NURC - Partnering for Maritime Innovation

Transitioning the Multistatic Tactical Planning Aid (MSTPA) towards decision support software

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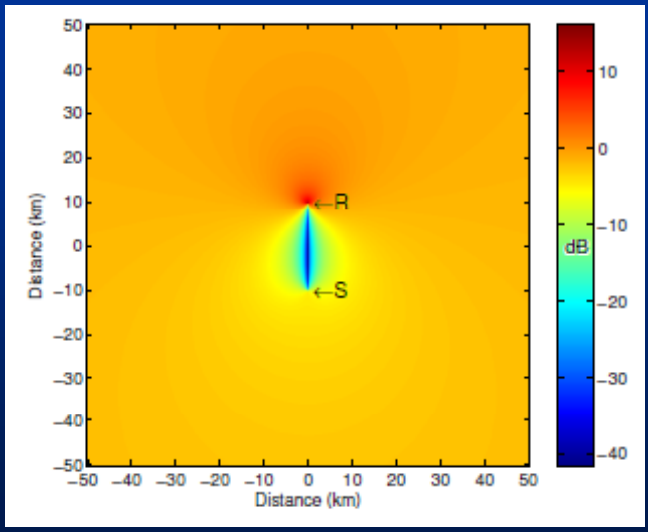
Introduction

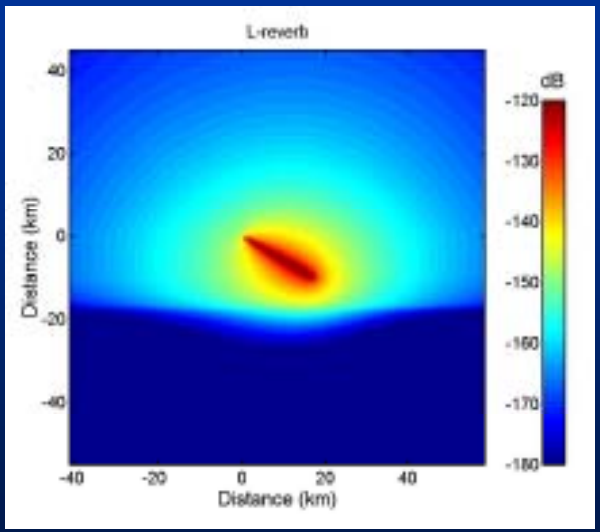
- Multistatic Tactical Planning Aid (MSTPA)
- More operational performance metrics
- Model entire process from Signal Excess to track classification
- Transition towards Decision Support Tool
- Need fast acoustic calculations to allow Monte Carlo and optimisation algorithms

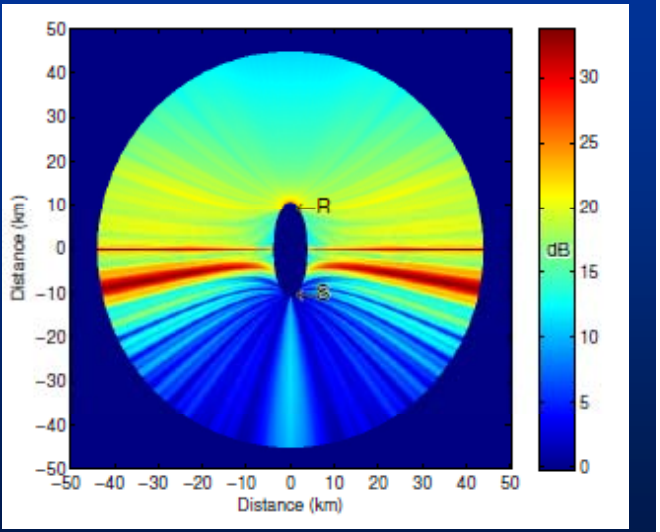
- What happens *after* we calculate dB

Signal Excess

- Closed form algorithms (developed by Dr. C Harrison at NURC)
- Range dependent SVP and Bathymetry
- Target Echo, Reverberation
- Add Doppler effects
- Add Bistatic target strength

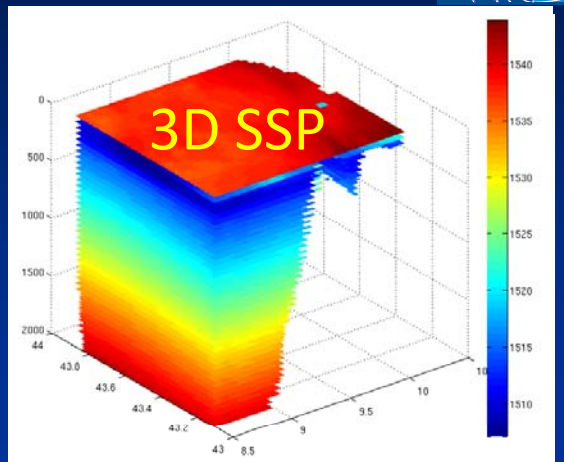


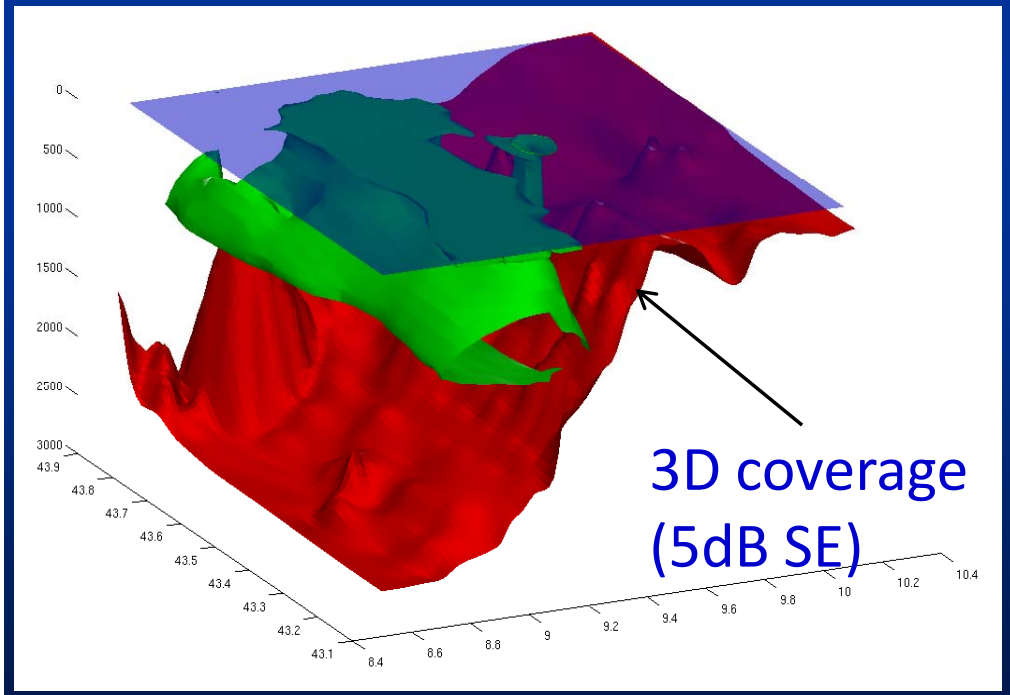




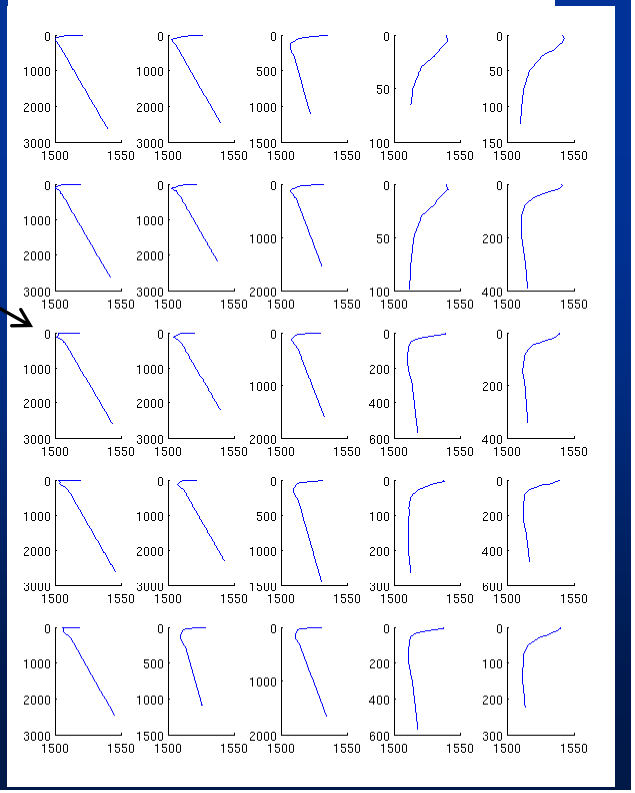
3D Acoustics

- Recent advances account for fully range dependent environment environment
- Load in GEBCO bathymetry
- MEDAR Temperature and Salinity (T&S)
- Determine Sound Speed Profile (SSP)





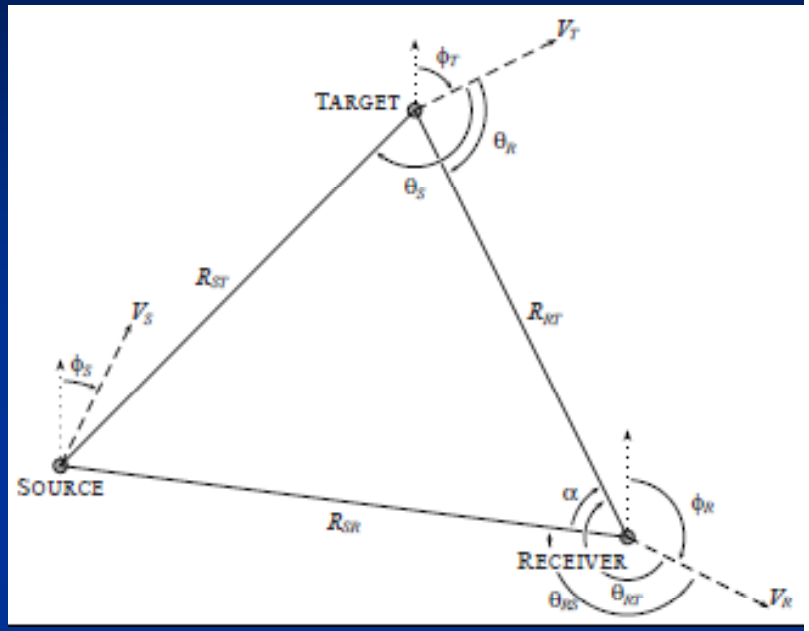
SSP at various points across scenario area



- What happens once we have Signal Excess?

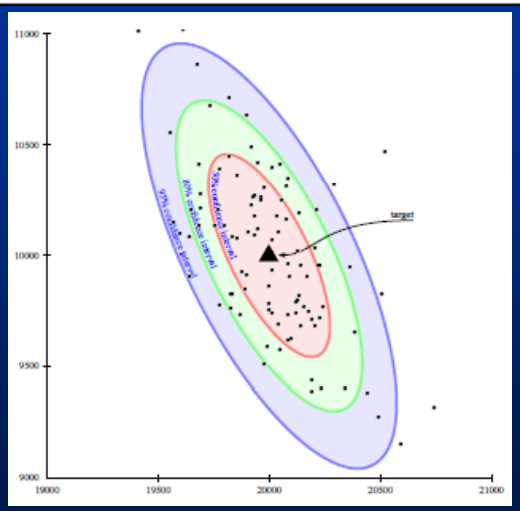
Generate a contact

- Determine contact position with localization error
- Errors
  - Time σ_t
  - Bearing $\sigma_{\theta RT}$
  - Receiver heading $\sigma_{\phi R}$
  - Source, Receiver position $\sigma_{x,y}$
  - Speed of sound σ_c
- Range to target



$$R_{RT} = \frac{c^2t^2 - R_{SR}^2}{2(ct - R_{SR}\cos(\alpha))}$$

Sample terms →

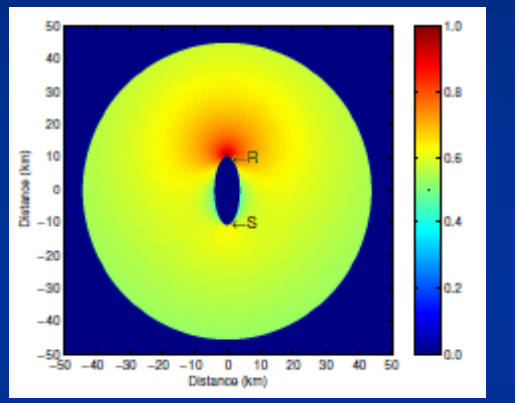


False contacts

- Currently add false contacts from noise and clutter
- Assume noise intensity is Rayleigh

$$Pfa = e^{-\frac{\pi}{4}DT_i^2}$$

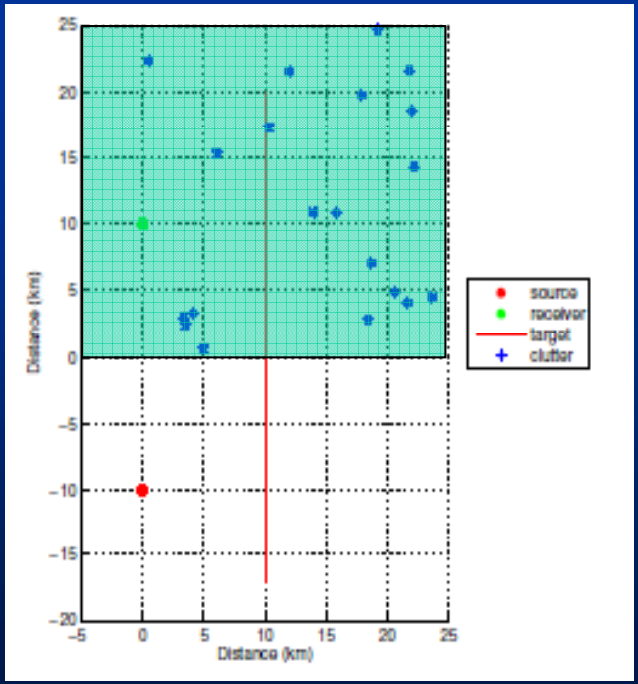
$$DTi = \sqrt{10^{\frac{DT}{10}}}$$

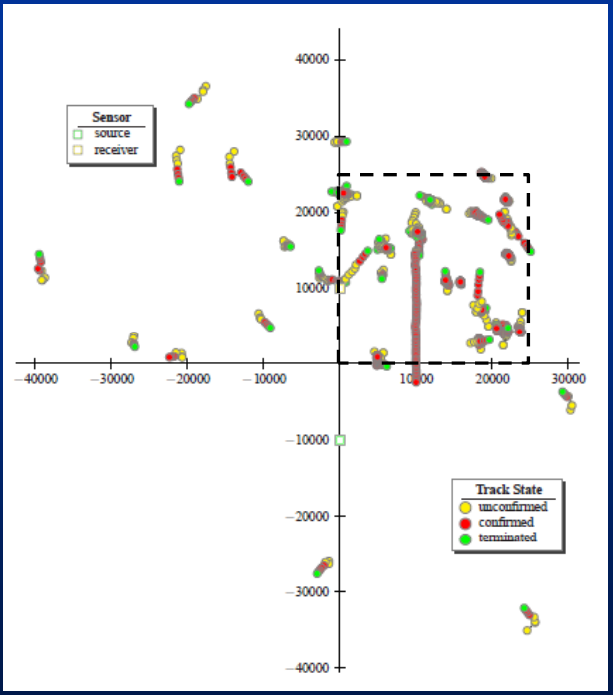


- Generate contacts in time bearing space with correct SNR distribution (use CPD)
- Convert to range and bearing from receiver
- Clutter represented as stationary target objects

