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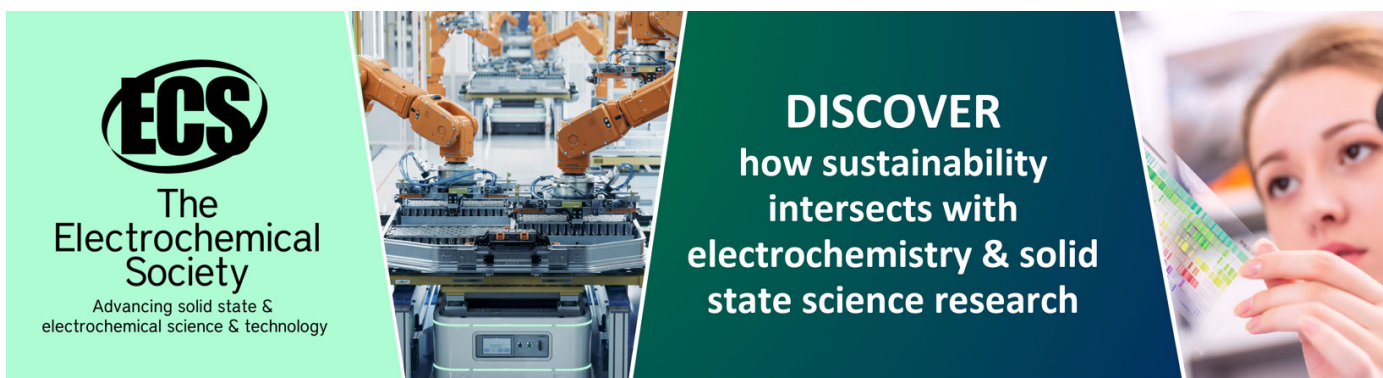
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Amazon Fire Monitoring and Analysis Based on Multi-source Remote Sensing Data

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Abstract. In August 2019, a large-scale fire broke out in the Amazon rainforest, bringing serious harm to the ecosystem and human beings. In order to accurately monitor the dynamic change of forest fire in Amazon rainforest and analyse the impact of fire spreading and extinction on the environment, firstly, based on NPP VIIRS data covering the Amazon fire area, the sliding window threshold method is adopted to extract the fire point, and the cause of fire change is monitored and analysed according to the time series. Secondly, based on the time series of CALIPSO data, the vertical distribution changes of atmospheric pollutants in the amazon fire area are analysed, and the comprehensive analysis is carried out by combining NPP VIIRS data. The experimental results show that only NPP VIIRS data is used to predict the fire, and the combination of CALIPSO data can better monitor the forest fire and predict the fire development trend. The combination of optical image and laser radar has greater advantages in dynamic fire monitoring and fire impact analysis. The method described in this paper can provide basic data reference for real-time and accurate prediction of forest fires and provide new ideas for dynamic fire monitoring.

1. Research background

Forest fire is a serious natural disaster, which not only damages forest resources, but also endangers human life and property. It has a noticeable impact on the ecosystem and is one of the main sources of air pollution. Accurate monitoring of forest fires and effective prediction of fire spreading trends are especially important for decision-making of forest fire fighting, protection of forest resources and maintenance of ecological balance.

At present, there have been related researches on forest fire monitoring and prediction based on remote sensing technology in domestic and foreign literatures. The commonly used methods for monitoring forest fires by remote sensing include brightness temperature threshold method, correlation method and fuel mask method. However, most of the research mainly uses single sensor data to carry out algorithm research and improvement for specific research areas. In 1978, Benson et al. [1] carried out supervised and unsupervised classification training through LANDSAT MSS data to realize temperate forest fire monitoring, which is the first application of optical remote sensing image in this field. After that, Domenikiotis et al. [2, 3] realized the fire point extraction by threshold method using NOAA/AVHRR data. In 1999 and 2002, NASA successively launched Terra and Aqua satellites.



MODIS sensors carried on them have higher temporal and spatial resolution, providing an important data source for the application of remote sensing in forest fire monitoring [4, 5]. Wang Caiyun et al [6, 7] realized fire point extraction of AVHRR and MODIS data by threshold method respectively. The results show that MODIS data with high spatial resolution has better extraction effect. Mark Wang et al [8, 9] compared the fire point extraction accuracy of storm riders satellite (FY-3A)VIRR with AVHRR and MODIS under the same algorithm. Experimental cases show that VIRR is more suitable for fire point extraction, FY-3A provides a new way for business and scientific researchers to monitor forest fires. Liu Shuchao and others [10] based on GF-1 data, extracted the fire zone boundary and fire zone area through visual interpretation and sub-supervised classification. In view of the fact that the existing fire detection algorithm is easy to miss detection of low temperature fire, Zhang yanfeng et al [11] analyzed the application of MODIS aerosol optical thickness (AOD) products in forest fire detection. the experimental results show that AOD has certain advantages in comprehensive analysis of forest fire monitoring. When forest fires occur, a single optical sensor is limited by revisit period, spectral range, spatial-temporal resolution and other factors, which often results in large deviation, resulting in certain limitations of the above research in practical application. Zhu Qingzhe and others [12] combined MODIS and CALIPSO data to analyze the impact of Russian forest fire smoke on air quality in Central Asia and northern China, showing that there is a strong correlation between air pollutants and forest fires. With the transmission and diffusion of aerosol in the atmosphere, air pollution is not only limited to the birthplace of forest fires, but also has a certain impact on a wide range of ecosystems. At the same time, it also shows the advantages of combined analysis of optical images and lidar data.

