Monitoring the water cycle over land 1: Rainfall and surface energy balance

→ EARTH OBSERVATION SUMMER SCHOOL

Earth System Monitoring & Modelling

30 July–10 August 2018 | ESA–ESRIN | Frascati (Rome) Italy

Zoltán VEKERDY
ITC Faculty of Univ. Twente, NL & Faculty of Agric. and Env. Sci., Szent István Univ., H
z.vekerdy@utwente.nl & vekerdy.zoltan@mkk.szie.hu

Defines the processes on the boundary between air and the land surface

Many slides by Rogier van der Velde (indicated)

SOIL MOISTURE

Remote sensing of soil moisture

"Direct" measurements

- Microwave
  - Active - SAR
  - Passive – scatterometers, radiometers

  Comment: Top 2-5 cm, shallower than 10 cm
- Optical (visible/near infrared)
  - Using solar radiation as a direct energy source

  Comment: Surface information

Root zone through assimilation/modelling

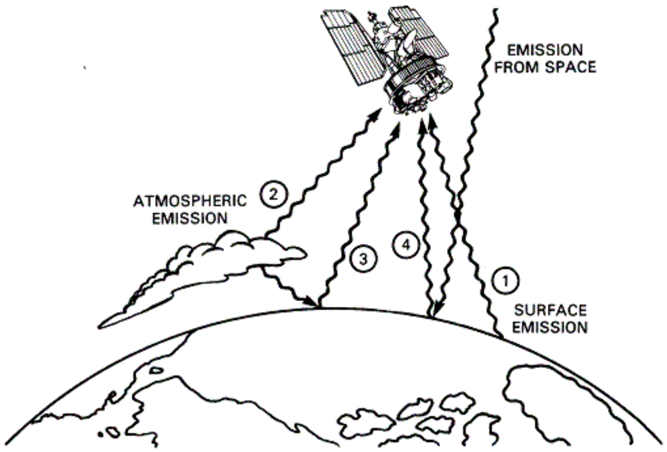
- Microwave: SMAP root zone product (modelling/assimilation)
- Thermal infrared techniques
  - Through assimilation/modeling to get root-zone soil moisture
  - Indirectly root-zone soil moisture

ACTIVE VS. PASSIVE MICROWAVE SENSORS

Active microwave instruments (Radars) measure the energy scattered back by a surface;

Passive microwave instruments (radiometers) measure the self-emission of the Earth's surface

Active Sensors



Passive Sensor

Rogier van der Velde

Passive microwave methods

- Passive microwave satellites provide estimates of soil moisture on a daily basis and on a regional scale (~10 km)
- Vegetation cover, soil temperature, snow cover, topography and surface roughness effect the microwave emission from the surface.
- Soil texture, bulk soil density, and atmospheric effects have a smaller influence.
- Approaches to retrieve soil moisture
  - Statistical approaches
  - Forward model inversion
  - Neural networks
  - Data assimilation

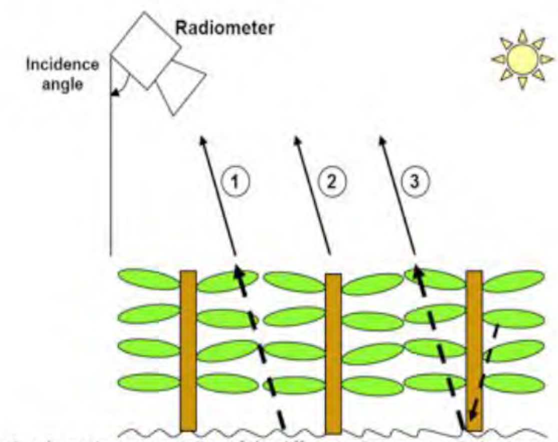


Figure 1. schematic representation of the different microwave emission terms over a vegetated surface.

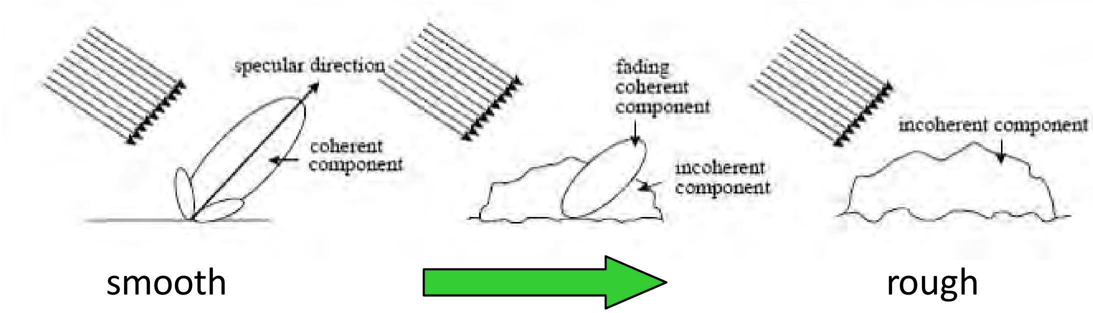
$$T_B = (e_s\Gamma)T_s + (1-\omega)(1-\Gamma)T_c + (1-e_s)(1-\omega)(1-\Gamma)T_c$$

Figure: Rogier van der Velde

Microwave measurements are affected by:

1. *Dielectric properties* (or electric permittivity, *ε*): is a measure for the electromagnetic density of an object and indicative for the strength of the reflection (*ε* for dry soil is ~ 3 and *ε* for water is 80).

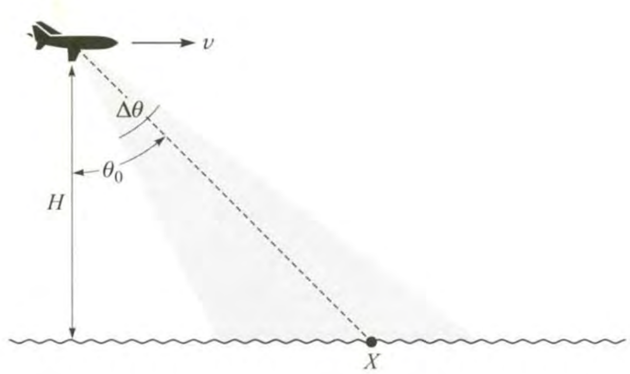
2. *Geometric properties*: defined by the shape of an object and determines the direction of scattering.



Rogier van der Velde

Active microwave (Scatterometers & SARs) instruments transmit electromagnetic waves to the earth' surface and measure the amount of radiation scattered back at the same position as where the waves were originally transmitted.

The power received by a radar antenna is a function of the transmitted power corrected for the two-way spreading losses and losses caused by the target.



Rogier van der Velde

RADAR EQUATION

Analytically, the previous formulation of the measurement principle can be expressed as,

$$P_r = \frac{P_t G_t A}{\left(4\pi R^2\right)^2}\sigma$$

P_r	~ received power [W]
P_t	~ transmitted power [W]
G_t	~ transmitter power gain [-]
A	~ effective area of the antenna [m2]
R	~ distance between the target and radar [m]
σ	~ scattering cross section of a target [-].

RADAR EQUATION

$$\frac{P_r}{P_t} \qquad \frac{G_t A}{\left(4\pi R^2\right)^2} \qquad \sigma \qquad \Rightarrow \qquad \frac{P_r}{P_t} \sim \sigma$$

1 2 3

1. Measured by the radar instrument;
2. Instrument characteristics (~ calibration constant);
3. Affected by properties of the target.

BACKSCATTER COEFFICIENT

<u>Single scatterer</u> <u>Collection scatterers</u>

$$\frac{P_r}{P_t} \sim \sigma \qquad \sigma^o = \frac{\langle \sigma \rangle}{A_0}$$

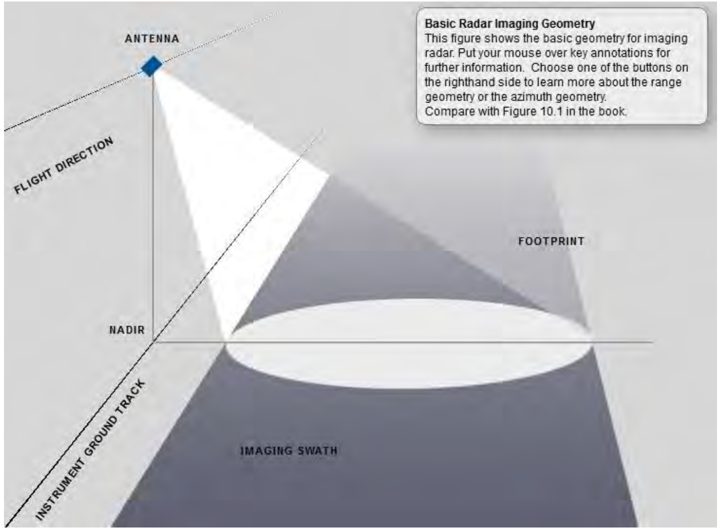
Illuminated area

The quantity measured by active microwave instruments is the **backscatter coefficient, σ^o.**

It is common to express the σ^o in **decibel (dB)**:

$$\sigma^o \ (dB) = 10 \log_{10} \sigma^o \left(in \ \mathrm{m}^2 \mathrm{m}^{-2} \right)$$

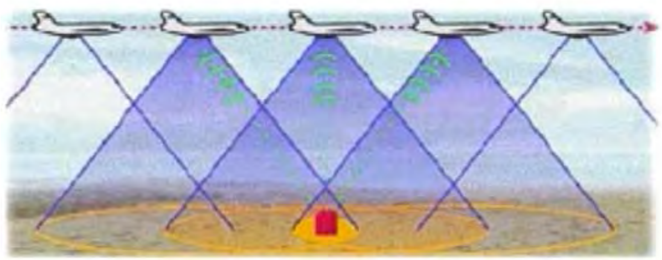
The Real Aperture Radar (RAR) concept is exactly the same as the *time pulsing* scatterometer. A much higher spatial resolution is, however, obtained using very short pulses.



http://xweb.geos.ed.ac.uk/~ihw/hype/radar/intro2radar.html

Rogier van der Velde

Through the Synthetic Aperture Radar (SAR) technique a high azimuth resolution can be obtained regardless of the platforms altitude.



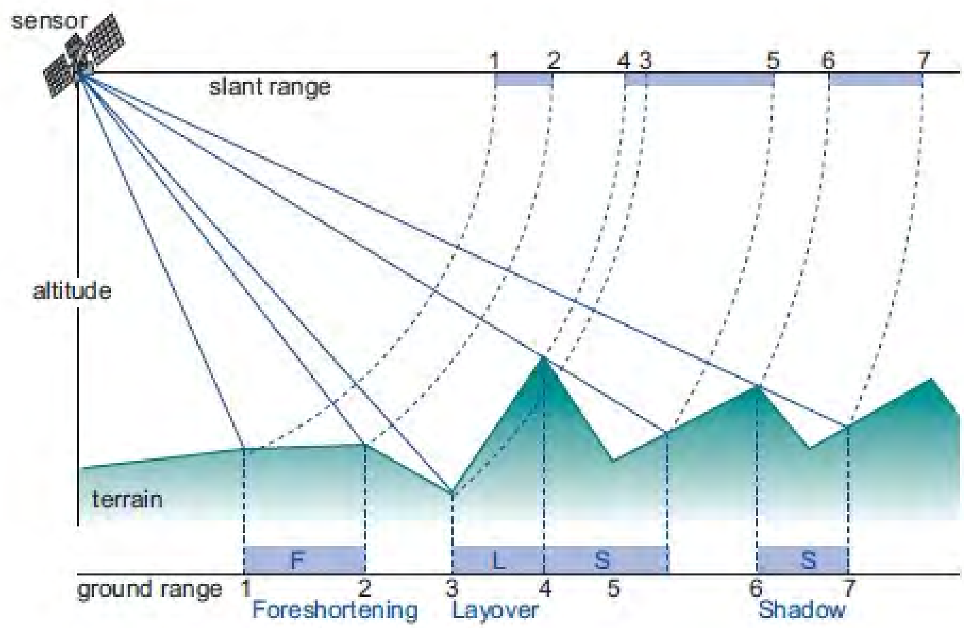
Synthetically a long aperture length is constructed from the different echoes X_1, X_2, ..$X_{n.}$

This can only be done when both the *amplitude* and *phase* of the individual echoes are recorded. SAR is, therefore, a *coherent* measuring technique.

