The direction of sunrise and sunset

or, the value of a good compass and the Nautical Almanac
to photographers... and lawyers.

Photographers sometimes need to know the precise direction of sunset so they can frame a picture precisely as they want it. A cheap compass will not do this as they cannot take bearings accurately enough to pinpoint a spot on the horizon. A good candidate for this task is the famous French model, known for some thirty years or more as the "hockey puck compass," though no importer uses that name directly. The newest incarnation of this fine instrument is from Weems and Plath in Annapolis. It sells for about $120. It can read a bearing to within ± 1° or so, but we cannot count on that being the exactly correct bearing because local disturbances can throw this off somewhat, no matter how remote. Leaning on a car would make much bigger errors than that. Your eyeglass frames could also, as well as your watch when holding this hand held instrument up to your eye.

So standard compass precautions must be taken, but that done, this compass will do the job nicely. It is is also small and rugged, which are bonuses in the field. We would like to think that the compass in our iPhone might do the job, but they are not dependable for this precision. All electronic compasses are very sensitive to tilt angle.

But having the right compass is just step one. We then need to know what the direction of the sun is when we want to photograph it. If we are sticking with sunrise and sunset, we do not have to worry about time keeping. It happens when it happens. Lawyers, on the other hand, might want to prove the sun was shining in their client's eyes at any random time of day, so they do have to worry about time keeping. We will come back to that.

I do not know of any one magic table that tells us exactly what we want, namely the magnetic bearing of the sun on the horizon for any latitude and longitude on any date. So we have to do a couple simple computations, after which we could create special tables for special locations.

First, the direction of the sun is an astronomical properly, totally independent of the magnetic field of the earth. Thus we must start with true directions. From the Nautical Almanac we can compute the direction of the sun at any time from any place, but this will be true directions (labeled T). That is, north is 000 T, east is 090 T, south is 180 T, and west is 270 T. Southwest would be 225 T. Or we can be more specific, as we will soon want to be, and the direction that is 20° south of west would be 250 T.

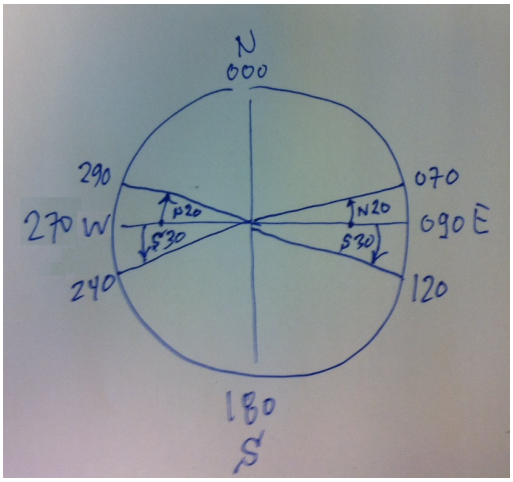
Now that the math is done, what do we need to know besides the date? We need to know our latitude and we need to know the local magnetic variation. You can get your latitude from Google Earth. Just find the location you care about and look to the bottom of the screen. Magnetic variation (often called declination on land) is the difference between True North and Magnetic North. You can get it from the National Geophysical Data Center (www.ngdc.noaa.gov). The variation will have a label, E or W. It is defined in such a way that true bearings = magnetic bearings + Var E (or – Var W). For our application, we will be going backwards, so:

Magnetic bearing = True bearing + Var W
or
Magnetic bearing = True bearing – Var E.

Now we are left to finding the true bearing of the sun at sunrise and sunset. A celestial navigator can compute this readily from the Nautical Almanac, but this takes tools we do not need. There is no one table that does this job specifically, but there is one we can use. It is called Table 22. Amplitudes of the Sun. It is from Bowditch's American Practical Navigator (1977 or earlier).

In this table, the word amplitude means the angular difference between the direction of sunrise and due east or the direction of sunset and due west. The motion of the sun is symmetric across the horizon, so these values are the same on a given day. If the sun rises 20° south of east, it will set 20° south of west. In this case the amplitude would be S 20°.

We do have to keep the mind engaged, however, because the arithmetic switches. This is apparent if you look at a compass rose—always a good idea at this stage. That is, 30° south of east means 090T + 30 = 120T, whereas 30° S of west means 270T – 30 = 240T.



Compass rose showing N20 and S30 amplitudes used to find directions of sunrise and sunset.

And we are now almost done. We are asking for a rather sophisticated result, so it should not be a surprise that we have a couple steps to take. Bear in mind as well that we are doing this with paper tables. If this were called for often enough, one could make an app for it!

To simplify its presentation, Table 22 does not use date, but rather uses the astronomically more significant parameter called the sun's declination. This is the same word as used on land for variation, but it is a totally different concept; it is the latitude directly below the sun at this day of the year. (You see now why mariners like to use magnetic variation rather than magnetic declination.) We are using sun's declination just as an index to access the tables.

Suppose we are at latitude 38N, on May 13, and the local magnetic variation is 10° W. What is the compass bearing of sunrise and sunset?

> Refer to Declination Table to learn that on May 13 the sun's declination is N 18° 14' (18.23°).
>
> Then turn to Table 22 for latitude 38 and see that the amplitude is about 23.5° (ie about half way between 23.1 and 23.7 — fractions of a degree do not matter here at all. You can round up or round down.)
>
> Then apply the label N or S to the amplitude that is the same as that of the declination. North in this case, so amplitude is N 23.5°.
>
> Then the true sunset direction would be located at 270 + 23.5 = 293.5T
>
> And the magnetic (compass) direction would since we have west variation:
>
> Compass of sunset = 293.5 + 10 = 303.5 M.

