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***Review Paper***

# Atmospheric Correction Algorithms for Hyperspectral Imageries: A Review

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## Abstract

*Hyperspectral image analysis has matured into one of the most potent and quickest growing technologies within the field of remote sensing over the past decade. Rich source of information produced in the form of spectrum at each pixel, can be used to identify surface materials. Intervening atmosphere poses an obstacle for retrieval of data, the atmospheric effects should be removed, to utilize the information for quantitative purposes. Over the years, the atmospheric correction algorithms have evolved from applied math approach to ways supported on rigorous radiative transfer modelling. They are used for the estimation of the signal below the atmosphere based on the signal quantified at the top of the atmosphere. Applied math approaches scale back atmospheric effects by empirical models that merelydepend upon statistics of image. The radiative transfer models are made at sensor radiance utilizing physics based radiative transfer equations and data from atmospheric and sun information archives. Radiative models utilize physical characteristics of the atmosphere to derive water vapour, aerosol, and mixed gas contributions to the atmospheric signal. More recently, researchers have used combinations of applied math approaches and radiativetransfer modelling approaches for the derivations of surface reflectance. This paper reviews hyperspectral atmospheric correction algorithms developed during the past years. An idealized universal atmospheric correction system has not been developed yet. Some critical elements are still lacking and need to be improved for a complete atmospheric processing.*

**Keywords**: Atmospheric correction, Applied math models, hyperspectral, Remote sensing, radiative transfer modeling.

## Introduction

Hyperspectral remote sensing, or imaging spectroscopy, is a comparatively new technology currently being investigated by researchers with reference to detection and identification of surface properties. Spectral data are often obtained using either space-based or airborne platforms. Hyperspectral sensors are the instruments that acquire images in very narrow, contiguous spectral bands throughout the visible to near infrared wavelength region. High spectral resolution across a wide range of the electromagnetic spectrum enables the identification of the chemical composition of the imaged target.

As the solar radiation on the sun-surface-sensor path in the visible and near-infrared spectral regions is subject to absorption and scattering by atmospheric particle, hyperspectral imaging data is more vulnerable to atmospheric effects. These effects have to be accounted for effective utilization of hyperspectral data. Different techniques have been proposed to correct measured radiances for atmospheric effects to extract the ground reflectance.

Atmospheric gases and aerosols have two types of effects on the radiance observed by a hyperspectral sensor. It absorbs or scatters the solar radiation[1]. Gases like $CO_2$, $O_2$, $CH_4$, CO and $NH_4$stay in relatively constant concentrations through the atmosphere, whereas $O_3$ predominantly occurs in the stratosphere. The concentration of water vapour and aerosols can vary with altitude, location and time. Aerosols over large cities have divergent concentrations than the rural atmosphere. The amount of water in the atmosphere is measured with total precipitable water vapour. It is the depth of a water layer on the Earth's surface if all water vapour in an atmospheric column above the surface would precipitate. Aerosol particles in the atmosphere include dust-like component, oceanic component, water soluble component, soot component etc. The concentration of aerosols decreases with altitude. The effect of aerosols on the transmission is measured with aerosol optical depth.

## Atmospheric Correction Techniques

Atmospheric correction algorithms for hyperspectral images have evolved since mid-1980s. These algorithms basically estimate the electromagnetic radiation below the atmosphere based on the measurement at the top of the atmosphere. Atmospheric correction methods can be classified into three: applied math based models, radiative transfer models and hybrid models[2]. In this paper, an overview of these atmospheric correction algorithms is given.

## Applied math based models

These models are scene based methods that depend on image statistics to predict the surface reflectance. The Internal Average Reflectance (IAR) approach[3] calculates the relative reflectance spectrum for a pixel from the ratio of spectrum of the pixel to the average spectrum of a scene. This method suits for arid areas without vegetation. The Flat Field (FF) approach[4] produces relative reflectance by dividing the mean spectrum of a user-defined region of interest by the spectrum of each pixel in the image. The region of interest should be a spectrally flat material within the wavelength range of the sensor. The flat-field chosen should have a high albedo to avoid decreasing signal-to-noise ratio. Empirical Line (EL) method[5] forces the image spectra to match reflectance spectra collected from the field. It requires at least two targets (light and dark) whose reflectance and at-sensor radiance are known and are linearly regressed to obtain gain and offset. The gain and offset are then applied to the whole image for the derivation of surface reflectance for the entire scene. This method can produce the most accurate results possible, but it requires ground truth information. QUick atmospheric correction (QUAC)[6] is a semi empirical algorithm for atmospheric correction and aerosol retrieval. It requires only approximate specification of sensor band locations (i.e., central wavelengths) and their radiometric calibration. QUAC is based on the assumption that the average reflectance of a collection of diverse material spectra, such as the end member spectra in a scene, is essentially scene-independent. The gain parameter is obtained from end member average and offset parameter from baseline subtraction.

## Radiative Transfer Modeling Methods

Radiative transfer (RT) codes try to simulate the very complicated transfer process of an electromagnetic wave in the atmosphere. Since 1990 numerous RTmodels have been developed, the most popular among these is a publicly available code MODTRAN, developed by Spectral Science, Inc. and Air Force Research Laboratory. The normally used RT codes are LOWTRAN[7], MODTRAN[8], 5S[9] and 6S[10].

The RT codes are used for the calculation of standard reference tables for varying geometrical and atmospheric conditions. The tables have distinct values of signals and atmospheric parameters. These values are interpolated to calculate intermediate values if required. Most of these codes assume a flat and lambertian landscape. The RT codes use different kinds of methods for the simulation of the radiative transfer in the atmosphere, such as Eddington approximation[11], the discrete ordinates method[12], Monte Carlo method[13], the spherical harmonics method [14] etc.

