Error Analysis on Estimation Method for Air-Temperature, Atmopspheric Pressure, and Realtive Humidity Using Absorption Due to CO_2, O_2, and H_2O Which situated at Around Near Infrared Wavelength Region

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***Abstract*—A method for air-temperature, atmospheric pressure and relative humidity using absorptions due to CO_2, O_2 and H_2O which situated at around near infrared wavelength region is proposed and is evaluated its validity. Simulation study results with MODTRAN show a validity of the proposed method.**

Keywords-absorption band; regressive analysis; air-temperature; atmospheric pressure and relative humidity estimations.

I. Introduction

Hyperspectrometer in the visible to near infrared wavelength regions are developed and used for general purposes of earth observation missions such as Agriculture, Mineralogy, Surveillance, Physics, Chemical Imaging, Environment, in particular, for mineral resources explorations and agricultural monitoring [1]-[15]. Hyperspectormeter allows estimate atmospheric continuants by using absorption characteristics of the atmospheric continuants because spectral bandwidth of the hyperspectrometer is quit narrow like an atmospheric sounders onboard earth observation satellites [16].

The aim of the paper is to propose the method for estimation of air-temperature, atmospheric pressure, and relative humidity on the sea level together with estimation accuracy assessment with the different bandwidth. Method for air-temperature, water vapor and atmospheric pressure estimations with spectral radiometer in near infrared wavelength regions is proposed. It can be assumed that there is no up-welling radiance from the ocean in near infrared wavelength regions. Therefore, the major contribution of the observed radiance is assumed to be derived from the atmosphere. Thus it is possible to estimate atmospheric continuants, oxygen, carbon dioxide, water vapor concentrations can be estimated.

There are absorption bands due to O_2, CO_2 and H_2O in the near infrared wavelength regions, 762nm, 1382nm and 980nm, respectively. It is possible to estimate atmospheric pressure (O_2), air-temperature (CO_2) and relative humidity (H_2O) by measuring the ocean at the wavelength of 762, 980 and 1382nm, respectively. Therefore, atmospheric pressure, air-temperature, and relative humidity is estimated.

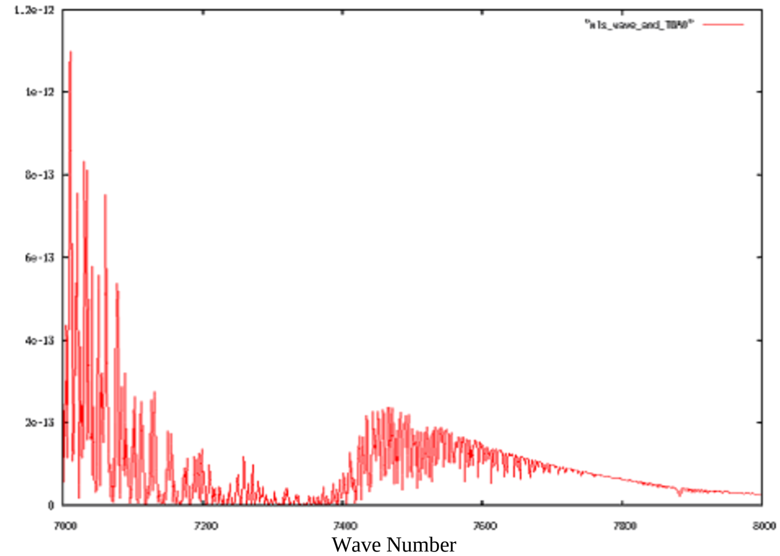
By using MODTRAN, the Top of the Atmosphere: TOA radiance, or at sensor radiance is calculated at the aforementioned wavelength with the different band width, 1, 2, 4, 8nm. TOA radiance for 10 bands, 5 bands, 2 bands and 1 band are calculated for 1, 2, 4, 8nm bandwidth at around 762, 980 and 1382nm. By using TOA radiance, regressive analysis is made based on logarithmic function. Regressive coefficients and Root Mean Square Error: RMSE are calculated for accuracy assessment.

The following section describes the proposed method for estimation of air-temperature, atmospheric pressure, and relative humidity with hyperspectrometer data followed by simulation study for assessment of estimation accuracy. Then conclusion is followed together with some discussions.

