Chapter 2

Solar Radiation

Terminology & Definitions ● Geometric & Atmospheric Effects ● Solar Power & Energy ● Measurements & Data

Overview

▶ **Defining basic terminology associated with solar radiation, including solar irradiance (power), solar irradiation (energy) and peak sun hours.**

▶ **Identifying the instruments used for measuring solar radiation.**

▶ **Understanding the effects of the earth's movements and atmospheric conditions on the solar energy received on the earth's surface.**

▶ **Locating the sun's position using sun path diagrams and defining the solar window.**

▶ **Accessing solar radiation data resources and quantifying the effects of collector orientation on the amount of solar energy received.**

Sun - Earth Relationships

93 million miles, average (1.5×10^8 km)

1 Astronomical Unit
(Distance traveled in 8.31 minutes at the Speed of Light)

Sun:

Diameter: 865,000 miles (1,392,000 km, 109 times earth)
Mass: 2×10^{30} kg (330,000 times earth)
Density: 1.41 g/cm^3
Gravity: 274 m/s^2 (28 g)

Surface Temperature: 10,000 F (5800 K)

Earth:

Diameter: 7,930 miles (12,756 km)
Mass: 5.97×10^{24} kg
Density: 5.52 kg/cm^3
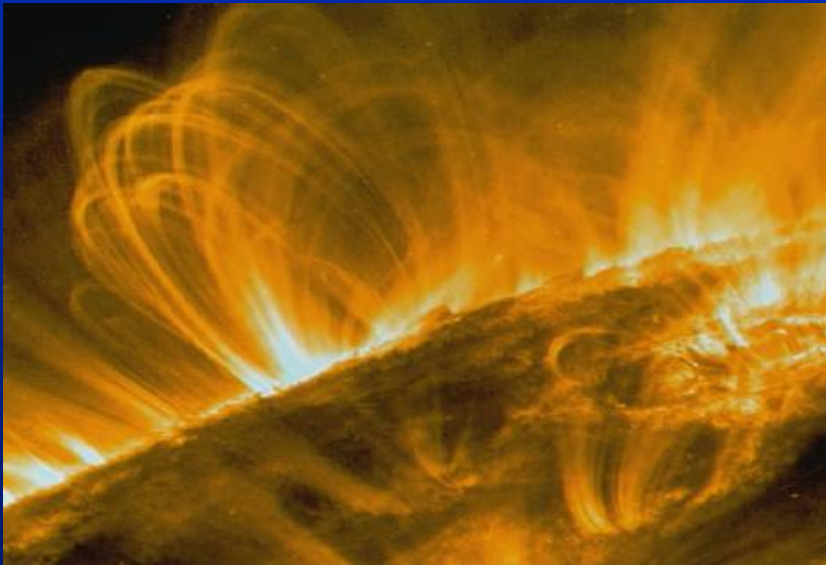**Gravity: 9.81 m/s^2 (1 g)**

Typical Surface Temperature: 68 F (300K)

Earth's Orbit Around Sun: 1 year
Earth's Rotation about its Polar Axis: 1 day

Solar Radiation

▶ *Solar radiation* is electromagnetic radiation ranging from about 0.25 to 4.5 μm in wavelength, including the near ultraviolet (UV), visible light, and near infrared (IR) radiation.

NASA

Common units of measure for electromagnetic radiation wavelengths:

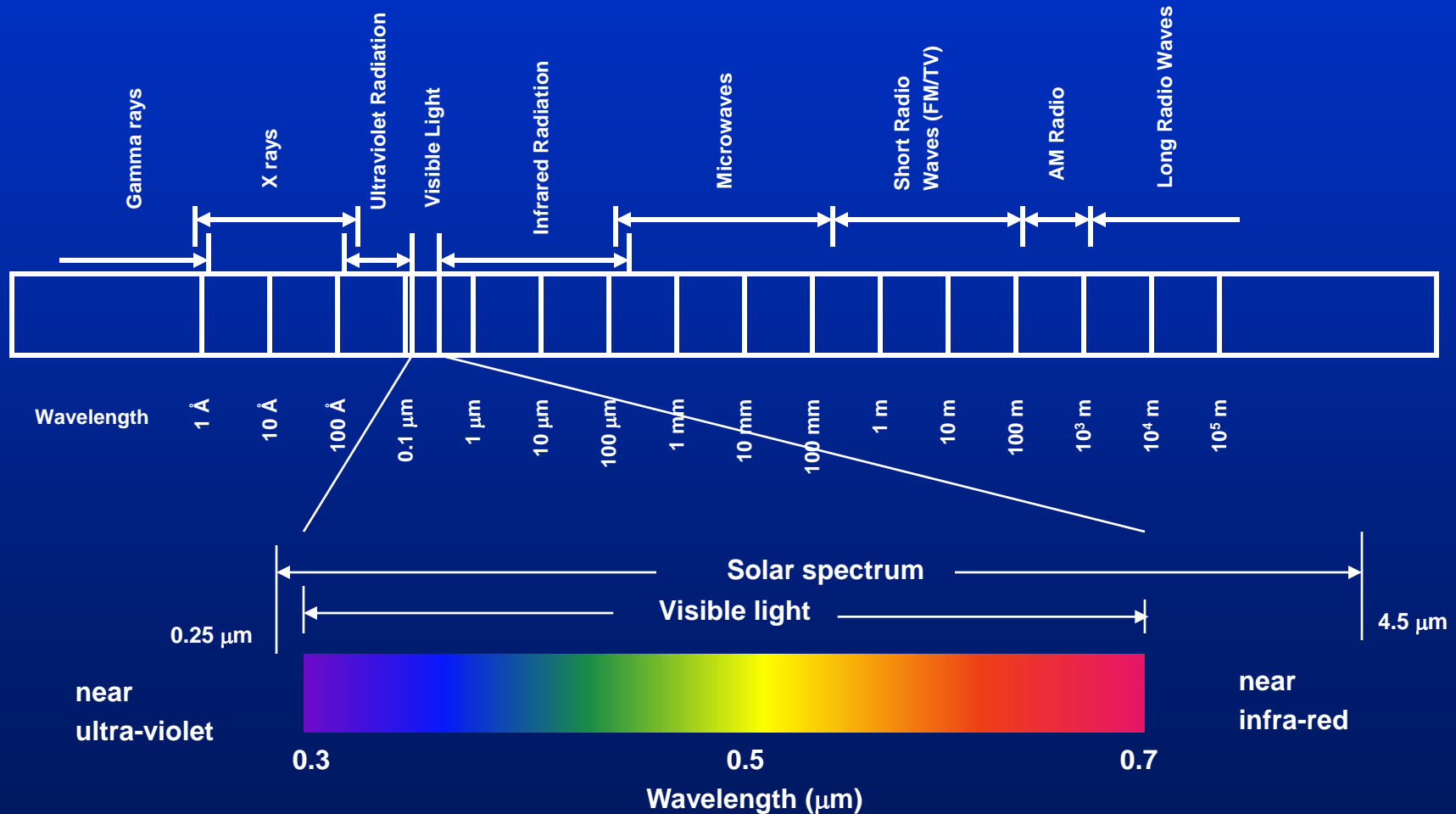1 Angstrom (Å) = 10^{-10} meter (m)
1 nanometer (nm) = 10^{-9} meter
1 micrometer (μm) = 10^{-6} meter
1 millimeter (mm) = 10^{-3} meter
1 kilometer (km) = 1000 meters

Electromagnetic Spectrum

Gamma rays

X rays

Ultraviolet Radiation

Visible Light

Infrared Radiation

Microwaves

Short Radio Waves (FM/TV)

AM Radio

Long Radio Waves

Wavelength

1 Å | 10 Å | 100 Å | 0.1 μm | 1 μm | 10 μm | 100 μm | 1 mm | 10 mm | 100 mm | 1 m | 10 m | 100 m | 10^3 m | 10^4 m | 10^5 m

Solar spectrum

Visible light

0.25 μm

4.5 μm

near ultra-violet
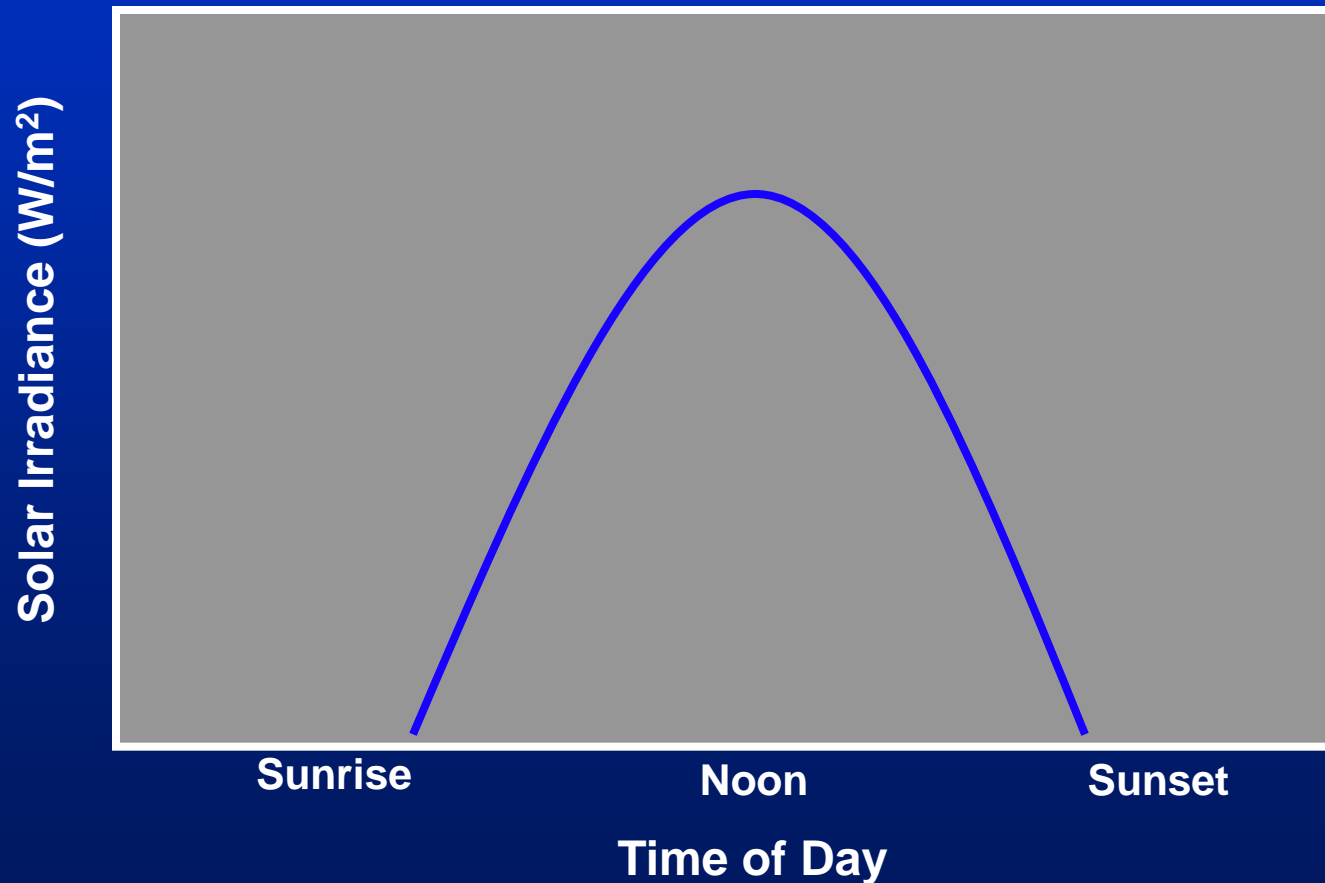
near infra-red

0.3

0.5

0.7

Wavelength (μm)

Solar Irradiance (Solar Power)

▶ *Solar irradiance* is the sun's radiant power, represented in units of W/m^2 or kW/m^2.

▶ The Solar Constant is the average value of solar irradiance outside the earth's atmosphere, about 1366 W/m^2.

▶ Typical peak value is 1000 W/m^2 on a terrestrial surface facing the sun on a clear day around solar noon at sea level, and used as a rating condition for PV modules and arrays.

