FIRST STATISTICAL STUDY OF BLANKETING SPORADIC E OVER THE JICAMARCA RADIO OBSERVATORY USING IMAGE PROCESSING TECHNIQUES AND MACHINE LEARNING ALGORITHMS

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Abstract

We report the results of the first statistical study of blanketing sporadic E (Esb) occurrence over the Jicamarca Radio Observatory using the Digital Portable Sounder (DPS) - 4 Digisonde data from 2001 to 2018. We found Esb occurs mainly during the December solstice and also during minimum solar years. We observe the occurrence of Esb mainly between 0700 and 2000 LT with a peak at 1600 LT. Additionally, we proposed a new criterion to identify Esb events taken into account the normal tendency of the F-layer minimum frequency of ionogram echoes due mainly to absorbance of the D-region. Esb events could be classified as rare events, in low latitude regions, and equatorial electrojet echoes often overlap with Esb echoes. A common methodology to identify Esb events have been done visually. We developed an algorithm and implemented a software to identify Esb events using image processing techniques and machine learning algorithms getting a sensitivity of 89% in its first version. Furthermore, we obtained the ΔH between Jicamarca and Piura to measure the intensity of equatorial electrojet and counter electrojet and its behaviour in time when Esb occurs. Finally, we have used the model of Muralikrishna et al. (2008) to discuss possible conditions that favor the formation of blanketing sporadic E.

The "Blanketing Sporadic E" layers

Sporadic E layers (Es):
- "Es" are regions of increased electron density, observed in the E region and made up of metal ions.

Blanketing sporadic E layers (Esb):
- "Es" are type blanketing (Esb) when they can partially or completely block the radio waves at the frequencies transmitted by the ionosonde for the sounding of the upper ionosphere (between 1.0 MHz and 14.0 MHz).

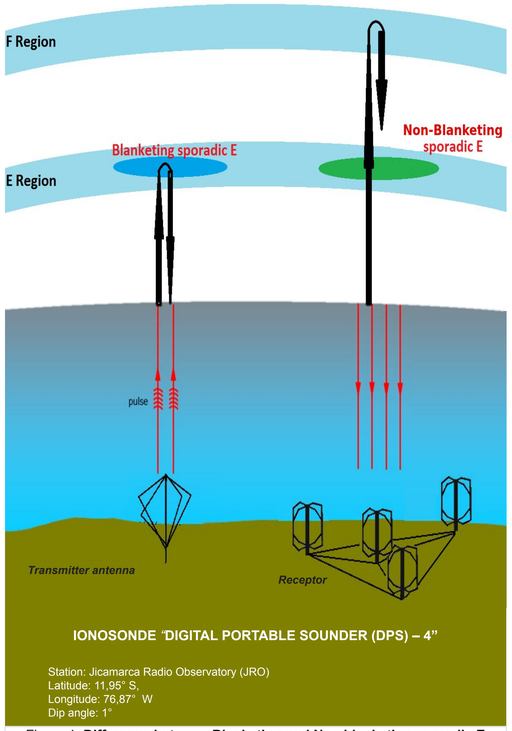


Figure 1. **Difference between Blanketing and Non blanketing sporadic E**

Visualization of Esb in ionograms

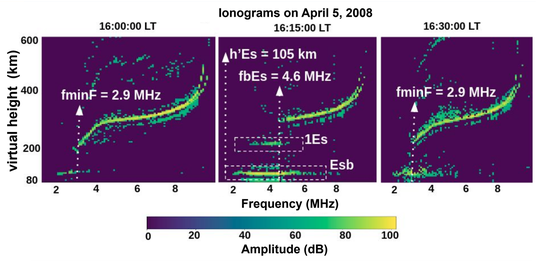
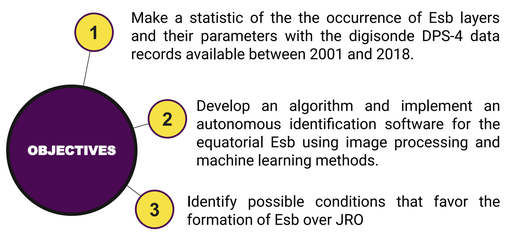


