Dubberly Design Office

Locating a ship at sea An early example of data fusion

Version 2 May 31, 2023

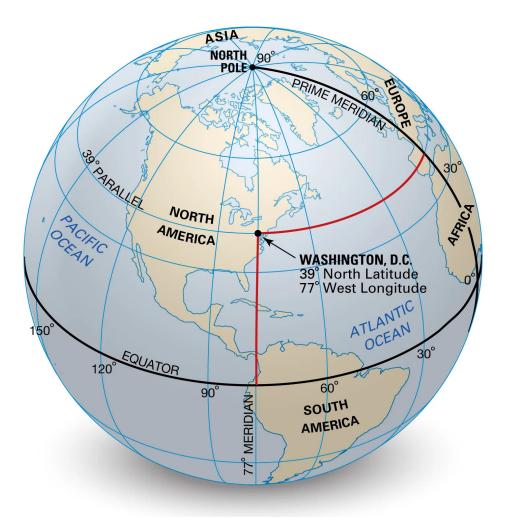
Oceans cover more than 70 percent of the Earth's surface; without landmarks for reference, **a ship may go off course and be lost**.

https://www.americanoceans.org/wp-content/uploads/2023/01/biggest-oceans.jpg

Dubberly Design Office

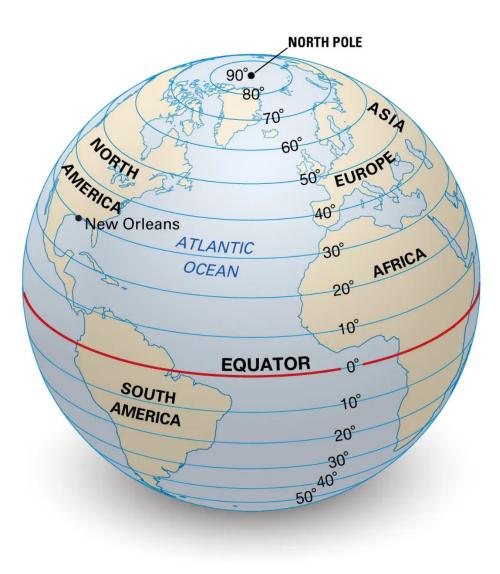
A ship's position is the intersection of two lines:

- Latitude, 38° 53' 42.4" N (or 38.9072°)
- Longitude, 77° 2' 10.93" W (or -77.0369°)



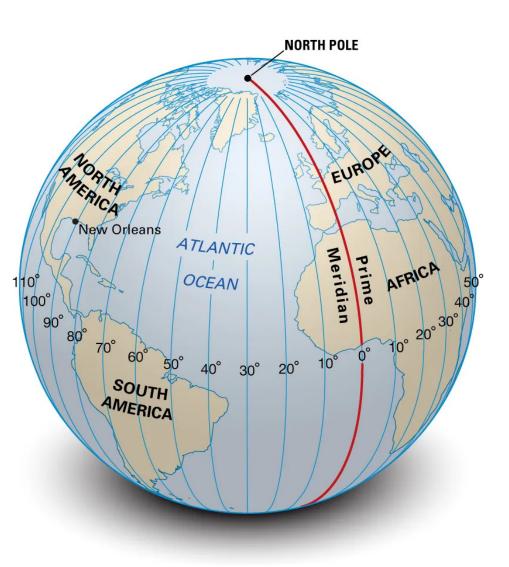
https://cdn.britannica.com/03/64903-050-3E1ED75A/globe-perspective-north-line-crossing-Washington-DC.jpg

Latitude is measured with reference to the Earth's equator — north or south, positive or negative.



https://cdn.britannica.com/07/64907-050-7ACA69C8/Facts-parallels-Lines-of-Latitude-angles-direction.jpg

Longitude is measured with reference to a prime meridian, typically centered on Greenwich, England east or west, positive or negative.



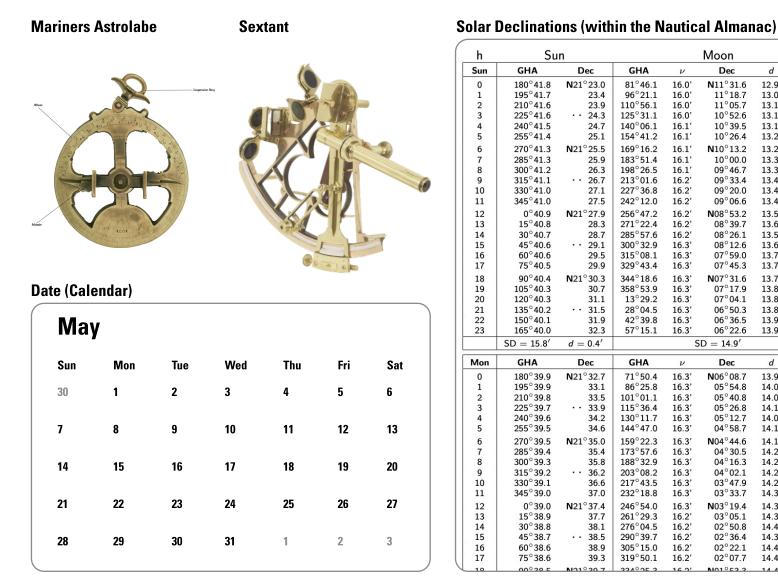
https://cdn.britannica.com/06/64906-050-675D6688/meridians-Facts-Lines-of-Longitude-angles-halves.jpg

Latitude may be found by measuring the angle of the sun, in early days using an astrolabe and later a sextant.

