Study of sporadic E layers based on GPS radio occultation measurements and digisonde data over the Brazilian region

Laysa C. A. Resende, Shi Jiankui, Christina Arras, Inez S. Batista, Clezio M. Denardini, Thainá O. Bertollotto, Juliano Moro, Liu, J., C. Wang

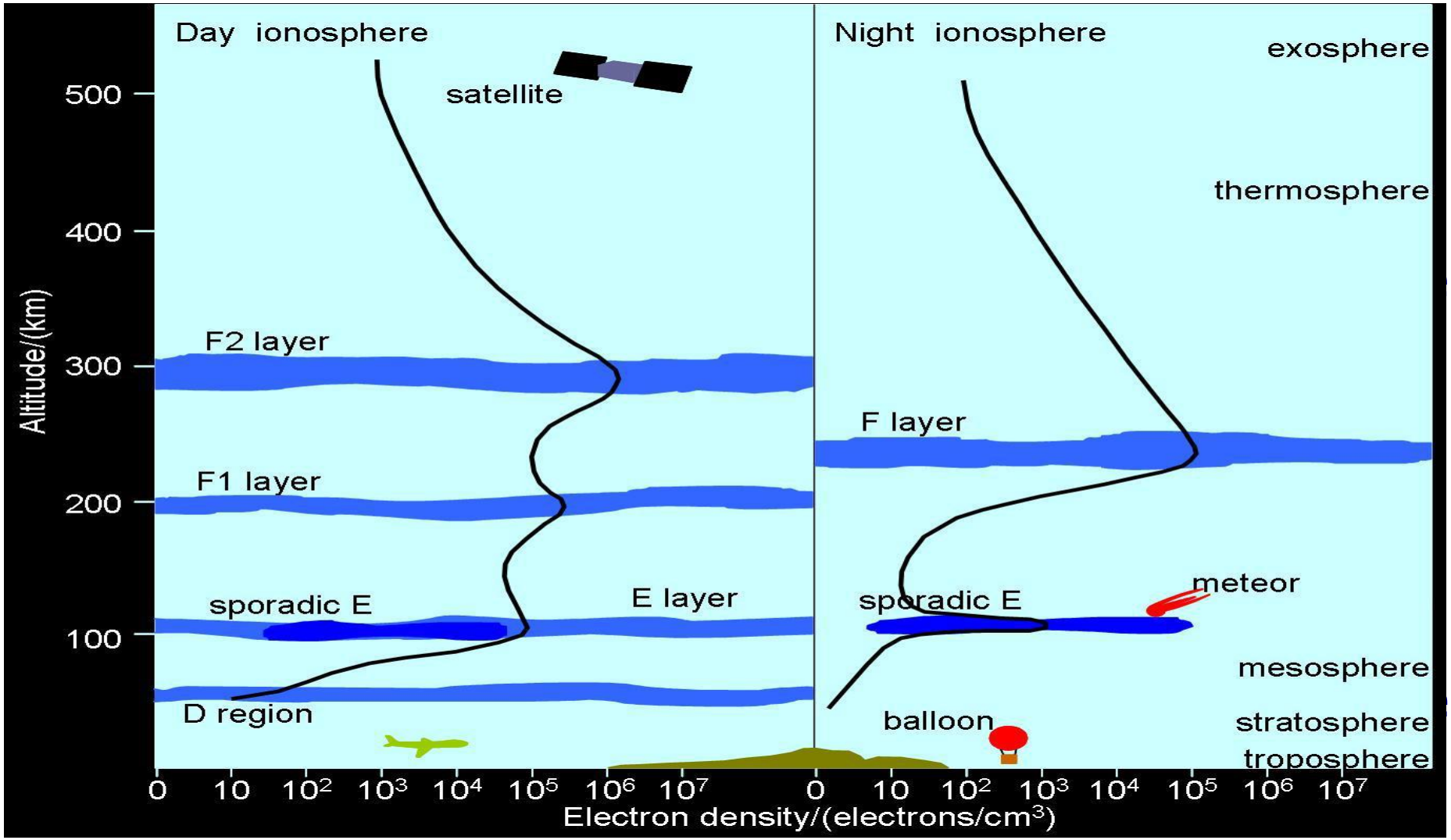
Reference Paper: Resende, L. C. A, Arras, C., Batista, I. S., Denardini, C. M., Moro, J., Bertollotto, T. O. (2018) Study of sporadic E layers based on GPS radio occultation measurements and Digisonde data over the Brazilian region, Annales Geophysicae, 36, 587–593, doi: 10.5194/angeo-36-587-2018

August, 21, 2019

Summary

- INTRODUCTION
  - ✓ Sporadic E layers (Es)
  - ✓ Formation Mechanism of Es layers
  - ✓ Digisonde
- RADIO OCCULTATION TECHNIQUE (RO)
- RESULTS
- CONCLUSION

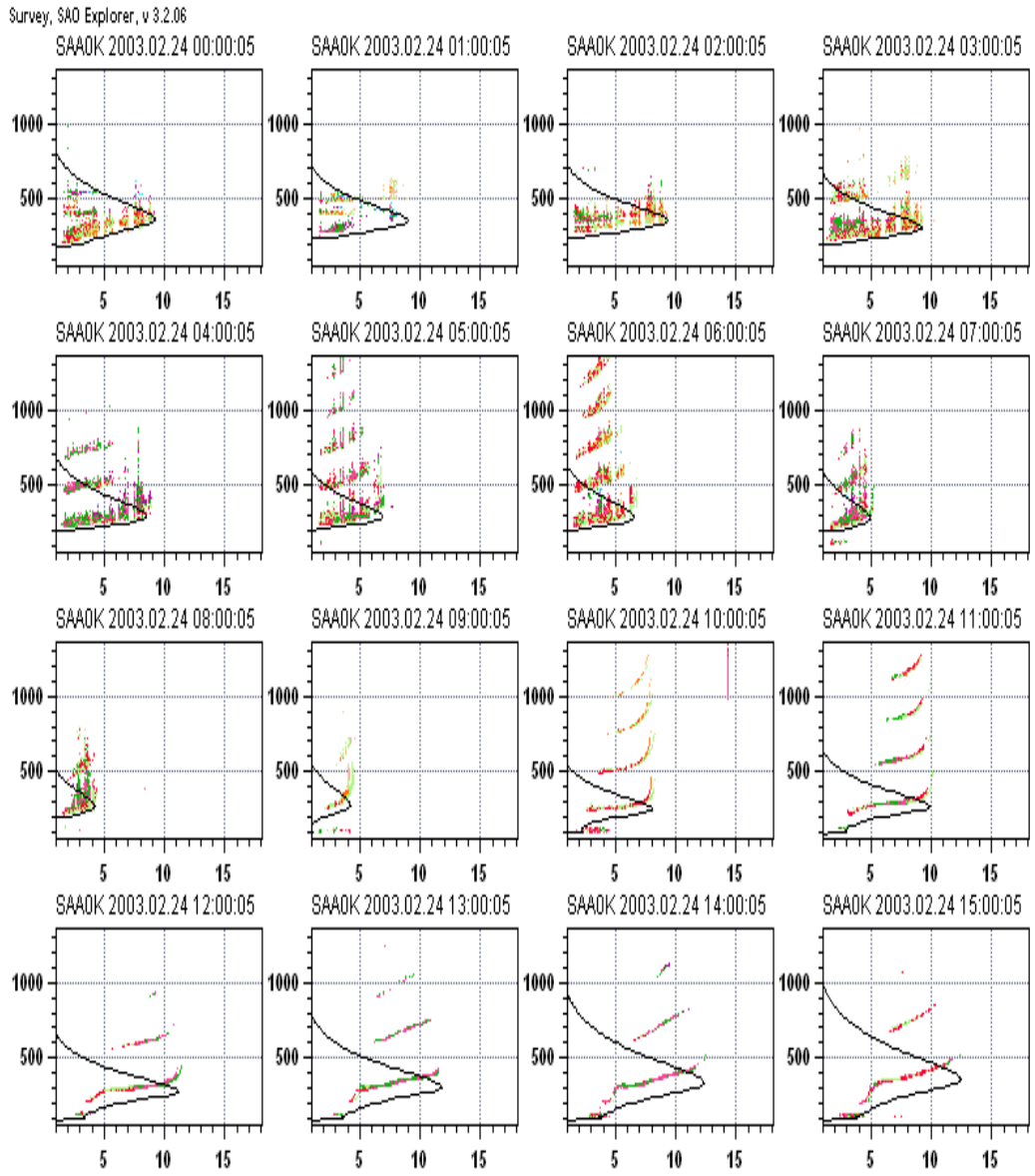
Sporadic E-layer (Es)