This method works with these tables included here alone and nothing more. My guess is these results will be right to within 1 or 2°, which is the best you can hope to measure the bearing. If you have a computer you can in principle get this data from various sources, but it is not quite as simple as one might guess. The main problem if you want accurate data (ie ±2°) is you have to get involved in time keeping, because on the computer approach you need to know the time of sunrise or sunset and the values you find in the newspapers will not be accurate, and the accurate ones you get from the links below will require you to adjust the times for your longitude… something we have not even mentioned here, etc.

If you care to pursue this, the place to start is www.starpath.com/usno. First navigate from that page to find the time of sunset for your location then come back to that page to get the precise true direction. You still have to apply the magnetic variation on your own, but you can get that very accurately from the link.

Anyone who might need such information as this at other times of day can contact starpath at helpdesk@starpath.com to arrange for specific solutions.

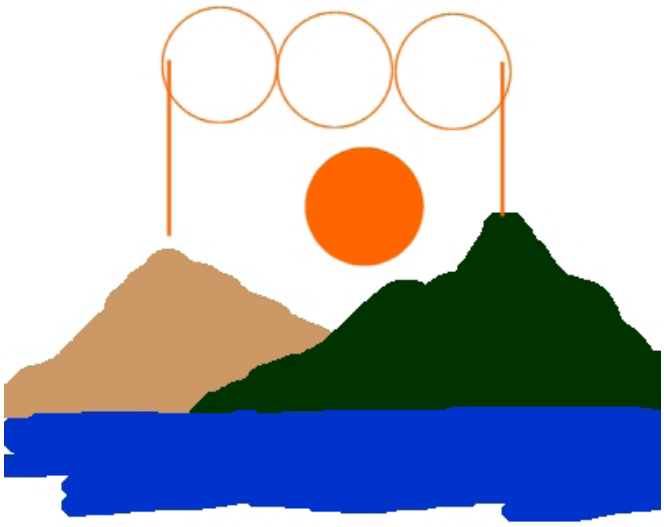
David Burch
Starpath School of Navigation
www.starpath.com
July 23, 2011

Hockey puck compass from Weems and Plath. See www.starpath.com/catalog/accessories/HP2.htm

Why accuracy matters

.... this is just a guess, since i am not a photographer.

Below is a picture of the horizon with a valley you want to catch the setting sun drop into. The question is -- with regard to bearing accuracies -- how far apart are the two peaks?



This is easily a picture one might imagine, and we have with it a perfect scale of the bearings, namely the width of the sun, which is 0.5°. Thus these two peaks are separated in bearing by about 1.5°. Clearly if you are trying to locate sunset locations to this precision you need to know where they are expected to be on the horizon and have a way to measure it.

