

# TRANSPARENCIAS DE TELEDETECCIÓN

## 4. Sensores RADAR

4.1 Dispersión radar de superficies

4.2 Polarimetría radar

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Marzo de 2000

## **4. Sensores RADAR**

**4.1 Dispersión radar de superficies**

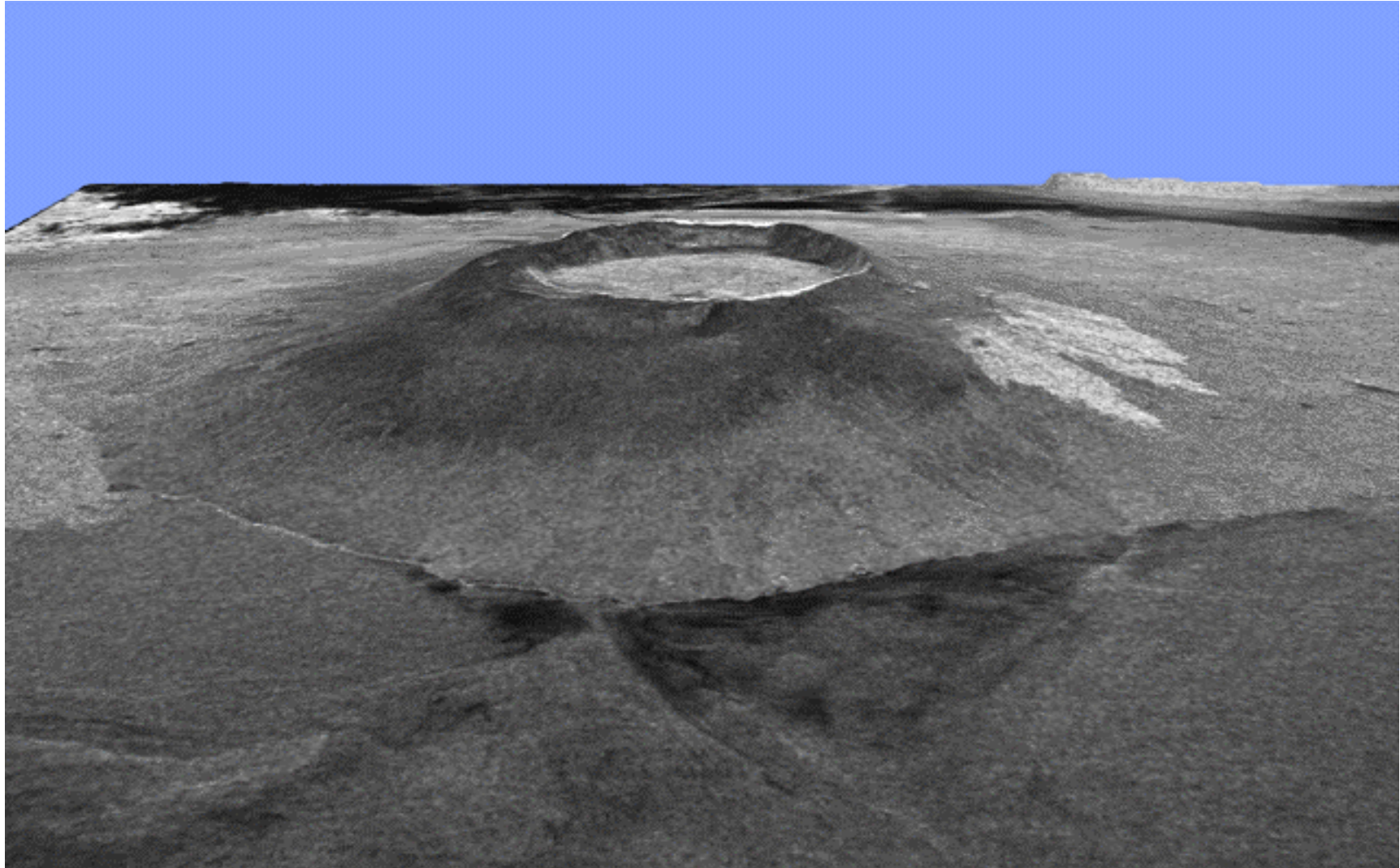
**4.2 Polarimetría radar**

**4.3 Radares de apertura total i sintética (SAR)**

**4.4 Reconstrucción de imágenes SAR**

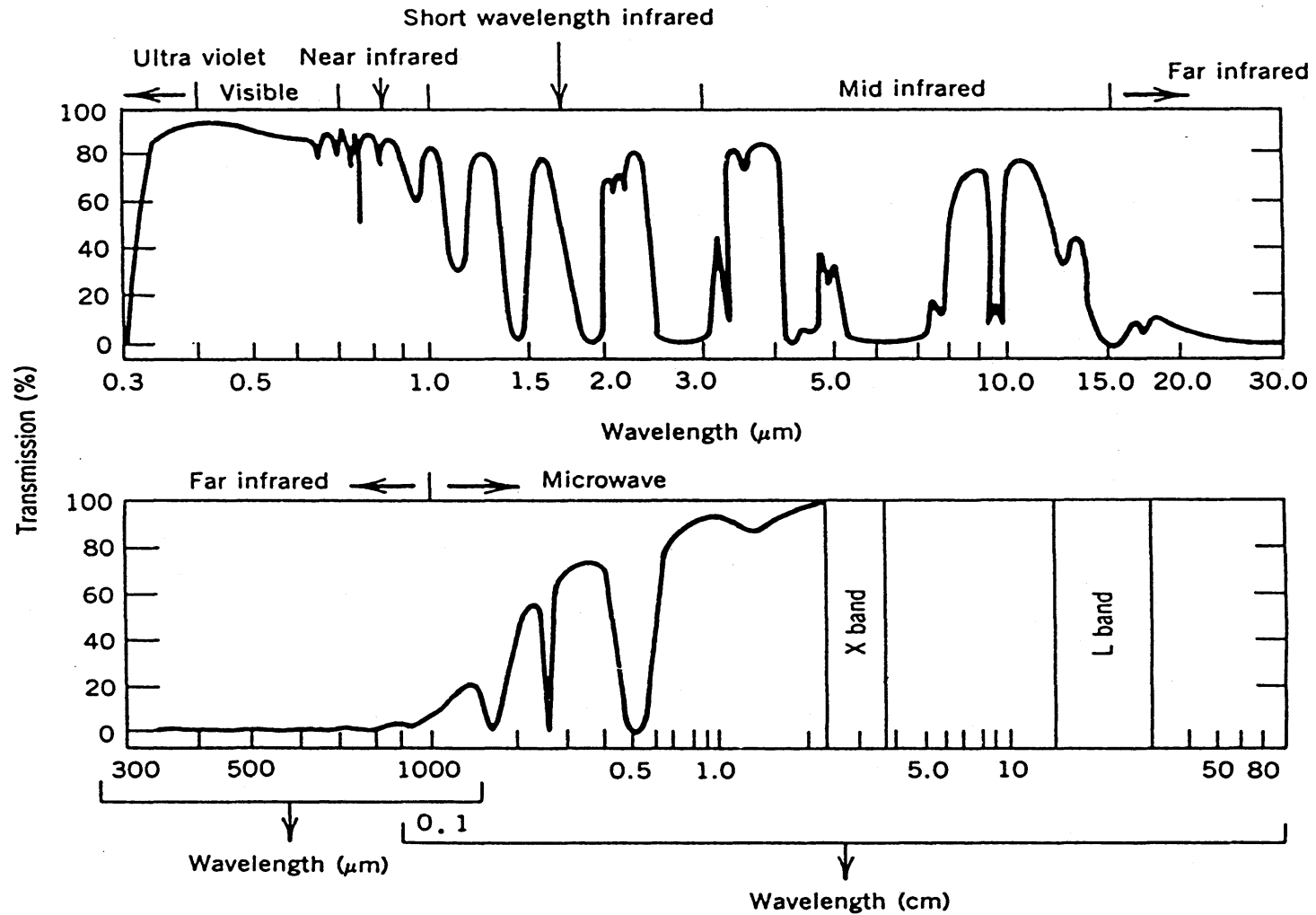
**4.5 Corrección geométrica y reducción de ruido en SAR**

**4.6 Otros sensores: dispersómetros y altímetros**



SIR-C/X-SAR Isla Isabela 3-D Galapagos

# Curva espectral de la transmisión atmosférica



Generalized absorption spectrum of the Earth's atmosphere at zenith. The curve shows the total atmospheric transmission.

## ¿ Por qué Microondas?

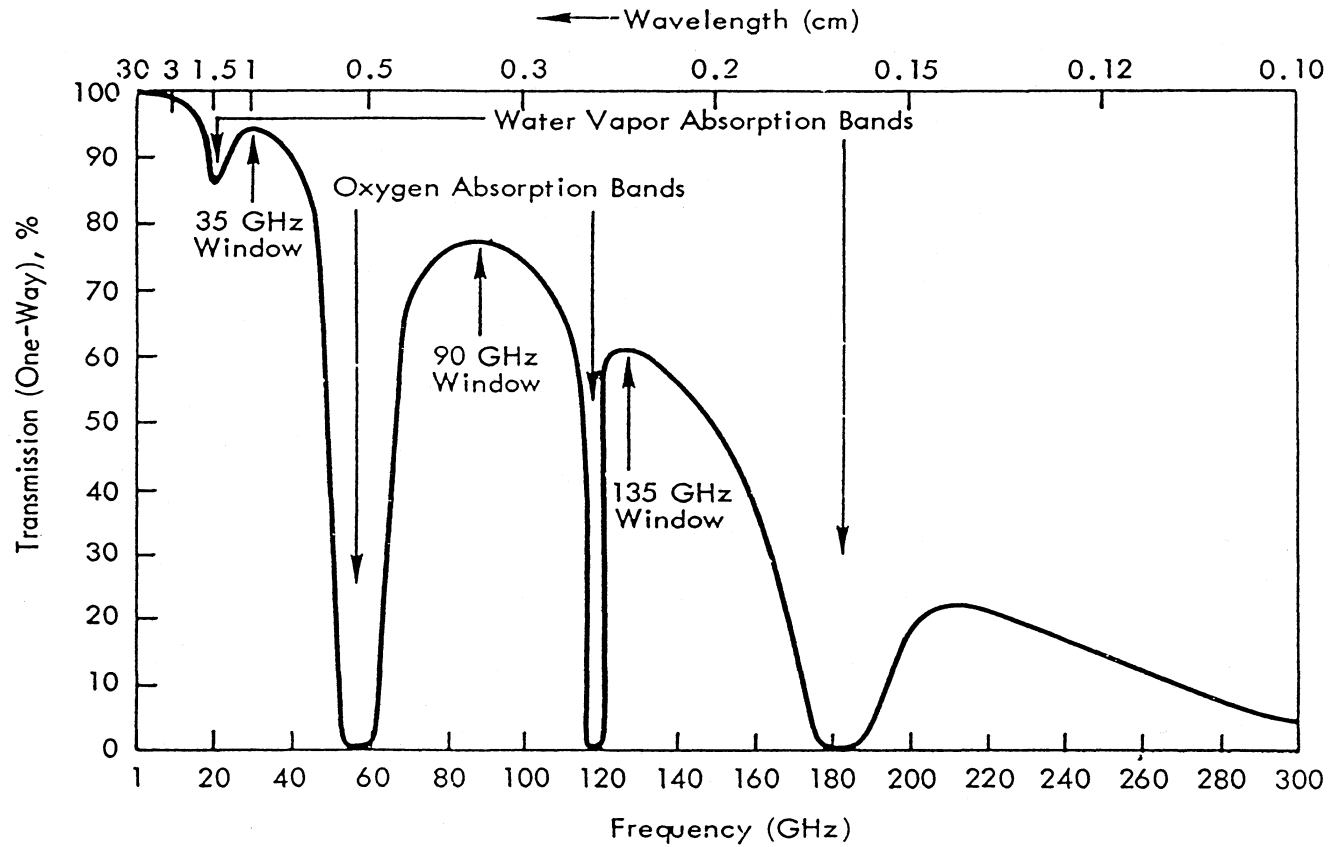
- Las nubes e hidrometeoros son transparentes.
- No dependen de la iluminación solar.
- Capaces de penetrar vegetación, nieve, suelo.
- Alta sensibilidad a: distancia, rugosidad, humedad, viento.
- Iluminación coherente: fase, polarización de la onda.

### **TELEDETECCIÓN DE MICROONDAS:**

**Técnicas activas: Radares (SAR, Dispersómetros, Altimetros).**

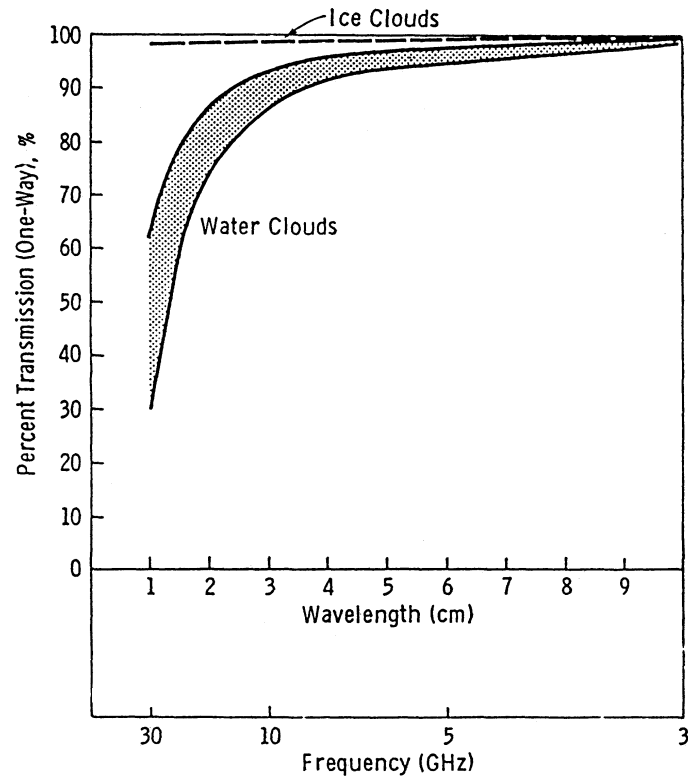
**Técnicas pasivas: Radiómetros.**

# Transmisión atmos. en condiciones de claridad y dirección vertical



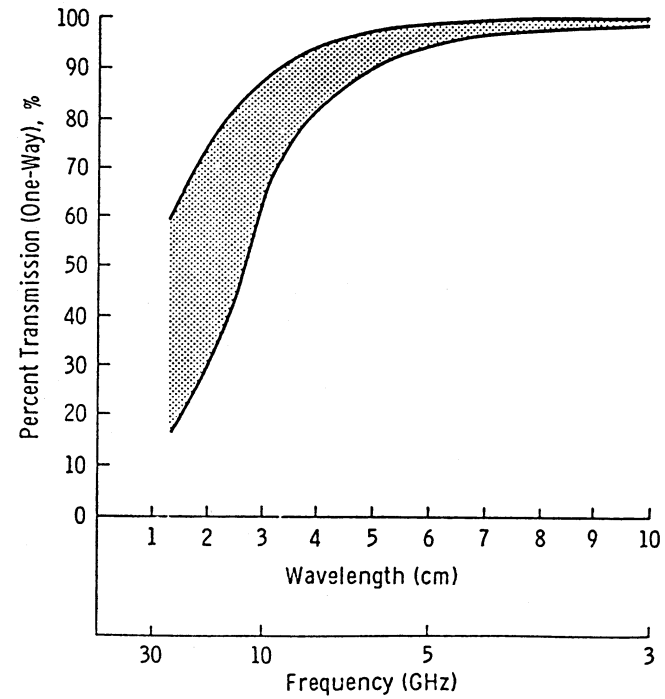
Percentage transmission through the earth's atmosphere, along the vertical direction, under clear sky conditions.

## Efecto de las nubes en la trans.



Effect of cloud on radio transmission from space to ground.

## Efecto de la lluvia en la trans.



Effect of rain on radio transmission from space to ground.

# ESPECTRO DE MICROONDAS

**Frecuencia: 1 - 100  
GHz**

**(1 GHz =  
1.000.000.000 Hz)**

**Longitud de onda  $\lambda$ :  
30 cm - 3 mm**

**Denominación de las bandas:**

**P 0.3 - 1 GHz**

**L 1 - 2 GHz**

**S 2 - 4 GHz**

**C 4 - 8 GHz**

**X 8 - 12 GHz**

**Ku 12 - 18 GHz**

**K 18 - 26 GHz**

**Ka 26 - 40 GHz**

**Bandas milimétricas > 40 GHz**



## Radar Frequency Allocations for Remote Sensing (GHz) (All are shared with other services)

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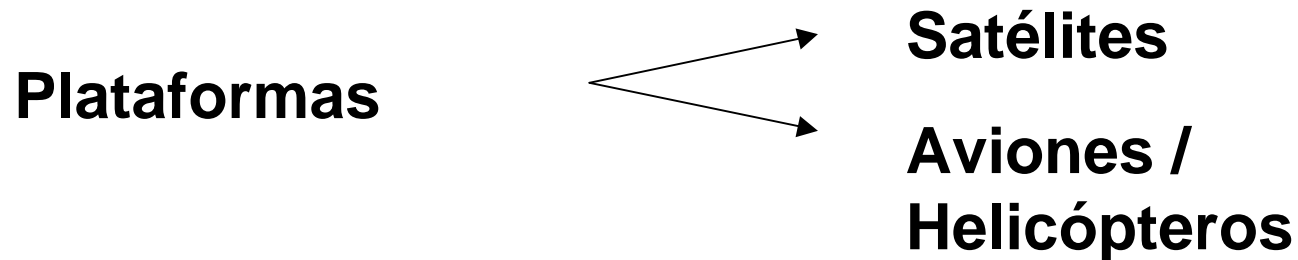
1.215–1.300, 3.1–3.3, 5.25–5.35, 8.55–8.65  
9.50–9.80, 13.4–14.0, 17.2–17.3, 24.05–24.25  
35.5–35.6, 78.0–79.0

### Examples of Other Allocations

|                      |  |
|----------------------|--|
| Radar altimeter      | 4.2–4.4  |
| Doppler navigator    | 8.8, 13.25–13.40                                       |
| Meteorological radar | 5.6–5.65, 9.3–9.5                                      |
| Coastal radar        | 5.35–5.65, 9.0–9.2, 10.0–10.55                         |
| Ship radar           | 5.46–5.47, 9.3–9.5, 14–14.3,<br>24.25–25.25, 31.8–33.4 |

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- **Normalmente se trabaja a grandes distancias:**



- **Existen también aplicaciones a cortas distancias:**

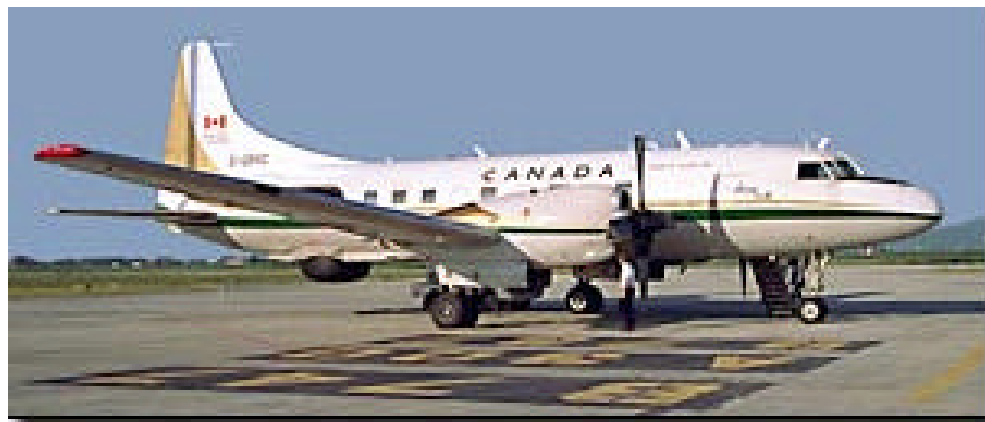
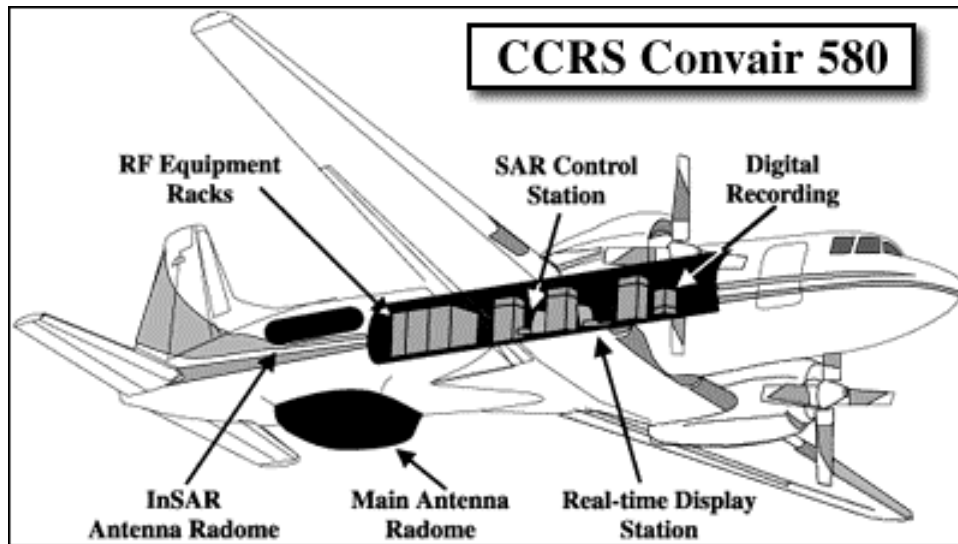
- **Radars de instrumentación:**