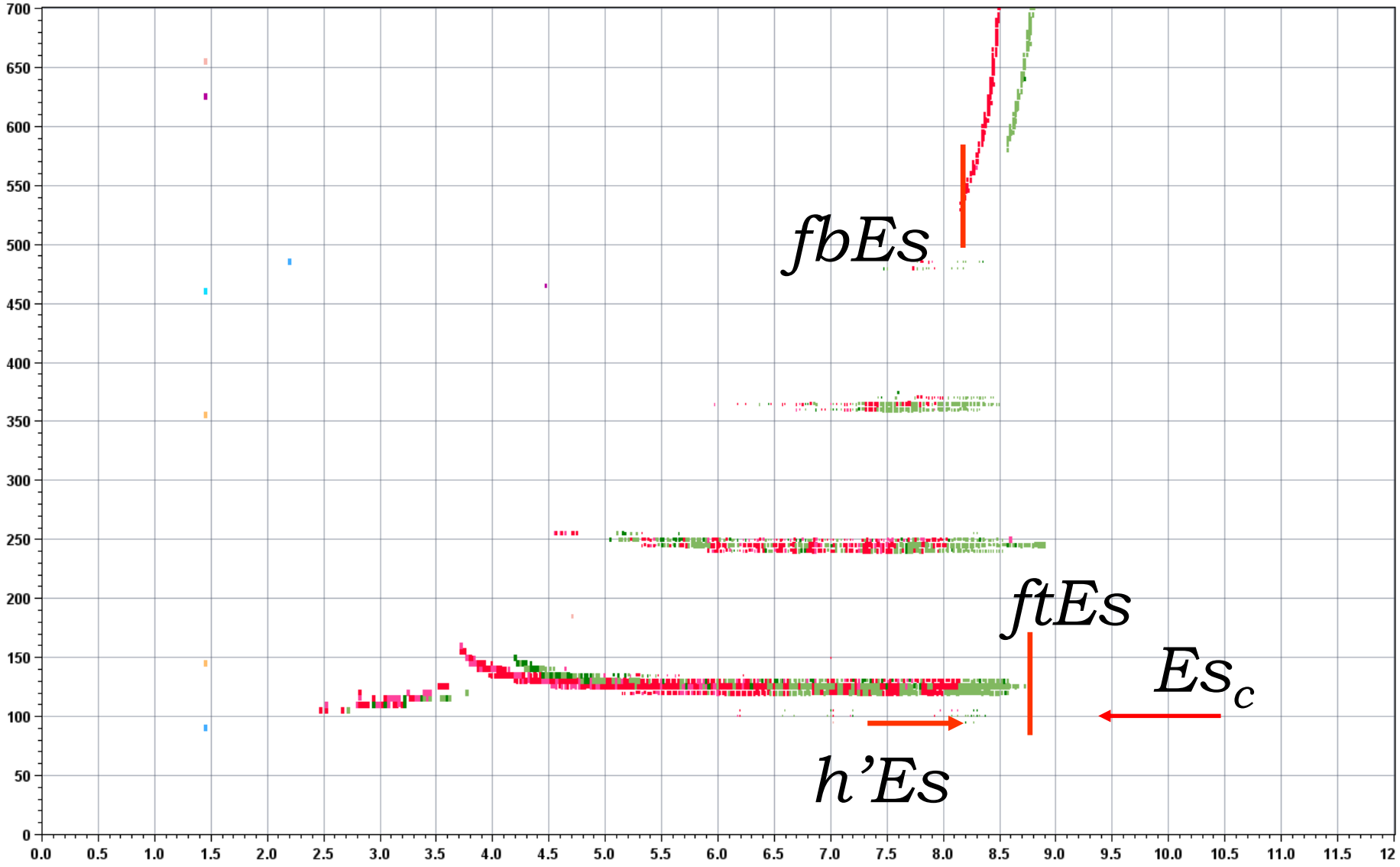
Sporadic E-layer (Es)

- High Latitudes → Particle Precipitation
- Equatorial Latitudes → Electrojet Current
- Low/Middle Latitudes → Wind Shear Mechanism

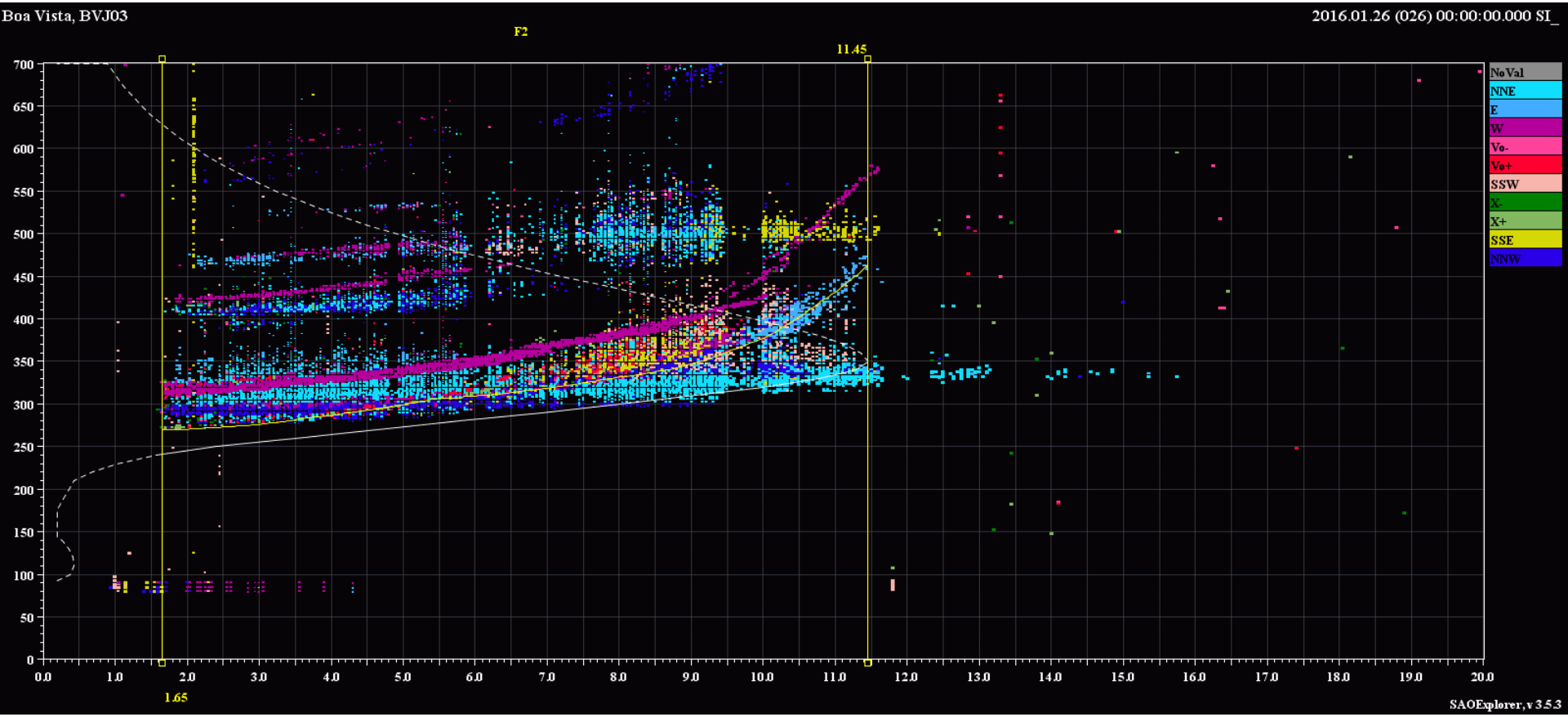
Digital Sounder



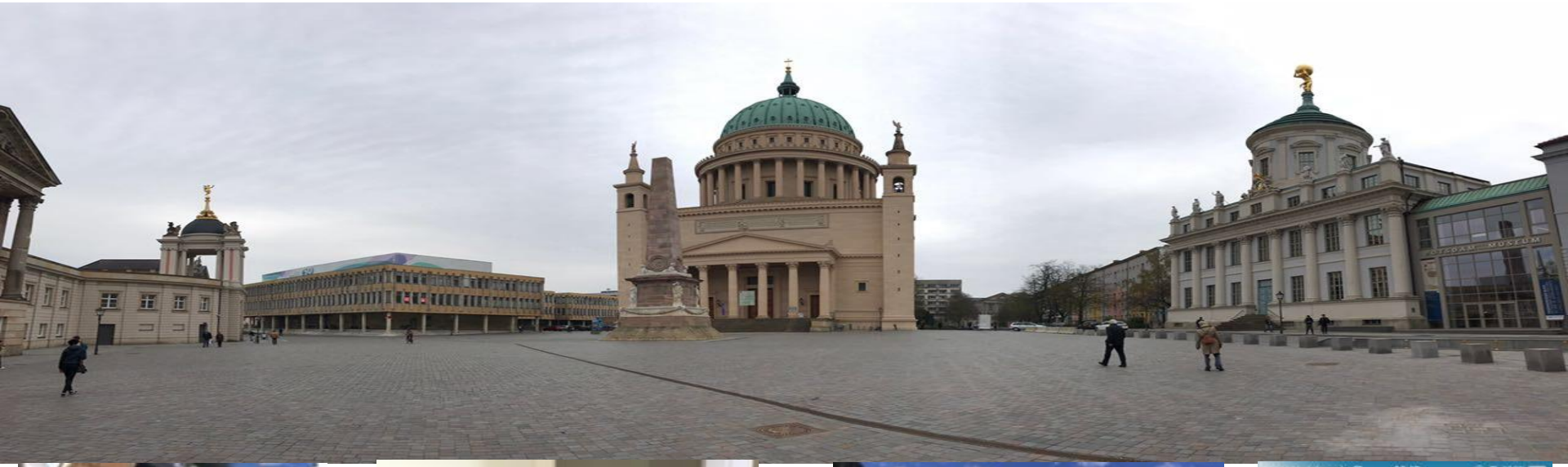
Ionograms –Es layers

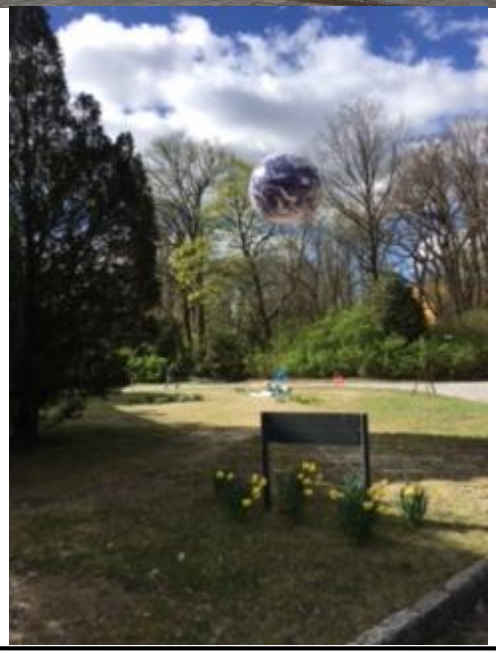


Sporadic E-layer (Es)

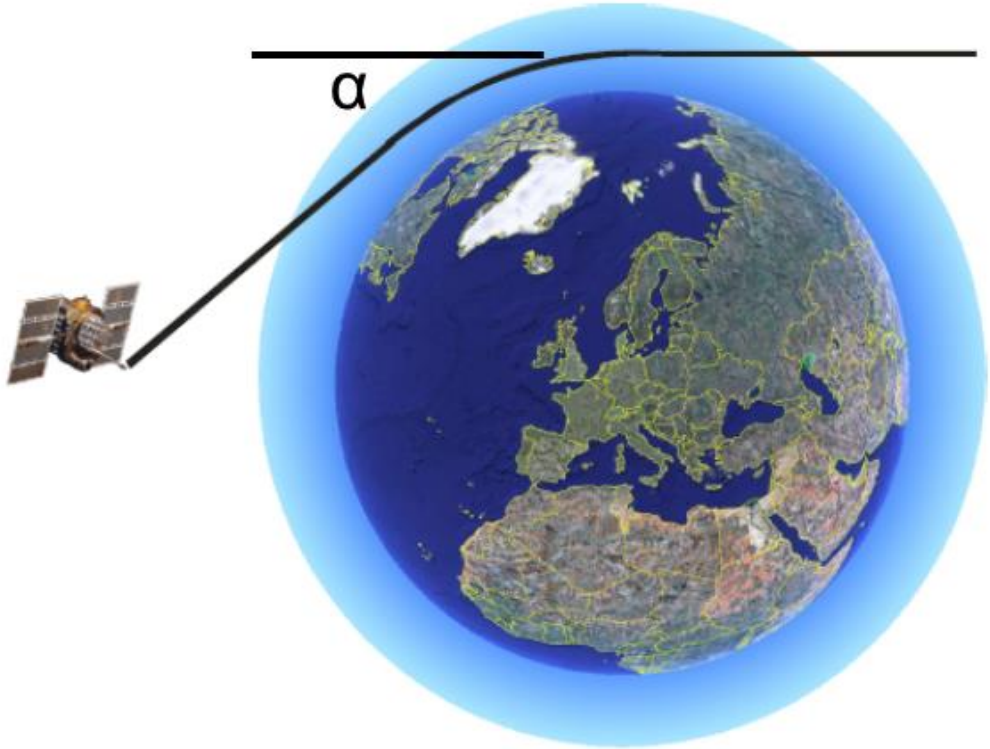


Brazil-German Cooperation





Radio Occultation (RO)