Figure 2. **Parameters of Esb in ionogramas**



Algorithm for identification of Esb

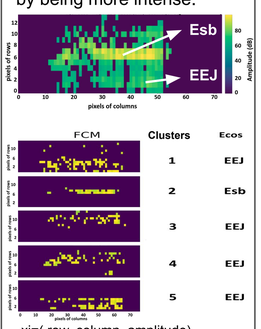
IONOGRAMS

"E" REGION ALGORITHM

Segmentation

FUZZY C MEANS (FCM)

This algorithm separates the echoes of the E region in clusters. One cluster stores Esb echoes and the rest of clusters stores the equatorial electrojet echoes. The former is characterized by being more intense.



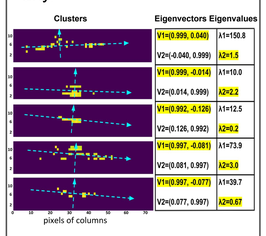
xi=(row, column, amplitude)
Number of clusters used: 8
δ value to stop process = 0,225

Figure 3. **FCM segmentation applied to ionograms of E region**

Identification

PRINCIPAL COMPONENT ANALYSIS (PCA)

To obtain the axes of maximum dispersion in order to obtain the slope of the Esb trace and a parameter associated with the width of the Esb layer, if any.



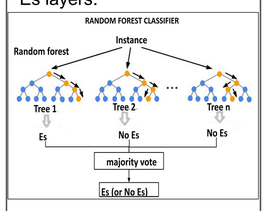
Elements:
xi=(row, column)
Minimum eigenvalue related to width of Esb

Figure 4. **PCA applied to each cluster**

Classification model

RANDOM FOREST

Ten explanatory variables corresponding to the Es characteristics were used, such as their heights, slope, layer width, maximum intensity and others in order to predict the presence of Es layers.



Program. language: Python 2.7
Module: sklearn
Method: RandomForestClassifier
criterion= 'entropy'
n_estimators = 3000
min_samples_leaf = 5
Max_depth = 6
Years to train the model: 2008, 2009, 2013, 20114 and 2015

Figure 5. **Random Forest model applied to identified Es in clusters**

"F" REGION ALGORITHM

Filter

ELIMINATION OF MULTIPLES ES (nES) AND 1 MULTIPLE F (1F)

This filter is carried out in order to eliminate the multiples of the Es (F) layer due to multiple reflections between the Es (F) layer and the earth.

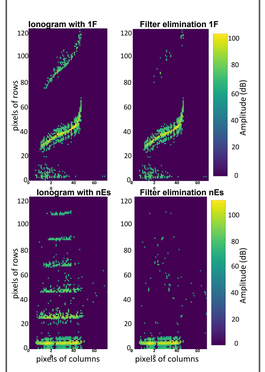


Figure 6. **Filter to delete multiples Esb (nEs) and first multiple of F layer (1F)**

Segmentation

SEGMENTATION: FUZZY C MEANS (FCM)

We obtain the following two cases: a) when there is presence of layer F, in some of the clusters a defined trace will be obtained and b) when there is spread-F, dispersed pixels will be obtained in all the clusters.

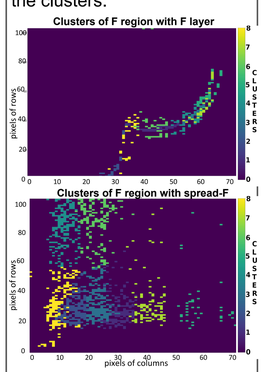


Figure 7. **Segmentation of F region when there is spread-F and F layer**

Identification

CHARACTERIZATION OF F REGION

Measuring the dispersion in the clusters, we obtain a characterization of the F region in ionograms, therefore if there is presence of spread-F, or only F layer or if there are no significant echoes in the F region.

