Augmentation Systems to Improve Navigation Procedures in Low Latitude Region

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AGENDA

I. PBN CONCEPTS AND BENEFITS

II. ICAO CONCEPT FOR GNSS AND AUGMENTATIONS SYSTEMS

III. IONOSPHERE EFFECTS OVER GNSS IN LOW LATITUDE

IV. EMPIRICAL TEC MODEL

V. BUSINESS CASE (PERUVIAN EXPERIENCE)

VI. REMARKS

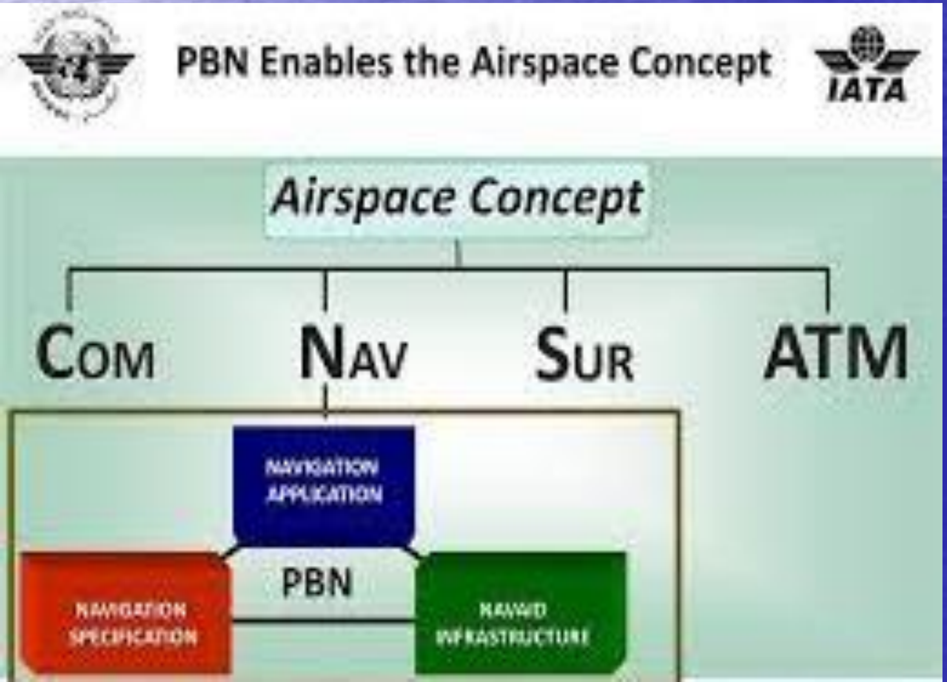
PBN CONCEPTS

PBN enables the airspace concept, describing the intended operations within an airspace, improved safety, increased air traffic capacity, improved efficiency, mitigation of environmental impact and as a result more efficient use of air space. The performance requirements are defined in term of accuracy, integrity, continuity, availability and also functionality.

The PBN is a shift from sensor-based navigation to performance-based navigation; there are two kinds of Navigation Specifications:

i) RNAV (Required Area Navigation)

ii) RNP (Required Navigation Performance)



A NAVIGATION APPLICATION is the application of a NAVIGATION SPECIFICATION and associated NAVAID INFRASTRUCTURE to ATS routes, instrument approach procedures and/or defined airspace volume in accordance with the Airspace Concept.

- Example in Terminal area
- **Navigation Specification : RNAV1 (1 Nm of accuracy)**
- **Navaid infrastructure: GNSS or DME/DME**

PBN: PERFORMANCE BASED NAVIGATION - RNAV/RNP

EN-ROUTE

RNP2 / RNAV 2&5

APROACH

APROACH

RNP 1 / RNAV1

RNP APCH / RNAV1

(DEPARTURE)

(LANDING)

SURFACE

SURFACE

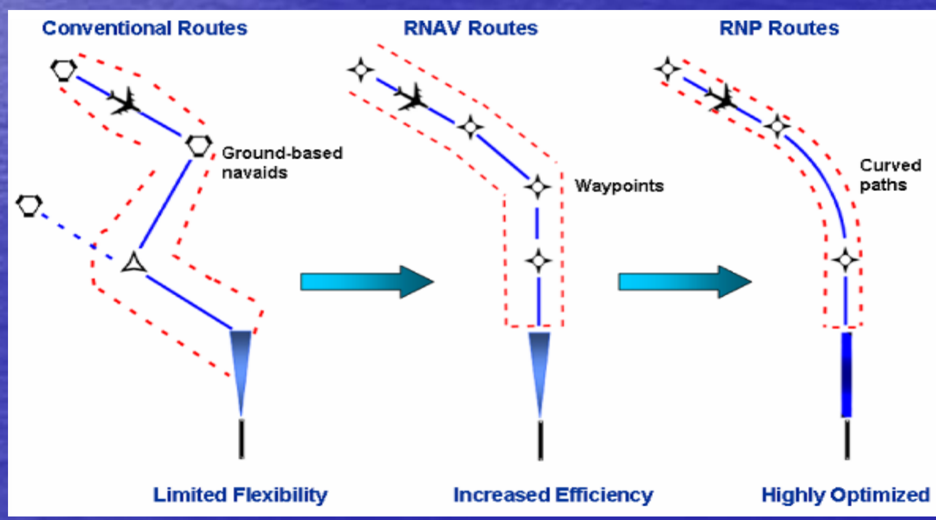
RNP 0.3

LIMA

CUSCO

PBN permits flying direct routings

ALL PBN Navigation specifications are based on GNSS either as the primary navigation infrastructure or as one element of the infrastructure



RNAV (Req. Area Navigation): It is based on area navigation that does not include the requirement for monitoring and alerting board performance, designated by the prefix RNAV, eg RNAV 5, RNAV 1

RNP (Req. Navigation Performance): It is based on area navigation that includes the requirement for monitoring and alerting board performance, designated by the prefix RNP, eg RNP 4, RNP APCH.

PBN BENEFITS

Benefits in terms of ATC (ICAO)

- **Safety culture**
- **Fewer radio transmissions**
- **Less chance of readback/hearback errors**
- **Greater predictability**
- **Airspace Containment**
- **Fewer go-arounds**
- **Less transit occupancy time in airspace**
- **Changing Roles and Responsibilities**
- **Best practices in route/space design**

-Segregated trajectories

-One-way routes

-arrivals on time

ALSO:

-improves accessibility in difficult geography

-reduces infrastructure costs

-low noise pollution

-reduces CO_2-fuel emissions, before the pandemic, better efficiency was estimated with savings of 1%, which would represent 1.2 million tons of CO_2 less emissions into the atmosphere

ICAO CONCEPT FOR GNSS

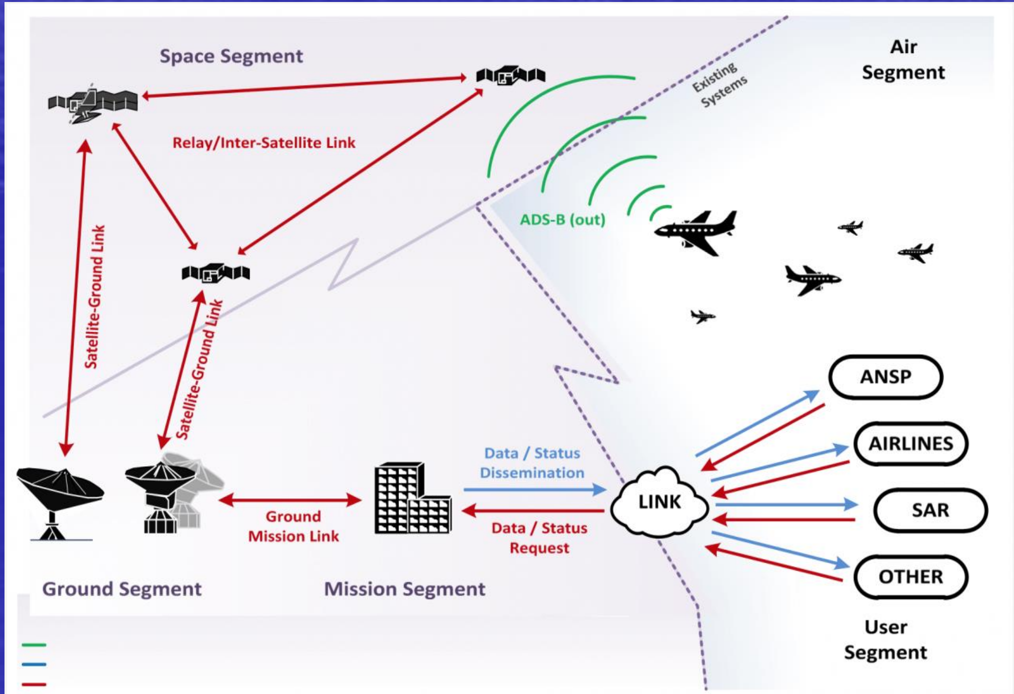
A worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation. (Ref. ICAO Annex 10, Vol. I).

There are four essential criteria: i) Accuracy, ii) Integrity, iii) Continuity, and iv) Availability, in correspondence with the new PBN (RNAV/RNP) procedure which permits flying direct routings, precise navigation capability and permits efficient operations in terrain constrained or congested airspace.

