The relationship between aerosol optical depth and PM from Landsat data satellite and ground-based measurements data

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Abstract This study used sunphotometer, lidar, and in situ particulate matter measurements to assess the capability of LANDSAT 7 aerosol optical depth (AOD) retrievals for air quality monitoring in Taiwan. In the past, many researches focus on the relationship between satellite AOD and the concentration of particulate matter (PM) near the surface, and suggest a strong seasonality as a result of aerosol profiles. The high correlations obtained in autumn between PM and AOD normalized by boundary layer height are attributed to stable and well- mixed boundary layers as opposed to the summer lows resulted from strong convection associated with unstable weather systems. Therefore, the correlations in cold season (September ~ February) are slightly better than the counterparts in warm season (March ~ August). Since the boundary layer height is different in seasonal weather system, the change of boundary layer should be taken into account to improve the correlation between AOD and PM, as well as the influence of the long-range transport of Asian dusts, pollutants and biomass burning from Southeast Asia in winter and spring under the prevalent flows. Trying to improve the relationship between SOD and PM,, we use the aerosol profile and boundary layer height from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) products and collocate MPLNET Lidar data to propose the approach of PM concentration retrieved from LANDSAT data in this study.

Keyword: LANDSAT, AERONET, MPLNET, Aerosol optical depth, Particulate matter

1. Introduction:

Particulate matter (PM) is one of the major air pollutants observed in the past decade in Taiwan (Taiwan Environmental Protection Administration, 2001-2008). Some particles are emitted directly from both human activities and natural events, while others are formed in the atmosphere through secondary chemical transformation. In general, particles are measured by size, known as $PM_{2.5}$ and

PM_{10} for aerodynamic diameters less than 2.5 and 10 mm, respectively. Particles small enough to penetrate deep into the lungs can cause serious health problems. For management planning strategy and policy-making, Taiwan Environmental Protection Administration (TWEPA) began to construct its moni- toring network of $PM_{2.5}$ pollutant, known as Taiwan Air Quality- monitoring Networks (TAQN) since late 2005. However, it is difficult to obtain a complete coverage over entire Taiwan with a limited number of ground stations because of high cost of a suite of instruments and facility maintenance. Spaceborne observations overcome such limitations and provide information of aerosol particles in the lower troposphere near the surface.

Many recent researches focused on examining the relationship between MODIS AOD and PM in various parts of the world with different spatial resolutions, such as in Hong Kong (1-km AOD) (Li et al., 2005a), Delhi (5-km AOD) (Kumar et al., 2007), and eastern US (5-km AOD) (Lewis et al., 2009), and modified aerosol optical properties (Li et al., 2005a). The presence of elevated aerosol layers can significantly affect the relationship. Engel-Cox et al. (2006) and He et al. (2006, 2008) pointed out that aerosol vertical profiles derived from lidar observations could improve the correlation between columnar AOD and surface measurements of PM or extinction. Thus it is important to test the assumption using collocated satellite, sunphotometer, lidar, and PM measurements. In this paper. We want to access the relationship between high special resolution satellite data-LANDSAT 7 AOD and PM to get a better relationship and apply to elevate air pollution level of Taiwan area.

2. Data

2.1 Landsat 7 level 1 data

The Landsat 7 data were acquired from Unite State Geological Survey(USGS) for the study period of 2010-2014 because of the availability of PM measurements in Taiwan. The LANDSAT 7 satellite overpass Taiwan one times on approximately on month. AOD (also denoted as τ_a) is most relevant to air quality, which is a dimensionless measure of scattering and absorption of sunlight by aerosols in the total vertical column from ground to the top of atmosphere. In this study, we used AOD at 0.52-0.6 μm wavelength from the Landsat 7 Band 2 channel aerosol products that retrieval by using Dispersion Coefficient Method (Sifakis and Deschamps,1992).

