Radar remote sensing for the monitoring of land Surfaces

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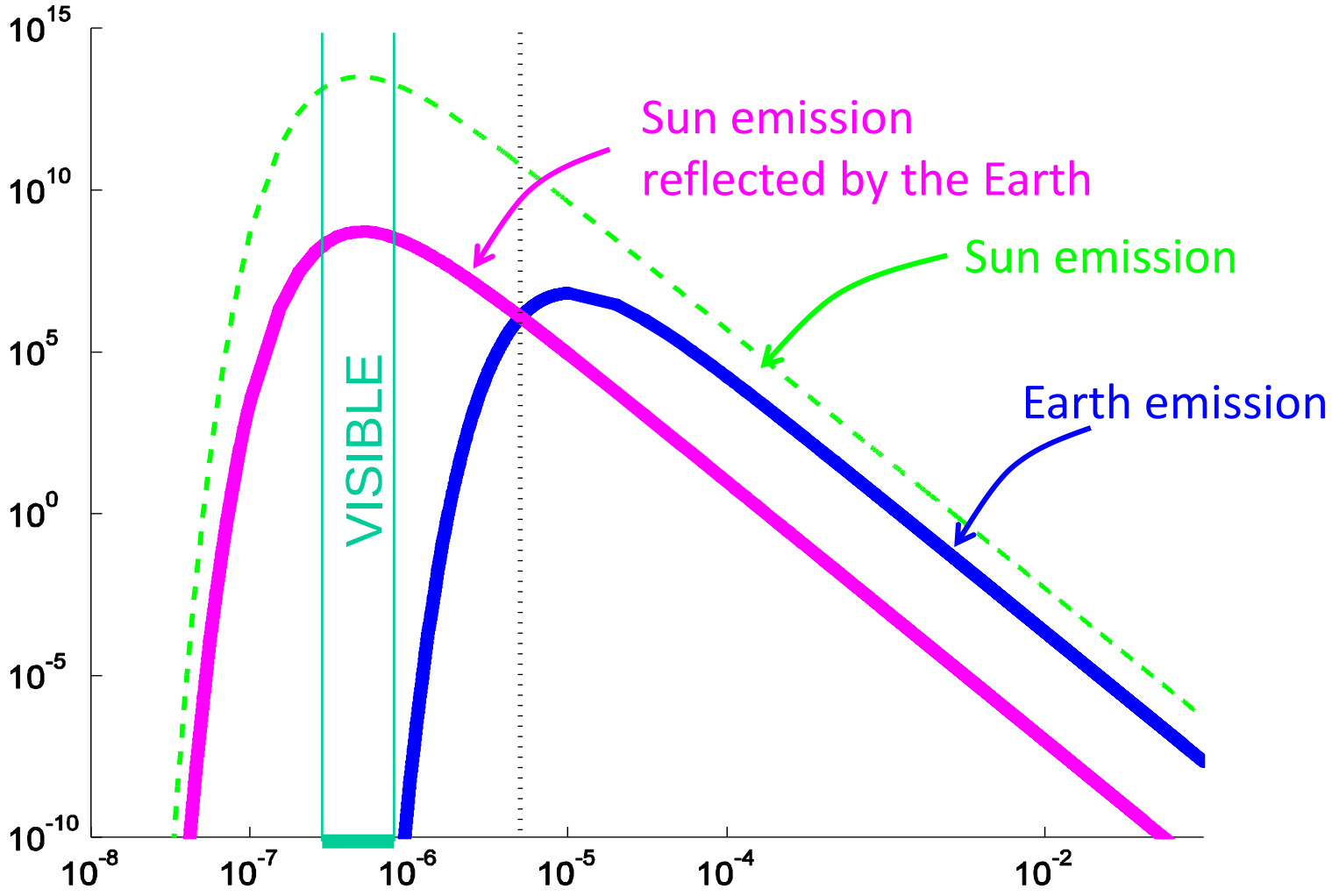
pierre-louis.frison@u-pem.fr

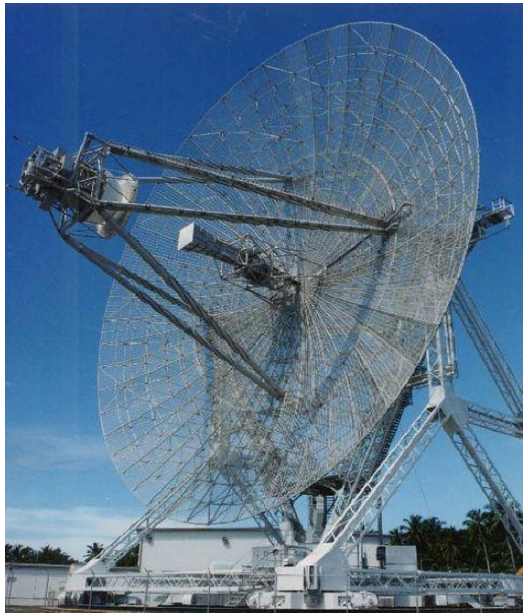
Electromagnetic radiation coming from the Earth



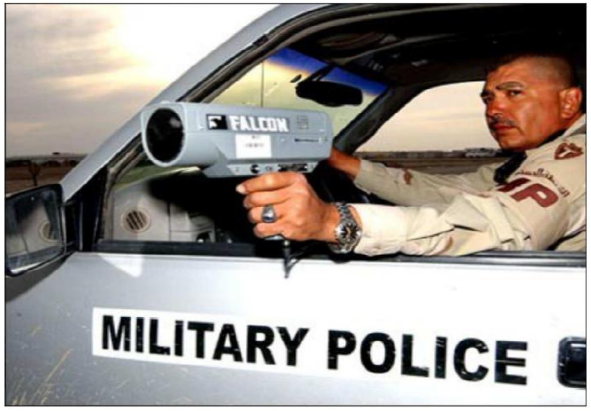
Radar Fundamentals

RADAR:
RAdio Detection And Ranging

Emition **of emw**
Reception **backscattered echoes**



US Army



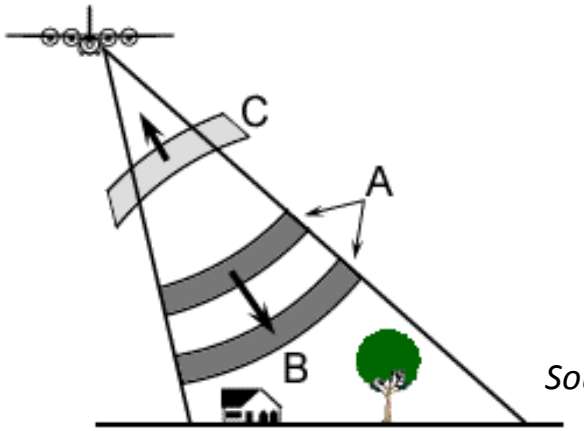
Road RADAR (© US police)

Imaging RADAR PALSAR (© NASDA)

Remote sensing:

Optical since 70's

Radar since 1991

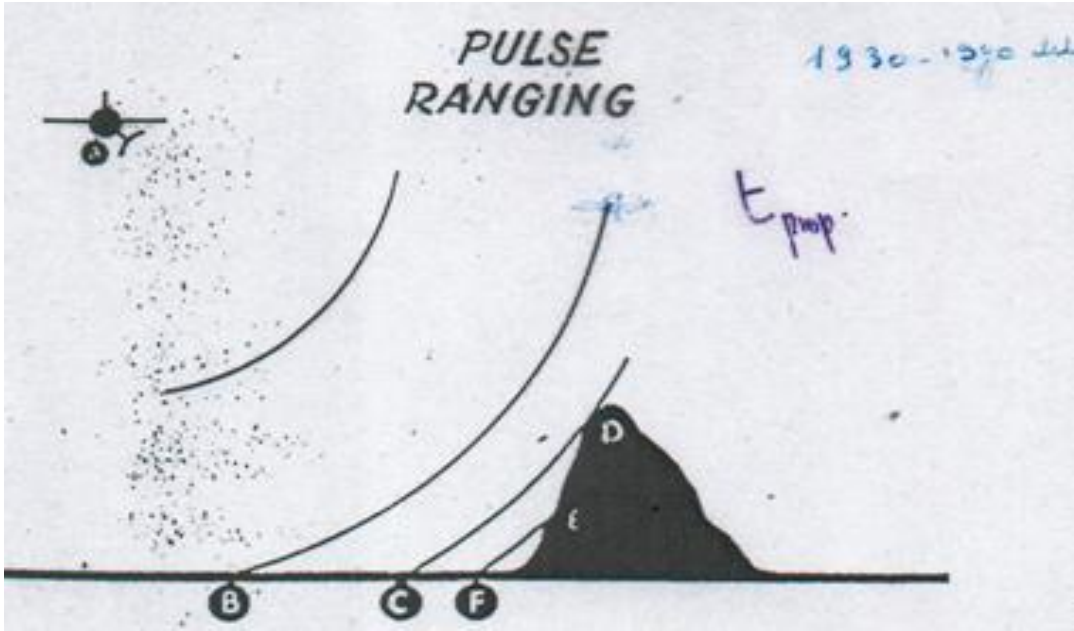


Source: CCT

wavelength: λ ***> 1cm***

Coherent wave

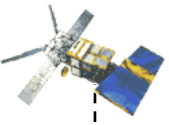
RADAR: Radio Detection and Ranging



Echoes are ranged according to

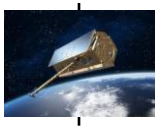
Antenna – target distance

Spaceborne Radar sensors

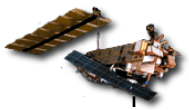


ERS1
SAR
Scatterometer
C Band

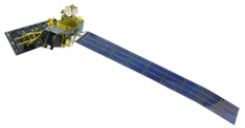
RADARSAT2
SAR
C Band



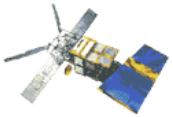
RADARSAT
SAR
C Band



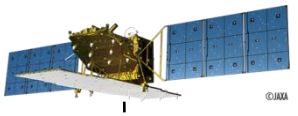
ENVISAT
RSO
Bande C

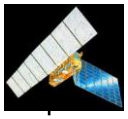


ALOS
SAR
L Bans

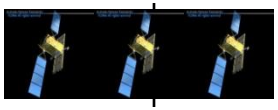


ERS2
SAR
Scatterometer
C Band

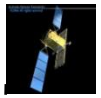




JERS
SAR
L Band

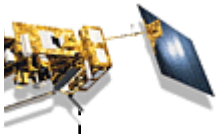


COSMO-SkyMed
SAR
X Band



ALOS 2
SAR
L Band

Quikscat
Scatterometer
Ku Band



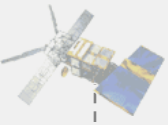
METOP
Sactterometer
C Band

Tandem X
SAR
X BAnd

1991 1992 1995 1999 2002 2006 2007 2010 2014 2016

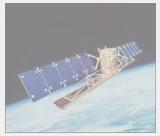
Spaceborne Radar sensors

COPERNICUS



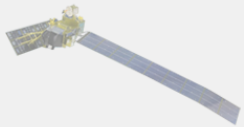
ERS1
SAR
Scatterometer
C Band

RADARSAT2
SAR
C Band



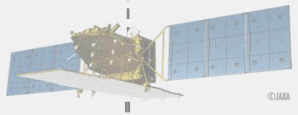
RADARSAT
SAR
C Band

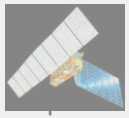
ENVISAT
RSO
Bande C



ALOS
SAR
L Bans

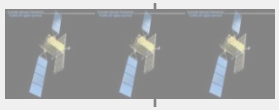
ERS2
SAR
Scatterometer
C Band





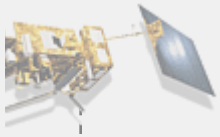
JERS
SAR
L Band

COSMO-SkyMed
SAR
X Band



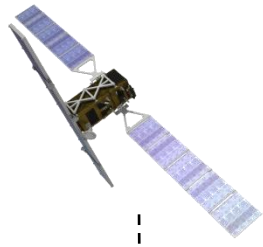
ALOS 2
SAR
L Band

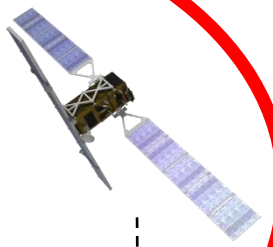
Quikscat
Scatterometer
Ku Band



METOP
Sactterometer
C Band

Tandem X
SAR
X BAnd



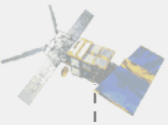


Sentinel-1
SAR
C Band

1991 1992 1995 1999 2002 2006 2007 2010 2014 2016

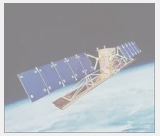
Spaceborne Radar sensors

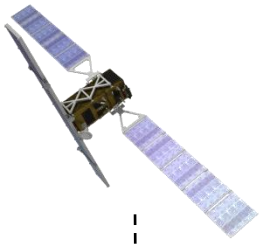
COPERNICUS

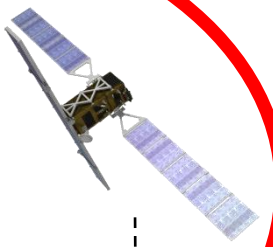


ERS1
SAR
Scatterometer
C Band

RADARSAT2
SAR
C Band



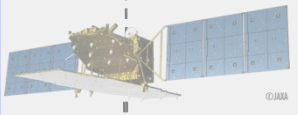




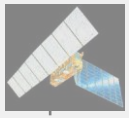
Sentinel-1
SAR
C Band

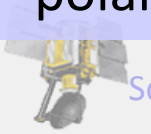
Diversity:

- wavelength (2 cm, 3 cm, 6 cm, 24 cm)
- Resolution
  - spatial: 1 m – 50 km
  - temporal: 1 day – 1 month
- polarization

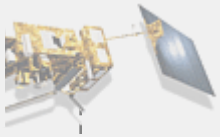


ALOS 2
SAR
L Band





Quikscat
Scatterometer
Ku Band



METOP
Sactterometer
C Band

Tandem X
SAR
X BAnd

1991 1992 1995 1999 2002 2006 2007 2010 2014 2016

Radar remote sensing for land surfaces monitoring

Remote sensing:

Optical since 70's

Radar since 1991

Diversity:

- wavelength (2 cm, 3 cm, 6 cm, 24 cm)
- Resolution
  - spatial: 1 m – 50 km
  - temporal: 1 day – 1 month
- polarization

Interest of Radar remote sensing:

Complementary observations (*vs* Optical)

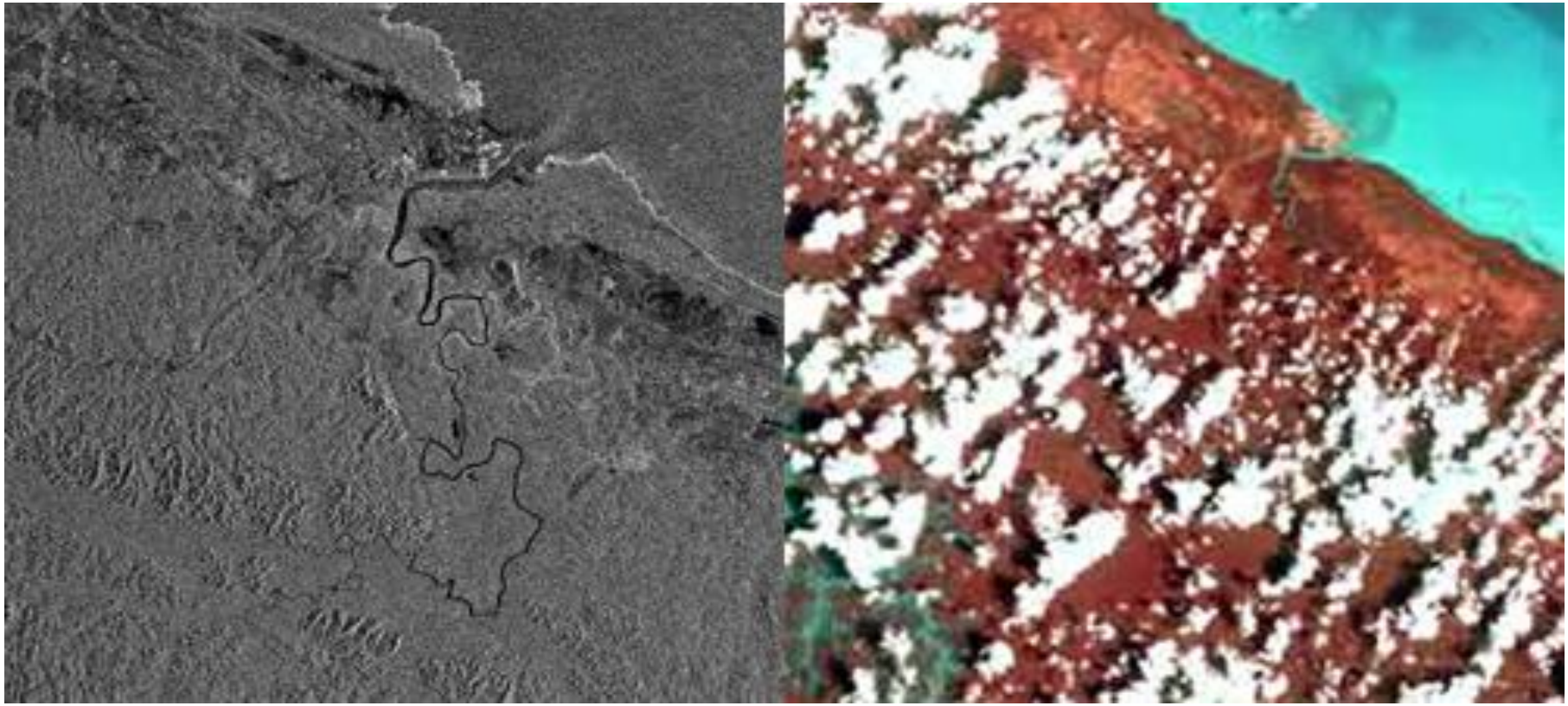
insensitive to the atmosphere and the presence of clouds

night/day observations

no problem with rain and cloudy conditions

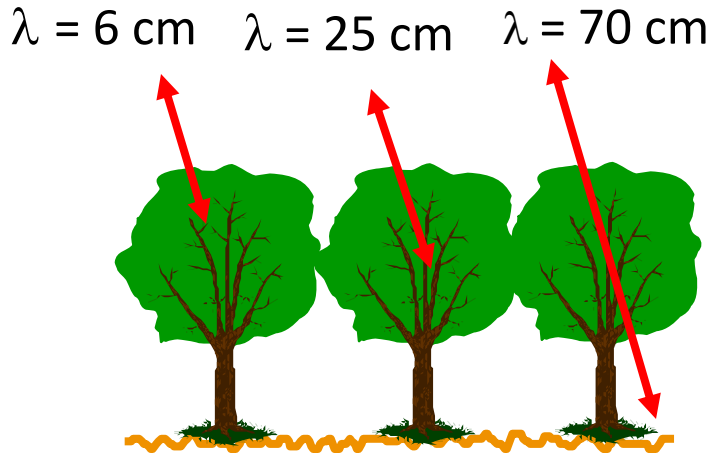
Radar, ERS

Optical, SPOT



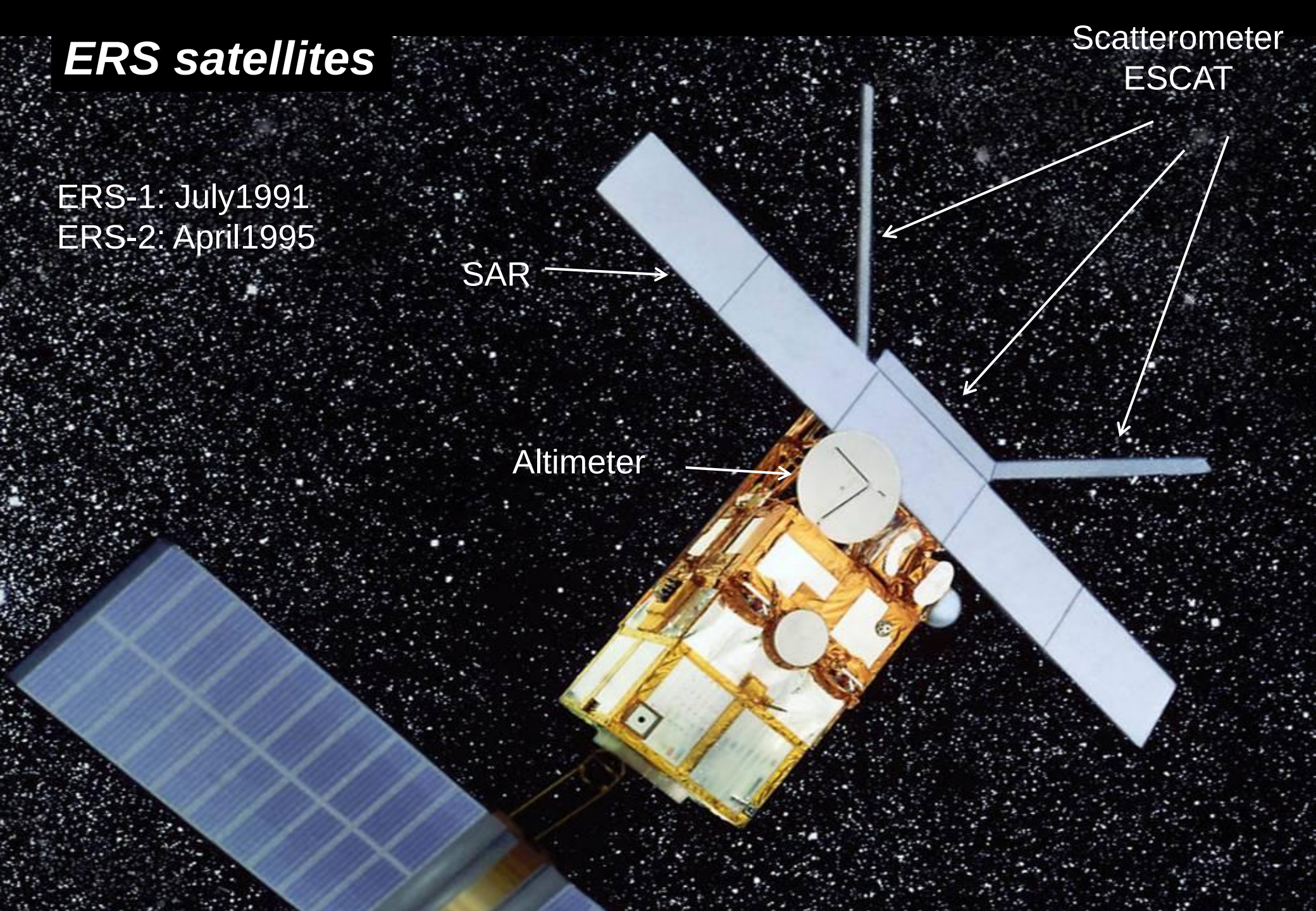
Radar sensitivity

- Biomass
- Stucture and moisture of the vegetation
- soil roughness and moisture

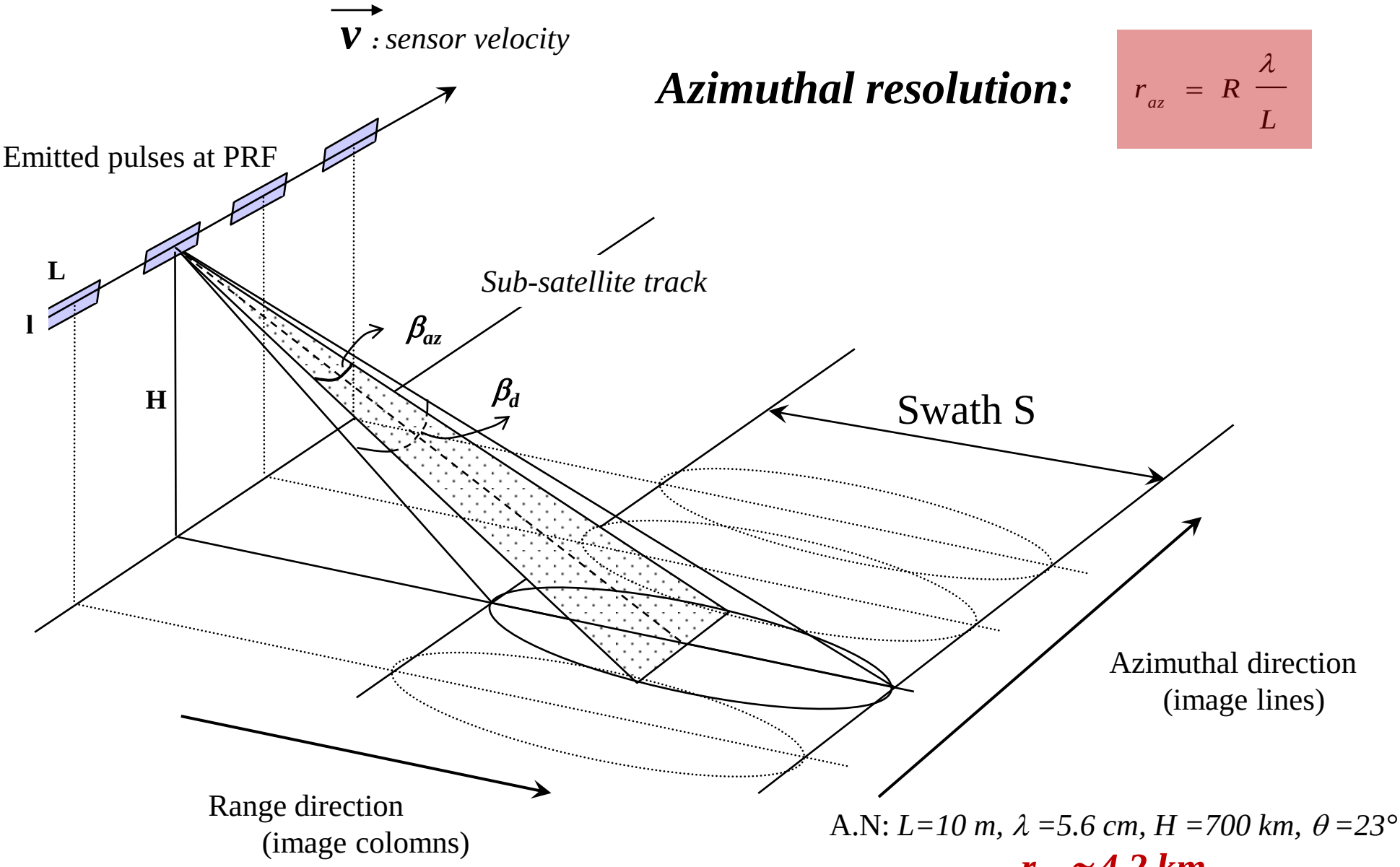


Access to key variables in ecosystems functioning

- vegetation discrimination (type, species, state,….)
- Net primary productivity
- Period of vegetation activity
- water state of vegetation cover (water potential, stress, ….)


ERS satellites
Scatterometer
ESCAT
ERS-1: July1991
ERS-2: April1995
SAR
Altimeter

Side looking Radar sensor



Azimuthal resolution:

$$r_{az} = R \frac{\lambda}{L}$$

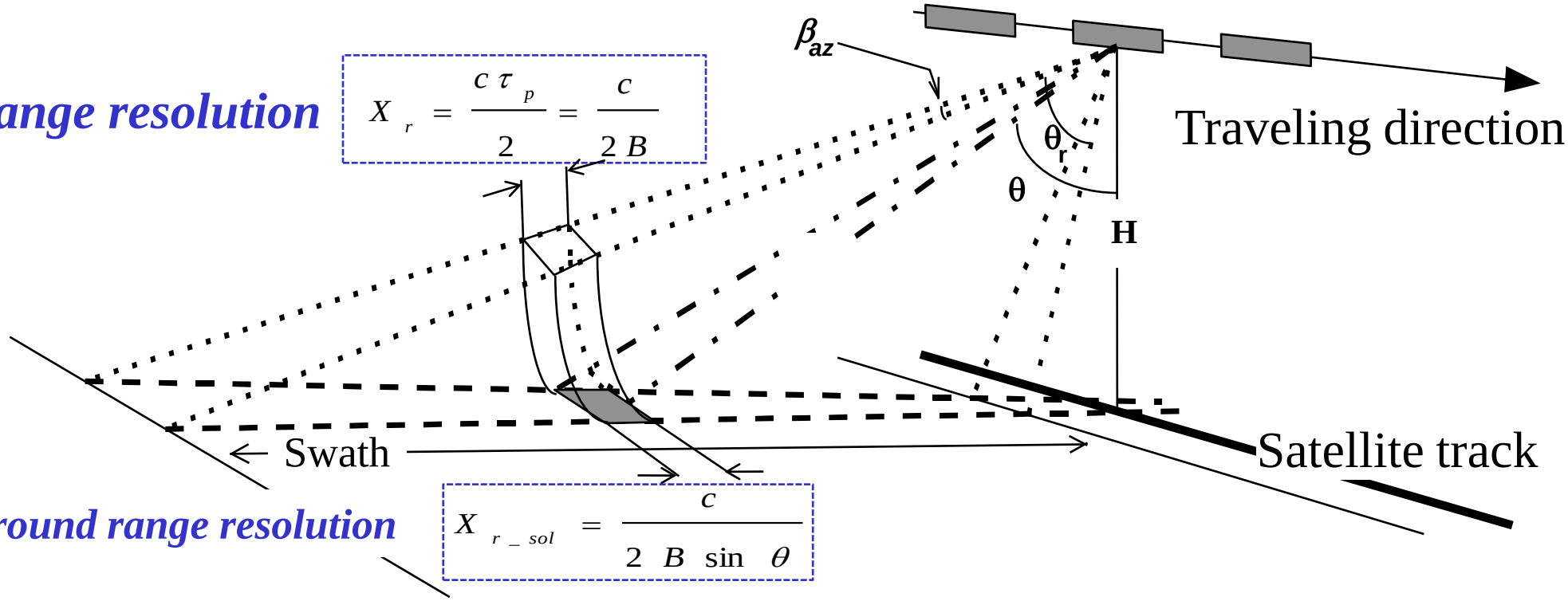
A.N: $L=10\ m$, $\lambda=5.6\ cm$, $H=700\ km$, $\theta=23°$

$$r_{az} \approx 4.2\ km$$

Radar Imaging – spatial resolution

Range resolution

$$X_r = \frac{c\,\tau_p}{2} = \frac{c}{2B}$$



Ground range resolution

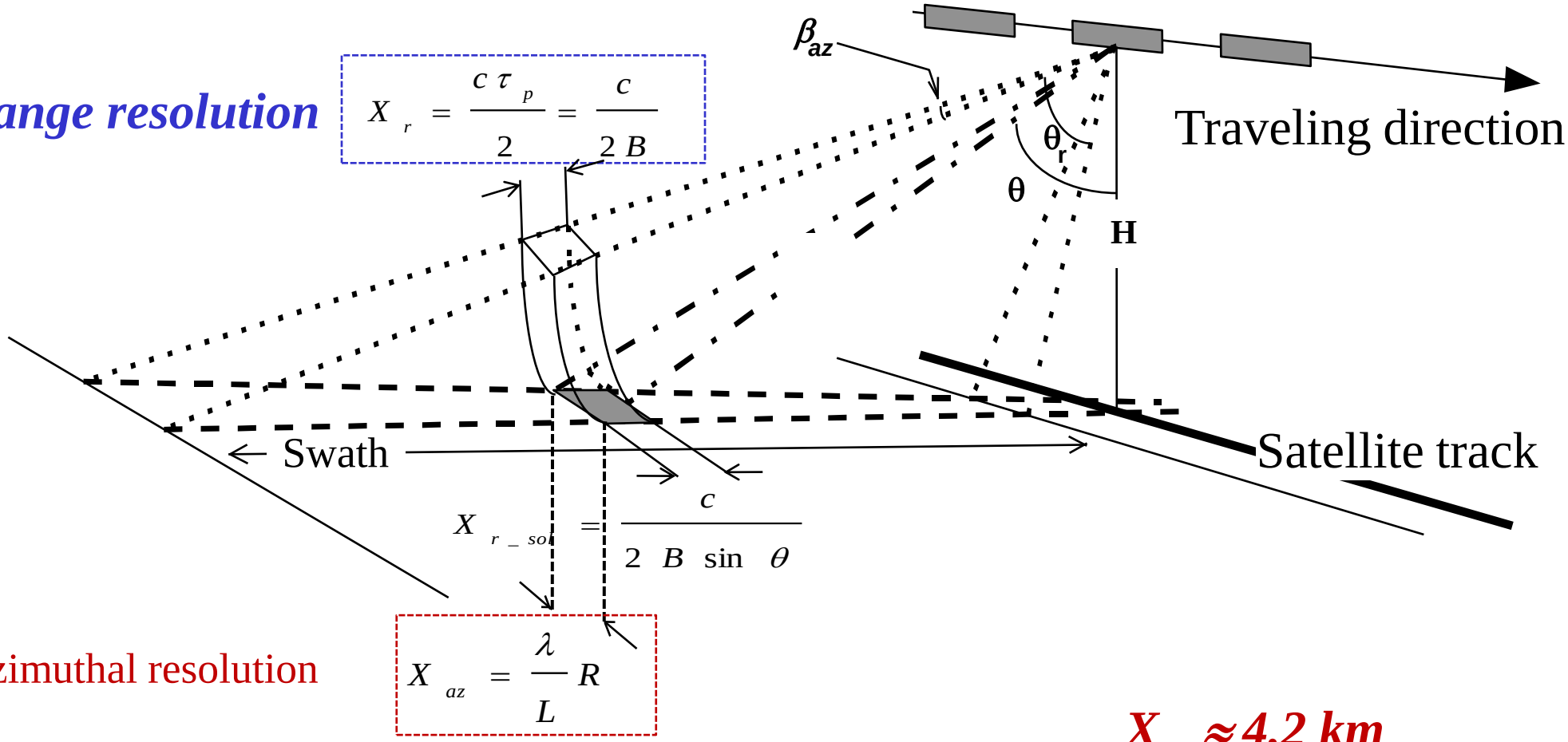
$$X_{r\_sol} = \frac{c}{2\,B\,\sin\,\theta}$$

