Air pollution monitoring and warning system

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Abstract **---** *Nowaday, remote sensing images have provided a large dataset with geospatial information at global scale at different resolutions, which is widely using in various domains. The usage of satellite technology for air pollution monitoring applications has been recently increasing especially to provide global-to-local distribution of aerosol and its properties for deriving Particulate Matter concentration (PM). The paper investigates aerosol retrieval for multi- resolution satellite images. After that, PM is estimated from aerosol products and meteorological parameters in order to provide dust observations at different spatial scales. A geographic information system for air pollution monitoring and warning is developed based on these research results.*

Keywords --- VIIRS, MODIS, LandSat, AOT, AOD, PM, AQI, modeling, monitoring, warning, air pollution, Hanoi, Vietnam

1. Introduction

Nowadays, Vietnam is facing to air quality problems as results of the rapid growth of industrial activities, traffic operations and agriculture activities, biomass burning … without any efficient waste treatment. At national scale, traffic operations contributed nearly 85% of Carbon monOxide (CO) and 95% of Volatile Organic Compounds (VOCs). Meanwhile, industrial activities are major sources of Nitrogen diOxide (NO_2) (~30%), Sulfur diOxide (SO_2) (~40%) and Total Suspended Particles (TSP) (~70%). Thermal power industry is also contributing a large amount of air pollution. [1].

According to the national environment report in 2010, the air quality is serious in Vietnam, especially over major cities such as Hanoi and Ho Chi Minh City. Analysis of dust pollution based on TSP and PM_{10} show that their concentrations are always surpassing the national allowed level in many cities consisting of Hai Phong, Vinh, Hue, Ha Long, Thanh Hoa, Lang Son, Da Nang, Dac Lac, Dong Nai, Ba Ria – Vung Tau, Hochiminh City, Long An, Tien Giang, Can Tho, Ca Mau and Hanoi [2]. As the results, citizen healths are declining by respiratory, blood pressure and cardiovascular diseases. Amount of citizens getting respiratory problems is always peaked in the total of human diseases [3].

In the air pollution monitoring applications, Aerosol Optical Thickness/Aerosol Optical Depth (AOT/AOD) is considered as one of the Essential Climate Variables (ECV) that influences climate, visibility and quality of the air. Sattelite derived AOD is representative for the amount of particulates in a vertical column of the Earth's atmosphere. Aerosol concentration can be measured directly by ground based sunphotometer or estimated by sensors onboard sattelites. Ground measurements have high accuracy and temporal frequency but they are representative of a limited spatial range around station. Conversely, sattelite data provide aerosol at larger scale with moderate quality and lower frequency. Recently, the accuracy of sattelite derived aerosol has been increasing and show an acceptable quality in comparison with ground based aerosol measurement.

Air pollution represented by Air Quality Index (AQI) is able to be derived from many factors such as PM, SO_2, CO, NO_2, O_3, Pb in which PM is one of the major pollutants. PM is a complex mixture of solid and liquid particles that vary in size. PM is classified into PM_1, $PM_{2.5}$ and PM_{10} by their aerodynamic diameters. PM is usually obtained from ground based instruments and therefore has high quality and frequency but limited range. This makes the use of PM for monitoring air pollution in large scale become chalenging.

The usage of sattelite derived aerosol and meteorological data for PM estimation in air pollution monitoring applications has been recently increasing. The relation between AOT and PM was considered over different areas such as Italy, French, Neitherland, USA, etc. and climatology conditions presented by related humidity mixing layer height, wind, temperature, pressure [4-7]. Based on those relationships, empirical data models for PM estimation are developed using different data regression techniques [8-12].

Based on direct or indirect measured data, information systems or portals such as AirNow, RSIG, AQICN for air pollution monitoring, prediction and warning has been developed and operated by national and international organizations [13-16]. The systems aim at providing air quality services to large amount of users including citizens, researchers, managers and organizations.