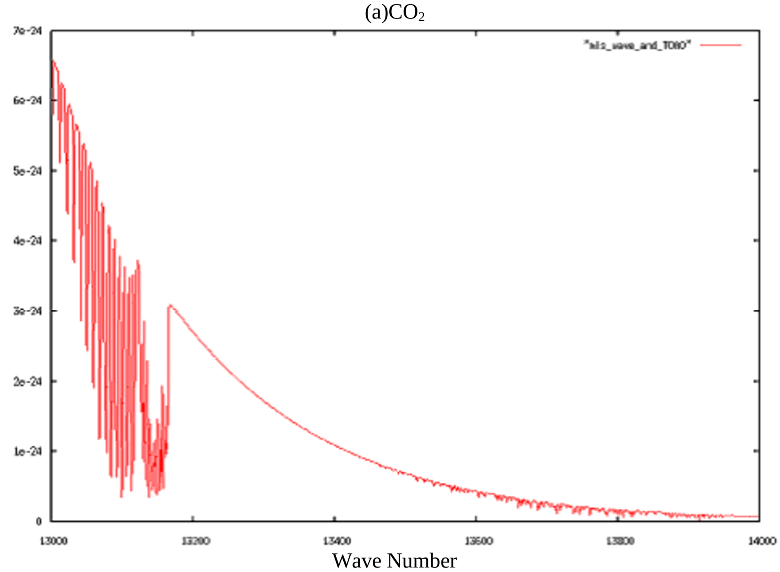
II. Proposed Method

A. *Absorption Characteristics of Oxygen, Carbon Dioxide, and Water Vapor*

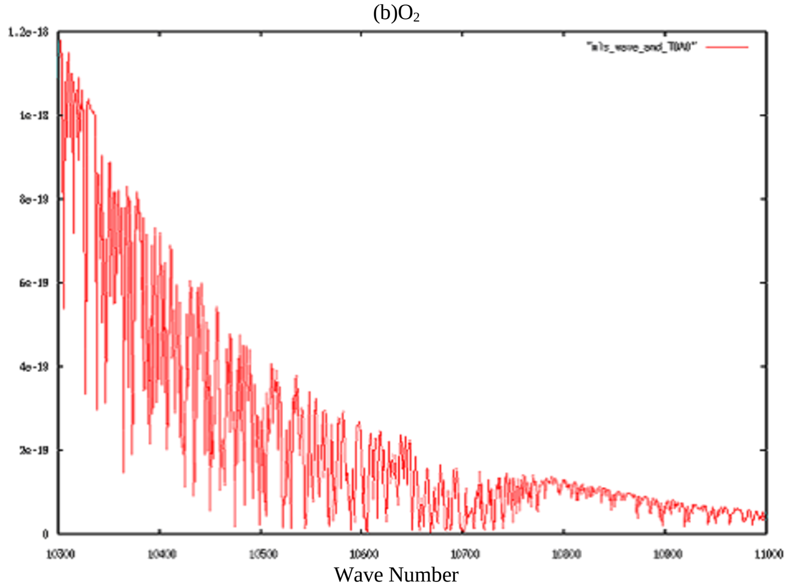
Figure 1 shows absorption characteristics of oxygen, carbon dioxide, and water vapor in the near infrared wavelength regions, 1394 to 1406 nm, 756 to 768 nm, and 934 to 946 nm which are corresponding to 7000 to 8000 cm^{-1}, 13000 to 14000 cm^{-1}, and 10300 to 11000 cm^{-1}, respectively. The vertical axis of Figure 1 shows TOA radiance in unit of $W/m^2/str$. As mentioned above, it is possible to estimate oxygen (Atmospheric Pressure), carbon dioxide (Air-Temperature), and water vapor (Relative Humidity) concentrations by using these absorption characteristics.



(a)CO_2



(b)O_2



(c)H_2O

Figure 1. Absorption characteristics of CO2, O2, H2O for estimation of air-temperature, atmospheric pressure and relative humidity with hyper-spectrometer

B. Procedure of the Proposed Method for Estimation of Air-Temperature, Atmospheric Pressure, and Relative Humidity

Assuming up-welling radiance from the ocean is negligible, at sensor radiance of hyperspectrometer is reflected by the absorption characteristics of oxygen, carbon dioxide, and water vapor. Using the at sensor radiance, Atmospheric Pressure: AP, Air-Temperature: AT, and Relative Humidity: RH is estimated with the following regressive equations.