2.2 Ground-based measurements

The sunphotometer and lidar measurements are used in this study to validate the LANDSAT 7 aerosol products and explore detailed information of aerosol vertical distribution, we choose

TWEPA-NCU(National Central University) site (24.97°N, 121.18°E) for the co-existent MPLNET (Micro-Pulse Lidar Network) and AERONET measurements at the National Central University (NCU), which is located on the hillside of Shuanglian in northern Taiwan. The TWEPA-NCU lidar is co-sponsored and maintained by TWEPA and NCU as a part of TAQN.

The sunphotometer and lidar data were obtained from NASA website (http://aeronet.gsfc.nasa.gov) and (http://mplnet.gsfc.nasa.gov) for the study period. Sunphotometer measures the attenuation of direct solar radiation transverse in the atmosphere, providing the direct information of total columnar AOD in 16 bands from 0.34 to 1.64 mm wavelength (Holben et al., 2003). There are three quality levels (1.0, 1.5, 2.0) of data. The level 1.0 and 1.5 data are available daily in near real-time, while the level 2.0 products require final calibration and manual inspection.

Micro-pulse lidar (Spinhirne, 1993; Spinhirne et al., 1995) developed at NASA Goddard Space Flight Center (GSFC) in the early 1990s is a compact design and eye-safe lidar system, capable of determining the range of aerosols at the wavelength of 0.523-0.527 mm. The PBL height and vertical extinction (coefficient) profile data that we used in this paper were from the version 2 level 1.5 products in correspondence to AERONET sunphotometer measurements.

The hourly PM2.5, PM10, and relative humidity (RH) measurements are acquired from TAQN at Pingcheng station (24.95_N, 121.20_E). Pingcheng station is located within 3 km from EPA-NCU site, equipped with Verewa F-701 BAM (b-ray Attenuation Monitor) for continuous mass concentration measurements with uncertainty of 2% (http://www.durag.com/html/ems/emsmain.html), which automatically measures the concentration of PM10 and PM2.5 with a screening device and a mass calculation system.

3 Methodology

3.1 approaches

AOD is an integral form of aerosol extinction (scattering and absorption) with height from surface to the top of the atmosphere (TOA). Since the majority of aerosol abundance resides in the boundary layer, the thickness of boundary layer has direct impacts on the correlation between AOD and PM. Expressed below are the integral form of AOD (Eq. (1)) and an approximation of the relationship between AOD (s$_a$) and PM (Eq. (2)).

$$\tau_{a,0.55\mu m} = \int_0^{TOA} \rho(z)\sigma^{ext}_{0.55\mu m}(z)dz \quad (1)$$

$$PM \approx \frac{\tau_{a,0.55\mu m}}{\left[f(RH)\sigma^{ext}_{0.55\mu m,dry}\right]_{surface} L_{mix}} \quad (2)$$

where $\sigma_{a;\ 0:55\ \mu m}$ is AOD at 0.55 μm wavelength; ρ(z) is aerosol mass concentration (μg m^{-3}); $\sigma^{ext}_{0.55\mu m}(z)$ is aerosol extinction cross section per unit mass (m^2 μg^{-1}) at 0.55 mm; $f(RH)$ is hygroscopic growth factor; $\sigma^{ext}_{0.55\mu m,dry}$ aerosol extinction cross section per unit mass at surface relative to dry particles at 0.55 μm; L_{mix} is aerosol mixing layer height (km).

3.2 Aerosol profile

Boundary layer is the lowest part of the atmosphere, directly influenced by its contact with the Earth's surface. It responds to changes in surface forcing at the time scale of an hour or less. The development of boundary layer (so-called planetary boundary layer, PBL) is related to wind velocity, temperature, and moisture. Based upon the lidar measurements at TWEPA-NCU, two types of aerosol vertical distributions are generally seen (Fig. 1). The first type assumes that aerosols are confined and mixed homogeneously within boundary layer, so the values of AOD normalized by PBL height (PBLH) could be regarded as extinction (km^{-1}) as one measured at surface. In this condition, the correlation between PM and AOD/PBLH would be high. The second type is comprised of a uniformly mixed PBL and aerosol abundance above PBL. The haze layer height is the sum of PBLH and scale height assuming extinction decreases exponentially with altitude above PBL. In other words, scale height (H) represents the height of a uniform extinction layer above PBL that aerosol extinction coefficient decreases to 1/e of that at PBLH. Mathematically (Chu et al. 2013)