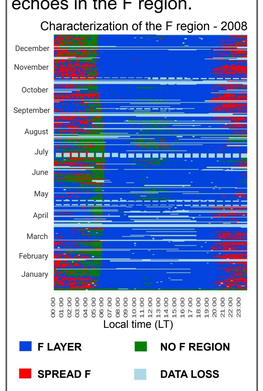


Figure 8. **Algorithm to identify F region scenery: Spread F, F layer or no echoes**

Scaling

SCALED OF F LAYER: ROTOR MODEL

The traces of the F layers are identified in order to find the minimum frequency of the F layer and obtain a time series of these minimum frequencies. We used a rotor model for scaling the ionograms.

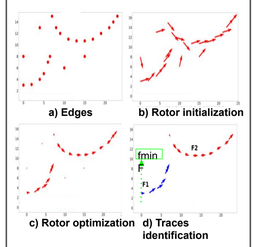


Figure 9. **Scaling of the F layer to identify a time series of fminF**

Ionograms with sporadic E layers identified

F region information

Time series of fminF

CRITERION TO IDENTIFY ESB EVENTS

Partial Esb: P1 and P2 and P3
Total Esb: P1 and ((P2 and P4) or P5)
- **P1:** Es identified by Random Forest model
- **P2:** fbEs fiited-fbEs >= 0.5MHz
- **P3:** 3.7 MHz <= fbEs <= 7.7 MHz
- **P4:** fbEs >= 7.7 MHz
- **P5:** No F region

NOTE: **Fitting of fminF to a parabola and condition P2 include D region absorption**

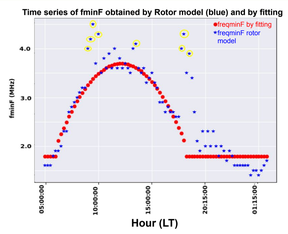


Figure 10. **Criterion to identify Esb events taking into account the absorption of the D region**

ESB IDENTIFIED EVENTS

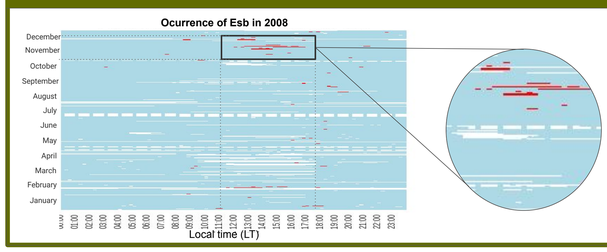


Figure 11. **Esb occurrence matrix by local time and day of the year**

Validation of the algorithm:

Years to test the algorithm;
2007, 2010, 2011 and 2016

Confusion matrix

	Esb identificado	Esb no identificado
Esb real	161	18
No Esb real	55	–

Validation metrics

Sensitivity = 89%
Precision = 72%
F1-Score = 80%

Results

Figure 12: Two occurrence peaks, in the morning (0800-0900 LT) and in the afternoon (1600 LT).
Figure 13: Greater occurrence in the summer solstice months.
Figure 14: Distinguishing heights mostly between 90 and 135 km with a peak at 100 km.
Figure 15: Highest occurrence of Esb events during minimum solar activity.

