Development of CubeSat instrumentation and ground-based receivers at the Jicamarca Radio Observatory for TEC measurements

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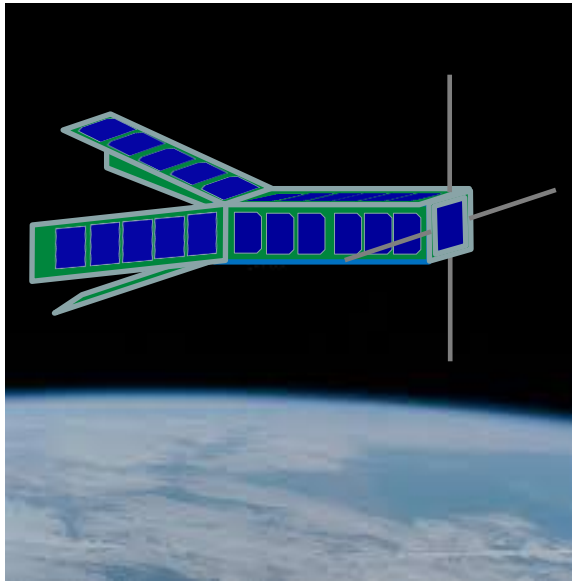
CubeSat instrumentation and ground-based receivers at the Jicamarca Radio Observatory for TEC measurements

Outline

- Motivation
- Introduction
- Methodology
- Transmitter
- Receiver
- Mission concept

JRO
Located at ~20 km east of Lima, Peru (11.95º S, 76.87º W).

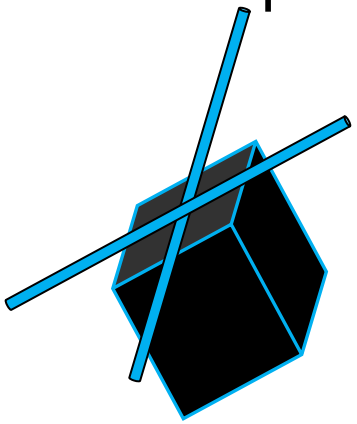
Motivation



- Obtain **TEC measurements**.
- Investigate the **ionospheric variability** by using space-based instruments in addition to the ground-based radar measurements.
- Detect **irregularities**, spread F.
- Combination with **Jicamarca measurements**.
- Extend network of receivers.
- Conjugate phenomena, LSWS.

Space-based instruments

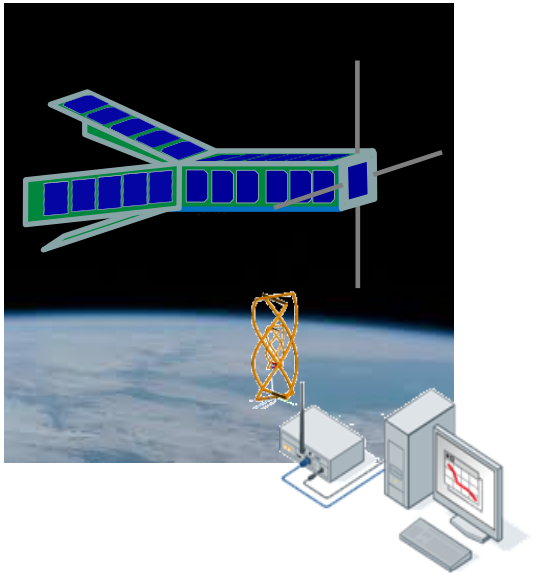
- New contribution:
  - Develop Radio beacon instrumentation for cubesats for TEC measurements.
  - First Peruvian satellite instrument for ionospheric research.
- Design and development phase



Methodology

- Develop a nanosatellite radio beacon for Low Earth Orbit.
  - 2 frequencies VHF, UHF.

    150, 400 MHz
  - Coherent signals.



- Develop a ground-based receiver.
  - Digital receiver based on software-defined radio.

Radio Beacon for rockets at Jicamarca

- PERSEUS
- EQUIS II
- Sounding rocket campaign

Radio Beacon installed on the rocket for EQUIS II.

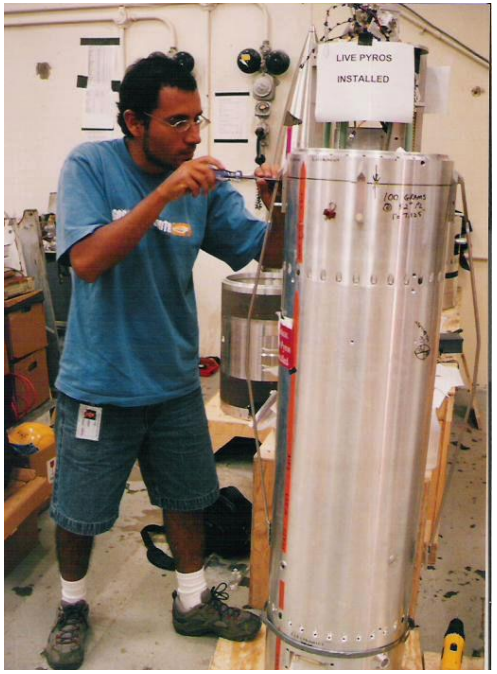
NASA EQUIS II Kwajalein campaign

Radio Beacon for rockets at Jicamarca

Terrier Orion Rocket with the radio beacon developed at JRO onboard before launch

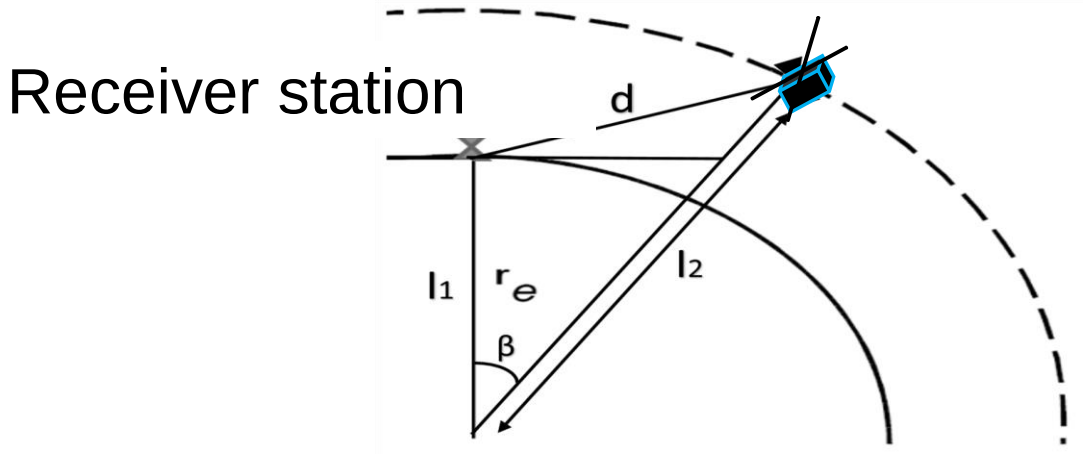
NASA Launches
Aug 7, 2004
Aug 14, 2004
Sept 7, 2004
Sept 17,2004

Radio Beacon for rockets at Jicamarca

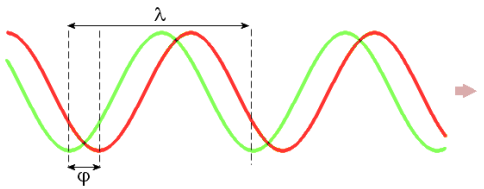


Measurements with satellites at JRO

- TEC can be used for studies of radio wave propagation and by combining several TEC measurements we can obtain an overall description of the ionization in the ionosphere to investigate its spatial and temporal variability and the occurrence of ionospheric irregularities.
- Origin spread F, conjugate phenomena.



TEC measurements



- Phase difference method
- Equations

$$\Delta\phi_f = \frac{\phi_1}{q_1} - \frac{\phi_2}{q_2} = \frac{80.6\pi N_T}{cf_0}\left(\frac{1}{q_1^2} - \frac{1}{q_2^2}\right) = \frac{8.447\times10^{-7} N_T}{f_0}\left(\frac{1}{q_1^2} - \frac{1}{q_2^2}\right) \text{ rad}$$

$$TEC = K * (8\emptyset_1 - 3\emptyset_2)$$

- Differential phase $\Delta\varphi_f$ measures the time delay by comparing the phases φ_1 and φ_2 of two signals on widely separated frequencies $f_1 = q_1 f_0$,and $f_{2=} q_2 f_0$ when they are translated to a common reference frequency f_0.
- N_T is total electron content TEC along the path.

Requirements

- Transmission power> batteries and solar panels.
- Satellite and instrumentation flying in the ionospheric region will be affected by solar radiation.
- The physical dimensions of the transmitter and its control system need to be adapted to the size allowed by the nanosatellite.
- Antennas have to be designed to obtain maximum gain and a stable link between the transmitter and receiver.