Rogier van der Velde

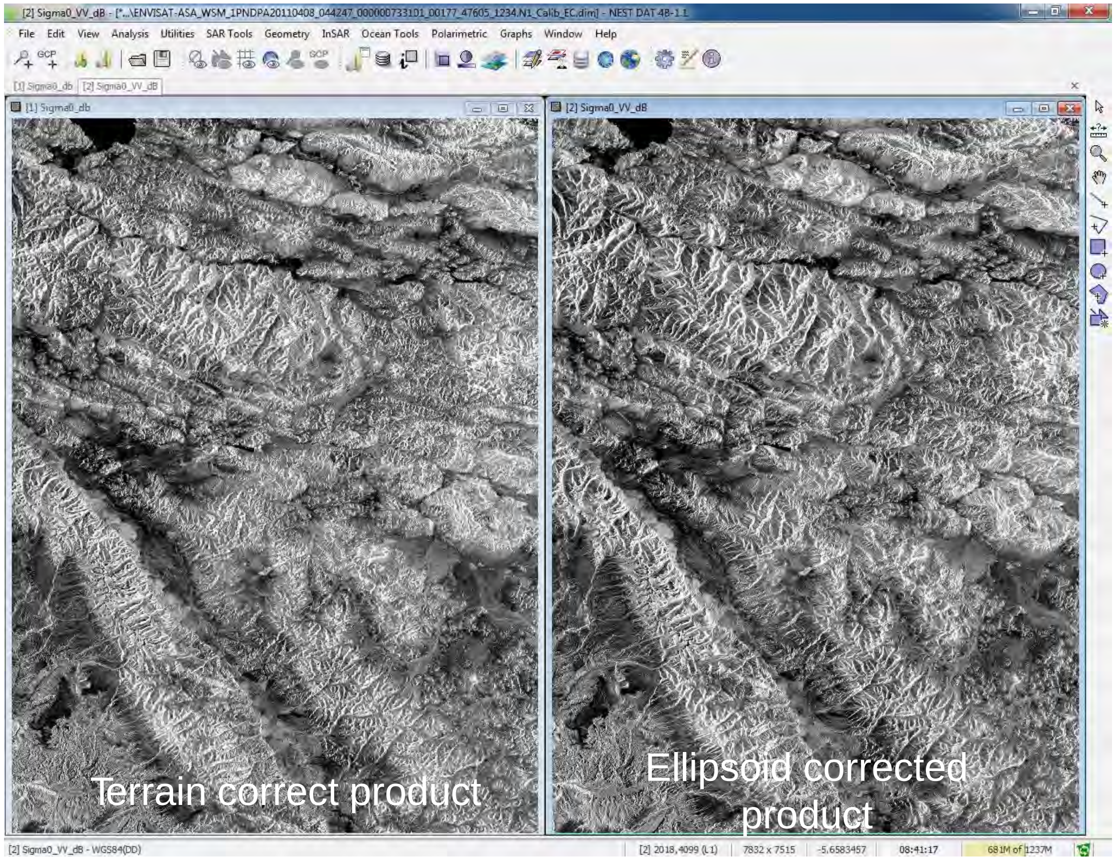
SAR DISADVANTAGE: IMAGE GEOMETRY

- Foreshortening
- Layover
- Shadow



Rogier van der Velde

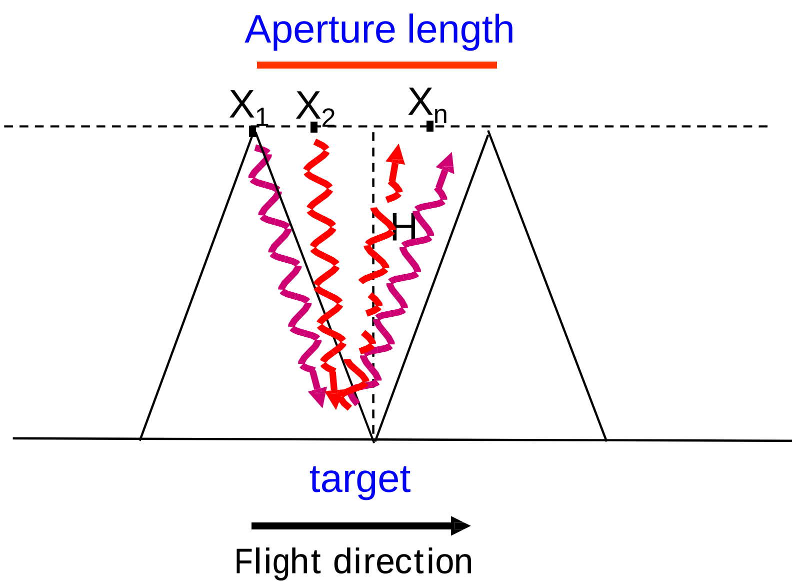
EXAMPLE: TERRAIN CORRECTION

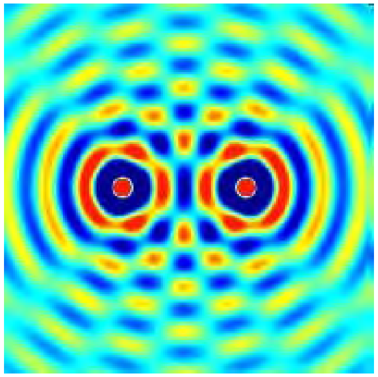


Rogier van der Velde

SAR DISADVANTAGE: SPECKLE

Inherent to coherent measuring techniques is that individual wave will interfere with each other, which creates a noise in the image and is called **speckle**.





Rogier van der Velde

SPECKLE MITIGATION (OR SPECKLE FILTERING)

If we assume that the noise component is Gaussian distributed and has a zero mean, the speckle can be reduced by averaging independent measurements (or samples).

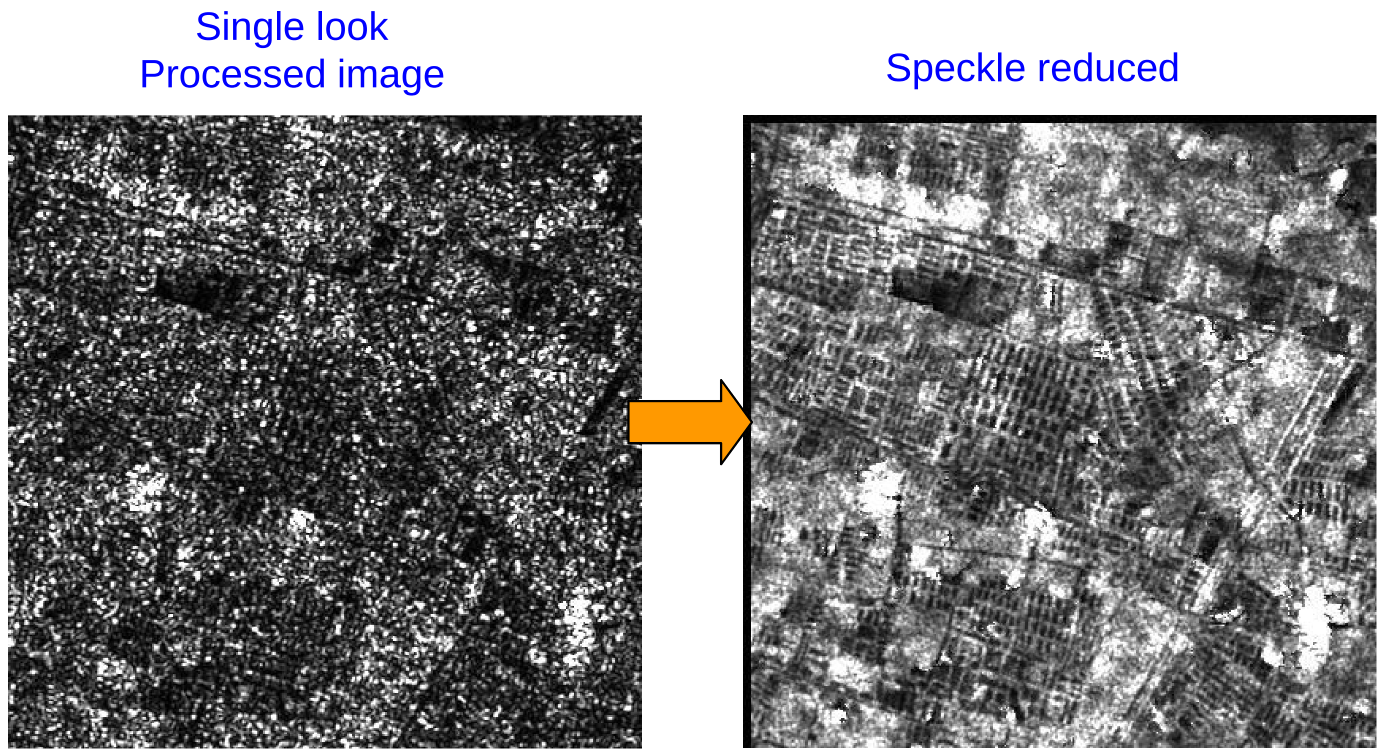
Two type of techniques:

- **Spatial averaging:**
  We sacrifice a part of the spatial resolution for an improved radiometric resolution.
  Assumption: land surface is the same over a short distance

- **Temporal averaging:**
  We sacrifice a part of the temporal resolution for an improved radiometric resolution.
  Assumption: changes in land surface conditions over time is
  limited or can be resolves

