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Lightning activity analyses with respect to the SPCZ location

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[1] The South Pacific Convergence Zone (SPCZ) stretches over the West Pacific warm pool Southeastward to French Polynesia. The Island Climate Update monthly publishes the mean location deduced from the total rainfall. On the other hand, the World Wide Lightning Location Network monthly provides data from which the lightning activity distribution in the 0°–30° South latitude and 150°–240° West longitude area can be drawn. Scanning this rectangle from West to East allows the spots of maximum lightning activity to be located versus the longitude. Fitting the location of these maxima with a polynomial function leads to a curve comparable with the monthly mean position of the SPCZ, showing that this band of cloudiness is one of the main sources of lightning in this whole area. **Citation:** Ortéga, P., and T. Guignes (2007), Lightning activity analyses with respect to the SPCZ location, *Geophys. Res. Lett.*, *34*, L11807, doi:10.1029/2007GL029730.

1. Introduction

[2] The global lightning activity can be related to the Earth's climate and strong connections have been put in evidence with climate parameters such as precipitation, temperature surface or upper tropospheric water vapour [*Carter and Kidder*, 1977; *Ezcurra et al.*, 2002; *Price and Federmesser*, 2006]. For instance, from the TRMM satellite data, an evident correlation between convective rainfall and lightning activity has been brought out although the relationship varies from region to region and/or season to season. Improving the understanding of these relationships may allow the lightning data to be used for forecasting purposes. In the present study we focus on the correlation between lightning activity and the position of the South Pacific Convergence Zone (SPCZ). The SPCZ has been defined as one of the most significant features of subtropical Southern Hemisphere Climate [*Kiladis et al.*, 1989; *Vincent*, 1994]. It is characterised by a band of low-level convergence which is linked, in its western part, to the Inter-Tropical Convergence Zone (ITCZ) in the West Pacific warm pool and which stretches southeastward, maintained by the interaction of the trade winds and disturbances in the mid-latitude westerlies. Its mean annual location thus extends from New-Guinea east-southeastward to French Polynesia. The location and the extension of the SPCZ vary with south Pacific climatic oscillations. *Trenberth* [1976] has shown that the location varies with the ENSO-related expansion and contraction of the western Pacific warm pool, moving northeast during El Niño events and southeast during La Niña events. *Folland et al.* [2002] have shown that the influence of the ENSO upon the SPCZ position is modulated by the Interdecadal Pacific Oscillation (IPO). The morphology of the SPCZ has first been analysed on satellite images. Reviewing the knowledge gained from various SPCZ studies, *Vincent* [1994] provides a convenient summary of the correlations between the SPCZ and the mean sea level pressure patterns, the maxima of sea surface temperatures, precipitation, cloudiness, low level convergence, the vertical motions and a minimum out-going long-wave radiation (OLR). These correlations are much pronounced in the southern summer (November–April). In their study, *Folland et al.* [2002] use the SPCZ Position Index (SPI) calculated from the difference between the mean sea-level pressures (MSLP) recorded in Suva (Fiji) and Apia (Samoa). The Island Climate Update (Sept 2005 to Sept 2006) monthly publishes the SPCZ mean location which has been identified from total rainfall and compared to the outgoing long-wave radiation anomalies. The aim of this paper is to propose an alternative to OLR, rainfall or SPI in order to study the evolution of the SPCZ location. The lightning data we use come from the World Wide Lightning Location Network (WWLLN), which is a network composed of about twenty sensors at VLF which are distributed all around the world [*Dowden et al.*, 2002]. The lightning flash locations are available on a monthly basis. The WWLL data allow us to locate the spots where the lightning activity reaches its maximum intensity as a function of the longitude in the area covered by the SPCZ. The monthly distributions of these maxima are compared with the monthly mean positions of the SPCZ. The comparison spans over one year, from September 2005 to August 2006.