Radio beacons and receivers

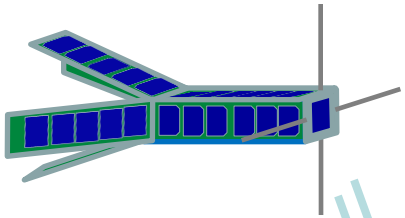
- Radio beacon instruments have been widely used onboard Low Earth Orbit satellites (OSCAR, Cosmos, DMSP F15, COSMIC and C/NOFS.) [Bernhardt, P. A., and C. L. Siefring, 2006].
- The Coherent Electromagnetic Radio Tomography (CERTO) instrument onboard the C/NOFS satellite was utilized to obtain TEC measurements at the low latitudes [*de La Beaujardierre* et al., 2004; *Hei* et al., 2004].

Cubesat Radio Beacons

- Currently, this type of space instrument has not been installed to operate on nanosatellites mainly due to restrictions of space, energy and weight.
- By developing radio beacons that can satisfy the technical requirements of nanosatellites it is possible to develop new missions for obtaining TEC measurements in the ionosphere with constellation of nanosatellites.

Main Concept

VHF	UHF
150 MHz	400 MHz

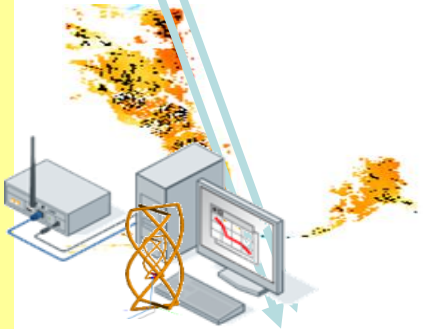


f1 VHF

f2 UHF

Power Tx ~ 1 W

Transmitter frequencies:



Methodology:

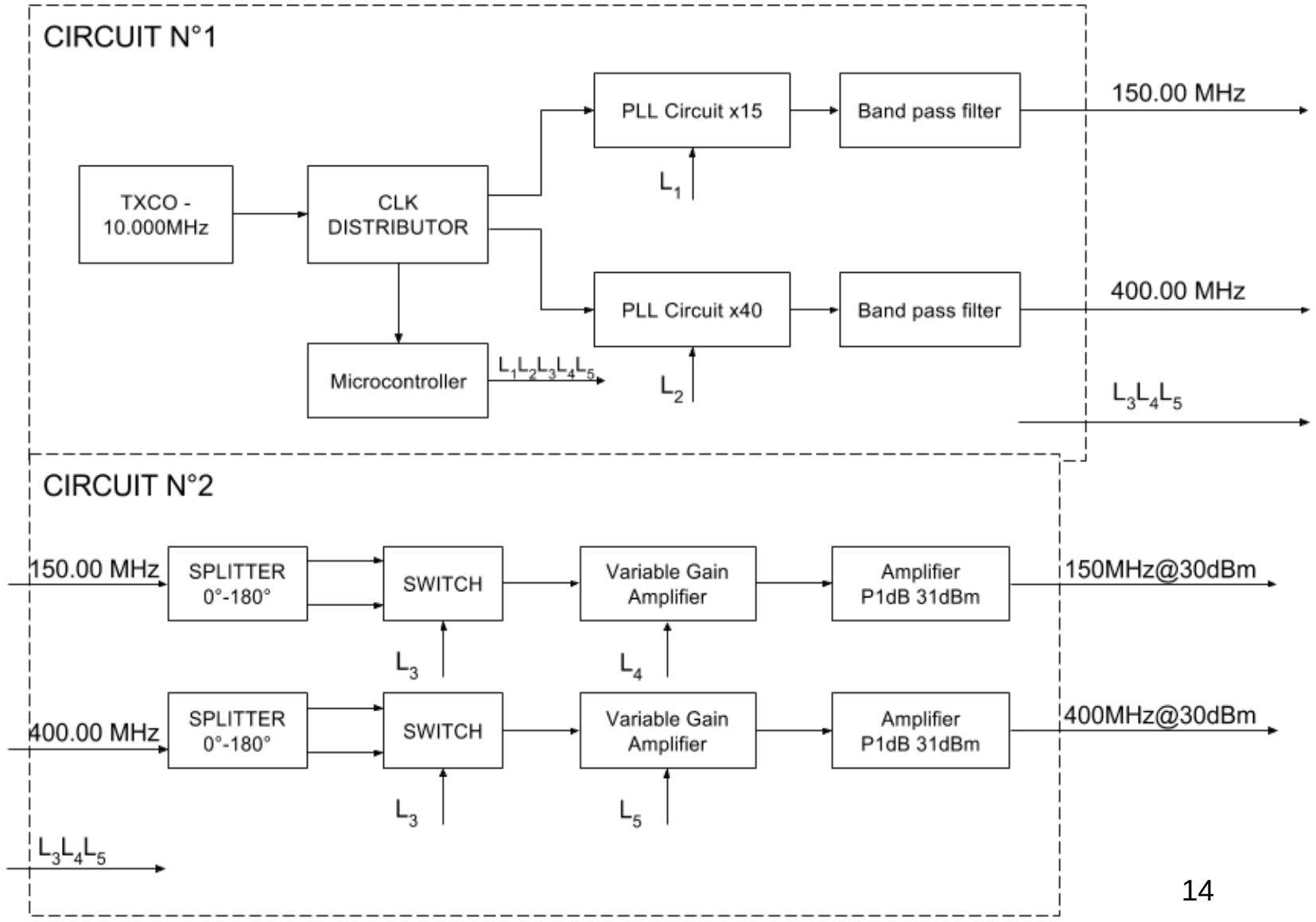
The phase difference between the two received frequencies provides the information of total electron content along the line-of-sight between the receiving station and the space vehicle at any given instant.

[Bernhardt and Siefring, 2006].

Radio waves emitted by the transmitter onboard the CubeSat will be received by ground-based stations.
TEC will be obtained after processing the signals received by detecting the phase difference of the received radio waves.

Receivers based on Universal Software Radio Peripheral (*USRP*) [Yamamoto, 2008].

