Correlating fractional hop whistlers detected on DEMETER with WWLLN lightning

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Abstract. It is well known that the number of lightning strokes at a particular location far exceeds the number of whistlers detected at the conjugate point. Correlation analyses between global lightning and whistlers have revealed that it is possible for the initiating lightning stroke to be a significant distance from the conjugate point. This study aims to further explore this result. Whistlers are frequently observed at Tihany, Hungary, which is magnetically conjugate to a point off the east coast of South Africa.Using broadband VLF data from the DEMETER satellite and lightning data from WWLLN, we have computed the regions which produce lightning capable of launching whistler mode waves into the magnetosphere above the conjugate point. DEMETER is a satellite in a quasi Sun-synchronous, low earth orbit which suffers from timing inaccuracies. Due to these inaccuracies, we have calibrated the data using data from the South African Lightning Detection Network.

1. Introduction

Whistlers are a very interesting Very Low Frequency (VLF) emission which have their origin in lightning. A lightning stroke in one hemisphere can result in a whistler being received in the conjugate hemisphere. Their generation mechanism was first described in [1]. This general idea of how whistlers are generated has remained as the accepted truth even until now, nearly 60 years later. This theory predicts that a lightning stroke will produce a whistler at the geomagnetic conjugate point of the lightning stroke. This hypothesis was supported by the findings of [2], who showed that the amplitude of up going fractional hop whistlers detected at Low Earth Orbit (LEO) drops off as the initiating lightning strokes are further from the footprint of the satellite. It was further tested by [3], who performed a correlation between global lightning data, and whistlers received at Tihany, Hungary. What they found was that the there was a significantly high correlation over the conjugate point of Tihany, which is just off the south-east coast of South Africa, as well as central Africa. But rather unexpectedly, other regions of high correlation were also found, over South America and the Maritime continent.

VLF waves can travel substantial distances in the wave-guide formed between the surface of the Earth and the Ionosphere [4]. Thus, the results of [3] does not specify what path the whistlers which are initiated by distant lightning have taken to Tihany. For instance, the sferic could have propagated subionospherically to Tihany's conjugate point, before undergoing the magnetospheric leg of the journey to Tihany. Alternatively, the sferic could have been launched straight up, undergoing magnetospheric travel to the conjugate point of the source region, and from there the whistler travels subionospherically to Tihany. The findings of [2], as well as the orientation of the trapping cone (see [5], Figure 3-31) show that the latter of these two situations is most likely. This work aims to address this issue, by correlating global lightning data from the World Wide Lightning Location Network (WWLLN) system, to upward propagating fractional hop whistlers detected by the DEMETER satellite near Tihany's conjugate point.

2. Methodology

The DEMETER satellite sits in a sun-synchronous LEO, meaning that it passes over the same region at approximately the same two times, each separated by 12 hours, every day. We have access to broadband, burst-mode, VLF data over a small region which contains Tihany's conjugate point (hereafter called the burst region). This amounts to approximately 4 minutes of data at around 08:00 UT and 20:00 UT each, every day. Our data spans two time periods, 2007/05/15 $\rightarrow$ 2007/11/24 and 2008/11/01 $\rightarrow$ 2009/03/31, with some small data gaps within these two sets. Whistler timeseries are obtained using an automatic whistler detector code, analogous to that used by the Automatic Whistler Detector [6].

Unfortunately, the clock on board the DEMETER satellite drifts during its orbit, and is only corrected by ground telemetry stations at certain times. Between these corrections, the on board clock can drift by $\sim$ 100ms. We have used the method described by [7] to correct for this timing offset, using lightning data from the South African Lightning Detection Network (SALDN), operated by the South African Weather Service (SAWS). Another benefit of doing this is that the time taken for the waves to travel through the ionosphere (which is variable depending on the ionospheric profile on a particular day) is also included in this calibration. One side effect of this process is that our analysis can only occur if these is an active lightning producing storm within the burst region.

