Development of normalized vegetation, soil and water indices derived from satellite remote sensing data

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Observer from outer space

Vegetation monitoring indices

- **NDVI cron developed for AVHRR**
  - **RVI (Ratio Vegetation Index)**
  - **PVI (Perpendicular Vegetation Index) [Richardson, 1987]**
  - **SAVI (Soil Adjusted Vegetation Index) [Huete, 1992]**
  - **VSW (VSW Index) [Yamagata, 1997]**
  - **BSI (Bidirectional Structure Index) [Honda, 2000]**
- **Newly developed indices for MODIS**
  - **EVI (Enhanced Vegetation Index) [Huete, 2000]**
  - **NDSI (Normalized Snow Index) [NSIDC, 2002]**
  - **NDWI (Normalized Water Index) [Gao, 1996]**

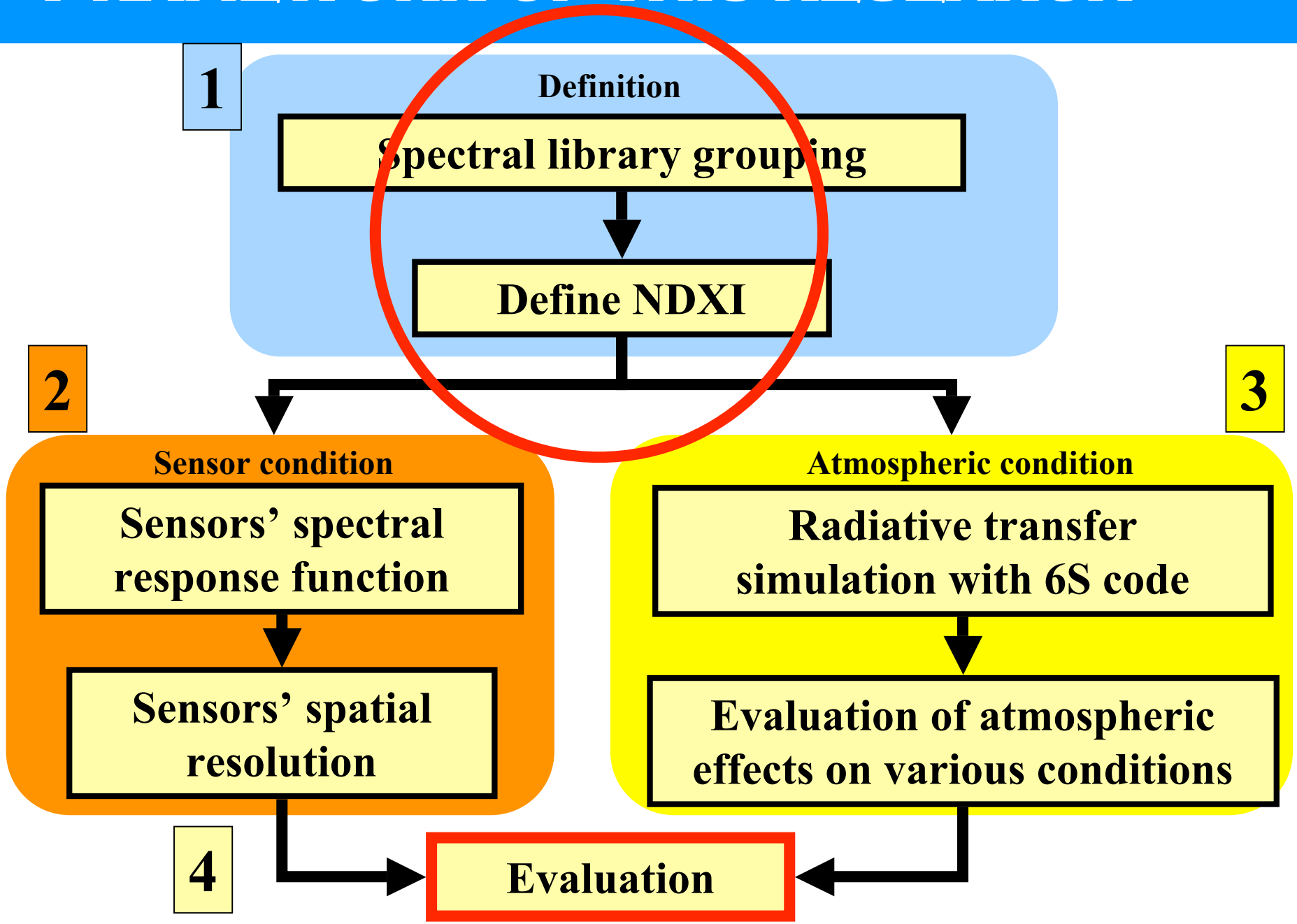
There is no method designed to monitor vegetation, soil and water simultaneously.