GNSS Segments:

1) Space: satellite constellations (GPS, GLONASS, GALILEO, BEIDOU)
2) Control: monitor, control and syncronization of satellites
3) Users: receivers, aircraft

There are Augmentation Systems like ABAS, SBAS (Satellite) and GBAS (Ground), to improve performance of GNSS systems



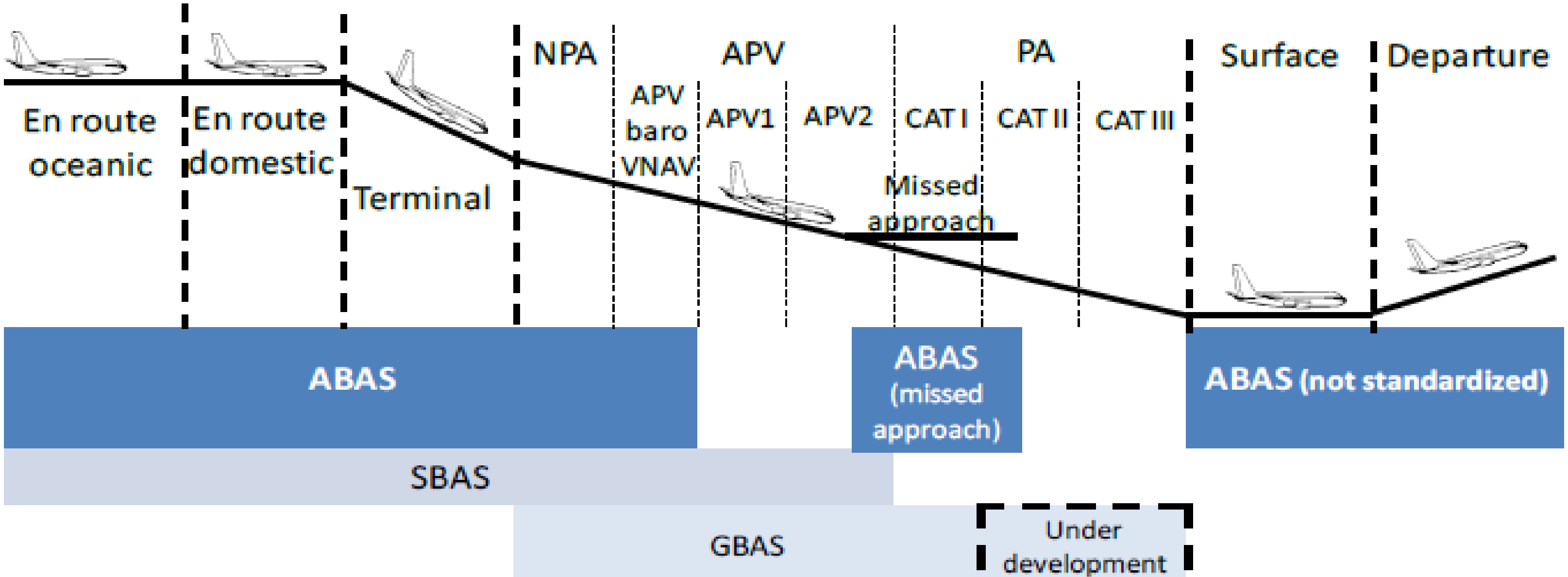
Values of Performance Requirements

Operation	Oceanic en-route	Continental en-route	Terminal	Non-precision approach	Approach procedure with vertical guidance (APV) APV-I	APV-II	Category I (CAT I)
Horizontal alert limit	7.4 km (4 NM)	3.7 km (2 NM)	1.85 km (1 NM)	556 m (0.3 NM)	40 m (130 ft)	40 m (130 ft)	40 m (130 ft)
Vertical alert limit	N/A	N/A	N/A	N/A	50 m (164 ft)	20 m (66 ft)	35 to 10 m (115 to 33 ft)
Time-to-alert	5 min	5 min	15 s	10 s	10 s	6 s	6 s

Doc. 9849 - ICAO, GNSS Manual

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

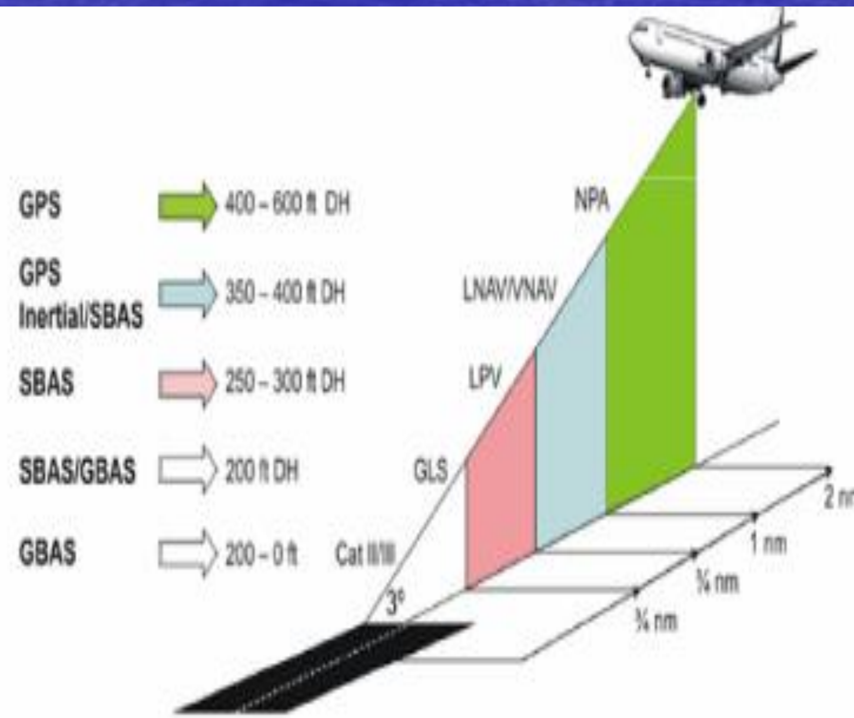
ICAO-Annex 10 – Aeronautical Communications, Volumen I,



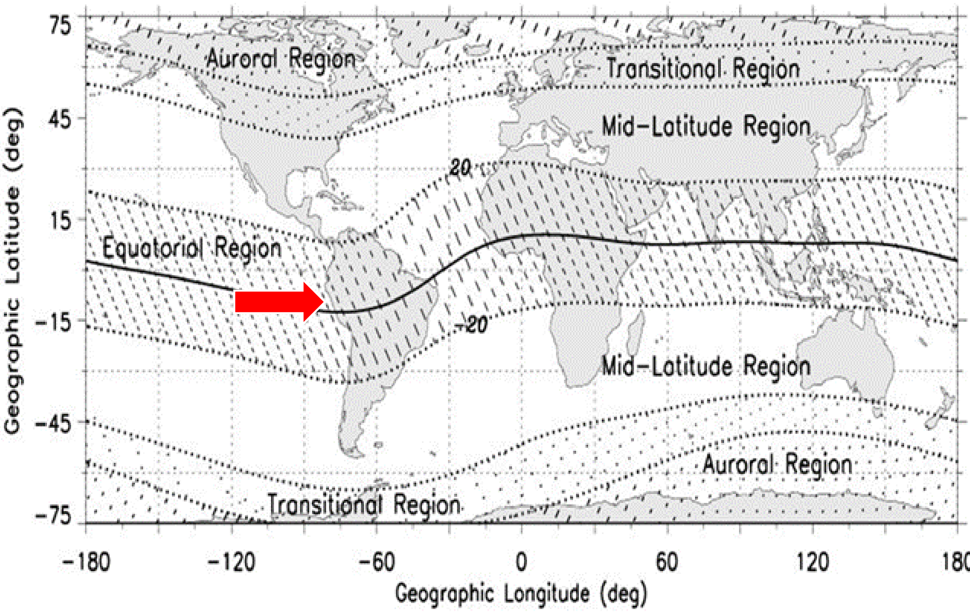
GBAS & SBAS FEATURES

-Less flight disruptions and associated costs caused by ILS interference
-Greater precision guidance for improved safety
-Improved airport capacity from accurately guided simultaneous operations reasons
Fuel savings, reduced noise and emissions from efficient, flexible flight path
Reduced traffic delays and congestions as a result of more accurate and efficient and predictable approaches
Reduced capital investment cost and lower on-going maintenance, as one GBAS covers all runways, compared to one ILS installation per one runway end -Flexibility to add or change Final Approach procedures without changing the system configuration
-Being able to dispatch to an airport based on a GNSS approach or at any required alternate
-Training cost savings by eliminating or reducing the frequency of training VOR/DME approach

Category	DH	RVR
CAT I	≥ 60 m (200 ft)	≥ 550 m
CAT II	200 ft > DH ≥ 100 ft	≥ 350 m
CAT III A	< 100 ft or no DH	≥ 200 m
CAT III B	< 15 m or no DH	200 > RVR ≥ 50 m
CAT III C	No minima	No minima

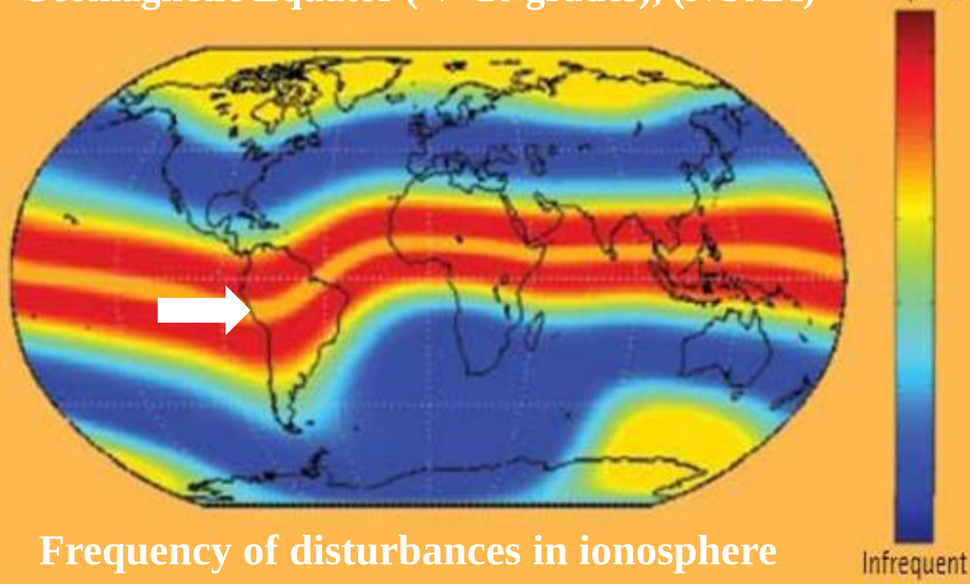


IONOSPHERE EFFECTS OVER GNSS IN LOW LATITUDE (EQUAT. REGION)



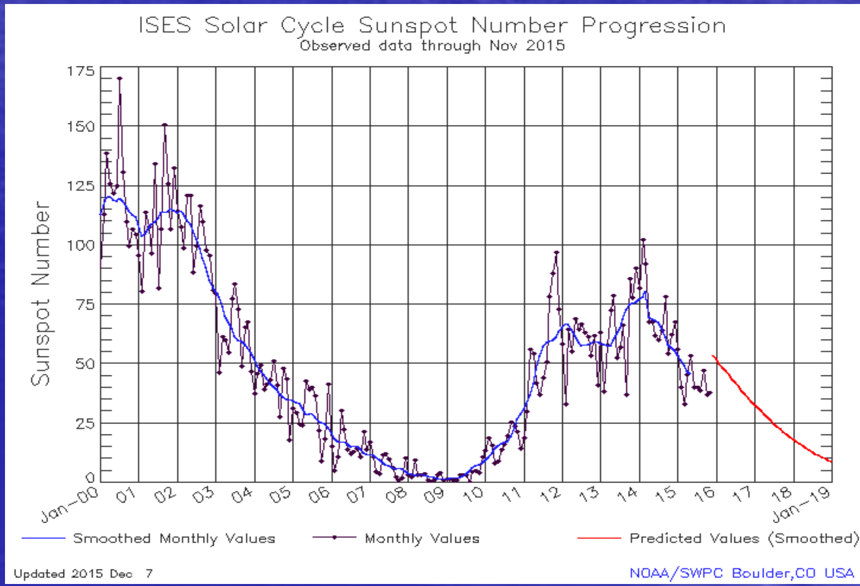
Lima-Peru is the Geomagnetic Equator in Southamerica Region (low latitude), that is why the peruvian air space has an intense ionosphere activity, as well as countries located between 20° N and 20° S (aprox) from the geomagnetic Equator, especially during periods of maximum solar activity.