The data analysis proceeds as follows: For every whistler, we search for lightning strokes which have occurred within 67ms, plus the calibrated delay, before the whistler. For each of these lightning strokes, we compute the difference between the time taken to propagate to the satellite's footprint and the delay between the two events. If this difference is $<$ 5ms, then we consider them to be matched. In cases where more than 1 lightning stroke is matched, we give preference to the one which is closer.

3. Results and Discussion

In Figure 1 we present the result of the correlation. The number of lightning strokes which have been matched to whistlers, in each 5° by 5° segment of the globe, are shown here. It is immediately evident that the highest number of matched strokes are in the region close to directly below the satellite, and also over central Africa. This is in agreement with the findings of [2; 3]. If we look further afield however, then other regions of high match counts are also evident, over South America and the Maritime continent (although the latter is to a much lesser extent). These distant source are a few thousand kilometers away in the case of central Africa, and $\sim$ 10000 kilometers away in the case of South America and the Maritime continent.

Two features of the data are of particular interest. The first is with regard to the reliability of the results. As discussed by [2], the amplitude of radiated sferics drops off significantly after traveling $\sim$ 2000km, and so how can one believe that we are seeing the sferics propagating from South America to South Africa (a distance $\sim$ 10000km). A simple answer is that the whistlers which are detected must indeed have a real source. If one were to count the whistlers occurring in the morning and at night, then one would see that during the night there are on average 2000 whistlers detected per day, while in the morning there are about 1000 detected per day, ie: around half. Lightning activity over South Africa is strongly diurnal, as is shown in the diurnal