The sun reaches its highest point at noon.

The angle at the highest point changes with the seasons.

Thus, to find the latitude, the angle must be correlated with the date, typically by looking it up in a reference table.

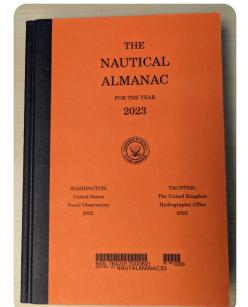


https://marinesavvy.com/what-is-a-sextant https://exploration.marinersmuseum.org/object/astrolabe/

https://thenauticalalmanac.com/TNARegular/2023 Nautical Almanac.pdf . https://aa.usno.navy.mil/publications/na history

		Moon		
GHA	ν	Dec	d	HP
81°46.1	16.0'	N11°31.6	12.9'	54.5'
96°21.1	16.0'	11°18.7	13.0'	54.5'
$110^{\circ}56.1$	16.0'	11°05.7	13.1'	54.5'
$125^{\circ}31.1$	16.0'	$10^{\circ}52.6$	13.1'	54.5'
$140^{\circ}06.1$	16.1'	$10^{\circ}39.5$	13.1'	54.5'
154°41.2	16.1'	10°26.4	13.2'	54.5'
169°16.2	16.1'	N10°13.2	13.2'	54.5'
183°51.4	16.1'	10°00.0	13.3'	54.6'
198°26.5	16.1'	09°46.7	13.3'	54.6'
213°01.6	16.2'	09°33.4	13.4'	54.6'
227°36.8	16.2'	09°20.0	13.4'	54.6'
$242^{\circ}12.0$	16.2'	09°06.6	13.4'	54.6'
256°47.2	16.2'	N08°53.2	13.5'	54.6'
271°22.4	16.2'	08°39.7	13.6'	54.7'
285°57.6	16.2'	08°26.1	13.5'	54.7'
300°32.9	16.3'	$08^{\circ}12.6$	13.6'	54.7'
$315^{\circ}08.1$	16.3'	07°59.0	13.7'	54.7'
329°43.4	16.3'	07°45.3	13.7'	54.7'
344°18.6	16.3'	N07°31.6	13.7'	54.7'
358°53.9	16.3'	07°17.9	13.8'	54.8'
13°29.2	16.3'	07°04.1	13.8'	54.8'
28°04.5	16.3'	06°50.3	13.8'	54.8'
42°39.8	16.3'	06°36.5	13.9'	54.8'
57°15.1	16.3'	06°22.6	13.9'	54.8'
	S	D = 14.9'		
GHA	ν	Dec	d	HP
71°50.4	16.3'	N 06°08.7	13.9'	54.9'
86°25.8	16.3'	05°54.8	14.0'	54.9'
$101^{\circ}01.1$	16.3'	$05^{\circ}40.8$	14.0'	54.9'
$115^{\circ}36.4$	16.3'	05°26.8	14.1'	54.9'
$130^{\circ}11.7$	16.3'	05°12.7	14.0'	54.9'
144°47.0	16.3'	04°58.7	14.1'	55.0'
159°22.3	16.3'	N 04°44.6	14.1'	55.0'
173°57.6	16.3'	04°30.5	14.2'	55.0'
188° 32.9	16.3'	$04^{\circ}16.3$	14.2'	55.0'
203°08.2	16.3'	$04^{\circ}02.1$	14.2'	55.1'
217°43.5	16.3'	03°47.9	14.2'	55.1'
232°18.8	16.3'	03°33.7	14.3'	55.1'
246°54.0	16.3'	N03°19.4	14.3'	55.1'
261°29.3	16.2'	03°05.1	14.3'	55.2'
276°04.5	16.2'	02°50.8	14.4'	55.2'
290°39.7	16.2'	02°36.4	14.3'	55.2'
$305^{\circ}15.0$	16.2'	$02^{\circ}22.1$	14.4'	55.2'
319°50.1	16.2'	02°07.7	14.4'	55.3'
2240 DE 2	16.0'	NIA10E2 2	14 4'	EE 2'

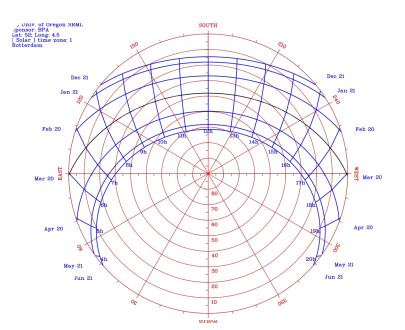
Nautical Almanac



The sun is highest at the beginning of summer; lowest at the beginning of winter.

