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Twins Ionospheric Links in Sudan and South Sudan Based on University of Khartoum Ionospheric Shells (UKIS)

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Abstract: The concept of UKIS is revised, illustrated graphically and represented by mathematical equations. Five cities have been chosen for this study: Khartoum, Wadihalfa, Nimule, Kassala and AlJunaynah. The concept of twin ionospheric links is introduced and different parameters for Twin links were studied. The relation between Twin links and UKIS is illustrated. Contour maps that show the strength and death time of UKIS for the country are attached to the paper. The study is based on empirical ionospheric modeling and the statistics are computed using the International Reference Ionosphere model (IRI).

Keywords: *HF communication; UKIS; International Reference Ionosphere; Twin ionospheric links*

1. INTRODUCTION

University of Khartoum Ionospheric Shells UKIS, named in the honor of (U of K), are regions that determine the optimum frequency for the HF communication during the 24 hours inside the border of the country. The number of shells depend on the solar radiation and, as a consequence, the ionization of the F layer during day and night. It varies from three to eight shells for the near border cities to the west and east of the country and from three to nine shells for the border cities to the north and south of the country according to the current conditions. UKIS concepts and principles are applicable inside the border of the country, and can also be used for other countries worldwide [1].

2. THE IONOSPHERE FORMATION

The ionosphere is an ionized, non-linear, and dynamic medium, formed mainly with Sun's extreme ultraviolet (EUV) and soft x-ray radiation. It is affected by space and terrestrial weather, and the Earth's magnetosphere. The boundaries of the ionosphere begin at no less than 50 km in altitude and extend into the plasmasphere, the edge of which is 4-8 Earth radii distance (depending on solar activity). The ionosphere is divided into several regions, or layers: D, E, F1, F2, the *topside ionosphere*, and the *protonosphere*. An illustration of these regions is provided in Fig. 1. Each ionospheric region is characterized with a peak ion density typically at a certain altitude range. Each corresponds to a different dominating ion composition, and is subject to different processes and rates of ion production and loss [2, 3].

The D layer is the innermost layer, 60 km to 90 km above the surface of Earth. High-frequency (HF) radio waves are not reflected by the D layer but suffer loss of energy therein. This is the main reason for absorption of HF radio waves, particularly at 10 MHz and below, with progressively smaller absorption as the frequency gets higher. The absorption is small at night and reaching its peak about midday. The layer shrinks greatly after sunset, and a small fraction remains due to galactic cosmic rays [2,3].

The E layer is the middle layer, 90 km to 120 km above the surface of the Earth. Ionization is due to soft X-ray and far ultraviolet (UV) solar radiation ionization of molecular oxygen (O_2). Normally, at oblique incidence, this layer can only reflects radio waves having frequencies lower than about 10 MHz and may contribute a little bit to the absorption on frequencies above. However, during intense sporadic E events the Es (sporadic E-layer) layer can reflect frequencies up to 50 MHz and higher. The vertical structure of the E layer is primarily determined by the competing effects of ionization and recombination. At night, the E layer rapidly disappears as the primary source of ionization is no longer present. After sunset the increase of the height of the E layer maximum increases the range to which radio waves can travel by reflection from the layer [2,3].

The Es layer is characterized with small, thin clouds of intense ionization, which can support reflection of radio waves (rarely up to 225 MHz). Sporadic-E events may last in just a few minutes to several hours. This propagation occurs most frequently during the summer months when high signal levels can be reached. The skip distances are generally around 1000 km. Distances for one hop propagation can be as close as 900 km or up to 2500 km. Double-hop reception over 3500 km is possible.

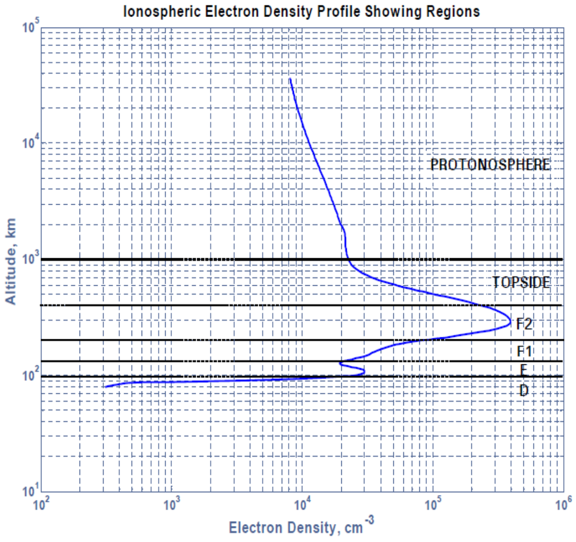


Fig. 1. Ionospheric Electronic density profile

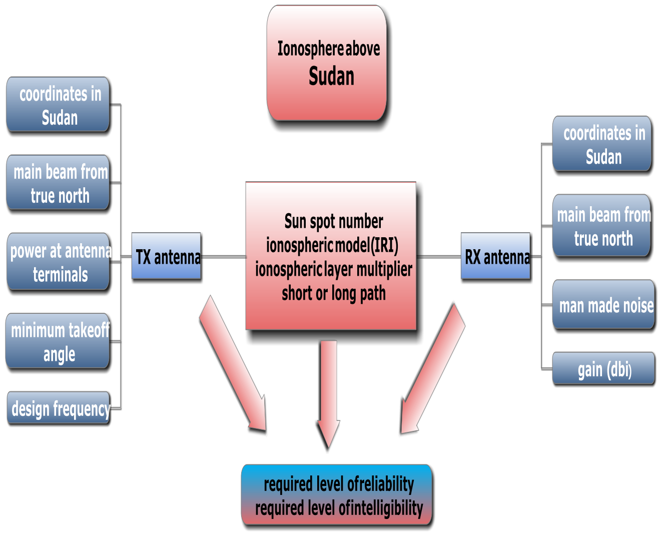


Fig. 2. Input parameters of the system

The F layer or region, also known as the Appleton layer extends from about 200 km to more than 500 km above earth level. It is the upper layer of the ionosphere. Here extreme ultraviolet (UV, 10–100 nm) solar radiation ionizes atomic oxygen. The F layer consists of one layer at night, but during the day, a deformation is often formed in a profile labeled F_1. The F_2 layer remains by day and night is responsible for most of the skywave propagation of radio waves, facilitating high frequency (HF, or shortwave) radio communications over long distances [1].

2.2 Frequency of Optimum Transmission (FOT)

In the concept of HF prediction, the highest effective frequency for a specific time and path that is predicted to be usable for 85% to 90% of the days of the month is called the Frequency of Optimum Transmission. This value is located between 85% to 90% of the Maximum Usable Frequency (MUF) [3].