FORMOSAT-3/COSMIC satellites

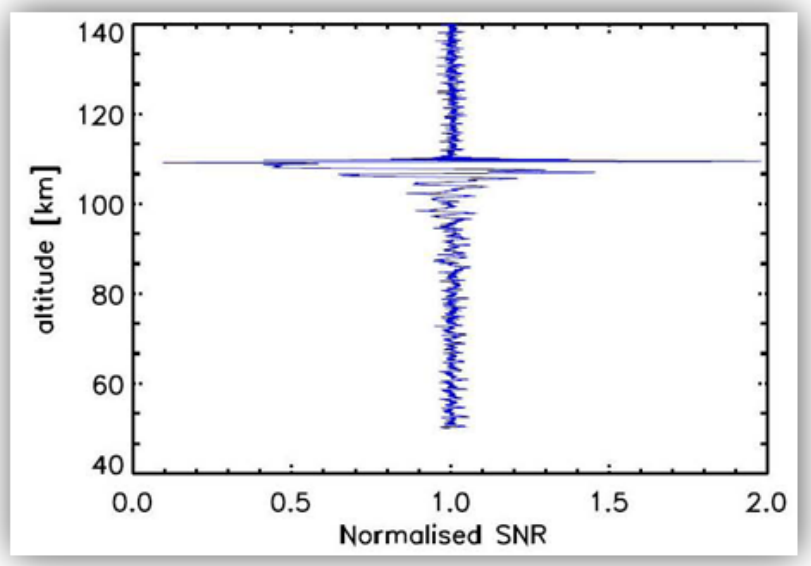
$$N = 77.6\,\frac{P}{T} + 3.73\,.10^5\,\frac{Pw}{T^2} - 40.3\,.10^5\,\frac{N_e}{f^2} + 1.4w.$$

Radio Occultation (RO) – Es layers

- The main method used for sporadic E layers detection from the GPS RO occultation measurements is via signal-to-noise ratio (SNR) profiles.
- Therefore, layers of enhanced electron density in the lower ionosphere such as Es can be identified through strong fluctuations in the SNR;
- In the ionosphere, the phase and SNR scintillations can be directly related to strong electron density fluctuations. In other words, the SNR value of the 50 Hz L1 occultation measurements is directly recorded by the GPS receiver on board LEO satellites. The enhancement layers in the ionosphere cause strong SNR fluctuations. Generally, above 85 km altitude, these fluctuations in the SNR are associated with the Es layers;
- The fluctuations are extracted from the background by applying a band pass filter, which only accepts disturbances stretching between 1.0 km and 12.5 km height range.

References: Arras, C., Wickert, J., Beyerle, G., Heise, S., Schmidt, T., Jacobi, C. (2008) A global climatology of ionospheric irregularities derived from GPS radio occultation, Geophys. Res. Let., 35 (14), L14809, doi:10.1029/2008GL034158.

Radio Occultation (RO) – Es layers

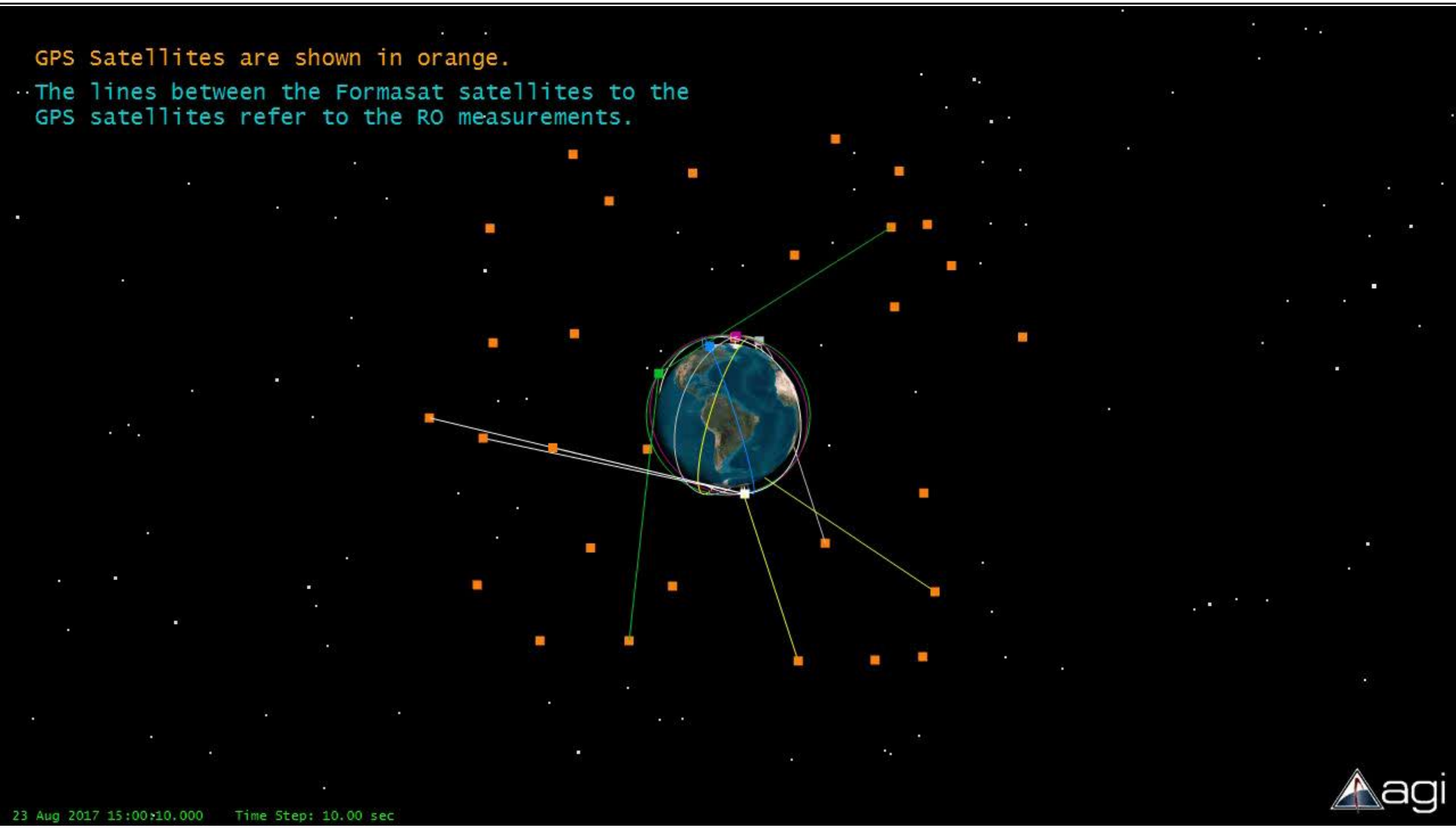


- SNR profiles (50 Hz) of GPS L1 signal (high vertical resolution of ~50 m)
- Normalise profiles
- Calculate standard deviation in 2.0 km running windows
- Identify vertically thin structures by applying a band pass filter
- calculate S4 index around the point of max deviation (51 values)

Information on:

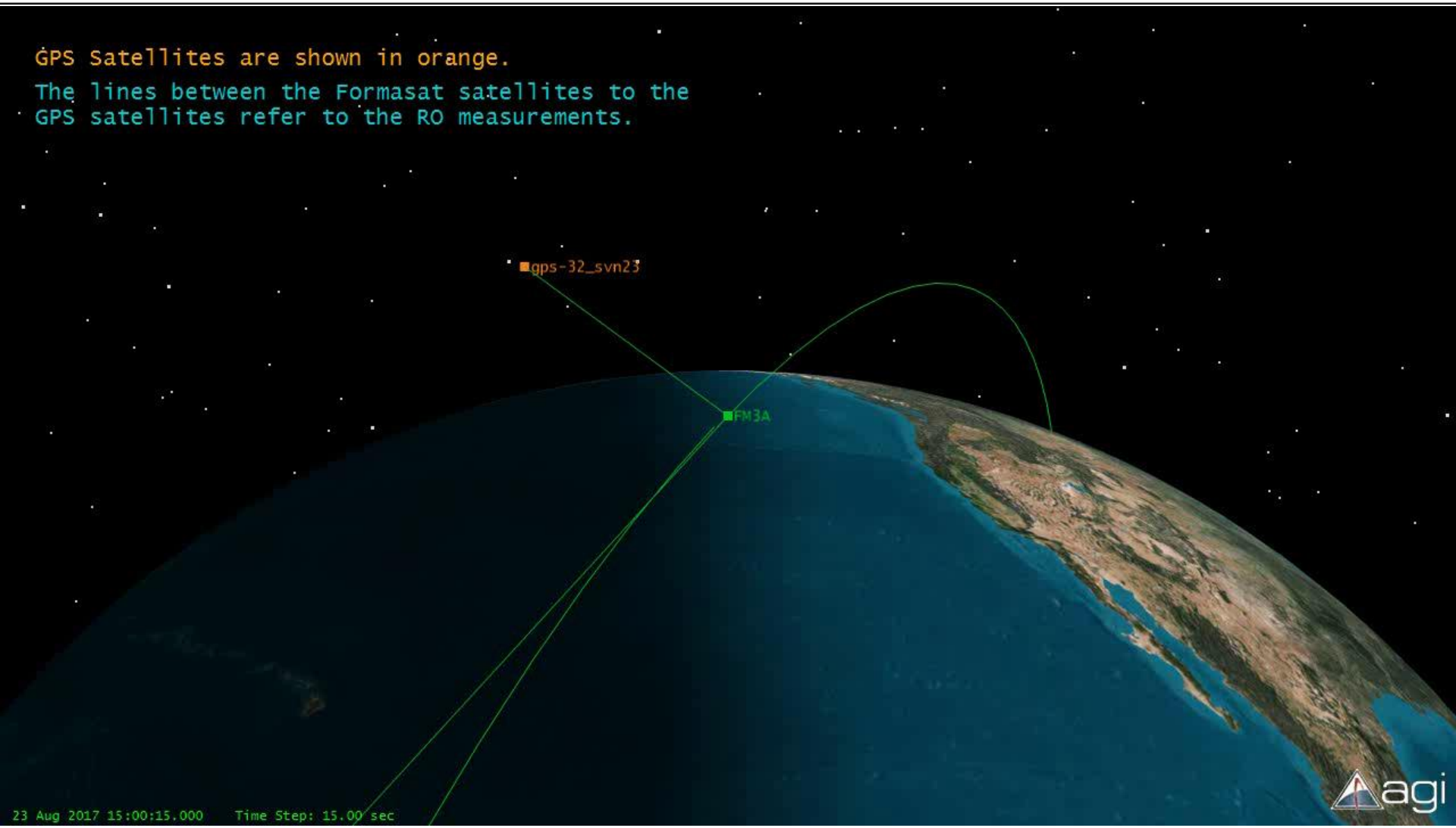
- altitude
- latitude/longitude
- local time
- intensity