In the article, we propose the approach for PM estimation at different spatial scales using different optical satellite images. The PM maps are going to be estimated from LandSat, VIIRS and MODIS aerosol products. The daily VIIRS and MODIS aerosol maps at 6x6 and 10x10 km are freely provided by NASA and NOAA. However, the high resolution aerosol products estimated from satellite images such as LandSat, SPOT need to be researched and developed. Furthermore, the techniques for PM estimation from satellite based aerosol and meteorological data are investigated and proposed. After that, the overview of the Air POllution Monitoring and warning system based on above core techniques, called APOM for short, is introduced. The system automatically analyses satellite images at different spatial resolutions to estimate PM using above techniques and then derive air quality maps. Based on those maps, air pollution information and warning services in the region of interest will be visualized and sent publicly and privately to users.

The paper is organized as follows. The methodologies including aerosol estimation from high resolution Landsat image and modeling techniques for PM estimation from aerosol and meteorological data will be presented in Section 2. Specification of monitoring and warning system including modules of processing, storage and warning is decribed in Section 3. Finally, conclusions are given in Section 4, together with future works.

2. Methodologies

2.1 Region of interest

Air pollution is daily monitored in Vietnam region using MODIS and VIIRS sattelite images with respective resolution of km and km.

Detailed air pollution information estimated from high spatial resolution LandSat image (from m to m) with 16 days frequency is applied at smaller regional scale such as cities or provinces. Hanoi city is selected for experiments.

2.2 Data collection

Sattelite based data

Sattelite data include daily aerosol and meteorological products provided by NASA. They are km MOD04 L2, MOD07 products and km VIIRS AOT and meteorological images. To create high spatial resolution aerosol and PM products, we use LandSat 8 Level 1T consisting of 9 spectral bands with spatial resolution of 30m and 15m for band Panchromatic and 2 thermal band with resolution of 100m.

Ground based data

Ground based data include AOT measured by the AERONET, which is used for satellite-based aerosol validation. Meanwhile, $PM_{2.5}$ or PM_{10} is collected from Centre for Environmental Monitoring (CEM), Vietnam Environment Administration (VEA) for modeling for PM estimation using satellite aerosol and/or meteorological data. Besides, manual ground PM measurements at the time of LandSat passed are collected for PM map generation at high spatial resolution.

GIS data

GIS data include national maps at scale of 1:50.000 with 7 layers of administration, transportation, topography, population, etc. GIS data are used for visualization and warning services.

2.3 Paticulate Matter concentration estimation at high spatial resolution

Due to the coarse spatial resolution of MODIS and VIIRS aerosol products, LandSat 8 image is used to estimate aerosol for higher spatial resolution following the method presented in [17, 18].

The input data is a pair of LandSat ETM+, Digital Elevation Model (DEM) over region of interest with ground based AERONET aerosol.

Firstly, Digital Number (DN) data in LandSat images are first converted to TOA Reflectance by following steps:

Geometric corection: LandSat 8 Level 1T is already corrected geometry by NASA.

Conversion to Radiance:

$$L_\lambda = M_L Q_{CAL} + A_L \qquad (1)$$

where L_λ is radiance value, M_L is band specific multiplicative rescaling factor from metadata, A_L is band specific additive rescaling factor from metadata and Q_{CAL} is digital number (DN).

Conversion to TOA Reflectance

$$p\lambda' = M_P Q_{CAL} + A_P \qquad (2)$$

where $p\lambda'$ is TOA reflectance without correction for solar angle, M_P is band specific multiplicative rescaling factor from metadata, A_P is band specific additive rescaling factor from metadata and Q_{CAL} is digital number (DN).

After that, aerosol is estimated using a pair of LandSat images. Each image is divided to grids of pixels:

$$\frac{\sigma_1(\rho^*)}{\sigma_2(\rho^*)} = e^{-\frac{\tau_1}{\cos\vartheta_{v1}}+\frac{\tau_2}{\cos\vartheta_{v2}}} \qquad (3)$$

where , $\sigma_1(\rho^*)$, $\sigma_2(\rho^*)$ is standard deviation of grids of pixels, τ_1, τ_2 is AOD value of grid of pixels, ϑ_{vq}, ϑ_{v2} is respectively sattelite zenith angle of two images.

