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Estimation of Methane Emission from Paddy Fields in Central Plain of Thailand by Scaling Technique

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Abstract

Since the rapid increase in atmospheric methane was recognized in the early 1980's, paddy fields have been considered to be one of the likely and most important sources of this problem. The objective of this study is to estimate the methane emission from paddy fields with remotely sensed data and the methane flux in situ.

In this paper, firstly, we developed a scaling technique to extrapolate the local information on land cover type combination from high spatial resolution data (OPS) to more extensive area through low spatial resolution data (AVHRR) with wide coverage. Paddy field area was extracted from OPS data, then AVHRR NDVI was statistically regressed with the corresponding paddy area ratio from OPS pixels for corresponding AVHRR pixel. With this regression model (scaling model), local information of the paddy area was estimated only from AVHRR data over extensive area outside the OPS data.

Secondly, this method is applied to the paddy field extraction in the Central Plain of Thailand. Finally, we estimated the methane emission from paddy fields by multiplying observed in situ methane flux and the total paddy area estimated in whole AVHRR.

1 Introduction

Since the rapid increase in atmospheric methane was recognized in the early 1980's, paddy fields have been considered to be one of the likely and most important sources of this problem. At the same time, rice is one of the major cereals for human beings.

The improved understanding of paddy field distribution at large spatial scales has increased the interest in deriving crop yield and methane emission estimations. Nevertheless, the collection of such data through field surveys is time-consuming and expensive in South-East Asia regions. Remotely sensing data from satellite images provide an alternative means of obtaining paddy field distribution.

High spatial resolution data is effective for monitoring the land cover type changes, but it can't cover a wide area because of it's narrow swath width. On the other hand, global scale data is indispensable to cover large area, but it is too coarse to get the detail information due to the low spatial resolution. So, it is necessary to get the method for the fusion of the data with different spatial resolution for monitoring the scale-differed phenomena.

A scaling technique is a new remote sensing method to extrapolate the local information based on the high spatial resolution data (OPS) to more global scale by using low spatial resolution data (AVHRR) with wide coverage [1]. Paddy field area was extracted from OPS data, then AVHRR image density was statistically regressed with the corresponding paddy area ratio from OPS pixels for corresponding AVHRR pixel. With this regression model (scaling model), local information of the paddy area was estimated only from AVHRR data over extensive area.

Secondly, this method was applied to the paddy field extraction in the Central Plain of Thailand. Finally, we estimated the methane emission from paddy fields by multiplying observed in situ methane flux and the total paddy area estimated in whole AVHRR.

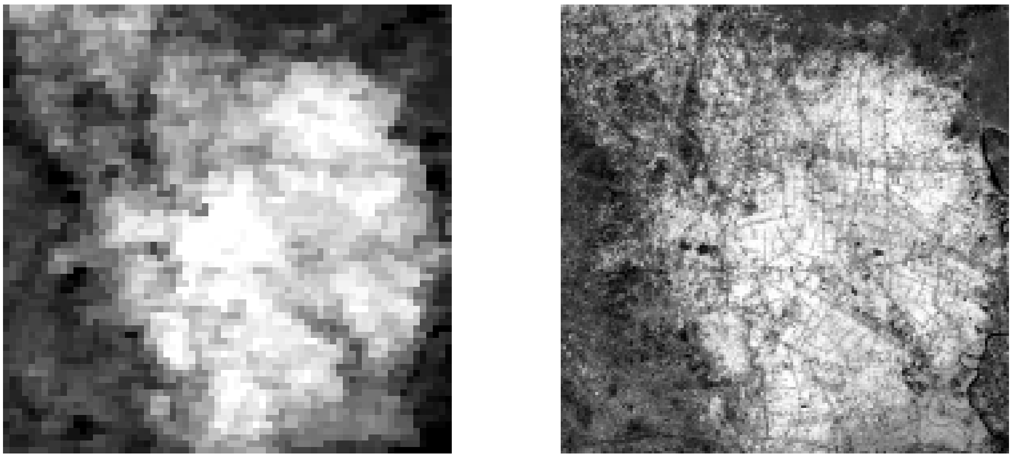
2 Comparison of NDVI between AVHRR and OPS data

