

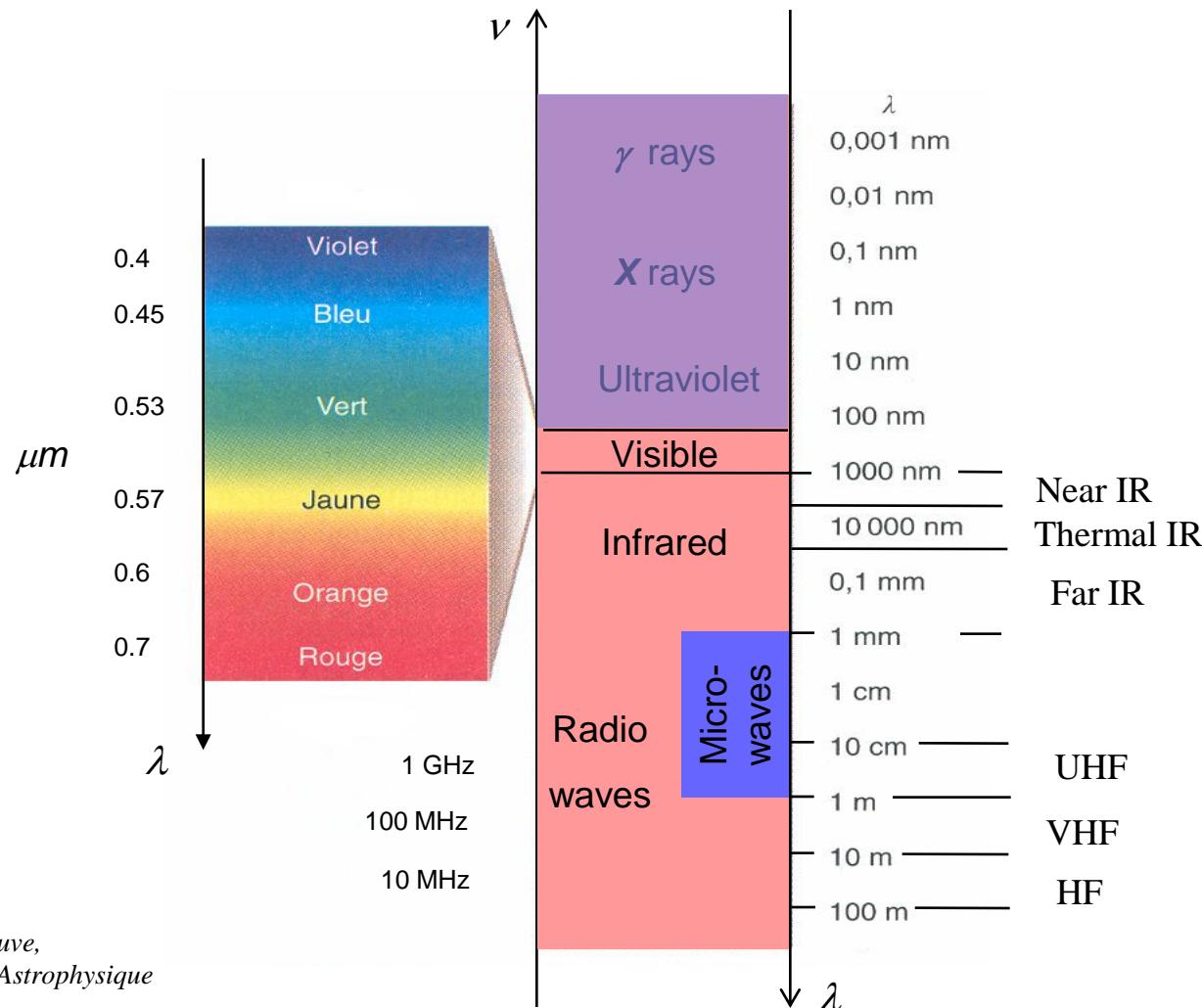
Radar Fundamentals

Pierre-Louis Frison

pierre-louis.frison@u-pem.fr

Electromagnetic coherent wave

Electromagnetic spectrum

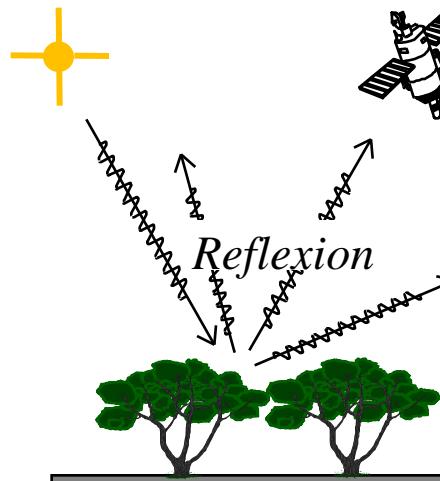


From Seguin & Villeneuve,
Astromnomie et Astrophysique

Radar Fundamentals

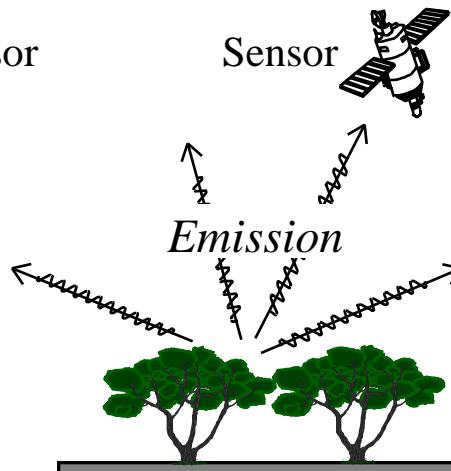
Remote Sensing observations mode

Solar radiation



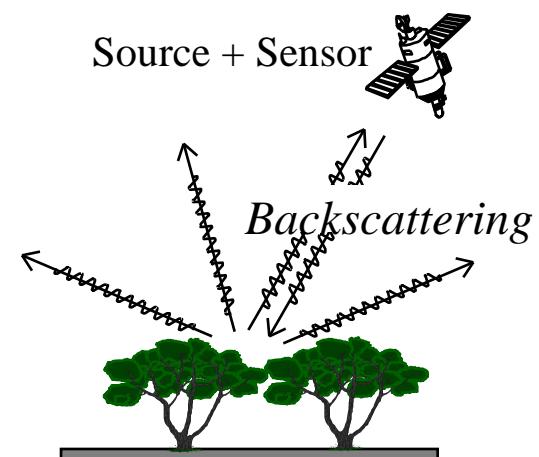
**Visible
Near/mid-Infrared**

Sensor



**Thermal Infrared
Microwaves**

Source + Sensor



Radar
= active microwaves

VIS + NIR + MIR

IRT

Microwaves

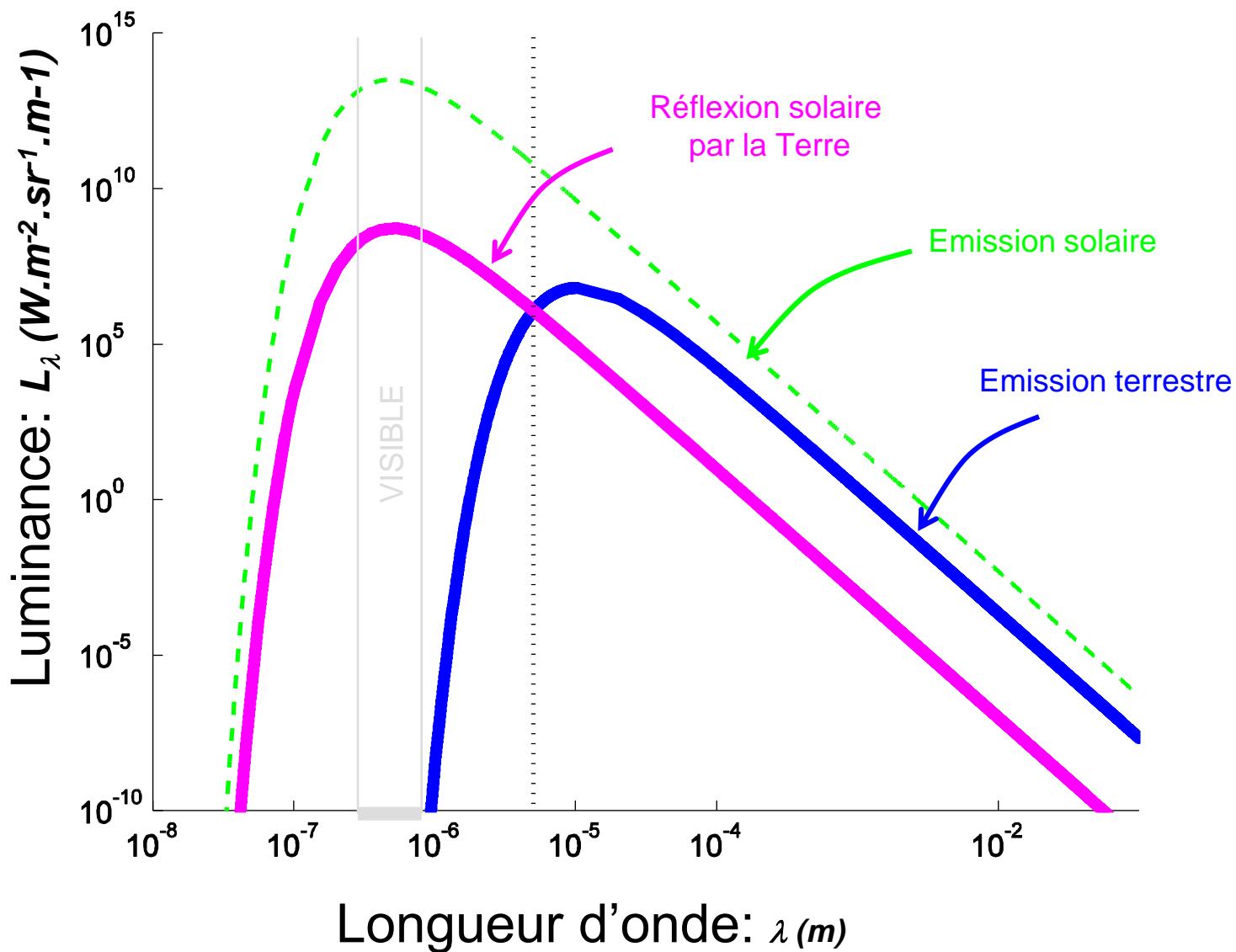
0.4-0.7 μ 0.9 μ 1.5 μ

> 5 μ

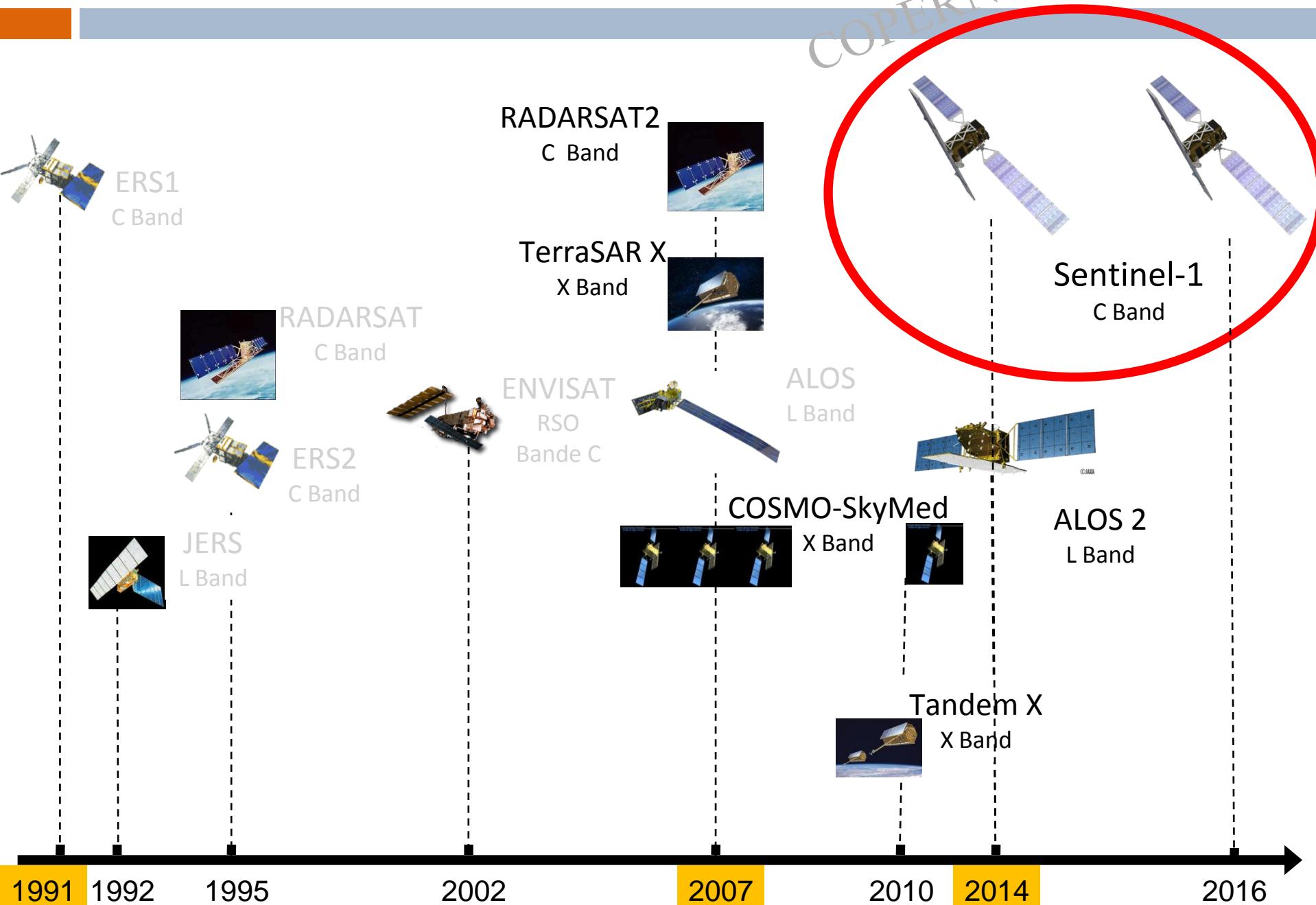
0.75-150 cm

λ

Le Rayonnement électromagnétique en provenance de la Terre



SPACEBORNE SAR SENSORS



SAR data: summary

Name	Acquisition period	Band Frequency	Polarization mode	Spatial resolution (m)	Revisit time (days)	Scene cover (km)
<i>ERS-1 / 2</i>	91 - 11	C	VV	20	35	185x185
<i>JERS</i>	92 - 98	L	HH	20	44	75 x 75
<i>Radarsat</i>	95 – 13	C	HH	10-100	24	35 x 500
<i>ASAR</i>	01-13	C	1 or 2 pol. HH/HV/VV	30-1000	few -35	100x500
<i>PALSAR</i>	07-11	L	Polarimetric HH/HV/VV	10-100	few-24	100-500
<i>Radarsat-2</i>	2007 -	C	Polarimetric HH/HV/VV	1-15	5 to 10	NA
<i>TerraSAR-X</i>	2007 -	X	1 or 2 pol. HH/HV/VV	1-20	few-11	5-100
<i>Cosmo-Skymed</i>	2007 -	X	1 or 2 pol HH/HV/VV	1-100	12 h	10-200
<i>SAOCOM</i>	2015	L	Polarimetric HH/HV/VV	7-100	few-16	60-320
<i>Sentinel 1</i>	2015	C	1 or 2 pol HH/HV/VV	5 - 100m	few-12	80-400
<i>ALOS-2</i>	2015	L	Polarimetric HH/HV/VV	3-100	few-14	25-350

Fréquence – Wavelength

$$f = \frac{c}{\lambda}$$

Band X	$\lambda \sim 3 \text{ cm}$	$f \sim 10 \text{ GHz}$
Band C	$\lambda \sim 6 \text{ cm}$	$f \sim 5 \text{ GHz}$
Band L	$\lambda \sim 25 \text{ cm}$	$f \sim 1,2 \text{ GHz}$
Band P	$\lambda \sim 70 \text{ cm}$	$f \sim 400 \text{ MHz}$

Radar Fundamentals

RADAR: RAdio Detection And Ranging

Emission of emw
Reception backscattered echoes



Road RADAR

(© US police)



US Army



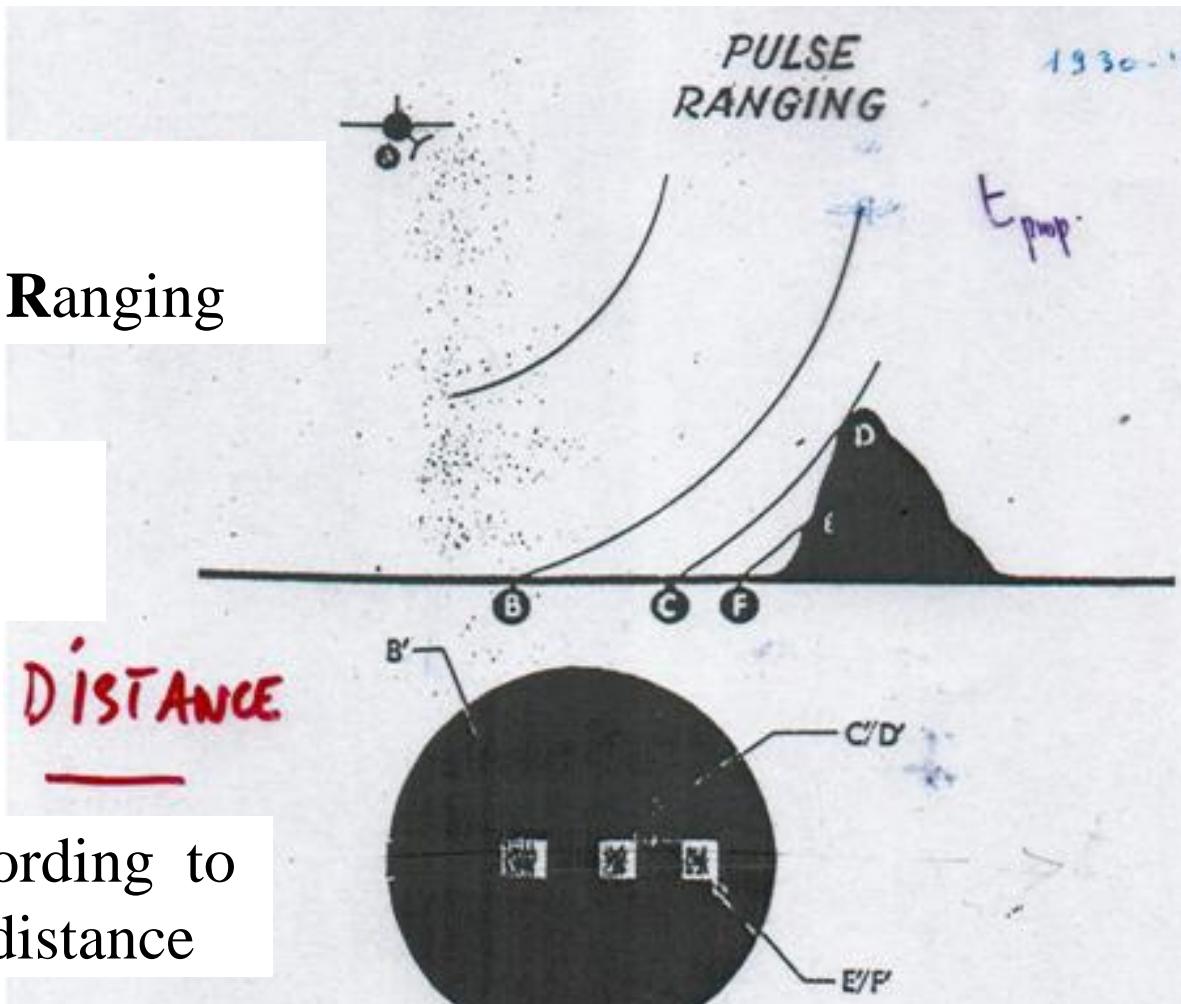
Imaging RADAR PALSAR

(© NASDA)

Radar Fundamentals

RADAR:
RAdio Detection And Ranging

Active mode
with **coherent wave**



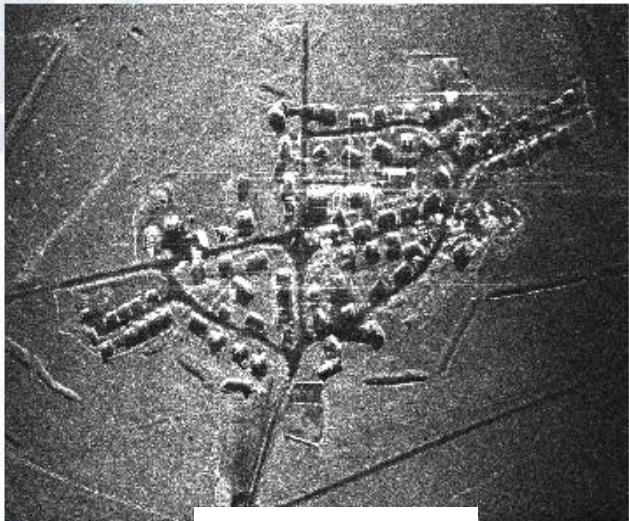
Echoes are ranged according to
Antenna – target distance

Figure 3.4 Imaging process and geometry of an image line (courtesy of Loral Defense Systems).