2. World Wide Lightning Location Network

[3] The World Wide Lightning Location Network (WWLLN), operated by LF-EM in New Zealand partnering with the University of Washington in Seattle, is a network of lightning location sensors at VLF (3–30 kHz) [*Dowden et al.*, 2002]. The sensors (24 stations in number today, one of which is in Tahiti) are arranged all around the world and may be several thousand kilometres distant from the stroke. Long-Range VLF lightning detection can provide global coverage including remote oceanic regions. The number of stations (N_W) used for one localisation and a time-of-arrival residual Δt (up to 200 μs) are associated to each lightning location. It is suggested that only the data determined from at least $N_W = 5$ and a $\Delta t < 30$ μs are considered as high quality data. Comparing the system with another detection array (LASA), *Jacobson et al.* [2006] have led to the conclusion that the spatial accuracy of the WWLL network is around 15–20 km. This is accurate enough for synoptic locations. It is shown that the higher the current amplitude, the higher the detection efficiency. As regards current amplitudes higher than 30 kA, the detection efficiency

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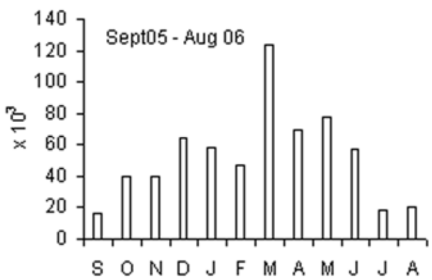

Figure 1. Annual distribution of the total amount of flashes recorded in the 0°–30°S and 150°–240°E rectangle by the WWLL network.

reaches a few percent. Therefore, the current magnitude of IC flashes being smaller than the one of CG flashes, the WWLL is statistically more sensitive to the CG flashes. The stroke locations are available monthly on a CD support. Though it underestimates the number of strokes, the WWLLN has provided a large quantity of data in the whole SPCZ area.

3. Description of the Method

[4] The area of study stretches from 0°S to 30°S in latitude and from 150°E to 240°E in longitude. This area can be referenced to an x, y coordinate system. That rectangle is sampled in X zonal and Y meridian meshes of constant size δx and δy respectively and located an x longitude and y latitude. The WWLL network can provide all the flashes detected in the whole rectangle for one month. Therefore, the number of detected flashes M(x, y) can be calculated in each mesh of the grid. For all the meshes localised at an x_i longitude (i.e. in a column), the distribution M(x_i, y) has a maximum, Ma, located at an y_i latitude. Ma(x_i) = M($x_{i,}$, y_i) is calculated using a mobile average and its standard deviation. This calculation leads to a Ma(x) spatial distribution from x = 150°E to 240°E. From the Ma(x) distribution, the best polynomial function of p degree fitting the data can be drawn and compared to the mean monthly position of SPCZ provided by the Island Climate Update.

[5] The polynomial function is representative of a band of maximum lightning activity (MLA) if the residues of the fitting remain relatively small. Furthermore, the objective being a comparison between the SPCZ position and the polynomial function, several parameters have thus to be adjusted to get acceptable residues and to optimise the correlation. First of all, the limit of the rectangle have been progressively adjusted, especially the South–North side. In the southwestern part, occasionally, a region of relatively high lightning activity induces a Ma(xi) far from the SPCZ area. The same thing is observed just south of the Equator line. As a consequence, the best area stretches from 5°S to 25°S. Secondly, the mesh size δx.δy has been increased from 0.5° to 2°, i.e. from 250 km^2 to 4000 km^2 squares. The size must be larger than the accuracy location (20 km^2) but not too large so as to be representative of the area. 1.2° × 1.2° is a good intermediate value. The number of m meshes taken into account for the calculation of the mobile average has no significant influence if it remains smaller than 5. The degree of the polynomial function does not have be definitively set but chosen within the range 2 to 5 according to the best fitting. Lastly, in many cases a large residue of the fitting polynomial function has remained inevitable because of some relatively low Ma(x) values. Those low values are often localised in the eastern part of the triangle. Therefore, to avoid this problem, a minimum value of Ma(x) has been imposed in order to reduce the residues. This threshold cannot be a constant. A function of the global amount of flashes N_{CG} monthly detected and of the size of the mesh have provided better results. That threshold is expressed as follows:

$$Th = \frac{2.N_{CG}}{X.Y} \quad (1)$$

X and Y being the number of meshes along the latitude and longitude axes respectively.

4. Results and Discussion

[6] In the present study, only data recorded from September 2005 to September 2006 have been analysed. We are aware that no definitive or reliable statistics can be deduced from only one year of data (and it is not the aim of this paper), however, they provide an interesting description of lightning activity.