Radio Occultation (RO)



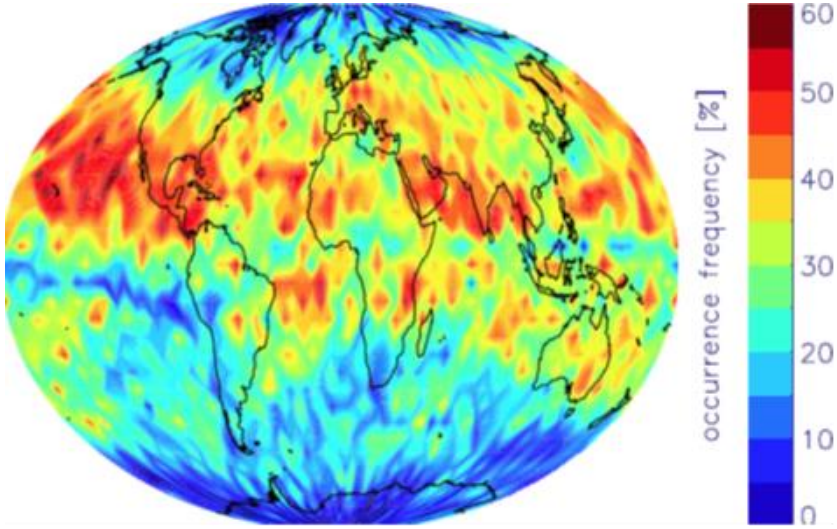
Cortesy: Dr. Chagas

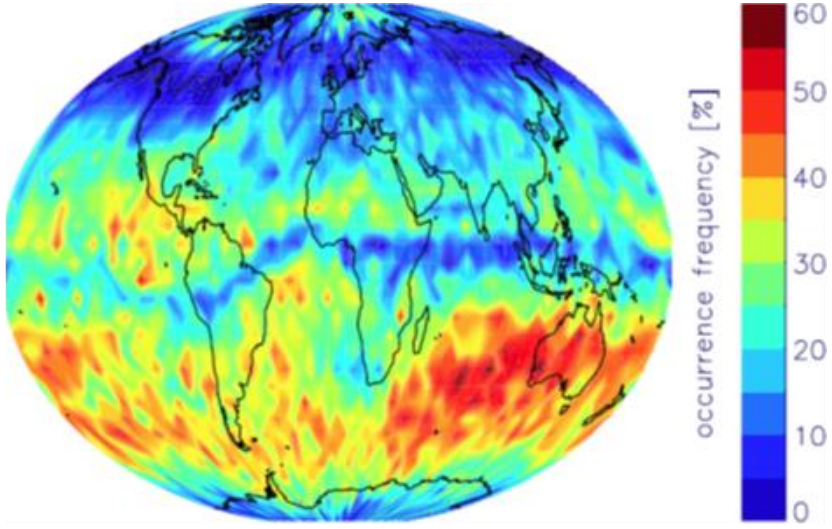
Radio Occultation (RO)



Cortesy: Dr. Chagas

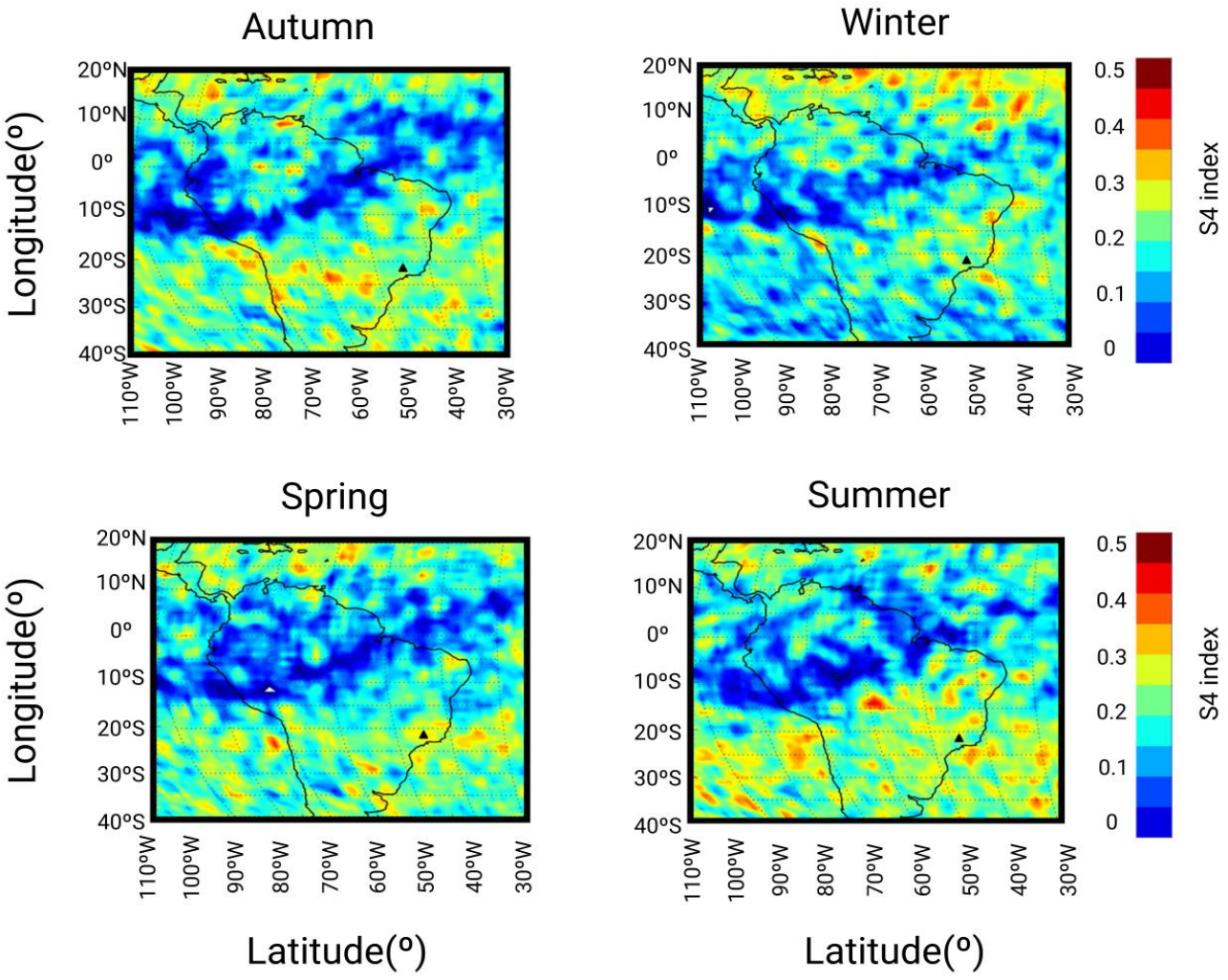
Results



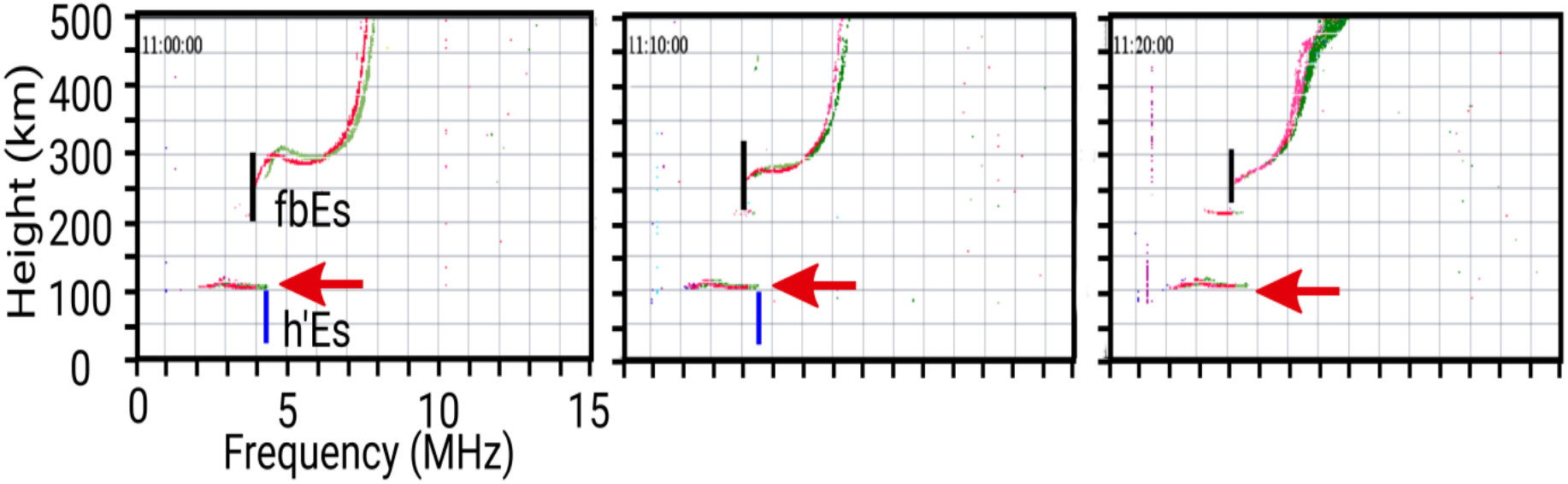


- Sporadic E is a phenomenon of the summer hemisphere
- Low Es rates at high latitudes
- Earth's magnetic equator

