

CNMCA, Sala Briefing dell'aeroporto "Mario de Bernardi"
Pratica di Mare-Pomezia (Roma)
Venerdì 13 Febbraio 2009, ore 10.30



"Simulazione e ricostruzione di immagini satellitari sul mare"

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Possibili applicazioni sul mare

Immagini bidimensionali ad alta risoluzione (da pochi metri a qualche decina di metri) dell'area osservata

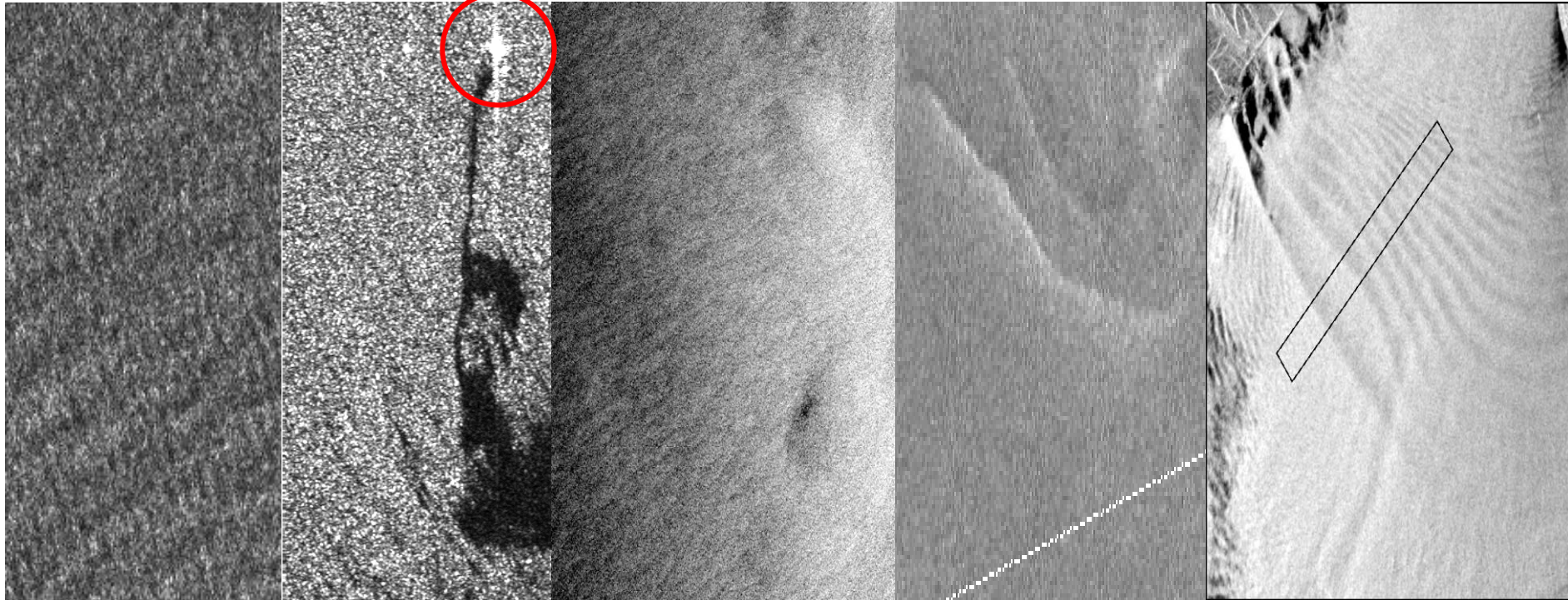
Onde

Oil spill

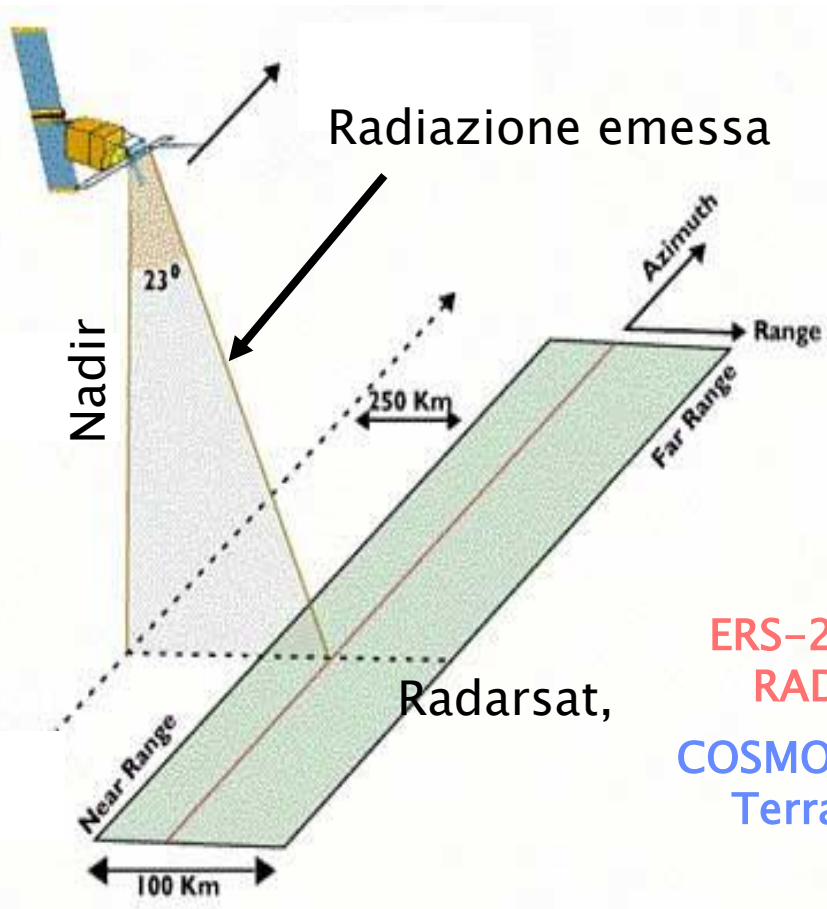
Vento

Correnti

Onde interne



IL SAR (Synthetic Aperture Radar)



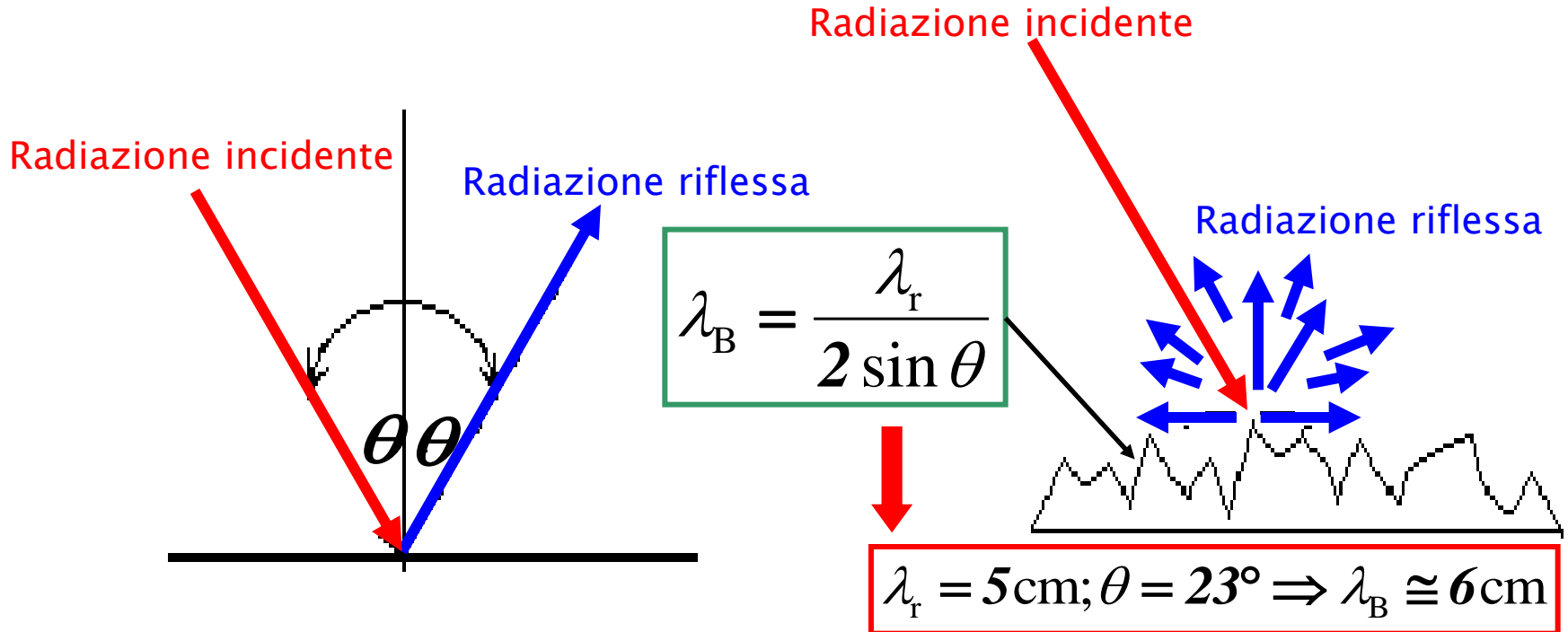
ERS-2; Envisat;
RADARSAT

COSMO - SkyMed;
TerraSAR - X

Sigla banda	Lunghezza d'onda	Frequenza
L	15 - 30 cm	1 - 2 GHz
S	8 - 15 cm	2 - 4 GHz
C	4 - 8 cm	4 - 8 GHz
X	2.5 - 4 cm	8 - 12 GHz
K	0.75 - 2.5 cm	12 - 40 GHz

Interferenza di Bragg

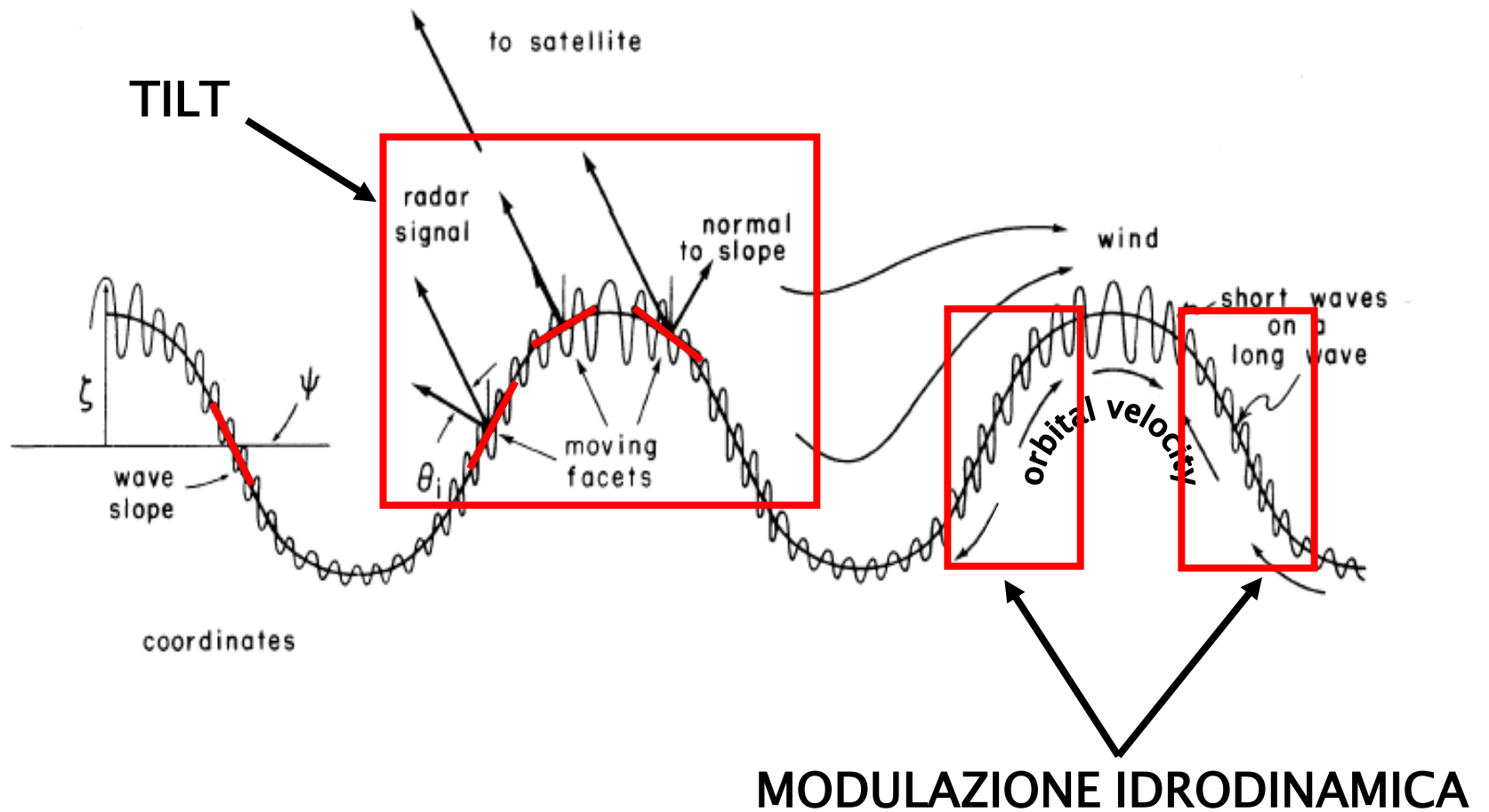
Meccanismo di backscattering della superficie marina



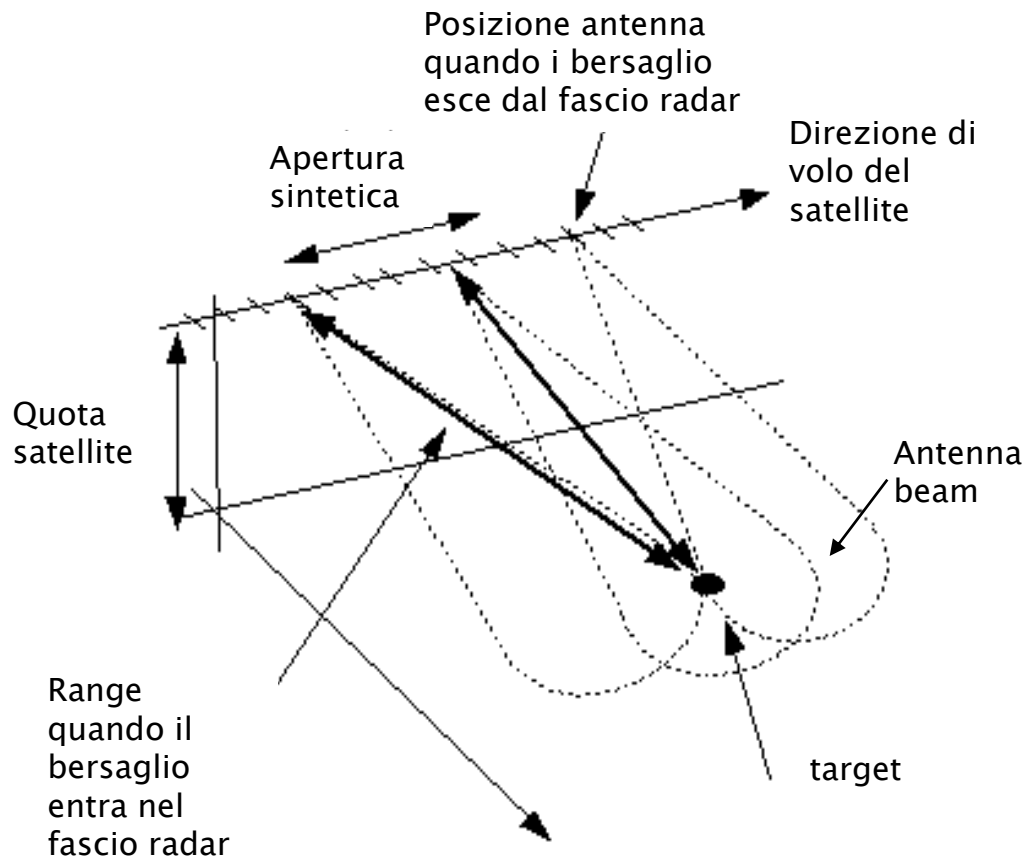
Riflessione speculare dell'energia incidente nel caso di superficie perfettamente piana

Riflessione diffusa dell'energia incidente in presenza di onde capillari o di Bragg (*Wright 1968 e Valenzuela 1978*)

Il modello a due scale (*Wright 1975*)



L'apertura sintetica



$$\delta = L_{sa} = \frac{\lambda_r R}{L_a}$$

Valori tipici per λ_r ed R sono rispettivamente: 5 cm ed 800 km



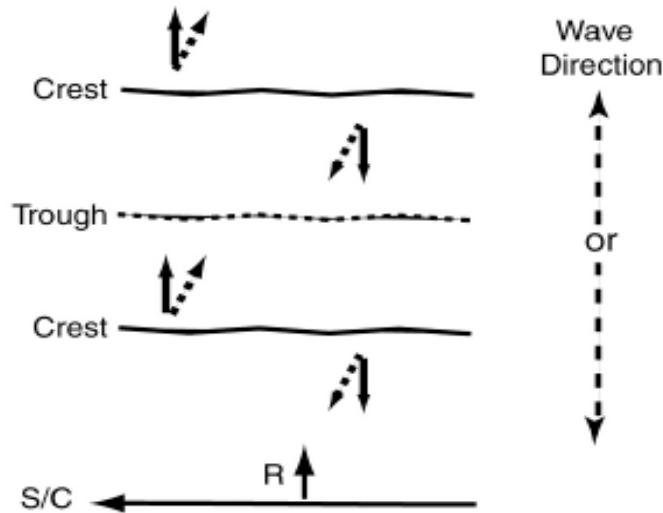
$L_a = 4$ km per avere una risoluzione al suolo δ di 10 m

$$\delta_{sa} = \frac{\lambda_r R}{2L_{sa}} = \frac{L_a}{2}$$

Doppler shift (Alpers)

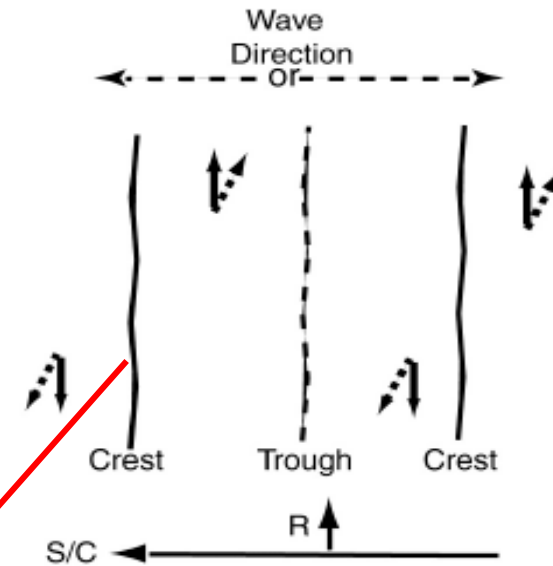
Onde con direzione ortogonale alla direzione di volo del satellite

Onde con direzione parallela alla direzione di volo del satellite



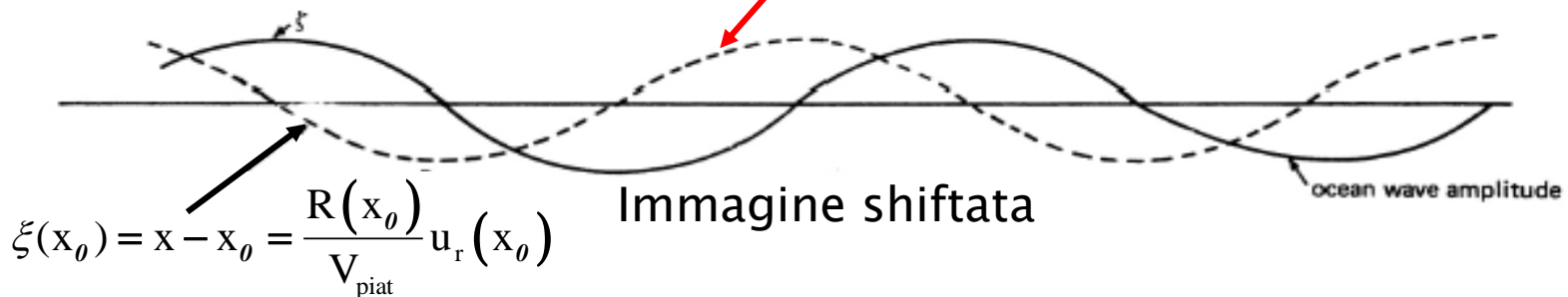
Direzione di volo del satellite

(A)



Direzione di volo del satellite

(B)



Procedura numerica

Bruening, C., Alpers W. & Hasselmann
(1990)

Bovolin; Cassese; Pugliese Carratelli
(1997)

Della Rocca; Pugliese Carratelli (2000)

.....

