

# 12.215 Modern Navigation

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# Review of last Class

- Motion of the Earth and Sun
  - Geometry of Earth/Sun system
  - Astronomical coordinates
  - Motion of the Earth around the sun
  - Equation of Time
- Astronomical positioning
  - Latitude and Longitude determination using astronomical bodies
- Error contributions to latitude and longitude measurements.

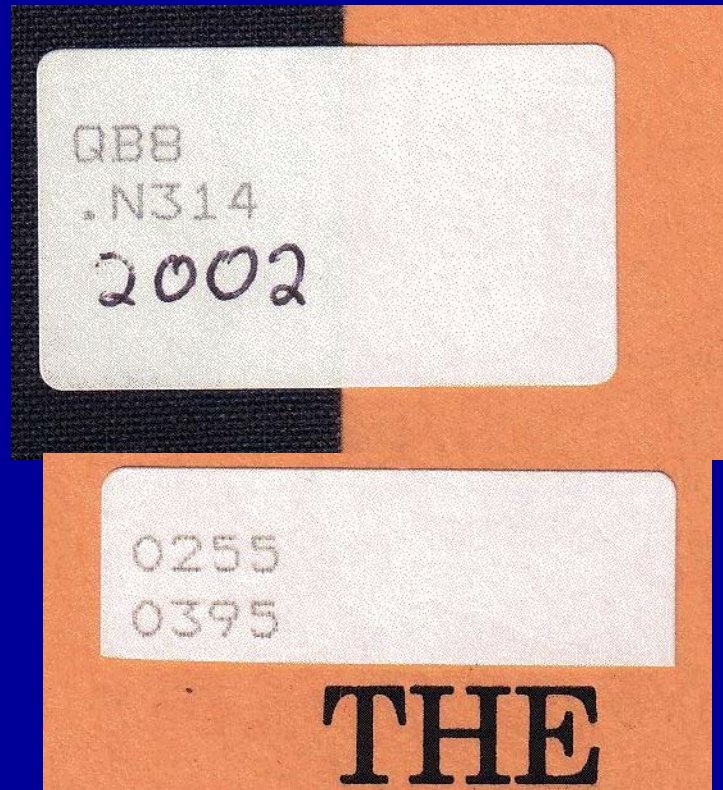
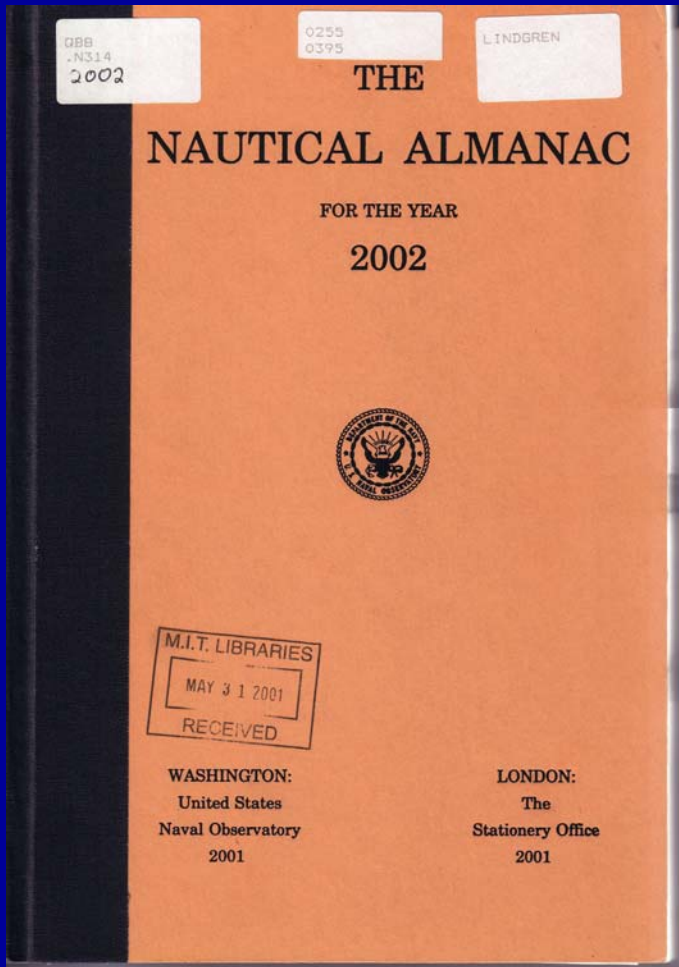
# Today's Class