**medida de la reflectividad de objetos y superficies.**

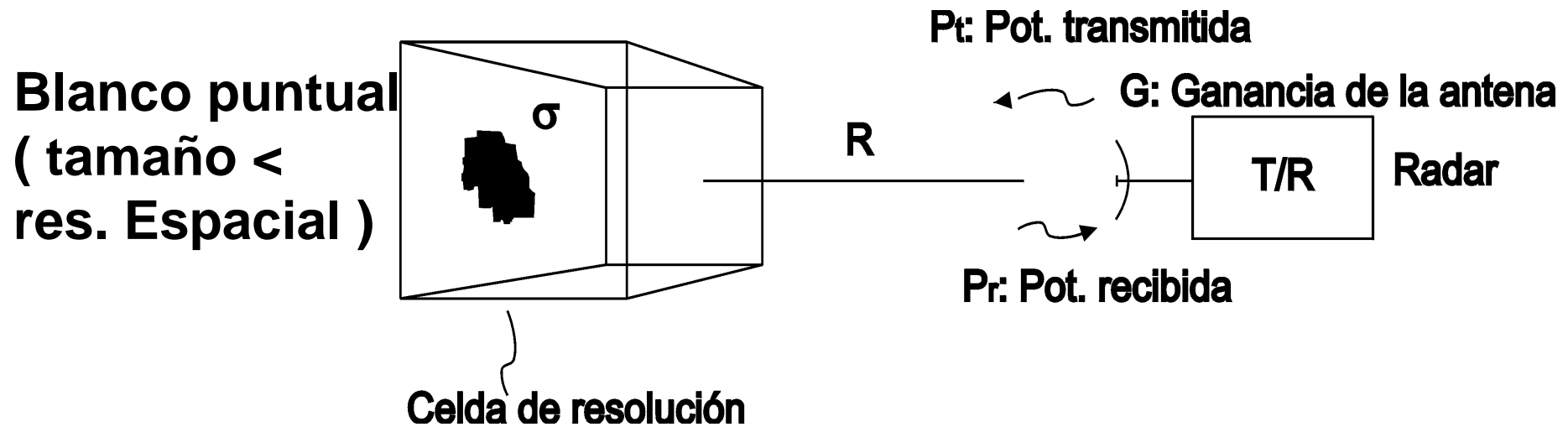
- **Sistemas tomográficos:**

**aplicaciones biomédicas e industriales.**

# AIRBORNE SAR



# SISTEMAS ACTIVOS: RADARES



## Ecuación de potencias RADAR

$$P_r = \frac{P_t G^2 I^2 s}{(4\pi)^3 R^4 L}$$

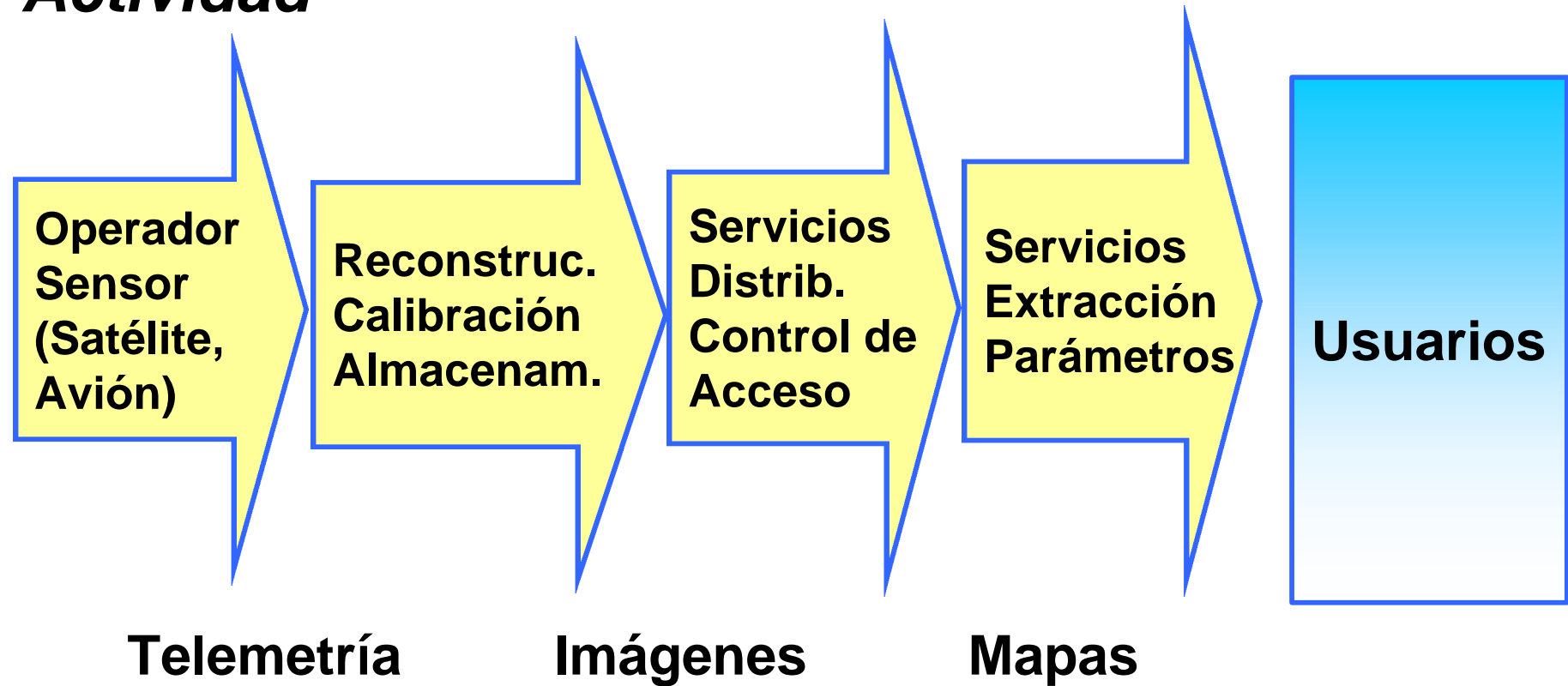
*Pérdidas*  $L = L_s L_a$

$L_s$  : *pérdidas sistema*

$L_a$  : *pérdidas atmósfera*

# La cadena de valor en Teledetección

***Actividad***



**Datos ≠ Información ≠ Conocimiento ≠ Decisiones**

# LA SECCIÓN RECTA RADAR

modela la potencia de eco retornada por el blanco

***s*** : *Sección recta radar del blanco*  $\Delta$   
= *área de un blanco isotrópico ideal*

$$\mathbf{s} = \lim_{R \rightarrow \infty} 4\mathbf{p} R^2 \left| \frac{E_s}{E_i} \right|^2$$

$E_i$  : *campo eléctrico incidente sobre el blanco*

$E_s$  : *campo eléctrico dispersado sobre el radar*

# Sección Recta Radar

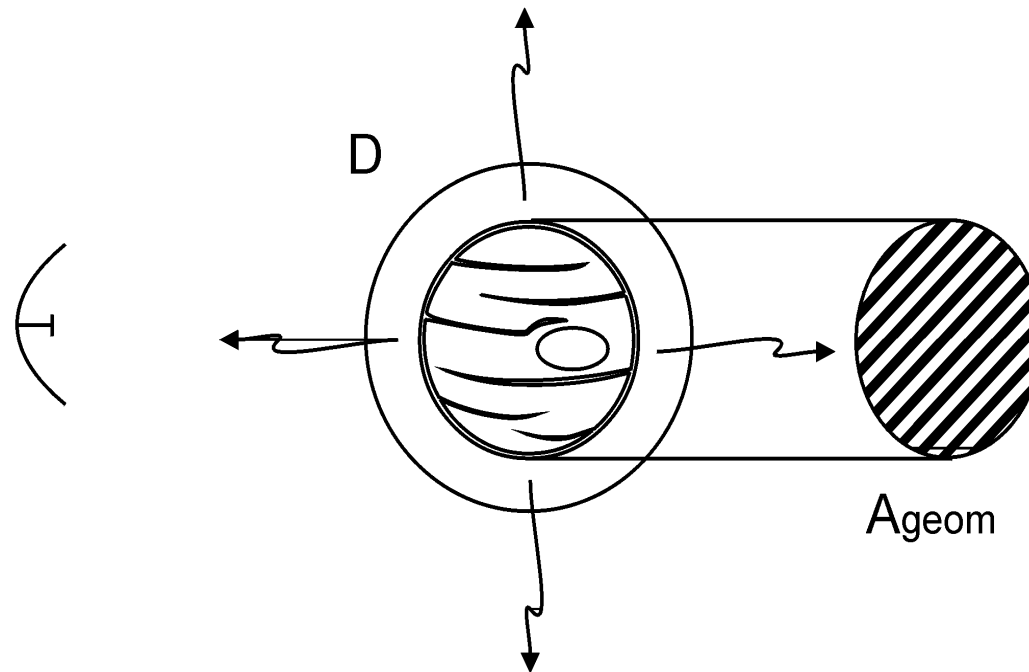
$\sigma$  tiene dimensiones de Área:  $m^2$  o dBsm

$$\mathbf{s} (dBsm) = 10 \log \mathbf{s} (m^2)$$

$\sigma$  puede interpretarse como el producto de tres factores:

$$\sigma = A.\text{geométrica} * \text{Directividad retrodispersión} * \text{Eficiencia}$$

# SECCIÓN RECTA RADAR (Ejemplos: 1)



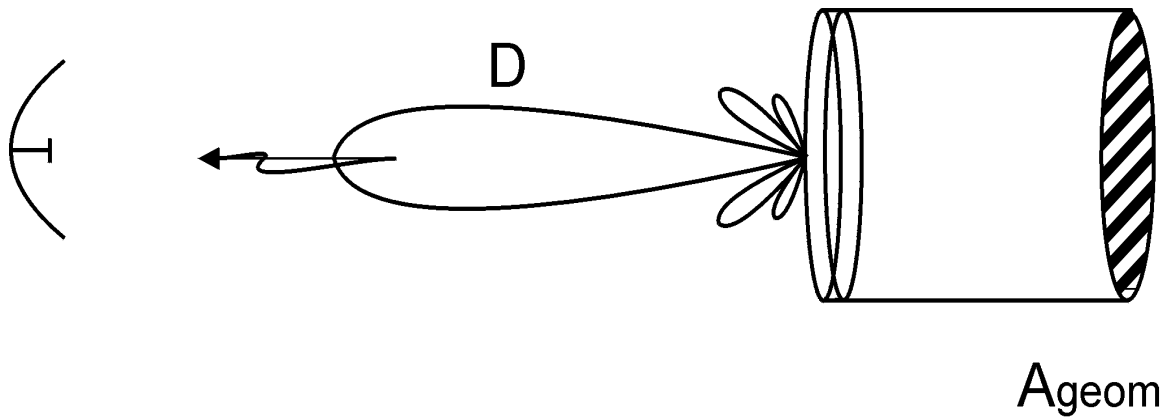
**Esfera metálica**

$$D \rightarrow 1 \quad \sigma \rightarrow A_{\text{geom}}$$

**Esto es para objetos eléctric. grandes tamaño  $\gg \lambda$**



## SECCIÓN RECTA RADAR (Ejemplos: 2)

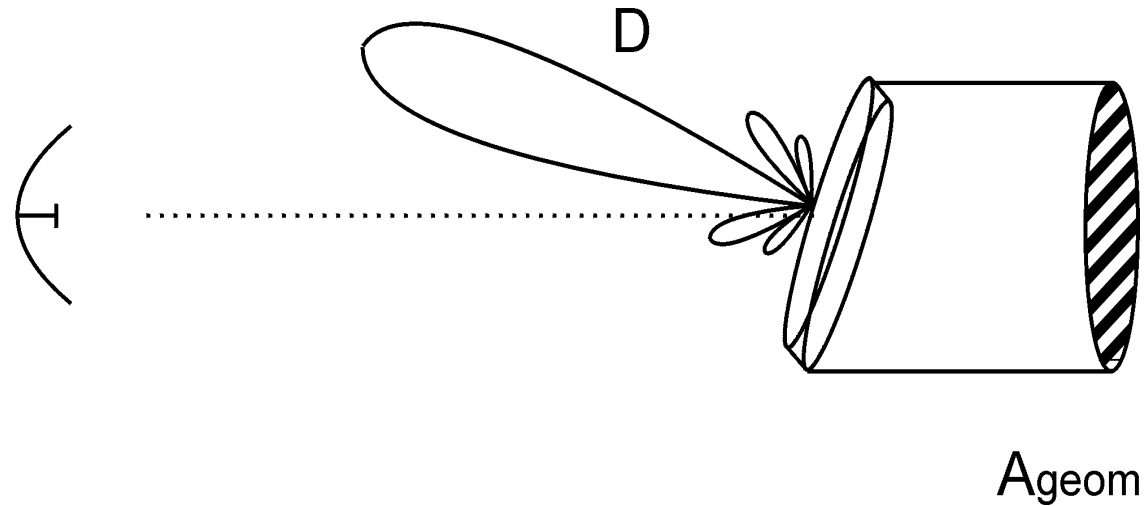


**Placa metálica normal a la dirección de incidencia**

$$D \gg 1 \quad \sigma \gg A_{\text{geom}}$$

**Esto es para objetos eléctric. grandes tamaño  $\gg \lambda$**

## SECCIÓN RECTA RADAR (Ejemplos: 3)



**Placa metálica oblicua a la dirección de incidencia**

$$D \ll 1 \quad \sigma \ll A_{\text{geom}}$$

**Esto es para objetos eléctric. grandes tamaño  $\gg \lambda$**

# RFK Stadium



## GEOLOGY

North shore of Lake Superior, July 1991.

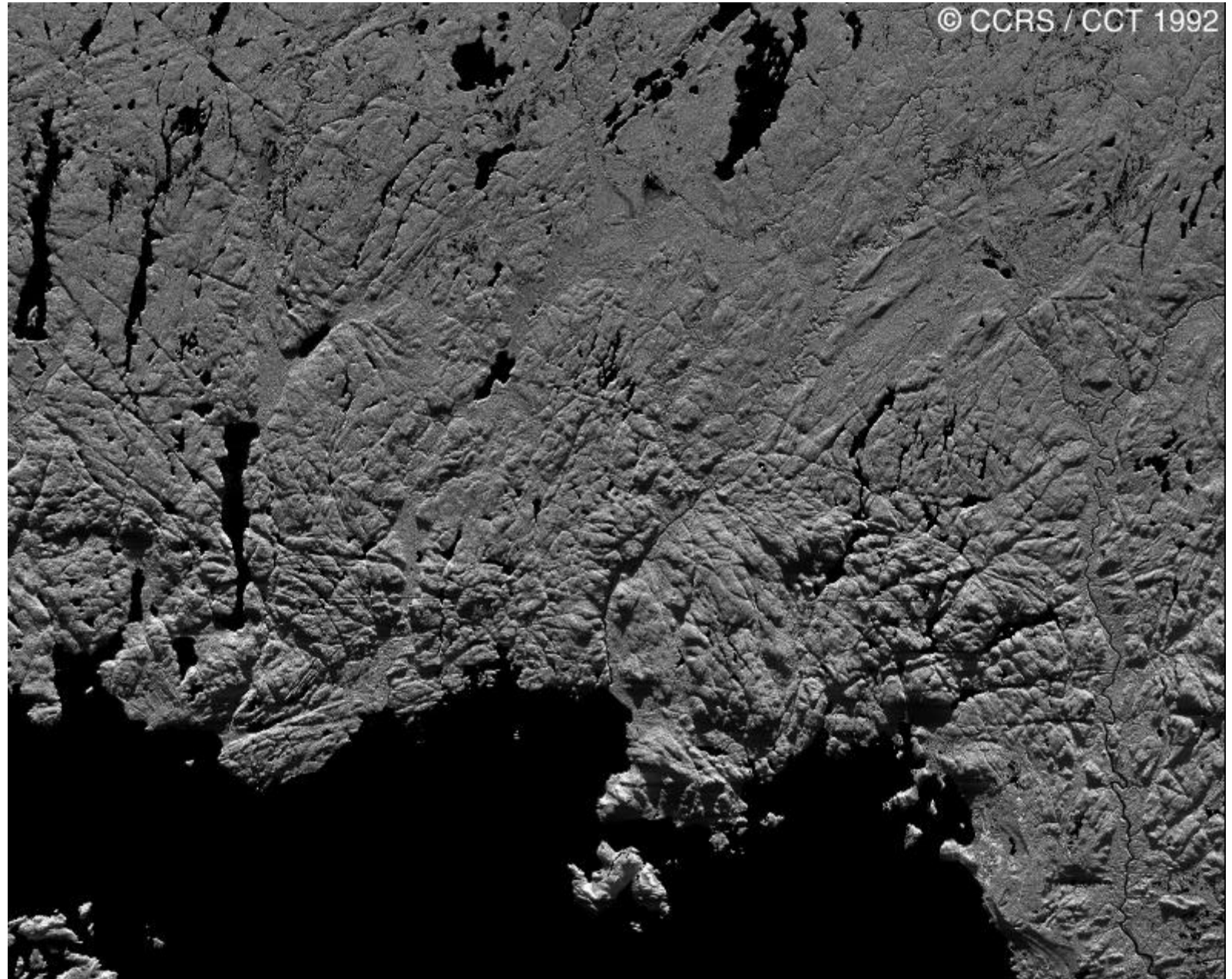
wide swath mode

displays 63km  
across the range

look direction to the  
south.

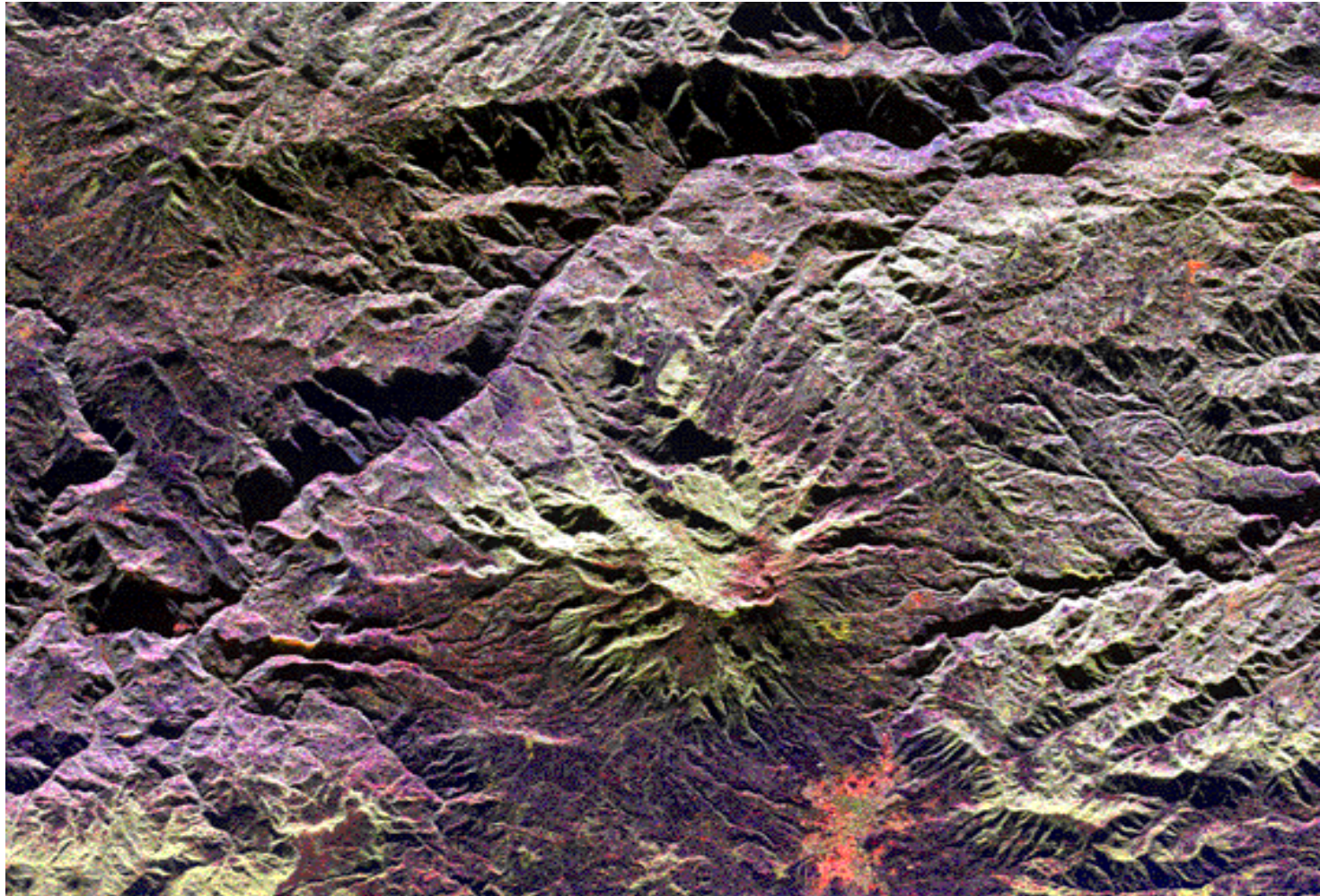
The near edge of the  
image, at the top, is  
at  $45^\circ$  and the far  
edge is at  $85^\circ$   
incidence angle  
respectively.

The wide range of  
shallow viewing  
angles is ideal for  
enhancing subtle  
terrain features  
which can be on the  
order of 2m in  
height.





