DST INDEX AS AN INDICATOR OF SPACE WEATHER; A PROBABILISTIC APPROACH

Tulunay Ersin[1], Tulunay Yurdanur[2]
[1] Dept. of Electrical and Electronics Eng. METU, Ankara, 06800 Turkey
[2] Dept. of Aerospace Eng., METU, Ankara, 06800 Turkey

Abstract

High Frequency (3-30 MHz) (HF) Ionospheric Channel is used for military, civilian and amateur communications. By using Ionosphere, communication for distances beyond the line of sight is achieved. The main advantage of this type of communication is that it does not to require a satellite to communicate with a point beyond the line of sight. Actually the Ionosphere is used instead of a satellite. To use Ionosphere but not a satellite means independent communication for a country.

- In this study signal to noise ratio (SNR) is considered as one of the characteristics to evaluate the quality of the technological system composed of HF equipment and HF Ionospheric channel.

- Disturbance Storm Time Index (DST) is considered as an indicator of space weather. An approach based on Conditional Probability Density Functions (cpdf) is used to demonstrate the relationship between the DST and SNR

Computing Joint Probability Density Functions

- Joint pdf (probability density function) is evaluated as following:

1. The x-y (e.g. SNR-DST plane) is separated into unit cells
2. The number of points in any unit cell is counted
3. The density related to any unit cell is the number of points in that cell divided by total number of points.

- As it is seen, the number of points in cell B is higher than the number of points in cell A.

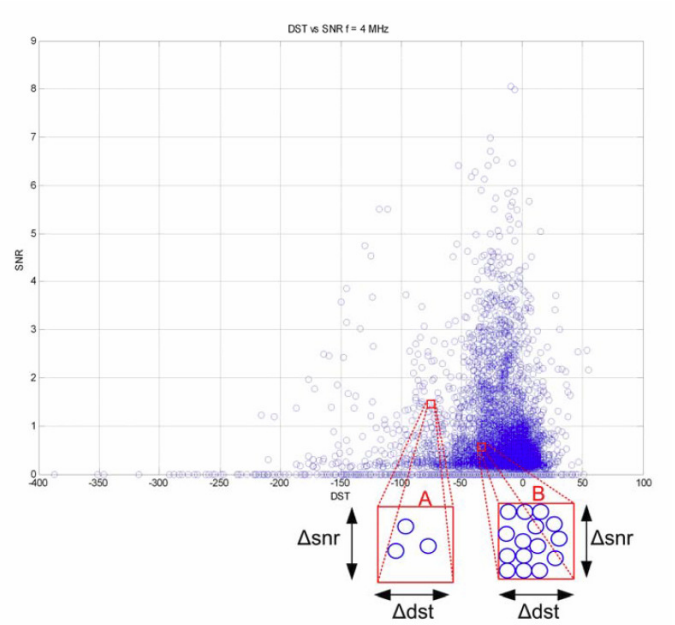

Figure 1 Calculation of joint pdf

- Figure 1 shows the scatter plot of hourly mean SNR and negative DST. Joint pdf is actually an mxn matrix
- where;

$$m_{\min} = ceiling\left(\frac{\max(SNR)}{\Delta snr}\right) \quad (1)$$

$$n_{\min} = ceiling\left(\frac{\left|\max(DST) - \min(DST)\right|}{\Delta dst}\right) \quad (2)$$

- Please note that since minimum value of SNR is zero and the minimum of DST is a negative number (e.g.-387 for year 2001), actually there is no difference between the formulae of minimum m and minimum n. m and n take larger values than these ones. This will result in adding zero rows or columns to joint pdf matrix accordingly.