Amazon rainforest is located in the Amazon basin of South America, with a total area of 5.5 million square kilometers, accounting for half of the total area of the world rainforest. In August 2019, fires frequently occurred in the Amazon rainforest, with more than 72,000 fires as of the 18th, an increase of 83% over the same period in 2018 [13]. The Amazon rainforest has not seen sustained severe dry weather this year, and fires are mostly caused by human activities. In order to expand the area of land used for grazing or farming, people continue to cut down the rainforest and clean up the site by burning tree trunks, branches, leaves, etc. These activities have led to the spread of fires to areas that have not been cut down, and the burning range involves many countries and cities in South America. Brazil's National Space Research Institute (INPE) said: From 15th to 20th of this month alone, satellites detected more than 9,500 forest fires, most of which occurred in Amazonia. Until the 23rd, Brazilian President Bosonaro signed an executive order to send troops to deal with the fire, so the scale of the Amazon forest fire began to gradually decrease, and it has continued to burn for more than 20 days [14]. In 2019, the Amazon forest fire is the fire that has the greatest impact on the global ecosystem in recent years. Based on the optical image NPP VIIRS and lidar CALIPSO data, this paper realizes the fire point extraction and vertical distribution analysis of atmospheric pollutants, accurately carries out continuous tracking and monitoring of the fire, provides effective prediction and evaluation of forest fires, and further provides scientific basis for disaster prevention and mitigation decision-making, which is of great significance.

2. Principle of Fire Point Extraction

Threshold method is widely used in the fire point extraction algorithm of NPP VIIRS data. This paper chooses the method to extract fire points from Amazon rainforest fire data. NPP data M13 (medium wave infrared) and M15 (long wave infrared, or thermal infrared) are mainly used. The specific information is as follows:

Table 1. NPP data partial band information

Band	Center wavelength/ μm	wavelength coverage/ μm	Spatial resolution/m	Band properties	Application range
M13	4.05	3.97~4.13	750	Mid-infrared	Ocean temperature, fire
M15	10.763	10.26~11.26	750	Thermal infrared	Ocean temperature

Using threshold method to extract fire point from NPP VIIRS data, the accuracy of product depends on the selection of threshold. In this paper, according to the algorithm flow adopted by NPP, the adaptive thresholds are calculated in the unit of sliding window. The pixels larger than the threshold are divided into fire point data, and the pixels smaller than the threshold are divided into non fire point data. The size of the sliding window is closely related to the accuracy of fire point extraction. When the window value is too small and the fire point distribution is dense, the threshold value will be too large and some fire points will be missed; when the window value is too large and the fire point distribution is relatively scattered, the threshold value will be too small and the background pixel will be mistakenly identified as fire point. In the experiment, the sliding window size mainly depends on the NPP official experience value and subjective choice. The process is as follows [15]:

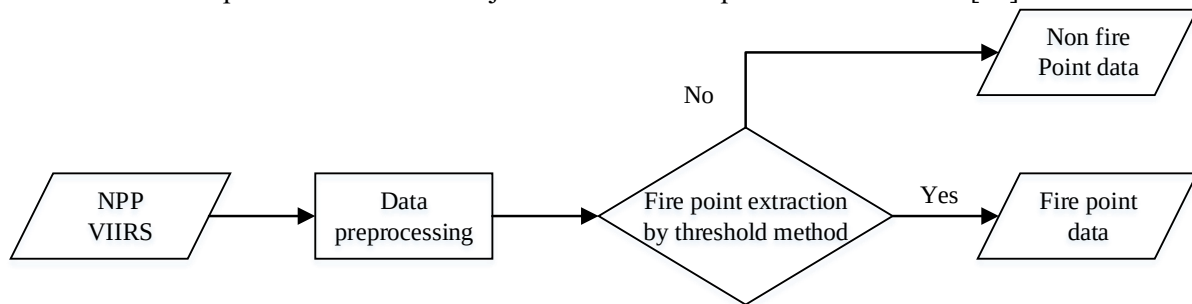


Figure 1. flow chart of fire point extraction

Firstly, the input NPP data is preprocessed, which mainly includes the steps of radiation brightness temperature conversion, geometric correction, cloud detection, etc. Secondly, the fire extraction threshold in the sliding window is calculated, and the pixels satisfying the conditions are output as fire data. Wherein, the radiation bright temperature threshold value for judging the fire point is calculated by the following formula:

$$T_{13} > T_{13b} + 4\delta T_{13b} \quad (1)$$

$$\Delta T > \Delta T_b + 4\delta \Delta T_b \quad (2)$$

Where, T_{13} represents the radiant brightness temperature value of the current pixel in M13 band; ΔT represents the radiant bright temperature difference between M13 and M15 bands of the current pixel; T_{13b} is the average value of the background pixel M13 band radiant brightness temperature; ΔT_b is the average value of bright temperature difference values of background pixels M13 and M15 bands; δT_{13b} is the standard deviation of the background pixel M13 band radiant brightness temperature; $\delta \Delta T_b$ is the standard deviation of the bright temperature difference values of background pixels M13 and M15 bands.

