WHAT DOES A WAVE RADAR ACTUALLY MEASURE?

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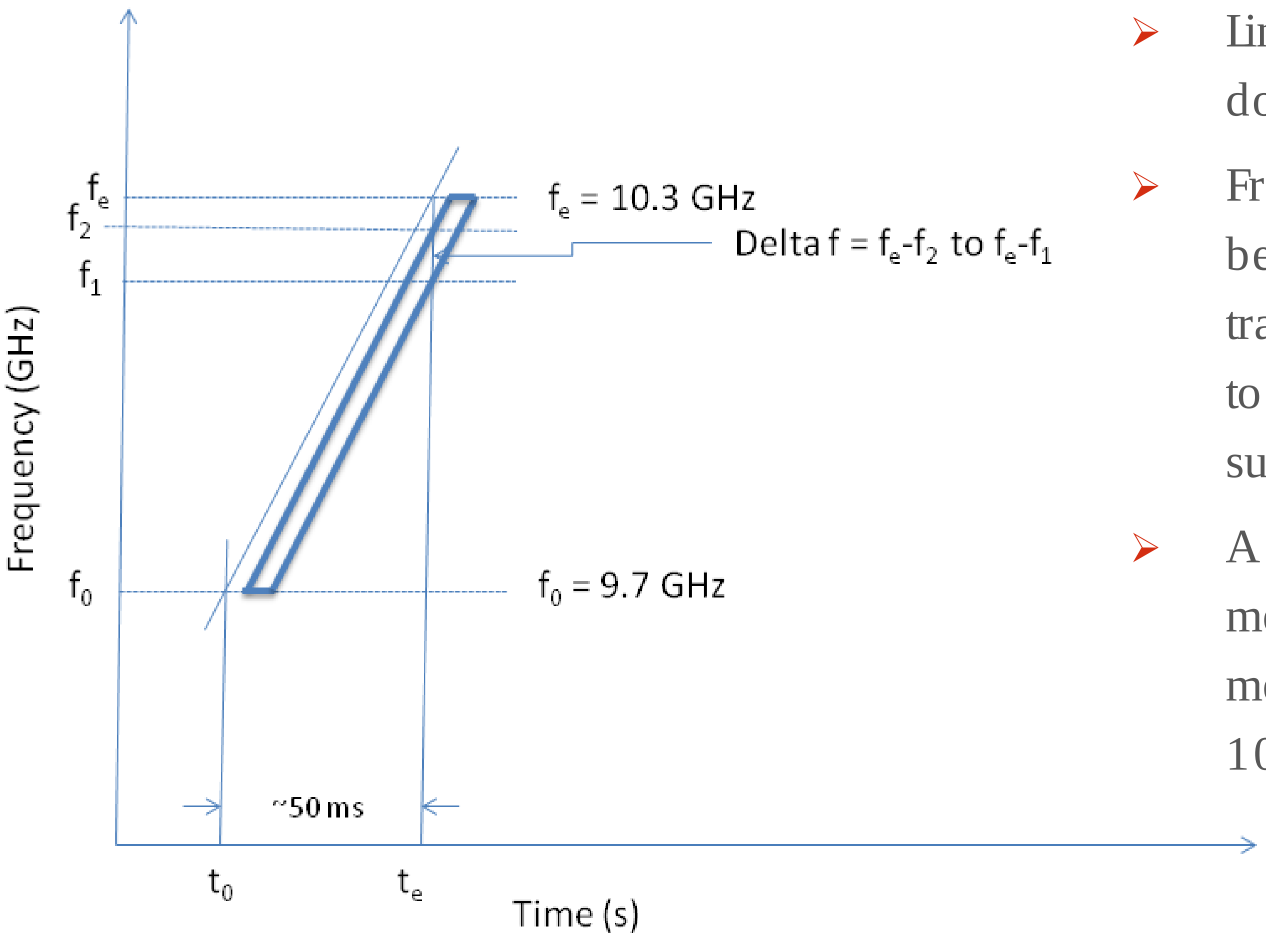
OUTLINE

- Background & Motivation
- The WaveRadar
- Simulations
  - Surface wave simulations
  - WaveRadar simulations
- Results
  - Long-crested regular wave
  - Linear random surface elevation
- Field Measurements
  - 10 Hz sample measurements
  - Comparisons with other sensors

BACKGROUND & MOTIVATION

- **The SAAB/ Rosemount WaveRadar widely used by offshore industry**
  - Shell have 12 platforms in North Sea and 10 in South China Sea with WaveRadar
  - More than 500 installed worldwide.
  - Easy to maintain and service and do not require expensive ship time needed for deployment and recovery of wave buoys
  - Can sample the sea surface elevation at up to 10 Hz.
  - Provided most (~95%) of the data for a recent study of extreme crests (CresT)
- **Performance**
  - Operationally reliable
  - Specified 10 degree beam width could lead to footprint issues
  - Noreika et al. (2011) compared WaveRadar against DWR
    - Wave Radar Hs 4%-10% less than DWR
    - Wave Radar Hs up to 16% less than DWR during large sea states during TC

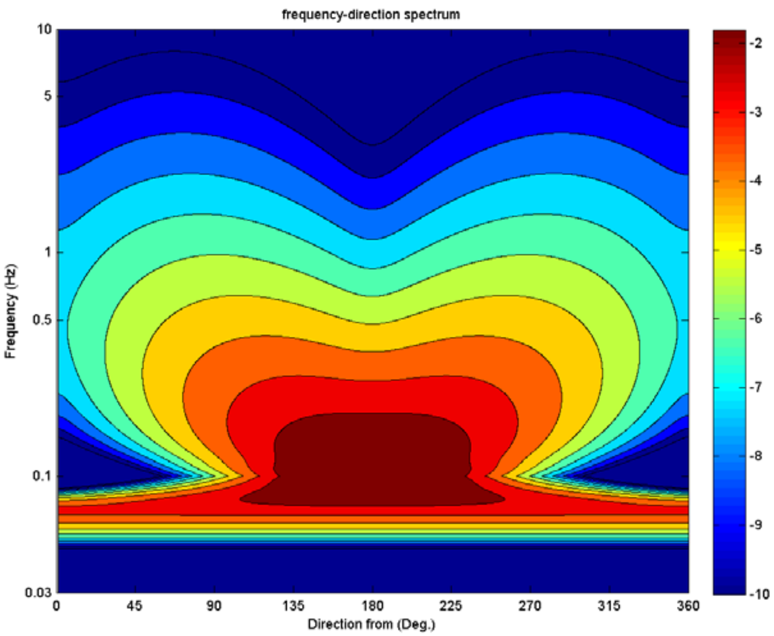
THE SAAB/ ROSEMOUNT WAVERADAR



- FMCW method
- Linear sweep – up & down
- Frequency difference between received and transmitted proportional to the distance to the surface
- A number of measurements over the measurement cycle of 10.3Hz and averaged

SIMULATIONS – SURFACE WAVE

- Long-crested plane sinusoidal wave – frequency = 2 Hz, Amplitude = 1 m
- Random linear wave field – JONSWAP frequency spectrum, fp = 0.10 Hz
  - JONSWAP frequency spectrum $\Delta f = 6.3 \times 10^{-4}$ Hz $\left[0,10\right]$ Hz
  - Bimodal directional distribution (Ewans, 1998)
  - 32,768 points with time step 0.0485 s (~ 26.5 minutes)
  - 5 metre square, resolution 0.01 metres (250,000 points)



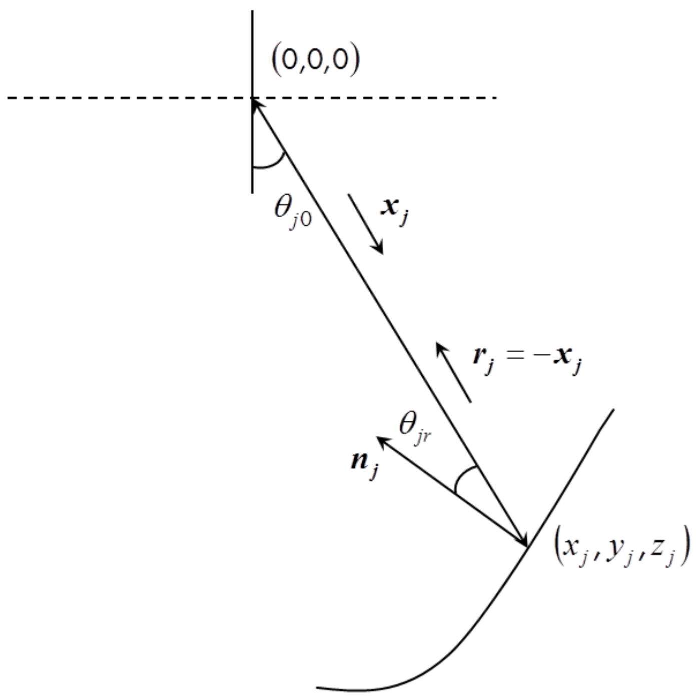
SIMULATIONS – RADAR

- Assume signal processing to convert the frequency differences to ranges is done perfectly by the WaveRadar
- Assume we have output of the FMCW frequency analysis – the reflected signal intensity (or gain) as a function of range – available directly.
- Assume that our signal is the summation of all the received signals reflected from the surface of the water at an instant of time

$$\sum_j E'_j\left(x_j, y_j, z_j\right)$$

$E'_j\left(x_j, y_j, z_j\right)$ is the signal reflected from the point $\left(x_j, y_j, z_j\right)$ and received at the antenna