JERS-1 OPS data of Feb. 7th, 1993 and NOAA AVHRR data of Feb. 5th, 1993 over in the central plain of Thailand were geometrically corrected and overlayed so that one pixel of AVHRR covers a set of OPS pixels in a rectangular block of 60×60 pixels. Spatial resolution of one pixel of AVHRR is around 1.1(km) and that of OPS is around 18(m). Then the relations between each pixel of AVHRR and corresponding block of 60x60 pixels of OPS were statistically investigated in NDVI (Normalized Difference Vegetation Index). NDVI for AVHRR and HRV are defined by

$$\begin{aligned} \mathrm{NDVI_{AVHRR}} &= (\mathrm{AV_2} - \mathrm{AV_1})/(\mathrm{AV_2} + \mathrm{AV_1}) && \text{(1-a)} \\ \mathrm{NDVI_{OPS}} &= (\mathrm{OPS_3} - \mathrm{OPS_2})/(\mathrm{OPS_3} + \mathrm{OPS_2}) && \text{(1-b)} \end{aligned}$$

where $\mathrm{AV_1}$, $\mathrm{AV_2}$, $\mathrm{OPS_2}$ and $\mathrm{OPS_3}$ are the CCT counts for NOAA AVHRR channel 1 and 2, and JERS-1 OPS band 2 and 3, respectively. Fig. 1 shows the NDVI from NOAA AVHRR and JERS-1 OPS data over the target area. The relation between NDVI value for each AVHRR pixel and an average NDVI value for a corresponding OPS block 60x60 is examined (Fig. 1). Regression analysis between $\mathrm{NDVI_{AVHRR}}$ and $\mathrm{NDVI_{OPS}}$ shows high correlation between the vegetation index of NOAA AVHRR and JERS-1 OPS (Eqn. 2).

$$\mathrm{NDVI_{AVHRR}} = 0.738\ \mathrm{NDVI_{OPS}} + 0.0651, \qquad (r = 0.91) \tag{2}$$



(a) AVHRR NDVI

(b) OPS NDVI

Figure 1. Comparison of NDVI between AVHRR and OPS data

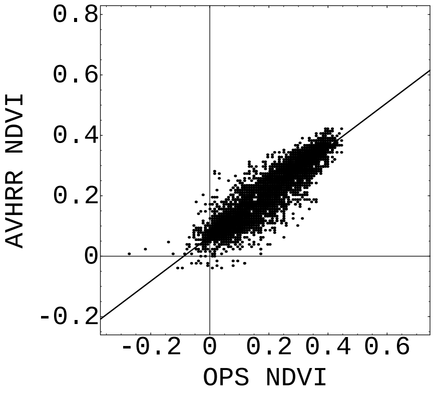


Figure 2. Scatter plot between AVHRR NDVI and OPS NDVI

3 Analysis

3.1 Paddy Field Extraction with OPS Data

The JERS-1 OPS is a high resolution imaging system with a ground resolution of 18x24(m) and has three spectral bands of green, red and near infrared wavelengths (0.52-0.60, 0.63-0.69, and 0.76-0.86(μm)). This high resolution data was used to unmix the AVHRR pixel with 1.1(km) resolution. The success of spectral unmixing depends on the selection of the endmember components. In this study, the VSW index was adopted as the endmember selection [2]. The definition of VSW index is shown in Fig. 3, which shows the relationship between VSW index and the endmember triangle(VSW triangle) on a Red-NIR scatter plot. The VSW index monitors vegetation, soil and water parameters simultaneously by measuring the distances PV, PS and PW for vegetation, water and soil, respectively.

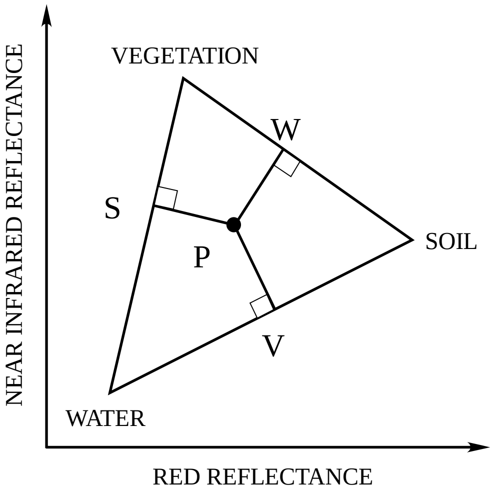


Figure 3. Relationship between VSW indices and the endmember triangle of Red-NIR Scatter plot

