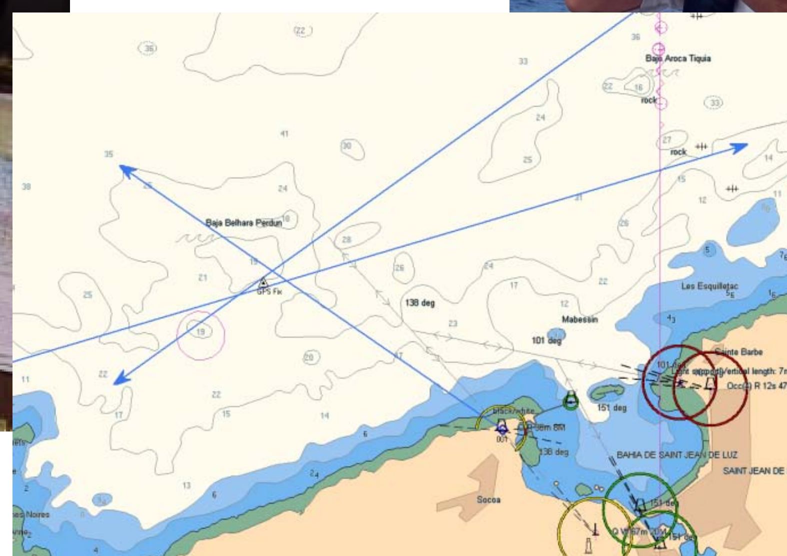
Navigation for Offshore Sailing



“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”

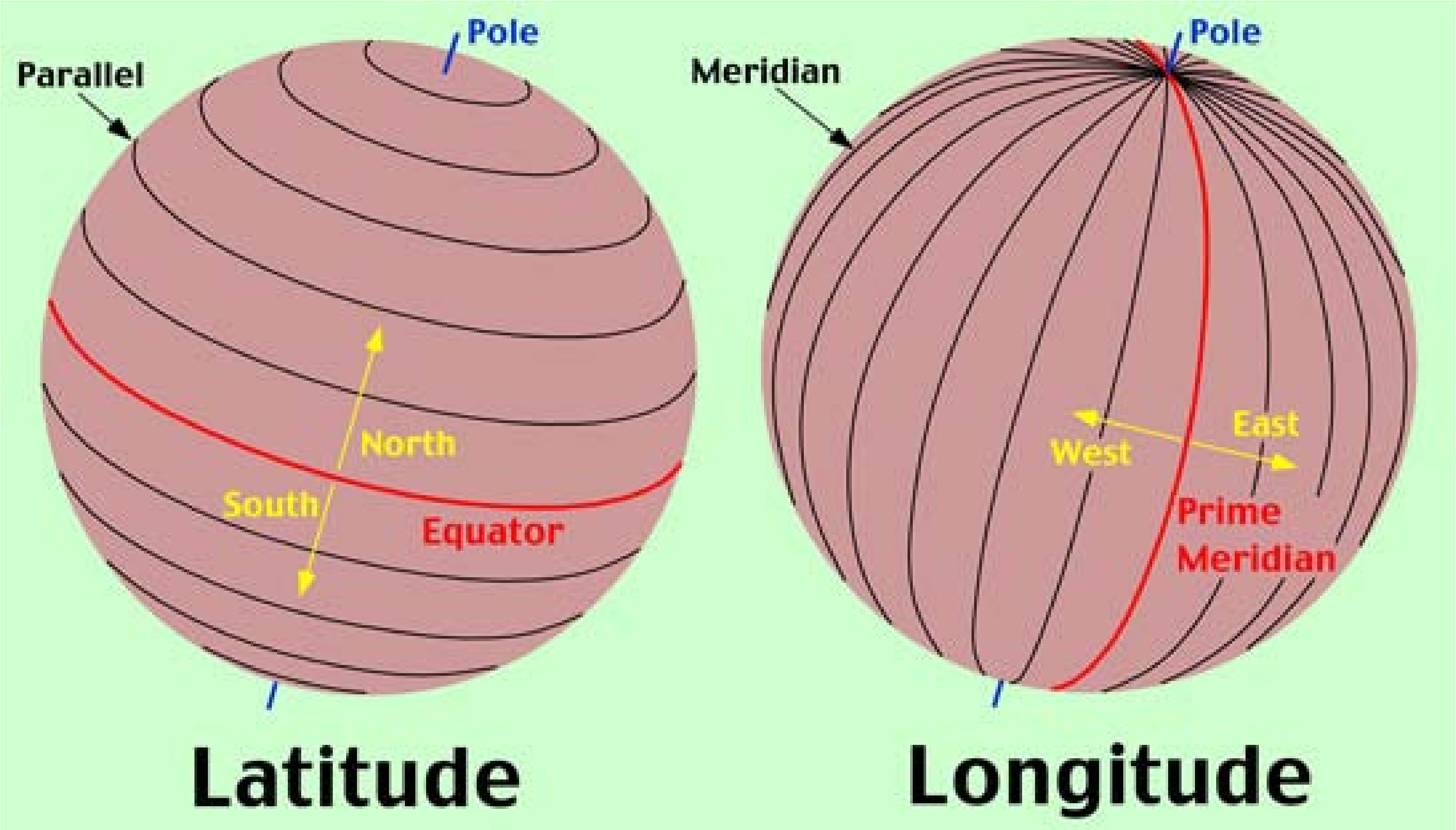
- Rudyard Kipling

Outline

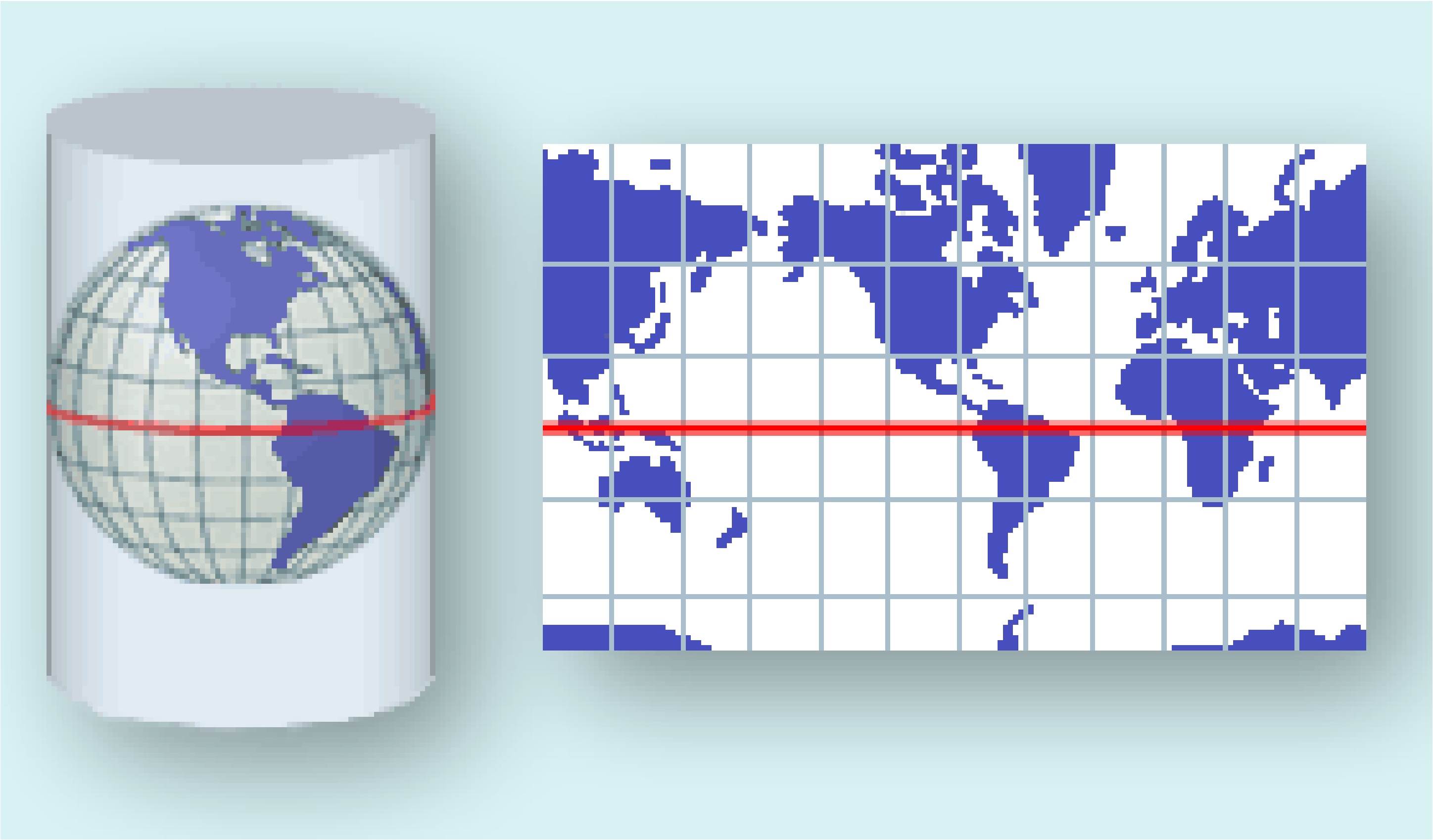
- Review
  - Nautical Chart types and scales
  - Buoyage System (IALA Region B)
  - Light characteristics
  - “Rules of the Road”
  - Tidal currents
  - Basic navigational inputs

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

Geographical Coordinate System



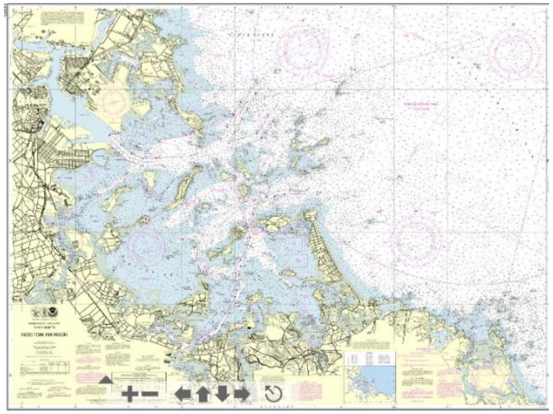
Mercator Projection



- 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 of latitude are exaggerated in polar regions

Nautical Chart Scales

- Boston Harbor
  - Large scale (1/25,000)
  - Covers small area

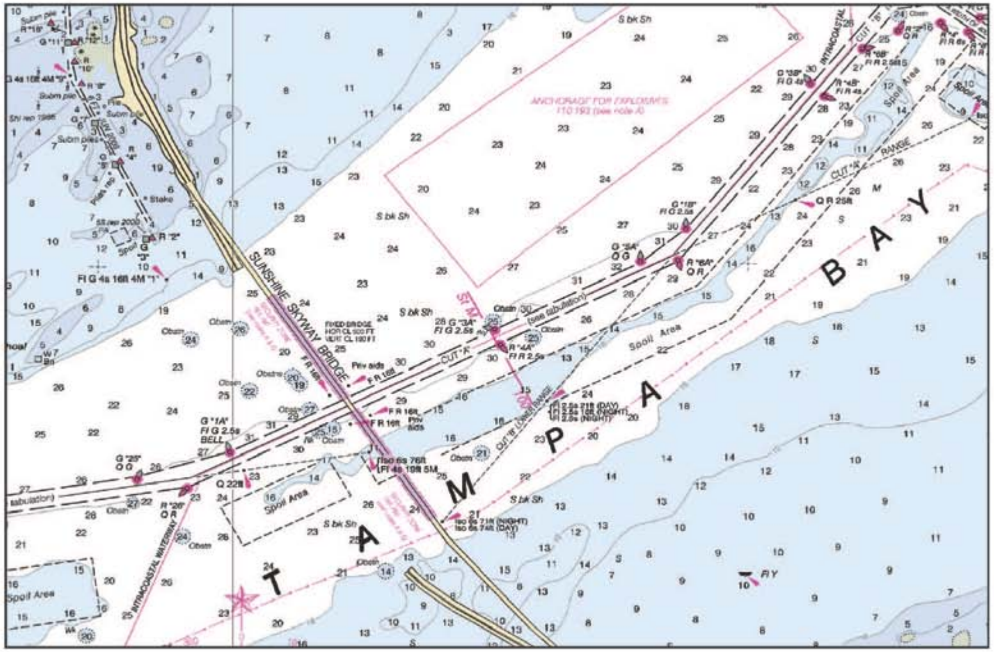


- Newport to Bermuda
  - Small scale (1/1,058,400)
  - Covers large area

Chart No. 1

UNITED STATES OF AMERICA

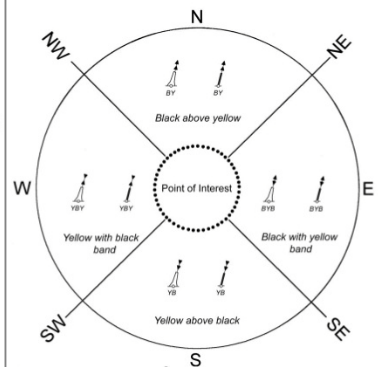
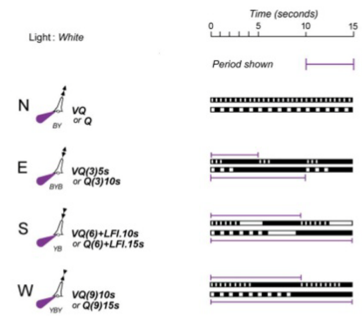
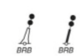
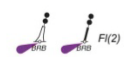
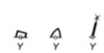
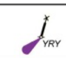
Nautical Chart Symbols, Abbreviations and Terms

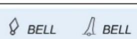
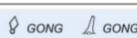


Eleventh Edition

November 2011

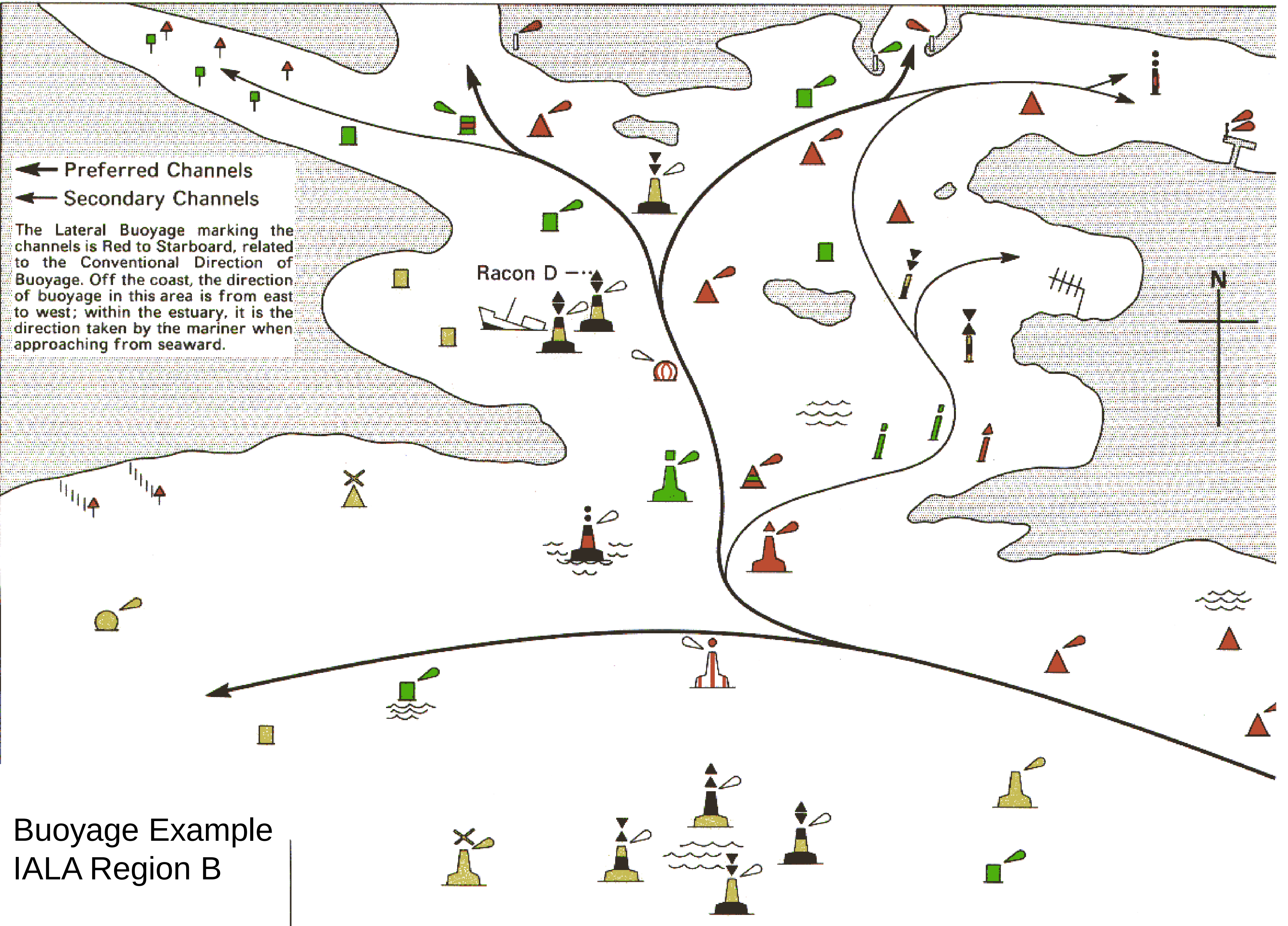
Q Buoys and Beacons

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*		
		 *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* 	
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* 	
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* 	
	In special cases yellow can be in conjunction with another color. 		

Supplementary National Symbols				
a		Bell buoy		
b		Gong buoy		
c		Whistle buoy		
d		Fairway buoy (red and white vertical stripe)		

- 8 Ways to Identify a Lateral Mark
  - Color (Green, Red)
  - Buoy shape (Cylindrical, Conical)
  - Dayboard (Green Square, Red Triangle)
  - Topmark (Cylinder, Cone (point upward))
  - Light Color (Green, Red)
  - Reflector Color (Green, Red)
  - ID Number (Odd, Even)
  - Sound (Gong (clang), Bell (ding))

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



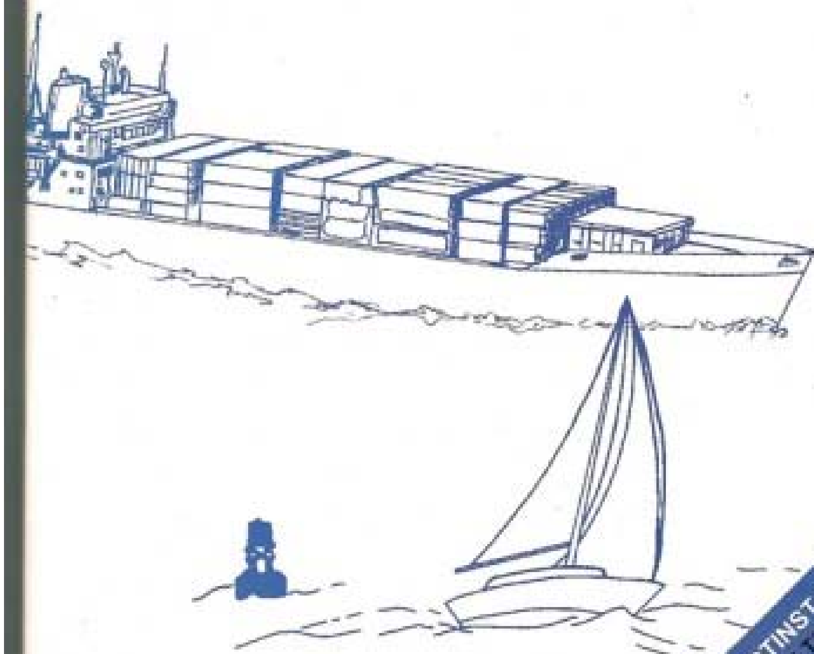
Buoyage Example
IALA Region B

U.S. Department of
Homeland Security

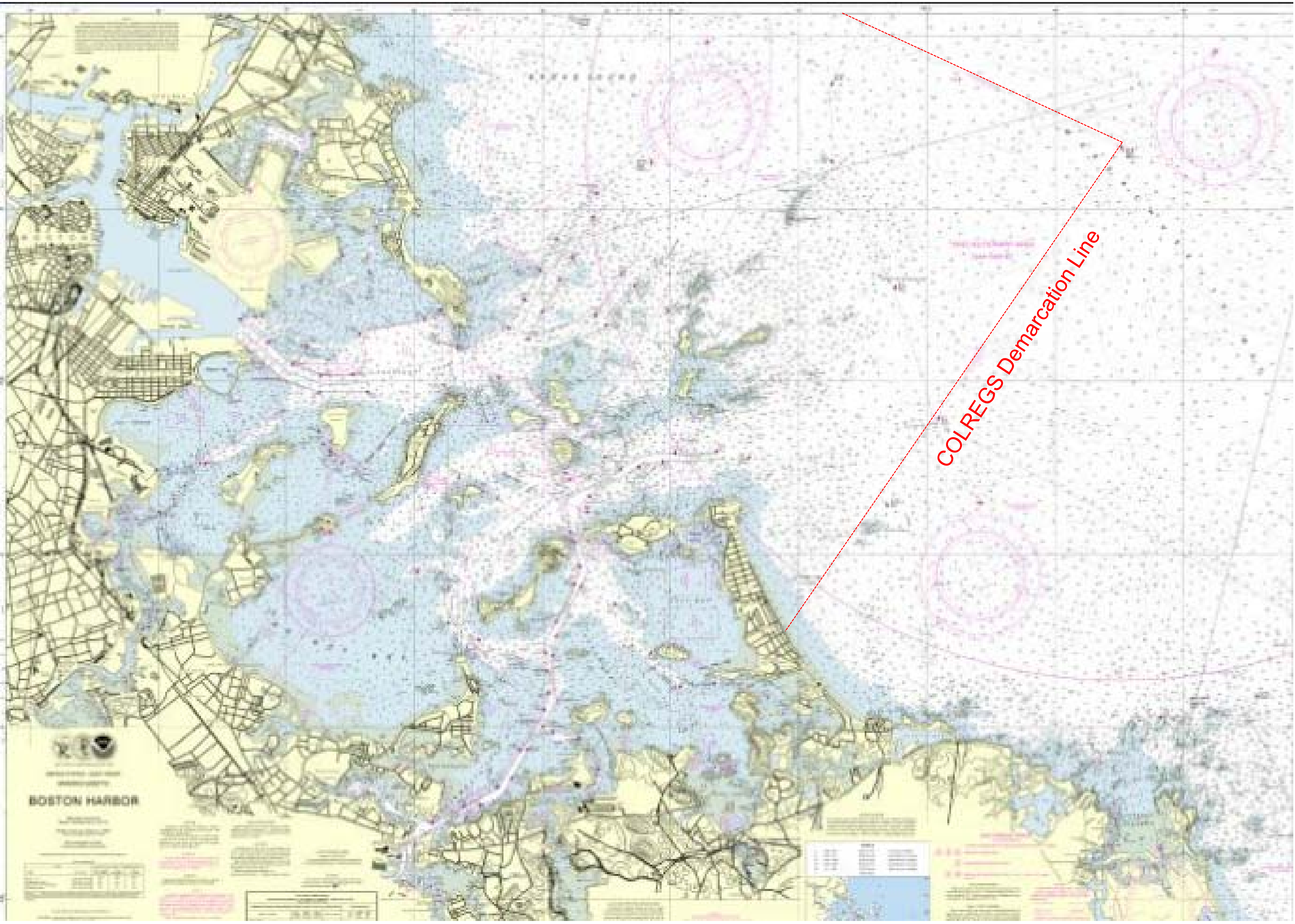
United States
Coast Guard

NAVIGATION RULES

INTERNATIONAL—INLAND



UPDATED COMDTINST M16672.2D
INCLUDES NOTICE TO MARINERS
52/00 & 16/04



COLREGS Demarcation Line
BOSTON HARBOR

Tidal Currents

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

Current Table

BOSTON HARBOR (Deer Island Light)

