

DRAFT

**Space Weather and Ionosphere Effects on
Air-navigation (Civil Aviation) in Low
Latitude – SAM Region**

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AGENDA

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AUGMENTATIONS SYSTEMS**

III. SPACE WEATHER

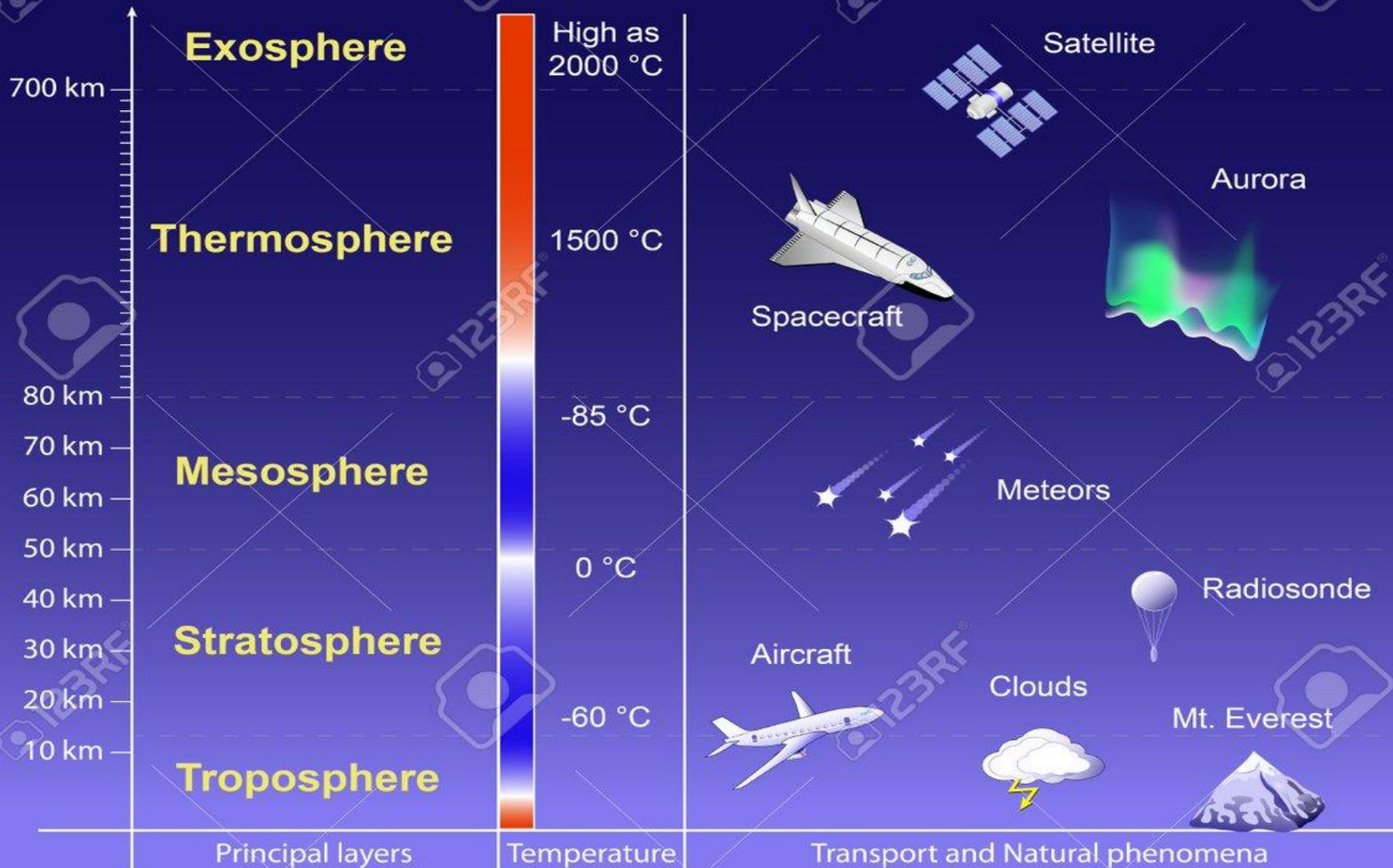
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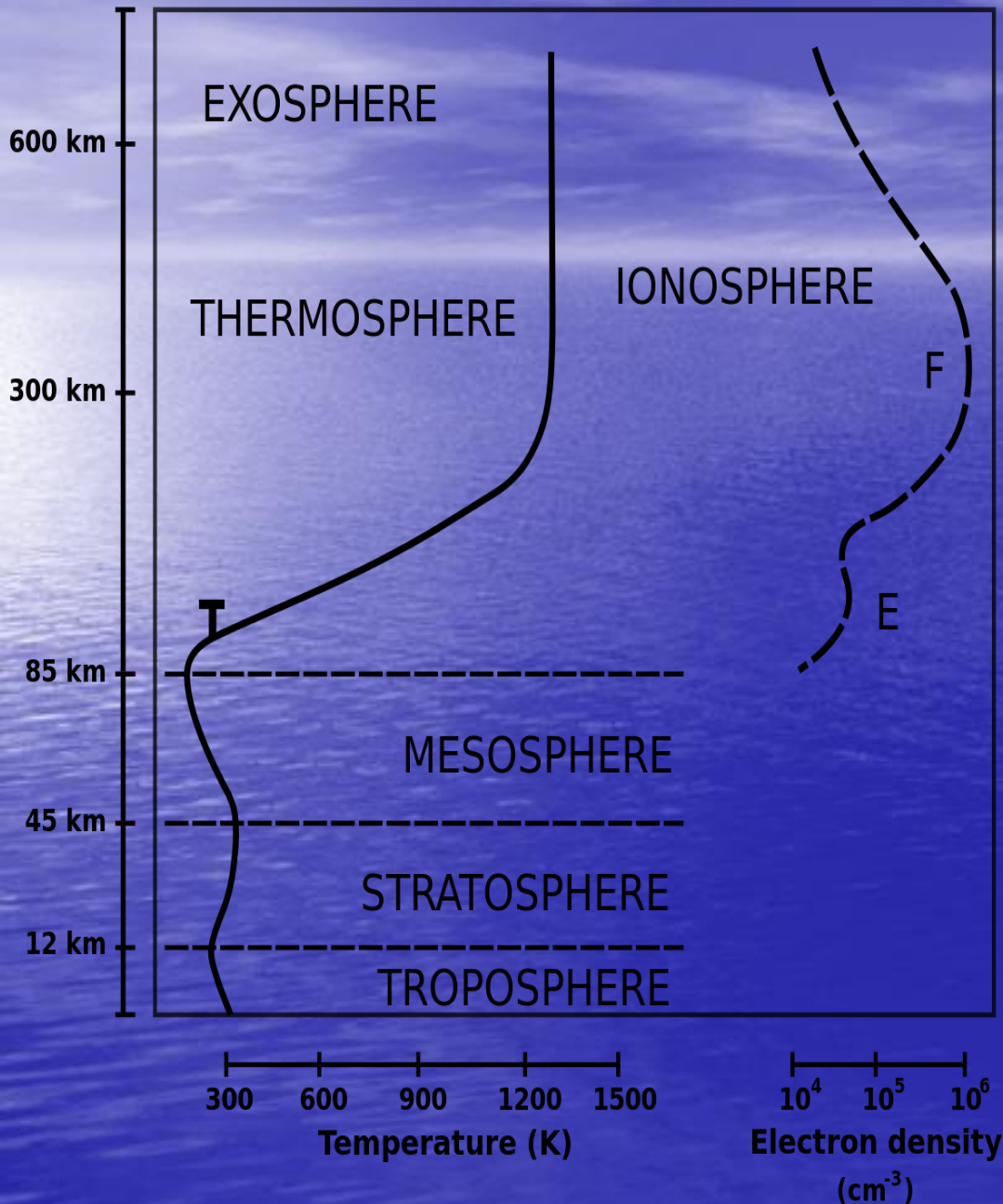
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I. INTRODUCTION

