Clouds Sensitivity Analysis Based on Limb Radiance Model

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***Abstract* — In this paper , we choose SCITRAN 3.2 model simulates Limb radiance. Study on SCIATRAN3.2 model structure and the atmospheric radiation theory, choose clouds as the object of the study. From the geometry of spaceborne Limb scattering observation technique we set radiance simulation environment. On this basis, select the range of the values and develop simulation programs, radiance simulation and make sure the results are correct. According to the simulation results, we analyze the sensitivity of Limb radiance. Results show that tangent height is Limb radiance sensitive factor. Radiance with band and tangent point height varies. The results show that cloud is Limb radiance sensitive factor. Water clouds and ice clouds effect differently, vary with the bands and the tangent point height.**

Keywords - The center point; Matlab; Tilt; Bending; Distortion

I. INTRODUCTION

Human activity is one of the main causes of atmospheric composition change. In recent years, human activities cause the hole in the ozone layer, the greenhouse effect and other serious consequences.

Compared with the traditional detection technologies, satellite remote sensing can provide a global atmospheric trace gases dynamic profile and volume measurements. The viewing geometry of satellite has been developed from traditional nadir and occultation (Chu and McCormick, 1989) to a recent limb (Flittner et al., 2000). Limb sounding is a well-established technique for measuring atmospheric composition, which combines the advantages of high vertical resolution and good global coverage compared to the other two techniques (Strong et al., 2002). There are several sensors using this technique. For example, on the Odin satellite OSIRIS (2001), the Hitchhiker SOLSE[1] on Junior (2003), on Aura satellite HIRDLS[2,3], MLS[4,5] (2004) and SCIAMACHY[6,7] on Envisat satellite (2002).

Atmospheric model plays an important role for the development, optimizing, calibration, testing, application and interpretation of remotely sensed data of the sensors of the satellites and other carrying platform [7]. Model of remote sensing data is to simulate the performance of the new sensor, optimizes the remoting parameters and data acquisition solution of sensor systems, provide simulation information for the assessment of the quality and potential of remote sensing data. In the normal operation of the satellites are in orbit, also and provide technical support for remote sensing data processing, information extraction and integrated evaluation. Atmospheric Limb scattering inversion makes reference to the study of the sensitive factors of Limb pattern radiance to optimize retrieval algorithm, avoiding disturbance of sensitive factors.

Now widely used atmospheric radiative transfer model has LOWTRAN of low spectral resolution, MODTRAN [8] of medium resolution; LIMBTRAN [9] CDI, SASKTRAN [10], CDIPI, and SCIATRAN of specialized mode for limb radiance simulation etc. The atmospheric radiative transfer model SCIATRAN is based on GOMETRAN++ by the University of Bremen in German of high spectral resolution atmospheric radiative transfer model [11, 12]. It designed from spaceborne passive sensing spectrometer sensor SCIAMACHY and GOME [13], provide quick and accurate simulation, in addition it can also be used ground-based or at any height in the atmosphere observation spectrum simulation [13].In 2005 A. Rozanov introduced the SCIATRAN2.0, the model in continuous improves, SCIATRAN2.X comes later, in 2008 years SCIATRAN3.0 [14, 15] comes, the calculation speed has greatly improved. In the past few years many published papers have confirmed the value of SCIATRAN model.

Clouds are made of water droplets and ice crystals, according to the composition clouds can be divided into water, ice, and hybrid clouds. Define the clouds whose optical properties are the same as vertically homogeneous clouds, whose optical parameters are different as vertically inhomogeneous clouds, and there are more vertically inhomogeneous clouds in the atmosphere [16]. Clouds are the main factor causing visible-light scattering in the atmosphere. Most scattering are Raman scattering. Raman scattering defines light changes in frequency through the medium due to the incident light interacts with molecular motion. It causes strong solar and land absorption lines fill and scattered radiation and incident radiation out of proportion [17]. Also, because in different wavelengths of radiation field Raman scattering is unique, so cannot be used in a strictly monochrome radiative transfer models to simulate. Cloud effect is the most difficult problem to solve in radiative transfer simulation.

