Analysis of the Aerosol Optical Depth and the Air Quality in Qingdao, China

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Abstract—Air quality plays an important role on human everyday life. Aerosols in the atmosphere can directly affect the air quality. Researches have already shown that the aerosol optical depth (AOD) or aerosol optical thickness (AOT) has relation to the air quality. The AOT can be retrieved from the multi-channel satellite data. MODIS data is used in this paper. Data for the Qingdao, Shandong area is selected. Further process is necessary to extract data that cover this area. The Air Pollution Index (API) can be obtained from China National Environmental Monitoring Centre. It is published for the main cities of China everyday. AOD data for each day from 2008 to 2009 is collected in this paper, the API in the same time range is also collected. We discussed the relationship between AOD and API. For part of the 2008 data, we get a correlation coefficient of 0.80. For the year 2009, the correlation coefficient of the whole year is 0.47, with p=0.12. The correlativity is not very well. Data from June to December is analyzed separately. Perfect result is obtained. The correlation coefficient is 0.87, with p=0.01. We also get the linear relation by regression.

Index Terms—Air Pollution Index (API), MODIS, Aerosol Optical Depth (AOD)

I. INTRODUCTION

Atmosphere aerosol is the suspension of solid particles or liquid droplets in air, with a radius less than several tens of micrometers. Examples are smoke, oceanic haze, air pollution, smog, etc.

Aerosols in the atmosphere can directly affect the air quality. Researches have already shown that the Aerosol Optical Depth (AOD) or Aerosol Optical Thickness (AOT) has relation to the air quality.

For air Pollution Studies, scientist in the Pennsylvania State University developed a general, predictive, hydrostatic meteorological model early in 1978 [1]. They presented several preliminary simulations with the two-dimensional analog. The model is shown to be energetically consistent to a good approximation, and capable of simulating hydro-static mountain waves realistically.

According to the Guidelines for the Reporting of Daily Air Quality by Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, an (AQI) is introduced[2]. The Air Quality Index is a comprehensive consideration of the index of Ozone, PM2.5, PM10, CO and SO2. Table.1 tells the relation of air quality to the range of AQI value.

Table. 1 Air Quality Index[2]

<table>
<thead>
<tr>
<th>AQI</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 50</td>
<td>Good</td>
</tr>
<tr>
<td>51 to 100</td>
<td>Moderate</td>
</tr>
<tr>
<td>101 to 150</td>
<td>Unhealthy for Sensitive Groups</td>
</tr>
<tr>
<td>151 to 200</td>
<td>Unhealthy</td>
</tr>
<tr>
<td>201 to 300</td>
<td>Very Unhealthy</td>
</tr>
<tr>
<td>301 and above</td>
<td>Hazardous</td>
</tr>
</tbody>
</table>

Air Pollution Index (API) is published daily for the main cities in China. The index is defined similar the Air Quality Index in reference [2]. Cogliani et al. [3] proved the API which represents the global urban air pollution situation is highly correlated with meteorological variables. This index is capable of identifying those variables that significantly affect the air pollution. The

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The correlation coefficients between AOD and boundary-center and the surface chemical data at Washington, D.C. (AOD) data from the instrument at Goddard Space Flight relatively weak correlations are most likely due to the ranged from about 0.42 to 0.55. They suggested that the product including an aerosol optical thickness is derived from these algorithms. The MODIS aerosol product monitors the ambient aerosol optical thickness over the oceans globally and over the continents. Daily Level2 aerosol product (MOD04) is produced at the spatial resolution of a 10x10km.

Yoram J. Kaufman and Didier Tanré described the algorithms for simultaneous remote sensing of aerosol from EOS-MODIS over land and ocean. The algorithms are used to monitor the aerosol optical thickness and size distribution of the ambient aerosol, over most of the globe on a daily basis. The standard MODIS MOD04 product including an aerosol optical thickness is derived from these algorithms. China Meteorological Data Sharing Service System publish a composed atmospheric products retrieved from the MODIS/TERRA data. The atmospheric products include the 550nm AOT for both land and ocean. Algorithm used to retrieve this AOT product is the same as that used for MOD04 product of NASA. The service can be visited from this website: http://cdc.cma.gov.cn/

Researches have proved the capability of MODIS AOD to monitor the air quality. In order to utilize satellite measurements of optical thickness over land for estimating aerosol properties during air pollution episodes, Kaufman et al. [5] measured and investigated the optical thickness from the surface. They derived Aerosol optical thicknesses from solar transmission measurements in eight spectral bands within the band λ440–870 nm during the summers of 1980 and 1981 near Washington, DC. They theoretically analyzed the effects of relative humidity and accumulation mode concentration on the optical thickness, and compared with the measurements.

Corbin et al. [6] compared the Aerosol optical depth (AOD) data from the instrument at Goddard Space Flight Center and the surface chemical data at Washington, D.C. The correlation coefficients between AOD and boundary-layer aerosol properties derived from the IMPROVE data ranged from about 0.42 to 0.55. They suggested that the relatively weak correlations are most likely due to the lack of information on the vertical profiles of aerosol mass concentration, composition, and relative humidity.

