Using MTSAT-2 Visible Images to Retrieve Aerosol Optical Depth

Chien-Ben Chou

Central Weather Bureau, Taipei 10048, Taiwan

Huei-Ping Huang

School for Engineering of Matter, Transport, and Energy, Arizona State University, Tempe, AZ 85281, USA

Abstract

A geostationary satellite can provide observations at a higher frequency and with greater area coverage than an orbital satellite. This study uses data from geostationary satellite MTSAT-2 to retrieve the aerosol optical depth over eastern Asia. The 6S radiative-transfer model is used to generate a look-up table to facilitate the estimate of surface reflectance and retrieval of the optical depth of aerosols. A comparison of the optical depth retrieved from MTSAT-2 observations with the visibility measured at ground stations reveals a good match in their spatial patterns. The aerosol optical depth from MTSAT-2 is hence useful for monitoring the daily evolution and distribution of aerosols.

1. Introduction

Aerosols comprise of liquid or solid particles suspended in the atmosphere. The concentration of aerosols is an important indicator for air quality and its effects on human health (Brunekreef and Holgate 2002; Pope et al., 2002). Aerosols also play a significant role in Earth's radiative energy budget which has implications for climate. The 'direct effect' of aerosols on the radiative energy balance is through the scattering and absorbing of solar and longwave radiation by the aerosols themselves (Charlson et at., 1992). The 'indirect effect' involves the changes in the formation and the optical properties of clouds by cloud microphysical processes with aerosols serving as nuclei for cloud condensation (Rosenfeld and Lensky, 1998).

Aerosols can be generated by natural or anthropogenic processes and their ingredients include a wide range of materials, from sea salt, dust, black carbon, organic carbon, to sulfate and smoke. The aerosol concentration can vary widely in its distribution of shape and size, and vertical profile. The heterogeneous sources generally lead to significant variability of aerosol concentration in space and time, making it particularly challenging for high-quality observations over a large area. With this background, this study explores the possibility of using the observations from a geostationary satellite to derive aerosol optical depth. The potential advantage of this approach is the greater spatial resolution and area coverage associated with a geostationary satellite, as compared to an orbital satellite. The data from geostationary satellite MTSAT-2 will be used for the retrieval of the aerosol optical depth.

2. Method and data

Most retrieval methods for estimating the optical depth of aerosols are based on the formula (Kaufman et al., 1997):

$$R_{sat}(\mu, \varphi, \mu_o, \varphi_o) = R_{atm}(\mu, \varphi, \mu_o, \varphi_o) + T_{atm}(\mu_o)\, T_{atm}(\mu) R_{surf} / (1 - R_{surf}\, S_\lambda) \quad , \qquad (1)$$

where R_{sat} is the apparent reflectance observed by the satellite at the top of the atmosphere, μ and μ_o are cosines of the satellite view and solar zenith angle, φ and φ_o are azimuth angles of the satellite view and solar path, R_{atm} is the reflectance contributed from the entire layer of the atmosphere that includes atmospheric molecules and the aerosol effect, $T_{atm}(\mu)$ is the upward transmission to the direction of satellite observation, $T_{atm}(\mu_o)$ is the downward transmission from the solar direction, R_{surf} is the surface reflectance (assuming a Lambertian surface), and S_λ is the atmospheric back-scattering ratio. In Eq. (1), $R_{atm}(\mu, \varphi, \mu_o, \varphi_o)$ can be written as the sum reflectance of aerosol and molecules (Rayleigh scattering) in the atmosphere:

$$R_{atm}(\mu, \varphi, \mu_o, \varphi_o) = R_{aerosol}(\mu, \varphi, \mu_o, \varphi_o) + R_{Ray}(\mu, \varphi, \mu_o, \varphi_o) \quad . \qquad (2)$$

Replacing the $R_{atm}(\mu, \varphi, \mu_o, \varphi_o)$ in Eq. (1) with Eq. (2) and rearranging the equation, we arrive at an expression for the reflectance of aerosol in terms of all other quantities:

$$R_{aerosol}(\mu, \varphi, \mu_o, \varphi_o) = R_{sat}(\mu, \varphi, \mu_o, \varphi_o) - R_{Ray}(\mu, \varphi, \mu_o, \varphi_o) - T_{atm}(\mu_o)\, T_{atm}(\mu) R_{surf} / (1 - R_{surf}\, S_\lambda) \quad . \qquad (3)$$