Pugliese Carratelli; Reale; Chapron;
Dentale (2008)

Generazione pseudo-casuale della superficie marina: teoria

La teoria lineare delle onde reali

$$1) \eta(x, y, t) = \sum_{i=1}^N \sum_{j=1}^M A_{i,j} \cos(k_i x \sin \theta_j + k_i y \cos \theta_j - \omega_i t + \phi_{i,j})$$

$$2) V_x(x, y, t) = g \sum_{i=1}^N \sum_{j=1}^M A_{i,j} \omega_i^{-1} k_i \cos(\omega_i t - k_i x \cos \theta_j - k_i y \sin \theta_j + \phi_{i,j})$$

Le fasi $\phi_{i,j}$ sono uniformemente distribuite nell'intervallo $[0, 2\pi]$

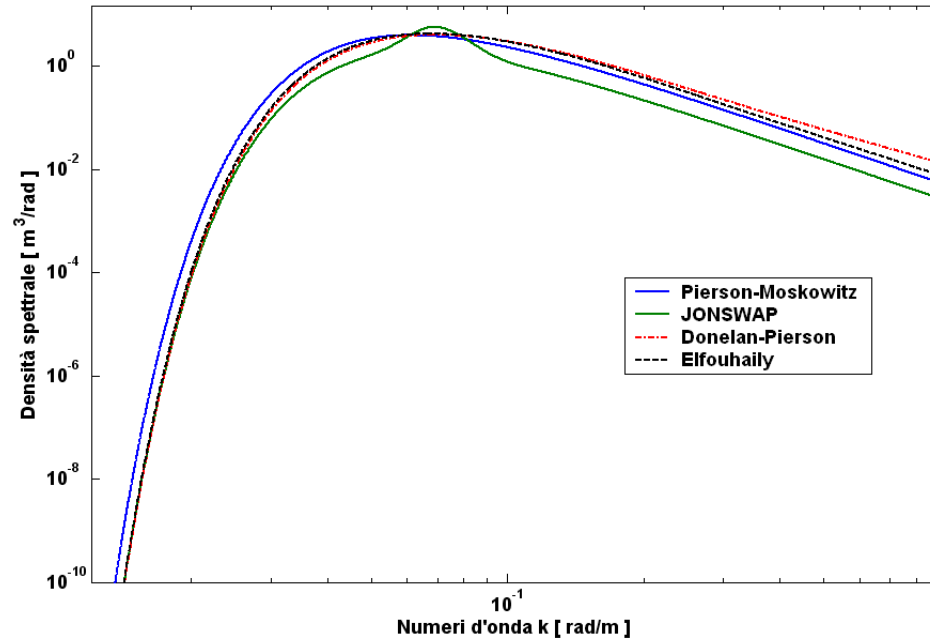
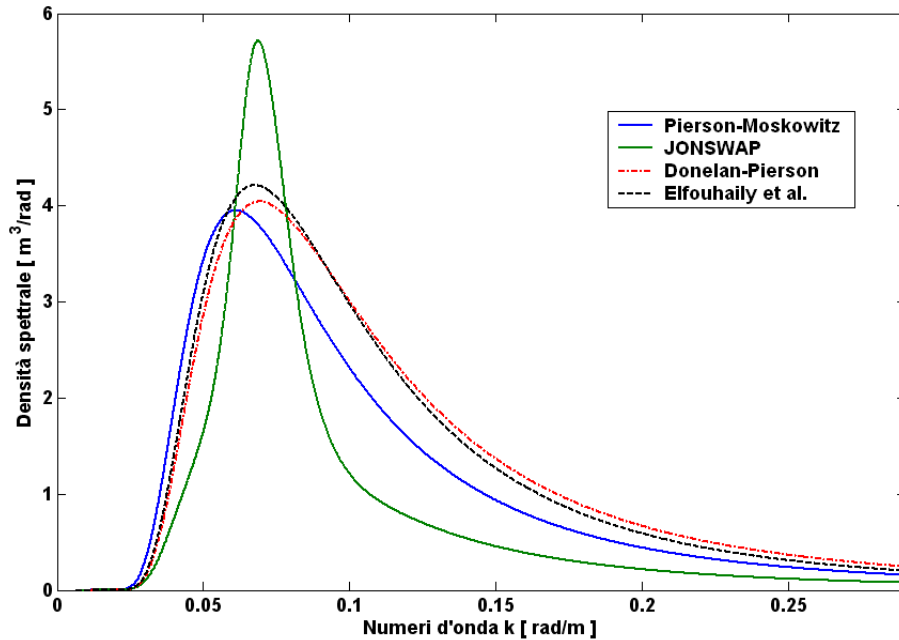
$$3) A_{i,j} = \sqrt{2 \cdot S_d(\omega_i, \vartheta_j) \cdot d\vartheta \cdot df} \quad A_{i,j} = \text{ampiezze spettrali}$$

4) I numeri d'onda k_i e le frequenze angolari ω_i sono legate dall'equazione della dispersione lineare

Gli spettri unidirezionali

Lo spettro JONSWAP

$$S_J(k) = 0.5 \cdot \beta \cdot H_S^2 \cdot k_P^2 \cdot k^{-3} \cdot \exp\left\{-1.25 \cdot \left(\frac{k_P}{k}\right)^2\right\} \cdot \gamma \exp\left\{-\frac{(\sqrt{k} - \sqrt{k_P})^2}{2 \cdot \sigma_J^2 \cdot k_P}\right\}$$



Spettri di mare nell'ipotesi di mare completamente sviluppato (inverse wave age $\Omega = 0.84$) e una velocità del vento $U_{10} = 10 \text{ ms}^{-1}$

Le funzioni di spreading per la dispersione direzionale

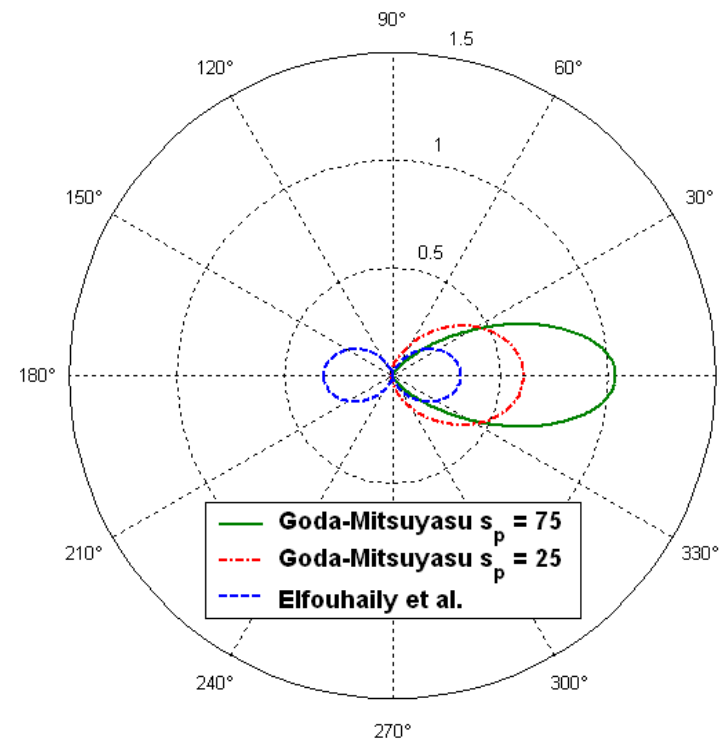
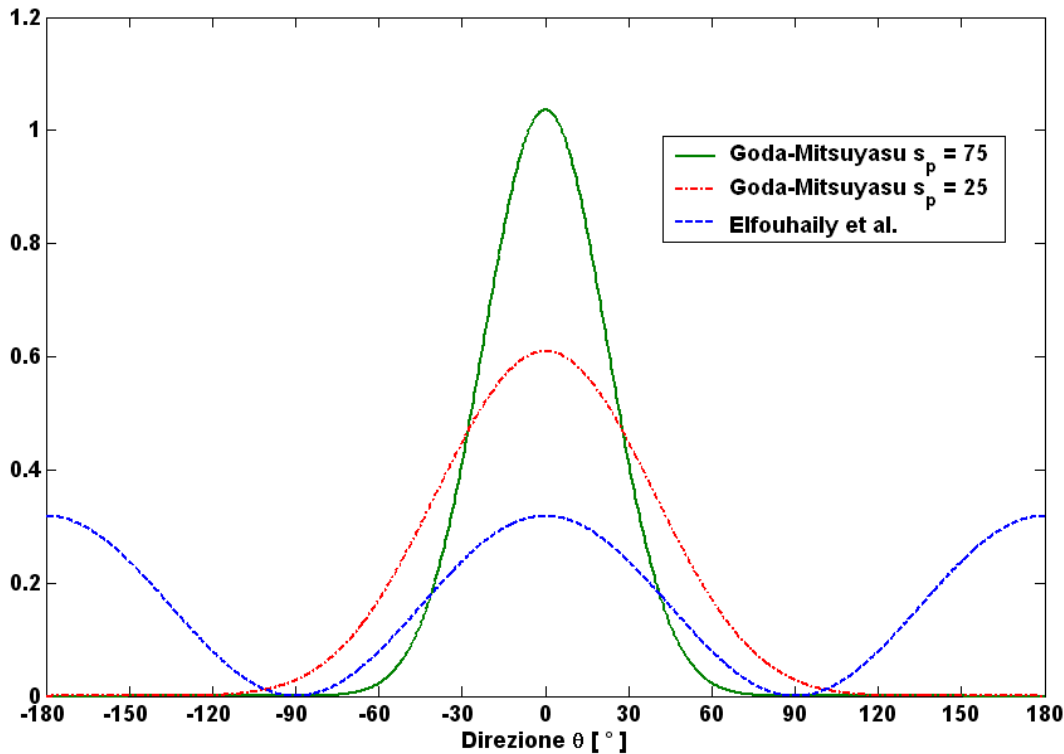
$$D(f, \theta) = G_\theta \cdot \left| \cos\left(\frac{\theta - \theta_\theta}{2}\right) \right|^{2s}$$

$$G_\theta = \frac{1}{\pi} \cdot 2^{(2s-1)} \cdot \frac{\Gamma^2(s+1)}{\Gamma(2s+1)}$$

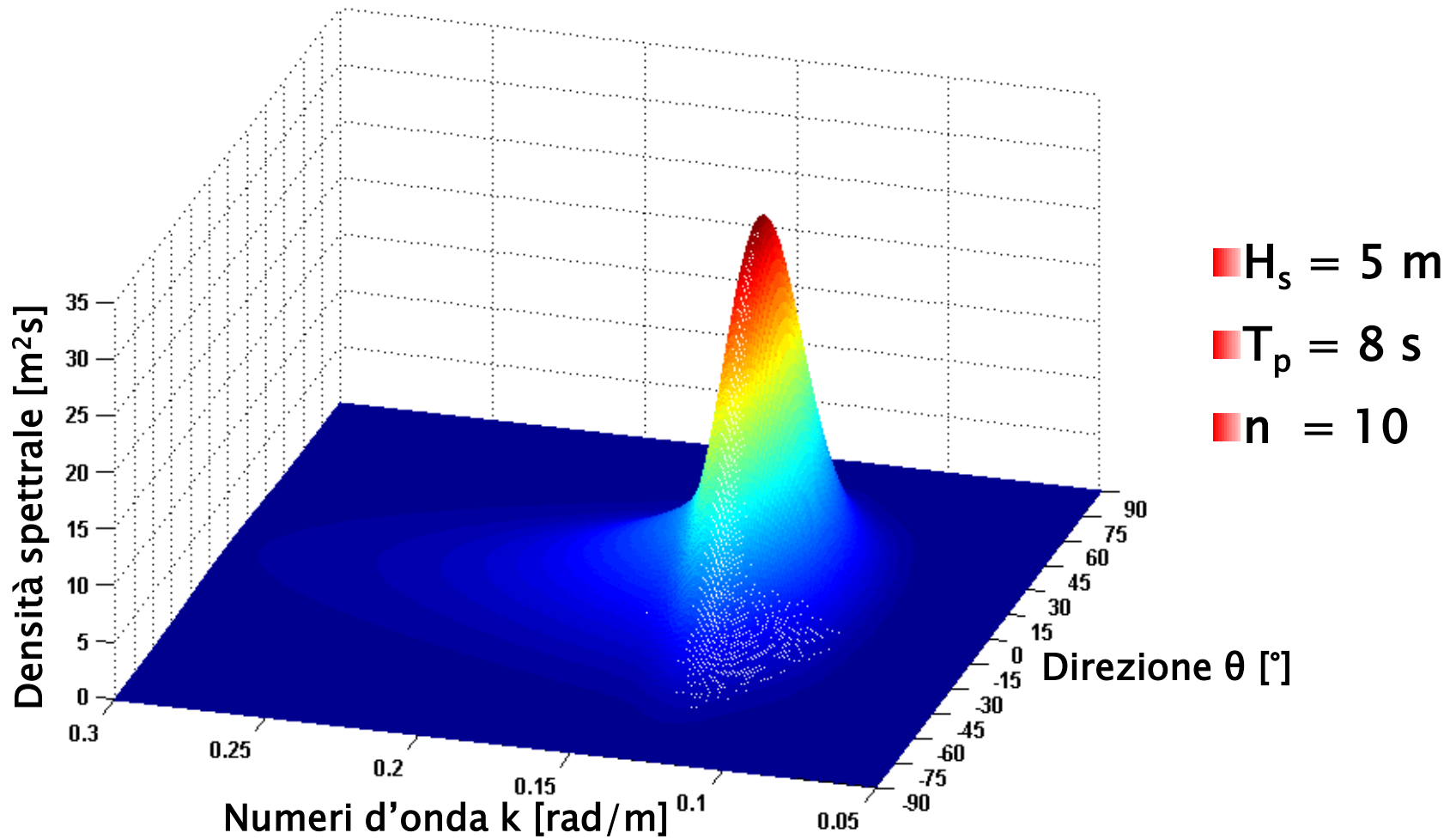
$$s = \begin{cases} s_p \cdot \left(\frac{k}{k_p}\right)^{2.5} & \text{se } k < k_p \\ s_p \cdot \left(\frac{k}{k_p}\right)^{-1.25} & \text{se } k \geq k_p \end{cases}$$

$$s_p = 11.5 \cdot \left(U_{10} \cdot \sqrt{\frac{k_p}{g}} \right)^{-2.5}$$

Goda-Mitsuyasu (1975)