3. Experimental results and analysis

3.1. Fire extraction based on NPP VIIRS data

Suomi NPP is a preparatory project for the cancelled National Polar-or-Biting Operational Environmental Satellite System (NPOESS) program in the United States. The full name is the Suomi

National Polar-Orbiting Partnership, designed and manufactured by NASA for NOAA. VIIRS is one of the five sensors carried by Suomi-Npp satellite, all of which are called visible infrared imaging radiometer suite (VIIRS). VIIRS sensors have 22 bands, 9 visible and near infrared bands, 12 mid-infrared and far infrared bands, and a DNB (Day/Night Band) band. Each pixel is quantized with 12 bit and the total data rate is 10.5 Mbps. It can be used to measure cloud cover and aerosol characteristics, ocean water color, ocean and land surface temperature, sea ice movement and temperature, fire, and earth albedo, etc.

As shown in the following figure, the monitoring results of fire points in Amazon forest area at different stages are based on the night observation data in the infrared band of VIIRS. The selected area is located between 34 46' W-81 20' W, 5 28' Nn-36 20' S. Figure 2 and Figure 3 show the nighttime timing observation and daytime timing observation of the fire point of Amazon forest fire respectively, where (a), (b) and (c) correspond to August 1, August 6 and August 15, 2019 respectively; (d), (e) and (f) correspond to 20 August, 25 August and 30 August 2019 respectively; (j), (h) and (i) correspond to September 1st, September 6th and September 10th, 2019 respectively. In addition, Table 2 shows the extraction quantity of night and day fire spots in Amazon forest.