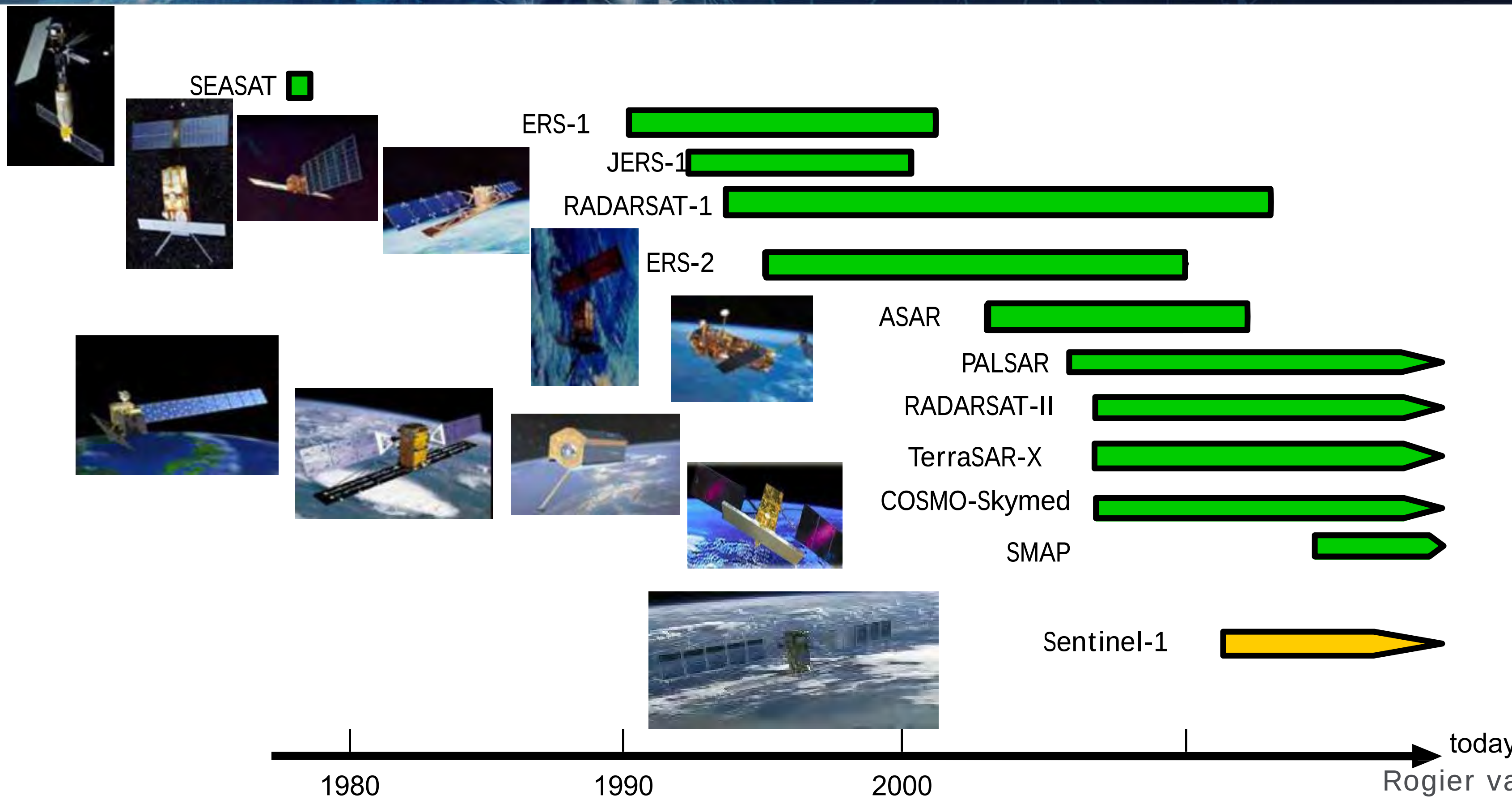
Rogier van der Velde

EXAMPLE: SPECKLE FILTERING



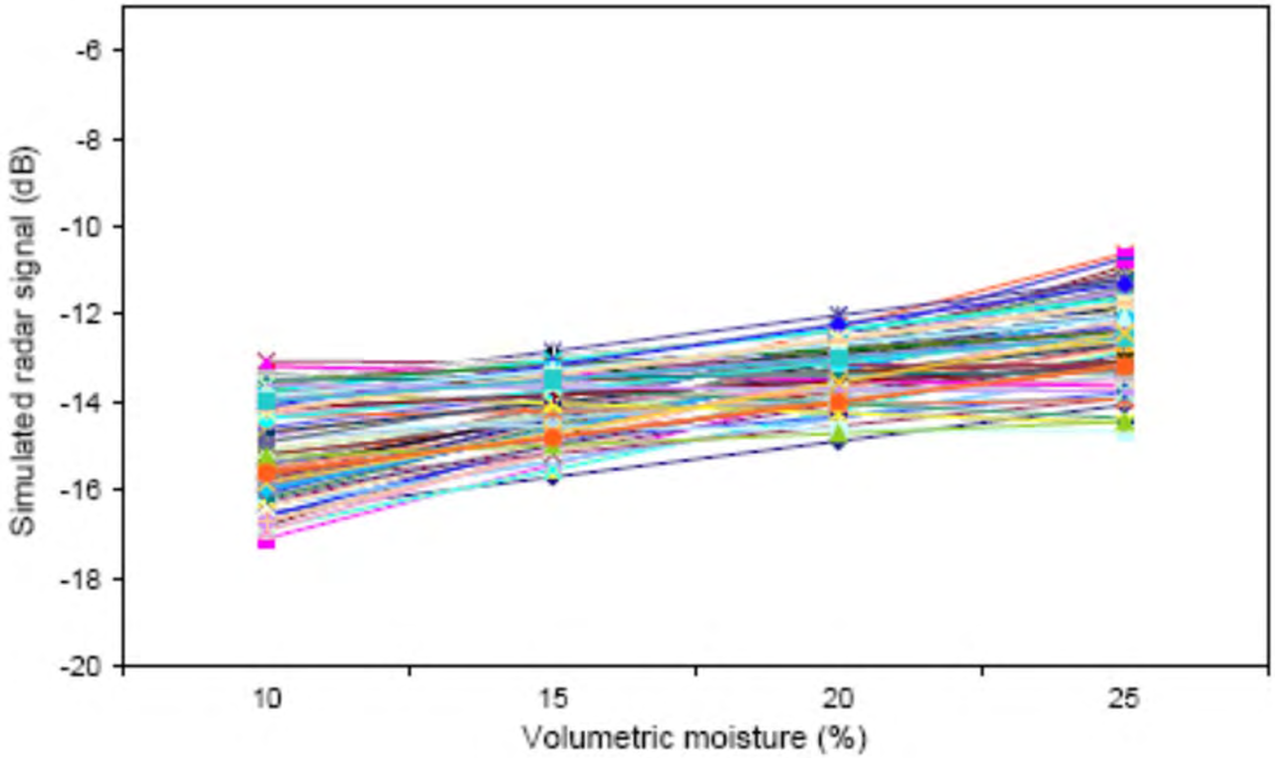
(Source: T. Le Toan)

SAR INSTRUMENTS (selected high res.)



Rogier van der Velde

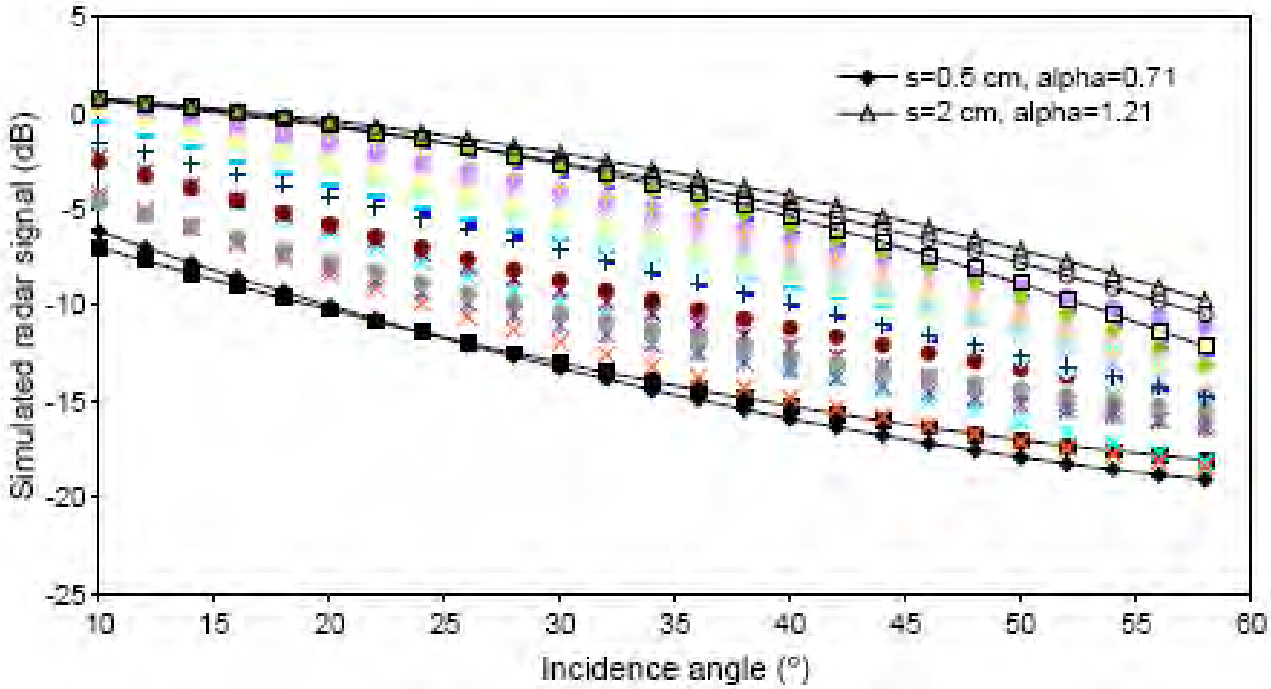
Relationship between backscatter and soil moisture



$$\sigma_0(\mathrm{dB}) = a \cdot W_s(\%) + b$$

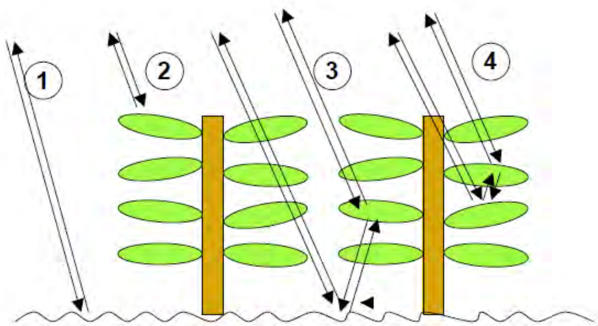
Zbiri et al. (2005)

Dependence on incident angle and vegetation



Inverse relation with incidence angle – soil moisture is a function of backscatter and incidence angle

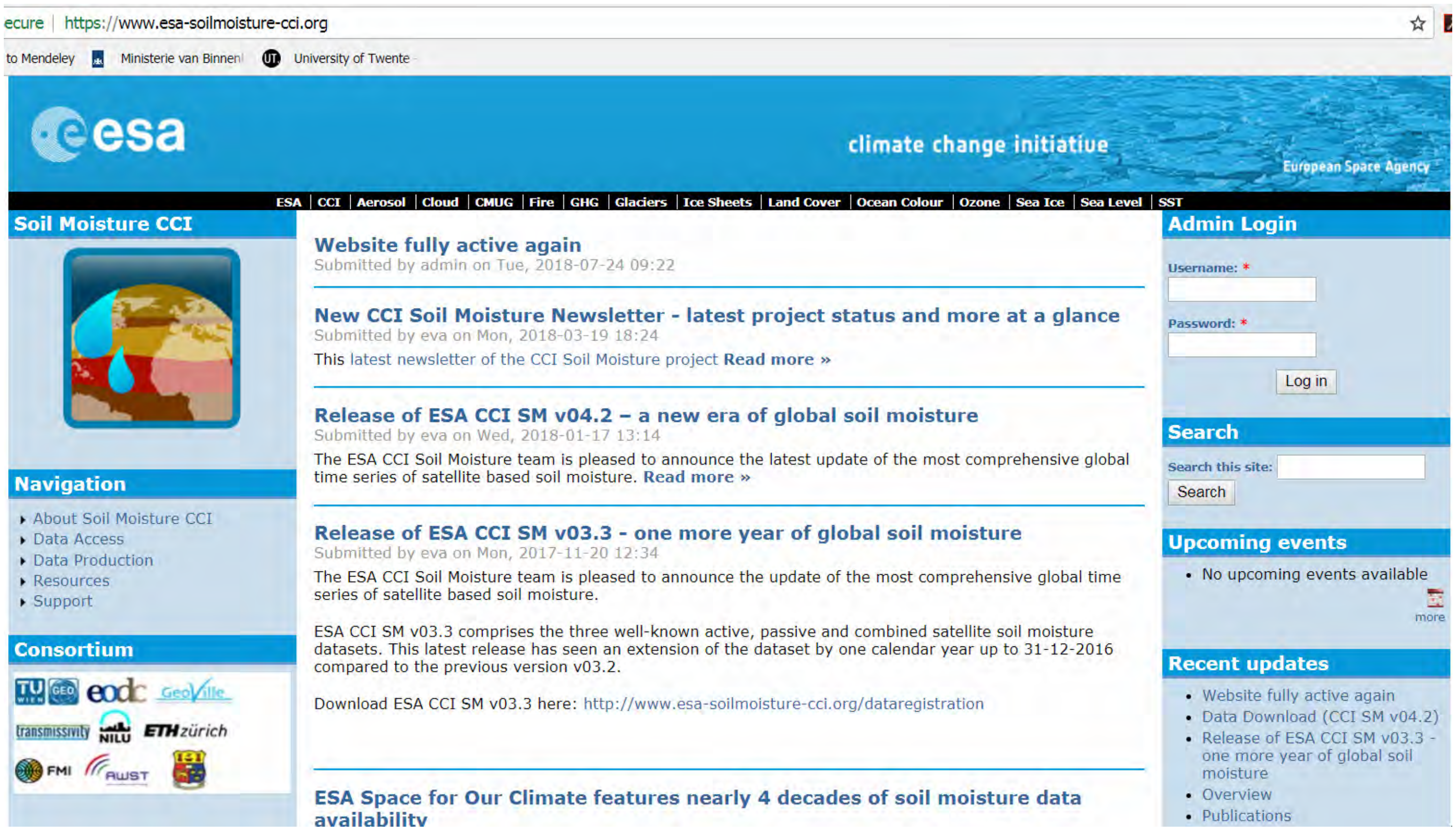
Zbiri et al. (2005)



