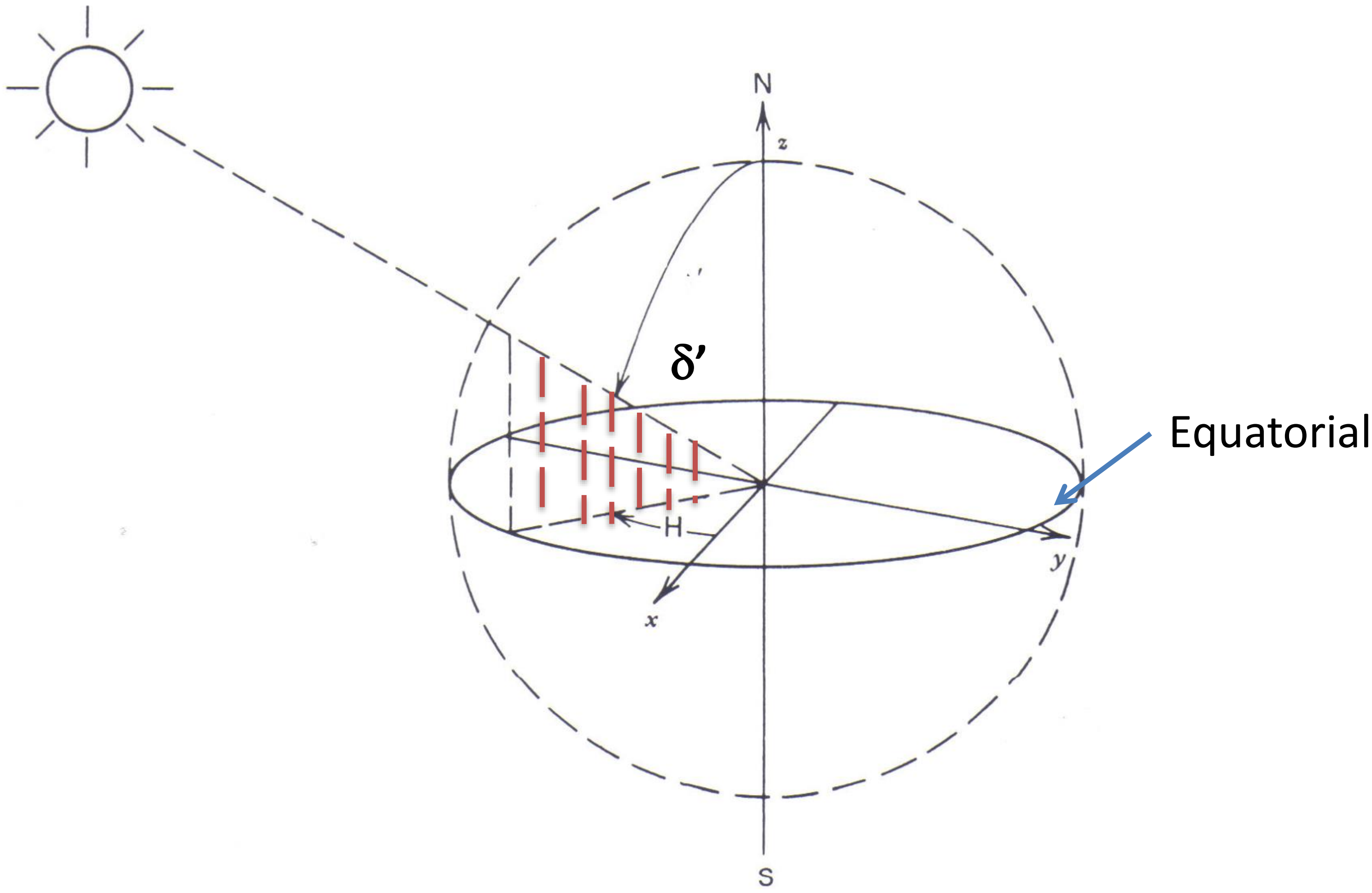
Solar Coordinates & Solar Insolation

Solar Coordinates

- Geocentric coordinate system based on earth's center!
- The position of the sun can be ultimately determined by two angles:

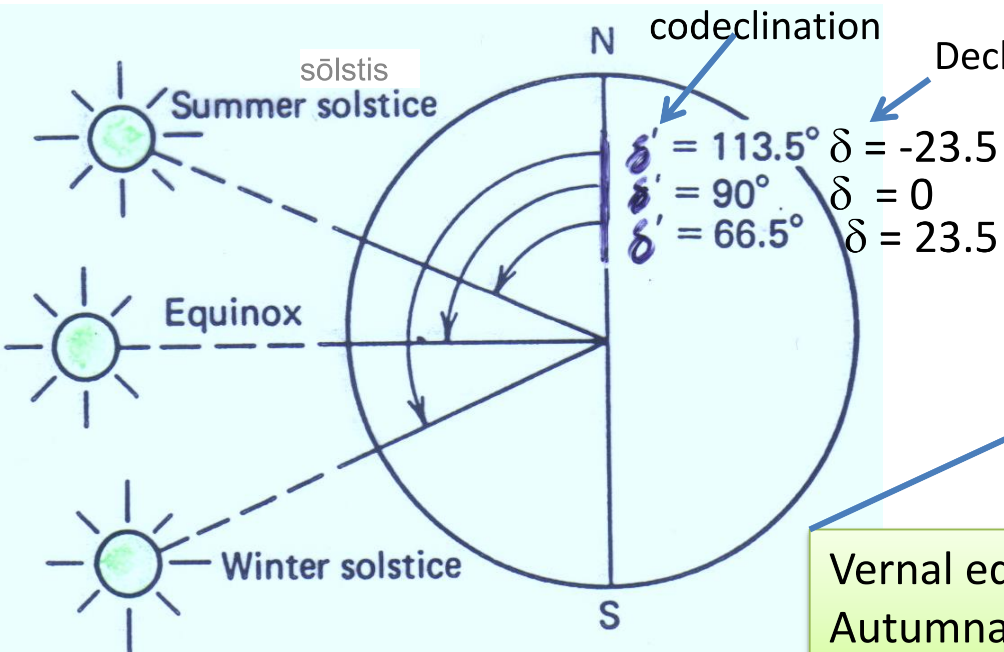
1. codeclination δ' (complement of declination δ). δ' varies from 66.5° at the summer solstice (June 22) to 113.5° at the winter solstice (Dec. 22).
2. hour angle H, = ±360t/24hr where t is the number of hours before or after solar noon. –ve refers to time before solar noon.

