Development of MRV system of Methane emissions from Rice paddies in the Mekong delta

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Cycle from Observation to Countermeasure

To target
Observ. Survey ➔ Modelling ➔ Simulation Forecast • eval.

To solution
Solution design ➔ optimization ➔ management ➔ Evaluation

To target

DATA ➔ information ➔ Estimation ➔ Strategy ➔ Policy ➔ Evaluation

Observation of the effect

GOSAT

K-computer, Fugaku

Effect

Each country must submit INDC (Intended Nationally Determined Contributions) to UNFCCC before 2020

Modified from Yasuoka 2015
alluvial soil
1.1 Mha, 28%
acid sulfate soil
1.1 Mha, 28%
potentially acid sulfate
0.5 Mha, 13%

Yan et al. 2009
Xuan and Matsui, 1998
- Continuously flooded nearly through a year
  + High straw production

- Anaerobic stress for rice production
  - High GHGs emission

AWD
(Alternate Wetting and Drying)
- Irrigation-water saving
- Anaerobic-stress mitigation
- GHGs mitigation

Drainage period
- Less $\text{CH}_4$

Flooded soil
- More $\text{CH}_4$

Modified from Yagi, 2010

Oxidative
- $\text{CH}_4, \text{H}_2\text{S}$
- Anaerobic bacteria

Reducive
- $\text{CO}_2 \cdot \text{H}_2 \cdot \text{acetate}$
- Anaerobic bacteria
Characteristics of the Mekong delta

Arai et al., 2018
Greenhouse gas emission derived from rice straw use

Straw use in TL2, Can Tho (ha ha⁻¹)

- Left on soil
- Feedstuffs for livestocks
- Compost for vegetable cropping
- Compost for Mushroom cultivation
- Free transfer to mushroom farmers
- Sold to mushroom farmers
- Burned

n=50
Greenhouse gas emission derived from straw burning
- Comparison among different straw size and moisture -
- Reduction of irrigation rate & GHGs (2012-2016)
- Increase of rice grains and its quality

Arai et al., 2018
## Flow chart

**Remote sensing on field water & vegetation**

- **PALSAR-2 Lv.1.1**
  - Coherency matrix [T3] generation
  - Quadruple 6m
  - Speckle filtering Lee-refined (7×7)
  - Freeman-Durden decomposition
  - Single scattering
  - Volume diffusion
  - Double bounce
  - Enhanced Lee filter (3×3)
  - HH, HV $\sigma^0$

- **PALSAR-2 Lv.1.1 SCAN-SAR**
  - Multi-looking
  - Co-registration
  - De-Grandi multi-temporal speckle filtering
  - HH, HV $\sigma^0$
  - Local Incidence angles
  - Inundated / non-inundated paddies classification

**Validation & integration with daily EO data**

- **AMSR-2**
  - 18.7 & 23.8 GHz (V), 10km
  - Normalized frequency Index

- **MODIS (MOD13Q1)**
  - Normalized Vegetation/Water index,
    Days after sowing, 1km
  - Local Maximum Fitting - Kalman filter

**Verification with GOSAT**

- **GOSAT (Retrieval)**
  - 10km
- **NICAM-TM (LETKF)**
  - Validation
  - CH$_4$ emission map

**Field observation & flux modeling**

- Field data collection
- CH$_4$ flux data & Soil map
- Field water level & cropping calendar
- Hierarchical bayesian modelling
- CH$_4$ emission estimation model

- Sampling (25-30 pixel) from each ROI
- Statistical analysis
- Inundated / non-inundated paddies characterization
Straw incorporation time and amount

Water regime prior to rice cultivation

<table>
<thead>
<tr>
<th>Straw incorporation time and amount</th>
<th>Water regime prior to rice cultivation</th>
<th>Water regime during rice cultivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>(1) &gt;30 days</td>
<td><img src="image1" alt="Illustration" /></td>
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<tr>
<td></td>
<td>(2) &lt;180 days</td>
<td><img src="image2" alt="Illustration" /></td>
</tr>
<tr>
<td>B.</td>
<td>(3) &gt;180 days</td>
<td><img src="image3" alt="Illustration" /></td>
</tr>
</tbody>
</table>

IPCC guideline (Tier1) [Emission factor × Scaling factor in IPCC guideline]
Cropping calendar evaluation with MODIS-NDVI (LMF-KF) for GCOM-C

Sowing days (days after 2001/01/08)

The adjacent fallow's length (days)

Samples of paddies

Paddy A (x:184, y:229):
Double cropping → Triple cropping

Paddy B (x:185, y:220):
Triple cropping

Arai et al., 2018
Semi-empirical daily CH$_4$ flux (mg C m$^{-2}$ hr$^{-1}$) Model

**CH$_4$ emission on a specific date**

\[ CH_4 = \gamma \times \text{carbon_management} / \text{non-inundated_fallow} / \text{inundated_fallow} \times \text{water_management} \times \alpha \times \beta \]

**carbon_management (Michaelis-Menten KINETICS)**

\[
\text{carbon_management} = \left[ \exp(-DAS \times \delta) - \exp(-DAS \times (\delta + \omega)) + \kappa \right]
\]

**non-inundated_fallow (OXYDATION CAPACITY)**

\[ \text{non-inundated_fallow} = [1 + \exp(-1 \times \zeta \times (\text{DAS} - \iota \times \text{days of nonflooding days of the former fallow}))] \]

**inundated_fallow**

\[ \text{inundated_fallow} = \exp(\epsilon \times \text{days of flooding days of the former fallow}) \]

