IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Monitoring of thunderstorms activity over the Antarctic Peninsula based on GPS sensing

Monitoring of thunderstorms activity over the Antarctic Peninsula based on GPS sensing

Wayan Suparta[1]

[1]Department of Electrical Engineering, Faculty of Science and Technology, Sanata Dharma University, Yogyakarta 55282, Indonesia

drwaynesparta@gmail.com

Abstract. This paper aimed to present the monitoring of thunderstorms using the Global Positioning System (GPS). With employing the Precipitable Water Vapor (PWV) sensed by ground-based GPS, the thunderstorm activity can be detected by delaying the GPS signals in the atmosphere. The research has been conducted at Carlini Base of Antarctic Peninsula (62.23°S and 58.63°W) during the 2017 summer campaign. To validate the measurement results, the meteorology sensors and the lightning sensor were also installed collocated with GPS receiver. Meteorology sensors measured the surface pressure, temperature, and relative humidity and simultaneously with GPS signals are used to obtain PWV. While lightning sensor detected the time, intracloud (IC), cloud-to-ground (CG) and the distance of the lightning. To detect the response of thunderstorm activities on GPS PWV, an hourly analysis is performed. Results showed that most of the thunderstorm create lighting where 96% of the lightning activity detected consists of IC type. The remaining 4% of the lightning is the CG type. The GPS PWV is delayed one hour prior to IC lightning occurrence and delayed half an hour to one hour for CG. The response of GPS PWV to CG and IG types show respective proportional and inversely trends indicating that thunderstorm correlates with moisture content.

1. Introduction

Thunderstorms are dangerous to our lives and environments. The occurrence of thunderstorms will produce lightning, especially for dry thunderstorm when small water droplets or no rain at all reaches the Earth's surface. The raindrops from thunderstorm clouds encountered the dry air so it will evaporate, and the lightning will occur nearby. However, in cold region like Antarctica, the lightning occurrence is rare. The characteristics of Antarctica continent with windiest, coldest, and driest with very little moisture [1] supports this classic hypothesis. This condition led to little research on modeling or prediction of thunderstorms in Antarctica is reported. In fact, there was lightning in Antarctic continents such as at Vostok station as reported by Troshichev et al. [2] and a report from Smith and Jenkins [3] regarding the natural electromagnetic noise at Halley station. These reports led the author's motivation to conduct research on the measurement of the thunderstorm in Antarctica because global climate change will due in Antarctica. Through the accuracy of the prediction of the thunderstorm, we can anticipate the emergence of extreme disturbances, life safety, and reduce the destruction of property.

Since the Antarctic is a remote continent and requires a heavy logistics, one method to study the thunderstorm occurrence is using the Global Positioning System (GPS). This method is cost-effective, robust and with better accuracy for estimating of meteorological parameters. With ground-based GPS measurements, the atmospheric water content can be sensed in term of precipitable water vapor (PWV) [4]. Water vapor is an engine of precipitation and driver the weather. Since water vapor is the source of the convective clouds, its variation and distribution affect the formation and development of the convective precipitation system. GPS signals delayed by water vapor are expected to detect thunderstorm events in the atmosphere. On the other hand, water vapor correlates with electric charges in the thundercloud due to the bumpers of the warm air that contains water droplet and cold air with ice crystal [5].

Every thunderstorm needs moisture, unstable air and lifts to form clouds and rain. When thunderstorms create lightning, it will have highly discharged electricity and become lightning strikes. There are several categories of lightning strikes such as cloud-to-ground (CG), intra-cloud (IC), cloud-to-cloud, cloud-to-air, ribbon, bead, ball, heat, pieces and rocket lightning [6]. For CG and IC type of lightning, it has a positive (+) and negative (-) polarity. The positive cloud-to-ground (+CG) is carrying the negative charges, and the negative cloud-to-ground (-CG) is carrying the opposite charges. For positive intra-cloud (+IC), it is the intra-cloud lightning strike from positive charges to negative charges and vice versa for the negative intra-cloud negative (-IC). It can be noted that the positive conduction current carries positive charges from the ionosphere and troposphere to the Earth. Meanwhile, the negative sign of a lightning charge means that the flash current points upward from the Earth to the ionosphere [7]. Most of them discharged occurred in the cloud itself rather than out. Typically, a thundercloud has a positive charge accumulating at the upper portion whereas the negative charges predominantly accumulate at the bottom [8].