LAYERS OF THE ATMOSPHERE



IONOSPHERE

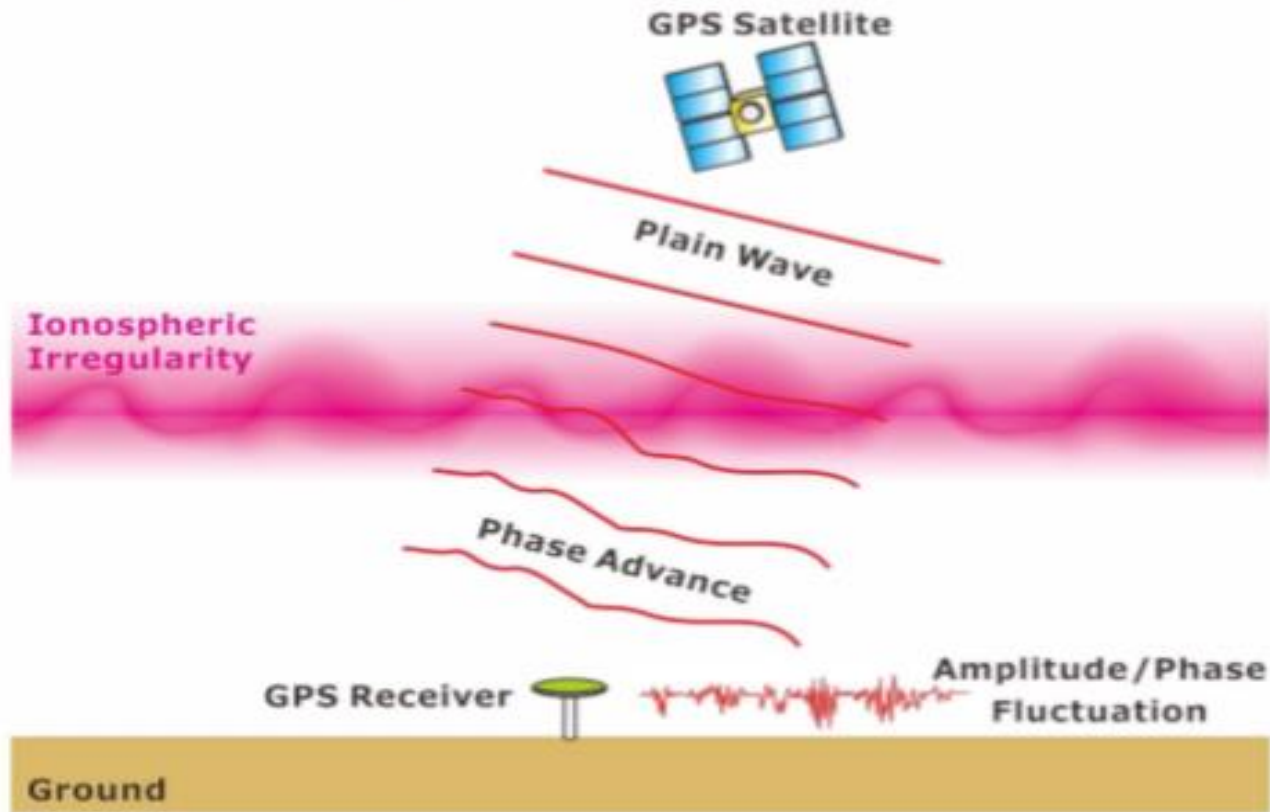


The Ionosphere is defined as the layer of the Earth's Atmosphere that is ionized by solar and cosmic radiation. It lies 80-600 km aprox.

Main characteristics of the Ionosphere:

- electron density profile
- TEC (Total electron content) Variability
- Solar Cycle
- Solar storms
- Equatorial anomalies and scintillations

Ionospheric scintillation



- Plasma bubbles include smaller scale (~ 100 -m scale) ionospheric irregularities.
- These ionospheric irregularities causes ionospheric scintillation, that is, amplitude and phase fluctuations on GNSS signals.

The Total Content of Electrons (TEC)

Total Electron Content (TEC) is the number of electrons in a column of a cross section per square meter along a transionospheric path.

It allows to determine the delay and changes of direction of a wave in the ionosphere. It can be obtained by different means, mainly GNSS and satellite altimeter signals

$$N_T = \int_S N(s) ds$$

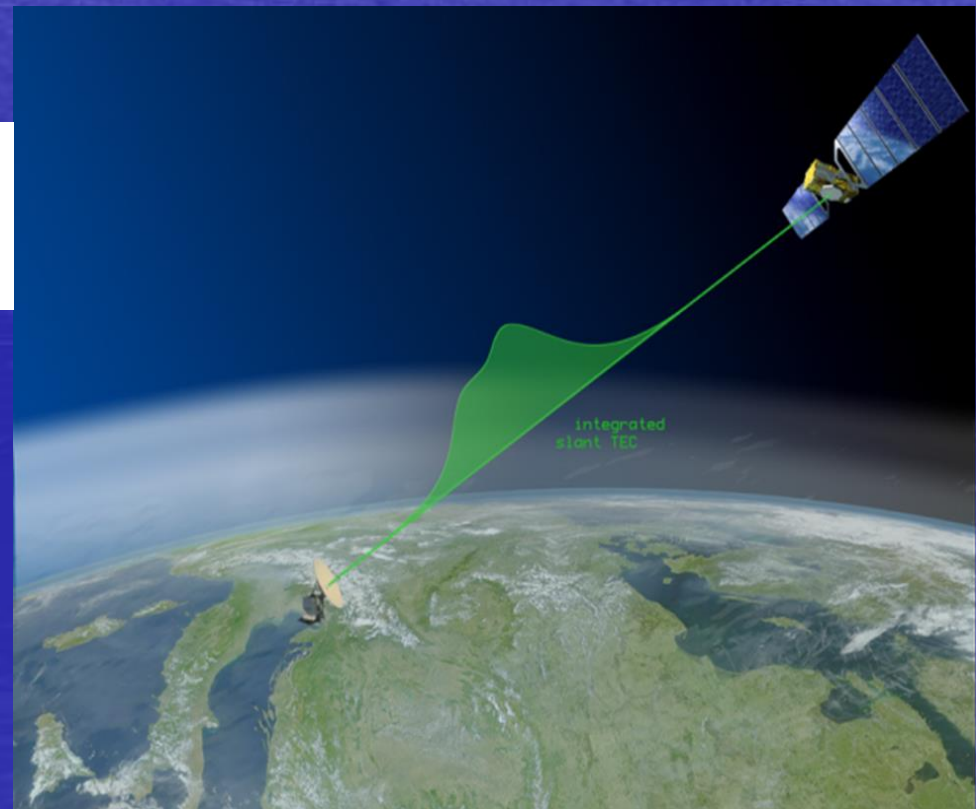
Ionospheric Delay

$$1 \text{ TEC} = 10^{16} \text{ m}^{-2}$$

$$I_\rho = \frac{40.3 \cdot \text{TEC}}{f^2}$$

Its unit of measurement is the TECU = 10E + 16 electrons per square meter

The TEC refers to the degree of ionization in the ionosphere (courtesy of ICTP)



GNSS-TEC Observations

- Total electron content (TEC) can be derived by comparing the pseudorange/phase delays of the two GPS signals.

$$P_1 = \rho + I/f_1^2 + \tau_1^r + \tau_1^s$$

$$P_2 = \rho + I/f_2^2 + \tau_2^r + \tau_2^s$$

$$L_1 = \rho - I/f_1^2 + \lambda_1 n_1 + \epsilon_1^r + \epsilon_1^s$$

$$L_2 = \rho - I/f_2^2 + \lambda_2 n_2 + \epsilon_2^r + \epsilon_2^s$$

P_1, P_2 : Pseudorange

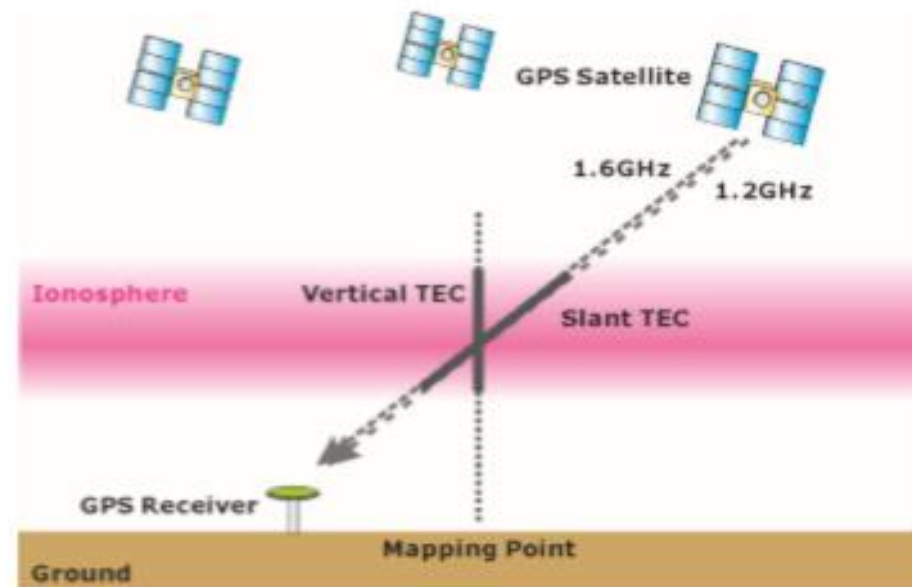
L_1, L_2 : Carrier phase

I : Total electron content

f_1, f_2 : Frequency

ρ : True range between the GPS satellite and receiver

- TEC is a measure of integrated electron density in 1m^2 column.
- Spatial resolution of TEC map depends on the number of GNSS satellites and GNSS receivers distribution.



II. ICAO CONCEPT FOR GNSS

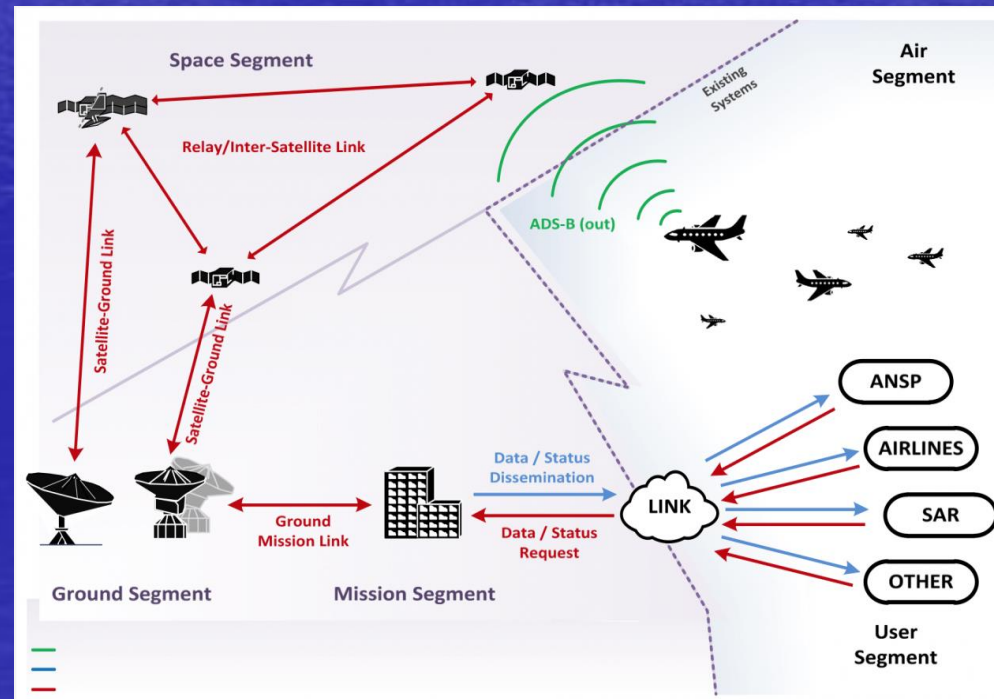
A worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation. (Ref. ICAO Annex 10, Vol. I).

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 synchronization of satellites
- 3) Users: receivers, aircraft

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





Aircraft Guidance Goals

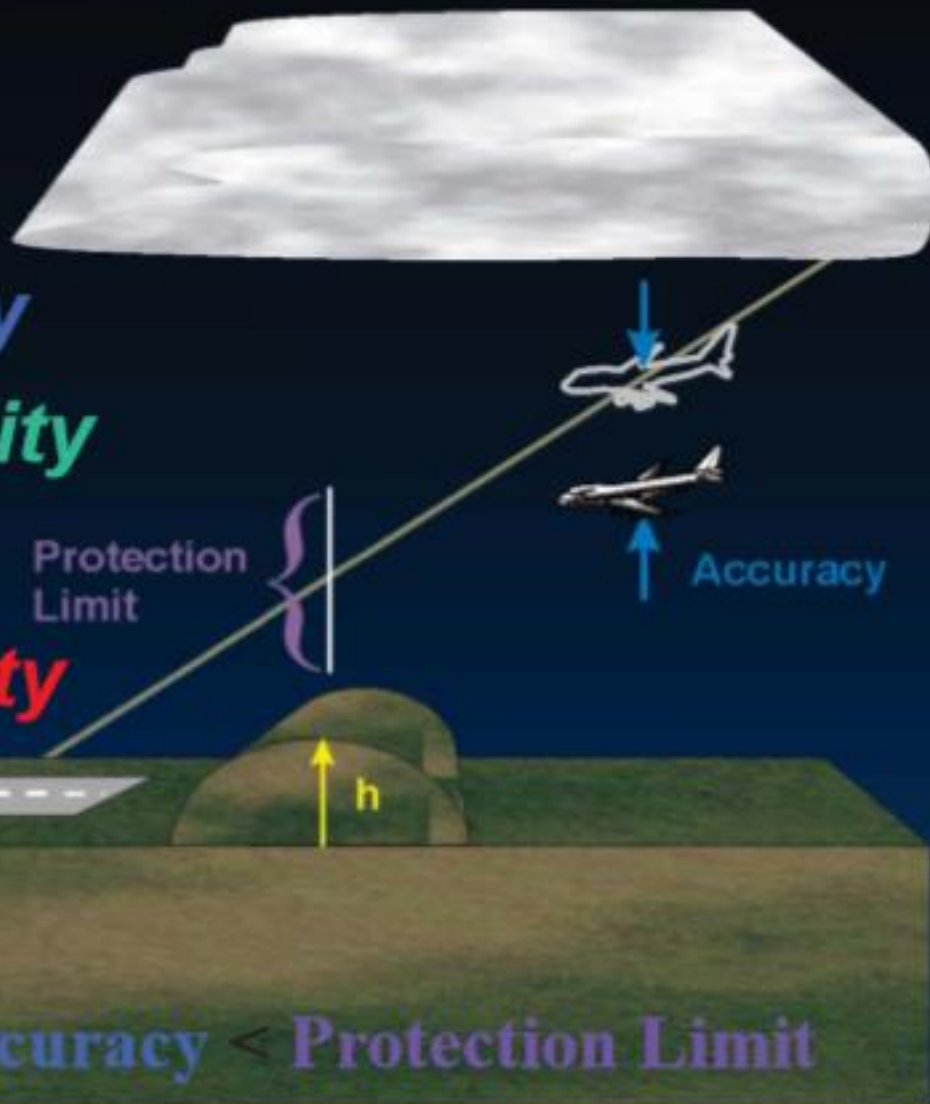
→ Key Elements:

→ Accuracy

→ Availability

→ Integrity

→ Continuity

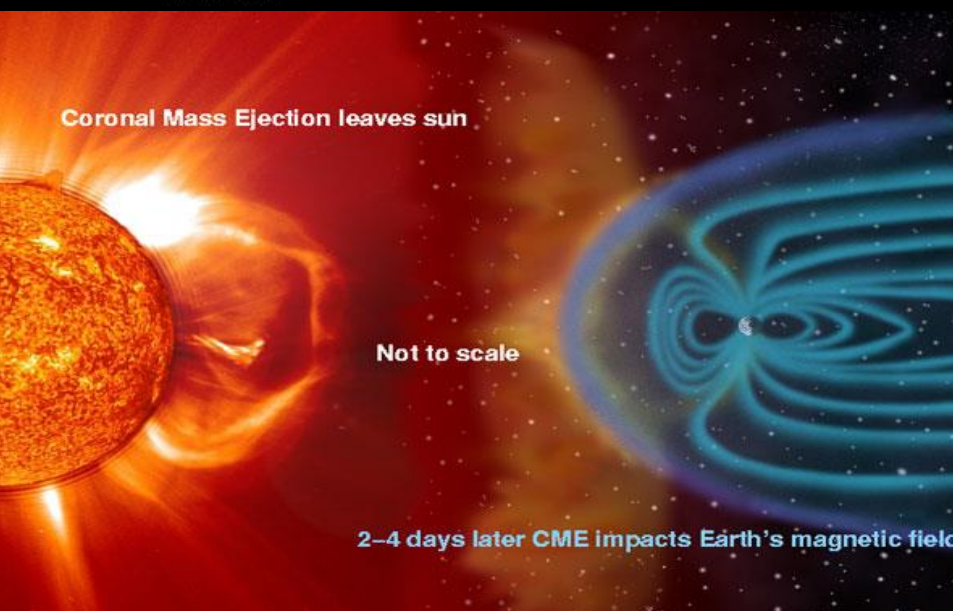
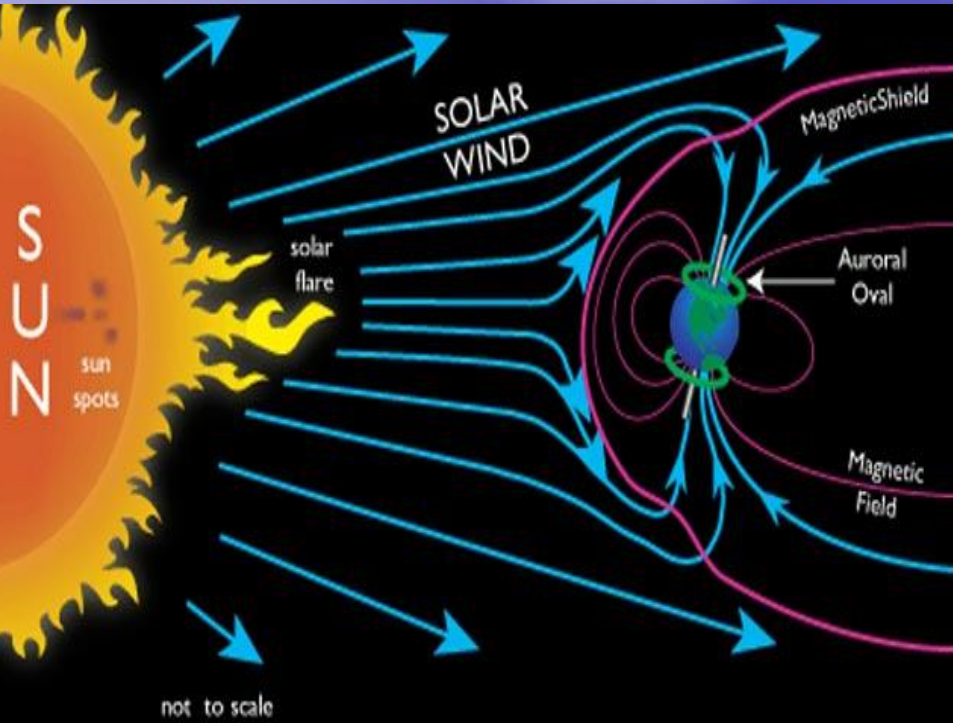


Integrity: Accuracy < Protection Limit

Courtesy:
Rich Fuller

Presented at ICTP
Copyright 2013
Todd Walter

III. SPACE WEATHER (SW)



Space weather is related to the behaviour of the Sun, the nature of Earth's magnetic field and atmosphere, and our location in the solar system. The active elements of space weather are particles, electromagnetic energy and magnetic fields, rather than the more commonly known weather contributors of water, temperature and air. Magnetic fields, radiation, particles and matter which have been ejected from the Sun can interact with the Earth's magnetic field and upper atmosphere to produce a variety of effects