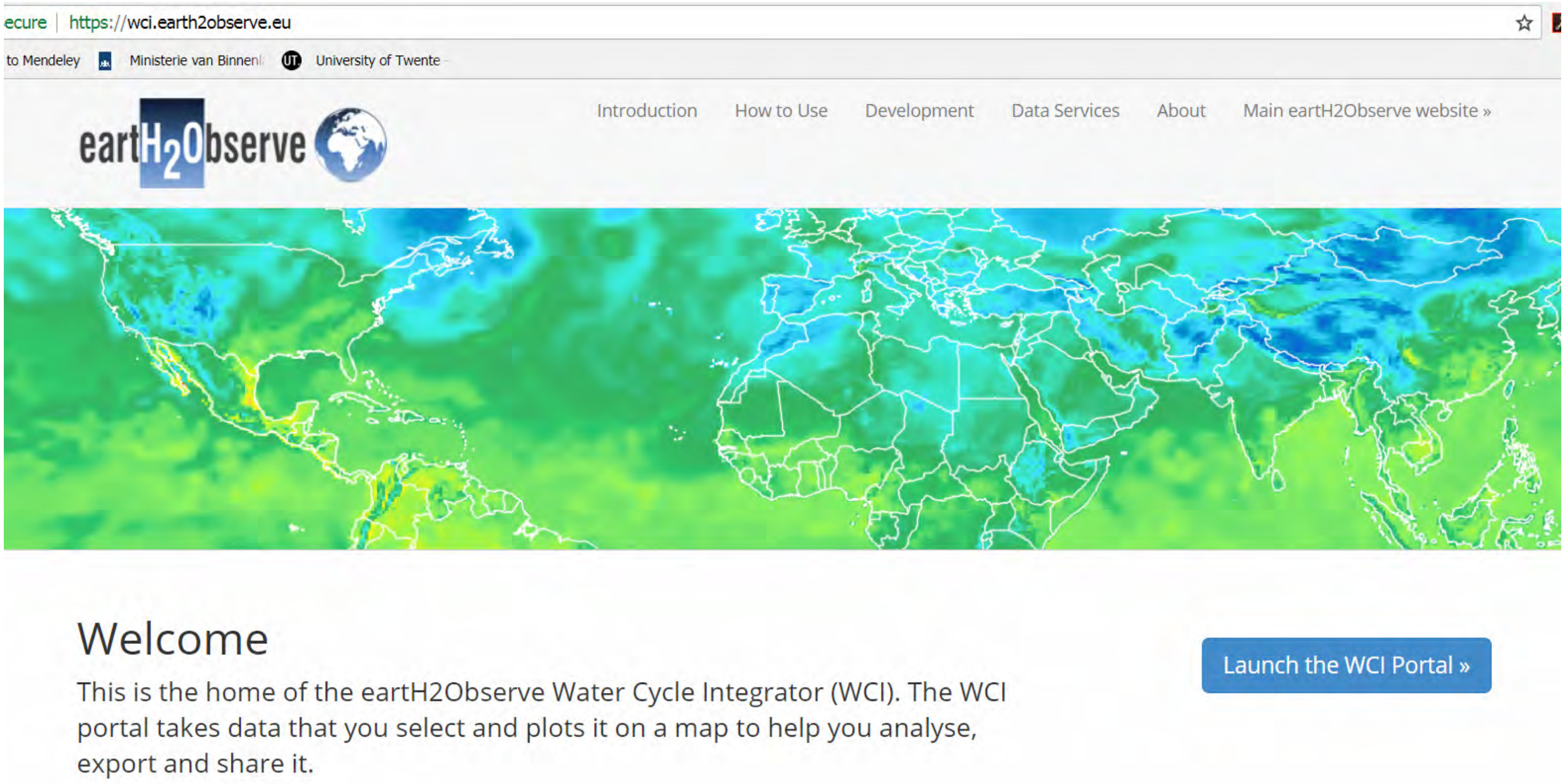
$$\sigma^o = \sigma^o_{sur} + \sigma^o_{veg} + \sigma^o_{sur-veg} + \sigma^o_{veg-veg}$$

Rogier van der Velde

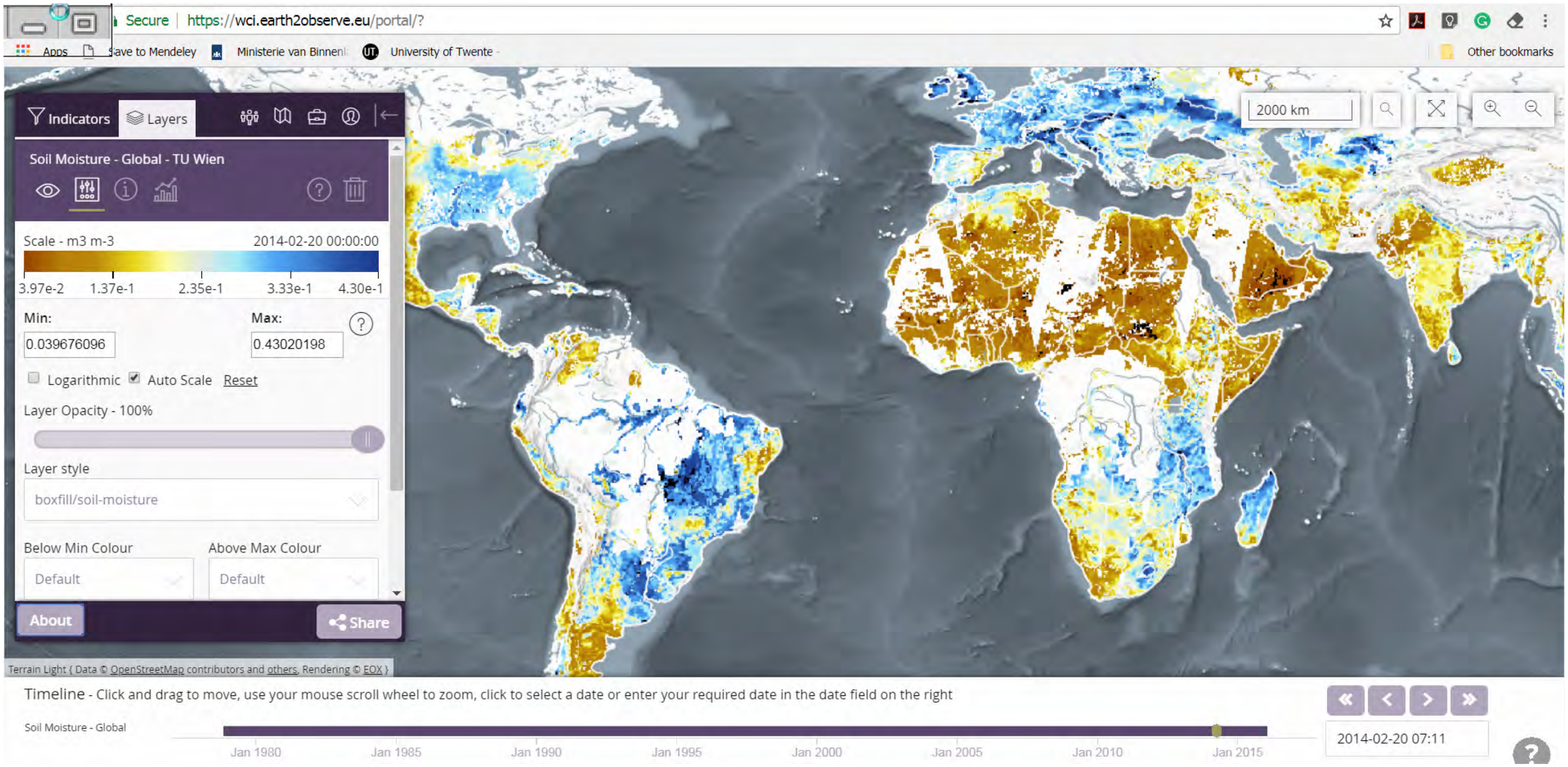
Global soil moisture data of ESA – combined passive and active method



ESA Water Cycle Integrator



ESA Water Cycle Integrator – example: soil moisture

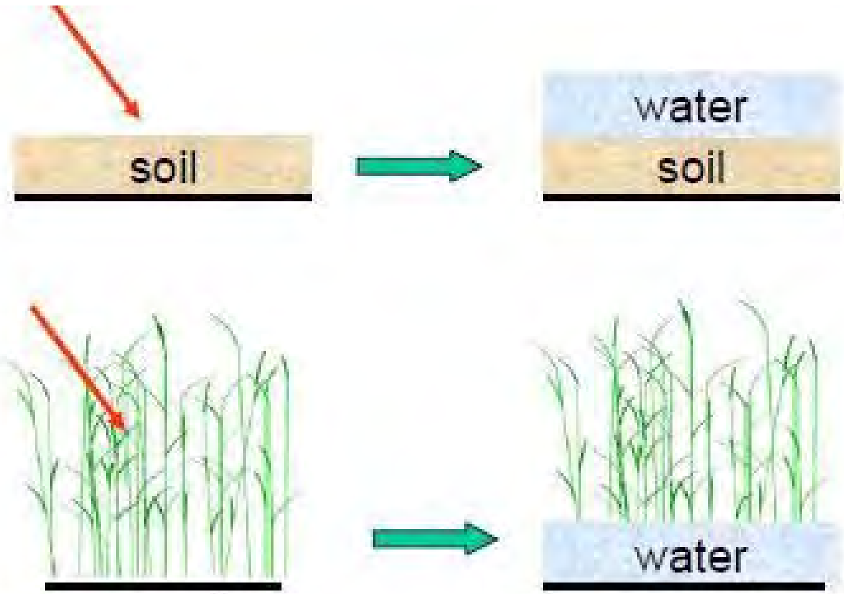


Global soil moisture time series

What is inundated, what is not?

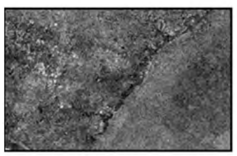
MONITORING WATER BODIES

Backscatter from inundated surface

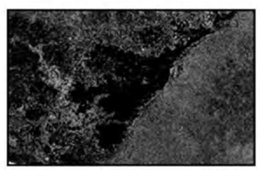


Rogier van der Velde

EXAMPLE: EASTERN CAPRIVI FLOODPLAIN



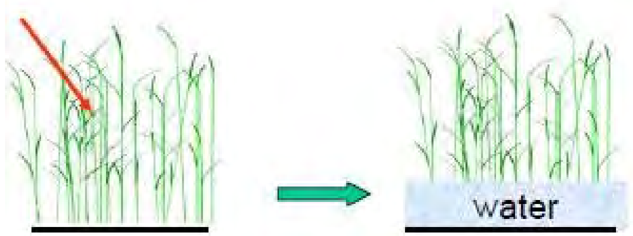
ASAR IMP Feb. 2004

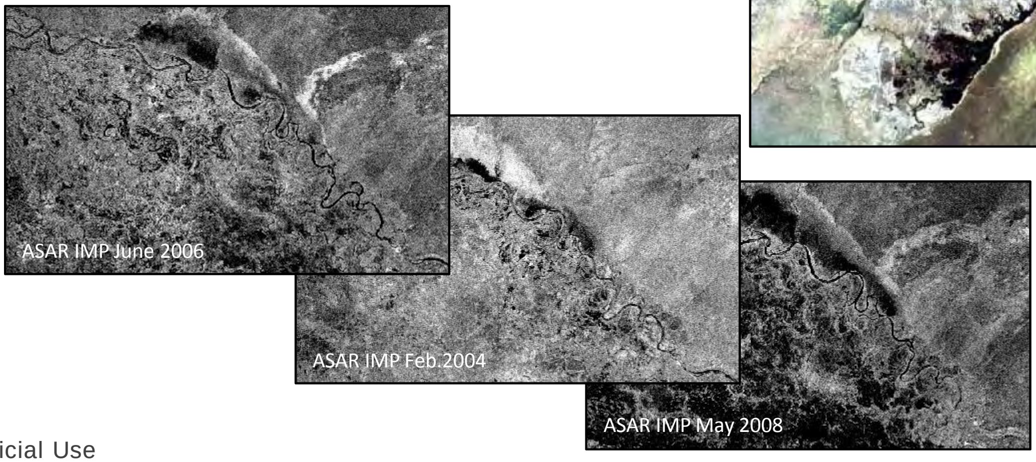


ASAR IMP May 2008

Rogier van der Velde[1]

