Coastal Navigation Pt. 1

- Introduction to Navigation
- Coordinate Systems
- Nautical Charts
- Aids to Navigation
- The Magnetic Compass

Coastal Navigation Pt. 2

- Tides
- 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 desired 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.

- 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; primarily GPS.

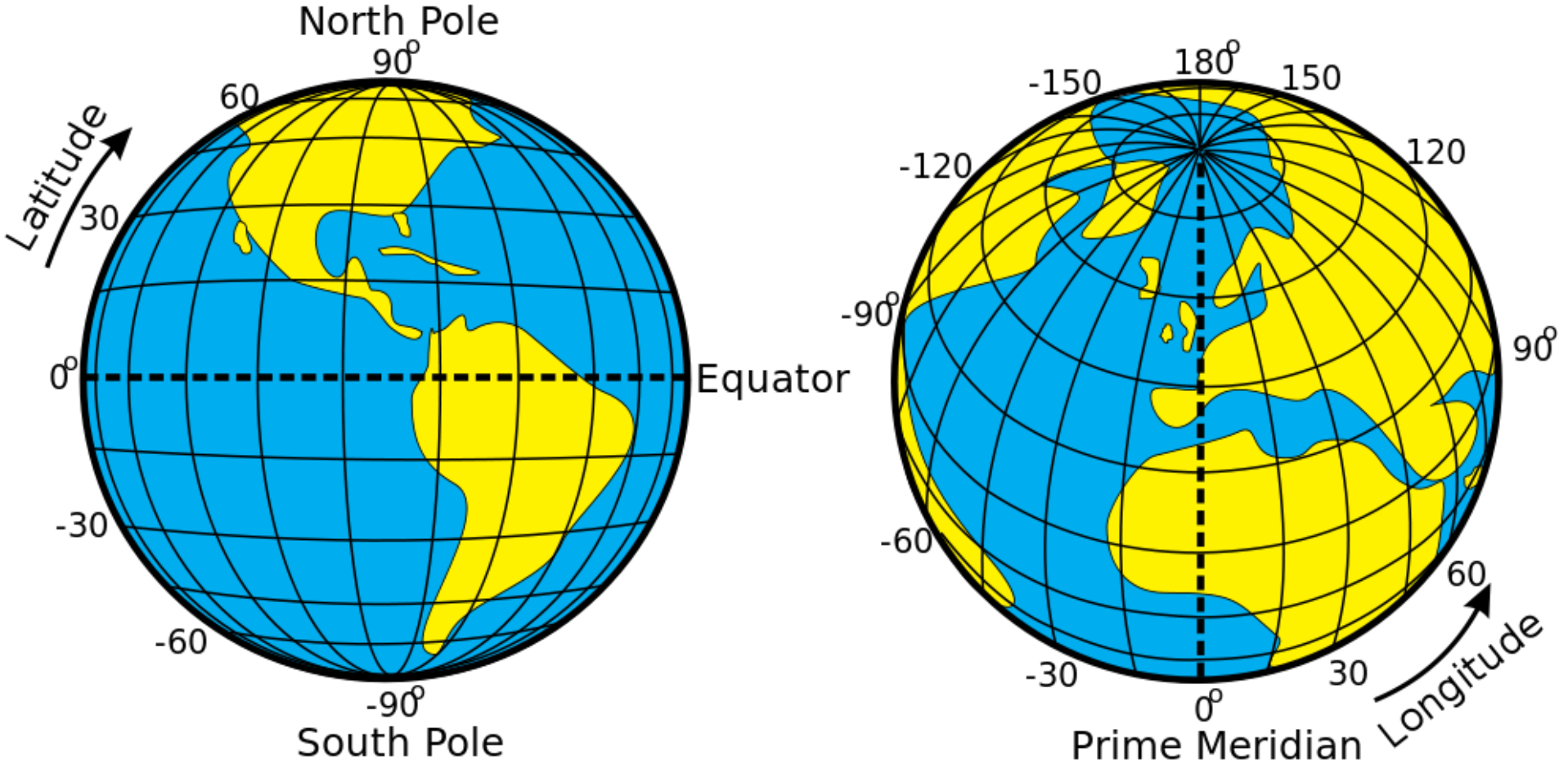
Marine Navigation

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.

Latitude and Longitude



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

360 degrees (°) in a circle
60 minutes (') in 1 degree
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North & East: positive
South & West: negative

Coordinates of MIT Sailing Pavilion:

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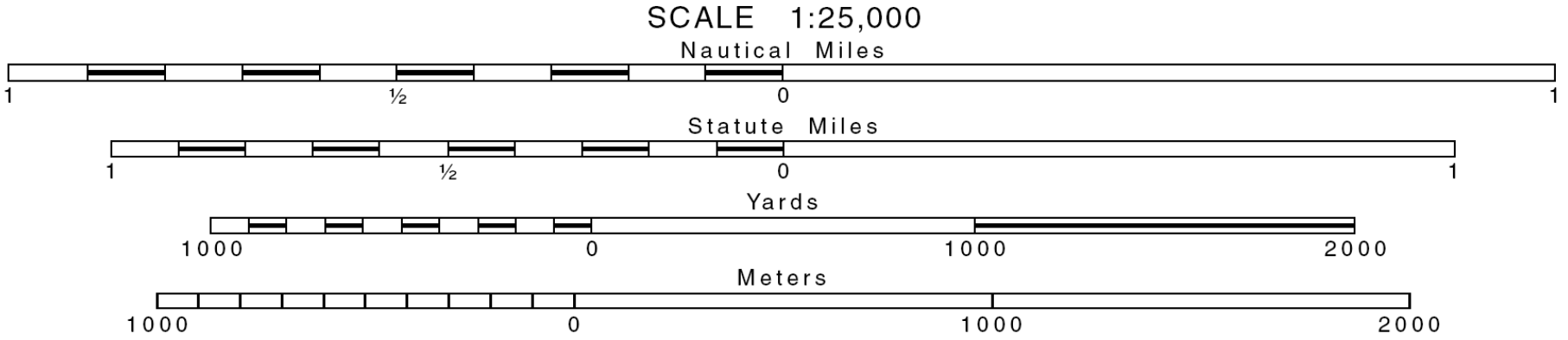
42.35845° N, 71.08776° W
42.35845, -71.08776

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 ≈ 6076.1 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.

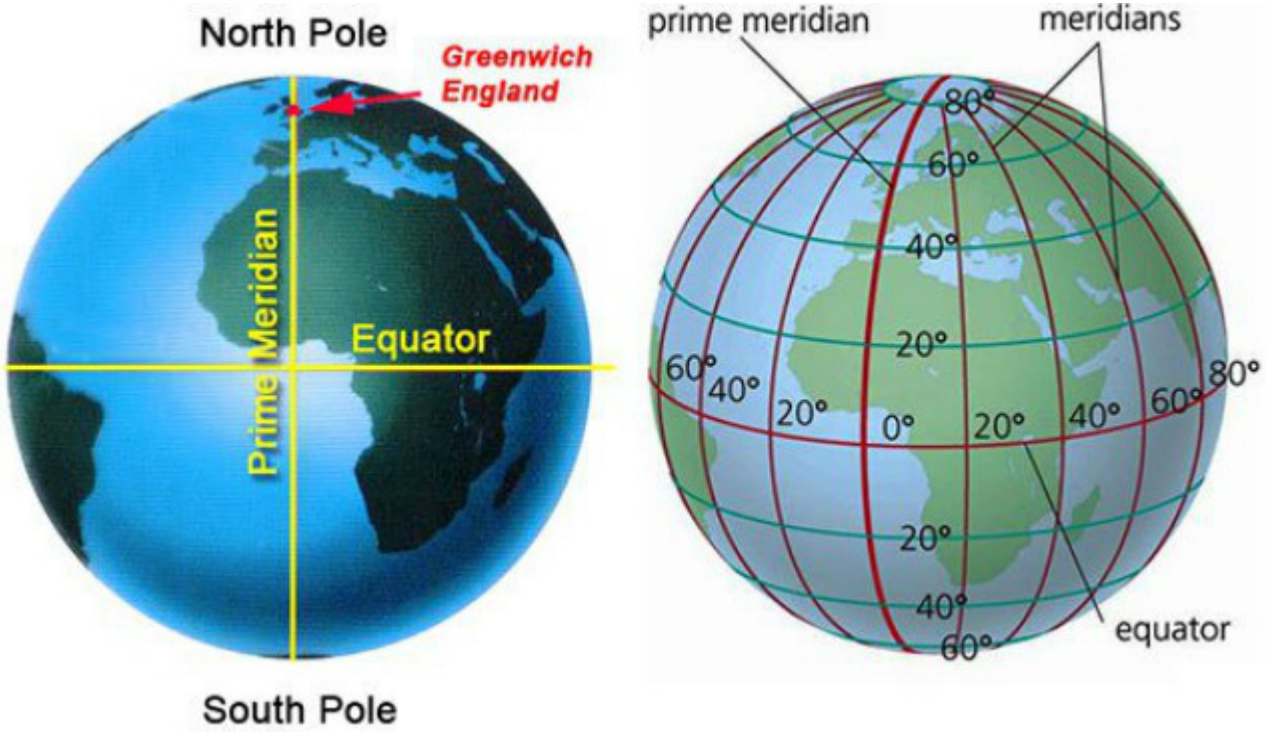
In Boston Harbor:

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)

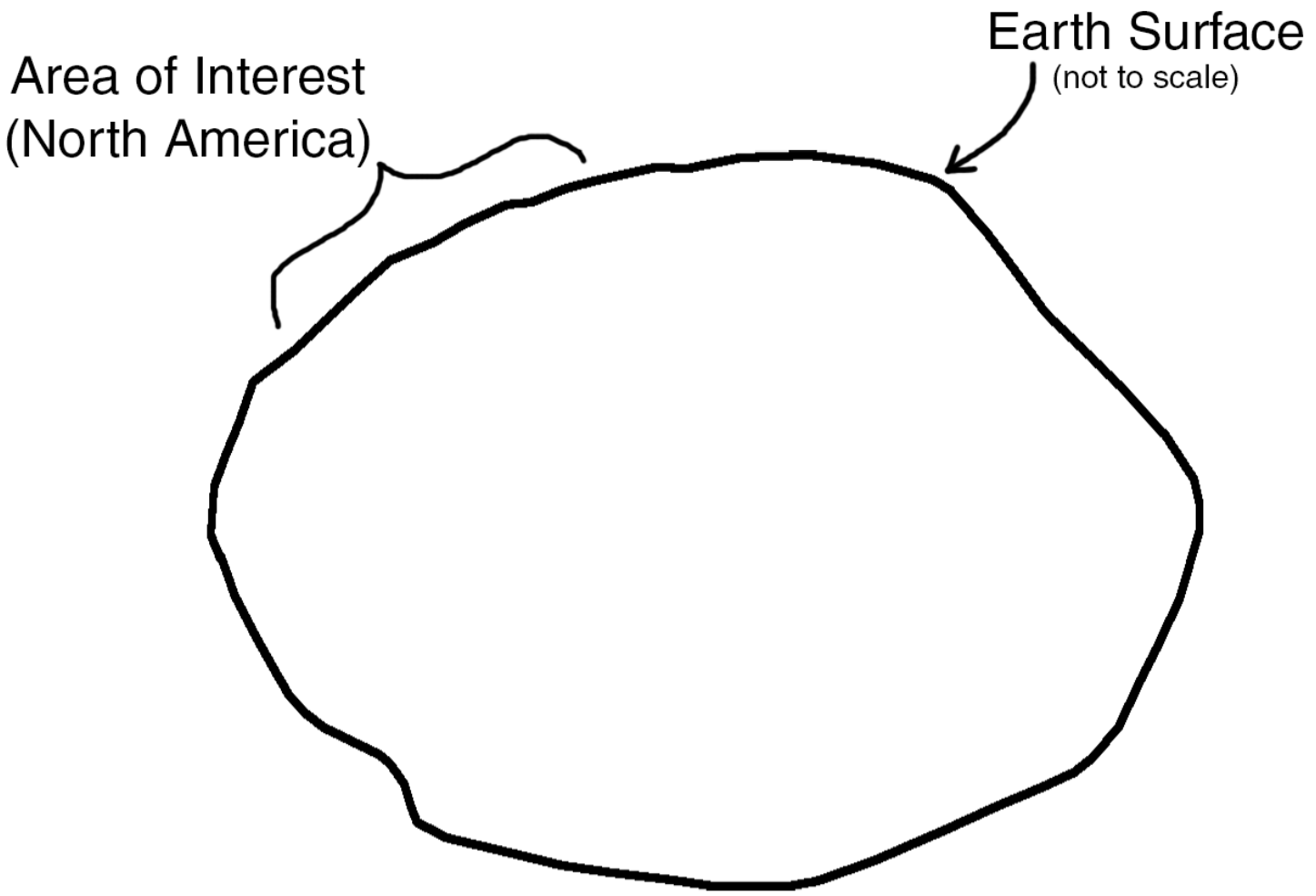


Horizontal Datum

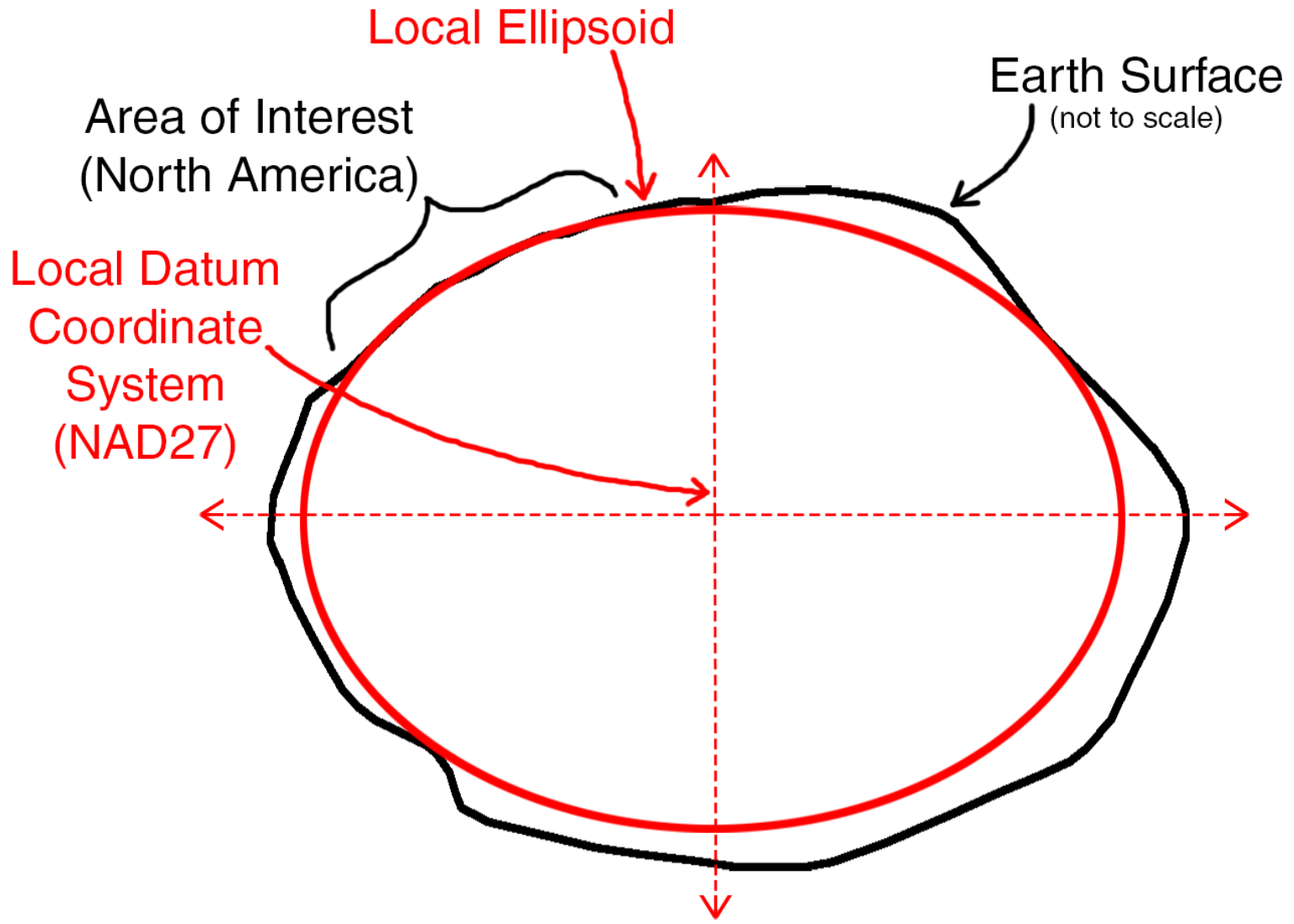
Make sure your GPS and other navigation instruments are using the same Horizontal Datum as your charts.

- 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.