SIMULATIONS – RADAR



$$E'_j(x_j, y_j, z_j) = E(\theta_{j0})A(2r_j)R(\theta_{jr})$$

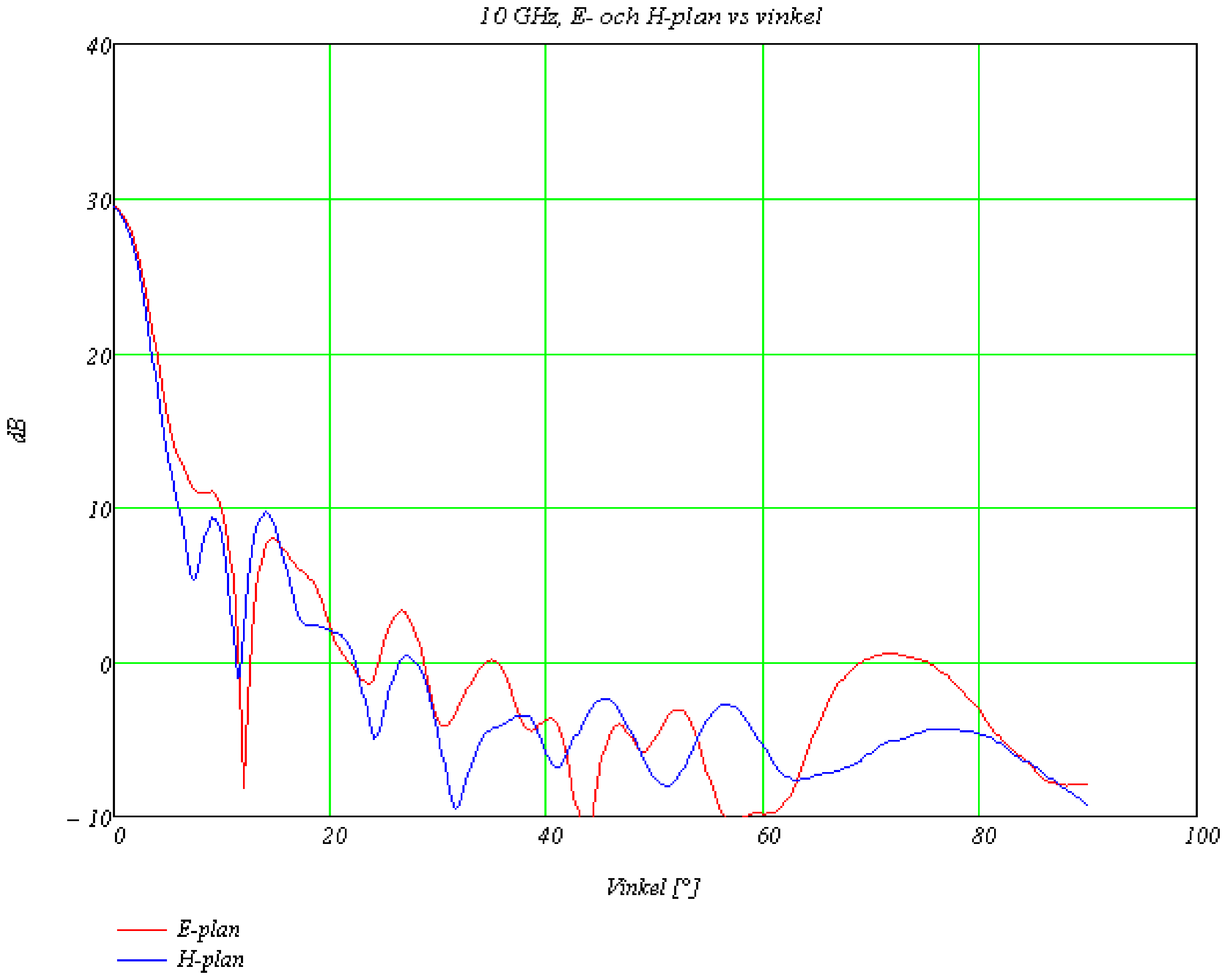
$E(\theta_{j0})$ is the antenna signal strength at angle θ_{j0}

$A(2r_j)$ is the attenuation associated with path-loss over the range r_j

$R(\theta_{jr})$ is the reflection coefficient corresponding to the radar signal reflection angle between the incoming ray from the radar and the local surface normal