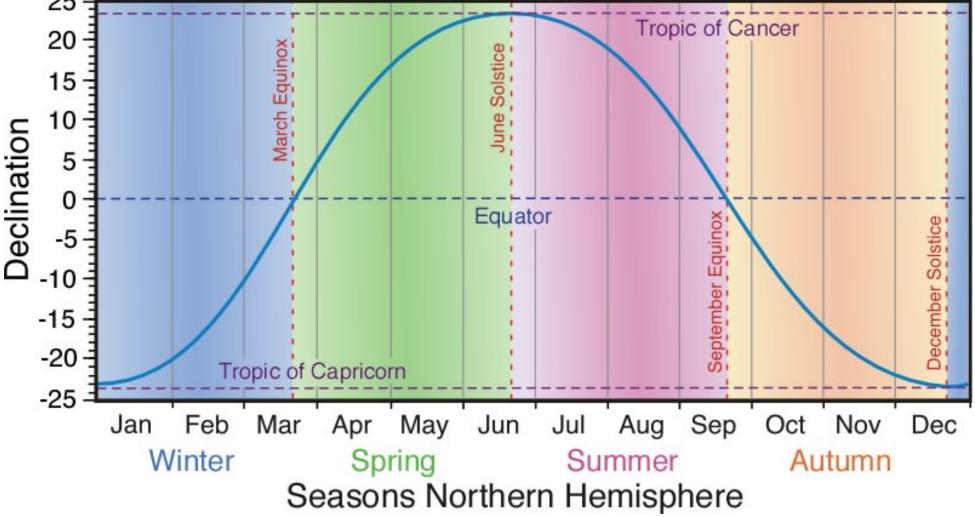
For example, if the sun is directly overhead, and the date is June 21, then your position is on the Tropic of Cancer.

23d 26' 22" (23.4394°) north of the Equator.





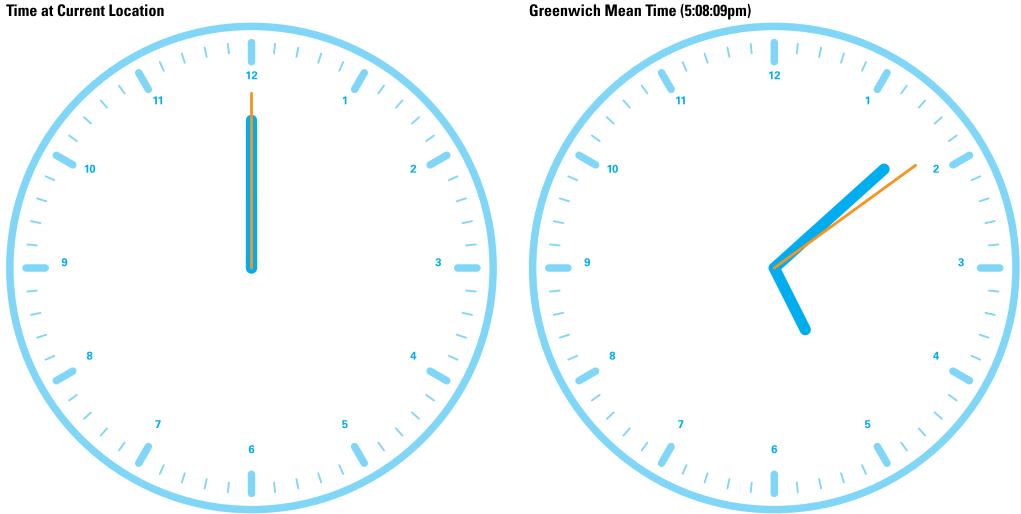
Declination of the sun



http://www.atmo.arizona.edu/students/courselinks/spring15/atmo336/lectures/sec4/declination.iog https://commons.wikimedia.org/wiki/File:Sun-path-polar-chart.svg

Longitude is found by measuring the difference in time between the current location and the reference location (i.e., Greenwich).

If the time at the current location is noon and the time in Greenwich is 5:08:09 pm, then the ship has traveled 77.0369° west, 4 minutes of time for each degree of longitude.



Measurement of longitude requires a very accurate clock, neither gaining or losing minutes or seconds over months at sea.

Making such a clock was a technical challenge. About 1759, John Harrison solved the problem with the H4 nautical chronometer.

In H4's first sea trial, an 81 day and 5 hour voyage from Portsmouth to Kingston, Jamaica— H4 only lost 3 minutes 36.5 seconds per day.

However, Harrison's next iteration of the nautical chronometer, H5, only lost 1/3 of a second per day.

John Harrison's 'H4'



John Harrison's 'H5'



https://en.wikipedia.org/wiki/John_Harrison#H4

Harrison was prompted to his invention by King George III, who offered **a prize of £20,000**, about \$3,000,000 in today's terms.



https://d3k6u6bv48g1ck.cloudfront.net/coin-image-1_Guinea-Gold-Kingdom_of_Great_Britain_(1707_1801)-t.bBwcl0FgUAAAEpGkEFQRcl.jpg

King George III was acting after a series of naval disasters; in particular the 1707 wreck at Scilly, in which 4 ships and ~2,000 lives were lost due to navigation errors.

