TANGOSat-Data For Sea Ice Research

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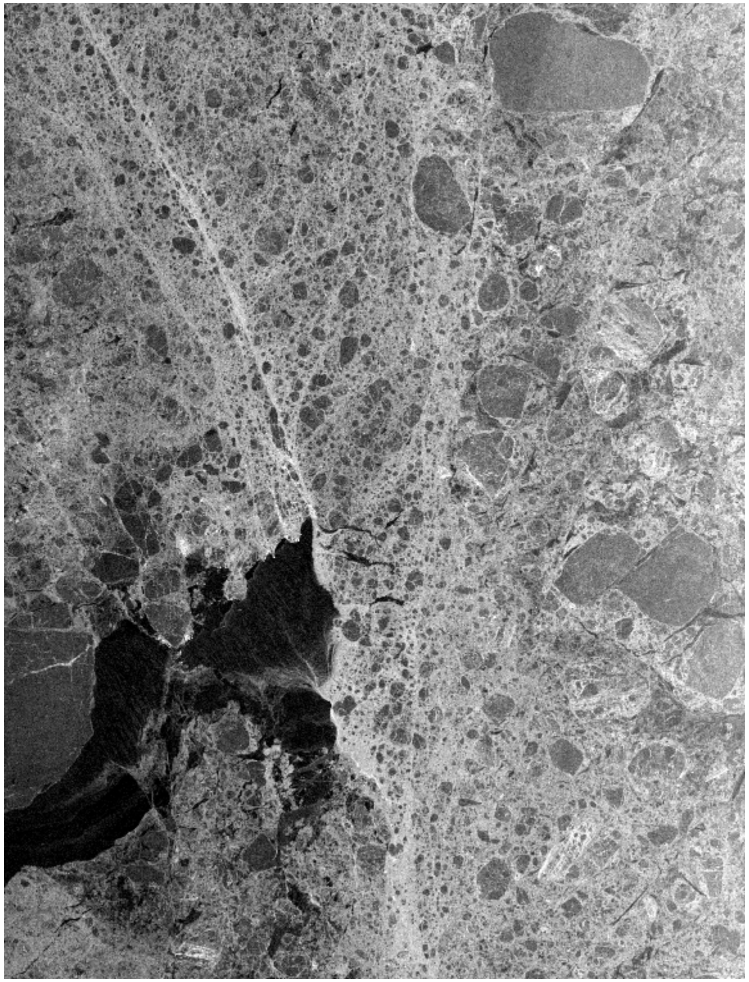
L-Band For Sea Ice Research

- high sensitivity to ice deformation structures
- better classification performance during the melt season
- less sensitive to surface covers such as frost flowers, snow crusts



JERS-1 SAR, Greenland Sea

Sea Ice Drift And Temporal Decorrelation

SAOCOM/TANGOSat:
Sea ice moves on temporal scales of hours
-> single-pass
interferometry required

Ice drift mainly in the range from 0-35km/day.
10 km/day = 0.116 m/s

Satellite velocity along orbit: 7.53 km/s
(H=620km, R=6371km,
T=97.2min)

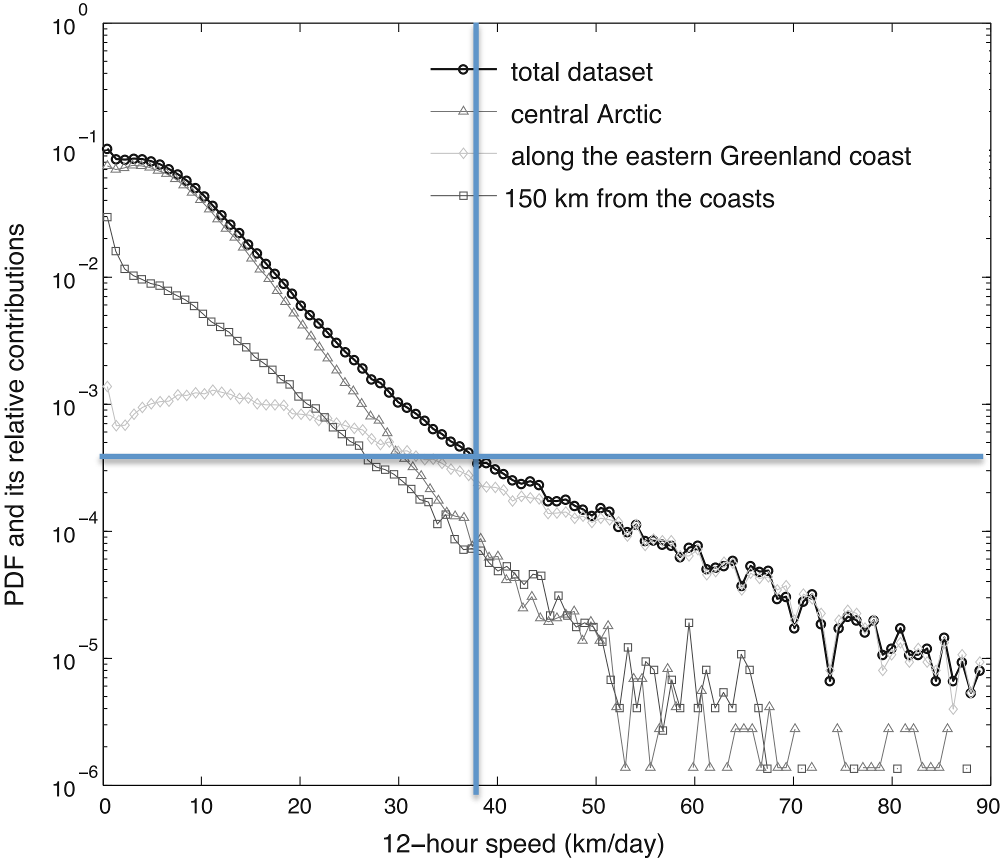


Figure 2. Probability density function of the 12-h speeds computed from the total IABP data set and its contributions coming from the regions drawn in Figure 1.