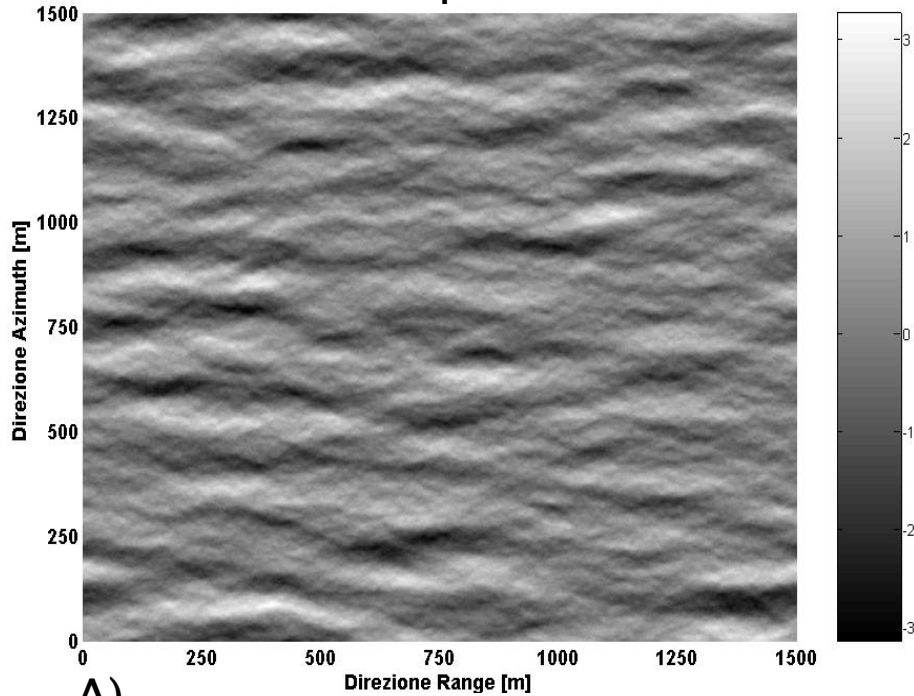


Lo spettro direzionale

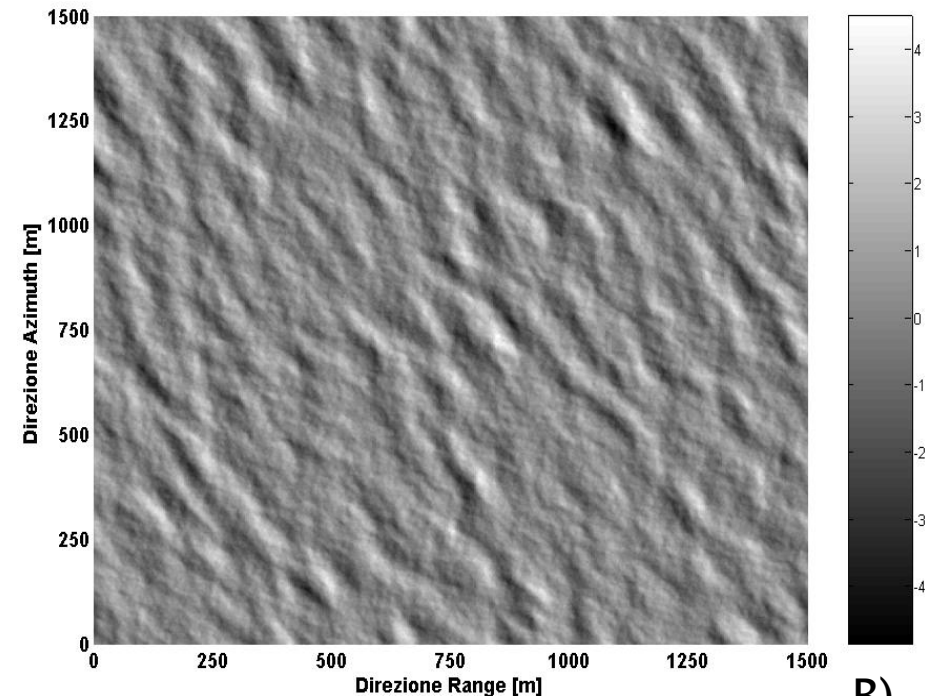


Generazione pseudo-casuale della superficie marina: risultati

Swell puro

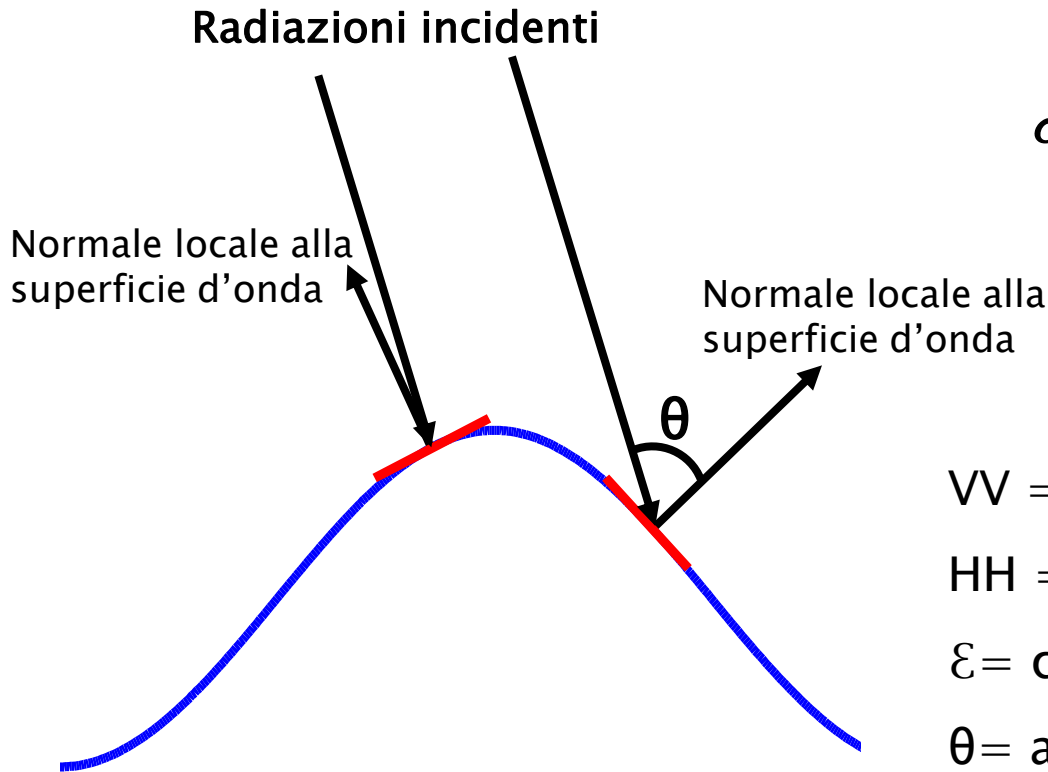


Mare di vento



Ricostruzione effetto di tilt

Valenzuela 1978



$$\sigma_{VV} = \cos^4 \theta \cdot \left[\frac{\epsilon^2 \cdot (1 + \sin^2 \theta)}{(\epsilon \cdot \cos \theta + \sqrt{\epsilon})^2} \right]^2$$

$$\sigma_{HH} = \cos^4 \theta \cdot \frac{\epsilon}{(\cos \theta + \sqrt{\epsilon})^2}$$

VV = polarizzazione verticale

HH = polarizzazione orizzontale

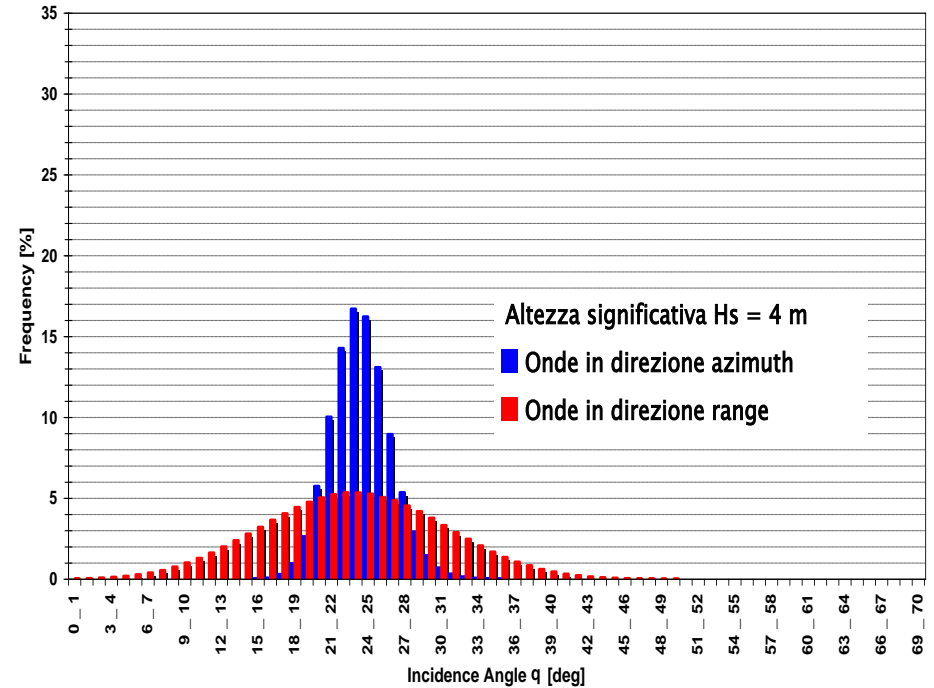
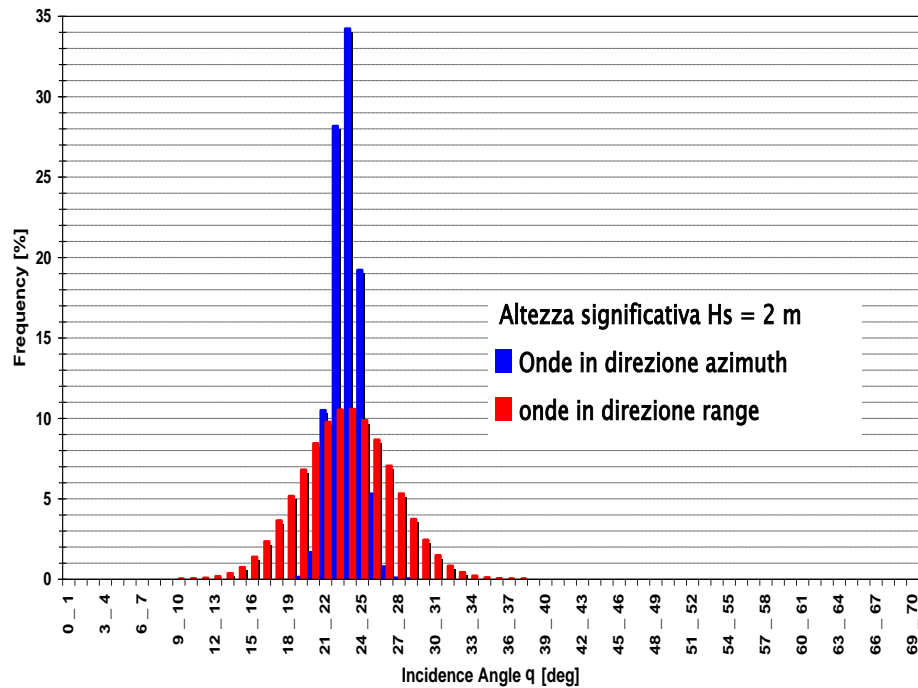
ϵ = costante dielettrica

θ = angolo d'incidenza locale

Cmod (LOCALE)

L'effetto di tilt

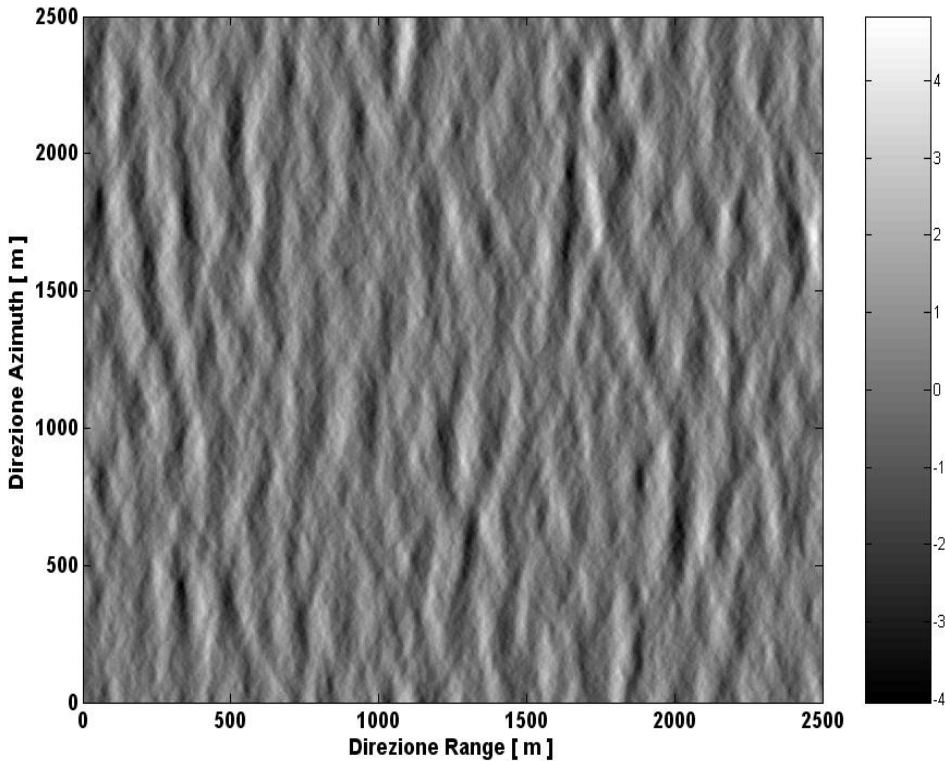
Distribuzioni di frequenza angoli d'incidenza locali



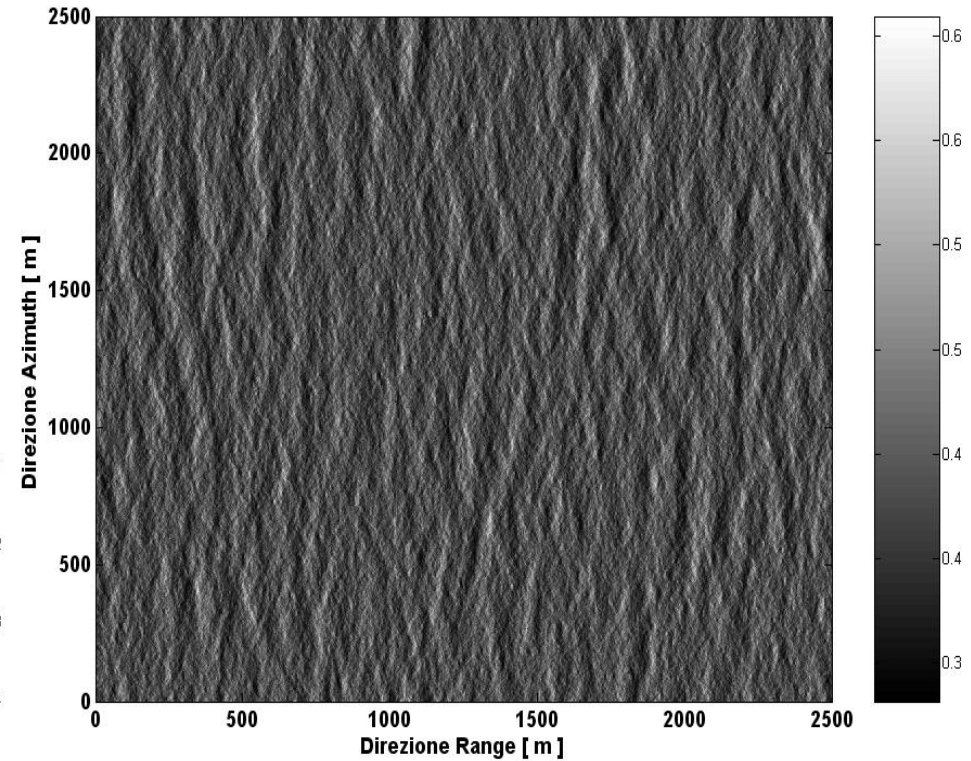
Risultati simulazione tilt: in direzione Range

Onde

Elevazione superficie marina



Modulazione RAR

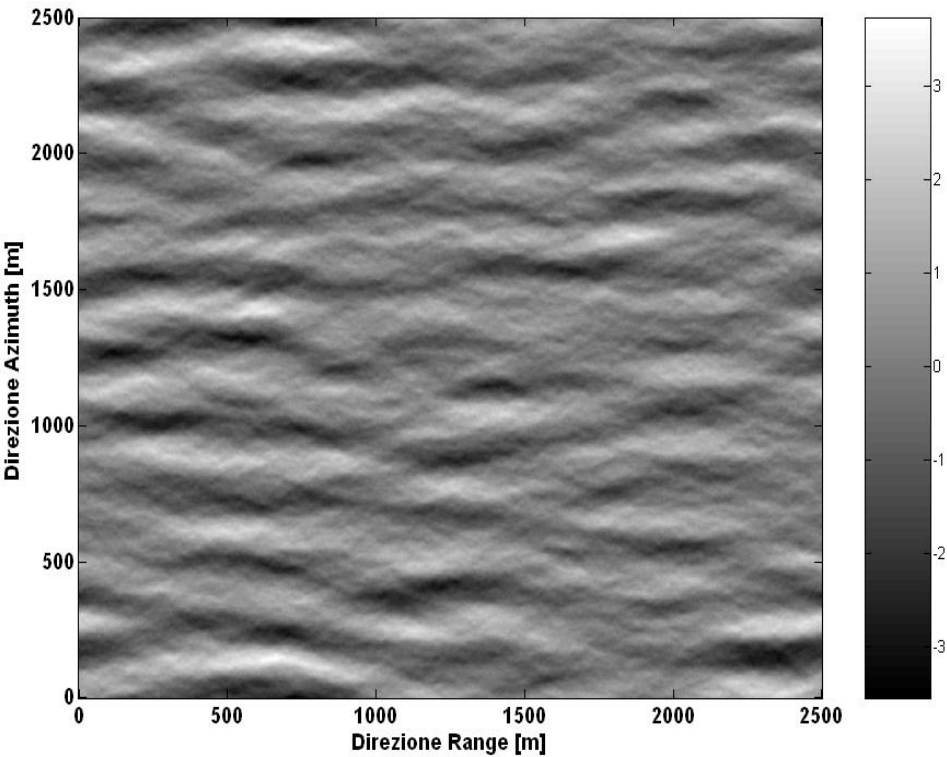


$$H_s = 4\text{m}; L_p = 150\text{m}; s_p = 75$$

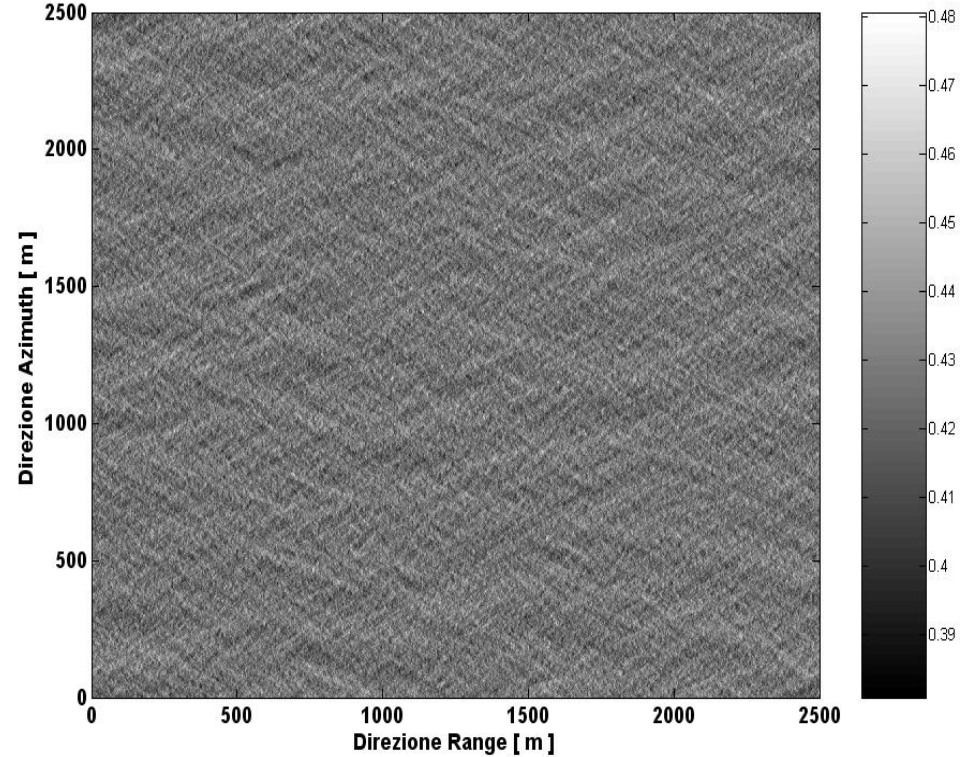
Risultati simulazione tilt: in direzione Azimuth

Onde

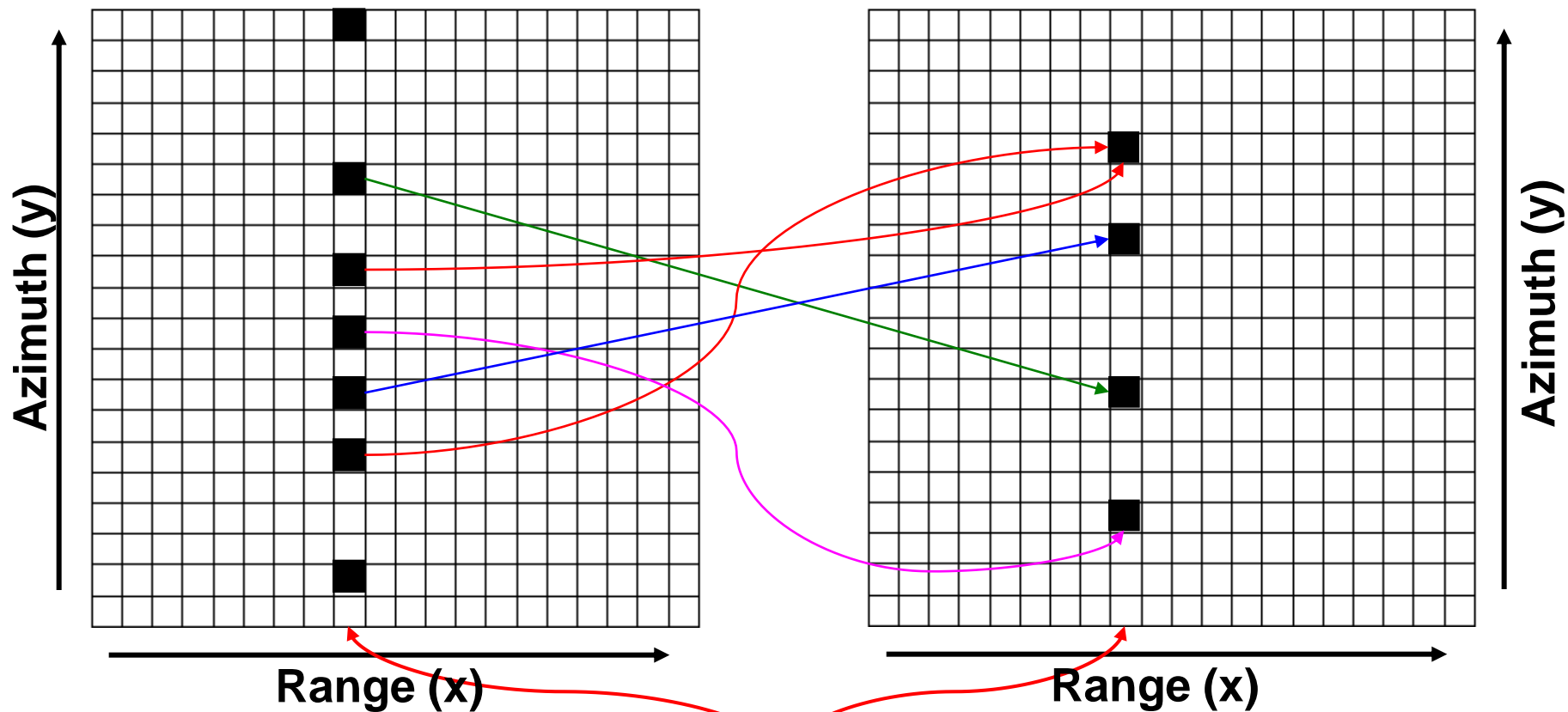
Elevazione superficie marina



Modulazione RAR



$$H_s = 4\text{m}; L_p = 250\text{m}; s_p = 75$$



I punti si spostano sulla stessa linea azimutale

```

function[Isar]=Doppler_shift(tilt,shift,dy);

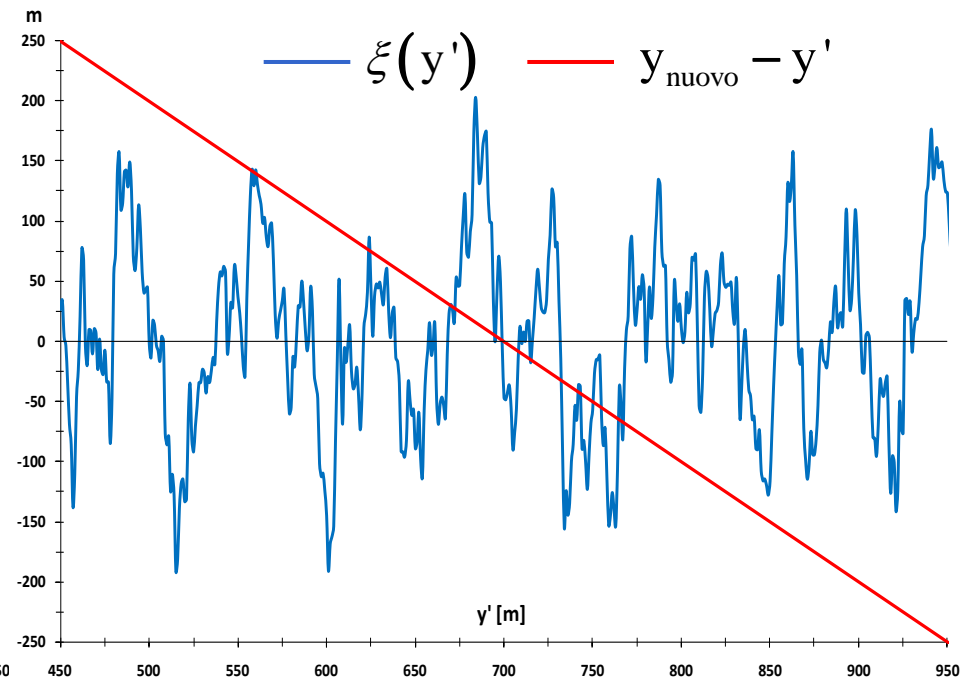
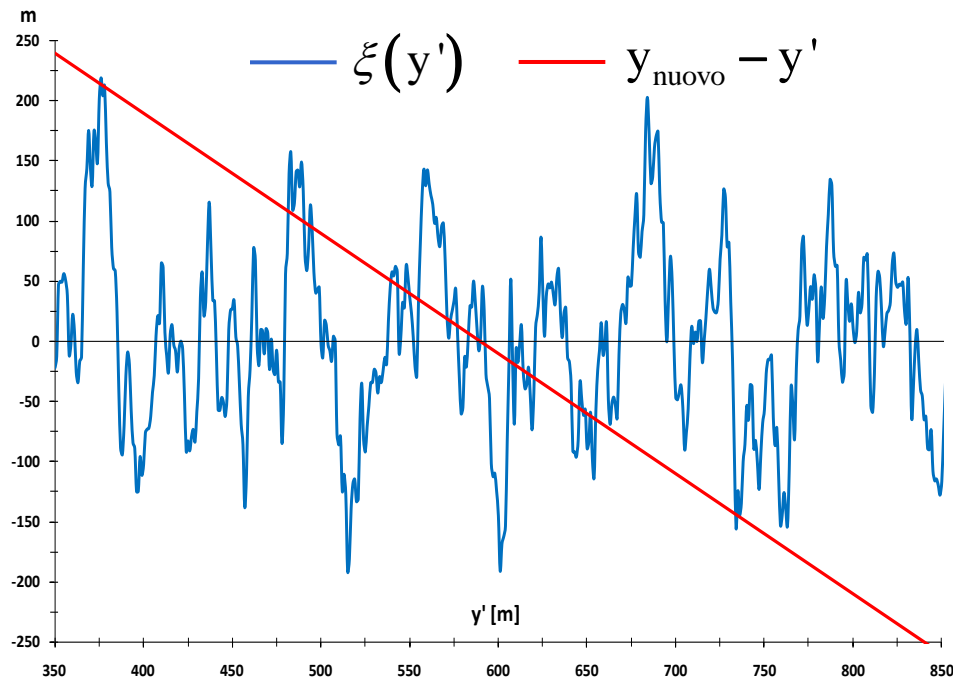
[Ny Nx]=size(tilt);
for ii=1:Ny
    for jj=1:Nx
        i_nuovo(ii,jj)=round(shift(ii,jj)/dy)+ii;
    end
end

Isar=zeros(Ny,Nx);
for ii=1:Nx
    for jj=1:Ny
        if (i_nuovo(jj,ii)>=1 & i_nuovo(jj,ii)<=Ny)
            Isar(i_nuovo(jj,ii),ii)=Isar(i_nuovo(jj,ii),ii)+tilt(jj,ii);
        end
    end
end
return;

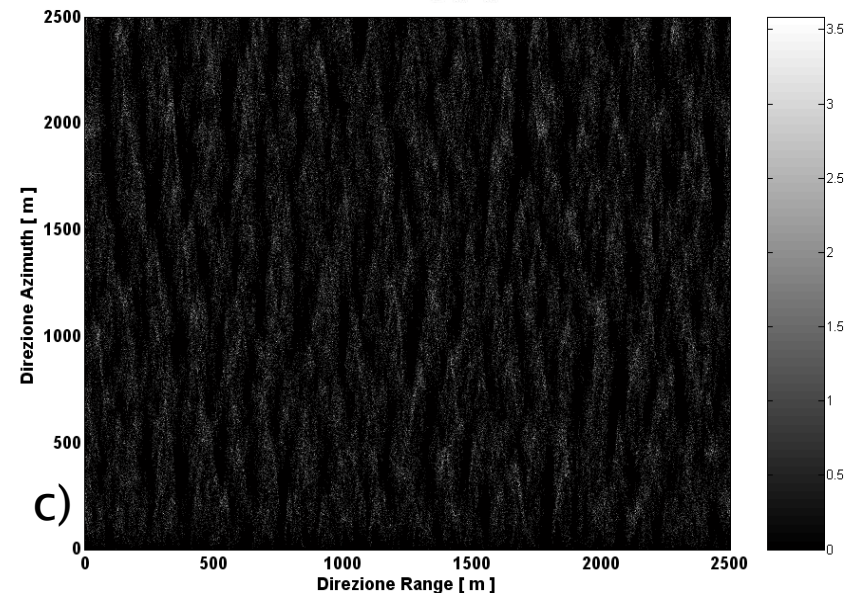
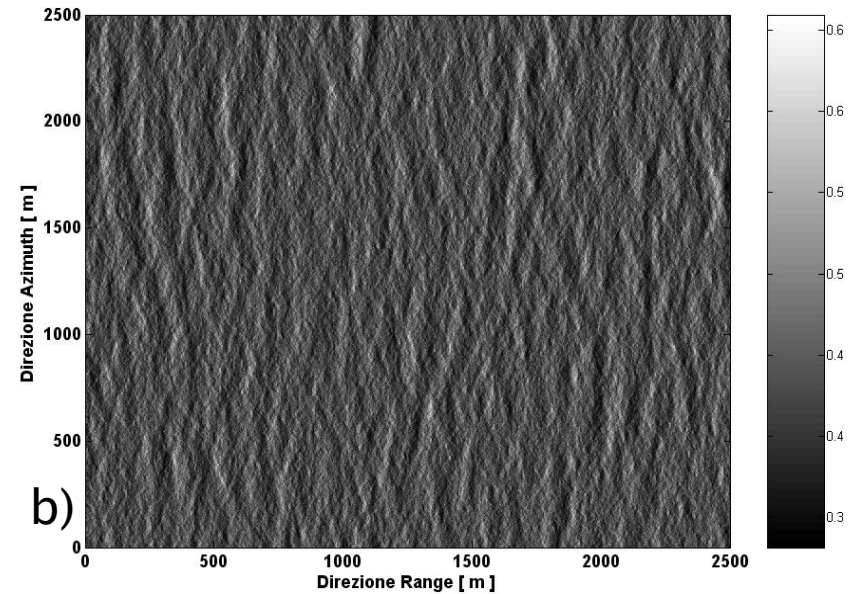
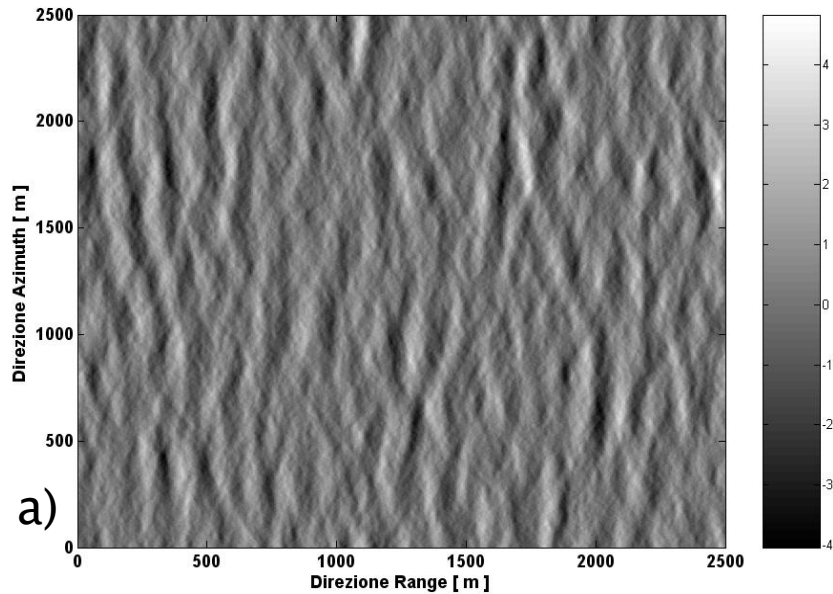
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Sovrapposizione delle faccette

$$y_{\text{nuovo}} = y' + \xi(y') = y' + \frac{R}{V_{\text{piat}}} u_r(y')$$



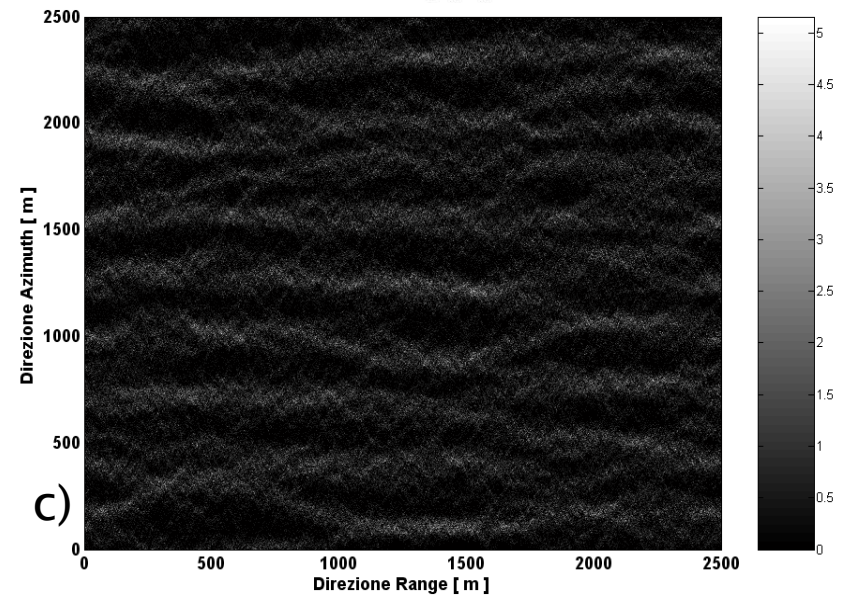
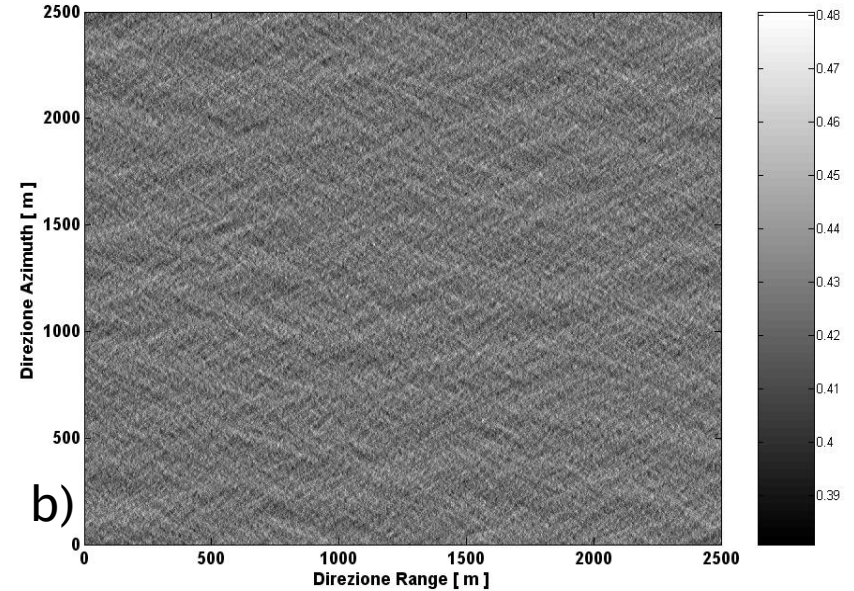
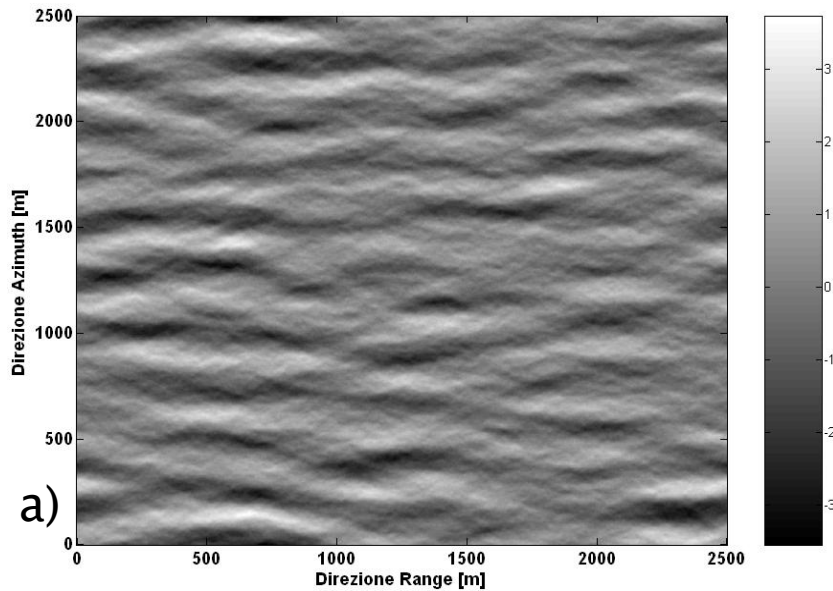
Risultati simulazione tilt + shift: Onde in direzione Range



$$H_s = 4\text{m}; L_p = 150\text{m}; s_p = 75$$

- a) Elevazione superficie marina
- b) Modulazione RAR (solo tilt)
- c) Modulazione SAR (tilt + shift)

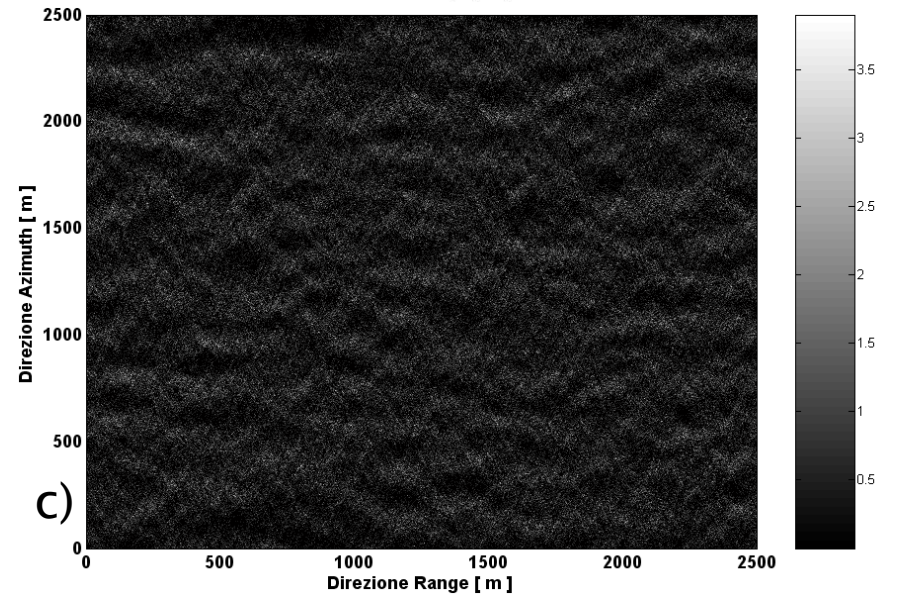
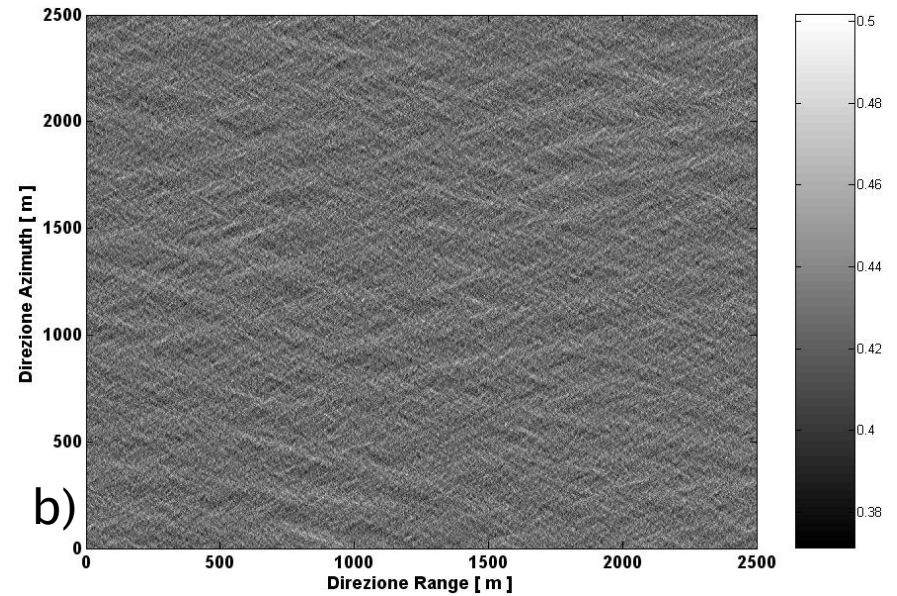
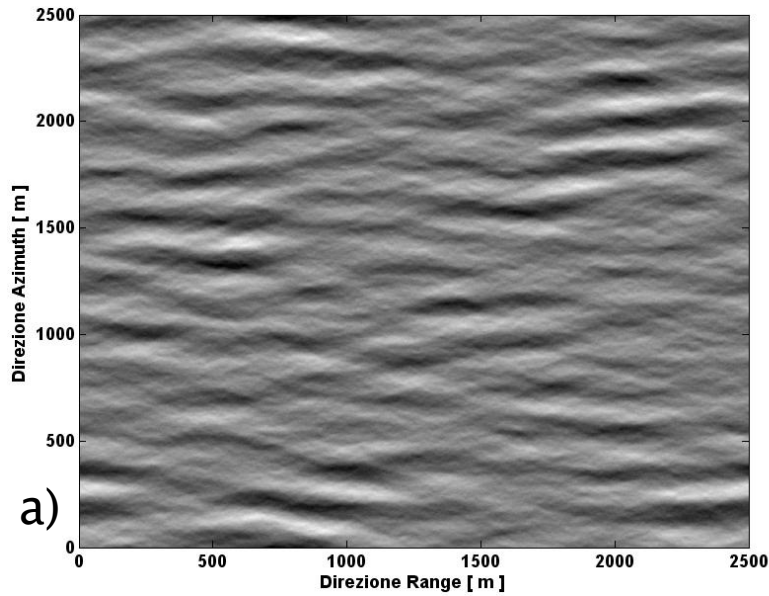
Risultati simulazione tilt + shift: Onde in direzione Azimuth



$$H_s = 4\text{m}; L_p = 250\text{m}; s_p = 75$$

- a) Elevazione superficie marina
- b) Modulazione RAR (solo tilt)
- c) Modulazione SAR (tilt + shift)

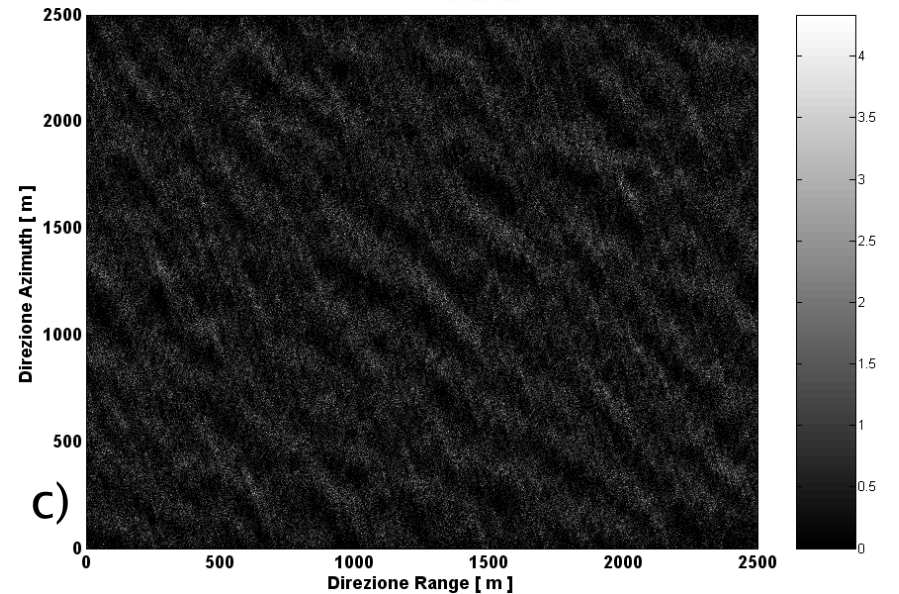
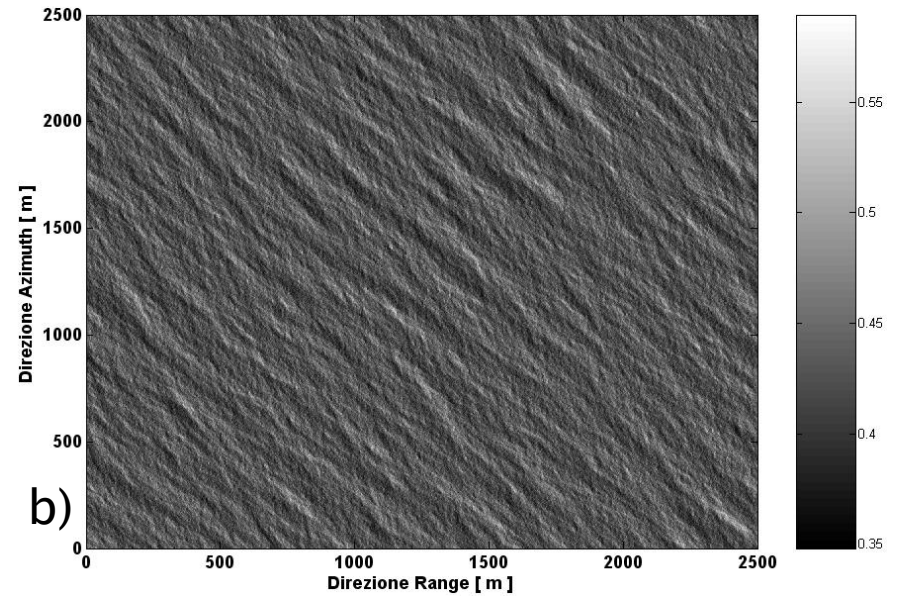
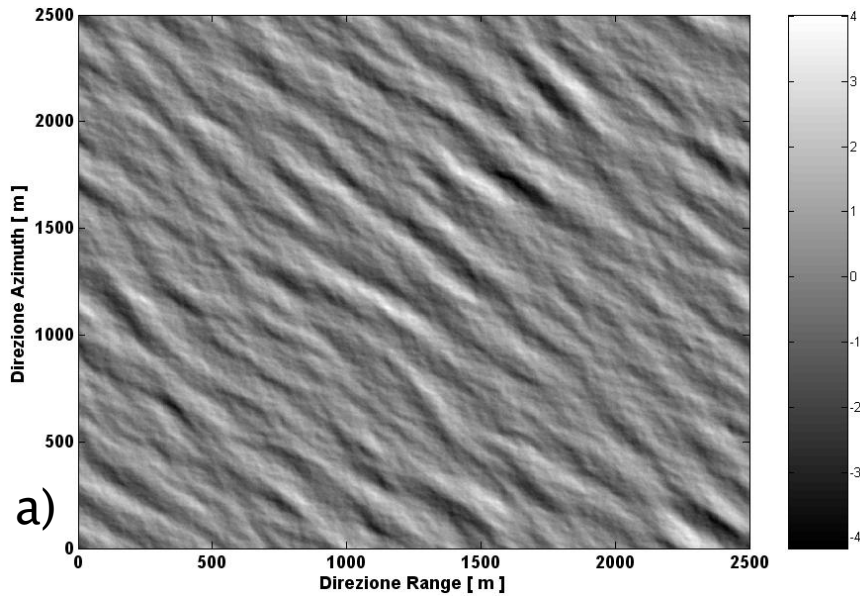
Cut-off



$$H_s = 4\text{m}; L_p = 200\text{m}; s_p = 75$$

- a) Elevazione superficie marina
- b) Modulazione RAR (solo tilt)
- c) Modulazione SAR (tilt + shift)

Risultati simulazione tilt + shift: Onde a 45°



$$H_s = 4\text{m}; L_p = 200\text{m}; s_p = 75$$

- a) Elevazione superficie marina
- b) Modulazione RAR (solo tilt)
- c) Modulazione SAR (tilt + shift)

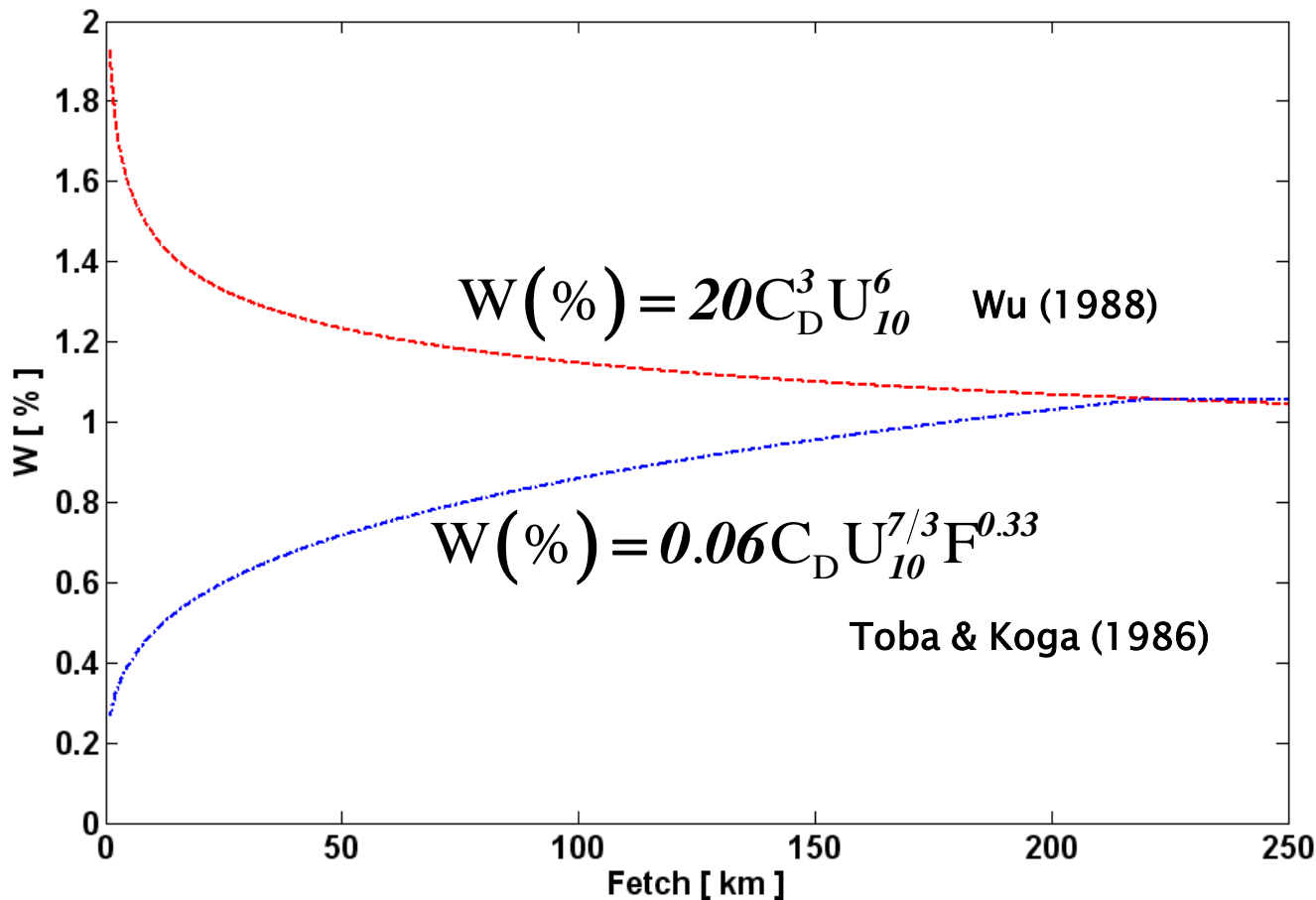
La rottura delle onde (whitecap formation)

(whitecap
formation)



Whitecap fraction variation

$$C_D = \frac{\kappa^2}{\left[12.505 + 0.358 \ln(F) - 2.716 \ln(U_{10})\right]^2} = \text{Wind drag coefficient}$$



Frazione di superficie di mare con presenza di whitecaps in funzione dell'estensione del fetch F e per una velocità del vento $U_{10} = 10 \text{ ms}^{-1}$