1 m

One Square Meter

Typical peak value per m^2

1000 watts = 1 kilowatt

1 m
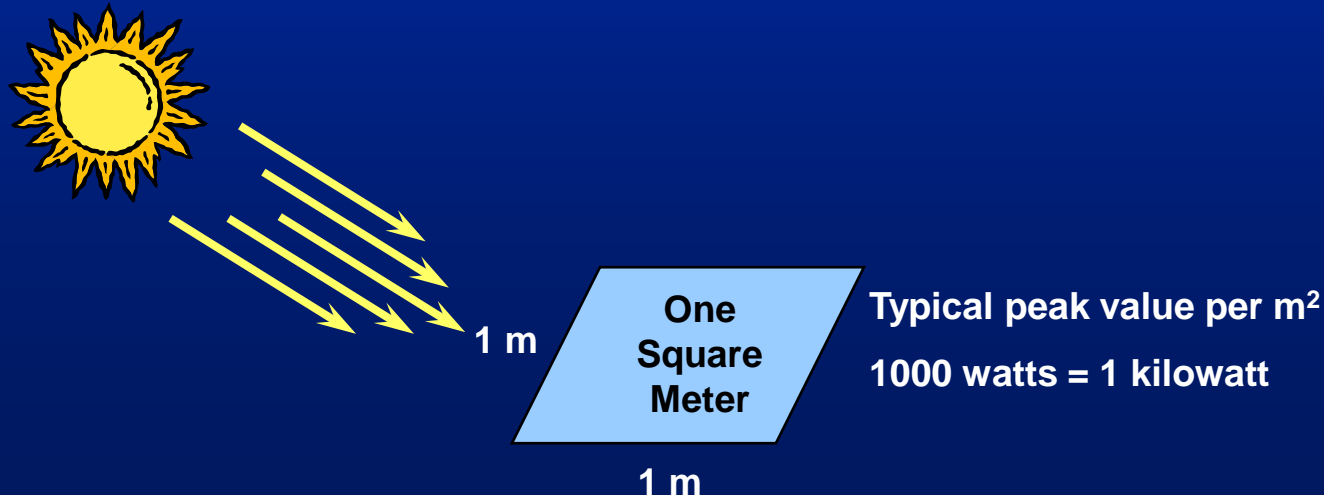
Solar Irradiance
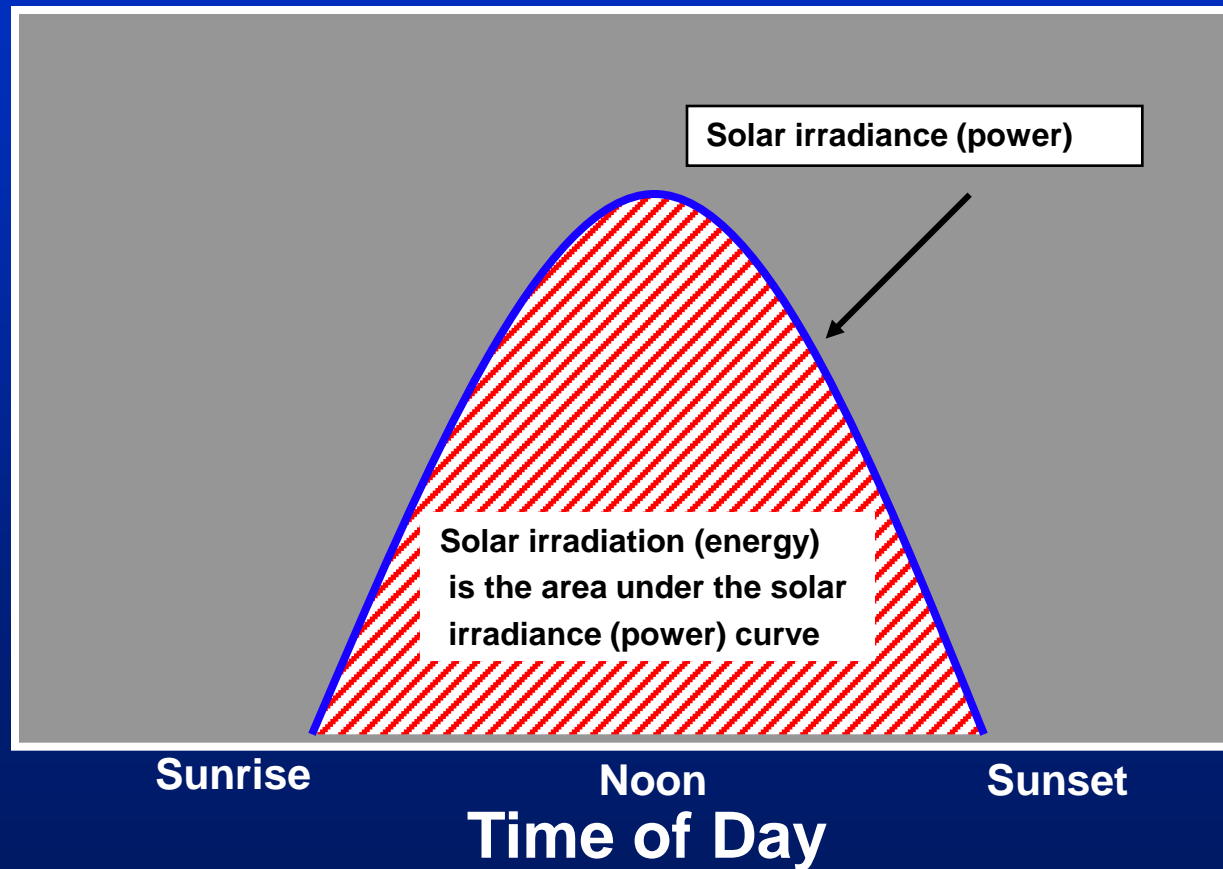
For south-facing fixed surfaces, solar power varies over the day, peaking at solar noon.
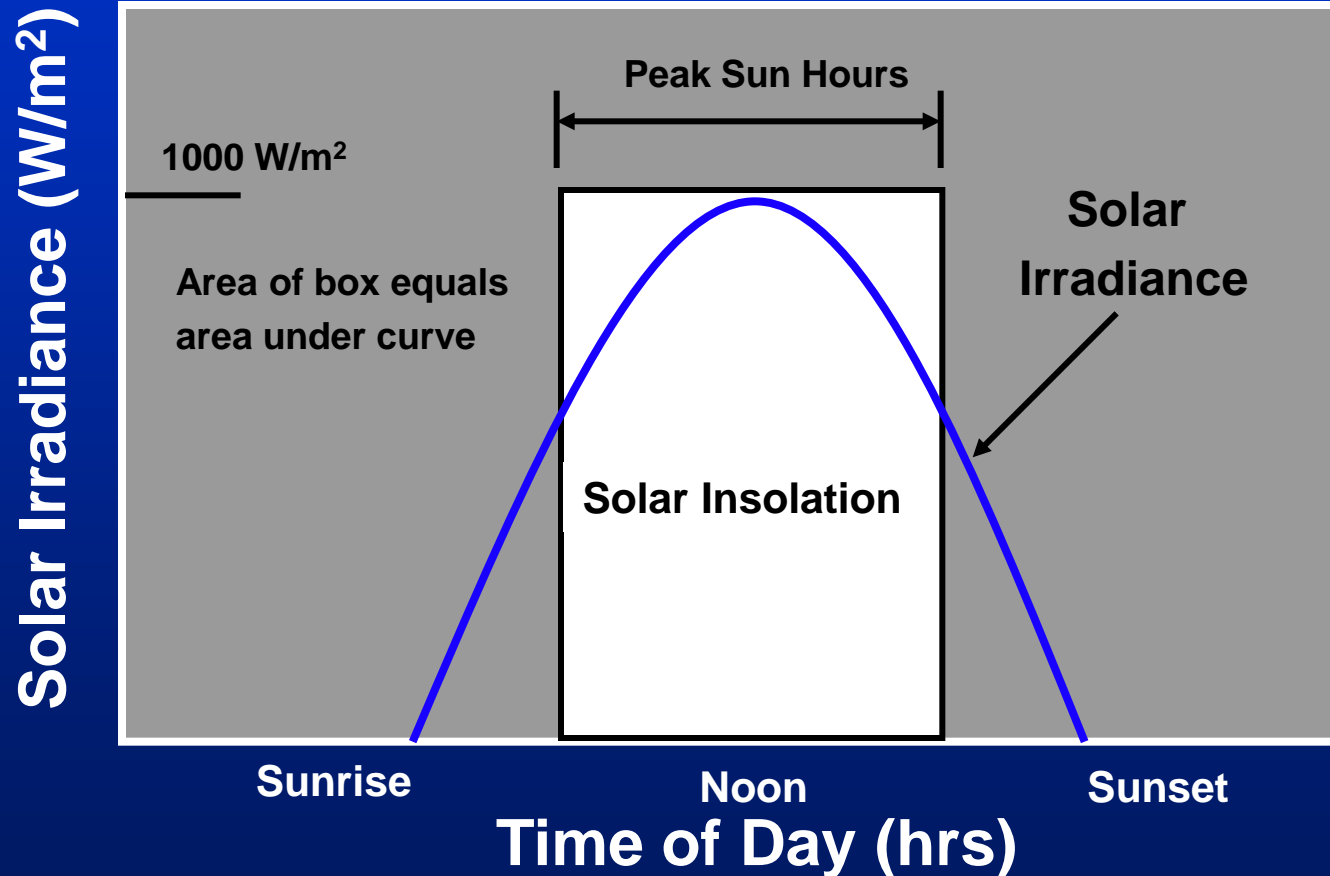
▶ *Solar irradiation* **is the sun's radiant energy incident on a surface of unit area, expressed in units of kWh/m^2.**

   ♦ Typically expressed on an average daily basis for a given month.

   ♦ Also referred to as solar insolation or peak sun hours.

▶ **Solar irradiation (energy) is equal to the average solar irradiance (power) multiplied by time.**

▶ *Peak sun hours (PSH)* **is the average daily amount of solar energy received on a surface. PSH are equivalent to:**

   ♦ The number of hours that the solar irradiance would be at a peak level of 1 kW/m^2.

   ♦ Also the equivalent number of hours per day that a PV array will operate at peak rated output levels at rated temperature.

Solar Power and Solar Energy

Solar Irradiance (W/m²)

Solar irradiance (power)

Solar irradiation (energy) is the area under the solar irradiance (power) curve

Sunrise   Noon   Sunset

Time of Day

Peak Sun Hours

Solar Irradiance (W/m²)

Peak Sun Hours

1000 W/m²

Area of box equals area under curve

Solar Insolation

Solar Irradiance

Sunrise

Noon

Sunset

Time of Day (hrs)

Solar Power and Energy: Examples

▶ **The solar power incident on a surface averages 400 W/m^2 for 12 hours. How much solar energy is received?**

◆ 400 W/m^2 x 12 hours = 4800 Wh/m^2 = 4.8 kWh/m^2 = 4.8 PSH

▶ **The amount of solar energy collected on a surface over 8 hours is 4 kWh/m^2. What is the average solar power received over this period?**

◆ 4 kWh/m^2 / 8 hours = 0.5 kW/m^2 = 500 W/m^2

▶ **A PV system produces 6 kW AC output at peak sun and average operating temperatures. How much energy is produced from this system per day if the solar energy received on the array averages 4.5 peak sun hours?**
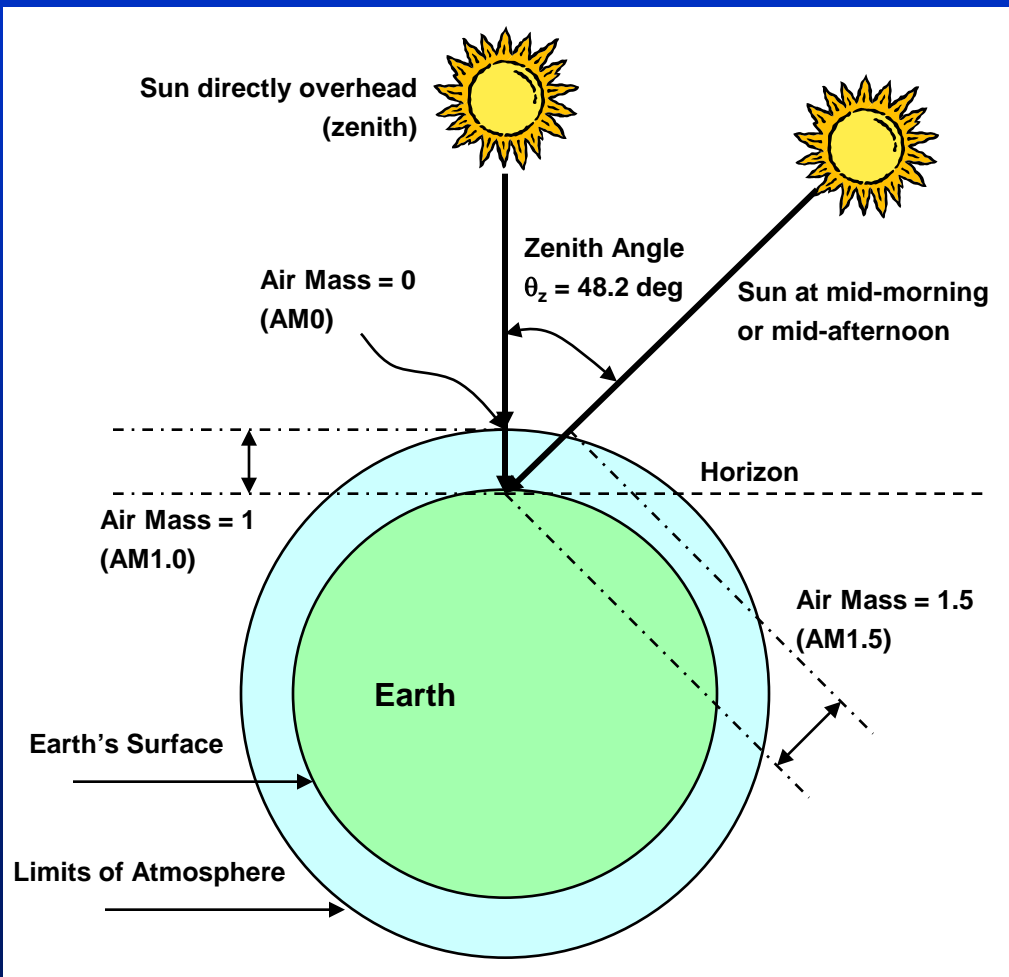
◆ 6 kW x 4.5 hours/day = 27 kWh/day

Atmospheric Effects

▶ **Approximately 30% of extraterrestrial solar power is absorbed or reflected by the atmosphere before reaching the earth's surface.**

♦ Effects vary significantly with altitude, latitude, time of day and year, air pollutants, weather patterns and wavelength of solar radiation.

