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Preliminary Study of Space Weather Effects on the HF and VHF Communications at Low Latitudes during an Early Stage of the Solar Cycle 25

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***Abstract*— The Sun is a decisive element for the control and development of several natural processes on the Earth, and, in addition, the solar activity can also have certain effects on some human activities, as per example, the radiofrequency communications. In this paper, results about an experiment developed in México in collaboration with the radio ham community, during 17 days of spring 2020 are exposed and discussed. The main objective of the experiment is obtaining a record of possible effects of the solar activity on the habitual radio links classified into two groups: between radio ham stations inside and outside Mexico, and between a couple terrestrial ham stations and two radio ham satellites operating at the low earth orbit. The evaluation of the performance for each link between radio ham stations is compared with the evolution of variables that describe the Space Weather conditions in the same time span such as planetary k-index, interplanetary magnetic field, solar wind speed and solar wind density, under very low Sun activity as result of an early stage of the solar cycle 25. Thus, the results analyzed and shown in this paper are the basis for future studies about the relationship of possible effects of the solar activity on radio communications, particularly at radio ham frequencies bands, taking as baseline the evolution stages for the current solar cycle. Moreover, these results can provide reference data for further development or complement of indirect techniques to understand and keep records regarding the relationship between geophysical phenomena on the Earth and the solar activity.**

Keywords— ionospheric communications, Space Weather, HF radio links, VHF/UHF satellite communications, radio ham

I. INTRODUCTION

As is well known, the ionosphere acts as a propagation medium for some radio communication systems, particularly those that operate at HF and VHF frequency bands where radio waves are reflected and refracted by the ionosphere so achieving long range communication links [1]. The ionosphere has a variable composition (height, extension, electron density, and so on) which is a function of the geomagnetic latitude, daytime, year season and solar cycle [2], hence, radio communications using this transmission medium dep depends on its behavior. Studies have been conducted about the ionospheric propagation and the effects that this atmosphere layer has on the communication systems, see [3-6] for instance. The temporal variability of the ionosphere is related to what is called Space Weather provided that it describes different parameters of the Sun activity and their effects on the Earth atmosphere. Moreover, the Space Weather parameters that impact on the ionosphere behavior are different for distinct latitude (there are different ionospheric compositions depending on the latitudes) and thus we can talk about a space-time ionospheric variation. Several research works have been published for studying the effects of these parameters on HF communications during a relatively high solar activity [7] and the importance of having more information for several Space Weather conditions is pointed out [6]. On the other hand, effects of solar activity on electronic and communication systems are more remarkable at high and mid-latitudes and many studies are reported in the open literature, although significant attention has also been paid to low latitudes

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[8]. In this context, Utlaut [4] graphically address how the ionosphere scattering is modified as a function of the geomagnetic latitudes, which impacts on the range of communication links. Davies and Smith [5], on their turn, explain the ionospheric scintillation phenomenon (variations of signal intensity, phase and angle of arrival), which is more pronounced in equatorial zones and high latitudes, and is of particular interest for global navigation systems because they operate based on phase locking schemes. For a review of ionospheric effects on communication systems at different latitudes, the interested reader can consult [9] and references therein. In the paper presented here, a set of observations of the performance of radio ham systems operating in Mexico (i.e. low magnetic latitude) at the HF and VHF frequency bands is reported and analyzed. The observation period was during spring 2020 and therefore corresponds to an early stage of the solar cycle 25 [10]. Through the observations, there was very low level of solar activity and so the results observed under these conditions can be useful as a reference for further investigations. Then, the rest of the paper is organized as follows: Section II exposes the Space Weather conditions for the observation period. The experimental settings are described in Section III. The observed results reported by the radio ham systems and their analysis are presented in Section IV. Finally, the concluding remarks are highlighted in Section V.

II. Space Weather Conditions

The most relevant characteristics of the Space Weather during our study period (May 18-June 3, 2020) are the very low level of solar activity and the almost total absence of sunspots on the Sun´s photosphere. Continuing the trend of 2019, when the Sun was blank 77% of the time, the current year presents a similar percentage of blank days so far.

The 17 days considered in our survey share this characteristic. In addition, during this time and according to NOAA data (http://www.sec.noaa.gov/today.html), the F10.7 index ranged between 68 and 71 sfu (solar flux unit), values close to its lowest limit, usually placed around 50 sfu.

Nevertheless, on May 29, at 7:24 UTC, an M1.1 solar flare took place on a sunspot region located near the Sun northeastern limb. This very short duration solar flare originated a minor R1 radio blackout and was followed by a small coronal mass ejection that did not impact the Earth, due to the location of the sunspot region on the Sun surface. This solar flare has a remarkable interest from the space meteorology point of view because it marks the end of a long period without this kind of events that started on 20 October 2017, and because it can be seen as the first event of the new solar cycle. But, as it will be commented below, it did not have any relevant influence on the ionosphere or the geomagnetic field during our study period. This is also the case of several small coronal holes that appeared in the Sun southwestern region on May 20 and 24, and did not affect our planet in a noticeable way.

Solar wind features registered at the L1 Lagrange point by ACE and DSCOVR during the study period [11], reflect this little solar activity. Speed varies between 294.5 km/, on May 27, and 408 km/s, on May 30. The increase registered this day can be partially due to the action of the coronal hole observed on May 24. All the records indicate slow solar wind [12], as depicted in Fig 1.

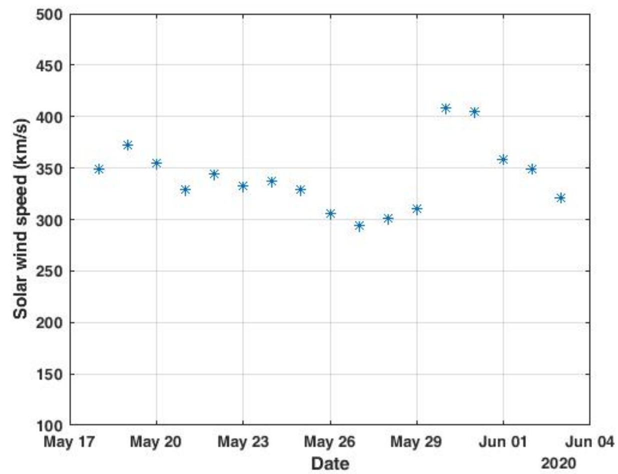

Fig. 1. Solar wind speed, http://www.spaceweather.com.

In its turn, protons density values range between 2.1 protons/cm^3, on June 3, and 14.5 protons/cm^3 on May 29, a density over the average for slow solar wind, as shown in Fig. 2.

The Interplanetary Magnetic Field (IMF) carried by the solar wind reaches the lowest value (2.1 nT) on May 23 and the highest (8.1 nT) on May 18. On May 29, probably the most interesting date of the series, the magnetic field is 7.9 nT. Twelve out of the 17 days have values lower than 5 nT that is the characteristic quantity for slow solar wind [12]. The Bz component near the Earth is positive on five days of May (18, 25, 27, 28 and 29) and its highest negative took place on June 1, reaching -6.6 nT.

As expected, the geomagnetic field did not experience any perturbation during our study period. The Kp index reached the level 3 (the highest for not disturbed conditions) only two days (May 30 and June 1), as shown in Fig. 3.

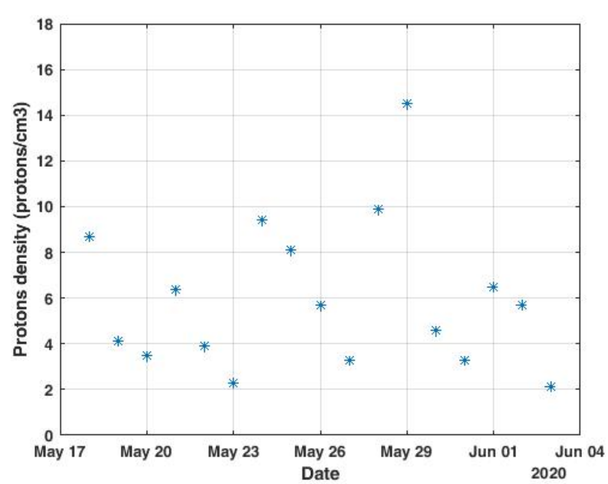

Fig. 2. Solar wind density, http://www.spaceweather.com.

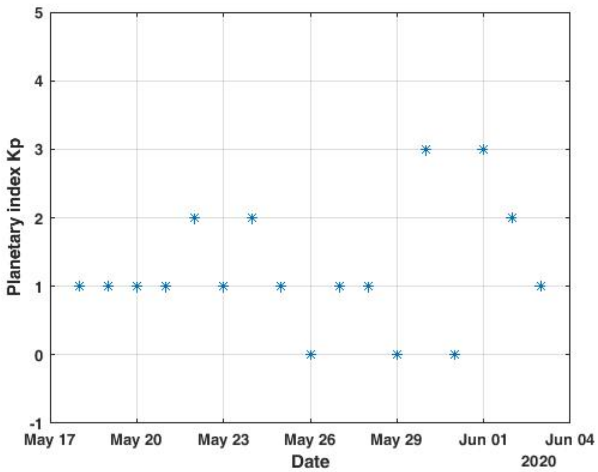

Fig. 3. Planetary index Kp, http://www.spaceweather.com.

The H component of the magnetic field registered at the Observatory of Teoloyucan, Mexico [13], did not show significant changes (see Fig. 4) except on May 21 and 30 and June 1 when the differences between the maximum and the minimum values reached 50, 57 and 54 nT, respectively.

III. Experimental settings

In order to conduct the observation campaign, a call for participation was open to members of the Mexican Federation of Radio-Experimenters (FMRE, for its acronym in Spanish) to have representative stations from the three zones in which radio amateurs are organized in Mexico [14]. Table I shows the 10 FMRE participants identified by their callsing, name of the geographical state in Mexico, and their grid locator. As can be seen, there were six stations from zone XE1, one from zone XE2 and three from zone XE3, where their location allowed to have as reference the possible propagation effects existing within Mexico.

In Fig. 5 are depicted on a Mexico map, each location of the FMRE stations, participants in the experiment, according to its grid locator. The main characteristics of the multi-band radio equipments used during the campaign are outlined in Table II.

TABLE I. Locations of the FMRE participating stations

Callsing	State	Grid
XE1AO	COLIMA	DK89
XE1AY	COLIMA	DK79
XE1HG	JALISCO	DL80
XE1BRX	GUANAJUATO	DL90
XE1R	CDMX	EK09
XE1YFJ	CDMX	EK09
XE2O	NUEVO LEON	DL95
XE3GAP	CHIAPAS	EK36
XE3ISS	QUINTANA ROO	EL61
XE3I	QUINTANA ROO	EL61

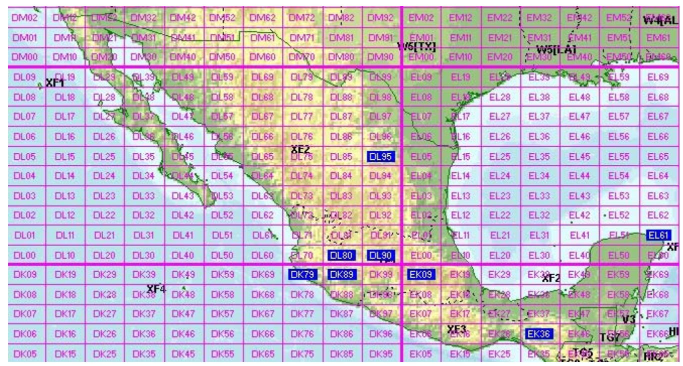

Fig. 5. Location of participating stations along Mexico.

TABLE II. Specifications of radios used by FMRE participants

Callsing	Radio Sensitivity	Modulation*	Antenna Gain (dBi)
XE1AO	-123 dBm	SSB, FM and AM	8.0
XE1AY	- 92 dBm	SSB, FM and AM	6.0
XE1HG	-124 dBm	SSB, FM and AM	12.34
XE1BRX	-123 dBm	SSB, FM and AM	3.0
XE1R	-123 dBm	SSB, FM and AM	11.0
XE1YFJ	-123 dBm	SSB, FM and AM	11.0
XE2O	-144 dBm	SSB, FM and AM	0
XE3GAP	-123 dBm	SSB, FM and AM	5.0
XE3ISS	-130 dBm	SSB, FM and AM	9.0
XE3I	-137 dBm	SSB, FM and AM	5.8

* SSB: Single Side Band; FM: Frequency Modulation; AM: Amplitude Modulation

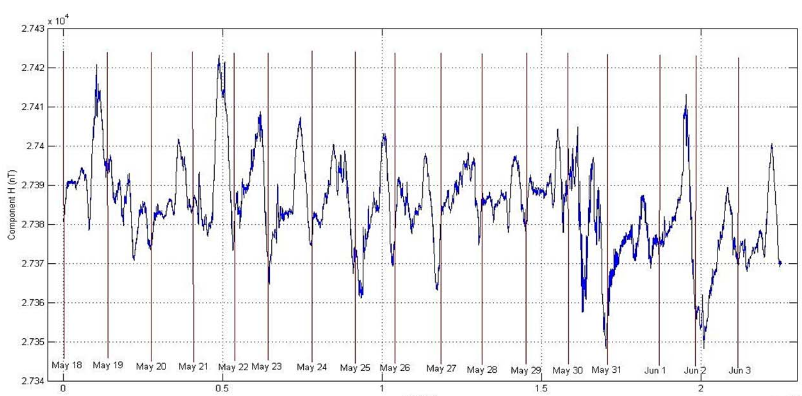

Fig. 4. Magnetogram (component H) generated from data registered at the Teoloyucan Magnetic Observatory-UNAM, Mexico [13].

Finally, it is worth mentioning that most of participants of the campaign carried out their observations preferably in the morning to avoid a thunderstorm that is more likely in the evening and that could affect the quality of the communication links. As a common practice their antennas were located relatively far from the ground (an average of 18.1 m). Also, it was suggested that each station should use the same antenna and radio that they reported on their record sheets to avoid measurement bias due to changes in receiver sensitivity or antenna gain. Initially the observation period covered from May 18 to 31, 2020, but such deadline was extended until June 03 based on the forecasting of the Mexico Space Weather Service [15]. The observations were carried out at the HF and VHF frequency bands, both terrestrial and satellite, where there usually are acceptable reception levels (good contact) as is described in Section IV.

IV. Observations and Data Analysis

The observation results to be presented here are organized in two groups: HF terrestrial radio links at 7 MHz (40 m band), and Low Earth Orbit (LEO) satellite at 145 MHz (VHF) for downlink and 435 MHz (UHF) for uplink. For this latter group we will report results for downlink only provided that we are here interested in the reception levels in Mexico.

During the observation period, 42 records were received from radio amateur stations affiliated with the FMRE. From these records, the general behavior of the radio links (both HF and VHF) in terms of the received power is as follows: 35.7% reported a received power of -73 dBm; 31% reported -63 dBm; 16% corresponds to a received power of -85 dBm; barely 4.8% with -91 dBm and there is only one record with -53 dBm. Since there are more than 66% links with received power levels higher than -73 dBm, we can state that there were good propagation conditions for most of radio links during the observation period.

We now present results of the behavior of received power levels for the two groups under consideration in a time scale. First of all, let us consider the case of terrestrial HF links operating at the 40 m band and whose result is depicted in Fig. 6 for the received power from 23 stations, most of them located in Mexico (see their callsigns given in Fig. 6). As can be appreciated, during the first two weeks of the observation period practically all radio links were stably received between -63 and -73 dBm depending on the relative positions between terrestrial stations. From May 31, however, we observe a generalized reduction of many received signals, below -73 dBm. Moreover, a wide variation is observed for the XE1YED station, for example, -85 dBm on May 28, then -97 dBm on June 2 and -73 dBm on June 3. This peculiar observation coincides with the solar activity mentioned in Section II.

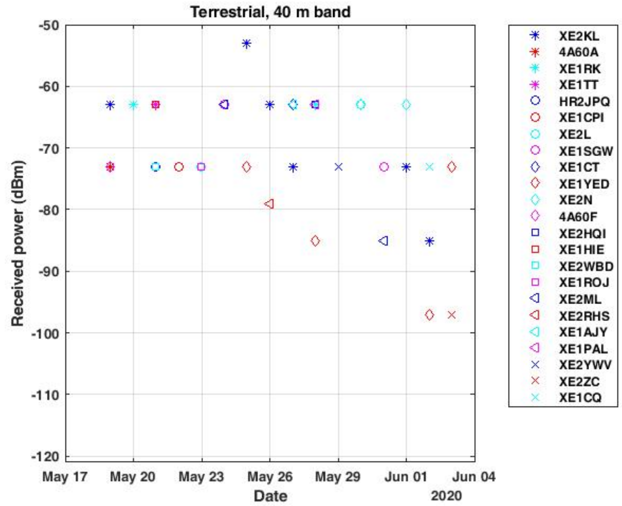

Fig. 6. Received power for different stations operating at the 40 m band (7 MHz) during the observation period.

Let us now present results regarding signals received from radio amateur satellite AO-91 and AO-92 which are CubeSats located at the LEO orbit and operating, as mentioned before, at VHF/UHF band (145 MHz for downlink and 435 MHz for uplink). For illustration purposes, Figs. 7 and 8 show the footprints of AO-91 and AO-92 satellites, respectively, reported by two FMRE operators during the experiment period.

Fig. 7. Footprint of AO-91 satellite on May 18th 2020, http://www.stoff.pl.

Fig. 8. Footprint of AO-92 satellite on June 1st 2020, http://www.stoff.pl.

On the other hand, Fig. 9 shows the levels of received power reported by two FMRE operators, which were generated from 15 stations, most outside of Mexico, and passing through these satellites. As was expected, in this case the average level of reception is lower than the corresponding results given in Fig. 6 provided the larger distance of the satellite links. Regarding the temporal behavior, we observe a relatively stable intensity of received signal and no contacts were reported during the days with a solar activity increase.

V. Final Discussion

Through Section IV results indicate that the low activity does not affect, in general, the communication links at 7 MHz (HF band) and 145 MHz (VHF band), although a particular reduction on the received power levels at 7 MHz observed during the days of small variation of the geomagnetic conditions related to the solar activity. On the other hand, it is worth including a short comment about the absence in the period of observation of phenomena as heavy rain or hurricanes than can affect the ionosphere and its influence on the transmission of electromagnetic waves. Because no strong earthquakes or significant meteorological phenomena did not occur during the period of observation, the possible influence of Space Weather on VHF and HF was studied without perturbation. The results only indicate small reductions on the received power levels when small variations of the geomagnetic field are present. It is also important to remark that this experiment represents a creative scientific collaboration among different institutions and paves the way for new similar experiments performed on different regions and periods, and under other Space Weather conditions.

VI. Conclusions

A preliminary study on HF and VHF radio communications performance during an early stage of the solar cycle 25 was presented in this paper. This study is based on an observations campaign carried out during 17 days of Spring 2020 in several locations of Mexico, which correspond to low magnetic latitudes.

The evolution of the Kp index (between 1 and 2) and the received power levels show that, during the period of low solar activity, the propagation conditions at HF frequencies (particularly at 7 MHz) did not represent significant problems in making communications among radio amateurs within Mexico. Nevertheless, we found a generalized reduction on the received power levels for the last days of the study period. This situation coincides with a small variation of the geomagnetic conditions due to the solar activity. On the other hand, results analyzed for LEO satellite links operating at VHF in the downlink (145 MHz) showed a very stable behavior (both the footprints and the received power levels), which indicates that the relatively calm solar activity did not impair these radio links.

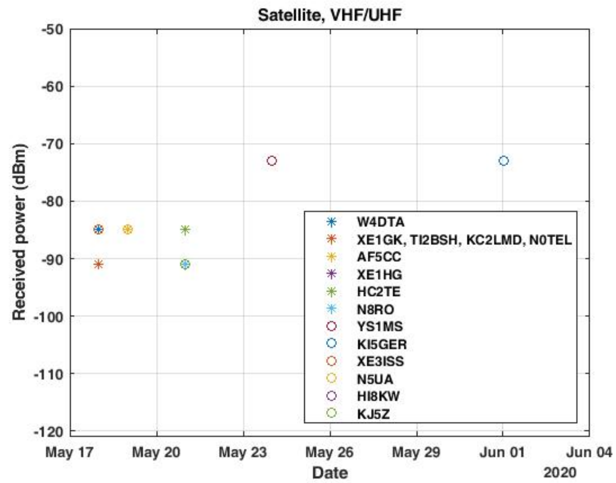

Fig. 9. Received power for satellite links operating at the VHF/UHF band.

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