This paper revises UKIS technique and the mathematical equations that give the optimum frequency for HF transmission within the border of Sudan and South Sudan, during the 24 hours. Also, the concept of twin ionospheric links is illustrated and different parameters for twin links are studied. The concept of Shells is shown graphically and its strength and dead time are discussed.

3. MODELING

Ionospheric model is a kind of numeric forecast. The state of the ionosphere is described by series of numbers and physical laws. By processing these numbers we can predict the state of the ionosphere at any time. This method of forecast is built on representing the ionosphere evolution by a set of basic physical laws and functions that approximate at best specific non-homogenous processes developed in the ionosphere. Figs 2 and 3 summarize the input and output parameters of the simulation.

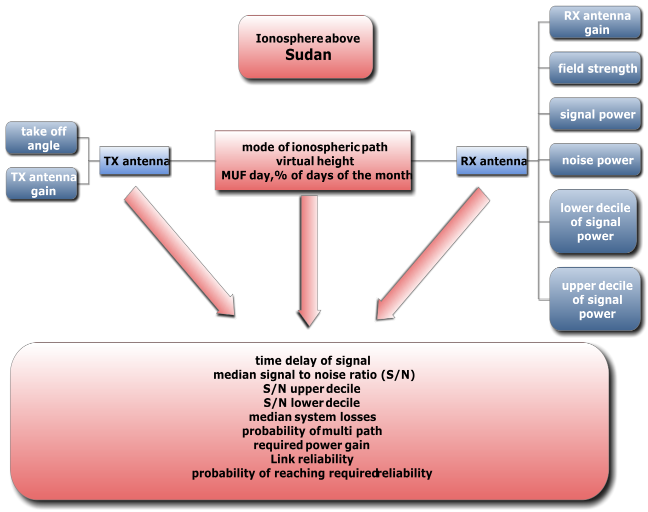


Fig. 3. Output parameters of the system

3.1 UKIS Terminology

The domains surrounded by the shells can be divided into three main categories (see Fig. 4):

1. Near distant shells which can be subdivided into adjacent near, near, far near or (A near, B near and C near) respectively.
2. Middle distant shells which can be subdivided into near middle, middle, and far middle or (A middle, B middle and C middle), respectively.
3. Far distant shells which can be subdivided into near far, far, and extreme far or (A far, B far and C far).

3.2 UKIS Topology

According to the location of the transmitter, the shells may have different orientations. East located transmitters generate shells that are west oriented. West located transmitters generate shells which are east oriented. North and south located transmitters generate shells that are south and north oriented respectively (see Fig. 5).

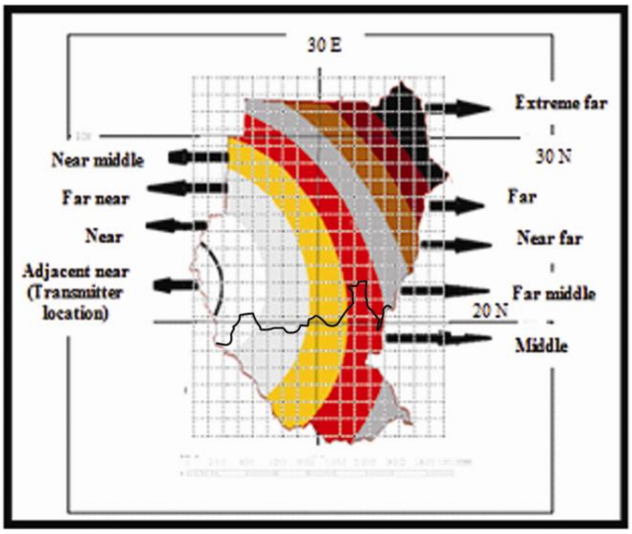


Fig. 4. UKIS various shells terminology for Sudan and South Sudan

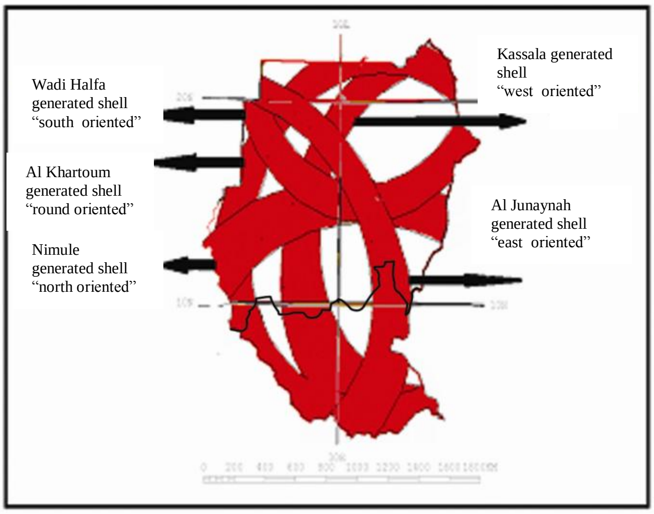


Fig. 5. UKIS orientations for Sudan and South Sudan.

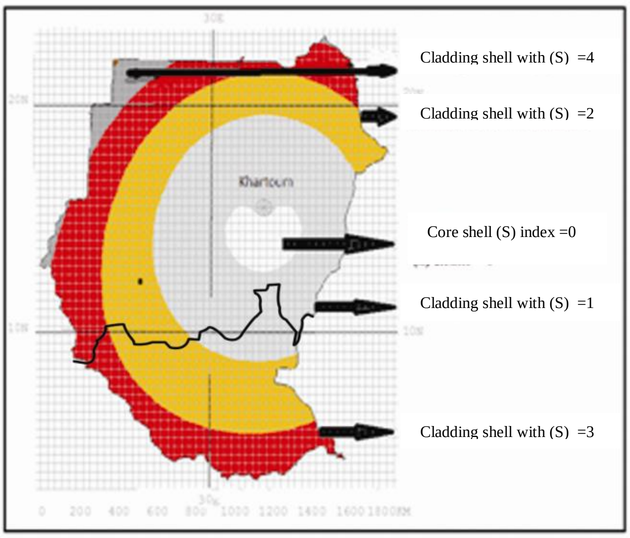


Fig. 6. SIS topology

In our design, each shell covers a range of 2 MHz and can be divided to Low and High sub-regions. The shells are centered around the transmitter location covering sectional oval shaped areas which are evacuated from inside. The core shell is the very inner one with cladding shells surrounding it in an ordered topology.