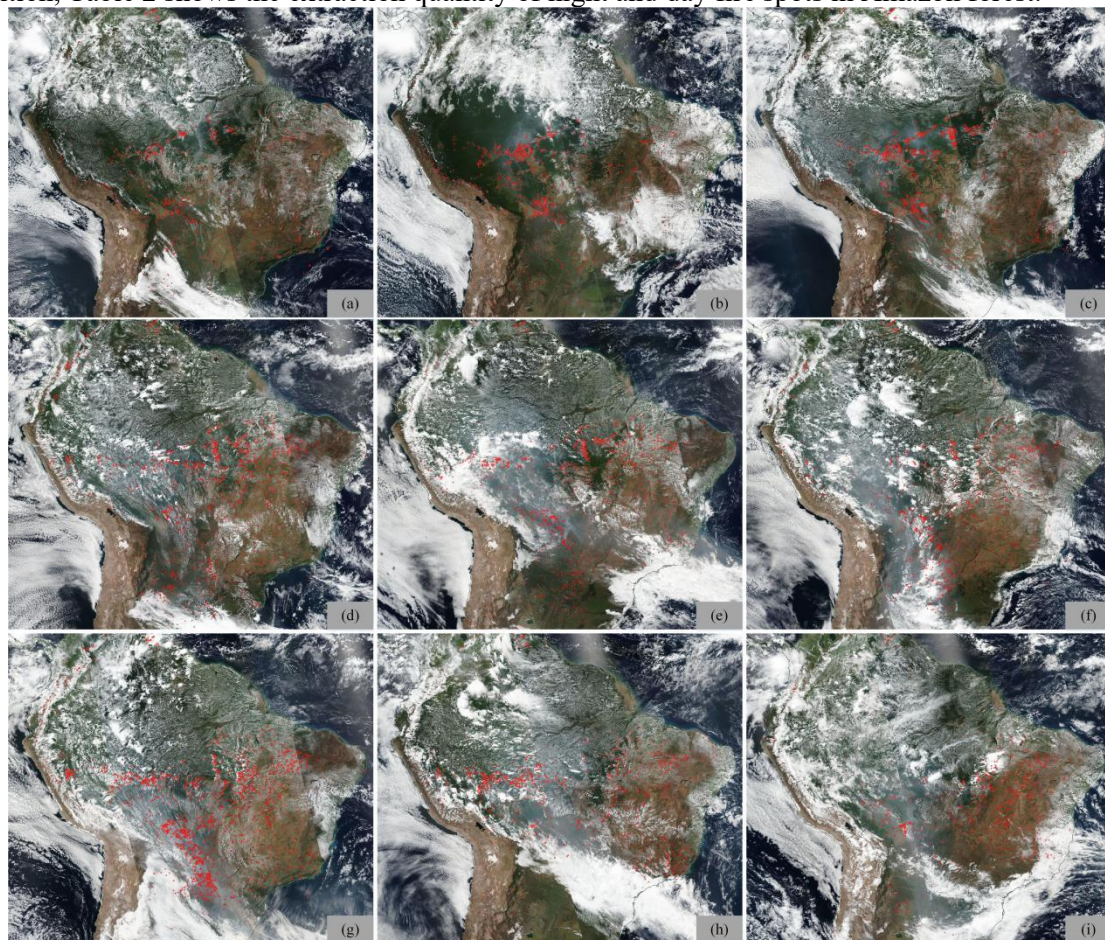


Figure 2. Night Time Series Observation of Amazon Forest Fire

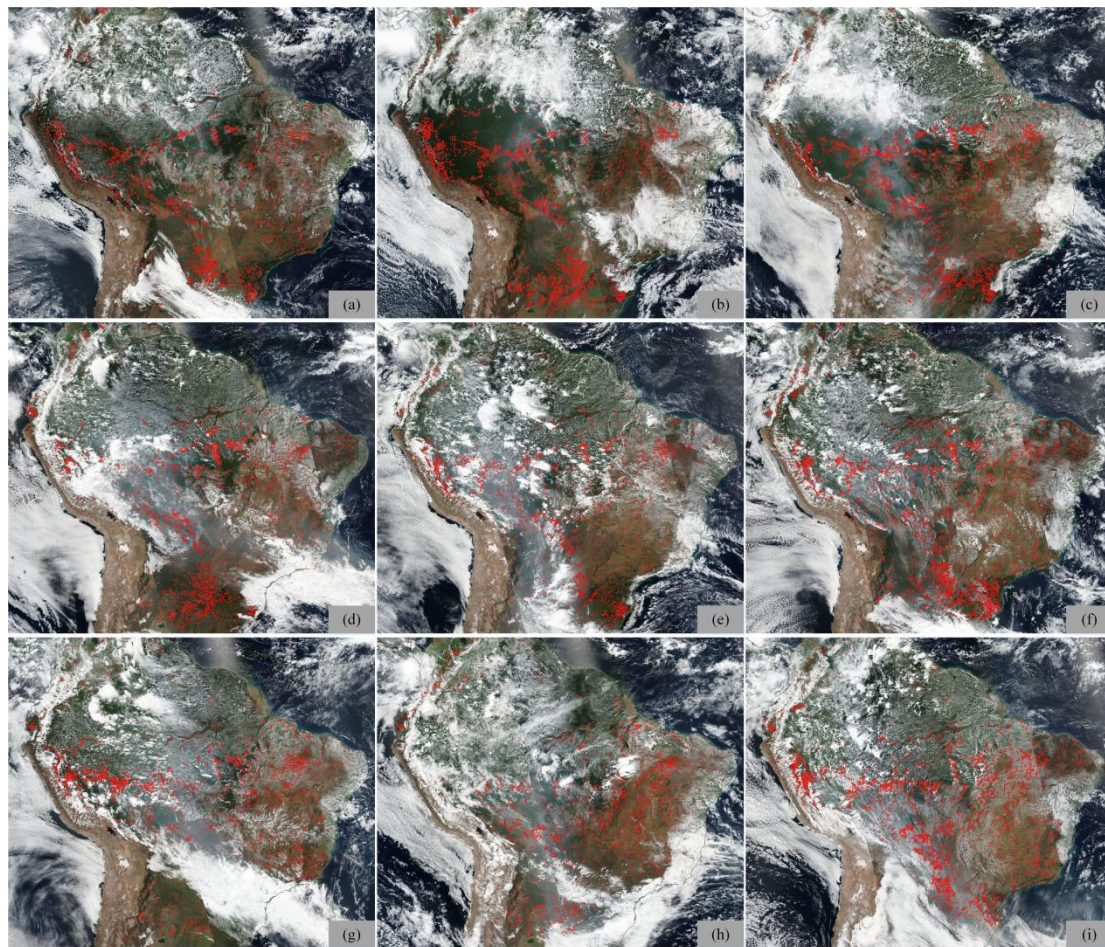


Figure 3. Day Time Series Observation of Amazon Forest Fire

Table 2. Number of Fire Points Extracted from Amazon Forest Fire

Date	2019.0801		2019.0806		2019.0815	
Number of fire points	night	9472	night	9161	night	12029
	day	26394	day	21381	day	22508
Date	2019.0820		2019.0825		2019.0830	
Number of fire points	night	12637	night	13443	night	18189
	day	27156	day	32758	day	49434
Date	2019.0901		2019.0906		2019.0910	
Number of fire points	night	15745	night	10108	night	19005
	day	30904	day	52009	day	40242

As shown in Figure 4, it is the variation curve of the number of fire spots extracted from Amazon rainforest area. It can be seen from the figure that: (1) the number of daytime NPP data fire points is much higher than that of nighttime NPP data fire points, which is about 2 times; (2) From August 5th to August 30th, the two kinds of data showed a relatively obvious upward trend, while the number of fire spots in September began to show a downward trend in varying degrees. Since June 1998, the Brazilian National Space Institute (Instituto Nacional de Pesquisas Espaciais, INPE) has started to make monthly statistics on forest fires in Brazil, and the Amazon rainforest is also under observation. Statistics show that forest fires occur all the time in the vast area of the rainforest. The lowest record was in April 1999, when there were 70 fires. The highest record was in September 2007, when there were over 73,000 fires. Every July, dry season enters all parts of South America, which is the peak

frequency of forest fires. It usually reaches its peak in September and greatly reduces in October due to various factors such as excessive logging and artificial forest burning along with the rain. In August 2019, the number of fire spots in the Amazon rainforest region increased intensively, even with the highest frequency in September. At 8: 00 p.m. on August 23th, the Brazilian president signed an executive order to send troops to deal with the fire. Starting on the 24th, the Brazilian Ministry of defense deployed 44,000 soldiers in the Amazon region to help put out the forest fire. However, as can be seen from the figure, this move had little effect until August 30th, when the fire was effectively controlled and the number of fire points began to drop significantly in September.