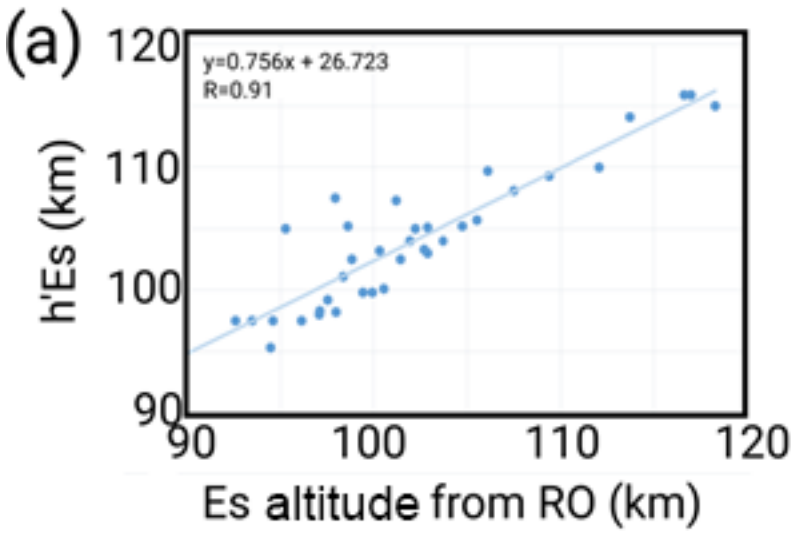
Brazilian Sector

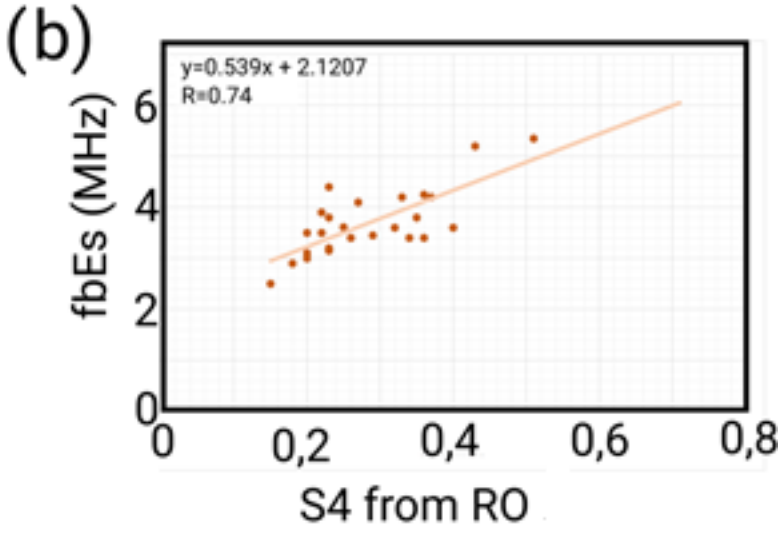


Cachoeira Paulista

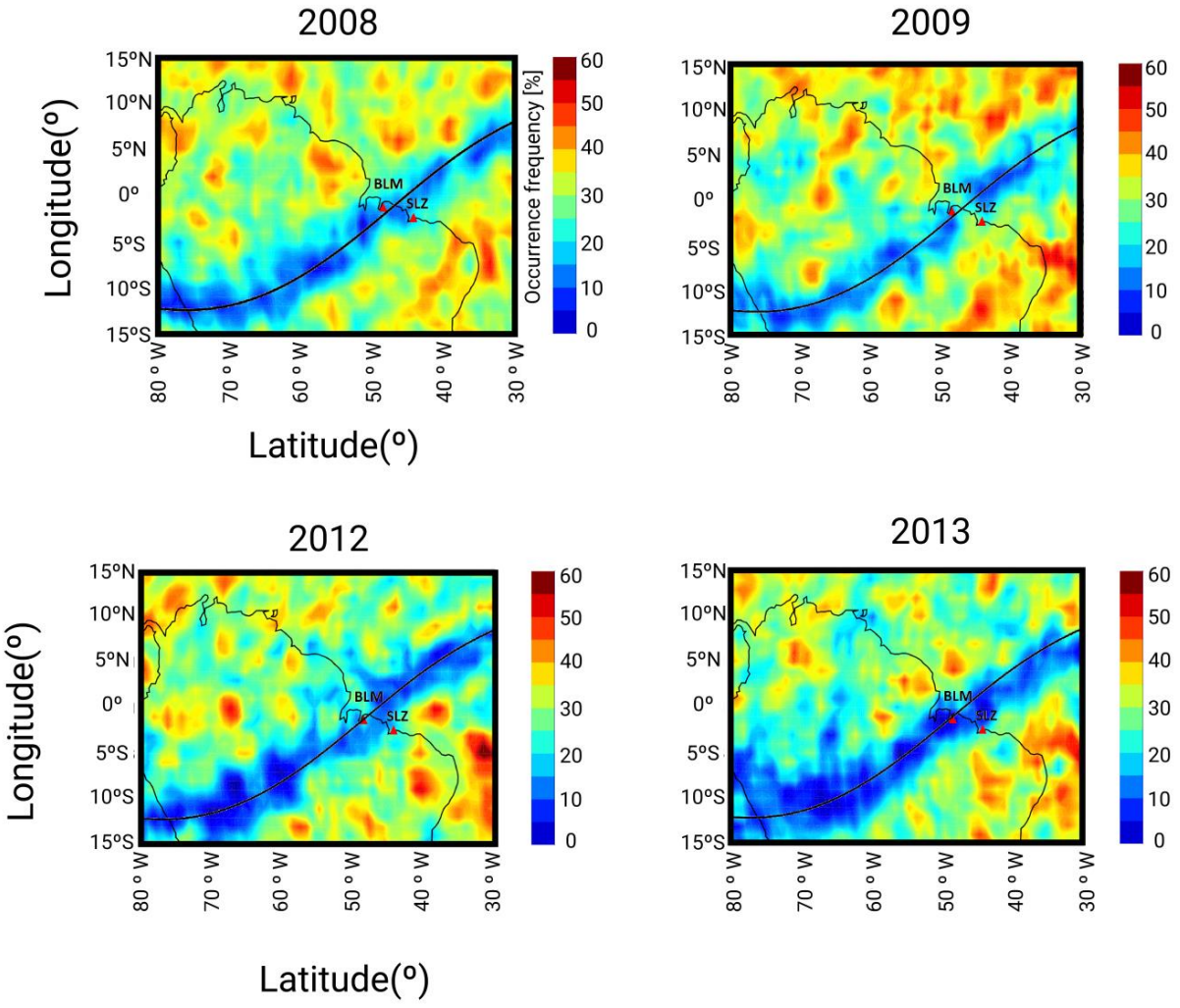


Brazilian Sector





Solar Cycle Effect



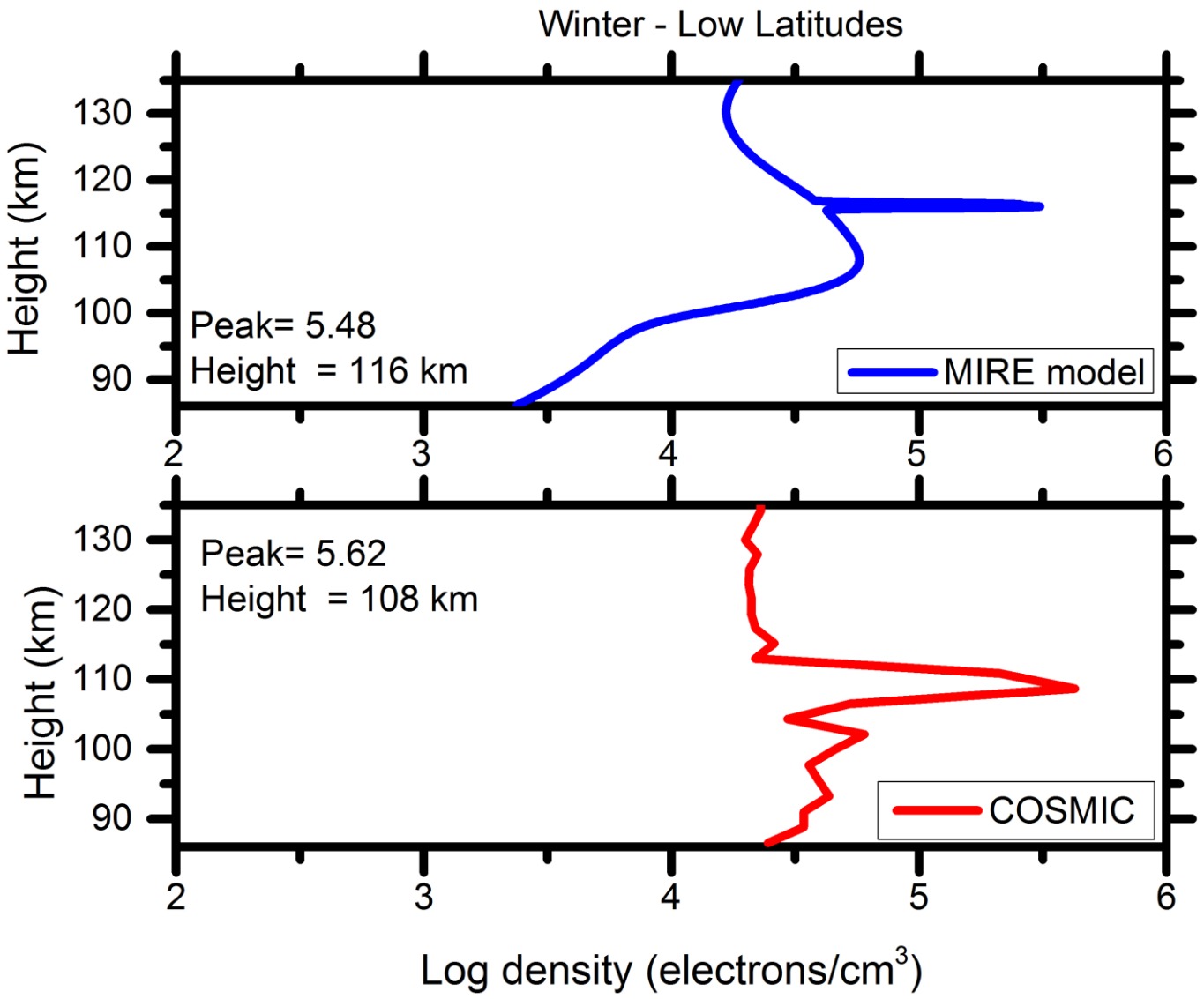
Conclusions

- We found that the agreement between the observations obtained from both analyzed techniques was satisfactory at low latitudes.
- The comparison of Es altitudes and intensities from RO profiles with those from coinciding ground-based digisonde data revealed that there is a large correspondence between both measurement techniques. The high correlation in the heights is explained by the exclusion of the "h" Es layer type in this analysis.
- The Es intensity maps presented here shows a seasonal variation of the S4 index. The results reveal that the Es layers are more intense in summer, agreeing with the accepted theory for these layers and the simulations over Cachoeira Paulista.
- Finally, we observed an anti-correlation with the solar cycle at low latitudes.

