Weather and Environmental Monitoring
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ABSTRACT

The Hong Kong Observatory (HKO) provides weather forecasting and warning services in Hong Kong. HKO makes extensive use of remote sensing technology in operating its weather services. In mid-2004, HKO installed a ground reception system for receiving direct broadcast data from MODerate resolution Imaging Spectroradiometer (MODIS) on-board NASA’s Earth Observing System (EOS) series of satellites. MODIS has 36 observational channels, covering a wide frequency spectrum ranging from visible to infra-red frequencies. This paper provides an account on the operational applications of MODIS data and products in weather and environmental monitoring in Hong Kong.

INTRODUCTION

In mid-2004, the Hong Kong Observatory (HKO) started receiving image data of MODIS from NASA’s EOS series of polar-orbiting satellites. The key features of MODIS are its large number of observational channels and its high-resolution imagery. MODIS has altogether 36 observational channels spanning from visible to infra-red frequencies. Resolution of imagery is as high as 250 m for bands 1-2, 500 m for bands 3-7 and 1000 m for bands 8-36. These features of MODIS data are useful in a number of disciplines such as meteorology, oceanography as well as environmental monitoring.

HKO generates a number of products from MODIS data such high resolution true colour imagery, sea surface temperature plot, chlorophyll concentration plot, vegetation index picture, thermal anomaly points and aerosol optical depth plots to support weather forecasting and environmental monitoring. Among these, the aerosol optical depth (AOD) imagery depicts the concentration of aerosols in the atmosphere. AOD is a measure of aerosol loading in the atmosphere. In general, a higher AOD value
indicates higher column of aerosol loading and hence lower visibility (Wang and Christopher, 2003). As such, AOD imagery of MODIS is useful for visibility monitoring. Research results (Li et al., 2005) indicate that AOD is correlated with the mass concentration of PM10 (particulate matter with diameter less than 10 µm) and is useful for air pollution monitoring.

Hong Kong is located on the southern coast of China. In Winter and Spring seasons, relatively dry and cool northeast monsoon prevails over the region. The relatively stable atmospheric condition favours formation of haze, leading to reduced visibility in Hong Kong (Li and Yung, 2005). The degree of visibility reduction is closely tied with the concentration of aerosols in the atmosphere.

CORRELATION BETWEEN AOD AND VISIBILITY

Generally speaking, high value of AOD suggests high concentration of aerosols. More aerosols in the atmosphere scatter off light more effectively, hence resulting in lower visibility. In the following, AOD data from MODIS are compared with the visibility data at the Hong Kong Observatory (HKO) headquarters for the period from October 2004 to January 2005 to illustrate their correlation.

Visibility is the greatest distance at which a black object of suitable dimensions can be seen and recognized against the horizon sky during daylight or could be seen and recognized during the night if the general illumination were raised to the normal daylight level. Sometimes visibility is not uniform in the horizontal direction. For weather reporting, visibility represents the lowest value in the horizontal direction (WMO, 1996).

MODIS AOD data are the aerosol optical depth values for the wavelength at 0.55 µm. The spatial resolution of AOD data is 10 km x 10 km. For the purpose of comparison, AOD value is taken at the pixel in the AOD imagery covering the HKO headquarters.

According to Qui (2003), AOD can be related to visibility by a simple expression:

\[
\text{AOD} = \frac{C_1}{V}
\]

where V is the visibility and C₁ is a constant. This equation can be expressed as:
\[ V = C_2 \tau \]

where \( \tau \) is \( 1/\text{AOD} \) and \( C_2 \) is a constant. This means that visibility is proportional to \( \tau \).

Figure 1 shows a time-series plot of visibility \( V \) and \( \tau \). It can be observed that the variation in visibility follows quite well with the variation in \( \tau \). For instance, the sudden decrease in \( \tau \) in late October 2004 followed closely the fall in visibility values. This result in Figure 1 is similar to the result from a study by Goddard Institute of Space Studies (Solis, 1999).

To illustrate the correlation between visibility \( V \) and \( \tau \), values of \( V \) and \( \tau \) are plotted in a scatter diagram in Figure 2. The correlation coefficient between \( V \) and \( \tau \) is somehow low at 0.38. There are several reasons for the weak correlation (Ichoku, 2002). First of all, the MODIS AOD data represents a spatial average over a pixel area of 10 km x 10 km, whereas visibility is observed at a single location. Secondly, visibility reading represents the lowest value in the horizontal direction and so may not represent the averaged conditions over an area of 10 km x 10 km. Thirdly, AOD (the inverse of \( \tau \)) is measured in the vertical sense, i.e. from the satellite to the ground surface, whereas visibility is observed horizontally. Fourthly, AOD and visibility are not observed at exactly the same time. All the above factors contribute to difference between visibility and \( \tau \) and therefore their weak correlation.

While the correlation between visibility and \( \tau \) is not high, the temporal variation in \( \tau \) matches reasonably well with the variation in visibility. The latter result is still useful for weather monitoring, in particular, in monitoring the trend in visibility change. The next section illustrates how AOD imagery is applied to weather monitoring.

**APPLICATIONS OF AOD IMAGERY IN HONG KONG**

AOD imagery is provided to weather forecasters for weather monitoring. The imagery is colour-coded to represent different values of AOD (see sample in Figure 3(a)). Lower values of AOD are depicted in blue and green colours (AOD value of 0.4 or below). This in general represents region with higher visibility. Higher values of AOD are represented in red and yellow colours (AOD value of 0.7 or above). This outlines region with lower visibility.
Using the linear regression line for visibility and $\tau$ in Figure 2 as reference, AOD value of 0.4 or below (i.e. $\tau$ of 2.5 or above) is translated to visibility of 10 km or above, indicating generally good visibility condition. AOD value of 0.7 or above (i.e. $\tau$ of 1.4 or below) is translated to visibility of 8.8 km or less, representing reduced visibility condition. Although the correlation between visibility and $\tau$ is not high, the linear regression equation so obtained does provide a reasonably good indication of high (low) visibility against low (high) value of AOD.

