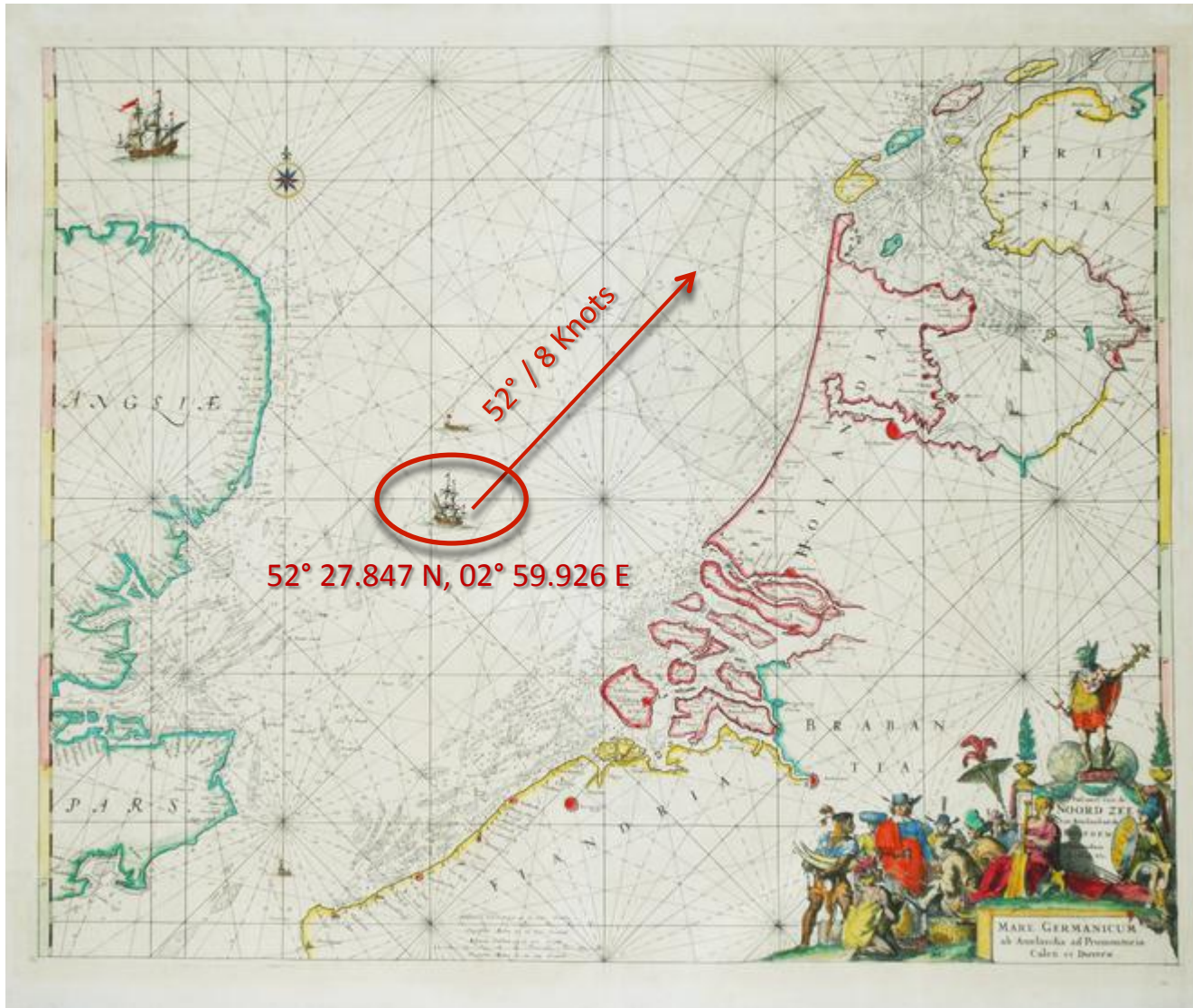
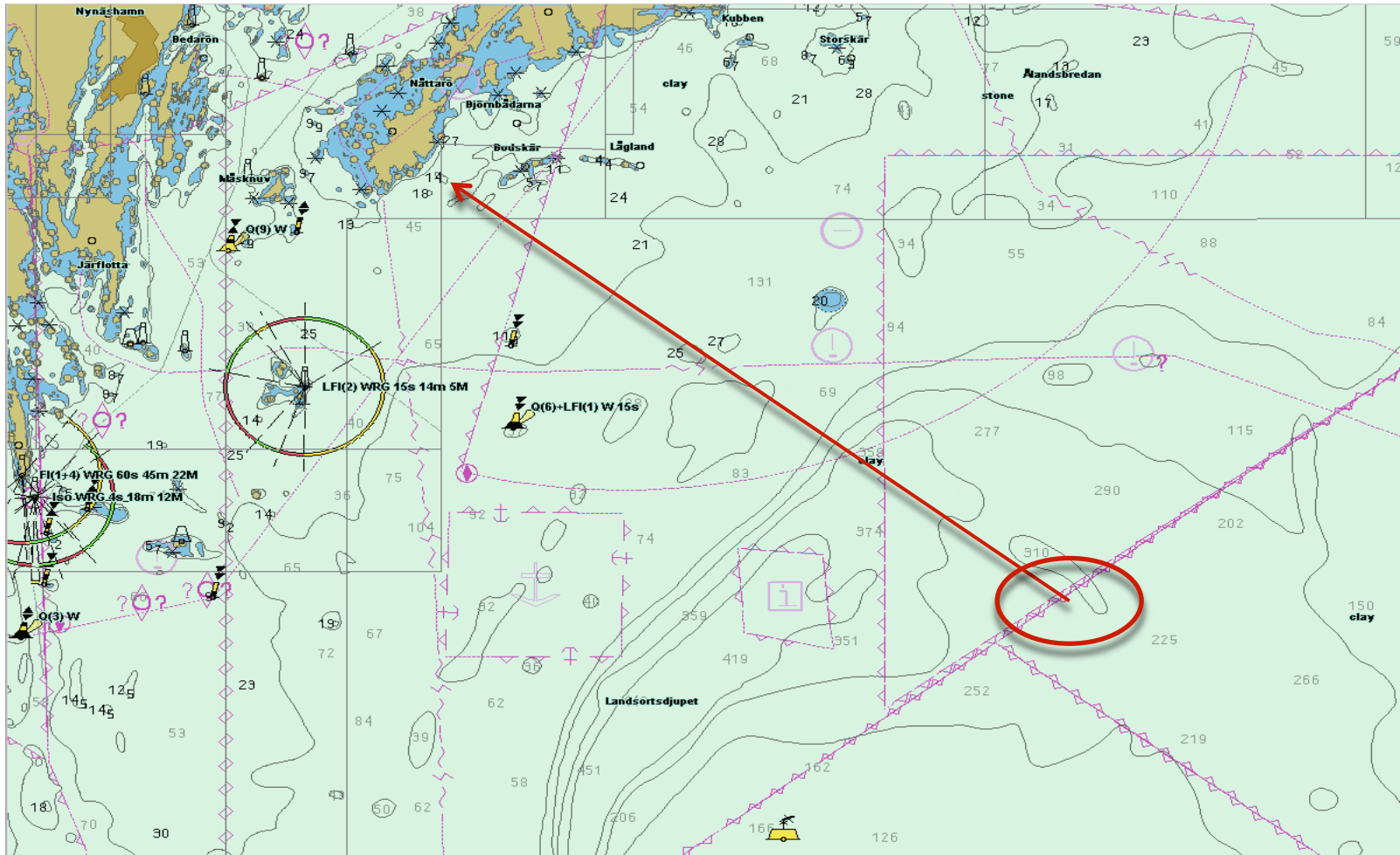


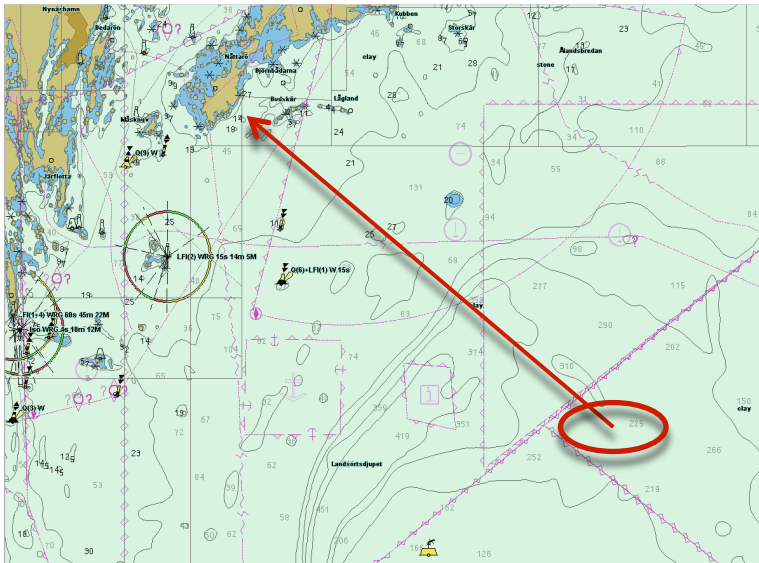
High speed navigation in littoral waters