[7] The WWLL network has recorded about 650,000 flashes in that region, and they are monthly distributed as is shown in Figure 1. This distribution is consistent with the SPCZ intensity since the highest precipitation rates in the SPCZ region take place in the Southern Summer (November to May, *Vincent* [1994]). Figure 2a shows the global flash distribution recorded in September 2005. Although the amount of flashes is season dependent, Figure 2a is roughly representative of the annual distribution which generally presents a diagonal structure. One can observe a band of high flash density stretching from 0–10°S southeastward, the extension length of which seems to be season dependent. In a parallel direction there appears a band of weak lightning activity stretching southeastward from 15–20°S/150°E to 30°S/185°E. Refining the description of the global structure of the flash distribution, the global flash distribution appears comparable to the description of the SPCZ location done by *Vincent* [1994] with a northwest sector zonally oriented and a diagonal portion extending from 10°S, 170°E to 30°S, 160°W.

[8] In Figure 2b are plotted the Ma(x) distributions deduced from the calculation described above and Figure 2c shows the profile of the Ma(x) values. Whatever the month of the year, the maximal flash density is nearly always located in the 5–10°S/150–160°E rectangle. Furthermore, those maxima are not highly season dependent (at least for that 13 month period). In Figure 2d, the Ma(x) distribution (without threshold) is compared to the average rainfall rate (mm/day) from TRMM for the same month. The maximum lightning activity seems to be correlated not with the maximum but with moderate rainfall rates. That comparison between rainfall and lightning activities in the south Pacific region must be the subject of further investigation.

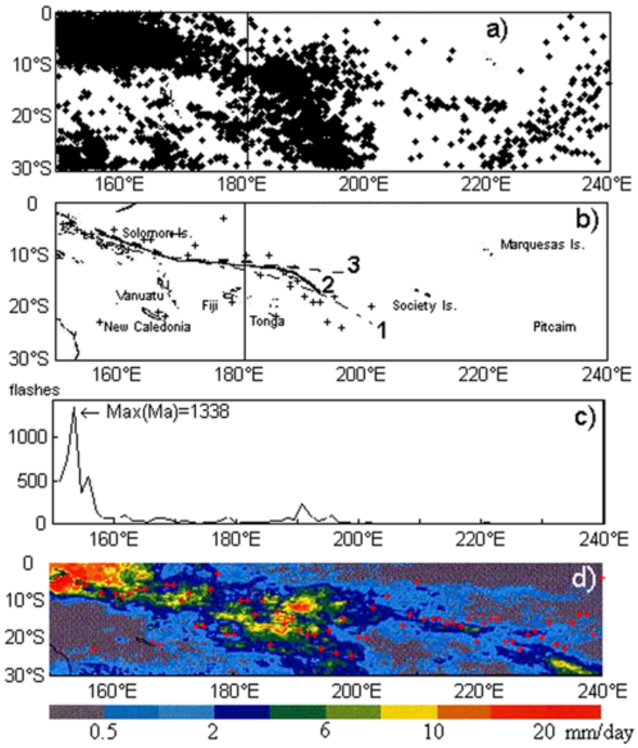

Figure 2. (a) Global flash distribution in September 2005. (b) Spatial distribution of the maximal flash density as a function of the longitude (+) in September 2005 and the corresponding fitting polynomial (1), SPCZ location in September 2005 (2), and its average position in September observed over 30 years (3). (c) Amount of maximal flashes, Ma, as a function of longitude. (d) Spatial distribution of the maximal flash density (without threshold) (+) with its polynomial regression (—) superimposed on the average rainfall rate from TRMM for September 2005 (Courtesy of the NASA/GSFC Earth Sciences (GES) Data and Information Services Center (DISC)).