Transmitter Block Diagram



PTx = 1.0 W

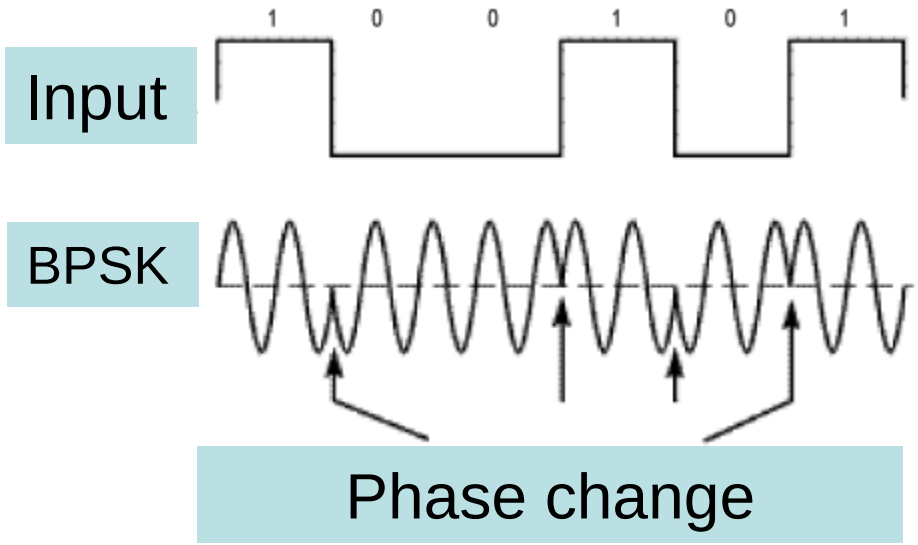
= 30dBm

Loss

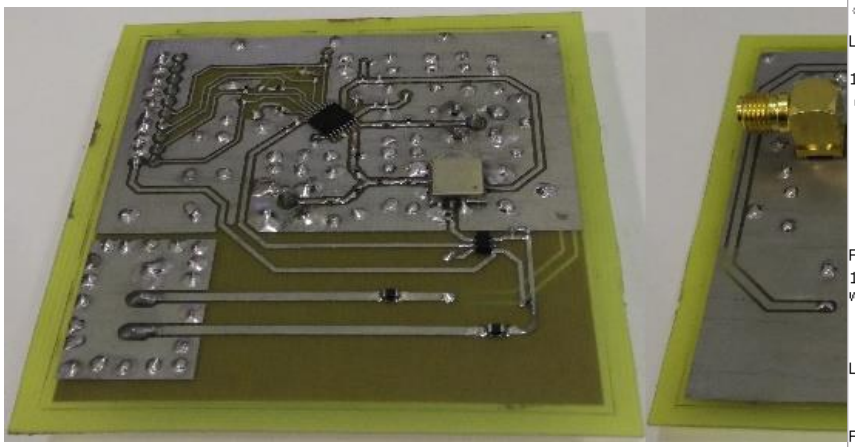
estimated=

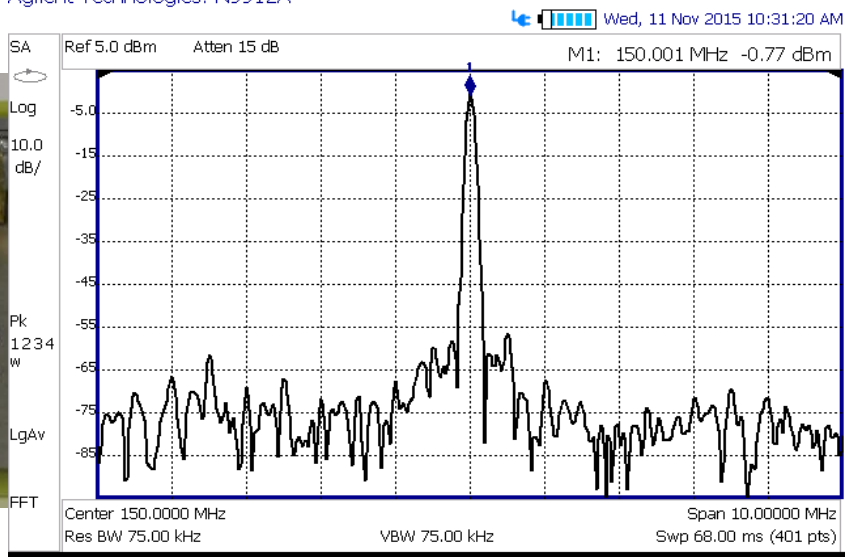
145dB

Modulation

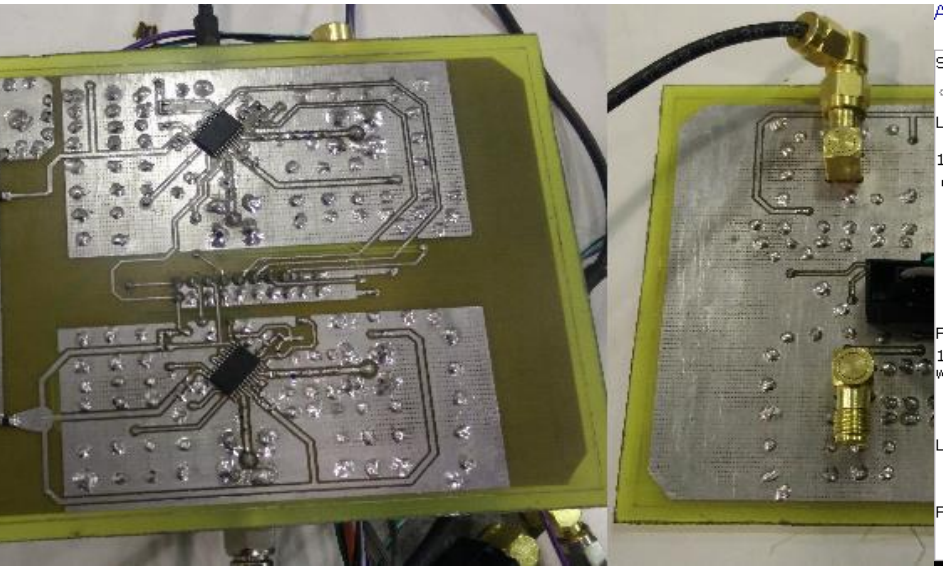


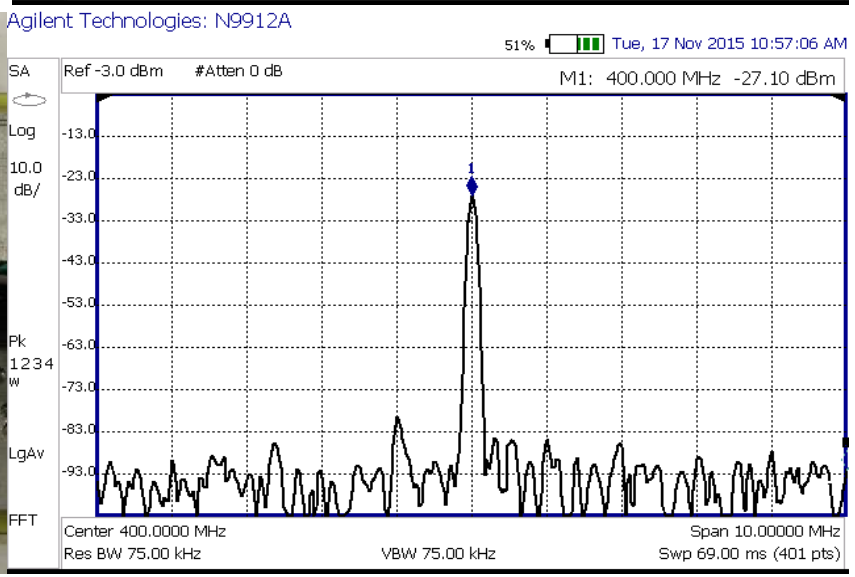
Prototypes





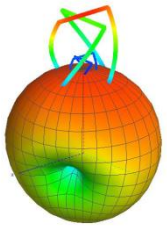
150 MHz

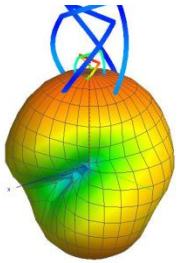


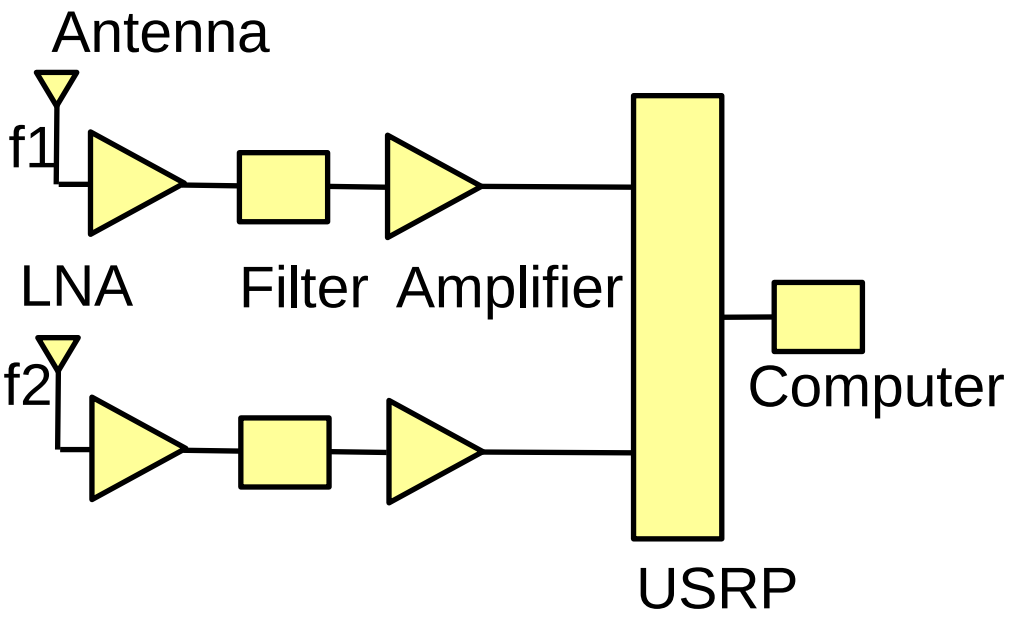


