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# Automatic identification and observations of blanketing sporadic E events in the equatorial region over Jicamarca

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## Abstract

In equatorial regions, equatorial electrojet (EEJ) echoes often overlap with blanketing sporadic E (*Esb*) echoes. Also, *Esb* events could be classified as rare events over the Jicamarca Radio Observatory (JRO). For that reason, *Esb* identification is a big challenge for current software. Until now, the conventional method identifies *Esb* echoes visually. In this work, an innovative approach for automatic identification and observation of *Esb* events is presented. We developed an algorithm and implemented the first software to identify *Esb* events using image processing techniques and machine learning algorithms getting a sensitivity of 89%. We proposed a new criterion to identify *Esb* events taken into account the normal tendency of the F-layer minimum frequency due mainly to absorbance of the D region. We report the results of the first statistical study of *Esb* occurrence over JRO (11.95° S, 76.87° W and dip angle ~1°) 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* with a main peak at 1600 LT and a second peak around 0800 – 0900 LT. Furthermore, we obtained the ΔH between Jicamarca and Piura to measure the intensity of EEJ and counter electrojet (CEJ) and its behavior in time when *Esb* occurs. Finally, we discuss possible conditions that favor the formation of *Esb*.

## 1 Introduction

Sporadic E layers (*Es*) are regions of increase in electron density observed in E region and made of metal ions of meteoric origin. The *Es* layers are blanketing type (*Esb*) when they can partially or completely block the radio waves at the frequencies transmitted by the ionosondes for probing the upper ionosphere (between 1.0 MHz and 14.0 MHz). *Esb* formation mechanisms in regions near the magnetic equator are still being studied. *Esb* layers can influence communications via high-frequency signals. One of the main challenges for the statistical study of *Esb* in equatorial stations is the way to identify them. Previously these have been identified only visually from the ionograms, probably because the available automatic scaling software fails to properly identify *Esb* events in equatorial regions because EEJ produces a lot of false positives. In this work, image processing techniques and machine learning algorithms have been used for the automatic *Esb* identification.

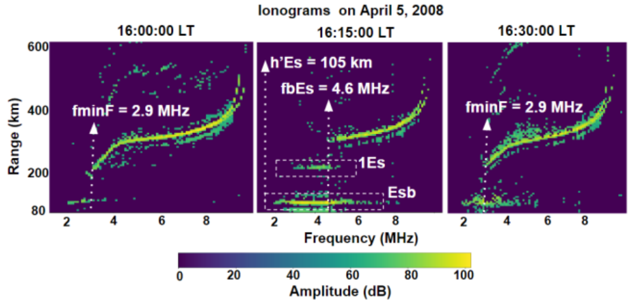


**Figure 1.** Ionograms with presence of *Esb* layer and its parameters. Ionograms observed on April 5, 2008.

Figure 1 shows a case of *Esb* occurrence on April 5, 2008 at 16: 15: 00 LT. It took place during 15 minutes before disappearing. As we can see, *Esb* changes the minimum frequency of F layer (*fminF*) observed in ionograms. Also, a multiple of *Esb* called 1*Es* which is generated due to multiple reflections between earth and *Esb*. The *fminF* for the *Esb* (fbEs) is 4.6 MHz and the altitude of the *Esb* (h'Es) is 105 km.

For this work, the first statistical study of the *Esb* occurrence over JRO has been obtained using ionograms from 2001 and 2018 usually recorded each 15 minutes. Additionally, the ΔH between the Jicamarca and Piura magnetometers has been obtained to measure the intensity of the EEJ and CEJ and its behavior in times when *Esb* occurs. Finally we discuss the possible conditions that favor the formation of the *Esb* based on our observations and Muralikrishna and Kulkarni's model [1].

