FFI Forsvarets forskningsinstitutt

X-band Radar Sea-clutter Measurements from Low-Medium Grazing Angles Recorded from a Helicopter Platform

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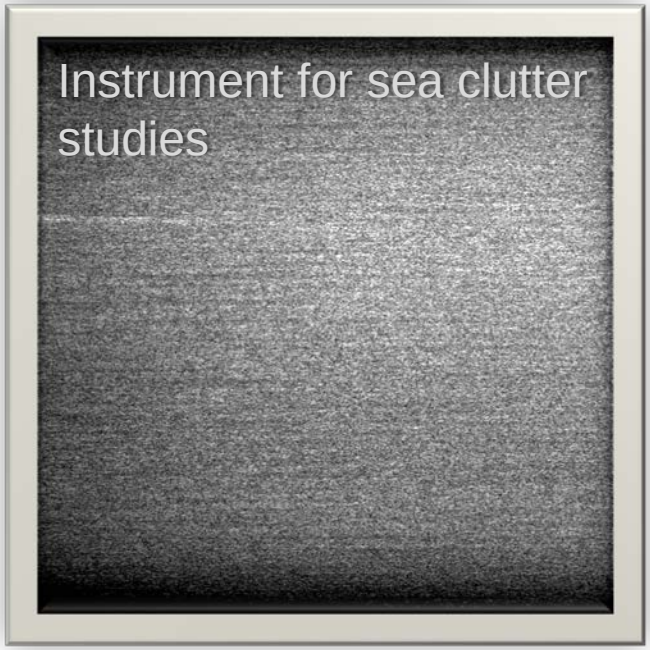
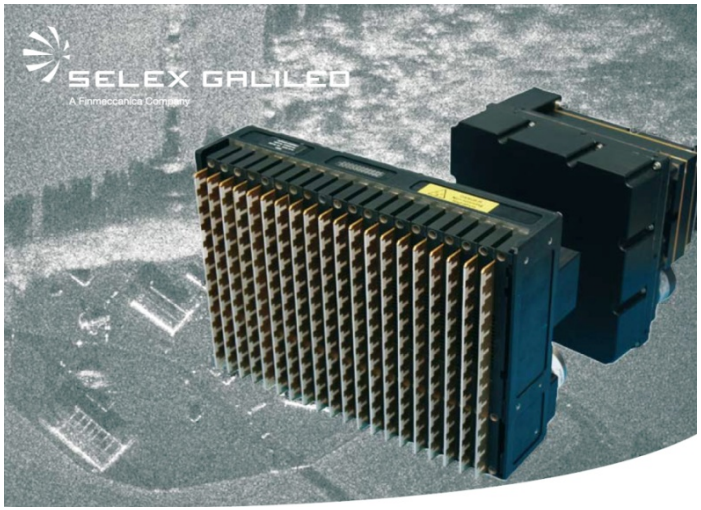
- Collection strategy and trials
  - Circular flights
  - Vertical climbing flights
- Data extraction
- Analysis
  - Sea conditions, Very low -> High
  - Reflectivity (azimuth and grazing angle)
  - Fitting data to a K-distribution
  - Doppler spectrum



PicoSAR Lightweight 10kg Synthetic Aperture Radar (SAR)

Masurement parameter settings

Frequency	X-band (9.4 GHz)
Chirp bandwidth	150 MHz
Range gate resolution	~1m (slant range)
Range (scene centre)	1850m
Pulse length	12 μs
PRF	1 kHz
Raw range cells	574
Beam width (3dB)	El = 9, Az = 6
Range gate az. width	~200m
Range gate size	1m x 200m
Polarization	Vertical



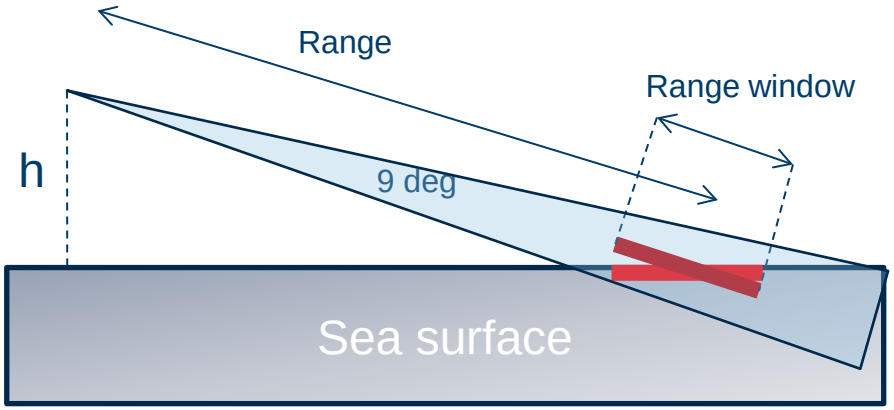
Sea-clutter trials

- Recordings in the Mediterranean Sea
  - NATO NEMO Trial 2013, Toulon France
  - NATO NEMO Trial 2014, Taranto Italy

Data extraction

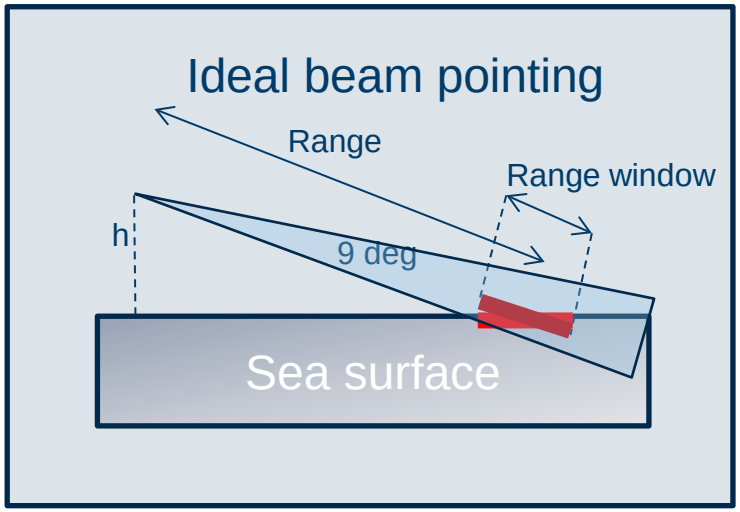
- Using Advanced mode settings
  - No use of predefined SAR modes
    - Shorter ranges

- Detailed parameter control
  - Chirp bandwidth
  - Pulse length
  - PRF
  - Sampling starting offset
  - Sample window



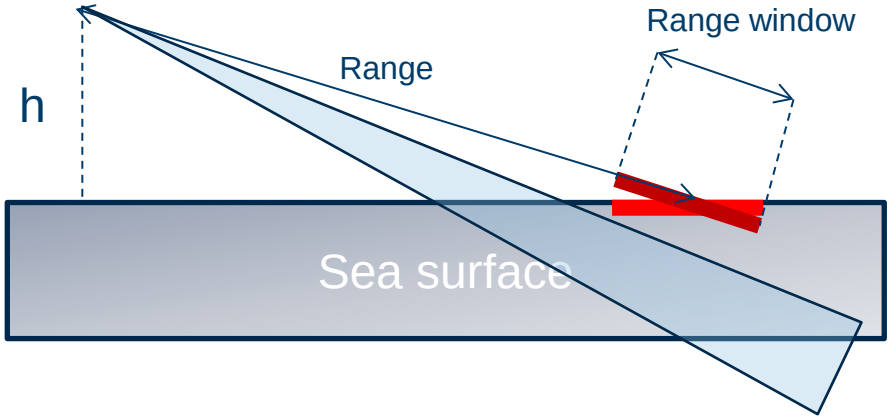
- Fixed range = 1850m
- Grazing angle up to 56 degrees
  - Restricted height