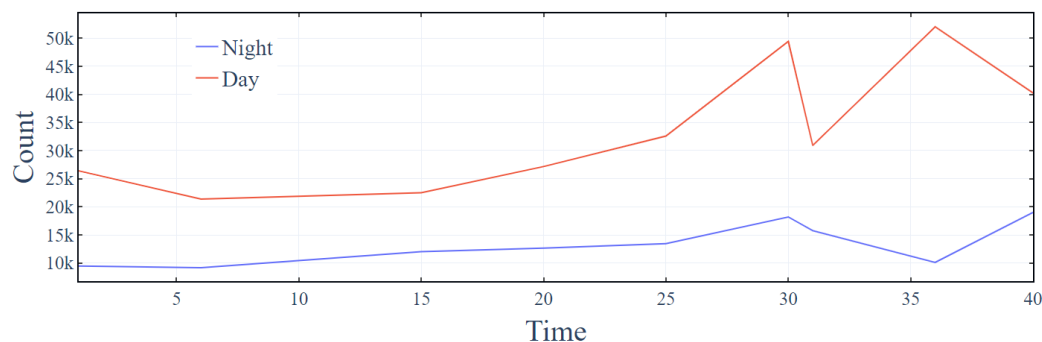


Figure 4. Analysis on the Change Trend of Fire Points in Amazon Rainforest

As shown in the figure, the images taken by unmanned aerial vehicles in the Amazon rainforest fire area on August 23th and 24th originated from Brazil's GreenPeace media. It can be seen that the fire caused irreparable damage. The Amazon rainforest is called the "lung of the earth", but its role in carbon sequestration is more important than oxygen supply. The tropical rain forest covers an area of 5.3 million square kilometers and is an important link in the carbon cycle in the world. It has 17% of the global carbon storage in terrestrial vegetation and has more carbon sequestration than other terrestrial ecosystems [16, 17]. Experts pointed out that unlike natural fires in grasslands and forests, fires in humid Amazon rainforests are mostly caused by human beings. In order to occupy more land for grazing or farming, people cut down the rainforest and clean up the site by burning tree trunks, branches, leaves, etc. The ashes left by burning vegetation can become nourishment for the land. Experts believe that only excessive deforestation can explain this phenomenon. According to data from Brazil's National Space Research Institute, in July 2019, 2,254 square kilometers of Amazon rainforest were cut down, up 278% year on year.



Figure 5. Images of Amazon Rainforest Fire Taken by Unmanned Aerial Vehicles

3.2. Forest fire analysis based on CALIPSO data

In the previous section, the fire point data in NPP VIIRS were extracted by threshold method, and more accurate results were obtained. However, in the process of fire fighting, the regional temperature may still be above the threshold value of fire point extraction, which has certain interference to the fire. Therefore, this section is further analyzed in combination with the meteorological lidar observation satellite CALIPSO. Although the rate and relative composition of air pollutants released by different fires are quite different, there is a certain correlation between the total amount and growth trend of air pollutants and the fire scale [18]. On April 28th, 2006, the United States launched the Cloud-Aerosol Lidar and Infrastructured Pathfinder Satellite Observation (CALIPSO) satellite, which is one of the five

constellations of NASA's A-Train program. CALIOP lidar uses 1064nm and 532nm dual wavelengths and has polarization detection capability at 532nm. It mainly observes the vertical distribution of clouds and aerosols, the ice/water state of clouds (through polarization channels) and aerosol size classification [19]. In this section, Level1 extinction backscatter data and Level2 Verticle Feature Mask data (VFM) are used.

As shown in the figure, 532nm backscatter data, color ratio data, and depolarization ratio data are sequentially displayed from left to right. The reason for choosing these data is that the time and scope of data acquisition are close to the fire point dense area, which can reflect the true vertical distribution of the atmosphere during the fire to the greatest extent. The depolarization ratio, is the ratio of 532nm vertical backscatter intensity to 532nm horizontal signal backscatter intensity, which reflects the irregularity of the measured particles. The color ratio is the ratio of 1064nm backscatter intensity to 532nm total backscatter intensity, which reflects the size of the measured particles. The larger the color ratio is, the larger the particle radius is.

On August 3rd, from the backscatter data, there were only some thin clouds and aerosol particles at altitudes of 3 and 7km above sea level. Judging from the depolarization ratio data, the distribution of particles in the atmosphere is relatively regular when the altitude is below 8km. Judging from the color ratio data, there are obviously particles such as soot with larger effective particle radius below the altitude of 4km, that is, below the concentration of thin clouds and aerosol particles. According to the information of fire spots extracted in the previous section, the number of fire spots began to increase gradually around August 3rd. Smoke dust, carbide and irregular particles caused by the fire gradually accumulated and caused great pollution to the atmospheric environment.

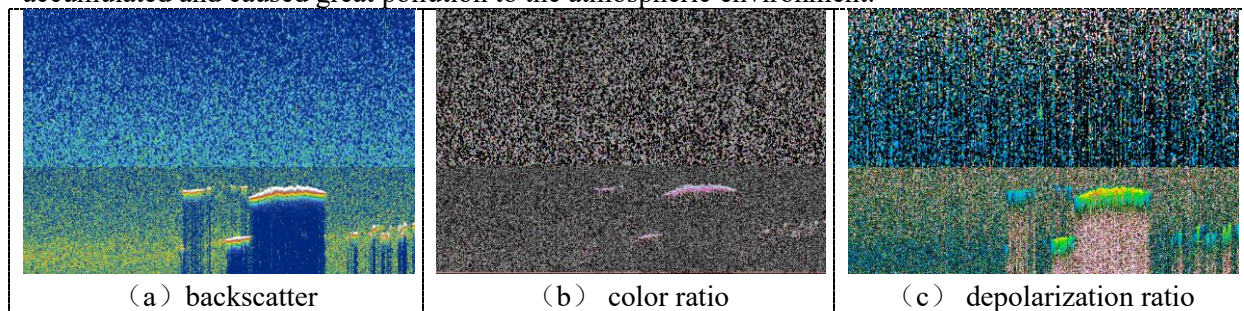


Figure 6. Dynamic monitoring of CALIPSO on August 3rd

On August 15th, from the backscatter data, there were thick clouds and aerosol particles in the altitude range of 14-15km, and there were thin clouds and aerosols in the altitude range of about 1km. Judging from experience, smoke dust with higher density may gather in this range. Judging from the depolarization ratio data, the distribution of particles in the atmosphere is relatively regular below the altitude of 14km. Judging from the color ratio data, there are a large number of soot and other particles with large effective particle radius. Compared with August 6th, the pollution is more serious.

