL PLATFORM
PLATAFORMA DE ENSAYO DE LA CSTB (CAR/SAM TEST BED)



CHAPTER 3

ANALYSIS OF THE DATA COLECTED

Description of CSTB data collection and analysis

Data Collection

3.1 The CARSAM Testbed was configured primarily for data collection. The Testbed Reference Stations (TRS) were configured to either send data to the Testbed Master Station or to collect the data locally. The measurements consisted primarily of GPS receiver satellite measurement data and collection of ephemeris messages. The TRS, which contained a Millenium receiver also collected the WAAS GEO measurement data and broadcast WAAS messages. The data was archived onto DVDs.

Data Analysis

3.2 Data for several information papers and reports was processed using the GPS Solution Post Process software tool. This tool uses the raw GPS measurement and ephemeris data as inputs and produces position and accuracy information in a text file called a .PDF file.

3.3 When the receiver is receiving a valid SBAS GEO message (which includes valid ionospheric data), the software can produce both accuracy and bounding information. For example, in the United States, this information is used to analyze the accuracy, integrity, and availability of WAAS. The analysis consists of the following:

Accuracy

3.4 The output of the GPS Solution Post Process software tool produces columns of the East, North, and Up error. This error is the difference between the computed position and the surveyed position of the TRS antenna. This data can be statistically analyzed or plotted to show the accuracy of the GPS-only or WAAS-corrected position.

Integrity

3.5 The output of the GPS Solution Post Process software tool produces columns of the Vertical Protection Level (VPL) and the Horizontal Protection Level (HPL), in addition to the columns of accuracy. The most basic determination of integrity is to use this data to confirm that the errors in the vertical and horizontal direction do not exceed the magnitude of the VPL and HPL. In order for this data to constitute a valid test, the SBAS master station software should have been certified to produce safe correction signals under all possible conditions; otherwise the test can give misleading results. The result of the bounding of the position error by the protection level can be analyzed statistically or plotted.

Availability

3.6 The output of the GPS Solution Post Process software tool produces columns of the Vertical Protection Level (VPL) and the Horizontal Protection Level (HPL); this data can be combined with the "Alert Level" for the specific operation under test (e.g., LNAV/VNAV) to determine whether the operation would have been available or whether the pilot would have been warned by the receiver to not continue the operation. As an example, under LNAV/VNAV, the Vertical Alert Limit (VAL) requirement is 50 meters. If the VPL went above 50 meters, the certified SBAS aircraft receiver would have generated a flag to warn the pilot to discontinue the approach, so the system would have been unavailable for that time. In order for this data to constitute a valid test, the SBAS master station software should have been certified to produce safe correction signals under all possible conditions; otherwise, the test can give misleading results. The result of the bounding of the protection level by the alert level can be analyzed statistically or plotted.

Data Display

3.7 Several plots were made using commercial GNUPLOT software to illustrate the data analysis concepts above.

Ionospheric Data

3.8 Analysis of the effects of the ionosphere on GPS and SBAS are performed in several ways. The effects of the disturbed ionosphere are to cause scintillation which causes receiver C/No fluctuations and occasional receiver dropouts, and these can be observed to effect position accuracy as discussed above. The raw C/No data can be plotted to observe strong scintillation and receiver dropouts on specific GPS or SBAS satellites. The receiver C/No is a column in an output file of the GPS Solution Post Process software tool.

3.9 Another effect of the disturbed ionosphere is to produce rapid changes in code or carrier range, and these can be plotted from the GpsSolutionPostProcess software tool. Several examples were provided in the paper of the severely disturbed features called "Depletions" which exist, at times, in areas near the geomagnetic equator.

Description of ionospheric problems and its influence over GPS systems

3.10 At the 11th Air Navigation Conference (ANConf/11) a recommendation was made to develop a worldwide ionospheric mitigation roadmap. The intent of the roadmap was to address technical concerns associated with Satellite Based Augmentation System (SBAS) performance in the equatorial regions. In response to this recommendation, the FAA established an initiative within its FAA Flight Plan 2004-2008 to establish the roadmap.

Background

3.11 An SBAS is capable of providing navigation services ranging from enroute, terminal to approach operations. For the US developed SBAS, known as the Wide-Area Augmentation System (WAAS), service availability extends from enroute down to what is called LPV (vertically guided approaches down to a 250 foot minimum) operations. One of the limiting factors WAAS must deal with is the ionosphere. The limitations associated with the ionosphere exist at a global level and will need to be addressed by those areas of the world that plan to implement an SBAS. Over the next several years, a number of SBAS will become operational and it's envisioned that satellite based navigation will eventually become a global reality (See **Figure 1**).

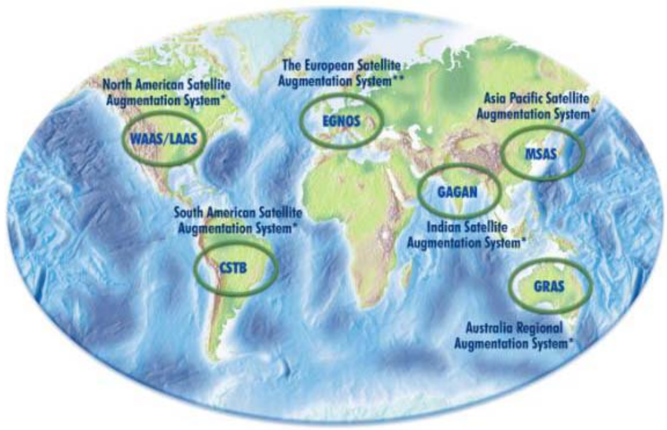


Figure 1 - Worldwide SBAS Development

3.12 At present, there is only one real obstacle to seeing this technology spread across the globe - *the ionosphere*.

The Ionosphere

3.13 The ionosphere is a region of the upper atmosphere that has the potential to disrupt signals from the Global Positioning System (GPS). The ionosphere contains free-electrons (measured in Total Electron Content (TEC) units) in sufficient density to slow the speed of GPS signals. By slowing the signal, the ionosphere creates a delay in the expected arrival of the GPS signal that will result in an incorrect position error if not corrected. Occasionally, more severe ionospheric disturbances, known as scintillation, may even prevent the reception of the signals. The effects of the ionosphere are cyclical and vary over time. A daily cycle has peak values occurring around 2 p.m. local time and minimum values after midnight. There are also seasonal, geographic and solar cycle differences. The most important aspect of these cycles is the significant dependence on the 11-year solar cycle, where ionospheric disturbances will be much greater near the peak of the cycle (most recently in 2000) than during the less active portions of the cycle (next expected in 2007). In many cases, the effects of the ionosphere can be mitigated by an SBAS and safe levels of vertical navigation can be provided. This is possible if the delays in the SBAS signals can be measured accurately and with high integrity. For many parts of the world, this is not a major problem.

3.14 However, in the equatorial regions this is not a simple task as the ionospheric delays can change very rapidly both in time and space. Figure 2 below highlights the different ionospheric regions across the globe and it can be seen that the equatorial regions encompasses roughly 30% of the earth's landmass.

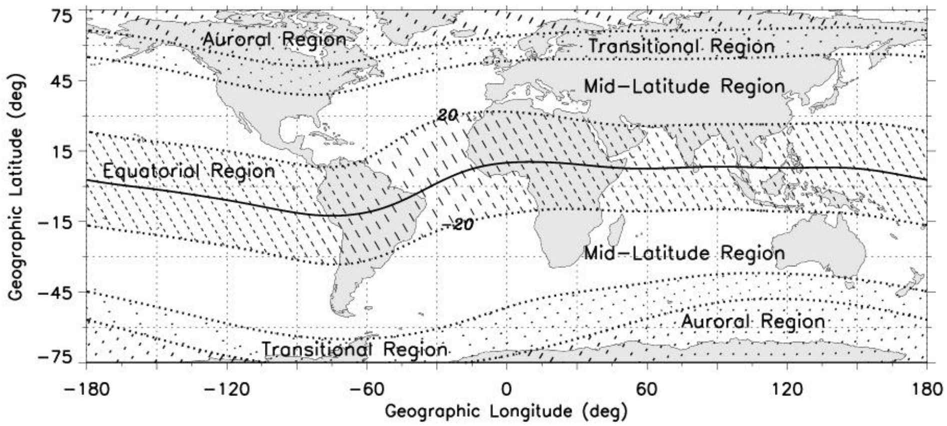


Figure 2 - Ionospheric Regions of the World

3.15 To support the implementation of SBAS in the near-equatorial regions of the world, the FAA has been supporting and conducting research focused on fully characterizing and then mitigating the effects of the ionosphere. The most recent effort has been to coordinate with international researchers in establishing a work plan for resolving issues associated with implementing an SBAS in the equatorial region. A major portion of this effort is in the establishment of a roadmap for mitigation of ionospheric effects to include the equatorial, mid-latitudes and auroral regions of the world.

3.16 The following information is the compilation of many years of research but it is of interest to note that there is still a significant level of work ahead for making SBAS a reality in the near-equatorial regions. It is very challenging to provide useful ionospheric corrections to these regions, but it is also very important as roughly 30% of population lie in these regions along with roughly 15% of the airports.

Findings to Date

3.17 The Global Positioning System (GPS) has been providing Position, Navigation and Time (PNT) to navigation users for nearly a decade. For those users using only GPS the ionosphere has not been shown to be a serious problem.

3.18 The RLA/00/009 project has invested a substantial amount of effort in developing data GPS collection from the TRS in order to verify the augmentation requirements for single frequency (L1) GPS receiver to account for range error due to ionospheric delay and to provide a bound for the remaining ionospheric error.

3.19 SBAS type WAAS transmits a grid of spatial vertical ionospheric delay information, which the user receiver interpolates and applies to each GPS range measurement. WAAS also generates an error bound for each grid point, called the Grid Ionospheric Vertical Error. The user receiver incorporates this error bound in his computation of the Vertical protection Level (VPL) and Horizontal Protection level (HPL) for the aircraft. The WAAS system assures the safety of the user by bounding the expected position error with the protection levels – and if the protection level exceeds the Alert Limit, then the pilot is warned to not continue the approach (if the runway is not in sight) [1].

3.20 WAAS informs the user receiver of ionospheric delay using a form of planar approximation. The system utilizes a bound for the possible ionospheric error resulting from potential irregularity in the ionosphere. The safety and availability SBAS systems, therefore, need to be considered when the ionosphere is disturbed and spatial delay becomes non-planar.

3.21 During the course of WAAS Initial Operational Capability (IOC) development, the FAA learned that the three-dimensional structure of the ionosphere in the aurora, polar cap, and mid-latitude regions can be well represented with a simplified two-dimensional model the majority of the time. This simplified model is used to condense the information so that it may be broadcast to users by means of a low data rate using geostationary satellites. Very rarely, near the peak of the 11-year solar cycle, significant disturbances occur in these regions that are not well modeled in two dimensions or that may escape detection altogether. WAAS has implemented an “irregularity detector” to identify times and locations where the ionosphere may not be well modeled. During these times, vertical guidance becomes unavailable. In addition, WAAS always inflates its broadcast confidence values to account for ionospheric disturbances that may be present, but not detected by the system.

3.22 This section overviews the GPS system augmentation features related to the ionosphere, and document several of the “bad” features and effects of the ionosphere that have been observed in the CONUS by the WAAS system, and in the CAR/SAM Region by the CSTB.

GNSS augmentation safety features related to ionospheric delay

3.23 The WAAS system continually tests the planar model of the ionosphere on which its safety depends; if any condition is detected over a radius of at least 800 km from a grid point which shows that ionospheric delay is not well represented by a smooth plane, then the GIVE for that grid point is set to 45 m, effectively removing it from use

3.24 Medium and large geomagnetic storms have been observed to create an irregular ionosphere over the continental United States, and the impact on WAAS has been to disable vertical guidance during these conditions. The system assures safety with a tradeoff in availability, and users of the system will either use an alternate landing aid, or conduct a Non-Precision Approach using WAAS or stand-alone GPS to land. Fortunately, the number of geomagnetic storms which are expected to disrupt the vertical guidance service of the WAAS system over a large area, are expected to be rare (perhaps zero, one or two per year), at the mid-latitude location of CONUS.

Ionospheric features at different latitudes

3.25 Unfortunately for the goal of worldwide standardization, ionospheric conditions differ substantially from the region near the geomagnetic equator (+/- roughly 20 degrees), and mid latitude locations. Mid-latitude areas may experience irregular ionospheric conditions relatively rarely, while the geomagnetic equator may see, at times, irregular conditions almost daily, due to two primary features – the equatorial anomaly and depletions The equatorial anomaly creates a bulge of ionospheric delay north and south of the geomagnetic equator during the day and seasonally, in the evening. The second and more extreme factor is depletions, which appear as elongated regions of decreased TEC on the order or hundreds of kilometers wide, or less.

Scintillation

3.26 A further negative effect related to an irregular ionosphere is scintillation. The effects of scintillation have been documented before. Recent results show that the level of signal fluctuations have been decreasing since the solar peak in 2001, but that scintillation has still been observed frequently up through March 2004 in data from the South American stations.

Ionospheric features near the geomagnetic equator

3.27 The ionospheric features that GPS augmentations systems face near the geomagnetic present three problems to solve (1) the irregularities from a planar surface are significant, (2) these irregularities occur fairly often, and (3) these irregularities are related to scintillation.

Ionospheric deviations from a smooth planar surface

3.28 The two main causes of the non-planar ionosphere are due to the equatorial anomaly and to plasma depletions. These initial attempts have not yet yielded an accepted method for SBAS to provide an ionospheric correction with a GIVE small enough to bind the error which would provide an available APV service while the severe irregular conditions exist.

Equatorial Anomaly

3.29 The Equatorial or Appleton Anomaly was recognized as early as the mid-1950's, and the physics is discussed in. The responsible force moves equatorial plasma north and south away from the equator. The equatorial anomaly varies in strength, and the result is an ionosphere with an increasing delay near the "anomaly region" (roughly +/- 15 degrees around the geomagnetic equator), and a decrease in delay near the geomagnetic equator.

3.30 Figures 9 shows a longitudinal cross section of the maximum vertical ionospheric delay derived from TRS data from many CARSAM and CONUS reference stations. The plot shows the "bulging" nature of the delay as one approaches the anomaly region and the smoother mid-latitude conditions.

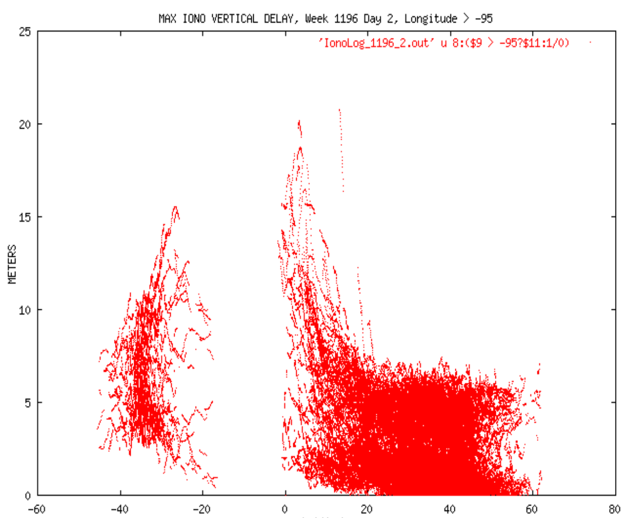


Figure 9. Equatorial Anomaly effect on maximum vertical delay

Equatorial Depletions

3.31 The anomaly itself contributes to the non-planar ionosphere, but this gradient (measured at 20 mm/km in [), is gradual compared to the gradient found in ionospheric depletions. The physical forces and mechanisms causing depletions have been studied for several decades. Some depletions spread further north-south more than others, and typically move west to east at 100-150 m/s, although there is a large range of speeds. Figure 10 illustrates size, gradients, and motion of a depletion observed in October 2001 by two receivers spaced 95 km apart east-west in the Rio de Janeiro area. One of the interesting times on the plot is at 346000, where neither site sees into the depletion on the line of site to the GEO, implying the entire depletion is contained within these points. The 10 meter change of TEC over a distance of (1/2) 95 km implies a gradient of roughly 200 mm/km.

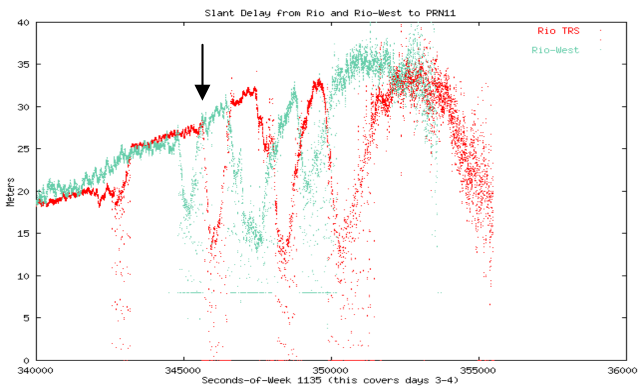


Figure 10: Depletion measurements in Rio de Janeiro

3.32 Figures 12 - 16 show the depletions measurements to PRN 7 on 5 consecutive nights from two nearly co-located receivers on Ascension Island. This shows the night-to-night variation possible during periods of severe depletions.