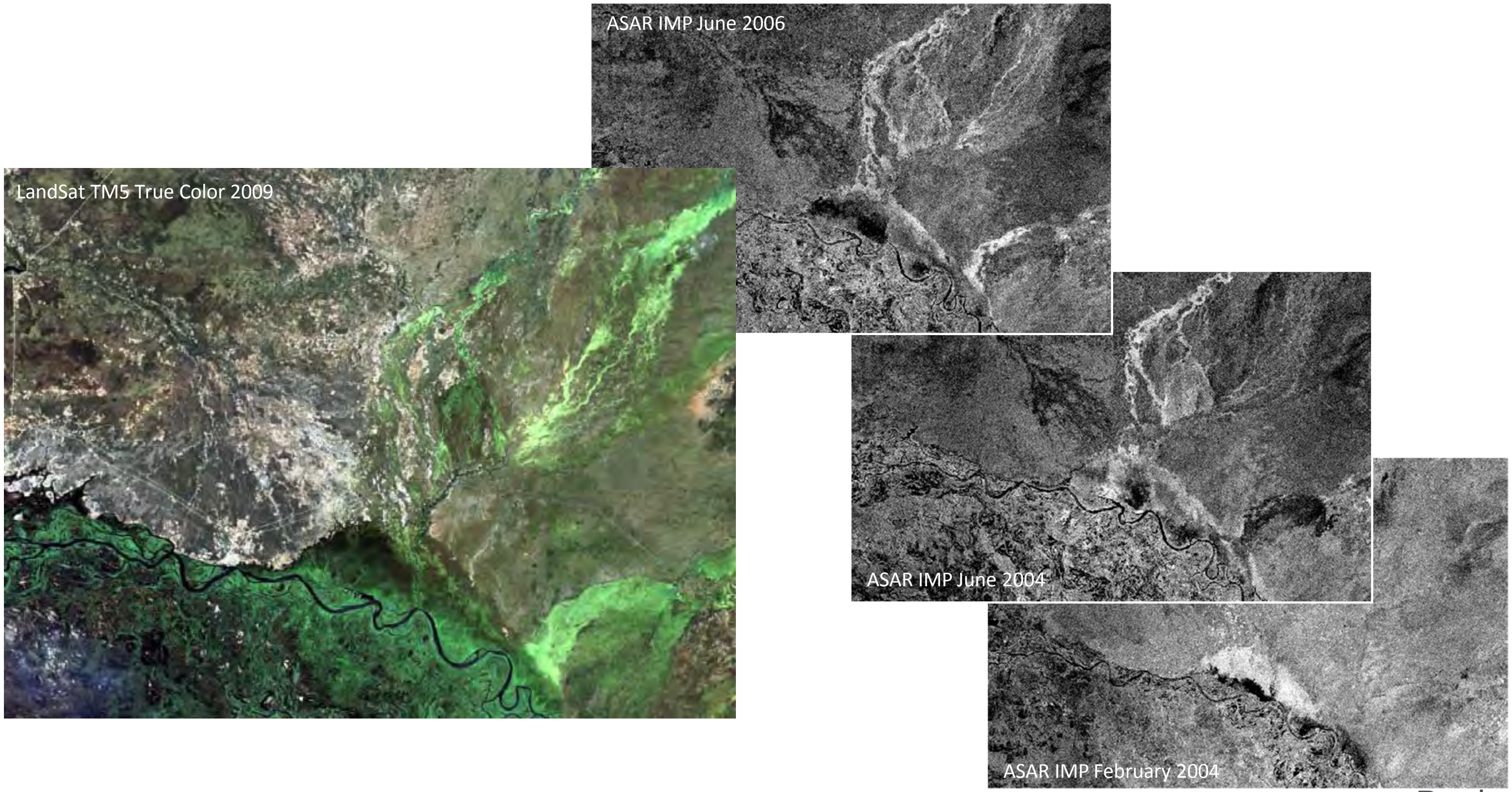
EXAMPLE: EASTERN CAPRIVI FLOODPLAIN





Rogier van der Velde

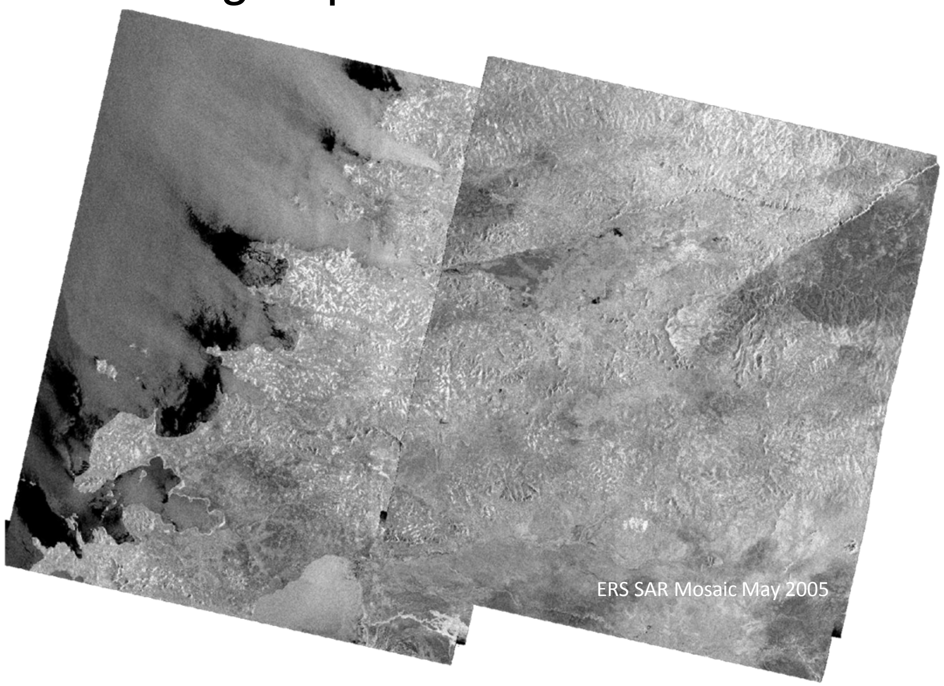
EXAMPLE: EASTERN CAPRIVI FLOODPLAIN



Rogier van der Velde

Calm vs. *Rough* open water

Landsat TM5 True Color
July 2009



Rogier van der Velde

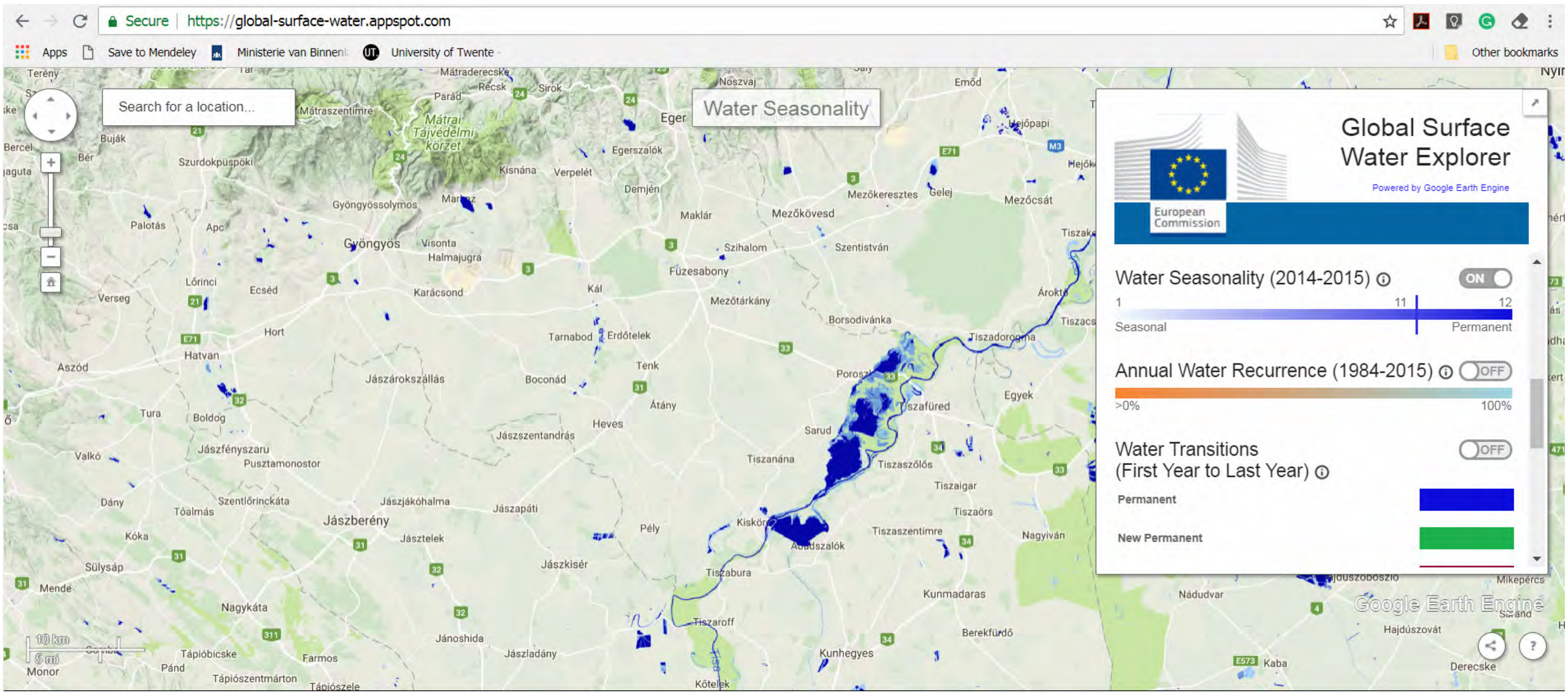
Flood and open water body mapping

Flood mapping is, in its very essence, based on thresholding, which can be performed with the use of:

- Single image (SAR or optical);
- Multi-band satellite data (index calculation / thresholding);
- Time series of satellite data;
- Base map derived from optical satellite data;
- Ancillary data, such as antecedent precipitation, Digital Elevation Model.

Rogier van der Velde

Copernicus Global Surface Water Explorer



Zoltán Vekerdy[1,2], Yun Qiu[1], Arno van Lieshout[1], Edina Czakó-Gál[2] Ádám Csorba[2]

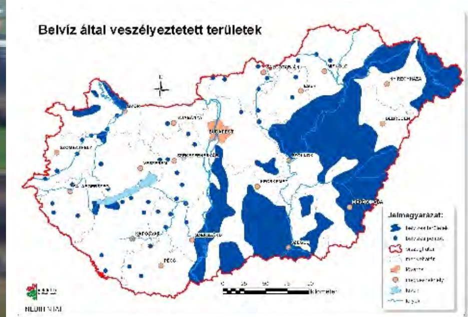
1: ITC Faculty of University of Twente, the Netherlands;

2: Faculty of Agricultural and Environmental Sciences, Szent István Unviersity, Hungary

Case study – originally presented on the Mapping Water Bodies from Space 2nd Conference, 27-28 March 2018 at ESRIN, Frascati

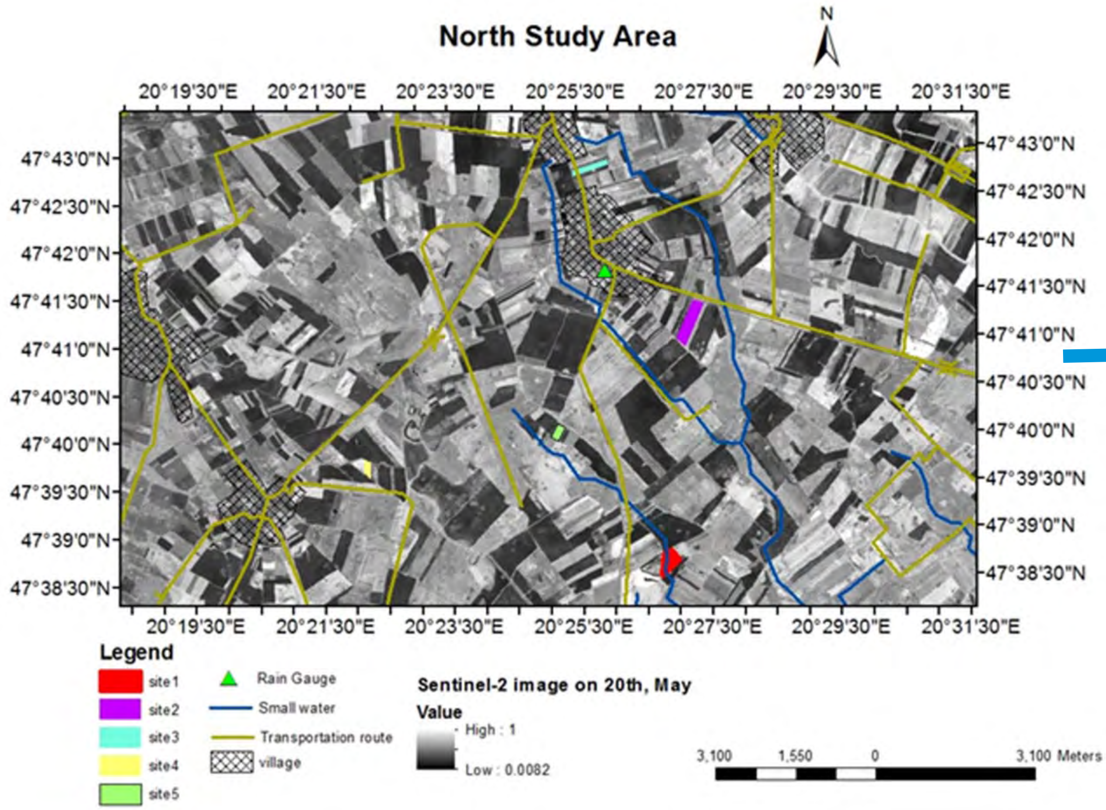
MAPPING TEMPORARY EXCESS WATER PONDING ON AGRICULTURAL FIELDS WITH SENTINEL-1 & 2

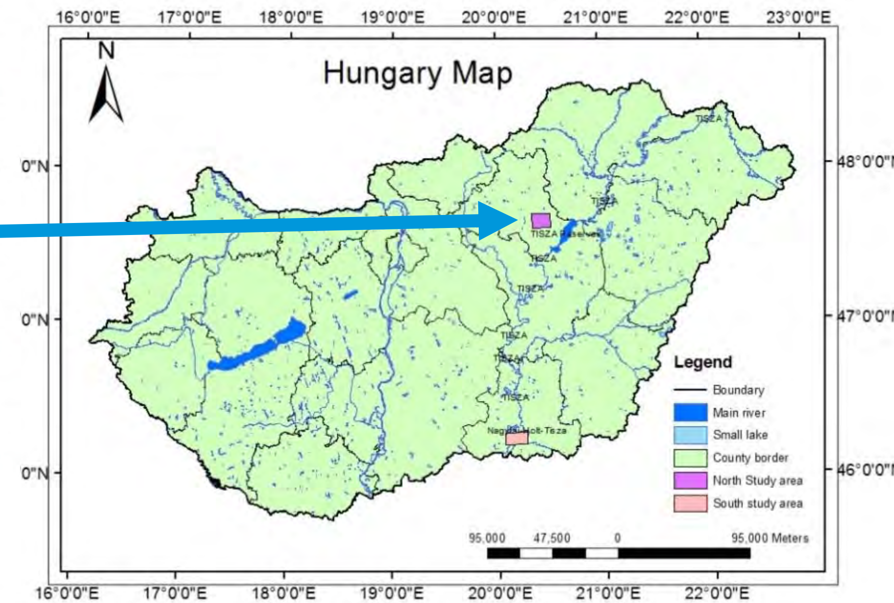
Inland excess water ponding



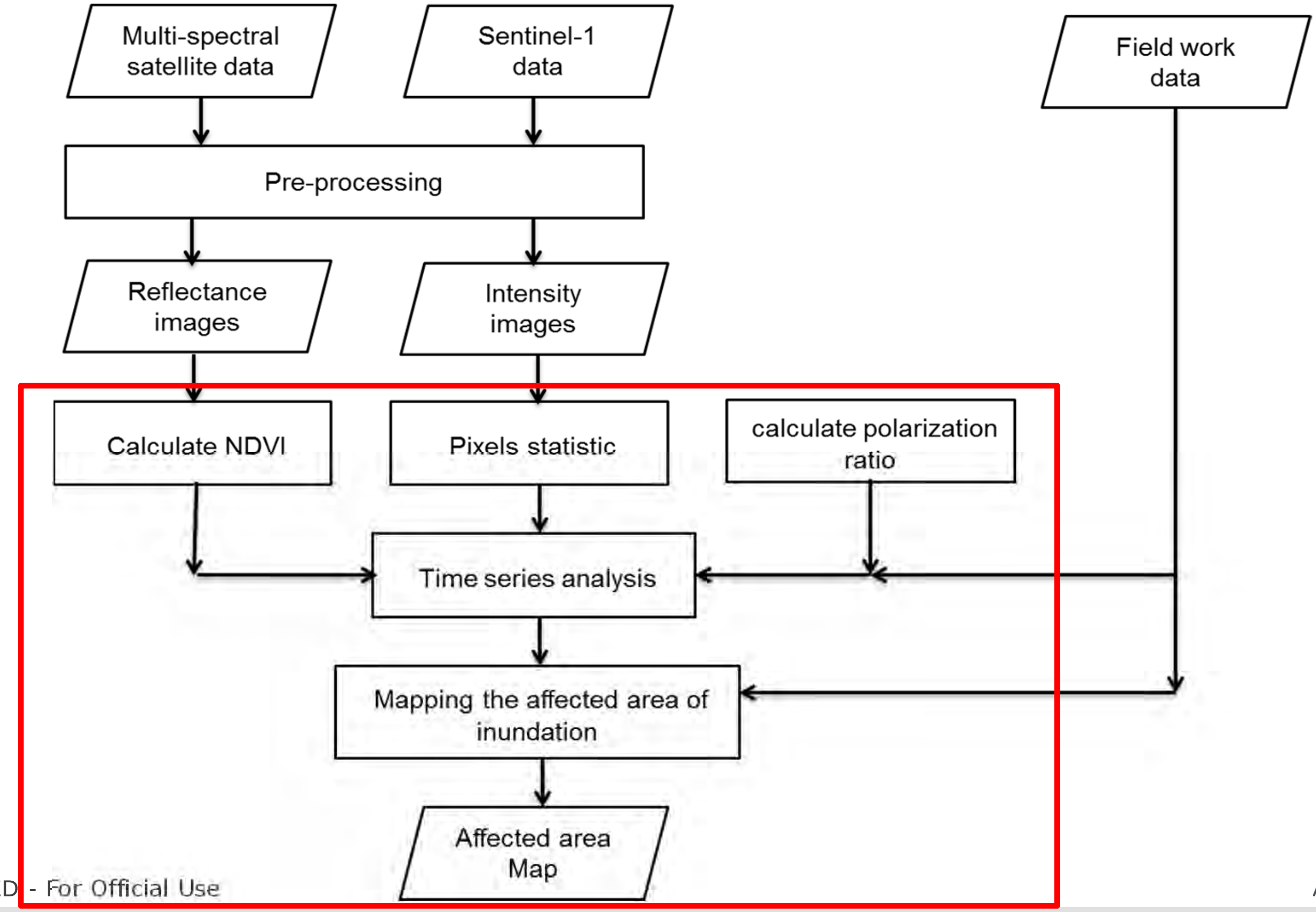
Source: http://portal.nebih.gov.hu

Test areas

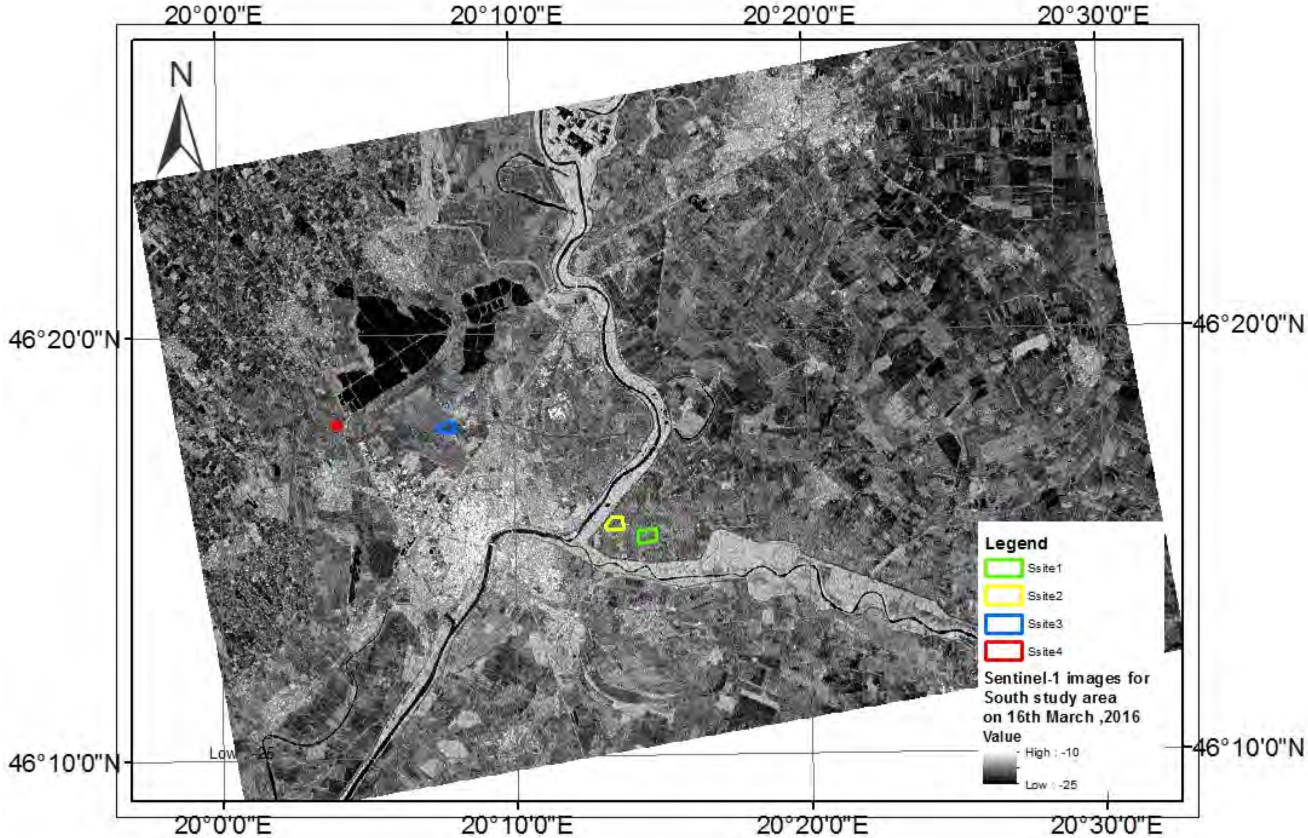

North Study Area
N
20°19'30"E
20°21'30"E
20°23'30"E
20°25'30"E
20°27'30"E
20°29'30"E
20°31'30"E
47°43'0"N
47°42'30"N
47°42'0"N
47°41'30"N
47°41'0"N
47°40'30"N
47°40'0"N
47°39'30"N
47°39'0"N
47°38'30"N
Legend
site1
site2
site3
site4
site5
Rain Gauge
Small water
Transportation route
village
Sentinel-2 image on 20th, May
Value
High : 1
Low : 0.0082
3,100 1,550 0 3,100 Meters


Hungary Map
N
16°0'0"E
17°0'0"E
18°0'0"E
19°0'0"E
20°0'0"E
21°0'0"E
22°0'0"E
23°0'0"E
48°0'0"N
47°0'0"N
46°0'0"N
Legend
Boundary
Main river
Small lake
County border
North Study area
South study area
95,000 47,500 0 95,000 Meters

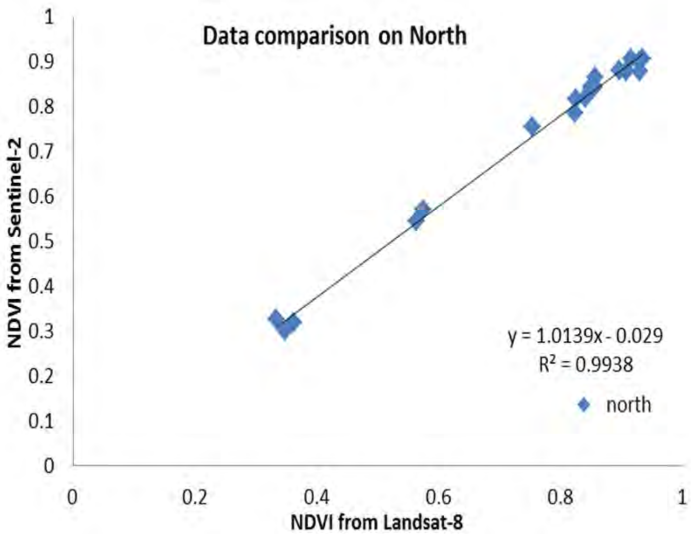
Processing

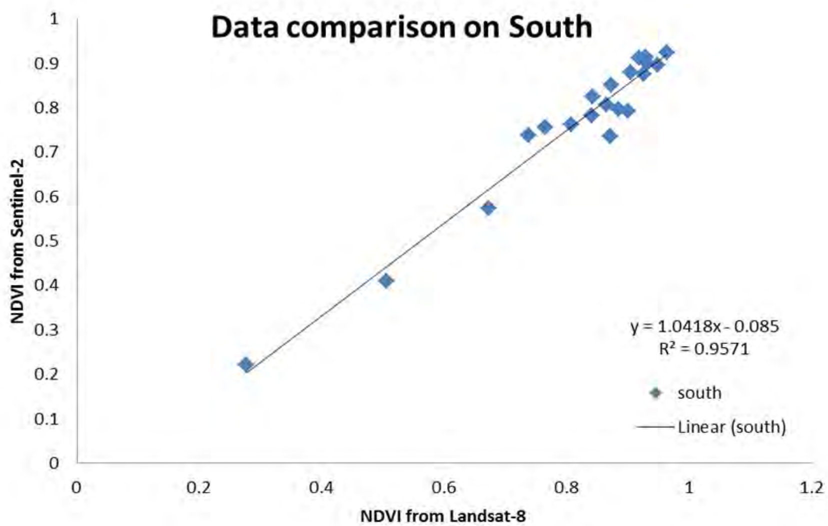

Multi-spectral satellite data
Sentinel-1 data
Field work data
Pre-processing
Reflectance images
Intensity images
Calculate NDVI
Pixels statistic
calculate polarization ratio
Time series analysis
Mapping the affected area of inundation
Affected area Map