$\text{msl} = -20$ metres

SIMULATIONS – RADAR BEAM PATTERN



SIMULATIONS – RADAR PATH LOSS

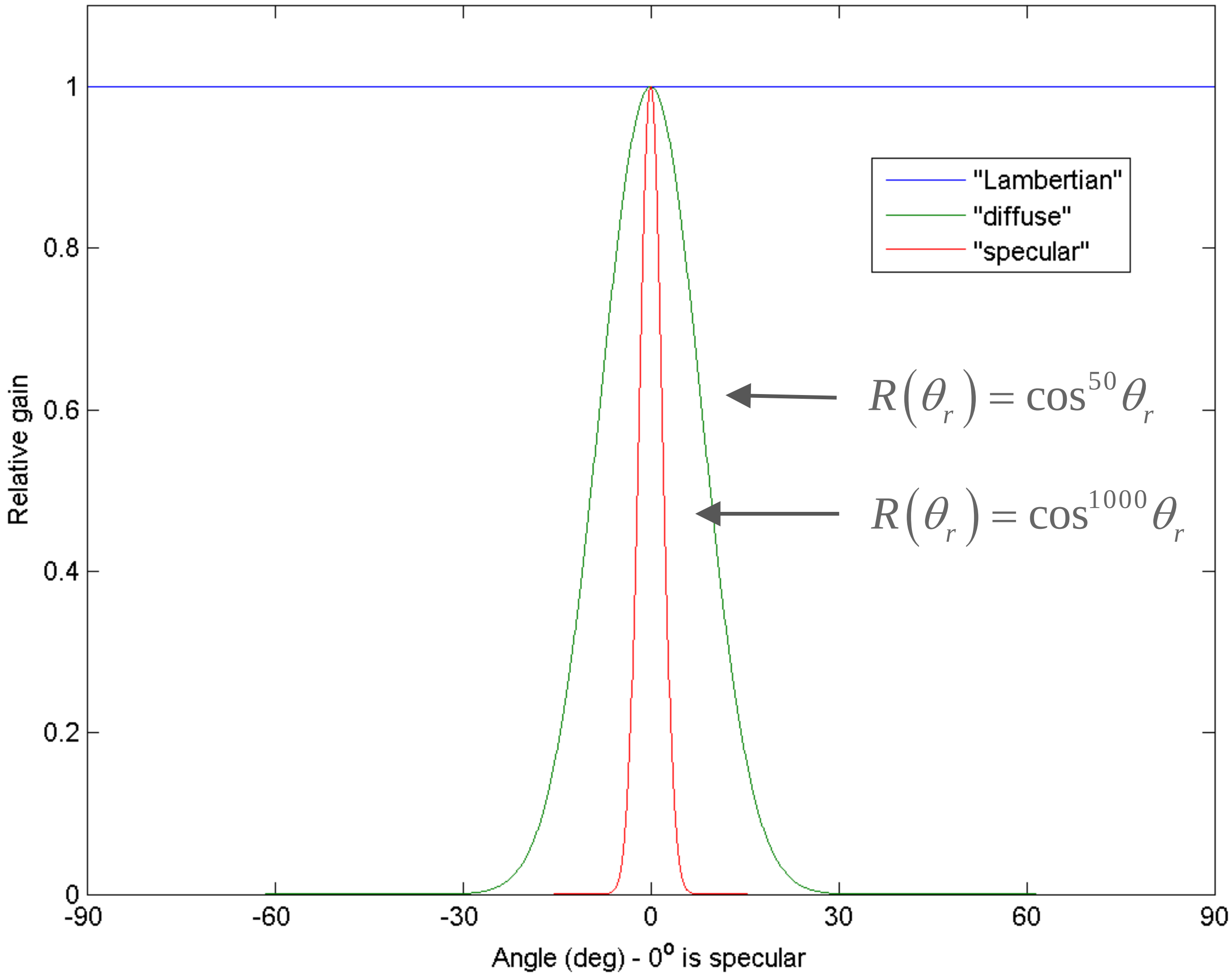
Friis – Free Space Path Loss

$$A_{dB}(r) = -20\log\left(\frac{4\pi 2r}{\lambda}\right)$$

r Range

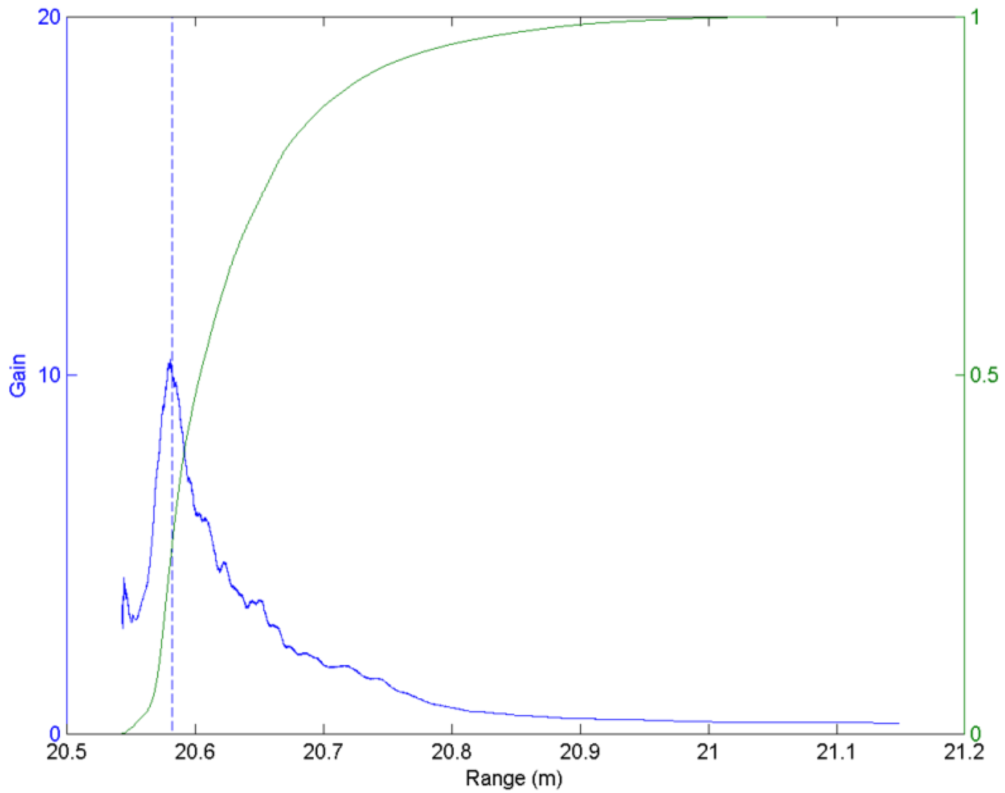
λ Radar wavelength

SIMULATIONS – RADAR SURFACE REFLECTION

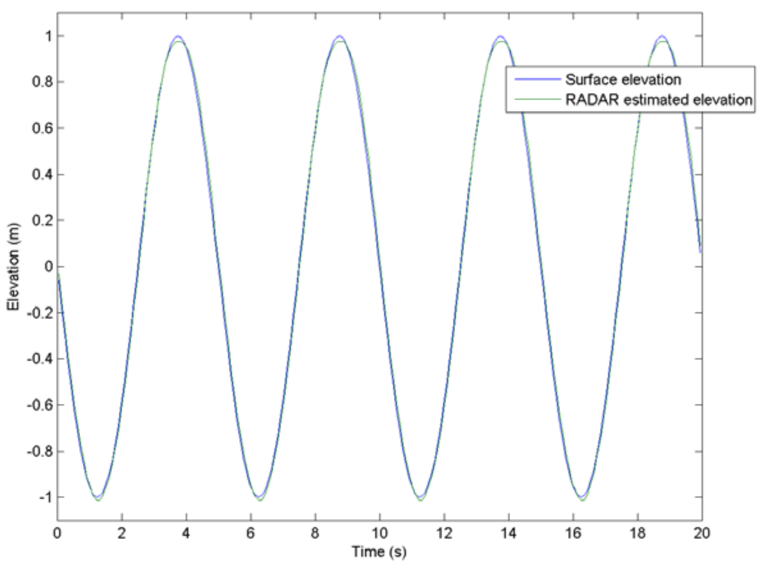


SIMULATIONS – RADAR SIGNAL PROCESSING

- Reflected signals from all of the surface points (~250,000) are accumulated
- The reflected signals are ordered in terms of range
- A cumulative sum of the gains calculated and smoothed
- The density function derived and the maximum determined