From the background above, this paper presents the monitoring of thunderstorm activity through PWV sensed by GPS. The location of the study was conducted at Carlini Base of Antarctic Peninsula. In order to achieve a capable measurement of thunderstorms that correlates with water vapor, two additional instruments such as lightning sensor and the surface meteorological sensor are installed.

2. Methodology

Assuming the Antarctic altitude contains thundercloud is up to 8-12 km, we are able to detect the thunderstorms from GPS measurements. At this point, the GPS system with a Trimble TS5700 dual-frequency GPS receiver, equipped with a Zephyr Geodetic 2 antenna, and connected to a desktop was installed on the roof of the Calbido Laboratory building. The cut-off elevation angle was set to 13 degrees to receive a maximized reception. To support the GPS measurements, the lightning sensor (LD-350), and the surface meteorology sensor (Vaisala PTU300) was also installed in the same building. The LD-350 is produced by Boltek. It has capability to detect lightning strikes until 1200 km in geographical distance with map facilities and mobile station of nexstorm. On the other hand, the base for this research is so-called Carlini Base which located inside the Potter Cove, King George Island, Antarctic Peninsula with the geographical coordinates of latitude 62.23°S and longitude 58.63°W as shown in Figure 1(a). The lab is located in a hill which is higher about 5 m as compared to the main base building.

The meteorology sensor (Vaisala PTU300) is connected with Raspberry Pi3 as a mini computer. The system is programmed in Python language under LINUX which capable of collecting the surface meteorological data such as pressure (mbar), temperature (°C), and relative humidity (%) every 5 seconds. Both GPS and the surface meteorological data are used to determine PWV. The algorithm of PWV determination is executed by using *TroWav* program under MATLAB [9]. As for the lightning sensors (LD-350), it was used to detect the lightning activities that occur between the Earth's surface and the upper atmosphere that can reach up to a radius of 800 km from the sensor. The system capable to detect the time, type of lightning with their polarities such as IC and CG and the distance of the lightning activities from the sensor. All the measurement systems is depicted in Figure 1(b). In this work, the PWV data are produced with an hour average from one-week measurement from 10 - 16 March 2017, and the lightning data were categorized into four main lightning activities that are +IC, -IC, +CG and -CG which are also produced on an hourly basis. The lightning data analyzed for this paper was occurred on 13 March 2017.

IOP Conf. Series: Earth and Environmental Science **169** (2018) 012001 doi:10.1088/1755-1315/169/1/012001

