Module 8

Modern Navigation Systems

Sextant Navigation

Module 8B
The Equation of Time

Summary of Module 8

- Students will use simulated and/or actual measurements of the angles of three or more stars above the horizon to determine their position on the surface of the earth at a known instant in time. (8A)
- **The Equation of Time will be Introduced (8B)**
- The concept of dilution of precision will be introduced and linked to the least squares algorithms developed earlier. (8C)

Reading/viewing

- Read the Wikipedia entry on the equation of time
- Read online about sundials
- Go outside and look at the sunset
- Note the equation of time entry at the bottom of each right-hand page in the daily entries of the Nautical Almanac

The equation of time

- Because of the earth's tilt, we have seasons, and the maximum "height" of the sun with respect to the northern and southern hemispheres over the course of a year is ± 23 ½ degrees
- Because the earth's orbit is elliptical, sometimes the relationship between actual "solar" time and GMT is a positive difference, and sometimes a negative difference.
- A plot of this time correction versus the apparent height of the sun over the span of a year yields an "analemma", the well-known "figure 8".
- The shadow cast by the sun at noon over the span of a year by a sundial traces out this curve, which is known as the *equation of time*. Such a sundial, with an engraving of the analemma, is shown in the next slide.

The equation of time plotted as part of a sundial

Figure 5. The “correction analemma” at the sundial at the Center for Computing Sciences in Bowie, Maryland.[12]

[12] The analemma is part of the sculpture “Sunwork,” by John Van Alstine, granite and stainless steel, 12 in × 40 in × 30 in, 1989. This photograph is used with permission of the artist. A photograph of the entire sculpture can be found at www.johnvanalstine.com. Dr. Neil Coletti provided significant input and guidance with respect to the astronomical accuracy of the sundial and analemma during its design and installation.

A “Geochron” wall clock showing the winter solstice and the equation of time

At the winter (northern hemisphere) solstice, the sun is at its southernmost point in the sky. At latitudes above the Arctic circle, there is 24 hours of darkness

A celestial globe

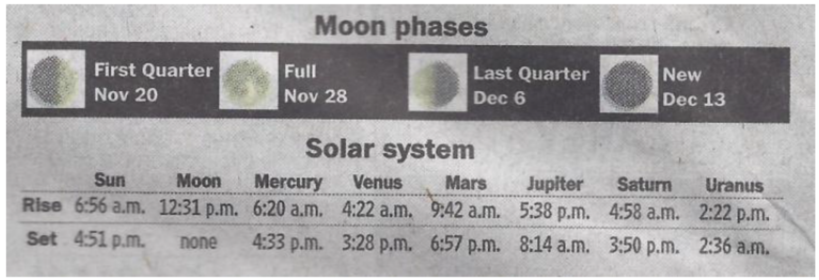
- A celestial globe shows all of the stars on the surface of a sphere, independent of the distance the stars are from the earth.
- The sun orbits the earth with a tilt angle of 23 ½ degrees, which corresponds to the 23 ½ degree tilt of the earth's rotational axis with respect to the earth's orbital plane around the sun.
- This tilt is one axis of the equation of time.
- The eccentricity of the earth's orbit accounts for the other axis.

A celestial globe

Each star has a lat/long on the celestial sphere; these are called GHA and Declination.