- Almanacs: Paper and electronics
  - Paper Almanacs: Nautical Almanac
  - Electronic: Available on many web sites

# Nautical Almanac

- Probably most common for ship navigation in US. Published by the US Naval Observatory and Her Majesty's Nautical Almanac Office.
- Contains all the necessary information for celestial navigation
- New volume published each year and contains information from Jan 1 to Dec 31 of that year
- Largest part of book gives the RA and Declinations of Sun, Moon, Aries, Venus, Mars, Jupiter and Saturn every hour of every day

# Cover of Nautical Almanac



Call Numbers

# Sun and Moon Tables

2002 OCTOBER 1, 2,

UT	SUN			MOON				
	GHA	Dec		GHA	$v$	Dec	$d$	HP
<b>1</b> 00	182 32.1	S 3 02.0		253 48.4	6.8	N24 48.9	3.7	57.7
01	197 32.3	03.0		268 14.2	6.8	24 45.2	3.9	57.7
02	212 32.5	03.9		282 40.0	6.8	24 41.3	4.0	57.8
03	227 32.7	04.9		297 05.8	6.7	24 37.3	4.1	57.8
04	242 32.9	05.9		311 31.5	6.8	24 33.2	4.3	57.8
05	257 33.1	06.8		325 57.3	6.7	24 28.9	4.5	57.9
06	272 33.3	S 3 07.8		340 23.0	6.8	N24 24.4	4.6	57.9
07	287 33.5	08.8		354 48.8	6.7	24 19.8	4.8	58.0
<b>T</b> 08	302 33.7	09.7		9 14.5	6.7	24 15.0	4.9	58.0
09	317 33.9	10.7		23 40.2	6.7	24 10.1	5.1	58.0
10	332 34.1	11.7		38 05.9	6.7	24 05.0	5.3	58.1
11	347 34.3	12.7		52 31.6	6.8	23 59.7	5.4	58.1
12	2 34.5	S 3 13.6		66 57.4	6.7	N23 54.3	5.5	58.1
13	17 34.7	14.6		81 23.1	6.7	23 48.8	5.7	58.2
14	32 34.9	15.6		95 48.8	6.7	23 43.1	5.9	58.2
15	47 35.1	16.5		110 14.5	6.7	23 37.2	6.0	58.3
16	62 35.3	17.5		124 40.2	6.7	23 31.2	6.1	58.3
17	77 35.5	18.5		139 05.9	6.8	23 25.1	6.3	58.3
18	92 35.7	S 3 19.4		153 31.7	6.7	N23 18.8	6.5	58.4
19	107 35.9	20.4		167 57.4	6.7	23 12.3	6.6	58.4
20	122 36.1	21.4		182 23.1	6.8	23 05.7	6.8	58.5
21	137 36.3	22.3		196 48.9	6.8	22 58.9	6.9	58.5
22	152 36.5	23.3		211 14.7	6.7	22 52.0	7.1	58.5
23	167 36.7	24.3		225 40.4	6.8	22 44.9	7.2	58.6

## Entries in Table

GHA - Greenwich Hour Angle

Dec - Declination

$v$  - Rate of change of GHA ('/hr)

$d$  - Rate of change of declination ('/hr)

