Marine Navigation Pt. 1

- Introduction to Navigation
- Coordinate Systems
- Nautical Charts
- Aids to Navigation
- Tides

Marine Navigation Pt. 2

- The Magnetic Compass
- Obtaining a Fix
- Dead Reckoning
- Navigation Rules
- Electronic Instruments
What Is Navigation?

**Navigation**: Determination of one's position, and velocity. (Where are you?)

**Guidance**: Determination of the path to a destination. (Where are you going? How will you get there?)

**Collision Avoidance**: Getting there safely.
Types of Marine Navigation

- **Dead Reckoning**
  Starting from a known location, track your position based on the speed and direction your vessel travels over measured periods of time.

- **Piloting**
  Navigating by sight in restricted waters using landmarks such as geographic features and other aids to navigation with reference to a nautical chart.

- **Celestial Navigation**
  Determining your position based on the positions of the sun, moon, stars, and other celestial objects, usually measured with a sextant.
Types of Marine Navigation

- **Radio Navigation**
  Determining your position based on radio signals (e.g. RDF, LORAN).

- **Radar Navigation**
  Using radar to determine direction and distance to nearby objects.

- **Inertial Navigation**
  Use of accelerometers and gyroscopes to keep an electronic dead reckoning. Not used much on sailboats.

- **Satellite Navigation**
  Use of satellite based electronic systems; such as GPS.
Marine Navigation

The Navigation Rules... expect prudent mariners to avail themselves of all available means appropriate... as to make full appraisal of the situation.

WARNING

The prudent mariner will not rely solely on any single aid to navigation, particularly on floating aids.
Parallels of **Latitude**: Position **North** or **South** of Equator

Meridians of **Longitude**: Position **East** or **West** of Prime Meridian (Greenwich)
Specifying Latitude and Longitude

360 degrees (°) in a circle
60 minutes (') in 1 degree
60 seconds (") in 1 minute

North & East: positive
South & West: negative

Coordinates of MIT Sailing Pavilion:

42° 21' 30.4" N, 71° 5' 15.6" W
42° 21.507' N, 71° 5.260' W
42.35845° N, 71.08776° W
42.35845, -71.08776

Latitude should be written first
Specifying Latitude and Longitude

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42.35845° N, 71.08776° W
42.35845, -71.08776

When specifying coordinates for use in navigation, use degrees and minutes. Be sure to include at least one decimal place for the minutes.
Nautical Mile

1 nautical mile = 1852 meters (exactly)
1 nautical mile ≈ one minute of latitude
1 nautical mile ≈ 1.15 statute miles
1 nautical mile ≈ 6076 feet

1 knot = 1 nautical mile per hour
1 knot = 1.852 kph (exactly)
1 knot ≈ 1.15 mph
Latitude and Longitude Distances

Latitude:
Parallels are evenly spaced.
1 minute ≈ 1 nm.

Longitude:
Meridians converge at poles.
1 minute ≈ cos(lat) × 1 nm.

In Boston Harbor:
1 minute longitude ≈ .74 nm.
Horizontal Datum

Coordinate system and set of reference points for assigning geographic coordinates (latitude and longitude) to physical locations on the Earth.

Location of Prime Meridian (where longitude = 0)
Horizontal Datum

Make sure your GPS and other navigation instruments are using the same Horizontal Datum as your charts.

- World Geodetic System 1984 (WGS84) global standard

- North American Datum 1983 (NAD83) official datum used on all U.S. Charts – varies less than 2 m from WGS84.

- North American Datum 1927 (NAD27) outdated – can vary up to 100 m from WGS84

- Hundreds of other local datums in use around the world.
Horizontal Datum

Datum Shift Between NAD 27 and NAD 83 (Meter)
Nautical Charts

- Map Projections (Mercator, etc.)
- Chart Features (legend, scale, etc.)
- Chart Symbols
- Aids to Navigation
Map Projections

- Cylindrical projection
- Conic projection
- Plane projection
- Interrupted projection
Map Projections

- Miller Cylindrical Projection
- Robinson Projection
- Gall-Peters Projection
- Sinusoidal Equal-Area Projection
- Winkel Tripel Projection
- Mollweide Projection
Mercator Projection

- Scale changes with latitude
Mercator Projection

- Scale changes with latitude
Mercator Projection

Scale 1:1,200,000 at Lat. 40°00'

North American Datum of 1983
(World Geodetic System 1984)
Mercator Projection

- Scale changes with latitude
- Meridians and parallels expand at the same rate
Mercator Projection