The sun

Put differently…



Moon phases

First Quarter	Full	Last Quarter	New
Nov 20	Nov 28	Dec 6	Dec 13

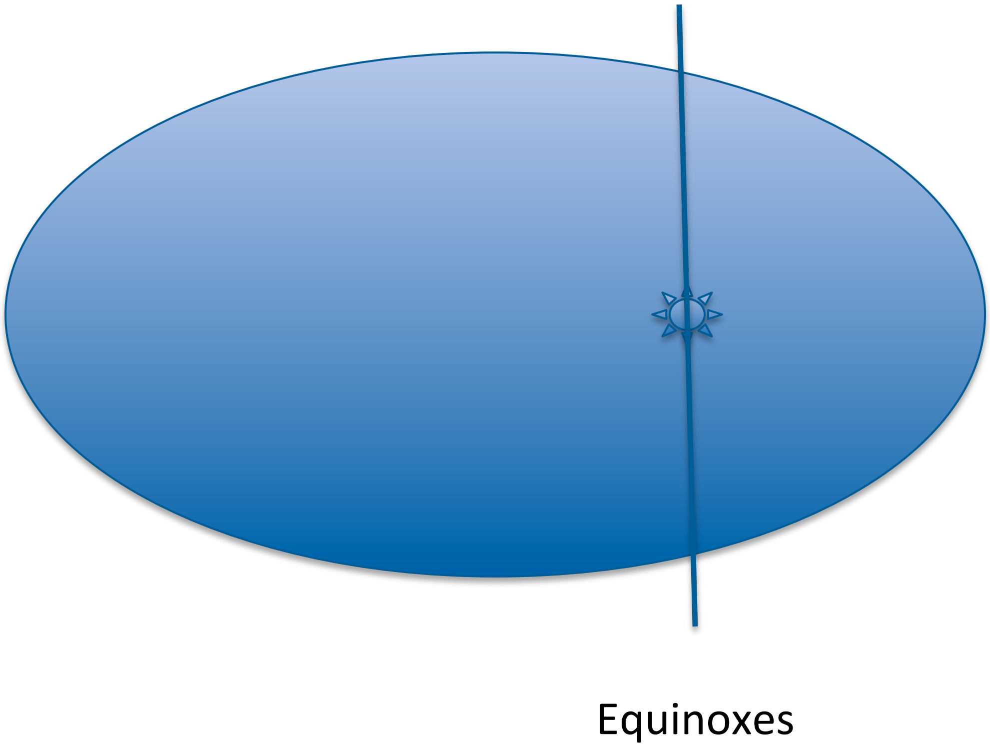
Solar system

	Sun	Moon	Mercury	Venus	Mars	Jupiter	Saturn	Uranus
Rise	6:56 a.m.	12:31 p.m.	6:20 a.m.	4:22 a.m.	9:42 a.m.	5:38 p.m.	4:58 a.m.	2:22 p.m.
Set	4:51 p.m.	none	4:33 p.m.	3:28 p.m.	6:57 p.m.	8:14 a.m.	3:50 p.m.	2:36 a.m.

Figure 8. Information for the sun, moon, and planets, published daily in The Washington Post, including Uranus, but not Neptune or Pluto.

Local noon should be halfway between sunrise and sunset, GMT.
To compute longitude, one need only note how many minutes prior to
or later then GMT noon local noon is, and scale accordingly using
15 degrees of longitude for every hour of time. For example, at 77 west longitude,
If local noon from the graph above isn't equal to "clock" noon, give or take the
offset due to the local time zone, then the location of Washington DC isn't precisely
the 75 degrees presumed for the Eastern time zone. However, except on two days each
year, when the equation of time = 0, there will be an error in this simple model.

Put even more differently…



The equinoxes are not midway through the earth's orbit around the sun either in time or position

Nor are perigee and apogee on the first days of summer or winter, except for once every 2000 or so years (cf. precession of the equinoxes.)

An equinox…

Figure 7. Sunset at Washington Circle along K St. In Washington, D.C. a few days after the equinox. This shows that K Street is a line of constant latitude. A statue of George Washington, lined up with Pennsylvania Avenue and pointing directly at the White House, is on the left.

