Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2016-380-AC3, 2017

Atmospheric Measurement Techniques Discussions

Interactive comment on "Lightning Data Analysis of the CMA Network in China" *by* Feng Li et al.

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Received and published: 29 August 2017

First of all, thank you very much for the comments. We have revised some content in manuscript according to the comments. The followings are point-by-point replies to the comments. In order to distinguish, our replies and modifications are used in red text.

Comment1: "From a technical perspective, the detection of lightning mainly depends on the base-line of stations and the threshold to define a lightning event. The analysis of spatial lightning distribution only makes sense when the resolution of detection efficiencies is homogeneous, i.e. the baseline of sensors and threshold are similar. There is no description of how lightning events are detected and extracted and there is no detailed description of the algorithm for the four presented methods. In addition, the distribution of sensors is not homogeneous and some regions are much denser than other areas, and there is also no station in Tibet. I think these missing elements should be included in the discussion."

PS: Thank you for reviewer comments. Q(1): Indeed, as reviewer say, the analysis of lightning data must be based on the homogeneous of the detection network and detector, i.e. threshold is similar. CMA LDN uses a unified model detector ADTD, to achieve homogeneous of sensor and threshold. Because the network inhomogeneous densities or inhomogeneous distribution of sensors, we use an automatic selection strategy for lightning location algorithms. For example, in the Tibetan Plateau and the surrounding site sparse area, the system can choose the "two station" algorithm, as long as a lightning weak signal can be received by two sensors, the lightning is detected and can be positioned. In the plains, more detectors involved in the detection and location, the system can choose "three station" or "four station" algorithms, which has higher accuracy. According to the lightning detection principle, different baseline may cause the difference in detection efficiency, but the strategy has been reduced the error to a minimum, under realistic conditions, this way is the most practical and reliable.

Q (2): This manuscript has introduced CMA LDN distribution and constructer, "2.2 Lightning Location Method"give lightning location method description, and we add detector ADTD information in introduction section. We think we have described how lightning was detected and extracted. Sorry, we don't know what else need to be added? Whether we need to give the working principle of the lightning detector in this manuscript? We don't think this is the focus of this job.

Q(3): Four lightning location algorithms are introduced in section "2.2 Lightning Location Method", and their more detailed description have been published in the literature "principles and techniques of lightning detectionïijĹMa. 2015ïijĽ". There are too many content descriptions and formulas about four algorithms, which is not suitable for detailed description in this article. If you are interested, you can refer to the literature (Ma,Q.M 2015). We have added literature information in references part. Below we will provide some reference content, see Figure 1-3). The main purpose of this paper is to analyze the application of these algorithms in the National Lightning network and the application of lightning data. And to evaluate the improvement of operation capability of lightning network by algorithms usage frequency variation. The algorithm itself is not the focus of this article.

Q(4): These discuss have been added in Summary and Conclusions (line 315-327) and other part (line 142-143).

(fig1-3 are Lightning location and current algorithms reference book and some algorithms examples)

Comment 2: The LF and VLF radio signal of CG lightning can propagate over a thousand kilometers or more. The baseline of this network is only 170 km. In my opinion, it should be possible to use more than 4 sensors to determine lightning locations. This reviewer finds it confusing that the authors still use M1, M2 and M4 as they also confirm that using more stations results in better locations in this paper. Further, there is a large section discussing the use of these four methods (Section 2.2), but it is unclear what the scientific meaning of the method 'usage frequency' is. I propose the authors clarify why these methods are used and what the scientific reason of comparing them is.

PS: This is a good question. Reviewer wondered what's purposes and scientific reasons for analysis and comparison of lightning location algorithms 'using frequency' in this manuscripts As we all know, the quality of the lightning detection network depends on the efficiency and accuracy of the lightning location. However, it is very difficult to confirm the efficiency and accuracy of lightning location. It is generally accepted that both the hybrid method and the multi-station method are better than the two-station method, the magnetic direction method and the amplitude method in the positioning efficiency and accuracy. Furthermore, the more sensors are involved in the localization algorithm, the more accurate the location is. However, by 2013, our multi-station positioning algorithm was most applied to the 4 sensors, and more than 4 sensors have not been applied to the multi-station positioning algorithm. Therefore, the multi-station method mentioned in this paper is the four station method. Due to the geographical conditions, the number of base stations and network layout, CMA lightning network cannot be all unified use multi-station positioning algorithm. Our strategy is to automatically select the location algorithm in the business software based on the number of detectors detected by one of the lightning signals. From the point of view of spatial distribution, where the higher the frequency of mult-station method is, the more reasonable the base station is, the higher the quality of lightning data. From the point of view of time variation, the higher frequency is selected by the multi-station method, the higher the detection ability of the whole lightning network, and the higher the quality of the lightning data, andÂăviceÂăversa. The above is the scientific reason and purpose of analyzing and comparing the frequency of using the lightning location algorithm in this paper. This also is a method to evaluate the performance of CMA lightning detection network in this manuscript.