Pointing angle

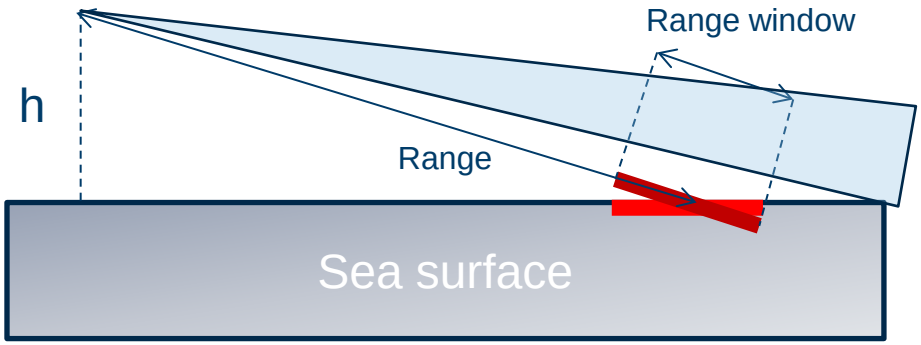


- Fixed range
- Circular flights at set at grazing angles
  - Fixed height

- Steeper pointing angle
  - Range gates outside main beam

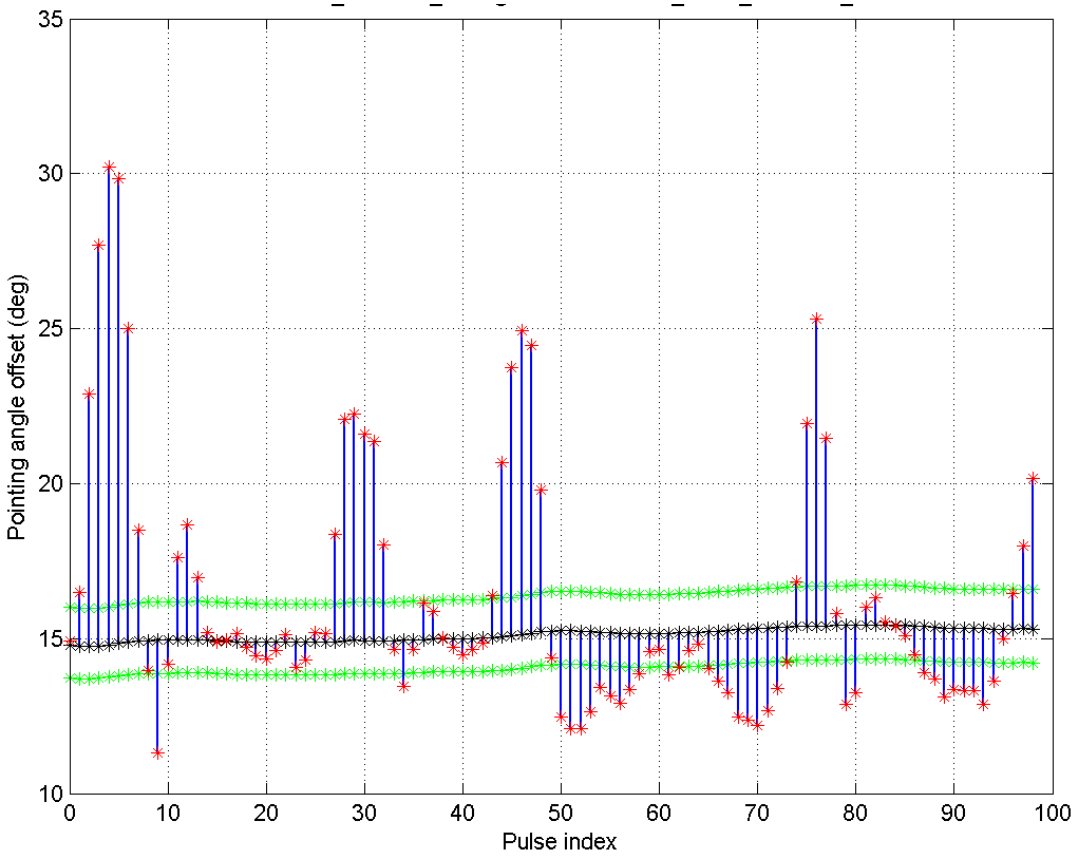


- Lower pointing angle
  - Range gates outside main beam



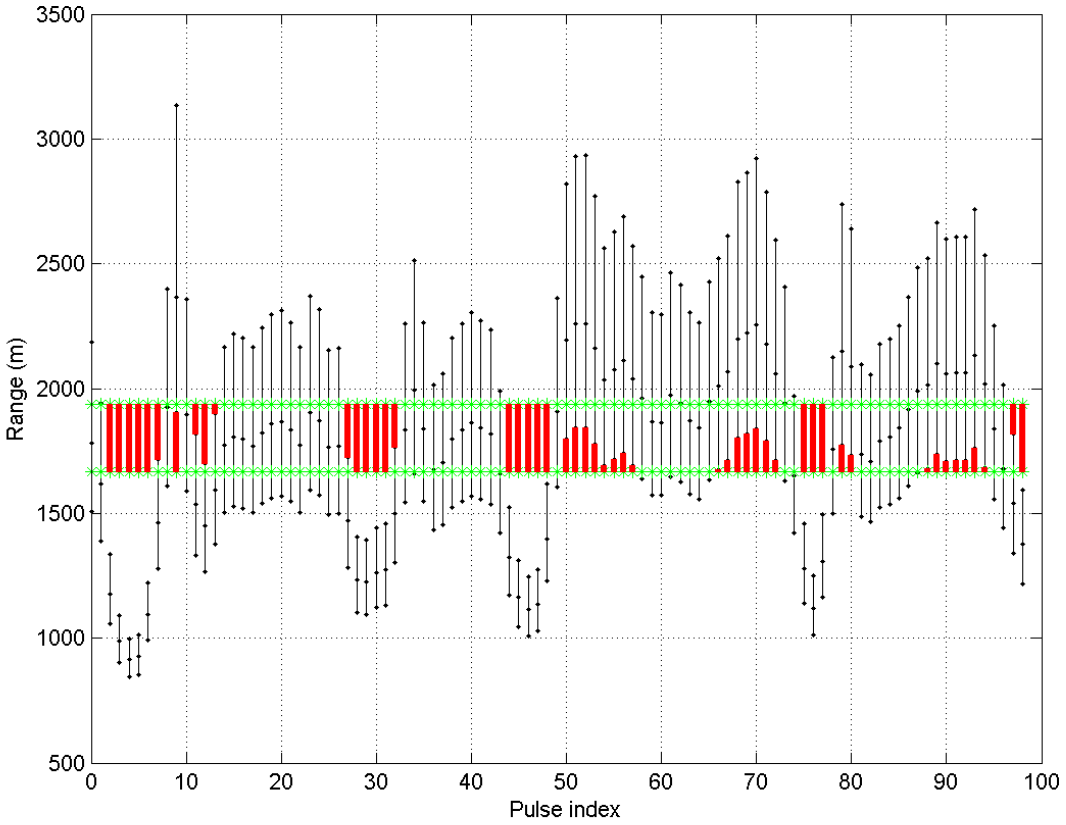
Data extraction

- Example of antenna beam pointing
  (Abscissa: 100k pulses = 100s)