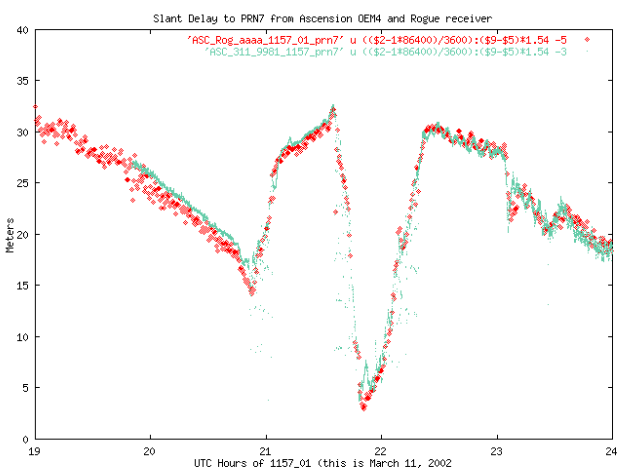


Figure 12: Depletion Measurements at Ascension Island, PRN 7, March 11, 2002

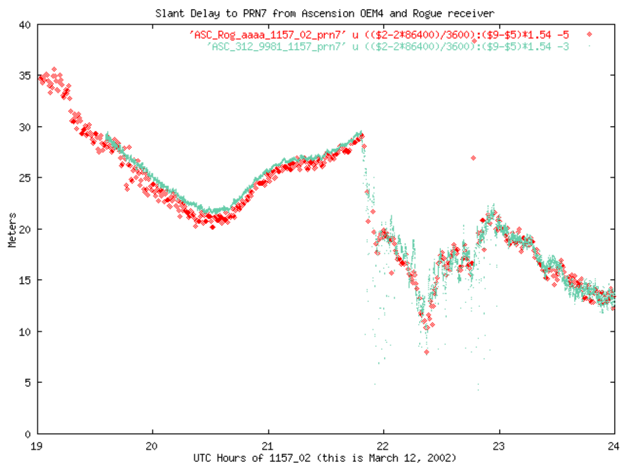


Figure 13: Depletion Measurements at Ascension Island, PRN 7, March 12, 2002

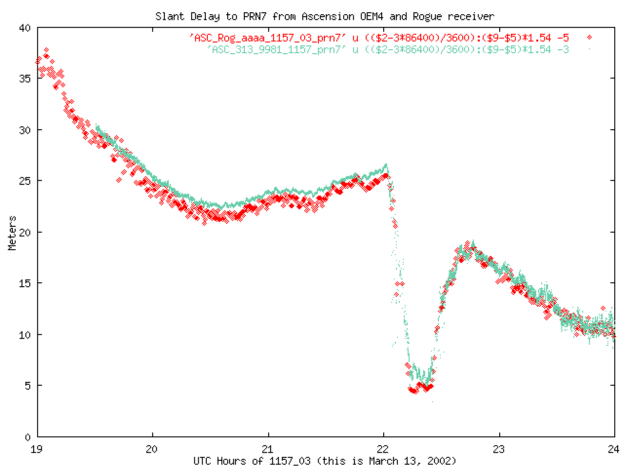


Figure 14. Depletion Measurements at Ascension Island, PRN 7, March 13, 2002

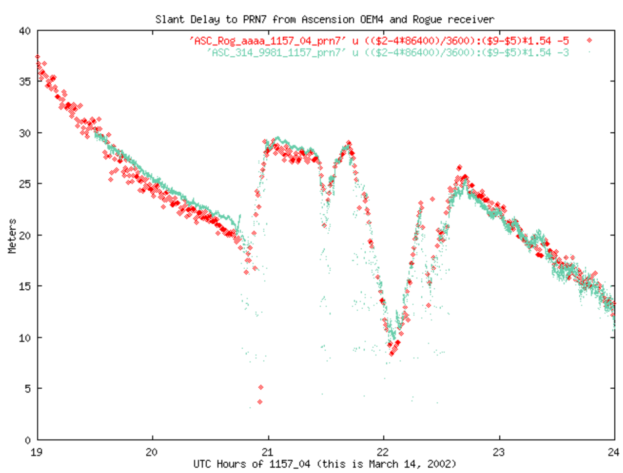


Figure 15: Depletion Measurements at Ascension Island, PRN 7, March 14, 2002

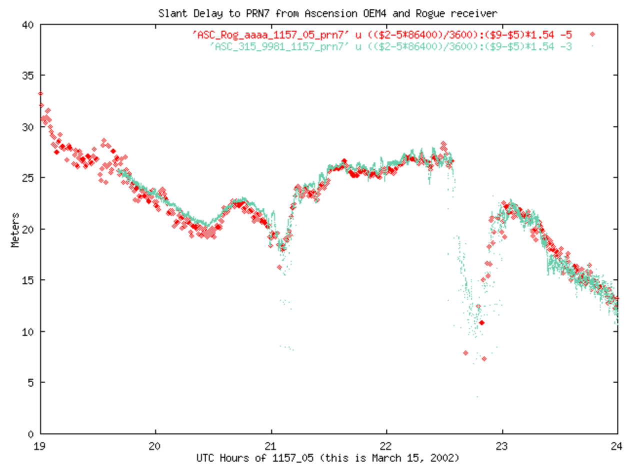


Figure 16: Depletion Measurements at Ascension Island, PRN 7, March 15, 2002

3.33 These figures show the extreme change in delay while the depletion exists in the years near the peak of the solar cycle (potentially over 30 meters of delay change); these figures also provide a graphic record that, when the season and times for depletion conditions exist, that they are common. Further down the solar cycle, in 2004, the observed depletions are generally smaller in magnitude (probably because the surrounding TEC is typically less than near the solar peak). A plot of the solar cycle is shown in Figure 17 (thanks to www.sec.noaa.gov).

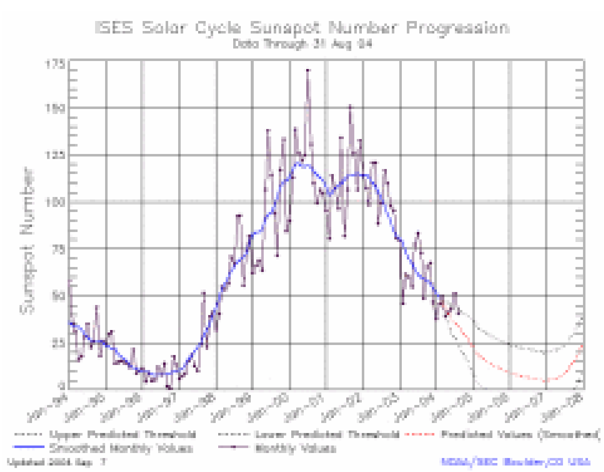


Figure 17: Current Solar Cycle

3.34 The next section will further investigate the frequency of occurrence in relation to the solar cycle, time of day, and season.

Depletion frequency of occurrence near the geomagnetic equator

3.35 Previous studies of equatorial depletions have also characterized their frequency of occurrence; depletions exist in Brazil as often as 86% of the evenings in January. Depletions are banana shaped holes in the ionosphereic plasma, aligned North – South from the geomagnetic equator. One convenient indicator of the existence of depletions on any given night is the fluctuation caused in the receiver reported GPS C/N_0 ratio. The fluctuations are due to the scintillation that occurs in conjunction with the depletions. The most convenient satellite to use for these observations is the Geosynchronus satellite transmitting the FAA's WAAS signal on L1. Figure 19 shows the fluctuations in the GEO SNR from receivers in Recife, Brasilia, and Rio de Janeiro (receivers are increasingly further from the geomagnetic equator but not in a straight line). Figure 19 shows strong fluctuations on two nights of the four in the Rio area, in October 2001, while the receivers further north show more days of occurrence. The nights and places where signal fluctuations are seen track the general understanding of the depletion. They start on the geomagnetic equator and grow North and South, until they reach the maximum extent under the existing conditions. Figures 20-22 show this data recorded for three weeks in January, 2004 (several years down from the peak of the solar cycle.) These figures show the similar characteristics of a higher probability of occurrence closer to the geomagnetic equator, but if depletions reach the Rio area the fluctuations can still be strong. From the figures it appears that the magnitude of the fluctuations has decreased, several years from the peak of the solar cycle, as is expected by studies on scintillation. Figure 20 makes this point clear since scintillation only reached the line of sight from Rio to AOR-W once during the week (elevation angle about 60 degrees looking roughly Northwest). The shape and extent of the depletions suggests that the number of satellite links affected and severity will be dependent on site location with respect to the geomagnetic equator. From Rio de Janeiro, for example, an azimuth angle looking north to the satellite is more likely to pass through a depletion on any night when depletions exist.

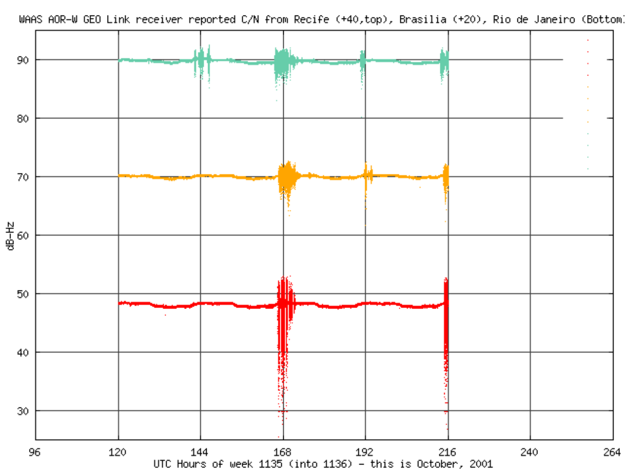


Figure 19. WAAS AOR-W GEO SNR fluctuations recorded by the Brazil Testbed, October, 2001

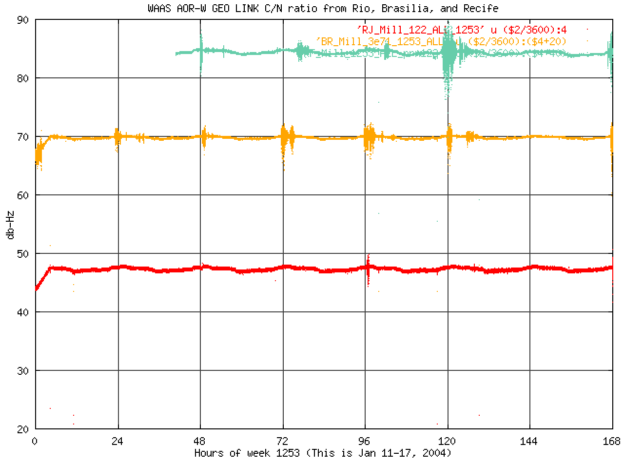


Figure 20. WAAS AOR-W GEO SNR fluctuations recorded by the Brazil Testbed, Jan 11-17, 2004

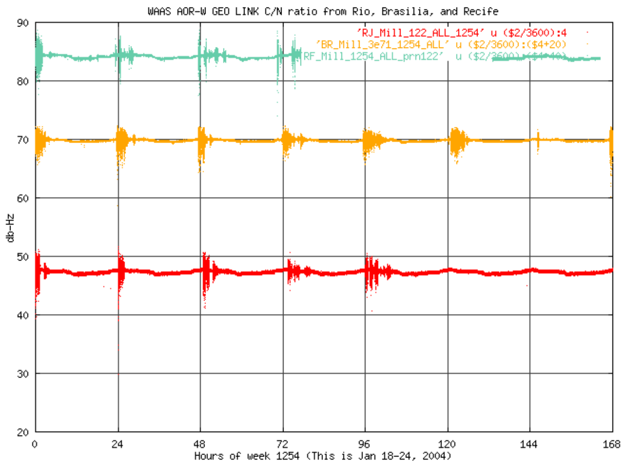


Figure 21. WAAS AOR-W GEO SNR fluctuations recorded by the Brazil Testbed, Jan 18-24, 2004

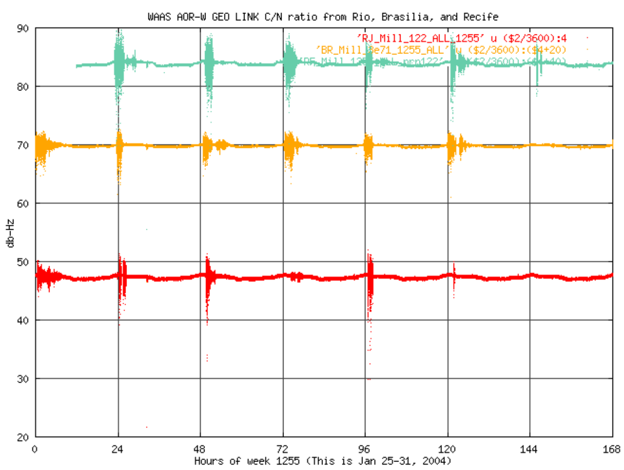


Figure 22. WAAS AOR-W GEO SNR fluctuations recorded by the Brazil Testbed, Jan 24-31, 2004

Dropouts due to scintillation

3.36 Figure 23 shows another example of a bubble, also to PRN 11 on the evening of October 13/14 2001, from both the Rio TRS and Rio-South (a remote receiver temporarily located South of Rio de Janeiro). The Ashtech (shown in green, L1 (code-carrier)/2) seemed to loose lock more easily, so I only have a limited portion of the bubble. However, the shape shows a very good agreement to the Rio-TRS data (in red) (which is 20 km north). This data also shows the lack of north-south motion, which is generally the case (but not guaranteed, as the vertical lift may appear like a north south motion on some satellite ray path). The magnitude of this bubble reaches approximately 20 meters.

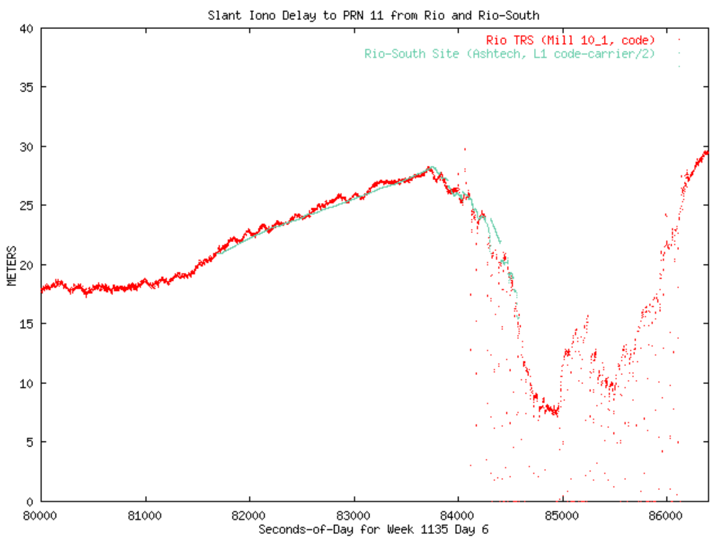


Figure 23: PRN 11 Iono Slant Delay from Rio TRS and Rio-South site

3.37 Scintillation is evident in most of the plots shown. One specific indicator of scintillation of importance is the loss of the GEO message resulting from scintillation. Data from the 3 southern Brazilian TRS sites showing loss of GEO messages is summarized in the following table:

Geo messages lost

Week/Day	1135_5	1135_6	1136_0	1136_1
Rio de Janeiro	2	1783	783	1197
Curitiba	0	967	2033	1029
Brasilia	3	1	0	0

3.38 A slight difficulty in understanding this table is caused by the fact that the scintillation event occurs in the evening, usually straddling two UTC days; so a more detailed mapping of the losses to the specific scintillation times will be done. However, from my observation of the data, the GEO message losses occur at the times of the scintillation events, and that generally the losses are grouped in bunches (up to 10-20 messages in a row, at least one case over 100 messages lost in a row).

Continuing research

3.39 Research is continuing on how to solve the problems of safe interpolation/extrapolation of ionopsheric delay from GPS augmentations systems to L1-only airborne users. The worst irregularities or non-planar features are formed in the ionosphere by geomagnetic storms in mid-latitudes and, more commonly, by Earth's ionospheric physics in areas near the geomagnetic equator. The ultimate answer is the use of dual frequencies, such as L5 - the second civil frequency, in GPS. This will permit the aircraft to directly measure the ionospheric delay and compensate for it, instead of trying to have the augmentation system estimate what ionospheric delay the aircraft's measurements might be experiencing. The additional civil frequency will not completely solve the problem of dropouts due to scintillation, however, so further research and specification in this area may be needed.

Analysis of the data collected

3.40 All data collected are stored in DVD at the FAA William J. Hughes Technical Center (WJHTC) in Atlantic City, New Jersey, USA. The data collection started in 2002 and ended in November 2005.

3.41 Data without processing from the TRS and recorded in the Atlantic City data base is available to Project RLA/00/009 participants upon requirement.

3.42 To obtain CSTB data, contact should be made with Mr. Tom Dehel (tom.dehel@faa.gov). In addition, the data collected by the NSTB during the last weeks to the date of access can be found at the following Web page: http://www.nstb.tc.faa.gov/

3.43 Non-aviation civil users will be the first group able to conduct dual frequency measurements on ionospheric delay with the introduction of the new L2C signal. L2C will not be available for civil aviation safety-of-life uses since it is not in a frequency band protected for aviation safety-of-life applications.

3.44 The L5 signal is a robust new signal designed to meet the needs of aviation users. It provides greater resistance to interference and improved acquisition properties. The data message will be new, and is designed to meet the accuracy needs and provide flexibility required by future users. The addition of this third civil frequency will provide worldwide, continuous availability of ionospheric measurement to all civil users.

3.45 Full capability of these signals will be provided when sufficient satellites are launched to provide adequate global coverage, and the GPS Control Segment is enhanced to monitor and control them. Initial operating capability (IOC) for L2C is approximately 2010, with full operating capability (FOC) in 2012. L5 IOC is approximated for 2013 with FOC in 2015. These schedules are approximate and therefore subject to change.

3.46 Satellite navigation for aviation provides an almost quantum leap in capability above conventional navigation aids, and the effects of the ionosphere on services like en route navigation and non-precision approach are almost nil. The use of satellite navigation for precision vertical guidance, however, requires precise correction and bounding of ionospheric delay estimation errors.

3.47 WAAS has already experienced major geomagnetic storms where vertical guidance has been automatically disabled for periods lasting several hours over the United States. Ionospheric features that exist often in areas near the geomagnetic equator continue to be studied, but a solution using a single-frequency SBAS system to provide vertical guidance has not yet been defined, at least for times when these severe features exist.

Data collected from the TRS

3.48 Figures 24 to 29 show the amount of data received per week at the FAA technological centre in Atlantic City, from each CSTB TRS (using day 3 of the week). The graphics were Developer using the tool named gnuplot. All these data are available at the afore indicated site.

3.49 In the figures, the **axis** shows the number of messages measured per site. One message per second would have to be received, one perfect collection day would have to have 86400 messages.

3.50 The figures show that great amount of data were received, but the problems encountered can be noted (hardware failure, untimely installation of communications lines, occasional failures of same, etc.).

3.51 The great amount of data collected reflects that the objective of the project, related with data collection, was complied with and that same would be providing information for the investigation (ionosphere).

