Direct Impact Monitoring of Lightning Activity on the GPS Signals Propagation

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Abstract: GPS data are now available at certain location around the world for any possible scientific uses. The greatest challenge is how to utilize GPS data to monitor lighting activity. This paper addressed the examination of direct impact of lightning activity on GPS signals. Three cases of severe lightning events on August 22 of 2009 at Launching Pad, Kennedy Space Center (KSC), Florida, USA is studied. The GPS receiver at CCV6 station used for this work is 18 km away from KSC. As well, the response of solar flares on GPS signals to the lightning activity is presented for a comparison impact. The analysis was made by differencing the GPS observables.

Key words: GPS, Solar flare, lightning.

INTRODUCTION

There are thousands of lightning strikes every day. Scientists think that lightning hits somewhere on the earth about 100 times every second and become a hazard to human life. More people are killed by lightning than by any other kind of storm, including hurricanes and tornadoes, as reported by Ronald et al., (2008). In Malaysia only, nearly one hundred to one hundred fifty people are killed and hundreds of others are injured every year as raised by Murty et al., (2009). Therefore, ability to predict the lightning presence is extremely beneficial to avoid lightning fatalities or injuries to our life.

The ordinary lightning detectors have limitations, including detection of false signals and poor sensitivity, particularly for inter-cloud (IC) lightning. Specifically, radio frequency (RF)-based detectors may misinterpret RF noise. Likewise, light-flash-based detectors may misinterpret flickering light generated in the environment, such as reflections from windows and sunlight through tree leaves (Heitkemper et al., 2008). In this study, the potential of lightning detection system is explored using a Global Positioning System (GPS). The system proposed is based on the RF at a gigahertz (GHz) frequency and definitely can overcome the weaknesses of the ordinary RF and light-flashed based lightning sensors. Therefore, this work aims to appreciate the available for GPS network can be fully utilized to monitor the lightning activity. The new attachment will contribute to the producing of precise and cost effective of lightning detection system.

GPS Signal Fading By Electromagnetic Interference:

The primary source of interference that affect wireless communication systems are electromagnetic in nature and can result in the magnetic and radio frequency disruption or intermittent failure of electronic, communication and information systems (Burrel, 2003). In GPS observation, which consists of Pseudorange (P), Carrier phase (Φ) signals and signal-to-noise ratio (SNR), fading by electromagnetic interference (EMI) with high radiation and proper polarization produced by solar flare can cause severe fading to GPS signals, such as reported by Charles et al., (2007). During these events, each lasting up to an hour, nearly identical patterns of intermittent signal fading were observed along all GPS satellite links from receivers located on thousand miles away around the world.

Relationship Between Lightning And Solar Flares:

The lighting strokes start with the charge separation, which is requiring strong updraft carry water droplets upward and then super cooling them to temperature between -10 and -20°C. As reported by Hugh and Milanie (2009), the ice particles within a cloud grow and interact; they collide, fracture and break apart. It is thought that the smaller particles tend to acquire positive charge, while the larger particles acquire more negative charge. These particles tend to separate under the influences of updrafts and gravity until the upper portion of the cloud acquires a net positive charge and the lower portion of the cloud becomes negatively charged. This separation of charge produces an enormous electrical potential both within the cloud and between the cloud and ground. This can amount to millions of volts, and eventually the electrical resistance in the air breaks down and a flash begins.
Lightning strikes are able to produce influential on radio wave signal at vertical and horizontal polarizations in the frequency range of 3 KHz to 10 MHz (shortwave radio). The very low frequency (VLF) (3 to 30 kHz) "lightning signatures" can travel around the world, enabling monitoring of worldwide lightning. In contrast, a solar flare is a large explosion in the Sun's atmosphere that can release as much as $6 \times 10^{25}$ joules of energy. Solar flares affect all layers of the solar atmosphere (photosphere, corona, and chromospheres), heating plasma to tens of millions of Kelvin’s and accelerating electrons, protons, and heavier ions to near the speed of light. They produce radiation across the electromagnetic spectrum at all wavelengths, from radio waves to gamma rays. X-rays and UV radiation emitted by solar flares can affect Earth's ionosphere and disrupt long-range radio communications (e.g., Davies, 1990). Direct shortwave radio signal is possible to perturb operations of radars and other devices operating at these frequencies. Hence, the mechanism of response of solar flare and lightning events are studied in this paper.