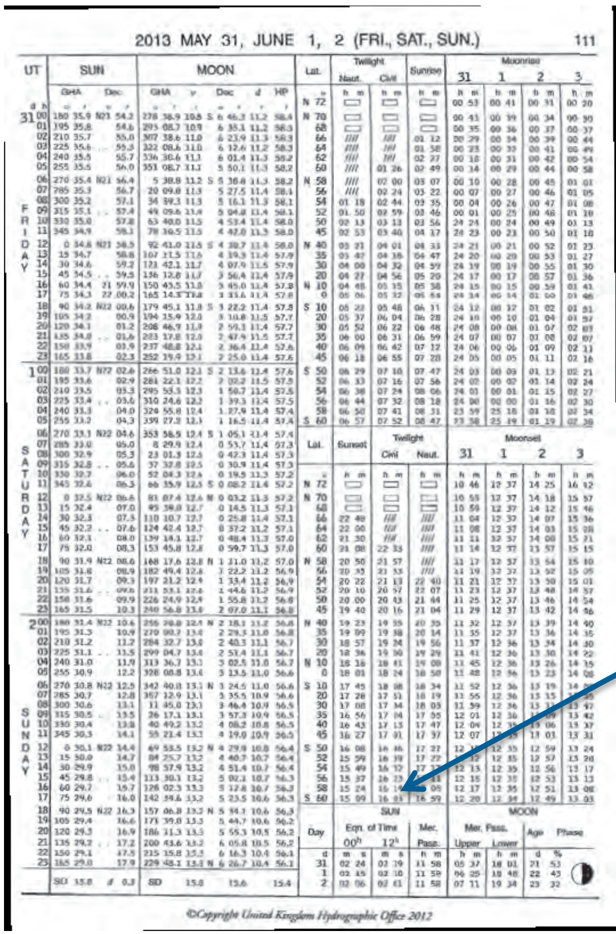
Equation of Time, 1804 Almanac

62 JUNE 1804. II.

Days of the Week.	Days of the Month.	THE SUN'S Longitude.	R^t. Afcen in Time.	Declin. North.	Equation of Time Sub.	Diff.
		S. D. M. S.	H. M. S.	D. M. S.	M. S.	S.
F.	1	2.10.41.57	4 36.24,9	22. 4 28	2 37,3	
Sa.	2	2.11.39.24	4.40 30,6	22 12 26	2.28,2	9,1
Sun.	3	2.12.36.50	4.44.36,7	22 20. 1	2.18,7	9,5
M.	4	2.13.34.15	4.48.43,2	22.27.13	2. 8,9	9,8
Tu.	5	2 14.31.40	4.52.50,0	22 34. 1	1.58,6	10,3
W.	6	2.15.29. 4	4.56.57,2	22.40.25	1.48,0	10,6
Th.	7	2.10.26.27	5. 1. 4,7	22.46 20	1.37,1	10,9
F.	8	2.17.23.50	5. 5.12,5	22.52 2	1.25,8	11,3
Sa.	9	2.18.21.12	5. 9.20,6	22.57.15	1.14,3	11,5
Sun	10	2.19.18.34	5.13 29,0	23. 2. 3	1. 2,6	11,7
M.	11	2.20.15.54	5.17.37,5	23. 6.27	0.50,6	12,0
Tu.	12	2.21.13.13	5.21.46,3	23.10.27	0.38,4	12,2
W.	13	2.22.10.32	5 25.55,2	23.14. 2	0 26,1	12,3
Th.	14	2.23. 7.49	5.30. 4,3	23.17.12	0.13,6	12,5
F.	15	2.24. 5. 6	5.34.13,5	23.19.58	0. 1,0	12,6
Sa.	16	2.25. 2 22	5.38.22,7	23.22.19	*Add* 11,6	12,6
Sun.	17	2.25.59.37	5 42.32,1	23.24.16	0.24,4	12,8
M.	18	2.26.56.51	5.46.41,5	23.25.48	0.37,2	12,8
Tu.	19	2.27.54. 5	5.50.51,0	23.26.55	0.50,1	12,9
W.	20	2 28.51.18	5.55. 0,4	23.27.37	1. 3,0	12,9
Th	21	2.29 48.30	5.59. 9,8	23.27.54	1.15,8	12,8
F.	22	3. 0 45 42	6. 3.19,3	23.27.47	1 28,6	12,8
Sa.	23	3. 1.42.53	6. 7.28.6	23.27.15	1 41,4	12,8
Sun	24	3. 2.40 5	6.11 37,9	23.26.18	1.54,1	12,7
M	25	3. 3.37.16	6.15 47,2	23.24.56	2. 6,8	12,7
Tu.	26	3. 4.34.27	6 19 56,3	23 23.10	2.19,3	12,5
W.	27	3. 5.31.38	6.24 5,3	23 20.59	2 31,7	12,4
Th.	28	3. 6.28.50	6.28.14,2	23.18.23	2.44,0	12,3
F.	29	3. 7.26. 1	6 32 22,9	23.15.23	2.56,1	12,1
Sa.	30	3. 8.23.13	6.36.31,4	23.11.58	3. 8,0	11,9

Equation of time

Equation of Time, Modern Almanac



Equation of time corrections

Assignment 8.2

1. Estimate the eccentricity *e* of the earth's orbit around the sun by taking account of the differing lengths of the seasons. You might find it useful to play with the orbit propagator simulation from Module 6 to generate an appropriate orbit, then match the orbital anomaly during the different seasons to the equinoxes and solstices shown on a modern calendar. Or, you can deduce this from the equation of time corrections in the Nautical Almanac.
2. Knowing the longitude of Washington, DC, estimate the date for which the data from the Washington Post in this sub-module are measured.

End of Mod 8B