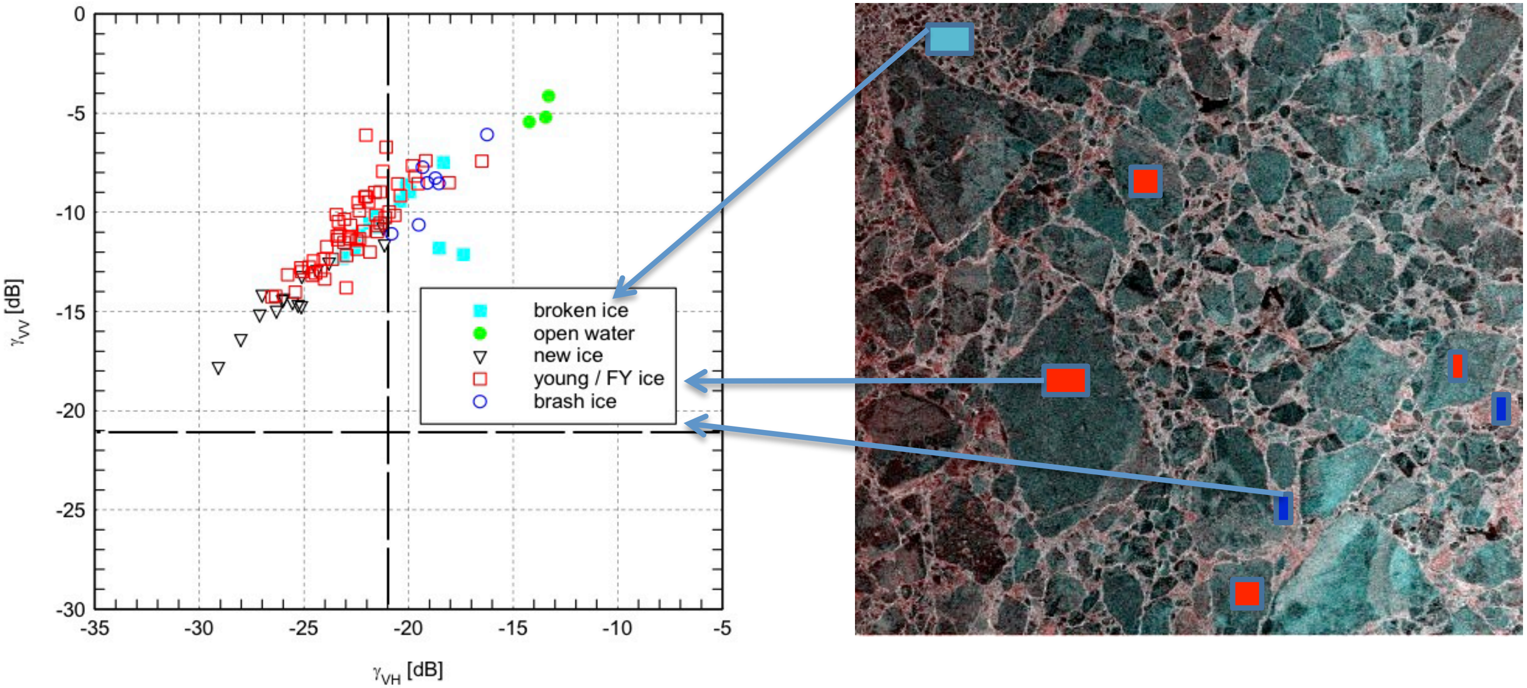
From Rampal et al., JGR, 2009

TANGOSat: Scientific Potential For Sea Ice

- Use of bistatic σ^0 for sea ice classification?
- XT-baseline: information about ice surface structure and ice freeboard?
- AT baseline: snapshots of ice drift components?
- Tomographic imaging for vertical profiles of scattering intensity: feasible at all?

Developing Sea Ice Classification Schemes Today

- monostatic measurements of, e. g., radar intensities for different ice types
- comparison with field data (e. g. airborne radar vs. air photos)
- cluster analysis for fixing thresholds
  (thresholds depend on sensor, ice regime, season)
- investigations available on multi-polarization, different frequencies



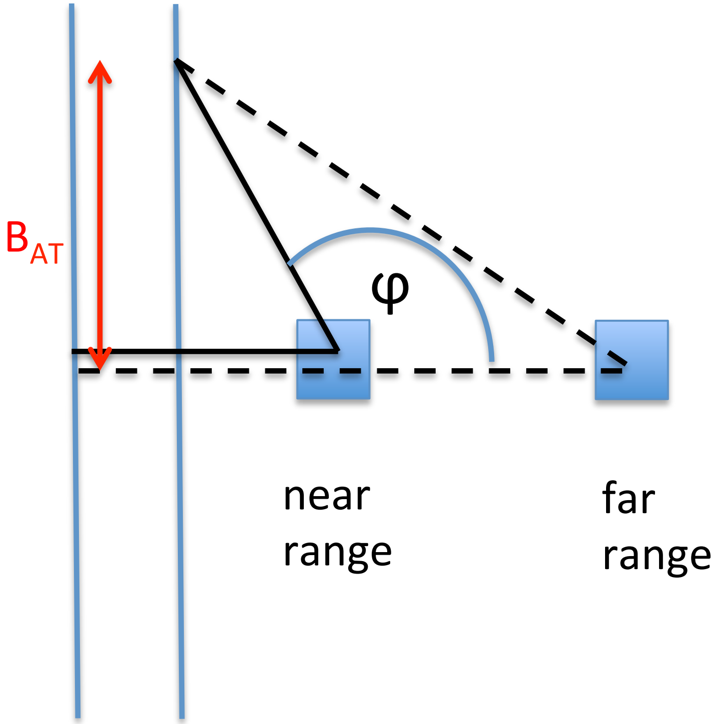
Airborne SAR data acquired during ICESAR 2007, preparation of ESA’s Sentinel-1 mission

TANGOSat For Ice Type Classification

Motivation using TangoSAT for sea ice classification:

- (SAOCOM: L-Band)
- Test classification performance when using both bistatic scattering coefficient $\sigma^0(\theta_1,\theta_2,\varphi_1,\varphi_2)$ and backscattering coefficient $\sigma^0(\theta)$

Bistatic σ^0 For Ice Type Classification



(projected on ground)

Measurements:

$\sigma^0_{pq}(\theta_i, \theta_s; \varphi_i=0°, \varphi_s)$

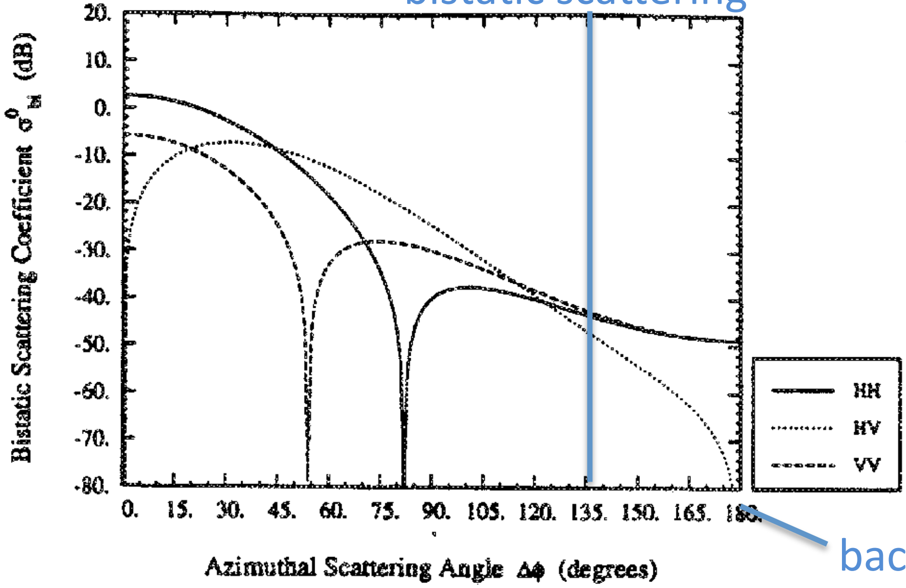
$\sigma^0_{pq}(\theta_i, \theta_s= \theta_i; \varphi_i=0°, \varphi_s=180°)$

Backscattering along-range:
incidence angle variations
PLUS
azimuth angle variations

Increasing along-track baselines:
differences 180°- φ_s and $\theta_s - \theta_i$
get larger
-> advantage for classification

Bistatic σ^0 For Ice Type Classification

Roger D. De Roo,
PhD thesis,
University of Michigan,
1996



bistatic scattering

backscattering

“large-scale”
surface
roughness

Figure 2.17: Geometric Optics bistatic scattering coefficients for all polarizations vs. azimuthal scattering angle with rms slope fixed at $m = 0.1$, $\sigma^0_{vh} = \sigma^0_{hv}$ for Geometric Optics $\epsilon_r = 3.0 - j0.0$, $\theta_i = \theta_s = 45°$. Backscattering corresponds to $\phi_\Delta = 180°$ and specular scattering corresponds to $\phi_\Delta = 0°$.

Model simulations of bistatic surface scattering, here for X-band; corresponding scaling of roughness -> L-band

Bistatic σ^0 For Ice Type Classification

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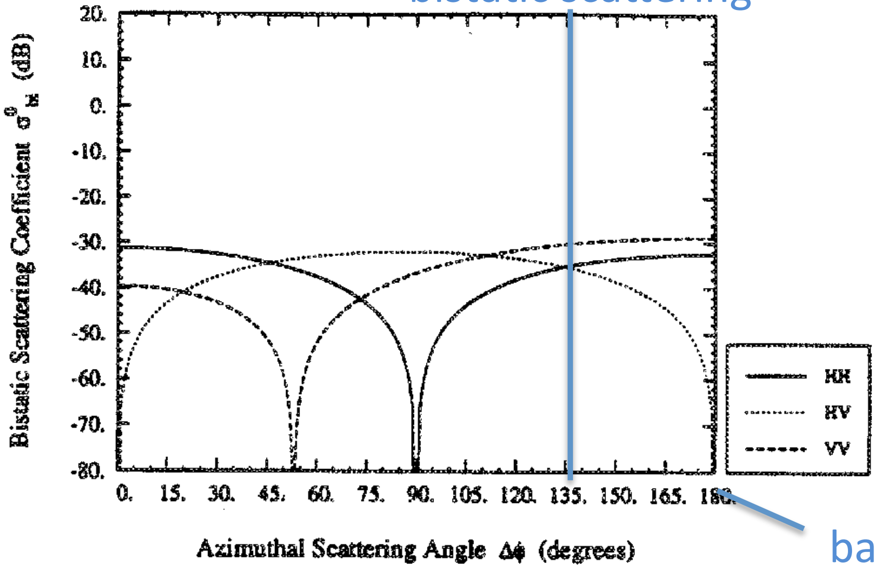


backscattering

“small-scale”
surface
roughness

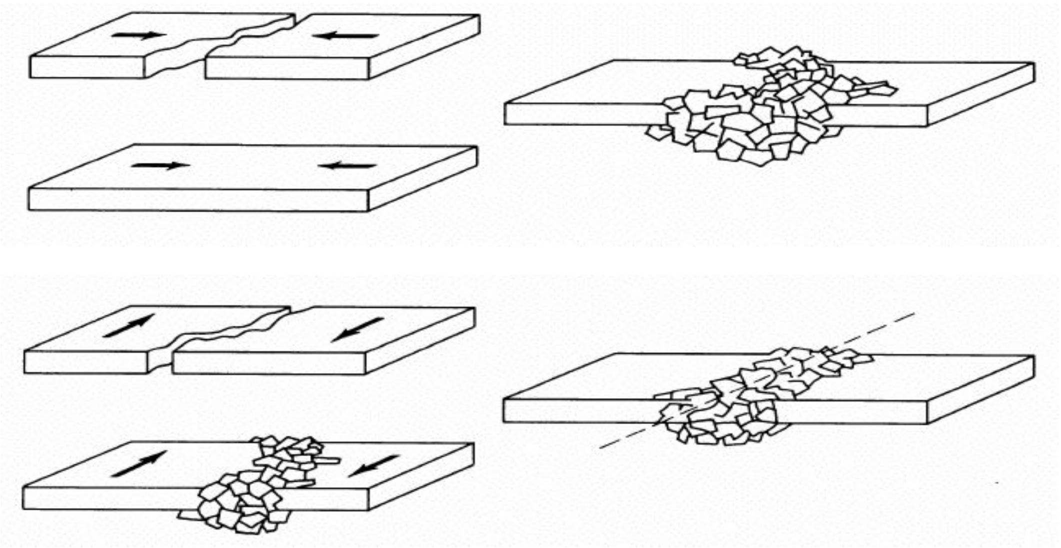
Figure 2.37: First Order Small Perturbation bistatic scattering coefficients for all polarizations vs. azimuthal scattering angle for a Gaussian surface with rms slope fixed at $m = 0.1$, $\epsilon_r = 3.0 - j0.0$, $k\sigma = 0.1$, $\theta_i = \theta_s = 45°$. Backscattering corresponds to $\phi_\Delta = 180°$ and specular scattering corresponds to $\phi_\Delta = 0°$. $\sigma^0_{vh} = \sigma^0_{hv}$.