Objectives of this study

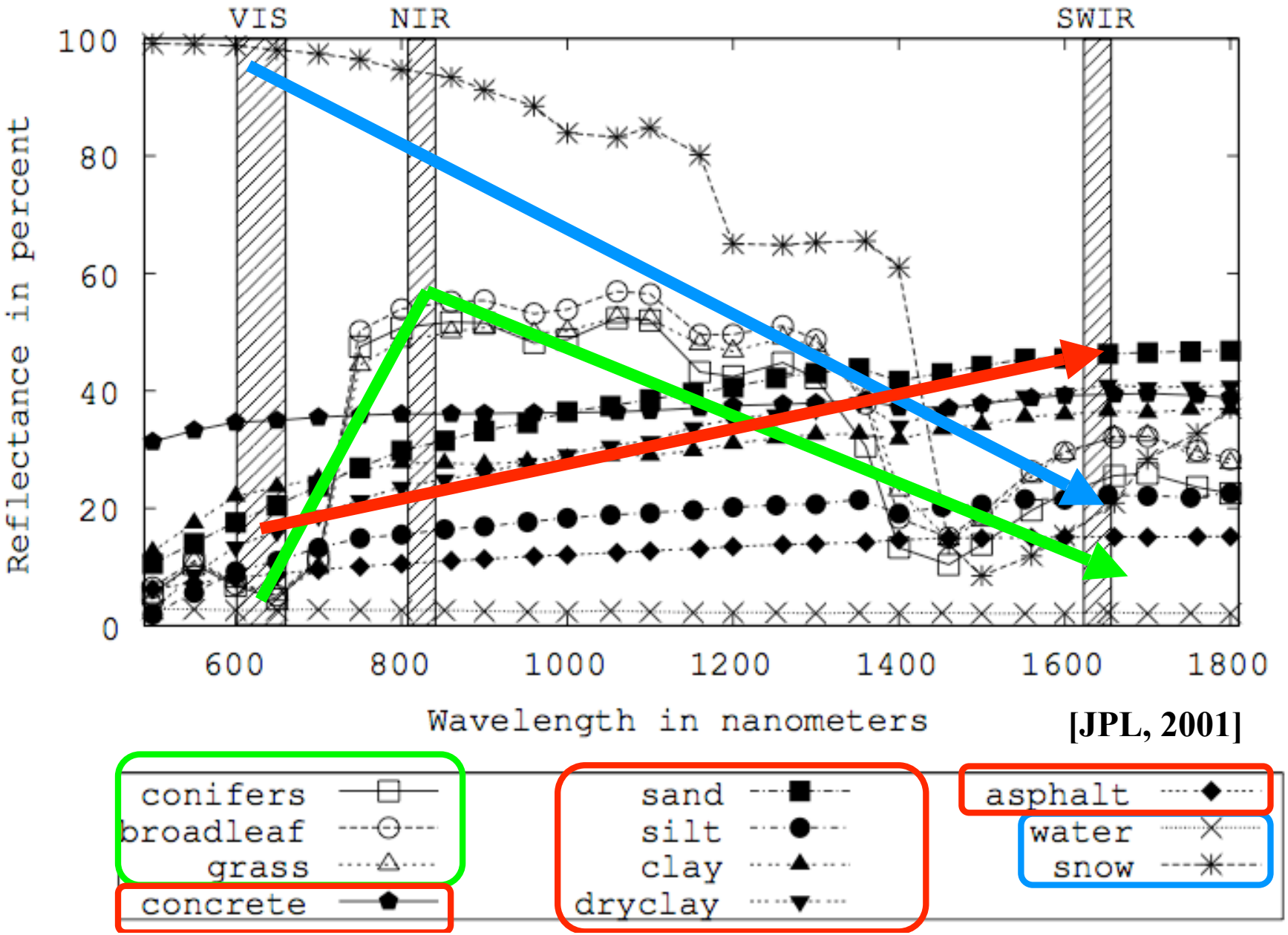
- ***To develop a set of normalized vegetation, soil and water indices (NDXI) by extending the idea of NDVI using SWIR channels.***

  - *Their spectral characteristics are investigated for a variety of land cover types.*
  - *Sensitive analysis is conducted with different spectral response sensors including ASTER, AVHRR, ETM and MODIS.*
  - *Atmospheric effects are evaluated using radiative transfer simulation under a variety of aerosol, visibility, topography and sun-target-sensor geometry.*

Framework of this research



Spectral varieties over land



[JPL, 2001]

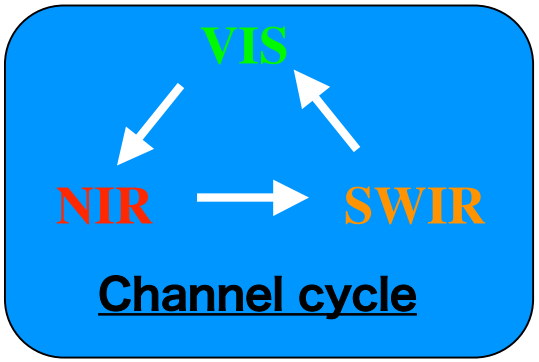
Spectral curve classification

- **Vegetation group (convexly curve)**
  - **Conifers, broadleaf, grass**
- **Soil group (ascending curve)**
  - **Concrete, sand, silt, clay, dryclay, asphalt**
- **Water group (descending curve)**
  - **Water, snow**

The spectral signatures over a variety of land covers are mainly classified into three categories including vegetation, soil and water.

Normalized vegetation-soil-water indices

$$\begin{cases} \text{NDVI} = (\text{NIR} - \text{VIS}) / (\text{NIR} + \text{VIS}) & (1) \\ \text{NDSI} = (\text{SWIR} - \text{NIR}) / (\text{SWIR} + \text{NIR}) & (2) \\ \text{NDWI} = (\text{VIS} - \text{SWIR}) / (\text{VIS} + \text{SWIR}) & (3) \end{cases}$$



where *VIS: Visible (630nm, channel1)*
NIR: Near infrared (860nm, channel2)
SWIR: Shortwave infrared (1620nm, channel6)

$$\overline{\sigma} = \int_{\lambda_1}^{\lambda_2} \Phi(\lambda)\sigma(\lambda)d\lambda$$

$\Phi(\lambda)$: **Spectral response of sensor**

$\sigma(\lambda)$: **Target reflectance**

LAND COVER CHARACTERIZATION WITH NDXI

Table 1. Comparison of NDXI values calculated for eleven types of land covers[1].

	CF	BL	GR	CC	SD	SL	CL	DC	AP	WT	SN
NDVI	0.83	0.83	0.81	0.08	0.23	0.22	0.14	0.24	0.15	0.06	0.05
NDSI	-0.47	-0.40	-0.35	-0.11	0.06	0.01	-0.02	0.11	0.02	-0.26	-0.72
NDWI	-0.60	-0.64	-0.65	0.03	-0.29	-0.23	-0.12	-0.34	-0.17	0.20	0.69

[1] Abbreviations in the list are as follows, CF:conifers, BL: broadleaf forest, GR: grass, CC: concrete, SD: sand, SL: silt, CL: clay, DC: dry clay, AP: asphalt, WT: water, SN: snow.