Geomagnétic Equator (+/- 20 grades), (NOAA)



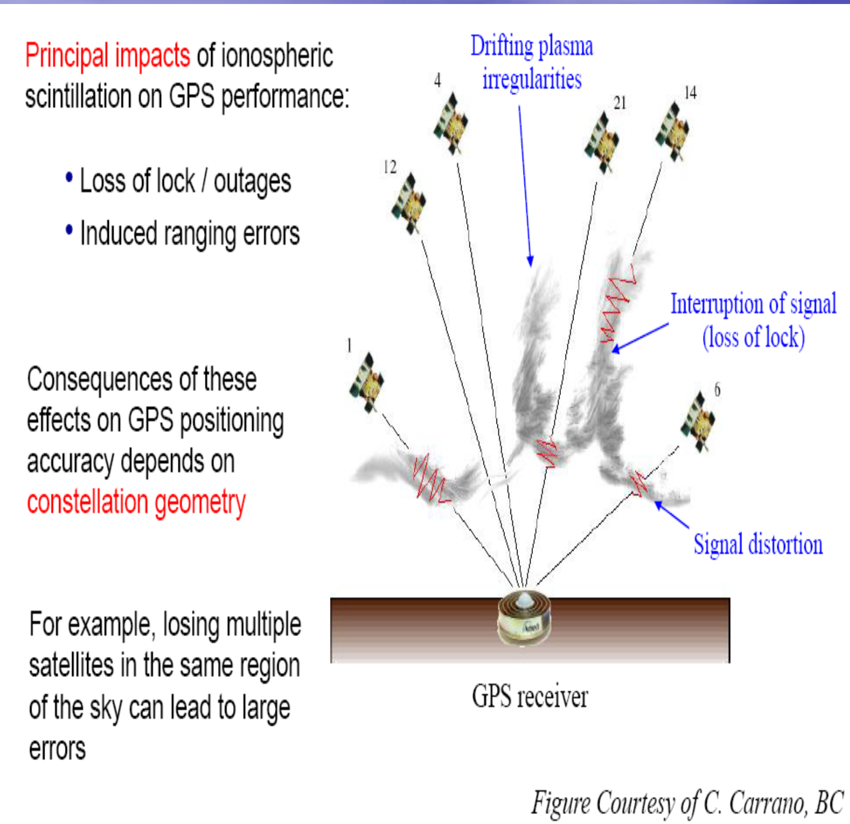
Frequency of disturbances in ionosphere

THE SOLAR CYCLE

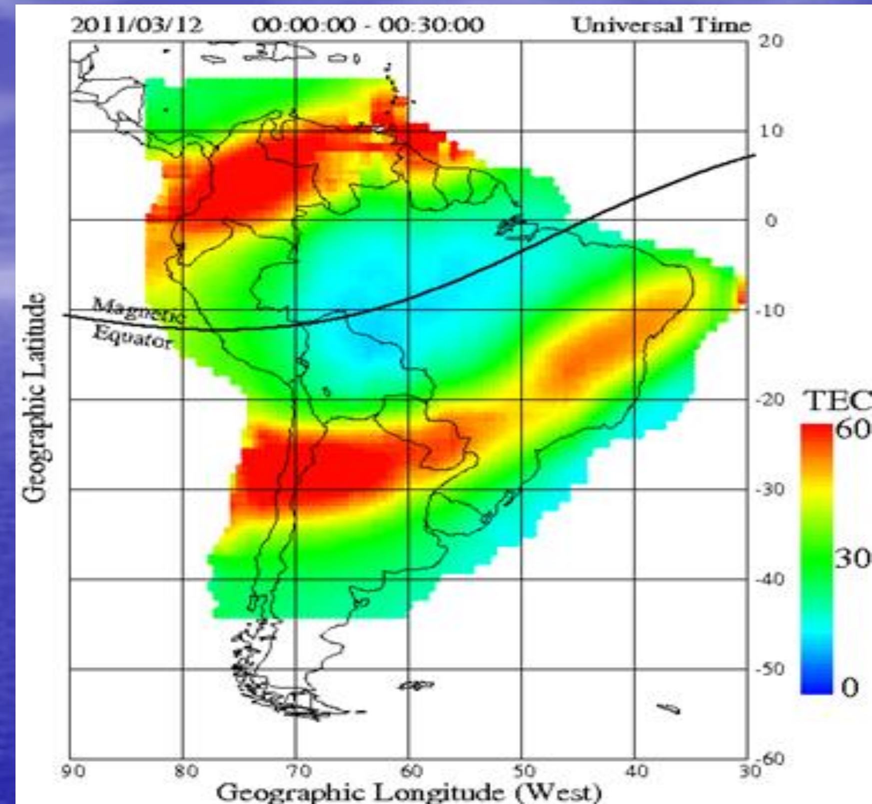


- At the end of 2013 and 2014 it was the maximum solar cycle Nr 24. Next cycle would be in 2025

SCINTILLATIONS AND TEC EFFECTS OVER GNSS



Scintillations generate fading over GNSS signals

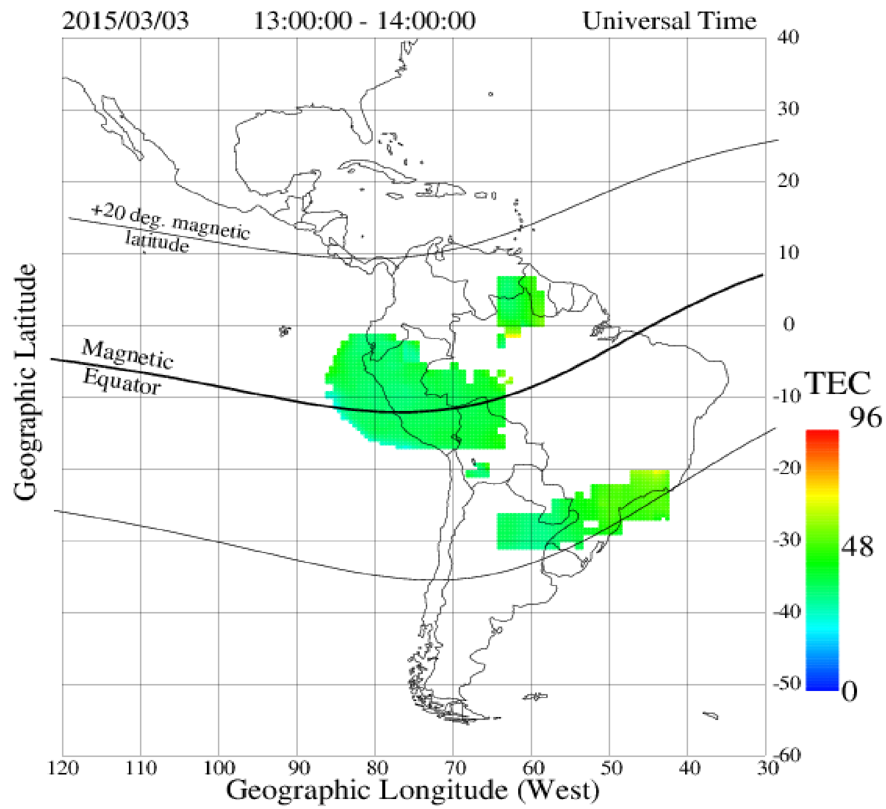


TEC generates delays, measurements made by LISN

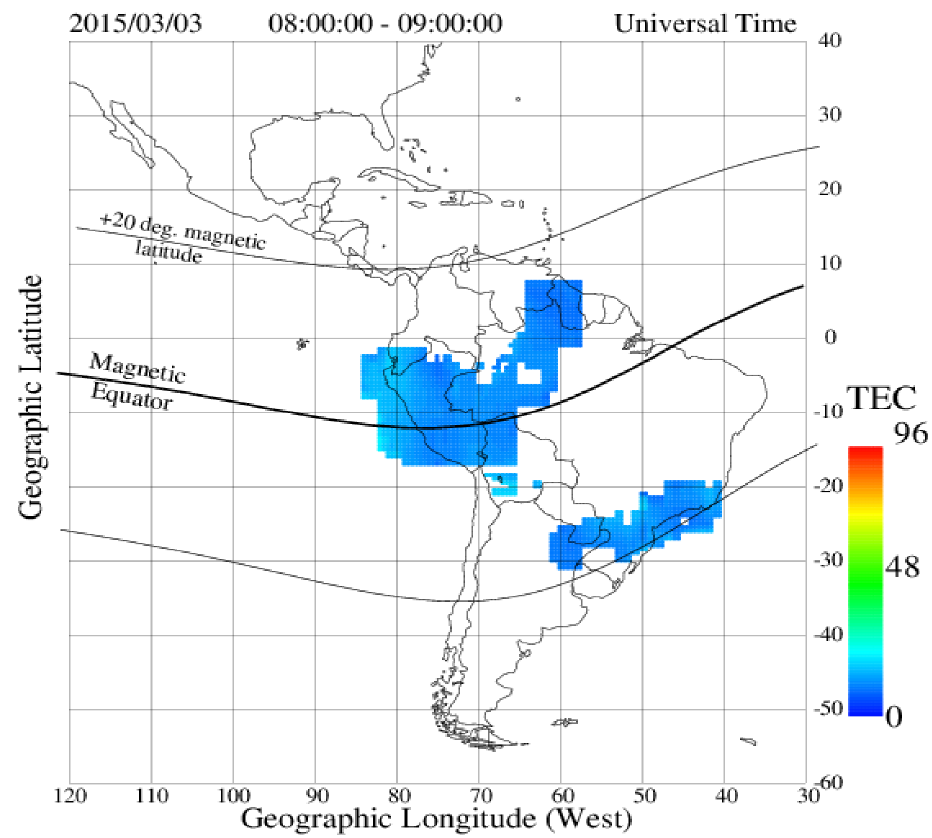
The Ionosphere can be characterized by the Total Electron Content (TEC) density highly dependent on the interaction of the solar activity and the earth geomagnetic field