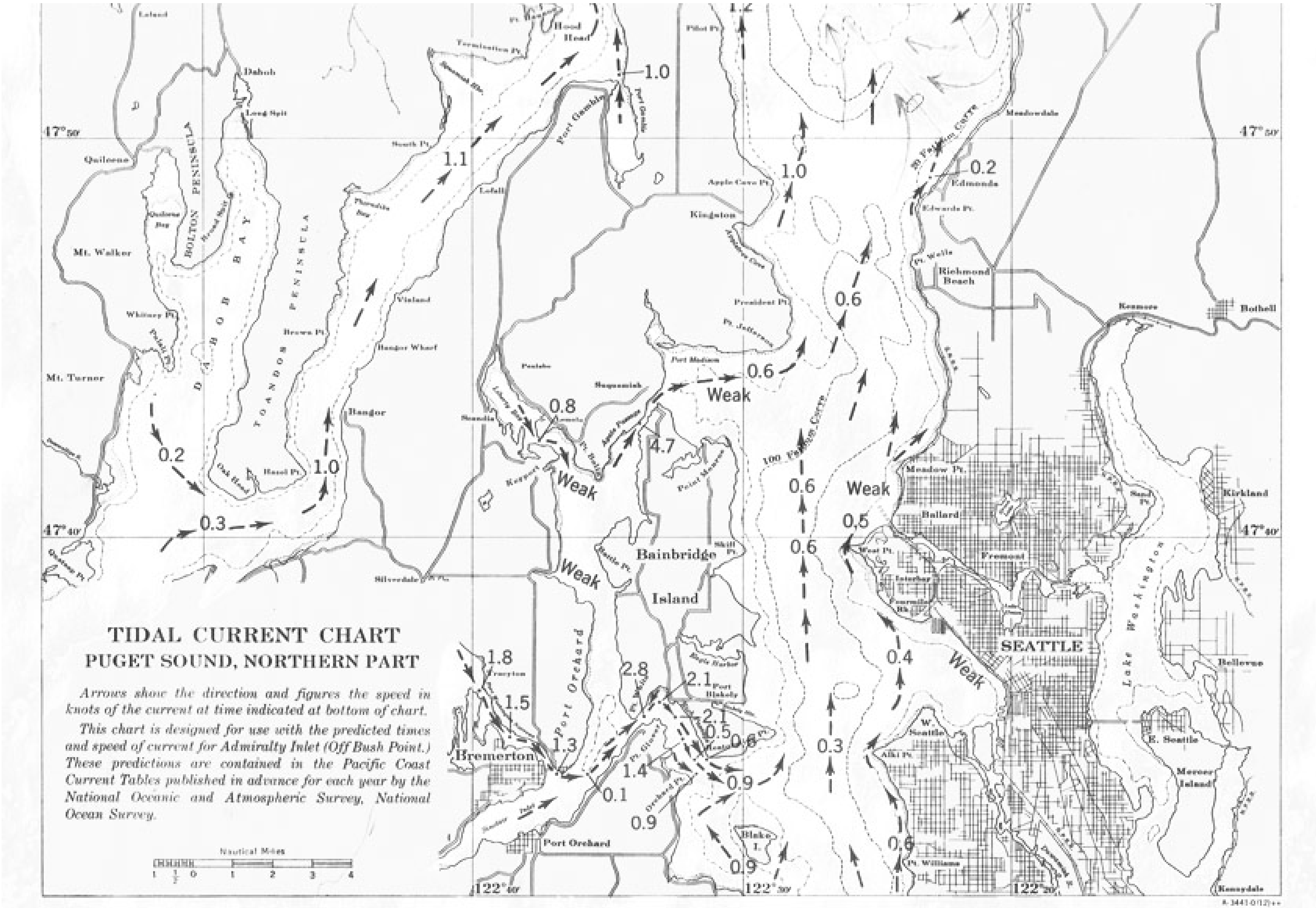
Predicted Tidal Current — April, 2008

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



ONE HOUR BEFORE MAXIMUM EBB OFF BUSH POINT. (E−1)

Tidal Currents

Rule of Thirds and 50/90 Rule

Slack Water — Max Current C (kt) — Slack Water

	Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6
Drift	1/3 C (nm)	2/3 C (nm)	3/3 C (nm)	3/3 C (nm)	2/3 C (nm)	1/3 C (nm)

Current (kt): 0 | .5C | .9C | C | .9C | .5C | 0

Basic Navigational Inputs

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

Outline

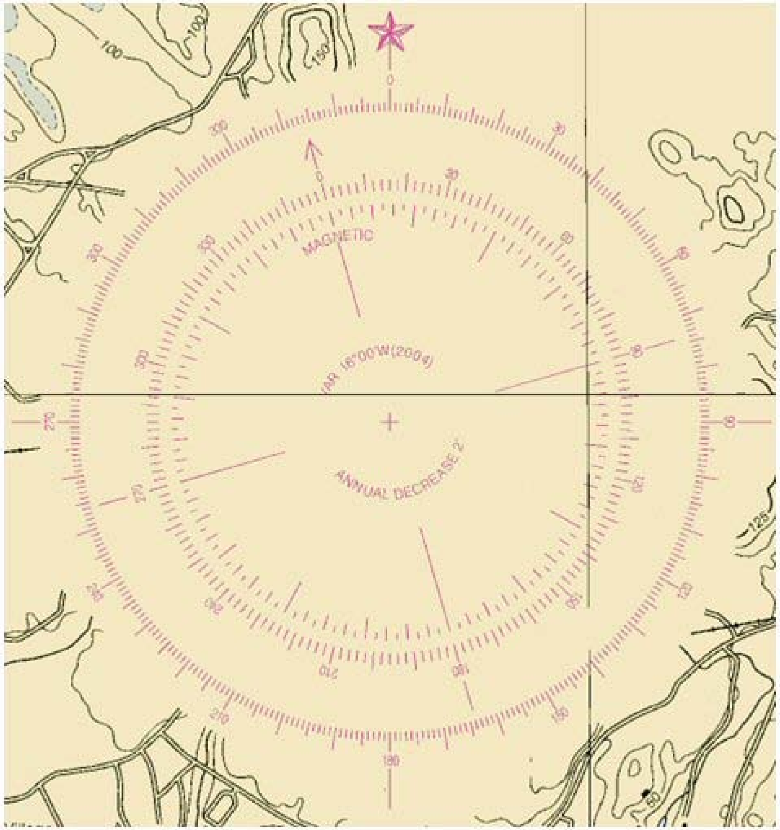
- Review
  - Nautical Chart types and scales
  - Buoyage System (IALA Region B)
  - Light characteristics
  - “Rules of the Road”
  - Tidal currents
  - Basic navigational inputs
- Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore 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 (less good)
  - By reference to wind (e.g., close hauled, broad reach)

- Use your chart plotter or parallel rulers on the chart to determine the direction to your destination
  - This will be a True Course
    - Professional navigators always plot True Course on the chart
    - Some navigators prefer to plot Magnetic 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 your chart when you are tired and seasick
  - Others will be reading your chart under similar conditions



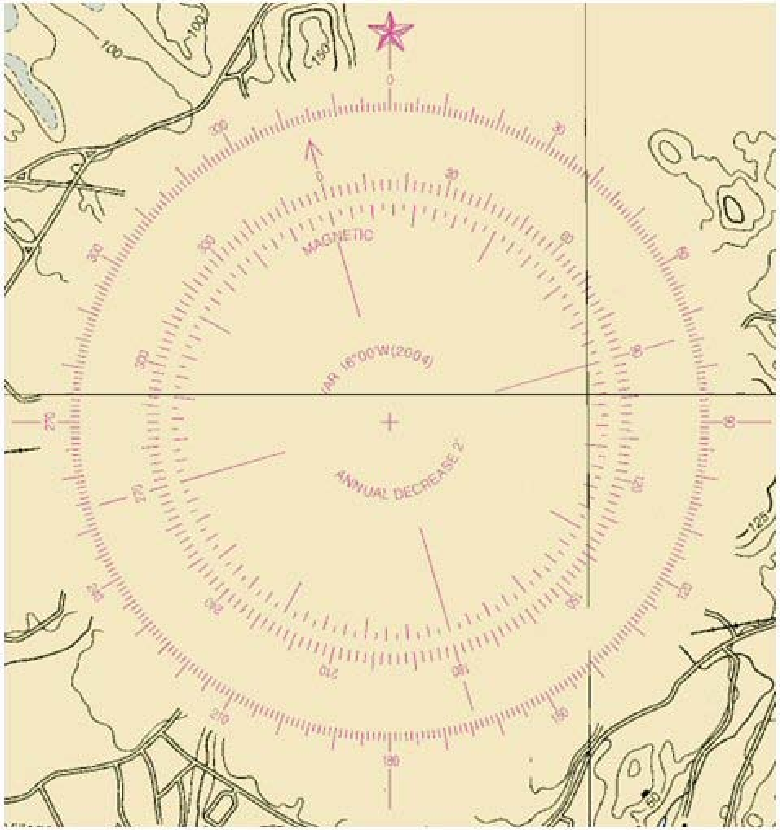
Plotting your Desired Course

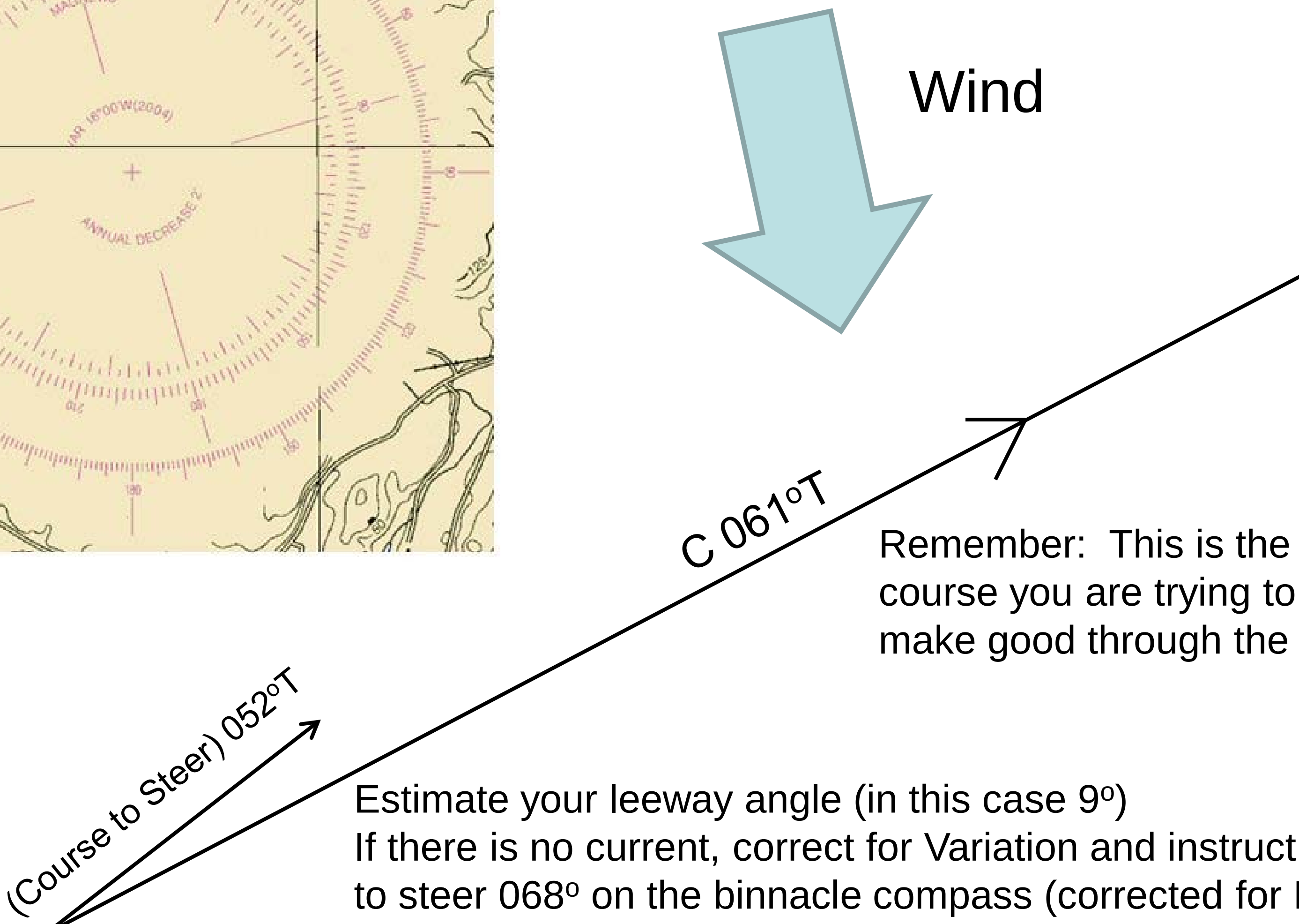
C 061°T or C 077°M

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

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 steered in the ship’s log

Correcting for Leeway
(no current)



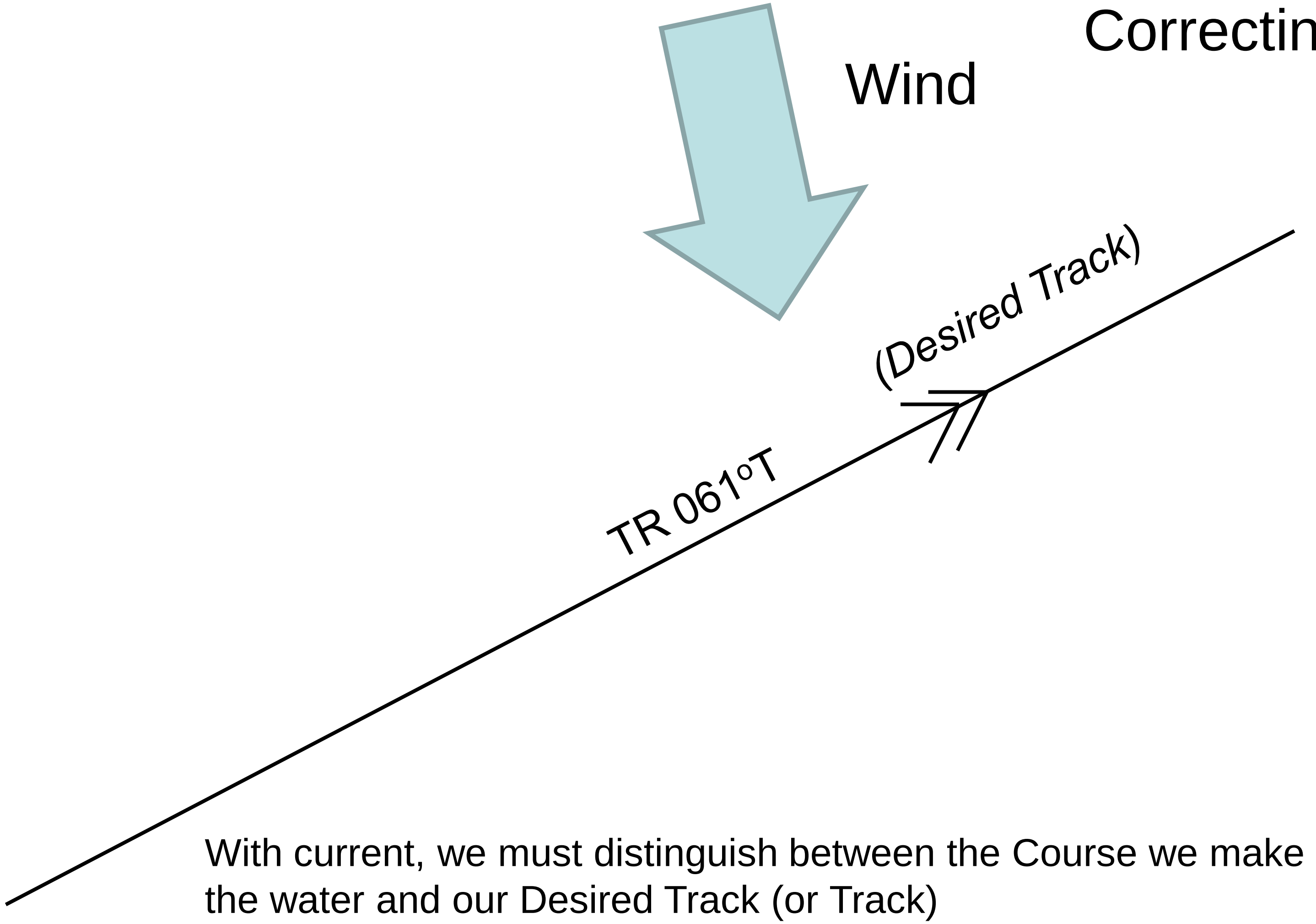


Remember: This is the course you are trying to make good through the water

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

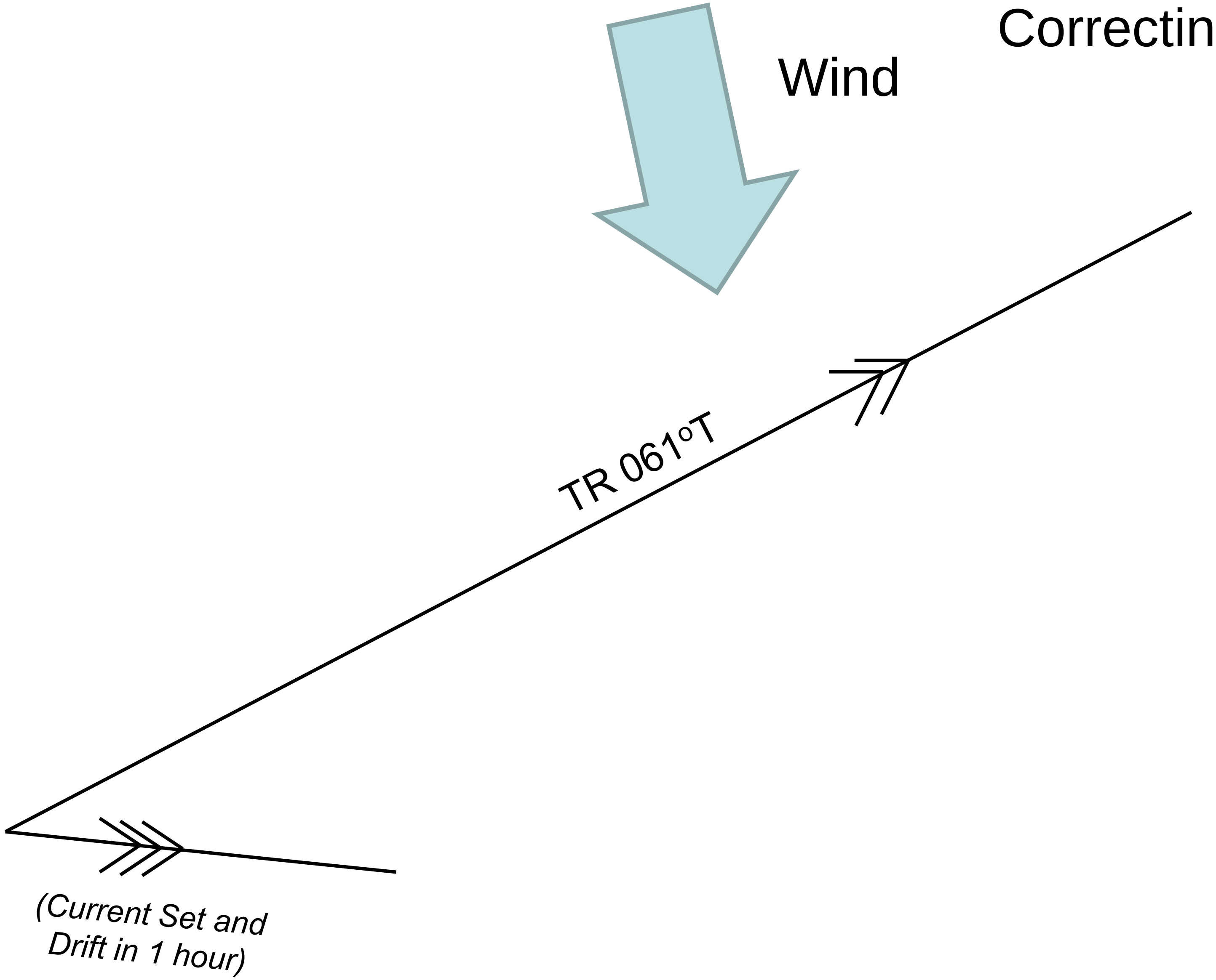


With current, we must distinguish between the Course we make good through the water and our Desired Track (or Track)