By running a forward radiative transfer calculation (using the 6S package) with a suitable aerosol model, one can obtain the dependence of $R_{aerosol}$ (which can be converted to the aerosol optical depth) on the apparent reflectance measured by satellite (R_{sat}) and the surface reflectance (R_{surf}). For each given set of the angular parameters, ($\mu, \varphi, \mu_o, \varphi_o$), one can build a look-up table for determining the aerosol optical depth from the apparent reflectance and the surface reflectance. Moreover, if the surface reflectance is pre-determined by other means, the aerosol optical depth can be estimated from the look-up table as a function of the apparent reflectance from satellite observation. We will use this strategy through this study.

An example of a look-up table is shown in Figure 1. It is constructed by running the 6S radiative transfer code with an aerosol model combining 6 % dust-like, 90 %

water-soluble and 4 % soot (personal communication with Gao Ling, Laboratory for Climate and Ocean-Atmosphere Studies, Department of Atmospheric and Oceanic Science, School of Physics, Peking University, Beijing 100871, China; National Satellite Meteorological Center, Beijing 100081, China). Shown in Fig. 1 is the relation between the apparent reflectance and aerosol optical depth for different values of surface reflectance, and for particular values of (μ, φ, μ_o, φ_o) as indicated in the figure. It is found that under the condition of small surface reflectance (or "dark target") aerosol optical depth increases with apparent reflectance. Under such a condition, the look-up table is useful for estimating aerosol optical depth from the satellite-observed apparent reflectance.

Our procedure requires the prior knowledge of surface reflectance such that aerosol optical depth can be uniquely determined from apparent reflectance in the look-up table. For this purpose, we pre-determine the surface reflectance based on the assumption that the value of surface reflectance at a given hour of the day varies little over a 30-day period. Moreover, during the 30-day period there will almost always be at least a day when the target location is under clear-sky condition, which allows us to determine the surface reflectance from the visible channel. In practice, we pick the second minimum value from the visible channel to avoid the shading effect.

In the procedure described above, to take into account the attenuation effect of aerosol we assume that the aerosol optical depth is 0.05 under the clear sky condition (assuming that only natural background aerosol is present). We then estimate the surface reflectance (removing the atmosphere and aerosol effect) from the satellite-observed apparent reflectance, again using a look-up table. An example, shown in Figure. 2, indicates that with a given aerosol optical depth and a fixed set of solar and satellite-view angles there exists a linear relation between apparent reflectance and surface reflectance. Each line in Fig. 2 corresponds to a given value of aerosol optical depth. The one with light-blue color is with the optical depth set to 0.05, which we will use to determine surface reflectance from the satellite-observed apparent reflectance.

Figure 3 shows an example of the estimated surface reflectance over East Asian for January 2014. Figure 4 further shows the surface reflectance at particular hour of the day from 00 to 08 UTC. High values of surface reflectance are found over northern China and Mongolia, due to desert-type of land cover and possibly snow cover. In those areas, the high surface reflectance would make it undesirable to use our procedure to retrieve aerosol optical depth from apparent reflectance.

The calculations in Section 3 will use the MTSAT-2 data from the CLAVR-x output. They include the observations from the MTSAT-2 visible and infrared channels and contain other useful information created by the CLAVR-x system. The latter includes parameters such as solar zenith and azimuth angles, satellite-view zenith and azimuth angles, cloud mask, sun glint, and snow cover. All are useful for the retrieval of the aerosol optical depth.

3. Results

A case of retrieval of aerosol optical depth for January 17, 2014, is shown in Figure. 5. For this date, ground-based measurements of visibility are available at 0000, 0300 and 0600 UTC at selected sites. They are superimposed on the map of the estimated aerosol optical depth. In panels (a), (d), and (g) of Figure. 5 we find that the sites with observed low visibility broadly match the areas with high aerosol optical depth. A notable exception is over the Indochina peninsula, possibly due to prolonged presence of haze in that area which affected our estimate of the surface reflectance. The reason for this phenomenon might be incorrect surface reflectance due to the duration of haze covering the Indochina peninsula.

Figure 6 compares two cases of retrieved aerosol optical depth (left panels) with the associated imagery from the visible channel (right panels). The low-visibility areas match the areas with large values of aerosol optical depth. Those areas with large aerosol optical depth correspond to the clear-sky pixels in the visible imagery with large reflectance.

