Overview of an application of remote sensing for agriculture and drought monitoring

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- Research interests
  - Remote sensing and GIS
  - Global carbon cycling
  - Global land cover and land use change
  - Management and policy for terrestrial ecosystems
- Academic background and career
  - 1999: B. Eng., Civil Engineering, U-Tokyo
  - 2001: M. Eng., Civil Engineering, U-Tokyo
  - 2004: Dr. Eng., Civil Engineering, U-Tokyo
  - 2004 - 2006: Research Associate, IIS, U-Tokyo
  - 2007 - 2010: Assistant Professor, IIS, U-Tokyo
  - 2007 - 2009: Visiting Assistant Professor, Asian Institute of Technology), Thailand
  - 2010 -: Associate Professor, IIS, U-Tokyo
  - 2010 - 2012: Director, JSPS Bangkok office


七尾鉄道発祥の地


いしかわの
優しい美知
ごあんない
日本海


3
ประเทศไทย
THAILAND

What we will learn in two days

- Overview of remote sensing and GIS technologies for agriculture monitoring
  - MODIS, MTSAT, GSMaP, AMSR-E
- Drought monitoring methods and implementation
  - NDVI, KBDI, SPI
- Demonstrate the case study on web-system
  - how to make drought map
  - interpret drought information to give an early warning
- Cost-benefit analysis
  - to evaluate the benefit of introducing counter measure against droughts for an irrigation facility
  - estimate possible future economic loss due to droughts

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 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.

Vietnam Feels the Heat of a 100-Year Drought

By MARTHA ANN OVERLAND / HANOI Thursday, Mar. 04, 2010

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The dried-up bed of the Red River, near Long Bien Bridge in Hanoi on Dec. 1, 2009
Nguyen Huy Kham / Reuters

Every year, even at the peak of Vietnam's dry season, when the Red River is at its lowest, Hanoi's skilled captains manage to negotiate their flat-bottomed boats through its shallow waters. But this year, with a drought gripping the entire country and water levels at record

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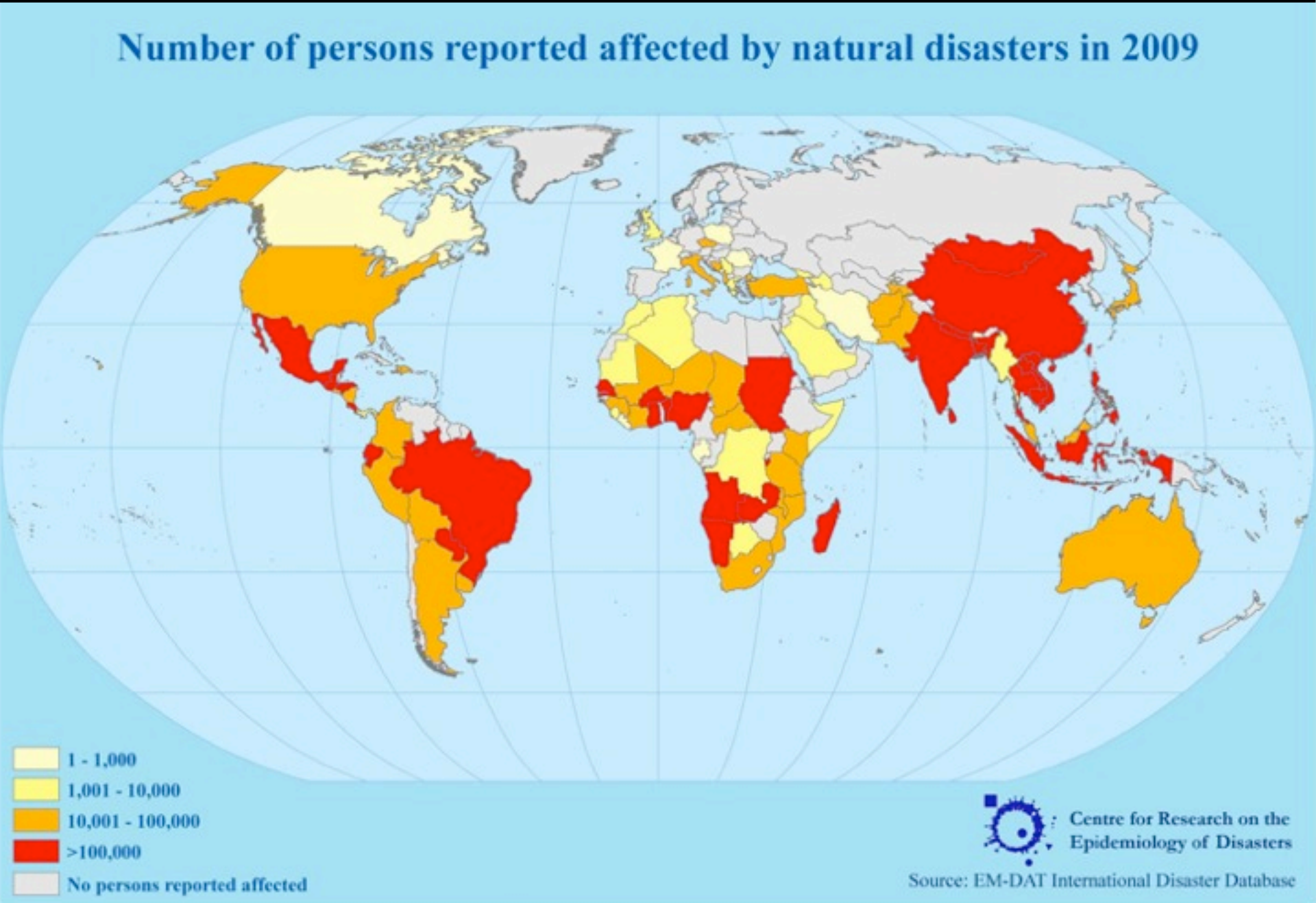
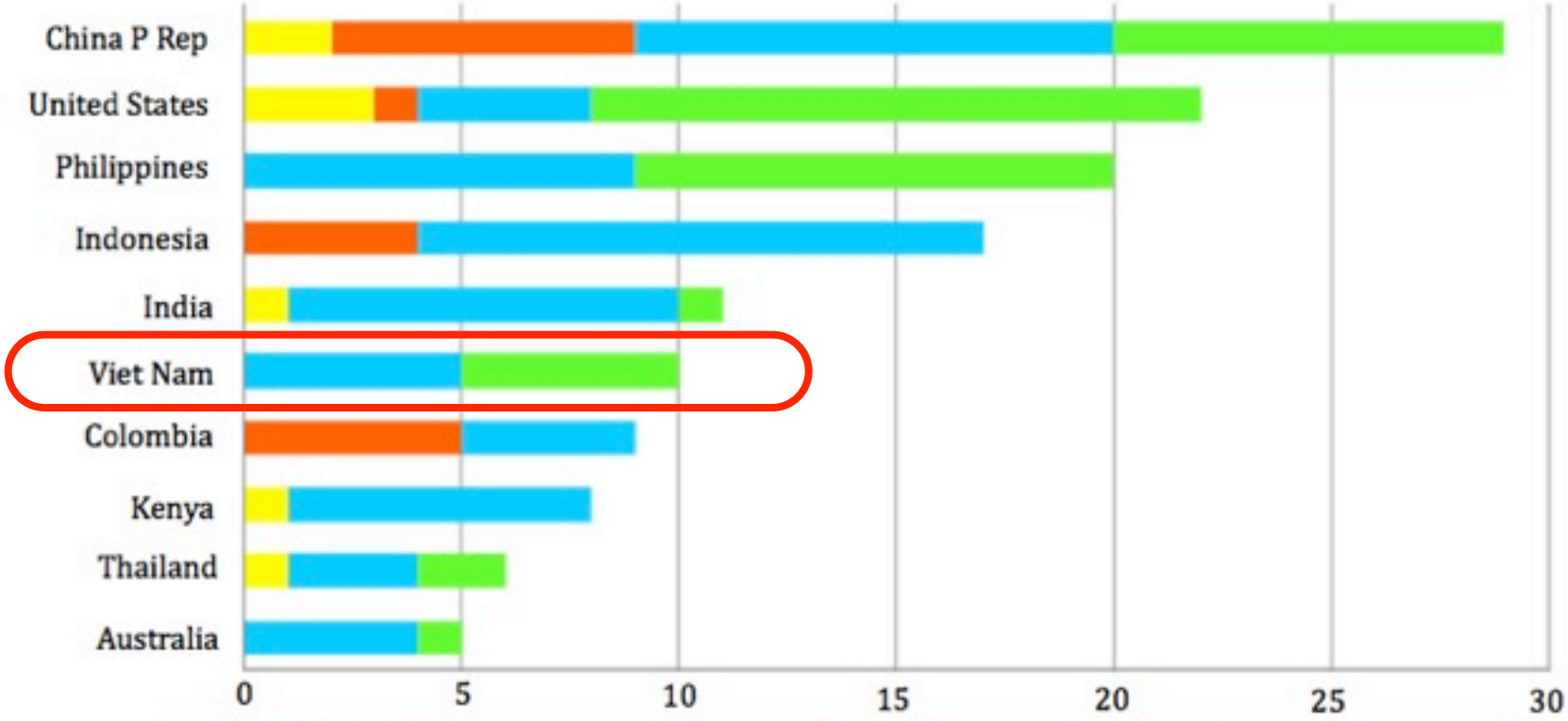
[TIME, Mar. 4, 2010]

Asia and Africa are very prone to natural disasters



Top 10 countries by the number of reported events in 2008



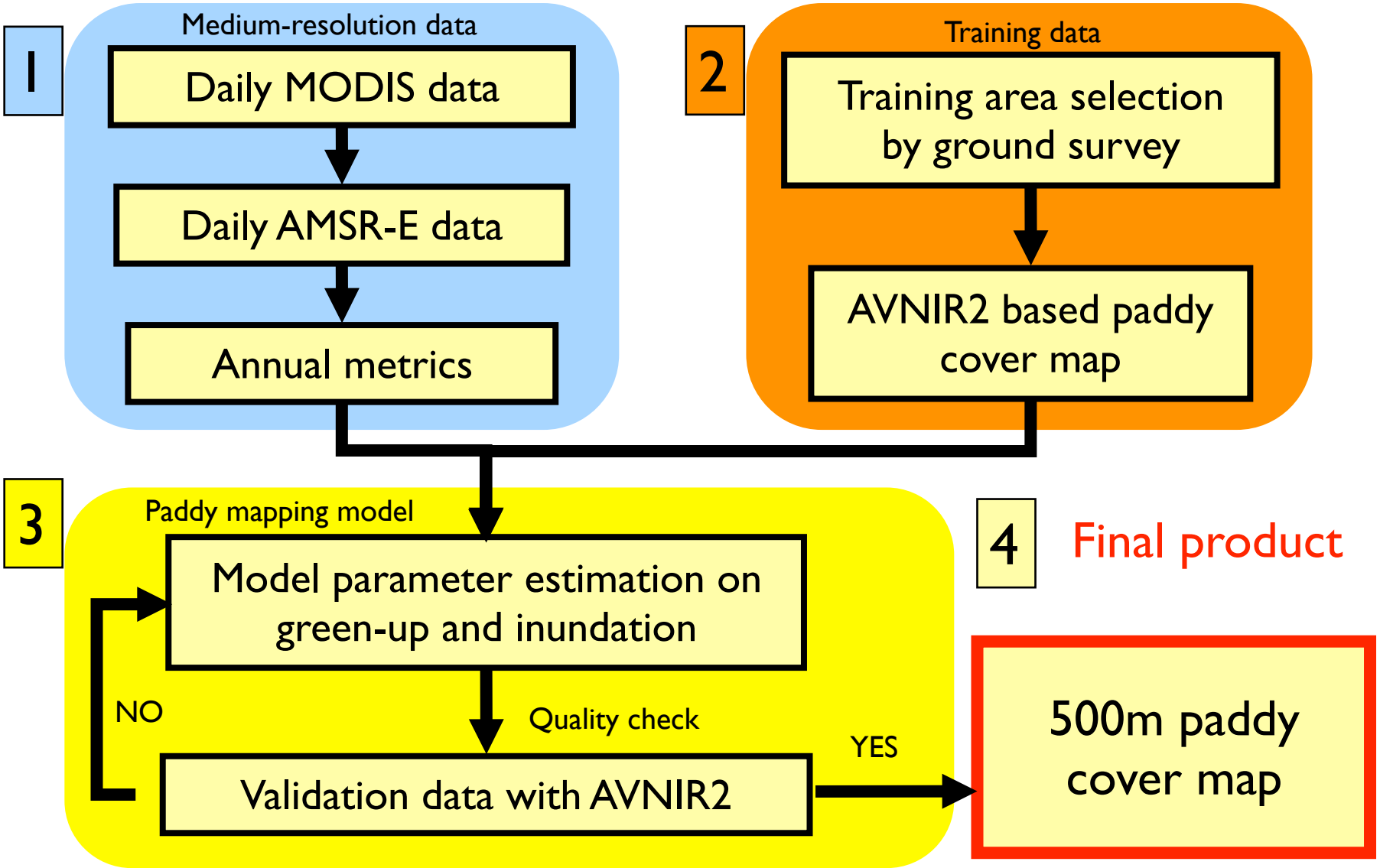
	China P Rep	United States	Philippines	Indonesia	India	Viet Nam	Colombia	Kenya	Thailand	Australia	Total
Climatological	2	3	0	0	1	0	0	1	1	0	**8**
Geophysical	7	1	0	4	0	0	5	0	0	0	**17**
Hydrological	11	4	9	13	9	5	4	7	3	4	**69**
Meteorological	9	14	11	0	1	5	0	0	2	1	**43**
Total	**29**	**22**	**20**	**17**	**11**	**10**	**9**	**8**	**6**	**5**	**137**

[EMDAT, 2009]

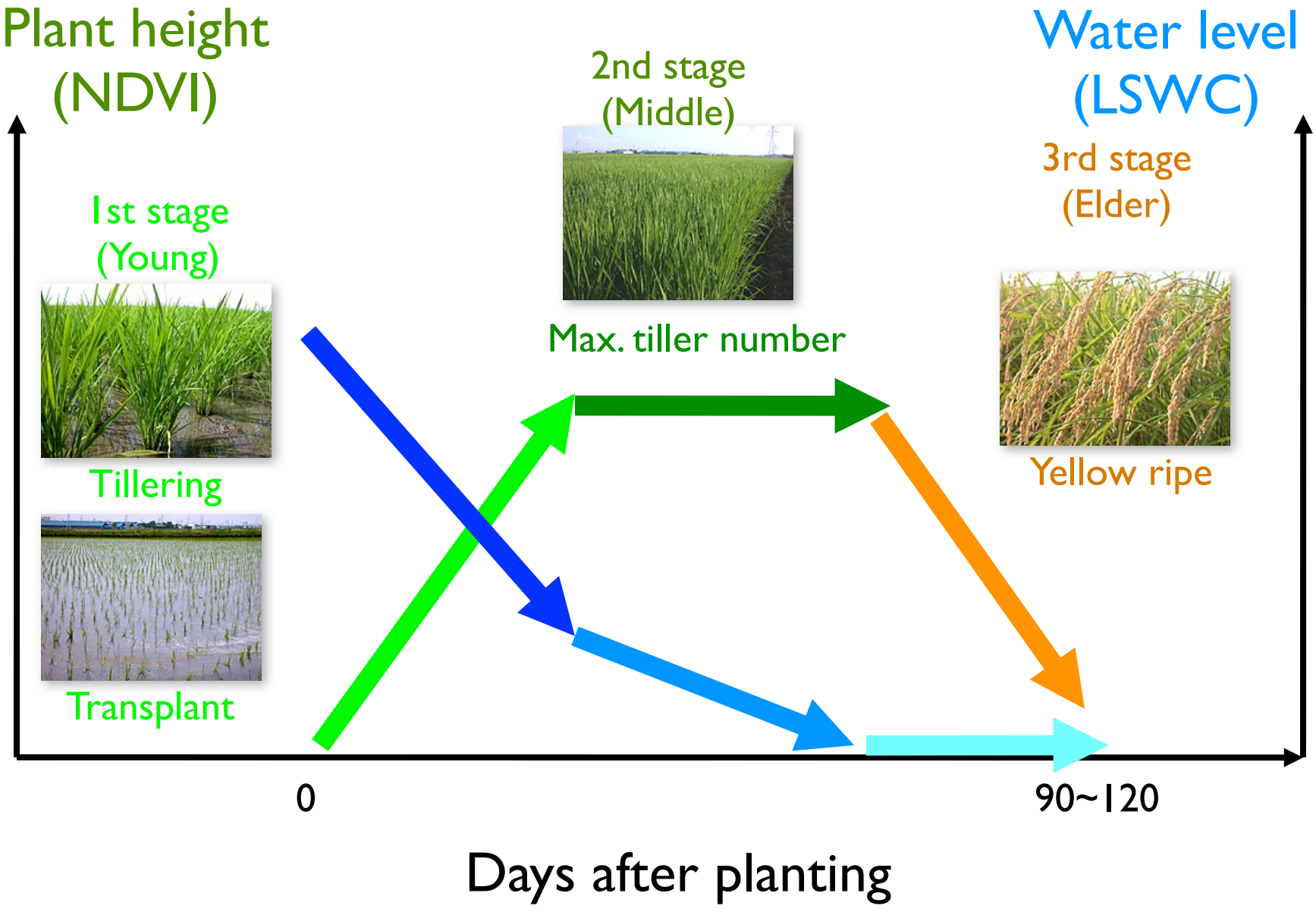
Type of droughts

- Meteorological droughts (everyday in 4km)
  - GSMaP SPI (rainfall)
  - MTSAT KBDI (rainfall + land surface temperature)
- Agricultural droughts (16days in 250m)
  - MODIS VCI (vegetation index)
  - MODIS TCI (thermal index)
  - MODIS VHI (vegetation+thermal index)
- Hydrological droughts (everyday in 10km)
  - 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.