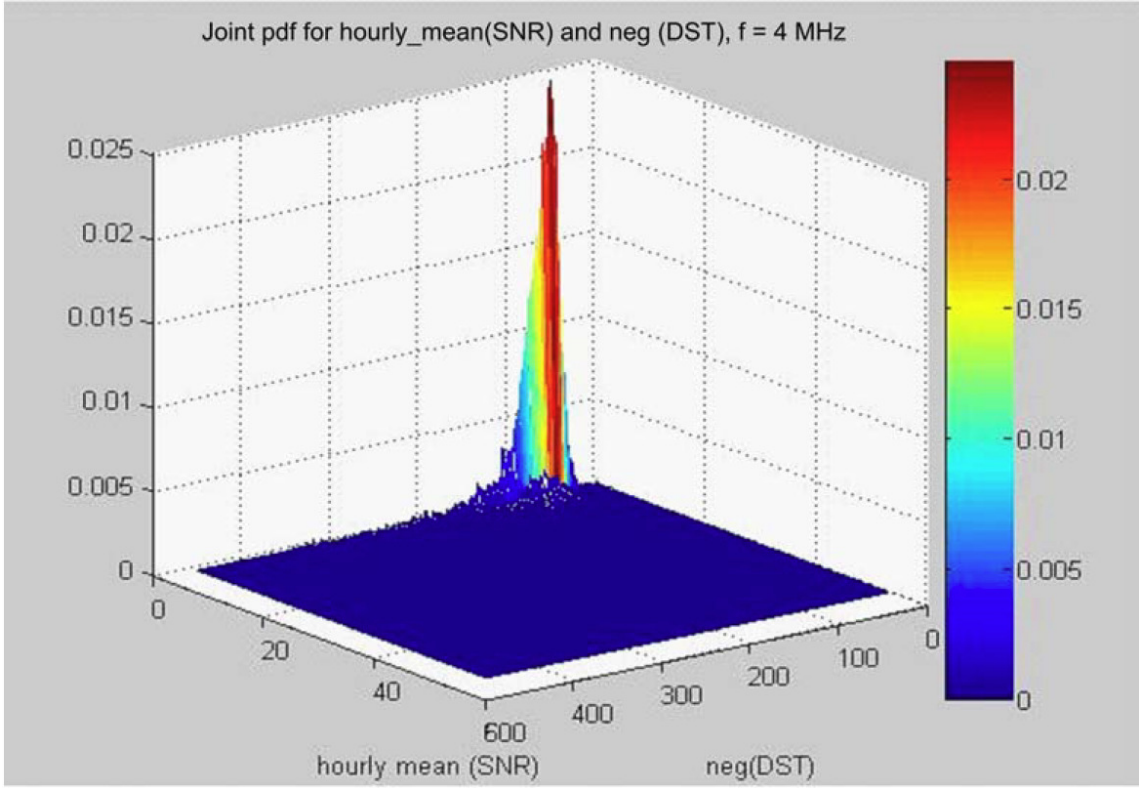

Figure 2: Joint pdf for hourly mean of SNR and negative of DST, f= 4 MHz

- It is obvious that choosing smaller “Δ” values (increasing resolution) will give better results. However due to computational difficulties, during joint pdf and conditional pdf calculations Δdst=1, Δsnr=0.5, Δmpspread=0.5 and Δdopspread=0.1 are selected. By doing so a joint pdf matrix of approximately 400x100x100x100 points is evaluated.

Computing Conditional Density Functions

- After obtaining joint density functions by using the method described, conditional pdfs are evaluated.
- As an example of calculation method, the conditional density function of SNR, related to DST will be investigated.
- DST parameter mostly takes negative values. To be able to compare the results of this parameter with ones of the other magnetic indices, the negative of DST value that is

$$nDST = -1 * DST$$

- will be used in the following sections.
- As described in previous section joint density function is an mxn matrix.

$$f_{SNR,nDST}(snr,ndst) = \begin{bmatrix} c_{1,1} & c_{1,2} & c_{1,3} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & c_{1,n} \\ . & . & & & & & & & & . \\ . & & . & & & & & & & . \\ . & & & . & & & & & & . \\ . & & & & c_{i,j} & & & & & . \\ . & & & & & . & & & & . \\ . & & & & & & . & & & . \\ . & & & & & & & . & & . \\ . & & & & & & & & . & . \\ c_{m,1} & c_{m,2} & c_{m,3} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & c_{m,n} \end{bmatrix}_{mxn}$$

where

$$\sum_i \sum_j c_{i,j} = 1$$

Let's define a conditional density function of SNR as $f_{SNR|nDST}$ $(snr|ndst=ndst_0)$ where $ndst_0$ is a known nDST value. This function is nothing but the normalized version of a column vector of $f_{SNR,nDST}(snr,ndst)$. Let us define this column vector as k^{th} column vector. Than the conditional density function will be

$$f_{SNR|nDST}\left(snr \mid ndst = ndst_0\right) = \frac{1}{\sum_{i=1}^{m} c_{i,k}} * \begin{bmatrix} c_{1,k} \\ c_{2,k} \\ . \\ . \\ . \\ c_{i,k} \\ . \\ . \\ . \\ c_{m,k} \end{bmatrix}_{mx1}$$

where

$$k = \frac{-1 * \min(nDST) + ndst_0}{\Delta dst} = \frac{\max(DST) - dst_0}{\Delta dst}$$