Comment 3: Some results in this paper, such as, that thunderstorms normally occur in the summer and that positive lightning is easier to trigger in winter thunderstorms, were presented before [e.g. Rakov, V. A., and M. A. Uman, 2003, Chapter 2 5). The results in this paper provide a description of the literature but don't present novel results. Overall, I would highly recommend that the authors include further analysis to produce more substantial evidence. For example, the correlation between lightning occurrences and some meteorological and climate information, the spatial distribution of positive lightning, because positive lightning normally occurs close to tall objects or close to objects of moderate height located on mountain tops.

QS: That's a very good suggestion. Study on Lightning climatology, scholars including China scholars, has done a lot of analysis, including the relationship between lightning and ground temperature, water vapor, aerosol concentration, weather system and geographical conditions, also reveals the characteristics and causes of lightning climate change. According to the suggestion of reviewers, we add analysis on the correlation

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between China's lightning changes and air temperature, atmospheric troposphere layer height and atmospheric water content, and to reveals the reasons for its abnormal climatology (line 213-233). According to reviewer suggestions, we analyzed the spatial distribution and changes of positive lightning in winter and summer. Winter (December as a representative,fig.5), positive lightning mainly distribute in southern Anhui, northern Jiangxi, North Central Guangxi, Yunnan and Western Xinjiang, these areas are basically mountainous, above 1500 meters above sea level. And summer (especially in June,fig4), positive lightning widely distribute in China's central and eastern regions, whether plain or mountain. According to the location of lightning, further statistics (fig6) shows that winter positive lightning is the most prone to in the 1000-2000 meters height mountains, accounted for 42.4The above content has been added to the manuscript (line 294-311), please review.

Fig.7-1-2 Positive lightning spatial distribution in Jun (left)and Dec (right)

Fig7-3 Positive lightning vertical distribution proportion with altitude in winter and summer

Comment 4: The newly added content about lightning current is brilliant. I would like to suggest to add some description about the lightning current calculation algorithm rather than just providing a result. PS: Thank you very much for your suggestion. Because the lightning current algorithm is also more complex, it will take too much space to describe here. The scope of this article mainly analyzes the lightning data of China, we does not want to involve more lightning detection technology. Lightning current algorithm has been published, if you are interested, the specific content can refer to reference (Ma, Q.M, 2015).

Below is an overview of the algorithms. Lightning current formula: (sorry, formula is missing here, formula please see PDF file) , This is a fitting formula, used of artificial lightning and lightning positioning system synchronous observation, obtained two sets of independent observation data, and then the two sets of data fitting. Among them, SNF expressed signal normalization factor. RNSS represents normalized to 100Km signal strength, and SS represents the original electric or magnetic field signal strength. In CMA LDN ADTD lightning positioning system, β is set to 1 (assuming the only signal measured is the radiation field), λ is set to infinity, SNF=0.392. RNSS' is averaging the normalized signal intensity RNSS of all station.

Thanks again for the reviewer's comments and suggestion.

Please also note the supplement to this comment:
https://www.atmos-meas-tech-discuss.net/amt-2016-380/amt-2016-380-AC3-supplement.pdf

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Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2016-380, 2017.