Firstly, for OPS data, the VSW index were calculated using endmember spectral points with an algorithm to fit a triangle to the Red-NIR spectral distribution. Then for the paddy field included in the OPS data, the relationship among VSW index were examined. Fig. 4 shows the linear relationship between V and W index. This is because that in the growing season, the paddy field is covered by vegetation and water, and there is no bare soil on the surface.

$$\text{V index} = -0.850 \text{ W index} + 0.893, \qquad (r = 0.92) \tag{3}$$

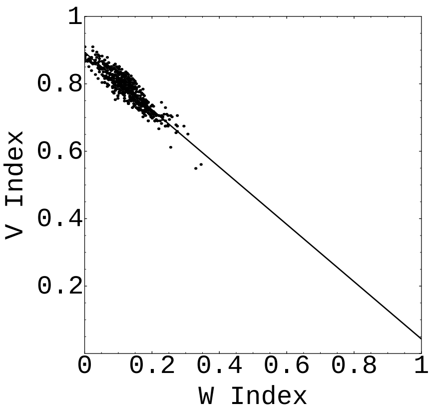
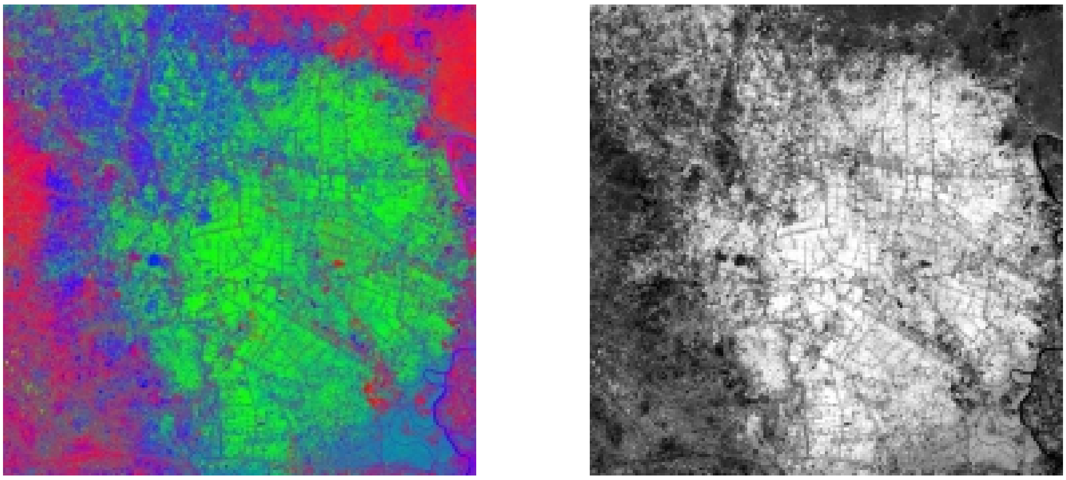


Figure 4. Linear relationship between V and W index

Secondly, assuming that the pixels along the regression line (Eqn. 3) within the error of 3σ are the paddy field, we extracted the paddy field over OPS data. Fig. 5 shows the VSW index image and the extracted paddy field image over OPS data.


(a) VSW index image (R:G:B=S:V:W)

(b) Extracted Paddy Field

Figure 5. Comparison of VSW index image and Extracted Paddy Field

3.2 Extrapolation to whole AVHRR Data

Firstly, each pixel of AVHRR data was classified into 6 categories including paddy field, crop, bare soil, water, forest and cloud with channel 3, 4 and 5. Then cloud, water, forest were screened out for the analysis. Then, the mixing ratio of paddy field in each pixel of AVHRR including paddy field, crop and bare soil, was calculated by counting the paddy field in each block of 60 × 60 pixels of OPS. This paddy field area ratio with corresponding OPS data is denoted as $\mathrm{P_{OPS}}$.

Secondly, AVHRR NDVI was correlated with $\mathrm{P_{OPS}}$ using least squares method. The linear equations obtained with high correlation is Eqn. 4.

$$\mathrm{NDVI_{AVHRR}} = \mathrm{a} * \mathrm{P_{OPS}} + \mathrm{b} * (1 - \mathrm{P_{OPS}}) \tag{4}$$

This relation shows that the paddy area ratio $\mathrm{P_{OPS}}$ can be solved inversely from Eqn. 4. This scaling model enables us to extrapolate the local information from OPS data to more extensive area through AVHRR data. Fig. 6 shows the distribution of paddy field for whole AVHRR coverage over Central Plain of Thailand.

