Tracking of tropical cyclones and their intensity changes in the South Pacific region using World-wide lightning location network

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Abstract
The cyclonic storms are associated with strong winds, rainfall, and thunderstorms generating strong lightning discharges. Tracking of thunderstorms and rapid intensification of cyclones are important challenges in weather forecasting in order to warn the potential threats to the communities. Our analysis of World-Wide Lightning Location Network (WWLLN) detected lightning data suggests that lightning activity is greatly enhanced in the rainbands with secondary maximum in the eyewall of a mature tropical cyclone. The movement of a March 2010 tropical cyclone in the South Pacific region and associated lightning activity in the eyewall and the rainbands are presented to demonstrate the potential of WWLLN data in timely forecasting of thunderstorms associated with cyclonic storms thus reducing the overall threat to the Pacific societies as well as to ocean shipping and airborne carrier services flying in and/or over the Southwest Pacific Ocean.

***Key words**: Tropical cyclones, lightning activity, forecast.*

Introduction

Tropical cyclones (TCs) are one of the main natural disasters in the South Pacific Region which can claim lives of people, cause damages to the physical structures, damage agriculture, and affect the overall economy of the Pacific Island Countries (PICs). A tropical cyclone is a rapidly-rotating storm system characterized by a low-pressure center, strong winds, and a spiral arrangement of thunderstorms that produce heavy rain. These tropical cyclones can have total lifetimes from a few days to 2-3 weeks at most, and generally spend most of their lifetime over the oceans. Tracking of cyclonic storms is well developed but their rapid intensity change is of challenge (Kaplan and DeMaria, 2003). Lightning discharges are also the potential threats for the community particularly during the cyclonic storms.

The lightning activity generated by tropical cyclones is not well understood. This is mainly because these storms spend most of their lifetimes over the ocean, away from land-based regional lightning networks. Recent studies have used satellite-based lightning detection and an extended regional network to investigate lightning activity in tropical cyclones before landfall. Cecil and Zipser (1999) used lightning data from the Tropical Rainfall Measurement Mission (TRMM) satellite to compare lightning activity and tropical cyclone intensity. Using the World-Wide Lightning Location Network (WWLLN) data to study spatial and temporal distributions of lightning for two Atlantic hurricanes (Rita and Katrina) and three western Pacific typhoons (Durian, Chanchu and Yagi), Solorzano et al. (2008) found an outbreak in eyewall lightning prior to an eyewall replacement cycle. Moreover, lightning activity during the complete lifetime of western Pacific tropical cyclones was studied by them for the first time. For all storms observed, they found three regions of distinct spatial behavior for lightning density with maxima in the rainband and eyewall regions. They also found that the eyewall lightning outbreak occurred prior or during most major intensity changes for all storms examined. They suggested that eyewall lightning activity might be used to identify convection intensification in strong tropical cyclones. Peaks in eyewall lightning activity were also observed before most landfalls. Abarca et al. (2011) investigated the lightning flash density for 24 Atlantic basin TCs that came within 400 km of the United States during 2004 to 2007 to identify whether lightning flashes provide information on TC intensity changes. Their results suggested that flash density in the inner core is a parameter with potential for distinguishing intensifying versus nonintensifying TCs, particularly in the weaker storm stages where flash densities are largest. The radial distribution of flash density was shown to exhibit a relatively narrow region of little activity (between 60 and 120 km from the eye), with increased activity in both regions closer to, and more distant from, the center (*i.e.*, the eyewall and outer rainbands, respectively). They also concluded that the WWLLN captures the convective activity in Atlantic basin TCs remarkably well, despite its low detection efficiency. LunXiang et al. (2010) studied seven super typhoons from 2005 to 2008 over the Northwest Pacific, using WWLLN data and found that there were three distinct lightning flash regions in mature typhoon, a significant maximum in the eyewall regions (20–80 km from the center), a minimum from

80–200 km, and a strong maximum in the outer rainbands (out of 200 km from the center). The lightning flashes in the outer rainbands were much more than those in the inner rainbands, and less than 1% of flashes occurred within 100 km of the center. Each typhoon produced eyewall lightning outbreak during the periods of its intensification, usually several hours prior to its maximum intensity. Little lightning occurred near the center after landing of the typhoon. De Maria et al. (2012) used a large sample of Atlantic and eastern North Pacific TCs (2005–2010) to investigate the relationships between lightning activity and intensity changes for storms over water using WWLLN data. Their results generally confirmed those from previous studies that the average lightning density decreased with radius from the storm center. Their results also showed that when the lightning density was compared with intensity change in the subsequent 24 h, Atlantic cyclones that rapidly weakened had a larger inner-core (0–100 km) lightning density than those that rapidly intensified. Thus, they concluded that a large inner-core lightning outbreaks are sometimes a signal that an intensification period is coming to an end. Conversely, the lightning density in the rainband regions (200–300 km) was found to be higher for those cyclones that rapidly intensified in the following 24 h in both the Atlantic and east Pacific sectors.