$$AT = a_0 + a_1 ln(b_1 TOA_1) + a_2 ln(b_2 TOA_2) + \_\,\_\,\_ + a_n ln(b_n TOA_n) \quad (1)$$

$$AP = c_0 + c_1 ln(d_1 TOA_1) + c_2 ln(d_2 TOA_2) + \_\,\_\,\_ + c_n ln(d_n TOA_n) \quad (2)$$

$$RH = e_0 + e_1 ln(f_1 TOA_1) + e_2 ln(f_2 TOA_2) + \_\,\_\,\_ + e_n ln(f_n TOA_n) \quad (3)$$

where TOAn denotes at sensor radiance for band number n while a to f denotes regressive coefficients. In these equations, Beer-Bouque-Lambert law is assumed for radiative transfer processes in the atmosphere.

III. EXPERIEMNTS (SIMULATION STUDIES)

A. Simulation Data Used

Utilizing MODTRAN of radiative transfer code, at sensor radiance is calculated by wave number by wave number. Bandwidth can be changed in the calculation of at sensor radiance. Other atmospheric conditions are set at the default values of Mid. Latitude Summer of atmospheric model which are included in the MODTRAN.

Air-Temperature, Atmospheric Pressure, and Relative Humidity are set at the default values and the default value plus minus 30% of additive biases as shown in Table 1. At sensor radiance is calculated with MODTRAN.

B. Simulation Results

Using these calculated at sensor radiance, regressive analysis is conducted based on the regressive equations, equation (1) to (3). Through the regressive analysis, regressive coefficients are determined together with Root Mean Square Error: RMSE, regressive error. Table 2 shows the results from the regressive analysis. Bandwidth are set at 1, 2, 4, and 8 nm which are reasonable ranges from the state of the art on hgyperspectrometer design and development.

As shown in Table 2, the regressive errors for Air-Temperature, Atmospheric Pressure, and Relative Humidity range from 0.033 to 1.61 (%), from 0.59 to 1.06 (%), and from 0.096 to 1.28 (%), respectively.

Although it is supposed that the regressive error of the 1nm bandwidth case is the best followed by the 2nm bandwidth case, and so on for all the geophysical parameters, Air-Temperature, Atmospheric Pressure, and Relative Humidity, it is no always true. For instance, the regressive error of the 2 nm bandwidth case is smaller than that of the 1 nm bandwidth case for atmospheric pressure..

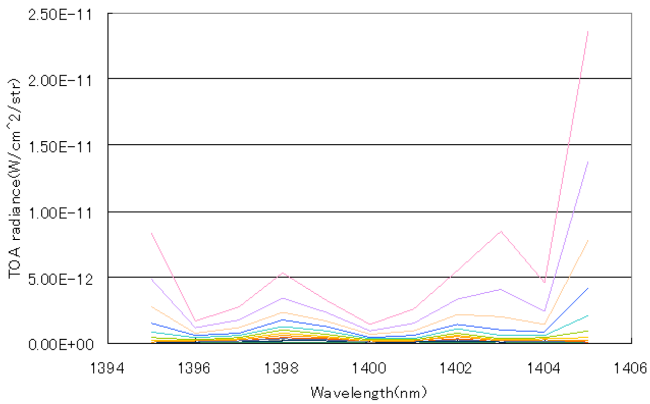
TABLE I. PARAMETERS SET TO MODTRAN FOR TOA RADIANCE CALCULATIONS

Additive Bias(%)	Air-Temp.[K]	Atm.Press[hPa]	RH[%}
30	382.46	1316.9	99.06
27.5	375.105	1291.575	97.155
25	367.75	1266.25	95.25
22.5	360.395	1240.925	93.345
20	353.04	1215.6	91.44
17.5	345.685	1190.275	89.535
15	338.33	1164.95	87.63
12.5	330.975	1139.625	85.725
10	323.62	1114.3	83.82
7.5	316.265	1088.975	81.915
5	308.91	1063.65	80.01
2.5	301.555	1038.325	78.105
0	294.2	1013	76.2
-2.5	286.845	987.675	74.295
-5	279.49	962.35	72.39
-7.5	272.135	937.025	70.485
-10	264.78	911.7	68.58
-12.5	257.425	886.375	66.675
-15	250.07	861.05	64.77
-17.5	242.715	835.725	62.865
-20	235.36	810.4	60.96
-22.5	228.005	785.075	59.055
-25	220.65	759.75	57.15
-27.5	213.295	734.425	55.245
-30	205.94	709.1	53.34

