A Comparative Analysis of A Global To A Regional Lightning Detection Network

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Abstract

The World Wide Lightning Location Network (WWLLN) provides global coverage of lightning activity in near real time using a network of Very Low Frequency (VLF) radio receivers. Although WWLLN provides superior spatial coverage to regional lightning detection networks, this comes at the price of relatively low efficiency. We document a technique which can be used to obtain realistic lightning flash rate densities from WWLLN data by using satellite lightning observations as a reference. The new flash rate densities are then validated using data from the South African Lightning Detection Network (SALDN).

Keywords — *Lightning, WWLLN, LIS/OTD, SALDN*

I. INTRODUCTION

Lightning is an electrical discharge driven by charge separation in the Earth's atmosphere. A lightning discharge can extend over several kilometers and typically only lasts a few milliseconds. Lightning can be classified as either cloud-to-ground (CG) or cloud-to-cloud (CC), where the latter category is by far the most common. A lightning flash consists of one or more strokes, each of which is an independent current pulse. The multiplicity (number of strokes in a flash) is known to vary with location and season[1].

Although lightning radiates electromagnetic energy over the entire electromagnetic spectrum, the peak intensity lies in the Very Low Frequency (VLF) range[2,3]. Due to the small attenuation of VLF signals in the Earth-Ionosphere Waveguide (EIWG), the pulse of electromagnetic energy, or sferic, can propagate over enormous distances. This makes the detection of lightning using a small number of VLF receivers possible.

II. LIGTHNING DETECTION SYSTEMS

WWLLN is a ground-based lightning detection network that uses VLF sferics to detect lightning activity. Each node in WWLLN consists of an antenna, a Global Positioning System (GPS) receiver and a processing computer with internet access. Since VLF waves propagate with low attenuation in the EIWG, these nodes can be placed thousands of kilometers apart. The system has gone from having less than 25 nodes in 2005 to more than 40 distributed across the Earth in 2010. This has led to a significantly increased detection efficiency (DE) over the last few years[4,5,6].

In contrast to WWLLN, the SALDN is a regional network which only detects lightning within the borders of South Africa. The limited spatial range of the network is due to the fact that it uses the Very High Frequency (VHF) signature of lightning, which is rapidly attenuated within a few hundred kilometres.

LIS and OTD are satellite instruments which use optical techniques to identify lightning discharges. The spatial resolution and efficiency of these instruments are very good. However, the nature of satellite observations is such that they only gather data within their field of view. In order to achieve global coverage, the data from many orbits must be combined. The LIS and OTD data sets have been inter-calibrated and merged to give lightning flash rate densities over a period of 10 years.

III. LIGTHNING MODEL

The WWLLN data were first converted into stroke rate densities (strokes/km^2/year) by dividing the number of strokes into 0.5° by 0.5° blocks which were then divided by the area of each block and lastly converted to yearly values. These stroke rate densities were then projected onto a 0.5° by 0.5° grid. In order to make the WWLLN data comparable to other lightning data sets, the stroke rate densities had to be converted to flash rate densities (flashes/km^2/year) by assuming an average multiplicity of 3.5 strokes per flash. Despite the excellent time resolution of WWLLN the DE of the system is very low with the maximum stroke rate density found to be around 3 flashes/km^2/year.

High resolution flash rate density maps derived from the WWLLN data averaged over 5 years (2005 - 2009) are given for each season in Figure 1. The corresponding LIS/OTD data is presented in Figure 2. It is clear that WWLLN generates flash rate densities which are significantly smaller than those obtained from LIS/OTD. This is due to the lower detection efficiency of WWLLN. The spatial distribution of the two data sets are however comparable and they both follow the expected seasonal variation with the highest lightning activity levels during the summer in the Southern Hemisphere. Also, WWLLN detects the most lightning over equatorial Africa, North America and the Maritime continent, which is to be excepted from previous lightning activity studies.

Since the LIS/OTD data were acquired from instruments with high efficiency, the data in Figure 2 can be regarded as being a true reflection of the average global distribution of lightning. However, these data were only achieved by averaging the LIS/OTD data over a long period of time. In contrast, minimal averaging is required to achieve a global lightning distribution from WWLLN data. However, the WWLLN data underestimate the absolute level of lightning activity. We propose to use the LIS/OTD data to bootstrap the WWLLN measurements.