In this paper we present the lightning evolution pattern for a South West Pacific TC named Ului which occurred in March 2010. We have used the WWLLN data to plot the lightning flash density for this cyclone during the period 13-16 March 2010, when the TC intensified and developed into a category 5 cyclone and eventually started fading.

Data and analysis

The lightning data used in this study are from the WWLLN, which detects lightning activity occurring globally. The WWLLN provides almost real time lightning locations by measuring the very low frequency (VLF) radiation (3–30 kHz) emanating from lightning discharges. These VLF signals can be received thousands of kilometers from the source. For a lightning flash to be accurately detected with error analysis, the VLF radiation from a flash must be detected at a minimum of 5 of the network’s 40 receivers around the world. Every receiving station consists of a whip antenna to measure VLF electric field, a GPS antenna for accurate timing, preamplifying electronics, and an internet-connected processing computer. Each receiver locally processes a flash’s waveform and sends the time of group arrival (TOGA) (Dowden et al., 2002) to the central processing station for location in Washington University, USA and Otago University, New Zealand. The data used here were obtained from the University of Washington for March 2010, where they were processed using the upgraded (version 2) algorithm which gives increased WWLLN detection efficiency by about 60% when compared to the old algorithm used prior to 2008 (Rodger et al., 2008). The lightning flash density for each day (24 h) for the period 13-16 March 2010 is plotted using matlab codes. The TC information was obtained from the website http://en.wikipedia.org/wiki/Cyclone_Ului. This TC (Ului) was chosen for study because it was first identified and named by the Fiji Meteorological Service (FMS) and falls in our region of South West Pacific.

Results and Discussion

In this work, in order to test if our results obtained from WWLLN data are representative of the lightning distributions in a typical mature cyclone as reported by previous researchers, we plot the lightning spatial distributions for the TC Ului for the period 13-16 March 2010.

Figure 1(a) shows the Infrared satellite image of Cyclone Ului undergoing rapid intensification from 13 to 14 March. The spiral arrangement of the cloud band and the eye could be easily identified. The path of the cyclone since its formation till the time it faded is displayed in Figure 1(b). Figure 2 shows the WWLLN plotted lightning flashes during the period 13-16 March. Each panel indicates the lightning flashes detected on a 24 hour period for the particular days marked as blue spots. The panel sizes are based on longitudes 150°E to 175°E and latitudes 6°S to 18°S to match the spatial distribution of the TC cloud band. The WWLLN data shows the radial lightning pattern. There are three distinct regions identifiable for a fully matured cyclone as seen and measured on 14 March: a weak density maximum for the eyewall (region within ~40 km off the center), a distinct area of minimum lightning activity at approximately 50 – 250 km from the eyewall, and the main, broader maximum lightning on the rainband region, outside the 250 km radius. Although shorter duration panels (~ 1 hr) of lightning flashes are not reported here, but it can be said that the eyewall lightning activity was enhanced on 13 and 14 March before the cyclone started weakening after 15 March. An asymmetric distribution of lightning was quite distinct, most of them occurred in the North-west and South-east quadrants on 14 and 15 March when the cyclone was most intense. As the TC weakened after 15 March, very few lightning flashes could be seen in the inner core and around the eyewall hence the eye of the cyclone could not be identified. A more thorough analysis of lightning flash record for shorter duration windows could possibly show the actual evolution of lightning during the cyclone intensification and weakening periods. There has been great improvement in TC forecasting over the last 40 years, however, factors including environment wind errors and storm structure errors can significantly contribute and may lead to errors in TC position forecasting (Thomas and Davis, 2013). The WWLLN lightning data could be well utilized to track the TCs especially their rapid intensity changes which could act as an indicator to the cyclone lifetime prediction, hence, providing timely information to the public for precautionary measures.

Conclusions

On the basis of WWLLN lightning data analysis during the major phase of the TC Ului in the South Pacific for the period 13-16 March 2010, we can draw following conclusions:

- WWLLN detected lightnings can be effectively used to study lightning patterns during cyclones.
- Lightning density parameters in strong tropical cyclones (particularly around eye wall) can be used to identify their convection intensification.
- The WWLLN data has the potential to improve the short-term prediction of tropical cyclone rapid intensity changes.