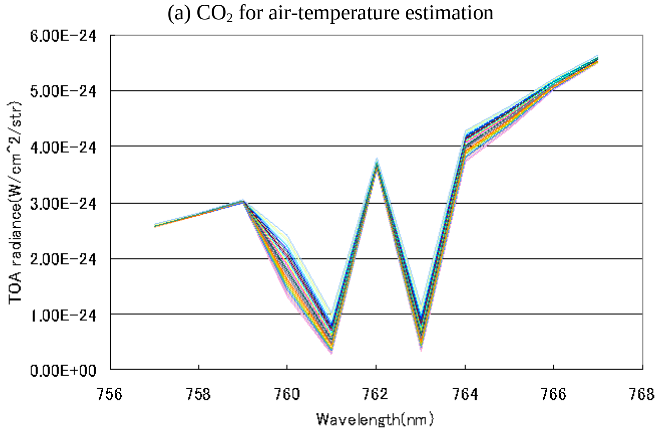
TABLE II. REGRESSIVE ERROR FOR ESTIMATION OF AIR-TEMPERATURE, ATMOSPHERIC PRESSURE AND RELATIVE HUMIDITY WITH HYPER-SPECTROMETER DATA

	Bandwidth(nm)	Default	Estimated	Difference
Air-Temperature	1	294.2	294.298	0.098
	2	294.2	294.445	0.245
	4	294.2	294.935	0.735
	8	294.2	299.05	4.85
Atm.Pressure	1	1013	1005.77	-7.23
	2	1013	1007.02	-5.98
	4	1013	1002.2	-10.8
	8	1013	1003	-10
Rel.Humidity	1	76.2	76.1886	-0.0114
	2	76.2	76.1556	-0.0444
	4	76.2	76.19266	-0.00734
	8	76.2	75.228	-0.972

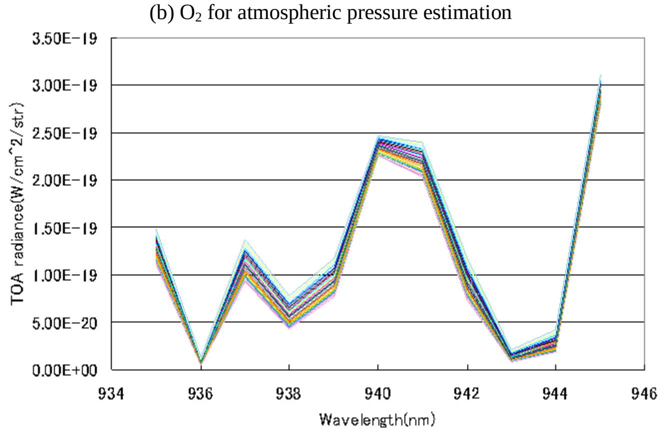
Also the regressive error of the 8 nm bandwidth case is better than that of the 4 nm bandwidth case for atmospheric pressure while the regressive error of the 4 nm bandwidth case is smaller than that of the 2 nm bandwidth case. This is because that the wavelength at which absorption starts is different among the bandwidth cases as shown in Figure 2. Figure 2 shows absorption characteristics of oxygen, carbon dioxide, and water vapor with 1 nm interval. Therefore, the band, or spectral response and bandwidth have to be determined properly by referring to the absorption characteristics. Otherwise, it is impossible to determine the best bandwidth.



(a) CO_2 for air-temperature estimation



(b) O_2 for atmospheric pressure estimation



(c)H_2O for relative humidity estimation

Absorption characteristics of CO2, O2, H2O for estimation of air-temperature, atmospheric pressure and relative humidity with hyper-spectrometer

IV. Conclusion

Method for air-temperature, atmospheric pressure and relative humidity using absorptions due to CO_2, O_2 and H_2O which situated at around near infrared wavelength region is proposed and is evaluated its validity. Simulation study results with MODTRAN show a validity of the proposed method.

It is found that the regressive errors for Air-Temperature, Atmospheric Pressure, and Relative Humidity range from 0.033 to 1.61 (%), from 0.59 to 1.06 (%), and from 0.096 to 1.28 (%), respectively. Also it is not always true that narrowest bandwidth shows the best estimation accuracy. Spectral responses of hyperspectrometer would be better to determine by referring absorption characteristics precisely.

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