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Modeling the Interaction of a Laser Target Detection Device with the Sea

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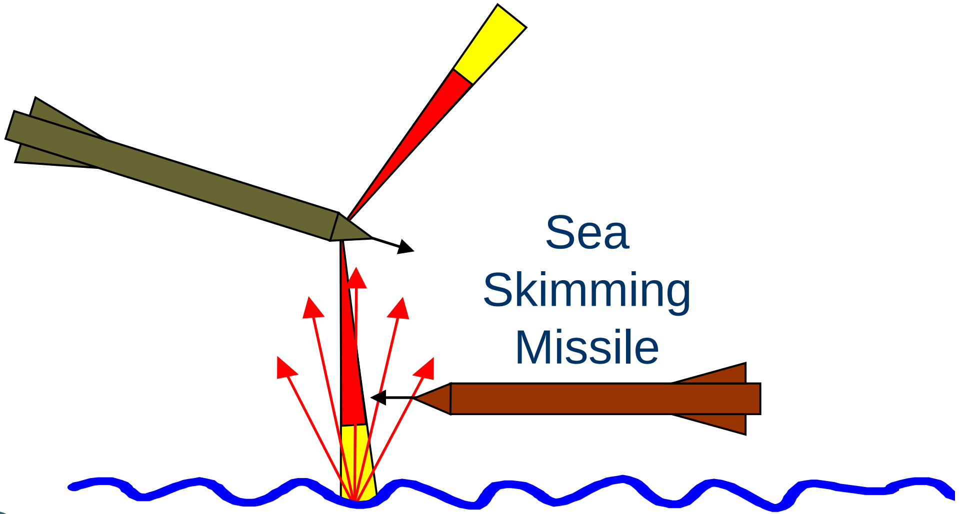
- Summary

Low Level & Embedded Threats

- Threat proximity to sea surface a challenge for the TDD
  - Sea skimming missiles close to sea clutter
  - Fast Inshore Attack Craft (FIACs) embedded in sea clutter
- Clutter reflections difficult to differentiate from target
  - Can be similar range and amplitude
- Analysis of TDD performance requires representative models of sensor interaction with the sea surface



Boston Whaler with rocket launcher

TDD Sensor Options for Low Level Threats

- TDDs for low level applications have historically employed Radar and/or Passive IR sensor technologies
  - Mature and validated models have been developed for simulation of the interaction of these sensors with the sea surface
- Active IR (laser) sensors offer an attractive alternative for reasons of detection precision and cost
  - Semiconductor laser sources in near IR
  - To date have not been employed in low level roles due to the uncertainty of their response to the sea surface
  - Absence of validated models with which to quantify the interaction

Dual Mode Radar and Passive IR Fuze

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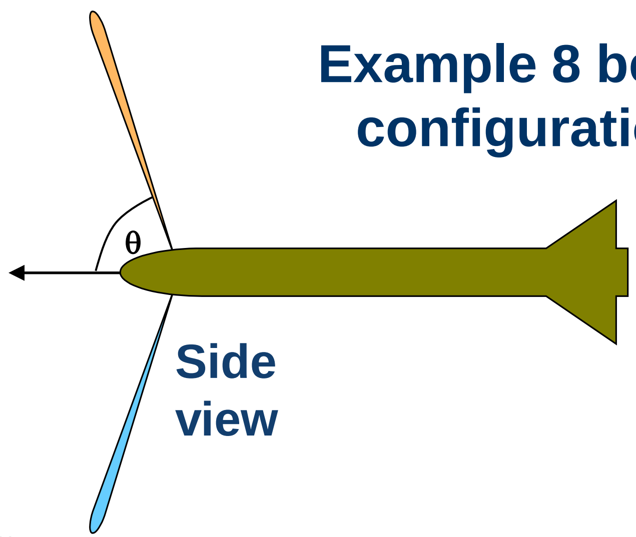
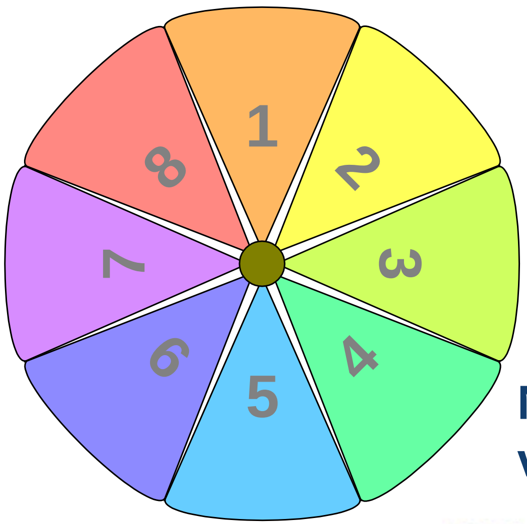
Multiple Fan Beam Laser Sensor TDD

- Multiple fan beams provide full azimuth coverage
  - Beam geometry approximates to a hollow cone
    - Forward looking with a semi angle to ~60°
    - Good match fragmenting warhead dynamics
  - Each fan a miniature Lidar able to measure range (time of flight)
    - Based on near IR pulsed semiconductor laser emitter technology and silicon pin diode receivers
  - Emphasis on use of low cost COTS opto-electronic components