Model simulations of bistatic surface scattering, here for X-band; corresponding scaling of roughness -> L-band

Sea Ice Surface Topography: Pressure Ridges

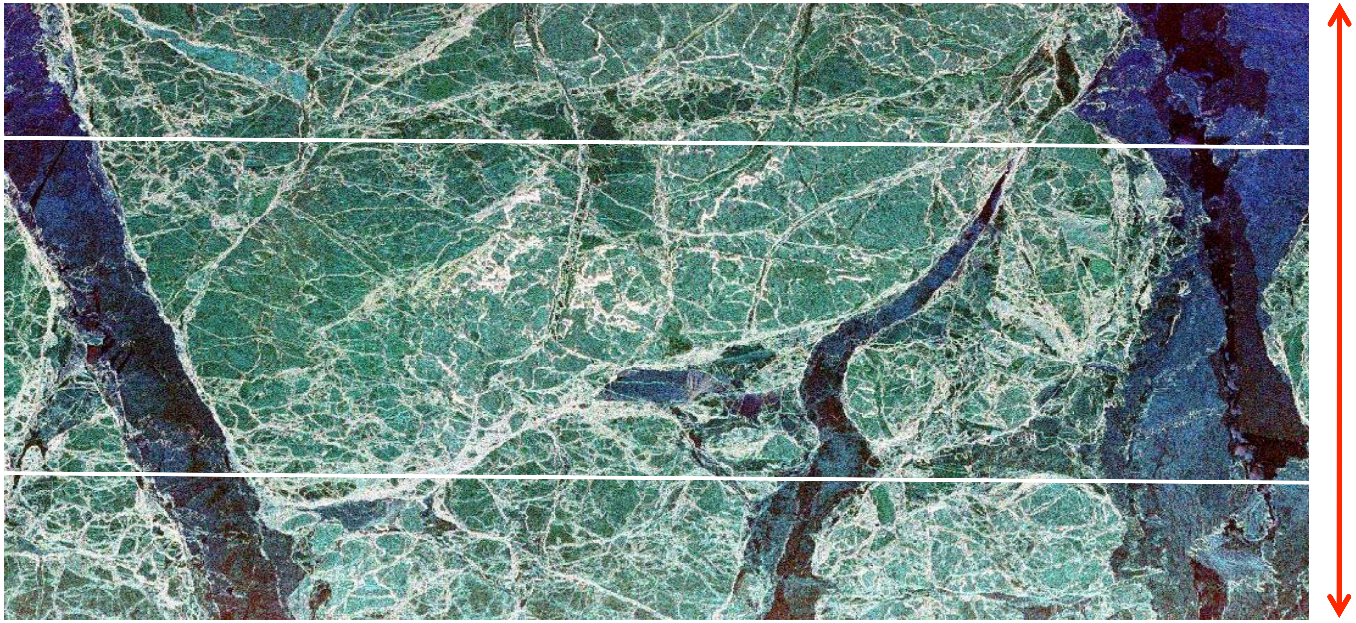
pressure ridges:

- height above level ice surface: typically 0.5 – 3 m, rarely > 10 m
- spacing: 10 – several 100s m



Ice Surface Structures In Optical And Radar Images

AWI/Optimare
Airborne
Color Line-Scanner
Resolution < 1m



DLR ESAR:
L-Band SAR
R: X-Pol.
G: H-Pol.
B: V-Pol.

3 km

spatial res. 3 m
5-8 looks

Fram Strait

Radar (at lower frequencies) “looks through“ the dry snow, volume structures in the ice are partly visble.

XTI for Ice Surface “Topography” And Freeboard

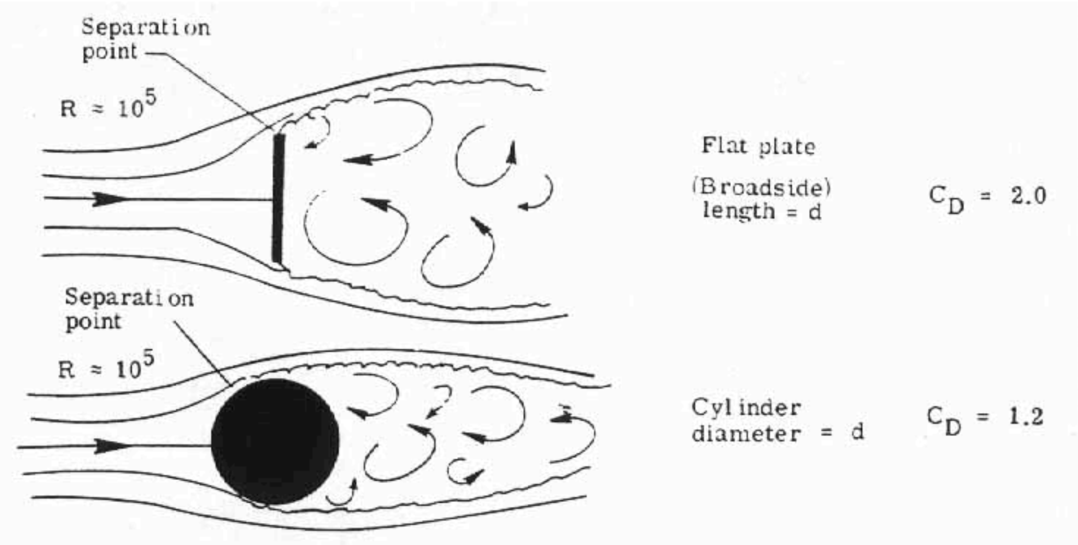
Retrieval of ice surface structure h(x,y) and freeboard f_{ice}

Motivation:

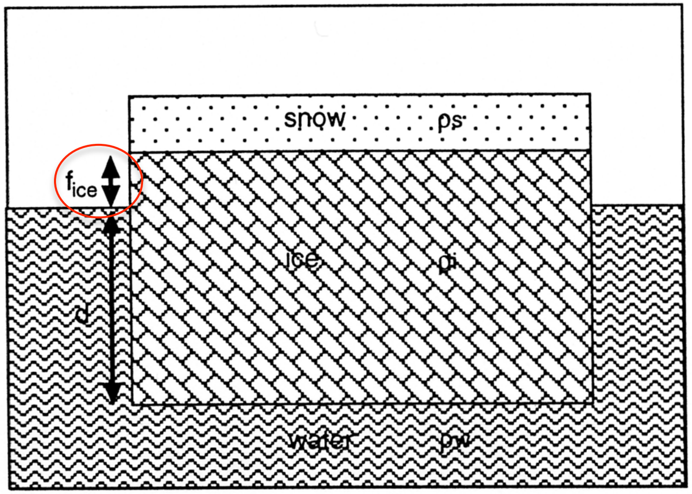
-> “roughness”: boundary layer meteorology