Fig. 7 shows the comparison of the estimated paddy field distribution with scaling model and the original extracted paddy field distribution with OPS data for the overlapped area. The performance of the scaling model was evaluated in terms of the root mean squared (RMS) error. For a paddy field , the RMS error is given as follows.

$$\mathrm{Error(analysis)} = \frac{1}{N}\Sigma[y_{lm}(\mathrm{analyzed}) - y_{lm}(\mathrm{ogirinal\ data})]^2 \tag{5}$$

The RMS error for this model was calculated **19.5** % over the image with validation of the high performance for this model.

4 Estimation of methane emission from paddy fields

Although there has been a number of studies in which methane flux data has been reported to date, there are significant temporal and spatial (site-by-site) variations in methane emission rates from paddy

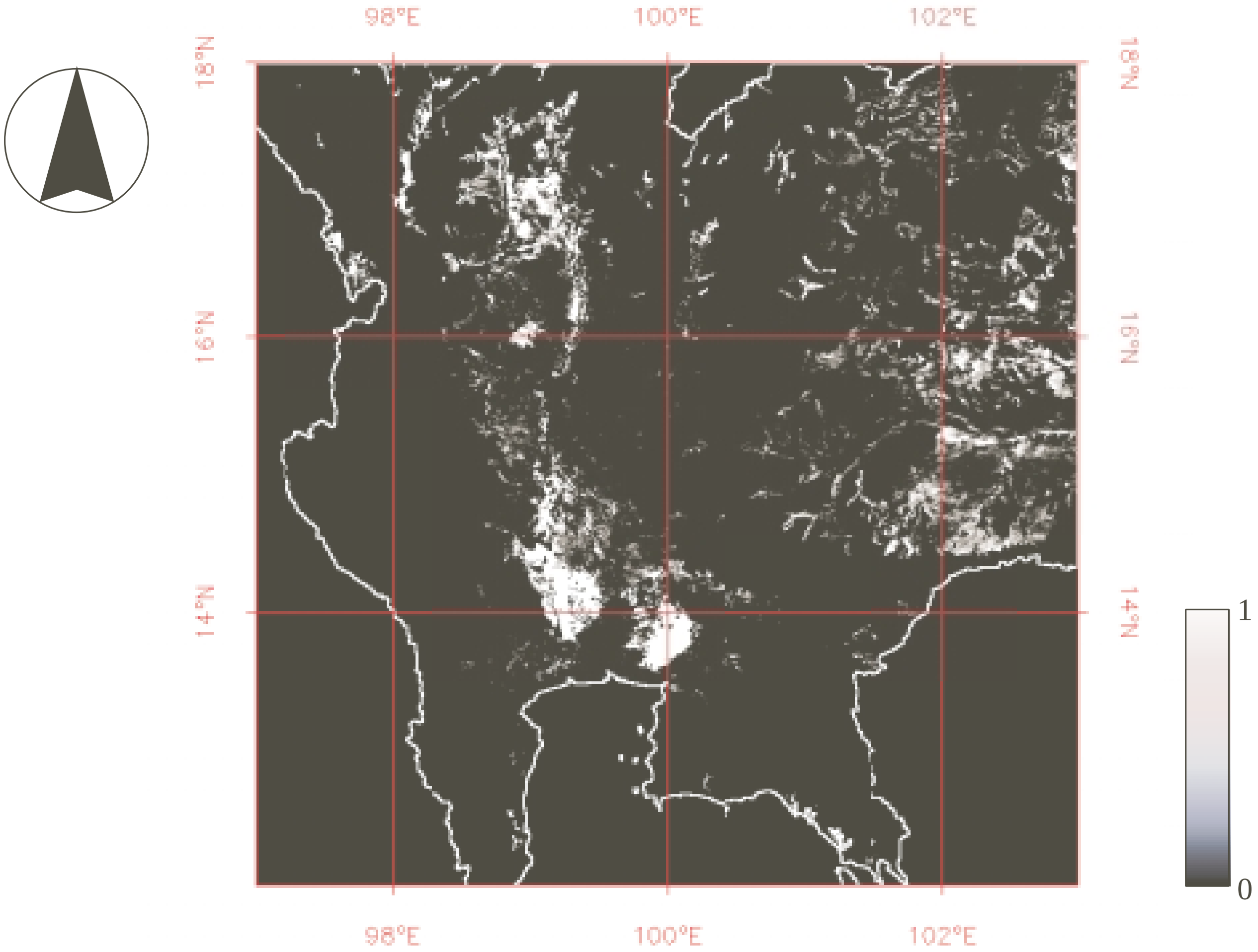
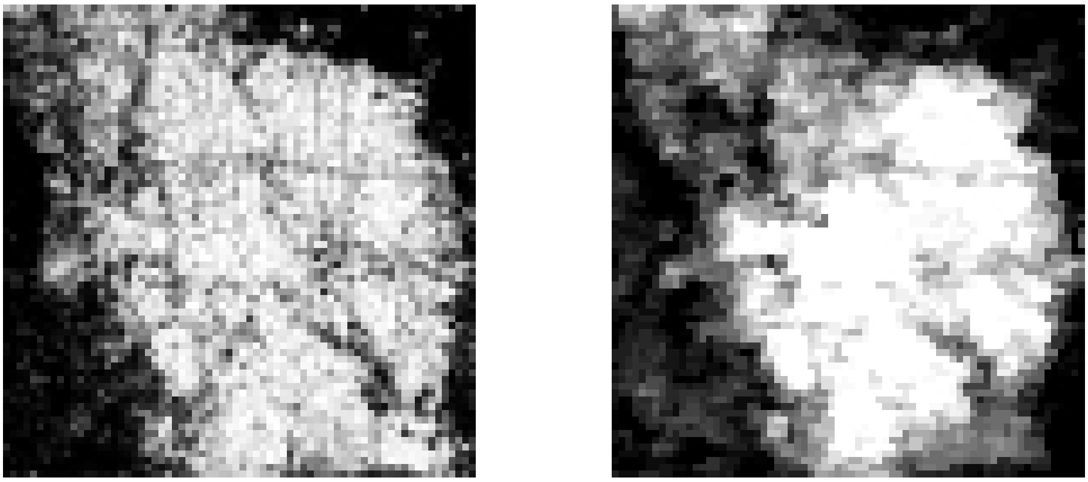