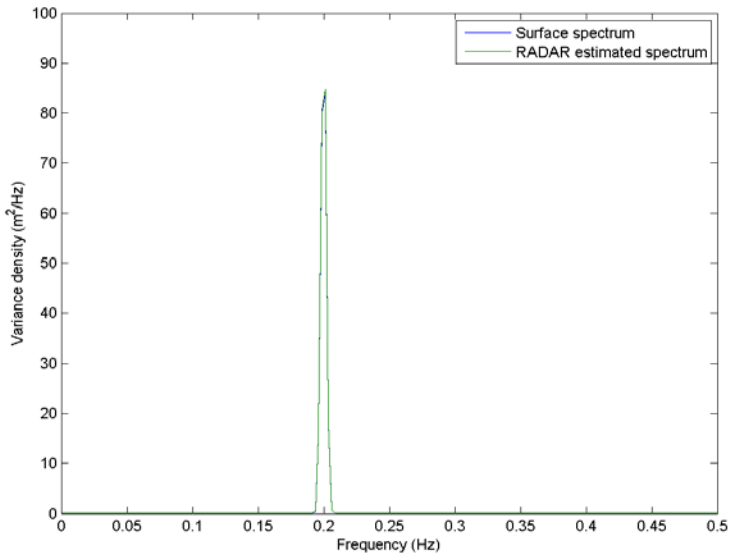


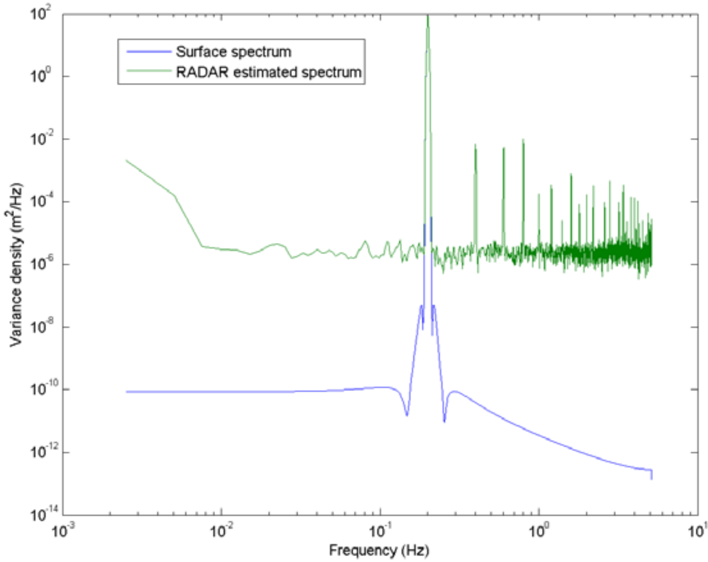
RESULTS – LONG-CRESTED REGULAR WAVE



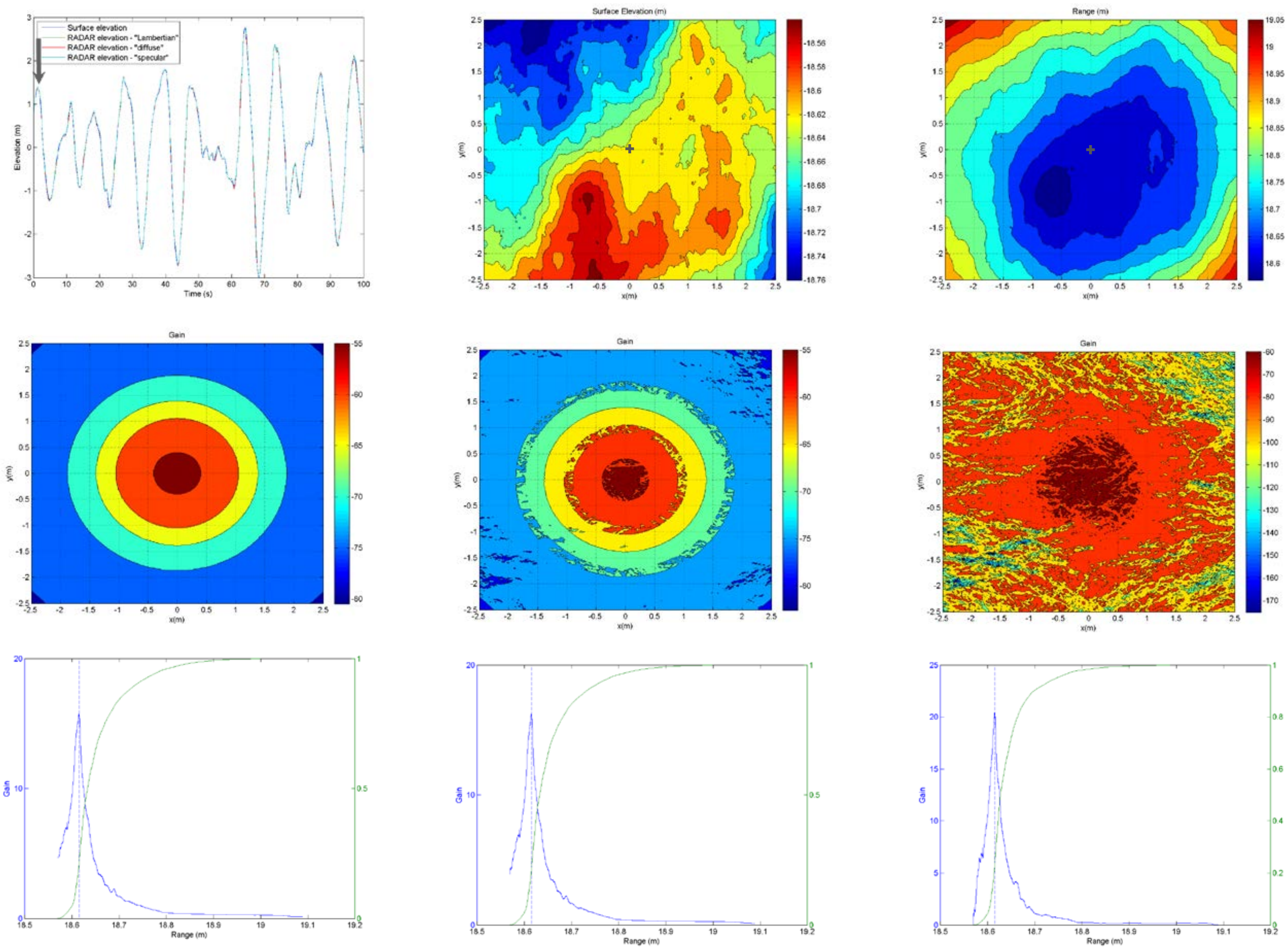
Amplitude = 1.0 m

Frequency = 0.20 Hz





RESULTS - RANDOM LINEAR SURFACE ELEVATION



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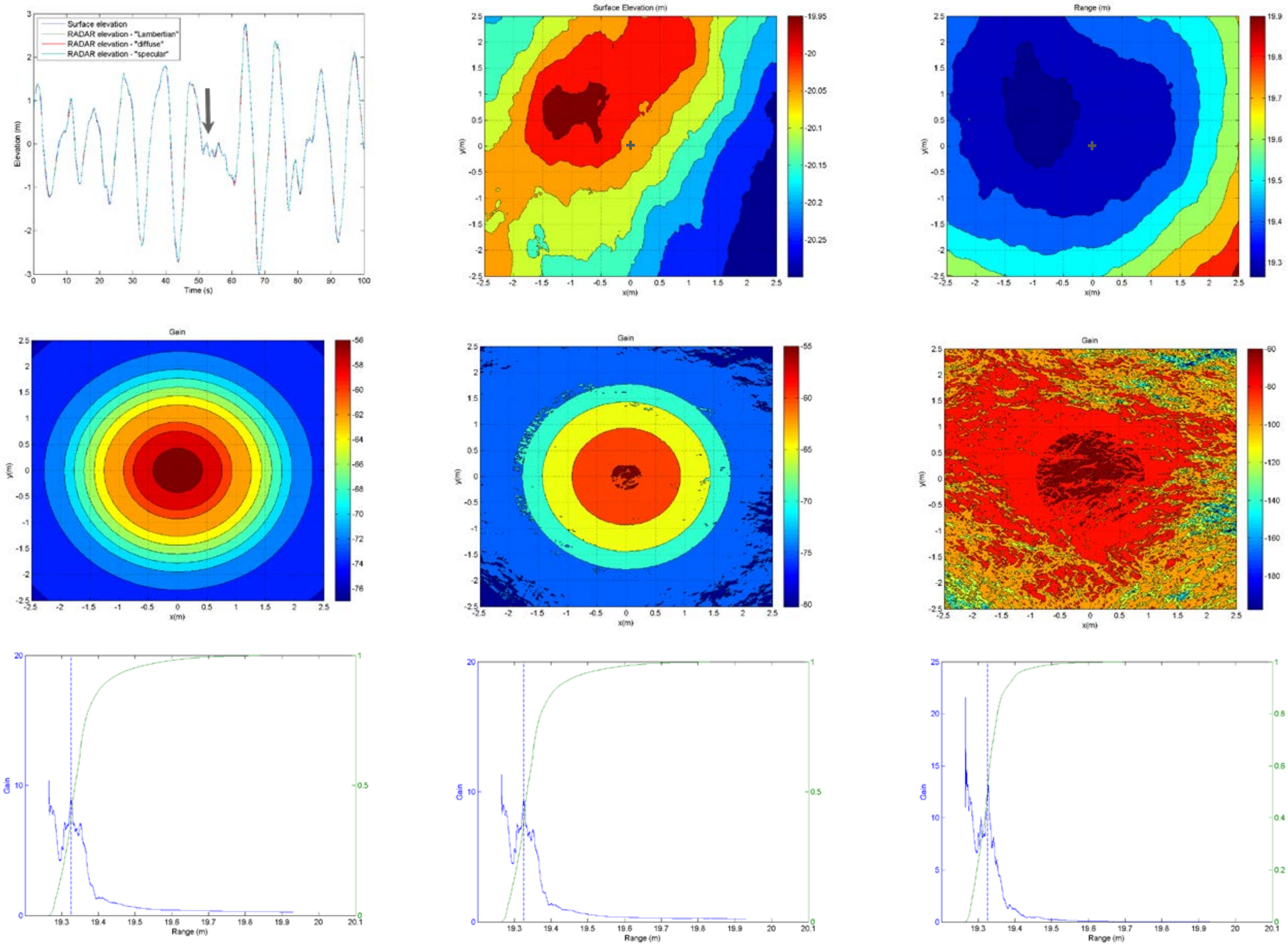

