GIS-based Evaluation of Diffusion Mechanism of PM2.5 in East Asia

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1 Background and objective

Recently, flying tiny particulate matter, PM2.5 is attracting much attention in Japan. Japan Meteorological Agency predicted yellow sand from China would fly to Japan islands, and PM2.5 is considered to be related with the yellow sands which diffuse from the north of China to Japan.

We proposed a MODIS false-color composite image method that consists of an aerosol enhancement reflectance index and a water index. By using the surface reflectance data of MODIS (MODerate-resolution Imaging Spectro-radiometer), the movement of air pollutants was clearly recognized with a time-series analysis of MODIS false-color images. On the other hand, with the observations of PM2.5 and meteorological data in Kyushu area, the ADMER (Atmospheric Dispersion Model for Exposure and Risk Assessment) model was available for a long-term assessment of average distribution of PM2.5 in Kyushu area. Comparing the false-color images and calculating results, the authors evaluated the diffusion mechanism of PM2.5 in Kyushu area.

2 Composition of false-color images based on GIS

Remote sensing technology is useful for the near real-time monitoring of air pollutants, and the interpretation of moderate resolution imaging spectro-radiometer (MODIS) true-color images is a common technique for conducting the real-time monitoring of air pollutants.

We proposed a new MODIS false-color composite image method that consists of an aerosol enhancement (AE) reflectance index and a water index (WI).

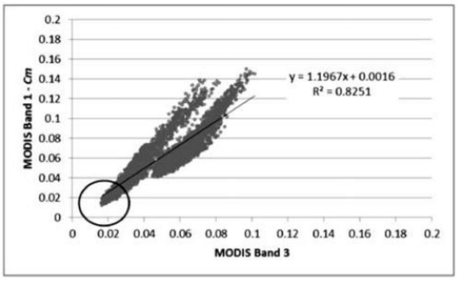


Fig.1 Band matching by wind speed (m/sec) and the frequency (%) of each direction.

2.1 Aerosol enhancement

By using MODIS data, we calculated the AE that shows the reflectance of aerosol.

$$AE = 2.0 * B3 - (B1 - Cm) \quad (1)$$

where, Cm is the modified minimum offset of band 1 and band 3.

2.2 Water index

Water index was calculated by using Thick Cloud Index (TCI), Aerosol Vapor Index (AVI), Normalized Difference Water Index (NDWI) and Normalized Difference Snow Index (NDSI), utilizing the following equations.

$$TCI=-1.0/(290-265)*BT32+11.6 \quad (2)$$

$$AVI = BT31 - BT32 \quad (3)$$

$$NDWI=(B2-B5)/(B2+B5) \quad (4)$$

$$NDSI=(B4-B7)/(B4+B7) \quad (5)$$

$$wi_{TCL} = TCI \quad (6)$$

$$wi_{AVI} = -\frac{1.0}{\exp(0.08*BT31-23.2)+1.0} * AVI \quad (7)$$

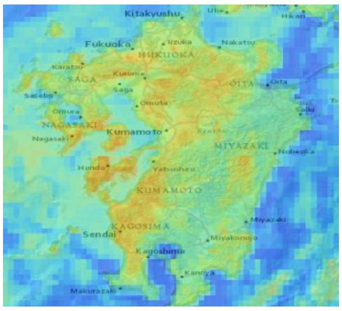
$$wi_{NDWI} = 1.8 * NDWI * landmask \quad (8)$$

$$wi_{NDSI} = 1.2 * NDSI * landmask \quad (9)$$

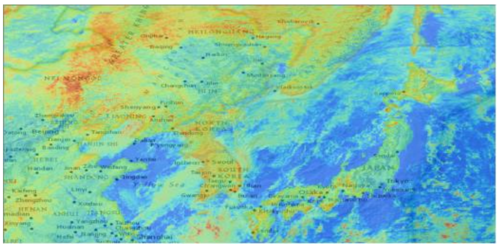
$$WI = \max(wi_{TCI}, wi_{AVI}, wi_{NDWI}, wi_{NDSI}) \quad (10)$$

2.3 False-color image

After the calculation of AE and WI, the authors used AE as R plain and G plain, WI as B plain to plot the RGB color image (Fig.2).



(a) False-color in Kyushu area



(b) False-color in East Asia

Fig.2 False color composite images.

3 Diffusion model based on ADMER

3.1 Study area

Kyushu area (latitude 30.55.00 N to 34.17.30 N and longitude 128.15.00 E to 132.11.15 E) was selected as a study area. A total of seven prefectures (Nagasaki, Saga, Fukuoka, Oita, Miyazaki, Kagoshima, and Kumamoto), as a calculation area for ADMER, were considered for simulation of the distribution of regional PM2.5 concentrations.