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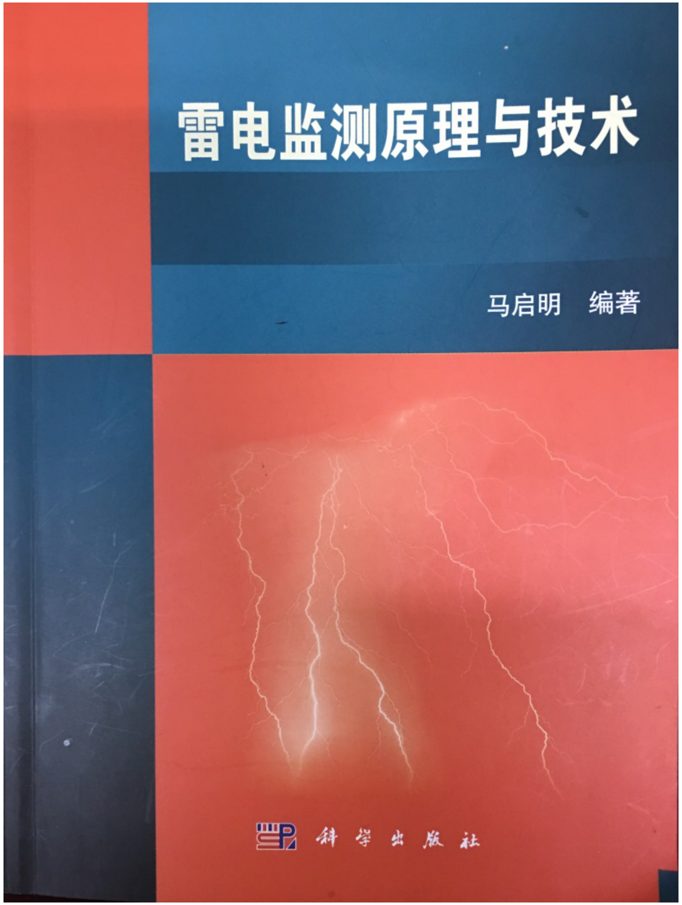

Fig. 1. Lightning location and current algorithms reference book

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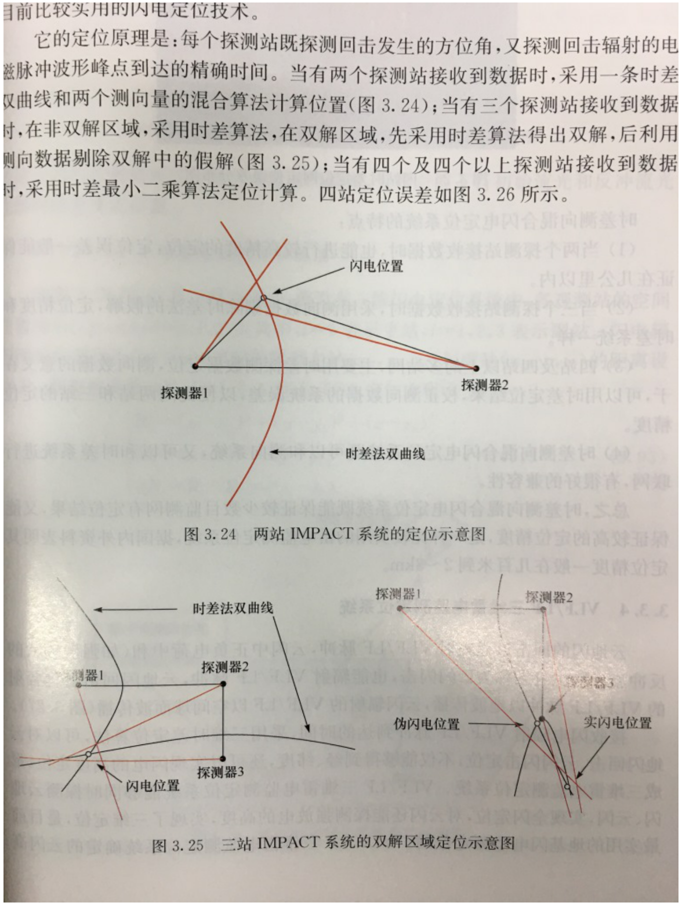
目前比较实用的闪电定位技术。

它的定位原理是：每个探测站既探测回击发生的方位角，又探测回击辐射的电磁脉冲波形峰点到达的精确时间。当有两个探测站接收到数据时，采用一条时差双曲线和两个测向量的混合算法计算位置(图 3.24)；当有三个探测站接收到数据时，在非双解区域，采用时差算法，在双解区域，先采用时差算法得出双解，后利用测向数据剔除双解中的假解(图 3.25)；当有四个及四个以上探测站接收到数据时，采用时差最小二乘算法定位计算。四站定位误差如图 3.26 所示。