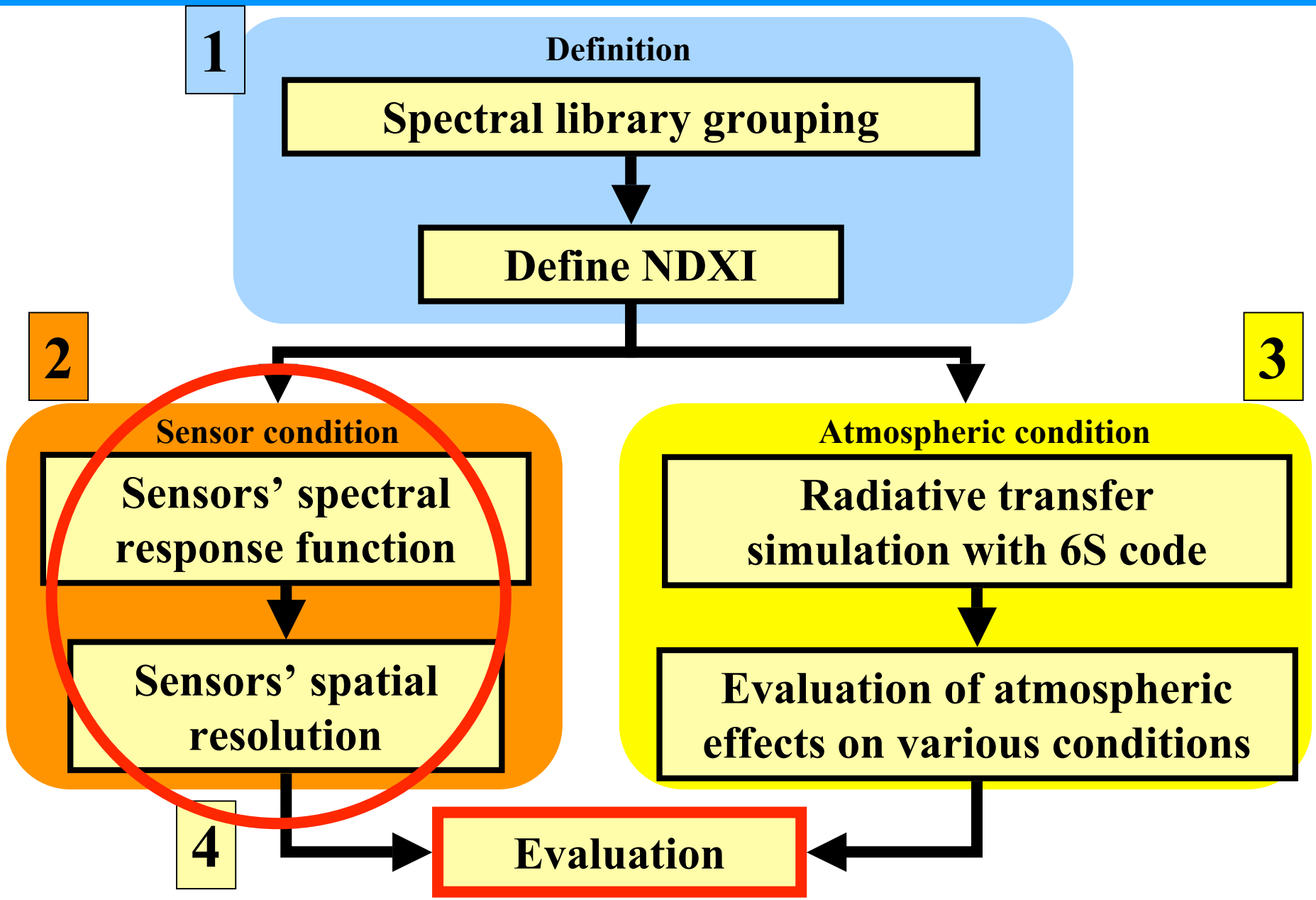
◆**NDVI has much higher positive values (0.81~0.83) in vegetation group (CF, BL, GR)**

◆**NDSI has larger values (-0.11~0.11) in soil group (CC, SD, SL, CL, DC, AP)**

◆**NDWI has positive values (0.20~0.69) only in water group (WT, SN)**

NDVI, NDSI, NDWI represents the existence of vegetation, soil and water respectively.

Framework of this research



Satellite borne sensors with SWIR

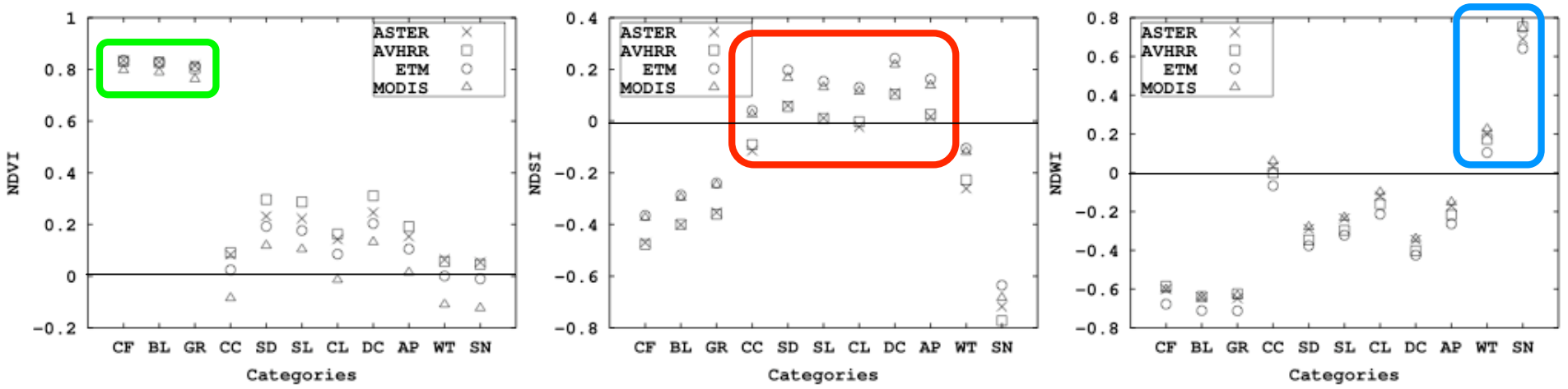
	AVHRR/3*		MODIS		ASTER		ETM
Ch.	Width	Ch.	Width	Band	width	band	Width
1	580-680	1	620-670	2	630-690	3	630-690
2	725-1000	2	841-876	3	760-860	4	780-900
3A	1580-1640	6	1628-1652	4	1600-1700	5	1550-1750

