〈一般研究課題〉　東海地方における緑地面積定量を目的とした環境衛星
データ解析アルゴリズムの研究

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東海地方における緑地面積定量を目的とした環境衛星データ解析アルゴリズムの研究

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Development of a parameter retrieval algorithm from data of environmental satellites for estimation of green coverage in Tokai area

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キーワード：緑地面積，衛星画像，ASTER， LAI，被植率，放射伝達

ABSTRACT

One important measure of living environment related to comfortableness is a fraction of area covered by green vegetation. This research is to develop a technique to retrieve such parameters related to amount of green vegetation over Tokai area Japan using space born satellite data from ASTER sensor on board Terra platform. The major challenge is an accurate estimation of fractional area covered by green vegetation within a single pixel at 15 m resolution. In this study, we took an approach of inverting a set of numerical models which simulates physical processes of interactions between solar radiation and vegetation. The results indicate that the proposed inversion technique performs quite well for retrieval of both one and two vegetation parameters with a few exceptions at some extreme conditions.

I. INTRODUCTION

Vegetation monitoring on land surface ecology can be addressed through study of a time series satellite data. One requirement of such studies is the consistency of parameter estimations of land surface among sensor generations and sensor types. Although several satellite sensors are currently on orbit, there are a few discrepancies in observations among those sensors. These differences mainly come from differences in both spatial and spectral characteristics of satellite sensor. For this reason, the continuity and compatibility of data product from satellite sensors become important [1].

Considering vegetation monitoring in Tokai region, Japan, data from a sensor with high spatial resolution are needed. ASTER sensor on board Terra platform has its spatial resolution of 15 m, hence it is suitable for this purpose despite its relatively course radiometric resolution of 8 bit. The challenge of using data from ASTER sensor is associated with its band configuration: it has three bands in visible and near infrared (NIR) wavelength ranges. Therefore, techniques of vegetation monitoring developed for other sensors need to be modified by only using these three bands. One objective of this research is to develop a technique to retrieve two vegetation biophysical parameters in addition to one parameter related to its background soil brightness for the purpose of processing the data from ASTER sensor.

II. VEGETATION ISOLINE EQUATIONS

A set of vegetation isoline equations, which describes relationships between red and NIR bands, was derived analytically by our early work [2]. The usefulness of these expressions can be understood from the fact that the coefficients of the isoline equation are functions of biophysical parameters and soil line parameters (slope and offset) written in the following form.

$$\rho_N = a\gamma(L)\rho_R + D(L) \tag{1}$$

$$\gamma(L) = \frac{T_{vN}^2(L)}{T_{vR}^2(L)} \tag{2}$$

$$D(L) = \rho_{vN}(L) + bT_{vN}(L) - a\gamma(L)\rho_{vR}(L) \tag{3}$$

where ρ_R and ρ_N are red and NIR reflectances, respectively, which are functions of both vegetation biophysical parameters and soil brightness. L represents values of LAI, a and b are the soil line slope and offset, respectively, and T_V^2 's and ρ_V 's are the' canopy-layer 'two-way transmittances and reflectances, respectively. Although all the variables in the above equations depend on view and illumination angles as illustrated in Fig. 1, we omit those angular variables for simplicity.