3.52 The graphics' **X axis** indicate the number of weeks per a tour-year period. The conversión from weeks to perids (months, years) is shown as follows:

Week	1150 -	January,	2002
Week	1200 -	January,	2003
Week	1250 -	December,	2003
Week	1300 -	December,	2004
Week	1350 -	December	2005

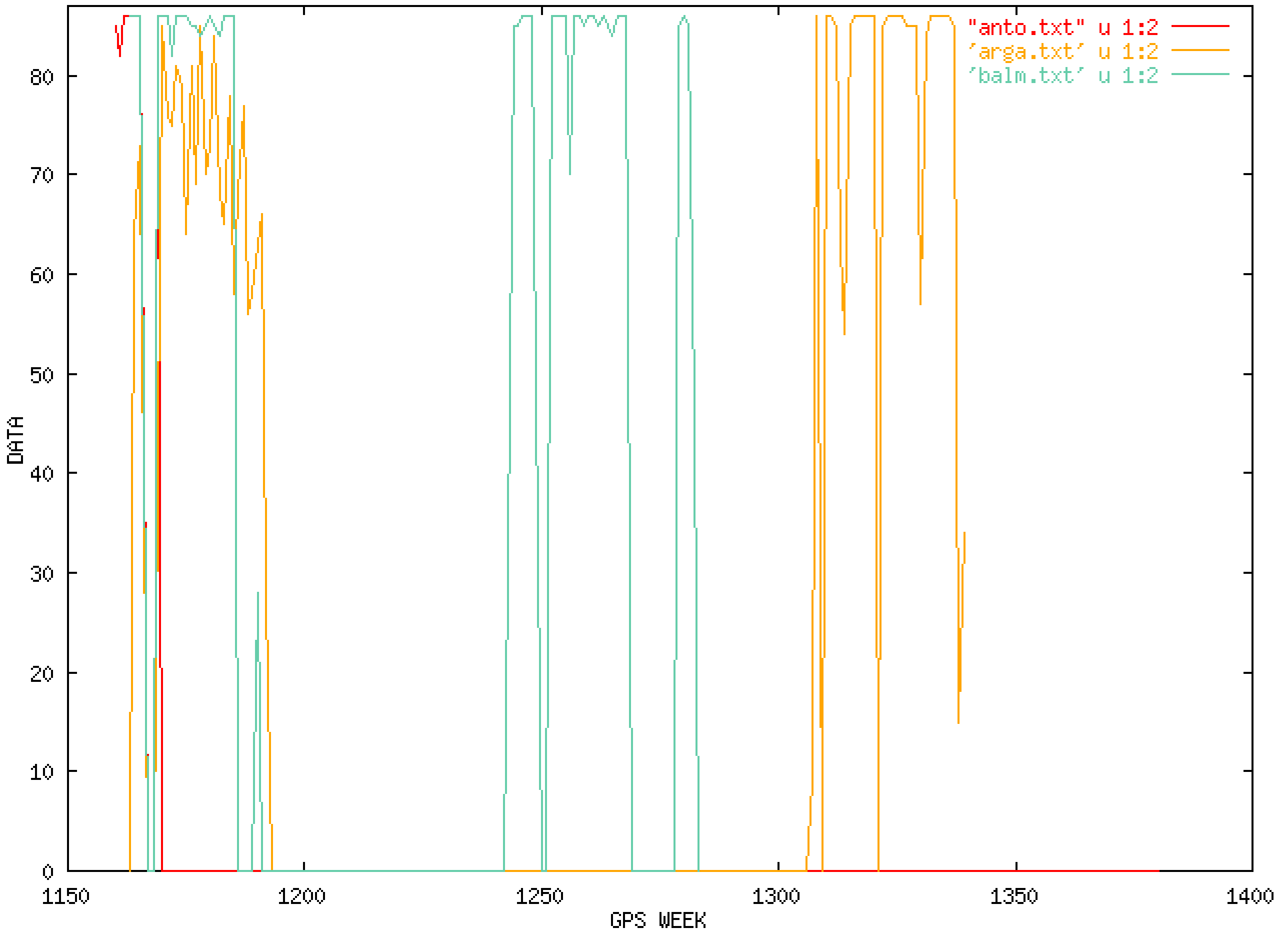


Figure 24. Data collected from Antofagasta, Argentina and Balmaceda

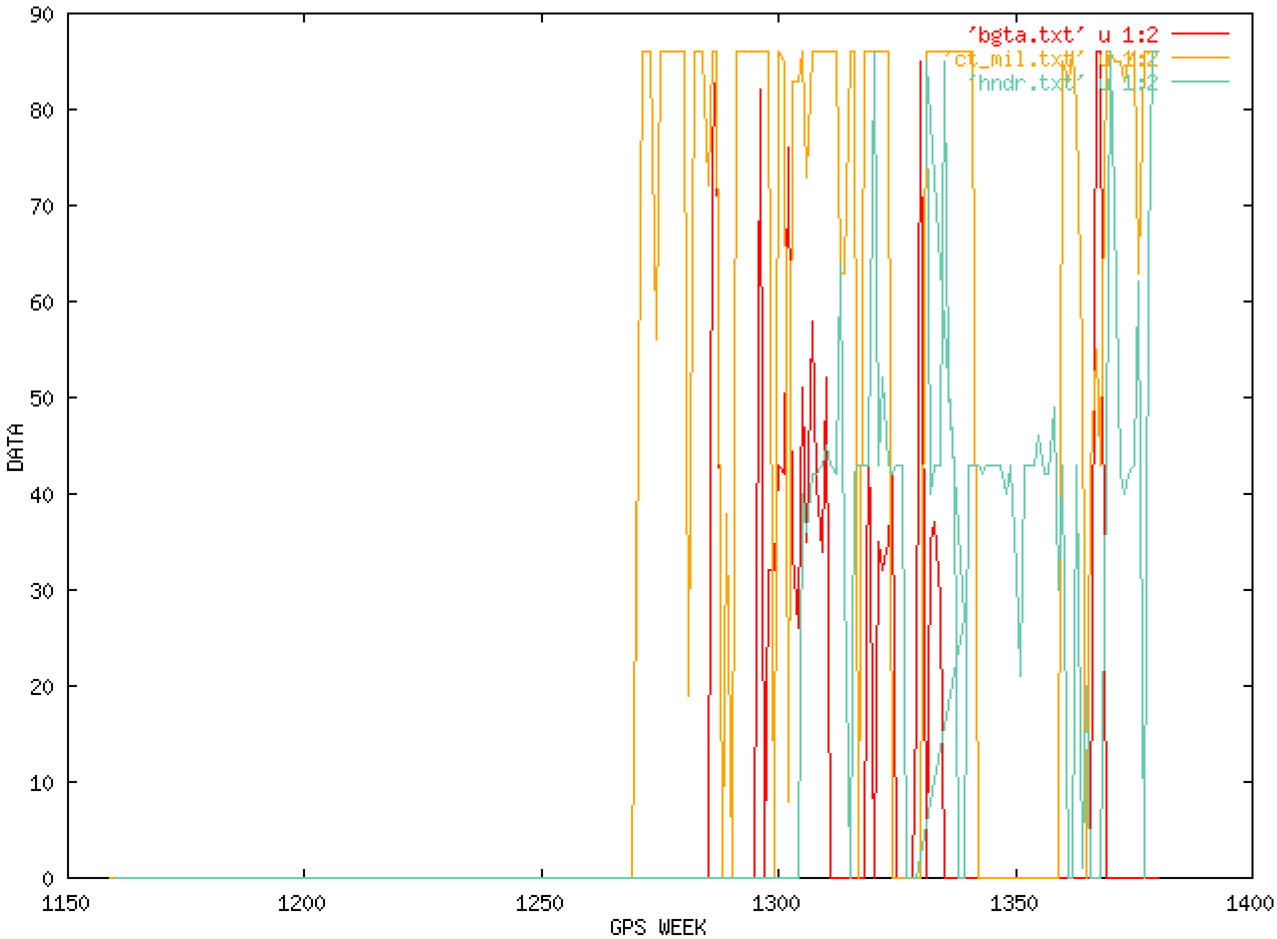


Figure 25. Data collected from Bogotá and Honduras

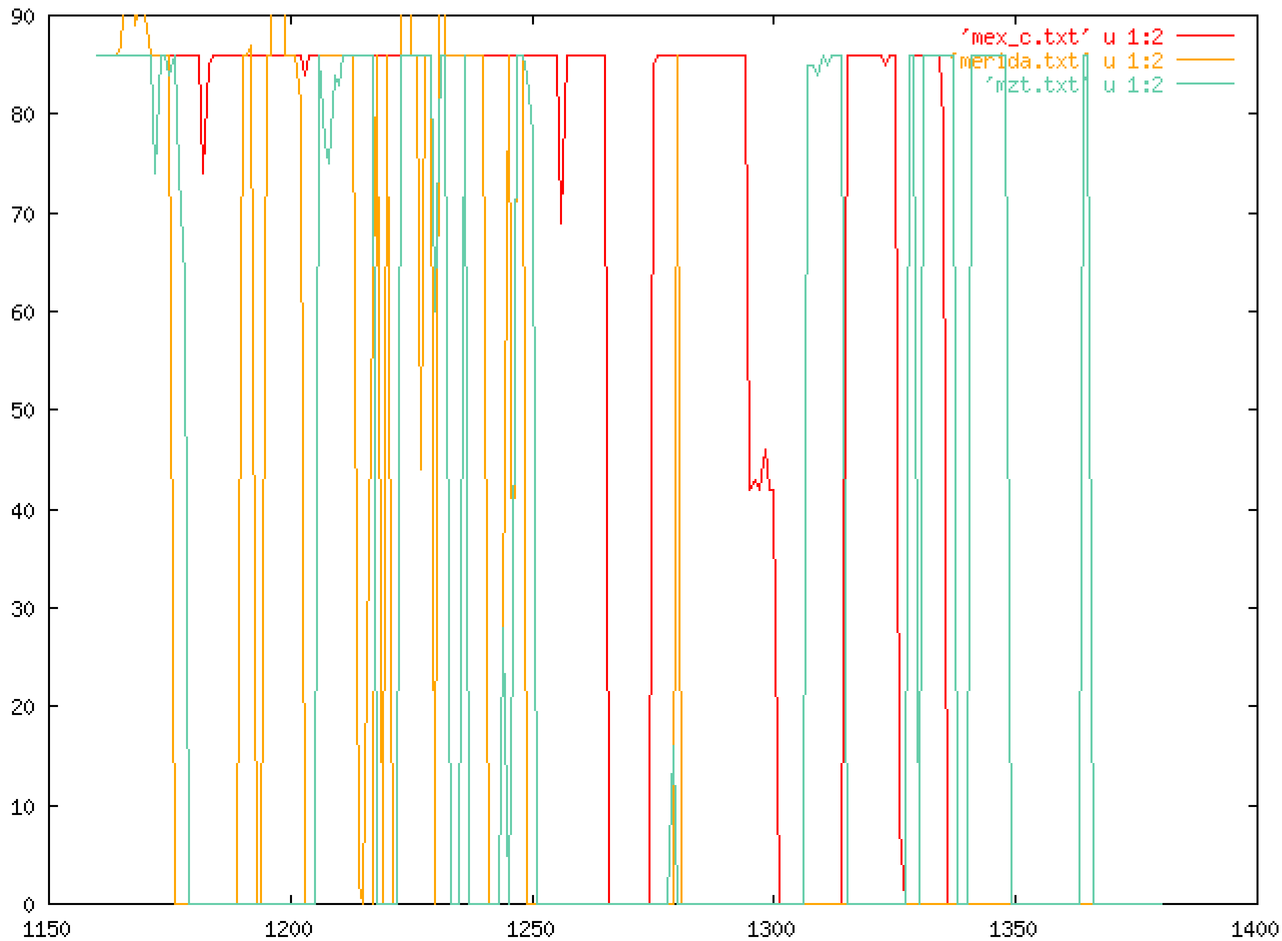


Figure 26. Data collected from México, Mérida and Mazatlan

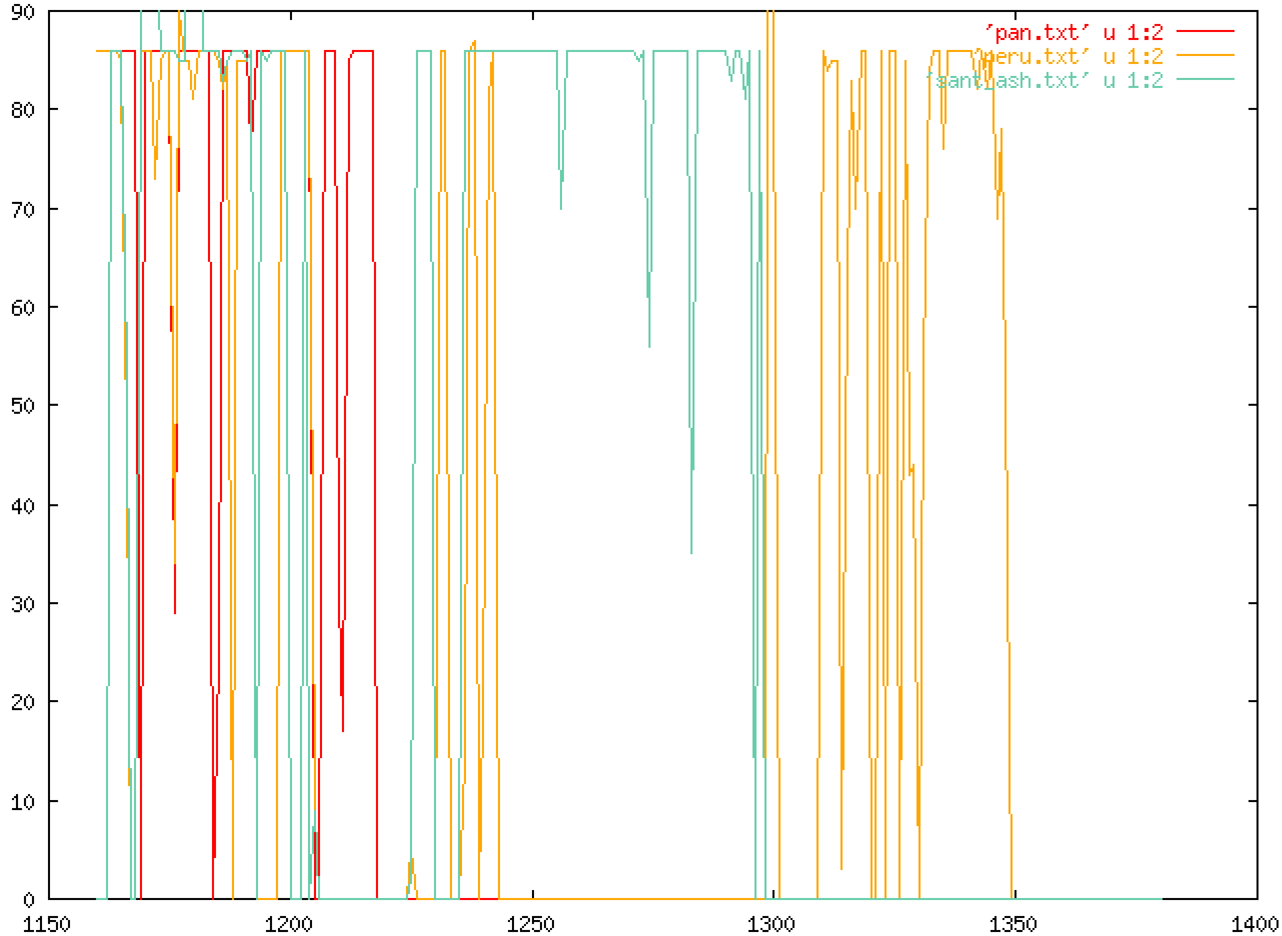


Figure 27. Data collected from Panamá, Perú and Santiago

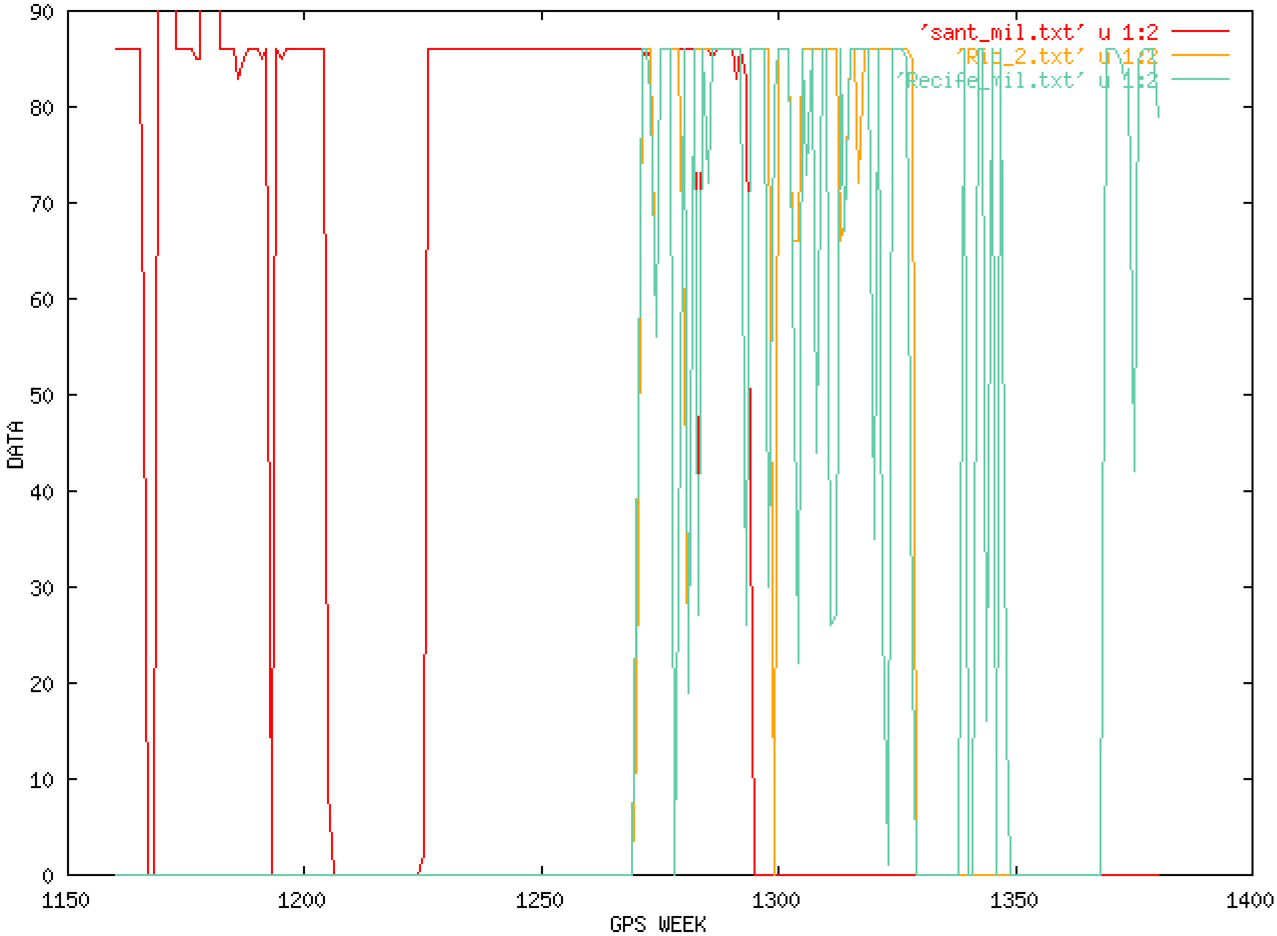


Figure 28. Data collected from Santiago and Recife

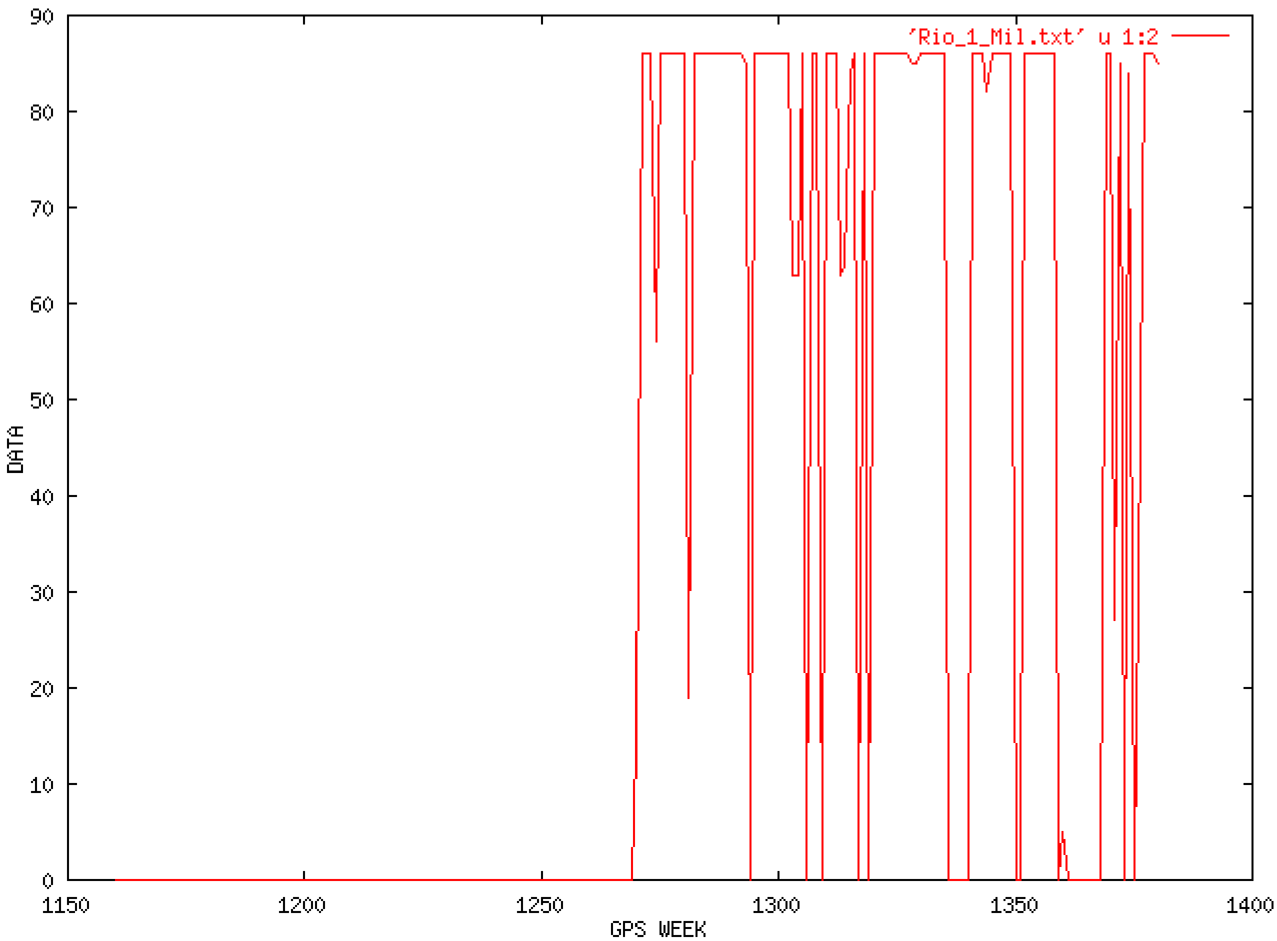


Figure 29. Data collected from Río de Janeiro

Accuracy analysis of raw GPS data collected from TRS stations

3.53 Figures 30 to 38 show horizontal and vertical error from sample of raw GPS data collected in Peru, Honduras, Colombia, Argentina, Chile, Panama, Mexico and Brazil, respectively.

3.54 For each plot **Y axis** is error in meters, and **x axis is** seconds of week. In each of the plot it is shown horizontal east and north error and vertical error.

3.55 From the analysis of the data it is shown that Honduras presented spikes due for momentary bad reception or bad geometry, Colombia presented higher picks in vertical error and in most time, Brazil plots present the accuracy by the presence of bubbles and present the worst precision error of all the samples.