Radar Fundamentals

Active mode → night acquisition

D
A
Y

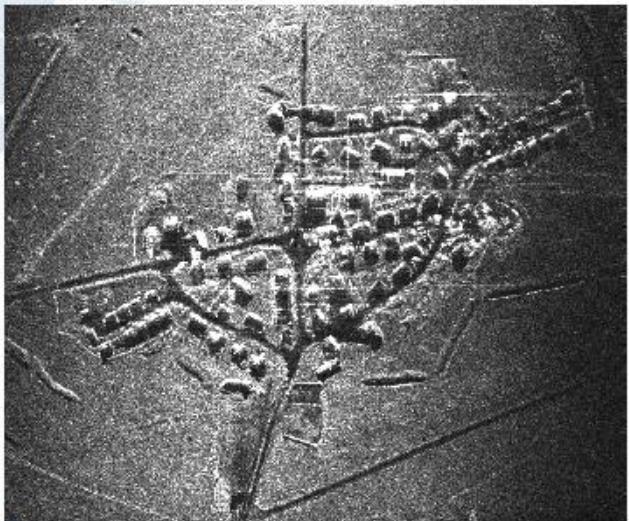


RADAR image



Optical image

N
I
G
H
T



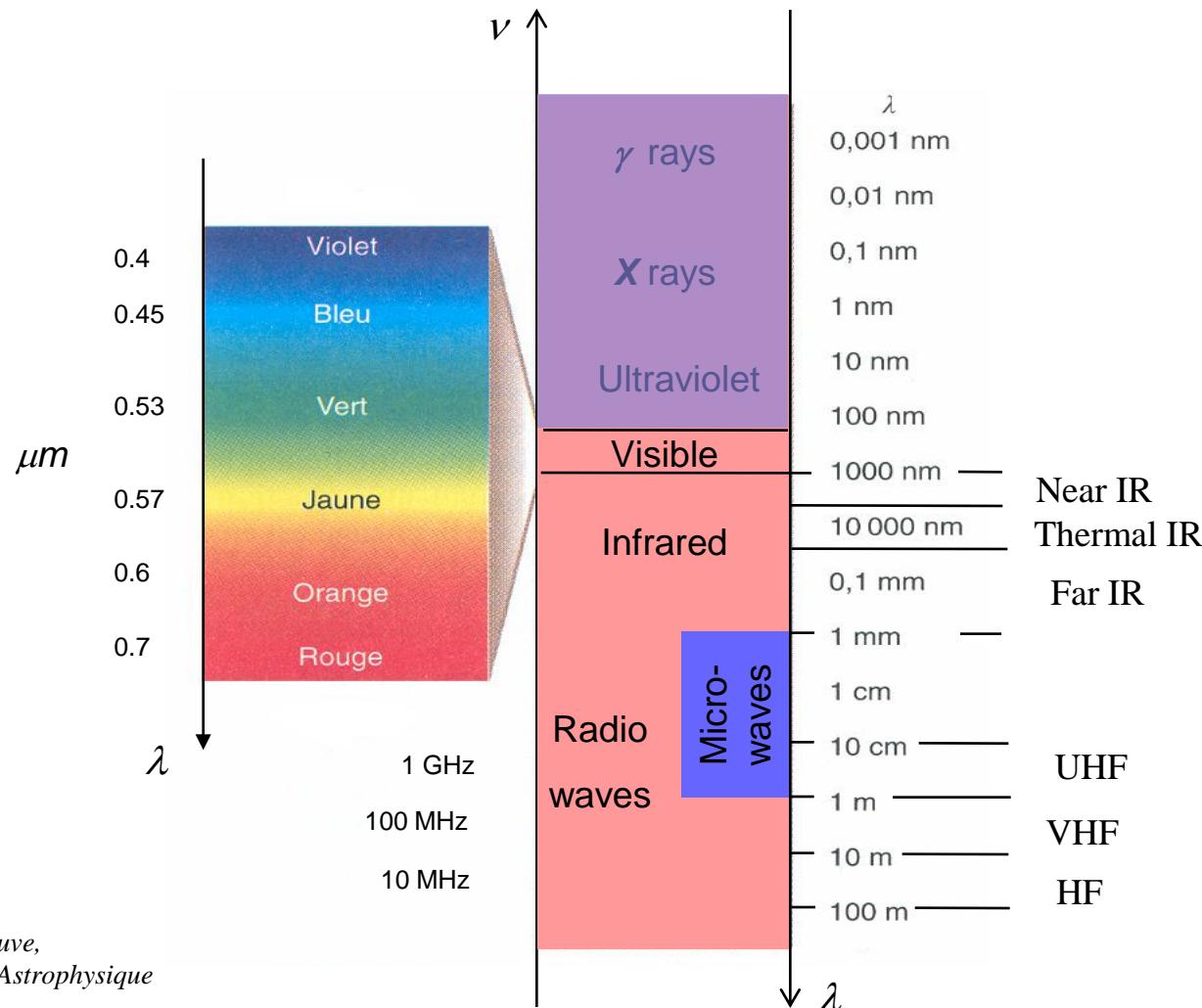
Source:
INFOTERRA

OUTLINE

- I. Electromagnetic coherent waves
- II. Radar imaging - Spatial resolution
- III. Frequency – wavelength
- IV. Polarization
- V. Radar response sensitivity
- VI. Relief effects

Electromagnetic coherent wave

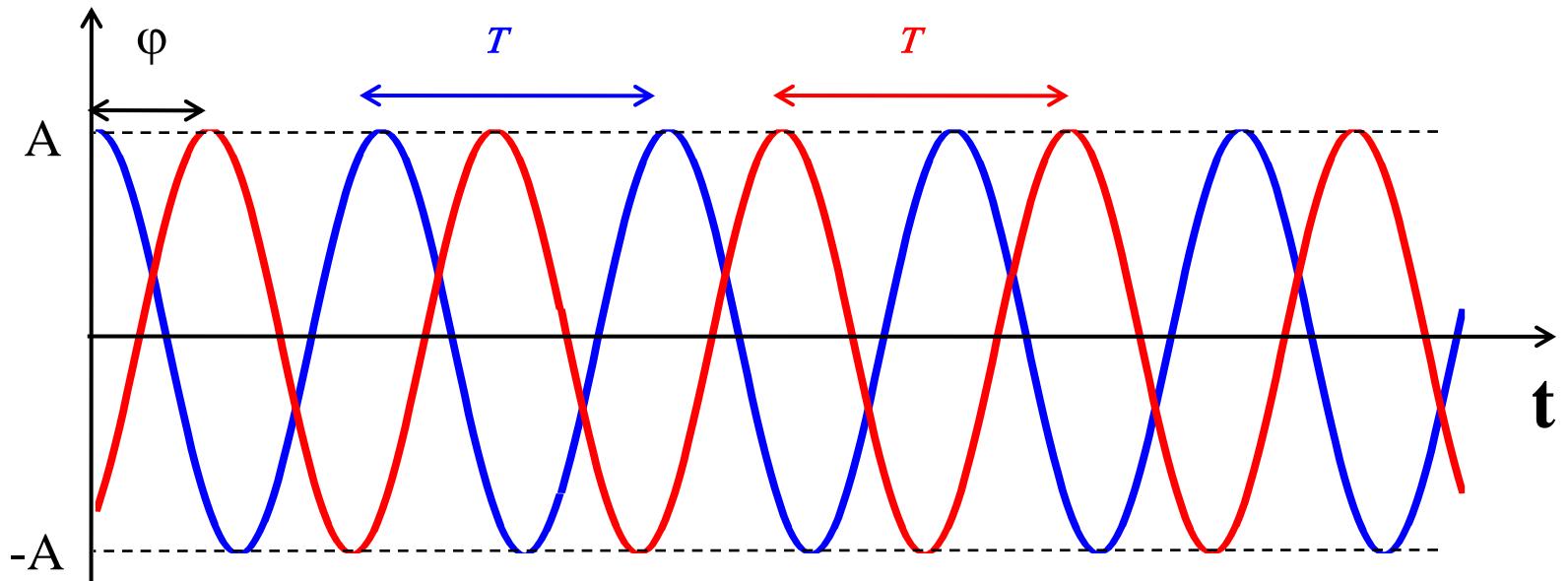
Electromagnetic spectrum



From Seguin & Villeneuve,
Astromnomie et Astrophysique

Electromagnetic coherent wave

Coherent wave: *temporal* behaviour



$$y(t) = A \cos\left(\frac{2\pi}{T} t\right)$$

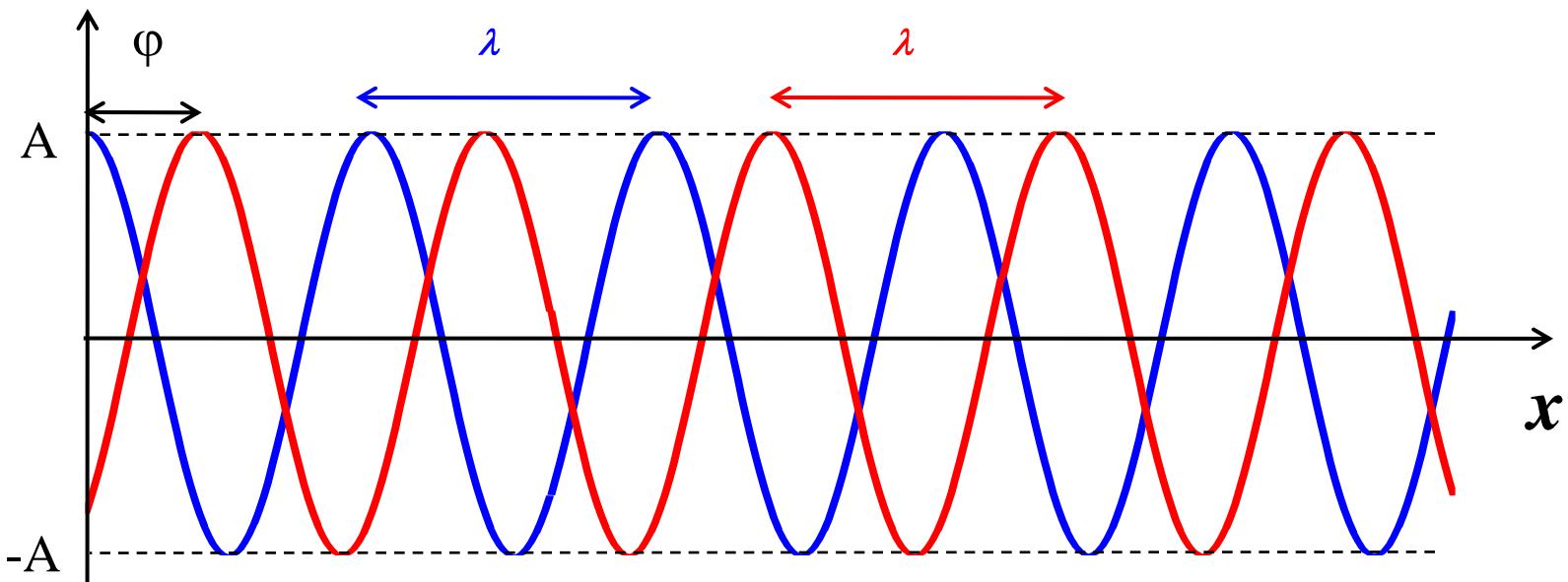
$$y(t) = A \cos\left(\frac{2\pi}{T} t - \varphi\right)$$

$$T = \frac{1}{f_0}$$

A: amplitude
 T : time period
 φ : phase shift

Electromagnetic coherent wave

Coherent wave: *spatial* behaviour



$$y(x) = A \cos\left(\frac{2\pi}{\lambda}x\right)$$

$$y(x) = A \cos\left(\frac{2\pi}{\lambda}x - \varphi\right)$$

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

A : amplitude

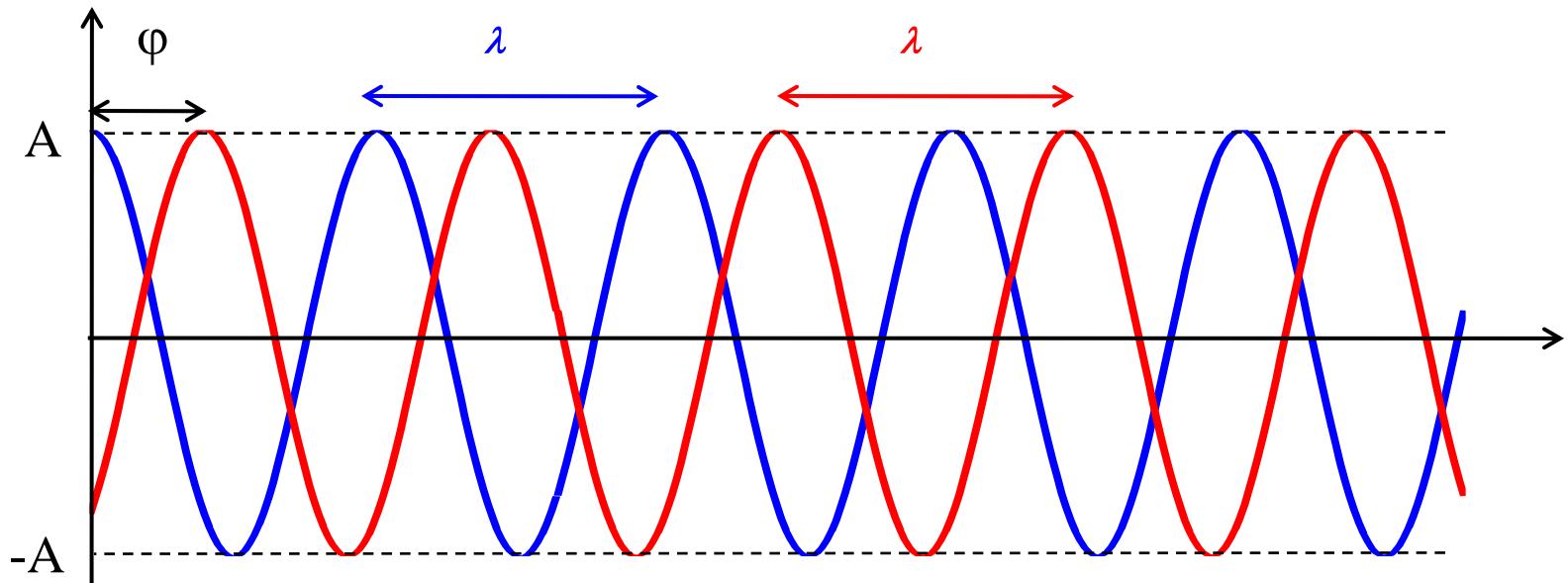
λ : spatial period = wavelength

φ : phase shift

c : light celerity = $3 \cdot 10^8$ m/s

Electromagnetic coherent wave

Coherent wave: *spatial* behaviour



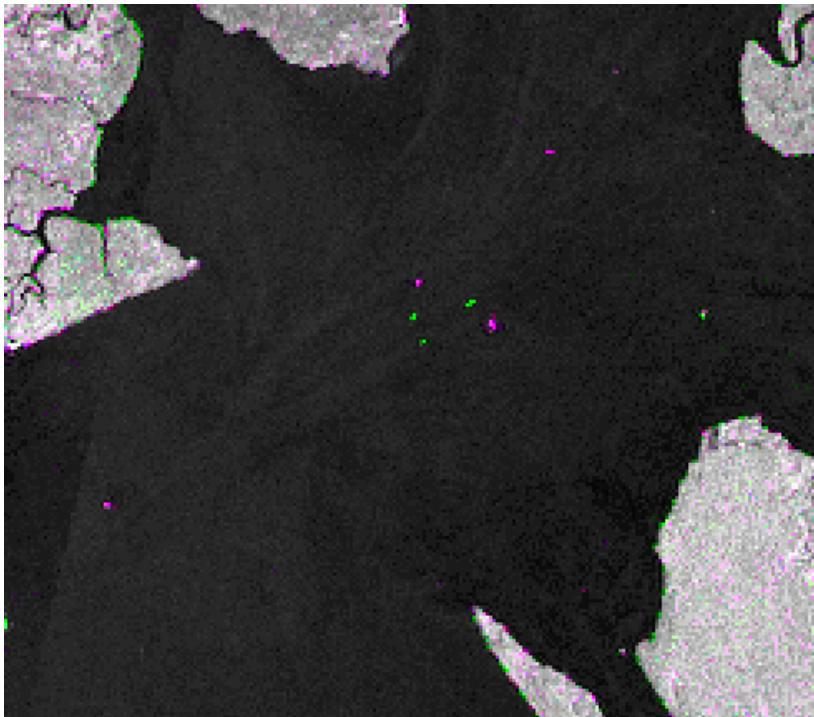
$$\psi(r, t) = A \cos \left(2\pi f_0 t - \frac{4\pi}{\lambda} r + \varphi \right)$$

OUTLINE

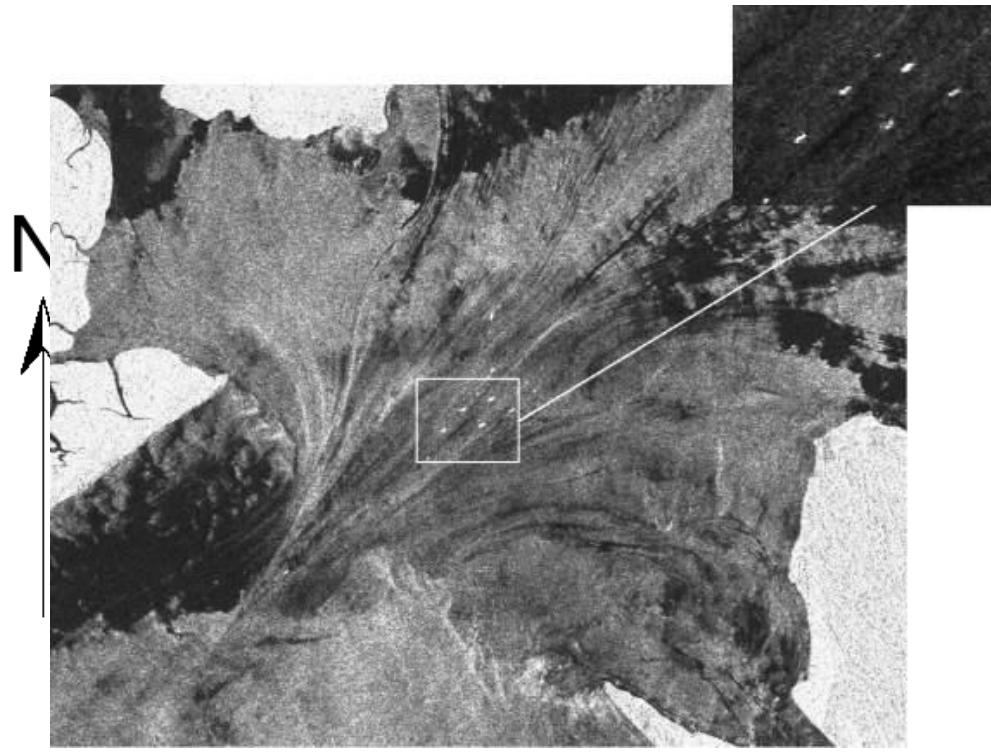
- I. Electromagnetic coherent waves
- II. Radar imaging - Spatial resolution
- III. Frequency – wavelength
- IV. Polarization
- V. Radar response sensitivity
- VI. Relief effects

Frequency - wavelength

Exercice: why is it required to know the wavelength λ ?