- Scale changes with latitude
- Meridians and parallels expand at the same rate
- Azimuths remain constant
Azimuth

Azimuth is a direction or angle parallel to the horizon, usually in degrees, referenced to true north.
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Azimuth is a direction or angle parallel to the horizon, usually in degrees, referenced to true north.
Mercator Projection

- Scale changes with latitude
- Meridians and parallels expand at the same rate
- Azimuths remain constant
- Azimuths can be measured on the chart
Mercator Projection

- Scale changes with latitude
- Meridians and parallels expand at the same rate
- Azimuths remain constant
- Azimuths can be measured on the chart
- Rhumb lines are straight lines
Mercator Projection

• A *rhumb line* is a path of constant azimuth. (also called a *loxodrome*).
Mercator Projection

• The shortest distance between two points on a sphere is along a great circle.
Mercator Projection

- Scale changes with latitude
- Meridians and parallels expand at the same rate
- Azimuths remain constant
- Azimuths can be measured on the chart
- Rhumb lines are straight lines
- Great circles are curved
Mercator Projection

Gnomonic Projection - North Polar Aspect

Great Circle Route

Proportion of Compass Rose

Compass Rose

Great Circle Route

Mercator Projection

87° Rhumb Line

Seattle

London
Polyconic Projection

Used on many charts of the Great Lakes
Nautical Chart Features

- Title block
- Scales
- Chart number and edition
- Geographic features (coastline, landmarks)
- Hydrographic features (depth contours, soundings)
- Compass rose
- Symbols and abbreviations
- Warnings and local information
Chart Title Block

UNITED STATES - EAST COAST

MASSACHUSETTS

BOSTON HARBOR

Mercator Projection
Scale 1:25,000 at Lat. 42°19'

North American Datum of 1983
(World Geodetic System 1984)

SOUNDINGS IN FEET
AT MEAN LOWER LOW WATER
Chart Scales

• Representative fraction (e.g. 1:80,000)

• A statement (e.g. “one inch equals 30 miles”)

• Graphic scale

• Latitude index along each side of the chart
Chart Scales

• “Large Scale” vs. “Small Scale”

Refers to the size of the printed images on the chart:

• 73,913 inches per nautical mile (≈72,000)

  1:72,000 scale → 1 nm. ≈ 1 inch
  1:25,000 scale → 1 nm. ≈ 3 inches
  1:800,000 scale → 1 nm. ≈ 1/10 inch
Chart Scales

- **Sailing Charts**
  very small scale – 1:600,000 or greater
  (covers areas over 300 miles)
- **General Charts**
  1:150,000 to 1:600,000
  (75 – 300 miles)
- **Coastal Charts**
  1:50,000 to 1:150,000
  (25 – 75 miles)
- **Harbor Charts**
  large scale – 1:50,000 or less
  (less than 25 miles)
Chart Number and Edition

Chart number: 5 digits
Above number is edition number and print date
Corrections to charts are published in Notices to Mariners (NM) and Local Notices to Mariners (LNM)
New corrections should be applied to chart

13270

Last Correction: 12/15/2015. Cleared through:
LOCAL NOTICE TO MARINERS

District: 1  Week: 52/15

COASTAL WATERS FROM EASTPORT, MAINE TO SHREWSBURY, NEW JERSEY

NOTES:
(1) Unless otherwise indicated, missing and destroyed structures are presumed to be in the immediate vicinity of assigned position. Mariners should proceed with caution.
(2) The Local Notice to Mariners is a weekly edition.
(3) Inquiries, published articles or Information: mail to: LNM@uscg.mil
(4) The U.S. Coast Pilot supplements the navigational information shown on nautical charts.
(5) The Coast Pilot, along with its corrections, are available online at http://www.nauticalcharts.noaa.gov/nsd/cpdownload.htm.

The Local Notice to Mariners is available online at:  http://www.navcen.uscg.gov/?pageName=LnmDistrict&region=1
The updated 2015 Light List is available online at: http://www.navcen.uscg.gov/?pageName=lightlistWeeklyUpdates
Reports of Channel conditions can be found at the Army Corps of Engineers website at:

• NM is for large ships, LNM is for all boats
• Published weekly, number refers to week/year
• Subscribe or download at http://navcenter.uscg.gov
Chart Geographic Features

- Land: tan
- Intertidal Zone: green
- Water: white
- Shallow Water: blue
Chart Geographic Features

Land:
- Heights are above HW
- Labels not slanted

Water:
- Depths are below LW
- Labels text is slanted
Compass Rose

Outside ring: True, Inside ring: Magnetic

Increase or decrease of absolute value
Chart Symbols

+  Rock (below water at low tide)