Antenna beam range gate coverage
(100k pulses = 100s)

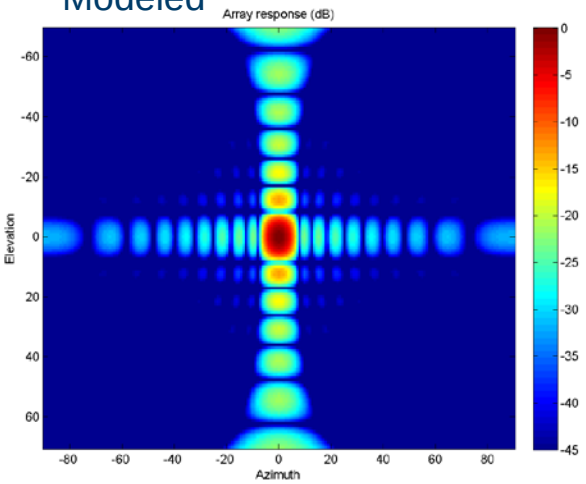
- Discard range gates outside from contaminating the analysis

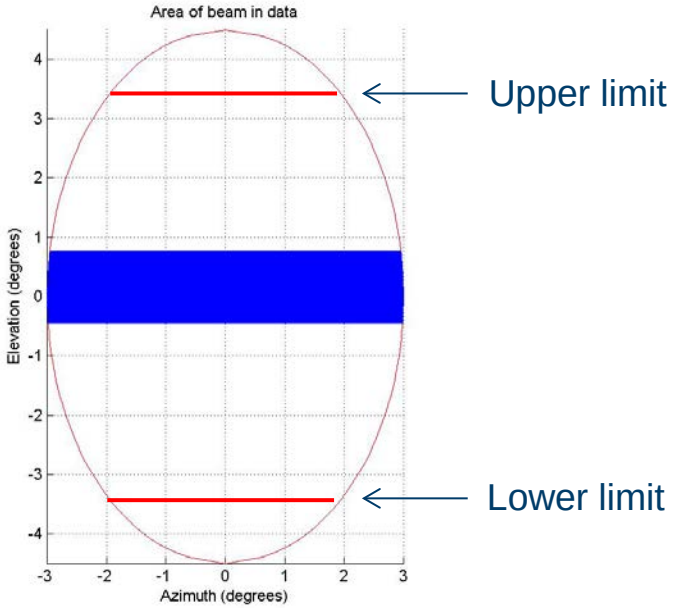


Radar antenna beam

- Beam width, 3dB
  - Elevation = 9 degrees
  - Azimuth = 6 degrees
- Beam position: Boresight
  - No azimuth squinting
- Data
  - Input: Sampled deramped IQ-data
  - Pulse by pulse
  - Range gate by range gate
- Compensating
  - Clutter patch width(r,α)
  - Range gate size(r,α)
  - Gain (el. angle in beam)