N. A.: Pulse Bandwith: B $\approx 15\ MHz$ ==> $X_r \approx 10\ m$

Radar Imaging – spatial resolution

Range resolution

$$X_r = \frac{c\,\tau_p}{2} = \frac{c}{2B}$$



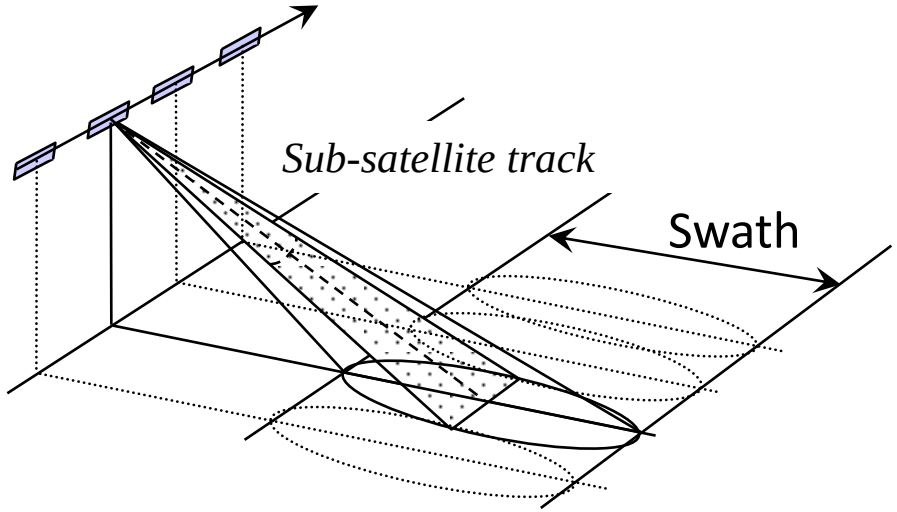
Azimuthal resolution

$$X_{az} = \frac{\lambda}{L} R$$

$X_{az} \approx 4.2$ km

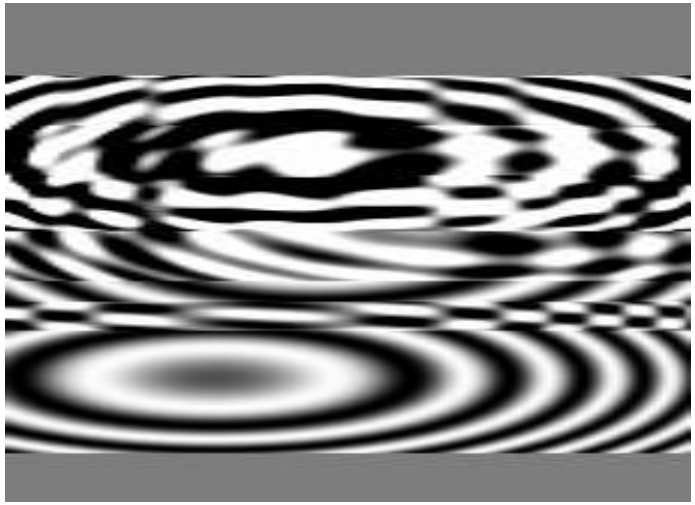
$X_r \approx 10$ m

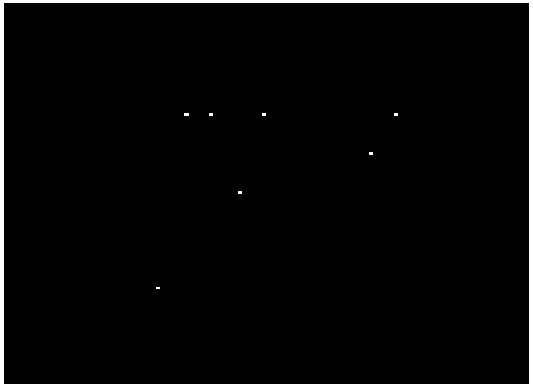
Side looking Radar sensor



Scatterometers		***SAR***
	Raw echoes processing	
Incoherent sum *(I)*		Coherente sum *(A, ϕ)*
	Spatial resolution	
low (10 – 50 km)		***high*** (1 - 30 m)
	Radiometric resolution	
high (ELN ~ 400)		***low*** (speckle)
	Temporal period acquisitions	
low *(~ day)*		***High*** *(~ month)* ☝ *up to 2015!*

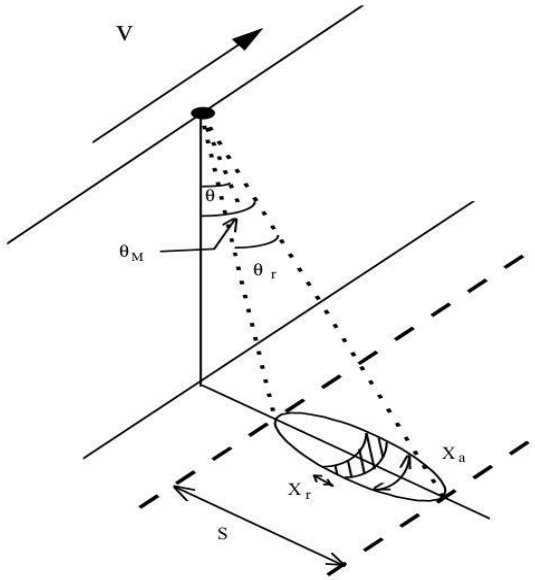
Raw echoes

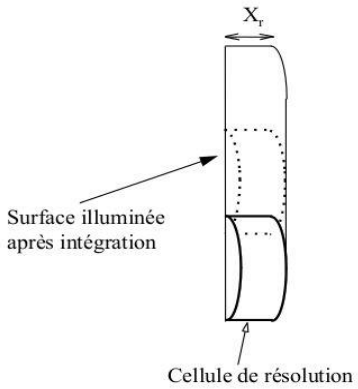


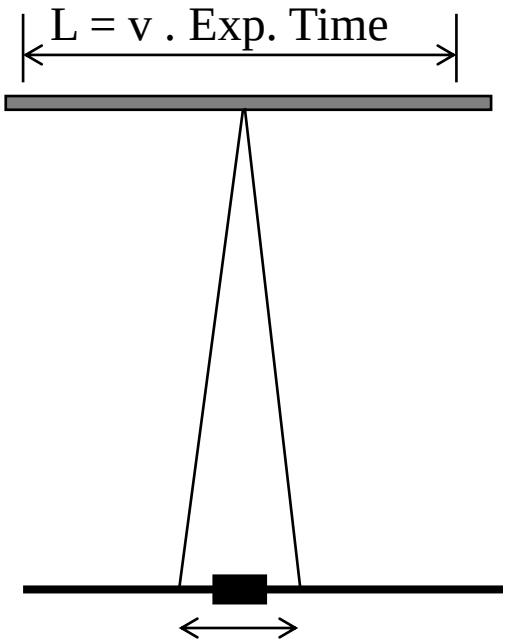


Ideal scene

Scatterometers		***SAR***
	Raw echoes processing	
Incoherent sum *(I)*		Coherent sum *(A, ϕ)*
	Spatial resolution	
Low (~ 10 – 50 km)		***Fine*** (1 - 30 m)
	Radiometic resolution	
High (ENL ~ 400)		***Low*** (speckle)
	Originally designed	
seas (winds)		*Land - seas*







Side looking radar sensors

Scatterometers:

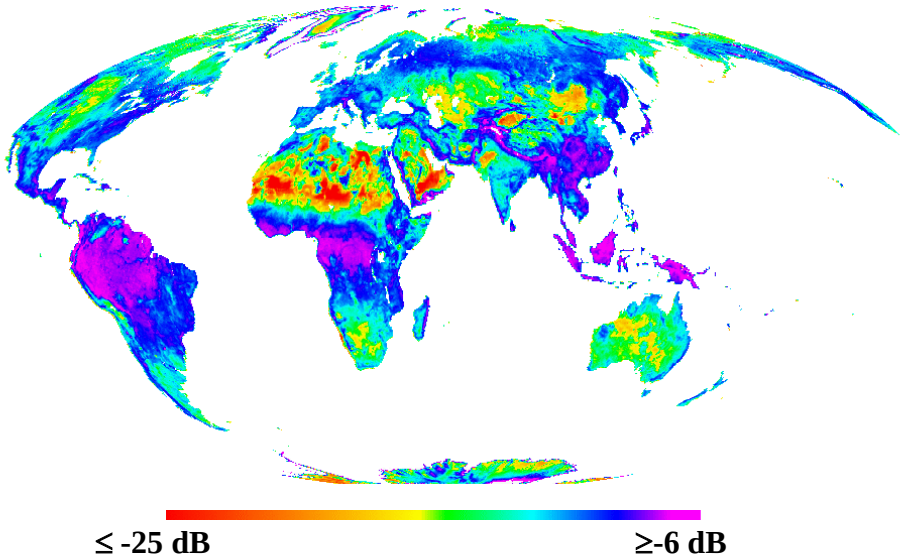
☞ *Radar eflectivity estimation (σ°)*

- ***low spatial resolution***: *~ 10 – 50 km*
- ***high frequency of acquisitions (~ day)***

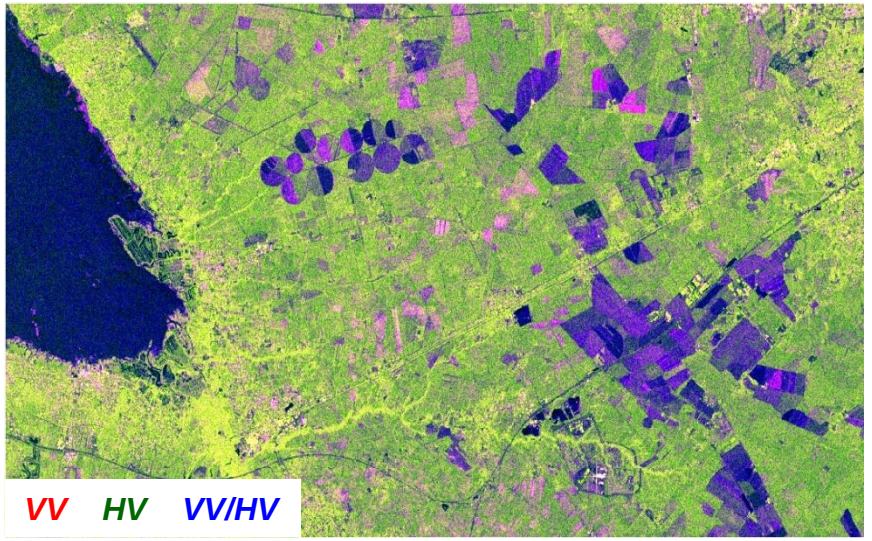
SAR:

☞ *surface imaging*

- ***high spatial resolution***: *~ 10 m*
- ***low frequency of acquisition (~ month)***



Scatt. ERS – May 1992



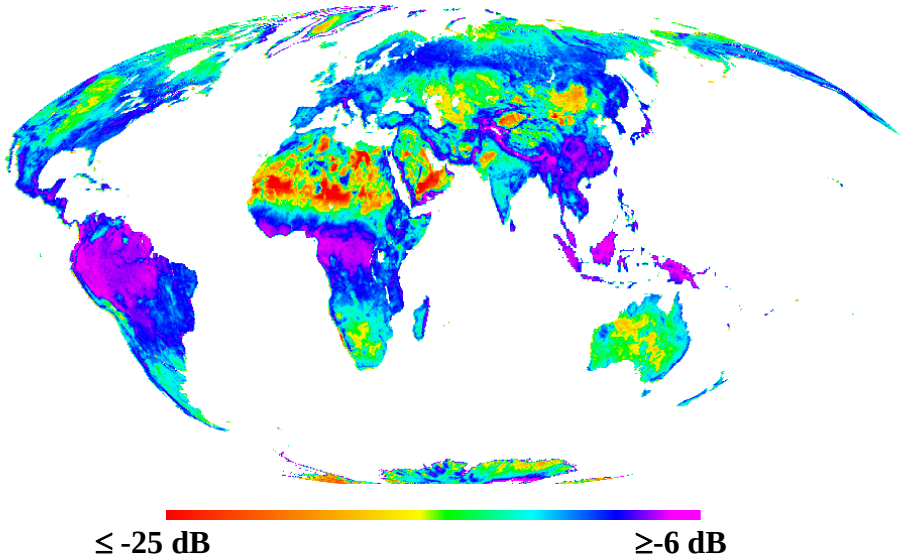
Sentinel-1
Les landes – March 2015

Side looking radar sensors

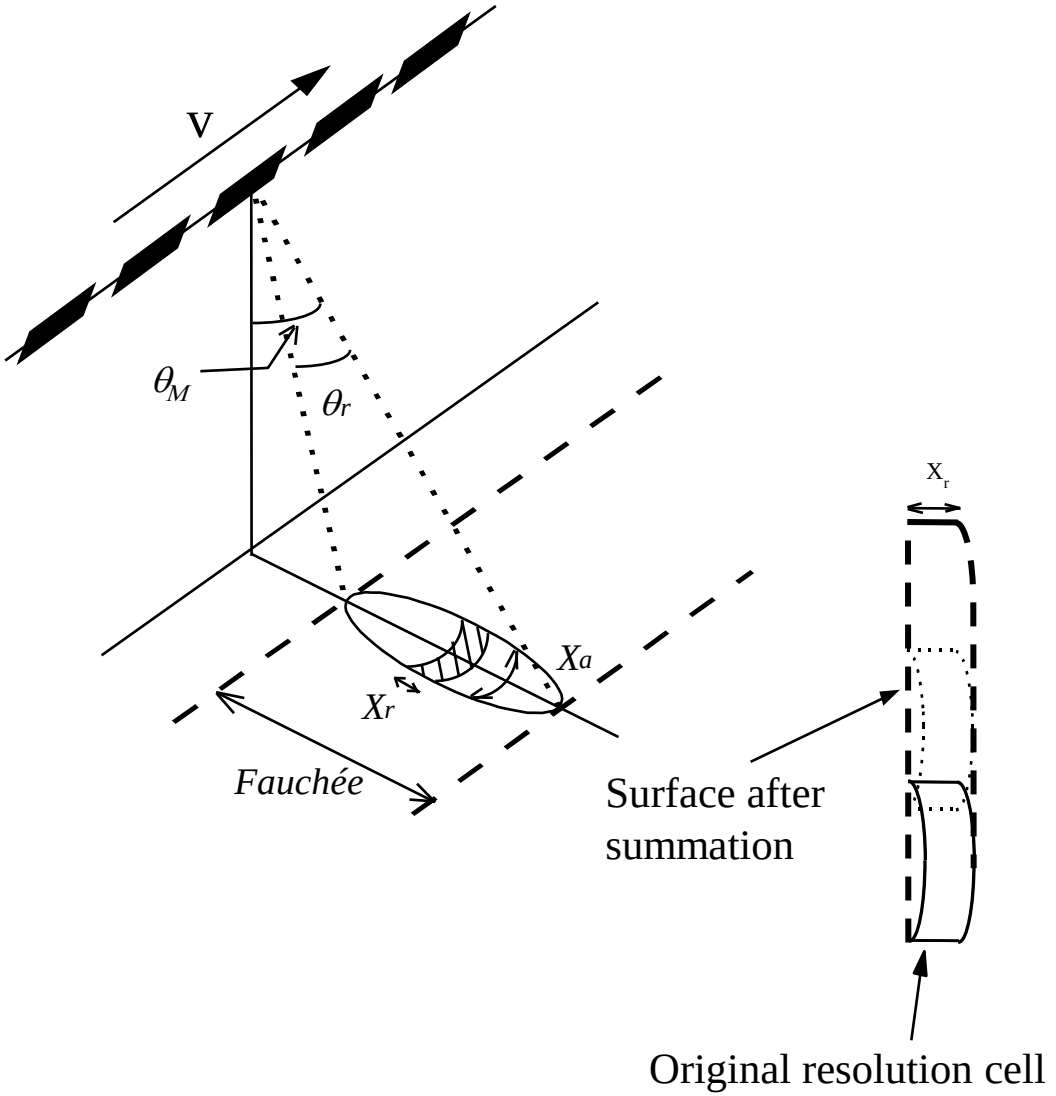
***Scatterometers*:**

☞ *Radar eflectivity estimation (σ°)*

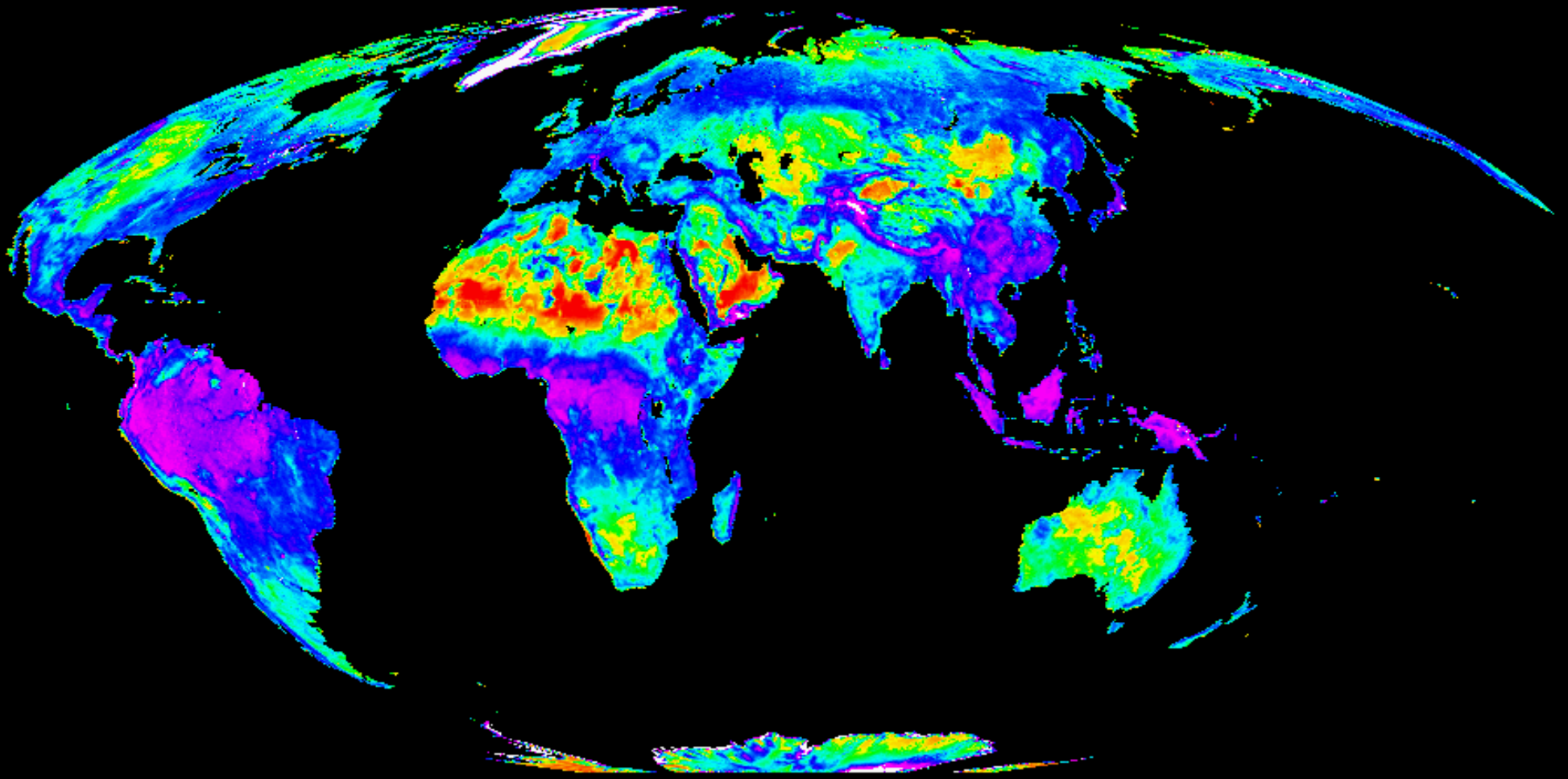
- ***low spatial resolution***: *~ 10 – 50 km*
- ***high frequency of acquisitions (~ day)***



