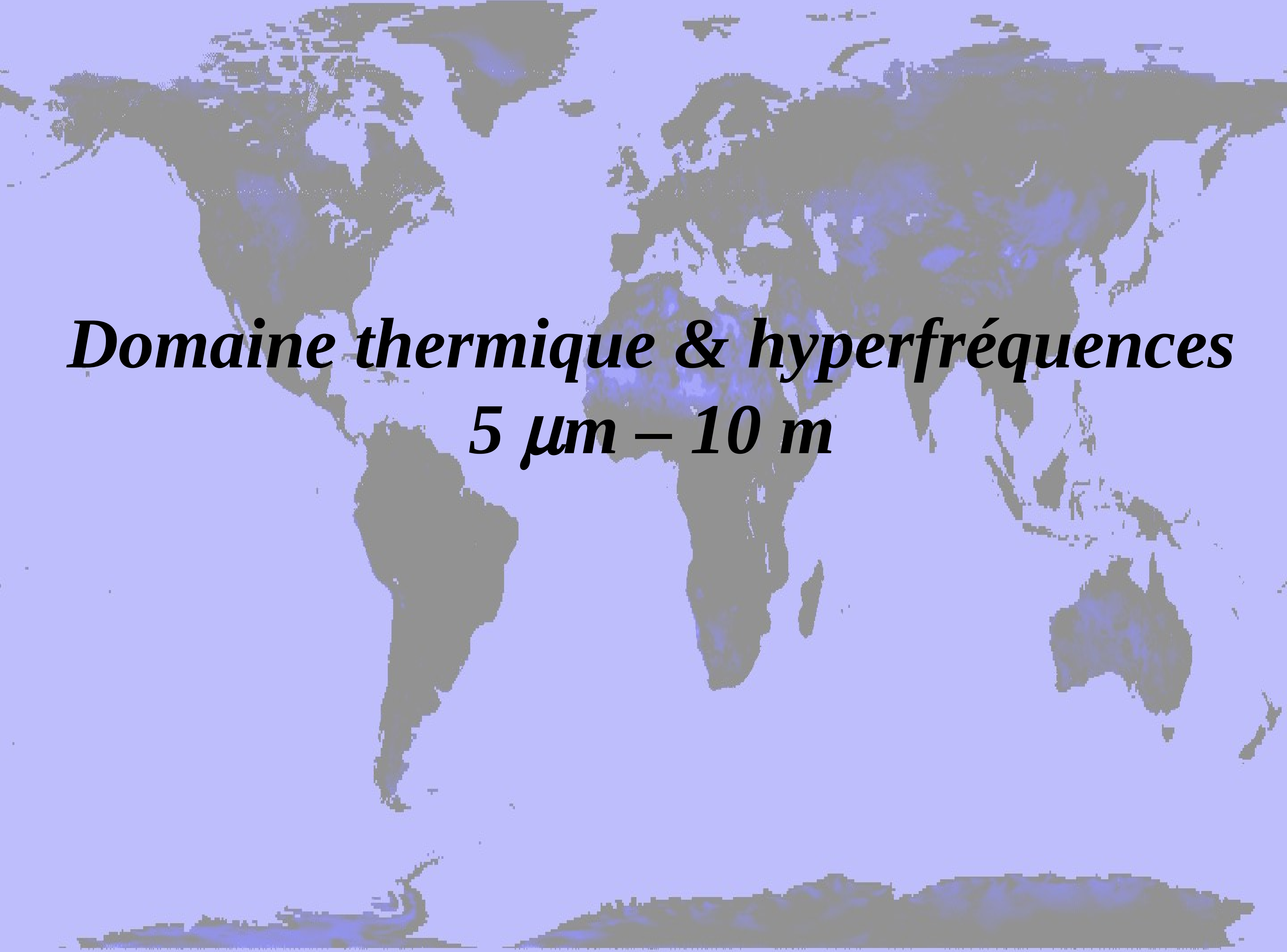
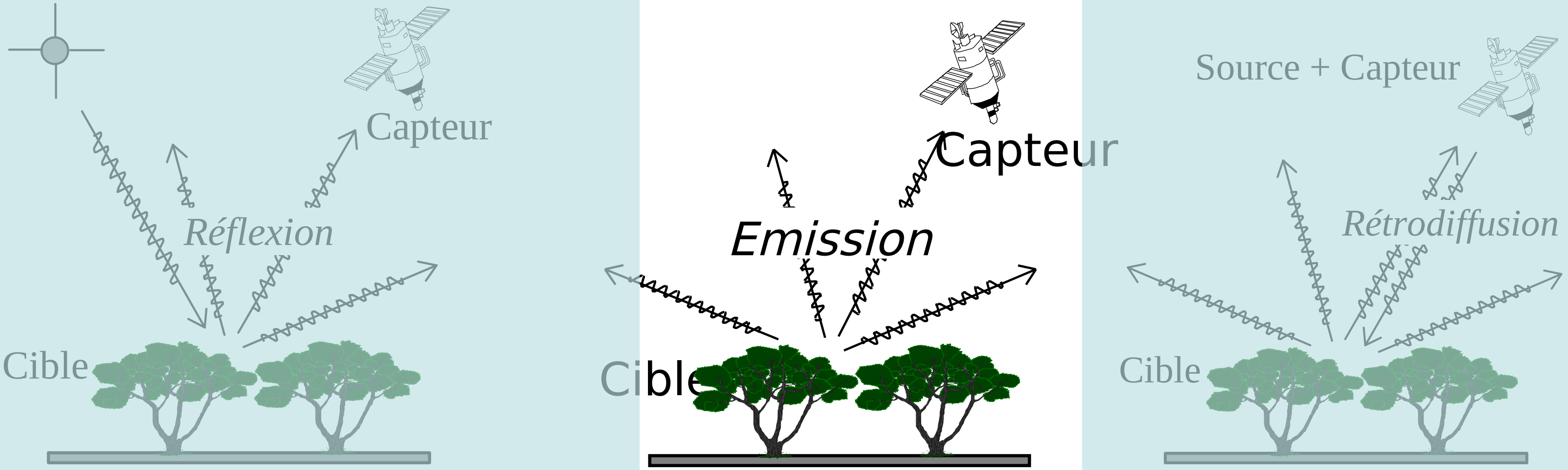


Domaine thermique & hyperfréquences

5 μm – 10 m

Modes d'observations



VIS
PIR, MIR

IRT
Micro-ondes passives

Micro-ondes
'actives'