EFFECTS OF IONOSPHERE AND SPACE WEATHER

Interior Charging



Magnetic Attitude Control

Micrometeoroids



Solar Cell Damage



Solar Flare Protons



Astronaut Safety

Atmospheric Drag

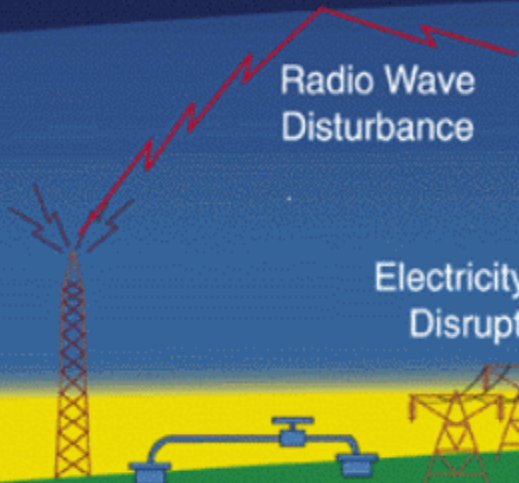


Ionosphere Currents



Plasma Bubble

Radio Wave Disturbance



Signal Scintillation



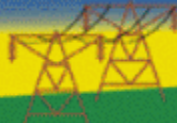
Airline Passenger Radiation



Rainfall Water Vapor



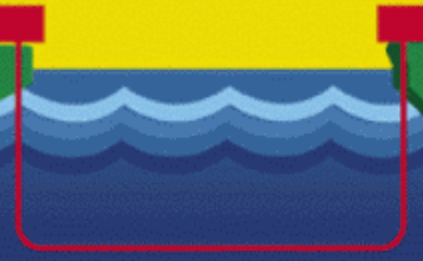
Electricity Grid Disruption



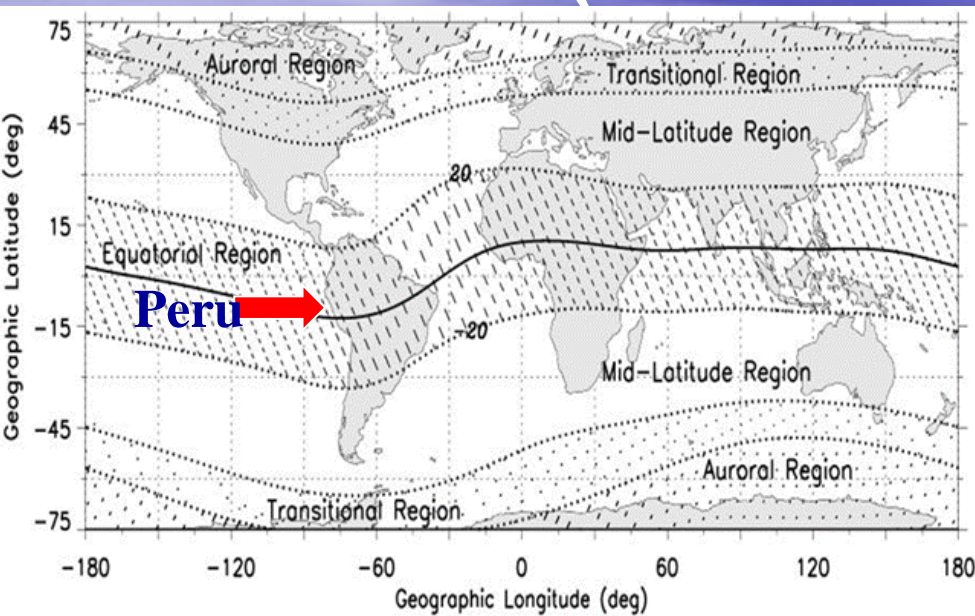
Earth Currents



Telecommunication

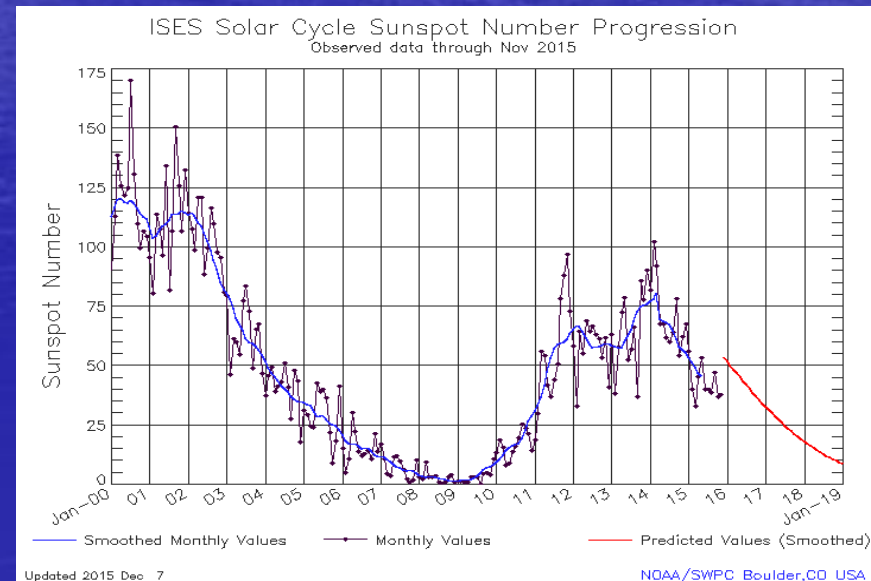


IV. SPACE WEATHER EFFECTS ON GNSS IN LOW LATITUDE (EQUAT. REGION)

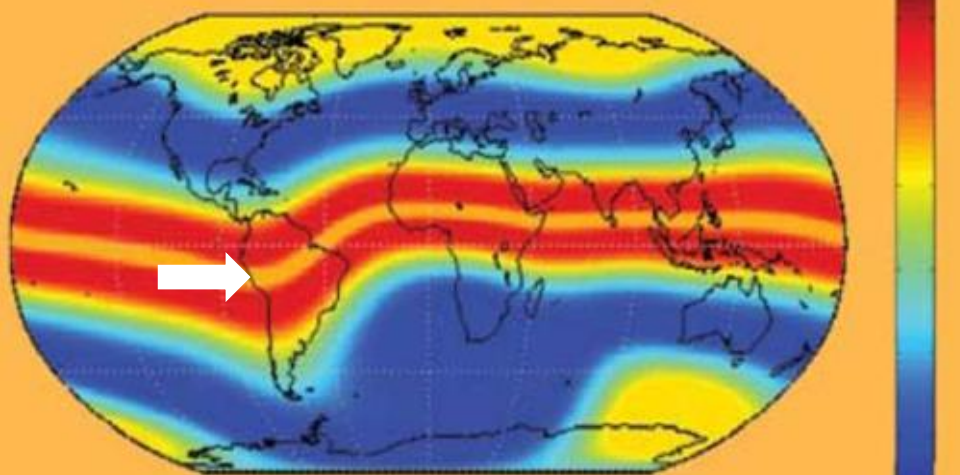


Lima-Peru is the Geomagnetic Equator in Southamerica Region (low latitude), that is why the peruvian airports have an intense ionosphere activity, as well as countries located between 20° N and 20° S (aprox) from the geomagnetic Equator, especially during periods of maximum solar activity.

THE SOLAR CYCLE



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



Frequency of disturbances in ionosphere

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

IV. (...) SCINTILLATIONS AND TEC EFFECTS OVER GNSS

Principal impacts of ionospheric scintillation on GPS performance:

- Loss of lock / outages
- Induced ranging errors

Consequences of these effects on GPS positioning accuracy depends on constellation geometry

For example, losing multiple satellites in the same region of the sky can lead to large errors

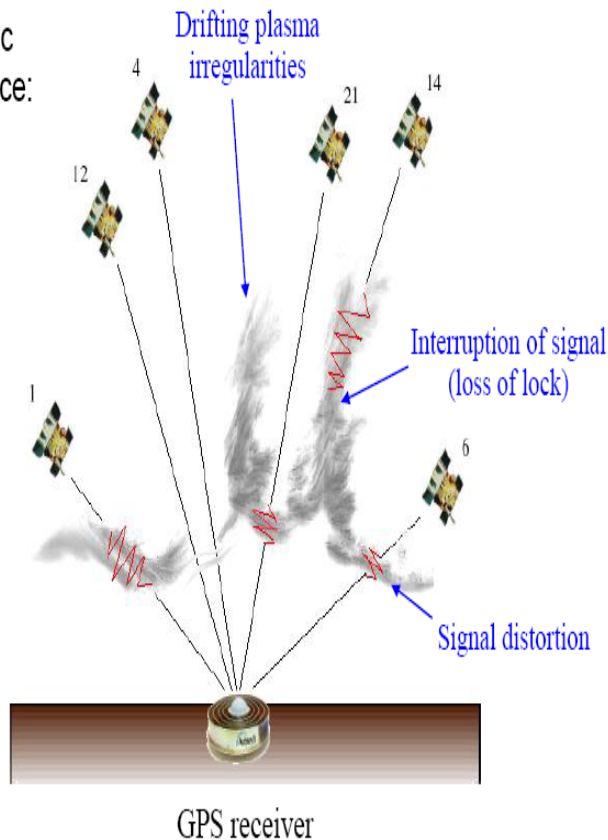
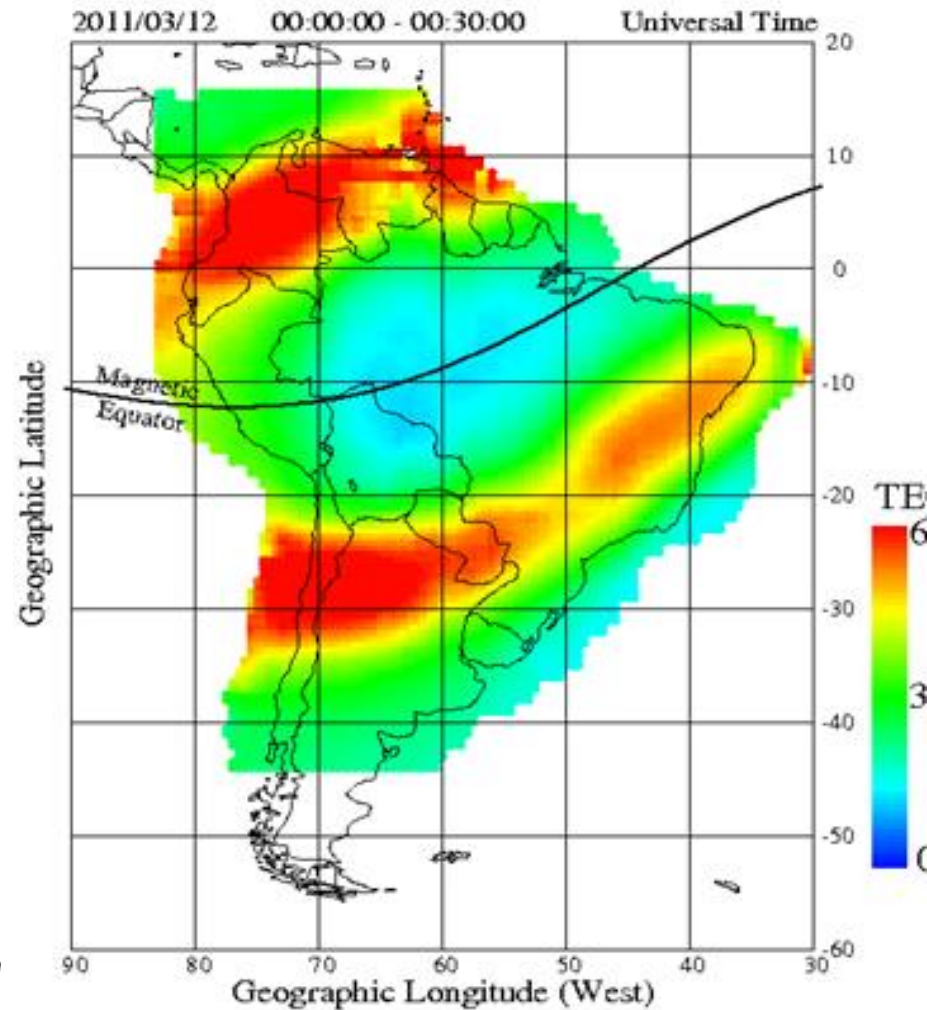