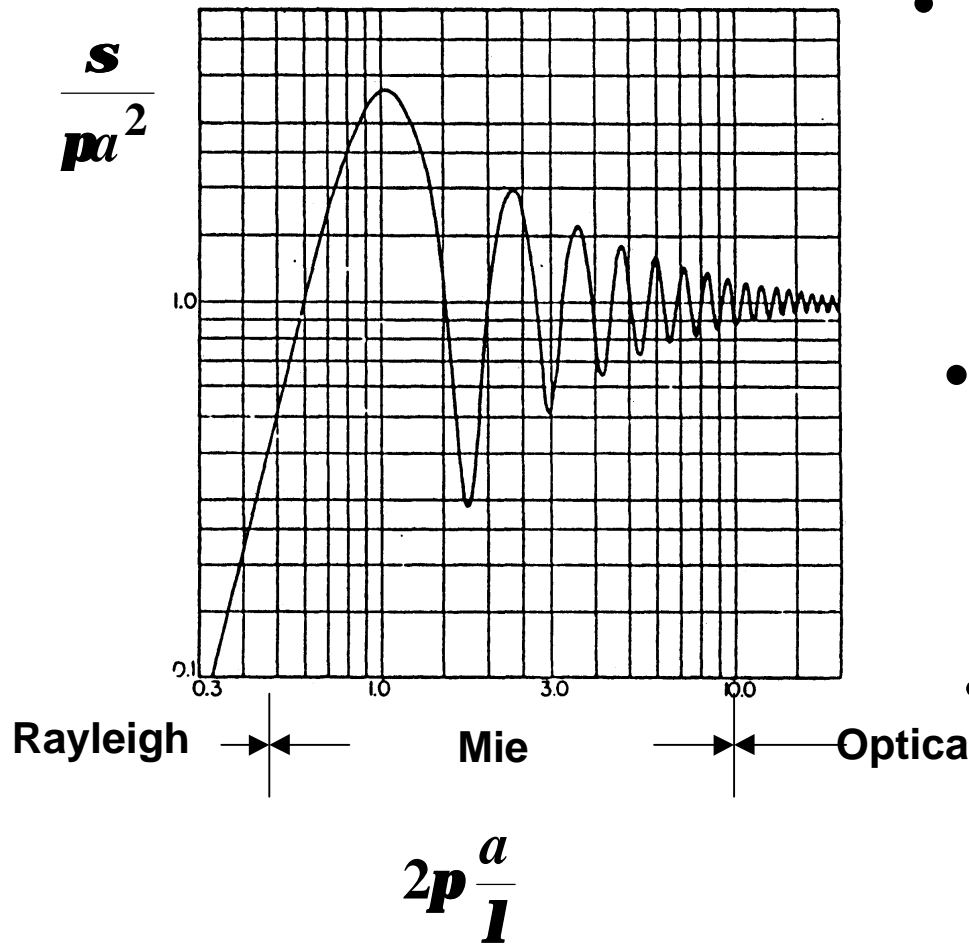
SIR-C/X-SAR Aorounga impact crater, Chad



SIR-C/X-SAR Galeras Volcano, Colombia

# Sección recta de cuerpos simples

Esfera metálica de radio  $a$

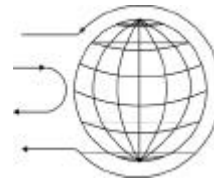


Zonas de validez:

- Rayleigh o de baja frecuencia  $2pa < 0.5l$

$$s \rightarrow 9 \left( \frac{2pa}{l} \right)^4 \propto f^4$$

- Mie o resonante  $0.5l < 2pa < 10l$

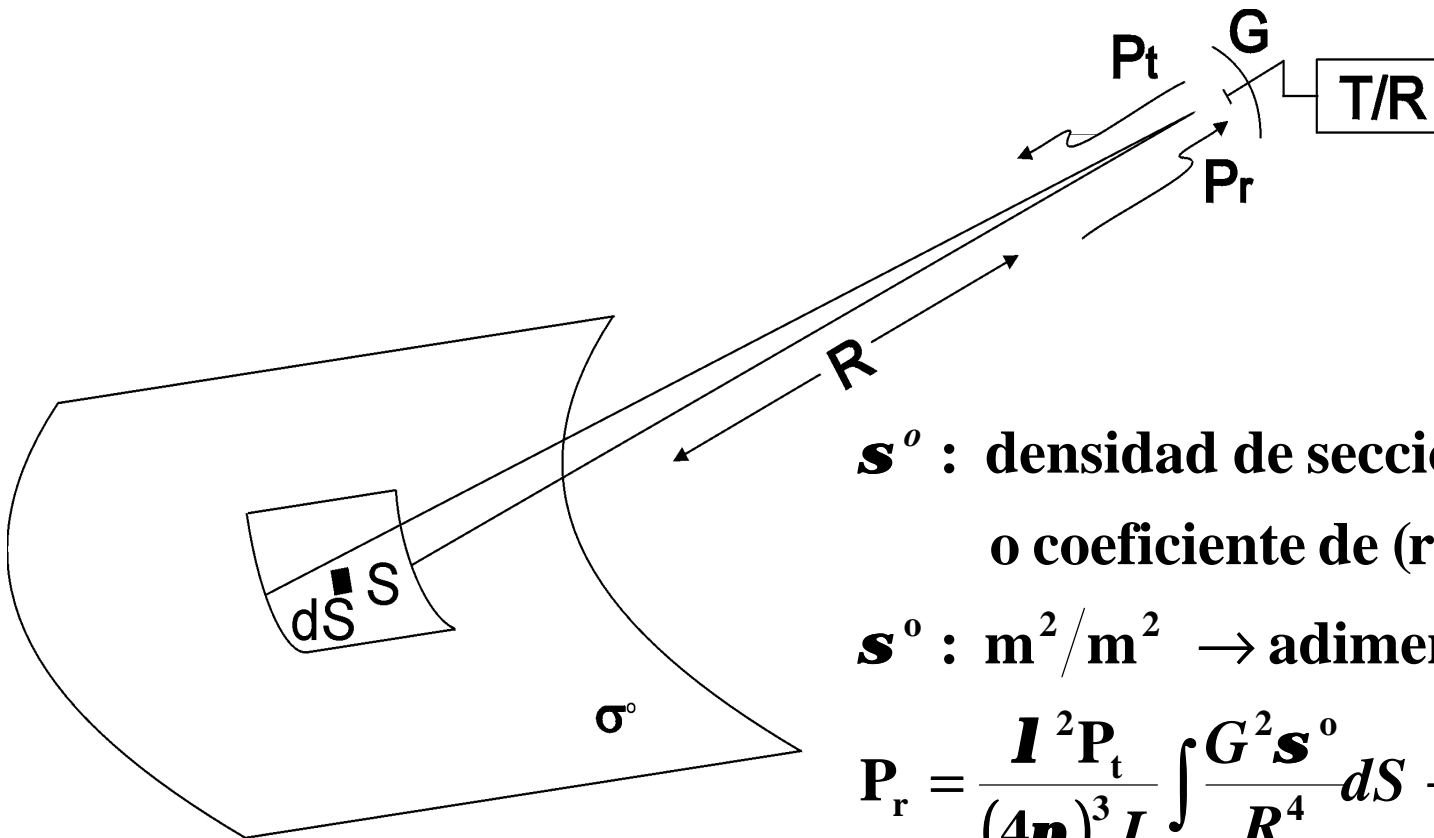


$s$  oscila alrededor de  $\pi a^2$

- Región óptica o de alta frec.  $2pa > 10l$

$$s \rightarrow \pi a^2$$

# Blanco superficial



$\sigma^0$  : densidad de sección recta superficial  
o coeficiente de (retro) dispersión

$\sigma^0$  :  $m^2/m^2 \rightarrow$  adimensional : dB

$$P_r = \frac{I^2 P_t}{(4\pi)^3 L} \int_S \frac{G^2 \sigma^0}{R^4} dS \rightarrow \frac{P_t G^2 I^2 \sigma^0 S}{(4\pi)^3 R^4 L}$$

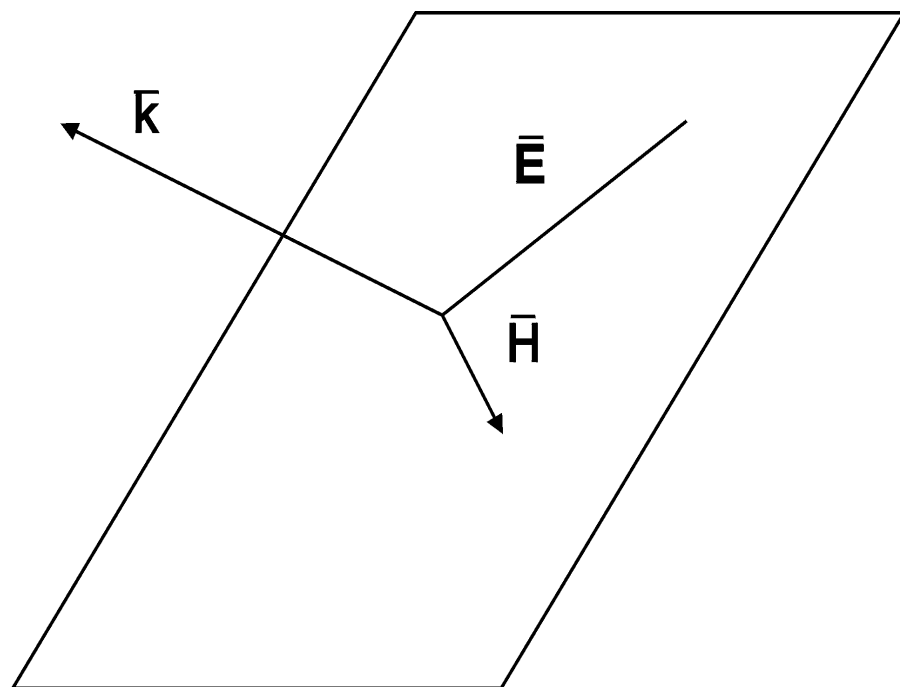
Si  $G, \sigma^0, \frac{1}{R^4} \rightarrow$  ctes. en  $S$



$\sigma, \sigma^{\circ}$   
dependen de:

- . frecuencia
- . ángulo de incidencia
- . polarización
- . material
- . rugosidad (geometría)

## Ondas planas



$$\vec{E}(\vec{r}, t) = \text{Re} \left\{ \vec{E}_0 \cdot e^{j(\omega t - \vec{k} \cdot \vec{r})} \right\}$$

$$\vec{H}(\vec{r}, t) = \frac{\vec{E}(\vec{r}, t)}{\mathbf{h}}$$

$\vec{E}, \vec{H}$  : campos eléctrico y magnético

$\vec{k} = k \hat{u}$ ,  $k = \omega \sqrt{\mathbf{m}\mathbf{e}}$  ( $n^\circ$  de onda),  $\hat{u}$  : dirección de propag.

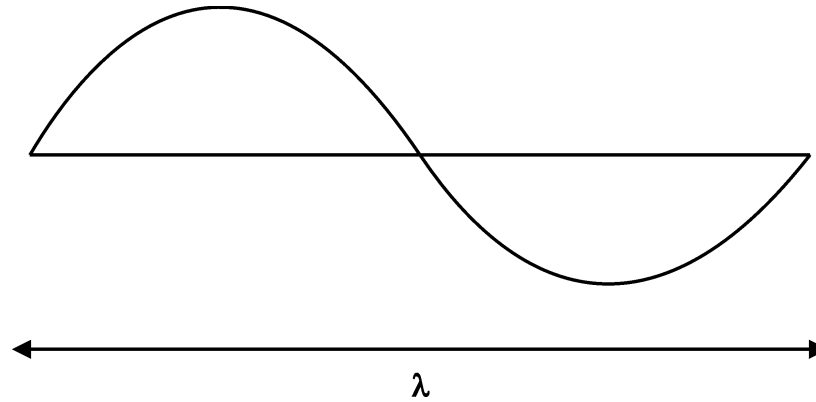
$\hat{u}, \vec{E}, \vec{H}$  ortog. entre sí,  $\mathbf{h} = \sqrt{\frac{\mathbf{m}}{\mathbf{e}}}$  impedancia de onda.

vacío :  $\mathbf{m} = \mathbf{m}_0 = 4\pi \cdot 10^{-7} \text{ H/m}$ ,  $\mathbf{e} = \mathbf{e}_0 = \frac{1}{36\pi} 10^{-9} \text{ F/m}$

## Medios sin pérdidas

$$c : \text{velocidad de propagación} = \frac{1}{\sqrt{\mathbf{ne}}}$$

$$k = \frac{\mathbf{w}}{c} = \frac{2\mathbf{p}}{\mathbf{l}}$$



Medios con pérdidas  $\epsilon$  es complejo  $\Rightarrow \epsilon^*$

$$\mathbf{e}^* = \mathbf{e}' - j\mathbf{e}'' = \mathbf{e}' - j\mathbf{S} / \mathbf{w} \leftarrow \text{conductividad}$$

Casi siempre se utilizan las permitividades relativas.

$$\mathbf{e}_r^* = \mathbf{e}_r' - j\mathbf{e}_r'' = \frac{\mathbf{e}'}{\mathbf{e}_0} - j\frac{\mathbf{e}''}{\mathbf{e}_0}$$

$k = \mathbf{w}\sqrt{\mathbf{m}\mathbf{e}}$  también es complejo,  $jk = \mathbf{a} + j\mathbf{b}$

donde  $\mathbf{a} = \mathbf{w}\sqrt{\mathbf{m}\frac{\mathbf{e}'}{2}\left[\sqrt{1 + \left(\frac{\mathbf{e}''}{\mathbf{e}'}\right)^2} - 1\right]}$

$$\mathbf{b} = \mathbf{w}\sqrt{\mathbf{m}\frac{\mathbf{e}'}{2}\left[\sqrt{1 + \left(\frac{\mathbf{e}''}{\mathbf{e}'}\right)^2} + 1\right]}$$

$\alpha$ : representa la atenuación de la onda:

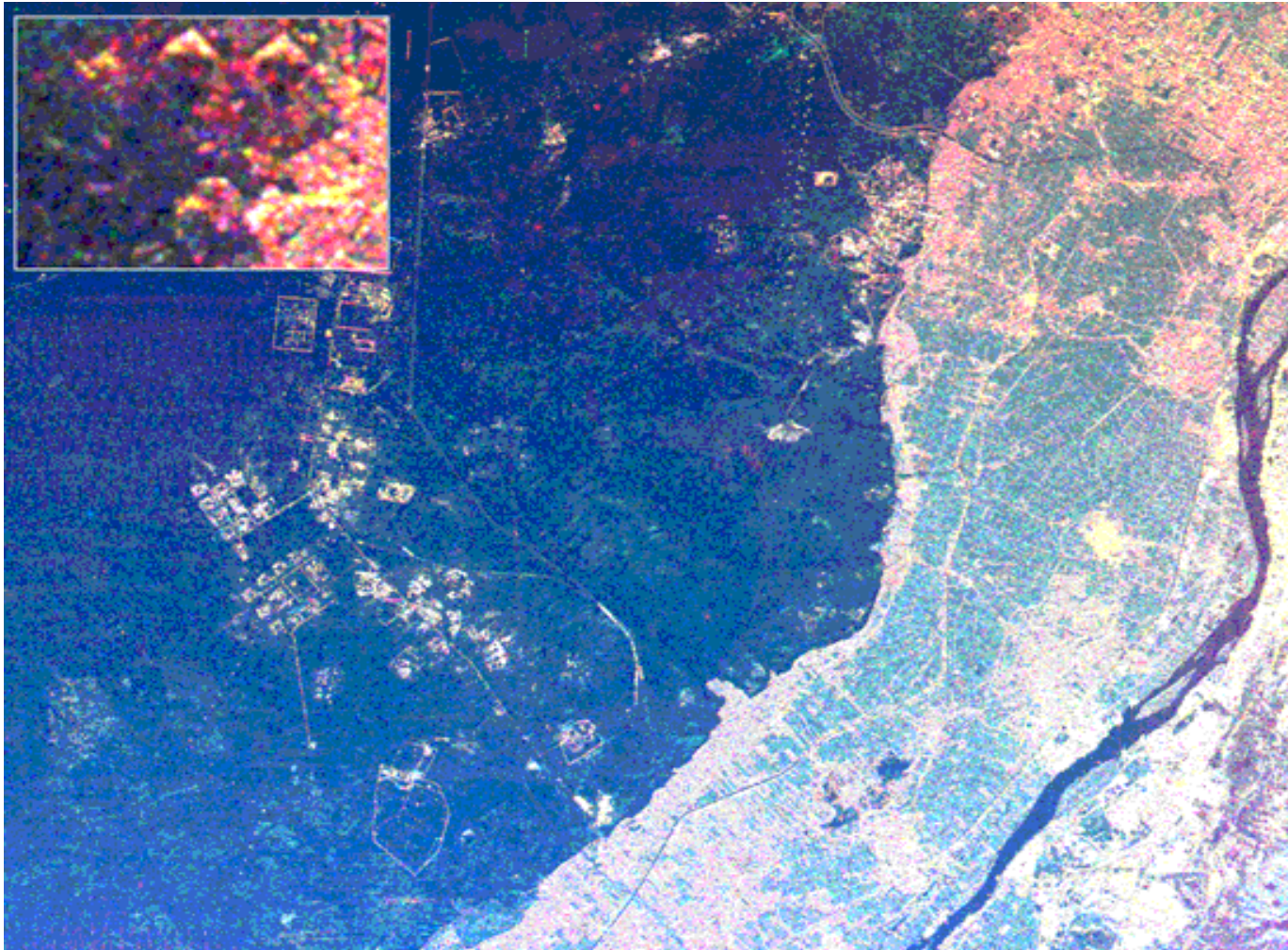
$$e^{-\mathbf{a} r} \quad \text{en } \mathbf{Nep/m}, \text{ en } \mathbf{dB/m} : \mathbf{8,686 a}$$

$\beta$ : cte. de fase en rad/m  $\lambda=2\pi/\beta$

Ejemplo: agua dulce @ 2.5 GHz, 20 °C

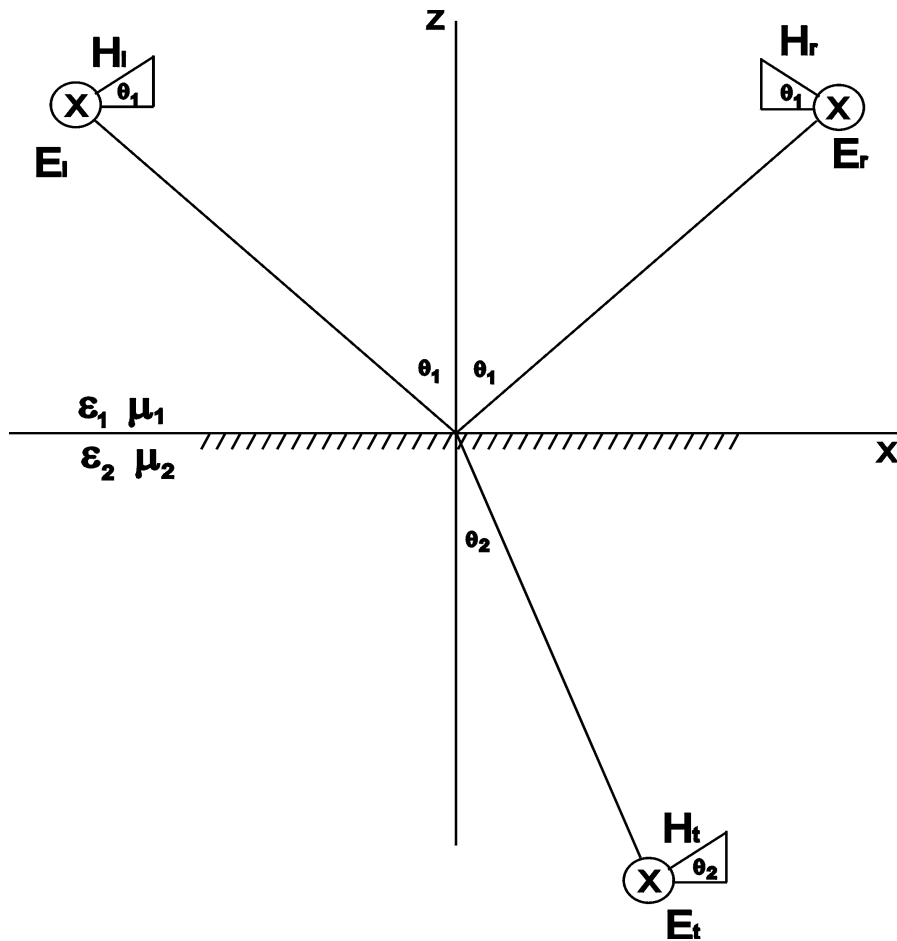
$$\mathbf{e}_r^* = 77 - j9 \quad \mathbf{a} \rightarrow 2 \mathbf{dB/cm}$$

$$\mathbf{l} \rightarrow 1,4 \mathbf{cm}$$



SIR-C/X-SAR Gizeh Pyramids

## Incidencia sobre un dieléctrico plano y homogéneo



Caso: E ortog. al plano de incidencia

$$E_i = \hat{y} E_o e^{-j(k_{1x}x - k_{1z}z)}$$

$$E_r = \hat{y} R_{\perp} E_o e^{-j(k_{1x}x - k_{1z}z)}$$

$$E_t = \hat{y} T_{\perp} E_o e^{-j(k_{2x}x - k_{2z}z)}$$

$$k_{ix} = k_i \sin \mathbf{q}_i, k_{iz} = k_i \cos \mathbf{q}_i$$

$$\text{Snell } k_2 \sin \mathbf{q}_2 = k_1 \sin \mathbf{q}_1$$

$$R_{\perp} = \frac{\mathbf{h}_2 \cos \mathbf{q}_1 - \mathbf{h}_1 \cos \mathbf{q}_2}{\mathbf{h}_2 \cos \mathbf{q}_1 + \mathbf{h}_1 \cos \mathbf{q}_2}$$

$$T_{\perp} = \frac{2\mathbf{h}_2 \cos \mathbf{q}_1}{\mathbf{h}_2 \cos \mathbf{q}_1 + \mathbf{h}_1 \cos \mathbf{q}_2}$$

$$1 + R_{\perp} = T_{\perp}$$

• Para  $E \parallel$  al plano de incidencia

$$R_{\parallel} = \frac{\mathbf{h}_1 \cos \mathbf{q}_1 - \mathbf{h}_2 \cos \mathbf{q}_2}{\mathbf{h}_1 \cos \mathbf{q}_1 + \mathbf{h}_2 \cos \mathbf{q}_2}$$

$$T_{\parallel} = \frac{2\mathbf{h}_1 \cos \mathbf{q}_1}{\mathbf{h}_1 \cos \mathbf{q}_1 + \mathbf{h}_2 \cos \mathbf{q}_2}$$

• Ángulos particulares

•  $\mathbf{q}_c$  : ángulo crítico  $\rightarrow$  reflexión total

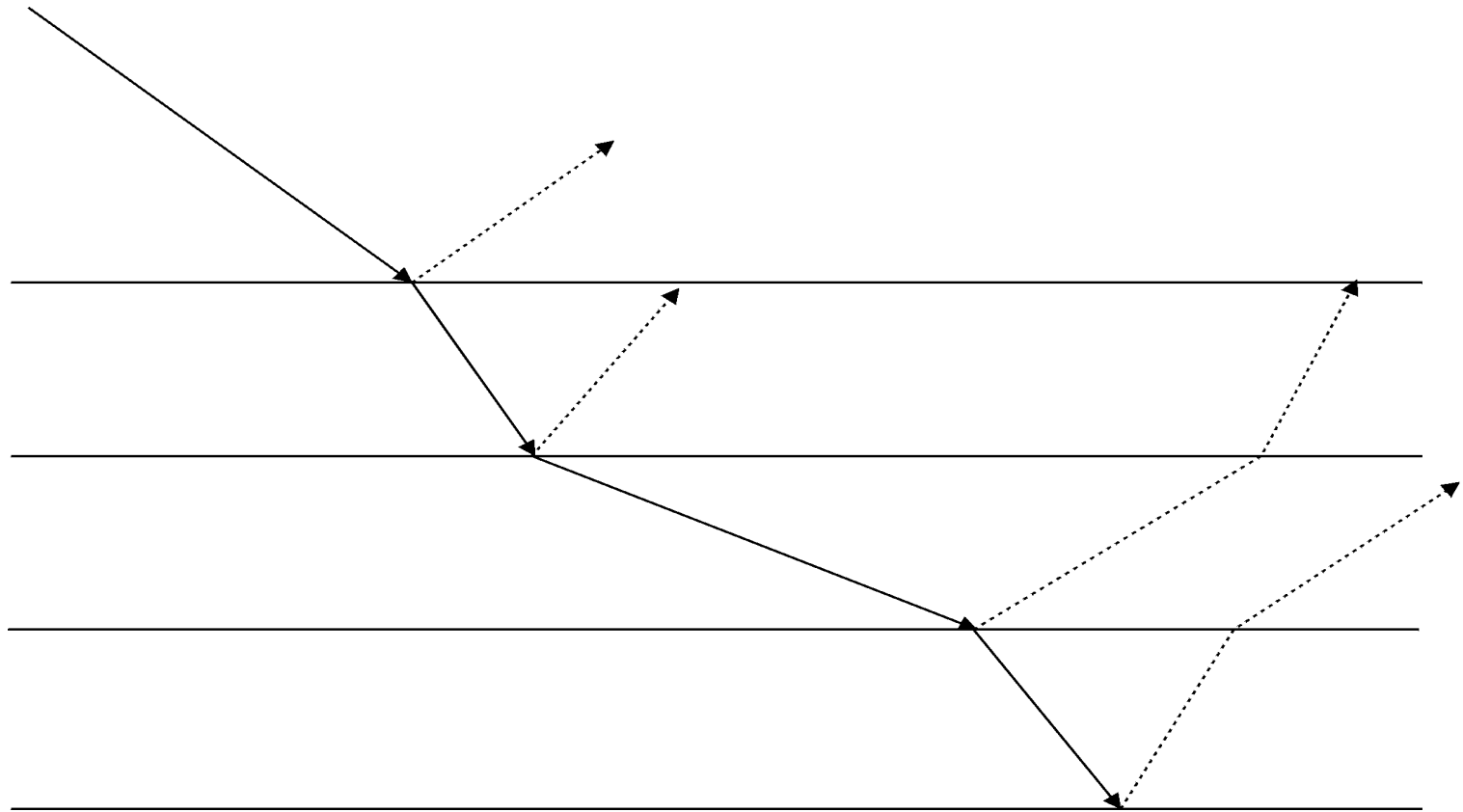
$$\text{sen } \mathbf{q}_c = \frac{k_2}{k_1}$$