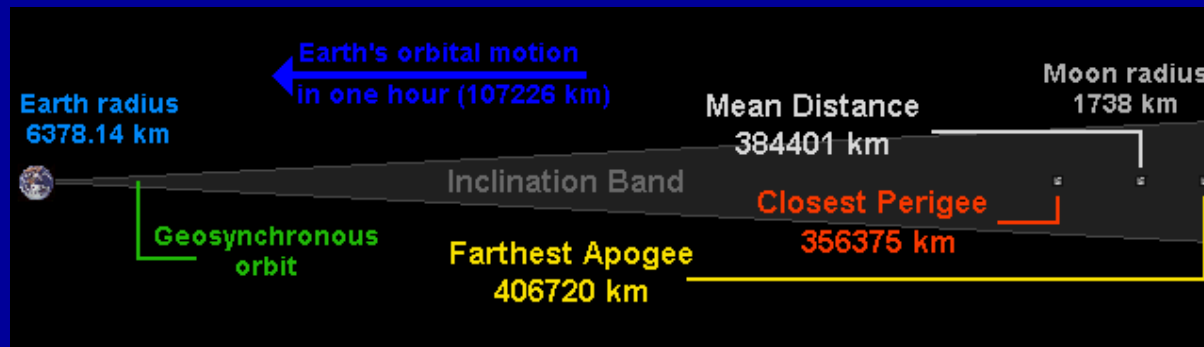
HP - Horizontal parallax

# Explanation

- Greenwich Hour Angle is the angle between a body and the Greenwich meridian measured positive west (note sign convention difference).
- The Greenwich Hour Angle of the Sun is always near 0 at 12:00UT (difference is equation of time).
- The GHA of the first point of Aries is the negative of Greenwich sidereal time.
- $v$  and  $d$  are computed simply by differencing values and make hand calculations easier

# Horizontal Parallax of Moon


- Tables are given to the center of a body from the center of the Earth. The moon is close enough that the finite sizes of the Earth and Moon affect measurements.
- HP of moon is difference in angles between edge of Earth and edge of moon. See [http://aa.usno.navy.mil/faq/docs/RST\\_defs.html](http://aa.usno.navy.mil/faq/docs/RST_defs.html)  
[http://www.fourmilab.ch/earthview/moon\\_ap\\_per.html](http://www.fourmilab.ch/earthview/moon_ap_per.html)





# Equation of Time

- Also given in the Almanac is the equation of time for each day of the year. From this entry you can calculate when the meridian crossing will be a Greenwich.
- The difference between the Greenwich meridian of the Sun and the local crossing is the longitude.

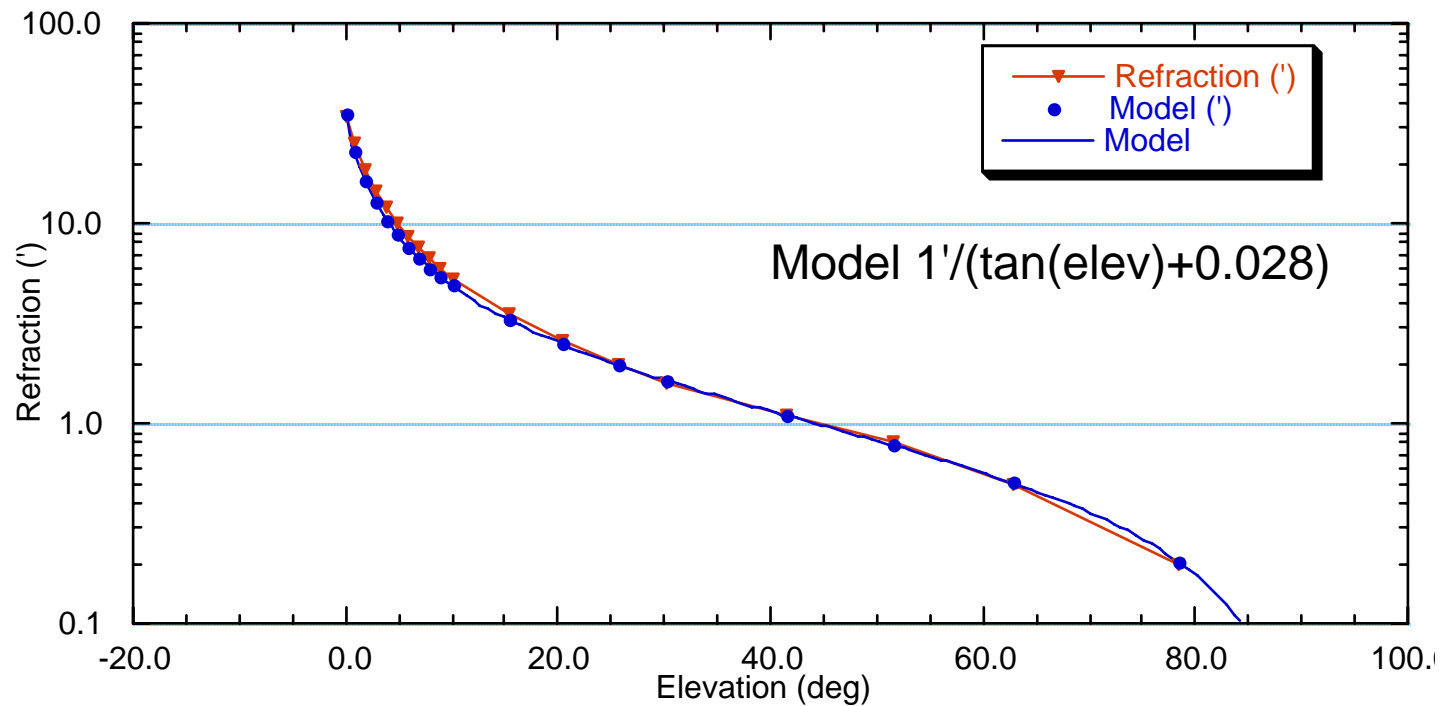
Day	SUN			MOON									
	Eqn. of Time		Mer.	Mer. Pass.		Age	Phase						
	00 <sup>h</sup>	12 <sup>h</sup>	Pass.	Upper	Lower								
d	m	s	m	s	h	m	h	m	d	%			
1	10	08	10	18	11	50	07	22	19	50	24	32	
2	10	27	10	37	11	49	08	19	20	47	25	22	
3	10	46	10	56	11	49	09	15	21	42	26	13	

