A New Algorithm for Estimating Aerosol Optical Thickness from Satellite Image Data and Its Accuracy

Y. Kawata, A. Yamazaki, M. Imanaka and Mouri
Environmental Information Research Laboratory
Kanazawa Institute of Technology

Tel: +81-76-248-1100, Fax: +81-76-248-7753
E-mail: kawata@infor.kanazawa-it.ac.jp

Abstract: In the atmospheric correction for space remote sensing images, the aerosol optical thickness at the satellite observation time is critically needed. It is highly desirable to estimate this value from the satellite measured data themselves. In this study, we proposed a new algorithm for estimating the aerosol optical thickness from satellite image data alone. In this algorithm, the meteorological range, V, was used as a free parameter to compute the surface albedo distribution from satellite image data. The aerosol optical thickness value for each band can be computed from the meteorological range. The analytical approximation method for atmospheric correction and Modtran code were also utilized in our algorithm.

As for the algorithm validation, several simultaneous ground and sky measurements with LANDSAT/TM and ADEOS/AVNIR were conducted in 1996 and 1997. We found that the accuracy of the proposed algorithm is less than 0.04 in the aerosol optical thickness. The surface albedo distribution image computed from ADEOS/AVNIR data (taken on April 24, 1997) was presented, by using the estimated aerosol optical thickness values.

1. INTRODUCTION

It is well known that the removal of atmospheric effects from the satellite image data is necessary in the quantitative remote sensing analysis. There has been many works on the atmospheric correction in a flat terrain case of satellite measured images (Turner and Spencer (1972)[1] , Odell and Weinman, 1975[2]; Otterman and Fraser, 1976[3], 1979[4]; Kawata et al., 1978[5], Ueno et. al., 1979[6], Tanre et.al., 1981[7]; Ueno 1982[8]; Kaufman and Fraser, 1984[9], Kawata et. al. 1987[10]). The comprehensive book on this problem was published by Kondratyev et al. [11]. It has been clear now that the atmospheric correction is possible when the truth data with the aerosol optical thickness and the target surface albedo, or at least one of them are available. There are, however, few atmospheric correction works when no truth data. In this paper an new algorithm for estimating atmospheric optical thcikness from the satellite image data set alone was presented. The validation results of the algorithm were also presented.

2. ATMOSPHERIC CORRECTION ALGORITHM

Let us consider the radiative transfer model in the atmosphere bounded by a flat Lambertian surface layer with a horizontally non-uniform albedo distribution. Let (x, y) and z are rectangular coordinates difining ground target position and height position in the atmosphere, respectively. We assume that atmospheric model is a plane paralell homogeneous, vertically inhomogeneous, and anisotropically scattering atmosphere with optical thickness of t, and parallel rays of a constant incident solar flux πF illuminates the top of the atmosphere($z=z_0$) from direction of $\Omega_0= (\theta_0=\cos^{-1}\mu_0, f_0)$, where μ_0 and f_0 are the cosine of the solar zenith angle and the solar azimuth angle, respectively.

The upwelling diffuse intensity $I(z_1, x, y, -\Omega)$ at the top of the atmosphere in the direction of $-\Omega$ can be expressed by Eq.(1) [12], allowing for a single reflection of radiation by the target surface (x, y) and up to double reflections of radiation by the adjacent surface,

$$I(z_1, x, y, -\Omega) = \mu_0 FR(\tau, \Omega, \Omega_0) + A_t(x, y) \times (s \cdot \bar{A} + t) + (p - s)\bar{A}^2 + (q - t)\bar{A} \quad (1),$$

where $A_t(x, y)$, $\bar{A}$, and $R(t, \Omega, \Omega_0)$ are the albedo of the target, the mean albedo of the adjacent surface, and reflection function of the atmosphere, respectively. Reflection function $R(t, W, W_0)$ can be computed by the Doubling and Adding method[13]. Furthermore, p, q, s, and t in Eq.(1) are the radiation cofficients which can be expressed by the reflection and transmition functions of the atmosphere[12]. The mean emergent intensity at the top of the atmosphere can be given approximately by Eq.(2).

$$\bar{I}(z_1, x, y, -\Omega) = \mu_0 FR(\tau, \Omega, \Omega_0) + p \cdot \bar{A}^2 + q \cdot \bar{A} \quad (2).$$

The mean albedo and the target albedo are given by Eq.(3) and Eq.(4), respectively.