•  $\mathbf{q}_B$  : ángulo de Brewster  $\rightarrow$  transm.  
total para  $\overline{E_{\parallel}}$

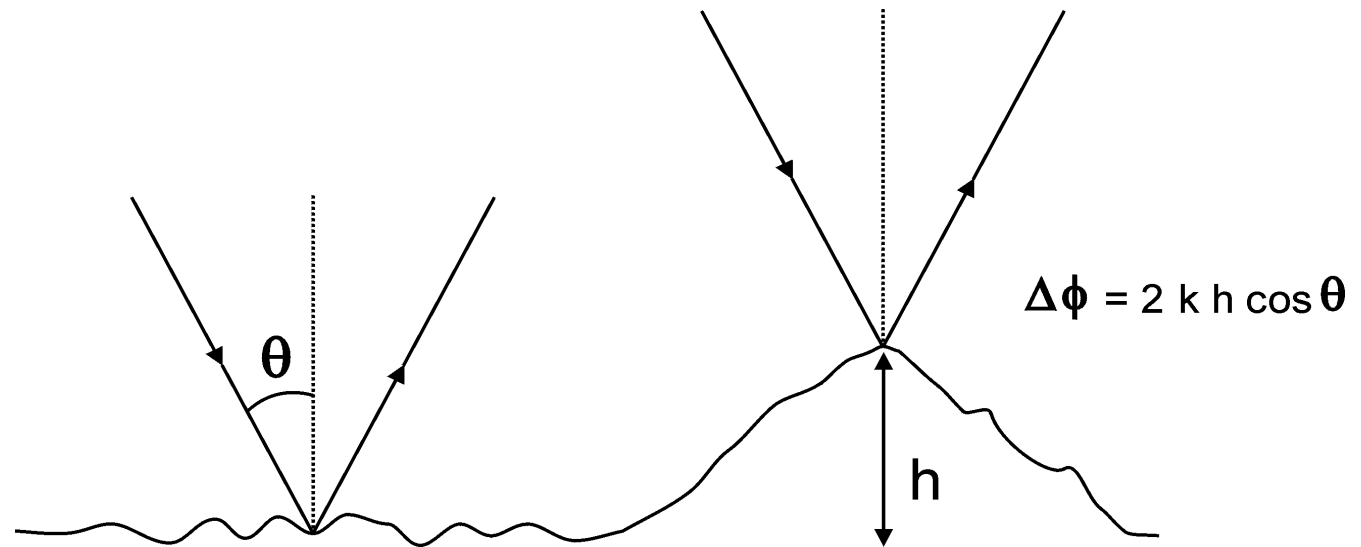
$$\text{tg } \mathbf{q}_B = \sqrt{\frac{\mathbf{e}_2}{\mathbf{e}_1}}$$



- El análisis puede aplicarse a N capas



## Criterio de Rayleigh de baja rugosidad



Si  $\Delta\mathbf{f} \ll \frac{\mathbf{p}}{2}$  rad.

$$h \ll \frac{\mathbf{l}}{8 \cos \mathbf{q}} \Rightarrow \mathbf{s} \ll \frac{\mathbf{l}}{8 \cos \mathbf{q}}$$

Donde  $\sigma$  es la desv. típica de la rugosidad

$$\text{SI} \quad \mathbf{s} < \frac{\mathbf{l}}{8 \cos \mathbf{q}}$$

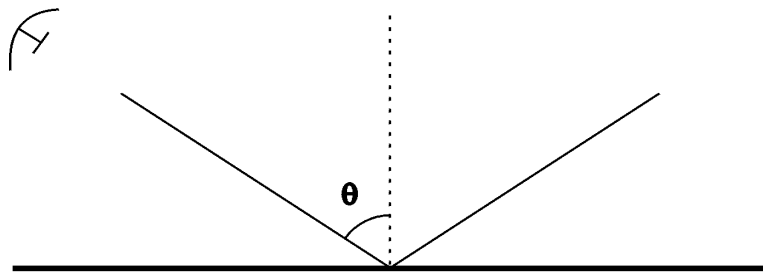
**Entonces:**

**la dispersión será muy directiva:**

- Una superficie rugosa para  $\theta$  pequeños (vertical) puede comportarse como lisa para incidencias rasantes  $\theta \rightarrow \pi/2$**
- Una superficie ópticamente rugosa puede ser plana a todos los efectos a frecuencia de microondas.**

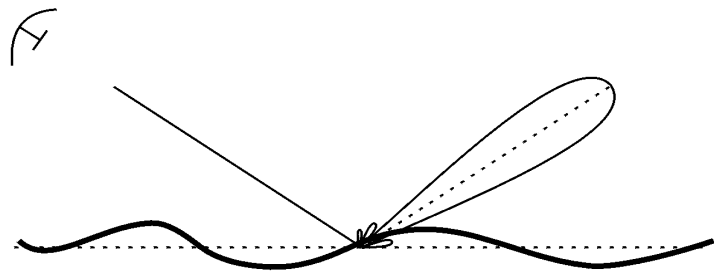
# Mecanismos de dispersión superficial

A) Superficie plana (especular)

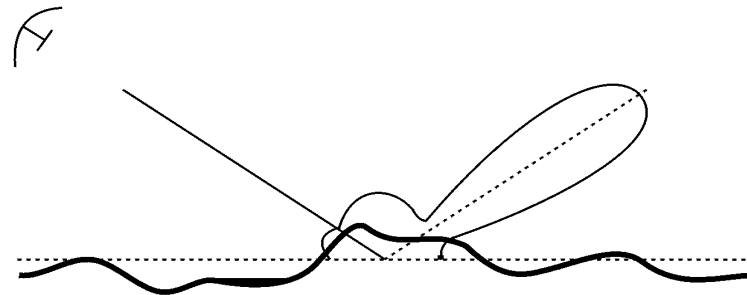


No hay retorno excepto si  $\theta = 0$

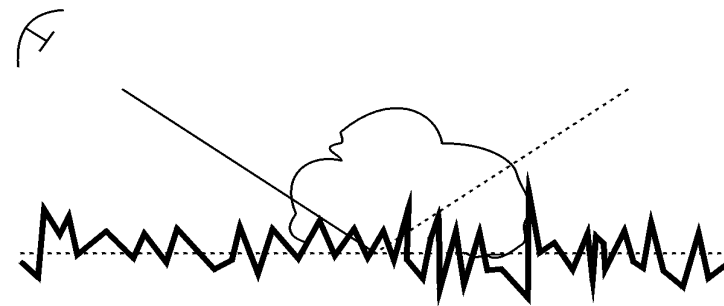
B) Superficie ligeramente rugosa



C) Superficie de rugosidad media

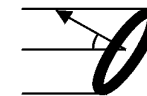


D) Superficie muy rugosa



$\approx$  Superficie Lambertiana

$$\sigma^\circ = \sigma_0^\circ \cos^2 \theta$$



## **Modelos de dispersión superficial**

- Grupo de pequeños dispersores independientes uniformemente distribuidos**

$$\sigma(\theta) = N \sigma_0 \cos^2 \theta \quad \text{(Lambertiana)}$$

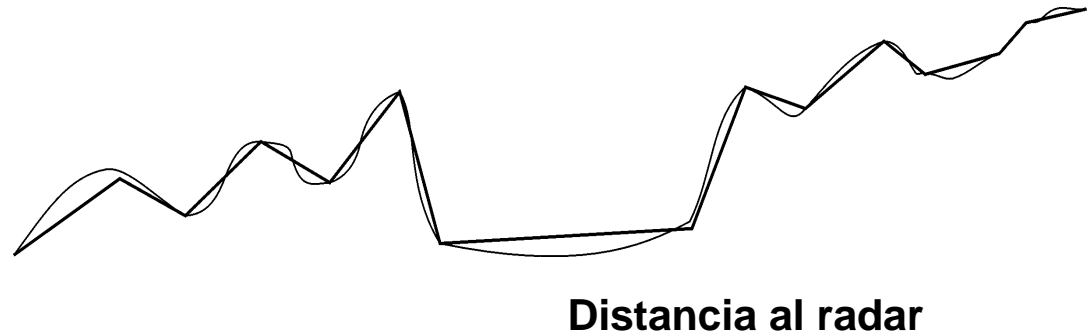
**(N dispersores de  $\sigma = \sigma_0$  / unidad de área)**

**$\theta$  es el ángulo de incidencia respecto a la normal a la superficie**

**modelo adecuado para rugosidades muy elevadas.**

# Modelos de dispersión superficial

- Modelo de facetas:  
conjunto de caras  
planas



Campo dispersado

$$E_s = \sum_i E_{si} e^{-j2kR_i}$$

Contribución faceta i

$$E_{si} = |E_i| \cdot R_{Fi} \cdot D(\mathbf{q}, S_i)$$

$E_i =$  Campo incidente

$R_F =$  Coef. reflexión de Fresnel

$D =$  Diagrama (directividad) de dispersión  
de la faceta

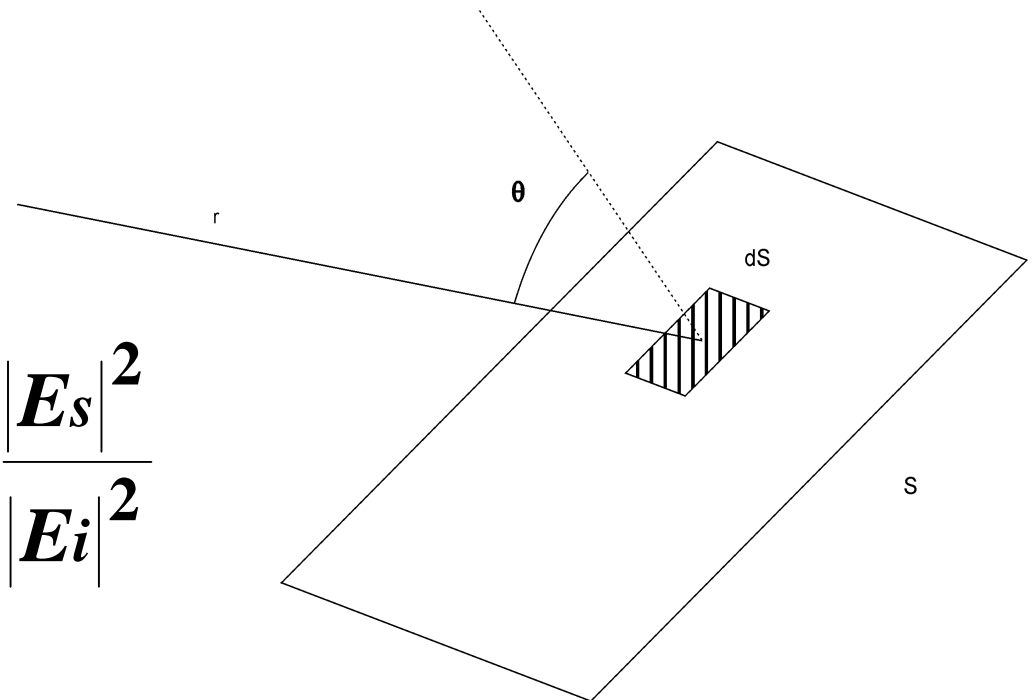
# Modelo de facetas

Si el lado  $L$  de la faceta es  $L \gg \lambda$

$D$  puede obtenerse mediante aproximación de óptica física.

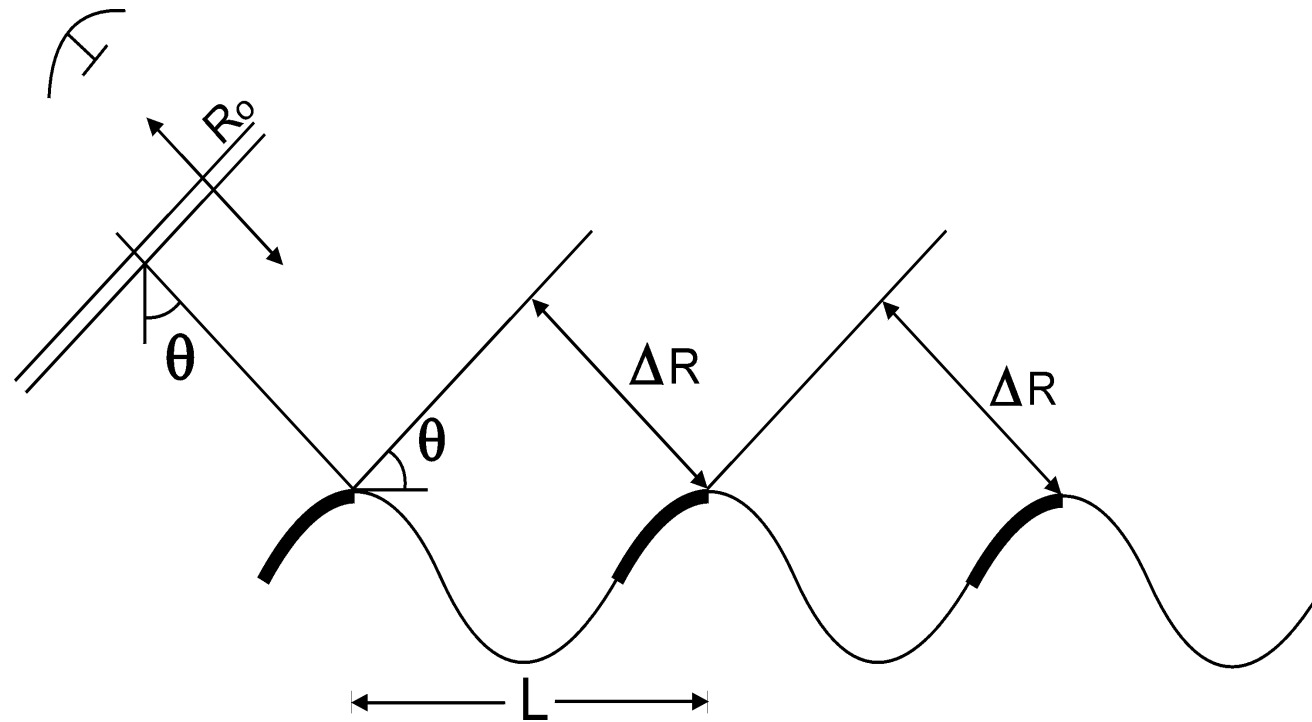
$$D(\mathbf{q}, S) = \int_S e^{-j2kr} dS$$

$$\mathbf{s} \propto |E_s|^2 \quad \mathbf{s} = 4 \mathbf{p} R^2 \frac{|E_s|^2}{|E_i|^2} \quad R \rightarrow \infty$$



El modelo de facetas es adecuado para superficies arbitrarias con variación lenta ( $l \gg \lambda$ )

# Resonancia Bragg

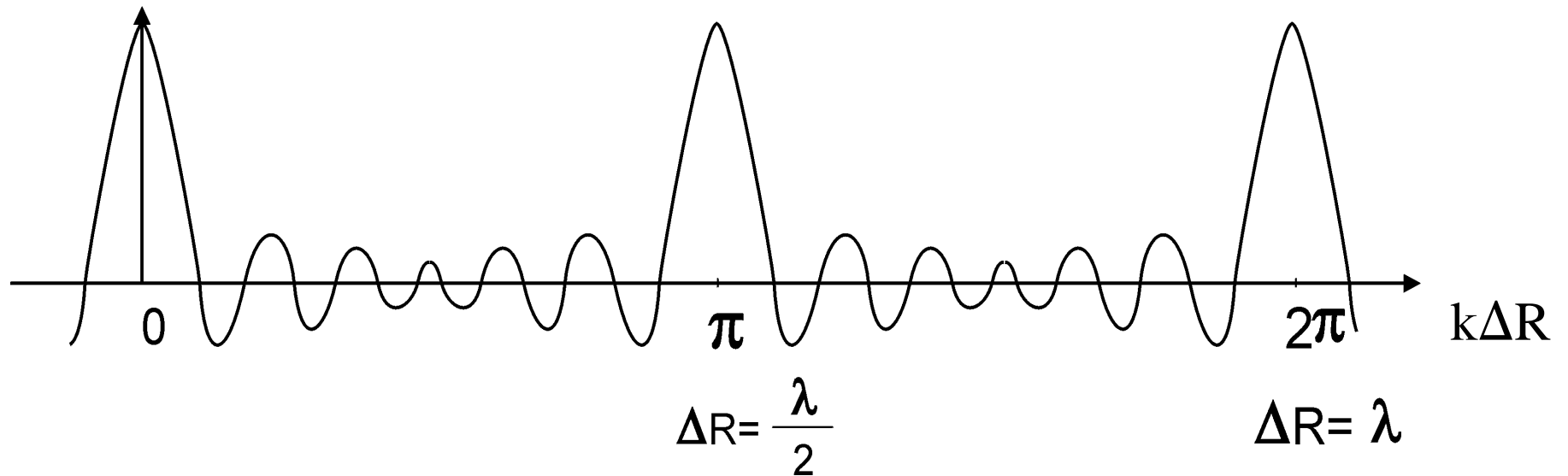


$$E_s = \sum_{l=0}^N |E_i| e^{-j2kR_o} e^{-j2kl\Delta R}$$

$$E_s = |E_i| e^{-j2kR_o} \frac{\text{sen} [(N + 1)k\Delta R]}{\text{sen} [k\Delta R]}$$

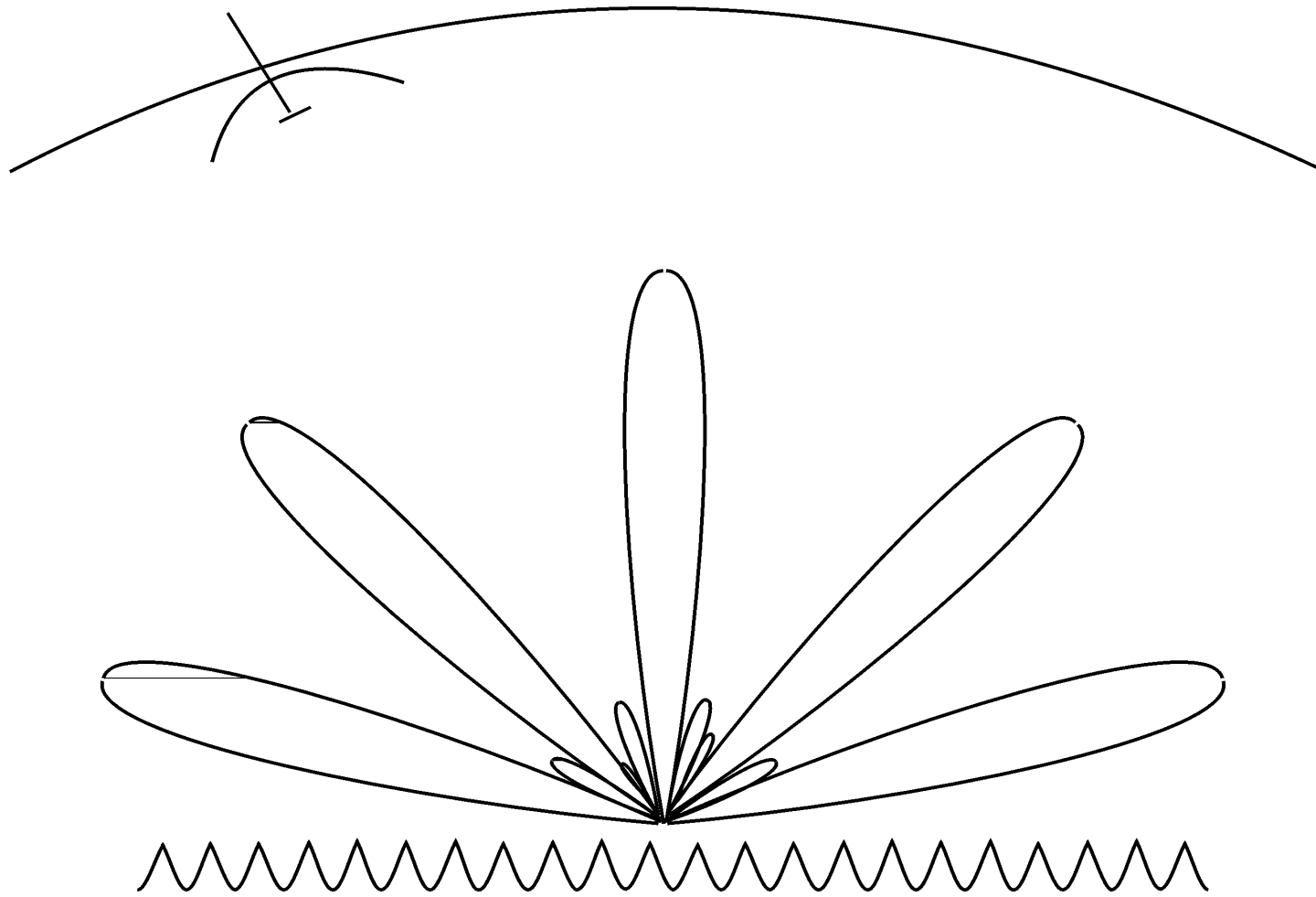


$$E_s = |E_i| e^{-j 2kR_o} \frac{\text{sen}[(N + 1)k\Delta R]}{\text{sen}[k\Delta R]}$$



$$\Delta R = L \text{ sen } \mathbf{q}$$

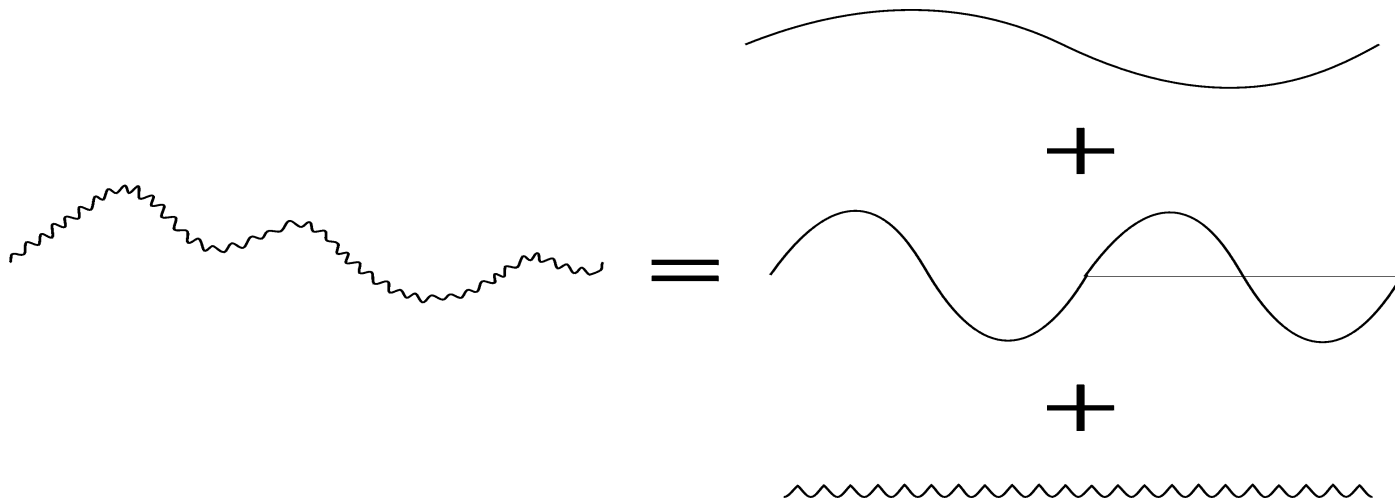
$$\text{max} \rightarrow k\Delta R = n\mathbf{p} \rightarrow \frac{2L}{\lambda} \text{ sen } \mathbf{q} = n \quad ; \quad n = 0, 1, 2, \dots$$



**Bragg: Modela la gran directividad de pequeños rizados (ondas capilares en el mar).**

## Modelo de Bragg:

descomposición en espectro de Fourier de la superficie.

