Growing Detection Efficiency of the World Wide Lightning Location Network

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Abstract. An experimental Very Low Frequency (VLF) World-Wide Lightning Location Network (WWLLN) is being developed through collaborations with research institutions across the globe. In this paper we report on the steady improvement in the Detection Efficiency (DE) of the WWLLN due to increasing station number, which led to a doubling in locations provided from 2003-2007. In addition, a new algorithm has recently been implemented which lead to DE improvements of 63%.

Keywords: Global lightning location, detection efficiency, location accuracy
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INTRODUCTION

An experimental Very Low Frequency (VLF) World-Wide Lightning Location Network (WWLLN) is being developed through collaborations with research institutions across the globe (Fig. 1 shows the July 2008 network configuration). The network exploits the considerable electromagnetic power radiated by lightning as "sferics" present in the VLF band (3-30 kHz). Very long range remote sensing is possible; these VLF signals can be received thousands of kilometers from the source, as the electromagnetic energy propagates with low attenuation inside the waveguide formed by the conducting Earth and the lower boundary of the ionosphere, termed the Earth-Ionosphere Waveguide (EIWG). The vertical electric field from strong lightning normally dominates over power line noise in the receiver bandwidth (6-22 kHz), although this is dependent upon the source-receiver distance. The developers of the WWLLN have indicated that the ultimate aim of the WWLLN is to provide real-time locations of cloud-to-ground lightning discharges occurring anywhere on the globe, with >50% flash detection efficiency and mean location accuracy of <10 km [e.g., 1].

The location accuracy and regional detection efficiency of the WWLLN have been examined by contrasting its observations with those from MF/HF lightning detection networks in Australia, Brazil, America, and New Zealand [e.g., 1,2,3,4], as well as from spacecraft [5]. Together, these reports provide a summary of the nature and development of the WWLLN. These studies indicated that the WWLLN does indeed detect high peak current lightning discharges in all parts of the Earth, and produced estimates for the global location accuracy. They have shown that the WWLLN detects both cloud to ground and intracloud lightning strokes, although due to the higher peak currents in intracloud strokes, the network is better suited for detecting cloud to ground. It has also been shown that the WWLLN detects lightning-producing storms with high efficiency inside a 3-hour time period, indicating that the WWLLN can be useful for locating deep convection for weather forecasting on the rather common meteorological 3-hour update cycle [2]. From these studies it is clear that the detection efficiency is low, with only a few percent of global lightning activity detected [e.g., 3]. However, for many scientific applications, the benefits of a global overview in real time can outweigh the very low total lightning detection.

In this paper we report on increases in the Detection Efficiency (DE) of the WWLLN due to increasing station number, and a new algorithm that has been implemented leading to significant DE improvements. Note that the figures presented in this paper are available in color from the lead-author: *crodger@physics.otago.ac.nz*.

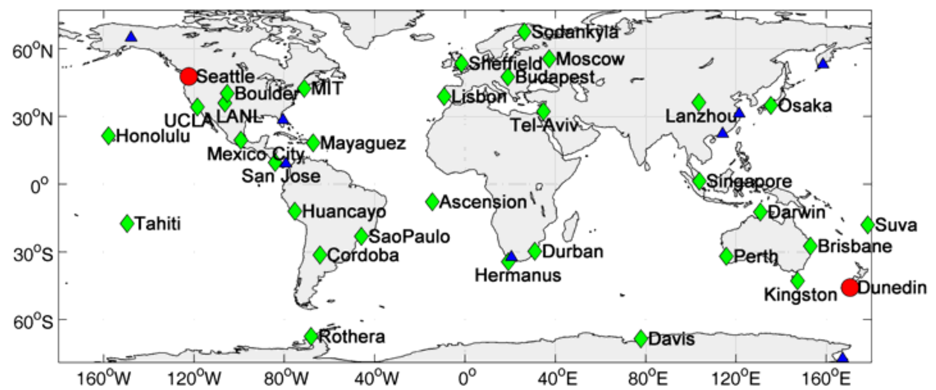

FIGURE 1. Locations of the 32 VLF receiving stations operating in the VLF World-Wide Lightning Location Network as of July 2008. The location of the central processing computers plus receiver is shown as a diamond, while the planned locations of future WWLLN (within the next 6 months) sites are shown as triangles.