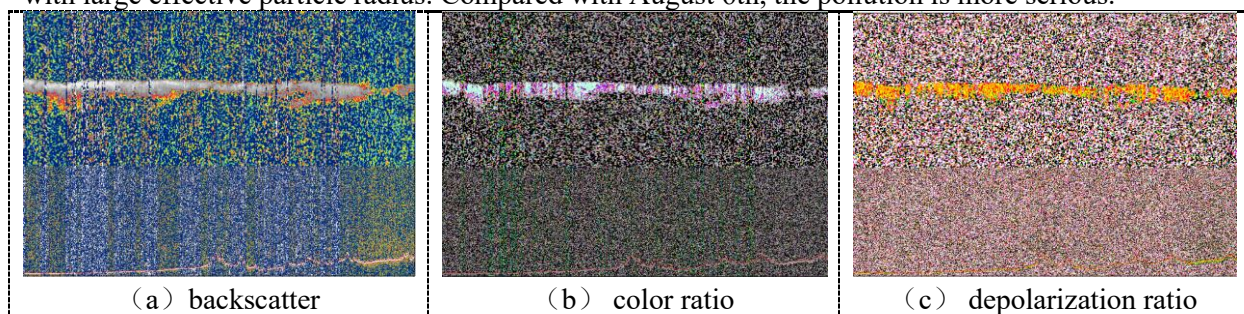


Figure 7. Dynamic monitoring of CALIPSO on August 15th

On August 30th, from the backscatter data, there were thick clouds and aerosol particles in the altitude range of 9-14km. Judging from the depolarization ratio data, the distribution of particles in the atmosphere is relatively regular below the altitude of 8km. Judging from the color ratio data, there are

obviously particles such as soot with larger effective particle radius below the altitude of 8km, that is, below the concentration of cloud and aerosol particles. Compared with August 25th, pollution has slightly increased.

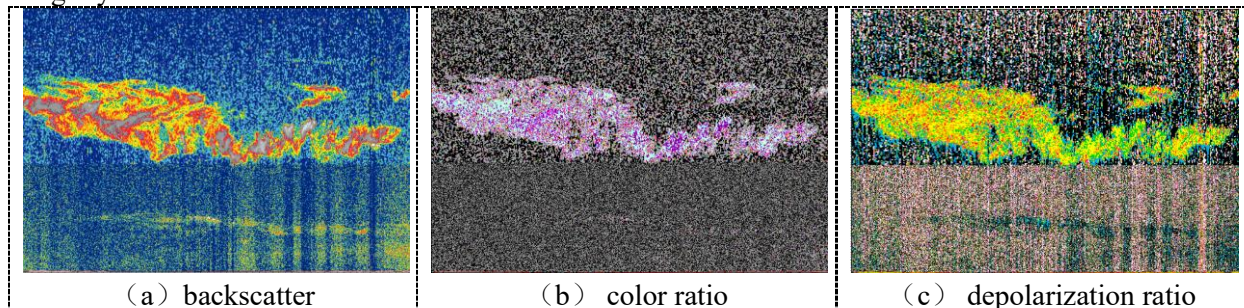


Figure 8. Dynamic monitoring of CALIPSO on August 30th

In order to quantitatively analyze the vertical distribution of air pollutants caused by fire, the impact and trend are analyzed based on the CALIPSO Level2 VFM data. VFM data divides signals into Clear Air, Aerosol, Cloud, Smoke and Dust, and No Signal according to backscatter data. The following figure is a statistical histogram of the percentage of each component in the total detection of CALIPSO on that day in August. Its overall trend is consistent with the NPP fire point extraction trend and shows an overall upward trend. However, there is some oscillation in the rising process, which may be due to the following reasons: (1) CALIPSO detection is the profile data of the orbital region, while NPP detection is the surface data, and CALIPSO data is not comprehensive for the detection of the experimental region; (2) the acquisition of CALIPSO data is different from place to place at the same time, and there is a certain chance. The detected profile data cannot represent the whole experimental area. Despite the above-mentioned shortcomings of the CALIPSO, CALIPSO has incomparable advantages in atmospheric vertical distribution detection. For atmospheric composition, aerosols, clouds and the like often appear on a scale of ten kilometers or even tens of kilometers, which enables the CALIPSO data to provide high-precision data support for small-scale regional atmospheric vertical distribution.