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

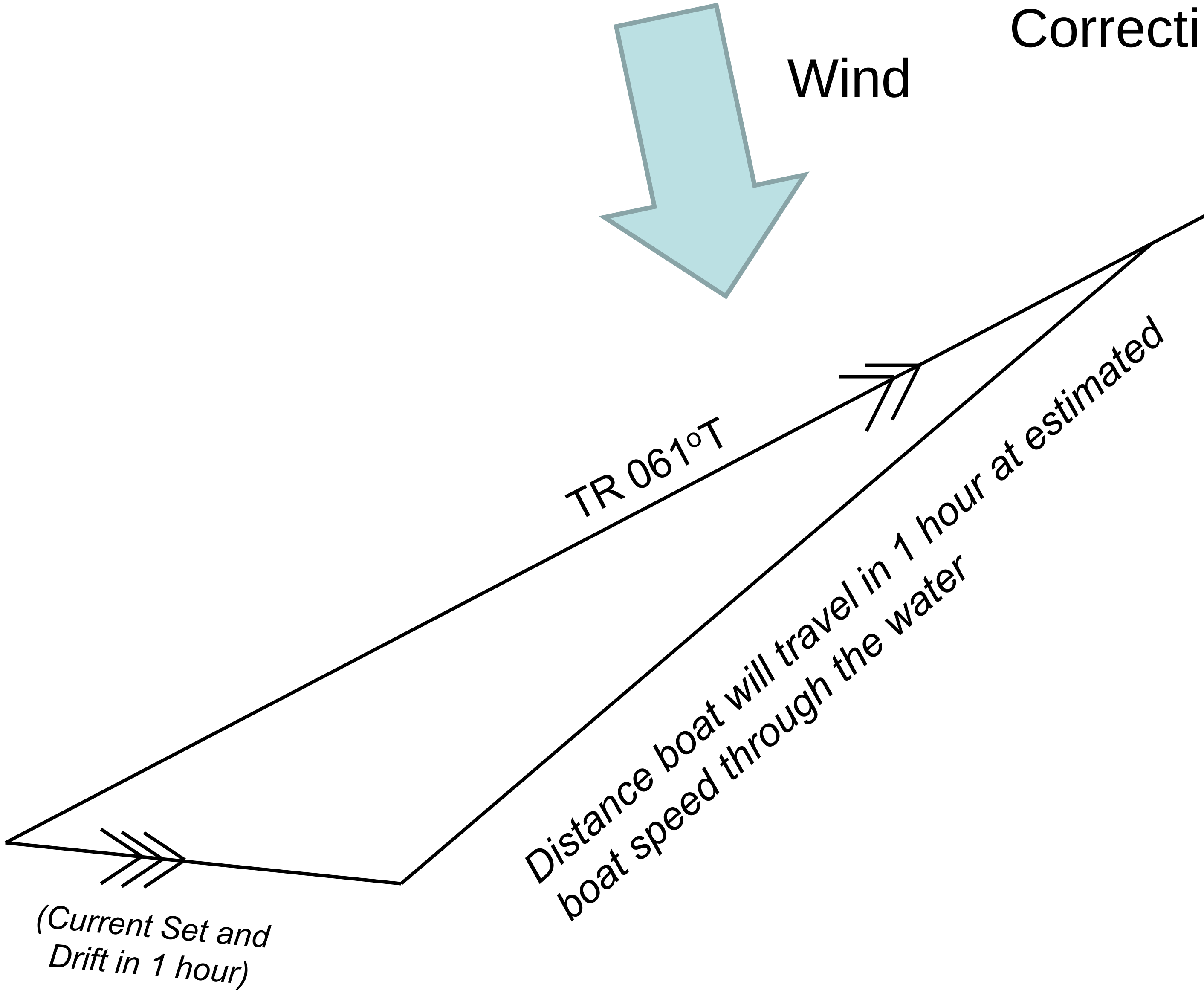
Correcting for Current



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

Label it as a current vector

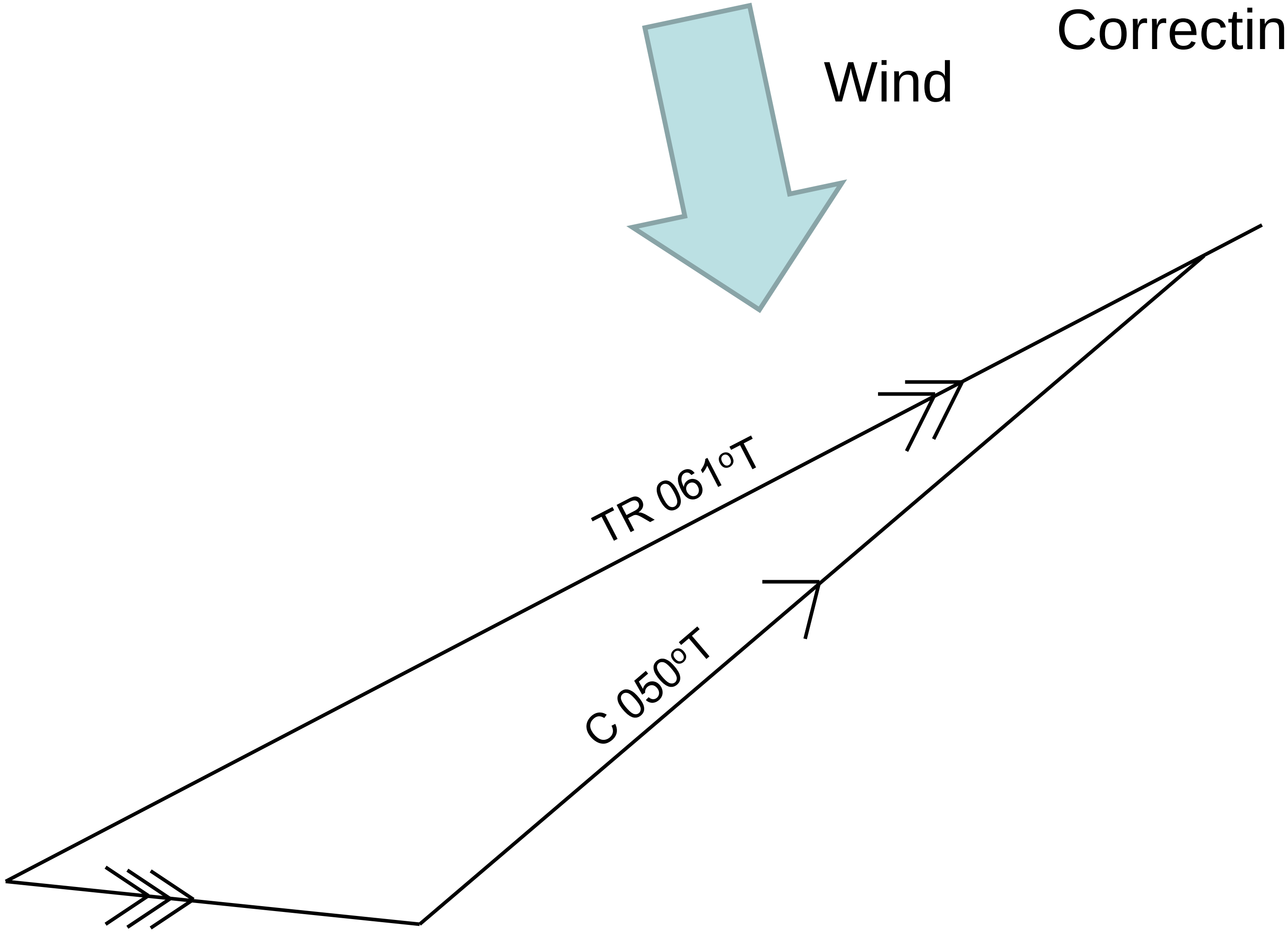
Correcting for Current



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

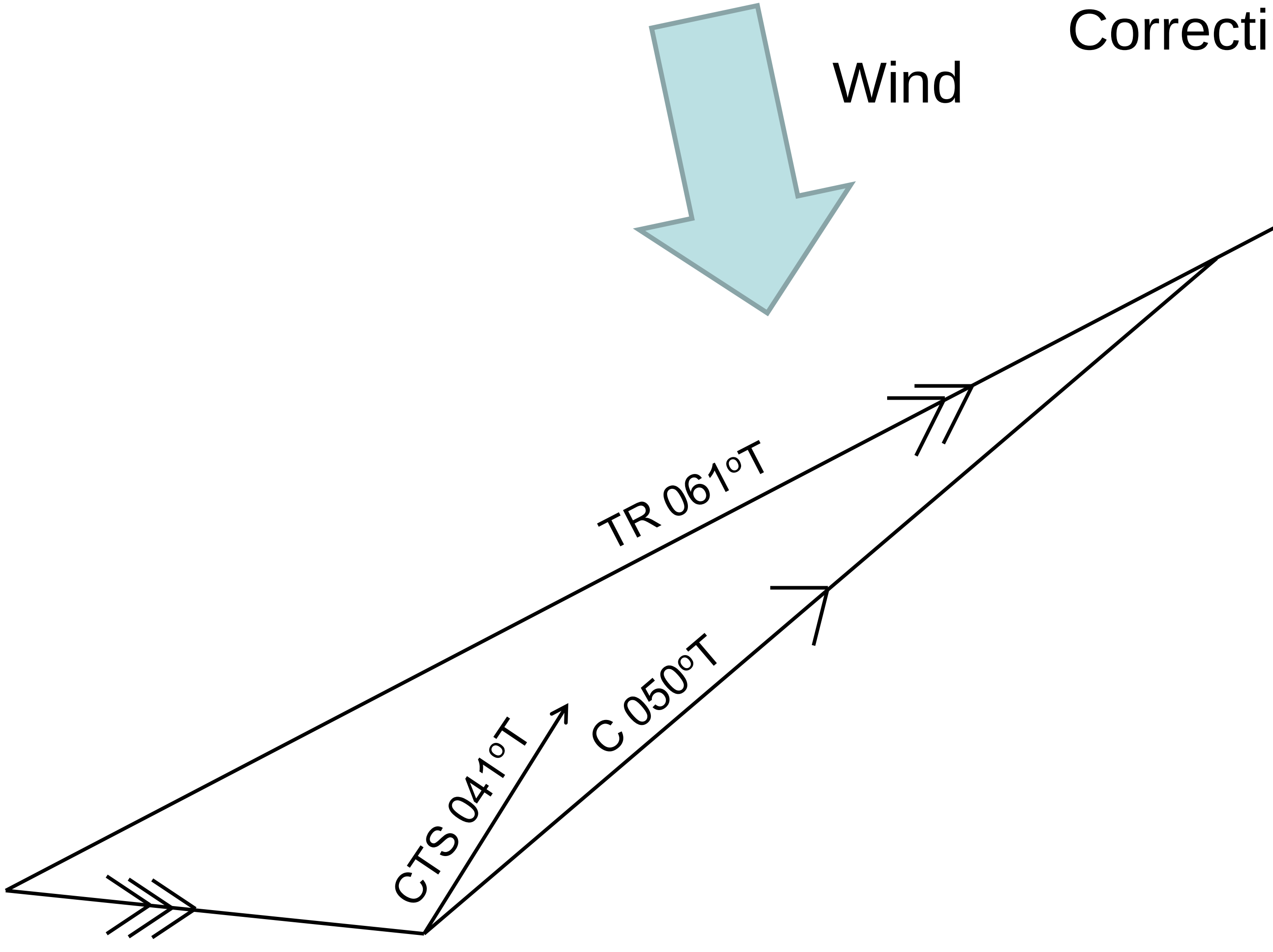
Note: You don't have to use 1 hour, it just makes the math easier

Correcting for Current



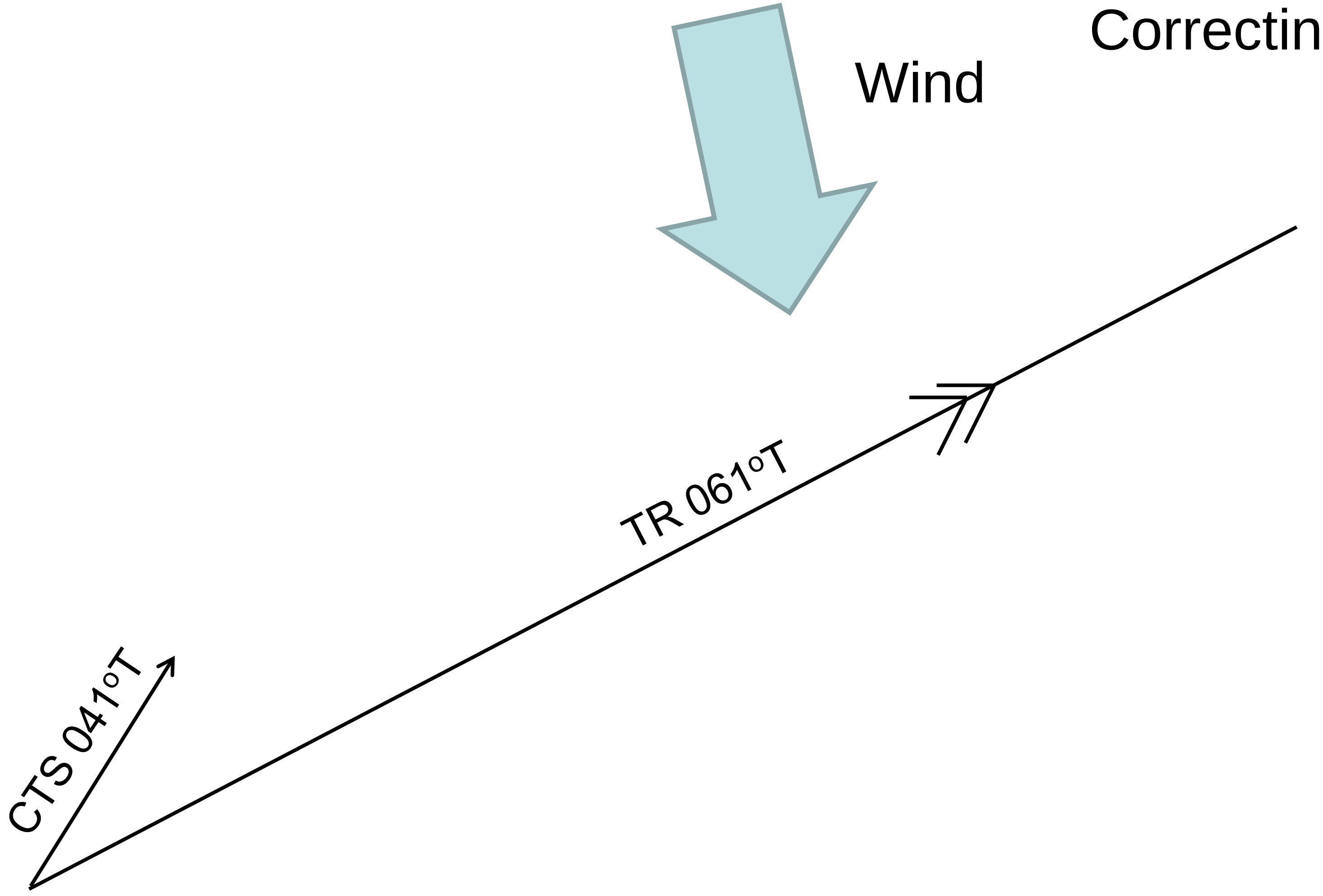
Label the desired course made good through the water

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
  - Buoyage System (IALA Region B)
  - Light characteristics
  - Basic navigational inputs

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

The Ship's Log

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

The 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

The 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

The 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?

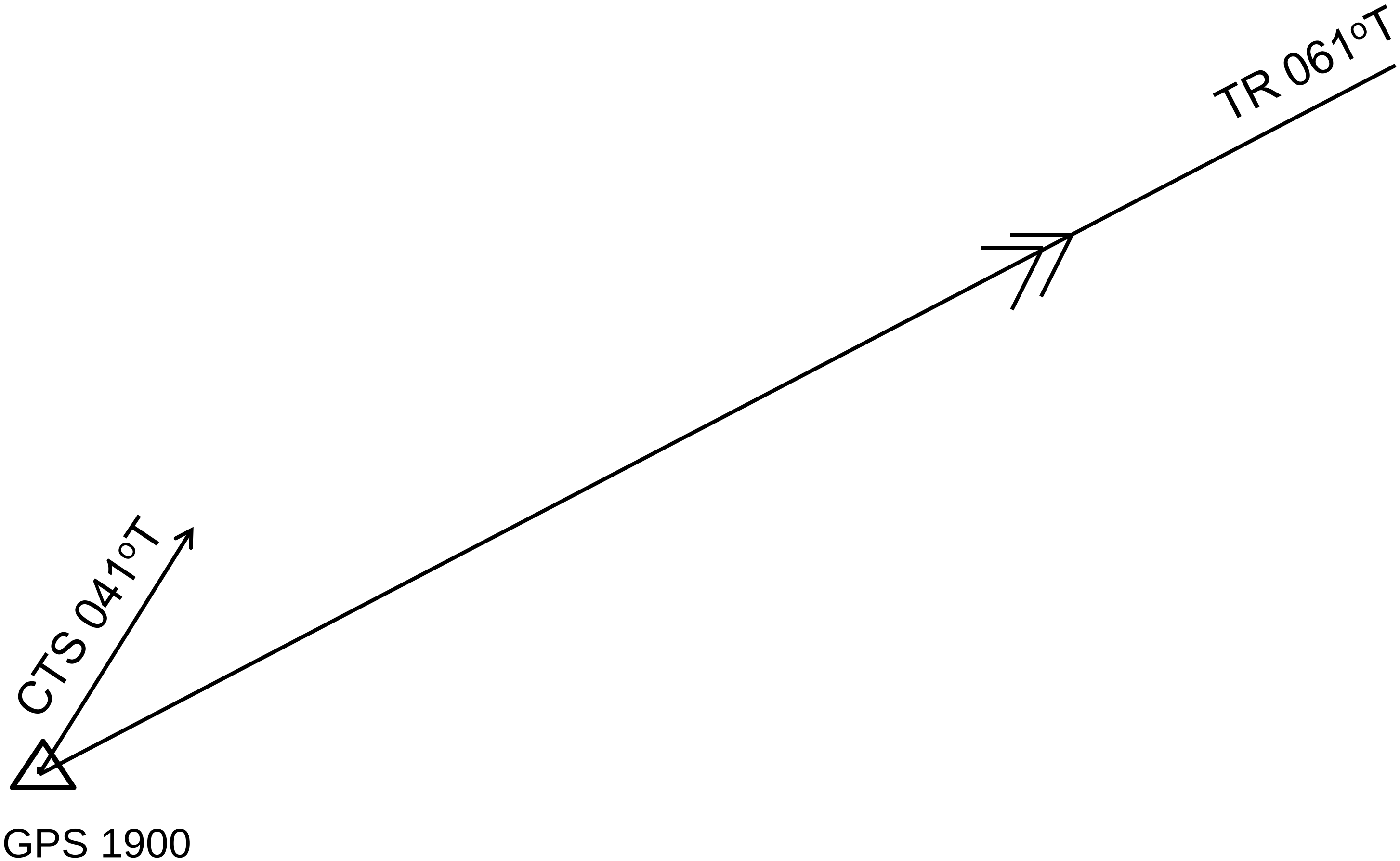
What do we do next?

Estimating Your Position

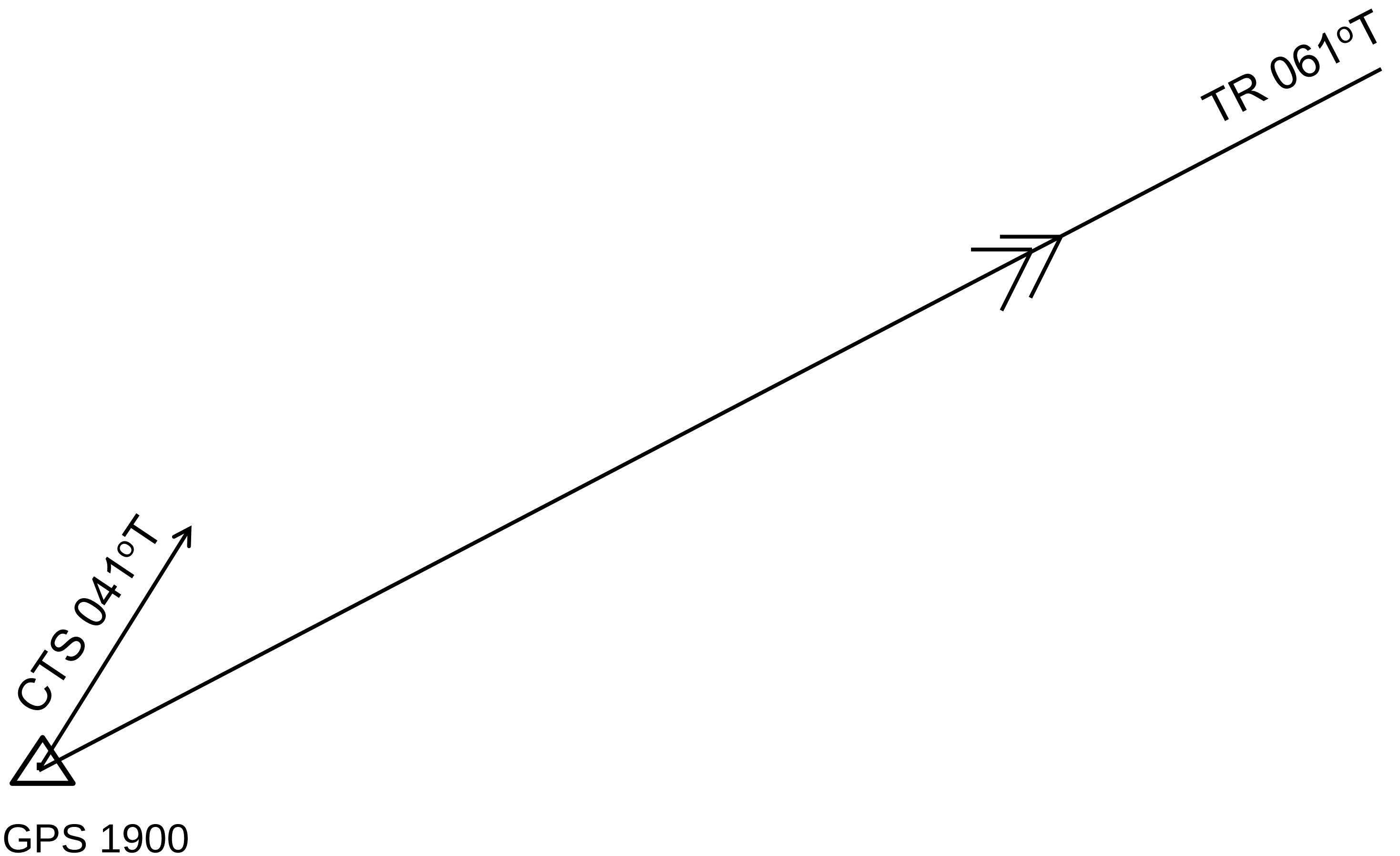
- Plot a Dead Reckoning Position
  - Course steered and distance logged
  - Use ship’s log as the source of information

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

Plotting a Dead Reckoning Position



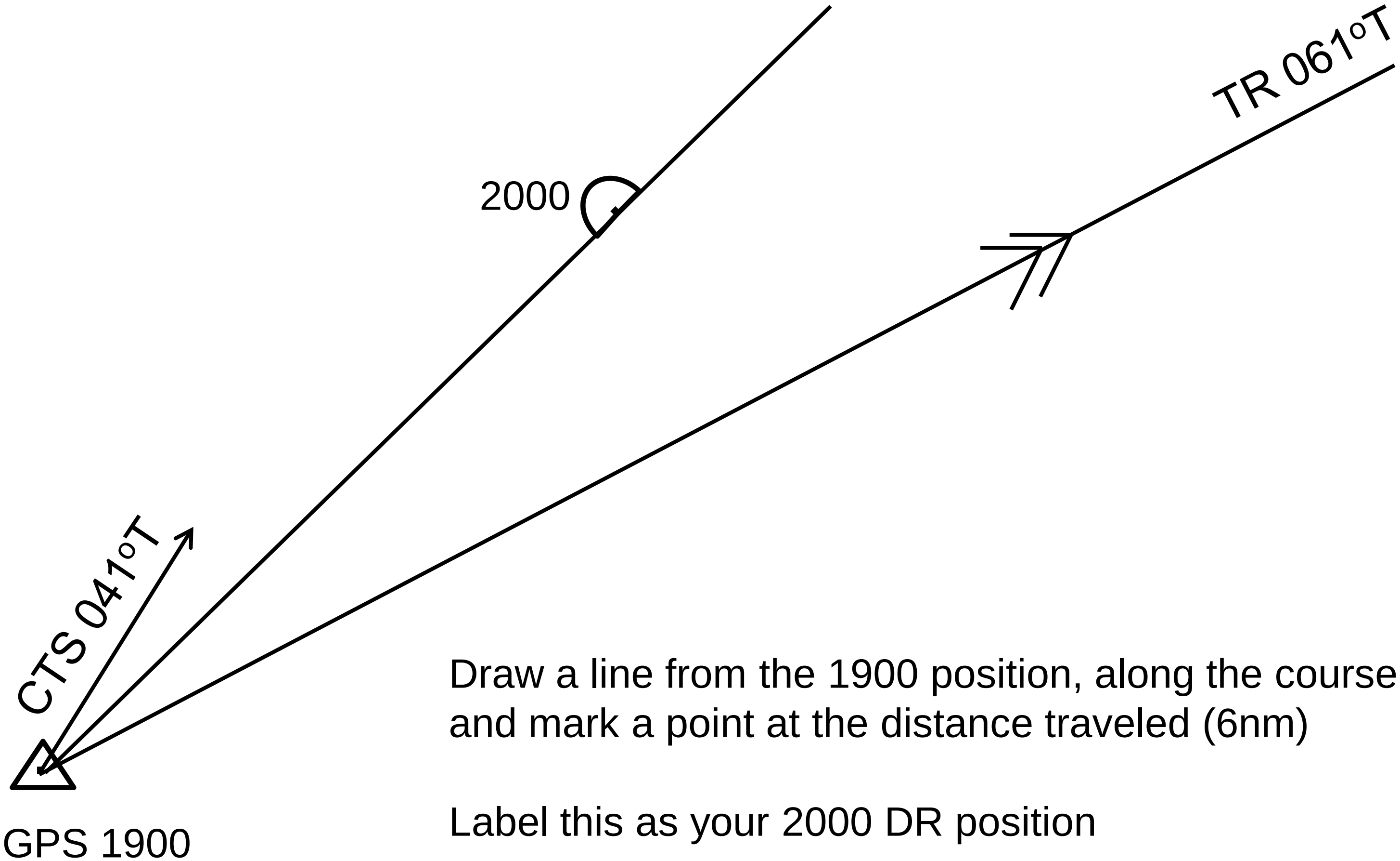
Plotting a Dead Reckoning Position



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

Course steered was 046ºT (Remember: TVMDC)