400 MHz

Receiver Block Diagram

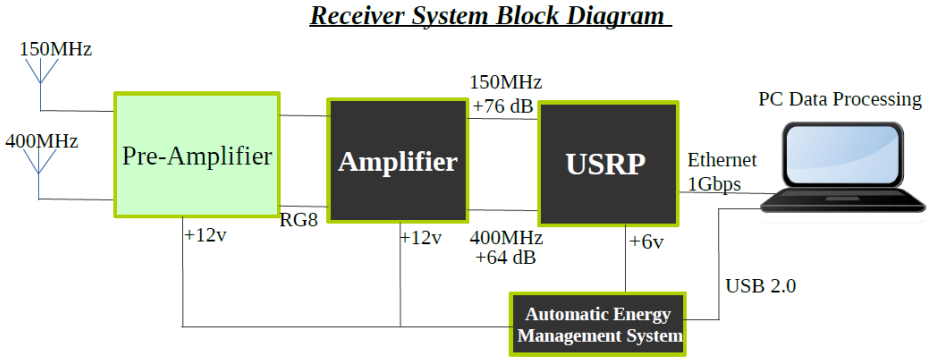




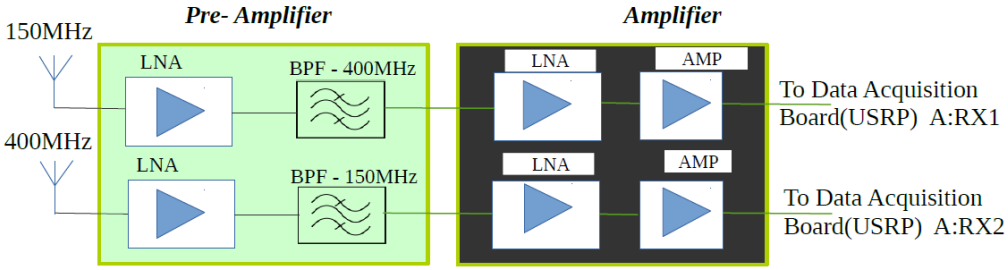


QFH antenna

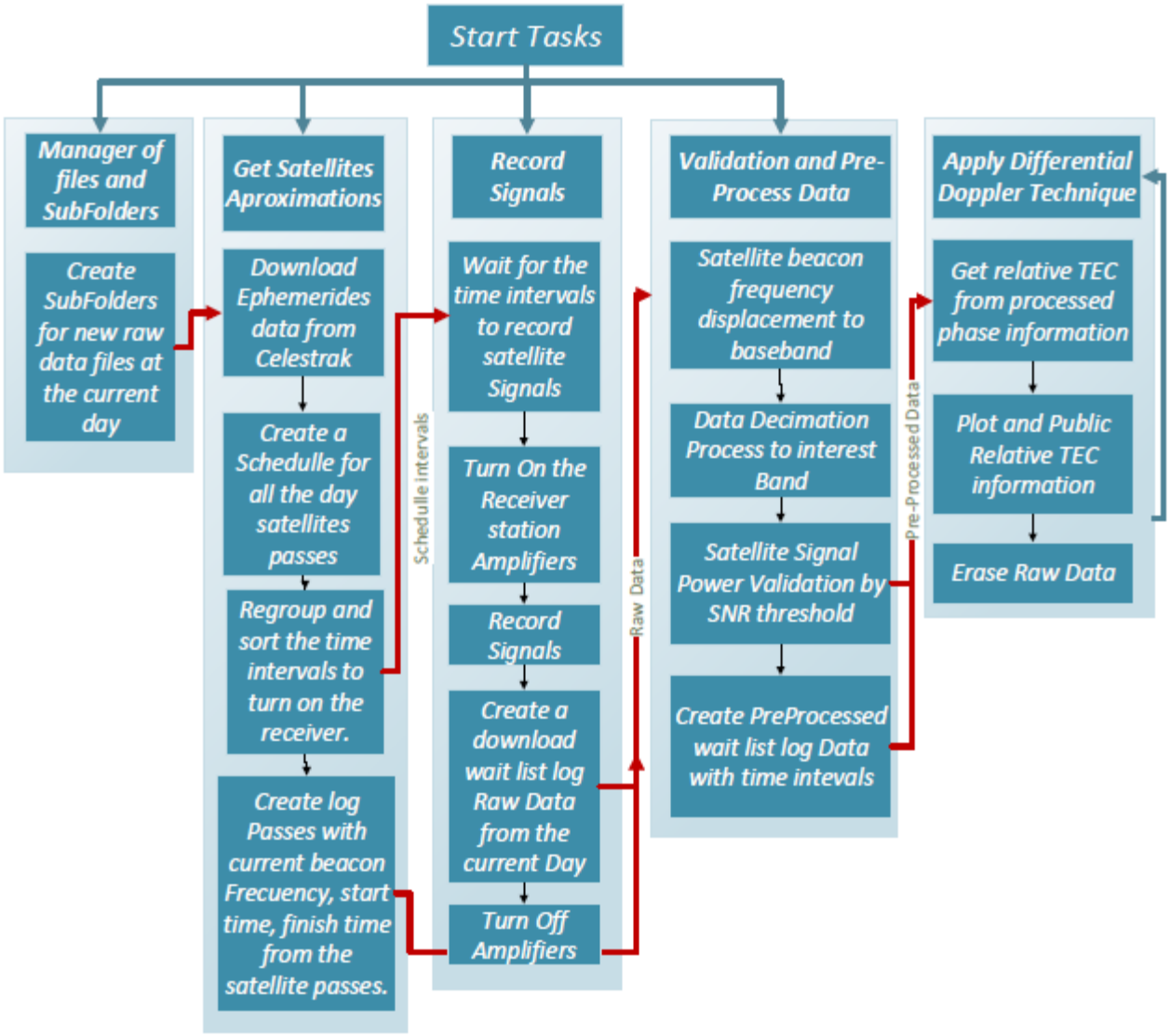
Receiver Block Diagram



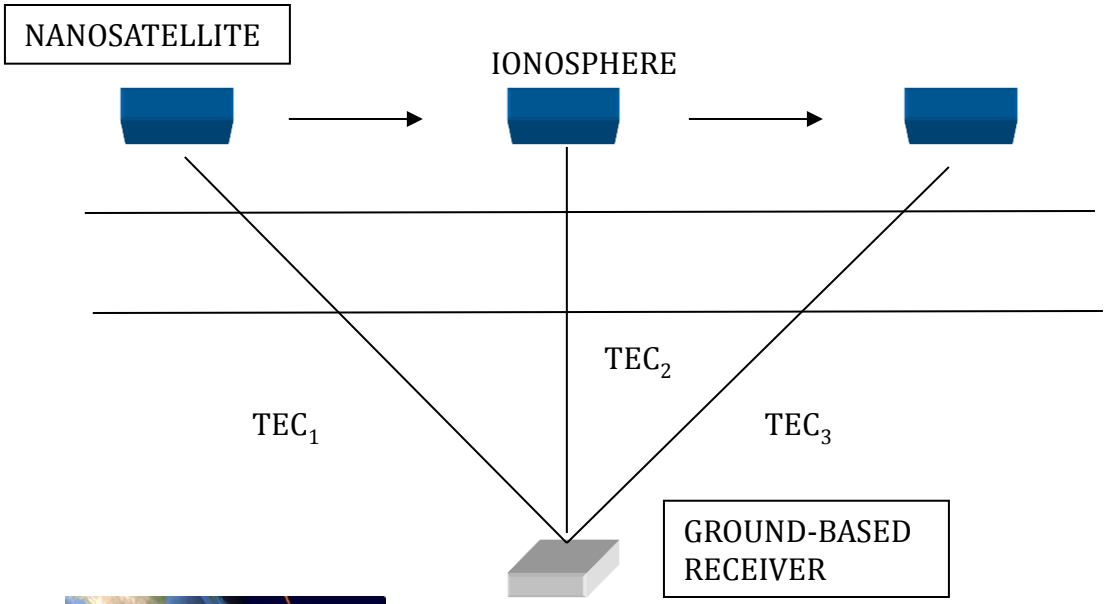
QFH antenna

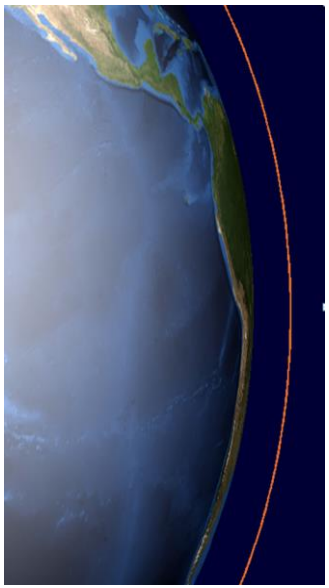


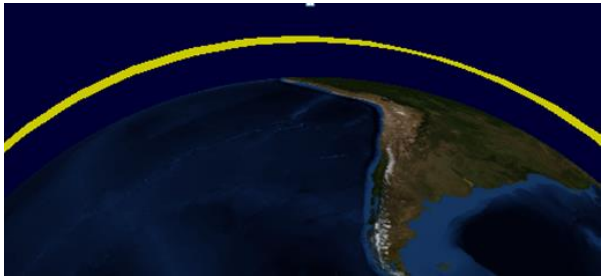
Receiver software algorithm



Proposed mission

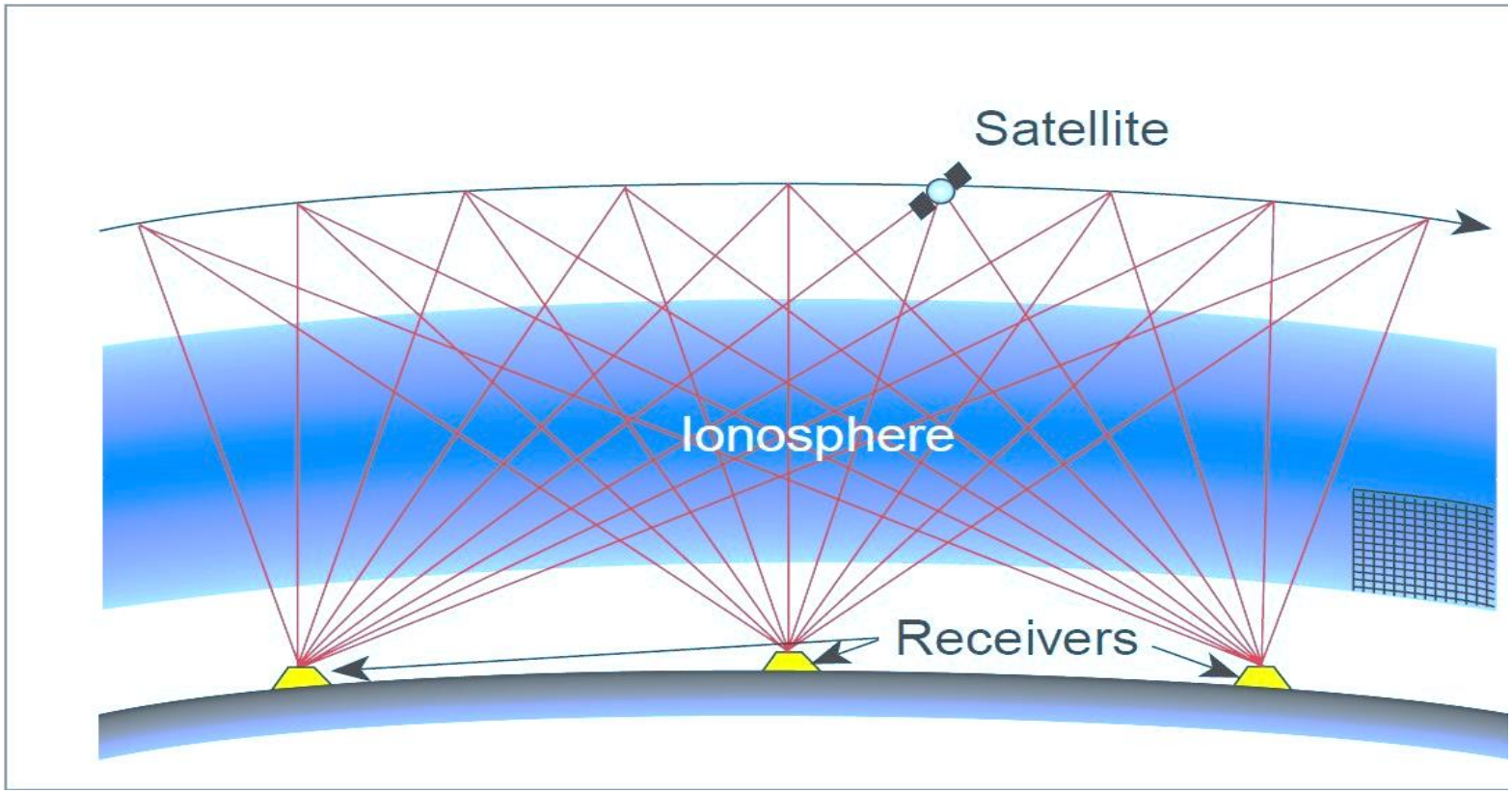