IMPROVEMENTS IN DETECTION EFFICIENCY

Growth in Number of Stations in the WWLLN

From 2003-2007 the receiving station network which makes up the WWLLN increased from 11 (12 March 2003) to 30 (24 April 2007) stations. The number of "high quality" lightning locations increased from 10.6 million (March-December 2003) to 28.1 million (2007). Although the triggering techniques altered across this time period [3], the strong differences in locations from the WWLLN over 2003 to 2007 have been primarily due to the growing and changing network configuration and operation. Table 1 summaries the growth in the number of receiving stations in the WWLLN, lightning locations, and the relative DE of the WWLLN when contrasted with the expected mean geographic global annual average flash rate of 44±5 flashes per second [6]. Note that here we follow the WWLLN data handling practice recommended by the WWLLN management team, where "high quality" locations are those with residuals ≤30μs and where ≥5 WWLLN stations contributed observations to the production of that location. The increase in stations in the WWLLN has roughly doubled the number of locations produced by the network, and hence roughly doubled the global DE. One expects that global DE will be roughly proportional to station number, as long as the stations are uniformly spread.

TABLE 1. Summary of the changing global DE of WWLLN.

Year	# WWLLN stations	# WWLLN locations	DE of Global Lightning
2003 (Mar-Dec only)	11	10.6 million	-
2004	19	19.7 million	1.4%
2005	23	18.1 million	1.3%
2006	28	24.4 million	1.8%
2007	30	28.1 million	2.0%
2007 (new algorithm)	30	45.7 million	3.0%

New Location Algorithm

While increasing the number of stations has improved the WWLLN DE, much less than half of the triggering events sent back by each station are used to produce valid locations. The initial, rather simple, algorithm used to group time of group arrival (TOGA) values [7] into locations was described in the early WWLLN papers. A new algorithm has been developed to overcome some of the limitations in the original approach, as outlined below. Consider a lightning discharge occurring at an unknown time and location on the surface of the Earth as shown in Figure 2. Receiving stations **a**, **b** and others, detect and measure the TOGA, t_a, t_b etc., of the electromagnetic radiation from this and many other lightning discharges. The goal of any lightning location algorithm is to determine the time and location of the discharges, from these TOGA measurements.

The original lightning location used in the WWLLN was a two step process. First TOGA measurements were grouped together such that for any given pair of TOGA measurements the difference in TOGA was less than the travel time between the two stations at which the measurements were made. The goal of this process was to sort the TOGAs into groups from a common lightning discharge. Referring to Figure 2, two TOGA measurements t_a and t_b were considered to be from the same common discharge if $|t_a - t_b|<r_{ab}/c$. Next, Nelder-Mead optimization was used to determine an optimum location such that computed values of TOGA agreed with the actual TOGA measurements from each station that detected the discharge.

While the test used in the original algorithm to group TOGA measurements together provided a necessary condition for grouping the TOGAs, it was not sufficient to determine that all of the observed TOGAs were due to a common discharge. Thus some groups of TOGA measurements could actually contain measurements from more than one lightning discharge and an optimal location for this discharge could not be determined. In the original algorithm, if a group of TOGA measurements failed to produce a valid location then the entire set of measurements was discarded. The new 2007 algorithm discards only the oldest TOGA measurement in the group and then attempts again to determine a valid location, on the basis that that the oldest TOGA has been trialed, and failed at that point. This process of discarding the oldest TOGA is repeated until either a valid location is found or insufficient (<5) measurements remain - at which point the remaining measurements are discarded.