++ Rock (at low water level)

* Rock (above water at low tide)

↓ Wreck (above water at low tide)

+++ Wreck (below water at low tide)

○ Bouy

● Lighted Bouy

• Light
# Chart Symbols

All chart symbols are listed in “Chart No. 1”

<table>
<thead>
<tr>
<th>No.</th>
<th>INT</th>
<th>Description</th>
<th>NOAA</th>
<th>NGA</th>
<th>Other NGA</th>
<th>ECDIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Danger line: A danger line draws attention to a danger which would not stand out clearly enough if represented solely by its symbol (e.g., isolated rock) or delimits an area containing numerous dangers, through which it is unsafe to navigate.</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Swept by wire drag or diver</td>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
<td><img src="image7" alt="Diagram" /></td>
<td><img src="image8" alt="Diagram" /></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Depth unknown, but estimated to have a safe clearance to the depth shown</td>
<td><img src="image9" alt="Diagram" /></td>
<td><img src="image10" alt="Diagram" /></td>
<td><img src="image11" alt="Diagram" /></td>
<td><img src="image12" alt="Diagram" /></td>
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</tbody>
</table>

### Rocks

<table>
<thead>
<tr>
<th>Plane of Reference for Heights → H</th>
<th>Plane of Reference for Depths → H</th>
<th><img src="image13" alt="Diagram" /></th>
<th><img src="image14" alt="Diagram" /></th>
<th><img src="image15" alt="Diagram" /></th>
<th><img src="image16" alt="Diagram" /></th>
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<td><img src="image18" alt="Diagram" /></td>
<td><img src="image19" alt="Diagram" /></td>
<td><img src="image20" alt="Diagram" /></td>
<td><img src="image21" alt="Diagram" /></td>
<td><img src="image22" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image23" alt="Diagram" /></td>
<td><img src="image24" alt="Diagram" /></td>
<td><img src="image25" alt="Diagram" /></td>
<td><img src="image26" alt="Diagram" /></td>
<td><img src="image27" alt="Diagram" /></td>
<td><img src="image28" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image29" alt="Diagram" /></td>
<td><img src="image30" alt="Diagram" /></td>
<td><img src="image31" alt="Diagram" /></td>
<td><img src="image32" alt="Diagram" /></td>
<td><img src="image33" alt="Diagram" /></td>
<td><img src="image34" alt="Diagram" /></td>
</tr>
</tbody>
</table>
SMALL CRAFT WARNINGS

Year round small-craft warnings will be displayed during daytime only on Metropolitan District Commission Police Patrol Boats underway in Inner Boston Harbor from Nantasket Beach (42° 16.2’ N, 70° 51.5’ W) to waters around Georges and Lovell Islands.

NOTE B

PRECAUTIONARY AREA

Traffic within the Precautionary Area may consist of vessels operating between Boston Harbor and one of the established traffic lanes. Mariners are advised to exercise extreme care in navigating within this area.

Recommended traffic lanes have been established for the approach to Boston Harbor. Use charts 13200 and 13267.
Aids to Navigation (ATONs)
ATONs

• Bouys – floating, anchored to bottom
• Beacons – fixed to land, lit or unlit
  • Lights – fixed to land and lit
  • Daybeacons – fixed to land and unlit
ATON Identification

Ways to identify buoys:
• Floating (bouys) or fixed to land (beacons)
• Color (red, green, yellow, etc.)
• Shape (cylinder, cone, tower, ball, etc.)
• Topmark (ball, cone)
• Light color and pattern
• Numbers or letters
• Sound (bell, gong, whistle, fog horn)
• Radar transponder (RACON)
ATON Usage

- Lateral marks – mark sides of a channel (red, green)
- Center channel markers (red/white striped)
- Danger marks (red/black or other)
- Cardinal indicators (indicate safe water in one direction)
- Warnings/restrictions (white/orange)
- Other special purposes (yellow)
Lateral Marks

“Red Right Returning”
Usually mark a channel. Can be bouys, lights or daybeacons. Keep red lateral marks to starboard (to the right) when “returning” to a smaller harbor from a larger body of water.