▶ *Direct beam (normal) radiation* **is the component of total global solar radiation incident on a surface normal to the sun's rays, that travels in parallel lines directly from the sun.**

▶ *Diffuse radiation* **is the component of the total global solar radiation incident on a surface that is scattered or reflected.**

♦ May also include ground reflected radiation (albedo).

▶ *Total global solar radiation* **is comprised of the direct, diffuse and reflected components (albedo).**

Atmospheric Effects

Parallel rays from sun

Sun

Reflection

Solar Constant = 1366 W/m²

Outer Limits of Atmosphere

Atmospheric Absorption, Scattering and Reflections

Cloud Reflections

Diffuse Radiation

Direct Radiation

Diffuse Radiation

Reflected (Albedo) Radiation

Earth's Surface

TOTAL GLOBAL SOLAR RADIATION - DIRECT + DIFFUSE
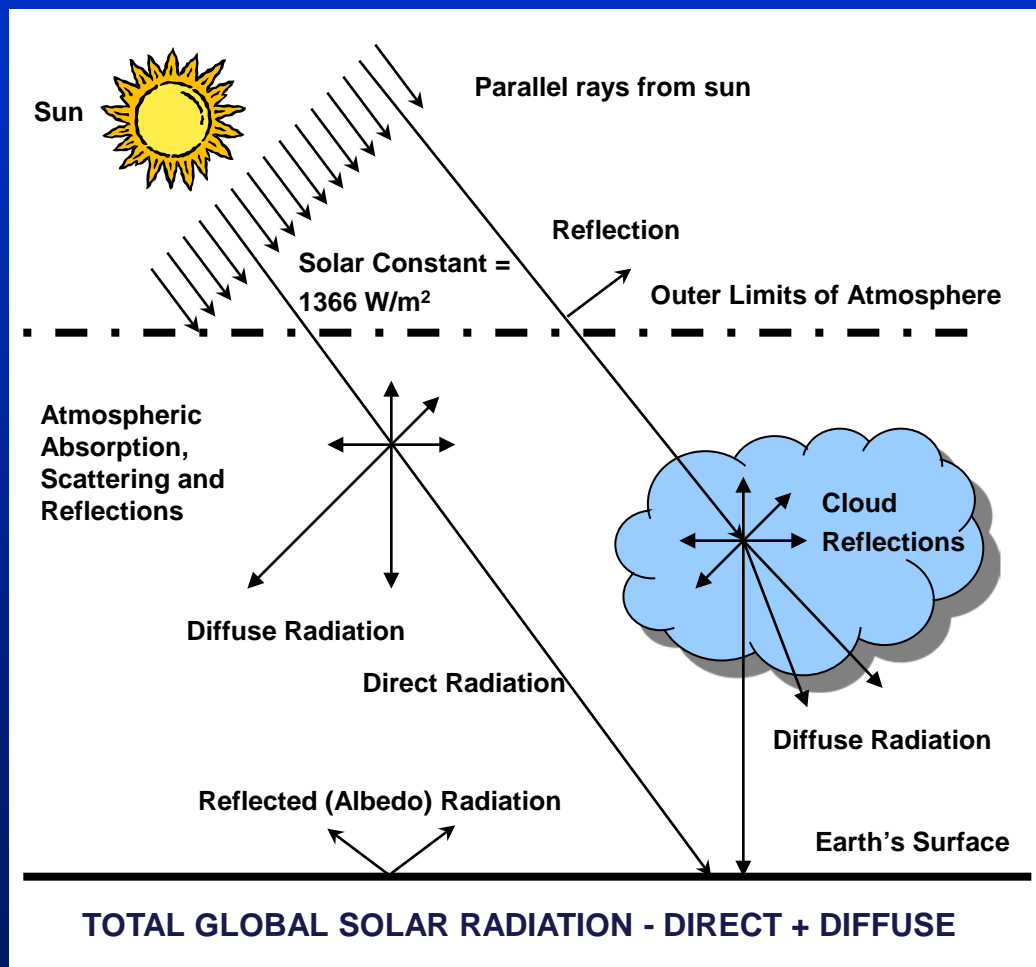
Air mass is calaculated by the following:

$$AM = \frac{1}{\cos\theta_z}\left[\frac{P}{P_o}\right]$$
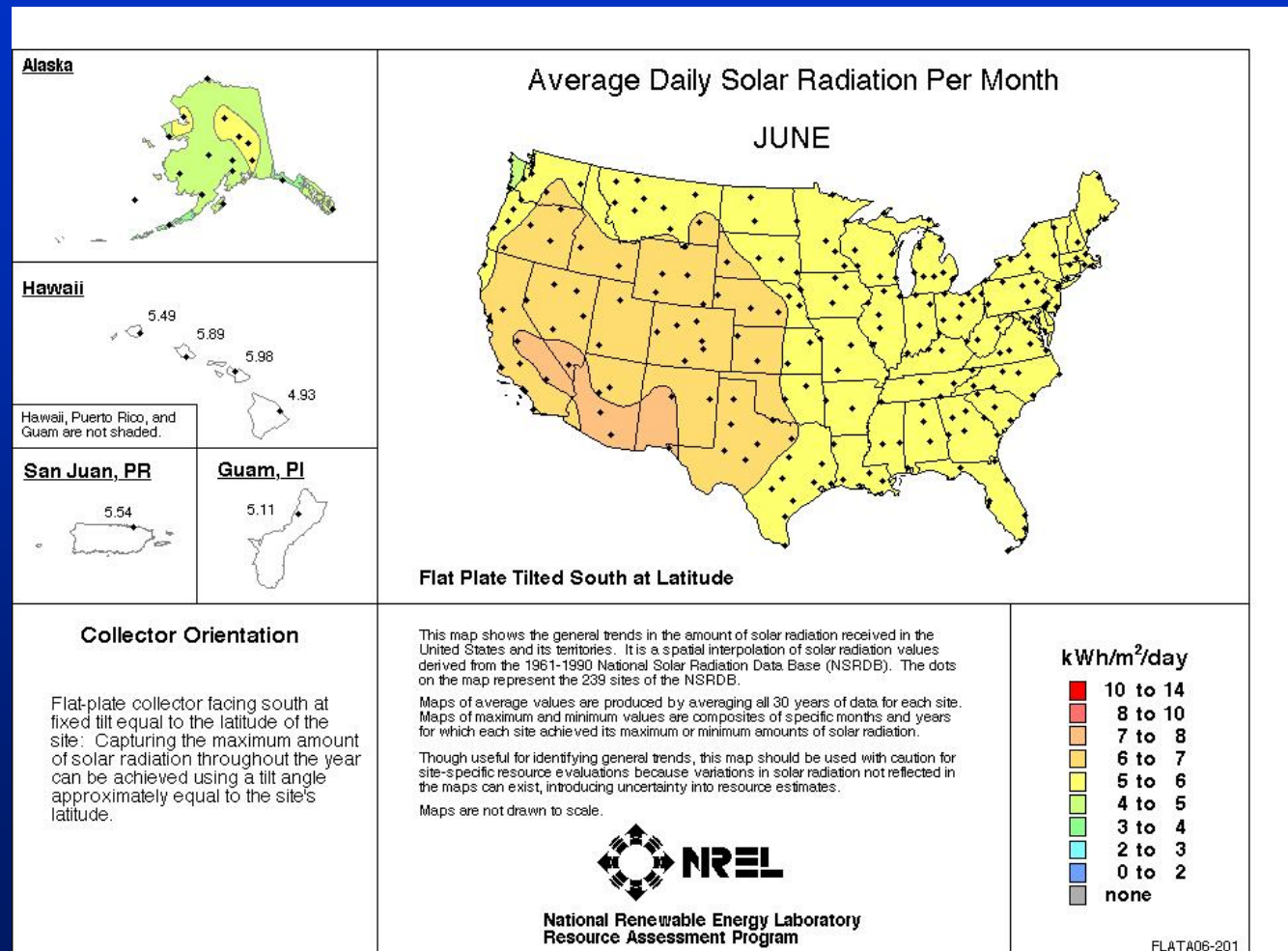
where
AM = air mass
θ_z = zenith angle (deg)
P = local pressure (Pa)
P_o = sea level pressure (Pa)

Zenith Angle:

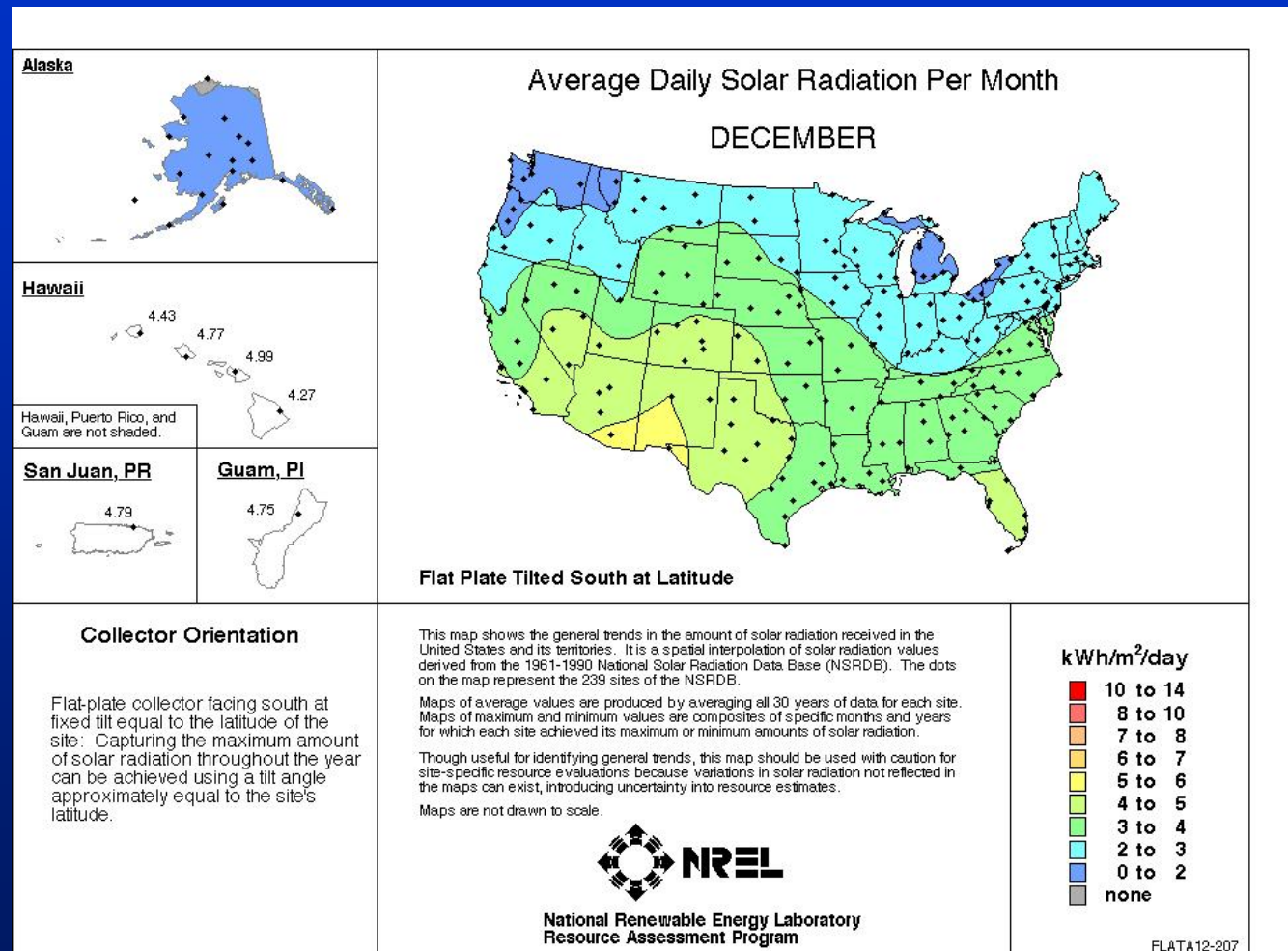$$\text{Tan } \theta z = \frac{\text{Length of shadow (l)}}{\text{Height of ruler (h)}}$$

$$\theta z = \text{arctan (l/h)}$$

Altitude Angle:

$$\text{Tan } \alpha = \frac{\text{Height of ruler (h)}}{\text{Length of shadow (l)}}$$

$$\alpha = \text{arctan (h/l)}$$

Sun

Vertical

Zenith Angle

θ_z

θ_z

Altitude Angle

α

Height of stake or ruler (h)