VIS | PIR-MIR | IRT | Micro-ondes

0.4-0.7 µm | 5 µm | 0.75-150 cm

OPTICAL DOMAIN

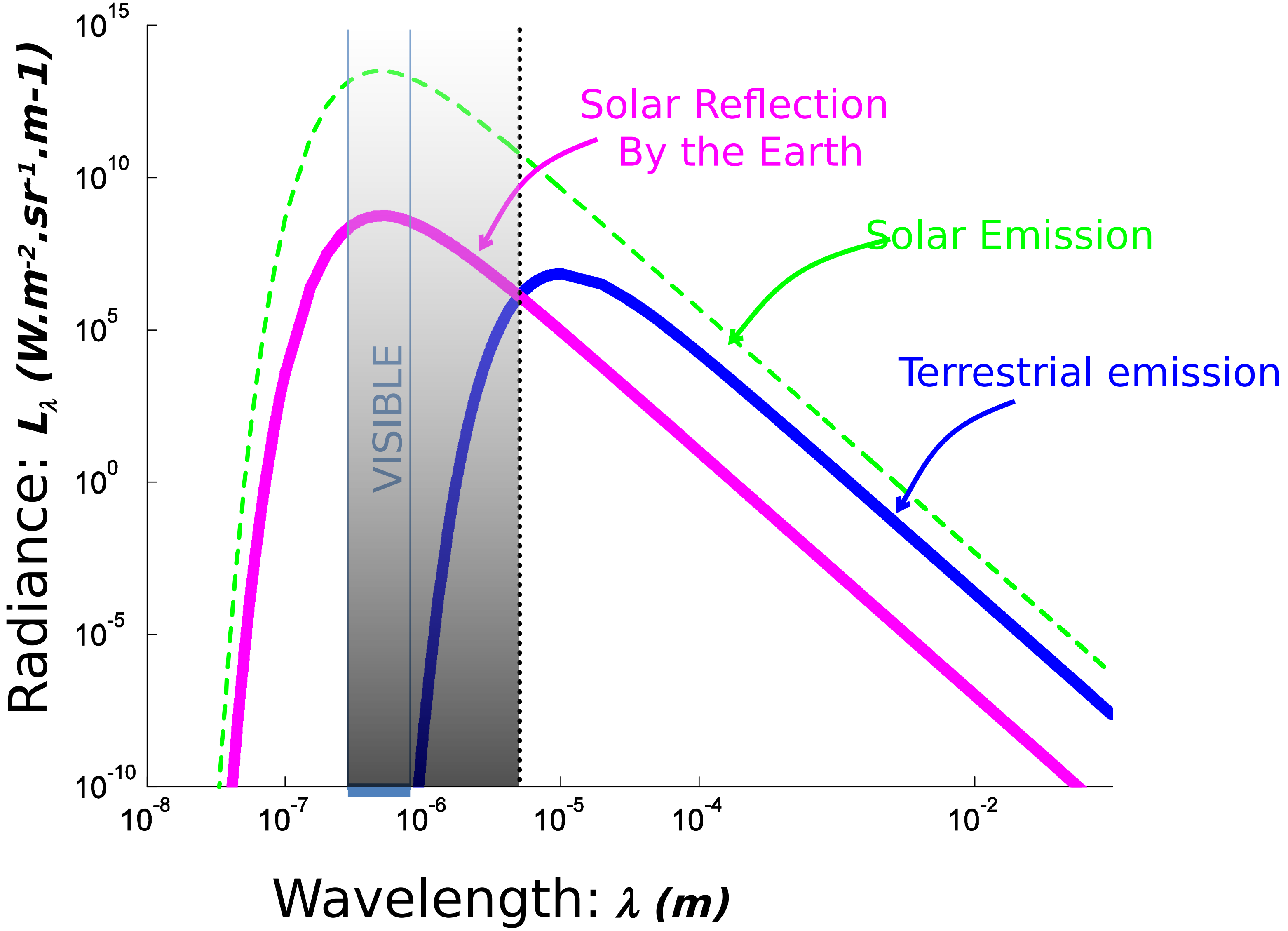


Image globale NOAA-AVHRR

Canal Rouge

1-10 avril 1992

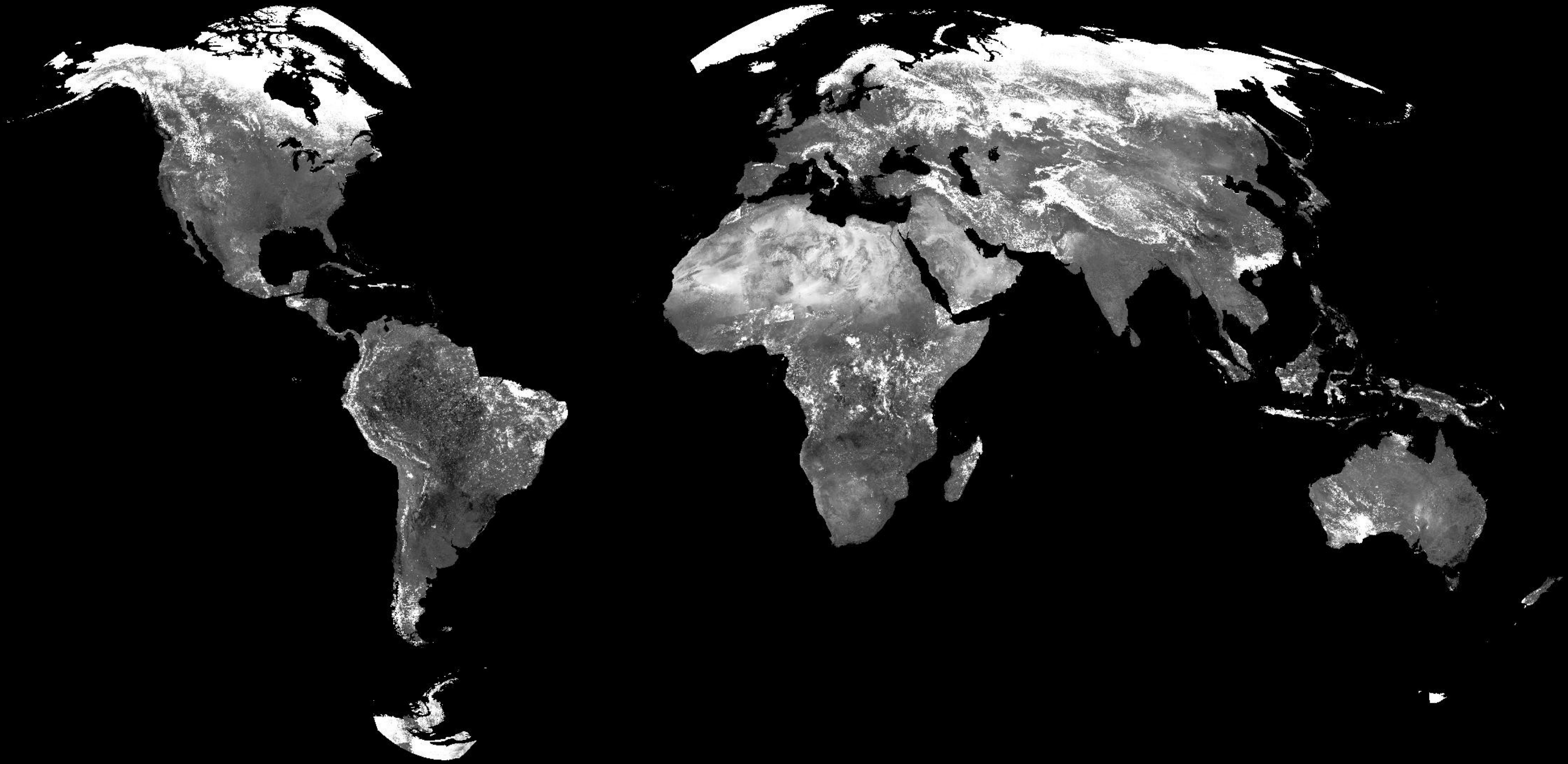


Image globale NOAA-AVHRR

Canal Proche-InfraRouge

1-10 avril 1992

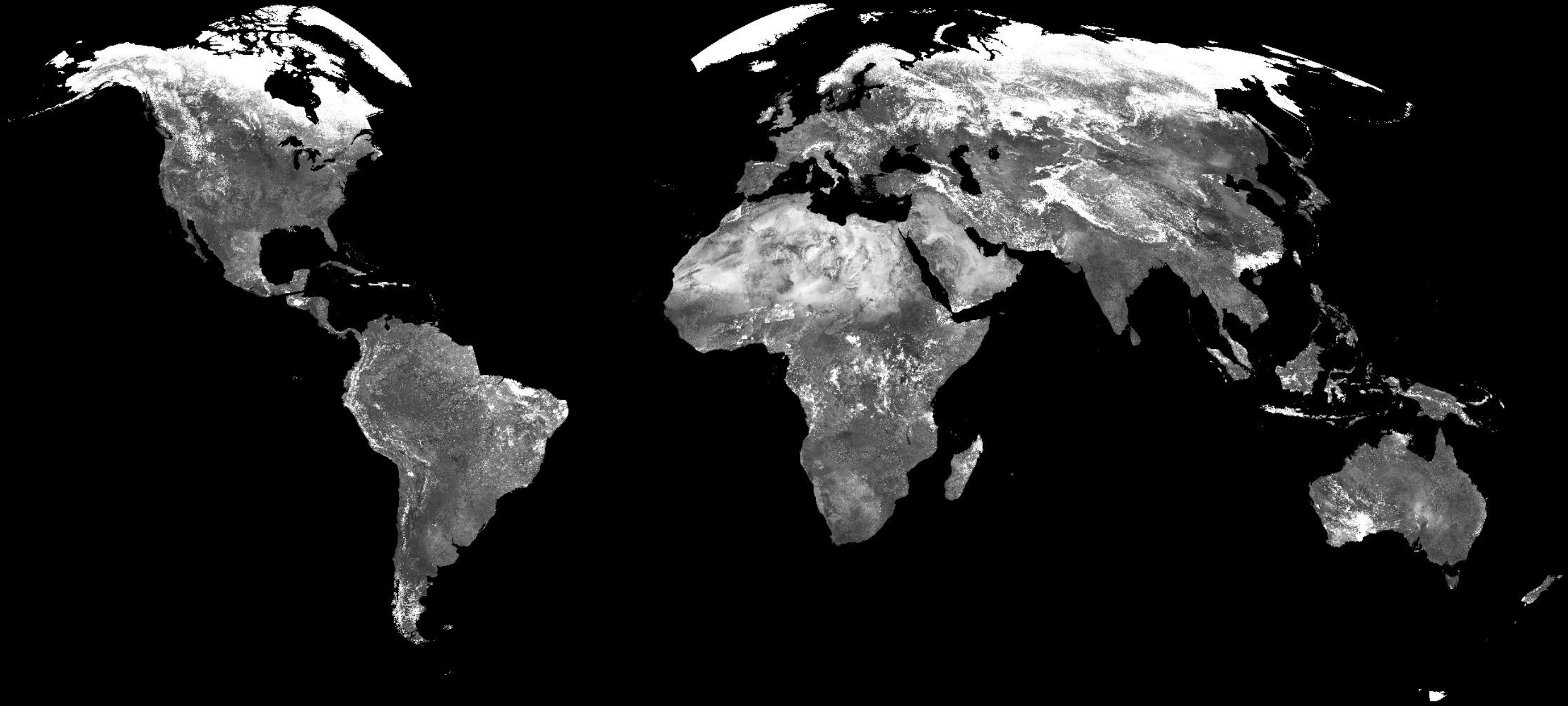
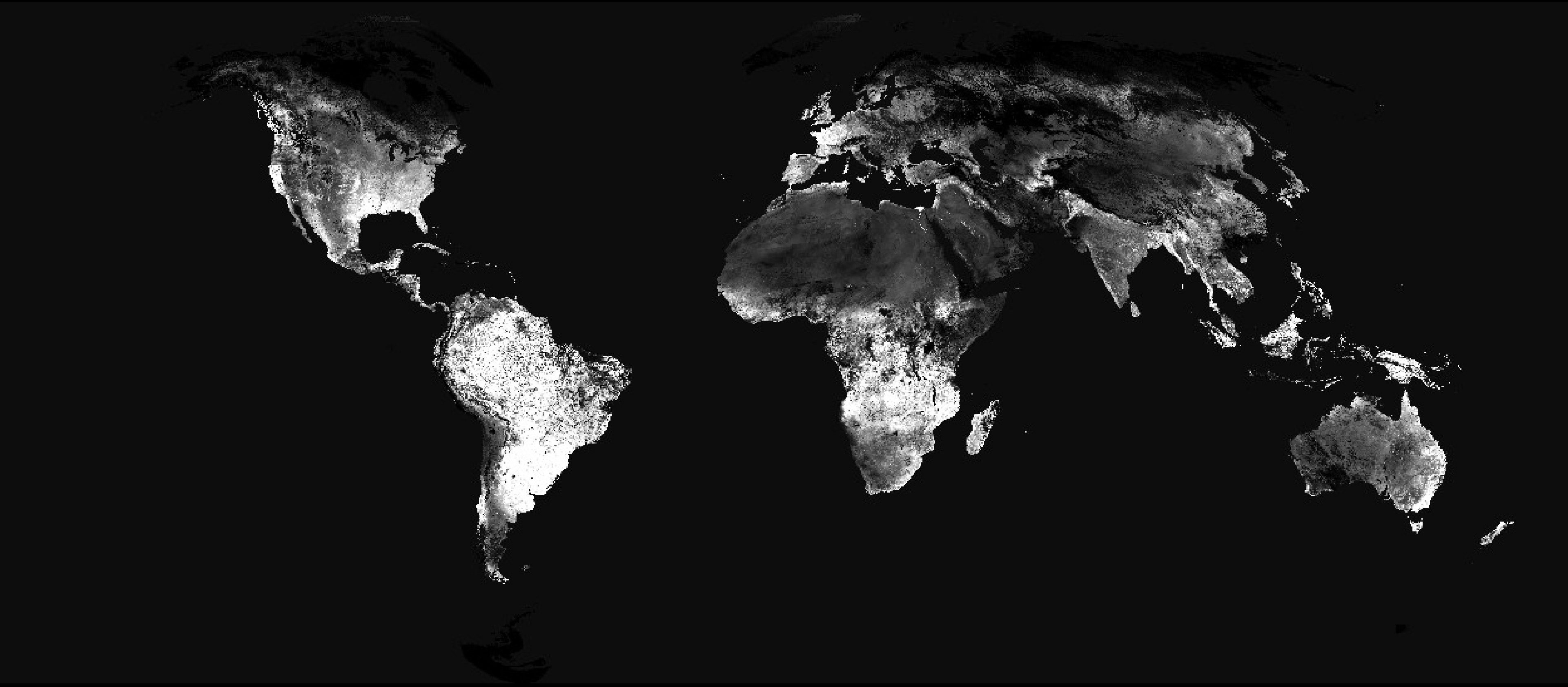


