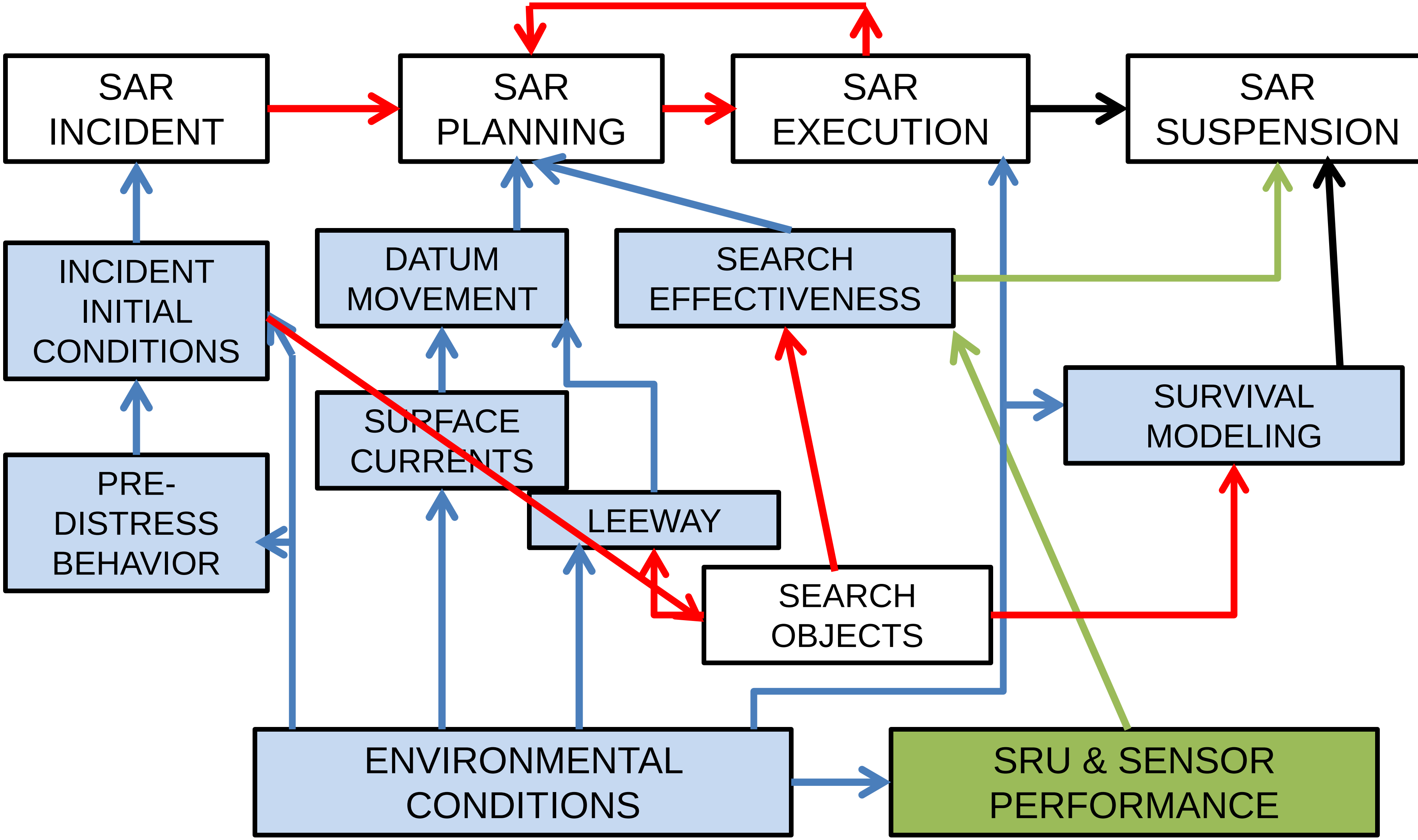
US Coast Guard
Search and Rescue Mission & Operational Oceanography
History, Model Skill, Future Work

Arthur Allen
US Coast Guard
Office of Search and Rescue

The SAR Problem



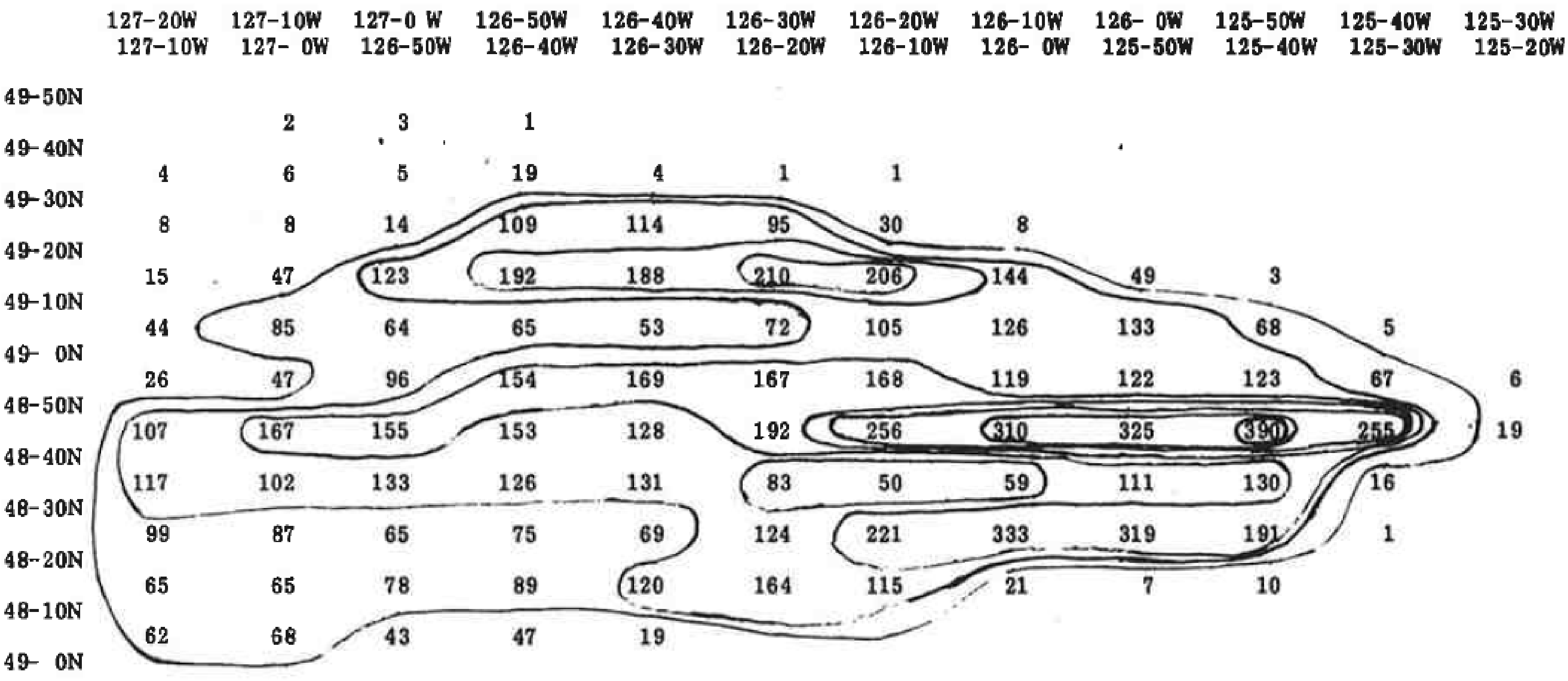
Computer-Assisted Search Planning

CASP operational in 1974

Monte Carlo particles, LKP&Voyages, Previous

Navy monthly currents 1ºx1º

US Navy FNOC 5ºx5º winds (0,12,24,36 hr)

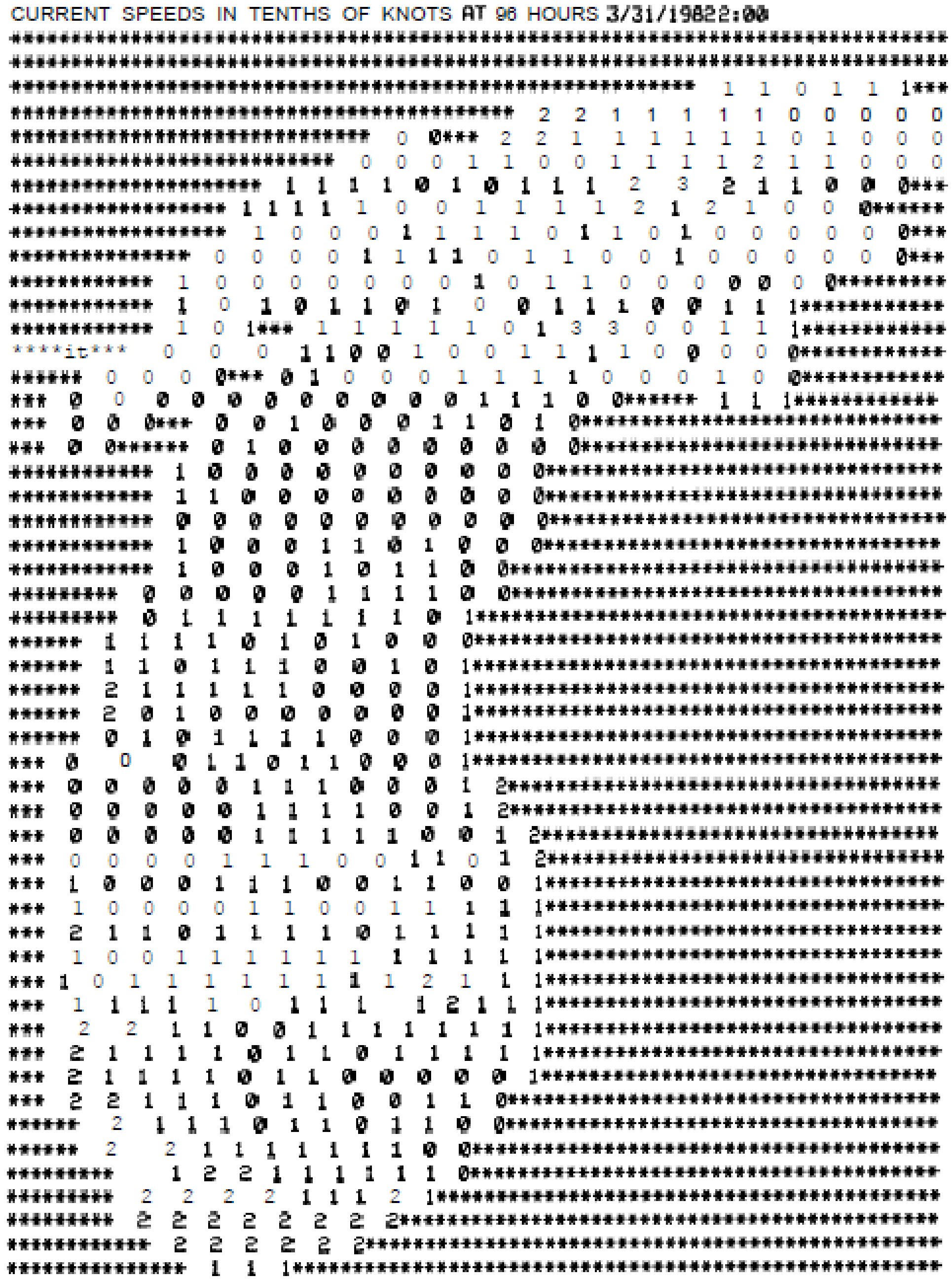


1984 PATHFINDER

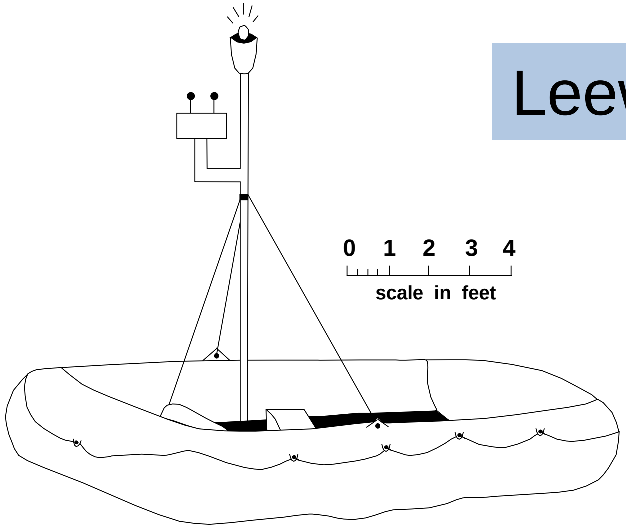
for the Great Lakes

Here in
Lake Michigan

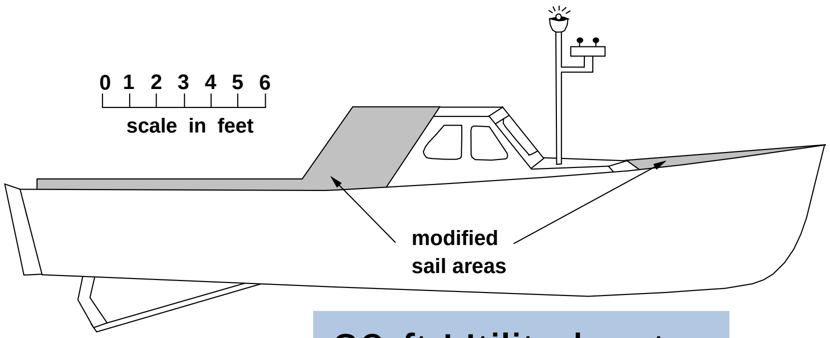
Hand enter winds
Wind driven flow
Teletype interface