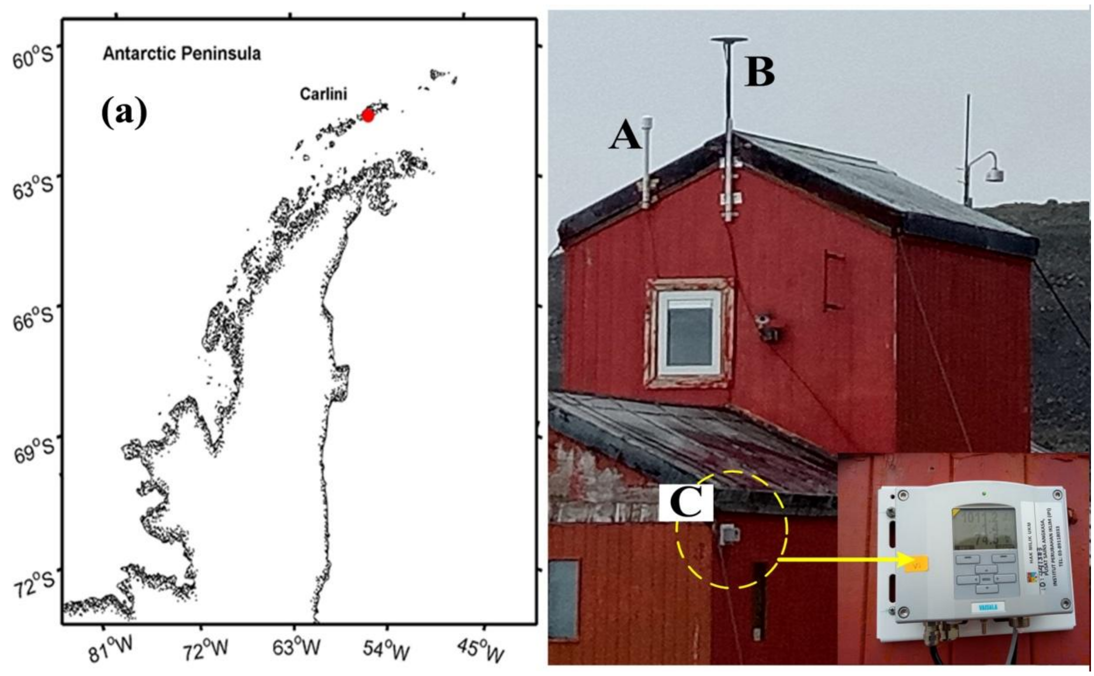

Figure 1. (a) Location of Carlini Base at the tip of the Antarctic Peninsula and (b) the three instruments installed labeled as A (lightning sensor), B (GPS antenna) and C (meteorology sensor).

3. Results and discussion

Figure 2 shows the hourly average of lightning activity measured at Carlini Base over the Antarctic Peninsula. The lightning activity is represented by a solid line for the positive polarity and dashed line for the negative polarity. From the figure, it shows that the IC type is frequent occurred as compared to the CG type. This indicates that the formation of ions in the atmosphere to discharge from the cloud to the ground is insufficient energy force, or the underlying layer is too cold and difficult to penetrate. Therefore, the lightning activity is more active between the clouds (where IC types dominate). However, a sudden increase after 3.00 pm was demonstrated by both +CG and -CG. This is possibly due to the surface layer of the Earth that began to warm due to the Sun activities. The +IC and -IC, on the other hand, show a sudden drop at the 5.00 pm before increase again, which is due to one of the day data detected has a very low amount of lightning activity and after 5.00 pm, there was no lightning activity detected.

Results show that the lightning activity with negative polarity in this region is higher than the positive charge. The percentage of the +CG and -CG only compromised 1.53% and 2.47%, respectively. While +IC and -IC is contributed 44.60% and 51.40%, respectively of the lightning activity that occurred in this study. The high amount of negative charge in the cloud compared to that reaches the ground surface due to the positive charge. Lightning occurs due to the displacement of the negative charge to the positive charge where electrons under the cloud are attracted by protons on the ground. In other words, the thunderstorm is more active in the upper layers of the troposphere and will reach the Earth’s surface when the underlying insulation layer is reduced by the external energy triggered from space or by daytime heating of the Earth surface (conduction process). The figure also shows that after 5 pm (local time), the thunderstorm activity is increased.