Due to the presence of cloud and water, calculated aerosol map has missing those values in some area. In order to create PM map, an interpolation technique, namely Kriging [19], is applied on LandSat aerosol and ground based PM measurements to fill up the missing values and create continuous PM maps.

2.4 Particulate Matter concentration estimation at coarse spatial resolution

This research is mainly replied on regression and Kriging interpolation techniques to estimate spatial distribution of PM concentration. The related works can be found in [20, 21]. The modeling process for MODIS images is desmotrated as in the Fig. 1. Firstly, satellite and ground based data are re-processed and ingested into a spatio-temporal databased. After that, data from different sources are integrated following spatial and temporal conditions. Since satellite images usually cover a very wide area, thus for each image, only pixels located within radius **R** to ground PM stations are selected. For ground observation data, they are collected in a period of **T** before and after the satellite passes.

The regression model based on the historical integrated data is created. Using this empirical data model, daily PM maps can be estimated from MODIS or VIIRS aerosol and meteorological datasets.

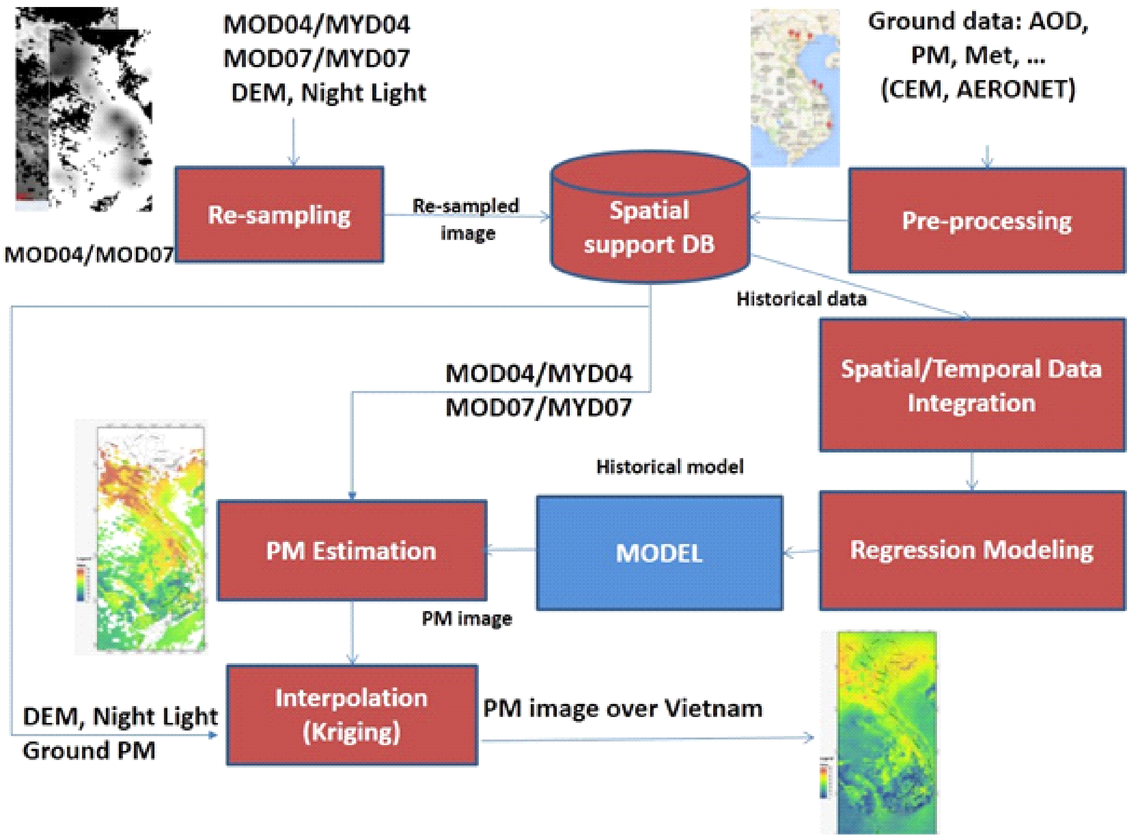

Figure 1. PM concentration estimation process for MODIS images

Due to the optical satellite images were covered by cloud, estimated PM images are not complete. Therefore, Kriging interpolation [19] is applied on PM and ancillary data such as Digital Elevation Model (DEM), night light or Land Cover (LC) data … to caculate PM values for empty area on the map.