TABLE 22
Amplitudes

Latitude	Declination													Latitude
	0°0	0°5	1°0	1°5	2°0	2°5	3°0	3°5	4°0	4°5	5°0	5°5	6°0	
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	0
10	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.6	4.1	4.6	5.1	5.6	6.1	10
15	0.0	0.5	1.0	1.6	2.1	2.6	3.1	3.6	4.1	4.7	5.2	5.7	6.2	15
20	0.0	0.5	1.1	1.6	2.1	2.7	3.2	3.7	4.3	4.8	5.3	5.9	6.4	20
25	0.0	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.5	6.1	6.6	25
30	0.0	0.6	1.2	1.7	2.3	2.9	3.5	4.0	4.6	5.2	5.8	6.4	6.9	30
32	0.0	0.6	1.2	1.8	2.4	2.9	3.5	4.1	4.7	5.3	5.9	6.5	7.1	32
34	0.0	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	34
36	0.0	0.6	1.2	1.9	2.5	3.1	3.7	4.3	4.9	5.6	6.2	6.8	7.4	36
38	0.0	0.6	1.3	1.9	2.5	3.2	3.8	4.4	5.1	5.7	6.4	7.0	7.6	38
40	0.0	0.7	1.3	2.0	2.6	3.3	3.9	4.6	5.2	5.9	6.5	7.2	7.8	40
42	0.0	0.7	1.3	2.0	2.7	3.4	4.0	4.7	5.4	6.1	6.7	7.4	8.1	42
44	0.0	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	44
46	0.0	0.7	1.4	2.2	2.9	3.6	4.3	5.0	5.8	6.5	7.2	7.9	8.7	46
48	0.0	0.7	1.5	2.2	3.0	3.7	4.5	5.2	6.0	6.7	7.5	8.2	9.0	48
50	0.0	0.8	1.6	2.3	3.1	3.9	4.7	5.4	6.2	7.0	7.8	8.6	9.4	50
51	0.0	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.8	9.6	51
52	0.0	0.8	1.6	2.4	3.2	4.1	4.9	5.7	6.5	7.3	8.1	9.0	9.8	52
53	0.0	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0	53
54	0.0	0.9	1.7	2.6	3.4	4.3	5.1	6.0	6.8	7.7	8.5	9.4	10.2	54
55	0.0	0.9	1.7	2.6	3.5	4.4	5.2	6.1	7.0	7.9	8.7	9.6	10.5	55
56	0.0	0.9	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.1	9.0	9.9	10.8	56
57	0.0	0.9	1.8	2.8	3.7	4.6	5.5	6.4	7.4	8.3	9.2	10.1	11.1	57
58	0.0	0.9	1.9	2.8	3.8	4.7	5.7	6.6	7.6	8.5	9.5	10.4	11.4	58
59	0.0	1.0	1.9	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7	10.7	11.7	59
60	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.1	12.1	60
61	0.0	1.0	2.1	3.1	4.1	5.2	6.2	7.2	8.3	9.3	10.3	11.4	12.5	61
62	0.0	1.1	2.1	3.2	4.3	5.3	6.4	7.5	8.5	9.6	10.7	11.8	12.9	62
63	0.0	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	10.0	11.1	12.2	13.3	63
64	0.0	1.1	2.3	3.4	4.6	5.7	6.9	8.0	9.2	10.3	11.5	12.6	13.8	64
65.0	0.0	1.2	2.4	3.6	4.7	5.9	7.1	8.3	9.5	10.7	11.9	13.1	14.3	65.0
65.5	0.0	1.2	2.4	3.6	4.8	6.0	7.3	8.5	9.7	10.9	12.1	13.4	14.6	65.5
66.0	0.0	1.2	2.5	3.7	4.9	6.2	7.4	8.6	9.9	11.1	12.4	13.6	14.9	66.0
66.5	0.0	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.1	11.3	12.6	13.9	15.2	66.5
67.0	0.0	1.3	2.6	3.8	5.1	6.4	7.7	9.0	10.3	11.6	12.9	14.2	15.5	67.0
67.5	0.0	1.3	2.6	3.9	5.2	6.5	7.9	9.2	10.5	11.8	13.2	14.5	15.9	67.5
68.0	0.0	1.3	2.7	4.0	5.3	6.7	8.0	9.4	10.7	12.1	13.5	14.8	16.2	68.0
68.5	0.0	1.4	2.7	4.1	5.5	6.8	8.2	9.6	11.0	12.4	13.8	15.2	16.6	68.5
69.0	0.0	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6	14.1	15.5	17.0	69.0
69.5	0.0	1.4	2.9	4.3	5.7	7.2	8.6	10.0	11.5	12.9	14.4	15.9	17.4	69.5
70.0	0.0	1.5	2.9	4.4	5.9	7.3	8.8	10.3	11.8	13.3	14.8	16.3	17.8	70.0
70.5	0.0	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.1	13.6	15.1	16.7	18.2	70.5
71.0	0.0	1.5	3.1	4.6	6.2	7.7	9.3	10.8	12.4	13.9	15.5	17.1	18.7	71.0
71.5	0.0	1.6	3.2	4.7	6.3	7.9	9.5	11.1	12.7	14.3	15.9	17.6	19.2	71.5
72.0	0.0	1.6	3.2	4.9	6.5	8.1	9.8	11.4	13.0	14.7	16.4	18.1	19.8	72.0
72.5	0.0	1.7	3.3	5.0	6.7	8.3	10.0	11.7	13.4	15.1	16.8	18.6	20.3	72.5
73.0	0.0	1.7	3.4	5.1	6.9	8.6	10.3	12.1	13.8	15.6	17.3	19.1	20.9	73.0
73.5	0.0	1.8	3.5	5.3	7.1	8.8	10.6	12.4	14.2	16.0	17.9	19.7	21.6	73.5
74.0	0.0	1.8	3.6	5.4	7.3	9.1	10.9	12.8	14.7	16.5	18.4	20.3	22.3	74.0
74.5	0.0	1.9	3.7	5.6	7.5	9.4	11.3	13.2	15.1	17.1	19.0	21.0	23.0	74.5
75.0	0.0	1.9	3.9	5.8	7.7	9.7	11.7	13.6	15.6	17.6	19.7	21.7	23.8	75.0
75.5	0.0	2.0	4.0	6.0	8.0	10.0	12.1	14.1	16.2	18.3	20.4	22.5	24.7	75.5
76.0	0.0	2.1	4.1	6.2	8.3	10.4	12.5	14.6	16.8	18.9	21.1	23.3	25.6	76.0
76.5	0.0	2.1	4.3	6.4	8.6	10.8	13.0	15.2	17.4	19.6	21.9	24.2	26.6	76.5
77.0	0.0	2.2	4.4	6.7	8.9	11.2	13.5	15.7	18.1	20.4	22.8	25.2	27.7	77.0