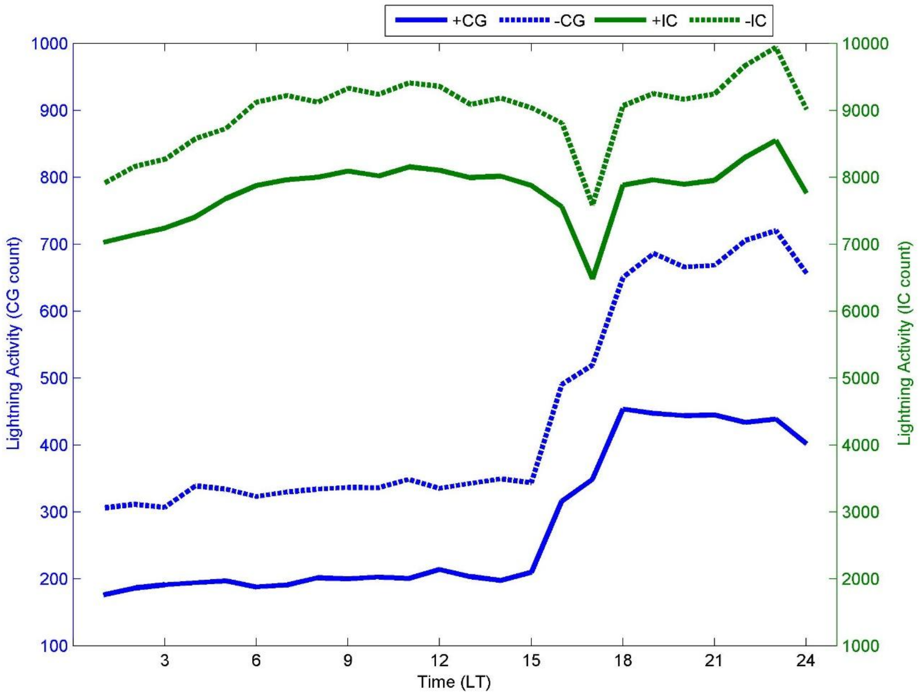

Figure 2. An hourly average of lightning activities over Antarctic Peninsula

Figure 3 shows the location of the cluster of lightning activities with the center of the map representing the location of the lightning sensor. The LD-350 equipped by the Astrogenic system will detect the lightning activity every one-minute and it will be captured in the form of a screenshot at every hour. All the lighting activities showed the occurrence at two locations, i.e. between Northwest (NW) and West (W) and another is between the East (E) and Southeast (SE). The thunderstorm activity is detected in the radius of 50 km from the sensors and even can detect within the radius of 500 until 800 km. From the screenshot, it looks to have two main clusters, where at this location, the lightning activity is in the South Pacific Ocean for the Northwest (NW) direction and Weddell Sea (Southeast direction) of Southern Ocean. The other two sides where the thunderstorm is not detected by the sensors is due to being blocked by the presence of the two mountains located in the Northeast and another in the Southwest of South Shetland Islands. From Figure 3(a) – (d), the screenshots clearly show that the thunderstorm occurrence can be monitored by the sensors, particularly during the summer's season.

Figure 4(a) shows the comparison between GPS PWV with +CG and -CG. The GPS PWV follows a similar trend as the CG type, especially -CG lightning, i.e. a delay of about half an hour to an hour as it approaches the end of the day as shown in the figure. In Figure 4(b), the GPS PWV shows an inversely proportional to the IC lightning amount. This can be observed when GPS PWV is low in value, the number of IC lightning strikes increases. By observing Figure 4, the change of lightning activity and GPS PWV can be seen between 12.00 WIB and 18.00. CG lightning increases rapidly while the amount of IC lightning drops before increasing again. The GPS PWV also shows some sudden changes to the lowest value of 21.30 mm before rising rapidly to a high value of 22.81 mm. From Figure 4, it can summarize that water vapor is correlated well with a thunderstorm when CG lightning occurred in the Earth's surface, while the thunderstorm is inversely correlated with IC lightning when a thunderstorm is more active in the clouds. These results indicate that the PWV parameter from GPS measurements can be used as indicators to monitor the occurrence of thunderstorm.

IOP Conf. Series: Earth and Environmental Science **169** (2018) 012001 doi:10.1088/1755-1315/169/1/012001