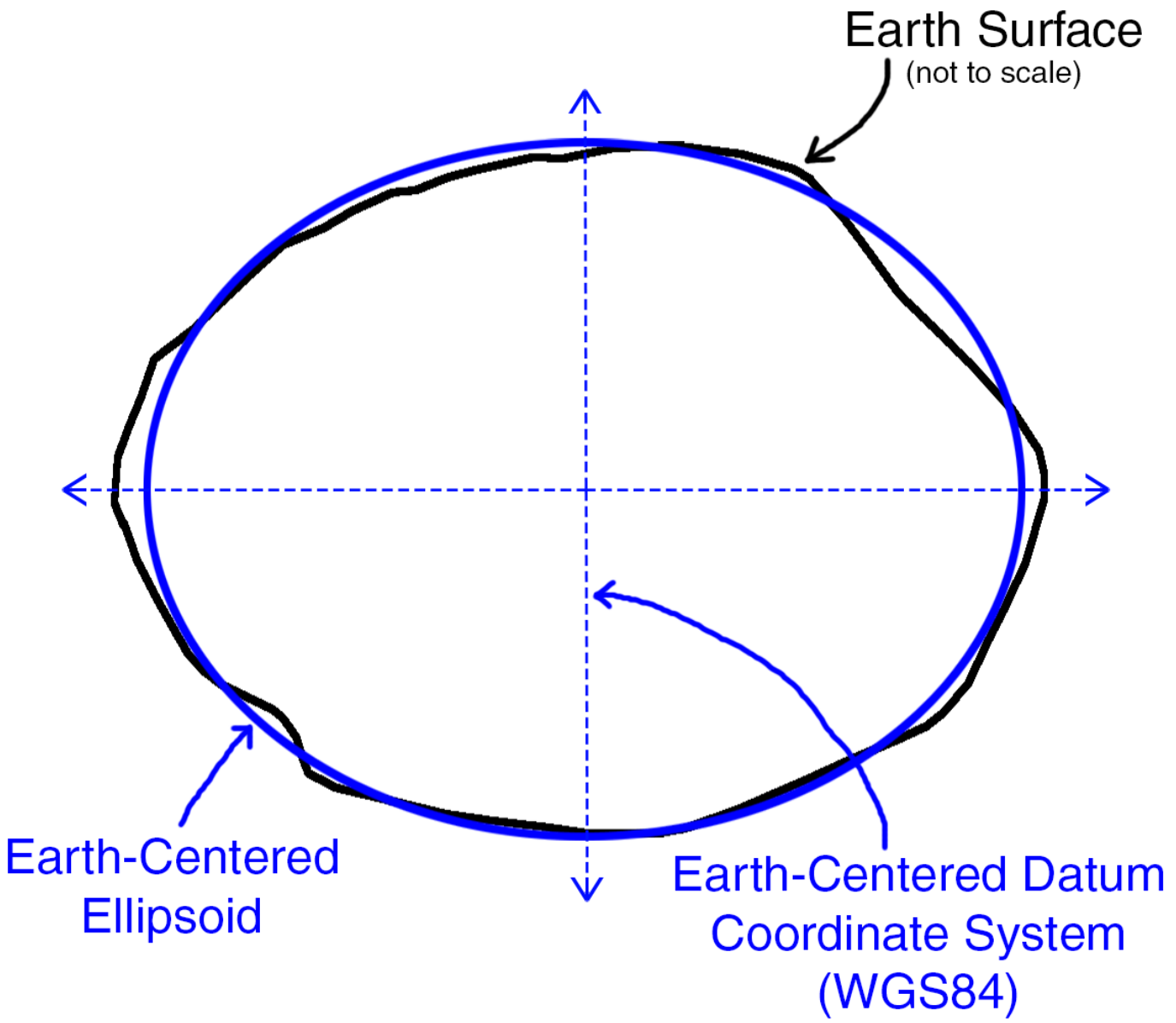
Horizontal Datum



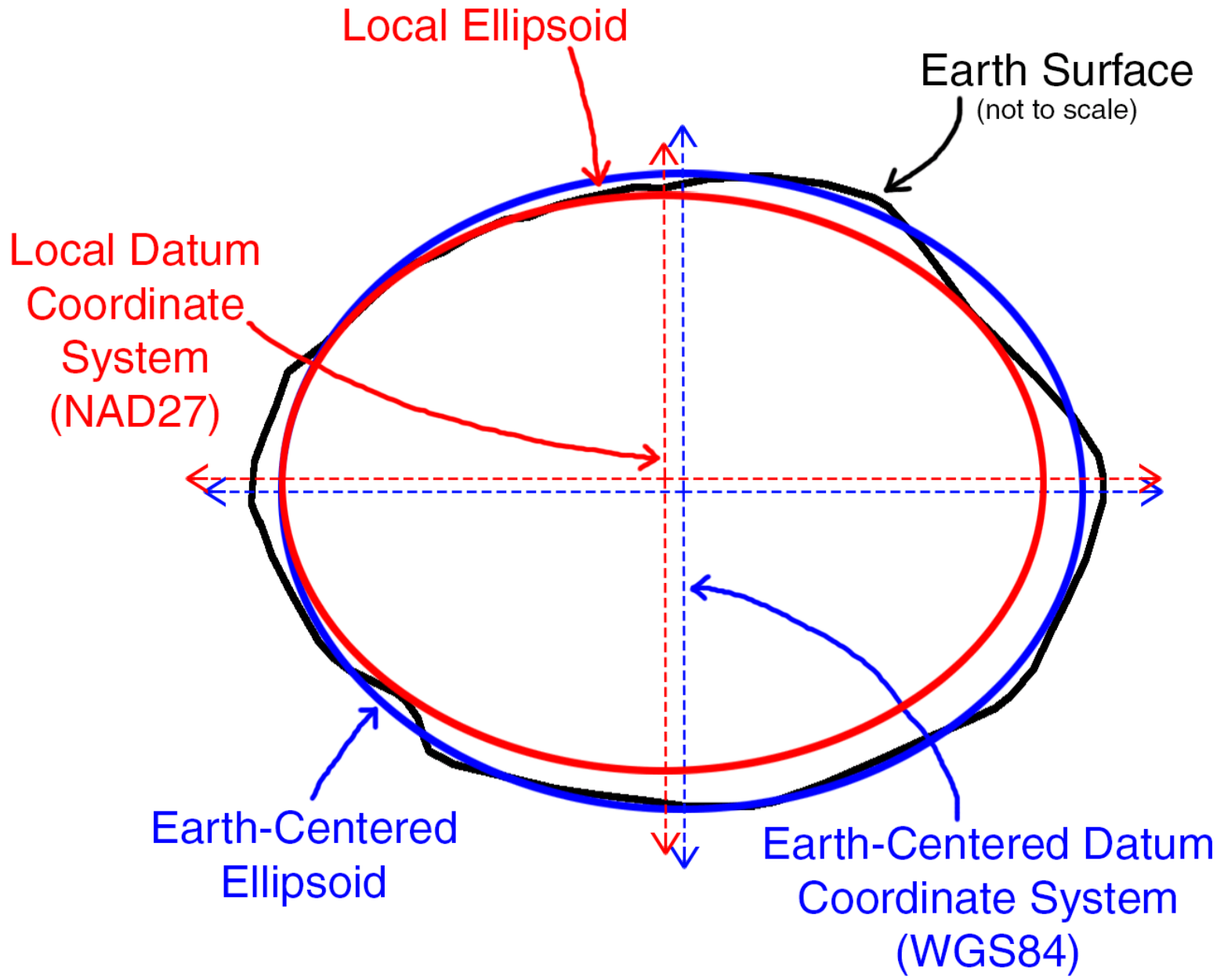
Horizontal Datum



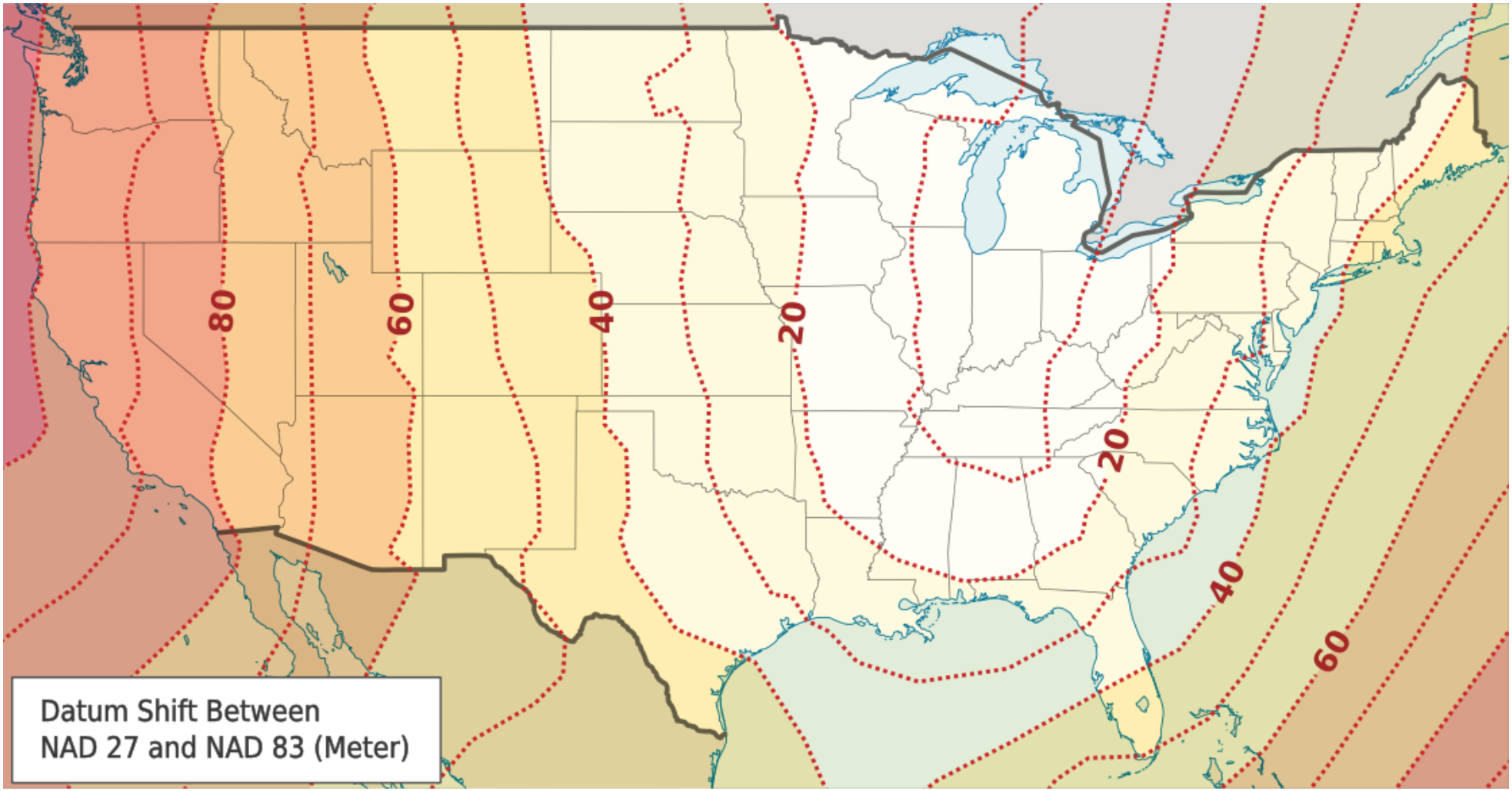
Horizontal Datum



Horizontal Datum

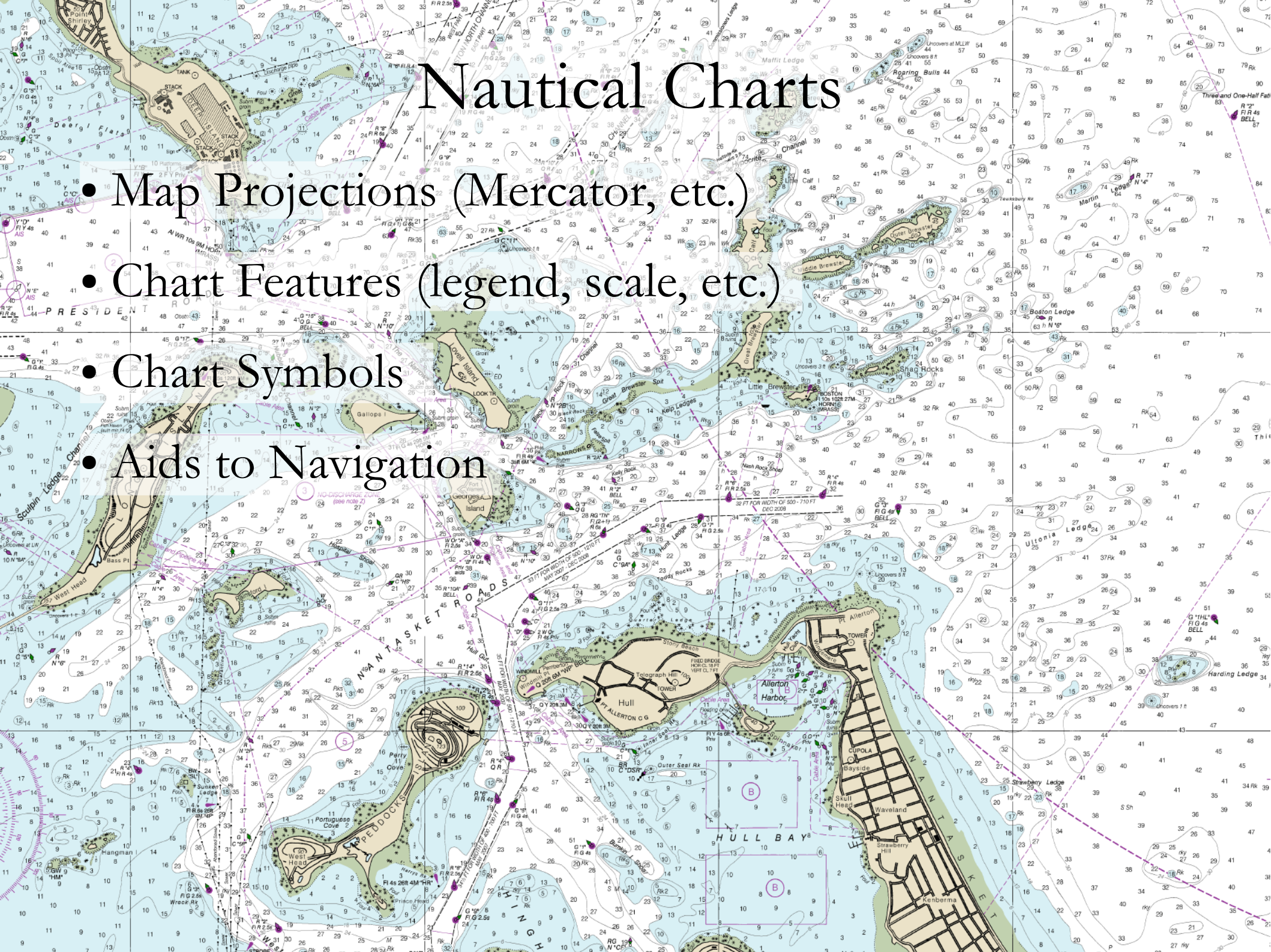


Horizontal Datum

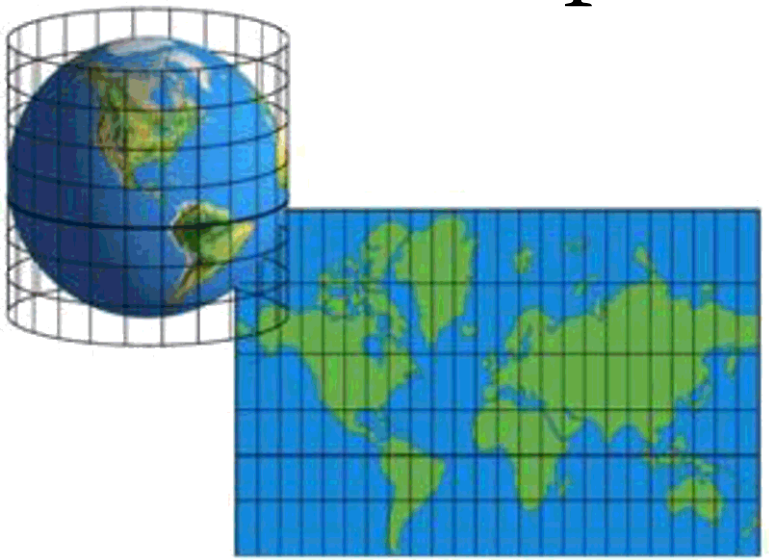


Nautical Charts

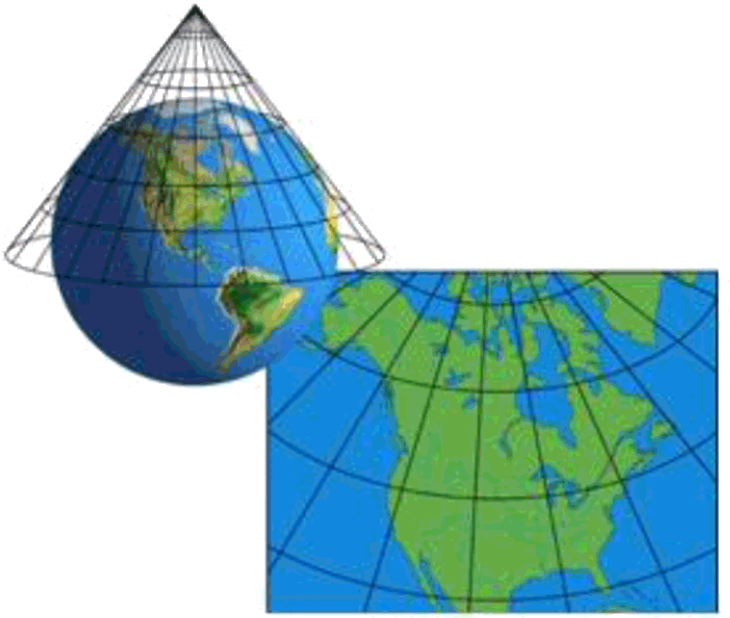
- Map Projections (Mercator, etc.)
- Chart Features (legend, scale, etc.)
- Chart Symbols
- Aids to Navigation