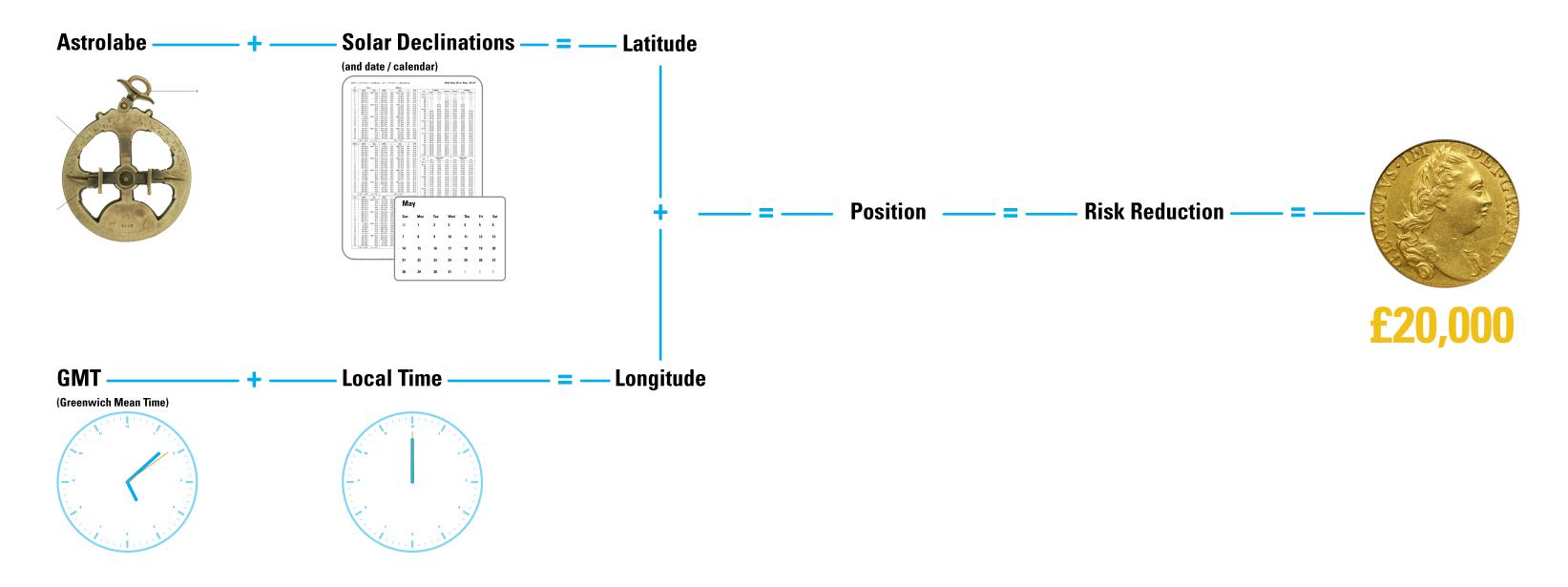


Scilly Naval Disaster Etching

https://en.wikipedia.org/wiki/Scilly_naval_disaster_of_1707



This early example shows the value of fusing four pieces of data. Individually, the separate pieces of data are not very useful; together, they may be the difference between life and death.



Appendix

Dubberly Design Office

Approximately between the early 16th through 18th centuries, a 'Chip Log' was used by mariners to **measure the speed of a vessel**.

They done so by counting 7–8 tied knots in the rope of the chip log shown at right.

This method of measuring is where the term / units 'Knots' came from.

Using the Chip Log in conjunction with the other tools aforementioned such as the Astrolabe, Declination Tables, and Chronometer, is the process of Dead Reckoning.

"In navigation, dead reckoning is the process of calculating the current position of a moving object by using a previously determined position, or fix, and incorporating estimates of speed, heading (or direction or course), and elapsed time."



Using the Sextant and Almanac

Before using the solar declinations of a nautical almanac, there are prior corrections that need to be made for:

1. Index errors

Aligning the mirrors of the Sextant.

2. **Dip errors**

Correcting for the height of the Sextant above the horizon.

3. **Refraction errors** Correcting for the amount that the light bends before reaching the Sextant.

4. **Semi-diameter errors** Correcting for the apparent size of the Sun during a certain time of year.

5. **Parallax errors** Correcting for the

differences of your vantage point to the Sun.

Sextant in use



https://thenauticalalmanac.com/TNARegular/2023 Nautical Almanac.pdf • https://commons.wikimedia.org/wiki/File:180423-N-DL434-149 (27894845758).jpg https://www.wikihow.com/Use-a-Sextant#:~:text=Add%20or%20subtract%20the%20declination,the%20eguator%2C%20add%20the%20declination.

Solar Declinations (Nautical Almanac)