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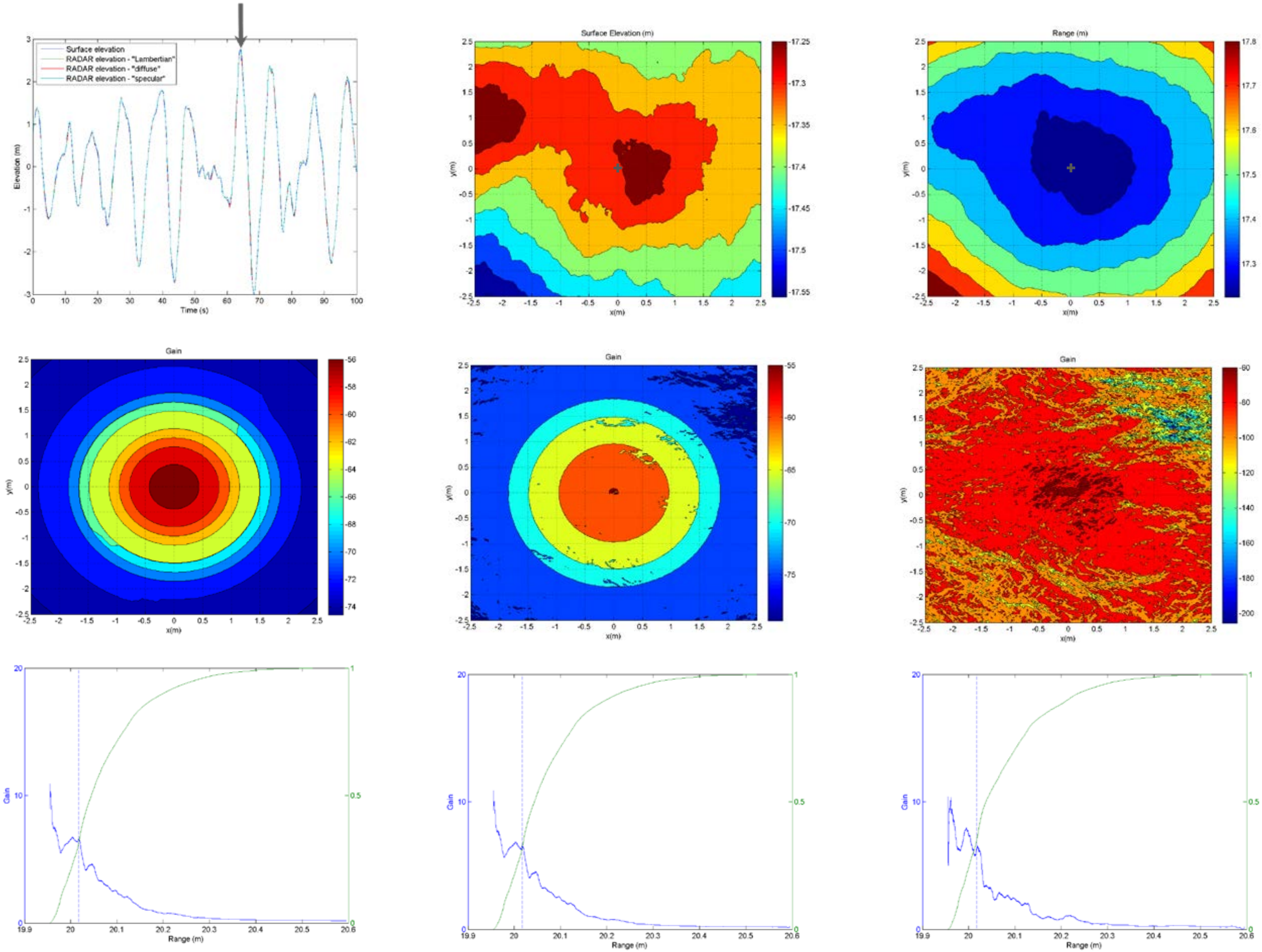

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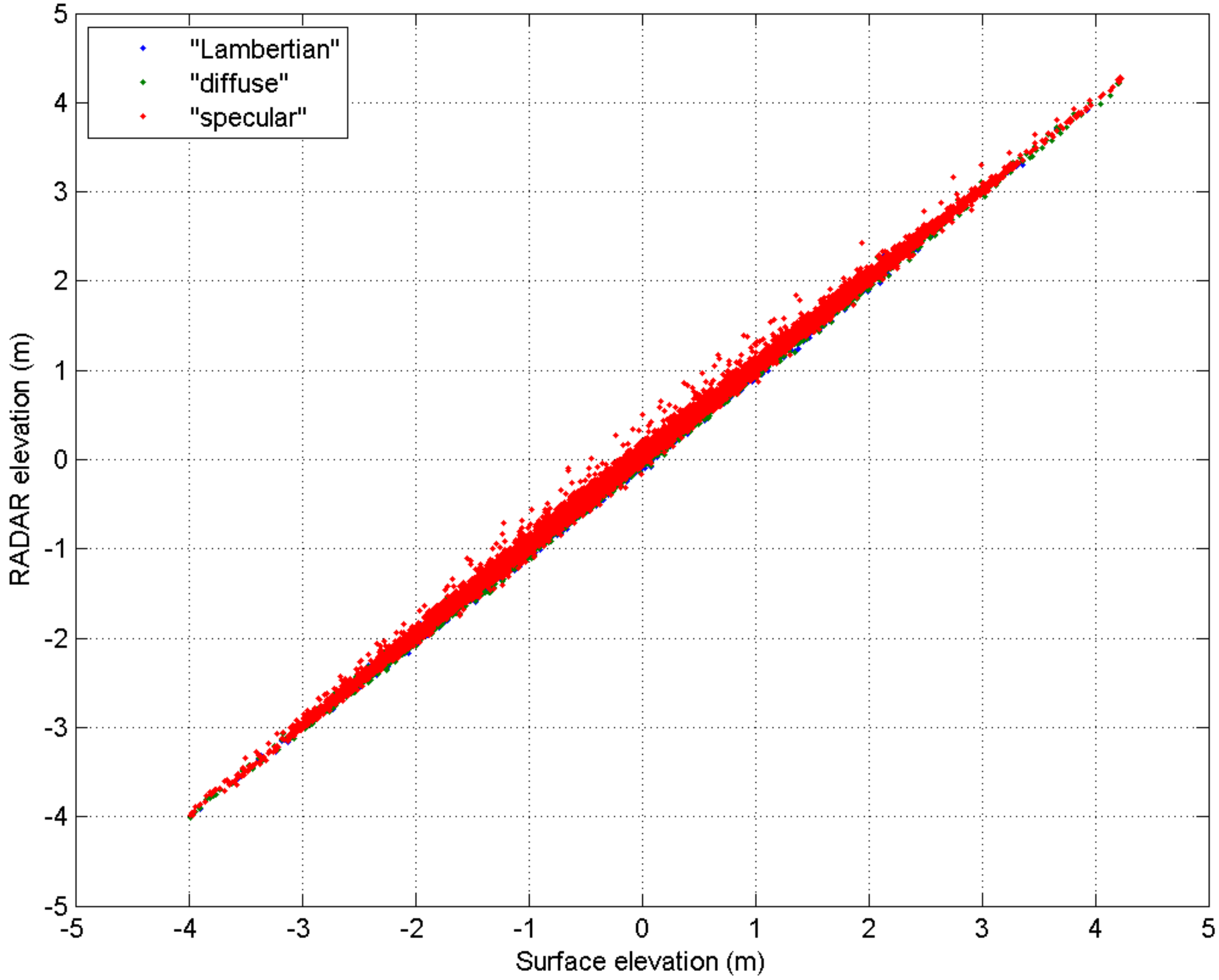