The evaluation of proposed regression and interpolation model is carried out by comparison of PM estimated from the model with ground measurements.

3. Air Pollution Monitoring and Warning System

3.1 System Architecture

The APOM system is designed according to three-layer architecture of the information system (see Figure 2).

Data Layer

The data used in the system could be divided into three major groups as satellite data, ground measurement data and GIS data. Satellite data include the MODIS and VIIRS AOT products collected offline from NASA data center or download online from the MODIS/NPP ground station at University of Technology, Vietnam National University Hanoi. The LandSat 8 or similar satellite images such as SPOT 5 are collected from open or closed databased only if they are required.

Ground measurements include AOT from AERONET, PM and meterological data from CEM and CENMA. GIS data refer to national maps at scale of 1:50.000 with 7 background layers of administration, transportation, topography, population, etc.

The data are researched about the structure and data characteristics. Solutions for multi-source, multi-temporal and multi-spatial data were proposed for storage and queries. All data are pre-processed, stored in hard disk and ingested into database of the system.

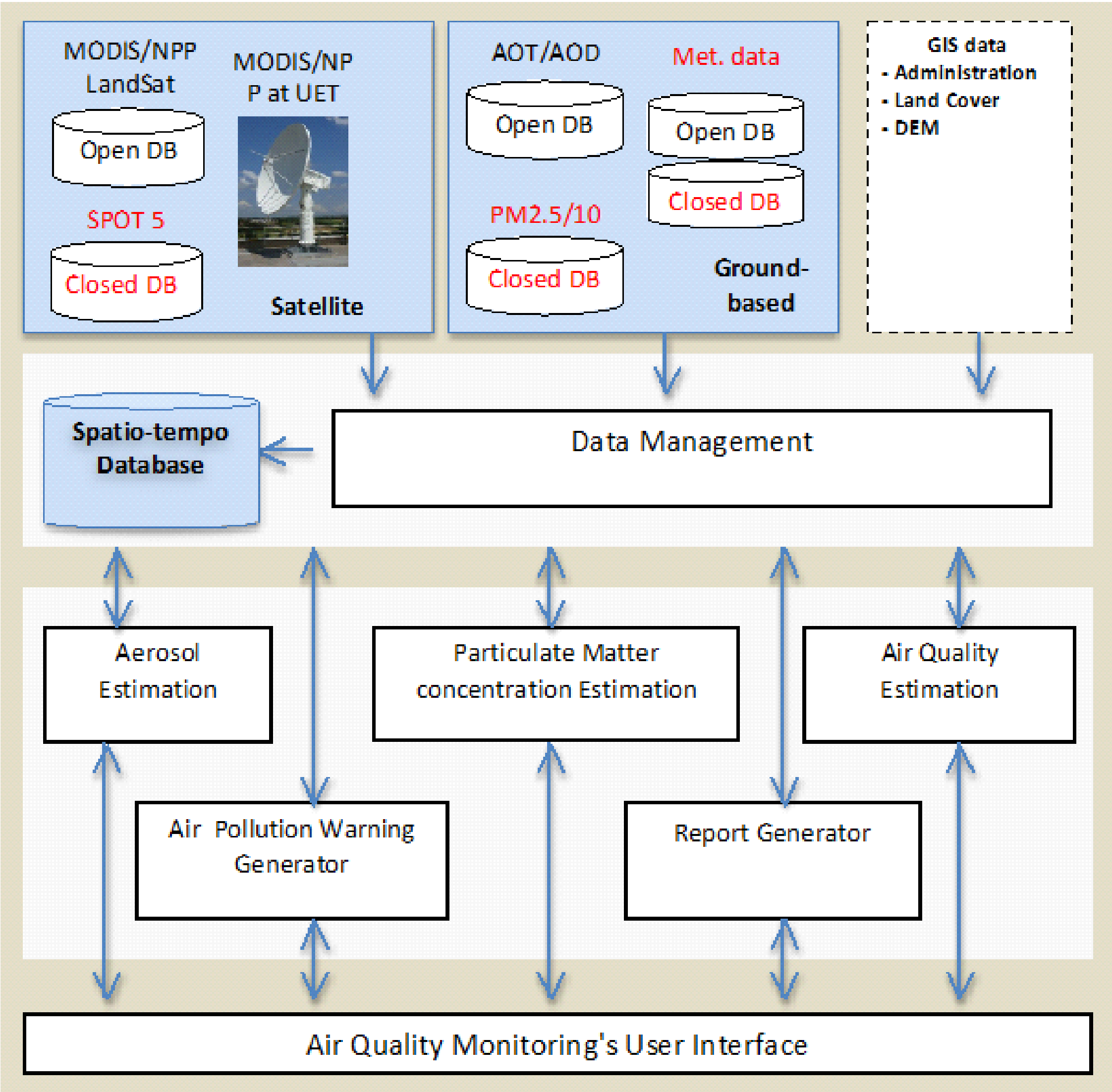

Figure 2. The Air Polution Monitoring and Warning System Architecture

Processing Layer

This layer contains components for data processing in order to produce LandSat's aerosol, PM concentration and AQI images and to provide warning and report services to the end users.

The component for estimating of aerosol takes LandSat images as input and the output is an aerosol. The high-spatial resolution Landsat-aerosol images will be processed together with immediate ground PM concentration measured in an area of interest to create a PM map. High spatial resolution PM maps provide useful additional data source for observing air pollution in specific area.

The component for estimating distribution of dust ($PM_{2.5}$ or PM_{10}) processes the aerosol images from MODIS, VIIRS and delivers corresponding PM maps.

The air quality estimation based on PM concentration images to deliver multi-level air quality maps following Vietnamese or international stardards.

The component for air pollution warning aims at offering warning information about air pollution levels and appropriate advices. The warning information is reported to the public through the website or emailed to registered users.

The component for report generation syntherizes information of different aerosols, dusts and air-quality to offer syntherized reports with different criteria.

User Interface Layer