II. ATMOSPHERIC RADIATION

Optical radiation transmission in the atmosphere is under the influence of atmospheric absorption, scattering and refraction. It makes the reached radiation energy of the receiver changes while the radiation also carries the air itself information. Atmosphere consists of trace gases, aerosols, clouds, gas molecules and other components. Effects of different components of the atmosphere to optical radiation are different.

A. Atmospheric Scattering And Absorption

Atmospheric scattering of solar radiation are atmospheric molecules' Rayleigh scattering and Raman scattering of clouds, absorption is the atmospheric absorption of molecules and aerosols.

1) The atmospheric scattering and absorption of molecules

Molecular scattering of solar radiation which is the elastic scattering in the atmosphere calls Rayleigh scattering. There is no energy conversion. There is is no correlation in the phase between incident light and the scattered light. Partially polarized scattered light needs to consider four Stokes vector [18] to describe completely. Rayleigh scattering intensity is described by Rayleigh scattering cross section ⇳□ (in cm^2) and Rayleigh scattering phase function.

A component of atmosphere X's Rayleigh scattering cross section ⇳□ (X) can be expressed as:

$$\chi_{\gamma}(X)=\frac{8\pi^3}{3N_A^2}\frac{\left(n^2(X)-1\right)^2}{\lambda^4}F_{King}(X) \quad (1)$$

Where N_A is Avogadro's constant, n(X) is refractivity and F_{King} (X) is King factor.

Atmospheric Rayleigh scattering cross section ⇳□ can be expressed as:

$$\chi_{\gamma}=\sum_X f(X)\chi_{\gamma}(X) \quad (2)$$

Where f(X) is the volume mixing ratio of the component X.

≻ can be expressed as:

$$\phi(\gamma)=\frac{1}{4\pi}\frac{3}{2}\frac{1}{2+d}\left[(1+d)+(1-d)\cos^2(\gamma)\right] \quad (3)$$

Where □ is scattering angle and the phase state function is normalized to the unit quantity[12].

Gaseous molecular absorption of solar radiation in the atmosphere mainly absorbs photon energy and quantum leap.

2) Aerosol-scattering and absorption

Scattering is often accompanied by absorbing and the absorbed energy is converted into other forms and no longer exists as light. Scattering and absorption can remove energy from the beam when it crosses the medium. The phenomenon of the energy is weakened call extinction.

The angular distribution of scattered light is simulated by the phase state function □i. At present, the widely used parameterization method is Henyer-Greenstein phase state function.

$$\xi_i(\gamma)=\frac{1-g^2}{\left(1+g^2-2g\cos\gamma\right)^{3/2}} \quad (4)$$

where the symmetry factor g ranges [− 1, 1] and Henyer-Greenstein phase function is normalized to 4 π [19].

3) Atmospheric Refraction

The atmospheric refractive index can cause the bending of light in the atmosphere, the path length and the tangent height of sight line changed. Therefore, it is necessary to consider the influence of it when calculating the line of sight. Refractive index is generally determined by the medium and the radiation frequency [12]. For a fixed frequency of monochromatic radiation, the refractive index of the medium is equal to the ratio of the wavelength in the vacuum to the wavelength in the medium.

When the refractive index is different in the two media interfaces, the propagation direction is changed according to Snail's law. A special form of this law can be used to obtain a spherical symmetrical refractive index n (r), which is applicable to the earth's atmosphere.

$$r_1 n(r_1)\sin(\psi(r_1))=r_2 n(r_2)\sin(\psi(r_2))=const \quad (5)$$

Where r is the radial coordinate of the system, there are different values of the constants in the different geometric relations. So it can be used to characterize the properties of each light.