-> “deformation”: ice mass balance

-> “freeboard”: ice thickness



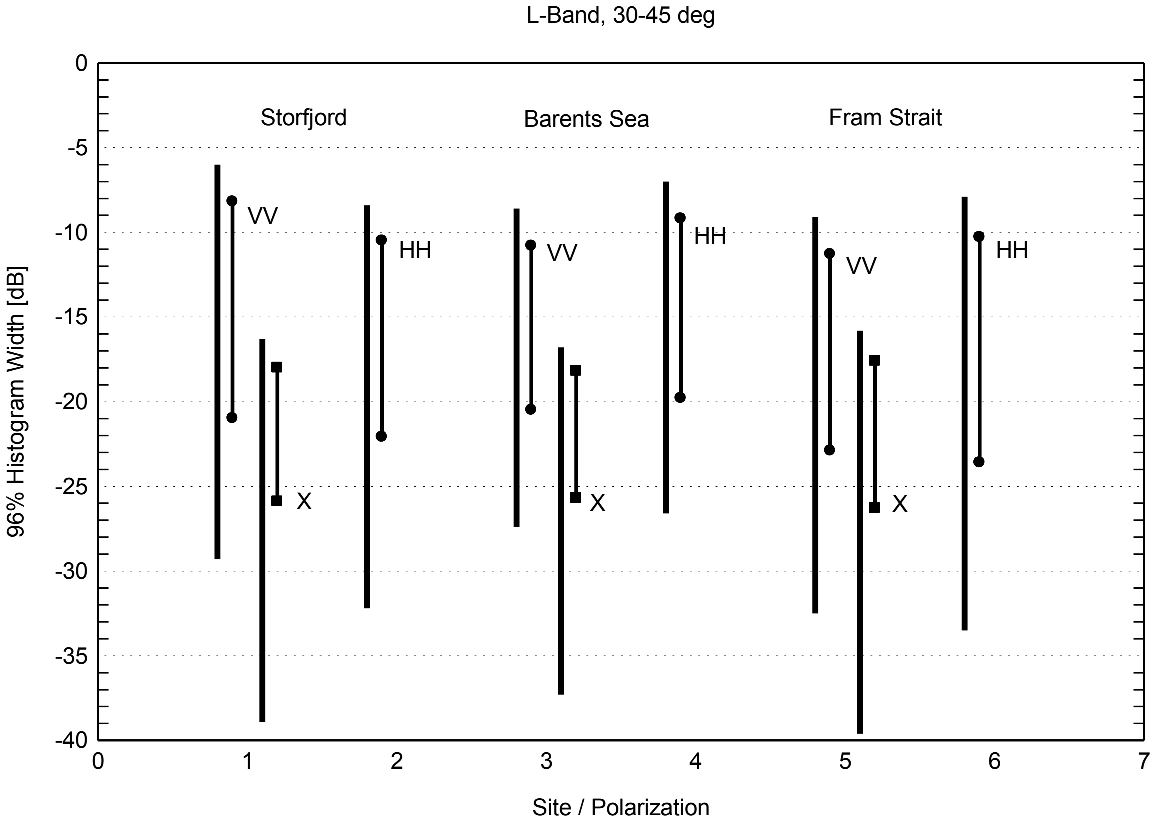
interaction sea ice – atmosphere:
parameterized by drag coefficient C_D
using information about surface structure



Ice thickness t_E at hydrostatic equilibrium and a snow load of mass m_S per unit area:

$$t_E = \frac{\rho_W}{\rho_W - \rho_E} f_E + \frac{1}{\rho_W - \rho_E} m_S$$

For SNR Analysis: Sea Ice σ^0 at L-Band



Measured intensity ranges of sea ice at L-band

Left bar: ESAR Right bar: PALSAR, FRM

(from: Dierking, TGRS 2010)

TangoSat NESZ: -25dB

σ^0 [dB]	SNR	σ_ϕ
-25 dB	1	1
-20 dB	3	0.6
-15 dB	10	0.3
-10 dB	32	0.2

Phase noise:

$$\sigma_\phi = \sqrt{\frac{1}{SNR}}$$

XTI for Ice Surface "Topography"

TANGOSat: only one-way propagation difference

Angular error as a function of phase noise

$$\sigma_{\theta|\phi} = \frac{\lambda}{2\pi B\cos\theta}\ \sigma_{\phi}$$

Equations from Madsen & Zebker, 1998
(assuming h<<H, α=0)

Height and cross-track errors, critical baseline

$$\sigma_{h|\theta} = H\tan\theta\,\sigma_{\theta}; \qquad \sigma_{y|\theta} = H\sigma_{\theta}$$

SNR=3, θ=30°, B_{XT}=1Km (5km)

-> height error: 9,3m (1.9m), cross-track error 16m (3.2m)

SNR=30, θ=30°, B_{XT}=1km (5km)

-> height error: 3.1m (0.6m), cross-track error 5.4m (1.1m)

XTI for Ice Surface “Topography”

Conclusions:

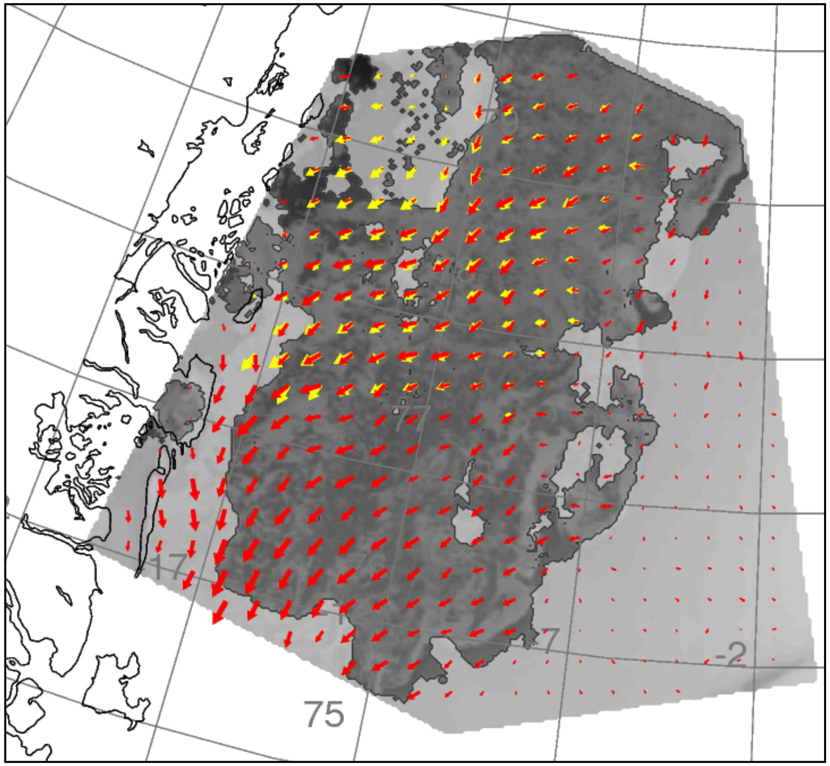
ridges are strong scatterers at L-band (high SNR) but level ice between ridges often reveal lower backscattering