Plotting a Dead Reckoning Position

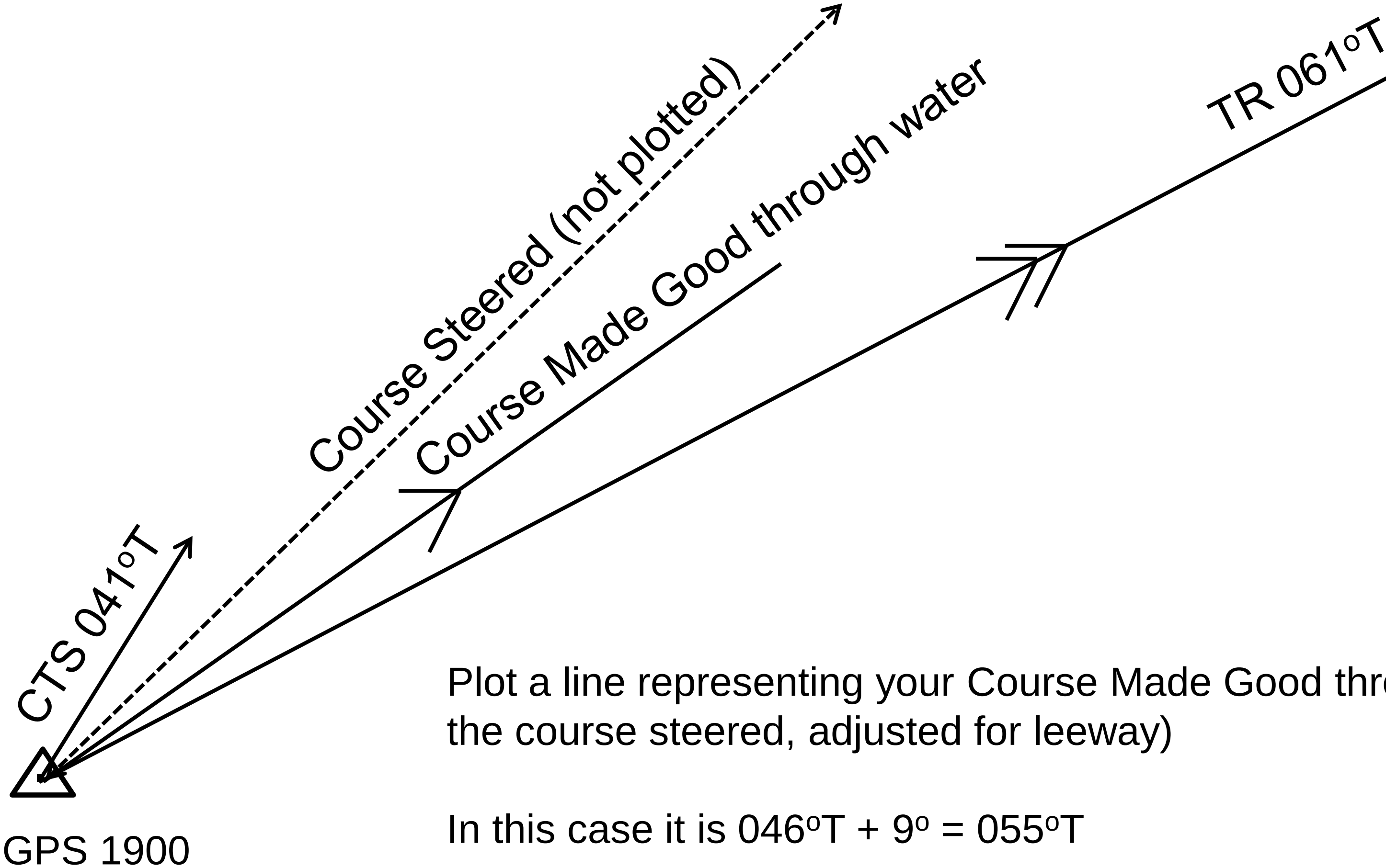


Draw a line from the 1900 position, along the course steered (046°T) and mark a point at the distance traveled (6nm)

Label this as your 2000 DR position

NOTE: DR position is not corrected for leeway or current

Plotting an Estimated Position

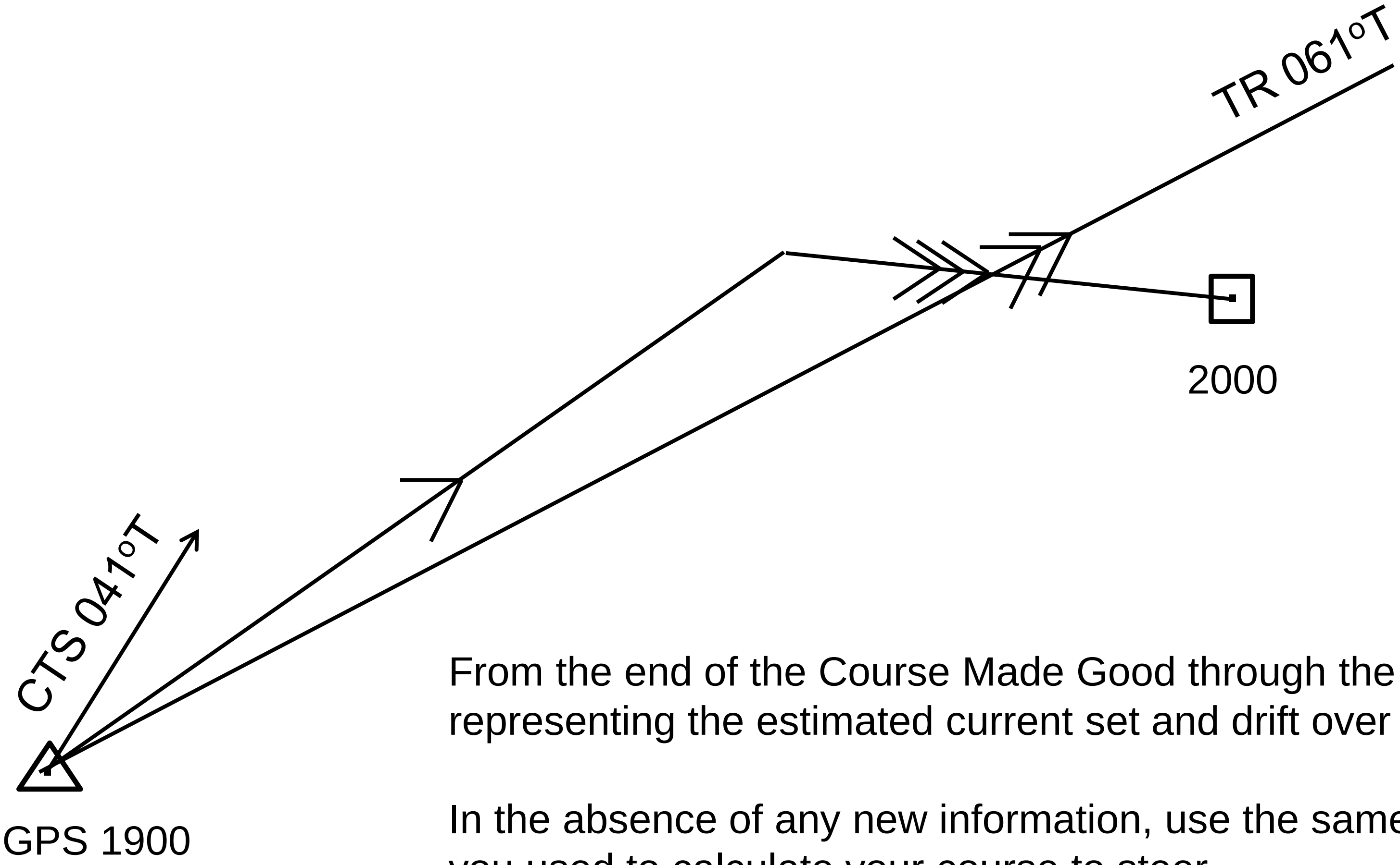


Plot a line representing your Course Made Good through the water (i.e., the course steered, adjusted for leeway)

In this case it is 046ºT + 9º = 055ºT

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

Plotting an Estimated Position

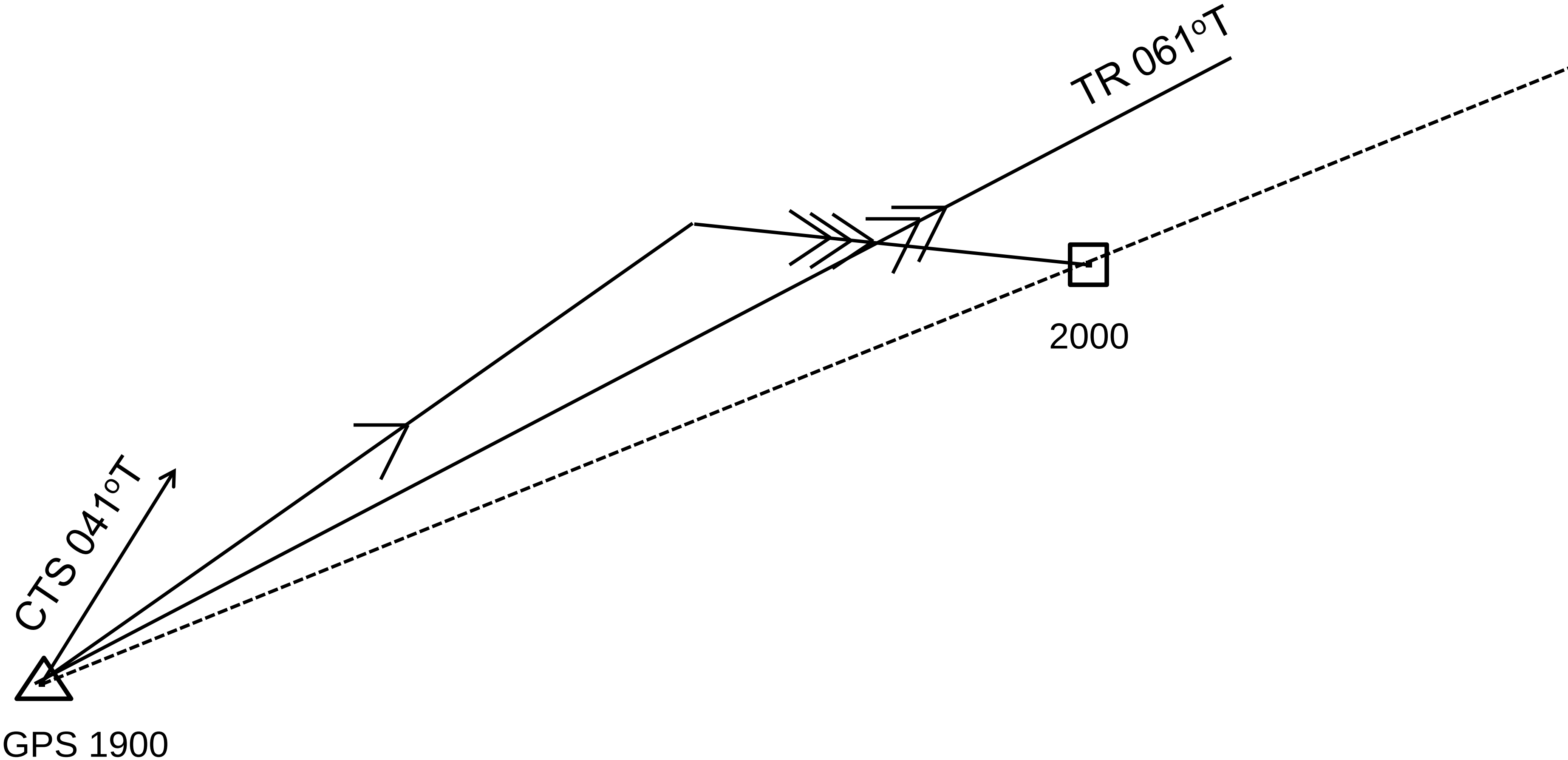


From the end of the Course Made Good through the water, plot a line representing the estimated current set and drift over the time period

In the absence of any new information, use the same set and drift that you used to calculate your course to steer

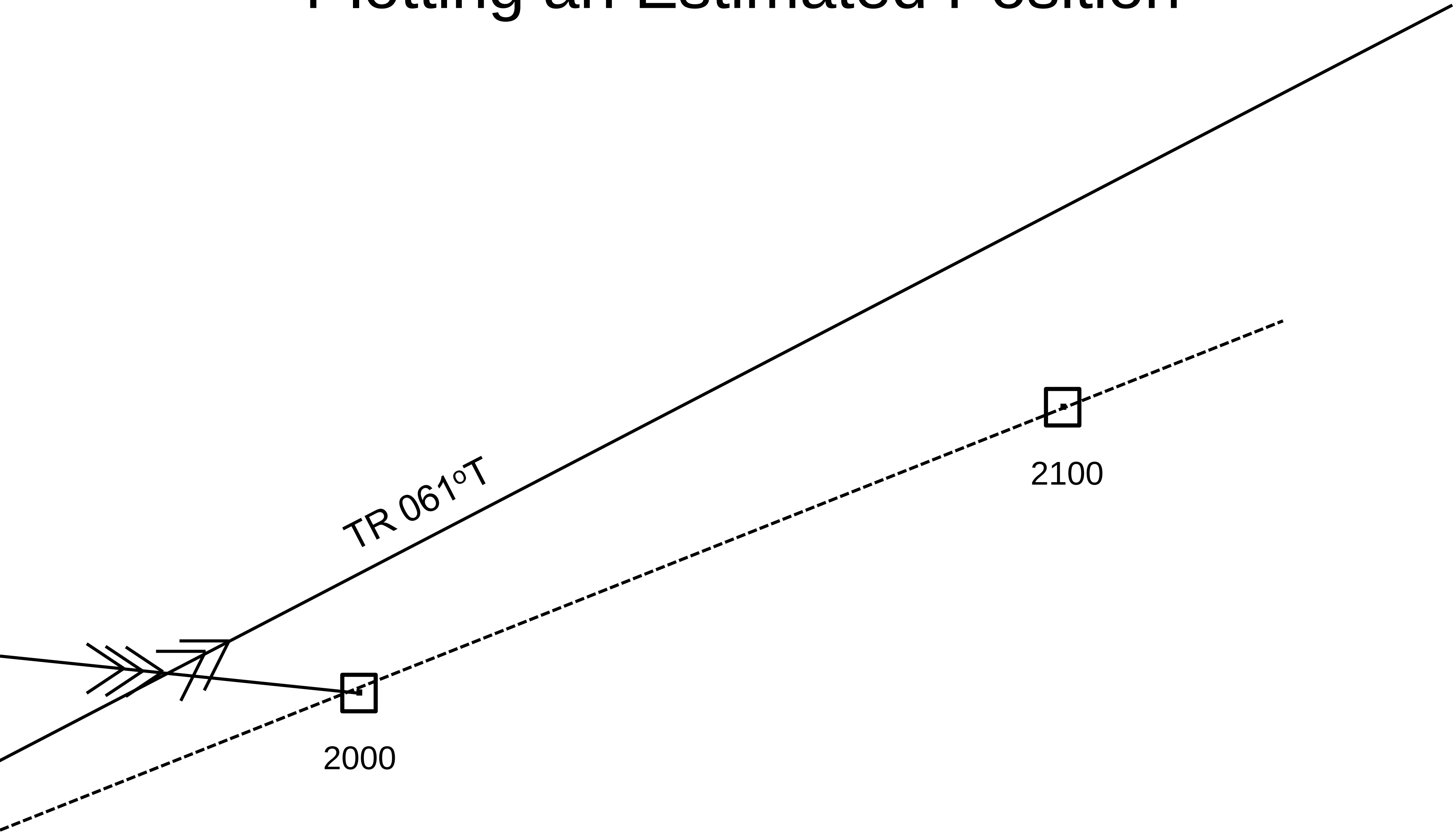
Label the resulting Estimated Position with the time

Plotting an Estimated Position



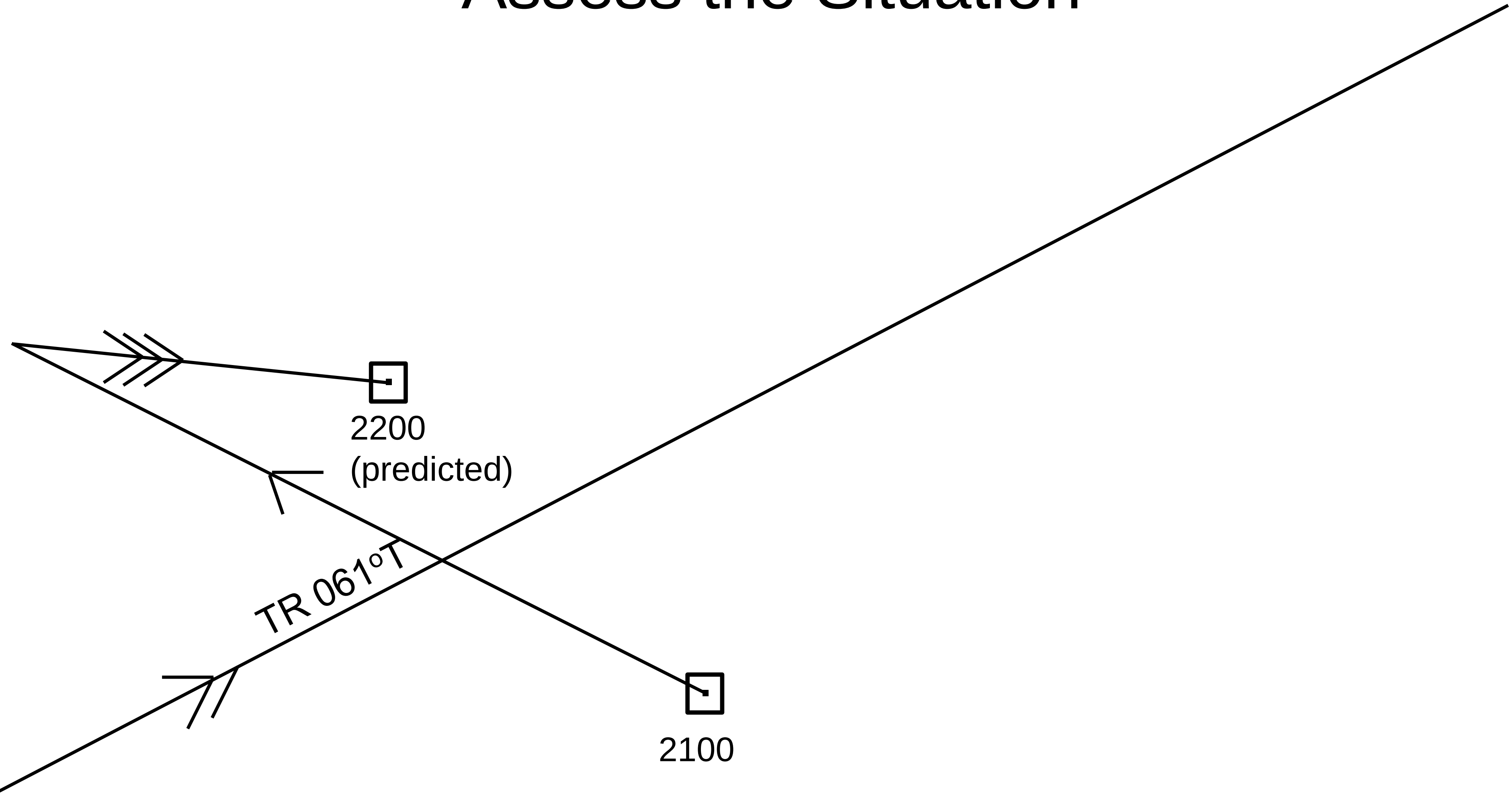
Since nothing changed between 2000 and 2100, you can simply lay your plotting tool along a line between the 1900 GPS Fix and the 2000 EP and mark the 2100 EP along the extension of that line

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

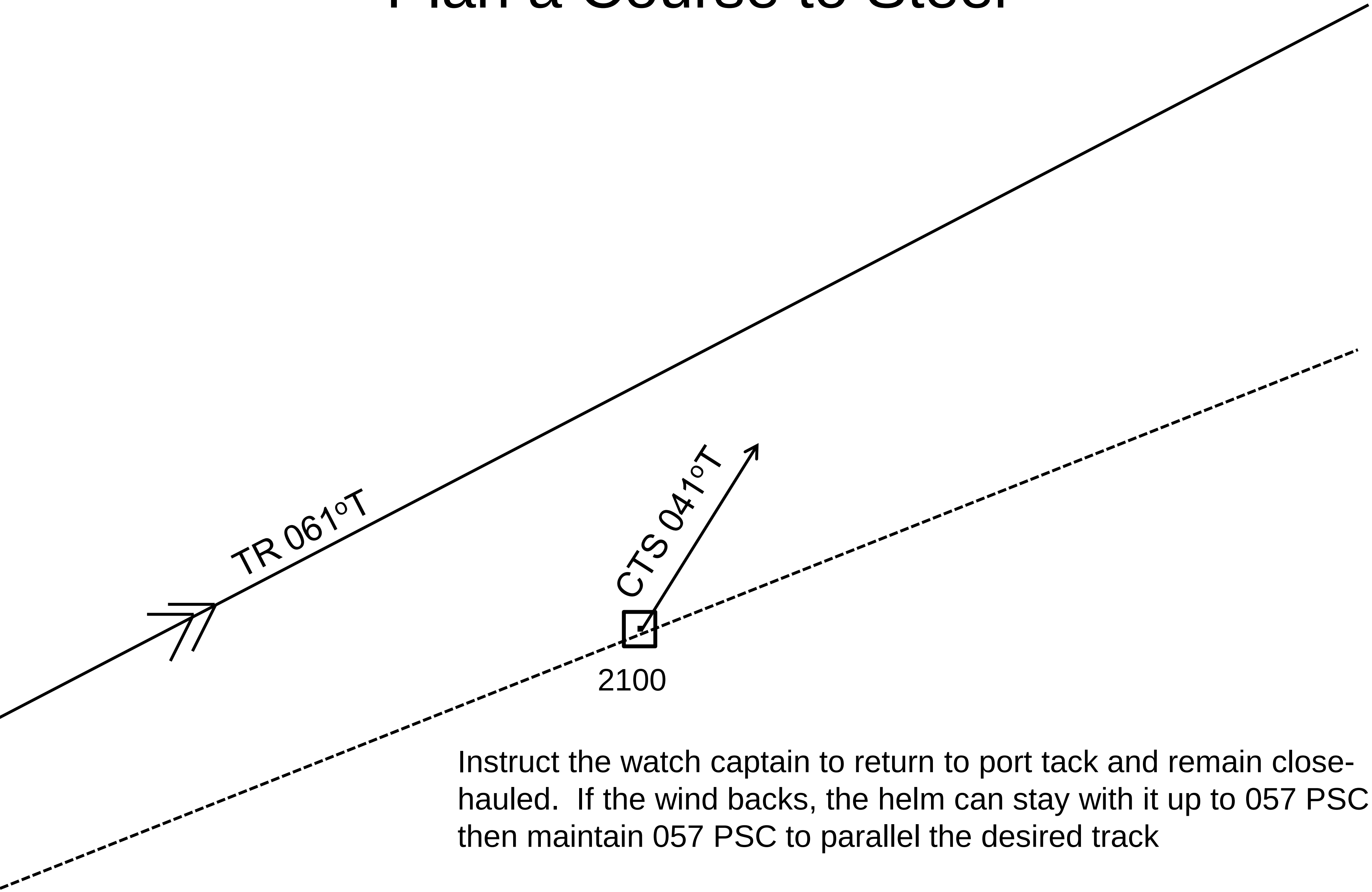


On the present tack, the helm is steering 322C (306T)