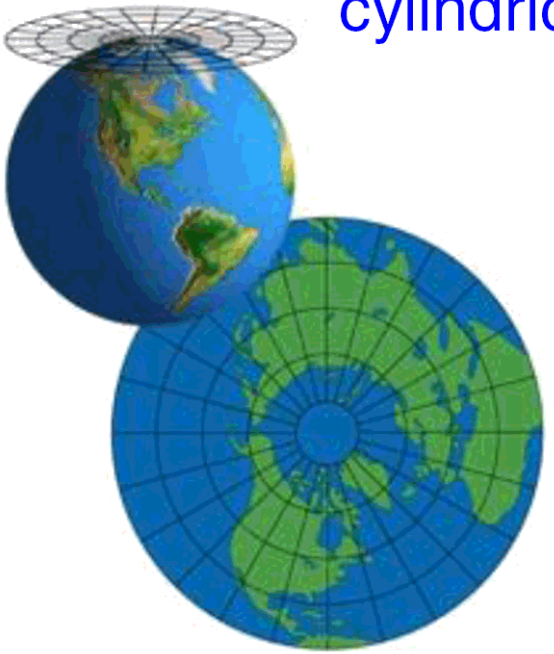
Map Projections



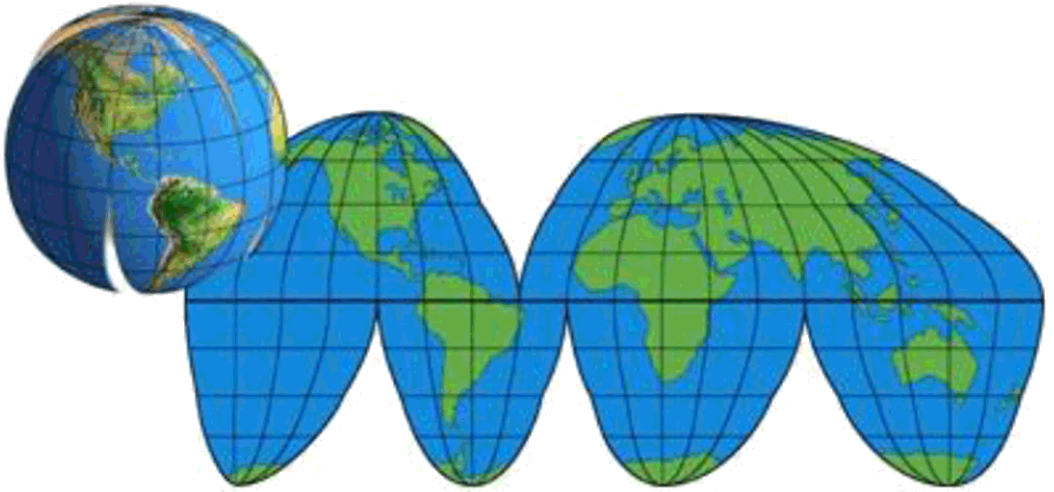
cylindrical projection



conic projection

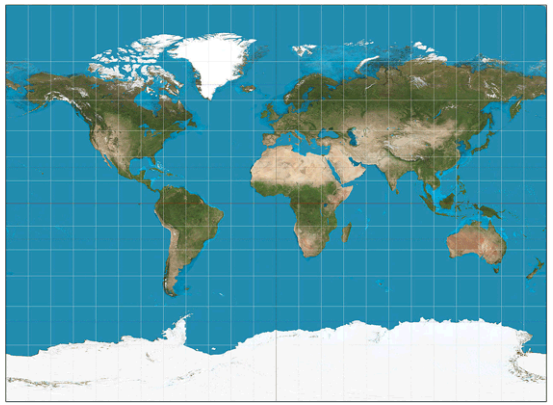


plane projection

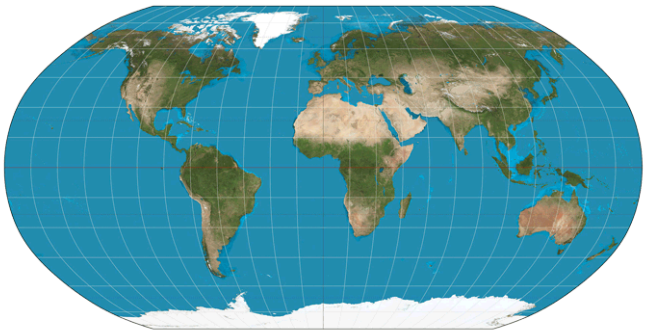


interrupted projection

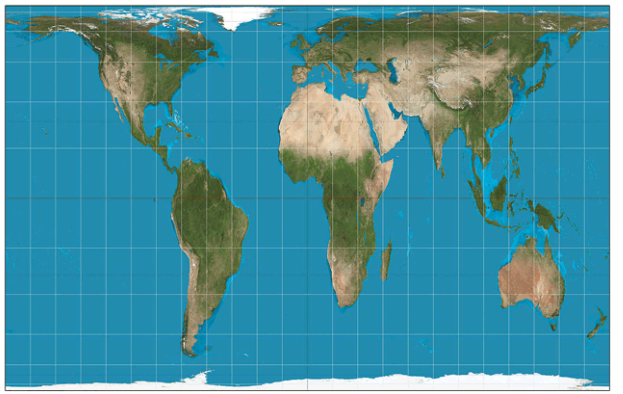
Map Projections



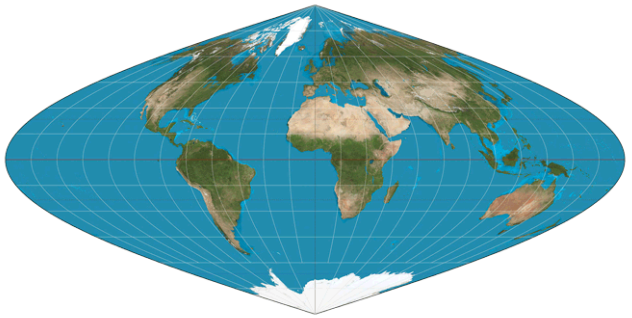
Miller Cylindrical Projection



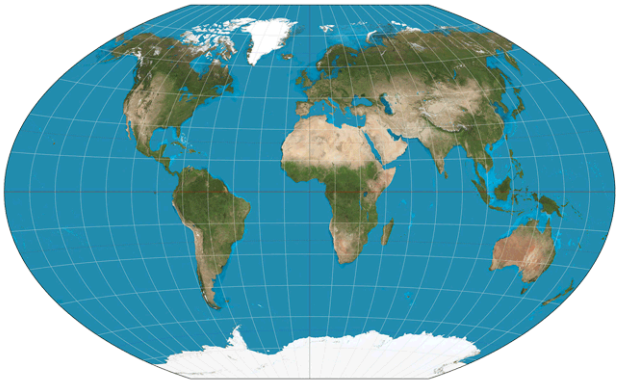
Robinson Projection



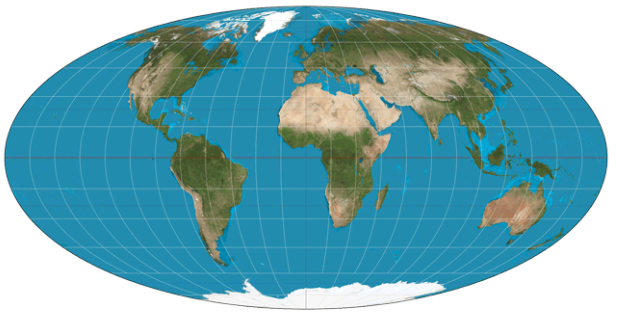
Gall-Peters Projection



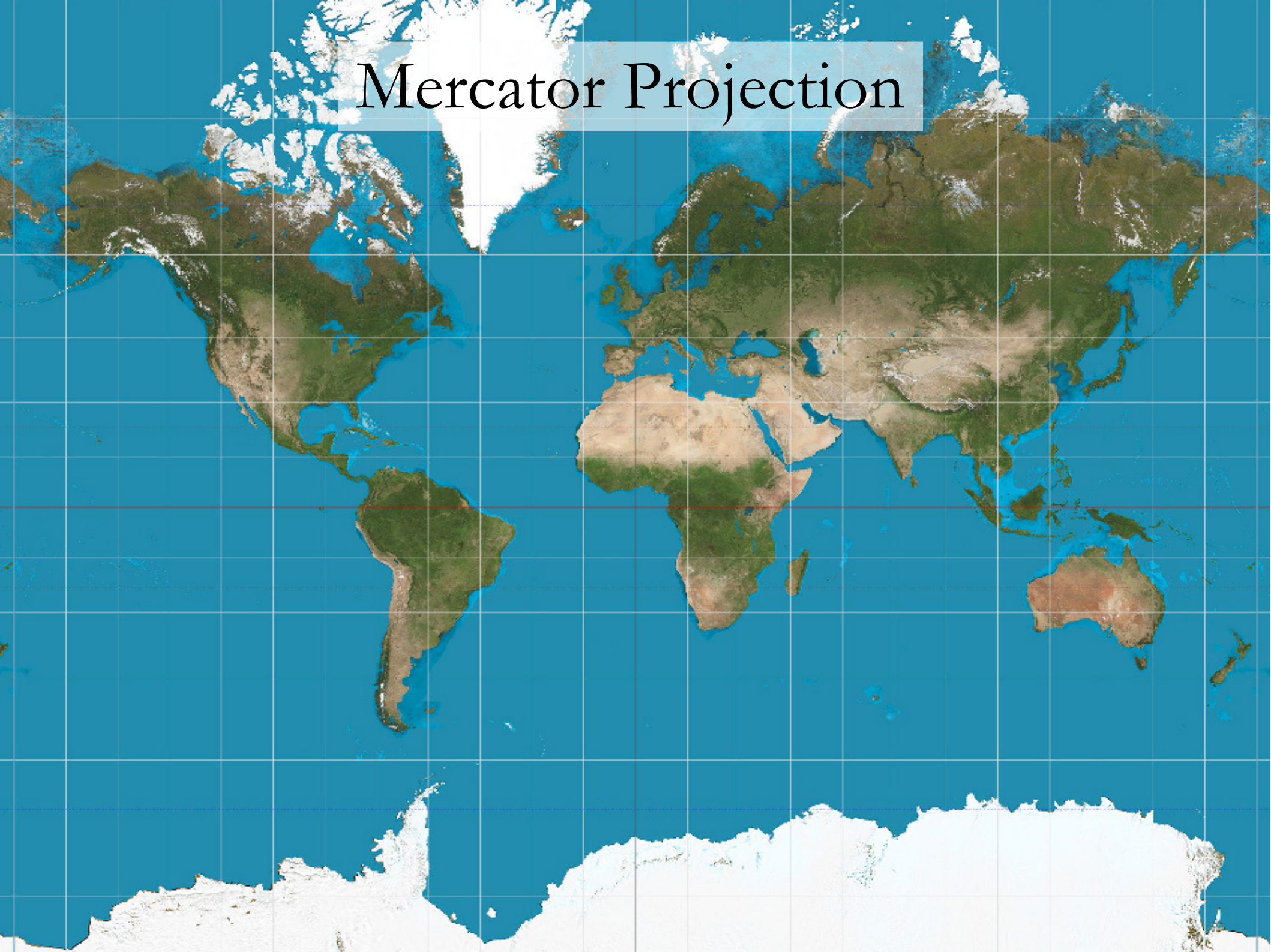
Sinusoidal Equal-Area Projection

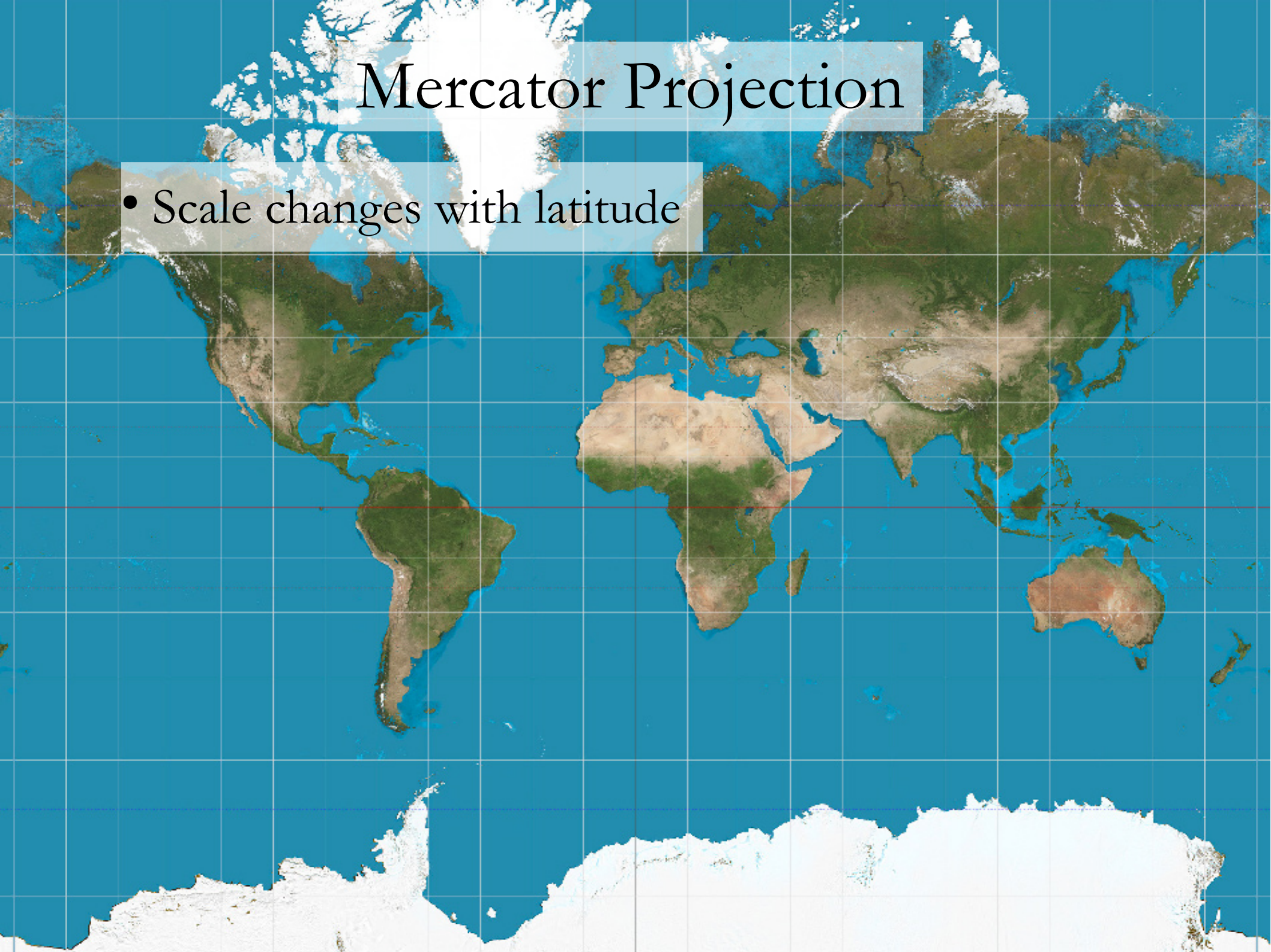


Winkel Tripel Projection



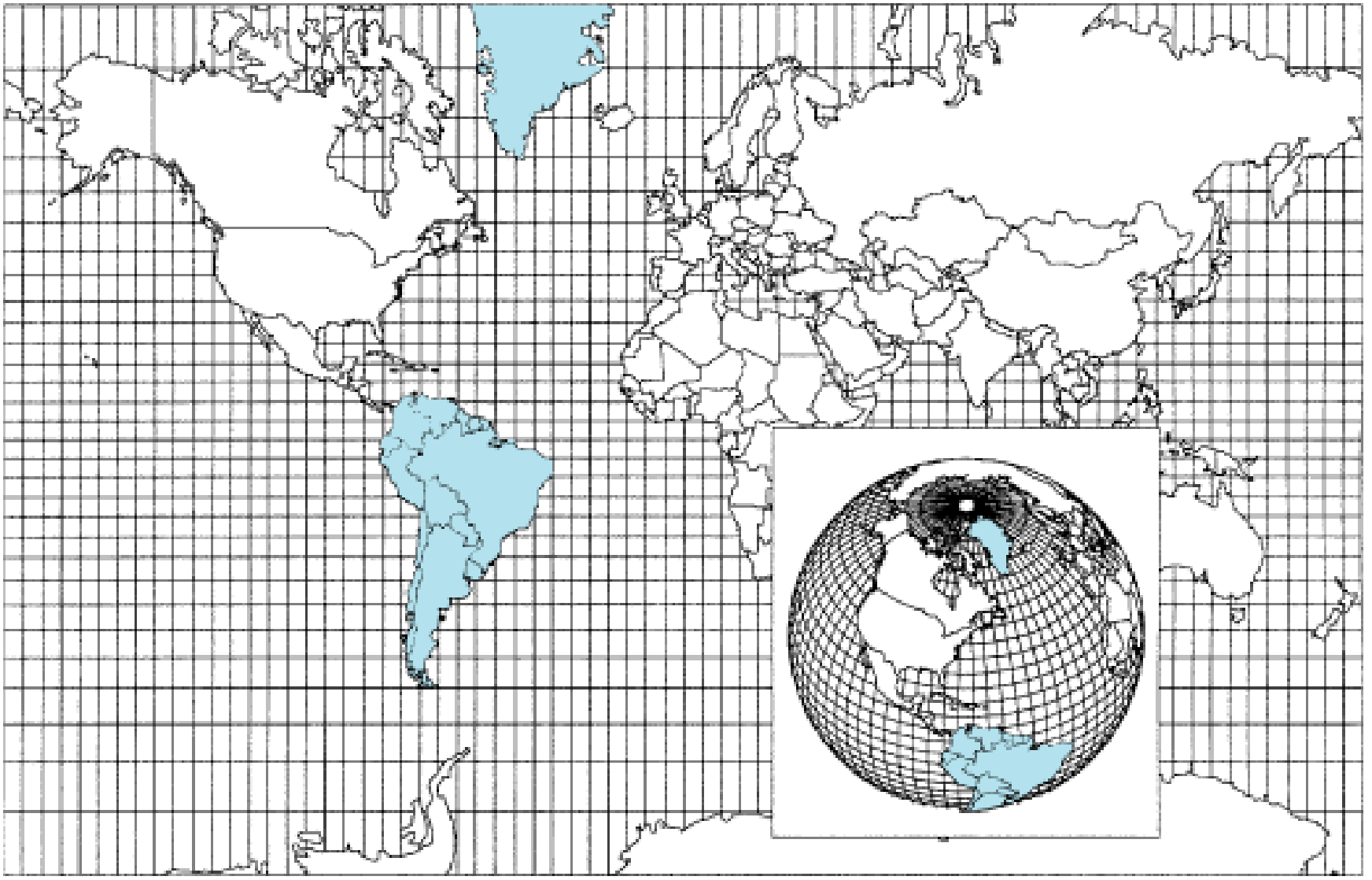
Mollweide Projection


Mercator Projection

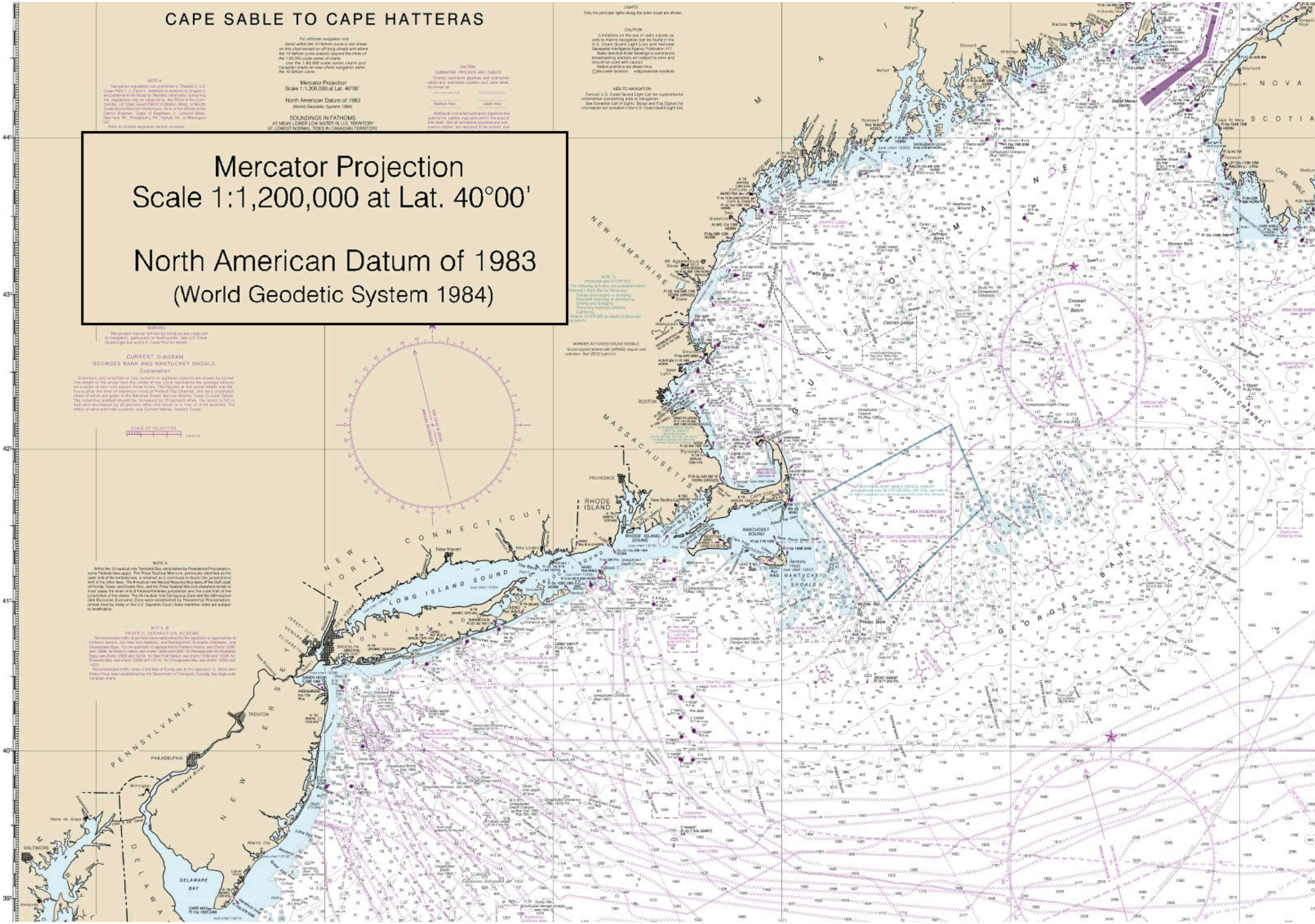

Mercator Projection
• Scale changes with latitude

Mercator Projection

- Scale changes with latitude



Mercator Projection



Change in Scale vs. Latitude

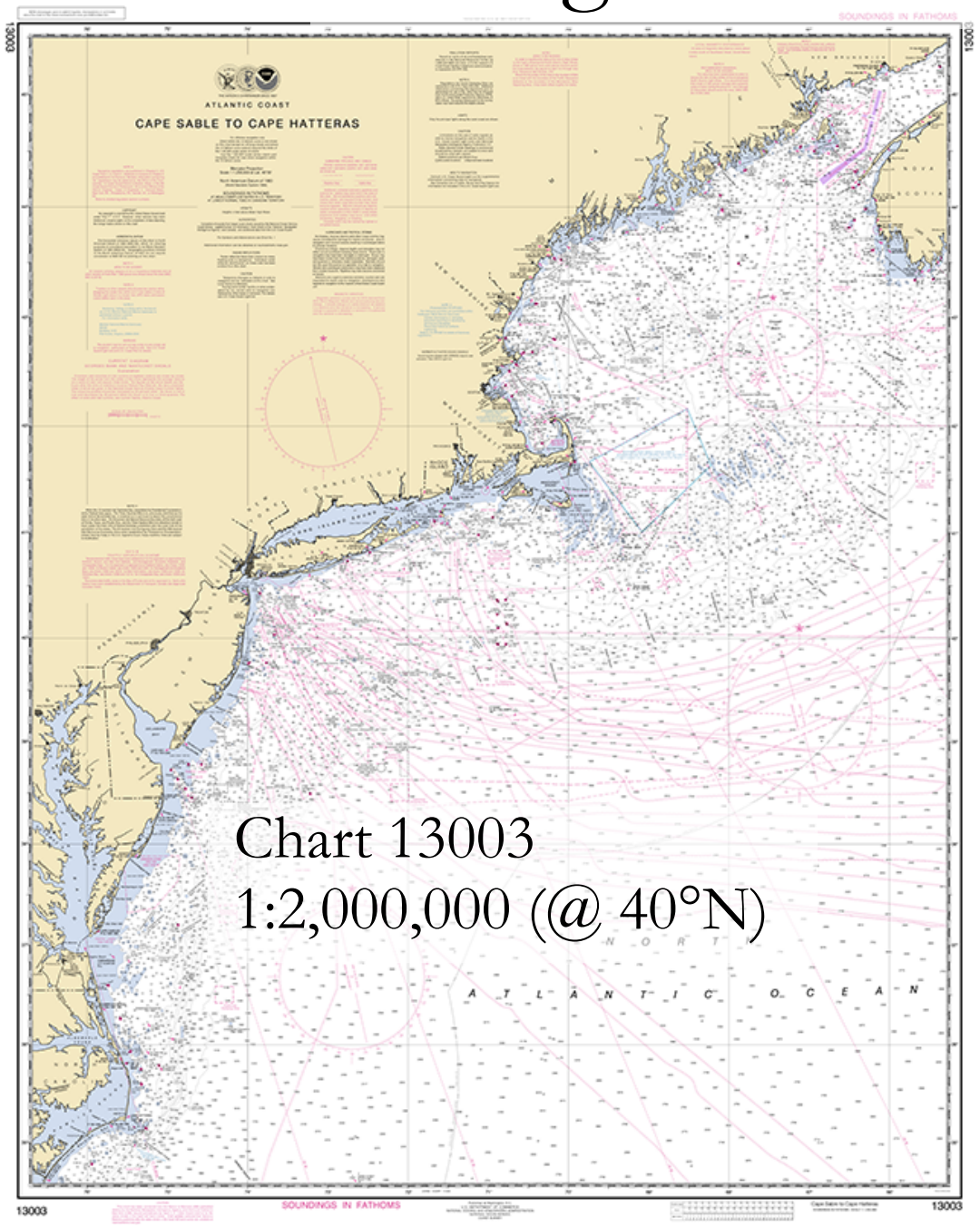


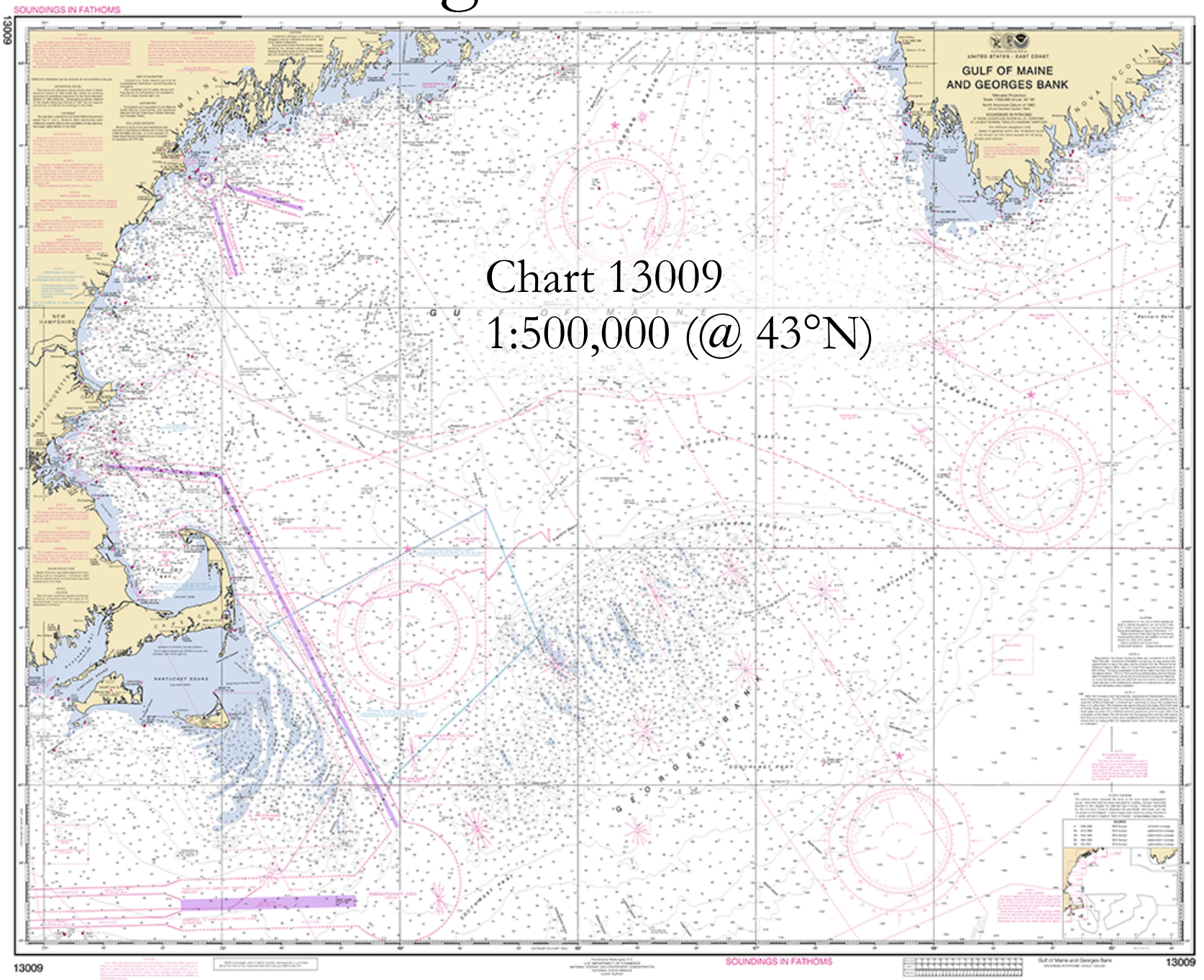
Chart 13003
1:2,000,000 (@ 40°N)

45°N: -8% error
2nm/inch
max error 72 nm
(for width of chart)

40°N

35°N: +7% error: 2nm/inch

Change in Scale vs. Latitude

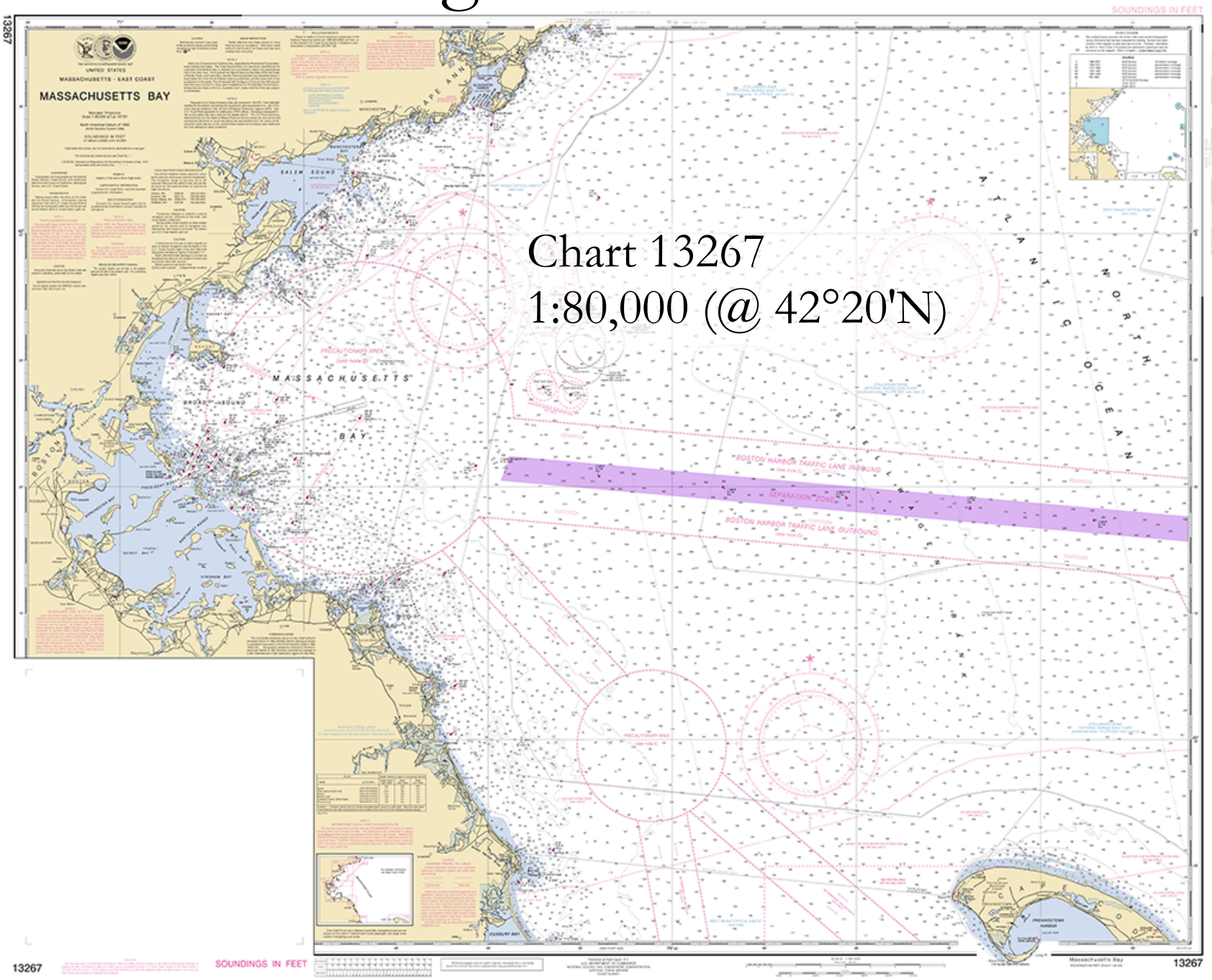


44°N
-1.6% error
0.1 nm/inch
(max error 5nm)

43°N

41°N
+3% error
0.2 nm/inch
(max err 9nm)

Change in Scale vs. Latitude



42°35'N
-0.4% error
27 feet/inch
(max error
0.2nm)

42°20'N

42°05'N
+0.4% error
27 feet/inch

Change in Scale vs. Latitude

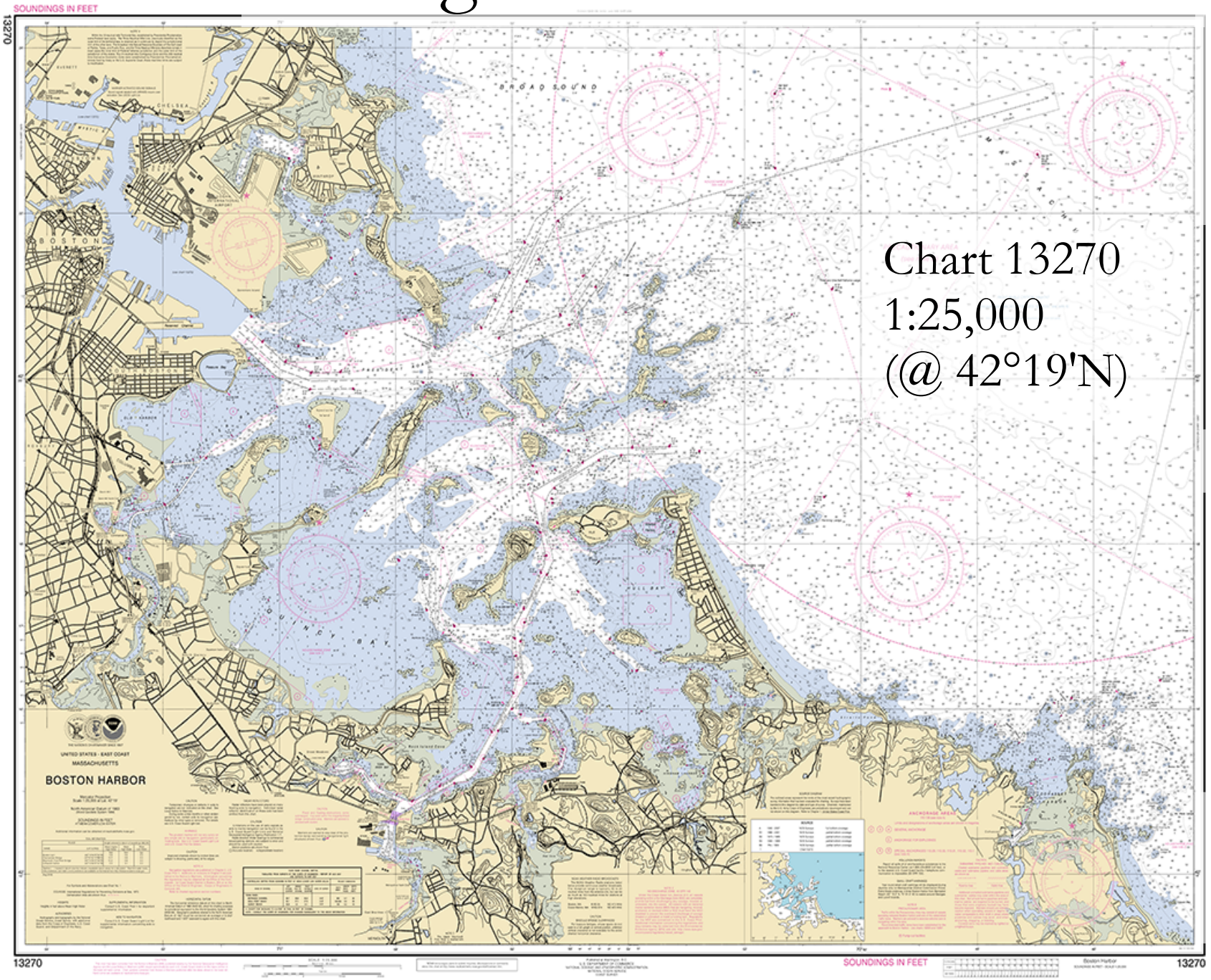
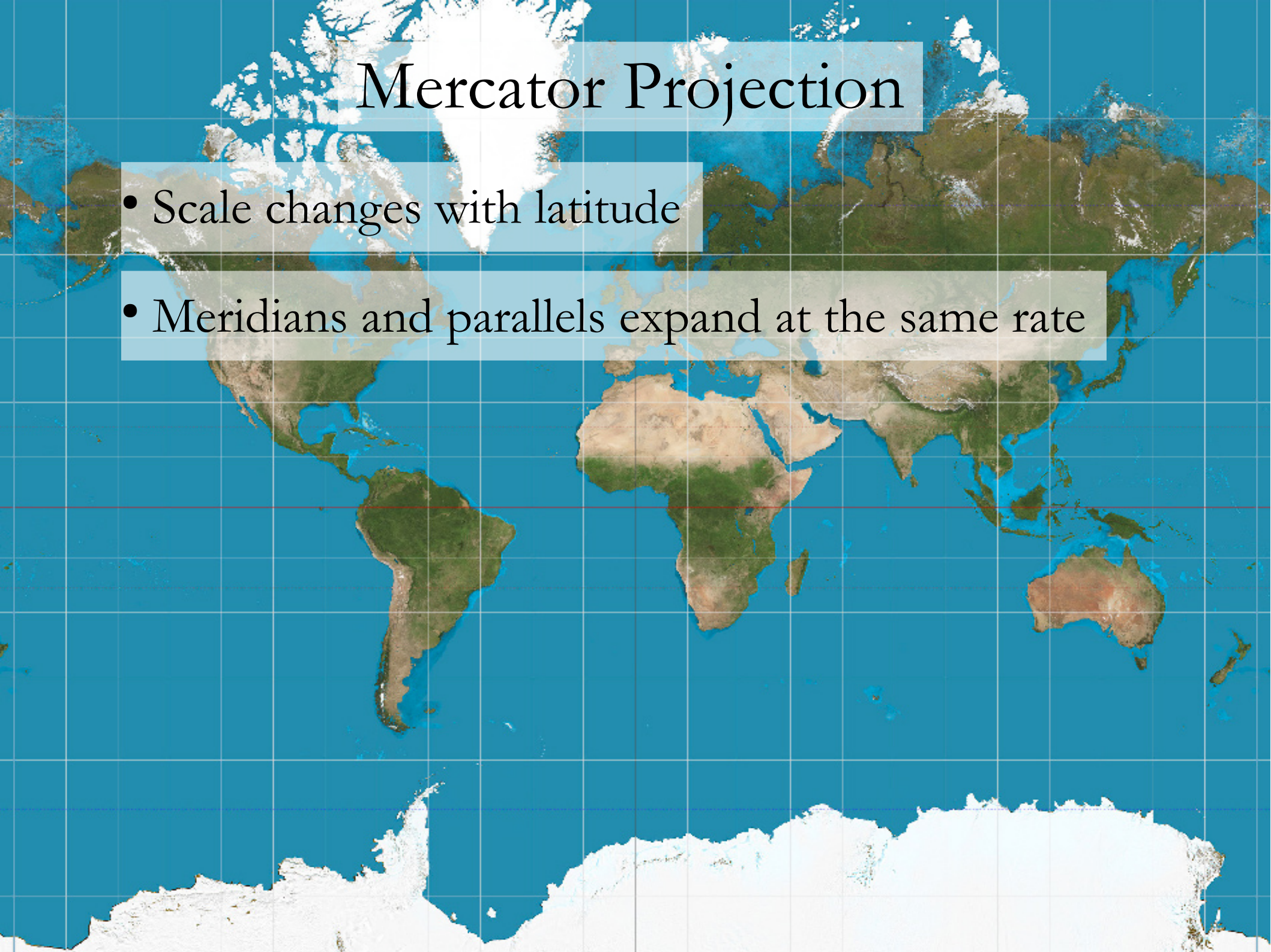


Chart 13270
1:25,000
(@ 42°19'N)

42°24'N
-0.14% error
3 feet/inch
(max err 150ft)