*Harald Nilsson, CEO
Sea Cross Marine AB, Sweden*

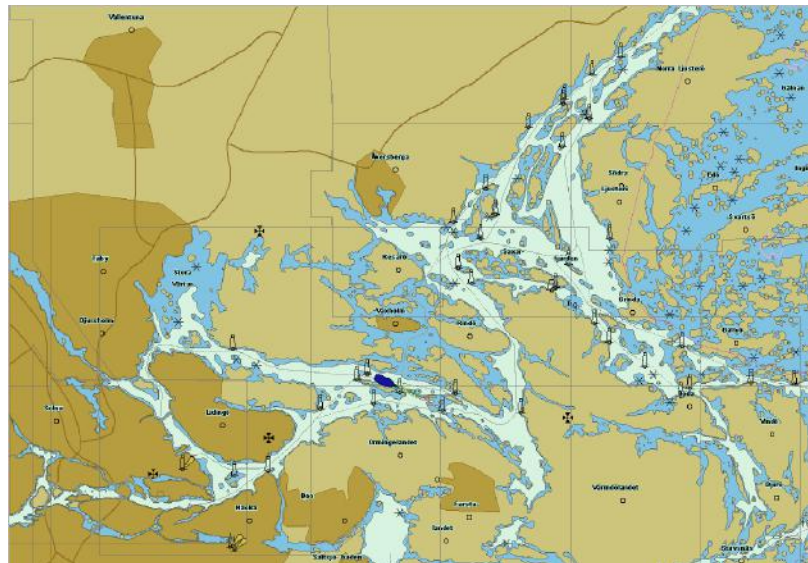




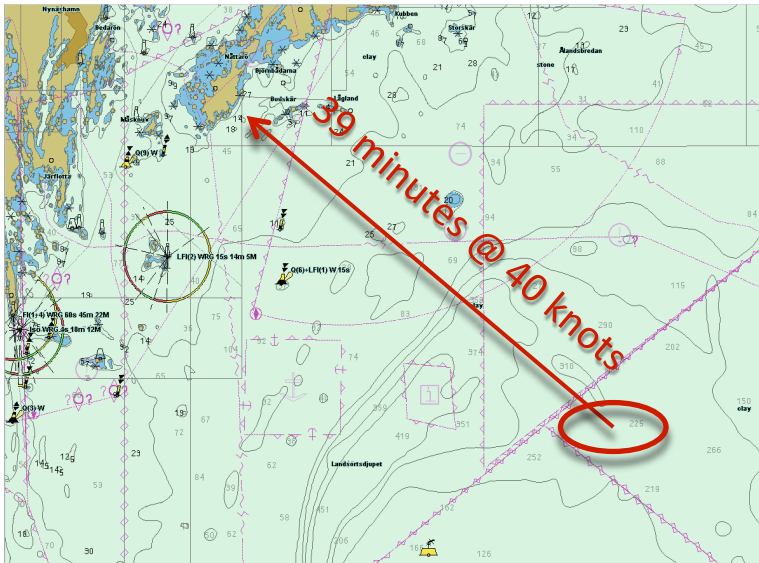
1 : 150 000 Open water navigation



1 : 150 000 Open water navigation



1 : 150 000 Littoral navigation