3.3 (S) Index

The Shimet index represents the order of the shell. The core shell has a zero (S) index, while upper cladding shells have non-zero positive integer values starting from 1, for the shell that surround the core shell, and the values of 2, 3, and 4 for upper shells, respectively. The minimum optimum transmission frequency is assigned to the core shell and greater values are required to cover upper cladding shells as shown by (UKIS) second equation: $f = f_c + 2(S)$. Fig. 6 illustrates shells topology for a transmitter located in Khartoum city at 7:00 pm (just after the sunset). The Figure shows the core shell and other cladding shells with values of (S) index assigned to each.

Table 1 gives the maximum value of the (S) index for a transmitter located in 5 different Sudanese cities during the 24 hours. The cities are at the far border of the country. As a consequence, they represent the extreme values of (s) index for HF communication in Sudan.

Table1. Maximum values for (s) index.

Time	Al-Junaynah	Kassala	Wadihalfa	Nimule	Khartoum
1:00	4	3	4	4	3
2:00	4	3	4	4	3
3:00	4	4	3	3	3
4:00	4	3	2	4	3
5:00	3	3	3	3	2
6:00	4	3	4	4	3
7:00	6	4	5	5	3
8:00	6	5	6	6	4
9:00	6	5	6	6	5
10:00	6	5	6	5	4
11:00	6	6	7	6	5
12:00	7	6	7	6	5
13:00	7	6	6	6	6
14:00	7	5	6	6	5
15:00	7	5	5	5	3
16:00	8	5	5	6	4
17:00	8	6	5	7	5
18:00	8	7	6	8	5
19:00	9	7	7	8	5
20:00	8	6	7	8	5
21:00	7	6	6	7	4
22:00	5	5	6	5	4
23:00	5	4	5	4	4
24:00	4	4	4	4	3

3.4 UKIS Mathematical Relations

UKIS are described by (UKIS) equations, which relate the optimum transmission frequency of any generated shell to the time during the 24 hours for a transmitter located anywhere in Sudan. The following relations show (UKIS) set of equations [4]:

$$S_{max} = ((f_s - f_c)/2) \quad (1)$$

$$f = f_c + 2(S) \quad (2)$$

Equation (1) gives the maximum value for S index for specific transmitter at specific time. Where f_c is the frequency of optimum transmission (FOT) for the core shell and f_s is the FOT for the farthest link in the border. f_c and f_s are calculated from critical frequencies and virtual heights obtained from the IRI. Equation (2) evaluates the optimum transmission frequency for the shells above the core shell which can be obtained by adding multiples of "two" to the optimum transmission frequency.
The number of generated shells can be calculated from Equation (3).

$$n = ((f_s - f_c)/2) + 1 \quad (3)$$

where f_c is the FOT for the core shell and f_s is the FOT for the farthest link in the border. [4]

3.4.1 The origin of these Equations

UKIS set of equations were experimentally derived according to the results obtained from the empirical ionospheric models above Sudan, for the five different cities throughout the 24 hours in August (2010). It was found that the shape of FOT coverage generated by any transmitter took the shape of ordered Shells with the same orientation covering the whole country. The FOT for the core shells was found to have the minimum value at 5:00 am and the maximum value at 7:00 pm for the five cities. These two times are called: dead time and strength time respectively.

4. TWINS IONOSPHERIC LINKS

Twins links are those ionospheric links from a specific transmitter to a specific shell. They have almost identical characteristics though they are located in different geographic locations. The concept of Twins ionospheric links in Sudan is totally related to UKIS. Twins links end points exist within the same shell. The phenomenon of twins links comes into being as a result of the gradient distribution of the electron densities in the ionospheric layers. The gradient effects can be neglected for small areas, but for larger areas it has significant effects.

4.1 Wadi-Halfa Vs Al-Muglad Ionospheric links

In this study a comparison between Khartoum- Wadi-Halfa and Khartoum- Al-Muglad ionospheric links were studied. The lengths of the two links are equal and have a value of 720 KMs. According to (UKIS) the two links end points lay on the same shell. It is expected that both links may have almost identical characteristics. The study compares seven parameters: the radiation angle for the transmitter; time delay; the virtual height; the MUF; the system loss; and the reliability of both links. The comparison shows that the two links are almost identical (twins) during the 24 hours, which validates the shell concept. Although the two links are widely separated geographically, they are the same in all characteristics. If compared to the country area, the two links are considered of medium length. The spectral analysis comparing the links characteristics of the two cities is shown in Figs 9-15.

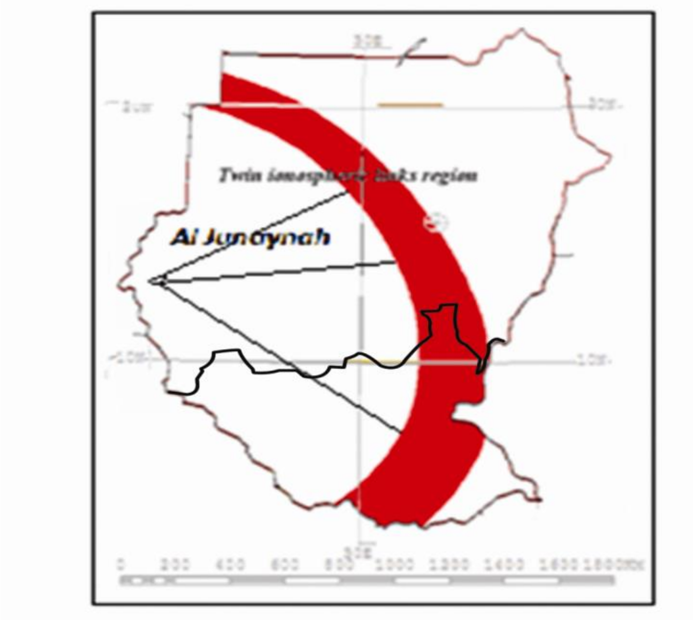


Fig. 7. Twins ionospheric links

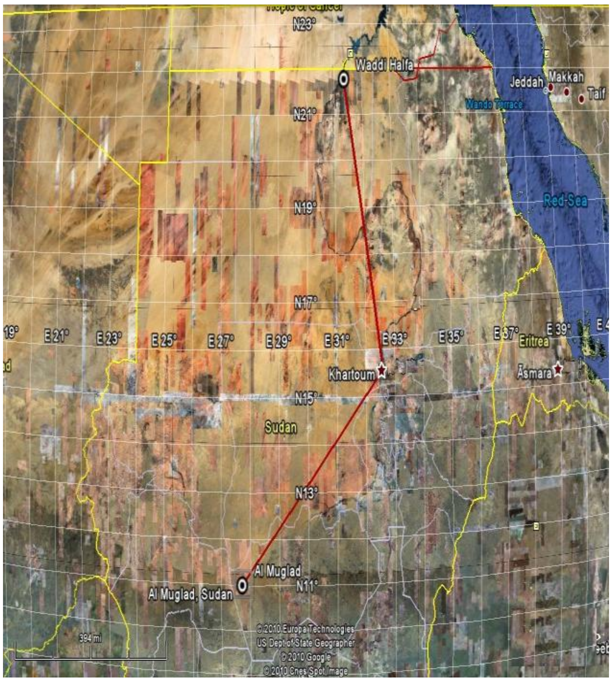


Fig. 8. Satellite image for Khartoum- Wadi-Halfa and Khartoum- Al-Muglad Ionospheric links