TABLE 22
Amplitudes

Latitude	Declination													Latitude
	6°0	6°5	7°0	7°5	8°0	8°5	9°0	9°5	10°0	10°5	11°0	11°5	12°0	
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	0
10	6.1	6.6	7.1	7.6	8.1	8.6	9.1	9.6	10.2	10.7	11.2	11.7	12.2	10
15	6.2	6.7	7.2	7.8	8.3	8.8	9.3	9.8	10.4	10.9	11.4	11.9	12.4	15
20	6.4	6.9	7.5	8.0	8.5	9.0	9.6	10.1	10.6	11.2	11.7	12.2	12.8	20
25	6.6	7.2	7.7	8.3	8.8	9.4	9.9	10.5	11.0	11.6	12.2	12.7	13.3	25
30	6.9	7.5	8.1	8.7	9.2	9.8	10.4	11.0	11.6	12.1	12.7	13.3	13.9	30
32	7.1	7.7	8.3	8.9	9.4	10.0	10.6	11.2	11.8	12.4	13.0	13.6	14.2	32
34	7.2	7.8	8.5	9.1	9.7	10.3	10.9	11.5	12.1	12.7	13.3	13.9	14.5	34
36	7.4	8.0	8.7	9.3	9.9	10.5	11.1	11.8	12.4	13.0	13.6	14.3	14.9	36
38	7.6	8.3	8.9	9.5	10.2	10.8	11.5	12.1	12.7	13.4	14.0	14.7	15.3	38
40	7.8	8.5	9.2	9.8	10.5	11.1	11.8	12.4	13.1	13.8	14.4	15.1	15.7	40
42	8.1	8.8	9.4	10.1	10.8	11.5	12.1	12.8	13.5	14.2	14.9	15.6	16.2	42
44	8.4	9.1	9.8	10.5	11.2	11.9	12.6	13.3	14.0	14.7	15.4	16.1	16.8	44
46	8.7	9.4	10.1	10.8	11.6	12.3	13.0	13.7	14.5	15.2	15.9	16.7	17.4	46
48	9.0	9.7	10.5	11.2	12.0	12.8	13.5	14.3	15.0	15.8	16.6	17.3	18.1	48
50	9.4	10.1	10.9	11.7	12.5	13.3	14.1	14.9	15.7	16.5	17.3	18.1	18.9	50
51	9.6	10.4	11.2	12.0	12.8	13.6	14.4	15.2	16.0	16.8	17.7	18.5	19.3	51
52	9.8	10.6	11.4	12.2	13.1	13.9	14.7	15.6	16.4	17.2	18.1	18.9	19.7	52
53	10.0	10.8	11.7	12.5	13.4	14.2	15.1	15.9	16.8	17.6	18.5	19.3	20.2	53
54	10.2	11.1	12.0	12.8	13.7	14.6	15.4	16.3	17.2	18.1	18.9	19.8	20.7	54
55	10.5	11.4	12.3	13.2	14.0	14.9	15.8	16.7	17.6	18.5	19.4	20.3	21.3	55
56	10.8	11.7	12.6	13.5	14.4	15.3	16.2	17.2	18.1	19.0	20.0	20.9	21.8	56
57	11.1	12.0	12.9	13.9	14.8	15.7	16.7	17.6	18.6	19.6	20.5	21.5	22.4	57
58	11.4	12.3	13.3	14.3	15.2	16.2	17.2	18.1	19.1	20.1	21.1	22.1	23.1	58
59	11.7	12.7	13.7	14.7	15.7	16.7	17.7	18.7	19.7	20.7	21.7	22.8	23.8	59
60	12.1	13.1	14.1	15.1	16.2	17.2	18.2	19.3	20.3	21.4	22.4	23.5	24.6	60
61	12.5	13.5	14.6	15.6	16.7	17.8	18.8	19.9	21.0	22.1	23.2	24.3	25.4	61
62	12.9	14.0	15.0	16.1	17.2	18.4	19.5	20.6	21.7	22.8	24.0	25.1	26.3	62