Accounting for leeway, the boat is making 297T through the water at ~6 knots

Even accounting for current, this looks like a bad tack

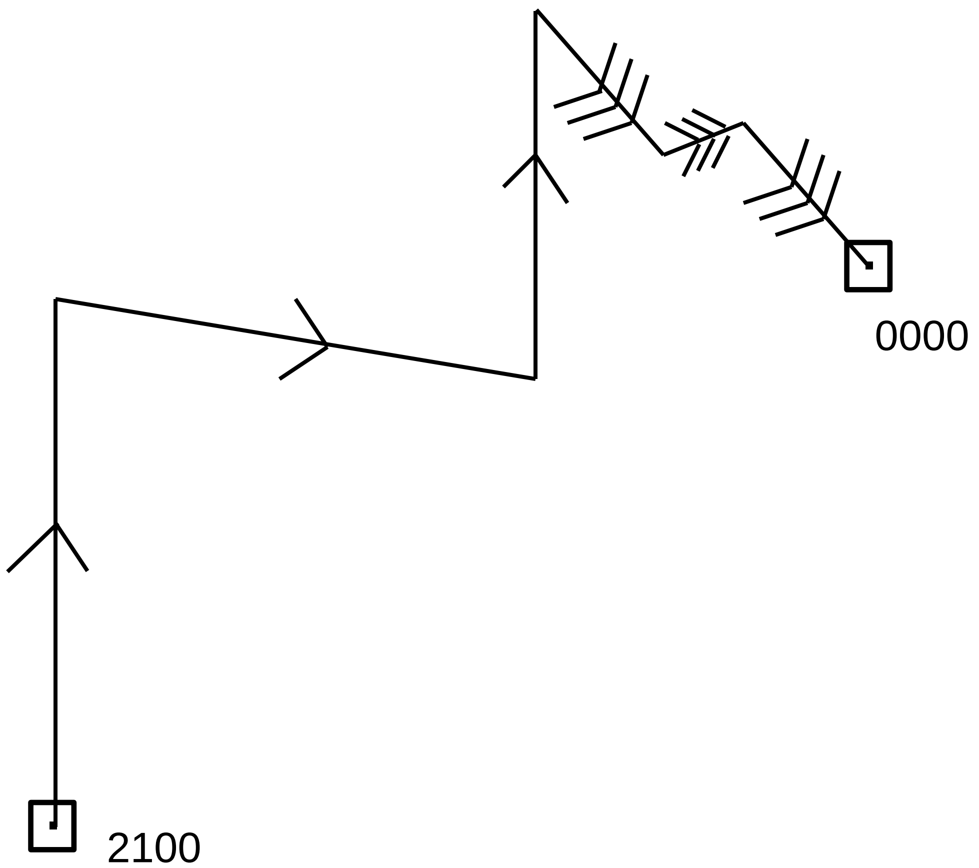
Plan a Course to Steer



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



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
  - Buoyage System (IALA Region B)
  - Light characteristics
  - “Rules of the Road”
  - Tidal currents
  - Basic navigational inputs

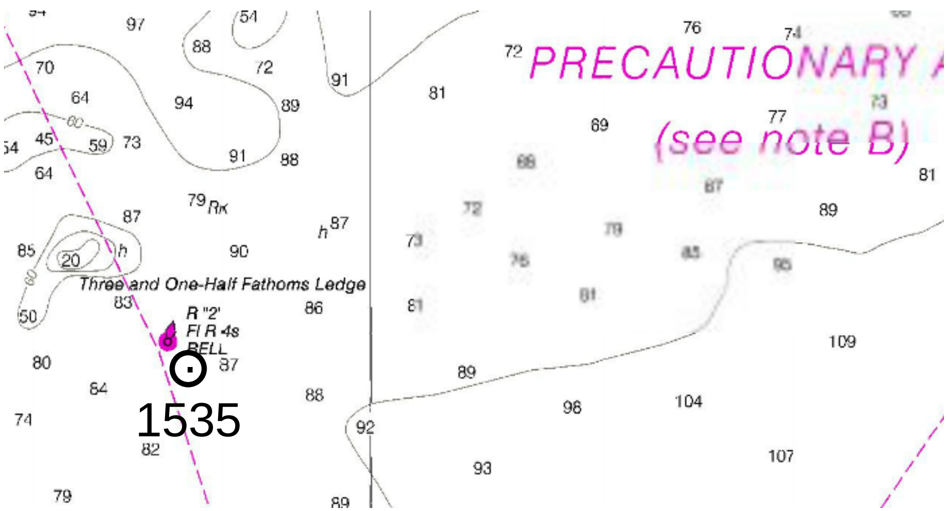
- Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore Pilotage

Knowing Where You Are

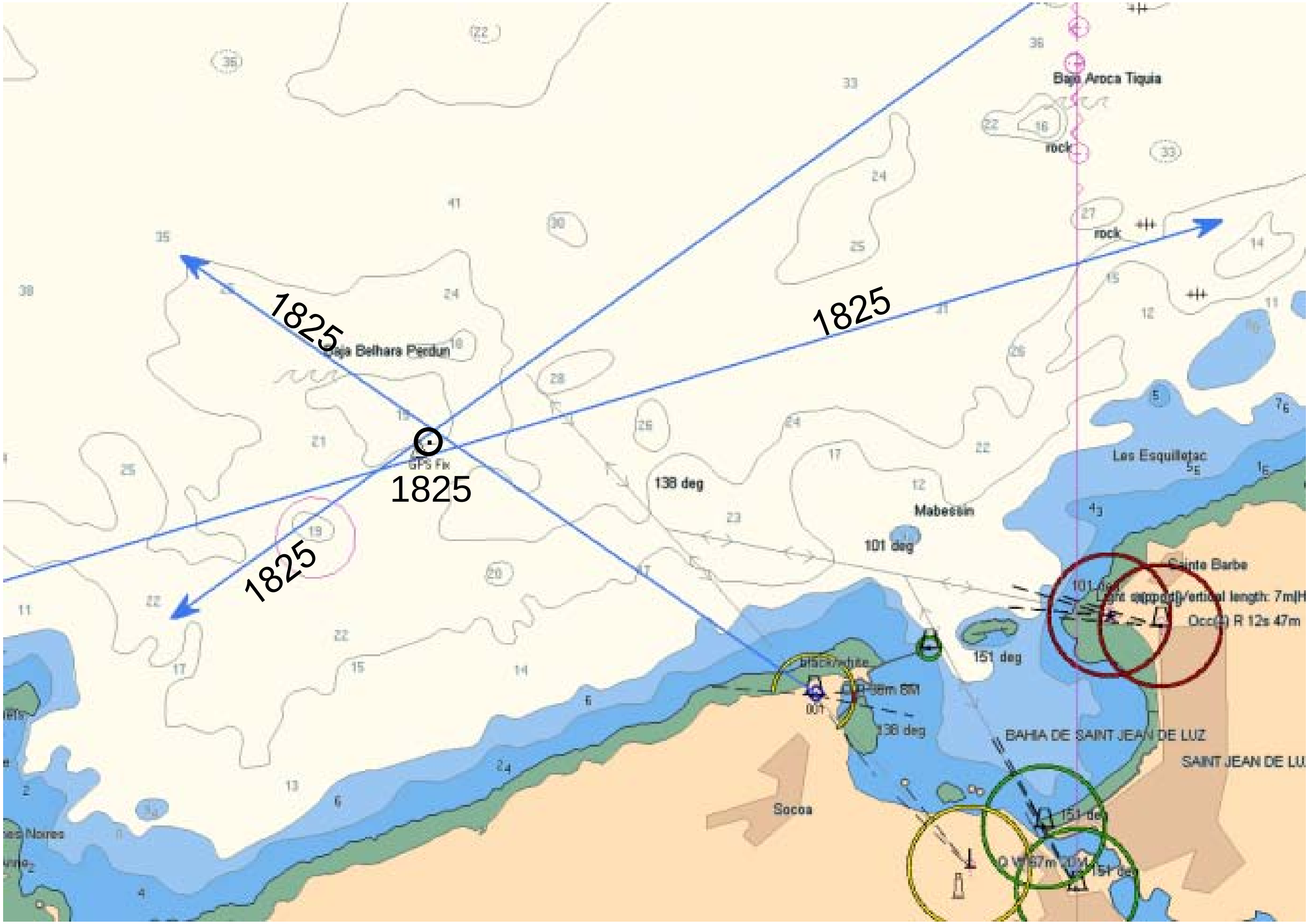
- Position by immediate observation
- Position Fixes defined by lines
- Running Fix

Position by Immediate Observation

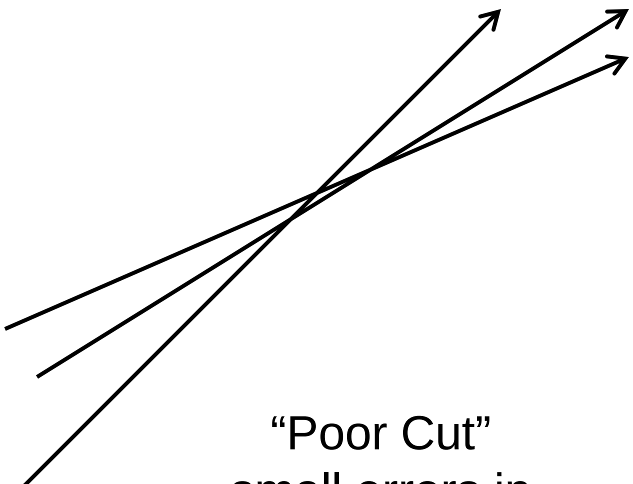
Log Entry: “ 1535: Abeam Red Bell #2 Three and One-Half Fathoms Ledge”



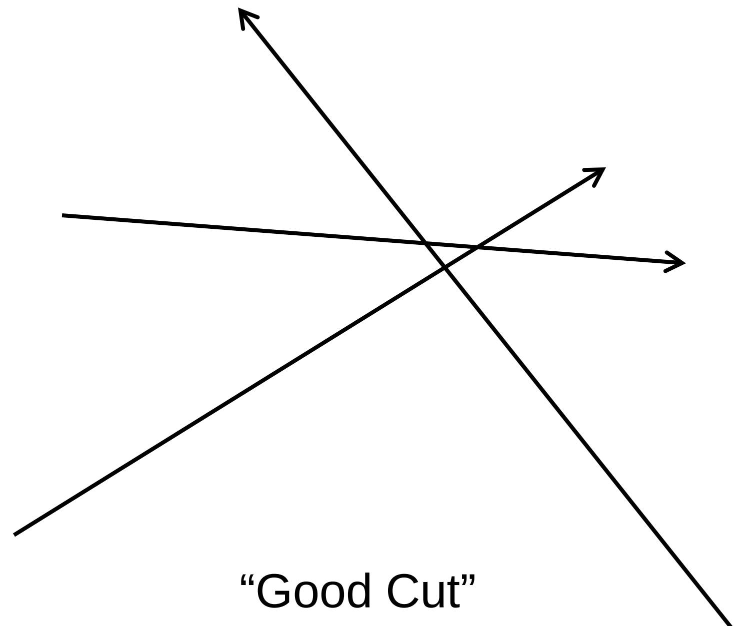
Position Defined by Lines



Position Defined by Lines



"Poor Cut"
small errors in
bearing produce
large position errors



"Good Cut"
position less
sensitive to bearing
errors

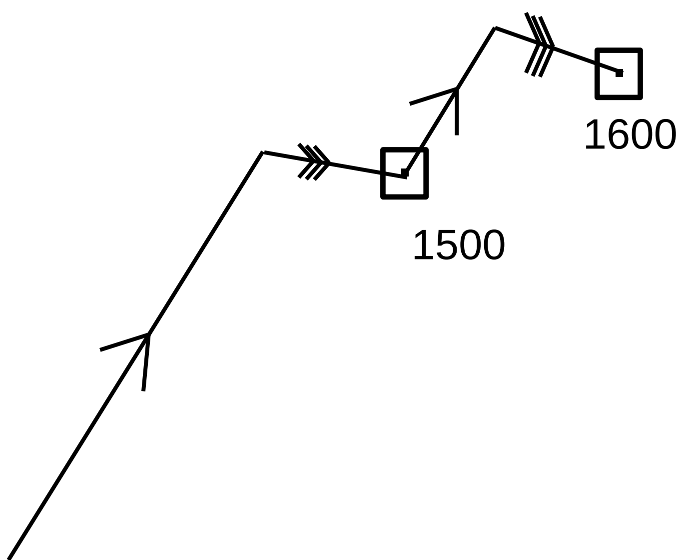
Try to select objects whose LOPs will intersect at 45^{o} or more

Sources of Lines of Position

- Ranges
  - “Official” range set up for navigation
    - Excellent quality
  - “Unofficial” range based on charted objects
    - Quality depends on objects chosen
- 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)

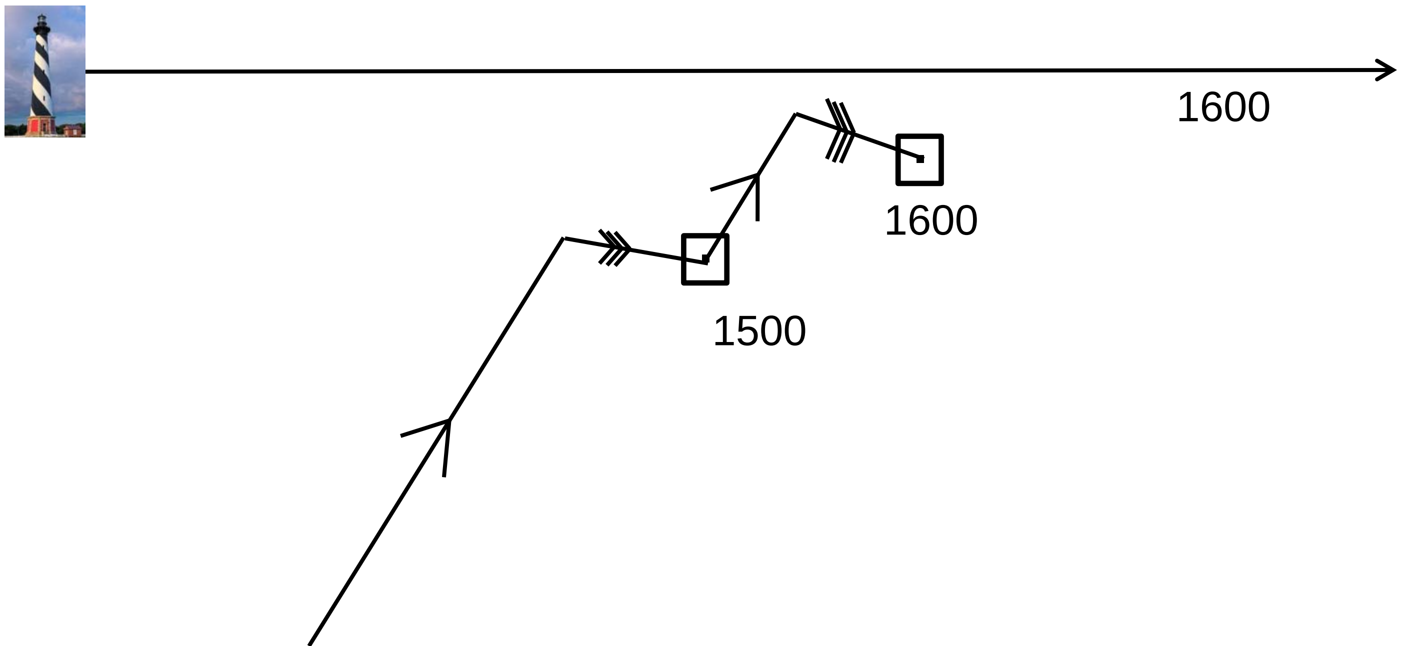
Using a Single Line of Position

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

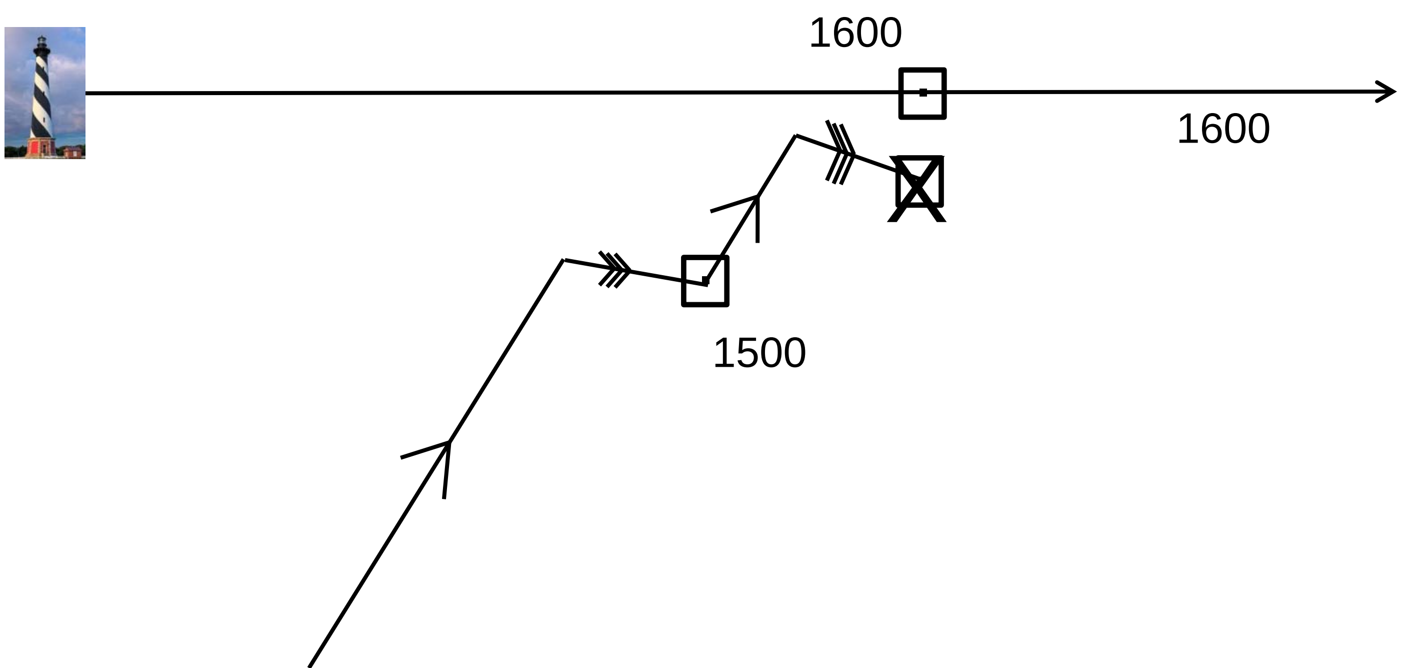
At 1600, you get a good single LOP from a mark



Using a Single Line of Position

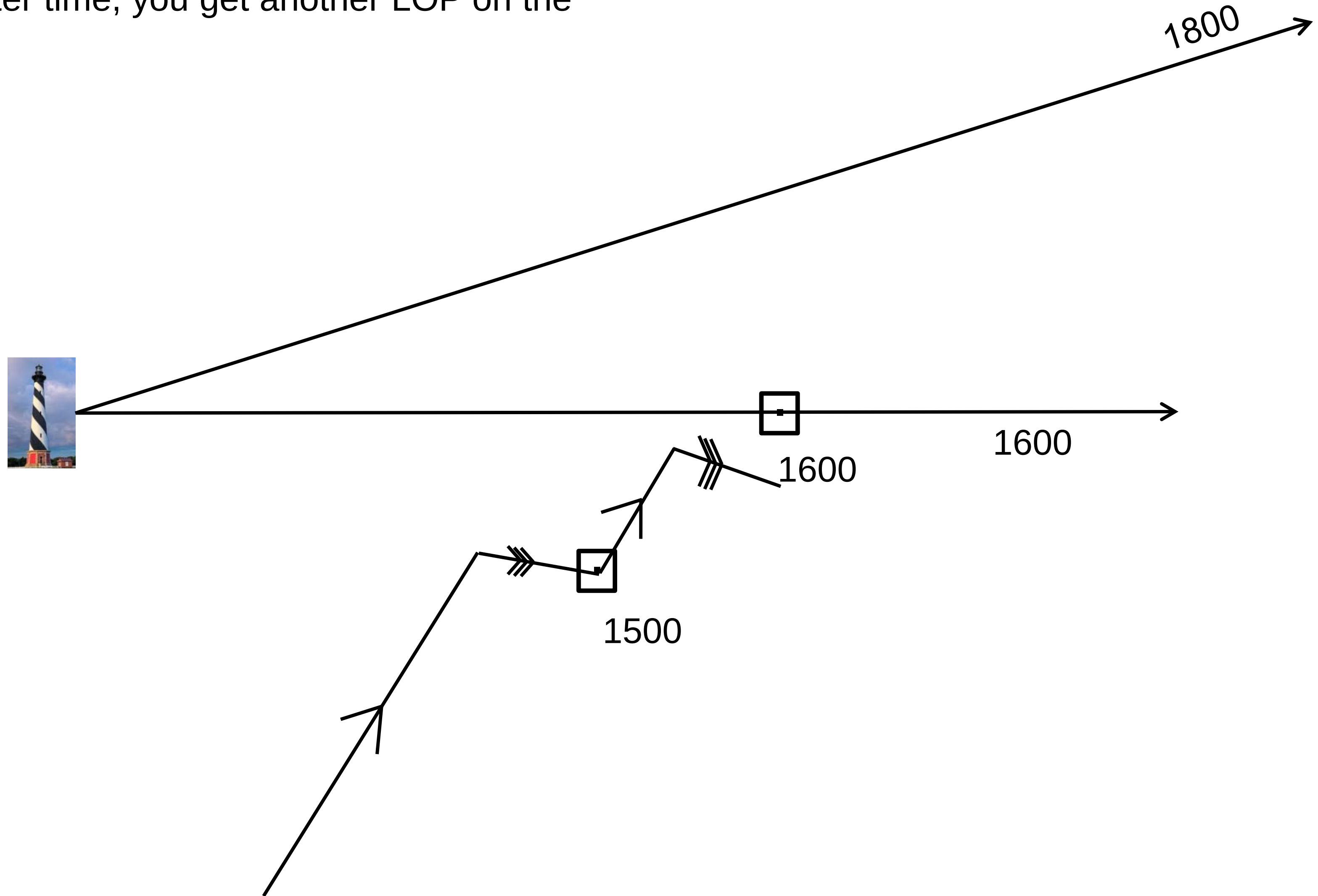
You can update your estimated position by moving it from your initial estimate to the closest point along the LOP