Example 8 beam configuration



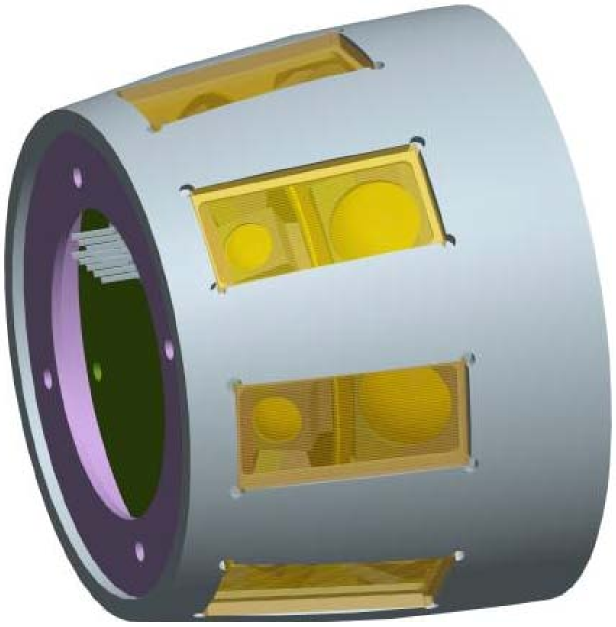
Side view



Nose on view

Multiple Fan Beam Laser Sensor TDD

- Part of the Thales 'Modular Vision for Future Target Detection Device Technology' briefed last year
  - Re-use of common signal processor and other key components
- TRL5/6 hardware demonstration of fan beam laser TDD
  - Subject of UK research over past 5 years



8 Beam packaging Concept

- Product now in full development
  - Body mounted configuration (ϕ<80mm)
  - Designed for volume manufacture
  - Extensive use of low cost moulded optical elements and mechanical parts
  - Light weight
  - Fully re-programmable
  - Development and qualification planned to complete by end 2010

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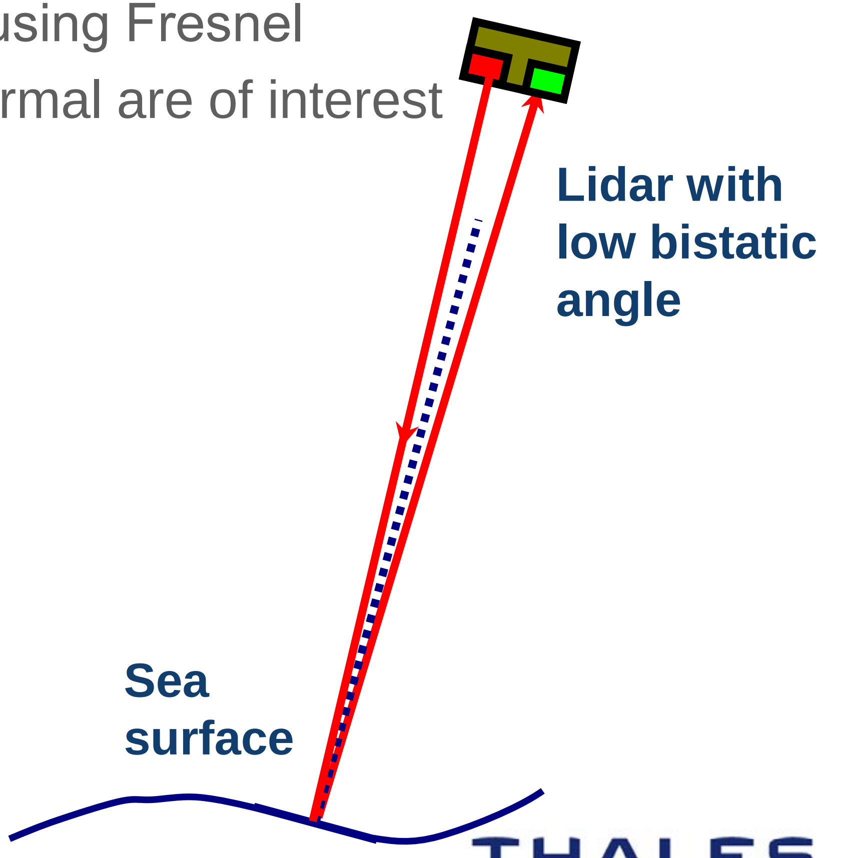
Laser Sensor Interaction with the Sea

- Operating at near IR wavelength (λ~0.9μm)
  - Imaginary component of refractivity (k) very small
  - Bulk absorption high hence volume backscatter can be ignored
  - Real component of refractivity (n) ~1.33 can be used to estimate surface reflectivity (ρ) using Fresnel
  - Only incident angles close to normal are of interest
    - Small sensor bistatic angle
    - Fresnel equations simplify
    - Reflectivity ~2%