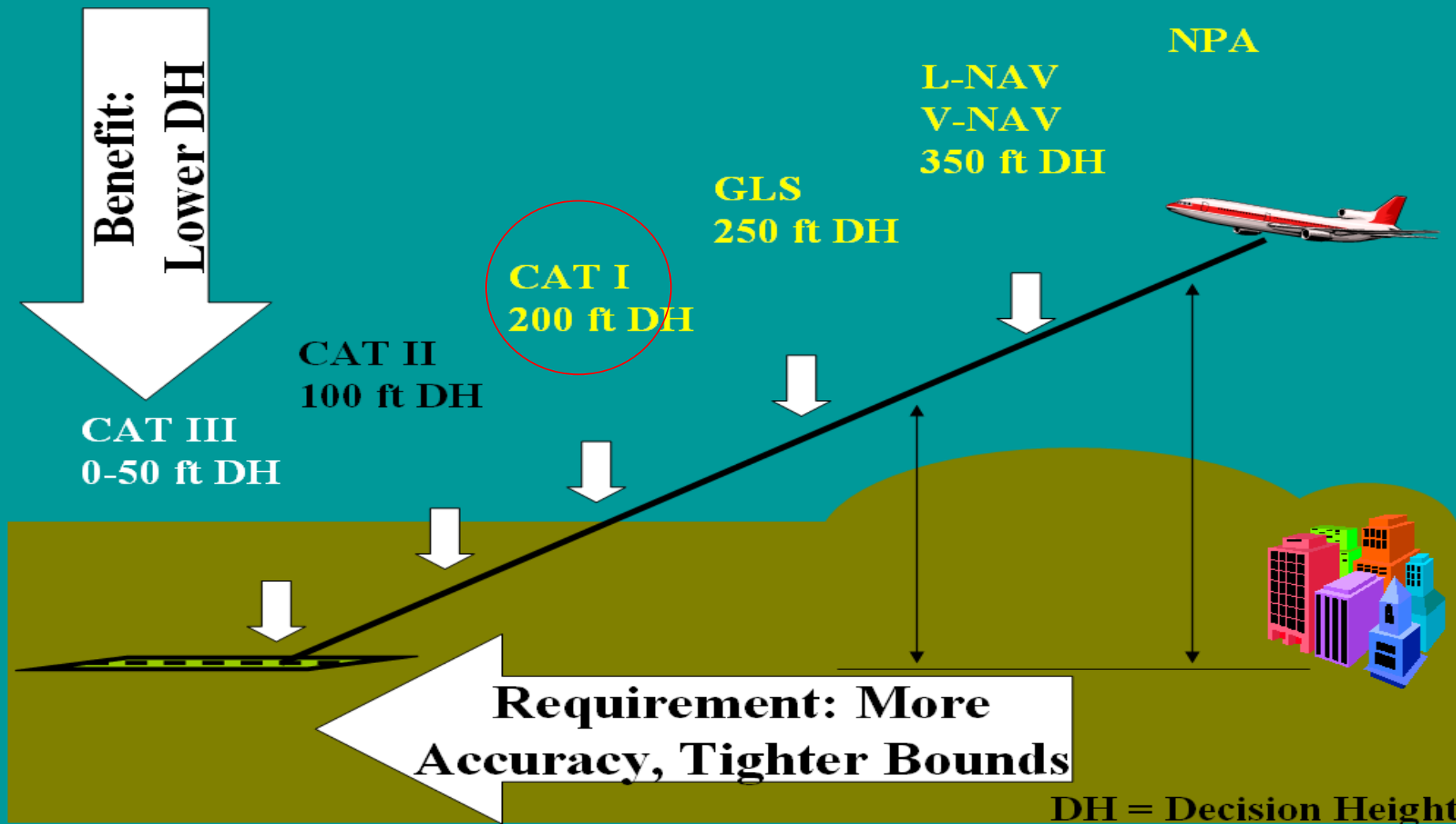
Figure Courtesy of C. Carrano, BC



Scintillations generate fading over GNSS signals

TEC generates delays, measurements made by LISN (Low-latitude Ionosphere Sensor Network) – Courtesy of Boston College

Vertical Guidance



Using this model, the most critical situation for GBAS operation would be an aircraft on approach (landing) receiving wrong correction from the ground station caused by different ionosphere delay received by aircraft and ground station (courtesy of ICTP-Stanford University)

