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RESEARCH ARTICLE

A Study of Lightning Activities and Their Impact in the Ionosphere Over Nepal

Drabindra Pandit[1*], Prasil Poudel[1], Romash Shoni[1], Nikesh Budha Chhetri[1], Binod Adhikari[1], Narayan Prasad Chapagain[2], Shriram Sharma[2]

[1]Department of Physics, St. Xavier's College, Kathmandu, Nepal

[2]Department of Physics, Amrit Campus, Kathmandu, Nepal

[*]E-mail: drabindra@sxc.edu.np

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Highlights

- This study analyzes the changes in the Total Electron Content (TEC) in relation with the thunderstorm activities taking into account of the lightning stroke density as a perturbing factor.
- The variation of TEC in association with stroke density during the pre-monsoon season was found to be significant
- Thunderstorms have been observed to have played a significant role in the ionospheric perturbation that may result in the disruption in communication.
- The outcome of this study can lay the foundation on the work to investigate the extent of perturbation and hence the communication disruption being emanated by thunderstorms.

Abstract

The ionosphere is a system that can experience dynamical perturbation due to external influences from solar dynamics and activities: geomagnetic storms, solar radiation and lower atmospheric events such as thunderstorms and gravity waves. In this study we have analyzed the changes in the Total Electron Content (TEC) in relation with the thunderstorm activities taking into account of the lightning stroke density as a perturbing factor. The data pertaining to TEC have been obtained from GNSS whereas the lightning stroke data have been obtained from VAISALA's GLD 360. Analyzing the data from 2015 to 2018 the variation of TEC in association with stroke density during the pre-monsoon season was found to be significant for the period of study (pre-monsoon period). This implies that thunderstorms play a significant role in the ionospheric perturbation that may result in the disruption in communication. The outcome of this study can lay the foundation on the work to investigate the extent of perturbation and hence the communication disruption being emanated by thunderstorms.

Keywords: *Ionosphere, Thunderstorm, Gravity Wave, Total Electron Content, Communication Disruption*

Introduction

Williams (2009) and Singh et al. (2012) proposed that thunderstorms function as electric generators, driving currents in the upper global electric circuit[1, 2]. In the worldwide circuit, the overall electric current from intracloud and cloud-to-ground lightning may range from 50 to 400 A [3], whereas maximum current may rises up to a few tens of kiloampere. Approximately 10% of the Earth's surface is covered by an average of 2000 active thunderstorms at any given time, with an average worldwide

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[*] *Corresponding author*

flash rate of 45 lightning discharges per second [4]. The world's lightning activity is not evenly spread; specific hotspots like the Caribbean, Central Africa, and Southeast Asia account for a large portion of it, with the majority of it occurring in the summer. In addition starting forest fires, lightning strikes also result in injury, fatalities, and damage to infrastructure, business, and property. According to estimates from Holle (2008), lightning kills 24,000 people annually throughout the world and resulting in $300 million in insured property damage in the United States [5]. According to the studies [6 - 9] the upward current is linked to an electric field that might cause $\vec{E} \times \vec{B}$ plasma drift and, in turn, redistribute plasma in the ionosphere, which would affect electron density. In their simulation of a tripole-charge structured thunderstorm, Kuo and Lee (2015) calculated the skyward goinging current into the ionosphere and which impact on the distribution of electron densities [10]. They demonstrated that an 8.3 A source current in the equatorial area might alter the total electron content by 1–10%. The creation of gravity waves is also connected to thunderstorms. Gravity waves are common over miniature, isolate-cell and mesoscale convective systems, according to statistical research [11]. The travelling waves may be produced by thunderstorm cloud tops that overshoot their boundaries [11, 12], travel skyward, along with carry lightning strikes and releases electrical energy into the ionosphere. Lightning strikes cause a strong electromagnetic pulse (EMP) to radiate in addition to their immediate effects on the ground. In 1964, Wait and Spies noted that long-distance propagation of this EMP makes it potentially dangerous for electronics and radio communications. The upper atmosphere includes the ionosphere where plasma interacts with the EMP energy as it travels upward. There have been numerous recent reports of perturbations in the thunderstorm-induced ionosphere-wide plasma dispersion [7, 8, 12, 13, 14, 15, 16, 17] There have been reports of thunderstorm-associated gravity waves in the ionosphere's D and F regions that have lasted more than five minutes [9]. Using GLD360 data and a computational model of the lightning EMP, according to Blaes et al. (2016), there is about 2 MW of continuous power dissipated globally in the lower ionosphere due to the whole amount of ionospheric heating caused by lightning [18]. A study by Kumar et al. (2017) found that the ionospheric disturbances away from the source zone of the thunderstorm and lightning may be due to both gravity waves traveling upward obliquely from the tropospheric convective region and the electric field of the lightning [19, 20].