3.56 The analysis for the other TRS sites (Peru, Argentina, Chile, Panama and Mexico) present good accuracy. However, considering that raw GPS data collected is not useful for NPA with vertical guidance in all the sites it is useful for en route and NPA without vertical guidance.

Peru accuracy plot

3.57 The accuracy shown is raw GPS accuracy - which shows very well that accuracy can be maintained.

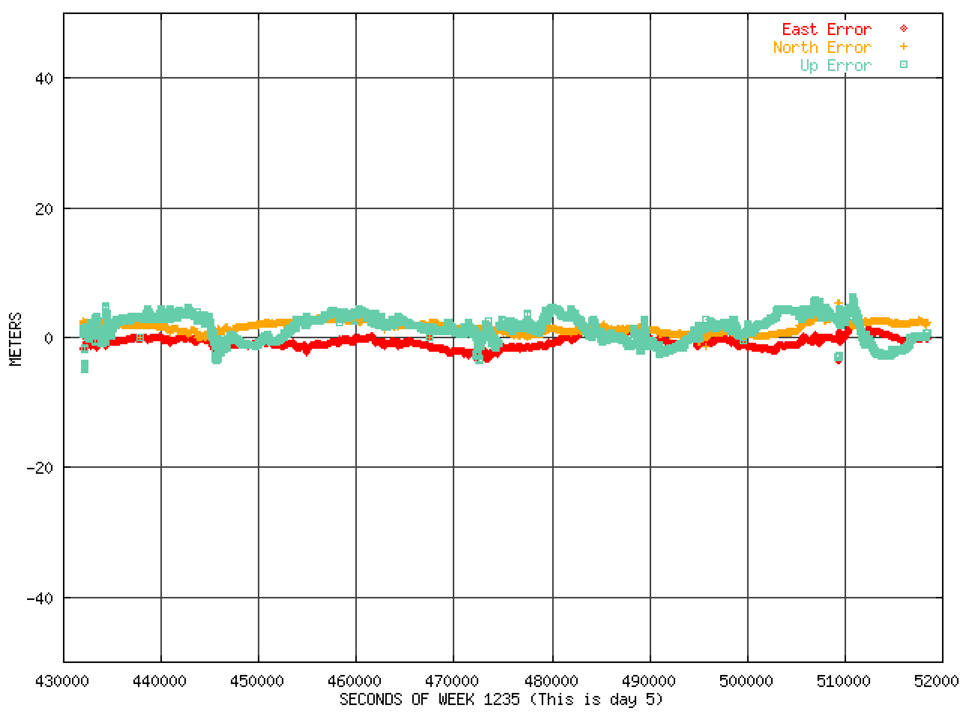


Figure 30. Horizontal and vertical error taken from GPS signal sample – Perú

Honduras accuracy plot

3.58 It shows some spikes in accuracy which are typical of momentary bad reception, but still looks OK for raw GPS.

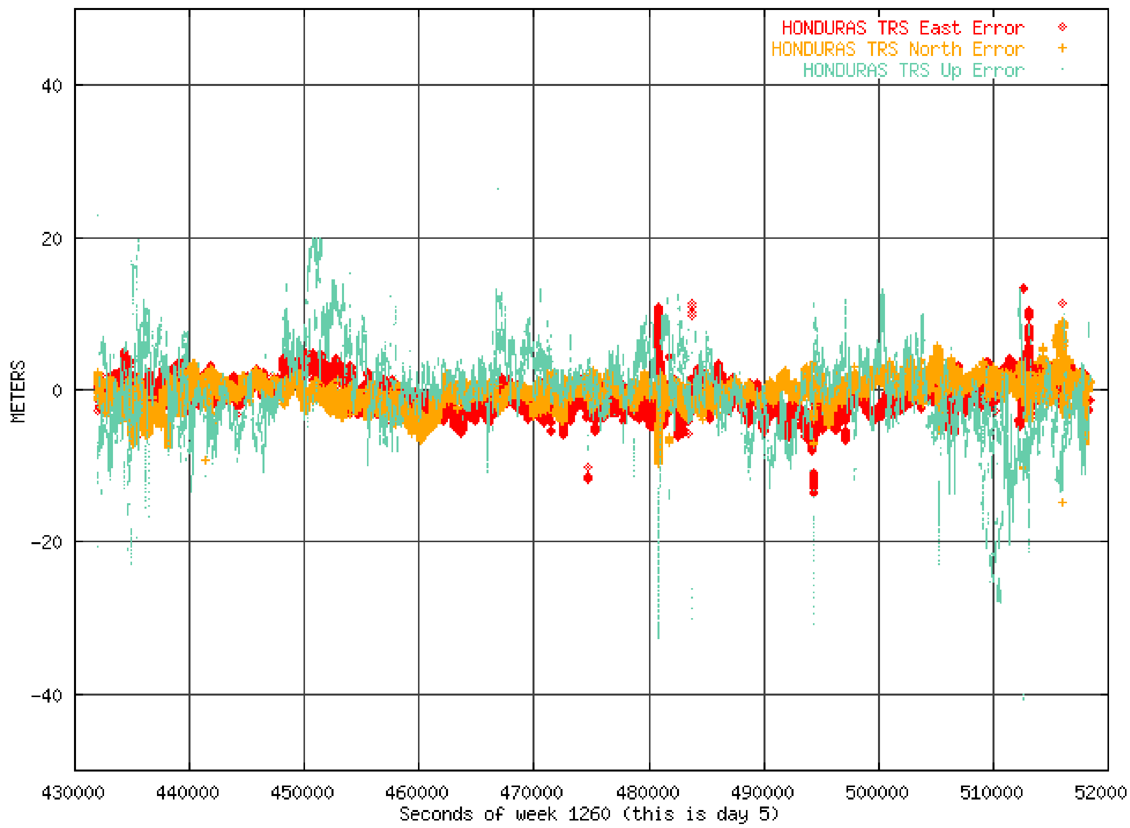


Figure 31. Horizontal and vertical error taken from GPS signal sample - Honduras

Colombia accuracy plot

3.59 This plot shows the vertical error in Colombia peaked higher than most sites at most times. It may be due to the ionosphere (poor klobuchar values) or a poor geometry. However, since raw GPS cannot be used to vertically guide an approach, the results are still acceptable.

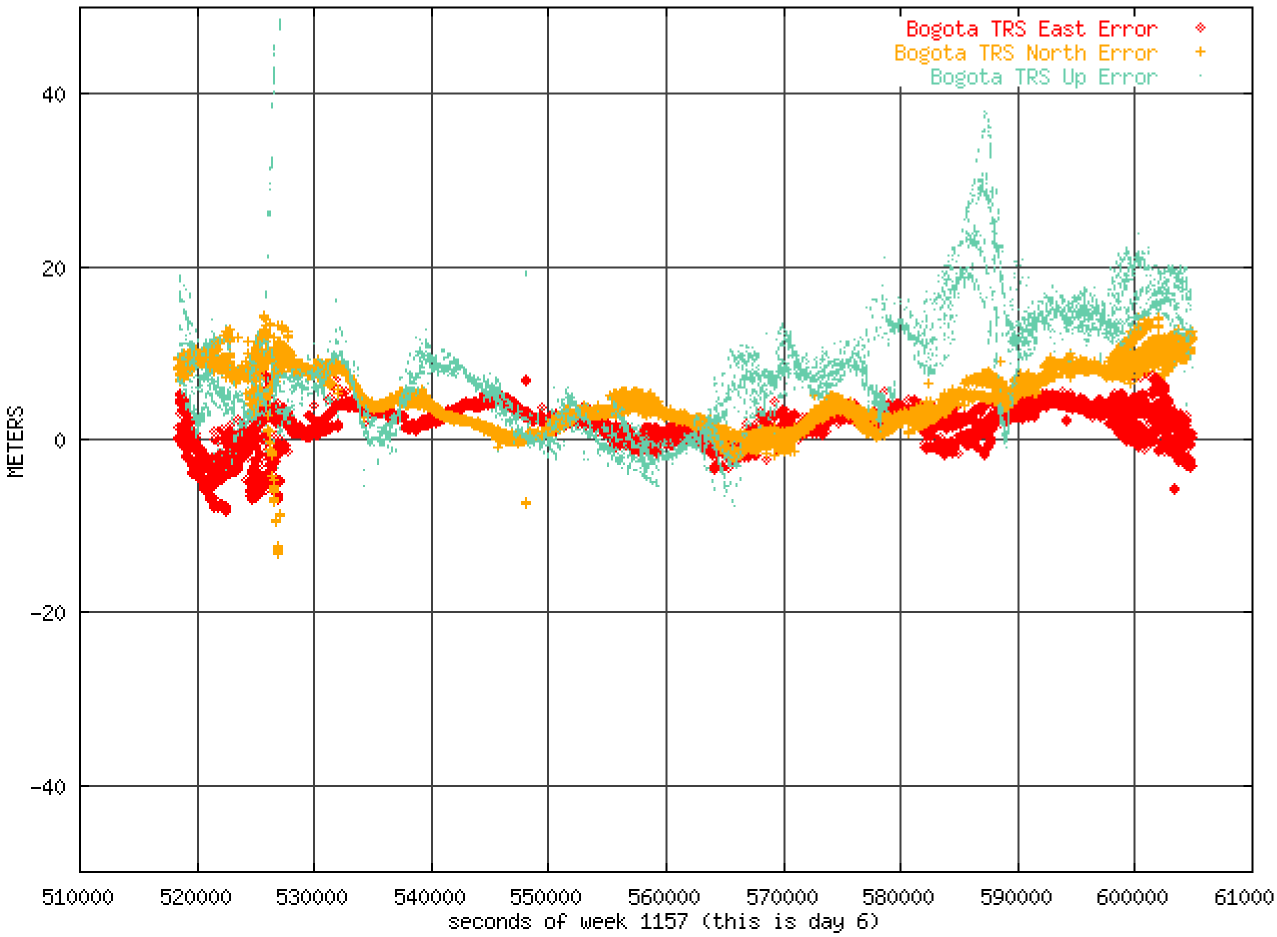


Figure 32. Horizontal and vertical error taken from GPS signal sample - Colombia

Argentina accuracy plot

3.60 In this plot the accuracy looks good.

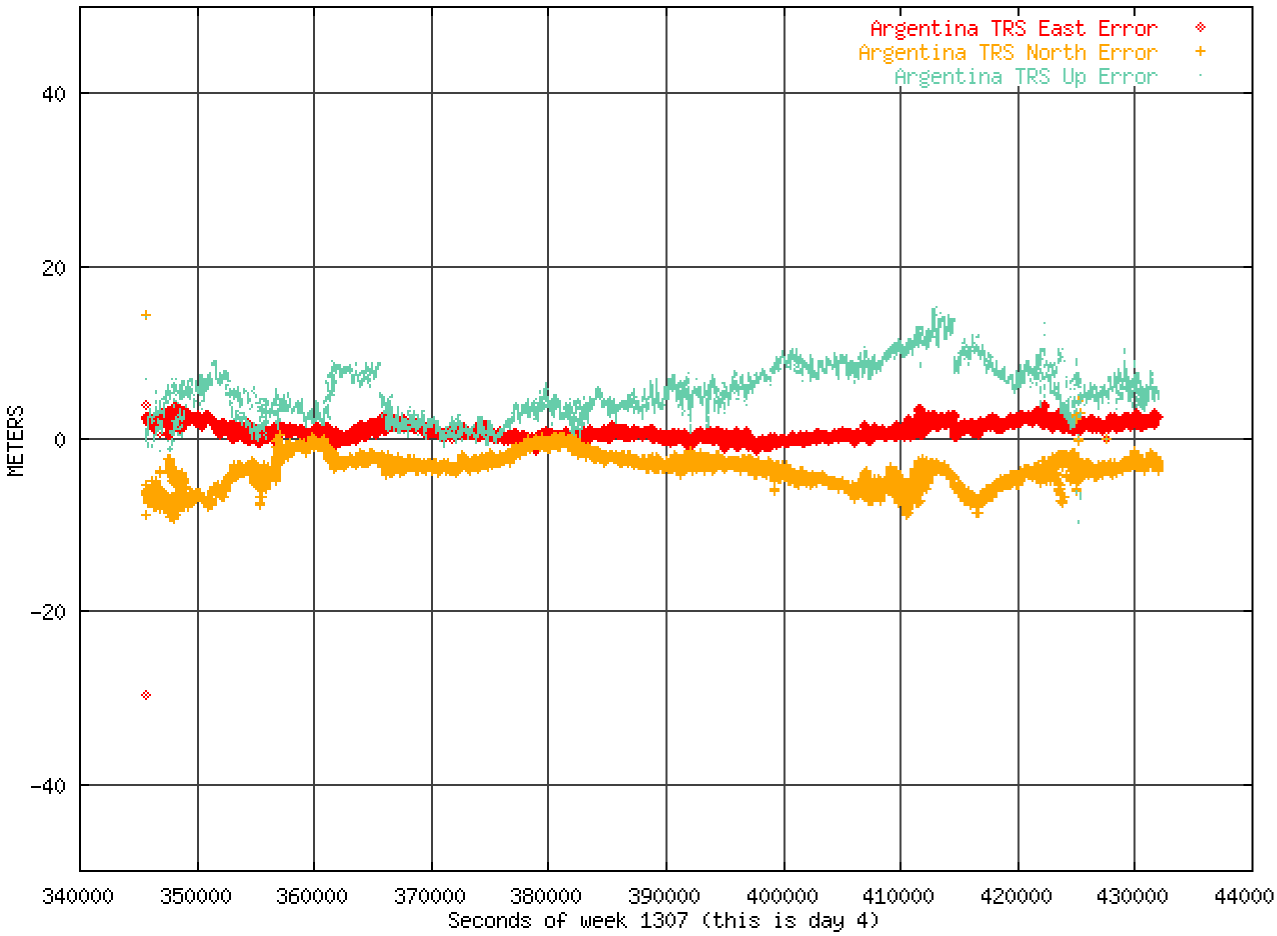


Figure 33. Horizontal and vertical error taken from GPS signal sample - Argentina