* NOAA15-17 for daily passes

SWIR is effective to monitor moisture conditions

- 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]

Sensitivity analysis on different sensors



(a) NDVI (b) NDSI (c) NDWI

◆**NDVI: in vegetation group, ETM has the largest value followed by AVHRR, ASTER and MODIS.**

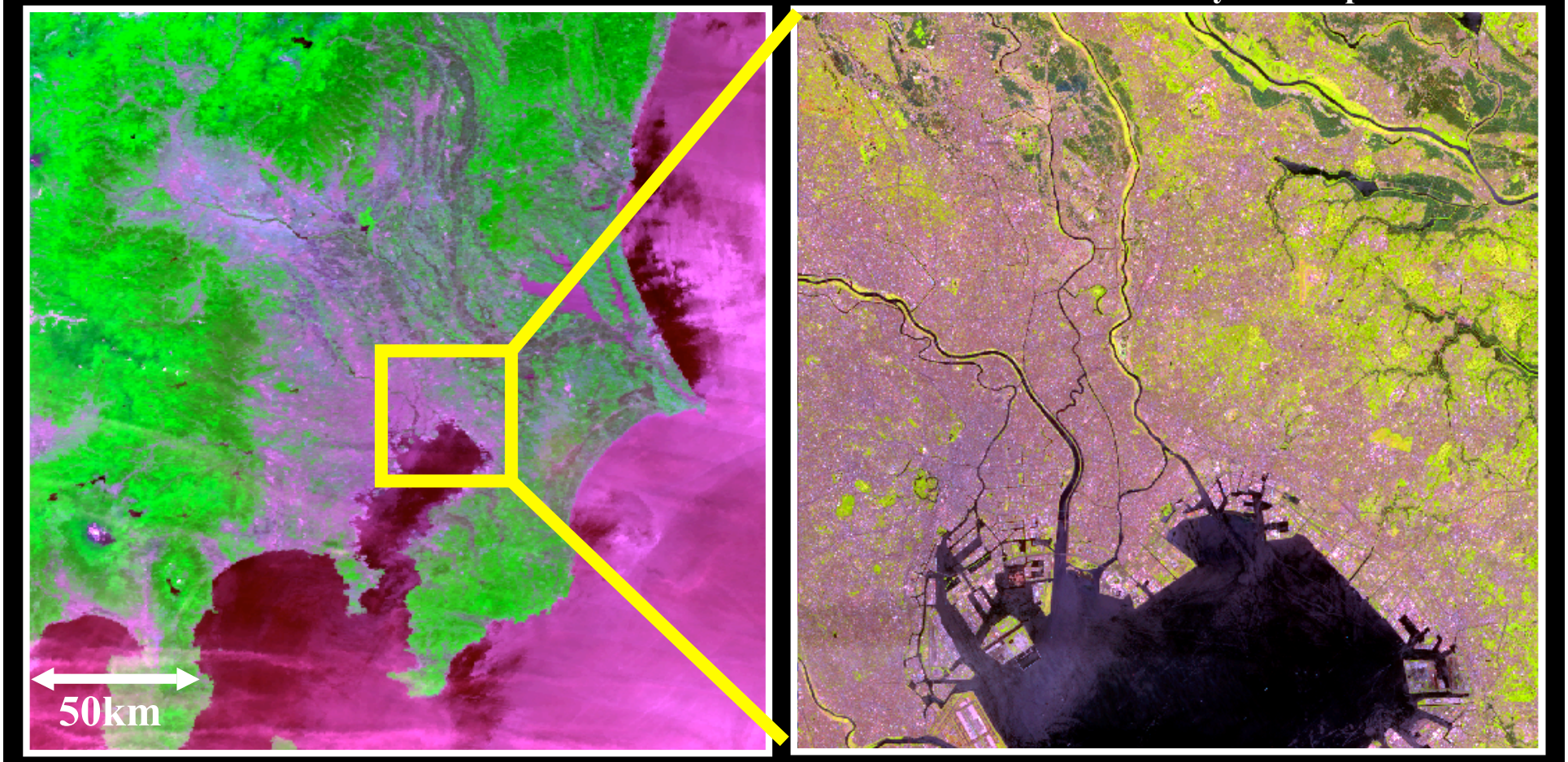
◆**NDSI: in soil group, ETM and MODIS have the same value, and ASTER and AVHRR have the same value lower than those of ETM and MODIS.**

◆**NDWI: in water group, MODIS has the largest value followed by ASTER, AVHRR and ETM.**

Soil group have relatively larger variations on NDXI in terms of sensors' difference.