Lastly, Figure. 7 shows a comparison of MTSAT-2 retrieved aerosol optical depth and its counterpart from the measurements using ground-based sun photometers (AERONET) at Taipei and Chiayi City in Taiwan. The retrieved aerosol optical depth is the average over a 10 x 10 Km box, after removing the top 5% largest values to alleviate cloud effect. The time difference between ANERONET and satellite observation is less than a half hour. A positive correlation is found between the satellite retrieval and ground-based observation. Again, this indicates the potential of using the MTSAT-2 product for monitoring aerosol optical depth. The bias as shown in Figure. 7 could be used to calibrate the satellite retrieval, if a large number of ground-based observations are available.

4. Remark

In this study, aerosol optical depth over a large area is retrieved from geostationary satellite observations using a look-up table generated by running a radiative transfer code. The results indicate the potential of this approach for monitoring aerosol concentration over regions with relatively low surface reflectance. This approach takes advantage of the relatively high temporal resolution and large area coverage of a geostationary satellite, compared to an orbital satellite. This work uses the data from MTSAT-2. The approach developed here could be applied to newer instruments such as Advanced Himawari Imager (AHI) on board Himawari-8.

References

Brunekreef, B., and S. T. Holgate 2002: Air pollution and health. Lancet, **360,** 1233-1240.

Charlson, R. J., S.E. Schwartz, J.M. Hales, R. D. Cess, J.A. Coakley, J.E. Hansen, and D.J.. Hofmann, Climate forcing by anthropogenic aerosol, Science, 255, 423-430, 1992.

Kaufman, Y. J., Tanre, D., Remer, L. A., Vermote, E. F., Chu, A., and Holben, B. N.: Operational remote sensing of tropospheric aerosol over land from EOS moderate resolution imaging spectroradiometer, *J. Geophys. Res*., **102**, 1751-17067, doi:10.1029/96JD03988, 1997.

Pope, C Arden; et al., Cancer, cardiopulmonary mortlity, and long-term exposure to fine particulate air pollution, J. Amer. Med. A1132-1141, doi:10.1001/jama.287.9.1132,2002

Rosenfeld, D., and I.M. Lensky, Satellite-based insights into precipitation formation processing in continental and maritime convective clouds, Bukk. Am. Met. Soc., &9, Met. Soc., 79, 2457-2476, 1998.

Figures and captions:

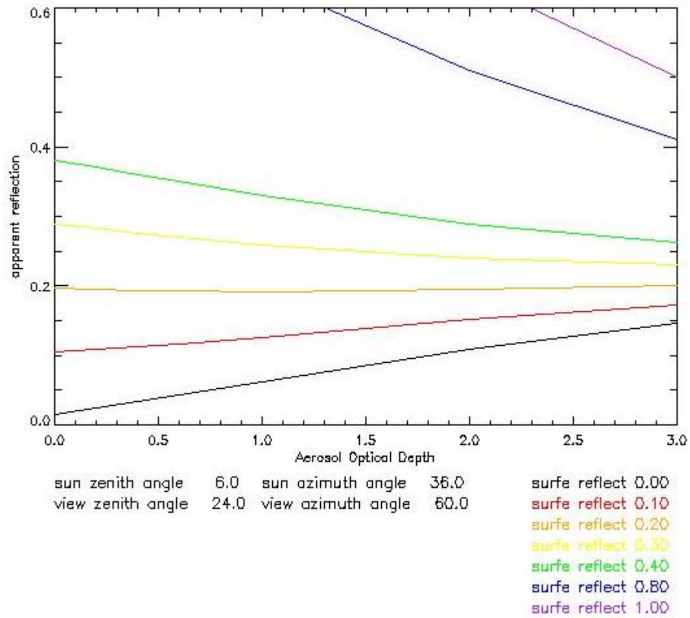


Figure 1. An example of a look-up table that show the relation between aerosol optical depth and apparent reflectance. The lines of different colors correspond to different values of surface reflectance. This example is for a particular set of solar and satellite-view zenith and azimuth angles, as indicated in the bottom of the plot.