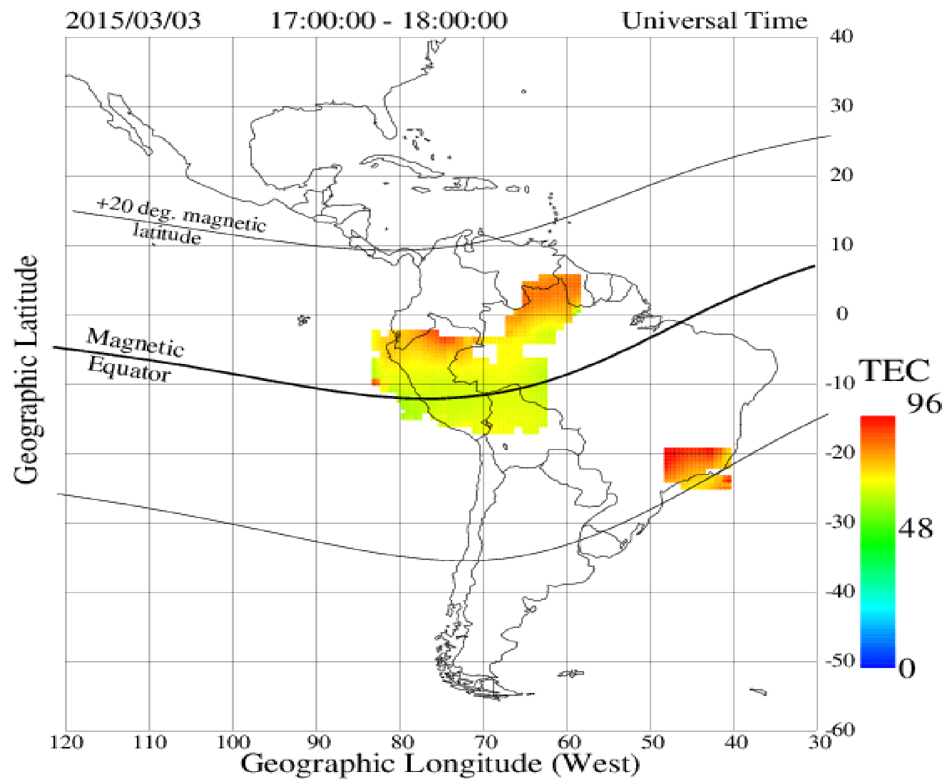
and (c) latitude

EMPIRICAL TEC MAPS OVER PERU

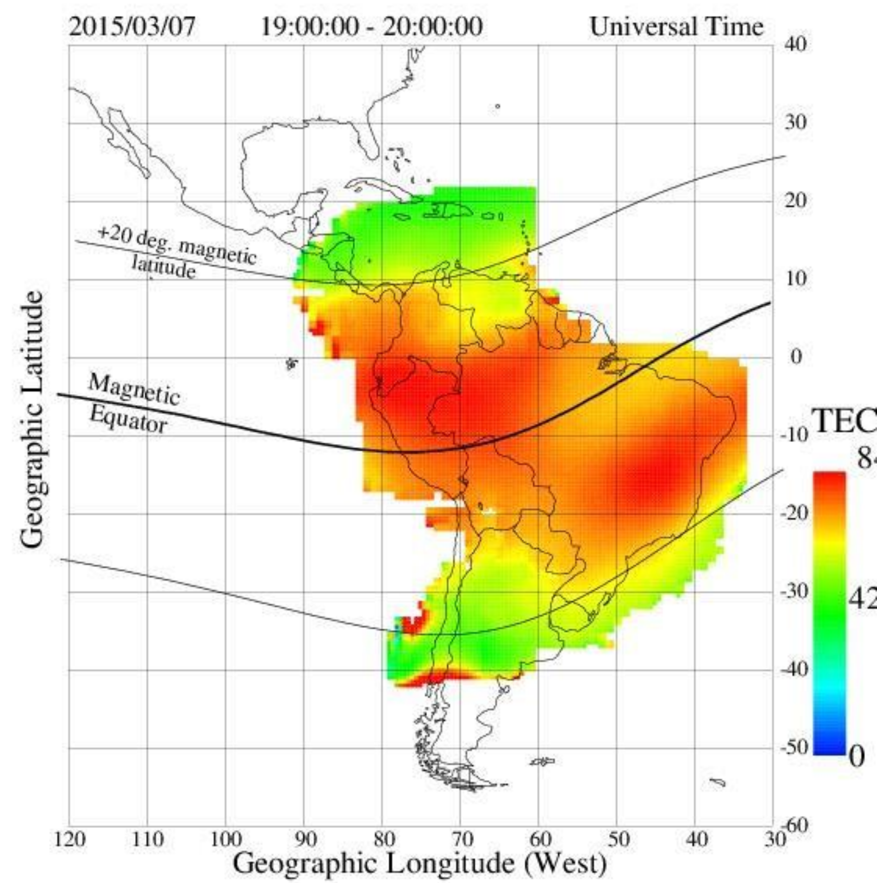


Note: use of LISN Data (ROJ)

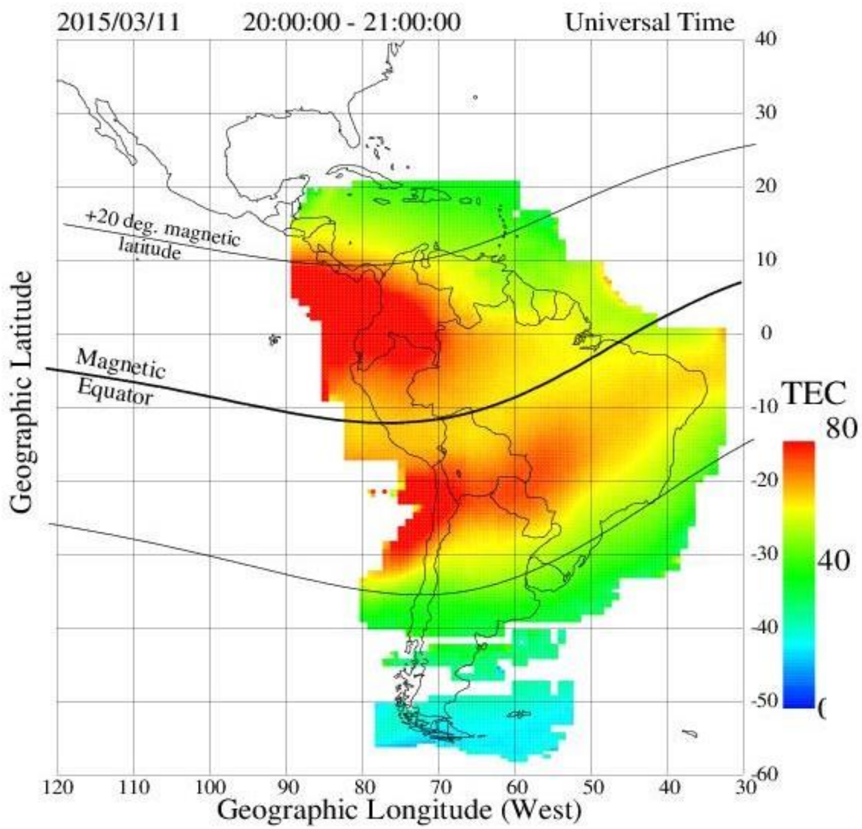




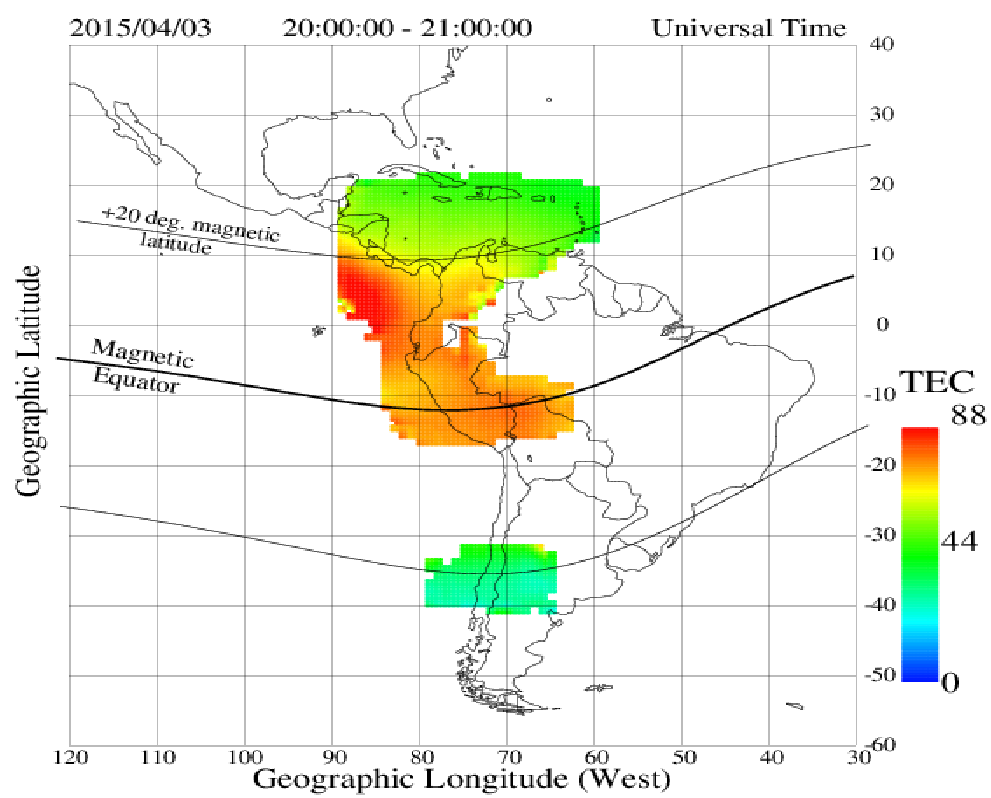
2015/03/03
17:00:00 - 18:00:00
Universal Time
+20 deg. magnetic latitude
Magnetic Equator
Geographic Latitude
Geographic Longitude (West)
TEC
96
48
0



