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ARTICLE

Characterization of $PM_{2.5}$ Mass Concentration in the Onshore of Sanya, China

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ABSTRACT

Numbers of real-time data (E-BAM) of $PM_{2.5}$ were collected in the period from Jan 8th 2012 to Jan 1st 2013 at the laboratory of Tropical Ocean University (Sanya, China). The average mass concentration was 19.7 μg/m³. The highest 40.5 μg/m³ in October compared to the lowest 14.1 μg/m³ in July. From a seasonal perspective, the average $PM_{2.5}$ mass concentration in fall and winter are relatively higher than that in both spring and summer. On the basis of satellite map of fire points and backward trajectories of the air masses, we primarily deduced that the $PM_{2.5}$ in Sanya may be caused by the biomass burning and industrial pollutants from the area of Pearl River Delta of China and the Indo-China peninsula (e.g. Vietnam, Laos).

1. Introduction

Fine particulate matter ($PM_{2.5}$) has been identified as the main cause of smog, posing a series of problems to China, not only aroused public health concern, but also led to other issues. High concentration of $PM_{2.5}$ could lead to the reduction of visibility, which can be hazardous to driving and shipping [1,8].

The increase in $PM_{2.5}$ has already become a severe problem in China and even the whole world. The research status of $PM_{2.5}$ in China is as follows, the physicochemical characteristic of $PM_{2.5}$ has been already studied years before [10], and the formation mechanism of $PM_{2.5}$ was also researched [14]. Furthermore, in 2014, Chinese Academy

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of Sciences found for the first time that the great contributions of high secondary aerosol to particulate pollution during haze events in China [4]. Biomass combustion is one of the main sources of fine particulate ($PM_{2.5}$) in Sanya. Mostly the $PM_{2.5}$ was emitted from open fire places, pallet stoves and boilers, wood, and crop waste [7]. Low combustion efficiency could cause high organic emissions and arouse the discharge of toxic substances.

Sanya is a coastal city located in southernmost China, enjoys a high level of reputation for its air quality compared with the other cities in mainland of China. The World Health Organization air quality guidelines state that the annual mean concentration of $PM_{2.5}$ should be below 10μg/m^3 [12] whereas the mass concentration of $PM_{2.5}$ in Sanya was around 19.73μg/m^3. Sanya is the only islet of China, where the air quality was easily affected by the monsoon climate. In addition, the air quality in Sanya is prone to be impacted by the biomass burning of the Indo-China peninsula and the industrial pollutants from the area of Pearl River Delta in China due to the air mass transportation [2]. Furthermore, as a typical transitional zone between land and ocean, it is worth conducting a series of research. So far, only limited of $PM_{2.5}$ research have been done throughout the world. In Sanya, both motor vehicle and biomass burning are the main emission source of $PM_{2.5}$, contributed PAH (polycyclic aromatic hydrocarbon) up to 60% of total emission [11]. A biomass burning research has been conducted in Jianfengling of Hainan Island, which indicates that the emission of toxic substances in winter is much higher than that in summer [15]. The study of characteristics of carbonaceous aerosol in Sanya has never been conducted in the previous researches.

The objectives of this study are to review available $PM_{2.5}$ and meteorological data and apply some proper techniques such as quantitative analysis and backward trajectories analysis in order to characterize the mass concentration of $PM_{2.5}$ in Sanya. Here, apart from analyzing the correlation between $PM_{2.5}$ mass concentration and meteorological factors, we also use backward trajectories and satellites images of fire points to trace the source of $PM_{2.5}$ caused by biomass combustion.