JERS sensor
(Bande L, $\lambda = 25$ cm)



ERS sensor
(Bande C, $\lambda = 6$ cm)

Band C

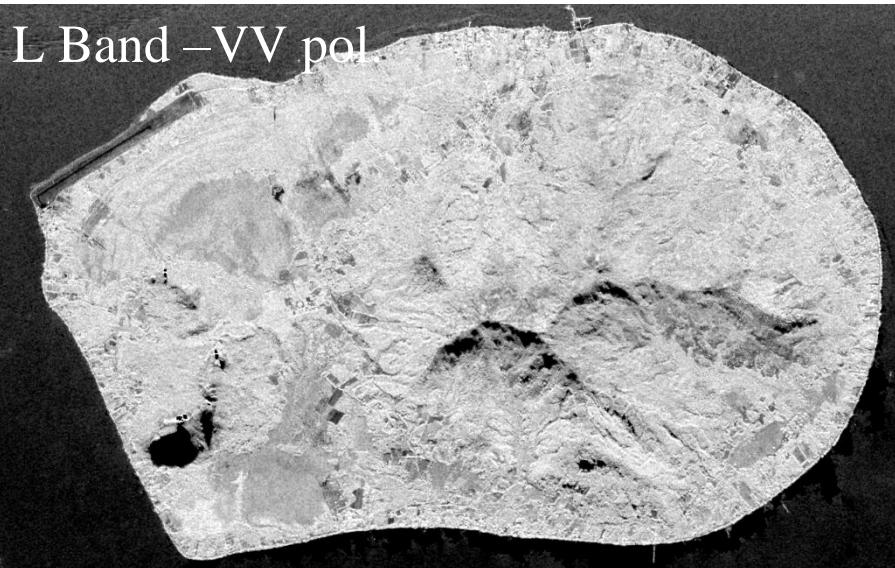


Radar response over French Guiana

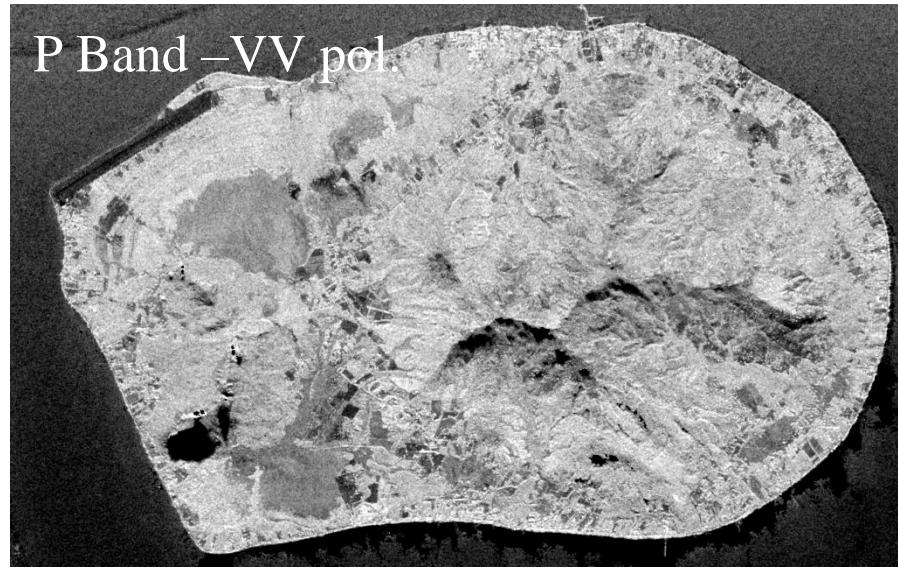
Frequency - wavelength

Tubuai Island, Vegetation discrimination

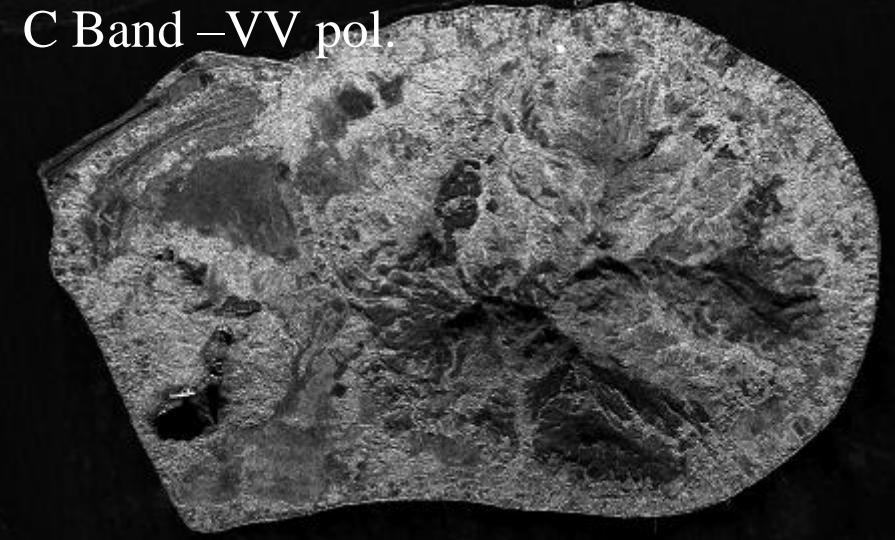
L Band –VV pol



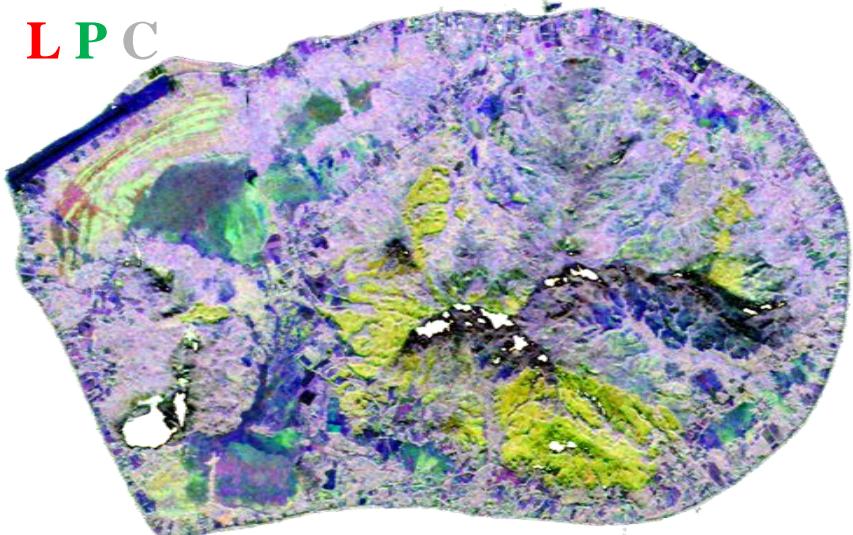
P Band –VV pol



C Band –VV pol



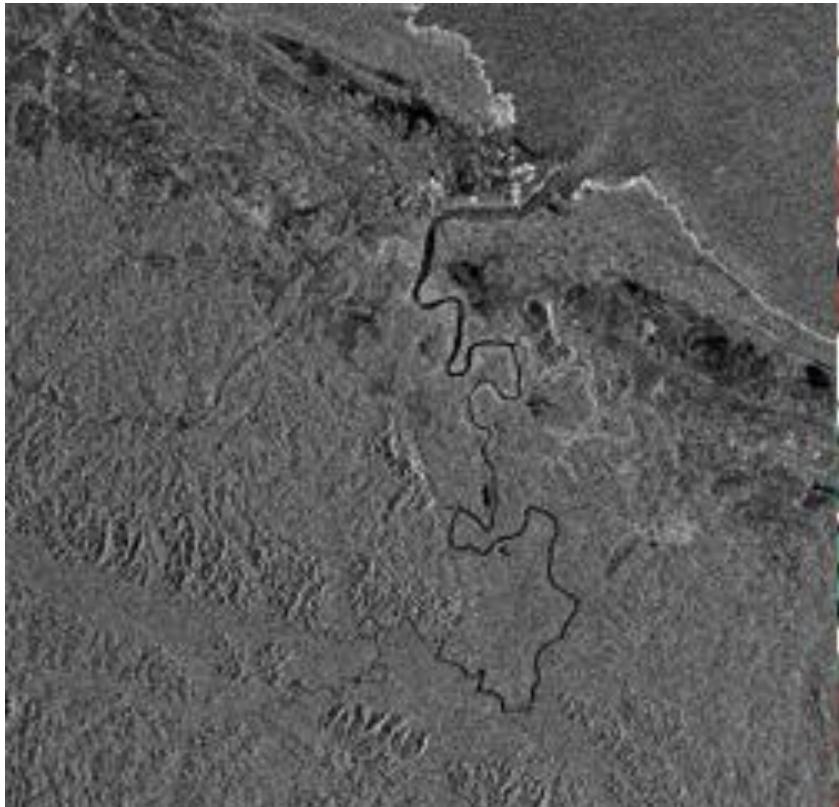
L P C



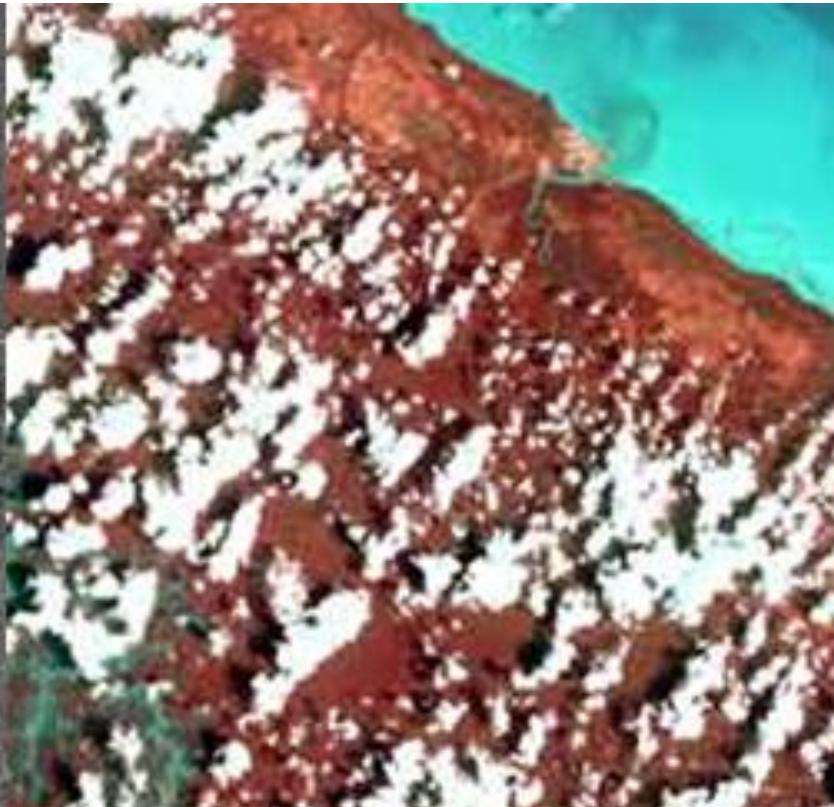
Frequency - wavelength

no problem with rain and cloudy conditions

Radar, ERS

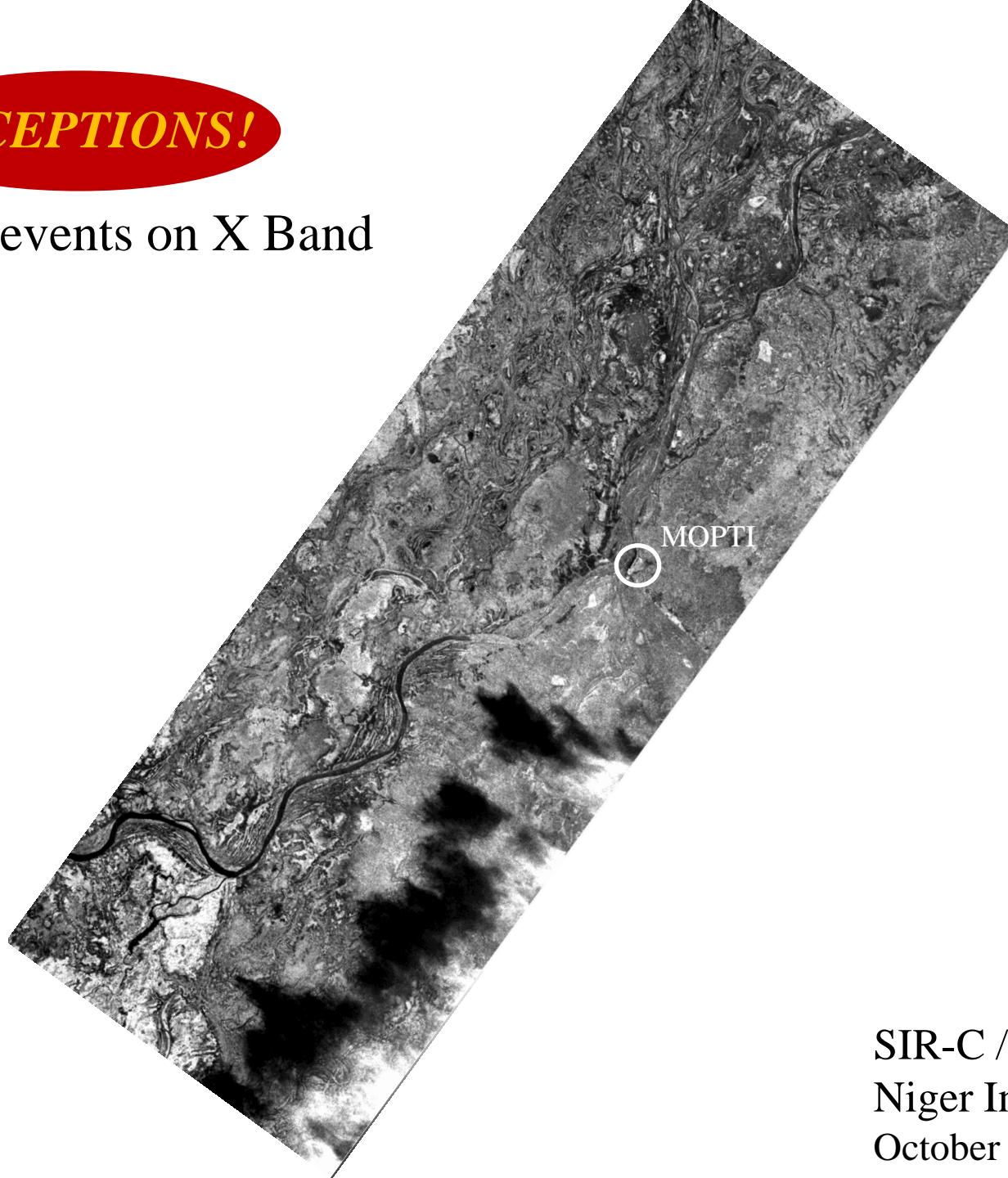


Optical, SPOT



EXCEPTIONS!

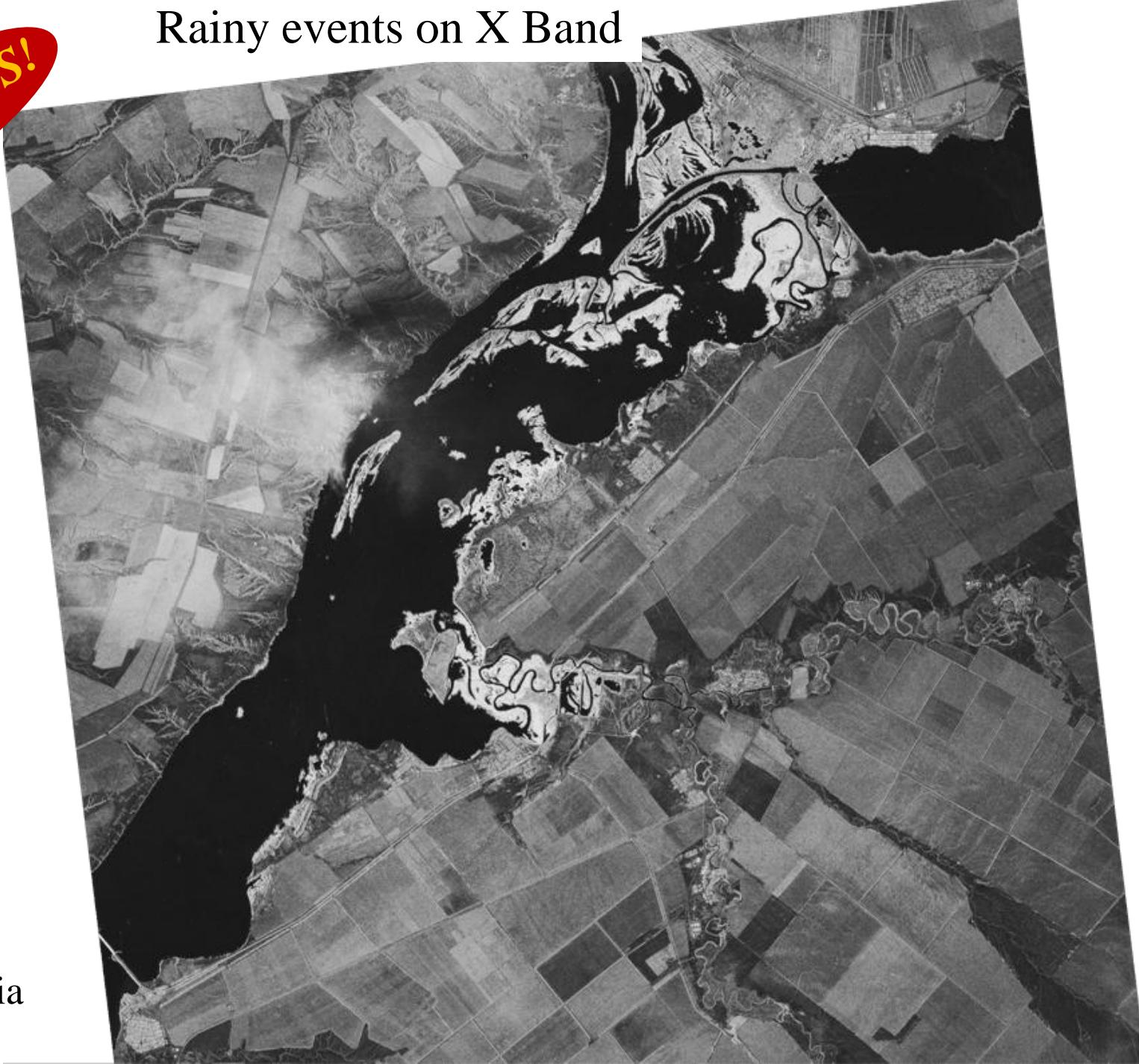
Rainy events on X Band



SIR-C / X-SAR
Niger Inner Delta, Mali
October 2, 1994

Rainy events on X Band

EXCEPTIONS!

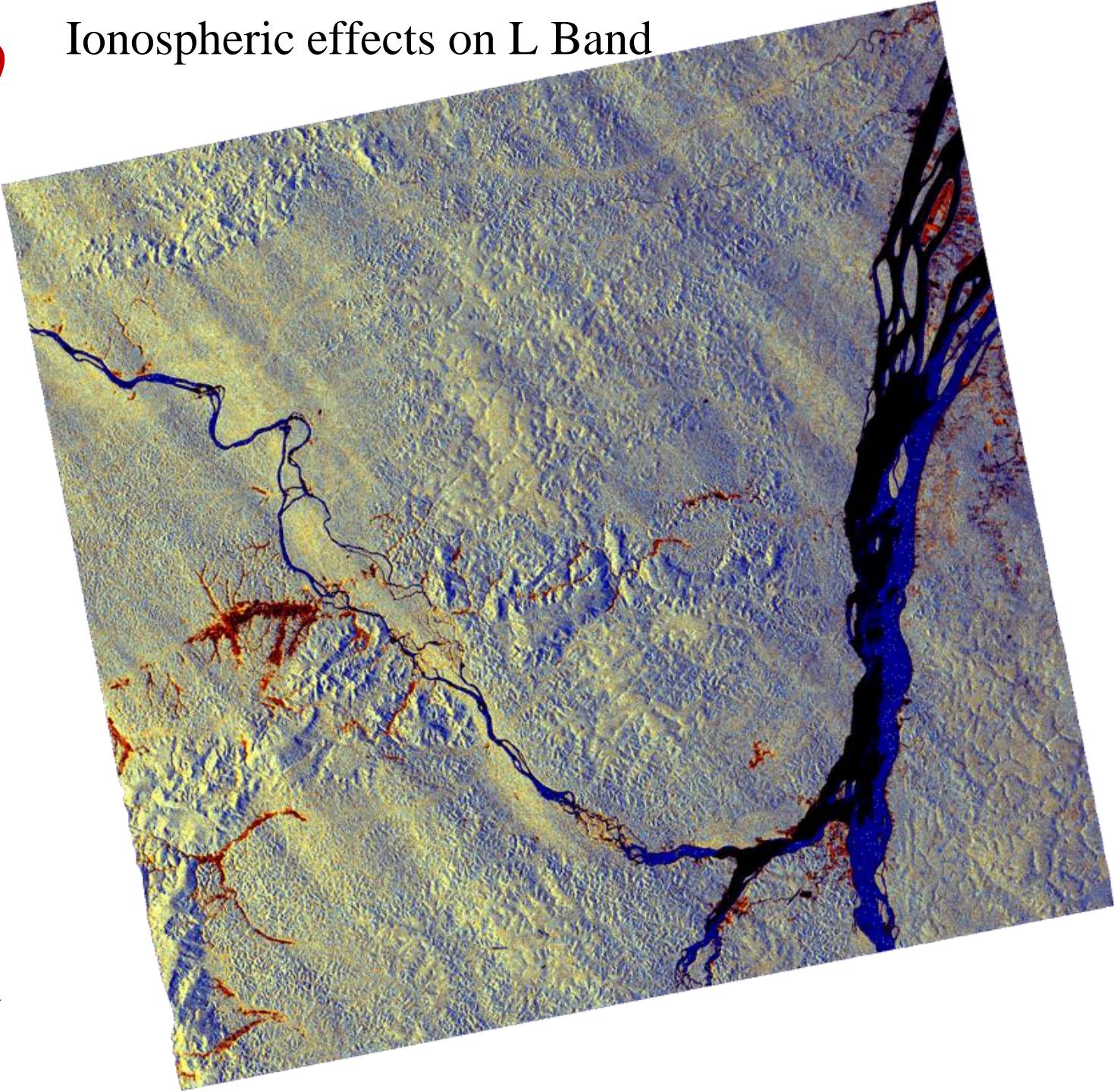


TerraSAR-X

Don River, Russia
June 19, 2007

EXCEPTIONS!