2015/03/07
19:00:00 - 20:00:00
Universal Time
+20 deg. magnetic latitude
Magnetic Equator
Geographic Latitude
Geographic Longitude (West)
TEC
42
0



2015/03/11
20:00:00 - 21:00:00
Universal Time
+20 deg. magnetic latitude
Magnetic Equator
Geographic Latitude
Geographic Longitude (West)
TEC
80
40
40
30
20
10
0
-10
-20
-30
-40
-50
-60
120
110
100
90
80
70
60
50
40
30



2015/04/03
20:00:00 - 21:00:00
Universal Time
+20 deg. magnetic latitude
Magnetic Equator
Geographic Latitude
Geographic Longitude (West)
TEC
88
44
0
40
30
20
10
0
-10
-20
-30
-40
-50
-60
120
110
100
90
80
70
60
50
40
30

Statistically the TEC is related to the change of distance according to:
meters = TEC / 6

A TEC of 60 TEC units would give an error of 10 meters. Which is significant if it is used to land but not so much for an approach of the aircraft. The problem is the slope of the TEC (higher inside the bubbles) and the scintillations.
Cintillations can cause that there is no signal of one or more GNSS and that it is necessary to take signal of another satellite. As a solution, it is possible to use multifrequency and multiconstellation receivers.

There are Ionosphere models for prediction (forecast) at low latitude and thus be able to mitigate their effects in navigation, like NeQuick or IRI model.
In the equatorial region there are many TEC variations.

The reference period was during the year 2015 (high solar activity) and empirically, a window of time of approximately 5am to 5pm was found that could use an augmentation systema like GBAS and should be backed up by a ground system like ILS or VOR/DME.

CURRENT SBAS/GBAS SITUATION IN PERU (SAM REGION)

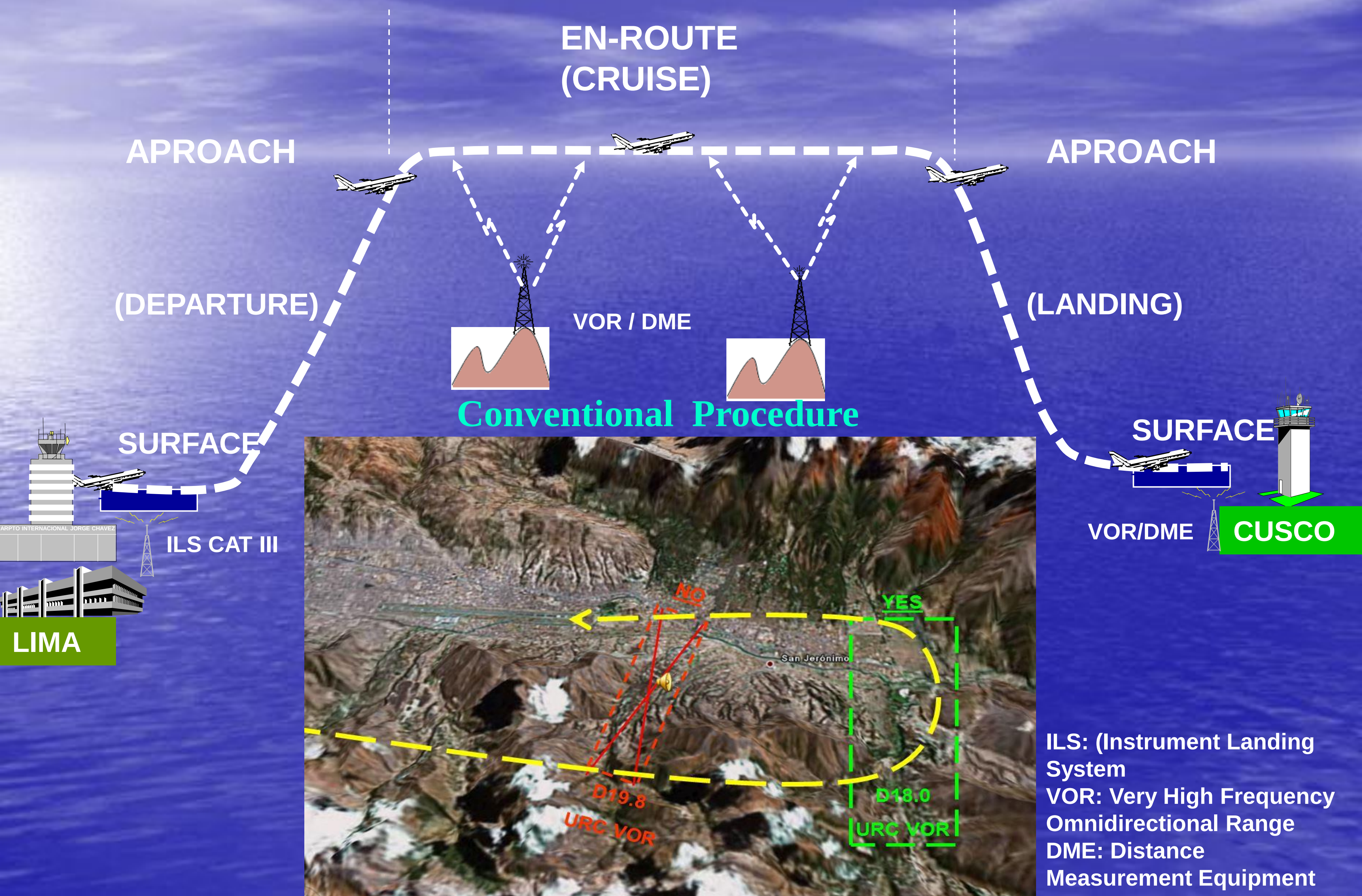
- No SBAS and GBAS operational in Peru and Southamerica (SAM) Region, No infrastructure deployed in SAM Region .

-Note: Test Bed SBAS/WAAS/GPS - Regional Project RLA/00/009 (ICAO – FAA).

- Ionospheric effects over the GNSS signals (Low Latitude)
- Data Collection and Development of Algorithms (Software).
- Cost-benefit analysis for SBAS/GBAS implementation.
- In Peru, use of GNSS is currently limited to supplemental navigation of “No-Precision” like GPS/RAIM on board and it is not enough.

  (New RNP AR procedure implemented in Cusco since 2015)
- Supplemental navigation system: Aircraft must equip other primary navigation system (e.g inertial) and the route is planned based on the primary navigation system; but they cannot fly RNAV route directly going to the destination by GPS/RAIM only, they need a lighting aids on ground (PAPI) and visual conditions.
- Additionally, RAIM prediction is mandatory; If GPS/RAIM is predicted unavailable for the intended operation, they should change the flight plan and/or fly to an alternate airport.

CURRENT NAVIGATION (BASED ON RADIO-AIDS)



ILS: (Instrument Landing System
VOR: Very High Frequency Omnidirectional Range
DME: Distance Measurement Equipment

BUSINESS CASE - PERUVIAN EXPERIENCE

As examples of peruvian experience there are procedures obtained at the Cuzco and Caxamarca Airports.

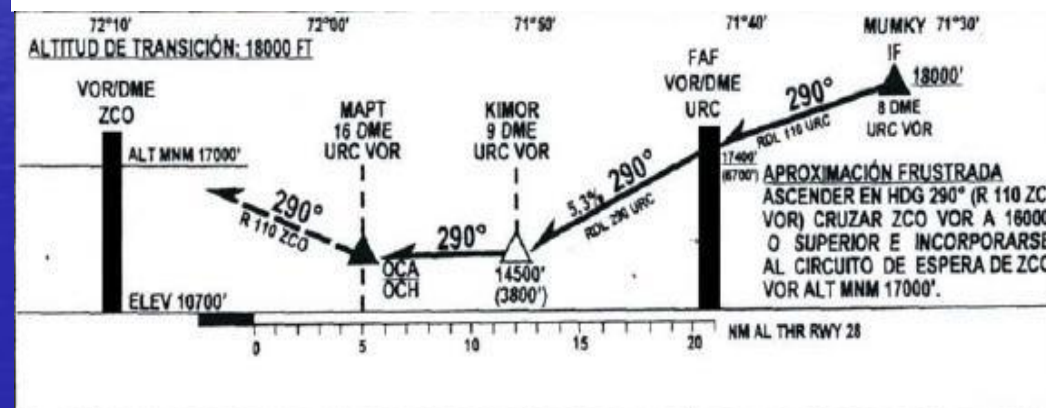
The first operational approach procedure (mix) based on GNSS and RNP Baro - VNAV information was authorized at the Cusco Airport in 2008

Cuzco Airport:

- Location: Cusco, Peru
- Elevation: 10745 ft.
- IFR Daylight operations only

RWY28 served by two IFR approaches, ending in visual circling maneuvers.

- Minimum approach (DA 14500',visibility required 8Km) often higher than actual weather conditions.