2. Methodologies

2.1 Sampling Site

The measurements of $PM_{2.5}$ were taken at the Department of Tropical Eco-environment Protection (Hainan Tropical Ocean University, 18°18'N, 109°31'E), situated in the northeast of the city of Sanya. Figure 1 illustrates the geographical location of Sanya. Sanya has a tropical coastal monsoon climate with a very humid and hot summer. Its ambient yearly humidity (AH) is generally around 90% in summer, and even higher (up to 95%) during the monsoon season (July-October). the AH is generally higher, around 95% of a month. Sanya receives a huge amount of rainfall every year with an average annual rainfall of 1263 mm and 90.2% of it concentrates in the monsoon season (June-October), namely rainy season (Weather Service of Sanya). As in the mainland of China, season was defined according to the meteorological division of seasons of 3 months each (spring: March–May, summer: June–August, fall: September–November, winter: December–February). We use an E-BAM (Environmental Beta Attenuation Monitor) particulate monitor to measure $PM_{2.5}$ mass concentrations, ambient temperature and relative humidity of the whole year of 2012, data have also been collected throughout the year. The meteorological patterns are quite different, the maximum temperature occurred in summer, at an average of 29 degrees Celsius. Similarly, the relative humidity (RH) also saw a high in summer, accounted for 95% in average, ranging from 87% to 99%. Compared to the winter, only around 23 degrees Celsius of temperature and 85% of RH.

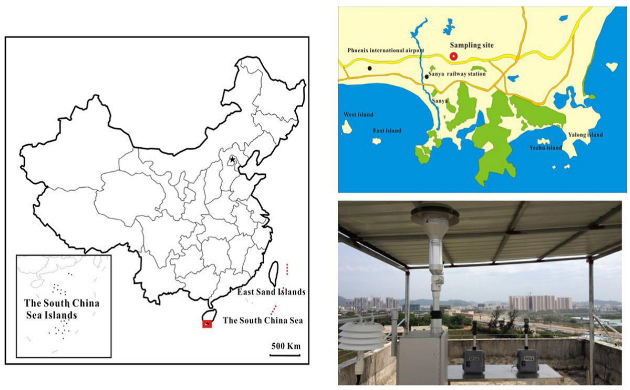

Figure 1. Location of the sampling site in Sanya, China

2.2 Methods

In total, 8132 pieces of data ($PM_{2.5}$ measurements) were collected from 2012.01.08 to 2013.01.01 on the top of the building for the Department of Science Studies, Hainan Tropical Ocean University. Data were not available during the monitor calibration and severe weather conditions, such as typhoon, the data will be analyzed on a scale of month, the individual missing data would be ignored. 24-hour averaged temperature, relative humidity (RH), wind speed (WS), and precipitation data from 2012.01.01 to 2012.12.31 were obtained from the Meteorological Bureau of Hainan province.

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2.2.1 E-BAM

The E-BAM samples the air and reports the measurements of samples continuously every minute. With the application of Beta Attenuation, E-BAM eliminates the outdated method of manual filter collection and weighing, and thereby facilitates the measurements of particulate matter. $PM_{2.5}$ concentration data were collected on hourly frequency, ambient temperature and relative humidity data were simultaneously collected. The E-BAM has been programmed to measure at virtually all times. Current data, historical data, and status information are available at all times without interrupting normal E-BAM operation.

2.2.2 Back Trajectories and the HYSPLIT4 Software

HYSPLIT4 model analysis was conducted to focus on the trajectories of airmass. Backward trajectories of the air mass are closely correlated to the wind direction and pollutants transmission path, which is helpful for us to analyze the spatial distribution of PM2.5. Forward trajectories were calculated by HYSPLIT4 (Hybrid Single-Particle Lagrangian-Integrated Trajectory) modeling software. This software was freely accessed through the Air Resource Laboratory (ARL) of the National Oceanic and Atmospheric Administration (NOAA). The HYSPLIT4 model referenced archived meteorological data for computing backward trajectories.

The vertical distribution of $PM_{2.5}$ ranging from 8m-300m in the atmosphere [9], due to the fact that airmass movement in the low altitude could be affected by buildings and anthropogenic activities, we will choose 100m as our primary height settings for conducting calculation of backward trajectory. In order to have a stable pattern of wind direction to trace the $PM_{2.5}$ sources of Sanya, we will also illustrate the airmass movements around 500m. The result could illustrate the airmass moving trajectory in the set period of time at 100m, 500m.