Chile accuracy plot

3.61 In this plot the accuracy looks good.

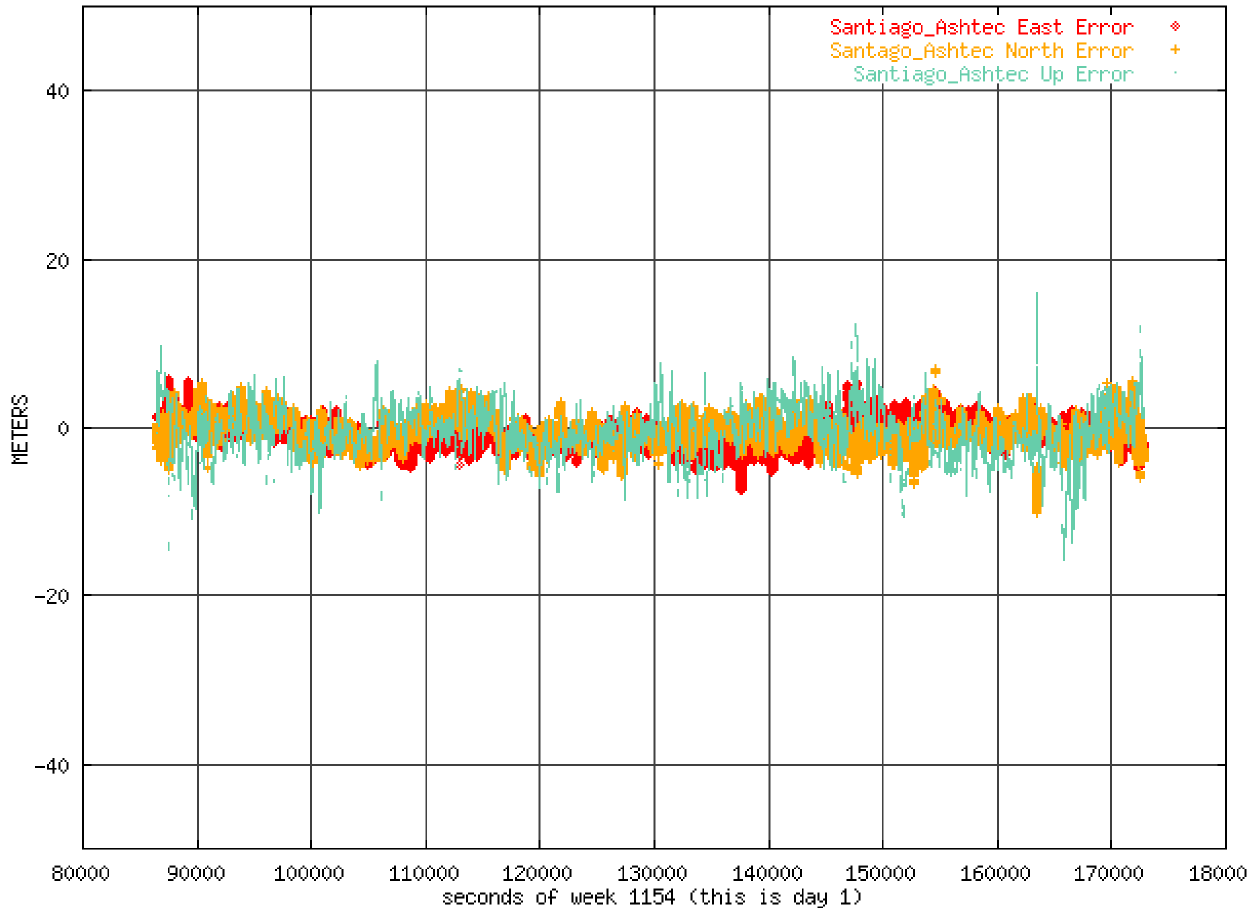


Figure 34. Horizontal and vertical error taken from GPS signal sample - Chile

Panama accuracy plot

3.62 This plot might show a slight offset in the vertical survey point. Otherwise looks good.

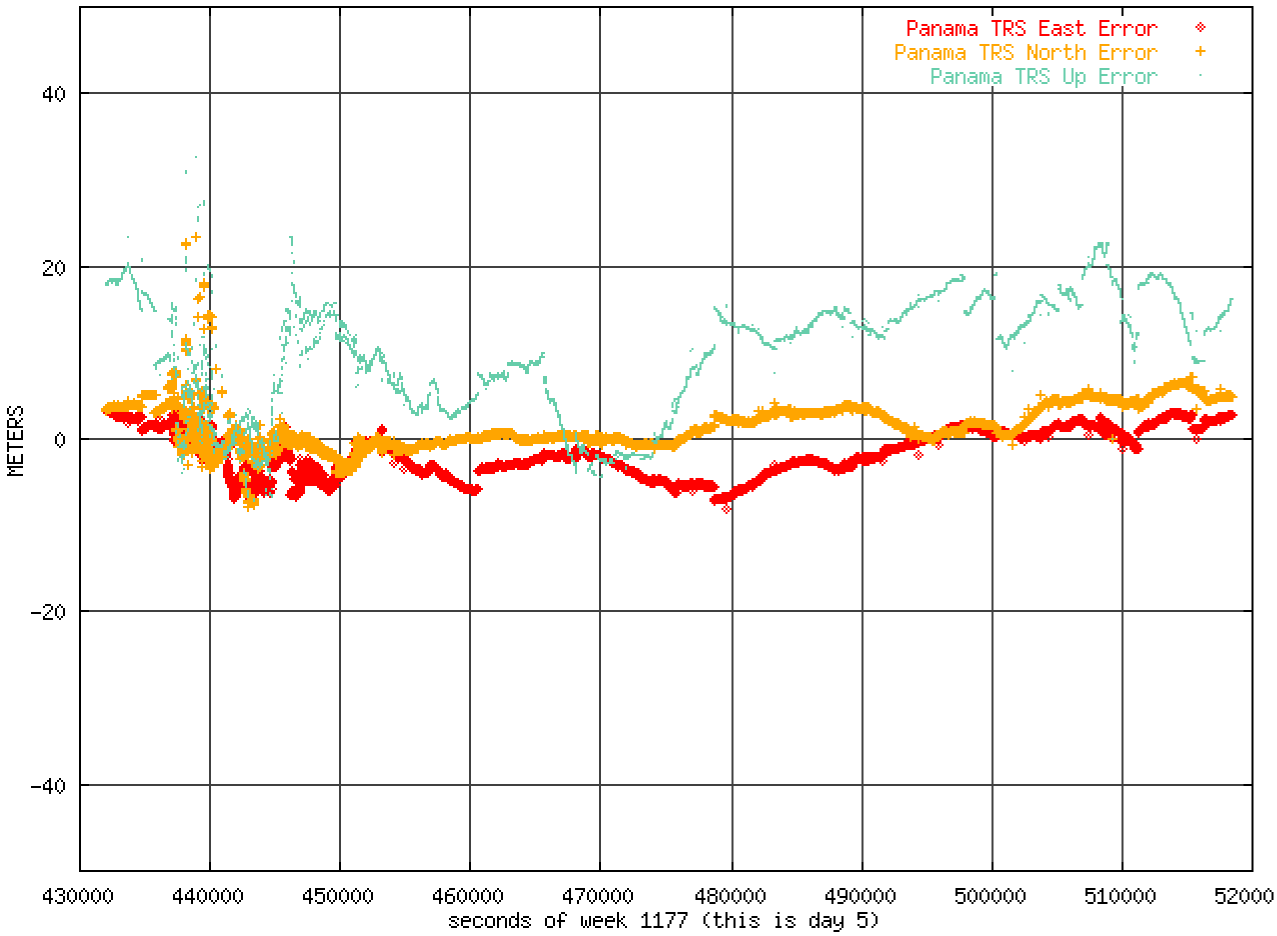


Figure 35. Horizontal and vertical error taken from GPS signal sample - Panamá

Mexico accuracy plot

3.63 In this plot the accuracy is very good.

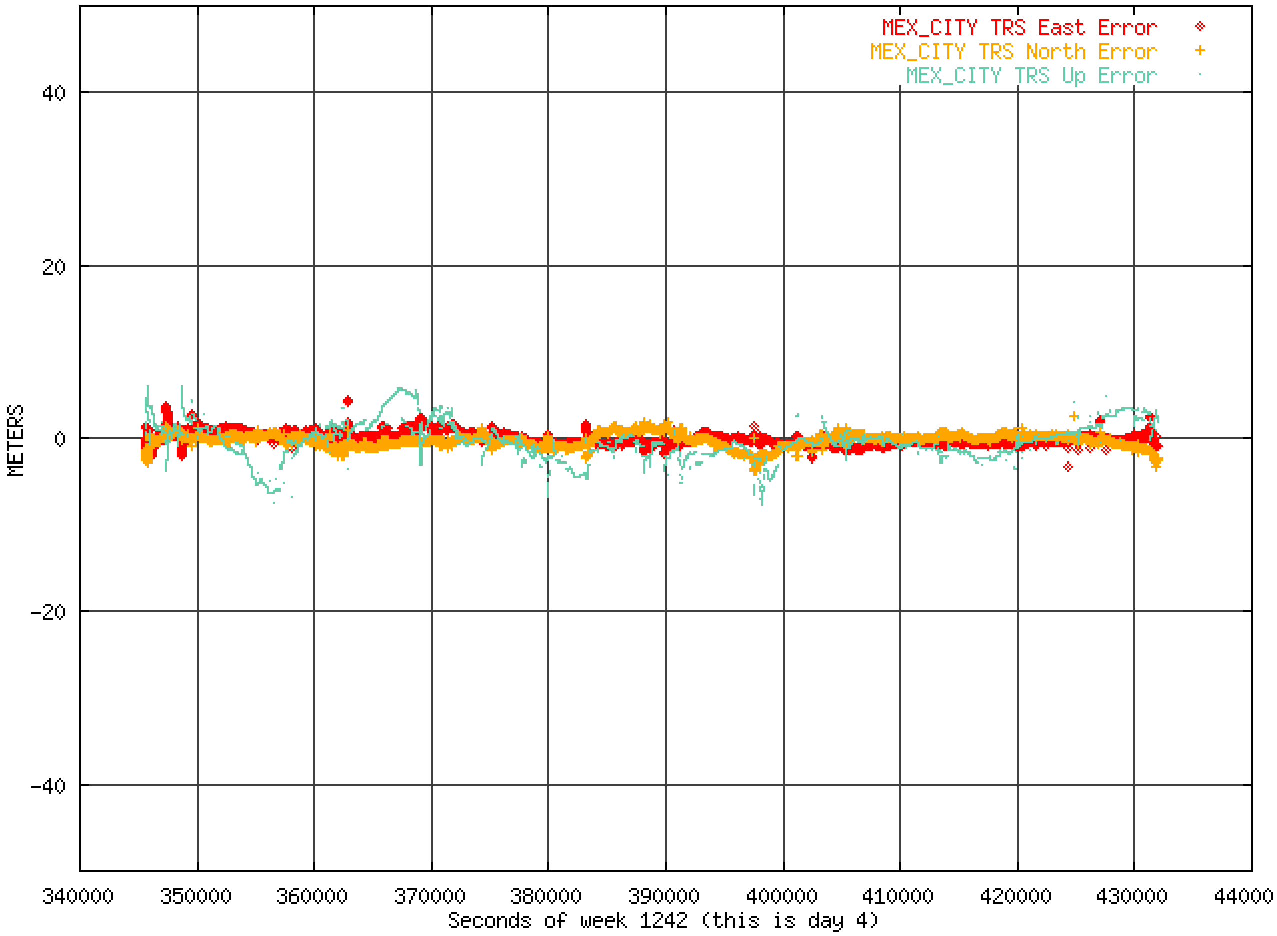


Figure 36. Horizontal and vertical error taken from GPS signal sample - Mexico

Brazil accuracy plots

3.64 The plots show the accuracy plot for Rio for a day with bubbles - you can see how the bubbles disrupt the GPS at the times that the bubbles are most severe (near the start of the plot). The C/No relation with the AOW-R GEO satellite under the effects of the bubble is also shown.

3.65 The Rio vertical accuracy is also worse than most others, due probably to the strong ionosphere anomaly during the day, which is not accounted for well by the Klobuchar parameters (in an L1-only system).

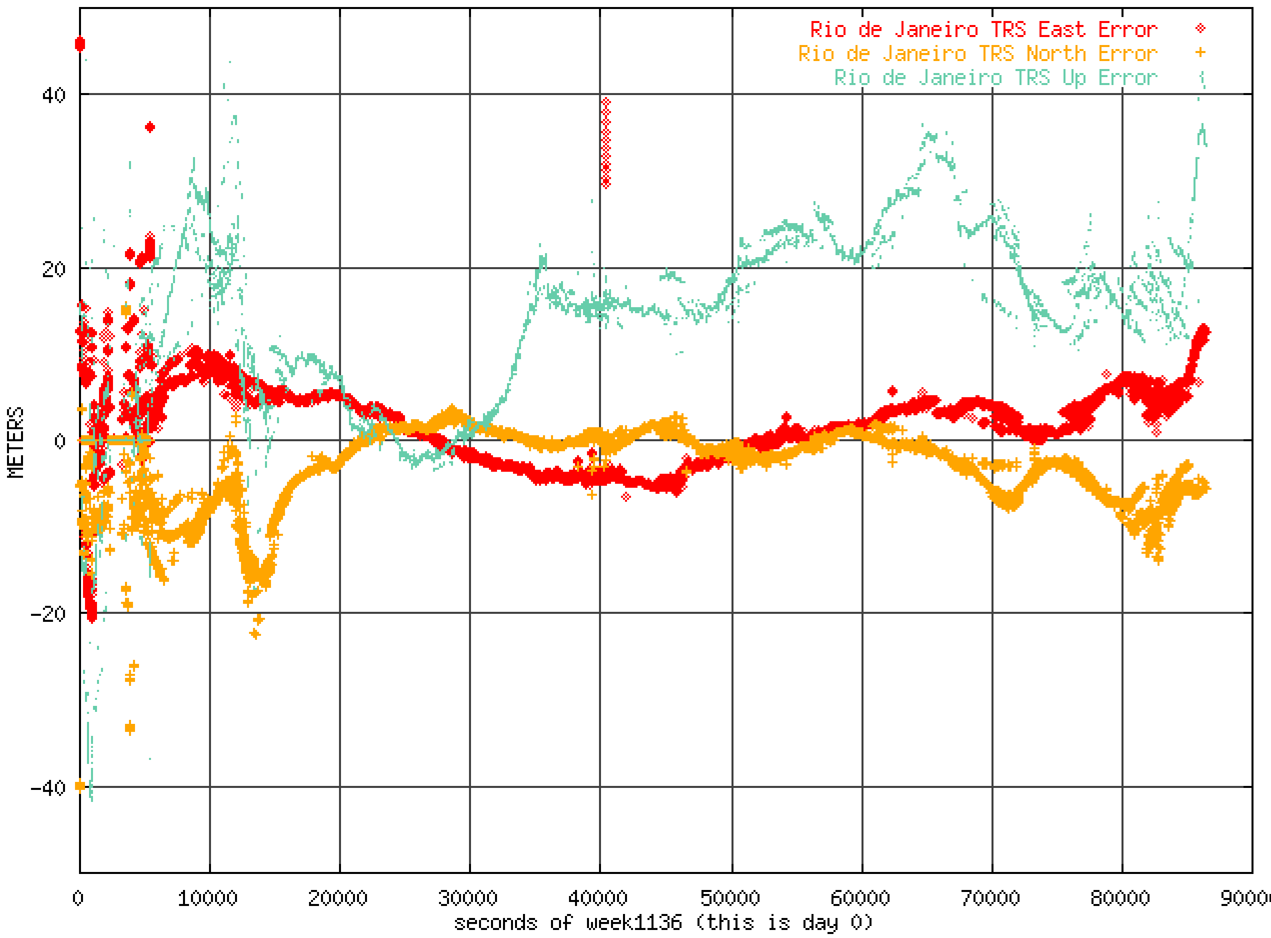


Figure 37. Horizontal and vertical error taken from GPS signal sample - Brazil

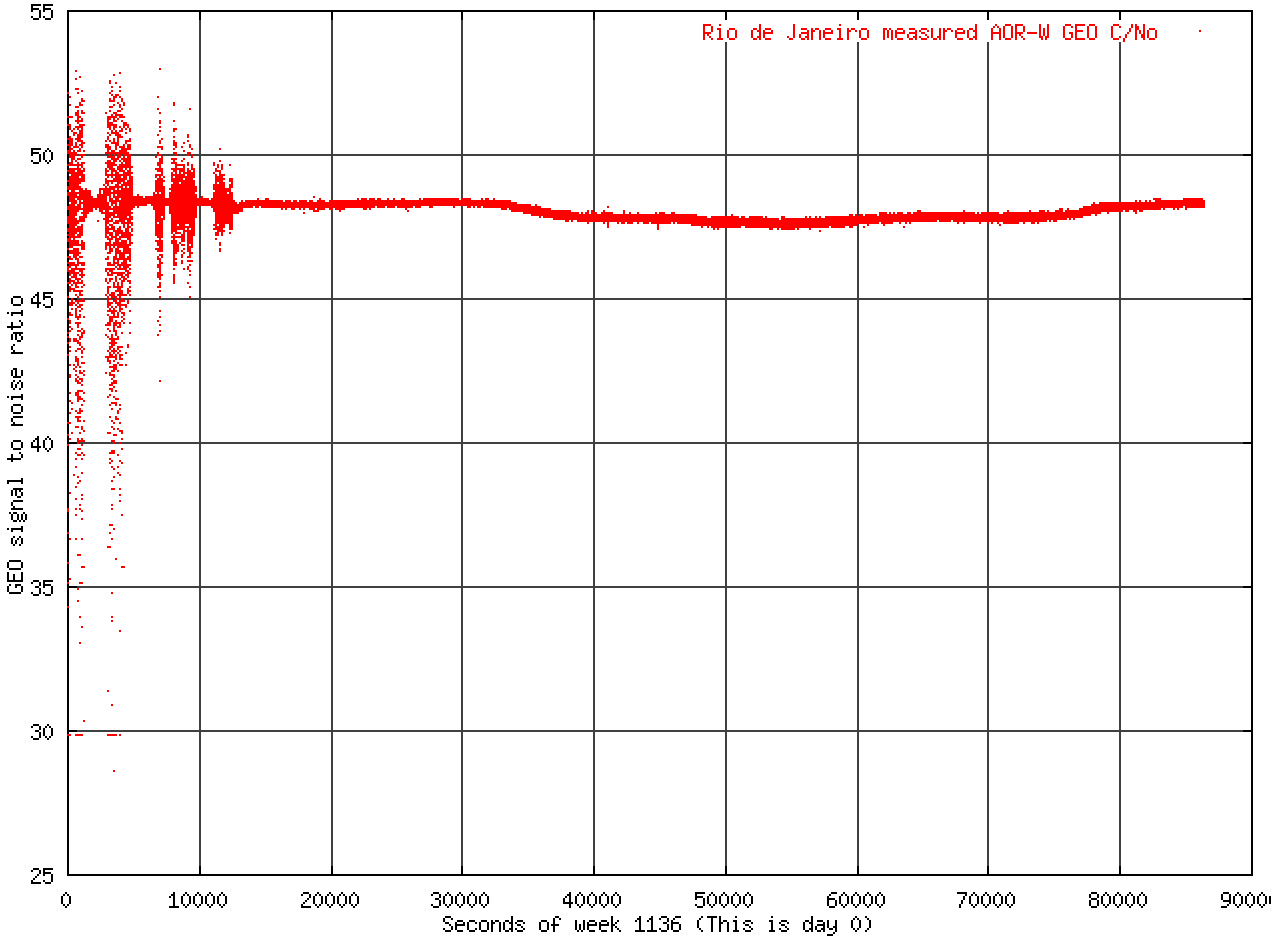


Figure 38. C/No relationship with AOR-W GEO satellite

CHAPTER 4

GNSS IMPLEMENTATION OPTIONS IN THE CAR/SAM REGION

4.1 The ICAO Regional Project for Latin America (RLA/00/009), which established a prototype Wide Area Augmentation System (WAAS) test bed capability throughout Central and South America (CSTB), has been conducting tests and trials since 2002. As a result of the tests completed and the ionosphere conditions that were uncovered as a result of initial tests, the RLA/00/009 project must recommend the most viable path forward for the Caribbean and South American (CAR/SAM) region for implementation of GNSS systems (GPS, WAAS/SBAS, and LAAS/GBAS).