# Comments on Nautical Almanacs

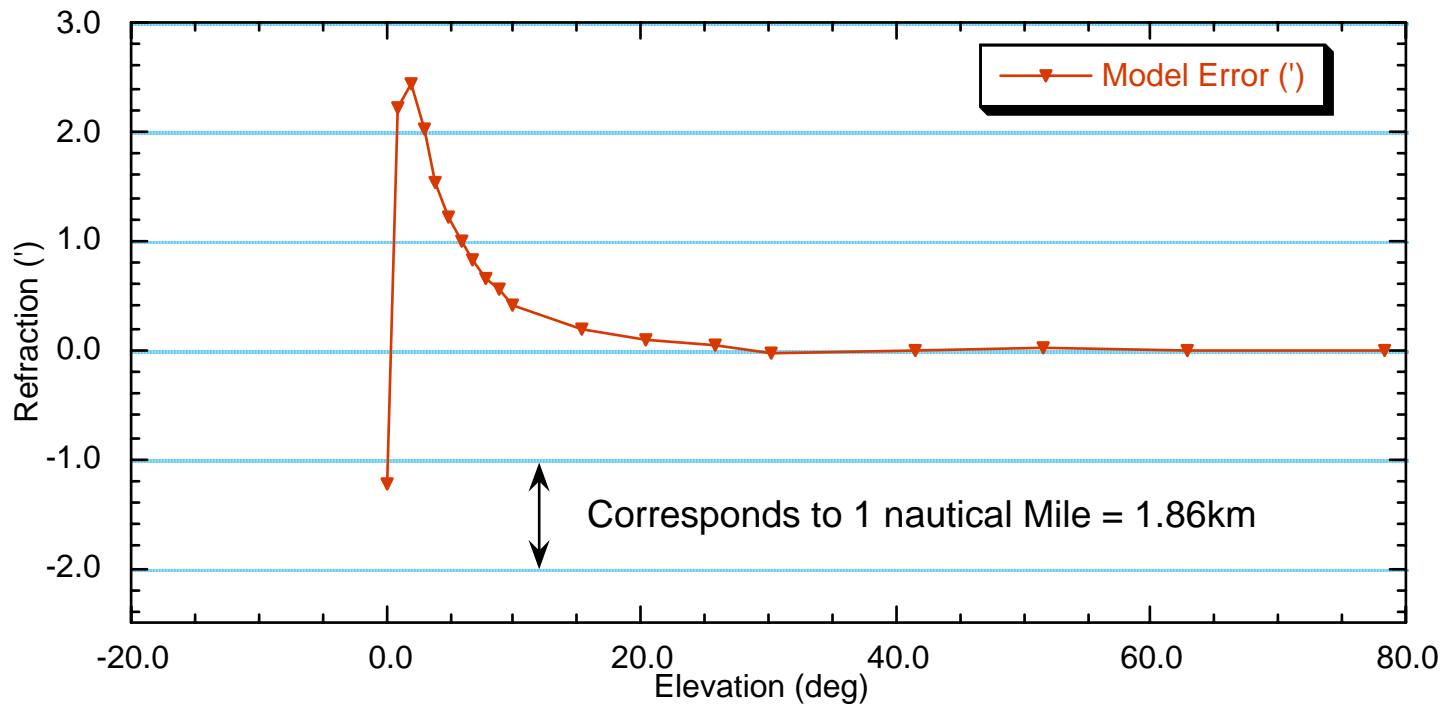
- The nautical Almanac contains many other tables and explanations. Many of these tables were used before the advent of calculators and computer programs.
- Paper almanacs are meant to be used by ships at sea with little computational power.
- Altitude (elevation angles) corrections are given for the size of the Sun (~16') and atmospheric refraction. For atmospheric refraction an approximate formula is (accurate to 5" at 20°)