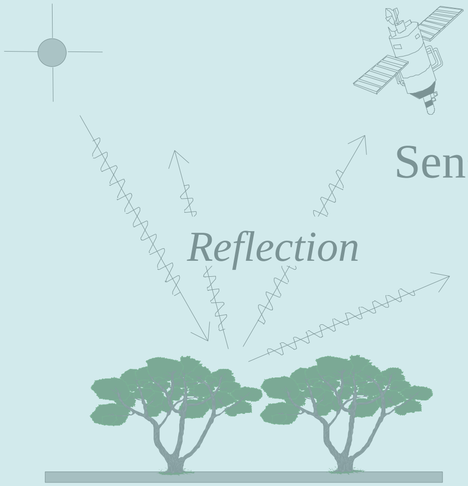
Image globale NOAA-AVHRR

NDVI

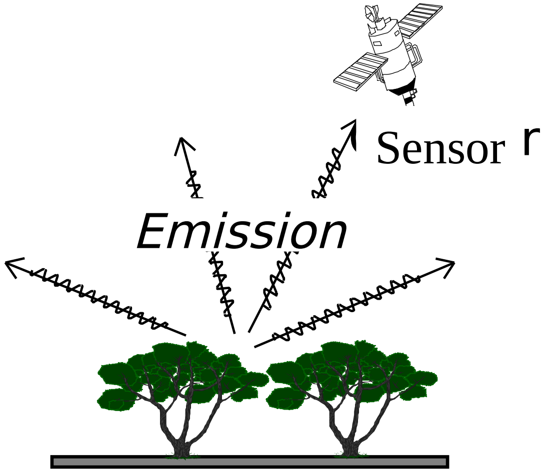
1-10 avril 1992



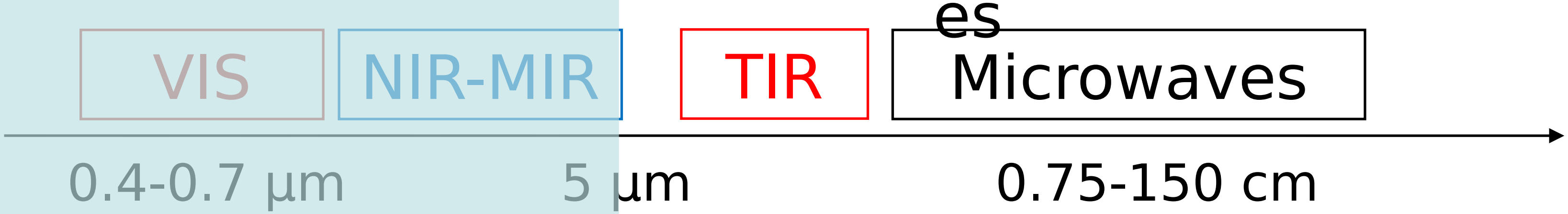
Observation Modes



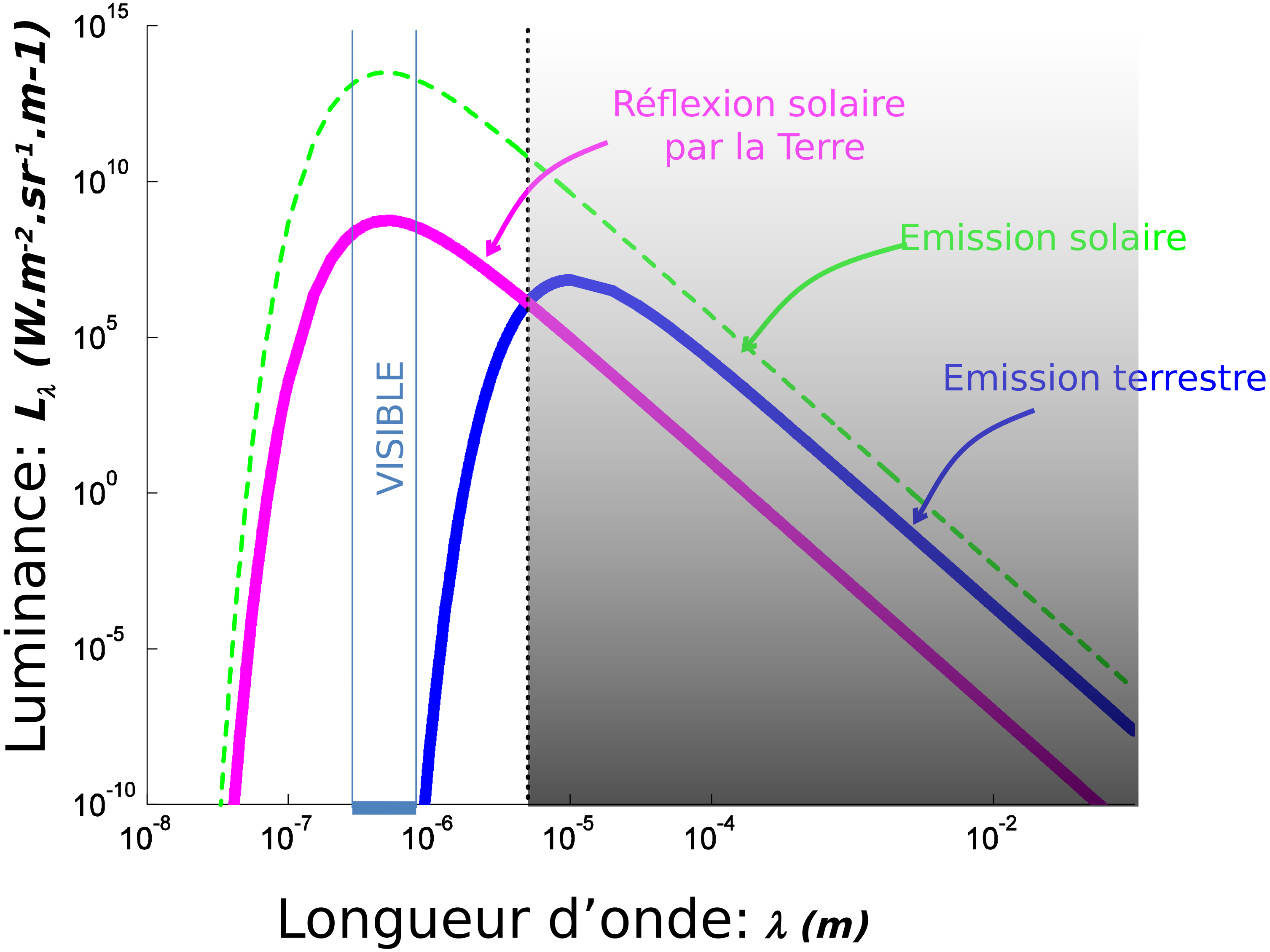
VIS
NIR, MIR



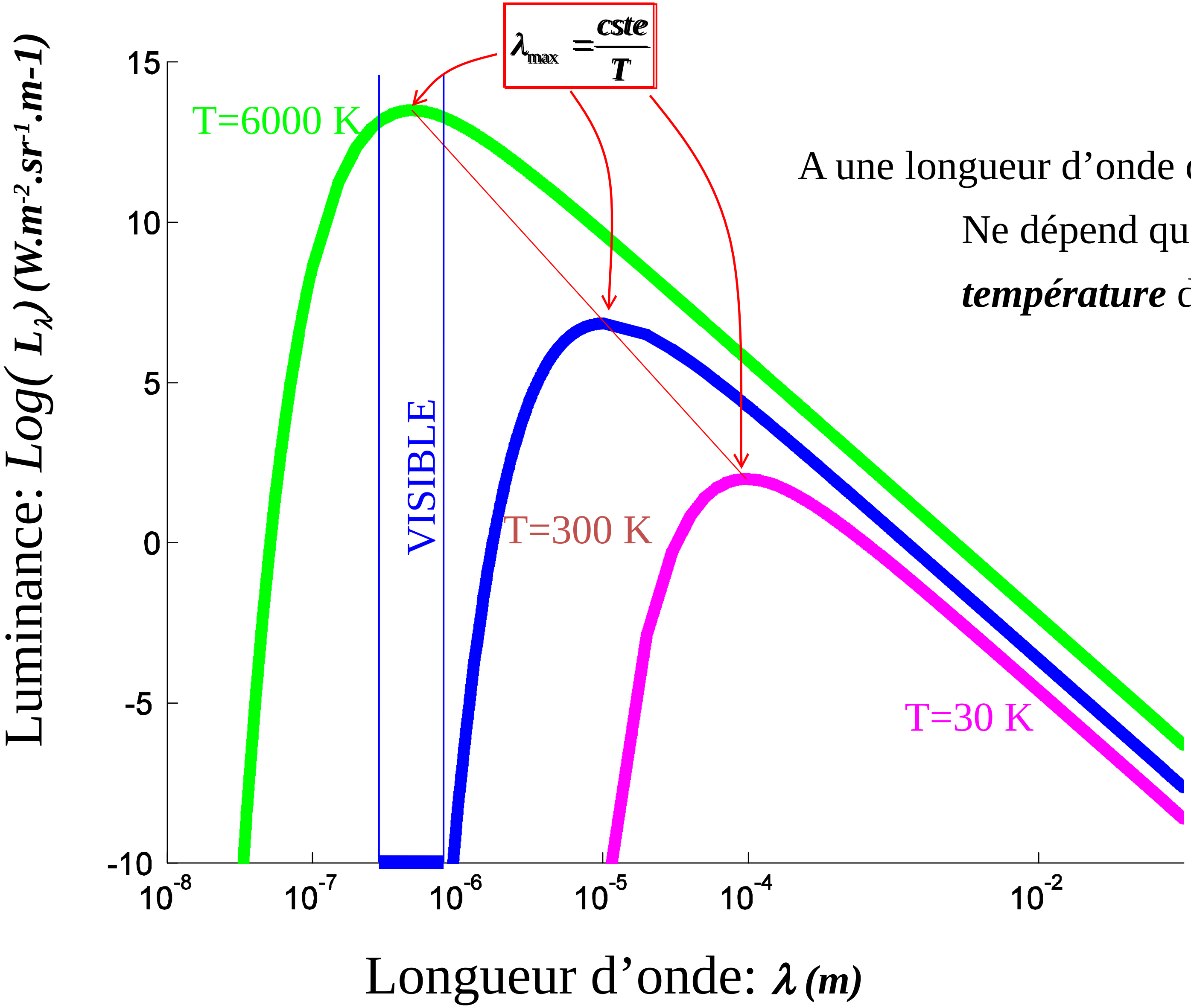
TIR
Passive
microwav
es



IR thermique – Hyperfréquences passives



Le Rayonnement du corps noir

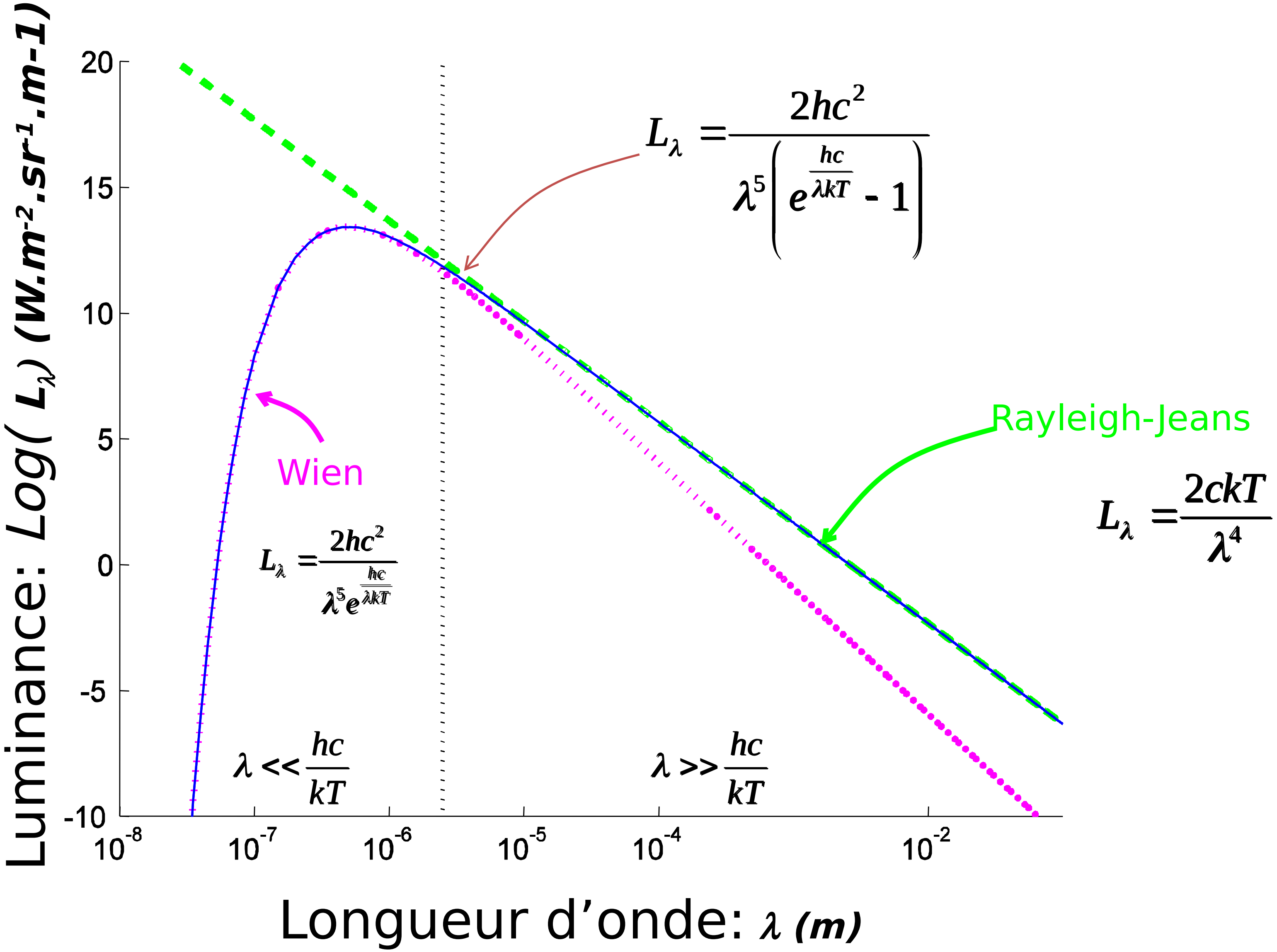


A une longueur d’onde donnée:

Ne dépend que de la

température du corps étudié

Rayonnement du corps noir: Approximations de Wien et de Rayleigh-Jeans



$$L_\lambda = \frac{2hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}} - 1\right)}$$

$$L_\lambda = \frac{2hc^2}{\lambda^5 e^{\frac{hc}{\lambda kT}}}$$

$$L_\lambda = \frac{2ckT}{\lambda^4}$$

$$\lambda << \frac{hc}{kT}$$

$$\lambda >> \frac{hc}{kT}$$

ine Thermique + hyperfréquences passives (5 μm

(rayonnement émis par les surfa

Grandes longueurs d'ondes: $L_\lambda = \frac{2ckT}{\lambda^4}$

Luminance du corps n
équivalent à même
température thermodyna

Luminance du
corps étudié

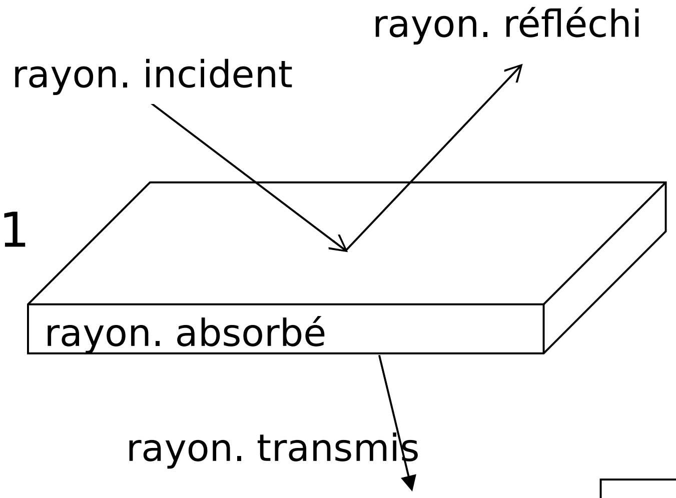
Corps noir (idéal) ≠ corps gris (naturels) ⇒ *Émissivité:* $\boldsymbol{L_\lambda = \varepsilon(\lambda)\, L_{\lambda\, cn}}$

$$0 \le \varepsilon(\lambda) \le 1$$

mpérature de brillance T_b: *température thermodynamique du corps noir qui émettrait le même rayonnement que le corps étudié*

$$\frac{2ckT_b}{\lambda^4} = \varepsilon \frac{2ckT}{\lambda^4} \quad \Rightarrow \quad \boxed{T_b = \varepsilon\, T}$$

onservation de l’énergie



rayon. incident

rayon. réfléchi

rayon. absorbé

rayon. transmis

$$0 \le \begin{matrix}\rho_\lambda \\ \alpha_\lambda \\ \tau_\lambda\end{matrix} \le 1$$

réflectance $\rho_\lambda = \dfrac{radiation \quad réfléchie}{radiation \quad incidente}$

absorptance $\alpha_\lambda = \dfrac{radiation \quad absorbée}{radiation \quad incidente}$

transmittance $\tau_\lambda = \dfrac{radiation \quad transmise}{radiation \quad incidente}$

$$\boxed{\rho_\lambda + \tau_\lambda + \alpha_\lambda = 1}$$

Cas particuliers:

Corps noir: $\rho = \tau = 0 \qquad \alpha = 1$

Corps opaque: $\tau = 0 \qquad \alpha + \rho = 1$

Loi de Kirchoff:

$$\boldsymbol{\alpha = \varepsilon}$$

(équilibre thermodynamique)

⇒ Corps noir: $\varepsilon = \alpha = 1$

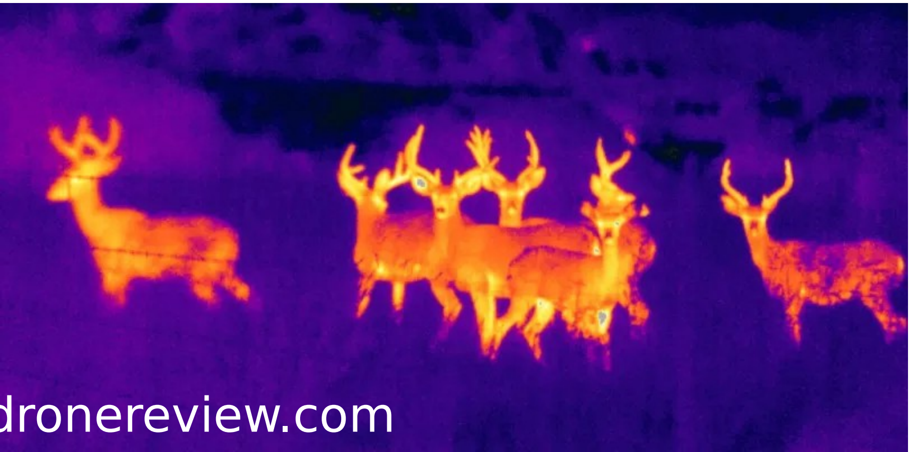
Corps opaque: $\varepsilon + \rho = 1$

ayonnement émis dans nfra-rouge Thermique

≠

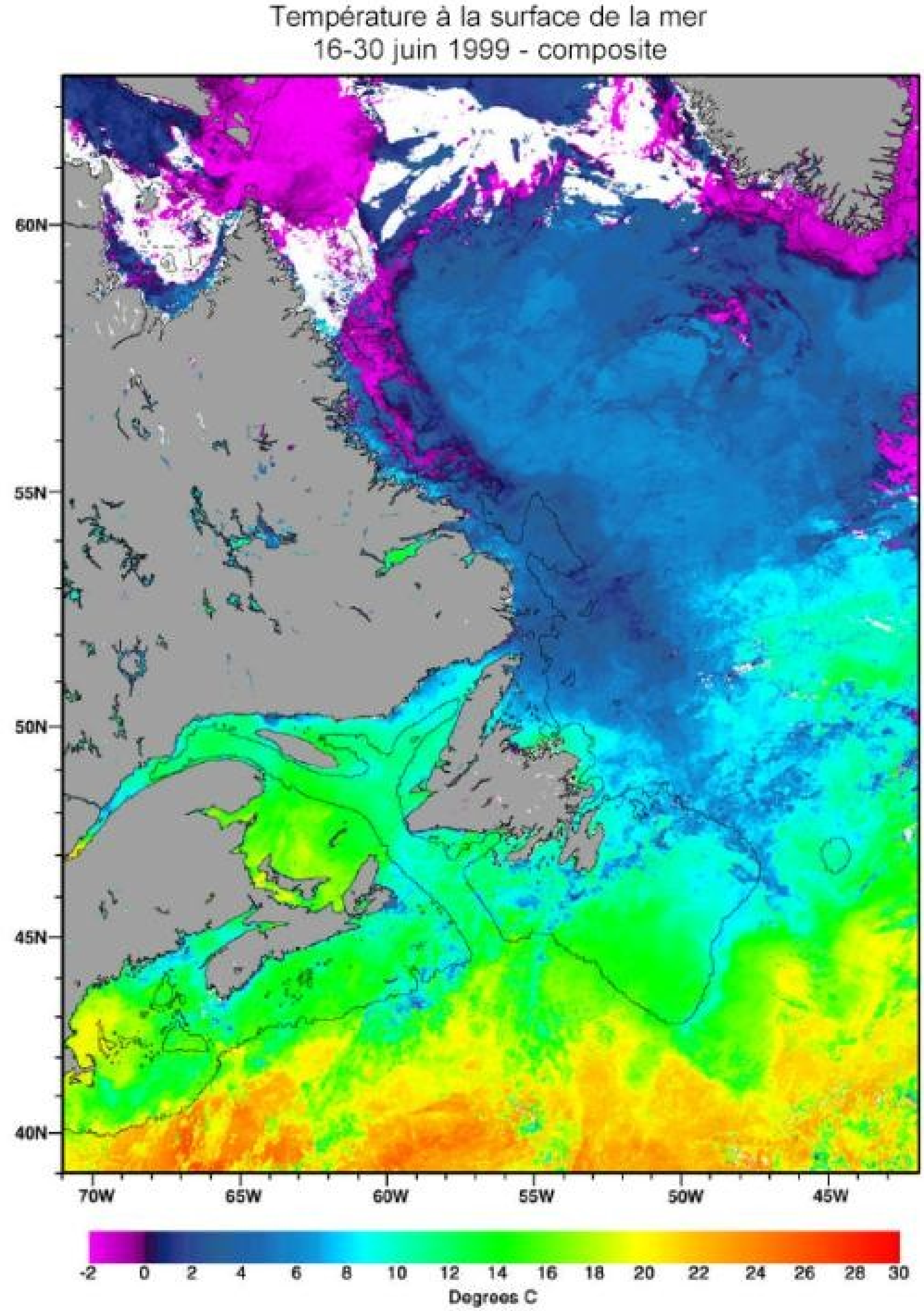
Rayonnement (amplifié) réfléchi dans le visible