图 3.24　两站 IMPACT 系统的定位示意图

图 3.25　三站 IMPACT 系统的双解区域定位示意图

Fig. 2. location algorithms examples printscreen

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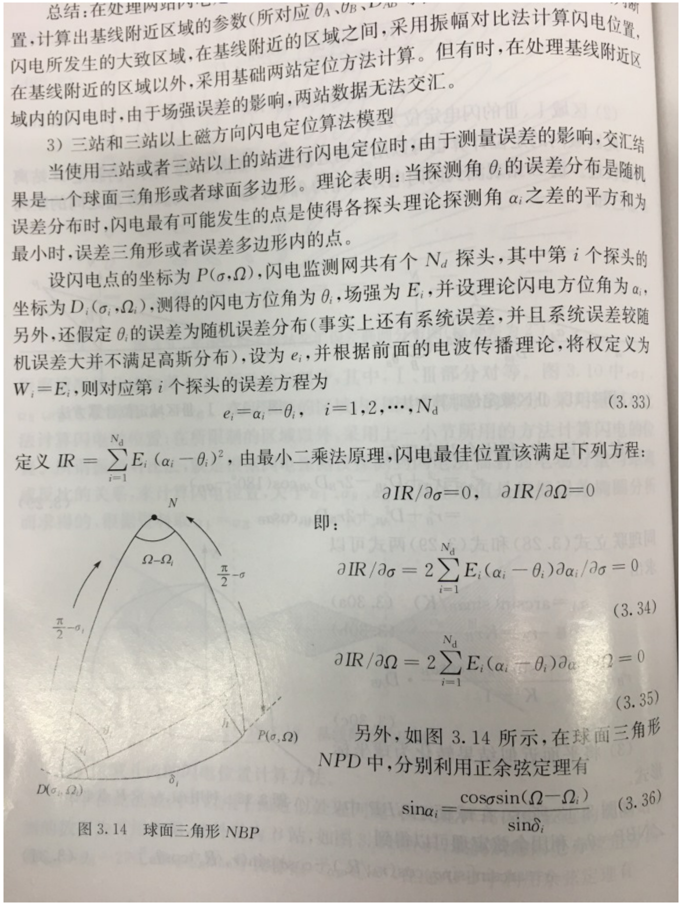

总结：在处理两站闪电定……

置，计算出基线附近区域的参数（所对应 θ_A、θ_B、D_{AB}……），采用振幅对比法计算闪电位置，

闪电所发生的大致区域，在基线附近的区域之间，采用基础两站定位方法计算。但有时，在处理基线附近区

在基线附近的区域以外，采用基础两站定位方法计算。两站数据无法交汇。

域内的闪电时，由于场强误差的影响，两站数据无法交汇。

3）三站和三站以上磁方向闪电定位算法模型

当使用三站或者三站以上的站进行闪电定位时，由于测量误差的影响，交汇结果是一个球面三角形或者球面多边形。理论表明：当探测角 θ_i 的误差分布是随机误差分布时，闪电最有可能发生的点是使得各探头理论探测角 α_i 之差的平方和为最小时，误差三角形或者误差多边形内的点。

设闪电点的坐标为 $P(\sigma,\Omega)$，闪电监测网共有个 N_d 探头，其中第 i 个探头的坐标为 $D_i(\sigma_i,\Omega_i)$，测得的闪电方位角为 θ_i，场强为 E_i，并设理论闪电方位角为 α_i，另外，还假定 θ_i 的误差为随机误差分布（事实上还有系统误差，并且系统误差较随机误差大并不满足高斯分布），设为 e_i，并根据前面的电波传播理论，将权定义为 $W_i=E_i$，则对应第 i 个探头的误差方程为

$$e_i=\alpha_i-\theta_i,\quad i=1,2,\cdots,N_d \tag{3.33}$$

定义 $IR=\sum_{i=1}^{N_d}E_i(\alpha_i-\theta_i)^2$，由最小二乘法原理，闪电最佳位置该满足下列方程：

$$\partial IR/\partial\sigma=0,\quad \partial IR/\partial\Omega=0$$

即：

$$\partial IR/\partial\sigma=2\sum_{i=1}^{N_d}E_i(\alpha_i-\theta_i)\partial\alpha_i/\partial\sigma=0 \tag{3.34}$$

$$\partial IR/\partial\Omega=2\sum_{i=1}^{N_d}E_i(\alpha_i-\theta_i)\partial\alpha_i/\partial\Omega=0 \tag{3.35}$$