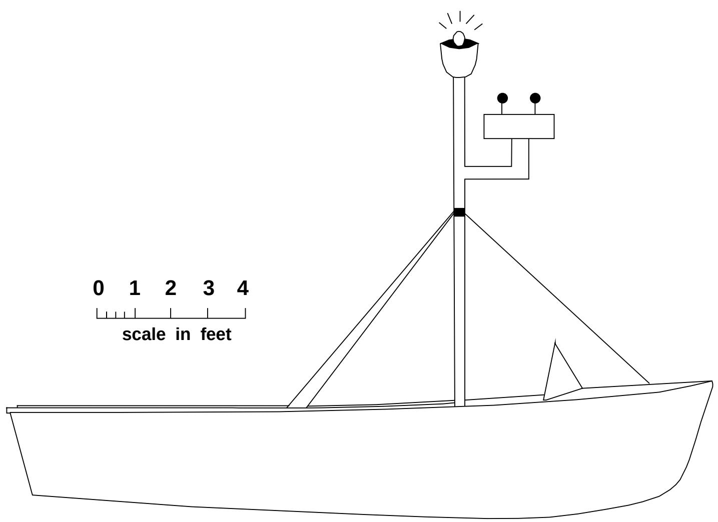
Leeway Studies 1960-1984



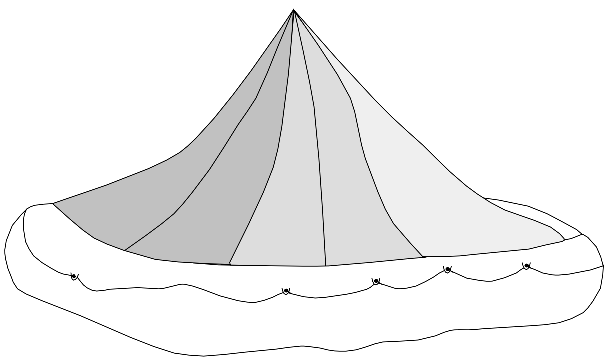
Mark 7 life raft



30-ft Utility boat



16-ft Outboard



Japanese 8-person life raft

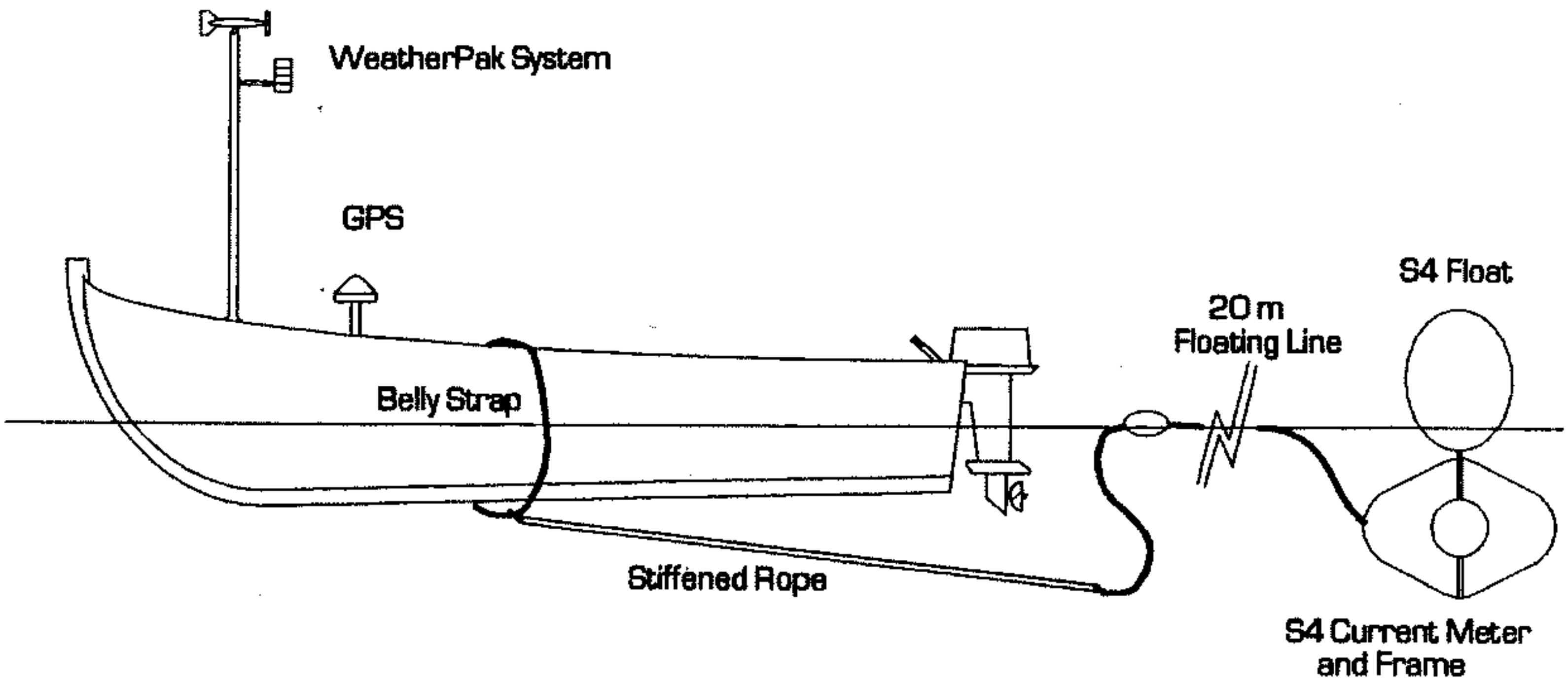
Leeway in 1980's

Search Object	Leeway eq (knots) U wind in knots	Reference
PIW	0	none
Surfboards	0.02 U	Chapline (1960)
Heavy Displ. deep draft sailing vessels	0.03 U	Chapline (1960)
Medium Displ. sailboats, fishing vessels	0.04 U	Chapline (1960)
Light Displ. cruisers, Outboards, rubber rafts w/ drogue	0.05 U- 0.12 kts	Hufford and Broida (1974); and Scobie and Thompson (1979)
Large Cabin Cruisers	0.05 U	Chapline (1960)
Light Displ. cruisers, Outboards, rubber rafts w/o drogue	0.07 U + 0.04 kts	Hufford and Broida (1974)

Indirect Method

- Search Object drift over ground
  - Navigation errors: range and bearing from ship or shore, DECCA, Loran-A or –C, MTS
- Subtract Currents
  - Drift nets, dye, high flyers, drifters
  - Same navigation errors as object
  - Reset drifters around drift object
- Measure Winds
  - Ship's anemometer, on board anemometer
  - Not adjusted or adjusted (1.22 or z/10to 1/7th)
- Short records, limited to fair weather conditions

Direct Method (July 1992)



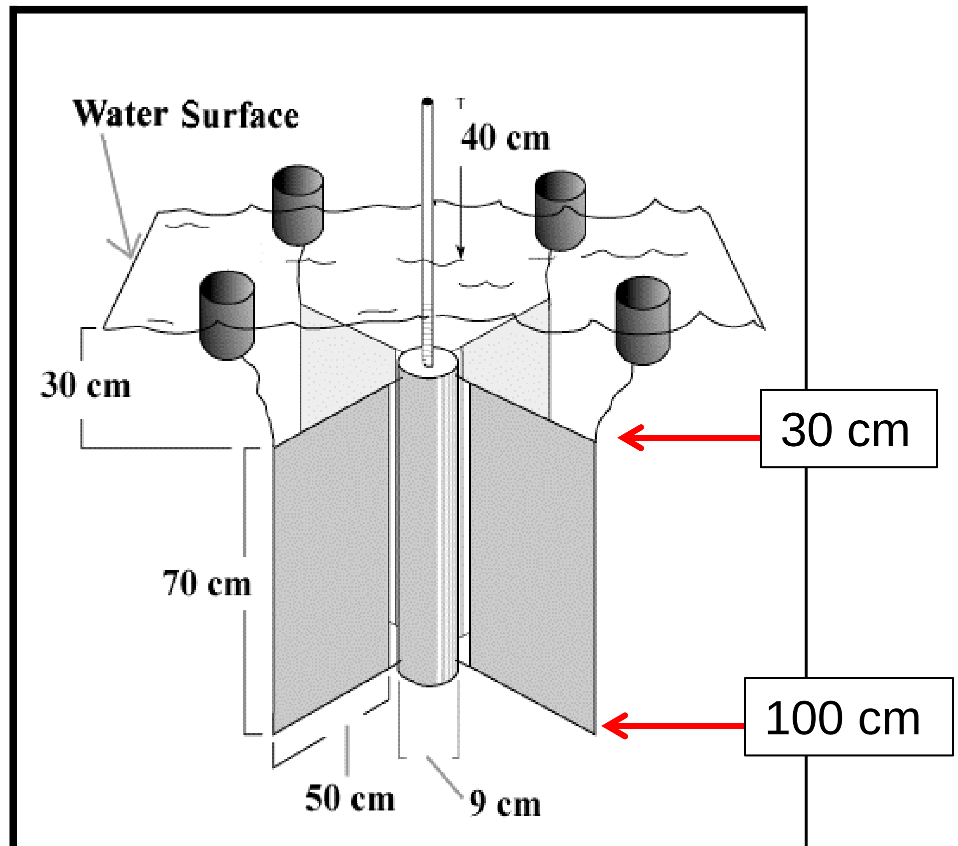
5.6 meter Open Boat

Direct Method

- Leeway measured directly by attaching self-recording current meter
  - Long continuous 10-minute vector averaged
  - Standard depth between 0.3 and 1.0 meter
- Measure winds on board or from nearby craft
  - Long continuous 10-minute vector averaged
  - Adjusted to 10-meters
- Search Object drift & relocation
  - On board Loran-C, then GPS data loggers
  - Argos, then Iridium & RDF beacons & lights
- Long continuous records thru storms

SLDMB (Feb 1993)

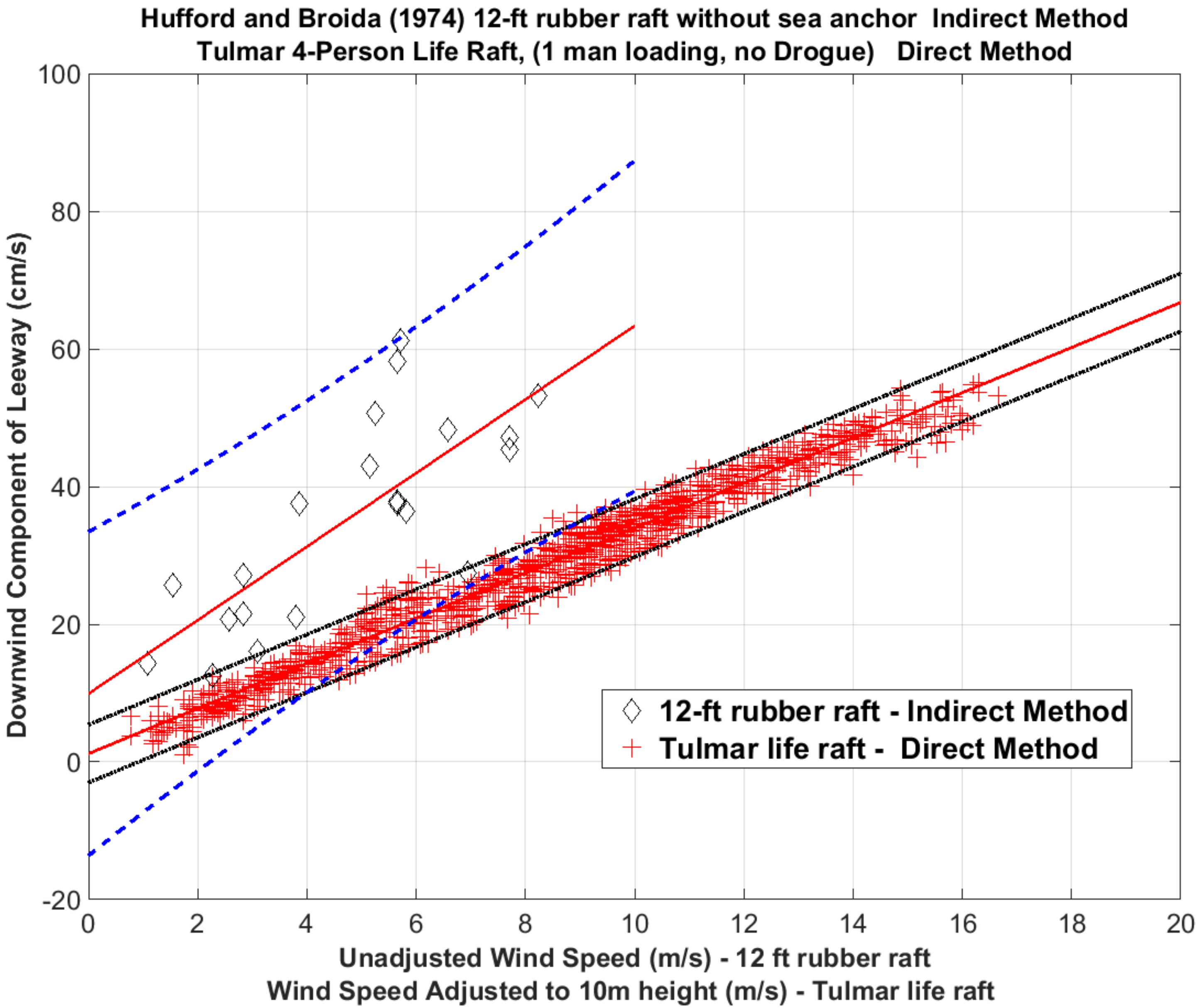
(Self-Locating Datum Marker Buoys) CODE/Davis surface drifters



Leeway Definition
(July 1984)

"Leeway is the velocity vector relative to the downwind direction at the search object as it moves relative to the surface currents as measured between 0.3m and 1.0m caused by winds (adjusted to reference height of 10m) and waves."

Indirect vs. Direct Method




20-person Beaufort life raft
GPS data loggers and Argos
& RDF beacons / lights
RM Young anemometer
At 2.8 meters
WeatherPak
InterOceans S4 EMCM at 75 cm
PM 1:17
DEC. 4 1993

Canadian Leeway in 1990's

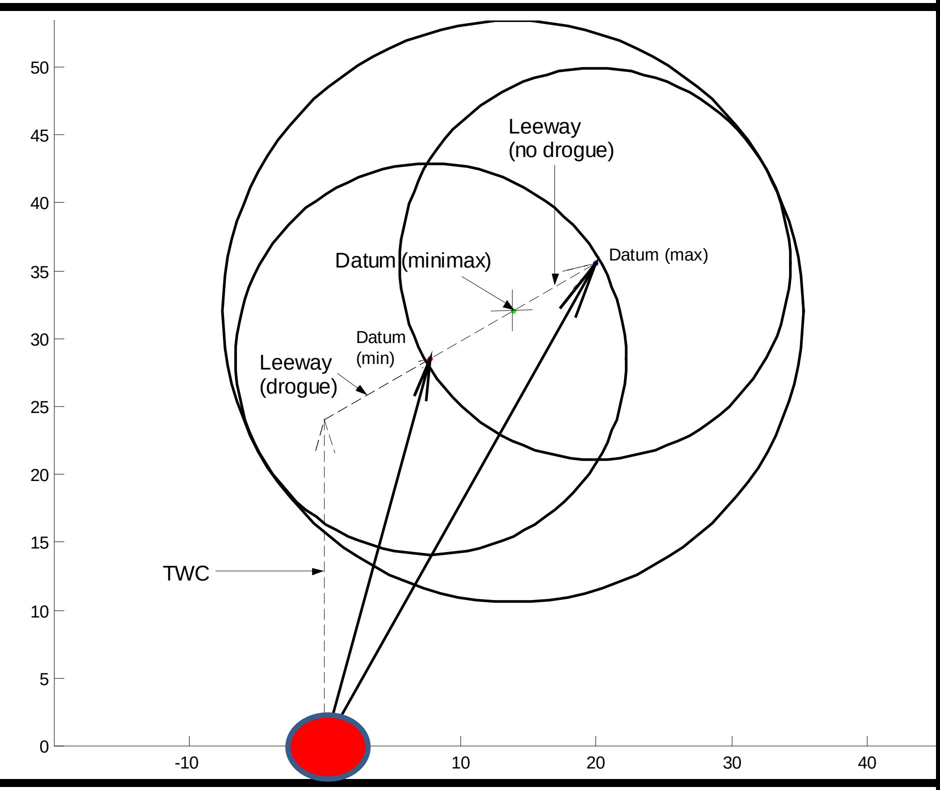
Type of Craft	With Drogue	No Drogue	Reference
PIW	0.0 U	0.0 U	
Surfboard	2.0% U	2.0% U	Chapline (1960)
Raft (any size) **capsized or swamped**	1.3% U –0.120	1.3% U –0.120	Allen & Fitzgerald (1997)
1 Person Raft	2.8% U-0.12	3.7% U +0.04	Fitzgerald, Finlayson & Allen (1994)
4 Person Raft	2.8% U-0.12	3.7% U +0.04	
6 Person Raft	2.8% U-0.12	3.7% U +0.04	
8 Person Raft	2.8% U-0.12	3.7% U +0.04	
10 Person Raft	2.8% U-0.12	3.7% U +0.04	
15 Person Raft	3.1% U-0.12	3.7% U +0.04	
20 Person Raft	3.1% U-0.12	3.7% U +0.04	
25 Person Raft	3.1% U – 0.12	3.7% U +0.04	
Power Boat <15ft	5.0% U –0.12	7.0% U +0.04	Hufford and Broida (1974)
Power Boat 15-25ft	5.0% U –0.12	7.0% U +0.04	
Power Boat 25-40ft	5.0% U	5.0% U	Chapline (1960)
Power Boat 40-65ft	5.0% U	5.0% U	
Power Boat 65-90ft	4.0% U	4.0% U	Chapline(1960)
Sailboat 15 ft	5.0% U-0.12	7.0% U+0.04	Hufford &Broida (1974)
Sailboat 20 ft	5.0% U-0.12	7.0% U+0.04	
Sailboat 25 to 40 ft	4.0% U	4.0% U	Chapline (1960)
Sailboat 50 ft	3.0% U	3.0% U	
Sailboat 65-75 ft	3.0% U	3.0 %U	
Sailboat 75-90 ft	3.0% U	3.0% U	
Ship 90-300 ft	3.0% U	3.0% U	