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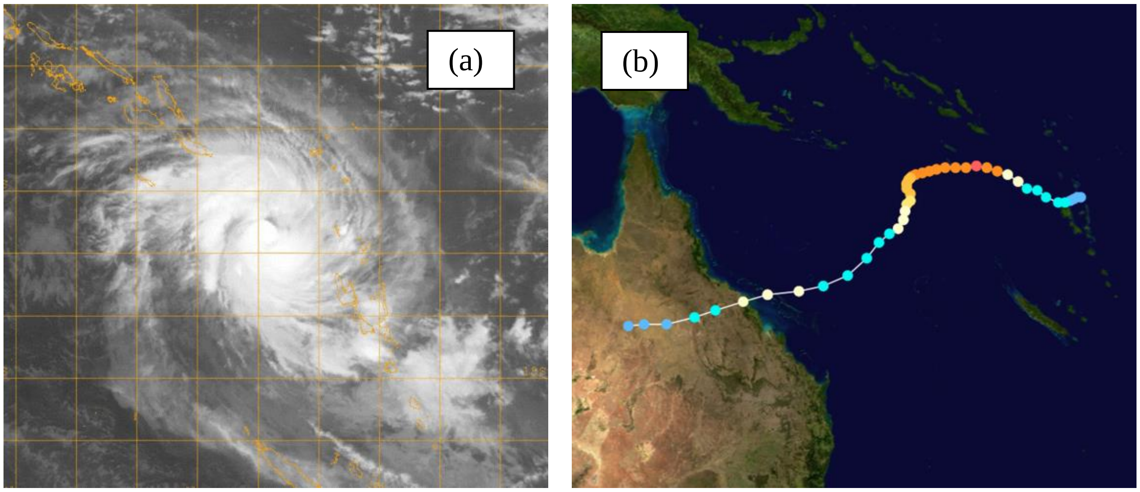

Figure 1: (a) Infrared satellite image of Cyclone Ului on 14 March 2010 and **(b)** the path of the cyclone during its lifetime (Source: http://en.wikipedia.org/wiki/Wikipedia:WikiProject_Tropical_cyclones/Tracks).

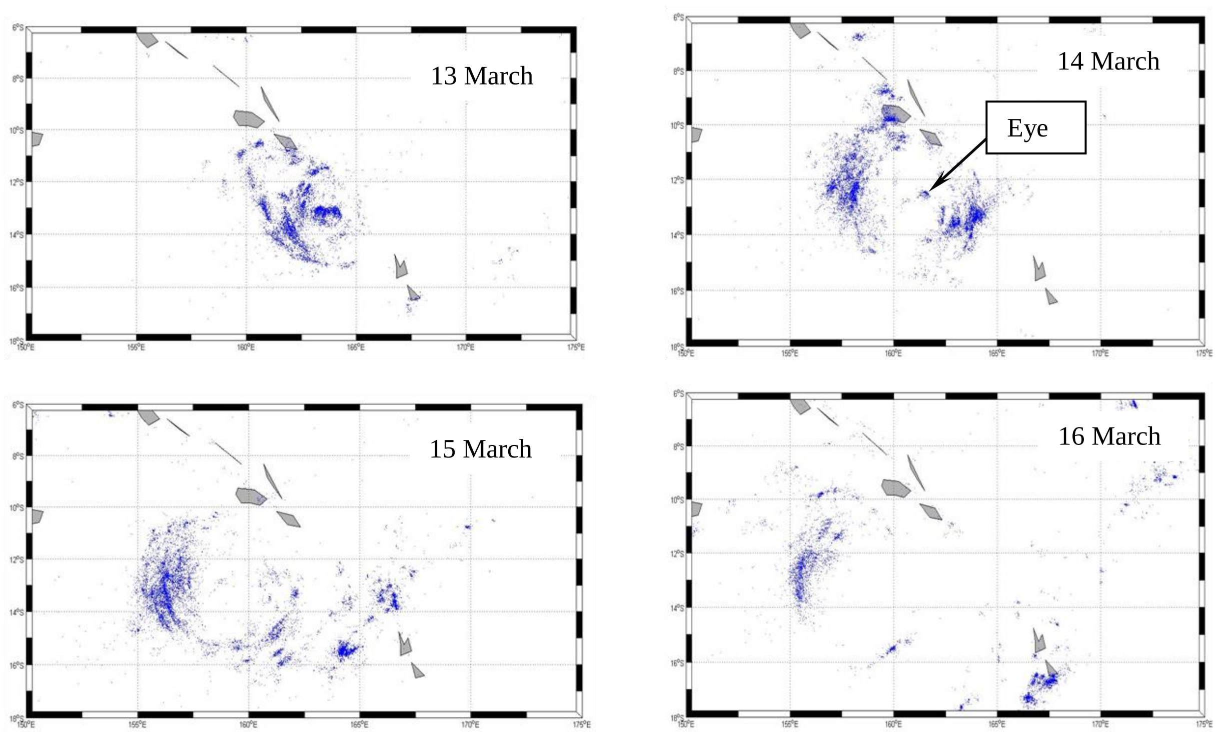

Figure 2: Evolution of lightning flashes (blue spots) for TC Ului during 13-16 March 2010. The lightning around the eyewall can be seen on 14 March.