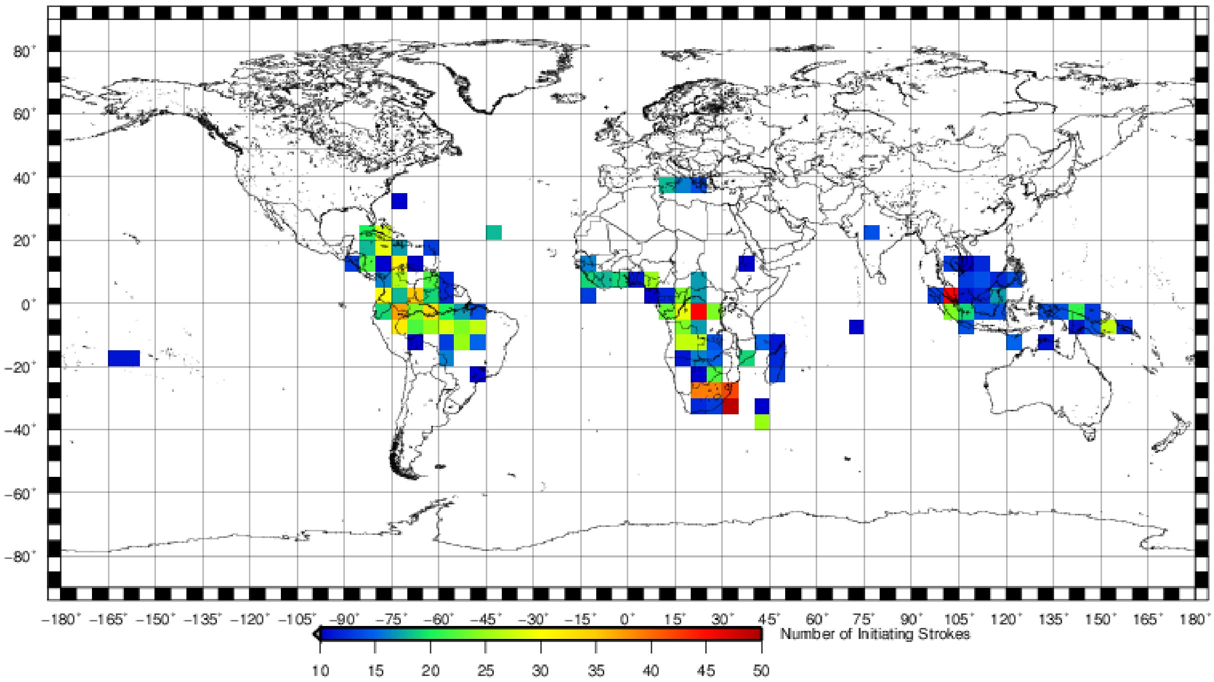

Figure 1. The global distribution of the number of lightning strokes matched to a whistler in the burst region with $5° \times 5°$ resolution.

variation plotted in Figure 2. From this one can see that at 08:00 UT there are about 4 times less lightning strokes than at 20:00 UT. This does not match up to the factor 2 difference in whistler counts, and so we can conclude that there must be an additional sferic input into the system.

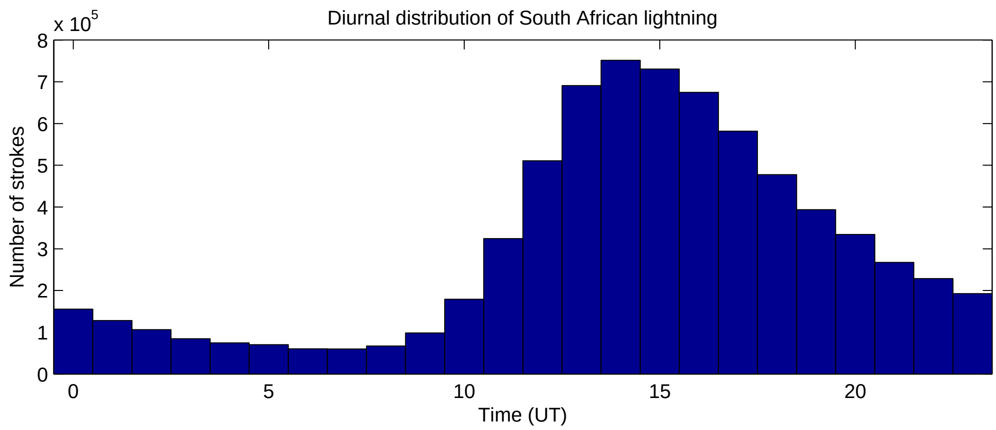

Figure 2. The diurnal variation of lightning activity in South Africa potted in UT.

The second issue is an apparent disagreement with [3], who reported that South America and the Maritime continent were source regions of comparable significance. The result in Figure 1 however shows that South America is a much more significant source for whistlers. Again, one must bear in mind that the analysis only takes place for a DEMETER half orbit for which there is an active thunderstorm over South Africa, These are predominantly at around 20:00 UT. During this time, South America is in the late evening/early night time, during which there is a peak in local lightning activity. Conversely, the Maritime continent is experiencing early morning hours, during which local lightning activity is at a minimum. This introduces the asymmetry into Figure 1. With this in mind, we can conclude that our results are in good agreement with those of [3], but that a more robust statistical test is required to confirm this statement.

4. Conclusion

We have presented correlation results between global lightning and upward propagating fractional hop whistlers detected above the conjugate point of Tihany, Hungary. Our results are in broad agreement of earlier results presented by [2; 3]. We found that the most probable source regions for these whistlers are directly beneath the satellite, but there were additional source regions found, from a few thousand kilometers (central Africa) to ten thousand kilometers (South America) away. We discussed the implications of diurnal whistler trends not agreeing with diurnal lightning activity over South Africa, and the apparent disagreement of the number of whistlers initiated by strokes in the Maritime continent and South America.

Acknowledgements

The research leading to these results has received funding from the European Communitys Seventh Framework Programme (FP7/2007-2013) under grant agreement 263218.

The author would also like to acknowledge the South African Weather Service for the SALDN lightning data provided by them.

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