63	13.3	14.4	15.6	16.7	17.9	19.0	20.2	21.3	22.5	23.7	24.9	26.0	27.3	63
64	13.8	15.0	16.2	17.3	18.5	19.7	20.9	22.1	23.3	24.6	25.8	27.1	28.3	64
65.0	14.3	15.5	16.8	18.0	19.2	20.5	21.7	23.0	24.3	25.5	26.8	28.1	29.5	65.0
65.5	14.6	15.8	17.1	18.3	19.6	20.9	22.2	23.5	24.8	26.1	27.4	28.7	30.1	65.5
66.0	14.9	16.2	17.4	18.7	20.0	21.3	22.6	23.9	25.3	26.6	28.0	29.4	30.7	66.0
66.5	15.2	16.5	17.8	19.1	20.4	21.8	23.1	24.5	25.8	27.2	28.6	30.0	31.4	66.5
67.0	15.5	16.8	18.2	19.5	20.9	22.2	23.6	25.0	26.4	27.8	29.2	30.7	32.1	67.0
67.5	15.9	17.2	18.6	19.9	21.3	22.7	24.1	25.5	27.0	28.4	29.9	31.4	32.9	67.5
68.0	16.2	17.6	19.0	20.4	21.8	23.2	24.7	26.1	27.6	29.1	30.6	32.2	33.7	68.0
68.5	16.6	18.0	19.4	20.9	22.3	23.8	25.3	26.8	28.3	29.8	31.4	33.0	34.6	68.5
69.0	17.0	18.4	19.9	21.4	22.9	24.4	25.9	27.4	29.0	30.6	32.2	33.8	35.5	69.0
69.5	17.4	18.9	20.4	21.9	23.4	25.0	26.5	28.1	29.7	31.4	33.0	34.7	36.4	69.5
70.0	17.8	19.3	20.9	22.4	24.0	25.6	27.2	28.9	30.5	32.2	33.9	35.7	37.4	70.0
70.5	18.2	19.8	21.4	23.0	24.6	26.3	27.9	29.6	31.3	33.1	34.9	36.7	38.5	70.5
71.0	18.7	20.3	22.0	23.6	25.3	27.0	28.7	30.5	32.2	34.0	35.9	37.8	39.7	71.0
71.5	19.2	20.9	22.6	24.3	26.0	27.8	29.5	31.3	33.2	35.1	37.0	38.9	40.9	71.5
72.0	19.8	21.5	23.2	25.0	26.8	28.6	30.4	32.3	34.2	36.1	38.1	40.2	42.3	72.0
72.5	20.3	22.1	23.9	25.7	27.6	29.4	31.3	33.3	35.3	37.3	39.4	41.5	43.7	72.5
73.0	20.9	22.8	24.6	26.5	28.4	30.4	32.3	34.4	36.4	38.6	40.7	43.0	45.3	73.0
73.5	21.6	23.5	25.4	27.4	29.3	31.4	33.4	35.5	37.7	39.9	42.2	44.6	47.1	73.5
74.0	22.3	24.2	26.2	28.3	30.3	32.4	34.6	36.8	39.0	41.4	43.8	46.3	49.0	74.0
74.5	23.0	25.1	27.1	29.3	31.4	33.6	35.8	38.1	40.5	43.0	45.6	48.2	51.1	74.5
75.0	23.8	25.9	28.1	30.3	32.5	34.8	37.2	39.6	42.1	44.8	47.5	50.4	53.4	75.0
75.5	24.7	26.9	29.1	31.4	33.8	36.2	38.7	41.2	43.9	46.7	49.6	52.8	56.1	75.5
76.0	25.6	27.9	30.2	32.7	35.1	37.7	40.3	43.0	45.9	48.9	52.1	55.5	59.3	76.0
76.5	26.6	29.0	31.5	34.0	36.6	39.3	42.1	45.0	48.1	51.3	54.8	58.7	63.0	76.5
77.0	27.7	30.2	32.8	35.5	38.2	41.1	44.1	47.2	50.5	54.1	58.0	62.4	67.6	77.0