B. Reflection Of The Earth's Surface

Currently people mainly use BRDF and albedo of the Earth's surface to simulate the reflection of solar radiation by the Earth's surface. BRDF is used to describe the reflection of each direction, mainly depending on the incident radiation direction, the surface position and the radiation wavelength. Albedo A is the ratio of the reflected radiation to the incident radiation, and the range is between 0-1.

Simulations will be assumed on the ground to be Lambertian object, for Lambertian reflected radiation is equal to the incident radiation power with albedo weight.

$$\hat{\rho}\left(\vec{r},\vec{\Omega}',\vec{\Omega}\right)=A\rho\left(\vec{\Omega}'\right) \quad (6)$$

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III. LIMB SCATTERING GEOMETRY

Limb-scattering observations mode scans and record the atmospheric spectrum from vertical height and horizontal position. Observation of sight points above the horizon. The minimum distance pointed in Earth's atmosphere to the surface is tangent height. Range can cover the entire troposphere, stratosphere and Mesosphere [20] scanning begins from the horizon and maintains the fixed tangent height along the vertical track. Scanning corrects the curvature of the Earth in the scanning process. The scan line of sight is up after a tangent height description. The next tangent-scanning scans on the opposite direction of the last. The sensor records one by one sight spectrum of solar radiation in the atmosphere on the path.

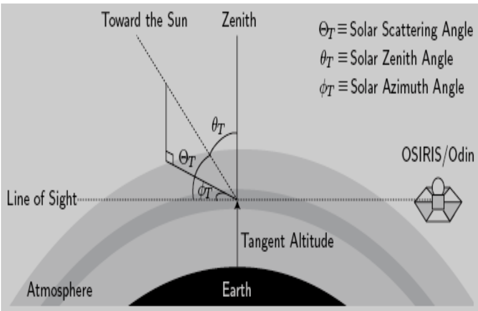

Fig.1 Limb Scattering Geometry (Adam E. Bourassa, 2007)

The sensor in Limb scattering observation receives three scattering components single scattering radiation (single scattering radiation entering the sensor when incident light is through the atmospheric (s)), two times of scattering radiation (radiation entering the sensor after two times of scattering when incident light is through the atmospheric (SS)) and scattering after reflection radiation(scattering radiation entering the sensor after reflection by the land when incident light is through the atmospheric (RS)).

IV. SCIATRAN MODEL STRUCTURE

Spectra in the range of SCIATRAN model has 175.44nm-2 400nm, spectral resolution is 0.24nm-0.5nm. Atmospheric models have spherical atmospheric, pseudo spherical atmosphere and parallel planes. Spherical atmosphere models assume that Earth's atmosphere is composed of homogeneous pixel [21] and pixel resolution can vary. Analog input control parameters are mainly geometric parameters of observation, cloud parameters, trace gases parameters, aerosol parameters and surface characteristics parameters. SCIATRAN model compared to the other models, provides a more detailed trace gas parameters and cloud parameter，introduced in the albedo of the Earth's surface BRDF(directional reflectance distribution function) [8,22], you can calculate the radiance, trace gases, pressure components.

We use in this paper the main control parameter file named ‘control.inp’, is mainly the overall control parameter settings, such as simulation using atmospheric models, considering clouds, aerosols, trace gases, analog-band, analog and analog output and so on.

Observation geometry parameter file named ‘control_geom.inp’, include satellite observation geometry information as the Sun Zenith angle, tangency point height, relative azimuth, altitude, the radius of the Earth.

V. SCIATRAN’S ENVIROMENTAL PARAMETERS

SCIATRAN has a total of 9 parameters input files, included the 3 kinds of atmospheric simulation models, hundreds of input parameters. According to the objective, observation geometry part of the model is as study parameters. Not just involved in the simulation study parameters, and need to set the emulation environment parameters, such as radiative transfer model, the type of results and satellite height. The entire research project, environmental parameters in simulating radiance values remain unchanged.