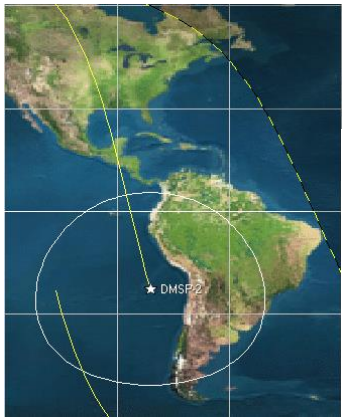


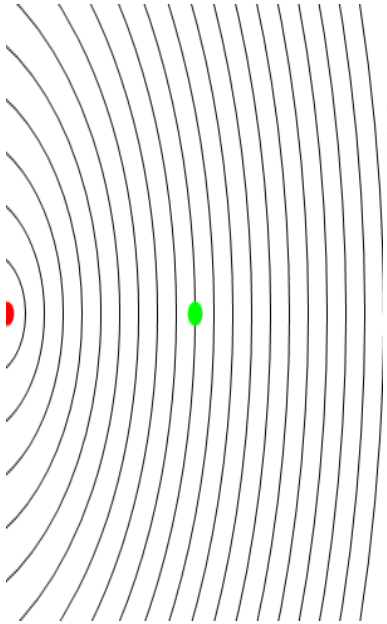
- Nanosatellite orbiting above the ground-base station sending signals at different times to measure TEC along different paths
- Polar (left) and low inclination (right) orbit possibilities for studies of the ionosphere near the Jicamarca Radio Observatory by using nanosatellite radio beacon and a ground-based receiver.