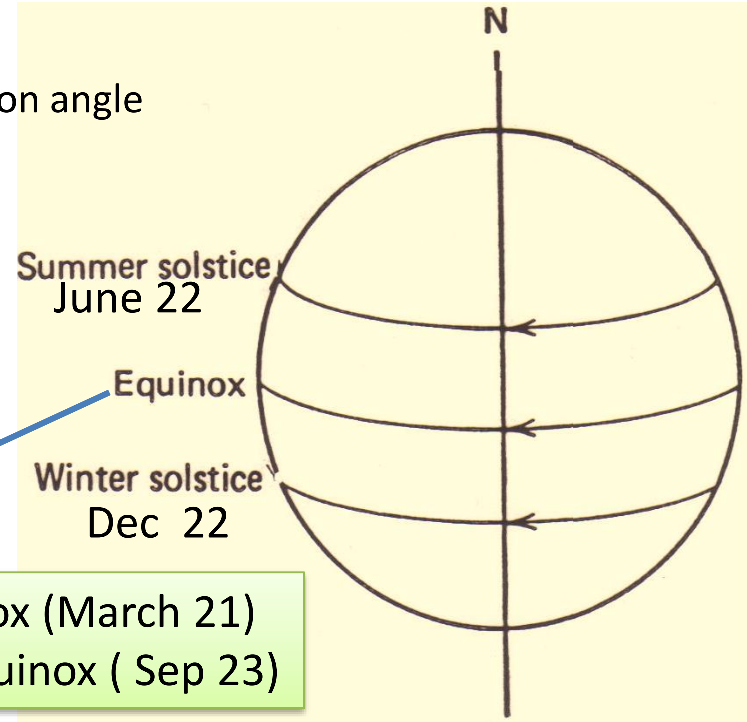
Solar Coordinates



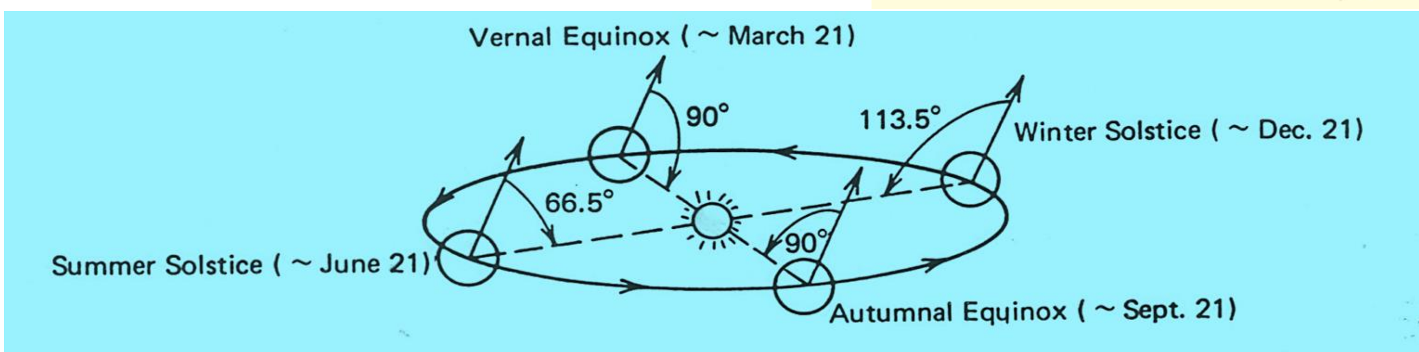
Geocentric coordinate system

The seasonal variation of the codeclination.





Vernal equinox (March 21)
Autumnal equinox (Sep 23)



The seasonal variation of the angle between the earth's polar axis and the earth–sun line.

Note

$$\cos\delta' = \sin 23.5^\circ \sin \frac{360^\circ n}{365.25\ days}$$

$$\delta = 90^\circ - \delta'$$

Where n is the number of days after the vernal equinox (March 21).