Horizontal Plane

Length of shadow (l)
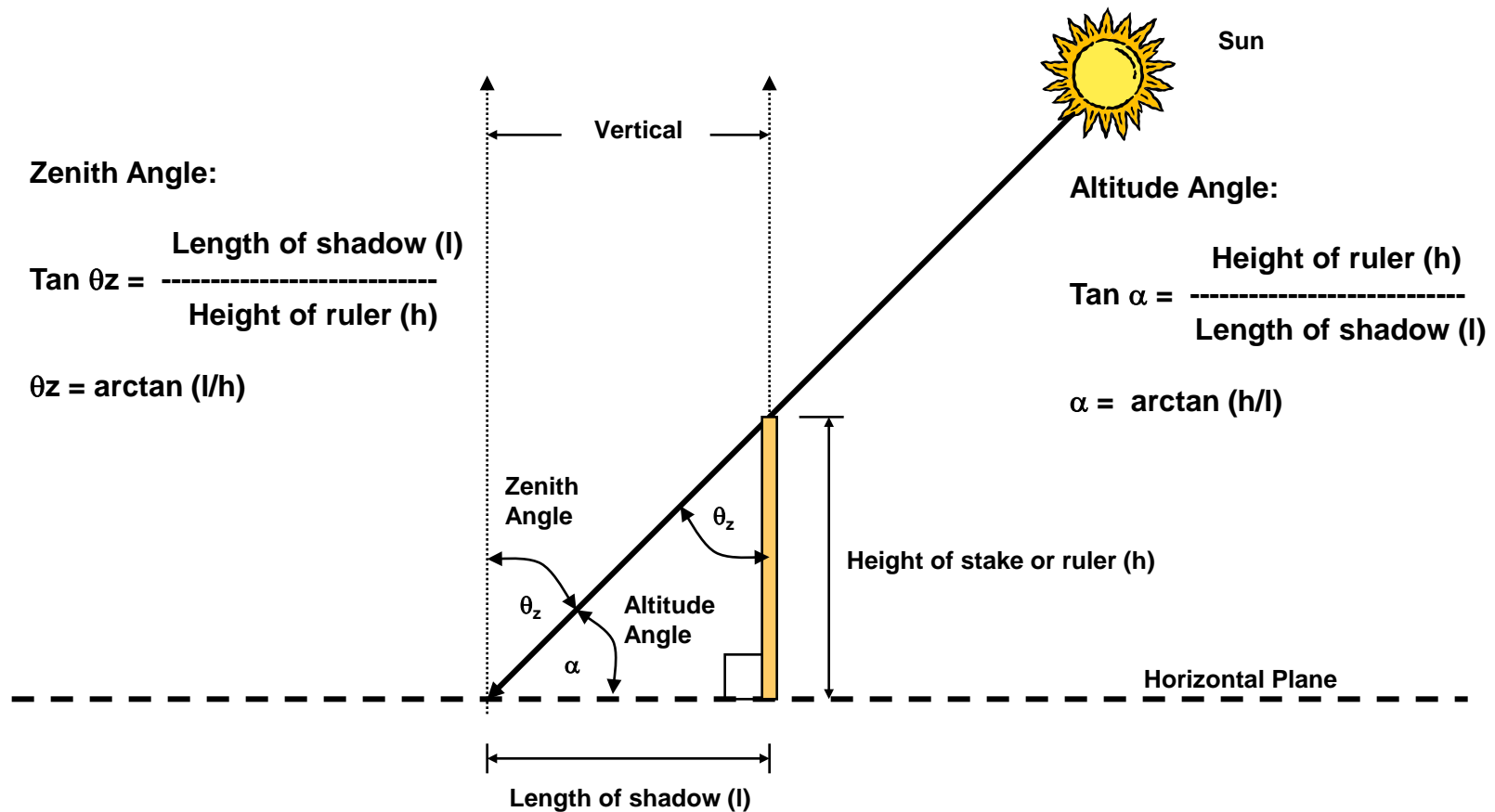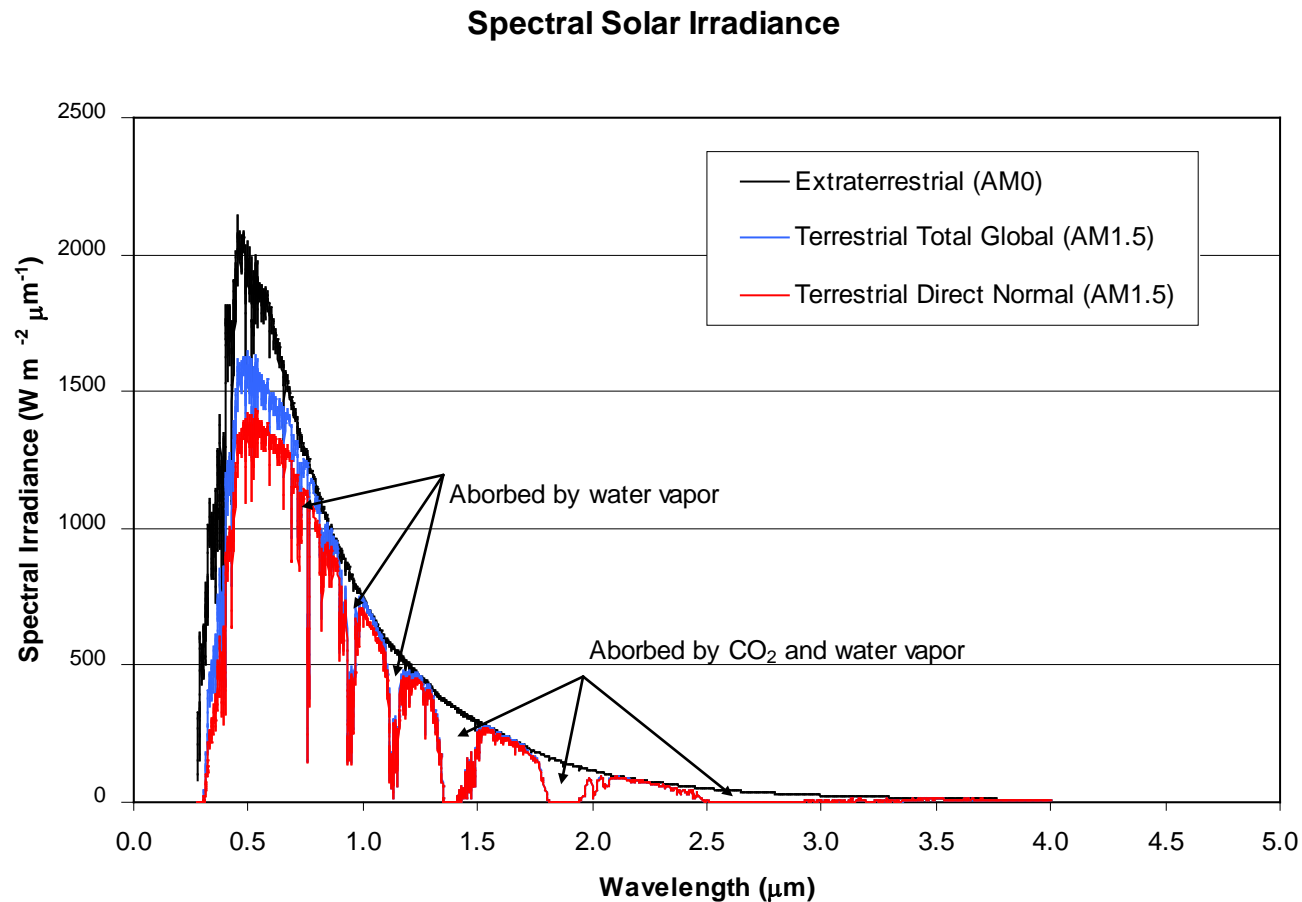
NREL

U.S. Solar Radiation Data

NREL
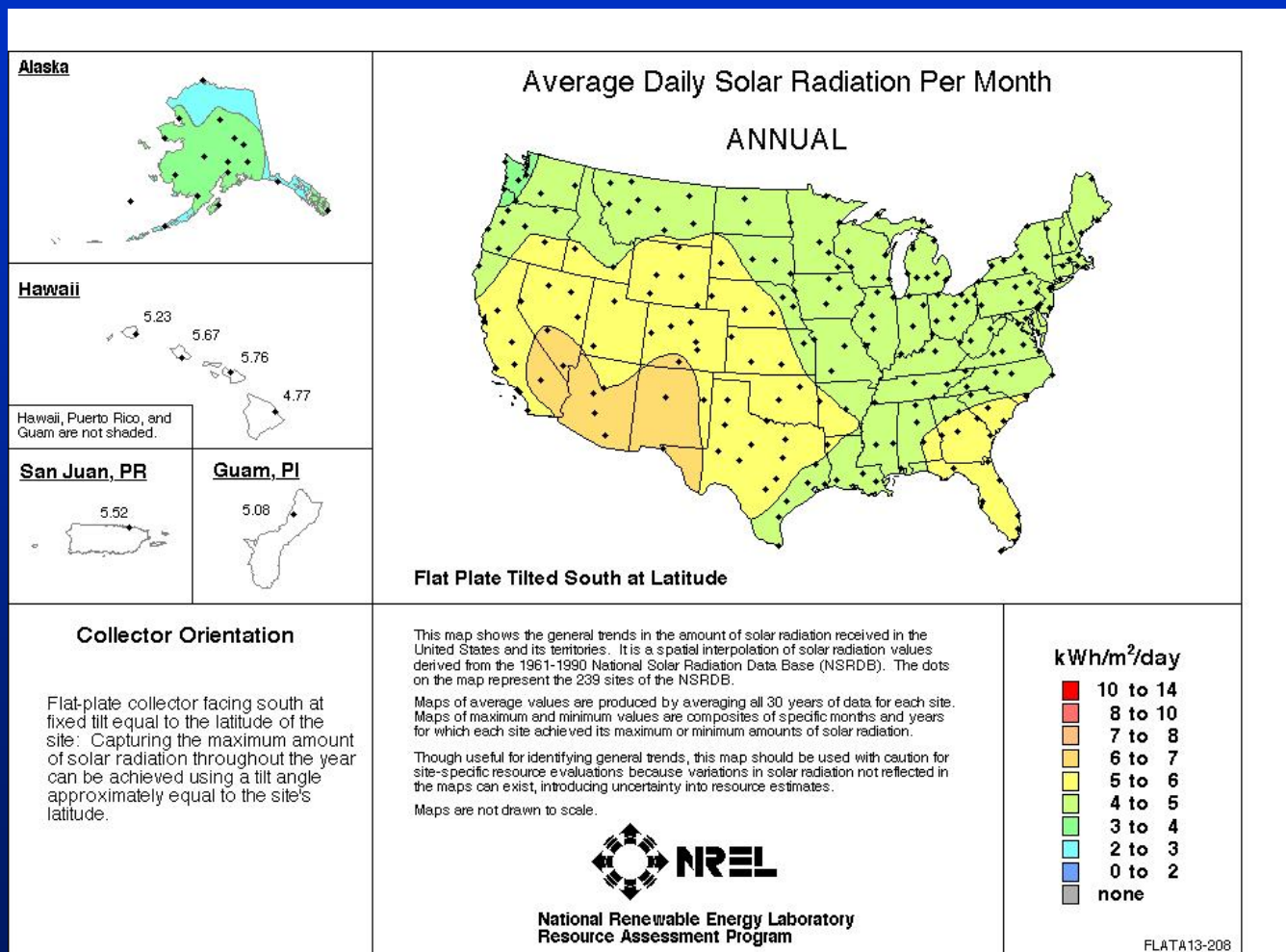
NREL

Solar Spectral Irradiance

Spectral Solar Irradiance

Solar Radiation Measurements

▶ **A *pyranometer* measures total global solar irradiance (solar power).**

- ♦ Measurements over time are integrated to calculate the total solar irradiation (solar energy) received.

▶ **Irradiance measurements are used in the field to translate the actual output of PV array and systems to a reference condition and verify performance with expectations.**

▶ **Small inexpensive meters using calibrated PV cells as sensors are available from $150 and up.**

- ♦ A small PV module with calibrated short-circuit current can also be used to approximate solar radiation levels.

Precision Spectral Pyranometer (PSP)

NREL, Steve Wilcox

▶ A *pyranometer* measures broadband global solar radiation (direct and diffuse) with a thermopile.

▶ Used for precision laboratory measurements and weather stations.

▶ Dual glass domes improve low incidence angle and thermal accuracy.

▶ $$$$

Normal Incidence Pyrheliometer (NIP)

- A *pyrheliometer* measures the direct normal component of total global solar radiation.

- Instrument must always track the sun.

- Sensor is located at the back of a long tube with a field of view of 5.7° - the width of the solar disk.

NREL/Tom Stoffer

- $$$$$

Photovoltaic Reference Cell
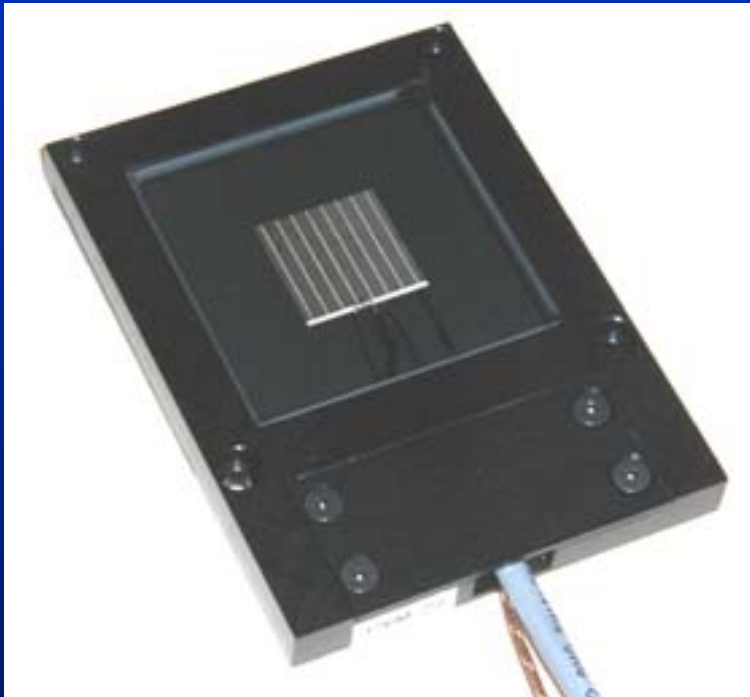
PV Measurements, Inc.

▶ A *reference cell* is a small PV device used to measure solar irradiance.

▶ Calibrated current output is proportional to solar irradiance.

▶ Used for measuring solar radiation for PV cell or module performance in indoor simulators.

LI-COR LI200 Pyranometer

▶ **Silicon pyranometers use a calibrated PV device to measure solar radiation.**

▶ **Meter sets instrument calibration, averages and integrates solar irradiance.**

▶ **Ideal for field use and long-term system performance monitoring.**

▶ **$$$**

Daystar Solar Meter

▶ **Handheld solar meters use a small PV cell to measure solar irradiance.**

▶ **Careful alignment with plane of array required for accurate measurements.**

▶ **Low cost, good for basic field measurements.**

▶ **$$$**

▶ **Measures and records solar irradiance, ambient and PV module temperatures, array orientation and tilt angles.**

▶ **200R features wireless connectivity with the PV150 Solar Installation tester, built-in data logger and USB interface.**

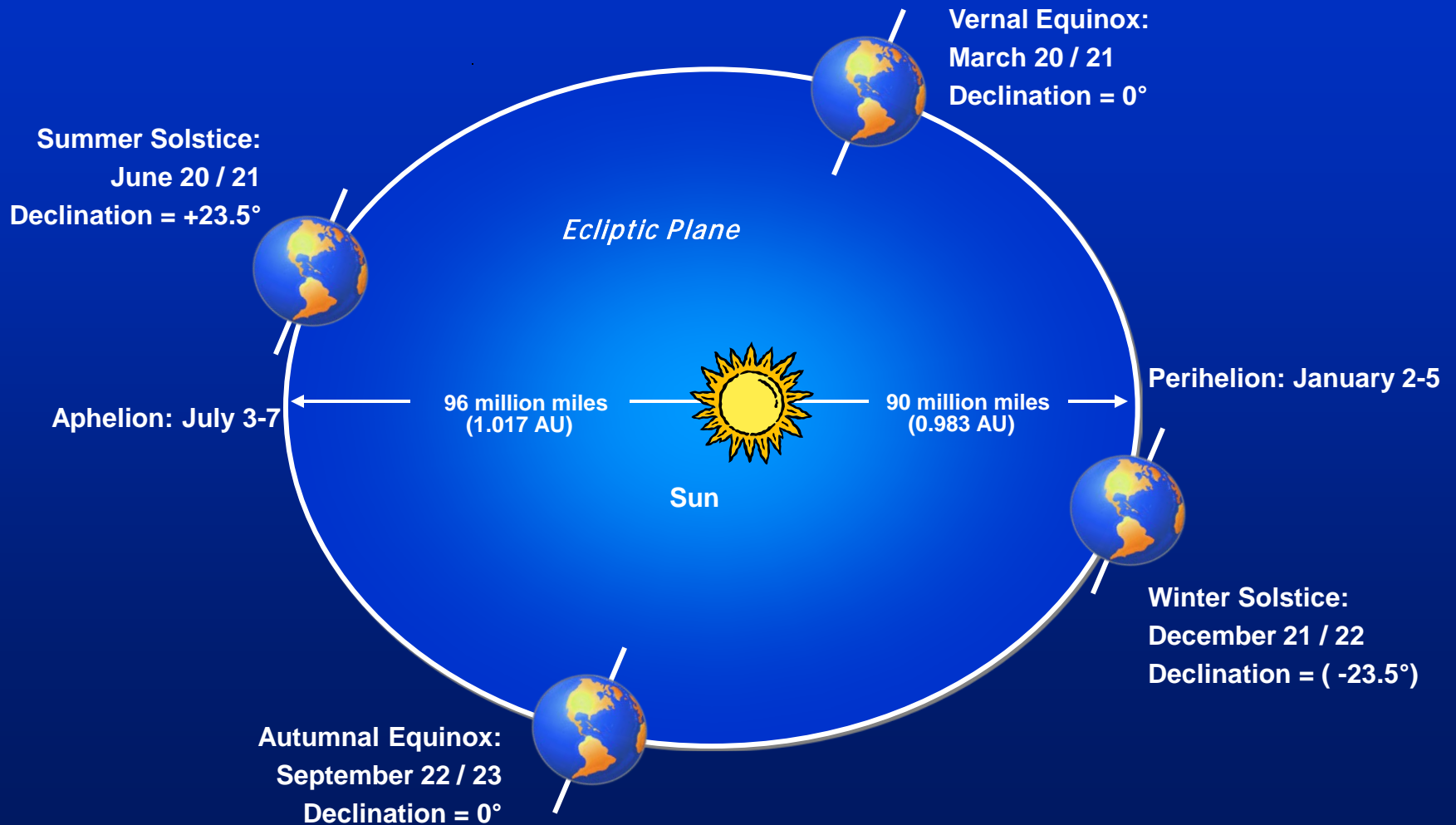▶ **See: www.seawardsolar.com**

Sun-Earth Geometric Relationships

▶ **Two major motions of the earth affect the solar radiation received on a surface at any location:**

- ♦ The rotation of the earth about its polar axis defines a day.
- ♦ The orbit of the earth around the sun defines a year.

▶ **The amount of solar radiation received at any location on earth depends on the time of day and year, the local latitude, and the orientation of the surface.**

- ♦ Also significantly affected by weather conditions.

Earth's Orbit

▶ **The *ecliptic plane* is the earth's orbital plane around the sun.**

▶ **The *equatorial plane* is the plane containing the earth's equator and extending outward into space.**

▶ **The earth's annual orbit around the sun is slightly elliptical.**
- ◆ Perihelion is the earth's closest approach to the sun in its orbit, which is about 90 million miles and occurs around January 3.
- ◆ Aphelion is the earth's furthest distance to the sun in its orbit, which is about 96 million miles and occurs around July 4.

▶ **One *Astronomical Unit (AU)* is the average sun-earth distance, which is approximately 93 million miles.**
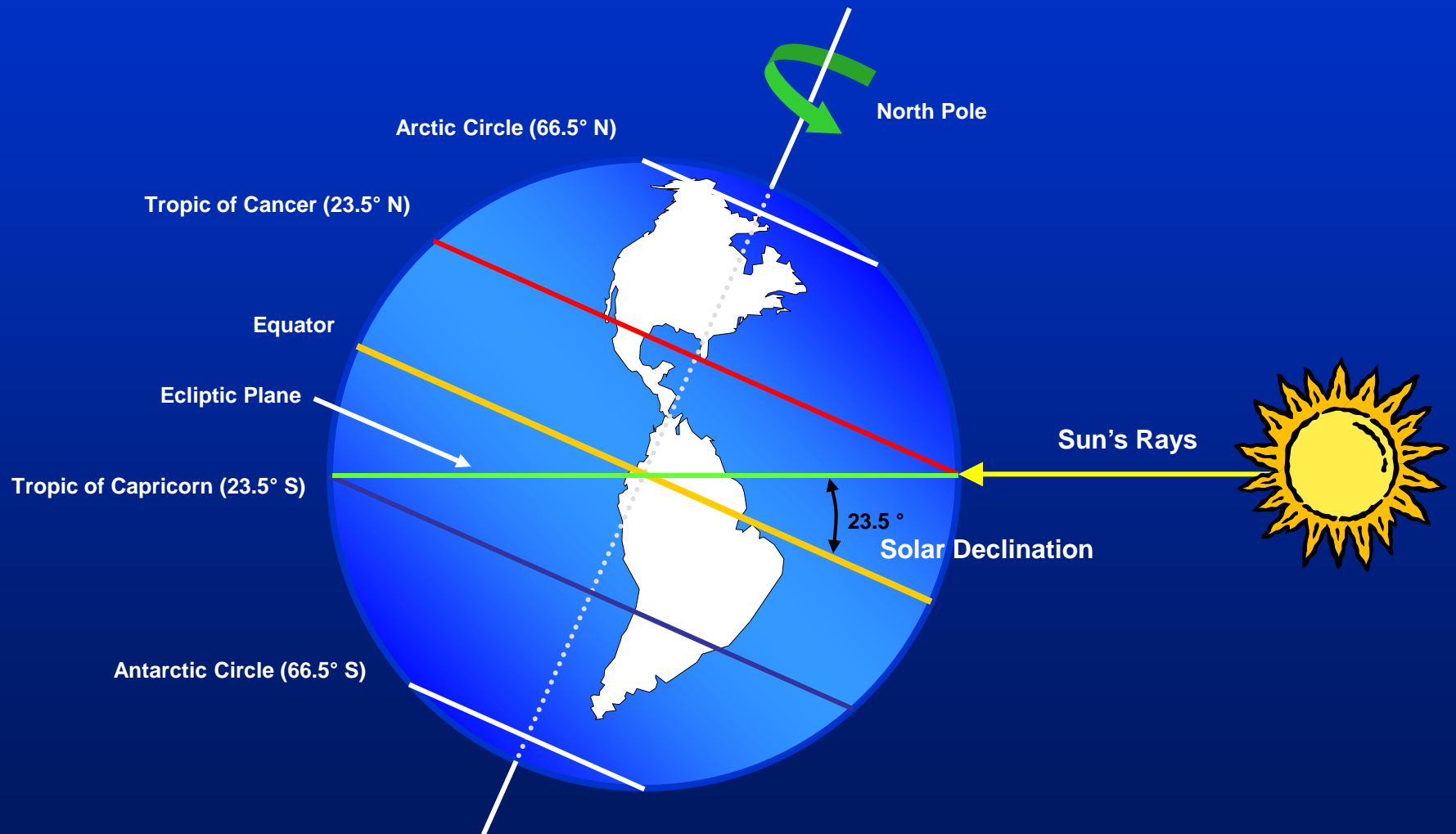
Earth's Orbit Around the Sun

Vernal Equinox:
March 20 / 21
Declination = 0°

Summer Solstice:
June 20 / 21
Declination = +23.5°

Ecliptic Plane

Aphelion: July 3-7

96 million miles
(1.017 AU)

90 million miles
(0.983 AU)

Perihelion: January 2-5

Sun

Winter Solstice:
December 21 / 22
Declination = (-23.5°)

Autumnal Equinox:
September 22 / 23
Declination = 0°

Earth's Polar Axis Tilt

▶ **The earth's polar rotational axis is tilted at a constant 23.5° angle with respect to the ecliptic plane.**

▶ **During its annual orbit around the sun, the earth's polar axis is never perpendicular to the ecliptic plane, but it is always inclined to it at the same angle, 23.5°.**

▶ **This results in a constantly varying angle between the earth's equatorial plane and the ecliptic plane as the earth orbits the sun over a year.**

▶ **Except at the equinoxes, the earth's axis is tilted either toward or away from the sun, causing the change in seasons.**

Solar Declination

▶ *Solar declination (δ)* **is the angle between the earth's equatorial plane and the sun's rays.**

▶ **Solar declination varies continuously in a sinusoidal fashion over the year due the earth's nearly circular orbit around the sun.**

▶ **Solar declination varies from −23.5° to +23.5°, and defines the limits of sun position in the sky relative to any point on earth.**
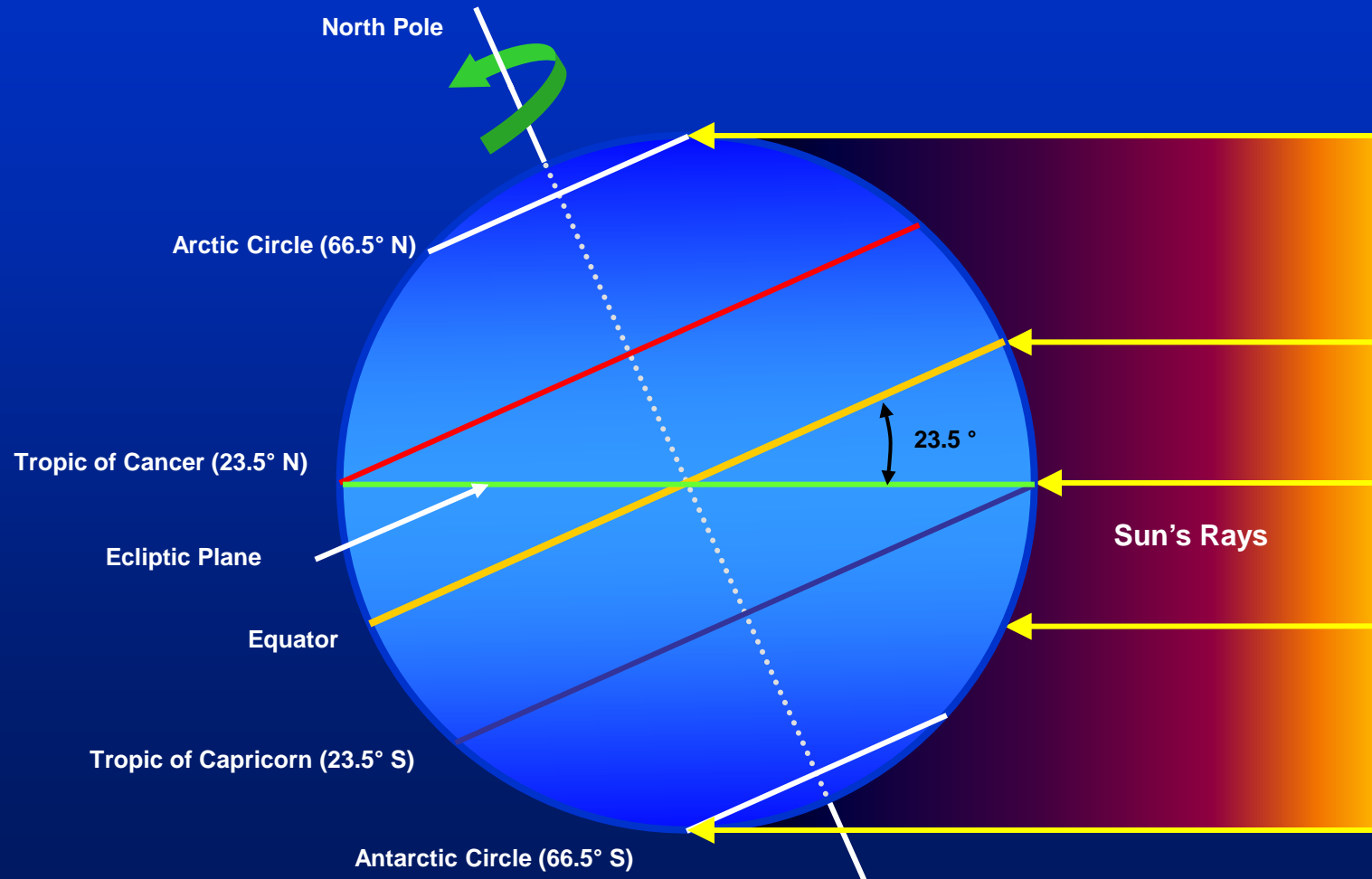
Solar Declination

Solar Declination

Solar Declination

Summer Solstice
June 21

Vernal Equinox
March 21

Autumnal Equinox
September 22

Winter Solstice
December 21

Solar Declination (deg)

Julian Day (1-365)
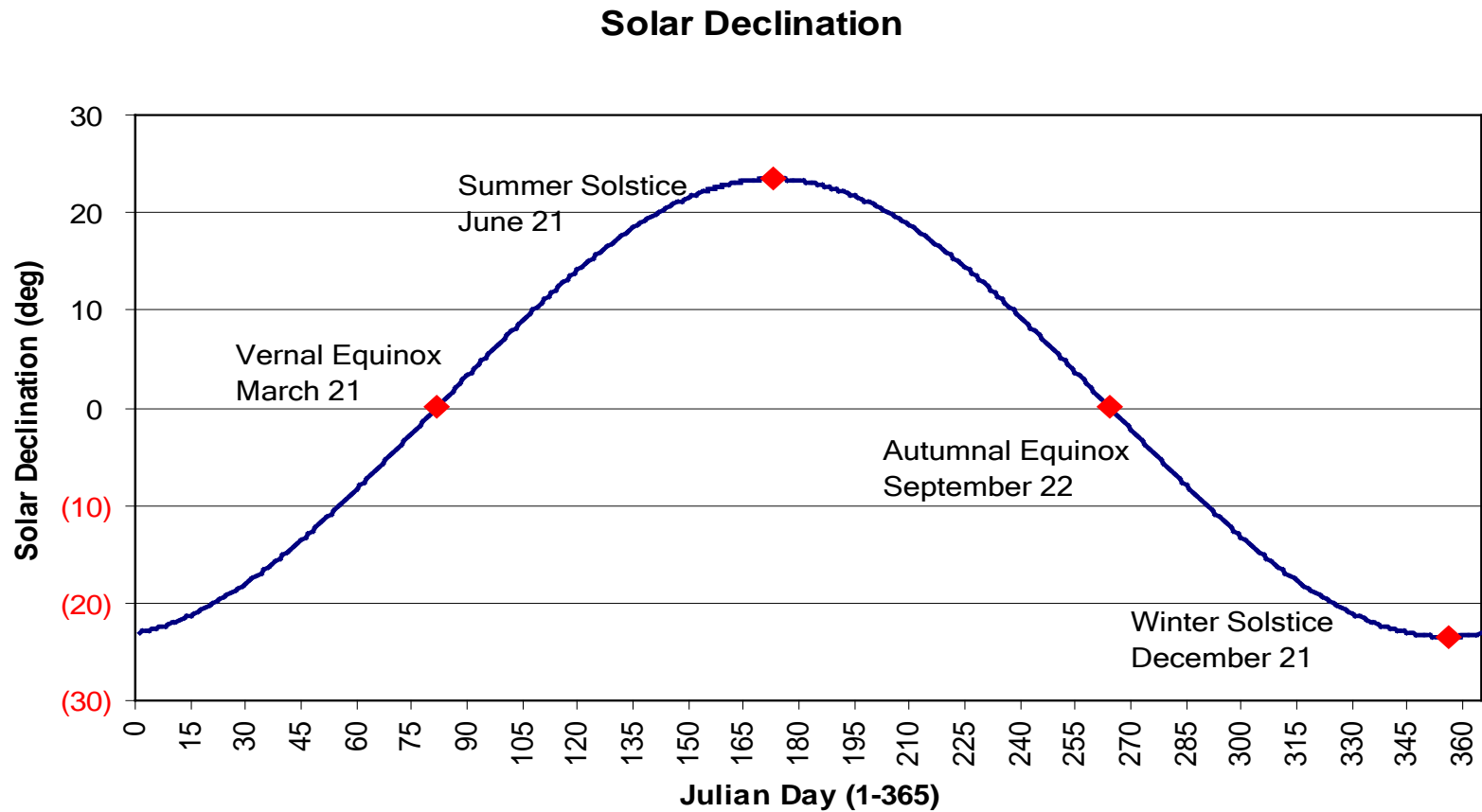
The Solstices

▶ The *solstices* define the points in earth's orbit around the sun having maximum and minimum solar declination.

▶ The solstices occur when the earth's axis is inclined at the greatest angle either toward or away from the sun, and defines the annual range of sun position relative to any point on earth.

▶ The *winter solstice* occurs on December 21 or 22 when solar declination is at its minimum (-23.5°) and the Northern Hemisphere is tilted away from sun.
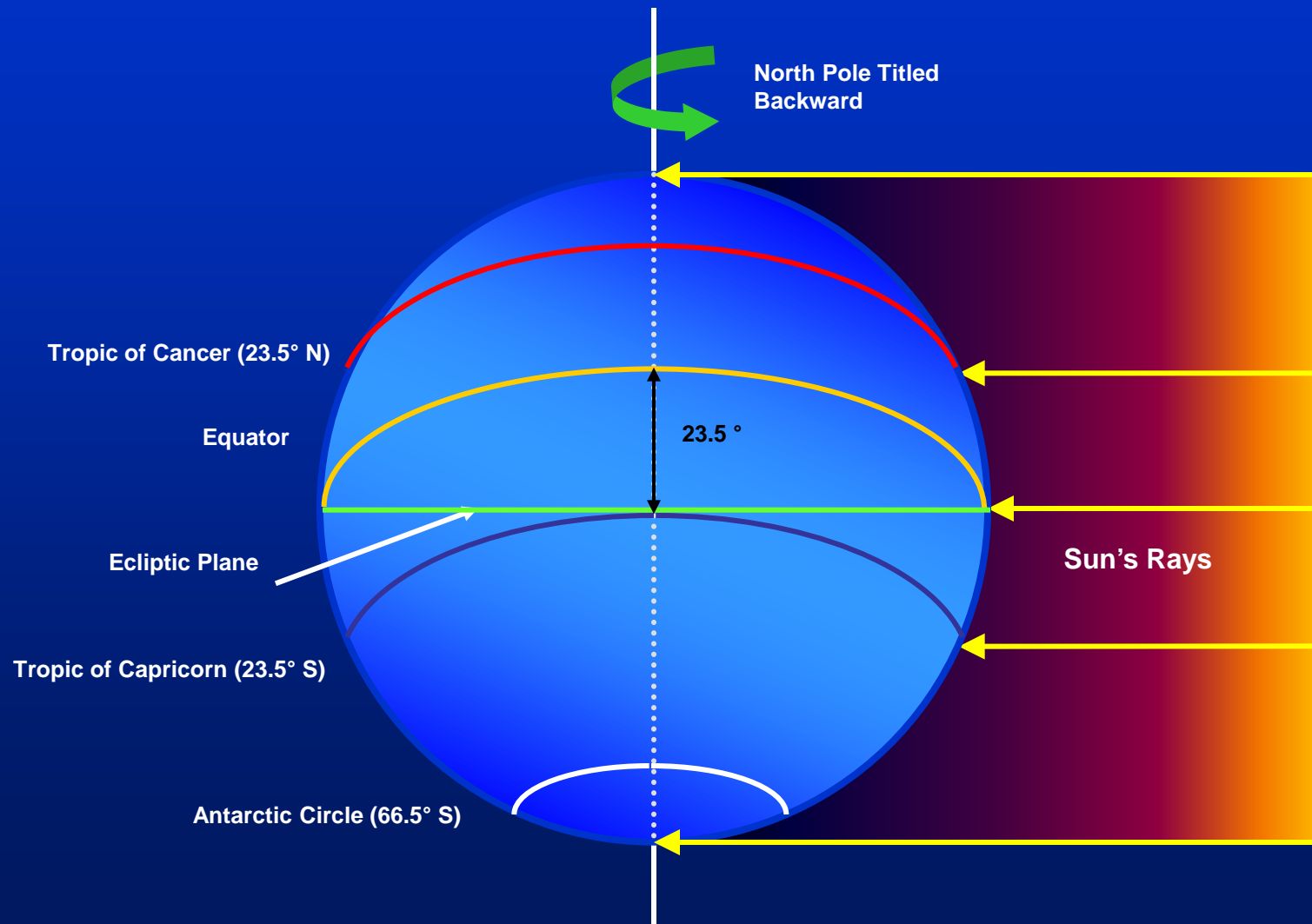
▶ The *summer solstice* occurs on June 21 or 22 when solar declination is at its maximum (23.5°), and the Northern Hemisphere is tilted towards the sun.

The Equinoxes

► **The *equinoxes* define the two points in earth's orbit around the sun having zero solar declination.**

► **On the equinoxes, the earth's axis is neither tilted toward or away from the suns rays, but is perpendicular.**
   ♦ The sun rises and sets due east and west, respectively, and days and nights equal length (12 hours) everywhere on earth.
   ♦ The sun is directly overhead at solar noon on the equator (at zenith).

► **The *vernal equinox* occurs on March 20 / 21.**
   ♦ Days become longer than nights in Northern Hemisphere for next six months.

► **The autumnal equinox occurs on September 22 / 23.**
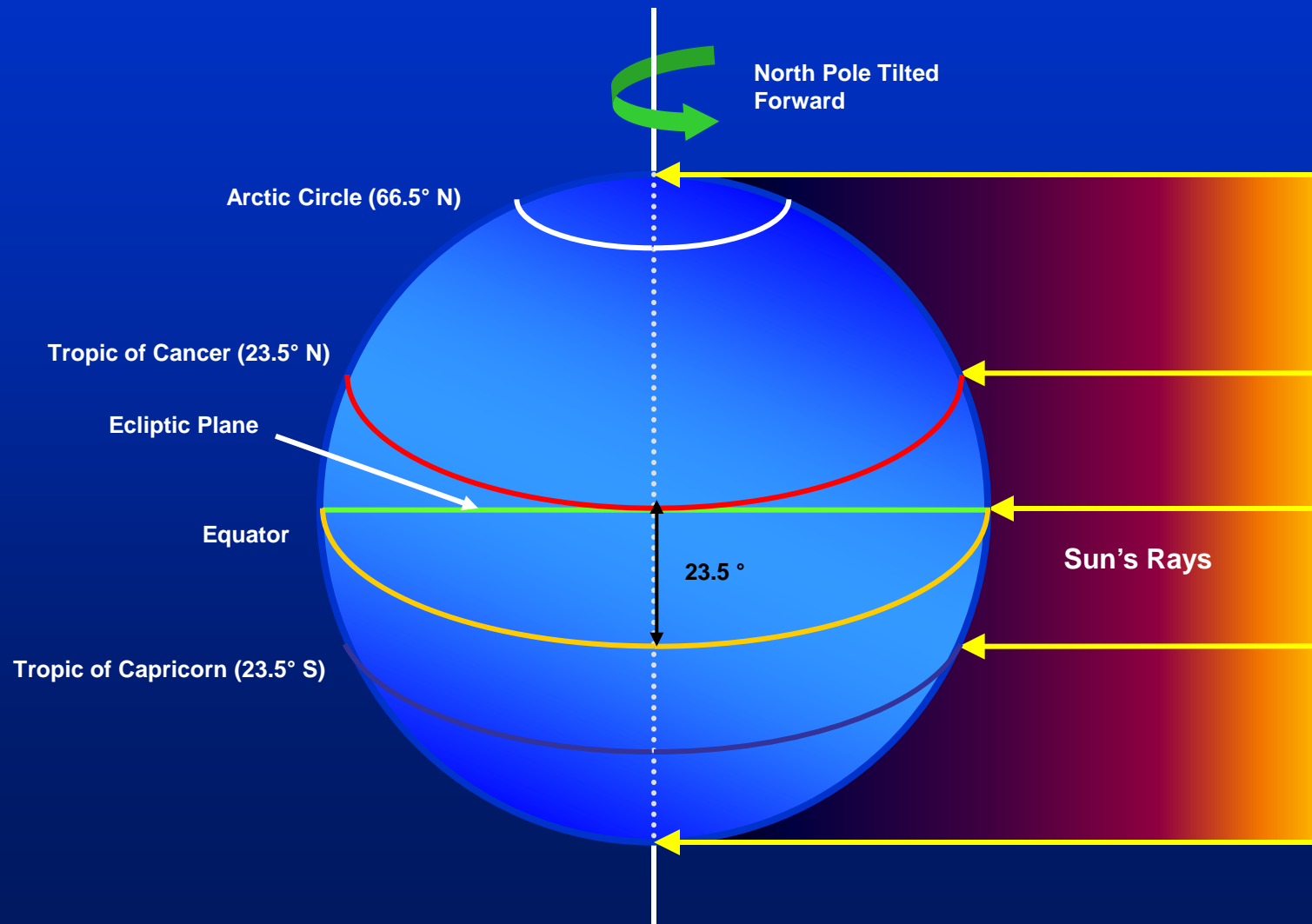   ♦ Days become shorter than nights in the Northern Hemisphere for next six months.