Note that this is not a fix. It is simply an adjusted estimated position



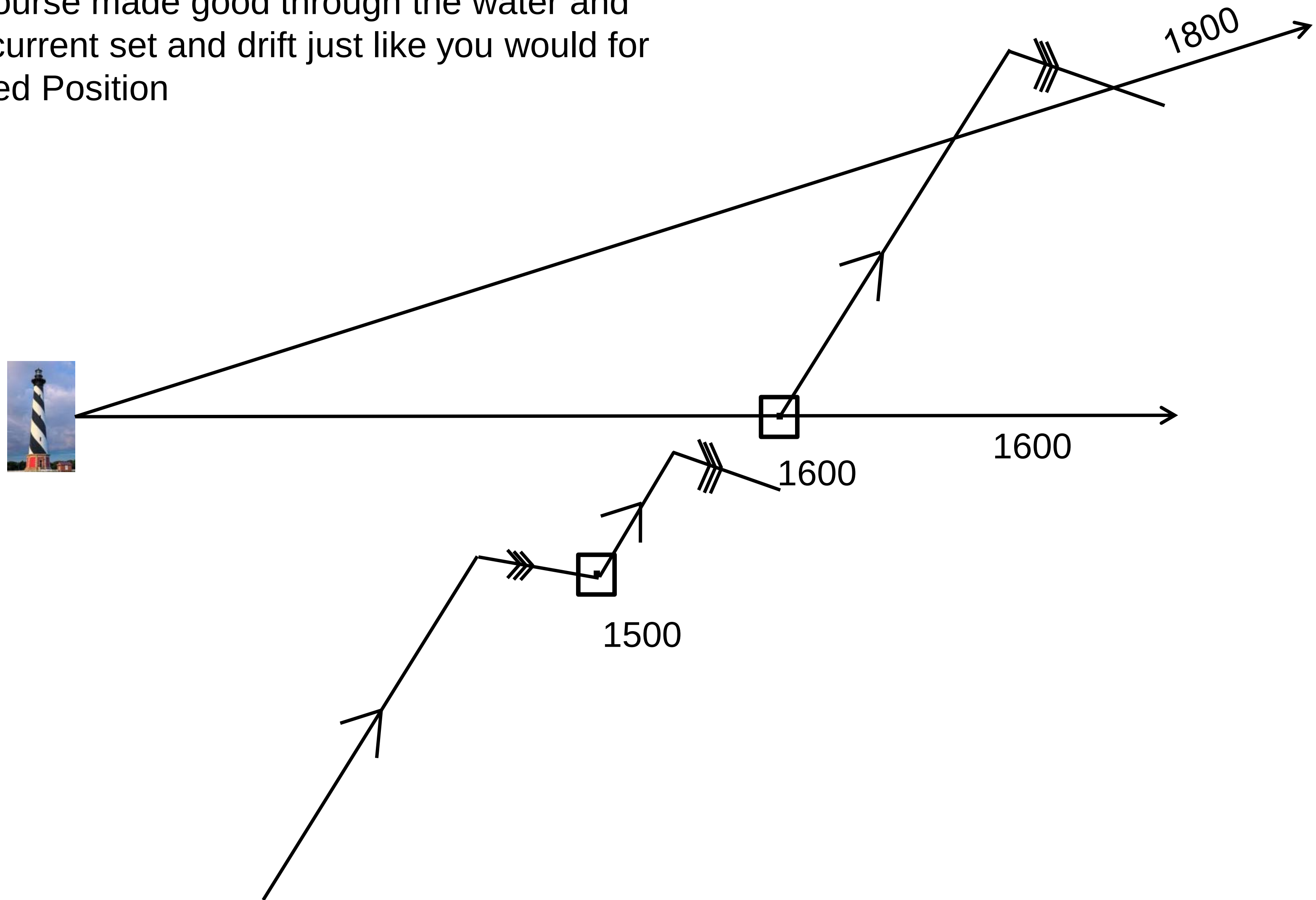
The Running Fix

At some later time, you get another LOP on the same mark



The Running Fix

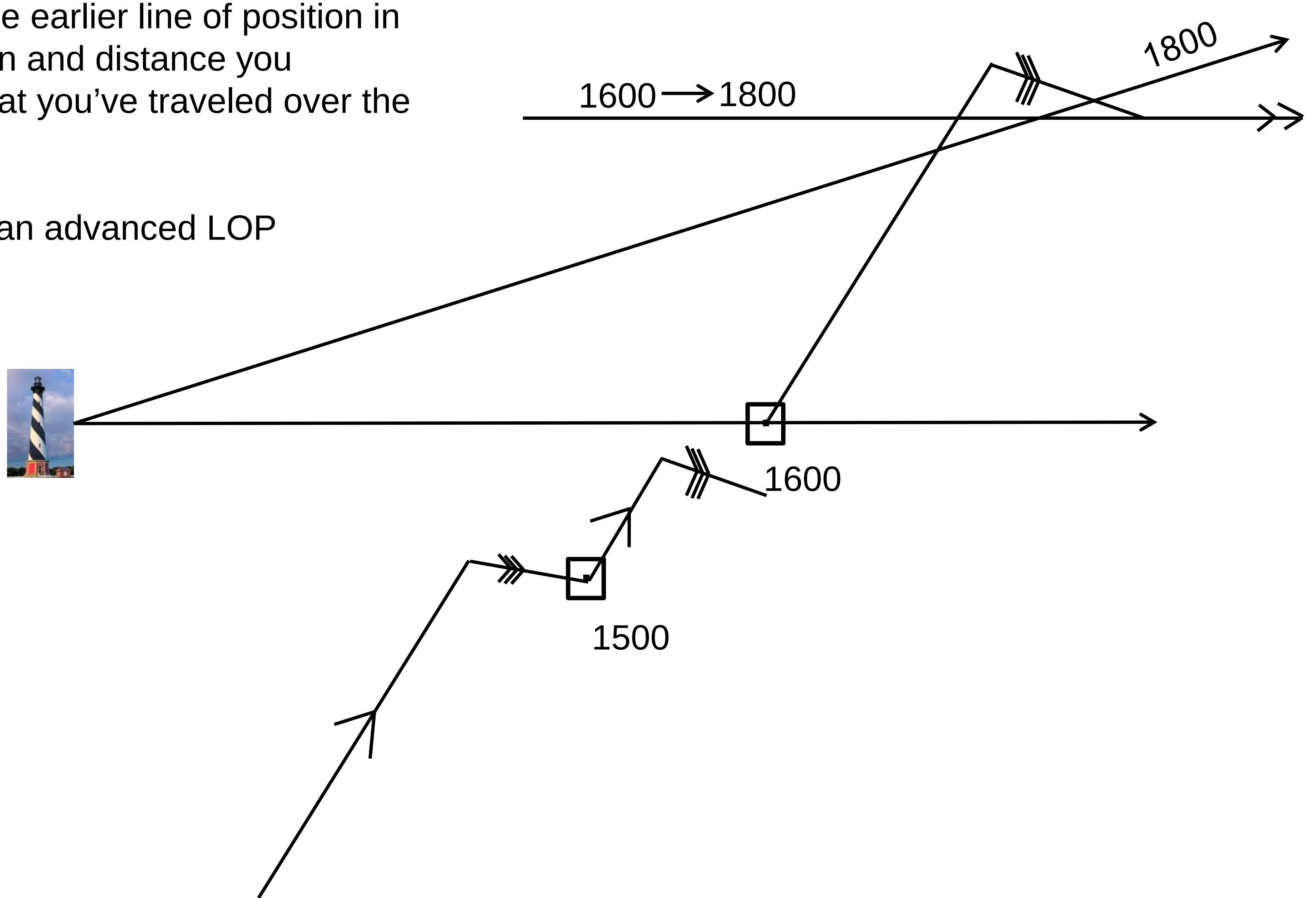
Plot your course made good through the water and estimated current set and drift just like you would for an Estimated Position



The Running Fix

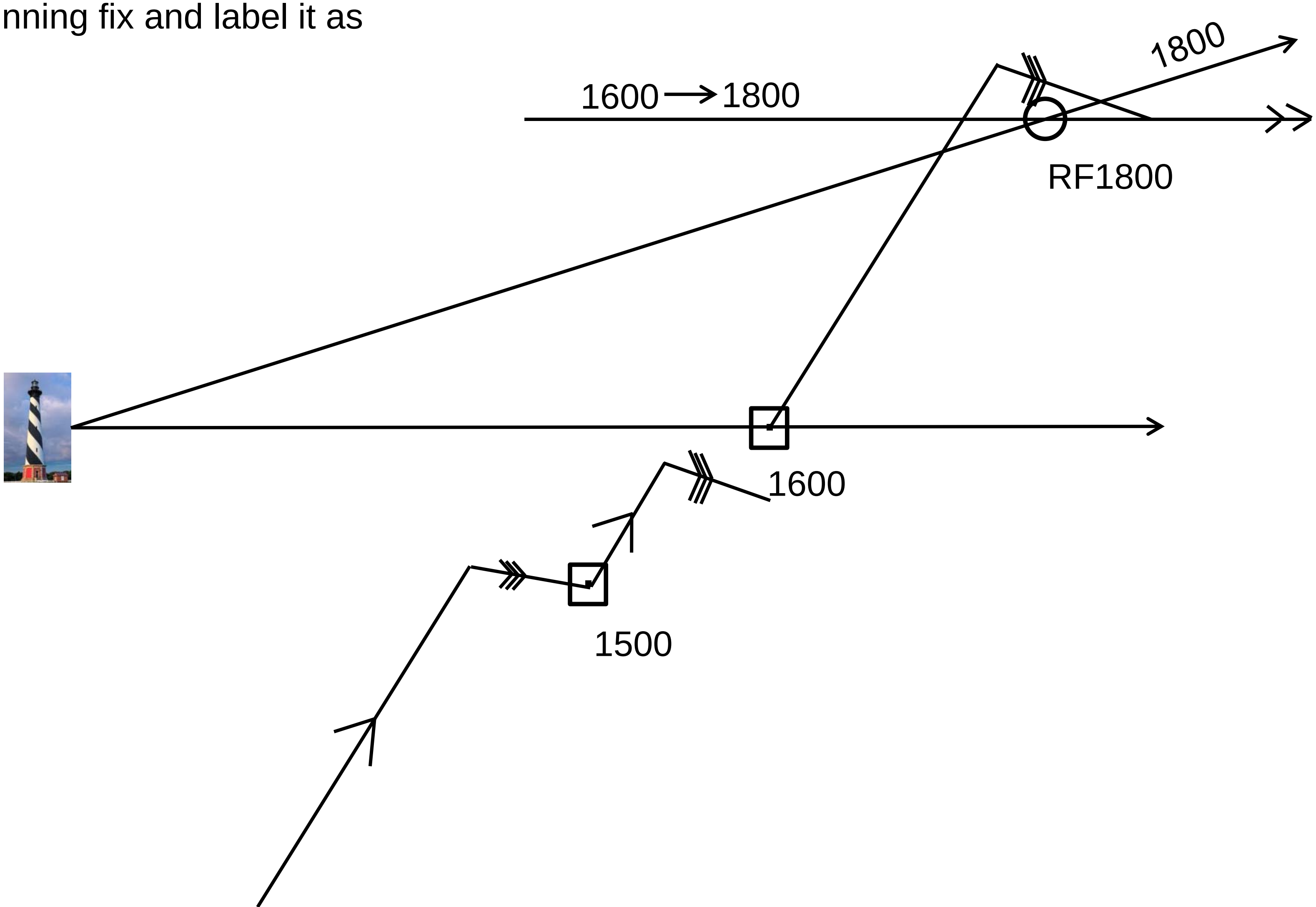
Advance the earlier line of position in the direction and distance you estimate that you've traveled over the bottom

Label it as an advanced LOP



The Running Fix

Plot your running fix and label it as such

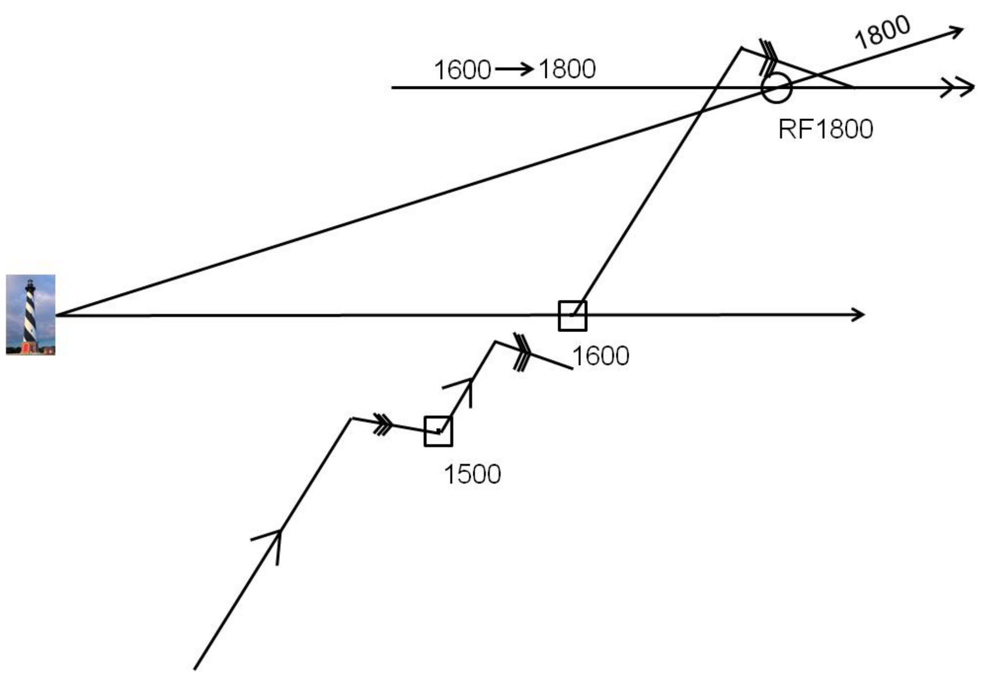


The Running Fix - Cautions

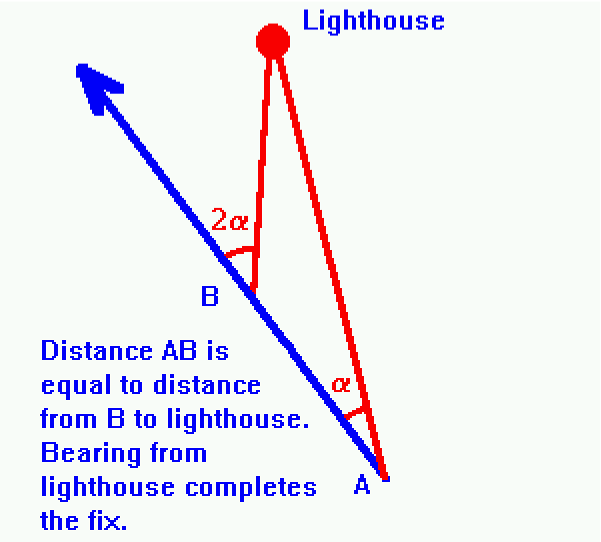
The running fix appears precise, but it is only as accurate as your ability to estimate your distance and direction traveled over the bottom

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

Running fixes are a very blunt navigational tool, but sometimes they’re all you have

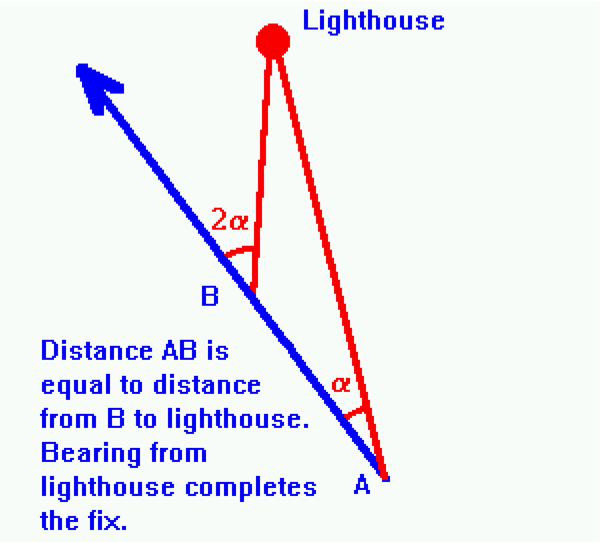


Special Cases of the Running Fix

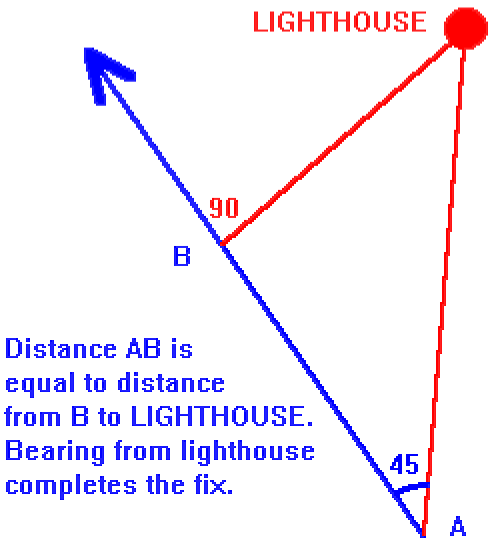


Doubling Angle on the Bow

Special Cases of the Running Fix

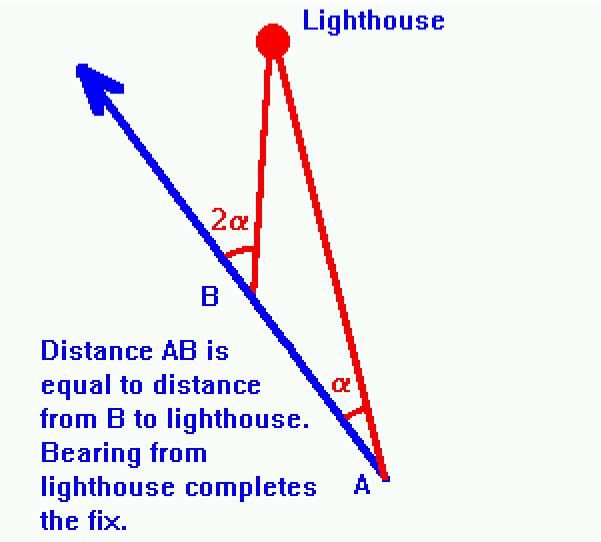


Doubling Angle on the Bow

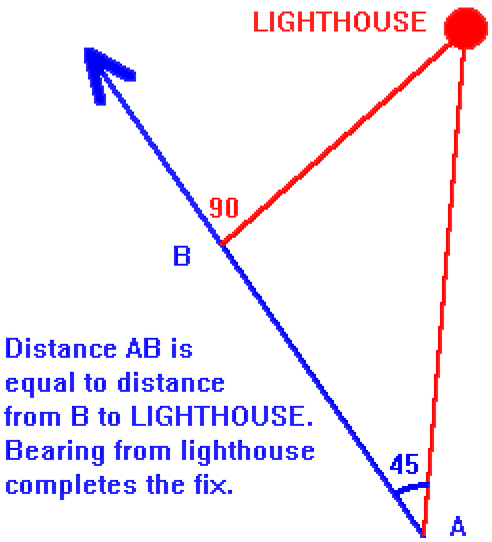


45-90 Doubling Angle

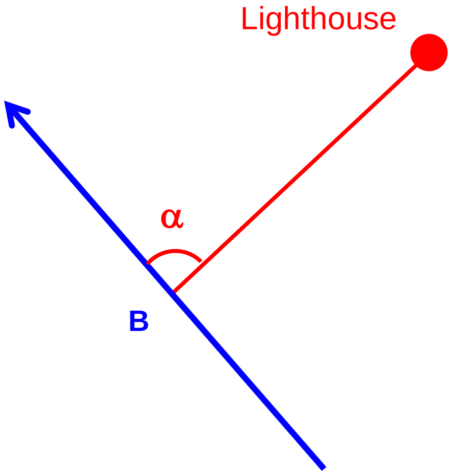
Special Cases of the Running Fix



Doubling Angle on the Bow



45-90 Doubling Angle



Beam Bearing Drift Rate

When abeam the Lighthouse, the distance between B and the Lighthouse 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)

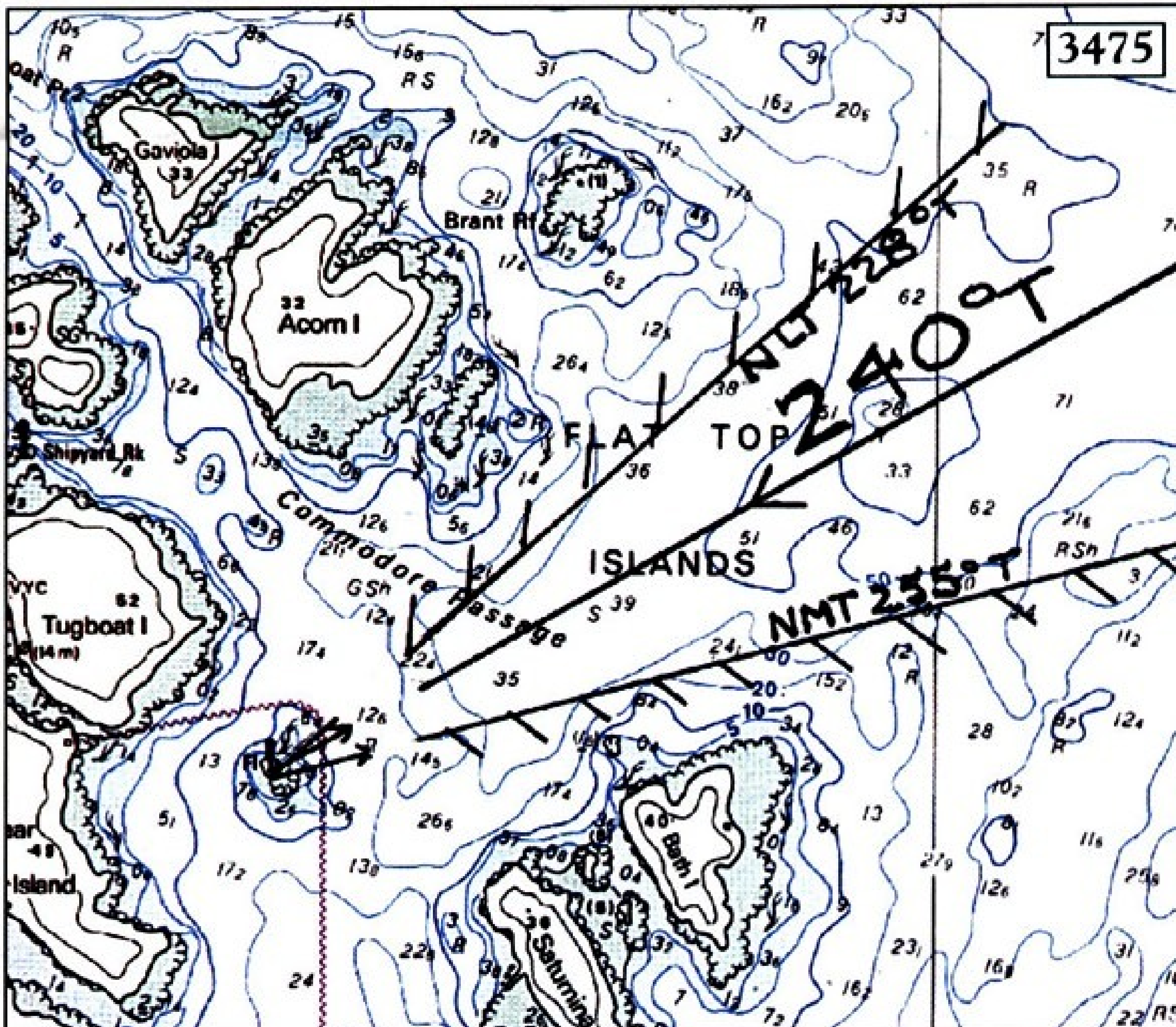
Outline

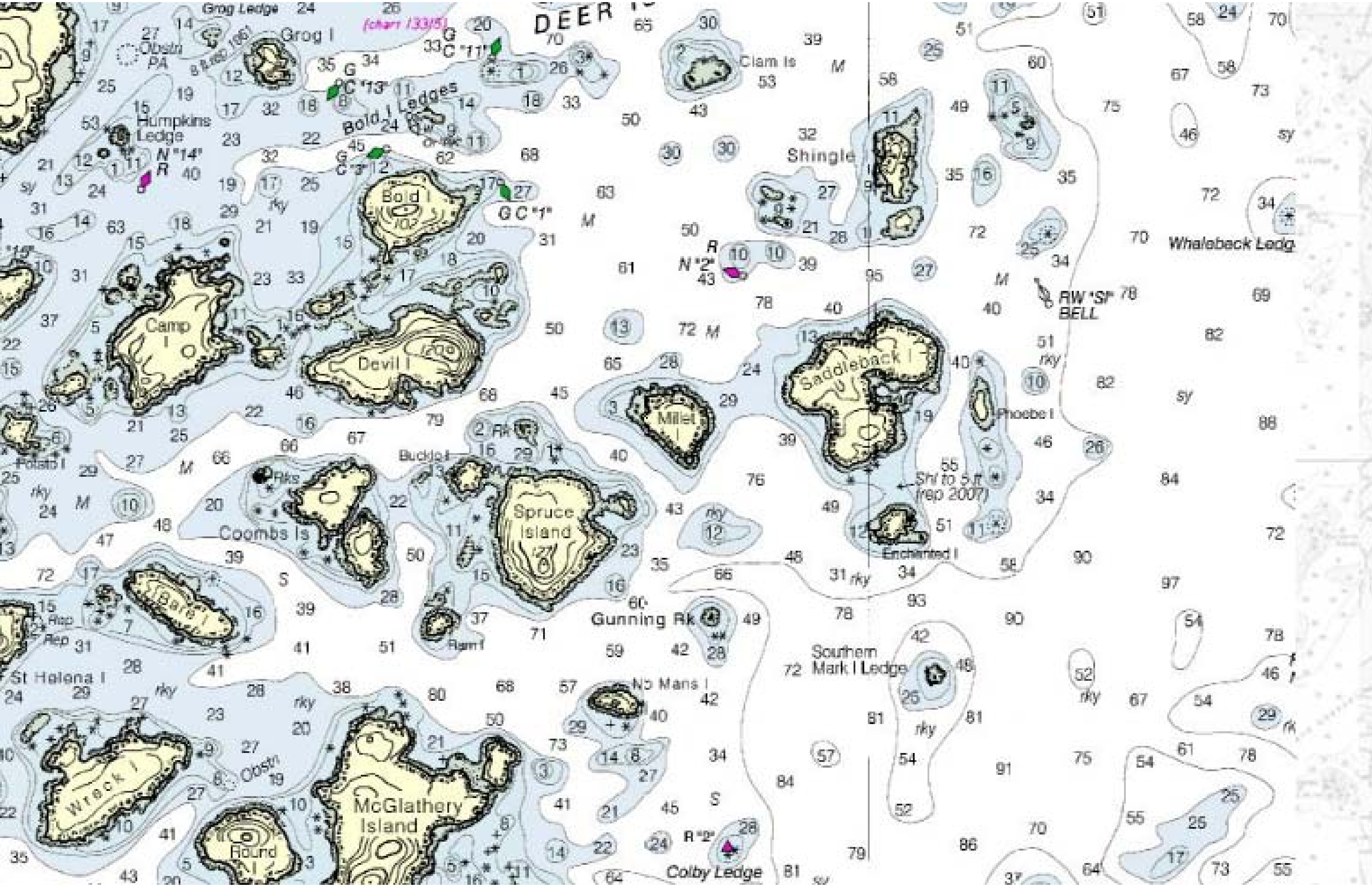
- Review
  - Nautical Chart types and scales
  - Buoyage System (IALA Region B)
  - Light characteristics
  - Basic navigational inputs
- Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore Pilotage

Inshore Pilotage

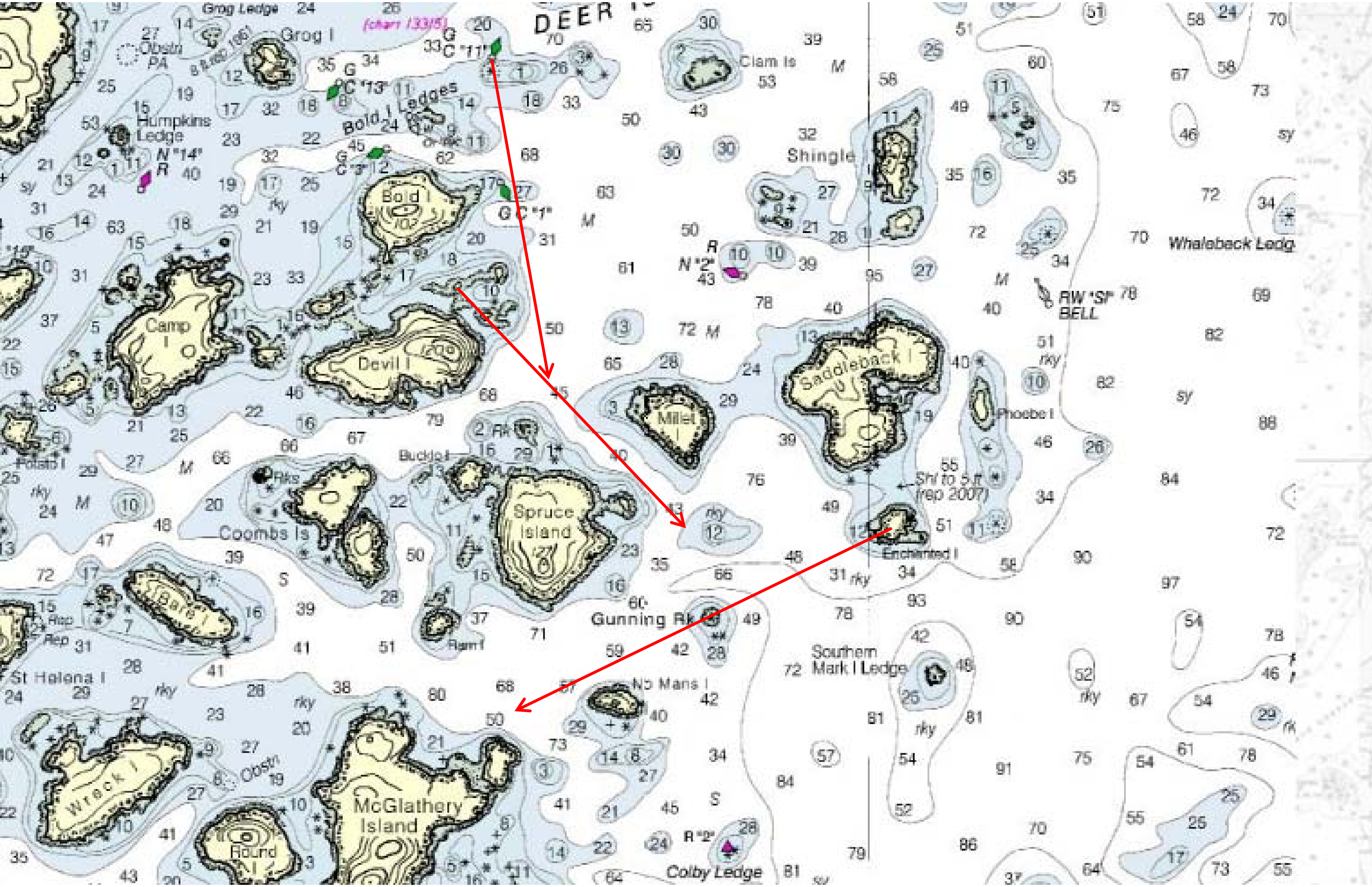
- In waters crowded with buoys, beacons, and hidden hazards, there is often no time for formal chartwork
- Typically these occur at beginning or end of a passage – often in unfamiliar waters
- Procedures must be simple to set up and follow
- Most navigation aboard X Dimension in and around Boston Harbor is inshore pilotage

Clearing or Danger Bearing





Grog Ledge
(chart 13315)
DEER
Grog I
Clam Is
Humpkins Ledge
Bold I Ledges
Shingle I
Bold I
Whaleback Ledg
RW "SI" BELL
Camp I
Devil I
Saddleback I
Millet I
Phoebe I
Potato I
Buckle I
Coombs Is
Spruce Island
Shl to 5 ft (rep 2007)
Enchanted I
Bare I
Gunning Rk
Ram I
St Helena I
Southern Mark I Ledge
No Mans I
Wreck I
McGlathery Island
Round I
Colby Ledge



Grog Ledge
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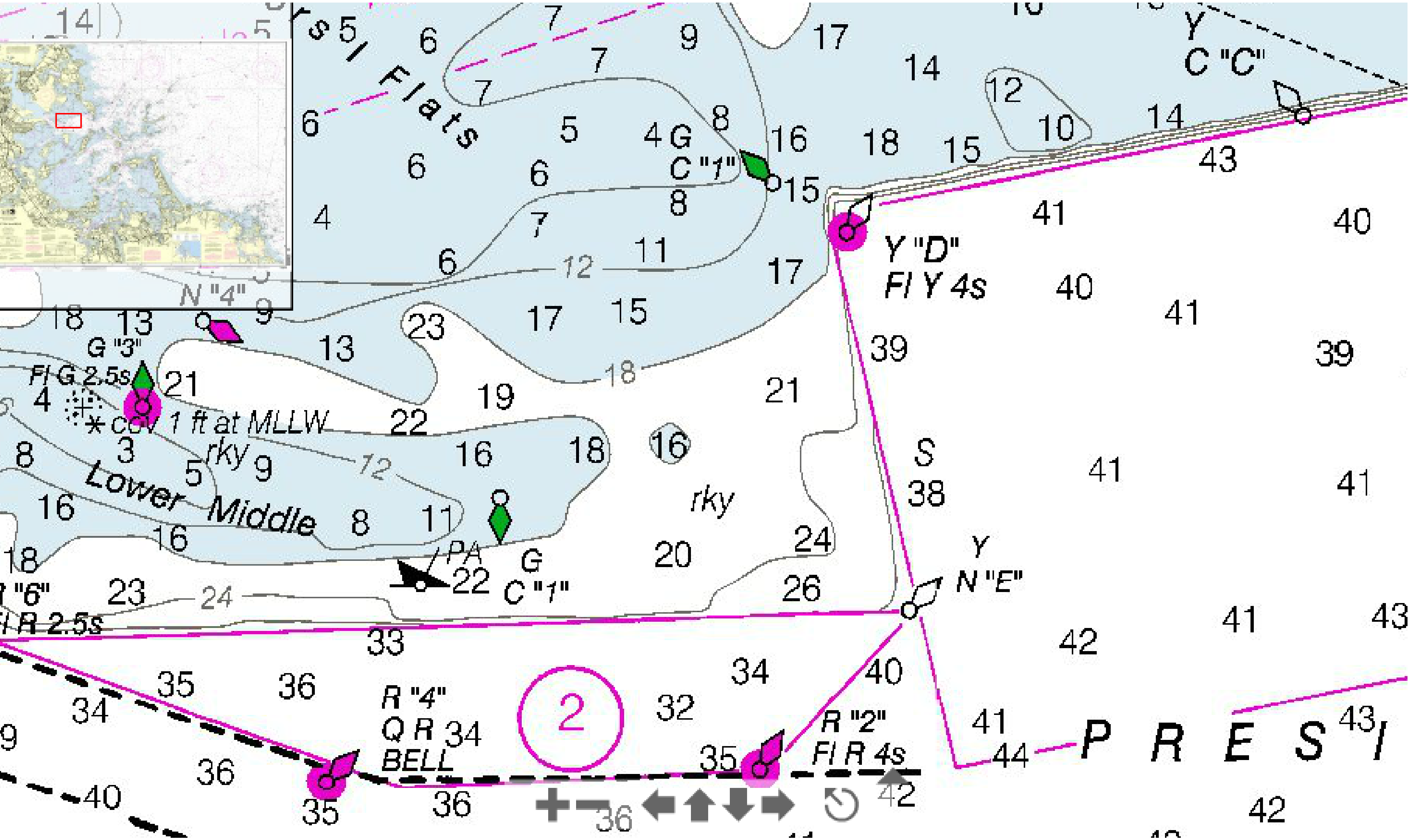
McGlathery Island
Round I
Colby Ledge

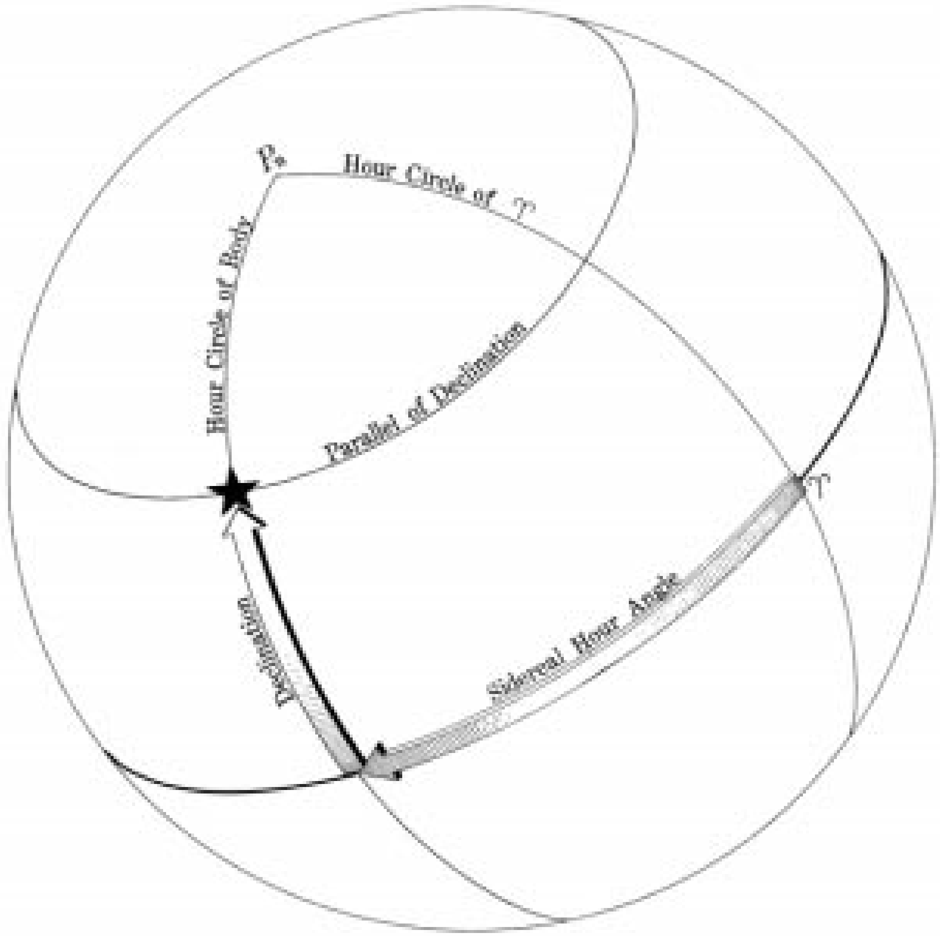
Inshore Pilotage Tips

- 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 possible to account for current
- Communicate clearly to helm and crew – give them time to prepare
- Check and double-check your information

Double Check Your Information



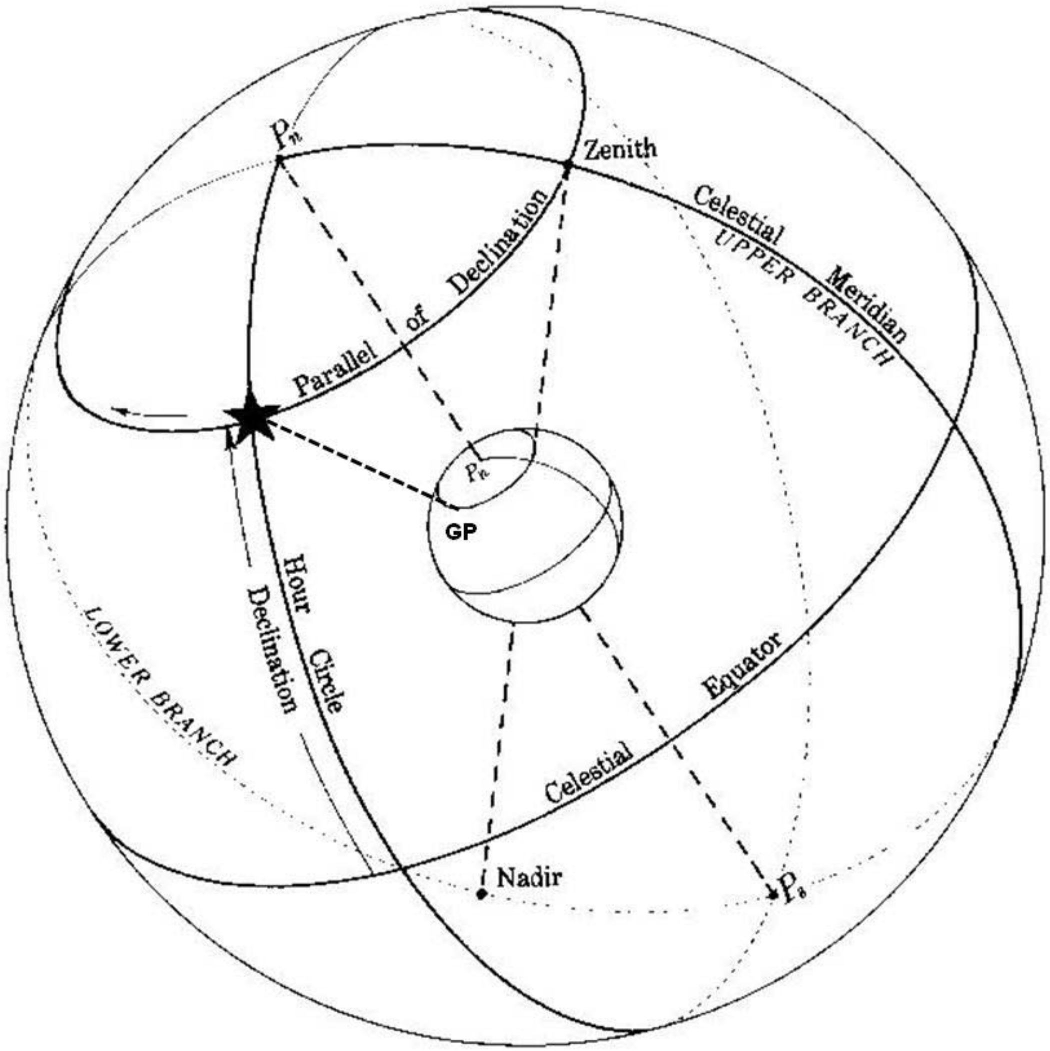
Celestial Navigation



Any point on the celestial sphere can be located by its Declination and Sidereal Hour Angle

Declination is measured in reference to the celestial equator (parallel to earth's equator)

Sidereal Hour Angle is measured in reference to the First Point of Aries (Vernal Equinox)

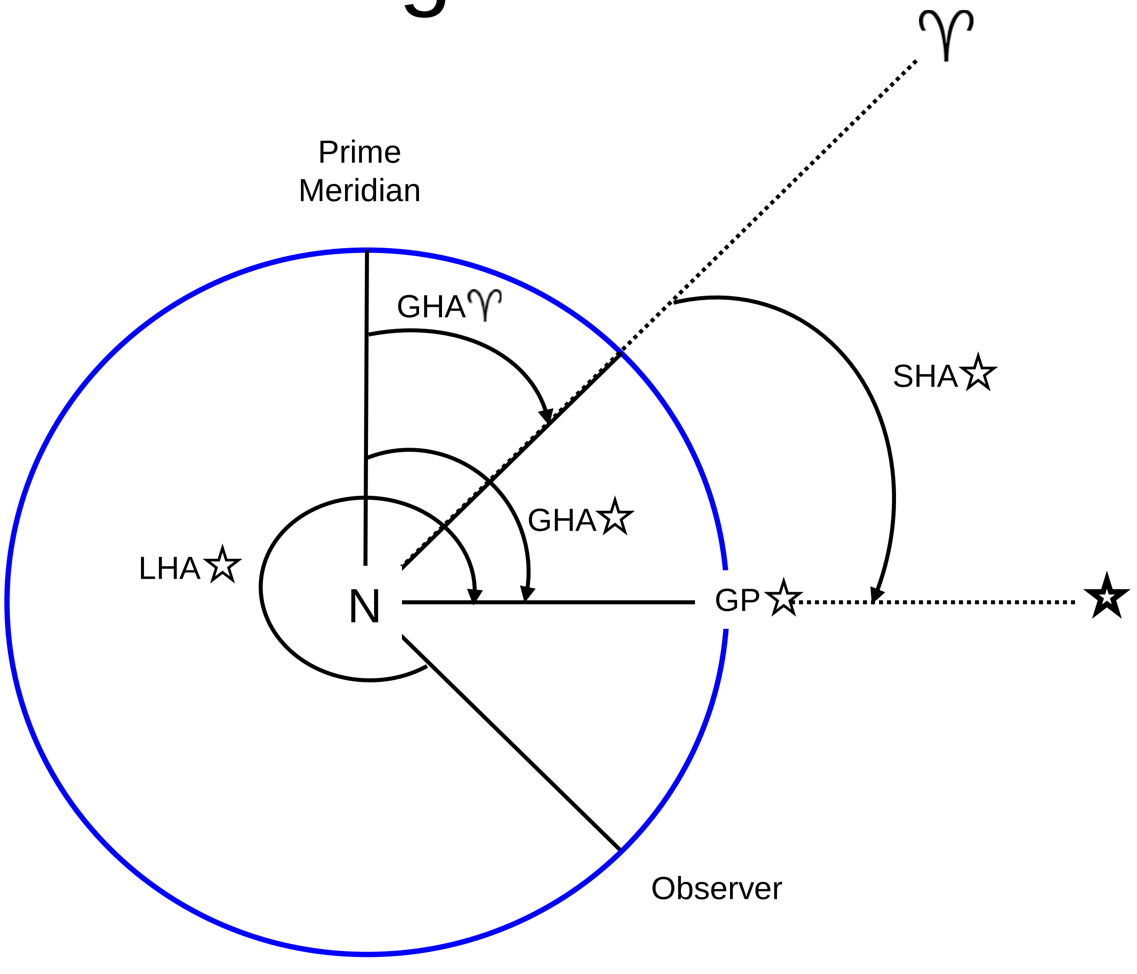


The Geographical Position of a celestial body is the point on Earth where the body is at the zenith

The Declination of the GP is the same as that on the celestial sphere (equivalent to Latitude)

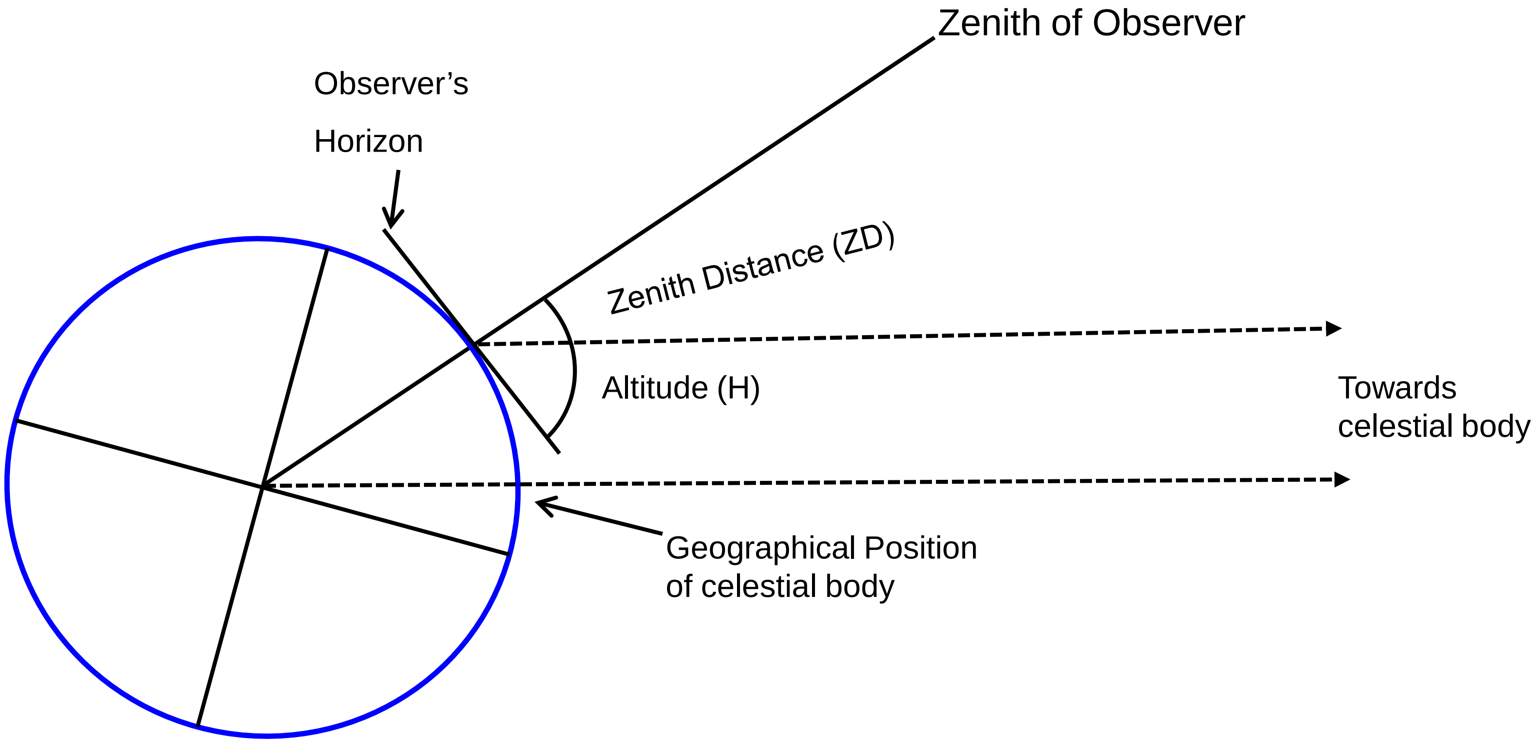
The Greenwich Hour Angle of the GP is referred to the Prime Meridian

Hour Angles



The Sidereal Hour Angle and Declination of 57 Navigational Stars are documented in the Nautical Almanac for each day of the year (Polaris is treated separately)

The Greenwich Hour Angle of Aries is documented in the Nautical Almanac for every second of the year

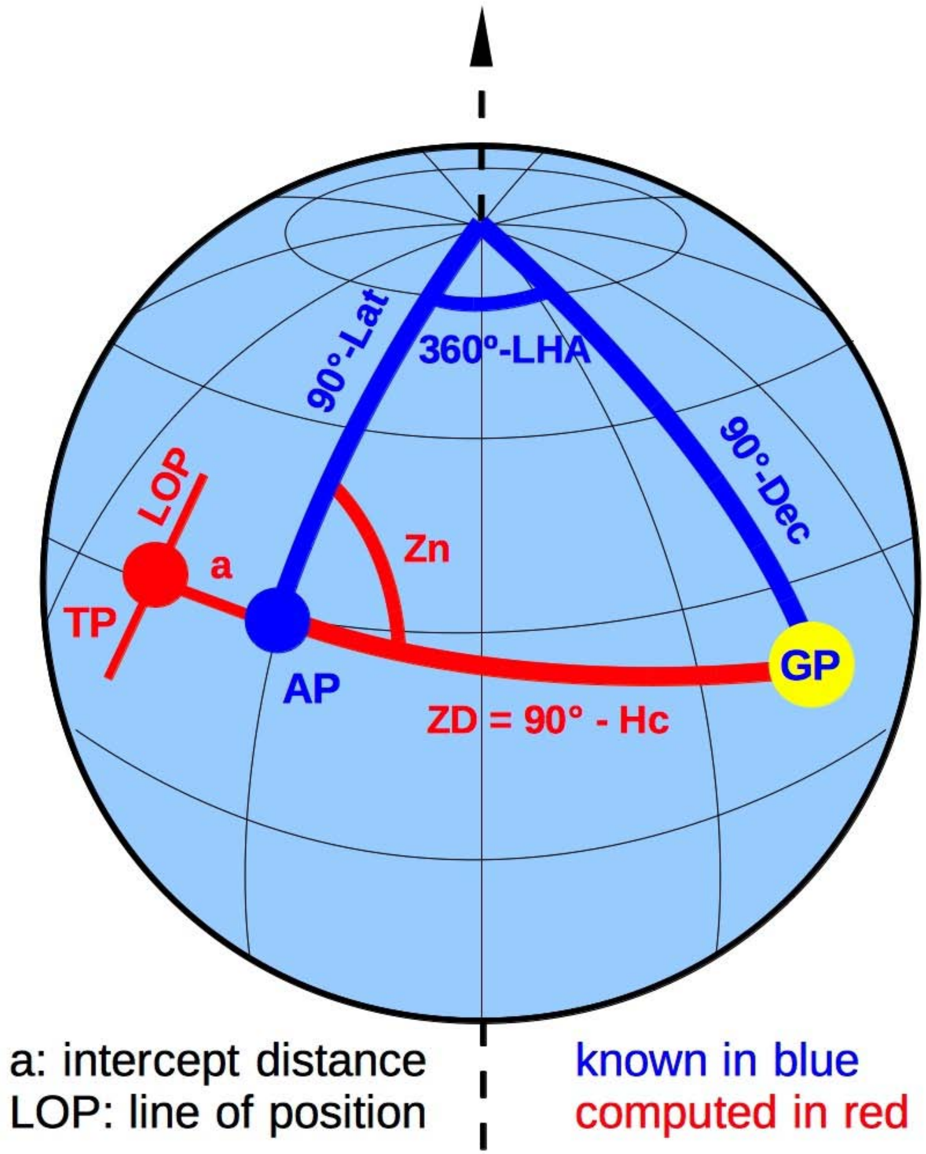


For any observer on the earth, the celestial body will appear at a certain angle from the zenith (ZD)

The body will also appear at an angular altitude (H) above the horizon ($ZD = 90^o – H$)

We measure H with a sextant

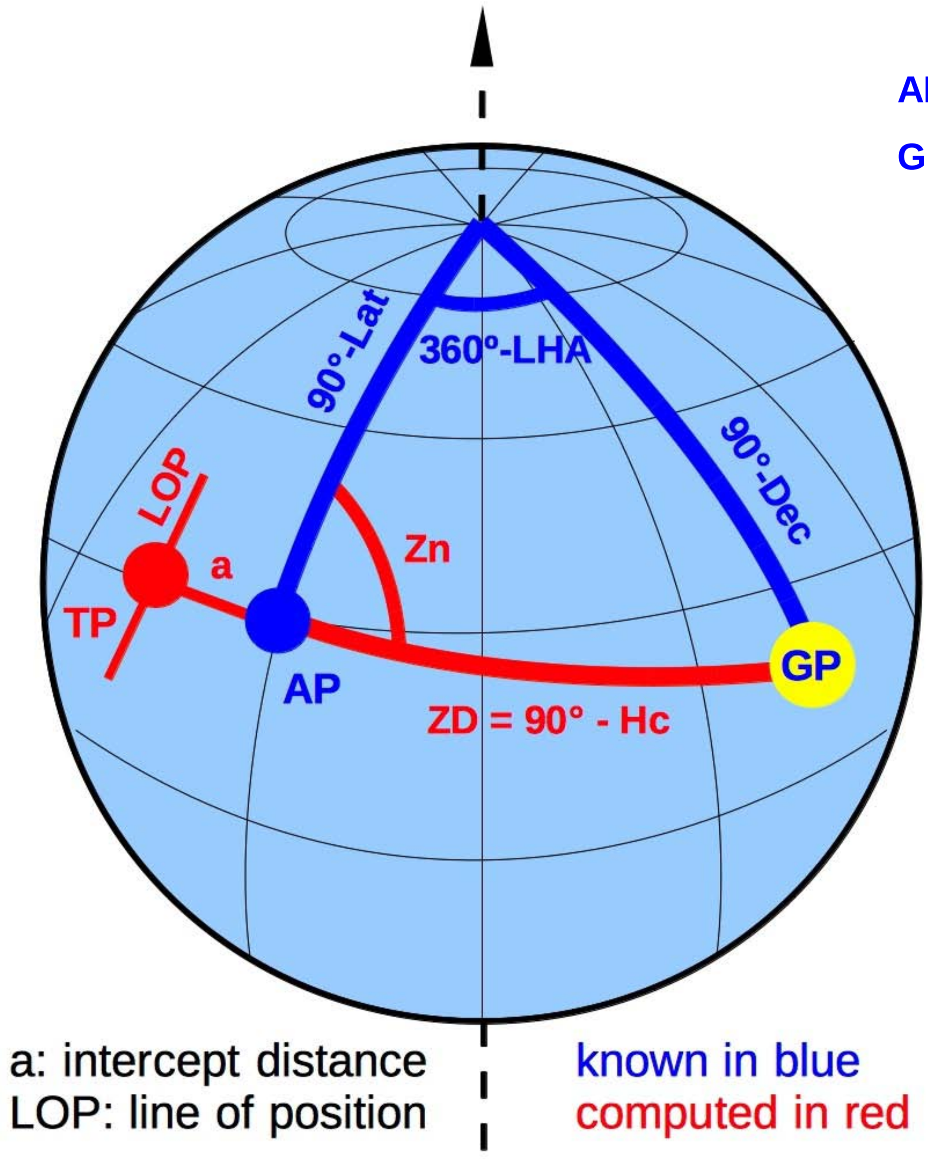
The Navigational Triangle



AP : **Assumed Position**

GP : **Geographical Position of Celestial Body**

The Navigational Triangle



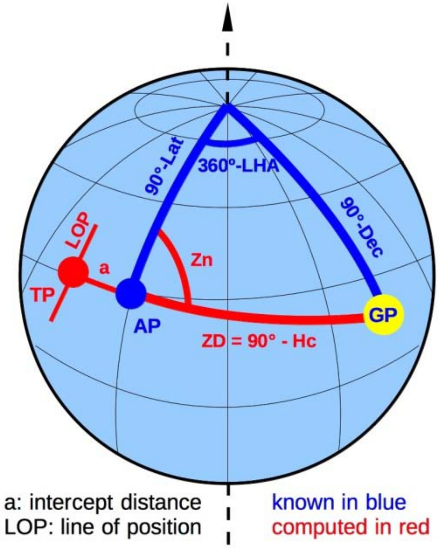
AP : **Assumed Position (Lat, Lon)**

GP : **Geographical Position of Celestial Body (Dec, GHA)**

Assumed Position comes from our Estimated Position

Geographical Position comes from the Nautical Almanac

The Navigational Triangle



<u>Knowns</u>:

Declination of body (Dec)

Local Hour Angle of body (LHA)

Assumed Latitude (Lat)

<u>From Law of Cosines for Spherical Geometry*</u>

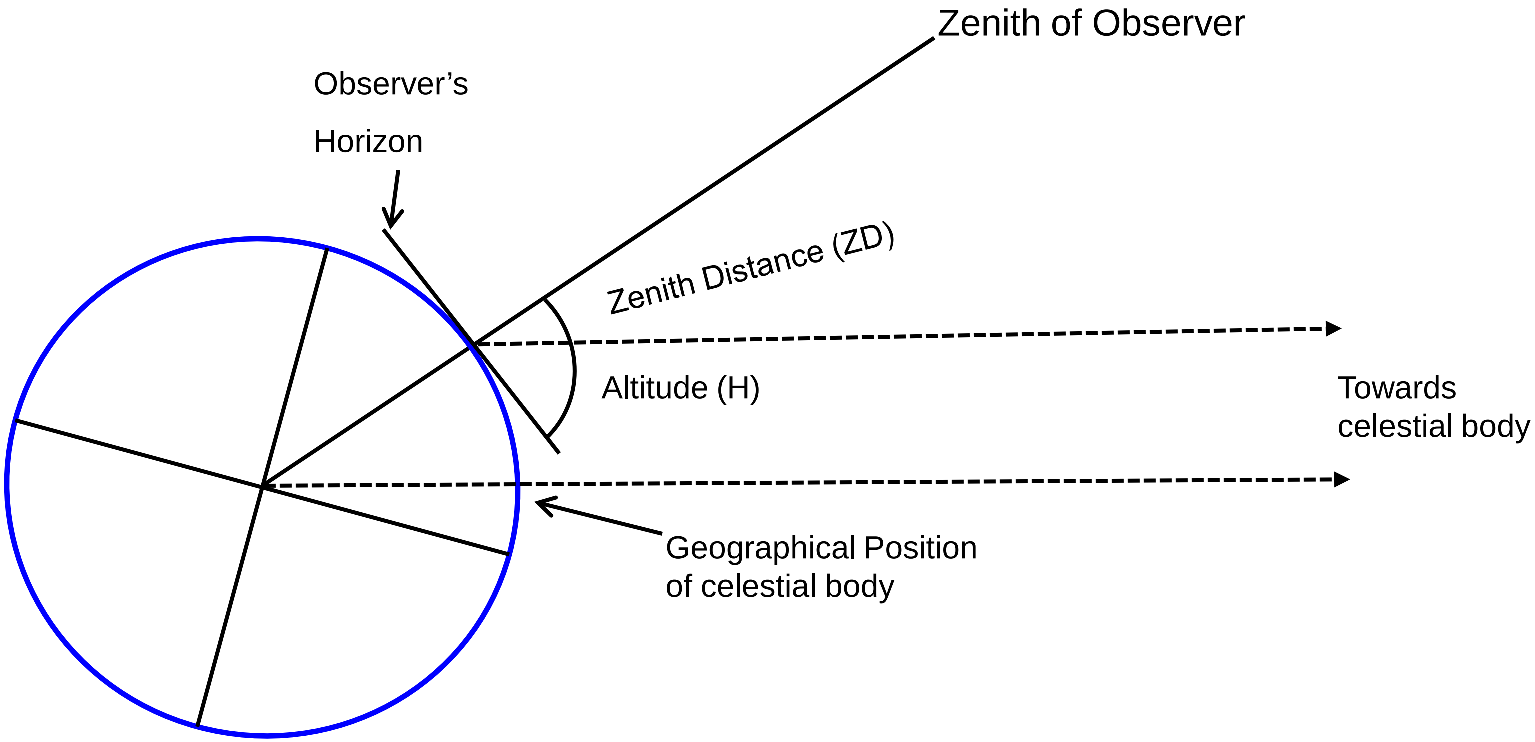
Sin (Hc) = Sin(Dec) x Sin(Lat) + Cos(Dec) x Cos(Lat) x Cos(LHA)

Cos(Z) = (Sin(Dec) – Sin(Lat) x Sin(Hc)) / (Cos(Lat) x Cos(Hc))

In Northern Latitudes:	Zn = Z when LHA > 180º
	Zn = 360º – Z when LHA < 180º
In Southern Latitudes:	Zn = 180º – Z when LHA > 180º
	Zn = 180º + Z when LHA < 180º

Given Dec, LHA, and Lat, one can solve for Hc and Zn

*Note: Southern declinations and latitudes have negative sign in these equations

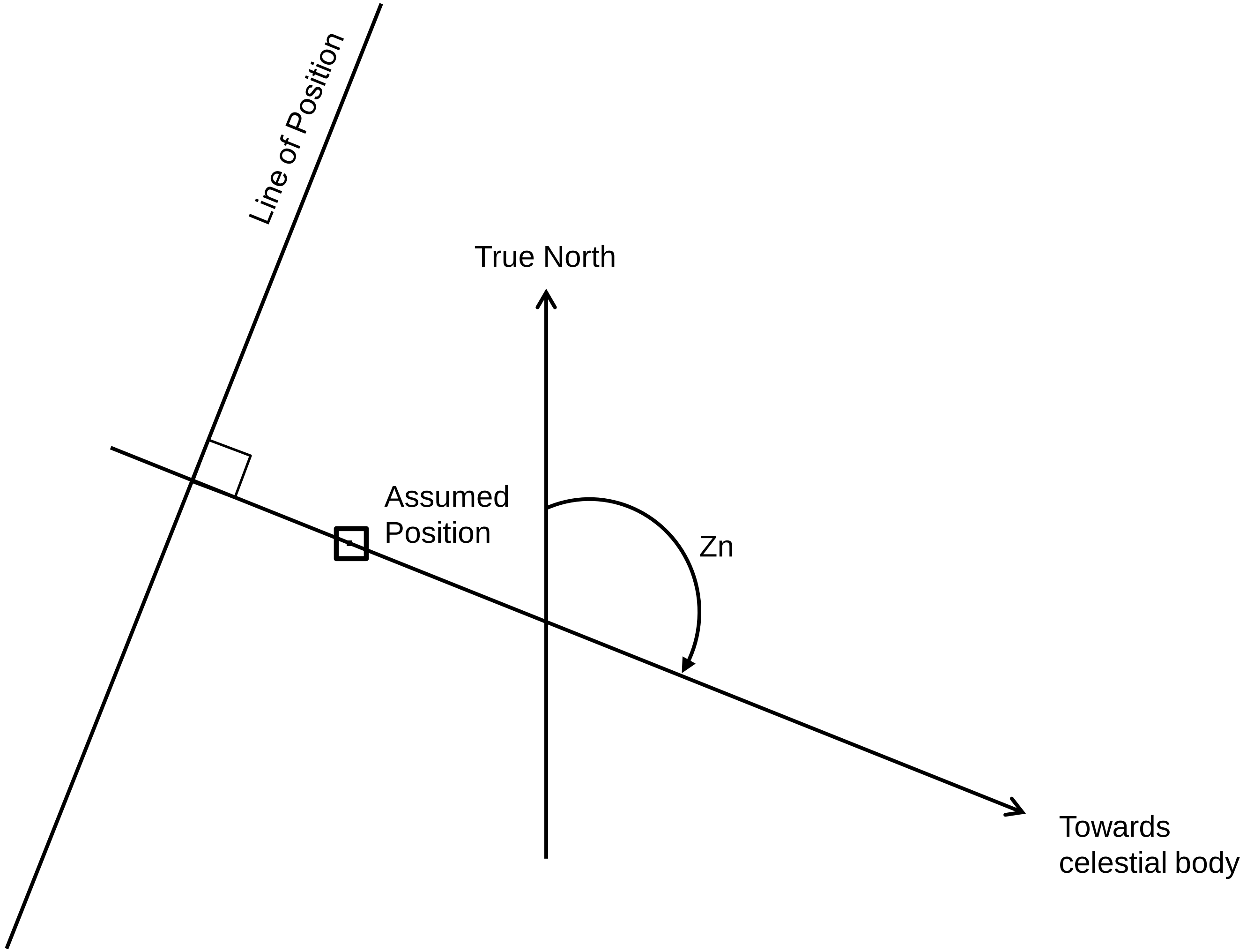


We know the Computed Altitude of the body at our Assumed Position (Hc)
(This is the altitude the body would have if we were at our Assumed Position)

We know the azimuth from our Assumed Position to the GP of the body (Zn)

We measure the Altitude of the body with our sextant and compare it with Hc

We draw a line of position, perpendicular to Zn



If our Observed Altitude (Ho) is less than Hc, then the LOP is plotted away from the celestial body by an amount equal to Hc – Ho (minute of arc = nautical mile)

If our Observed Altitude (Ho) is greater than Hc, then the LOP is plotted toward the celestial body by an amount equal to Ho – Hc (minute of arc = nautical mile)

Summary Procedure

- Make an observation with the sextant and note the time, Hs, and the body name
- Convert Hs to Ho (corrections for refraction, sextant error, etc.)
- Get the GHA and Declination of the body from the Nautical Almanac for the time of the observation
- Compute the LHA of the body based on your Assumed Longitude
- Enter the the Sight Reduction Tables with LHA, Dec, and Assumed Latitude and get Hc and Zn
- Compare Hc to Ho and plot the Line of Position perpendicular to Zn

So Why is Celestial So Hard?

- You need to make a very accurate sextant measurement from a moving platform
- You need to make corrections to the sextant measurement
  - Sextant index error, refraction, height of eye, parallax, diameter of body
  - Requires table look-ups and arithmetic
  - Several opportunities for error
- You need to get data from Nautical Almanac
  - Requires several table look-ups and more arithmetic
  - More opportunities for error
- You need to reduce the sights to find Zn and Hc
  - Requires choosing a proper assumed position to use the tables
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- You need to correctly plot the LOPs

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“**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

RFIX 1332 EDT

33° 05' N
065° 20' W

CALCULATOR FIX: 33° 06' N
065° 20' W

CRS TO KITCHEN SHOAL: 138° T
3 miles (30 min) TO 50 mi RANGE