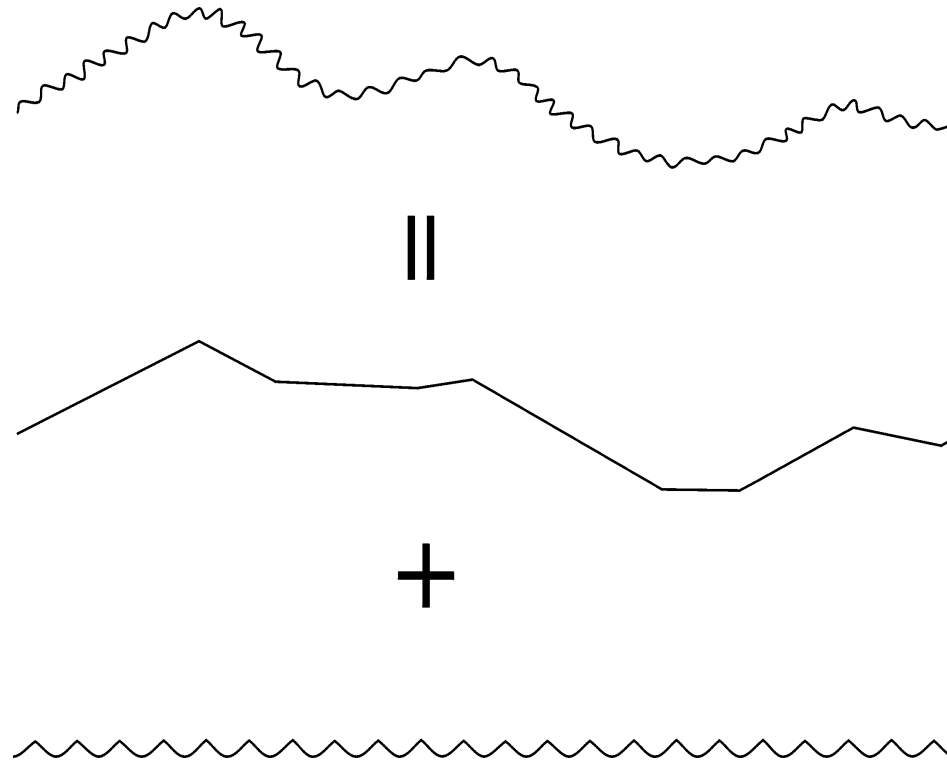


$$\mathbf{s}(\mathbf{q}) \cong 8k^4 h^2 \cos^4 \mathbf{q} \mathbf{a}^2 W(2k \text{sen } \mathbf{q})$$

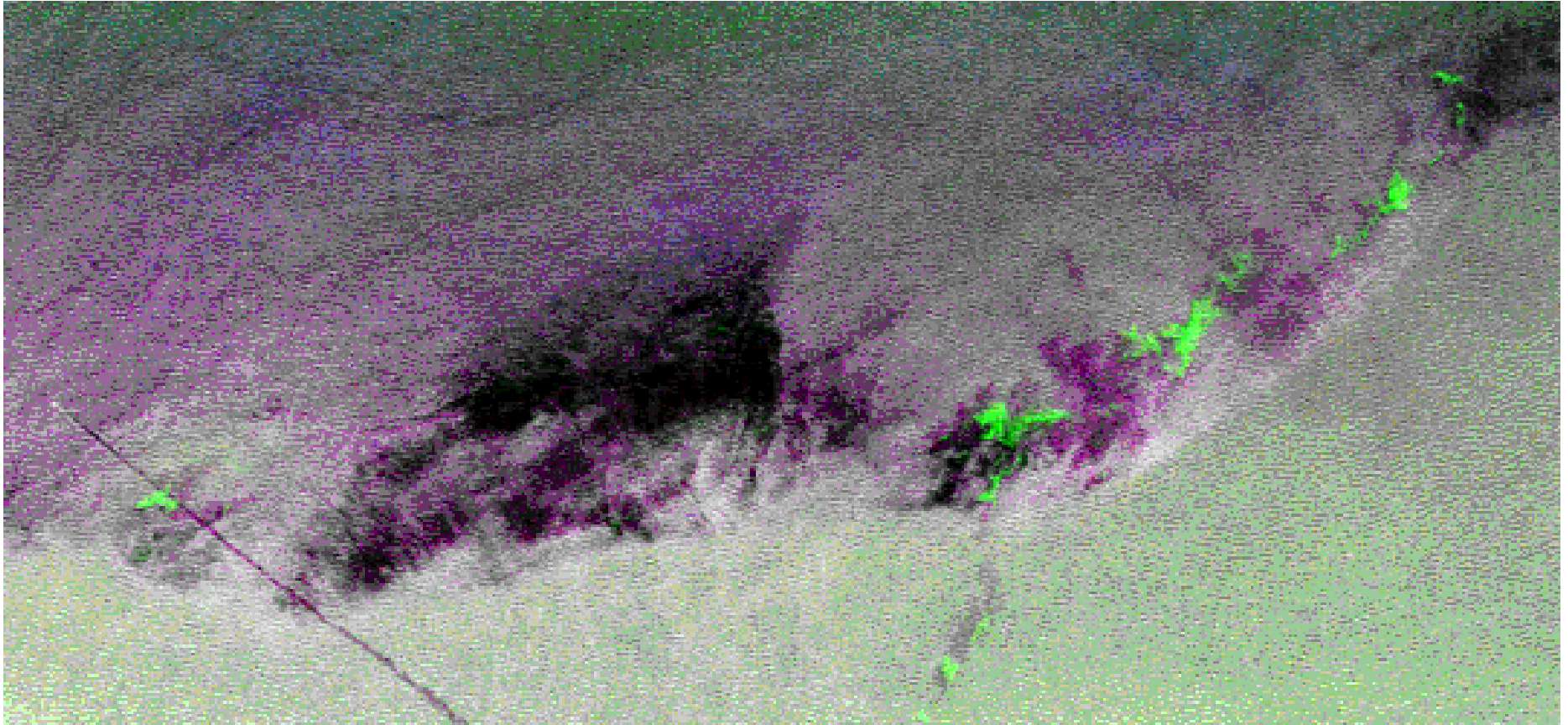
$$k = 2\mathbf{p} / \mathbf{l}, h : \text{desviación estándar altura}$$

$$W = F\{\mathbf{r}(x)\} \leftarrow \text{autocorrelación alturas}$$

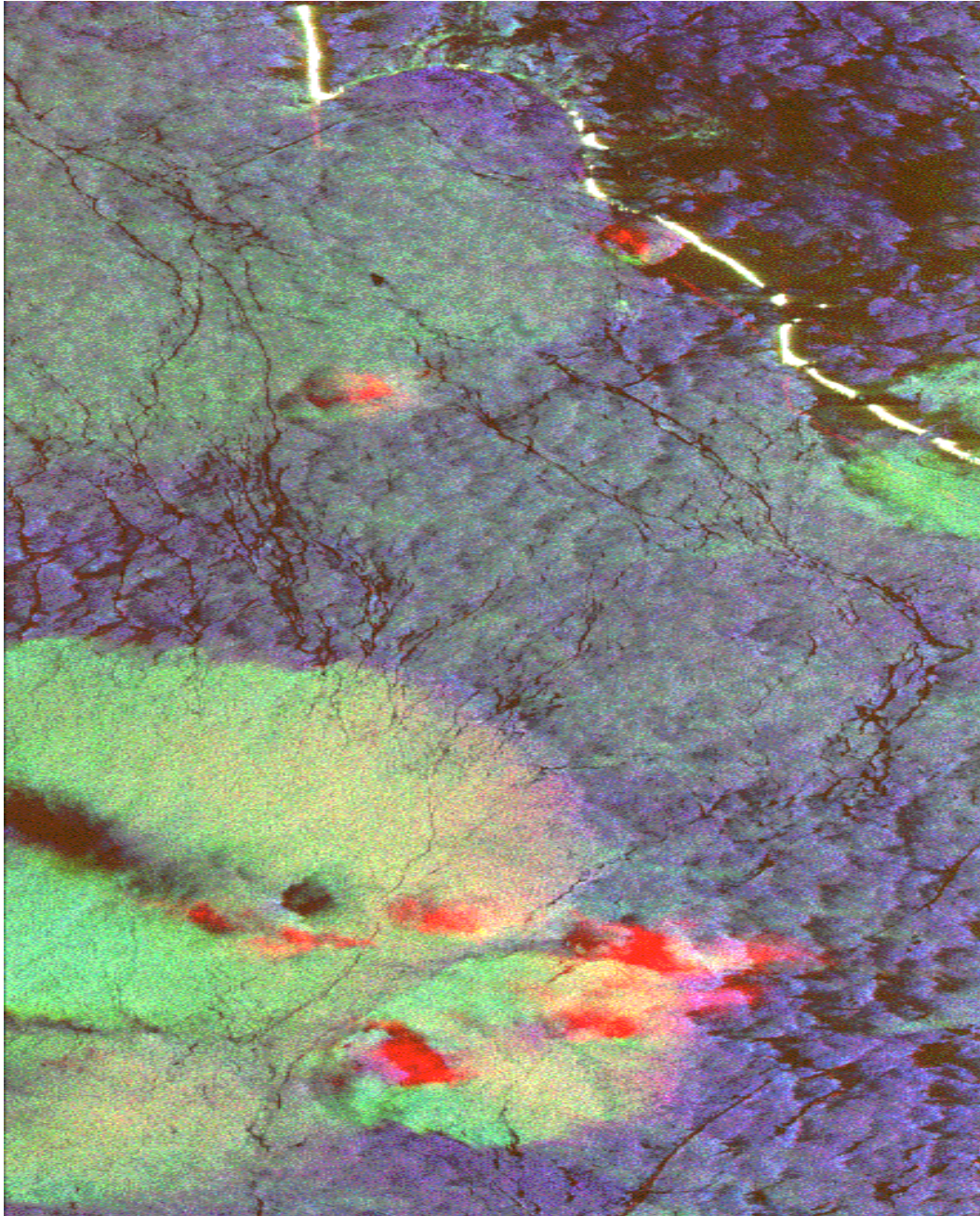
**Cada modelo tiene su margen de aplicación: pueden combinarse.**



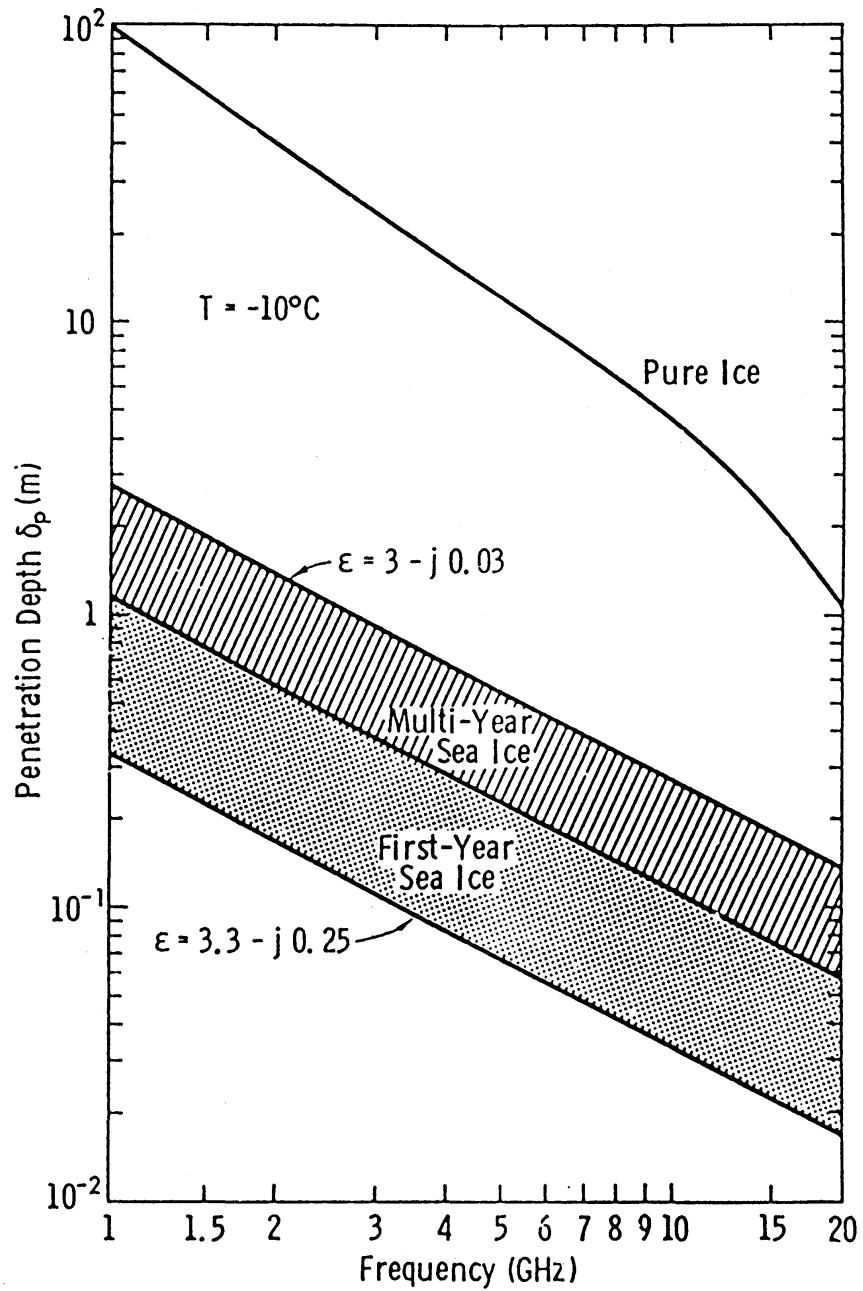
**‘+’ no tiene porque ser adición de resultados. P.ej. la inclinación de la faceta interviene en la dispersión de Bragg: problemas no lineales.**



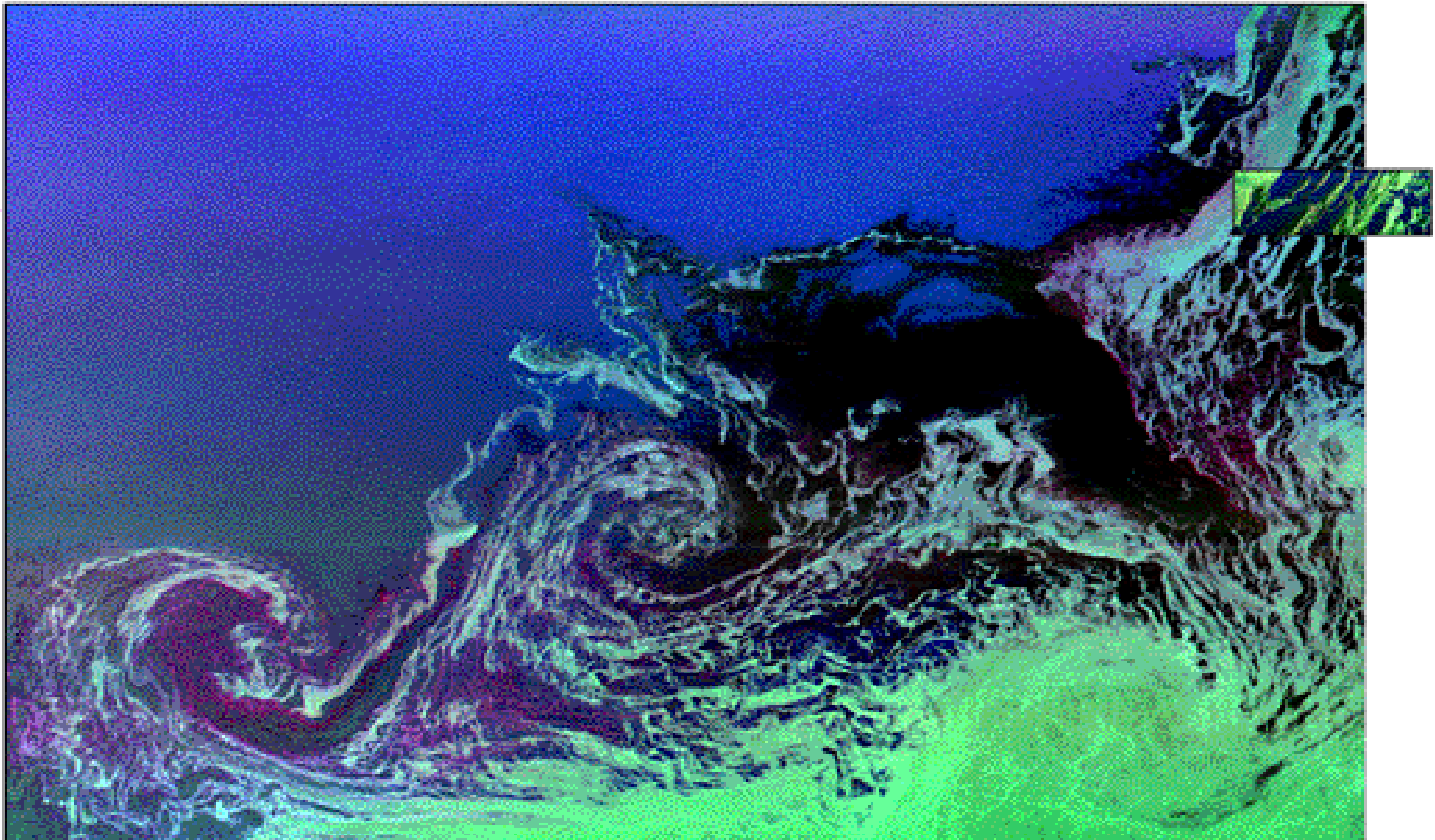
SIR-C/X-SAR North Atlantic Ocean



SIR-C/X-SAR Rain Cells

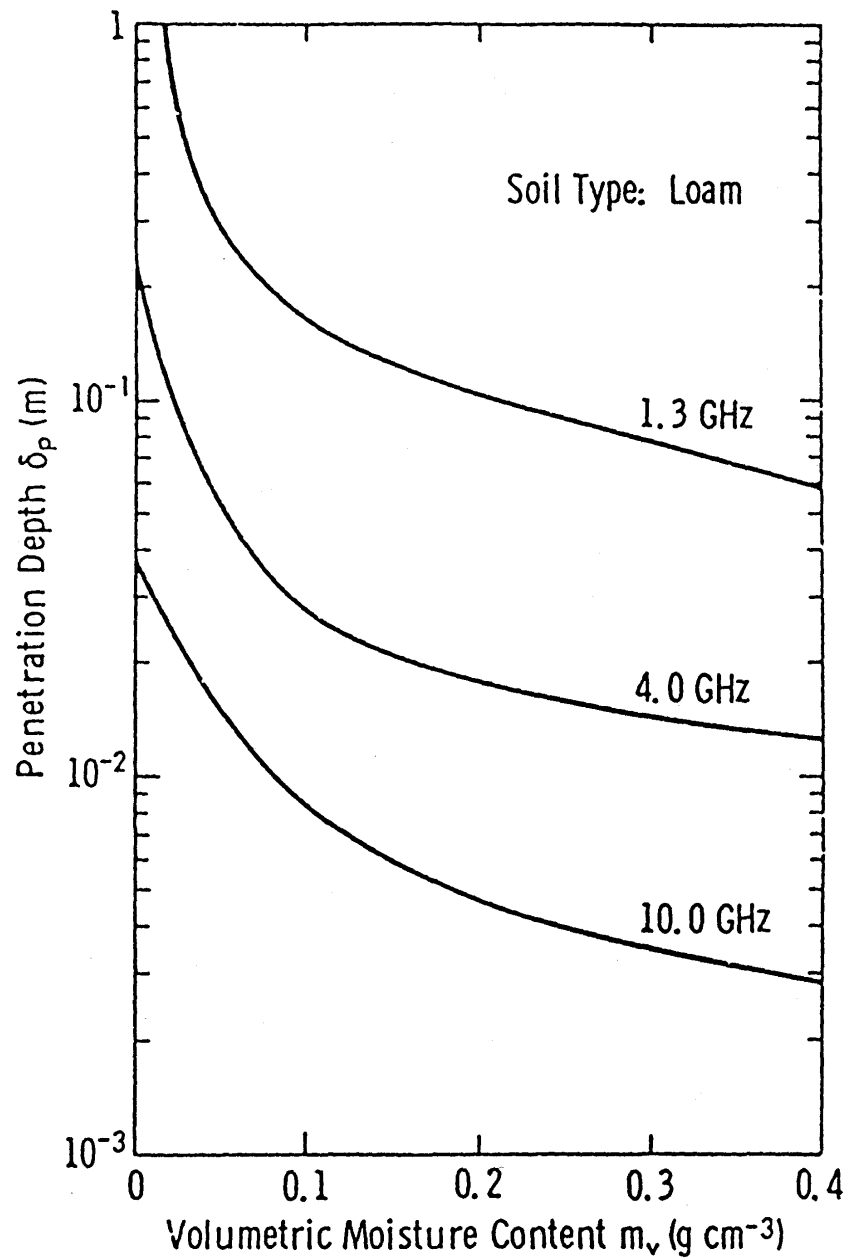


## Profundidad de penetración en hielo

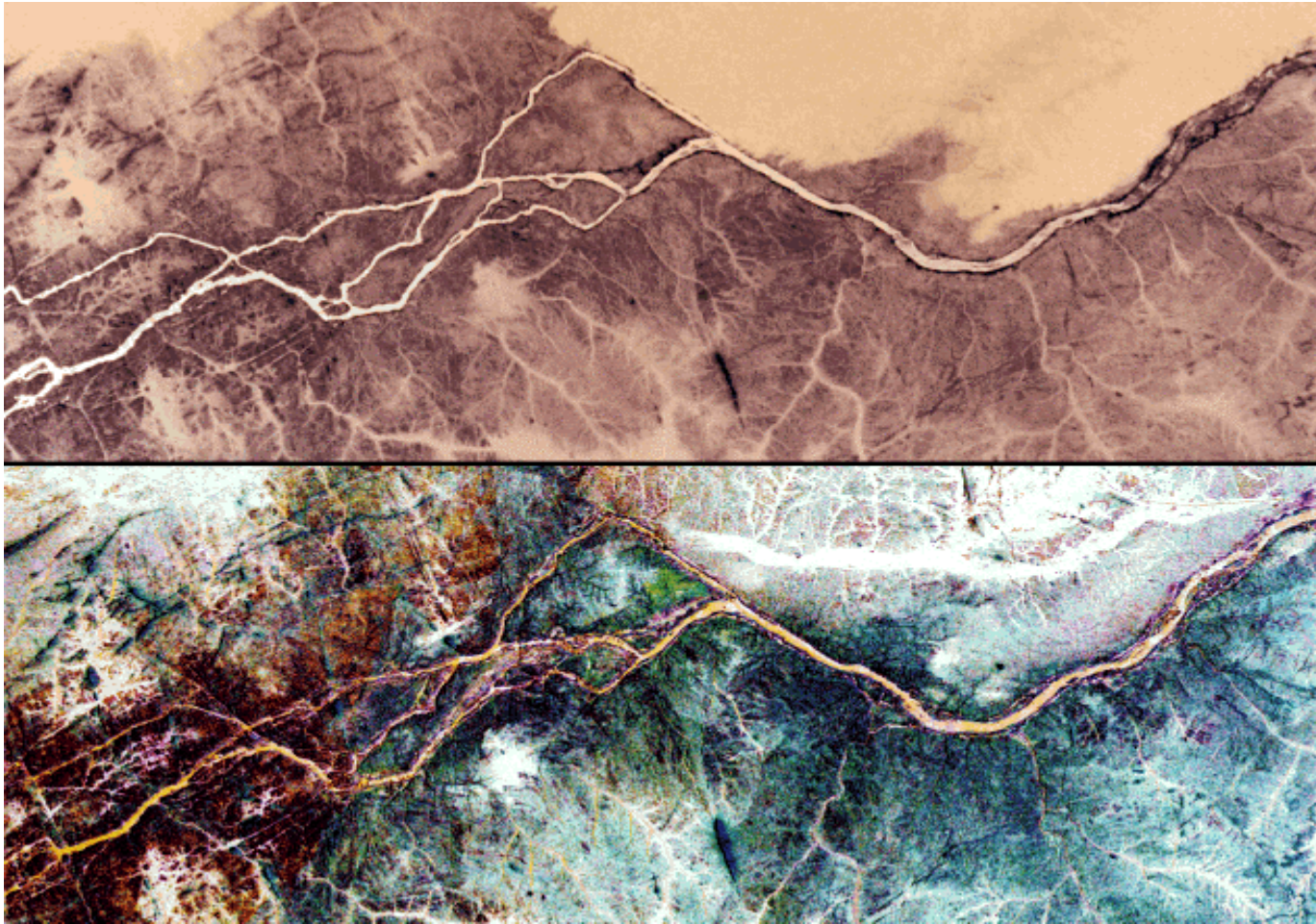


SIR-C/X-SAR Weddell Sea/ScanSAR





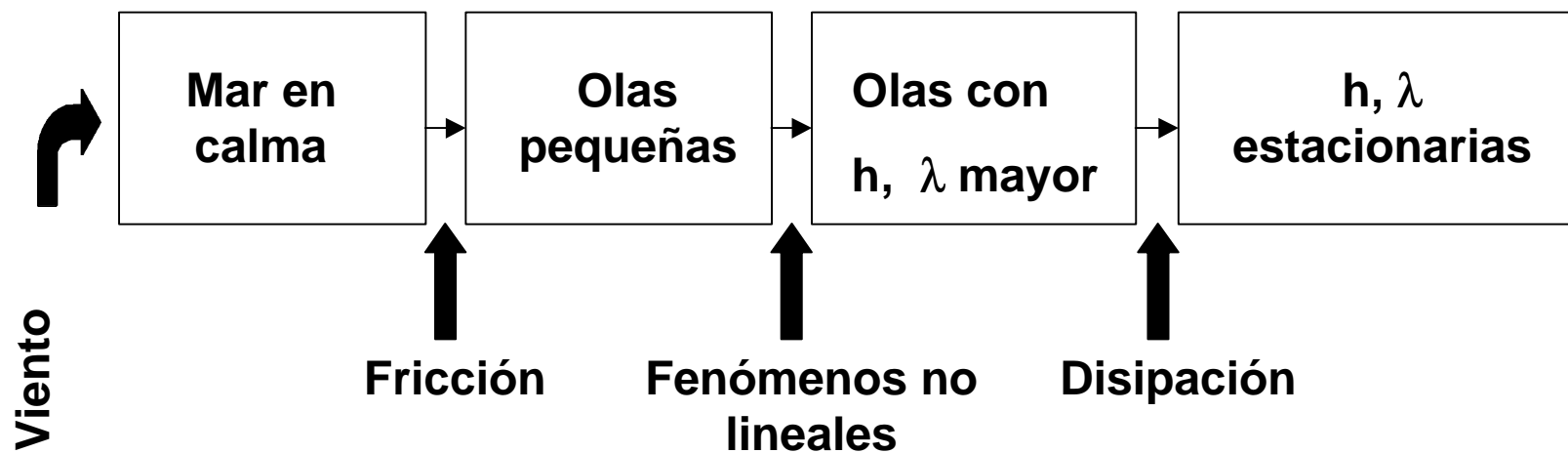
**Profundidad de penetración en terreno arcilloso**



SIR-C/X-SAR Nile River, Sudan

# REFLECTIVIDAD RADAR MARINA

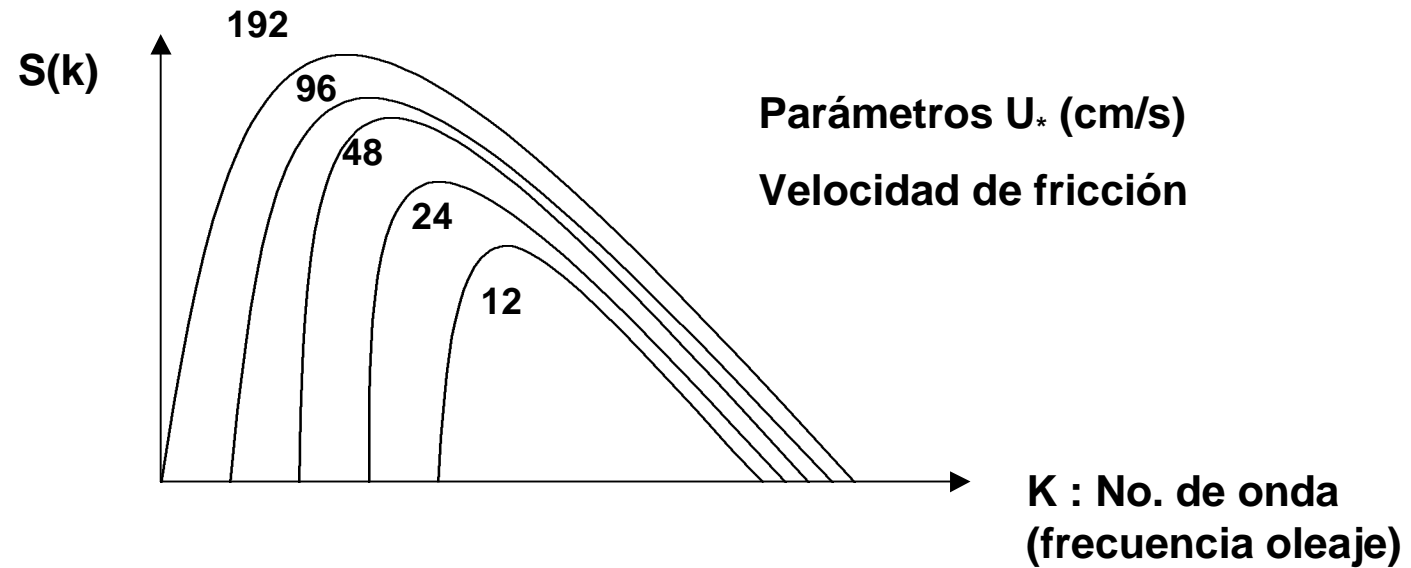
## Construcción del oleaje, regímenes y espectro



**Atenuación  $\propto \lambda^{-1} \Rightarrow$**

**Superficie = Olas cortas locales +  
Olas largas globales.**

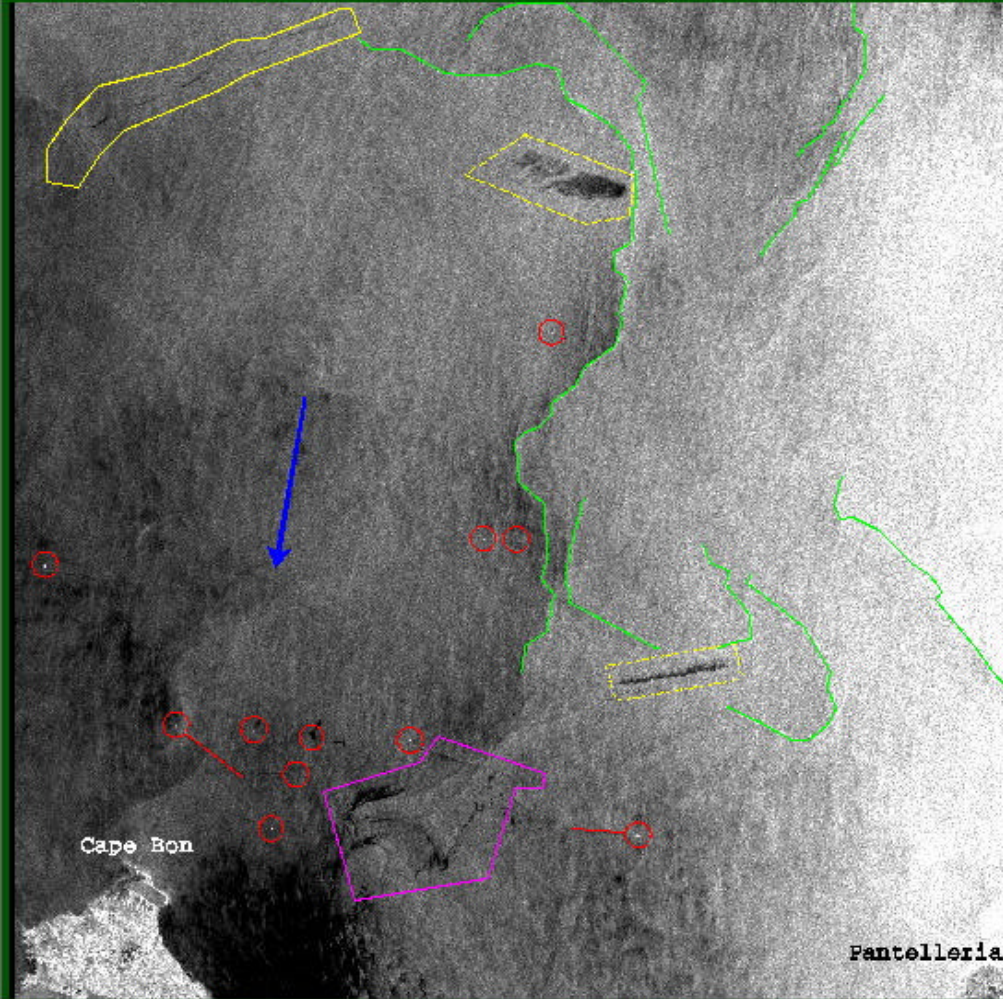
# Espectro en equilibrio de la altura de las olas



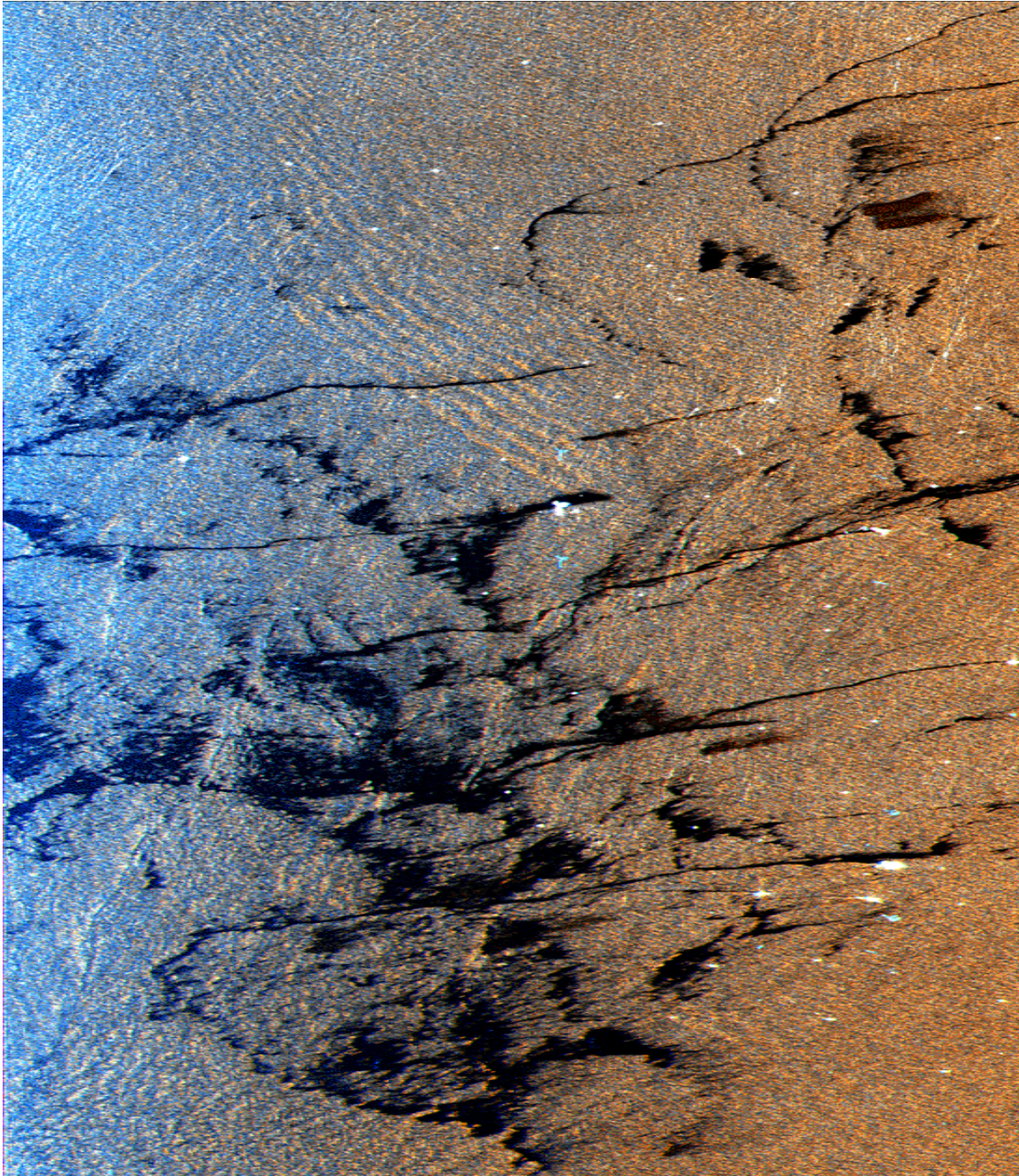
$K$  grandes: amp. crece rápid. con el viento  $\Rightarrow$  vector viento

$K$  pequeñas: olas globales  $\Rightarrow$  viento no local

ERS-SAR Strait of Tunis 920130, 9:56 100 km x 100 km

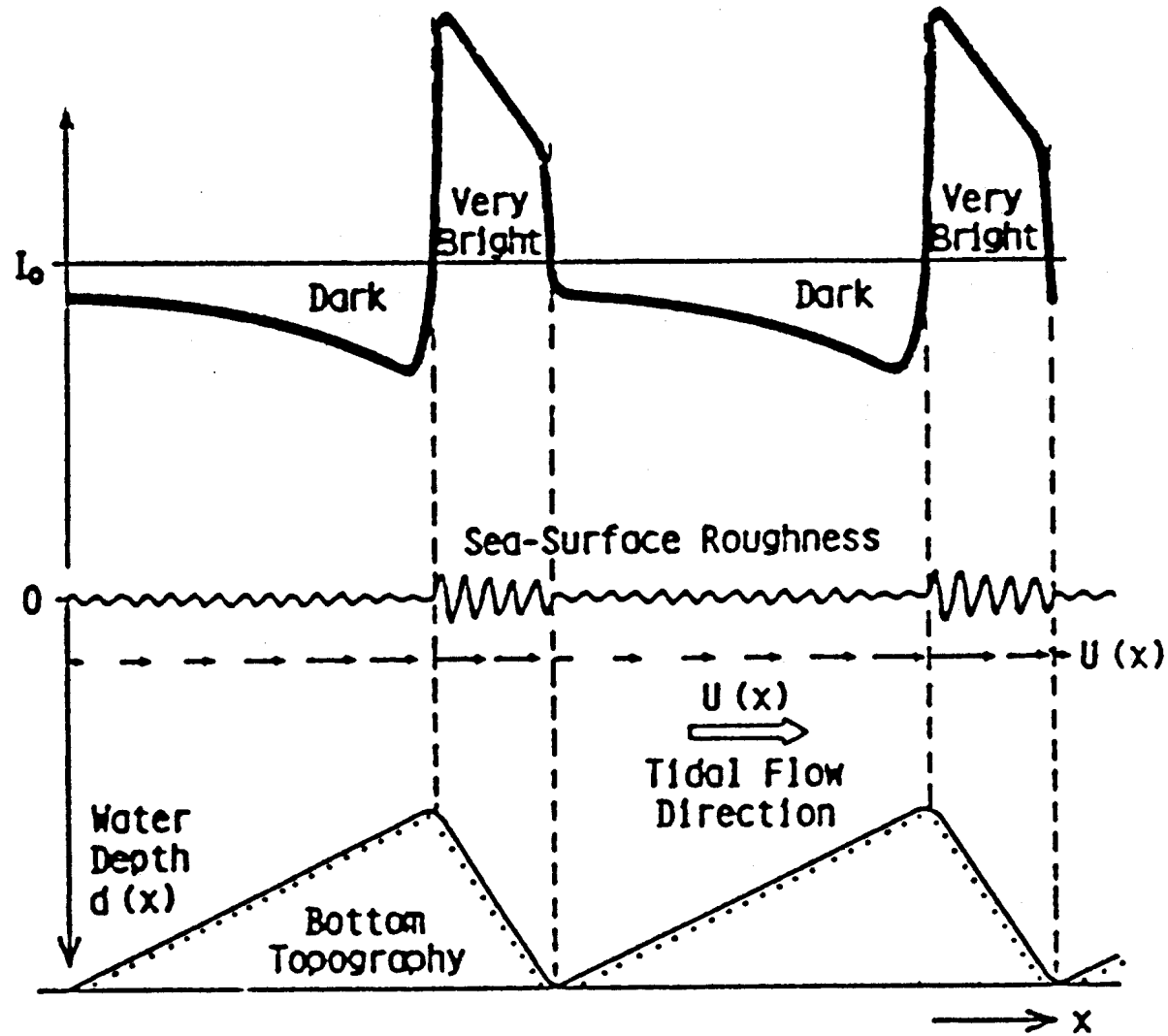


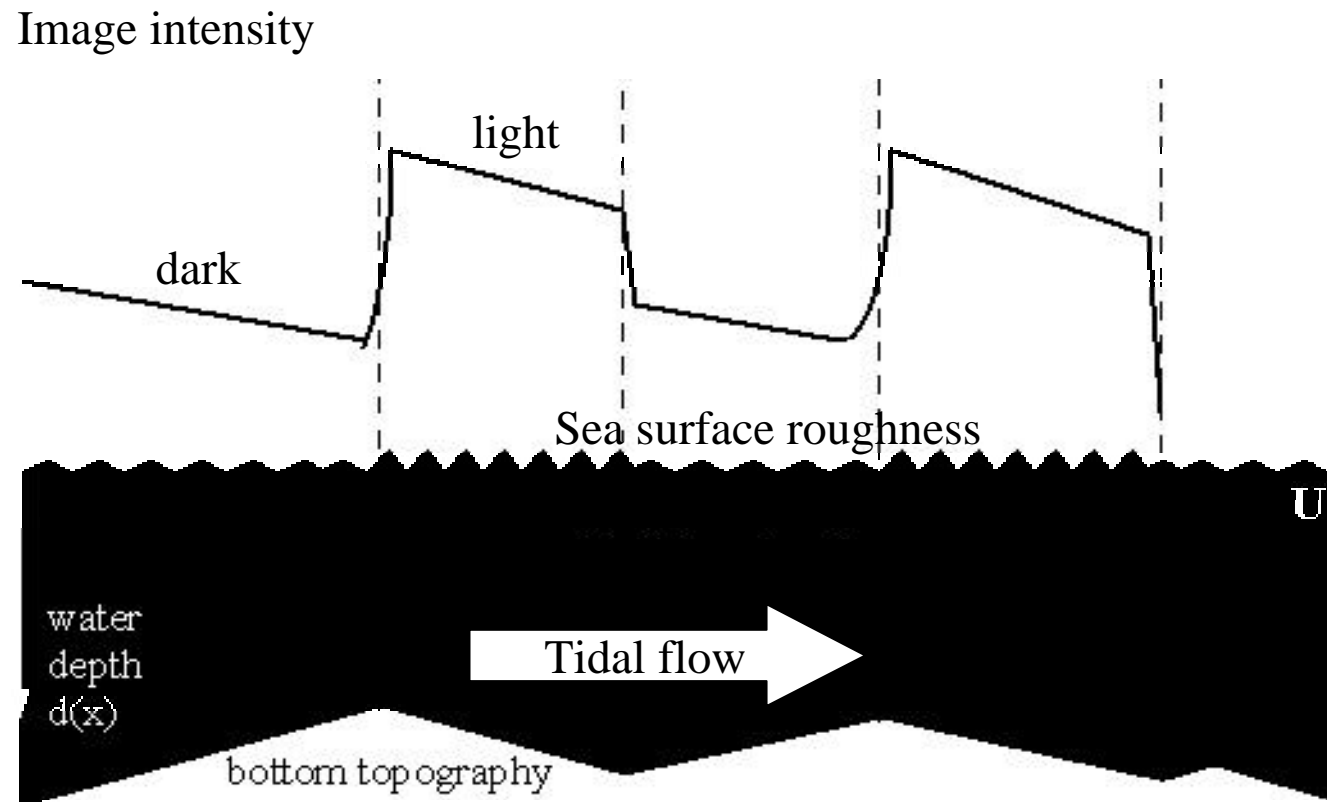
- ship wake
- ship
- oil spill high probability
- oil spill low probability
- estimated wind direction
- sea current feature
- natural oil film
- oil spill medium prob.
- wind speed: low