Also δ can be found from tables (solar tables)

Local Solar Coordinates

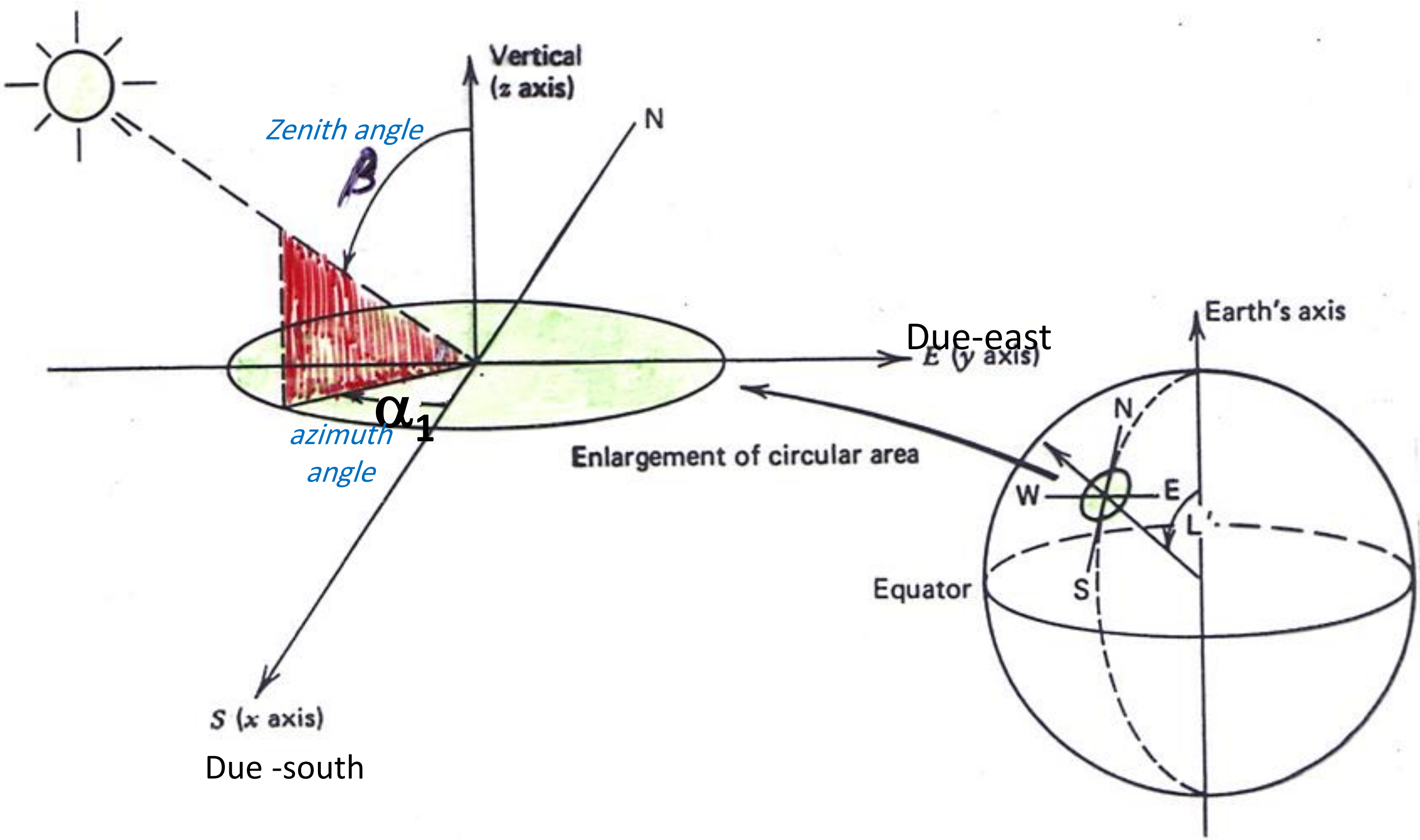
- Geocentric sys. is not suitable for the observer on the earth surface.

- The following coordinate is more appropriate:

  1. zenith angle β and its complement is called the altitude of the sun β_1
  2. azimuth angle α_1.

Due – south ~ x axis Due –east ~ y axis Vertical to equator is z axis

Local solar coordinates—the zenith angle β and the azimuth angle α_1



Altitude (β_1) and Azimuth (α_1) angles "Solar angles"