Study the value of Limb radiance result, so need to select the type value of radiation intensity values of RTM mode. ‘RTM Mode’ need to choose ‘wf’-intensity/radiance and weighting functions (see "control_wf.inp" for weighting functions). Atmospheric model of ‘RTM mode’ need to choose ‘spher_scat’-scattered light in a spherical atmosphere (Only HG type of aerosol phase function is implemented in this mode). ‘RTM-CORE’ need to choose ‘DOM_S’ - Scalar discrete ordinate technique: RTE will be solved excluding polarization effects. ‘Filename user provided solar spectrum’ need to choose '../../DATA_BASES/SPECTRA/thkur.dat.gpp'.

A. *Observation Geometry Parameters*

‘Position of the instrument’ need to choose 'user' - user defined instrument position (the altitude is to be specified by the "User-defined output altitude" control parameter). ‘Viewing direction’ need to choose 'dn' - downwards, registration of the upwelling radiation. ‘Do refractive geometry' need to choose 't' (true). 'Angle selection mode' need to choose 'all' - line of sights defined by all possible combinations of input angles (solar zenith angle, viewing angle and azimuth angle) are considered. 'Number of user-defined output altitudes' need to define '1'. 'User-defined output altitude' need to define '600' (km). 'Type of LOS definition' need to choose 'th' - tangent height in [km]. 'Earth radius' need to define '6371.004' (km). 'Field of view size' need to define '0.02D0'. 'Azimuth angles' need to define '45'.

VI. SENSITIVITY ANALYSIS

According to the SCIATRAN model and the Limb radiance simulation results, by scientific software, using two dimensional graphs, study radiation sensitivity of the geometric parameters. Taking into account sensitivity's in different tangent point height and frequency effects might be different, so the analysis involved in band, point height, parameter and radiance-the four dimensions. Because there are too much bands and tangency point height values, using a two-dimensional graph shows the four-dimensional information, information content is too large. Be divided into two two-dimensional curve of the expression using two "parameter value-radiance values", namely, horizontal for the parameter value, corresponding radiance for the vertical axis value. Where a picture is with a different line of the tangent point heights, another is with a different line of bands.

Radiation values sensitivity analysis of the observed geometry parameter mainly considers the Sun Zenith angle. Study on the bands of 280nm, 330nm, 380nm, 570nm, 760nm, 785nm, 810nm, 1260nm, 1270nm and 1530nm. In the study of radiance to solar Zenith angle-sensitive analysis in limb-scattering observations model, the tangency point height selects 0km, 15km, 20km, 30km, 40km, and 60km, solar Zenith angle ranges from -130 ° to +130 ° total of 87. Because of too much data, there is no list.

From fig.2 we can see the radiance values about 0 ° symmetry, so just research the Changes between 0 °-130 °. From the geometry we can understand this. Radiation intensity decreases sharply between 98 °-110°, between 110 °-130 ° there is two small pick-ups.

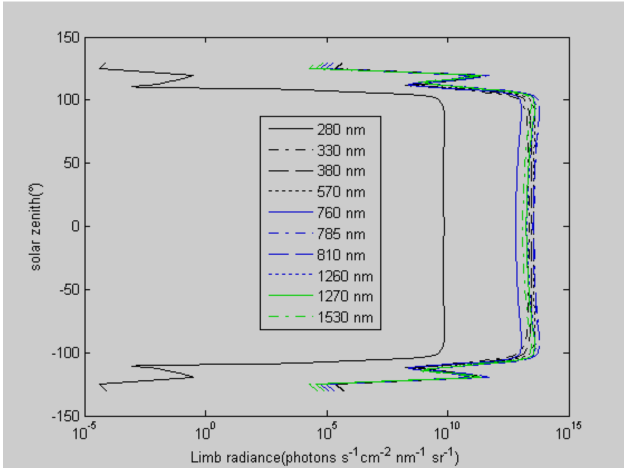

Fig.2 Different Band Zenith Angles Effect On The Radiance Of The Sun (0km)