The WWLLN was first scaled and shifted so that the mean and standard deviation agreed with that of the LIS/OTD data. Thereafter normalisation factors were created which varied across the surface of the globe. These are the ratio of the average LIS/OTD to the average WWLLN flash rate density for every 15° by 15° grid block. A different set of factors was created for each season. Figure 3 illustrates how the normalisation factors were found to vary with the WWLLN node distribution.

Larger normalisation factors were mostly found to correlate with a lower node density. For example over South America and Southern Africa. However this was not always the case: over the oceans the normalisation factors were small although the node density in those regions is low. This is probably due to the flash rate densities of both WWLLN and LIS/OTD being at a minimum over the oceans. Figure 4 represents the seasonal variation of the normalised WWLLN flash rate densities. These data are now more comparable to those from Figure 2 as well as the global lightning map published by Christian et al[8].

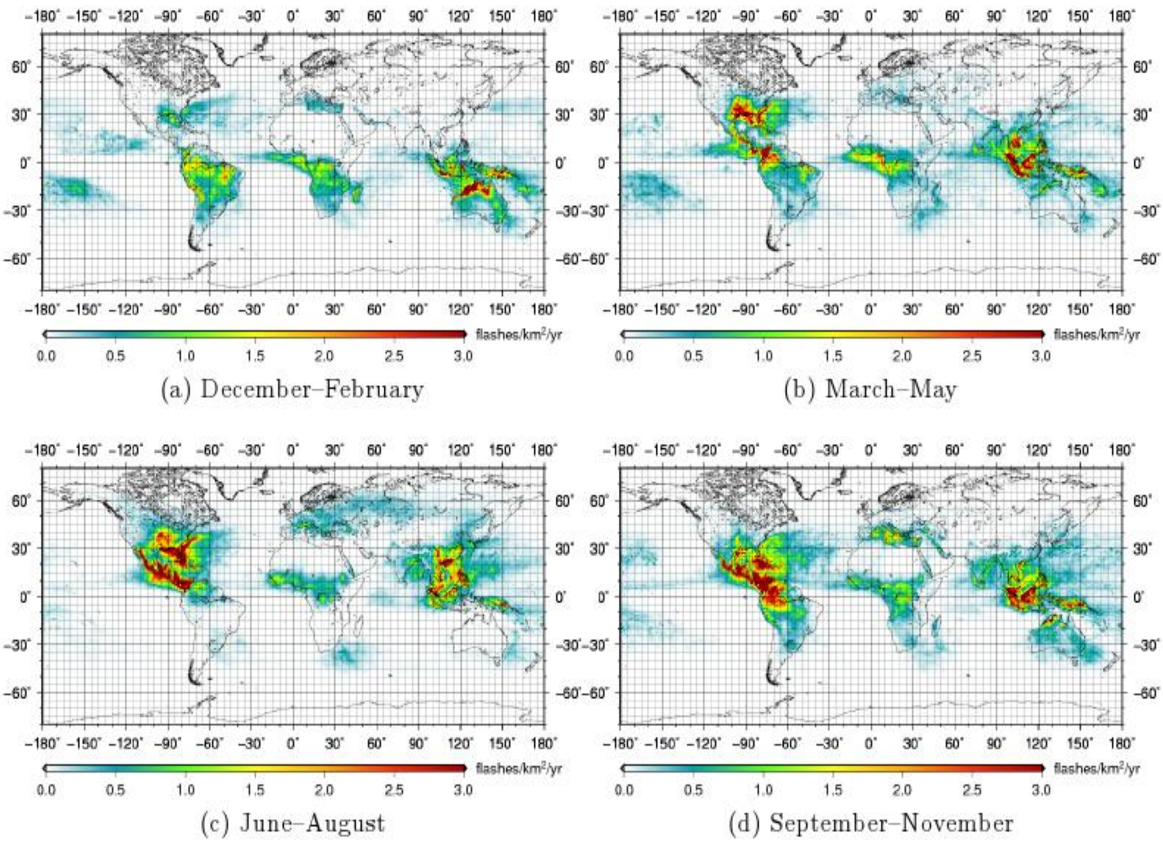

Fig 1: The average seasonal patterns of global flash rate densities derived directly from the original WWLLN data