$$\sin\beta_1 = (\cos L)(\cos\delta)(\cos H) + (\sin L)(\sin\delta)$$

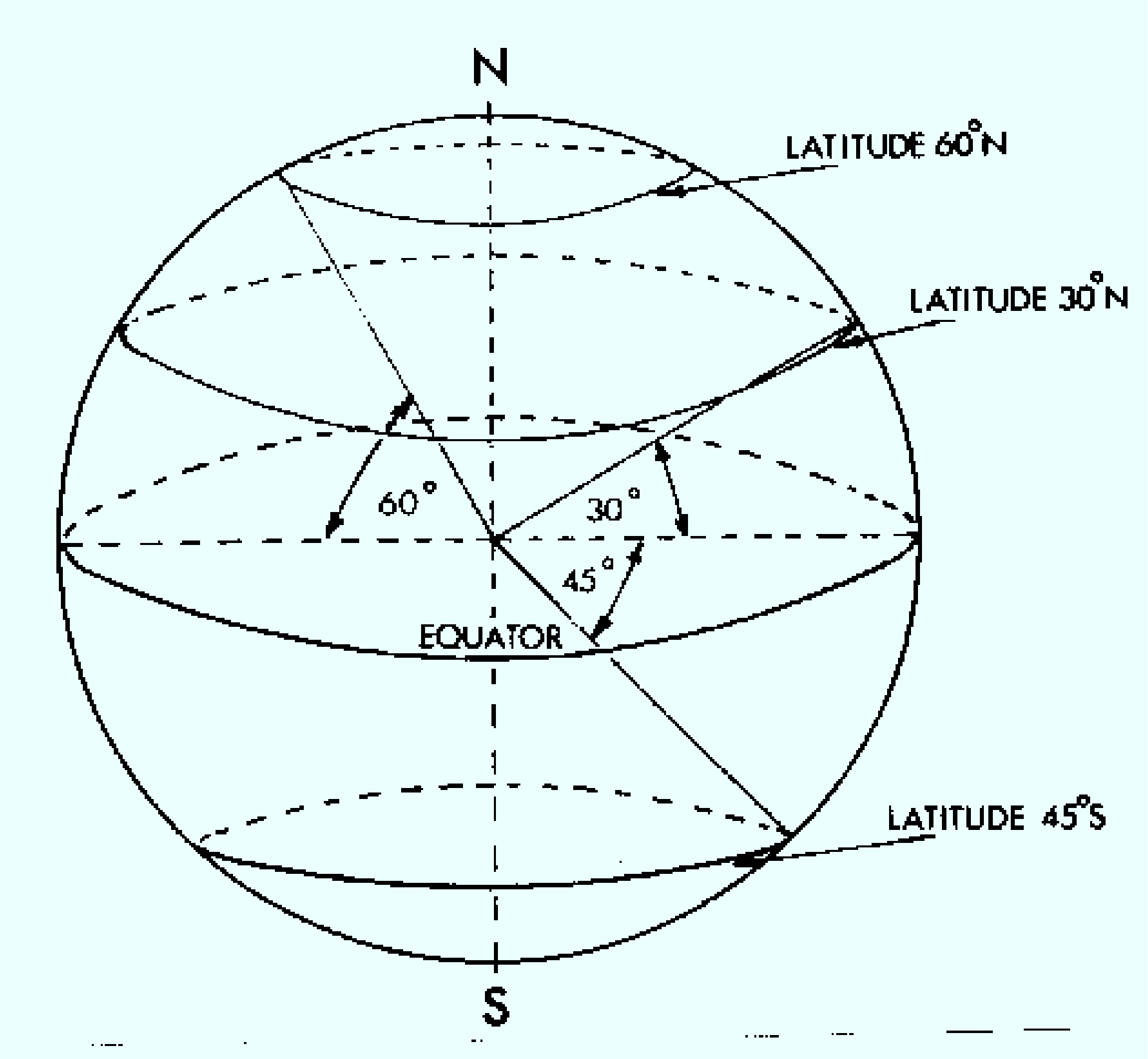
$$\sin\alpha_1 = \frac{\cos\delta \sin H}{\cos\beta_1}$$

Where L is the Latitude angle

Note

The values of α_1 and β_1 are given in the recommended text.

Latitude Angle



Solar time

- Equation of time (EOT): it is the cumulative variation of the solar noon. The following table shows the EOT in minutes.

Day of Month	January	February	March	April	May	June	July	August	September	October	November	December
1	−4	−14	−13	−4	+3	+2	−3	−6	0	+10	+16	+11
4	−5	−14	−12	−3	+3	+2	−4	−6	+1	+11	+16	+10
7	−6	−14	−11	−2	+3	+2	−5	−6	+2	+12	+16	+9
10	−8	−14	−10	−1	+4	+1	−5	−5	+3	+13	+16	+7
13	−9	−14	−10	−1	+4	0	−6	−5	+4	+14	+16	+6
16	−10	−14	−9	0	+4	0	−6	−4	+5	+14	+15	+4
19	−11	−14	−8	+1	+4	−1	−6	−4	+6	+15	+15	+3
22	−12	−14	−7	+1	+4	−2	−6	−3	+7	+15	+14	+2
25	−12	−13	−6	+2	+3	−2	−6	−2	+8	+16	+13	0
28	−13	−13	−5	+2	+3	−3	−6	−1	+9	+16	+12	−2

- Solar Noon = 12:00 – 0:04($Long_{st}$ – $long_{loc}$) - EOT

Standard Meridian Longitude

For the observer

Local Meridian Longitude

- Mean Sun Time, MST = local standard time + $0{:}04(Long_{st} - long_{loc})$
- Apparent Sun Time, AST = MST + EOT

Important for hour angle

- Examples : Standard meridian for USA
  - 75 °W Long. (EST), Eastern standard meridian
  - 90 ° W Long.(CST), Central standard meridian
  - 105 ° W Long. (MST), mountain standard meridian
  - 120 ° W Long. (PST), Pacific standard meridian

Parameters for solar calculations (on the 21st day of each month)