ww.thermalground.com



dronereview.com

ww.shutterstock.com

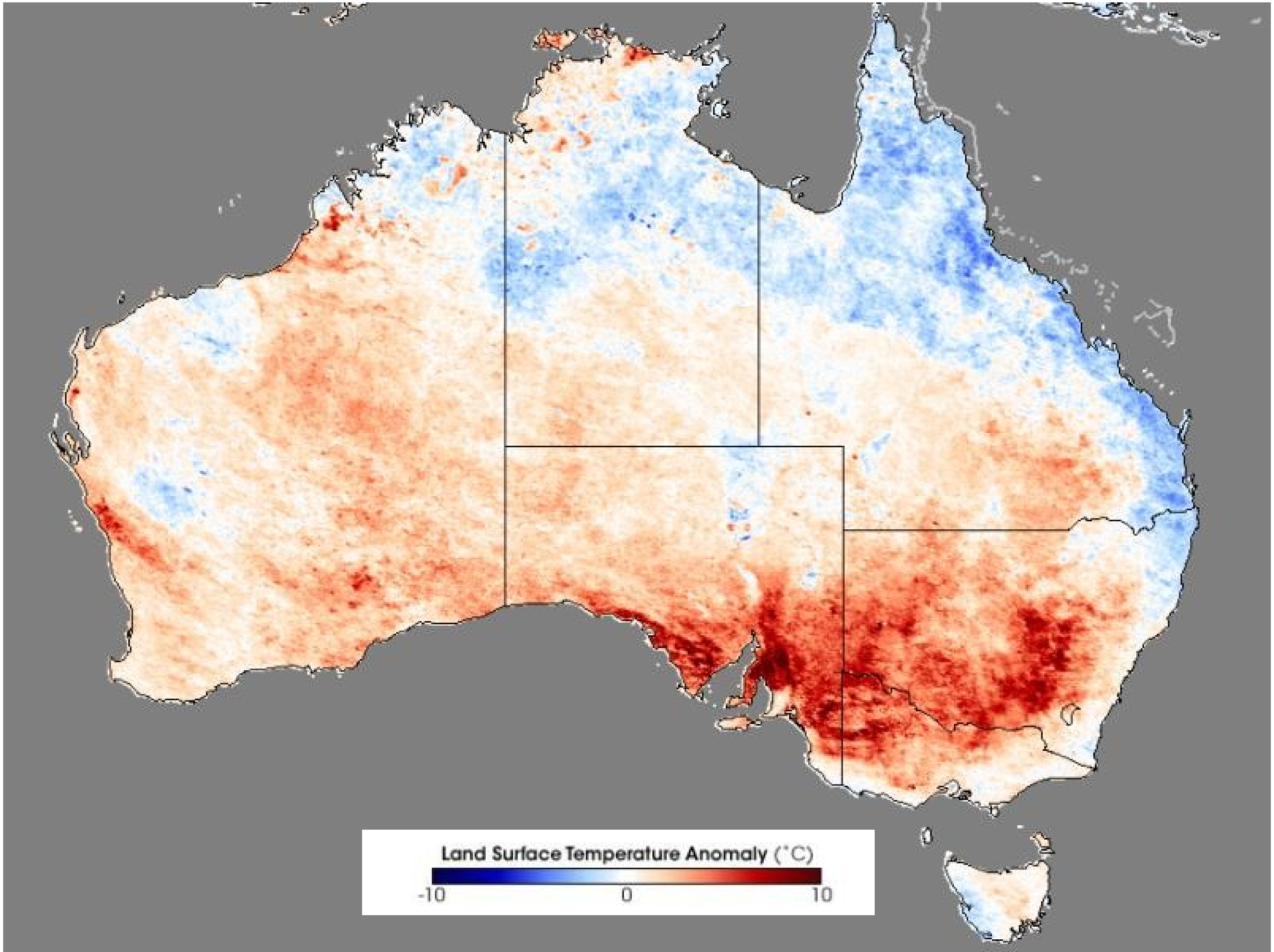


SeaWIFS
Température de l ’eau
Observée à partir de
canaux dans l’InfraRouge

MODIS

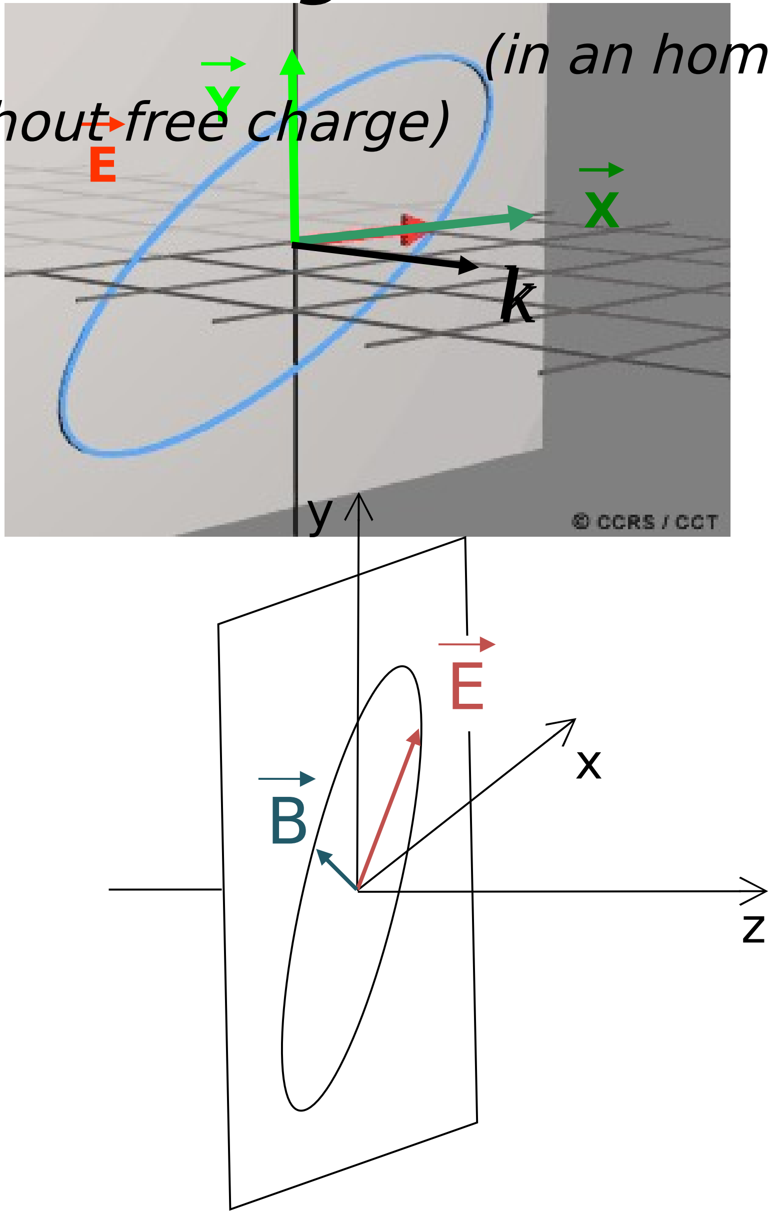
Température de surface mensuelle: septembre 2006

(*vs* 2000-2005)



Polarization of a Electromagnetic wave

(in an homogeneous medium without free charge)



$$\boxed{E = E_0 \cos(\omega t - kz)}$$

frequency: *f*

fréq. ang.: $\omega = 2\pi f$

Wave number: $k = \frac{2\pi f}{c}$

Phase speed: $v = \frac{\omega}{k} = \frac{1}{\sqrt{\varepsilon \mu}} = \frac{c}{\sqrt{\varepsilon_r \mu_r}}$

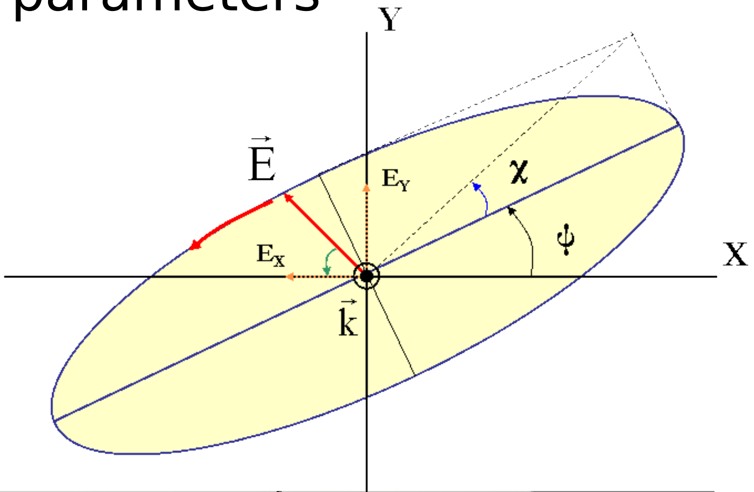
Relative permitivity: $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$

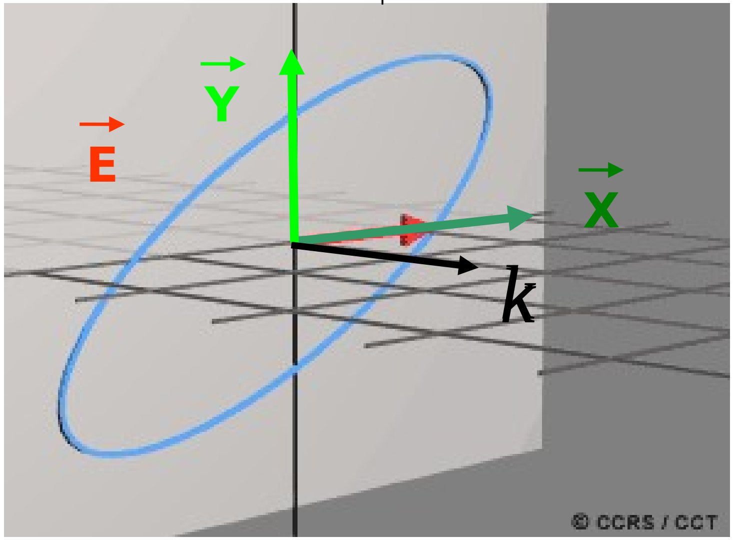
Relative permeability: $\mu_r = \frac{\mu}{\mu_0} \approx 1$

Polarization ***of a Electromagnetic wave***

Ellipse of polarization

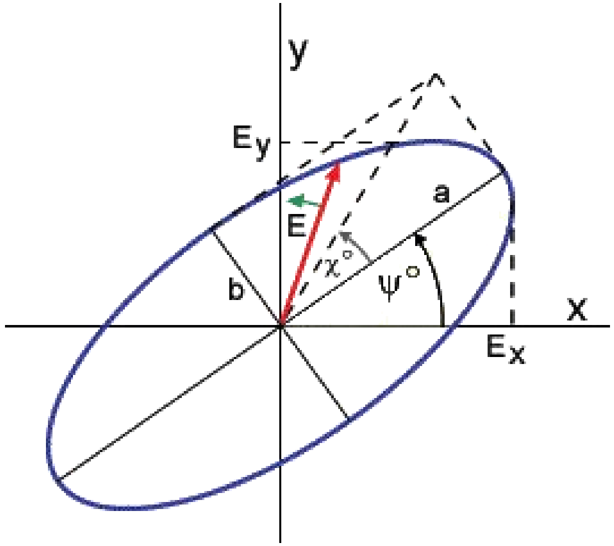
C*oherent* sensor (amplitudes + phase of field E) : 3 parameters

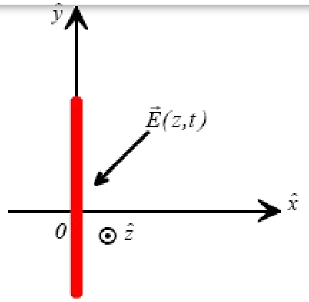




- **Orientation Ψ**
- **Ellipticity χ**
  - linear: χ = 0
  - Circular:
    - Left χ = 45°
    - Right χ = -45°
- **Amplitude**