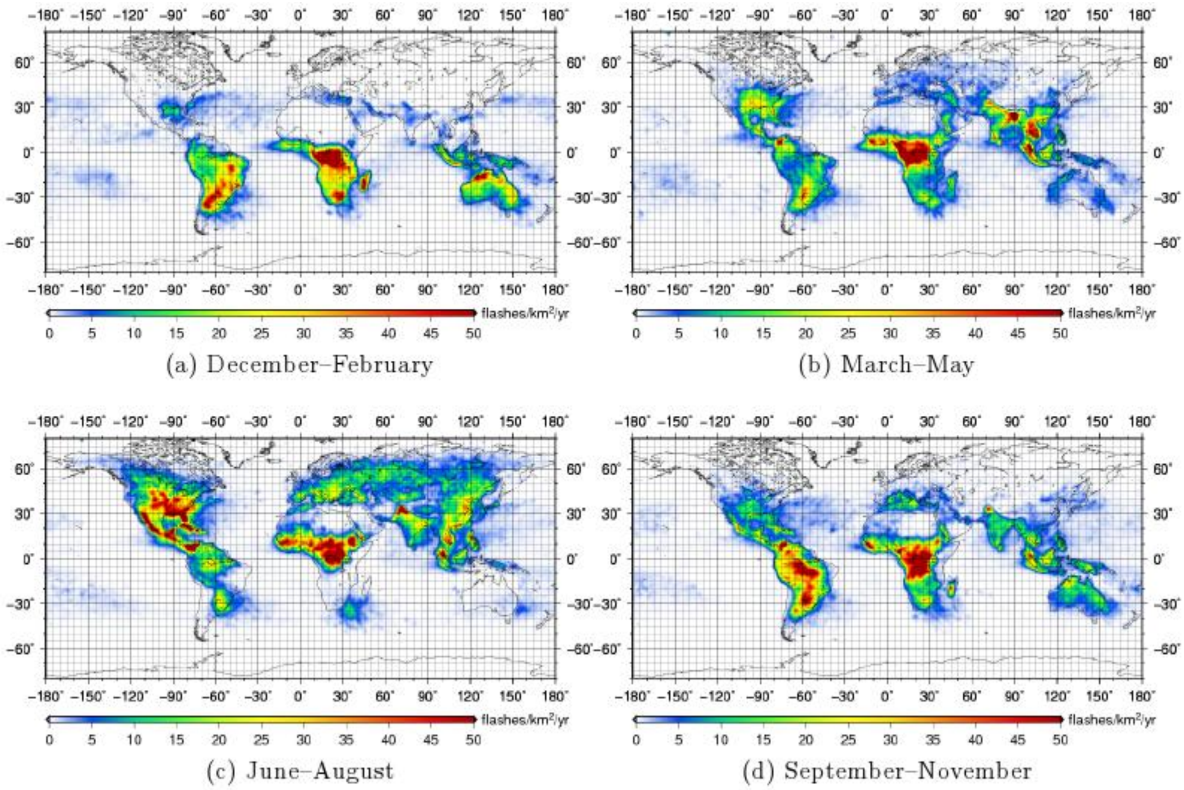

Fig 2: The average seasonal patterns of global flash rate density from the LIS/OTD data.