Preprocessing result – Southern Area



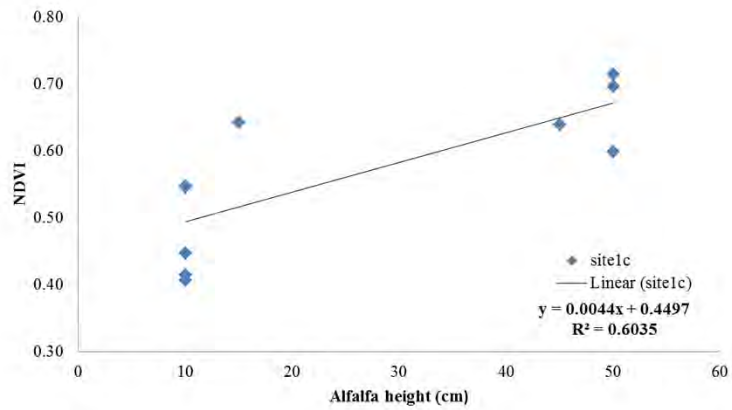
Cross calibration of Sentinel-2 and Landsat-8 NDVI

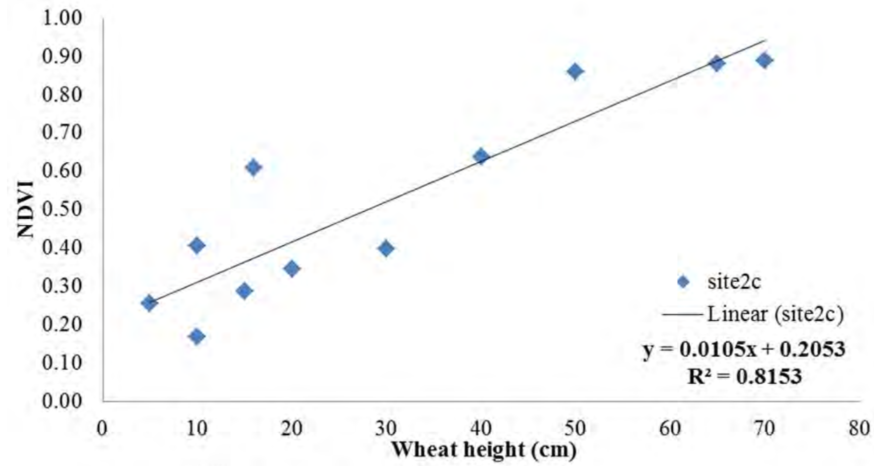


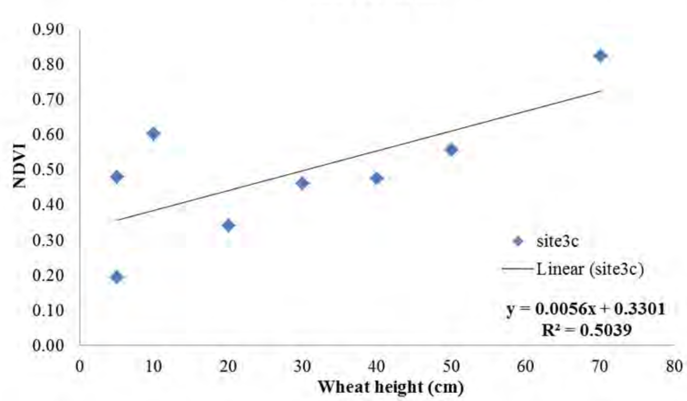


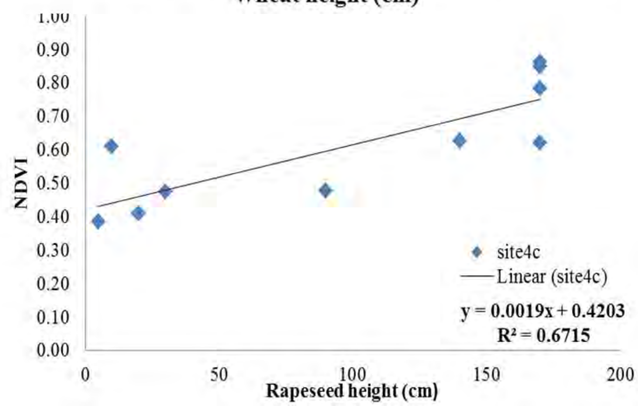
Optical images: less frequent coverage due to clouds, thus different sources (Landsat 8 and Sentinel-2) were merged into one time series.