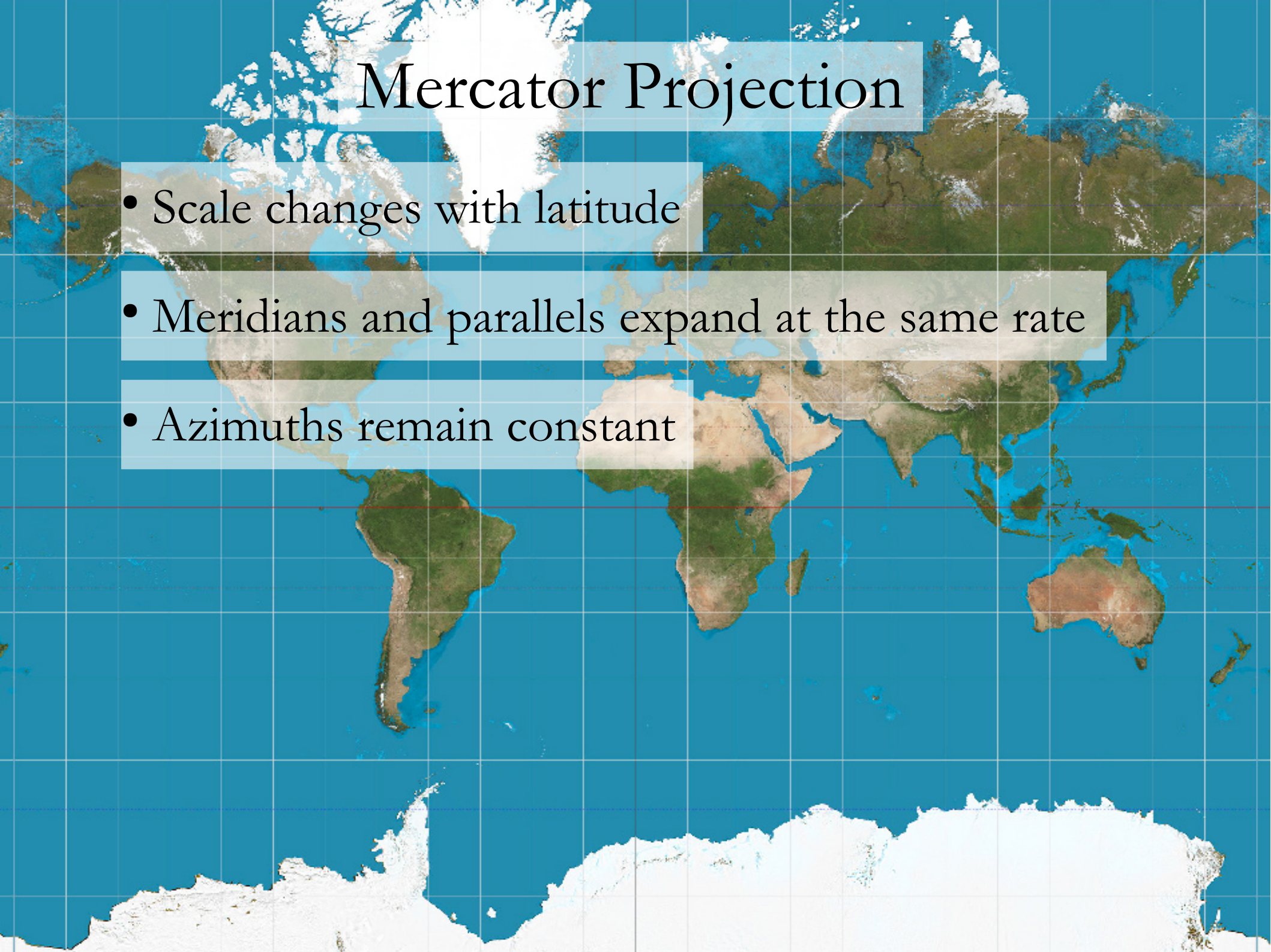
42°19'N

42°14'N
+0.13% error
3 feet/inch



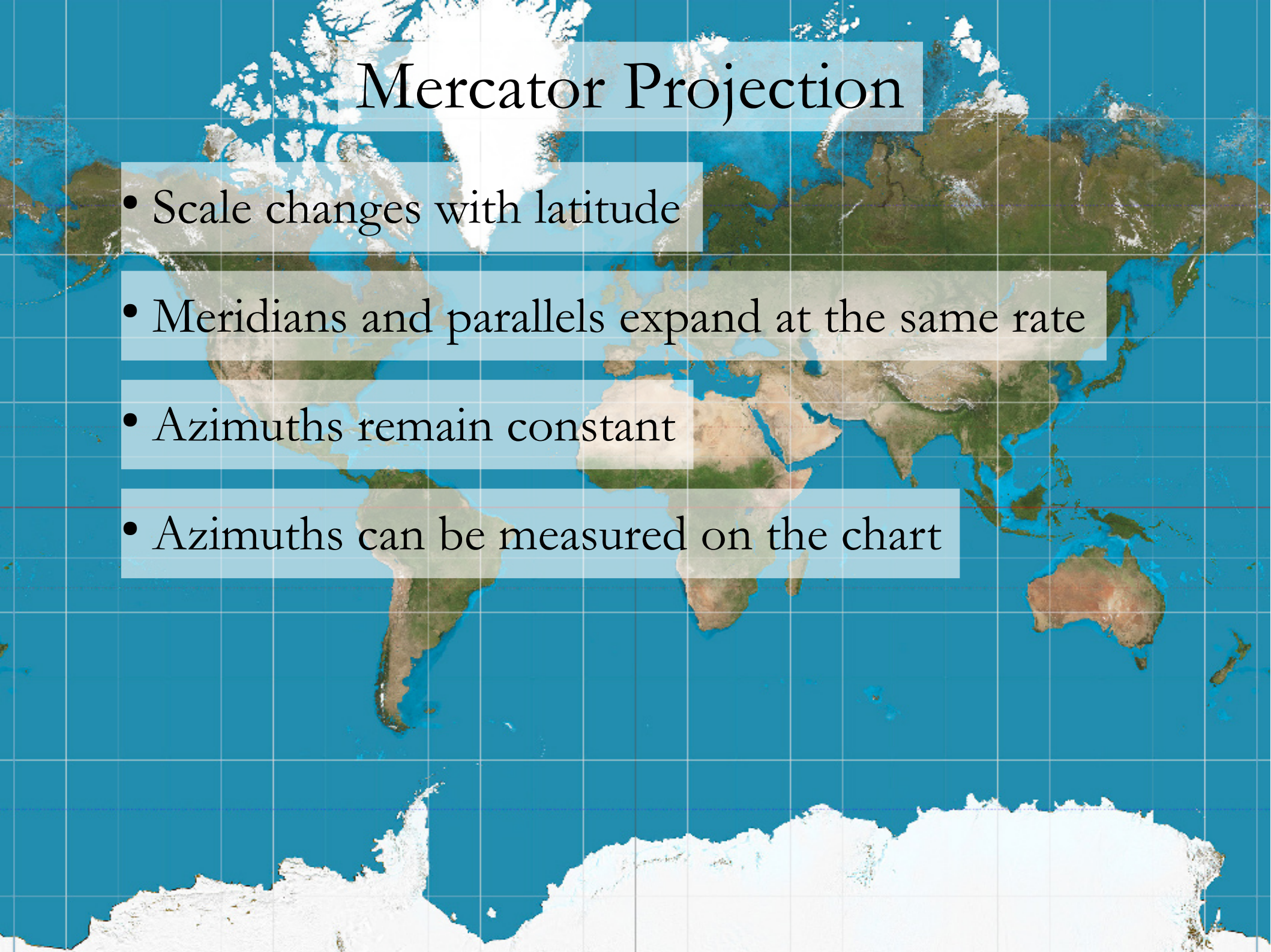
Mercator Projection

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



Mercator Projection

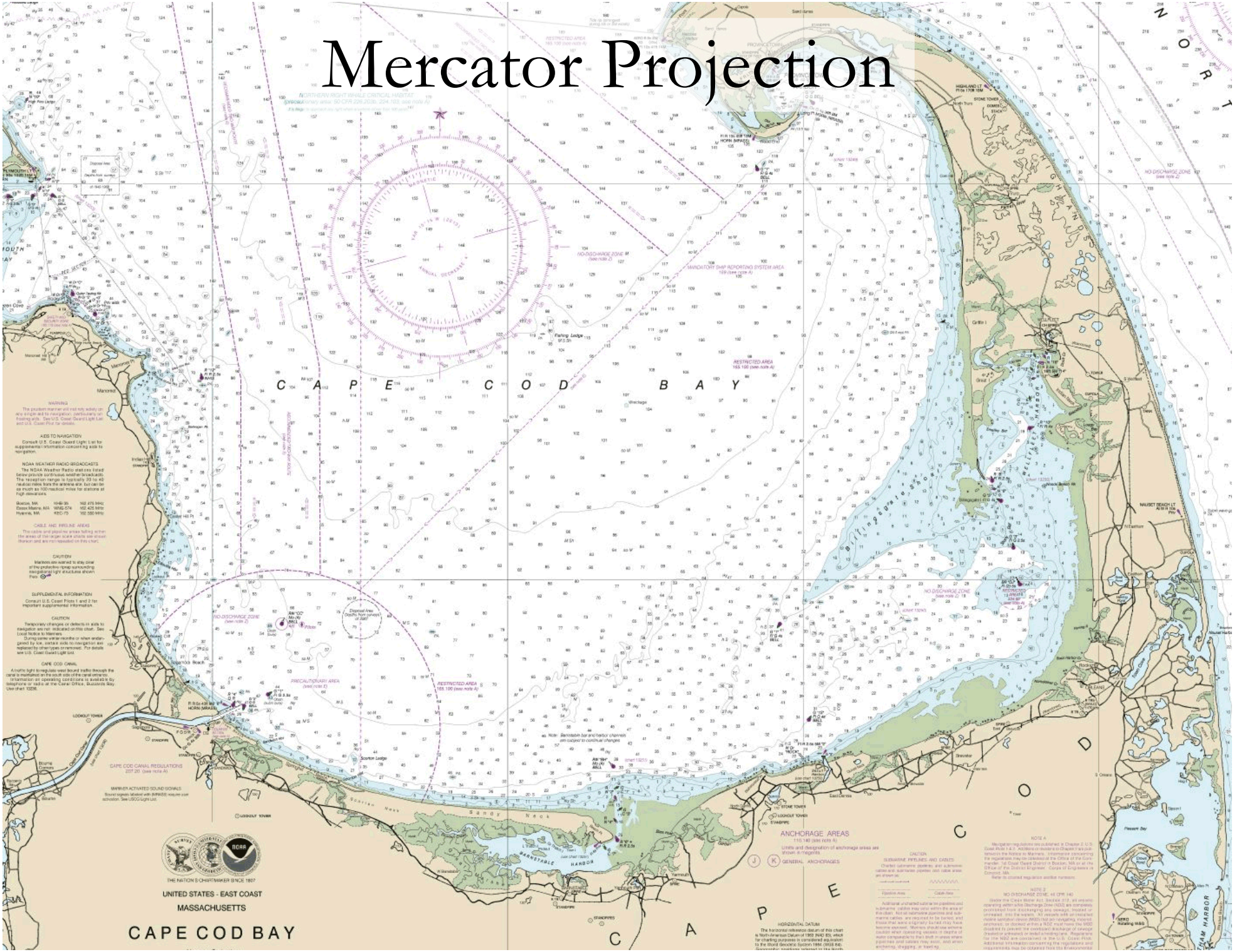
- Scale changes with latitude
- Meridians and parallels expand at the same rate
- Azimuths remain constant