## 2 Methodology

We propose an algorithm which is shown in figure 2. This algorithm uses supervised and unsupervised learning algorithms. The first inputs are the ionograms obtained by DPS-4 over JRO. We separate the ionograms into E region and F region. Subsequently, both regions are the inputs for different stages. The first one takes E region as an input in order to identify ionograms with sporadic E layers (not necessarily *Esb*). The second one takes F region as an input in order to obtain two outputs: F region characterization (Spread F, F layer or no echoes) and time series of *fminF*. These three outputs (from these two stages) are the inputs for the criterion to identify *Esb* events.

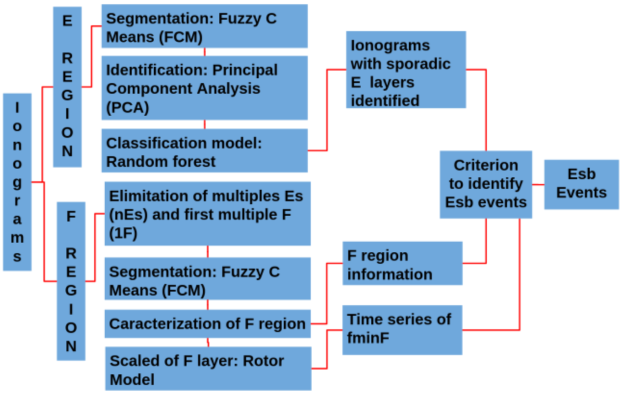


**Figure 2.** Scheme of the *Esb* layer identification algorithm for equatorial regions.

## 2.1 E region algorithms

**Segmentation: Fuzzy C means (FCM)** is a clustering technique and an unsupervised learning algorithm that allows you to group elements into groups or clusters according to a neighborhood criteria. We applied this technique to the E region of the ionograms to separate the echoes due to the *Es* layers, which are more intense and defined than those due to the EEJ. Figure 3 shows the result of applying the FCM considering five clusters. It should be noticed that the second cluster contains echoes of the *Es* and the other clusters contain echoes due to the EEJ. In this case, our elements to be grouped are the three-dimensional coordinates (row, column, amplitude) of each pixel of the image. It is necessary to perform a standard scaling before applying FCM. For the final segmentation (for E and F region), we used eight clusters.

**Identification: Principal component analysis (PCA)** was applied taking elements as two-dimensional (row, column) in order to obtain the slope of the *Es* layer (see figure 4), obtained from the first eigenvector (**V1**), and a measure of the width of the layer, obtained from the minimum (second) eigenvalue (**λ2**) given by this method. *Esb* layer usually have small values for minimum eigenvalue because *Esb* are "thin", and negative values (or near to zero) for the first eigenvector's slope. EEJ echoes usually show high values for minimum eigenvalue and any value for the first eigenvector's slope. At that time, the first eigenvector's slope and the second eigenvalue have morphological information from the *Esb* layer, and they will be used as parameters in the next step. We applied PCA for each single cluster (eight clusters were previously taken in FCM) and for combination in groups of two (in order to fix the usual problem related to the predefined number of clusters).

**Classification: Random Forest** is a supervised learning algorithm that we applied to identify the *Es* layers in the E region. Ten explanatory variables were used for the model, these variables were (1) the slope, (2) the width of the *Esb* layer (obtained by PCA for each cluster and for combination in groups of two), and eight other variables related to the morphology of the *Es* traces, as (3) frequency range, (4) *Es* height, (5) a measurement of compactness, (6) total number of pixels by E region, (7) maximum intensity rate between clusters and E region, (8) median intensity rate between clusters and E region, (9) pixel number rate of clusters and E region, and (10) median intensity rate between clusters and E regions of the hour. This model was implemented using sklearn module from python, the method was 'RandomForestClassifier', the criterion was 'entropy', the number of decision trees was 3000, the minimum number of samples required to split an internal node was 5 and the maximum depth of trees was 6.