4.2 Because of the severity of the ionosphere conditions in the geomagnetic equatorial region (and +/- 20° degrees around equator line) it is recommended that the CAR/SAM region only look at the possible implementation of an SBAS for Lateral Navigation (LNAV) or Non-Precision Approach (NPA).

4.3 The future precision approach services based on GNSS in the region will be provided in the future after the availability of either Category I capable Ground Based Augmentation System (GBAS) or the global availability of a second civil GPS signal at L5. At this time the ionosphere situation basically goes away. Also, the planned implementation of new satellite constellations such as Galileo and the continued modernization of the U.S. Global Positioning System (GPS) will contribute to this improvement in GNSS precision approach capability.

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Short Term GNSS Alternative implementation

4.4 Three GNSS alternatives were considered to cover NPA operations in the CAR/SAM Region for a short term:

a) Use of GPS with Receiver Autonomous Integrity Monitoring, or RAIM (ABAS)

b) Use of the U.S. WAAS system

c) The development and use of an independent CAR/SAM regional SBAS system

4.5 For each alternative, a Service Volume Module (SVM) was made showing the availability of these options to provide NPA or lateral navigation (LNAV) services to the CAR/SAM region. For the SVM, the following assumptions were made for the modelling:

Two constellation were assumed

24 GPS standard constellation

- IFOR failure probabilities for GPS
- 24 hours with samples at 5 minutes intervals

29 GPS as of June 04,2006 with PRN 25 out of service (28 working GPS satellites)

- No GPS satellite failures (other than PRN 25)
- 24 HOURS at 1 minute intervals.

WAAS GEO at 107 W and 133 w; SAAS GEO ; SAAS GEO at 54 W

NO GEO failures

UDRE =4.5M for WAAS GEOs ,15m for SAAS GEO

- SAAS lacks the wide spread WRS configuration needed for a smaller GEO UDRE.

Five degree elevation mask angle

No BARO altimeter aiding.

LNAV horizontal alert limit , HAL is 556 m

Single frequency TSO –C145 a and /or TSO – C146 a SBAS receiver

URA =6M assumed for GPS RAIM availability
GEO ranging with GEO UDRE used for RAIM availability

GPS with RAIM for LNAV/NPA

4.6 The SVM showed in **Figure 1a and Figure 1b** show the LNAV or NPA availability for GPS with RAIM for the entire CAR/SAM region. It shows NPA availability all of North America, as well as Central and South America and the Caribbean. Based on different numbers of GPS constellation size (24 GPS with stochastic failures and 28 GPS with no failures). **Figure 1c and figure 1d** show the SVM for GPS with RAIM for LNAV considering two intensity cases of scintillation effect.

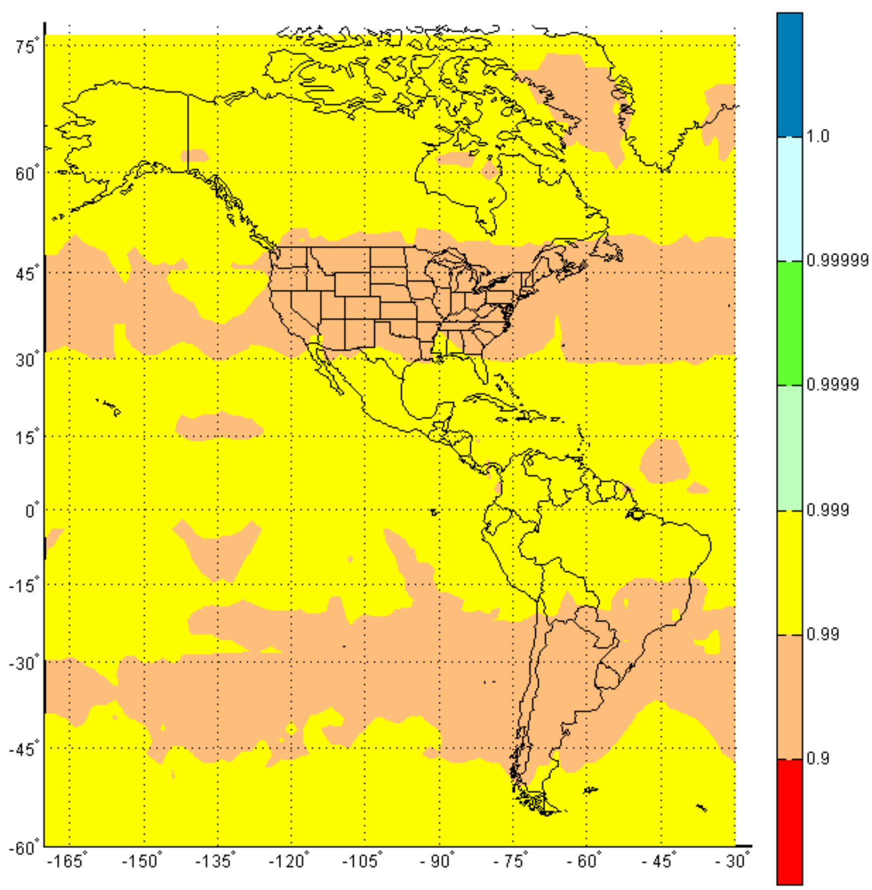

Figure 1a: LNAV availability from RAIM (24 GPS with stochastic failures SBAS receiver) Effect of scintillation not modelled.

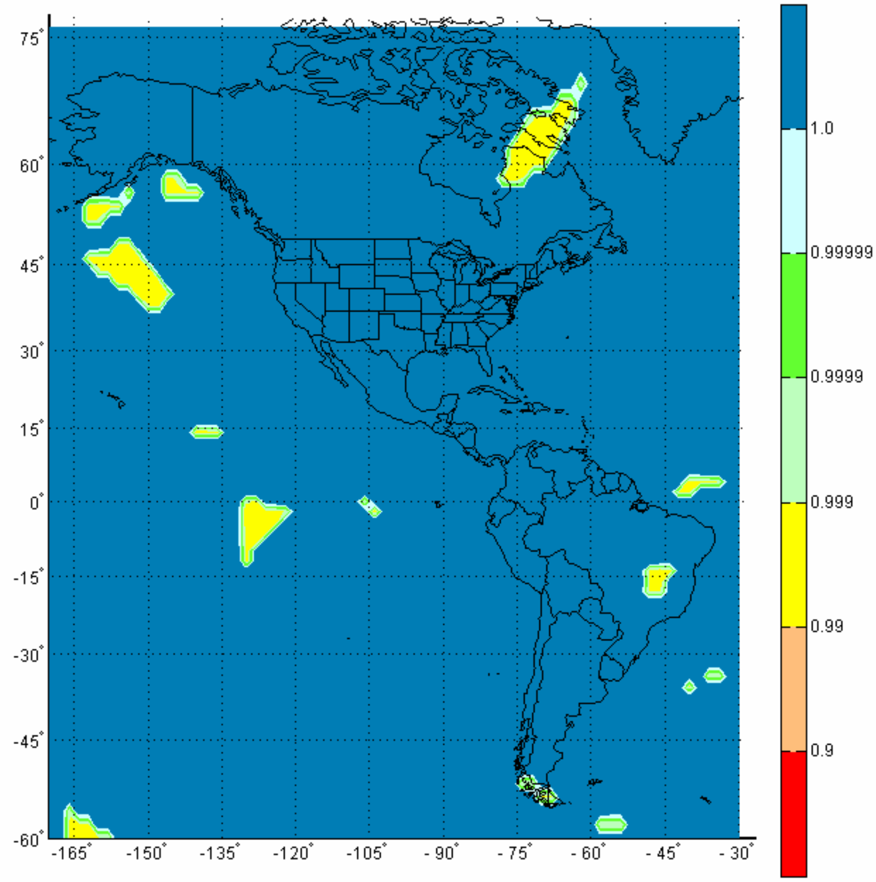

Figure 1b: LNAV availability from RAIM (28 GPS with no failure SBAS receiver) Effect of scintillation not modelled.

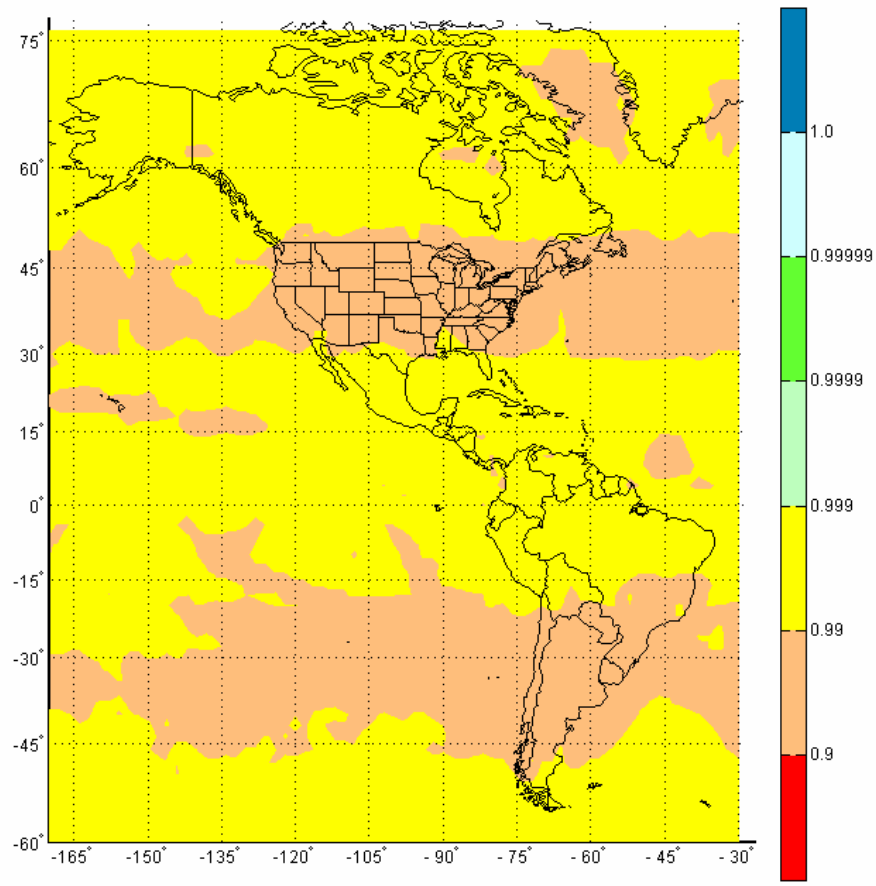

Figure 1c: LNAV availability from GPS RAIM considering 50th percentile of scintillation

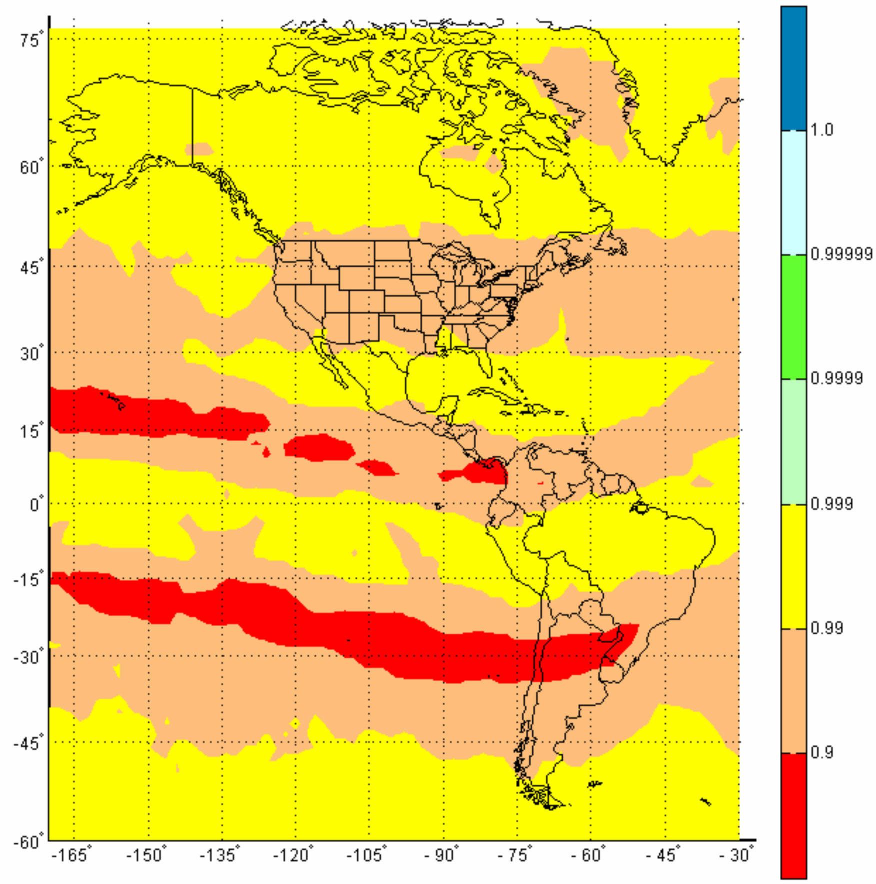

Figure 1d: LNAV availability from GPS RAIM considering 95th percentile of scintillation

U.S. WAAS Coverage in CAR/SAM for LNAV/VNAV

4.7 The SVM in **Figure 2a and 2b** shows the availability of the U.S. WAAS (including the Mexico and Canada sites and all current WAAS assumptions) for LNAV or NPA availability over the entire CAR/SAM Region. **Figure 2a and 2b** shows the availability of the US WAAS for LNAV for two cases of scintillation effect.

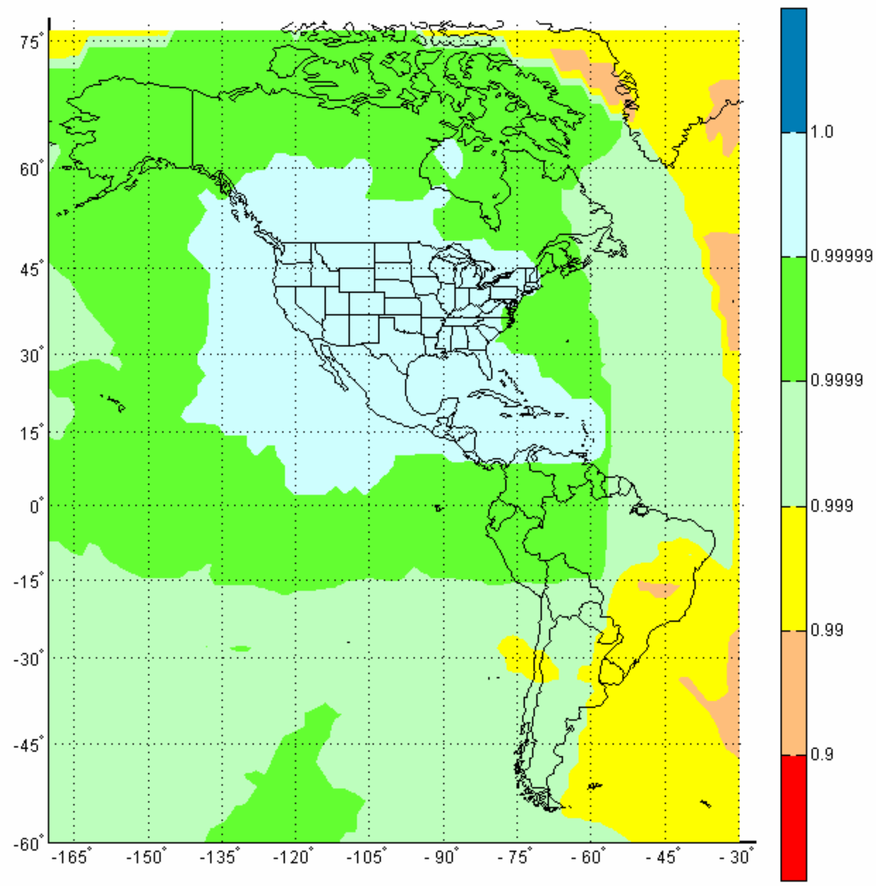

Figure 2a: LNAV availability from WAAS (24 GPS with stochastic failures) Effect of scintillation not modelled.

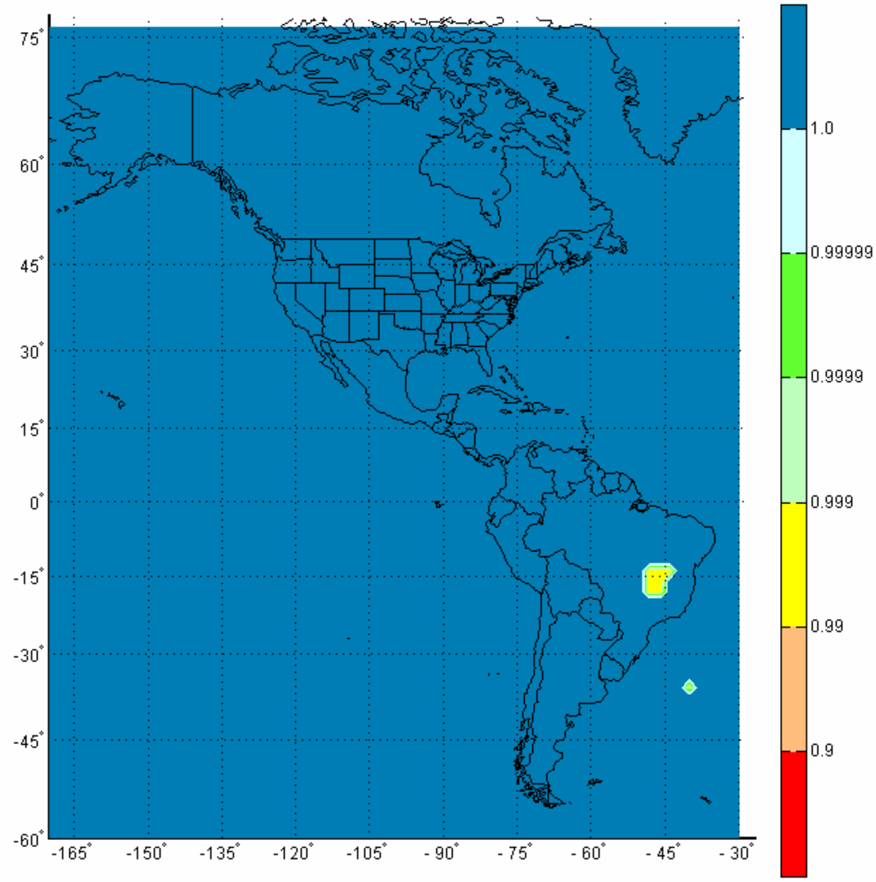

Figure 2b: LNAV availability from WAAS (28 GPS with no failure) Effect of scintillation not modelled.

