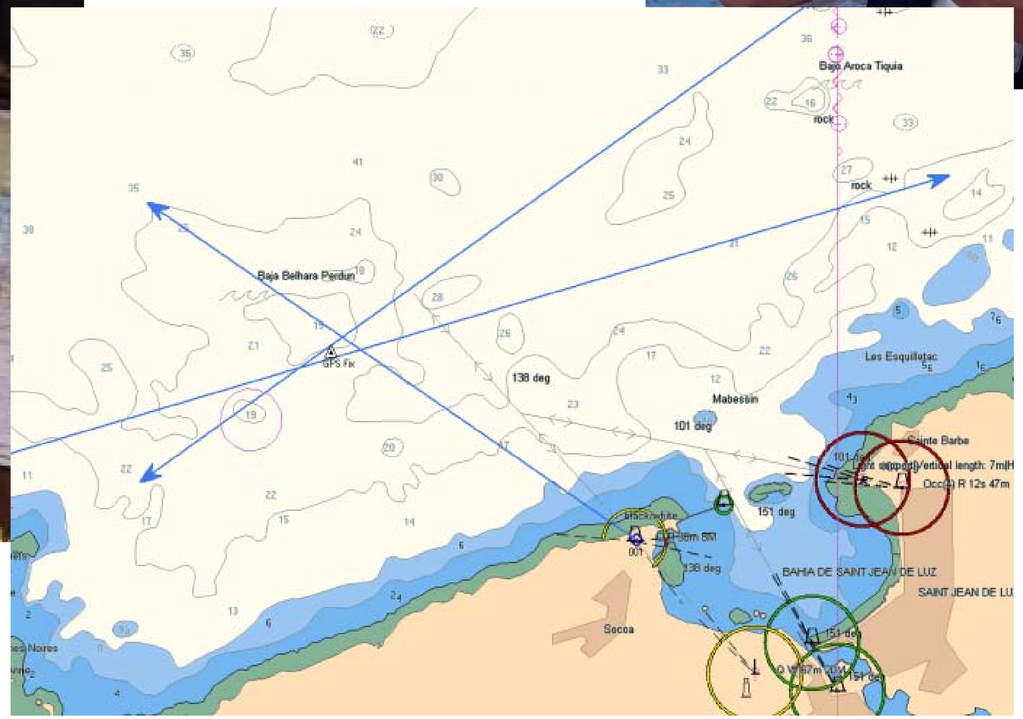
Navigation for Offshore Sailing



MITNA
January 2015

Matthew Wall
Scott Dynes
Steve Bussolari

"This new ship here, is fitted according to the reported increase of knowledge among mankind. Namely, she is cumbered, end to end, with bells and trumpets and clocks and wires which, it has been told to me, can call Voices out of the air or the waters to con the ship while her crew sleep. But sleep thou lightly...It has not yet been told to me that the Sea has ceased to be the Sea"

- Rudyard Kipling

Outline

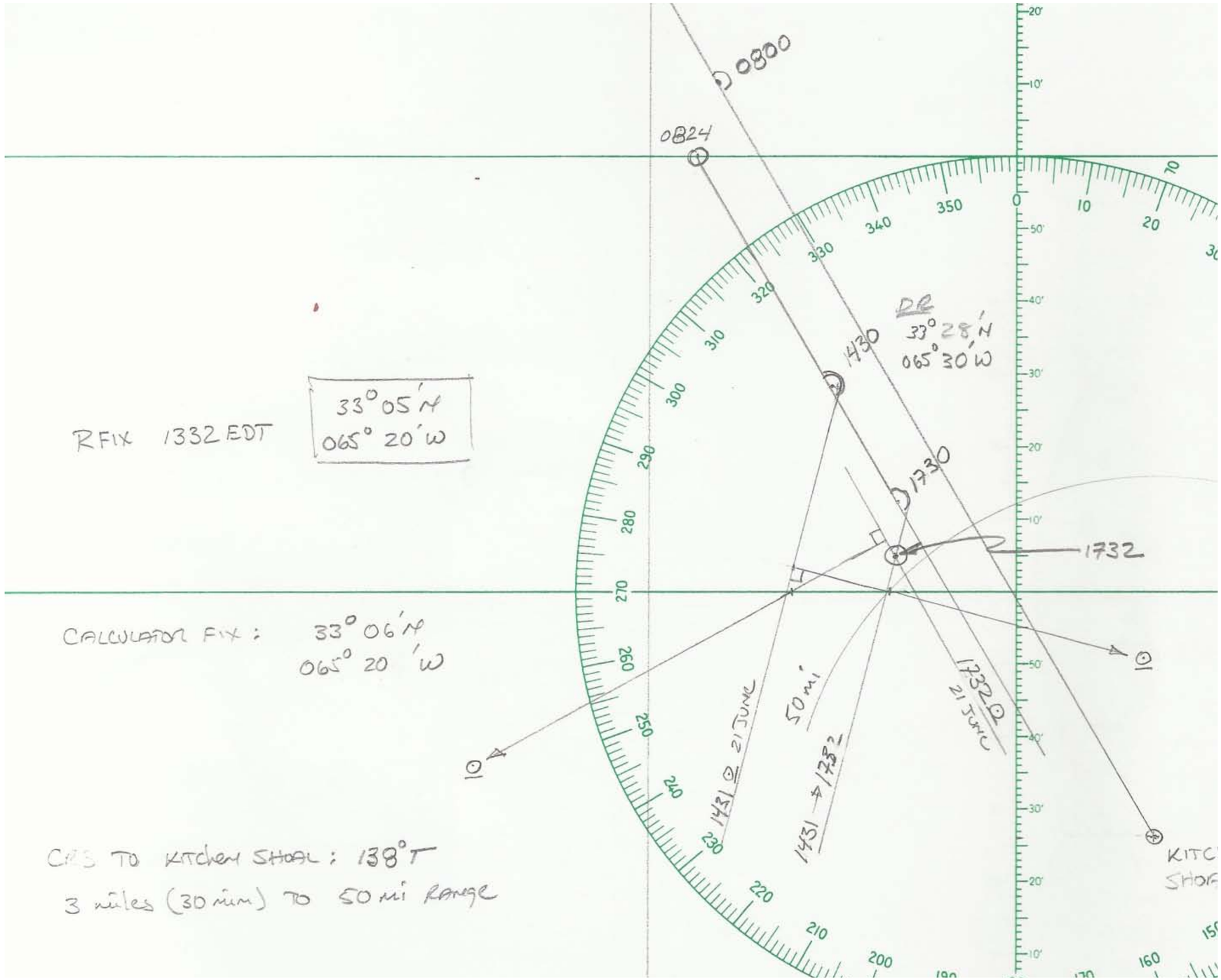
- Review
  - Nautical chart types and scales
  - Bouyage system (IALA Region B)
  - Light characteristics
  - Rules of the Road
  - Tidal currents
  - Basic navigational inputs

- Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore pilotage

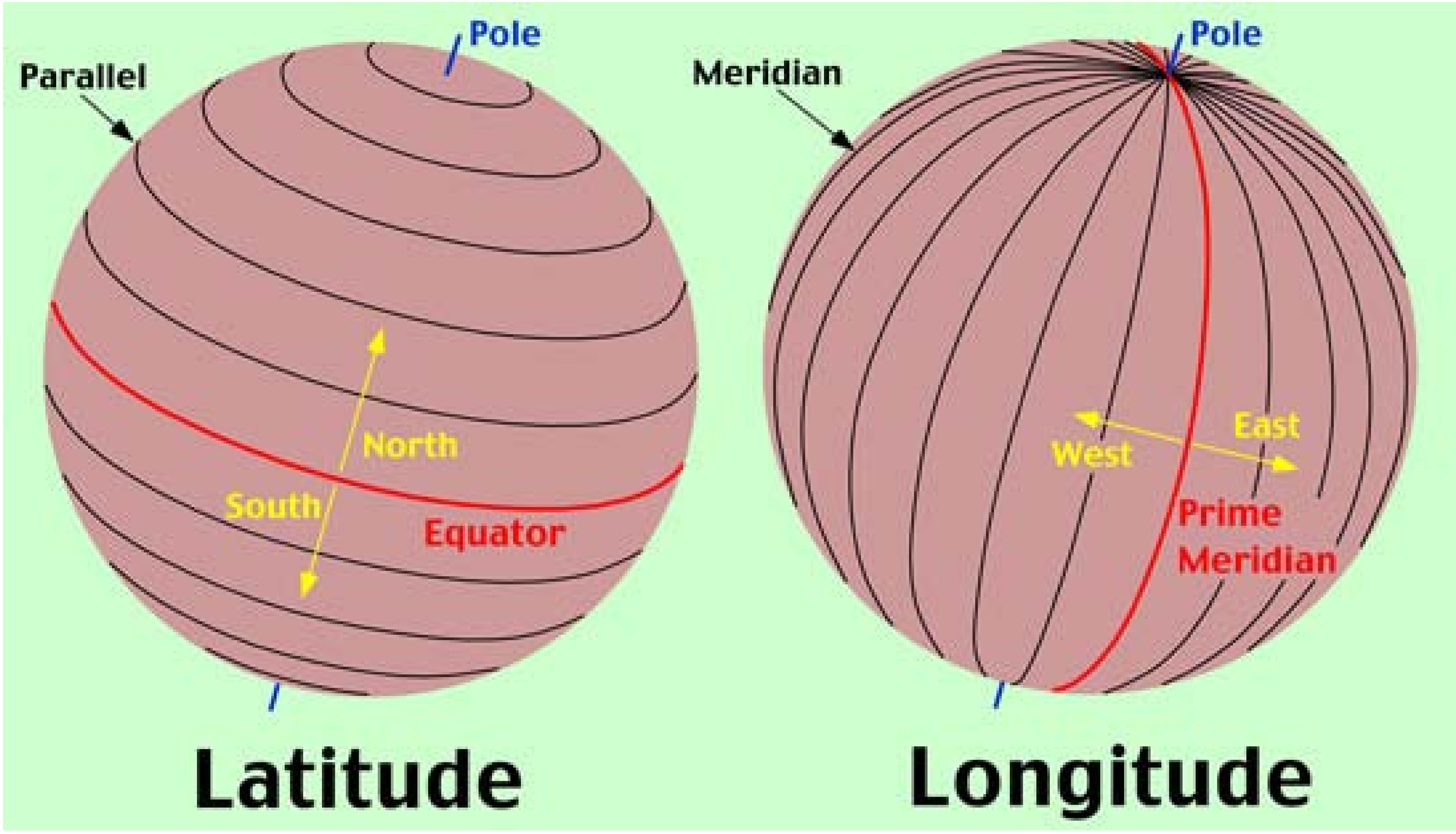
Tools

- Pencil
- Eraser
- Paper
- Parallels
- Divider
- Clock
- Calculator
- Handheld Compass
- Binoculars
- Sextant

Worksheets



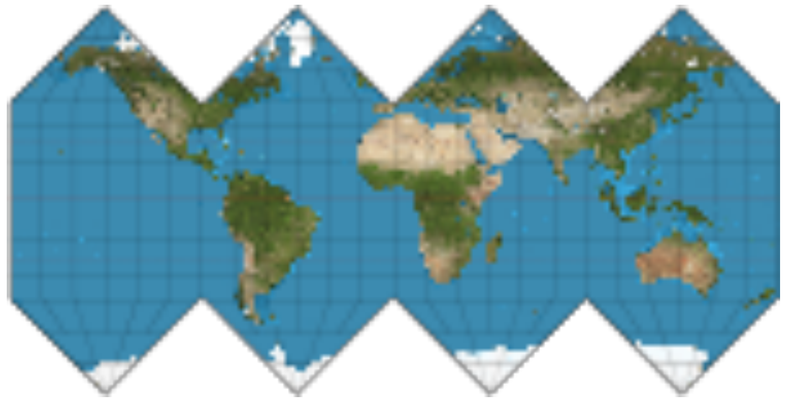
Geographical Coordinate System



Projections

61 different projections listed at wikpedia
http://en.wikipedia.org/wiki/List_of_map_projections

Equirectangular



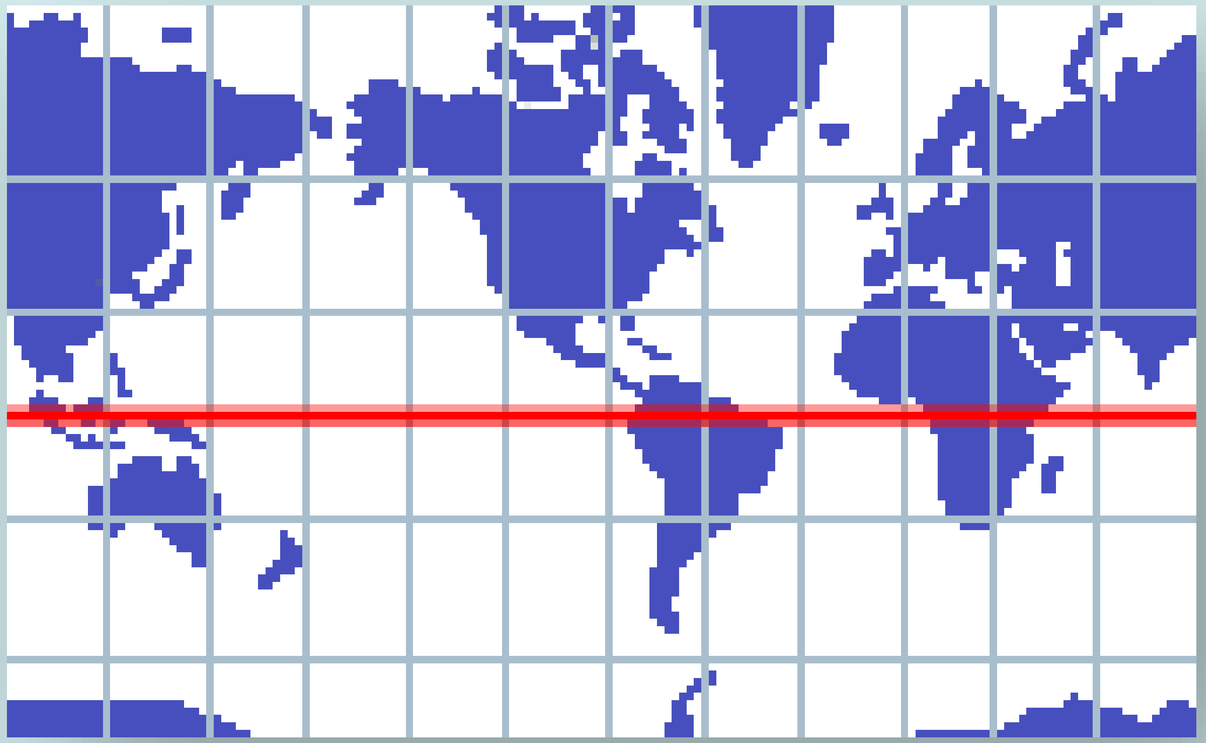
HEALPix

Cassini

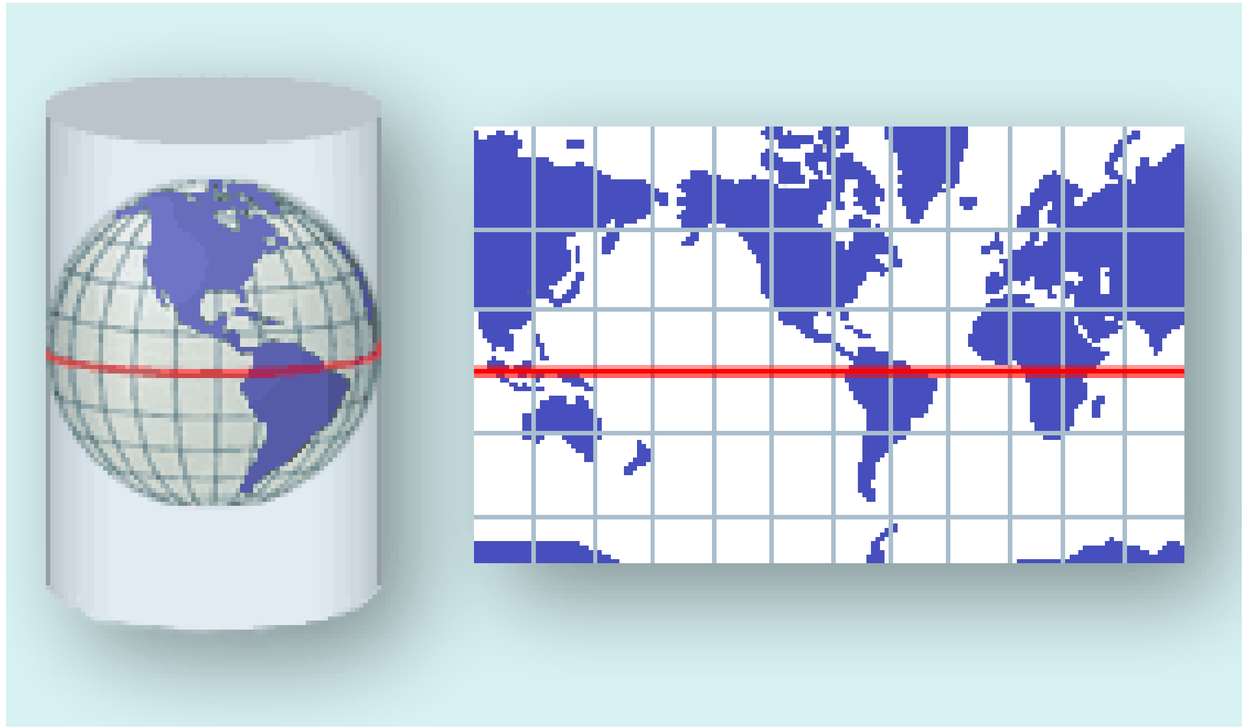
Robinson

Goode homolosine

Mercator Projection



Mercator Projection

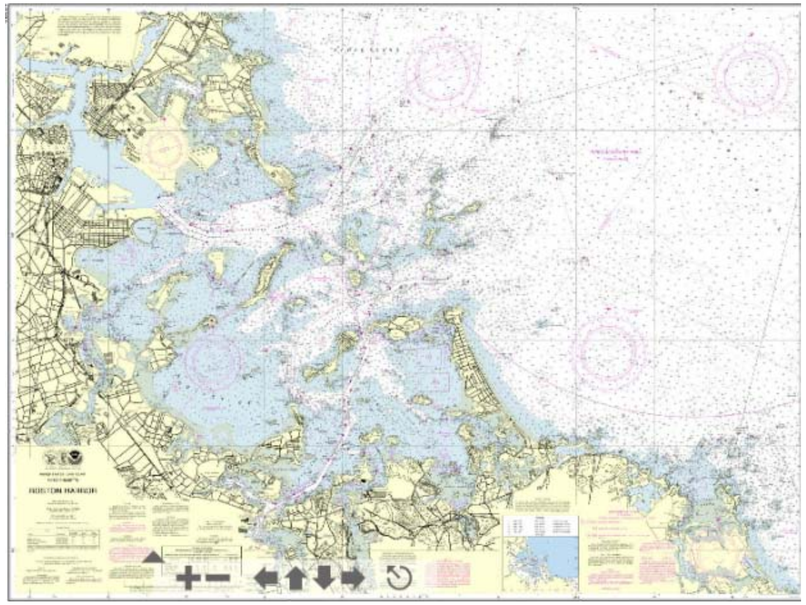


- Advantages
  - easy-to-use rectangular grid
  - straight lines cross meridians at constant angle (Rhumb Lines)

- Disadvantages
  - chart scale not constant with position
  - distance between lines oflatitude are exaggerated in polar regions

Nautical Chart Scales

- Boston Harbor
  - large scale (1/25,000)
  - covers small area



- Newport to Bermuda
  - small scale (1/1,058,400)
  - covers large area

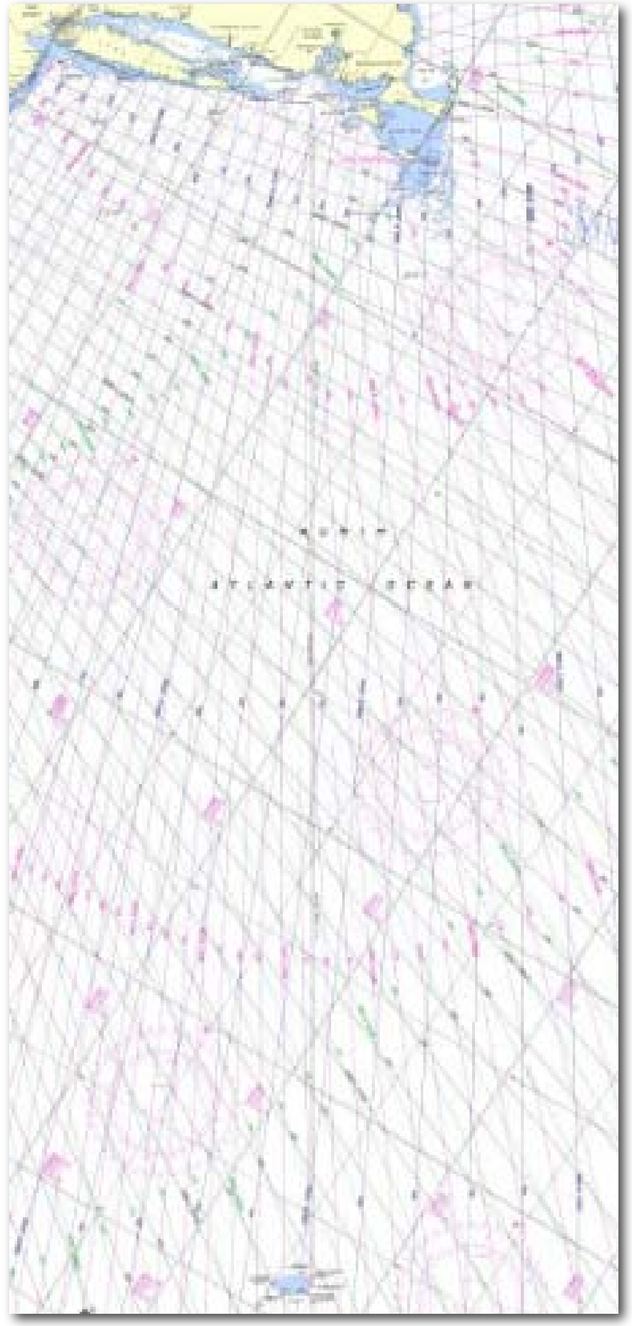
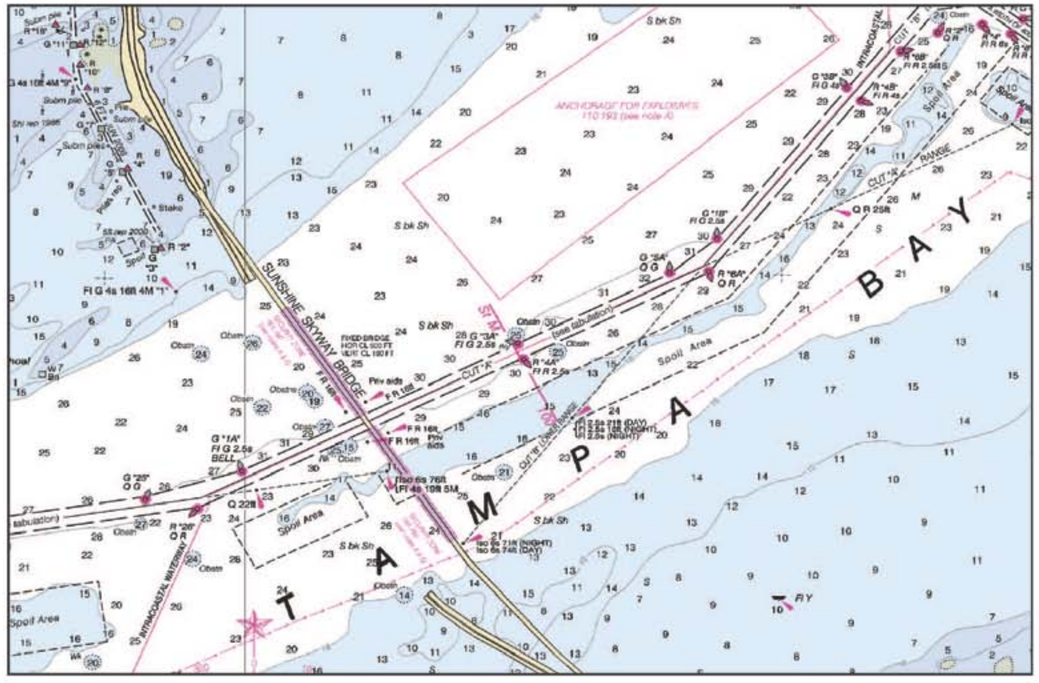


Chart Number 1

Chart No. 1

UNITED STATES OF AMERICA

Nautical Chart Symbols, Abbreviations and Terms

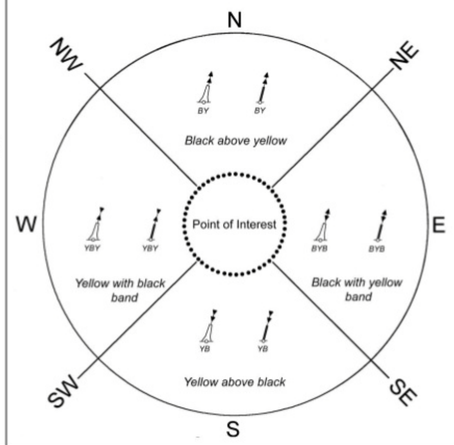


Eleventh Edition

November 2011

Chart 1: Q Bouys and Beacons

Q Buoys and Beacons

130.3	**Cardinal Marks**: indicating navigable water to the named side of the marks. In the illustration, all marks are the same in Regions A and B.	
	UNLIT MARKS	LIGHTED MARKS
		Topmark: *2 black cones* Light: *White* Time (seconds) 0 5 10 15 Period shown N *VQ or Q* E *VQ(3)5s or Q(3)10s* S *VQ(6)+LFl.10s or Q(6)+LFl.15s* W *VQ(9)10s or Q(9)15s* *The same abbreviations are used for lights on spar buoys and beacons. The periods 5s, 10s, and 15s may not always be charted.*
130.4	**Isolated Danger Marks** stationed over dangers with navigable water around them.	
	Body: *black with red horizontal band(s)* Topmark: *2 black spheres*	Light: *White* *Fl(2)*
130.5	**Safe Water Marks** such as mid-channel and landfall marks.	
	Body: *red and white vertical stripes* Topmark (if any): *red sphere*	Light: *White* ***Iso*** *or* ***Oc*** *or* ***LFl.10s*** *or* ***Mo(A)***
130.6	**Special Marks** not primarily to assist navigation but to indicate special features.	
	Body*(shape optional)*: *yellow* Topmark (if any): *yellow X*	Light: *yellow, rhythm optional* *Fl.Y*
	In special cases yellow can be in conjunction with another color.	

Supplementary National Symbols

a		Bell buoy	BELL BELL	
b		Gong buoy	GONG GONG	
c		Whistle buoy	WHIS WHIS	
d		Fairway buoy (red and white vertical stripe)	RW	

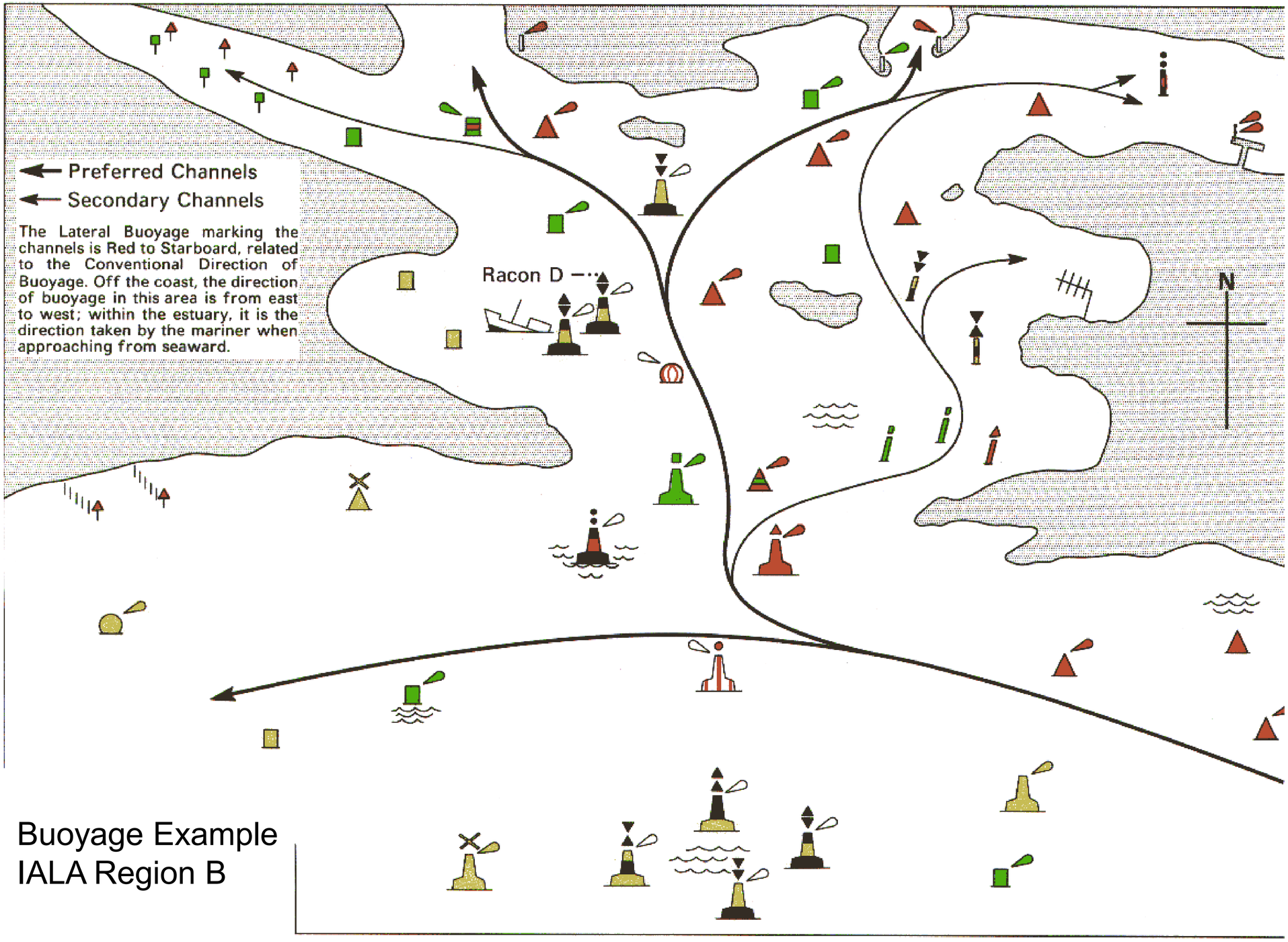
Bouys: Identification

- 8 ways to identify a lateral mark
  - color (green, red)
  - shape (cylindrical, conical)
  - dayboard (green square, red triangle)
  - topmark (cylinder, cone)
  - light color (green, red)
  - reflector color (green, red)
  - ID number (odd, even)
  - sound (gong - clang, bell - ding)

Bouys: Light Rythms

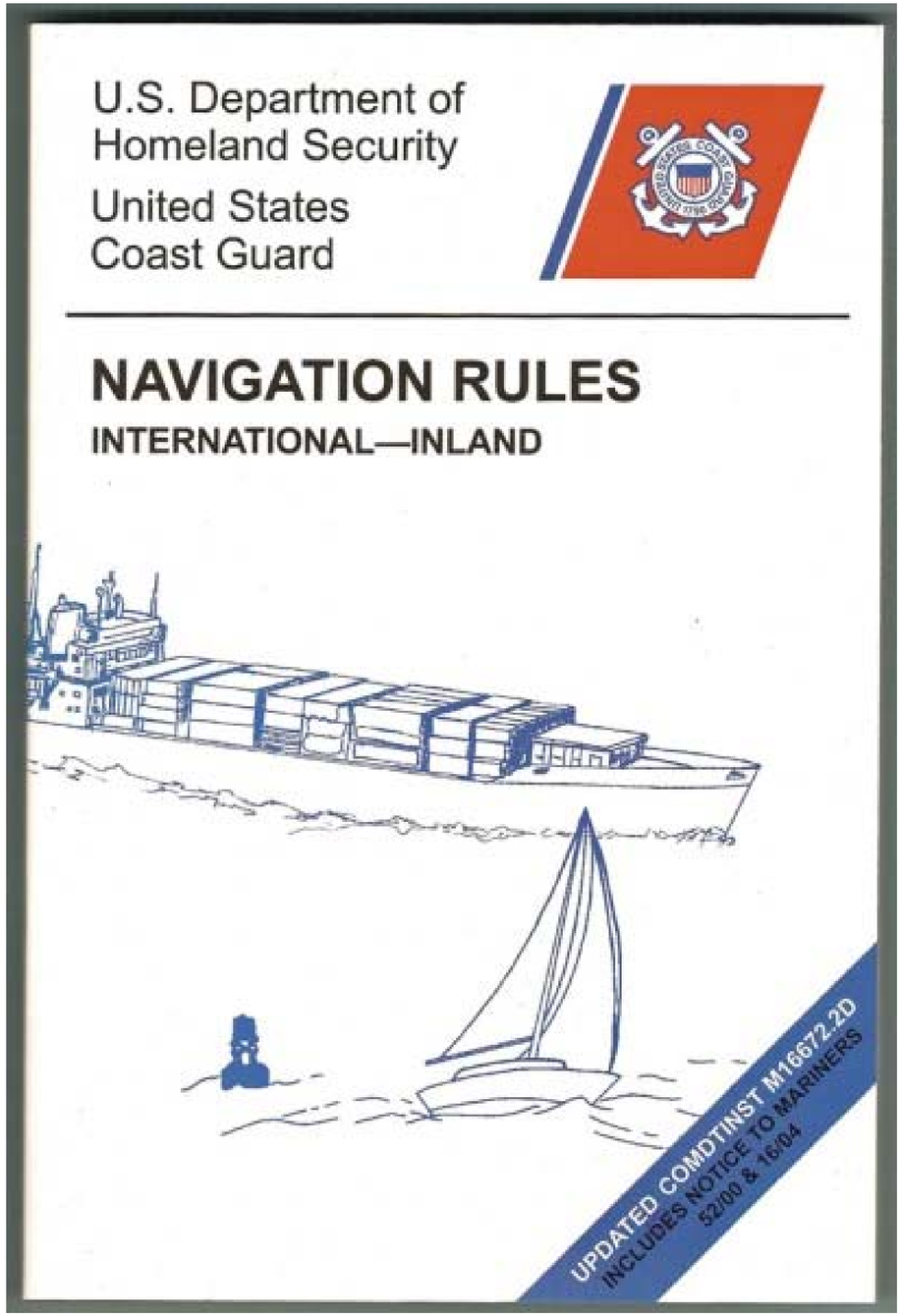
- Fixed
- Occulting
- Isophase
- Flashing
- Quick
- Group or Composite Group
- Morse Code
- Fixed and Flashing
- Alternating

Bouyage Example

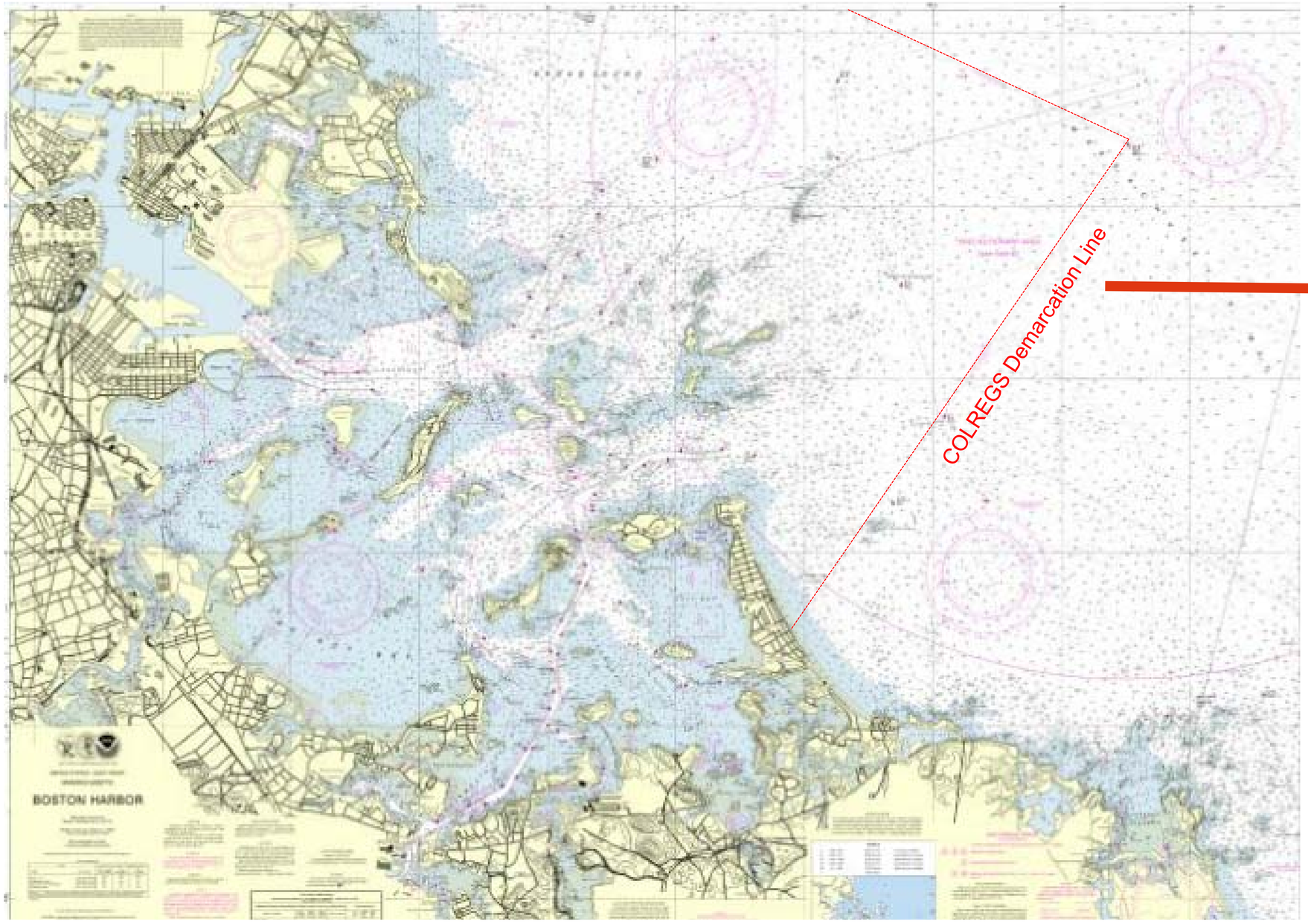


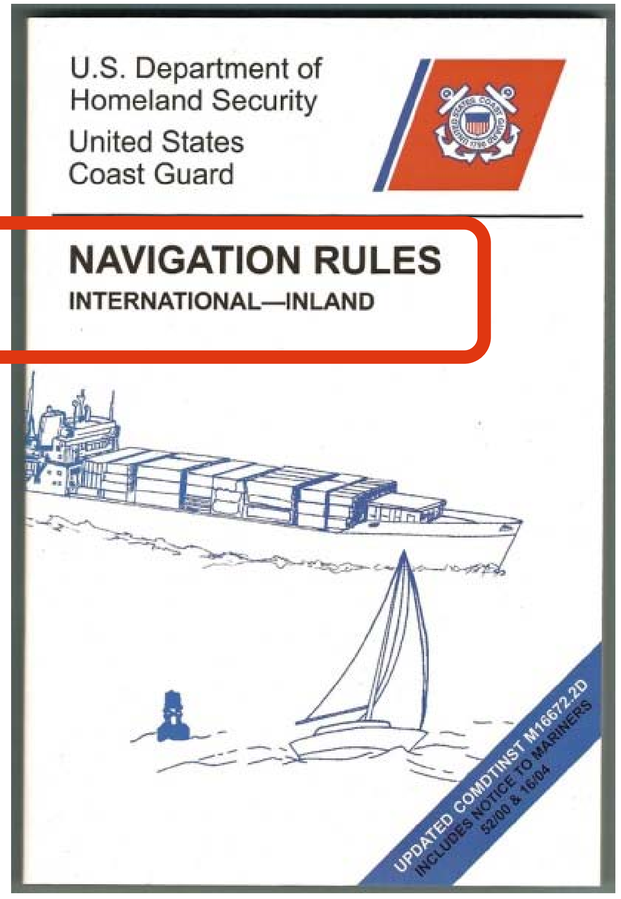
Buoyage Example
IALA Region B

Navigation Rules



Navigation Rules





Tidal Currents

- **Set**: *direction* in which an object will travel at a given time if carried by the tidal current (displayed opposite to the way wind is represented)
- **Drift**: *distance* an object will trael in a given time if carried by the tidal current
- **Current** (or Flow): *speed* at which an object will travel at a given time if carried by the tidal current
- **Ebb**: tidal current in the *falling* phase of the tide
- **Flood**: tidal current in the *rising* phase of the tide

Current Table

BOSTON HARBOR (Deer Island Light)

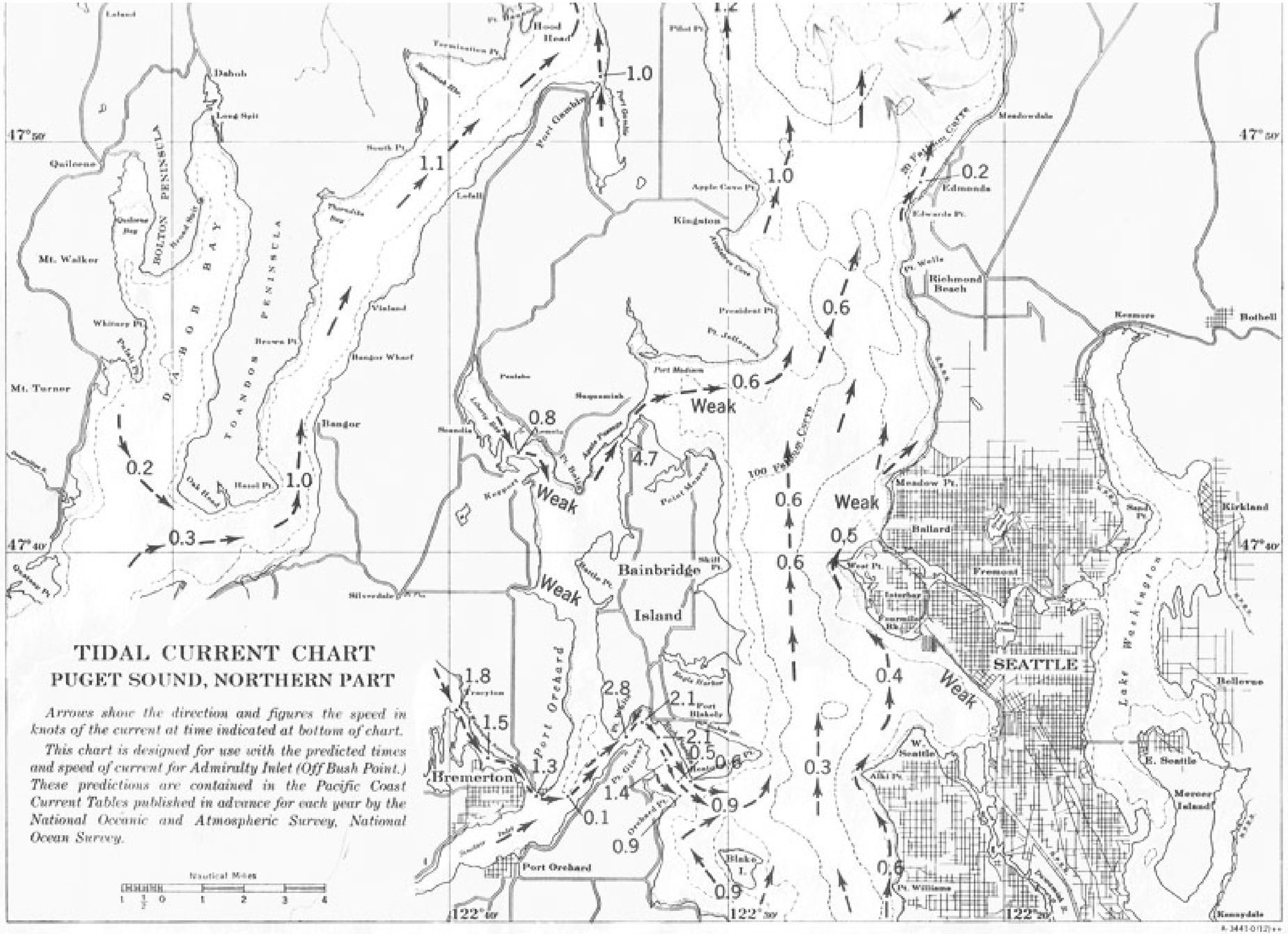
Predicted Tidal Current — April, 2008

Flood Direction, 254 True. — Ebb (-)Direction, 111 True.

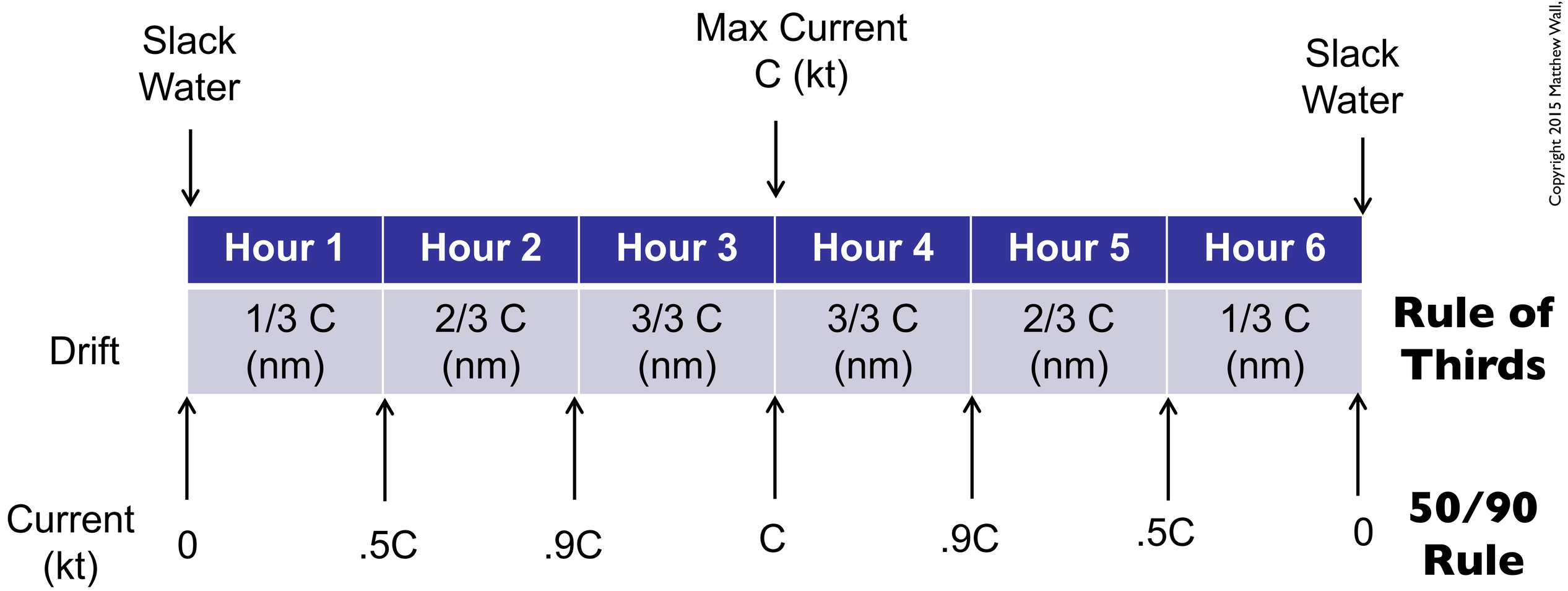
NOAA, National Ocean Service

	Slack Water	Maximum Current		Slack Water	Maximum Current		Slack Water	Maximum Current		Slack Water	Maximum Current		Slack Water	Maximum Current	
Day	Time h.m.	Time h.m.	Veloc knots	Time h.m.	Time h.m.	Veloc knots	Time h.m.	Time h.m.	Veloc knots	Time h.m.	Time h.m.	Veloc knots	Time h.m.	Time h.m.	Veloc knots
1	0151	0500	+1.0	0733	1206	-1.1	1422	1738	+1.1	2010					
2		0032	-1.1	0245	0556	+1.1	0828	1249	-1.2	1511	1827	+1.2	2102		
3		0115	-1.2	0336	0646	+1.2	0920	1328	-1.3	1559	1911	+1.4	2151		
4		0152	-1.3	0424	0730	+1.3	1010	1400	-1.3	1644	1950	+1.5	2237		
5		0223	-1.4	0511	0810	+1.4	1057	1429	-1.4	1729	2026	+1.6	2322		
6		0254	-1.5	0558	0847	+1.5	1143	1503	-1.4	1813	2059	+1.6			

Current Chart



Tidal Currents: Rules



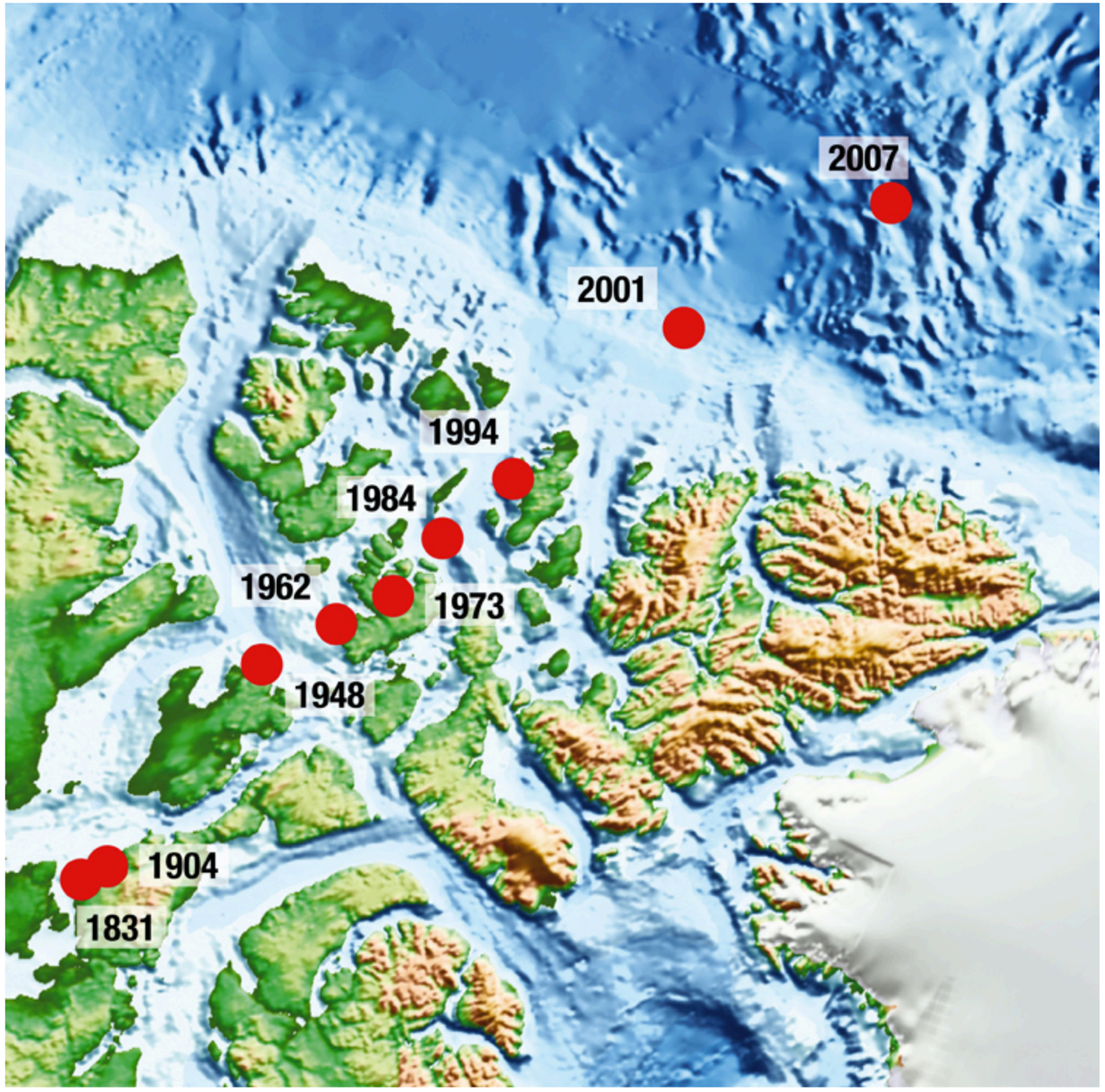
Basic Navigational Inputs

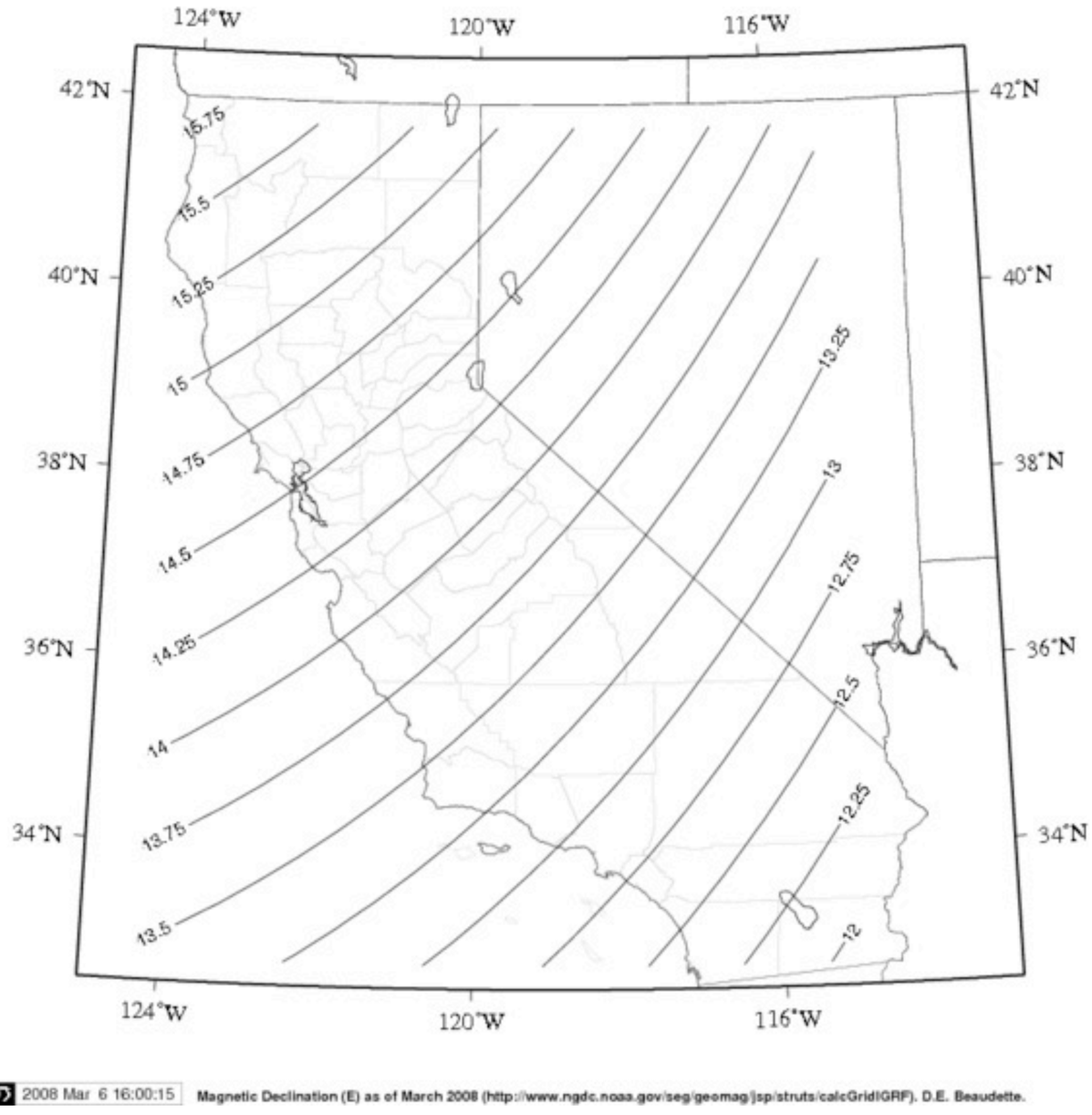
- Your eyes
  - Look around
  - Orient the chart
  - Relate your visible surroundings to the chart
- Log/Clock
  - Speed
  - Distance run
- Depth Sounder
  - Local depth
- Compass
  - True Heading
  - Variation
  - Magnetic Heading
  - Deviation
  - Compass Heading

Declinations

Location	Declination	Change (Minutes per year)	
Nassau	8˚3' W	0˚ 5' West per year	
Punta Gorda Belize	0˚19' E	0˚ 8' W	
Boston, MA, USA	14˚49' W	0˚ 4' E	Sommerville
San Diego, CA, USA	11˚ 46' E	0˚ 5' W	
Athens, Greece	4˚ 10' E	0˚ 6' E	
Wellington, NZ	22˚ 25' E	0˚ 4' E	
Graves Lighthouse	14˚ 54' W	0˚ 4' E	WMM2015
Graves Lighthouse	14˚ 55' W	0˚ 4' E	IGRF12

The Poles are Moving





Graves Light

Date		**Lat**	**Long**	**Magnetic Declination**	**Annual Change** minutes/year
1/21/2015	Today	42.3649 North	70.8691 West	14˚ 55.14' West	3.6 East
1/21/2005	10 Years Ago	42.3649 North	70.8691 West	15˚ 33.36' West	3.8 East
1/21/1990	25 Years Ago	42.3649 North	70.8691 West	15˚ 51.84' West	-1.5 West
1/21/1965	50 Years Ago	42.3649 North	70.8691 West	15˚ 31.44' West	.4 East
1/21/1915	100 Years Ago	42.3649 North	70.8691 West	14˚14.64' West	-5.2 West

Changes in magnetic declination for Graves Light, Boston Harbor

Outline

- Review
  - Nautical chart types and scales
  - Bouyage system (IALA Region B)
  - Light characteristics
  - Rules of the Road
  - Tidal currents
  - Basic navigational inputs

- Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore pilotage

Planning a Course to Steer

- Course to Steer is what you tell the helm to steer
  - by reference to a clear, distant, motionless visual mark (best)
  - by reference to the compass at the helm (not as good)
  - by reference to the wind (e.g., close hauled, broad reach)

- Use the chart plotter or parallel rulers on the chart to determine the direction to your destination
  - this will be a True Course
  - correct for leeway and current to get Course to Steer (in degrees True)
  - correct for variation and deviation to get Course to Steer (in degrees Per Steering Compass, or "PSC")

- Whatever system you use, be clear and consistent
  - you will be reading the chart when you are tired and seasick
  - others will read the chart under similar conditions

Conventions

0130

054

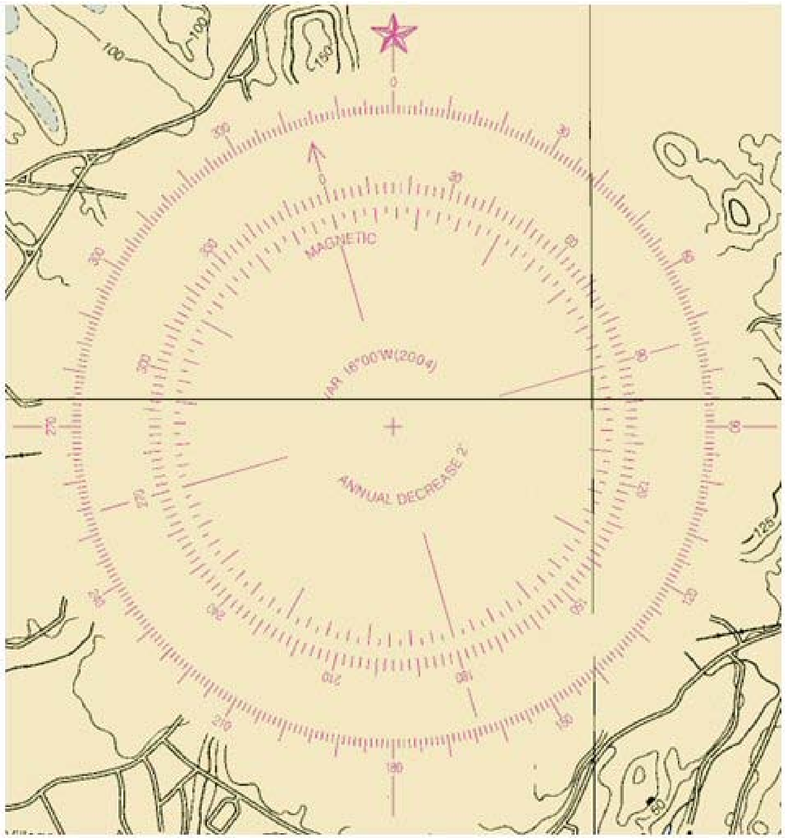
06

Conventions

0130	1:30 AM
054	54°
06	6 knots

Conventions

0130	1:30 AM	054M	54° Magnetic
054	54°	054T	54° True
06	6 knots	054CTS	Course To Steer



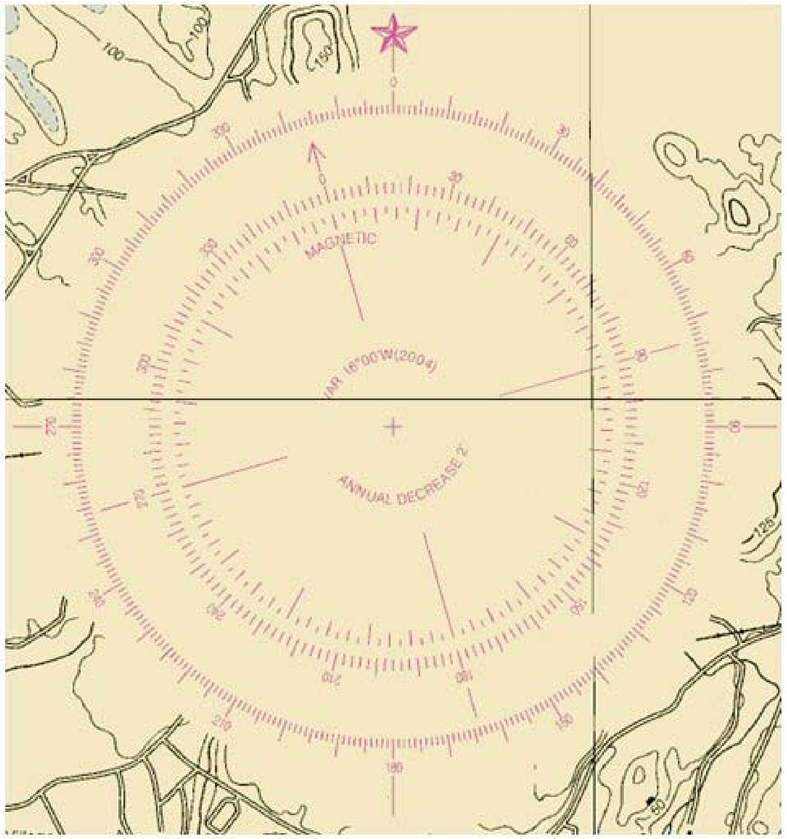
Plotting a Course

Arrowhead indicates a course
Prefix C indicates Course
Suffix T or M indicates True or Magnetic

C 061°T or C 077°M

If there is no leeway or current, you can correct this for Variation and Deviation and hand up to the helm as Course to Steer. Note the compass course in the ship's log.

Correcting for Leeway (no current)



Wind

(Course to Steer) 052°T

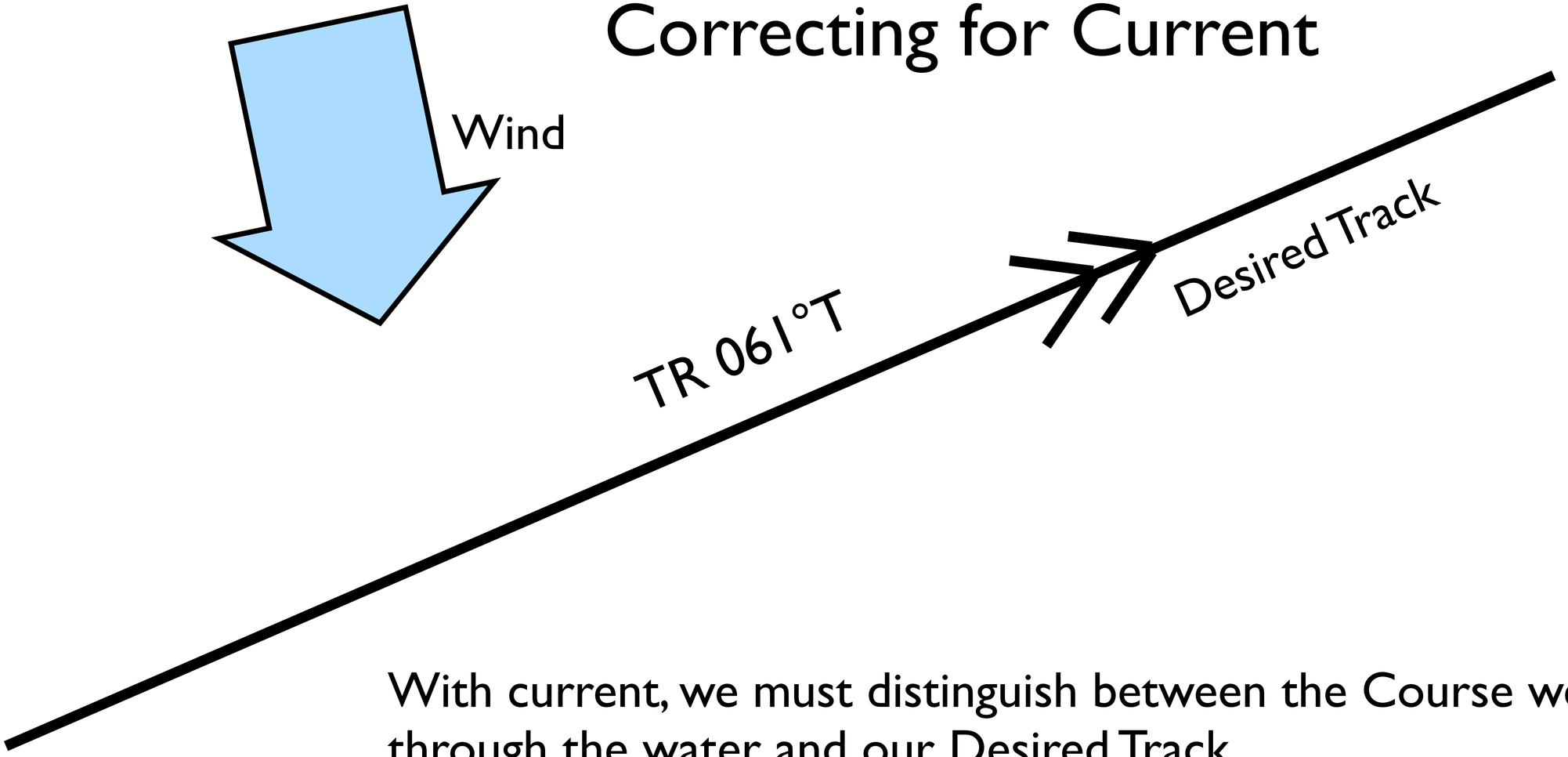
C 061°T

Remember: This is the course you are trying to make good through the water

Estimate your leeway angle (in this case 9°)
If there is no current, correct for Variation and instruct the helm to steer 068° on the binnacle compass (corrected for Deviation if necessary)

Note the compass course steered in the ship's log (068° PSC)

Correcting for Current

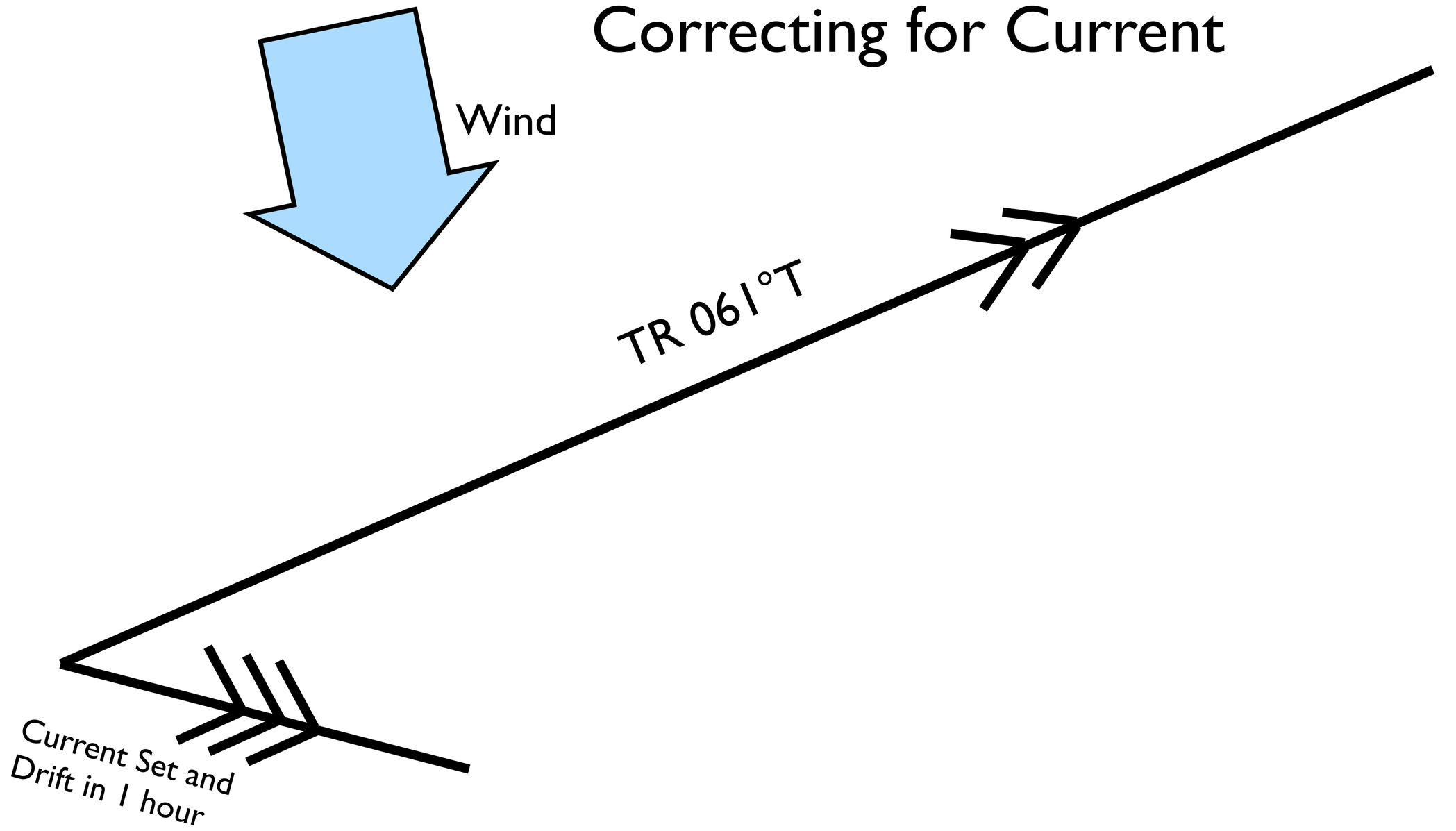


With current, we must distinguish between the Course we make good through the water and our Desired Track

The Track is often called the "Course Made Good Over the Bottom"

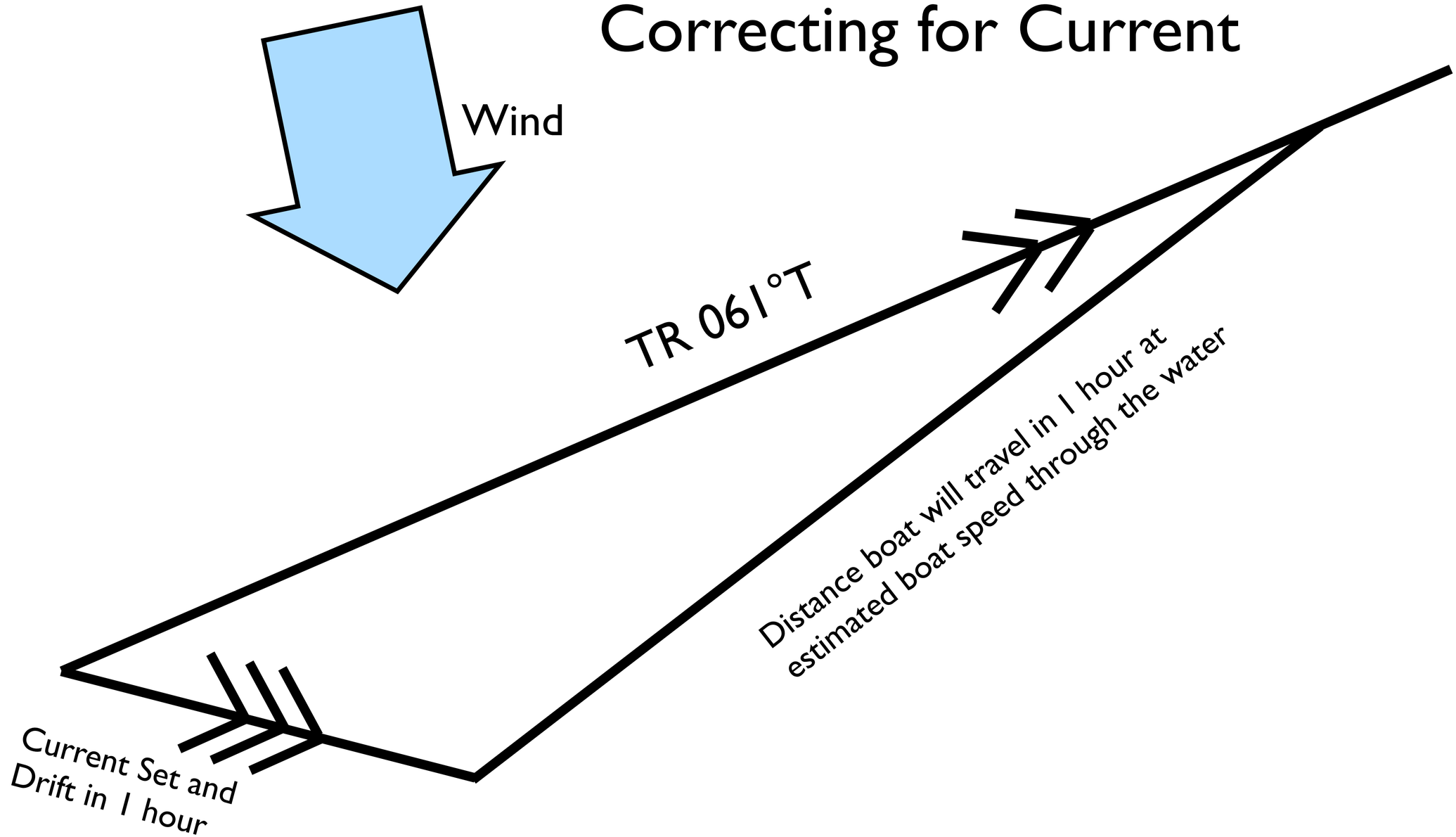
Since the Track will be different than our Course made good through the water, we label it differently

Correcting for Current



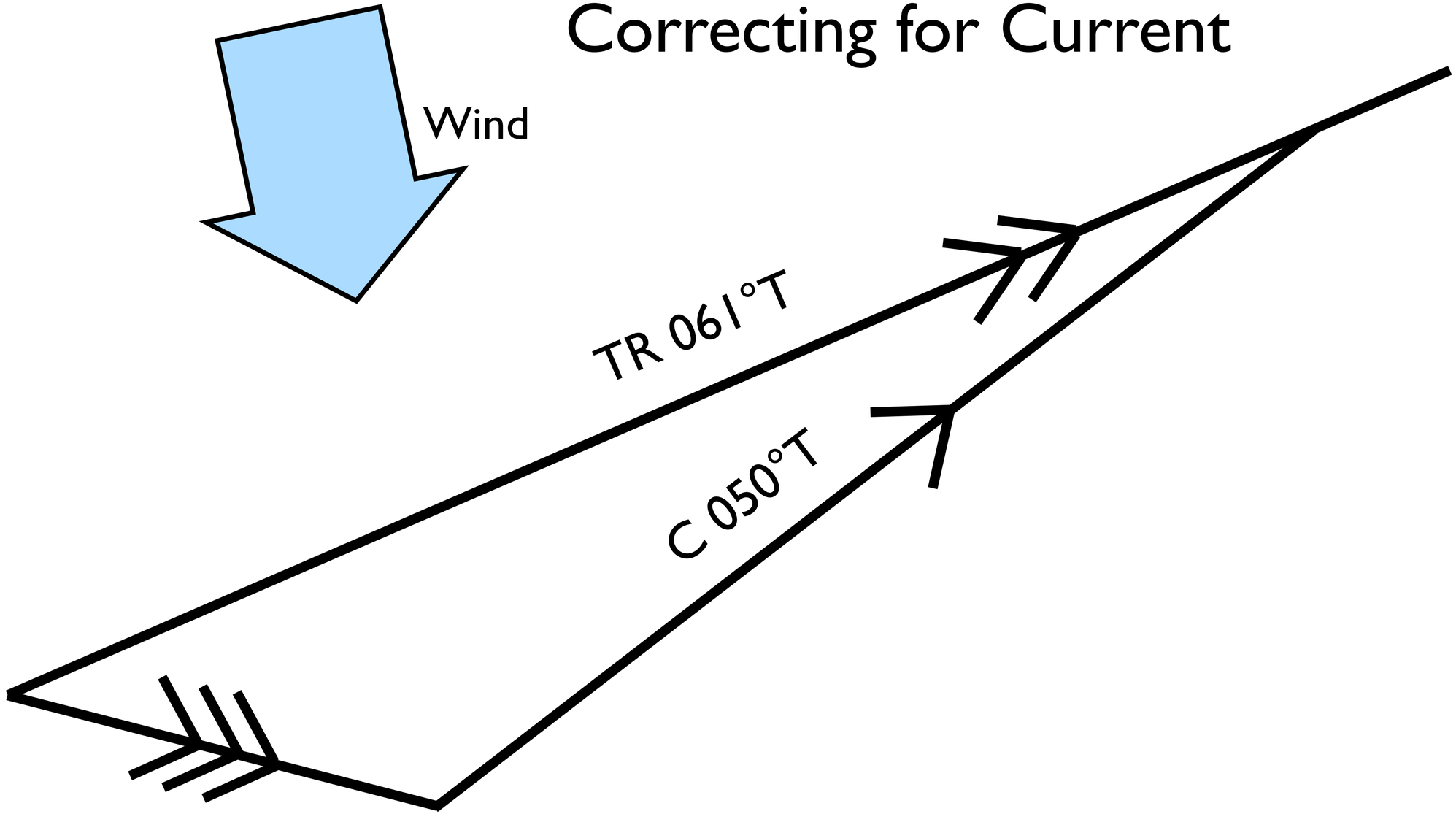
Draw a vector with the estimated 1 hour current set (direction) and drift (distance)
Label it as a current vector

Correcting for Current



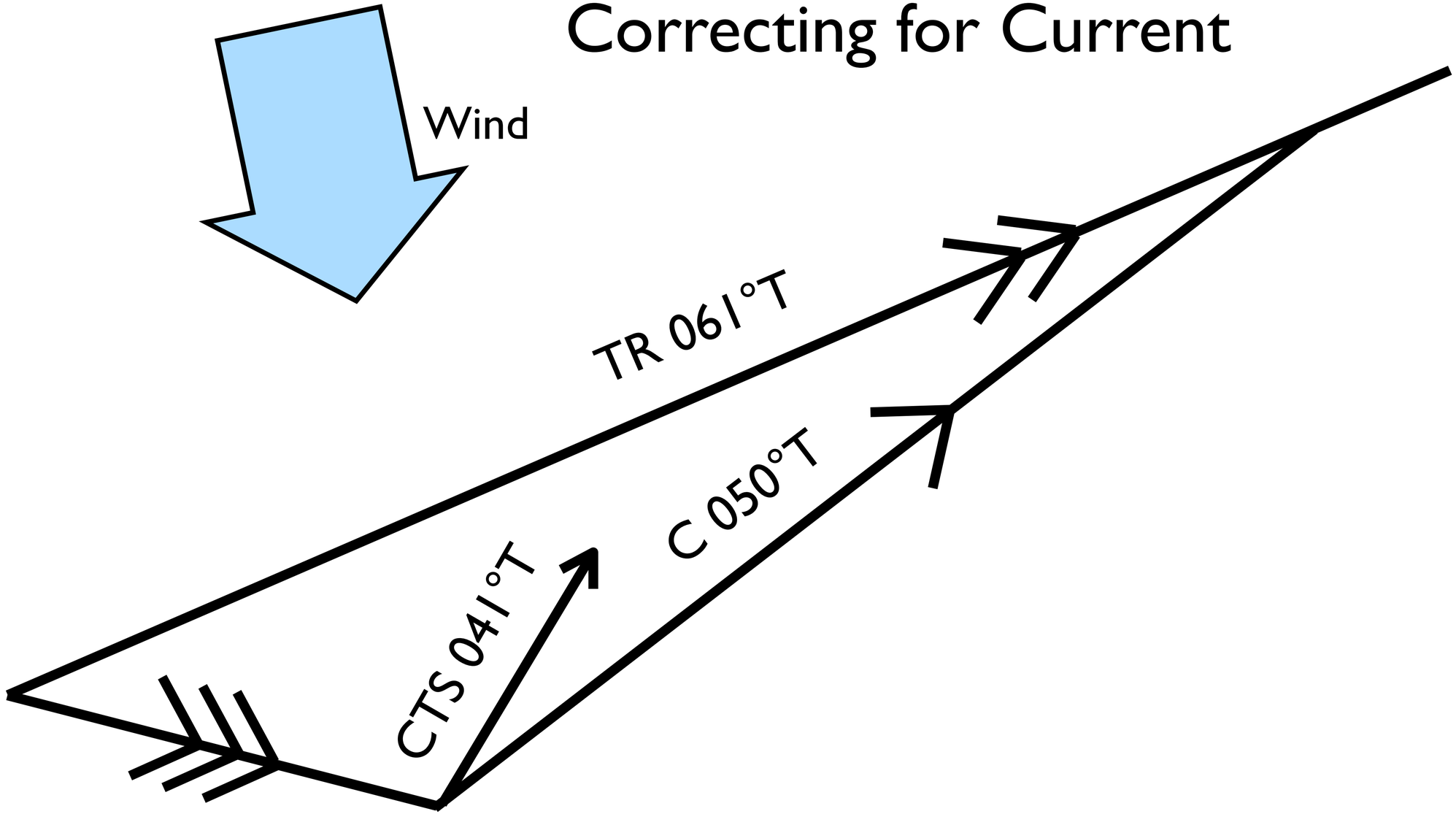
Connect the current vector to the desired track using estimated distance the boat will travel through the water in the same interval (1 hour)

Correcting for Current



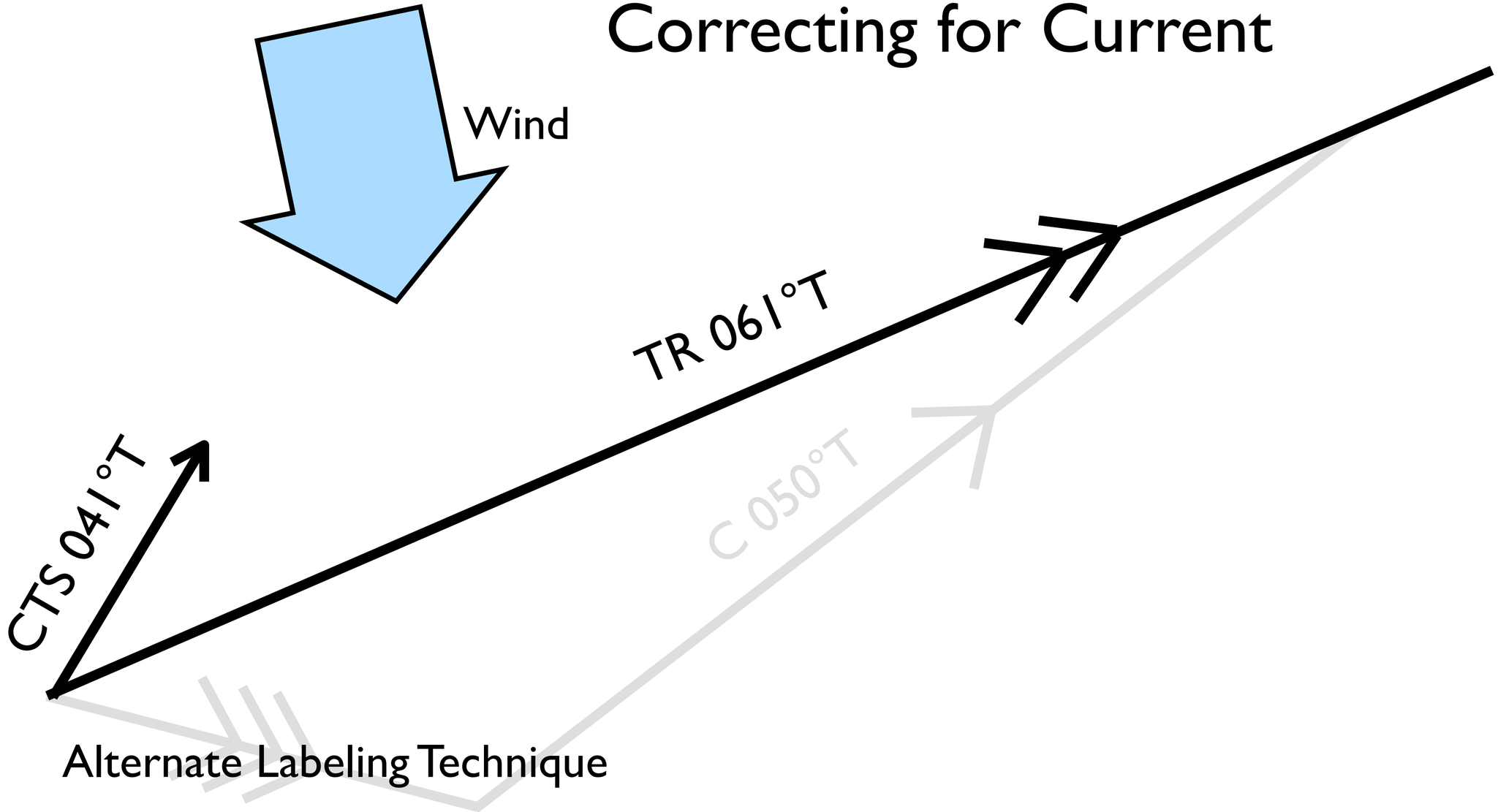
Label the desired course made good through the water

Correcting for Current



Correct for leeway and label as course to steer (if desired)
Correct for variation and deviation and hand up to the helm
Note compass course steered (057° PSC) in ship's log

Correcting for Current



Alternate Labeling Technique

Construct current correction triangle on a separate plotting sheet or clear area on chart

Plot Course to Steer directly on Track

Outline

- Review
  - Nautical chart types and scales
  - Bouyage system (IALA Region B)
  - Light characteristics
  - Rules of the Road
  - Tidal currents
  - Basic navigational inputs

- Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore pilotage

Ship's Log

Time	Log	Course	Weather	Remarks
1900	33.5	057 PSC	NNW10, 1005mb, Fair	GPS Fix, GPS OFF

Ship's Log

Time	Log	Course	Weather	Remarks
1900	33.5	~~057 PSC~~ 062 PSC	~~NNW10~~, 1005mb, Fair N10	GPS Fix, GPS OFF, Close hauled on Port Tack
2000	39.5	062 PSC	N10, 1005mb, Fair	Close hauled, Port

Ship's Log

Time	Log	Course	Weather	Remarks
1900	33.5	~~057 PSC~~ 062 PSC	~~NNW10~~, 1005mb, Fair N10	GPS Fix, GPS OFF, Close hauled on Port Tack
2000	39.5	062 PSC	N10, 1005mb, Fair	Close hauled, Port
2100	45.5	322 PSC	N10, 1005mb, Fair	Tacked, Close hauled, Stbd

Ship's Log

Time	Log	Course	Weather	Remarks
1900	33.5	~~057 PSC~~ 062 PSC	~~NNW10~~, 1005mb, Fair N10	GPS Fix, GPS OFF, Close hauled on Port Tack
2000	39.5	062 PSC	N10, 1005mb, Fair	Close hauled, Port
2100	45.5	322 PSC	N10, 1005mb, Fair	Tacked, Close hauled, Stbd

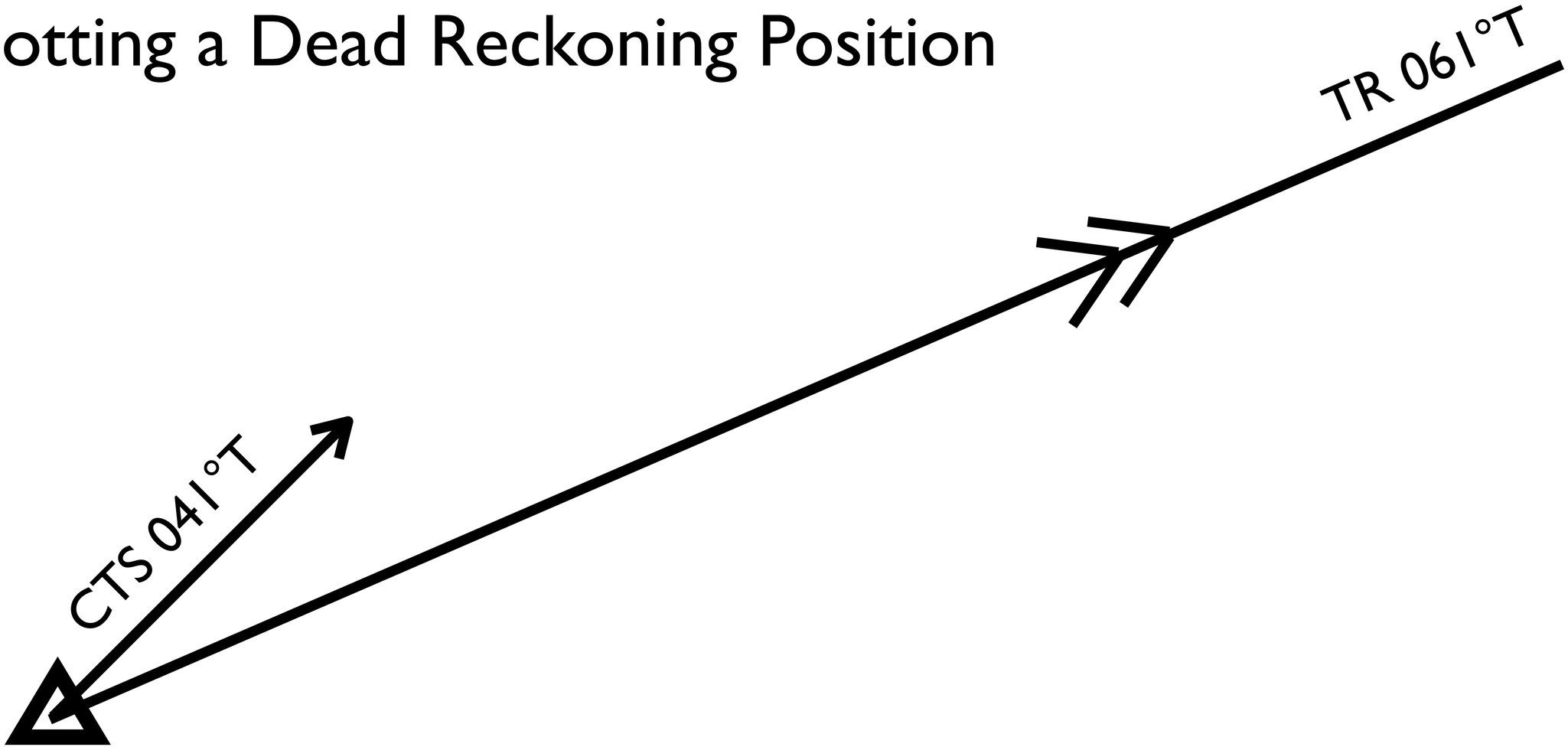
Where are we?
What do we do next?

Estimating Your Position

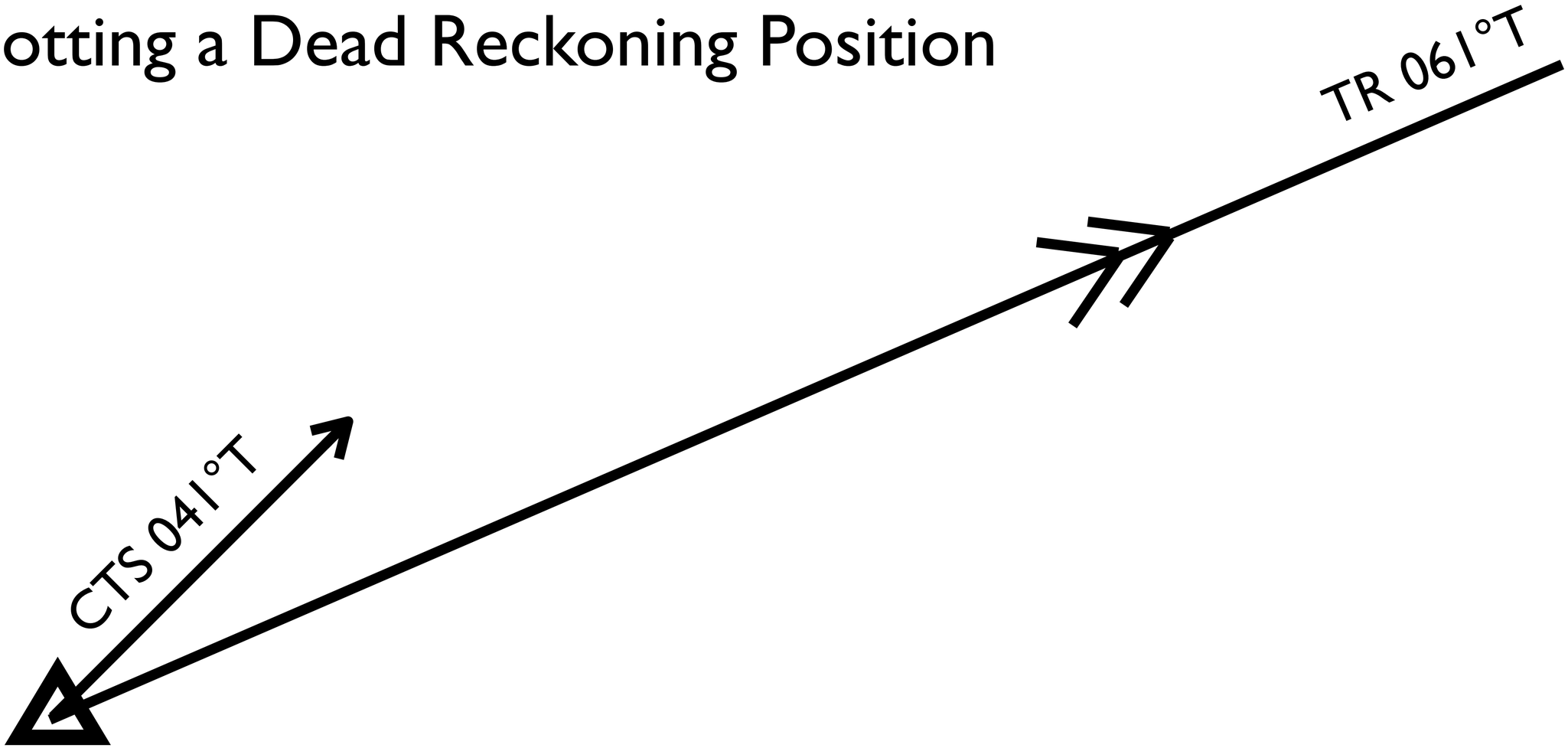
- Plot a Dead Reckoning Position
  - Course steered and distance logged
  - Use ship's log as the source of information

- Plot an Estimated Position
  - Position adjusted for leeway and current

Plotting a Dead Reckoning Position



Plotting a Dead Reckoning Position

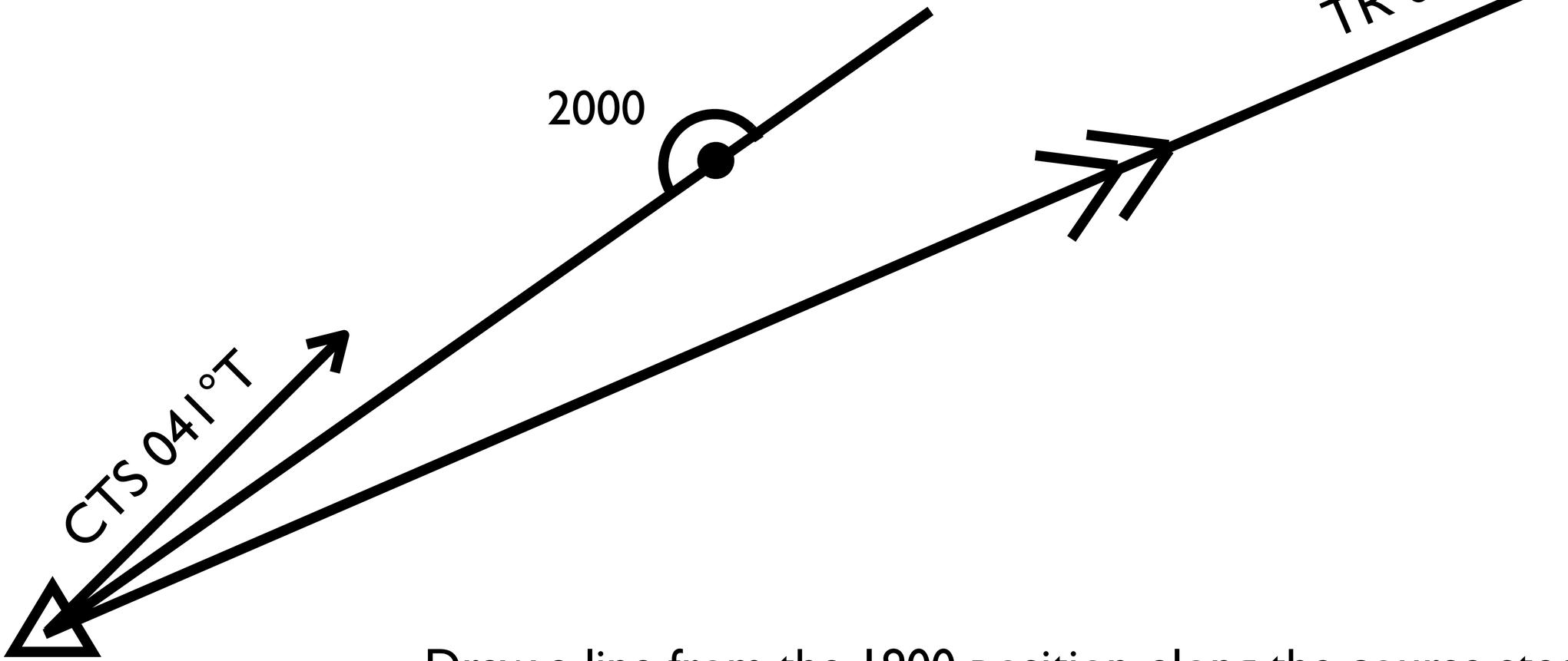


GPS 1900

From 1900 to 2000, compass course steered was 062°PSC and log difference is 6nm (39.5-33.5)

Course steered was 046°T (remember TVMDC)

Plotting a Dead Reckoning Position

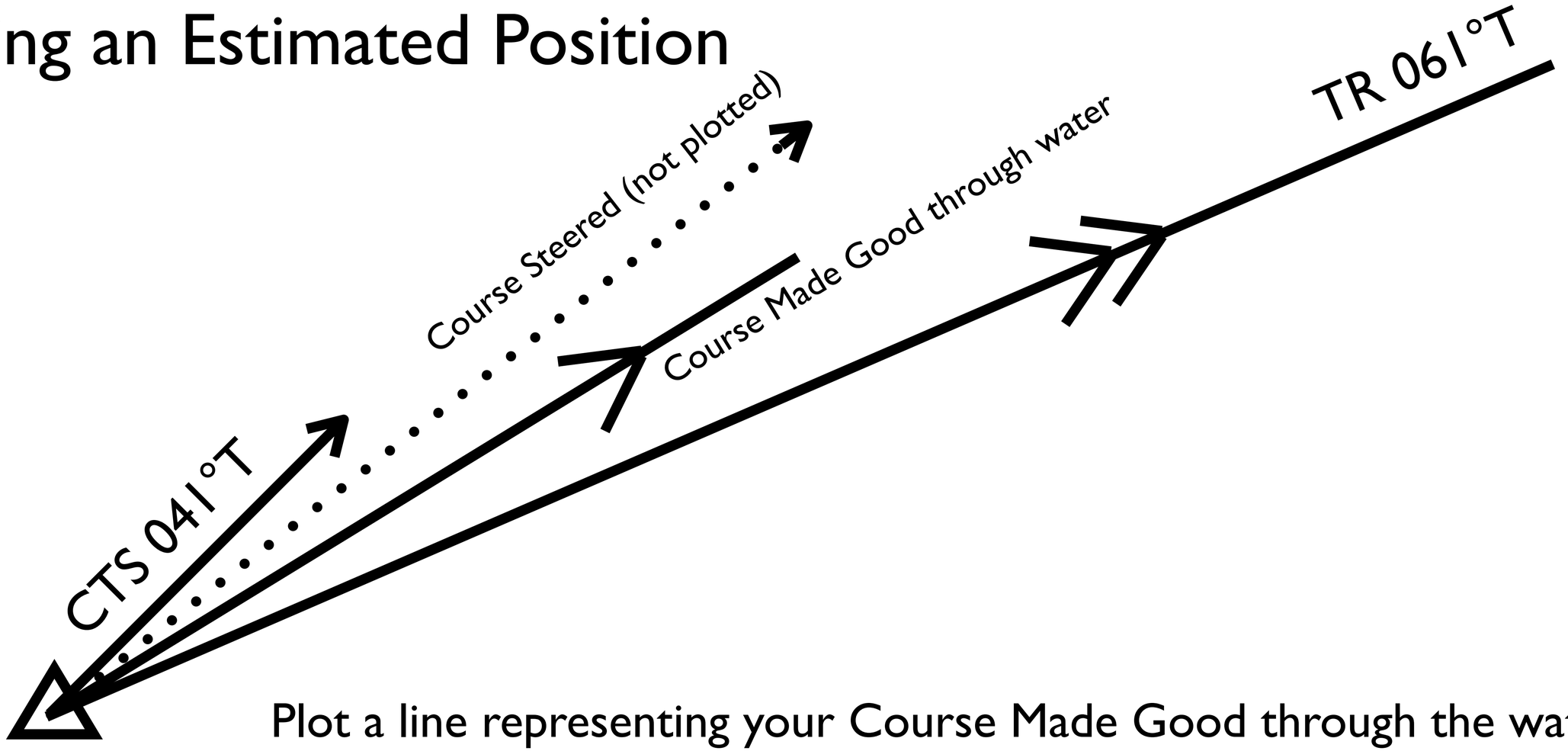


GPS 1900

Draw a line from the 1900 position, along the course steered (046°T) and mark a point at the distance traveled (6nm)

Label this as the 2000 DR position (DR is not corrected for leeway or current)

Plotting an Estimated Position



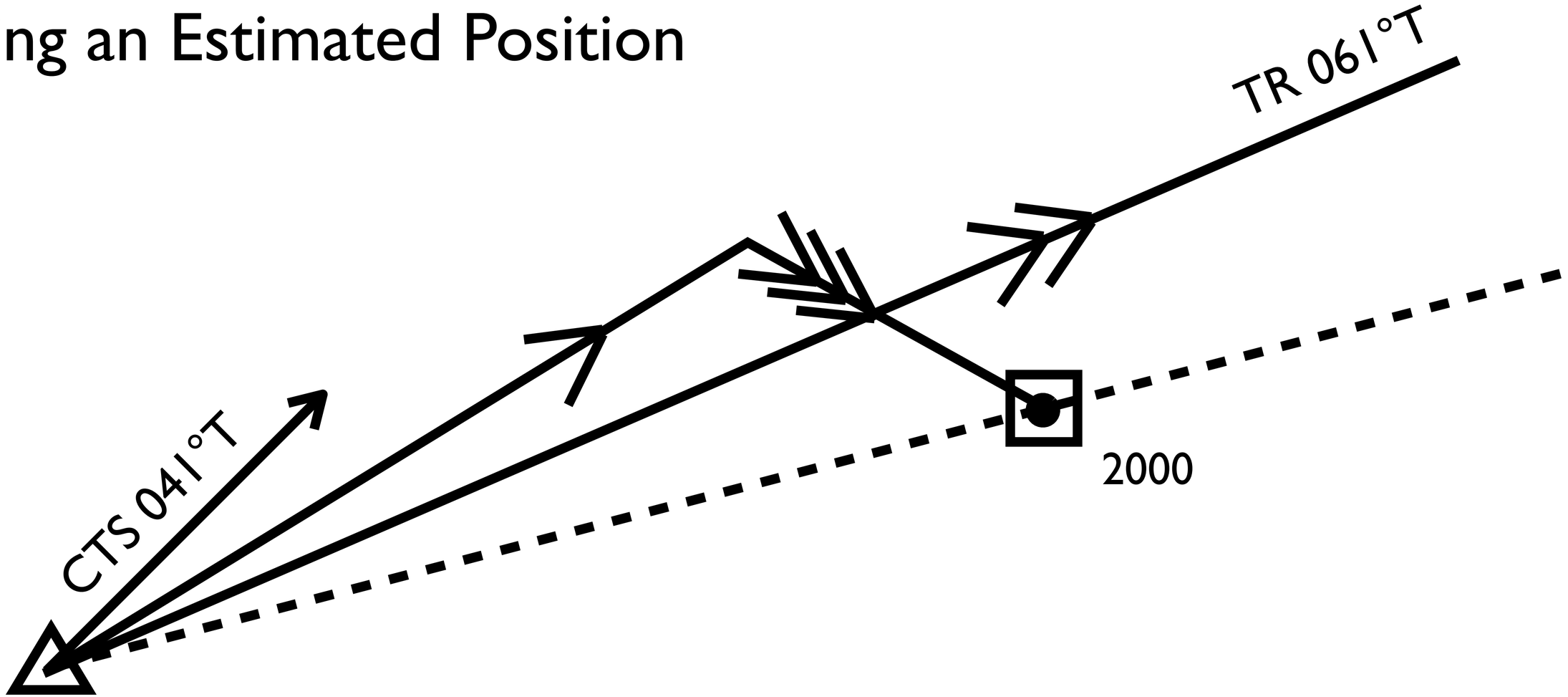
GPS 1900

Plot a line representing your Course Made Good through the water (i.e., the course steered, adjusted for leeway)

In this case it is 046°T + 9° = 055°T

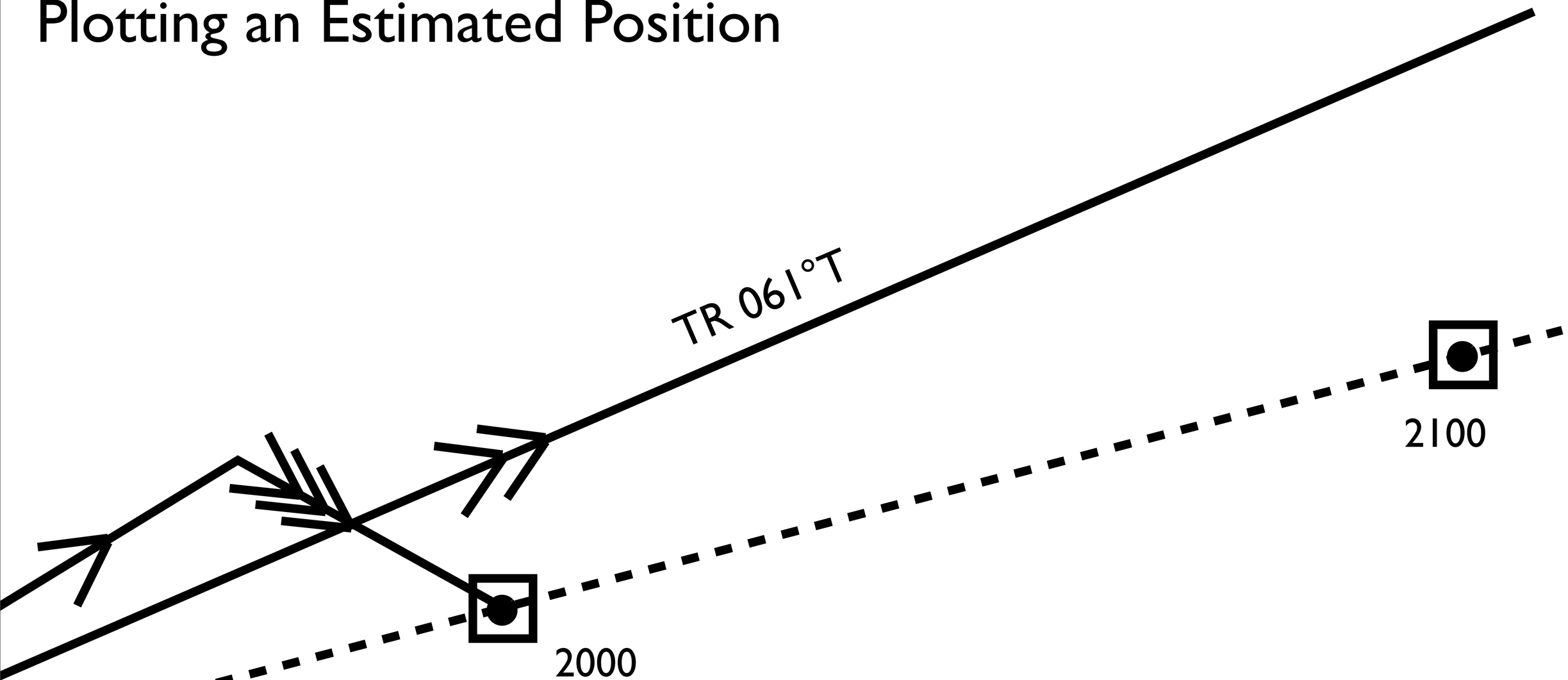
Make the length of the line the distance traveled from 1900-2000 (6nm)

Plotting an Estimated Position



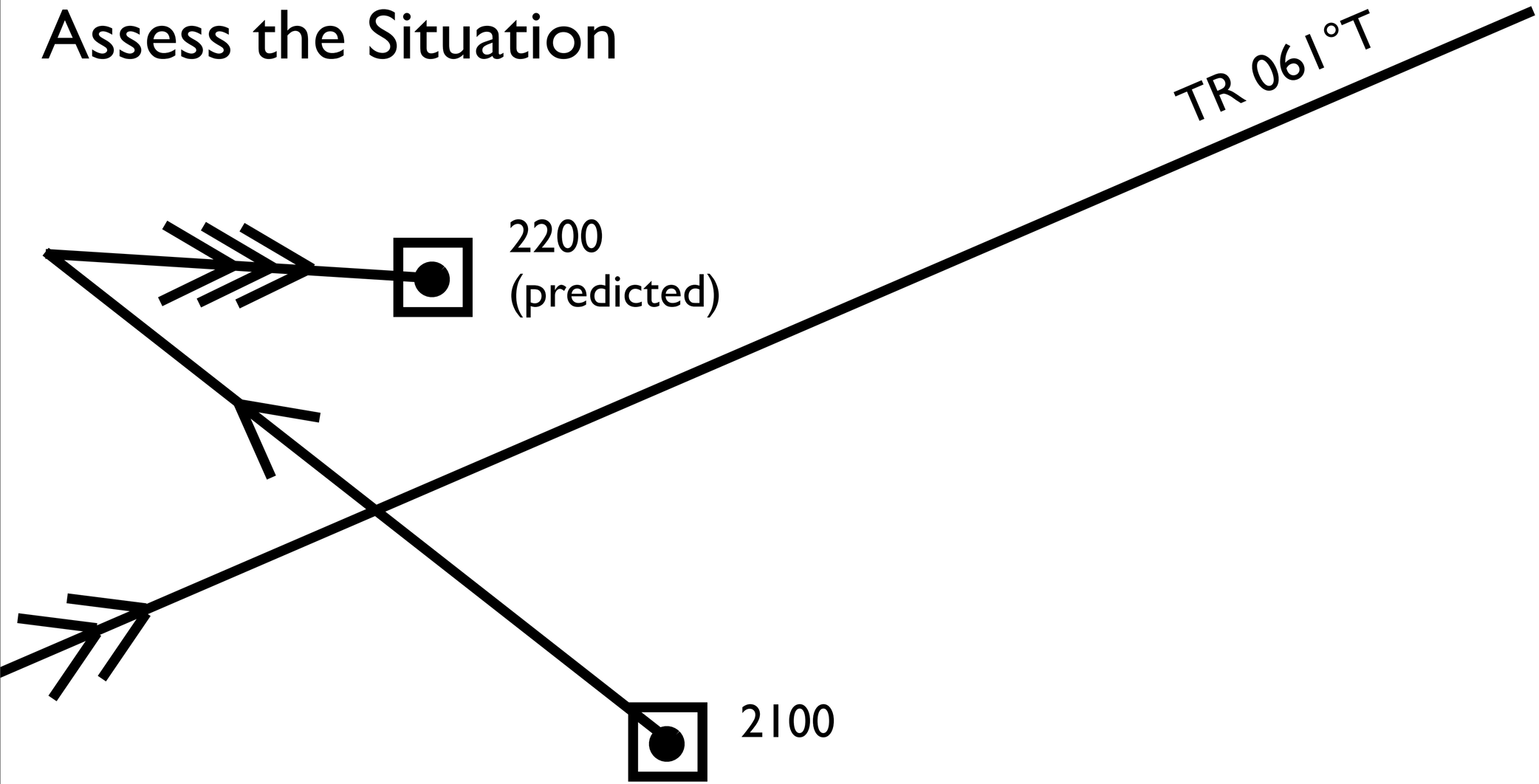
Since nothing changed between 2000 and 2100, you can simply lay your plotting tool along a line between the 1900 GPS Fix and the 2000 EP and mark the 2100 EP along the extension of that line

Plotting an Estimated Position



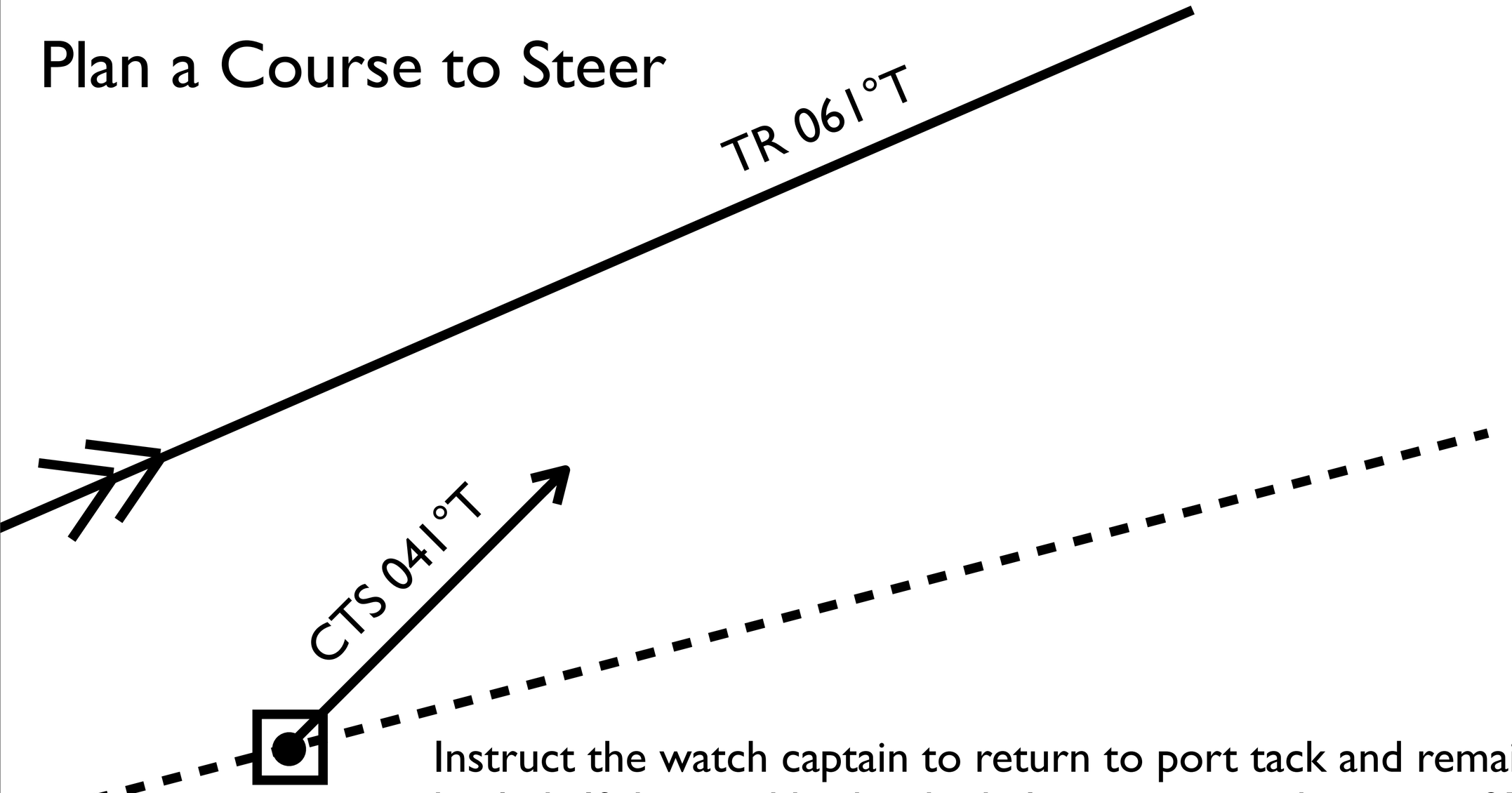
The distance between the 2000 EP and the 2100 EP should be the same as between the 1900 GPS Fix and the 2000 EP

Assess the Situation



On the present tack, the helm is steering 322C (306T)
Accounting for leeway, the boat is making 297T through the water at ~6 knots
Even accounting for current, this looks like a bad tack

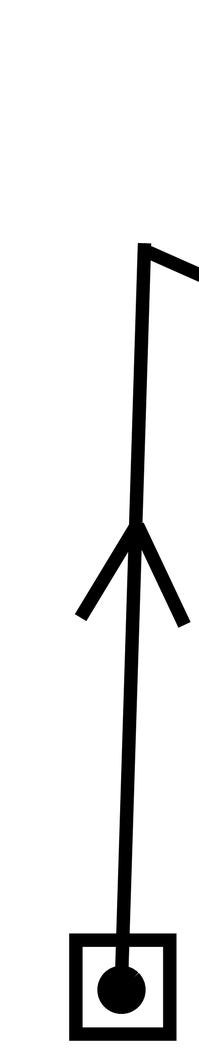
Plan a Course to Steer



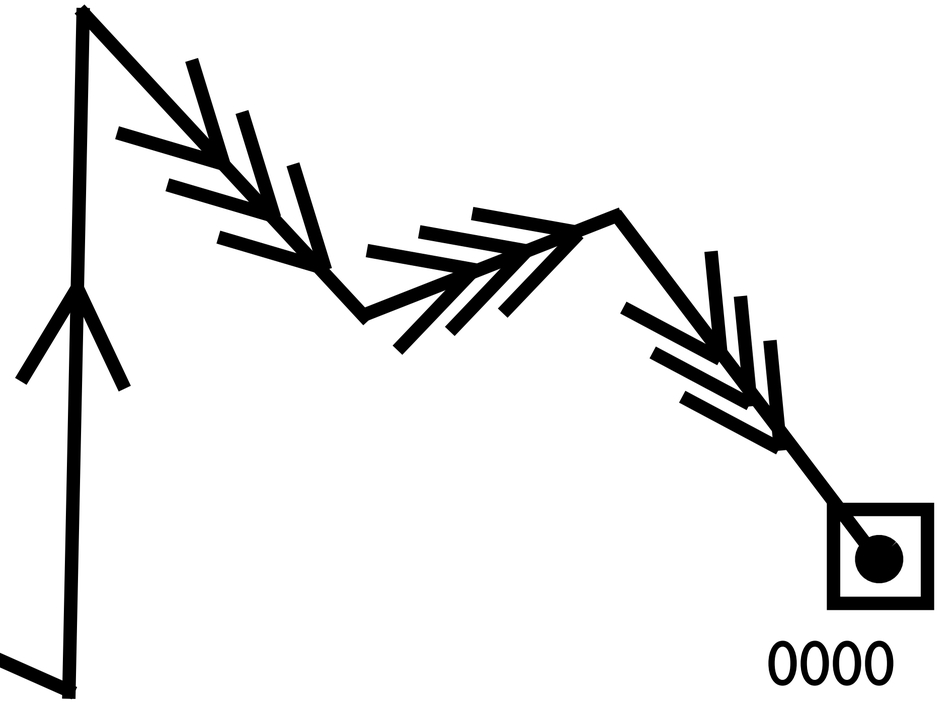
Instruct the watch captain to return to port tack and remain close-hauled. If the wind backs, the helm can stay with it up to 057 PSC, then maintain 057 PSC to parallel the desired track

After tacking, make a log entry and get some sleep...

Variations



2100



0000

You can string multiple tacks together with multiple current estimates

This is particularly helpful with tidal currents and longer passages

Outline

- Review
  - Nautical chart types and scales
  - Bouyage system (IALA Region B)
  - Light characteristics
  - Rules of the Road
  - Tidal currents
  - Basic navigational inputs

- Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore pilotage

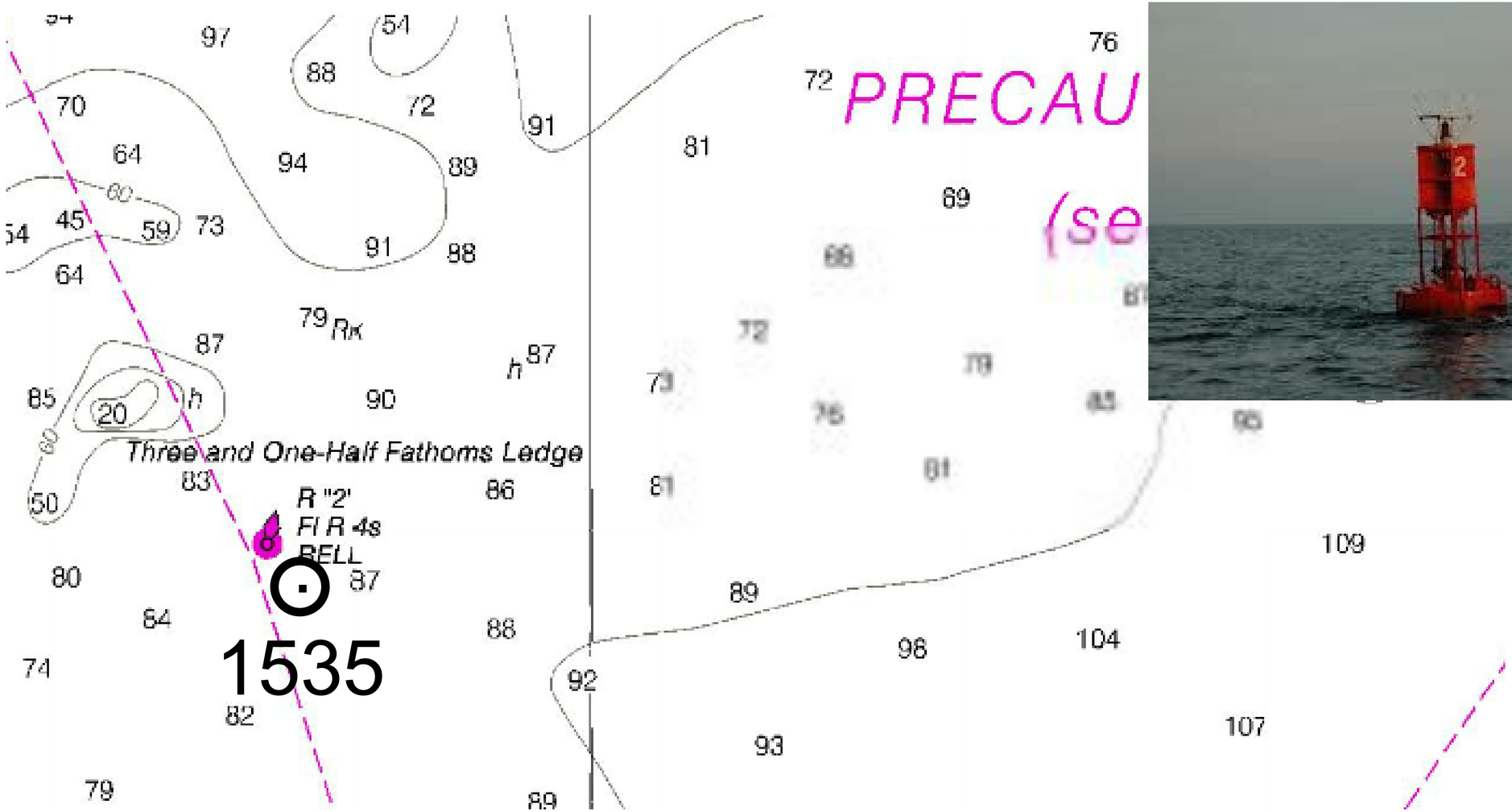
Knowing Where You Are

- Position by immediate observation

- Position fixes defined by lines

- Running fix

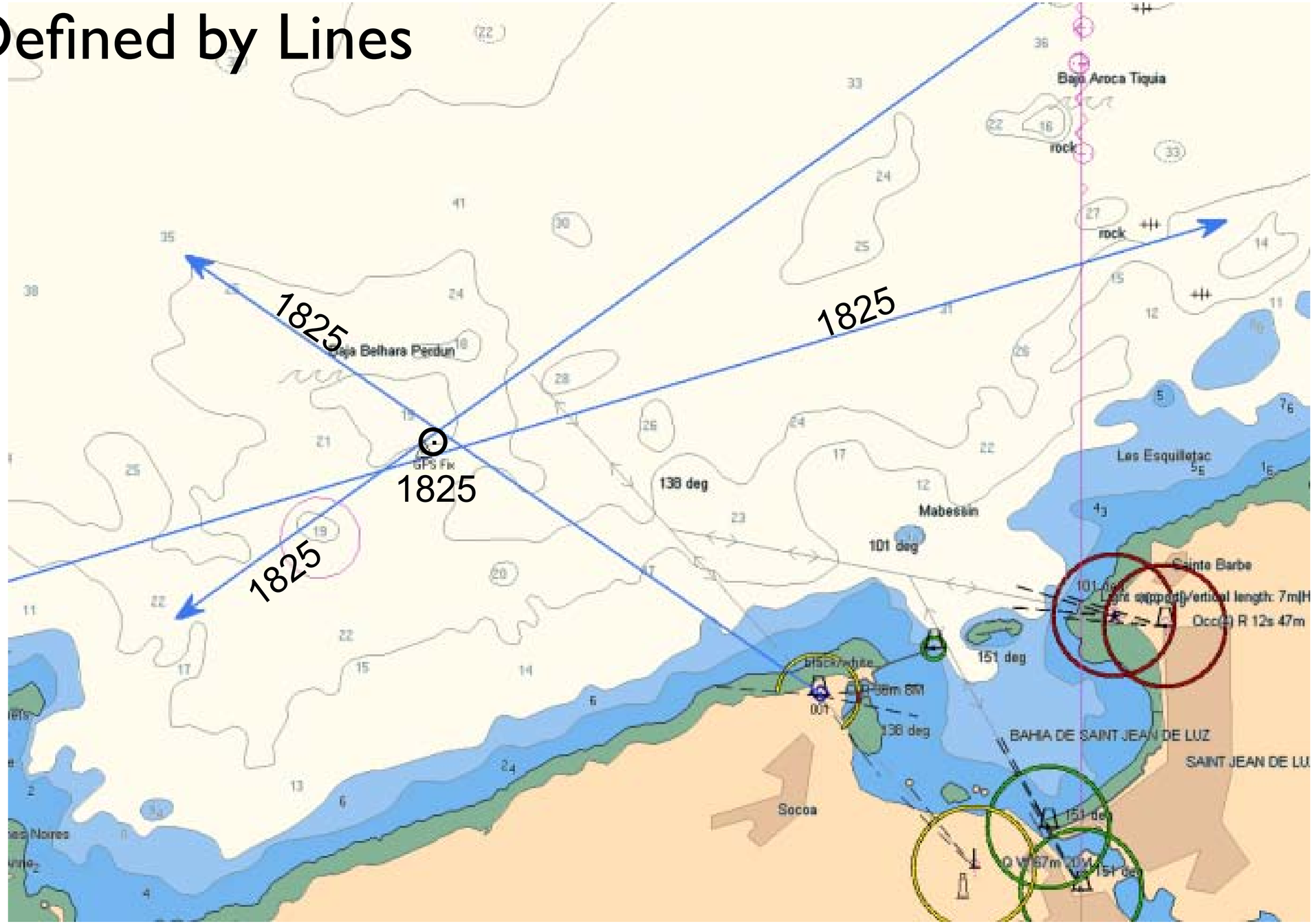
Position by Immediate Observation



Log Entry:

1535: abeam red bell #2 three and one-half fathoms ledge

Position Defined by Lines



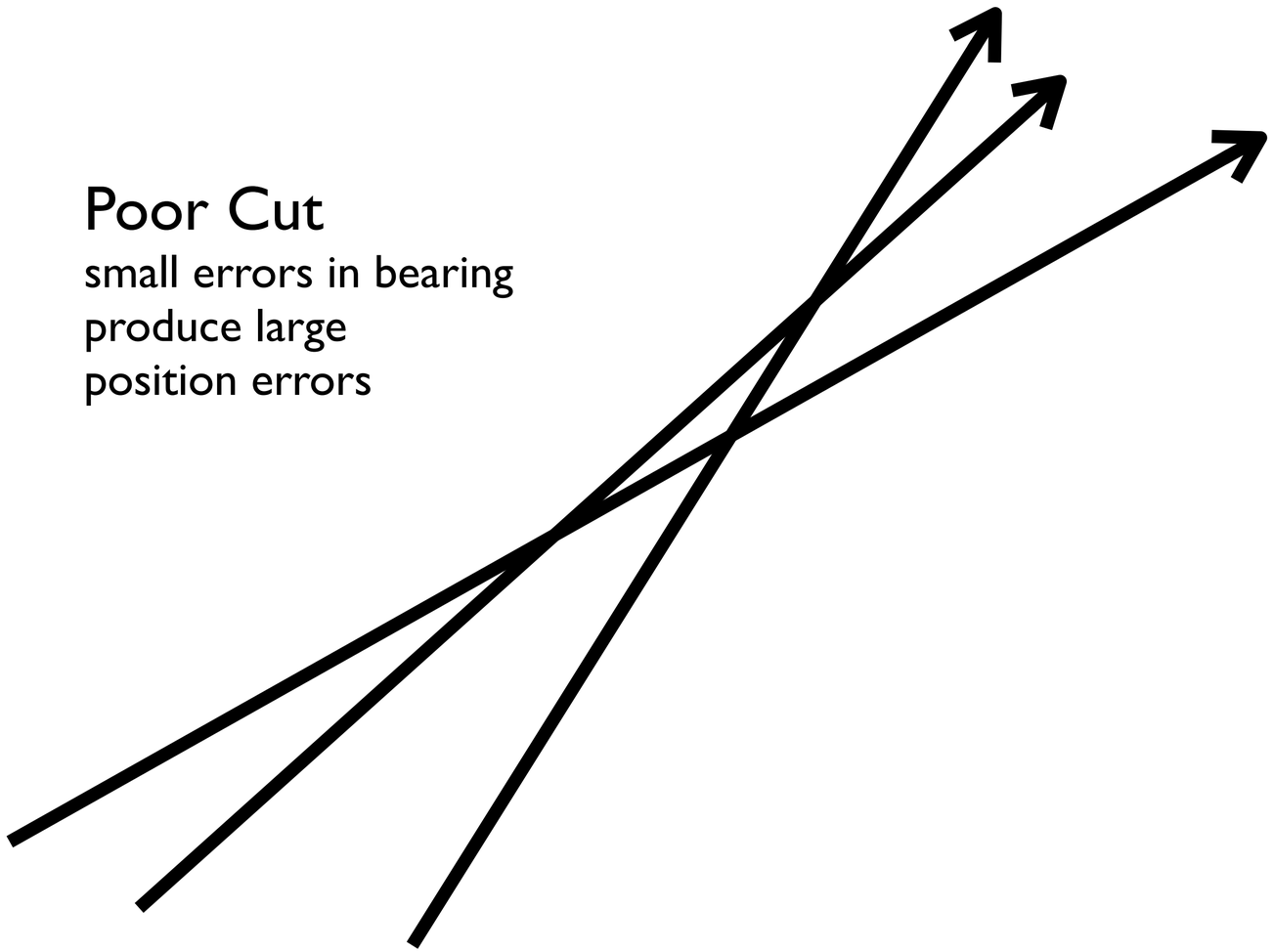
Position Defined by Lines

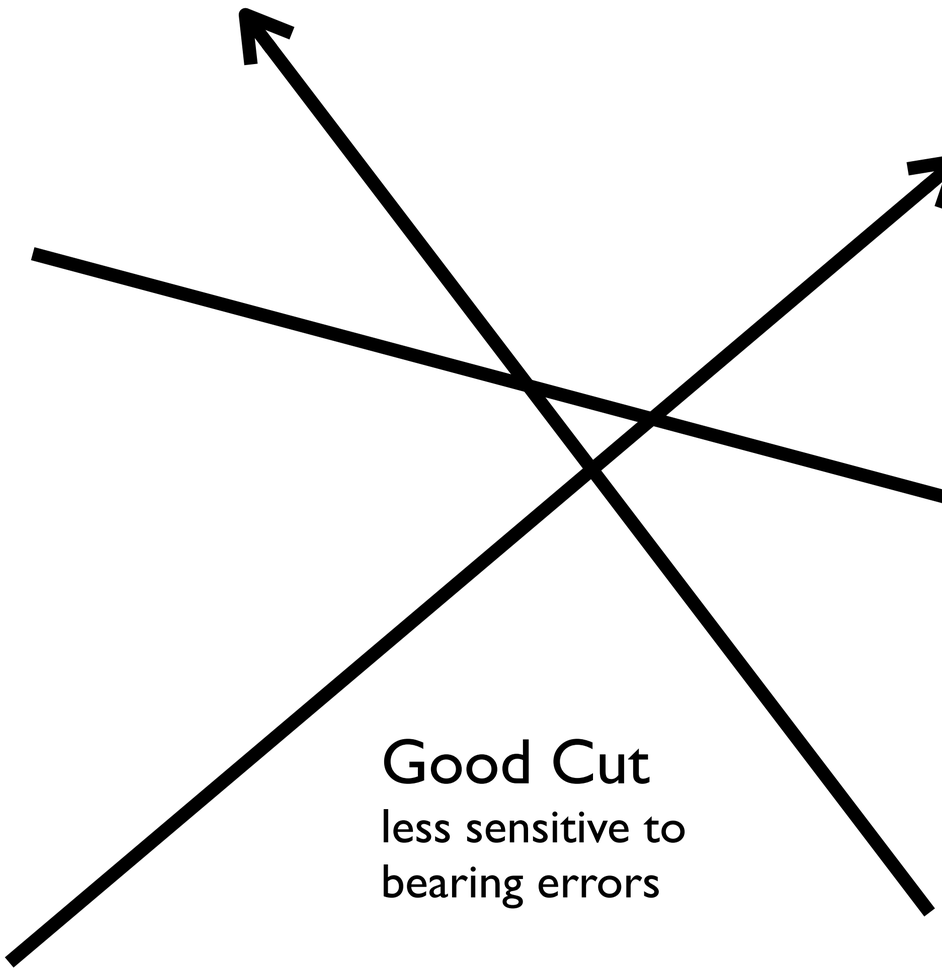
Try to select objects whose LOPs will intersect at 45° or more

Position Defined by Lines

Poor Cut

small errors in bearing
produce large
position errors





Good Cut

less sensitive to
bearing errors

Try to select objects whose LOPs will intersect at 45° or more

Sources of Lines of Position

- Ranges
  - "Official" range set up for navigation
  - "Unofficial" range based on charted objects

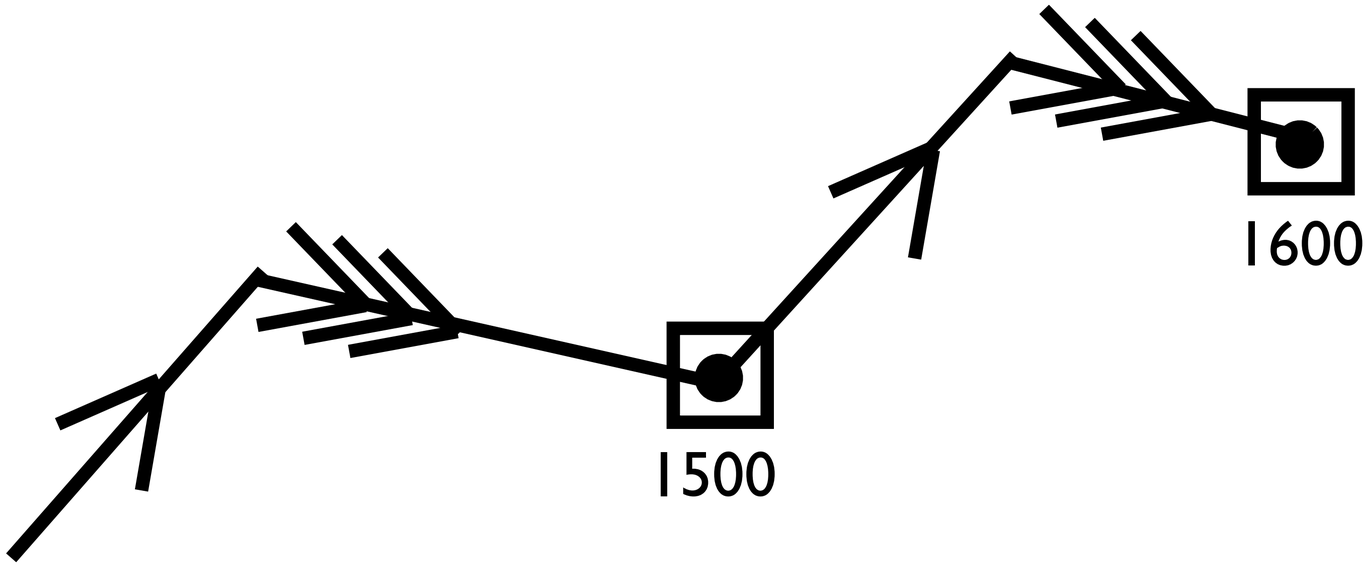
- Compass bearings on objects
  - Quality depends on compass, observation conditions, and position stability of object

- Depth contours
  - Quality depends on bottom contour, condition, and tide

- Distance off
  - Measured by RADAR
  - Measured by sextant
  - Dipping of object of known height (typically lighthouses)

Using a Single Line of Position

Let's say that you are keeping a series of estimated positions, using your estimates of your course made good through the water and current set and drift



Using a Single Line of Position

At 1600 you get a good single LOP from a mark

Using a Single Line of Position

You can update your estimated position by moving it from your initial estimate to the closest point along the LOP

This is *not* a fix. It is simply an adjusted estimated position

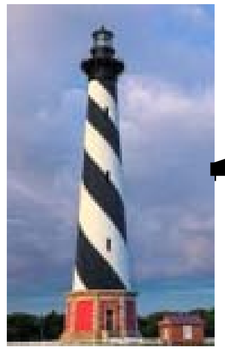
1600

1600

1500

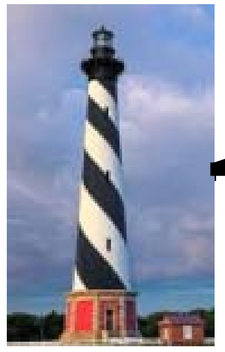
Running Fix

Some time later you get another LOP on the same mark



Running Fix

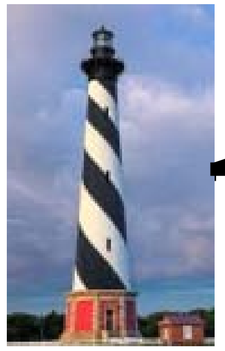
Plot your course made good through the water and estimated current set and drift just as you would for an Estimated Position



Running Fix

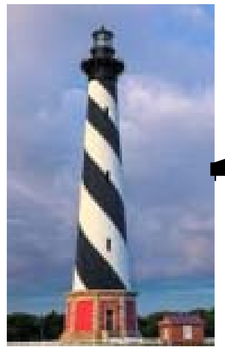
Advance the earlier line of position in the diretion and distance you estimate that you've traveled over the bottom

Label it as an advanced LOP



Running Fix

Plot your running fix
and label it as such

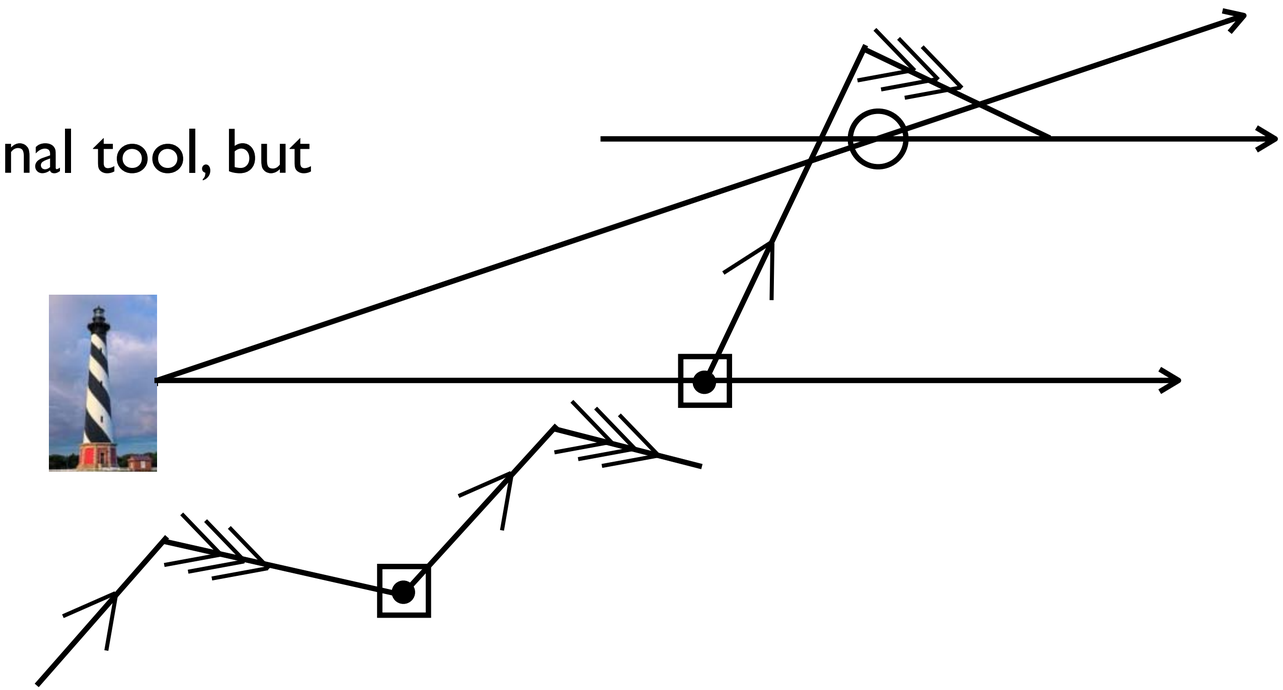


Running Fix: Caution

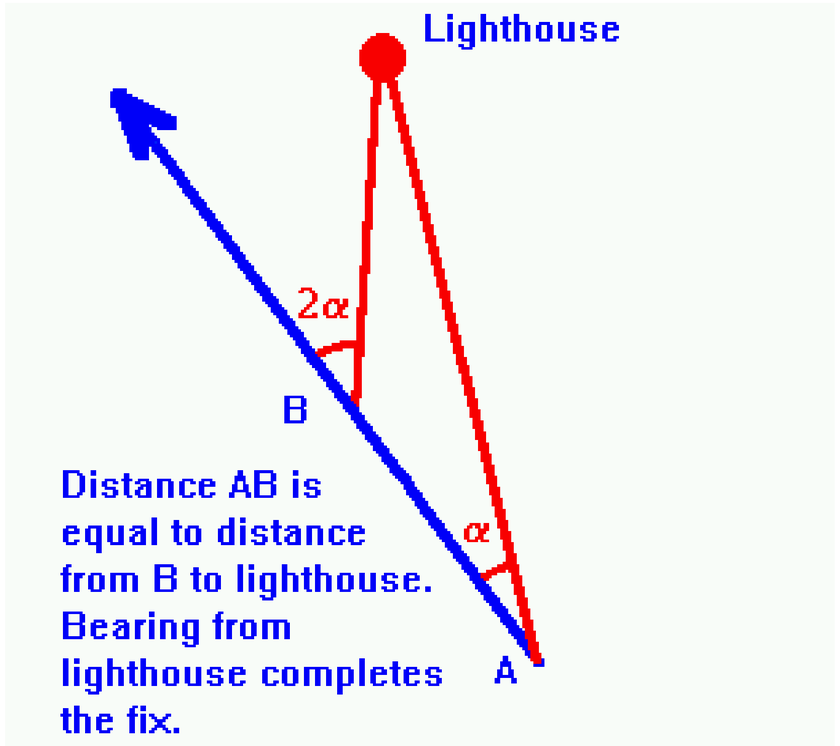
The running fix appears precise, but it is only as accurate as your ability to estimate your distance and direction traveled over the bottom

Your LOPs should subtend and angle of no less than 45-60 degrees

Runningn fixes are a very blunt navigational tool, but sometimes they're all you have