$$\Delta\varepsilon = 60'' / (\tan \varepsilon + 0.028)$$

# Atmospheric refraction

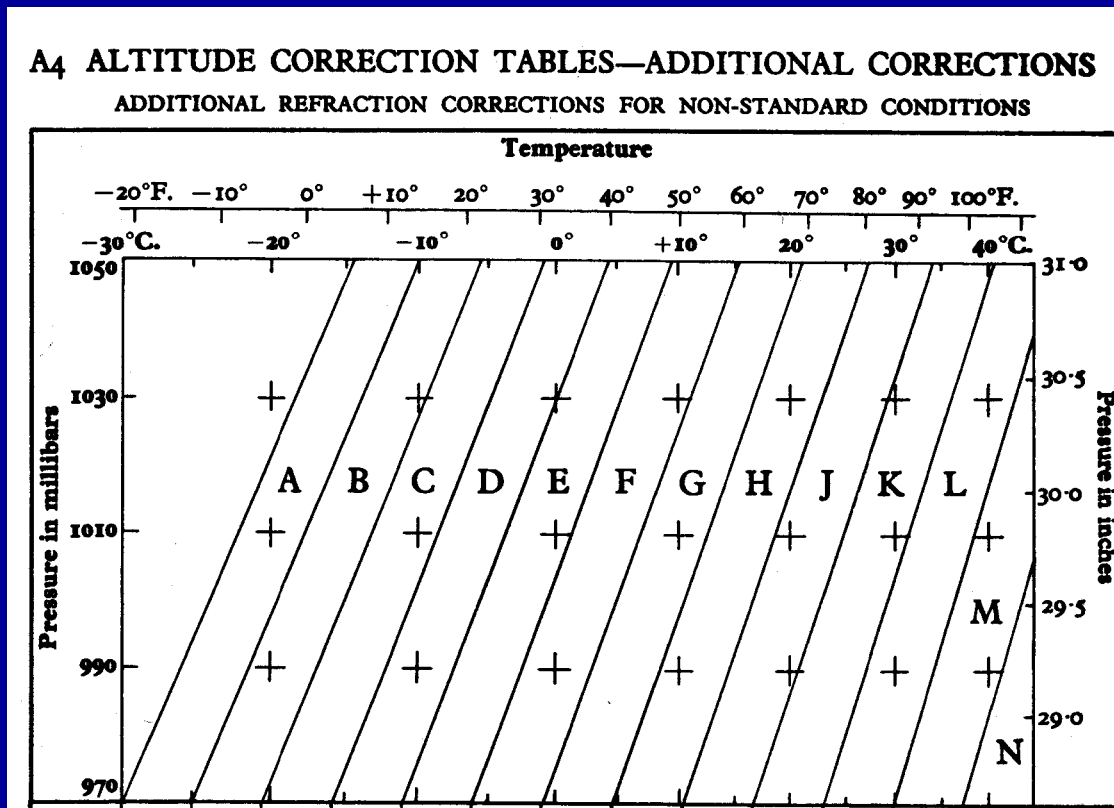


# Error in simple refraction model



# Nautical Almanac Correction

- Based on Pressure and temperature zone A-N



# Corrections

- From Zone and altitude additional correction applied

App. Alt.	A	B	C	D	E	F	G	H	J	K	L	M	N	App. Alt.
0 00	-6.9	-5.7	-4.6	-3.4	-2.3	-1.1	0.0	+1.1	+2.3	+3.4	+4.6	+5.7	+6.9	0 00
0 30	5.2	4.4	3.5	2.6	1.7	0.9	0.0	0.9	1.7	2.6	3.5	4.4	5.2	0 30
1 00	4.3	3.5	2.8	2.1	1.4	0.7	0.0	0.7	1.4	2.1	2.8	3.5	4.3	1 00
1 30	3.5	2.9	2.4	1.8	1.2	0.6	0.0	0.6	1.2	1.8	2.4	2.9	3.5	1 30
2 00	3.0	2.5	2.0	1.5	1.0	0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	2 00
2 30	-2.5	-2.1	-1.6	-1.2	-0.8	-0.4	0.0	+0.4	+0.8	+1.2	+1.6	+2.1	+2.5	2 30
3 00	2.2	1.8	1.5	1.1	0.7	0.4	0.0	0.4	0.7	1.1	1.5	1.8	2.2	3 00
3 30	2.0	1.6	1.3	1.0	0.7	0.3	0.0	0.3	0.7	1.0	1.3	1.6	2.0	3 30
4 00	1.8	1.5	1.2	0.9	0.6	0.3	0.0	0.3	0.6	0.9	1.2	1.5	1.8	4 00
4 30	1.6	1.4	1.1	0.8	0.5	0.3	0.0	0.3	0.5	0.8	1.1	1.4	1.6	4 30
5 00	-1.5	-1.3	-1.0	-0.8	-0.5	-0.2	0.0	+0.2	+0.5	+0.8	+1.0	+1.3	+1.5	5 00
6	1.3	1.1	0.9	0.6	0.4	0.2	0.0	0.2	0.4	0.6	0.9	1.1	1.3	6
7	1.1	0.9	0.7	0.6	0.4	0.2	0.0	0.2	0.4	0.6	0.7	0.9	1.1	7
8	1.0	0.8	0.7	0.5	0.3	0.2	0.0	0.2	0.3	0.5	0.7	0.8	1.0	8
9	0.9	0.7	0.6	0.4	0.3	0.1	0.0	0.1	0.3	0.4	0.6	0.7	0.9	9
10 00	-0.8	-0.7	-0.5	-0.4	-0.3	-0.1	0.0	+0.1	+0.3	+0.4	+0.5	+0.7	+0.8	10 00