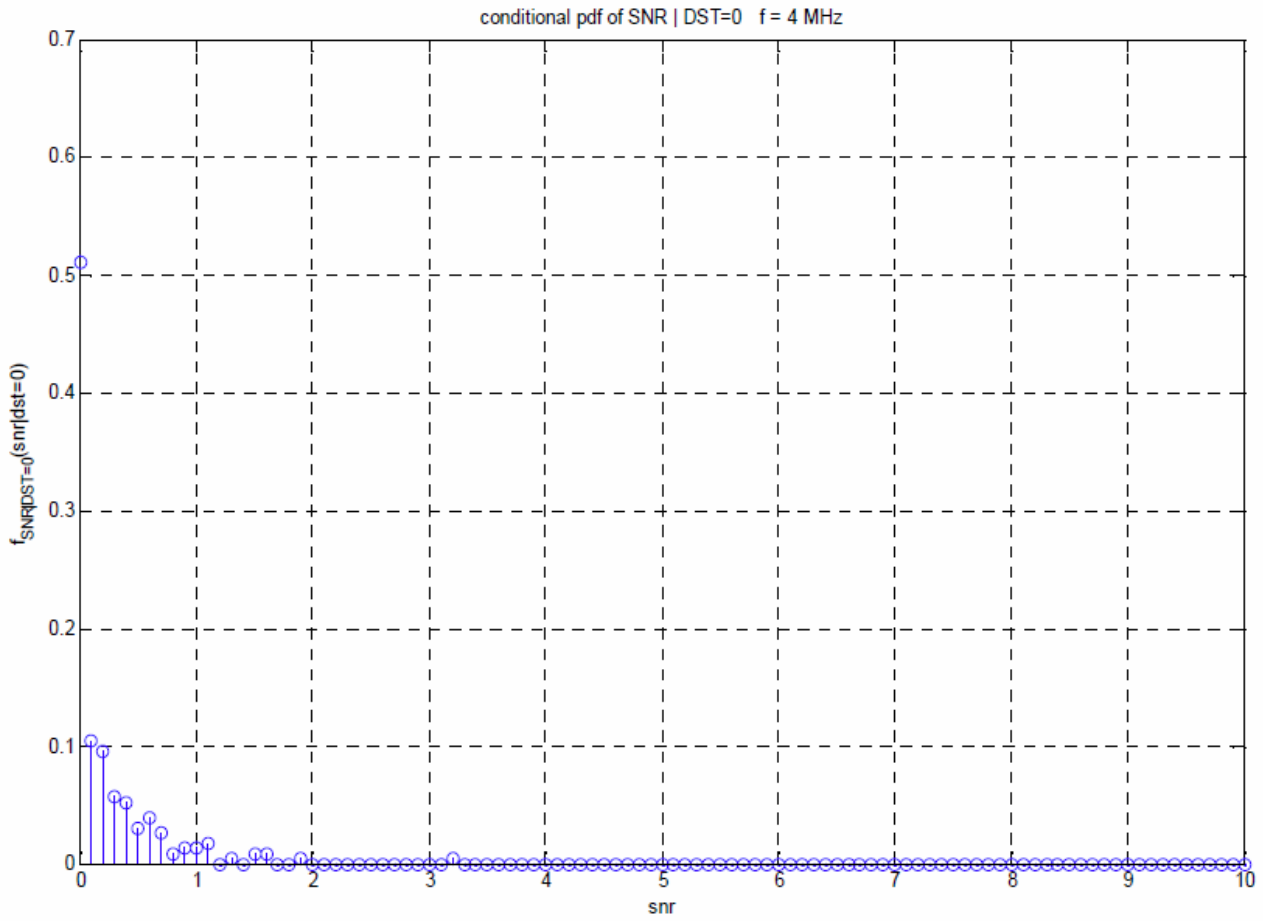

Figure 3: Conditional pdf of hourly mean of SNR, DST= 0, f=4 MHz

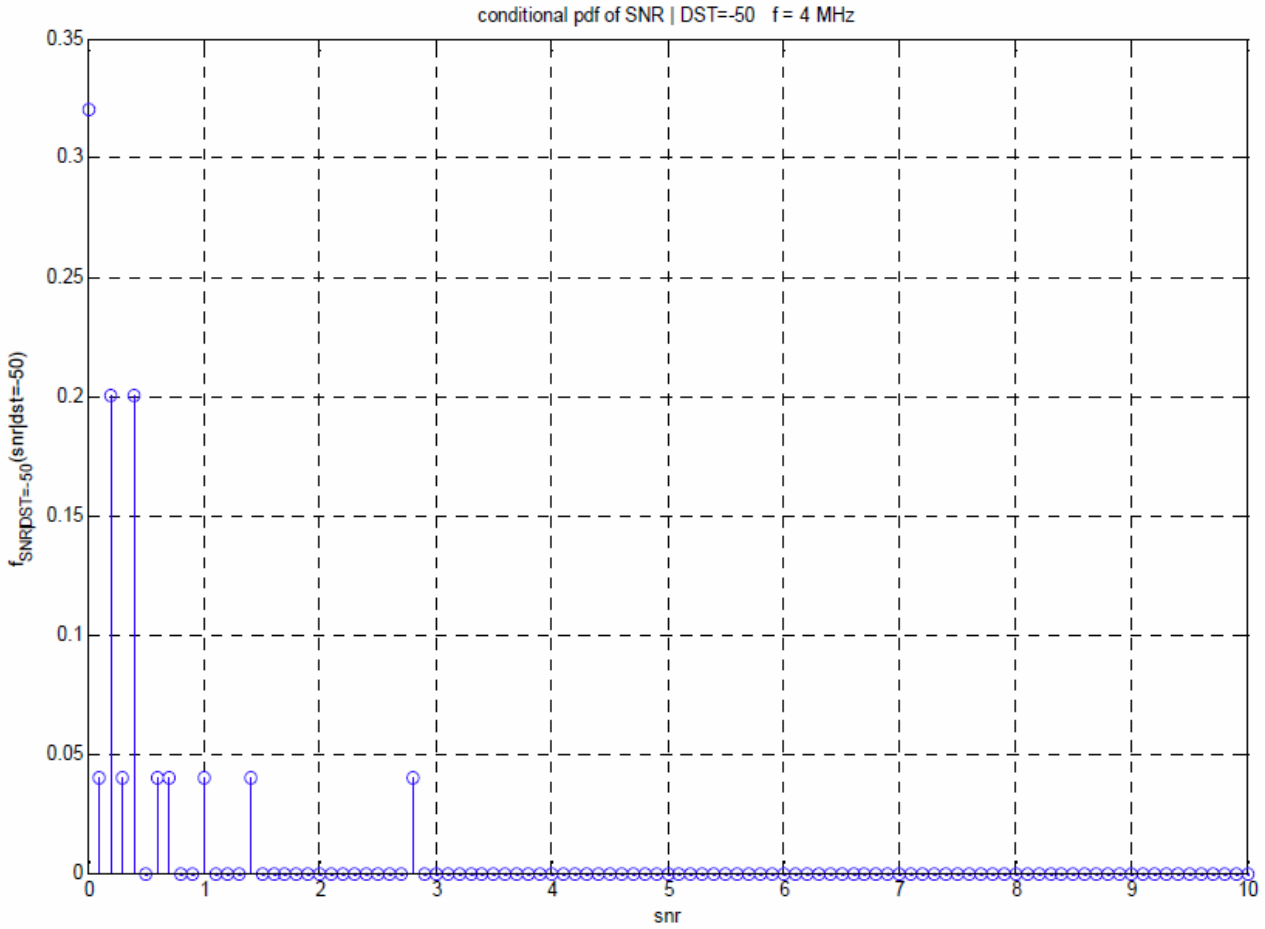

Figure 4 Conditional pdf of hourly mean of SNR, DST= -50, f=4 MHz

