Global agricultural crop intensity and calendar mapping with sub-pixel land cover characterization

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Need for better information

Importance of rice paddy for Asian life

- 90% of paddy fields in the world are in Asian countries and they are important as a staple food source.
- Source of atmospheric methane $\text{CH}_4$ [Wessmann, 2003].
- Important variable for modeling of regional biochemical cycle and climate [Dickinson, 1995].
- The improved understanding of paddy field distribution over large spatial scale has increased the interest in the above mentioned issues.
Remote sensing of rice paddy

- Landsat ETM or ASTER: high spatial resolution (15m~) - low data frequency and narrow coverage [Okamoto, 1996]
- SAR: all-weather monitoring (20m~) - few spectral information and narrow coverage [Li, 2003]
- AVHRR or MODIS: wide coverage - too coarse (250m~) for regional classification [Loveland, 1995]
- AMSR-E: all-weather monitoring - low too coarse (10km~) for regional classification [Njoku, 2005]

No single sensor is a suitable infrastructure for long-time monitoring of rice cropping over continental scale
Framework of paddy mapping

1. Medium-resolution data
   - Daily MODIS data
   - Daily AMSR-E data
   - Annual metrics

2. Training data
   - Training area selection by ground survey
   - AVNIR2 based paddy cover map

3. Paddy mapping model
   - Model parameter estimation on green-up and inundation
   - Validation data with AVNIR2

4. Final product
   - Rice paddy cover and intensity map

Quality check

YES

NO

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Rice plant morphology measured from satellites

- Plant height (NDVI/LAI)
- Water level (LSWC)
- 1st stage (Young)
- 2nd stage (Middle)
- 3rd stage (Elder)
- Max. tiller number
- Tillering
- Transplant
- Yellow ripe

Days after planting:
- 0
- 90~120
Radar and visible hybrid
20030101
GCOM-W1 “SHIZUKU” was successfully launched on May 18, 2012 (JST).
AMSR-E and AMSR2 well captures SST, sea ice and land surface water coverage.
MODIS monthly composites have no clouds and well captures phenology.
Normalized VSW indices

\[
\text{NDVI} = \frac{(\text{NIR} - \text{VIS})}{(\text{NIR} + \text{VIS})} \quad (1)
\]

\[
\text{NDSI} = \frac{(\text{SWIR} - \text{NIR})}{(\text{SWIR} + \text{NIR})} \quad (2)
\]

\[
\text{NDWI} = \frac{(\text{VIS} - \text{SWIR})}{(\text{VIS} + \text{SWIR})} \quad (3)
\]

where

\begin{align*}
\text{VIS} & : \text{Visible (630nm, channel 1)} \\
\text{NIR} & : \text{Near infrared (860nm, channel 2)} \\
\text{SWIR} & : \text{Shortwave infrared (1620nm, channel 6)}
\end{align*}

SWIR wavelength is effective to monitor moisture conditions on land surface

- Water stress on tree canopy with Landsat TM [Tucker, 1980]
- Moisture on a leaf in laboratory measurement [Cibula, 1992]
- Land surface water condition with MODIS [Gao, 1996]

[Takeuchi, 2007]
Metric Median Imagery

R:G:B = NDSI:NDVI:NDWI
Normalized Polarization Index (NDPI)

\[
NDPI = \frac{36.5V - 36.5H}{36.5V + 36.5H}
\]

[Takeuchi, 2008]
LSWC mapping by AMSR-E

1. MODIS VNIR and SWIR 2km mosaic (2006, 8-day composite)
2. AMSR-E 18.7 and 23.8GHz 16km daily mosaic (2006)

1. MODIS NDWI (8x8 pixels)
   - Water pixel
   - Non-water pixel

2. MODIS LSWC (1 pixel)
   - 25%

3. AMSR-E NDPI (1 pixel)
   - ??

Steps:
1. Normalized Water Index (NDWI)
2. Water mask and spatial aggregation into AMSR-E resolution (LSWC)
3. Calibrate LSWC as a function of NDFI

LSWC by AMSR-E NDFI and temporal interpolation via BISE method
LCWC calibration between AMSR-E and MODIS

\[
\text{LSWC} = \frac{100.0}{1 + 241.9 \times \exp(-80.0 \times \text{NDPI})}
\]

[Takeuchi, 2008]
Rice harvested area
Surface water level measurement at Sukhothai in Central Thailand