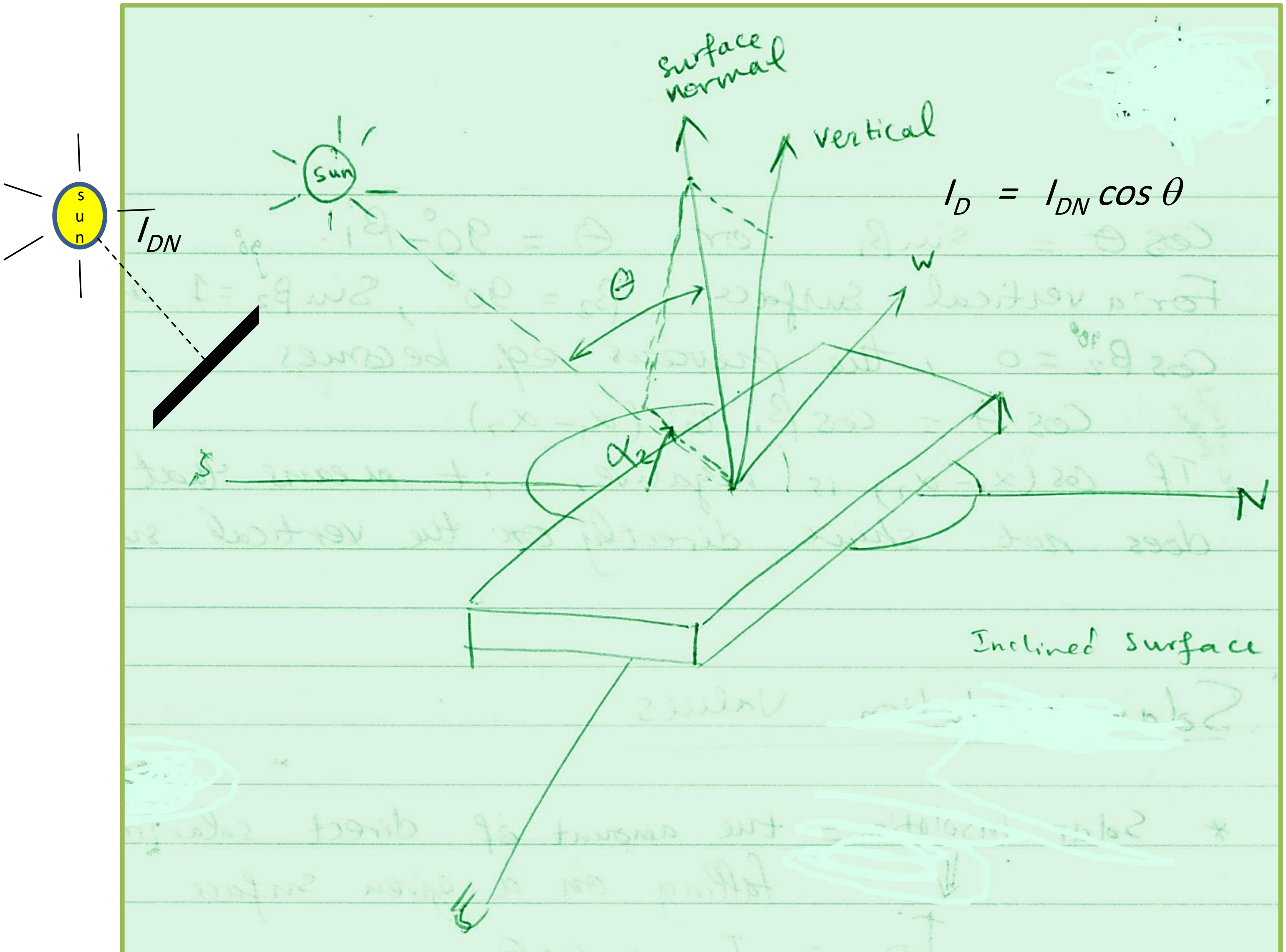
Month	January	February	March	April	May	June	July	August	September	October	November	December
Day of the year	21	52	80	111	141	173	202	233	265	294	325	355
Declination, degrees	−19.9	−10.6	0.0	+11.9	+20.3	+23.45	+20.5	+12.1	0.0	−10.7	−19.9	−23.45
Equation of time, min	−11.2	−13.9	−7.5	+1.1	+3.3	−1.4	−6.2	−2.4	+7.5	+15.4	+13.8	+1.6
Solar noon	Late			Early		Late			Early			
A, Btu/h·ft²†	390	385	376	360	350	345	344	351	365	378	387	391
B, 1/m	0.142	0.144	0.156	0.180	0.196	0.205	0.201	0.177	0.160	0.149	0.149	0.142
C, dimensionless	0.058	0.060	0.071	0.097	0.121	0.134	0.136	0.122	0.092	0.073	0.063	0.057

† *A* is the apparent solar irradiation at air mass zero for each month.
B is the atmospheric extinction coefficient.
C is the ratio of the diffuse to direct normal irradiation on a horizontal surface.

Solar Insolation "I_D"

<u>Definition</u>: **Solar Insolation** (**in**cident or **in**coming **sol**ar radi**ation**) is the total amount of solar radiation energy received on a given surface area during a given time. It is also called **solar irradiation** and expressed as "hourly irradiation" if recorded during an hour or "daily irradiation" if recorded during a day

Solar Insolation "I_D"_Inclined surface



$$I_D = I_{DN} \cos\theta$$

Determination of the angle between the sun's rays and the normal to the surface "θ"

Firstly the orientation of the surface must be specified:

I. α_2 : the azimuth angle of the surface. It is the angle between the horizontal projection of the normal to the surface and the due-south line measured in a clockwise direction. (**See the previous slid**)

II. β_2: tilt angle of the surface. It is the angle between the surface and the horizontal.

θ can be determined from the following equation:

$$\text{Cos}\ \theta = \text{Sin}\ \beta_1\ \text{Cos}\ \beta_2 + \text{Cos}\ \beta_1\ \text{Sin}\ \beta_2\ \text{Cos}\ (\alpha_1 - \alpha_2)$$

Summary

Solar Insolation & Collector Energy Absorption

Solar Insolation Values

- Total solar energy flux, I_t

$$I_t = I_D + I_{DS} + I_R \qquad (1)$$

- *Where* I_D *is the direst solar beam*

  I_{DS} *is the diffuse component*

  I_R *is the reflected solar radiation from surroundings.*

Note: The third component , I_R*, is found from the laws of heat transfer by radiation.*

Direct solar energy flux

- In general, the direct solar energy flux falling on a given surface is equal to the product of the direct radiation falling on a surface normal to the sun's rays, I_{DN}, and $\cos\theta$ or:

$$I_D = I_{DN} \cos\theta$$

- I_{DN} can be estimated from:

$$I_{DN} = A_s \exp \frac{-B_s}{\sin\beta_1}$$

- Where

  A_s is the apparent extraterrestrial insolation.

  B_s is the atmospheric extinction coefficient. It depends on the time of year and the amount of water vapor present in the average atmosphere.
- Both of A_s and B_s are given in tables (solar tables). See next slids.

Date	Angle of declination δ	Equation of time, min	A_S,† kW/m²‡	B_S,† am§	C_S†	Day of year
January						
1	−23.0	−3.6	1231	0.142	0.057	1
11	−21.7	−8.0	1230	0.142	0.058	11
21	−19.6	−11.4	1229	0.142	0.058	21
31	−17.3	−13.5	1224	0.142	0.058	31
February						
1	−17.0	−13.6	1223	0.143	0.059	32
11	−13.9	−14.4	1218	0.143	0.059	42
21	−10.4	−13.8	1213	0.144	0.060	52
28	−7.6	−12.6	1206	0.147	0.063	59
March						
1	−7.4	−12.5	1205	0.148	0.063	60
11	−3.5	−10.2	1195	0.152	0.067	70
21	0.0	−7.4	1185	0.156	0.071	80
31	4.3	−4.3	1169	0.164	0.079	90
April						
1	4.7	−4.0	1167	0.165	0.080	91
11	8.5	−1.1	1151	0.172	0.088	101
21	12.0	1.2	1135	0.180	0.096	111
30	14.9	2.8	1126	0.185	0.104	120

Date	Angle of declination δ	Equation of time, min	A_S,† kW/m²‡	B_S,† am§	C_S†	Day of year
May						
1	15.2	2.9	1125	0.186	0.105	121
11	17.9	3.7	1114	0.191	0.113	131
21	20.3	3.6	1103	0.196	0.121	141
31	22.0	2.5	1098	0.199	0.125	151
June						
1	22.1	2.4	1097	0.199	0.126	152
11	23.1	0.6	1092	0.202	0.130	162
21	23.45	−1.5	1087	0.205	0.134	172
30	23.1	−3.4	1086	0.206	0.135	181
July						
1	23.1	−3.4	1086	0.206	0.135	182
11	22.1	−5.6	1085	0.206	0.135	192
21	20.6	−6.2	1084	0.207	0.136	202
31	18.1	−6.2	1091	0.205	0.132	212
August						
1	17.9	−6.2	1092	0.205	0.132	213
11	15.2	−5.1	1099	0.203	0.126	223
21	12.0	−3.1	1106	0.201	0.122	233
31	8.7	−1.5	1120	0.193	0.113	243
September						
1	8.2	0.0	1122	0.192	0.112	244
11	4.4	3.3	1136	0.185	0.097	254
21	0.0	6.8	1150	0.177	0.092	264
30	−2.9	9.9	1162	0.172	0.086	273
October						
1	−3.3	10.2	1164	0.171	0.086	274
11	−7.2	13.1	1177	0.166	0.079	284
21	−10.8	15.3	1191	0.160	0.073	294
31	−14.3	16.2	1200	0.157	0.070	304
November						
1	−14.6	16.3	1201	0.156	0.069	305
11	−17.5	15.9	1211	0.153	0.066	315
21	−20.0	15.1	1220	0.149	0.063	325
30	−21.7	11.3	1224	0.147	0.061	334
December						
1	−21.9	11.0	1224	0.147	0.061	335
11	−23.0	6.8	1228	0.144	0.059	345
21	−23.45	2.0	1232	0.142	0.057	355
31	−23.1	−3.1	1231	0.142	0.057	365

th's atmosphere).

Diffuse component, I_{DS}

- The diffuse component can be estimated from

$$I_{DS} = C_s I_{DN} F_{ss}$$

Where C_s is the ratio of diffuse to direct solar radiation falling on a horizontal surface. Its value is given in the previous tables.

F_{ss} is the radiation shape factor for radiation leaving the surface that hits the sky.