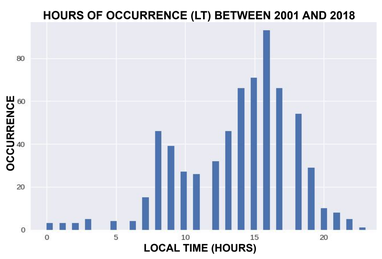


Figure 12. **Histogram of hours of occurrence of Esb**

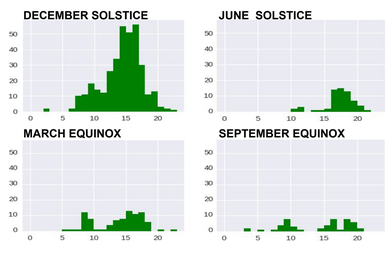


Figure 13. **Histogram of hours of occurrence by hour by season.**

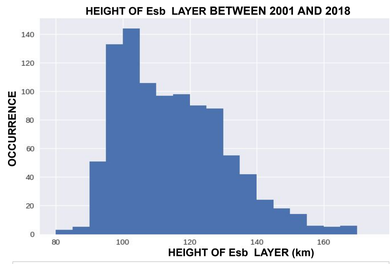


Figure 14. **Histogram of altitudes of Esb between 2001 and 2018.**

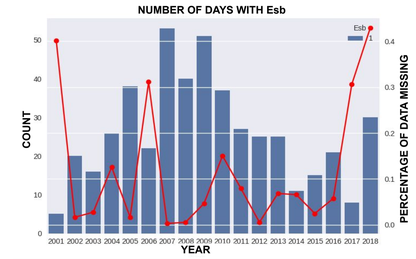


Figure 15. **Histogram of days of Esb ocurrence between 2001 and 2018**

Magnetograms in Esb occurrence

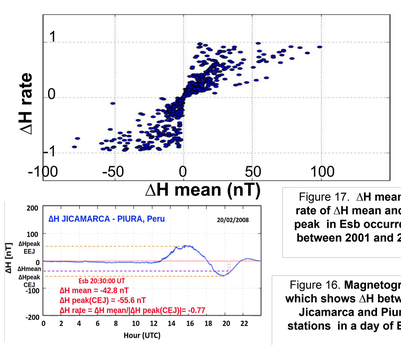


Figure 17. **ΔH mean vs rate of ΔH mean and ΔH peak in Esb occurrence between 2001 and 2008**

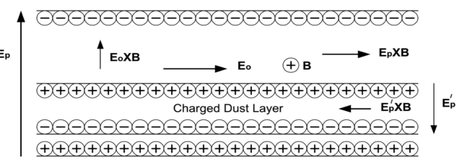
Figure 16. **Magnetogram which shows ΔH between Jicamarca and Piura stations in a day of Esb.**

Figure 16:
$\Delta H = H_{JICAMARCA} - H_{PIURA}$

ΔH is related to intensity of current of EEJ.
Figure 17:
- Similar occurrence of Esb events in conditions of counter equatorial electrojet (ΔH < 0 nT) and weak equatorial electrojet (0 <= ΔH < 25nT). In this second condition Esb ocurrs mostly when EEJ is starting (y axis values less than 0.5)

Discussion

Figure 18. **Muralikrishna et al. (2008) model**



POSSIBLE CONDITIONS THAT FAVOR THE Esb FORMATION
- Muralikrishna et al. (2008) model explains the consequence of dust meteor particle in the generation of counter electrojet.
- This model and our observations can permit us to explain possible conditions that favor the formation of Esb:
  - Presence of meteoric dust particles
  - Adequate level of ionization
  - Normal EEJ current not very intense

Conclusions

- Esb layers occur with greater frequency in the months of the summer solstice. Esb events appear more frequently during years of minimum solar activity than during years of maximum solar activity. These events occur between 0700 and 2000 LT, with a main peak at 1600 LT and a secondary peak at 0800-0900 LT.
- An algorithm has been developed and implemented for the autonomous identification of sporadic E blanketing layers in equatorial regions with a F1-score of 80%.

References

- Yadav, V., Kakad, B., Bhattacharyya, A., and Pant, T. (2017). Quiet and disturbed time characteristics of blanketing es (esb) during solar cycle 23. Journal of Geophysical Research: Space Physics, 122(11).
- Muralikrishna, P. and Kulkarni, V. (2008). Modeling the meteoric dust effect on the equatorial electrojet. Advances in Space Research, 42(1):164–170.

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