Datasets and Methodology

Extraction of TEC Data: TEC data is obtained from ground GPS stations located in Nepal JMSM (Jomsom 28.77° N, 83.77° E) and KKN4 (Kakani 27.82° N, 85.24° E) are from website www.unavco.org. The GPS TEC data is available in RINEX format and it is extracted in ASCII format using Fluery's software which runs in MATLAB program. This application has examined and extracted data from the observation and navigation RINEX file that is required to calculate the TEC. A mapping function is used to transform the obtained slant total electron content (STEC) to vertical TEC (VTEC) (Kumar et al., 2015). Since the value of VTEC data is independent of satellite receiver position, it was utilized instead of STEC data. Since we have taken into account quiet time conditions Kp-index < 4 as well as Dst-index lying between 0 to 30 nT during the lightning and the day in which there is no lightning, every disturbance in TEC > 0.1 TECU has been attributed to lightning activity (Kumar et al., 2017).

Data for Lightning Stroke: The lightning stroke data have been obtained from VAISALA's GLD 360 from year 2015 to 2018.The data is converted into hourly average and used in our study for the physical interpretation..

Results and Discussion

In this section we discuss about the variation in lightning strokes with total electron content, temperature and relative humidity, respectively. The lightning data observed from VAISALA's GLD 360 used in this research to project thunderstorm activity in Nepal. Figure 1 showing map of Nepal (source: google map). There have been significant lightning strikes between 0700 and 1900 UT. The observatory reports very intensive cloud movement during this time. According to data from the Atmospheric Infrared Sounder satellite (website: https://giovanni.sci.gsfc.nasa.gov), the cloud top temperature stayed about ~30°C. At around 8 kilometers in altitude, the clouds appear to represent an intensive convective system. Gravity waves appear to be able to be produced by the system. The GPS TEC data over the area are accessible for analysis between 0600 and 1800 UT. These data have been used to examine how thunderstorm and lightning activity affects the ionosphere. Fig. 2(a - d) represents variation in total electron content (TEC) and lightning strokes with time (UT). The x-axis represents universal time (hour), the y-axis left represents variation in TEC and y-axis right represents variation in lightning strokes.

These plot shows that TEC has maximum values during equinoxes March-April and September-October. Lightning stokes shows similar trend of maximum value twice in a year. Among these two maximum values the highest has noted around the pre-monsoon period. Fig. 3 (a - c) represents variation in relative humidity (RH) and lightning strokes with time (UT). The x-axis represents universal time (hour), the y-axis left represents variation in RH and y-axis right represents variation in lightning strokes. The plots indicate that relative humidity has lower value during the month of May in 2015 and in May of year 2016 and 2017 respectively. Fig. 4 (a - c) represents variation in temperature and lightning strokes with time (UT). The x-axis represents universal time (hour), the y-axis left represents variation in temperature and y-axis right represents variation in lightning strokes.

Fig.1. Map of Nepal (source: Google map)