Review of Leeway – Sept 1998 (Allen and Plourde, 1999)

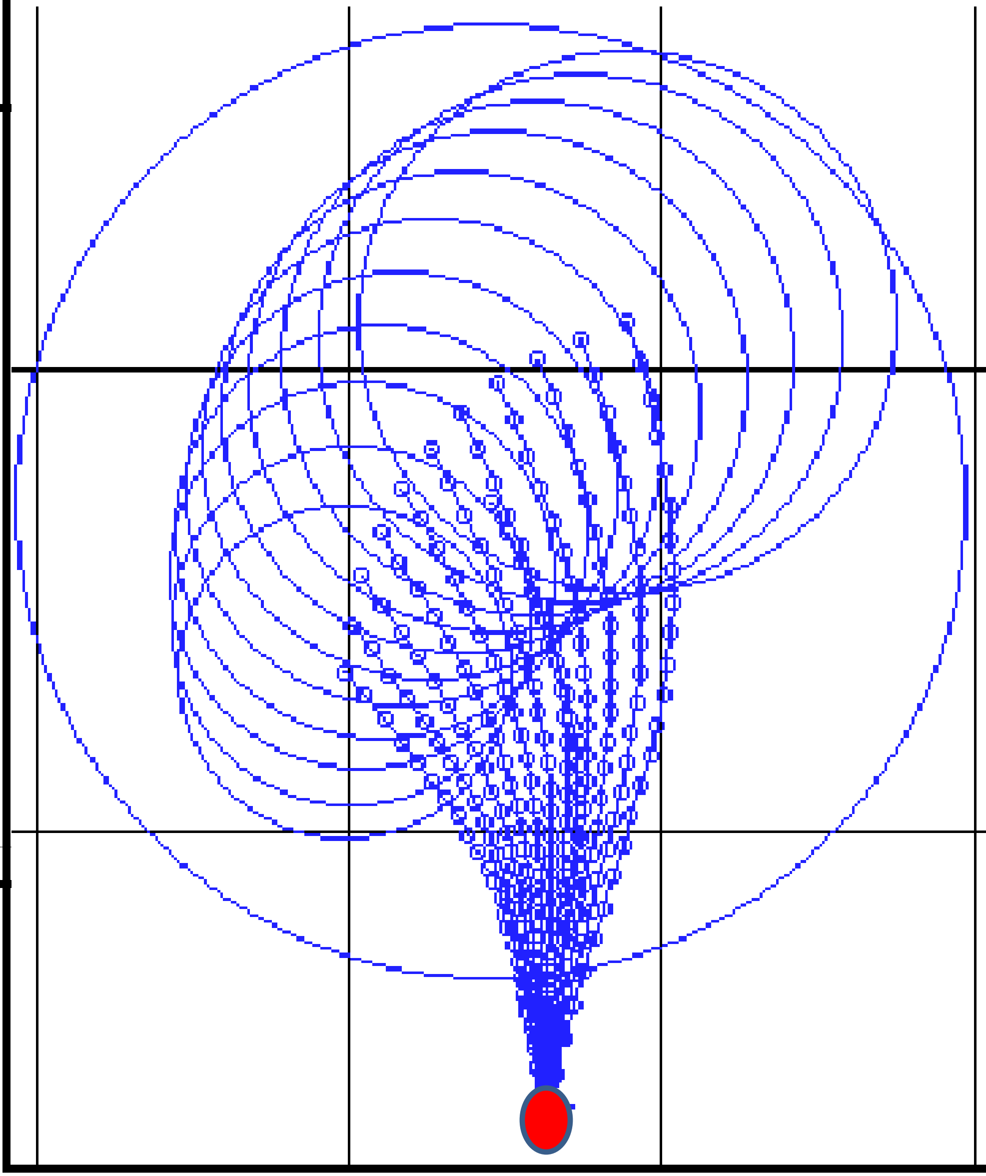
- Who studied what and how?
  - 95 objects from 25 studies
  - Indirect – 17 studies before 1990
  - Direct – 1 study in 1977, 7 studies after 1990
- How was leeway modeled?
  - Leeway Rate and Divergence Angle
  - Search Area growth related to distance from LKP
- New leeway model proposed:
  - Down and crosswind components of leeway
  - Spread according to standard error term and time
- Leeway taxonomy classes proposed.
  - Combined data sets
  - Recommended 63 leeway categories of search objects

Review of Search Theory (Jack Frost & Larry Stone 2001)

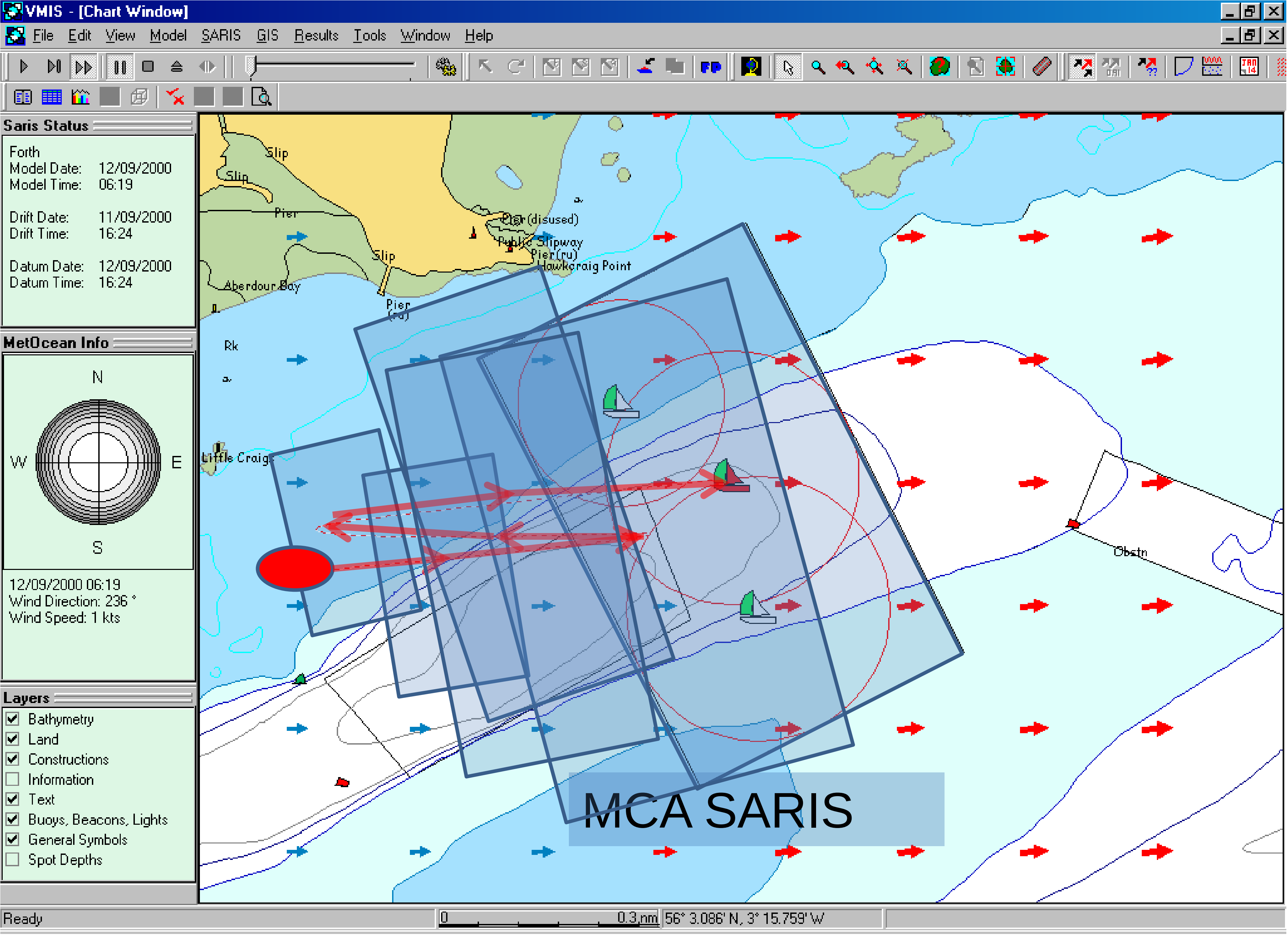
- Reviewed manual methods of search planning
  - Initially done by paper, pencil, and plotting on charts
  - Many simplifications required
  - Later automated on PCs
  - CANSARP, SARMAP, SARIS, C2PC
    - Electronic charts, tidal models
- CASP’s use of Monte Carlo, Bayesian method
- USCG was using 3 SAR planning tools



USCG Min-Max solution



Canada CANSARP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File Edit View Model SARIS GIS Results Tools Window Help
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Forth
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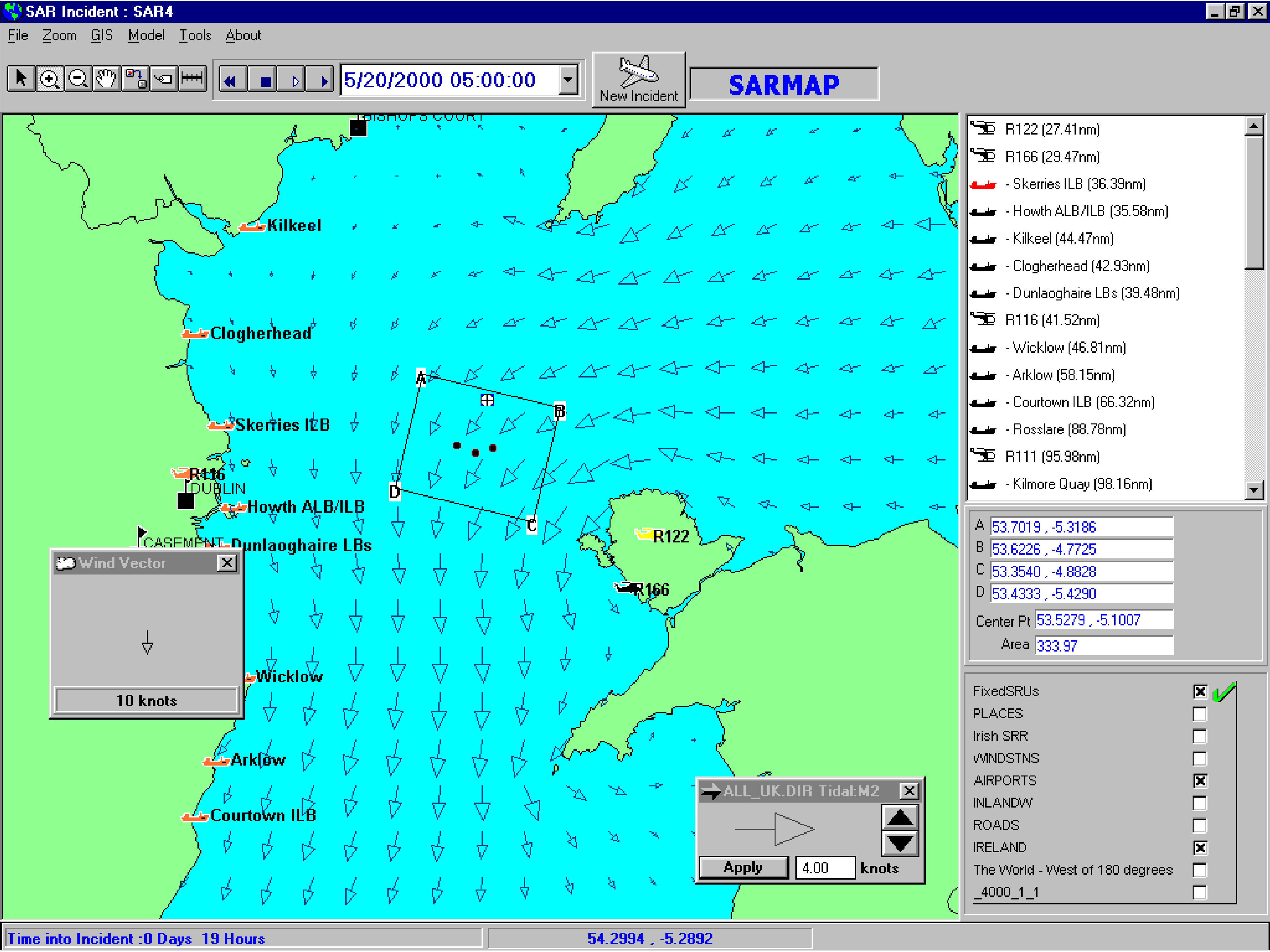
Model Time: 06:19
Drift Date: 11/09/2000
Drift Time: 16:24
Datum Date: 12/09/2000
Datum Time: 16:24
MetOcean Info
N
W
E
S
12/09/2000 06:19
Wind Direction: 236 °
Wind Speed: 1 kts
Layers
Bathymetry
Land
Constructions
Information
Text
Buoys, Beacons, Lights
General Symbols
Spot Depths
Slip
Slip
Pier
Slip
Pier (disused)
Public Slipway
Pier (ru)
Hawkcraig Point
Aberdour Bay
Pier (ru)
Rk
Little Craig
Obstn
MCA SARIS
Ready
0
0.3 nm
56° 3.086' N, 3° 15.759' W