Track

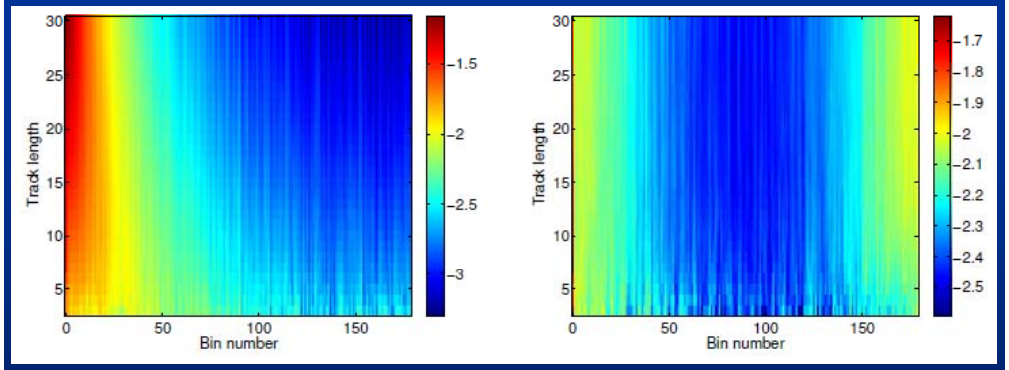
- All contacts (noise, clutter & target) sent to Kalman filter
- Global Nearest Neighbor Association
- Contact level fusion – all Tx Rx combinations

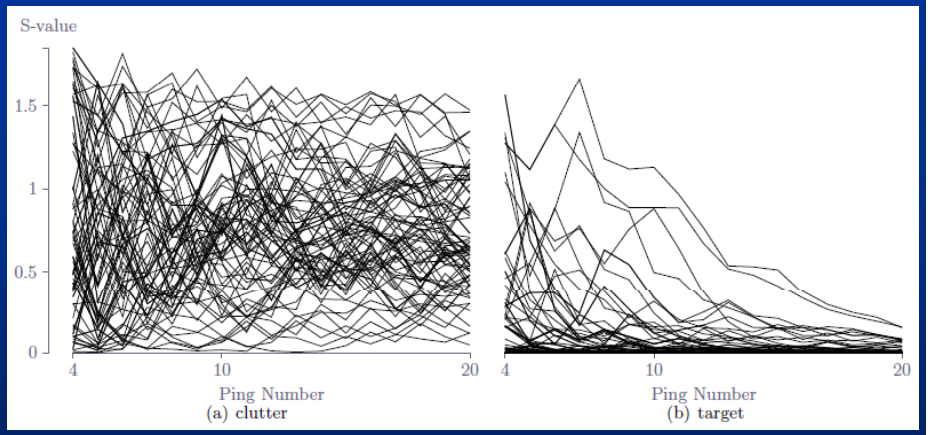




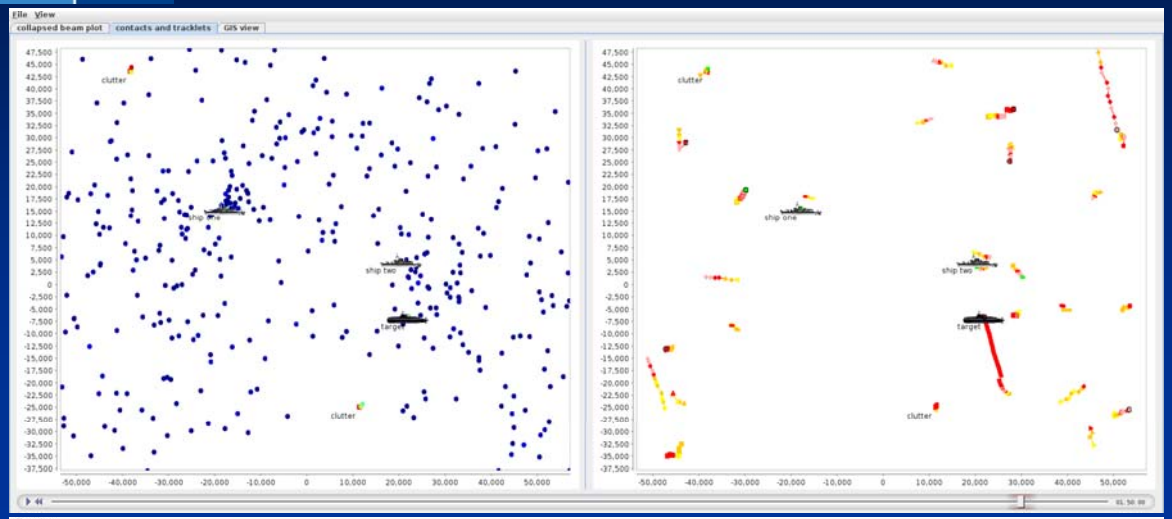
Classify

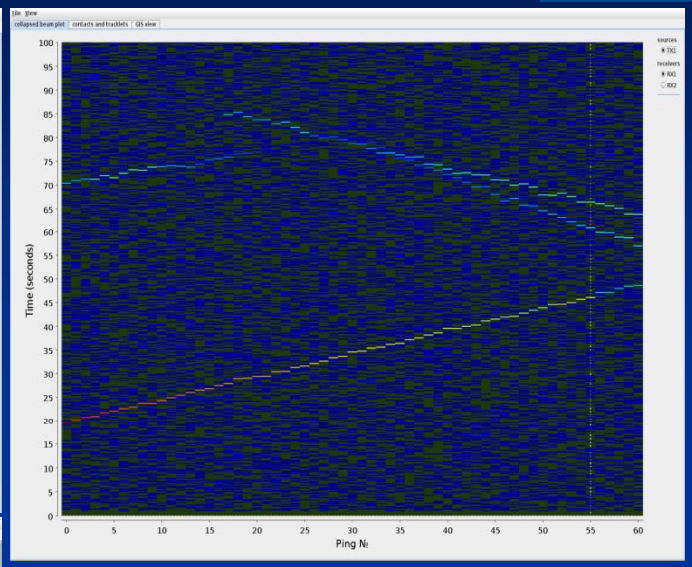
- Machine learning sequential probability ratio test (SPRT)
- Trained distribution of track heading and displacement