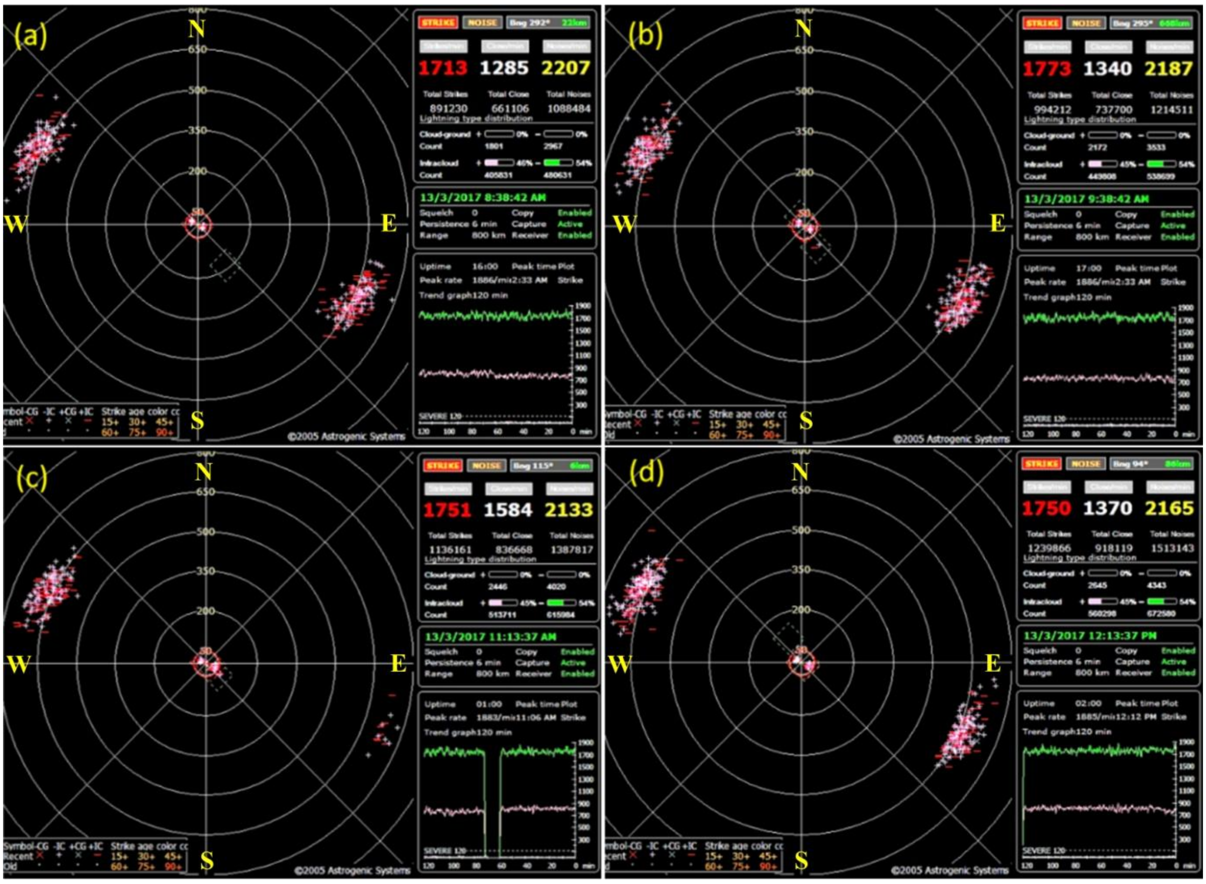

Figure 3. A screenshots of the location of the thunderstorm activities

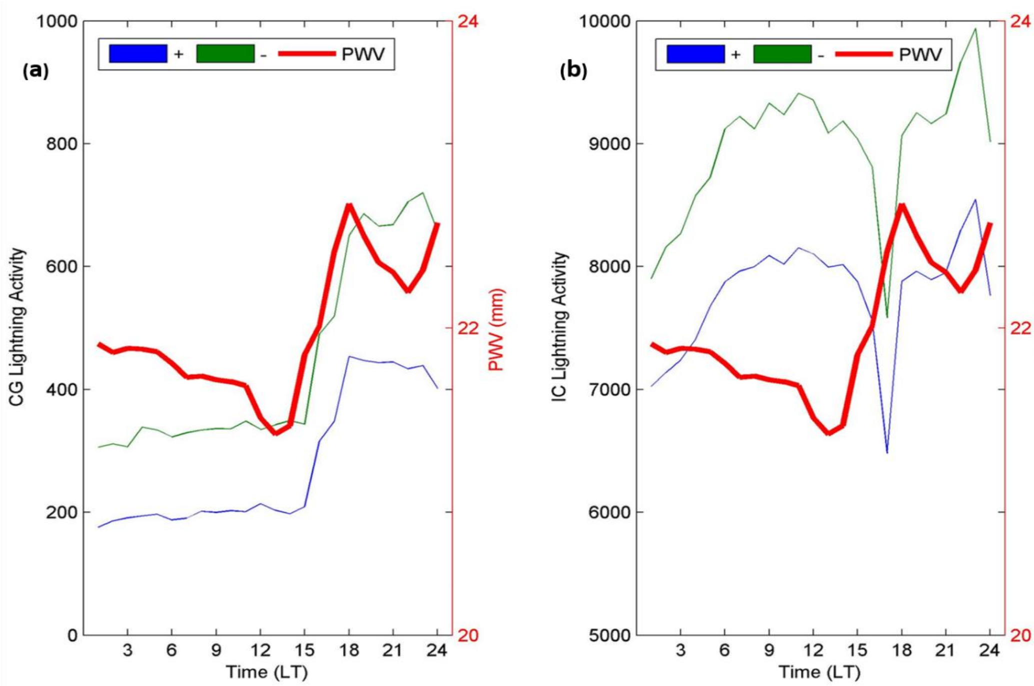

Figure 4. The comparison of GPS PWV (red line) with the CG and IC lightning

4. Conclusion

The lightning sensor that was installed at Carlini Base in the Antarctica Peninsula capable detected lightning activities with an average of 16220 of lightning strikes at every hour. Most of the lightning strikes are IC type which covers the 96% of the lightning activities detected with half of it are the -IC type lightning; the remaining 4% were from +CG and -CG types. The hourly GPS PWV shows a proportional relationship with the CG with a lag of half an hour to one hour. Oppositely, GPS PWV shows an inverse relationship when compared with the IC type with a lag of about one hour time delay. There are changes in the lightning activities and the GPS PWV between 12.00 pm until 6.00 pm. In conclusion, the thunderstorm measured through lightning strikes at Carlini Base give an indicator that during the summer, the atmosphere of the Antarctic Peninsula is very active and has the potential to generate storms. However, further analysis is required, such as monthly and seasonal responses between GPS PWV and lightning activity to observe whether thunderstorm exists throughout the season in this region.

Acknowledgements

This work is partly supported by the Research Institutions and Community Service (LPPM) Universitas Sanata Dharma Yogyakarta, Indonesia and the Ministry of Science, Technology and Innovation Malaysia (MOSTI) under the Flagship Program: ZF-2014-016 grant. The author would like to thank the Instituto Antártico Argentino (IAA) for the hospitality, the base facilities for installation of equipment, and all those who have assisted to carry out the expedition to Antarctica in 2017. Special thanks to Siti Khalijah Zainudin for processing GPS and lightning data used in this paper.