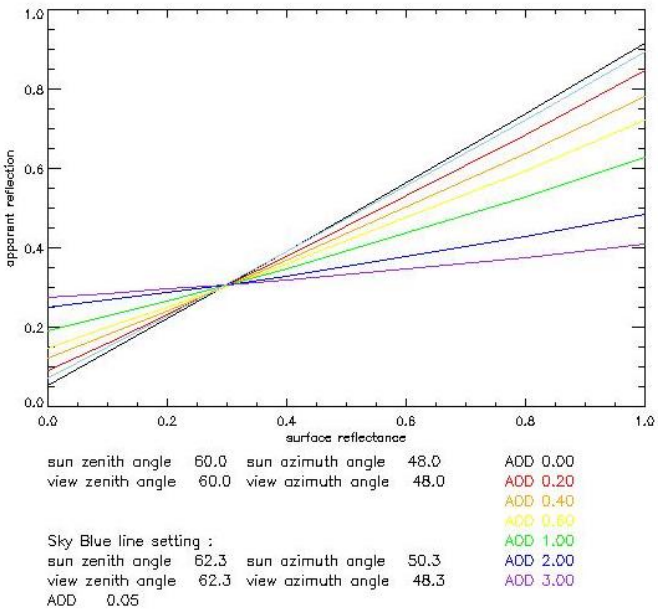
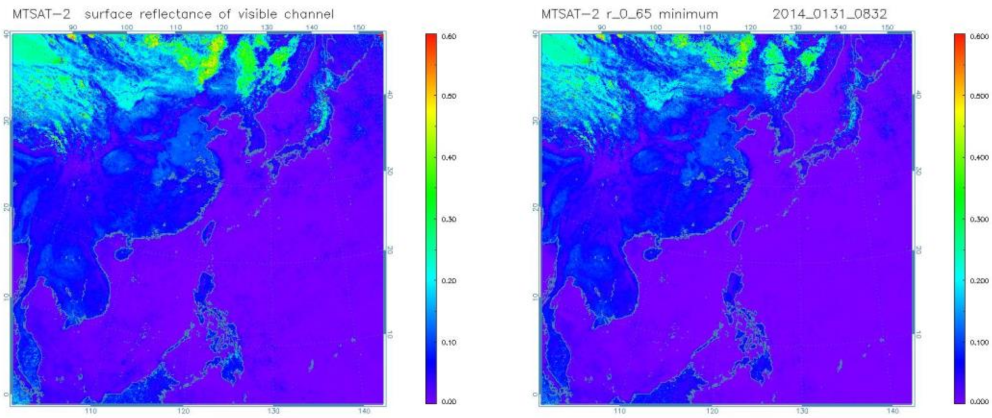
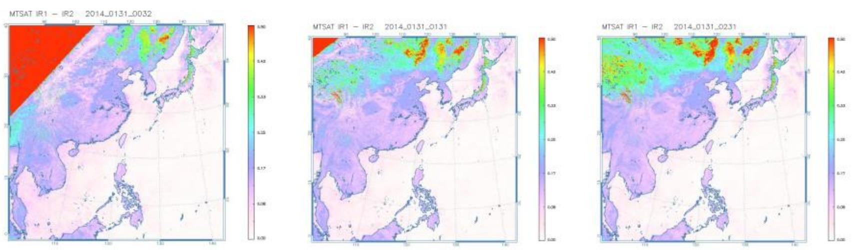


Figure 2. An example of a look-up table in the same format as Fig. 1 but for extracting the relation between surface reflectance and apparent reflectance. The different colors indicate different given values of aerosol optical depth. The light-blue line represents the case when aerosol optical depth is set to 0.05.

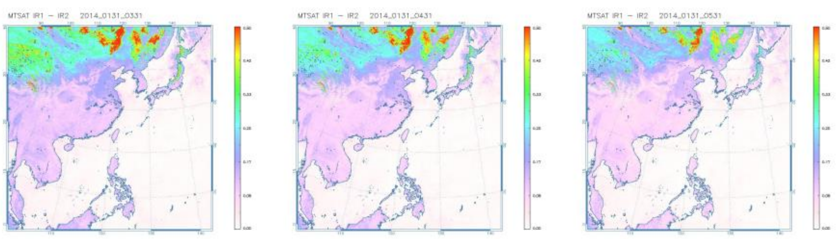


(a) (b)

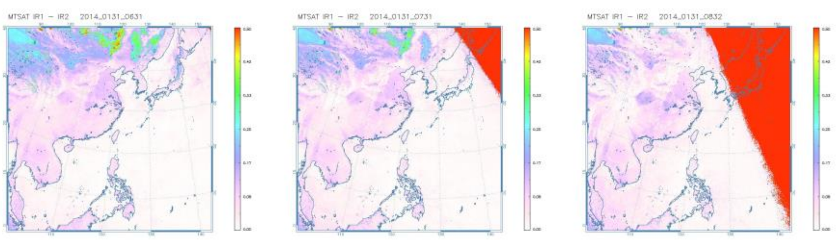
Figure 3. (a) Surface reflectance for January 2014 as estimated from the second minimum value. (b) Minimum value of surface reflectance. Both use a look-up table to correct the atmospheric effect with aerosol optical depth set to 0.05.



(a) (b) (c)

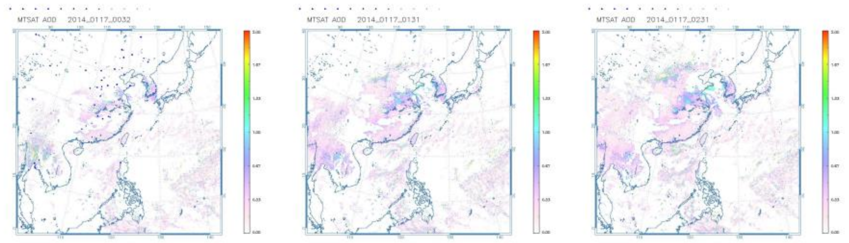


(d) (e) (f)

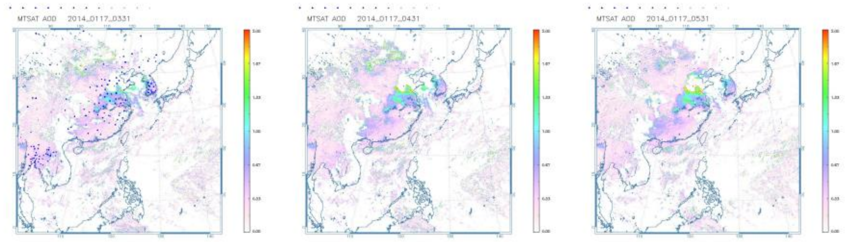


(g) (h) (i)

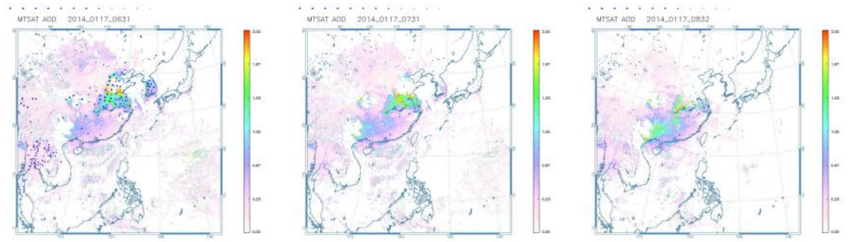
Figure 4 Estimated surface reflectance for January, 2014. From (a) to (i) are the reflectance at particular times of the day, from 0000 to 0800 UTC step 1 hour. The maximum of color bar is 0.5 and minimum is 0.



(a) (b) (c)

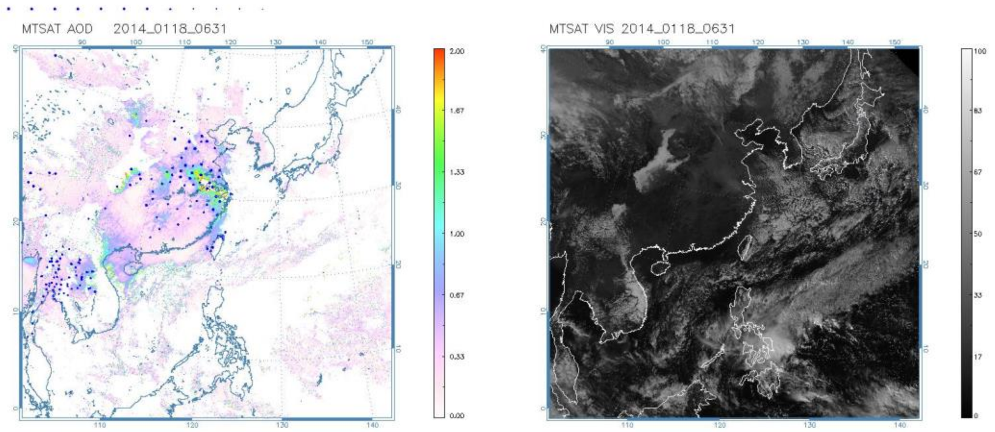


(d) (e) (f)

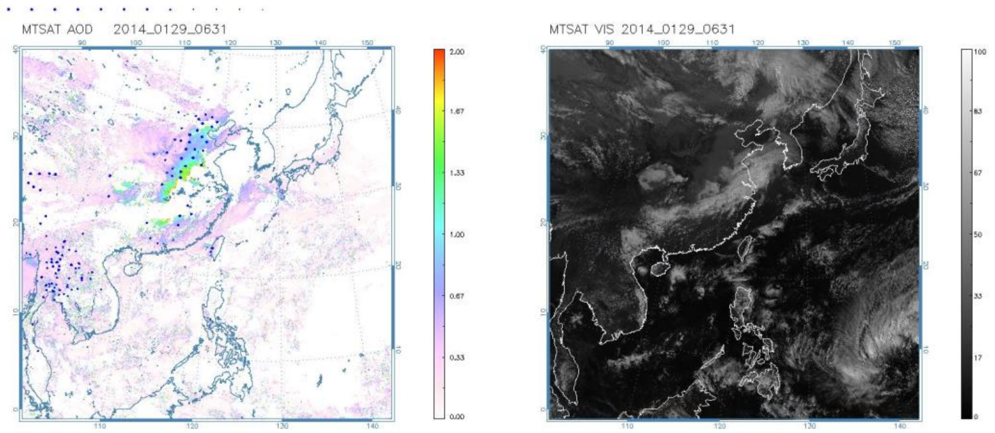


(g) (h) (i)

Figure 5 Retrieved aerosol optical depth for January 17, 2014. From (a) to (i) are the hourly maps from 0000 to 0800 UTC. Blue dots represent the observations of visibility from ground stations. The largest dot indicates visibility less than 1 km, second largest indicates visibility less than 2 km, and so on. The maximum value of color bar is 2.0 and minimum is 0.

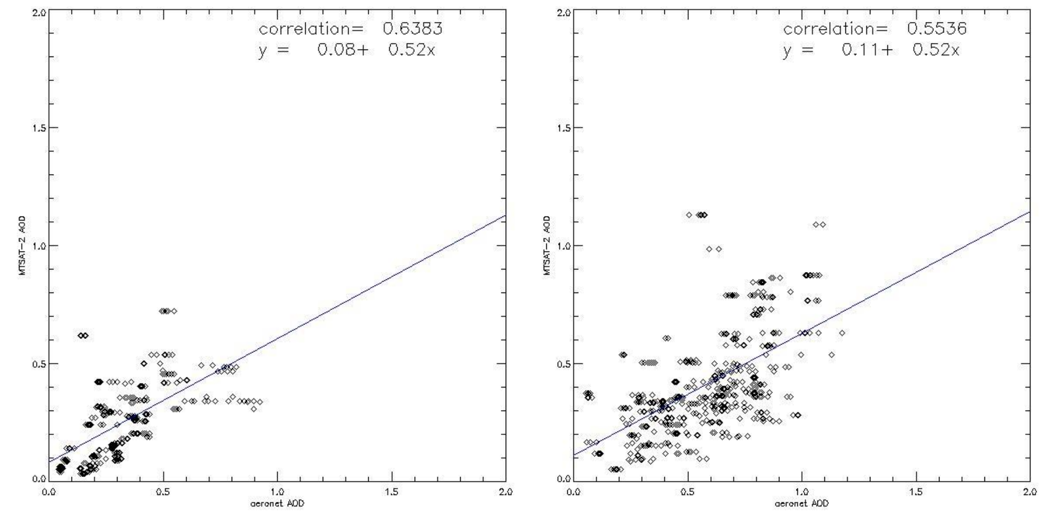


(a) (b)



(c) (d)

Figure 6 (a) Retrieved aerosol optical depth for January 18, 2014, at 0631 UTC. Blue dots represent the observations of visibility from ground stations. The largest dot indicates visibility less than 1 km, second largest indicates visibility less than 2 km, and so on. (b) Visible channel imagery. Figures (c) and (d) are same as (a) and (b) but for January 29, 2014, at 0631 UTC.



(a) (b)

Figure 7 (a) Comparison of the aerosol optical depth retrieved from MTSAT-2 data and its counterpart from AERONET (0.55ν m) observation at Chiayi City in Taiwan. (b) Same as (b) but for Taipei City.