12	0.7	0.6	0.5	0.3	0.2	0.1	0.0	0.1	0.2	0.3	0.5	0.6	0.7	12
14	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	14
16	0.5	0.4	0.3	0.3	0.2	0.1	0.0	0.1	0.2	0.3	0.3	0.4	0.5	16
18	0.4	0.4	0.3	0.2	0.2	0.1	0.0	0.1	0.2	0.2	0.3	0.4	0.4	18
20 00	-0.4	-0.3	-0.3	-0.2	-0.1	-0.1	0.0	+0.1	+0.1	+0.2	+0.3	+0.3	+0.4	20 00
25	0.3	0.3	0.2	0.2	0.1	-0.1	0.0	+0.1	0.1	0.2	0.2	0.3	0.3	25
30	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	30
35	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	35
40	0.2	0.1	0.1	0.1	-0.1	0.0	0.0	0.0	+0.1	0.1	0.1	0.1	0.2	40
50 00	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	+0.1	+0.1	+0.1	+0.1	50 00

# On-line almanacs

- If access to the internet is possible then the on-line versions of almanacs are much easier to use
- Computer programs are also available which can be run locally. All of the values in the Almanac are now computed (observations are no longer needed).
- <http://aa.usno.navy.mil/data/> has many resources including an on-line version of MICA (Multi-Year Interactive Computer Almanac)  
[http://aa.usno.navy.mil/data/docs/WebMICA\\_2.html](http://aa.usno.navy.mil/data/docs/WebMICA_2.html)
- Other on-line sources:  
<http://www.tecepe.com.br/nav/almanac.html-ssi>  
<http://www.tecepe.com.br/scripts/AlmanacPagesISAPI.isa>  
For the remainder of the class we will examine these on-line sources and compare the results to the paper Nautical Almanac