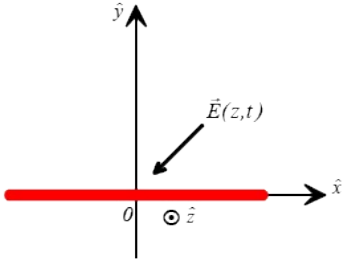
POLARISATIONS





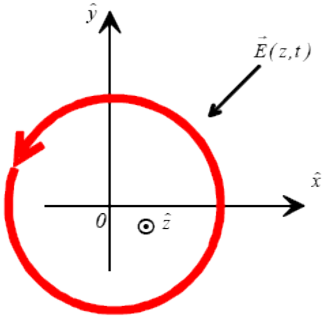
Polarisation Verticale : *V*

$\chi = 0, \ \psi = \Pi/2$



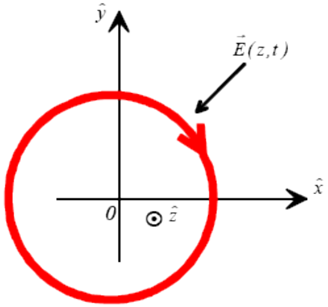
Polarisation Horizontale : *H*

$\chi = 0, \ \psi = 0$



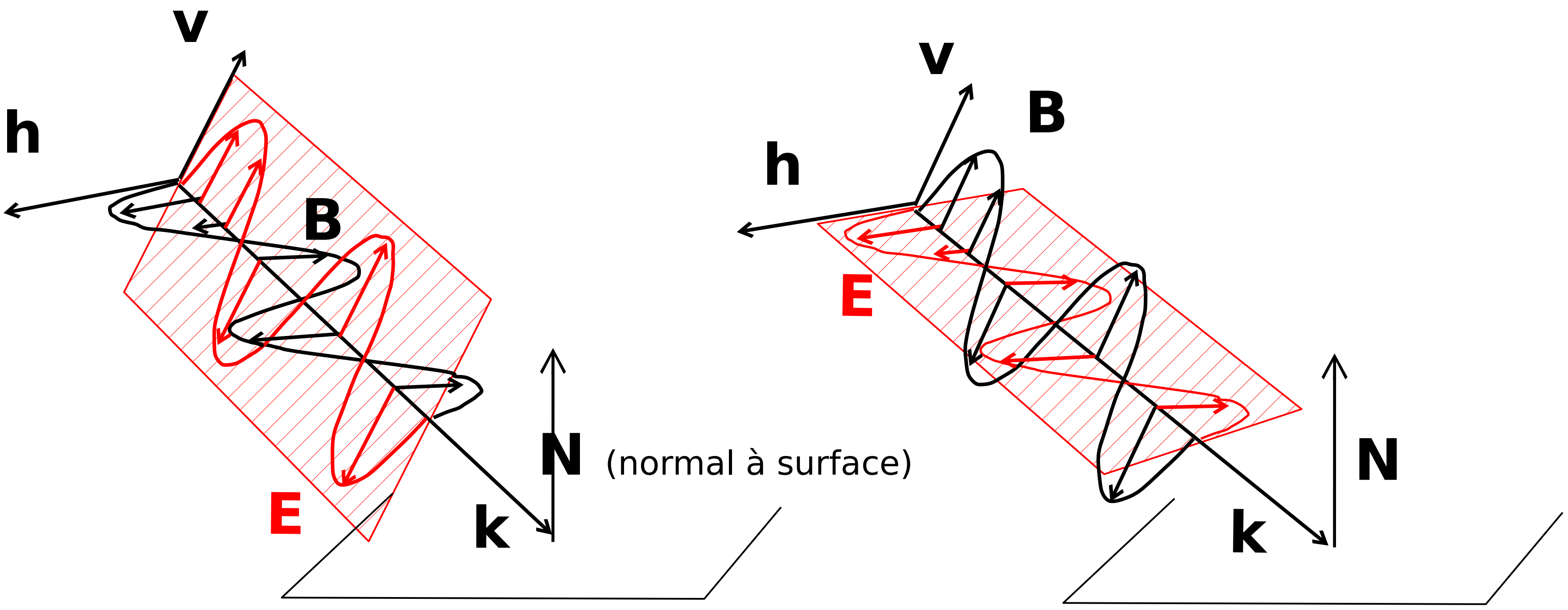
Polarisation Circulaire Droite : *D*

$\chi = -\pi/4$



Polarisation Circulaire Gauche : *G*

$\chi = \pi/4$

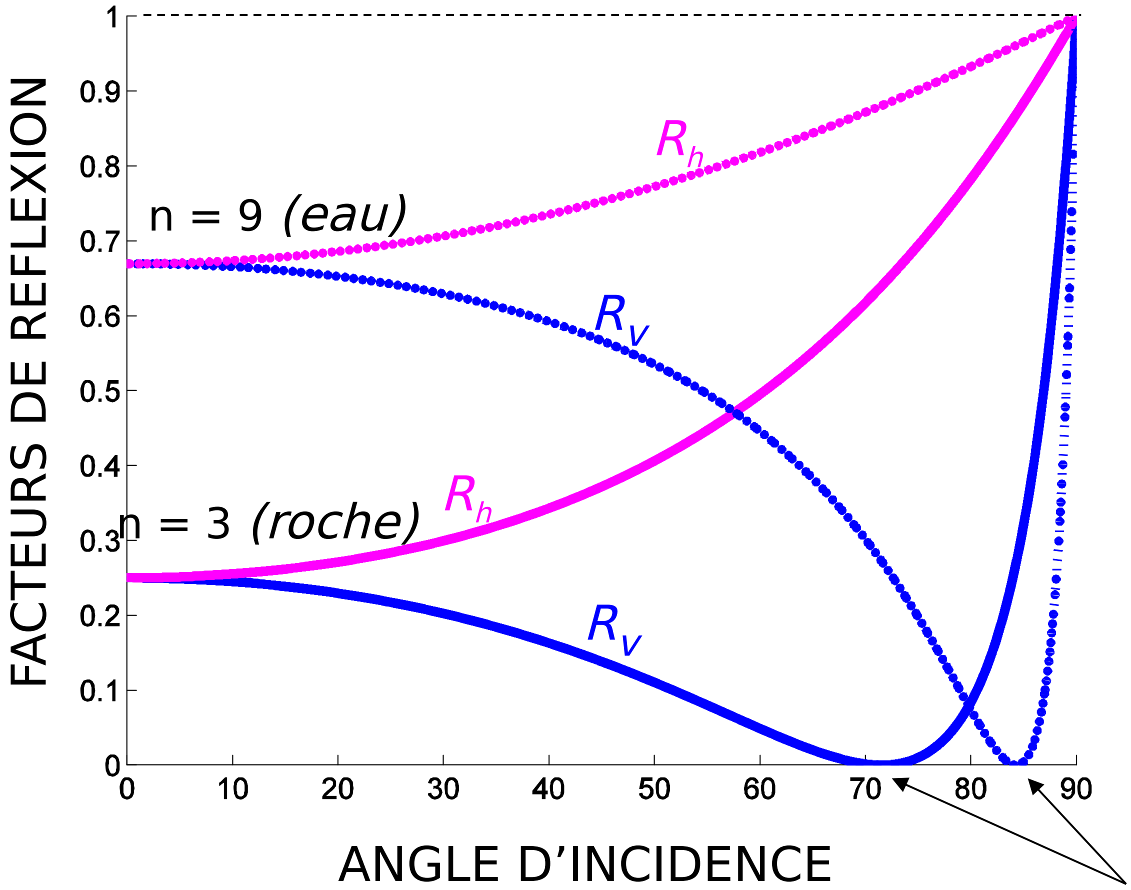


(**k**, **N**): plan d 'incidence

Polarisation verticale
parallèle
TM (transverse magnétique)

Polarisation horizontale
orthogonale
TE (transverse électrique)

Facteurs de réflexion $R = |r|^2$



Angles de Brewster

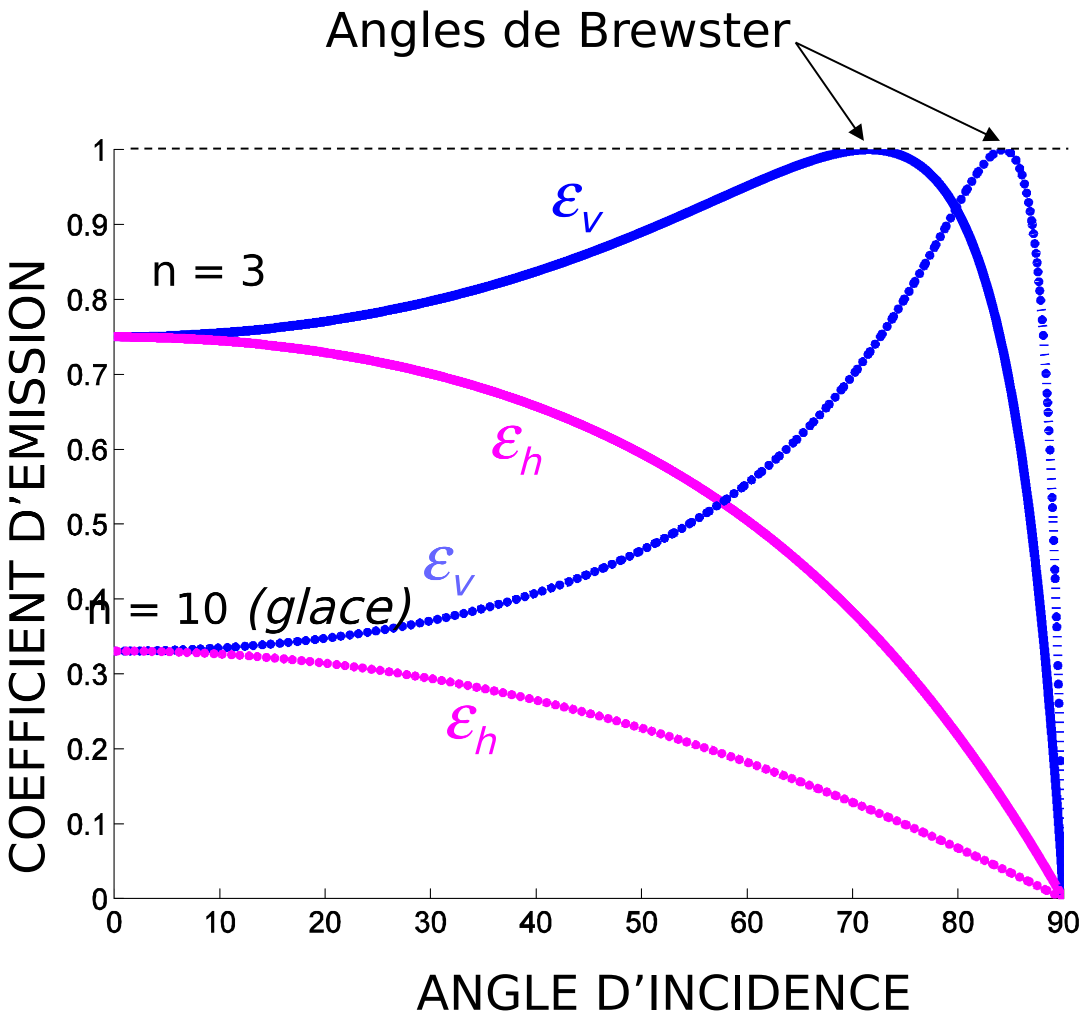
$$E_r = r E_i$$

$$r_v = \frac{\sqrt{\varepsilon_r - \sin^2\theta_1} - \varepsilon_r \cos\theta_1}{\sqrt{\varepsilon_r - \sin^2\theta_1} + \varepsilon_r \cos\theta_1}$$

$$r_h = \frac{\cos\theta_1 - \sqrt{\varepsilon_r - \sin^2\theta_1}}{\cos\theta_1 + \sqrt{\varepsilon_r - \sin^2\theta_1}}$$

Indice de réfraction: $n = \sqrt{\varepsilon_r}$

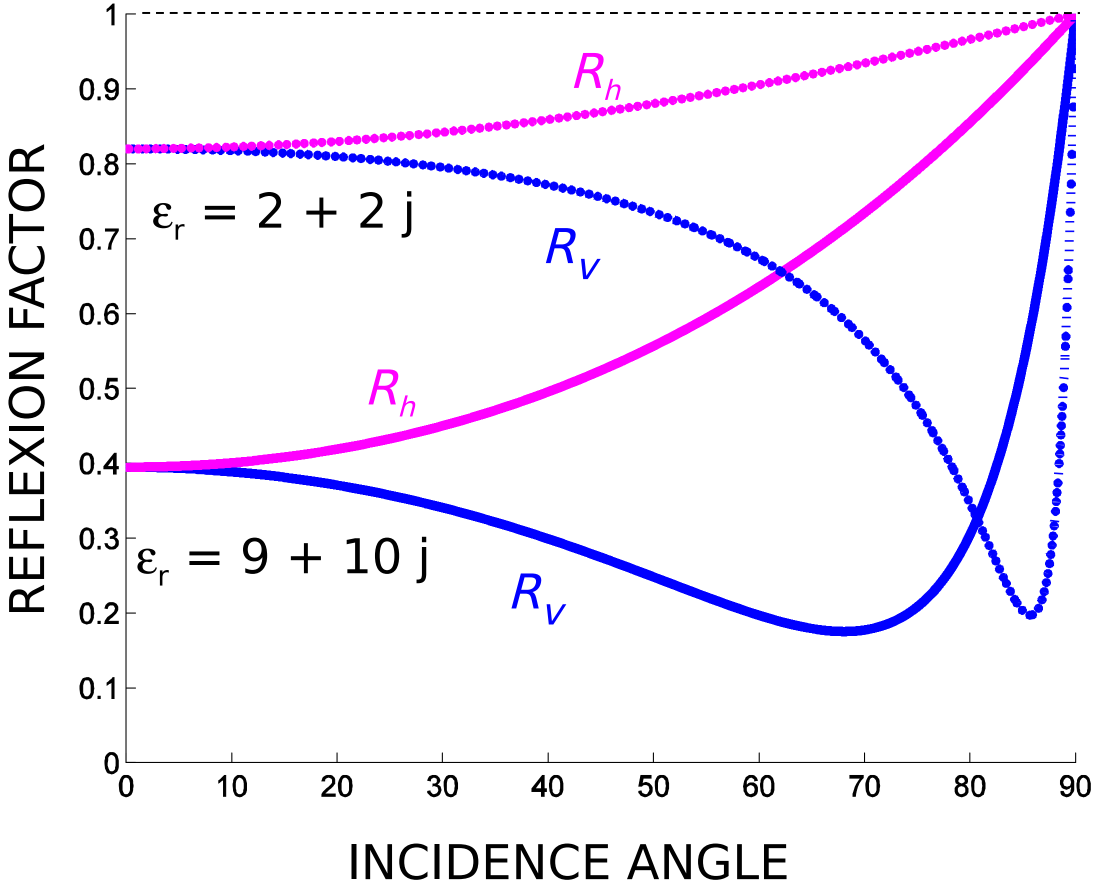
Émissivité pour une surface lisse



$$\mathcal{E} = 1 - R$$

Reflexion factor (energy): $R = |r|^2$

If dispersive medium



$$E_r = r E_i$$

$$r_v = \frac{\sqrt{\varepsilon_r - \sin^2\theta_1} - \varepsilon_r \cos\theta_1}{\sqrt{\varepsilon_r - \sin^2\theta_1} + \varepsilon_r \cos\theta_1}$$

$$r_h = \frac{\cos\theta_1 - \sqrt{\varepsilon_r - \sin^2\theta_1}}{\cos\theta_1 + \sqrt{\varepsilon_r - \sin^2\theta_1}}$$

Refractive index: $n = \sqrt{\varepsilon_r}$

Caractéristiques de SSM/I

Figure 5-10. SMMR instrument in its handling fixture.