F_{ss} *can be approximated by*

$$F_{ss} = \frac{1 + cos\beta_2}{2}$$

Solar energy absorbed by a given surface

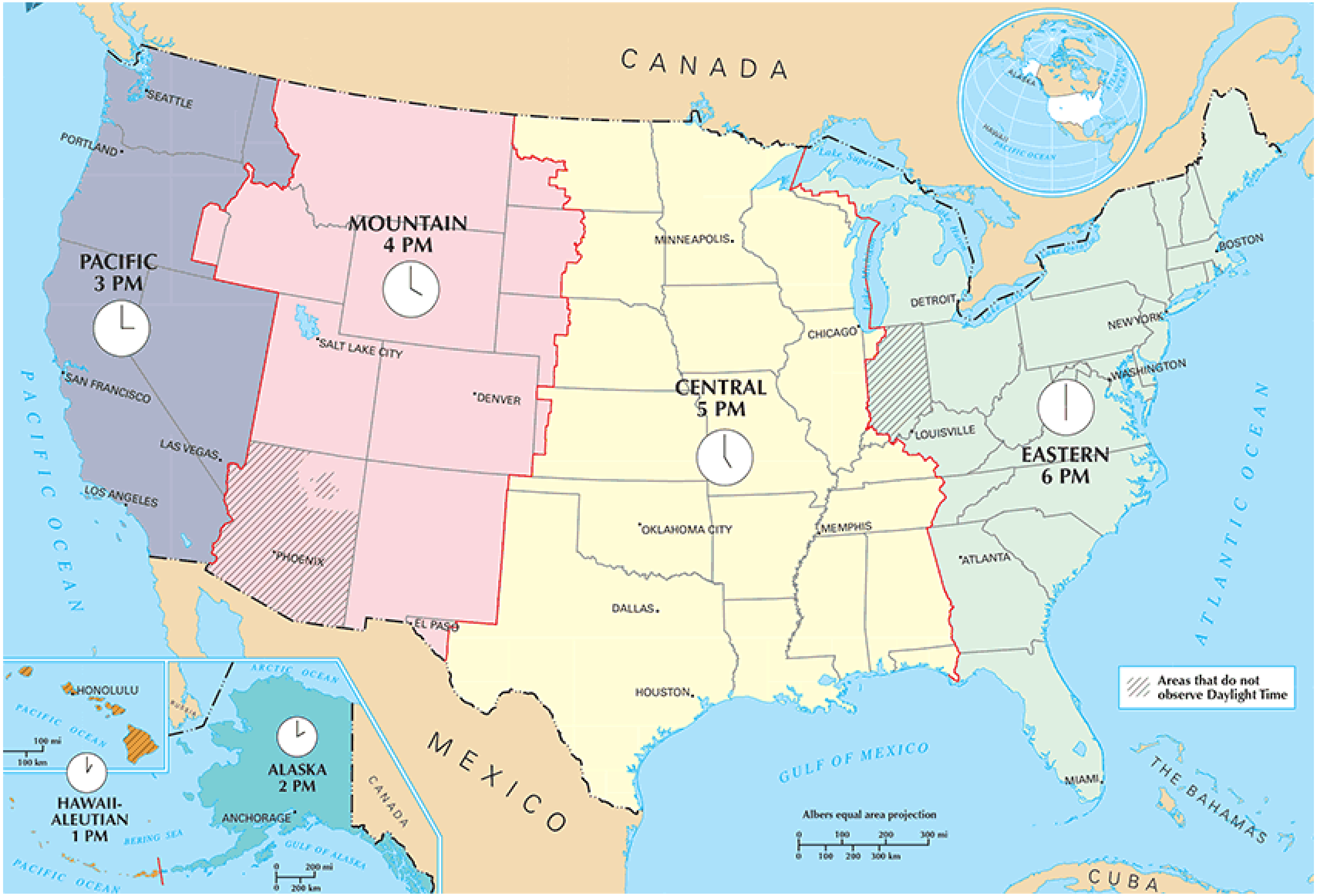
- *The product of I_t and the absorptivity or emissivity of the surface or:*

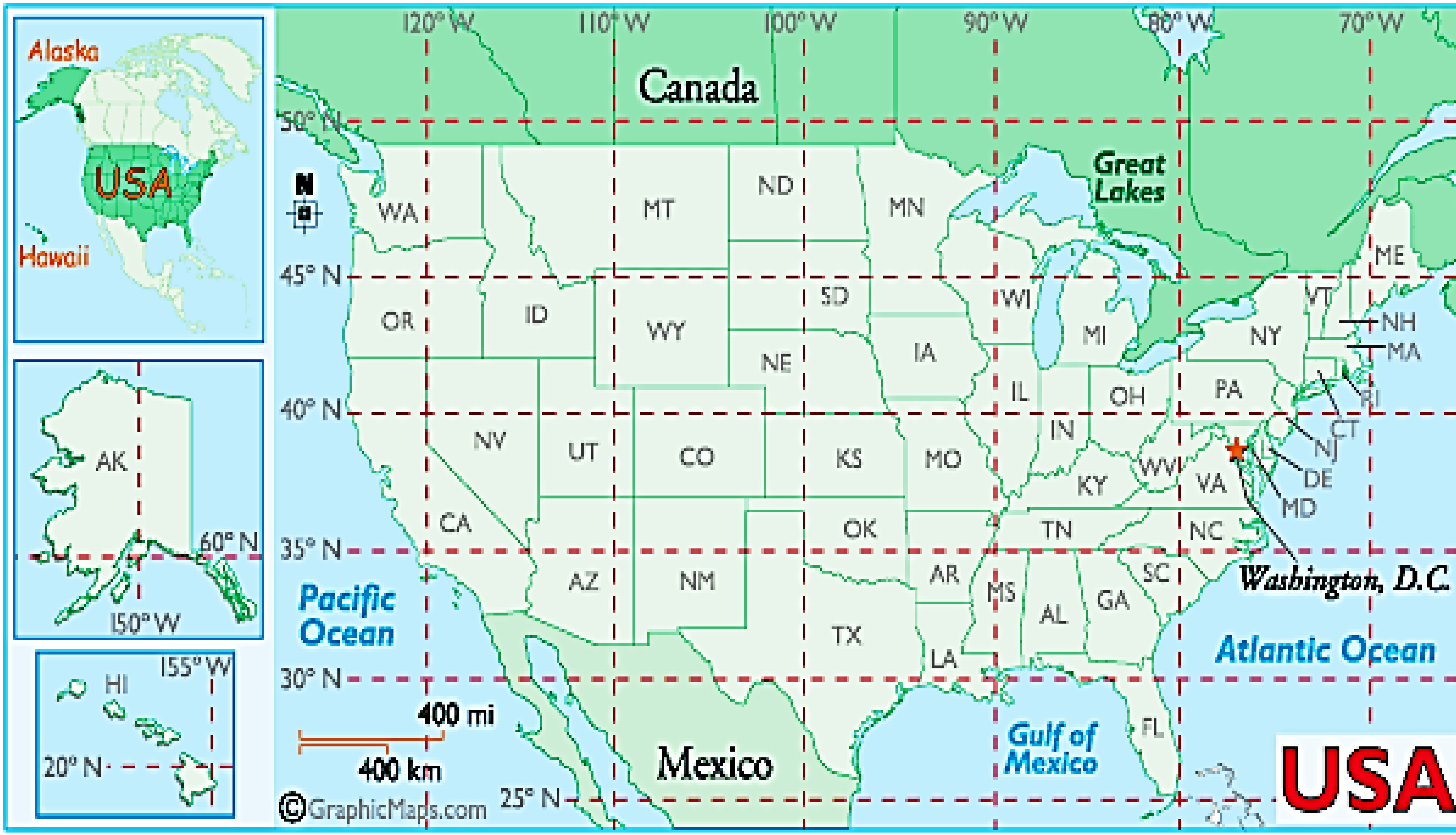
$$\textit{Absorbed solar energy flux} = I_t * \varepsilon$$