h	Su	n			Moon		
Sun	GHA	Dec	GHA	ν	Dec	d	HP
0	180°41.8	N21°23.0	81°46.1	16.0'	N11°31.6	12.9'	54.5'
1	195°41.7	23.4	96°21.1	16.0'	$11^{\circ}18.7$	13.0'	54.5'
2	210°41.6	23.9	$110^{\circ}56.1$	16.0'	$11^{\circ}05.7$	13.1'	54.5'
3	225°41.6	· · 24.3	125°31.1	16.0'	$10^{\circ}52.6$	13.1'	54.5'
4	240°41.5	24.7	$140^{\circ}06.1$	16.1'	$10^{\circ}39.5$	13.1'	54.5'
5	255°41.4	25.1	154°41.2	16.1'	$10^{\circ}26.4$	13.2'	54.5'
6	270°41.3	N21°25.5	169°16.2	16.1'	N10°13.2	13.2'	54.5'
7	285°41.3	25.9	183°51.4	16.1'	$10^{\circ}00.0$	13.3'	54.6'
8	300°41.2	26.3	198°26.5	16.1'	09°46.7	13.3'	54.6'
9	315°41.1	· · 26.7	213°01.6	16.2'	09°33.4	13.4'	54.6'
10	330°41.0	27.1	227°36.8	16.2'	09°20.0	13.4'	54.6'
11	345°41.0	27.5	242°12.0	16.2'	09°06.6	13.4'	54.6'
12	0°40.9	N21°27.9	256°47.2	16.2'	N08°53.2	13.5'	54.6'
13	15°40.8	28.3	271°22.4	16.2'	08°39.7	13.6'	54.7'
14	30°40.7	28.7	285°57.6	16.2'	08°26.1	13.5'	54.7'
15	45°40.6	· · 29.1	300°32.9	16.3'	08°12.6	13.6'	54.7'
16	60°40.6	29.5	315°08.1	16.3'	07°59.0	13.7'	54.7'
17	75°40.5	29.9	329°43.4	16.3'	07°45.3	13.7'	54.7'
18	90°40.4	N21°30.3	344°18.6	16.3'	N07°31.6	13.7'	54.7'
19	105°40.3	30.7	358°53.9	16.3'	07°17.9	13.8'	54.8'
20	120°40.3	31.1	13°29.2	16.3'	07°04.1	13.8'	54.8'
21	135°40.2	· · 31.5	28°04.5	16.3'	06°50.3	13.8'	54.8'
22	150°40.1	31.9	42°39.8	16.3'	06°36.5	13.9'	54.8'
23	165°40.0	32.3	57°15.1	16.3'	06°22.6	13.9'	54.8'
	SD=15.8'	d = 0.4'		S	D = 14.9'		
Mon	GHA	Dec	GHA	ν	Dec	d	HP
0	180°39.9	N21°32.7	71°50.4	16.3'	N 06°08.7	13.9'	54.9'
1	195°39.9	33.1	86°25.8	16.3'	05°54.8	14.0'	54.9'
2	210°39.8	33.5	101°01.1	16.3'	05°40.8	14.0'	54.9'
3	225°39.7	· · 33.9	115°36.4	16.3'	05°26.8	14.1'	54.9'
4	240°39.6	34.2	130°11.7	16.3'	05°12.7	14.0'	54.9'
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6	270°39.5	N21°35.0	159°22.3	16.3'	N04°44.6	14.1'	55.0'
7	285°39.4	35.4	173°57.6	16.3'	04°30.5	14.2'	55.0'
8	300°39.3	35.8	188° 32.9	16.3'	04°16.3	14.2'	55.0'
9	315° 39.2	· · 36.2	203°08.2	16.3'	04°02.1	14.2'	55.1'
10	330° 39.1	36.6	217°43.5	16.3'	03°47.9	14.2'	55.1'
11	345°39.0	37.0	232°18.8	16.3'	03°33.7	14.3'	55.1'
12	0°39.0	N21°37.4	246°54.0	16.3'	N 03°19.4	14.3'	55.1'
13	15°38.9	37.7	261°29.3	16.2'	03°05.1	14.3'	55.2'
14	30°38.8	38.1	276°04.5	16.2'	02°50.8	14.4'	55.2'
15	45°38.7	· · 38.5	290°39.7	16.2'	02°36.4	14.3'	55.2'
16	60°38.6	38.9	305°15.0	16.2'	02°22.1	14.4'	55.2'
17	75°38.6	39.3	319°50.1	16.2'	02°07.7	14.4'	55.3'
10	00000 E	NI010 20 7	2240 DE 2	16 0'	NIA10ED D	14 4'	EE 2'

Using the Sextant and Almanac

- Then you can take a reading with the Sextant and combine with the information previously described to get a 'corrected altitude'.
- 2. Subtract the

'corrected altitude' from 90°. (i.e. the equinox— the time of year when the sun is at 90° to the equator)

- Solution 3. Find the declination that corresponds with the required date and time.
 - 4. Add or subtract the declination from your corrected altitude. (Since these declinations are all North of the equator, they would be added)

Sextant in use



https://thenauticalalmanac.com/TNARegular/2023_Nautical_Almanac.pdf • https://commons.wikimedia.org/wiki/File:180423-N-DL434-149_(27894845758).jpg https://www.wikihow.com/Use-a-Sextant#:~:text=Add%20or%20subtract%20the%20declination.the%20eguator%2C%20add%20the%20declination.

Solar Declinations (Nautical Almanac)

h	Sur	1			Moon		
Sun	GHA	Dec	GHA	ν	Dec	d	HP
0	180°41.8	N21°23.0	81°46.1	16.0'	N11°31.6	12.9'	54.5'
1	195°41.7	23.4	96°21.1	16.0'	$11^{\circ}18.7$	13.0'	54.5'
2	210°41.6	23.9	$110^{\circ}56.1$	16.0'	11°05.7	13.1'	54.5'
3	225°41.6	·· 24.3	125°31.1	16.0'	$10^{\circ}52.6$	13.1'	54.5'
4	240°41.5	24.7	$140^{\circ}06.1$	16.1'	$10^{\circ}39.5$	13.1'	54.5'
5	255°41.4	25.1	154°41.2	16.1'	10°26.4	13.2'	54.5'
6	270°41.3	N21°25.5	169°16.2	16.1'	N10°13.2	13.2'	54.5'
7	285°41.3	25.9	183°51.4	16.1'	10°00.0	13.3'	54.6'
8	300°41.2	26.3	198°26.5	16.1'	09°46.7	13.3'	54.6'
9	315°41.1	· · 26.7	213°01.6	16.2'	09°33.4	13.4'	54.6'
10	330°41.0	27.1	227°36.8	16.2'	09°20.0	13.4'	54.6'
11	345°41.0	27.5	242°12.0	16.2'	09°06.6	13.4'	54.6'
12	0°40.9	N21°27.9	256°47.2	16.2'	N08°53.2	13.5'	54.6'
13	15°40.8	28.3	271°22.4	16.2'	08°39.7	13.6'	54.7
14	30°40.7	28.7	285°57.6	16.2'	08°26.1	13.5'	54.7
15	45°40.6	· · 29.1	300°32.9	16.3'	08°12.6	13.6'	54.7
16	60°40.6	29.5	315°08.1	16.3'	07°59.0	13.7'	54.7'
17	75°40.5	29.9	329°43.4	16.3'	07°45.3	13.7'	54.7'
18	90°40.4	N21°30.3	344°18.6	16.3'	N07°31.6	13.7'	54.7
19	105°40.3	30.7	358°53.9	16.3'	07°17.9	13.8'	54.8'
20	120°40.3	31.1	13°29.2	16.3'	07°04.1	13.8'	54.8'
21	135°40.2	· · 31.5	28°04.5	16.3'	06°50.3	13.8'	54.8
22	150°40.1	31.9	42°39.8	16.3'	06°36.5	13.9'	54.8'
23	165°40.0	32.3	57°15.1	16.3'	06°22.6	13.9'	54.8'
	SD = 15.8'	d = 0.4'	01 1011		D = 14.9'	1010	0.110
Mon	CHA	Dec				d	
Mon	GHA	Dec	GHA	ν 16.2'		d	HP
0	180°39.9	N 21°32.7	71°50.4	16.3'	N06°08.7	13.9'	54.9'
0 1	180° 39.9 195° 39.9	N21° 32.7 33.1	71°50.4 86°25.8	16.3' 16.3'	N06°08.7 05°54.8	13.9' 14.0'	54.9' 54.9'
0 1 2	180° 39.9 195° 39.9 210° 39.8	N21° 32.7 33.1 33.5	71°50.4 86°25.8 101°01.1	16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8	13.9' 14.0' 14.0'	54.9' 54.9' 54.9'
0 1 2 3	180° 39.9 195° 39.9 210° 39.8 225° 39.7	N21° 32.7 33.1 33.5 •• 33.9	71°50.4 86°25.8 101°01.1 115°36.4	16.3' 16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8 05°26.8	13.9' 14.0' 14.0' 14.1'	54.9' 54.9' 54.9' 54.9'
0 1 2 3 4	180°39.9 195°39.9 210°39.8 225°39.7 240°39.6	N21° 32.7 33.1 33.5 •• 33.9 34.2	71°50.4 86°25.8 101°01.1 115°36.4 130°11.7	16.3' 16.3' 16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8 05°26.8 05°12.7	13.9' 14.0' 14.0' 14.1' 14.0'	54.9' 54.9' 54.9' 54.9' 54.9'
0 1 2 3 4 5	180° 39.9 195° 39.9 210° 39.8 225° 39.7 240° 39.6 255° 39.5	N21° 32.7 33.1 33.5 •• 33.9 34.2 34.6	71°50.4 86°25.8 101°01.1 115°36.4 130°11.7 144°47.0	16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8 05°26.8 05°12.7 04°58.7	13.9' 14.0' 14.0' 14.1' 14.0' 14.1'	54.9' 54.9' 54.9' 54.9' 54.9' 55.0'
0 1 2 3 4 5 6	180° 39.9 195° 39.9 210° 39.8 225° 39.7 240° 39.6 255° 39.5 270° 39.5	N21° 32.7 33.1 33.5 •• 33.9 34.2 34.6 N21° 35.0	71°50.4 86°25.8 101°01.1 115°36.4 130°11.7 144°47.0 159°22.3	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8 05°26.8 05°12.7 04°58.7 N04°44.6	13.9' 14.0' 14.0' 14.1' 14.0' 14.1' 14.1'	54.9' 54.9' 54.9' 54.9' 54.9' 55.0' 55.0'
0 1 2 3 4 5 6 7	180° 39.9 195° 39.9 210° 39.8 225° 39.7 240° 39.6 255° 39.5 270° 39.5 285° 39.4	N21° 32.7 33.1 33.5 · · 33.9 34.2 34.6 N21° 35.0 35.4	71°50.4 86°25.8 101°01.1 115°36.4 130°11.7 144°47.0 159°22.3 173°57.6	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8 05°26.8 05°12.7 04°58.7 N04°44.6 04°30.5	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2'	54.9' 54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0'
0 1 2 3 4 5 6 7 8	180° 39.9 195° 39.9 210° 39.8 225° 39.7 240° 39.6 255° 39.5 270° 39.5 285° 39.4 300° 39.3	N21° 32.7 33.1 33.5 •• 33.9 34.2 34.6 N21° 35.0 35.4 35.8	71°50.4 86°25.8 101°01.1 115°36.4 130°11.7 144°47.0 159°22.3 173°57.6 188°32.9	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8 05°26.8 05°12.7 04°58.7 N04°44.6 04°30.5 04°16.3	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2'	54.9' 54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0'