**Methodology:**

The utilization of GPS data for lightning monitoring is studied for the case of GPS receiver collocated with lightning sensors in Florida. Figure 1 shows the partial map of Florida, USA. GPS station in that map is located at CAPE CANAVERAL 6 (CCV6), Florida. Pads A and B shown in the figure are Kennedy Space Center (KSC) Launching Pad, where the lightning sensors have been installed. The sensors can detect the lightning strokes up to five nautical miles (9.26 km) away from the base effectively. The distance between GPS station and Launching Pads A and B is 17.5 km and 19.9 km, respectively.

**Lightning Event Time Selection:**

The lightning data in monthly basis was downloaded from the Spaceport Weather Data Archive (http://trmm.ksc.nasa.gov). The data selection is based on the location of lightning event as shown in Figure 1. Lightning event on August 22, 2009 was selected due to the largest event, which are occurred at the northwest GPS station from 20:18 UT to 21:19 UT. There are 486 lightning event has been recorded at KSC on August 22, 2009 and only three event’s were recorded as a largest amplitude, which occurred at 20:49:41.68 UT (-84.5 kA), 21:11:03.17 UT (-65.5 kA) and 20:33:20.53 UT (-62.0 kA), respectively.

**PRN Selection:**

Lightning phenomenon only occurred at certain areas depends on negative and positive charge composition in the clouds (e.g., Hugh and Milanie, 2009). Therefore, the GPS data has been taken from the selected PRN’s which is depending on the satellite elevation angle. The estimated altitude of charged clouds is 10 to 15 km over the ground, while the predicted distance from GPS station to lightning vicinity is 8.24 km. The method to estimate the elevation angle in order to identify the suitable PRN’s is shown in Figure 2.
Skyplot:

Skyplot is a tool to visualize the PRN’s routes at a desired time. To produce the skyplot needs a GPS navigation file. Figure 3 shows the PRN route and the elevation angle from 20:00 to 21:30 UT on August 22, 2009 above CCV6 station. There are 8 PRN’s are visualized in the skyplot, while PRNs #8 and #28 were chosen because of the route is in the northwest region and partially inside the desired area corresponding to the elevation angle. This characteristic is based on the information achieved from Figs. 1 and 2 in Section 2.1. From skyplot, the occurrences of lightning event from 20:18 until 20:40 UT was observed using data from PRN#8, while the lightning event from 20:40 until 21:19 hours was observed using data from PRN#28. The data from both PRNs were used due to the movement of PRN.

Data Analysis:

SNR data (S1 and S2) is used to represent the original signal strength value given by the receiver for L1 and L2 tracking. P is measured range between GPS satellite and receiver, which can be determined through the travel time computation by comparing the transmitted code and receiver code then multiplying the result by the speed of light gives the range between the satellite and the receiver. At the CCV6 receiver, the available P consists of C1 and P2 and both of them were designed with different C/A-code. While $\Phi$ is the sum of the total number of full carrier phase plus fraction cycles at the receiver and the satellite, multiplied by the carrier wavelength (El-Rabbany, 2002).