The layer is built for information visualization and interaction with users. Through the interface, users could extract information and use services provided by the APOM system.

3.2 Technical Solutions

Based on the synthesis and analysis of user requirements, reviewing of existing systems and techniques, solutions are selected in order to ensure the effectiveness, stability, safety, economy and user satisfaction.

DataBase Management System (DBMS): The APOM DBMS's solution is PostgreSQL. This is a reliably DBMS guaranteed data consistency, fast data retrieval, high security, auto backup and storage and easy for maintenance and expansion.

WebGIS server application: Besides the ArcGIS commercial software, there are many open source softwares, of which the most notable is the GeoServer (Open Source Geospatial Foundation), UMN MapServer (University of Minnesota) and Deegree. All of these WebGIS servers support the OGC basic standards (Open Geospatial Consortium) and have the ablility to connect and exploit data from the common DBMS such as Oracle Spatial, PostgreSQL/PostGIS, ArcSDE, …

The Geoserver is selected with features to allow users to connect the available geographic information on Web sites using open standard geographic, manage interfaces supporting for multiple output data formats and share geospatial data on Google Earth through "network link" properties using the KML.

System Architecture: The system is built following the client-server model. All data and application are stored at server side located at the University of Engineering and Technology, Vietnam National University, Hanoi. Client side includes end-user interfaces able to be accessed through web browser and based on open source platforms (see Fig. 3).

Figure 3. The APOM System Deployment

4. Conclusion

In this paper, we studied and proposed methodologies to analyze multi-source and multi-resolution satelite data to estimate the PM concentration distribution and thus, providing AQI maps for air quality monitoring at regional to local scale. The usage of satllite images in air pollution monitoring is an effective approach supporting traditional methods mainly based on ground measurements.

Besides, we have developed a WebGIS system to collect, process, store, provide air quality information, monitoring and warning services. The system aims at providing daily information of air pollution for user and research communities through geographic information system on the Web.

In future, we are implementing proposed approaches. The methodologies need to be experimented and validated. Meanwhile, the APOM system with monitoring and warning services is conducting.

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