Figure 6. Estimated Paddy Field in Central Plain of Thailand



(a) Original Image

(b) Estimated Image

Figure 7. Comparison of Paddy field distribution between original data and estimated data

fields. The large diurnal, seasonal, and inter-annual variations in emission rates require frequent and long-term measurement of the methane emission rate from a field. The large spatial variation makes it difficult to estimate the regional and global scale.

The results from the three Thailand sites showed that one field had relatively high flux and the other two had relatively low fluxes, depending on the chemical composition of the soils. The available nitrogen and free iron oxides of the three Thailand sites were not greatly off the midpoint of those values in the tropical paddy soils (38-620 ($mg/m^2/day$)) [3]. Therefore, emission rates 500 ($mg/m^2/day$) was used to estimate methane emission from paddy fields in Central Plain of Thailand.

As discussed by Yagi [4], the development of soil reduction caused by flooding is essential to the production and emission of methane from paddy fields. The field measurement results showed that the period of methane emission from paddy fields closely matched the period that the fields were flooded. To estimate methane emissions, it is important to take account of the period of flooding. Here, we adapted the 90 days for flooding period, which is the typical period for the irrigated paddy fields in dry season all over South East Asia. As a result, the total emission from the paddy fields in Central Plain of Thailand was estimated as follows

$$\begin{aligned} \text{Total Emission} &= \text{Paddy Area} \times \text{Flux} \times \text{Flooding Period} \\ &= 9,538(km^2) \times 500(mg/m^2/day) \times 90(day) \\ &= \mathbf{0.41}(\mathrm{CH_4T}g) \end{aligned}$$

5 Conclusion

The aim of this study is to find an expression useful for the regional mapping of the paddy field ratio in AVHRR pixel with high resolution spectral data. For that purpose we have investigated the linear relationship between V and W index and extracted the paddy field with OPS data. Then the AVHRR NDVI was statistically regressed with paddy field area ratio from OPS data and the high performance was demonstrated with the error of 19.5 %. Finally, the methane emission in Central Plain of Thailand was estimated with the combination of paddy field distribution and the methane flux data in situ.

Since most of the global issues originate from local events such as extensive logging, monitoring earth surface changes requires that the observation of land cover embraces the terrain from local to global. Linking local with global is one of the key aspects in global environmental issues. The method proposed in this study is expected to play an important role in bridging the local and the global in remote sensing.

Acknowledgment

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