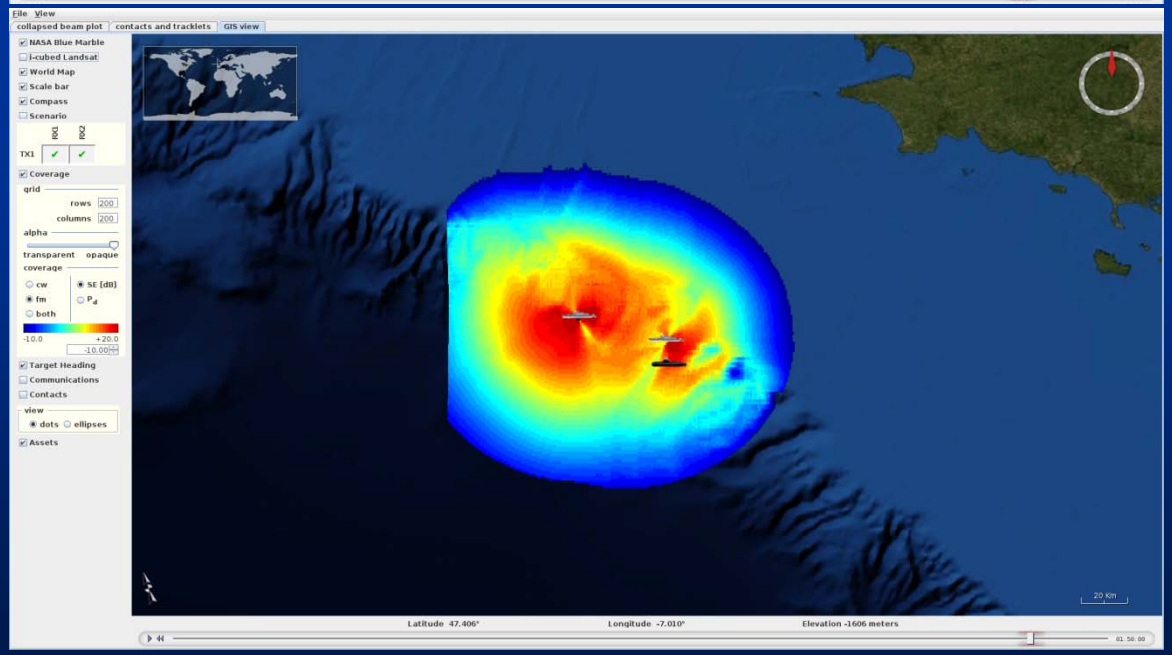




Displays







Output files generated in Matlab format to allow for advanced plotting.
KML files generated for geo-referencing

Towards Decision Support

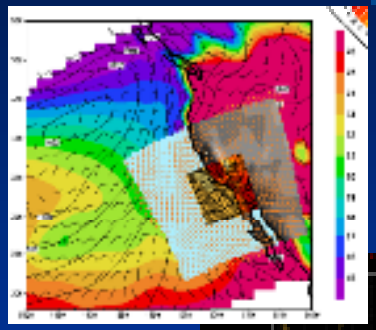
- Up to this point it is just a model
- Simulate potential sensor deployment with scripted target tracks
- Provides operational metrics for a given scenario
  - track holding
  - time to classify
  - area coverage
  - ….

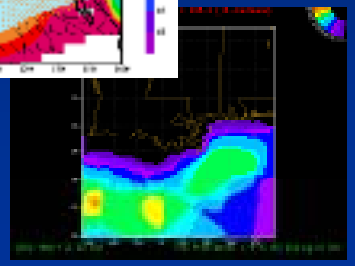
Towards Decision Support

- Need to be operational
- Provide decision support to multistatic (and monostatic) operations at sea
- Now investigating
  - Read in MEDAR climatology measurements
  - NETCDF format, GEBCO bathymetry data
  - Model Intelligent threat
  - Decision theory / Game theory
  - Optimisation
  - Display results/decisions to operator
  - Account for environmental uncertainty

Environmental uncertainty

- Currently analysing REP10 data
- Rapid environmental assessment
  - Gliders
  - Satellite images
  - Towed measurements
- Data assimilated in various models
- Super ensemble generates full 3D temperature and salinity over scenario
- Forecast values and uncertainty

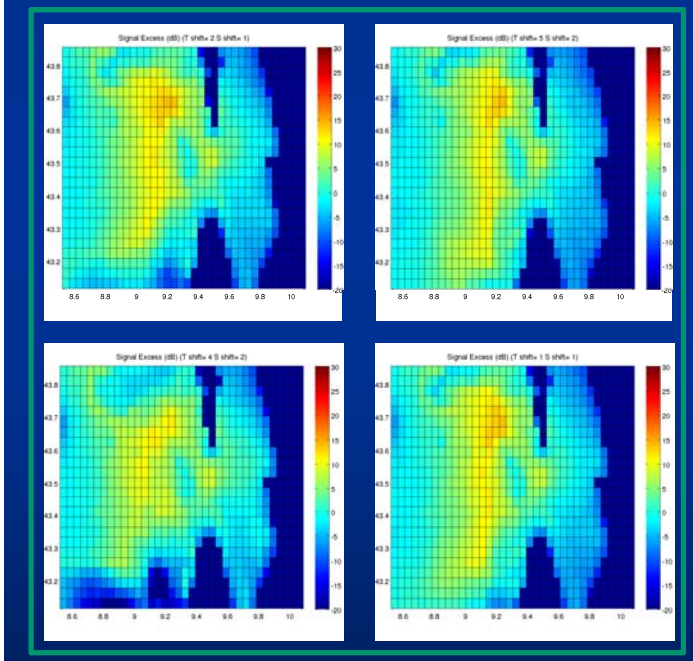


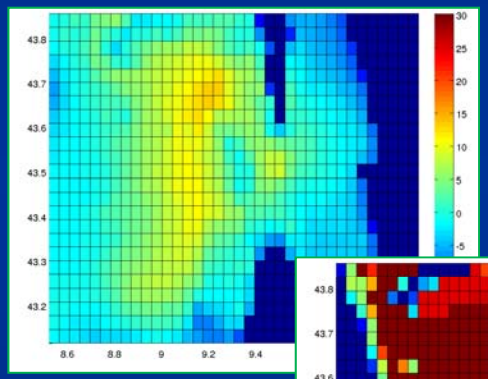


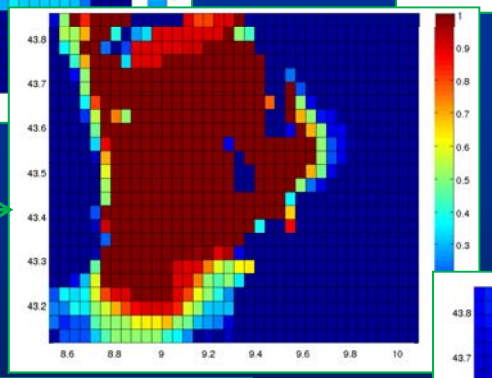
- CLOSE THE LOOP (oceanography → ASW)

Environmental uncertainty

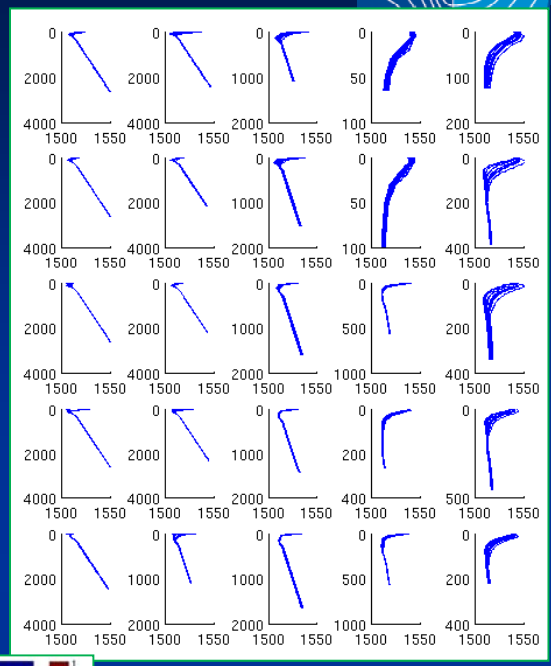
- Investigate transition of uncertainty from T & S to Signal Excess
- REP10 glider data extrapolated over scenario area using 3D super ensemble
- Perturb T & S according to uncertainties