Comparison of different sensors

Tokyo metropolitan area

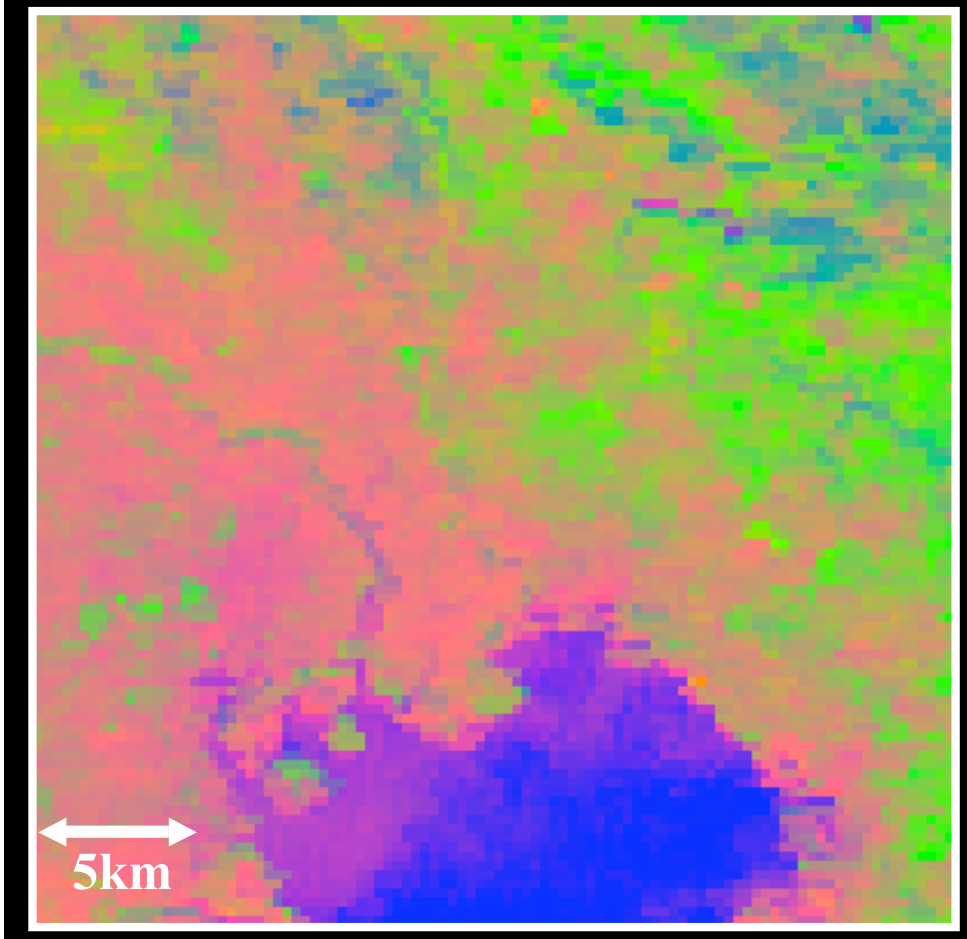


Terra MODIS (500m) **Terra ASTER (30m)**

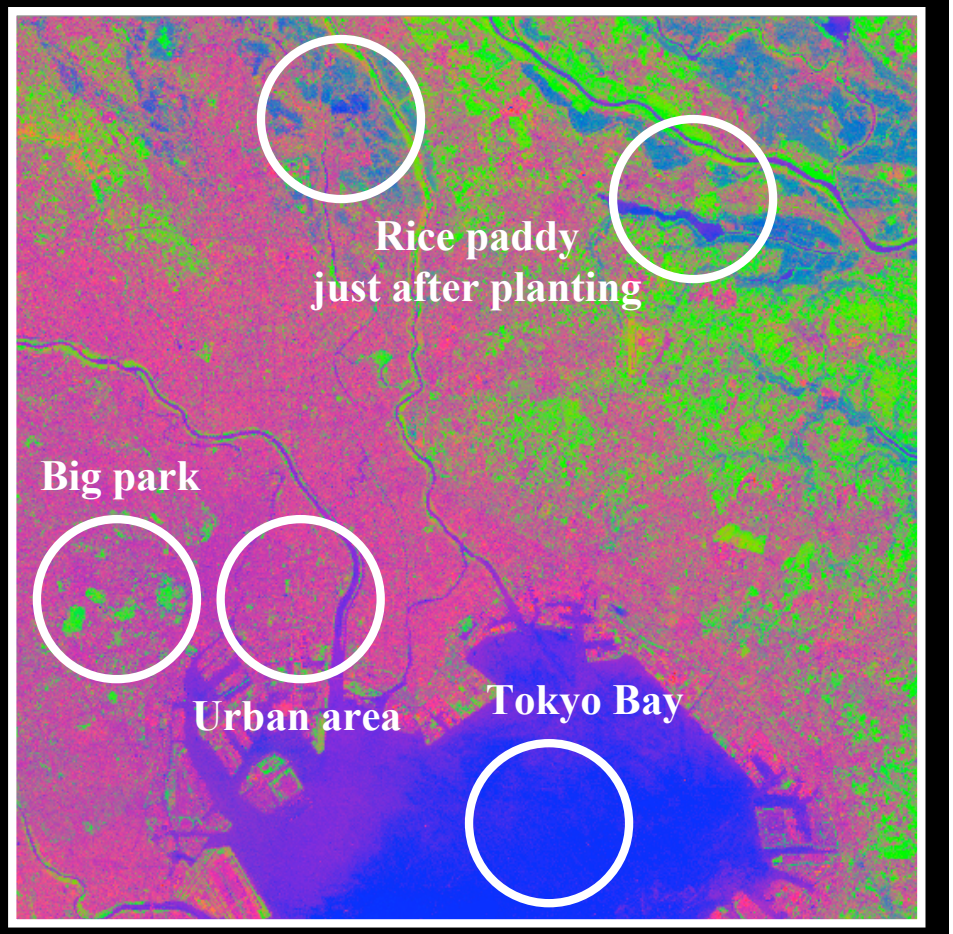
Evaluate the difference of spatial resolution on the same observation condition (Jun. 4th, 2001 at 2:49 GMT)