NDVI and canopy height

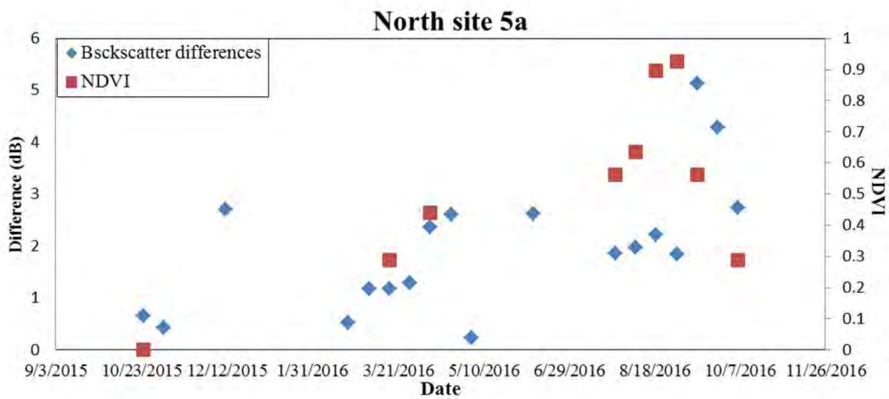


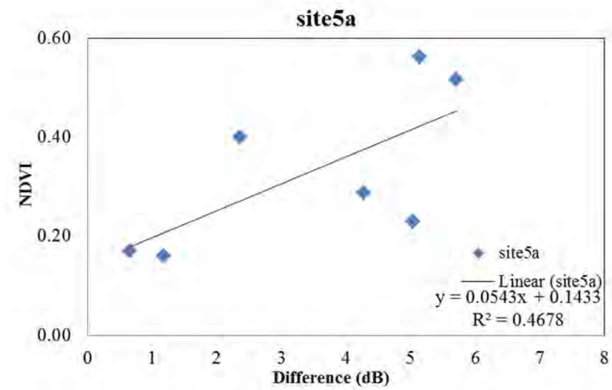


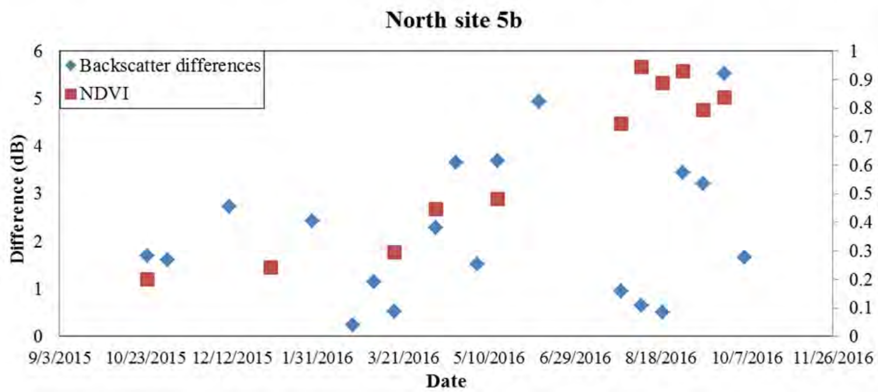


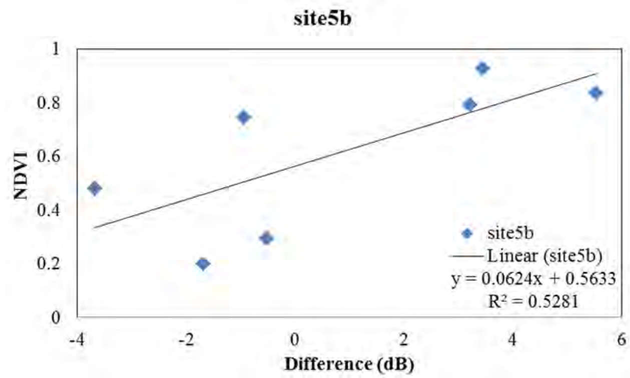


Polarization ratio (Difference in dB) and NDVI

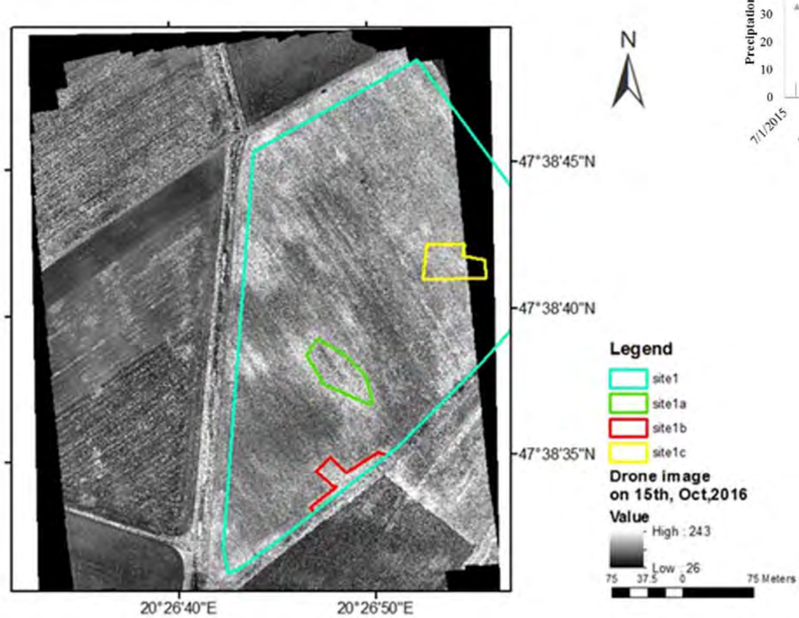


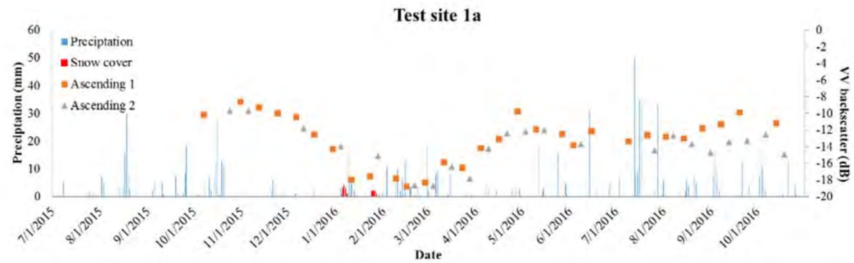


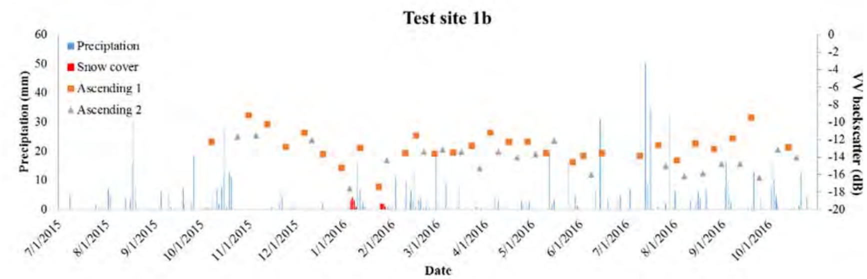


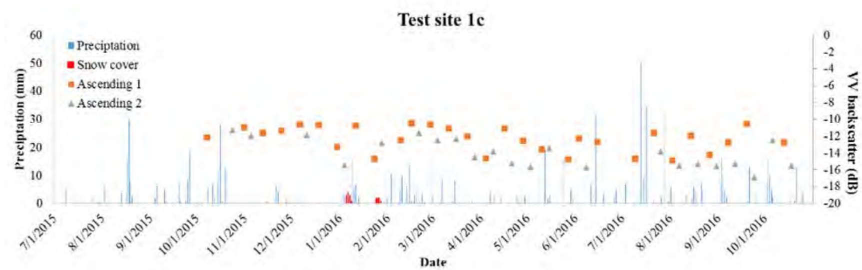


Test site 1 – different water cover characteristics

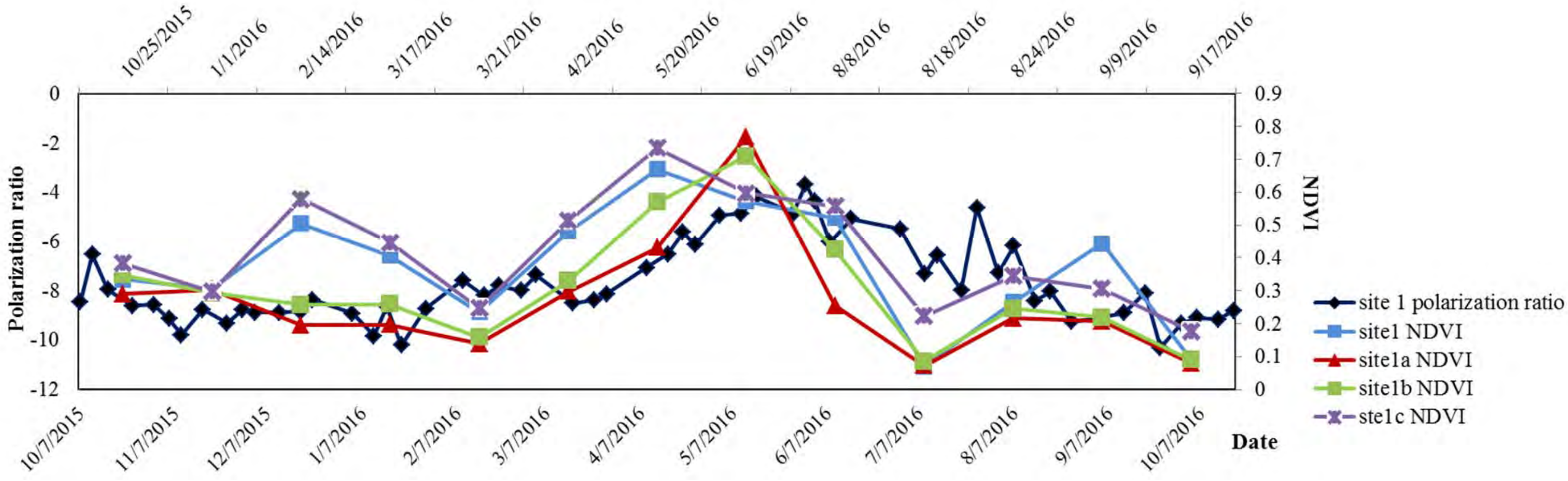






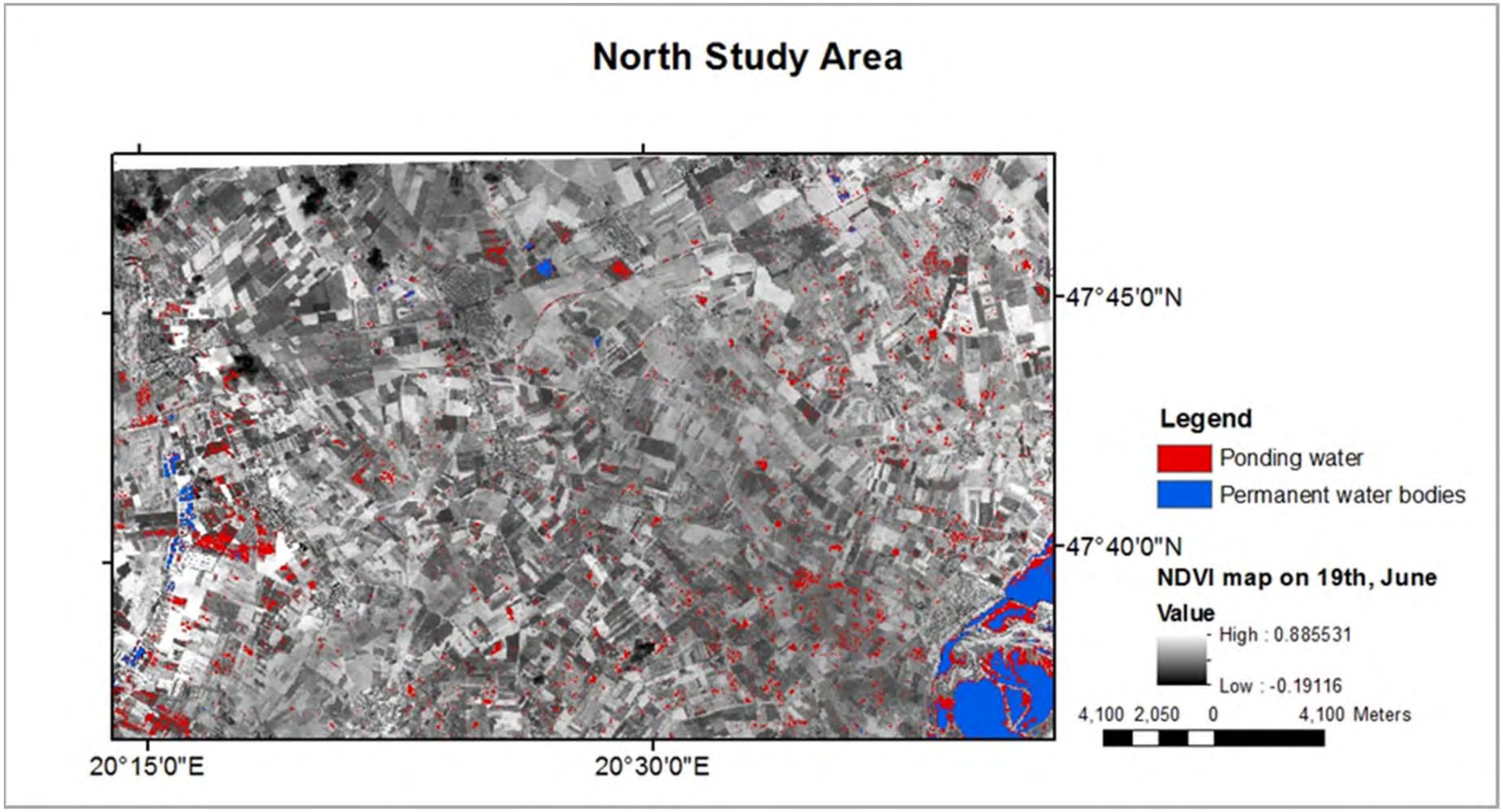


Comparison of polarization ratio and NDVI



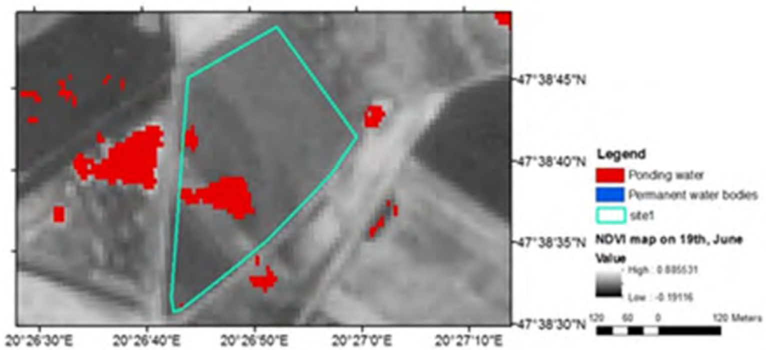
Lower frequency is due ONLY to cloud cover

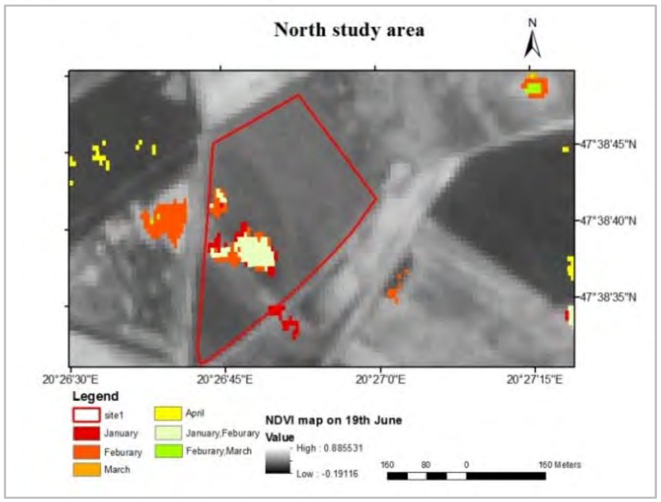
Improving accuracy of SAR-based information about crop canopy is needed.

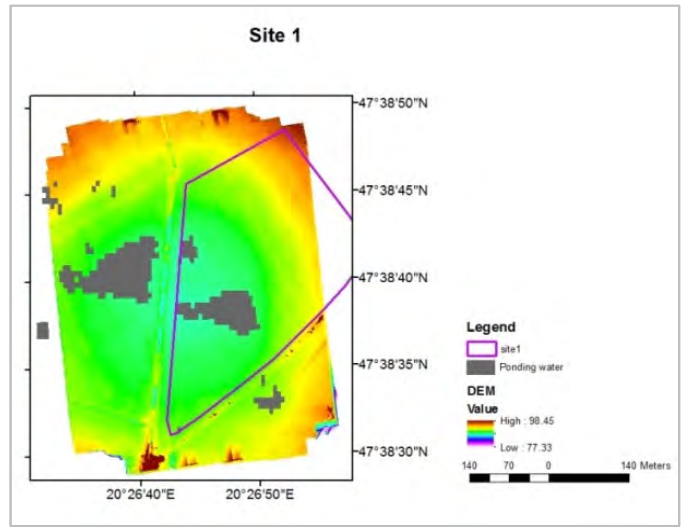

North Study Area
47°45'0"N
47°40'0"N
20°15'0"E
20°30'0"E
Legend
Ponding water
Permanent water bodies
NDVI map on 19th, June
Value
High : 0.885531
Low : -0.19116
4,100 2,050 0 4,100 Meters

Site 1

Site 1


47°38'45"N
47°38'40"N
47°38'35"N
47°38'30"N
20°26'30"E
20°26'40"E
20°26'50"E
20°27'0"E
20°27'10"E
Legend
Ponding water
Permanent water bodies
site1
NDVI map on 19th, June
Value
High : 0.885531
Low : -0.19116
120 60 0 120 Meters


North study area
N
47°38'45"N
47°38'40"N
47°38'35"N
20°26'30"E
20°26'45"E
20°27'0"E
20°27'15"E
Legend
site1
January
Feburary
March
April
January,Feburary
Feburary,March
NDVI map on 19th June
Value
High : 0.885531
Low : -0.19116
160 80 0 160 Meters


Site 1
47°38'50"N
47°38'45"N
47°38'40"N
47°38'35"N
47°38'30"N
20°26'40"E
20°26'50"E
Legend
site1
Ponding water
DEM
Value
High : 98.45
Low : 77.33
140 70 0 140 Meters

Conclusions

- Radar and optical provides information about **different aspects** of the surface water ponding
- Backscatter from canopy causes **polarization shift that is proportional to canopy volume / height**, as was proved with optical images
- The two Sentinel-1 satellites provide 2-3 days revisit time that is sufficient for the inundation mapping and provide **information about the dynamics** (indices related to frequency, duration, etc.).
- Information from **SAR can be used as substitute of optical image based information** about the crops and excess water inundation under cloud cover

Further problems to be solved

- Canopy influence and its dependence on incidence angle
- Temporal consistency (e.g., influence of snow)
- Integration of soil moisture development
- Integration with Agricultural Parcel Identification System
- Assessment of crop damage


Thank you for your attention!
Any questions?