SAR Incident : SAR4
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Zoom
GIS
Model
Tools
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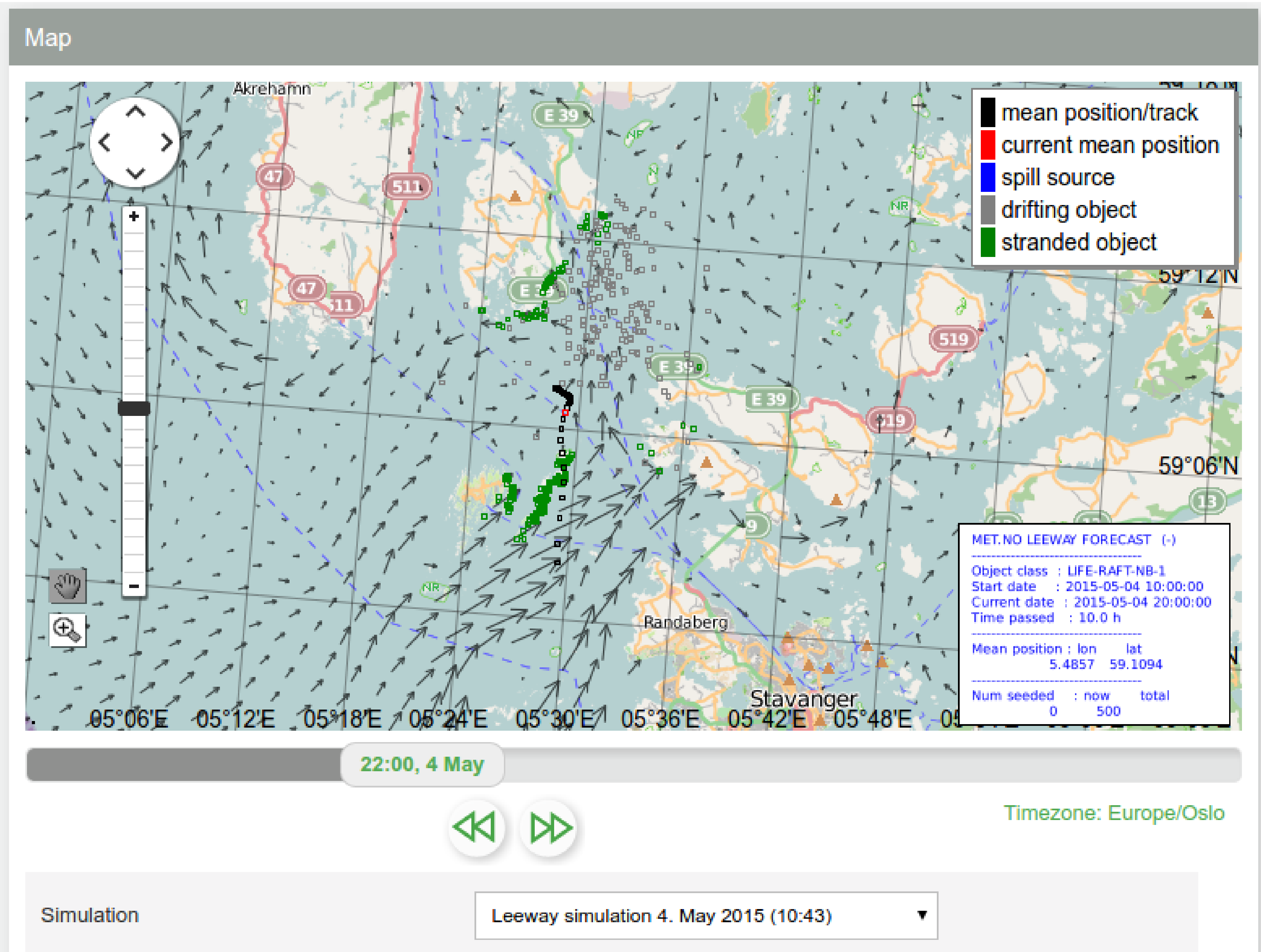
New Incident
SARMAP
BISHOPS COURT
Kilkeel
Clogherhead
Skerries ILB
R116
DUBLIN
Howth ALB/ILB
CASEMENT
Dunlaoghaire LBs
Wicklow
Arklow
Courtown ILB
R122
R166
A
B
C
D
Wind Vector
10 knots
ALL_UK.DIR Tidal:M2
Apply
4.00
knots
R122 (27.41nm)
R166 (29.47nm)
- Skerries ILB (36.39nm)
- Howth ALB/ILB (35.58nm)
- Kilkeel (44.47nm)
- Clogherhead (42.93nm)
- Dunlaoghaire LBs (39.48nm)
R116 (41.52nm)
- Wicklow (46.81nm)
- Arklow (58.15nm)
- Courtown ILB (66.32nm)
- Rosslare (88.78nm)
R111 (95.98nm)
- Kilmore Quay (98.16nm)
A 53.7019 , -5.3186
B 53.6226 , -4.7725
C 53.3540 , -4.8828
D 53.4333 , -5.4290
Center Pt 53.5279 , -5.1007
Area 333.97
FixedSRUs
PLACES
Irish SRR
WINDSTNS
AIRPORTS
INLANDW
ROADS
IRELAND
The World - West of 180 degrees
_4000_1_1
Time into Incident :0 Days 19 Hours
54.2994 , -5.2892

Leeway Divergence (Allen 2005)

- Allen and Plourde's Leeway Divergence methods
  - 2 Std Dev of Leeway angle - 18 leeway categories
  - Mean + 1 Std Dev of leeway angle – 9 leeway categories
  - Mean + 2 Std Dev of leeway angle – 8 leeway categories
  - Visually estimated from fig - 3 leeway categories
  - Assigned from other categories – 25 leeway categories
- 38 of 63 Leeway categories without Down&Crosswind components of Leeway (DWL / CWL)
  - Best fit for the 25 categories with both Rate/Angle and DWL/CWL
  - Apply to 38 categories
- Now all 63 Leeway categories have DWL/CWL coefficients:
- Jibing Model (4% per hour) added.

Norwegian Met Office’s ‘LEEWAY’ operational drift model 2002 Breivik & Allen (2008)

- Operational high-resolution ocean and met models for the Norwegian Sea
- 63 Leeway categories using DWL & CWL equations from Allen (2005)
- Jibing Model (4% per hour) added.
- Only a trajectory model, no resource planning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519
13
NR
Randaberg
Stavanger
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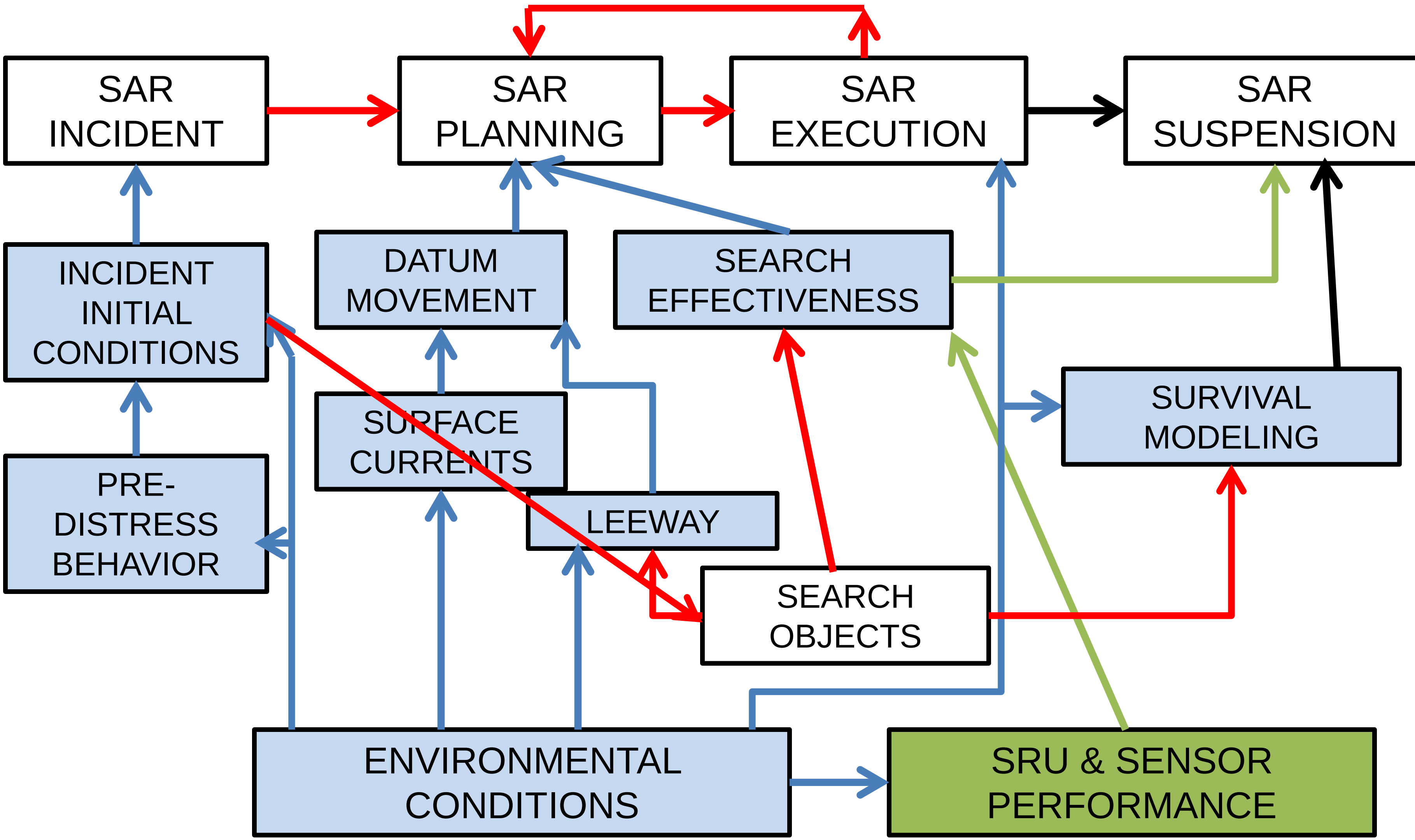
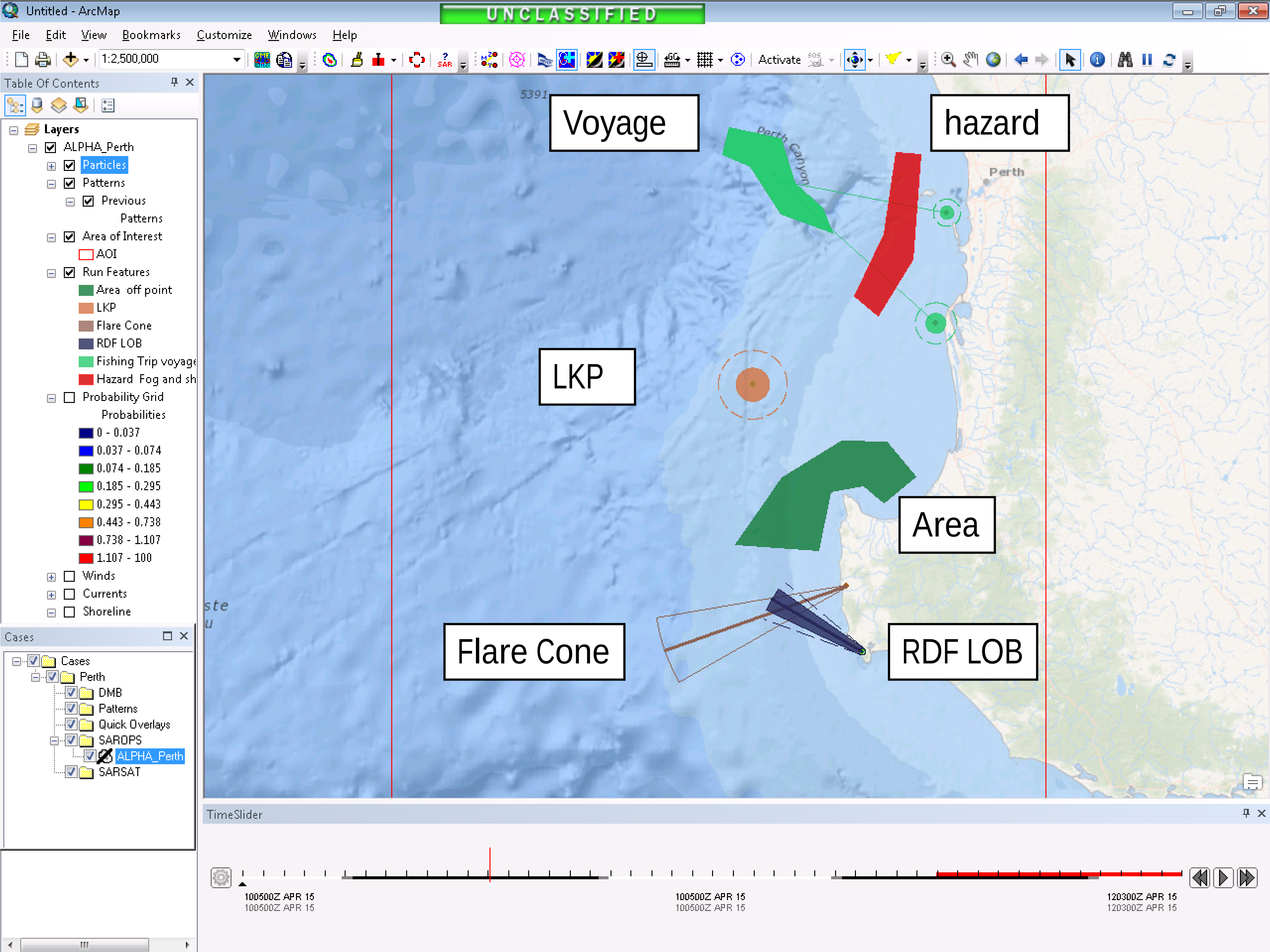
59°06'N
05°06'E
05°12'E
05°18'E
05°24'E
05°30'E
05°36'E
05°42'E
05°48'E
mean position/track
current mean position
spill source
drifting object
stranded object
MET.NO LEEWAY FORECAST (-)
Object class : LIFE-RAFT-NB-1
Start date : 2015-05-04 10:00:00
Current date : 2015-05-04 20:00:00
Time passed : 10.0 h
Mean position : lon lat
5.4857 59.1094
Num seeded : now total
0 500
22:00, 4 May
Timezone: Europe/Oslo
Simulation
Leeway simulation 4. May 2015 (10:43)

SAROPS (Jan 2007 operational)

- Monte Carlo (2.5K, 5K, 10K particles)
- Multiple Scenarios
  - (LKP, Area, Voyage, Flare, LOB)
- 63+ Leeway categories using DWL & CWL
- Multiple Winds & Currents sources from EDS
- Optimal Search Plans
  - Lateral Range Curves of Detection on particles
- Bayesian update of previous searches
- ArcGIS based