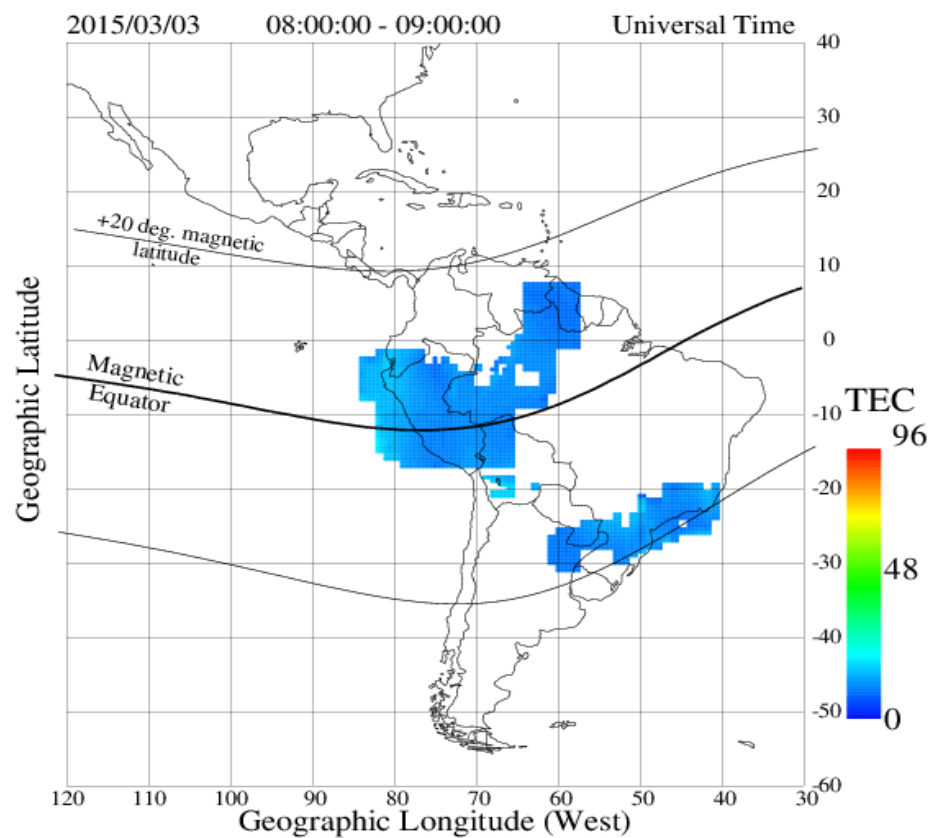
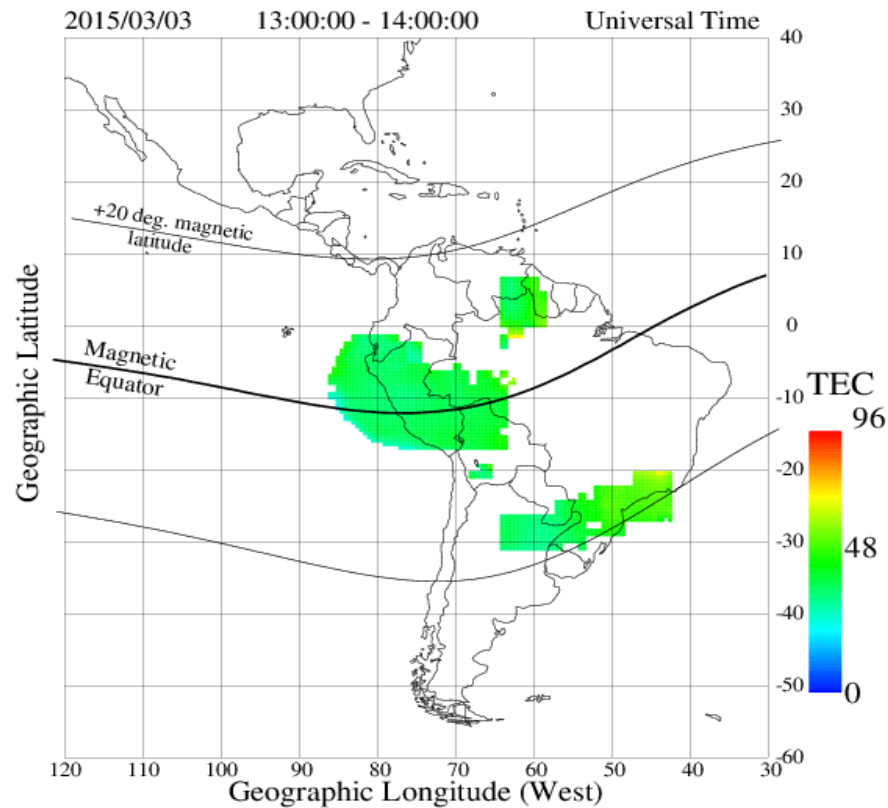
V. EMPIRICAL TEC MAPS OVER PERU

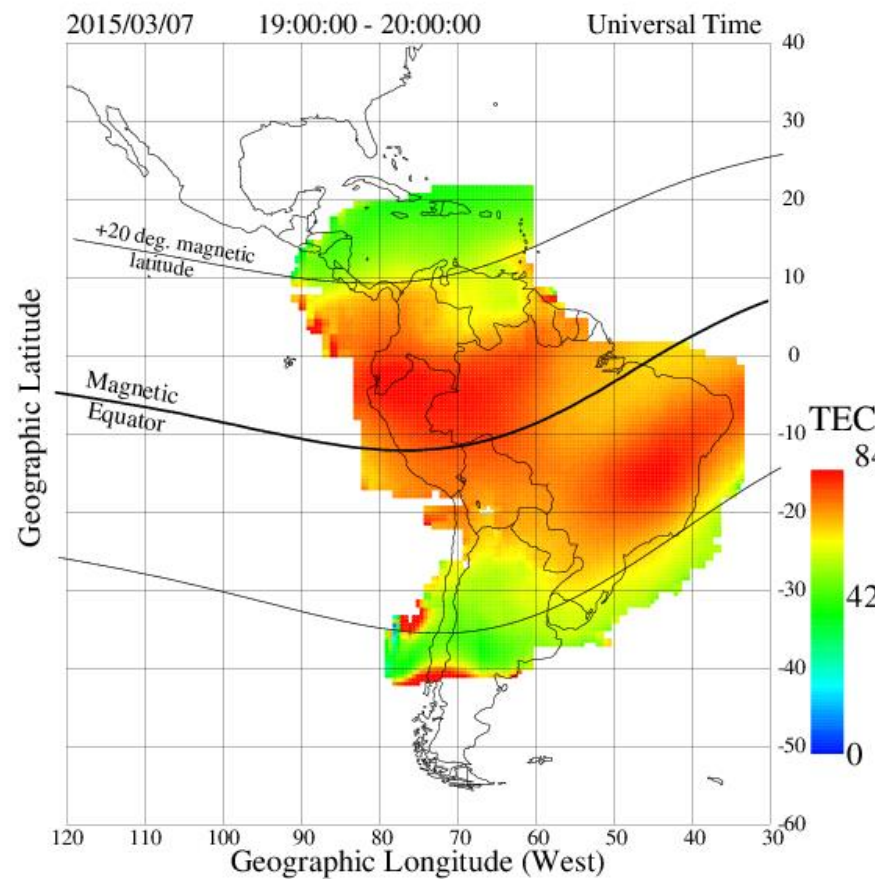
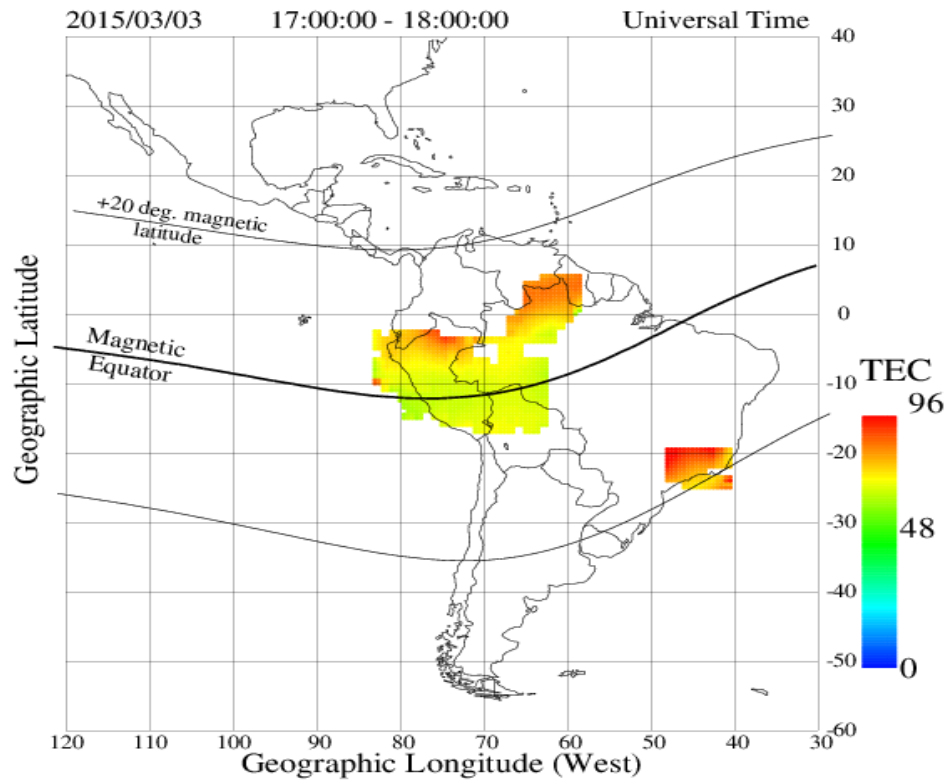
The Ionosphere is characterized by the Total Electron Content (TEC) density highly dependent on the interaction of the solar activity and the earth geomagnetic field

