Using Koschmieder theory to develop a simple proxy for suspended dust concentrations based on visual range

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Dust storms are a frequent occurrence in the Mediterranean region. Cyprus recently experienced a dust event during early September 2015, with PM$_{10}$ concentrations reaching 7.6 mg/m^3 in Limassol on the 8th September. During other global dust events, PM$_{10}$ concentrations reached 12 mg/m^3 in Beijing in March 2002 (Zhang et al., 2002), and 15.4 mg/m^3 near Sydney in September 2009 (Leys et al., 2011). Although analytical techniques are required to estimate PM concentrations accurately, simplified methods for determining the concentration of suspended dust concentrations based on visual range (x_v) would be highly attractive. Development of such a metric would enable distributed estimates of dust concentrations to be made.

Figure 1. Northwards view at 15:40 PM (UTC) from CyI in Nicosia, Cyprus (7th September 2015). The PM$_{10}$ concentration is approximately 3 mg/m^3. Visual range is about 500 m.

The Koschmieder equation (Koschmieder, 1924) establishes a relationship between visual range and the extinction co-efficient through simplifications to the radiative transfer equation. Assuming a threshold contrast of ε=0.02, it is given by:

$$b_{ext} = \frac{\ln \varepsilon}{x_v} \approx \frac{3.912}{x_v}. \qquad (1)$$

For monodisperse aerosols, the extinction coefficient is given by (Finlayson-Pitts and Pitts, 2000):

$$b_{ext} = nA_pQ_{e,} \qquad (2)$$

where n is the particle number concentration, A_p is the cross sectional area of the particle and Q_e is the single-particle extinction efficiency. Setting b_{ext} from Eq. 2 to the result of Eq. 1, assuming spherical particles, multiplying both sides by $\rho D_p/2$ and integrating across all particle diameters yields:

$$\underbrace{\frac{\rho\pi}{8}\int_0^\infty nD_p^3 dD_p}_{TSP} = \frac{3.912\rho}{2x_v}\int_0^\infty \frac{D_p dD_p}{Q_e}, \qquad (3)$$

where *TSP* denotes total suspended particulate mass.

Dust storms are characterised by particles that are much larger than the wavelength of light (Jayaratne et al. 2011). Geometric scattering is predominant for super-micron particles with Q_e (Jung and Kim, 2007) given by:

$$Q_e = 2\left\{1 + \left(\frac{\pi d_p}{\lambda}\right)^{-\frac{2}{3}}\right\}, \qquad (4)$$

Here λ is the wavelength of light which we assume to be 0.5 μm. This wavelength corresponds to the maximum intensity for incident radiation (Seinfeld and Pandis, 2006).

Also, by assuming a particle density of 2.65 g/cm^3 (representative of quartz) and a mean particle size of 2 μm, total suspended particulate mass can be predicted in the monodisperse case (TSP_{mono}) via:

$$TSP_{mono} = \frac{4374}{x_v}. \qquad (5)$$

After integrating Eq. 3 numerically, total suspended particulates in the polydisperse case (TSP_{poly}) can be predicted by:

$$TSP_{poly} = \frac{1296}{x_v}. \qquad (6)$$

Predictions of TSP from x_v were compared with observations of PM$_{10}$ from air quality monitoring stations (Table 1).

Table 1. Comparison of observations of PM$_{10}$ in Nicosia with Eqs. 5 and 6 based on rough estimates of visual range.

Visibility	**x_v (m)**	**TSP$_{mono}$ (mg/m^3)**	**TSP$_{poly}$ (mg/m^3)**	**PM$_{10}$ mg/m^3**
fair	2000	2.2	0.65	0.23
poor	1000	4.4	1.3	0.55
very poor	500	8.7	2.6	3.1

Predictions are in reasonable agreement with observations in the polydisperse case, showing that visual range can be used as a proxy for estimating dust concentrations by making some simplifying assumptions.

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