Framework of paddy mapping



Rice plant morphology




A
B
C
D

MODIS drought codes

- **Vegetation Condition Index (VCI)** associates with moisture condition of vegetation:

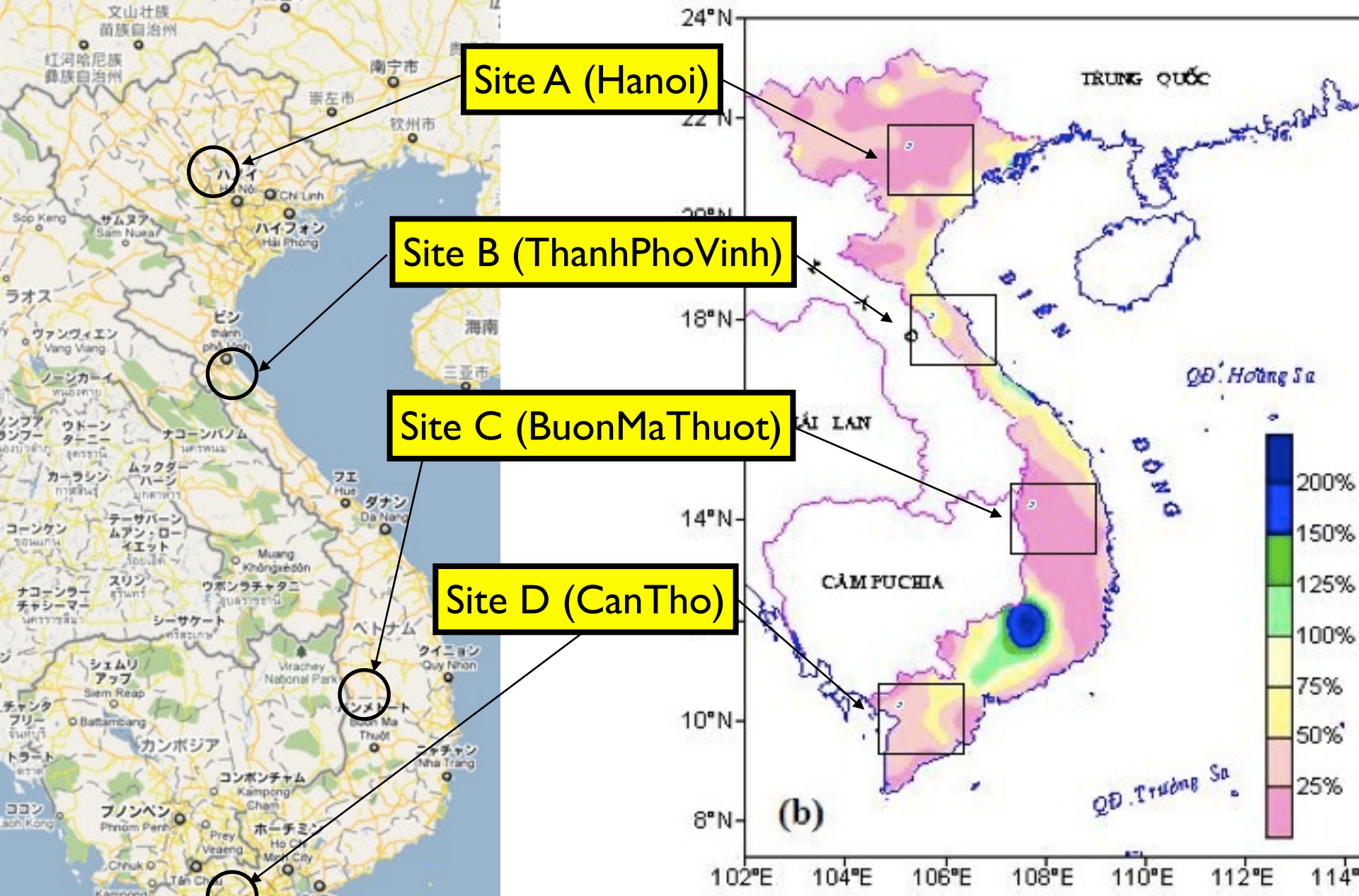
$$VCI = 100x\frac{EVI - EVI_{\min}}{EVI_{\max} - EVI_{\min}}$$

- **Thermal Condition Index (TCI)** associates with thermal condition of vegetation:

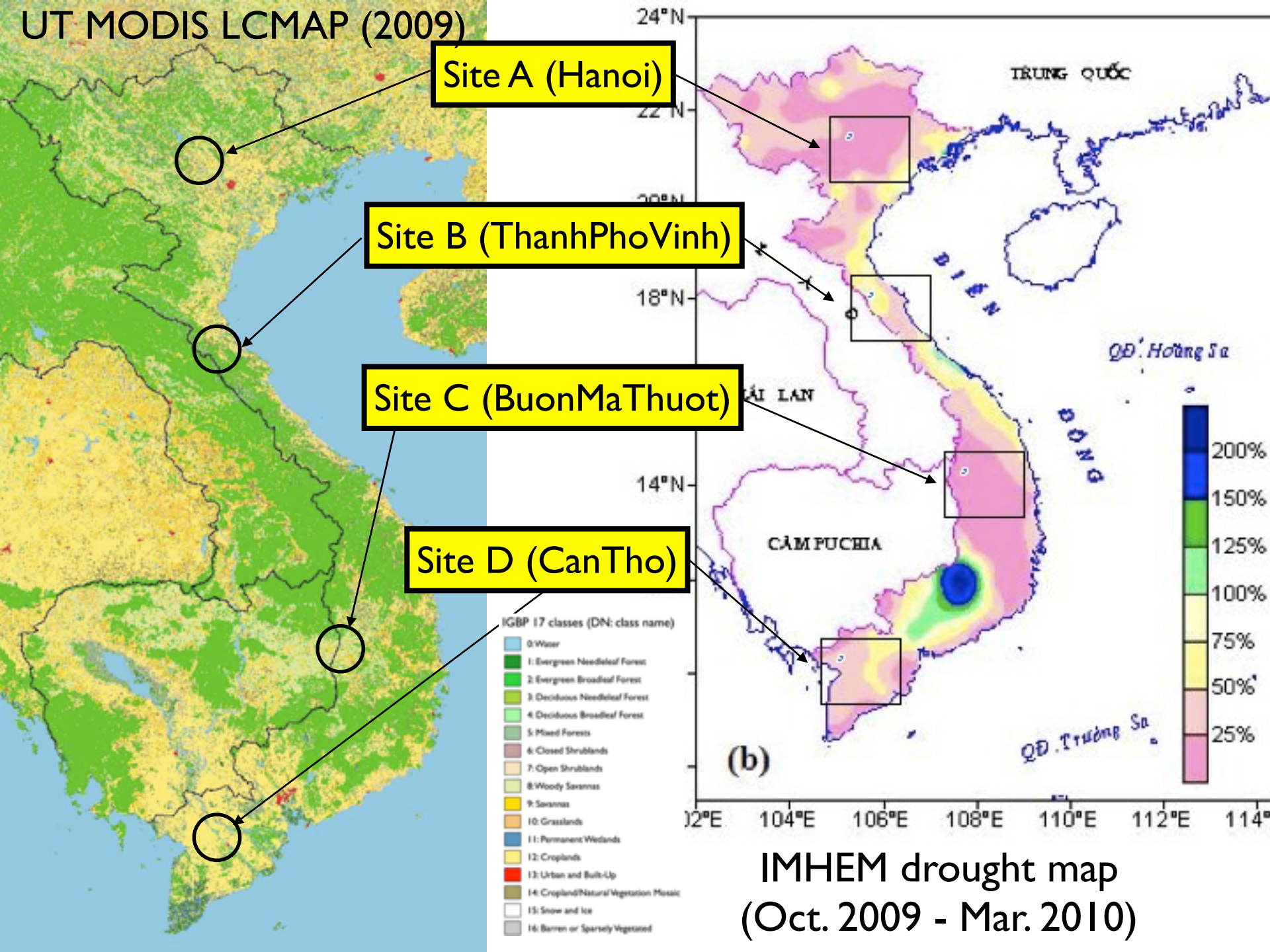
$$TCI = 100x\frac{LST_{\max} - LST}{LST_{\max} - LST_{\min}}$$

- **Vegetation Health Index (VHI)** represents overall vegetation health: $VHI = 0.5(VCI + TCI)$

[Kogan, 2002]



IMHEM drought map
(Oct. 2009 - Mar. 2010)

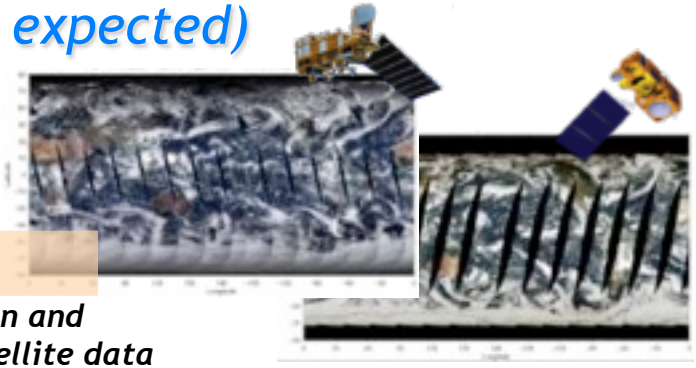


IMHEM drought map
(Oct. 2009 - Mar. 2010)

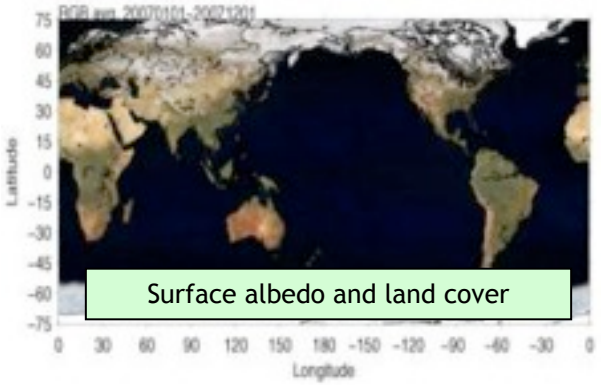
JAXA GCOM-C/SGLI take over Aqua/Terra MODIS

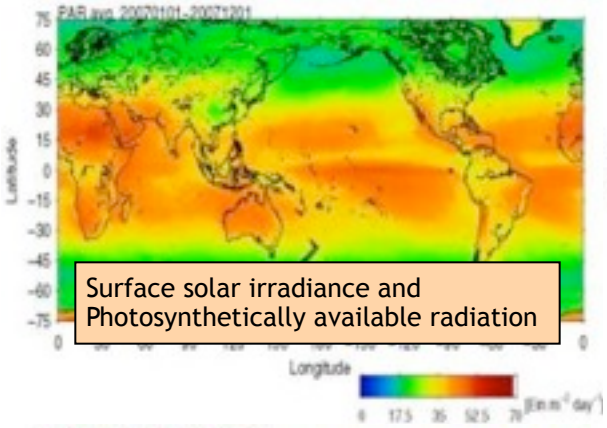
for global land observation (FY2014 expected)

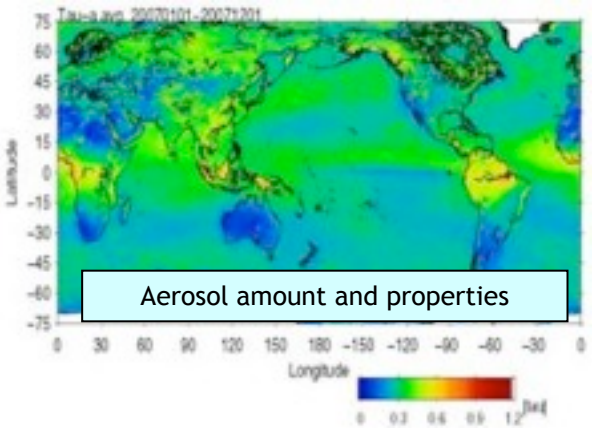
GCOM-C observation

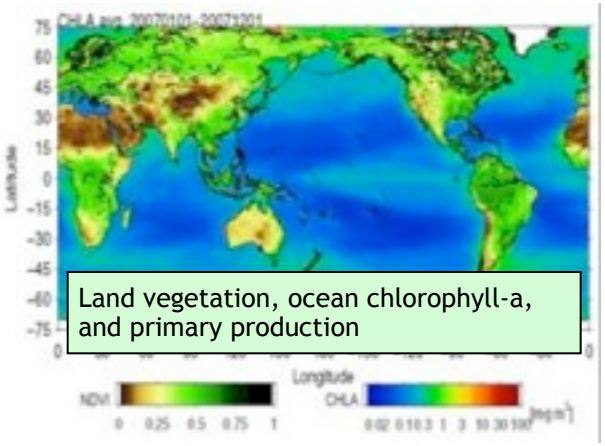


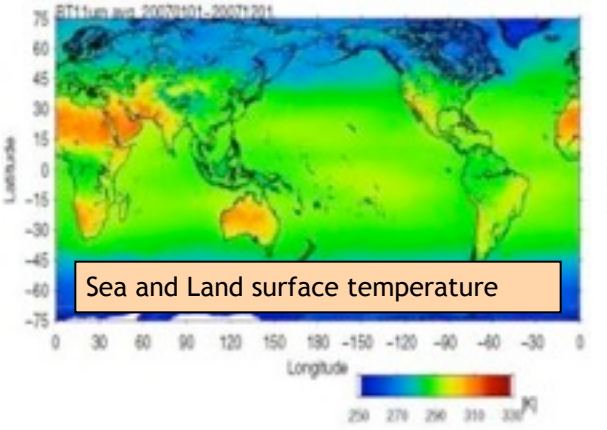
Global data accumulation and synthesis with other satellite data

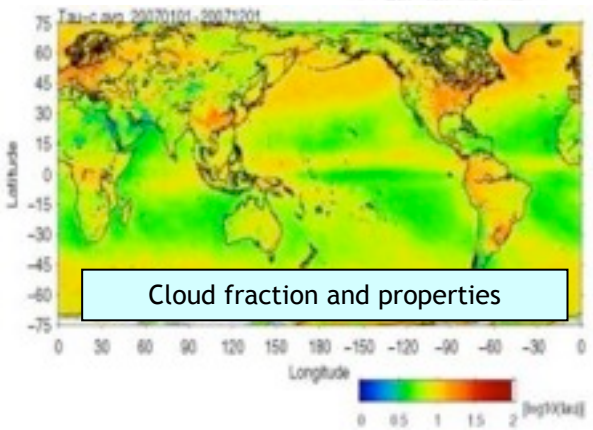




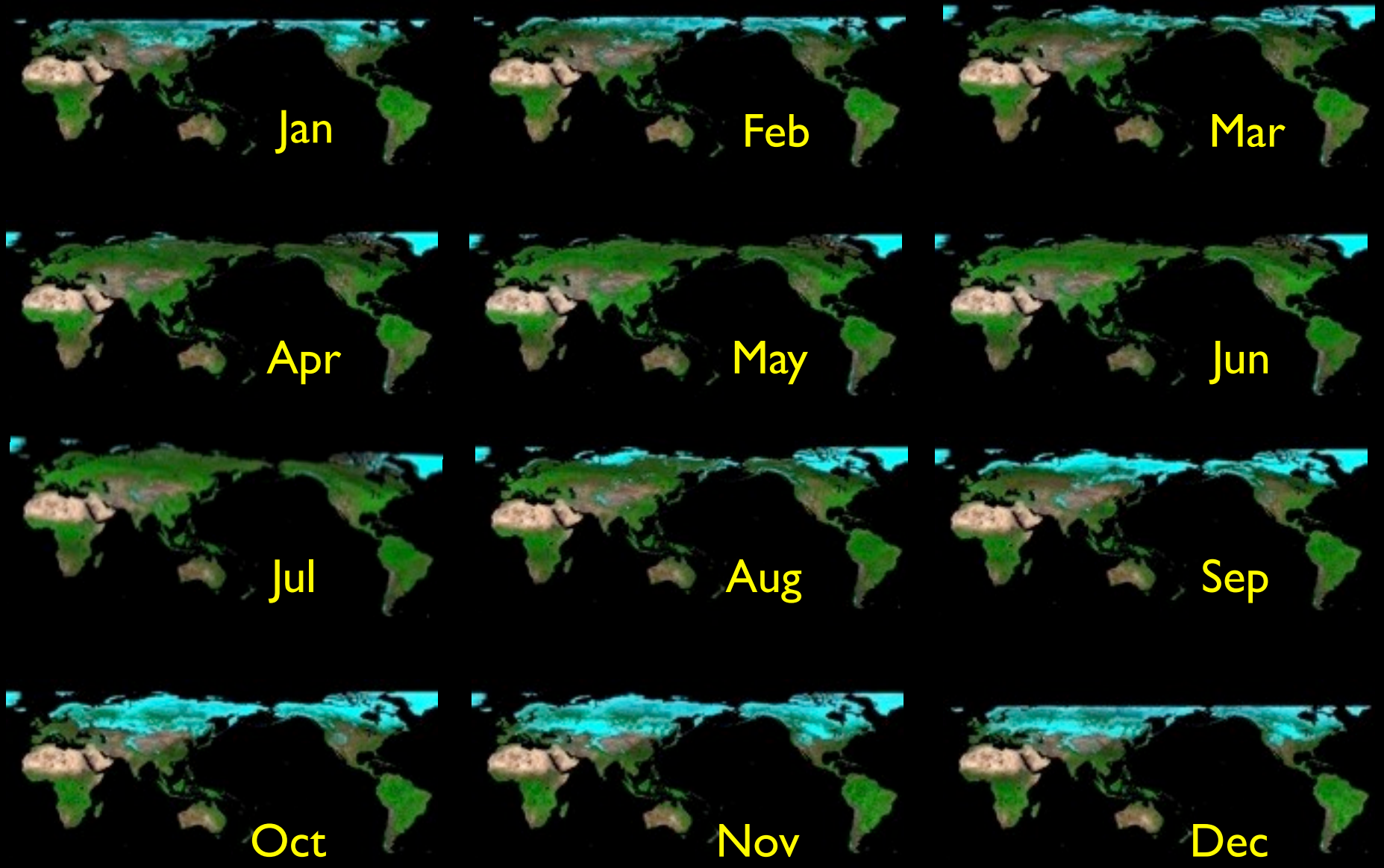






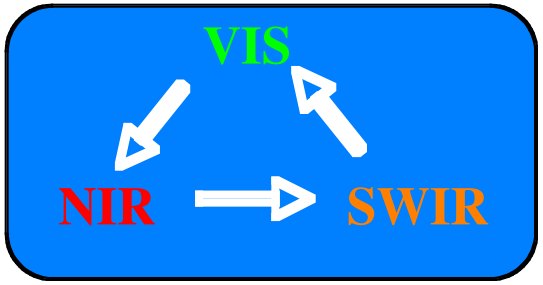


MODIS monthly composites have no clouds and well captures phenology



Normalized VSW indices

$$NDVI = (NIR - VIS) / (NIR + VIS) \quad (1)$$
$$NDSI = (SWIR - NIR) / (SWIR + NIR) \quad (2)$$
$$NDWI = (VIS - SWIR) / (VIS + SWIR) \quad (3)$$

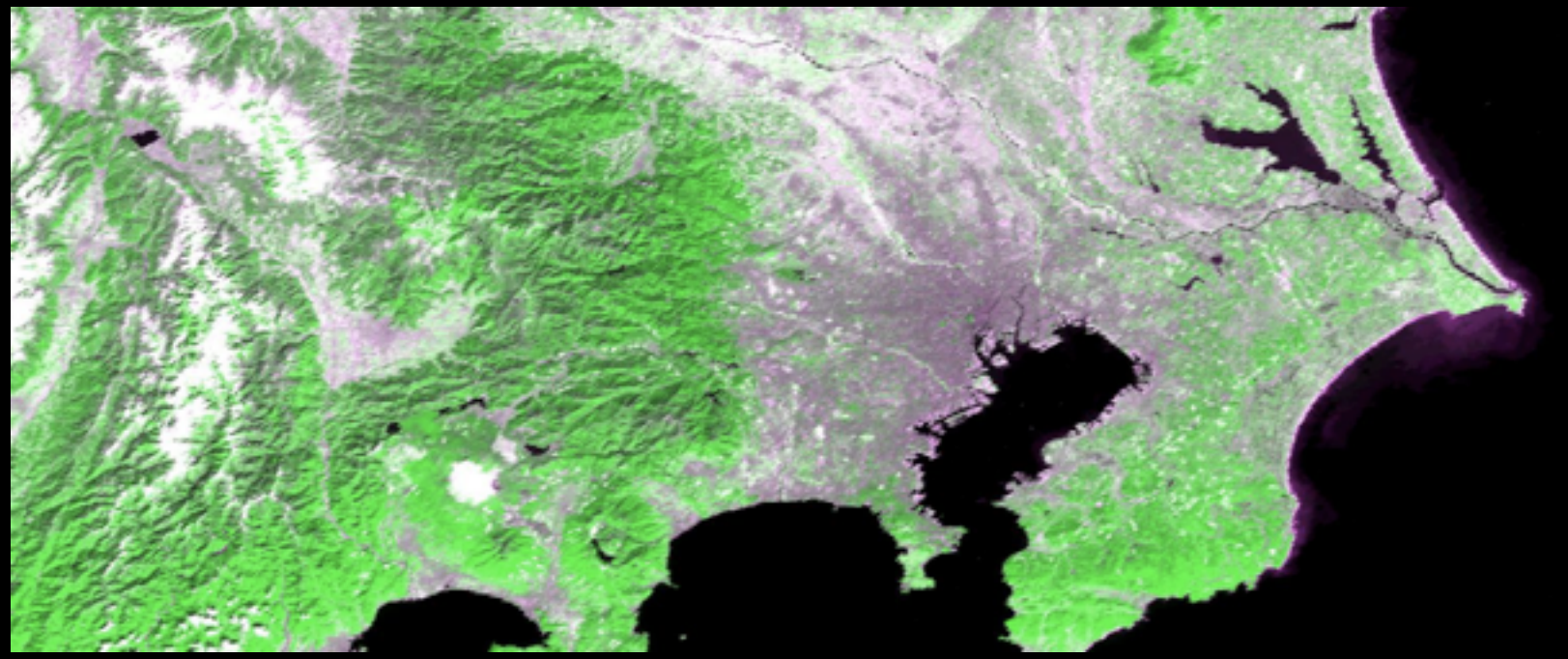


where
VIS: Visible (630nm, channel1)
NIR: Near infrared (860nm, channel2)
SWIR: Shortwave infrared (1620nm, channel 6)

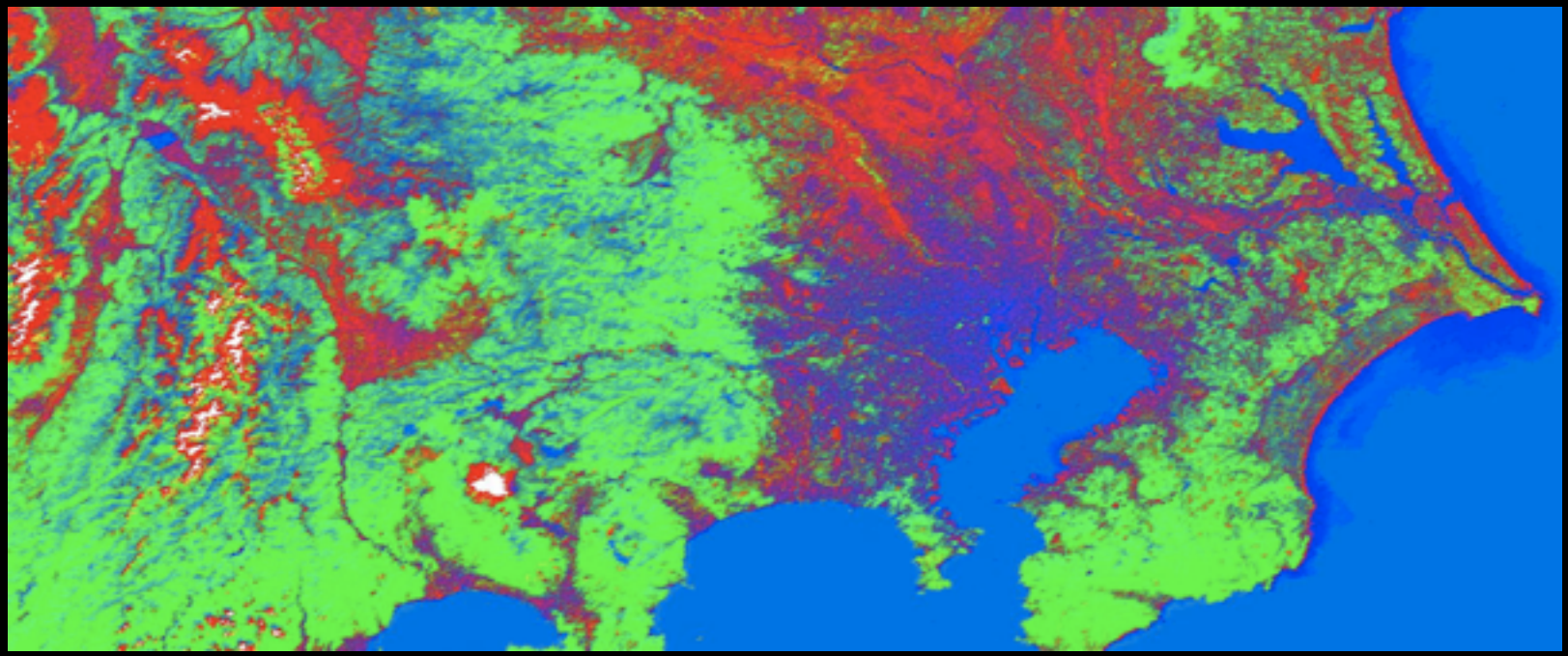
SWIR wavelength is effective to monitor moisture conditions on land surface

- 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]

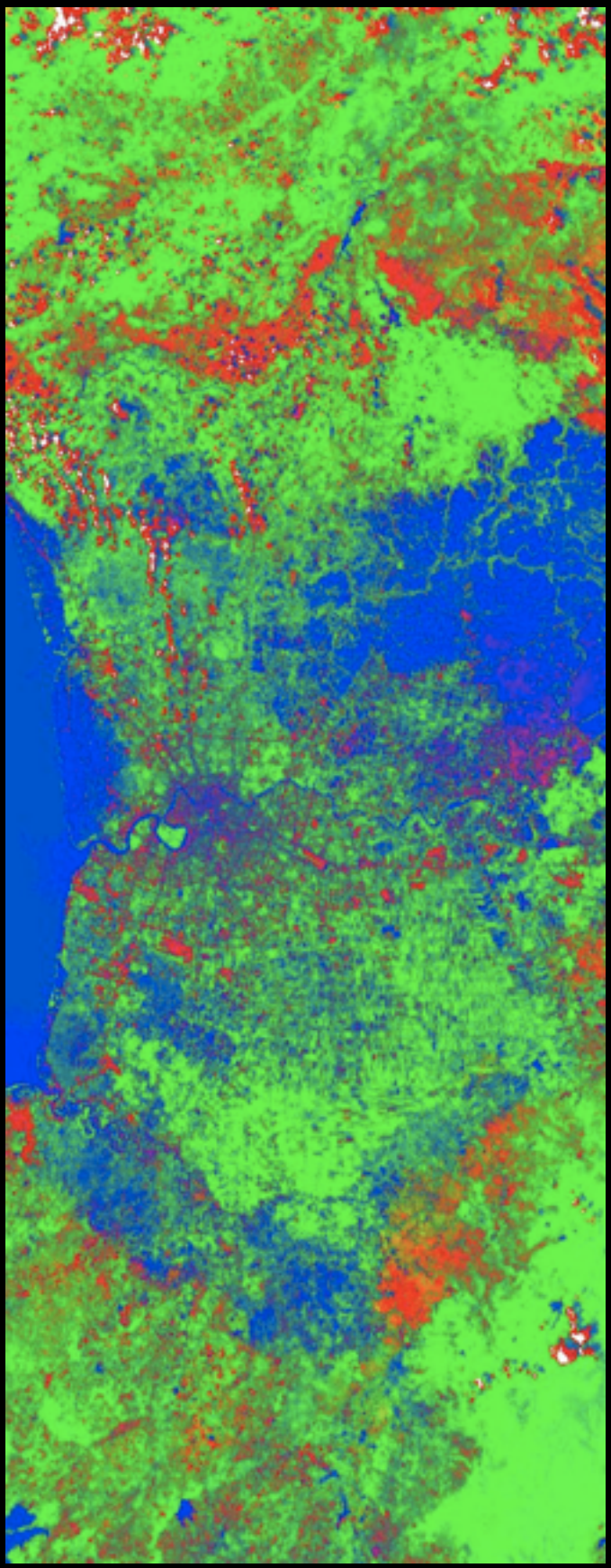
MODIS VNIR



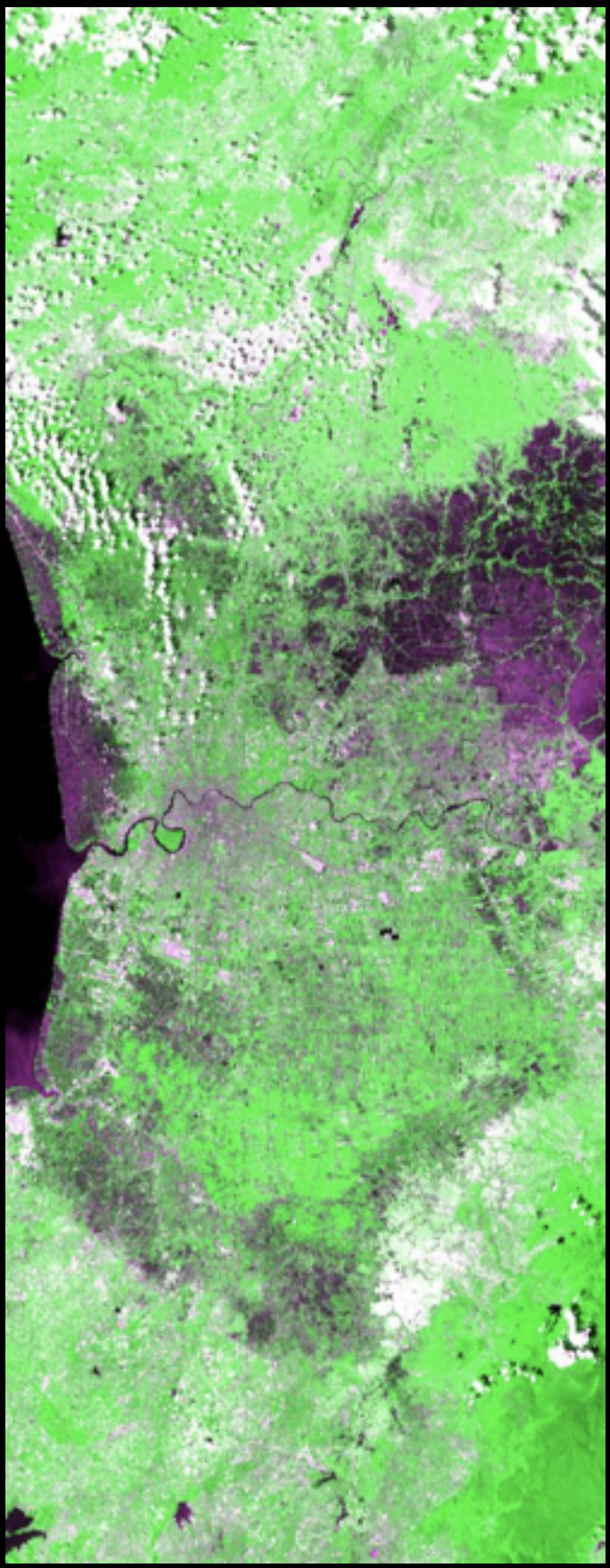
MODIS VSW



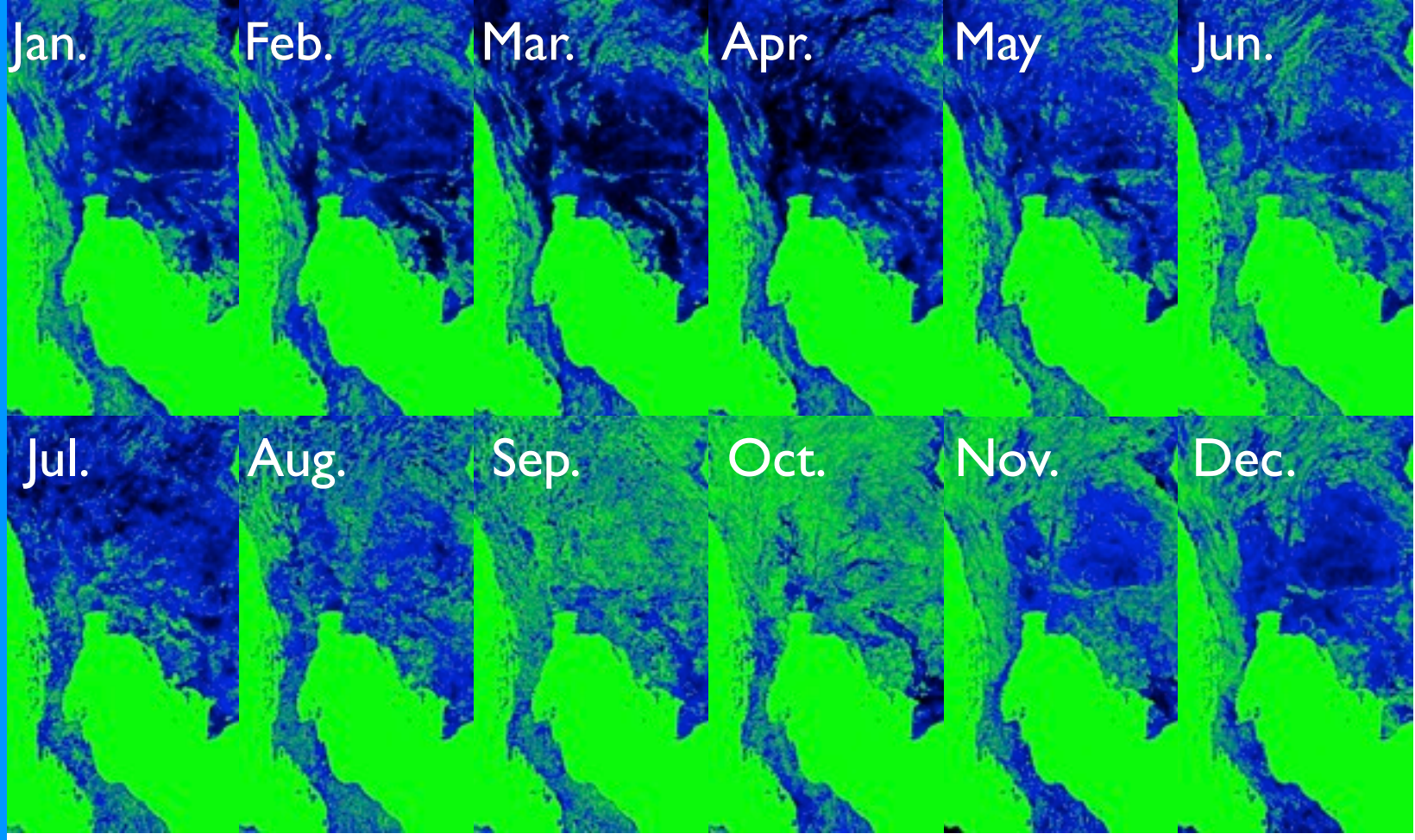
MODIS VSW

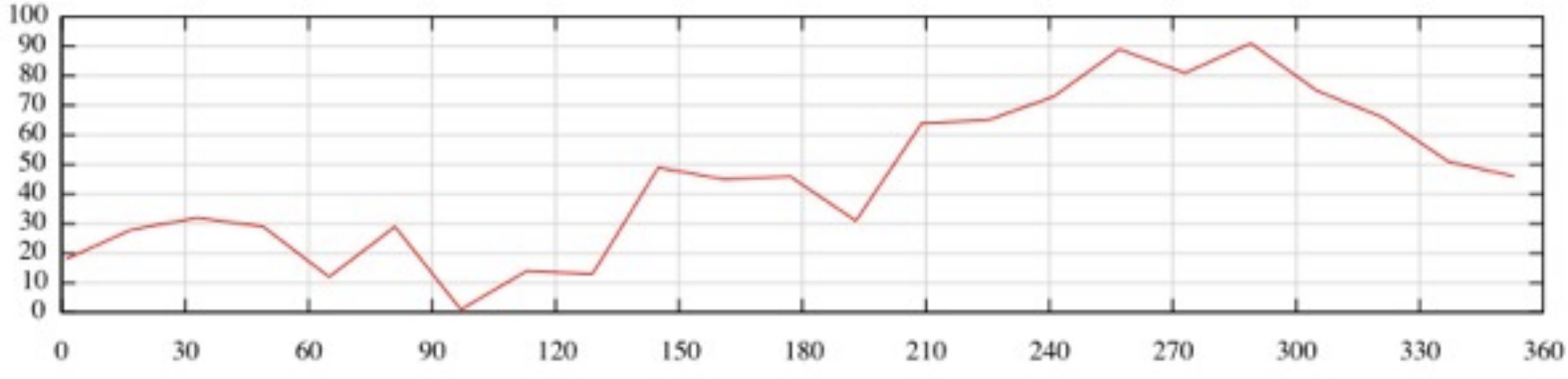


MODIS VNIR

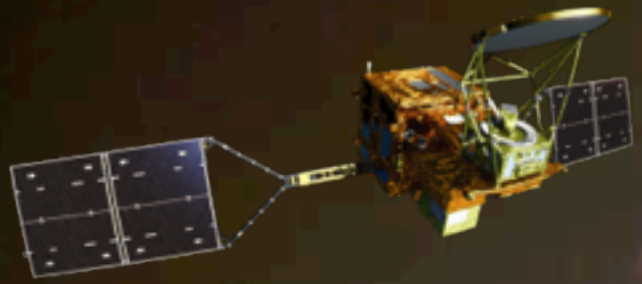


MODIS VCI captures 2010 agricultural patterns in Northeast Thailand

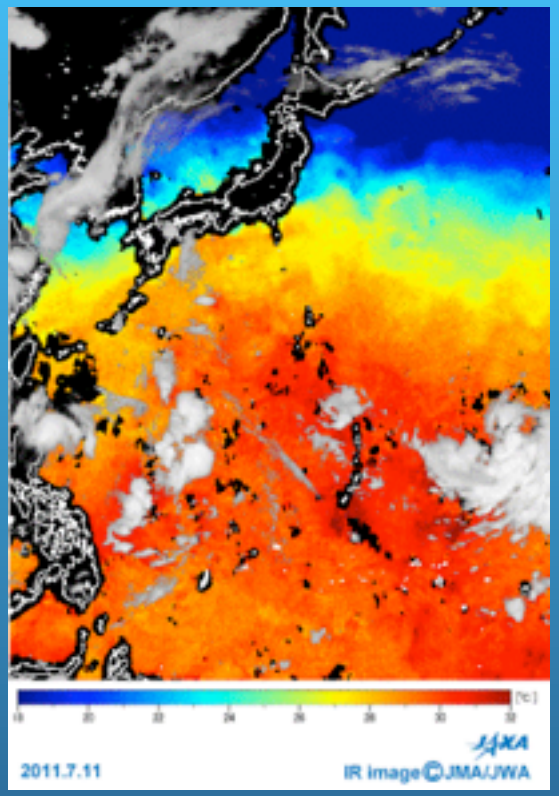


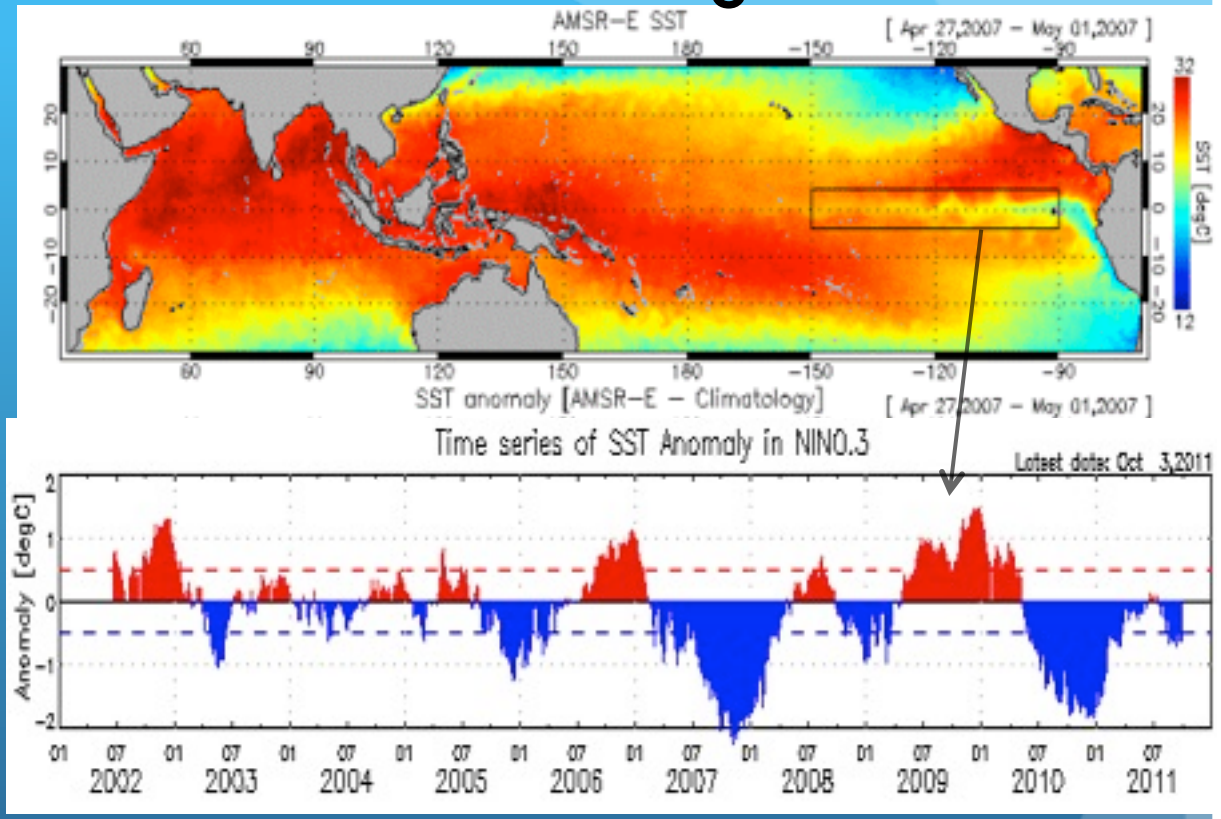


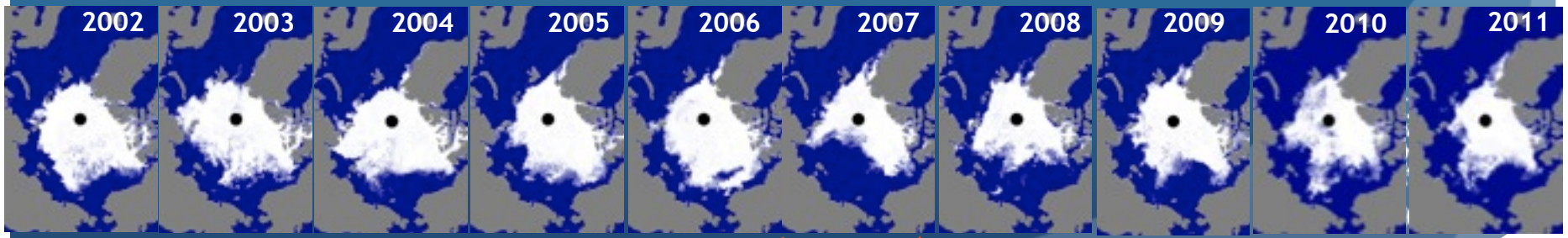
GCOM-W1 "SHIZUKU" was successfully launched on May 18, 2012 (JST).



AMSR-E and AMSR2 well captures SST, sea ice and land surface water coverage

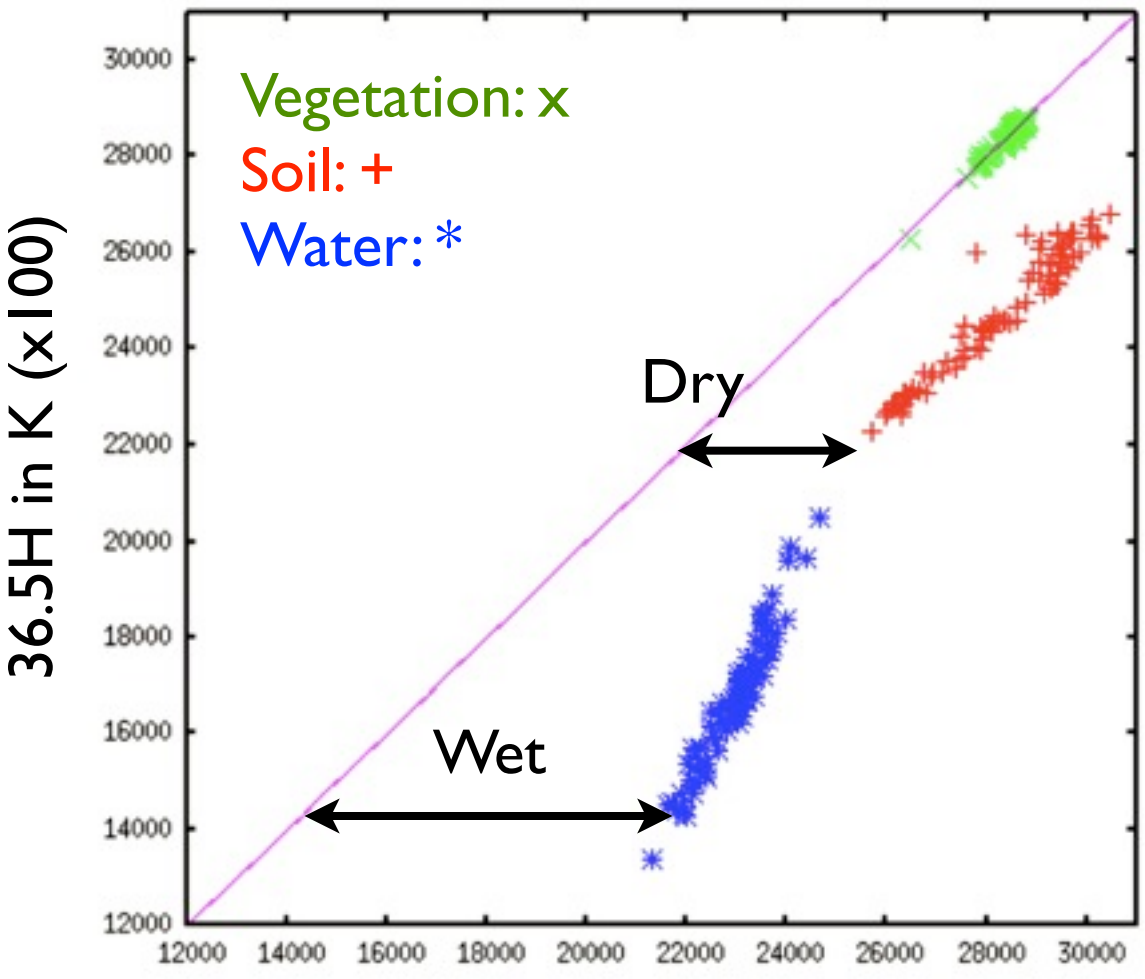






Lowest record

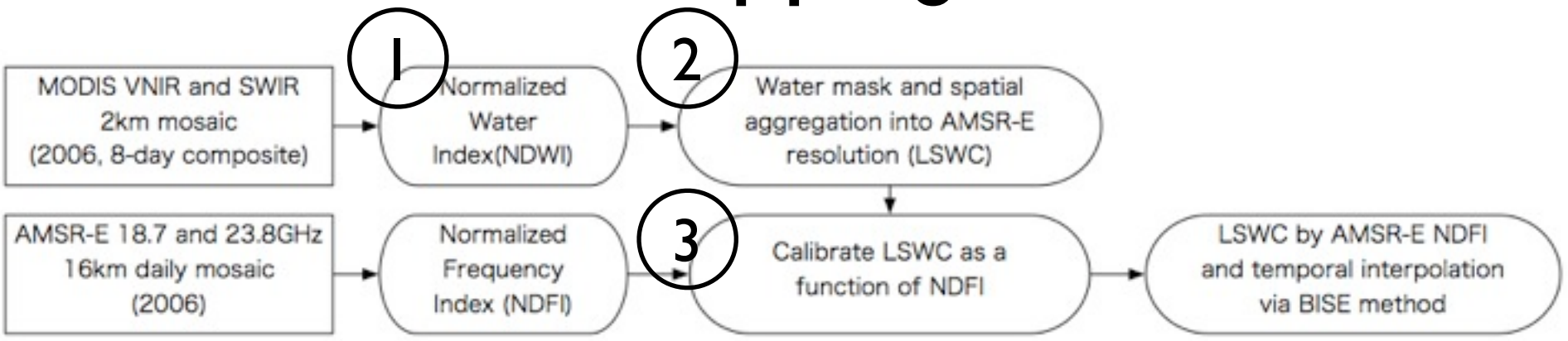
Normalized Polarization Index (NDPI)

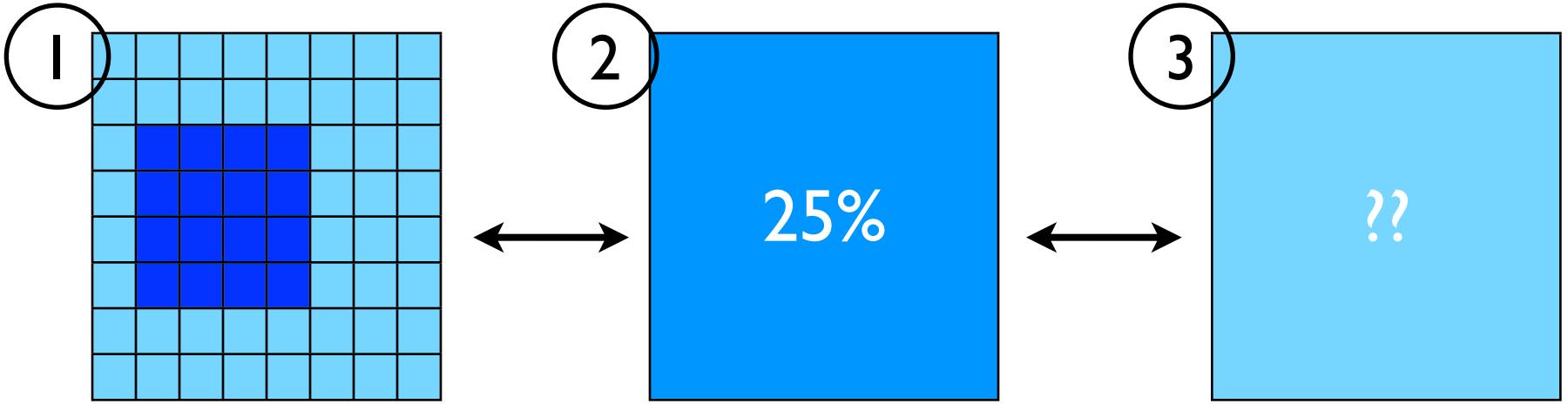


[Takeuchi, 2008]

NDPI = (36.5V - 36.5H) / (36.5V + 36.5H)

LSWC mapping model





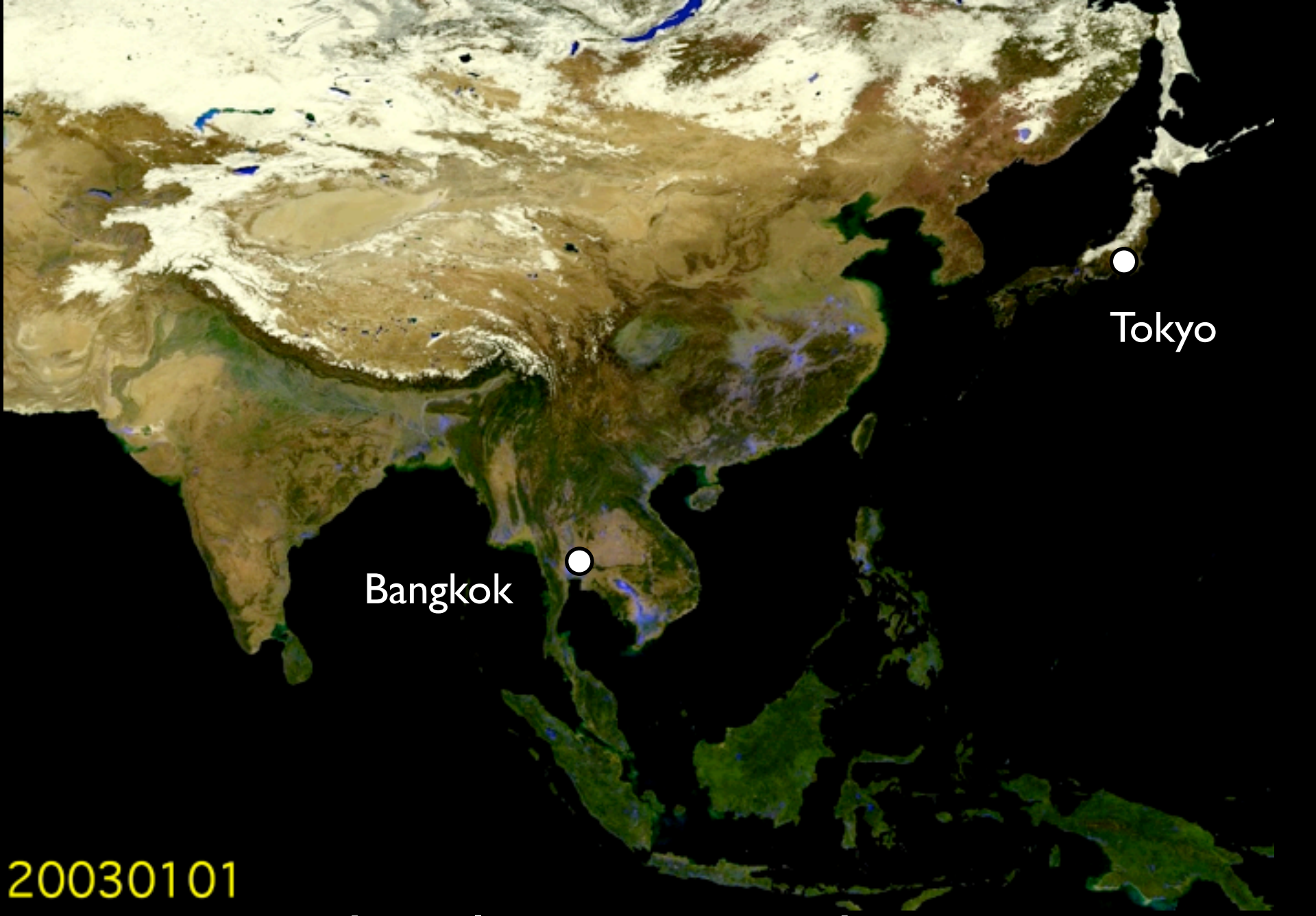
MODIS NDWI
(8x8 pixels)

MODIS LSWC
(1 pixel)

AMSR-E NDPI
(1 pixel)

Water pixel

Non-water pixel



Vegetation phenology, snow and water coverage

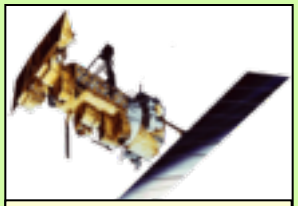
Production of "GSMaP" from Multi-satellite Data

GSMaP: Global Satellite Mapping of Precipitation

TRMM
TMI

Aqua
AMSR-E

DMSP
SSM/I, SSMIS



NOAA&MetOp
AMSU-A/MHS

Geostationary
Satellite

Rain models developed from PR observations

Rainfall data retrieved from each microwave imager and/or sounder

Calculate cloud moving vectors

Hourly merged microwave rainfall map

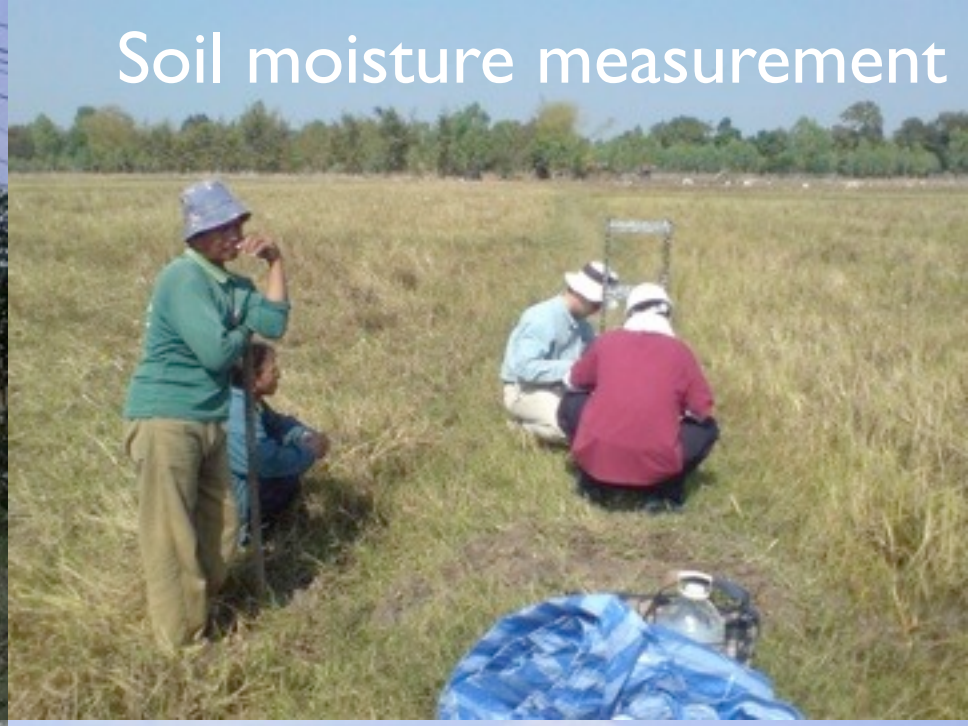
GSMaP rainfall in 0.1-deg grid and hourly


A


B
Landsat image (30m)


C


Harvest

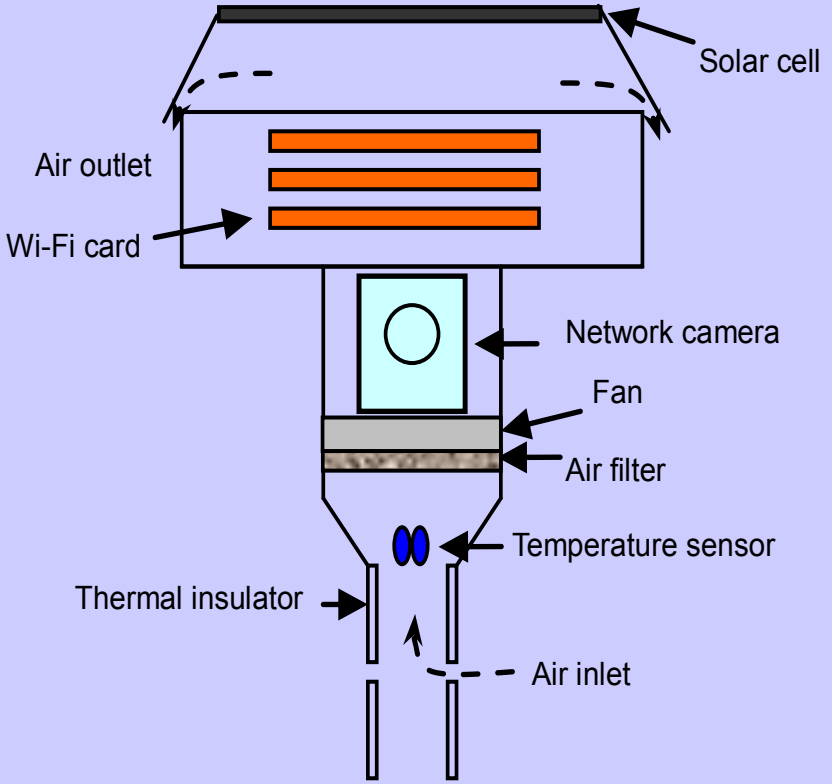

Soil moisture measurement


Flooding


Buffalo

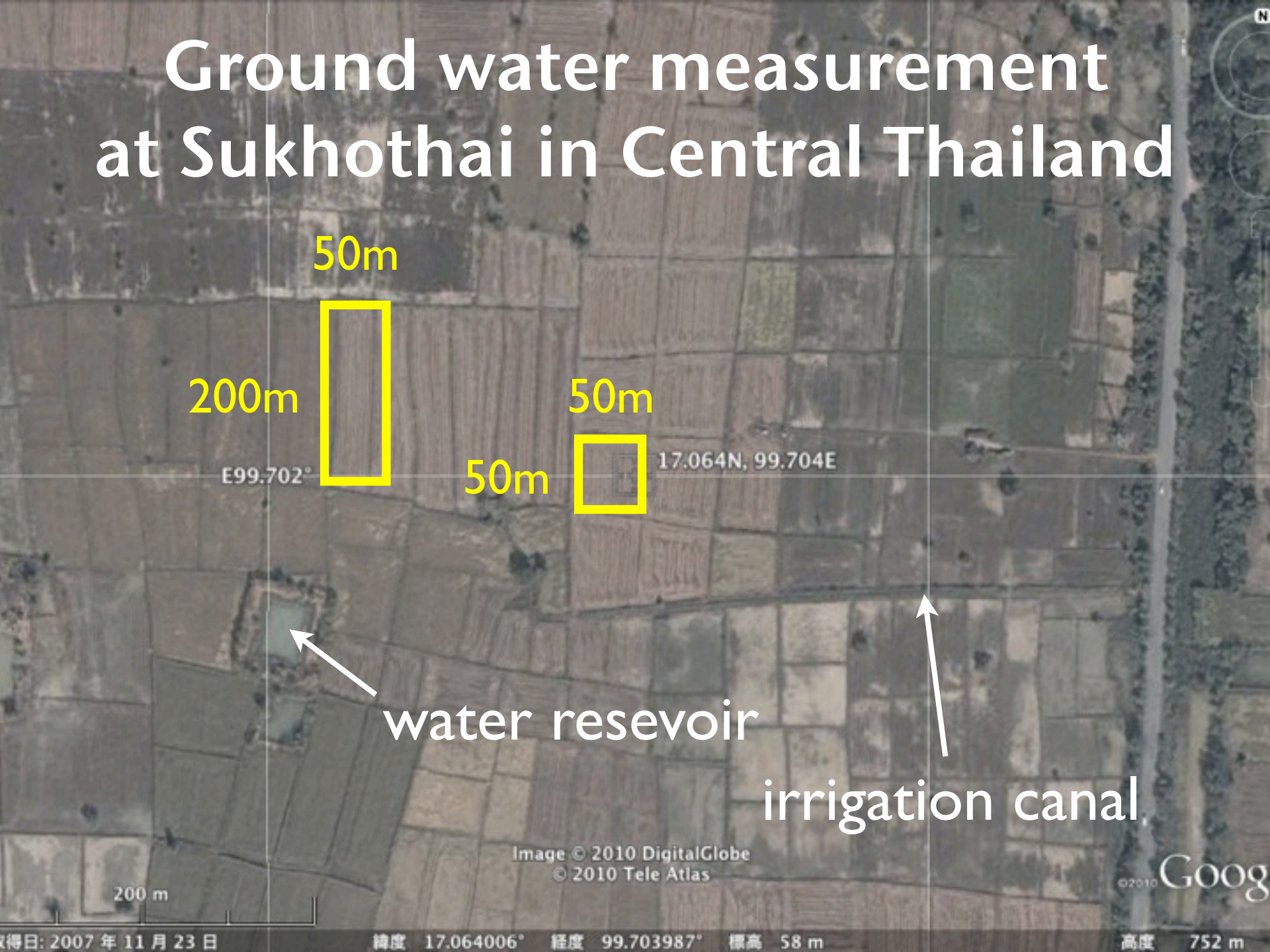
Field server

Vegetation cover (Daily)
Water cover (hourly)



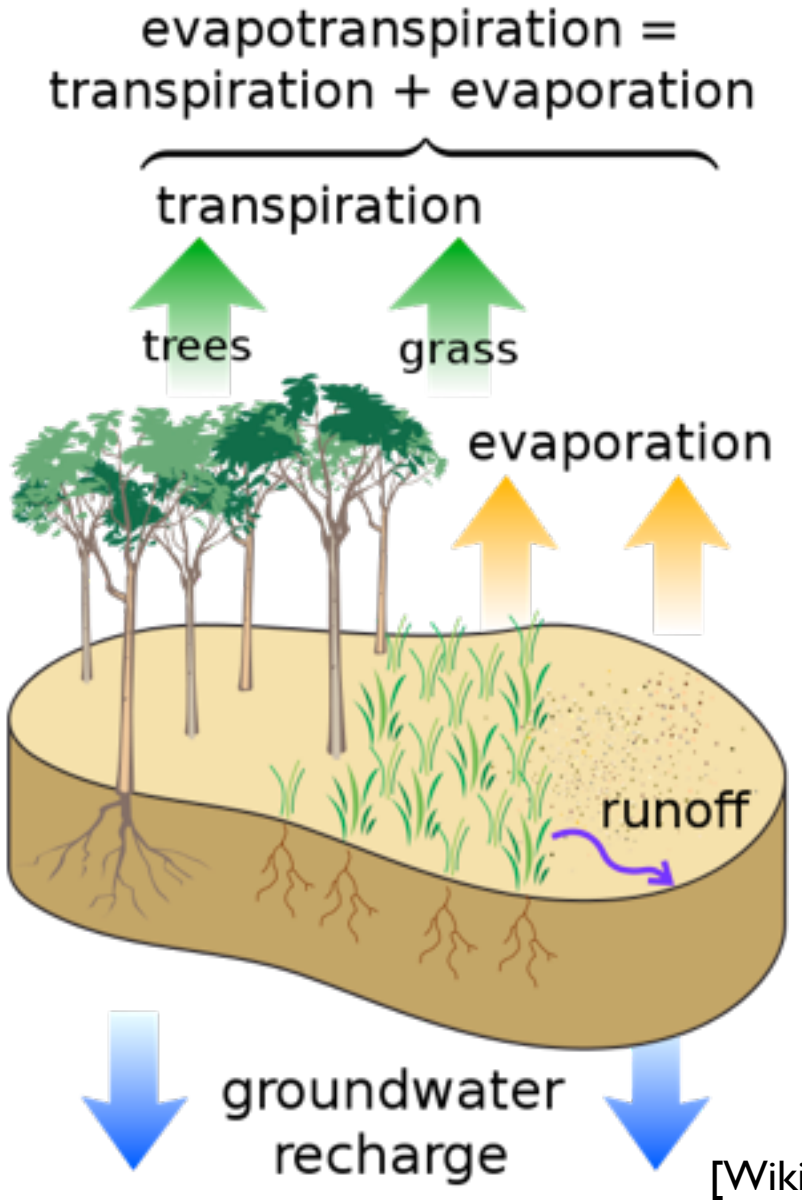
[Hirafuji, 2007]

Ground water measurement at Sukhothai in Central Thailand



Rice field in Khon Kaen
(Oct. 8, 2011 to Nov. 8, 2011)

Surface water storage and flow

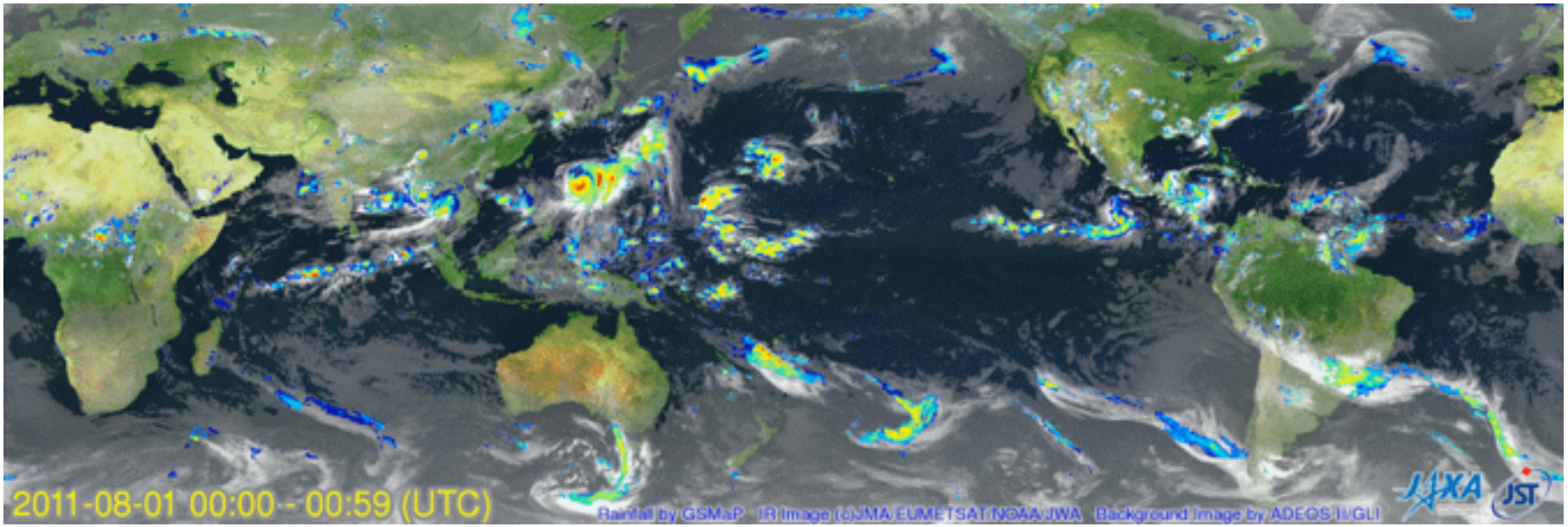


[Wikipedia]

- 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.

JAXA/EORC Global Rainfall Watch

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/

Keetch-Byram Drought Index (KBDI)

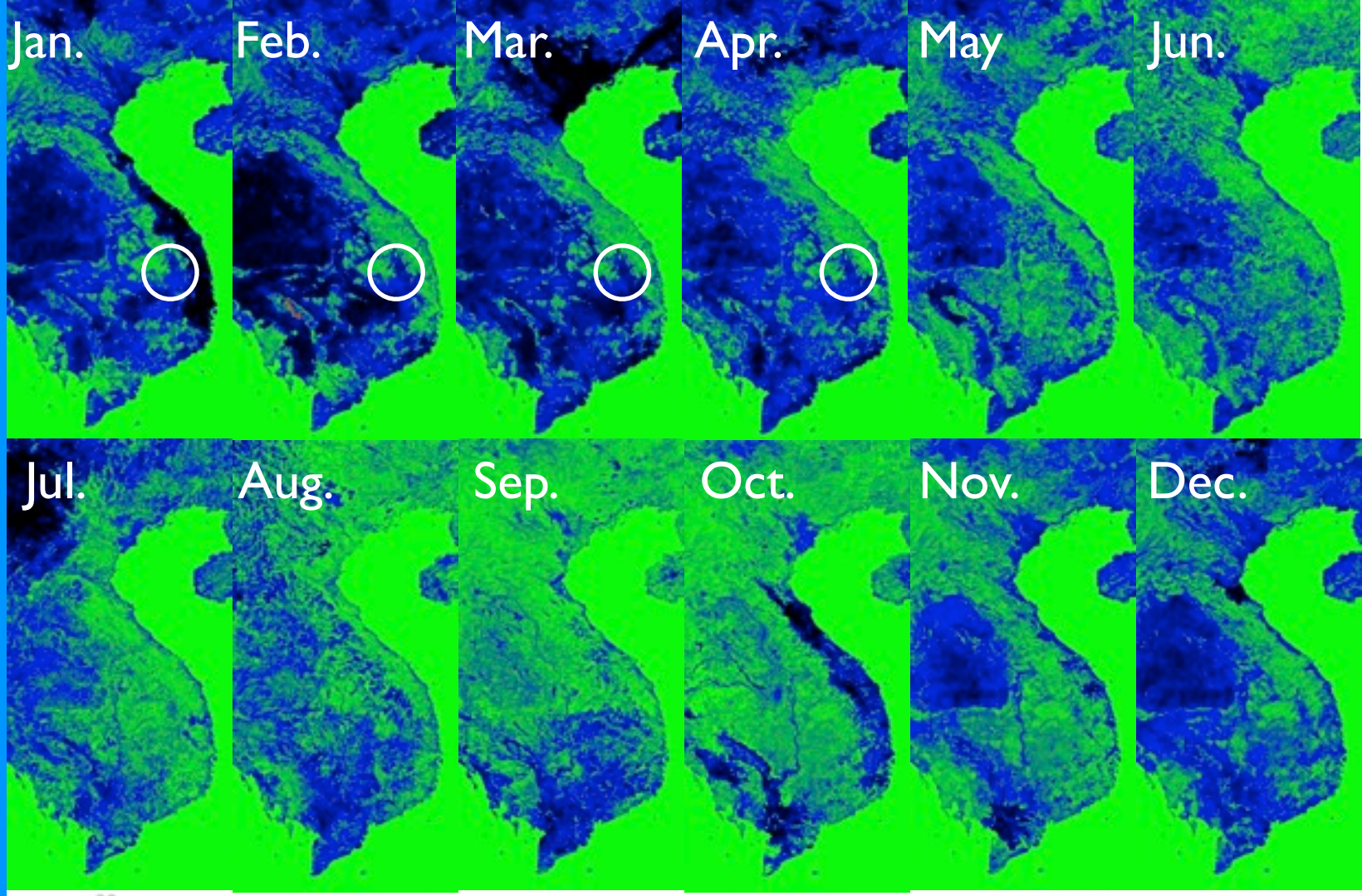
$$dQ = \frac{[\,800-Q\,][\,.968\,\exp(.0486T) - 8.30\,]\,d\tau}{1 + 10.88\,\exp(-.0441R)} \times 10^{-3}$$

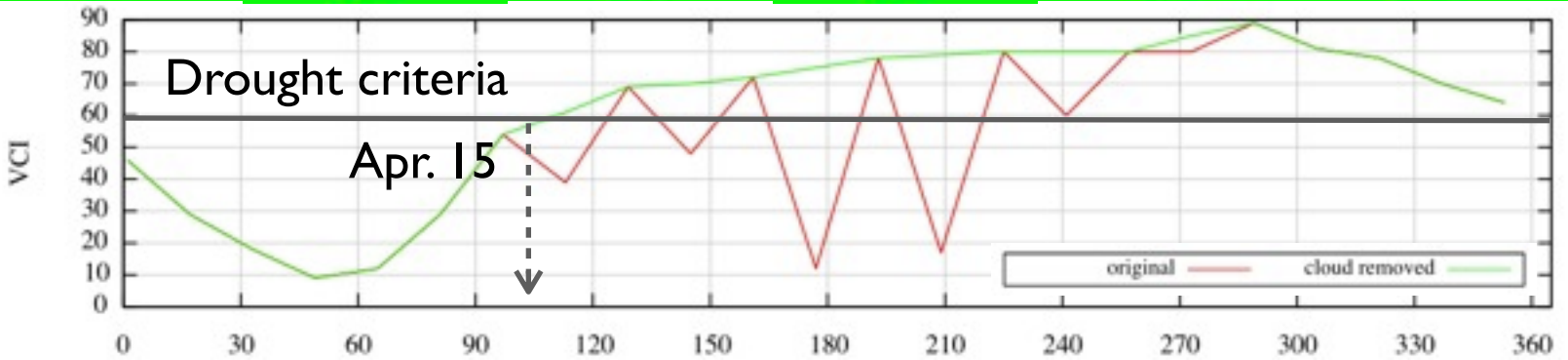
where
T: maximum daily temperature (F)
R: annual rain fall (inch)

[Keetch *et. al*, 1965]

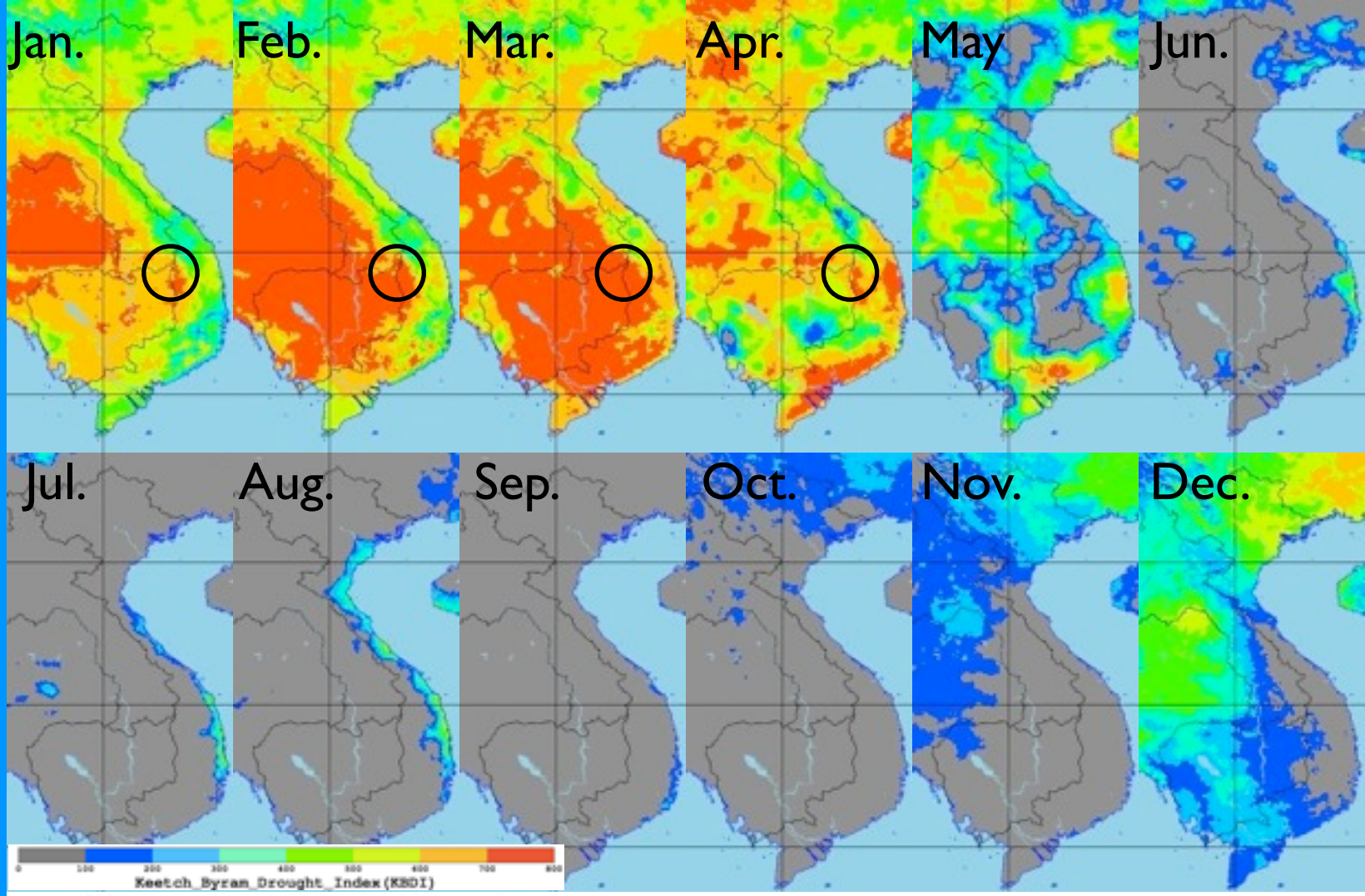
- The rate of moisture loss in a forested area depends on the vegetation density.
- The rate of moisture loss from soil is determined by evapotranspiration relations.
- The depletion of soil moisture with time follows an exponential curve.
- The depth of the soil layer considered has a field capacity of eight inches of available water.

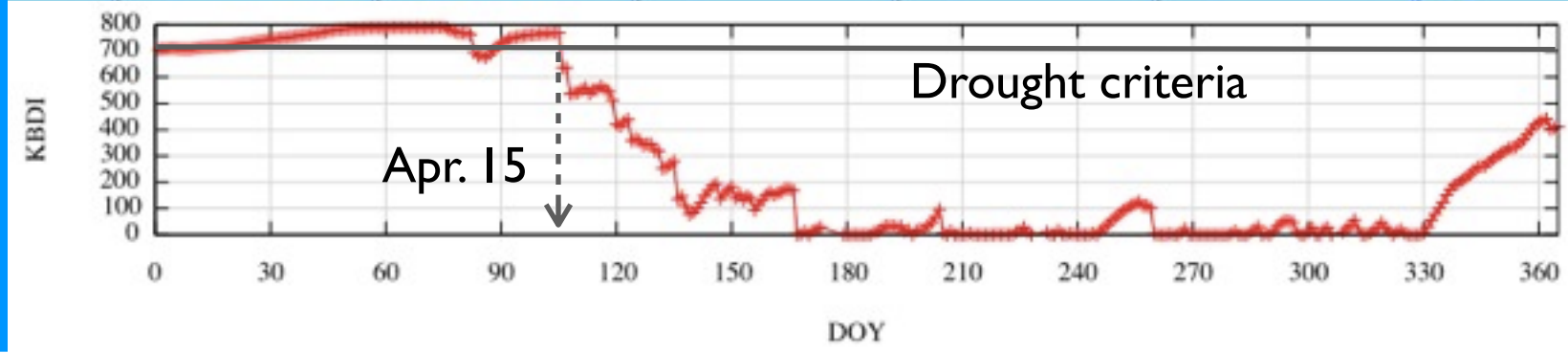
MODIS VCI captures 2007 agricultural patterns in central highland



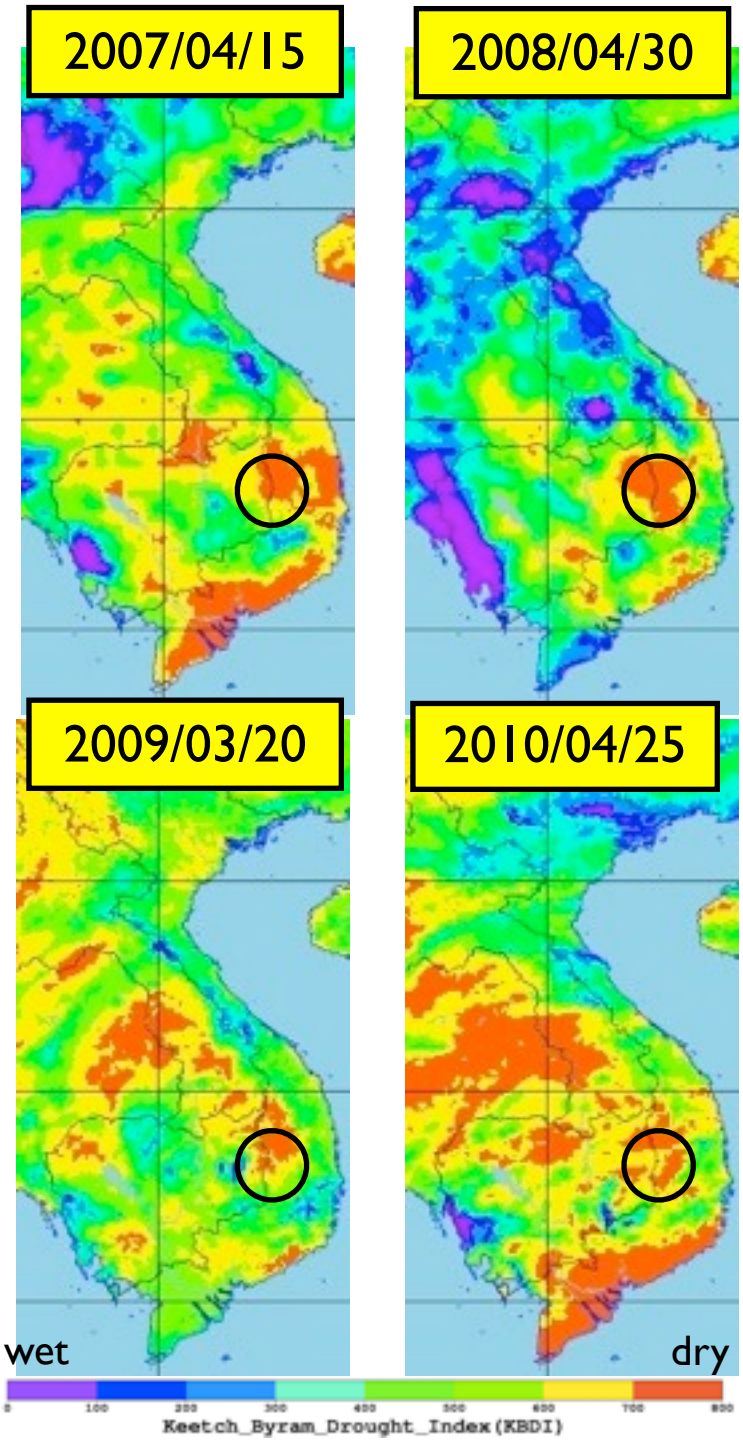


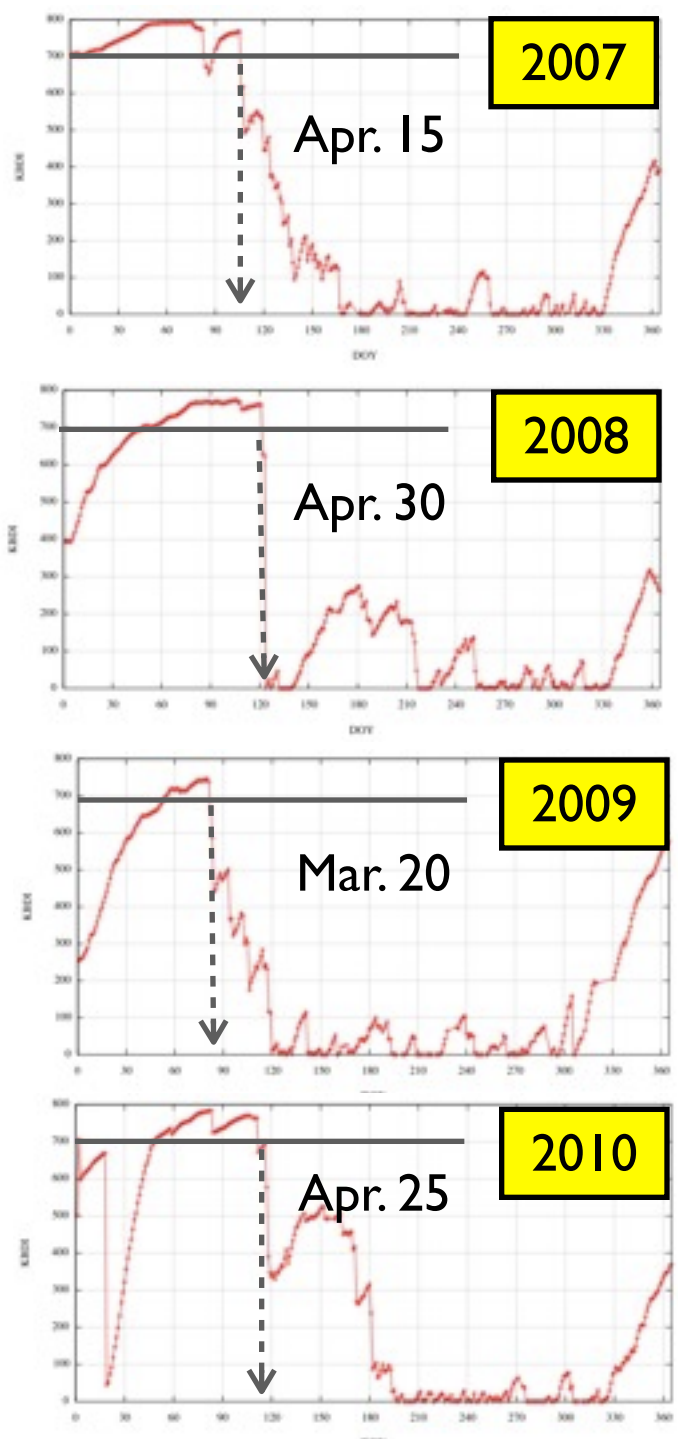
KBDI captures 2007 drought offset in central highland



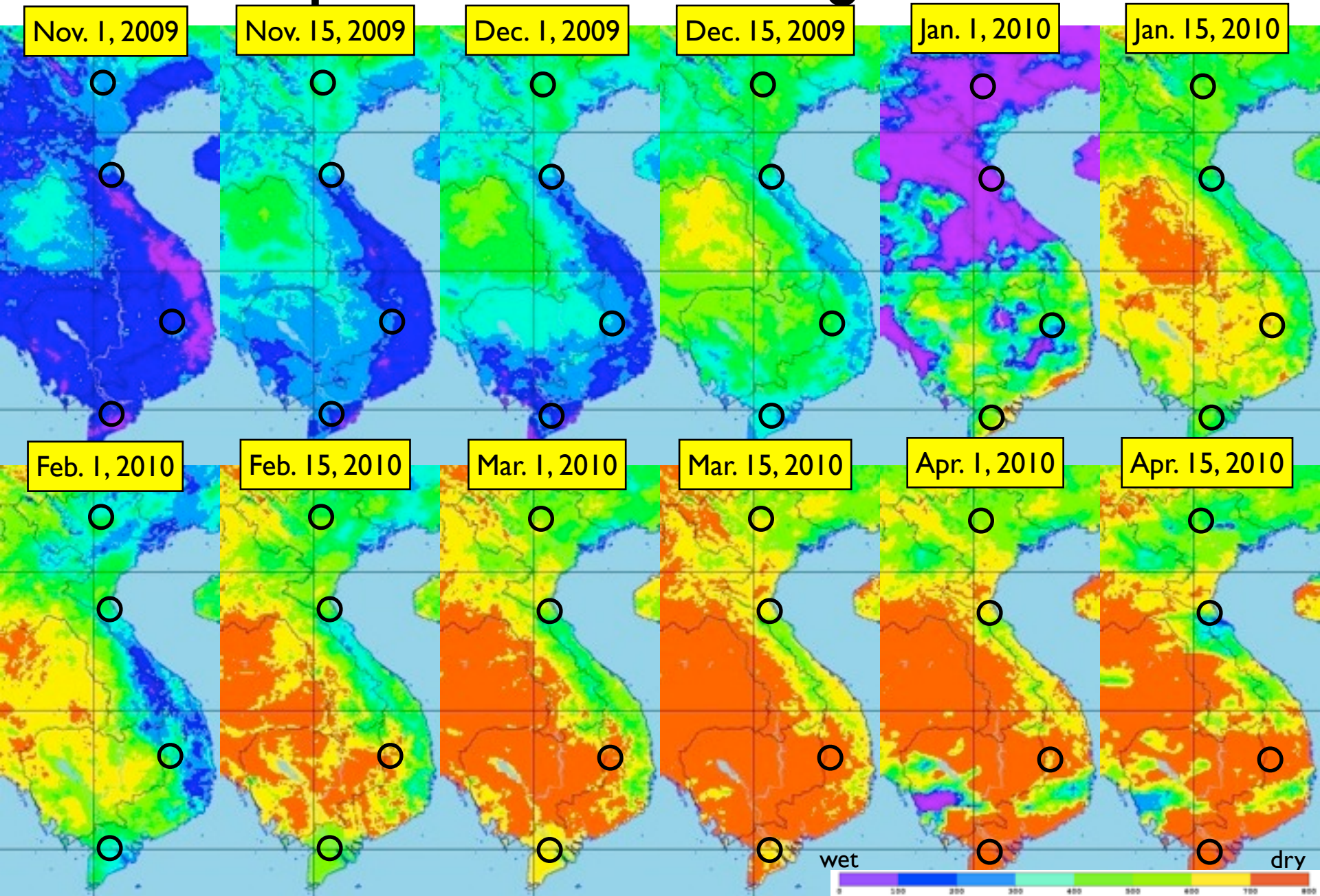


KBDI based drought offset in MuonMaThuot

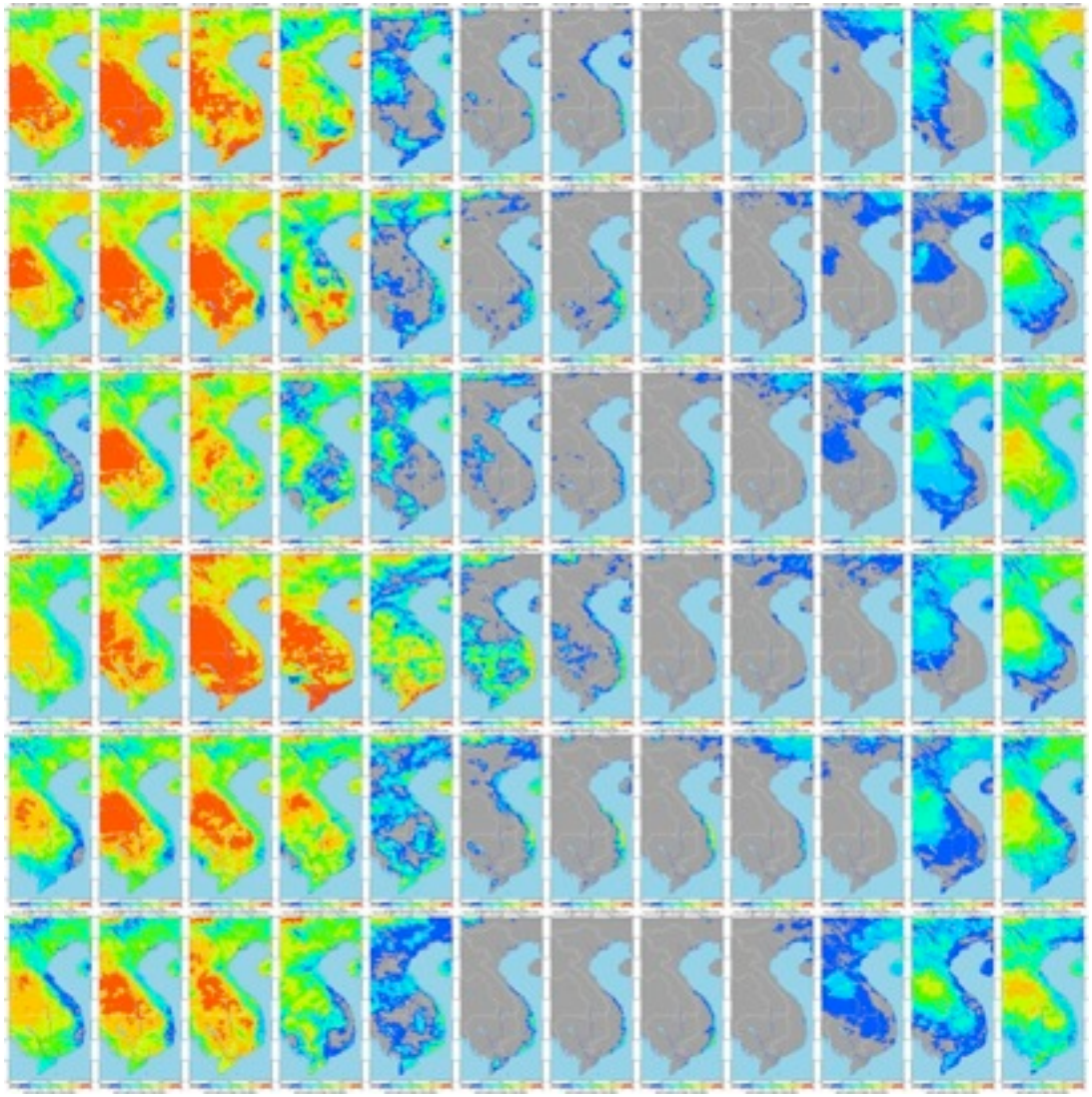




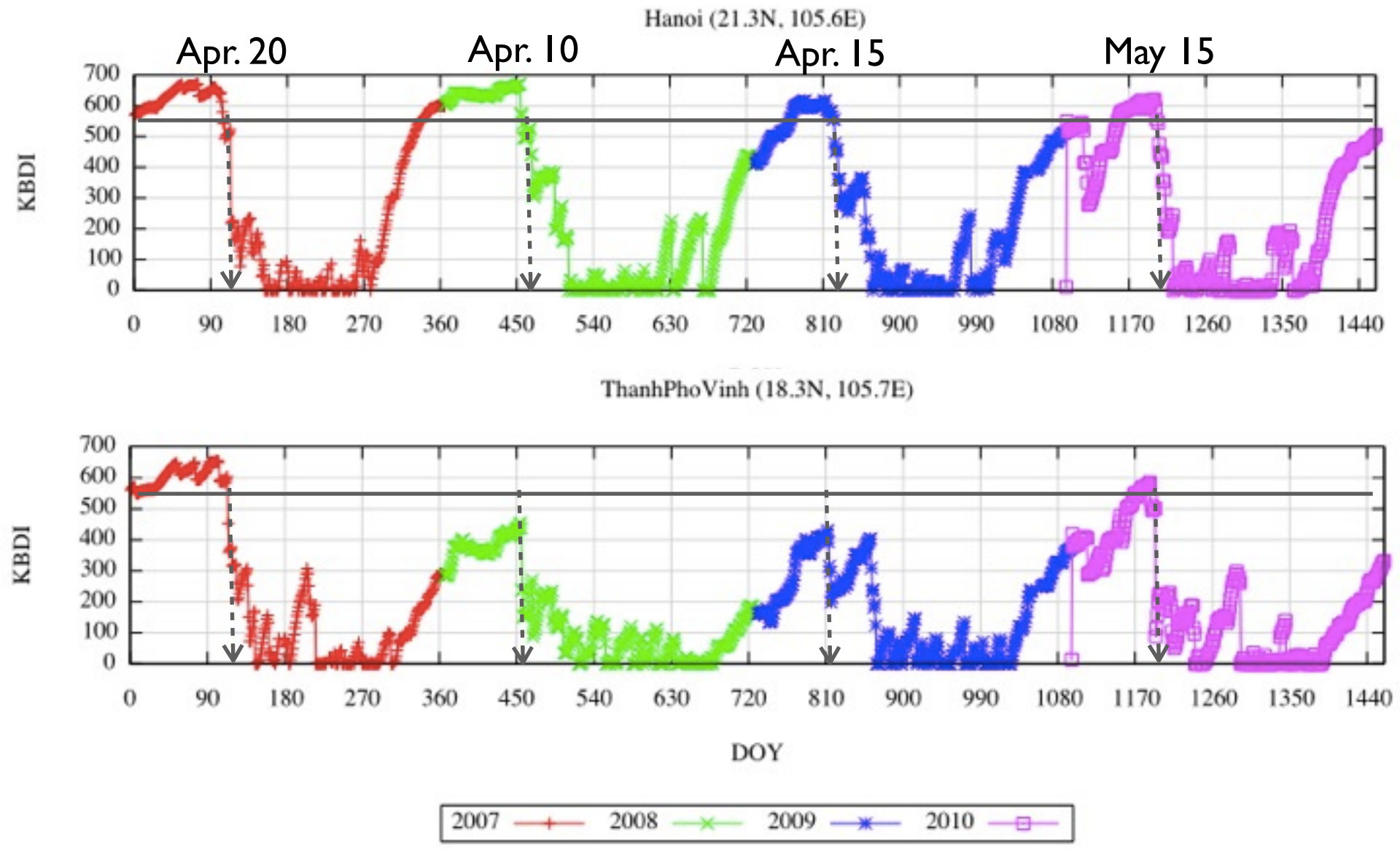
KBDI captures 2010 drought in Vietnam



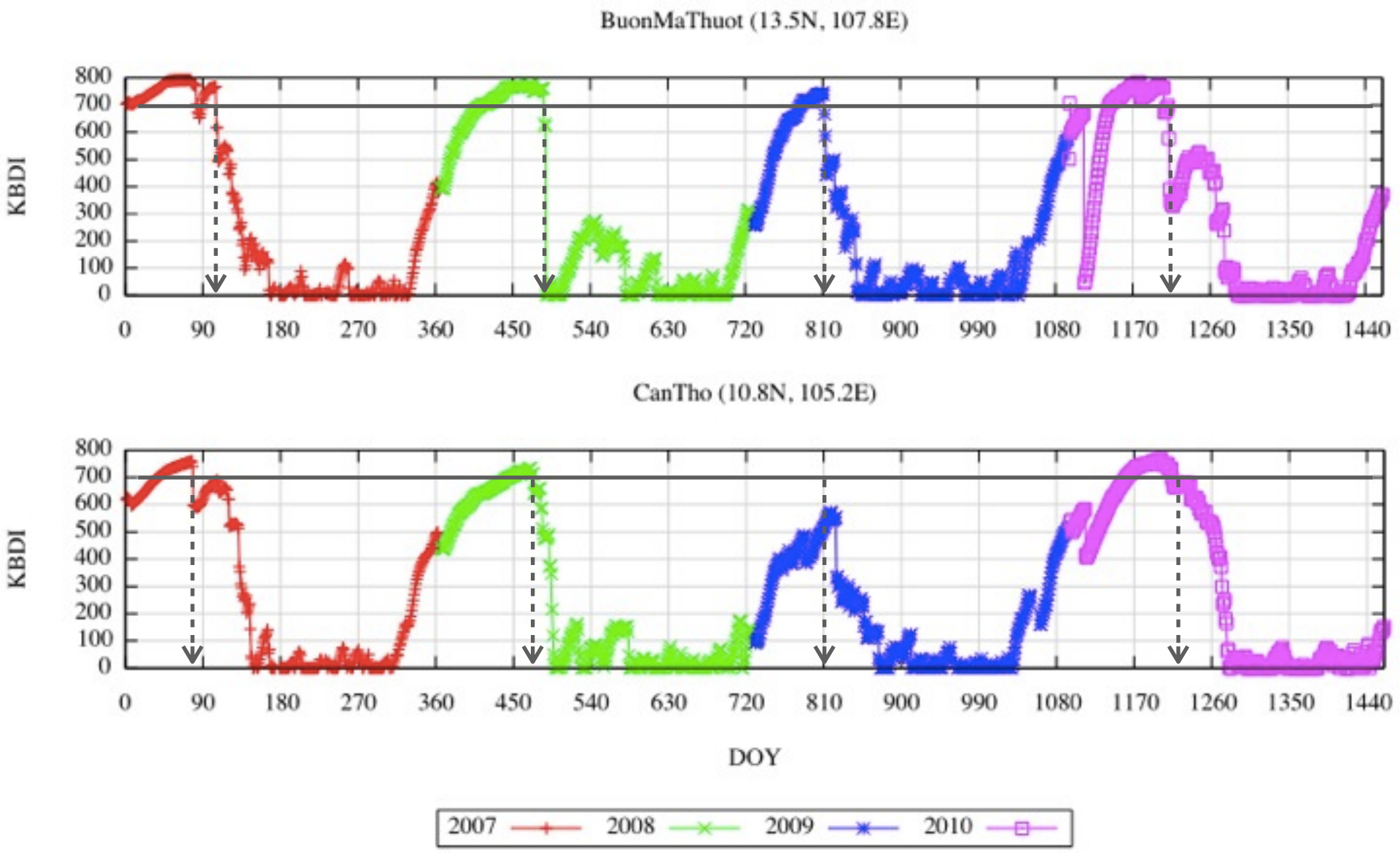
Monthly drought index map from 2007 to 2012 (Jan-Dec from left to right)