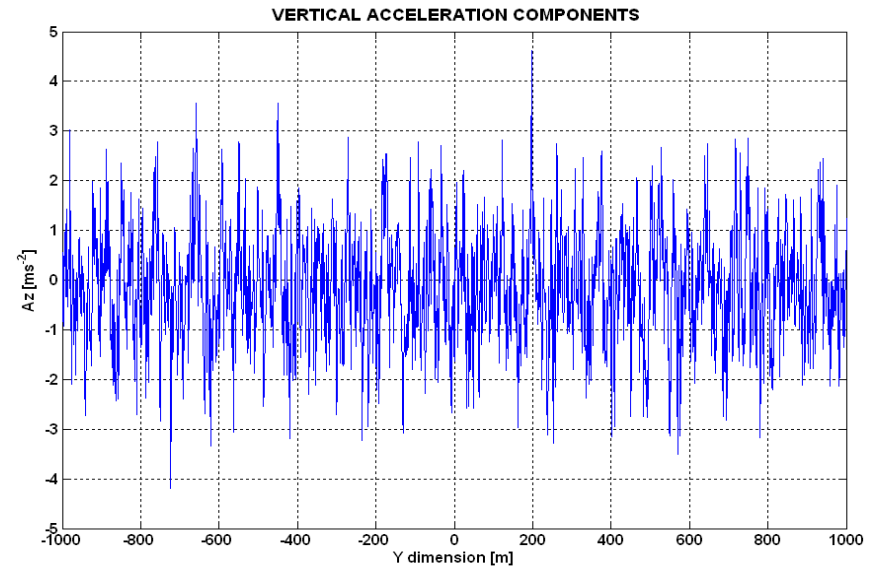
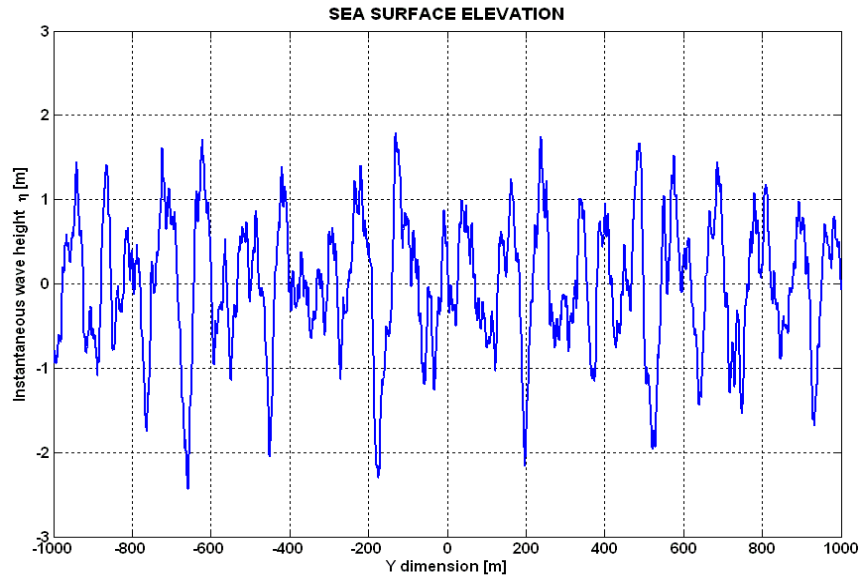
Problematiche

- 1) Dove è localizzata materialmente la rottura delle onde e la conseguente presenza di schiuma?
- 2) Qual è il coefficiente di backscattering della schiuma?

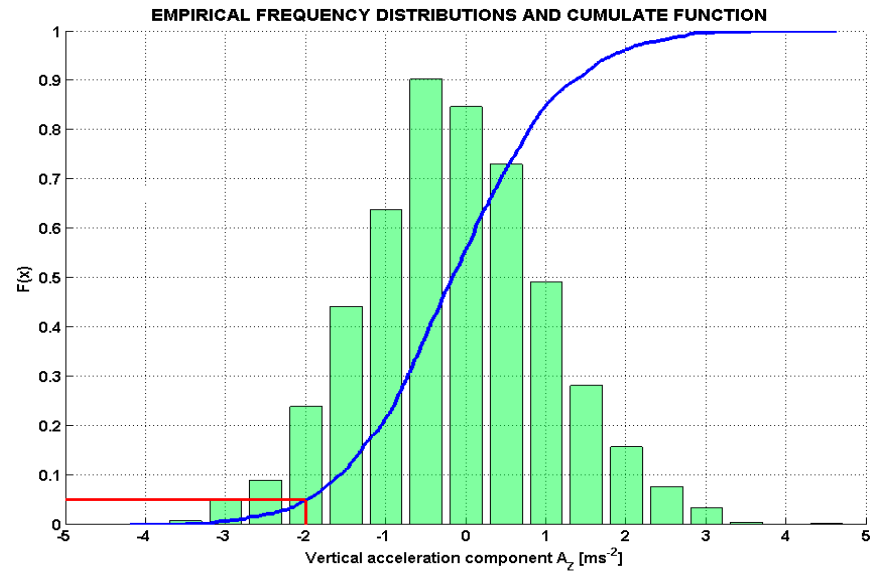
Sang - HO OH (2004)

- 1) Geometrico: la rottura avviene quando si ha il superamento di determinati valori soglia da parte di alcuni parametri legati alla geometria delle onde. Il parametro usato in genere è la ripidità dell'onda definita come rapporto H/gT^2 ed il valore soglia è fissato pari a 0.2
- 2) Cinematico: la rottura avviene quando il rapporto tra la componente orizzontale u delle velocità orbitali in cresta e la celerità di fase c delle onde è > 1
- 3) Dinamico: la rottura avviene quando la componente verticale negativa delle accelerazioni locali è inferiore ad un limite prefissato

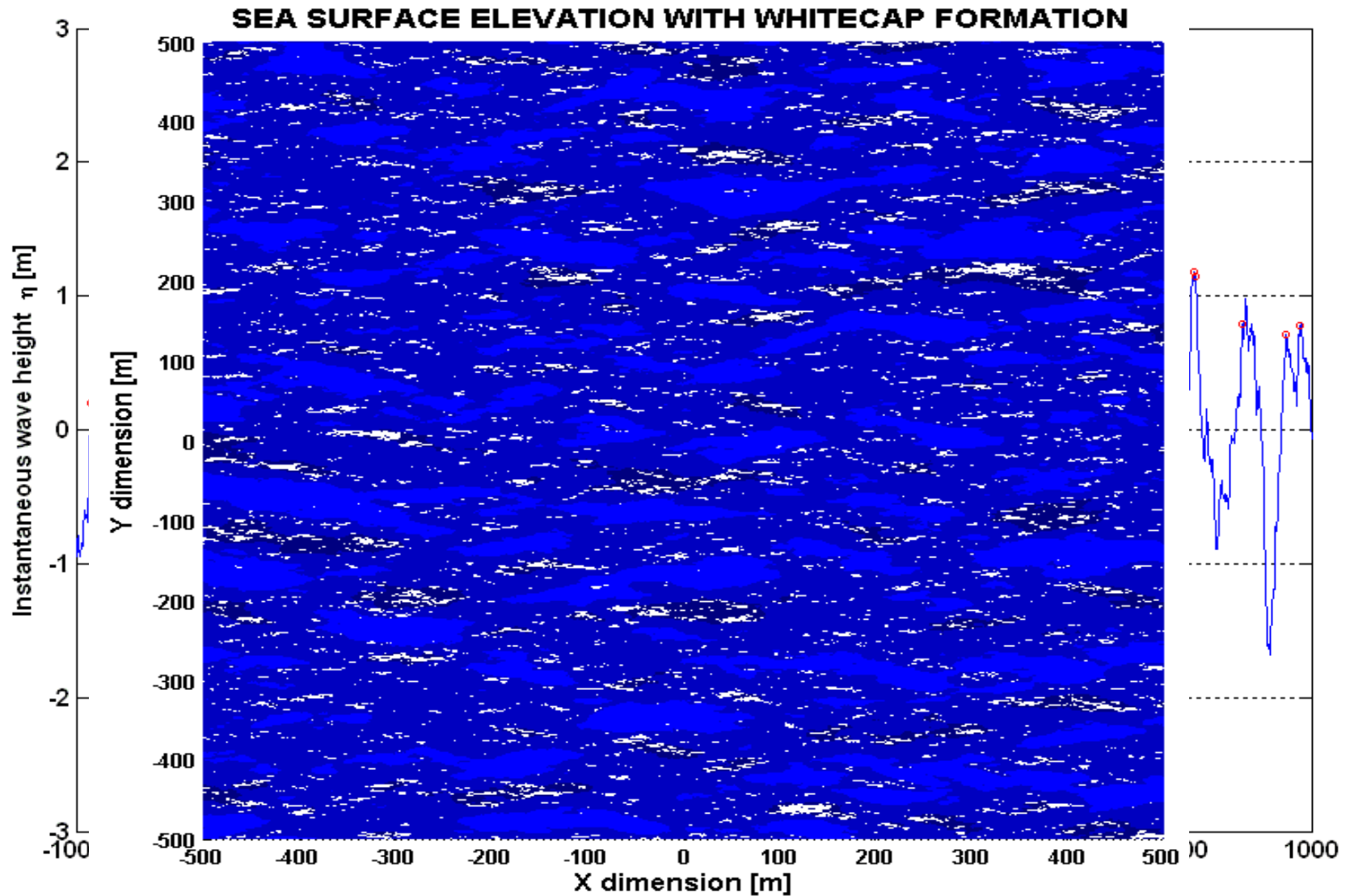
Inserimento della rottura nel nostro modello



Sang-HO OH
(2004)



Esempio pratico



Applicazione ad un caso reale

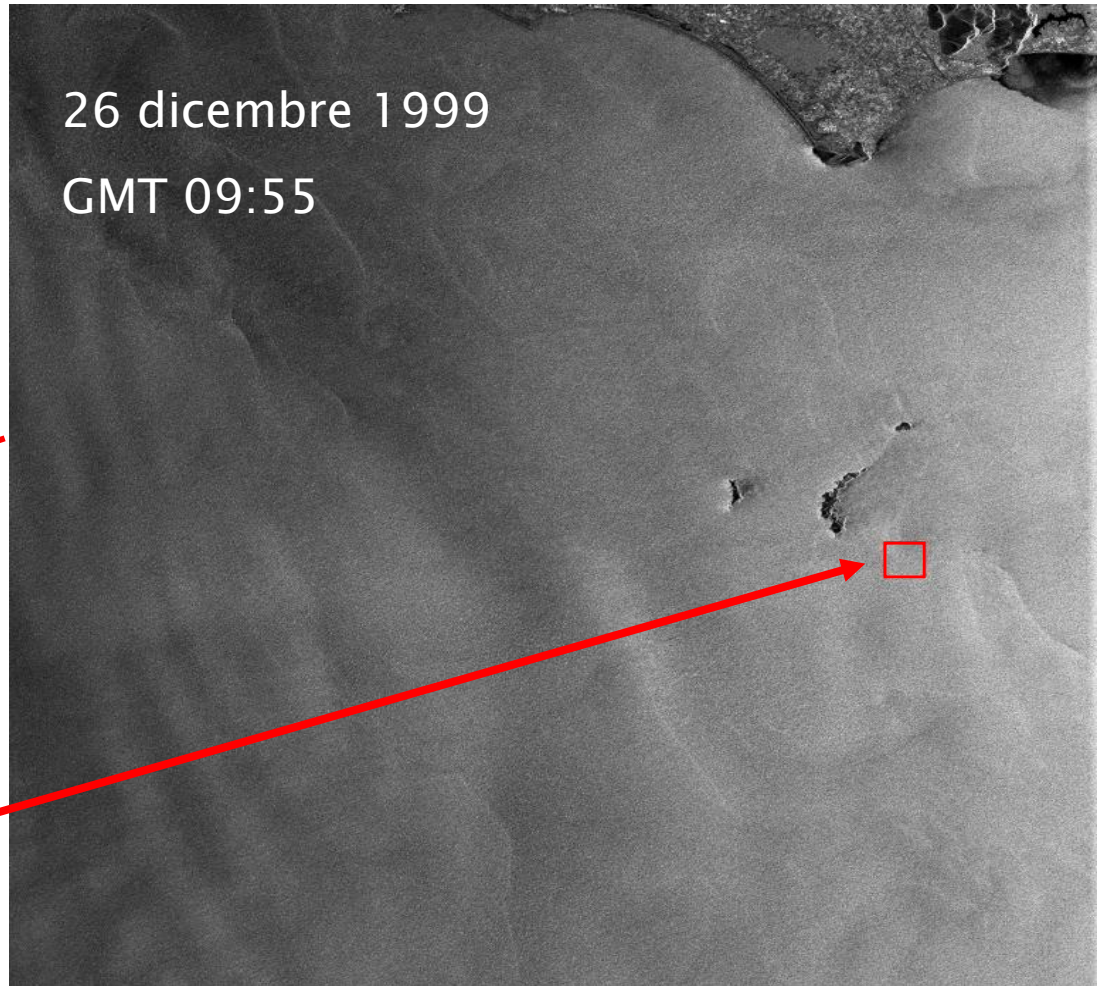
Satellite: ERS - 2
Orbita: 24482
Traccia: 79
Frame 2781
Passaggio
discendente