Scatt. ERS – May 1992

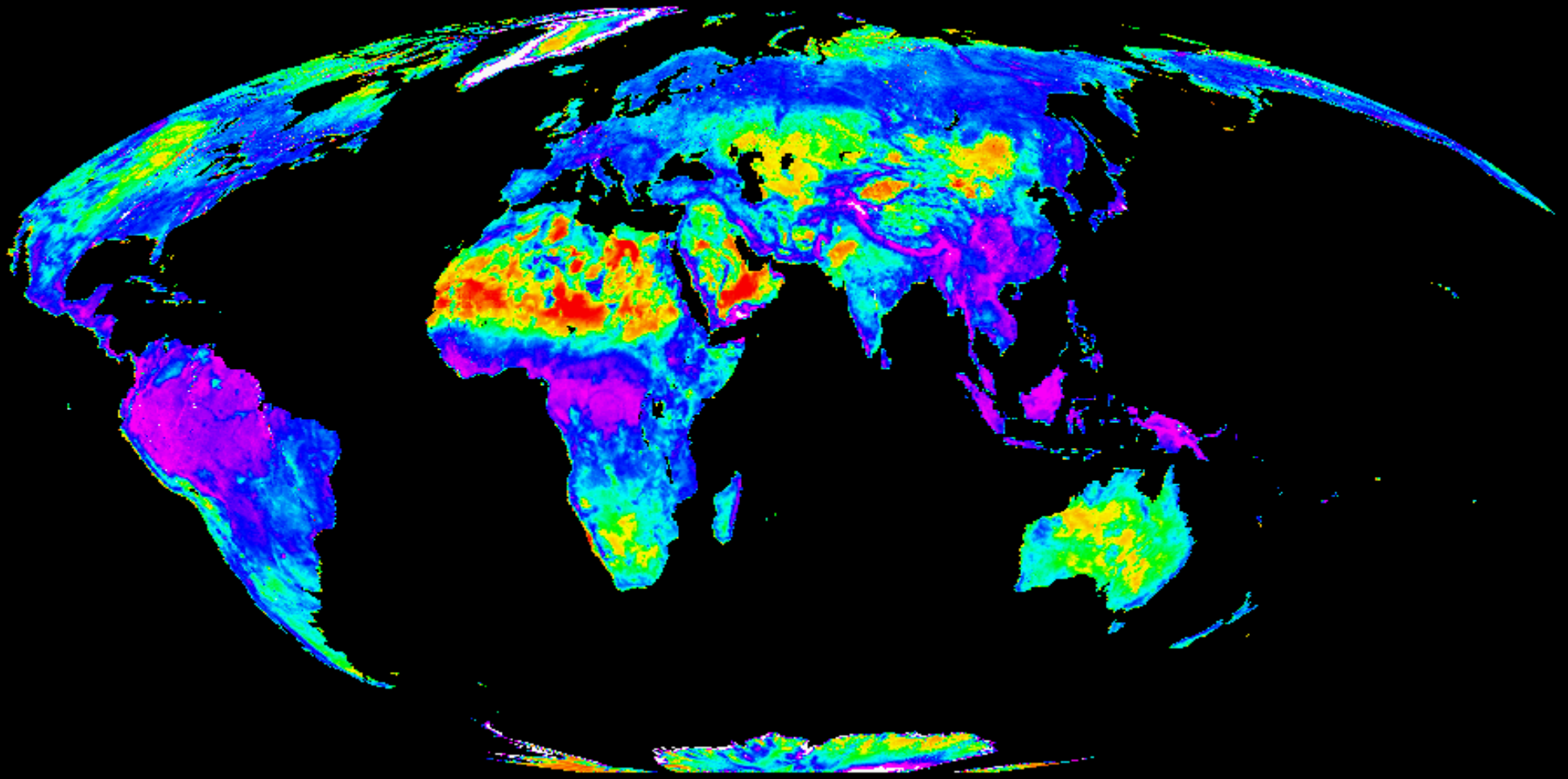


ERS Scatterometer: global image of $\sigma^0(40°)$



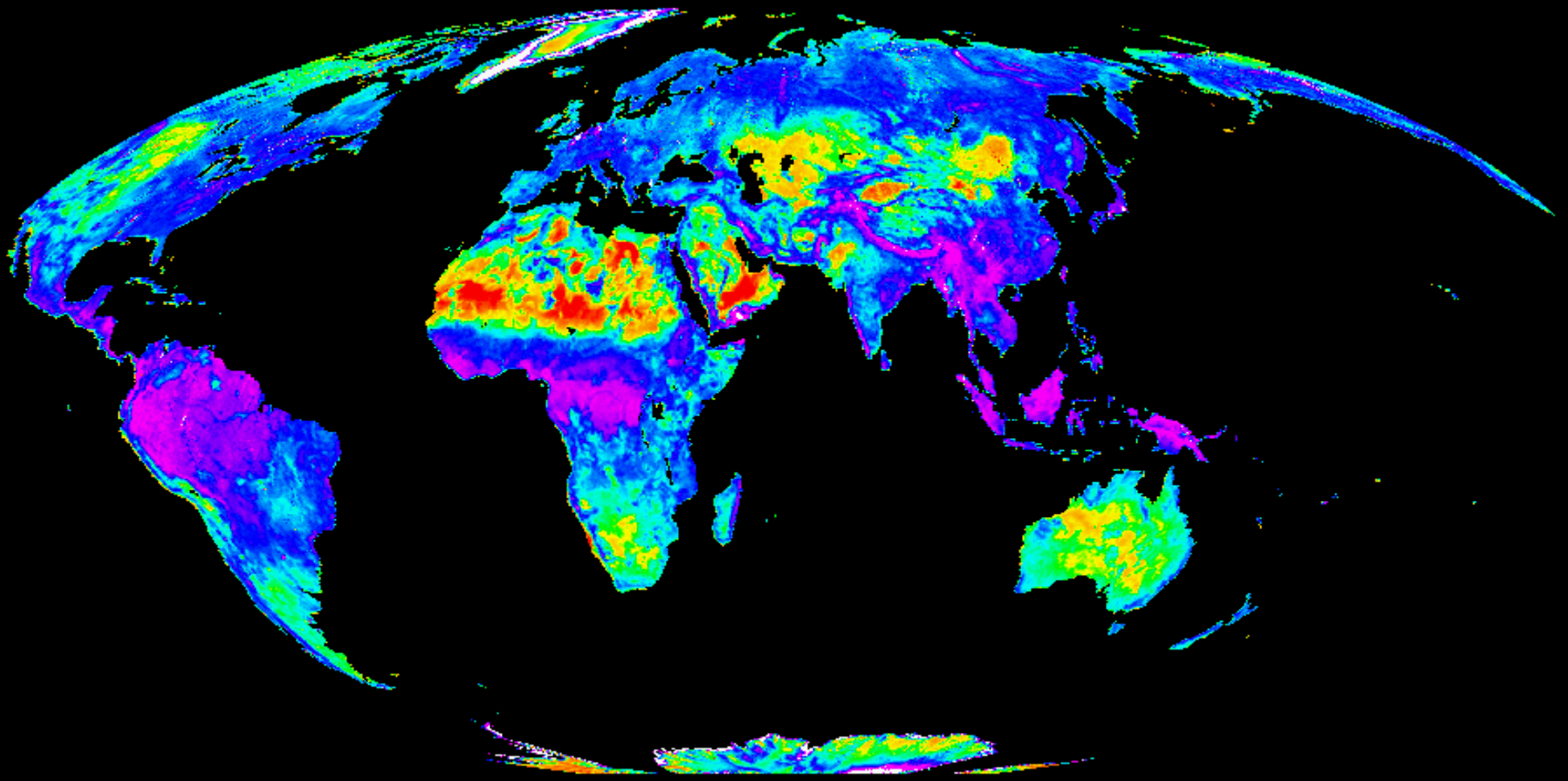
May 1992

ERS Scatterometer: global image of $\sigma^0(40°)$



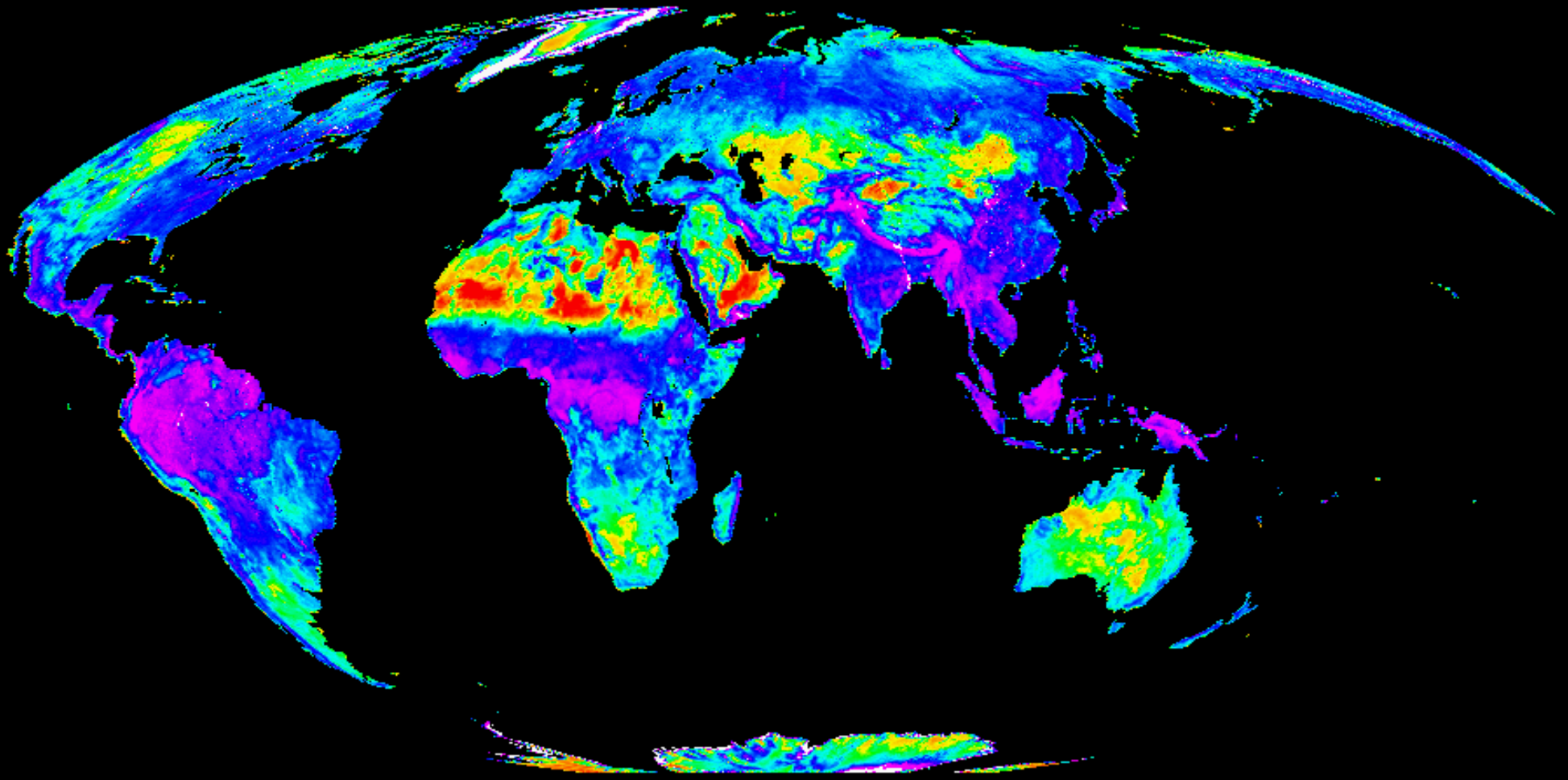
June 1992

ERS Scatterometer: global image of $\sigma^0(40°)$



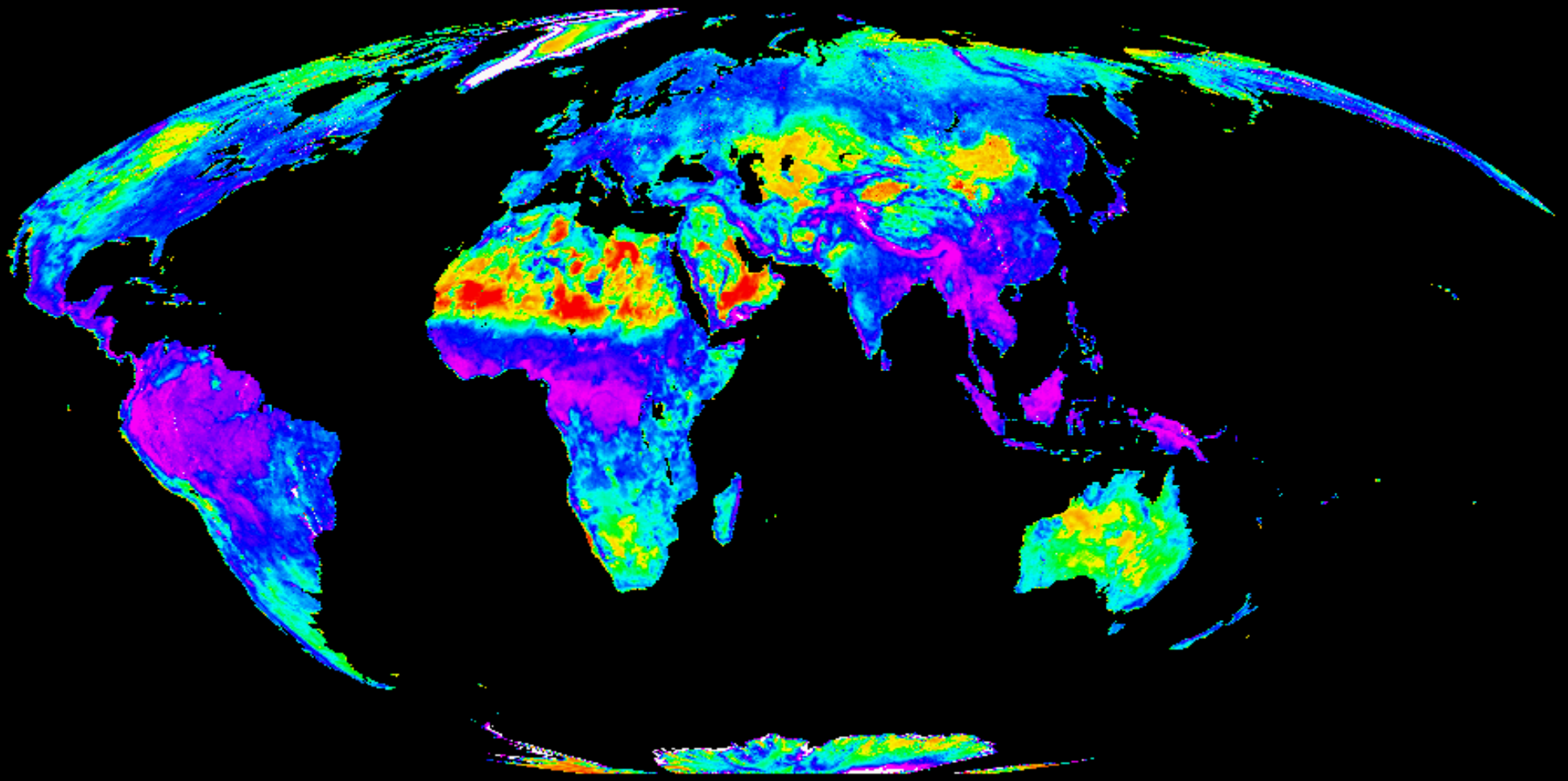
July 1992

ERS Scatterometer: global image of $\sigma^0(40°)$



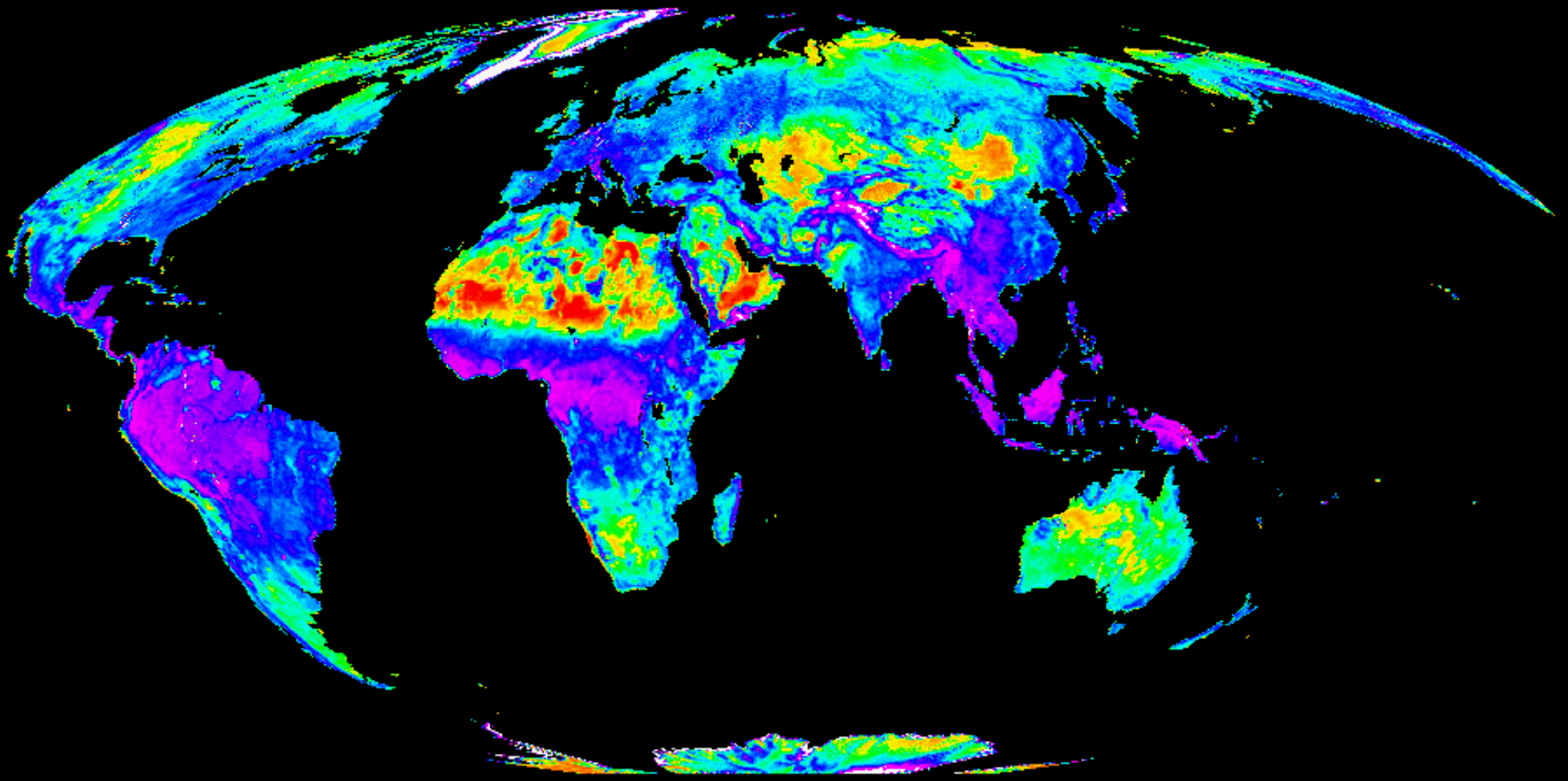
August 1992

ERS Scatterometer: global image of $\sigma^0(40°)$



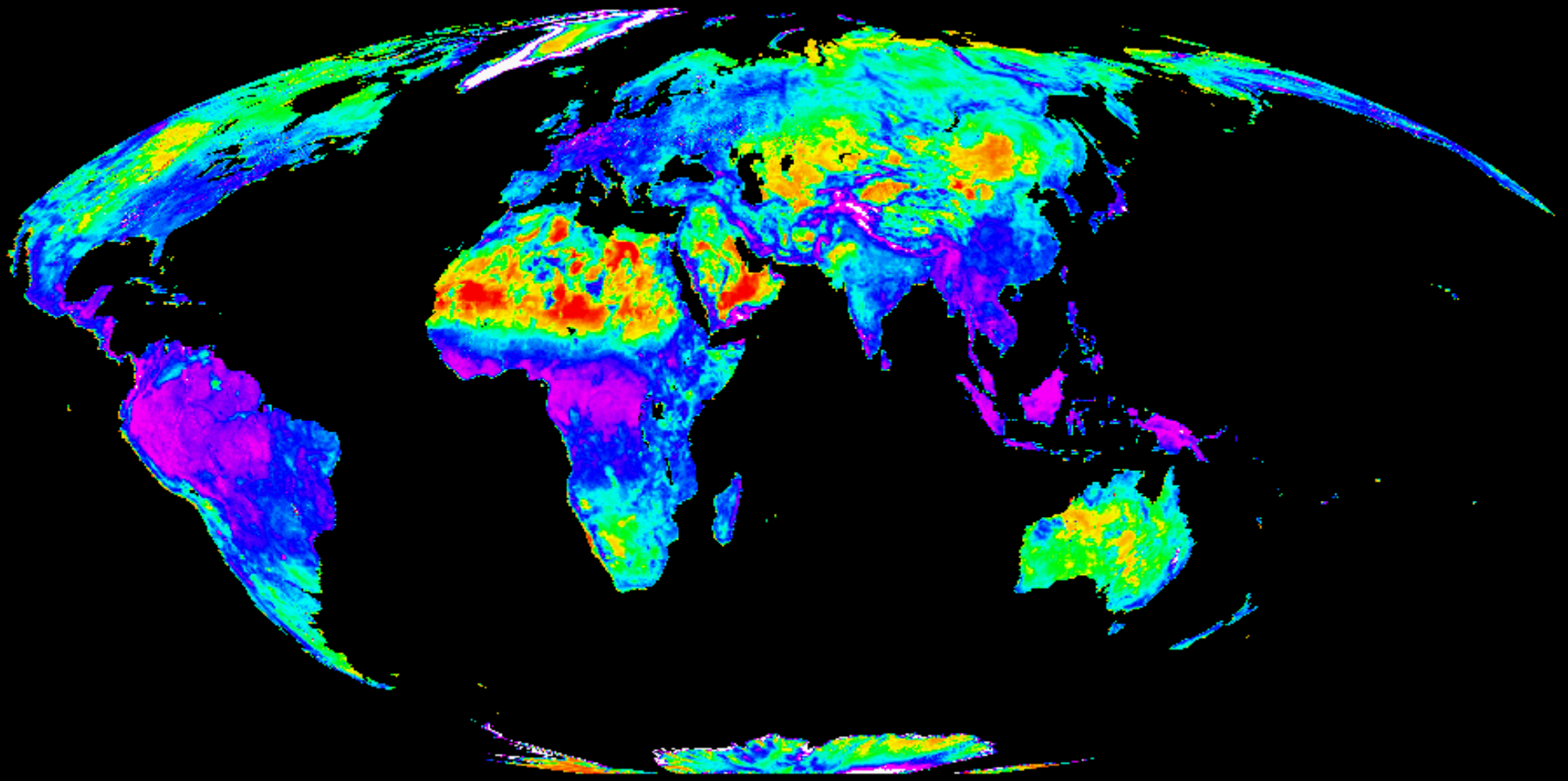
Sept. 1992

ERS Scatterometer: global image of $\sigma^0(40°)$



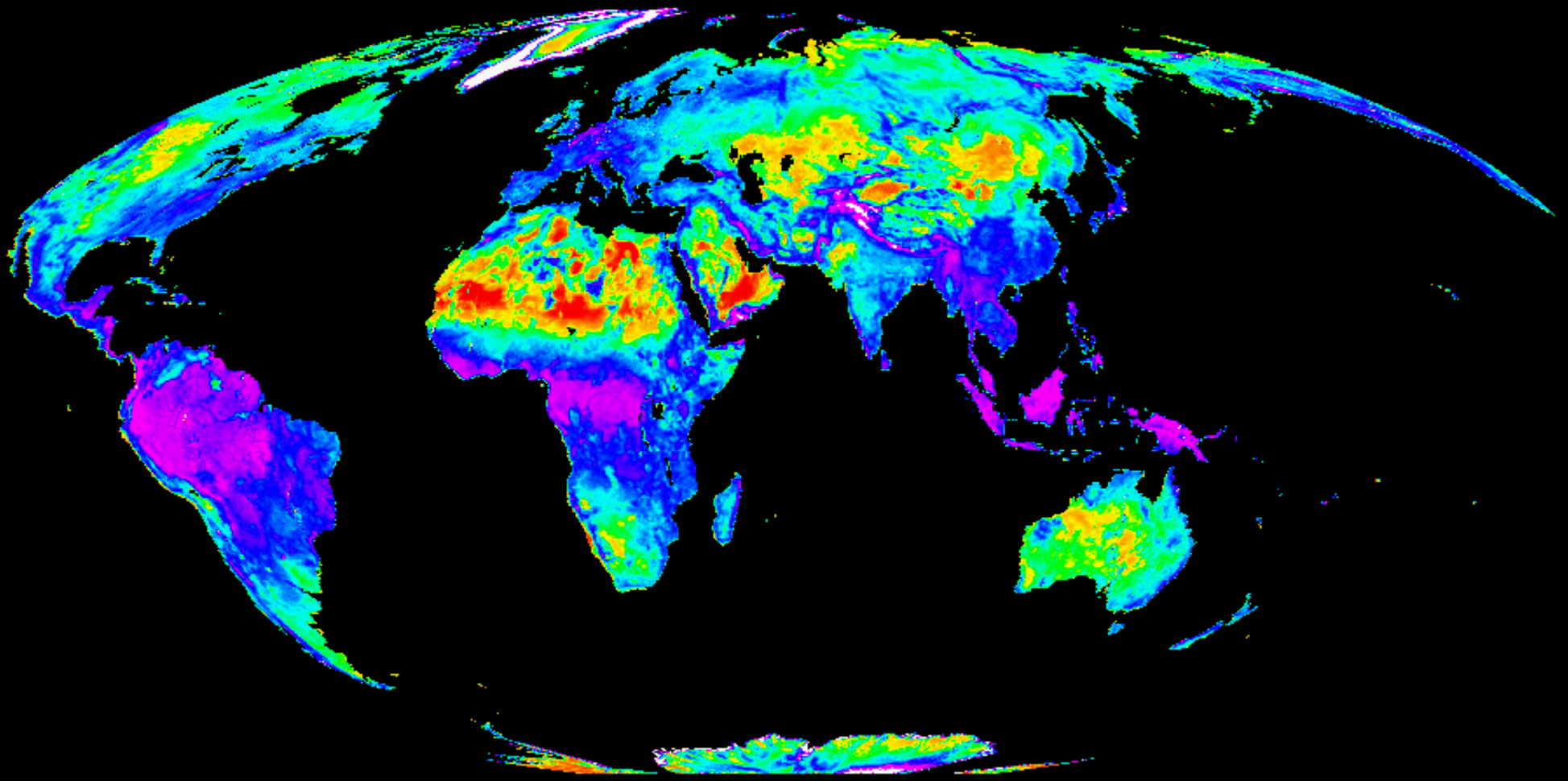
October 1992

ERS Scatterometer: global image of $\sigma^0(40°)$



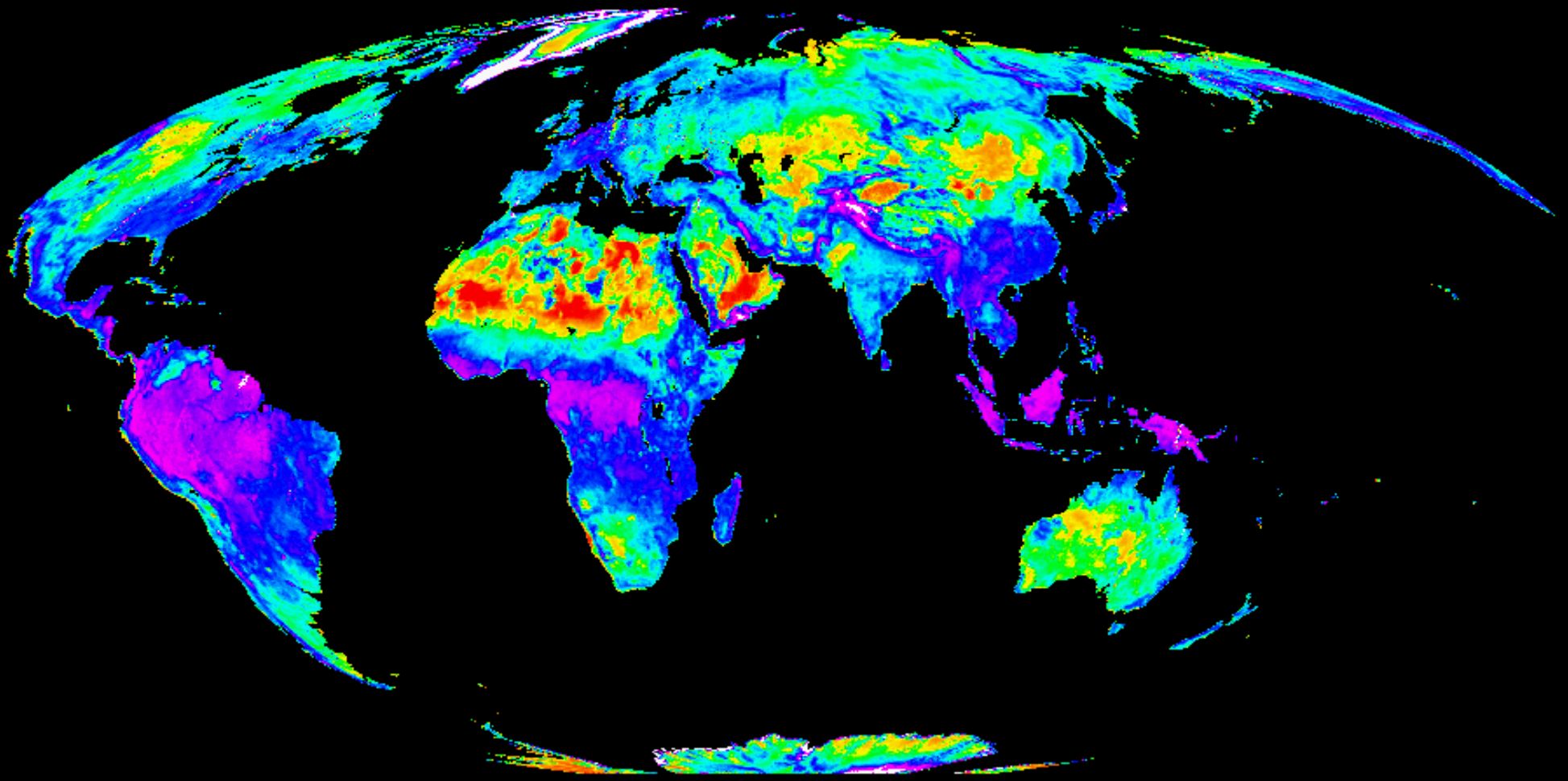
Nov. 1992

ERS Scatterometer: global image of $\sigma^0(40°)$



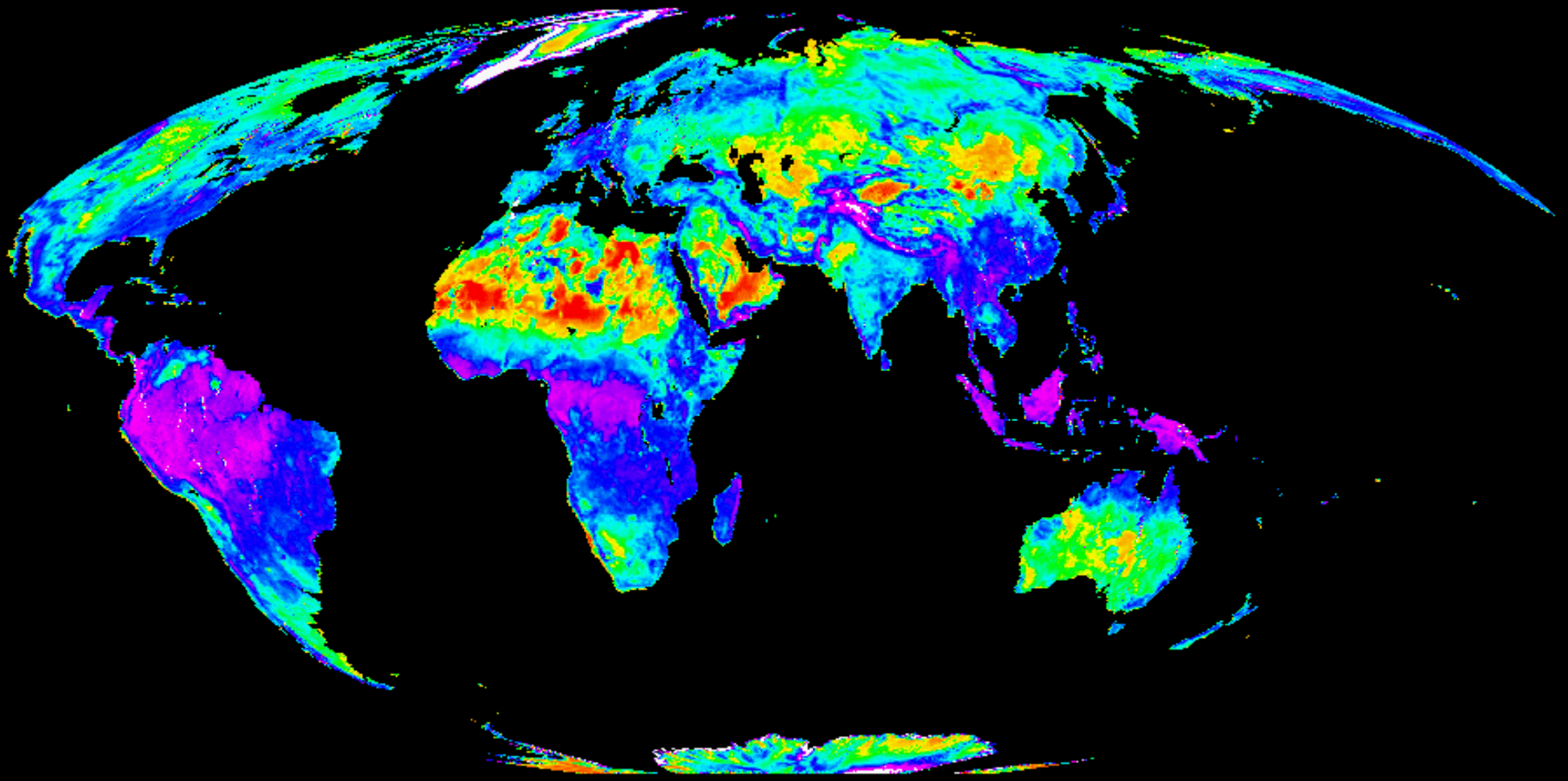
Dec. 1992

ERS Scatterometer: global image of $\sigma^0(40°)$



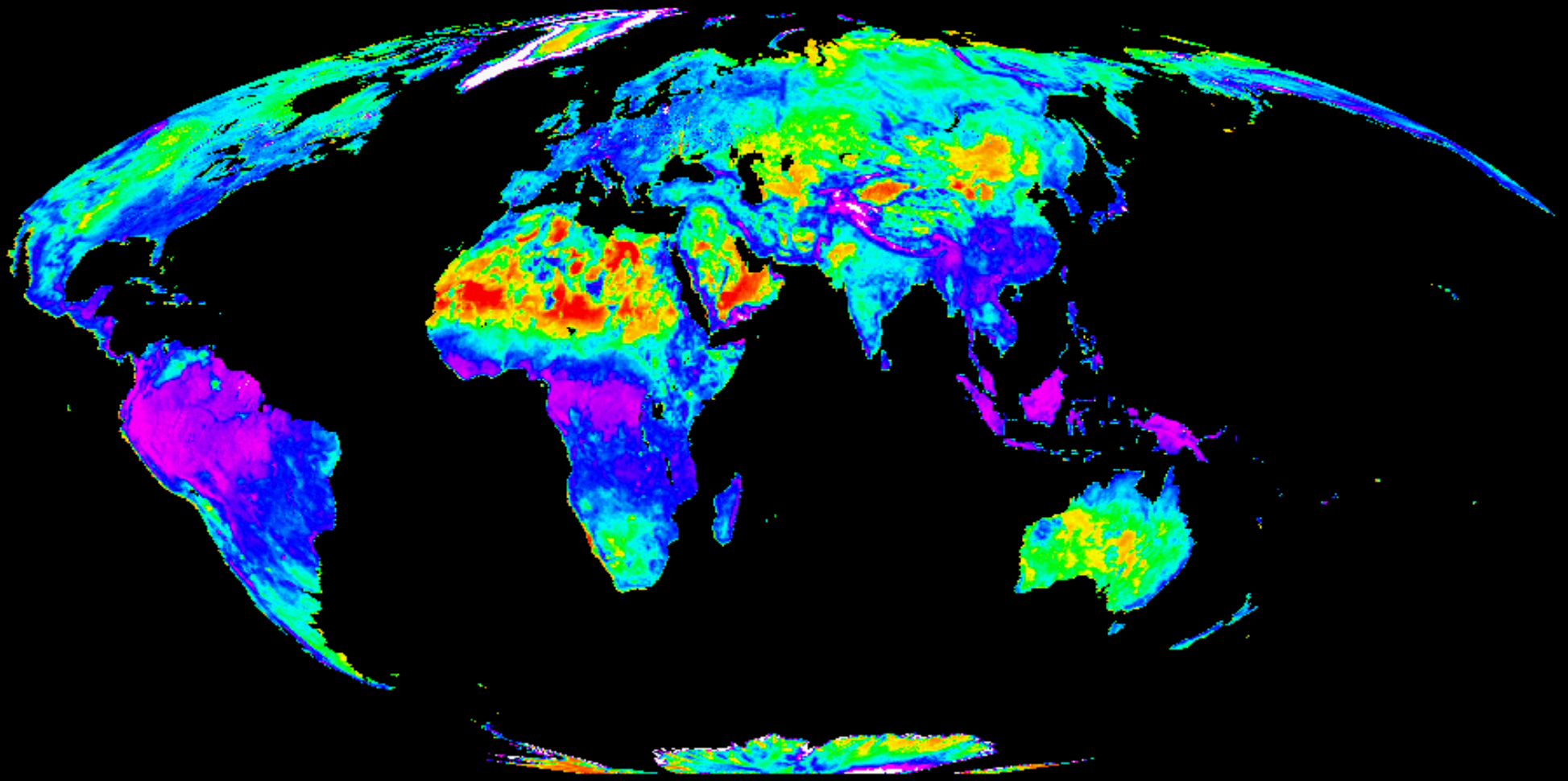
January 1993

ERS Scatterometer: global image of $\sigma^0(40°)$



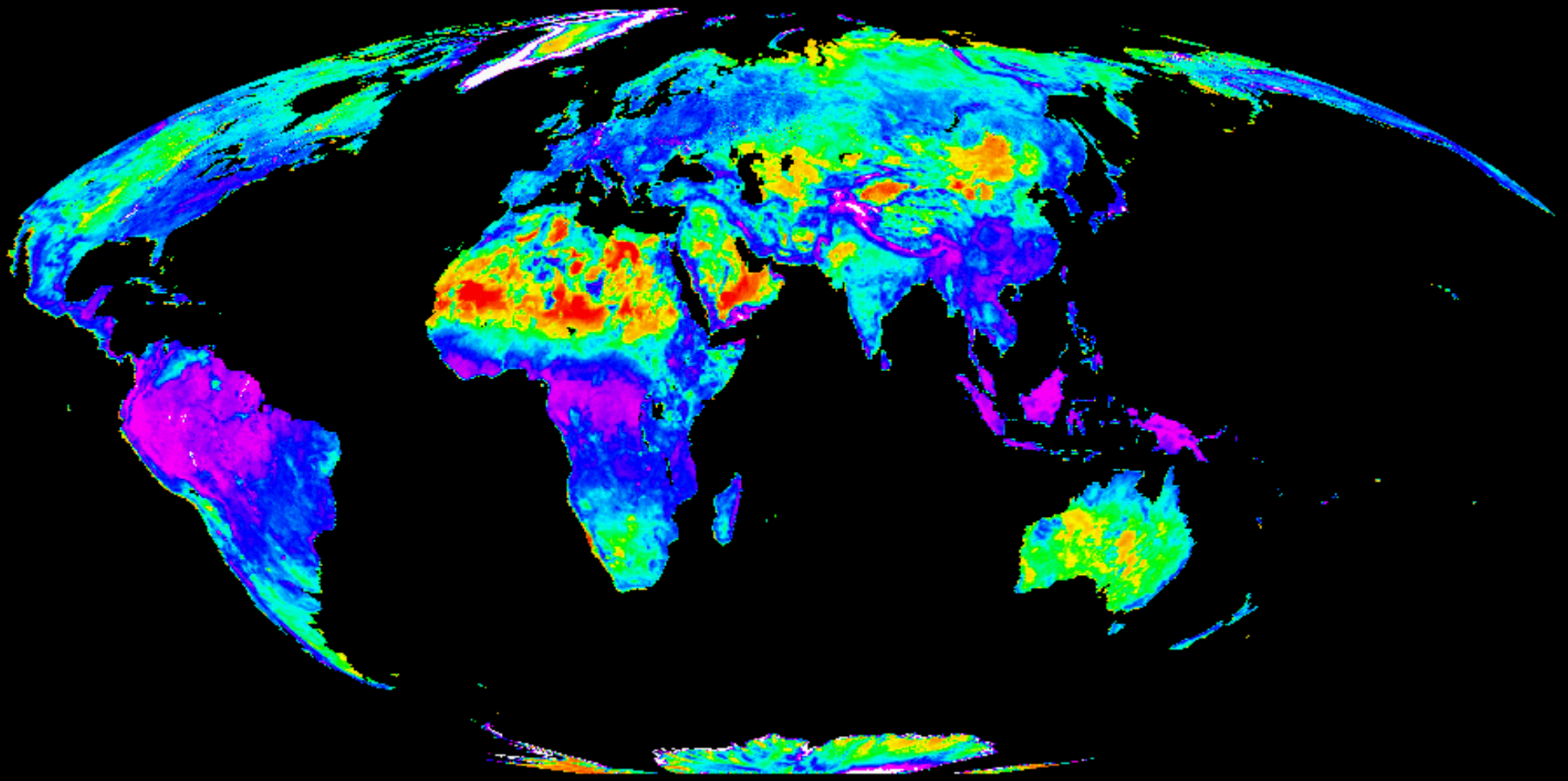
February 1993

ERS Scatterometer: global image of $\sigma^0(40°)$



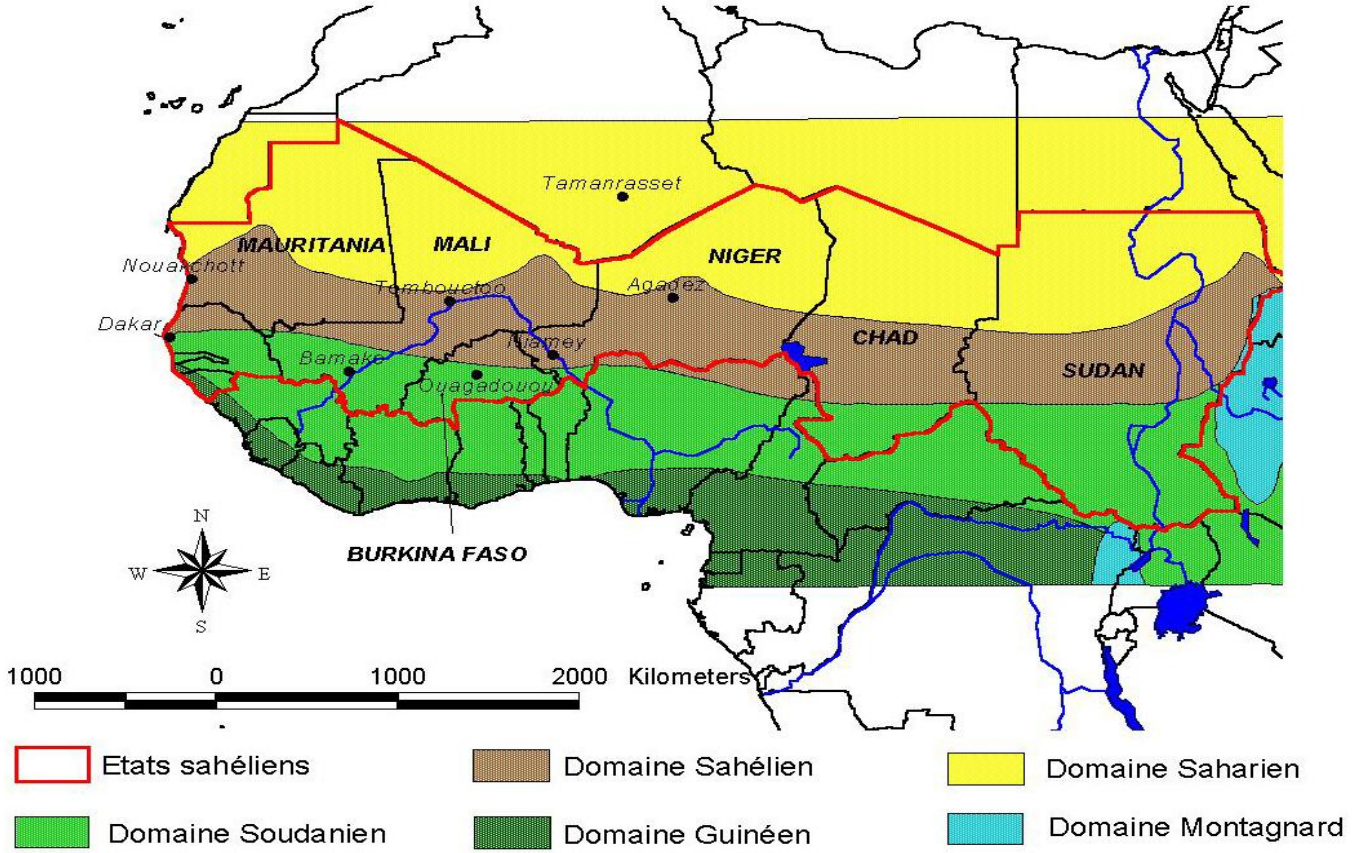
March 1993

ERS Scatterometer: global image of $\sigma^0(40°)$

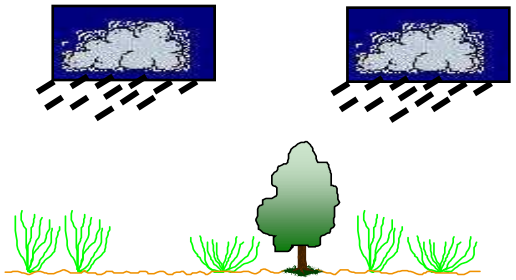


April 1993

The African Sahel



- Alarge dry season (from October to June) followed by a short rainy season (June-September)



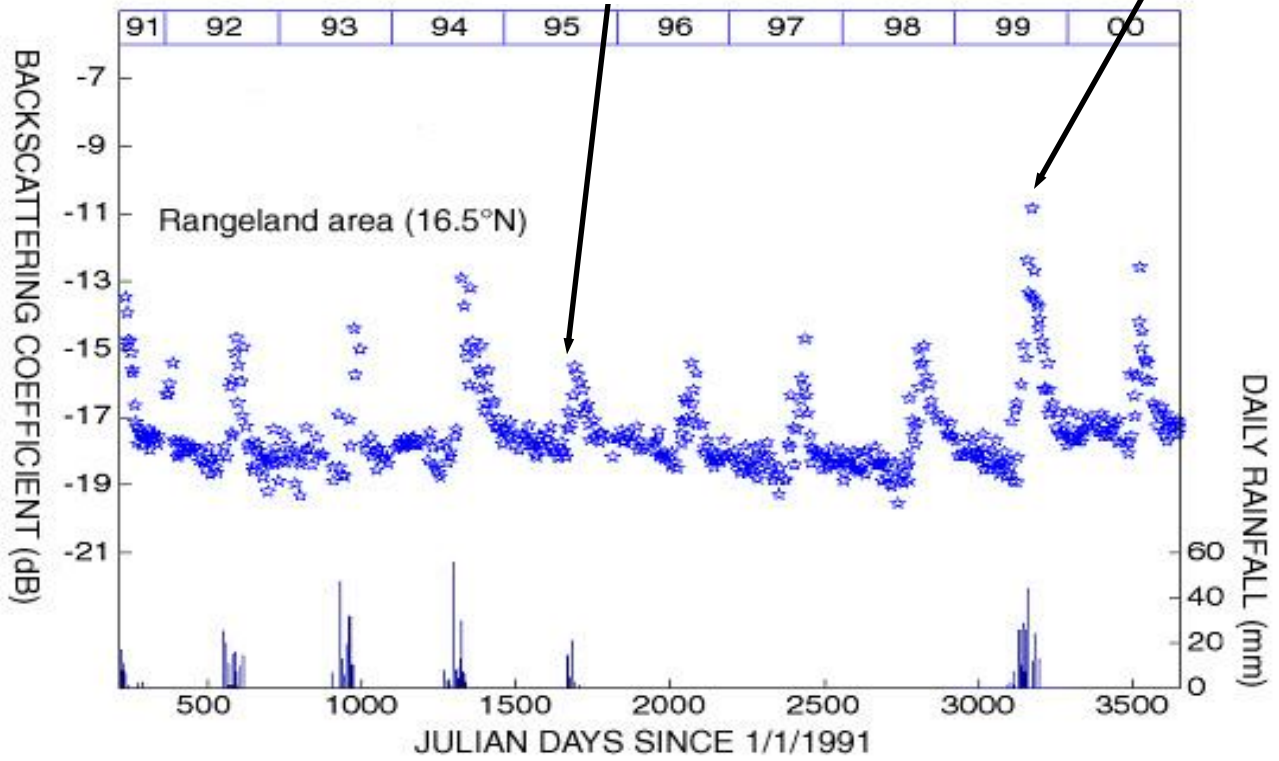
- Vegetation (natural or crops)
  ⇨ strongly linked to precipitation system

Temporal evolution of $\sigma^0(45°)$: Rharous

Dry year

Wet year

σ^0 (45°)



Modelization

Calibration with *in situ* biomass measurements

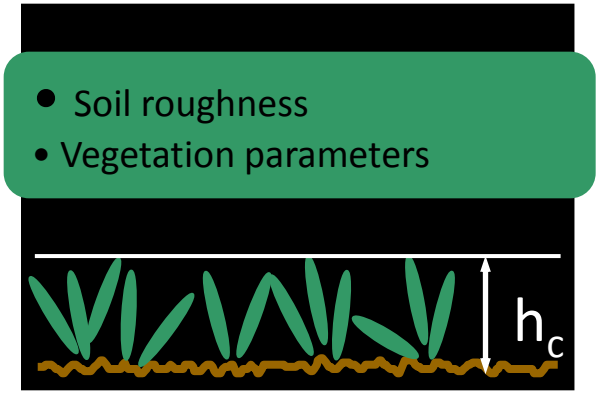
Sahelian vegetation Growth model (STEP)

- Daily meteo data
- Soil parameters

Daily surface parameters :
- Biomass
- Soil moisture

Radiative Transfert model (Karam, 1992)

- Soil roughness
- Vegetation parameters

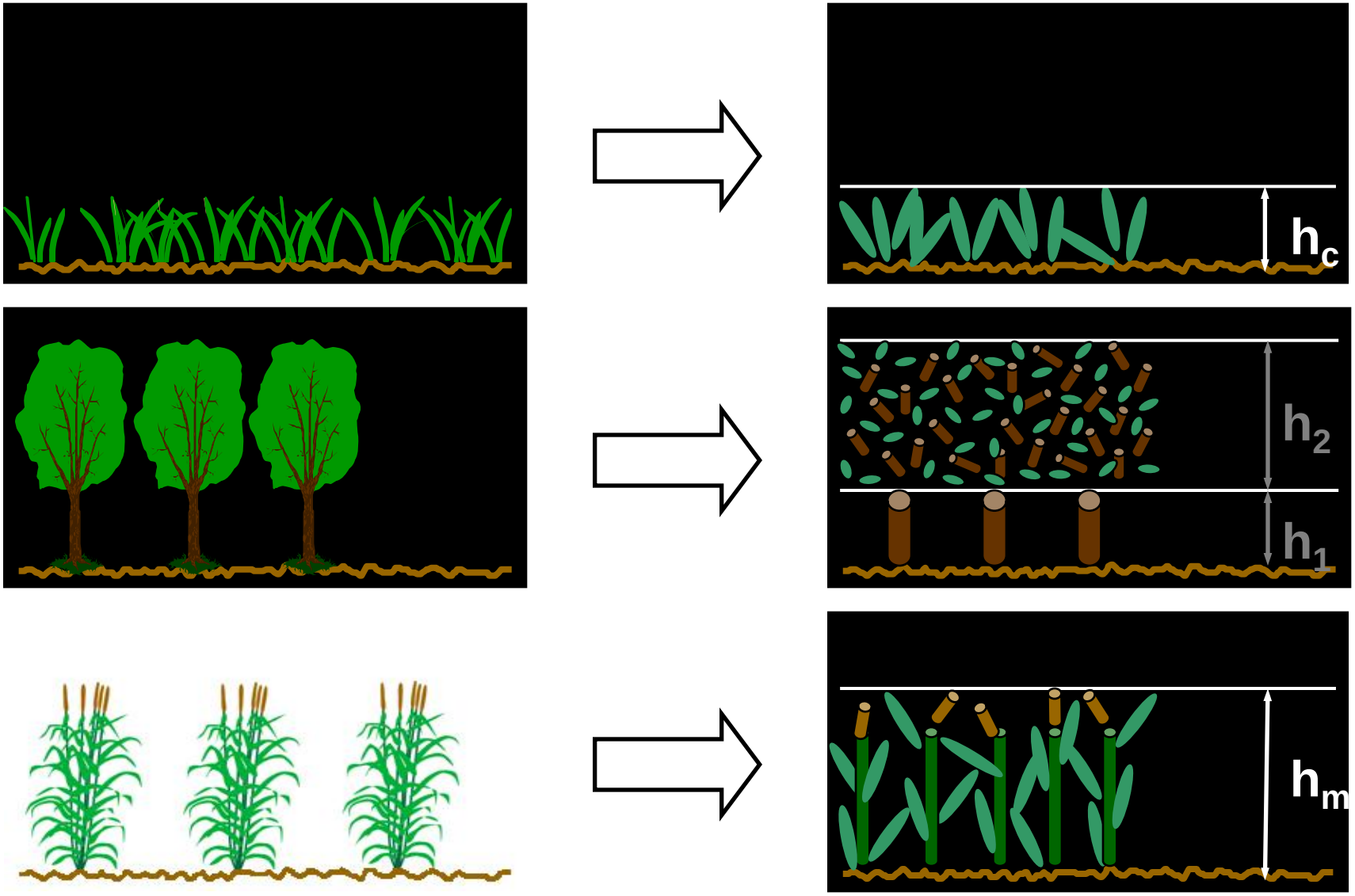


Simulated Backscattering coefficient $\sigma^0(t)$

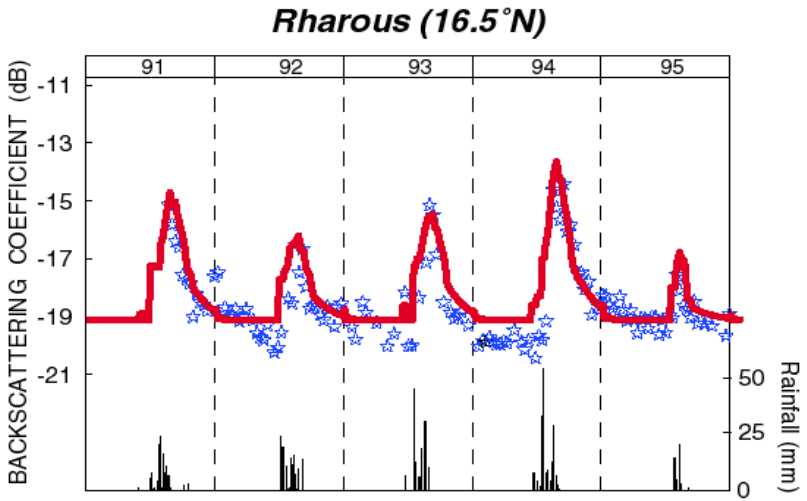
Radiative transfert model

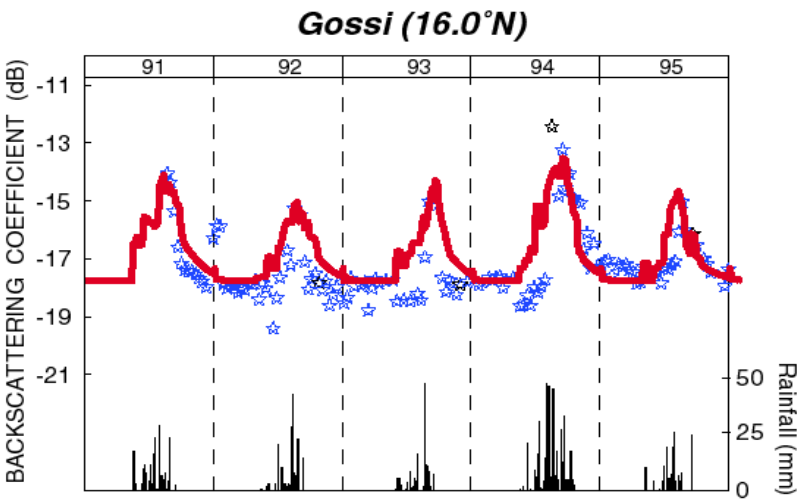
Observed scene

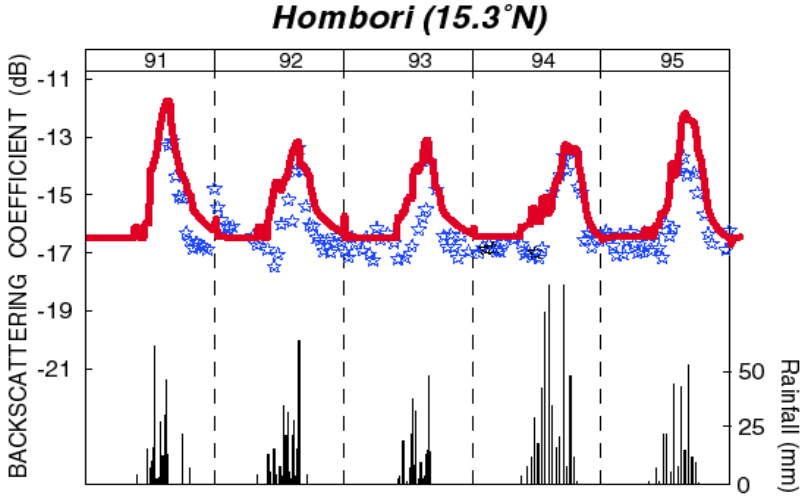
Simulated scene

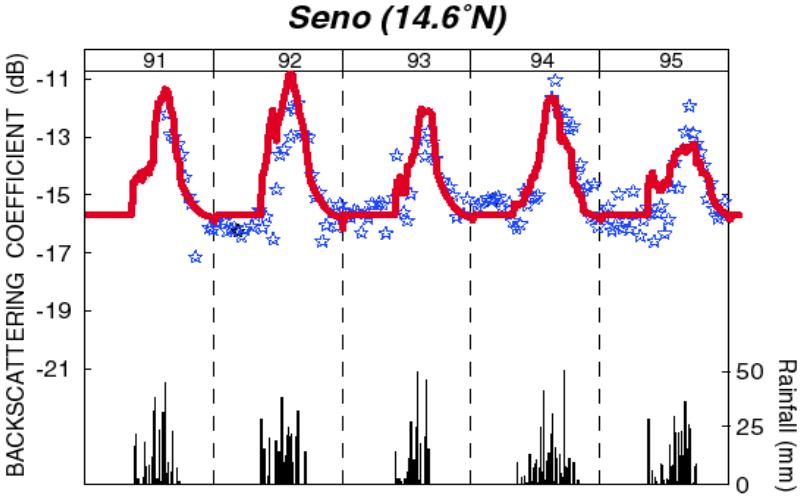


Résultats de modélisation à 45°

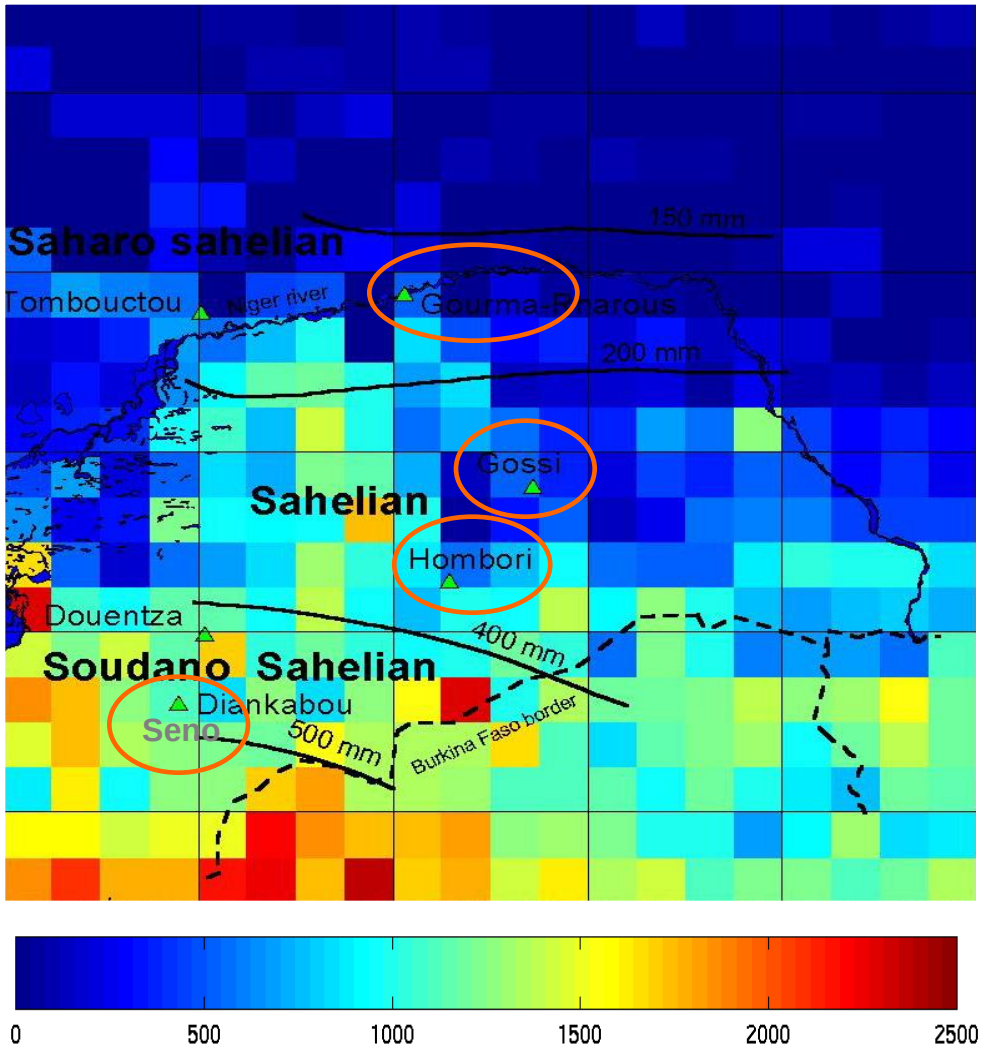








Inversion method : *Biomass production map at a regional scale*



Biomass + soil moisture:

➔ERS WSC + METEOSAT

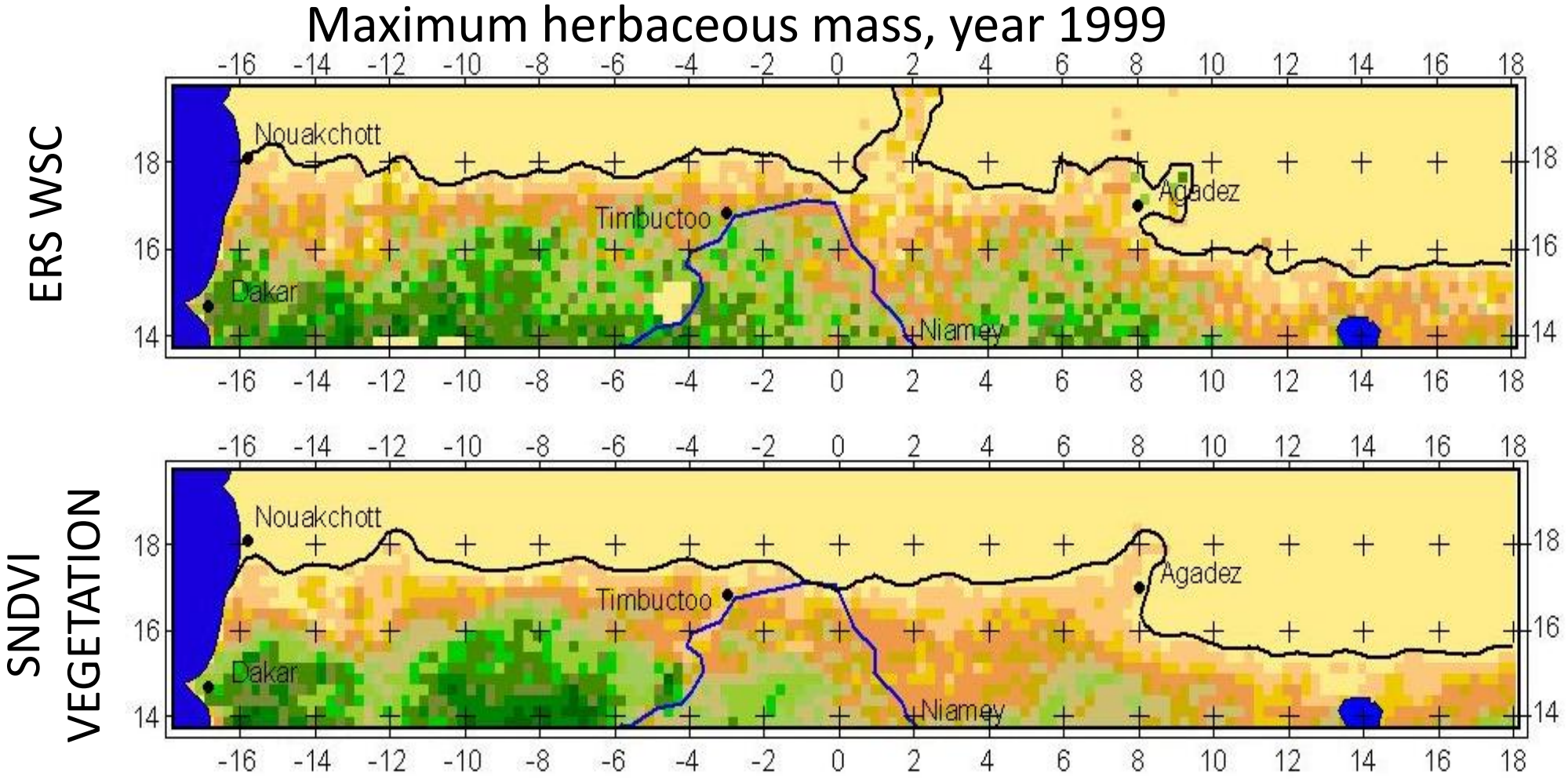
Validated over 4 pastoral sites (Gourma and Seno regions)

Absolute errors:

~ 200 kg DM / ha

❄ Relative error : **17 %**

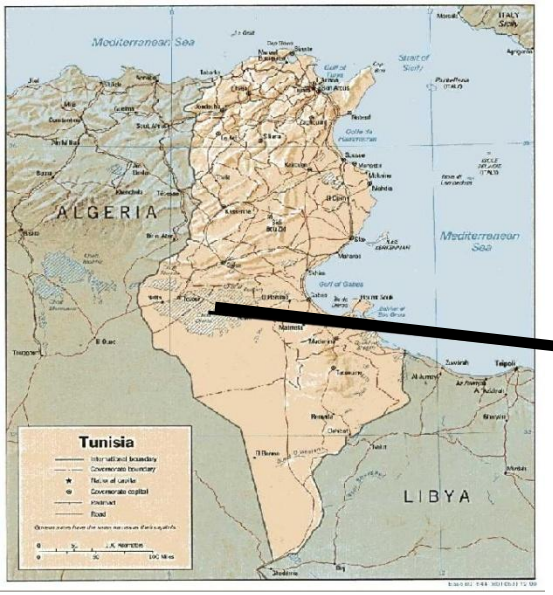
Spatialisation : Comparaison à VEGETATION/SPOT4 (2)



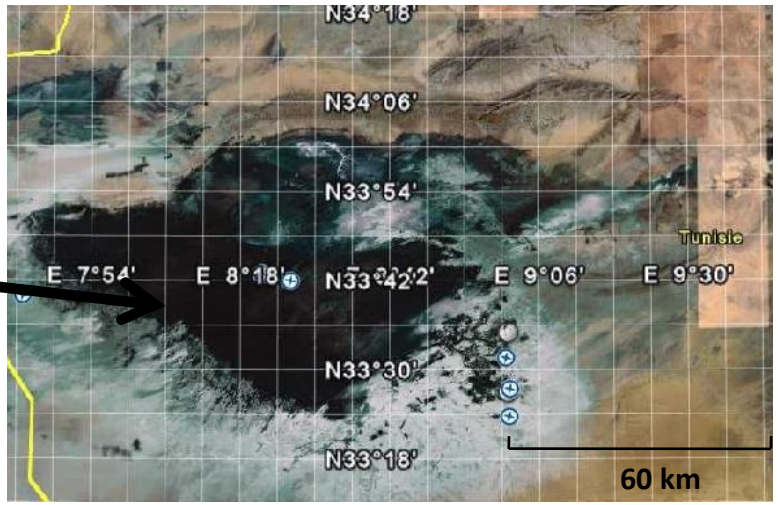
overall good agreement between both sensors

weaker values with respect to vegetation

The Chott El Jerid, Tunisia



A vast evaporitic (80 x 120 km) playas (evaporite = saline deposits)



Discharge playa from a major aquifere + occasional runoff from neighbouring playa (Fedjadj).

➔ ***Temporary flooding*** ➔ Flooded / dry surface

Wettest months

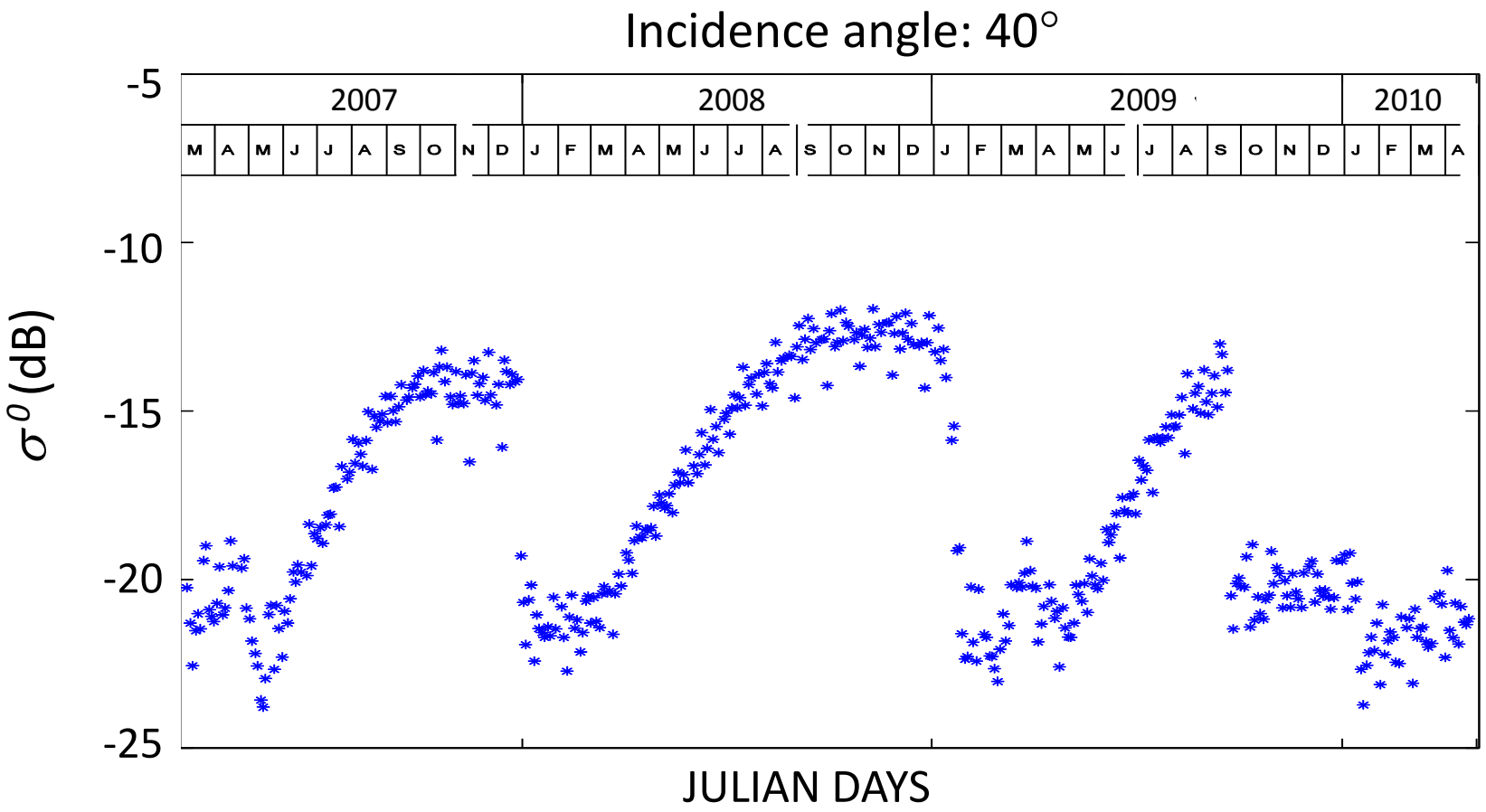
sudden smoothing due to dissolution of saline crust

+ dramatic change of diel. const. (saline solution)

Summer months:

evaporation ➔ halite crystal growth ➔ increase of roughness

ASCAT temporal signature over the ***Chott el Jerid***

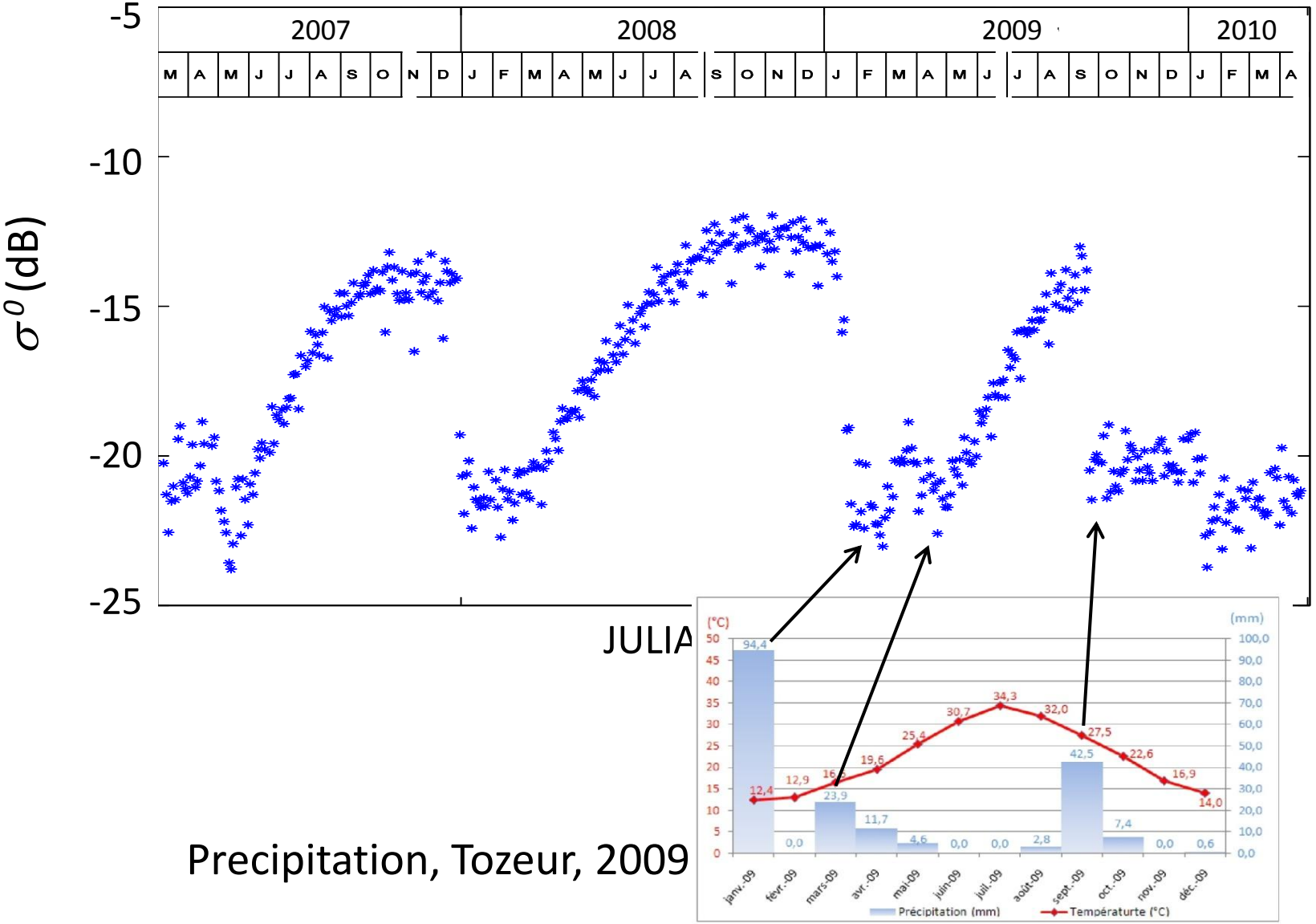


High temporal dynamic (> 10 dB)

Linked to environment seasonal variations

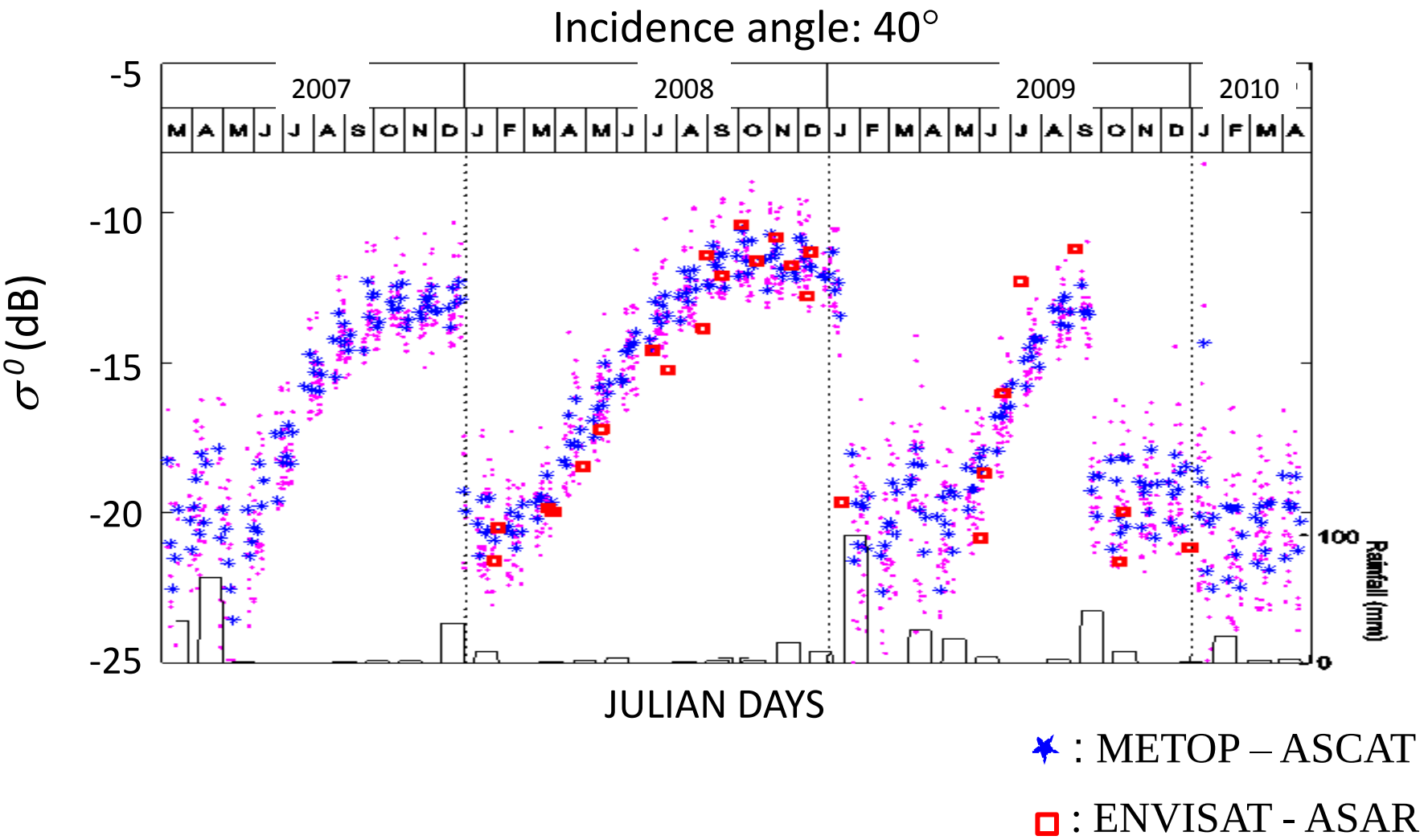
ASCAT temporal signature over the *Chott el Jerid*

Incidence angle: 40°



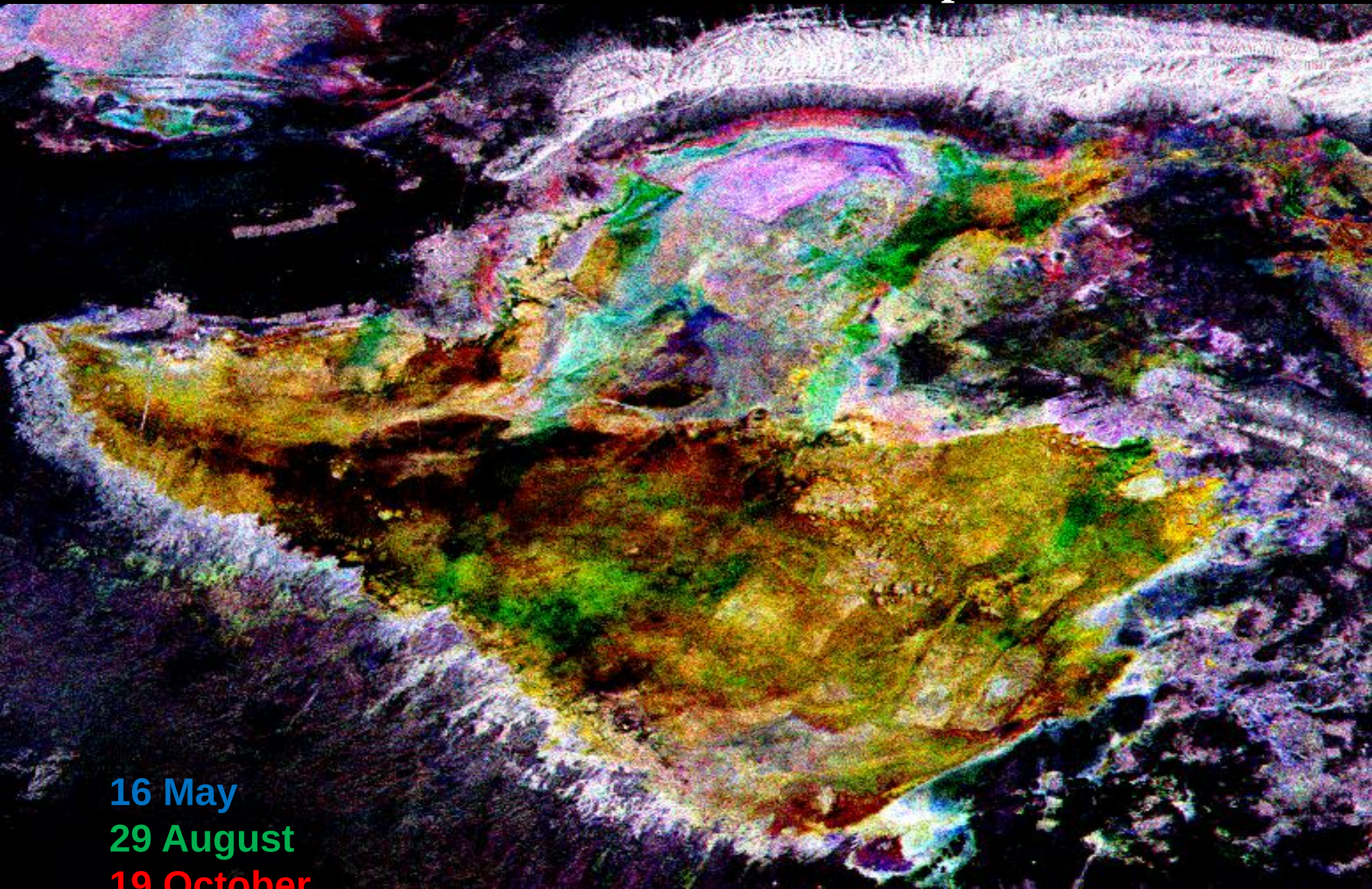
Precipitation, Tozeur, 2009

ASCAT temporal signature over the ***Chott el Jerid***

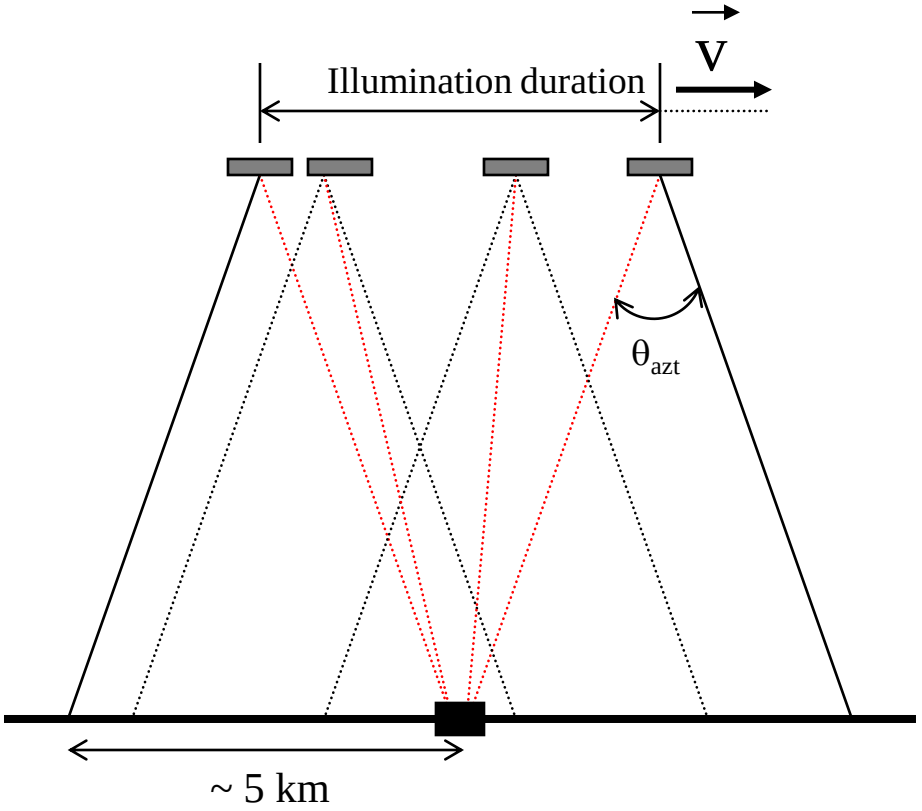


Satterometer temporal frequency (< 2 days) well suited for monitoring seasonnal dynamic

ASAR – WIDE SWATH: Multidate composition (year 2009)



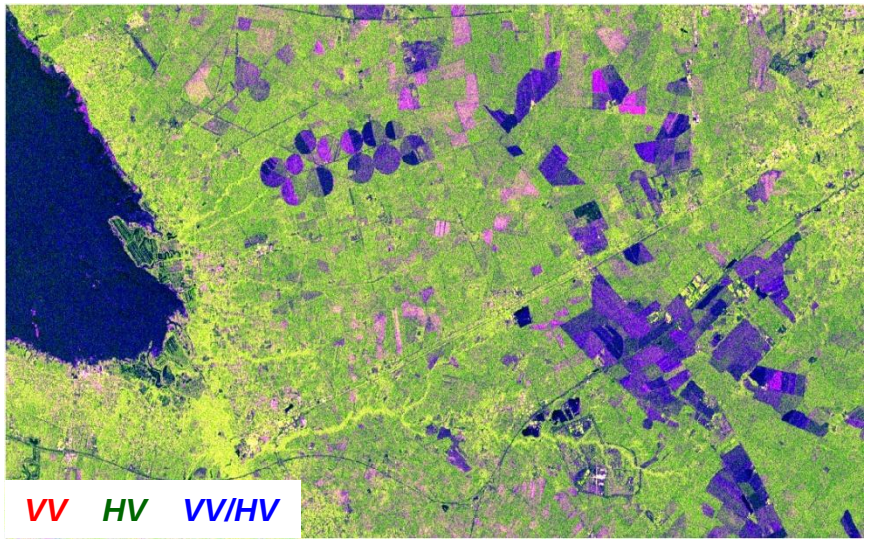
Side looking radar sensors



SAR:

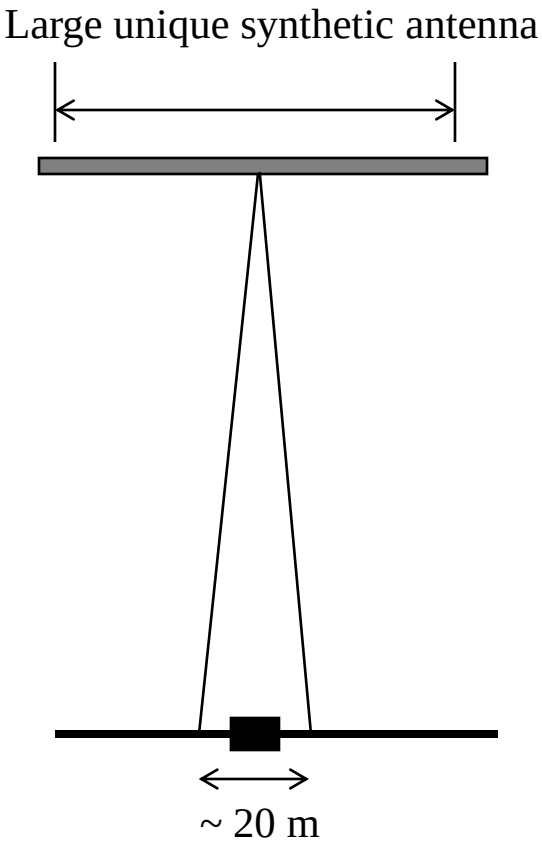
☞ *surface imaging*

- ***high spatial resolution***: *~ 10 m*
- ***low frequency of acquisition (~ month)***



Sentinel-1
Les landes – March 2015

Side looking radar sensors



SAR:

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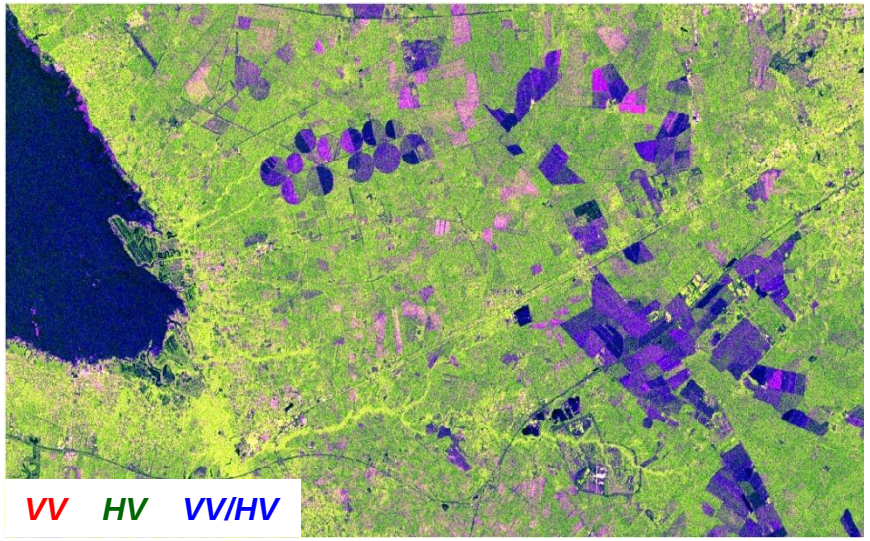
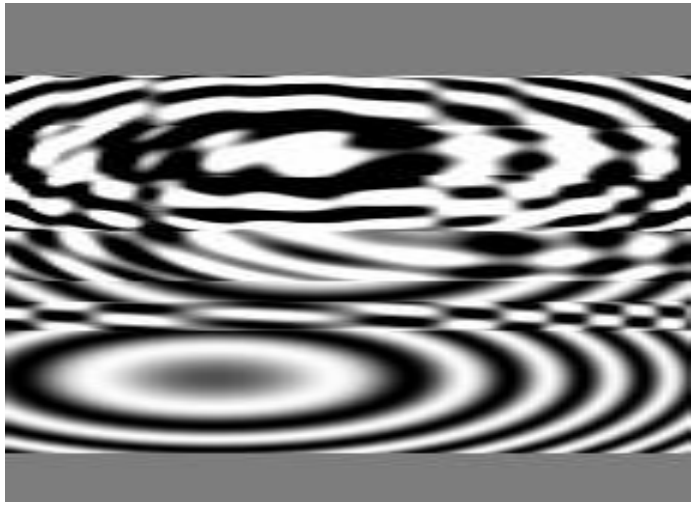
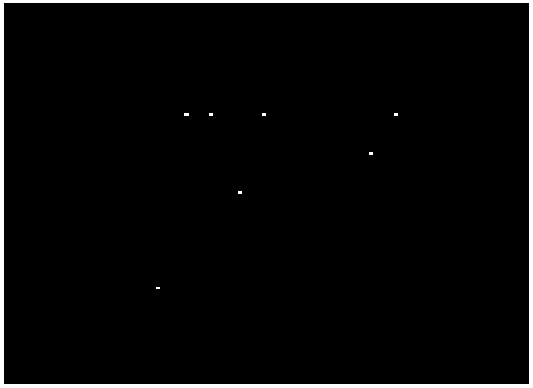
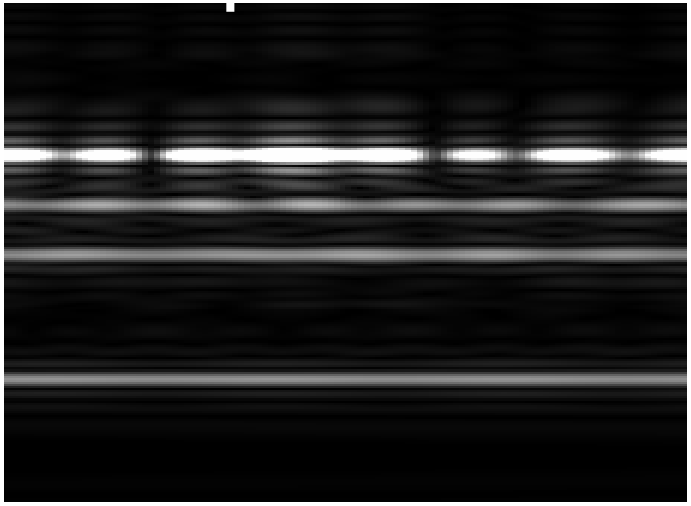
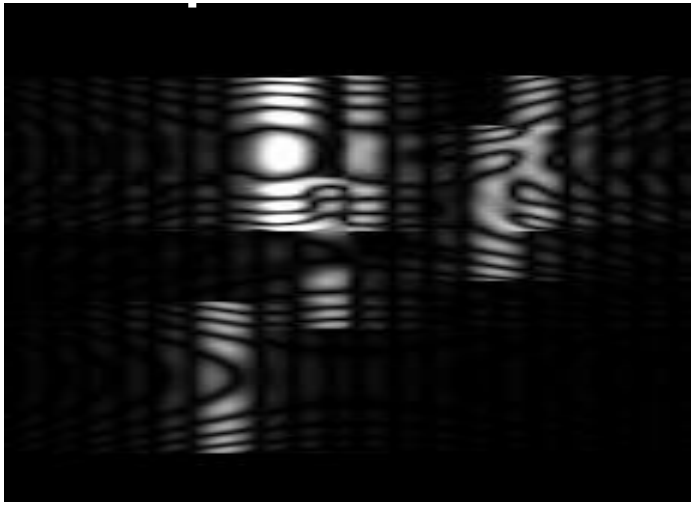


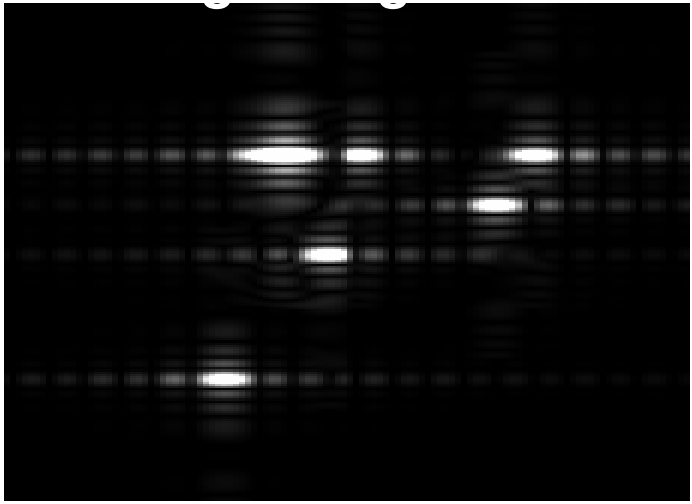
Sentinel-1
Les landes – March 2015







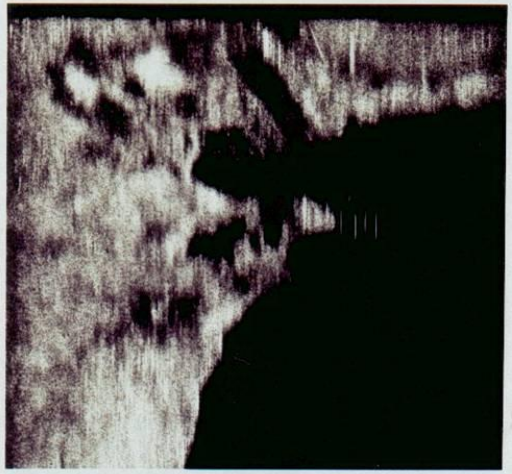




NON COMPRIME DISTANCE
NON COMPRIME AZIMUT

NON COMPRIME DISTANCE
COMPRIME AZIMUT

Document CNES



COMPRIME DISTANCE
NON COMPRIME AZIMUT

COMPRIME DISTANCE
COMPRIME AZIMUT

Frequency - wavelength

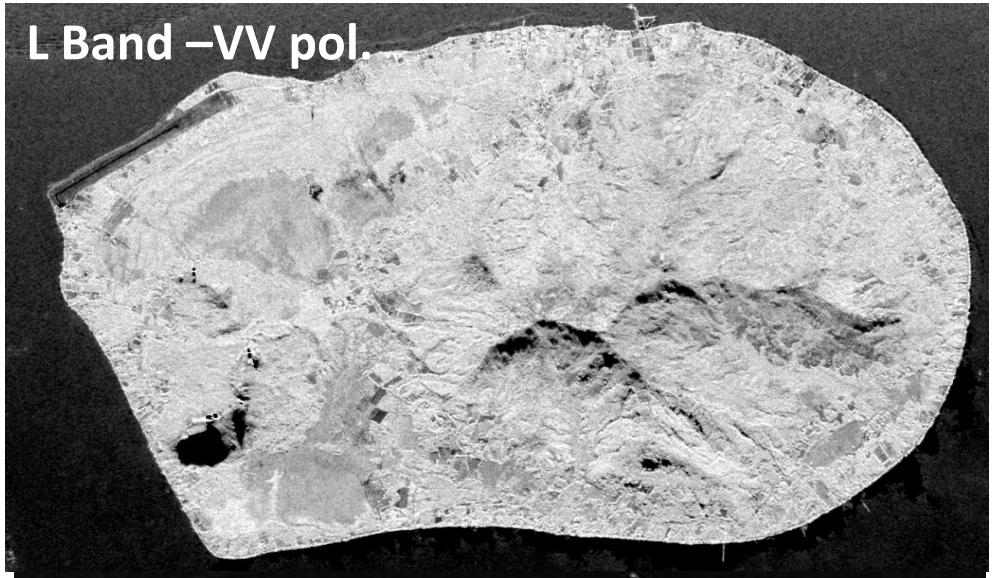
Radar band frequencies / wavelengths

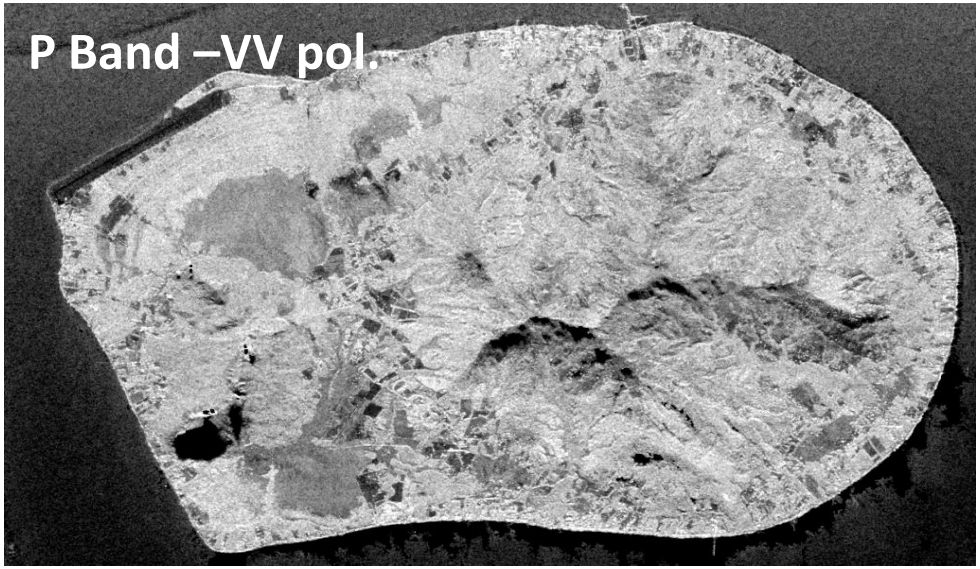
$$\lambda = c\,T = \frac{c}{f_0}$$

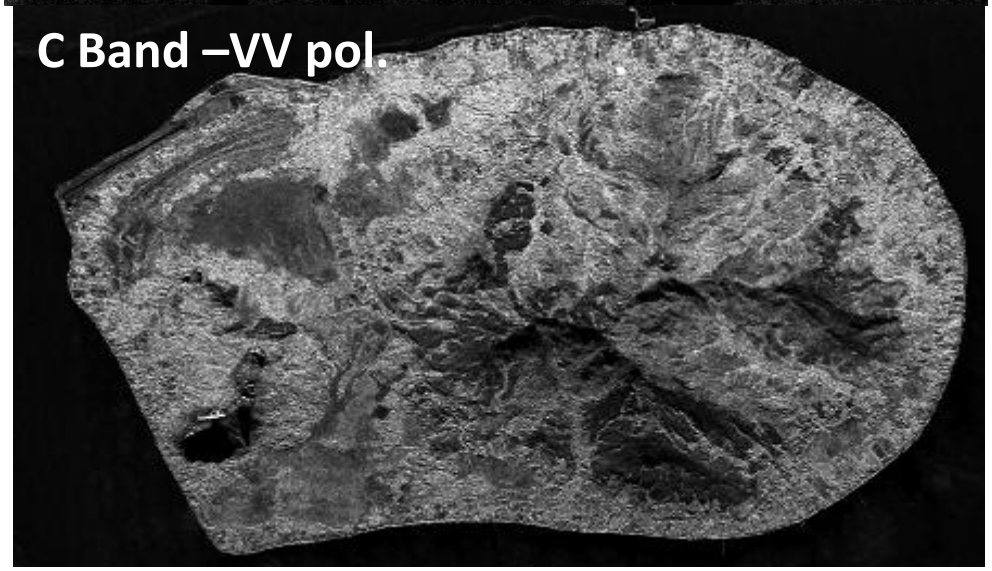
Bande X	**λ ~ 3 cm**	**F ~10 GHz**
Bande C	**λ ~ 6 cm**	**F~5 GHz**
Bande L	**λ ~ 25 cm**	**F~1,2 GHz**
Bande P	**λ ~ 60 cm**	**F~500 MHz**

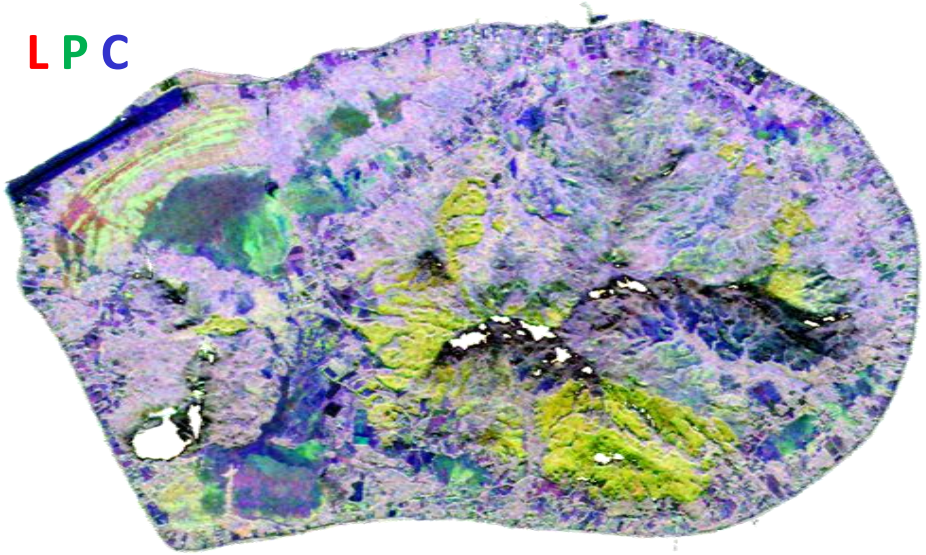
Frequency - wavelength

Tubuai Island, Vegetation discrimination



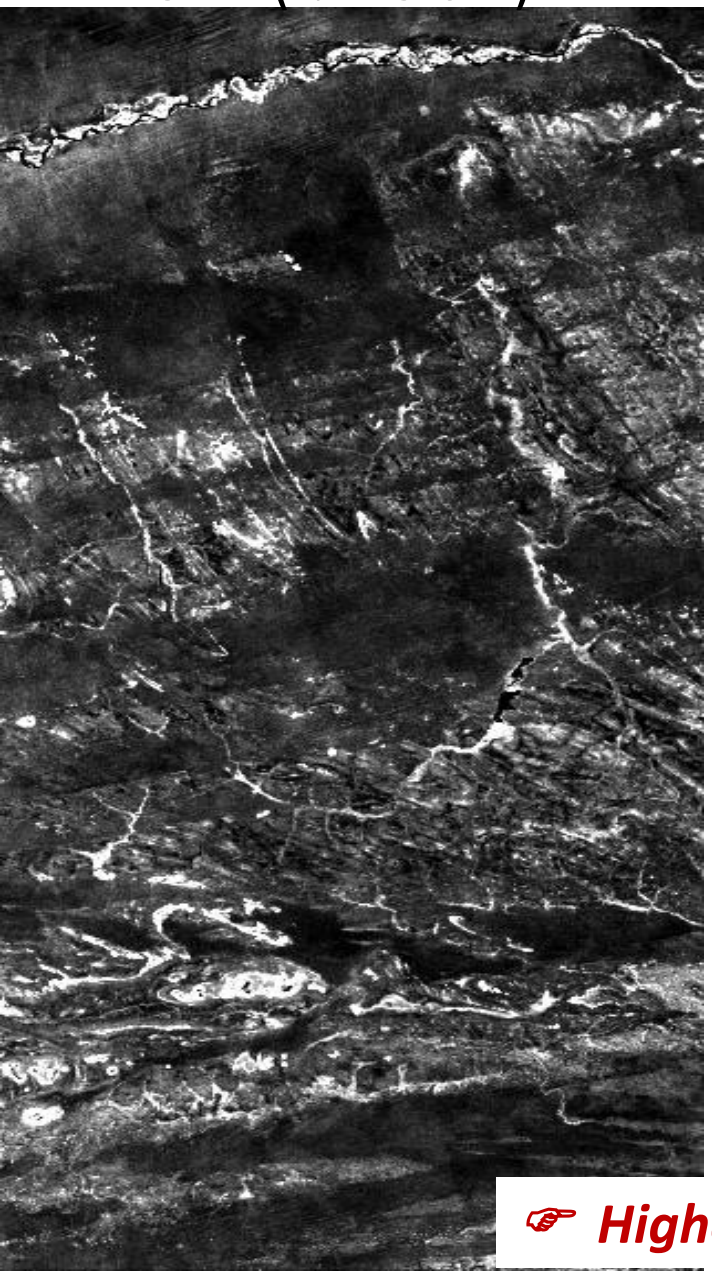






Comparison between C and L band

ASAR (λ = 6 cm)



PALSAR (λ = 24 cm)

C Band (ASAR):
Sensitive to sandy soils

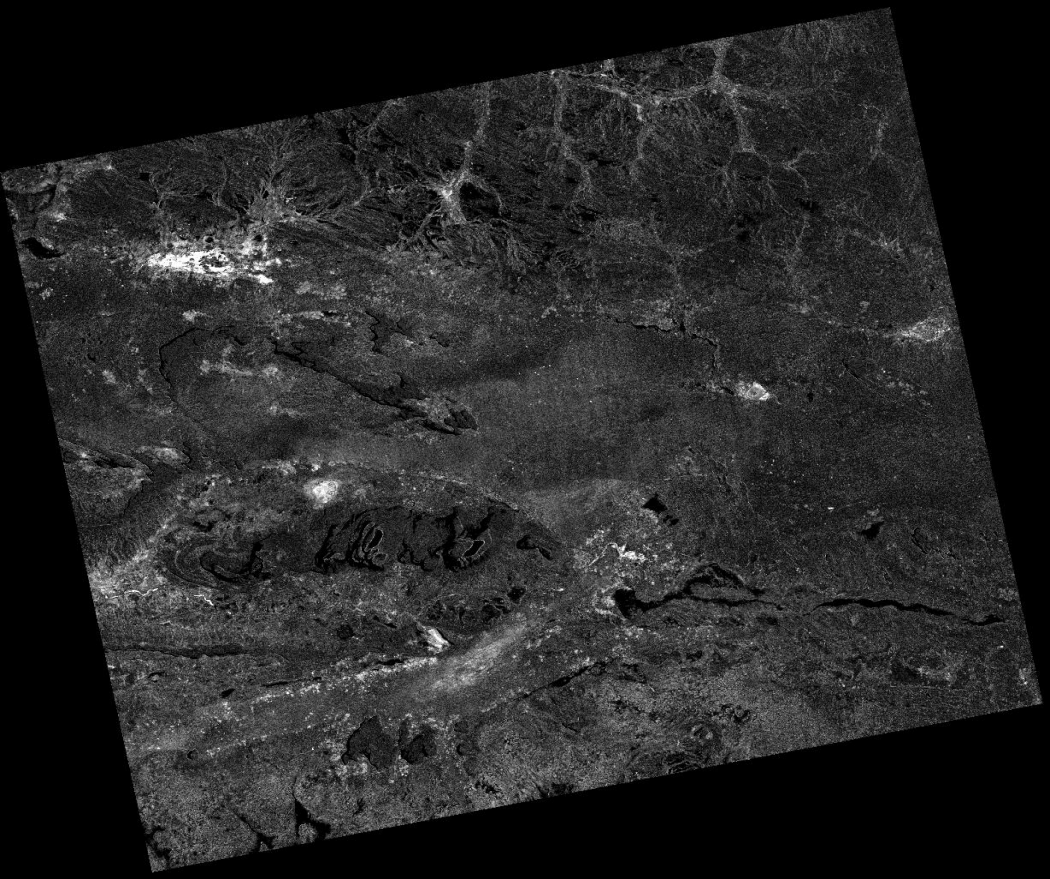
L Band (PALSAR):
Better discrimination of buried geological features

Remnant of alluvial systems

☞ ***Higher penetration of L band over sandy soils***

Comparison C band / L band for change detection

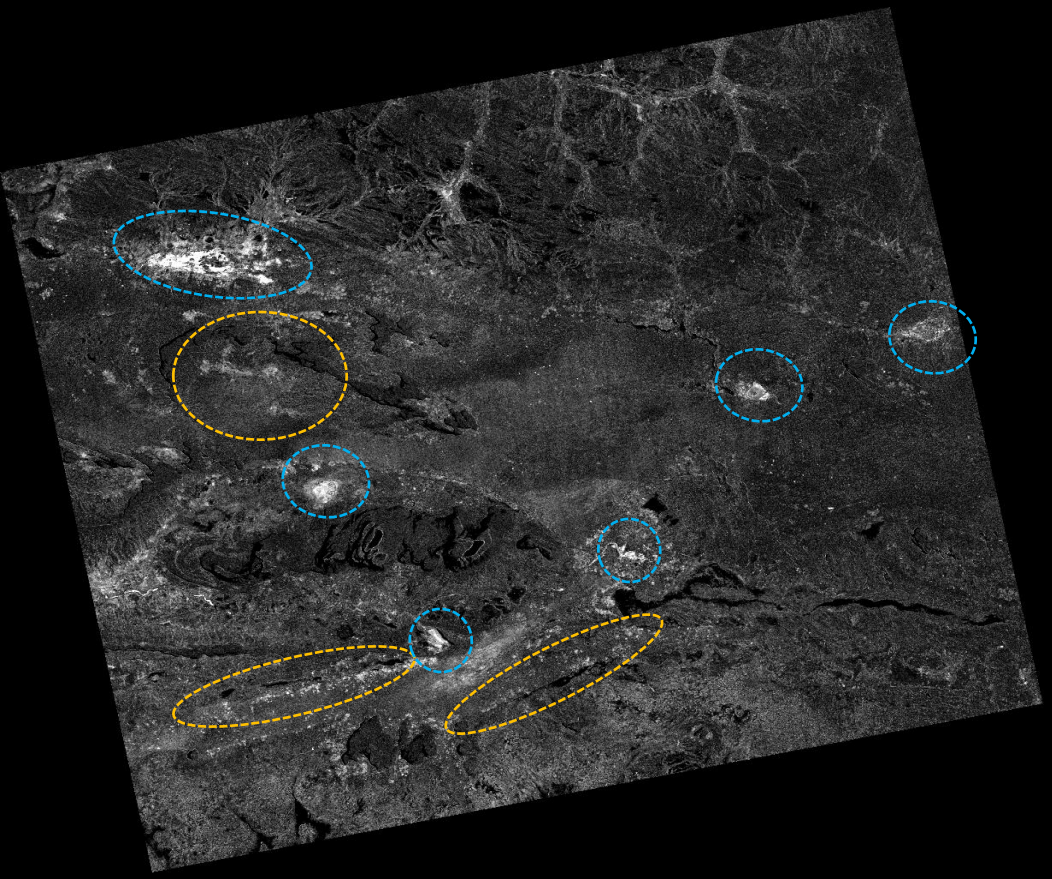
PALSAR (λ = 24 cm)
12 images: Jan. 2007 – avr. 2009



ASAR (λ = 6 cm)
5 images: Jul. 2005 – Dec. 2005

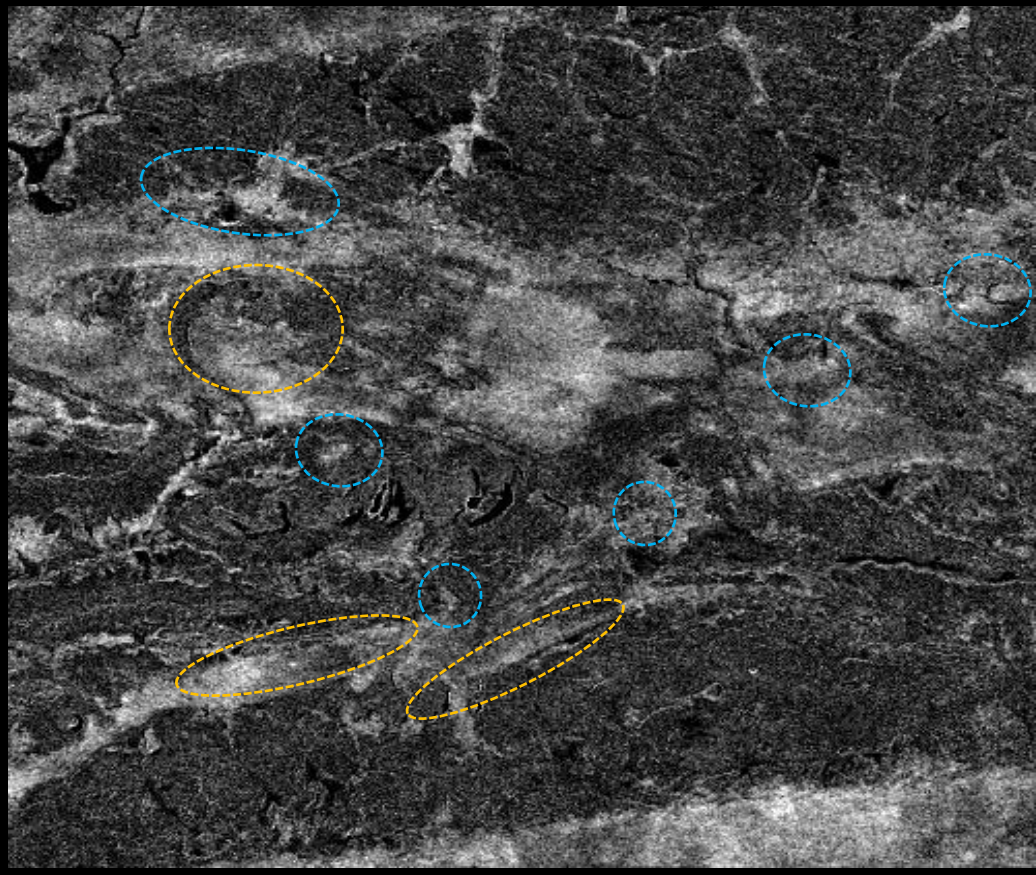
Comparison C band / L band for change detection

PALSAR (λ = 24 cm)
12 images: Jan. 2007 – avr. 2009



High penetration over sandy soils
changes over water ponds
+ millet fields

ASAR (λ = 6 cm)
5 images: Jul. 2005 – Dec. 2005

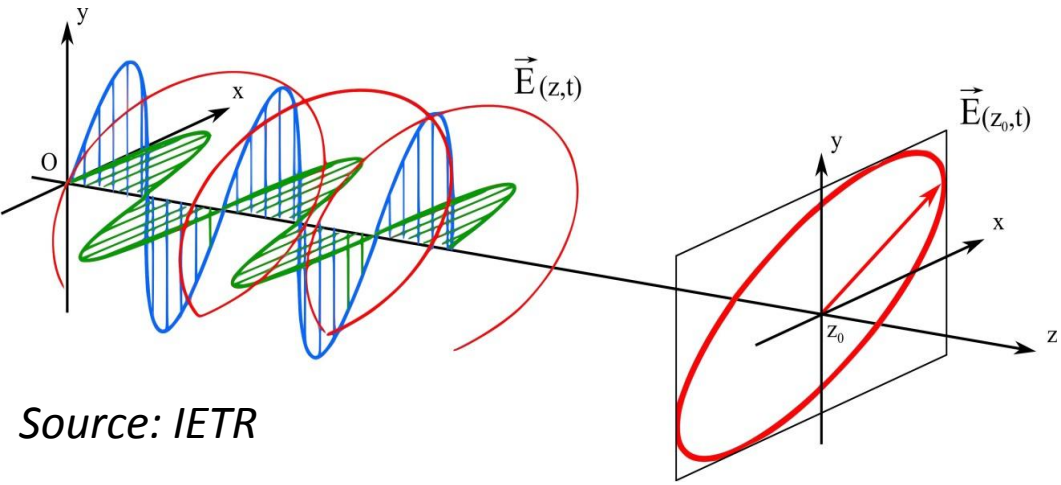


Low penetration over sandy soils
changes due to surface states variations
+ water ponds

Polarization

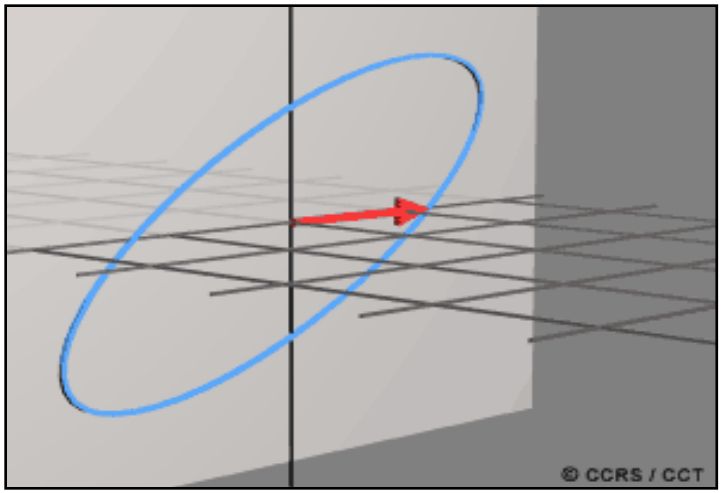
Important characteristics of cohetent EMW:

Electromagnetic field evolution is predictable



Source: IETR

Most general: ***Elliptical*** *polarization*



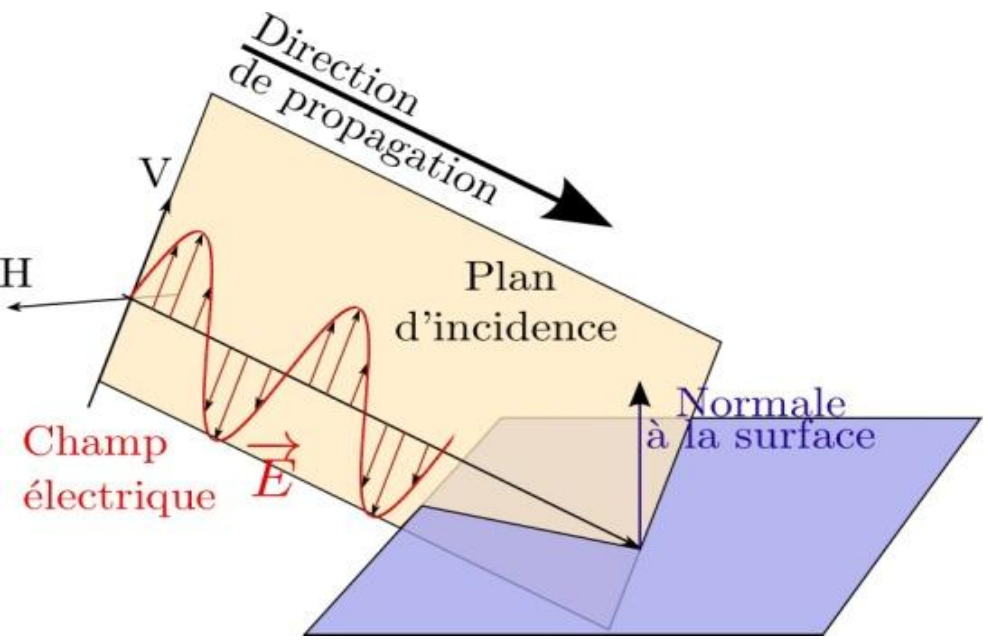
Polarization

Radar :

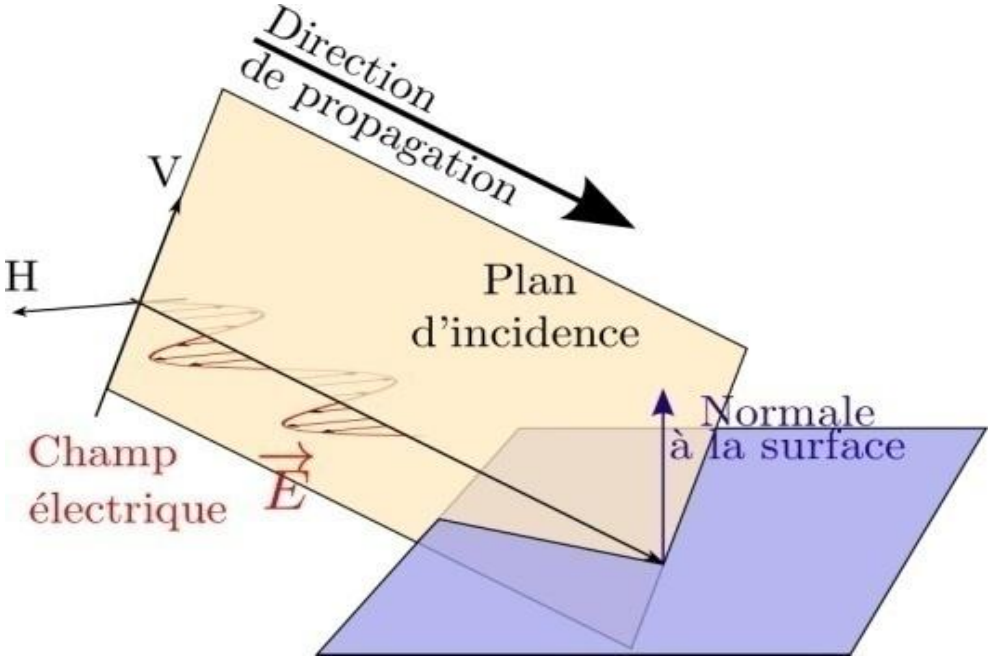
transmits a EMW in a given polarization

measures the backscattered wave contribution in a given polarization

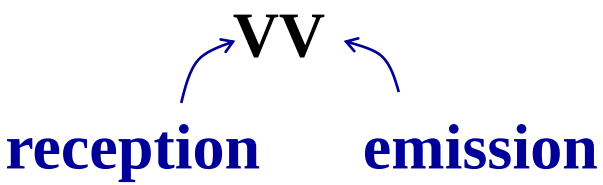
Vertical polarization



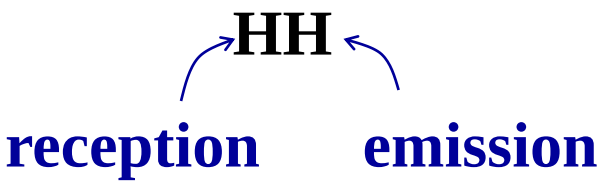
horizontal polarization



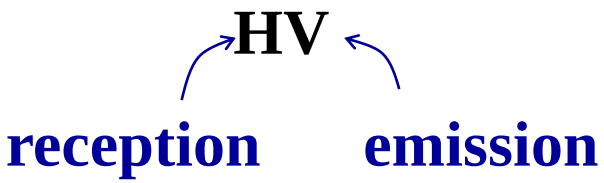
Polarization characterisation of a radar acquisition:



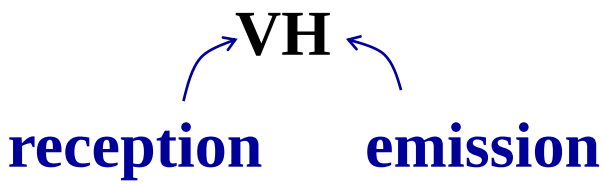
ERS, ASAR



JERS, RADARSAT, PALSAR

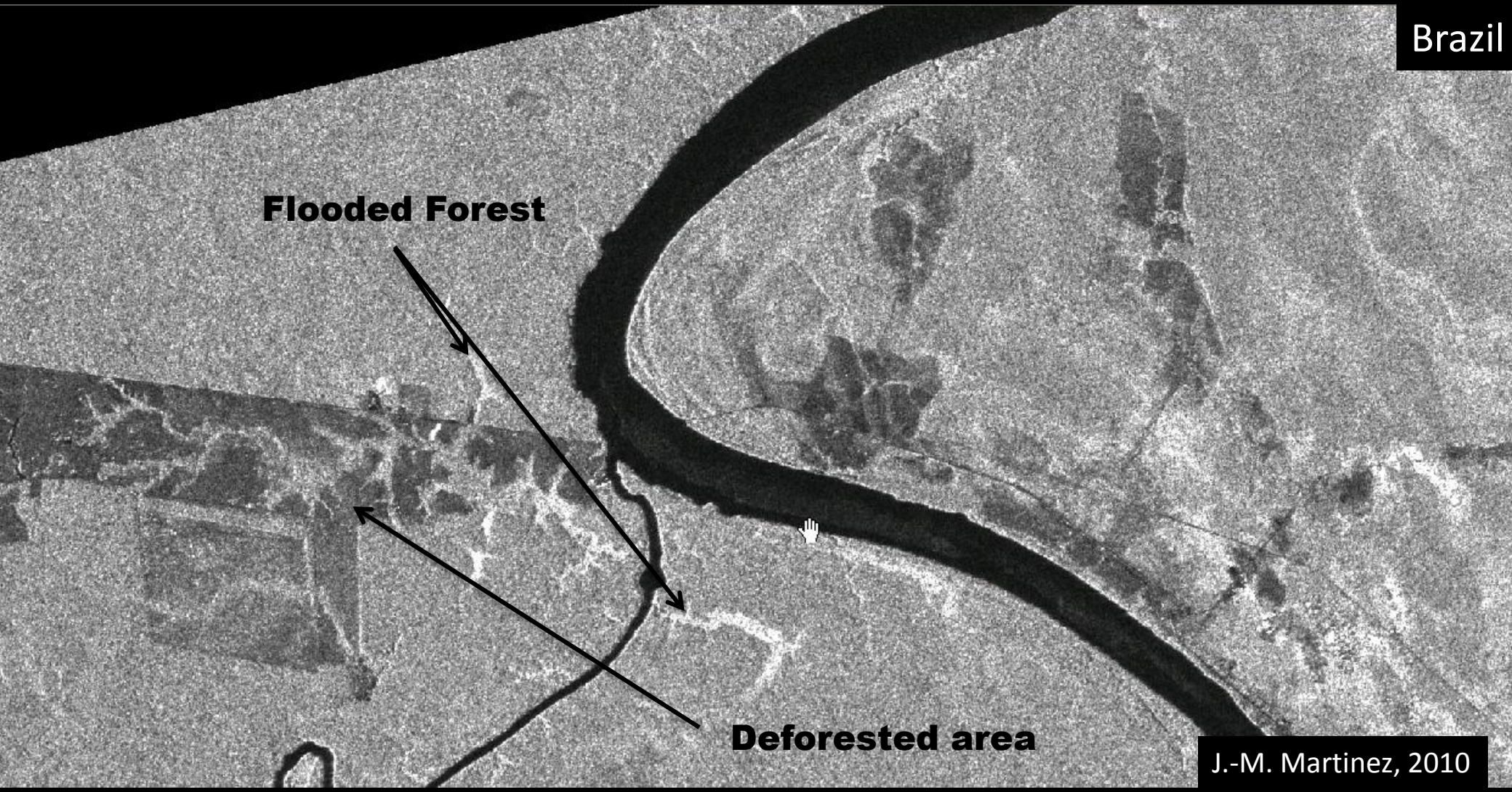


ASAR, PALSAR



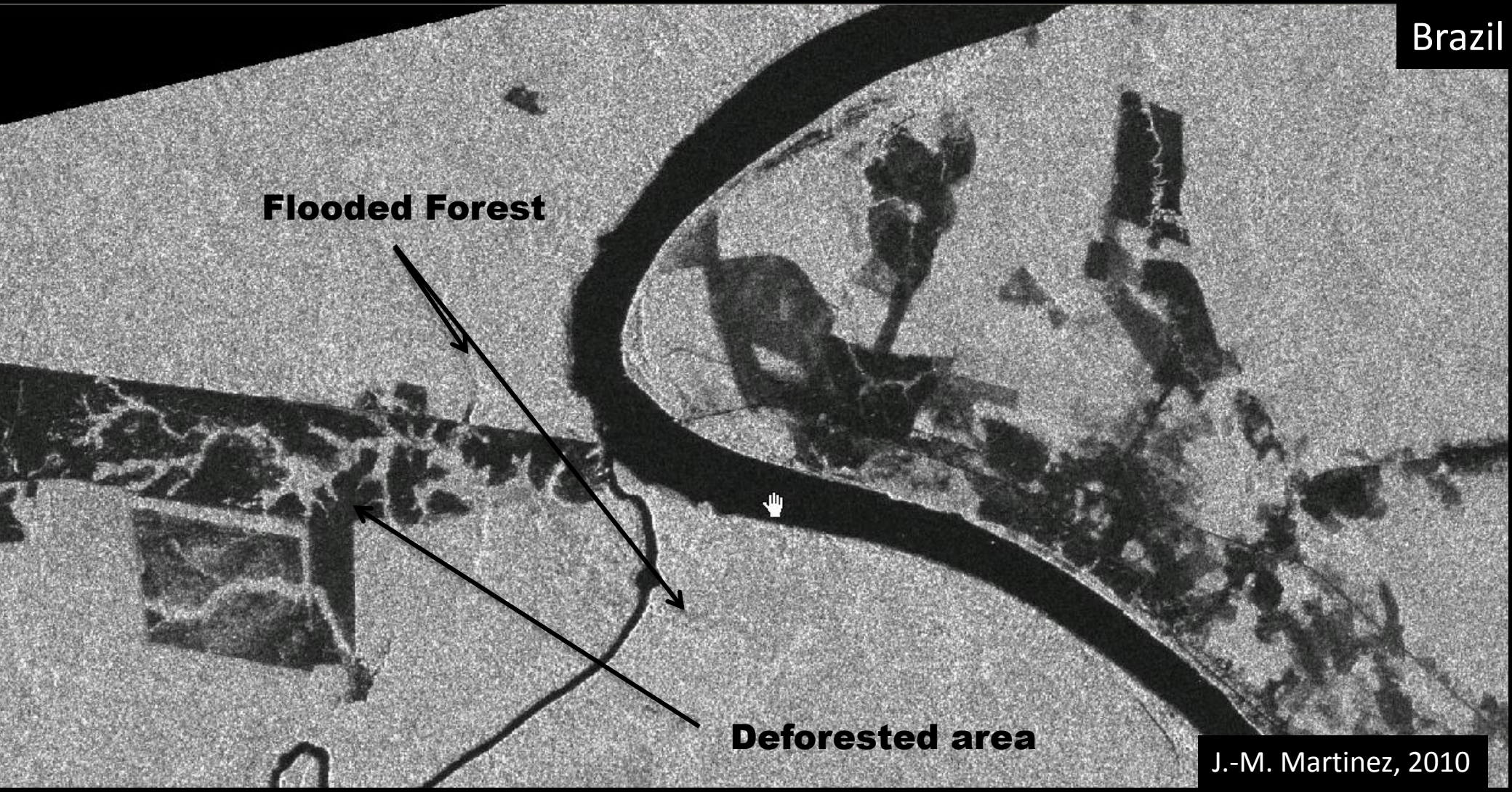
ASAR, PALSAR

Polarization



ALOS acquisition (λ = 24 cm)- ***HH*** Polarization

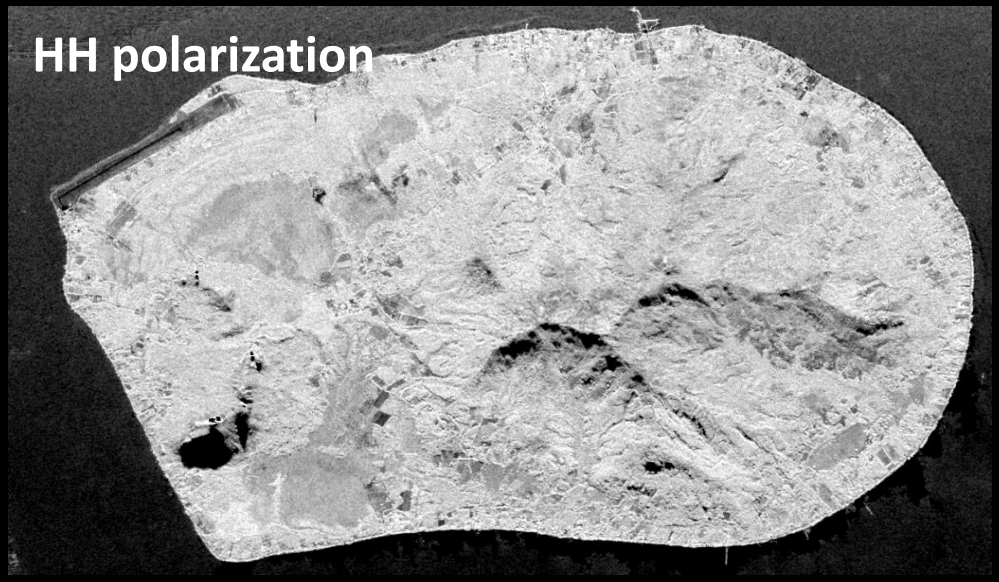
Polarization

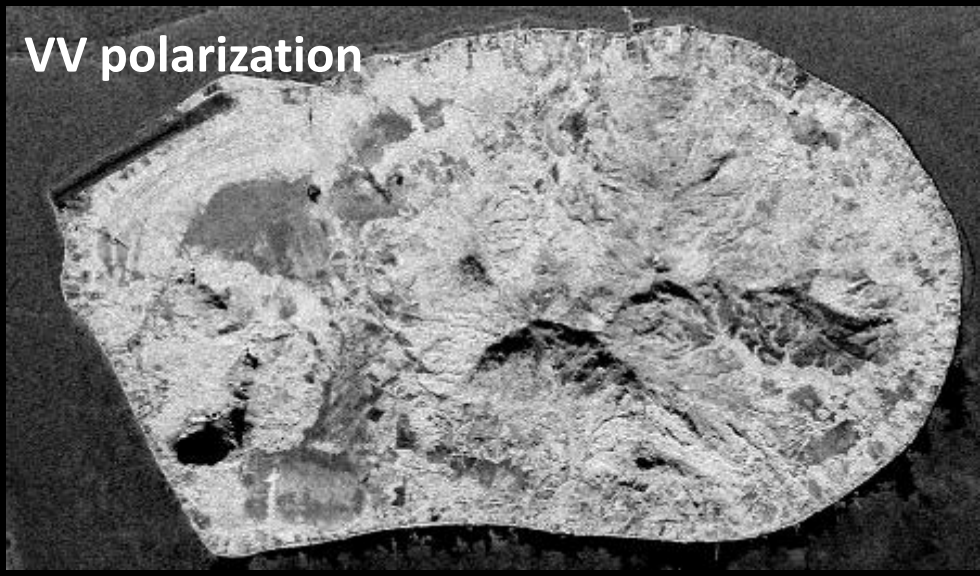


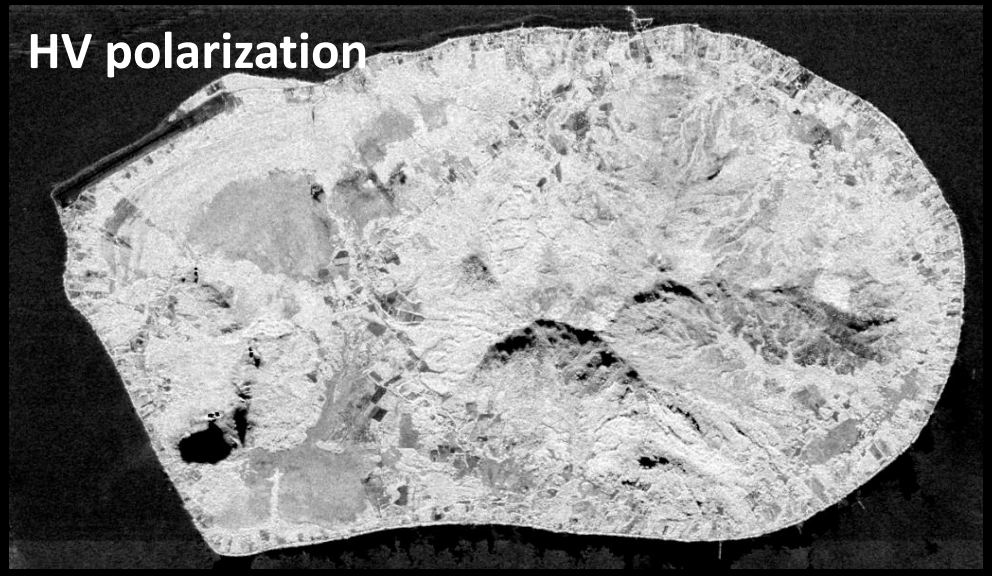
ALOS acquisition (λ = 24 cm)- ***HV*** Polarization

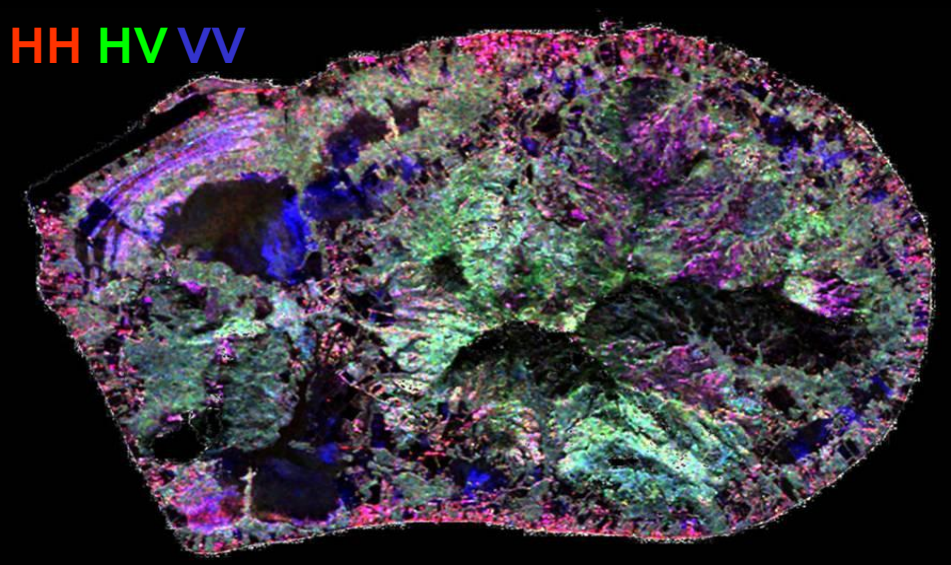
Polarization

Tubuai Island, vegetation discrimination, L Band





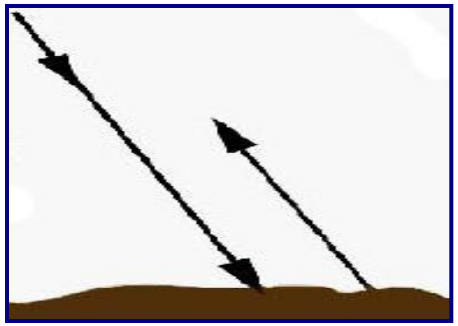




Radar polarimetry:

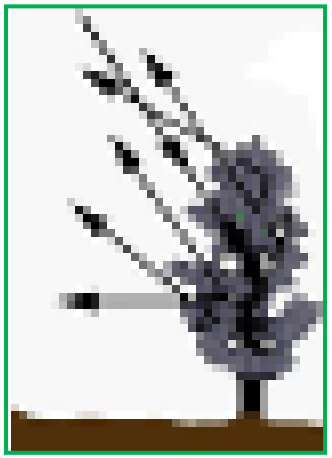
sensitive to ***scattering mechanisms*** within a resolution cell

==> Sensitive to ***vegetation geometrical structure***



Surface scattering *(bare soil)*

Double bounds *(flooded vegetation or urban areas)*



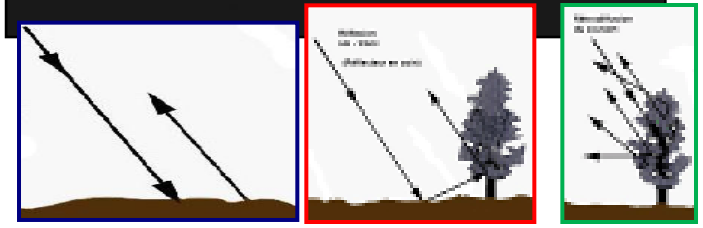
Volume scattering
(dense vegetation)

SAR polarimetry for vegetation cartography

Île de Tubuai, Polynésie française

Quickbird

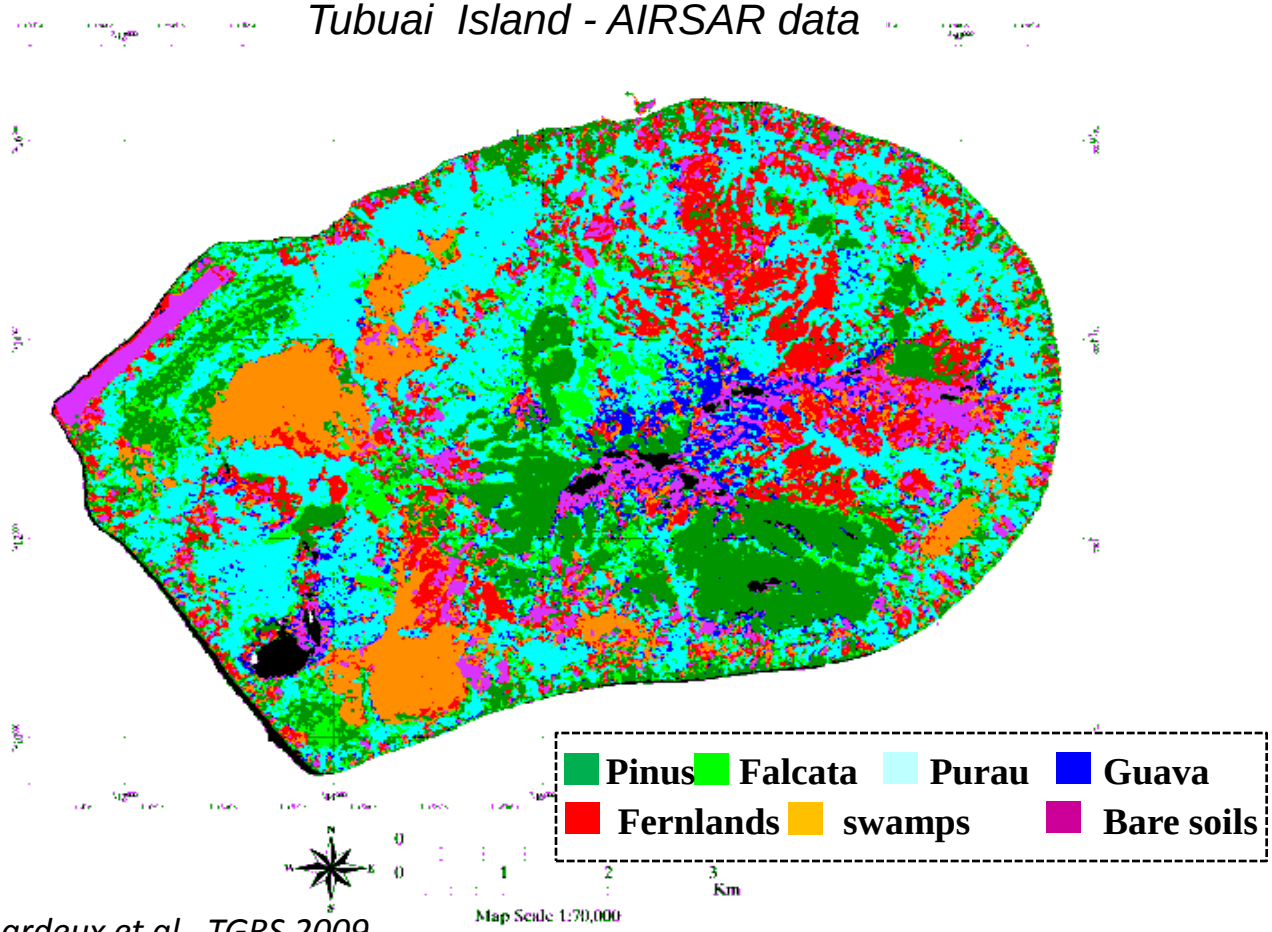
AIRSAR, bande L
Août 2004



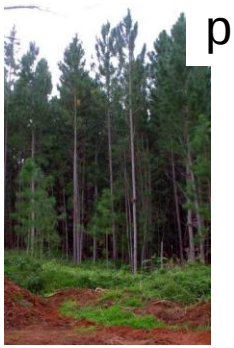
SAR polarimetry for vegetation cartography

Classification polarimetric data

Tubuai Island - AIRSAR data



Lardeux et al., TGRS 2009



pinus

Falcata

Purau

Guava

☞ ***REDD+ ==> collaborations ONF -International***

The Sentinel-1 misions

Sentinel-1A: launched the 3rd April 2014
== > SAR data from March 2015 — Revisit time: 12 days

Sentinel-1B: launched the 22th April 2016 — Revisit time: 12 days
== > SAR data from September2016

} ***6 days!!***

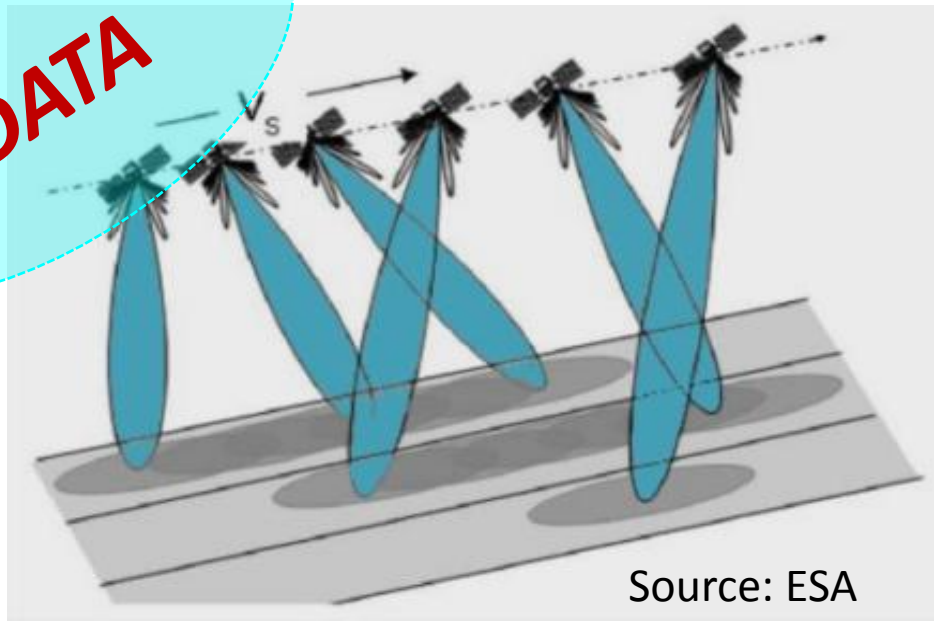
- C band
- Spatial resolution: 20 m
- Swath width: 250 km
- Two polarizations over land surfaces: VV and VH

SAR ⟷ **SENTINEL-1** ⟷ **Scatterometers**

Acquisitions period: ***12 days*** (S1-A) – ***6 days*** (S1- A+B)

Planned mode over land surfaces: ***Interferometric Wide (IW)***

BIG DATA



Source: ESA

2 Polarisations: ***VV –VH***

Swath: 250 km (3 sub-swaths)

GRD Products :

- Spatial resolution: **20 m**
- Pixel: 10 m

SLC Products

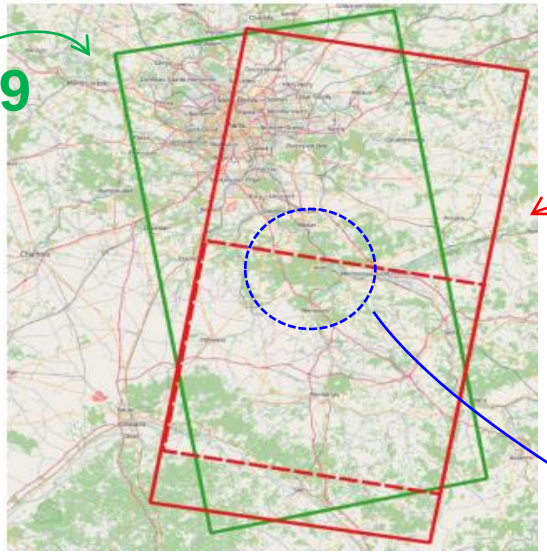
- Spatial resolution: 3 x 20 m;
- Pixel: 2 x 14 m (rge x az.)

Temporal monitoring of seasonal variations of land surfaces

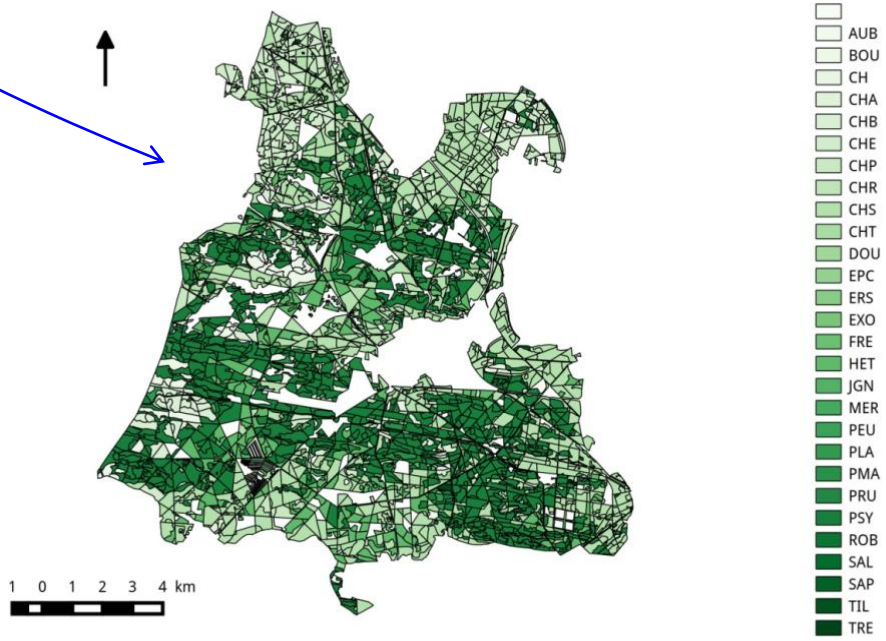
Radar Backscattering Coefficient σ^0

Interferometric Coherence $|\rho|$

Acquisitions over the Paris region



Fontainebleau Forest

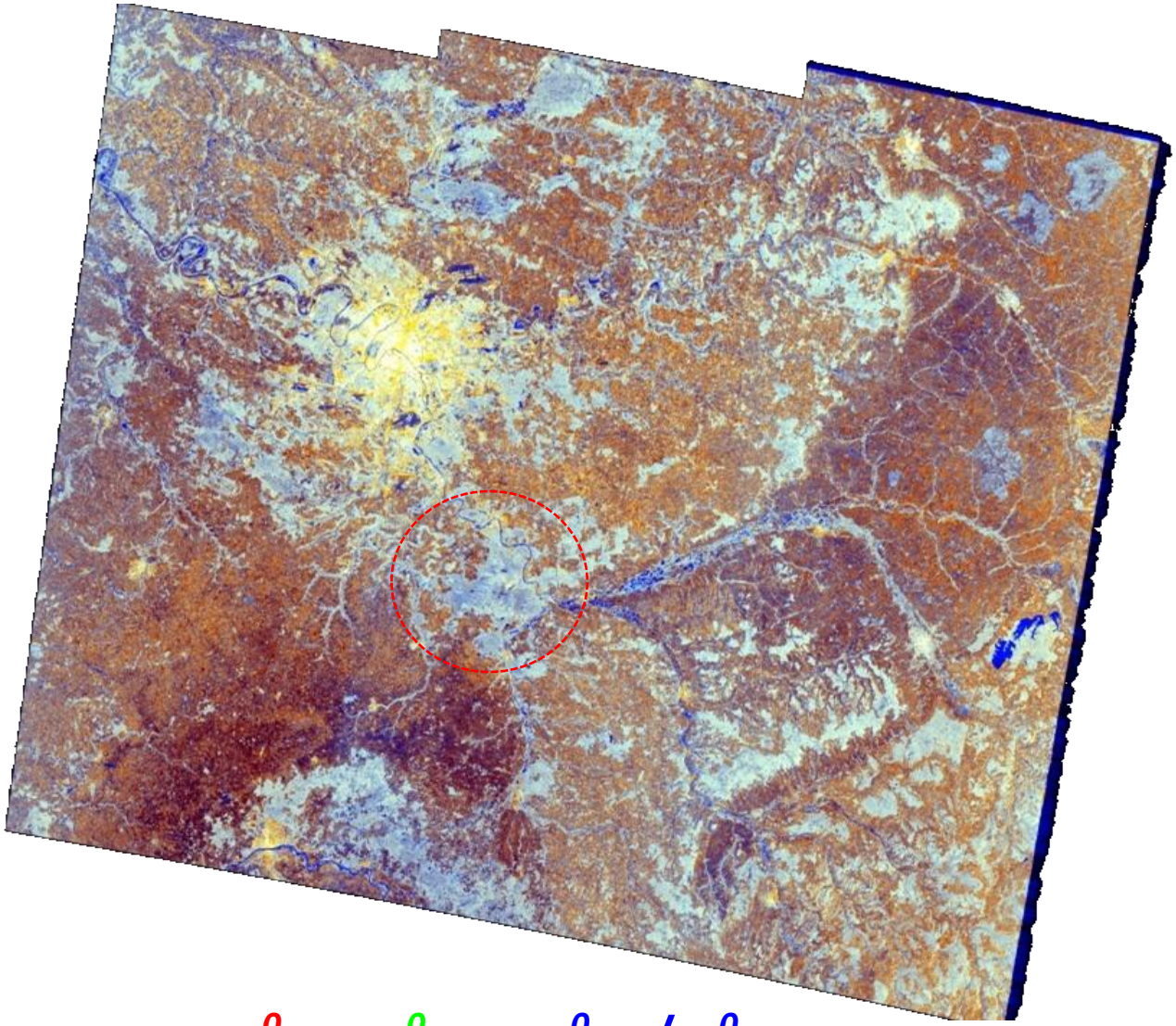


Oaks, pines and beeches stands

Collab. ESE / Paris Sud

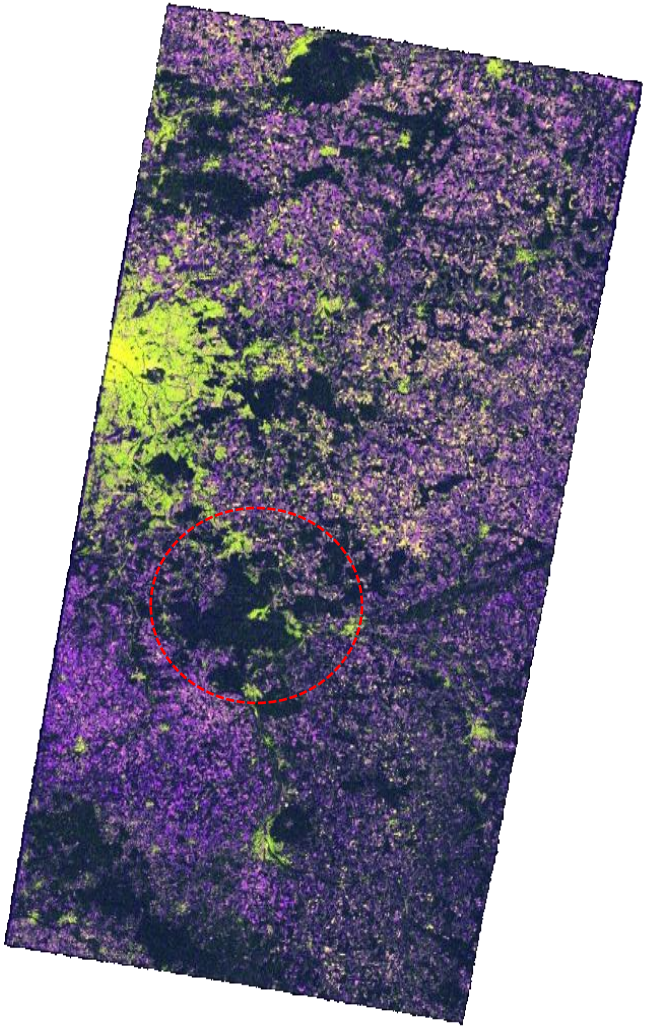
18th March 2015 IW Acquisition

Radar reflectivity (σ^0) image



σ^0_{VV} σ^0_{VH} $\sigma^0_{VH} / \sigma^0_{VV}$

18 – 30 March coherence image

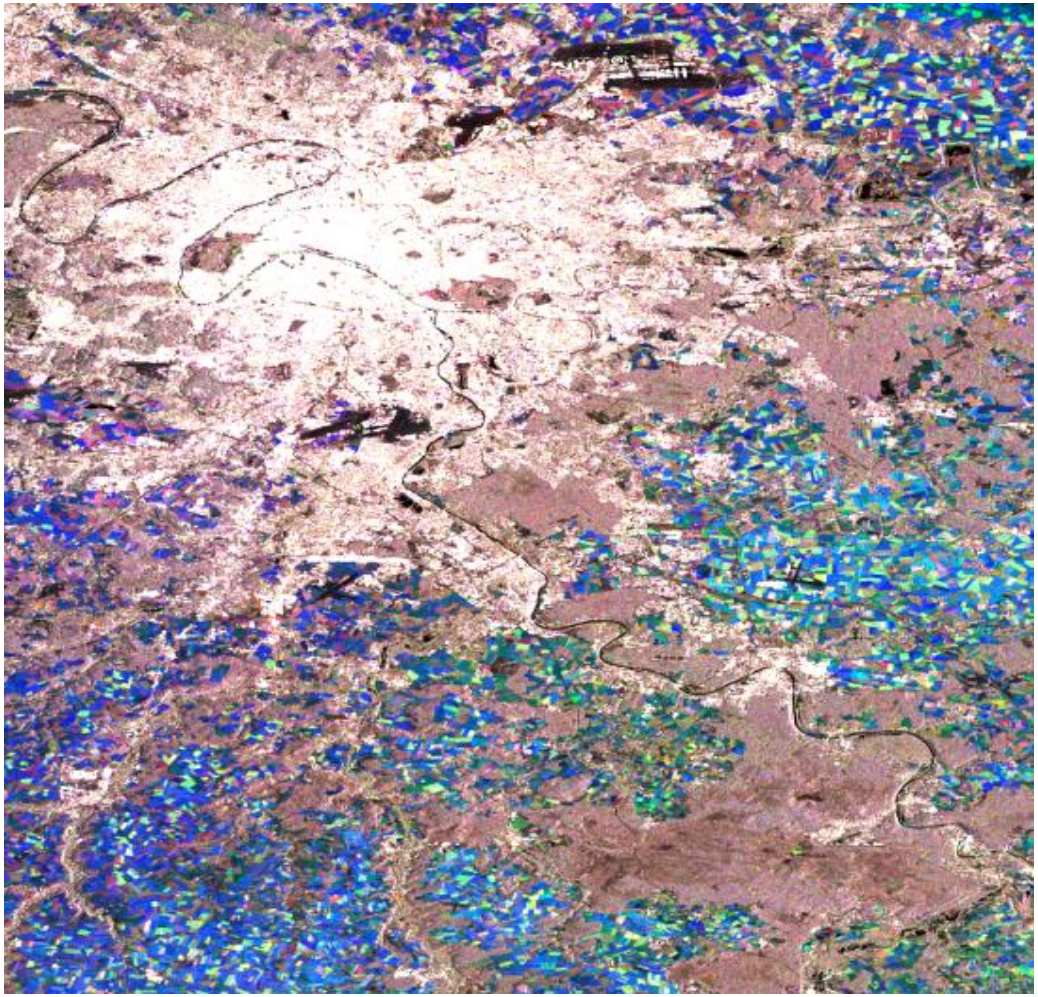


$|\rho_{VV}|$ $|\rho_{VH}|$ $\rho_{VV} / |\rho_{VH}|$

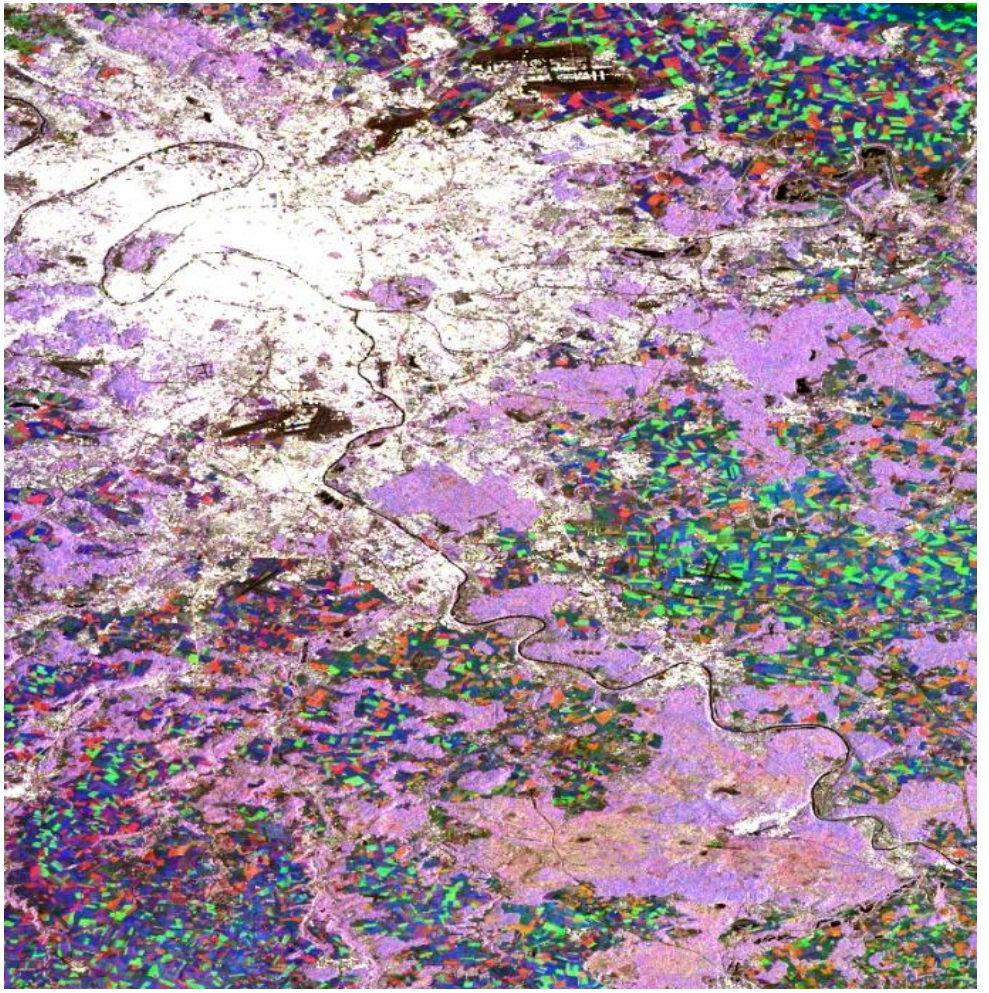
σ^0 Color composite image

5 May - 2 Sept. - 19 Dec. 2015

Polarisation VV



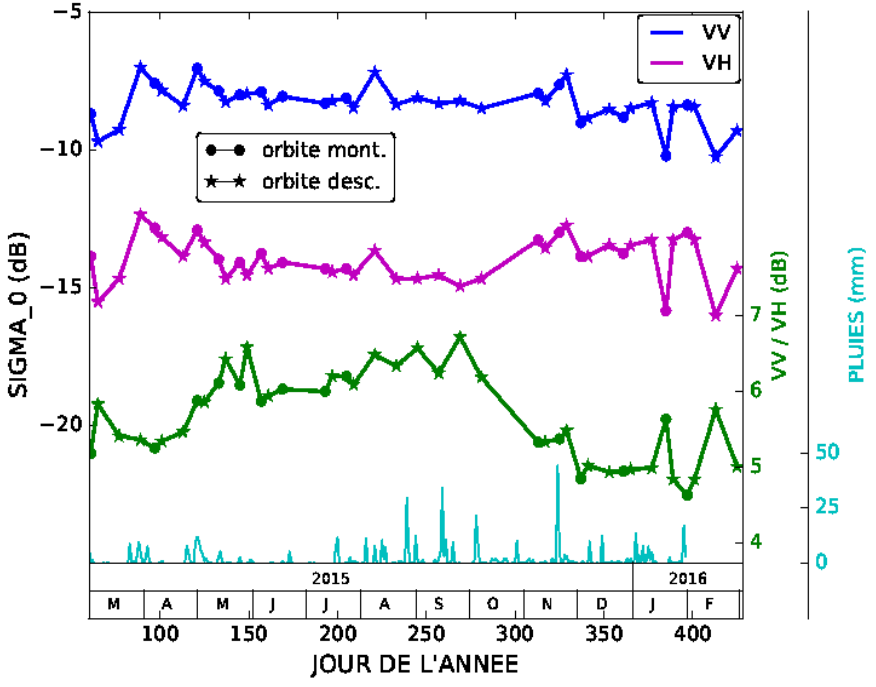
Polarisation VH



☞ ***High spatio-temporal variability over crop fields***

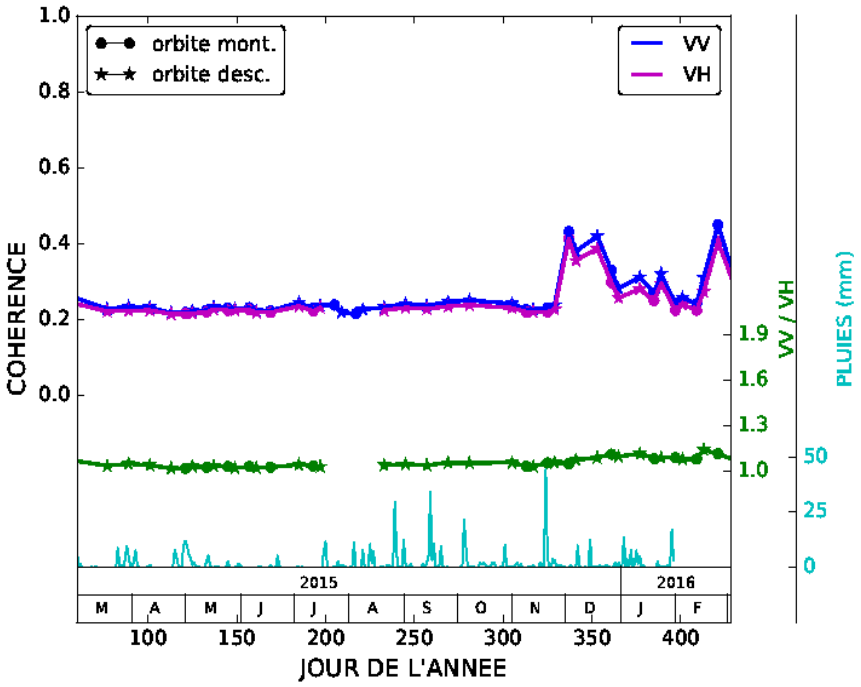
Fontainebleau Forest

Radar reflectivity



- No seasonal cyle σ^0_{VV}
- seasonal cycle σ^0_{VH} ==> σ^0_{VV} / σ^0_{VH}

coherence

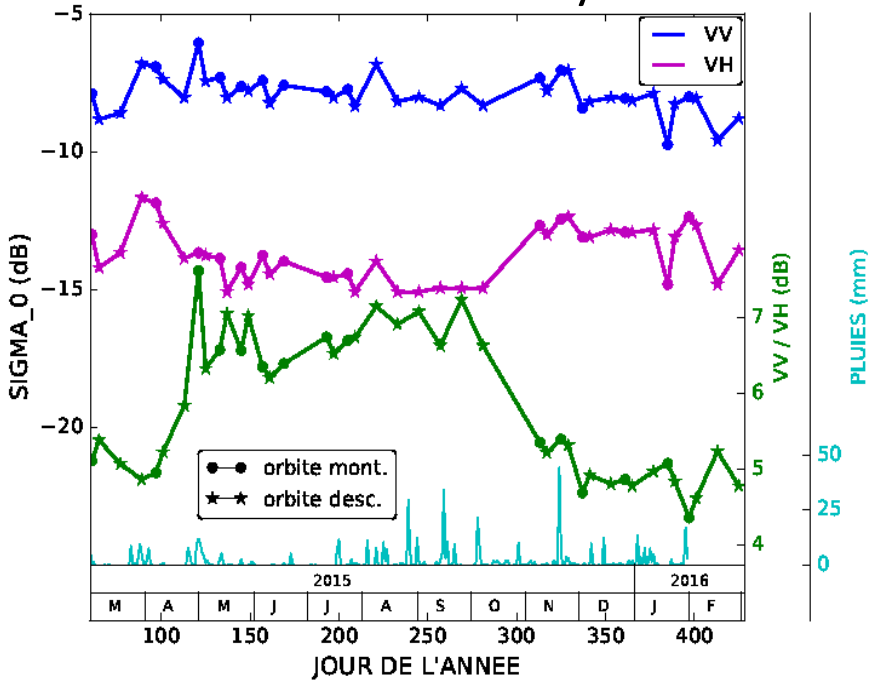


- signal low ans constant (Mars-Nov.)
- $|\rho_{VV}|$ et $|\rho_{VH}|$ identical

Low correlation with precipitations

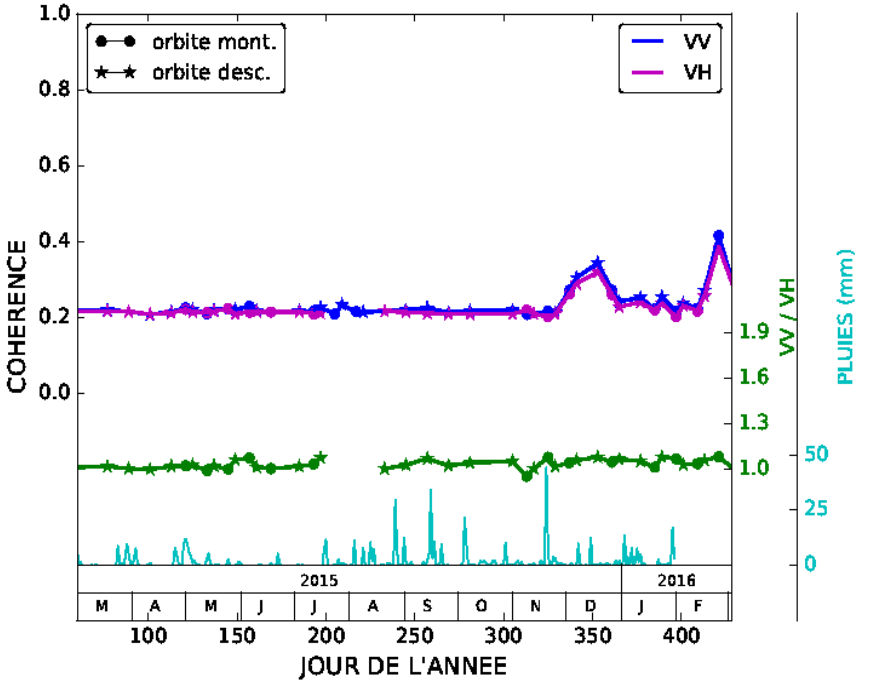
Oaks stand

Radar reflectivity



- No seasonal cyle σ^0_{VV}
- seasonal cycle σ^0_{VH} ==> $\sigma^0_{VV} / \sigma^0_{VH}$

coherence

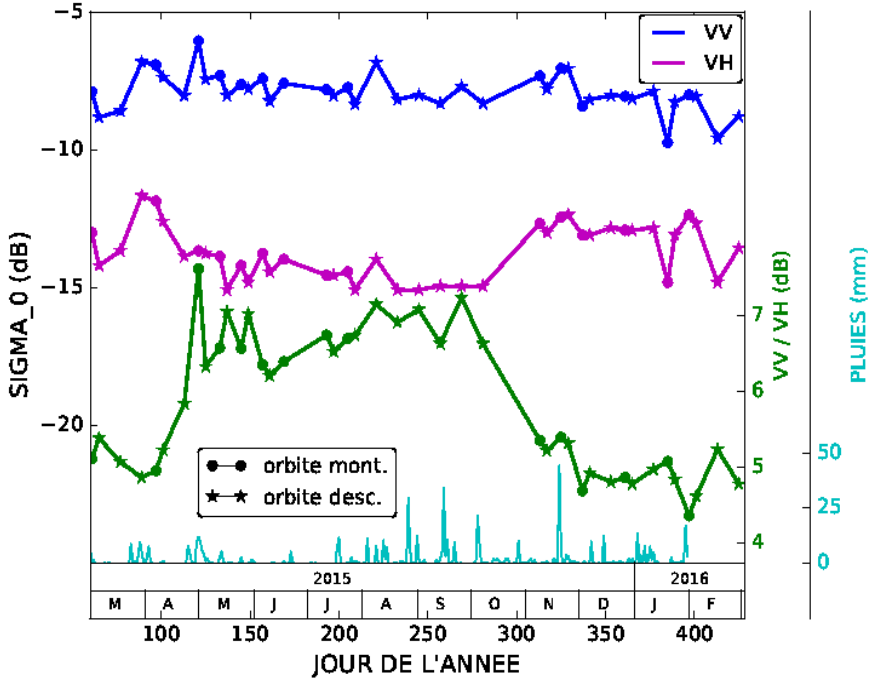


- signal low ans constant (Mars-Nov.)
- $|\rho_{VV}|$ et $|\rho_{VH}|$ identical

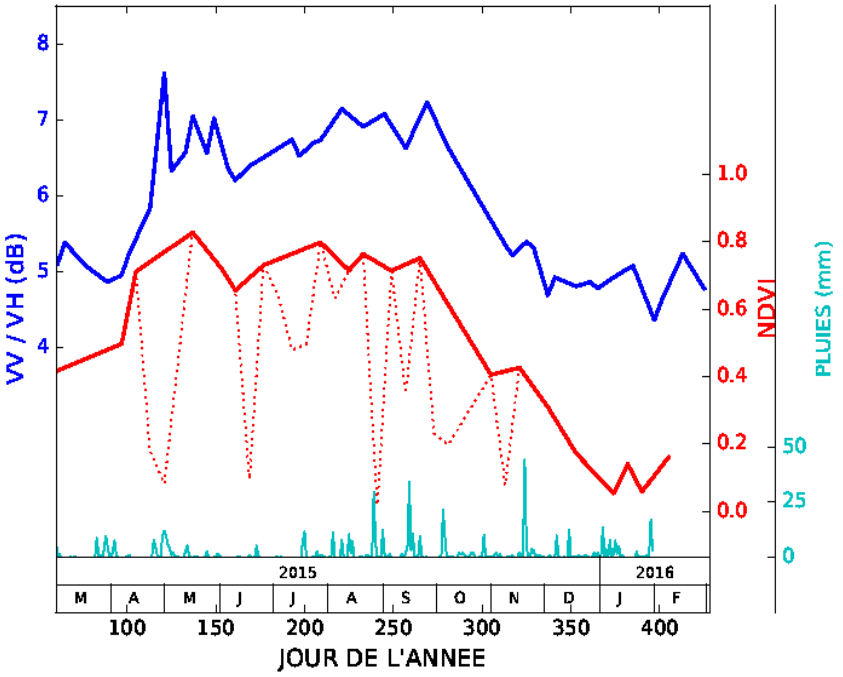
Low correlation with precipitations

Oaks stand

Radar reflectivity



σ^0_{VV} / σ^0_{VH}



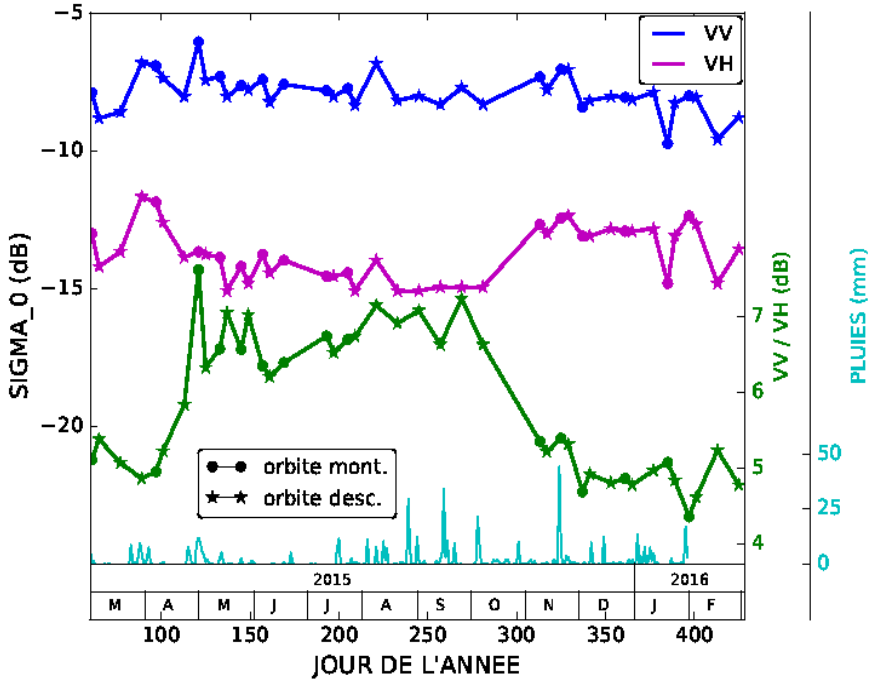
- No seasonal cyle σ^0_{VV}
- seasonal cycle σ^0_{VH} ==> σ^0_{VV} / σ^0_{VH}

σ^0_{VV} / σ^0_{VH} *and NDVI in phase*

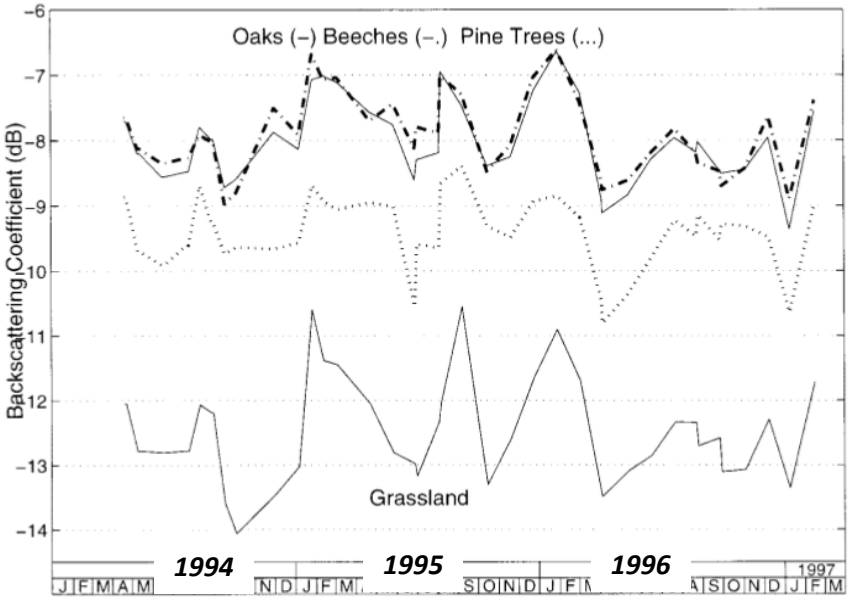
==> Sensitivity of C Band to foliar activity

Oaks stand

Sentinel-1



ERS *(VV pol.)*



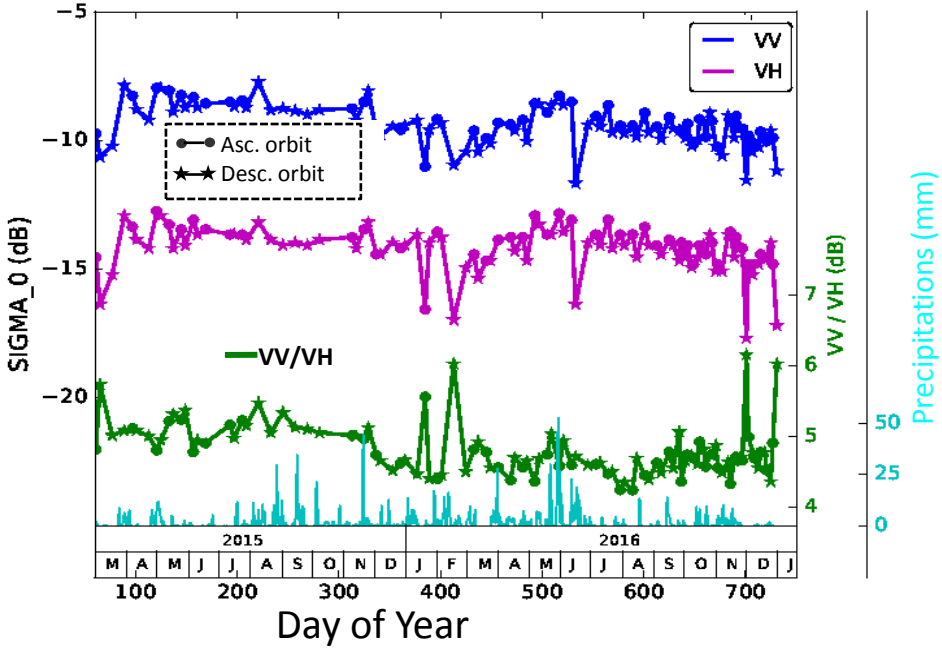
Proisy et al., 1999

- No seasonal cyle σ^0_{VV}
- seasonal cycle σ^0_{VH} ==> σ^0_{VV} / σ^0_{VH}

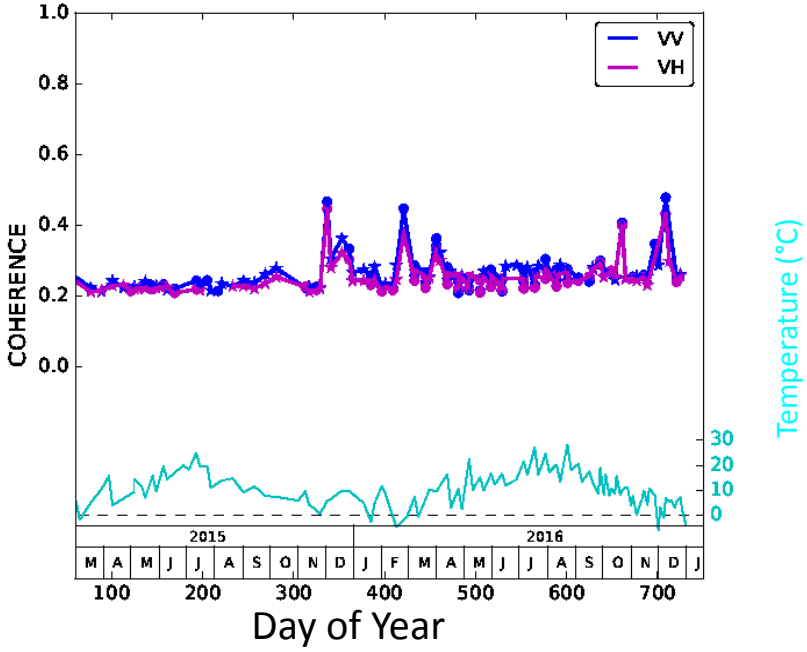
☞ ***No conclusion was possible with ERS data (35 days)***

Pine trees

Radar reflectivity

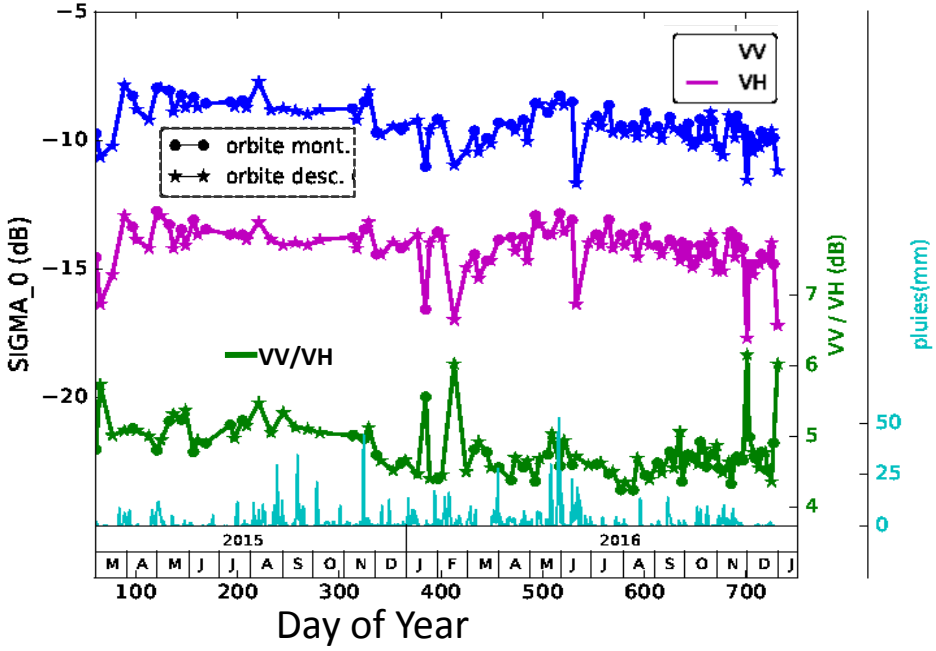


coherence

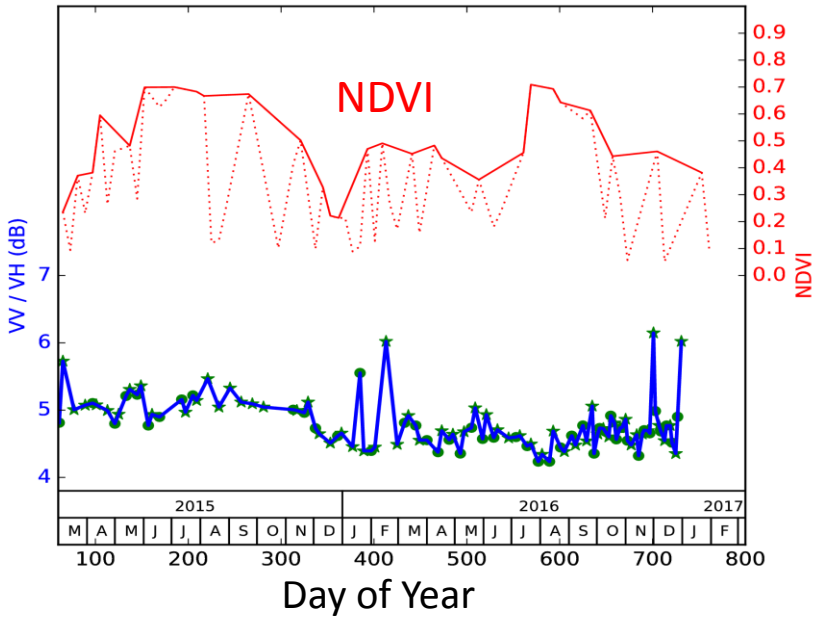


Pine trees

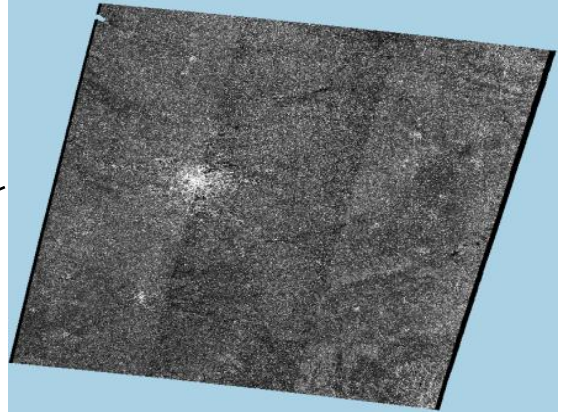
Radar reflectivity



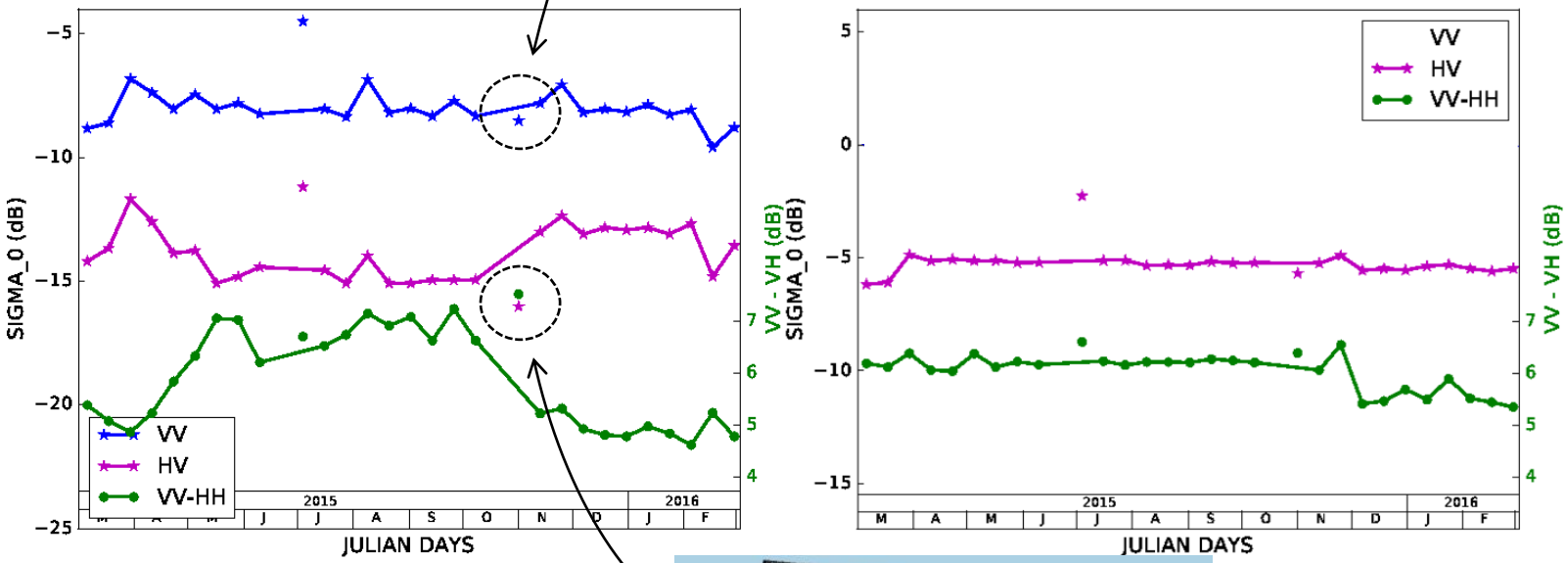
$\sigma^0_{VV} / \sigma^0_{VH}$

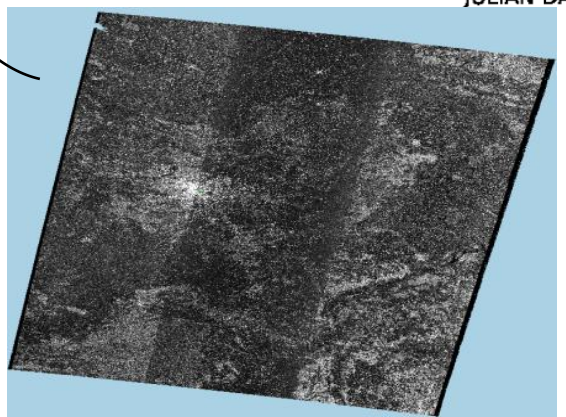


High temporal frequency …..