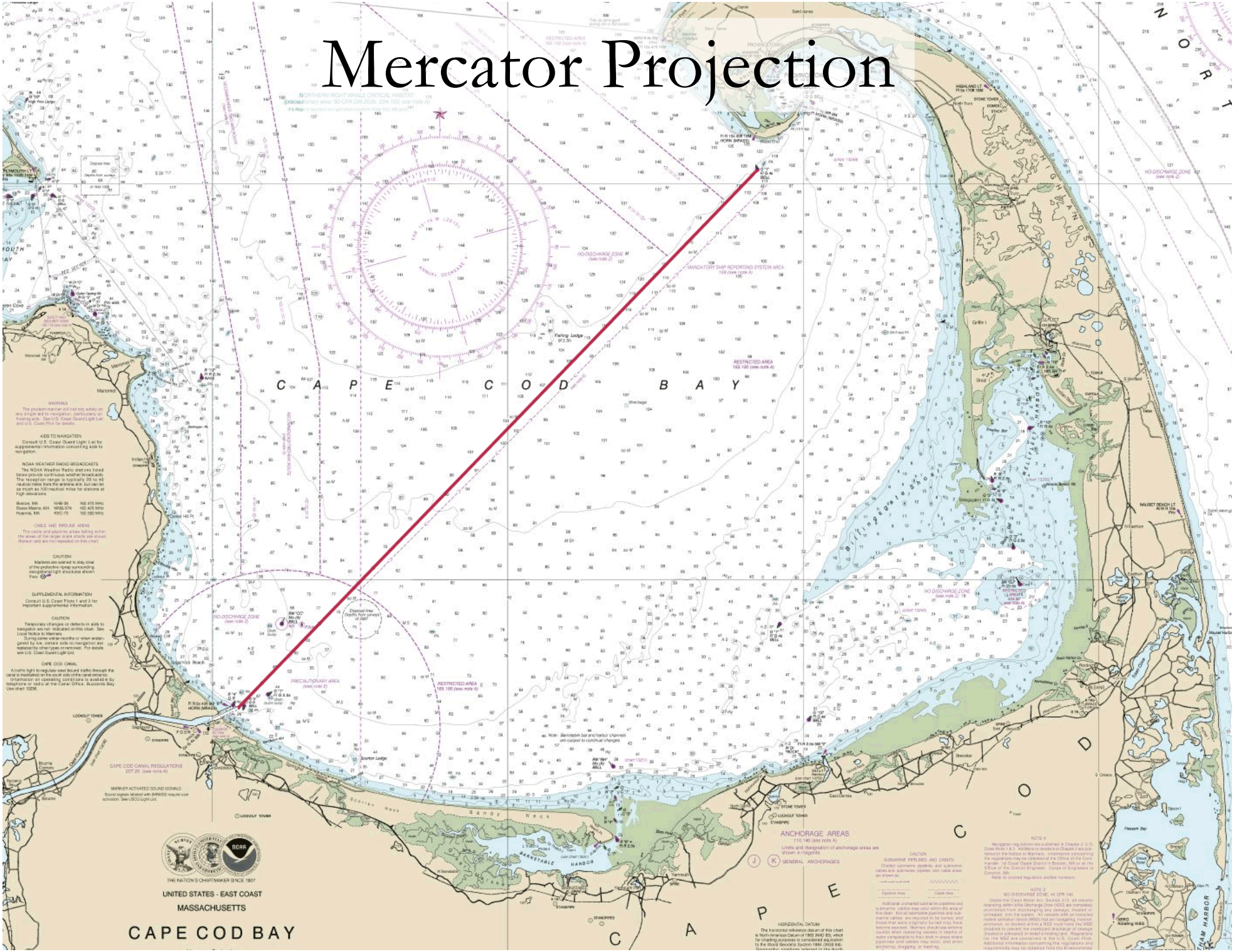
Mercator Projection

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

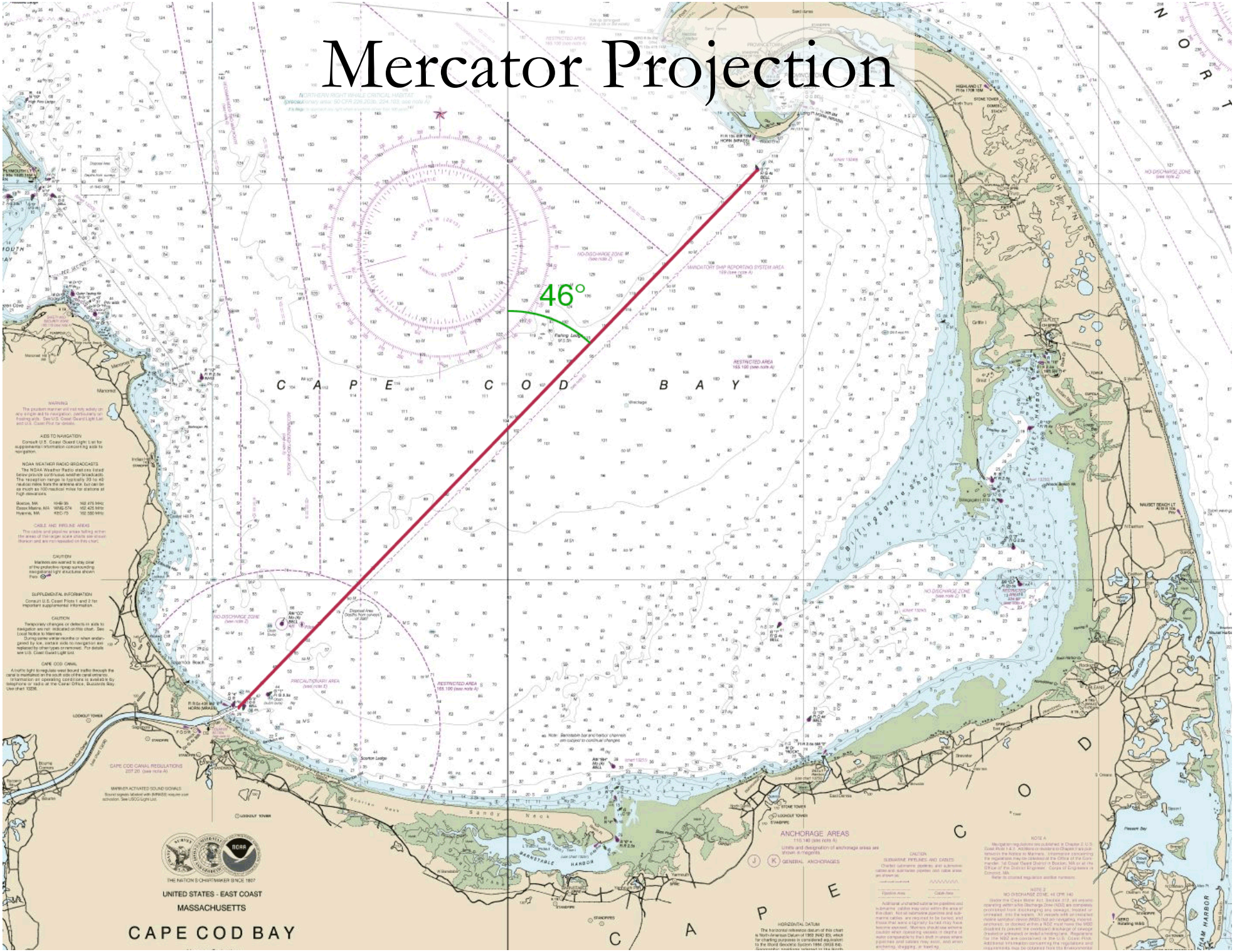
Mercator Projection

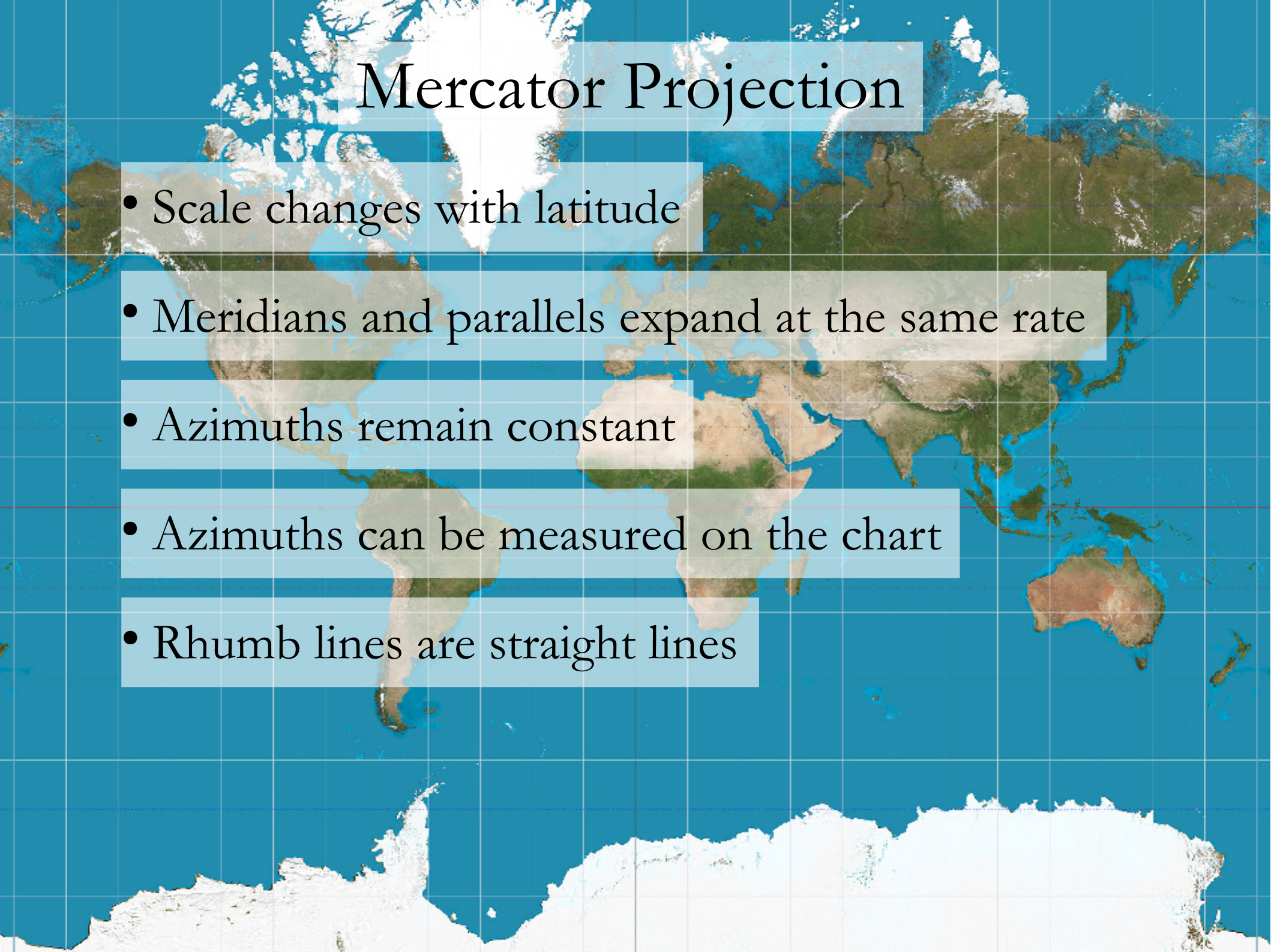


Mercator Projection



Mercator Projection



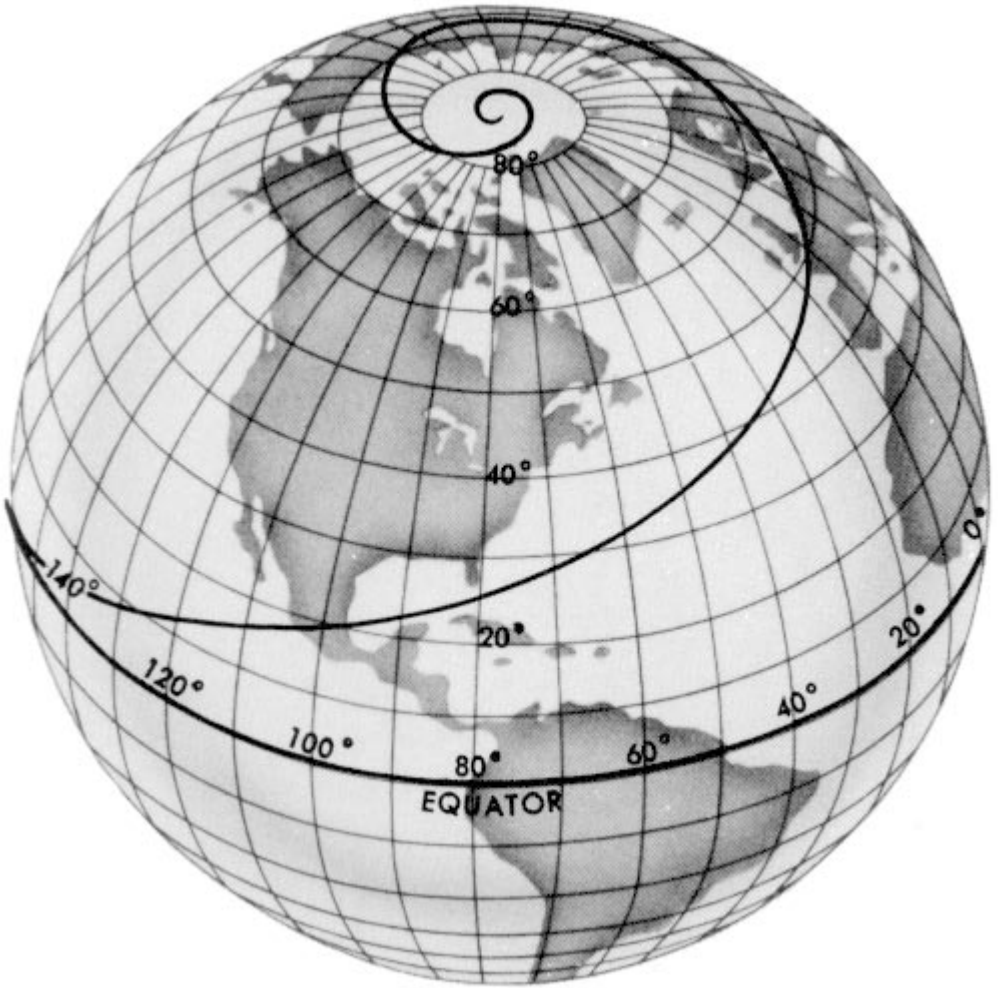


Mercator Projection

- 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

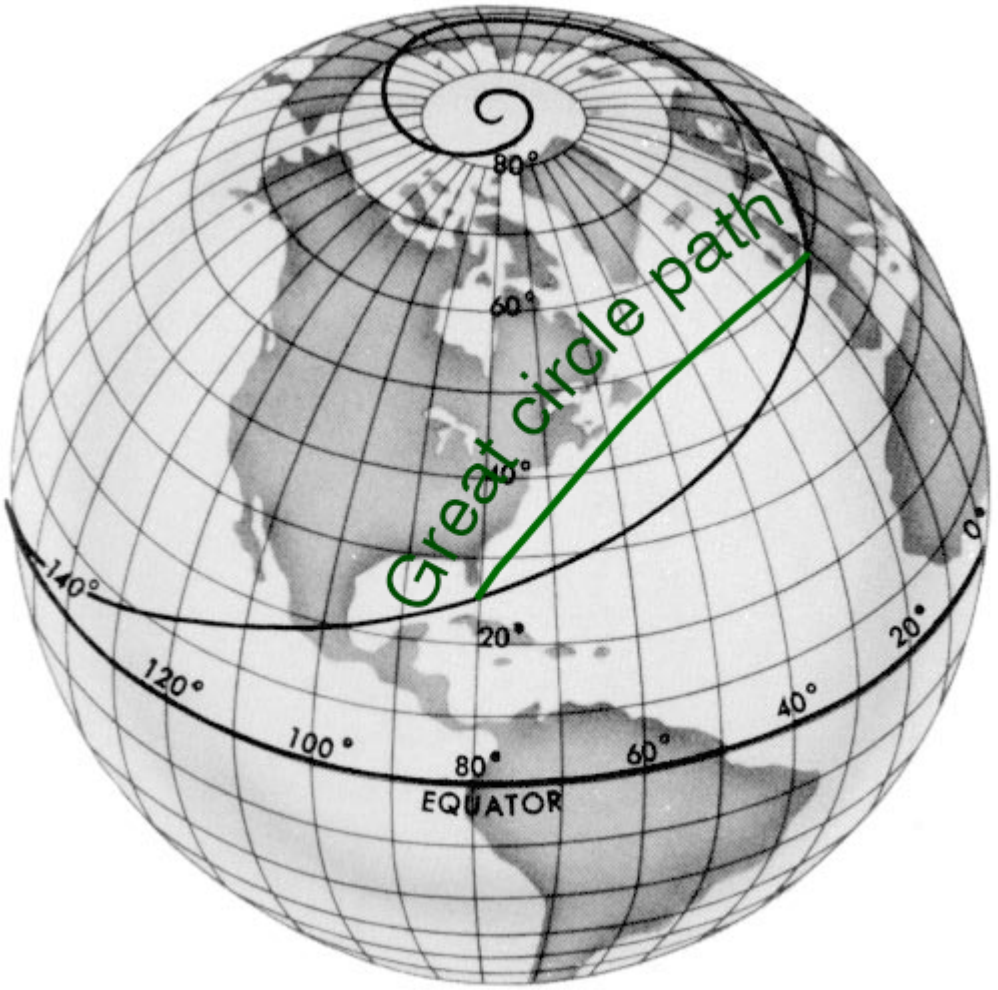
Mercator Projection

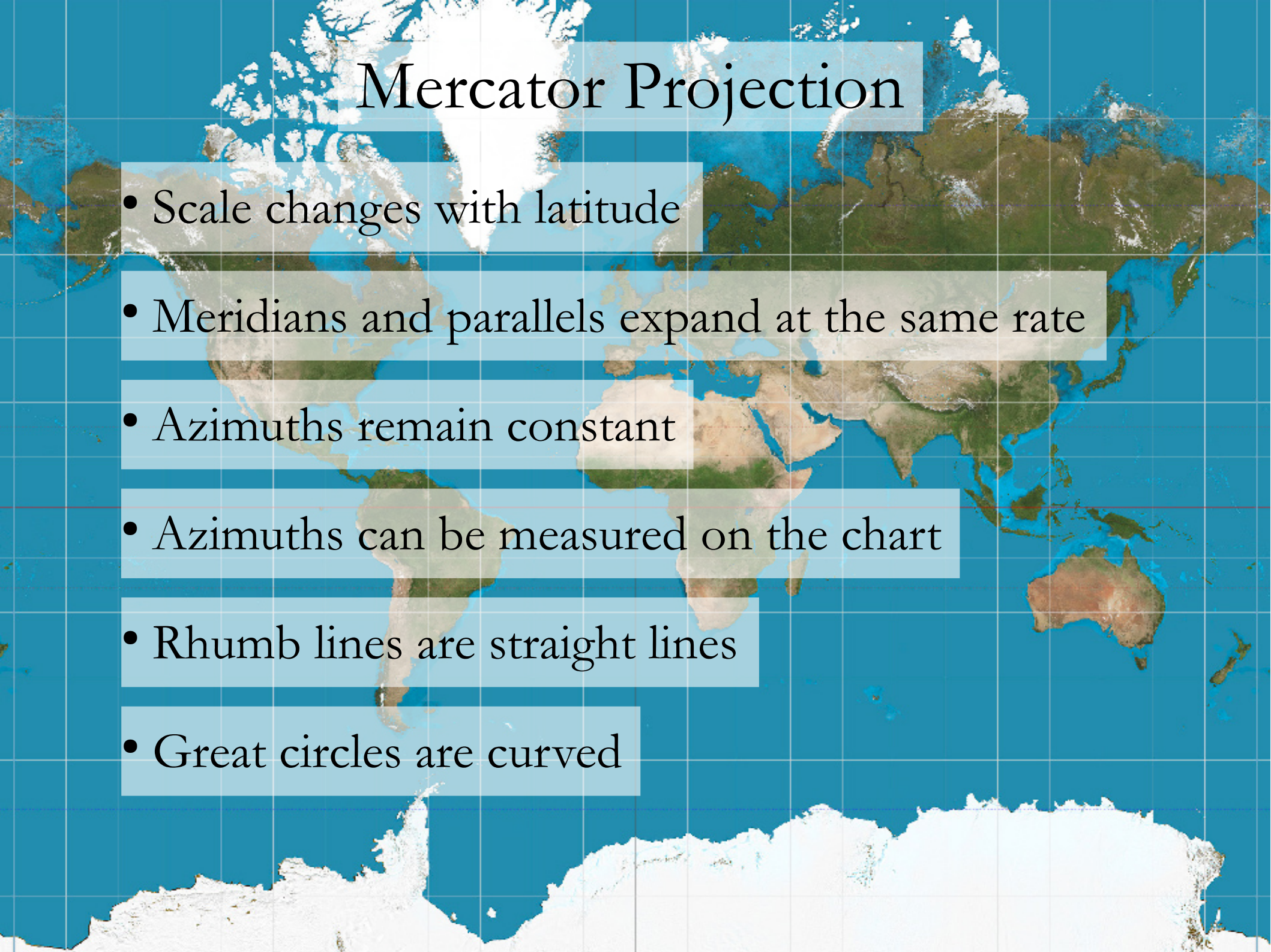
- A *rhumb line* is a path of constant azimuth. (also called a *loxodrome*).



Mercator Projection

- The shortest distance between two points on a sphere is along a great circle.

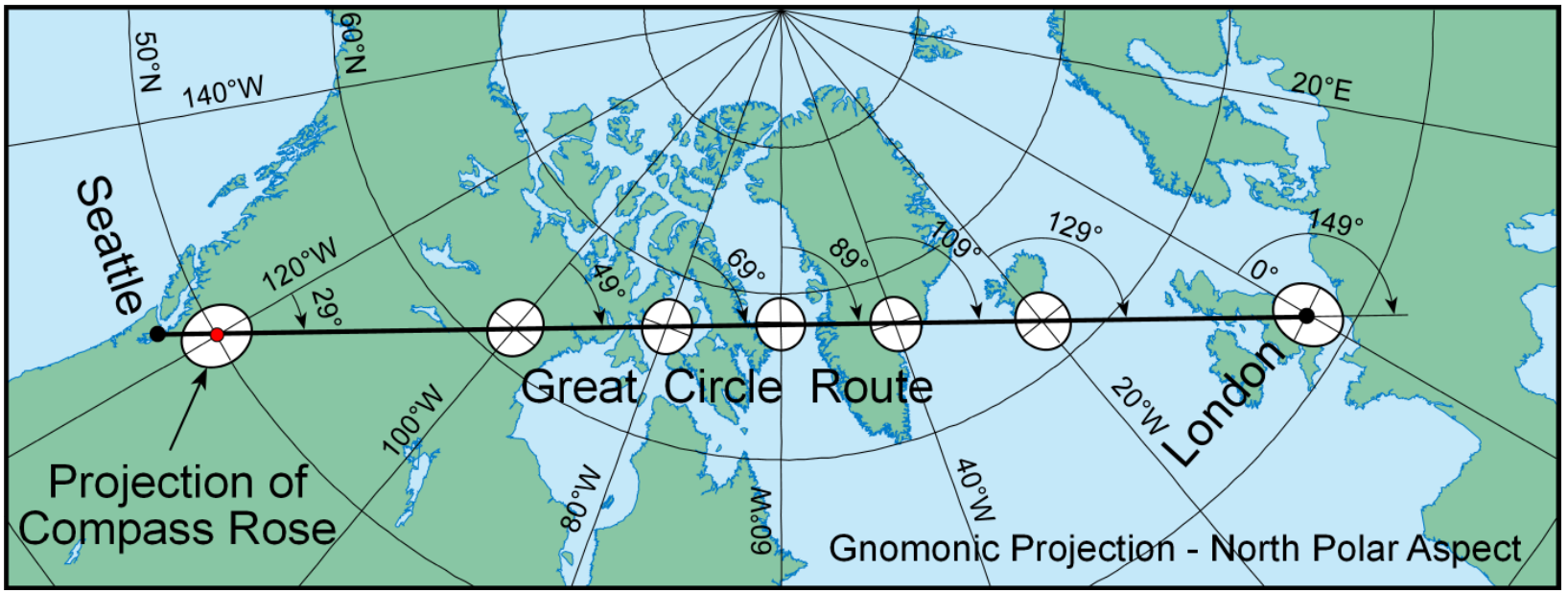


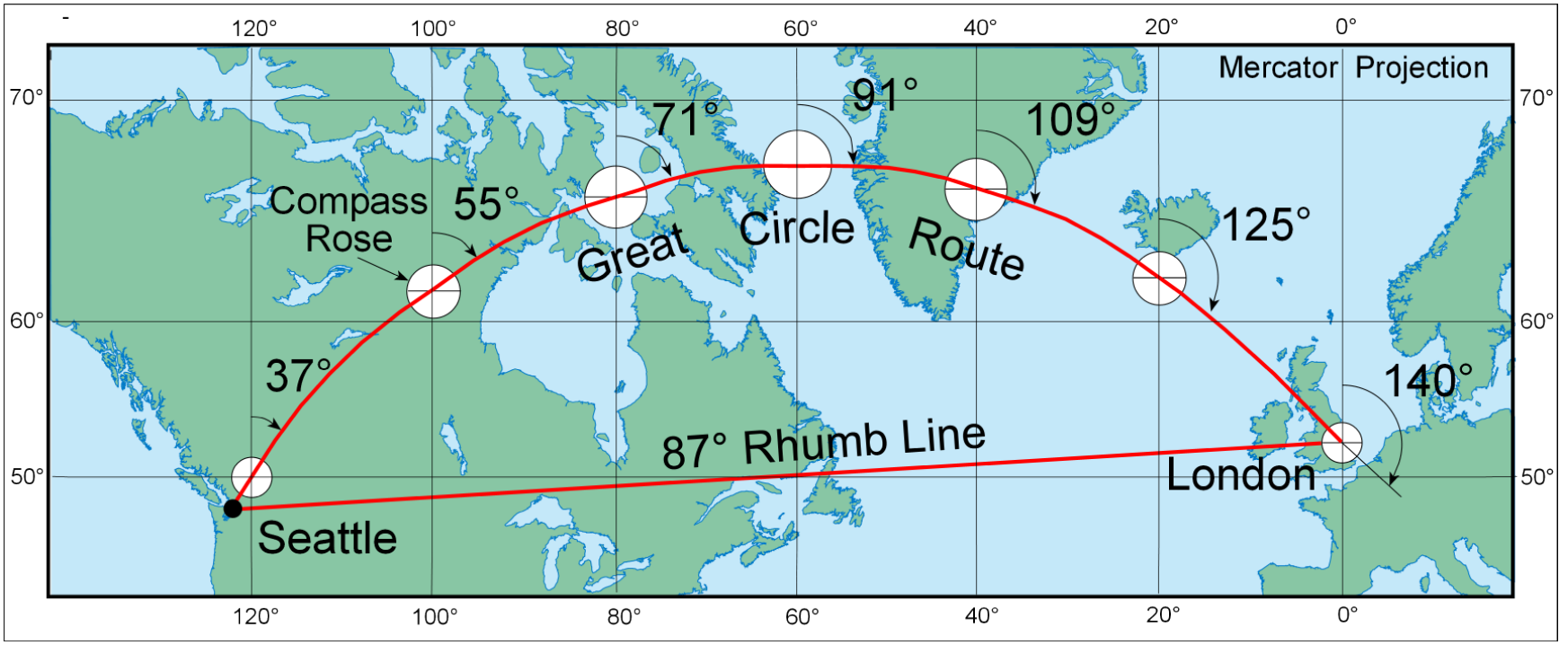


Mercator Projection

- 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

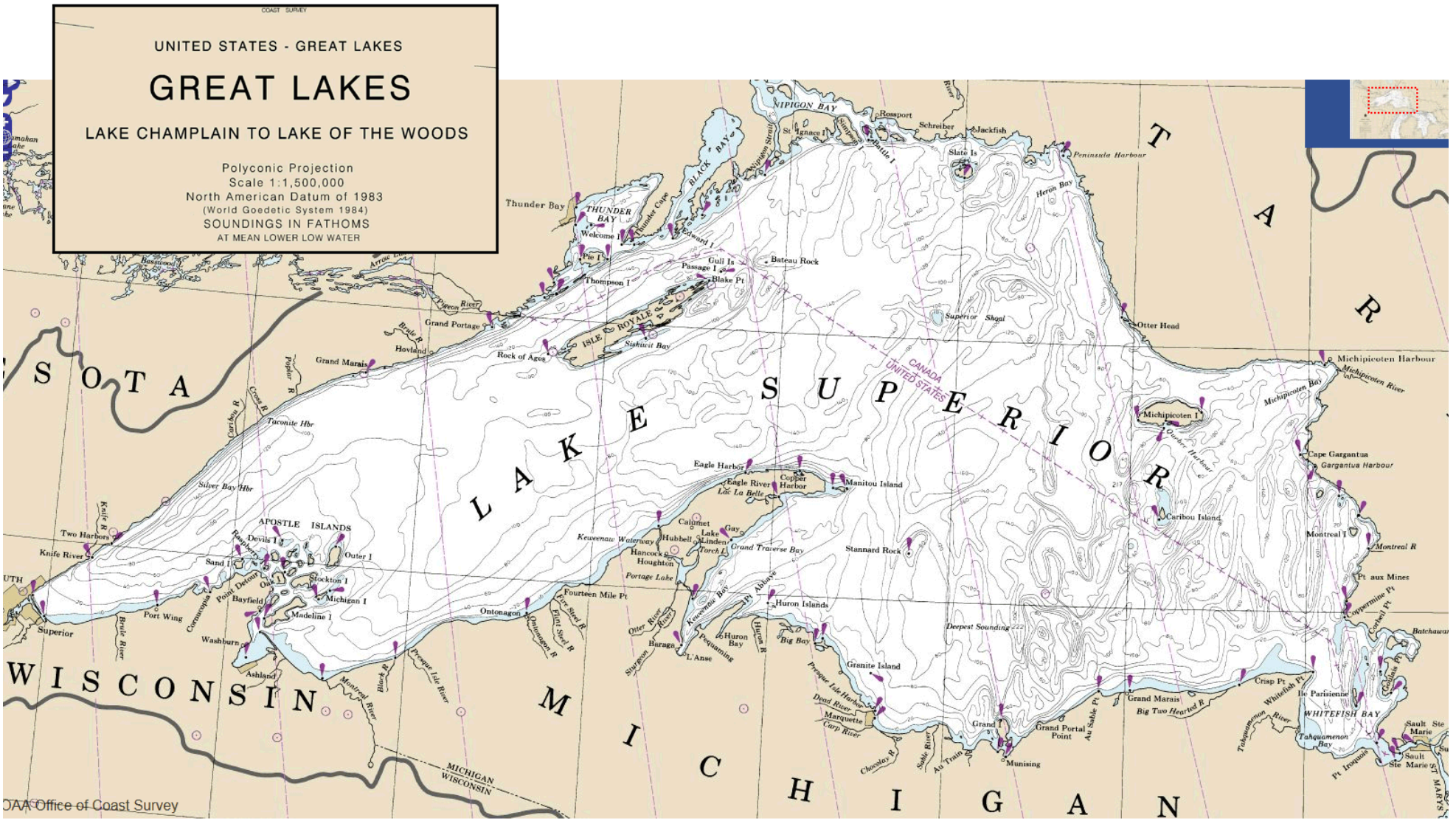
Mercator Projection





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

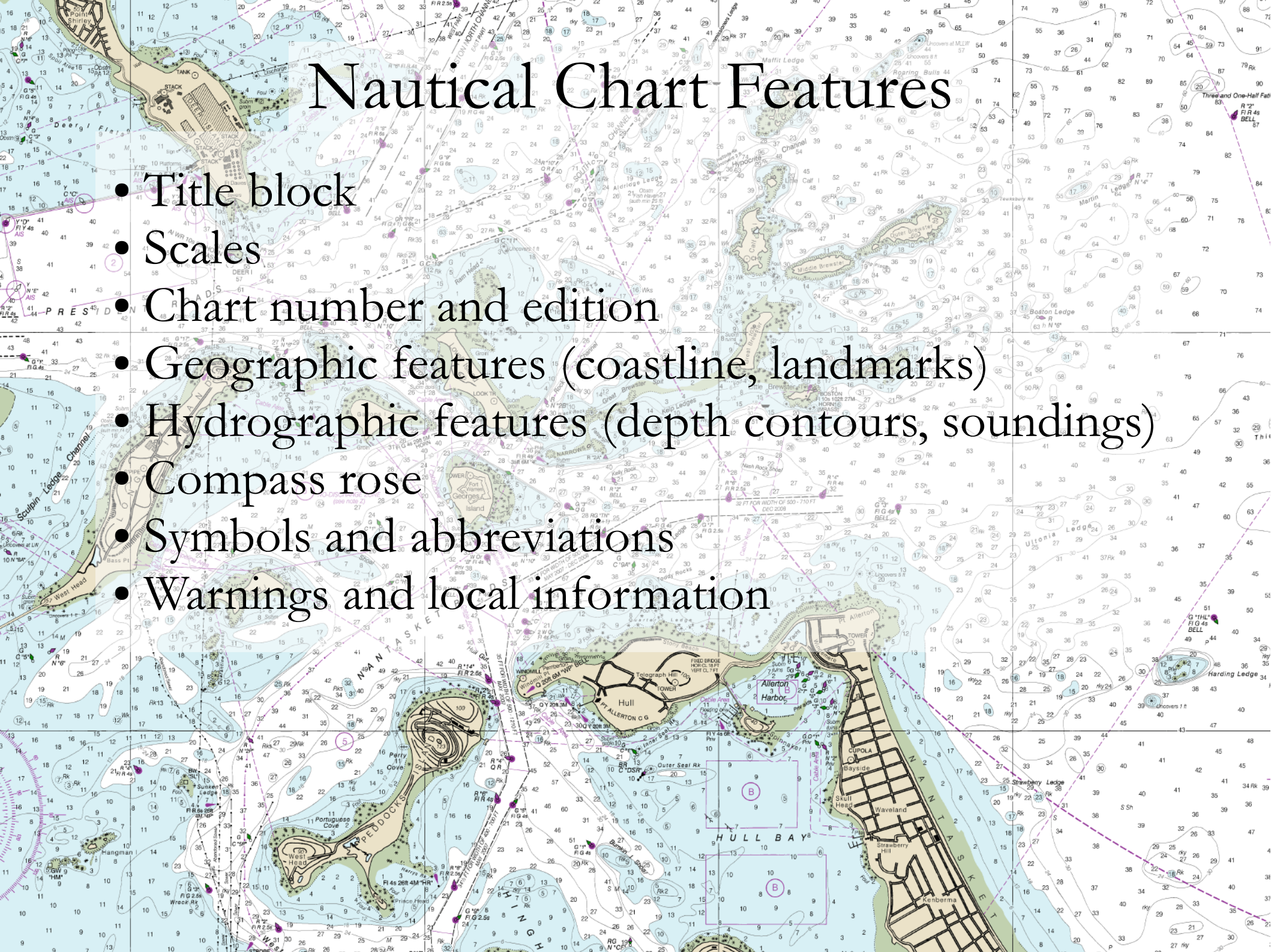


Chart Title Block

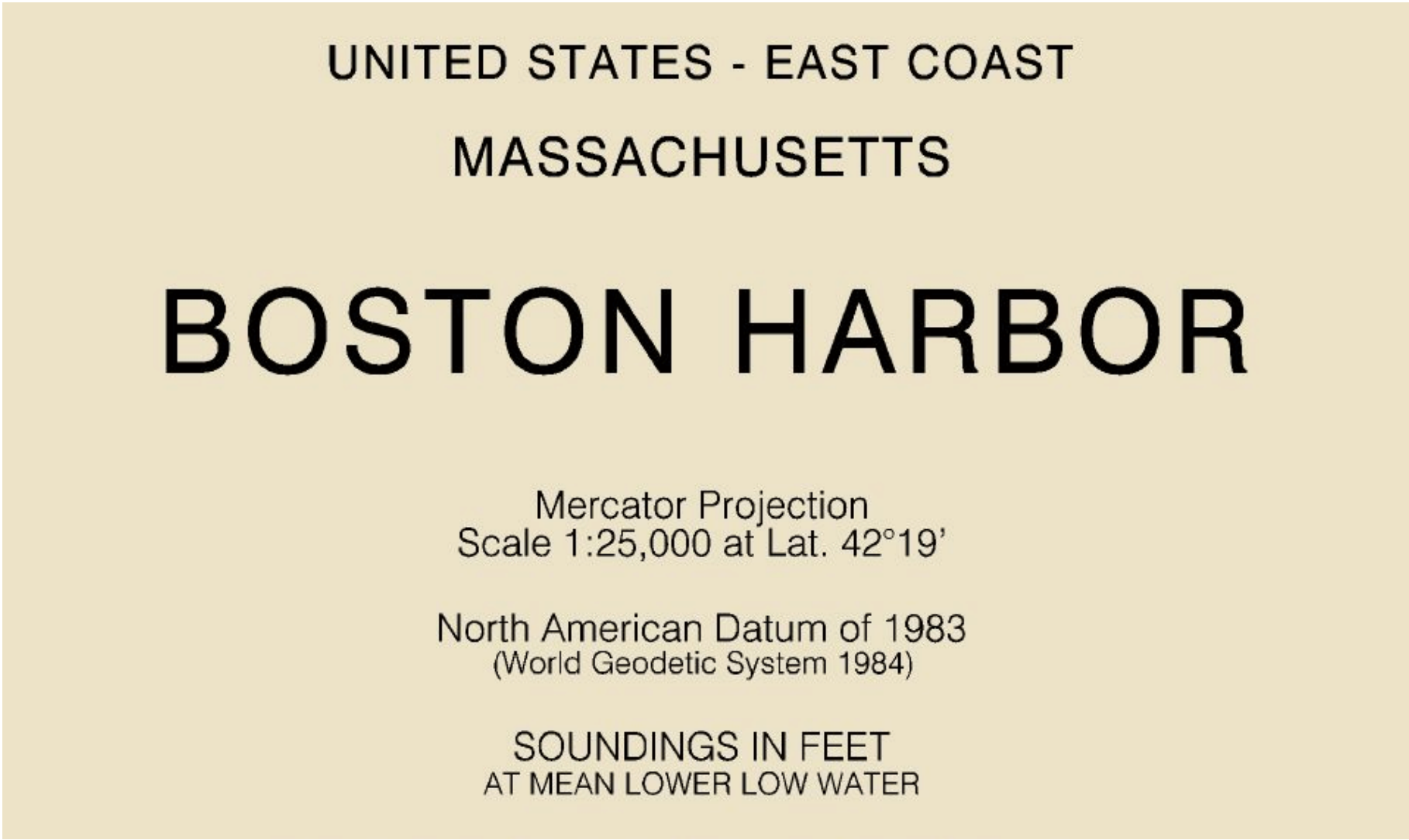
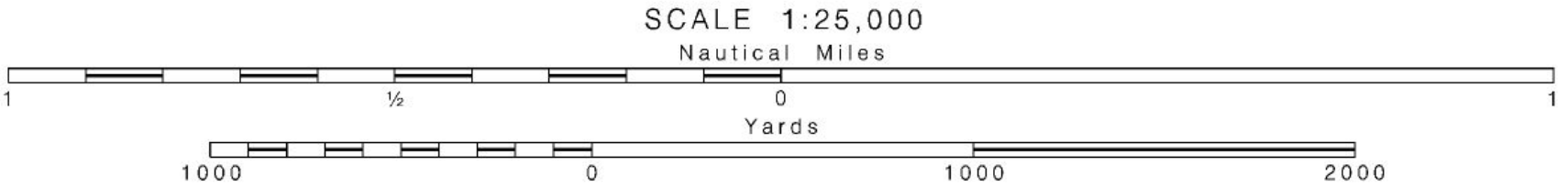