SIR-C/X-SAR west of  
Bombay, India

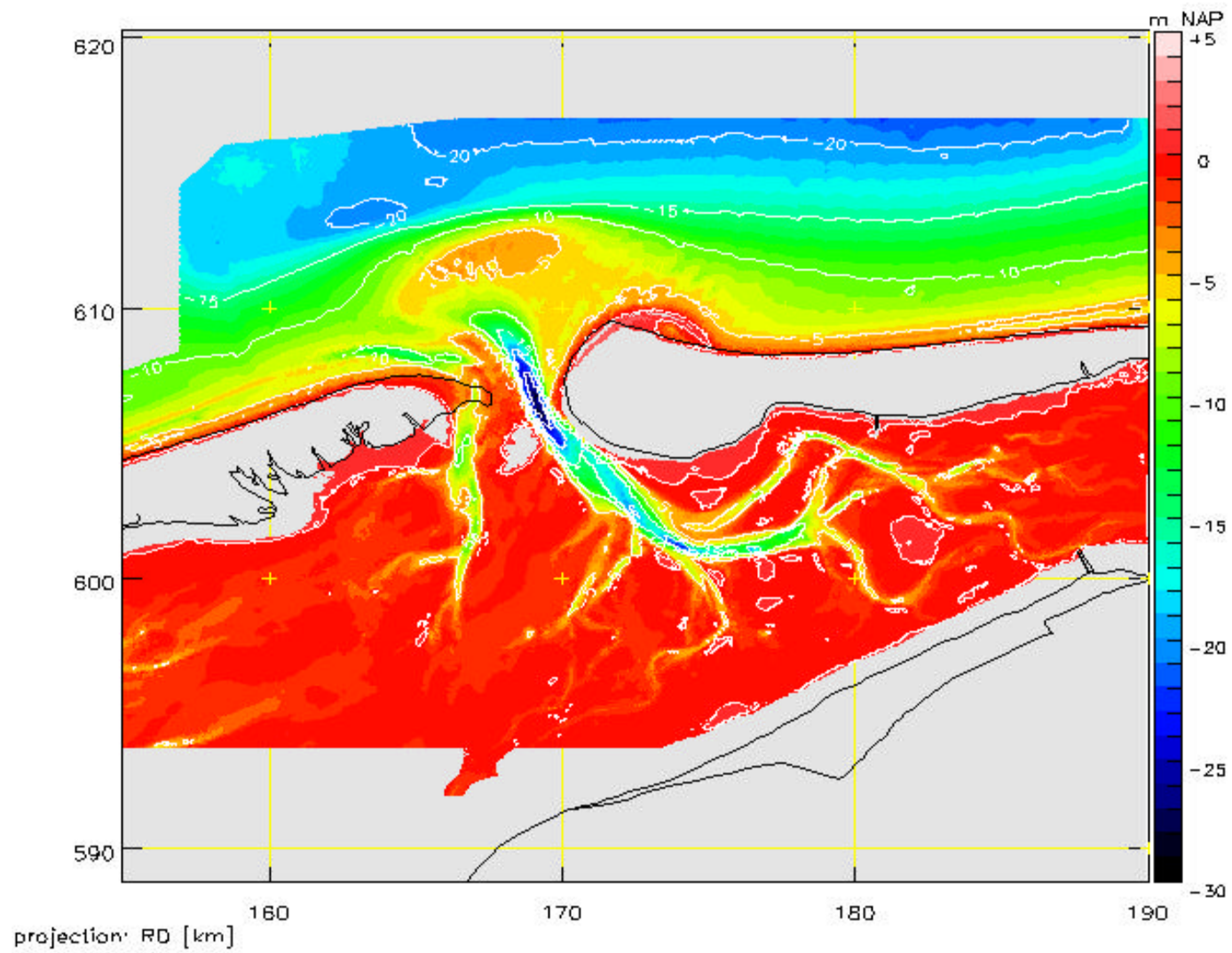
# Reflectividad radar marina: Topografía submarina





## SAR Batimetry



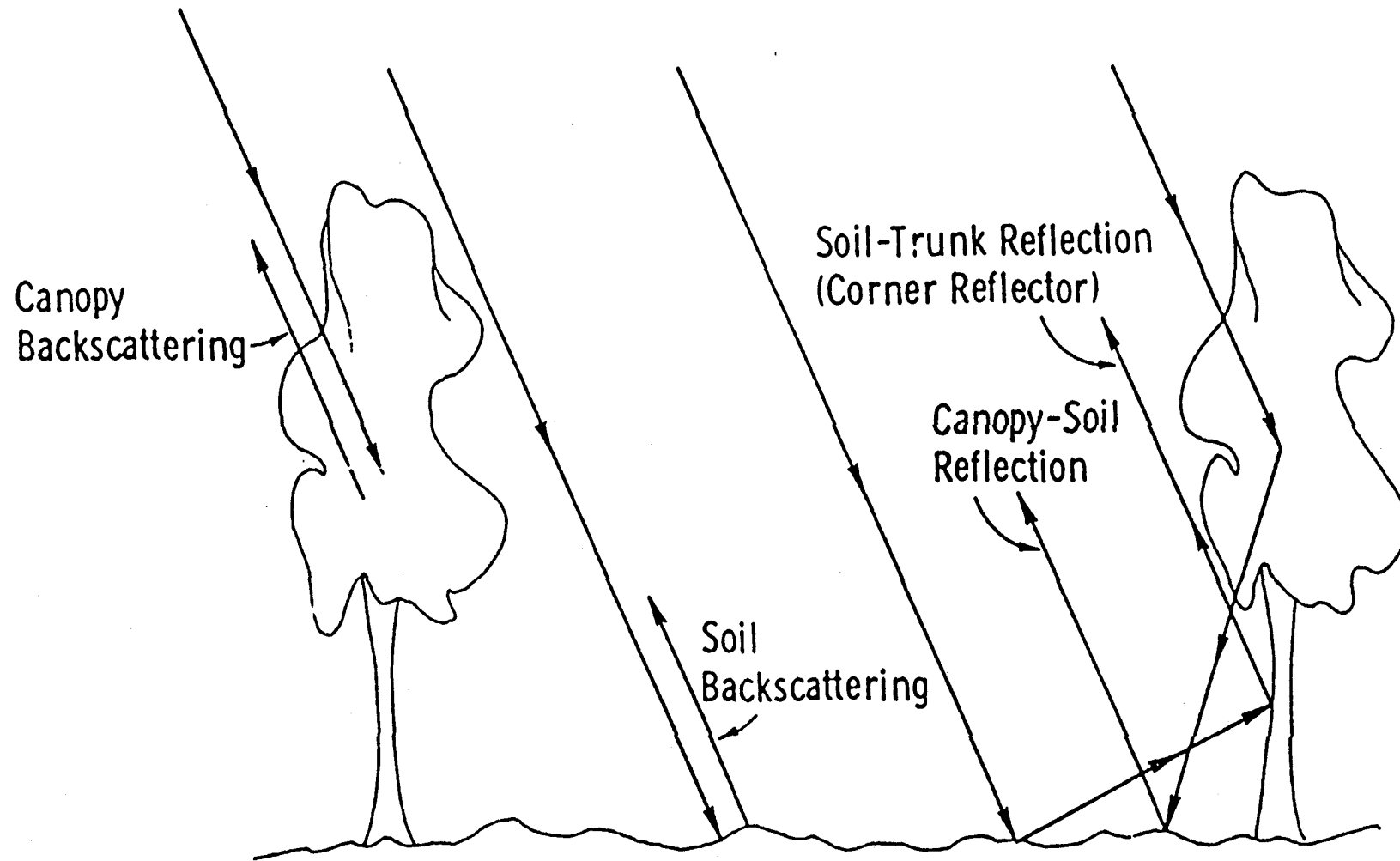


Batimetric map



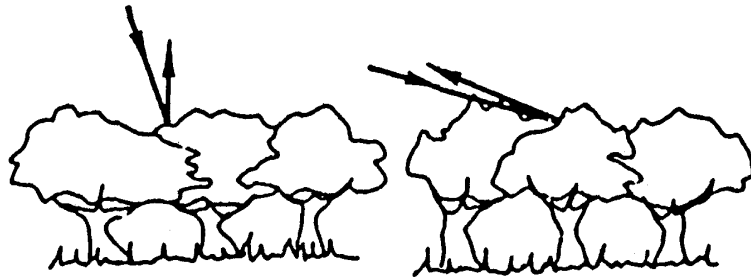


# Dispersión volumétrica



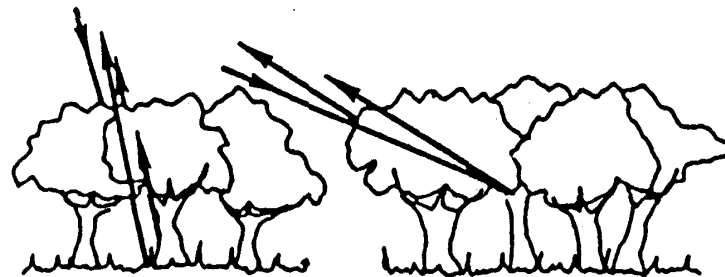
# Dispersión volumétrica

1cm WAVELENGTH



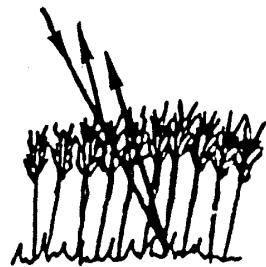
RADAR SIGNAL FROM TREE TOPS

1m WAVELENGTH

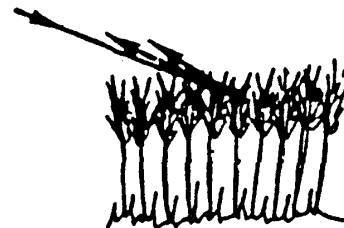


SIGNAL FROM  
TOPS, TRUNKS,  
GROUND

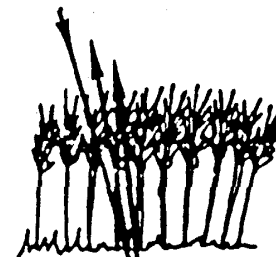
SIGNAL FROM  
TOPS, TRUNKS



SIGNAL FROM  
WHEAT AND  
SOIL



SIGNAL FROM  
WHEAT



SIGNAL FROM  
SOIL AND  
SUBSOIL



SIGNAL FROM  
WHEAT AND  
SOIL

MORE PENETRATION IF VEGETATION IS DRY THAN IF WET

ESAR (DLR), Processed by RSL

Platform: Dornier Do-228

Frequency: **X-Band (9.6 GHz)**

Bandwidth: 100 MHz

Polarisation: VV

Number of Looks: 18 Azimuth,

2 Range Motion Compensation:  
based on DGPS and Inertial  
Measurement Unit (IMU)

Original Ground Resolution: 1.5 m

Area: 1.1 x 1.1 km



E-SAR DLR, Processed by RSL

Frequency: **L-Band (1.3 GHz)**

Bandwidth: 100 MHz

Polarisation: multipol, image is HH

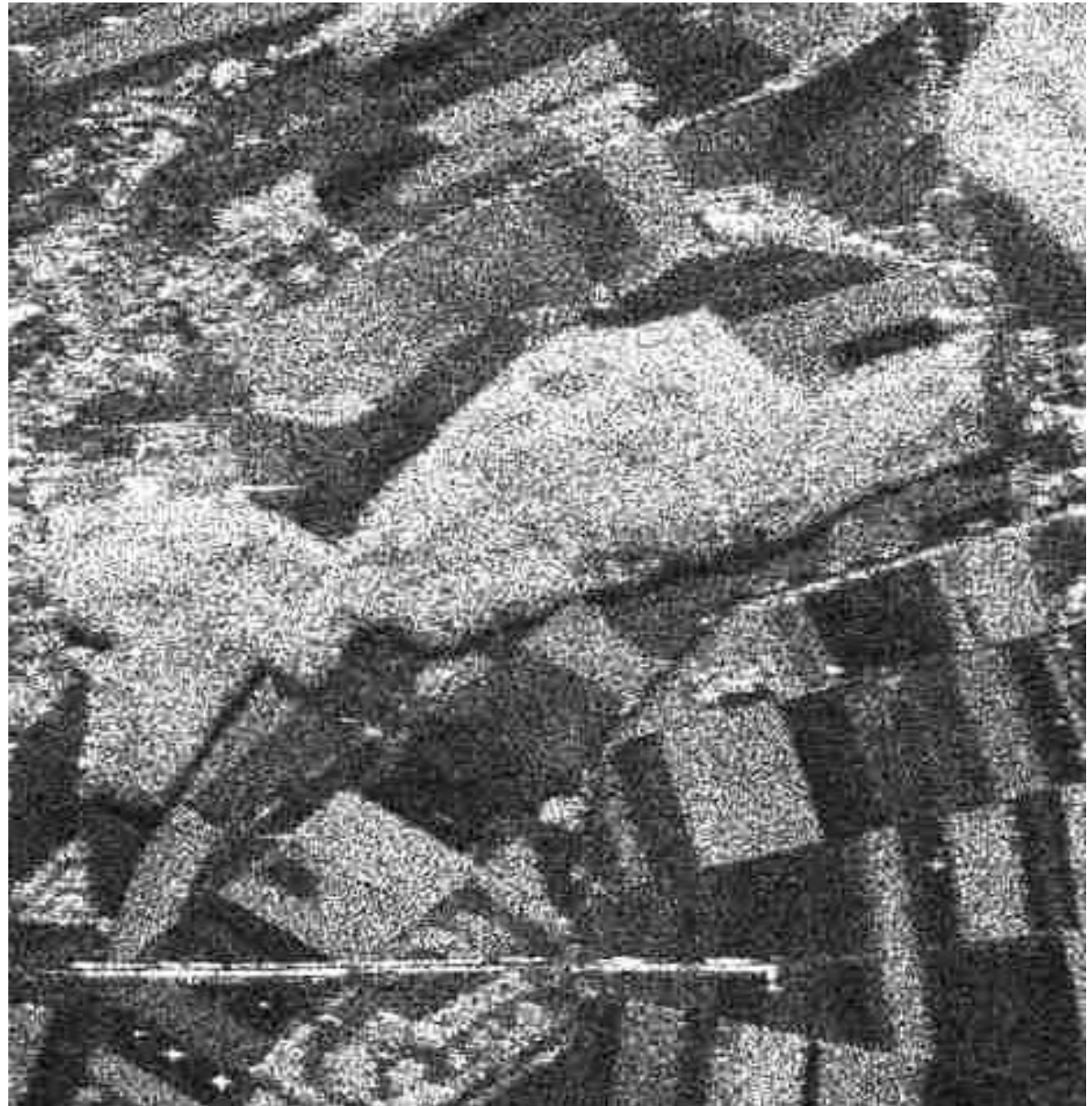
Number of Looks: 8 Azimuth, 2

Range Original Ground Resolution:  
1.5 m max

Area: 1.1 x 1.1 km

Location: Near City of Solothurn,

Switzerland Flight Campaign: August  
1997



ESAR (DLR), Processed by RSL

Frequency: **P-Band (0.45 GHz)**

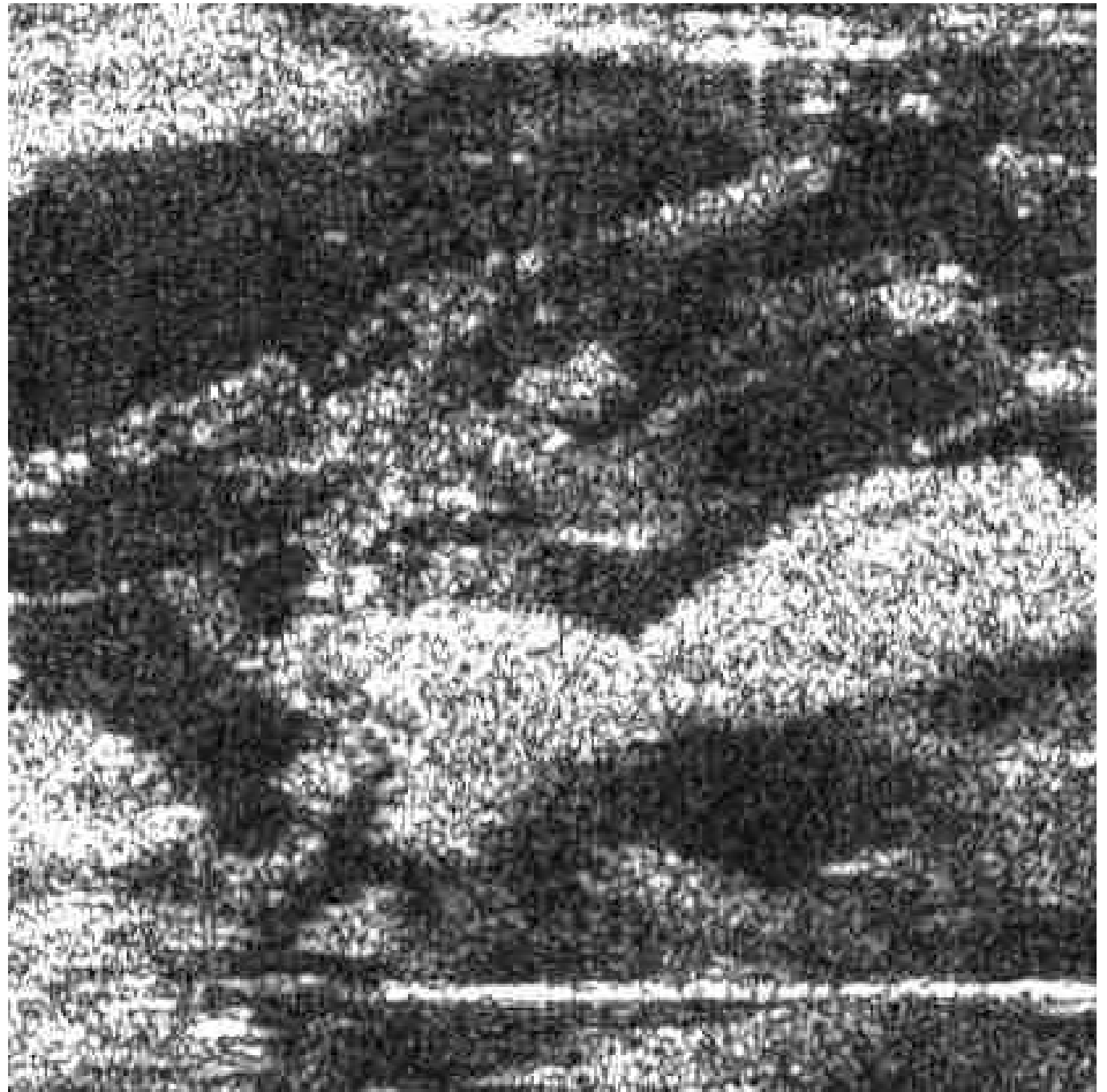
Bandwidth: 18 MHz

Polarisation: multipol, image is HH

Number of Looks: 16 Azimuth, 2

Range Original Ground Resolution:  
8.5 m max

Area: 1.1 x 1.1 km



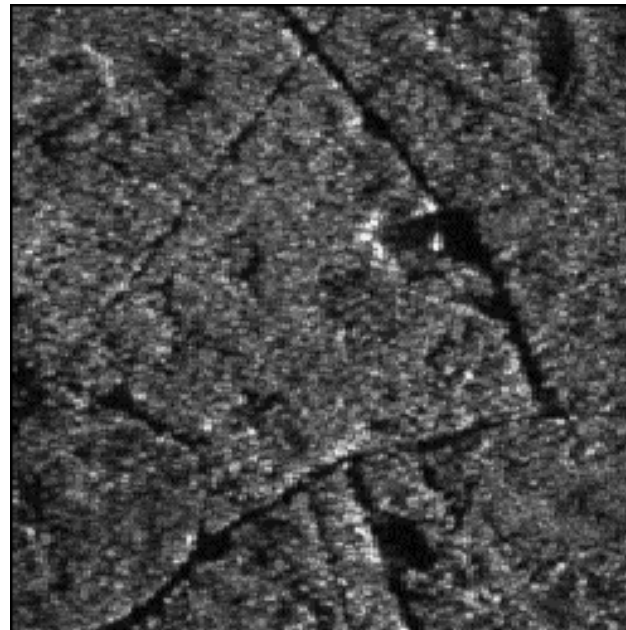


# FORESTRY APPLICATIONS

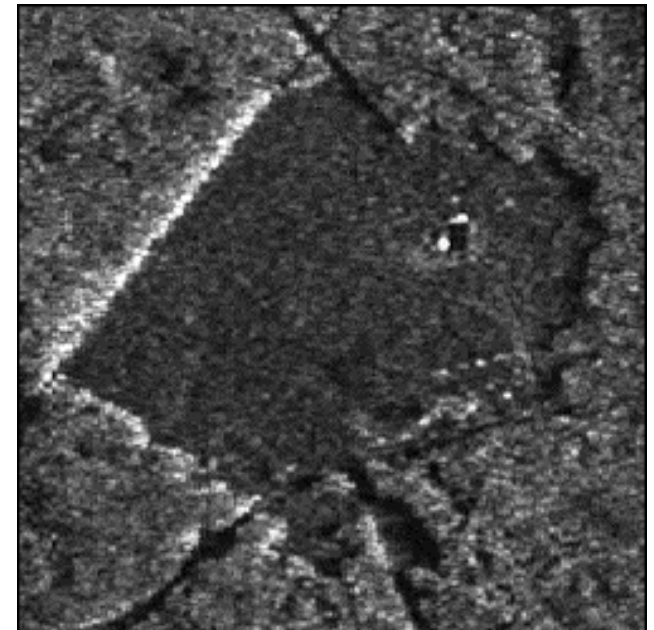
Acquired using the CCRS C-SAR (C-HH) in nadir mode pixel spacing of 3.89 metres (azimuth) by 4.0 metres (range).