Area esaminata

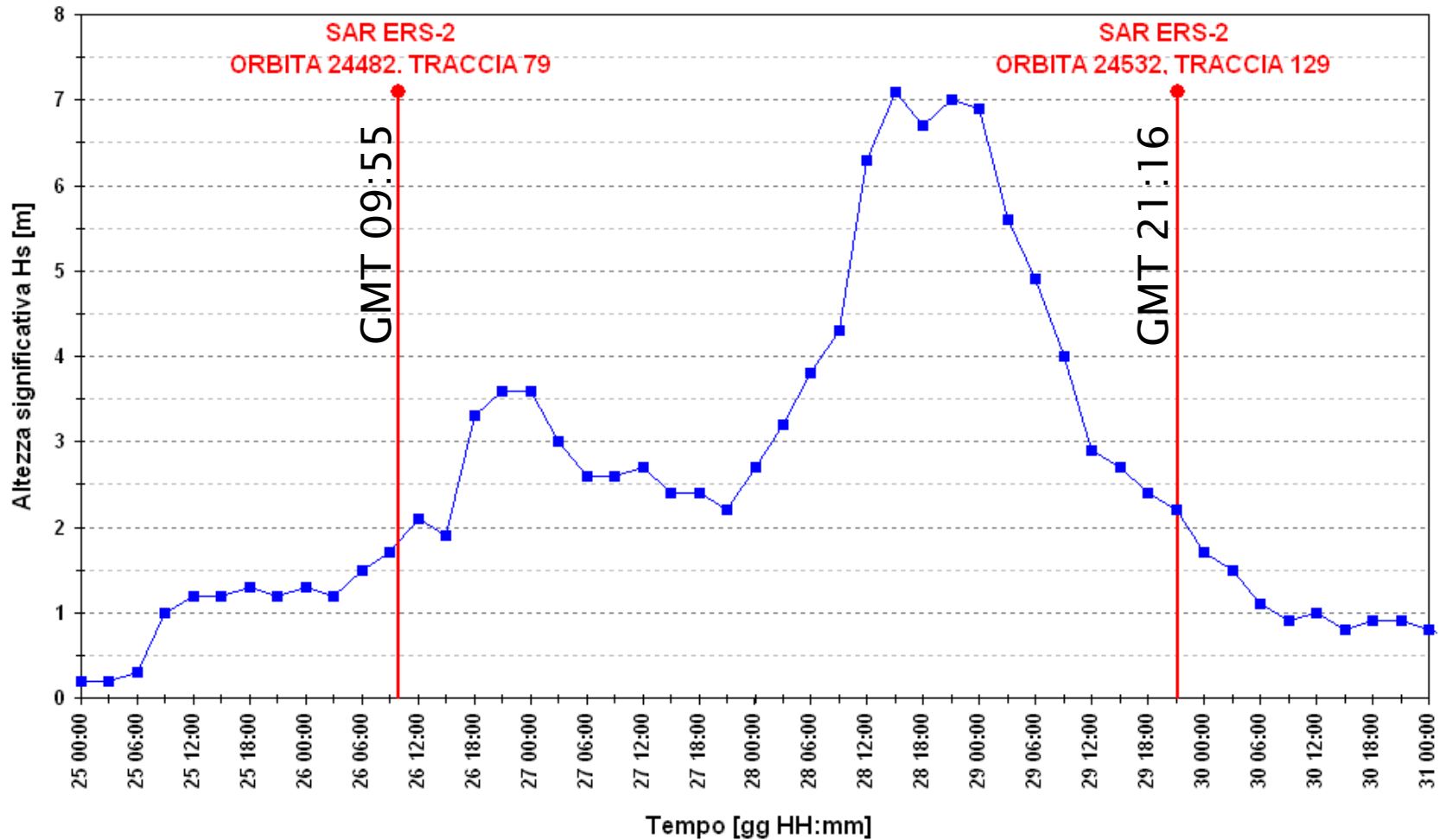
Immagine SAR nel mar Tirreno

26 dicembre 1999
GMT 09:55



Evento nel Tirreno del dicembre 1999

DATI BOA DI PONZA CON PASSAGGI SAR



Area esaminata e dati boa di Ponza

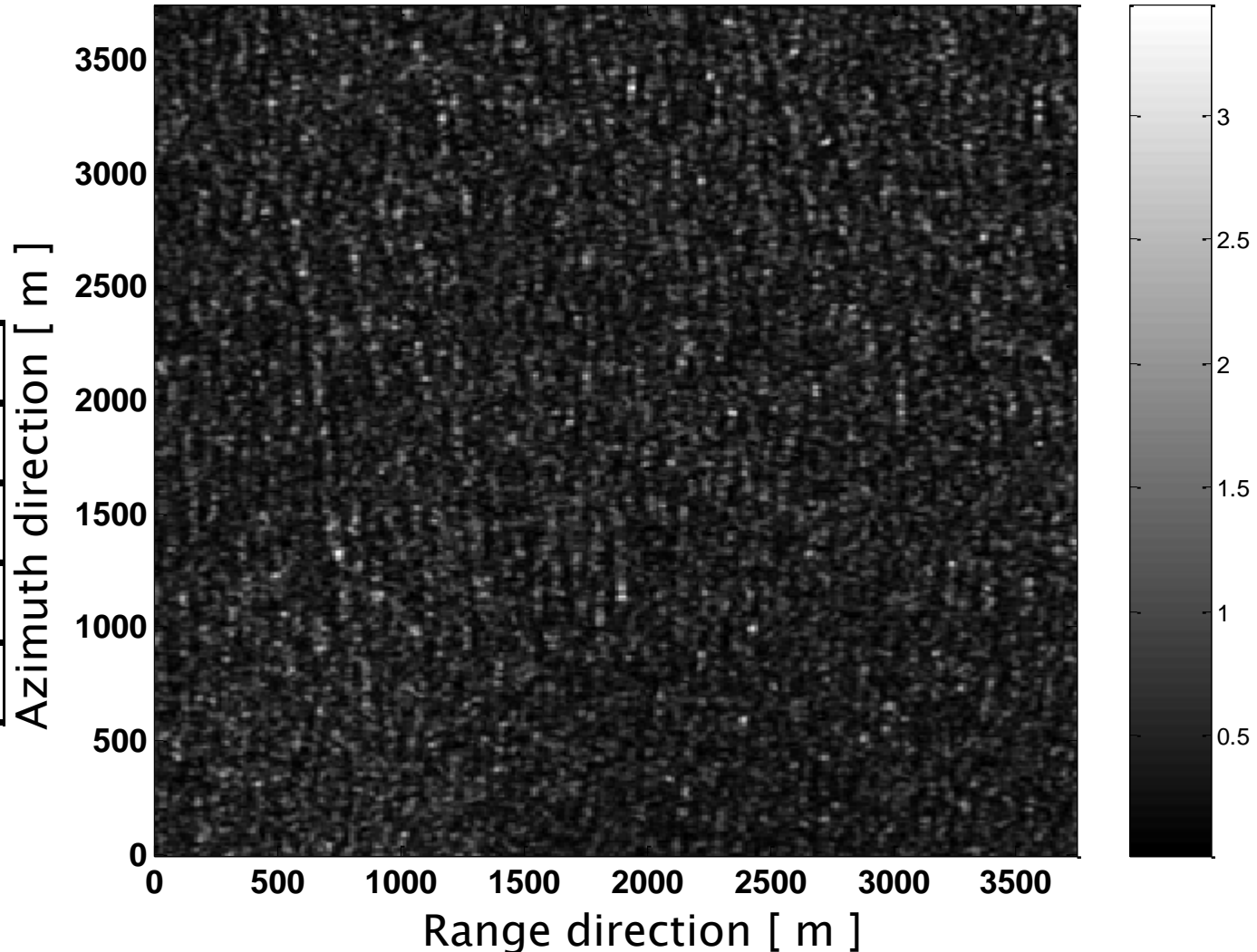
Dimension: 300 x 300 pixel

Backscattering coefficients σ_0

About 4km x 4km

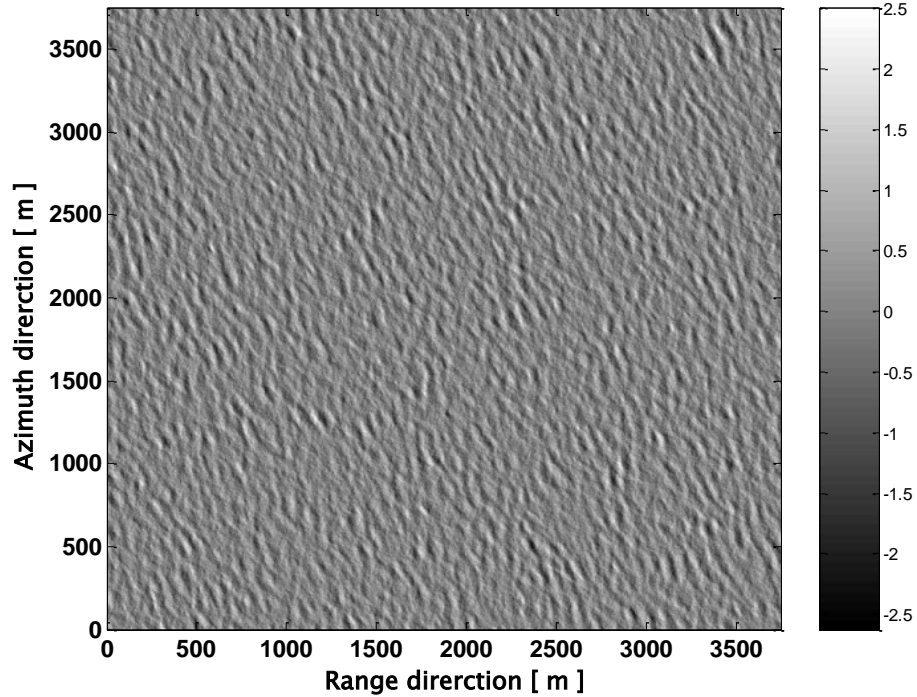
Wave data by Ponza
wave buoy

26 December 1999	
Time: 09:00	Time: 12:00
Hs = 1.70 m	Hs = 2.10 m
Tp = 6.7 s	Tp = 7.1 s
Dir = 66°	Dir = 56°

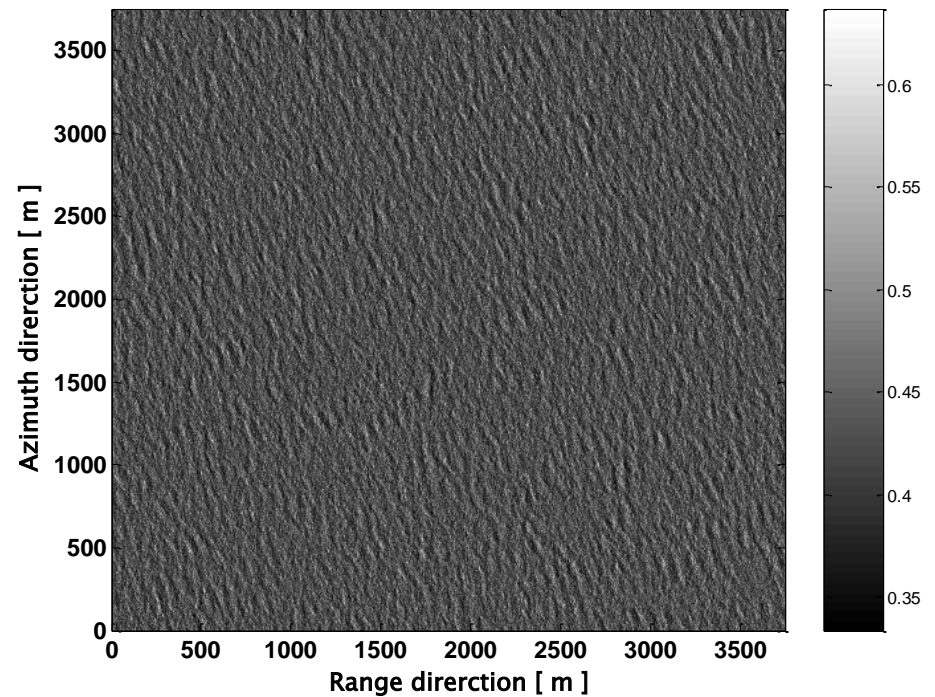


Risultati simulazione

SEA SURFACE ELEVATION

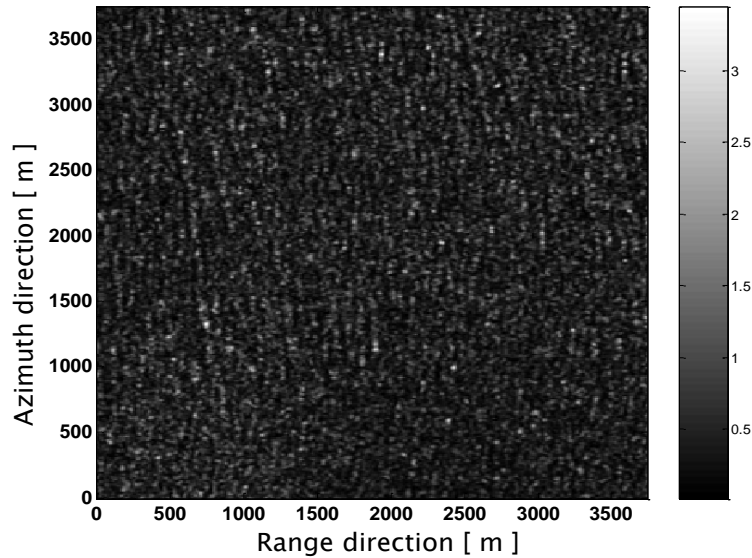


TILT EFFECT RECONSTRUCTION pixel dimension 1 m x 1 m



Risultati simulazione

Backscattering coefficients σ_0



SAR IMAGE RECONSTRUCTION pixel dimension 12.5m x 12.5m

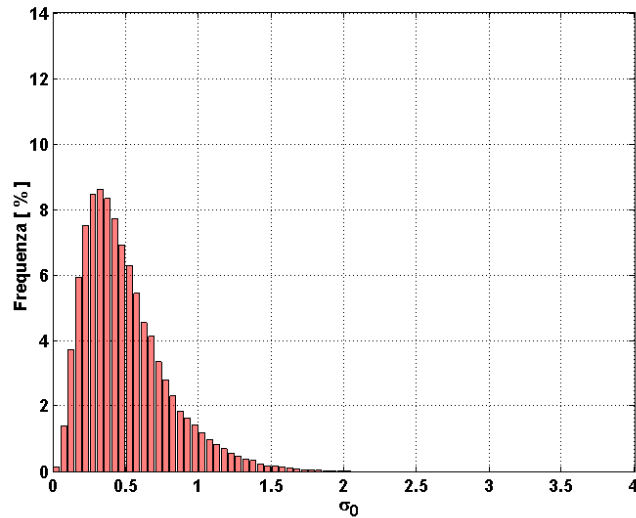
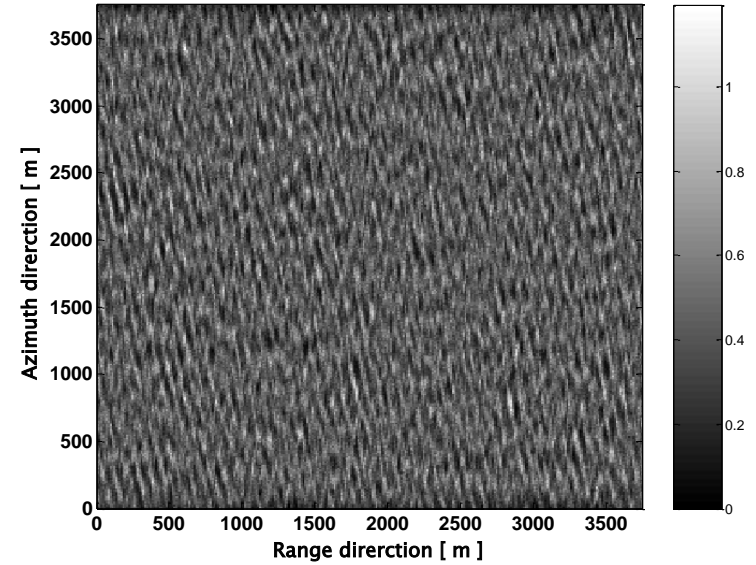


Immagine reale

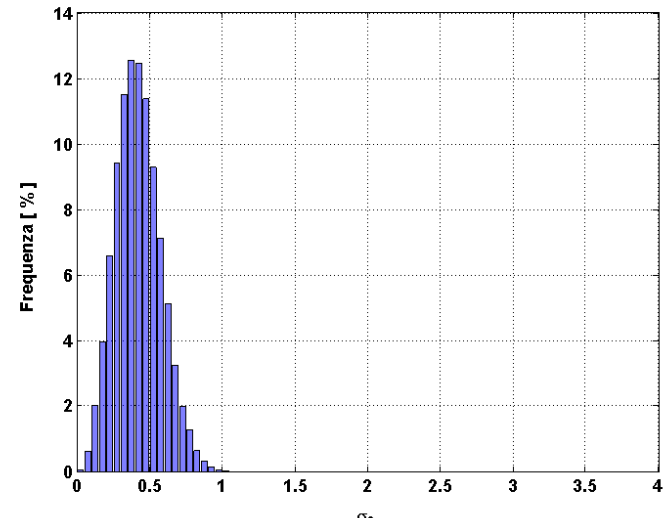
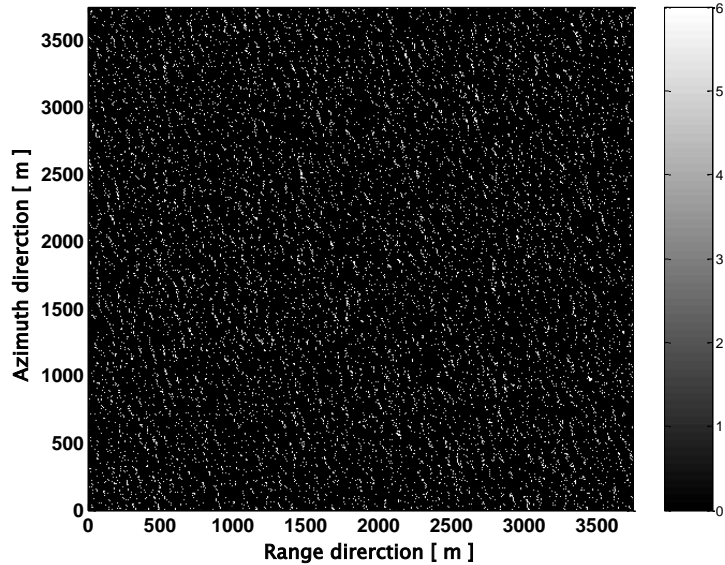


Immagine σ_0 simulata

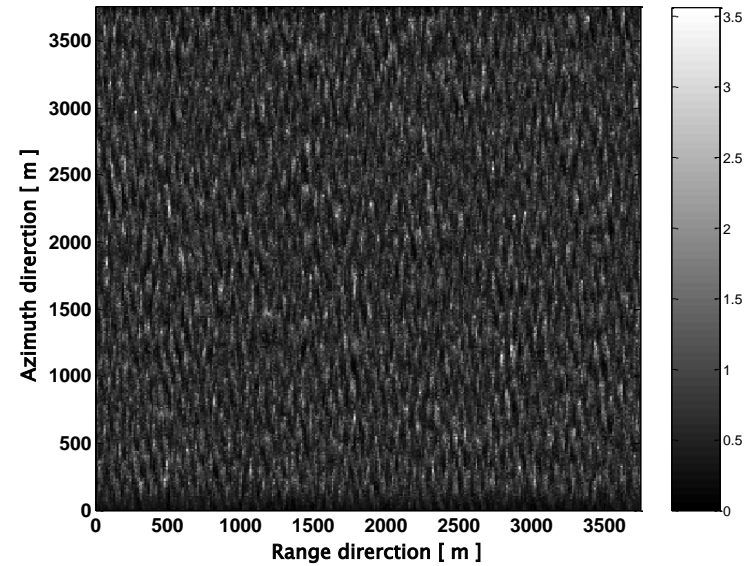


Introduzione whitecaps

WHITECPAS LOCATION

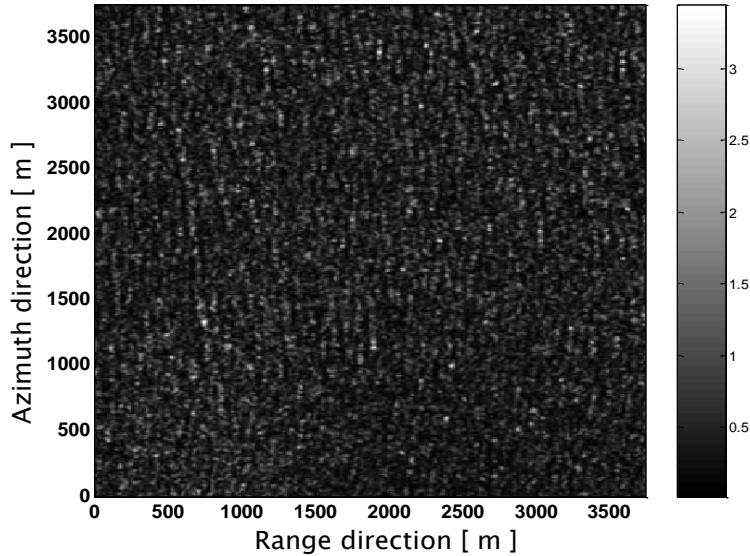


SAR IMAGE WITH WHITECAPS pixel dimension 12.5m x 12.5m