Central Frequency Pol. (GHz)	**19.35**	**22.24**	**37.0**	**85.5**
Radiometric Pol. (V/H) **(*)**	V, H	V	V, H	V, H
Thermal resolution (K)	0.8	0.8	0.6	1.1
Integrated FOV (Km)	70x45	60x40	38 x 30	16x14
Spatial sampling (Km)	25	25	25	12.5
Scan angle			102.4 °	
Sweep periodicity			1.9s	
Ground incidence			53.1°	
Swath width			1394 Km	
Antenna diameter			65 cm	
Weight			120 Kg	
Power			70 W	

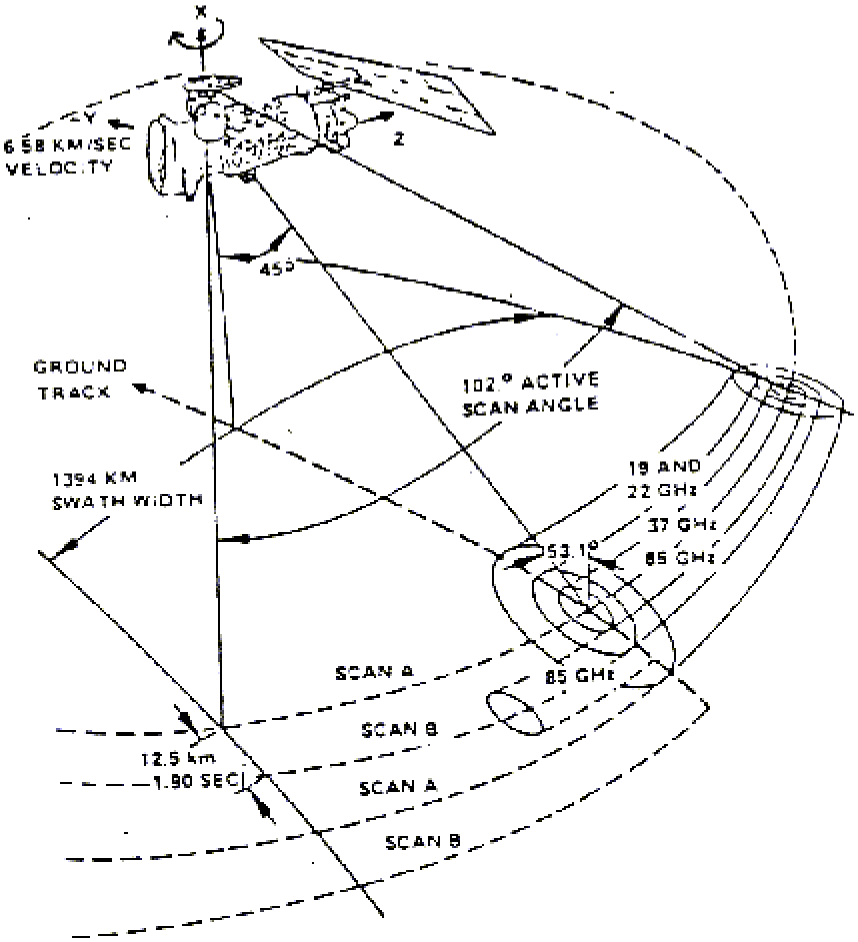


Image globale NOAA-AVHRR

Canal Proche-InfraRouge

1-10 avril 1992

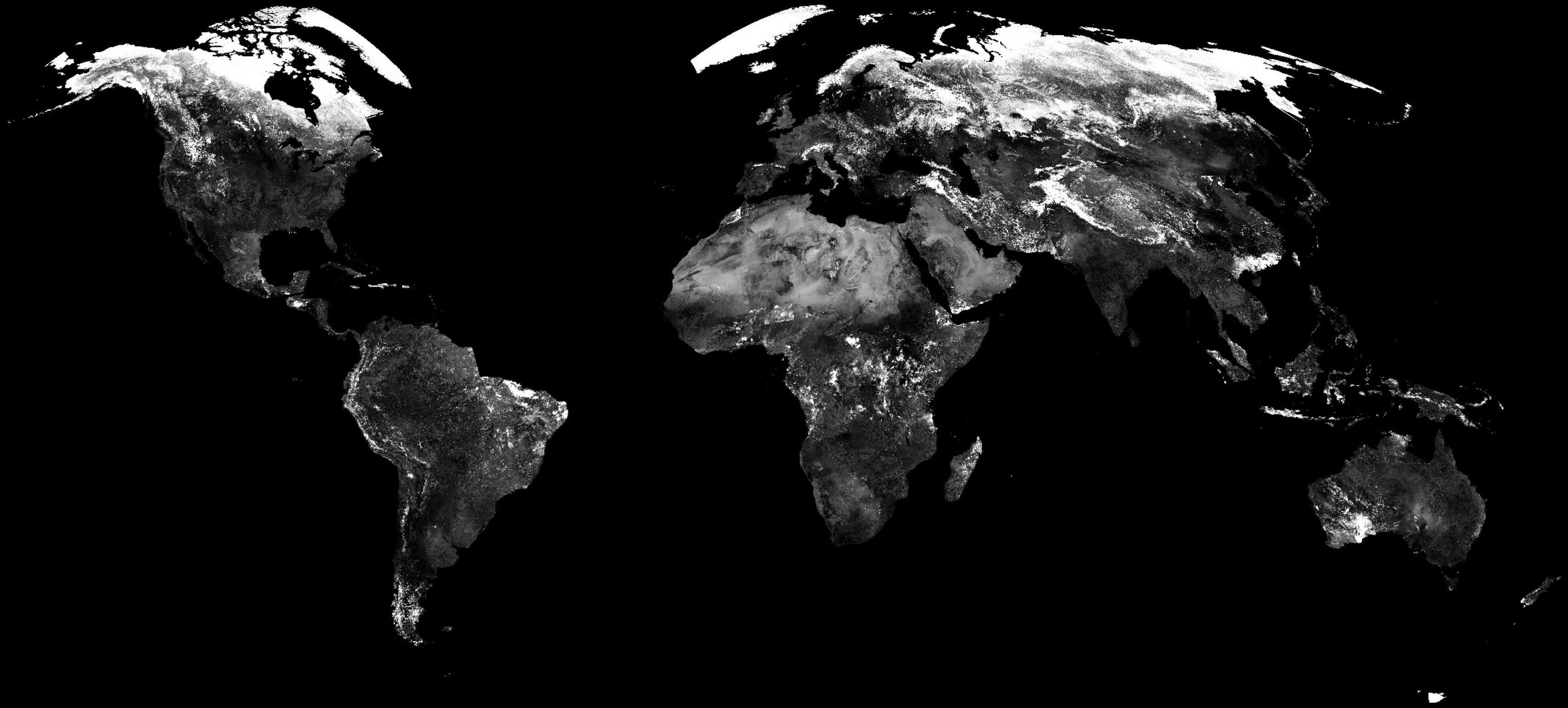


Image globale NOAA-AVHRR

Canal InfraRouge thermique (12 μm)

1-10 avril 1992

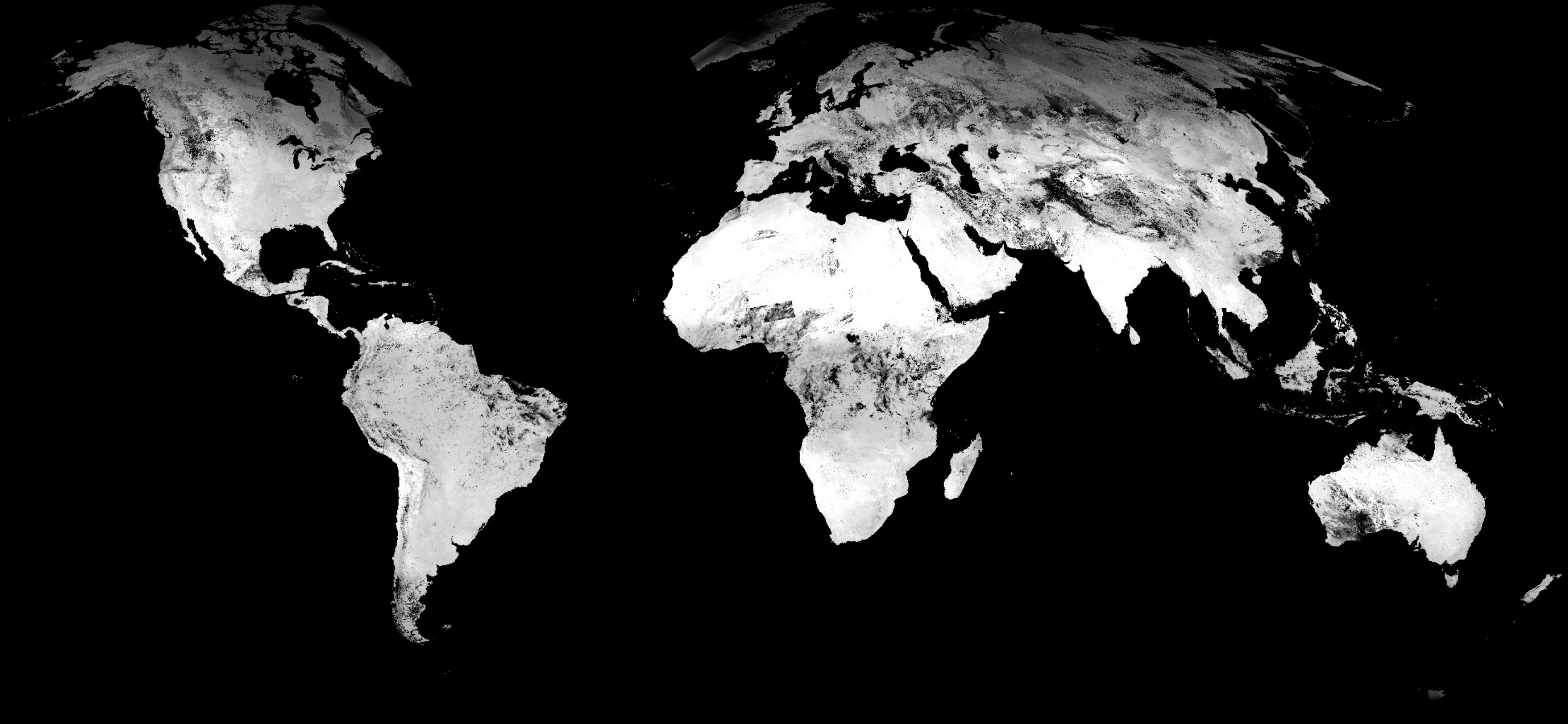
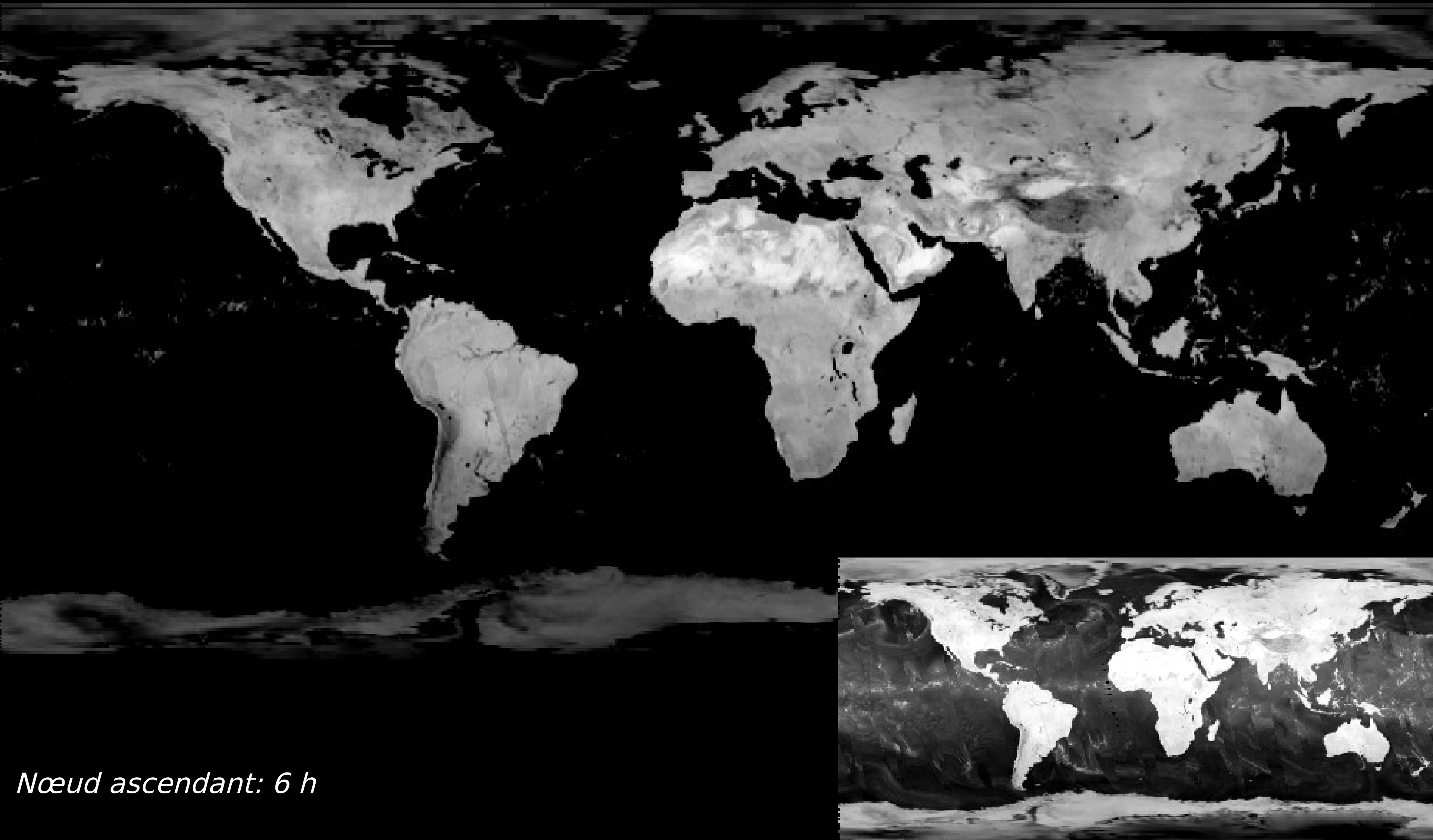
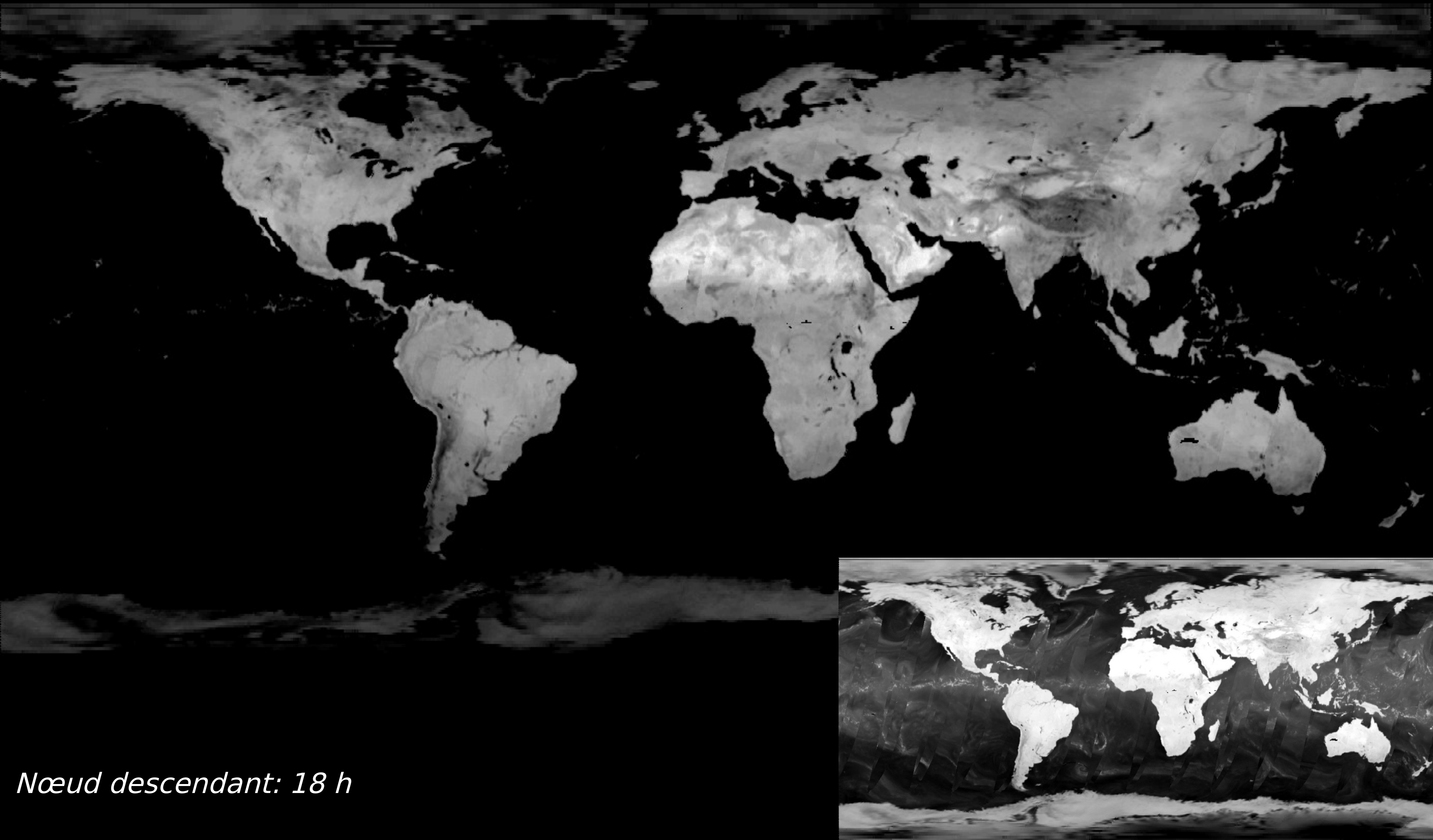