The SAR Problem

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Patterns
Previous Patterns
Area of Interest
AOI
Run Features
Area off point
LKP
Flare Cone
RDF LOB
Fishing Trip voyage
Hazard Fog and sh
Probability Grid
Probabilities
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Currents
Shoreline
Cases
Cases
Perth
DMB
Patterns
Quick Overlays
SAROPS
ALPHA_Perth
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Voyage
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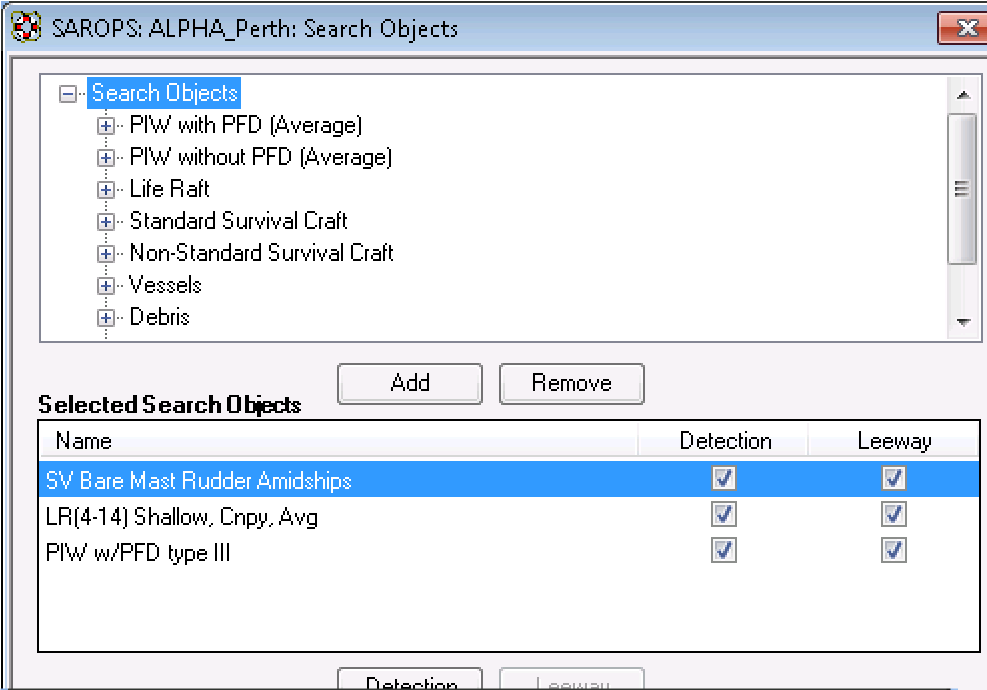
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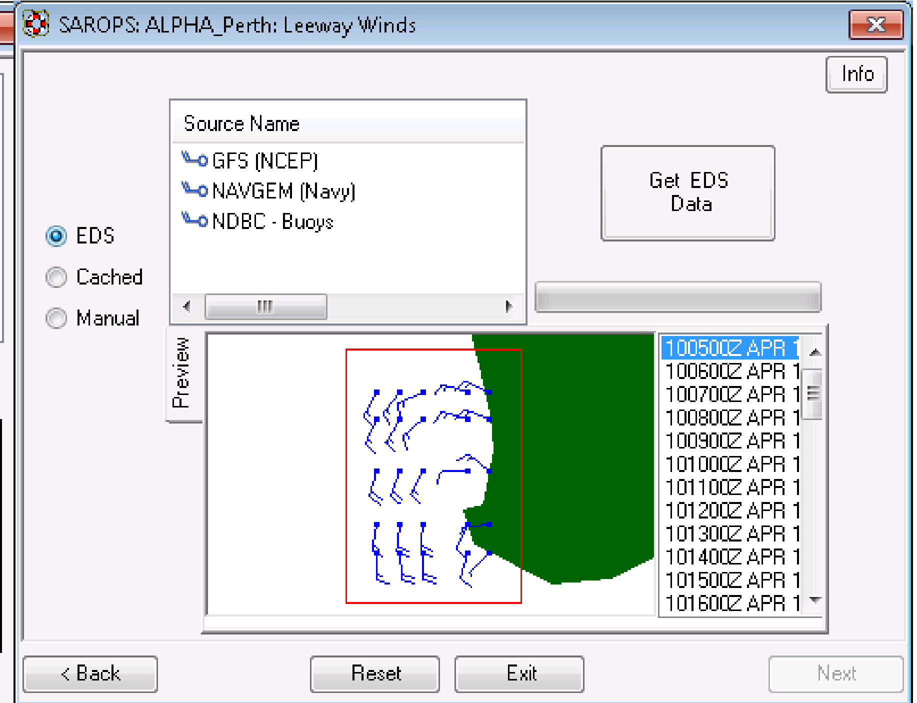
Search Objects
PIW with PFD (Average)
PIW without PFD (Average)
Life Raft
Standard Survival Craft
Non-Standard Survival Craft
Vessels
Debris
Add
Remove
Selected Search Objects
Name
Detection
Leeway
SV Bare Mast Rudder Amidships
LR(4-14) Shallow, Cnpy, Avg
PIW w/PFD type III
Detection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GFS (NCEP)
NAVGEM (Navy)
NDBC - Buoys
Get EDS Data
EDS
Cached
Manual
Preview
100500Z APR 1
100600Z APR 1
100700Z APR 1
100800Z APR 1
100900Z APR 1
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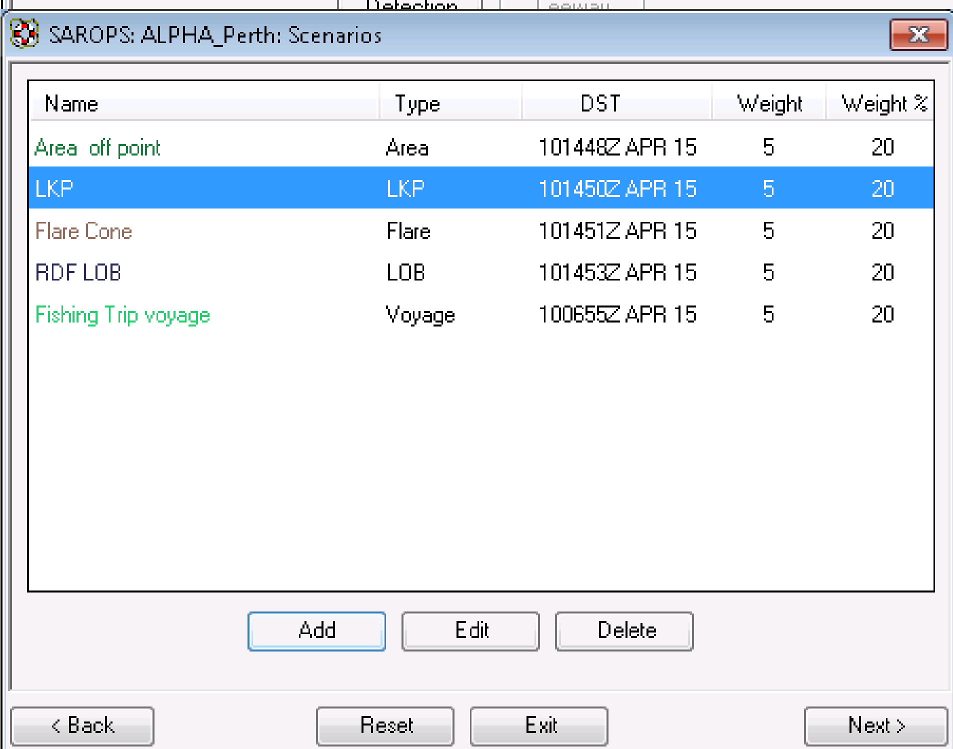
Next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Weight
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LKP
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5
20
Flare Cone
Flare
101451Z APR 15
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LOB
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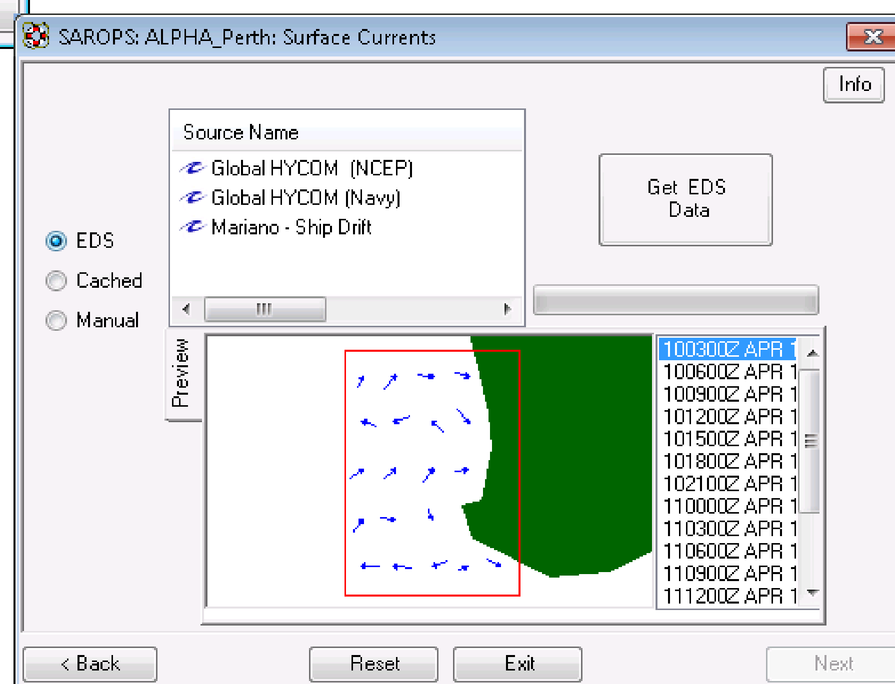
Exit
Next >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Global HYCOM (Navy)
Mariano - Ship Drift
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Manual
Preview
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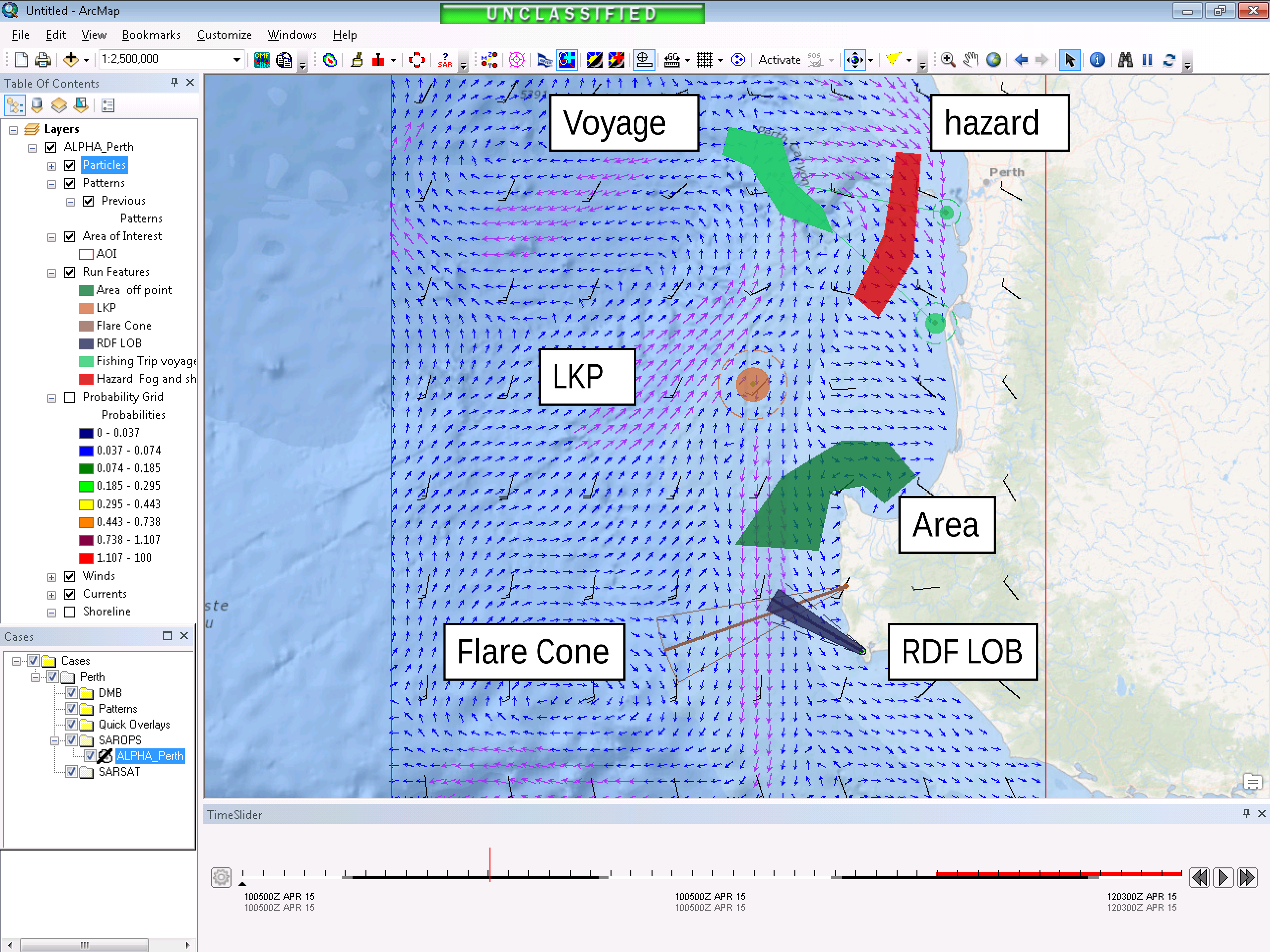
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1.107 - 100
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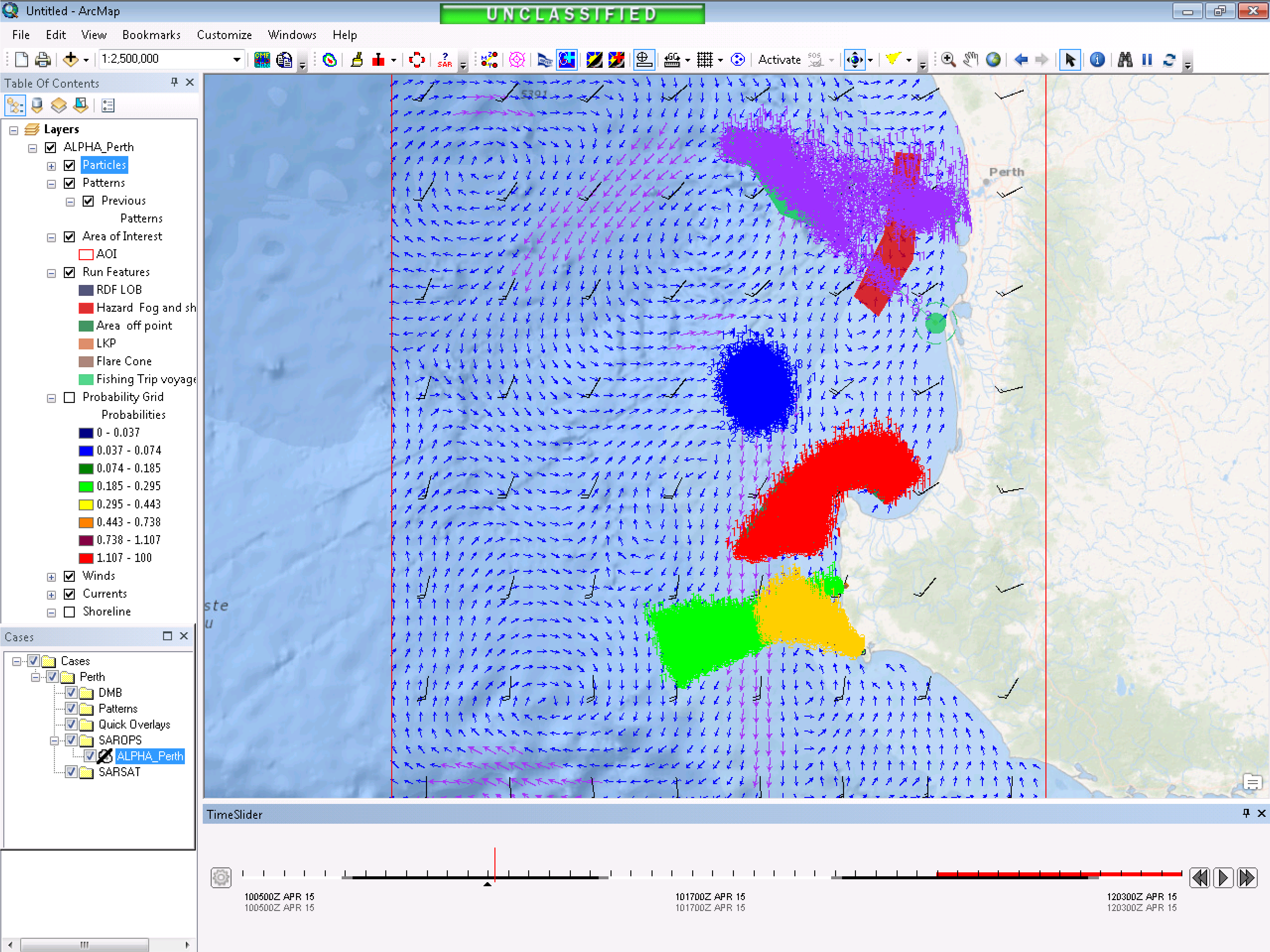
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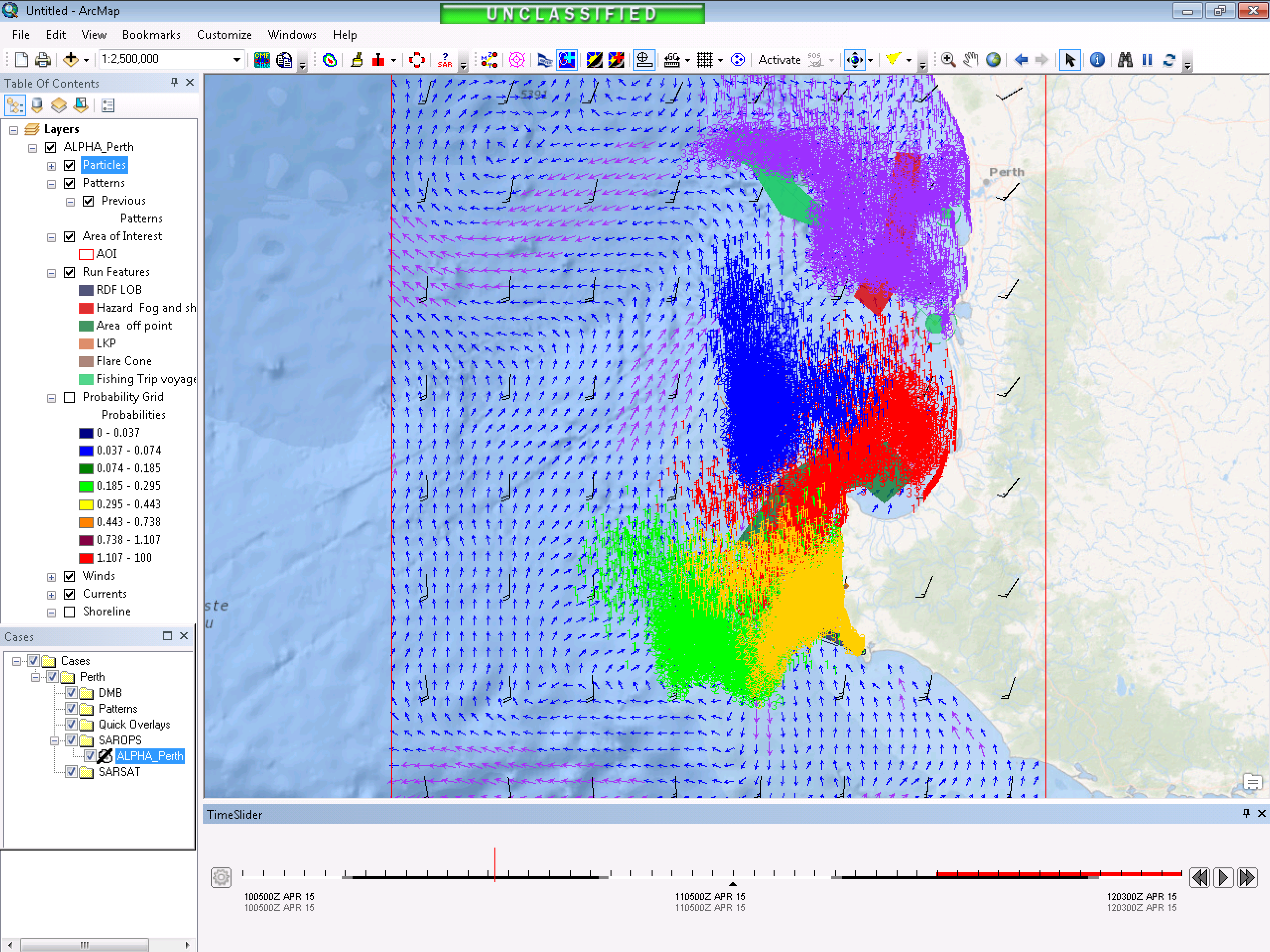
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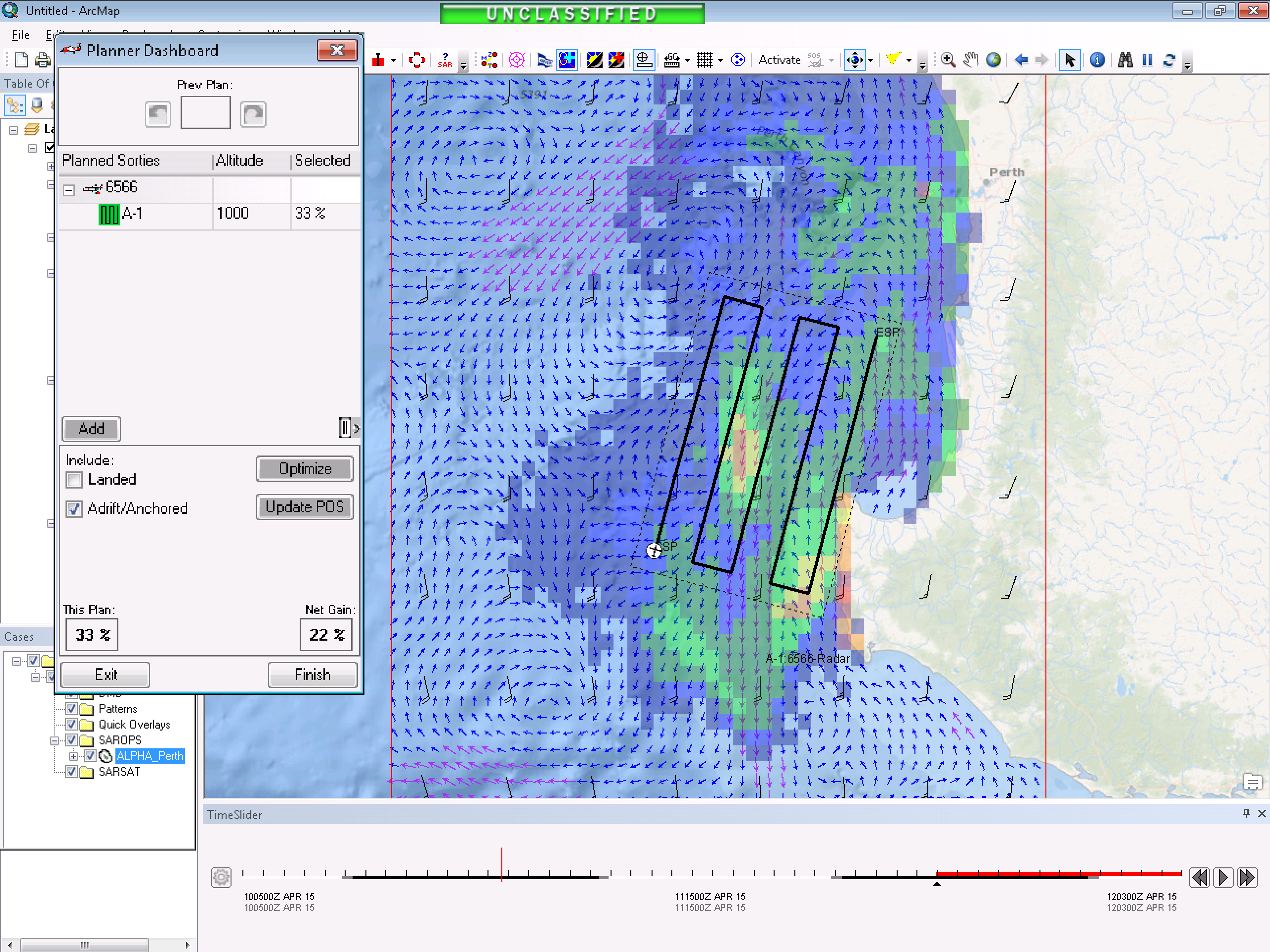