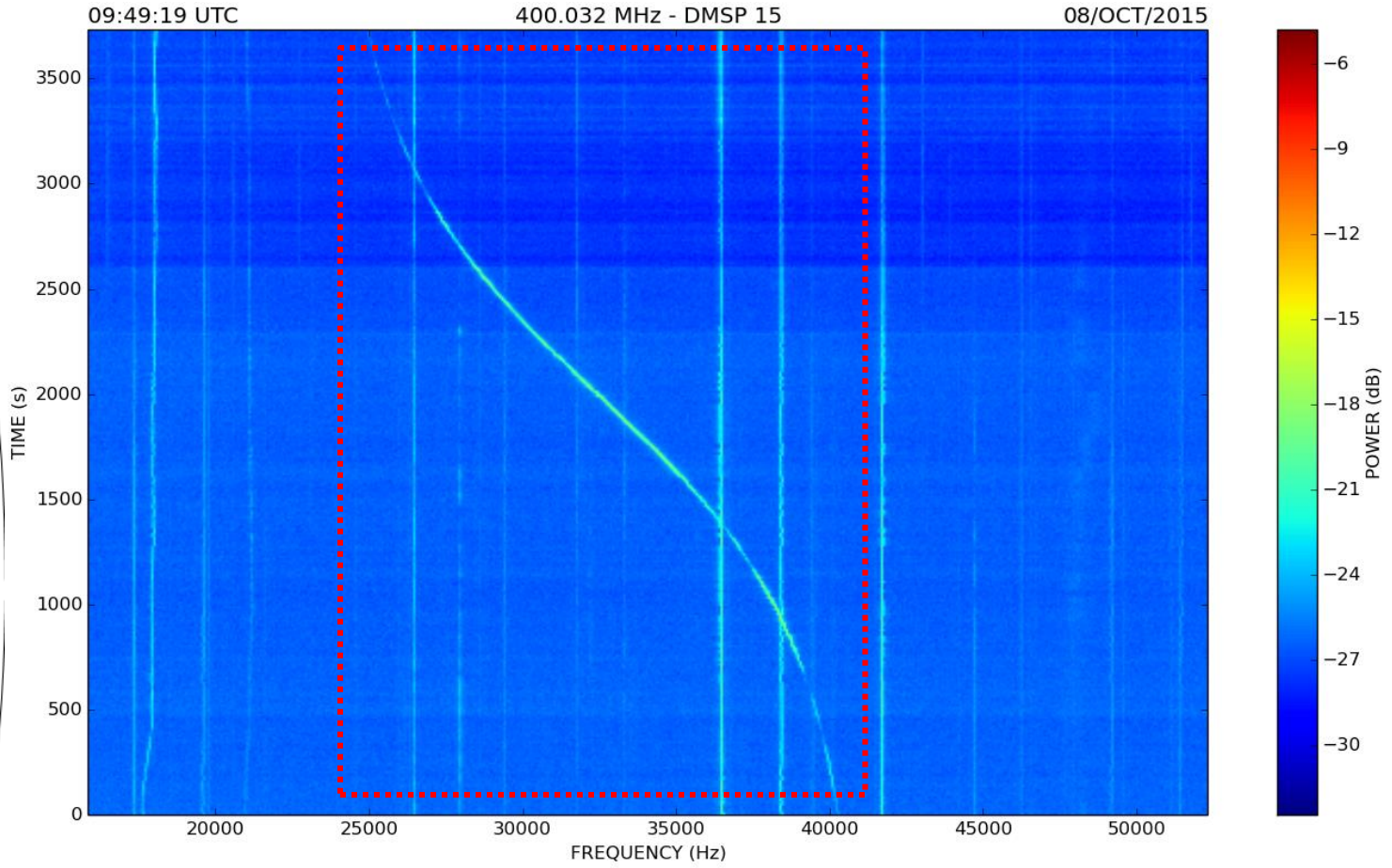
Future work



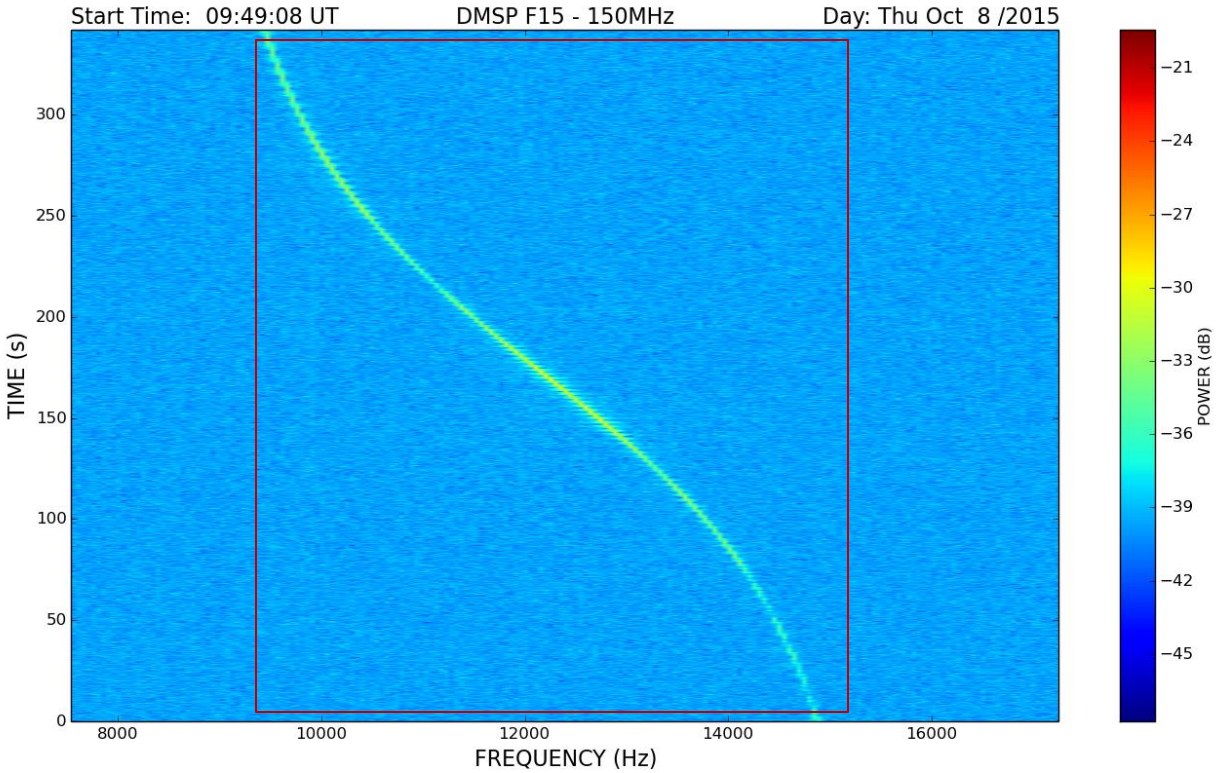
Received satellite signal at 400 MHz





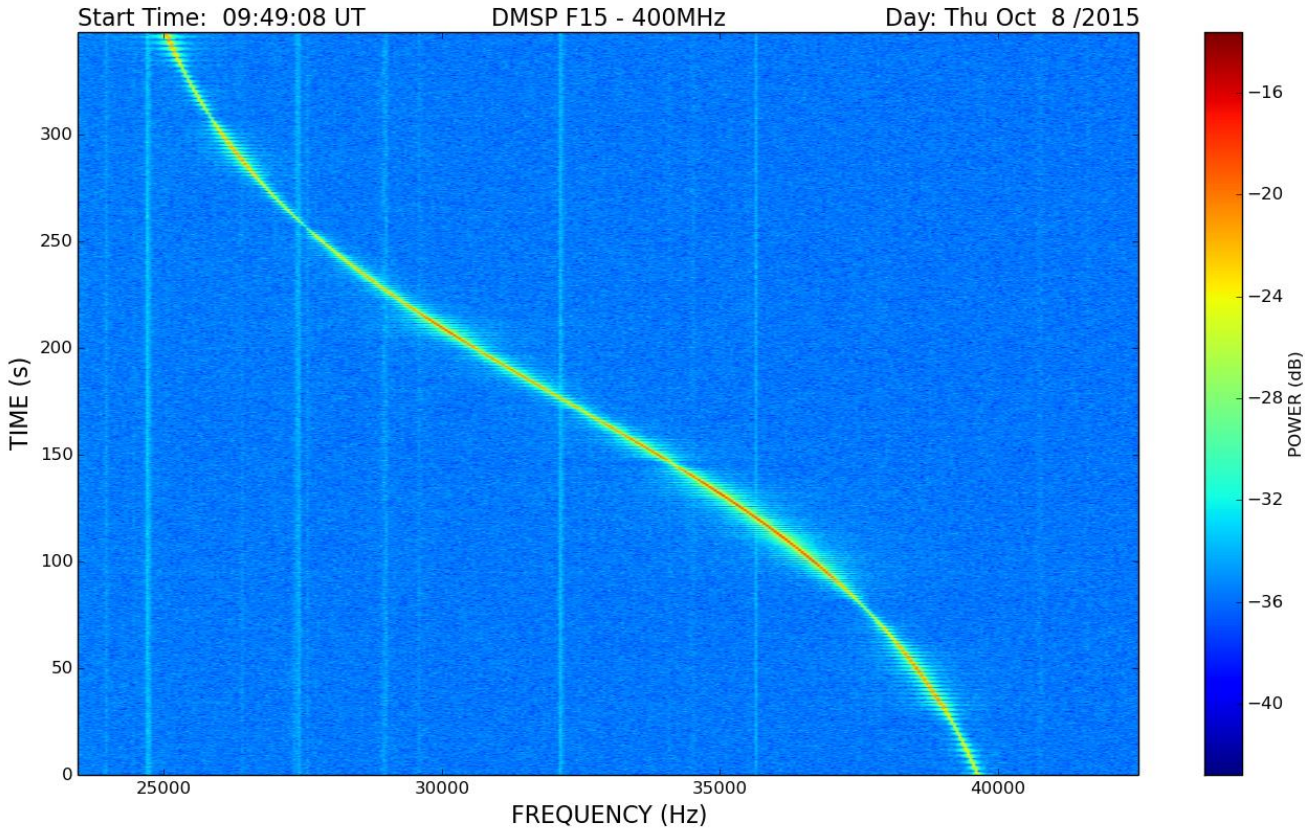


Preliminary measurements



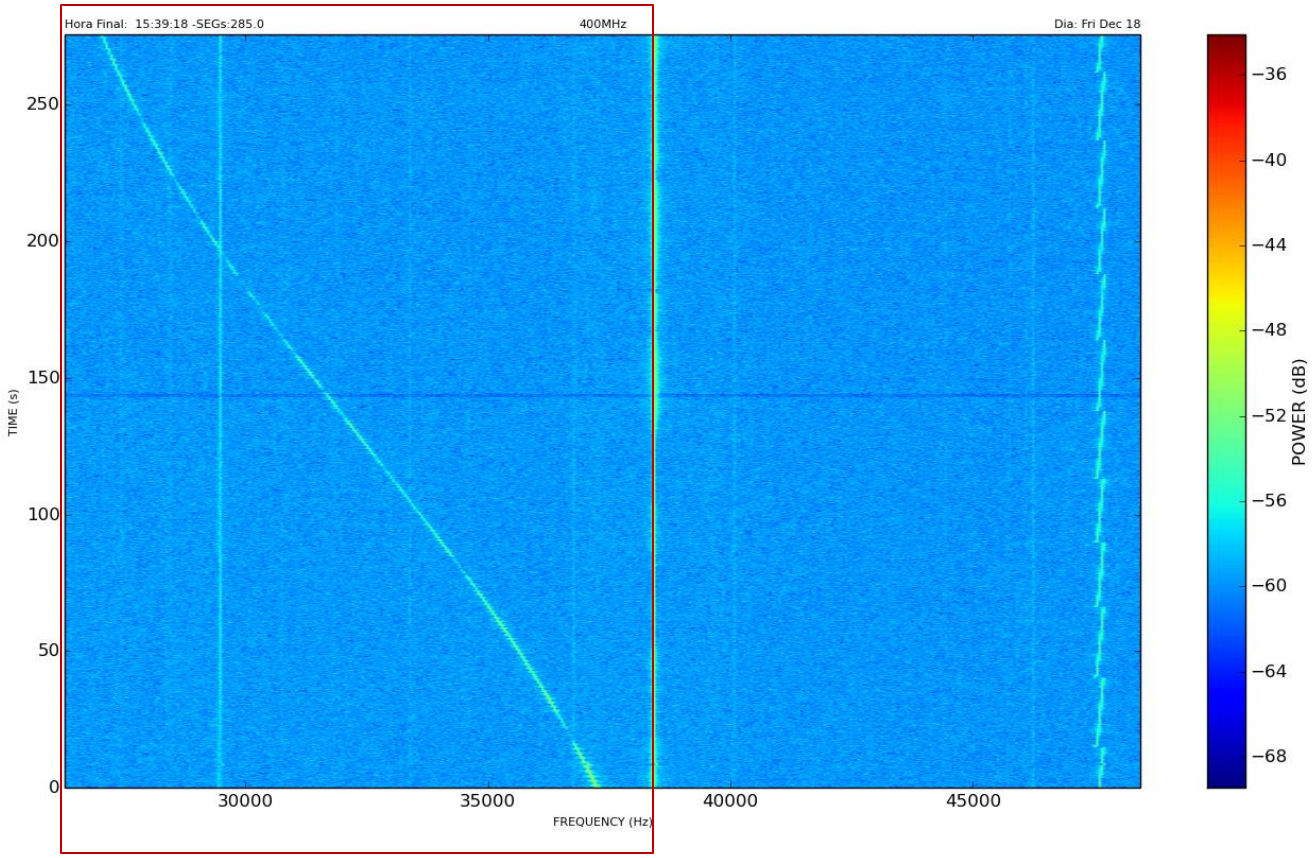
- DMSP when it was orbiting near Dallas, USA.
- The frequency spectrum obtained by applying FFT to the RF signal is shown.
- The Doppler effect is observed in the s-shaped curves.
- The 150 MHz beacon signal with the Doppler effect is observed between 150.009 and 150.015 MHz and the 400 MHz between 400.025 and 400.040 MHz.