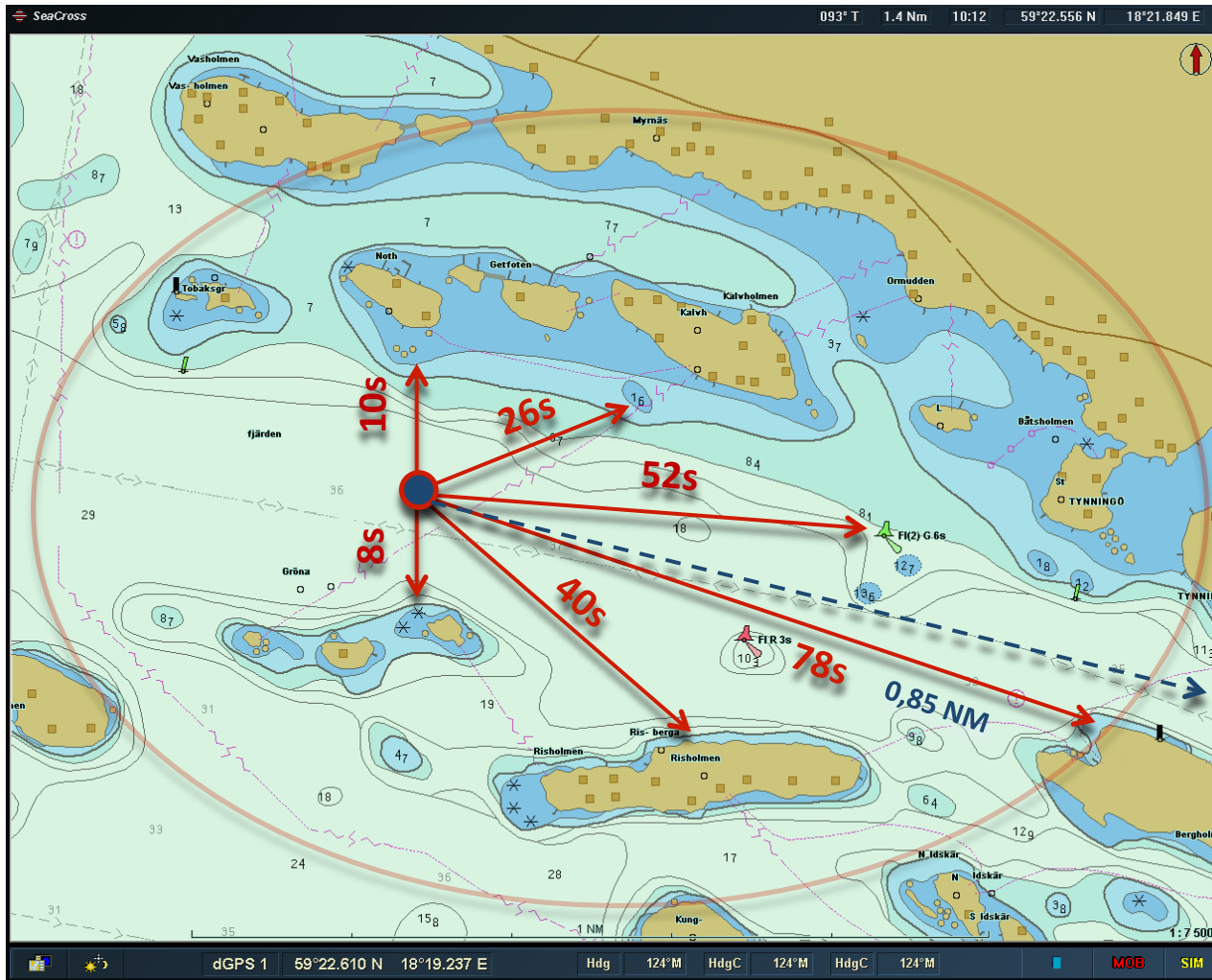


1 : 150 000 Open water navigation



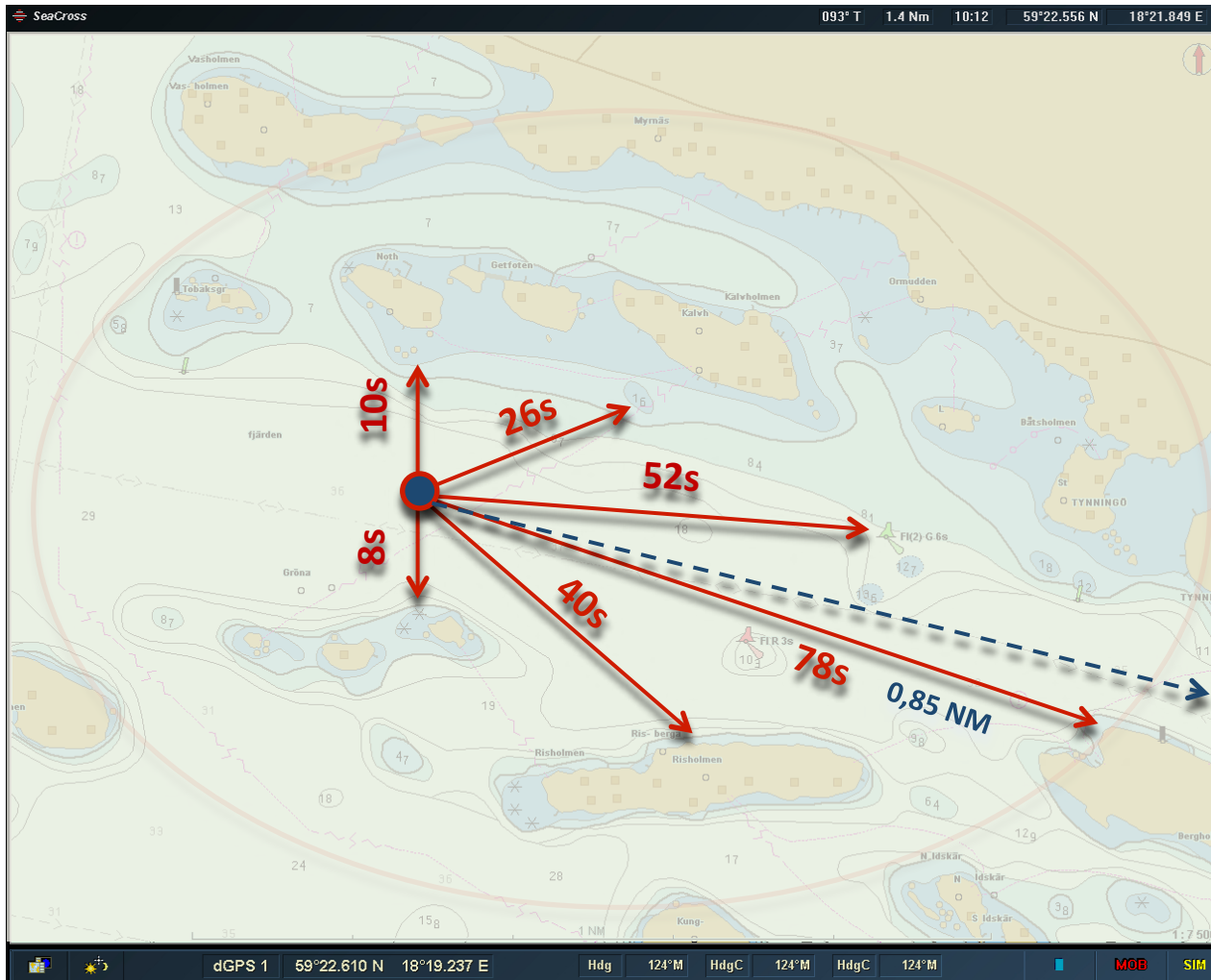
1 : 150 000 Littoral navigation

High speed navigation in littoral waters



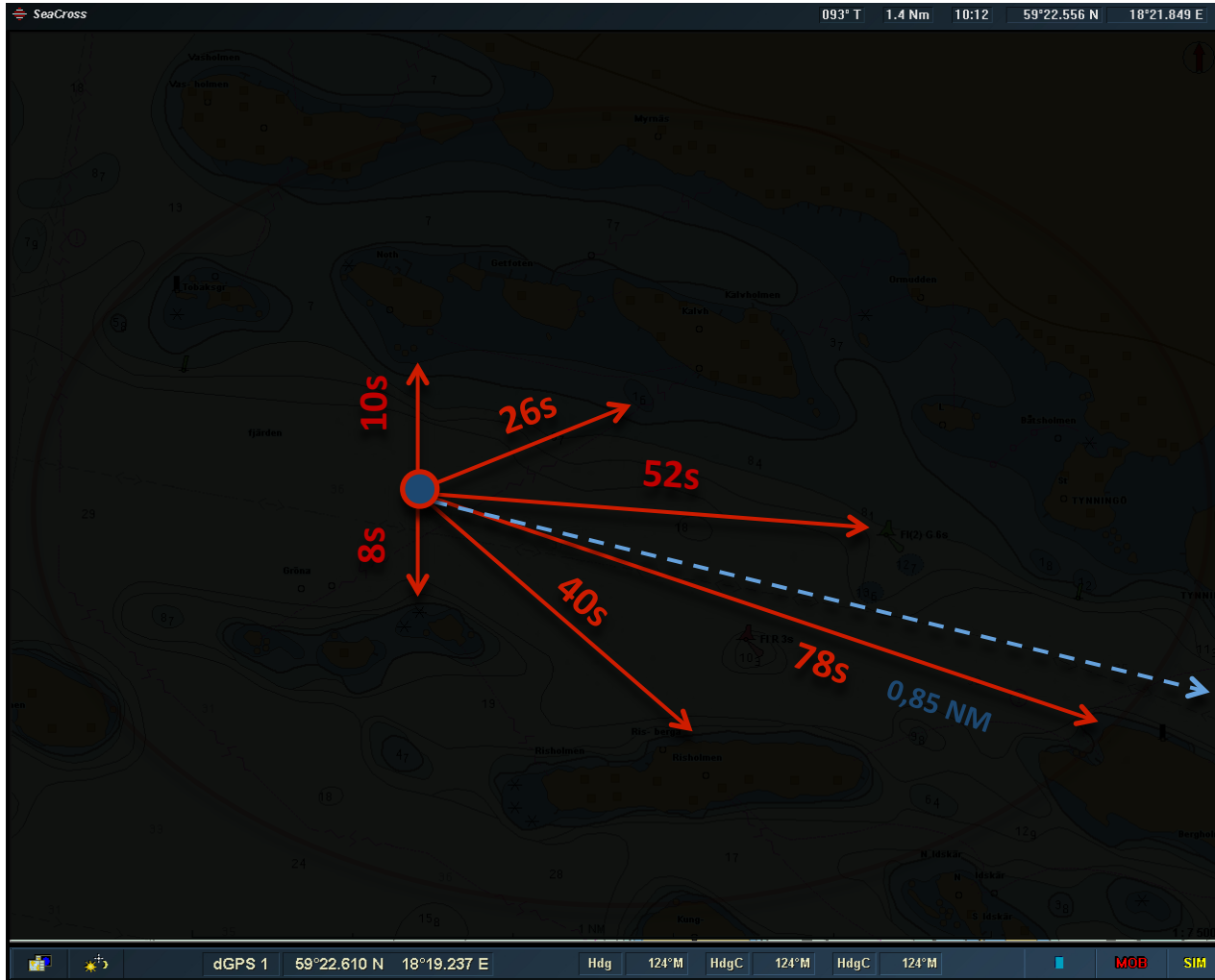
1 : 7 500 Safety margins in seconds @ 40 knots