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Prev Plan:
Planned Sorties
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A-1
1000
33 %
Add
Include:
Landed
Adrift/Anchored
Optimize
Update POS
This Plan:
33 %
Net Gain:
22 %
Exit
Finish
Activate
Table Of
Cases
Patterns
Quick Overlays
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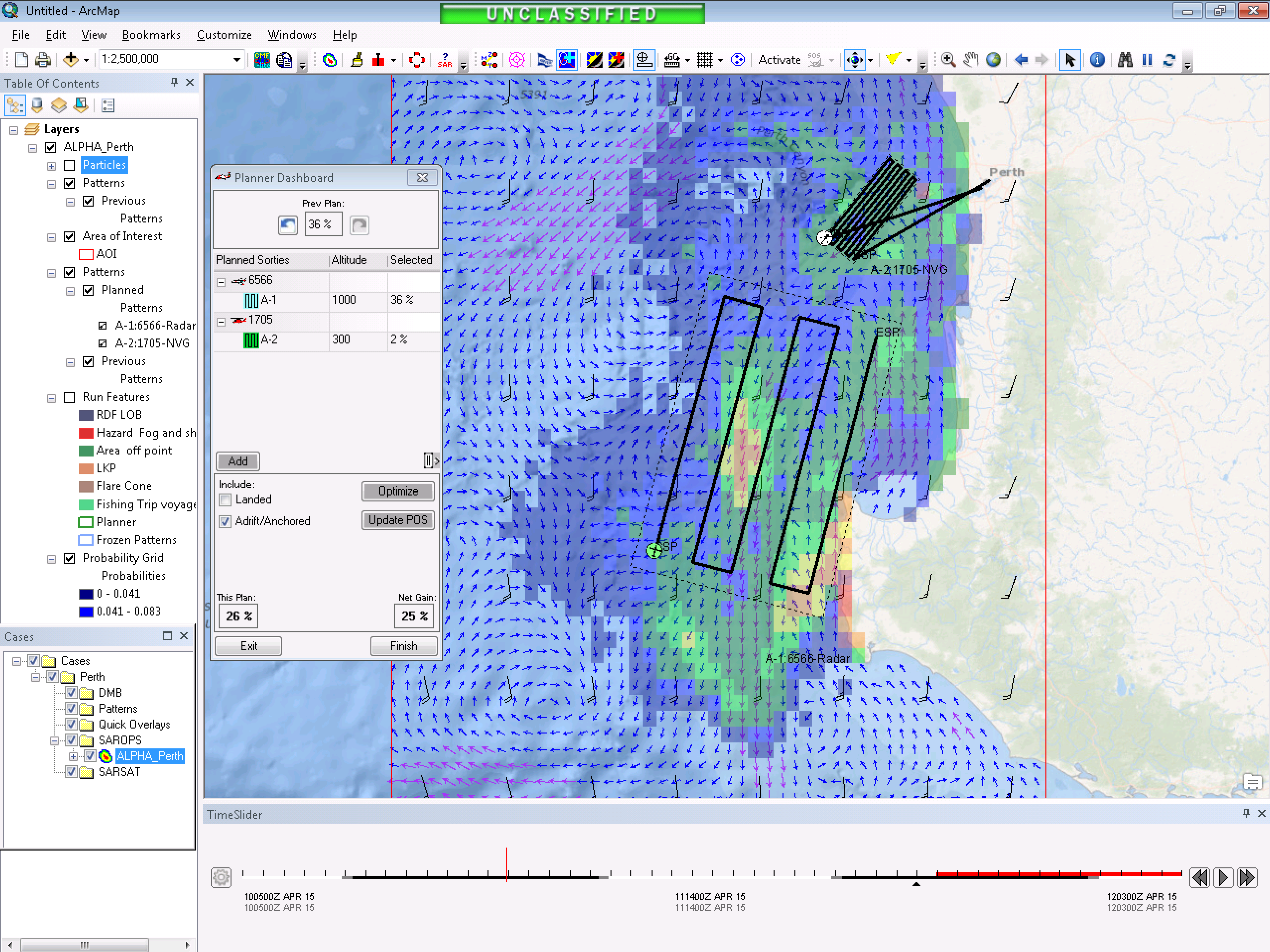
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Previous Patterns
Run Features
RDF LOB
Hazard Fog and sh
Area off point
LKP
Flare Cone
Fishing Trip voyage
Planner
Frozen Patterns
Probability Grid
Probabilities
0 - 0.041
0.041 - 0.083
Cases
Cases
Perth
DMB
Patterns
Quick Overlays
SAROPS
ALPHA_Perth
SARSAT
Planner Dashboard
Prev Plan:
36 %
Planned Sorties
Altitude
Selected
6566
A-1
1000
36 %
1705
A-2
300
2 %
Add
Include:
Landed
Adrift/Anchored
Optimize
Update POS
This Plan:
26 %
Net Gain:
25 %
Exit
Finish
Perth
A-2:1705-NVG
ESP
SP
A-1:6566-Radar
TimeSlider
100500Z APR 15
111400Z APR 15
120300Z APR 15

EDS Products (for USCG)

- 2 global met models, 16 regional met models
- 429 moored and land based met stations
- 2 Global HYCOM ocean models
- 1 global model aggregated with a tidal model
- 25 regional ocean models
- 7 tidal models
- 5 HF radar regions, 2 HF radar predictions
- 1 river flow
- 2 historical models
- SLDMBs