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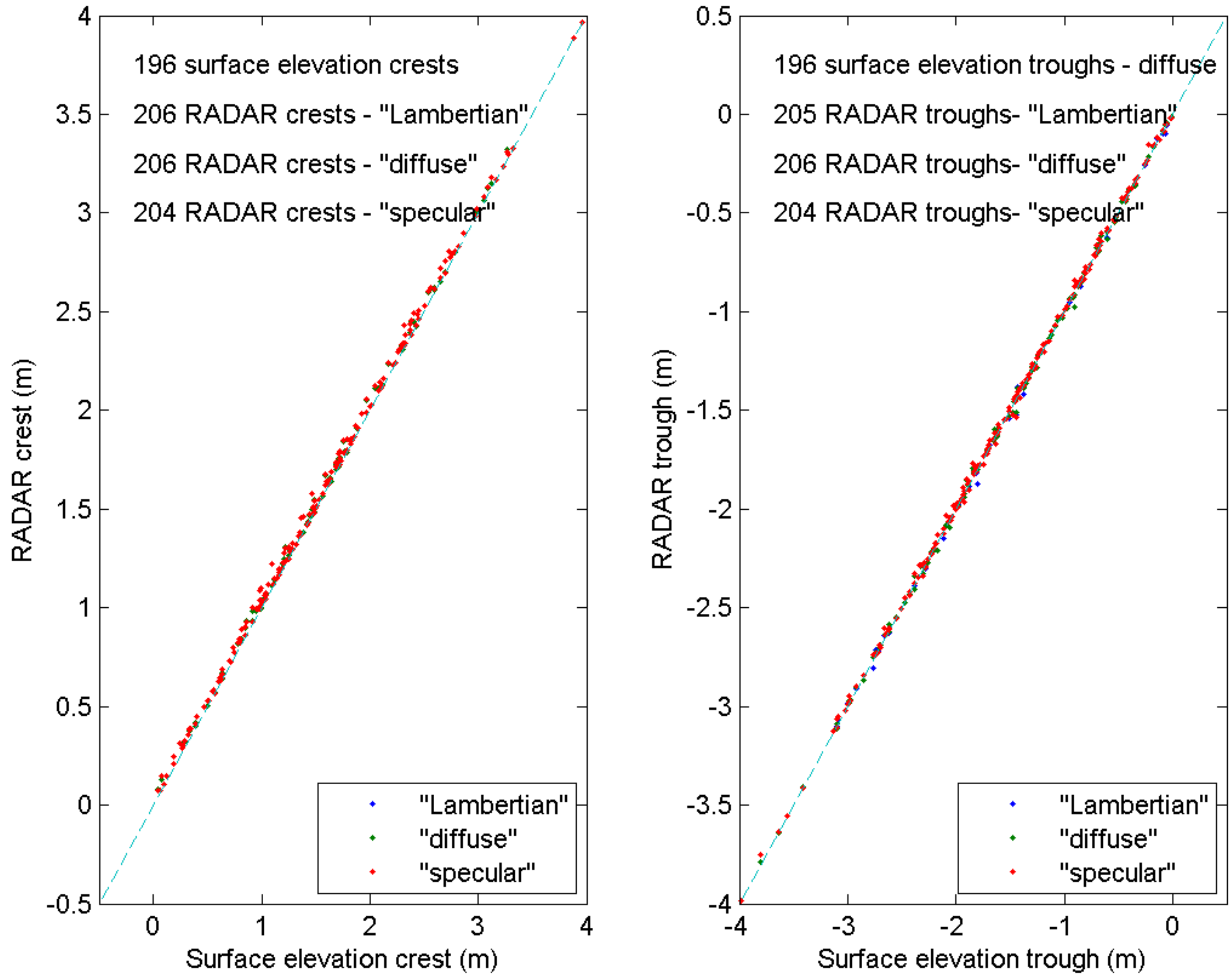

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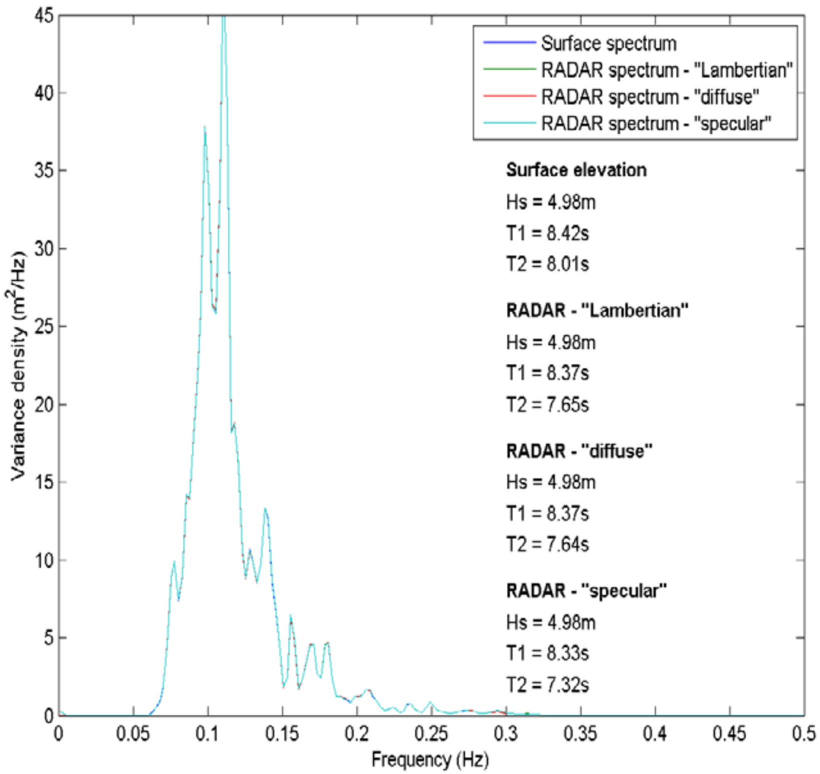
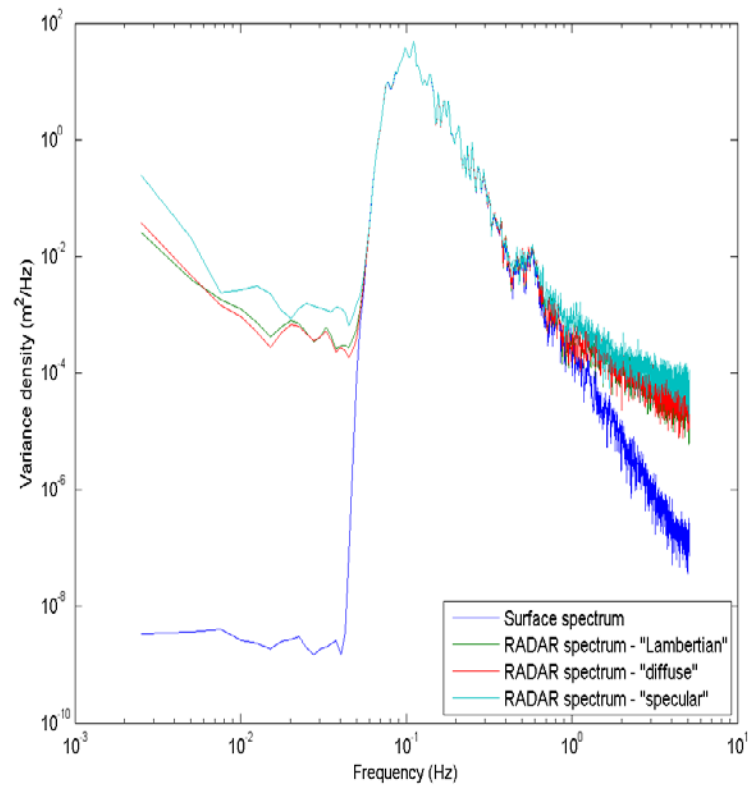
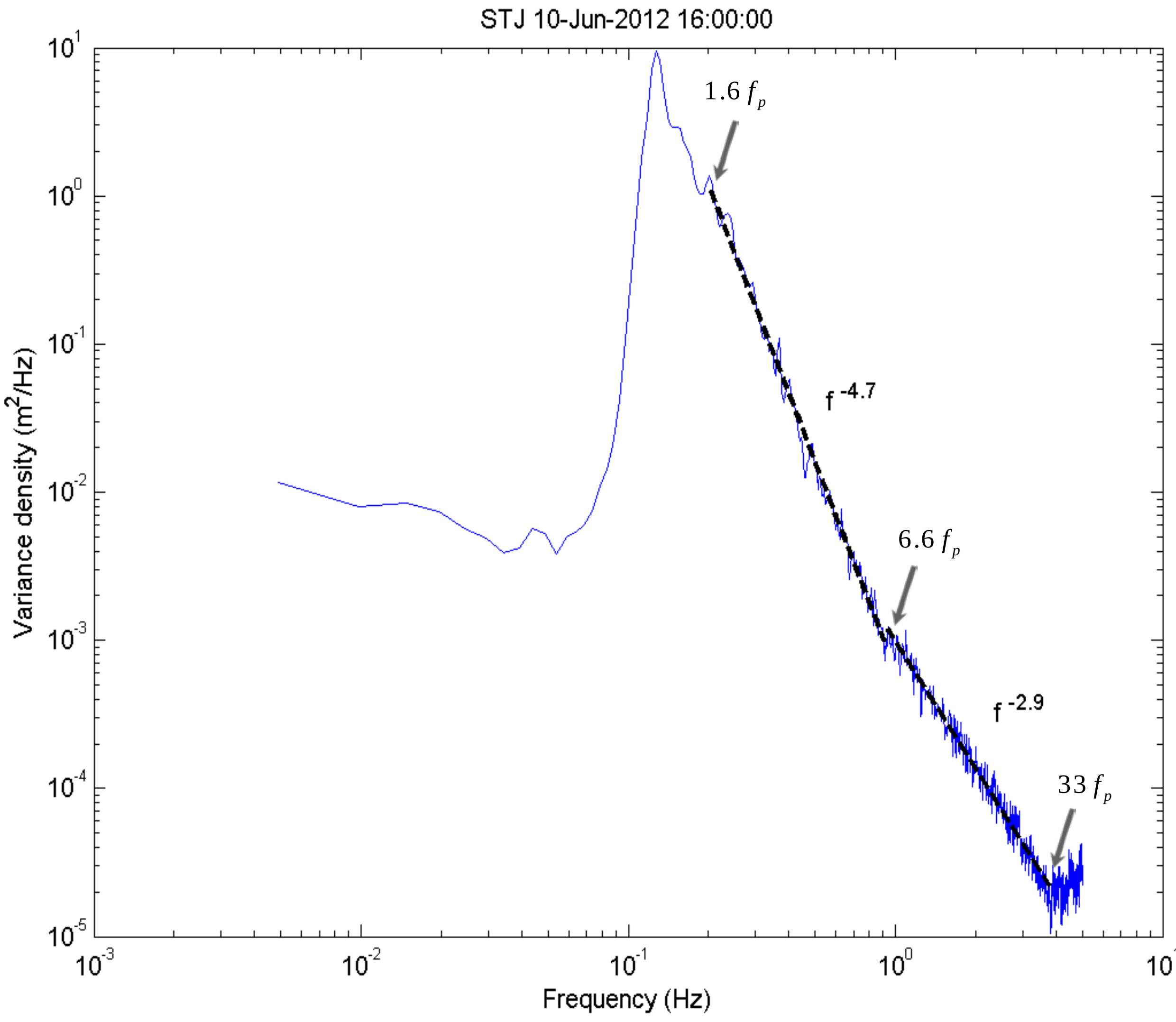
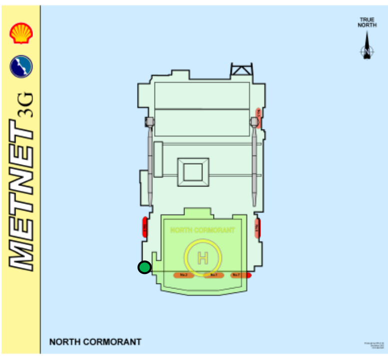