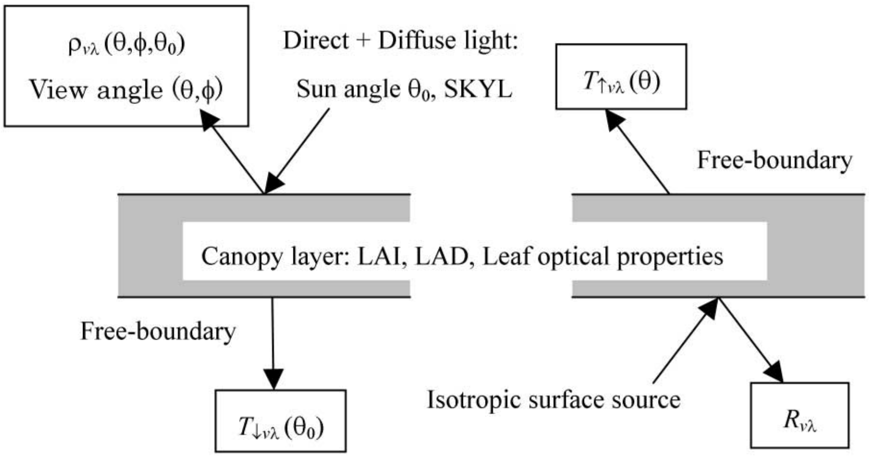


Fig.1 IIlustration of transmittances and reflectances of leaf canopy

The above equations indicate the possibilities of retrieving biophysical parameters such as LAI, by relating a pair of ρ_R and ρ_N observed by a satellite sensor to the slope and offsets of (1). More specifically, our approach is to find an LAI value which results in the slope and offset of the vegetation isoline that goes through an observation point, (ρ_R, ρ_N), in red-NIR reflectance space.

The above set of equations were farther modified for the purpose of estimating area of green coverage within a pixel [3]. The extension was done by introducing a parameter, β, which represents a fraction of area covered by green vegetation within a single pixel. Using the parameter, the equations of vegetation isoline become as follows.

$$\rho_N = a\gamma(L,\beta)\rho_R + D(L,\beta), \tag{4}$$

where

$$\gamma(L,\beta) = \frac{\beta T_{vN}^2(L) + (1-\beta)}{\beta T_{vR}^2(L) + (1-\beta)}, \tag{5}$$

$$D(L,\beta) = D_N(L,\beta) - a\gamma(L,\beta)D_R(L,\beta), \tag{6}$$

$$D_N(L,\beta) = \beta\rho_{vN}(L) + b[\beta T_{vN}^2(L) + (1-\beta)], \tag{7}$$

$$D_R(L,\beta) = \beta\rho_{vR}(L), \tag{8}$$

Figures 2 and 3 shows the behavior of isoline slope and offsets. The purpose of using these expressions is to retrieve L and β, from a given set of reflectance values (reflectance spectrum). Since the ASTER sensor provides reflectance values at three wavelengths one sample from green, red and NIR wavelength ranges, the idea of our inversion technique is to retrieve L and β, by implicitly eliminating the effect of vegetation background brightness. Therefore, three unknowns, L, β, and the background brightness (soil brightness) will be retrieved from these three observations (by the green, red and NIR channels). The key information for this inversion technique is the slope, Eq. (5), and offset, Eq. (6), of the vegetation isoline represented by Eq. (4). We will find a pair of L and β which satisfies Eq. (4) with a given set of observed reflectances by the sensor.