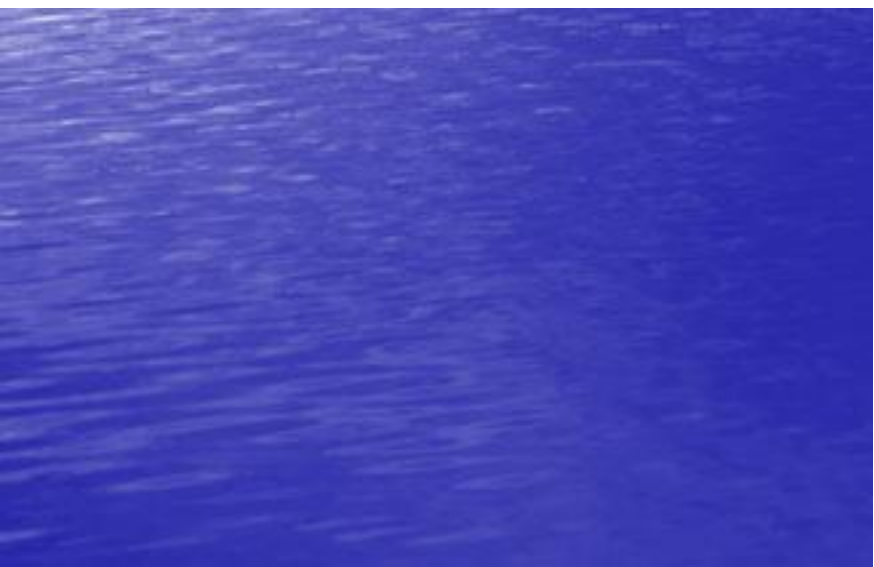
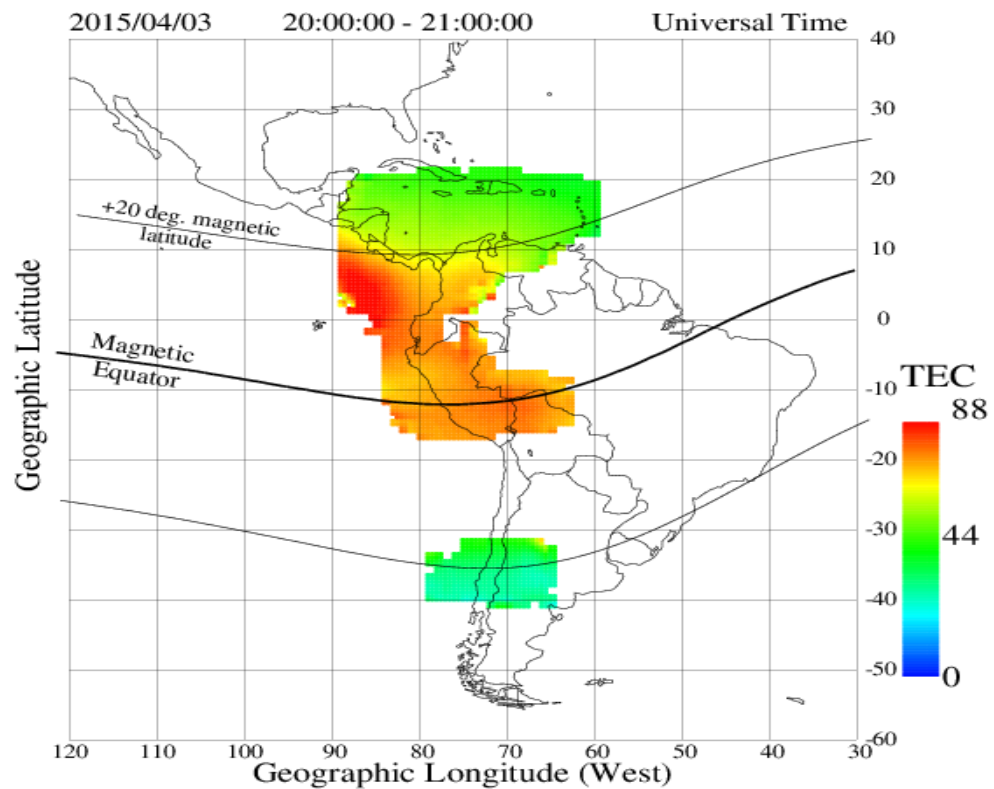
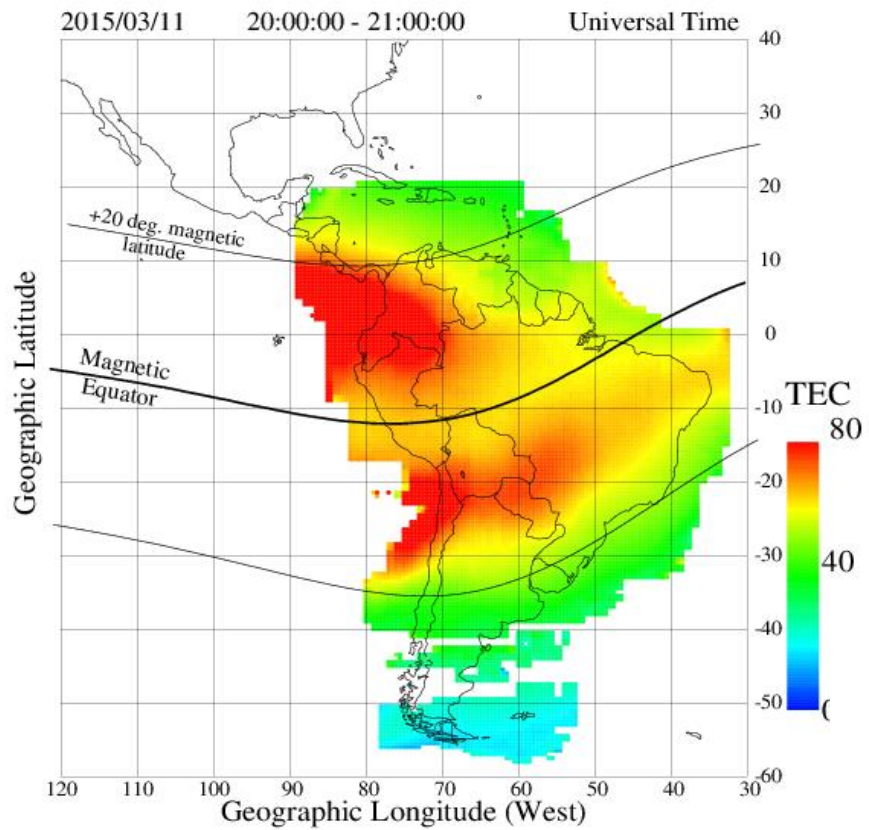
DATA OF LISN

Low-Latitude Ionospheric Sensor Network (LISN) is an international project that monitors the low, middle and high atmosphere in the equatorial region with the purpose of studying and forecasting the ionospheric phenomena, with special emphasis in dynamic and photochemical energy transport processes. For this purpose LISN is a permanent array of new geophysical instruments in South America, closely coordinated as a “Distributed Observatory”. All of these instruments have been installed near the position reference of the Magnetic Equator and the Meridian 70°W .

For this “Distributed Observatory”, LISN contemplates the set up of 50 GPS stations, 5 Magnetometers and 5 Ionosondes, centralized at Jicamarca Radio Observatory (Lima, Peru).







Statistically the TEC is related to the change of distance according to:

$$\# \text{ meters} = \text{TEC} / 6$$

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. Scintillations can cause that there is no signal of one or more GPS / 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).



AUGMENTATION SYSTEM FOR PERU AND/OR SOUTHAMERICAN REGION:

- Equatorial region (Low Latitude) is hostile for the GNSS signals, requires more investigation.
- Less air traffic in Southamerica than Northamerica (Medium Latitude) .
- Continuos study of the scintillation in more detail as the main constraint on the use of two frequencies (L1 and L5) for vertical guidance.
- The scintillation can seriously affect the continuity and availability of GNSS. -
- Empirical model of a TEC Map to evaluate the feasibility of implementing a Ground Augmentation System (GBAS) or a Satellite Augmentation System (SBAS) at Low Latitude Region
- Cost - benefit analysis



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)**
- **Need of strategy analysis to identify SBAS/GBAS implementation.**
- **Space Weather effects happen in the Ionosphere from 80 to 600 km approx.**
- **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.**



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