References

[1] Turner J, Colwell S R, Marshall G J, Lachlan-Cope T A, Carleton A M, Jones P D, Lagun V, Reid P A and Iagovkina S 2005 Antarctic climate change during the last 50 years *International Journal of Climatology* **25** 279

[2] Troshichev O A, Frank-Kamenetsky A, Burns G, Füllekrug M, Rodger A and Morozov V 2004 The relationship between variations of the atmospheric electric field in the southern polar region and thunderstorm activity *Advances in Space Research* **34** 1801

[3] Smith A J and Jenkins P J 1998 A survey of natural electromagnetic noise in the frequency range f = 1–10 kHz at Halley station, Antarctica: 1. Radio atmospherics from lightning *Journal of atmospheric and Solar-Terrestrial Physics* **60** 263

[4] Suparta W, Abdul Rashid Z A, Mohd Ali M A, Yatim B and Fraser G J 2008 Observations of Antarctic precipitable water vapor and its response to the solar activity based on GPS sensing *Journal of Atmospheric and Solar-Terrestrial Physics* **70** 1419

[5] Keogh S J, Hibbett E, Nash J and Eyre J 2006 The Met Office Arrival Time Difference (ATD) system for thunderstorms detection and lightning location *Forecasting Research Tech Rep* **488** 22 pp

[6] Dwyer J R and Uman M A 2014 The physics of lightning *Physics Reports* **534** 147

[7] Surkov V V, Nosikova N S, Plyasov A A, Pilipenko V A and Ignatov V N 2013 Penetration of Schumann resonances into the upper ionosphere *Journal of Atmospheric and Solar-Terrestrial Physics* **97** 65

[8] Rakov V A and Uman M A 2003 Lightning, physics and effects *Cambridge University Press* 687 pp

[9] Suparta W 2014 The development of GPS *TroWav* tool for atmospheric – terrestrial studies *Journal of Physics: Conference Series* **495** 012037