Color composite of NDXI as RGB

Tokyo metropolitan area



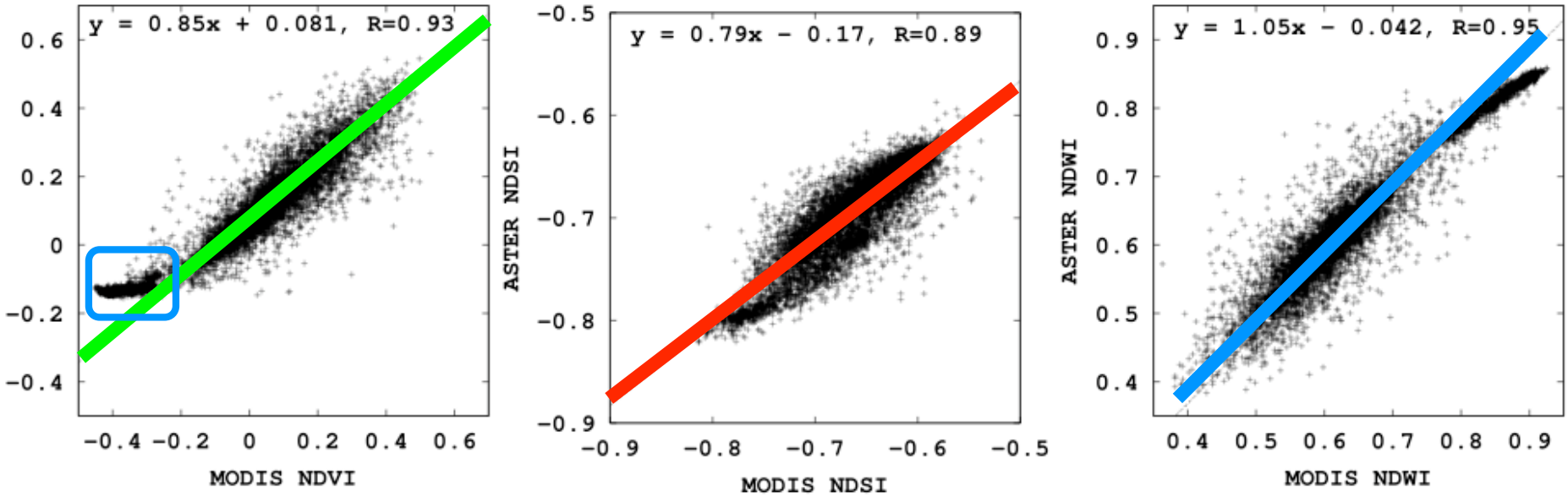
Terra MODIS (500m)



Terra ASTER (30m)

R:G:B=NDSI:NDVI:NDWI

Comparison of NDXI different sensors

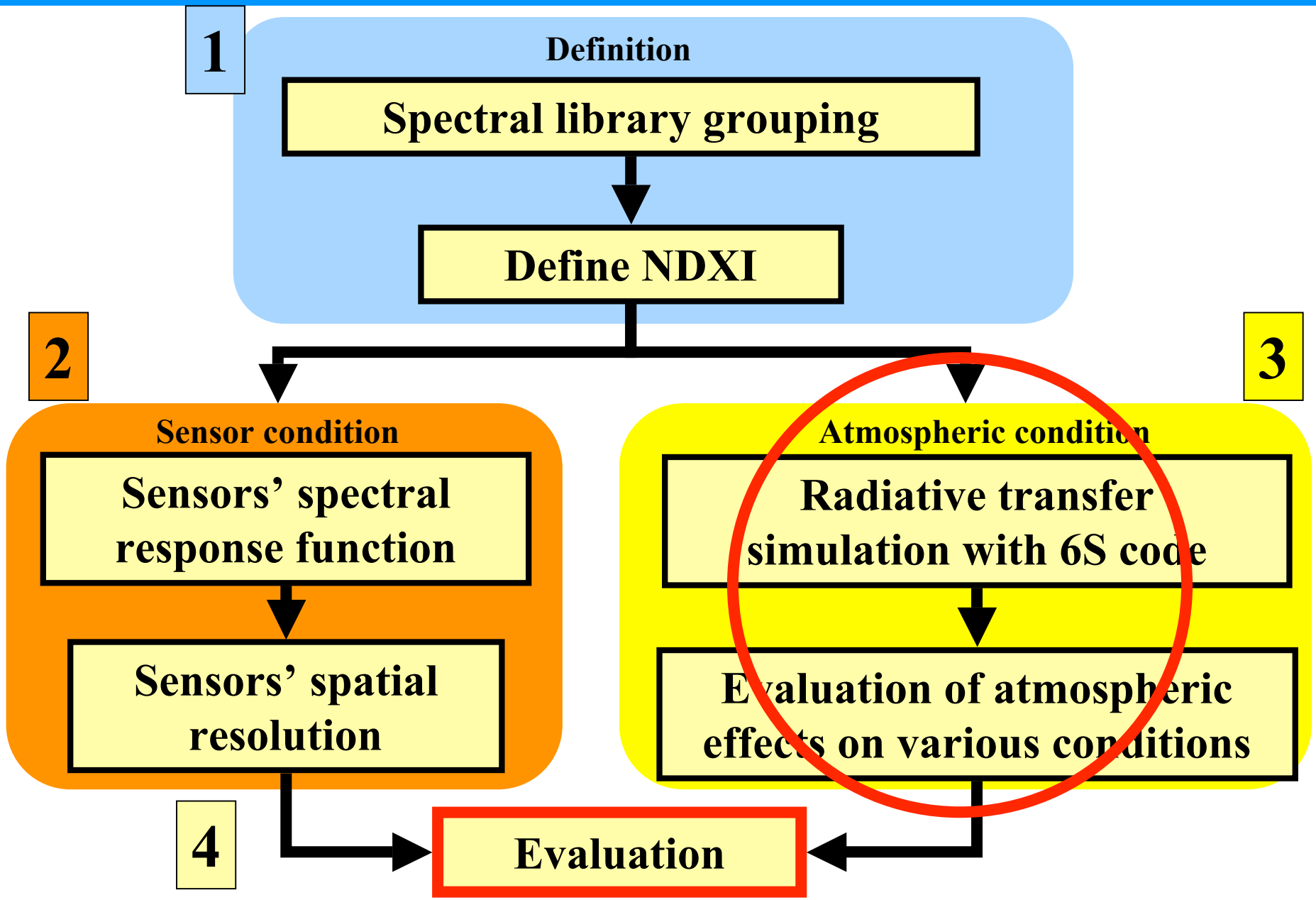


(a) NDVI (b) NDSI (c) NDWI

$$
\begin{aligned}
\mathrm{NDVI}_{\mathrm{ASTER}} &= 0.85\,\mathrm{NDVI}_{\mathrm{MODIS}} + 0.081, \quad R = 0.93 \\
\mathrm{NDSI}_{\mathrm{ASTER}} &= 0.79\,\mathrm{NDSI}_{\mathrm{MODIS}} - 0.170, \quad R = 0.89 \\
\mathrm{NDWI}_{\mathrm{ASTER}} &= 1.05\,\mathrm{NDWI}_{\mathrm{MODIS}} - 0.042, \quad R = 0.95
\end{aligned}
$$