$$\bar{A} = \frac{\left\{-q + \sqrt{q^2 - 4p \cdot (\bar{I}_{obs} - \mu_0 FR(\tau, \Omega, \Omega_0)}\right\}}{2p} \quad (3),$$

$$A_t(x, y) = \frac{\left\{I_{obs} - (p - s) \cdot \bar{A}^2 - (q - t) \cdot \bar{A} - \mu_0 FR(\tau, \Omega, \Omega_0)\right\}}{s \cdot \bar{A} + t} \quad (4).$$

The atmospheric correction algorithm is given as follows and the algorithm was tested against Landsat/ MSS, /TM, and MOS-1/MESSER data[11],[12]:

(1) Adopt an appropriate atmospheric model and its optical parameters.

(2) Compute the reflection and transmission functions, and the radiance coefficients, p, q, s, and t for a given incident solar illumination condition and a given wavelength band.

(3) Compute the mean adjacent albedo $\bar{A}$ from Eq.(3) by using $\bar{I}_{obs}$.

(4) Compute A_t(x, y) for each corresponding image pixel from Eq. (4) using the observed satellite-level intensity I_{obs}.

(5) Repeat the above steps (2) to (4) and compute A_t(x, y) for all image pixels in each wavelength

band.

3. METEOROLOGICAL RANGE ESTIMATION

In our proposed algorithm, all atmospheric optical parameters, except for aerosol amounts in the boundary layer (altitudes: 0 - 2 km), are assumed to be kept constant and they are given by MODTRAN code[14]. Sincethe aerosol optical thickness in the boundary layer can be found by inputting the meteorological range V at 0.55μm in MODTRAN code, we shall use V as a free varying atmospheric parameter, defining the atmospheric haze condition at the satellite observation time.

The estimation algorithm of V from the satellite data with n wavwlength bands is as follows:

(1) First, select appropriate atmospheric and aerosol models for a satellite measured scene, based on the measured date and geographic location.

(2) Set band number, i =1.

(3) When i > n, then move to step (6). Otherwise, go to step (4).

(4) Set an initial Meteorological Range for band i, V_0(i)= $\alpha$and k = 1, where α is a samall value in unit of [km].

  a. Compute the atmospheric optical parameters, using Modtran Code in the case of V_0(i) .

  b. Compute the surface albedo value for each pixel from the measured satellite data, by applying our atmospheric correction algorithm, using the atmospheric optical param eters found in (4)-a.

  c. When R > 0.01 and k = 1, then set V_0(i)= V_0(i) + ΔV_0 and go back to step (4)-a. Here, R is defined as a ratio of the number of pixels with negative albedo value to the total number of pixels within theimage. We suppose that the increment ΔV_0 takes a typical value of a few km. When R < 0.01 and k = 1, then move to step (4)-d. When R < 0.01 and k = 2, then go to step (5).

  d. Because we can judge that an appropriate value of V_0(i) exists between the present and previous ones, set V_0(i)= V_0(i) + ΔV_s and k = 2, whereΔV_s,= 0.1[km] and move to step (4)-a.

(5) Set i = i +1 and go back to step (3).

(6) Choose V = Max{ V_0(1), V_0(2),...., V_0(n)} as the appropriate Meteorological range and exit.

4. VALIDATION OF ALGORITHMS

We made the field experiments for the validation of our Meteorological Range retrieval algorithm at Heijo-Gu(the Old Palace Site) in Nara City, Japan on Dec.12, 1996 and at Meteorological Research Institute(MRI) in Tsukuba City, Japan on Jan. 8, 1997. Simultaneous ground measurements of the atmospheric optical thickness and surface reflectance at LANDSAT overpassing time were made on these dates. The sunphotometer (POM-01:Prede) and spectroradiometer (PS-1000: Ocean Optics) were used for the sky and surface albedo observations, respectively. The values of Meteorological Range for the test-site, obtained from the sunphotometer observations were V = 18.0 [km] and V = 50.0 [km] at Heijo-Gu and that at MRI, respectively. We showed the estimated values of Meteorological Range from TM data by applying our retrieval algorithm in the band.

3. METEOROLOGICAL RANGE ESTIMATION

In our proposed algorithm, all atmospheric optical parameters, except for aerosol amounts in the boundary layer (altitudes: 0 - 2 km), are assumed to be kept constant and they are given by MODTRAN code[14]. Sincethe aerosol optical thickness in the boundary layer can be found by inputting the meteorological range V at 0.55μm in MODTRAN code, we shall use V as a free varying atmospheric parameter, defining the atmospheric haze condition at the satellite observation time.