-> only 10 m spatial resolution is interesting, longer baseline required (≈ 5km – not realistic at high latitudes)

retrieval of ice freeboard?
-> not achievable
freeboard typically in the range of 0-0.6m (Rickers et al. TC 2014)

-> even MY level-ice reveals relatively low backscattering at L-band (lack of volume scattering) -> low SNR
-> baseline of 10 km at high SNR=30: height error already 0.3 m

Sea Ice Drift Retrieval Using SAR, Conventional Method



Radarsat-2 image pair 16.09.2012
from Greenland Sea, HH-polarization,
Vectors – red: automatically derived;
yellow: reference, obtained manually

By courtesy of Stefanie Linow, AWI

-> ice drift is typically derived from a pair of SAR images using cross- and phase correlation approaches

-> time gap between images: between a few hours and days

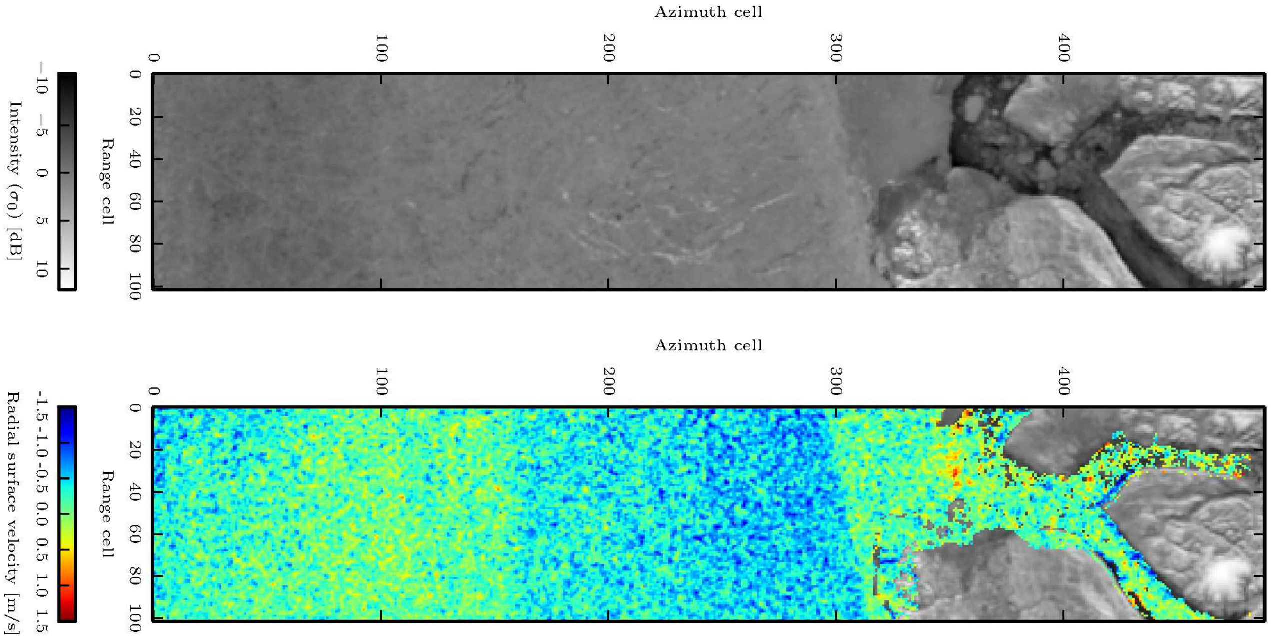
-> only displacement between identical spots in the 2 images can be derived, irregular motion during time interval between image acquisitions remains unknown

ATI: Snapshots of LOS Ice Drift Component

Motivation:

- complementary information to conventional ice tracking
- “present” velocity is obtained, but only LOS-component!
- directly comparable to Doppler-approach

(Doppler-shift derived from the frequency spectrum of *one* image, averaging over some spatial area, e. g. 4 by 4 kilometres)



Ice drift estimation from Doppler shift, example from Kraemer et al., TGRS, in print

ATI: Snapshots of LOS Ice Drift Component

Movement along-track: no LOS-component
Movement across-track: $V_R = V_{drift} \sin\theta$, θ incidence angle

$\Theta = 30°$, $V_{drift} = 0.12 m/s$, $V = 7.53 km/s$, $\lambda = 0.235 m$

$$\phi_{AT} = \frac{2\pi B_{AT}}{\lambda} \frac{V_{drift}}{V}$$

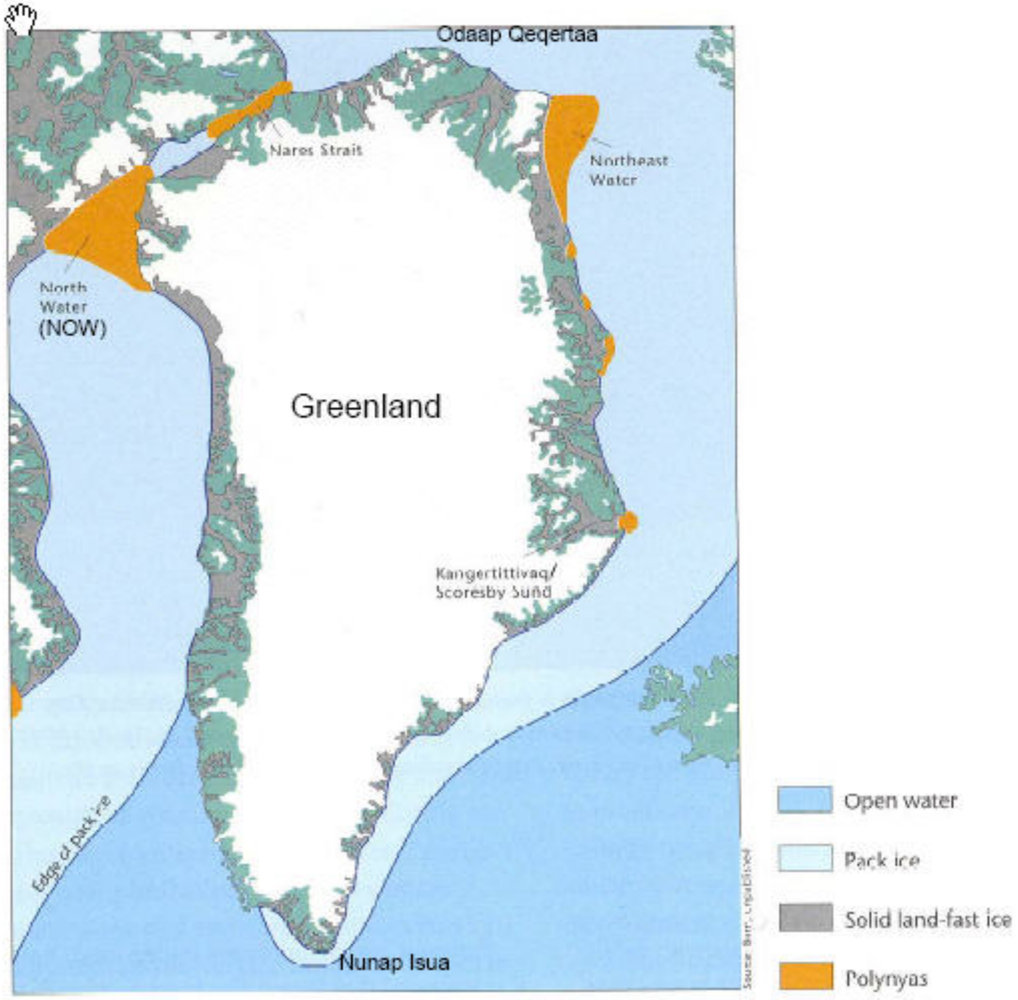
Madsen & Zebker, 1998

$B_{AT} = 1 km$ -> $\phi_{AT} = 0.43\pi$

Conclusion: with AT-baselines around 1-10 km, it is possible to determine even small line-of-sight drift velocities

Decorrelation? Large drift speed: 30km/day -> 0.35m/s
10 km baseline -> 1.3 s -> ice moves 0.46m
100 km baseline -> 13 s -> ice moves 4.6m

Tomographic Applications



http://na.nefsc.noaa.gov/

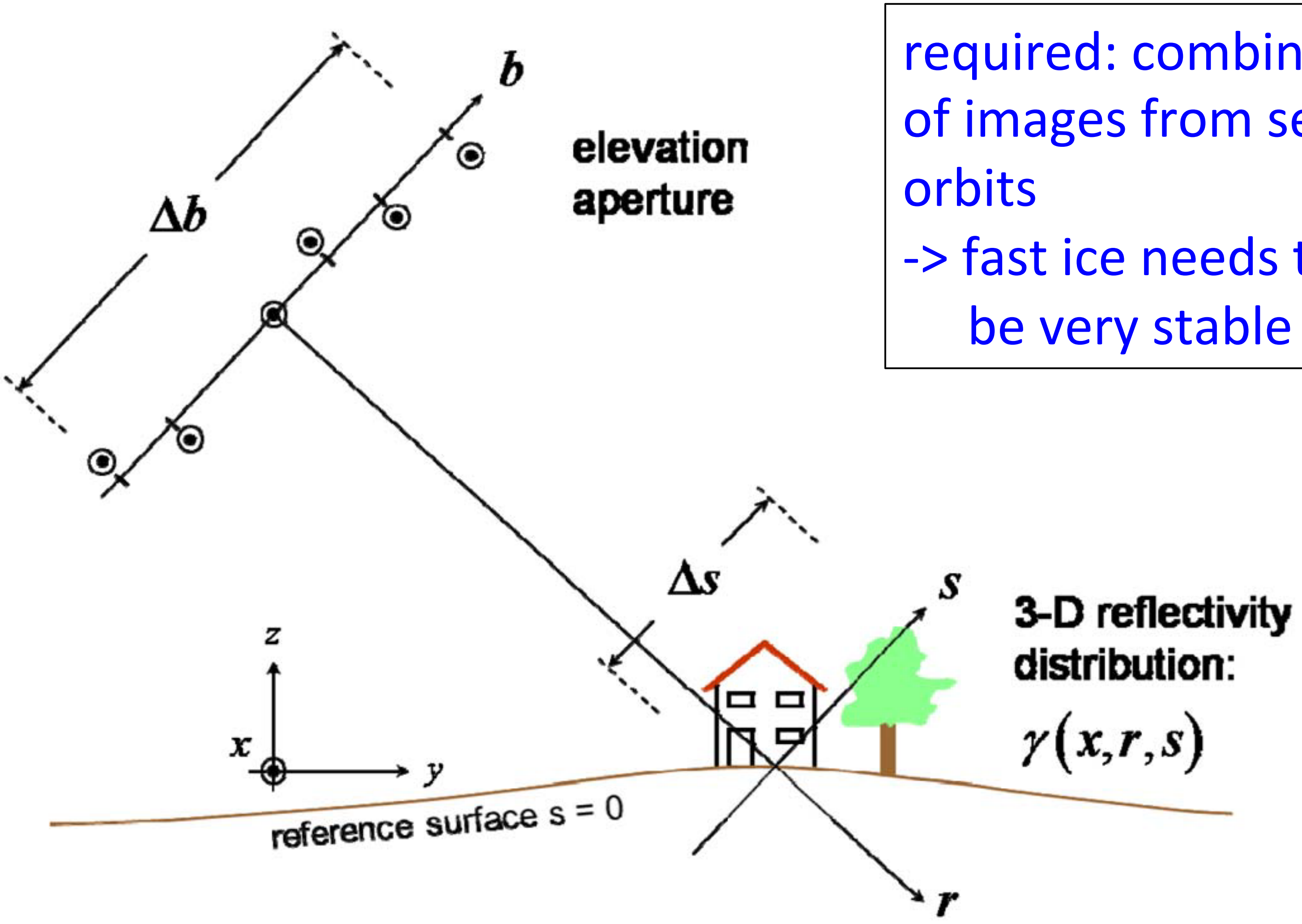
Motivation:
Can we determine depth of scattering centers?