- **NDVI, NDSI and NDWI values are in linear relationship between MODIS and ASTER**
- **The portion where NDVI are negative correspond to water and MODIS and ASTER are in non-linear formula.**

Framework of this research



RADIATIVE TRANSFER SIMULATION

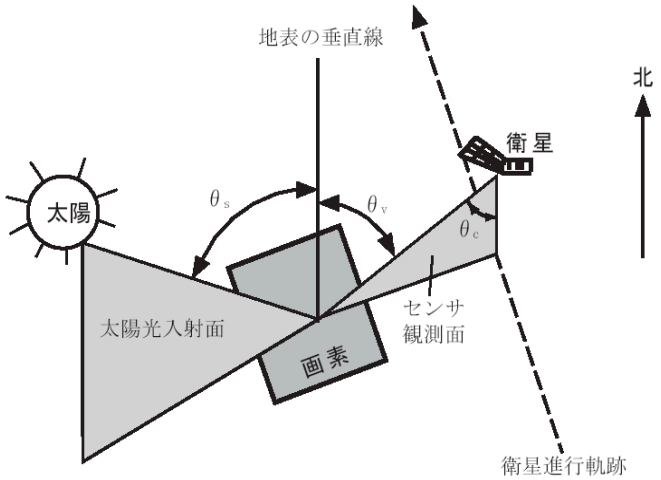
6S code [Vermote, 1997]

- Designed for satellite sensors
- Absorption by water vapor and ozone
- Scattering by aerosol
- Optical thickness
- Elevation of the target

Table 2. List of input parameters for 6S code.

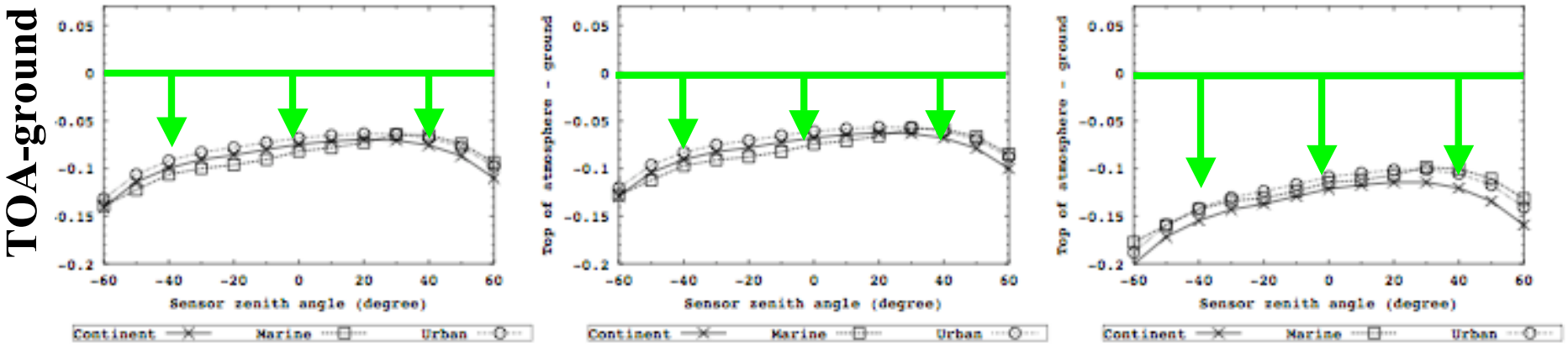
Item	Variable
Date	June 4th 11:00 (JST)
Solar zenith / azimuth	14.85 deg., 144.91 deg.
Sensor zenith / azimuth	0 to 50 every 5 deg, 180 deg.
Sensor type	MODIS channel 1, 2, 6
Visibility	0 to 50 every 5 km
Atmospheric model	Mid latitude summer
Aerosol model	Continent, marine, urban
Elevation	0 to 10 every 1 km
Apparent reflectance	0

Sun Target Sensor Geometry (STSG)



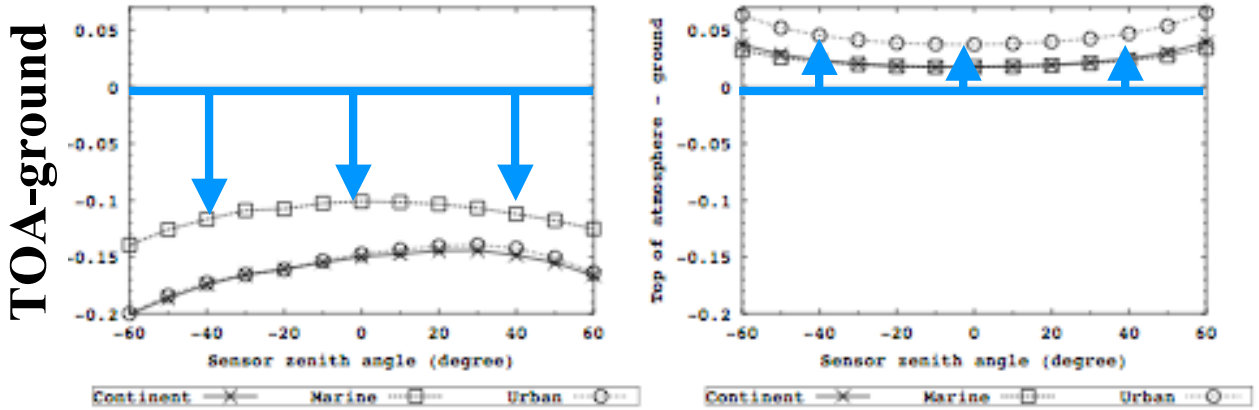
Calculate the differences between the top of atmosphere (TOA) NDXI and ground based NDXI on a variety of STSG and atmospheric conditions