North Pole

Arctic Circle (66.5° N)

Tropic of Cancer (23.5° N)

Ecliptic Plane

Equator

Tropic of Capricorn (23.5° S)

Antarctic Circle (66.5° S)

23.5 °

Sun's Rays

Summer Solstice

Autumnal Equinox

North Pole Tilted Forward

Arctic Circle (66.5° N)

Tropic of Cancer (23.5° N)

Ecliptic Plane

Equator

23.5 °

Tropic of Capricorn (23.5° S)

Sun's Rays
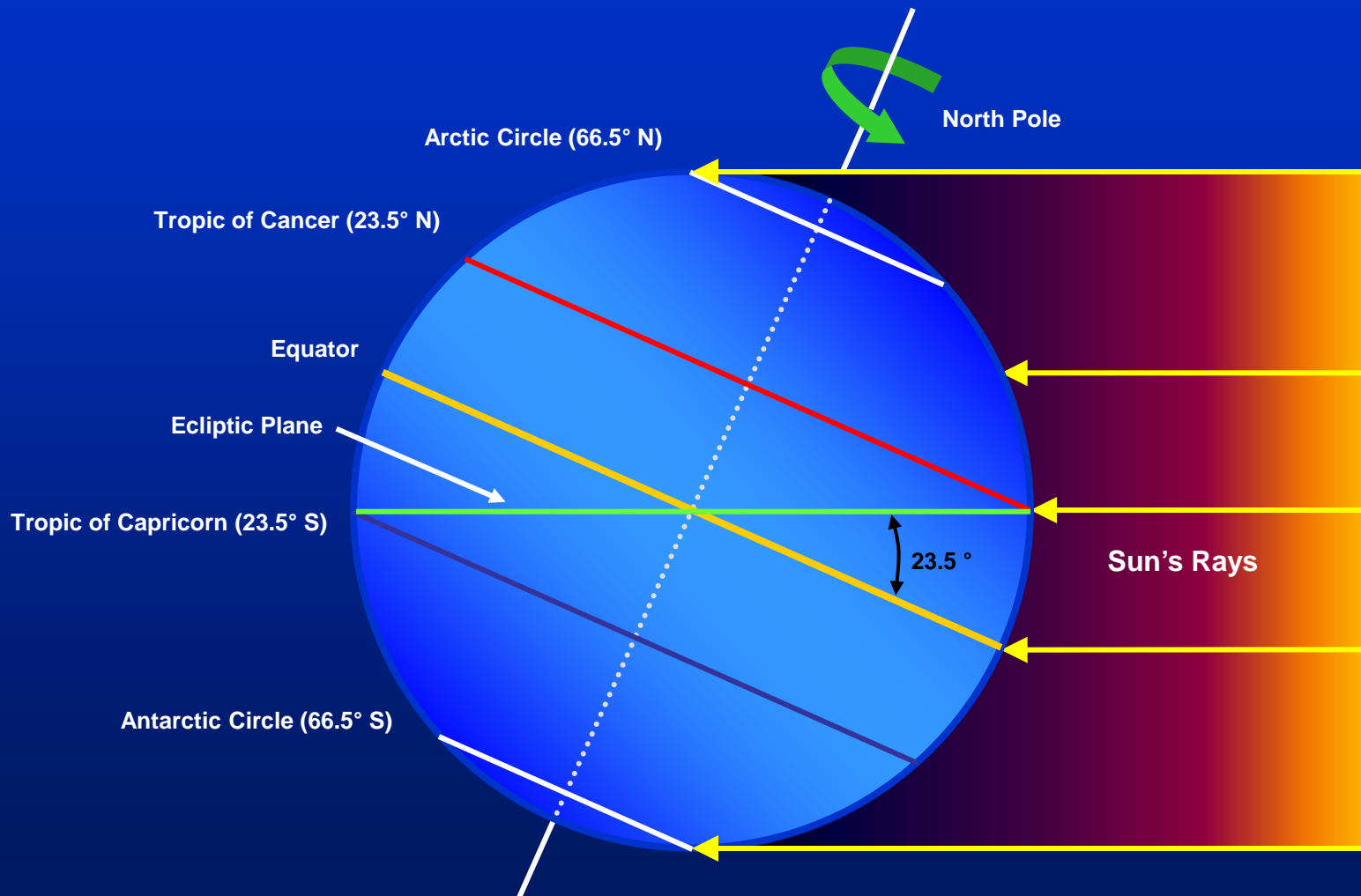
Solar Time

▶ *Apparent solar time* is based on the interval between daily sun crossings above a local meridian. Apparent solar time can be measured by a sundial.

▶ *Mean solar time* is based on the average position of the sun assuming the earth rotates and orbits at constant rates.

▶ The *equation of time (EOT)* is the difference between mean and apparent solar time.

♦ EOT varies annually with apparent time ahead of mean solar time by about 16.5 min on November 3, or behind by about 14 min on February 12.

♦ Due to changing speed of earth at points in elliptical orbit around sun.

Equation of Time
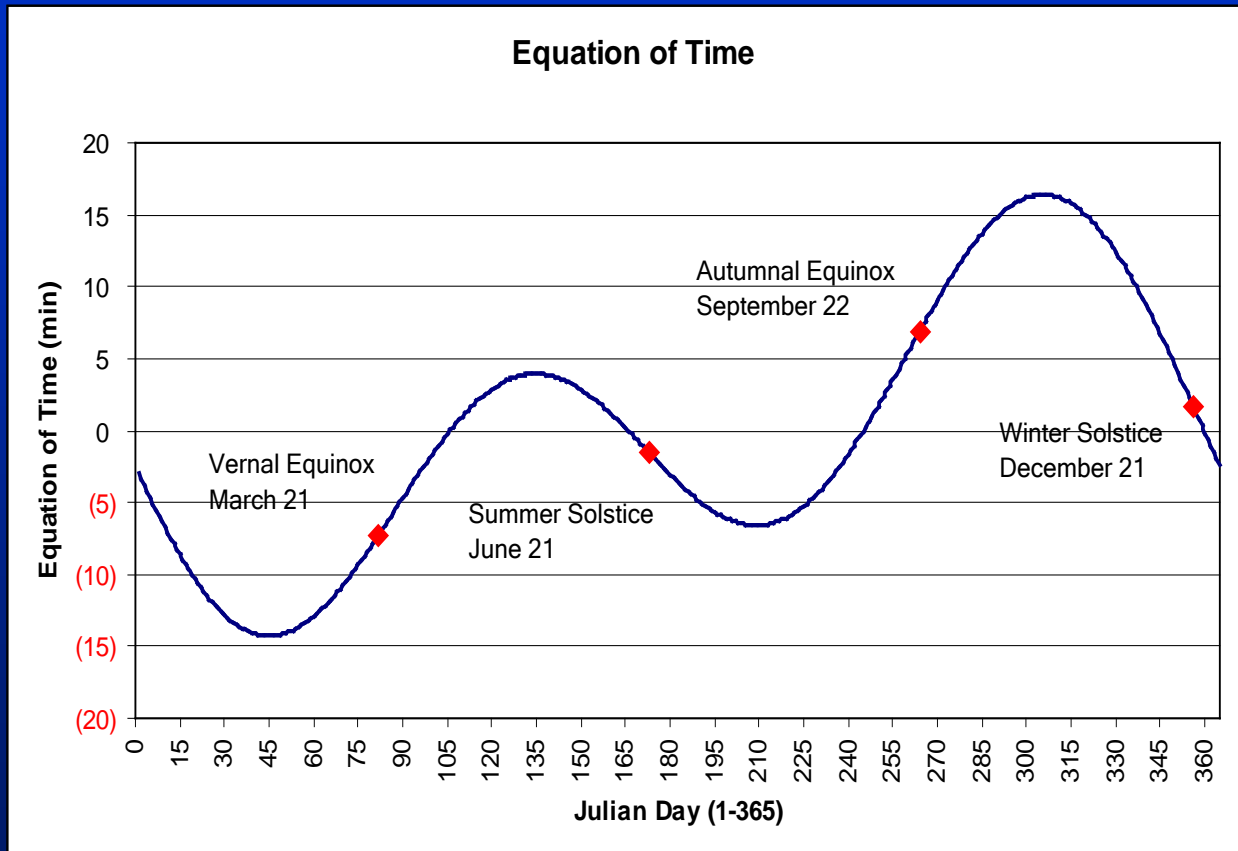
Standard Time and Time Zones

▶ *Coordinated Universal Time (UTC)* **is based on an atomic clock and mean solar time at the Royal Observatory in Greenwich, London, UK.**

♦ The prime meridian passes through Greenwich and is arbitrarily taken as 0° longitude.

▶ *Standard time* **is based on sun crossing reference meridians or geographical boundaries, generally separated by 15° of longitude.**

♦ Local standard time is referenced to UTC
♦ Eastern Standard Time is UTC-5 hours (UTC-4 during Daylight Savings Time)

▶ **UTC varies from local solar time by as much as +/- 45 min depending on the day of year, whether Daylight Savings Time is in effect, and longitude of the specific location with respect to the reference time zone meridian.**

U.S. Time Zones

UTC with no Daylight Savings Time

Alaska
UTC-9

Hawaii
UTC-10

Guan
UTC+10

Pacific
UTC-8

Mountain
UTC-7

Samoa
UTC-11

Central
UTC-6

Eastern
UTC-5

Atlantic
UTC-4

PACIFIC TERRITORIES
(APPROX. SCALE)
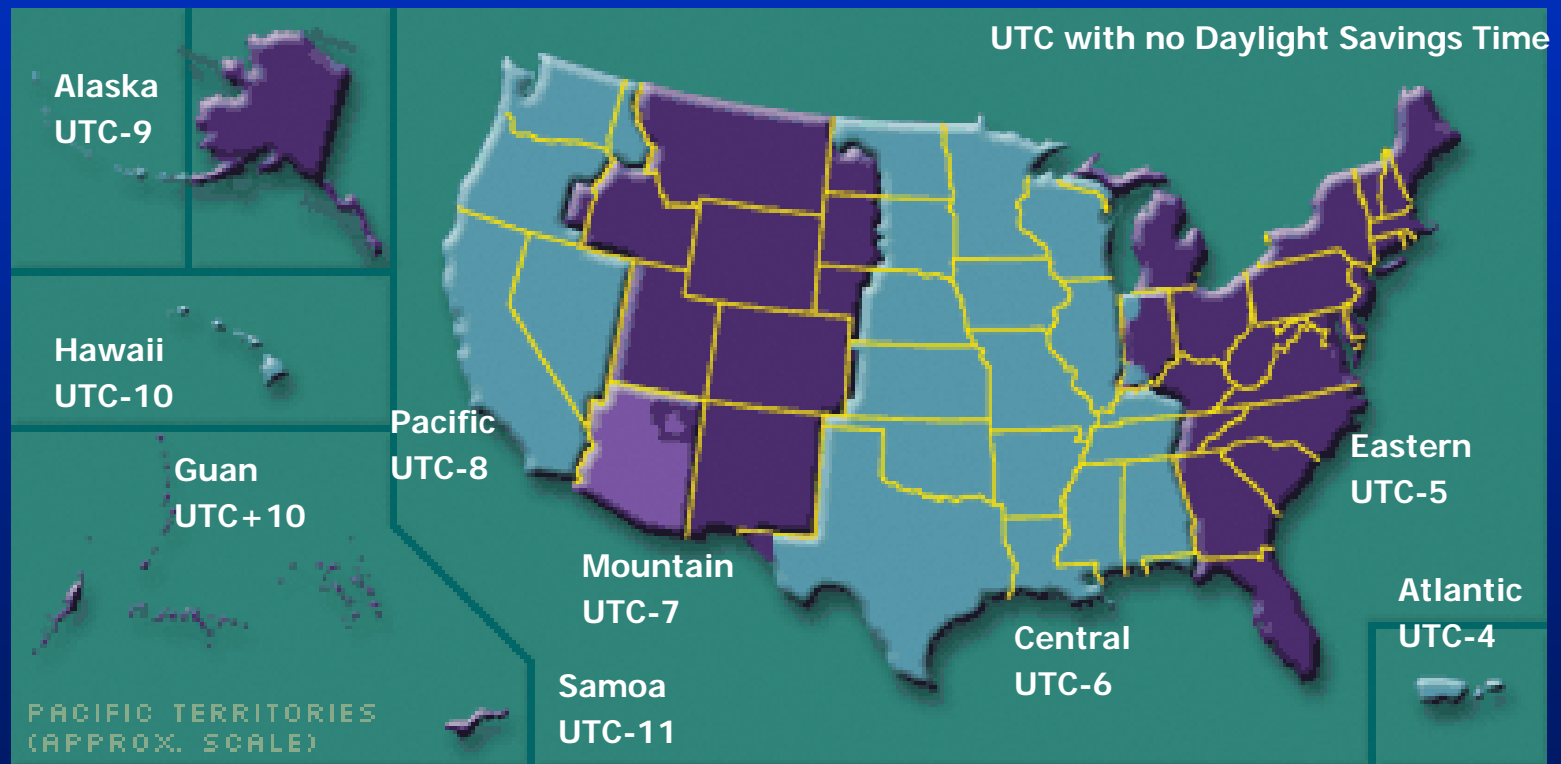
NIST/USNO

Solar and Standard Time Conversions

Example: Determine the local standard time that solar noon occurs on November 3 in Atlanta, GA (33.65° N, 84.43° W) .