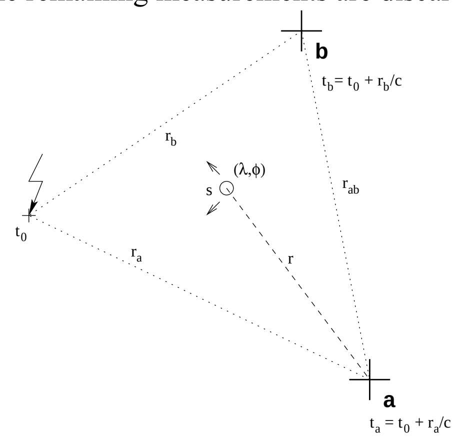

FIGURE 2. A lightning flash on the surface of the Earth. Stations **a** and **b** measure the time of group arrival (TOGA) of the electromagnetic radiation from the discharge. The location algorithm attempts to find an optimal position (λ, ϕ) for the discharge based on the TOGA measurements.

Figure 3 shows a comparison between the WWLLN-reported global lightning activity for 2007, with the original algorithm displayed in the lower panel and the new algorithm in the upper panel. The two plots are generated from exactly the same set of "raw" TOGA observations reported from the WWLLN receiving stations, but the new algorithm leads to ~63% more lightning locations.

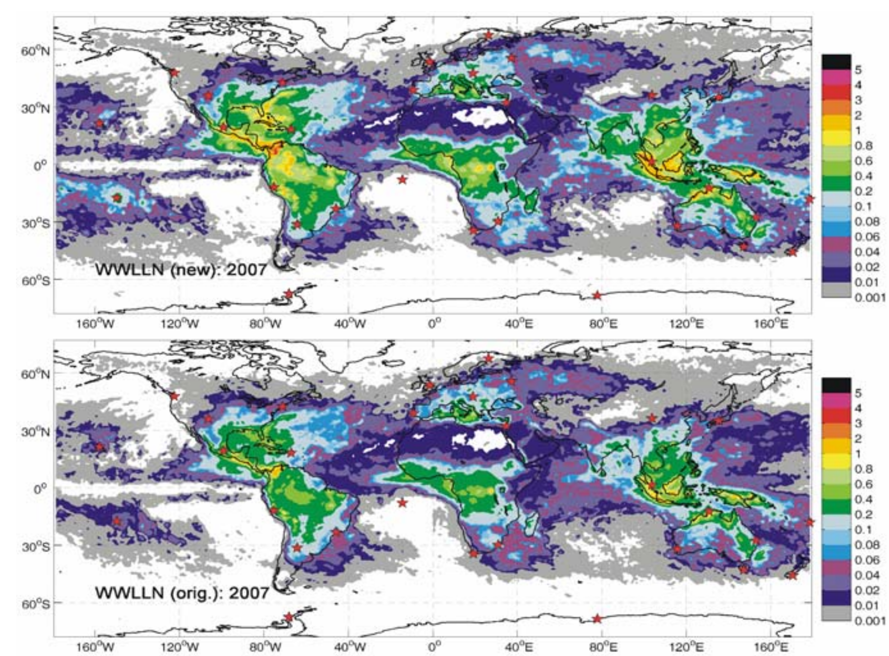

FIGURE 3. Contrast between the results of the new (upper) and original (lower) location algorithm for 2007. Stations in the WWLLN are shown as stars. The maps have units of strikes km^{-2} yr^{-1}.

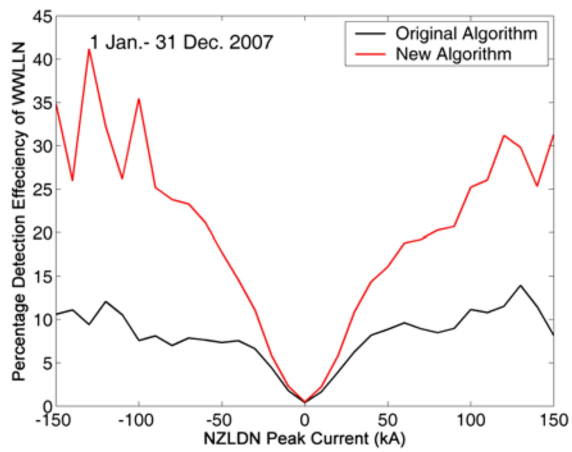

FIGURE 4. Variation in the WWLLN CG stroke detection efficiency with NZLDN determined return stroke peak current for the old and new algorithms.