There are a range of software programs available to model the atmosphere including ATREM (ATmosphericREMoval algorithm), ATCOR (ATmosphericCORrection), FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes), ISDAS (Imaging Spectrometer Data Analysis System), HATCH (High-accuracy ATmosphere Correction for Hyperspectral data) and ACORN (Atmospheric CORrection Now).

ATREM[15], uses channel band ratio technique[16] to estimate water column; narrowband spectral model[17], based on the HITRAN 92[18] database to derive the transmittance spectra of the atmospheric gases and the 5S code to model scattering effects due to atmospheric molecules and aerosols. Major upgrades to the ATREM code were made in the late 1990s and early 2000s. The band model was replaced with a line-by-line atmospheric transmittance model[19] and the HITRAN2000 line database[20,21]. The 5S computer code was replaced with the newer 6S code for modeling atmospheric scattering effects. A module for modeling atmospheric $NO_2$ absorption effects in the 0.4–0.8 μm spectral region was added.

ATCOR[22], uses lookup tables based on MODTRAN4. Several versions of ATCOR codes[23,24] were developed. ATCOR 2 is used for flat terrain while ATCOR 3 handles rugged terrain by integrating a DEM. ATCOR4 performs the combined atmospheric and topographic correction accounting for the angular and elevation dependence of the atmospheric correction functions and calculates surface reflectance and surface temperature based on the geocoded and orthorectified imagery.

FLAASH[25] is MODTRAN4-based atmospheric correction software package developed jointly by the Air Force Phillips Laboratory, Hanscom AFB and Spectral Sciences, Inc.One key feature of FLAASH is that it corrects for adjacency effect i.e. spatial mixing of radiance among nearby pixels. Secondary outputs such as surface albedo, water vapour column, aerosol and cloud optical depths can also be obtained from hyperspectral data.

ISDAS[26] is an image and spectral analysis software package developed at the Canada Center for Remote Sensing for efficient processing and analysis of hyperspectral imaging data. The ISDAS tools, mostly coded in C, can be divided into the five main categories; data input/output, data visualization, data preprocessing, simulation of future sensor data, and information extraction.

HATCH[27,28] uses correlated k-method[29] for gaseous absorption calculation. The correlated-k data in HATCH is generated by the line-by-line code[30] based on HITRAN 96 database. It provides an explicit way to accurately account for the interaction between multiple scattering and absorption. It uses smoothness test to retrieve water vapour amount and absorbing gases, such as carbon dioxide and methane. HATCH also allows different aerosol types to be mixed externally.

ACORN developed by Analytical Imaging and Geophysics, LLC[31], works on MOTRAN-4 code. It gives the relationship from contributions of the exo-atmospheric solar source, the atmosphere, and the surface to the radiance measured by an earth-looking sensor for a homogeneous plane parallel atmosphere. ACORN uses spectral fitting to estimate water vapour and suppress effects of liquid water on the surface.

The SIERRA code (Spectral reflectance Image Extraction from Radiance with Relief and Atmospheric correction)[32] is a new method for extracting ground reflectance and water vapour content over mountainous areas from hysperspectral imagery. A correction of the reflectance's bi-directional effects is proposed for large incidence or emergence angles.

## Hybrid Methods

Hybrid methods include combinations of applied math based approaches and radiative modeling for the derivation of surface reflectance from hyperspectral imaging data. Clark *et al.*[33] first suggested the use of combination of ATREM radiative transfer correction method followed by ground calibration using EL method that produced better results than RT or EL models alone. It provides sound correction as a function of elevation, while removing artifacts from errors in the radiative models and solar spectrum. Ben-Dor*et al.*[34] showed that combined HATCH and EL produce good results when tested using synthetic imaging spectroscopy data. Tuominen and Lipping[35] showed that combined ATCOR4 and EL method produces better results compared to model based ATCOR alone. The disadvantage is that the EL method requires in-situ field measurements. Thus in spite of the promising research results, combined methods are seldom used in the processing of hyperspectral data.

## Literature gap and Conclusion

All the atmospheric correction algorithms discussed were built on their own assumptions and thus have limitations. An idealized universal atmospheric correction system has not been developed yet. The method used for atmospheric correction should be a function problem type, remote sensing data type, amount of available in situ atmospheric information history and the accuracy of bio-physical information extracted from the remote sensing data.

The applied math based methods are not always reliable especially for hyperspectral data, since they depend on image statistics only. The atmosphere is not considered as such. But these methods are used for quick correction of images. The EL method which involves field calibration produces more accurate results. But it requires much effort.

The RT methods model the atmosphere and do atmospheric correction of image. Most of RT methods assume flat lambertian surface. Under optimal conditions they produce precise results. However the external effects like ground topography, variation in the sun exo-atmosphere solar spectra, differences in spectral and radiometric calibration,adjacency effects etc. may increase the difference in recovering reflectance information from radiance data. In addition non-uniformities of imaging spectroscopy systems cause problems like spectral smile effects. Cloud and cast shadow correction remains as a current research topic. Aerosol retrieval works well over areas of dark objects. Aerosol retrieval over bright surfaces are still under development[36].

It is also found that hybrid methods, despite the promising research results, are not often used in the processing of hyperspectral data. Hybrid methods can be tried with physical models and other scene dependent properties of the area. New approaches like atmospheric correction of hyperspectral imageries using neural networks[37], open possibilities in the improvement of the topic.

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