Image globale SSM/I (19GHz)
température de brillance – pol. V
3-8 août 1991



Nœud ascendant: 6 h

Image globale SSM/I (19GHz)
température de brillance – pol. V
3-8 août 1991

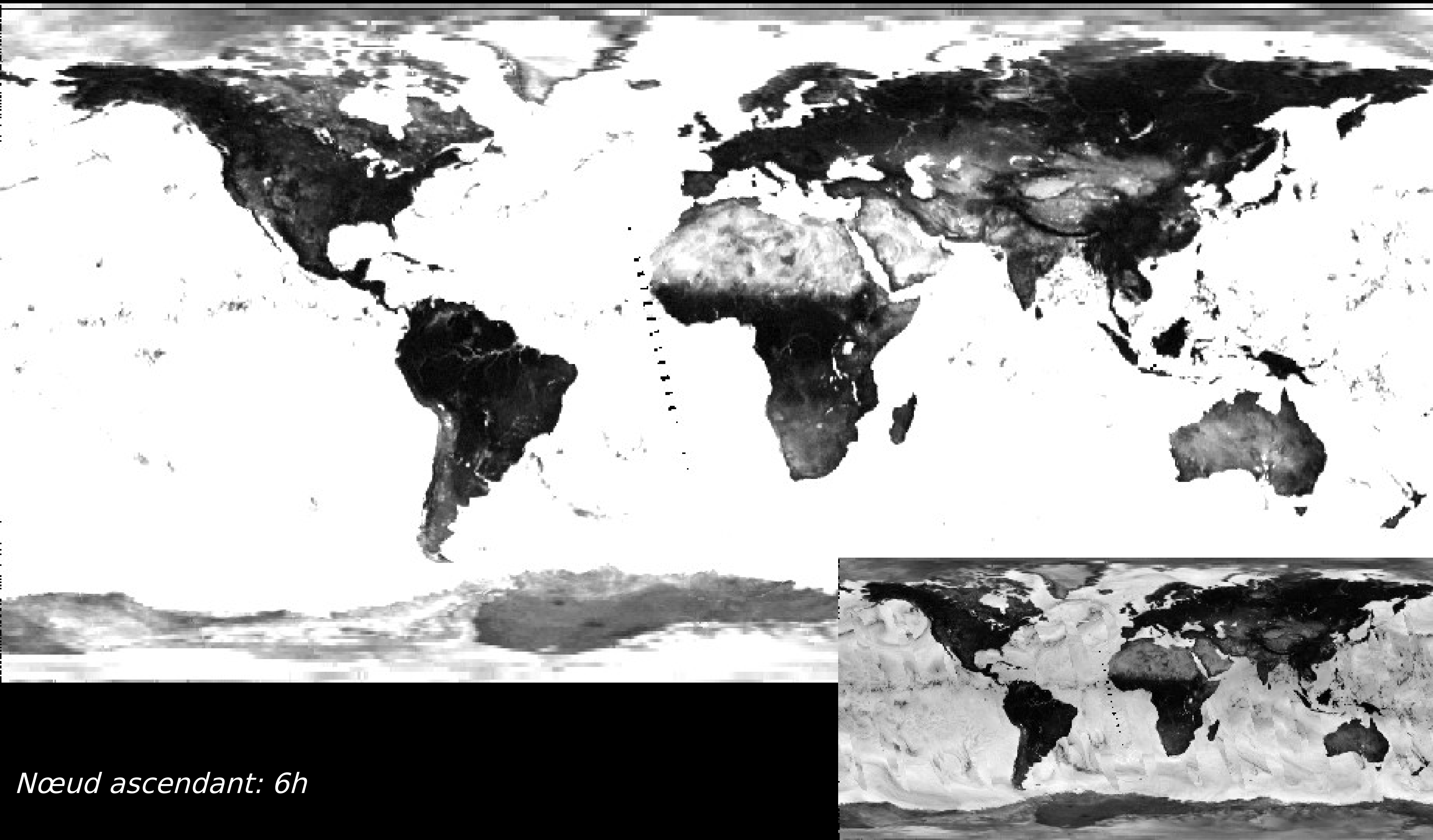


Nœud descendant: 18 h

Image globale SSM/I (19GHz)

$\Delta T = T_V - T_H$

3-8 août 1991

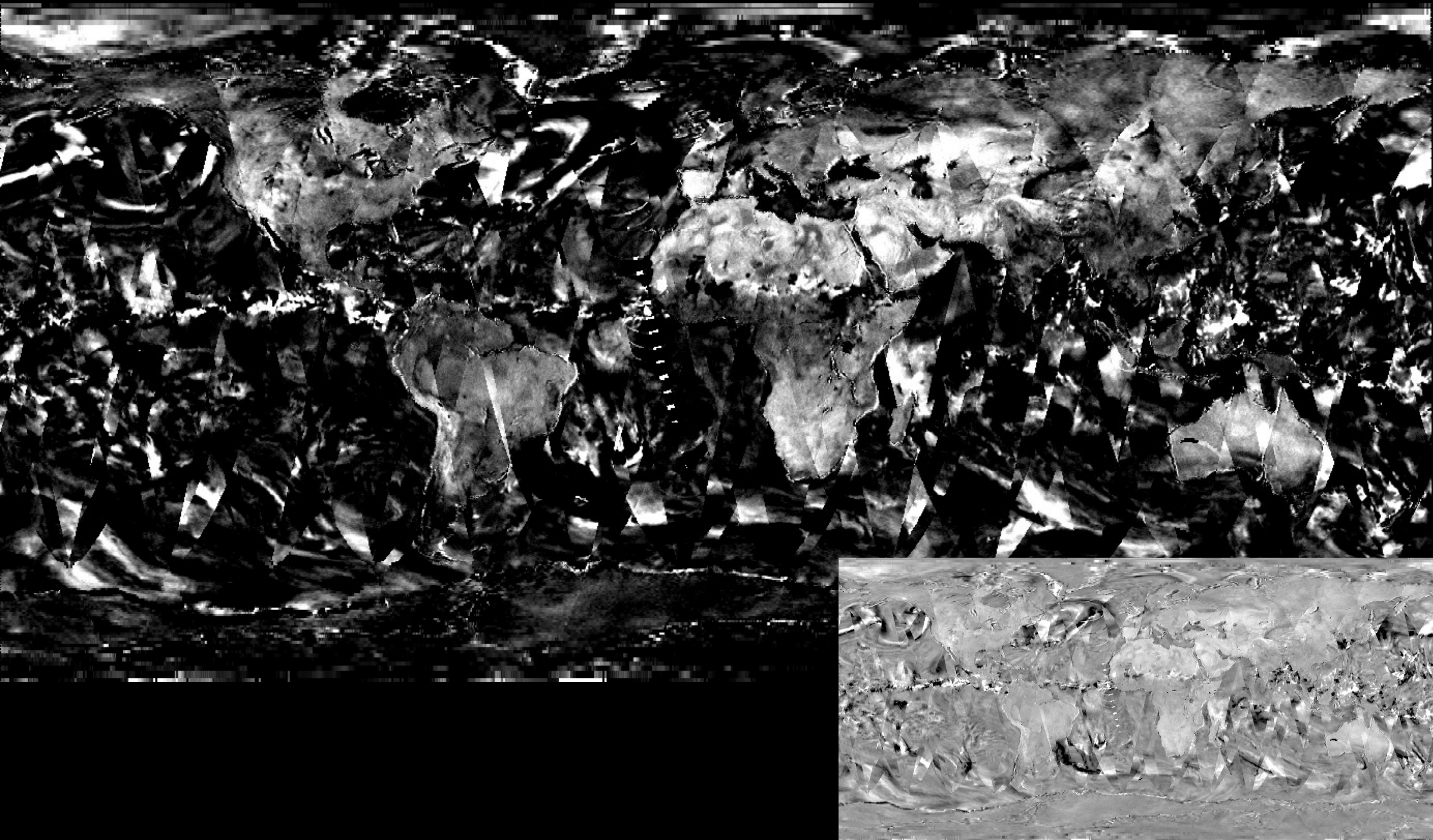


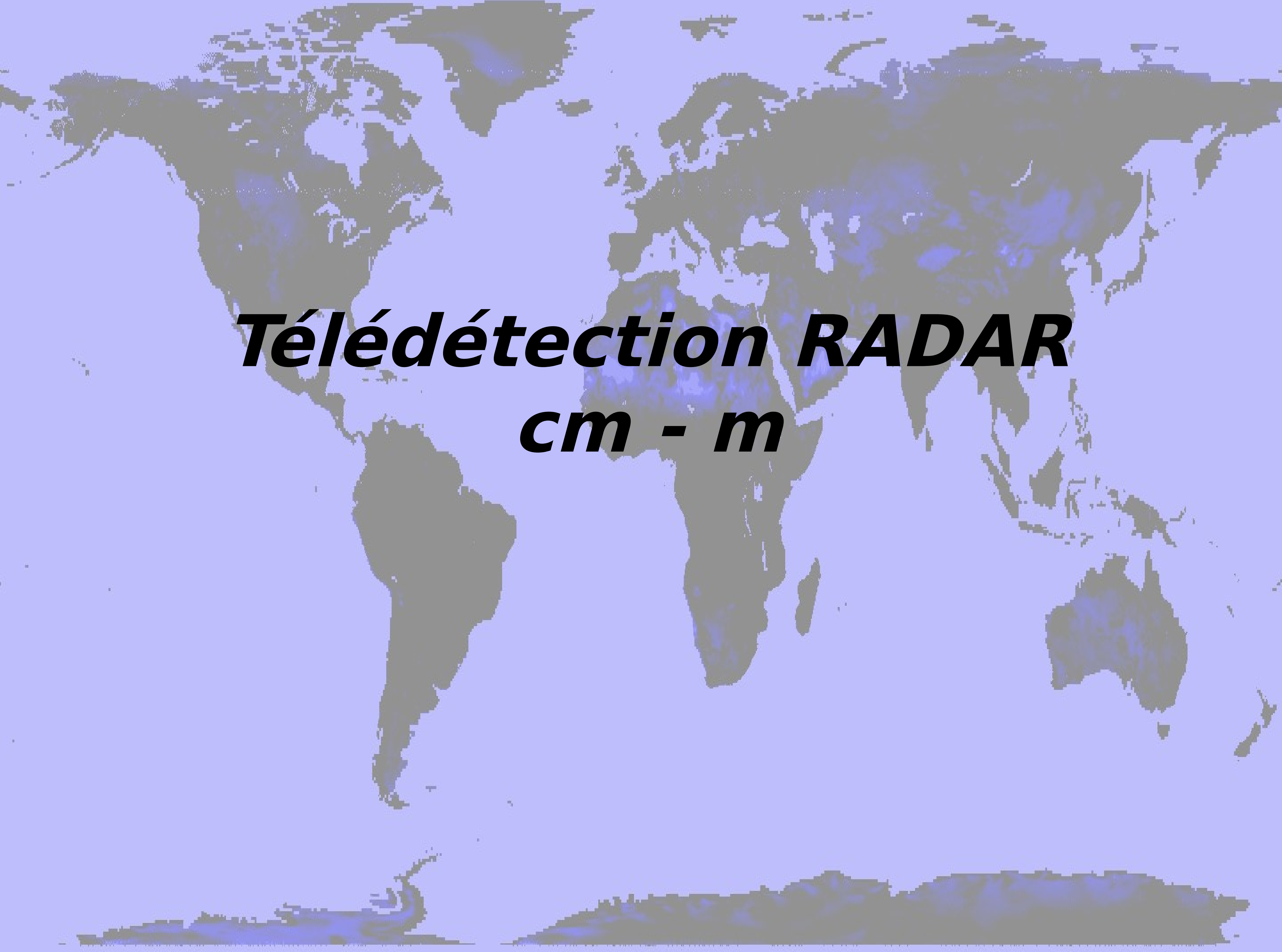
Nœud ascendant: 6h

Image globale SSM/I (19GHz)