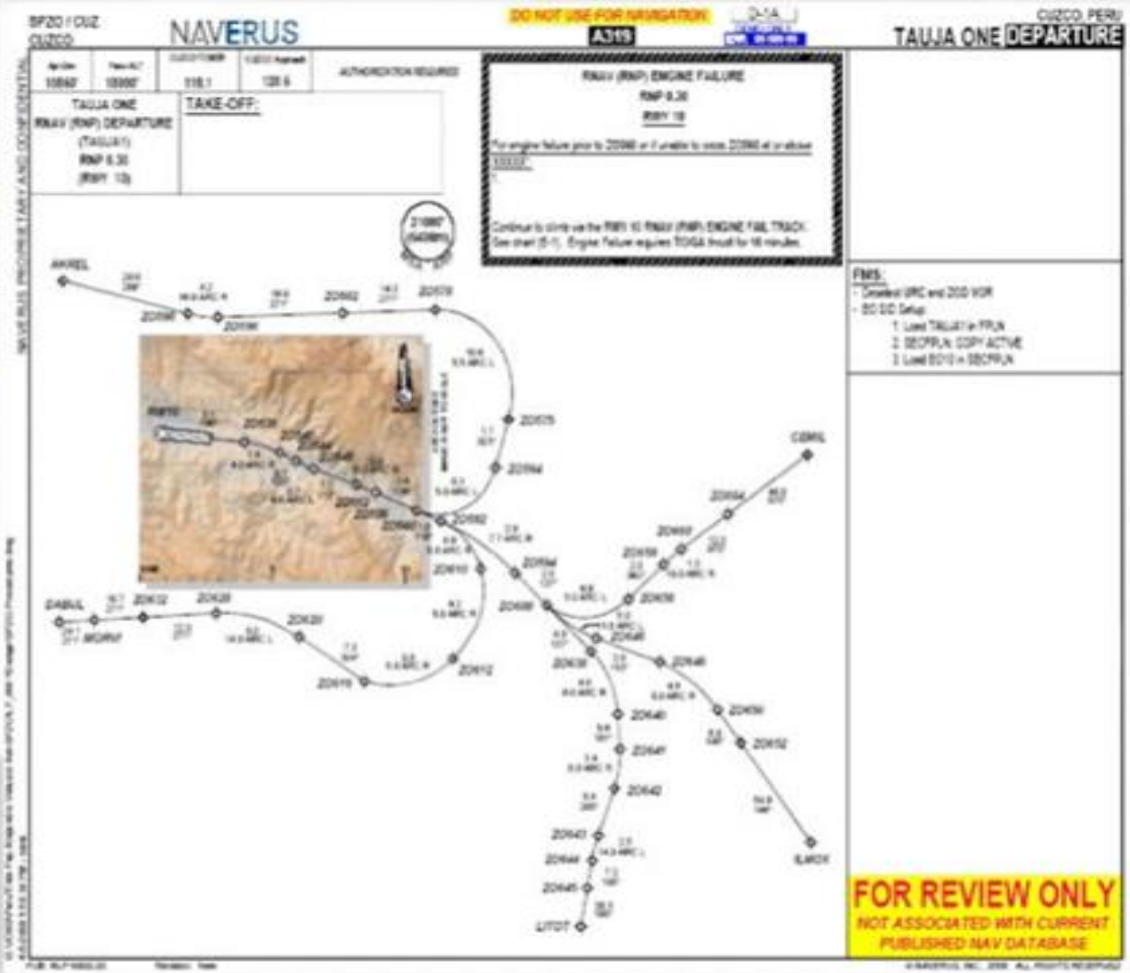


OCA / H	A - B - C - D	MÍNIMOS DE UTILIZACIÓN DEL AD
EN CIRCUITO RWY 28	14500' (3800')	TECHO DE NUBES: 1200 M VISIBILIDAD : 8 KM

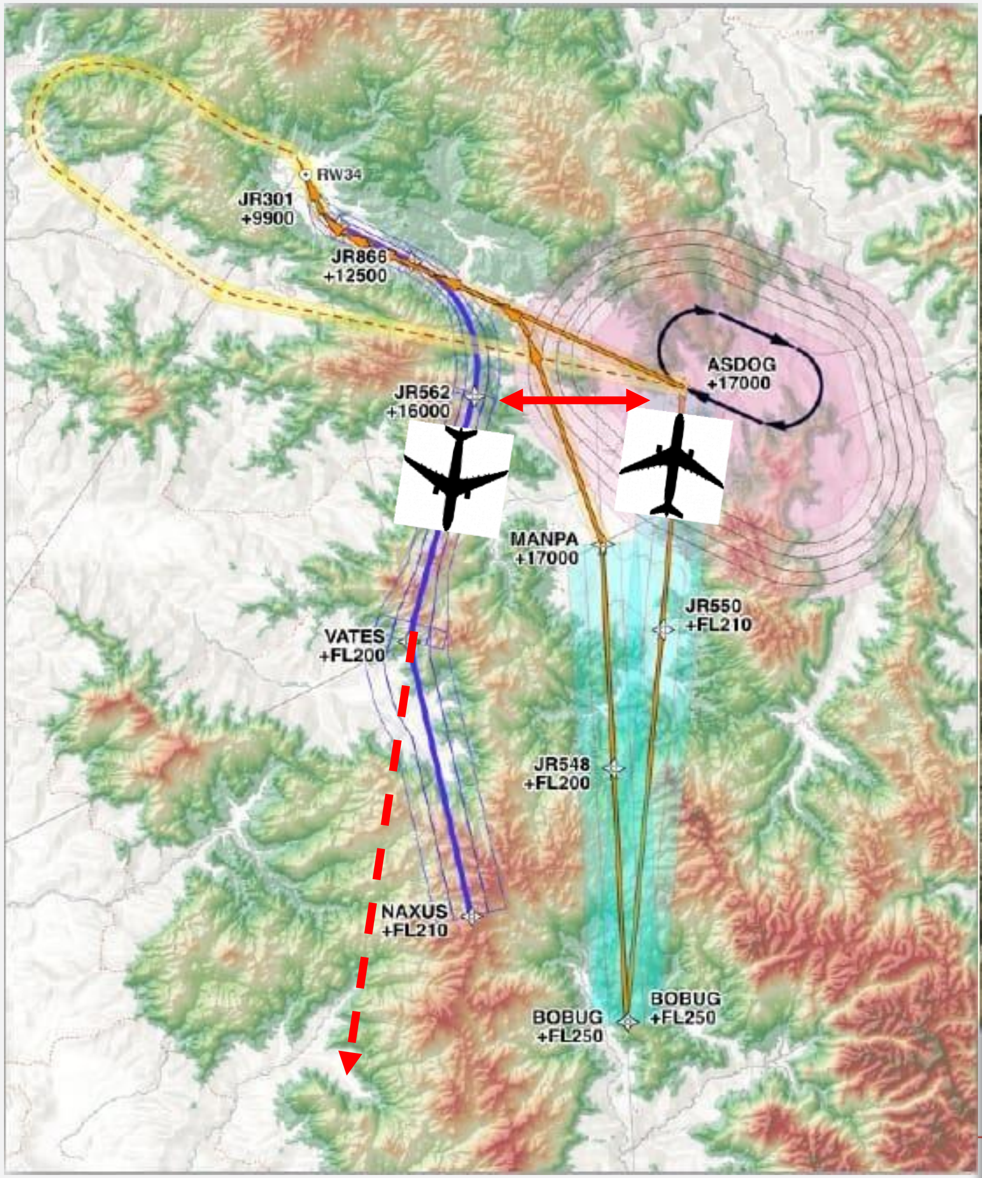
Cuzco

- RNP Departure.
- Provision for 5 exit gates, depending on flight destination.

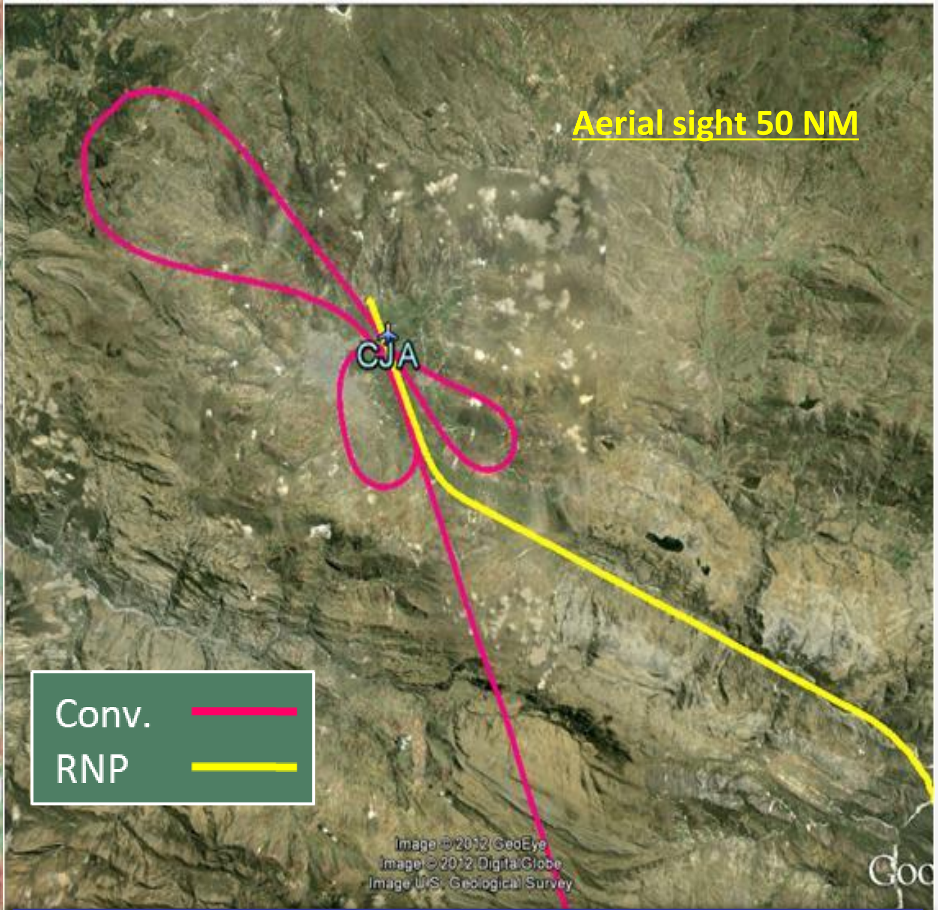
Operacional
Since 2015



New Flight Procedures

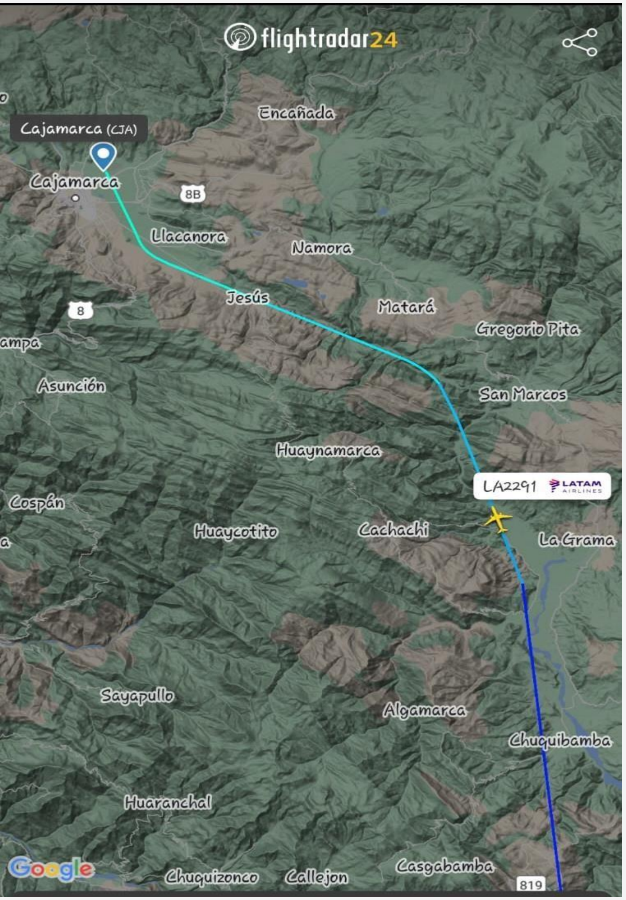


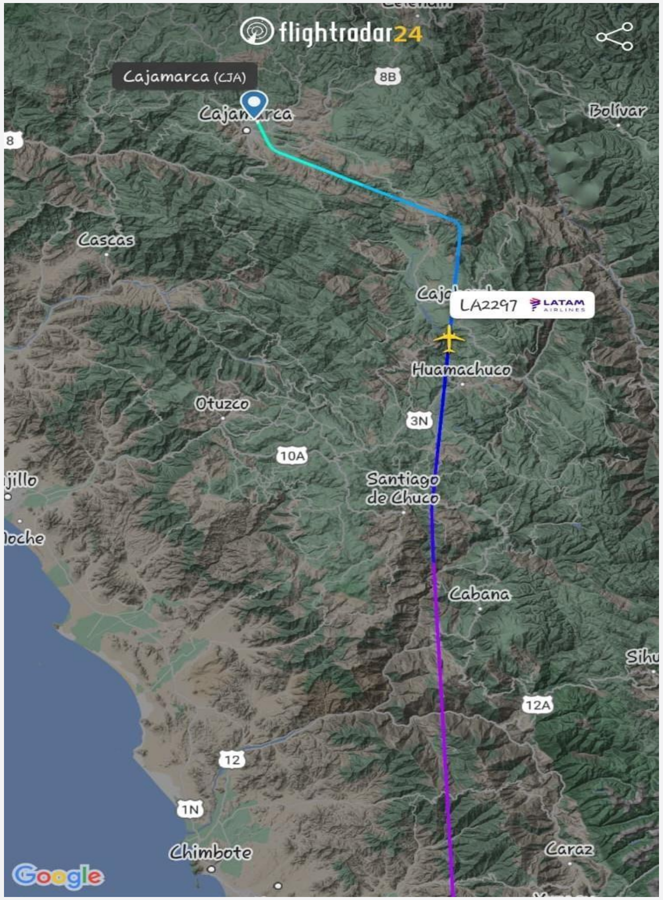
Shorter Flight distance/Best minimum of Approach