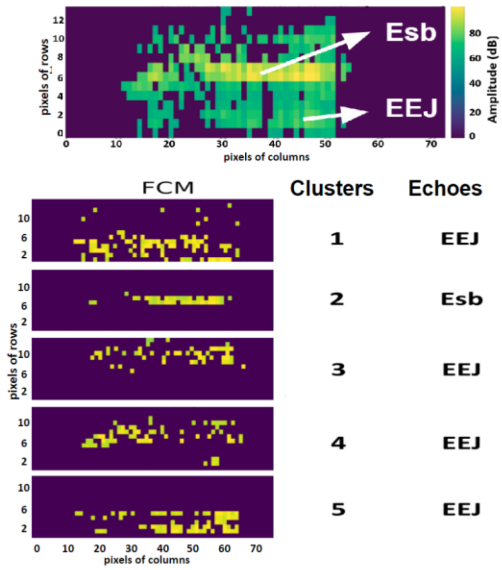


**Figure 3.** Fuzzy C Means applied to the E region of an ionogram on 02/16/2008 at 2000 UT. For this example, 5 clusters have been used. The second cluster identifies the *Esb* echoes.

## 2.2 F region algorithms

**Elimination of multiples *nEs* and *1F***: In this region of the ionograms, a filter was first performed to eliminate the echoes that arise due to the multiple reflections of the electromagnetic wave with the *Esb* layers and Earth.

**Segmentation:** Then the FCM algorithm was applied to segment the F region echoes using eight clusters.

**Characterization of F region:** Measurement of dispersion from the previous segmentation process allowed to obtain information from the F region (that is to say if there is presence of a well-defined trace of the F layer, if there is the presence of an ionospheric phenomenon called spread F or no echoes obtained from the F region).

**Automatic scaling of F layer:** The traces of the F layers are identified from the ionograms in order to find *fminF*. We used a rotor model [2] for scaling the ionograms.

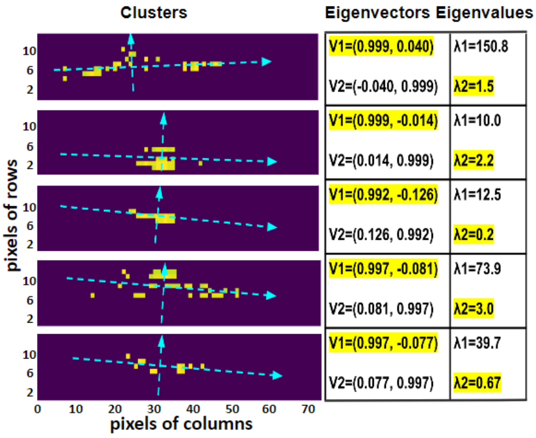


**Figure 4.** PCA applied for each cluster. Eigenvectors (**V1** and **V2**) are the main components and the eigenvalues (**λ1** and **λ2**) measure the degree of dispersion for each component.

## 2.3 Criterion to identify *Esb* events

From the three outputs obtained with the previous algorithms, an identification criterion was proposed that takes into account the trend of *fminF* due to the absorption of the D region. This criterion considers the abrupt changes in *fminF* due to partial or total blockage of the *Esb* layers. This change is measured from the difference between *fminF* (when the F layer is observed) and the inverted parabola curve adjusted on each day (see figure 5), which represents the behavior of ionospheric absorption. An *Esb* layer will then be obtained when the random forest algorithm had identified an *Es* layer, and in addition, this difference should be greater or equal to 0.5 MHz (for partial *Esb*) or when the information in the F region indicates that there are no echoes in that region (total *Esb*). Also, we used a threshold of fbEs equal to 3.7 MHz for partial *Esb*, and 7.7 MHz for total *Esb* (when the F layer is observed).