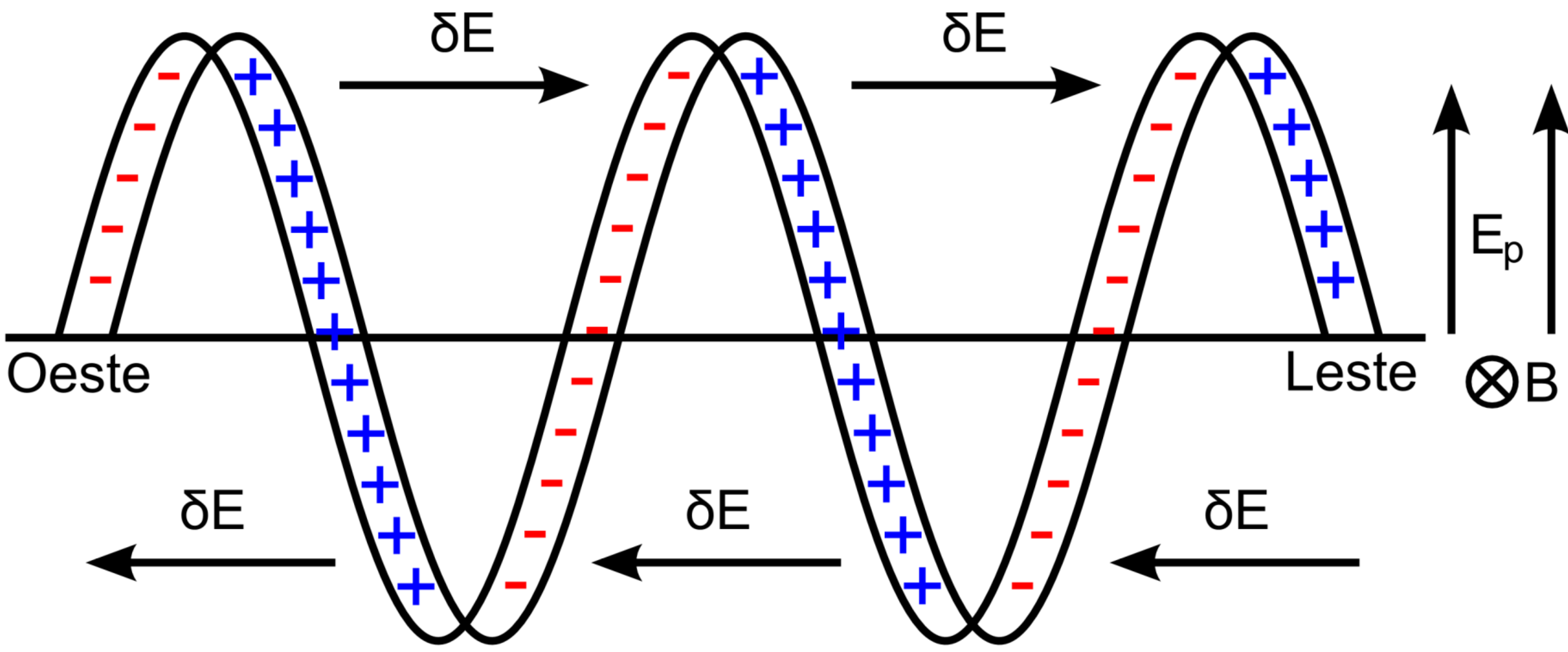
Thank you!

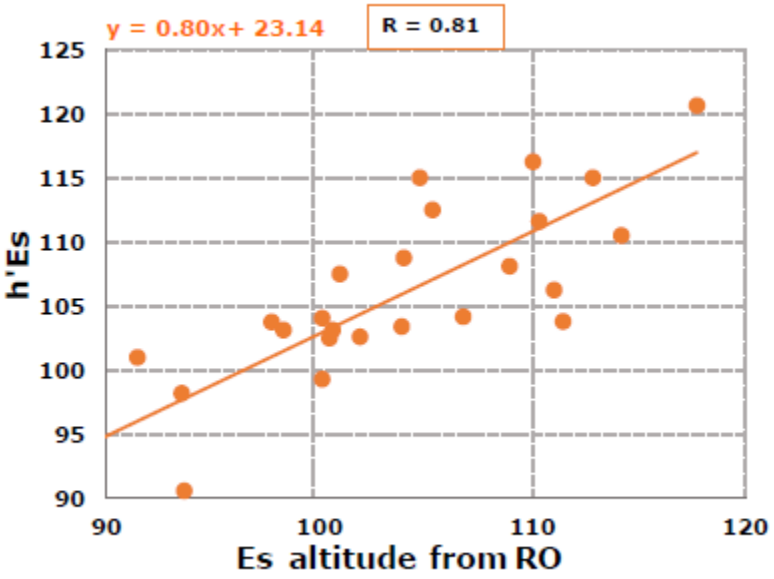
NSSC

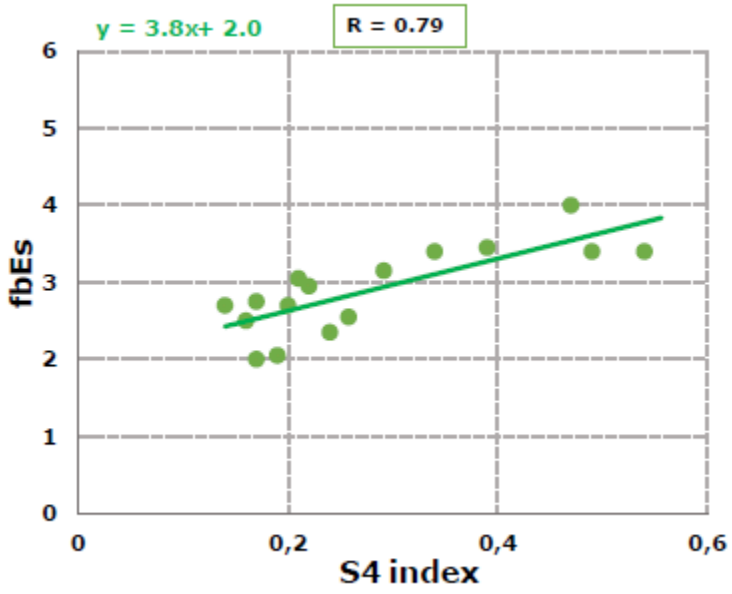
Resultados – Setor Brasileiro



Camada Es Equatorial




y = 0.80x+ 23.14
R = 0.81
h'Es
Es altitude from RO
125
120
115
110
105
100
95
90
90
100
110
120


y = 3.8x+ 2.0
R = 0.79
fbEs
S4 index
6
5
4
3
2
1
0
0
0,2
0,4
0,6

- GPS satellite continuously transmits signals at two L-band frequencies, L1 at 1.57542 GHz (~19 cm) and L2 at 1.227 GHz (~24.4 cm);
- The detected time series of phase modulation of the received signal are accompanied by a variation in frequency because the time derivation of the phase is directly proportional to the frequency shift;
- To extract the atmospheric part, the fraction from the relative satellite motion is subtracted from the total shift;
- This fact corresponds to the Doppler shift that is dependent on the relative movement of GPS and COSMIC satellites. The atmospheric Doppler shift can be used to derive the atmospheric bending as function of the asymptotic miss distance. In other words, the bending angle of each occultation ray is derived from the time derivative of the atmospheric excess phase (Doppler frequency) of the occultation link after appropriate filtering.

References: Hajj, G. A., Romans, L. J. (1998) Ionospheric electron density profiles obtained with the Global Positioning System: Results from the GPS/MET experiment, Radio Sci., 33, 175–190, 1998.

Liou, Y. Pavelyev, A. G., Liu, S. Pavelyev, A. A., Yen, N., Huang, Y., Fong, C. FORMOSAT-3/COSMIC GPS Radio occultation mission: Preliminary results, IEEE Transactions on Geoscience and Remote Sensing, 45, 11, 3813-3825, doi: 10.1109/TGRS.2007.903365, 2007.