Green:
• Odd Numbers
• Square or Cylinder

Red:
• Even Numbers
• Triangle or Cone
Cans & Nuns

- Are never lighted.
- Never have sounds
- When used as lateral marks:

Cans:
- Green
- Odd number

Nuns:
- Red
- Even number
Tower Bouys

- May be lighted or have sounds.
- Light color usually matches bouy color
Preferred Channel Bouys

- Red/Green/Red or Green/Red/Green
- Placed at channel intersections
- Top color indicates preferred channel
- No numbers, may be lettered

RG “PR”
Fl (2+1) R 6s
Lateral System
Center Channel Bouys

- Red & white vertical stripes
- Ball topmark
- If lit, white morse-A light pattern (•—)
- Sometimes have whistles
- Sometimes have radar transponders
Danger Bouys

- Red & black
- Two black ball topmarks
- No numbers, may be lettered
- If lit, white (2) group flashing pattern
Lights

Scituate North Jetty Light 2A
Flashing Red 4s
23 feet above high water
4 miles nominal visibility
Lights

Minot Light
Group flashing (1+4+3) 45 sec.
85 feet above high water
10 miles nominal visibility
Fog Horn (MRASS)
Daybeacons

- No lights and fixed to land.
Daybeacons
Do Not Tie Up to Navigational Aids
<table>
<thead>
<tr>
<th>Description</th>
<th>Characteristic</th>
<th>Chart Abbreviation</th>
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<tbody>
<tr>
<td>Flashing</td>
<td></td>
<td>FI</td>
</tr>
<tr>
<td>Quick flashing</td>
<td></td>
<td>Q</td>
</tr>
<tr>
<td>Group flashing</td>
<td></td>
<td>FI (2)</td>
</tr>
<tr>
<td>Composite Group flashing</td>
<td></td>
<td>FI (2+1)</td>
</tr>
<tr>
<td>Occulting</td>
<td></td>
<td>Oc</td>
</tr>
<tr>
<td>Group occulting</td>
<td></td>
<td>Oc (3)</td>
</tr>
<tr>
<td>Fixed</td>
<td></td>
<td>F</td>
</tr>
<tr>
<td>Isophase</td>
<td></td>
<td>Iso</td>
</tr>
<tr>
<td>Morse</td>
<td></td>
<td>Mo (letter)</td>
</tr>
<tr>
<td>Alternating</td>
<td></td>
<td>AI RWG</td>
</tr>
</tbody>
</table>
Light Characteristics

Group 1

- **R “6”**
  - Fl R 4s
  - ![Image](image1)

- **G “3”**
  - Fl G 6s
  - ![Image](image2)

- **Y “B”**
  - Fl Y 2.5s
  - ![Image](image3)

- **RG “PR”**
  - Fl (2+1) R 6s
  - ![Image](image4)

- **Fl (2) 5s 65ft 10M**

- **Fl (4) 15s 35ft 12M**

- **Fl 10s 102ft 27M**

- **G “20”**
  - Q G
  - ![Image](image5)
Light Characteristics

Group 2

Oc R 4s  Oc (2) G 15s  Iso Y 6s  RW “NC”  Mo (A)  WHIS

Oc (3) 15s  Iso R 4s  Al RW 6s  F G
Light Characteristics

Group 3

A
B
C
D

E
F
G
H
# Light Characteristics

Group 3

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td><strong>B</strong></td>
<td><strong>C</strong></td>
<td><strong>D</strong></td>
</tr>
<tr>
<td>Iso R 6s</td>
<td>Fl (2+1) G 6s</td>
<td>Fl (4) Y 15s</td>
<td>Fl (1+4+3) 45s</td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>E</strong></td>
<td><strong>F</strong></td>
<td><strong>G</strong></td>
<td><strong>H</strong></td>
</tr>
<tr>
<td>Oc (2) 15s</td>
<td>Fl R 4s</td>
<td>Fl (2) 12s</td>
<td>Oc G 4s</td>
</tr>
</tbody>
</table>
# Light Characteristics

**Group 4**

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<tr>
<td>?</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Light Characteristics

Group 4

A  
Fl R 2.5s

B  
Q G

C  
Fl Y 6s

D  
Oc (3) 15s

E  
Mo (A)

F  
Fl R 4s

G  
Al RW 10s

H  
Fl (2+1) G 6s
Light List

Full details on all official ATONs can be found in the “Light List” (navcen.uscg.gov) including:

- Official number
- Official name
- Latitude & longitude
- Light pattern details (if lit)
- Height (if on land)
- Nominal Range (if lit)
- Physical description (e.g. “White Conical Tower with Red Stripe”, or “Steel Tripod with Mast”)
- Additional Comments
The Magnetic Compass
The Ship's Compass

The compass is usually mounted on a pedestal called a "binnacle". It is directly in front of the helm, so the helmsman can steer by it.