Figures 3(a) to 3(c) illustrate an example of application of AOD imagery. On 30 October 2004, an easterly airstream prevailed over Hong Kong, holding off an area of haze (in red and yellow colours in Figure 3(a)) to the northwest. AOD value over Hong Kong was low, generally less than 0.4 and visibility at HKO headquarters was well above 10 km, occasionally reaching 23 km that day. Meanwhile, AOD value over the Pearl River Delta was higher than 0.7. In fact, visibility at Guangzhou dropped to a low of 2500 m.

On 31 October 2004 (Figure 3(b)), the easterly winds around Hong Kong abated. The region of haze spread south but remained outside Hong Kong. AOD value over Hong Kong remained low of less than 0.4 and visibility at HKO headquarters still exceeded 10 km. In Guangzhou, the AOD value was higher than 0.7. Visibility there was low with a minimum of 2000 m.

As winds turned to the north on 1 November 2004 (Figure 3(c)), haze spread further south to cover Hong Kong. AOD value over Hong Kong rose above 0.7. Visibility at HKO headquarters dropped below 10 km, down to 3000 m in places during that day.

The above example indicates that AOD imagery provides a general picture of aerosol concentration in and around Hong Kong. Successive AOD images indicate the general evolution and movement of haze area, facilitating the monitoring of reduced visibility.

**FORECAST OF REDUCED VISIBILITY**

One possible enhancement in application of AOD is to forecast reduced visibility due to haze by forecasting the evolution and movement of regions of haze. To achieve this, a suitable dispersion model may be necessary. Yet a simple combination of AOD
image with forecast winds from numerical weather prediction model may also give clue to change in visibility. To demonstrate this, we use the example in the previous section and concentrate on the drop in visibility in Hong Kong from 31 October 2004 to 1 November 2004. The model we adopted is the Operational Regional Spectral Model (ORSM) of the Hong Kong Observatory. This is a regional spectral model with a horizontal resolution of 20 km and with 36 vertical layers covering a domain of 10-35°N and 100-128°E.

Figure 4(a) is the model output of ORSM for 11 p.m. on 31 October 2004 based on model run of 11 a.m. on 31 October 2004. This model run is chosen because its start time is closest to the time of the AOD image in Figure 3(b) on 31 October 2004. Figure 4(b) is the model output for 11 a.m. on 1 November 2004 based on the same model run. These two model outputs provide the predicted winds near Hong Kong from the early hour to the early afternoon of 1 November 2004. The forecast wind for 11 p.m. on 31 October 2004 was 5 knots from the east (095 bearing) while the forecast wind for 11 a.m. on 1 November was 5 knots from the northwest (320 bearing).

Assuming that there was no significant dispersion of aerosols during transportation by winds such that the aerosol concentration did not change significantly, we can then use the model predicted winds to ‘back-track’ the region of high AOD values that was transported to Hong Kong on 1 November 2004. Based on the forecast winds and the AOD image in Figure 3(b), the back-tracked AOD values that would be ‘transported’ to Hong Kong were 0.24 for 11 p.m. on 31 October 2004 and 0.86 for 11 a.m. on 1 November 2004 (see Figure 3(b)). This suggests that AOD values would increase from a low of 0.24 (less than 0.4, indicating good visibility) at 11 p.m. on 31 October 2004 to a high of 0.86 (more than 0.7 indicate a reduced visibility trend) at 11 a.m. on 1 November 2004. As a matter of fact, the visibility at the HKO headquarters was over 10 km around 11 p.m. on 31 October 2004 but fell to 6 km at 11 a.m. on 1 November 2004.

The example above indicates the AOD imagery can be used to forecast the trend in visibility change by coupling with numerical weather prediction model output.

[Note: It is noted that aerosol concentration does change during wind transportation, but the above assumption is good enough for the purpose of illustrating the use of AOD imagery for assessing changes in visibility.]
CONCLUDING REMARKS

The large number of observational channels of MODIS provides valuable data for a number of disciplines including meteorology, oceanography as well as environmental monitoring. One potential application is in visibility monitoring. AOD data are found to provide reasonably good indication of visibility. In combination with predicted winds from numerical weather prediction models, AOD data are useful for assessing variation in visibility.

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REFERENCES


Figure 1 Time series of visibility at the HKO headquarters and $\tau$ from October 2004 to January 2005
Figure 2 Plot of visibility at HKO headquarters against $\tau$ from October 2004 to January 2005

Figure 3(a) AOD image at 11:32 a.m. on 30 October 2004. Easterly winds prevailed over Hong Kong, holding off the haze (in red and yellow colours) to the northwest.
Figure 3(b) AOD image at 10:37 a.m. on 31 October 2004. Easterly winds over Hong Kong weakened. Haze over the Pearl River Delta spread south but still outside Hong Kong. Point A is the ‘back-tracked’ location based on wind of 095/5kt for 11 p.m. on 31 October 2004 and Point B is the ‘back-tracked’ location based on wind of 320/5kt for 11 a.m. on 1 November 2004.

Figure 3(c) AOD image at 11:20 a.m. on 1 November 2004. Haze spread south to cover Hong Kong as winds turned to the north.
Figure 4 (a) 12 hour forecast for 11 p.m., 31 October 2004 by HKO’s ORSM.

Figure 4 (b) 24 hour forecast for 11 a.m., 1 November 2004 by HKO’s ORSM.