The estimation algorithm of V from the satellite data with n wavwlength bands is as follows:

(1) First, select appropriate atmospheric and aerosol models for a satellite measured scene, based on the measured date and geographic location.

(2) Set band number, i =1.

(3) When i > n, then move to step (6). Otherwise, go to step (4).

(4) Set an initial Meteorological Range for band i, V_0(i)= αand k = 1, where α is a samall value in unit of [km].

   a. Compute the atmospheric optical parameters, using Modtran Code in the case of V_0(i).

   b. Compute the surface albedo value for each pixel from the measured satellite data, by applying our atmospheric correction algorithm, using the atmospheric optical param eters found in (4)-a.

   c. When R > 0.01 and k = 1, then set V_0(i)= V_0(i) + ΔV_0 and go back to step (4)-a. Here, R is defined as a ratio of the number of pixels with negative albedo value to the total number of pixels within theimage. We suppose that the increment ΔV_0 takes a typical value of a few km. When R < 0.01 and k = 1, then move to step (4)-d. When R < 0.01 and k = 2, then go to step (5).

   d. Because we can judge that an appropriate value of V_0(i) exists between the present and previous ones, set V_0(i)= V_0(i) + ΔV_s and k = 2, whereΔV_s,= 0.1[km] and move to step (4)-a.

(5) Set i = i +1 and go back to step (3).

(6) Choose V = Max{ V_0(1), V_0(2),...., V_0(n)} as the appropriate Meteorological range and exit.

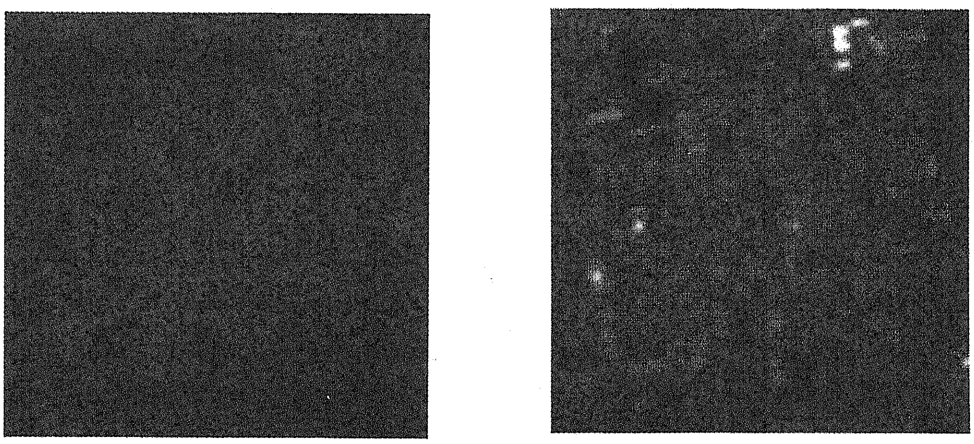
4. VALIDATION OF ALGORITHMS

We made the field experiments for the validation of our Meteorological Range retrieval algorithm at Heijo-Gu(the Old Palace Site) in Nara City, Japan on Dec.12, 1996 and at Meteorological Research Institute(MRI) in Tsukuba City, Japan on Jan. 8, 1997. Simultaneous ground measurements of the atmospheric optical thickness and surface reflectance at LANDSAT overpassing time were made on these dates. The sunphotometer (POM-01:Prede) and spectroradiometer (PS-1000: Ocean Optics) were used for the sky and surface albedo observations, respectively. The values of Meteorological Range for the test-site, obtained from the sunphotometer observations were V = 18.0 [km] and V = 50.0 [km] at Heijo-Gu and that at MRI, respectively. We showed the estimated values of Meteorological Range from TM data by applying our retrieval algorithm in the previous section in Table 1.