[9] The Island Climate Update publishes the position of the SPCZ identified from the total rainfall recorded every month. Furthermore, for the 12 months of the year, average positions on the basis of available 1971–2000 rainfall data have been calculated. Therefore, the SPCZ position, its average position and the Ma(x) distribution are plotted in the same graph and compared to one another. From September 2005 to September 2006 a general conclusion about the correlation between SPCZ positions and Ma distributions cannot be expressed. Two behaviours have to be distinguished. In the first instance, the SPCZ position and its average position are similar. That occurs over 5 months, preferably in the southern winter period. Secondly, regarding the remaining 8 months, the SPCZ position is clearly different from its average position. Figure 2b shows the results of September 2005 which correspond to the first instance. The Ma(x) distribution is also represented by a Pa(x) polynomial function (degree 3). As described above, the polynomial only fits the Ma(x) values that are greater than the threshold (equation (1)). This is why Pa(x) stops at x = 202°E. It can be seen that the three curves are very close to one another. A good correlation between Pa(x) and the SPCZ position is always observed in that first instance. As to the second instance, two cases can be distinguished. In Figure 3 (top) (October 2005), Pa(x) is close to the monthly position whereas in Figure 3 (middle) (November), Pa(x) is close to the average position. In the first case (October) the departure between the monthly and the average positions of the SPCZ is due to a negative anomaly of rainfall in the area of the SPCZ average position whereas in November the departure is due to a positive anomaly out of the SPCZ average position. That second case is more frequent and Pa(x) always remains close to the average position. In that second instance, the threshold of Equation1 allows the eastern limit of the polynomial to coincide with the eastern limit of the SPCZ. Lastly, another scenario must be analysed where no correlation between Pa(x) and neither the average position nor the monthly position is observed. This occurs when a marked double ITCZ occurs, one lying south of the Equator from the Date Line eastwards to South America. This usually occurs during the La Nina phase in the austral autumn [*Mullan*, 2006]. Figure 3 (bottom) (March 2006) shows that Pa(x) is strongly diverted to the ITCZ area.

[10] Another example of a comparison can be made by observing the lightning activity evolution in the same month over several years. Since the WWLLN has provided data from September 2003 up to nowadays, we can compare the evolution of the band of maximum lightning activity over four consecutive December months (2003 to 2006). This is shown in Figure 4 with the average position of the SPCZ (dotted line) in December (Island Climate Update). In 2003 and 2005 the band of MLA lies South of the SPCZ position. In return, the MLA band crosses the SPCZ line on its Northern side and develops farther eastward. In December 2003 and 2005 the Tropical Pacific Ocean was described to be in a neutral state (Island Climate Update n° 40 and 64) with a Southern Oscillation Index equal to 0.9 and −0.1 respectively. This Index was −0.9 and −0.5 in December 2004 and 2005, the Tropical Pacific Ocean being in a weak El Niño state. Folland et al. have shown that the SPCZ tends to move north-east in the El Niño phase.

[11] Notice that on the eastern side, over the four December months, the Polynomial function starts far from the SPCZ position because of a high lightning activity close to the Eastern Australian coast.

5. Conclusion

[12] Even if the present analysis is limited to 13 months, a correlation between the SPCZ position and the maximal lightning activity can be inferred. The average position of the distribution of the maximal lightning activity can be described by a polynomial. The correlation can be optimised by the choice of the size of the mesh grid and the definition of the limits of the rectangle. A threshold of the total amount of flashes can be expressed in order to estimate the eastern limit of the SPCZ position. A quick analysis shows that the correlation seems to disappear when strong positive rainfall anomalies are recorded and when a branch of the ITCZ lies South to the equator as is the case during the La Niña phase. The present analysis shows that the western part of the South Pacific is a region of high lightning activity and, more than a correlation with the SPCZ position, relationships with the rainfall rates could be