But, how good are the ocean models we use? Measure the Skill

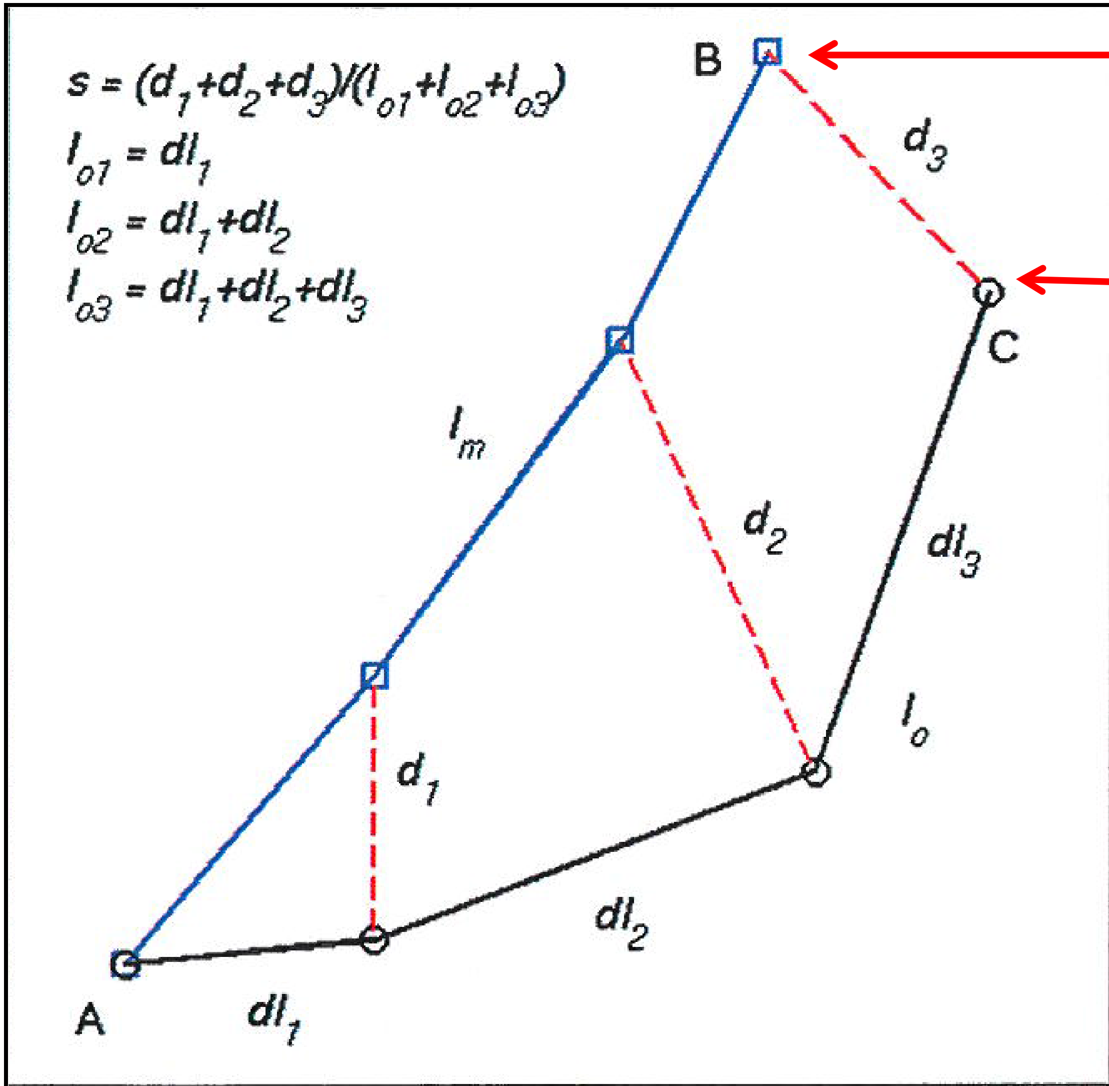
By

Skill at determined by Liu and Weisberg (2011)

“Evaluation of trajectory modeling in different dynamic regions using normalized cumulative Lagrangian separation” JGR, **116**:C09013

Skill of Models at predicting SLDMB drift

Skill = 0.51



Model Simulated Drift end point

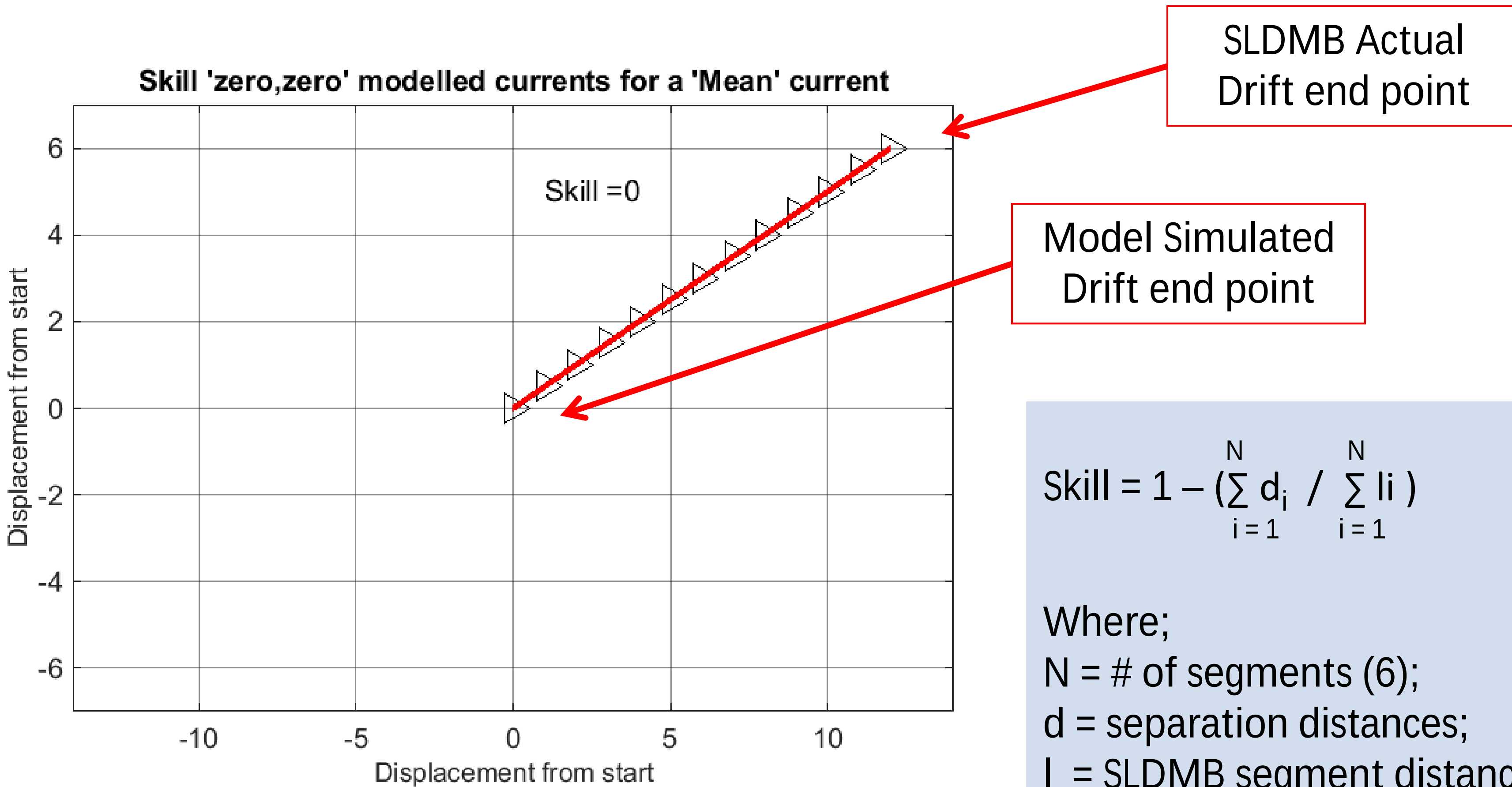
SLDMB Actual Drift end point

$$\text{Skill} = 1 - \left(\sum_{i=1}^{N} d_i \;/\; \sum_{i=1}^{N} l_{oi}\right)$$

Where;
N = # of segments (6);
d = separation distances;
lo = cumulative sum of SLDMB segment distances

Liu & Weisberg (2011)

Zero currents; Skill = 0

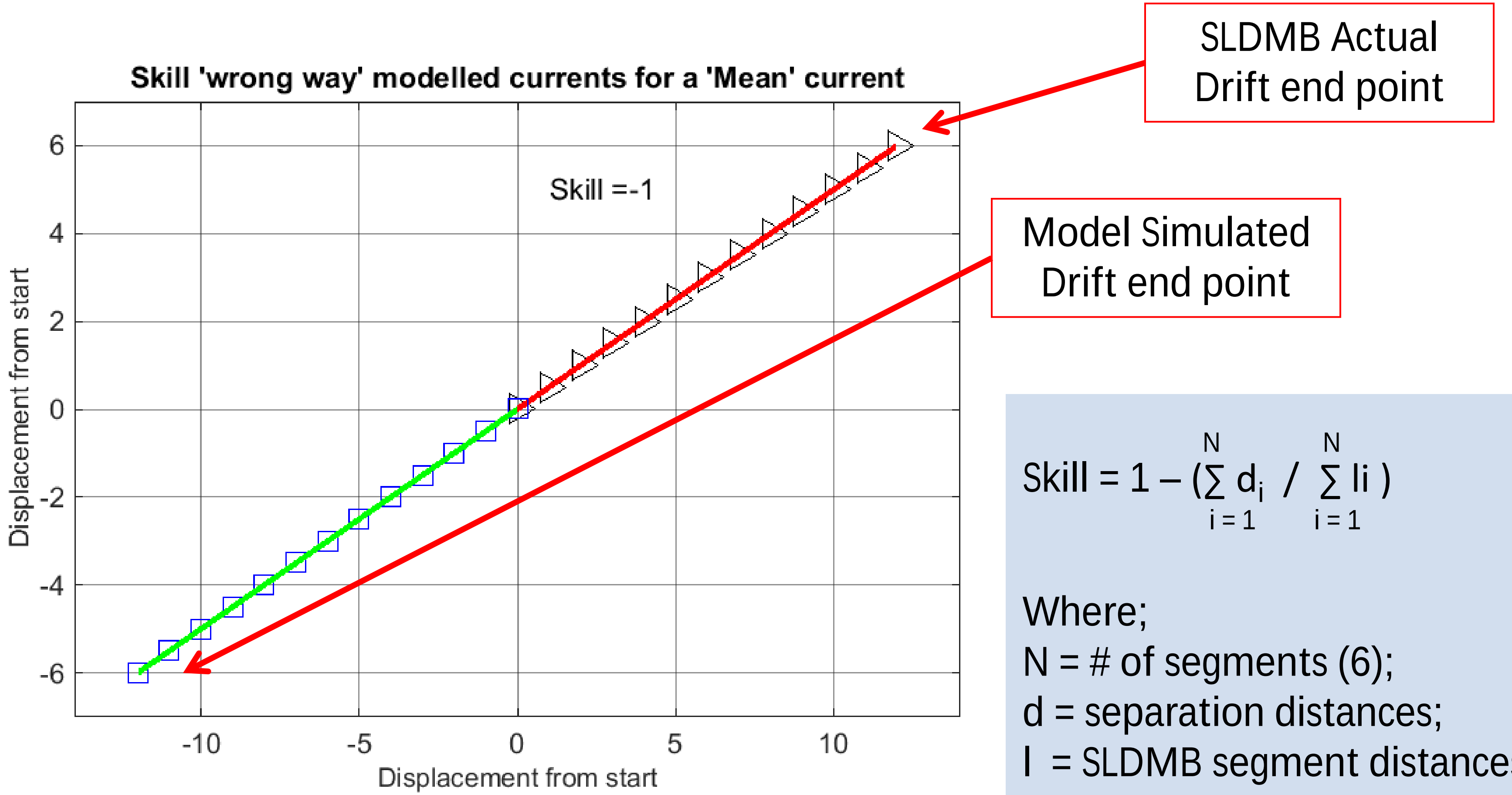


$$\text{Skill} = 1 - \left(\sum_{i=1}^{N} d_i \;/\; \sum_{i=1}^{N} li\right)$$

Where;
N = # of segments (6);
d = separation distances;
l = SLDMB segment distances

Liu & Weisberg (2011)

Wrong way currents; Skill = -1



$$\text{Skill} = 1 - \left(\sum_{i=1}^{N} d_i \Big/ \sum_{i=1}^{N} li\right)$$

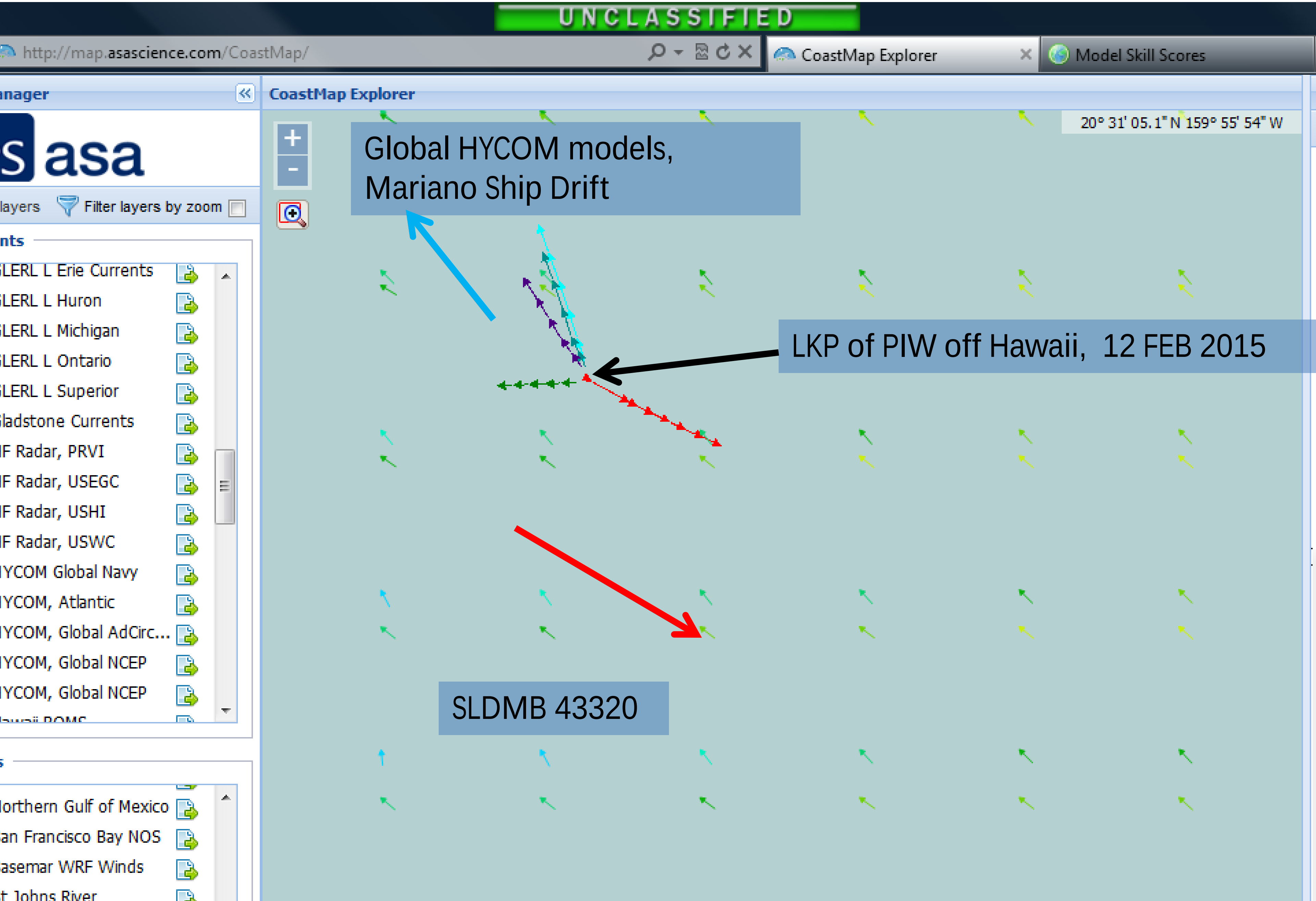
Where;
N = # of segments (6);
d = separation distances;
l = SLDMB segment distances