图 3.14 球面三角形 NBP

另外，如图 3.14 所示，在球面三角形 NPD 中，分别利用正余弦定理有

$$\sin\alpha_i=\frac{\cos\sigma\sin(\Omega-\Omega_i)}{\sin\delta_i} \tag{3.36}$$

Fig. 3. location algorithms examples printscreen

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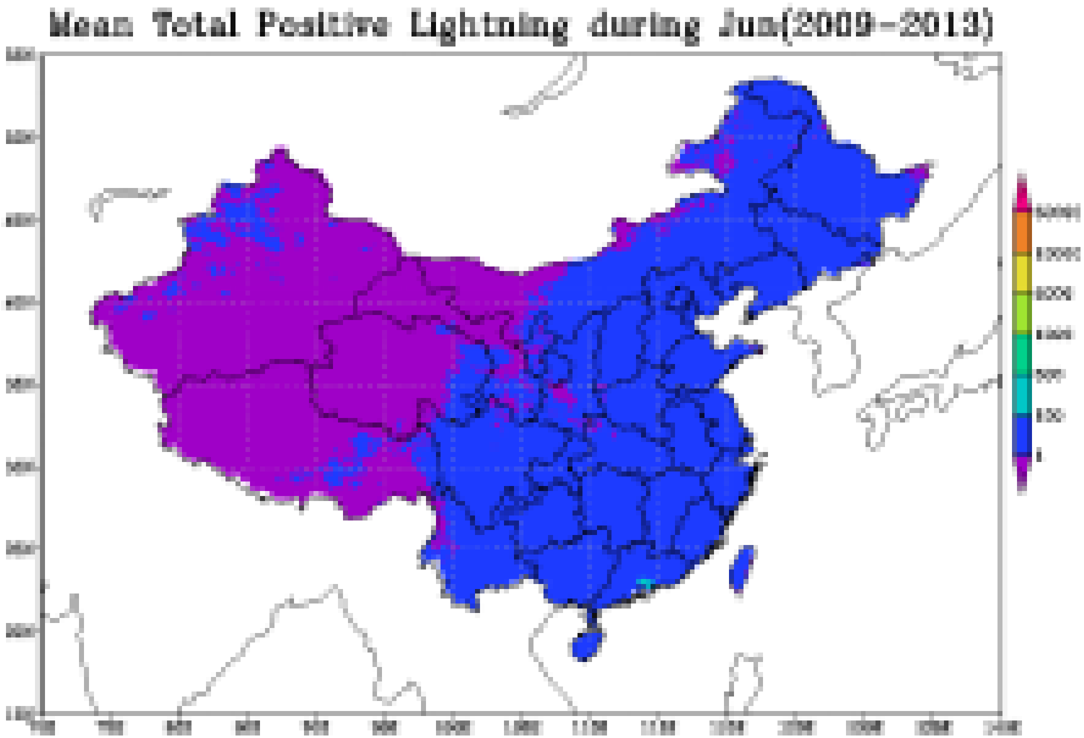