2.2.3 Active Fire Map

Humans use fire as a tool in slash-and-burn agriculture to speed up the process of breaking down of unwanted vegetation into the soil. Small forest fires also occurred in winter (November to March) in Southern China, including Yunnan, Guangdong and Guangxi Autonomous Regions [6]. In this case, the $PM_{2.5}$ may increase by these activities. It has the possibility that the local $PM_{2.5}$ could to some extent, transported by wind to other provinces like Hainan province, so we decide to combine the local $PM_{2.5}$ data and fire map to see whether there is a correlation between airmass trajectory and fire map.

The Figures of Active Fire and thermal anomalies were captured and compiled by TERRA/MODIS (NASA data pool). MODIS fire location data are distributed in a variety of forms (e.g. interactive web mapper, GIS, Google Earth, text files) through the Fire Information for Resource Management System (FIRMS) at the University of Maryland. Besides, the VIIRS (Visible Infrared Imaging Radiometer Suite) satellite data were also collected. The current MODIS and VIIRS satellite data could be downloaded from https://firms.modaps.eosdis.nasa.gov/.

3. Results and Discussion

3.1 Daily, Monthly, Annual Variations of $PM_{2.5}$ Mass Concentrations

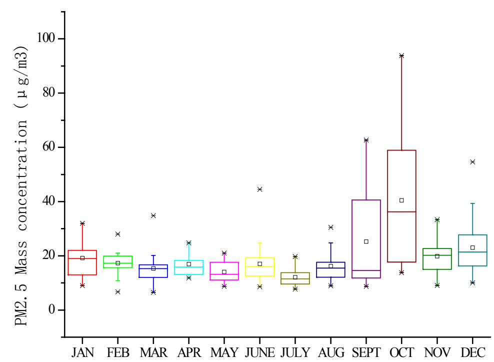

Figure 2. The Monthly variation of $PM_{2.5}$ mass concentration in 2012

The variation of average $PM_{2.5}$ mass concentration ranked as October (40.5μg/m³) > September (25.2μg/m³) > December (23μg/m³ > Rest of months). High values occurred during October and took up the most part of $PM_{2.5}$ mass concentration in Sanya in 2012, with a high of 93.8μg/m³. The Figure 2 of $PM_{2.5}$ mass concentration in October is remarkably higher than the rest of month, almost twice as much as that in September and three times as in rest of months. It is also noticeable that in the period from January to August, the contents of $PM_{2.5}$ are relatively lower than that in the period from September to December, which remained the same level from 14μg/m³ to 19.2μg/m³. Since the development of industry was never allowed by the policy of Chinese government. And this region is not like some northern cities which need coal burning for heating. We deduced that the $PM_{2.5}$ in October are from somewhere else. It is also noticeable that the maximum $PM_{2.5}$ value is not connected with the box in February, March, June, August and December, which may be caused by the data outlier in these months.

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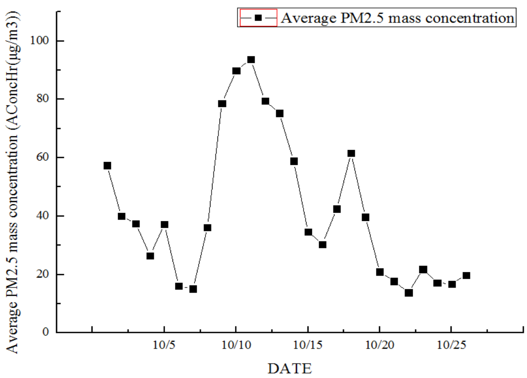

Figure 3. Daily $PM_{2.5}$ mass concentration in October, 2012 and Chinese/USEPA standard