**water_management**

\[ \text{water_management} = \exp(\eta \times \text{inundated days during the last 10 days}) \]

- \( DAS \) ← days after sowing
- \( \alpha \) ← straw incorporation coefficient
- \( \beta \) ← acid sulfate · coastal sandy soil coefficient
- \( \gamma, \eta, \delta, \epsilon, \omega, \zeta, \iota, \kappa \) ← constant (>0)

Arai et al., 2018
ALOS-2/PALSAR-2 – Lband-Synthetic Aperture Radar –

PALSAR-2 Lv.1.1 (quad. CEOS) 23 scenes
- Coherency matrix [T3] generation
- Speckle filtering
  - LEE refined (7×7)
- Polarimetric decomposition
  - Freeman-Durden
  - Cloud-Pottier
- Sampling (25-30 pixel) from each ROI & Statistical analysis

PALSAR-2 Lv.1.1 (SCANSAR CEOS) 105 scenes
- Multilooking
- Co-registration
- De Grandi multi-temporal filtering
- Geocoding & Radiometric calibration
- Incidence angle
- Rice paddy masking & Statistical analysis

Classification of inundated paddies and non-inundated paddies which is covered by rice plants

Cambodia

Strip map

Alluvial soils
1.1 Mha, 28%

Acid sulfate soils
1.1 Mha, 28%

Potential acid sulfate soils
0.5 Mha, 13%

5 paddies × 4 villages
30 paddies × 1 village

Modified from Avtar et al. 2012
Inundated (cropping)
Non-inundated (fallow)

Fallow after plowing or flooding fallow

Inundated
Non-inundated

Dry fallow (+rice stumps)

Volume diffusion (%)
Double bounce (%)

Single scattering(%)
SCANSAR (25m)

Full-polarimetry (3m)

(a) Quadruple-polarimetry

Inundated  Non-inundated

- 0-20 days after sowing
- 21-40 days after sowing
- 41-60 days after sowing
- 61-100 days after sowing

Fallow paddies

Arai et al., 2018
SCAN-SAR (25m)

HH threshold (dB) = 0.550*HV + 12.9*cosine(IA) - 11.2

y = 242983x^2 - 360742x + 77749
R² = 0.7936

y = 242983x^2 - 360742x + 77749
R² = 0.9321

Arai et al., 2018
Our data integration scheme

$$T^* = \frac{\sigma_B^2 T_A + \sigma_A^2 T_B}{\sigma_A^2 + \sigma_B^2}, \sigma^* = \frac{\sigma_A^2 \sigma_B^2}{\sigma_A^2 + \sigma_B^2}$$

Prediction

Estimate actual irrigation practice

Irrigation/field water-level

Model simulation

Truth (Unknown)
Simulation scheme with 25m-spatial resolution
- Hysteresis of soil matric potential energy-

Irrigation, potential energy >> Side flow, ground water flow

Field water level (cm)

https://slideplayer.com/slide/5038747/
**Model structure**

**Implicit RK4 integration model**

\[ WL = \text{field water level} \]

Matric-potential at irrigation index \( (Di) = \Sigma (\text{soil inundation rate before the irrigation, days after sowing, clay content}) \cdot \alpha_i \]

\( t = \text{days after irrigation} \)

Gravitational-potential at irrigation index \( (G) = \text{field water level after irrigation} \cdot \beta \)

\[
\frac{dWL}{dt} = \gamma \exp \left( \delta \left[ 1 - \log \left( \exp \left( Di \cdot (t - G) \right) + 2 + \exp \left( -Di \cdot (t - G) \right) \right) \right] \right) \cdot Di \cdot (t - G)
\]

- \[
\frac{\delta \left[ \exp \left( Di \cdot (t - G) \right) - \exp \left( -Di \cdot (t - G) \right) \right] \cdot Di \cdot (t - G)}{\exp \left( Di \cdot (t - G) \right) + 2 + \exp \left( -Di \cdot (t - G) \right)}
\]

\[
+ Di \cdot \left[ 1 - \log \left( \exp \left( Di \cdot (t - G) \right) + 2 + \exp \left( -Di \cdot (t - G) \right) \right) \right] + \text{rain-fall}
\]

**Irrigation function**

if \( WL < \text{threshold} \):

irrigate (i.e., \( WL += X \))

**Parameter update by the analysis with EO data**

**Graphs**

- Observed vs. Estimated (cm)
- Volumetric Soil Water Content vs. Matric Potential

https://slideplayer.com/slide/5038747/
Direct comparison between GOSAT and emission data is meaningless...

→ GOSAT data assimilation with NICAM-TM!
Implementation of variable localization scheme in NICAM-TM-LETKF (PREPBUFR&GOSAT)

Back ground covariance matrices
Kang et al., 2012

Increment of XCH₄ (ppb, 950 hpa) w/ VL

Increment of XCH₄ (ppb, 950 hpa) w/o VL

2014051718-1803 Glevel 6, Inflation with RTPS=1

→ Flux parameter estimation!
Economic assessment of GHG mitigation under various uncertainties

Kalnay et al. 2017

Transparent MRV system on baselines/mitigation-effects with satellite data is the key!

Arai., 2015

State and trends of the carbon market 2012,
# Spot and Secondary offset market
2011, 1,822MtCO₂ = 23,250million USD

GHG from mushroom
GHG from field burning
GHG from paddy soil
Mushroom seeds
Irrigation cost
Land preparation
Grain threshing
Seed (OM4218)
Seed (Jasmine 85)
KCl
NPK
DAP
Urea
Mushroom
Straw
Rice

Staw Management