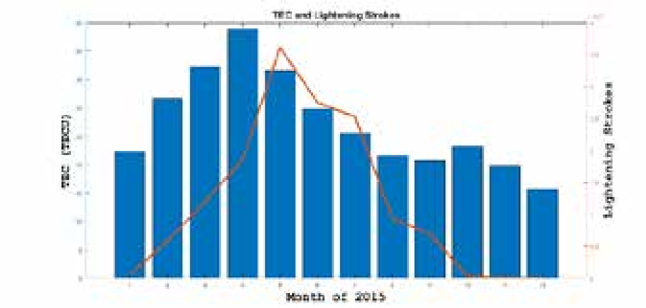

Fig. 2a. TEC and lightening strokes in 2015

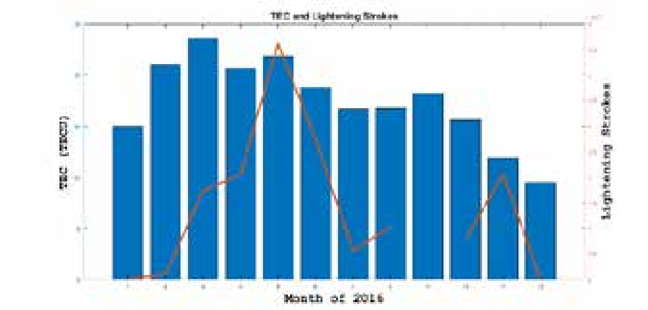

Fig. 2b. TEC and lightening strokes in 2017

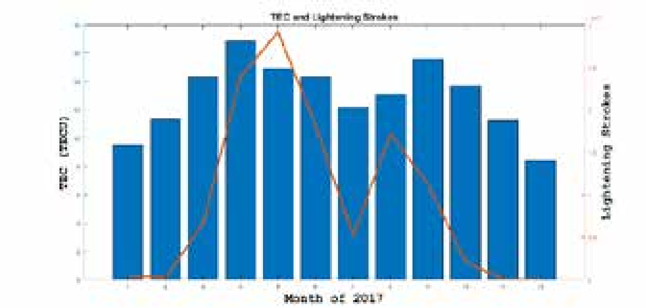

Fig. 2c. TEC and lightening strokes in 2017

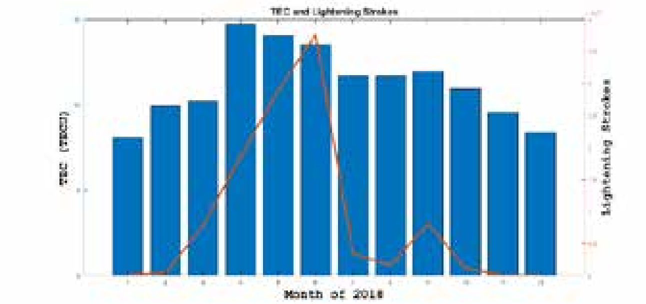

Fig. 2d. TEC and lightening strokes in 2018

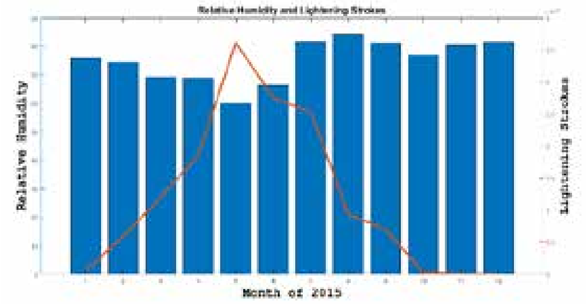

Fig. 3a. Relative humidity and lightening strokes in 2015

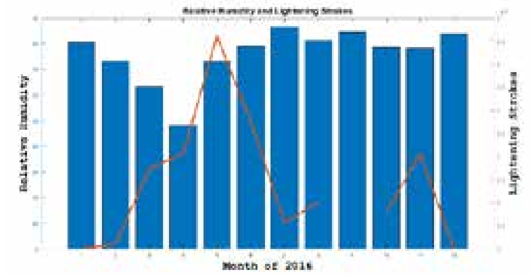

Fig. 3b. Relative humidity and lightening strokes in 2016

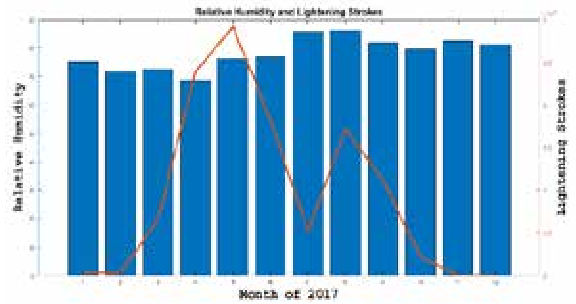

Fig. 3b. Relative humidity and lightening strokes in 2017

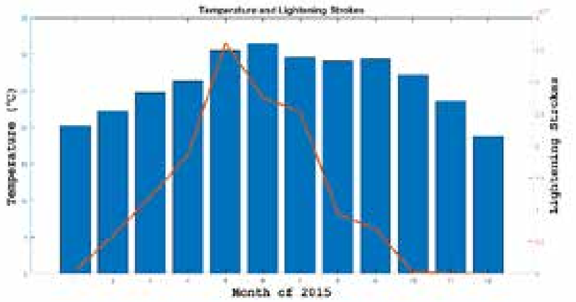

Fig. 4a. Temperature and lightening strokes in 2015

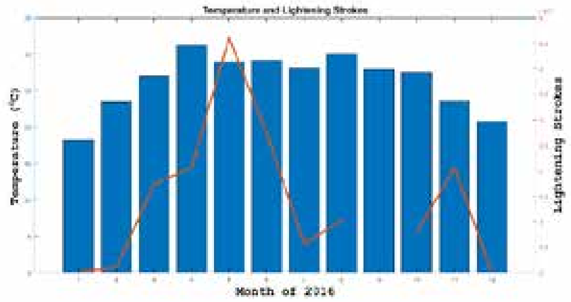

Fig. 4b. Temperature and lightening strokes in 2016

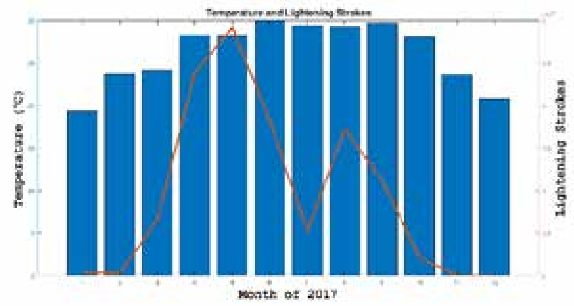

Fig. 4c. Temperature and lightening strokes in 2017