Figure 3 provides the information of daily average $PM_{2.5}$ concentrations in October. The US Environmental Protection Agency (EPA) set a standard in 1997 which indicates the diurnal $PM_{2.5}$ ($\leq 35\mu g/m^3$), we can observe from the data in October that only 12 days (46%) have reached the EPA standard. In comparison with the standard (diurnal $PM_{2.5} \leq 75\mu g/m^3$) from Ministry of Environmental Protection of The People's Republic of China, only 5 days (19%) exceeded the standard. From the graph, the highest measurement occurred on 11st Oct, around $93\mu g/m^3$, compared to 7^{th} Oct, only accounted for $15\mu g/m^3$. Overall, the $PM_{2.5}$ mass concentration in October fluctuated to a large extent reached the maximum at 11st Oct and then fell to the same level as 7^{th} Oct at 26^{th} Oct.

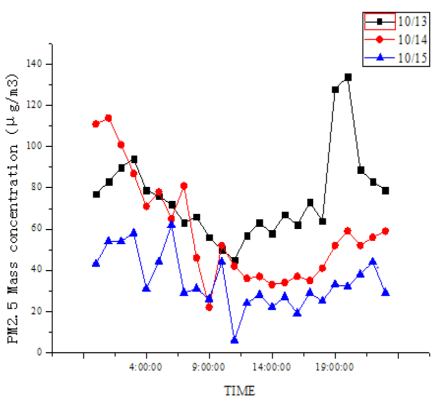

Figure 4. Hourly $PM_{2.5}$ variations on 13th, 14th, 15th Oct, 2012

To examine the diurnal variations in $PM_{2.5}$ mass concentration. We used Hourly $PM_{2.5}$ contents data (collected by E-BAM) to make a line chart above (Figure 4). Overall, $PM_{2.5}$ mass concentration in all three days were at a high level in the midnight, around $78\mu g/m^3$(10/13), $110\mu g/m^3$(10/14), $42\mu g/m^3$(10/15) respectively. Then the Figures saw a decrease from midnight to 5-8:00 a.m. After that, the contents of $PM_{2.5}$ have remained steady until 7:00 pm. In combination with the human activity, the increase of vehicles in the rush hour probably contributed some aerosol contamination including $PM_{2.5}$. Eventually, it saw an increasing trend from 7:00 pm to the following midnight.