Ionospheric effects on L Band



ALOS-PALSAR
AMAPA, Brazil

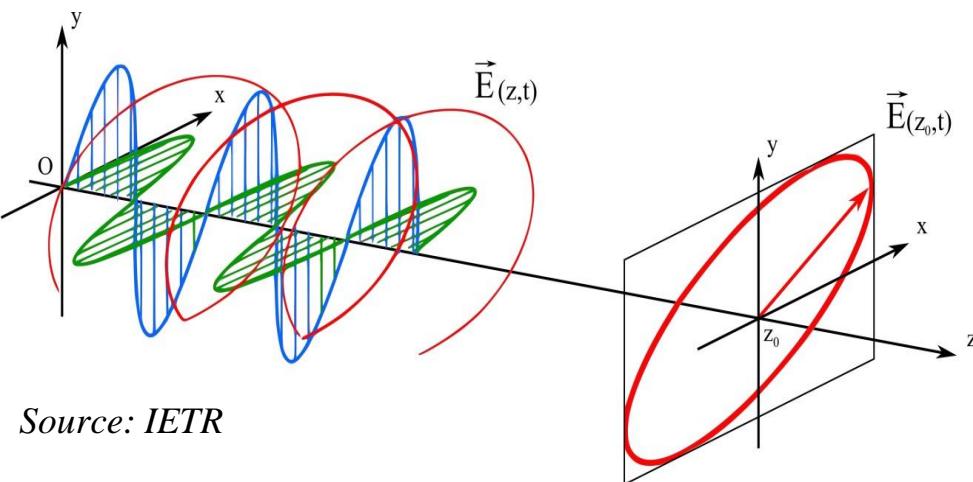
OUTLINE

- I. Electromagnetic coherent waves
- II. Radar imaging - Spatial resolution
- III. Frequency – wavelength
- IV. Polarization - Polarimetry
- V. Radar response sensitivity
- VI. Relief effects

Polarization

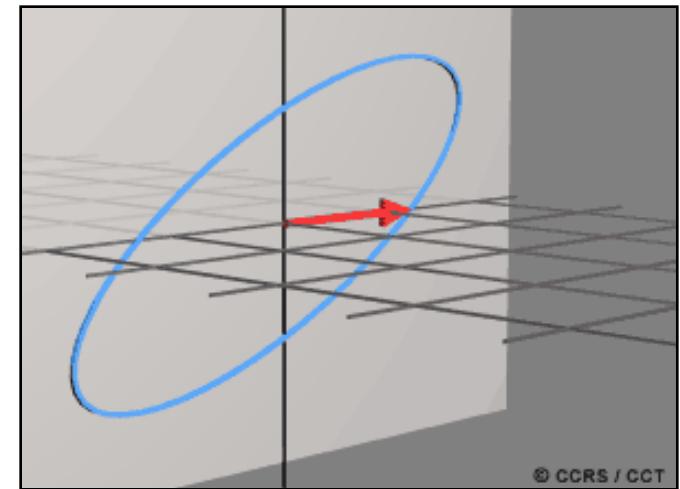
Important characteristics of coherent EMW:

Electromagnetic field evolution is predictable



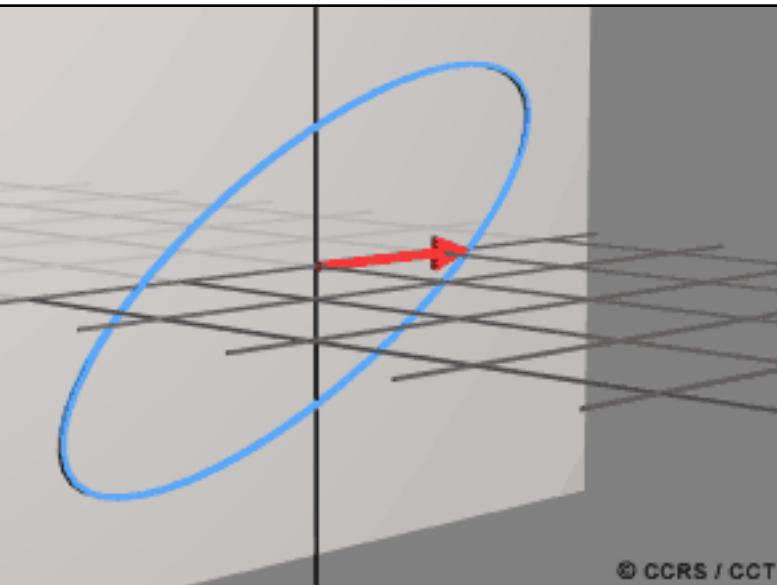
Source: IETR

Most general: *Elliptical polarization*

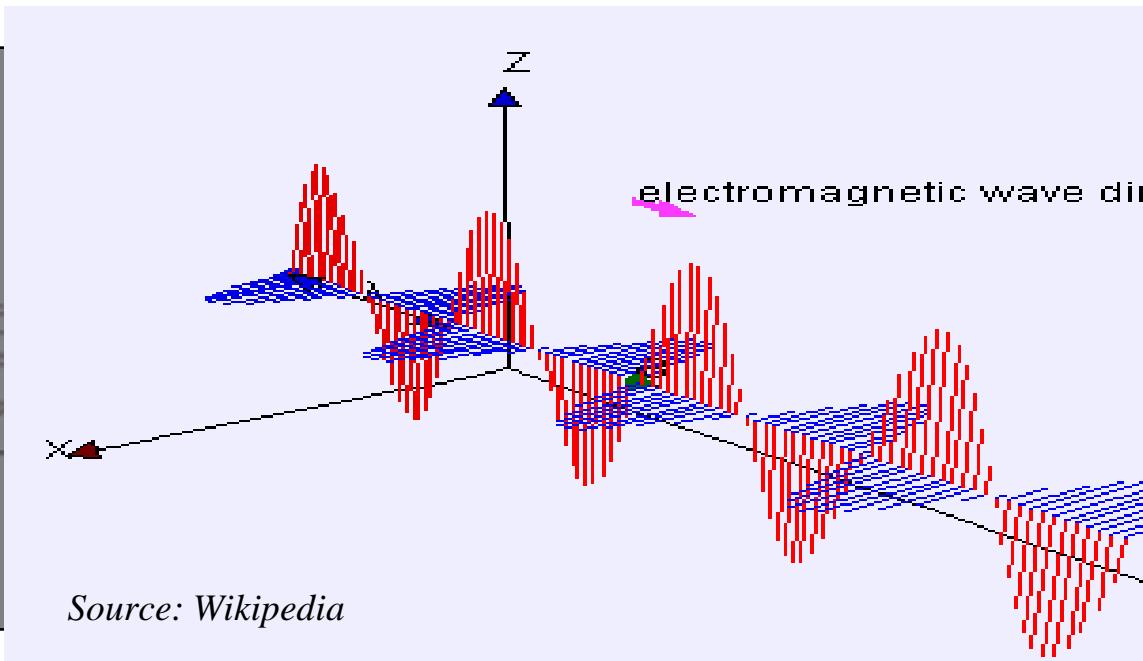


Polarization

Most general:
Elliptical polarization



Common radar sensor:
Linear polarization



Source: Wikipedia

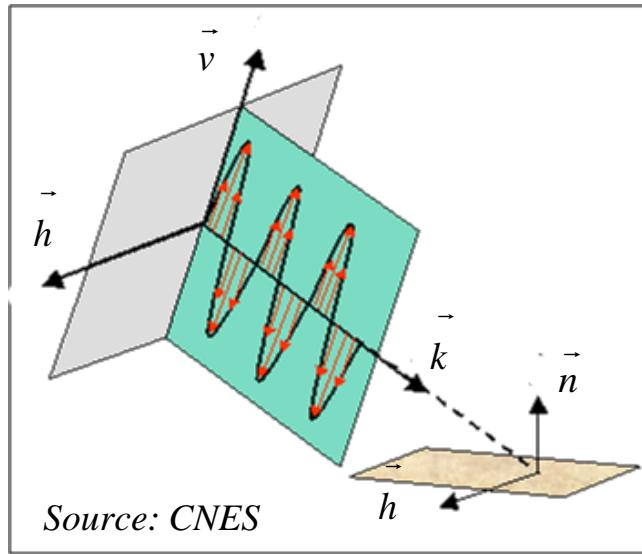
Polarization

Radar :

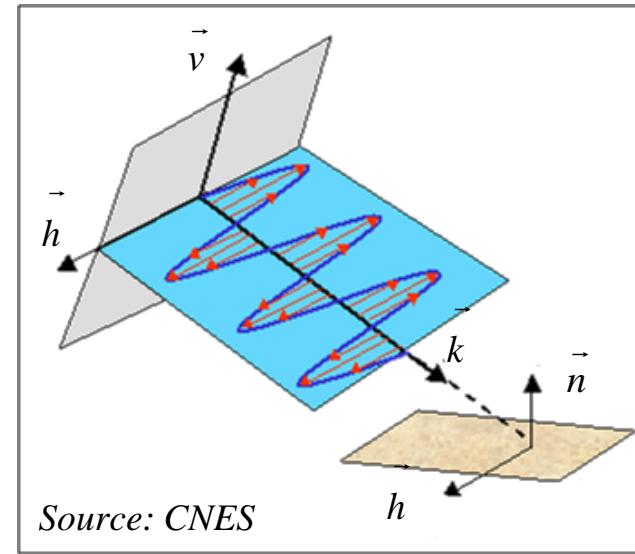
transmits a EMW in a give polarization

measures the backscattered wave contribution in a given polarization

Vertical polarization



horizontal polarization



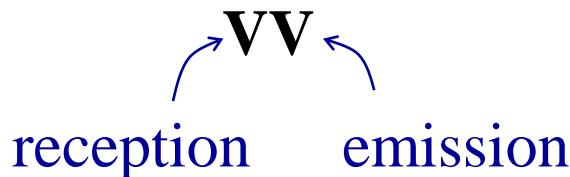
(\vec{k}, \vec{n}) : incident plane

\vec{k} : Direction of illumination

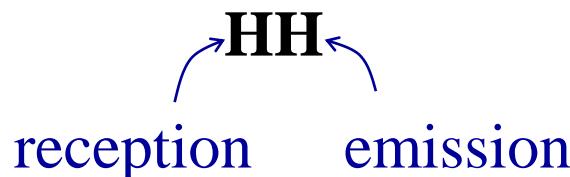
\vec{n} : Normal to the observed surface

Polarization

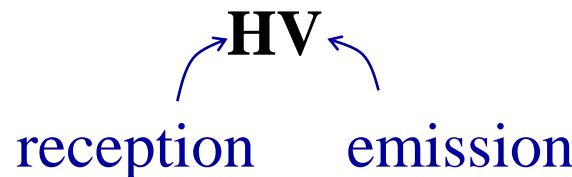
Polarization characterisation of a radar acquisition:



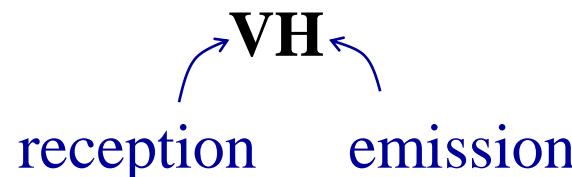
ERS, ASAR



JERS, RADARSAT, PALSAR



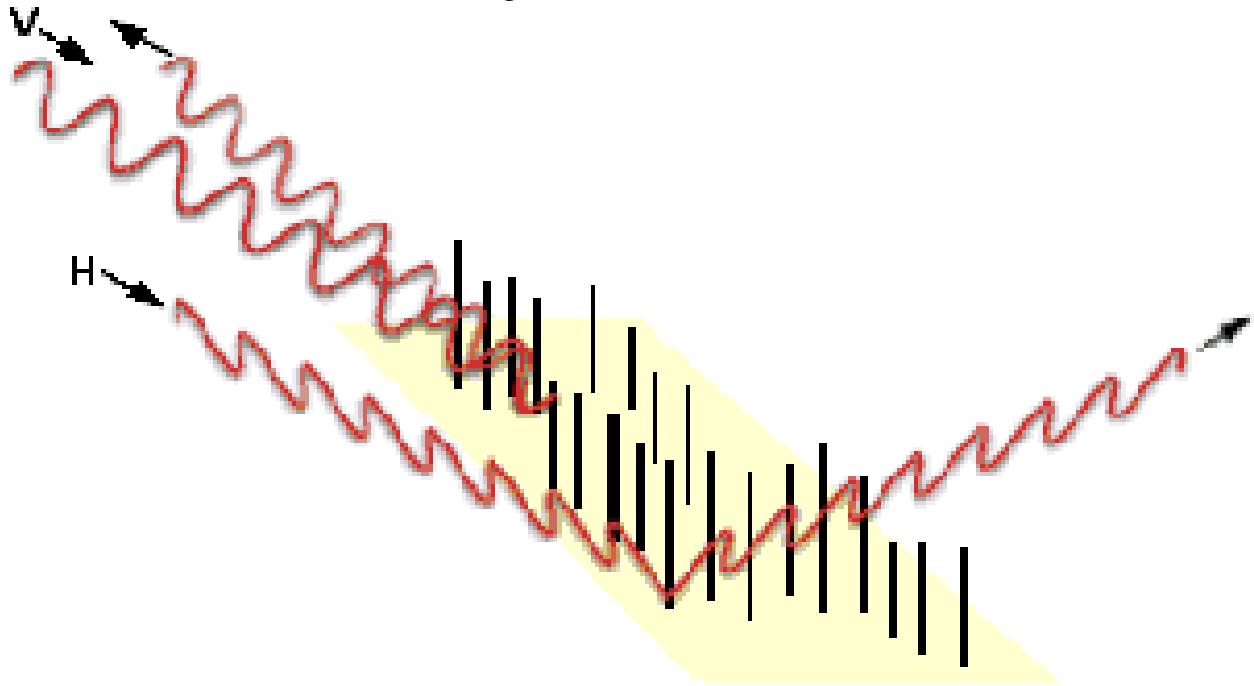
ASAR, PALSAR



ASAR, PALSAR

Polarization

Surface with vertical structures



☞ *What is the point?*

Polarization

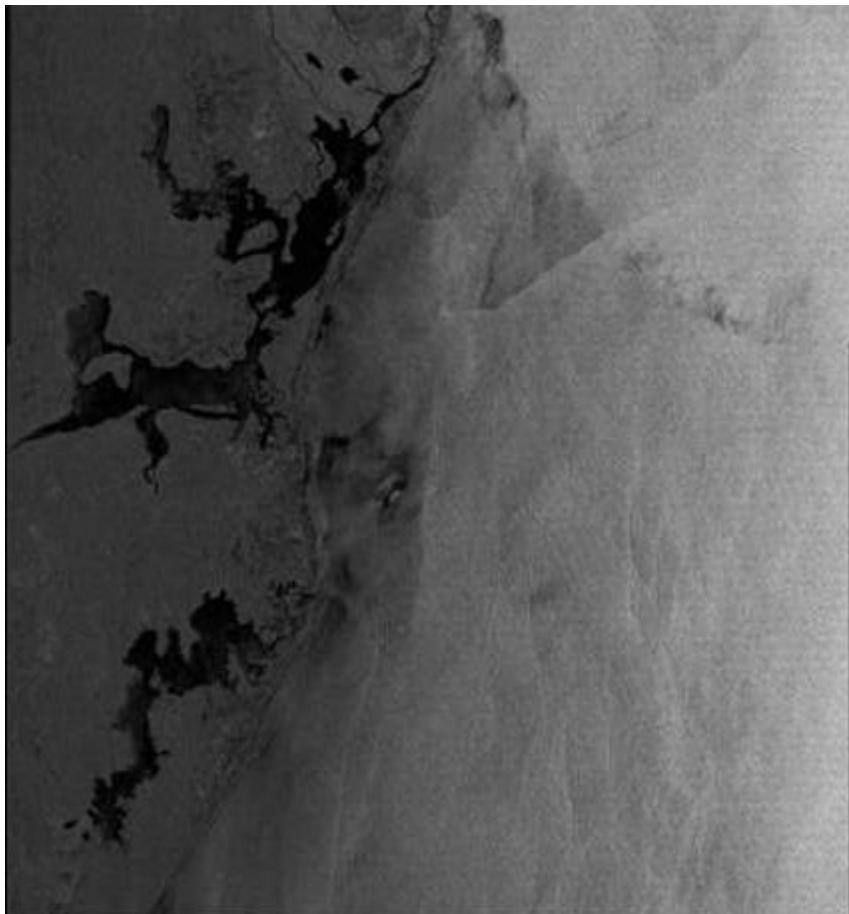
Microwave oven



☞ *What is the point?*

Polarization

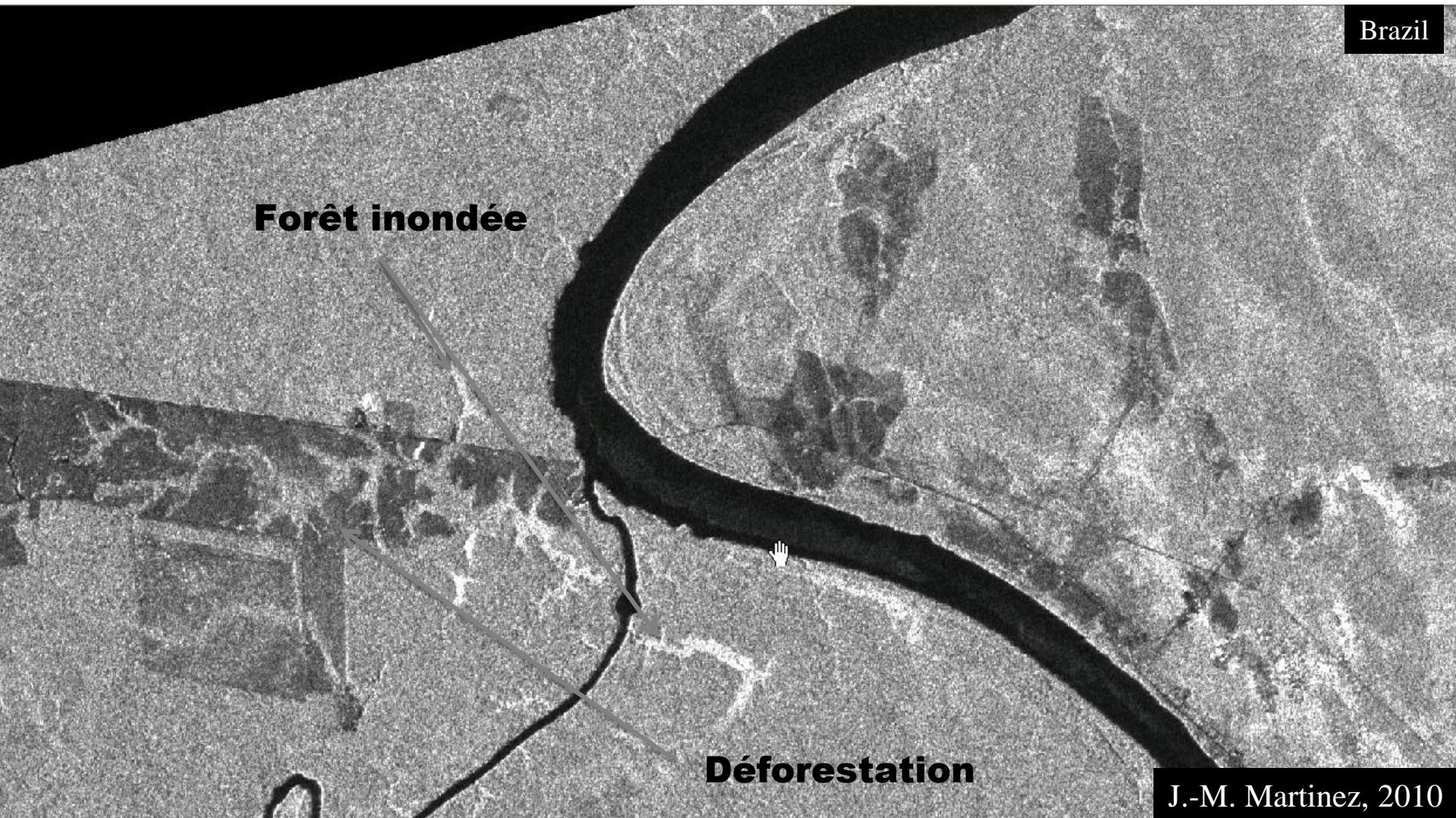
polar VV



polar HV



Polarization



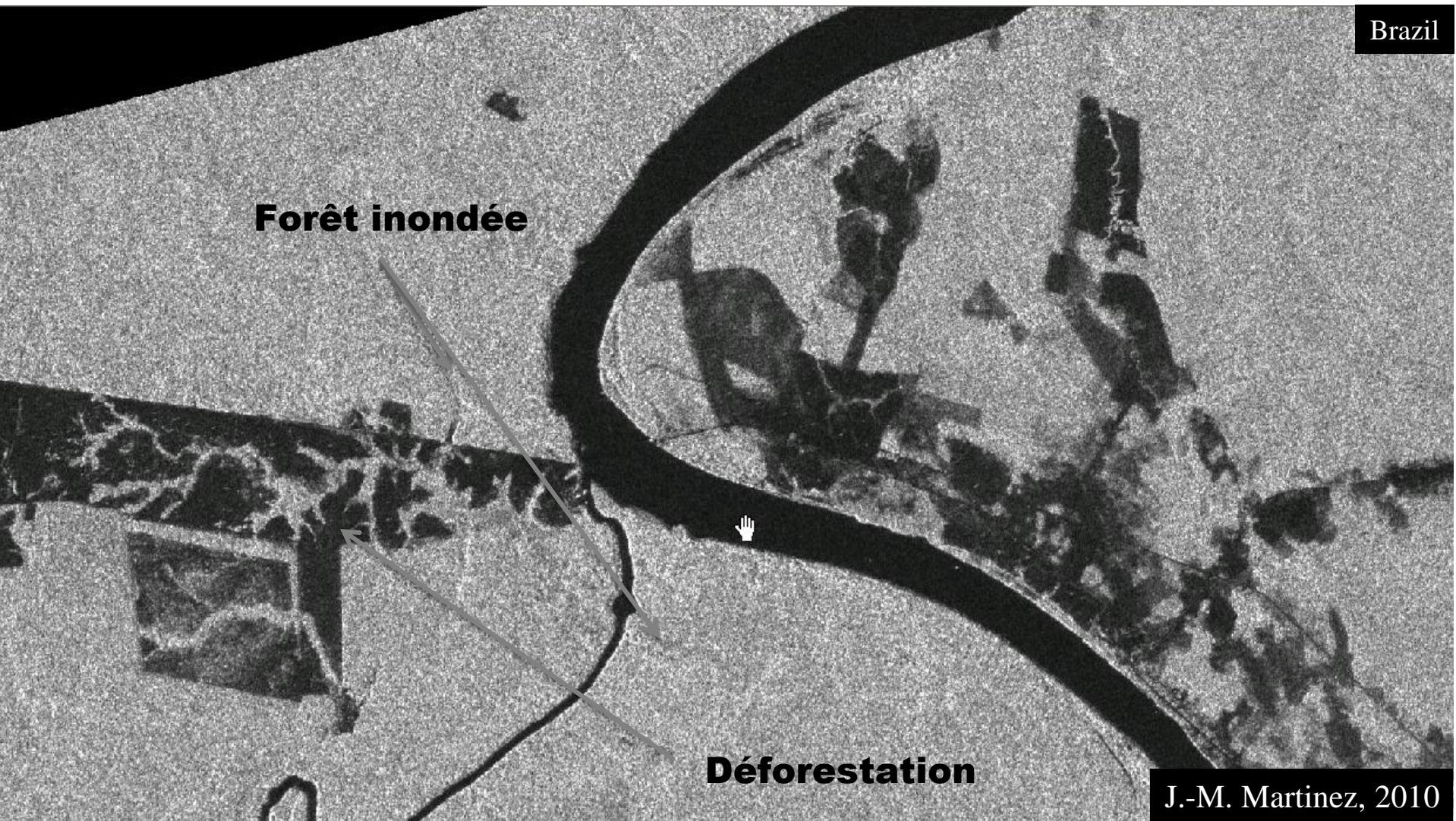
Brazil

Déforestation

J.-M. Martinez, 2010

ALOS acquisition ($\lambda = 24$ cm)- Polarization ***HH***

Polarization



ALOS acquisition ($\lambda = 24$ cm)- Polarization ***HV***

Polarization

Monitoring of the Petit Saut Dam, French Guiana, Flooding beginning: 1994

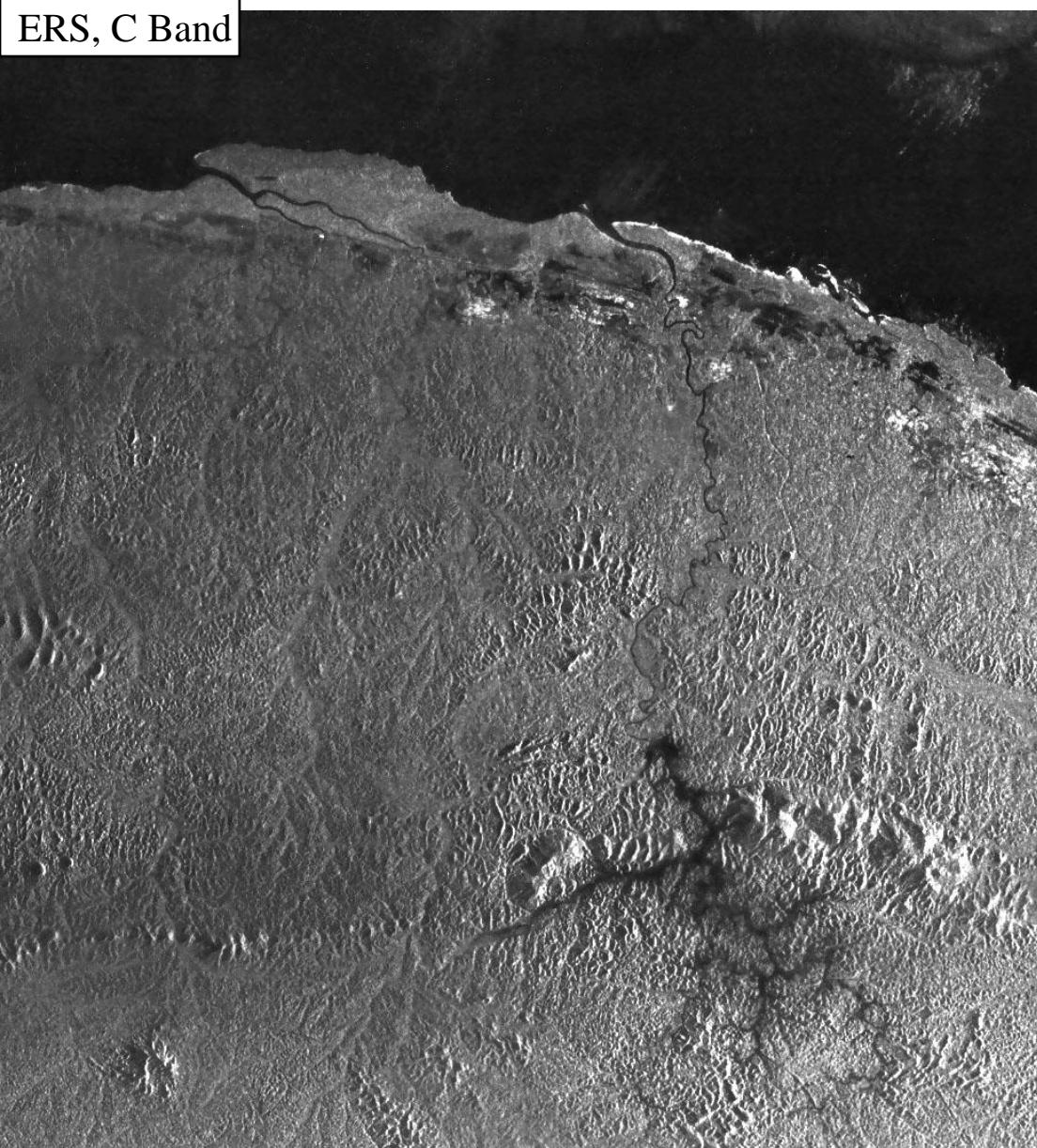


Polarization

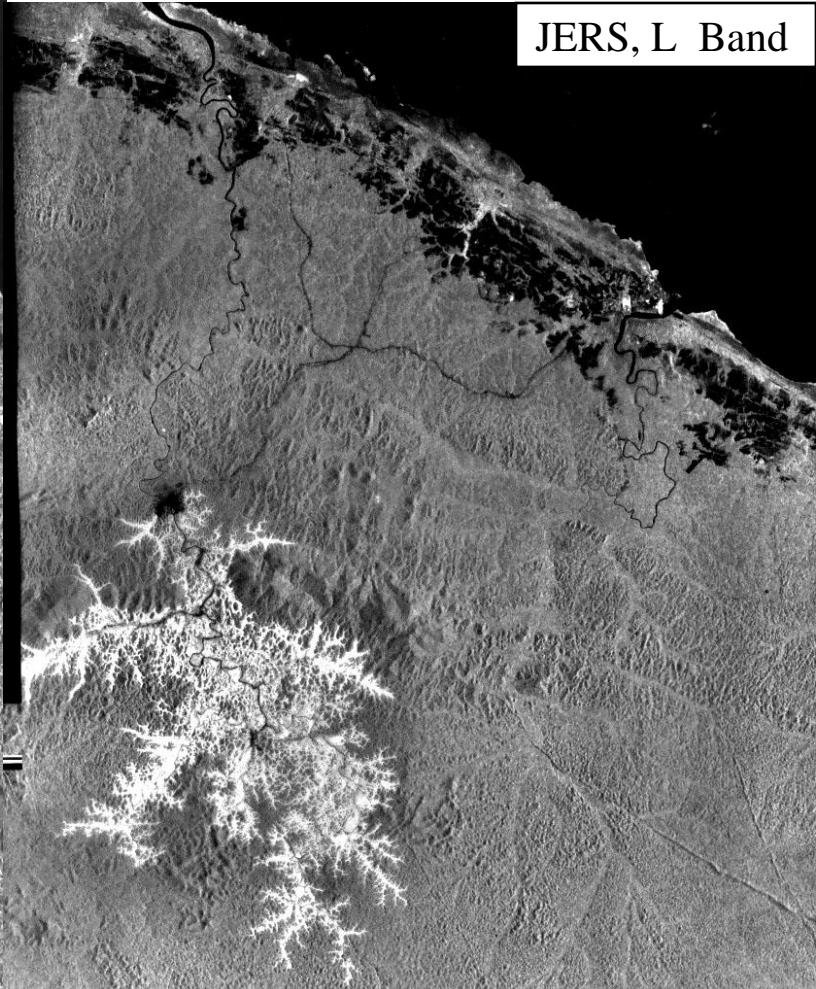


Polarization

ERS, C Band

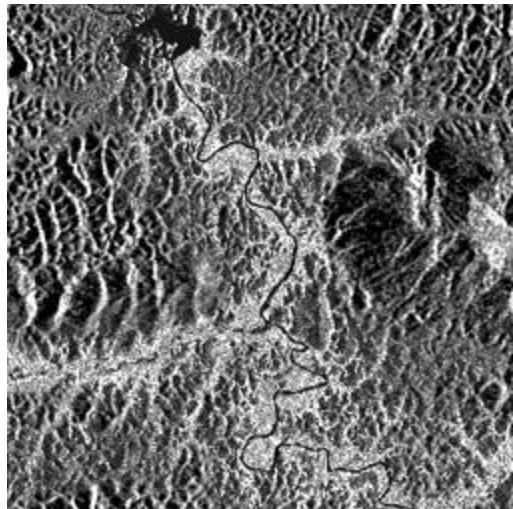


JERS, L Band

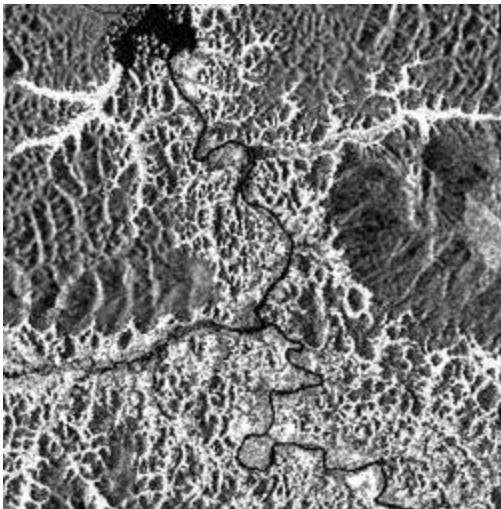


Polarization

1995



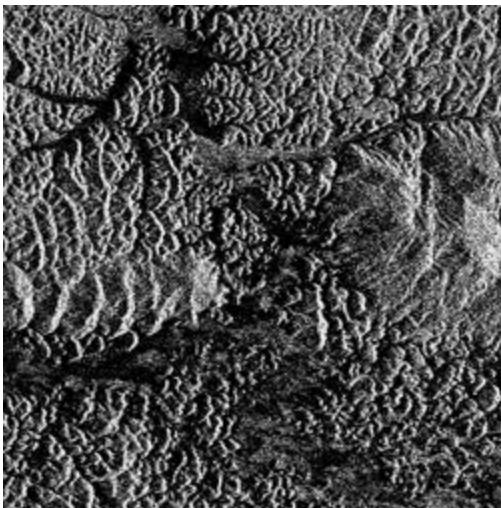
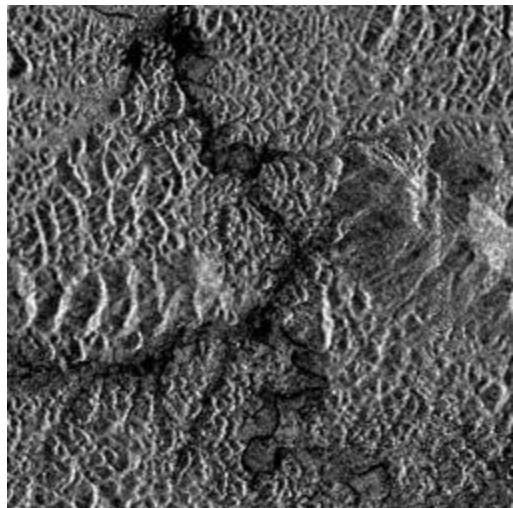
1997



JERS



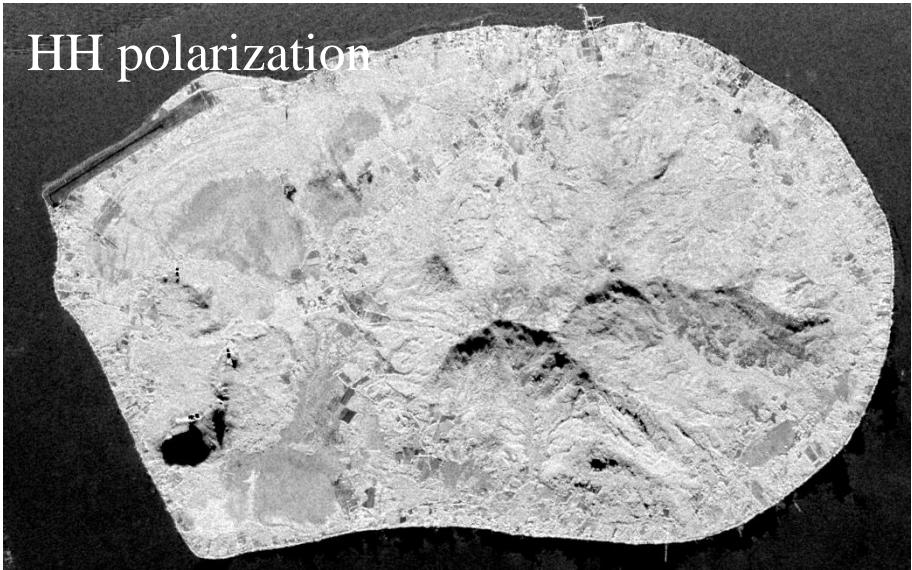
ERS



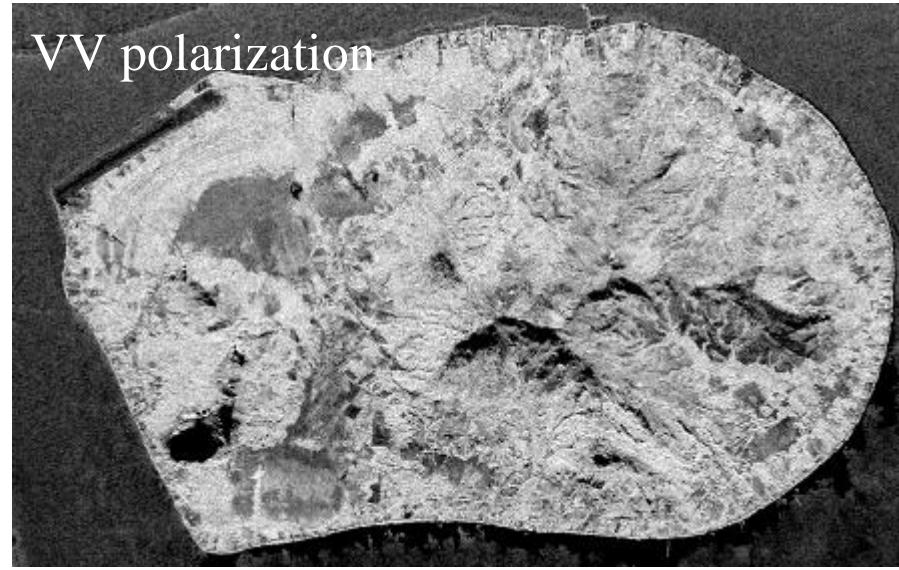
Polarization

Tubuai Island, vegetation discrimination, L Band

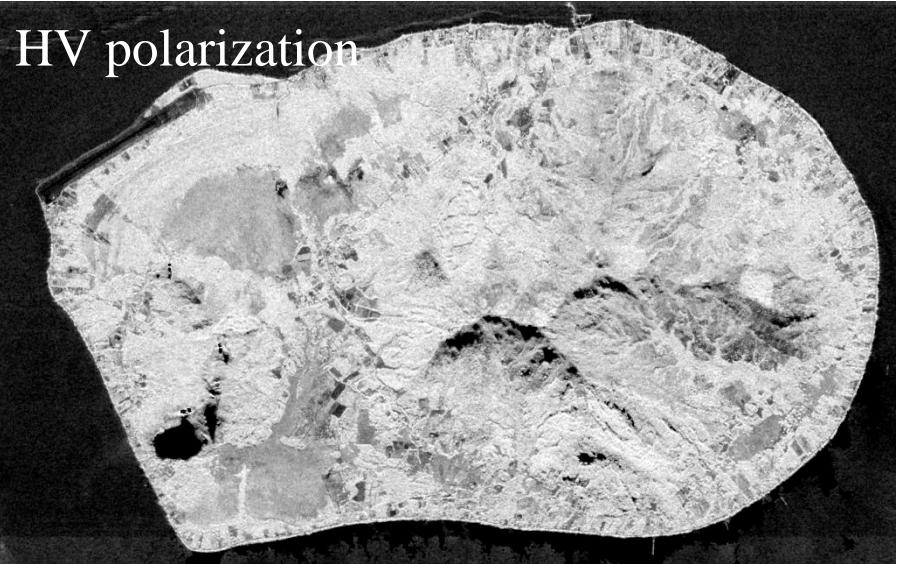
HH polarization



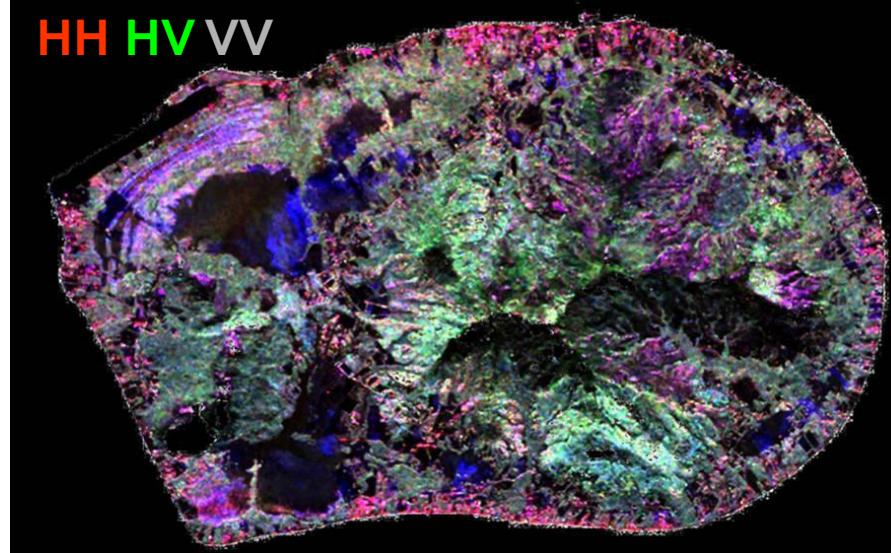
VV polarization



HV polarization



HH HV VV



Polarimétrie radar pour la cartographie des forêts

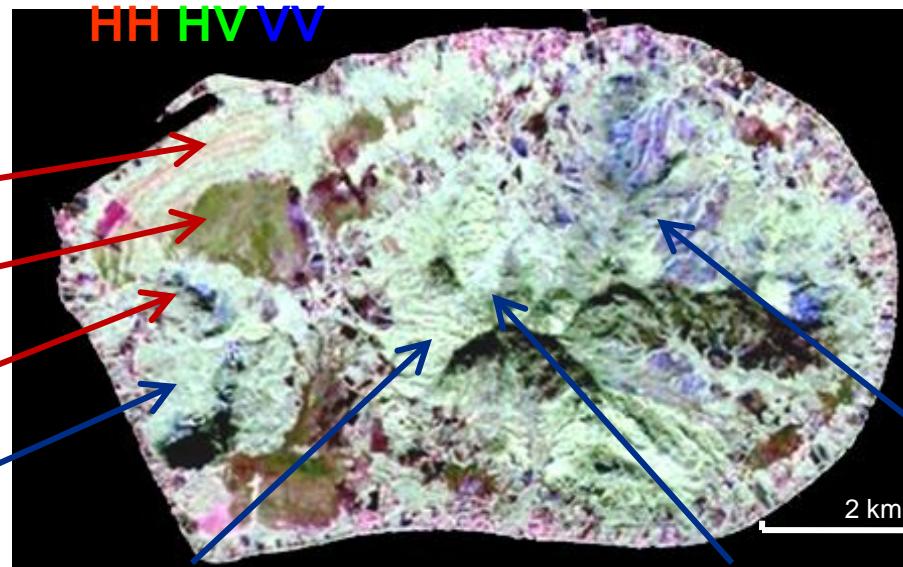
Île de Tubuai, Polynésie française

7 différentes classes:

- sols nus
- marécages
- landes à fougères

4 espèces forestières

- Purau



Radar images interpretation rules

Intensity (or Amplitude) Images

Surface scattering (bare soils)	smooth	rough
$VV > HH$	low	high
$HV \sim 0$		
Volume scattering (Dense forest)		
HH, VV high		
HV high		
Double reflexion (urban areas, flooded vegetation)		
$HH > VV$		
Wild areas (urban areas, disorderly rocks)		
$VV \sim HH \sim HV$		

Radar images interpretation rules

Amplitude (or Intensity) Images

Surface scattering (bare soils)

Amplitude

$$VV > HH$$

$$HV \sim 0$$

Volume scattering (Dense forest)

HH, VV high

HV high

Double reflexion (urban areas, flooded vegetation)

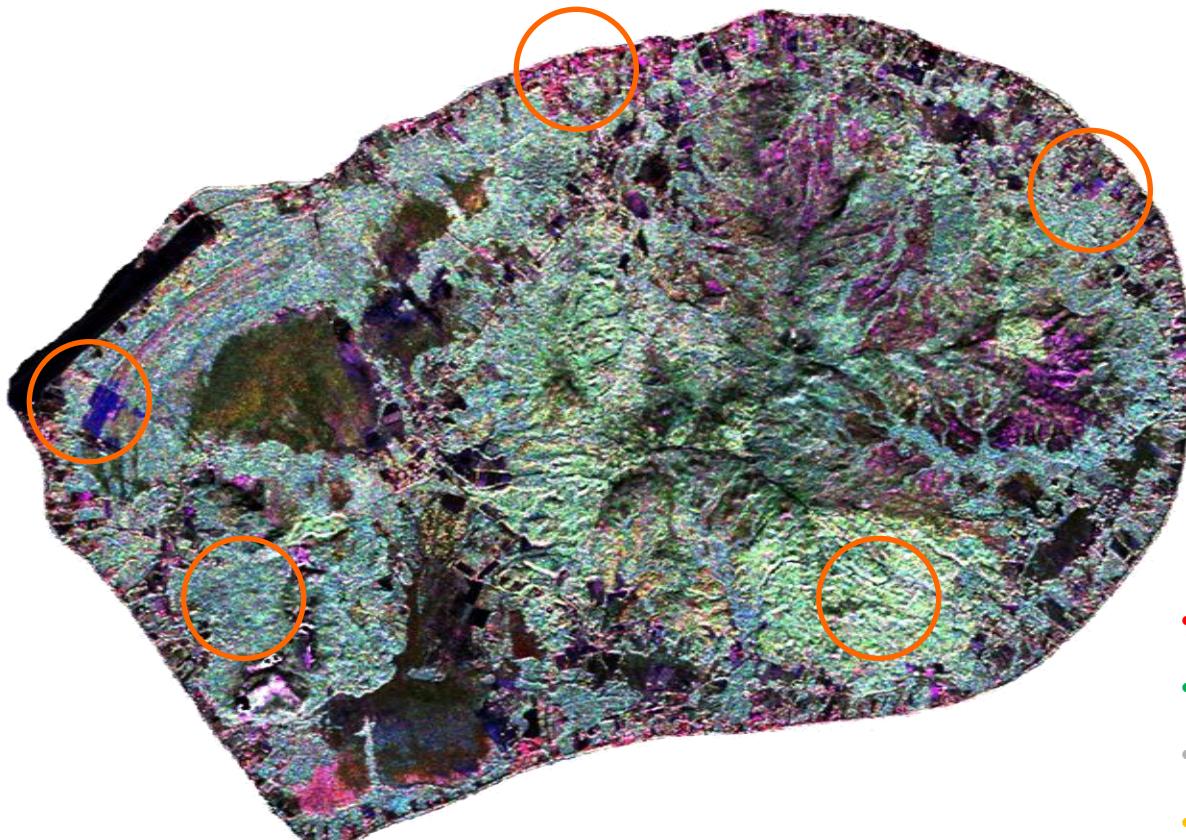
HH > VV

Wild areas (urban areas, disorderly rocks)

VV ~ HH ~ HV

Radar images interpretation rules

Intensity Image



Tubuai Island
AISAR data, L Band

- Double bounds
 - Dense vegetation
 - Bare soil
 - Pinus et Falcata
- ~ Purau

HH HV VV



OUTLINE

- I. Electromagnetic coherent waves
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- III. Frequency – wavelength
- IV. Polarization
- V. Radar response sensitivity
- VI. Relief effects

The radar equation

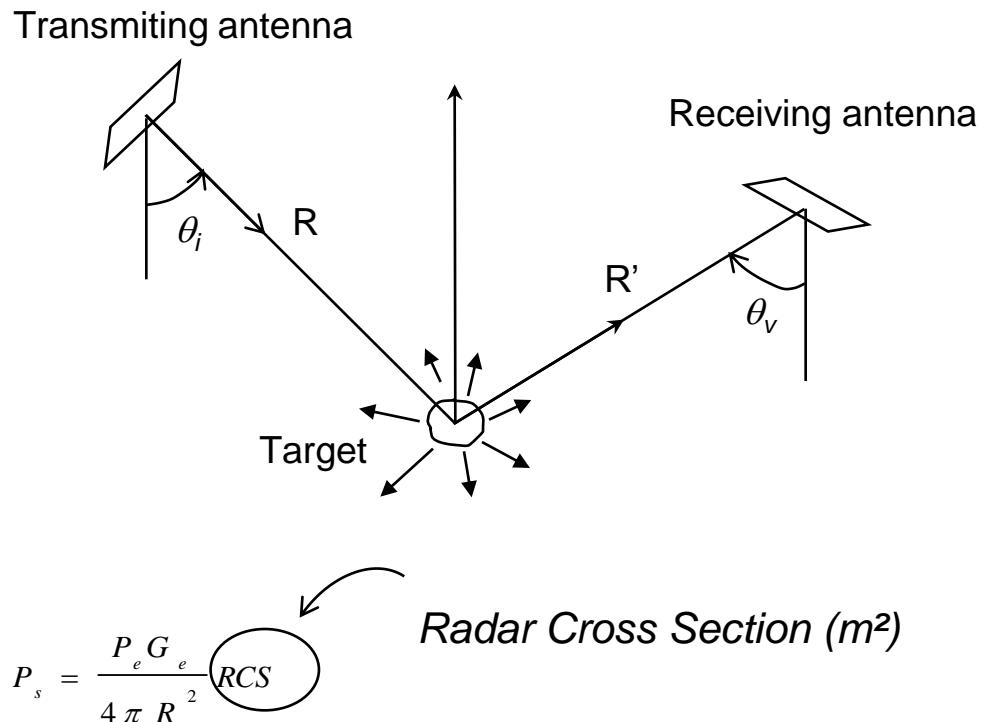
Transmited power:

$$P_i = \frac{P_e G_e}{4\pi} d\Omega \quad (W)$$

Receiving irradiance at distance R:

$$E_i = \frac{P_e G_e}{4\pi R^2} \quad (W/m^2)$$

Intercepted power from the target (W):



Intensity emitted from the target (isotrope):

$$I = \frac{P_s}{4\pi} = \frac{P_e G_e}{4\pi R^2} \frac{RCS}{4\pi} \quad (W/sr)$$

Power received by surface dS at distance R' :

$$P_r = I d\Omega = I \frac{dS}{R'^2} = \frac{P_e G_e}{4\pi R^2} \frac{RCS}{4\pi R'^2} dS \quad (W)$$

The radar equation

Power received by dS at distance R'

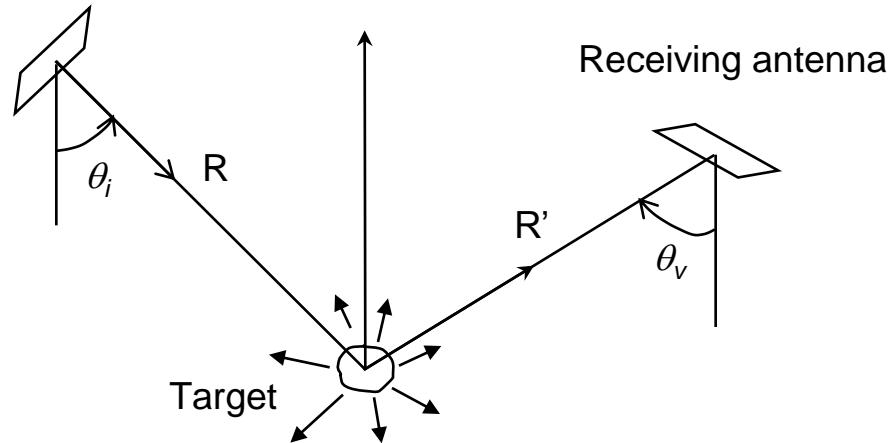
$$P_r = \frac{P_e G_e}{4\pi R^2} \frac{RCS}{4\pi R'^2} dS \quad (W)$$

Received irradiance at distance R'

$$E_r = \frac{P_e G_e}{4\pi R^2} \frac{RCS}{4\pi R'^2} \quad (W/m^2)$$

Power received by the antenna: $P_r = E_r dA = E_r \frac{G_r \lambda^2}{4\pi} = \frac{P_e G_e}{4\pi R^2} \frac{SER}{4\pi R'^2} \frac{G_r \lambda^2}{4\pi} \quad (W)$

Transmitting antenna



The radar equation

Power received by the antenna:

$$dP_r = \frac{P_e G_e}{4\pi R^2} \frac{RCS}{4\pi} \frac{G_r \lambda^2}{4\pi R^2} \quad (W)$$

Case of expanse surfaces:

Radar Backscattering Coefficient:

$$\sigma^0 = \frac{RCS}{d\Sigma} \quad (m^2/m^2)$$

→ Analogous to the reflectance in Optical domain

$$dP_r = \frac{P_e G_e}{4\pi R^2} \frac{\sigma^0 d\Sigma}{4\pi} \frac{G_r \lambda^2}{4\pi R^2}$$

$$\sigma^0 = \frac{(4\pi)^3}{\lambda^2} \frac{\langle P_r \rangle}{P_e} \frac{R^4}{\iint_{Surf_obs} G_e G_r d\Sigma}$$

σ^0 high dynamic

==> dB units (log. scale)

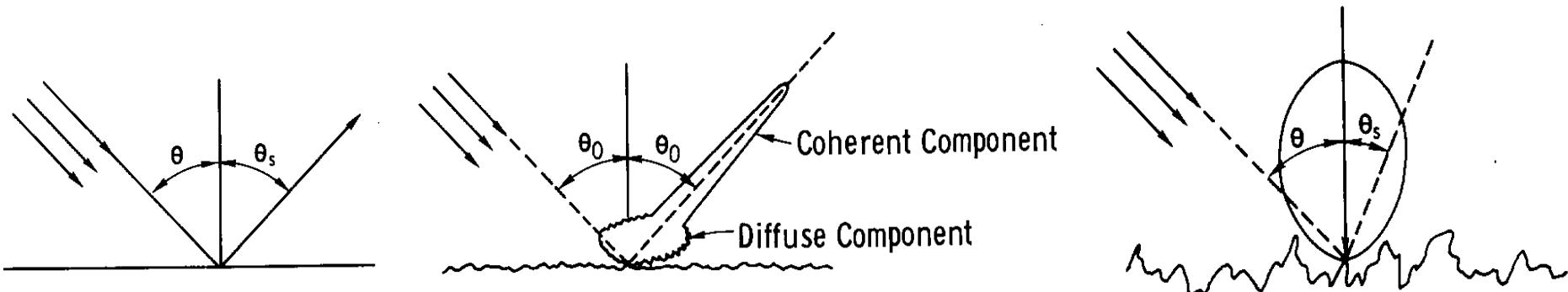
$$\sigma_{dB}^0 = 10 \cdot \log_{10} (\sigma_{Nat}^0)$$

Radar images interpretation rules

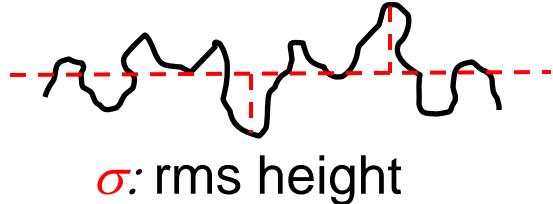
Surface scattering

Soil: homogeneous medium ==> scattering at the interface

Influence of roughness



Surface roughness is referred to the radar wavelength



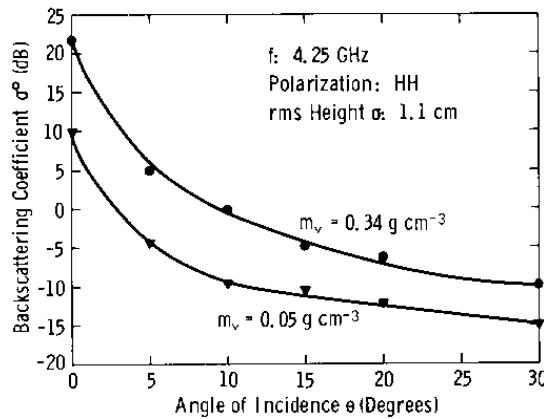
$$\sigma < \frac{\lambda}{8 \cos \theta} \quad ==> \text{smooth surface}$$

ERS ($\lambda = 5 \text{ cm}$, $\theta = 23^\circ$): $s > 2 \cdot 10^{-2}$: every soil is rough!

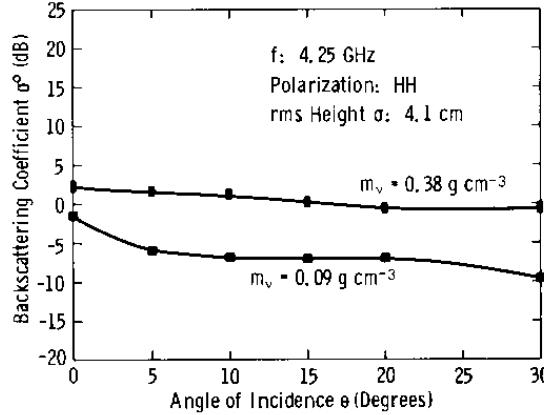
Radar images interpretation rules

Surface scattering

Smooth surface



Rough surface

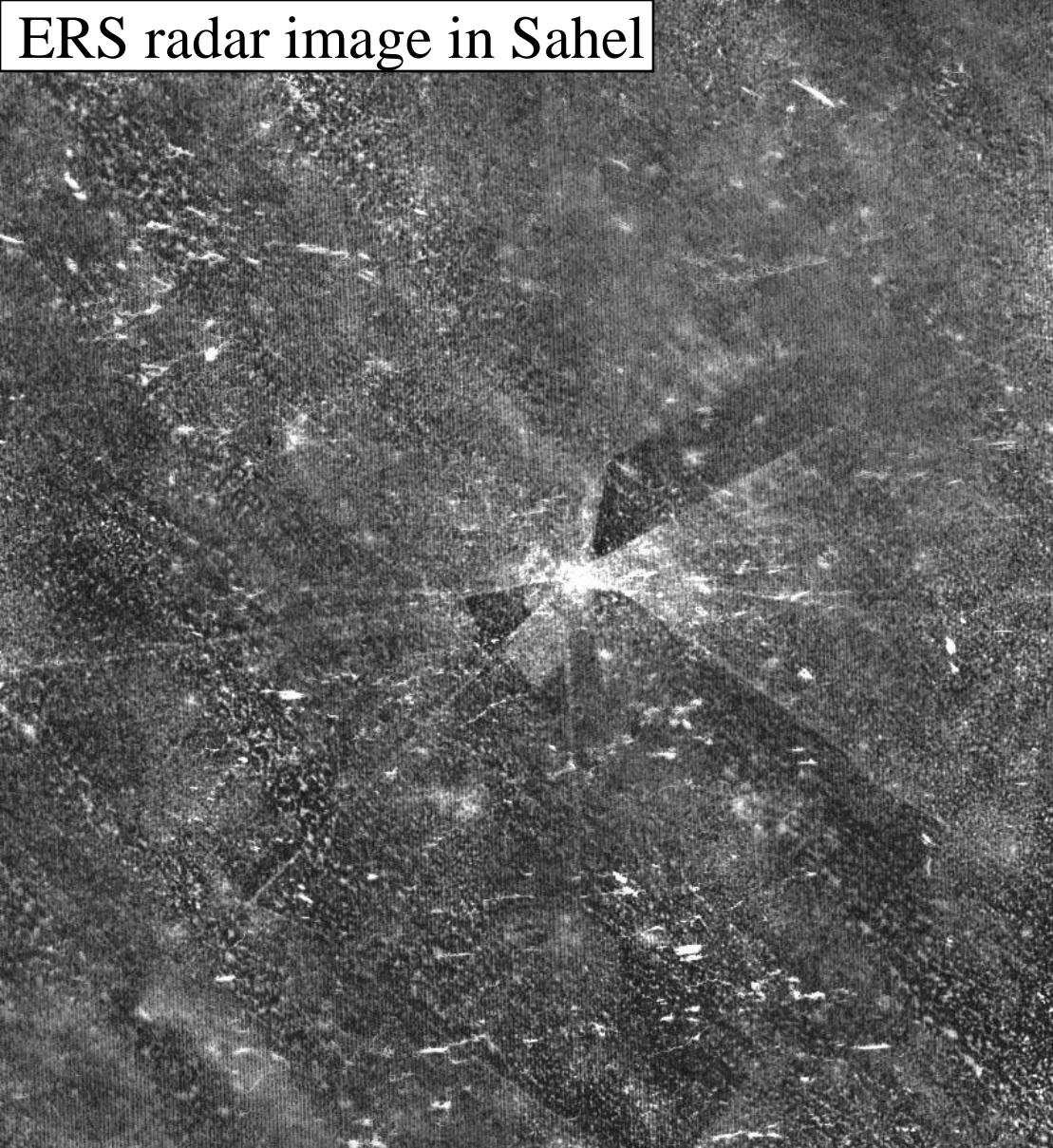


(b)