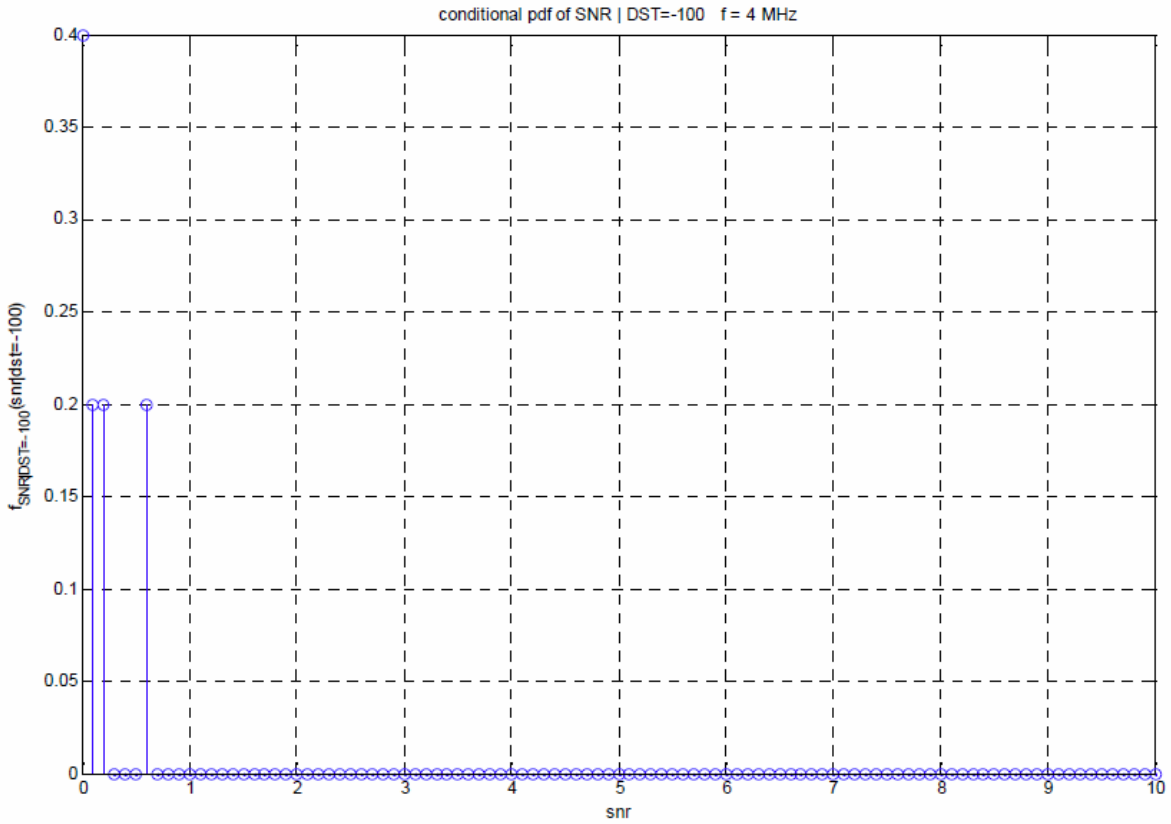

Figure 5 : Conditional pdf of hourly mean of SNR, DST= -100, f=4 MHz

Please note that

$$dst_0 = -1 * ndst_0$$

Figures 3, 4 and 5 show the conditional pdfs of SNR data (transmission frequency= 4 MHz) with DST= 0, DST= -50, DST=- 100.

Computing Marginal Density Functions

- Figure 6 shows the marginal pdf of SNR data (transmission frequency= 4 Mhz) calculated from joint density function $f^{SNR,nDST}(snr,ndst)$.