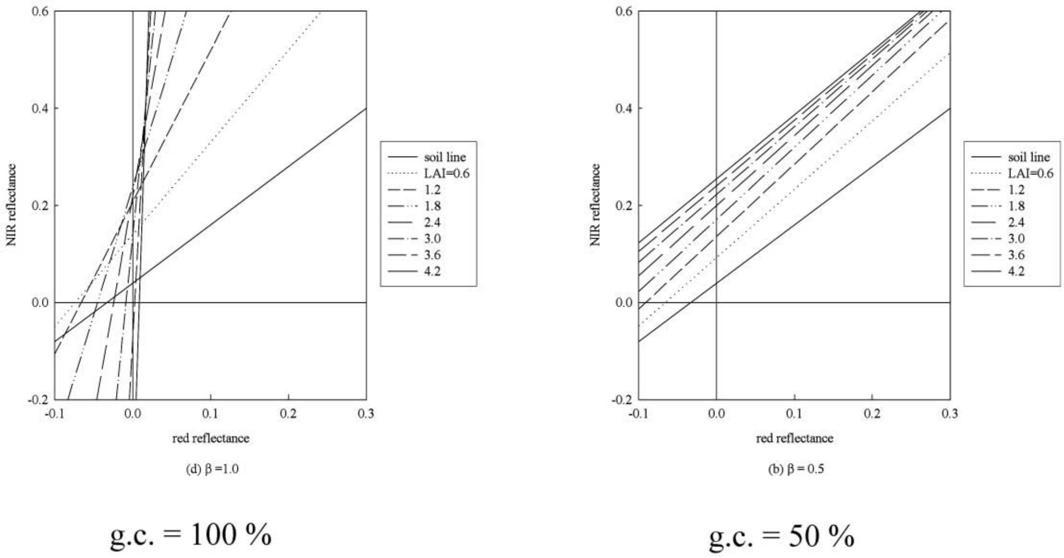


Fig.2　Vegetation isolines under 100% and 50% green cover

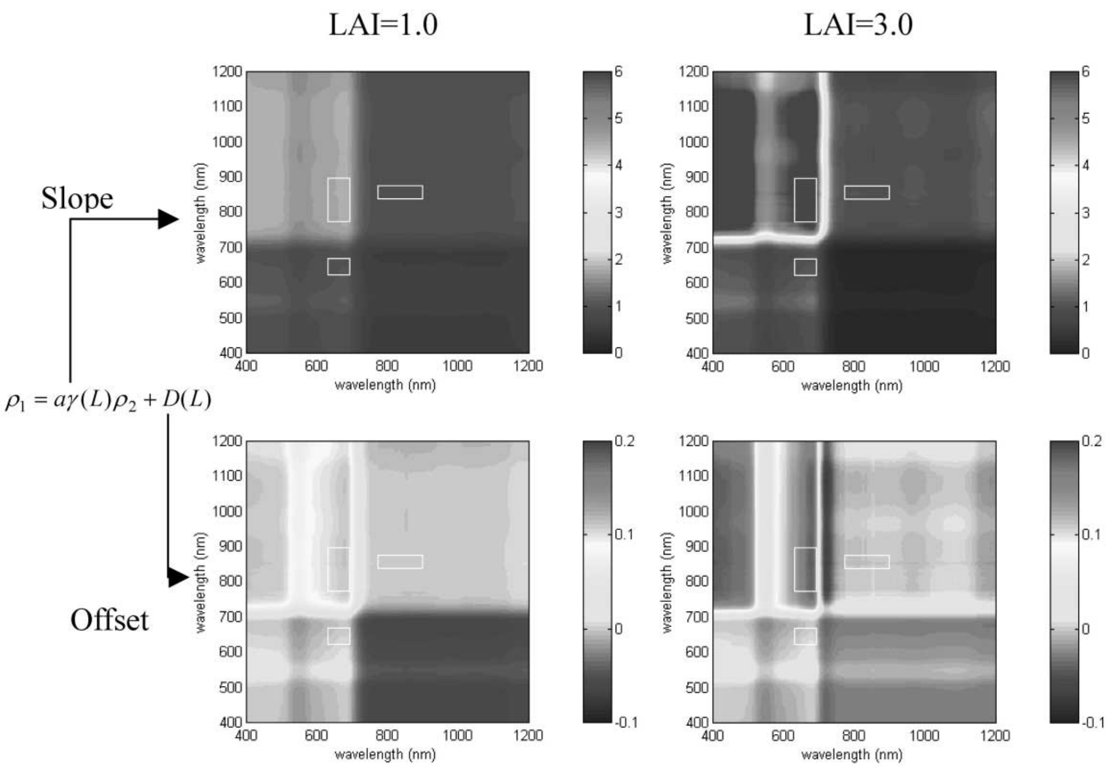


Fig.3　Isoline slope and offset for various combinations of wavelength

III. LAI RETRIEVAL

Several parameters need to be prepared prior to the inversion process. We first discretize *L* into N bins, denoted by subscript' i ,' so that the entire red-NIR reflectance space can be divided into (N+1) sub-regions. γ and *D* are then computed at those discrete points of *L* using a numerical canopy model [2]. The estimation of LAI value, $\nu_i(\rho_R, \rho_N)$, for sub-region-*i* is obtained by

$$\nu_i(\rho_R, \rho_N) = L_i + m_i sin\theta_{t,i}, \tag{9}$$

with the definitions of m_i and $\theta_{t,i}$,

$$m_i = \frac{L_{i+1} - L_i}{sin\theta_i}, \tag{10}$$

$$sin\theta_i = \frac{|a(\gamma_i - \gamma_{i+1})|}{\sqrt{(1 + a^2\gamma_i^2)(1 + a^2\gamma_{i+1}^2)}}, \tag{11}$$

$$sin\theta_{t,i} = \sqrt{1 - cos^2\theta_{t,i}}, \tag{12}$$

$$cos^2\theta_{t,i} = \frac{[(\rho_R - x_{C,i}) + a\gamma_i(\rho_N - y_{C,i})]^2}{[(\rho_R - x_{C,i})^2 + (\rho_N - y_{C,i})^2](1 + a^2\gamma_i^2)}, \tag{13}$$

$$x_{C,i} = \frac{D_i - D_{i+1}}{a(\gamma_{i+1} - \gamma_i)}, \text{ and} \tag{14}$$

$$y_{C,i} = \frac{\gamma_{i+1}D_i - \gamma_i D_{i+1}}{\gamma_{i+1} - \gamma_i}. \tag{15}$$

The LAI retrieval is done using the coefficients demoted by 'i' where the sub-region-i includes the reflectance point, (ρ_R, ρ_N).

The inversion procedure consists of the following three steps.

Step-1: Find the sub-region in the reflectance space where the reflectance point, (ρ_R, ρ_N), is included.

Step-2: Obtain from (12) to (15).

Step-3: Compute $\nu_i(\rho_R, \rho_N)$ from (9).

This inversion process can be optimized based on the spectral band-pass filters (BPFs) of the target sensors by specifically preparing the vegetation isoline parameters, γ and D.

III. SIMULTANEOUS RETREIVAL OF LAI AND FRACTION OF GREEN COVER

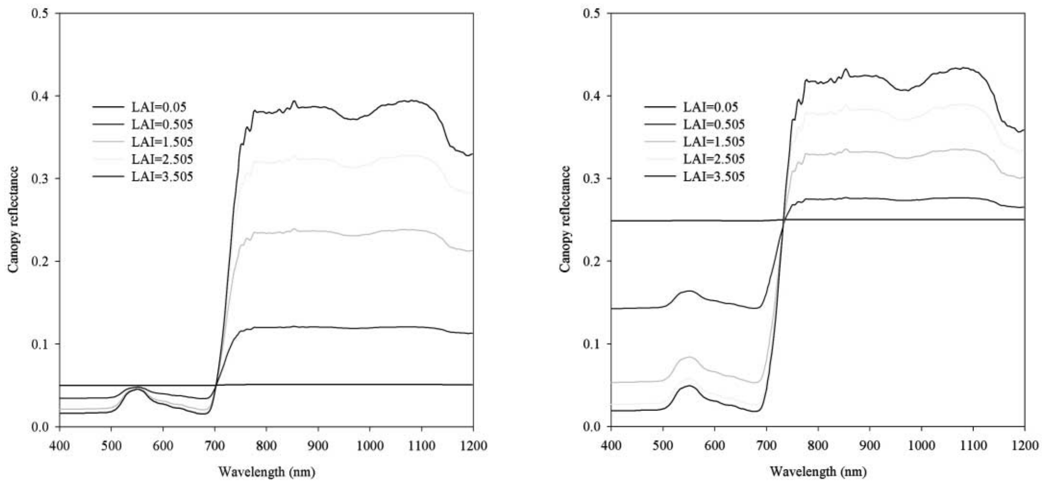
Our final goal is to retrieve both *L* and β simultaneously from observed reflectances regardless the brightness of vegetation background. For this purpose, two pairs of reflectances (red-NIR and green-NIR) are used to retrieve *L* independently represented by $L_{rN}(\beta)$ and $L_{gN}(\beta)$ by assuming a value of β by applying the above procedure. Then, these processes are repeated until the cost function defined by the following equation becomes sufficiently small.

$$\chi^2(\beta) = [L_{rN}(\beta) - L_{gN}(\beta)]^2$$

IV. NUMERICAL EXPERIMENTS

In order to examine the proposed technique, we conduct numerical studies by using models of leaf and canopy radiative transfer by assuming hypothetical background soils. Leaf reflectance and transmittance were simulated using PROSPECT [4], and then the results were used as inputs of SAIL canopy model [5]. When the simulations of the top-of-the-canopy reflectance were conducted, we assumed a ‘flat-soil spectrum,’ whose reflectance is constant throughout entire wavelength at two magnitudes, from 0.05 to 0.3 to simulate soil of various brightness. Sample spectra by those simulations were plotted in Fig. 4. Sensor outputs were then simulated based on the sensor band-pass filters. Fig. 5 shows the simulated reflectances in red-NIR reflectance space.

The vegetation isoline parameters were obtained for each band pairs (red-NIR and green-NIR) based on the sensor reflectances. Therefore, two sets of vegetation isoline parameters were prepared prior to the inversion. The inversion is then conducted using the sensor-specific inversion coefficients against the reflectances shown in Fig. 5.



Canopy reflectance spectra for different LAI values with the soil reflectance of 0.05 Canopy reflectance spectra for different LAI values with the soil reflectance of 0.25

Fig.4 Simulated vegetation spectra

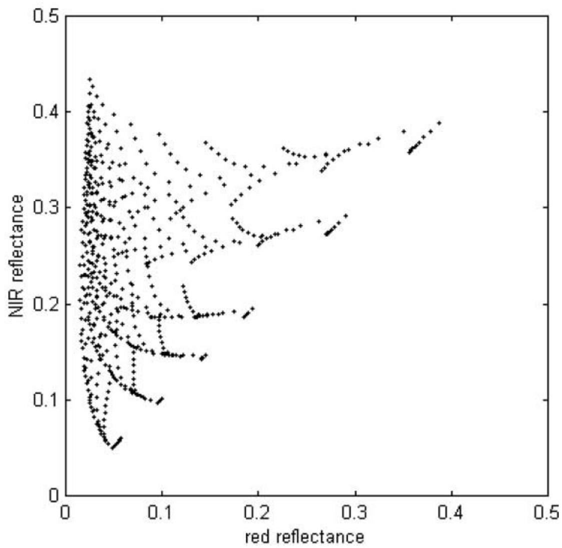


Fig.5 Scatter plot of simulated reflectance spectra in red-NIR reflectance space

V. RESULTS AND DISCUSSIONS

We first show the retrieval of L under a know value of β. Fig. 6 shows errors in the estimation of L under two soil brightness. The results indicate two things. L was retrieved quite successfully for most of the cases except few points. The retrieval tends to be unsuccessful when the cases with high L and low β. This trend of performance difference comes from the fact that we expect very small differences in values of reflectance spectra when L becomes large at low β, since this corresponds to‘ thick ’ vegetation within a very small portion of area in a target pixel. Thus, inversion becomes extremely difficult at this extreme condition for any techniques.

Knowing the tendency of the retrieval difficulties we then move on to the simultaneous retrieval of both L and β. Figures 7 and 8 show the errors in L and β at two values of soil brightness, 0.05 and 0.1 in reflectance units, respectively. The tendency of retrieval error becomes more complicated than the estimation of single parameter. However, the trend of difficulty stays almost the same as the previous cases: the parameter retrieval becomes harder at the combination of higher L and lower β. One distinct difference between the results of Fig. 6 and Figs. 7 and 8 is that the errors in both L and β become relatively higher at low LAI throughout entire range of green cover. This may indicates the breakdown of the uniqueness of solution. Farther studies will be needed to identify the causality of this trend.

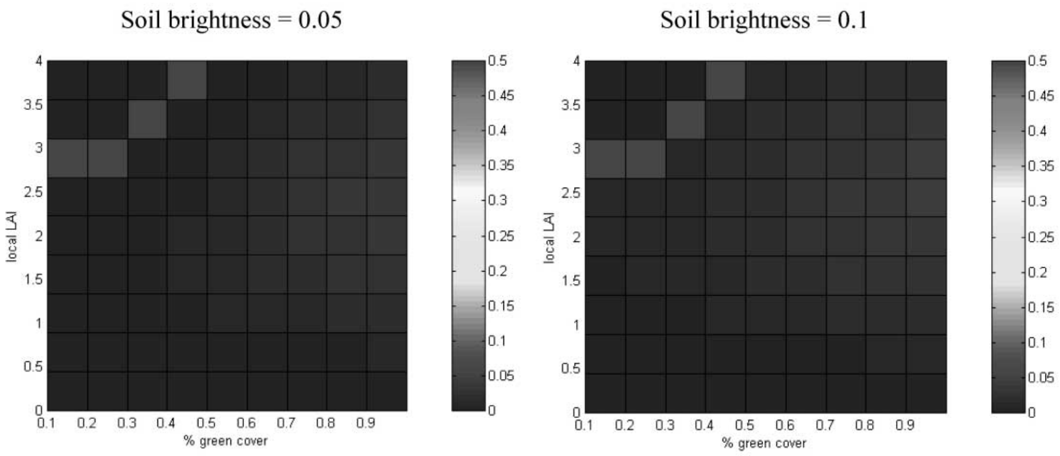


Fig.6 Error in retrieved LAI values under two kinds of soil brightness

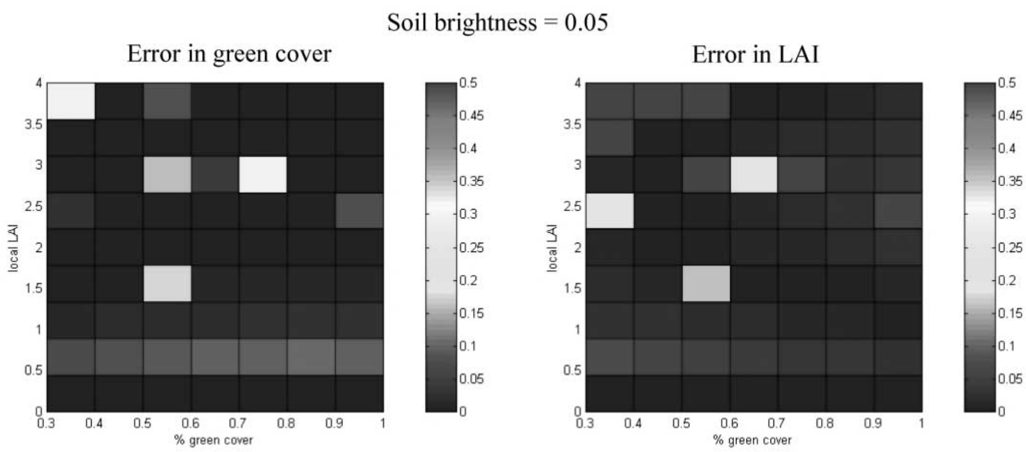


Fig.7 Errors in retrieved values of LAI and fraction of green cover under darker soil

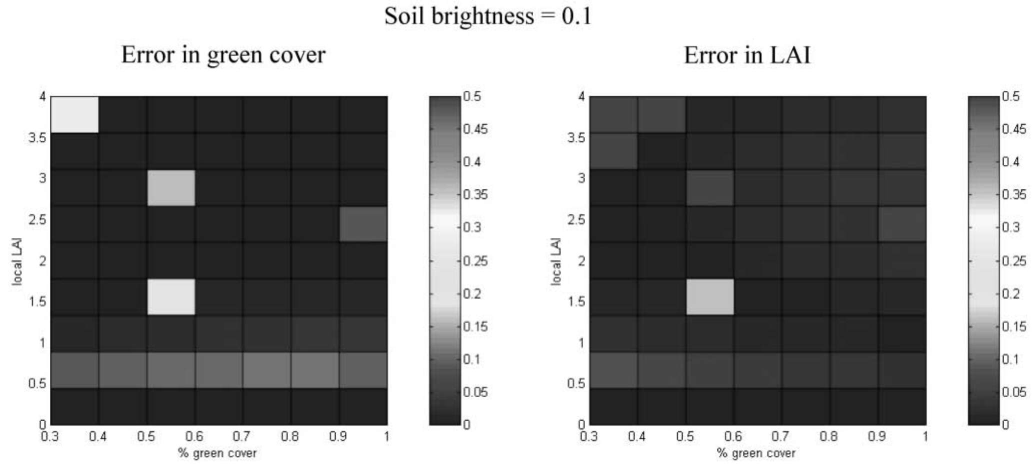


Fig.8 Errors in retrieved values of LAI and fraction of green cover under brighter soil

VI. CONCLUDING REMARKS

An inversion technique developed for the use of ASTER sensor based on the vegetation isoline equation was introduced and demonstrated its performance with a numerical experiment assuming a ' spectrally flat 'soil. The results showed good performance of the LAI retrieval for the entire range of LAI with a few exceptions. We also extend the technique to the simultaneous retrieval of two parameters, L and β. Numerical experiments indicated that simultaneous retrieval becomes harder when LAI is small in addition to the cases where single parameter retrieval was unsuccessful. One possible reason is that several combinations of these parameters may result in very similar spectra. In that case, the parameter combinations can not be determined uniquely. Farther studies are needed to clarify this point.

ACKNOWLEDGEMENT

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