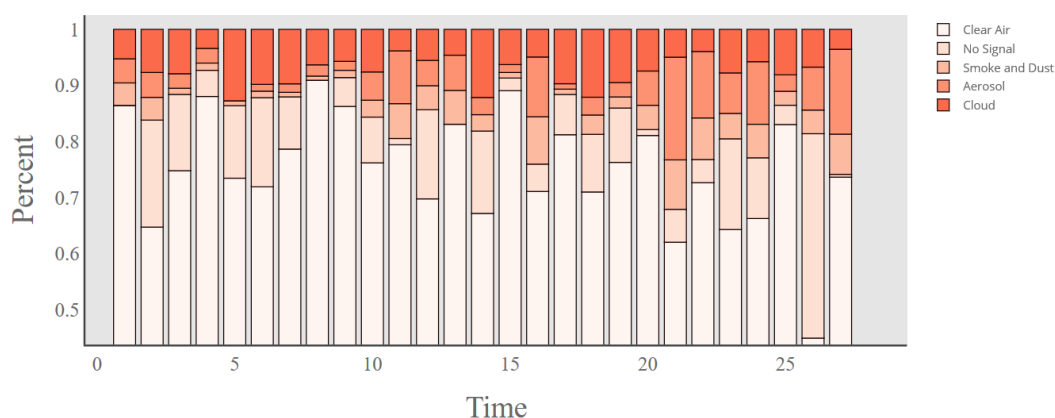


Figure 9. Statistical Distribution of Atmospheric Composition in Amazon Rainforest Region in August 2019

As shown in the figure, it is an area map of atmospheric composition changes in the Amazon rainforest in August, which reflects in detail the subtle changes of each composition with time. It can be seen that aerosols, clouds, smoke and dust have relatively consistent trends. Different from the trend of the number of ignition points extracted by NPP, the CALIPSO data shows that the composition of air pollutants first decreased, then increased and then decreased in August. At the beginning of the month, there were a small amount of smoke, aerosol and a large number of clouds, which may be caused by the large-scale burning of trees in Brazil. In the process of combustion, a

large amount of smoke dust and aerosol will be generated, and water vapor at higher temperature will decrease in temperature and form clouds as it rises. This effect continued until the middle of the month. Due to human factors and meteorological conditions, air pollutants continued to increase and reached a new peak on the 22nd. After that, affected by the Brazilian President's disaster relief and the establishment of a buffer zone, the fire situation eased somewhat and air pollutants showed a certain downward trend since the 24th. However, after the 25th, the air pollutants began to rise gradually. Due to the smoke cover and other reasons, the CALIPSO laser beam could not penetrate, resulting in a wide range of No Signal.

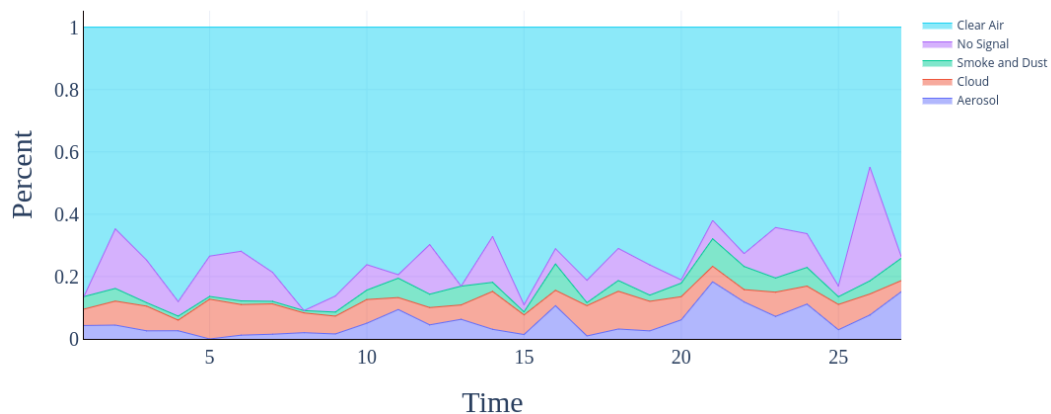


Figure 10. Statistical Distribution of Atmospheric Composition in Amazon Rainforest in August 2019

The following figure is the cross-sectional data acquired by CALIPSO in the experimental area on August 25, 2019, which are acquired from left to right. It can be seen that there is a great coincidence with the fire point data extracted by NPP, and the number of fire points is dense in places with dense clouds and smoke.