Let's define the marginal density function of SNR as $f_{SNR}(snr)$.

$$f_{SNR}(snr) = \begin{bmatrix} \sum_{t=1}^{n} c_{1,t} \\ \sum_{t=1}^{n} c_{2,t} \\ \vdots \\ \sum_{t=1}^{n} c_{i,t} \\ \vdots \\ \sum_{t=1}^{n} c_{m,t} \end{bmatrix}_{mx1}$$

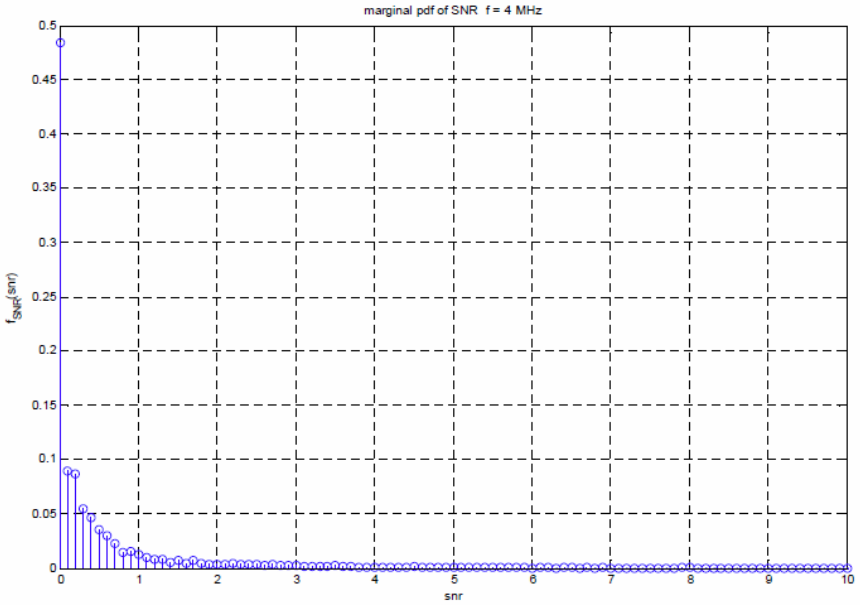

Figure 6 Marginal pdf of hourly mean of SNR, f=4 MHz

Independence

According to Bayes' Theorem, if SNR and DST are independent then

$$f_{SNR,nDST}(snr, ndst) = f_{SNR}(snr) * f_{nDST}(ndst) \quad (10)$$

$$f_{SNR,DST}(snr, dst) = f_{SNR}(snr) * f_{DST}(dst) \quad (11)$$

Independence check is performed for different combinations of transmission frequency and DST. After this study, dependence of SNR and DST is observed as expected.

The method followed to check the independence of the parameters is explained below. For simplicity the SNR and DST parameters are used in the explanation.

1. Joint pdf, $f_{SNR,nDST}(snr,ndst)$ is evaluated
   Please note that $f_{SNR,nDST}(snr,ndst)$ is an mxn matrix.

2. Marginal pdfs $f_{SNR}(snr)$ and $f_{nDST}(ndst)$ are evaluated as mentioned in .Please note that $f_{SNR}(snr)$ is an array of length m and $f_{nDST}(ndst)$ is an array of length n.

3. A dummy matrix with no physical meaning $F=f_{SNR}(snr)*f_{nDST}(ndst)$ is evaluated. Please note that F is an mxn matrix.

4. The difference matrix $D= f_{SNR,nDST}(snr,ndst)-F$ is evaluated.

5. The largest singular value of the D matrix is found.

6. If the value found in 5. is different than 0, than DST and SNR are dependent.

Calculating the Modem Availability

Modem availability is defined . For a given magnetic condition modem availability is calculated according to following procedure:

1. Conditional probability density functions of SNR, Doppler Spread and Modified Power Delay Spread are obtained.

2. The probabilities of the points that are on the upper side of the modem surface (available points) are evaluated by using the conditional probability functions.

Conclusions

- In this presentation, DST index is used. However other magnetic indices can also be used. It should be noted that DST is a planetary index and is unique over the Earth.
- Proposed method is not limited to the use of one parameter.
- The approach is used in this presentation to demonstrate the effects of space weather on communications.

Acknowledgement

- This presentation is based on the MS. Thesis by Murat Özgür Sarı carried out in the Electrical and Electronics Engineering Department, Middle East Technical University, Ankara, September 2006 under the supervision of Prof. Dr. Ersin Tulunay with the consultation of Prof. Dr. Yurdanur Tulunay.
- We acknowledge the devoted care of Oktay Sipahigil of METU, EEE Department in the preperation of the presentation.