3.2 Weather and $PM_{2.5}$

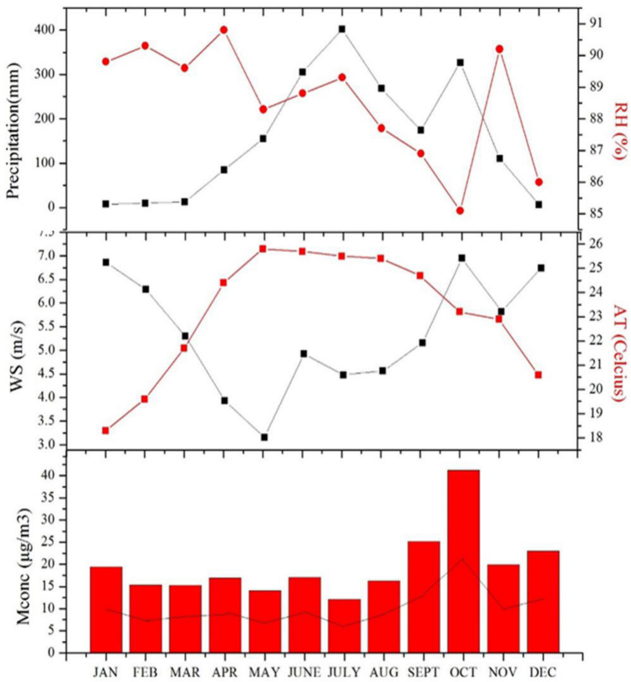

Figure 5. Monthly variation of major meteorological

Figure 5 illustrates Monthly variation of main meteorological parameters in 2012, including monthly average precipitation, relative humidity, daily wind speed and average temperature. The precipitation in winter (December, January and February) were the lowest throughout the whole year, around 7.4mm, 9.9mm, and 6.4mm respectively. It went higher from March (12.8mm) and saw the climax in July (402.2mm). Then the rainfall remained at the high level until November. In terms of relative humidity (RH), in every month, Sanya always maintained at a high level of that because Sanya is a tropical city and stand not far from the sea, the Figure 5 of RH were no less than 85% of a whole year. It has been observed that the wind speed in October were the fastest (6.95m/s), closely followed by January (6.86m/s) and December (6.74m/s), whereas the wind is usually calm from March to September, ranging from 3.16-5.82m/s. As regard daily mean temperature, the highest were in the range of April to September (24.4-25.7 ℃). Overall, the relative humidity, average temperature, and monthly precipitation were irrelevant to $PM_{2.5}$ mass concentrations. However, it is clearly from the charts that in the period from May to December in 2012, the variation of wind speed was more or less correlated with the $PM_{2.5}$ mass concentration.

3.3 Relationship between Active Fire and Backward Trajectories

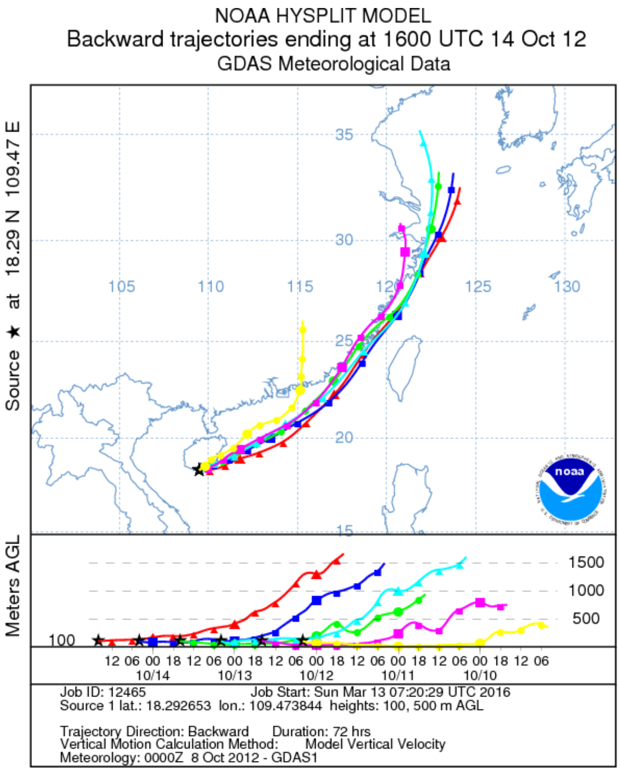

Figure 6. Backward trajectory of Sanya (18.29N 109.47E) in October, 2012

5-day Backward trajectories from the location (18.29N 109.47E) have been calculated using the HYSPLIT 4 model (HYbrid Single-Particle Lagrangian Integrated trajectory) (Figure 6). The certain trajectory that was created started at Tropical Ocean University (18.29N 109.47E) at (100,500) meters above ground level and was calculated back seventy-two hours.

The backward trajectory of 0000 UT from October 12, 2012 was chosen as an example for the path that air pollutant went because this trajectory began its journey in the Guangdong Province, where the industries well-developed and factories are scattered. Nevertheless, the rest of backward trajectories saw a same travel route that most of them were along with the coastal cities.

From the backward trajectory made above we can tell that airborne contaminant (100-500m) in Sanya in October 2012 were possibly transported from Guangdong Province and a series of coastal cities of China.