The compass contains a magnetized "card" floating in oil, weighted so it stays level, even if the ship is heeling. The heading is indicated by the numbers, written on the card, when they line up with the fixed "lubber's line".
The Earth's Magnetic Field

The Earth's magnetic field is a three-dimensional vector field that changes in magnitude and direction over the surface of the Earth.

The magnetic field also varies slowly over time.
The Earth's Magnetic Field

The magnetic poles (created by the Earth's magnetic field) are not at the same locations as the geographic poles (defined by the rotation of the planet).

Note that compasses do not point at the magnetic poles, they point parallel to the Earth's magnetic field lines.
The Earth's Magnetic Field

The geomagnetic field can be described at any given location on the surface of the Earth by two components.

- The vertical component (called the “dip”)
- The horizontal component (called the “declination” by land-lubbers, and called the “variation” by sailors).

Because of the dip, a compass needs to be kept level to give accurate readings.
The Earth's Magnetic Field
Compass Rose
Outside ring: True, Inside ring: Magnetic
The Earth's Magnetic Field

LOCAL MAGNETIC DISTURBANCE

Differences of as much as 8° from the normal variation have been observed in an area around Ellingwood Rock for approximately 1 nautical mile in all directions.
Magnetic Variation

Magnetic variation is the difference between a “true” direction (relative to the direction of the Geographic North Pole) and a “magnetic” direction (as indicated by a magnetic compass).

- Can be determined from compass rose on chart
- Can be calculated by a computer (GPS)
- Can be looked up in a variety of locations.

Bearings, courses and headings always need to be specified whether they are “true” or “magnetic”.
Magnetic Deviation

Magnetic deviation is the error in the compass reading caused by various local sources:

- Electric currents in nearby wires
- Nearby steel or other ferrous metals
- Nearby magnets (speakers, magnetized metal, etc)
- Poor compass manufacturing or installation

Deviation is a function of the boat's heading. Each compass on each boat may have a slightly different deviation function.
Magnetic Deviation

To determine deviation of a ship's compass:

- Point the boat in a known true heading (!)
- Take a compass reading
- Correct for magnetic variation
- Write down the difference
- Repeat for several different headings
- Plot the results on a graph
- Create a table of deviations for each heading
Magnetic Deviation

A Deviation Table

<table>
<thead>
<tr>
<th>Heading (C)</th>
<th>Deviation</th>
</tr>
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<tbody>
<tr>
<td>000</td>
<td>4W</td>
</tr>
<tr>
<td>022.5</td>
<td>2W</td>
</tr>
<tr>
<td>045</td>
<td>0</td>
</tr>
<tr>
<td>067.5</td>
<td>2E</td>
</tr>
<tr>
<td>090</td>
<td>4E</td>
</tr>
<tr>
<td>112.5</td>
<td>5E</td>
</tr>
<tr>
<td>135</td>
<td>6E</td>
</tr>
<tr>
<td>157.5</td>
<td>5E</td>
</tr>
<tr>
<td>180</td>
<td>4E</td>
</tr>
<tr>
<td>202.5</td>
<td>2E</td>
</tr>
<tr>
<td>225</td>
<td>0</td>
</tr>
<tr>
<td>247.5</td>
<td>2W</td>
</tr>
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<td>270</td>
<td>4W</td>
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<td>292.5</td>
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</tr>
<tr>
<td>315</td>
<td>6W</td>
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<tr>
<td>337.5</td>
<td>5W</td>
</tr>
<tr>
<td>360</td>
<td>4W</td>
</tr>
</tbody>
</table>
Compass Heading Correction

Can Compass
Dead Deviation
Men Magnetic
Vote Variation
Twice? True

(at Elections) (add East)
Compass Heading Correction

Can 195° Compass
Dead 3°E Deviation
Men 198° Magnetic
Vote 15°W Variation
Twice? 183° True

(at Elections) (add East)
Compass Heading De-correction

True
Virtue
Makes
Dull
Conversation

True
Variation
Magnetic
Deviation
Compass

(add Whiskey)  (add West)
Compass Heading De-correction

<table>
<thead>
<tr>
<th>True</th>
<th>46°</th>
<th>True</th>
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<tr>
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<tr>
<td>Dull</td>
<td>2°E</td>
<td>Deviation</td>
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<tr>
<td>Conversation</td>
<td>59°</td>
<td>Compass</td>
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</tbody>
</table>

(add Whiskey) (add West)
Online Resources:

- navcen.uscg.gov
- charts.noaa.gov
- ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml