MEXICAN GEOMAGNETIC K INDEX

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ABSTRACT

Solar activity affects the Earth's magnetic field in multiple ways. Geomagnetic storms are probably the most intense effects of solar activity in the geomagnetic field. Geomagnetic storms are of main importance because they threaten technology and facilities related with security of nations. One of the main tools for estimating the intensity of a geomagnetic storm is the geomagnetic K index. The K index is a scale for assessing the effects associated with the geomagnetic field variations. In this work we present the procedures to calibrate and calculate the geomagnetic index K (Kmex). Additionally, we present the record of a geomagnetic storm using the Kmex index. Kmex index is a collaboration between the National Space Weather Laboratory (LANCE) and the Magnetic Service of the Geophysics Institute (UNAM).

Keywords: Geomagnetic K index, Geomagnetic Dst index, Geomagnetic Storm, Space Weather

RESUMEN

La actividad solar afecta de múltiples maneras el campo magnético de la Tierra. Las tormentas geomagnéticas son las afectaciones más intensas que la actividad solar provoca en el campo geomagnético. Las tormentas geomagnéticas son de especial importancia puesto que están asociadas a afectaciones en tecnología e infraestructura primordiales para la seguridad de las naciones. Una de las principales herramientas para estimar la intensidad de una tormenta geomagnética es el índice geomagnético K. El índice K es una escala para valorar las afectaciones asociadas a las variaciones del campo geomagnético. En este trabajo presentamos el procedimiento de cálculo y de calibración del índice geomagnético K (Kmex). Adicionalmente, presentamos el registro de una tormenta geomagnética por medio del índice Kmex. El índice geomagnético Kmex es una colaboración entre el Laboratorio Nacional de Clima Espacial (LANCE) y el Servicio Magnético del Instituto de Geofísica de la UNAM.

Palabras clave: Índice geomagnético K, índice geomagnético Dst, tormenta geomagnética, clima espacial

1. Introducción

It is widely accepted that solar activity affects the geomagnetic field. Possibly the most important effects that solar activity has on the terrestrial magnetosphere are geomagnetic storms. Geomagnetic storms occur when the plasma's magnetic field of the interplanetary medium interacts with the geomagnetic field. The phenomenon allows electrons to flow from interplanetary medium into the environment of the Earth. This derives into alterations in the currents of Earth's ionosphere, especially in the ring current, that induce perturbations, at planetary scale, on the geomagnetic field known as geomagnetic storms (Moldwin M., 2008)

The Space Weather studies the effects of solar activity on the magnetosphere and terrestrial ionosphere, as well as its effects on our technology. Geomagnetic storms are of great interest for the Space Weather studies, since they are associated to harmful effects in: telecommunications, global positioning systems and production and distribution of energy (*e.g.* electricity, oil and gas). This has motivated the development of tools to estimate the impact of geomagnetic storms. An example is the disturbance storm time (Dst) index that is associated with the behavior of the ring current. Another example is the geomagnetic index K (Moldwin M., 2008).

A regional K index is an attempt to estimate the effects of both, interplanetary medium as well as the local ionospheric currents on the regional geomagnetic field. In addition to regional K indexes, there is a planetary K index (Kp), which averaged a number of K indexes from different Earth's locations. In order to calculate the K index it is necessary to remove from H its cyclic variations (<H>). Subsequently, in intervals of three hours, we must calculate the maximum and minimum values of H- <H>; and with them, we calculate the maximum differences. Finally, the K index grows almost linearly with the logarithm of such maximum variations (Mayaud P.N., 1980).

Recently, the National Space Weather Laboratory (LANCE) and the Magnetic Service (MS), both of the Geophysics Institute at the National and Autonomous University of Mexico (UNAM), have been given the task of calculating the K index for the central region of Mexico (Kmex). Whereas the MS provides the data of the terrestrial magnetic field; the LANCE provides the computational infrastructure for the calculation of the Kmex. It is important to emphasize that the Kmex is an experimental product in validation process that the LANCE, in collaboration with the MS, offers to its users. Here's how we calculate the Kmex index

2. Mexican geomagnetic K index

2.1 Geomagnetic data from central Mexico

As previously mentioned, we use data delivered by the Magnetic Service (MS). The magnetic data is measured at the Teoloyucan Geomagnetic Observatory (TGO) located in central Mexico (LAT 19.746 °, LON -99.190 °). The TGO is the main magnetic observatory of the MS housed in the Institute of Geophysics of the National Autonomous University of Mexico (UNAM). The TGO operates with a 3 components variograph fluxgate DFI, a magnetometer Overhauser POS N 129 and a DI-flux ZEISS THEO20B, with a backup variograph FGE HDZ. The MS reports the data recorded by the TGO in near real time with a cadence of one minute and a resolution of 1 nT. The MS release one file per day in Extended IAGA2002 format. These are the files we use in the calculation of the Kmex index.

2.2 Variations on the geomagnetic horizontal component

In order to remove the cyclic variations in the horizontal component (H) of the geomagnetic field, our first step is to calculate the median value of H (<H0>) along the previous 27 days, for a given time t = t0. We select a period of 27 since it is the duration of a solar rotation and thus, this period is long enough to take into account many of the solar and terrestrial cyclic effects of H. This allows us to define the variations of H (dH) for a given time t0 as:

$$dH\ (t0) = H\ (t0) - \langle H0 \rangle \quad (1)$$

Once known the value of dH(t), our next step is to calculate its maximum (MH) and minimum (mH) values in lapses of 3 hours. With MH and mH known, we proceed to calculate the maximum tri-hourly variation of dH (DH):

$$DH = |MH - mH|. \quad (2)$$

We calculate eight different values of DH per day through equation (2). Next we use DH to calculate the Kmex.

2.3 Kmex calibration

In order to calculate the Kmex index through the DH values, we compared the values of the natural logarithm of DH (*Ln*(DH)) with values of the planetary K index (Kp). Our purpose is to find out which values of Kp correspond to the calculated DH ranges. In other words, we aim to calibrate the TGO measurements.

The Figure 1 shows a comparison of the calculated values of DH and the corresponding values of the index Kp for the period 01-Jan-2014 to 01-Jan-2017. We compare the values of Kp and DH at the same date and hour. The DH values presented in the figure (open gray squares) are calculated by a Gaussian fit (uncertainty bars correspond to the associated standard deviation).

We appreciate in the figure a linear tendency (solid black line) between *Ln*(DH) and Kp. Such a tendency allows us to define the scale that associates the values of DH with a local value of K index, *i.e.* Kmex. Table 1 shows the resulting scale to calculate the Kmex from the TGO measurements.

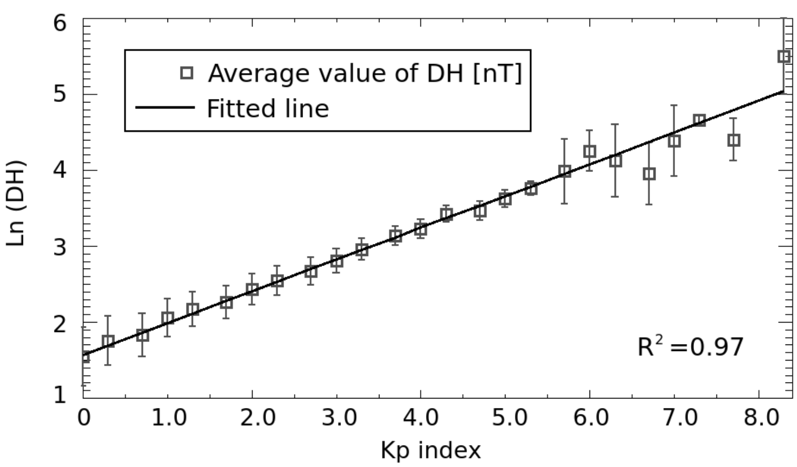

Figure 1. Average values of DH, as function of Kp, during 01-Jan-2014 to 01-Jan-2017. Solid black line is the fit to the data.

It is important to note that the values presented in Table 1 are not definitive. This is relevant for Kmex values above 6. Because in the period used for calibration, there were very few events with Kp larger than 6. We can appreciate this in Figure 1, where data relative to Kp>6 detach away from the linear tendency commented on before.

3. Kmex and space weather on Mexico

Kmex preliminary results already registered recent space weather events. The reader can find such registers in the special and quarterly reports that the LANCE generates and distributes through its space weather service (SCiESMEX). The most recent geomagnetic storm occurred during May 27 and 28, 2017. The LANCE and its collaborators registered this phenomenon and SCiESMEX made two different special reports of the event (both in Spanish, www.sciesmex.unam.mx/productos-y-servicios/).

3.1 Study case

The Figure 2 shows data from the geomagnetic field between May 27 and 29. The upper panel shows the Dst index (solid black line) and the hourly averaged dH (solid blue line). It is important to note that both profiles are significantly similar. In both of them it is observed a sudden commencement (spontaneous increment) at the end of May 27. Such a signature was due to the arrival of an interplanetary shock wave that compressed the geomagnetic field.

Table 1. Values of Kp according the calculated value of DH.

Kmex	DH [nT]		Kmex	DH [nT]
00	[0, 5.5)		47	[34.4, 39.0)
03	[5.5, 6.4)		50	[39.0, 44.2)
07	[6.4, 7.3)		53	[44.2, 52.3)
10	[7.3, 8.3)		57	[52.3, 59.2)
13	[8.3, 9.8)		60	[59.2, 67.2)
17	[9.8, 11.1)		63	[67.2, 79.4)
20	[11.1, 12.6)		67	[79.4, 90.0)
23	[12.6, 14.9)		70	[90.0, 102.1)
27	[14.9, 16.9)		73	[102.1, 120.7)
30	[16.9, 19.1)		77	[120.7, 136.9)
33	[19.1, 22.6)		80	[136.9, 155.2)
37	[22.6, 25.6)		83	[155.2, 183.5)
40	[25.6, 29.1)		87	[183.5 208.0)
43	[29.1,34.4)		90	[208, ...)

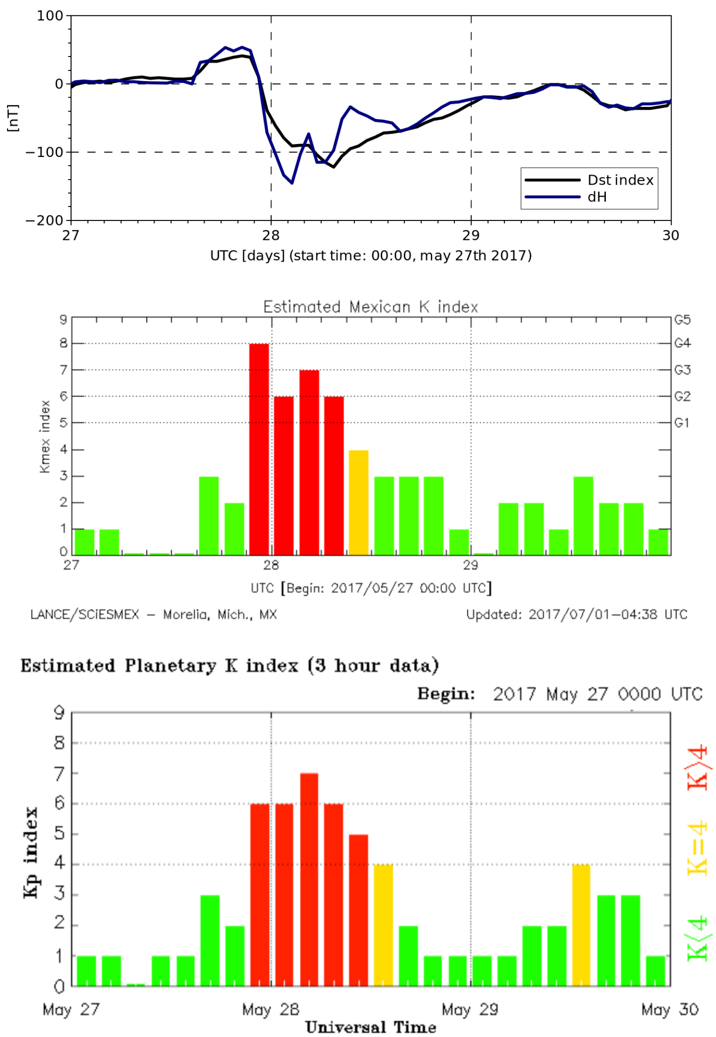

Figure 2. Upper: Dst (black) index and hourly averaged dH (blue). Middle: Estimated Kmex index. Bottom: Estimated Kp by SWPC/NOAA.

A few hours later, in the early hours of May 28, a coronal mass ejection (CME) impacted the Earth's space environment. The magnetic configuration of the CME allowed it to interact with the geomagnetic field, resulting in a "Strong" geomagnetic storm, according to NOAA scales. In the upper panel of Figure 2 we can appreciate the main phase of the geomagnetic storm as an abrupt descent that decreases the Dst and dH values to -122 nT and -150 nT, respectively.

The middle and bottom panels of Figure 2 show the Kmex and Kp index values during the event. Notice that Kmex index is qualitatively similar to its planetary counterpart. The sudden increase in the values of the K indexes observed at the end of May 27 is due to the arrival of the shock wave. The high values of the K indexes are maintained due to the geomagnetic storm, and they reached a maximum value of 7 and 8 for Kp and Kmex, respectively.

From midday on May 28, the magnetic configuration of the CME no longer favored the reconnection with the Earth's magnetosphere. This triggers the beginning of the recovery phase. We appreciate this in the panels of Figure 2 as a tendency to return to the pre-storm conditions for mid May 29.

4. Discusión y conclusiones

In this work we presented the calibration and preliminary calculations of the geomagnetic K index for the central region of Mexico (Kmex). Which is calculated from OGT data, whose calibration (see Table 1) was performed through the Kp index. It is important to mention that Kmex calibration is not finished, for we require geomagnetic data related with large values of Kp

In addition, in Figure 2 we present geomagnetic data, including the Kmex index, to describe the geomagnetic storm of May 27-28, 2017. We notice consistencies between the Kmex index and the Kp. This suggests that our methodology for calculating Kmex is adequate. Additionally, we found significant agreements between dH values and the Dst index. However, it is important to notice (in the upper panel of Figure 2) the presence of differences between the Dst and dH at the last (first) hours of May 27(28). The upper panel of Figure 3 shows such differences between these profiles. A detailed inspection allows us to conclude that such differences are possibly local effects of ionospheric currents

The middle and bottom panels of Figure 3 show the total electron content (TEC) (red solid line) and its expected value (solid blue line) for the central region of Mexico (LAT 19.813°, LON 101.694°). In the middle we notice the deviations of the electron content (red) during the period of the geomagnetic storm. The figure's bottom panel shows the electron content deviation in the central region of Mexico. It is important to note that the largest deviations of the TEC (bottom panel) coincide with the differences between the Dst and dH (upper panel). This suggests that both effects are related.

Although the Kmex index is in validation stage, the results showed in this work suggest that it is possible to use the Kmex index for the analysis of space weather events. In addition, an additional result derived from the Kmex calculation is the value of dH, which is consistent with the Dst index. Finally, our results highlight the local effects of space weather on the regional geomagnetic field.

Acknowledgements

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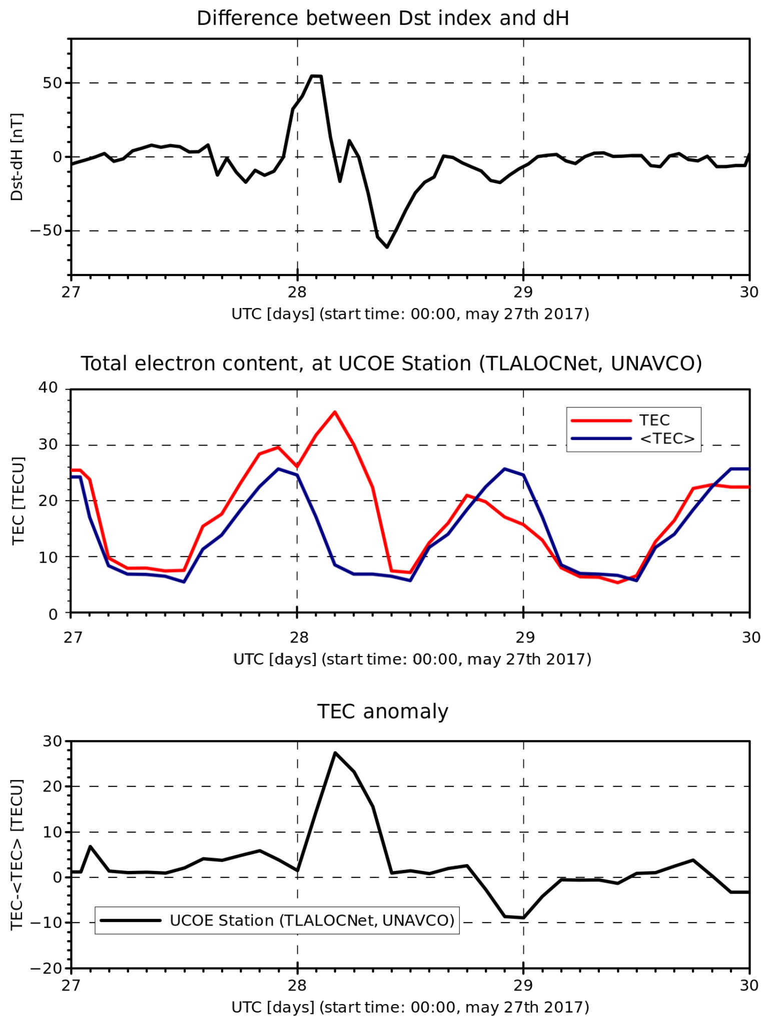

Figure 3. Upper: Difference between Dst and dH. Middle: Measured (red) and expected (blue) total electron content (Yasyukevich et.al., 2015). Bottom: Anomaly in measured total electron content.

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References:

Moldwin M., 2008. An Introduction to Space Weather. *Cambridge University Press, New York, 134pp.*

Mayaud P.N., 1980. Derivation, Meaning, and Use of Geomagnetic Indices. *American Geophysical Union, Washington, D. C.,* 154 pp.

Yasyukevich Yu. V., Mylnikova A.A., Kunitsyn V.E., Padokhin A.M., 2015. Influence of GPS/GLONASS Differential Code Biases on the Determination Accuracy of the Absolute Total Electron Content in the Ionosphere. *Geomagnetism and Aeronomy 55, 6,* 763-769.