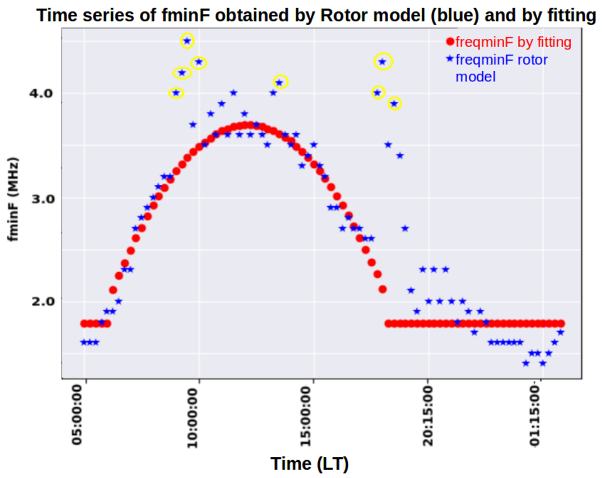


**Figure 5.** Criterion to identify *Esb* events taking into account the absorption of the D region. Yellow circles show possible *Esb* layers.

## 3 Results and observations

The *Esb* identification program has a sensitivity equal to 89%, the accuracy is 72% and the F1-score is 80%. A mean square root error (RMSE) is obtained for *Esb* parameters. RMSE for fbEs is 0.4 MHz and RMSE for h'Es is 4.6 km. An accuracy of 72% is due to poor quality ionograms in those days when there is interference from the main radar of the JRO. During some days, traces of the layers observed in the ionograms appeared very weak (due to high absorbance) that even for the human eye make it difficult to detect *Esb* under these conditions, affecting the accuracy. For this accuracy, it would be necessary to discard visually false positives in the final identification, and taken into account that *Esb* events are rare events, this is not hard work. For stations where there is no significant interference and operate modern ionosondes, it would not be necessary. On the other hand, the sensitivity reaches a high level using this approach.

From the events identified automatically and discarding false positives, the following statistics are obtained for the occurrence of the *Esb* layers from 2001 to 2018. Figure 6 shows the occurrence as a function of local time with two occurrence peaks, the main around 1600 LT and the second around 0800 – 0900 LT.

Figure 7 shows the seasonal *Esb* occurrence variability as a function of height. The highest occurrence was observed during December solstice (local summer) and mostly between 90 and 135 km. During June solstice and the equinoxes, *Esb* occurs mostly between 95 and 110 km. Figure 8 shows that these events appear mainly in the years of minimum solar activity.

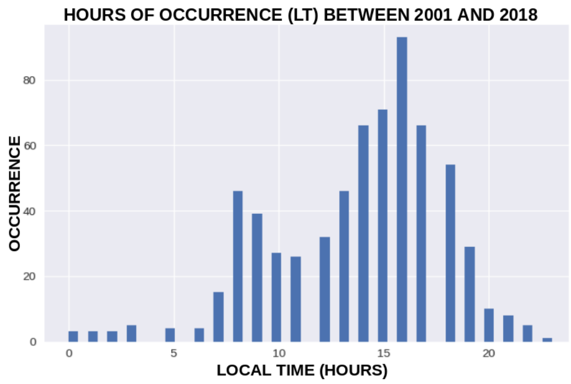


**Figure 6.** Histogram of *Esb* occurrence events as a function of local time from 2001 to 2018.

In order to measure whether the *Esb* layers occurred under conditions of EEJ or CEJ, we obtained the difference between the horizontal components of the magnetic field (ΔH) recorded in Piura (station outside the magnetic equator) and JRO (station at the magnetic equator). When ΔH is positive (negative), EEJ (CEJ) has taken place. The average ΔH (ΔH mean) was calculated in a range of 6 minutes before and after the occurrence of an *Esb* layer.

On the other hand, the ratio (ΔH rate) of this average value between the maximum (minimum) peak was calculated if there was an EEJ (CEJ) condition. Figure 9 shows similar occurrence of *Esb* layers in CEJ conditions (ΔH mean less than 0 nT) and weak EEJ (ΔH mean between 0 and 25 nT, and ΔH rate less than 0.5).