[Komori, 2008]
Rice field in Khon Kaen, Thailand
(Oct. 8, 2011 to Nov. 8, 2011)
Validating LULC result with GPS photo

The ground survey data available on Internet can be used to validate the processing result.
GPS Photo App on

- GPS Photo application
- Taking photos
- Retrieving latitude & longitude
- Editing altitude
- Selecting Land Cover type
- Making Description
- Uploading data to server

[Van, et. al, PE&RS, 2012]
GPS Photo App on iPad

[Van, et. al, PE&RS, 2012]
Water coverage change timing delay to surface water level changes

(a) AMSR-E land surface water coverage measurements

(b) In-situ surface water level measurements
MODIS VCI and AMSR-E LSWC captures single rice cropping patterns.
MODIS VCI and AMSR-E LSWC captures double rice cropping patterns.
JAXA GCOM-C/SGLI take over Aqua/Terra MODIS for global land observation (FY2014 expected)

GCOM-C observation

Global data accumulation and synthesis with other satellite data

SGLI VNR one-day coverage

Surface albedo and land cover

Surface solar irradiance and Photosynthetically available radiation

Aerosol amount and properties

Land vegetation, ocean chlorophyll-a, and primary production

Sea and Land surface temperature

Cloud fraction and properties
Cropping pattern mapping via Fourier transform

Suphan Buri, Thailand

Calculate by using Prov. averaged NDVI

Growing Cycle
- Single cropping
- Double cropping
- Triple cropping

Power spectrum reveals crop intensity and timing
Global crop intensity map (1km)
Global crop calendar map (1st peak of NDVI)

[Jonai, 2012]
Global crop calendar map (2nd peak of NDVI)

[Jonai, 2012]
Global crop calendar map (3rd peak of NDVI)

[Jonai, 2012]
Thailand, Cambodia, Laos, Vietnam
India, Bangladesh, Nepal
Rice yield statistics and annual maximum NDVI

Rice yield statistics are from ASEAN Food Security Information System (AFSIS), http:// afsis.oae.go.th/index.php

Figure 2. Rice cropping pattern monitored by NDVI and LSWC

Figure 4. Relationship between NDVI and rice yield in GMS countries
Rice yield statistics and crop patterns
Comparison with global land cover products


UMD [Hansen, 2000]  USGS [Loveland, 2000]  UT [This study]
Comparison with country-level statistics

AARS
BU
JRC
UMD
USGS
UT
Asia and Africa are very prone to natural disasters.
Natural disaster classification

Biological
- Epidemic
  - Viral Infectious Disease
  - Bacterial Infectious Disease
  - Parasitic Infectious Disease
  - Fungal Infectious Disease
  - Prion Infectious Disease
- Insect Infestation
- Animal Stampede

Geophysical
- Earthquake
- Volcano
- Mass Movement (Dry)
  - Rockfall
  - Landslide
  - Avalanche
  - Subsidence

Hydrological
- Flood
  - General Flood
  - Flash Flood
  - Storm Surge / Coastal Flood
- Mass Movement (Wet)
  - Rockfall
  - Landslide
  - Avalanche
  - Subsidence

Meteorological
- Storm
  - Tropical Cyclone
  - Extra-Tropical Cyclone
  - Local Storm

Climatological
- Extreme Temperature
  - Heat Wave
  - Cold Wave
  - Extreme Winter Condition

- Drought
- Wildfire
  - Forest Fire
  - Land Fire

[EMDAT, 2009]
Type of Droughts

- Meteorological droughts
  - GSMaP SPI (rainfall)
  - MTSAT KBDI (rainfall + land surface temperature)
- Agricultural droughts
  - MODIS VCI (vegetation index)
- Hydrological droughts
  - AMSR-E LSWC (land surface water coverage)

If we have a prediction of the above indices based on weather forecasting, it is called a potential drought.
Surface water storage and flow

- KBDI index are used to compute the balance between evapotranspiration and precipitation. [Keetch et. al, 1965]

- Presently, this index is derived from satellite observation:
  - land surface temperature (LST) from MTSAT received at IIS/U-Tokyo
  - rainfall from global satellite mapping (GSMaP) provided by JAXA EROC.
1-8 August 2011 (6-hourly) - Typhoon No.9 in 2011 “MUIFA” can be seen near Okinawa, Japan.