0 1 2 3 4 5 6 7 8 9	180° 39.9 195° 39.9 210° 39.8 225° 39.7 240° 39.6 255° 39.5 285° 39.4 300° 39.3 315° 39.2	N21° 32.7 33.1 33.5 ·· 33.9 34.2 34.6 N21° 35.0 35.4 35.8 ·· 36.2	71°50.4 86°25.8 101°01.1 115°36.4 130°11.7 144°47.0 159°22.3 173°57.6 188°32.9 203°08.2	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8 05°26.8 05°12.7 04°58.7 N04°44.6 04°30.5 04°16.3 04°02.1	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2' 14.2'	54.9' 54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0' 55.0' 55.0' 55.1'
0 1 2 3 4 5 6 7 8 9 10	$\begin{array}{c} 180^\circ 39.9\\ 195^\circ 39.9\\ 210^\circ 39.8\\ 225^\circ 39.7\\ 240^\circ 39.6\\ 255^\circ 39.5\\ 270^\circ 39.5\\ 285^\circ 39.4\\ 300^\circ 39.3\\ 315^\circ 39.2\\ 330^\circ 39.1 \end{array}$	$\begin{array}{c} \text{N21}^\circ 32.7 \\ 33.1 \\ 33.5 \\ \cdots 33.9 \\ 34.2 \\ 34.6 \\ \text{N21}^\circ 35.0 \\ 35.4 \\ 35.8 \\ \cdots 35.8 \\ \cdots 36.2 \\ 36.6 \end{array}$	$\begin{array}{c} 71^\circ 50.4\\ 86^\circ 25.8\\ 101^\circ 01.1\\ 115^\circ 36.4\\ 130^\circ 11.7\\ 144^\circ 47.0\\ 159^\circ 22.3\\ 173^\circ 57.6\\ 188^\circ 32.9\\ 203^\circ 08.2\\ 217^\circ 43.5 \end{array}$	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06°08.7 05°54.8 05°40.8 05°26.8 05°12.7 04°58.7 N04°44.6 04°30.5 04°16.3 04°02.1 03°47.9	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2' 14.2' 14.2' 14.2'	54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0' 55.0' 55.1' 55.1'
0 1 2 3 4 5 6 7 8 9 10 11	$\begin{array}{c} 180^\circ 39.9\\ 195^\circ 39.9\\ 210^\circ 39.8\\ 225^\circ 39.7\\ 240^\circ 39.6\\ 255^\circ 39.5\\ 270^\circ 39.5\\ 285^\circ 39.4\\ 300^\circ 39.3\\ 315^\circ 39.2\\ 330^\circ 39.1\\ 345^\circ 39.0 \end{array}$	N21°32.7 33.1 33.5 • 33.9 34.2 34.6 N21°35.0 35.4 35.8 • 36.2 36.6 37.0	$71^{\circ}50.4\\86^{\circ}25.8\\101^{\circ}01.1\\115^{\circ}36.4\\130^{\circ}11.7\\144^{\circ}47.0\\159^{\circ}22.3\\173^{\circ}57.6\\188^{\circ}32.9\\203^{\circ}08.2\\217^{\circ}43.5\\232^{\circ}18.8$	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06° 08.7 05° 54.8 05° 40.8 05° 26.8 05° 12.7 04° 58.7 N04° 44.6 04° 30.5 04° 16.3 04° 02.1 03° 47.9 03° 33.7	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2' 14.2' 14.2' 14.2' 14.2'	54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0' 55.0' 55.1' 55.1'
0 1 2 3 4 5 6 7 8 9 10 11 12	$\begin{array}{c} 180^\circ 39.9\\ 195^\circ 39.9\\ 210^\circ 39.8\\ 225^\circ 39.7\\ 240^\circ 39.6\\ 255^\circ 39.5\\ 270^\circ 39.5\\ 285^\circ 39.4\\ 300^\circ 39.3\\ 315^\circ 39.2\\ 330^\circ 39.1\\ 345^\circ 39.0\\ 0^\circ 39.0\end{array}$	N21° 32.7 33.1 33.5 · 33.9 34.2 34.6 N21° 35.0 35.4 35.8 · 36.2 36.6 37.0 N21° 37.4	$71^{\circ}50.4\\86^{\circ}25.8\\101^{\circ}01.1\\115^{\circ}36.4\\130^{\circ}11.7\\144^{\circ}47.0\\159^{\circ}22.3\\173^{\circ}57.6\\188^{\circ}32.9\\203^{\circ}08.2\\217^{\circ}43.5\\2217^{\circ}43.5\\232^{\circ}18.8\\246^{\circ}54.0$	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06° 08.7 05° 54.8 05° 40.8 05° 26.8 05° 12.7 04° 58.7 N04° 44.6 04° 30.5 04° 16.3 04° 02.1 03° 47.9 03° 33.7 N03° 19.4	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2' 14.2' 14.2' 14.2' 14.3'	54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0' 55.0' 55.1' 55.1' 55.1' 55.1'