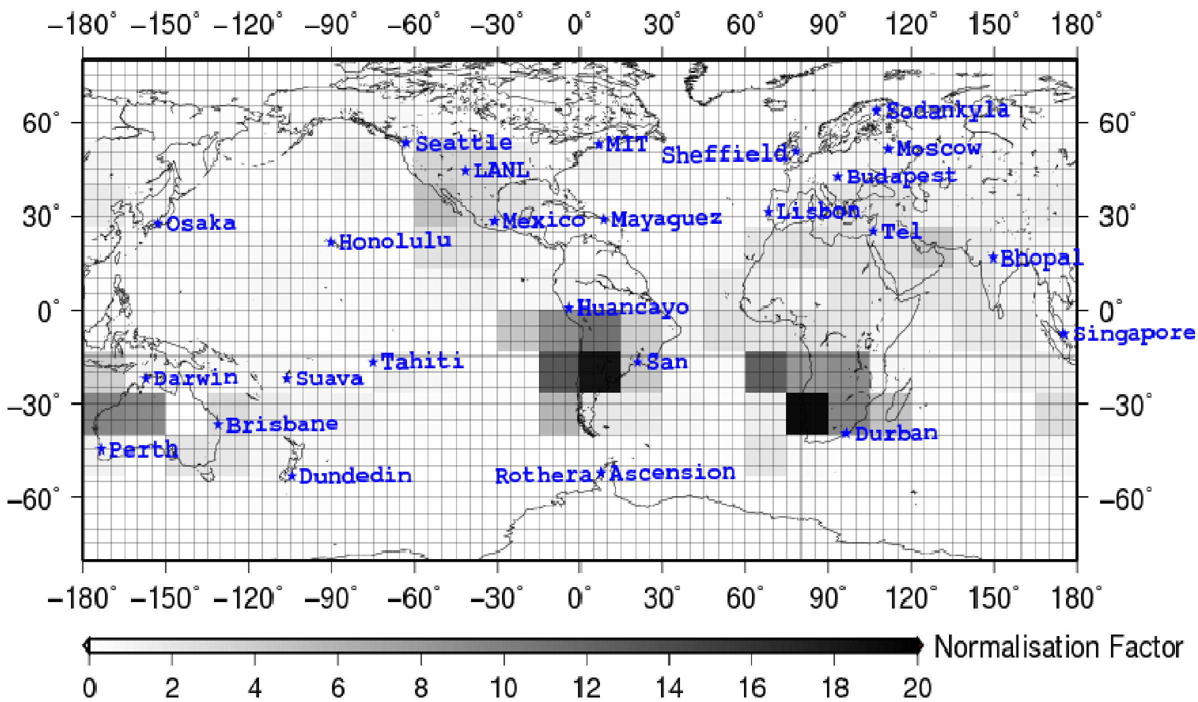

Fig 3: An example of the normalisation factors for WWLLN.

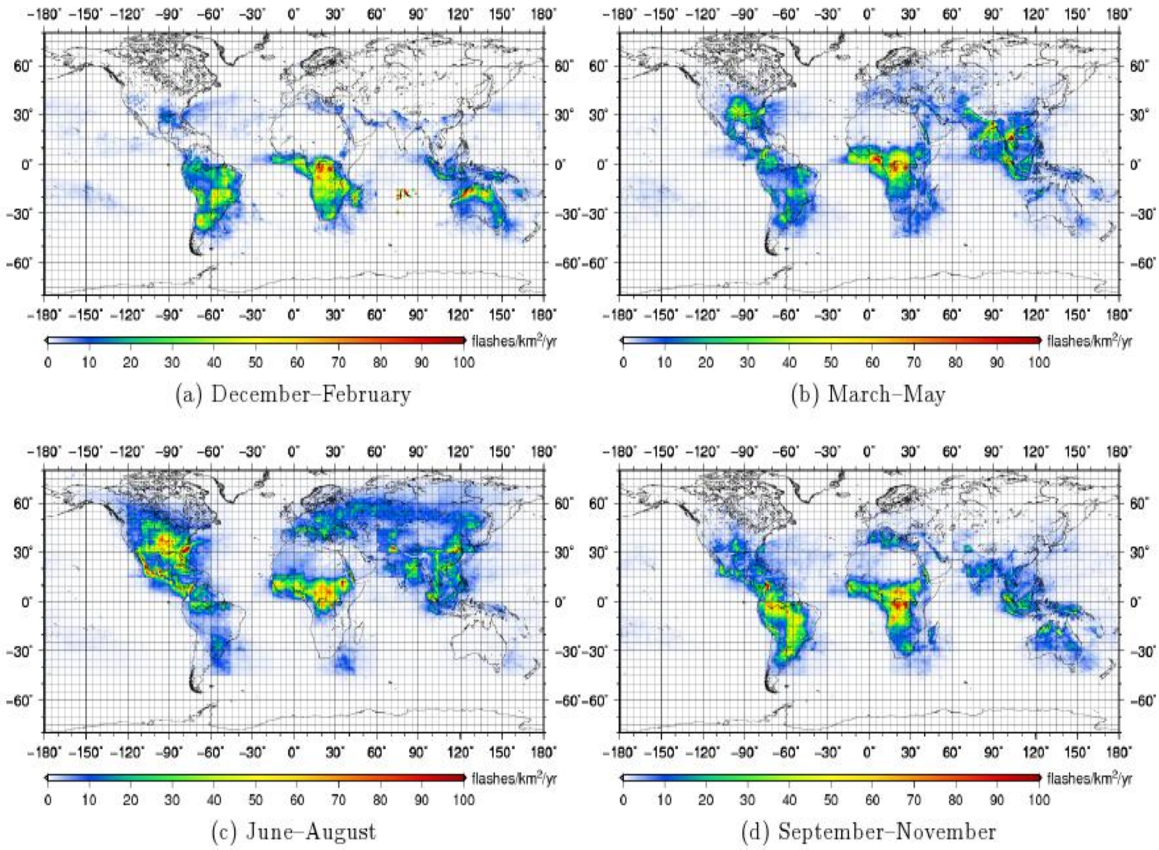

Fig 4: The average seasonal patterns of global flash rate densities derived directly from the normalised WWLLN data.

IV. COMPARISON TO REGIONAL DATASETS

In order to validate the normalised WWLLN flash rate densities they were compared to regional data from SALDN. These data have a very good DE within a specific region and are therefore useful in the validation process. The comparison was conducted using a χ^2 test. Both normalised WWLLN and the SALDN data were projected onto a 1° by 1° grid. The comparison was confined to the area covered by the SALDN, which is effectively within the borders of South Africa. The null hypothesis for the χ^2 test was that the distribution of the two data sets was the same.

A few days during February were chosen for comparison as this is the time during which South Africa has its highest lightning activity levels. Most of the lightning activity occurs over KwaZulu-Natal and the Highveld region. Since SALDN measures strokes, a multiplicity of 2.5 as found by Gill[9] was assumed for the SALDN data. Figures 5 and 6 represent the results from two of the days chosen for the comparison. The first two panels in each Figure, (a) and (b), indicate the individual lightning locations detected by each of the systems. The second two panels, (c) and (d), compare the SALDN flash rate density to the flash rate density derived from the WWLLN data prior to normalisation. It is apparent that there is a significant difference in the results from SALDN and WWLLN. Finally the last two panels, (e) and (f), compare SALDN and the normalised WWLLN data. It is clear that the normalisation process has made the WWLLN flash rate densities quite comparable to those from SALDN. Furthermore, although the SALDN data are confined to the boundaries of South Africa, the normalised WWLLN data extends beyond these boundaries. The distribution of lightning flashes in Figure 5 on the 4 February 2007 agrees well with the average annual lightning ground flash density distribution shown in Figure 2 of Gijben[9]
where both figures show that most of the lightning occurs over the northern parts of KwaZulu-Natal, the Mpumalanga Lowveld and Gauteng.

These findings were also confirmed by the results from the χ^2-test shown in Table 1. Where the first column gives the date of comparison, the second the χ^2-test value, the third the degrees of freedom and the fourth the p-value. A statistical test's main purpose is to determine how well the observed data agrees with the expected data. A null hypothesis (H_0) is set up to be refuted in order to support an alternative hypothesis (H_1), where the null hypothesis implies that there is no difference between the observed and expected data. If the p-value of the χ^2-test is less than a chosen significance level, where the p-value is the probability that a given result could have been obtained by chance, the null hypothesis is rejected. Table 1 shows that, according to the χ^2-test that the normalised WWLLN and SAWS data are comparable on the chosen days.

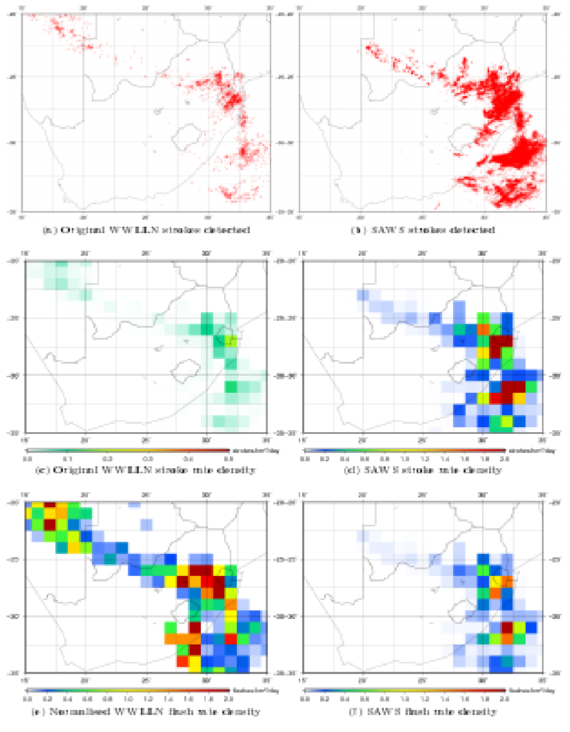

Fig 5: A comparison of WWLLN against Figure 7: A comparison of WWLLN against SAWS for 4 February 2007.

Table 1: Results of the χ^2-test for the WWLLN-SAWS comparison.

Dataset	Chi-square	Degrees of Freedom (df)	P-value
20070204	23.9907	69	1
20070210	14.8031	97	1
20070227	3.9593	55	1
20070228	9.7084	41	1

V. CONCLUSIONS

A statistical lightning model was created using data from the World Wide Lightning Detection Network (WWLLN). When WWLLN started operating in 2005 it had only 25 nodes. Five years later in 2010, the number of nodes had gone up to more than 40 and it is still increasing.

Unfortunately the detection efficiency of WWLLN is relatively low. This has been thought to be due to a low node density over specific regions but is also related to the detection mechanism. This prompted the use of LIS/OTD data to normalise the WWLLN data. The normalisation factors were found to vary with node distribution. Where the highest factors were often found to be over the ocean and in close proximity to a node. In order to test the accuracy of the statistical model, the normalised WWLLN flash rate densities were validated against those of a regional lightning detection system. Both a visual and χ^2-test was done. WWLLN seemed to have much better agreement to the regional systems after the normalisation process than before it. The ideal would be to obtain more WWLLN and especially more SAWS data in order to do the comparison over a longer time period. One could then look at the seasonal and annual variations of the two data sets and examine the similarities and differences.

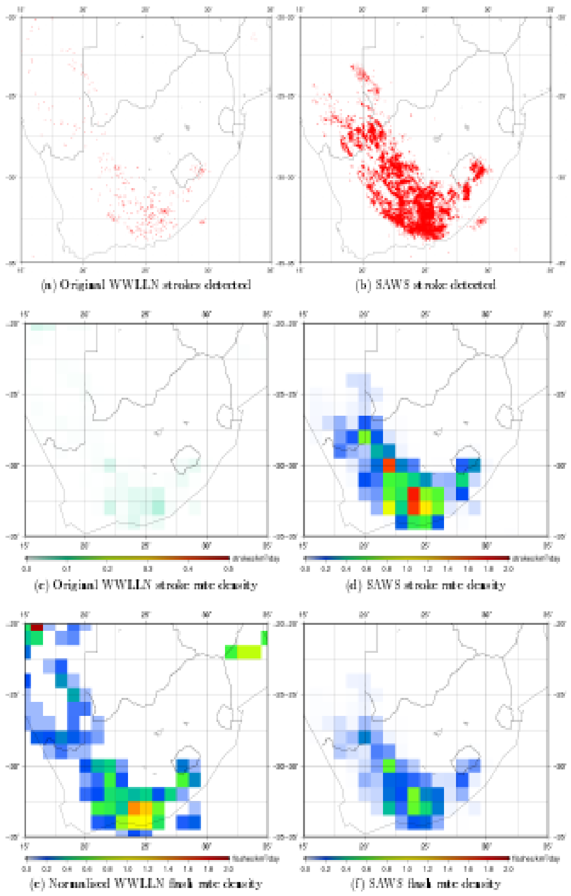

Figure 6: A comparison of WWLLN against SAWS for 27 February 2007

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