Liu & Weisberg (2011)

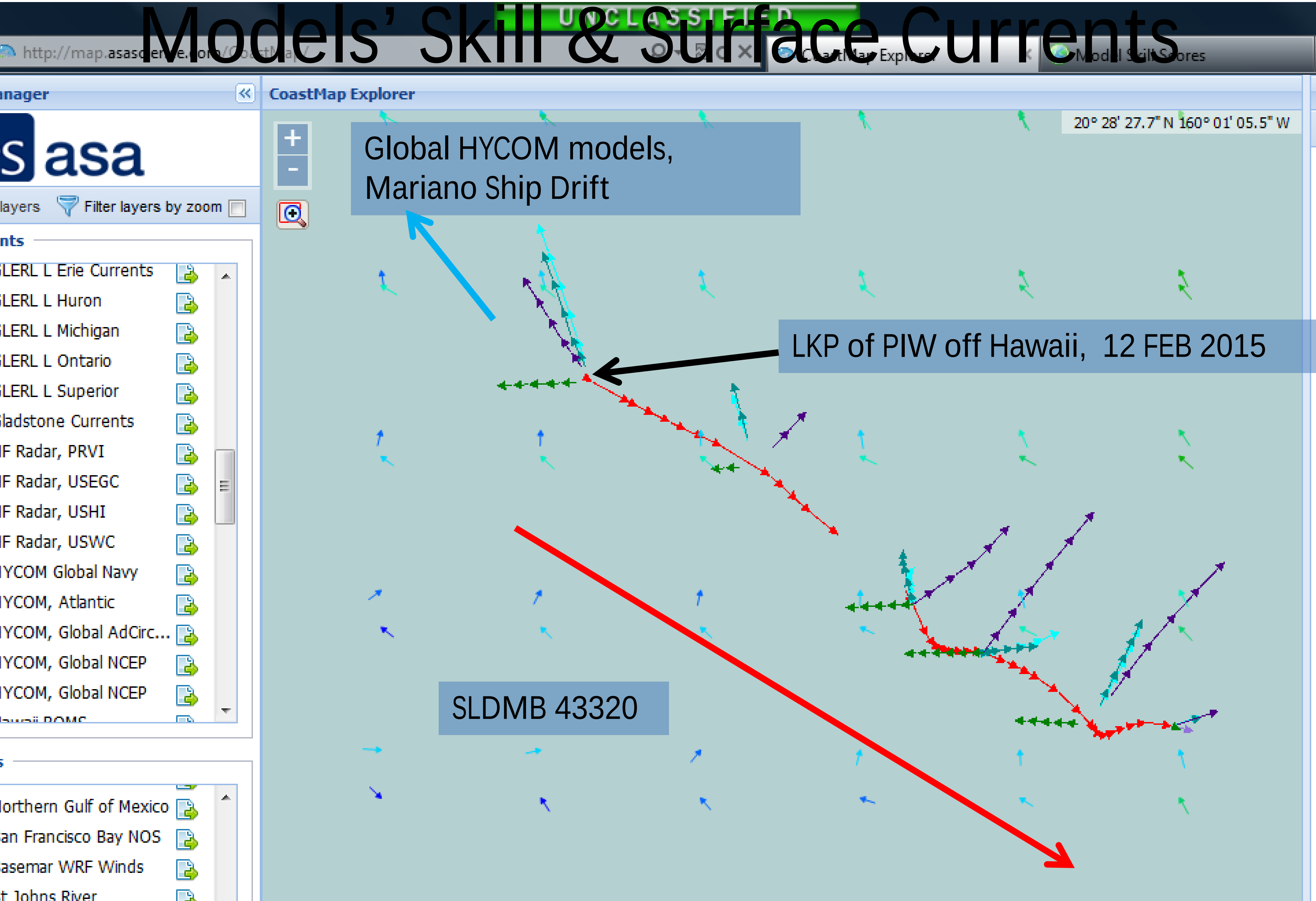
So, how good are the ocean models we use? An example

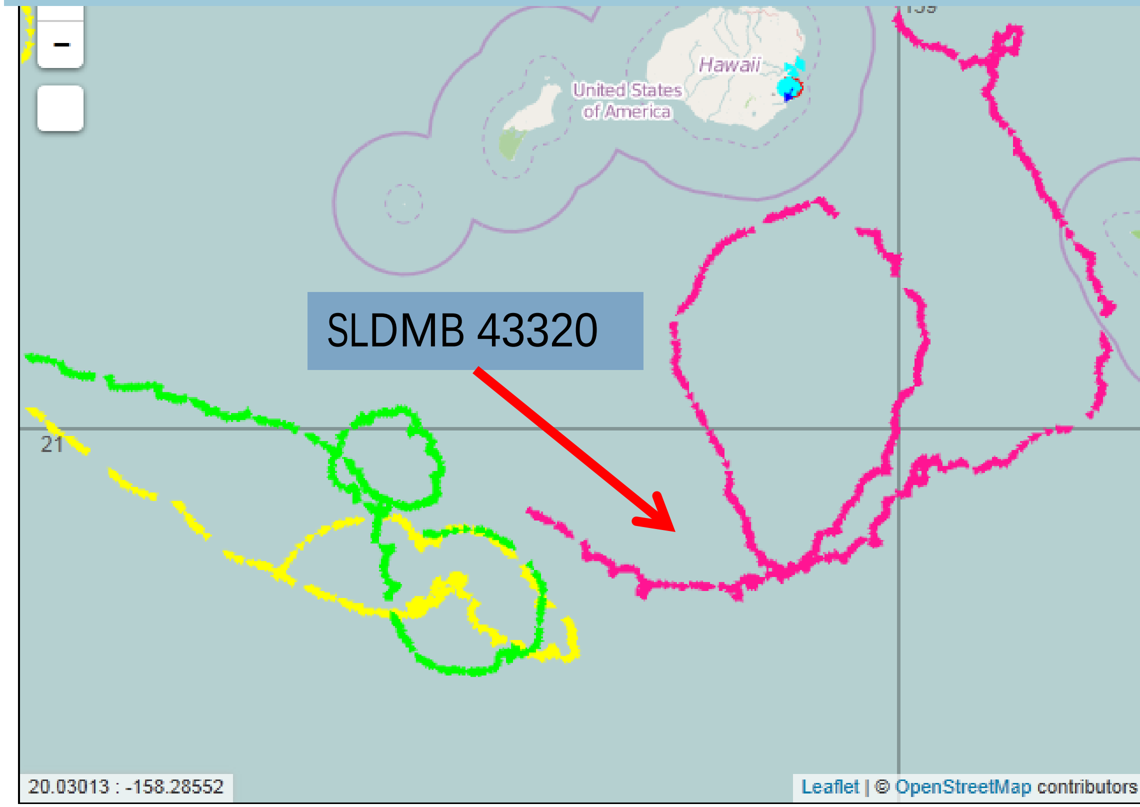
Hawaii, 12 FEB 2015, 150nm south of Kauai
Japanese cadet lost of training vessel
No model agrees with the drift of the SLDMB
Used SLDMBs to generate surface current field

Skill at determined by Liu and Weisberg (2011)


UNCLASSIFIED
http://map.asascience.com/CoastMap/
CoastMap Explorer
Model Skill Scores
anager
CoastMap Explorer
asa
layers
Filter layers by zoom
nts
LERL L Erie Currents
LERL L Huron
LERL L Michigan
LERL L Ontario
LERL L Superior
ladstone Currents
F Radar, PRVI
F Radar, USEGC
F Radar, USHI
F Radar, USWC
YCOM Global Navy
YCOM, Atlantic
YCOM, Global AdCirc...
YCOM, Global NCEP
YCOM, Global NCEP
orthern Gulf of Mexico
an Francisco Bay NOS
asemar WRF Winds
t Johns River
20° 31' 05.1" N 159° 55' 54" W
Global HYCOM models,
Mariano Ship Drift
LKP of PIW off Hawaii, 12 FEB 2015
SLDMB 43320

Models' Skill & Surface Currents





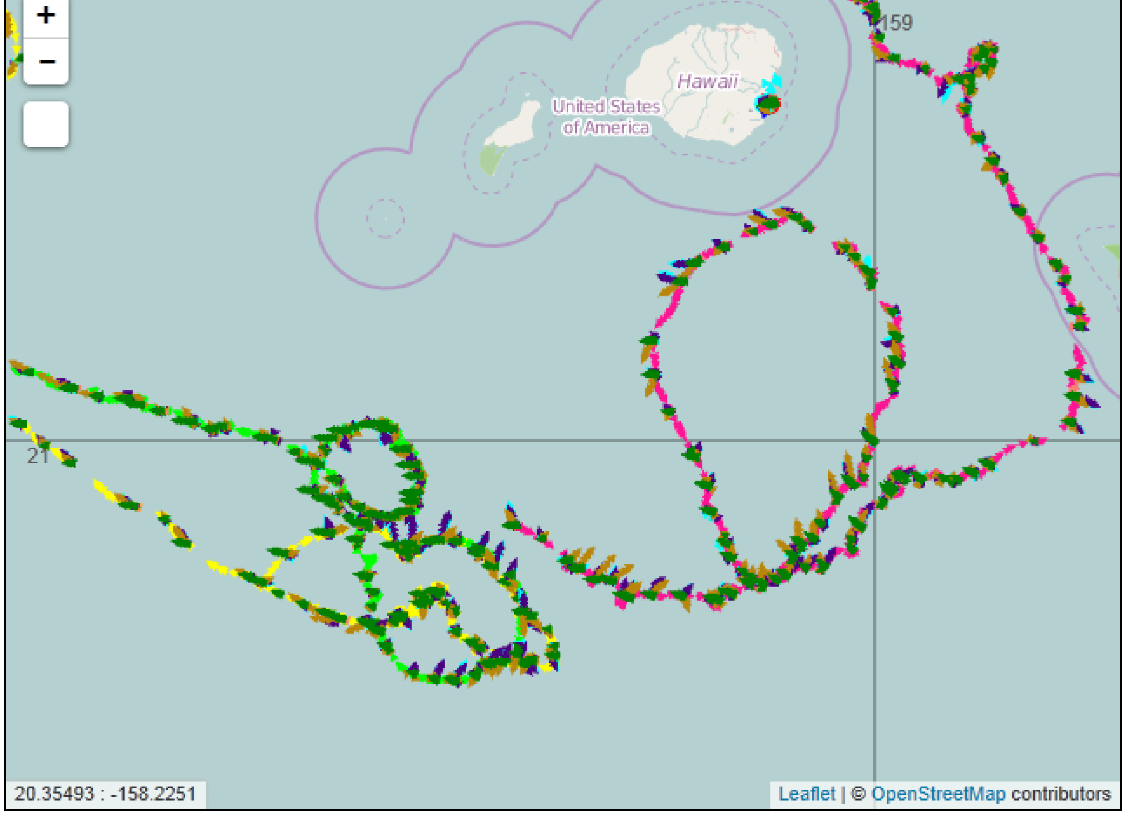
Navy's Global HYCOM model's skill:
+ 0.23
5 SLDMBS
1012 hrs

☑ Turn Graticules on/off ☑ Turn WMS Buoys on/off ☐ Turn WMS Skill Score on/off

Display Skill Scores | Download Skill Data | Case Start: 2015-02-12 00:00

Average skill scores in AOI (19.99,-161.70 to 22.45, -158.18).

Model	Percent Cover	Lifetime			6 Month			Case Start		
		Skill Score	Num Buoys	Track Hours	Skill Score	Num Buoys	Track Hours	Skill Score	Num Buoys	Track Hours
HFRADAR_USHI	n/a	0.0505	7	1254	0.0515	5	997	0.0515	5	997
STATIC	n/a	0.1699	12	2111	0.1488	9	1500	0.151	5	1021
HYCOM_GLOBAL	n/a	0.1754	12	2073	0.1665	9	1475	0.1504	5	1016
HAWAII_ROMS	n/a	0.0956	7	1047	0.1162	4	446	0	0	0
AGG	n/a	0.1756	12	2078	0.1658	9	1480	0.1463	5	1016
HYCOM_GLOBAL_NAVY	n/a	0.2195	12	2069	0.2227	9	1470	0.2323	5	1012



☑ Turn Graticules on/off ☑ Turn WMS Buoys on/off ☑ Turn WMS Skill Score on/off

Display Skill Scores **Download Skill Data** Case Start: 2015-02-12 00:00

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Future SAR Trajectory Work

- Ensemble Current products
  - Treat like scenarios, add particles, weight
- Use Skill
  - Order EDS products by Skill x % coverage of AOI
  - Scale Dispersion
  - Real-time verification of models
- Leeway of Aircraft debris, capsized vessels
- Model Sailboat voyages
- Numerical model of Leeway

Future SAR Optimization Work

- Detection and Sensor Performance
  - New sensors
  - New platforms (UAVs)
  - New search strategies (swarms of UAVs from ship)
  - Combine numerical modeling of sensor performance, verified by field testing results
  - Multiple sensors on a search platform
  - Time series of sensor effectiveness along SRU trackline
- Probability of Success dependent on Survival

Future Survival Work

- Models of Survival
  - Finite element models of the human
  - Post Incident Survival Web Site
  - Survival model provides probability of survival distributions to SAR planning tool.
  - Probability of Success dependent on Survival
    - Optimize on finding the survivors alive

Future Oceanographic Modeling Work for SAR

- Ensemble Models
  - Connection between models and trajectory tools
- Use Skill
  - Real-time verification of models
  - Improve models
- Output standard 1-m thick surface currents
- Capture time series of environmental data
  - From L/L point
  - From an area
  - For Survival / Detection

Challenges for SAR

- Increasing Cyber Infrastructure demands
  - Commercial upgrades of software is faster than gov’t upgrades
- Increasing Cyber Security demands
  - Slows releases
  - Take an ever increasing toll
- Fewer persons lost
- Higher expectation that all will be recovered safely

Thank You

Art Allen

CG-SAR

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21 July 2015