Preliminary measurements



- DMSP above Dallas, TX
- 400 MHz between 400.025 and 400.040 MHz.

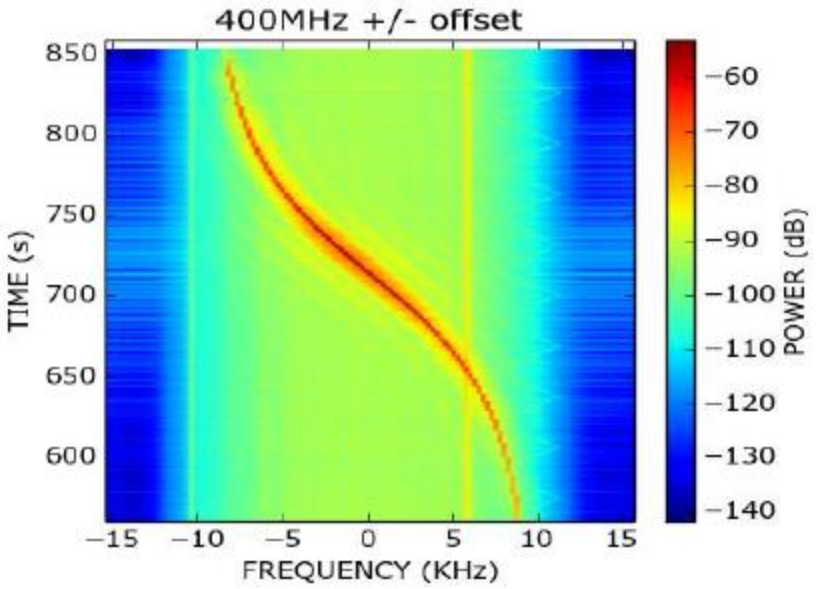
Preliminary measurements

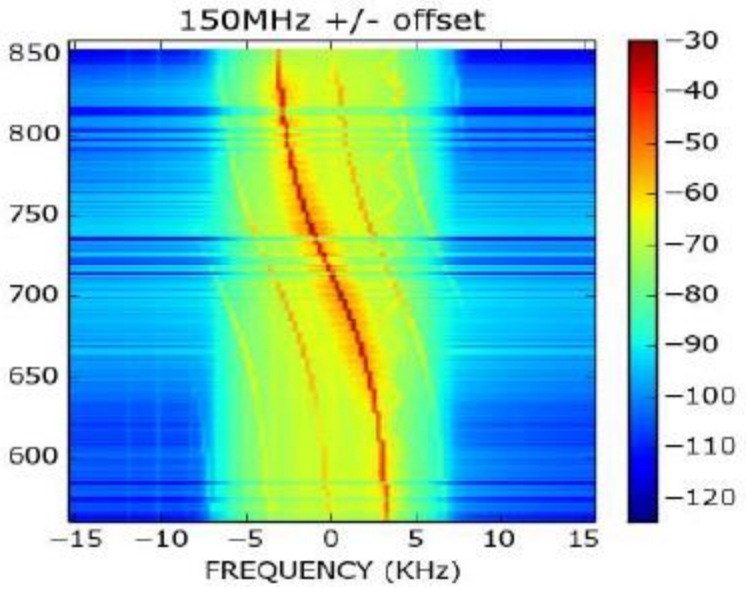


- Measurements of DMSP radio beacon at 400 MHz above Jicamarca

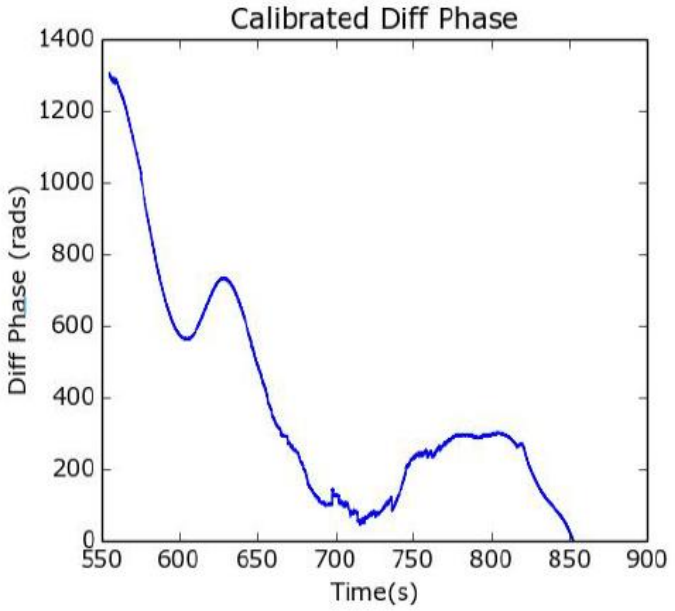
- DMSP 400 MHz signal with Doppler effect in the frequency spectrum.
- The frequency range is detected between 400.025 and 400. 040 MHz
- December 18 2015 near 1535 LT during this satellite pass.

Preliminary measurements at Jicamarca





Cassiope Satellite Plot data relative TEC results, from 15th June 2016 1:17UT.



Cassiope Satellite
Plot data relative
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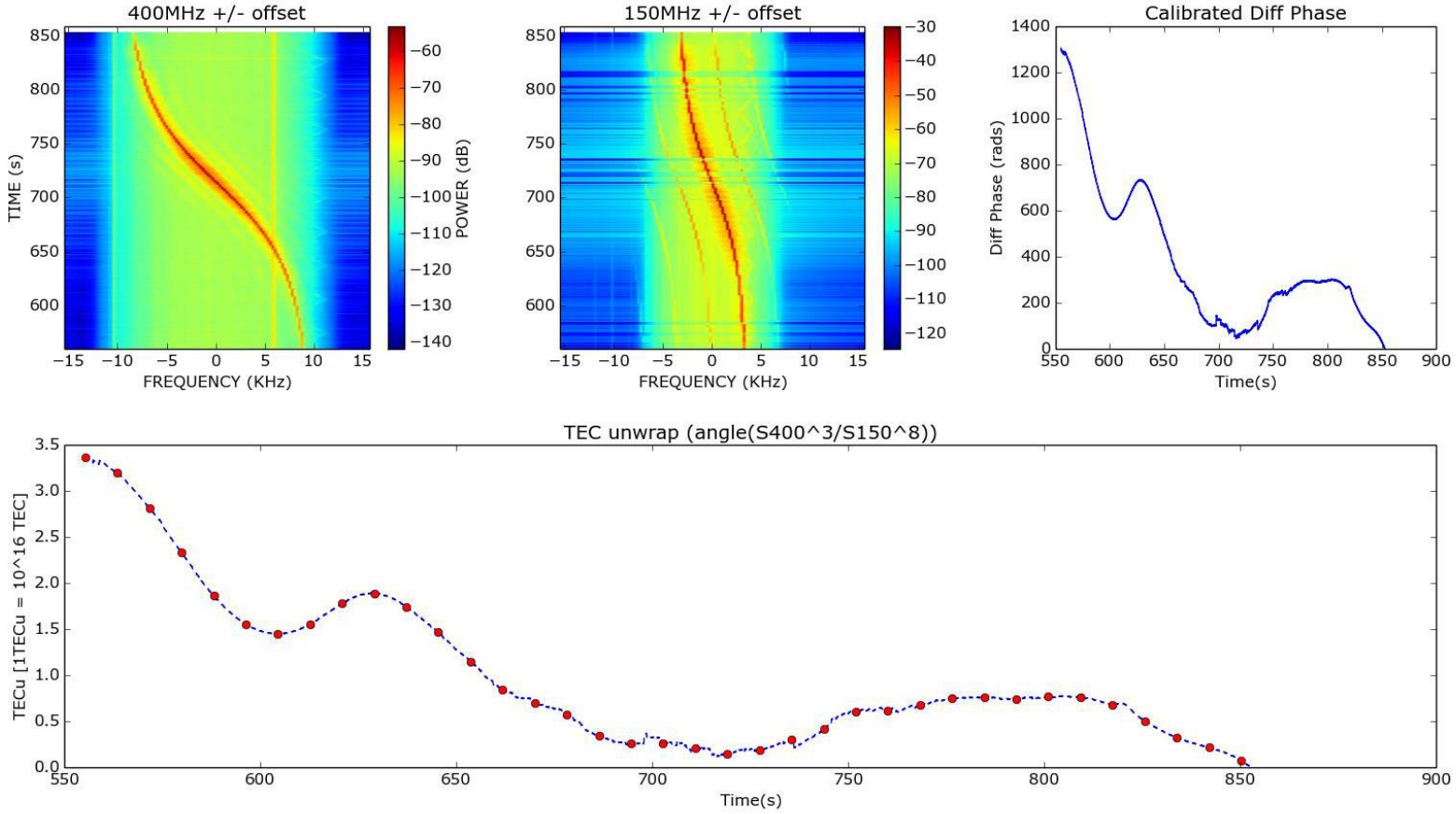