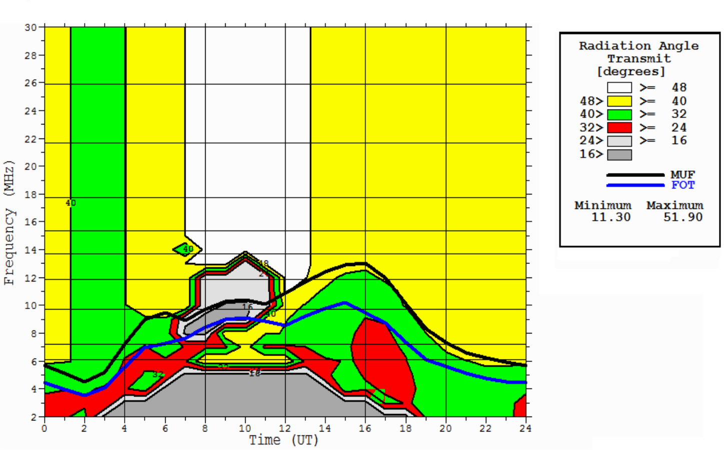


Fig. 9.a. The radiation angle for Khartoum city (transmitter location) to Wadi-Halfa ionospheric Circuit in June/2010, SSN= 18

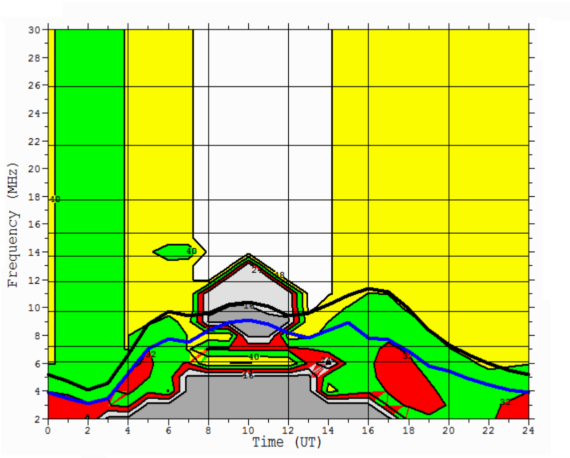


Fig. 9.b. The radiation angle for Khartoum city (transmitter location) to Al-Muglad ionospheric Circuit in June/2010, SSN= 18

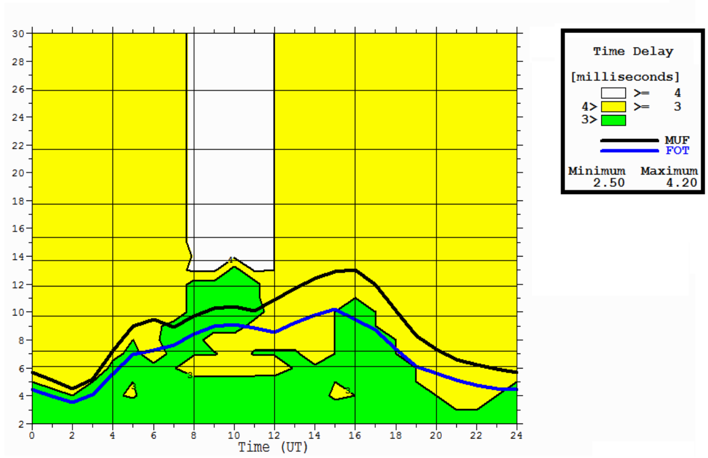


Fig. 10.a. The time delay for Khartoum city (transmitter location) to Wadi-Halfa ionospheric Circuit in June/2010, SSN= 18

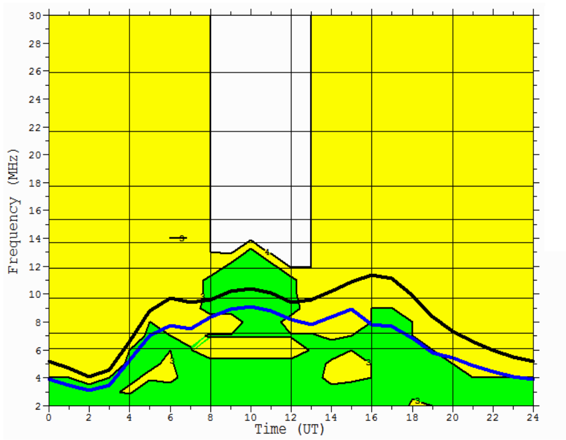


Fig. 10.b. The time delay for Khartoum city (transmitter location) to Al-Muglad ionospheric Circuit in June/2010, SSN= 18

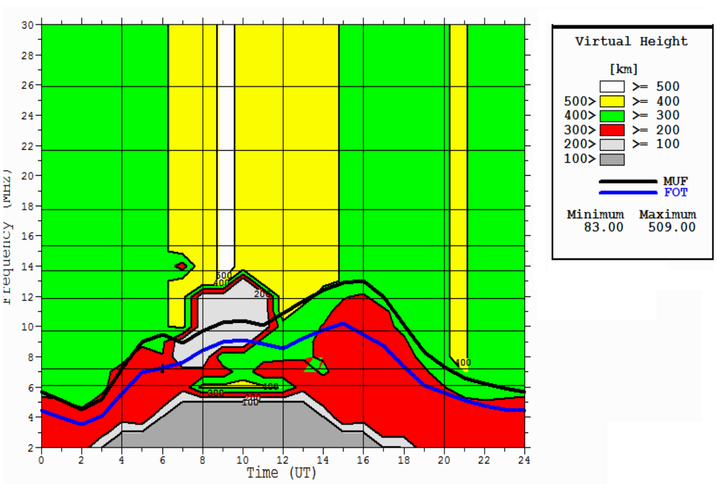


Fig. 11.a. The virtual height for Khartoum city (transmitter location) to Wadi-Halfa ionospheric Circuit in June/2010, SSN= 18