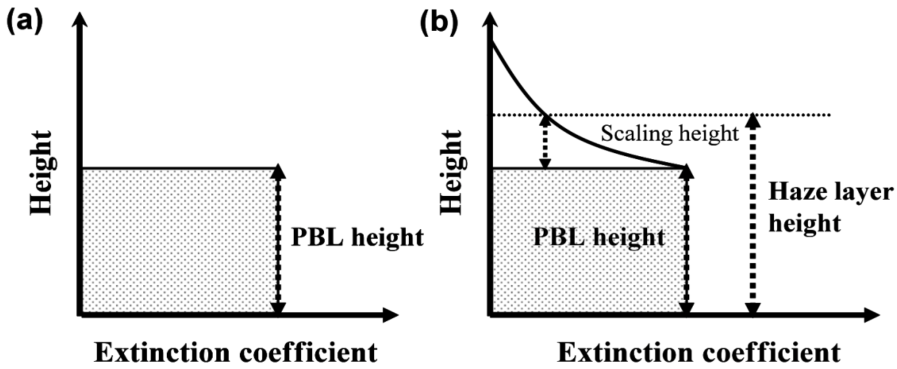

Fig. 1. Schematic aerosol vertical profile: (a) Type I, aerosols are well-mixed and confined in the PBL and (b) Type II, two-layer aerosol distribution characterized by aerosol well- mixed in the PBL and exponential decay of aerosol extinction coefficient with height above the top of the PBL.

4. Case study and discussion

The coincident measurements of sunphotometer, lidar, and PM at the research and operational site TWEPA-NCU of TAQN provide the baseline to assess the LANDSAT-7 derived AOD products for air quality monitoring in Taiwan. The pass research evident that aerosol vertical height is critical to the relationship between $PM_{2.5}$ and AOD. The strong seasonality of correlation reflects to high correlations obtained in autumn by normalizing AOD with boundary layer height (or equivalent haze layer height) as attributed to a stable and well-mixed boundary layer compared to the summer low values resulted from strong convective mixing associated with unstable weather systems.

The AOD retrieval by LANDSAT 7 Band 2 using Dispersion Coefficient Method with 15x15 pixel is looking good when compare with the AERONET TWEPA-NCU site (Table1). The AOD of 2012/07/10 is using the observation by AERONET.

Table 1

The AOD retrieval by LANDSAT 7 Band 2 at 2012/07/10 using Dispersion Coefficient Method with different pixel

	AOD(AERONET)	15x15	31x31	51x51
2012/07/10	0.1			
2010/3/31	0.934	0.9944	0.853	1.0617

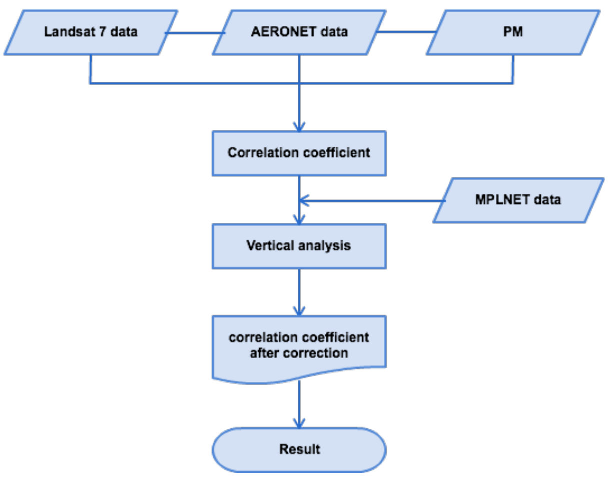

Fig2. Flow chart of research

We are going to follow the flow chat processing. After the AOD retrieval, we have to find the relationship between AOD and PM, because the aerosol is sensitive with high (most is PBLH), in other to acquire better correlation coefficient. it is necessary to analysis atmospheric vertical layer by the MPLNET data.

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