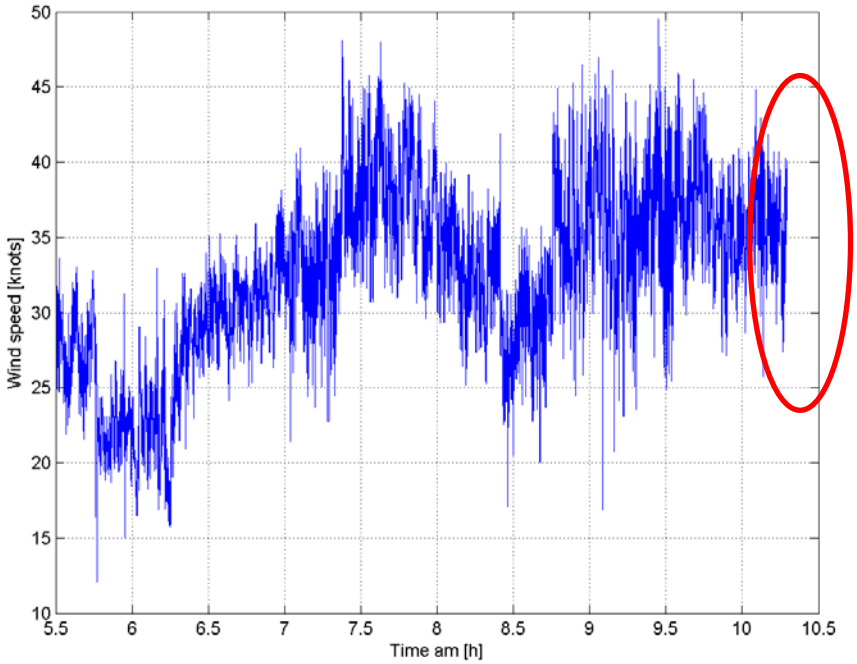
Modeled

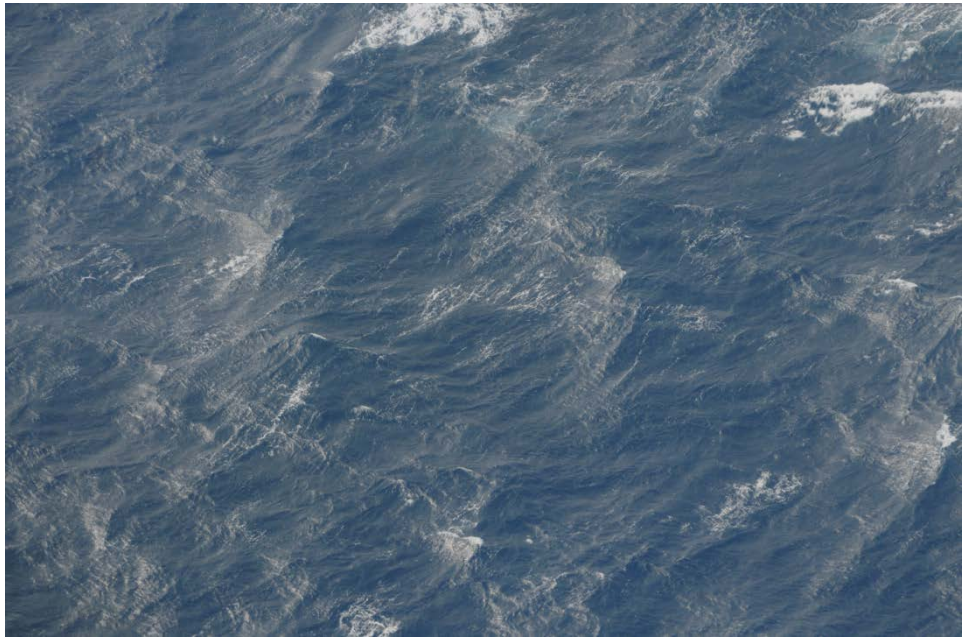




NATO NEMO Trial 2013

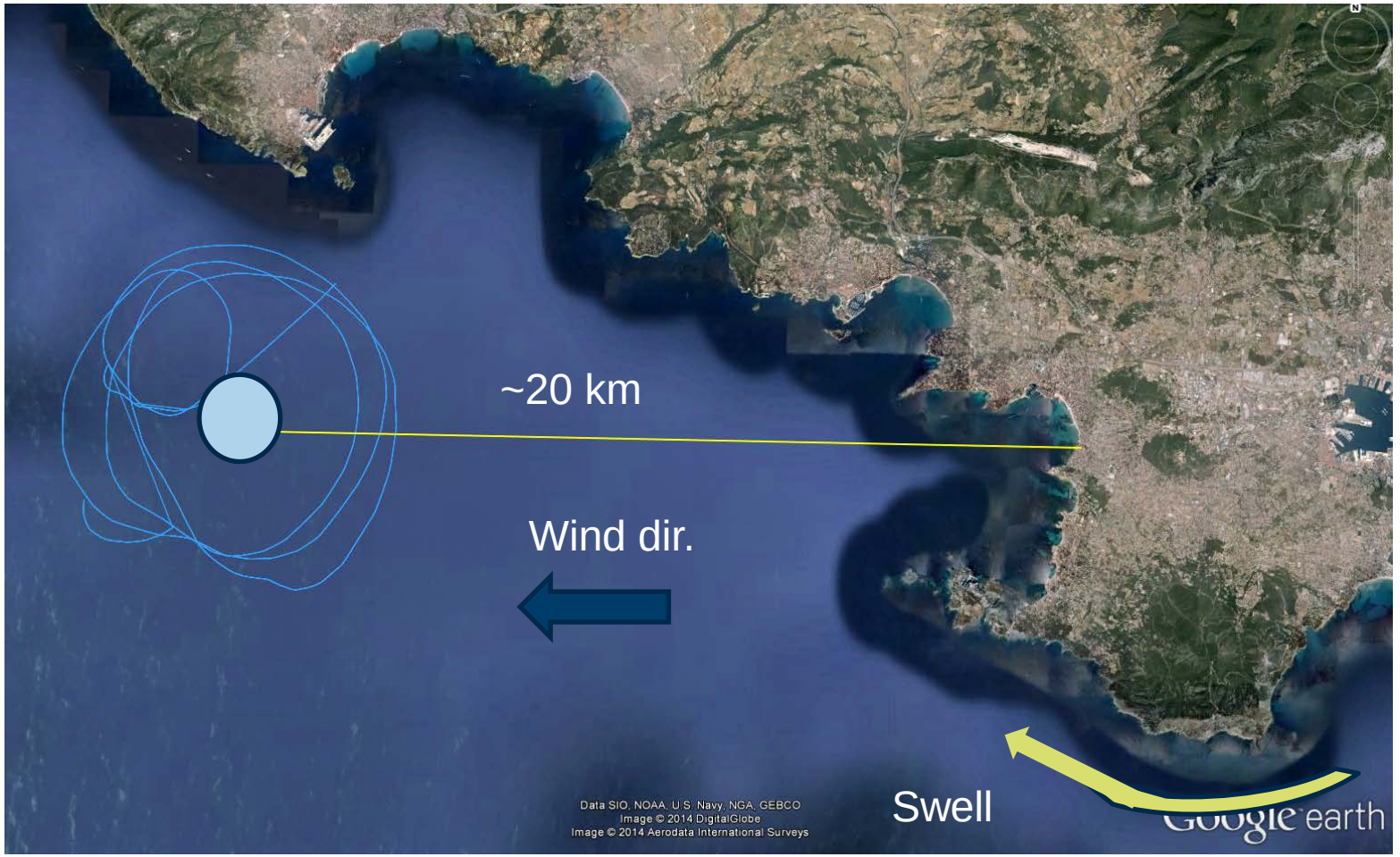
- Circular flight experiment
  - Grazing angle: 5, 10, 15, 20, and 25 degrees
- High wind speed