3.2 Emission data

The source of PM2.5 emission was assumed as a point source. 10 points located across the Kyushu area were considered in the calculation. The value of emissions per square meter per second referred to the observation data from the website of Ministry of the Environment Government of Japan (Fig.3).

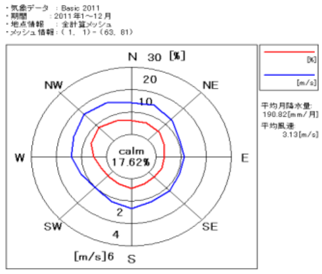


Fig.3 The annual wind rose of the point source area in 2011. Blue and red lines indicate annual mean

Table 1. Atmospheric stability

Atmospheric stability	A	B	C	D	E	F
Suburbs	0.07	0.07	0.1	0.15	0.35	0.55
Urban	0.15	0.15	0.2	0.25	0.3	0.3
Mixing layer height	600m	500m	400m	200m	70m	70m

3.3 Concentration calculation

Emission calculation was carried out in two ways. When the wind speed was less 1 m/s, the puff model was adopted. When the wind speed was more than 1 m/s, the plume model was adopted. The Puff model and Plume model are:

Puff model: $$c_0 = \int_0^t \frac{q}{2\pi h \sigma_y^2} \exp\left(-\frac{x^2+y^2}{2\sigma_y^2}\right) dt \quad (11)$$

Plume model: $$c_0 = \frac{q}{\sqrt{2\pi\sigma_y^2}Uh} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \quad (12)$$

Wind speed height correction:

$$U_s = U_{ref}\left(\frac{h_s}{Z_{ref}}\right)^p \quad (13)$$

The index p calculated in Table 1.

Evaluation of decomposition and settling volume:

Decomposition:

$$C_t = C_t \exp(-k_d * t) \quad (14)$$

Settling:

$$k_{dry} = \frac{V_d}{h} \quad (15)$$

where, t: calculating time, q: emission intensity, σ_y: diffusion in y axis, x: leeward direction distance, y: lateral direction, h: mixing layer height, U_s: desired value of wind velocity, h_s: 50m, U_{ref}: measured wind velocity, Z_{ref}: measured height, k_{dry}: dry settling fixed value, h: mixing layer height, v_d: dry settling velocity.

The settling caused by rain was not studied.

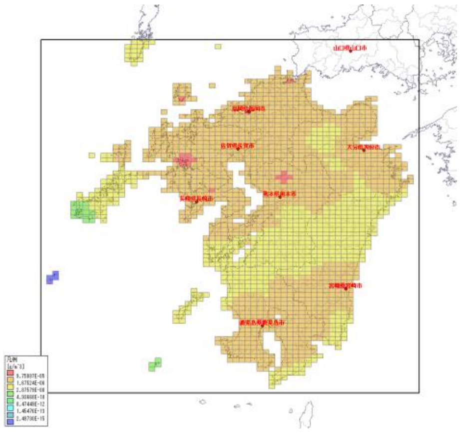


Fig.4 Annual mean concentration distribution of PM2.5 calculated with ADMER

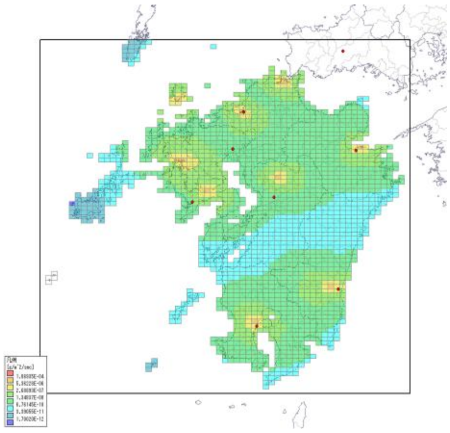


Fig.5 Annual mean settling distribution of PM2.5 calculated with ADMER

4 Discussions and Conclusions

The annual mean concentration and the annual mean settling distributions of PM2.5 calculated with ADMER are shown in Fig. 4 and Fig. 5 respectively. From Figures 2, 4 and 5, we can find the concentrations of PM2.5 in the areas with closed point sources are higher than other areas. The direction of diffusion is affected by wind and topography. The concentrations in the south of Kyushu Island and offshore islands are obviously less than other areas. The central areas between Kumamoto, Oita and Kagoshima undergo little influences because most of them are mountainous areas covered mainly by forests and a few loads or rivers. The results of false color and ADMER model are in good consistency.

5 Reference

1) Izumi NAGATANI, et al.: A New MODIS Data Method for Understanding Transboundary Air Pollution Movements, Journal of The Remote Sensing Society of Japan, Vol.33, No.4,pp.298-307, 2013.