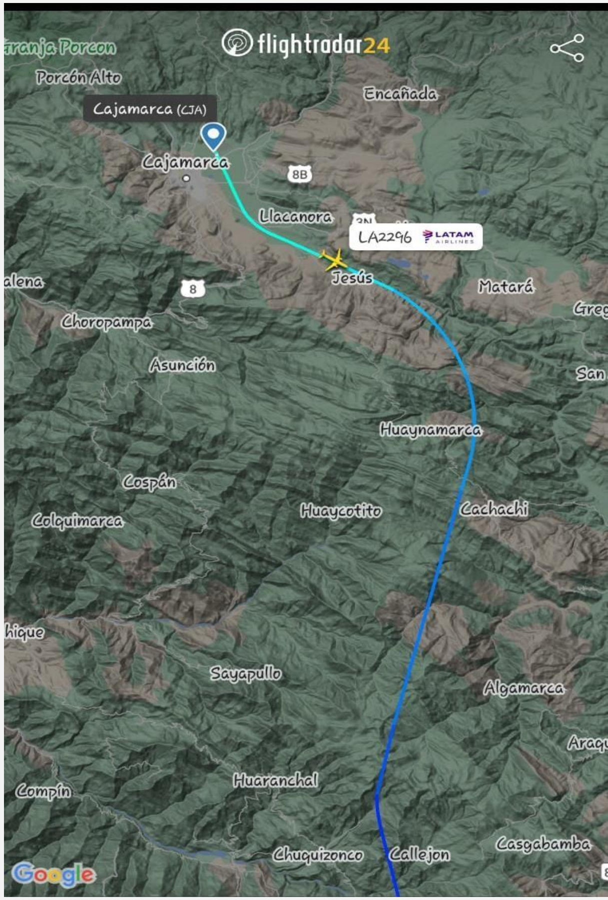


Saving per flight			
Distance	Time	Fuel	CO2
34.8 nm	11.6 min	375.9 gal	1186 kg

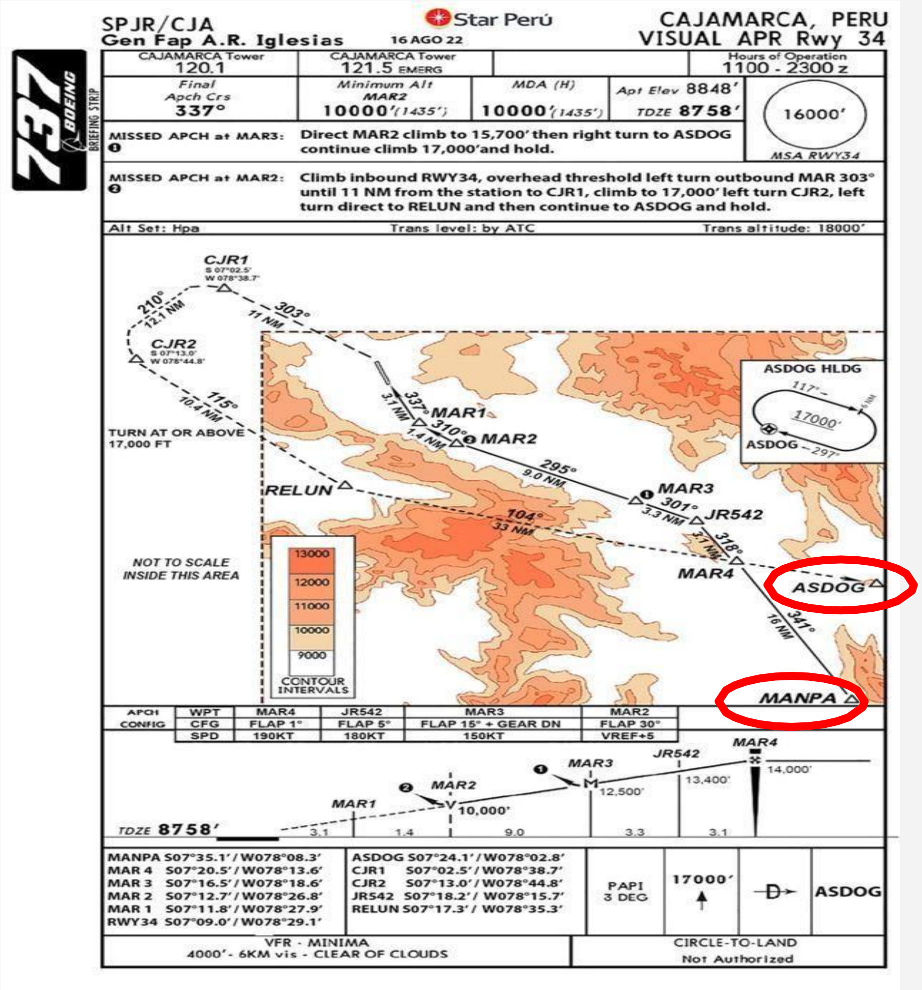
Flight Traceability

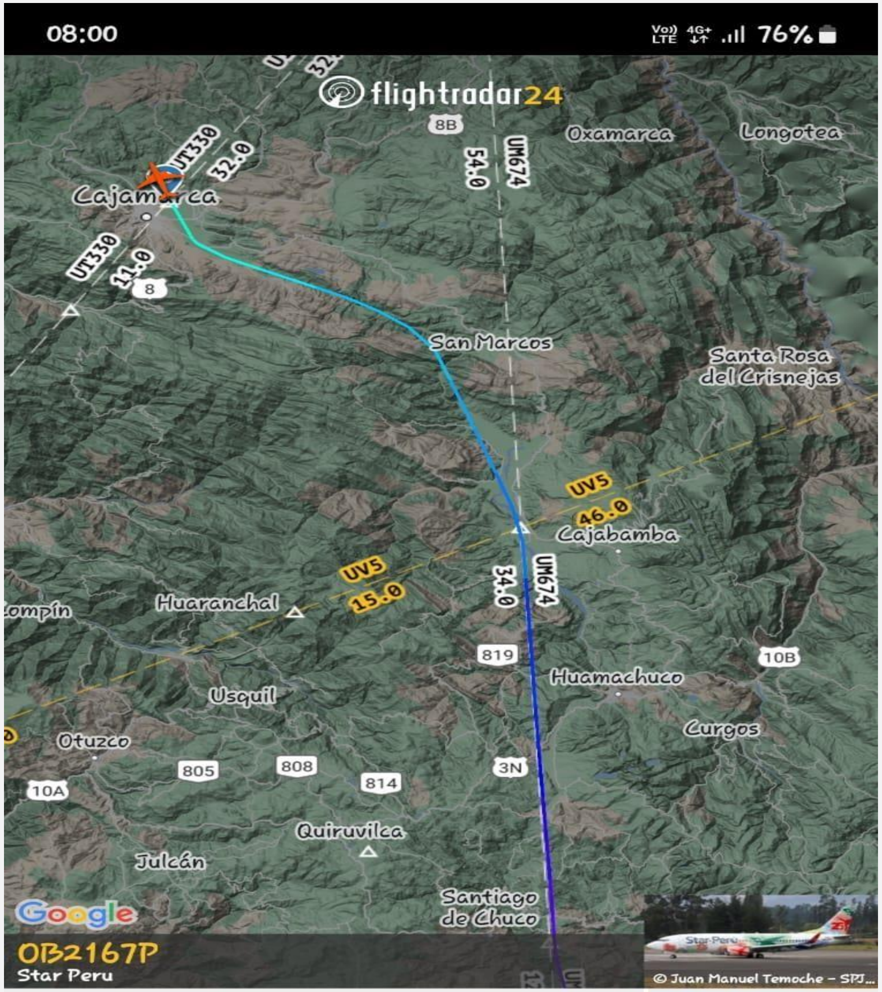




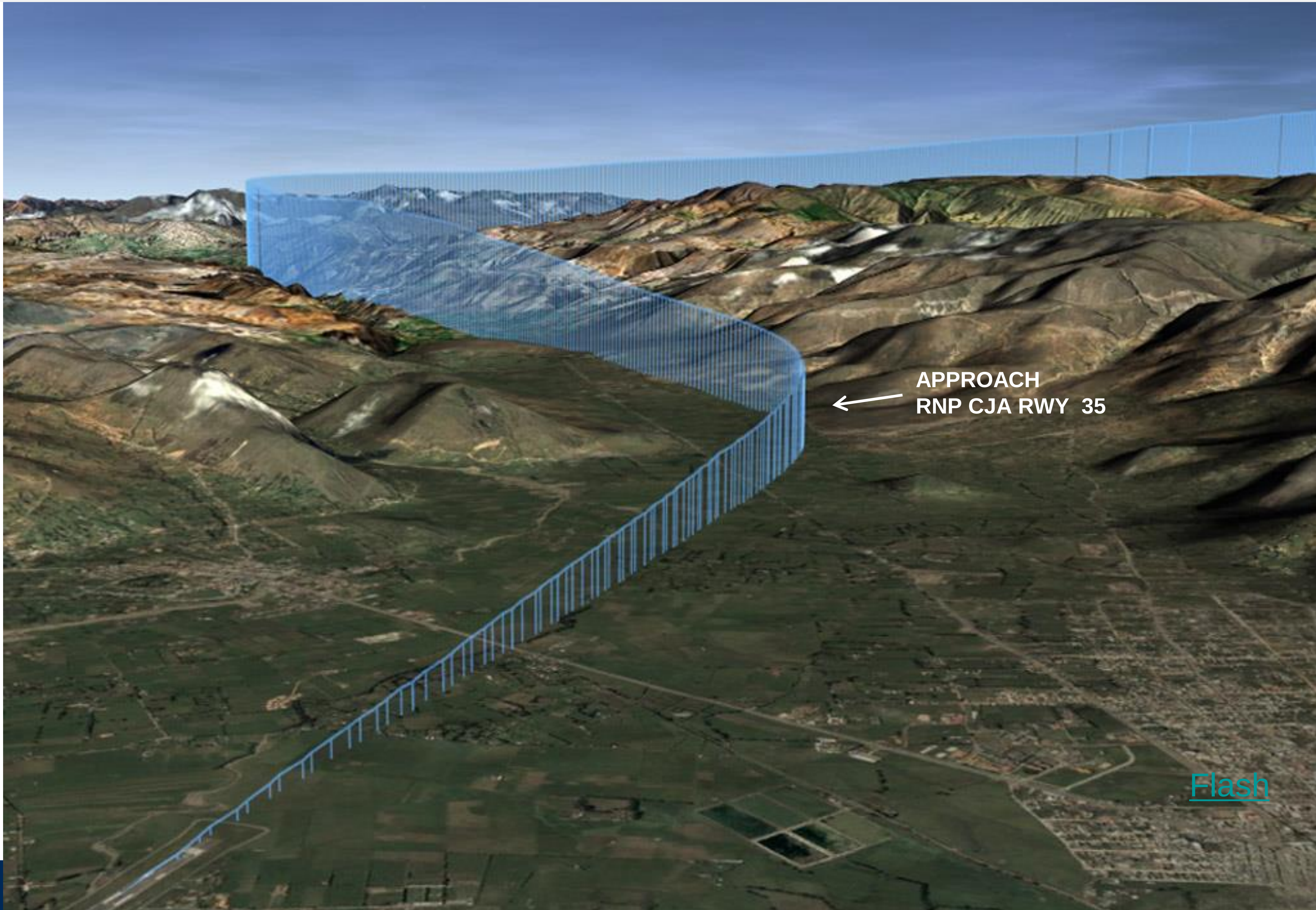


Visual Procedures Supported by GNSS





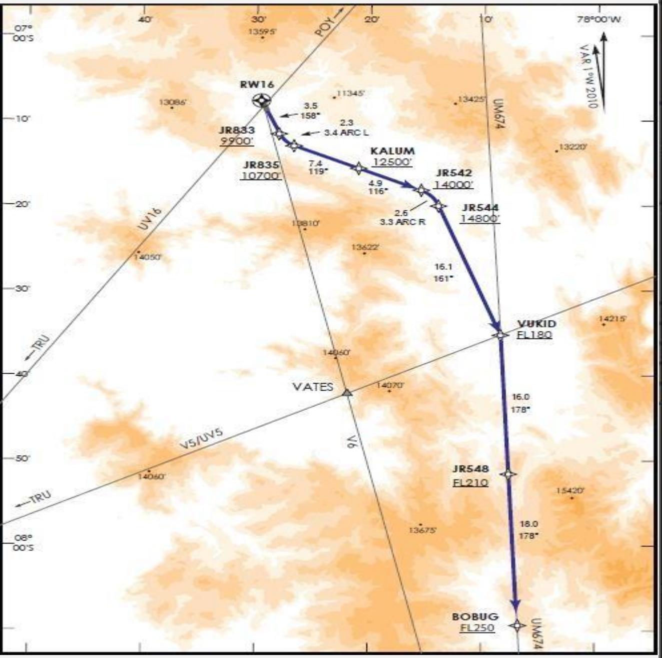
RNP Procedures Caxamarca

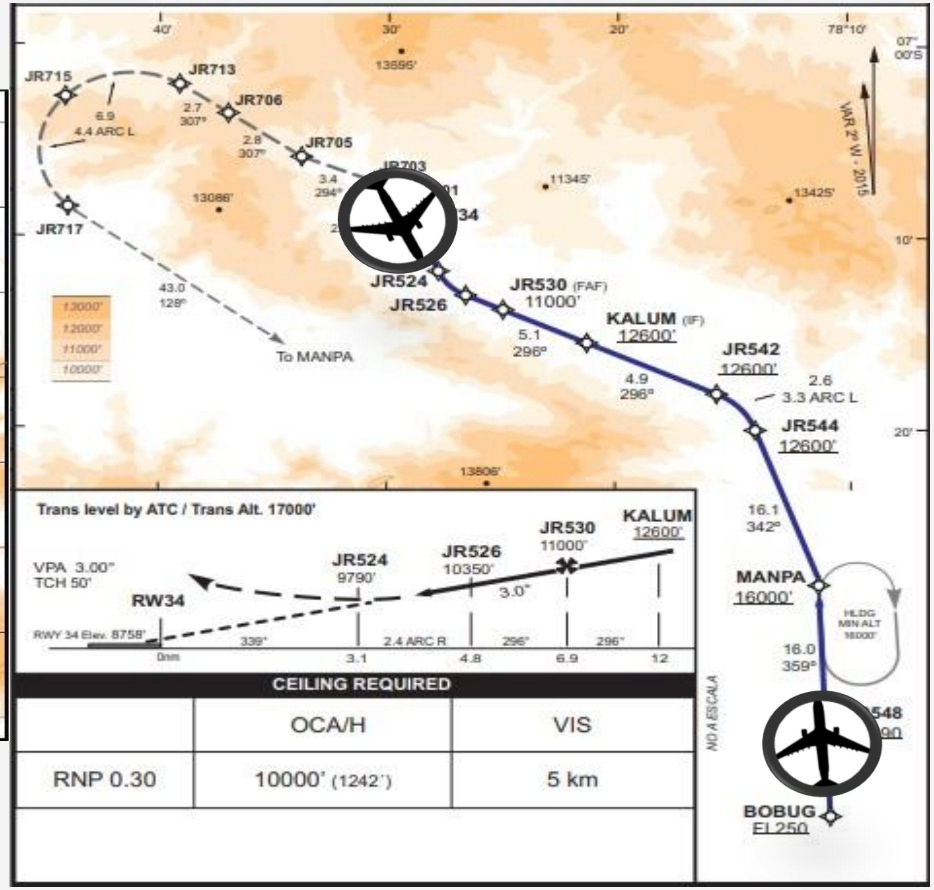


Flash

PERÚ Ministerio de Transportes y Comunicaciones

REDUCTION OF WAITING TIME ON THE GROUND FOR AIRCRAFT ON APPROACH





30 MINUTES

12 MINUTES

REMARKS

- No SBAS and GBAS operation in Peru and Southamerica (SAM) Region, No infrastructure deployed in SAM Region
- Ionospheric effects over the GNSS signals (Low Latitude)
- Cost-benefit analysis for SBAS/GBAS implementation.
- Empirical model of a TEC Map (ionosphere is characterized by TEC) to evaluate the feasibility of implementing an Augmentation System (GBAS and/or SBAS) at Low Latitude Region like Peru.
- Threat model would be the key to GBAS implementation, considering validation of a regional ionospheric threat model..

-The receivers used the L1/L2 GPS frequencies.

- Most countries in South America would have to base their national airspace on GNSS/GBAS/ABAS (no SBAS)
- Development of a valid Iono Threat Model for Low Latitudes is key to augmentation system like GBAS
- -Test Bed SBAS/WAAS/GPS - Regional Project RLA/00/009 (ICAO – FAA).

- In Peru, use of GNSS is currently limited to supplemental navigation of “No-Precision” like GPS/RAIM on board and it is not enough. New RNP AR procedure implemented in Cusco since 2015.

THANK YOU!!

Note: The opinions expressed here are solely those of the author