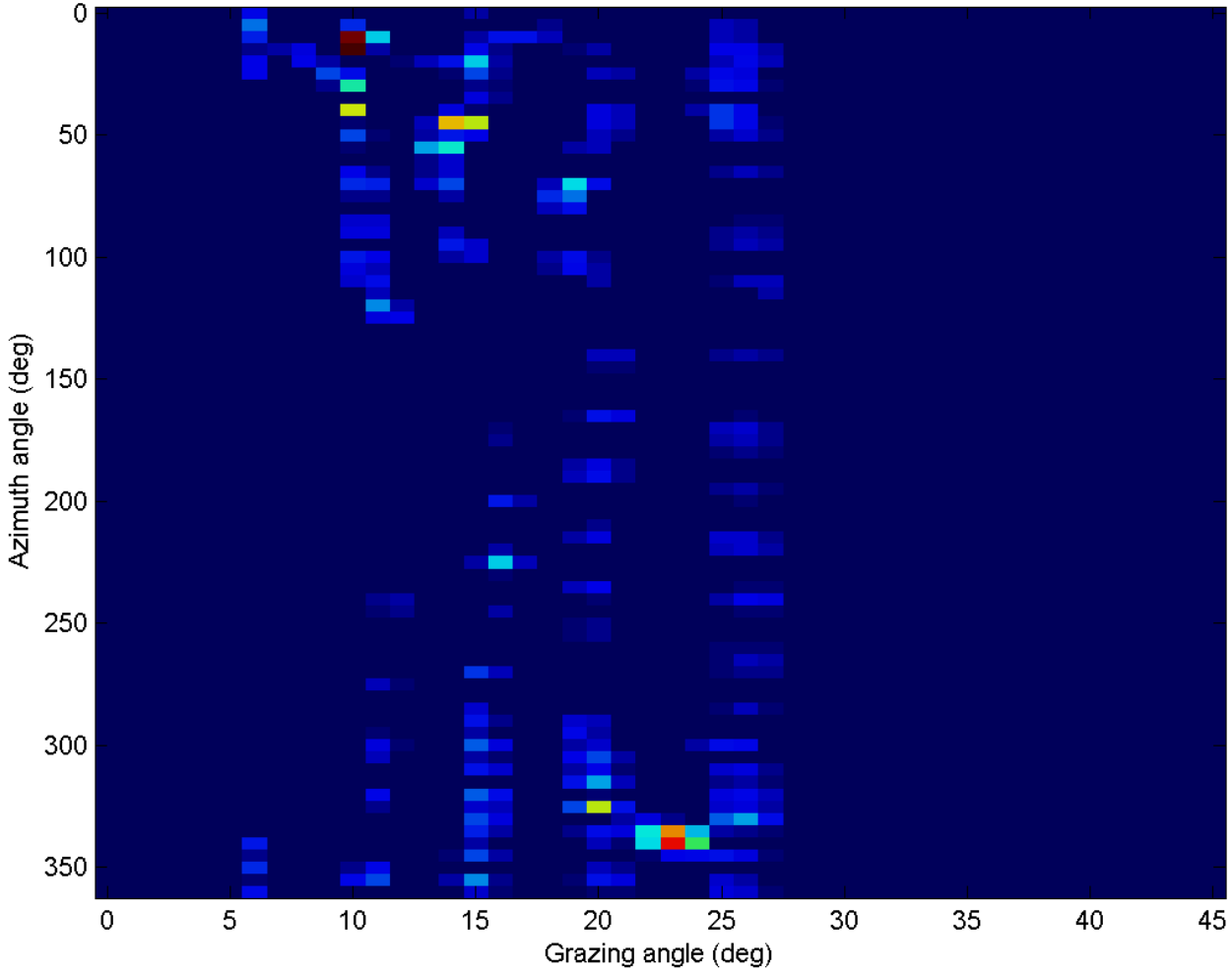


Wind direction

- Short fetch - ‘’Young sea’’
- Swell



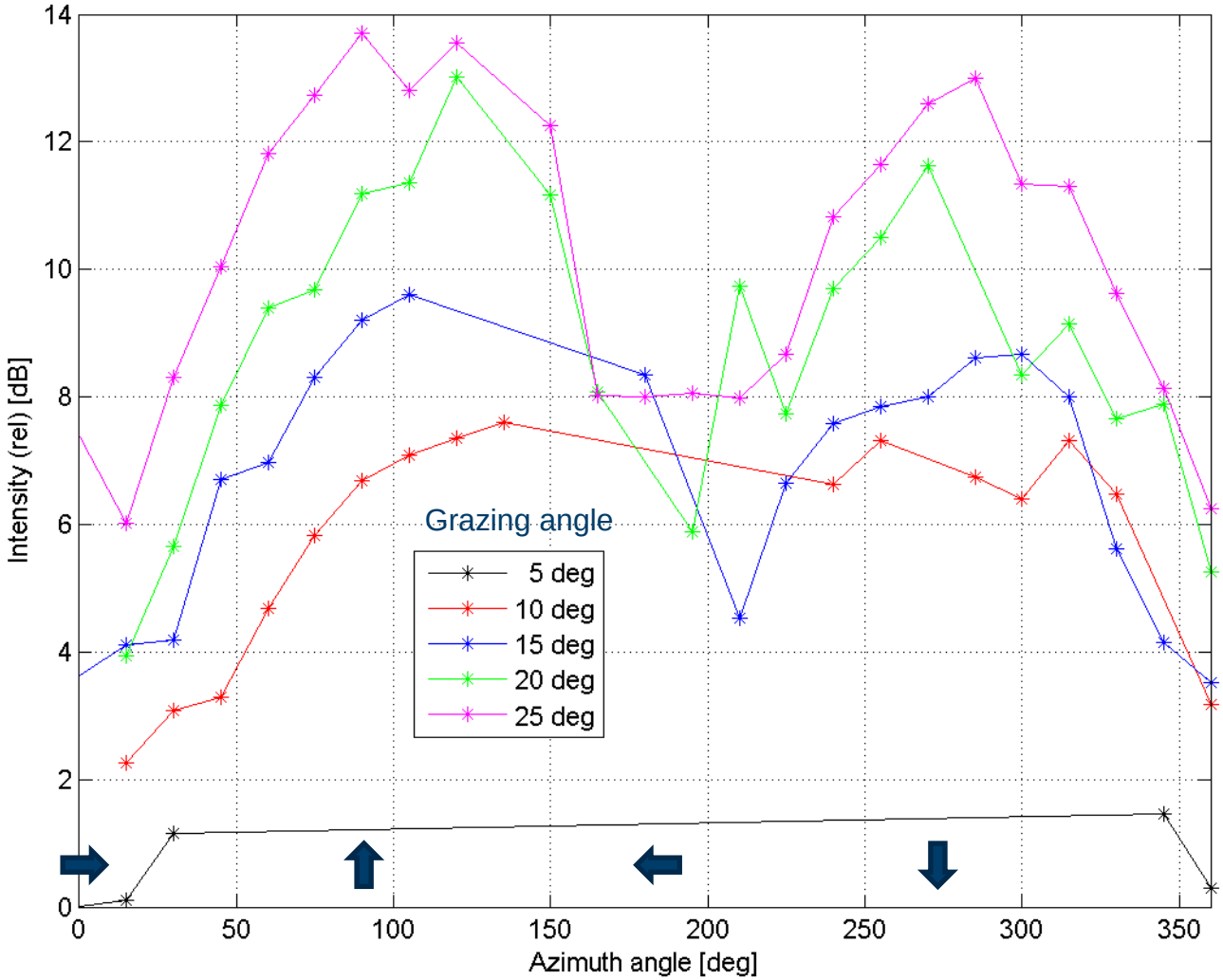
Azimuth & Grazing angle coverage



Relative intensity of sea clutter reflectivity

- Binning size
  Azimuth: 15 deg
  Grazing: 5 deg

- Arrows
  - View direction
  - Up
  - Cross
  - Down



Fitting reflectivity data

- Compound K-distribution

$$p(x) = \frac{2c}{\Gamma(\nu)}\left(\frac{cx}{2}\right)^{\nu} K_{\nu-1}(cx)$$

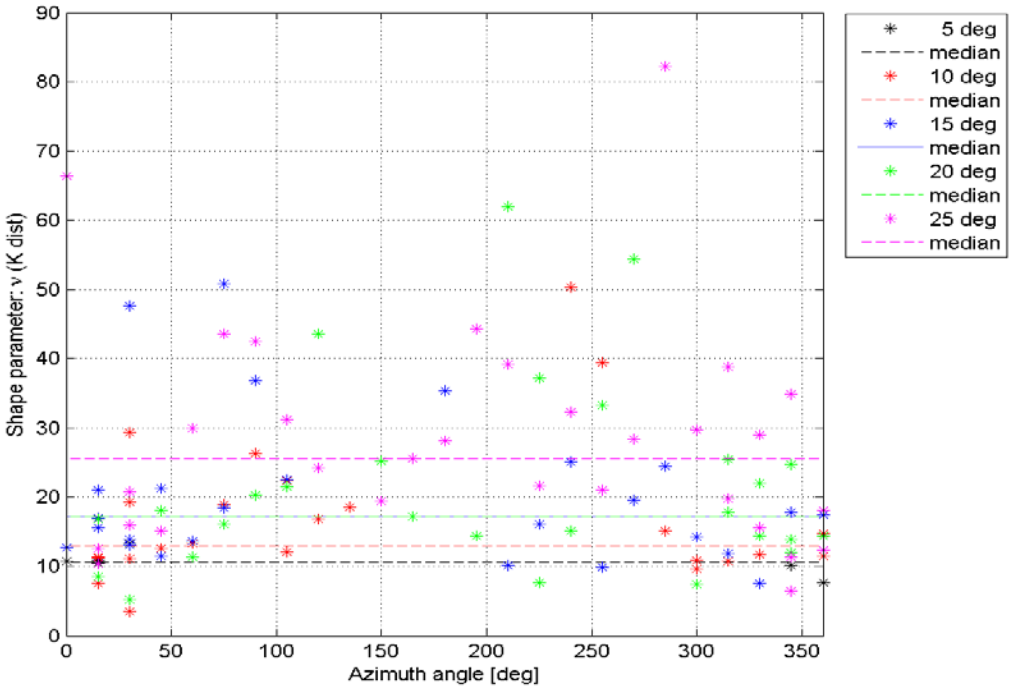
- Method of Moments (MoM)
  - Estimate shape parameter ν
  - Second moment