Butler et al. [7] researched the Mass concentrations and constituents of the air using the data from a monitoring network established in metropolitan Atlanta, Georgia. They proved that mass concentrations varied significantly with season and time of day. Approximately 75% of the mass can be identified using various chemical speciation analyses. of the identifiable portion, carbonaceous material, sulfate, ammonium, and nitrate were the largest constituents.

The Center for Space Research (CSR), in conjunction with the Monitoring Operations Division (MOD) of the Texas Commission on Environmental Quality (TCEQ), evaluated the use of remotely sensed satellite data to assist in monitoring and predicting air quality in Texas. CSR and MOD personnel have applied MODIS data to several classes of pollution that routinely impact Texas air quality. Their Results demonstrate MODIS data and products can detect and track the migration of pollutants. They also concluded that MODIS provides the basis for developing advanced data products that will, when used in conjunction with ground-based observations, create a cost-effective and accurate pollution monitoring system for the entire state of Texas.

Wang et al. [9] explored the relationship between column aerosol optical thickness (AOT) derived from MODIS and hourly fine particulate mass (PM2.5) measured at the surface at seven locations in Jefferson county, Alabama for 2002. Their Results indicate that there is a good correlation between the satellite-derived AOT and PM2.5 (linear correlation coefficient, R = 0.7). There is excellent agreement between the monthly mean PM2.5 and MODIS AOT (R = 0.9). They proved that the MODIS AOT can be used quantitatively to estimate air quality categories as defined by the U.S. Environmental Protection Agency (EPA) with an accuracy of more than 90% in cloud-free conditions. They also discussed the factors that affect the correlation between satellite-derived AOT and PM2.5 mass, and emphasize that more research is needed before applying these methods and results over other areas.

The Center for Space Research (CSR) explored approaches to integrate data collected by the MODIS sensor into a real-time prediction methodology to support operational air quality forecasts in Texas[10]. They demonstrated a method to forecast air quality from remotely sensed satellite observations when the transient pollution can be isolated from local sources.

The EPA researchers use the Aerosol optical depth (AOD) from MODIS to improve fine particulate matter (PM2.5) air quality forecasts[11]. They demonstrated a prototype tool for improving fine particulate matter (PM2.5) air quality forecasts using satellite aerosol observations.

Remer et al. [12] Compared the MODIS aerosol products with ground-based AERONET observations of aerosol optical depth (AOD). They found that Collection 5 MODIS aerosol products estimate AOD to within
expected accuracy more than 60% of the time over ocean and more than 72% of the time over land.

Zhang et al. investigated the relation between MODIS AOD and PM2.5 over the 10 U.S. Environmental Protection Agency (EPA)-defined geographic regions in the United States on the basis of a 2-yr (2005-2006) match-up dataset of MODIS AOD and hourly PM2.5 measurements[13]. The AOD retrievals demonstrate a geographical and seasonal variation in their relation with PM2.5. Good correlations are mostly observed over the eastern United States in summer and fall. The southeastern United States has the highest correlation coefficients at more than 0.6. The southwestern United States has the lowest correlation coefficient of approximately 0.2. The seasonal regression relations derived for each region are used to estimate the PM2.5 from AOD retrievals, and it is shown that the estimation using this method is more accurate than that using a fixed ratio between PM2.5 and AOD.

During the ICARTT field campaign over eastern North America in summer 2004, researchers use an ensemble of satellite (MODIS), aircraft, and ground-based aerosol observations[14]. They found that Inference of surface PM2.5 from our MODIS AOD retrieval shows good correlation to the EPA-AQS data (R = 0.78). The ensemble of MODIS, aircraft, and surface data are consistent in pointing to a model overestimate of sulfate in the mid-Atlantic and an underestimate of organic and dust aerosol in the southeastern United States.

Wang et al. developed a new algorithm, using the MODIS satellite reflectance and aerosol single scattering properties simulated from a chemistry transport model (GEOS-Chem) to retrieve aerosol optical thickness (AOT) over land in China during the spring dust season. Concentrations derived using this improved AOT retrieval show better agreement with ground observations than those derived from GEOS-Chem simulations alone.[15]

Hadjimitsis et al also developed an algorithm to allow the quantification of the aerosol optical thickness (AOT) over land using the archived time series Landsat TM data over an urban area in the vicinity of Heathrow Airport (UK).[16]

II. DATA PROCESSING

Location

The research area is Qingdao, Shandong, China. It locates at (36.04, 120.34), which is marked out in Figure 1 by a white circle.

AOD Data

MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment.

http://modis.gsfc.nasa.gov/about/

Terra MODIS data is used in this paper. MODIS is published freely by NASA. A data collection is also published by China Meteorological Data Sharing Service System, including a MODIS/Terra Composed atmospheric product collection. The time ranges from 1 January, 2008 to 2 months before now. Daily data for the year 2008 and 2009 is used in this paper.

There is one swath of MODIS/Terra every 5 minutes, 228 files is obtained everyday. For one swath can only spatially cover a small part of the world, we prepared a batch file to choose the swaths that cover the research area.

Several swaths are selected out from the 228 files everyday according to the latitude and longitude. Figure 2 is an example of one month (July, 2008).