FIELD MEASUREMENTS – 10 HZ ST JOSEPH PLATFORM

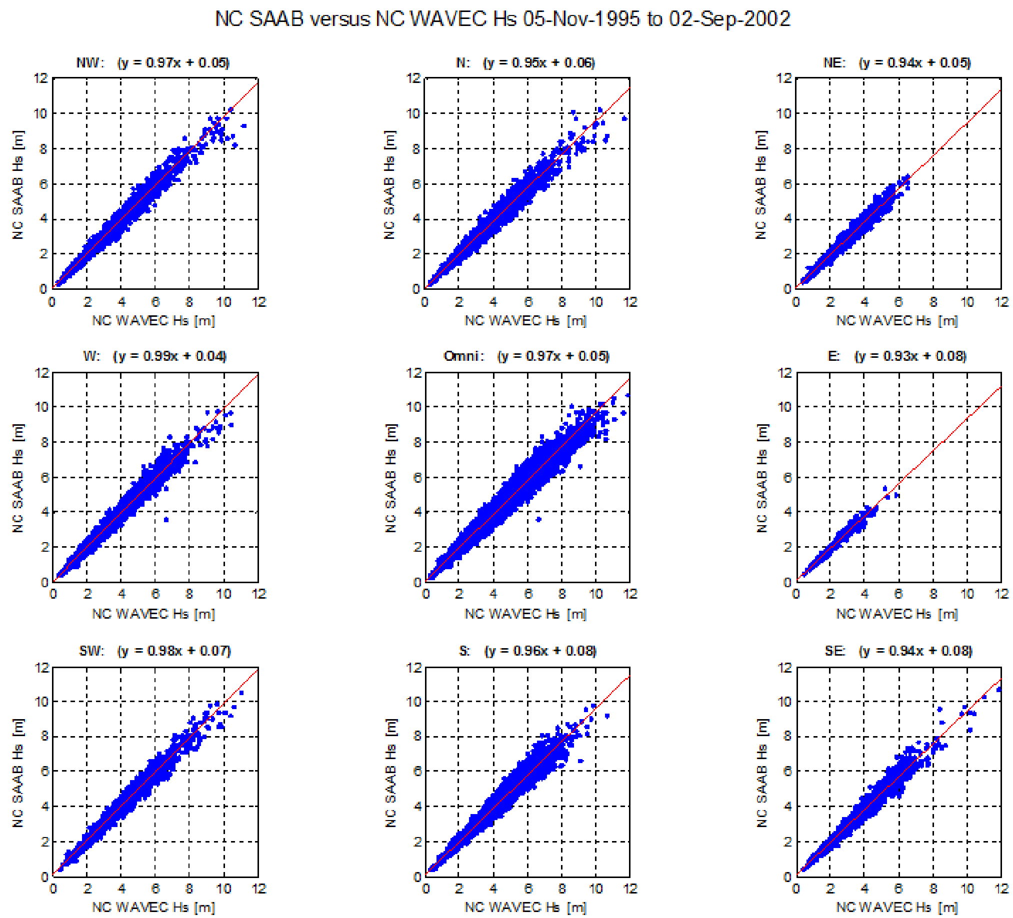


FIELD MEASUREMENTS – NORTH CORMORANT



SAAB WaveRadar
elevation 28.7 metres

Datawell WAVEC
~ few kilometres



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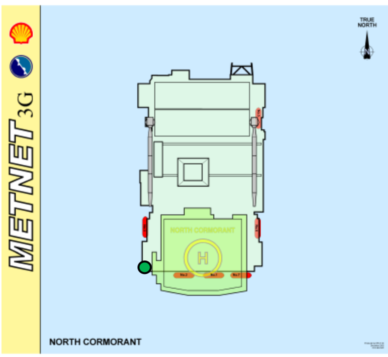
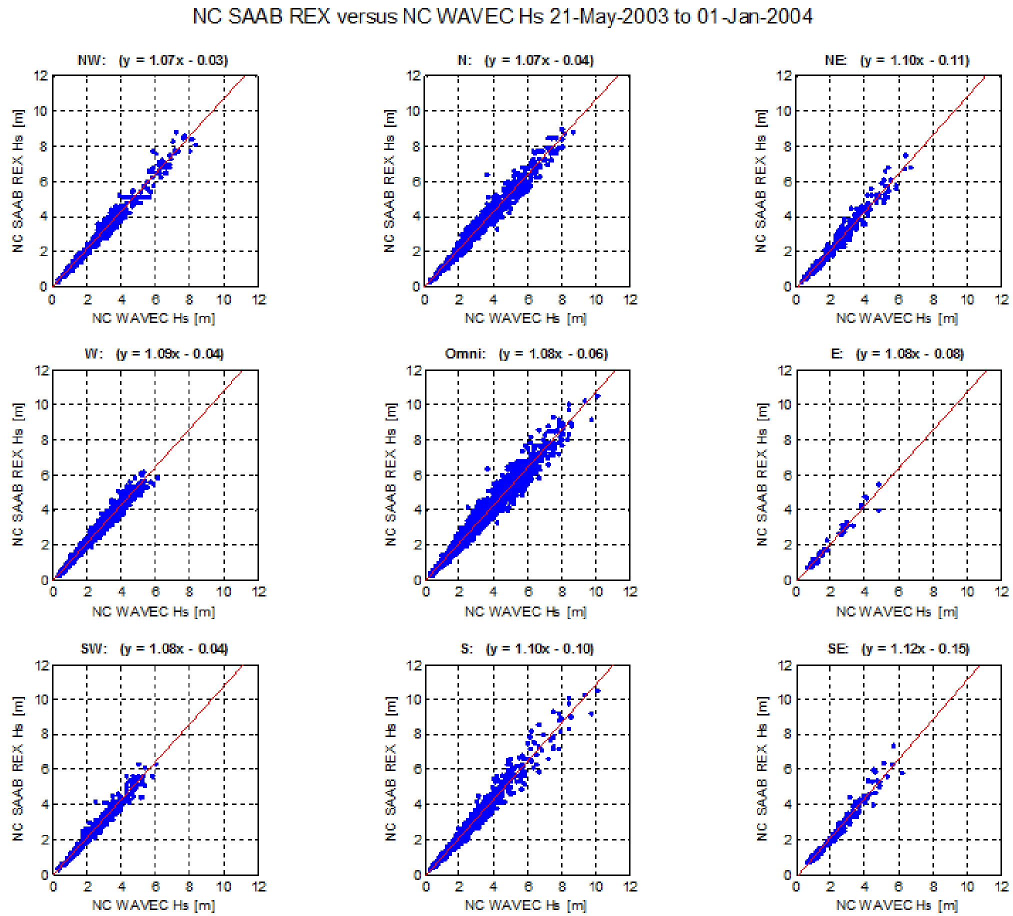
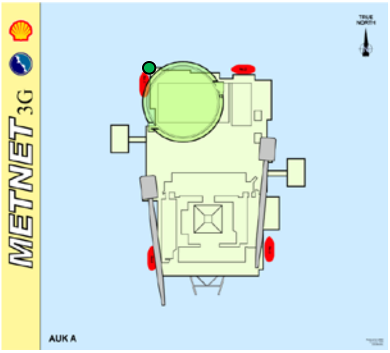