$$\overline{x^2} = \frac{4\nu}{c^2}$$

  - Small ν -> Long-tailed dist.
  - Large ν -> Rayleigh

- Weak trend: Median ν increases with grazing angle

Grazing angle

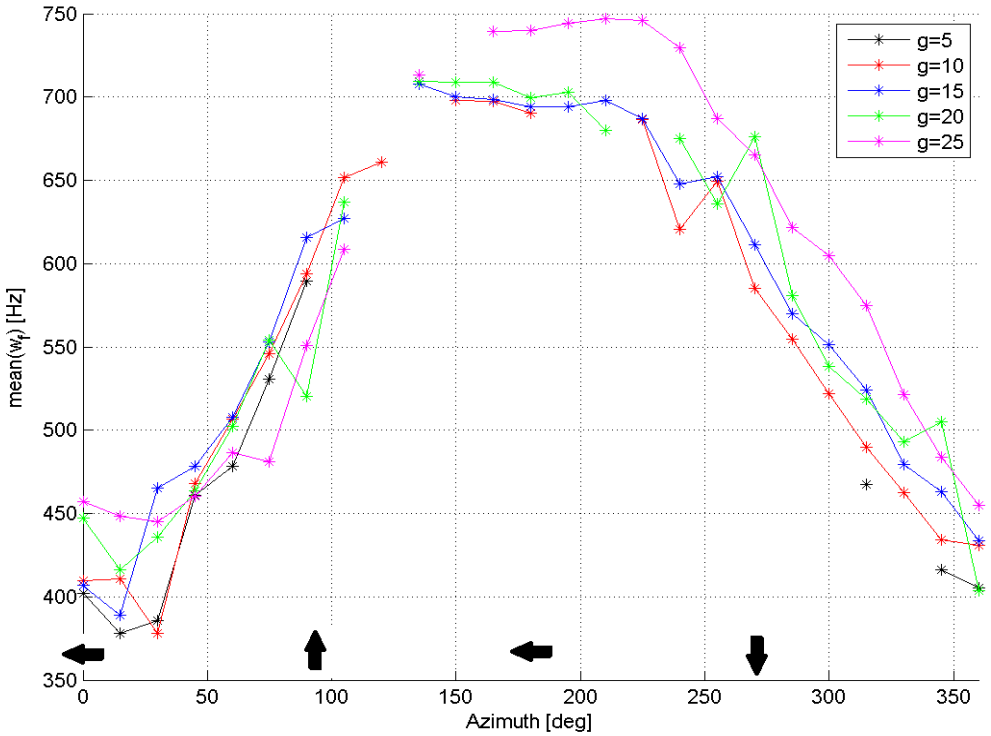


Mean Doppler spectrum width

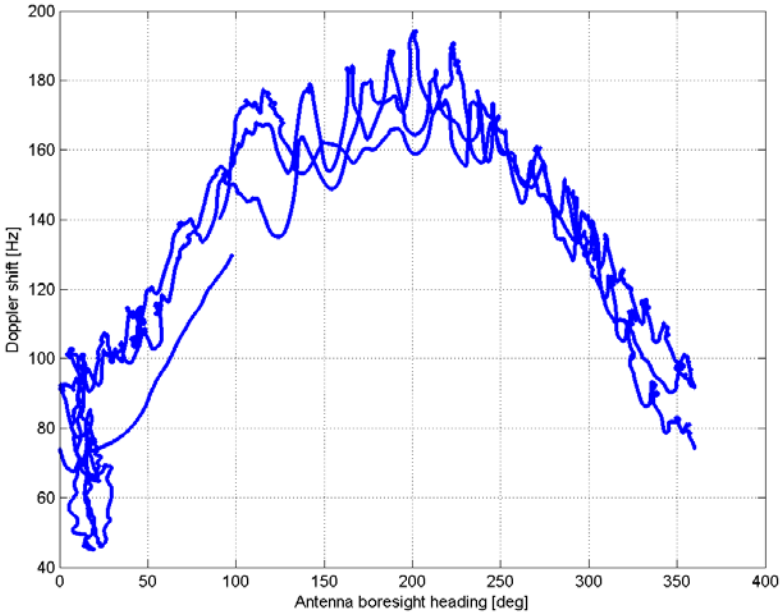
Recorded sea spectrum: Convolution of response from sea and antenna pattern

$$f_d = 2v\frac{f_c}{c}\sin\varphi_a\cos\theta_g$$

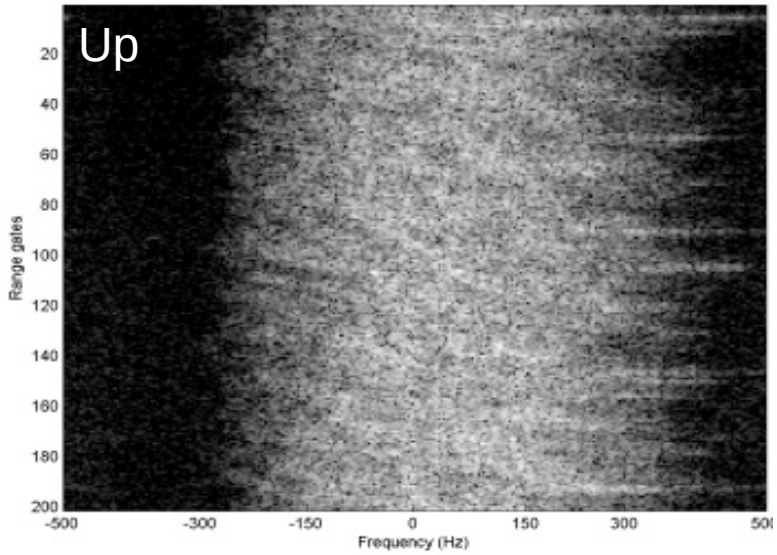
- Experimental data

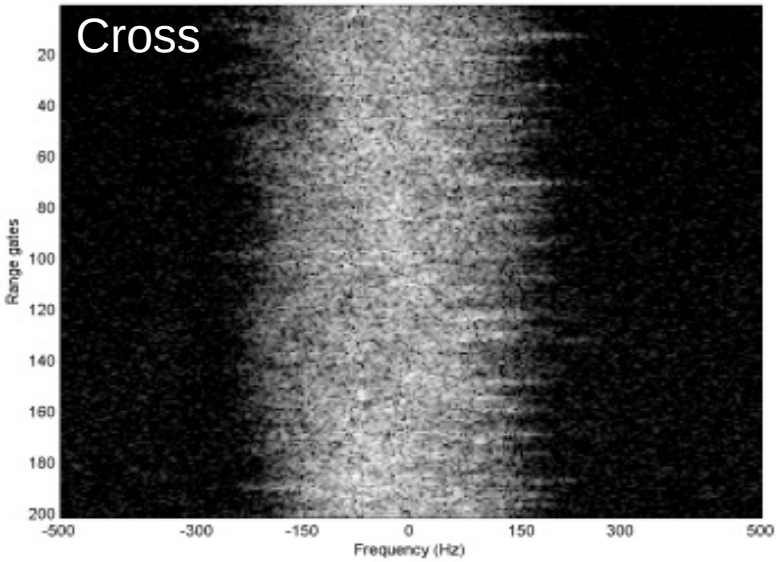


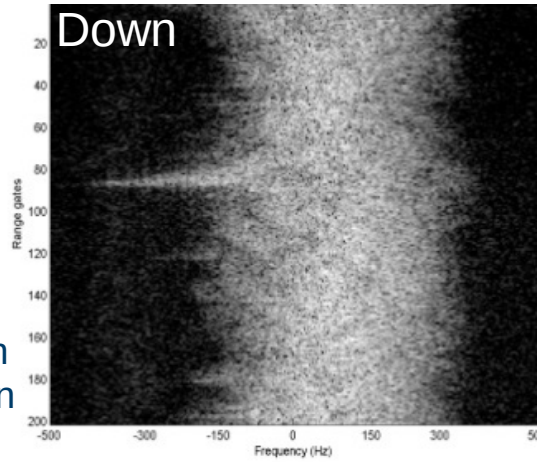
- Doppler shift due to antenna pattern
  - Velocity differs
    - Up, down and cross
  - Half beamwidth
    - 3dB crossing