Conclusions

- We are developing a project that consists in the design and implementation of a **ground-based receiver station and a nanosatellite radio beacon transmitter** for ionospheric investigation in the Peruvian sector.
- Total electron content (**TEC**) measurements will be obtained for studying the **variability of the ionosphere** and the occurrence of phenomena such as irregularities.
- The receiver station will be based on software-defined radio equipment and it will be **capable of detecting not only the nanosatellite radio beacon signals but other radio beacons currently in operation** that orbit above the Jicamarca Radio Observatory.
- The TEC measurements will add and **complement the observations** of the already existing ground-based instruments utilized for the investigation of the ionosphere.
- Since we are the prototype design stage **we expect to improve the performance of the hardware and software** used in the implementation of the receiver to obtain good quality TEC measurements.
- The development is at the initial stage but **we plan to increase the number of receiver stations in Peru** to enhance the TEC database in the near future.

Acknowledgments

- **Acknowledgments**

The Instituto Geofísico del Perú gratefully acknowledges the Programa Nacional de Innovación para la Competitividad y Productividad from the Peruvian Ministry of Production for their financial funding support under contract No. 410-PNICP-PIAP-2014 for the project Development of nanosatellite instrumentation and ionospheric measurements and the Pontificia Universidad Católica del Peru for accepting to collaborate with us in our proposed scientific mission.

We also thank The University of Texas at Dallas and Fabiano Rodrigues for their support for our visit and the opportunity to use their equipment for the preliminary tests.

We also thank Jeff Klenzing, Paul Bernhardt, Julio Urbina for their help during our visit to their institutions at the initial phase of the project.

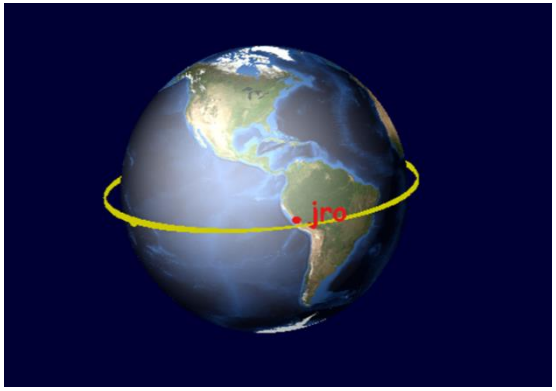
Radio Observatorio de
JICAMARCA
Radio Observatory

Thank you!

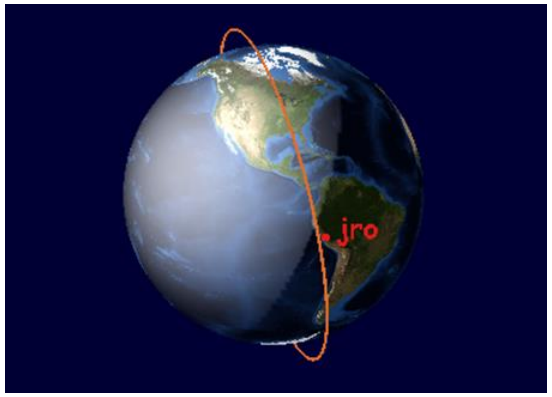
Thank you!

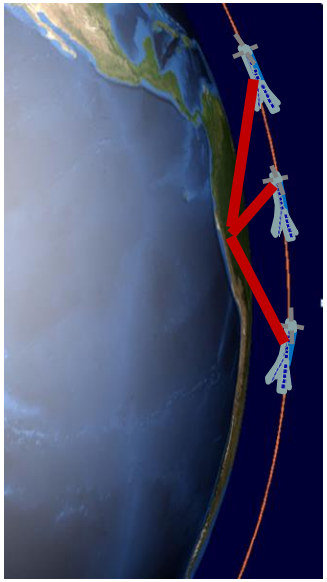
Mission Concept

Low inclination orbit



High inclination orbit





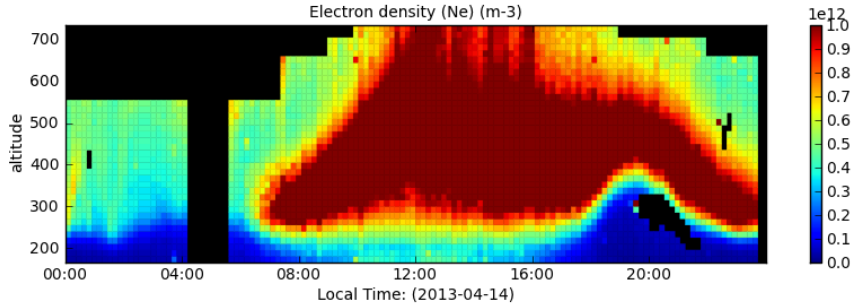
TEC measured at different times

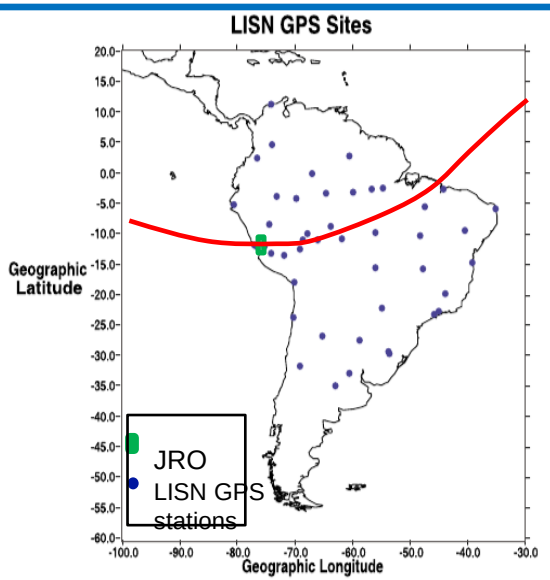
Jicamarca measurements

- Combination of radar measurements
- Density
- Ion drifts
- TEC LISN
- Ionosondes

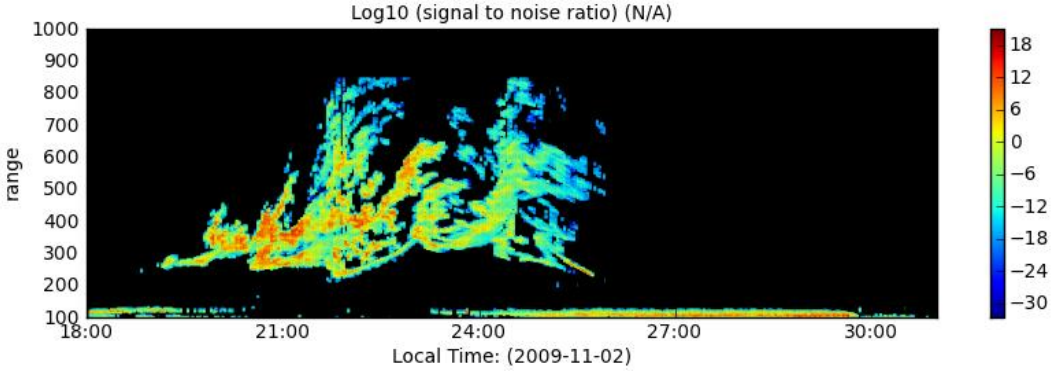
Research

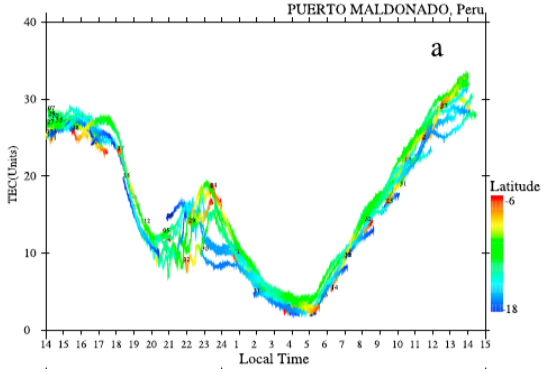
Ne density





Irregularities





LISN TEC

Research Applications

- Investigate ionospheric variability
- TEC mesurements
- Irregularities, spread F
- Longitudinal, latitudinal variations
- Plasma density maps