Chart Scales

- 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

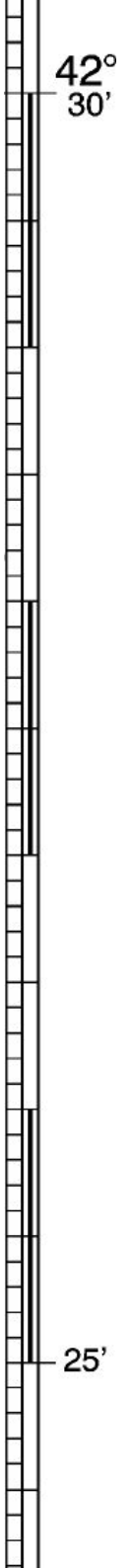
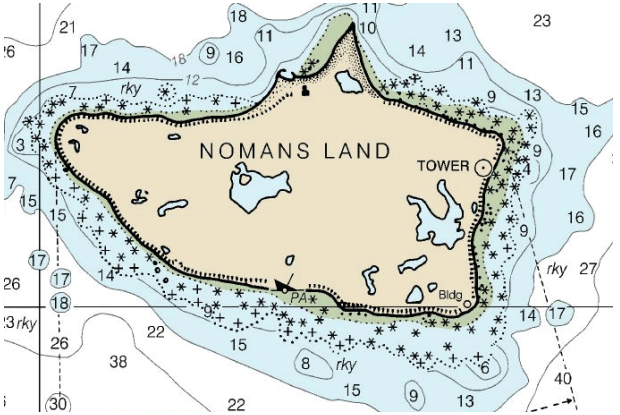
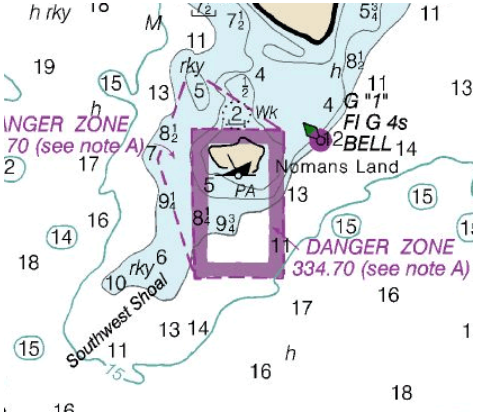


Chart Scales

- "Large Scale" vs. "Small Scale"

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





- 73,913 inches per nautical mile

  1:72,000 scale → 1 nm. ≈ 1 inch

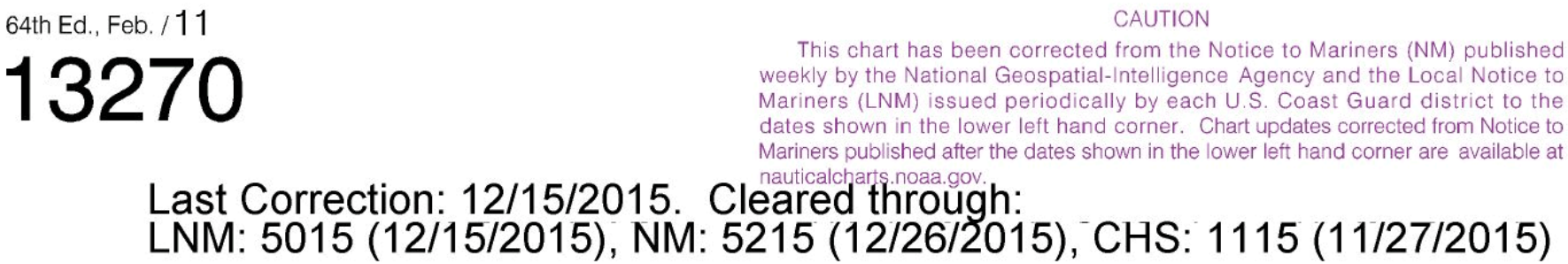
  1:25,000 scale → 1 nm. ≈ 3 inches

  1:800,000 scale → 1 nm. ≈ 1/10 inch

Chart Scales

- Sailing Charts
  very small scale – 1:600,000 or greater
- General Charts
  1:150,000 to 1:600,000
- Coastal Charts
  1:50,000 to 1:150,000
- Harbor Charts
  large scale – 1:50,000 or less

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

U.S. Department
of Homeland Security

**United States
Coast Guard**

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
Information on Private Aids to Navigation is available at: http://www.uscg.mil/d1/prevention/NavInfo/navinfo/paton.htm
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

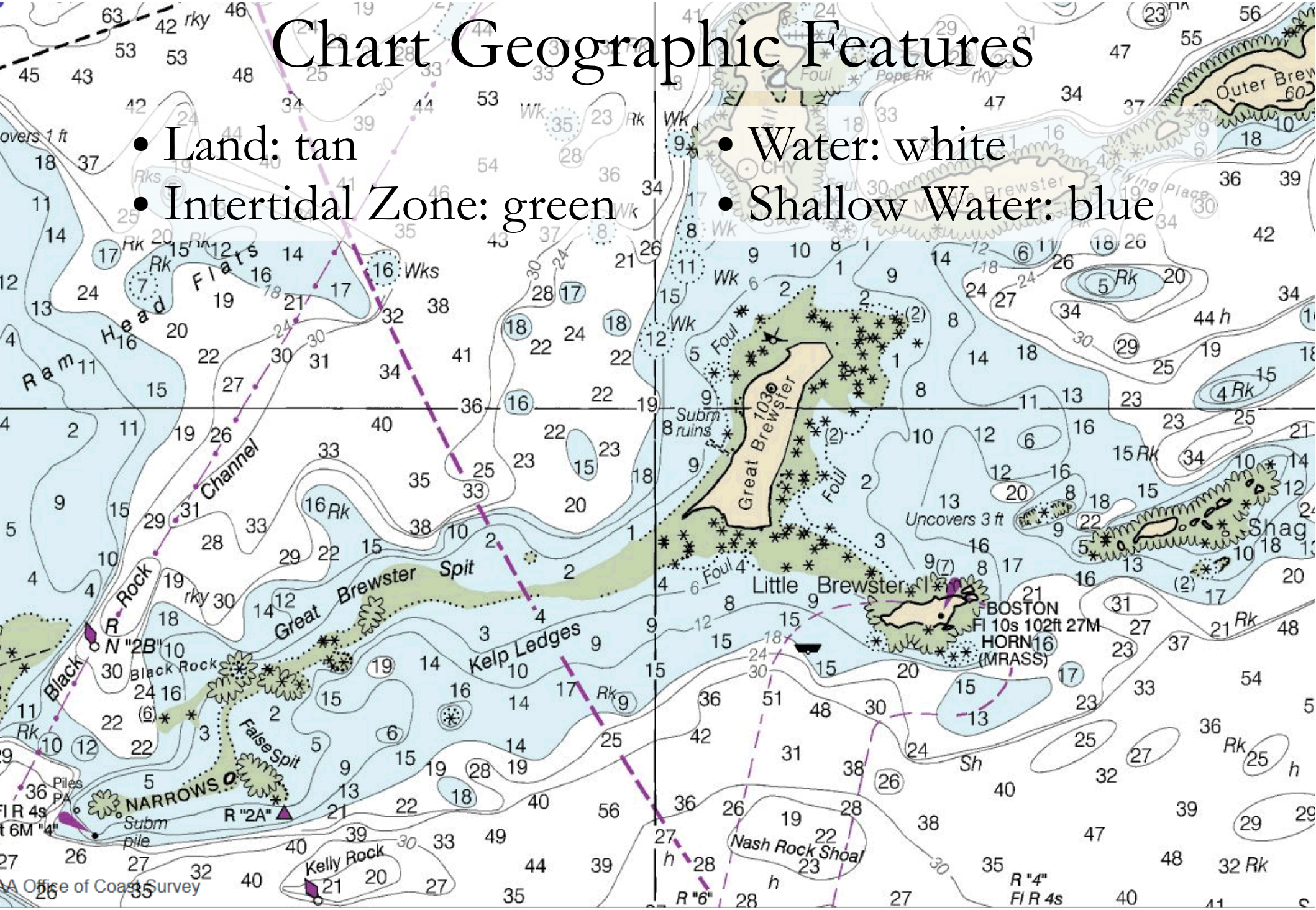
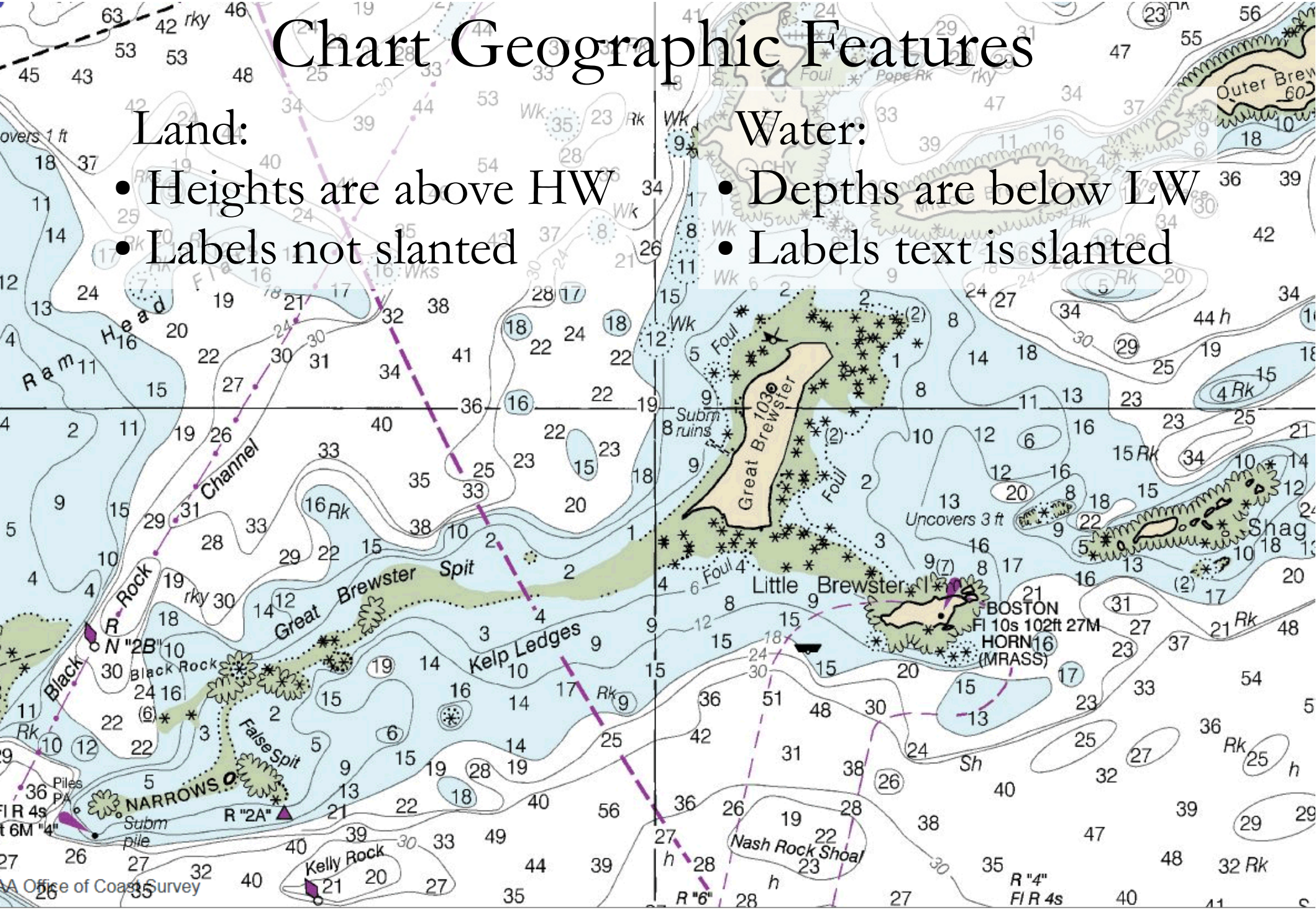
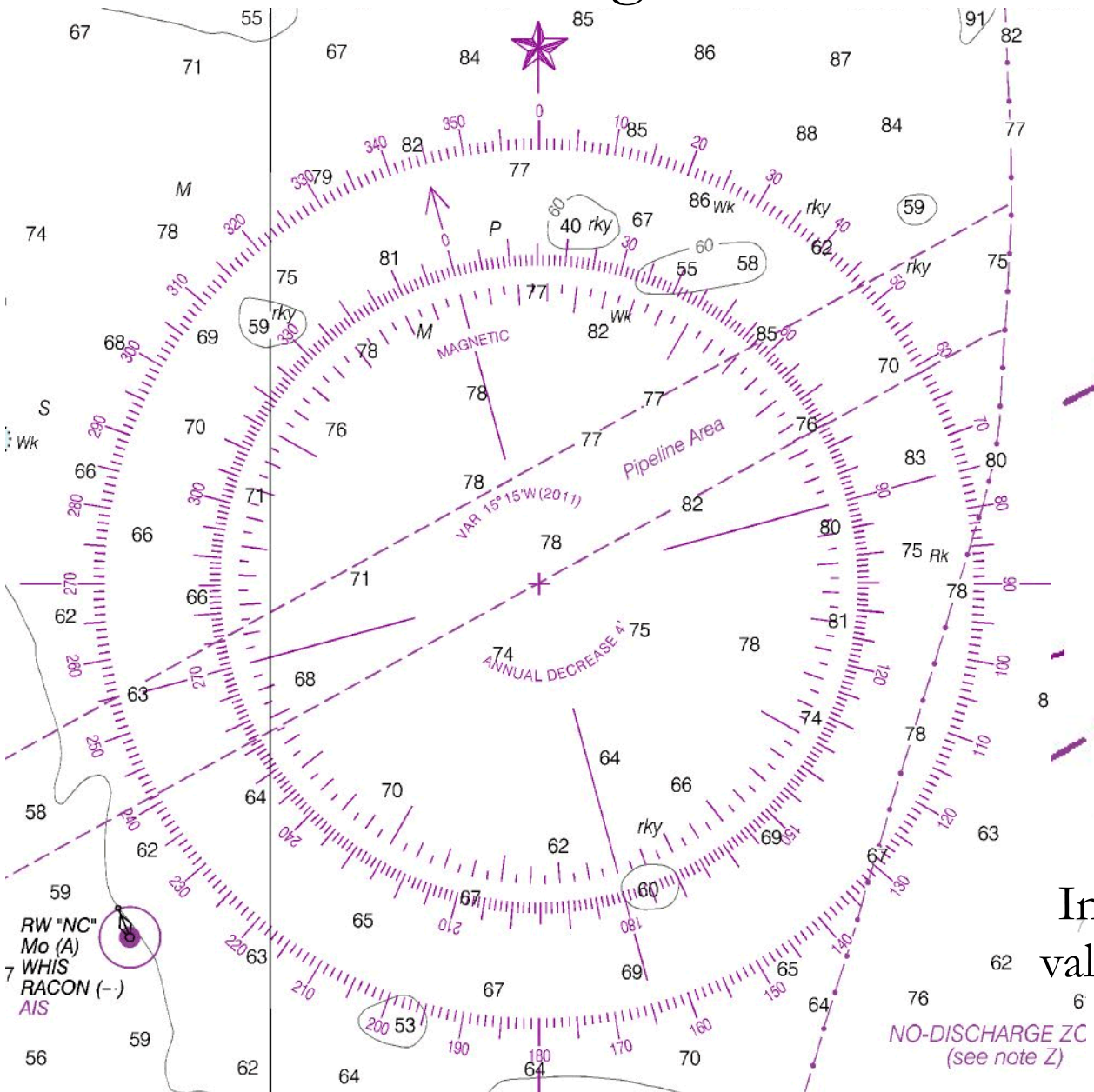


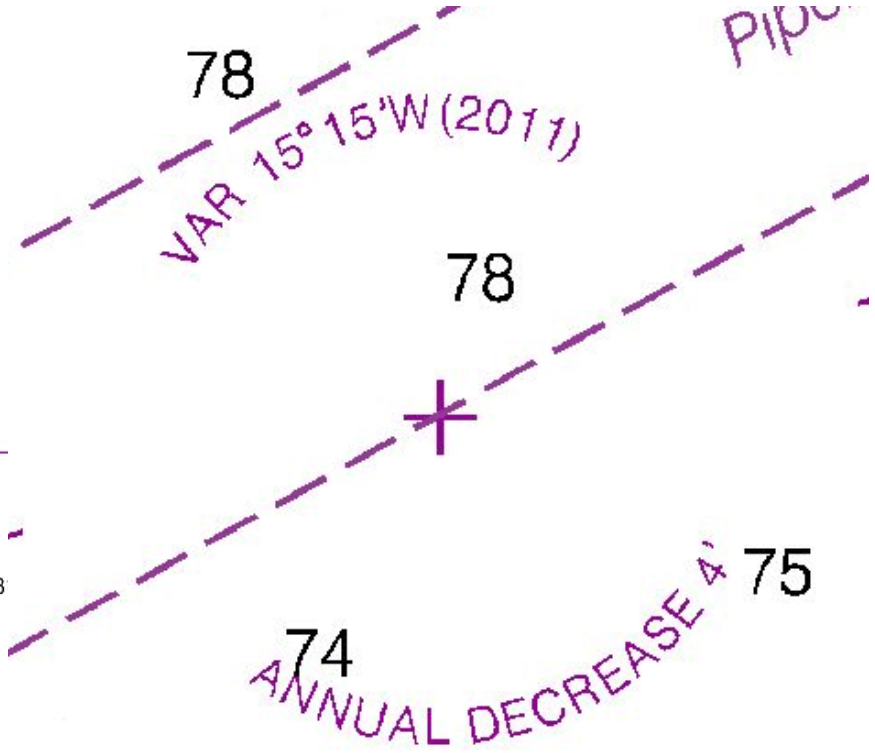
Chart Geographic Features



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)

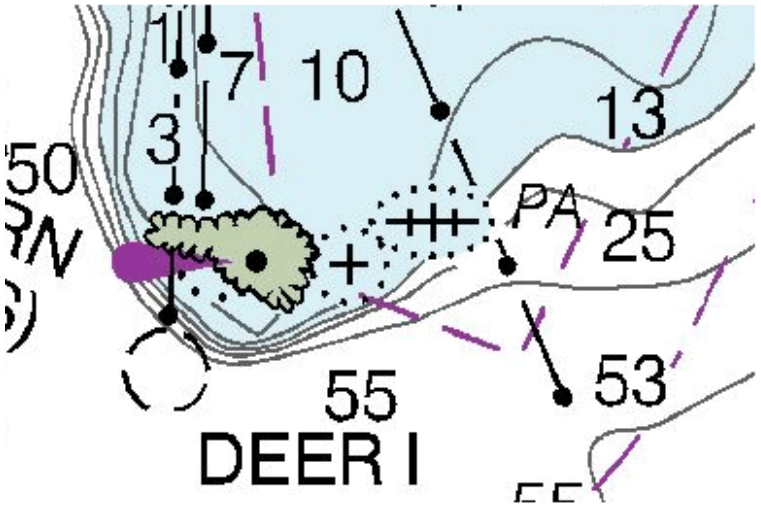
Wreck (above water at low tide)

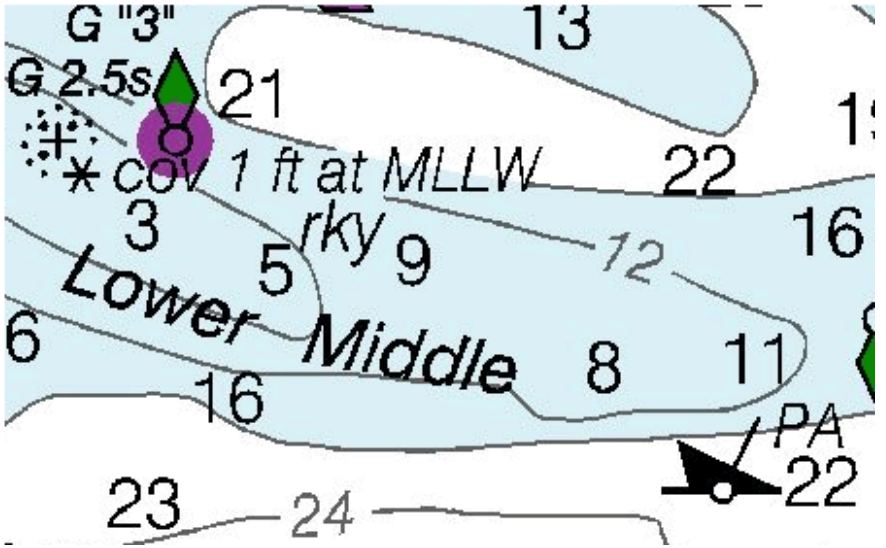
Wreck (below water at low tide)

Bouy

Lighted Bouy

Light





Lower Middle Channel

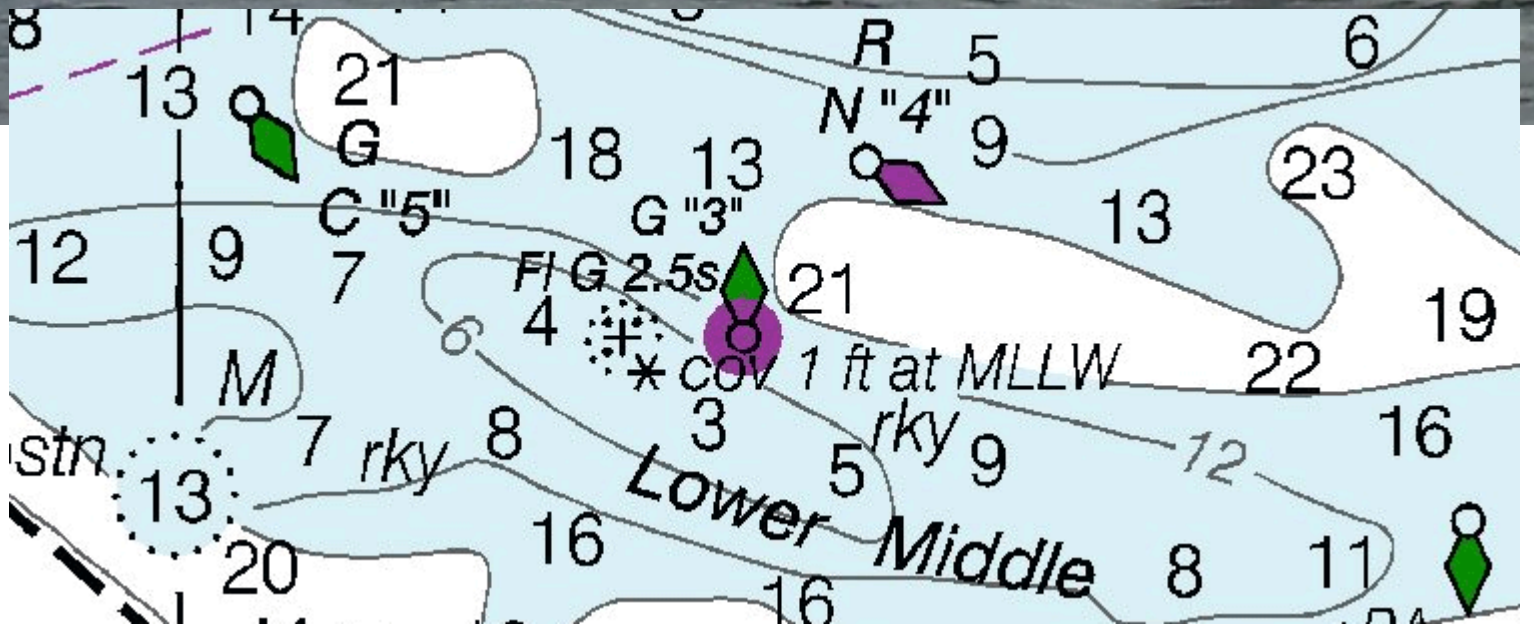


Chart Symbols

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

Rocks, Wrecks, Obstructions, Aquaculture K

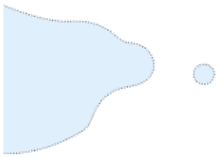
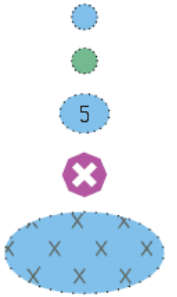
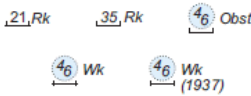
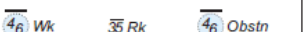
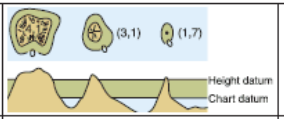
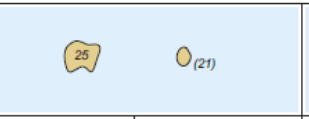
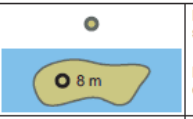
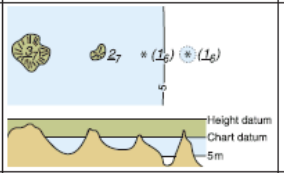
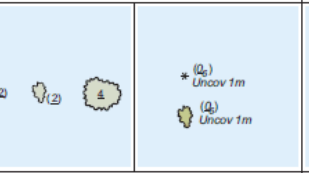
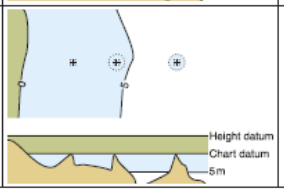
No.	INT	Description	NOAA	NGA	Other NGA	ECDIS	
General							
1		Danger line: A danger line draws attention to a danger which would not stand out clearly enough if represented solely by its symbol (e.g. isolated rock) or delimits an area containing numerous dangers, through which it is unsafe to navigate					Obstruction, depth not stated Obstruction which covers and uncovers Underwater hazard with depth of 20 meters or less Isolated danger of depth less than the safety contour Foul area, not safe for navigation
2		Swept by wire drag or diver					Swept sounding, less than or equal to safety depth Swept sounding, greater than safety depth
3		Depth unknown, but estimated to have a safe clearance to the depth shown				ECDIS displays safe clearance depths in the same manner as known depths.	
Rocks							
Plane of Reference for Heights → H		Plane of Reference for Depths → H					
10		Rock (islet) which does not cover, height above height datum					Land as a point at small scale Land as an area, with an elevation or control point
11		Rock which covers and uncovers, height above chart datum					Rock which covers and uncovers or is awash at low water Underwater hazard which covers and uncovers with drying height Isolated danger of depth less than the safety contour
12		Rock awash at the level of chart datum					Rock which covers and uncovers or is awash at low water Underwater hazard which covers and uncovers Isolated danger of depth less than the safety contour

Chart Warnings & Local Information

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.