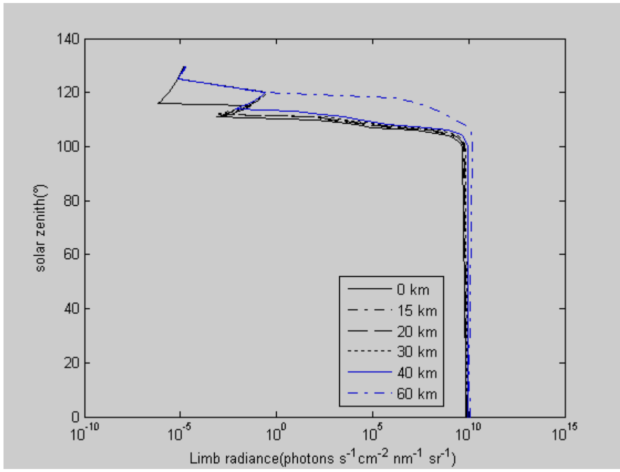

Fig.3 Radiance Of Different Viewing Angles (280nm)

From fig.3 we can see two minimums at 0km and at 40 km recover gradually to the value in 130 °.Close to 60km, the second minimum value disappears.

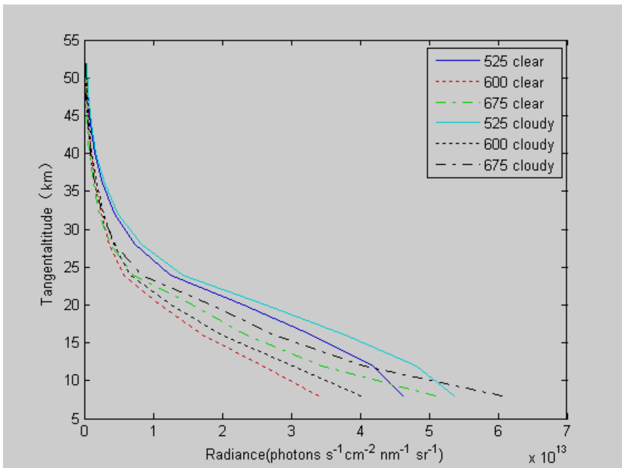

Fig.4 Radiance Of Clear And Water Clouds

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Study on the bands of 525nm, 600nm, 675nm. In 'control.inp' 'Clouds present?' we choose 't' . In 'cloud.inp' 'Thermodynamic state' we choose water.

From fig.4 we can see the radiance values are bigger when there are water clouds than it's clear.

In 'Thermodynamic state' of the 'cloud.inp' we choose 'ice'. In 'Cloud layer base and top' we choose "5 - 6".

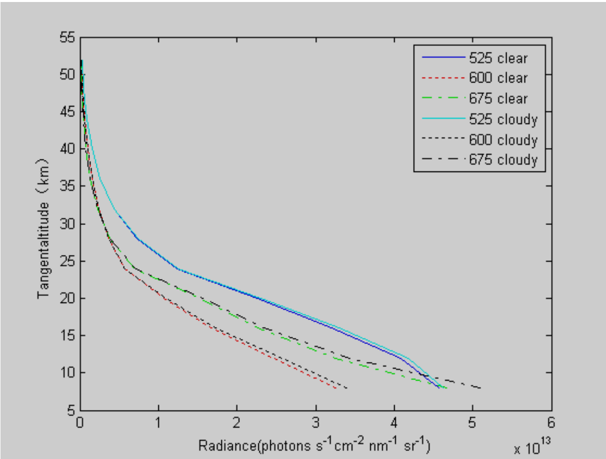

Fig.5 Radiance of Clear And Ice Clouds

From fig.5 we can see the radiance basically remains the same clear or when there are ice clouds above 19km.The radiance values are bigger when there are ice clouds than it's clear.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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