Figure 3 is amount of the collected AOD data; there are more than 6000 swaths for each month. 156,000 swaths need to be processed totally. Figure 4 is the amount of the selected swaths that cover Shandong area. The data from the China Meteorological Data Sharing Service System is in the HDF (Hierarchical Data Format) format; matrixes of longitude, latitude, AOT at 550nm for land and ocean in size of 135x203 are included in the HDF file. The spatial resolution for each pixel is 10km.

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The AOT data obtained from the HDF is not geographic corrected. Each pixel should be on the geographic location for further use. Fortunately, each AOT value has a corresponding longitude and latitude. Using the longitude and latitude, a geographic look-up table can be constructed. Then, the AOT data can be geographic corrected using this look-up table. The flow chart for geographic correction is shown in Figure 5.

A batch file is developed to process all the AOD data automatically. Steps to finish the automatic data processing are as follows:

Firstly, ingest one swath data to the memory; extract the AOD, longitude and latitude data from the swath.

Second, a geographic look-up table is constructed according to the latitude and longitude

Third, AOD is geographic corrected to the world map according to the geographic look-up table.

The forth, extract the AOD data of Qingdao, Shandong area from the geographic corrected AOD data.

Fifth, write the extracted AOD data onto the disk and start the next process.

Figure 6 is an example of geographic corrected AOT. The area inside the red rectangle is Shandon province of China. Any Region of Interest (ROI) can be extract from this mapped data. The AOT inside the area of Qingdao is obtained in this paper.

Air Quality Data

Air Quality Data of the main cities in China is published by the China National Environmental Monitoring Centre daily. Air Pollution Index (API) for every day is included in this Data. The time range is from May, 2008 till now. Data for Qingdao City from May 1, 2008 to December 31, 2009 is collected in this research. Figure 7 is an example of the daily API data for December, 2008.
III. ANALYSIS

The use of remotely sensed satellite data to assist in monitoring and predicting air quality in Texas is evaluated [8] in 2003. Results demonstrate MODIS data and products can detect and track the migration of pollutants. Hutchison etc. analyzed the MODIS AOD to predict air quality [10] in 2004. The results demonstrate a method to forecast air quality from remotely sensed satellite observations.

The relation between MODIS AOD and PM2.5 over the 10 U.S. Environmental Protection Agency (EPA)-defined geographic regions is investigated [13] by Zhang etc. in 2009. The southeastern United States has the highest correlation coefficients at more than 0.6 in their research.

The AOD and the API data for Qingdao, China are prepared for further analysis. For the AOD data, monthly averages, Standard Deviation (STDEV) are calculated. Figure 8 is the monthly average of AOD, according Figure 2; the average is base on more than 6000 MODIS swath for each month. Figure 9 is the corresponding Standard Deviation for each month. The AOD of 2008 cover a range of 0.1 to 0.16. The STDEV is in the range of 0.06 to 0.09. The low standard deviation indicates that the AOD of the 6000 swathes for each month in the Qingdao area tend to be very close to the average value.

The same statistics result is obtained for the AOD data of 2009, see Figure 10 and Figure 11. The AOD of 2009 cover a range of 0.1 to 0.14. The STDEV is also in the range of 0.06 to 0.09. Namely, the AOD of the 6000 swath for each month in the Qingdao area tend to be very close to the average value.

Daily API of Qingdao is obtained from the China Meteorological Data Sharing Service System. Data from January to April of the year 2008 is absent. The daily API data is monthly averaged for the purpose of compare with the monthly averaged AOD (see Figure 13). For the year 2008, according to Figure 12 and Figure 13, the AOD and the API has a similar variation trend except May. The AOD has a lower value, while the API value very high in May. Correlation analysis is performed for the data from June to December. Daily data of AOP and API is checked later.
Correlation analysis for data from June to December, 2008 is performed. The correlation coefficient is 0.80, with p=0.03, the correlativity is well. A linear regression is performed for the AOD and the API (Figure 14). The relation is as follow.

$$\text{AOD}=0.0002 \times \text{API}+0.1278$$

Because the AOD has a lower value, while the API value very high in May. The daily data is checked. Figure 15 is the API of May; very high value is found on the day 29 and 30, especially the day 29. According to the record of China Weather Bureau, a dust storm happened on this day in Qingdao, while the AOP (Figure 16) data on this day is missed. This may be the reason that makes the monthly average data in May abnormal.

For the year 2009, correlation analysis of the whole year is performed first. The correlation coefficient is 0.47, with p=0.12. The correlativity is not very well. Data from June to December is analyzed separately. Perfect result is obtained. The correlation coefficient is 0.87, with p=0.01.

A linear regression is performed for data from June to December, getting the following relation.

$$\text{AOD}=0.0009 \times \text{API}+0.0650$$

In short, the AOD have relation to the API, it can be used to estimate the API using the regression equation. In some case, for example on May, 2008, a dust storm happened; this makes the correlation be poor. Errors may also be induced by the spatial or temporal mismatch, for example, the AOD data may be absent for rainy or cloudy.
ACKNOWLEDGMENT

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REFERENCES