Table 1. Values of Meteorological Range for each band, by retrieval algorithm

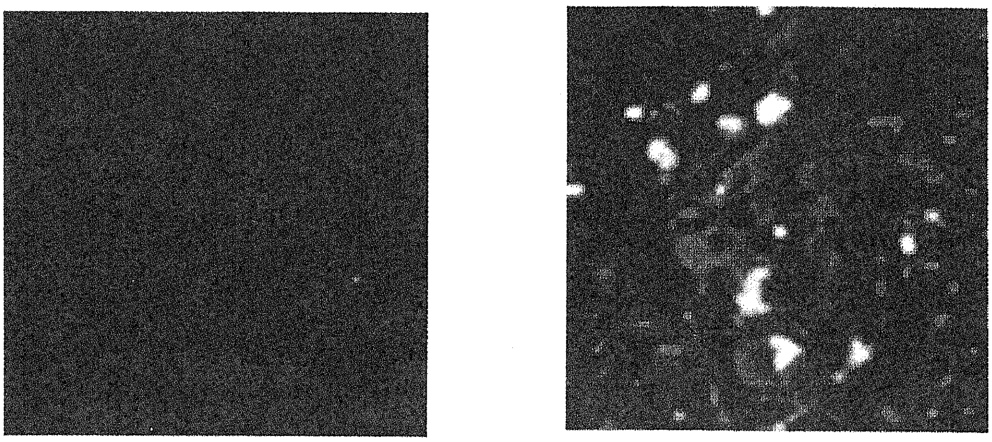
	Estimated meteorological range V [km]			
	Band 1	Band 2	Band 3	Band 4
Dec,12,1996	17.4	18.4	8.0	8.3
Jan, 8,1997	29.8	40.0	13.6	19.4

From Table 1, the appropriate Meteorological Ranges at Heijo-Gu (12/08/96)and MRI (01/08/97) are V = 18.4 [km] and V = 40.0 [km], respectively. We found that the agreement between the estimated and measured values is quite excellent. The differences in optical thickness between the measurement and estimation are less than 0.01 and less than 0.04 for Heijo-Gu and MRI cases, respectively.The target site in original TM band 4 image and in the albedo image (after the atmospheric correction, assuming V = 18.4 [km]) at at Heijo-Gu and MRI are shown in Fig. 1 and 2, respectively. The significance of the atmospheric correction is very clear by comparing two images (a) and (b).



(a) TM Band 4 image (b) Band4 albedo image

Fig. 1. The Landsat TM image and the estimated albedo image near Heijyougu.



(a) TM Band 4 image (b) Band4 albedo image

Fig. 2. The Landsat TM image and the estimated albedo image near MRI.

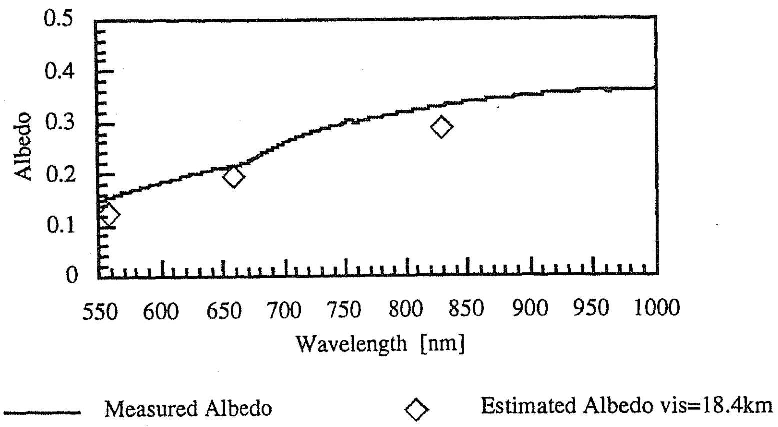


Fig. 3. Measured and estimated albedo values of dry grass at Heijyo-gu.

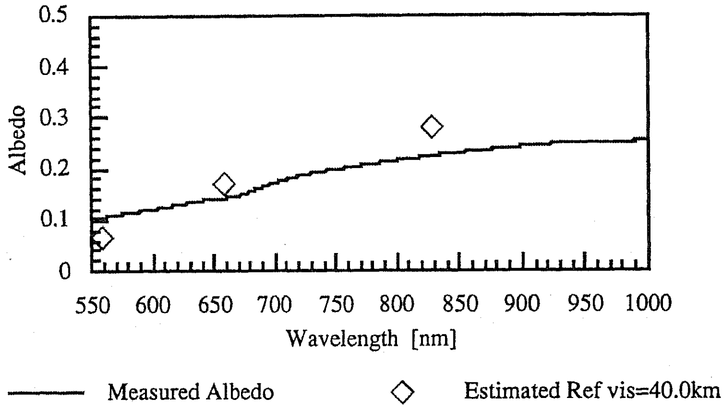


Fig.4. Measured and estimated albedo values of dry grass at MRI

Fig. 2. The Landsat TM image and the estimated albedo image near MRI.