All GPS observables (L1, L2, C1, P2, S1 and S2) are possible to be attenuated by the lightning activity when the GPS signals route from satellite to the receiver on the earth. In this work, the analyses of signal distortion are thoroughly observed through the value of delta ($\Delta$) rather than the original data, as this perhaps can provide the value in response to the EMI due to a lightning. The $\Delta$ values were computed by minus the GPS data with a means of the quiet day (QD). In this paper, GPS data on August 15 and 16, 2009 were employed as the QD. Note that QD used is defined based on the International quite (Q)-days from Geo Forschungs Zentrum Postdam (http://www.gfz-postdam.de) (see Suparta et al., 2008).
RESULTS AND DISCUSSION

Solar activity in 2009 is begun to ascend and there is no significant flare of this year. Instead, solar flares in 2006 are selected to spot the impact of GPS signal by solar activity. There are four X class of solar flares were reported on December 5, 6, 13 and 14 with X-ray flux strength X9.0, X6.5, X3.4 and X1.5, respectively. However, the event on December 6 had recorded the largest impact on GPS signal as reported by Charles et al., (2007). Hence, the GPS data from the University of Dela Seirra Mexico on this date was selected for analysis. From the graphs, the SNR was degraded up to 20 dB for S1 and 25 dB for S2 as well as P and Φ as shown in Figure 4. This finding is a significant guideline and become a motivation on the way to search the probability of GPS signal can be faded by the lightning.

Fig. 4: GPS signal disruption at University of Dela Seirra, Mexico, during solar flare on December 6, 2006.

Figures 5 and 6 shows the GPS data in Δ for PRNs #8 and #28, respectively from August 20 to 22, 2009. It noted that, there are two graphs in the figure are drawn as comparators with labeled as graph 1 (August 20, 2006) and graph 2 (August 21, 2006). Both graphs 1 and 2 are shifted by adding the y-axis with 1.5 units and -1.5 units, respectively. Furthermore, the delay as much as 4 minutes per day has been considered to ensure that all three graphs are referring the same elevation angle where graph 3 is used as a reference. As shown in Figure 5, the first lightning event was occurred on August 22, 2009 at 20:33 UT. The scintillation along ΔS1 and ΔS2 graphs represents the normal change in signal strength at the receiver. On the contrary, start from 20:29 UT until 20:36 UT, the graphs for ΔL1, ΔL2, ΔC1 and ΔP2 is gradually increased, and the increment does not reflect any interference that may be associated with lightning activity as graph 3 shows a similar response to the graphs 1 and 2.

The second lightning in Figure 6 stroked at 20:49 UT with the largest amplitude was -84.5 kA. From the figure, there is nothing suspicious signed was observed, except ΔS1 is increased from -20 dB at 20:46 UT up to 40 dB at 20:51 UT. However, the trend of the increment was due to the GPS satellite approaching the receiver. This was proven by similar shape overall the graph, although carrier phase at all measurements was seen gradually increased at 20:36 UT, 21:03 UT and 21:07 UT. The third flashed was occurred on August 22, 2006 at 21:11 UT and the variations remained unchanged,
except for $\Delta S_1$, which is slightly dropped. However, the $\Delta S_1$ dropped does not reflect to any circumstances and is consistent with comparators changes. From monitoring overall the graphs, there was no signature exist on graph 3 can be associated with attenuation due to lightning strokes likely event recorded during the solar flare took place as presented before.

Fig. 5: GPS data for PRN#8 on August 20, 21 and 22, 2009 from 20:00 UT to 20:42 UT.

Fig. 6: GPS data for PRN#28 on August 20, 21 and 22, 2009 from 20:30 UT to 21:24 UT.
Conclusion:

Looked at the responses between lightning and solar flare activities, both events were generating an enormous EMI but with a different frequency band. Lightning generated EMI in all directions at VLF band, while a solar flare generated EMI in all directions at almost throughout the radio spectrum from Extremely Lower Frequency (ELF) to Extremely Higher Frequency (EHF). Fading on the GPS signal due to lightning events observed by differencing techniques is insignificant. On the other hand, the direct impact of lightning activity on GPS signals for the case at KSC location was hardly detected from GPS observables due to its different response between the upper and the lower levels of the atmosphere. In this case, the upper atmosphere response to the GPS signals at Ultra High Frequency (UHF) was sensitive compared to the lightning activity, which is common occurred in the upper troposphere layer. Further work is necessitated to investigate the direct impacts of lightning events in another location for clarification as well as indirect impacts through the GPS derived precipitable water vapor (PWV) in the lower atmosphere.

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