High speed navigation in littoral waters

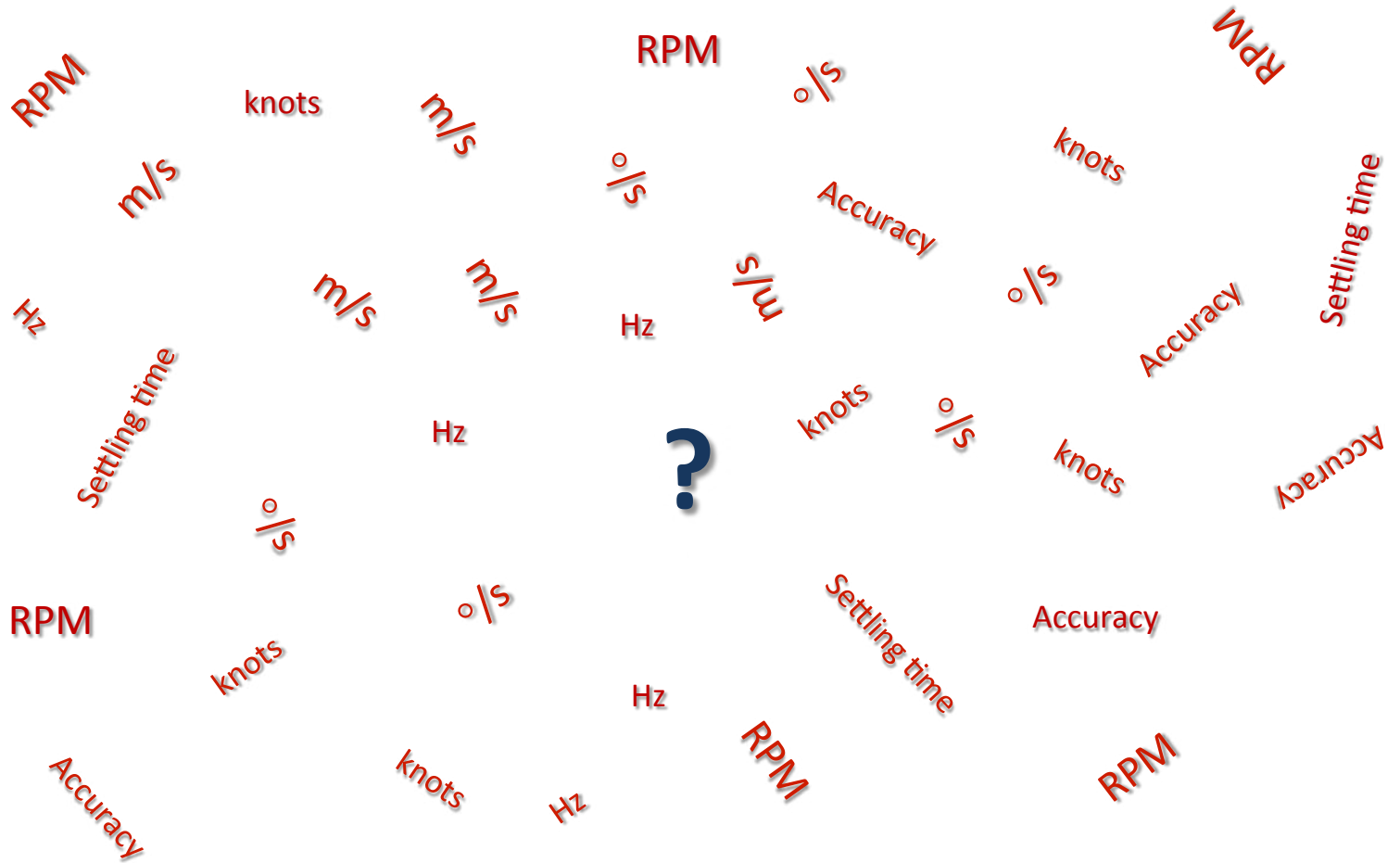


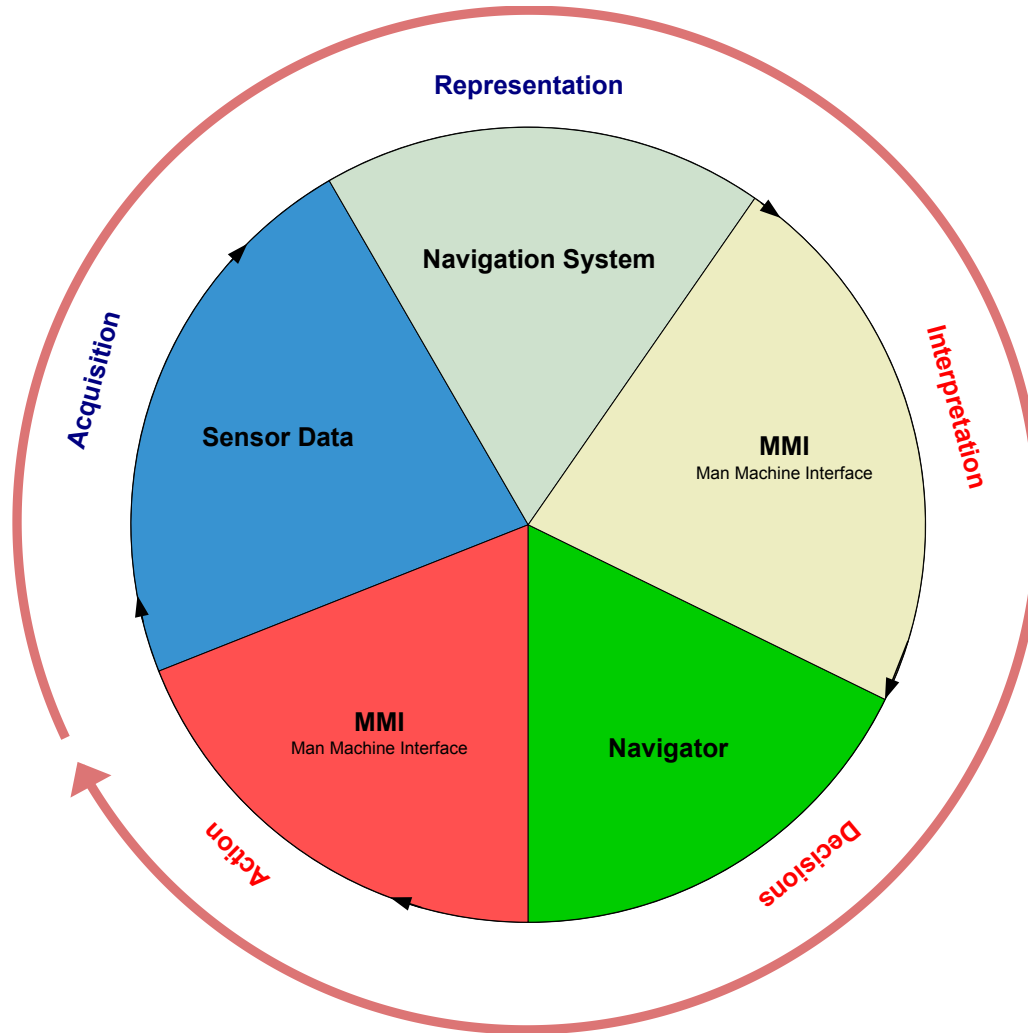
1 : 7 500 Safety margins in seconds @ 40 knots

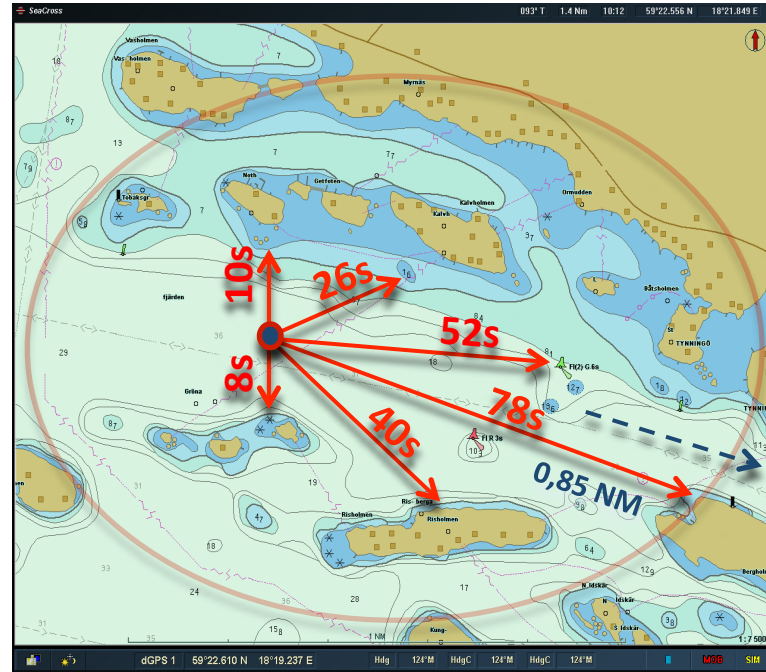
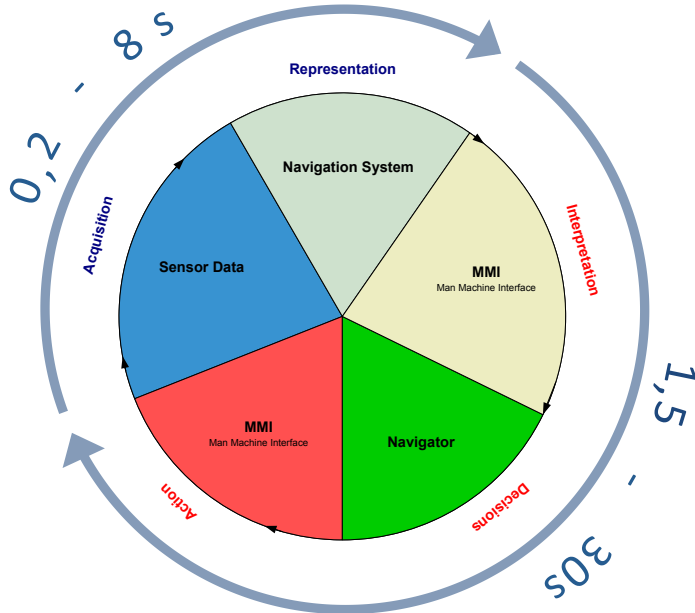
High speed navigation in littoral waters



1 : 7 500 Safety margins in seconds @ 40 knots

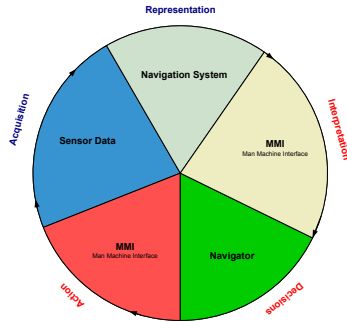






Step	System	Latency / Cycle rate (typical)
Acquisition	Sensors	0,1 – 3 s
Representation	Navigation system	0,1 – 5 s
Interpretation	Navigation system / Navigator	0,5 - 10 s
Decision	Navigator	0,5 – 10 s
Action	Navigation system / Navigator	0,5 – 10 s
Total		1,7 – 38 s

Example – Navigation process latency



Navigation process

Sensor and system update rates

- Own position
- Heading
- Radar

Interpretation and execution

- MMI / Man Machine Interface
- Navigator response and execution

Own position

Accuracy (typical)

dGPS antenna

WAAS/EGNOS +/- 7m, no correction +/- 15m

+/- 2m

Sea Chart

NOOA: 1 mm of scale, +/- 5 m @ 1:10 000

+/- 4 m

Plotter algorithms

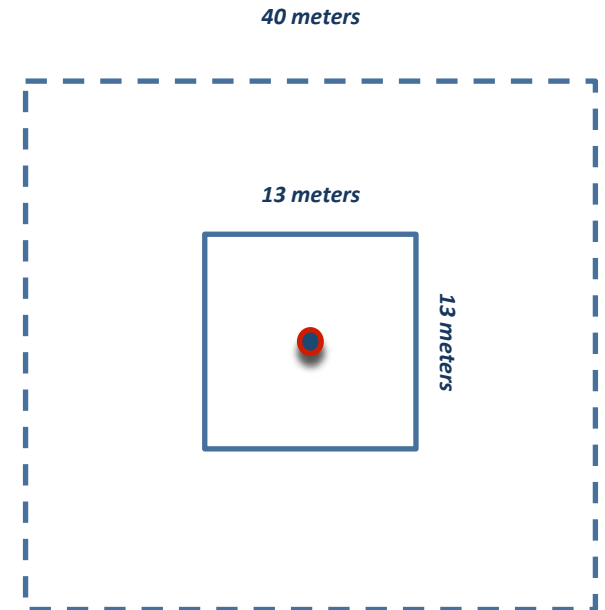
\$GPGLL +/- 9m

+/- 0,5 m

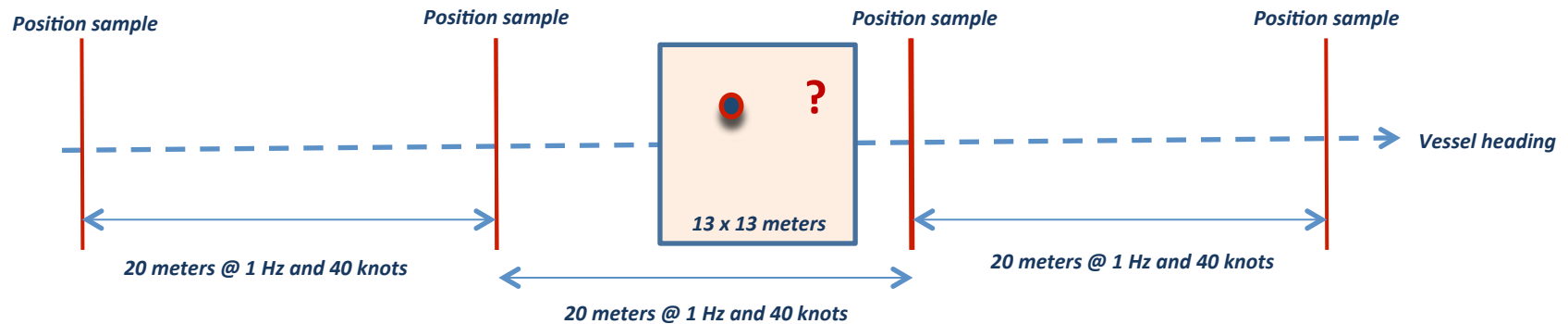
Total

(Worst case +/- 20 m or more)

+/- 6,5 m



Update rate



The vessel cannot alter its transversal speed dramatically in between samples.
The vessel cannot alter its longitudinal speed dramatically in between samples.



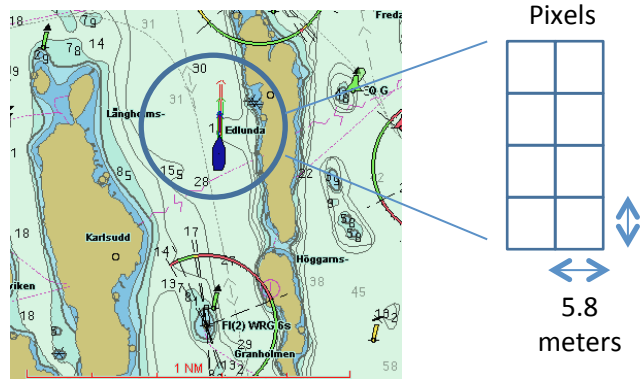
Own position update rate is not paramount



GPS derived position accuracy is less critical than the chart accuracy

Display resolution

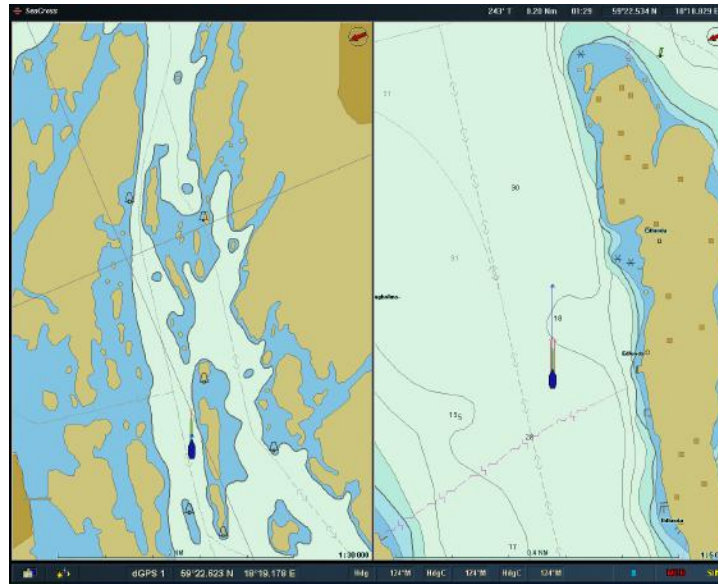
Typical pixel size is 0.29mm, which leads to



Scale	1 mm = in meters	meters/pixel
1:10 000	10	3,4
1:15 000	15	5,1
1:25 000	25	7,5
1:50 000	50	17
1:75 000	75	26



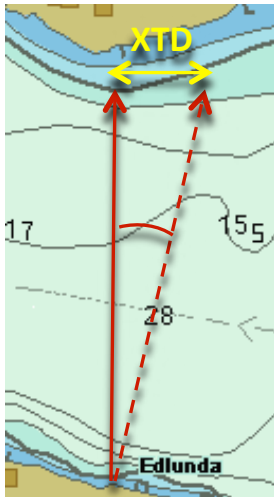
Except at small scales, display resolution is often detrimental to the accuracy achieved by GPS and chart.



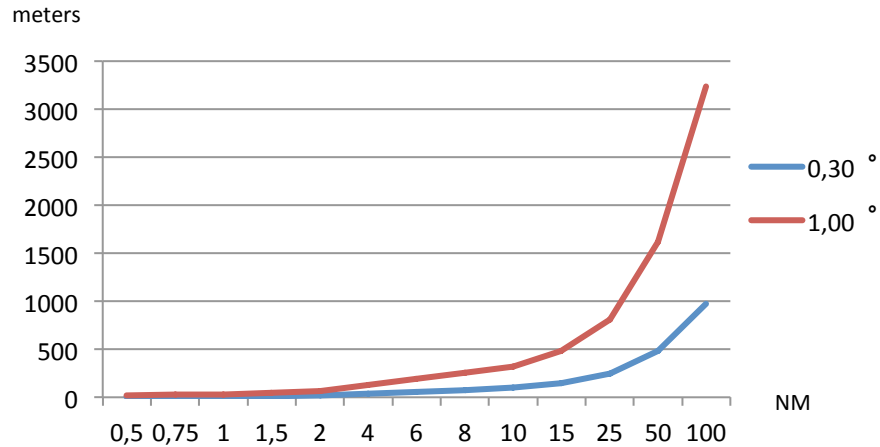
- ➔ High speed navigation systems must be capable of simultaneously showing multiple charts at different scales.
- ➔ Displays should be large enough (15"+) to display charts at readable scales and resolutions.

Heading

Accuracy



Cross Track Distance vs Accuracy and Distance



Crossing a 2 NM wide bay will yield a cross track error at the point of destination approximately +/- 5m or +/- 16 m for heading sensor accuracies of 0,3° / 1.0° respectively.

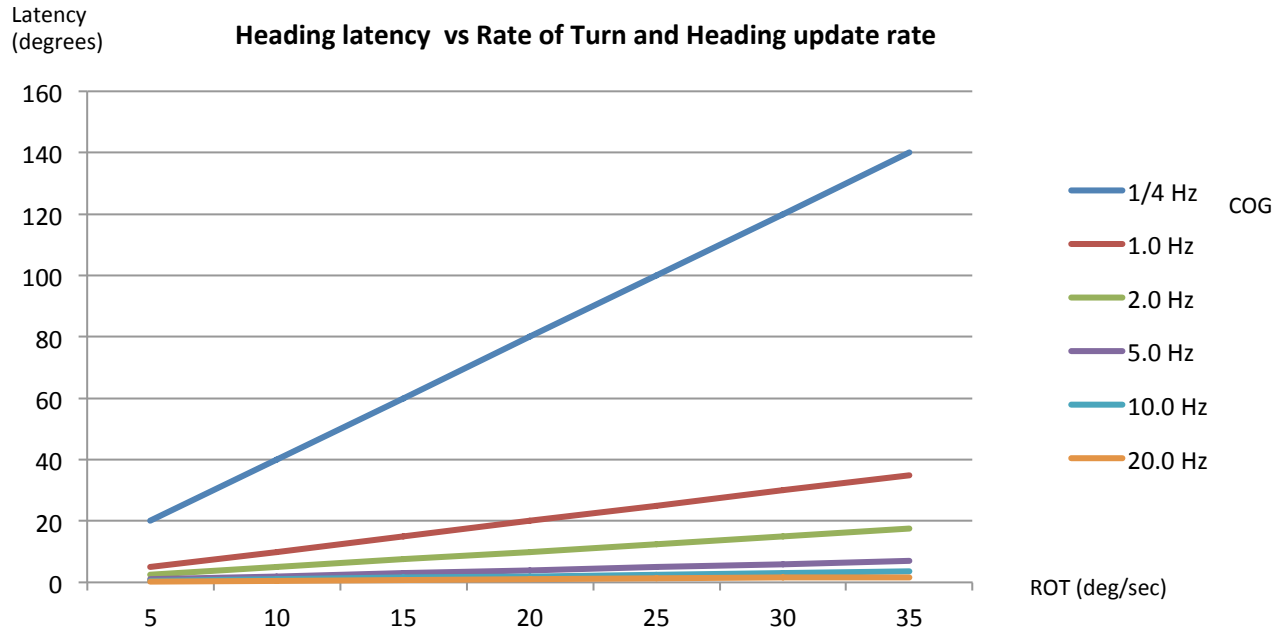


Heading sensor accuracy is not critical to littoral navigation



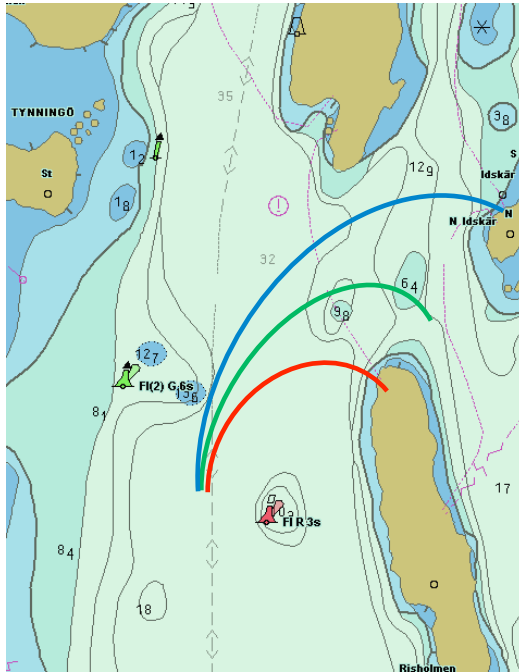
Heading sensor accuracy is of importance for target tracking




Update rate – dangerous latencies



Heading sensor update rate is of paramount importance to safety in high speed navigation systems

Low update rate – risks and consequences



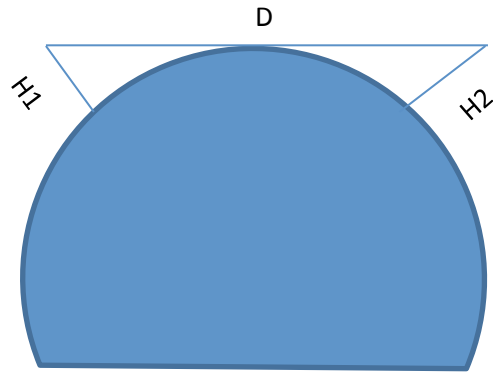
-  Intended heading
-  Displayed Heading
-  Actual heading



Heading sensor update rate is of paramount importance to safety in high speed navigation systems

Radar

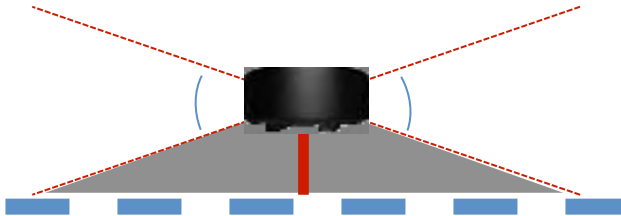
Range



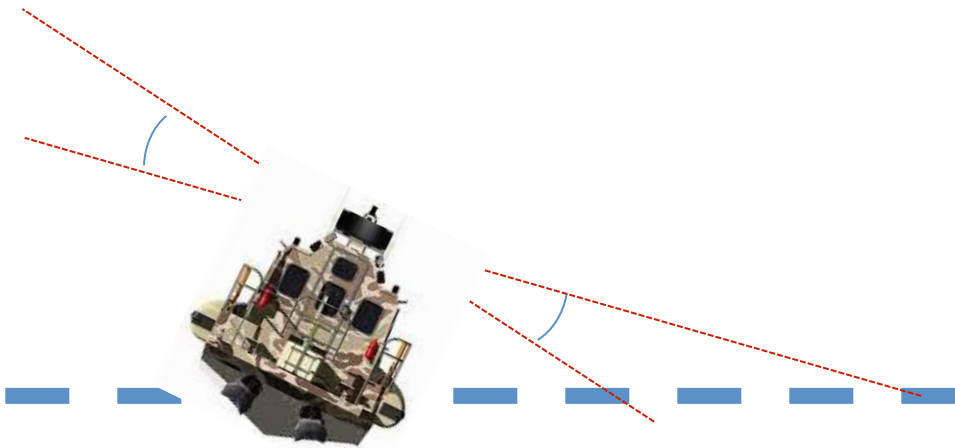
$$D = 2.08 \times \text{SQRT}(H1+H2)$$

Mounting height	Distance to horizon
1 m	2,0 NM
2 m	3,0 NM
3 m	3,6 NM
4 m	4,1 NM
5 m	4,7 NM
6 m	5,1 NM
7 m	5,5 NM

Blind zone



Mounting height	Blind zone radius
2 m	9 m
3 m	13,5 m
4 m	16,8 m
5 m	22,6 m
6 m	27,1 m
7 m	31,5 m

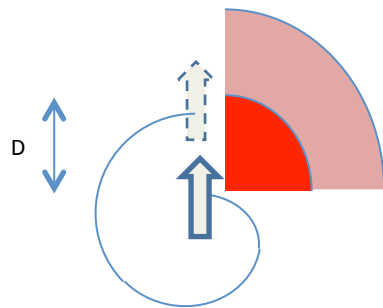


Mounting height	Roll	Distance to "horizon"	Roll	Distance to "horizon"
1 m	12°	0,03 NM	15°	0,01 NM
2 m	12°	0,06 NM	15°	0,02 NM
3 m	12°	0,09 NM	15°	0,02 NM
4 m	12°	0,12 NM	15°	0,03 NM
5 m	12°	0,15 NM	15°	0,04 NM
6 m	12°	0,18 NM	15°	0,05 NM
7 m	12°	0,21 NM	15°	0,05 NM

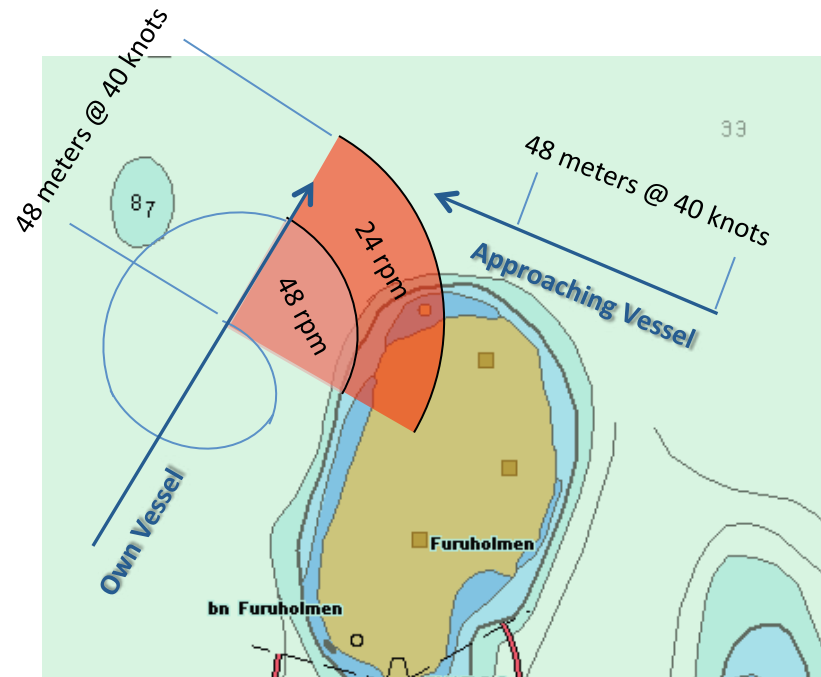
Values are influenced by unevenly distributed radiation energy

Roll > Vertical lobe angle / 2

Update rate



Distance made good during one revolution



@ 24 rpm
@ 48 rpm

25 meters to CPA from first detection
60 meters to CPA from first detection

High ROT - Rate of Turn

Clockwise turn – ROT at which blank sectors are generated

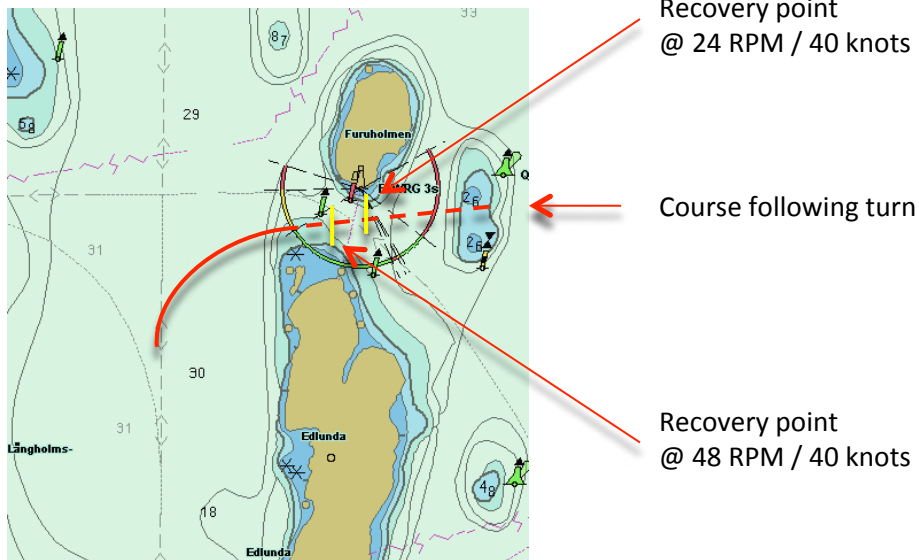
Sector resolution	1 deg lobe	2 deg lobe	3 deg lobe	4 deg lobe
4096	10 °/s	20 °/s	30 °/s	40 °/s
2048	5 °/s	10 °/s	15 °/s	20 °/s

Counter Clockwise turn – Update rate reduction

	ROT 10 °/s	ROT 20 °/s	ROT 30 °/s	ROT 40 °/s
RPM	-1,7	-3,3	-5	-6,7

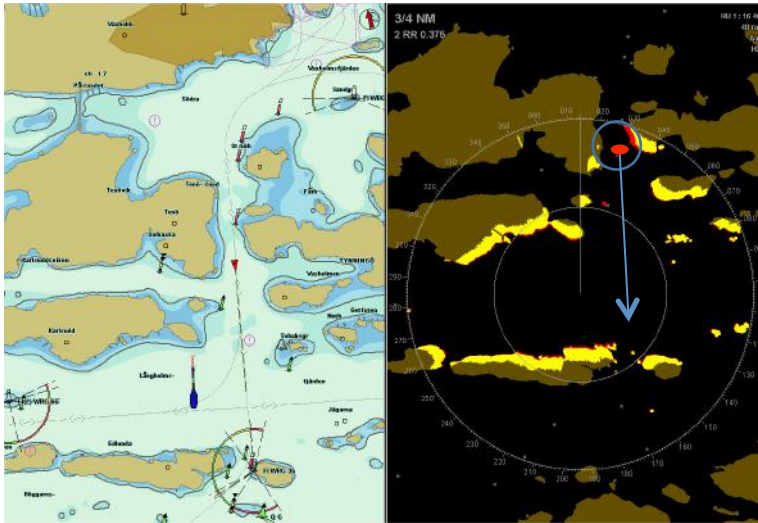
 High ROT distorts image and / or slows down radar image update