TABLE 22
Amplitudes

Latitude	Declination 12°0	12°5	13°0	13°5	14°0	14°5	15°0	15°5	16°0	16°5	17°0	17°5	18°0	Latitude
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	0
10	12.2	12.7	13.2	13.7	14.2	14.7	15.2	15.7	16.3	16.8	17.3	17.8	18.3	10
15	12.4	12.9	13.5	14.0	14.5	15.0	15.5	16.1	16.6	17.1	17.6	18.1	18.7	15
20	12.8	13.3	13.9	14.4	14.9	15.5	16.0	16.5	17.1	17.6	18.1	18.7	19.2	20
25	13.3	13.8	14.4	14.9	15.5	16.0	16.6	17.1	17.7	18.3	18.8	19.4	19.9	25
30	13.9	14.5	15.1	15.6	16.2	16.8	17.4	18.0	18.6	19.1	19.7	20.3	20.9	30
32	14.2	14.8	15.4	16.0	16.6	17.2	17.8	18.4	19.0	19.6	20.2	20.8	21.4	32
34	14.5	15.1	15.7	16.4	17.0	17.6	18.2	18.8	19.4	20.0	20.7	21.3	21.9	34
36	14.9	15.5	16.1	16.8	17.4	18.0	18.7	19.3	19.9	20.6	21.2	21.8	22.5	36
38	15.3	15.9	16.6	17.2	17.9	18.5	19.2	19.8	20.5	21.1	21.8	22.4	23.1	38
40	15.7	16.4	17.1	17.7	18.4	19.1	19.7	20.4	21.1	21.8	22.4	23.1	23.8	40
41	16.0	16.7	17.3	18.0	18.7	19.4	20.1	20.8	21.4	22.1	22.8	23.5	24.2	41
42	16.2	16.9	17.6	18.3	19.0	19.7	20.4	21.1	21.8	22.5	23.2	23.9	24.6	42
43	16.5	17.2	17.9	18.6	19.3	20.0	20.7	21.4	22.1	22.9	23.6	24.3	25.0	43
44	16.8	17.5	18.2	18.9	19.7	20.4	21.1	21.8	22.5	23.3	24.0	24.7	25.4	44
45	17.1	17.8	18.5	19.3	20.0	20.7	21.5	22.2	22.9	23.7	24.4	25.2	25.9	45
46	17.4	18.2	18.9	19.6	20.4	21.1	21.9	22.6	23.4	24.1	24.9	25.7	26.4	46
47	17.7	18.5	19.3	20.0	20.8	21.5	22.3	23.1	23.8	24.6	25.4	26.2	26.9	47
48	18.1	18.9	19.6	20.4	21.2	22.0	22.8	23.5	24.3	25.1	25.9	26.7	27.5	48
49	18.5	19.3	20.1	20.8	21.6	22.4	23.2	24.0	24.8	25.7	26.5	27.3	28.1	49
50	18.9	19.7	20.5	21.3	22.1	22.9	23.7	24.6	25.4	26.2	27.1	27.9	28.7	50
51	19.3	20.1	20.9	21.8	22.6	23.4	24.3	25.1	26.0	26.8	27.7	28.5	29.4	51
52	19.7	20.6	21.4	22.3	23.1	24.0	24.9	25.7	26.6	27.5	28.3	29.2	30.1	52
53	20.2	21.1	21.9	22.8	23.7	24.6	25.5	26.4	27.3	28.2	29.1	30.0	30.9	53
54	20.7	21.6	22.5	23.4	24.3	25.2	26.1	27.0	28.0	28.9	29.8	30.8	31.7	54
55	21.3	22.2	23.1	24.0	24.9	25.9	26.8	27.8	28.7	29.7	30.6	31.6	32.6	55
56	21.8	22.8	23.7	24.7	25.6	26.6	27.6	28.5	29.5	30.5	31.5	32.5	33.5	56
57	22.4	23.4	24.4	25.4	26.4	27.4	28.4	29.4	30.4	31.4	32.5	33.5	34.6	57
58	23.1	24.1	25.1	26.1	27.2	28.2	29.2	30.3	31.3	32.4	33.5	34.6	35.7	58
59	23.8	24.8	25.9	27.0	28.0	29.1	30.2	31.3	32.4	33.5	34.6	35.7	36.9	59
60	24.6	25.7	26.7	27.8	28.9	30.1	31.2	32.3	33.5	34.6	35.8	37.0	38.2	60
61	25.4	26.5	27.6	28.8	29.9	31.1	32.3	33.5	34.6	35.9	37.1	38.3	39.6	61
62	26.3	27.5	28.6	29.8	31.0	32.2	33.5	34.7	36.0	37.2	38.5	39.8	41.2	62
63	27.3	28.5	29.7	30.9	32.2	33.5	34.8	36.1	37.4	38.7	40.1	41.5	42.9	63
64	28.3	29.6	30.9	32.2	33.5	34.8	36.2	37.6	39.0	40.4	41.8	43.3	44.8	64
65.0	29.5	30.8	32.2	33.5	34.9	36.3	37.8	39.2	40.7	42.2	43.8	45.4	47.0	65.0
65.5	30.1	31.5	32.9	34.3	35.7	37.1	38.6	40.1	41.7	43.2	44.8	46.5	48.2	65.5
66.0	30.7	32.1	33.6	35.0	36.5	38.0	39.5	41.1	42.7	44.3	46.0	47.7	49.4	66.0
66.5	31.4	32.9	34.3	35.8	37.3	38.9	40.5	42.1	43.7	45.4	47.2	48.9	50.8	66.5
67.0	32.1	33.6	35.1	36.7	38.3	39.9	41.5	43.2	44.9	46.6	48.4	50.3	52.3	67.0
67.5	32.9	34.4	36.0	37.6	39.2	40.9	42.6	44.3	46.1	47.9	49.8	51.8	53.9	67.5
68.0	33.7	35.3	36.9	38.6	40.2	41.9	43.7	45.5	47.4	49.3	51.3	53.4	55.6	68.0
68.5	34.6	36.2	37.9	39.6	41.3	43.1	44.9	46.8	48.8	50.8	52.9	55.1	57.5	68.5
69.0	35.5	37.2	38.9	40.6	42.5	44.3	46.2	48.2	50.3	52.4	54.7	57.0	59.6	69.0
69.5	36.4	38.2	40.0	41.8	43.7	45.6	47.7	49.7	51.9	54.2	56.6	59.2	61.9	69.5
70.0	37.4	39.3	41.1	43.0	45.0	47.1	49.2	51.4	53.7	56.1	58.7	61.5	64.6	70.0
70.5	38.5	40.4	42.4	44.4	46.4	48.6	50.8	53.2	55.7	58.3	61.1	64.3	67.8	70.5
71.0	39.7	41.7	43.7	45.8	48.0	50.3	52.7	55.2	57.8	60.7	63.9	67.5	71.7	71.0
71.5	40.9	43.0	45.1	47.4	49.7	52.1	54.7	57.4	60.3	63.5	67.1	71.4	76.9	71.5
72.0	42.3	44.5	46.7	49.1	51.5	54.1	56.9	59.9	63.1	66.8	71.1	76.7	90.0	72.0
72.5	43.7	46.0	48.4	50.9	53.6	56.4	59.4	62.7	66.4	70.8	76.5	90.0		72.5
73.0	45.3	47.8	50.3	53.0	55.8	58.9	62.3	66.1	70.5	76.3	90.0			73.0
73.5	47.1	49.6	52.4	55.3	58.4	61.8	65.7	70.2	76.0	90.0				73.5
74.0	49.0	51.7	54.7	57.9	61.4	65.3	69.9	75.8	90.0					74.0
74.5	51.1	54.1	57.3	60.9	64.9	69.5	75.6	90.0						74.5