The bending angle profile, α, of the neutral atmosphere is inverted to a refractive index profile (n) by an Abel transformation:

$$n(a) = \int_{a}^{\infty} \frac{1}{\sqrt{a'^2 - a^2}} \frac{d\ln\alpha}{da'} da'$$

$$N = (n-1).10^6$$

- The main method used for sporadic E layers detection from the GPS RO occultation measurements is via signal-to-noise ratio (SNR) profiles.
- Therefore, layers of enhanced electron density in the lower ionosphere such as Es can be identified through strong fluctuations in the SNR;
- In the ionosphere, the phase and SNR scintillations can be directly related to strong electron density fluctuations. In other words, the SNR value of the 50 Hz L1 occultation measurements is directly recorded by the GPS receiver on board LEO satellites. The enhancement layers in the ionosphere cause strong SNR fluctuations. Generally, above 85 km altitude, these fluctuations in the SNR are associated with the Es layers;
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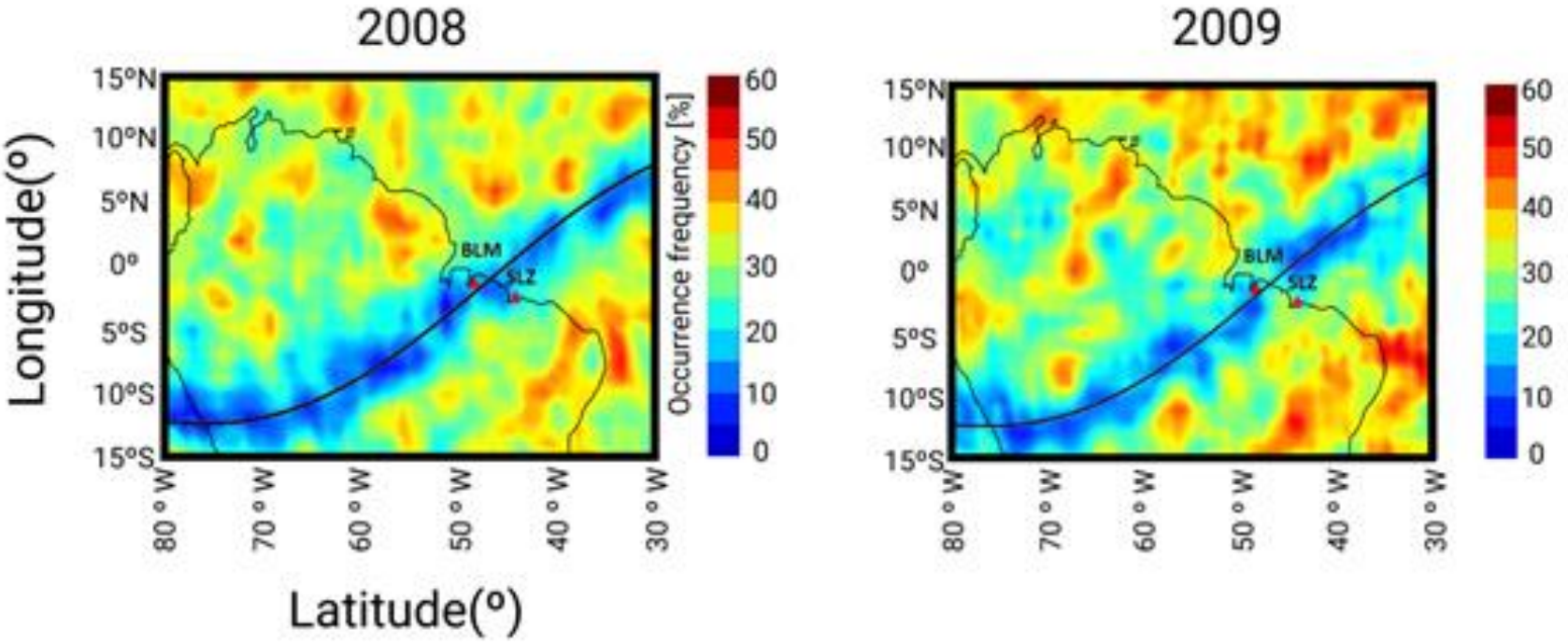
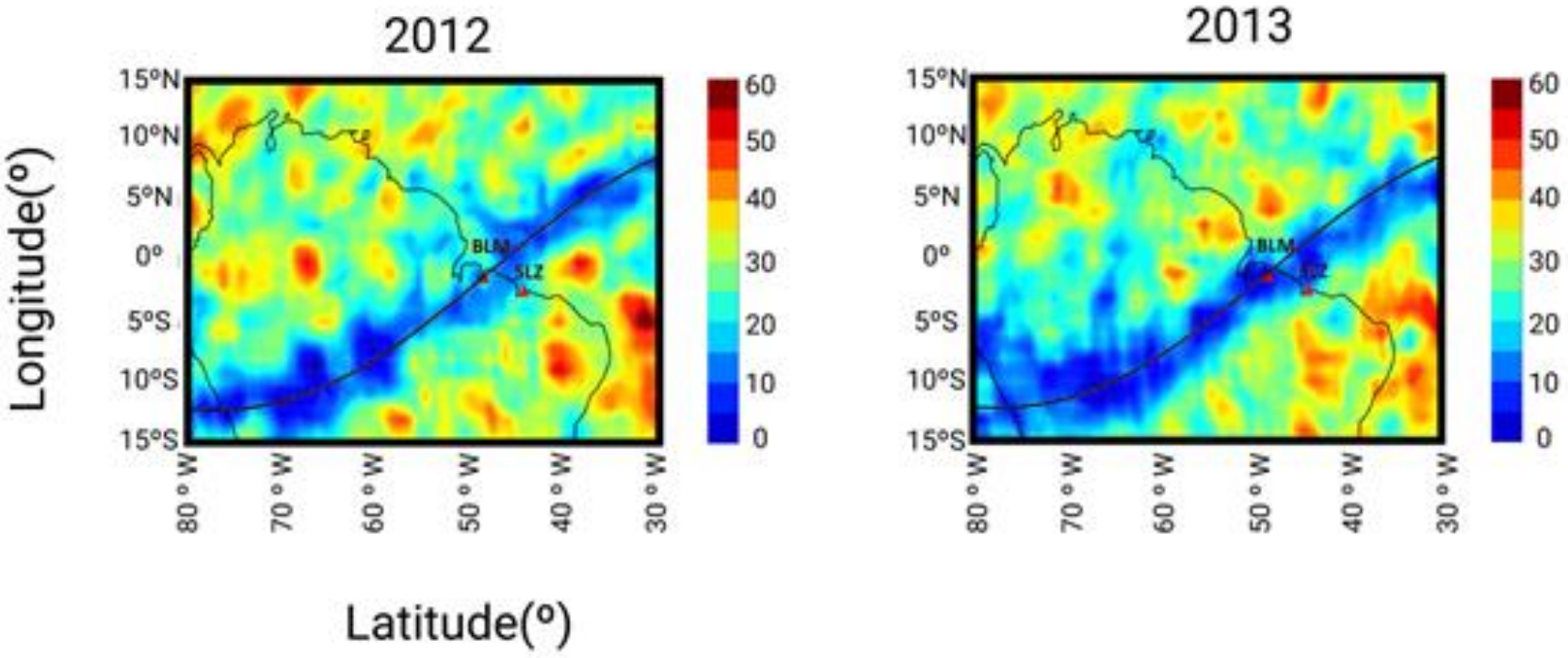
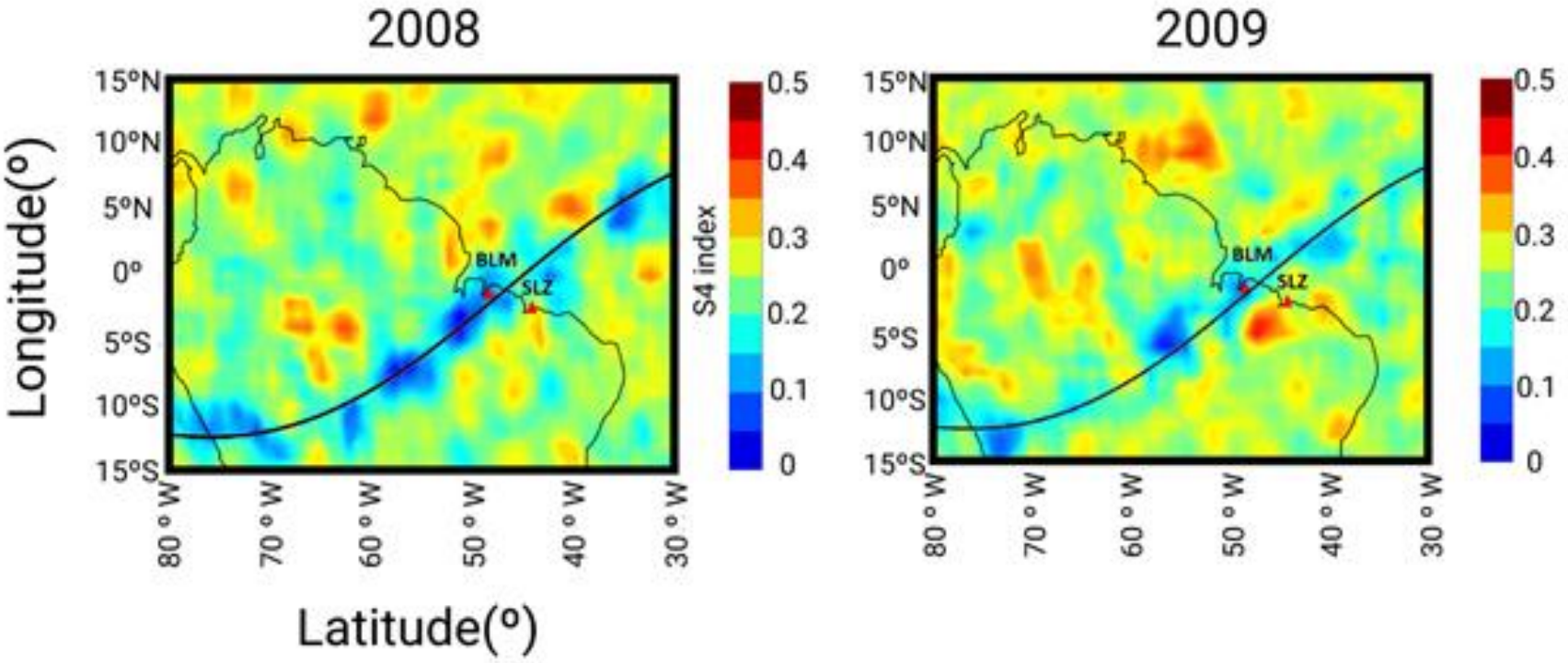
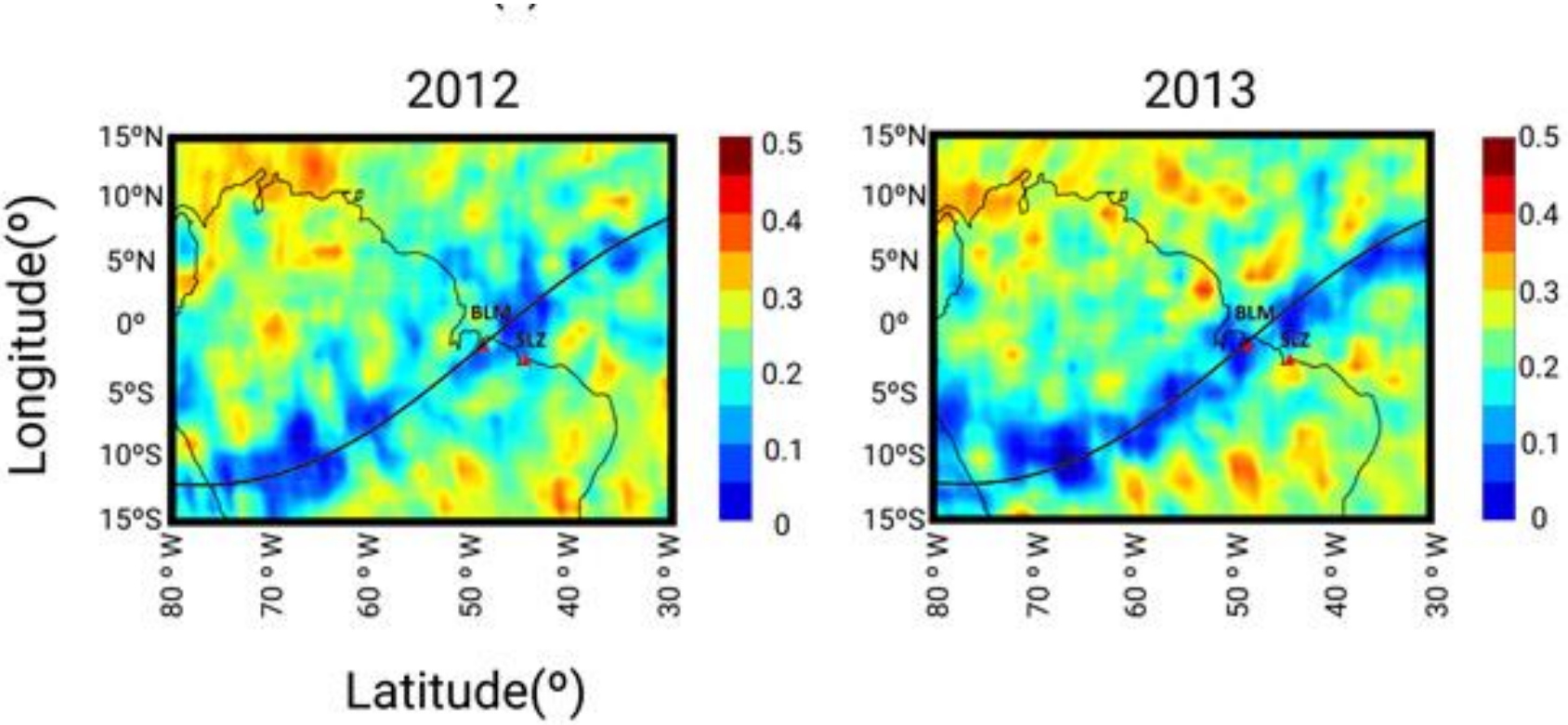
$$S_4^2 = \frac{< I^2 > - < I >^2}{< I >^2}$$