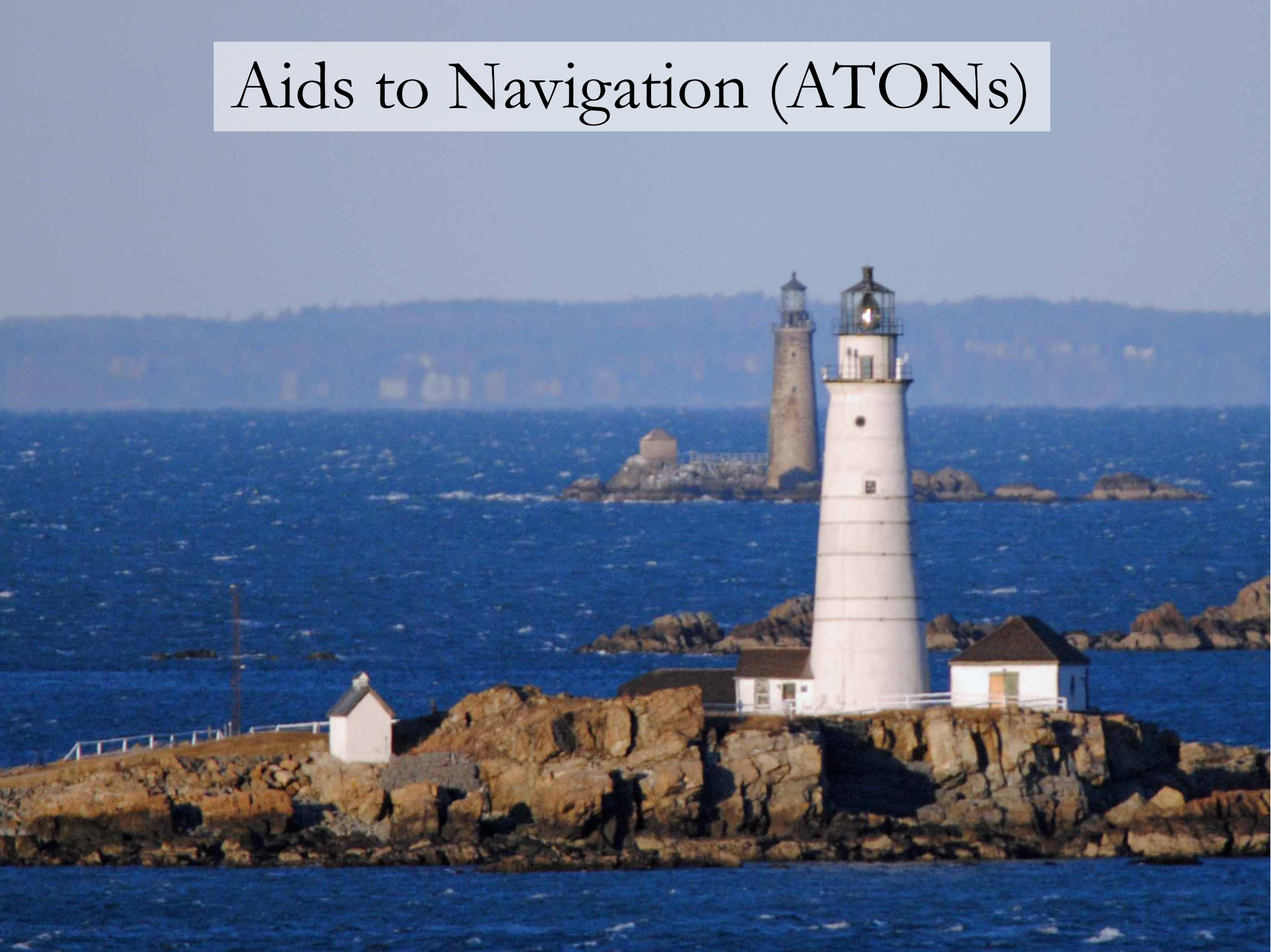
NOTE B

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

- Buoys – 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

Features of ATONs:

- Floating (buoys) 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)

Light Characteristics

Description	Characteristic	Chart Abbreviation
Alternating		Alt. R.W.G.
Fixed		F.
Flashing		Fl.
Group flashing		Gp Fl.(2)
Occulting		Occ.
Group occulting		Gp Occ(3)
Quick flashing		Qk.Fl.
Very quick flashing		V.Qk.Fl.
Isophase		Iso.
Morse		Mo.(letter)

Lateral Marks

"Red Right Returning"

Usually mark a channel. Can be buoys, 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:

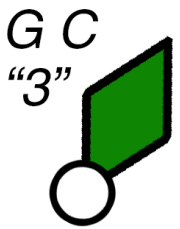
- Even Numbers
- Triangle or Cone

Cans & Nuns

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

Cans:

- Green
- Odd number

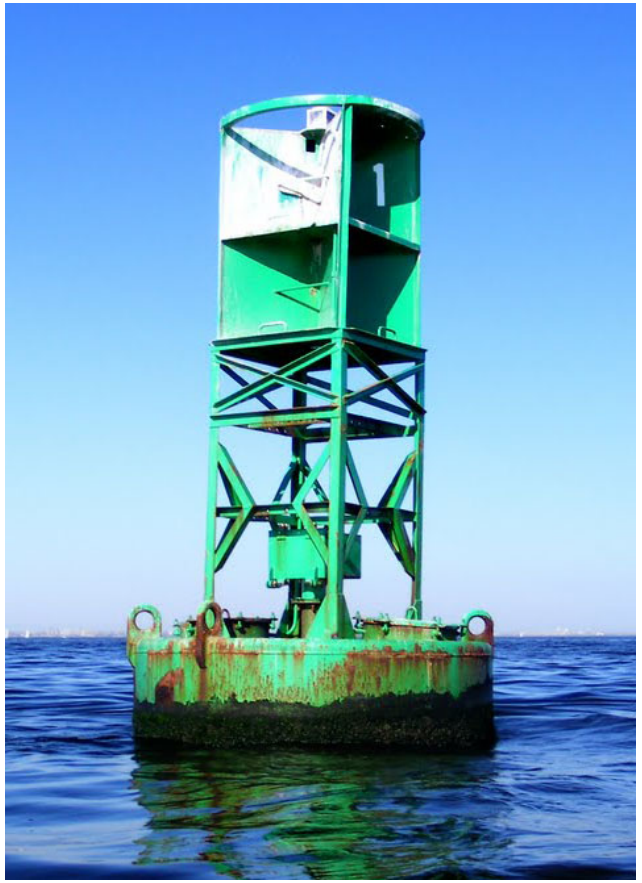


Nuns:

- Red
- Even number

Tower Buoys

- May be lighted or have sounds.
- Light color usually matches buoy color



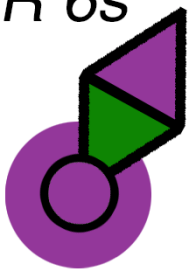
G “1”
Fl G 4s

R “20”
Q R

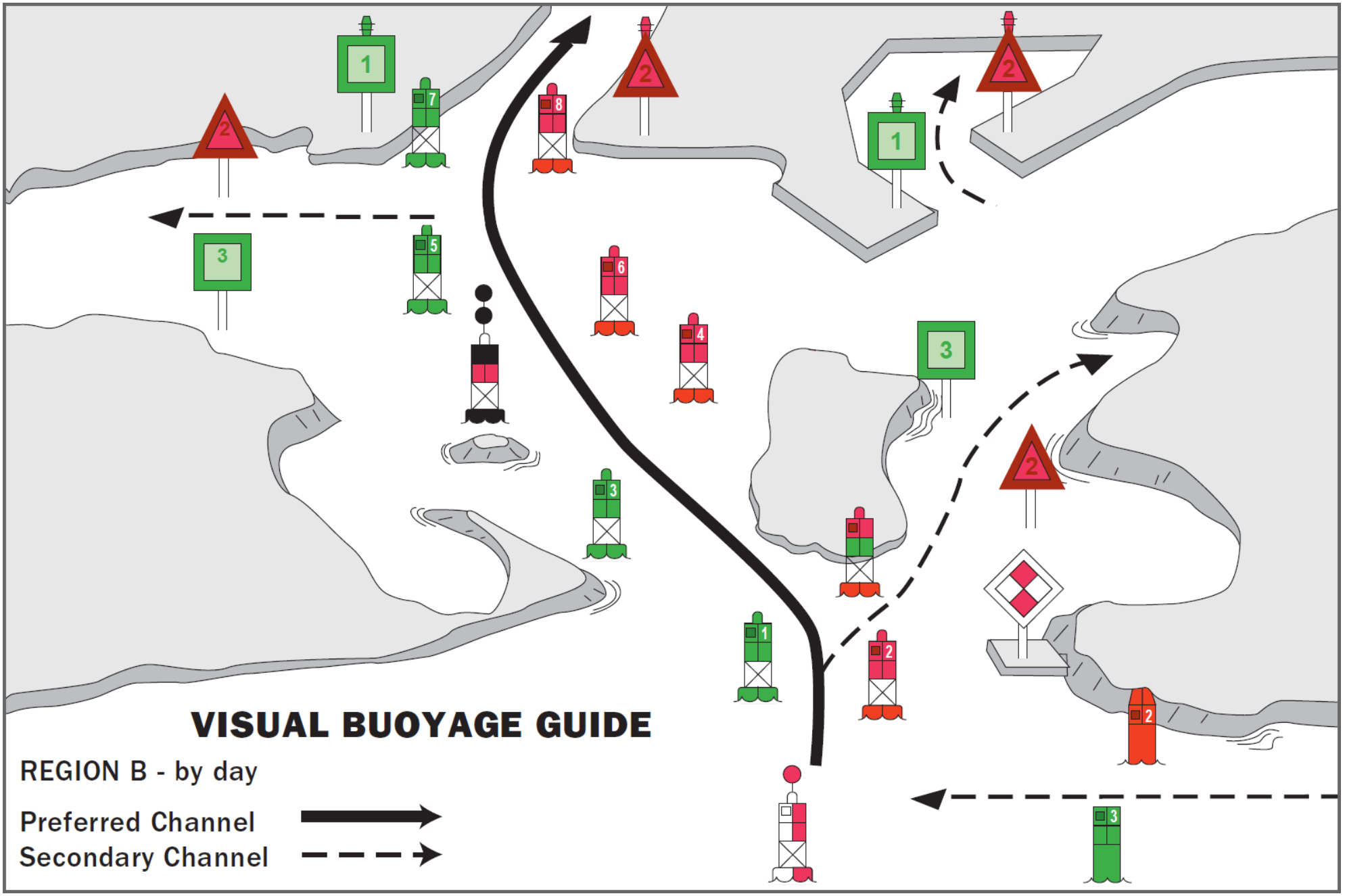
Preferred Channel Buoys

- 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

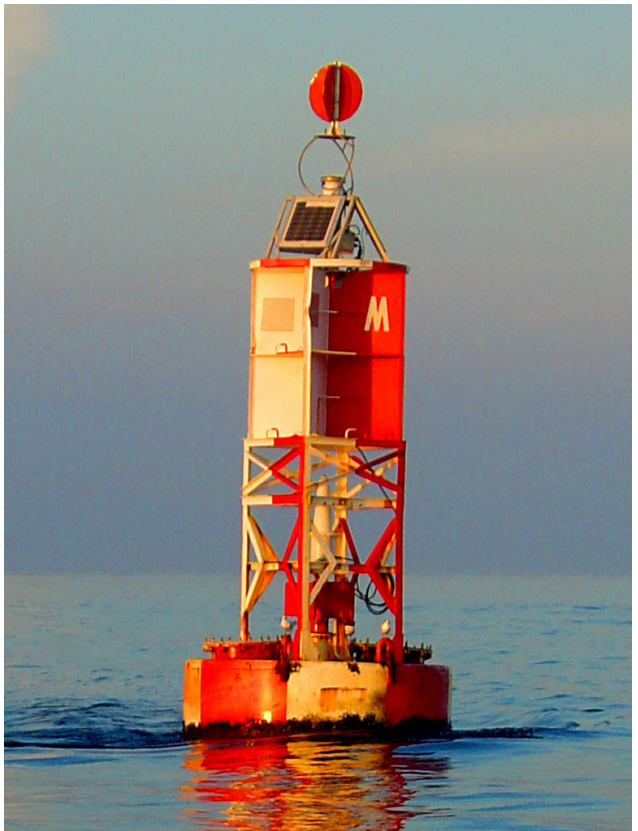


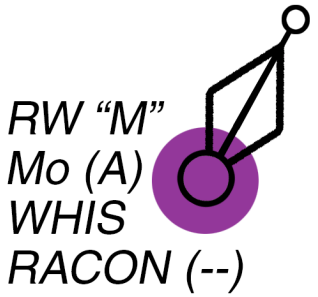
Lateral System



Center Channel Buoys

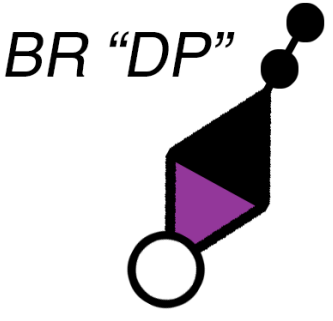
- Red & white vertical stripes
- Ball topmark
- If lit, white morse-A light pattern (•–)
- Sometimes have whistles
- Sometimes have radar transponders



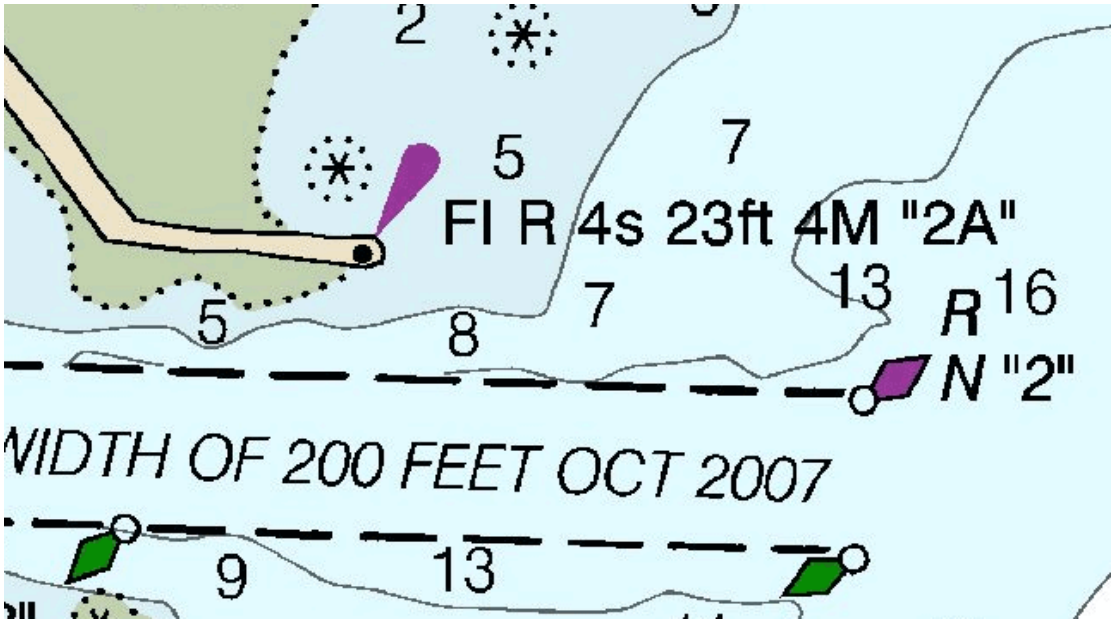


Danger Buoys

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

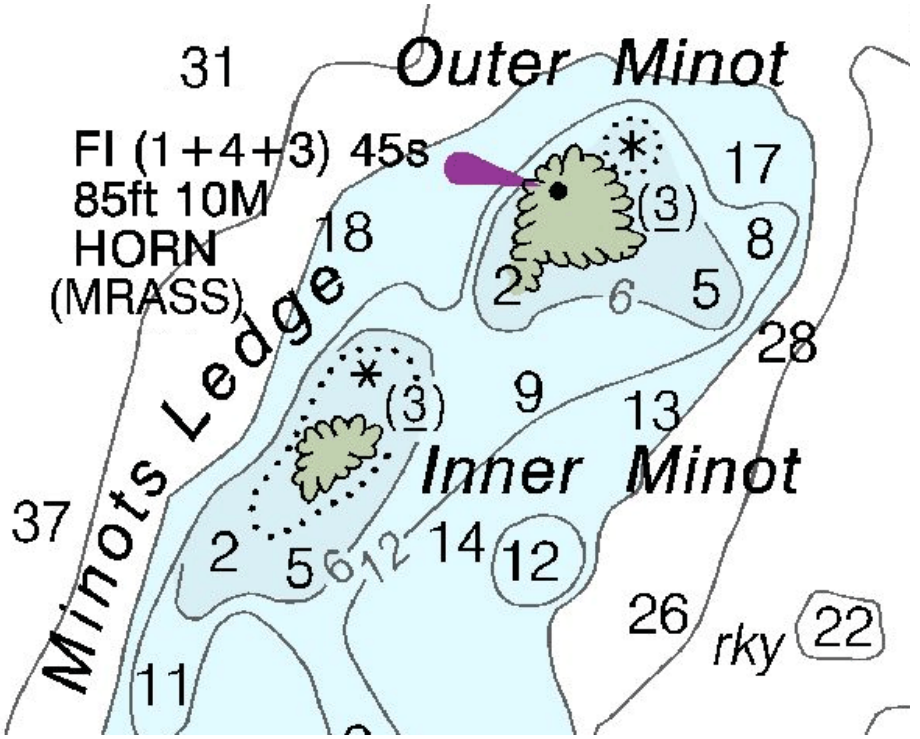


Lights



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.

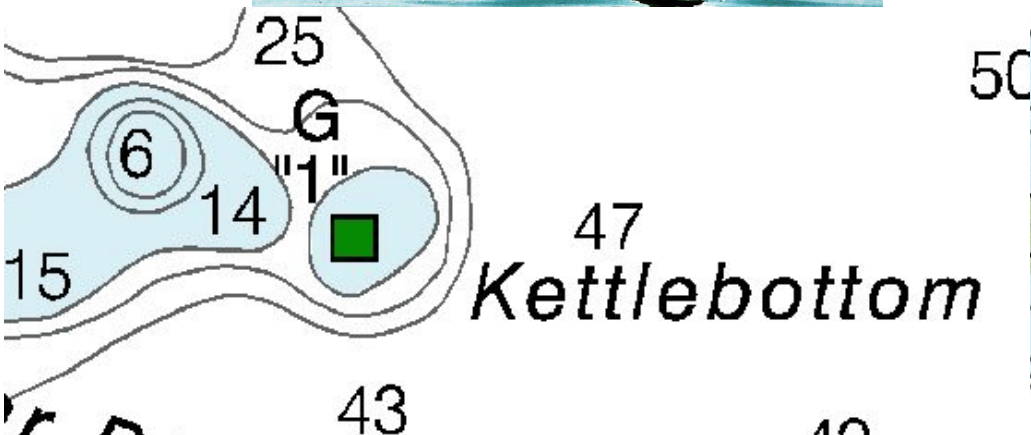
85 feet above high water

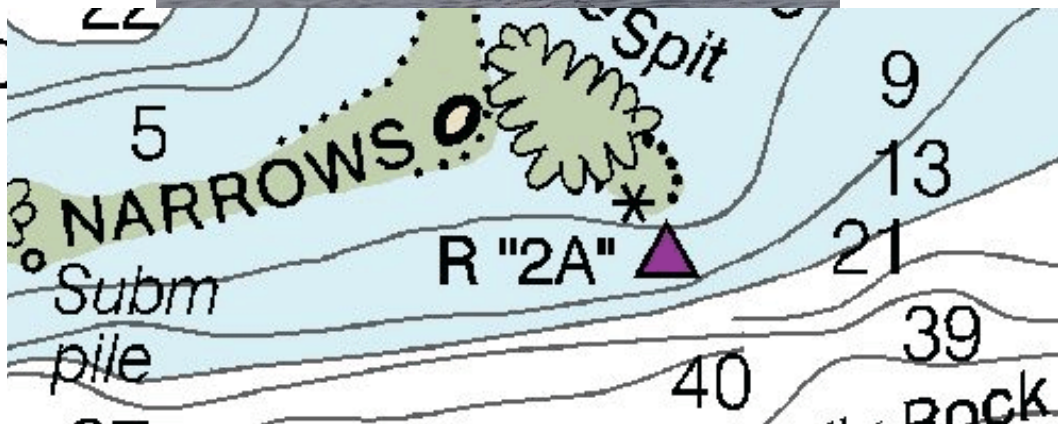
10 miles nominal visibility

Fog Horn (MRASS)

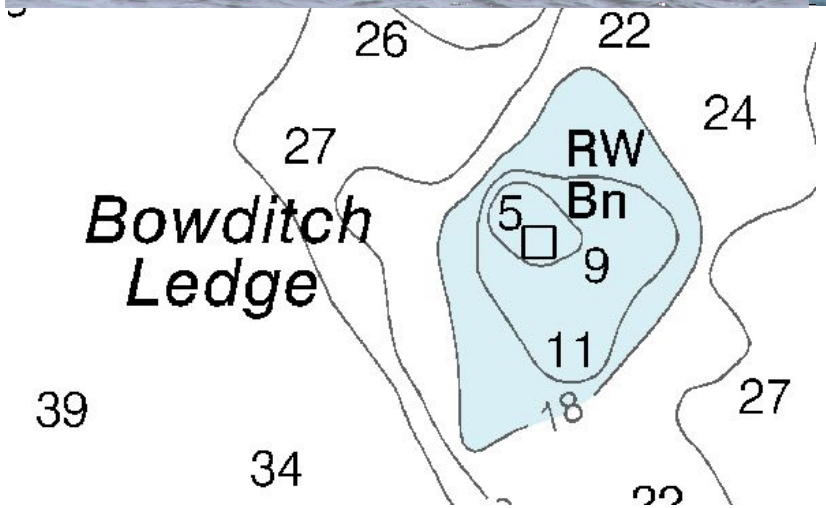
Daybeacons

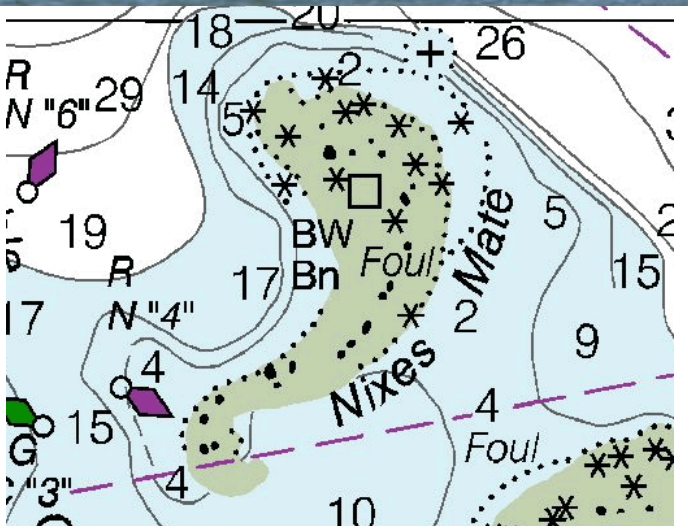
- No lights and fixed to land.