$$\rho = \left(\frac{(n-1)}{(n+1)} \right)^2 \approx 0.02$$



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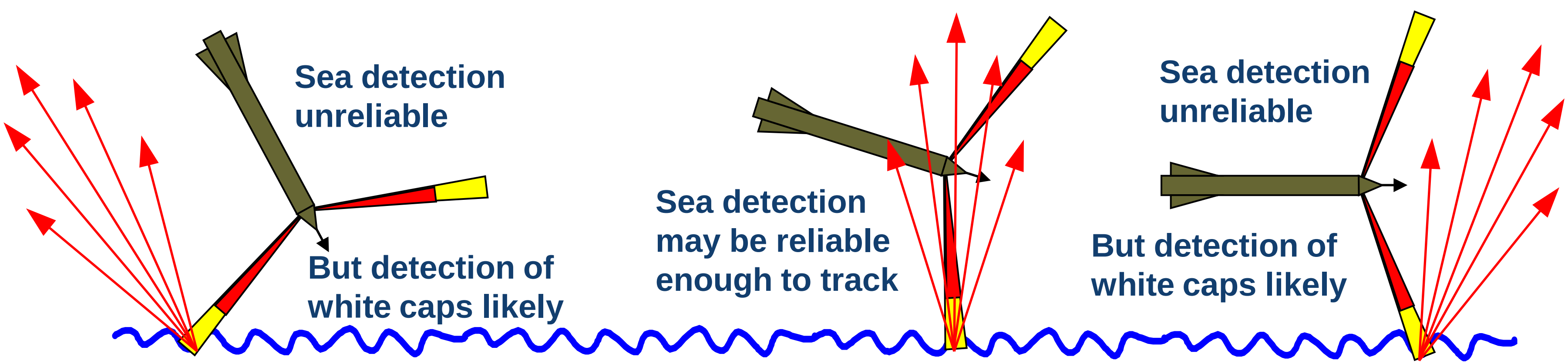
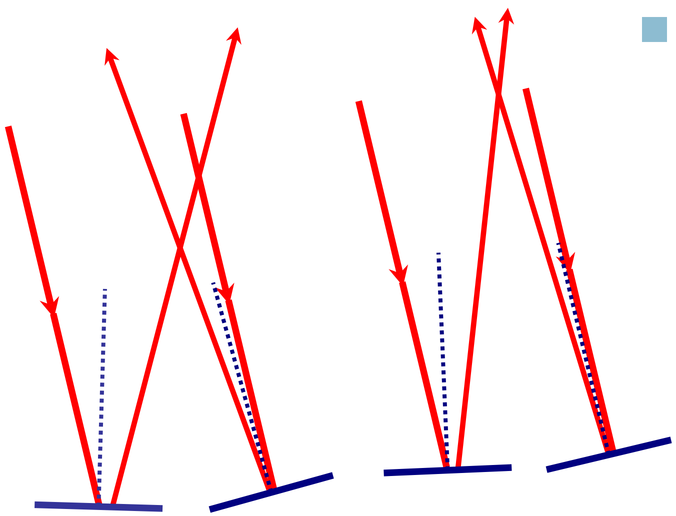
Laser Sensor Interaction with the Sea

- Active IR (laser) sensor response to sea ‘intermittent’
  - Sea surface behaves like a rippled mirror with a 2% reflectivity
    - Strong reflection if surface elements intersect beam near normal
    - Very low response if illuminated surface not close to normal
    - Response depends upon complex geometry of beam and rippled shape of sea surface
  - White caps can present a diffusely scattered signature
    - Detected over a broad range of illumination angles



Modelling the Sea Surface

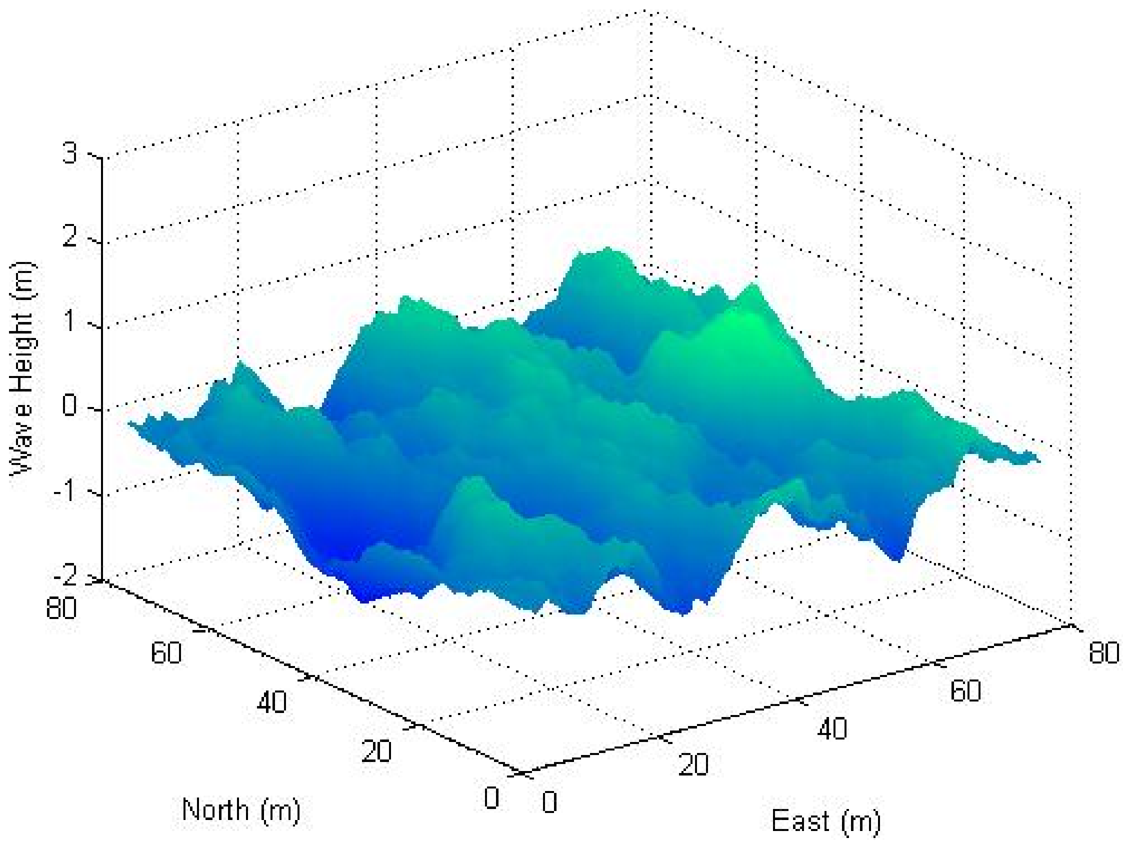
- Sea surface modelled as an array of small 2% reflectors
  - Contiguous surface comprising non planar facets
    - 5mm x 5mm (or smaller)
  - Arranged to represent 3D geometry of sea surface
  - Model shares origins with existing radar TDD interaction model
    - Smaller facets due to much shorter wavelength (~1μm versus ~10cm)
    - 64bit PC with large memory capacity used to run analyses (slowly)



- TDD sensor interaction model
  - Multiple fan beam geometry modelled
  - Defined engagement trajectories
  - Intersection of beams with 3D sea model
  - ‘Pulse by pulse’ response modelled
  - Summation of reflected pulse components from multiple facets computed

Modelling the Sea Surface

- Model uses wave spectrum proposed by Elfouhaily
  - Both gravity & surface capillary waves modelled
  - Capillary waves (e.g. λ<25mm) significant at laser wavelengths



- Parameters adjusted to vary sea conditions
  - Fetch
  - Wind speed & Direction
  - Resolution (e.g. 5mm)
  - Patch Size
- Wide variety of sea conditions modelled
  - Case shown a 80m by 80m patch, 12m/s wind, 500km fetch

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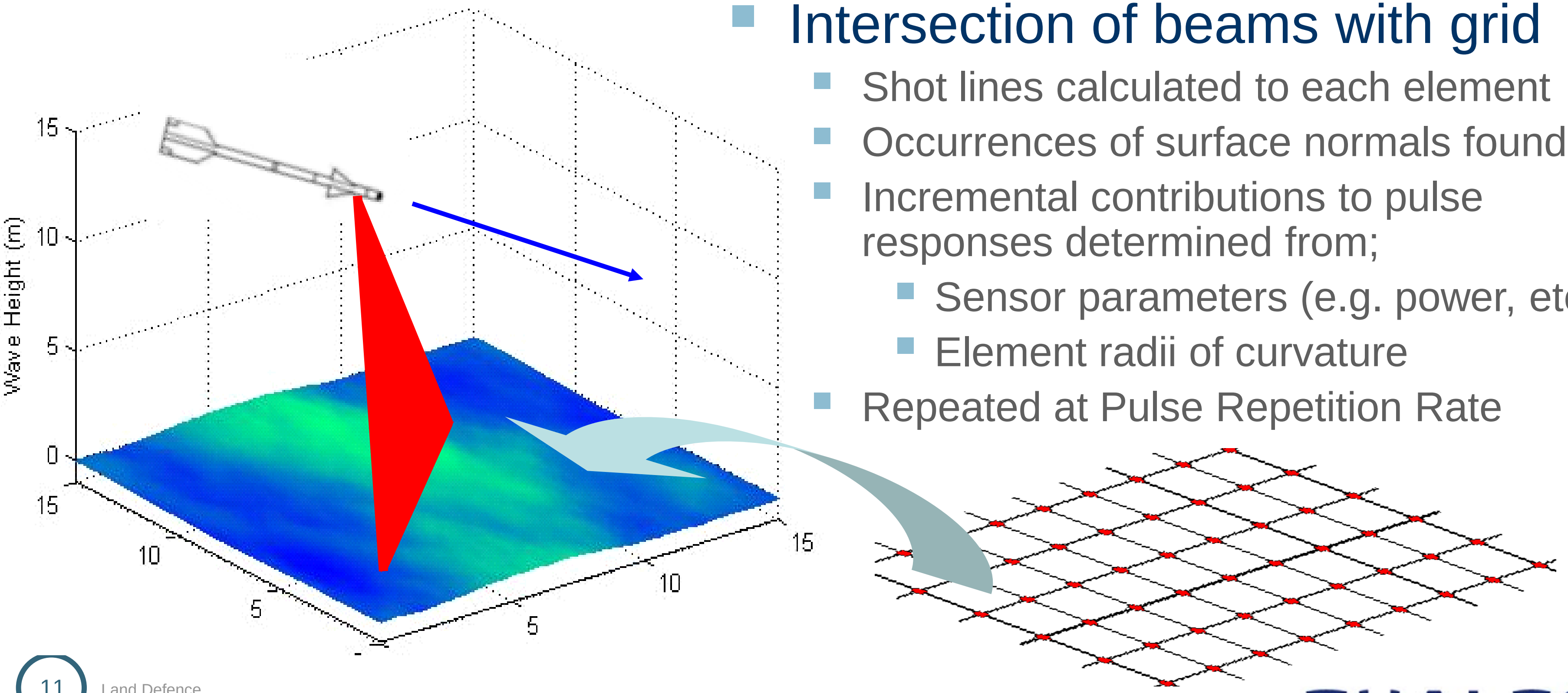
Modelling Sensor Response to the Sea

- Sea surface modelled as a regular grid of heights
  - Height at each vertex derived using the Elfouhaily spectrum
  - Characteristics of each element calculated from adjacent vertices
    - Normal vector of each element
    - Radii of curvature in two orthogonal axes
- Intersection of beams with grid
  - Shot lines calculated to each element
  - Occurrences of surface normals found
  - Incremental contributions to pulse responses determined from;
    - Sensor parameters (e.g. power, etc)
    - Element radii of curvature
  - Repeated at Pulse Repetition Rate



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Model Validation – Sea Data Gathering

Initial Pencil Beam Laser Sensor Trials

Metric	Trials Value	Model Value	Comment
Detection rate %	~30%	~34%	~ 6kt wind

- Pulsed laser sensor
  - Narrow beam width <1°
  - Sensitivity calibrated
- Mounted on bows of vessel
  - Beam viewing sea surface ahead of wake
  - Adjustable pitch & roll angles
  - Adjustable height
  - Vessel speed ~13 knots
  - Wind speed/bearing recorded
- Threshold crossings recorded
  - Fair correlation with model
  - Provided initial validation

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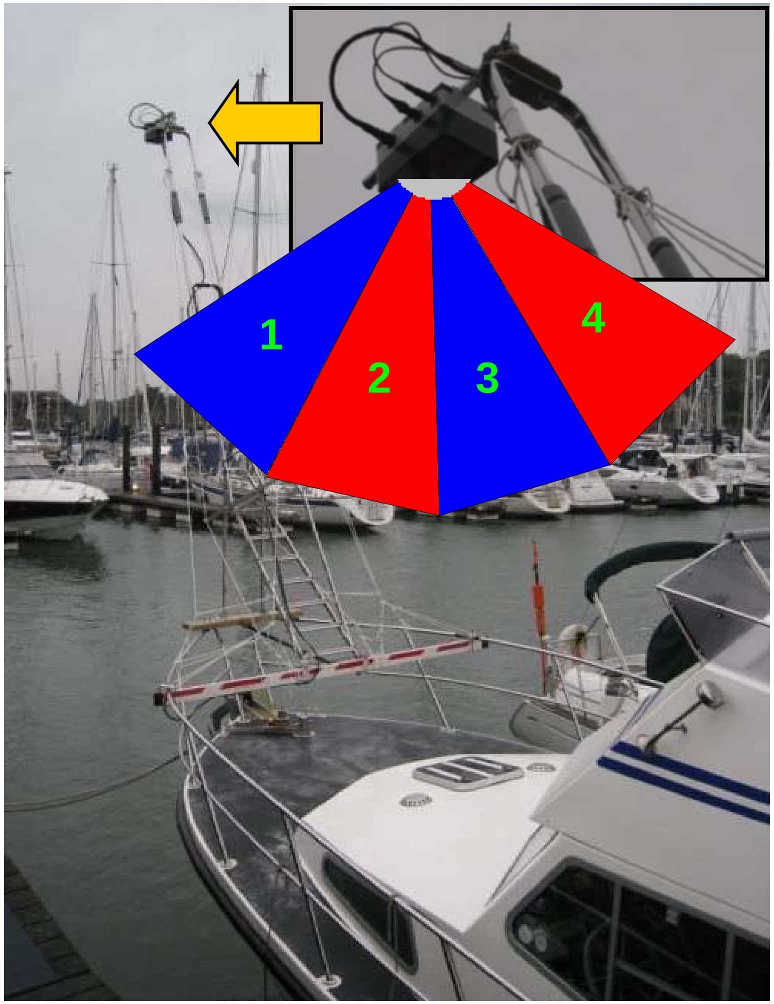
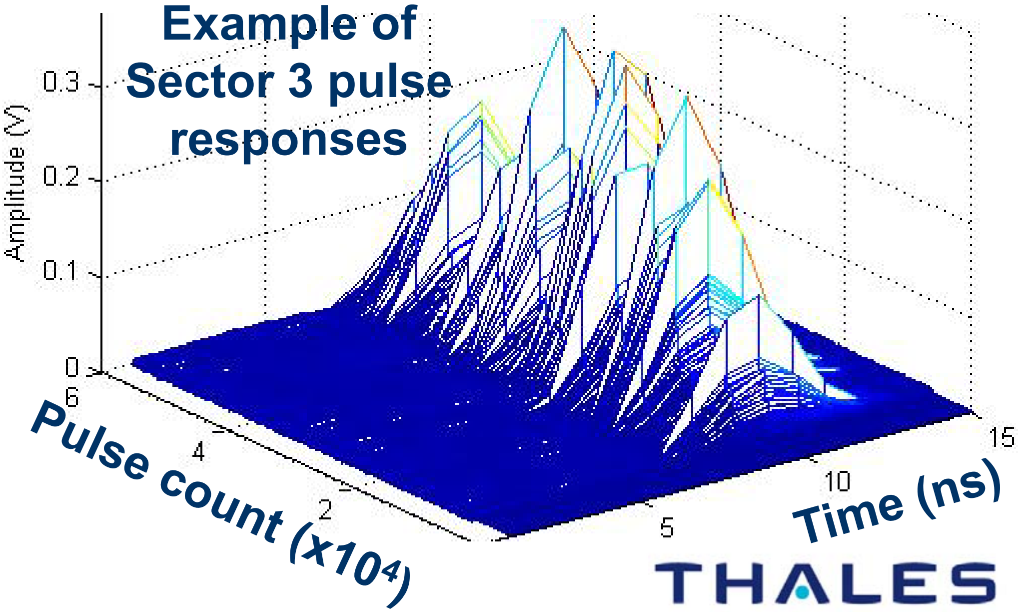
Model Validation – Sea Data Gathering

Multiple Fan Beam Laser Sensor Trials



- Experimental form of future TDD
  - Four 30° contiguous fan beams
  - Partial azimuth coverage (only downward beams see reflections)
  - Received pulse waveforms digitised
  - Data recorded for various sensor orientations and sea conditions



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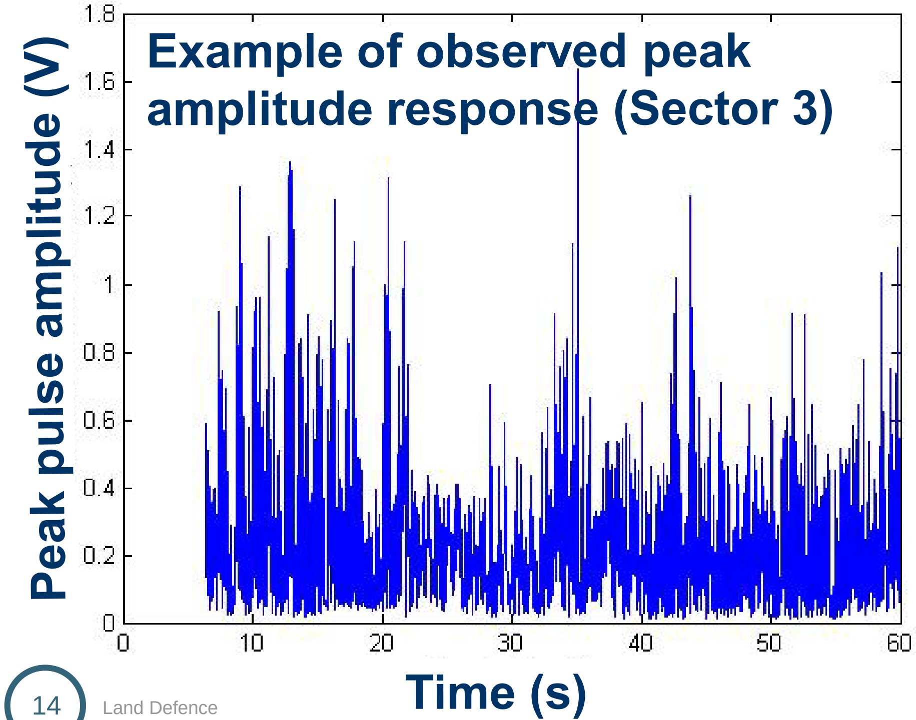
Detection rate (%) Averaged over Multiple Cases

Sensor Height	Fan Beam Angle from Vertical (°)					
	0°		10°		20°	
	Trial	Model	Trial	Model	Trial	Model
3.4 m	89	93	86	56	36	13
5 m	80	91	83	39	9	8



- Fair agreement between Model and practise
  - Good comparison between modelled and observed detection rates
  - Fair comparison between predicted and observed pulse amplitude distributions

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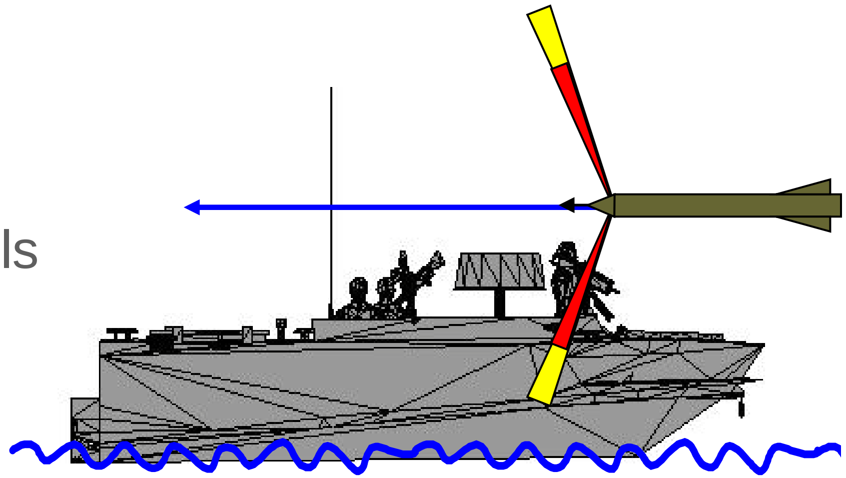
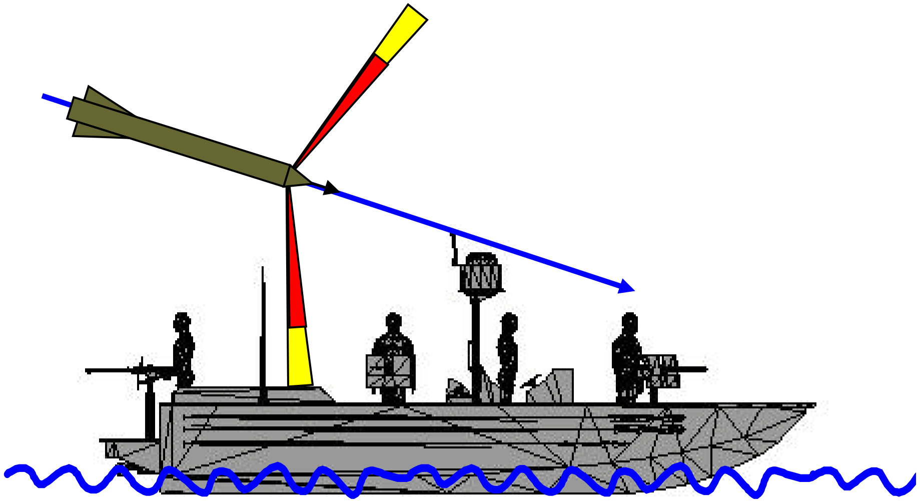
- FIAC targets modelled
  - 3D facet models
    - Diffuse Lambertian reflectors
  - Embedded in sea clutter models
  - Various dive angles modelled
  - Combined response to target and clutter modelled





- Algorithm development
  - Sea clutter rejection
  - Reliable target detection
  - Initial algorithms constructed and tested
  - Initial results encouraging
  - Validation in progress

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Model Applications – Anti FIAC Algorithms

Example Model Output – Case of Horizontal Trajectory

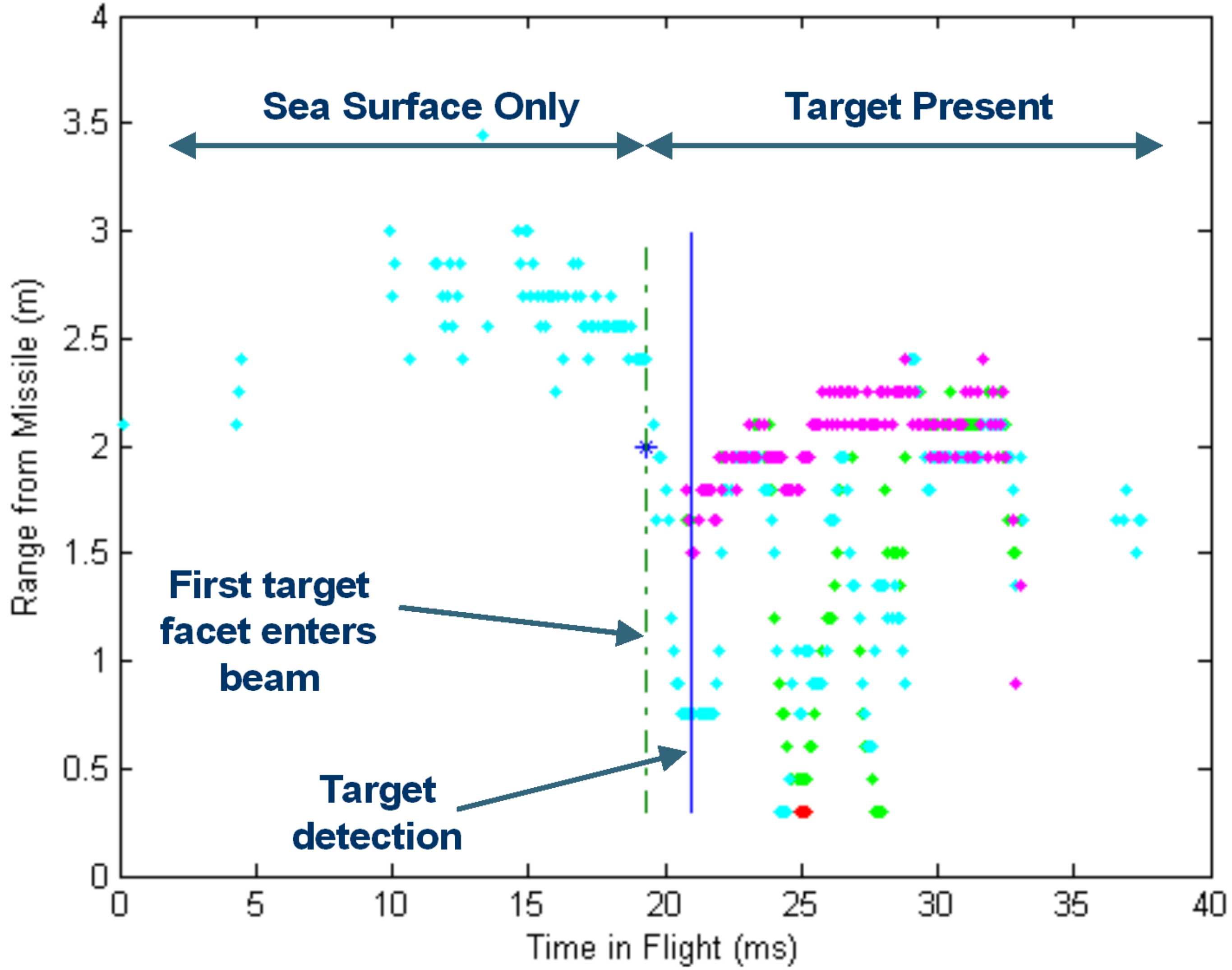
Sector 1 - Red

Sector 2 – Green

Sector 3 – Cyan

Sector 4 – Mager

Sector 4 – Black



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Model Applications – Anti FIAC Algorithms

Example Model Output – Case of Diving Trajectory

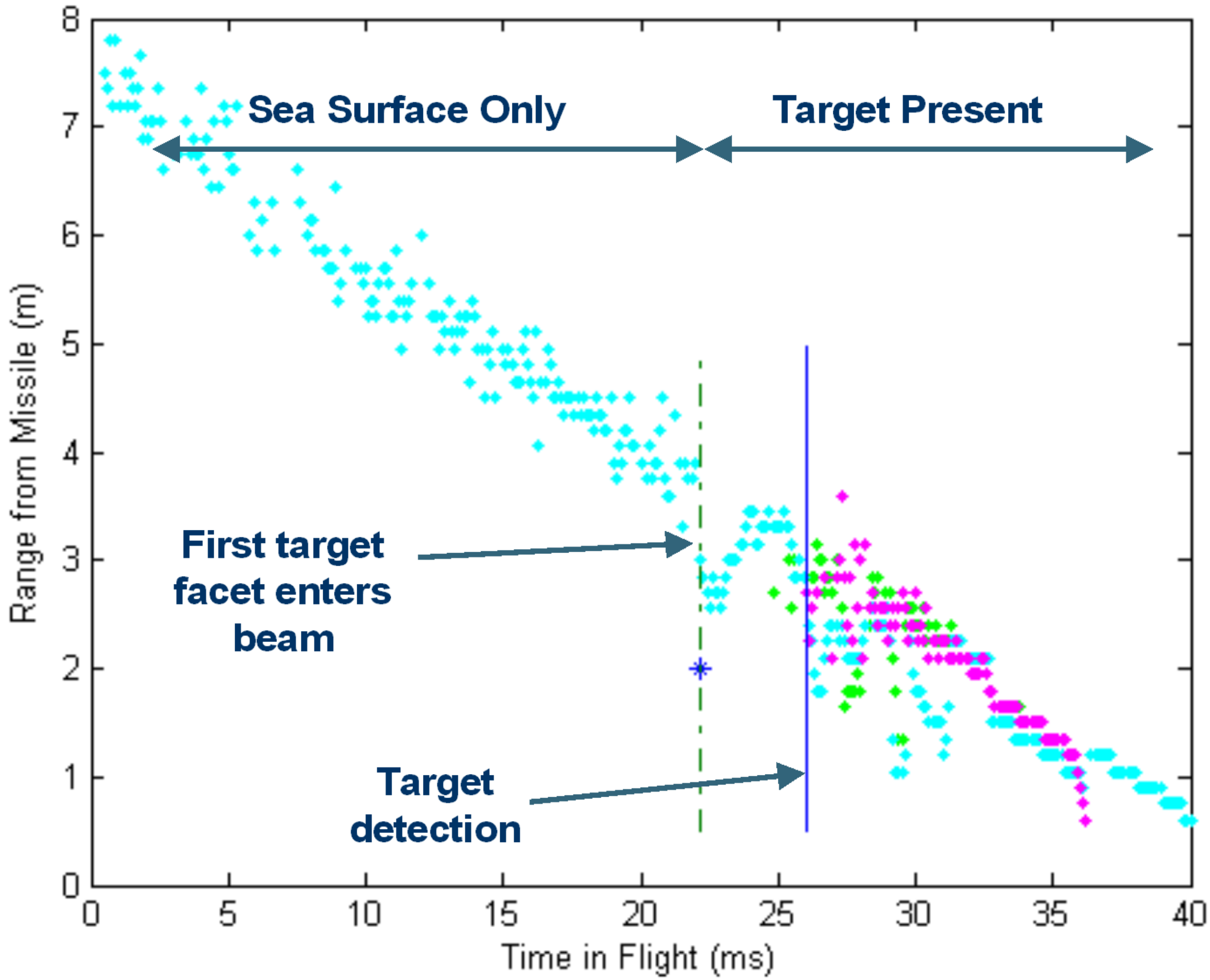
Sector 1 - Red

Sector 2 – Green

Sector 3 – Cyan

Sector 4 – Magenta

Sector 4 – Black



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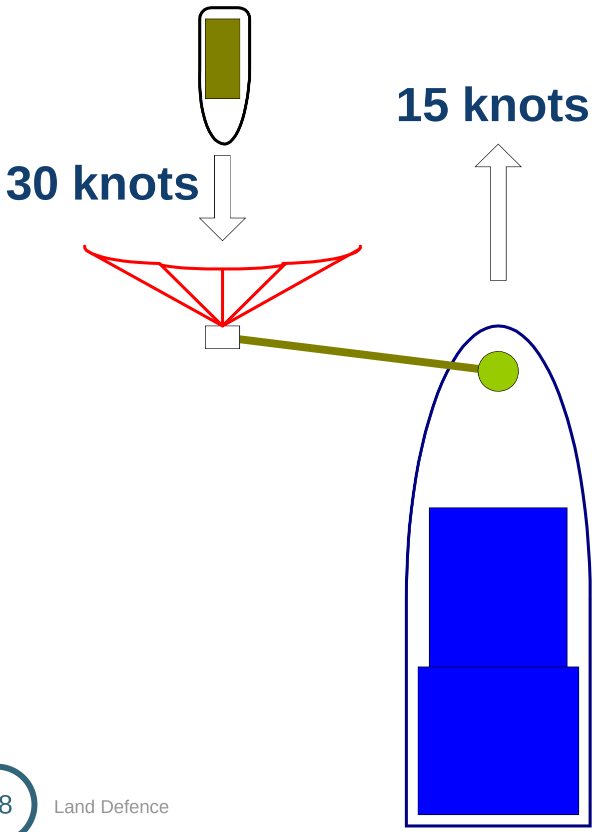
Recent ‘AFIAC’ Sea Data Gathering Trial

- Sensor deployed on boom to one side of vessel
- Rib ‘target’ travelling at speed under / to one side of sensor
  - Provides representative wake data
  - Data to be used for validating models and developing algorithms



Recent ‘AFIAC’ Sea Data Gathering Trial

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Recent ‘AFIAC’ Sea Data Gathering Trial

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Summary

- A model for the response of a multiple fan beam laser TDD to the sea surface has been developed
- Initial data gathering and model validation performed
  - Received signal levels estimated by the model compare favourably with those of the trials data
  - The predicted variability of the signal returns from the sea appears to be confirmed by the trials
- Facility to embed targets in scene
  - e.g. FIACs and sea skimming missiles
  - Supports the development of a lidar sensor TDD for Anti FIAC and anti Sea Skimmer missile applications

Any Questions ?

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