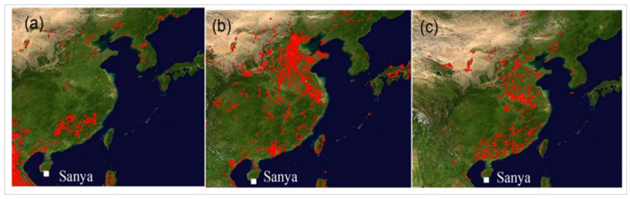

Figure 7. 8-day composite fire products during 22th February- 29th February 2012(a); 9th July-18th July 2012(b) and 7th October - 16th October 2012(c)

Figure 7 show the locations of actively burning fires around the world, detected by instruments aboard NASA satellites. The NASA MODIS global fire digital maps are calculated from Terra and Aqua MODIS data, designed primarily to serve the needs of the emissions modeling Community. The red dots illustrate fire and thermal anomalies detected by MODIS Aqua/Terra satellite. The yellow dots also present the fire and thermal anomalies in the set period of time; however, the data was collected from the VIIRS (Visible Infrared Imaging Radiometer Suite).

These fire products present a similar, locally coherent, spatio-temporal progression of burning. Each of these 3 fire maps accumulates the locations of the fires detected by MODIS on board the Terra and Aqua satellites and VIIRS over an 8-day period. Each colored dot indicates a location where MODIS detected at least one fire or thermal anomalies during the compositing period.

From the fire maps shown above, it is clear that during the period of 7th October - 16th October in 2012, the active fires occurred more frequently in those coastal cities of China than that in the February. However, the fire chances of coastal city in July was relatively lower than the chances in October.

In combination with the backward trajectory of the same period in October, there is a great chance that the airborne contamination including Particulate Matters were transported from the coastal cities of mainland of China.

3.4 Discussion

$PM_{2.5}$ particulate is scattered at different height, it could be transported by wind, and the transportation could be affected by aerosol optical properties, winds, relative humidity and also temperature [3]. Besides, other weather variation could have an impact on the transmission of atmospheric particles to some extent. For example, the precipitation amount could accelerate the sedimentation speed of particulate matter in the air [13]. The vertical distribution of $PM_{2.5}$ is from 8-300m, and the $PM_{2.5}$ amount at different height could be various [5,9]. The paper only simulated the backward trajectory at a height of 100m and 500m, the result may not be able to restore the transmis-

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sion trajectory of all particulate matters in the air, anomalies caused by topography and constructions may exist in the airmass trajectory at lower height.

Other possible $PM_{2.5}$ sources exist in this city such as in winter, a substantial amount of people moving to Sanya city to spend the winter time because of less air pollution and higher temperature in this city. People from the mainland have brought a great mount of vehicles from other provinces for their commuting convenience, which could be a potential sources of aerosol pollutants. The sample were collected by the Hainan meteorological bureau in Hedong monitoring station which located near city center, in this case, the particulate data could be affected by the sudden increase of vehicles in Sanya city in winter.

4. Conclusion

The monthly and daily variations of the $PM_{2.5}$ mass concentrations were carried out using E-BAM aerosol contamination monitor the major findings of this present study are as follows:

(1) In the period of September-November in 2012, the $PM_{2.5}$ mass concentration increased remarkably compared to the rest of months, which hinted that whether there was a new source of pollution in Sanya or the $PM_{2.5}$ in fall were transported from somewhere else.

(2) The daily $PM_{2.5}$ mass concentration in October took up the most of $PM_{2.5}$ in 2012, only 46% days have reached the EPA standard (≤35μg/m^3) but 81% met the Chinese $PM_{2.5}$ standard (diurnal $PM_{2.5}$≤75μg/m^3).

(3) The correlation analysis between $PM_{2.5}$ concentration and meteorological factors indicated that the relative humidity, average temperature, and monthly precipitation were mostly irrelevant to $PM_{2.5}$ mass concentrations, but it saw some correlations between $PM_{2.5}$ contents and wind speed in the chart.

(4) Observed backward trajectory in combination with fire products in the same period of 2012, we primarily deduced that the aerosol pollution including $PM_{2.5}$ are come from Guangdong Province and the coastal cities of China.

Acknowledgments

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