TABLE 22
Amplitudes

Latitude	Declination 18°0	18°5	19°0	19°5	20°0	20°5	21°0	21°5	22°0	22°5	23°0	23°5	24°0	Latitude
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	0
10	18.3	18.8	19.3	19.8	20.3	20.8	21.3	21.8	22.4	22.9	23.4	23.9	24.4	10
15	18.7	19.2	19.7	20.2	20.7	21.3	21.8	22.3	22.8	23.3	23.9	24.4	24.9	15
20	19.2	19.7	20.3	20.8	21.3	21.9	22.4	23.0	23.5	24.0	24.6	25.1	25.6	20
25	19.9	20.5	21.1	21.6	22.2	22.7	23.3	23.9	24.4	25.0	25.5	26.1	26.7	25
30	20.9	21.5	22.1	22.7	23.3	23.9	24.4	25.0	25.6	26.2	26.8	27.4	28.0	30
32	21.4	22.0	22.6	23.2	23.8	24.4	25.0	25.6	26.2	26.8	27.4	28.0	28.7	32
34	21.9	22.5	23.1	23.7	24.4	25.0	25.6	26.2	26.9	27.5	28.1	28.7	29.4	34
36	22.5	23.1	23.7	24.4	25.0	25.7	26.3	26.9	27.6	28.2	28.9	29.5	30.2	36
38	23.1	23.7	24.4	25.1	25.7	26.4	27.1	27.7	28.4	29.1	29.7	30.4	31.1	38
40	23.8	24.5	25.2	25.8	26.5	27.2	27.9	28.6	29.3	30.0	30.7	31.4	32.1	40
41	24.2	24.9	25.6	26.3	26.9	27.6	28.3	29.1	29.8	30.5	31.2	31.9	32.6	41
42	24.6	25.3	26.0	26.7	27.4	28.1	28.8	29.5	30.3	31.0	31.7	32.5	33.2	42
43	25.0	25.7	26.4	27.2	27.9	28.6	29.3	30.1	30.8	31.6	32.3	33.0	33.8	43
44	25.4	26.2	26.9	27.6	28.4	29.1	29.9	30.6	31.4	32.1	32.9	33.7	34.4	44
45	25.9	26.7	27.4	28.2	28.9	29.7	30.5	31.2	32.0	32.8	33.5	34.3	35.1	45
46	26.4	27.2	27.9	28.7	29.5	30.3	31.1	31.8	32.6	33.4	34.2	35.0	35.8	46
47	26.9	27.7	28.5	29.3	30.1	30.9	31.7	32.5	33.3	34.1	35.0	35.8	36.6	47
48	27.5	28.3	29.1	29.9	30.7	31.6	32.4	33.2	34.0	34.9	35.7	36.6	37.4	48
49	28.1	28.9	29.8	30.6	31.4	32.3	33.1	34.0	34.8	35.7	36.6	37.4	38.3	49
50	28.7	29.6	30.4	31.3	32.1	33.0	33.9	34.8	35.6	36.5	37.4	38.3	39.3	50
51	29.4	30.3	31.2	32.0	32.9	33.8	34.7	35.6	36.5	37.5	38.4	39.3	40.3	51
52	30.1	31.0	31.9	32.8	33.7	34.7	35.6	36.5	37.5	38.4	39.4	40.4	41.3	52
53	30.9	31.8	32.8	33.7	34.6	35.6	36.5	37.5	38.5	39.5	40.5	41.5	42.5	53
54	31.7	32.7	33.6	34.6	35.6	36.6	37.6	38.6	39.6	40.6	41.7	42.7	43.8	54
55	32.6	33.6	34.6	35.6	36.6	37.6	38.7	39.7	40.8	41.9	42.9	44.0	45.2	55
56	33.5	34.6	35.6	36.7	37.7	38.8	39.9	41.0	42.1	43.2	44.3	45.5	46.7	56
57	34.6	35.6	36.7	37.8	38.9	40.0	41.1	42.3	43.5	44.6	45.8	47.1	48.3	57
58	35.7	36.8	37.9	39.1	40.2	41.4	42.6	43.8	45.0	46.2	47.5	48.8	50.1	58
59	36.9	38.0	39.2	40.4	41.6	42.8	44.1	45.4	46.7	48.0	49.3	50.7	52.2	59
60.0	38.2	39.4	40.6	41.9	43.2	44.5	45.8	47.1	48.5	49.9	51.4	52.9	54.4	60.0
60.5	38.9	40.1	41.4	42.7	44.0	45.3	46.7	48.1	49.5	51.0	52.5	54.1	55.7	60.5
61.0	39.6	40.9	42.2	43.5	44.9	46.3	47.7	49.1	50.6	52.1	53.7	55.3	57.0	61.0
61.5	40.4	41.7	43.0	44.4	45.8	47.2	48.7	50.2	51.7	53.3	55.0	56.7	58.5	61.5
62.0	41.2	42.5	43.9	45.3	46.8	48.2	49.8	51.3	52.9	54.6	56.3	58.1	60.0	62.0
62.5	42.0	43.4	44.8	46.3	47.8	49.3	50.9	52.5	54.2	56.0	57.8	59.7	61.7	62.5
63.0	42.9	44.3	45.8	47.3	48.9	50.5	52.1	53.8	55.6	57.5	59.4	61.4	63.6	63.0
63.5	43.8	45.3	46.9	48.4	50.0	51.7	53.4	55.2	57.1	59.1	61.1	63.4	65.7	63.5
64.0	44.8	46.4	48.0	49.6	51.3	53.0	54.8	56.7	58.7	60.8	63.0	65.5	68.1	64.0
64.5	45.9	47.5	49.1	50.8	52.6	54.4	56.3	58.4	60.5	62.7	65.2	67.9	70.9	64.5
65.0	47.0	48.7	50.4	52.2	54.0	56.0	58.0	60.1	62.4	64.9	67.6	70.7	74.2	65.0
65.5	48.2	49.9	51.7	53.6	55.6	57.6	59.8	62.1	64.6	67.3	70.4	74.1	78.8	65.5
66.0	49.4	51.3	53.2	55.2	57.2	59.4	61.8	64.3	67.1	70.2	73.9	78.6	90.0	66.0
66.5	50.8	52.7	54.7	56.8	59.1	61.4	64.0	66.8	70.0	73.7	78.5	90.0		66.5
67.0	52.3	54.3	56.4	58.7	61.1	63.7	66.5	69.7	73.5	78.4	90.0			67.0
67.5	53.9	56.0	58.3	60.7	63.3	66.2	69.5	73.3	78.2	90.0				67.5
68.0	55.6	57.9	60.4	63.0	65.9	69.2	73.1	78.1	90.0					68.0
68.5	57.5	60.0	62.7	65.6	68.9	72.9	77.9	90.0						68.5
69.0	59.6	62.3	65.3	68.7	72.6	77.7	90.0							69.0
69.5	61.9	65.0	68.4	72.4	77.6	90.0								69.5
70.0	64.6	68.1	72.2	77.4	90.0									70.0
70.5	67.8	71.9	77.2	90.0										70.5
71.0	71.7	77.1	90.0											71.0
71.5	76.9	90.0												71.5
72.0	90.0													72.0