Fig. 4. Positive lightning spatial distribution in Jun

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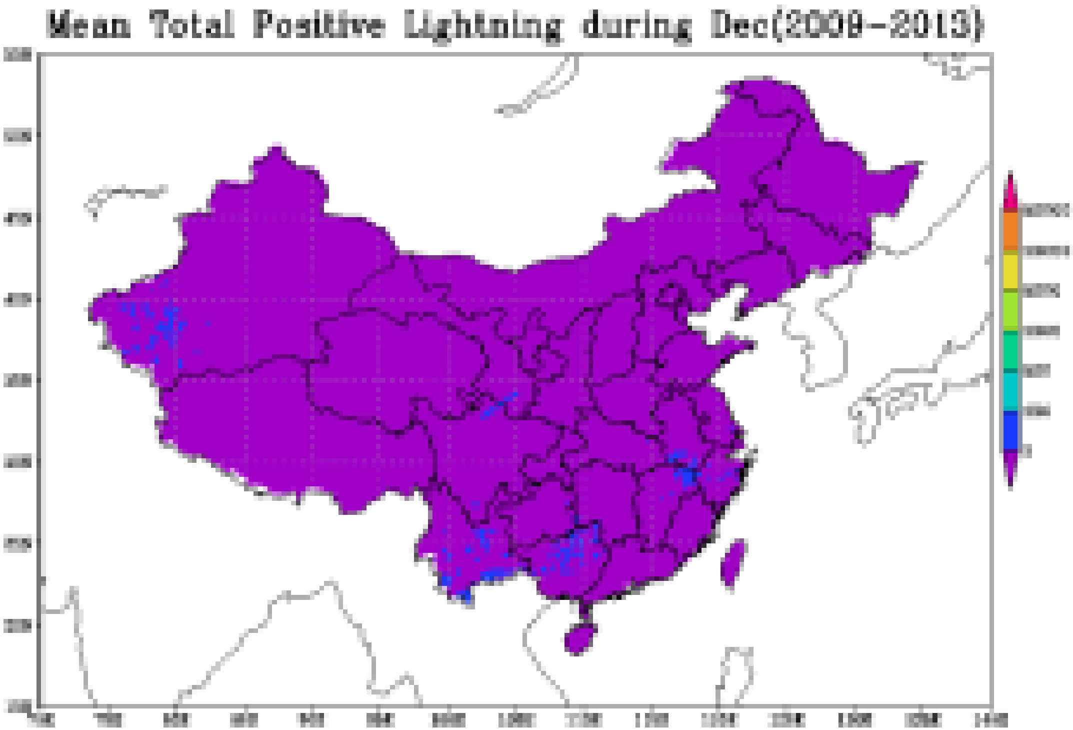

Fig. 5. Positive lightning spatial distribution in Dec

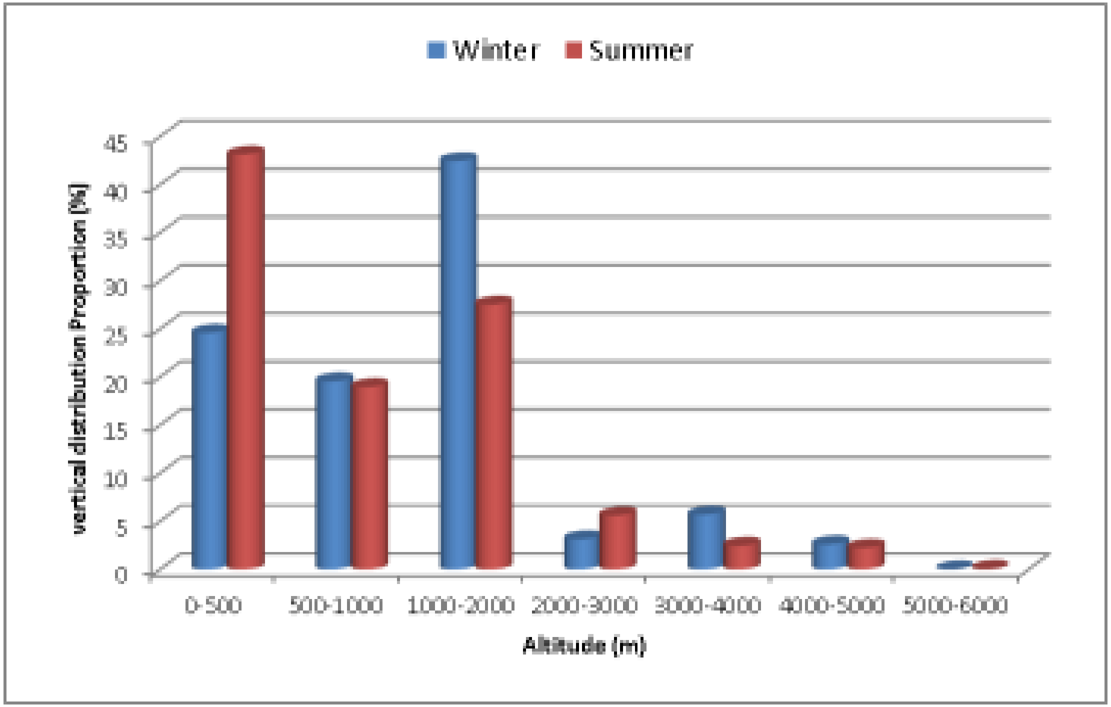

Fig. 6. Positive lightning vertical distribution proportion with altitude in winter and summer

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