High ROT - and recovery



 **High ROT distorts radar images. High RPM yields shorter recovery time**

Target acquisition



HS-ARPA Target acquisition latency

@ 24 RPM ⇔ 12-24 s

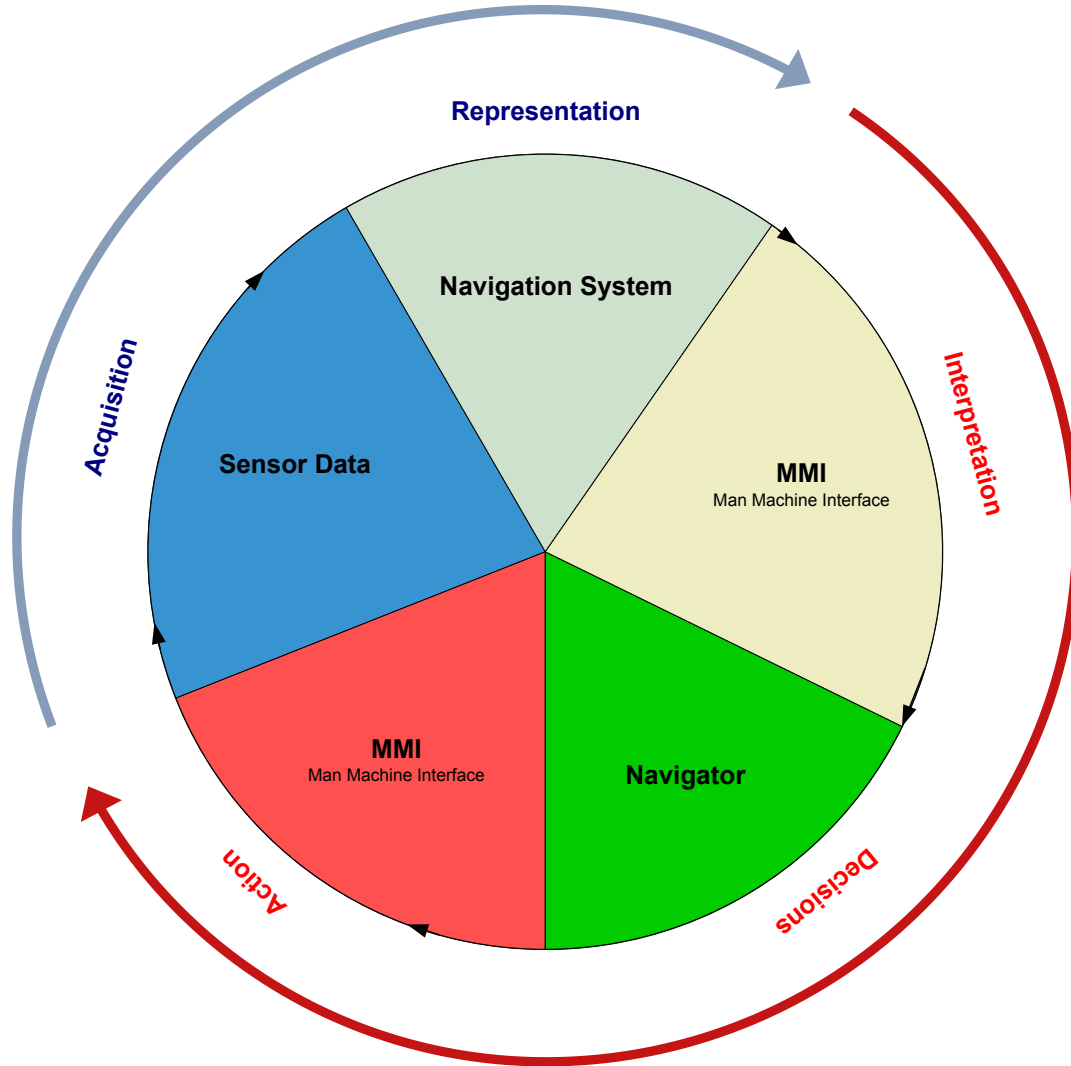
@ 48 RPM ⇔ 6 -12 s

Example, distance 1000 m

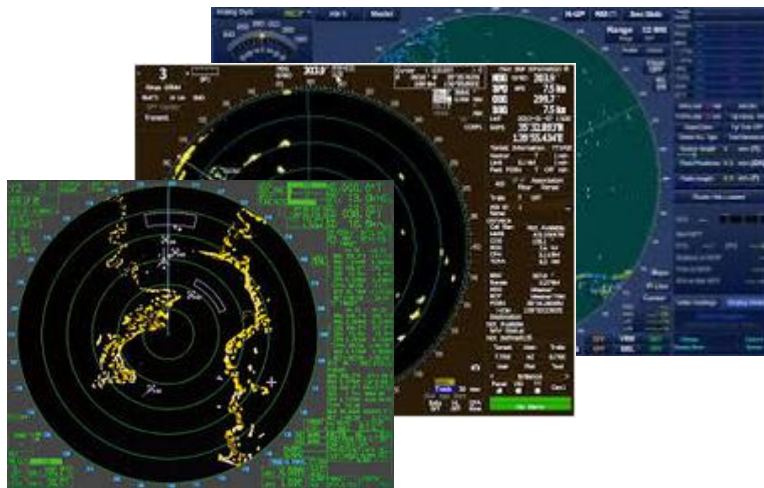
Own+Target speed	CPA
20	100 s
40	50 s
60	30 s
80	12 s



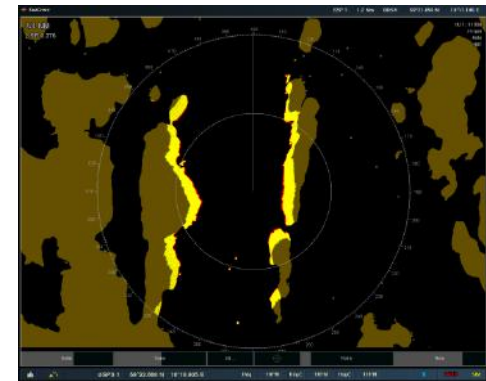
High RPM yields quicker target acquisition



Interpretation and Execution



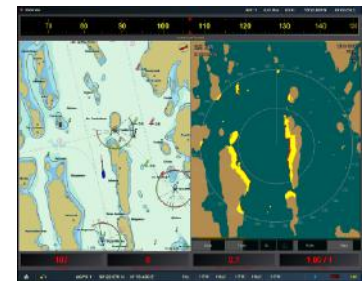
Typical open water radar display



High speed navigation, radar display



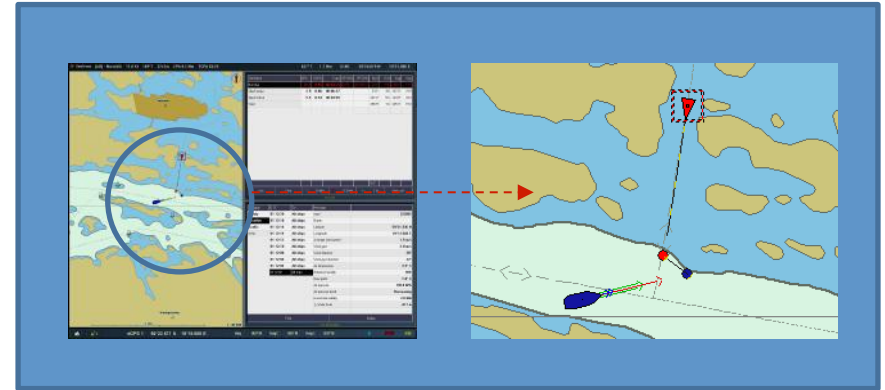
Typical open water display



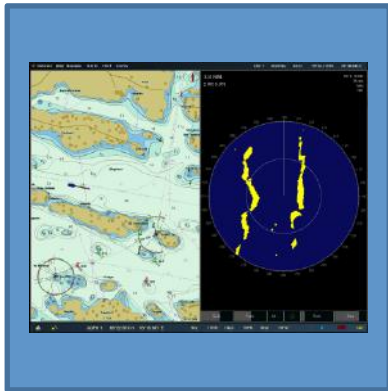
High speed navigation, display



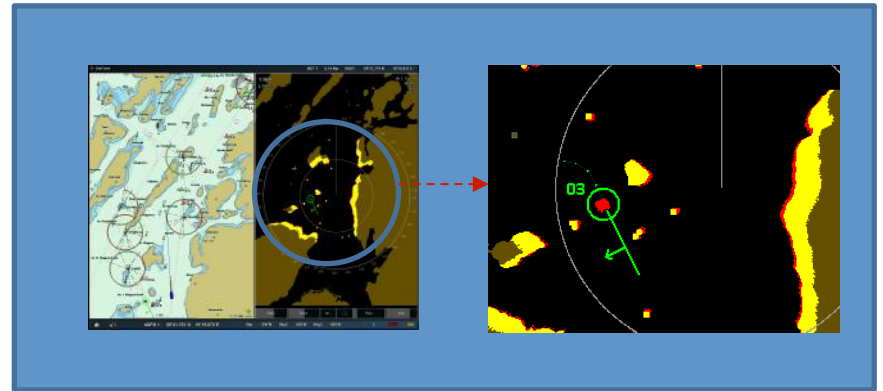
Typical AIS/ARPA cpa display



High speed navigation, AIS/ARPA cpa display



Typical radar display



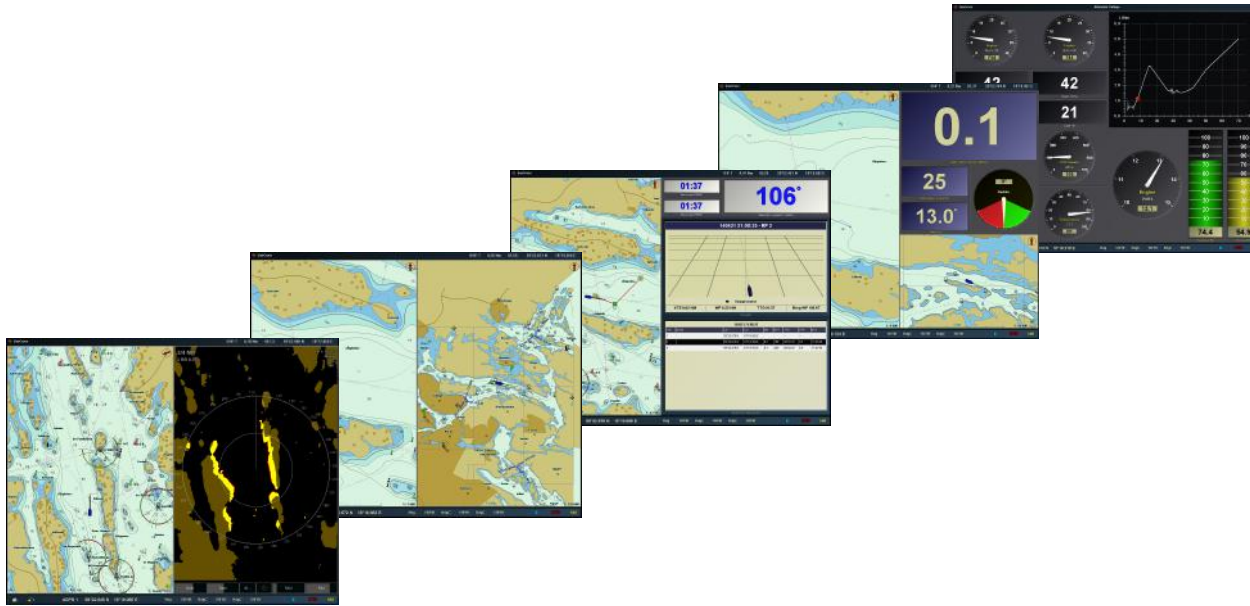
High speed navigation radar display



Typical open water system's user interfaces



High speed navigation, control devices



High speed navigation, “one click away” templates

Conclusions



Sensor performance

Sensor	Required	Preferred	Weight
Position – update rate	1 Hz	5 Hz	2
Position – accuracy	< 5 m	< 4 m	2
Heading sensor – update rate	10 Hz	10 Hz	1
Heading sensor – accuracy	< 0,5 degrees	< 0,5 degrees	2
Radar – update rate	45+ RPM < 1.5 NM	48 RPM < 1.5 NM	1
Radar – range	6+ NM	24 NM	1
Display size (at 0.29 mm pixel size)	15"	19"	1



System performance

System update rates \geq sensor update rates, i.e. 100 Hz



MMI – Man machine interface

- Relevant data output
- High readability
- Intuitive data representation
- Noncomplex user controls operable in all sea states
- Preplanned user selectable display layout

Thank you!