Previous studies have emphasized that the WWLLN is strongly biased towards higher peak current lightning [e.g., 2,5]. To further illustrate the improvements from the new algorithm, we contrast the WWLLN locations against those reported by the New Zealand Lightning Detection Network (NZLDN). Here we are basically following the approach of our earlier study [5], except that we now limit the locations to those reported within 300 km of any of the 10 NZLDN stations, to ensure that NZLDN has near 100% DE for CGs. Figure 4 shows the variation in the WWLLN CG stroke DE against NZLDN-determined return stroke peak current with 10 kA bins. This approach was first taken in the comparison of lightning observations between the Los Alamos Sferic Array and the WWLLN [2], and also produced a "bathtub" curve. In the NZ region, the new algorithm leads to DE which are ~3 times higher for large peak current lightning, emphasizing that there will be regional differences in the DE-improvements, as the global improvement is ~63% rather than ~100% as was found on comparison with NZLDN. These differences require further analysis.

It has also been shown how "Monte Carlo" modeling can be used to estimate the location accuracy of the WWLLN [4], producing estimates which show reasonable agreement with the regional comparisons. The WWLLN location accuracy varies

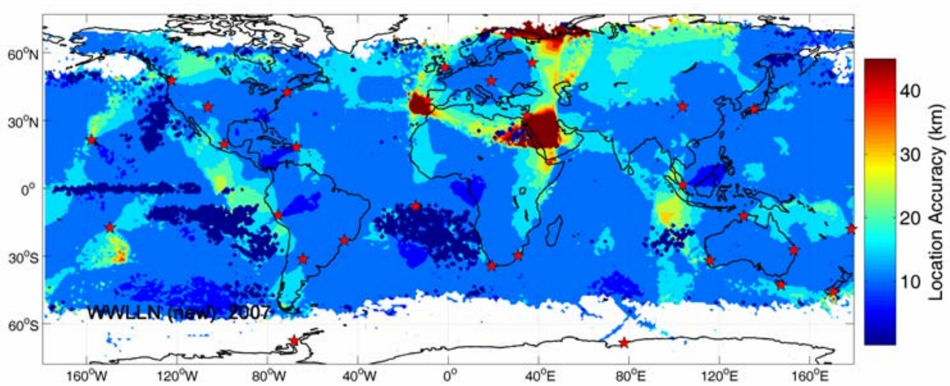

FIGURE 5. Estimate of the global location accuracy of the new algorithm location data for the WWLLN in 2007, following the analysis of the 2007 NZLDN CGs.

globally, both due to network geometry and also on the number of stations typically involved in lightning locations for any given point on the Earth [4, Fig. 8]. Figure 5 shows the estimated global location accuracy of the WWLLN for the 2007 locations provided by the new algorithm using a representative Gaussian timing error of ~30 μs. Here the comparison with NZLDN CGs has been used to provide a regional "ground-truth", and the mean number of stations contributing to the location have been used to weight the Monte Carlo simulations to produce a representative estimate for each 1º lat./long. bin.

SUMMARY

Since 2003, increasing the number of stations in the WWLLN has led to steady improvements in the total number of lightning locations, with strong improvements in global coverage. Increasing station numbers have roughly doubled the number of locations. Recent improvements in the algorithm through which the WWLLN observations are combined to produce lightning locations have also improved the detection efficiency of the network, by 63%. The existing WWLLN real-time lightning locations, presented at *wwlln.net* are now processed with the new algorithm. The historic TOGA observations reported by the WWLLN stations are now being re-processed with the new algorithm such that an improved WWLLN database will be available for global lightning from 10 August 2004 onwards.

ACKNOWLEDGMENTS

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