0 1 2 3 4 5 6 7 8 9 10 11 12 13	180° 39.9 195° 39.9 210° 39.8 225° 39.7 240° 39.6 255° 39.5 270° 39.5 285° 39.4 300° 39.3 315° 39.2 330° 39.1 345° 39.0 0° 39.0 15° 38.9	N21°32.7 33.1 33.5 33.9 34.2 34.6 N21°35.0 35.4 35.8 .36.2 36.6 37.0 N21°37.4 37.7	$71^{\circ}50.4\\86^{\circ}25.8\\101^{\circ}01.1\\115^{\circ}36.4\\130^{\circ}11.7\\144^{\circ}47.0\\159^{\circ}22.3\\173^{\circ}57.6\\188^{\circ}32.9\\203^{\circ}08.2\\217^{\circ}43.5\\232^{\circ}18.8\\246^{\circ}54.0\\261^{\circ}29.3$	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06° 08.7 05° 54.8 05° 40.8 05° 26.8 05° 12.7 04° 58.7 N04° 44.6 04° 30.5 04° 16.3 04° 02.1 03° 33.7 N03° 19.4 03° 05.1	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2' 14.2' 14.2' 14.3' 14.3'	54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0' 55.0' 55.1' 55.1' 55.1' 55.1' 55.1' 55.2'
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14	$\begin{array}{c} 180^\circ 39.9\\ 195^\circ 39.9\\ 210^\circ 39.8\\ 225^\circ 39.7\\ 240^\circ 39.6\\ 255^\circ 39.5\\ 270^\circ 39.5\\ 285^\circ 39.4\\ 300^\circ 39.3\\ 315^\circ 39.2\\ 330^\circ 39.1\\ 345^\circ 39.0\\ 0^\circ 39.0\\ 15^\circ 38.9\\ 30^\circ 38.8\\ \end{array}$	N21° 32.7 33.1 33.5 33.9 34.2 34.6 N21° 35.0 35.4 35.8 36.2 36.6 37.0 N21° 37.4 37.7 38.1	$\begin{array}{c} 71^\circ 50.4\\ 86^\circ 25.8\\ 101^\circ 01.1\\ 115^\circ 36.4\\ 130^\circ 11.7\\ 144^\circ 47.0\\ 159^\circ 22.3\\ 173^\circ 57.6\\ 188^\circ 32.9\\ 203^\circ 08.2\\ 217^\circ 43.5\\ 232^\circ 18.8\\ 246^\circ 54.0\\ 261^\circ 29.3\\ 276^\circ 04.5\\ \end{array}$	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06° 08.7 05° 54.8 05° 40.8 05° 26.8 05° 12.7 04° 58.7 N04° 44.6 04° 30.5 04° 16.3 04° 02.1 03° 47.9 03° 33.7 N03° 19.4 03° 05.1 02° 50.8	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2' 14.2' 14.2' 14.3' 14.3' 14.3' 14.3'	54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0' 55.0' 55.1' 55.1' 55.1' 55.1' 55.1' 55.2' 55.2'
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	$\begin{array}{c} 180^\circ 39.9\\ 195^\circ 39.9\\ 210^\circ 39.8\\ 225^\circ 39.7\\ 240^\circ 39.6\\ 255^\circ 39.5\\ 270^\circ 39.5\\ 285^\circ 39.4\\ 300^\circ 39.3\\ 315^\circ 39.2\\ 330^\circ 39.1\\ 345^\circ 39.0\\ 0^\circ 39.0\\ 15^\circ 38.9\\ 30^\circ 38.8\\ 45^\circ 38.7\\ \end{array}$	N21°32.7 33.1 33.5 33.9 34.2 34.6 N21°35.0 35.4 35.8 36.2 36.6 37.0 N21°37.4 37.7 38.1 . 38.5	$\begin{array}{c} 71^\circ 50.4\\ 86^\circ 25.8\\ 101^\circ 01.1\\ 115^\circ 36.4\\ 130^\circ 11.7\\ 144^\circ 47.0\\ 159^\circ 22.3\\ 173^\circ 57.6\\ 188^\circ 32.9\\ 203^\circ 08.2\\ 217^\circ 43.5\\ 232^\circ 18.8\\ 246^\circ 54.0\\ 261^\circ 29.3\\ 276^\circ 04.5\\ 290^\circ 39.7\\ \end{array}$	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.2' 16.2'	N06° 08.7 05° 54.8 05° 40.8 05° 26.8 05° 12.7 04° 58.7 N04° 44.6 04° 30.5 04° 16.3 04° 02.1 03° 47.9 03° 33.7 N03° 19.4 03° 05.1 02° 50.8 02° 36.4	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2' 14.2' 14.2' 14.2' 14.3' 14.3'	54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0' 55.0' 55.0' 55.1' 55.1' 55.1' 55.1' 55.1' 55.2' 55.2'
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14	$\begin{array}{c} 180^\circ 39.9\\ 195^\circ 39.9\\ 210^\circ 39.8\\ 225^\circ 39.7\\ 240^\circ 39.6\\ 255^\circ 39.5\\ 270^\circ 39.5\\ 285^\circ 39.4\\ 300^\circ 39.3\\ 315^\circ 39.2\\ 330^\circ 39.1\\ 345^\circ 39.0\\ 0^\circ 39.0\\ 15^\circ 38.9\\ 30^\circ 38.8\\ \end{array}$	N21° 32.7 33.1 33.5 33.9 34.2 34.6 N21° 35.0 35.4 35.8 36.2 36.6 37.0 N21° 37.4 37.7 38.1	$\begin{array}{c} 71^\circ 50.4\\ 86^\circ 25.8\\ 101^\circ 01.1\\ 115^\circ 36.4\\ 130^\circ 11.7\\ 144^\circ 47.0\\ 159^\circ 22.3\\ 173^\circ 57.6\\ 188^\circ 32.9\\ 203^\circ 08.2\\ 217^\circ 43.5\\ 232^\circ 18.8\\ 246^\circ 54.0\\ 261^\circ 29.3\\ 276^\circ 04.5\\ \end{array}$	16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3' 16.3'	N06° 08.7 05° 54.8 05° 40.8 05° 26.8 05° 12.7 04° 58.7 N04° 44.6 04° 30.5 04° 16.3 04° 02.1 03° 47.9 03° 33.7 N03° 19.4 03° 05.1 02° 50.8	13.9' 14.0' 14.0' 14.1' 14.1' 14.1' 14.1' 14.2' 14.2' 14.2' 14.2' 14.3' 14.3' 14.3' 14.3'	54.9' 54.9' 54.9' 54.9' 55.0' 55.0' 55.0' 55.0' 55.0' 55.1' 55.1'