Soil roughness: angular effect

Soil moisture: shift level effect

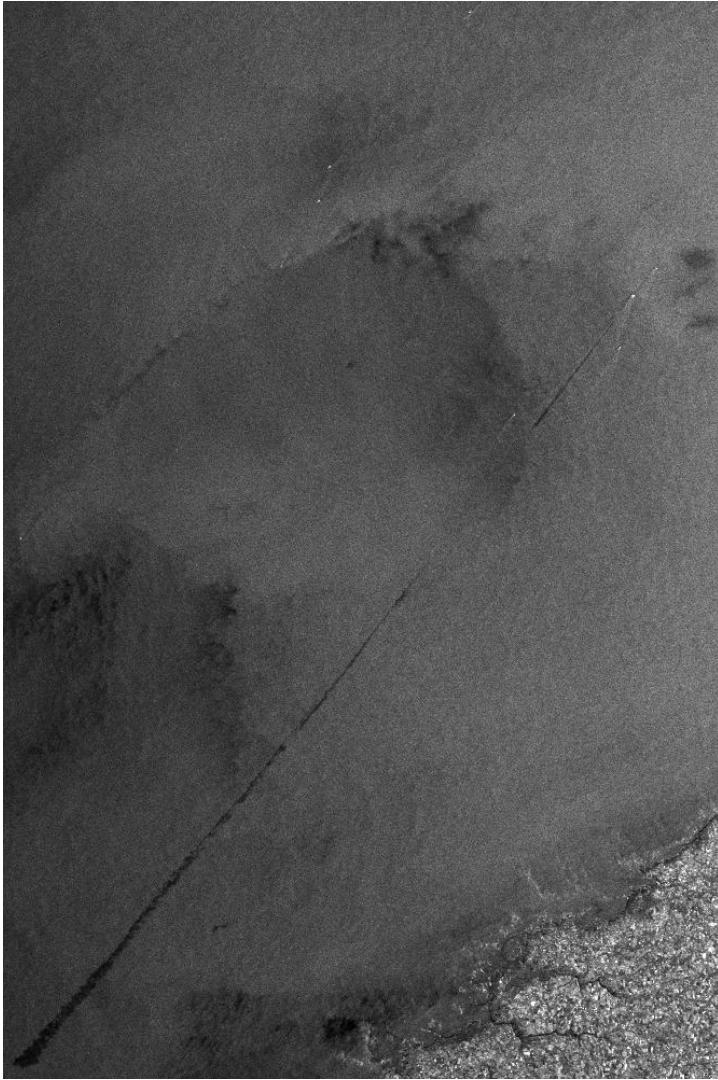
ERS radar image in Sahel



Over bare soil: depends on
Roughness
Soil moisture

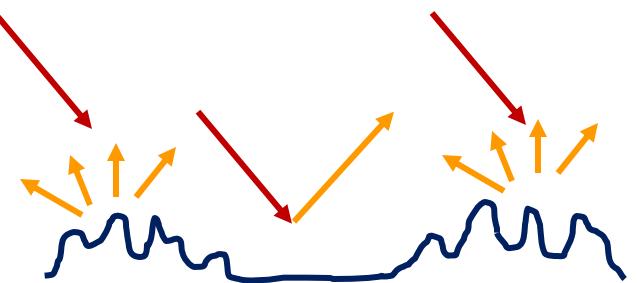


Radar response sensitivity



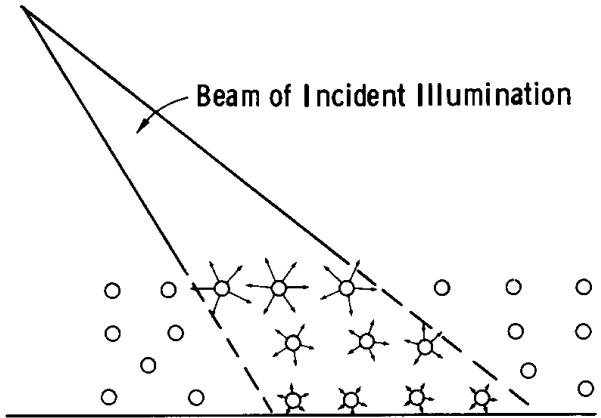
ERS (bande C, 23°, VV): 9 mars 1999

Over surface water:
surface roughness too



Radar images interpretation rules

Volume scattering



Inhomogeneous medium (vegetation cover)

each inhomogeneity (leaves, branches....)
scatters incident wave in all directions

Multiple scattering

+

Absorption

} ==> wave attenuation within the layer

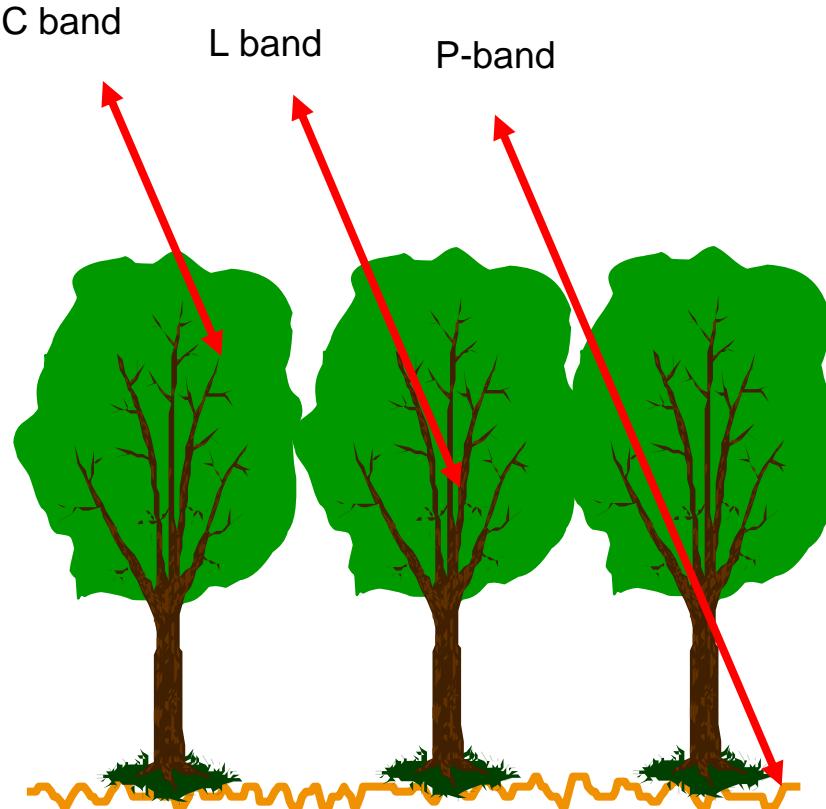
Radar images interpretation rules

Volume scattering

Penetration Depth:

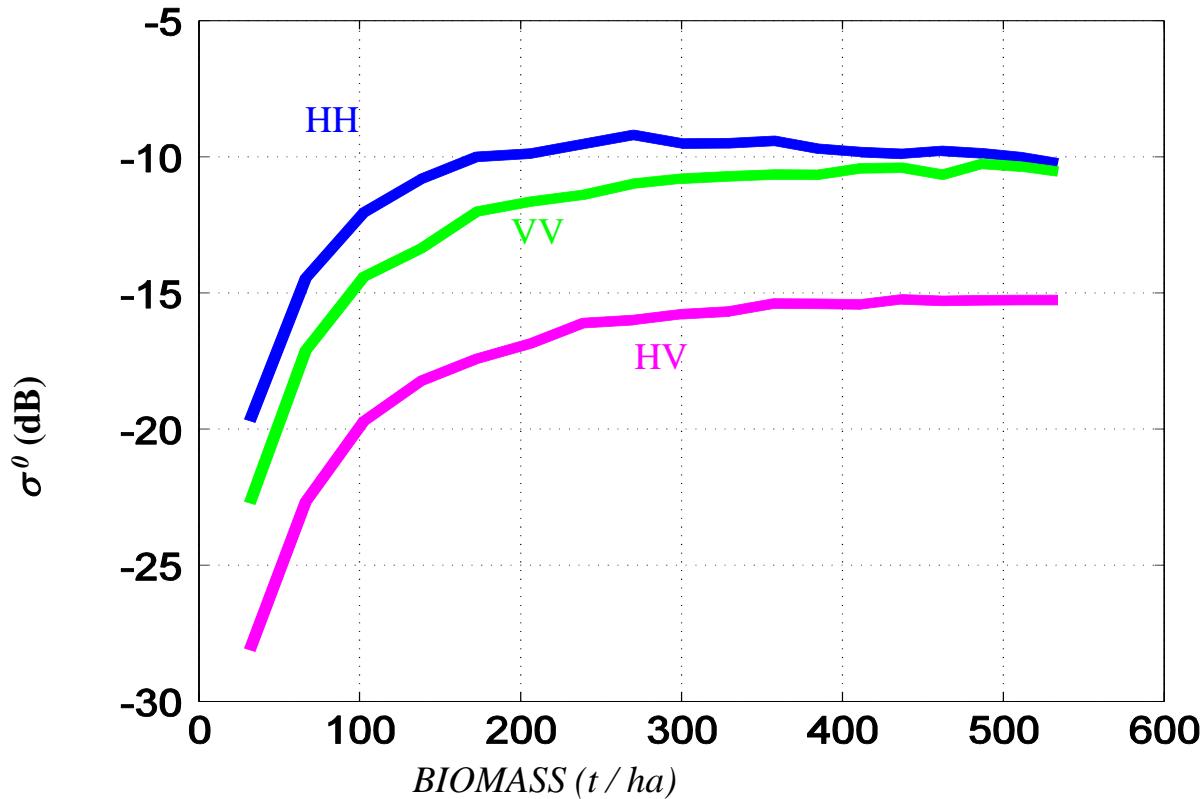
$$\delta = \frac{\lambda}{4\pi \operatorname{Im}(\sqrt{\epsilon})}$$

Penetration { Biomass
 wavelength



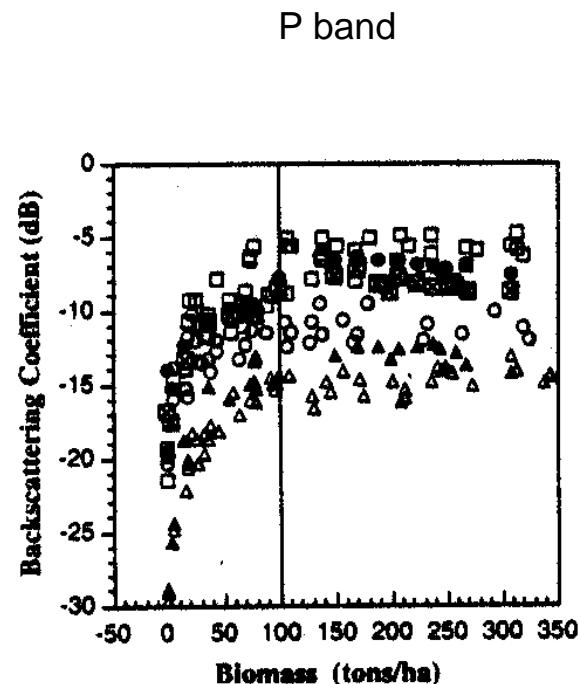
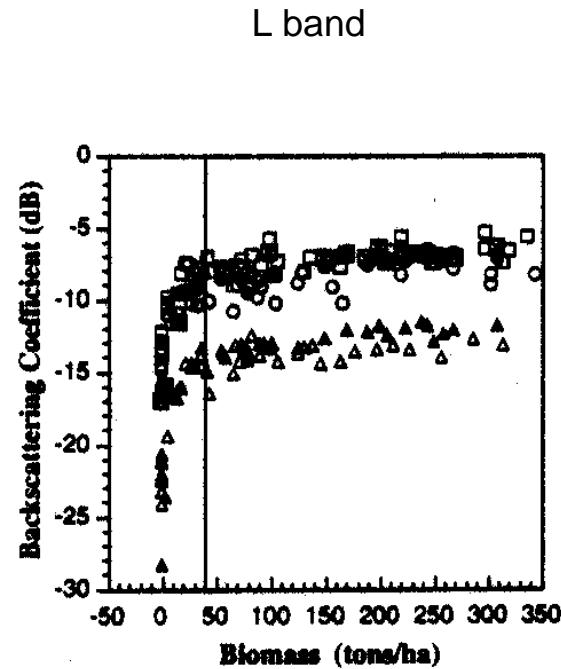
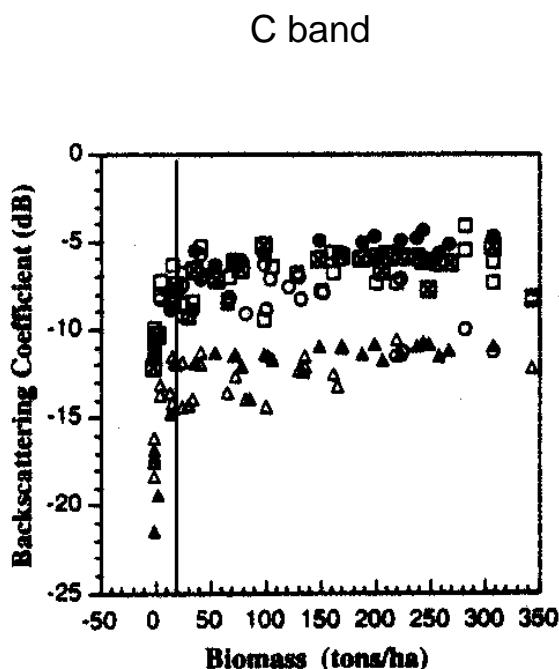
Radar images interpretation rules

Radar response over forest



Volume Scattering

Radar saturation level with vegetation density



20 tons/ha

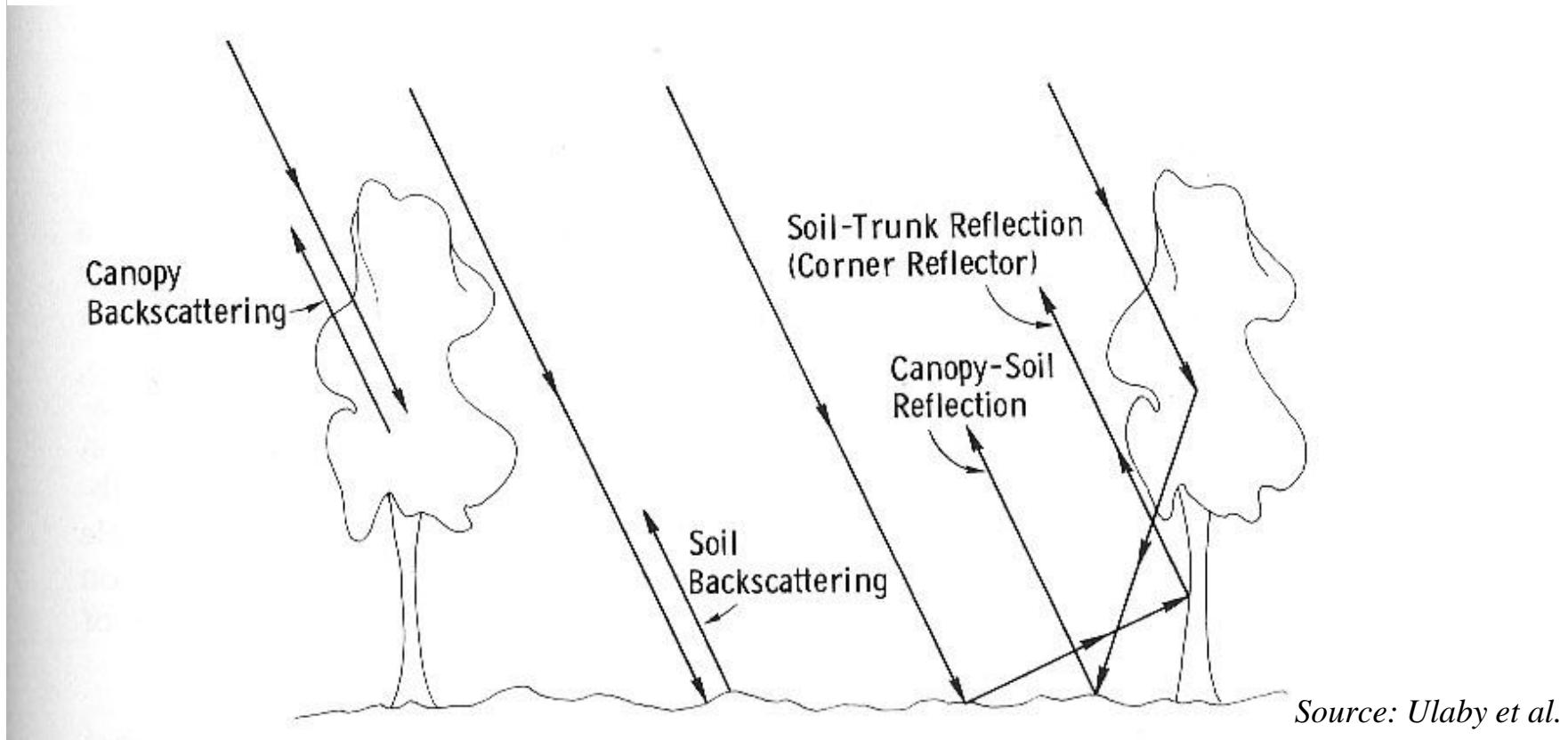
40 tons/ha

100 tons/ha

from Imhoff et al. 19?