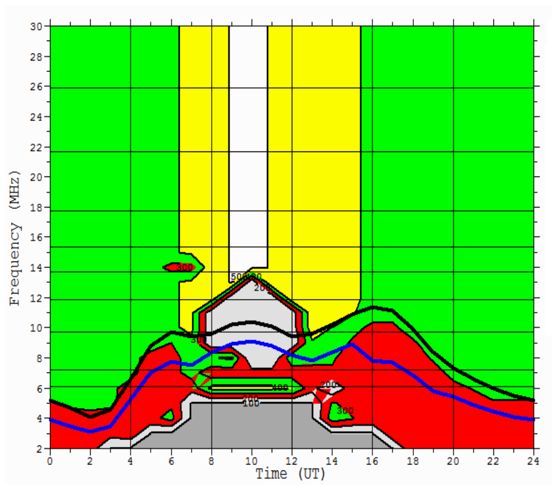
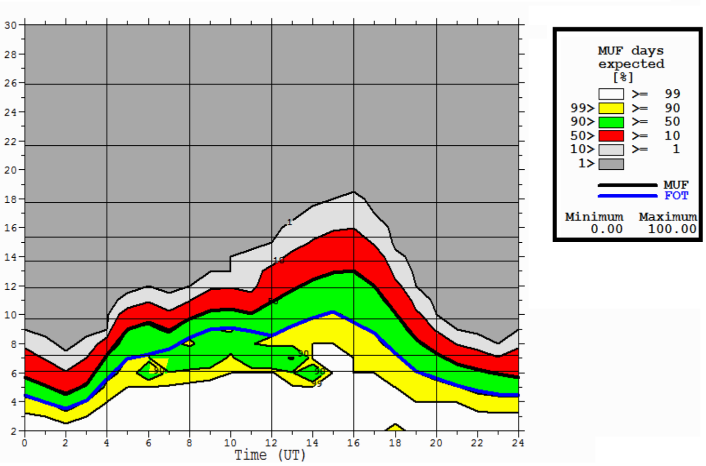


Fig. 11.b. The virtual height for Khartoum city (transmitter location) to Al Muglad ionospheric Circuit in June/2010, SSN= 18



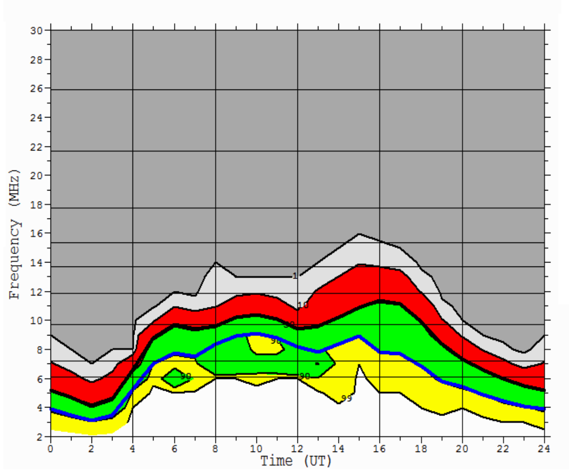
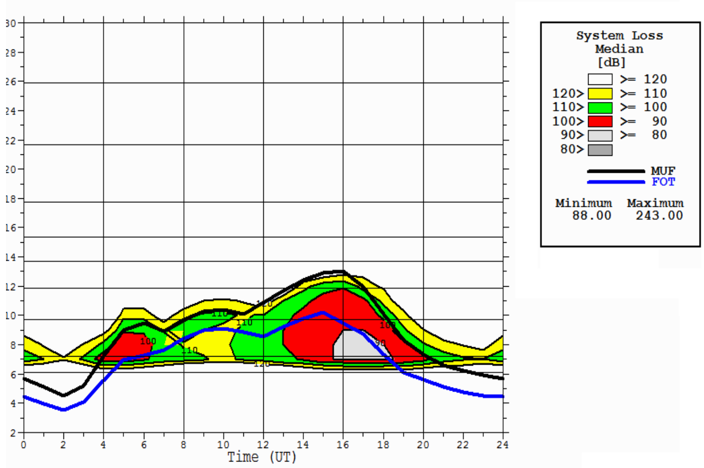


Fig. 12.a. The MUF for Khartoum city (transmitter location) to Wadi-Halfa ionospheric Circuit in June/2010, SSN= 18

Fig. 12.b. The MUF for Khartoum city (transmitter location) to Al-Muglad ionospheric Circuit in June/2010, SSN= 18



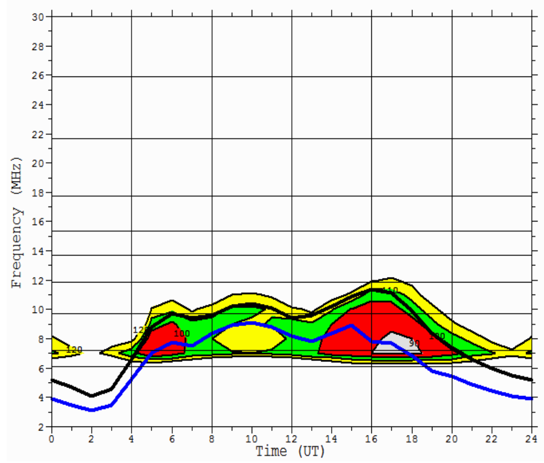
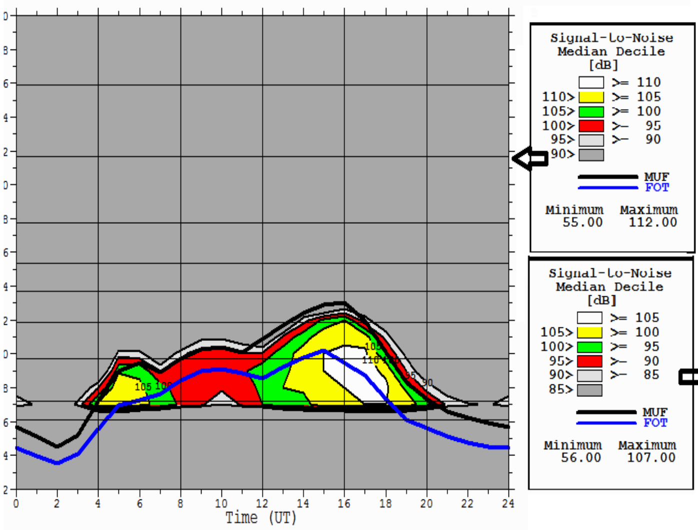


Fig. 13.a. System loss for Khartoum city (transmitter location) to Wadi-Halfa ionospheric Circuit in june/2010, SSN= 18

Fig. 13.b. System loss for Khartoum city (transmitter location) to Al- Muglad ionospheric Circuit in june/2010, SSN= 18