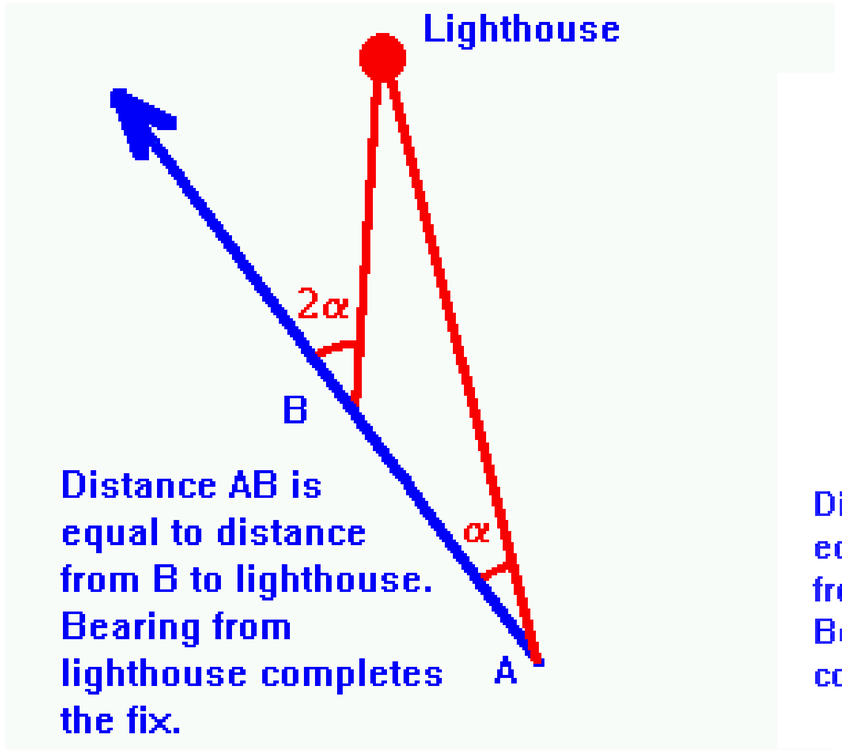


Running Fix: Special Cases

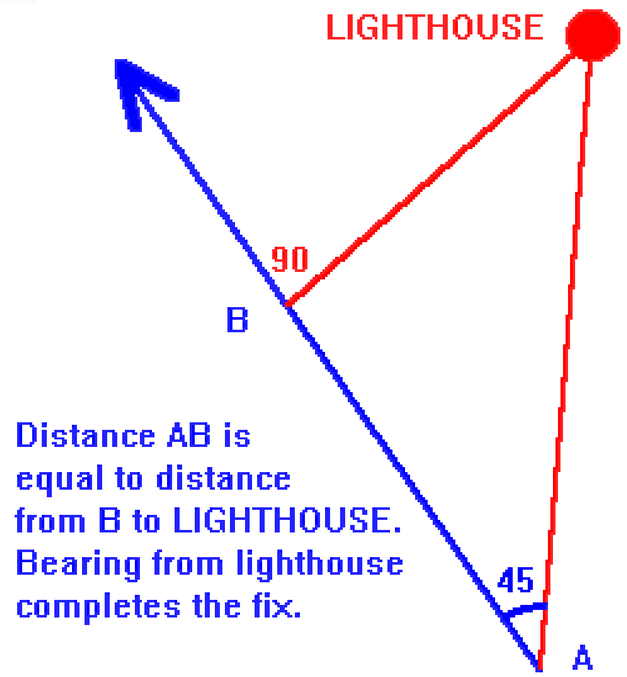


Doubling Angle on the Bow

Running Fix: Special Cases

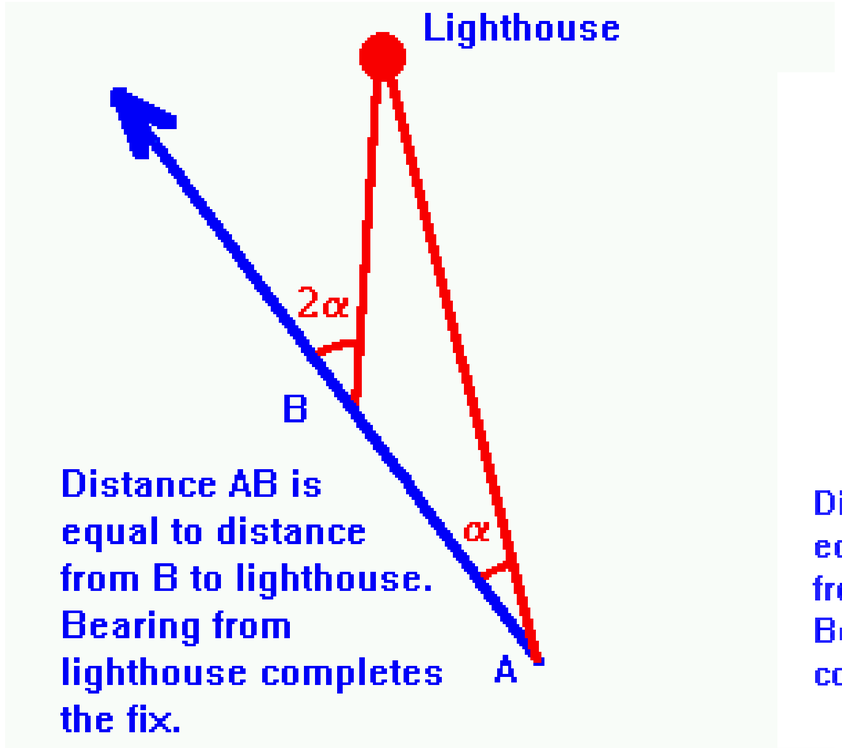


Doubling Angle on the Bow

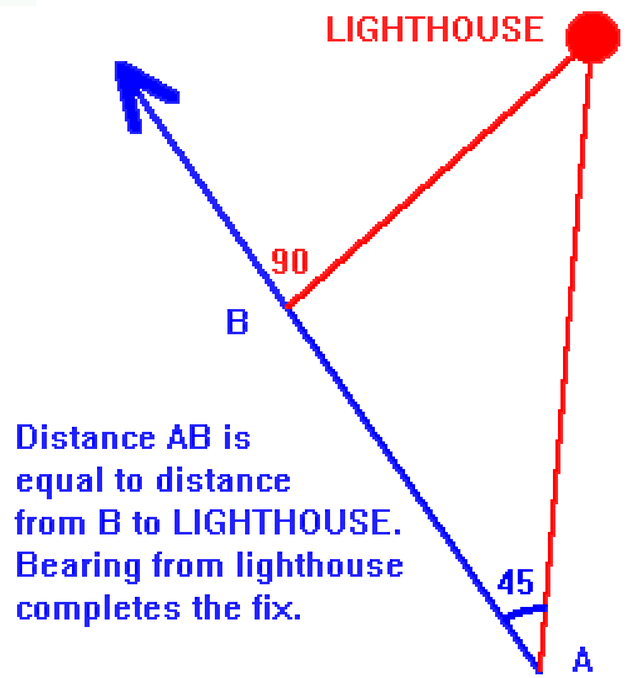


45-90 Doubling Angle

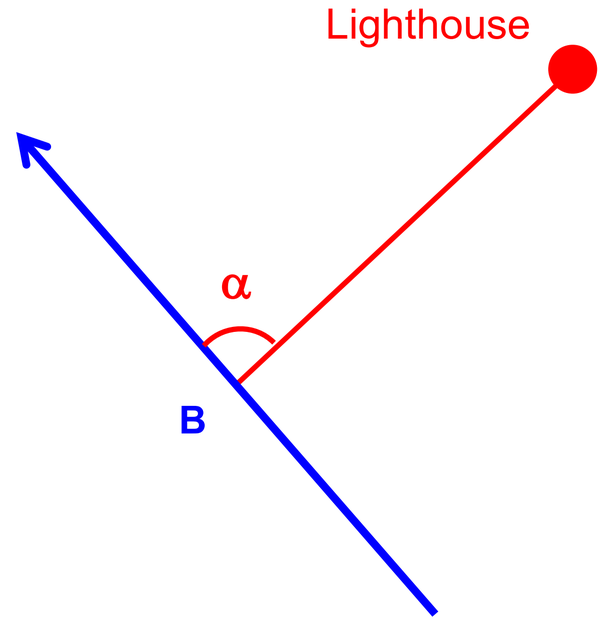
Running Fix: Special Cases



Doubling Angle on the Bow



45-90 Doubling Angle



Beam Bearing Drift Rate

When abeam the mark, the distance between B and the mark is equal to the time (in minutes) that it takes the bearing angle to change (in degrees) an amount equal to the vessel speed (in knots)

Outline

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  - Inshore pilotage

Inshore Pilotage

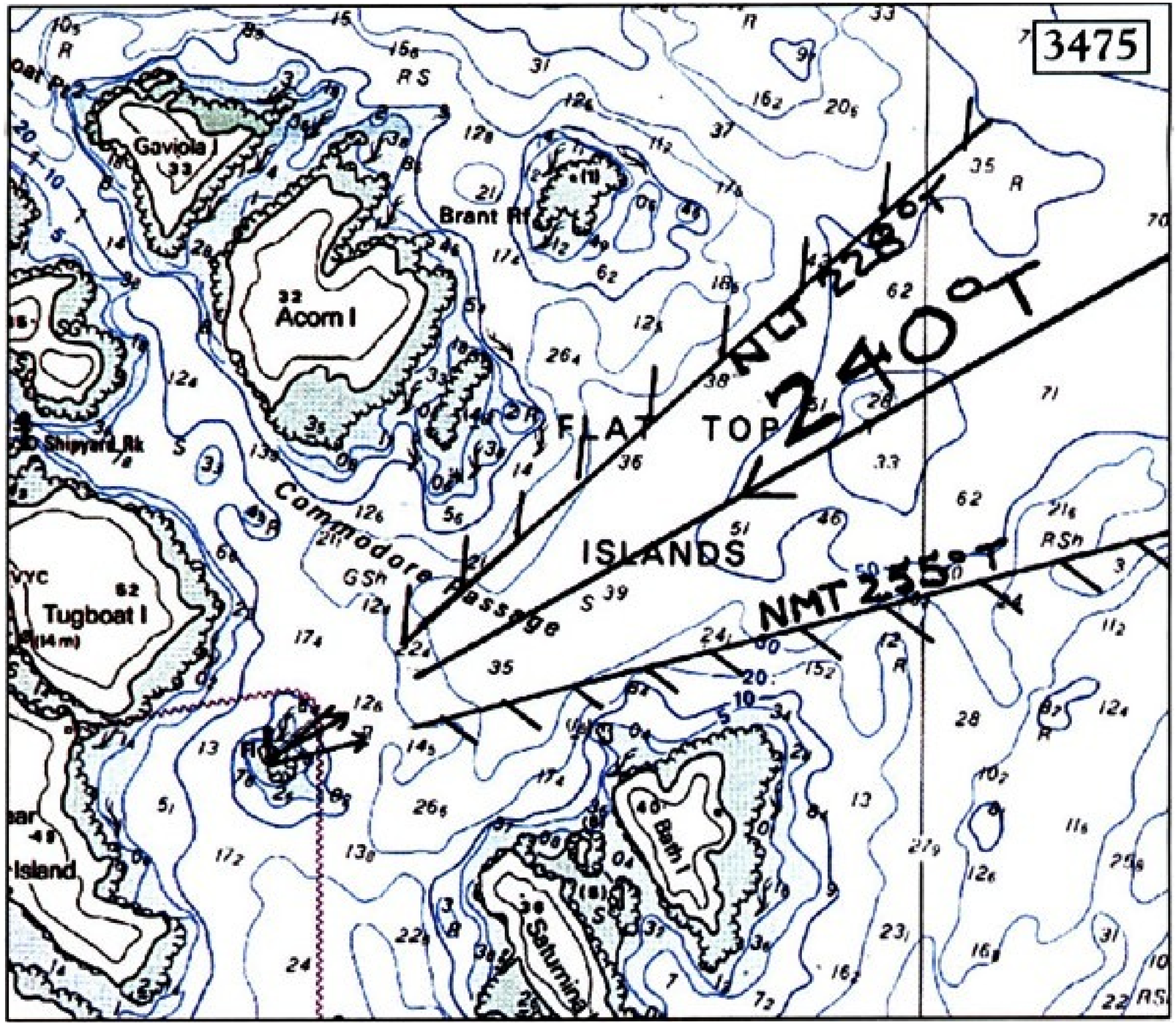
- In waters crowded with bouys, beacons, and hidden hazards, there is often no time for formal chartwork

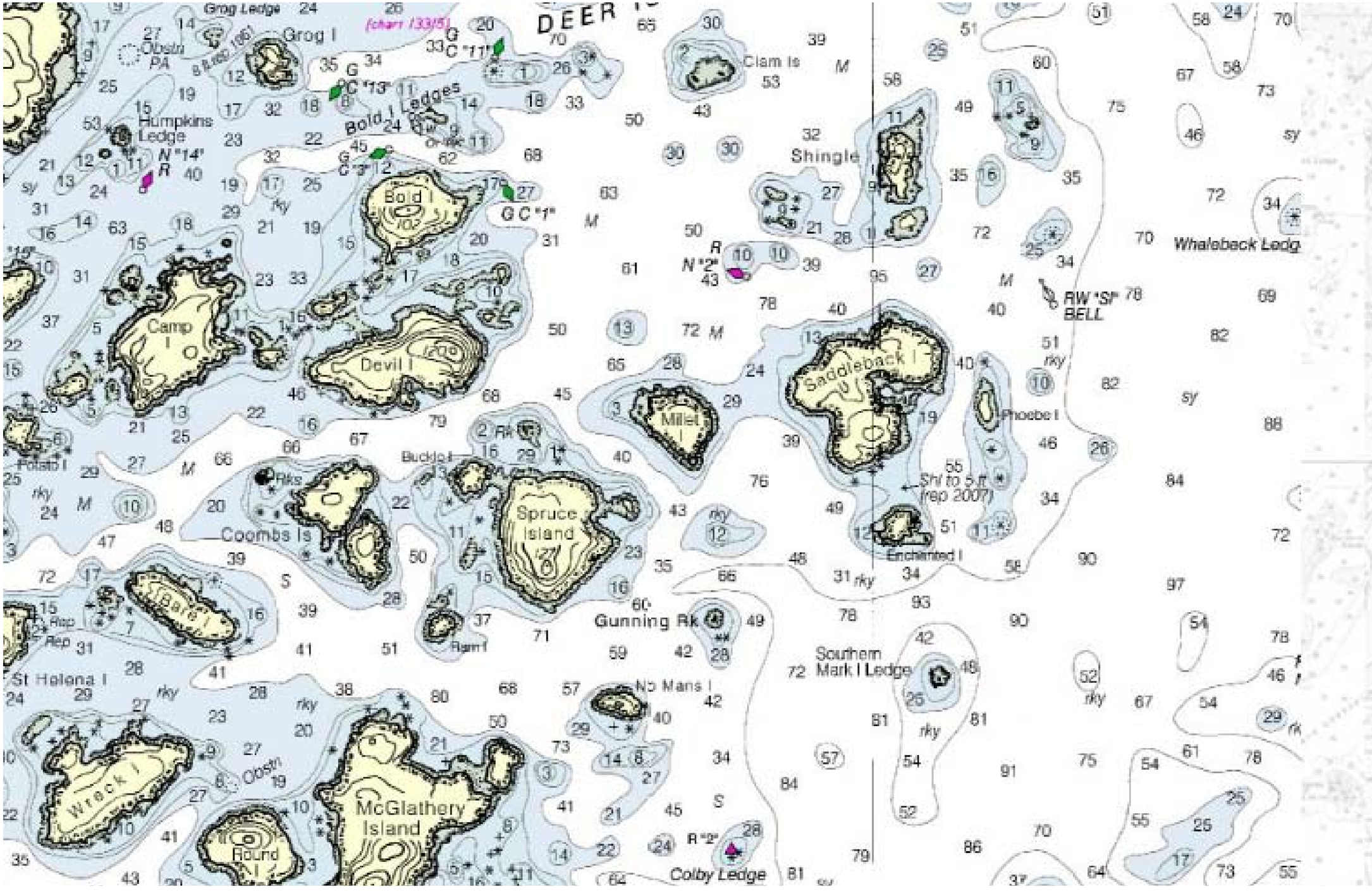
- Typically these occur at beginning or end of a passage - often in unfamiliar waters

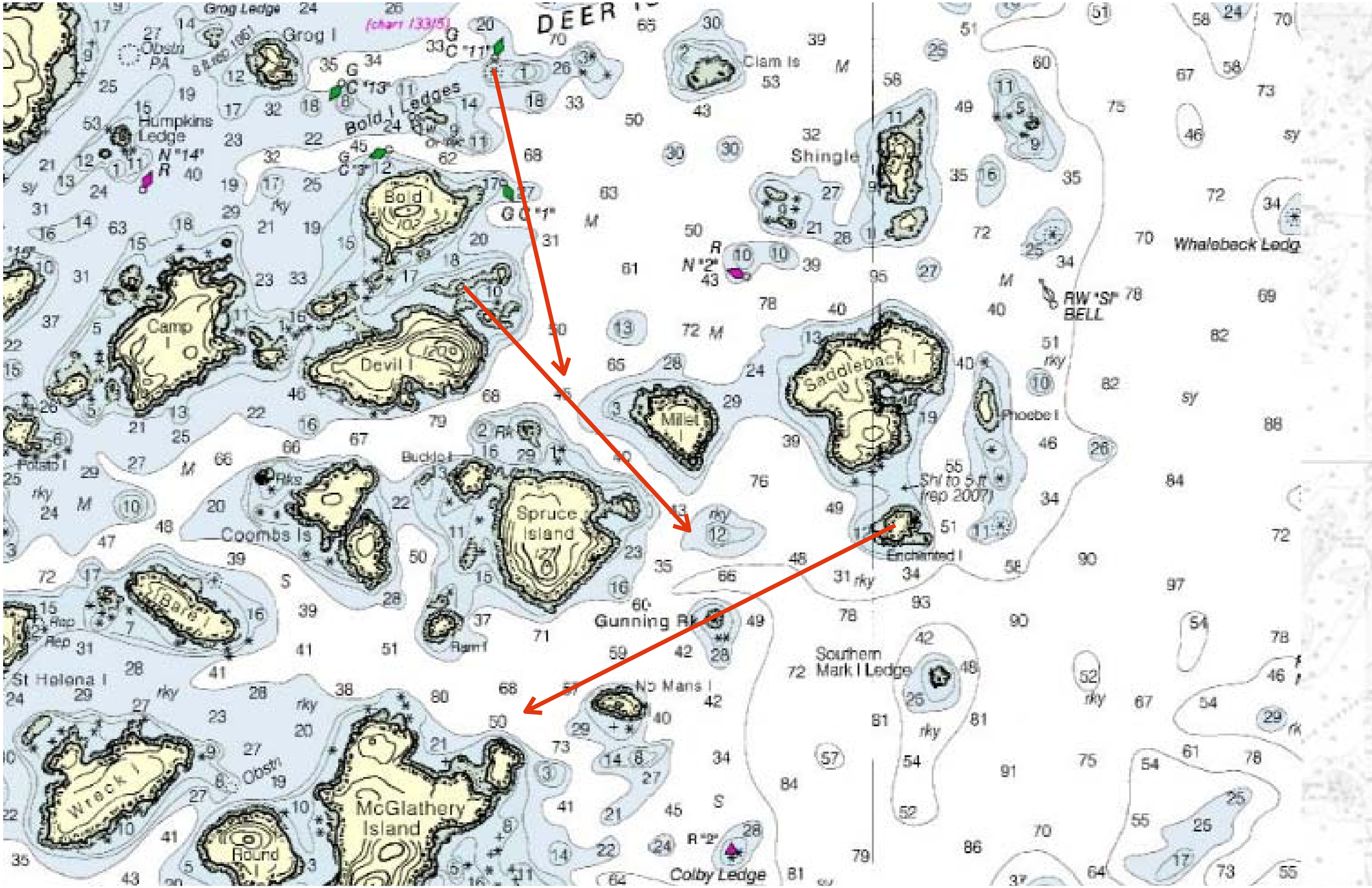
- Procedures must be simple to set up and follow

- Most navigation aboard X-Dimension in and around Boston Harbor is inshore pilotage

Clearing or Danger Bearing



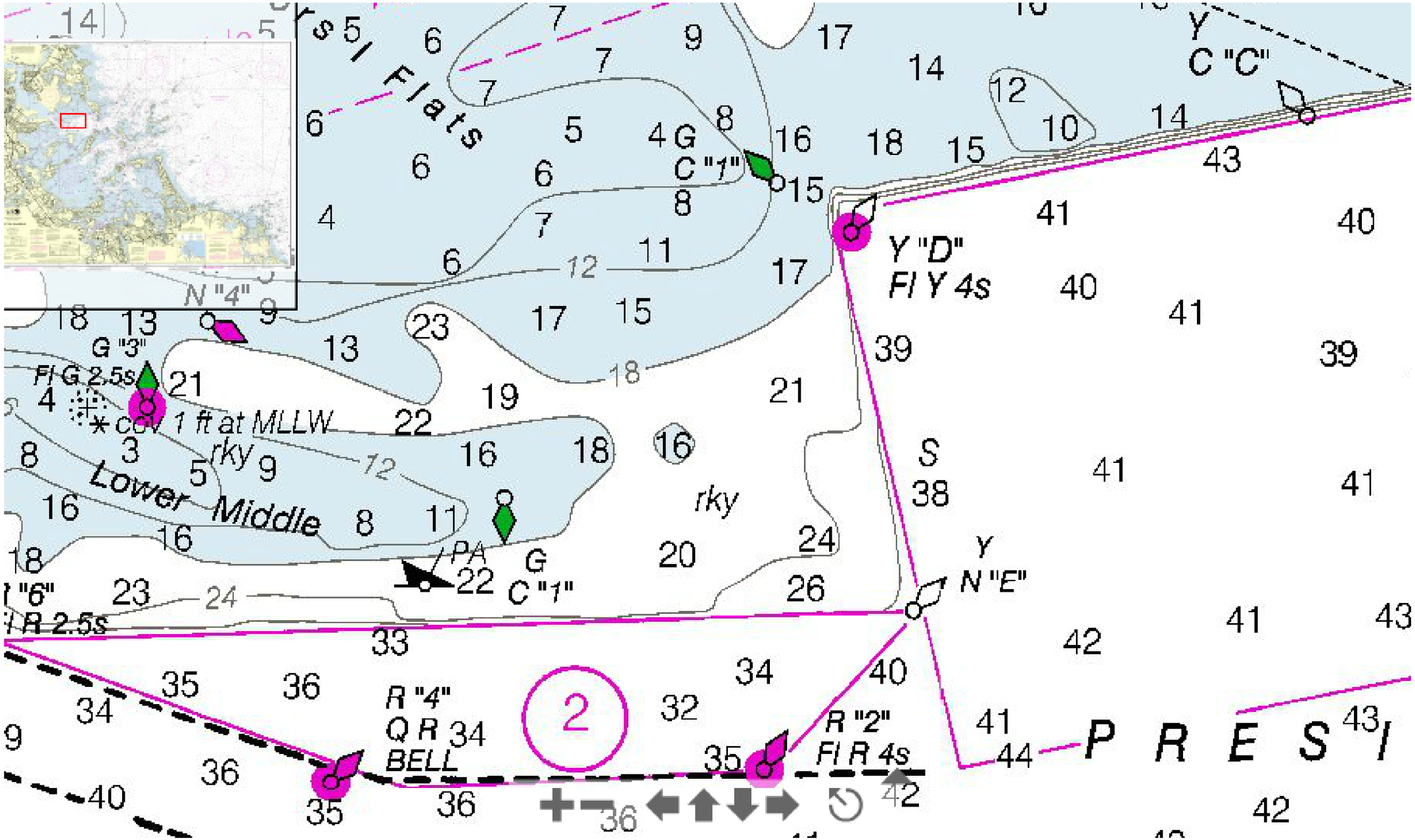




Inshore Pilotage Tips

- For complex harbor entries, plan ahead with appropriate bearings and informal ranges
- For landfall in low visibility, bias your course to steer so you know which way to turn when shore becomes visible
- Keep a chart on deck with you and refer to it often, even in familiar waters
- “Prove” your bearings with informal ranges where possibel to account for current
- Communicate clearly to helm and crew - give them time to prepare
- Check and double-check your information

Double-Check Everything



Celestial Navigation

"Sextant: an entertaining, albeit expensive, device, which, together with a good atlas, is of use in introducing the boatman to many interesting areas on the earth's surface which he and his craft are not within 1,000 nautical miles of."

- Beard and McKie

“I looked in the Nautical Almanac and found that on that very day, June 7, the sun was behind time 1 minute and 26 seconds, and that it was catching up at a rate of 14/67 seconds per hour. The chronometer said that at the precise moment of taking the sun's altitude it was 25 minutes after 8:00 in Greenwich. From this date it would seem a schoolboy's task to correct the Equation of Time. Unfortunately I was not a schoolboy.”

- Jack London, The Cruise of the Snark