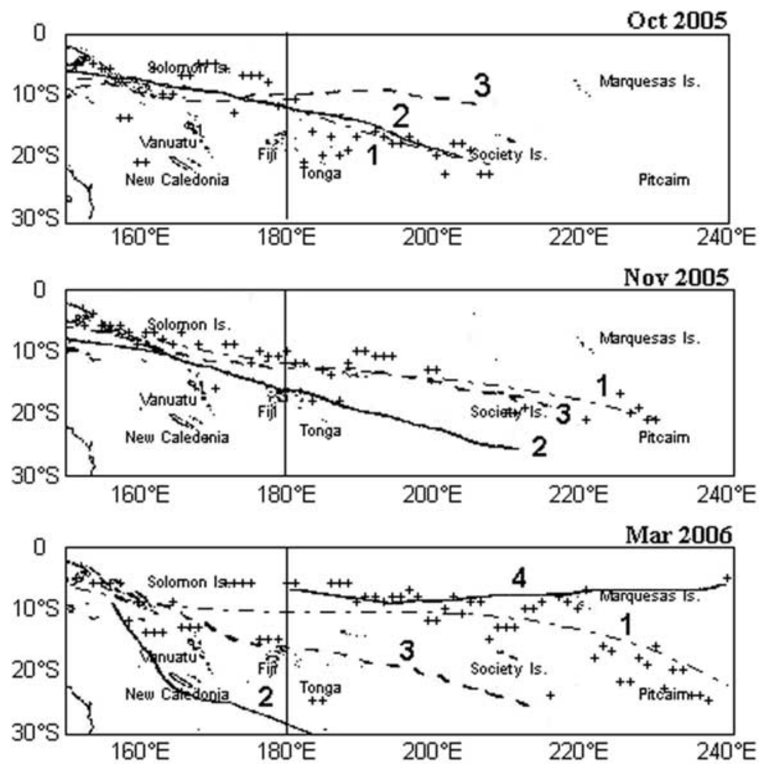

Figure 3. Spatial distribution of the maximal flash density as a function of the longitude (+) with the corresponding fitting polynomial (1), the SPCZ location of the month (2) and its average position (3), and the ITCZ position (4) (in Figure 3, bottom, only).

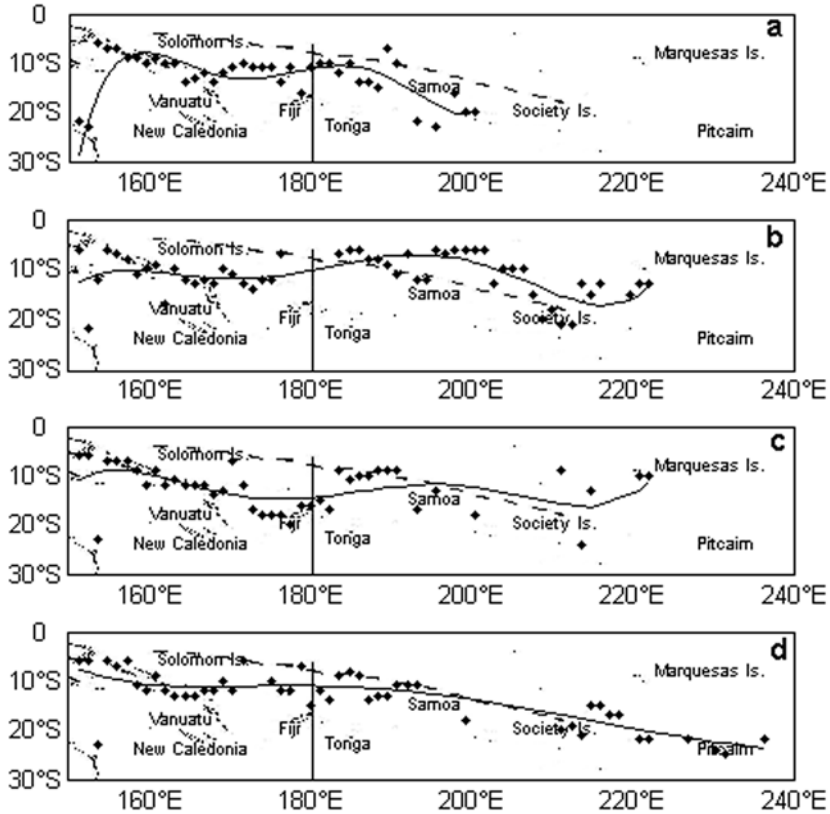

Figure 4. Spatial distribution of the maximal flash density as a function of the longitude (+) with the corresponding fitting polynomial (line) and the December average SPCZ position in (a) December 2003, (b) December 2004, (c) December 2005, and (d) December 2006.

put in evidence in future investigations. The lightning activity in specific locations could be used as a supplementary proxy.

[13] **Acknowledgments.** Special thanks to V. Laurent at Météofrance for enlightening discussions and to the Project Director of the Island Climate Update for permission to use the graphs. The data relative to the SPCZ positions come from The Island Climate Update n° 62 to 72.

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