Daybeacons


26
22
24
27
RW
Bn
5
9
Bowditch
Ledge
11
18
27
39
34


18
20
26
R
N "6"
29
14
2
5
19
BW
Bn
Foul
17
R
N "4"
Mate
5
15
2
9
Nixes
4
15
Foul
4
"3"
10

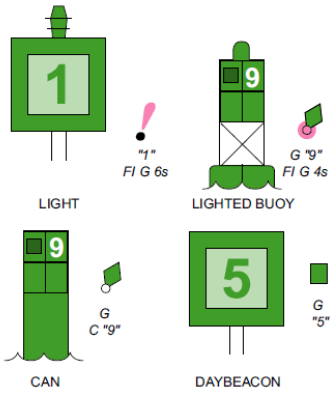
Do Not Tie Up to Navigational Aids

LATERAL SYSTEM AS SEEN ENTERING FROM SEAWARD

PORT SIDE
ODD NUMBERED AIDS

GREEN LIGHT ONLY

FLASHING (2)
FLASHING
OCCULTING
QUICK FLASHING
ISO

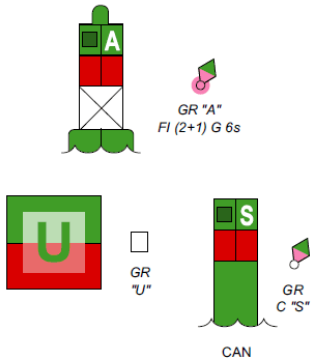


PREFERRED CHANNEL
NO NUMBERS - MAY BE LETTERED

PREFERRED
CHANNEL TO
STARBOARD
TOPMOST BAND
GREEN

GREEN LIGHT ONLY

COMPOSITE GROUP FLASHING (2+1)

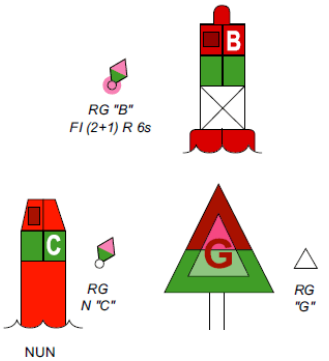


PREFERRED CHANNEL
NO NUMBERS - MAY BE LETTERED

PREFERRED
CHANNEL TO
PORT
TOPMOST BAND
RED

RED LIGHT ONLY

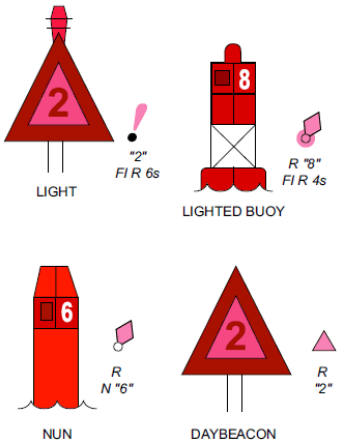
COMPOSITE GROUP FLASHING (2+1)



STARBOARD SIDE
EVEN NUMBERED AIDS

RED LIGHT ONLY

FLASHING (2)
FLASHING
OCCULTING
QUICK FLASHING
ISO

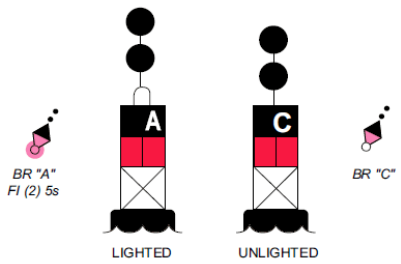


AIDS TO NAVIGATION HAVING NO LATERAL SIGNIFICANCE

ISOLATED DANGER
NO NUMBERS - MAY BE LETTERED

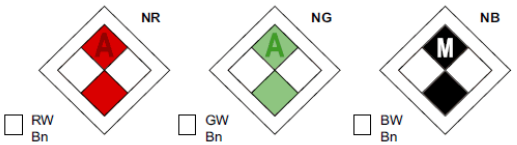
WHITE LIGHT ONLY

Fl (2) 5s



DAYBOARDS - MAY BE LETTERED

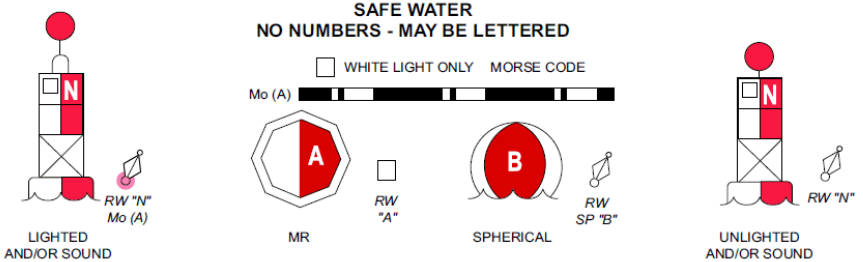
WHITE LIGHT ONLY



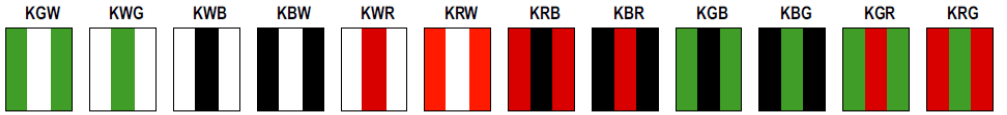
SAFE WATER
NO NUMBERS - MAY BE LETTERED

WHITE LIGHT ONLY MORSE CODE

Mo (A)



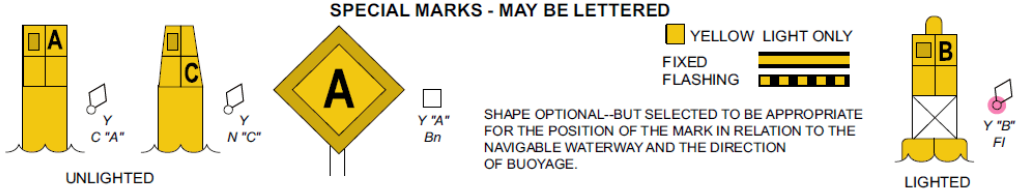
RANGE DAYBOARDSÑMAY BE LETTERED



SPECIAL MARKS - MAY BE LETTERED

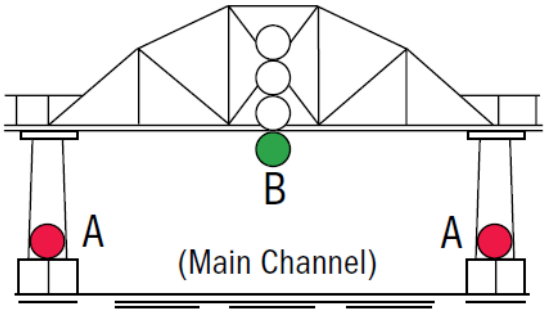
YELLOW LIGHT ONLY

FIXED
FLASHING

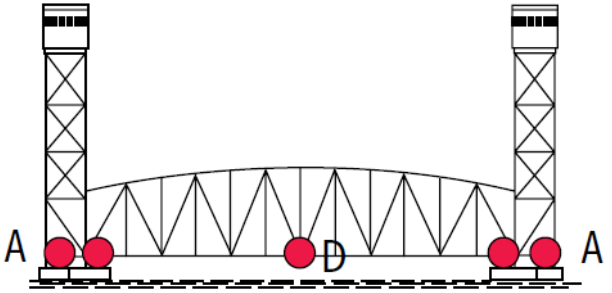


SHAPE OPTIONAL--BUT SELECTED TO BE APPROPRIATE FOR THE POSITION OF THE MARK IN RELATION TO THE NAVIGABLE WATERWAY AND THE DIRECTION OF BUOYAGE.

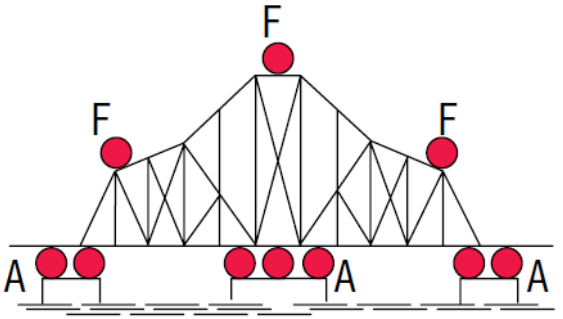
Bridges



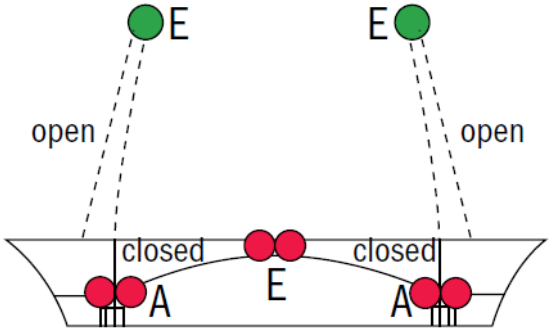
Fixed Bridge



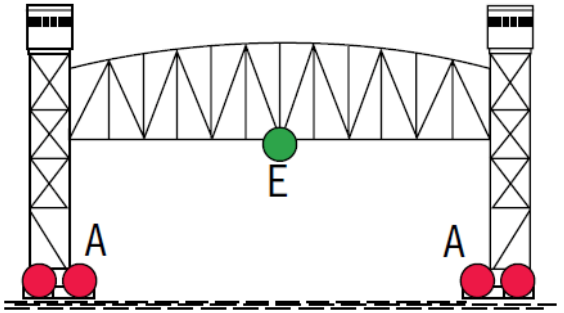
Vertical Lift Span Bridge
(closed)



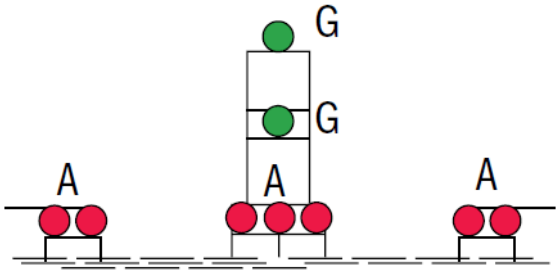
Double-Opening Swing Bridge
(closed)



Double Leaf (Lift) Bascule Bridge



Vertical Leaf Span Bridge
(open)



Double Opening Swing Bridge
(open)

Light List

Full details on all official ATONs can be found in the "Light List" 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

https://navcen.uscg.gov/?pageName=lightlists

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 magnetic poles (created by the Earth's magnetic field) do not line up with the geographic poles (defined by the rotation of the planet).

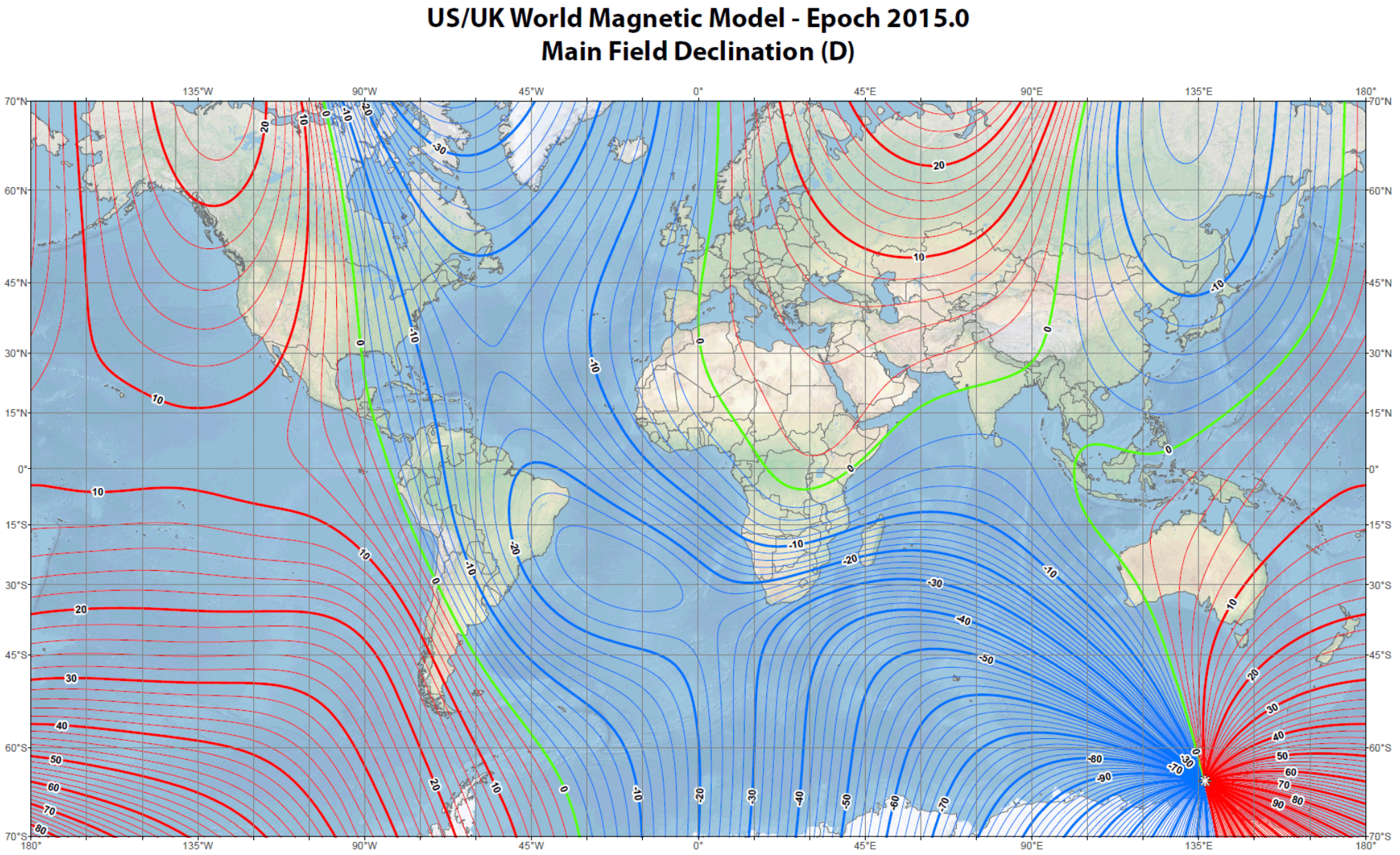
The Earth's Magnetic Field

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).

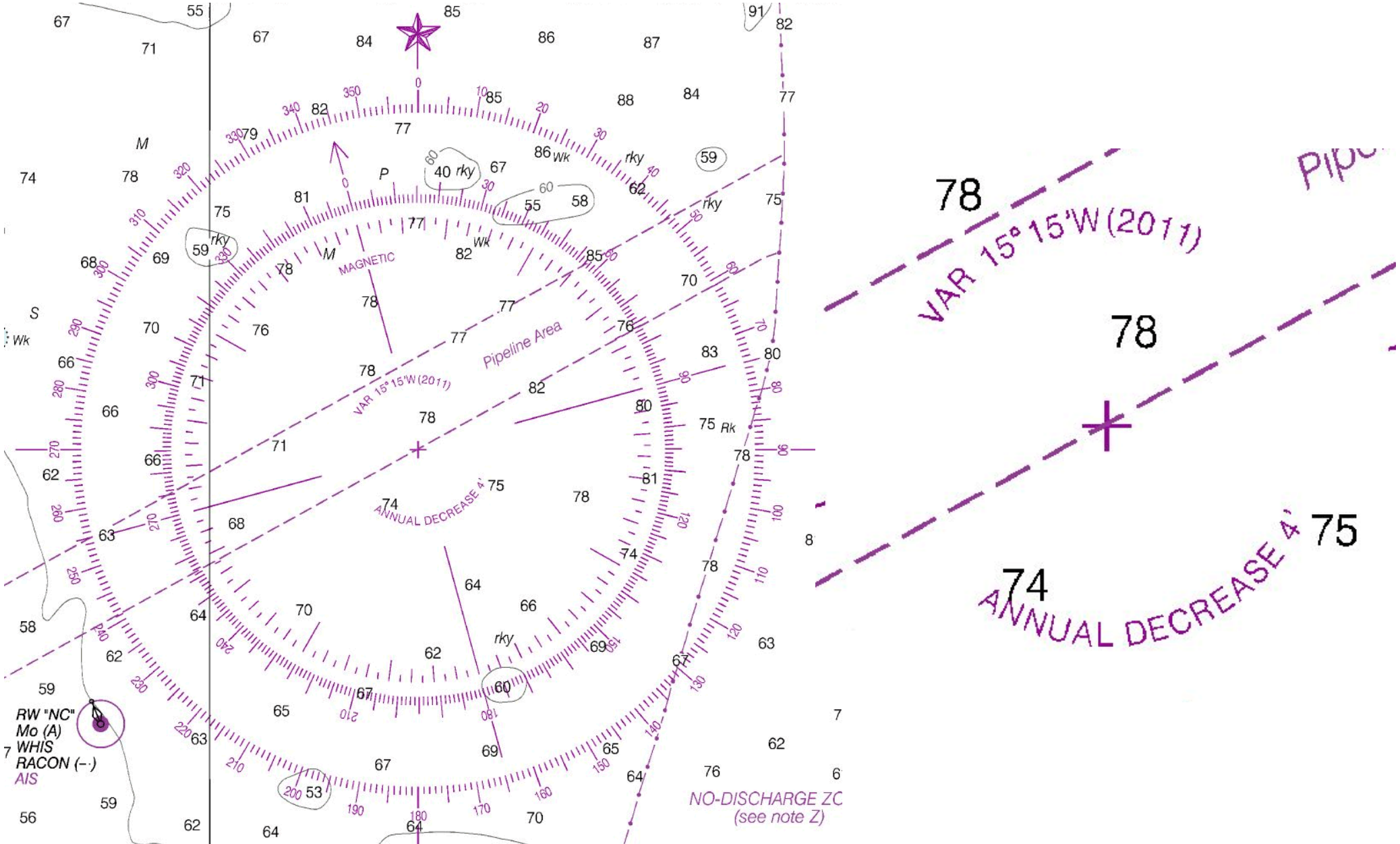
Because of the dip, a compass needs to be kept level to give accurate readings.

The Earth's Magnetic Field

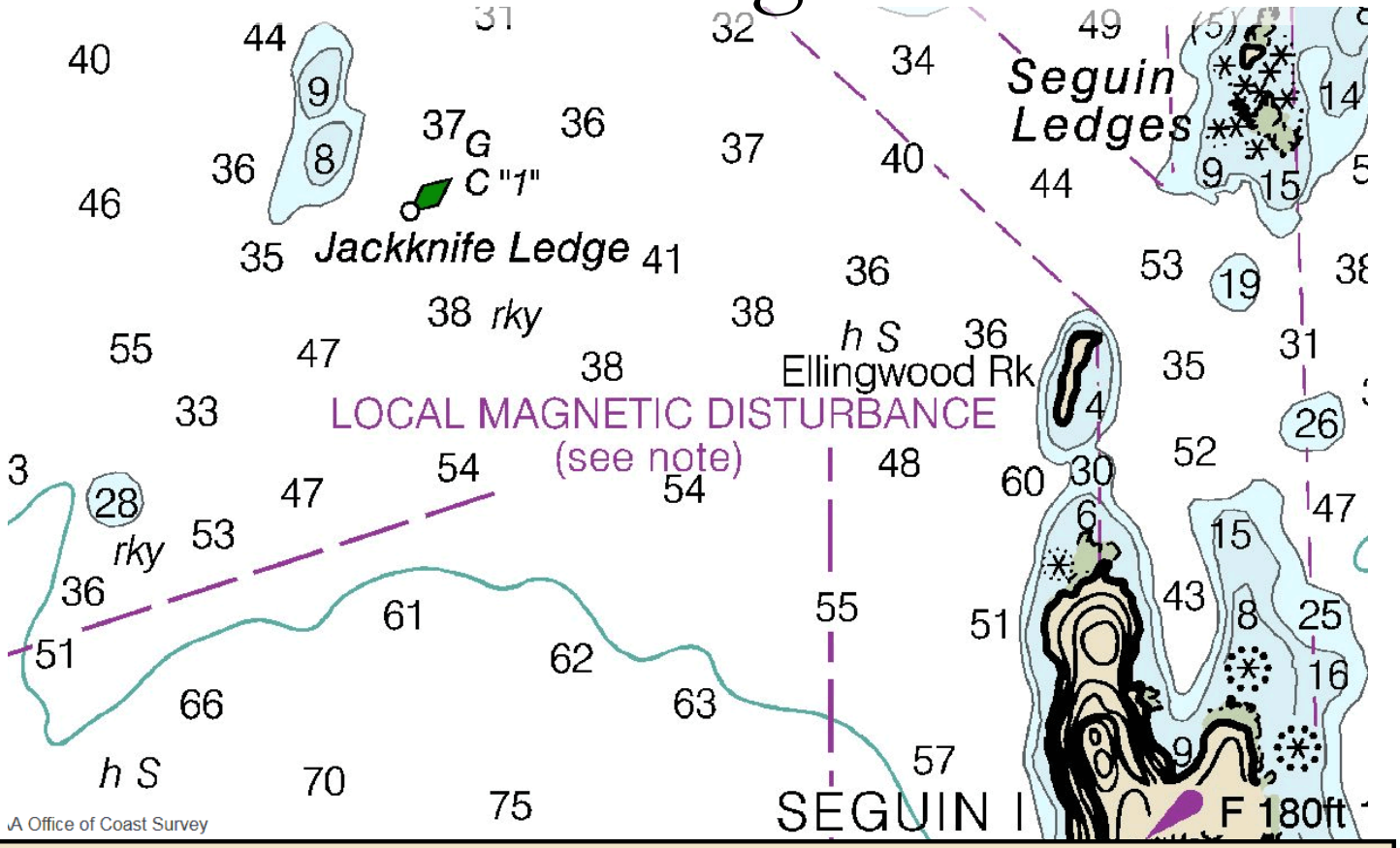


Compass Rose

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 and a "magnetic" direction (that which would be read from an ideal 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 nearby magnetic field sources:

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

Deviation is a function of the direction the compass is pointing. Each compass on each boat will have a slightly different deviation function.

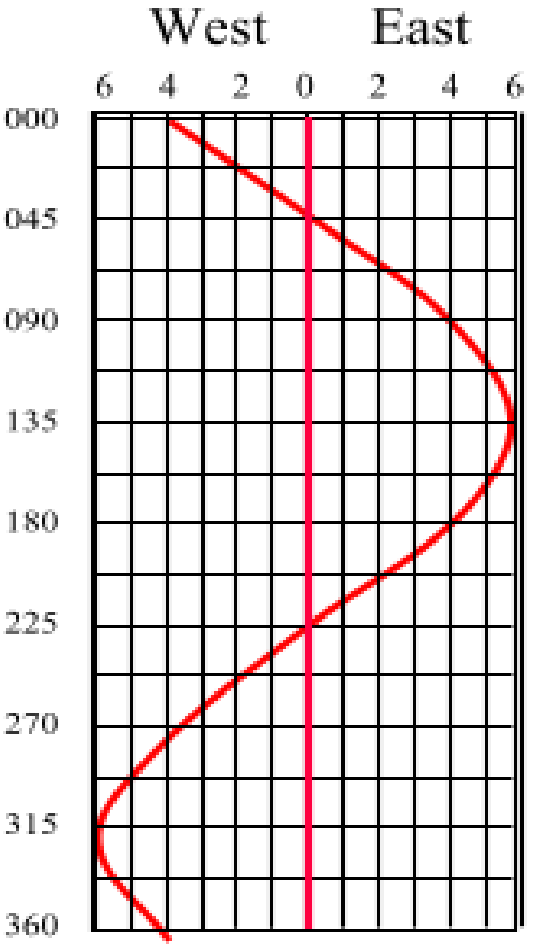
Magnetic Deviation

To determine deviation of a ship's compass:

- Point the boat in a known 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



Heading (C)	Deviation
000	4W
022.5	2W
045	0
067.5	2E
090	4E
112.5	5E
135	6E
157.5	5E
180	4E
202.5	2E
225	0
247.5	2W
270	4W
292.5	5W
315	6W
337.5	5W
360	4W

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	True
Virgins	Variation
Make	Magnetic
Dull	Deviation
Companions	Compass
(add Whiskey)	(add West)

Compass Heading De-correction

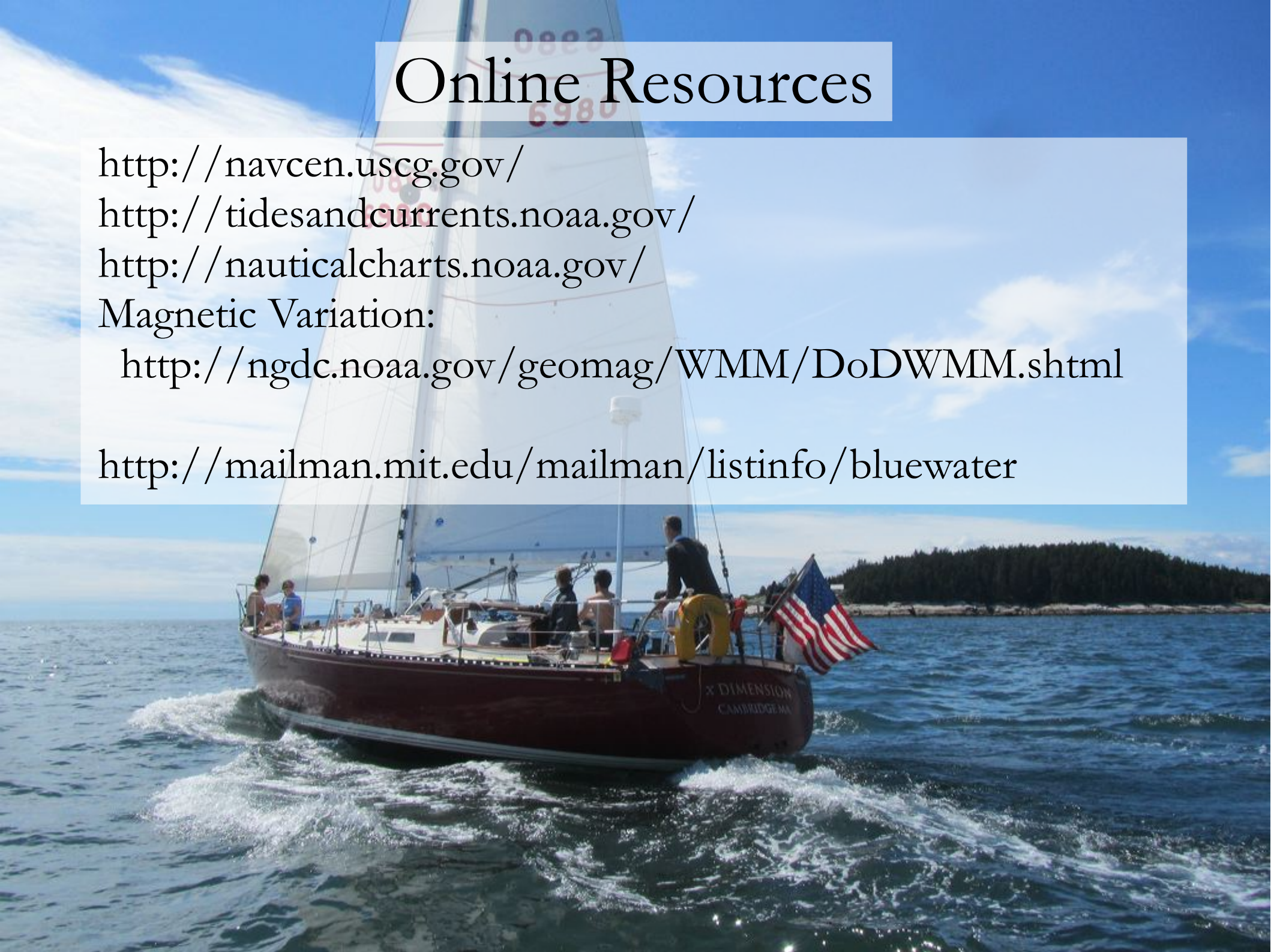
True	46°	True
Virgins	15°W	Variation
Make	61°	Magnetic
Dull	2°E	Deviation
Companions	59°	Compass

(add Whiskey) (add West)

Online Resources

http://navcen.uscg.gov/
http://tidesandcurrents.noaa.gov/
http://nauticalcharts.noaa.gov/
Magnetic Variation:
http://ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml

http://mailman.mit.edu/mailman/listinfo/bluewater



Further Reading

Chapman Piloting and Seamanship
by Jonathan Eaton

Annapolis Book of Seamanship
by John Rousmaniere

Piloting and Dead Reckoning
by Capt. H.H. Shufeldt and G.D. Dunlap

American Practical Navigator (BOWDITCH)
https://msi.nga.mil/NGAPortal/MSI.portal

- https://en.wikipedia.org/wiki/Geodetic_datum
- https://en.wikipedia.org/wiki/Tide
- https://en.wikipedia.org/wiki/Dead_reckoning
- https://en.wikipedia.org/wiki/Piloting_(navigation)
- https://en.wikipedia.org/wiki/Magnetic_declination
- https://en.wikipedia.org/wiki/Rhumb_line