Atmospheric effects - veg. and water



(a) Conifers (b) Broadleaf (c) Grass

In vegetation group, NDVI of TOA is 0.07 to 0.2 smaller than that of ground

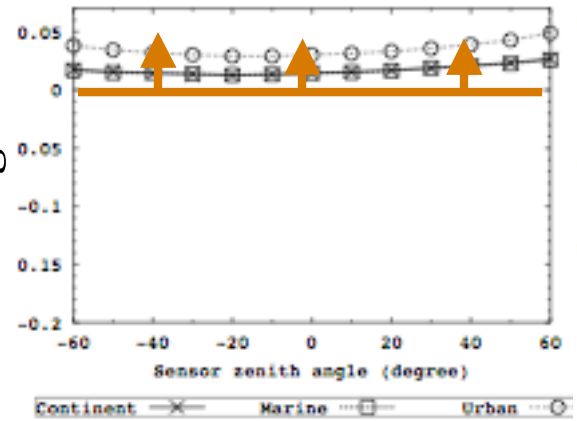


(j) Water (k) Snow

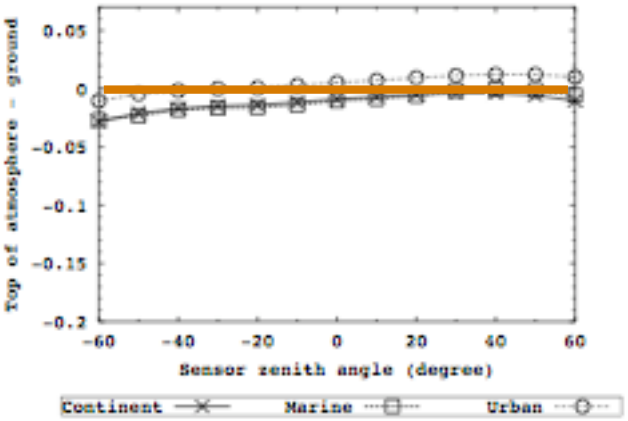
In water group, NDWI of TOA is 0.02 larger than that of ground

Atmospheric effects - soil

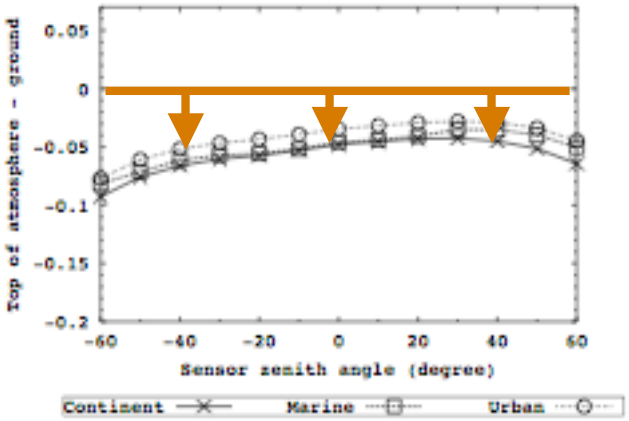
TOA-ground



(d) Concrete

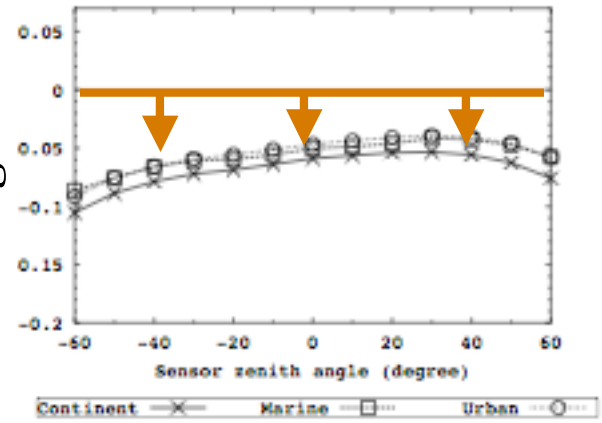


(e) Sand

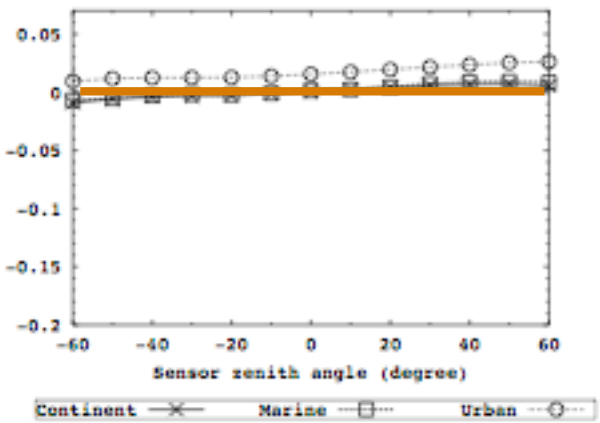


(f) Silt

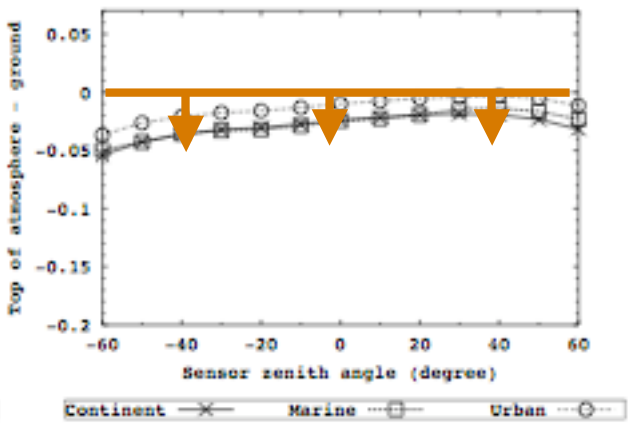
TOA-ground



(i) Asphalt



(g) Clay



(h) Dryclay

In soil group, NDVI of TOA is 0.01 to 0.07 smaller than that of ground

Concluding remarks

- NDVI, NDSI, NDWI represents the existence of vegetation, soil and water respectively.
- Soil group has relatively larger variations on different sensors in terms of NDXI.
- NDVI, NDSI and NDWI values are in linear relationship between MODIS and ASTER.
- TOA values of NDVI and NDSI get smaller than those of ground due to atmospheric effects.

Thank you for attention!!

Photo at Phitsanulok (2004 Feb.)