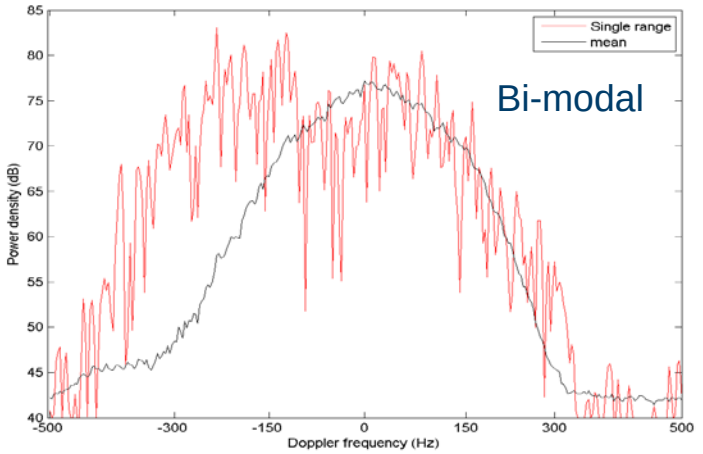
Doppler spectrum of sea clutter (300ms, 300 pulses)







Large Excursion
- 1.5s duration

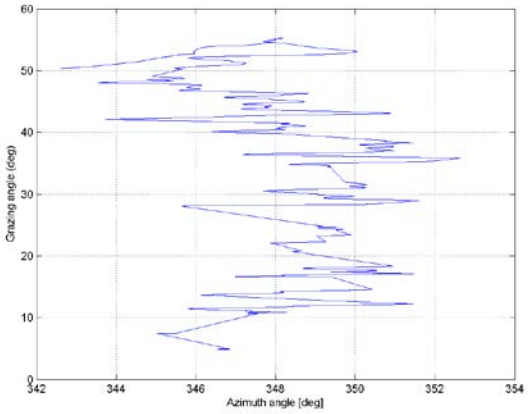


NATO NEMO 2014 Trial (Taranto bay)

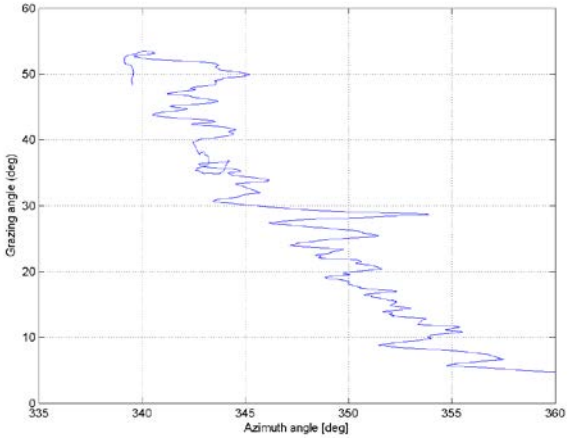
- Vertical climb flights
  - Upwind
  - Small lateral movement
- Fetch – 20km
  - Young sea
- Grazing angles
  - [3 – 55] deg
- Day 1
  - 10-12 m/s
- Day 2
  - 1-2 m/s

Upwind pointing variation and sea condition

- Day 1
  10-12 m/s
  Short fetch



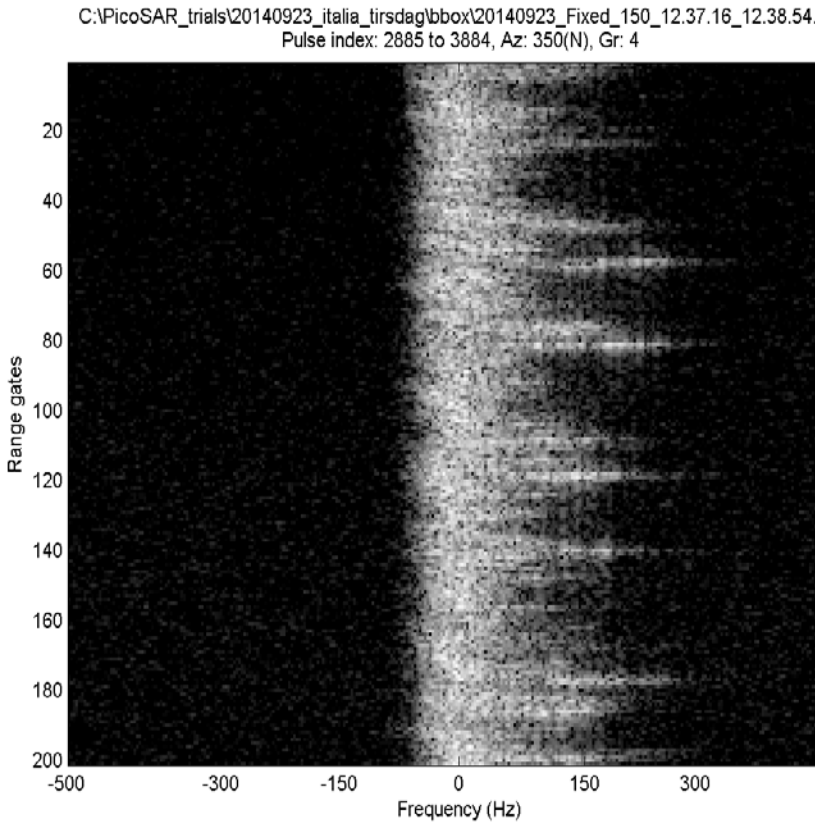
- Day 2
- 1-2 m/s
- Open sea



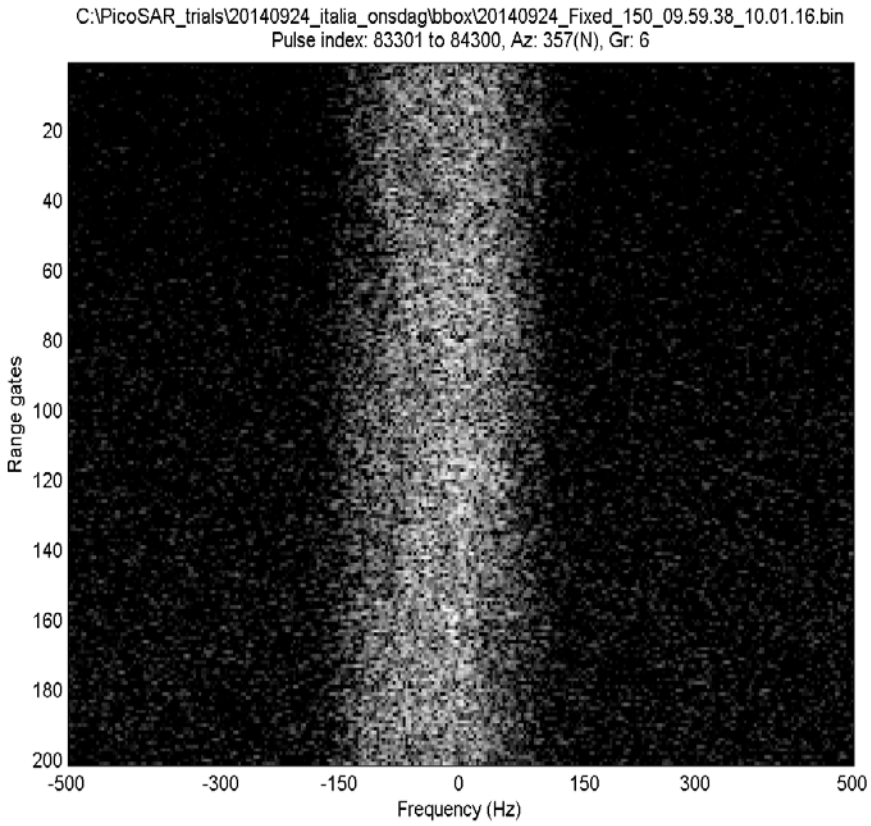
Range-Doppler spectrum (300ms, 300 pulses)