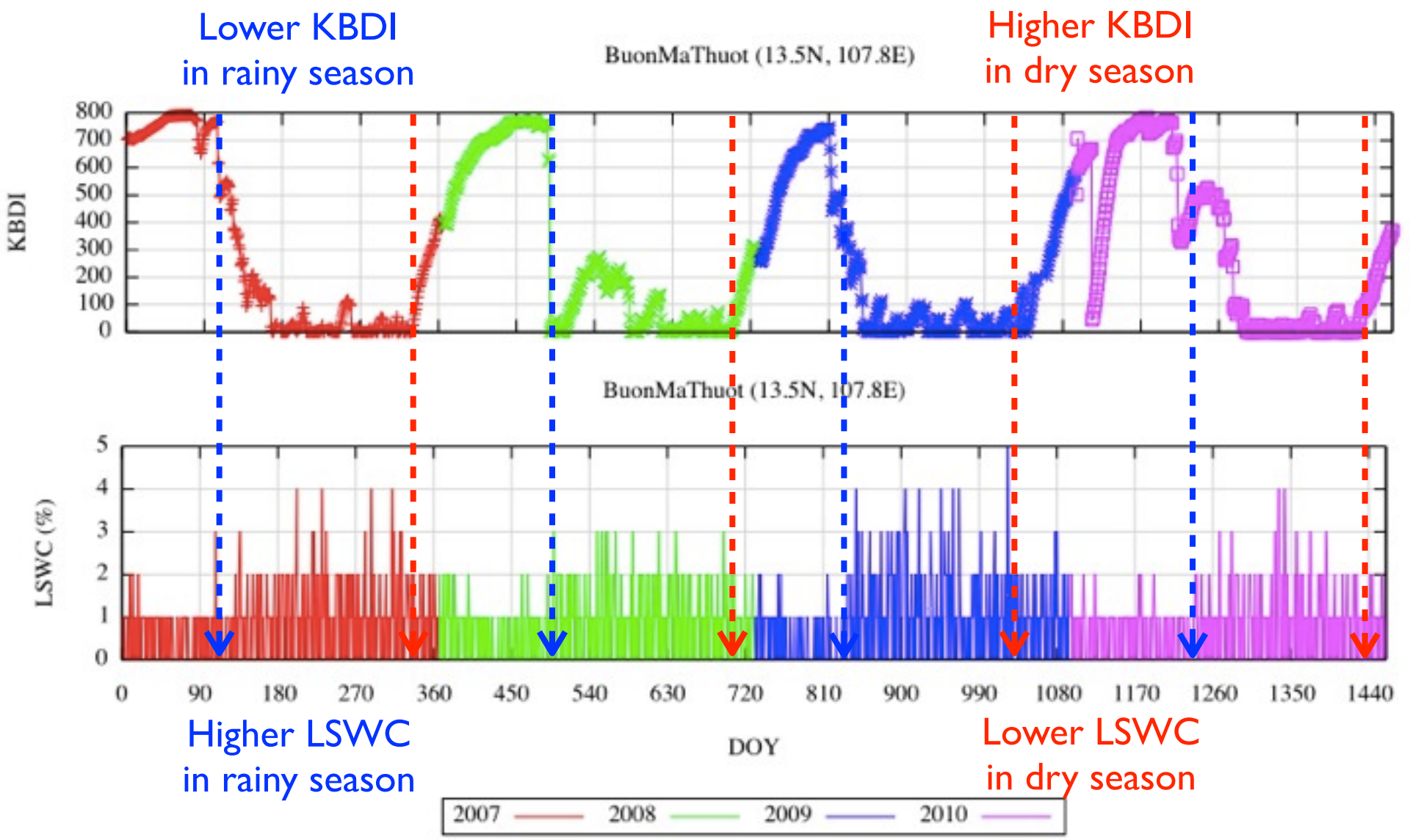
Drought offset in Hanoi and ThanhPhoVinh



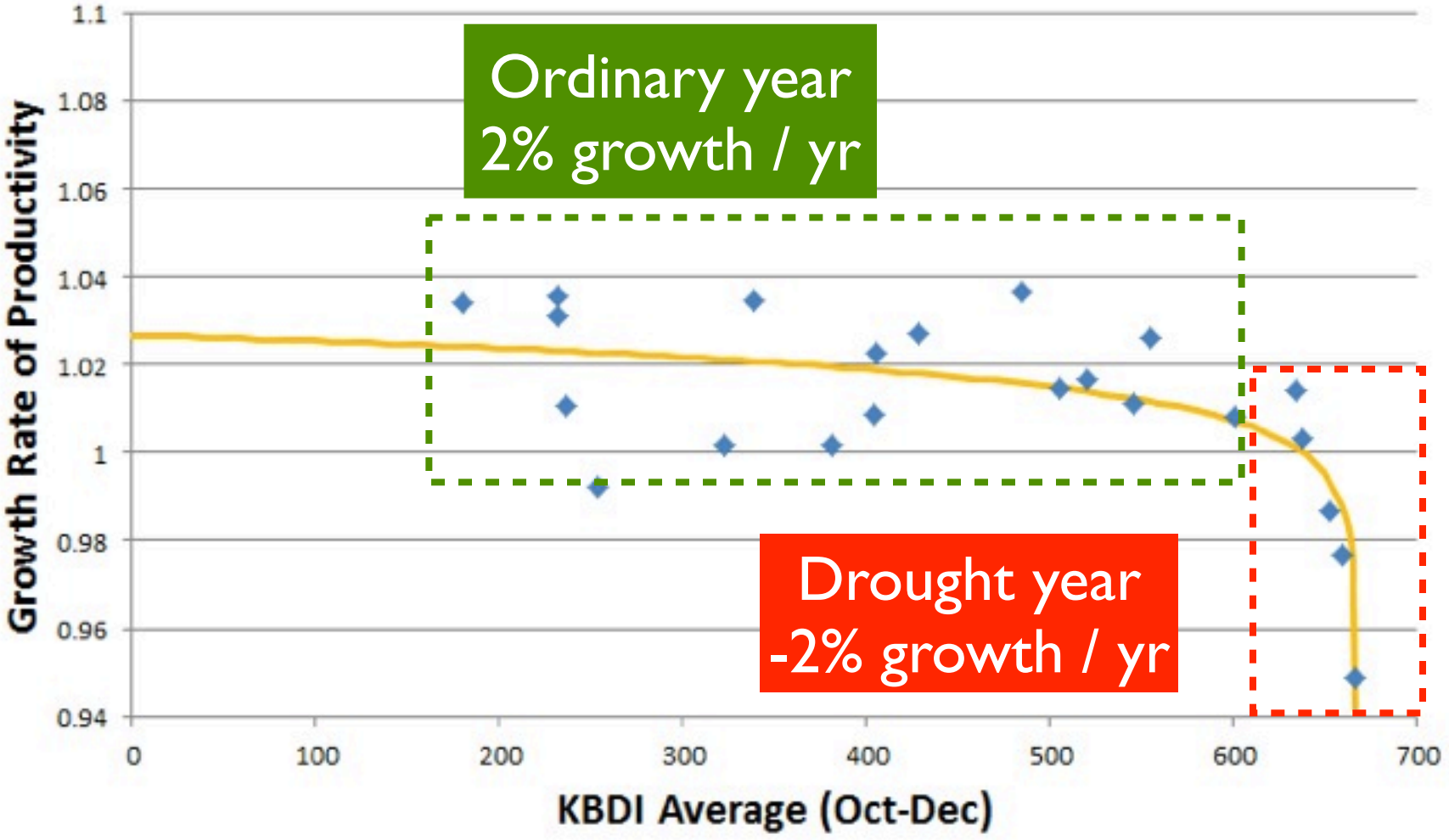
Drought offset in BuonMaThuot and CanTho



Drought onset/offset timing synchronized via KBDI and LSWC in BuonMaThuot



Higher KBDI in rice growing period causes loss of rice productivity



[Hosoya, 2011]

Cost and benefit analysis for irrigation facility development

Country	Total cost (JPY)	Area (ha)	Cost (JPY/ha)
Thailand	4,800,000,000	48,000	100,000
Indonesia	6,953,000,000	25,589	271,718
Vietnam	4,874,000,000	15,700	310,446

[ODA, 2010]

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)

[Hosoya, 2011]

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]

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.

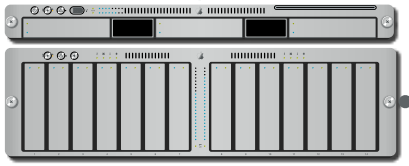
Concluding remarks (cont'd)

- Both MODIS based drought codes and KBDI can monitor areas of climatological and agricultural drought.
- KBDI represents both LST and precipitation anomaly and well capture a drought onset date.
- KBDI is possibly related to rice production, however, there is no clear evidence that proves the correlation at the moment.
- KBDI can be applied for a future prediction if we incorporate a weather forecast results including LST and precipitation (coming soon).

System configuration of web-based drought monitoring in GMS

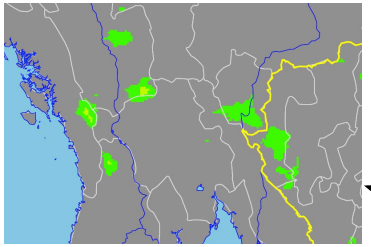
UT data processing

MTSAT, MODIS and GSMaP

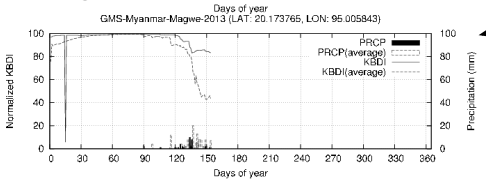


Automatic daily update

Drought early warning map
(10km level)



Historical drought condition
graph in province level



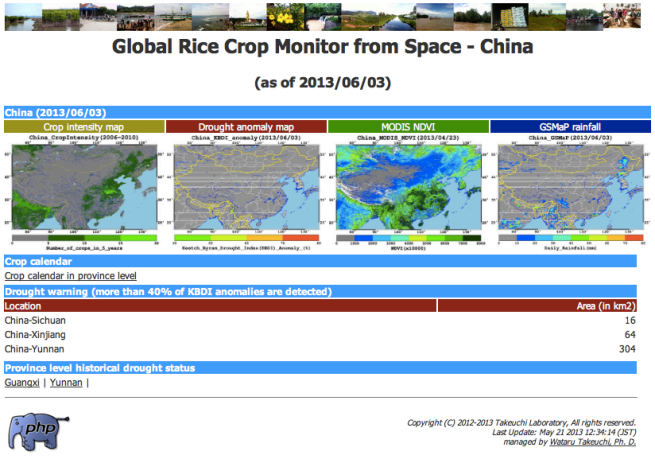
GMS-AIN server

Mirror database only
Web-interface are customized

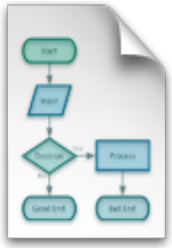
<u>System requirement</u>
% mirror database daily from UT
(drought map in jpeg)
% Runs under Linux (PHP+Apache2)
% 4GB memory + 500GB disk space

GMS countries user access via web

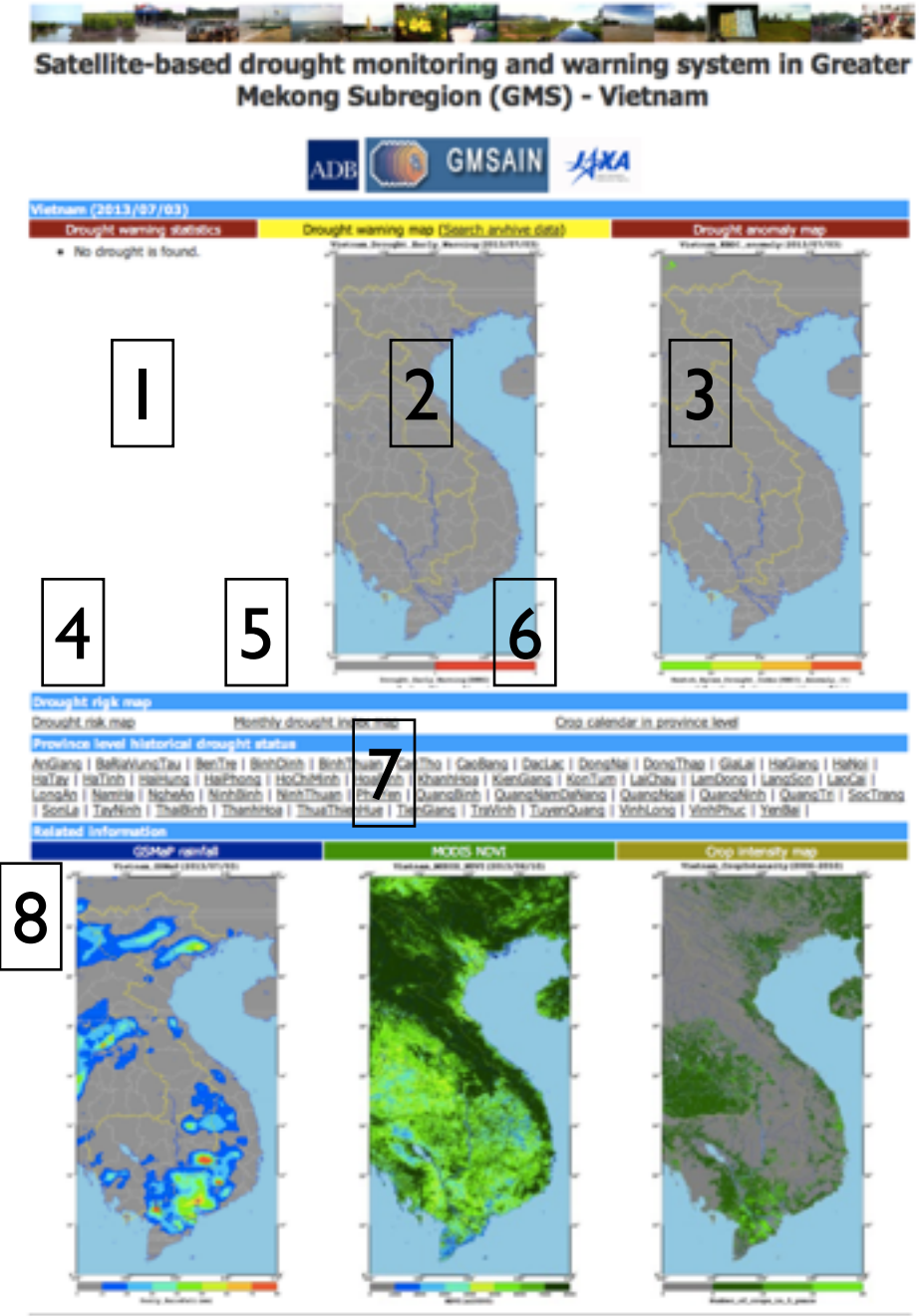
AIN server in GMS countries



Cost and benefit analysis



Make a report of
drought condition



Practical use for your operational job and study

1. Daily use
   a) Drought warning statistics -> 1, 2, 3
   b) Understand the situation (how long and where) -> 6, 7
2. Annual use
   a) Identify severe drought areas on a map -> 4
3. Multiple year use
   a) Understand the drought trend on a map -> 5

paddy.iis.u-tokyo.ac.jp/GMS/Vietnam/

Thank you

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