0.1-deg and hourly global rainfall product available 4-hour after observation via internet.

http://sharaku.eorc.jaxa.jp/GSMaP/
Korean Drought Worst In A Century For North And South Korea

06/26/12 09:28 PM ET AP

130 people recommend this. Be the first of your friends.

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Enter email  SIGN UP

FOLLOW: North Korea, South Korea, Video, North Korea Drought, Korea Drought, Korea Dry Spell, Korean Drought, Korean Peninsula Drought, North Korea Weather, South Korea Drought, South Korea Weather, World News
KBDI captures 2012 drought in DPR Korea
MODIS VCI v.s. MTSAT KBDI

MODIS VCI (250m, 16days)

MTSAT KBDI (10km, 1days)

Stressed

Jul, 2009
Aug, 2009
Sep, 2009
Oct, 2009
Nov, 2009
Dec, 2009

Stressed

drought criteria>=700

wet
dry
KBDI based drought onset in Indramayu

2007/09/01

2008/07/15

2009/08/15

2010/09/01

Sep. 1

Jul. 15

Aug. 15

Never
Both SPI, VHI and KBDI indices can also represent the El Nino Condition during 2009.
Both SPI, VHI and KBDI indices can also represent the La Nina Condition during 2010.

Source: [http://www.bom.aus/](http://www.bom.aus/)
Higher KBDI in rice growing period causes loss of rice productivity.

Ordinary year: 2% growth / yr

Drought year: -2% growth / yr

[Hosoya, 2011]
# Cost and benefit analysis for irrigation facility development

<table>
<thead>
<tr>
<th>Country</th>
<th>Total cost (JPY)</th>
<th>Area (ha)</th>
<th>Cost (JPY/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thailand</td>
<td>4,800,000,000</td>
<td>48,000</td>
<td>100,000</td>
</tr>
<tr>
<td>Indonesia</td>
<td>6,953,000,000</td>
<td>25,589</td>
<td>271,718</td>
</tr>
<tr>
<td>Vietnam</td>
<td>4,874,000,000</td>
<td>15,700</td>
<td>310,446</td>
</tr>
</tbody>
</table>

Suppose project life cycle is 20 years,

Average cost = 260,000 (JPY/ha)
Target area in Indonesia = 2,660,00 (ha)
Total cost = 693,753,870,000 (JPY) + 
Depreciation expense 424,275,368,288 (JPY)
Cost and benefit analysis for irrigation facility development

based on the assumption that
• rice area does not change in 20 years
• rice price is constant (4000Rp/kg)
• drought occurs at the same frequency from 2007 to 2011 over the next 20 years
• rice yield growth rate are:
  • 0.98 in drought year at rain-fed rice field
  • 1.02 in normal year at irrigated rice field

To compute rice yield over 20 years in two cases:
• no development, let rice field as rain-fed
• with development, irrigation facility at rice field

Total benefit = 419,364,046,532 (JPY) < Total cost

[Hosoya, 2011]
This drought monitoring system will be implemented to GMS countries and can be expanded to ASEAN+3 level (Addition to AFSIS (ASEAN Food Security Information System)) and global level (GEO GLAM (Global Agricultural Geo-Monitoring) supported by G20).
Concluding remarks

- The new procedure for depicting a continuous field of paddy cover map using MODIS and AMSR-E derived metrics is an improvement over the past efforts using AVHRR data.
- The un-mixing approach seems to work compared with traditional discontinuous classification method.
- The metrics was able to limit the inclusion of atmospheric contamination.
- The data during the early-planting (water) and growing (rice plant) are important for paddy field mapping.
Concluding remarks (cont’d)

- Both MODIS based drought codes and KBDI can monitor areas of climatological and agricultural drought.
- KBDI is related to rice production, however, more validation efforts must be done for the improvement of the rice yield estimation model and coupled with a weather forecasting model.
- Rice drought monitoring system will be expected to serve as a basic data of a cost and benefit analysis for irrigation facility development so that Indonesian government can loan a fund from Japanese government and to order an contract for Japanese private sectors.
- This system will be implemented over Greater Mekong Subregion (GMS) as a decision making tool aided by Asian Development Bank (ADB) in FY2013.
Wataru Takeuchi and Yoshifumi Yasuoka
Sub-pixel mapping of rice paddy fields over Asia using MODIS time series.
Global mapping of irrigated and rainfed cropland areas (remote sensing applications), CRC, ISBN-10 1420090097.
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Thank you