…. to detect erroneous data!

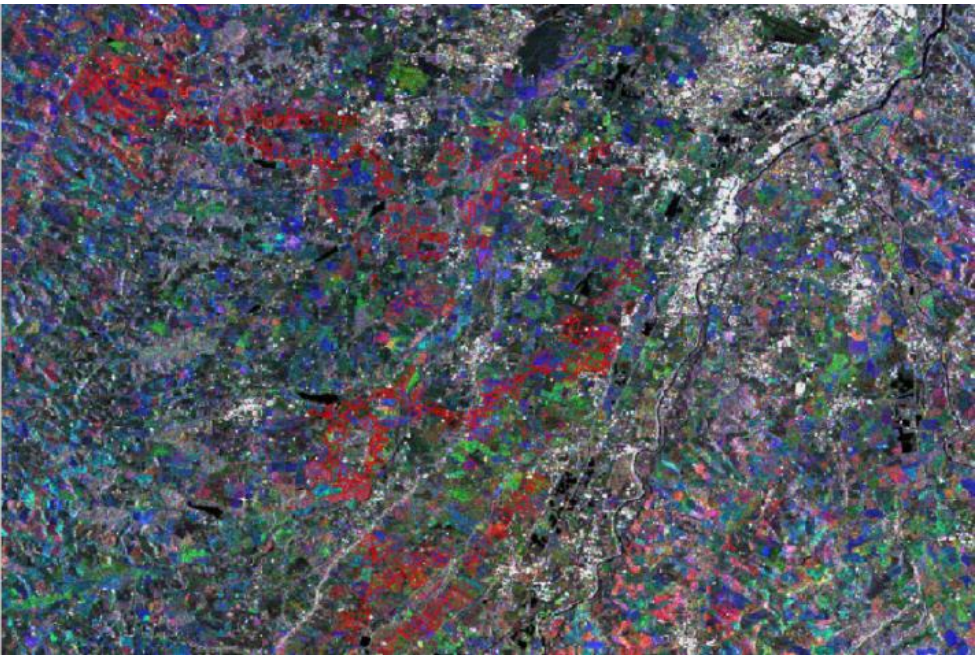




Agricultural area (Lamasquère region)

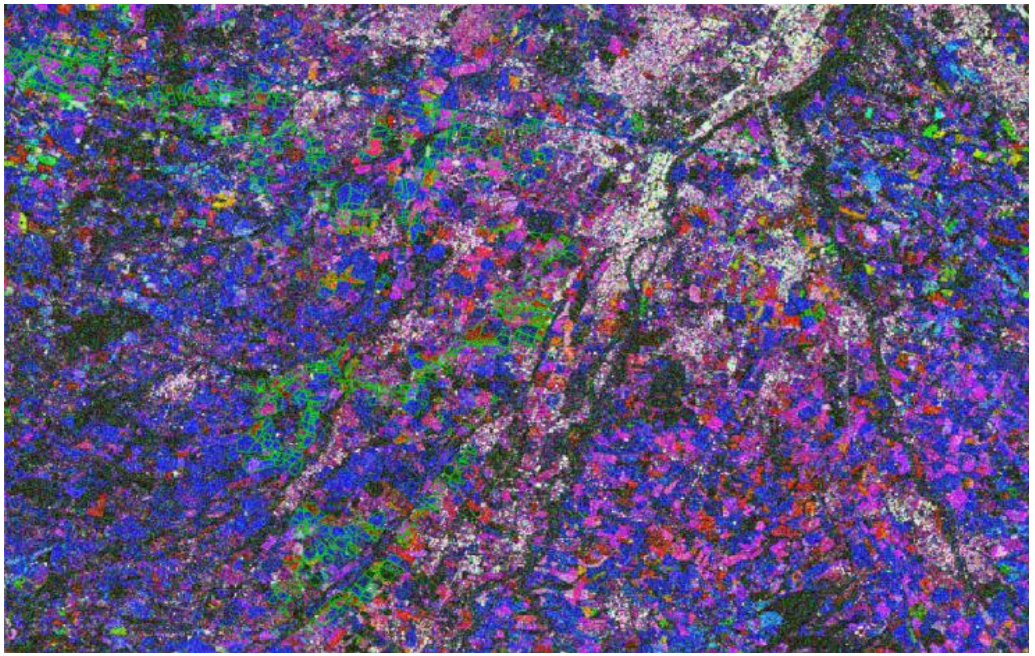
Multi-temporal color-composite images

Coeff. radar



10 June **14 Sept.** **7 Dec.**

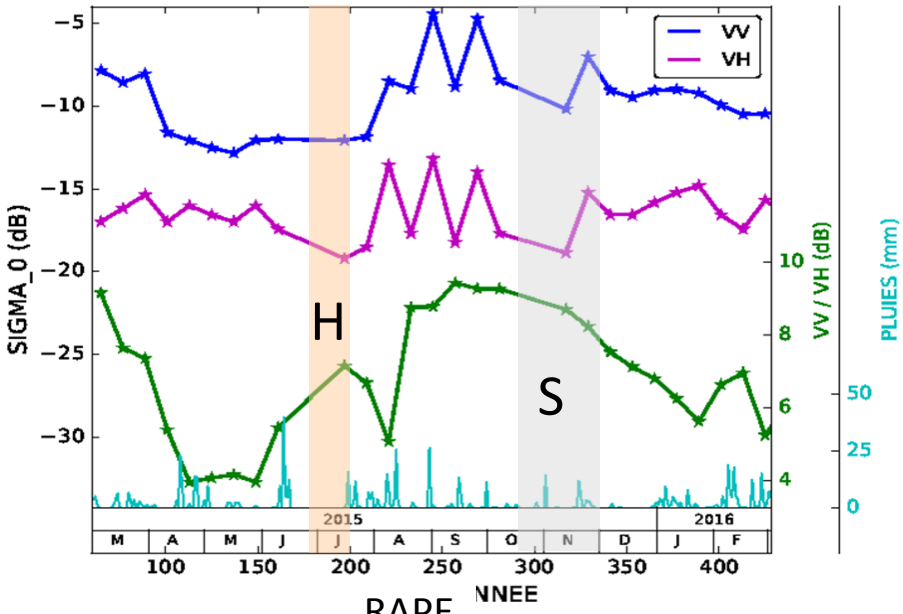
Cohérence



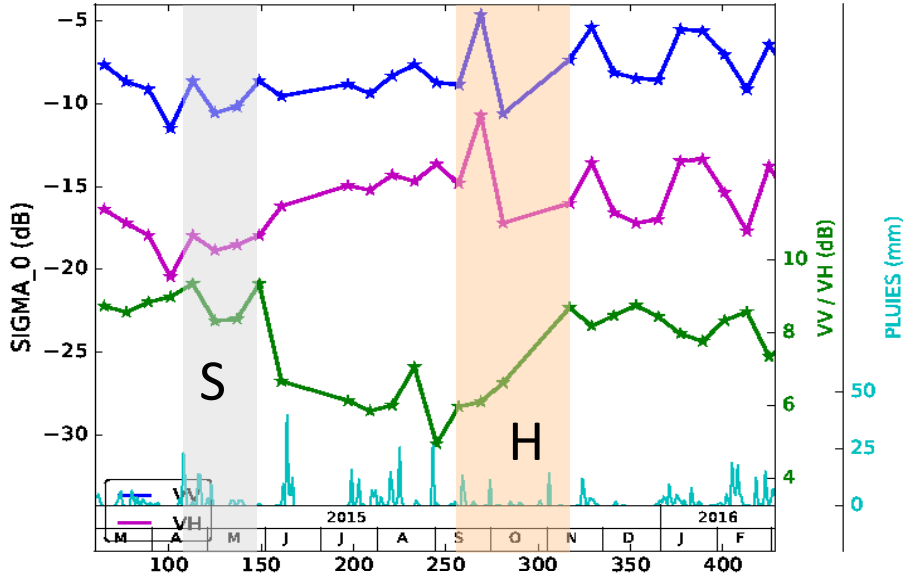
4-16 Jul . **9-16 Aug.** **7-19 Dec.**

CROP FIELDS: Temporal profile σ^0

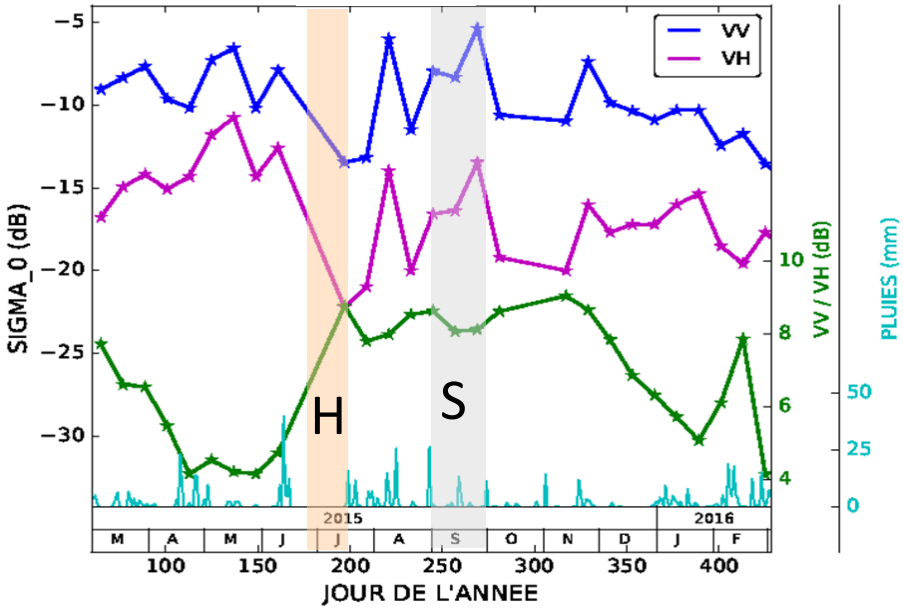
WHEAT



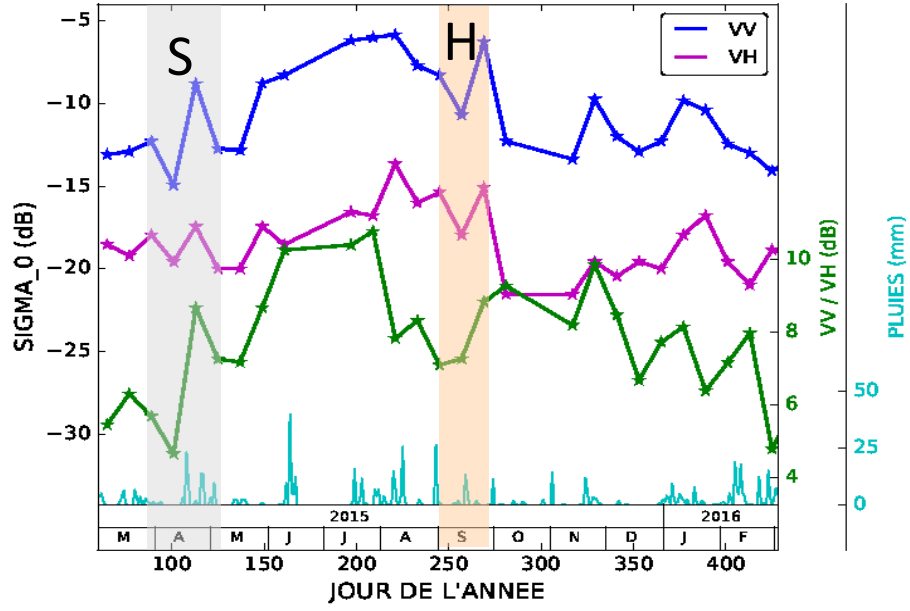
CORN – SOYA - SORGHUM



RAPE

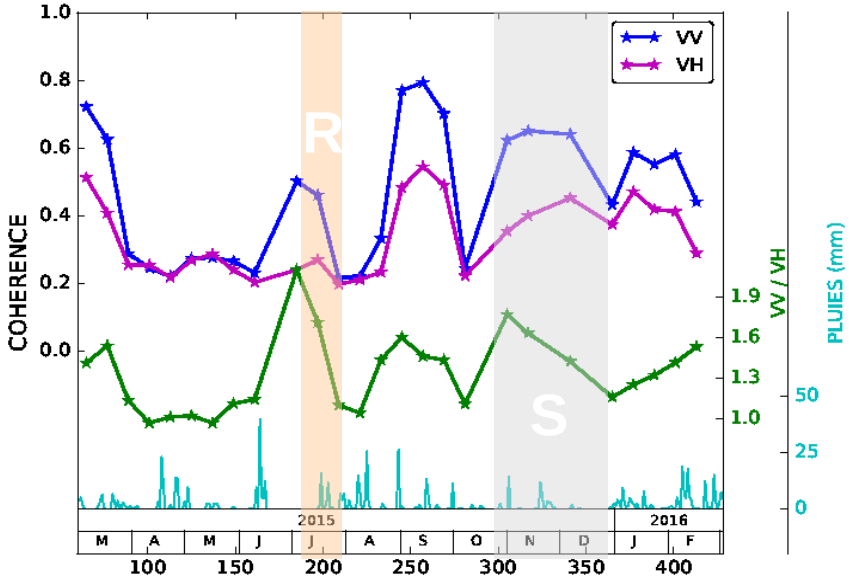


SUNFLOWER

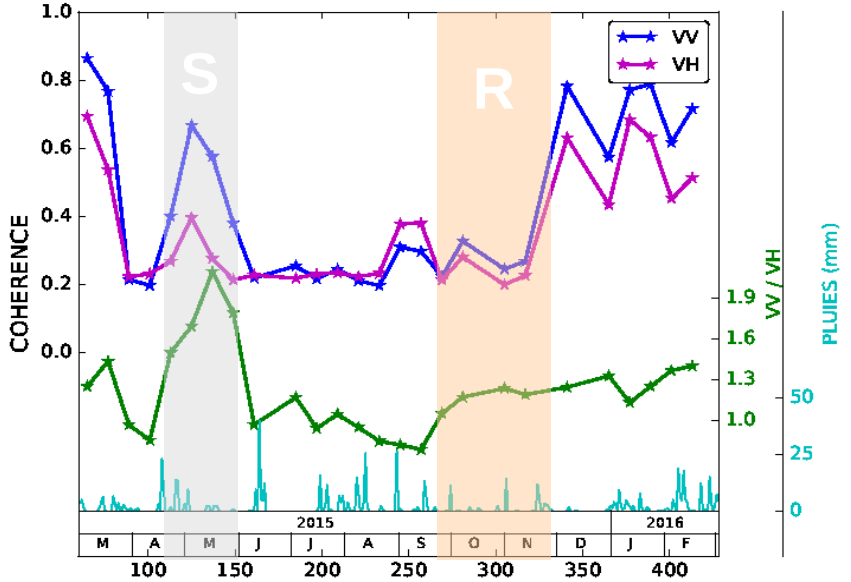


CROP FIELDS: Temporal profiles coherence

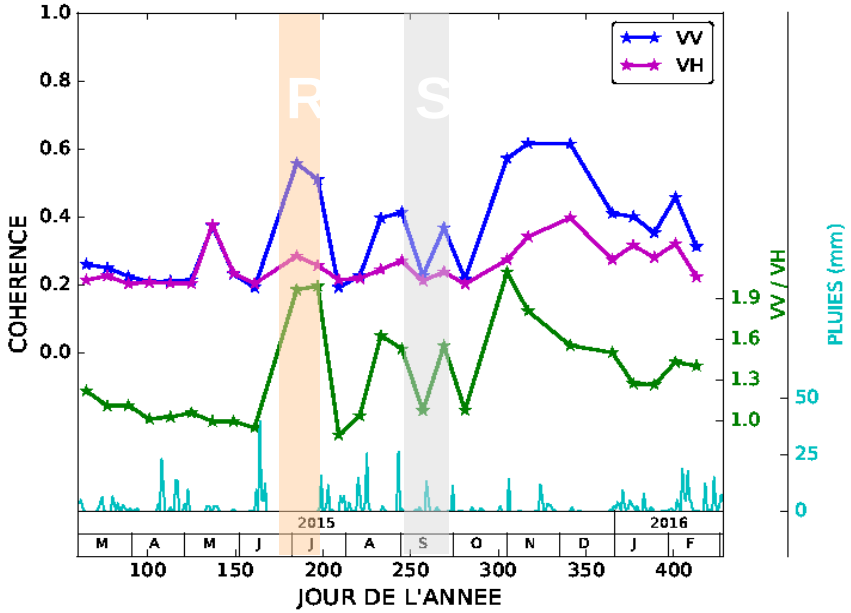
BLE - ORGE



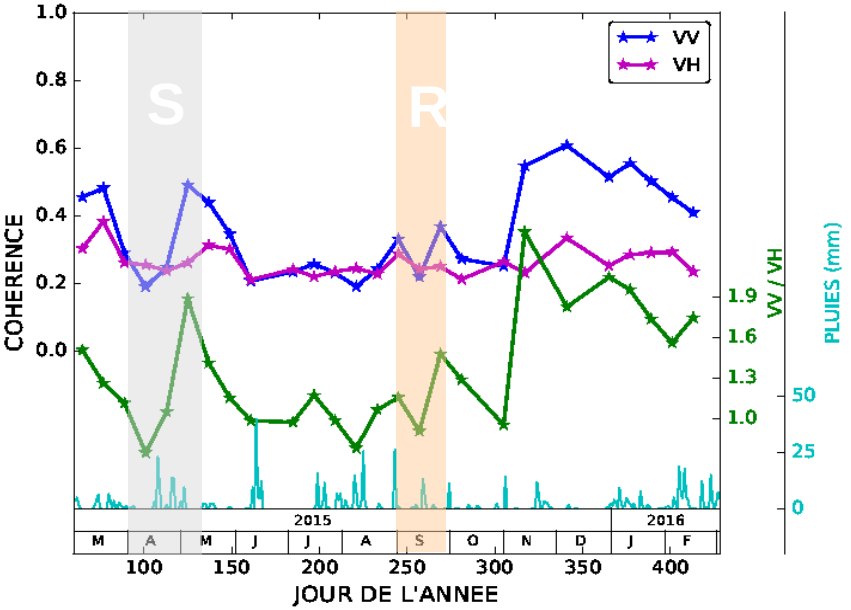
MAIS – SOJA - SORGHO



COLZA



TOURNESOL



CONCLUSION

Radar brings complementary information to optical

(diversity wavelengths, polarization)

Seasonal variation of land surfaces:

☞ ***High temporal frequency*** of acquisition is necessary

Possible in the old time with ***scatterometer*** at ***regional*** scales

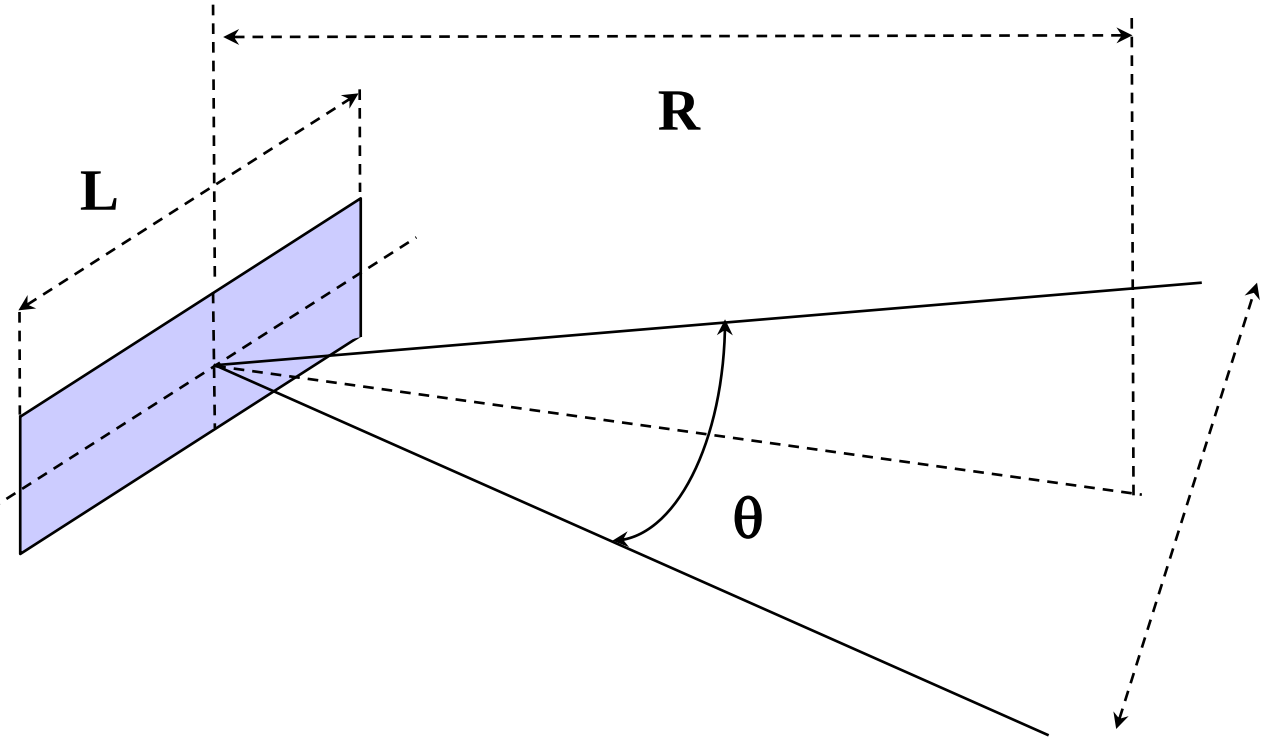
Accessible now with ***Sentinel-1*** data at ***local*** scales

Potential for ***forest*** and ***crop monitoring***

(cf. CESBIO, Th. Le Toan & Hoa Thi Phan for rice monitoring!)

Side Looking Airborne Radar (SLAR)

Rayonnement d'une antenne



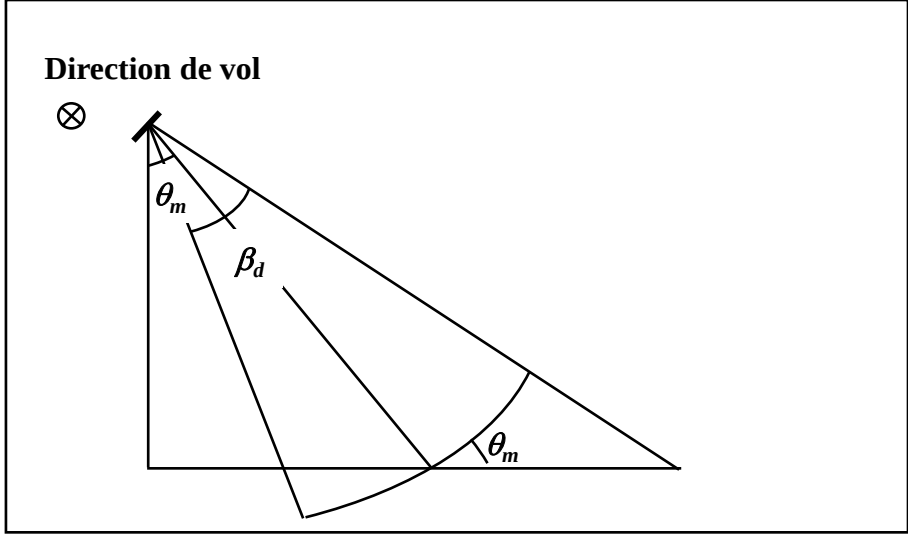
$$\theta = \frac{\lambda}{L}$$

Résolution: $\delta r = \theta . R$

A.N.: L = 4 m, R = 4 km (aéroporté), λ = 3 cm (bande X) $\delta r = 30\ m$

L = 10 m, R = 800 km (spatial), λ = 6 cm (bande C) $\delta r = 4{,}5\ km$

Swath width



$\vec{V}$: *vitesse du capteur*

Emitted pulses at PRF

L

l

H

Trace au sol

β_{az}

β_d

Swath S

$$S \approx \frac{\lambda}{l}\frac{H}{\cos^2\theta}$$ (Flat Earth)

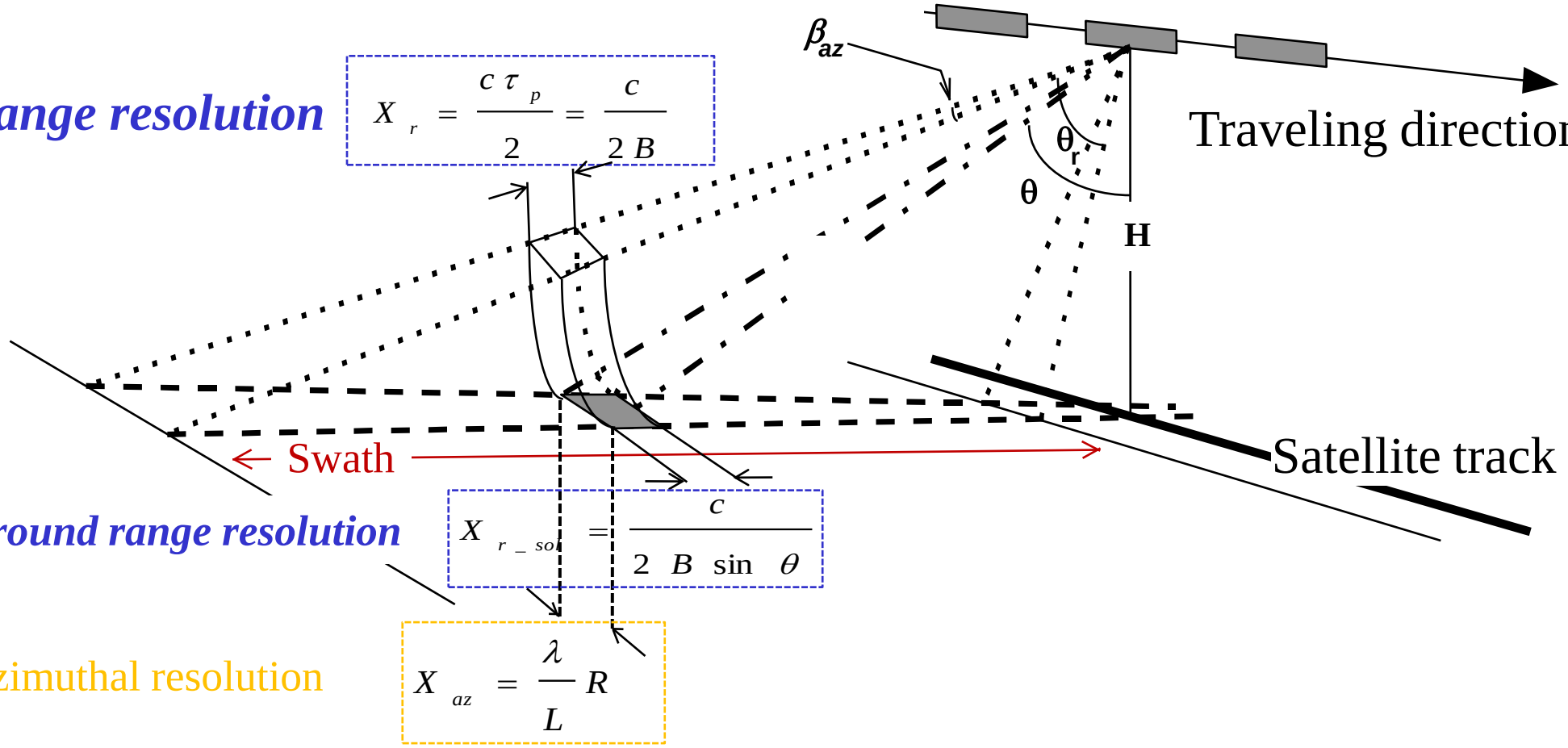
Range direction
(columns)

Azimuthal direction
(lines)

A.N: $l = 1m$, $\lambda = 5.6\ cm$, $H = 700\ km$, $\theta = 23°$

$S \approx 50\ km$

Radar Imaging – spatial resolution

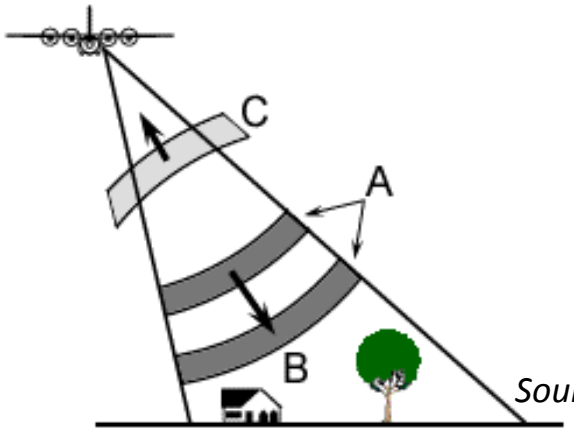


Pulse duration $= \tau_p = 1/B$

Remote sensing:

Optical since 70's

Radar since 1991

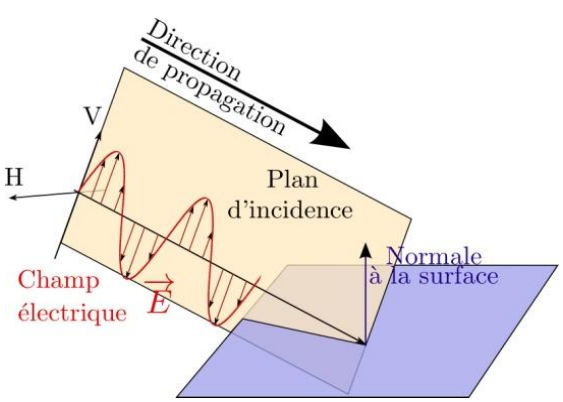


Source: Centre canadien de télédétection

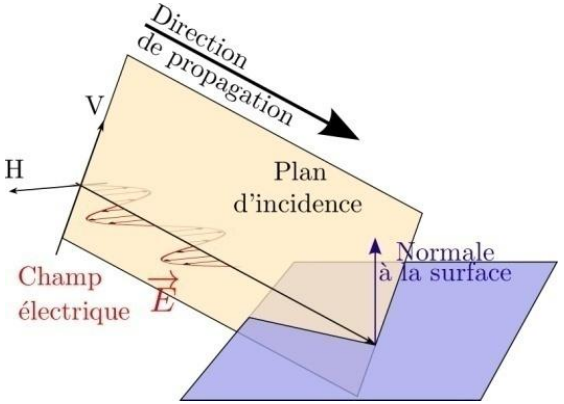
*wavelength: λ **> 1cm***

Coherent wave

Polarisation diversity



Polarisation V



Polarisation H