SAAB RexWaveRadar
elevation 28.7 metres

Datawell WAVEC
~ few kilometres

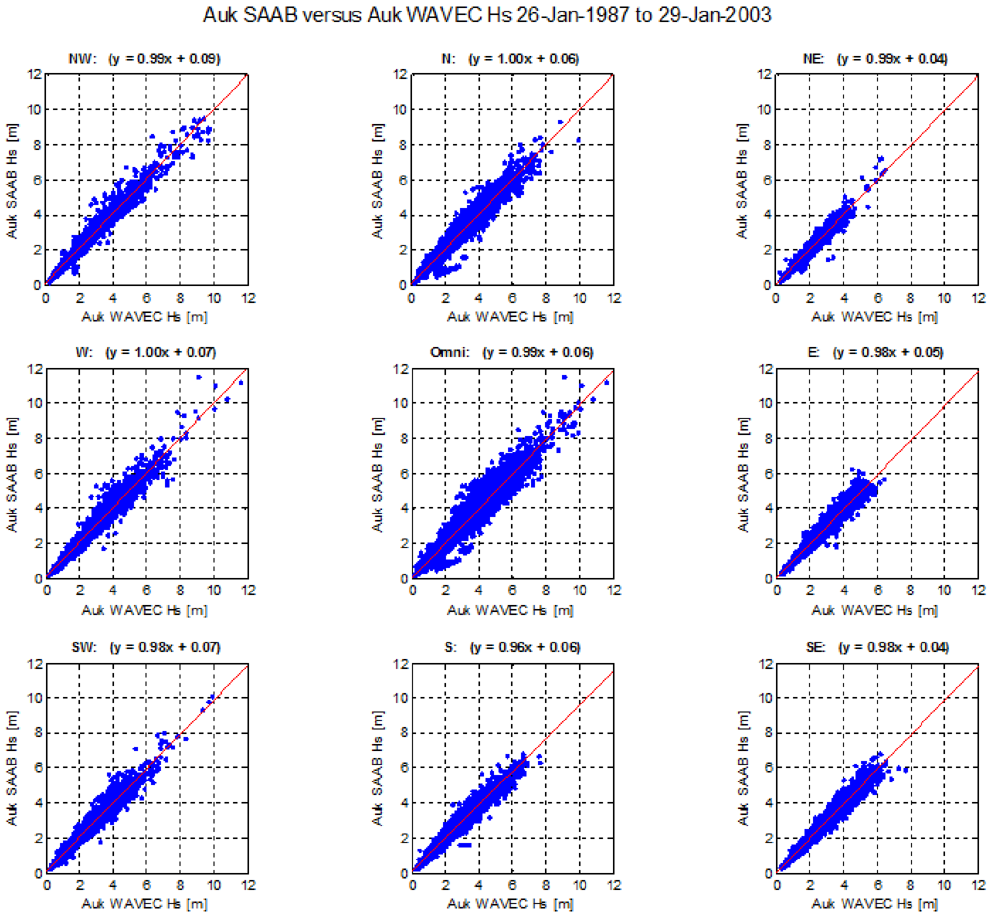


FIELD MEASUREMENTS – AUK



SAAB WaveRadar
elevation 24.3 metres

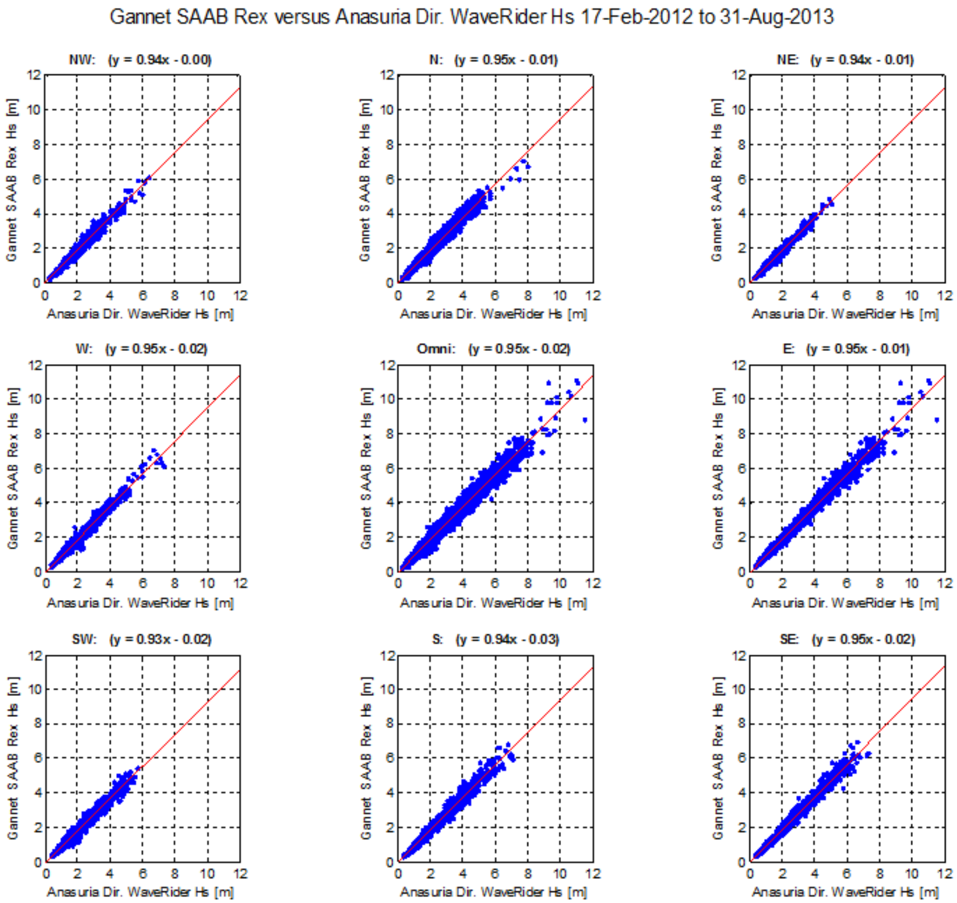
Datawell WAVEC
~ few kilometres



FIELD MEASUREMENTS – GANNET & ANASURIA

SAAB Rex WaveRadar
elevation 22.5 metres

Datawell DWR
~ 15 kilometres



CONCLUSIONS - SIMULATIONS

- Simulations of WaveRadar measurements of a random linear surface wave field indicate that the WaveRadar should faithfully measure the surface elevation at a point directly below the radar at frequencies between 0.06 Hz and 0.6 Hz
- The main cause for the departures in the simulated measurements outside that frequency band is due to the particular method we have employed for processing the reflected radar signals, and especially the peak-picking method
  - no effect on the significant wave height
  - elevated spectral levels above 0.6 Hz can bias the spectral moment periods high by a few percent, if the calculation of the spectral moments includes frequencies above 0.6 Hz
  - the departures in the simulated measurements outside that frequency band have no appreciable effect on the calculated zero-crossing crests and troughs, though a small spread is seen for small values of those parameters

CONCLUSIONS – FIELD MEASUREMENTS

- The field measurements made at a sampling frequency of 10 Hz indicate that the WaveRadar performs much better than the our simulations suggest
  - roll-off in spectral density continuing to much higher frequencies than the simulations
  - low-frequency plateau occurring an order of magnitude lower relative to the spectral peak
- Significant wave height of WaveRadar measurements against Datawell wave buoy measurements made in the North Sea generally show fairly good agreement
  - Comparisons between the earlier WaveRadar units and the Wavec buoy are in very good agreement for wave directions not expected to be affected by the platform and small reductions in the WaveRadar values compared with the buoy values for directions expected to be affected by the platform
  - Comparisons of the Rex WaveRadars against the wave buoys show systematic differences in the significant wave height in some cases, though the differences are relatively small (~10% at worst). This cannot be explained by platform interference, but appears to be more related to the specific setup of the instrumentation

CONCLUSIONS – OVERALL

- WaveRadar provides good measurements of the surface wave
  - Supporting offshore operational activities and engineering requirements
  - Investigating fundamental aspects of ocean surface waves