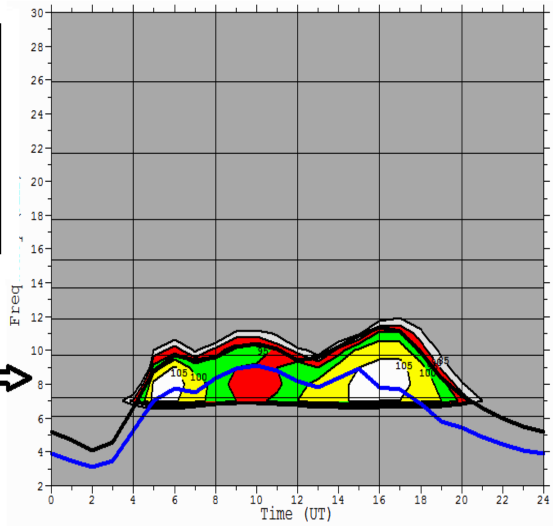


Fig. 14.a. Signal to Noise values for Khartoum city (transmitter location) to Wadi-Halfa ionospheric Circuit in June/2010, SSN= 18

Fig. 14.b. Signal to Noise values for Khartoum city (transmitter location) to Al-Muglad ionospheric Circuit in June/2010, SSN= 18

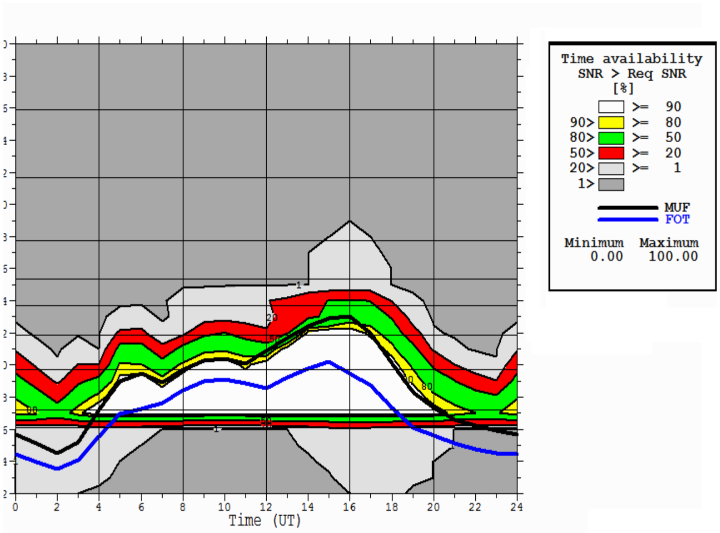


Fig. 15.a. The link reliability for Khartoum city (transmitter location) to Wadi-Halfa ionospheric Circuit in June/2010, SSN= 18

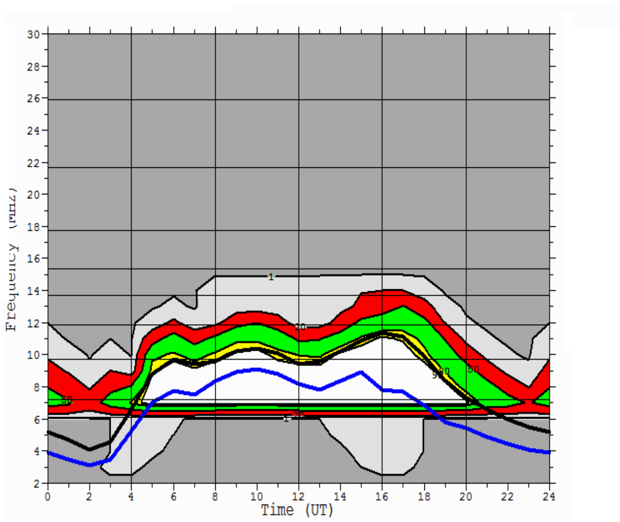


Fig. 15.b. The link reliability for Khartoum city (transmitter location) to Al-Muglad ionospheric Circuit in June/2010, SSN= 18

5.1 UKIS VARIATION

UKIS vary during the 24 hours according to the variation of the ionization in the F layer. The ionization starts by the sun rise and continues until the sun set. A reversed cycle of a decomposition of the ionized particles starts by the sun set, due to the absence of the sun radiations, and ends by the sun rise of the next day. In this paper three factors that are influenced by this variation have been studied. The first factor is the number of generated shells by a transmitter located anywhere in the country. The study has found that the number of the generated shells is in a direct relation to the variation of the ionization. Another factor that is affected by this variation is the width of the shell. This factor is inversely related to the ionization i.e. the width of the shell has its maximum value just before the sun rise (low ionization conditions) and conversely has its minimum value just after the sun set (high ionization conditions). The third factor is the range of the optimum frequencies that should be used by a transmitter in order to cover the surrounding shells. The study has found that this range is related directly to the variation of the ionization (i.e. the range of the optimum frequencies that cover the surrounding shells occupy higher values just after sunset, high ionization conditions, and occupies its minimum values just before sunrise, low ionization conditions).

Figs 16 to 20 illustrate two parameters: Firstly, the optimum frequency for the core shells and Secondly, the number of shells surrounding a transmitter located at five different cities, the four geographic directions and Khartoum city. The green line represents the frequency of the optimum transmission of the core shell during the 24 hours. The optimum frequency for the shells that surrounds the core shell can be obtained by adding 2 MHz for each shell starting from the shell that surrounds the core shell outwards the desired shell.

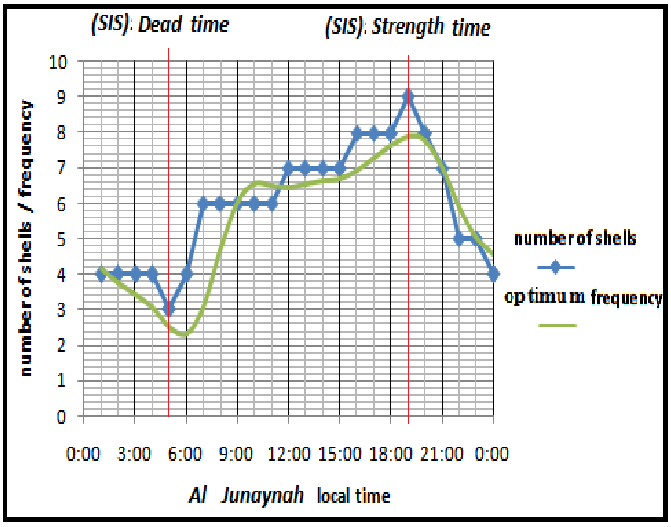


Fig. 16. Number of SIS and its core FOT in ALJunaynah

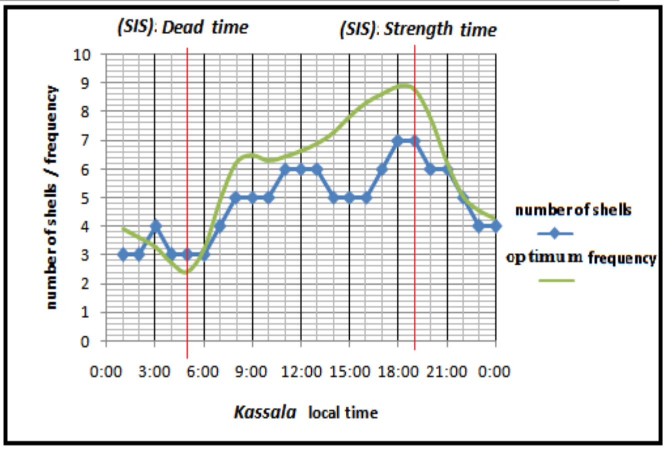


Fig. 17. Number of SIS and its core FOT in Kassala

The following polynomial relates the optimum transmission frequency of the core shell to the time for a transmitter located in Al-Junaynah city during the 24 hours:

$$f_c = -43.51t^3 + 57.36t^2 - 13.86\,t + 4.208 \quad (4)$$

where t represents time 0≤t≤24, the optimum transmission frequency for the shells above the core shell can be obtained by adding a factor of 2 multiplied by the number of surrounding shells:

$$f = f_c + 2(S)$$

The following set of equations gives the optimum transmission frequency of the core shell and the cladding shells for a transmitter located in Kassala city during the 24 hours:

$$f_c = -47.86t^3 + 58.22t^2 - 10.76\,t + 3.815 \quad (5)$$

$$f = f_c + 2(S)$$

The following set of equations gives the optimum transmission frequency of the core shell and the cladding shells for a transmitter located in Wadi-Halfa city during the 24 hours:

$$f_c = -64.51t^3 + 84.65t^2 - 22.31\,t + 5.358 \quad (6)$$

$$f = f_c + 2(S)$$

The following set of equations gives the optimum transmission frequency of the core shell and the cladding shells for a transmitter located in Nimule city during the 24 hours:

$$f_c = -34.54t^3 + 41.28t^2 - 6.091\,t + 4.318 \quad (7)$$

$$f = f_c + 2(S)$$

The following set of equations gives the optimum transmission frequency of the core shell and the cladding shells for a transmitter located in Khartoum city during the 24 hours:

$$f_c = -49.32t^3 + 62.13t^2 - 13.23\,t + 4.086 \quad (8)$$

$$f = f_c + 2(S)$$

5.1 Dead time for UKIS

As mentioned earlier the ionization of the ionospheric gases reaches its minimum level just before the sun rise, this low ionization condition reduces the range of frequencies for HF communication to its minimum range while the transmission remains in its minimum operation. The following contour maps, in figure 21, illustrate the shells at 5:00 am (local time) for the five cities. It is found that the number of generated shells and the frequencies of optimum transmission were the minimum during the 24 hours. The number of the shells generated by a transmitter located anywhere in the country has a minimum value at the dead time (two or three shells) while the range of frequencies required to cover the shells is the narrowest during the dead time (between 2MHz to 8 MHz). The shells have a maximum width during this time.

From UKIS equations for Al-Junaynah, Kassala, WadiHalfa, Nimule and Al Khartoum (Equation 4 to 8), the optimum transmission frequency for the core shell during the 24 hours

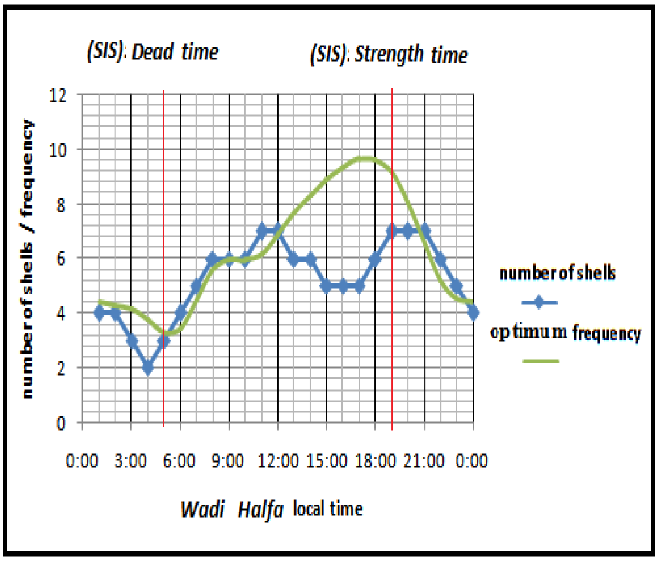


Fig. 18. Number of SIS and its core FOT in Wadi- Halfa

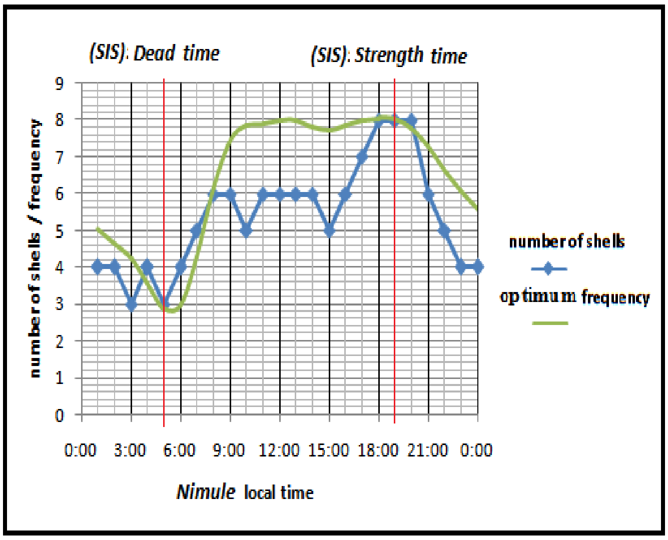


Fig. 19. Number of SIS and its core FOT in Numule

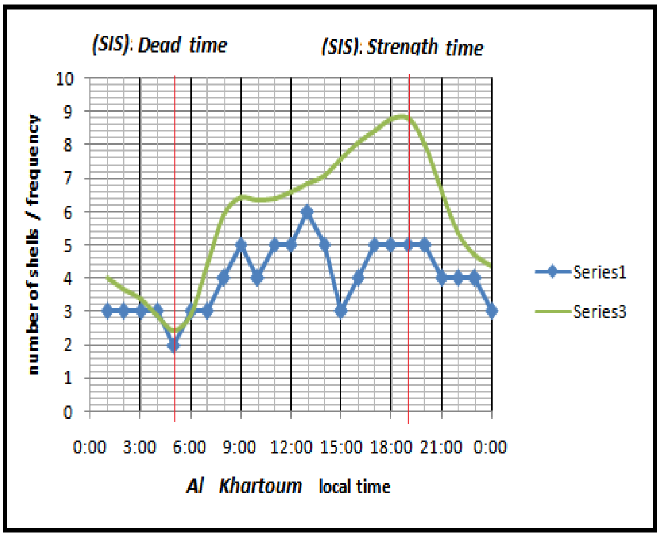


Fig. 20. Number of SIS and its core FOT in Khartoum

can be calculated. By evaluating these equations for t = 5:00, yield the value of f_c between 1.8 MHz and 3.8 MHz. Referring back to the table we notice that the maximum value of the (S) index at 5:00 am is equal to 3 for the four cities (except 2 for Khartoum city). Thus the cladding shell with (S) index = 1 has optimum transmission frequency of 3.8MHz to 5.8MHz for the five cities, this is if we assume that the core shell optimum frequency is between 1.8 to 3.8, and the cladding shell with (S) index equal 2 have optimum transmission frequencies between 5.8 MHz to 7.8 MHz .