Solar Emissivities

Solar emissivities

Materials	Infrared (low-temp.) radiation	Solar radiation
Building materials:		
Red brick, tile, concrete	0.85–0.95	0.65–0.77
Yellow and buff brick	0.85–0.95	0.50–0.70
Plaster	0.90–0.95	0.50–0.70
Asphalt pavement	0.90–0.95	0.82–0.88
Roofing materials:		
Asphalt	0.90–0.95	0.86–0.90
Galvanized iron, dirty	0.25–0.35	0.87–0.91
Galvanized iron, new	0.20–0.30	0.64–0.68
Roofing paper	0.85–0.95	0.85–0.90
Slate	0.90–0.98	0.85–0.95
Paints:		
Aluminum (bright), gilt	0.25–0.65	0.30–0.50
Black, flat	0.95–0.98	0.85–0.95
Dark (red, brown, green, etc.)	0.75–0.95	0.65–0.83
White, flat	0.95–0.99	0.12–0.25
Metals:		
Aluminum, nickel, chromium (polished)	0.02–0.10	0.10–0.40
Copper, brass, monel metal (polished)	0.02–0.15	0.30–0.50
Dull aluminum, brass, copper, and polished iron	0.20–0.50	0.40–0.65
Iron oxide	0.60–0.65	0.70–0.80


CANADA
SEATTLE
PORTLAND
PACIFIC
3 PM
MOUNTAIN
4 PM
SALT LAKE CITY
DENVER
SAN FRANCISCO
LAS VEGAS
LOS ANGELES
PHOENIX
EL PASO
MINNEAPOLIS
CHICAGO
CENTRAL
5 PM
OKLAHOMA CITY
MEMPHIS
DALLAS
HOUSTON
DETROIT
NEW YORK
BOSTON
WASHINGTON
LOUISVILLE
EASTERN
6 PM
ATLANTA
MIAMI
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
CUBA
THE BAHAMAS
Lake Superior
Areas that do not observe Daylight Time
Albers equal area projection
HONOLULU
HAWAII-ALEUTIAN
1 PM
ALASKA
2 PM
ANCHORAGE
ARCTIC OCEAN
BERING SEA
GULF OF ALASKA



Examples : Standard meridian for USA

75 °W Long. (EST), Eastern standard meridian

90 ° W Long.(CST), Central standard meridian

105 ° W Long. (MST), mountain standard meridian

120 ° W Long. (PST), Pacific standard meridian

Jordan's latitude and **longitude**

- For Jordan: 31.0167° N, 36.6167° E
- **Jordan's latitude** and **longitude** is 31° 00' N and 36° 00' E


Arctic Ocean
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ARCTIC
CIRCLE
66°30'N
ASIA
EUROPE
Caspian
Sea
Black
Sea
Aral
Sea
Med. Sea
MIDDLE
EAST
TROPIC OF
CANCER
23°5'N
Jordan
Red
Sea
Arabian
Sea
Bay
of
Bengal
Pacific
Ocean
OCEANIA
AFRICA
Gulf of
Aden
EQUATOR
Indian
Ocean
TROPIC OF
CAPRICORN
23°5'S
1500 mi
AUSTRALIA
1500 km
worldatlas

0
50
100 km
0
50
100 mi
LEB.
Mediterranean Sea
SYRIA
Golan Heights (Israeli occupied)
IRAQ
alignment approximate
Irbid
Jordan River
Az Zarqa'
West Bank*
AMMAN
Gaza Strip*
Dead Sea
Al Karak
ISRAEL
SAUDI ARABIA
Ma'ān
EGYPT
Al 'Aqabah
Jabal Umm ad Dāmī
Gulf of Aqaba
*Israeli occupied with current status subject to the Israeli-Palestinian Interim Agreement; permanent status to be determined through further negotiation.