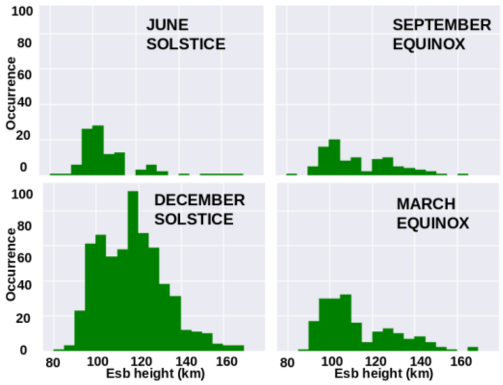


**Figure 7.** Histogram of *Esb* altitudes by seasons between 2001 and 2018.

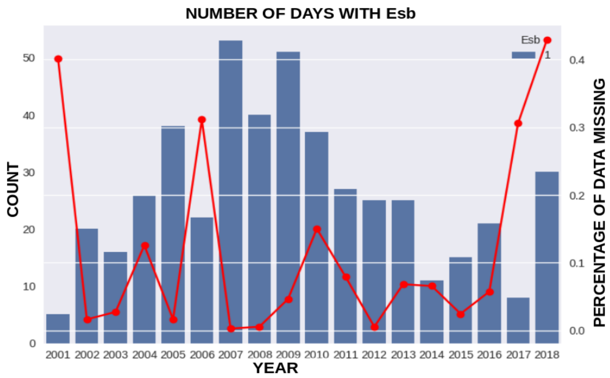


**Figure 8.** Histogram of days of *Esb* occurrence by year from 2001 to 2018.

## 4 Discussion

Based on our results and the model developed by Muralikrishna and Kulkarni (2008), who explained the effect that meteoric dust particles have on reducing the intensity of the EEJ and the generation of the CEJ, three conditions have been proposed that favor the formation of these *Esb* layers in equatorial regions. The first condition is the adequate presence of meteoric dust particles since greater dust concentration can capture more electrons generating denser *Esb* layers. Secondly, a sufficient level of ionization would be required. Higher ionization would make it easier for the meteoric ions to capture more electrons. Our observations that show a peak occurrence of *Esb* during summer and afternoon hours support these possible explanations because ionization is higher in the summer months and the afternoon hours than at other seasons and morning local times. Third, the condition of weak EEJ current was proposed. An intense EEJ current, generated by a strong main electric field, would not favor electrons to be captured by meteoric dust. In our results, the highest *Esb* occurrence during minimum solar years when EEJ is less intense than maximum solar years supports this last proposed idea. Similar *Esb* occurrence features were observed by Yadav et al. [3].

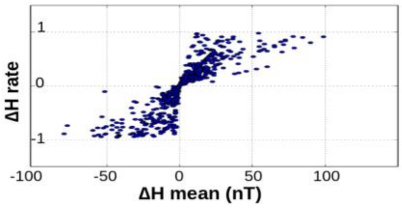


**Figure 9.** ΔH mean vs rate of ΔH mean and ΔH maximum (minimum) in case of EEJ (CEJ) in *Esb* occurrence between 2001 and 2008.

## 5 Conclusions and Future Work

In this work, it has been developed and implemented the first algorithm for automatic *Esb* identification over equatorial regions from ionograms. It has been obtained the first statistic of *Esb* occurrence over JRO using digisonde data from 2001 to 2018. Our observations have shown similar results obtained in other equatorial stations. *Esb* events occur more frequently in the months near to the summer solstice and in the years of minimum solar activity, also there is a main peak of occurrence at 1600 LT and a second peak around 0800 – 0900 LT. Three conditions have been proposed that favor the formation of these *Esb* layers in equatorial regions. In the future, it should be possible to apply this innovative approach to generate a global map of the *Esb* occurrence and study their characteristics at different locations using digisonde data.

## 6 Acknowledgements

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## 7 References

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