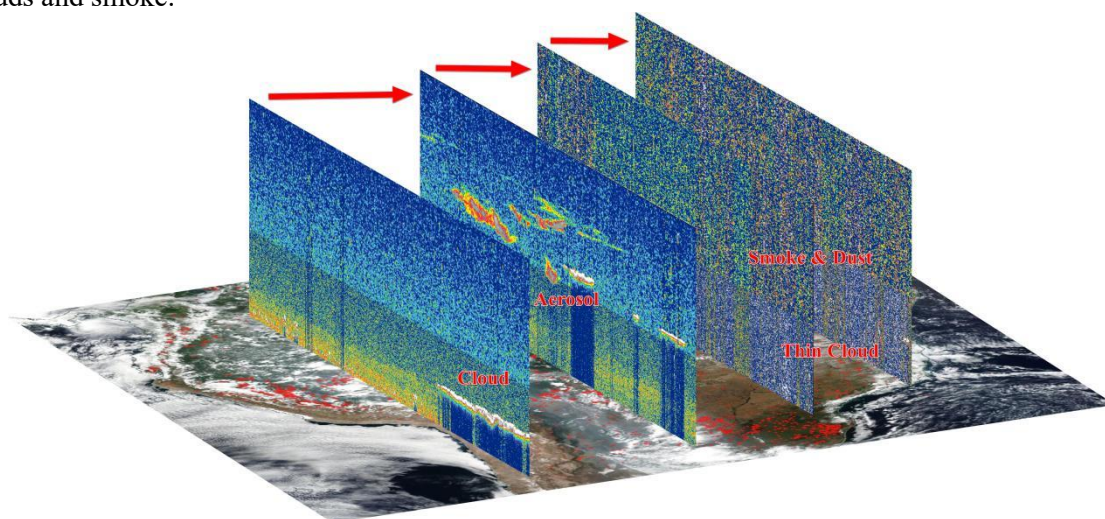


Figure 11. CALIPSO Time Series Observation on August 25th

4. Conclusion

Amazon rainforest is closely related to the global ecological environment, carbon cycle and human living environment. The Amazon fire over 20 days led by human factors has seriously affected the atmospheric environment. Based on NPP VIIRS and CALIPSO time series data, the changes in the number of fire spots and the vertical changes of atmospheric pollutants in the Amazon rainforest fire area are analyzed, which provides powerful data support for monitoring the changes in forest fire range and predicting the fire in both optical images and atmosphere. Based on multi-source remote sensing data, forest fires are monitored and analyzed, and continuous tracking and monitoring of the

fires are carried out with low cost, high efficiency, intuition and accuracy, thus providing effective prediction and evaluation of forest fires, and further providing scientific basis for disaster prevention and mitigation decision-making, which is of great significance.

The experimental results show that: (1) the fire point data extracted from NPP VIIRS data at night is more accurate than that extracted during the day; (2) There is a strong correlation between fire and air pollutants, especially with aerosols. (3) The combination of NPP VIIRS and lidar CALIPSO is more suitable for dynamic fire monitoring and fire impact analysis than single optical image results.

References

- [1] Feng B Y. 2011. Progress in remote sensing monitoring of natural fire. *J Public Communication of Science & Technology*. **14**(1) 260-261.
- [2] Domenikiotis, C., A. Loukas, and N.R. Dalezios 2003 The use of NOAA/AVHRR satellite data for monitoring and assessment of forest fires and floods *J Natural Hazards & Earth System Sciences* **3**(1/2) 115-28
- [3] Luo X X, QI Z X and Chen X D 2016 Application of S-NPP and VIIRS in the Forest Fire Monitoring. *J Geospatial Information* **14**(11) 78-81.
- [4] Liu L 2014 Study on Forest Fire Monitoring and Danger Warning Based on MODIS in Chongqing *J Chongqing Normal University*.
- [5] Liu L M and Yan J J 2004 Fire Detection Based on EOS MODIS Data. *J Editorial Board of Geomatics and Information Science of Wuhan University* 58-60+1+98
- [6] Wang C Y 2010 Monitoring Comparison of AVHRR and MODIS Data in Forest Fires in Tibet. *J Tibet's Science and Technology* 74-76.
- [7] Fu Y C, Shu Y Z, and Zhong X J 2008 Automatic extraction of information on small cool fires based on modis imagery. *J Journal of South China Normal University (Natural Science Edition)* **3** 115-121
- [8] Wang Z 2011 Research and evaluation of the algorithm of land surface fire detection based on FY3-VIRR data. *J Fire Safety Science*. **03** 20-25.
- [9] Dong X R. 2018 Forest fire monitoring system based on FY3 remote sensing image. *D Harbin engineering university*.
- [10] Liu S C 2019 Application of GF-1 Satellite 02/03/04 in Forest Fire Monitoring. *J Satellite Application* **01** 50-53.
- [11] Wang Y f 2018 Application of MODIS AOD Products to Monitoring Forest Fire in Forest Area of Southwestern China. *J Journal of Arid Meteorology* **36**(5) 820—27.
- [12] Zhu, Q, A numerical simulation study on the impact of smoke aerosols from Russian forest fires on the air pollution over Asia. *J Atmospheric Environment* 182.
- [13] Zhou X Z. The number of forest fires in Brazil soared, with more than half occurring in the Amazon rainforest. (2019-08-23): http://www.xinhuanet.com/world/2019-08/23/c_1124910024.htm.
- [14] Song X M. The lung of the earth is facing an unbearable burden. the Amazon forest fire has been burning for 16 days. (2019-08-24): <http://m.news.cctv.com/2019/08/22/ARTIMoyFmbUvSw9bAXEO09Bc190822.shtml>.
- [15] Zhou Y B, Han H. Research Overview of Forest Fire Monitoring Based on Remote Sensing Data. *J Geomatics & Spatial Information Technology*. 2014. **37**(03): p. 134-136.
- [16] Barlow, J. and C.A. Peres, Fire-mediated dieback and compositional cascade in an Amazonian forest. *J Philosophical Transactions of the Royal Society of London*, 2008. **363**(1498): p. 1787-1794.
- [17] C, A.L.E.O., et al., 21st Century drought-related fires counteract the decline of Amazon deforestation carbon emissions. *J Nature communications*, 2018. **9**(1).
- [18] Fu Y Y. Satellite-Observed Impacts of Wildfires on Regional Atmosphere Composition and the Shortwave Radiative Forcing: A Multiple Case Study. *R Journal of Geophysical Research: Atmospheres*, **2018**.

- [19] Winker D M, Hunt W H, Hostetler C A. Status and performance of the CALIOP lidar. *R Proceedings of SPIE - The International Society for Optical Engineering*, 2004, **5575**:8-15.