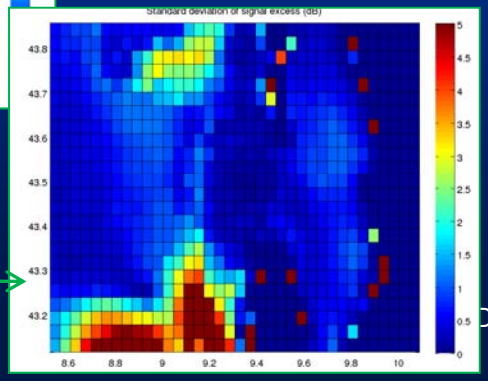






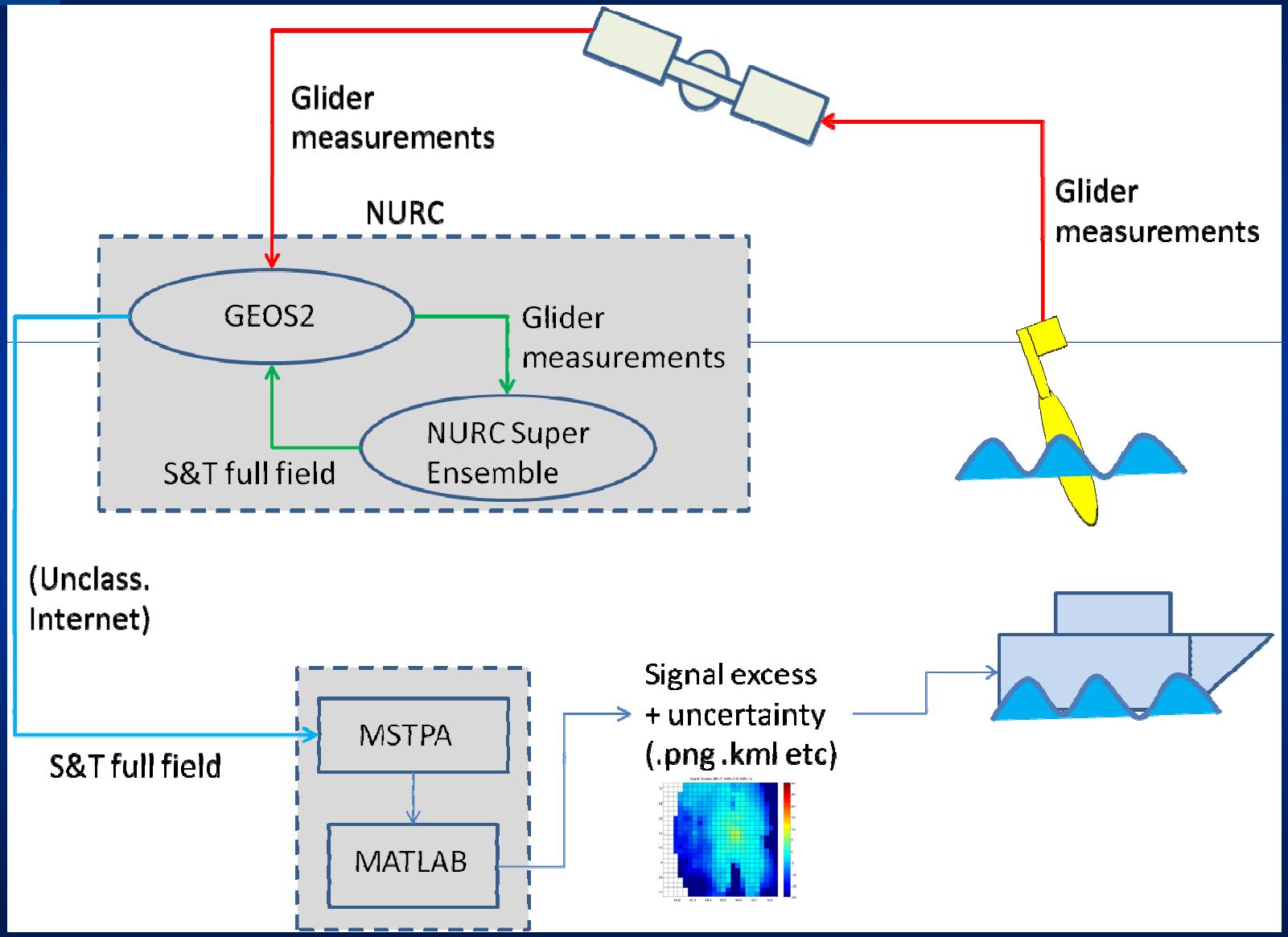
Probability of detection
(fraction of sampled SE > 0)



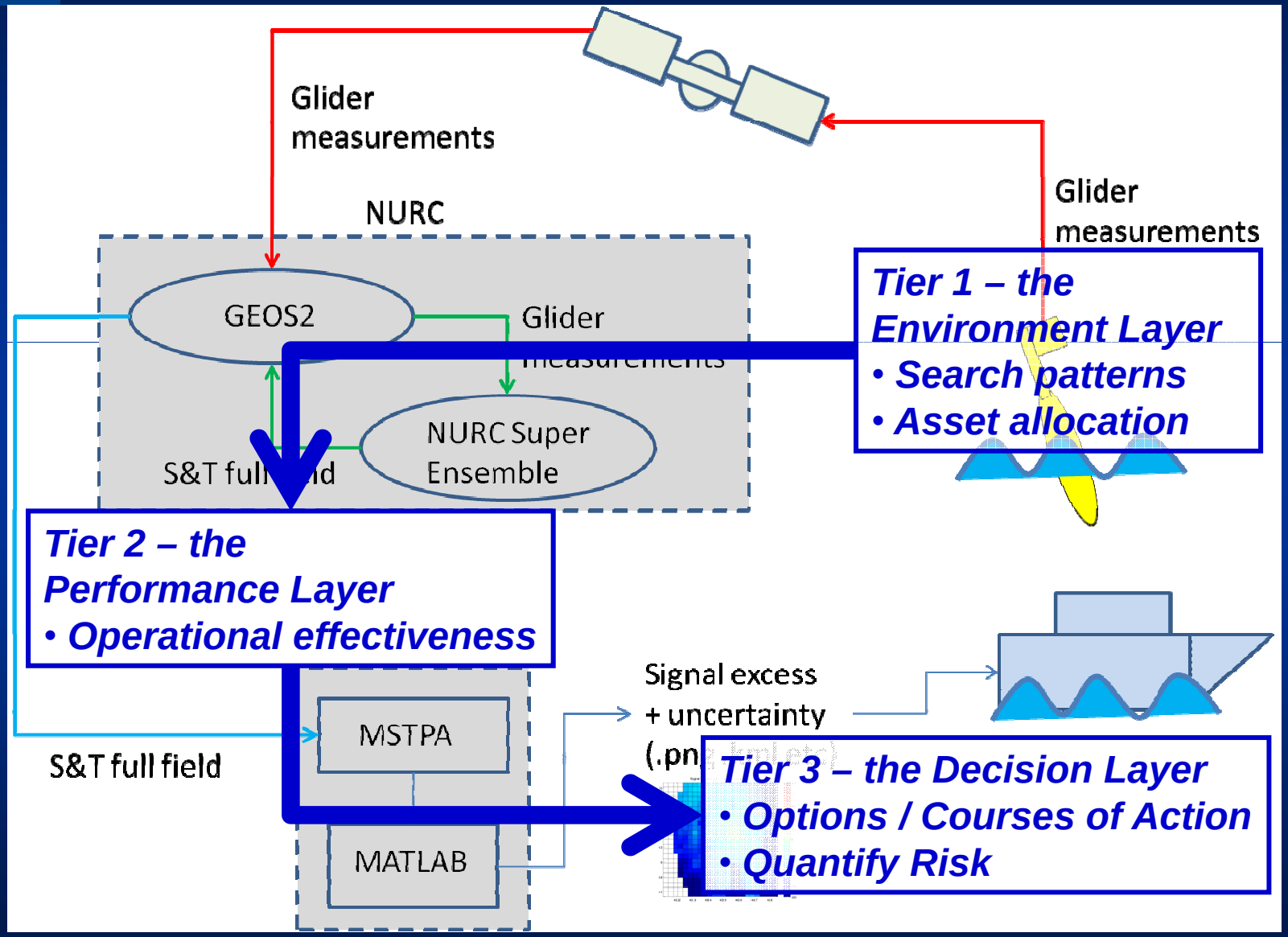


Standard deviation of SE
(uncertainty)

Environmental uncertainty



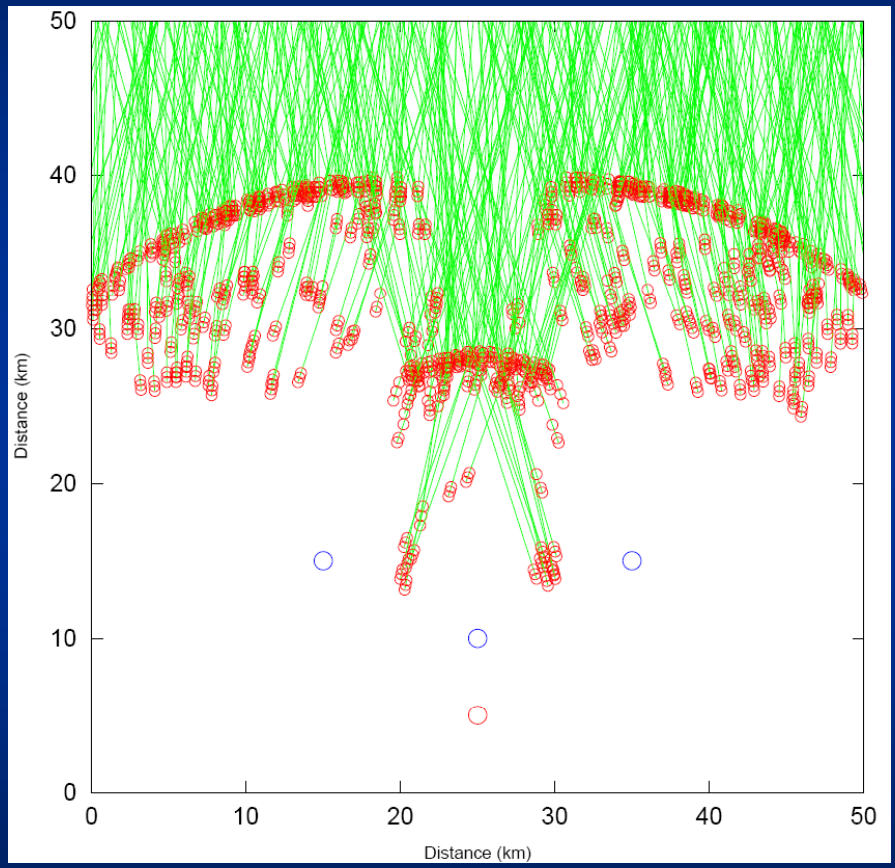
Environmental uncertainty



Intelligent threat

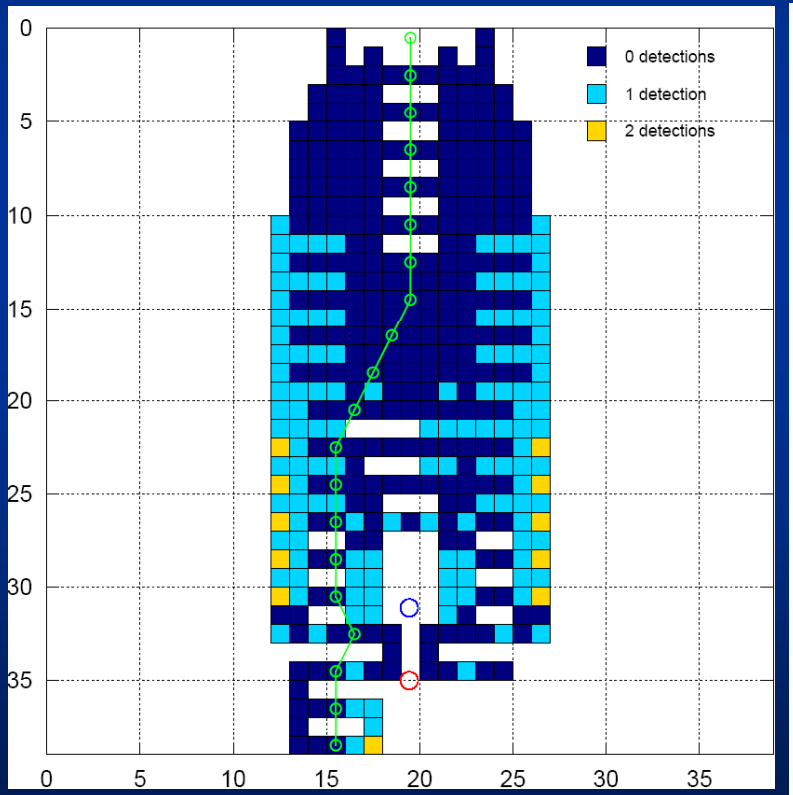
- Optimise geometry against a straight running threat
- Montecarlo – many targets
- Calculate percentage detected/tracked/classified
- No targets get through
- Barrier appears solid

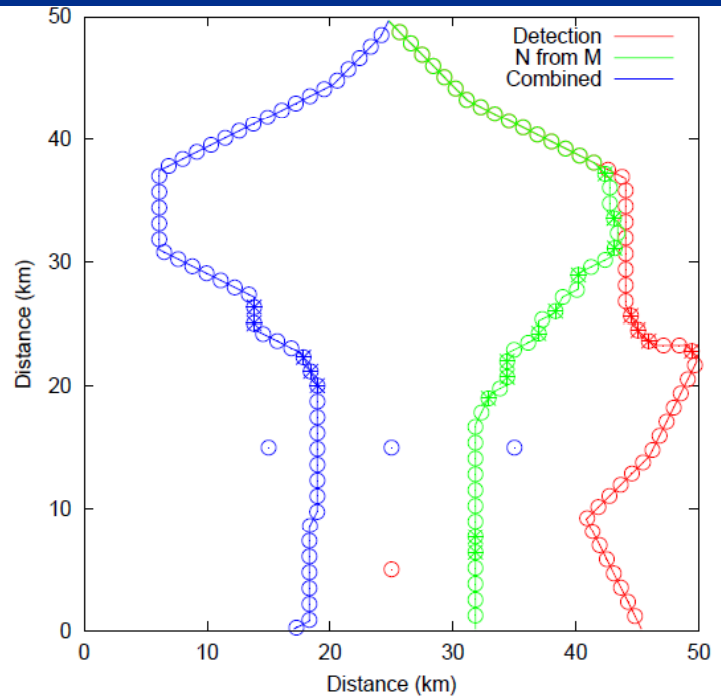
- However – target can alter course to minimise target strength …



Intelligent threat

- Use A* path planning algorithm
- Target determines optimum path through network
  - Minimise detections or track initiations or combination

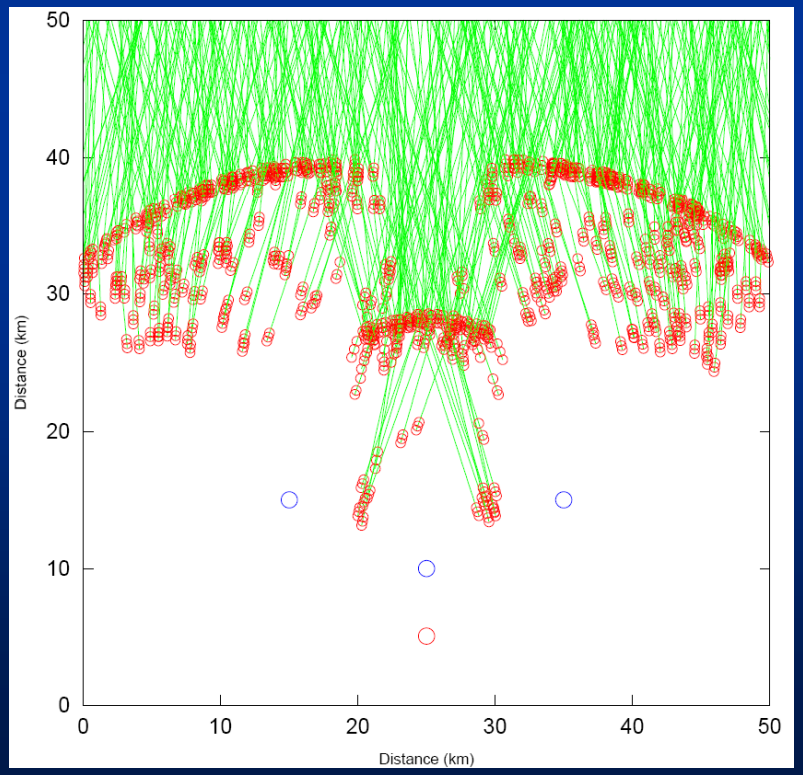


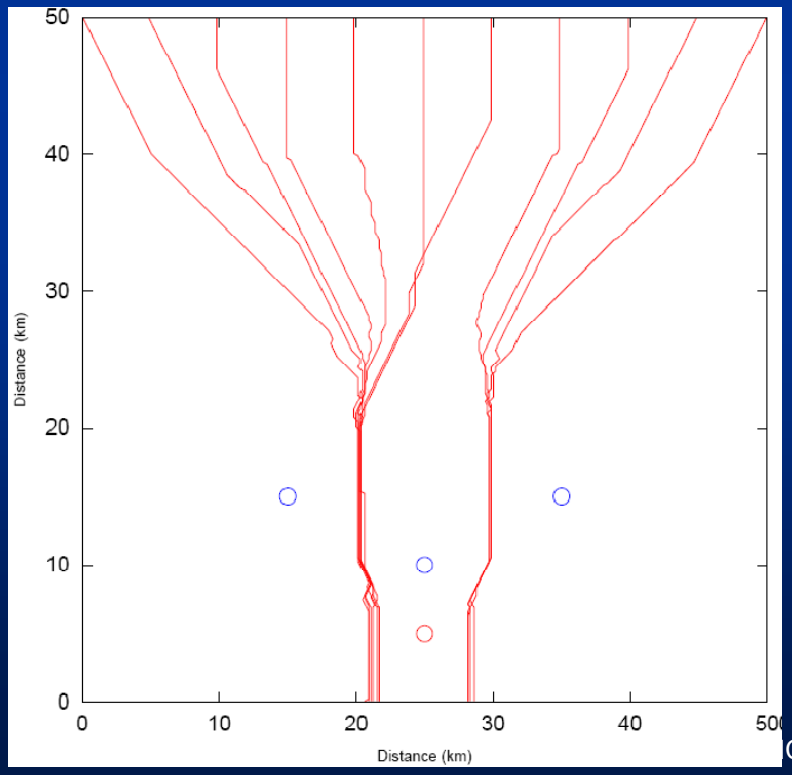


	A* cost measure		
	Detection	N from M	Combined
Number of detections	4	11	5
Number of N from M	4	3	3
Path Length (km)	68.0	65.4	68.4

Intelligent target

- A network optimised against worst case threat will be more robust
- Provides information on weak points
- BUT - assumes target has complete knowledge of network …..