T_{PM} - T_{AM} pol. V

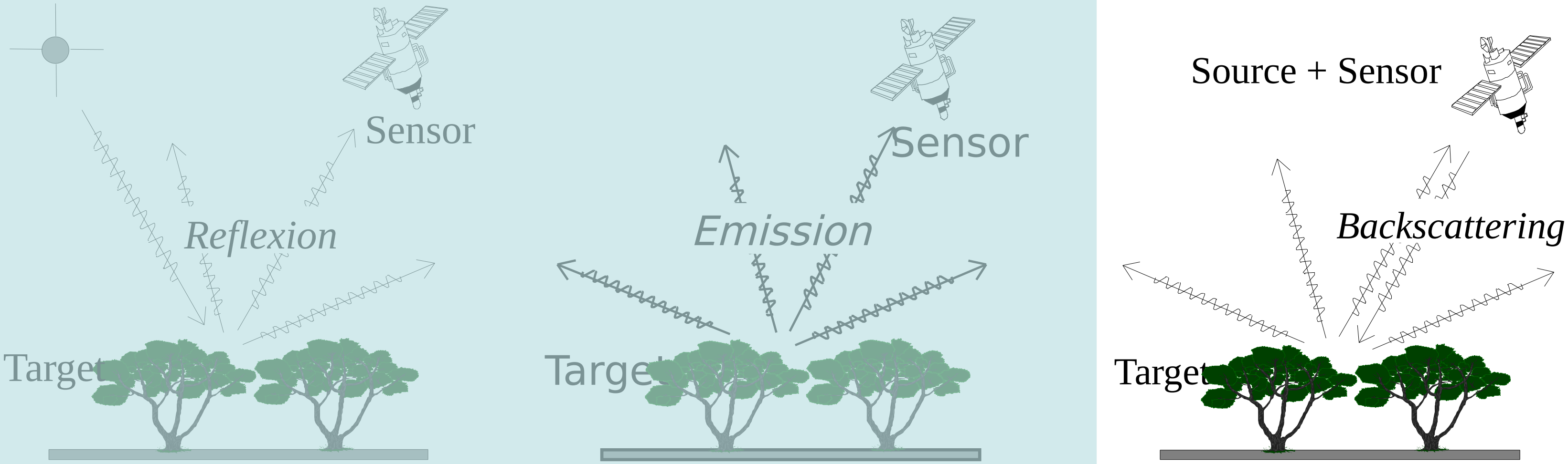
3-8 août 1991





Télédétection RADAR
cm - m

Observation modes



VIS
NIR, MIR

TIR
Microwaves

‘active’
microwaves

VIS

NIR-MIR-TIR

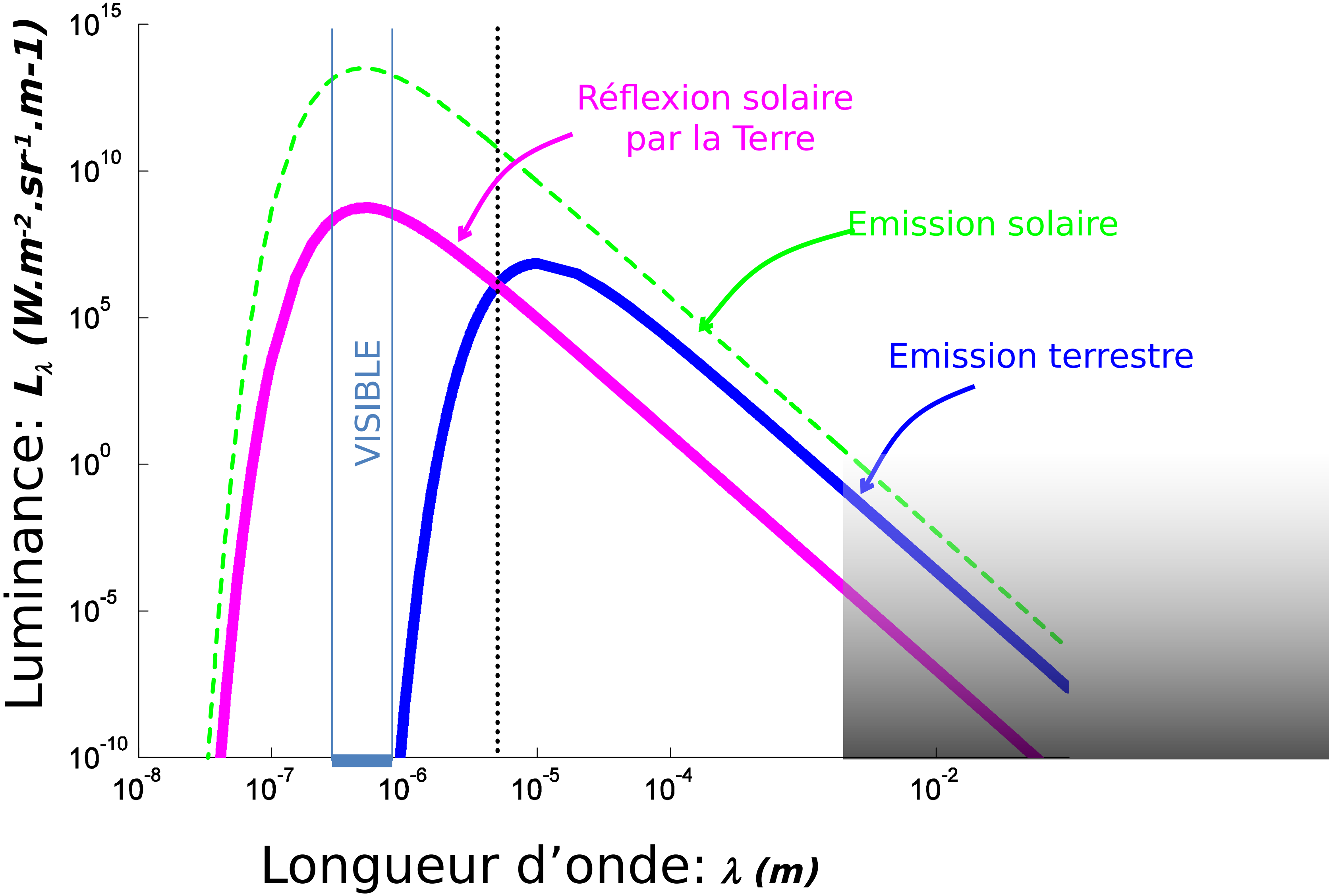
Microwaves

0.4-0.7 µm

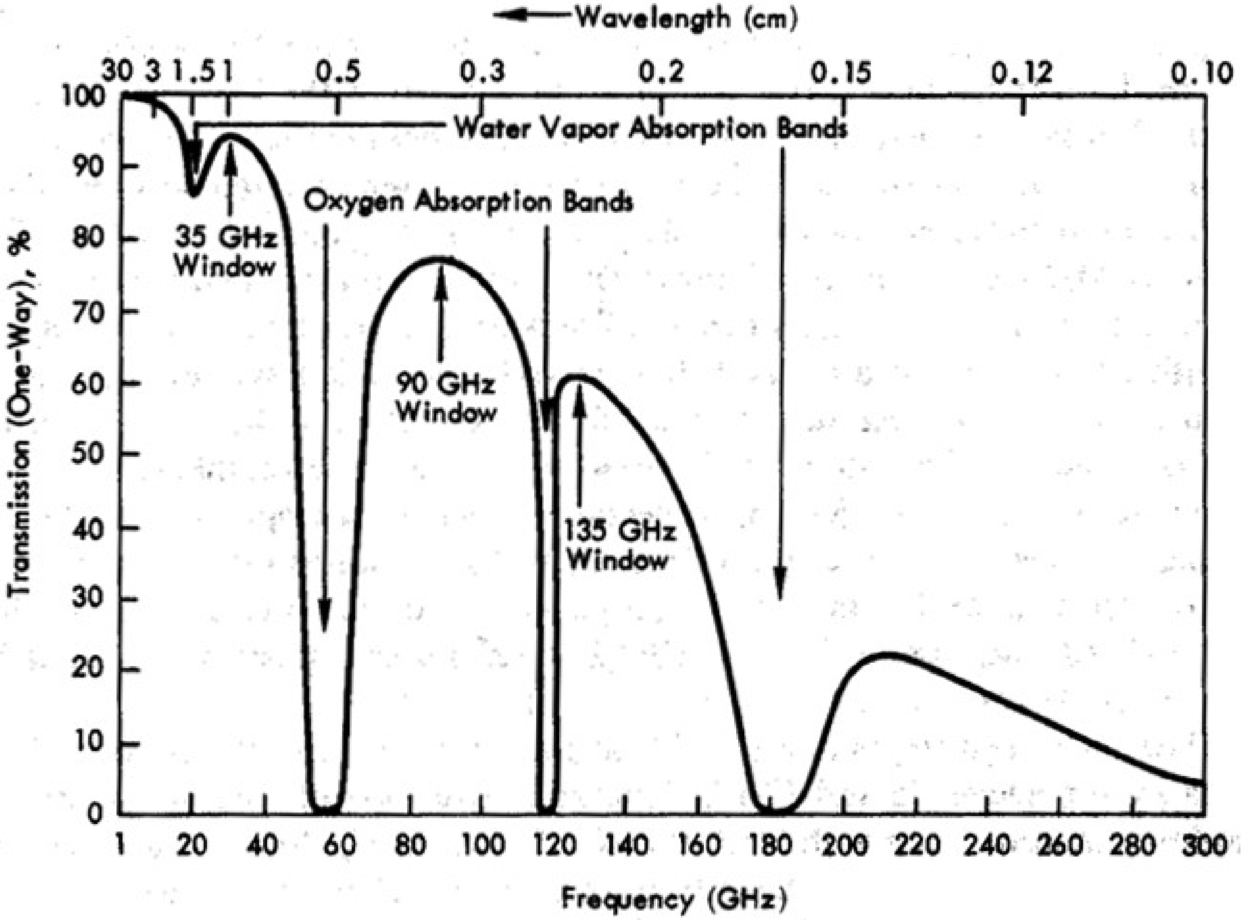
0.7-7500 µm

0.75-150 cm

Hyperfréqences actives: RADAR



Microwave spectrum behaviour



Source: Ullaby *et al.*

Radar imageur SAR: un système tout temps

ERS (bande C, 23°, VV)

Landsat TM

Waterford, Irelande, 09/08/91

Surface: 50 x 50 km

Passage Landsat: 10h43

Passage ERS-1: 11h25

Source ESA

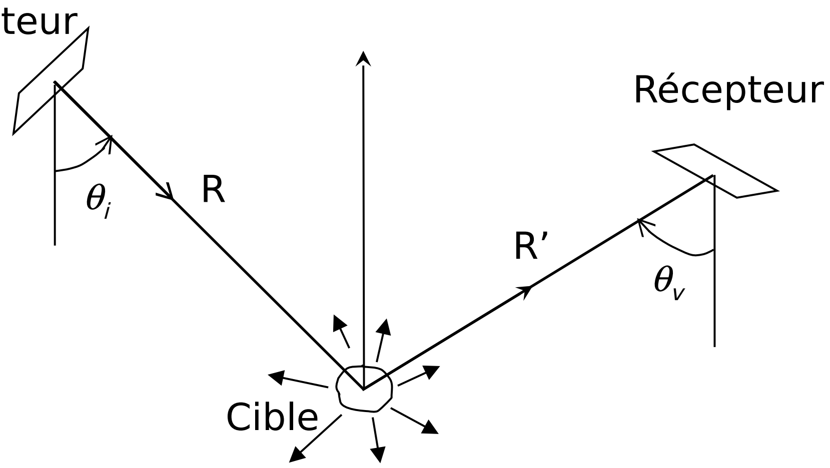
r: système actif => - image de jour comme de nuit

- observation hautes latitudes

es centimétriques => insensible conditions météorologiques

(10% des images optiques sont sans nuages sur l'Europe)

L'EQUATION RADAR



uissance émise par un radar:

$$P_i = \frac{P_e G_e}{4\pi} d\Omega$$

clairement reçu à distance R:

$$E_i = \frac{P_e G_e}{4\pi R^2}$$

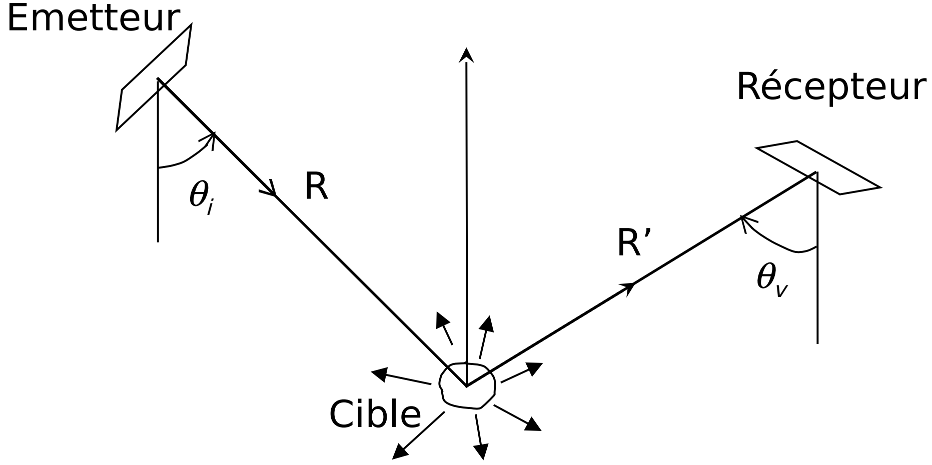
uissance interceptée pas cible: $P_s = \frac{P_e G_e}{4\pi R^2} \boxed{SER}$

Section efficace radar (m²)

ensité émise par la cible (sup. isotrope): $I = \frac{P_s}{4\pi} = \frac{P_e G_e}{4\pi R^2} \frac{SER}{4\pi}$

uissance reçue par surface dS à distance R': $P_r = I\, d\Omega = I \frac{dS}{R'^2} = \frac{P_e G_e}{4\pi R^2} \frac{SER}{4\pi R'^2} dS$

L’EQUATION RADAR (2)



uis. reçue par dS à distance R’:

$$P_r = \frac{P_e G_e}{4\pi R^2}\frac{SER}{4\pi R'^2} dS$$

Eclairement reçu à distance R’:

$$E_r = \frac{P_e G_e}{4\pi R^2}\frac{SER}{4\pi R'^2}$$

Puissance reçue par antenne:

$$P_r = E_r\, dA = E_r \frac{G_r \lambda^2}{4\pi} = \frac{P_e G_e}{4\pi R^2}\frac{SER}{4\pi R'^2}\frac{G_r \lambda^2}{4\pi}$$

L'EQUATION RADAR (3)

uissance reçue par antenne: $dP_r = \frac{P_e G_e}{4\pi R^2} \frac{SER}{4\pi} \frac{G_r \lambda^2}{4\pi R^2}$

as de cibles étendues:

coefficient de rétrodiffusion radar: $\sigma^0 = \frac{SER}{d\Sigma}$ (m²/m²)

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

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

Télédétection radar (λ > cm)