5.3 Strength time for UKIS

In contrast to the dead time, the ionization of the ionospheric gases reaches its peak just after the sunset. So, the transmission reaches its maximum peak and the range of frequencies shifts to its highest values. The following contour maps (figure 22) illustrate the shells at 7:00 pm (local time). It is found that the number of the generated shells for all Sudanese cities and the frequencies will be at their maximum peak during the 24 hour.

From UKIS equations 4,5,6,7, and 8 for Al-Junaynah, Kassala, WadiHalfa, Nimule and Al Khartoum, respectively, the optimum transmission frequency for the core shell during the 24 hours can be calculated. By evaluating above equations for t = 21:00, yield the value of f_c between 7.8 MHz and 9.8 MHz for four cities (and between 9.8 MHz and 11.8 MHz for Wadi-Halfa) and by referring back to the table. It is found that the maximum value of the (S) index at 7:00 pm is equal to 7, 6, 6, 7 and 4 for the five cities, respectively. Thus the cladding shells with (S) index equal 1 have optimum transmission frequencies of 9.8MHz to 11.8MHz, for four cities (11.8MHz to 13.8MHz for Wadi-Halfa). The cladding shells with (S) index equal 2 have optimum transmission frequencies of 11.8MHz to 13.8MHz (13.8MHz to 15.8MHz for Wadi-Halfa). The cladding shells with (S) index equal 3 have optimum transmission frequency of 13.8 to 15.8 (15.8MHz to 17.8MHz for Wadi-Halfa). When we reach the cladding shell with (S) index equal 7. It is found that the optimum transmission frequencies are between 21.8 MHz to 23.8MHz.

6. CONCLUTIONS

The concept of ***UKIS*** is revised, illustrated graphically and investigated over Sudan. The investigation was carried out by using International Reference Ionosphere model. Empirical relations were developed to compute the optimum transmission frequency, (polynomials). The coefficients of this polynomial depend on the location of the city. The polynomial coefficients were determined for Five cities in Sudan, namely Al Junaynah, Kassala, WadiHalfa, Nimule and Khartoum. The optimum transmission frequency is also computed for these cities. The concept of twin ionospheric links was introduced and different parameters for Twin links were studied.

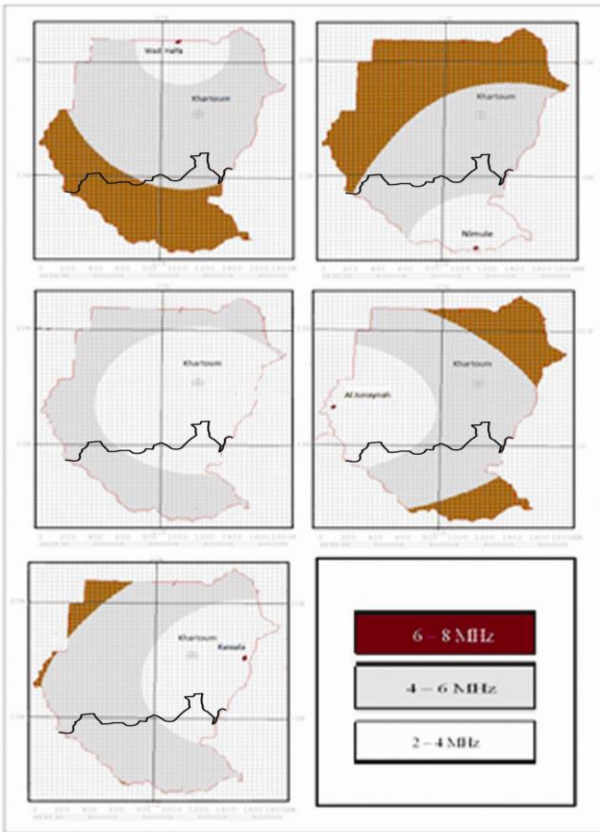


Fig. 21. Dead time for UKIS

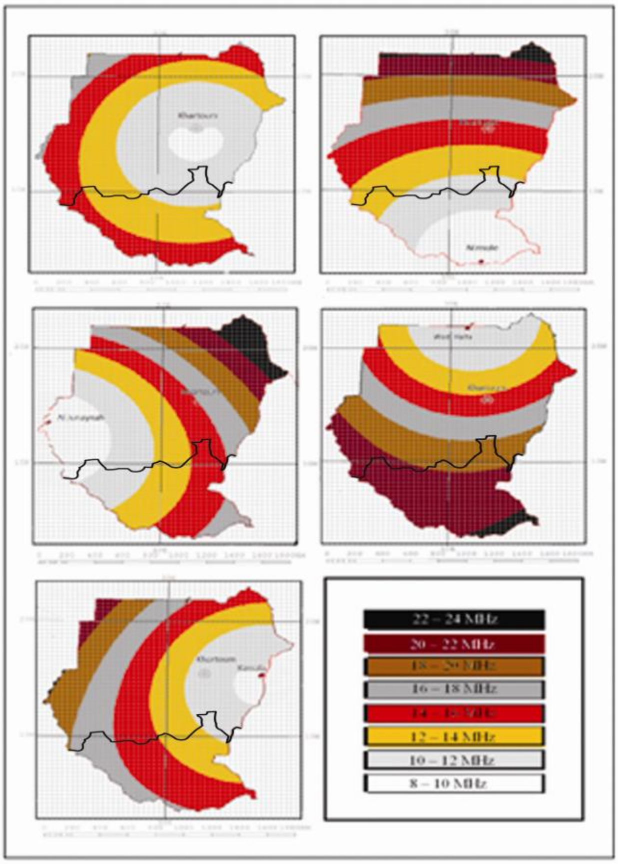


Fig. 22. Strength time for UKIS

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