The overflights were done during the winter to improve the contrast between the cutovers (which would be snow-covered) and the surrounding standing forest.

The imagery was UTM-registered with cubic convolution re-sampling to a 5 metre x 5 metre pixel spacing.



C-HH SAR: Whitecourt, Alberta, 03/18/91



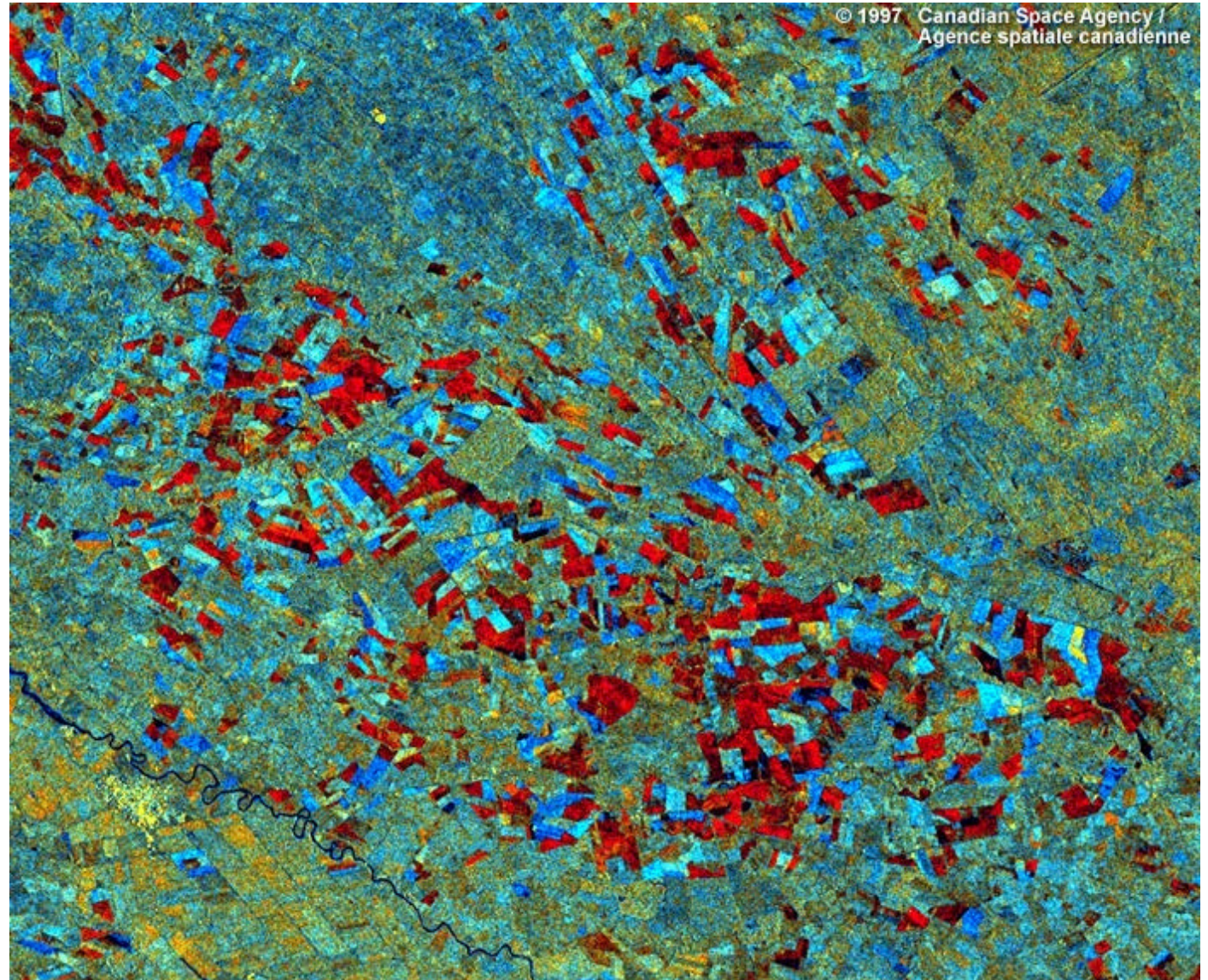
C-HH SAR: Whitecourt, Alberta, 02/08/92

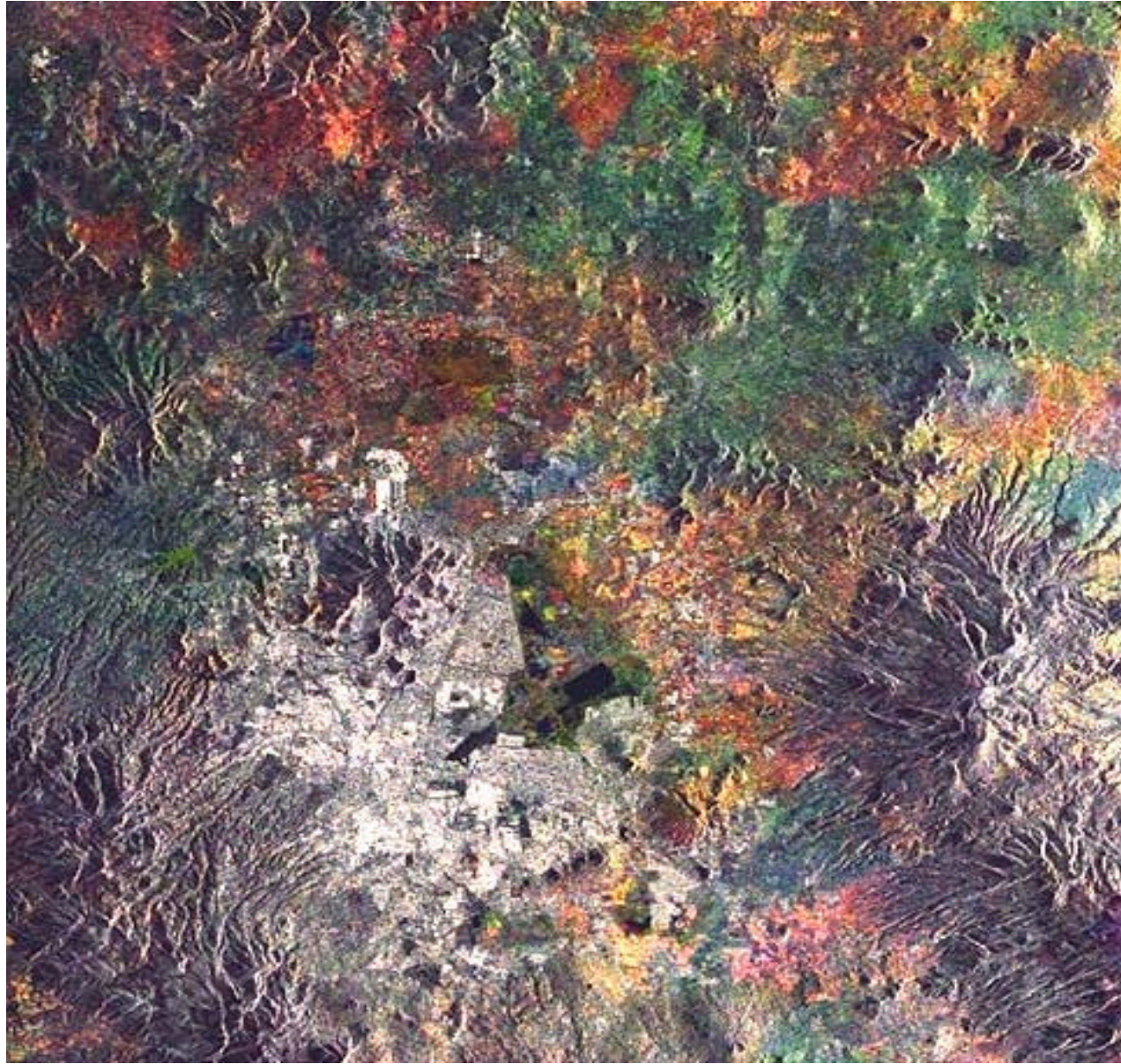
# MULTITEMPORAL SAR IMAGE (Llanos, Venezuela)

This image is a multi-temporal combination of 2 S7D RADARSAT images. The first image (red channel) was acquired at the beginning of the agriculture growing season (June 23, 1997) and the second image (green channel) was acquired at the end of the growing season (September 03, 1997). The third image (blue channel) was generated by subtracting the September image from the June image.

Changes from the beginning to the end of the growing season are displayed as red fields. The fields in blue are a result of no change or fallow fields.

Ramiro Salcedo of Instituto de Ingeniería, Caracas, Venezuela.





ERS-1 Mexico City

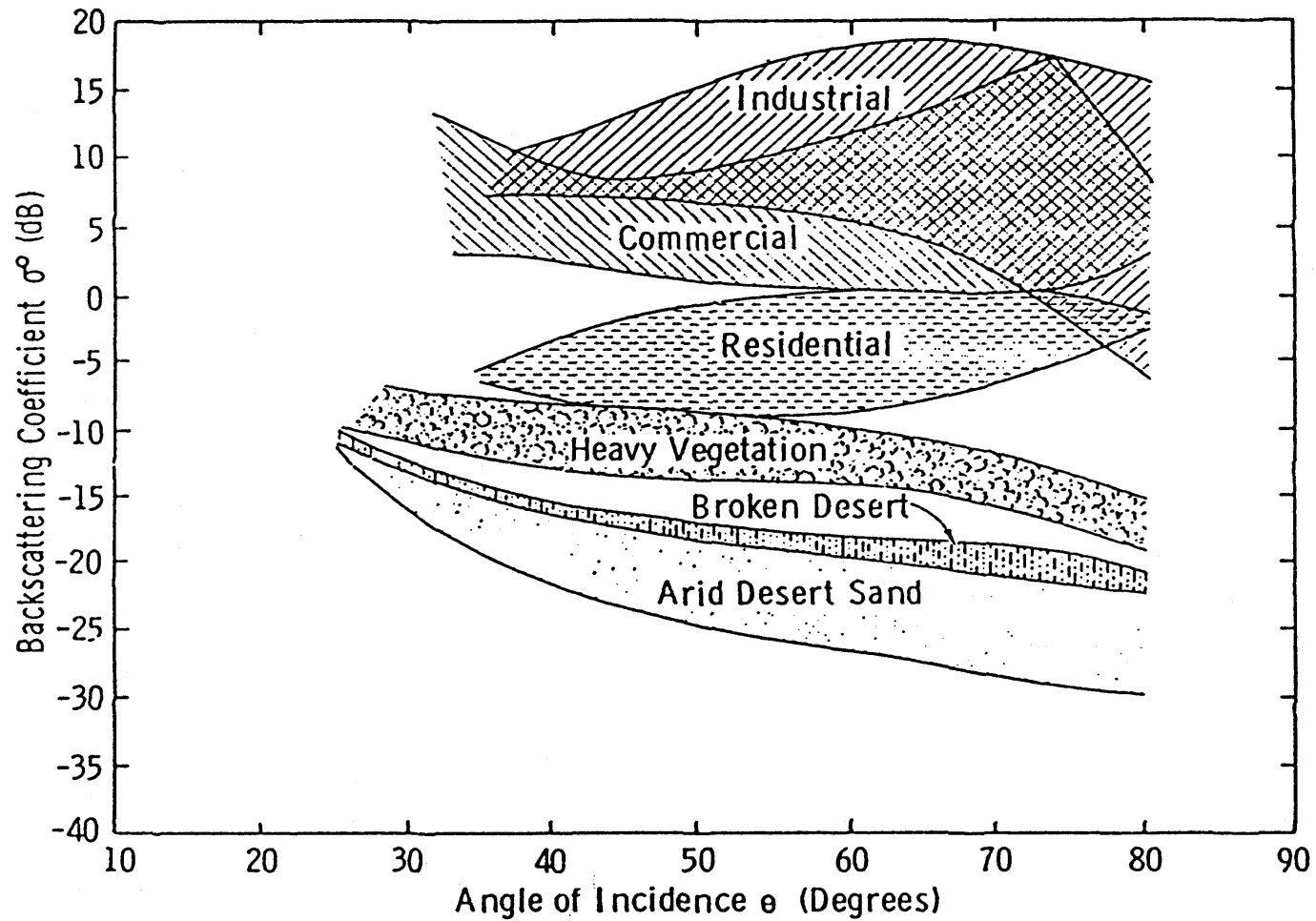
# Pentágono



# Pipe line over Rio Grande

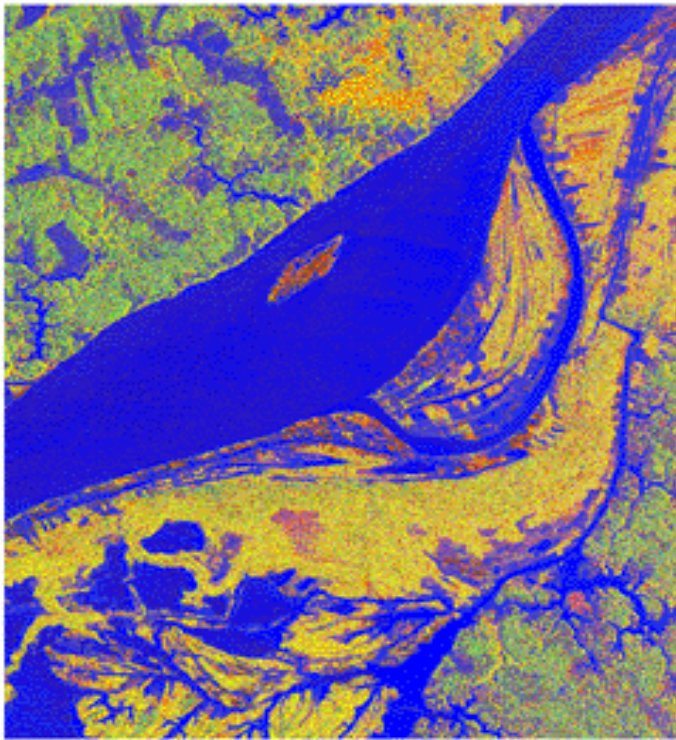


# Backscattering coefficient

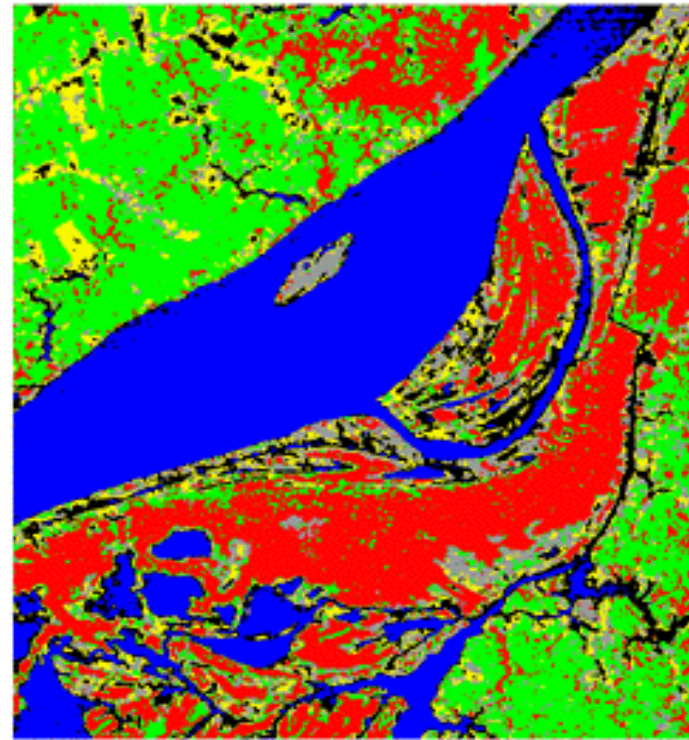


Observed ranges for the backscattering coefficient of several terrain classes at 9.375 GHz (Newbry, 1961).

SIR-C/X-SAR  
MANAUS, BRAZIL SUPERSITE  
INUNDATION MAP  
APRIL 12, 1994



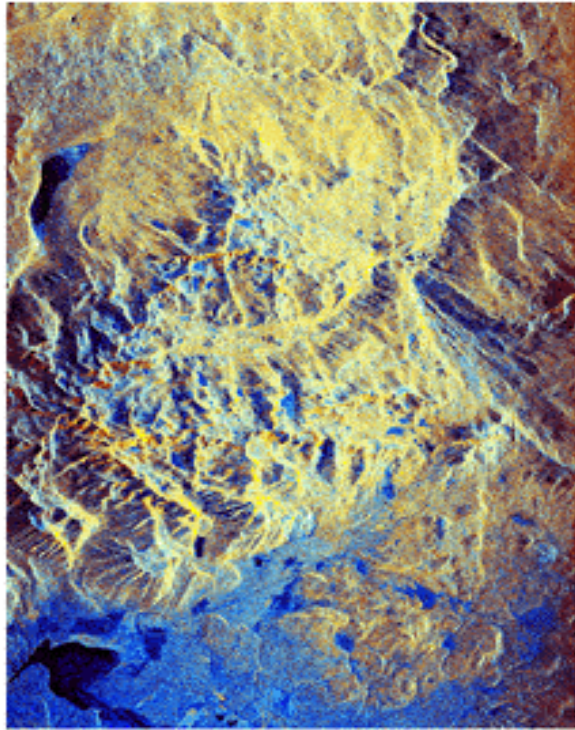
SIR-C IMAGE



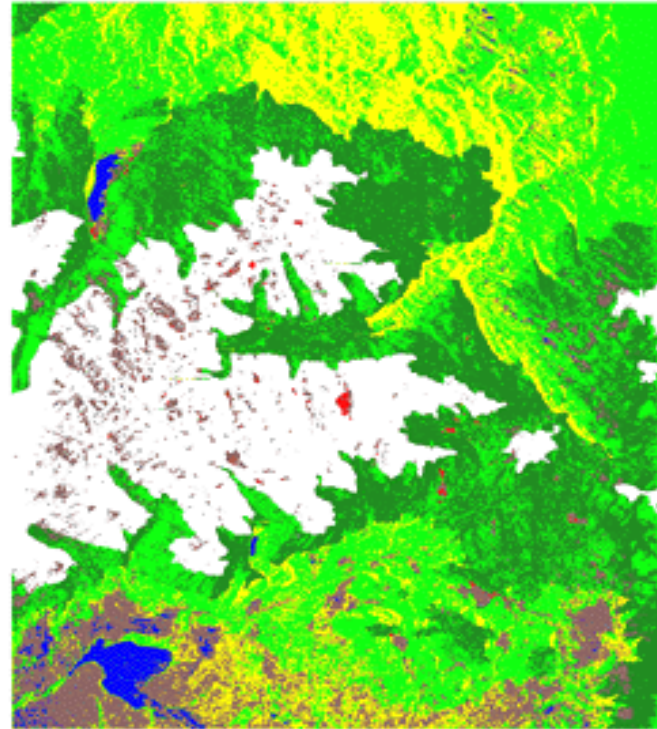
INUNDATION MAP



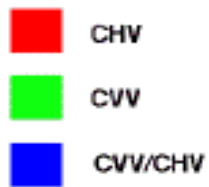
SIR-C/X-SAR  
MAMMOTH, CALIFORNIA  
LAND COVER MAP  
APRIL 13, 1994



SIR-C IMAGE



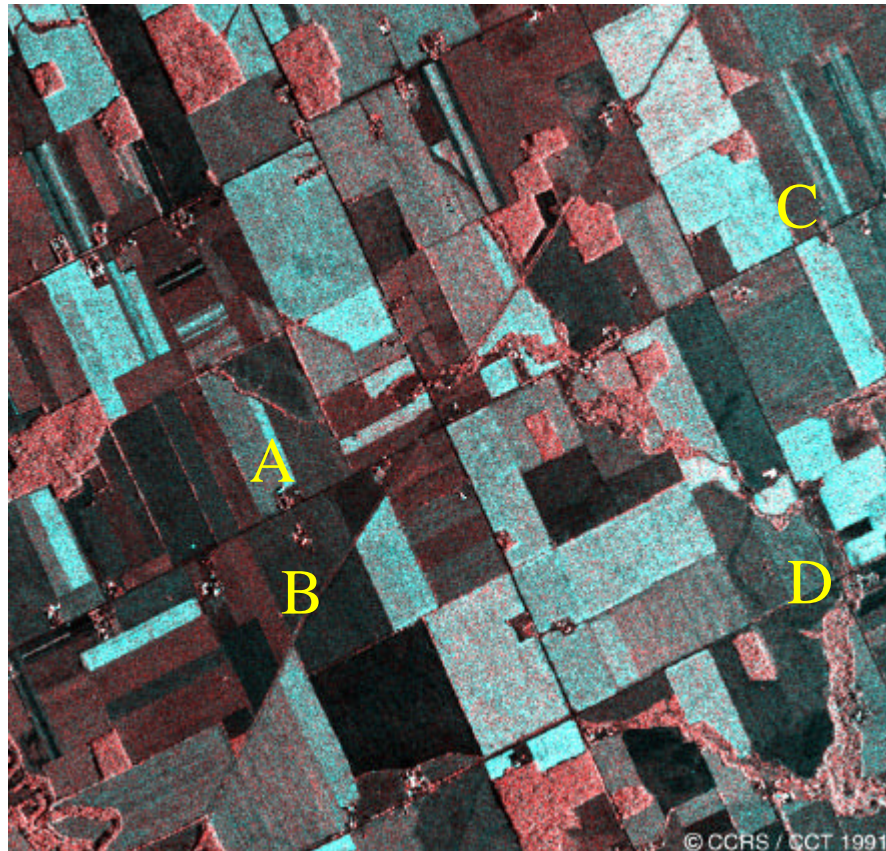
LAND COVER MAP





# CCRS SAR Oxford County

C band SAR composite image was created from HH and HV data, collected October 18, 1991.



(A) indicates a field of corn stubble in which no-tillage cultivation has been implemented.



Field (B) is a permanent pasture, considered a good conservation practice.



The corn stubble field (C) is a reduced tillage field.



Field (D) is a conventional tillage field and has a higher radar backscatter due to the surface roughness of the field.