Makes only sense over landfast ice (which does not move for a longer time), interesting only for low-salinity ice

Landfast ice: 1-2 m thick, part towards coast mostly smooth level ice, seawards it can be highly deformed

Tomographic Applications

required: combination of images from several orbits
-> fast ice needs to be very stable



From Xu & Bamler, TGRS 2010

Tomographic Applications

Elevation resolution depends on / is proportional to
- distance SAR – object,
- radar wavelength,
- 1/ Δb, with Δb – elevation aperture length (sufficiently dense sampling of Δb provided).

$$\rho_s = \frac{\lambda H}{2\cos\theta}\frac{1}{\Delta b}$$

H=620km
λ=0.235m
θ=30°

$$\rho_s = 84120\frac{1}{\Delta b}\;[m]$$

TANGOSat: possible values for Δb (in meters)?

(After Xu & Bamler, TGRS 2010)

Tomographic Applications

Location of individual scatterers possible at much better "effective" resolution ->
elevation estimation using Cramer-Rao lower bound (CLRB):
(After Xu & Bamler, TGRS 2010)

$$\sigma_s = \frac{\lambda H}{4\pi \cos\theta \sqrt{2SNR}} \frac{1}{\sigma_b \sqrt{NOA}}$$

NOA -> number of acquisitions
σ_b -> standard deviation of the baseline distribution

Corresponding figures for TANGOSat?
For (fast) sea ice, the required effective resolution is on the order of 0.1 m! Cannot be achieved with TANGOSat.

Summary: Scientific Potential of TANGOSat For Sea Ice (Status Oct. 2014)

- Sea ice bistatic/INSAR studies only possible with configurations such as TANGOSat
- *Bistatic measurements for sea ice classification are realistic and meaningful*
- *XTI: ice surface structure can be measured only at higher spatial resolution (10 m) and with longer baselines (>5 km) but such baselines cannot be achieved at higher latitudes*
- *ATI: snapshots of ice drift components possible*
- *Tomographic mode: spatial resolution not sufficient for sea ice, anyway restricted to fast sea ice*

XTI – Critical Baseline

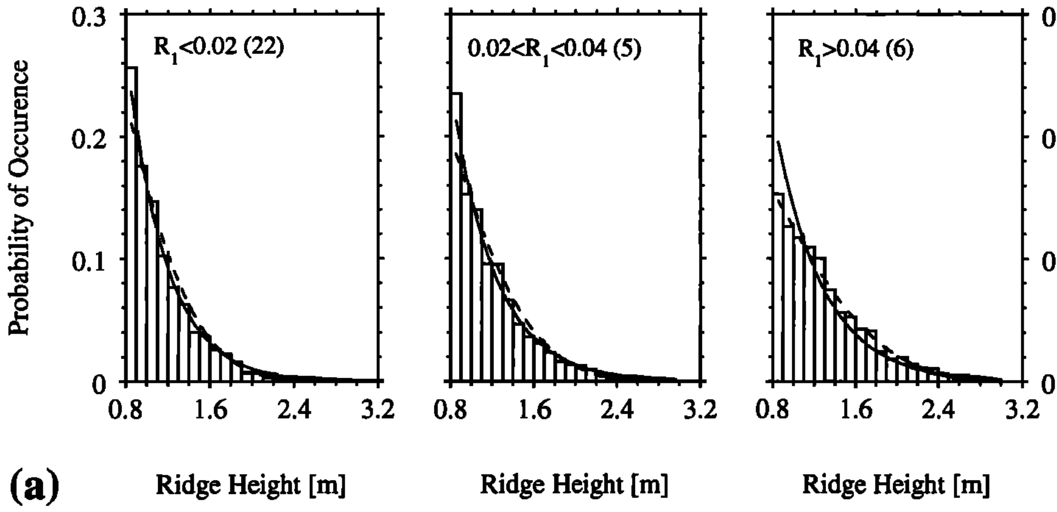
TangoSat:
λ=0.235m, H=620km, θ =30°
spatial ground range resolution Δy=10 & 100m
XT-baselines up to 12 km

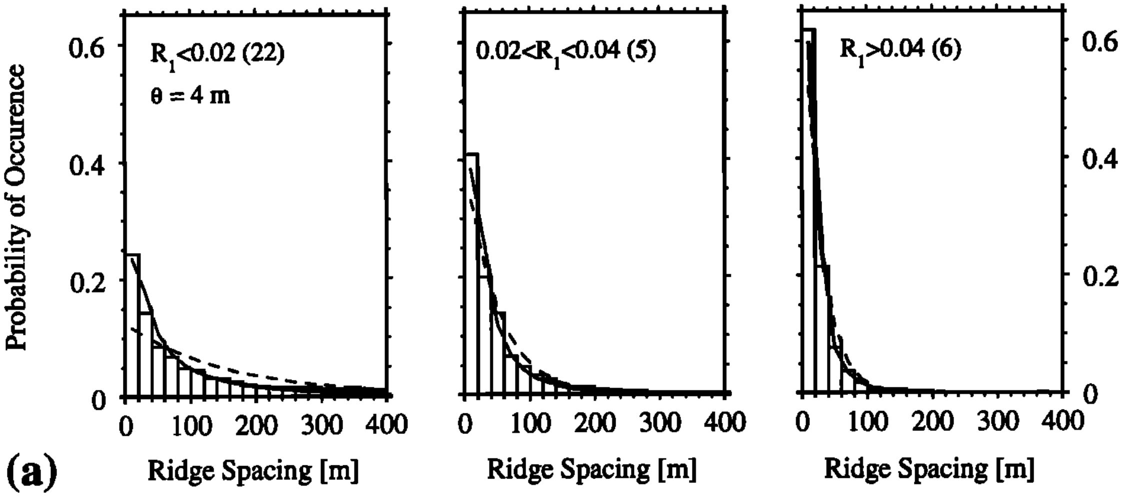
$$B_c = \frac{H\lambda}{\Delta y \cos^3\theta}$$

Equation from Madsen & Zebker, 1998
(setting α=0, ρ≈H/cosθ)

Critical baselines (B_c-XTI = B_c): 22,4km (Δy=10m)
2,24km (Δy=100m)

Observed Ridge Heights And Spacings





Example from
Weddell Sea

Dierking, JGR 1995