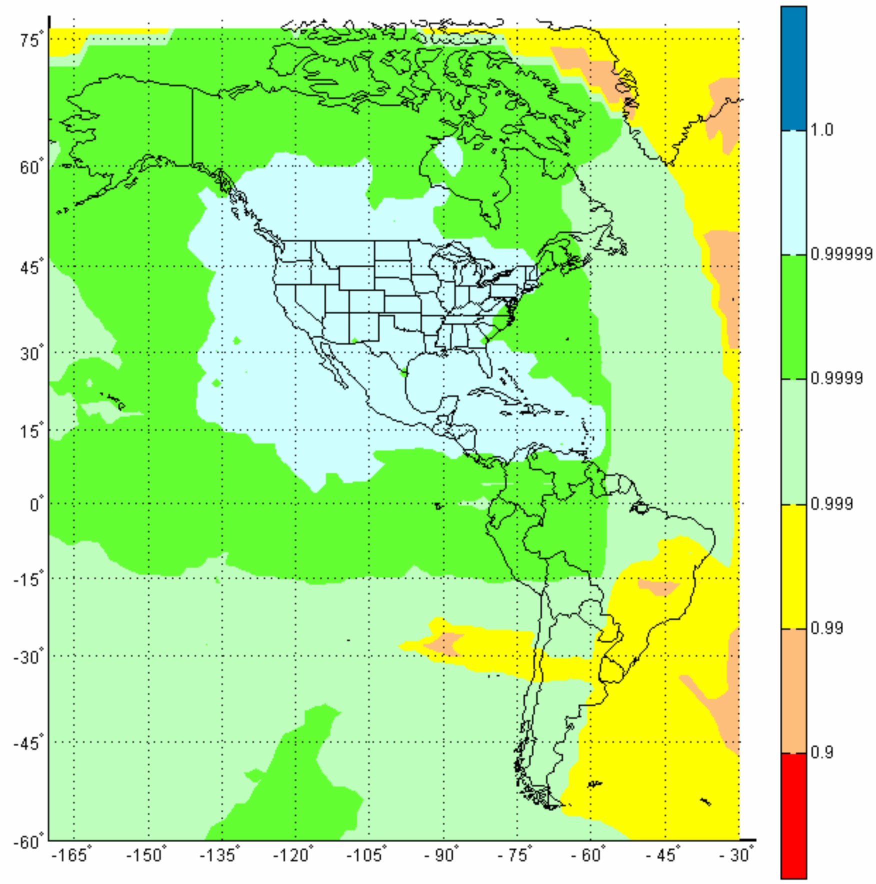

Figure 2c LNAV availability from WAAS Effect of 50th percentile of scintillation.

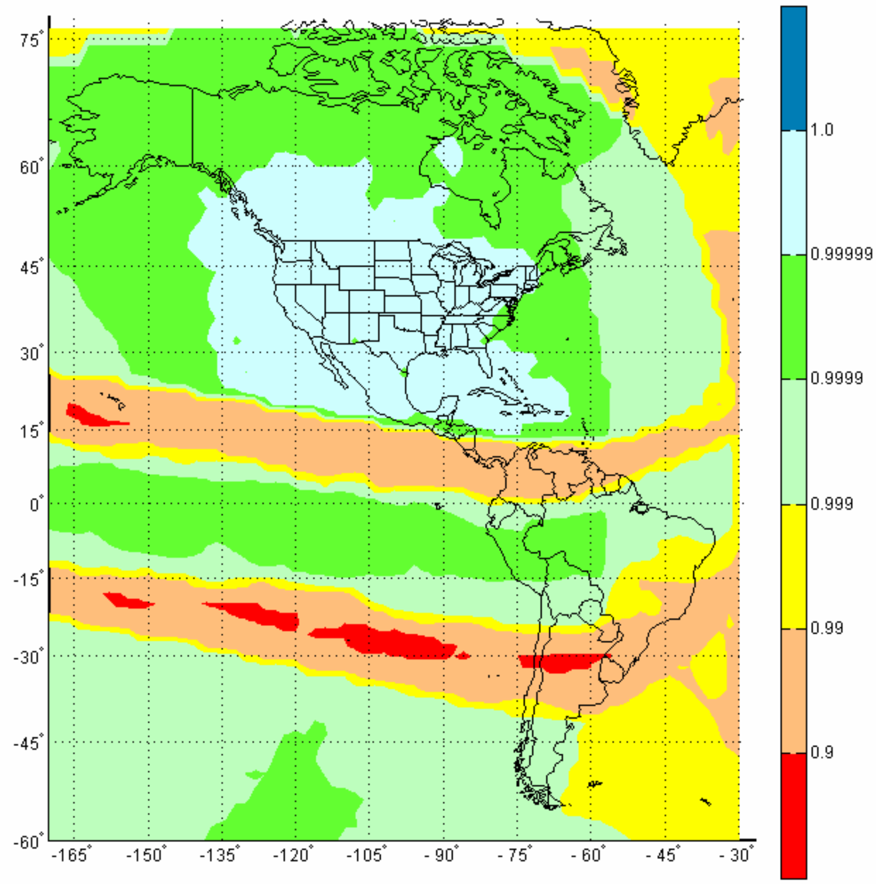

Figure 2d LNAV availability from WAAS Effect of 95th percentile of scintillation.

Independent CAR/SAM SBAS system

4.8 Two SBAS architecture configurations were considered: One based on the current WAAS Test Bed Reference and Master Station locations and the other with a reduced architecture to show the "minimal" number of reference stations needed to get high availability of LNAV or NPA service.

4.9 **Figure 3a and 3b** shows the SVM for LNAV/NPA availability for an architecture composed of 13 WRS, 2 WMS, 1 GUS (Ground Up link Station) and a GEO centrally located over S. America GEO at 54 W . The location for the reference stations and master stations are the same of the CSTB.

13 WRS:	Tegucigalpa (Honduras), Bogotá (Colombia), Lima (Peru), La Paz (Bolivia), Santiago, Balmaceda and Antofagasta (Chile), Buenos Aires (Argentina), Rio, Manaus, Recife, Curitiba and Brasilia (Brazil).
2 WMS:	Rio de Janeiro (Brazil) and Santiago (Chile)
1 GUS:	Rio de Janeiro (Brazil)
1 GEO:	Centrally located over S. America

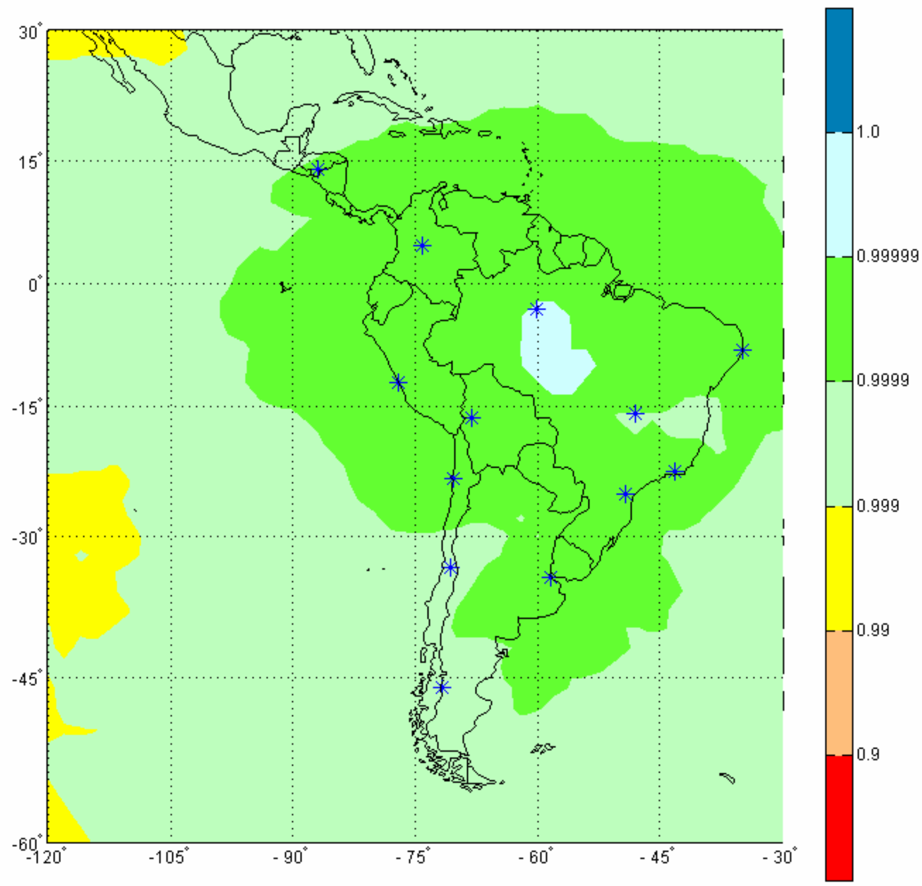

Figure 3a: LNAV availability from SAAS alone (13 WRS) (24 GPS with stochastic failures) Effect of scintillation not modelled. 13 WRS shown with blue *.

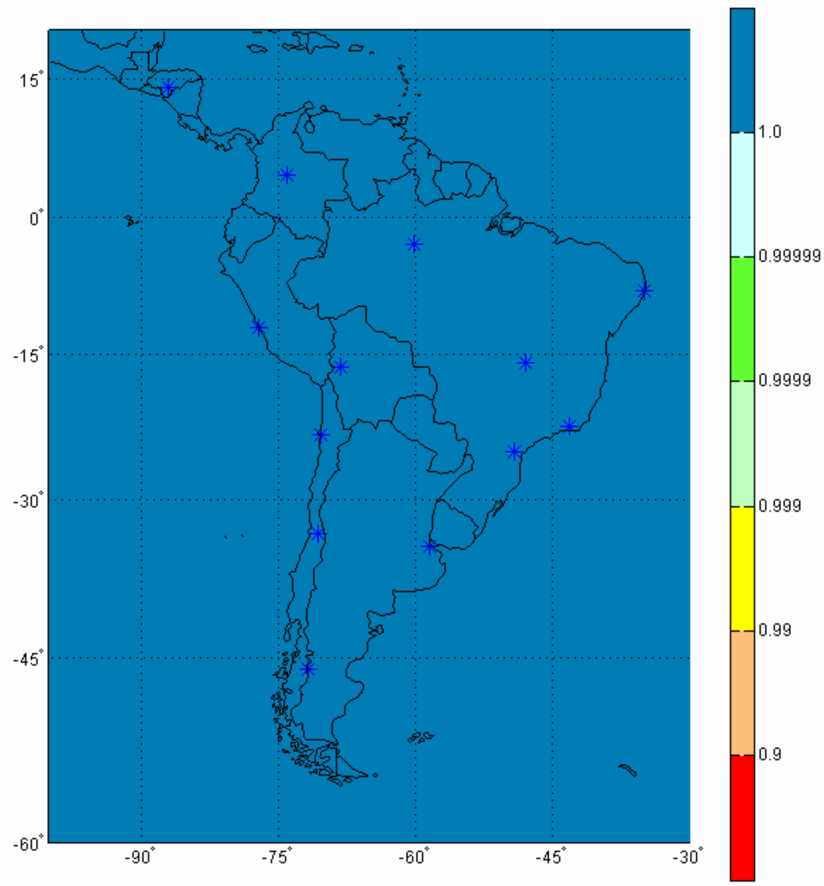

Figure 3b:LNAV availability from SAAS alone (13 WRS) (28 GPS with no failures) Effects of scintillation not modelled. The 13 WRS are indicated in blue *.

4.10 **Figure 4a and 4b** shows the SVM for NPA/LNAV with 6 WRS This SBAS architecture provides LNAV/NPA (no vertical or iono corrections, but will provide clock, ephemeris and accuracy corrections).

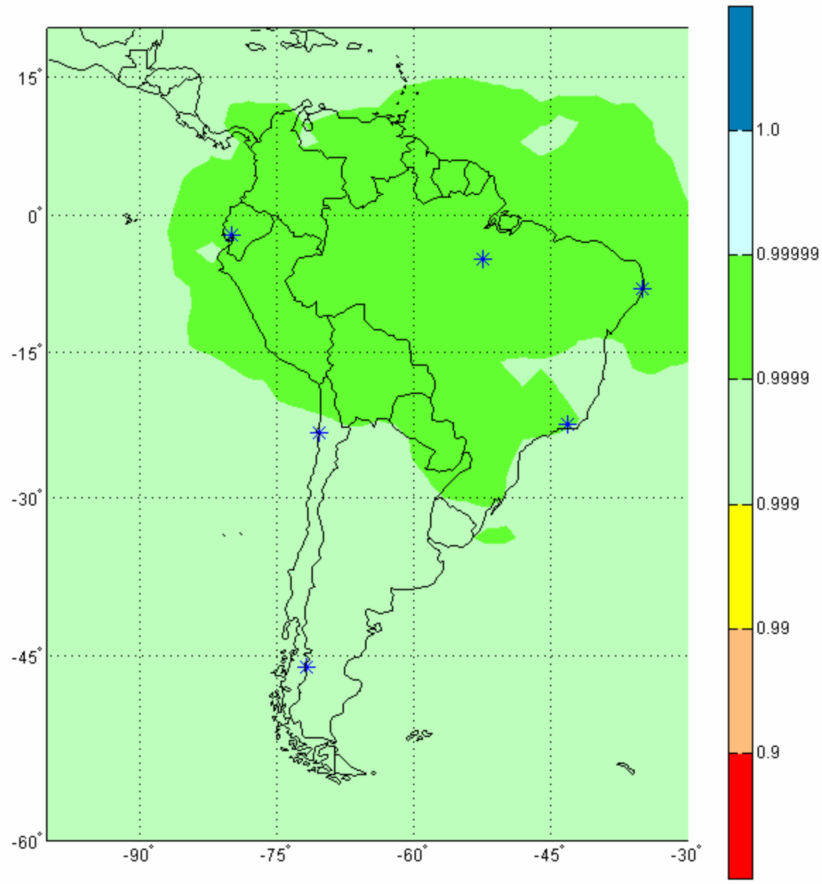

Figure 4a: LNAV availability from SAAS alone (6 WRS). (24 GPS with stochastic failures**)** Effects of scintillation not modelled. The six WRS are indicate in blue *.

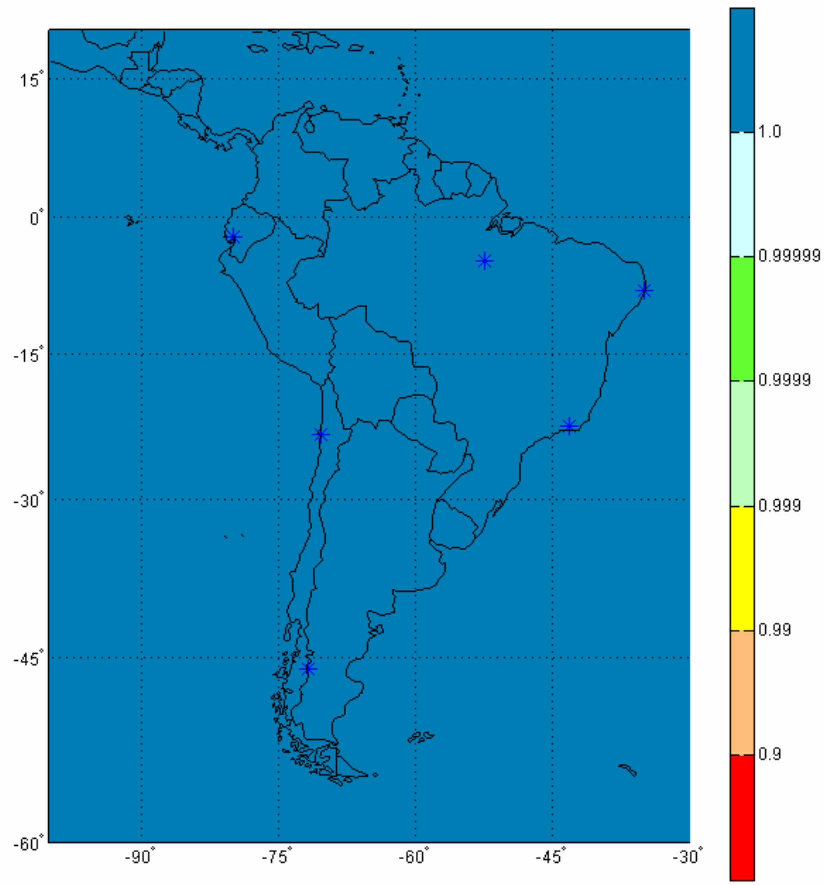

Figure 4b: LNAV availability from SAAS alone (6 WRS) (28 GPS with no failures) Effects of scintillation not modelled. The 6 WRS are indicated in blue *.

4.11 The configuration for this alternative will be:

6 WRS	Quito, Lima, Balmaceda , Manaus , Recife y Curitiba.
1 WMS	Rio de Janeiro (Brazil)
1 GUS	Rio de Janeiro (Brazil)
1 GEO	Centrally located over S. America

4.12 **Figure 5a and 5b** shows the SVM for NPA/LNAV with 8 WRS This SBAS architecture provides LNAV/NPA (no vertical or iono corrections, but will provide clock, ephemeris and accuracy corrections).