Radar response sensitivity

Backscattering mechanism on vegetation

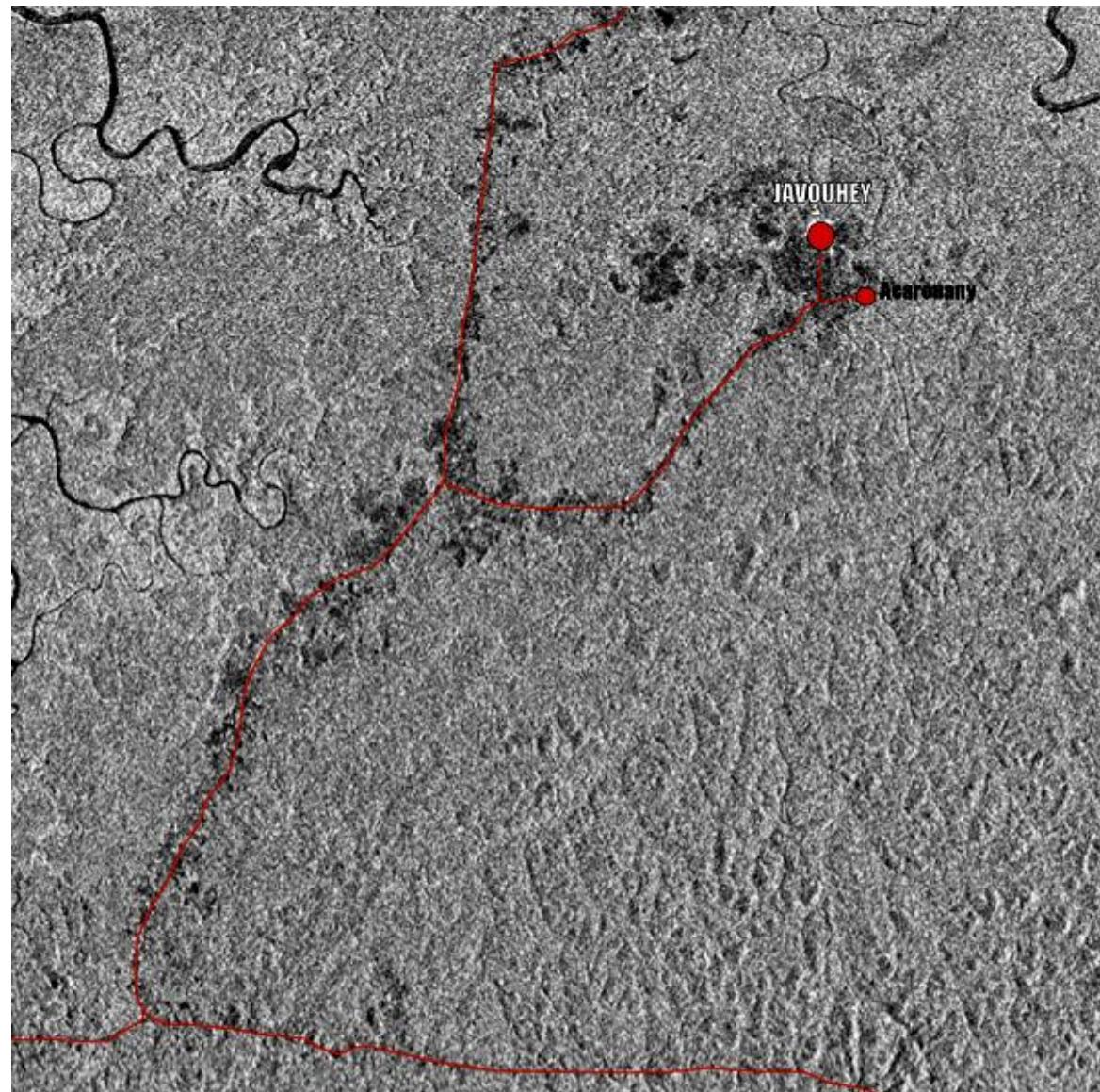


Radar response sensitivity

Local Agricultural Deforestation along road



Radar response sensitivity



Radar response sensitivity

Cameroun (région Ngaoundéré): Cultural practice, burned area

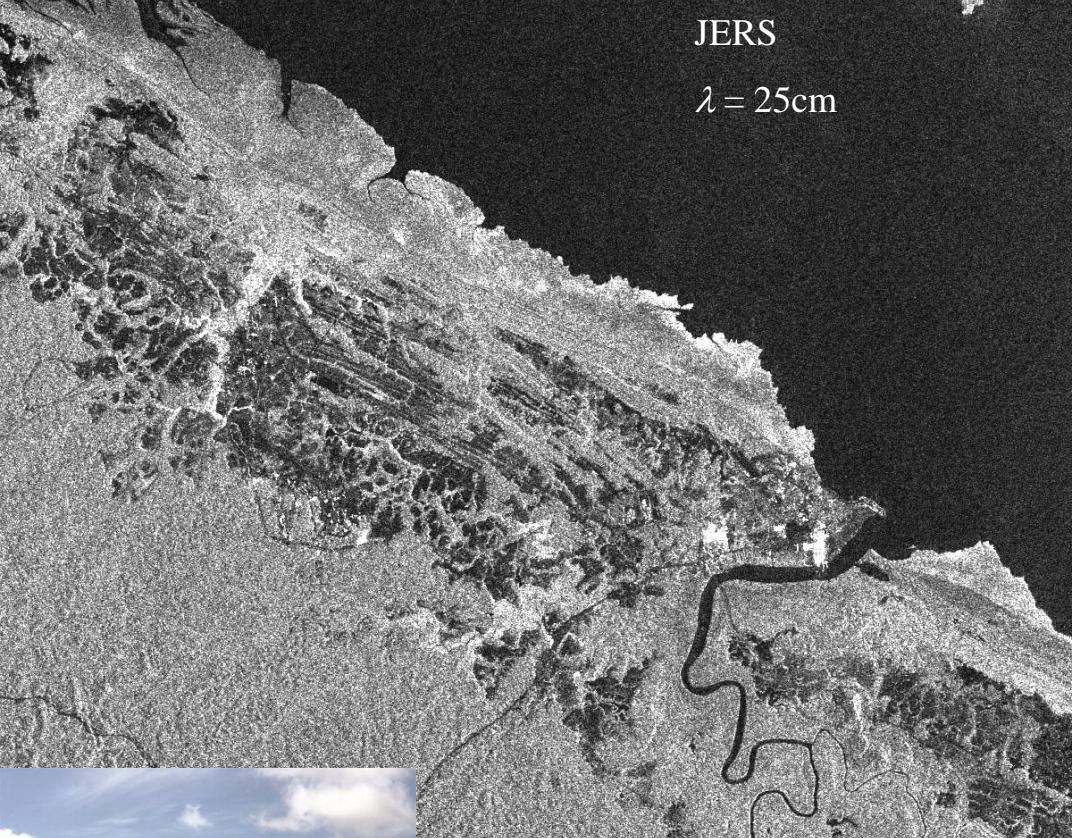


ERS C band $\lambda=6\text{cm}$



JERS

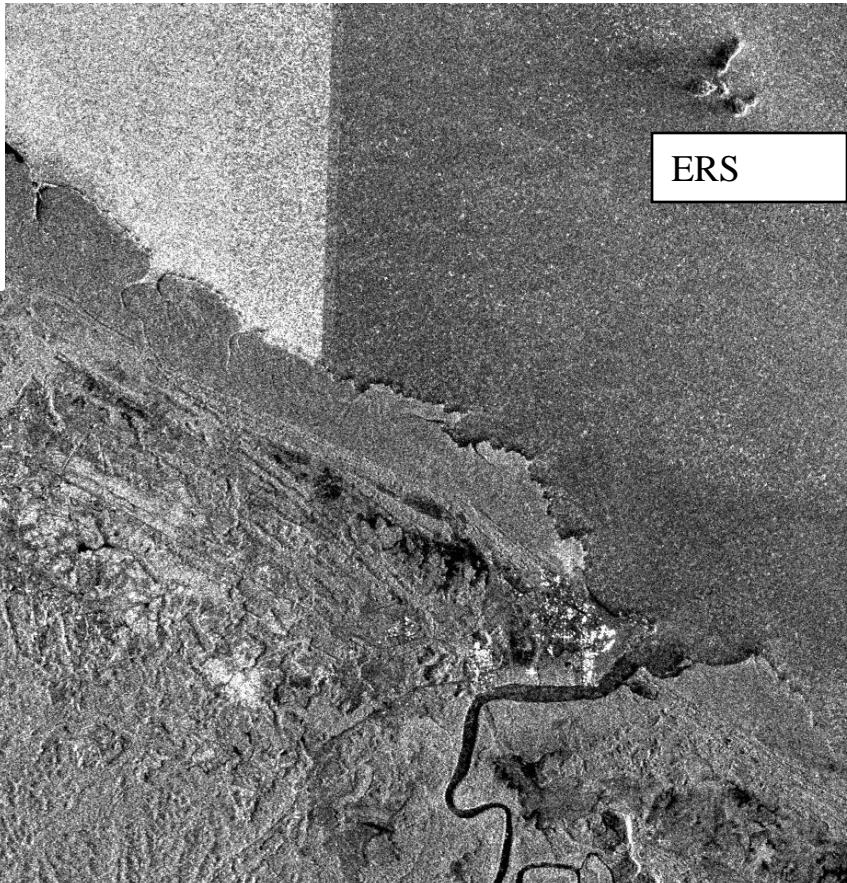
$\lambda = 25\text{cm}$



Saison sèche

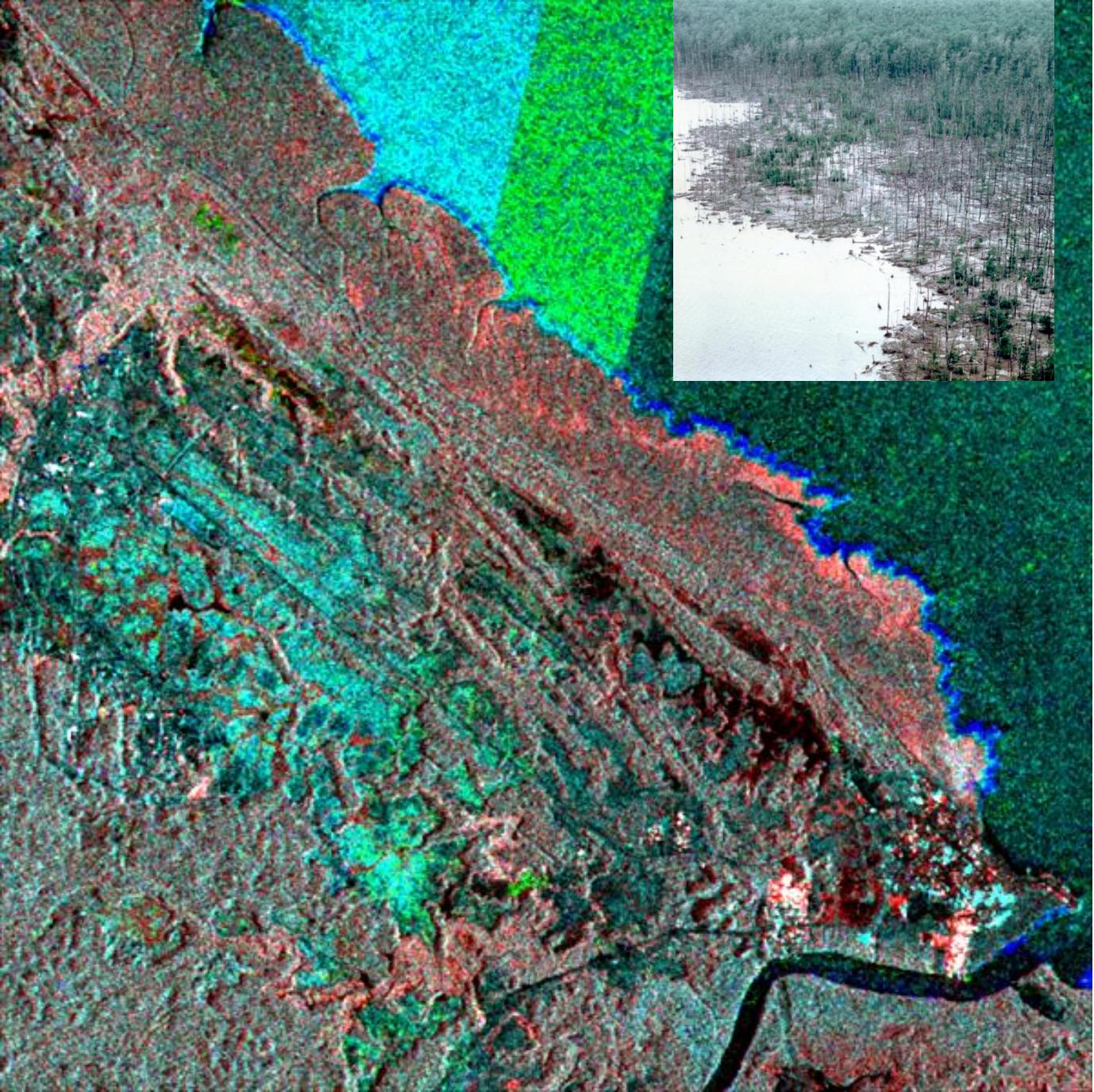


Saison humide



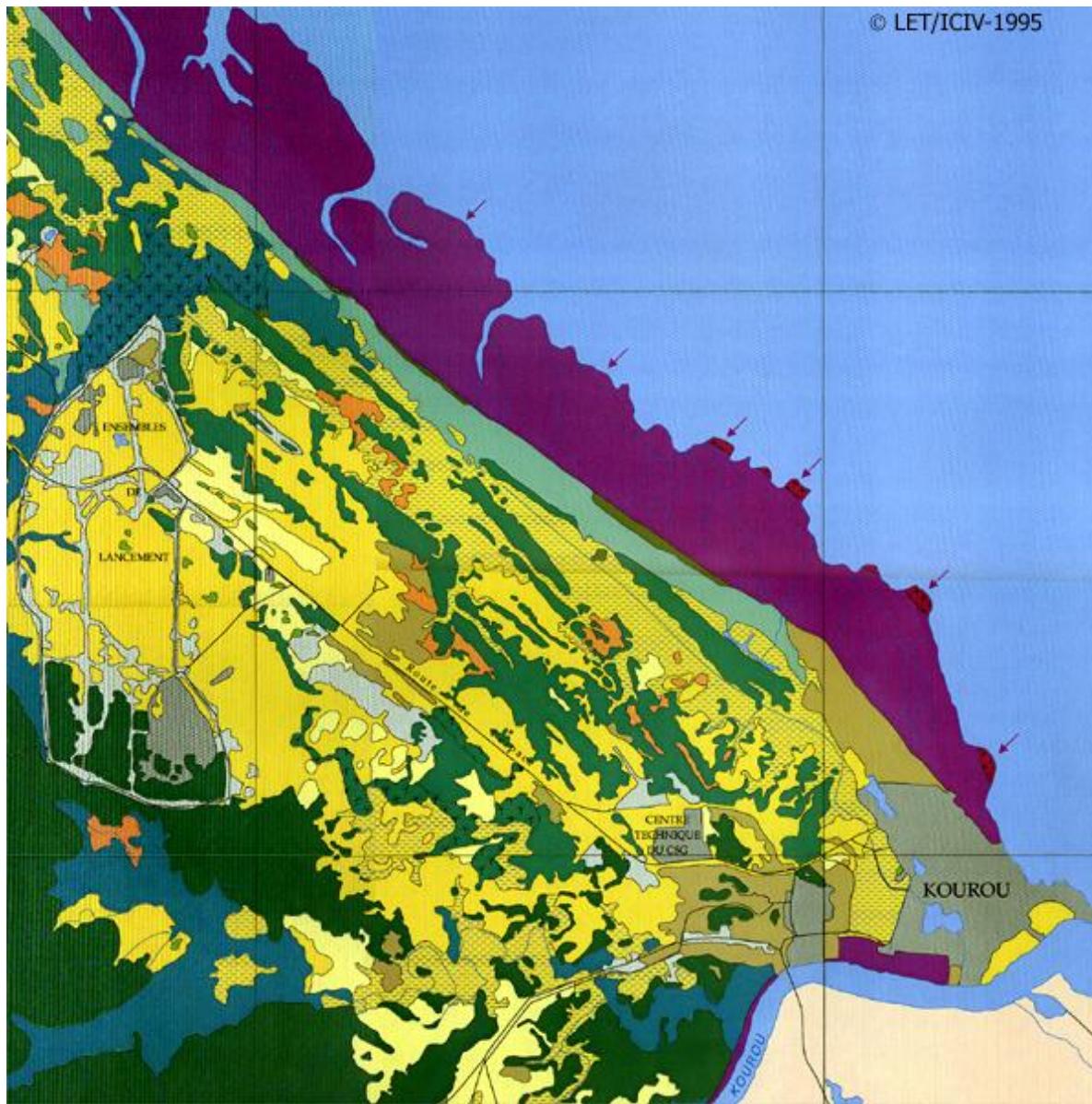
ERS





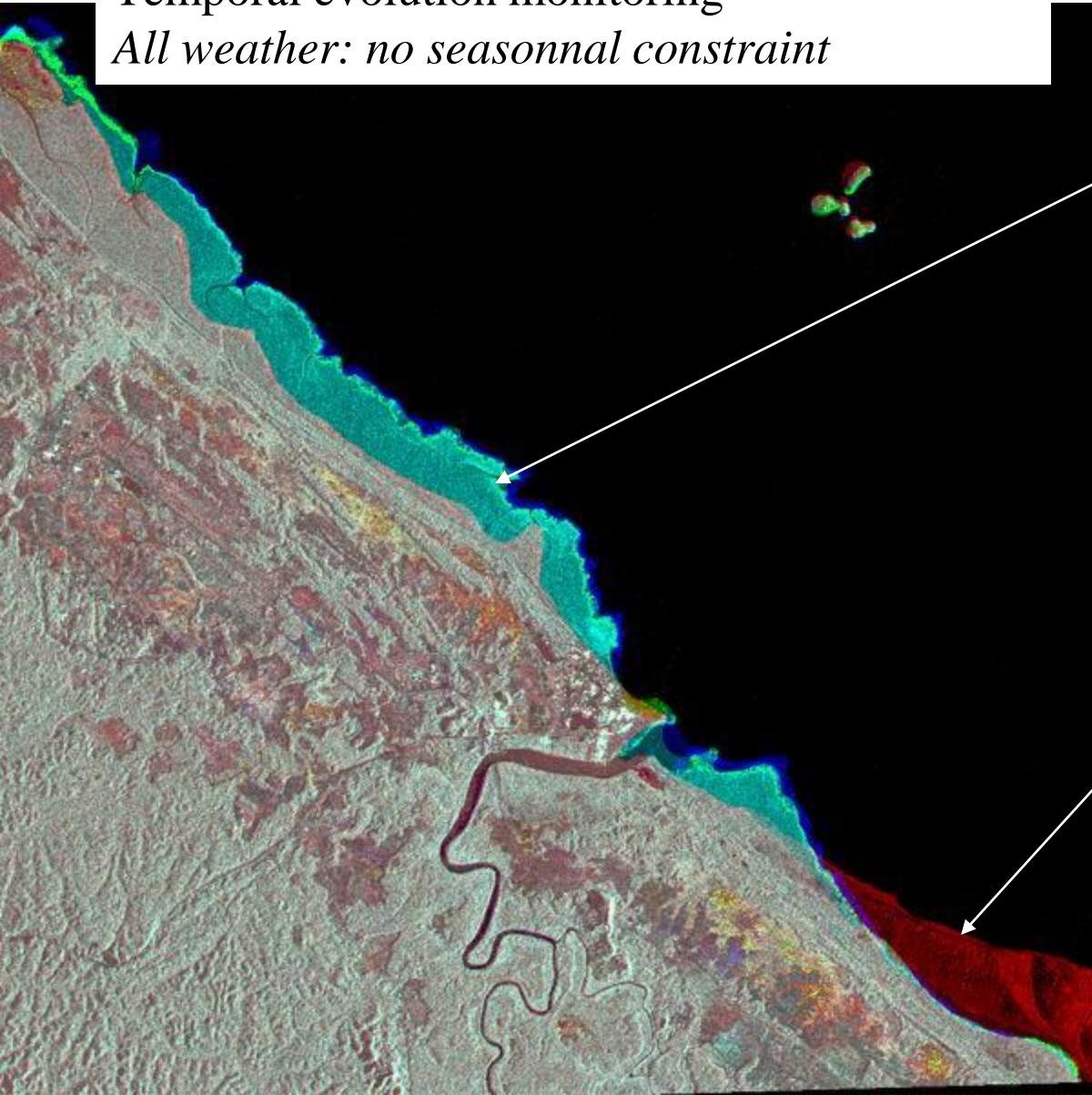
Color Composite
ERS and JERS

Radar response sensitivity

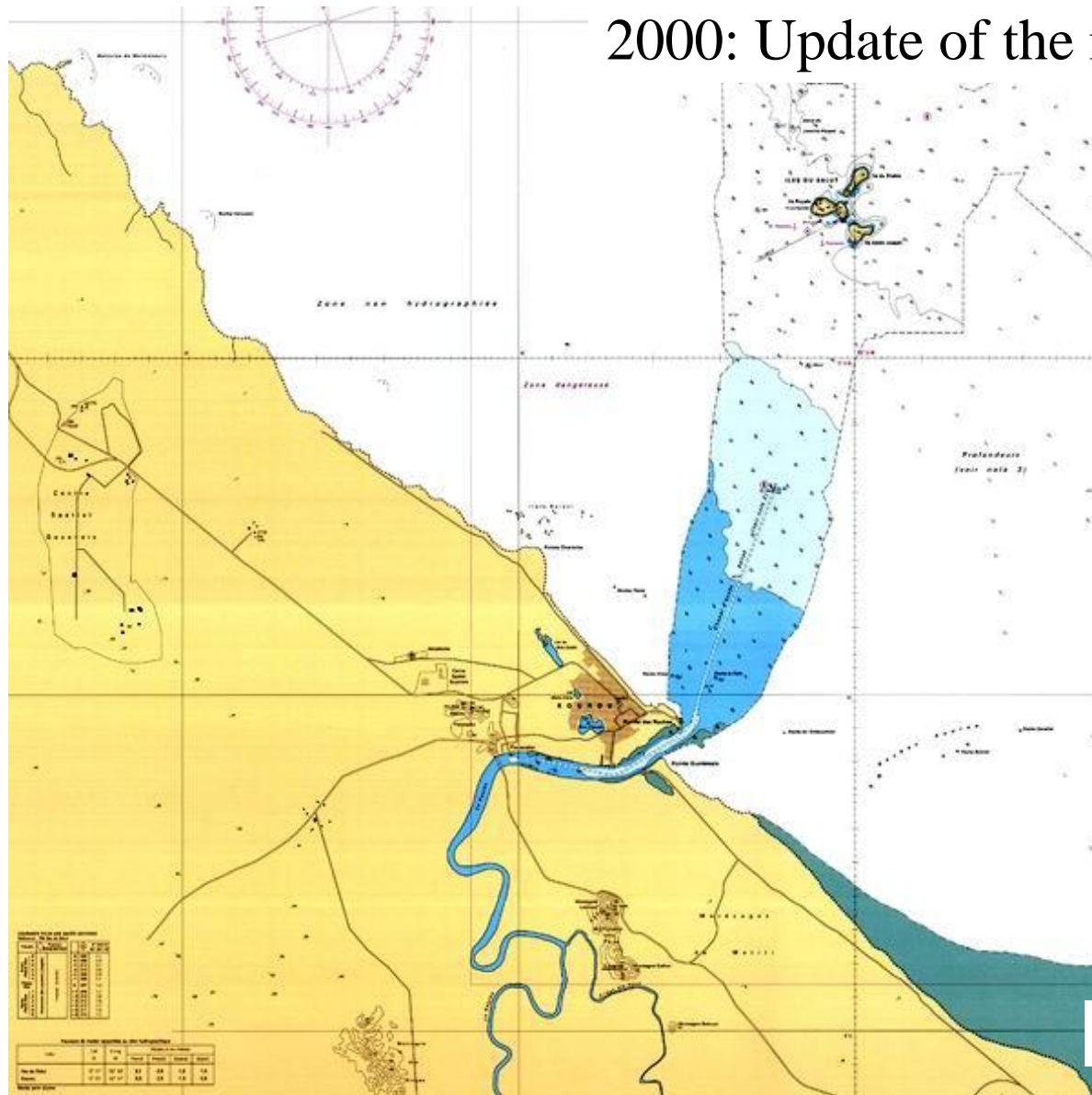


Radar response sensitivity

Temporal evolution monitoring
All weather: no seasonnal constraint



Radar response sensitivity



2000: Update of the marine map

Source: SHOM/ Univ-MLV