- Day 1

  10-12 m/s



- Day 2
- 1-2 m/s

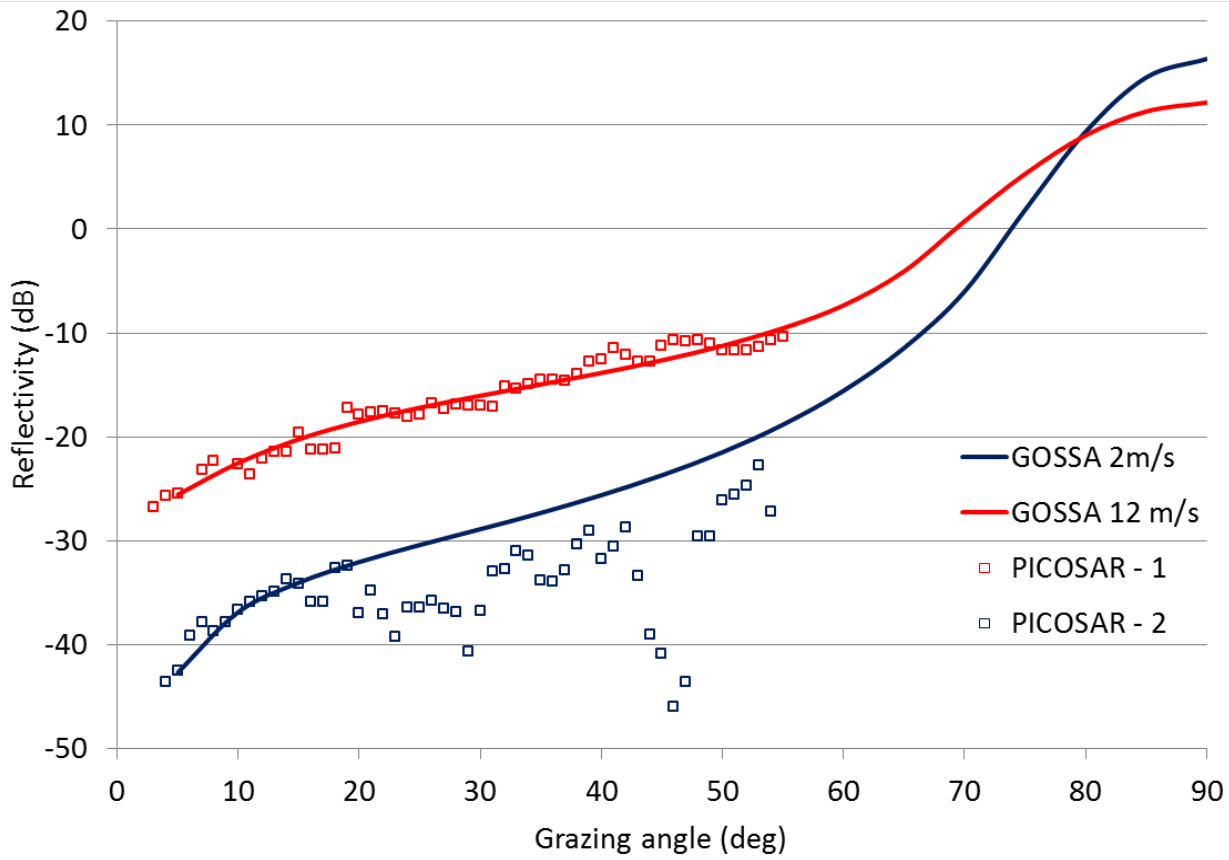


Reflectivity versus grazing angle

- Upwind

- Red 10-12m/s
- Blue 1- 2m/s

- PicoSAR data
- Modeled reflectivity
  GOSSA model (ONERA)



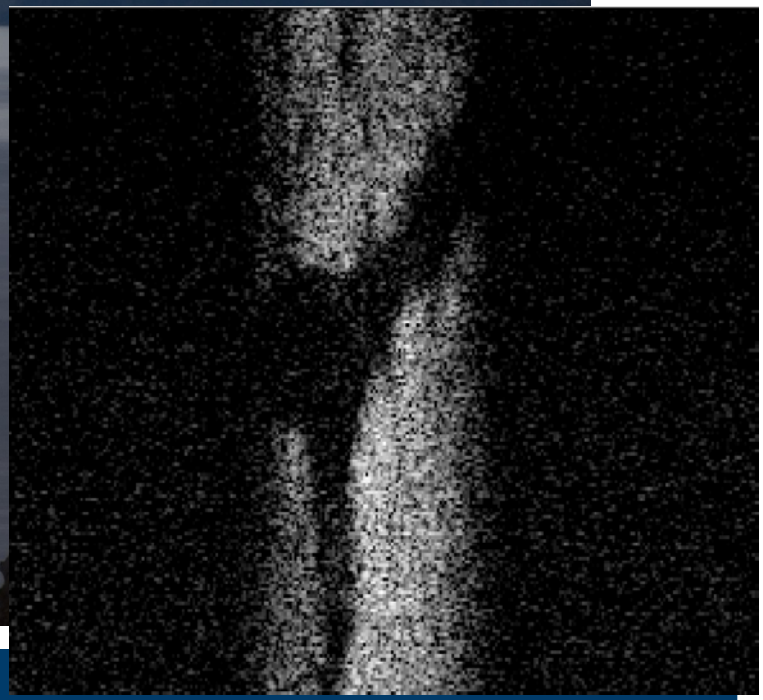
Summary

- PicoSAR sea clutter data
- Analyzed radar sea clutter from two trials
  - Short fetch (≈20km)
  - Low and high wind conditions
- Circular flights
  - Reflectivity angle dependencies
  - Trend of increasing shape parameter with grazing angle
- Vertical climbing flights
  - Reflectivity data shows good correspondence with modeled data as a function of grazing angle
  - Doppler spectra showing variations in Doppler excursions

Range-Doppler spectrum (300ms, 300 pulses)

- Low wind
- Grazing ang: 20 deg

- Transition region?
  - Wind ⟺ no-wind



Sea clutter

- ‘’Footprint’’ showing wave fronts in range compressed data
  - Range gates(time), 5s window