O índice S4 é o desvio padrão de um minuto de dados de 50 amostras por segundo.
O mapeamento é feito através de valores interpolados do indice S4 nos pontos sub-ionosféricos para satélites com o angulo de elevação mas que 30 graus.
Ponto sub-ionosférico é o ponto onde o sinal do satélite cruza a ionosfera numa altitude de 350 Km para a região F e 100 km para a região E.


2008
2009
Longitude(°)
Latitude(°)
15°N
10°N
5°N
0°
5°S
10°S
15°S
80 ° W
70 ° W
60 ° W
50 ° W
40 ° W
30 ° W
BLM
SLZ
Occurrence frequency [%]
60
50
40
30
20
10
0

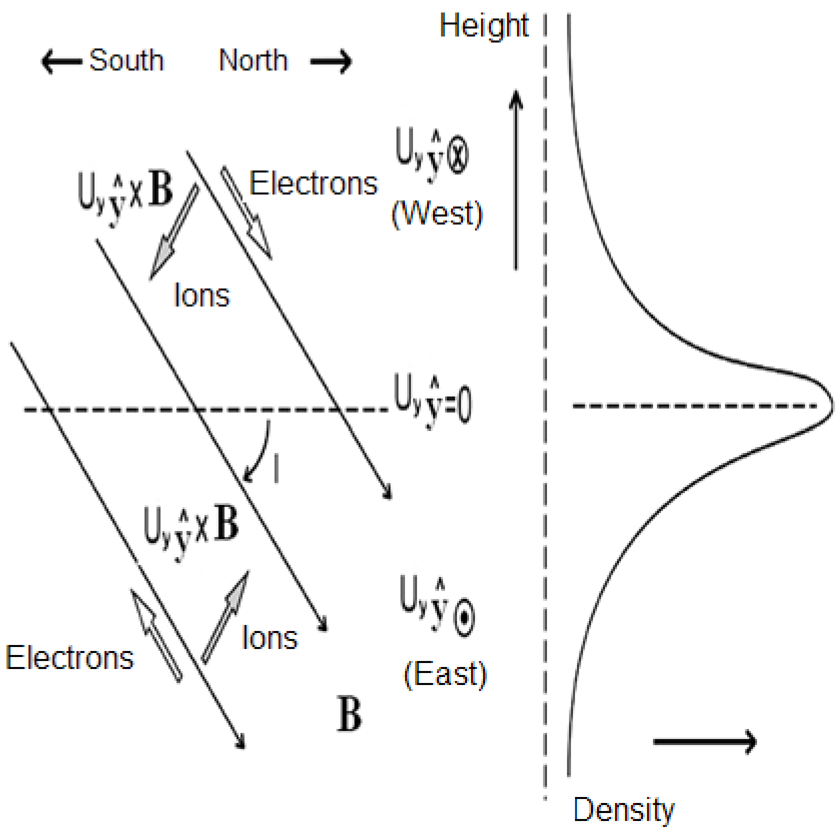

2012
2013
Longitude(º)
Latitude(º)
15ºN
10ºN
5ºN
0º
5ºS
10ºS
15ºS
80 º W
70 º W
60 º W
50 º W
40 º W
30 º W
BLM
SLZ
60
50
40
30
20
10
0


2008
2009
15°N
10°N
5°N
0°
5°S
10°S
15°S
Longitude(°)
80 ° W
70 ° W
60 ° W
50 ° W
40 ° W
30 ° W
Latitude(°)
BLM
SLZ
S4 index
0.5
0.4
0.3
0.2
0.1
0


2012
2013
15°N
10°N
5°N
0°
5°S
10°S
15°S
80 ° W
70 ° W
60 ° W
50 ° W
40 ° W
30 ° W
BLM
SLZ
0.5
0.4
0.3
0.2
0.1
0
Longitude(°)
Latitude(°)

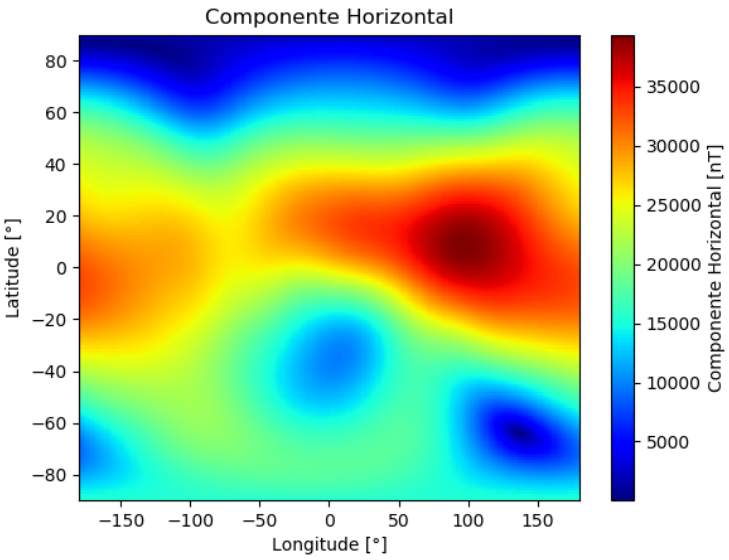
Es layers of Low/Mid Latitudes

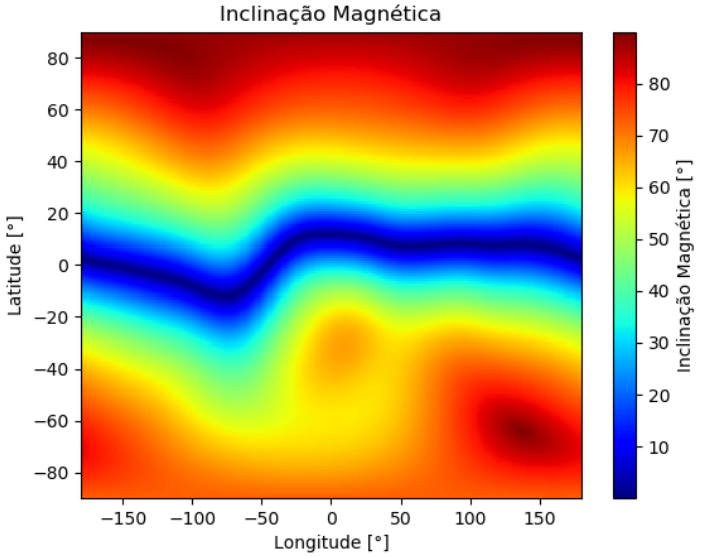
Wind Shear Mechanism



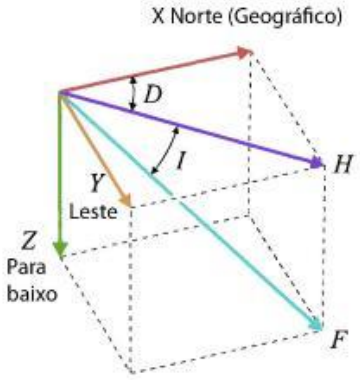
Carrasco (2005)

- According to the theory, a vertical shear in the horizontal wind can produce a layer at the height where the vertical ionization drift vanishes;
- a vertical wind shear characterized by a westward wind above and an eastward wind below;
- as the ions drift with the wind to the west above (east below) to drift downwards (upwards), therefore converging at an angle to the wind shear null to accumulate and form a layer;
- the electrons are Coulomb-forced to follow the ions, moving along the magnetic field lines to maintain plasma neutrality.





$$V_{iz} = \frac{\omega_i^2}{(\nu_{in}^2 + \omega_i^2)} \left[cos(I)sen(I)U_x + \frac{\nu_{in}}{\omega_i} cos(I)U_y + \frac{1}{\nu_{in}} \frac{e}{m_i} cos(I)sen(I)E_x + \frac{e}{\omega_i m_i} cos(I)E_y + \frac{e}{\omega_i m_i} \left(\frac{\nu_{in}^2}{\omega_i^2} + sen^2(I) \right) E_z \right].$$



$$I = \arctan\left(\frac{Z}{H}\right)$$