Risultati simulazione con whitecaps

Backscattering coefficients σ_0



SAR IMAGE WITH WHITECAPS pixel dimension 12.5m x 12.5m

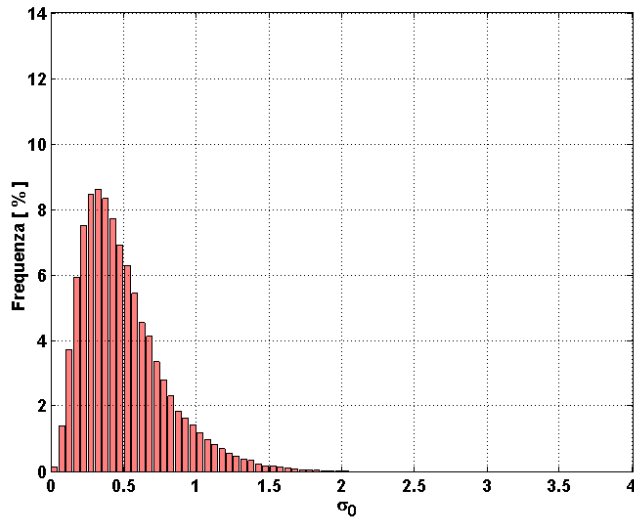
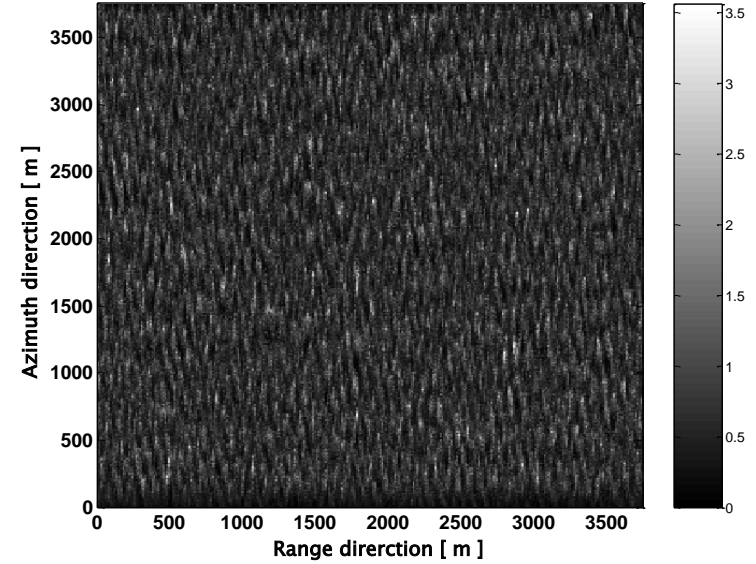


Immagine reale

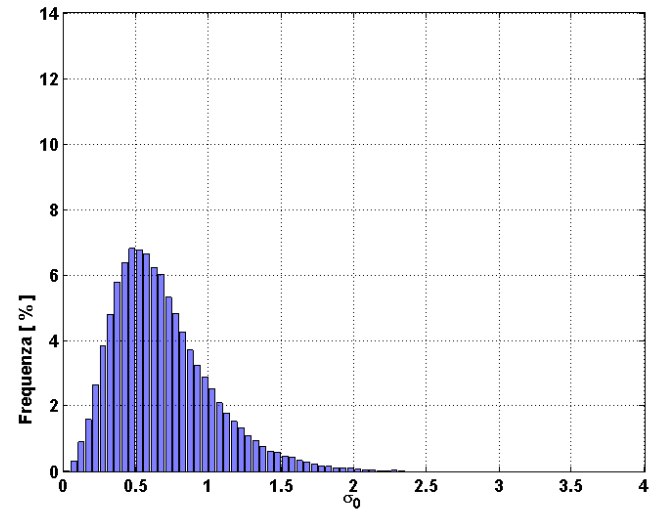


Immagine simulata

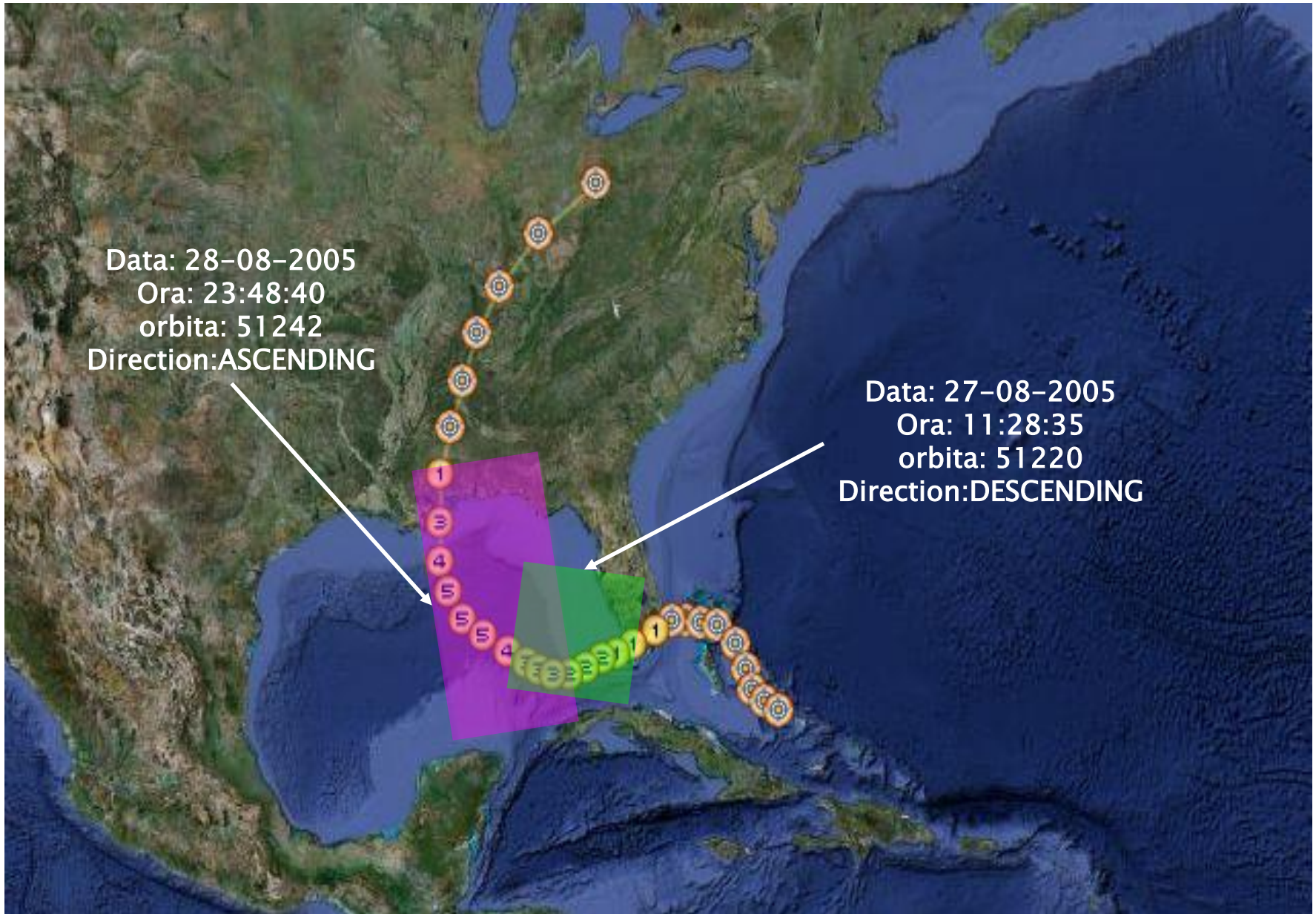


RADARSAT HURRICANE APPLICATIONS PROJECT



Principal Investigators (PIs)	PI Affiliations	Co-Investigators (CIs)	CI Affiliations
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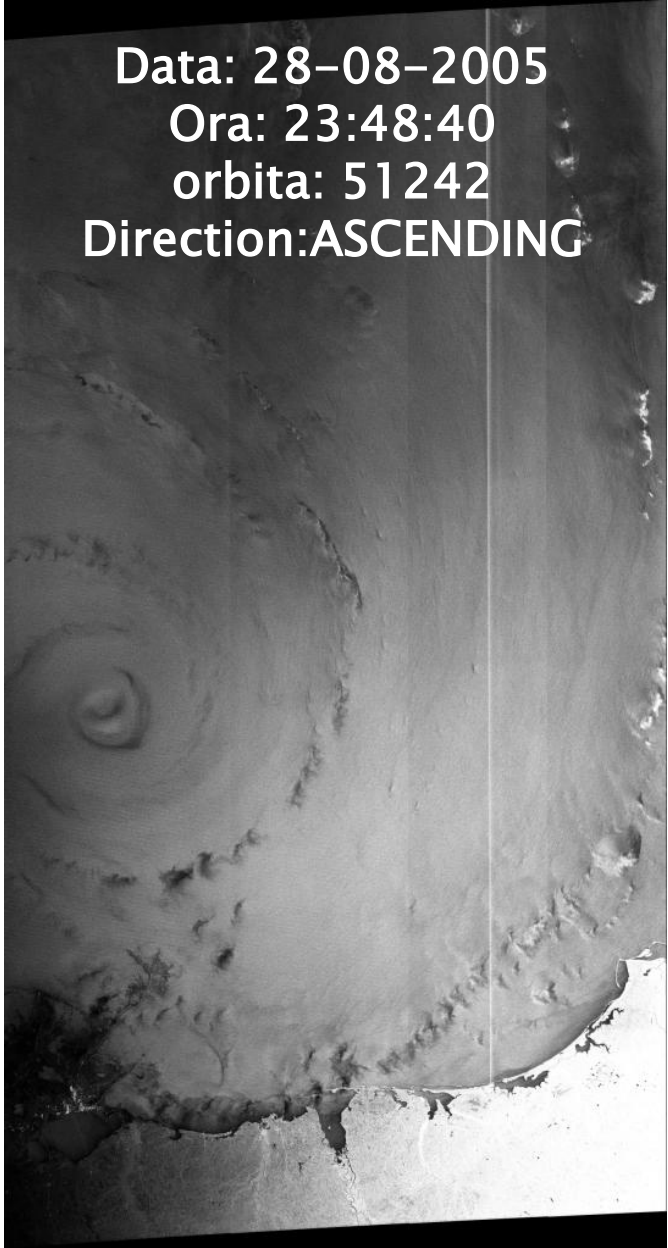
L'uragano Katrina

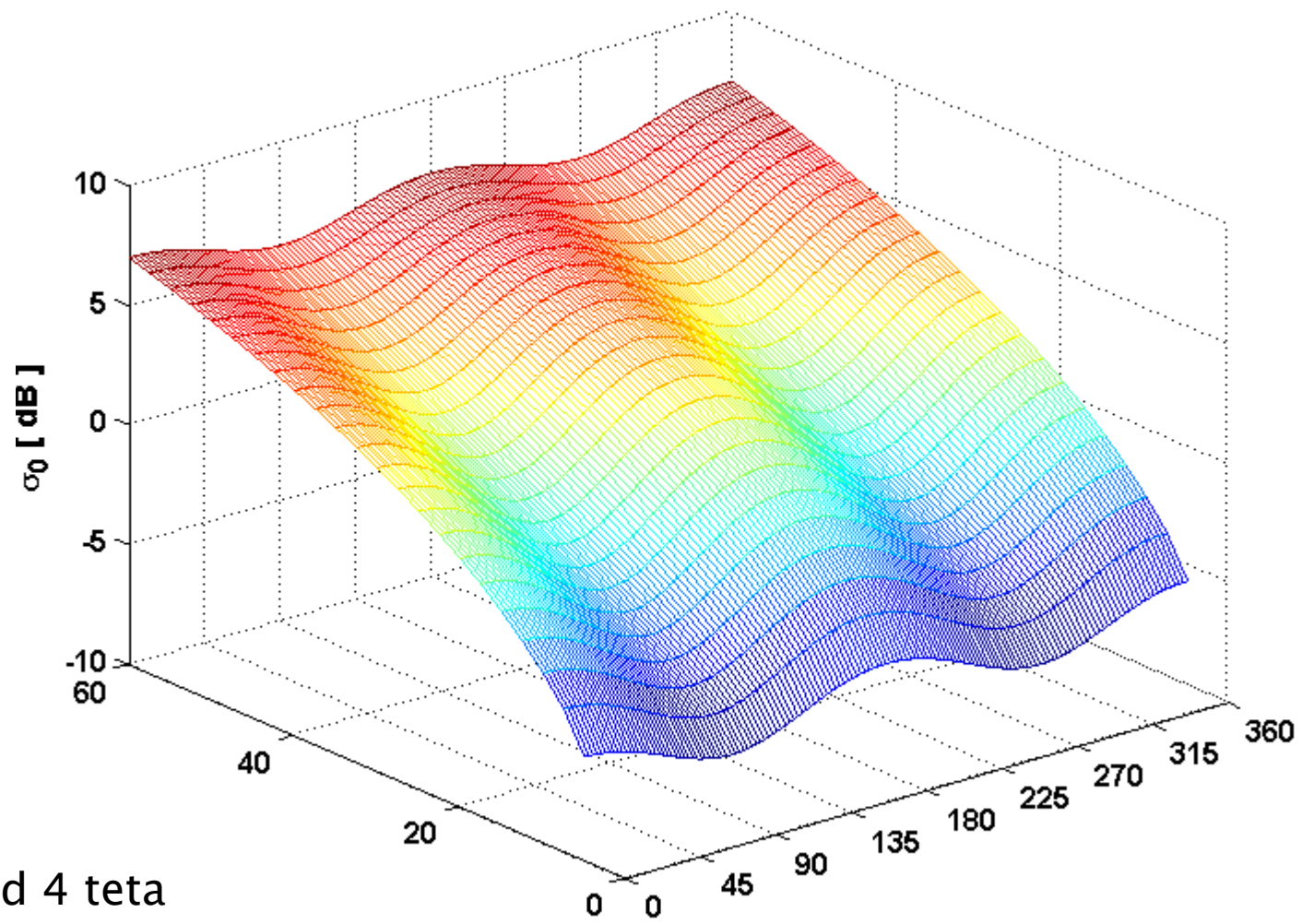


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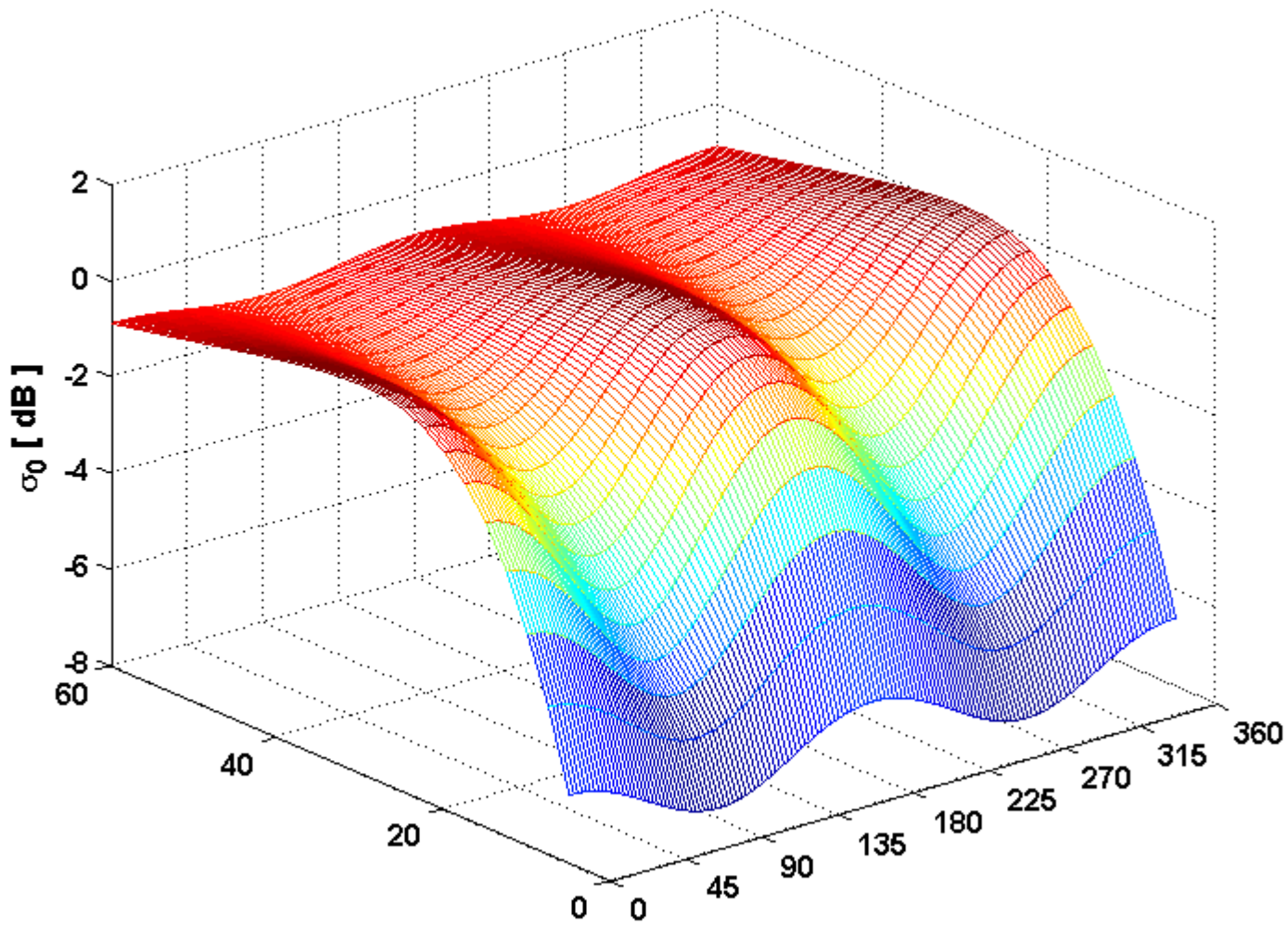


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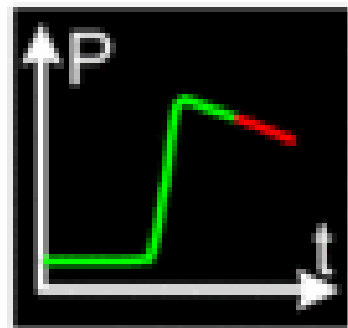
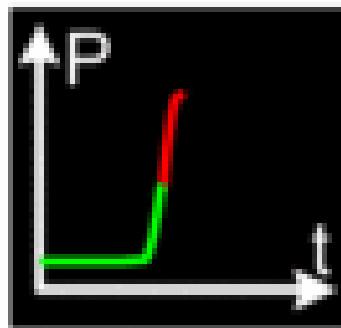
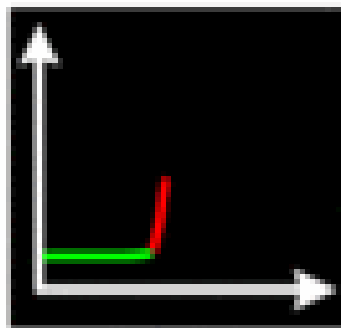
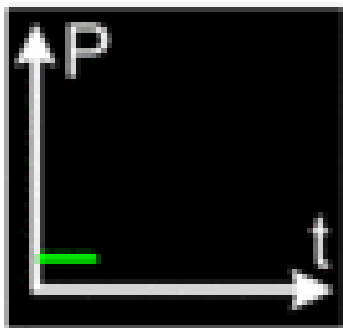
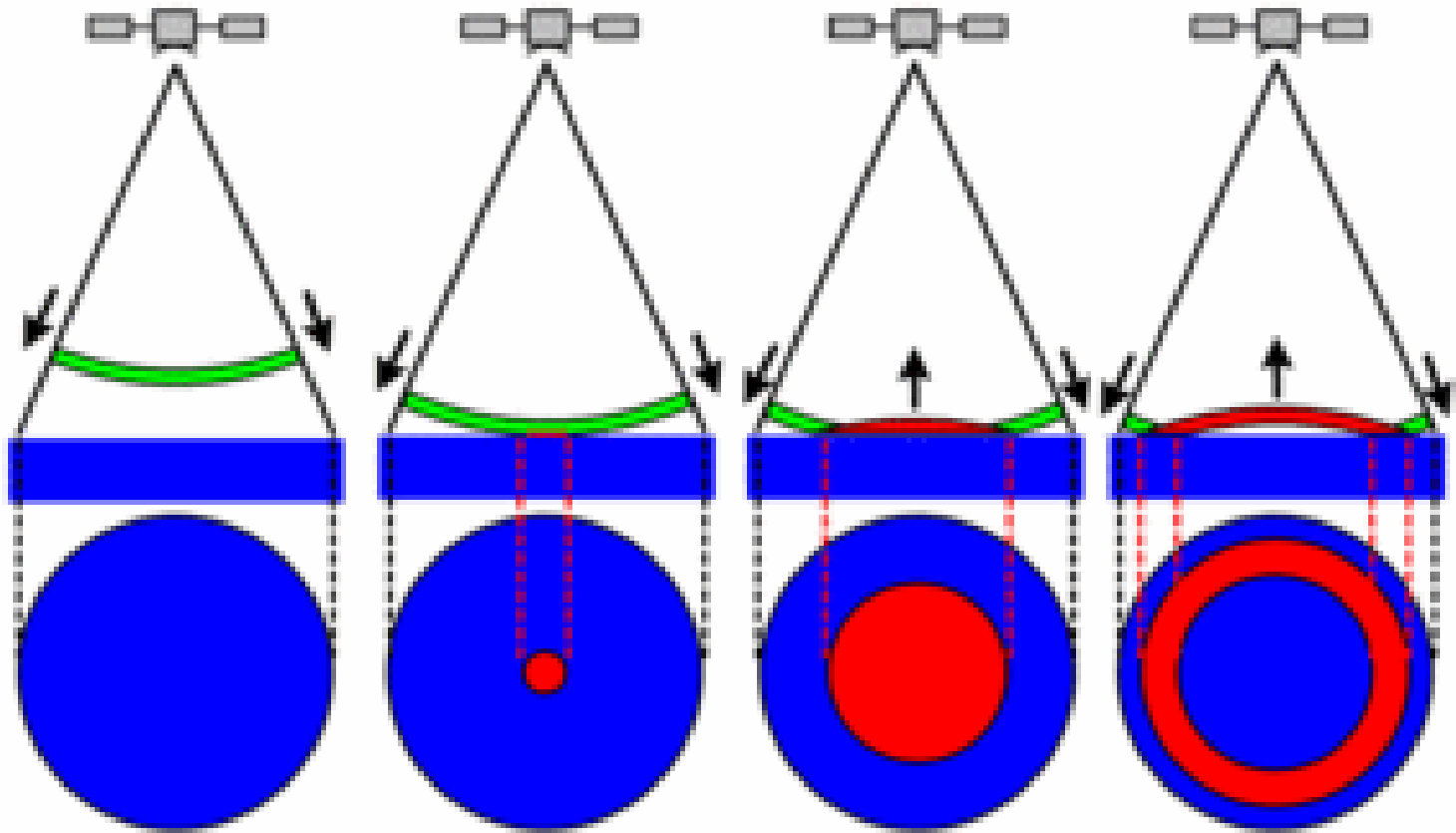


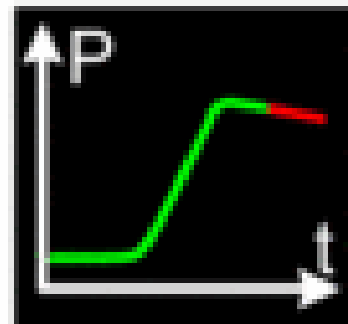
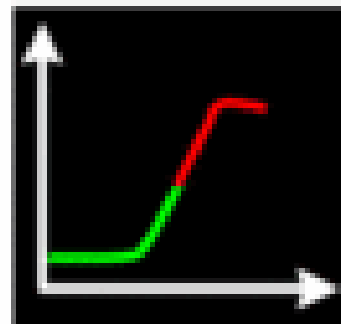
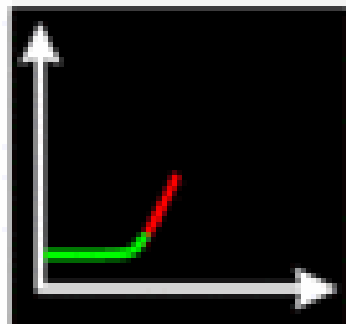
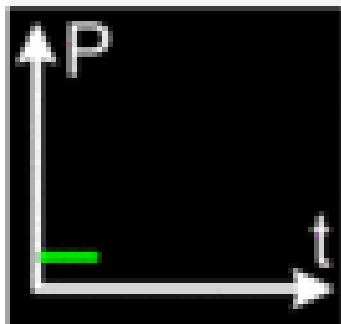
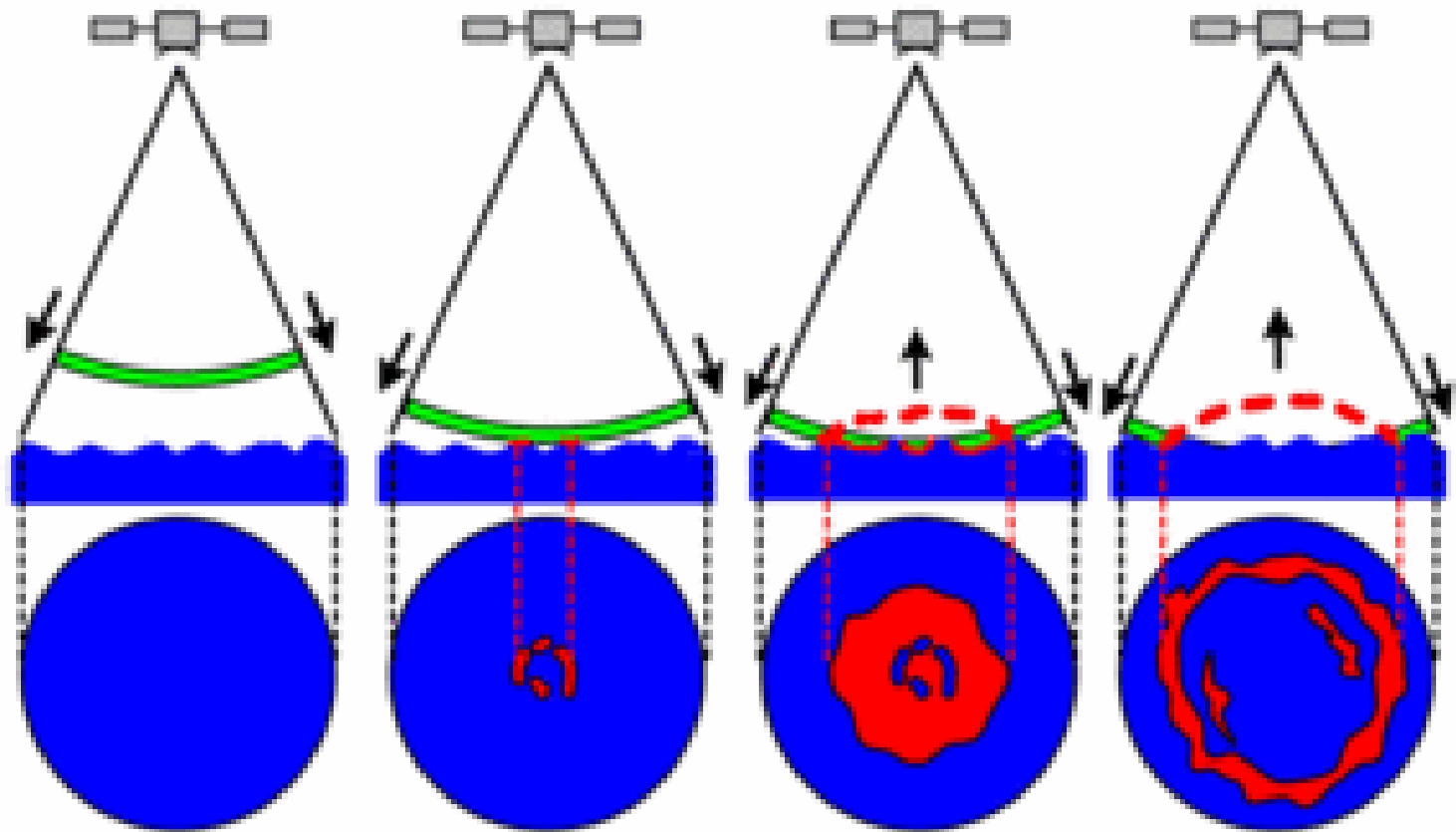


Cmod 4 teta
=23°



Cmod 5 teta ()
=23°





epoch at
mid-height τ