Table of the Sun's Declination

Mean Value for the Four Years of a Leap Year Cycle

Day	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	S23° 04'	S17° 20'	S7° 49'	N4° 18'	N14° 54'	N21° 58'	N23° 09'	N18° 10'	N8° 30'	S2° 57'	S14° 14'	S21° 43'
2	S22° 59'	S17° 03'	S7° 26'	N4° 42'	N15° 12'	N22° 06'	N23° 05'	N17° 55'	N8° 09'	S3° 20'	S14° 34'	S21° 52'
3	S22° 54'	S16° 46'	S7° 03'	N5° 05'	N15° 30'	N22° 14'	N23° 01'	N17° 40'	N7° 47'	S3° 44'	S14° 53'	S22° 01'
4	S22° 48'	S16° 28'	S6° 40'	N5° 28'	N15° 47'	N22° 22'	N22° 56'	N17° 24'	N7° 25'	S4° 07'	S15° 11'	S22° 10'
5	S22° 42'	S16° 10'	S6° 17'	N5° 51'	N16° 05'	N22° 29'	N22° 51'	N17° 08'	N7° 03'	S4° 30'	S15° 30'	S22° 18'
6	S22° 36'	S15° 52'	S5° 54'	N6° 13'	N16° 22'	N22° 35'	N22° 45'	N16° 52'	N6° 40'	S4° 53'	S15° 48'	S22° 25'
7	S22° 28'	S15° 34'	S5° 30'	N6° 36'	N16° 39'	N22° 42'	N22° 39'	N16° 36'	N6° 18'	S5° 16'	S16° 06'	S22° 32'
8	S22° 21'	S15° 15'	S5° 07'	N6° 59'	N16° 55'	N22° 47'	N22° 33'	N16° 19'	N5° 56'	S5° 39'	S16° 24'	S22° 39'
9	S22° 13'	S14° 56'	S4° 44'	N7° 21'	N17° 12'	N22° 53'	N22° 26'	N16° 02'	N5° 33'	S6° 02'	S16° 41'	S22° 46'
10	S22° 05'	S14° 37'	S4° 20'	N7° 43'	N17° 27'	N22° 58'	N22° 19'	N15° 45'	N5° 10'	S6° 25'	S16° 58'	S22° 52'
11	S21° 56'	S14° 18'	S3° 57'	N8° 07'	N17° 43'	N23° 02'	N22° 11'	N15° 27'	N4° 48'	S6° 48'	S17° 15'	S22° 57'
12	S21° 47'	S13° 58'	S3° 33'	N8° 28'	N17° 59'	N23° 07'	N22° 04'	N15° 10'	N4° 25'	S7° 10'	S17° 32'	S23° 02'
13	S21° 37'	S13° 38'	S3° 10'	N8° 50'	N18° 14'	N23° 11'	N21° 55'	N14° 52'	N4° 02'	S7° 32'	S17° 48'	S23° 07'
14	S21° 27'	S13° 18'	S2° 46'	N9° 11'	N18° 29'	N23° 14'	N21° 46'	N14° 33'	N3° 39'	S7° 55'	S18° 04'	S23° 11'
15	S21° 16'	S12° 58'	S2° 22'	N9° 33'	N18° 43'	N23° 17'	N21° 37'	N14° 15'	N3° 16'	S8° 18'	S18° 20'	S23° 14'
16	S21° 06'	S12° 37'	S1° 59'	N9° 54'	N18° 58'	N23° 20'	N21° 28'	N13° 56'	N2° 53'	S8° 40'	S18° 35'	S23° 17'
17	S20° 54'	S12° 16'	S1° 35'	N10° 16'	N19° 11'	N23° 22'	N21° 18'	N13° 37'	N2° 30'	S9° 02'	S18° 50'	S23° 20'
18	S20° 42'	S11° 55'	S1° 11'	N10° 37'	N19° 25'	N23° 24'	N21° 08'	N13° 18'	N2° 06'	S9° 24'	S19° 05'	S23° 22'
19	S20° 30'	S11° 34'	S0° 48'	N10° 58'	N19° 38'	N23° 25'	N20° 58'	N12° 59'	N1° 43'	S9° 45'	S19° 19'	S23° 24'
20	S20° 18'	S11° 13'	S0° 24'	N11° 19'	N19° 51'	**N23° 26'**	N20° 47'	N12° 39'	N1° 20'	S10° 07'	S19° 33'	S23° 25'
21	S20° 05'	S10° 52'	**0° 00'**	N11° 39'	N20° 04'	**N23° 26'**	N20° 36'	N12° 19'	N0° 57'	S10° 29'	S19° 47'	**S23° 26'**
22	S19° 52'	S10° 30'	N0° 24'	N12° 00'	N20° 16'	**N23° 26'**	N20° 24'	N11° 59'	N0° 33'	S10° 50'	S20° 00'	**S23° 26'**
23	S19° 38'	S10° 08'	N0° 47'	N12° 20'	N20° 28'	**N23° 26'**	N20° 12'	N11° 39'	**N0° 10'**	S11° 12'	S20° 13'	**S23° 26'**
24	S19° 24'	S9° 46'	N1° 11'	N12° 40'	N20° 39'	N23° 25'	N20° 00'	N11° 19'	S0° 14'	S11° 33'	S20° 26'	**S23° 26'**
25	S19° 10'	S9° 24'	N1° 35'	N13° 00'	N20° 50'	N23° 24'	N19° 47'	N10° 58'	S0° 37'	S11° 54'	S20° 38'	S23° 25'
26	S18° 55'	S9° 02'	N1° 58'	N13° 19'	N21° 01'	N23° 23'	N19° 34'	N10° 38'	S1° 00'	S12° 14'	S20° 50'	S23° 23'
27	S18° 40'	S8° 39'	N2° 22'	N13° 38'	N21° 12'	N23° 21'	N19° 21'	N10° 17'	S1° 24'	S12° 35'	S21° 01'	S23° 21'
28	S18° 25'	S8° 17'	N2° 45'	N13° 58'	N21° 22'	N23° 19'	N19° 08'	N9° 56'	S1° 47'	S12° 55'	S21° 12'	S23° 19'
29	S18° 09'	S8° 03'	N3° 09'	N14° 16'	N21° 31'	N23° 16'	N18° 54'	N9° 35'	S2° 10'	S13° 15'	S21° 23'	S23° 16'
30	S17° 53'		N3° 32'	N14° 35'	N21° 41'	N23° 13'	N18° 40'	N9° 13'	S2° 34'	S13° 35'	S21° 33'	S23° 12'
31	S17° 37'		N3° 55'		N21° 50'		N18° 25'	N8° 52'		S13° 55'		S23° 08'