Fig. 5 represents variation in temperature and lightning strokes with time (UT) on 19 April 2018. The x-axis represents universal time (hour), the y-axis left represents variation in TEC and y-axis right represents variation in lightning strokes. It has been noted from the plot that lightning strokes has maximum values around 9 UT, 1 UT and 18 UT respectively.

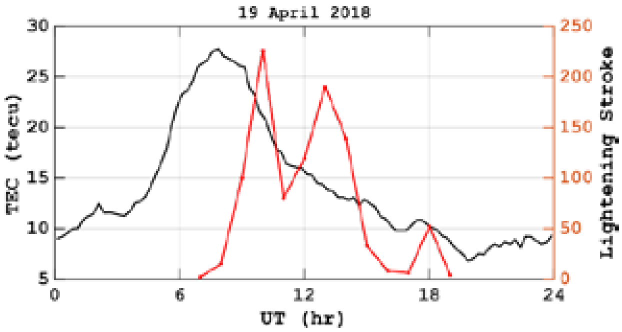

Fig. 5. Variation in TEC on 19 April 2018 with lightening strokes

Fig. 6 represents variation in delta TEC with time (UT) on 19 April 2018. The x-axis represents universal time (hour) the y-axis left represents deviation in TEC. Delta variation of TEC is calculated by subtracting value of quiet days TEC on 9 April 2018 with lightning day TEC on 19 April 2018. The plot shows corresponding to the maximum values of lightning stroke, there is variation in the TEC. Around 9 UT increase in TEC has identified whereas the slight decrease in TEC has noted during 1 UT and 18 UT respectively.

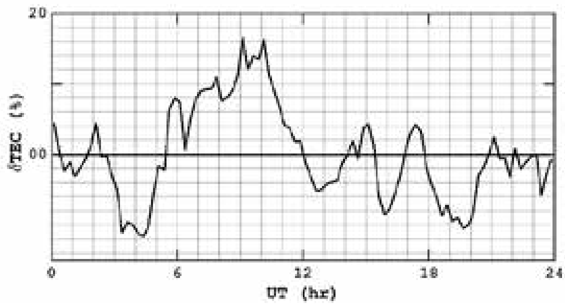

Fig. 6. Percentage change in TEC due to lightening reference quiet day is taken as 9 April 2018.

Thunderstorms are linked to the production of gravitational waves and electric fields, which have the potential to enter the ionosphere and disturb the distribution of ionization, changing the total electron content (TEC). The westward E field created by the thunderstorm's skyward current generates the $\vec{E} \times \vec{B}$ plasma drift, which in turn causes the plasma to travel downward[20, 21]. Electron density enhancement is produced by travelling gravity waves that moves to the ionosphere during thunderstorm activity, along with the electric field [9, 14]. Gravitational waves can penetrate to the lower ionosphere and cause ionization through heating effects, but this process can take one to two hours [22]. While GPS-TEC provides information on the entire ionosphere, with the F area ionosphere contributing the most, VLF measurements typically probe the D region ionosphere. The primary thunderstorm activity that numerous GPS stations in the Hong Kong region observed on April 1, 2014, between 1100 and 1600 UT, on a geomagnetic quiet day ($Kp \leq 4$) is shown to have led to heightened ionospheric disturbances in GPS-TEC (DTEC) [19]. Additionally, their findings indicate that the ionospheric disturbances are seen outside of the lightning and thunderstorm originated zone, and these may related with both the inclining skyward propagating gravity waves produced in the tropospheric translation sector and the lightning electric field. In a study at equatorial Congo Ogunsua et al. (2020) found that the maximum rise in height in TEC of ~±1.5 TECUs, the thunderstorm-related TEC variations were mostly found to spread in a particular direction from the event point[24]. The thunderstorm creates an upward gravity wave effect during convective processes, it results in the upward movement of momentum and kinetic energy between the atmosphere's layers. The wave transfer between the atmospheric layers changes in amplitude due to upward density differences. The ensuing shift in amplitude near the mesosphere may occasionally cause the wave to become critical, breaking and releasing momentum fluxes in the process that creates secondary waves [25]. Through this process, gravity waves have the potential to reach ionospheric heights and cause ionosphere disturbances. TEC variations, which can range from 0.5 to 1.5 TECUs, are produced during the day by the action of gravity waves. But around the equator, the fingerprints of thunderstorm gravity waves are largely undetectable at night [24].

Conclusions

The current study has examined the ionospheric disturbance caused by lightning/thunderstorm activities in the vicinity of the Nepal. After a thorough analysis of the data spanning from 2015 to 2018, it was shown that there was a considerable fluctuation in TEC during the pre-monsoon season in relation to stroke density over the research period. This suggests that ionospheric turbulence caused by thunderstorms is important and could lead to communication disruptions. The findings of this study can be utilized as a foundation for further investigations that seek to quantify the level of disturbance and, in turn, the communication interruption brought on by thunderstorms.

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References

1. E. R. Williams, (2009), T”he global electrical circuit: A review,” Atmos. Res., vol. 91(2–4), pp. 140–152, 2009.
2. D. Siingh,, R. P. Singh, A. K. Singh, S. Kumar, M. N. Kulkarni, and A. K. Singh, “Discharges in the stratosphere and mesosphere”, Space Sci. Rev., vol. 169(1–4), pp. 73–121, 2012.
3. E. A. Mareev, S. A. Yashunin, S. S. Davydenko, T. C. Marshall, M. Stolzenburg, and C. R. Maggio, “On the role of transient currents in the global electric circuit”, Geophys. Res. Lett., vol. 35, pp. L15810, 2008.
4. H. J. Christian, “Global frequency and distribution of lightning as observed from space by the optical transient detector,” J. Geophys. Res., vol. 108(D1), pp. 4005, 2003.
5. R. L. Holle, “Annual rates of lightning fatalities by country, paper presented at 20th International Lightning Detection Conference,” pp. 1–14, Tuczon, Ariz., 21–23 Apr., 2008.
6. P. Vellinov, C. Spassov, and S. Kolev, “Ionospheric effects of lightning during the increasing part of solar cycle 22,” J. Atmos. Terr. Phys.,54(10), pp. 1347–1353, 1992.
7. C. G. Johnson and C. J. Davis, “The location of lightning affecting the ionospheric sporadic-E layer as evidence for multiple enhancement mechanisms,” Geophys. Res. Lett., vol. 33, pp. L07811, 2006.
8. C. J. Davis and K.-H., “An enhancement of the ionospheric sporadic-E layer in response to negative polarity cloud-to-ground lightning,” Geophys. Res. Lett., vol. 35, pp. L05815, 2008.
9. E. H. Lay, X. M. Shao, and C. S. Carrano (2013), Variation in total electron content above large thunderstorms, Geophys. Res. Lett., 40, 1945–1949, doi:10.1002/grl.50499
10. C. L. Kuo and L. C. Lee, “Ionospheric plasma dynamics and instability caused by upward currents above thunderstorms,” J. Geophys. Res. Space Physics, vol. 120, pp. 3240–3253, 2015.
11. H. E. Lay, X. Shao, A. K. Kendrick, and C. S. Carrano, “Ionospheric acoustic and gravity waves associated with midlatitude thunderstorms,” J. Geophys. Res. Space Physics, vol. 120, pp. 6010–6020, 2015.
12. S. L., Vadas and D. C. Fritts, “Thermospheric responses to gravity waves arising from mesoscale convective complexes,” J. Atmos. Sol. Terr. Phys., vol. 66(6), pp. 781–804, 2004.
13. J. R. Wait and K. P. Spies, Characteristics of the Earth-ionosphere waveguide for VLF radio waves, Tech. Note 300, National Bureau of Standards, Boulder, Colo, 1964.
14. C. G. Johnson, C. G., and C. J. Davis, “The location of lightning affecting the ionospheric sporadic-E layer as evidence for multiple enhancement mechanisms,” Geophys. Res. Lett., vol. 33, pp. L07811, 2006.
15. H. E. Lay, X. Shao, A. K. Kendrick, and C. S. Carrano, “Ionospheric acoustic and gravity waves associated with midlatitude thunderstorms,” J. Geophys. Res. Space Physics, vol. 120, pp. 6010–6020, 2015.
16. T. J. Immel, S. B. Mende, M. E. Hagan, P. M. Kintner, and S. L. England, “Evidence of tropospheric effects on the ionosphere,” Eos Trans. AGU, vol. 90(9), pp. 69–70, 2009.
17. V. V. Kumar, M. L. Parkinson, P. L. Dyson, and G. B. Burns (2009a), “The effects of thunderstorm-generated atmospheric gravity waves on mid-latitude F-region drifts”, J. Atmos. Sol. Terr. Phys., vol. 71(17), pp. 1904–1915, 2009a.
18. V. V. Kumar, V. V., M. L. Parkinson, P. L. Dyson, and G. B. Burns, “Thunderstorm-associated responses in the vertical motion of the mid-latitude F-region ionosphere”, J. Atmos. Sol. Terr. Phys., 71, pp. 787–793, 2009b.
19. P. R. Blaes, R. A. Marshall, and U. S. Inan (2016), “Global occurrence rate of elves and ionospheric heating due to cloud-to-ground lightning,” J. Geophys. Res. Space Physics, vol. 121, pp. 699–712, 2016.
20. S. E. Kumar, and D. Murti (2015), “Impacts of solar activity on performance of the IRI-2012 model predictions from low to mid latitudes”, Earth, Planets Space,” vol. 67(1), pp. 42, 2015.
21. S. Kumar, W. Chen, M. Chen, Z. Liu, and R. P. Singh, (2017), “Thunderstorm-/lightning-induced ionospheric perturbation: An observation from equatorial and low-latitude stations around Hong Kong,” J. Geophys. Res. Space Physics, vol. 122, pp. 9032-9044, 2017.
22. U. S., Inan, D. C. Shafer, W. Y. Yip, and R. E. Orville (1988), “Subionospheric VLF signatures of nighttime D region perturbations in the vicinity of lightning discharges,” J. Geophys. Res., vol. 93(A10), pp. 111455–111472, 1988.
23. C. L. Vadas & Liu, H. L., “Generation of large-scale gravity waves and neutral winds in the thermosphere from the dissipation of convectively generated gravity waves,” Journal of Geophysical Research: Space Physics, vol. 114(A10), pp. 310, 2009.
24. B. O. Ogunsua, A. Srivastava, J. Bian, X. Qie., D. Wang, R. Jiang, & J. Yang “Significant day-time ionospheric perturbation by thunderstorms along the West African and Congo sector of equatorial region. Scientific Reports,” vol. 10(1), pp. 8466, 2020.
25. T. Tsuda, M. Shepherd, & N. Gopalswamy, “Advancing the understanding of the Sun–Earth interaction—the Climate and Weather of the Sun–Earth System (CAWSES) II program.” Progress in Earth and Planetary Science, vol. 2, pp. 1-18, 2015.