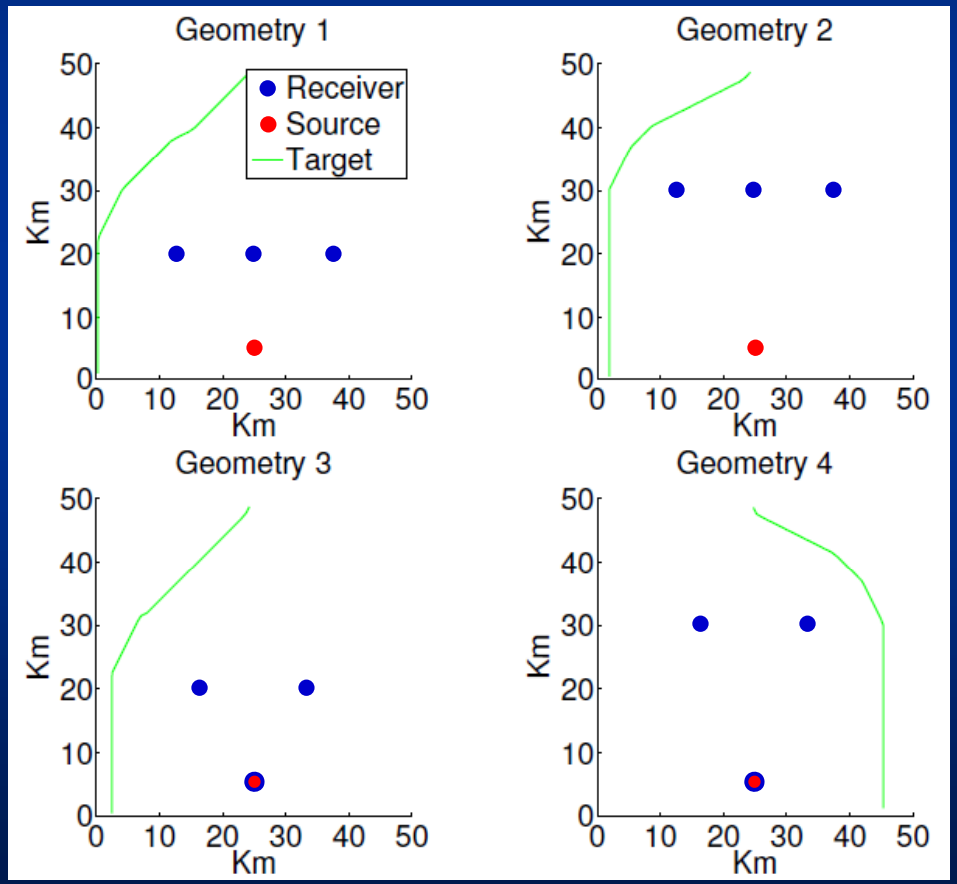


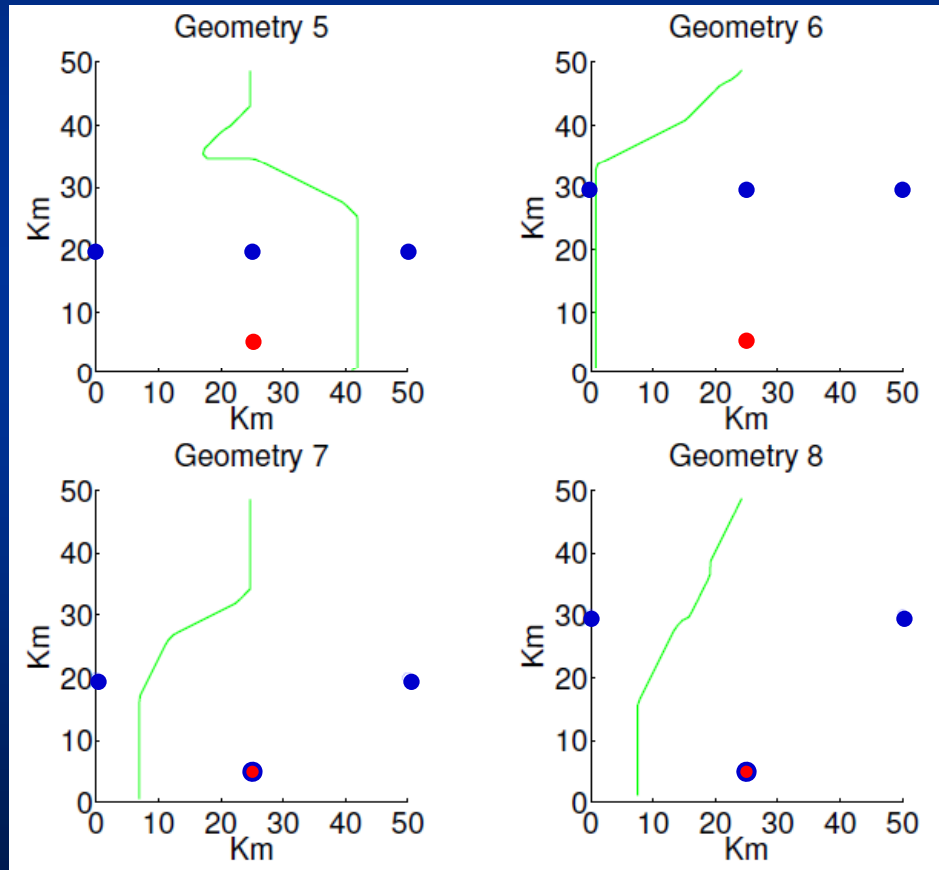
Game theory

- Target counter-detects source – what will he do?
- Target hypothesizes a number of potential receiver geometries – uses A* against each
- Planner hypothesizes the same geometries (necessary assumption of equal knowledge)
- Determine number of detections for all geometries against each target optimum track
- E.g. if target assumed geometry 3 what happens if it was actually geometry 2
- Target does not know the exact geometry – must make a best guess – considering his opponent
- Approach is scalable – can include bathymetry etc – limited by processing power only

Game theory

- Preliminary results
- 1×Source
- 3×Receivers
- 50×50 km scenario
- 8 geometries
- Some include monostatic





Game theory

- Payoff matrix
- Planner Payoff is number of detections
- Target Payoff is negative number of detections
- Zero sum two player game

- Solve the game !

- Determine optimum strategy mix for planner

		Target optimizes against geometry							
		G1	G2	G3	G4	G5	G6	G7	G8
Planner lays geometry	G1	0	14	0	10	16	14	16	9
	G2	9	0	5	0	13	9	13	9
	G3	11	21	0	15	15	16	15	9
	G4	15	11	8	0	13	14	13	11
	G5	19	29	22	42	1	20	9	11
	G6	10	12	7	7	10	1	10	1
	G7	23	20	14	19	10	16	0	0
	G8	20	17	17	17	14	14	9	0

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	G8	20	17	17	17	14	14	9	0

Game Theory

- Seemingly endless loop
  - ‘he knows that we know that he knows …’
- Mathematical techniques can solve the game
- Determine an optimum strategy mix
  - The probability you should lay each geometry
- Decision aid roles a dice accordingly to recommend a geometry
- ‘Chance engine’
- Target cannot predict exactly which geometry is laid.

Game Theory

			Target optimizes against geometry							
			G1	G2	G3	G4	G5	G6	G7	G8
		Pn	0	0	0.2	0.1	0.4	0	0	0.3
Planner lays geometry	G1	0.1	0	14	0	10	16	14	16	9
	G2	0	9	0	5	0	13	9	13	9
	G3	0	11	21	0	15	15	16	15	9
	G4	0.7	15	11	8	0	13	14	13	11
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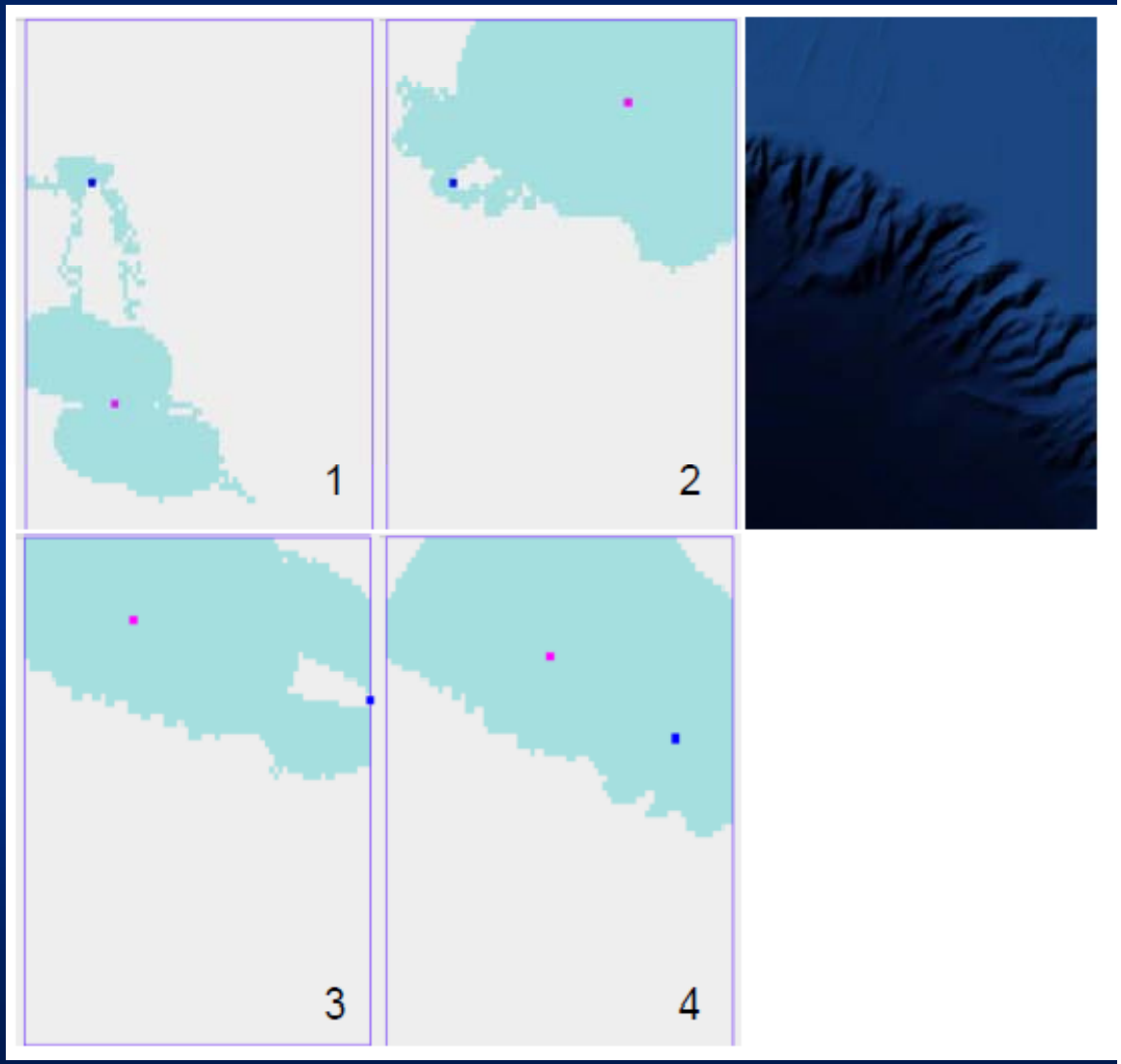
	G8	0	20	17	17	17	14	14	9	0

Optimisation

- Genetic Algorithm
- 1000 fitness calls
- Coverage grid 75×75
- 5625000 SE calculations
- Real bathymetry but iso-velocity
- 7.5 minutes



Questions?