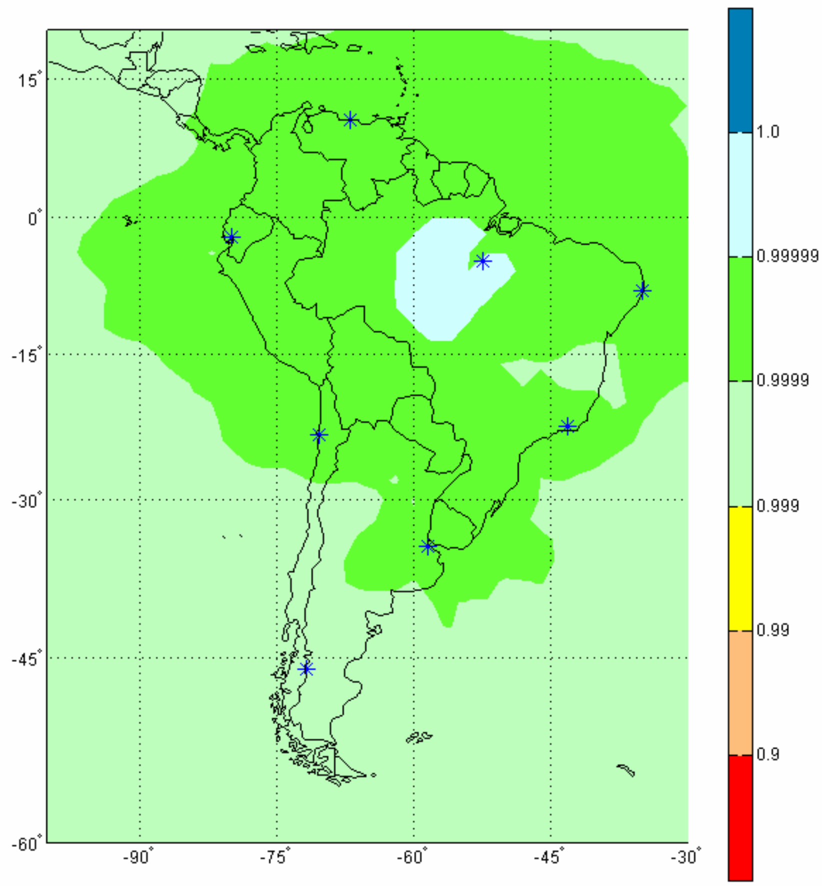

Figure 5a: LNAV availability from SAAS alone (8 WRS). (24 GPS with stochastic failures**)** Effects of scintillation not modelled. The eight WRS are indicate in blue *.

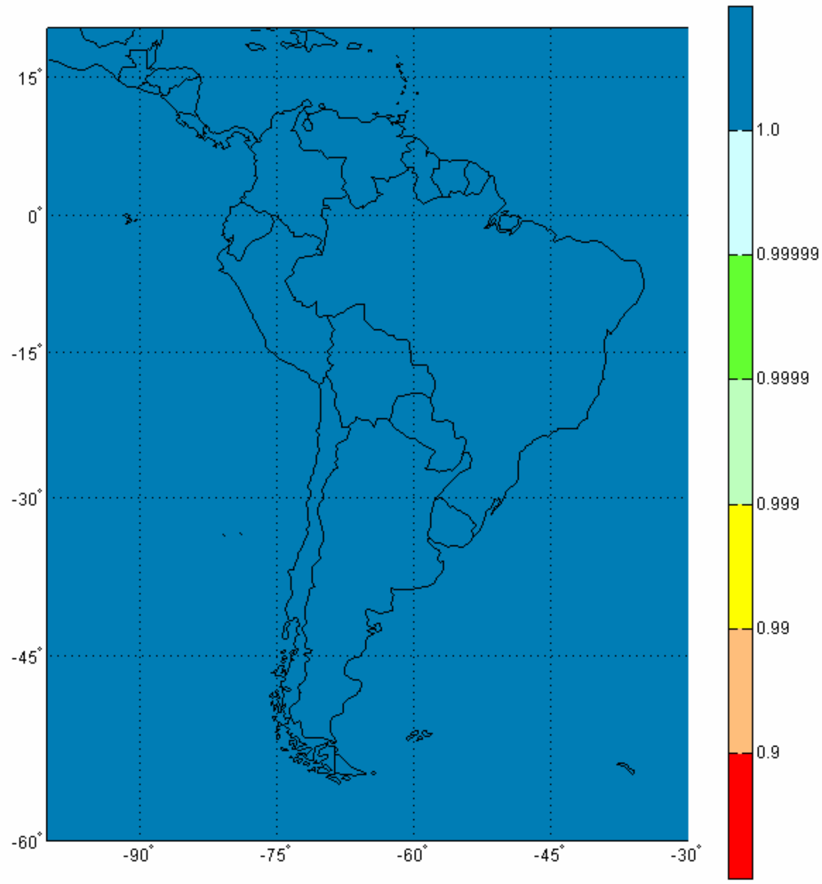

Figure 5b: LNAV availability from SAAS alone (8WRS) (28 GPS with no failures) Effects of scintillation not modelled. The 8 WRS are indicated in blue *.

4.13 The configuration for this alternative will be:

8 WRS	Caracas, Quito, Lima, Balmaceda, Manaus, Recife, Curitiba y Buenos Aires.
1 WMS	Rio de Janeiro (Brazil)
1 GUS	Rio de Janeiro (Brazil)
1 GEO	Centrally located over S. America

Scintillation effect

4.14 Scintillation is expected to reduce service availability in the Equatorial region. **Figure 6a and 6b** show the effect of scintillation in the model for two different scintillation intensities. The following assumptions were made:

- Date: September 15 (DAY =258)
  In the equatorial Region, the worst scintillation occurs during Equinox months.

- Sunspot number (SSN) =150 corresponds to peak of solar cycle.

- Kp geomagnetic index =1
  Quiet ionosphere; no geomagnetic storm.

- WBMOD is used to generate scintillation parameters for each line of sight
  Version Number: 13.04, Version Date: 24 January 1996.
  A newer version was requested from the AF in June 2006

  The 50th & 95th percentile values of S4 (a measure of amplitude scintillation) and σφ (a measure of phase scintillation) are generated. A receiver model determines whether the generated S4 and σφ values cause a loss of lock on the satellite signal

  The satellite is not used in the position solution when a loss of lock occurs.
- The output of WBMOD is more conservative then the actual data.

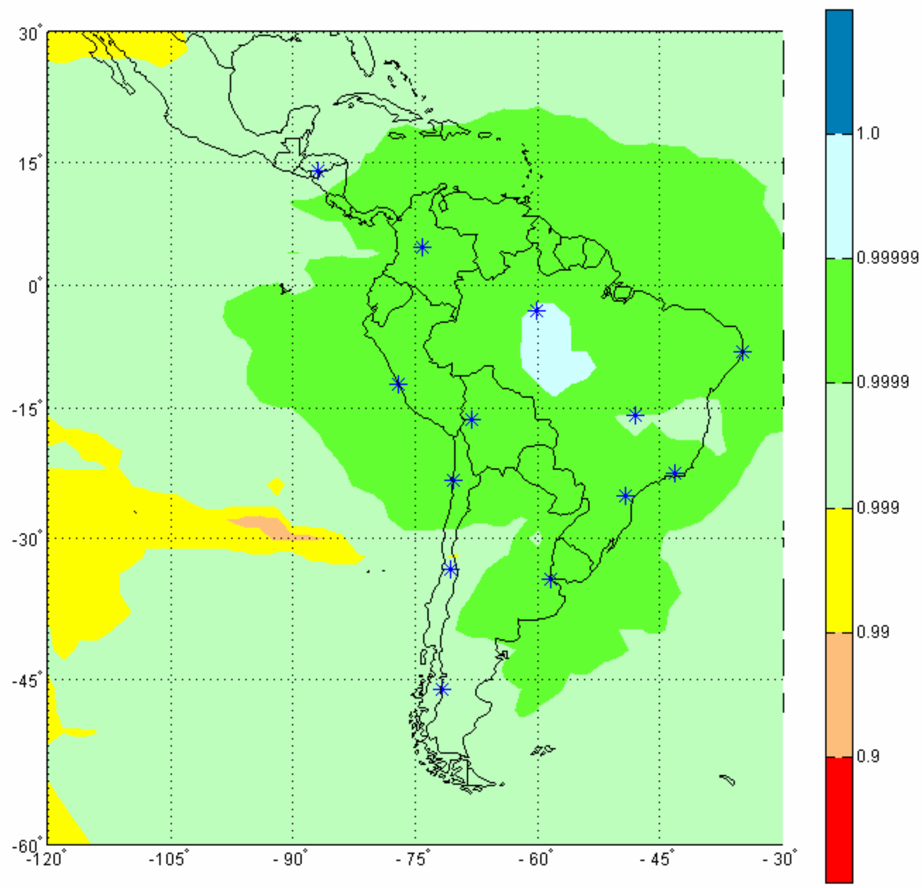

Figure 6a: LNAV Availability from SAAS alone with Average Scintillation (24 GPS with stochastic failures) 50th percentile scintillation . SAAS with 13 WRSs.

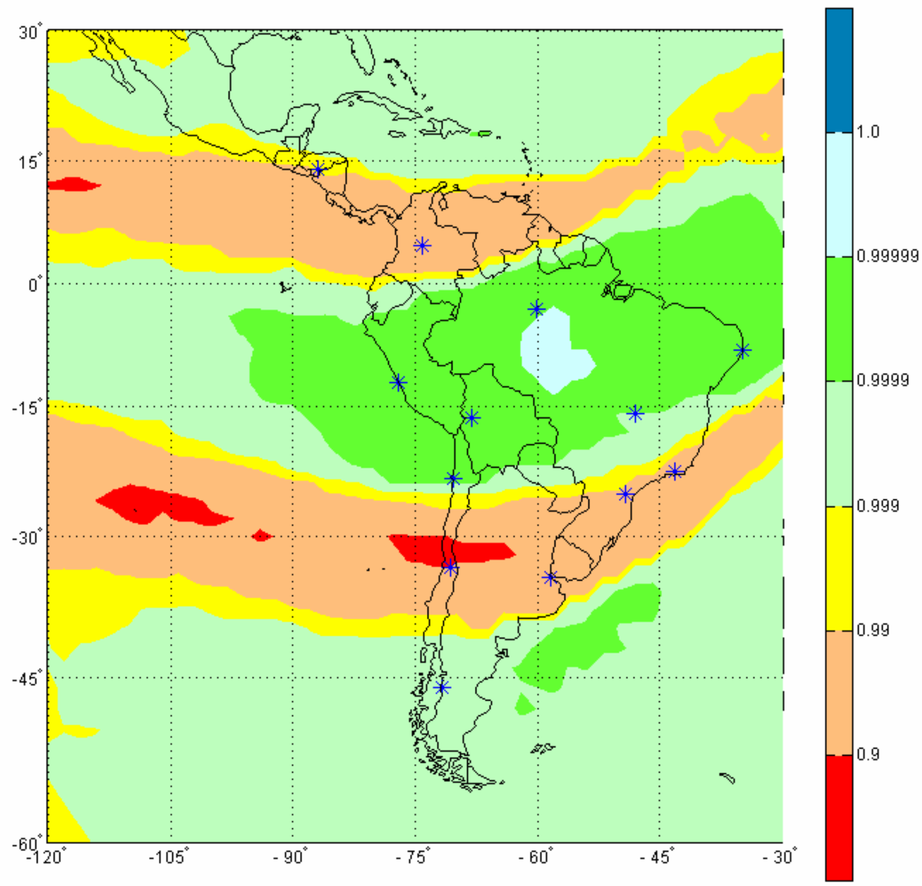

Figure 6b: LNAV Availability from SAAS alone with Average Scintillation (24 GPS with stochastic failures) 95th percentile scintillation . SAAS with 13 WRSs.

Estimated Cost for CAR/SAM SBAS system

4.15 The estimated cost (US dollars) for each of the elements, based the existing CSTB architecture and the costs of equipment within the WAAS program, are as follows:

1 WRS (triple redundant equipment)	$343,000	x 13	$4,459,000
1 WMS	$247,000	x1	$247,000
1 Ground Earth Station (GES)	$2,245,000	x1	$2,245,000
1 GEO (annual commercial lease)	$6,000,000	annual	$6,000,000

Preliminary measures for GNSS implementation

4.16 Although the GNSS still needs improvement, significant benefits can be obtained immediately from its use, especially for en-route, oceanic and non-precision approach (NPA) applications. The high level of investment, potential obsolescence, and the uncertainty with respect to back-up requirements make it difficult to assess the financial risk; thus the need to be cautious. The rationalisation of avionics and ground navigation infrastructure, which is where the aircraft operators of the States could expect significant savings, is a concern, since back-up requirements will affect the rationalisation process on the ground, and will almost eliminate it for the airborne avionics supplement.

4.17 Considering the need to minimise risk and optimise benefits, the following implementation steps are suggested. These steps could be started immediately. Activities include those related to the development of GPS non-precision and precision approaches. The following paragraphs and charts show the milestones and timetables related to these steps.

Introduction of GNSS-based non-precision approach

4.18 The main tasks associated to the gradual implementation of NPA are:

a) obstacle survey;
b) conversion of all coordinates to the WGS-84 system;
c) creation of data bases; and
d) establishment of regulations and procedures (NOTAM), etc.

4.19 Taking into account the complexity involved in the drafting of procedures, ICAO should organise a workshop to make the rules and procedures that govern the development of procedures known, and to inform about the tools that are available to assist in said process.

4.20 Through investigations to extend WAAS capability to South America, the FAA has learned that the two-dimensional model frequently fails to adequately model the true ionospheric behavior in the region over Brazil. The features that limit WAAS capability in this region are best described as holes or depletions in an otherwise dense ionosphere. In the Brazilian region, depletions occur in the evening hours and are most apparent between the months of October and April, with peak activity occurring in January. Between the months of May and September, depletion activity is much less frequent. Other near-equatorial regions are similarly affected by depletion activity. However, there are known longitudinal differences in the frequency and seasonal dependence of these features. Depletions are a severe threat to integrity. Simple changes to the information broadcast to the user to help better capture these disturbances (smaller focus area, more rapid update frequency, etc.) will not solve these issues. As a result, more significant changes have been proposed; however, none have yet been proven to be both practical and effective.

Actions to Meet the Challenges

4.21 In the SBAS Systems implementation, the following actions should be taken:

a) Develop Algorithm Changes and Field Additional International Reference Stations. This will lessen the impact of unobserved ionospheric threats to WAAS.

b) Develop a Catalog of Threatening Features. Like other SBAS threats, we desire to develop a universal threat model. Unfortunately, the exact magnitude of the threat depends on the specific implementation. Instead, we will identify a catalog of threatening features:

- For **mid-latitudes**, we can identify every major ionospheric storm for the last solar maximum period and highlight observations of North American threats.
- For **equatorial regions** we will identify periods of time when threats are likely to be greatest, and provide examples of very significant ones, but these threats cannot be confined to a list of just a few days or events.
- In **all cases**, the available data will also be provided. All service providers should be aware of features that may be present in their service area and be confident that they treat them adequately.

To do this, data from other regions from the last solar maximum must be collected and analyzed to assess impact in all parts of the globe.

c) Use L1 and L5 Airborne Frequencies as the Long-Term Solution to Both Severe Storms and the Unobserved Ionospheric Threats

d) Continue to Study Scintillation in Greater Detail. Scintillation is the dominant limitation to the use of two frequencies for vertical guidance. If it proves to be a significant impediment to operations, several forms of mitigation may be investigated, such as:

- Receiver tracking loop modifications, possibly including integration with inexpensive inertials
- Integration of a baro-altimeter for VNAV
- Additional ranging sources such as Galileo

Expected Performance[1]

a) For all regions, combined L1/L5 users are expected to achieve Category I service greater than 99% of the time.
b) For all regions, single frequency users are expected to achieve NPA service greater than 99.999% of the time.
c) For polar-cap, auroral and mid-latitude regions, single frequency users are expected to achieve LPV service greater than 99% of the time.

[1] *The ability to reduce the effects of the ionosphere has a direct impact on type of navigation service that can be reliably achieved. Additionaly, the use of multiple frequencies can help reduce the effects of the ionosphere to achieve higher levels of service.*

Long Range Vision

4.22 The current 11-year solar cycle is approximately 4 years past its peak. Absolute TEC values and the occurrence and severity of scintillation and depletions are expected to be much lower for the next several years. When a full constellation of satellites with L5 becomes available (2015-2020), the TEC related problems will be solved. In addition, availability of an L2 civil signal will provide increased robustness for monitoring the ionosphere by the ground stations.

4.23 This roadmap will be coupled with the FAA's efforts to standardize future GPS and SBAS signals. It is expected that this ionospheric research will take place over the next 3-5 years and the outputs from this work will be critical in defining those necessary changes to current SBAS standards in order to support use of SBAS anywhere on the globe.

4.24 And that this same architecture, with the future availability of a 2^{nd} civil frequency (either L5 or Galileo or a combination), would theoretically be able to provide a level of vertical guidance potentially down to LPV since the iono corrections could be done in real-time in the cockpit. The envisioned CAR/SAM LNAV-only SBAS would be built as an investment banking on a future capability upgrade to APV/LPV when L5 or Galileo becomes a reality.

4.25 In looking at the several SVM charts for the various CSTB configurations of 13, 8, and 6 reference stations, one can summarize the following general points:

- Building an independent SBAS for the CAR/SAM region will be an expensive endeavor. This is based not so much on the cost of the WRS and WMS, but the required satellite uplink stations and the annual lease costs for commercial satellites.
- Utilizing the existing U.S. WAAS service for LNAV in the region would drastically reduce implementation costs. Some sort of monitoring capability

would need to be established to generate NOTAMs, but the use of basic GPS with RAIM and/or U.S. WAAS provides very good LNAV availability to most of the CAR/SAM region.

- If an independent SBAS is the desired choice of the region, several options were analysed in order to determine the least expensive implementation option for the region.
- A 13 WRS configuration does not provide much better regional LNAV availability than a 6 WRS or 8 WRS configuration.
- There are only slight differences between the 6 WRS and 8 WRS configurations, and probably not enough regionally to justify the extra expense.
- Based on the models performed, a configuration of 6 WRSs would provide good availability of LNAV service throughout the region, and be the most economical choice.
- Further SVM models could be completed to determine if a lesser number of WRSs could also achieve similar availability.
- Given the general costs of the satellite segment of an SBAS system, and the general uncertainty of the ionosphere situation at the geomagnetic equator, the CAR/SAM region needs to make a decision on whether to
    - Implement a simple SBAS for LNAV service that will be able to provide precision approach services once a 2nd civil frequency is available, or
    - Utilize existing technologies (basic GPS with RAIM, basic GPS with baro VNAV, and/or the U.S. WAAS) to provide LNAV and limited precision approach capability. Precision approach capability can then be accomplished with a CAT-I GBAS system or the 2nd civil GPS frequency.