We found that the albedo differences in band 2, 3, and 4 between the measurement and estimation are within $\pm$ 0.04 in the case of Heijyo-gu. We had similar results in the case of MRI, except for band 6, in which the difference is less than $\pm$ 0.06. We also made simultaneous sky observation measurements with ADEOS/AVNIR on April, 24, 1997. The validation results will be presented at the CERes Intl. meeting on Atmospheric Correction.

5. CONCLUSIONS

We came to conclusions by this study as follows:

(1) We presented an algorithm for estimating Meteorological Range(V) in the boundary layer from the measured satellite data alone.

(2) The estimation of the target's spectral albedo from the TM data set was done by applying our atmospheric correction algorithm by using the estimated Meteorological Range. We found that the difference in albedo between the measurement and estimation is within $\pm$ 0.06 in all bands.

(3) We also found that the estimated value of V depends on the size of a satellite image. We still have a problem how to treat with the variability of the atmospheric condition within a full scene. It

is certain that more simultaneous ground measurements with satellites should be done to establish an algorithm for retrieving aerosol optical thickness from satellite data alone.

This study was supported by the Research Contract No. NASDA-PSPC-18282, National Aeronautics and Space Developement Agency of Japan.

REFERENCES

[1] Turner, R.E., and Spencer, M.M., 1972. "Atmospheric model for correction of spacecraft data", Proc. of 8th Intl. Symp. on Remote Sensing of Environ., ERIM, pp.895-934.

[2] Odell, S.R., and Weinman, J.A., 1975. "The effect of atmospheric haze an image of the Earth's surface", J. of Geophys. Res., vol.80, pp.5035-5040.

[3] Otterman, J.,and Fraser, R.S., 1976. "Earth-atmosphere system and surface reflectivities in arid regions from Landsat MSS data", Remote Sensing of Environ., vol.5, pp.247-266.

[4] Otterman, J., and Fraser, R.S., 1979. "Adjacency effects on imaging by surface reflection and atmospheric scattering", Applied Optics, vol.18, pp.2852-2869.

[5] Kawata, Y., Haba, Y., Kusaka, T., Ueno, s., and Terashita, Y., 1978. "Atmospheric effects and their correction in airborne sensor and Landsat MSS data", Proc. of 12th Intl. Symp. on Remote Sensing of Environ., ERIM, pp.1241-1257.

[6] Ueno, S., Haba, Y., Kawata, Y., Kusaka, T., and Terashita, Y., 1979. "Theatmospheric blurring effect on renotely sensed Earth imagery", In Remote Sensing of Atmosphere, (Edited by Fymat, A.L. and Zuev, V.E., Elsevier(Amsterdam), pp.303-319.

[7] Tanre, D., Herman, M., and Deschamps, P.Y., 1981, "Influence of background contribution upon space measurements of ground reflectance", Applied Optics, vol.20, pp.3676-3684.

[8] Ueno, S., 1982. "Remote sensing-research experience and problem" In Marine Remote Sensing, (Edited by Vernberg, F.J., and Diemer, F.D.) Univ. of South Carolina Press, pp.451-510.

[9] Kaufman, y.J., and Fraser, R.S., 1984. "Atmospheric effect on classification of finite field", Remote Sensing of Environ., vol.15, pp.95-118.

[10] Kawata, Y., Kusaka, T., and Ueno, S., 1987. "Landsat Imaging:Removal of atmospheric effect", In Encyclopedia of Systems and Control, vol.4,(Edited by Siggh, M.) Pergamon Press, pp.2652-2655.

[11] Kondratyev, V.V. Kozoderov, and O.I. Smokty. 1992. Remote Sensing of the Earth from Space: Atmospheric Correction, Springer-Verlag, Berlin, 476p.

[12] Y. Kawata,and et.al. 1988, "Radiometric Correction for Atmospheric and Topographic Effects on Landsat MSS Images", Int. J. Remote Sensing, Vol.9,No.4, pp.729-748.

[13] J.E. Hansen, and L. Travis, "Light Scattering in Planetary Atmospheres, " Space Sci. Review , vol. 16, pp. 527-610, 1974.

[14] A. Berk, Bernstein,L.S.,Robertson,D.C. , "A Moderate Resolusion Model for LOWTRAN 7", GL-TR-89-0122, 1989.