The adjustment for longitude is determined by:

$$t_L = (L_{local} - L_S) \times 4$$

where

$t_L = $ *longitude time correction (min)*

$L_{local} = $ *local longitude (deg)*

$L_S = $ *longitude at standard meridian (deg)*

$$t_L = (84.43 - 75) \times 4 = 37.7 \ min = 37{:}43 \ mm{:}ss$$

Local standard time of solar noon is determined by:

$$t_S = t_0 - t_E + t_L$$

where

$t_S = $ *local standard time (hh:mm:ss)*

$t_0 = $ *solar time (hh:mm:ss)*

$t_E = $ *Equation of Time (mm:ss)*

$$t_S = 12{:}00{:}00 - (00{:}16{:}30) + (00{:}37{:}43) = 12{:}21{:}13 \ EST$$

Sunlight on Earth

Day   Night

Near Equinox

Near Summer Solstice

Night   Day

NIST/USNO

Analemma

Summer Solstice
June 21

Jul 21   May 21

Aug 21   Apr 21

Vernal Equinox
March 21

Autumnal Equinox
September 22

Feb 21   Oct 21

Jan 21   Nov 21

Winter Solstice
December 21

Solar Declination (deg)

<< Sun Slow <<   Equation of Time (min)   >> Sun Fast >>
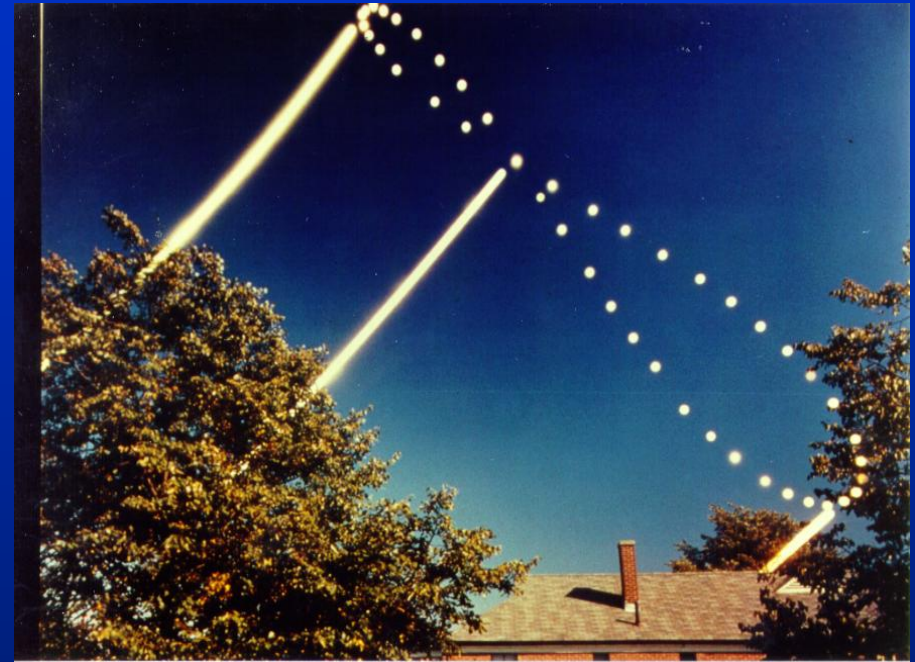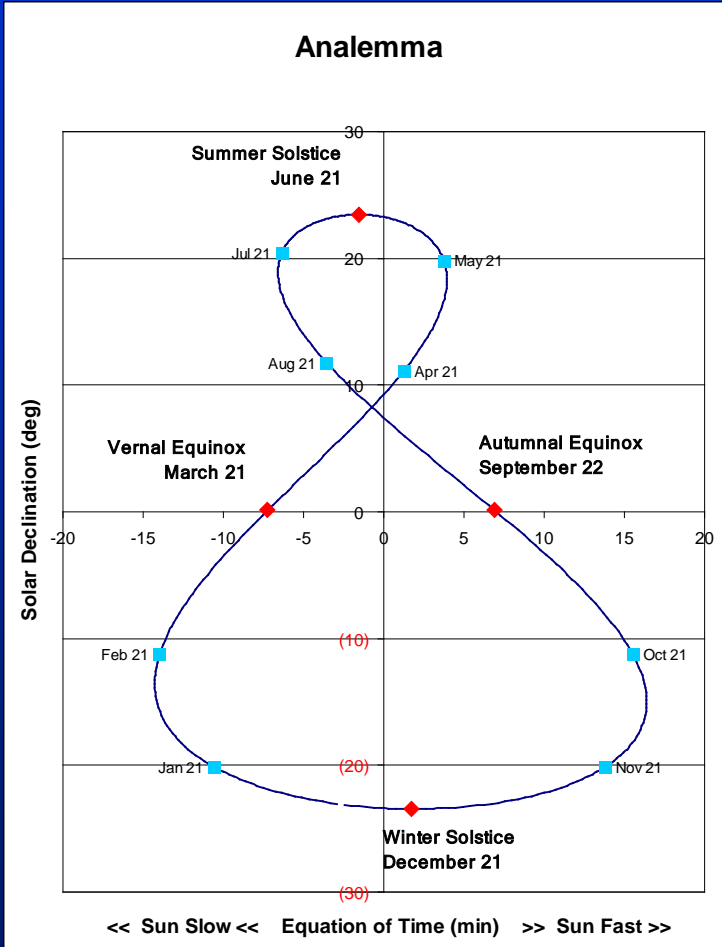
FSEC

This Analemma was created by superimposing photographs of the sun taken in the morning at the same clock time, each week of the year, and represents the variation in solar declination and the equation of time over the year.

Sun Position

▶ **The sun's position in the sky at any moment relative to an observer on earth is defined by two angles.**

▶ **The *solar altitude angle (α)* is the angle between the sun's rays and the horizon.**

▶ **The *solar azimuth angle (θ_z)* is the angle between the horizontal projection of a the sun's rays and geographic due south.**

▶ **The zenith angle is the angle between the line to the sun and directly overhead.**

  ♦ The zenith and altitude angles are complementary: $\alpha + \theta_z = 90°$
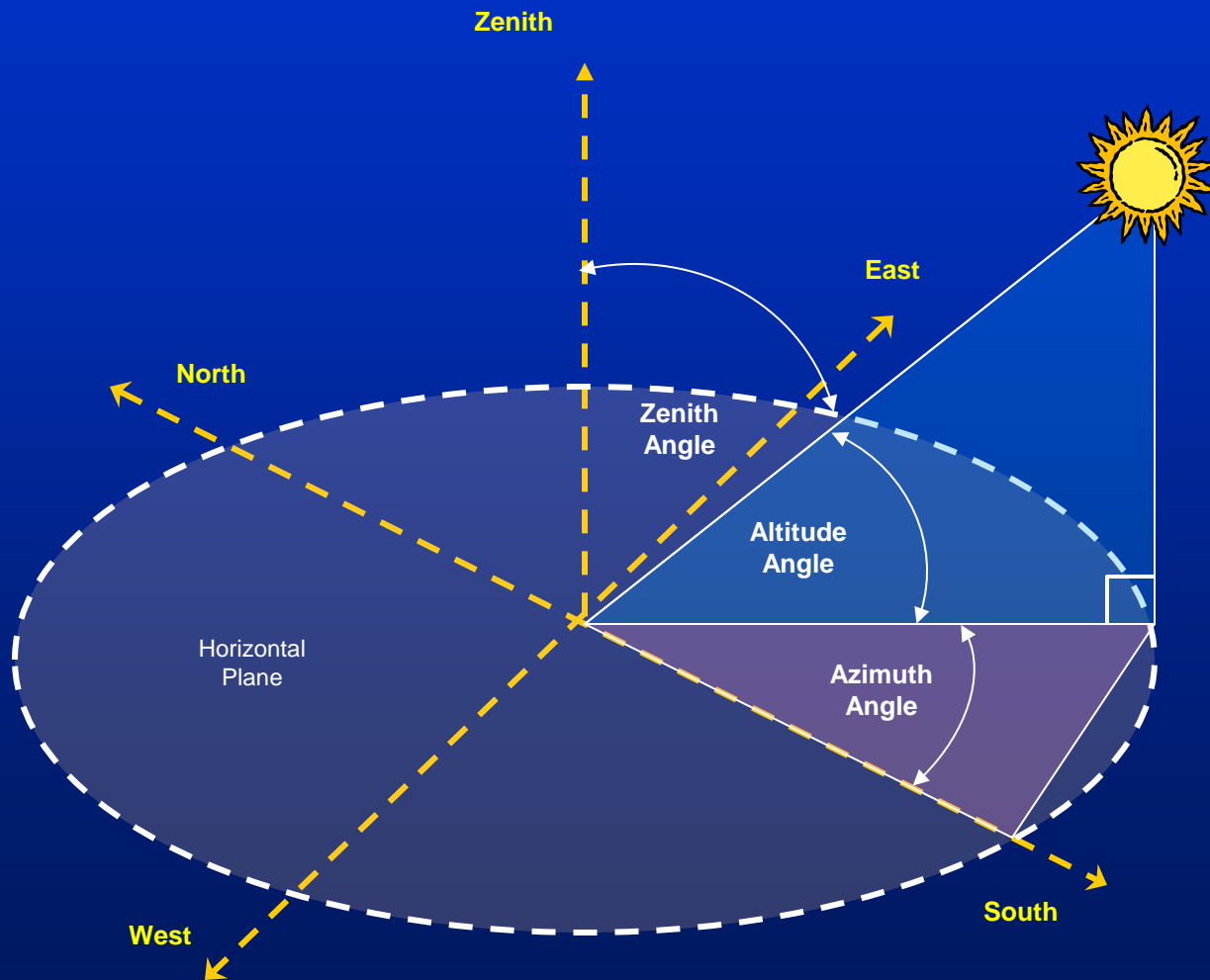
Sun Path Diagrams at the Equinoxes
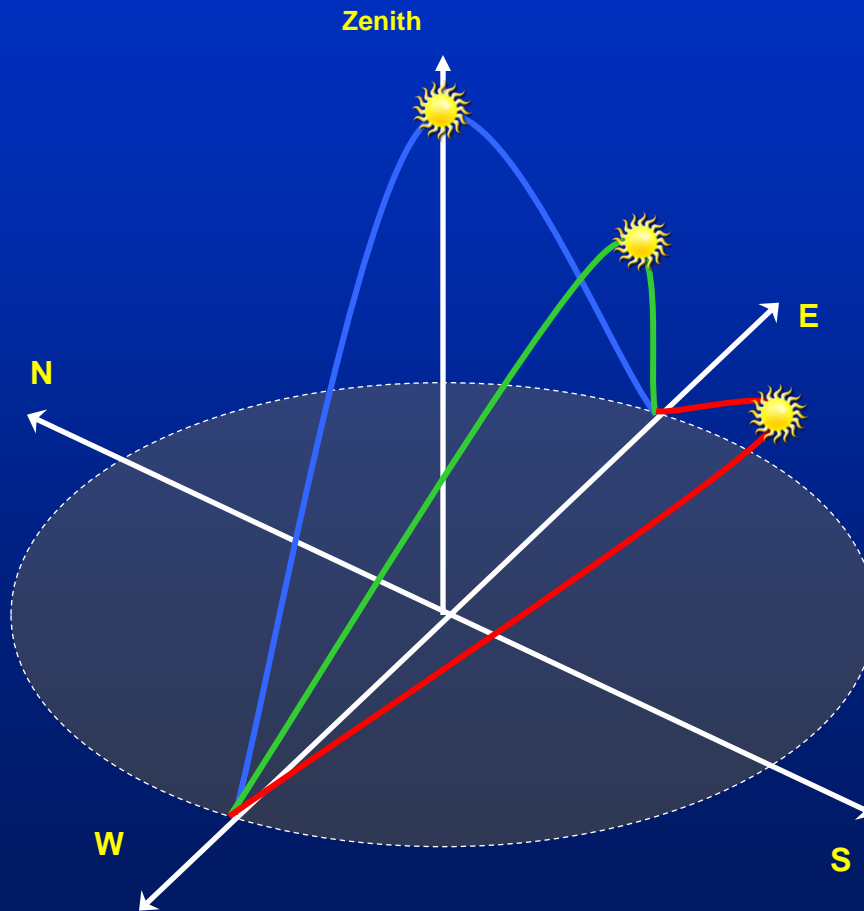
0° Latitude (Equator):
Altitude at Solar Noon = 90°

23.5° N Latitude (Tropic of Cancer):
Altitude at Solar Noon = 66.5°

47° N Latitude (Seattle, WA):
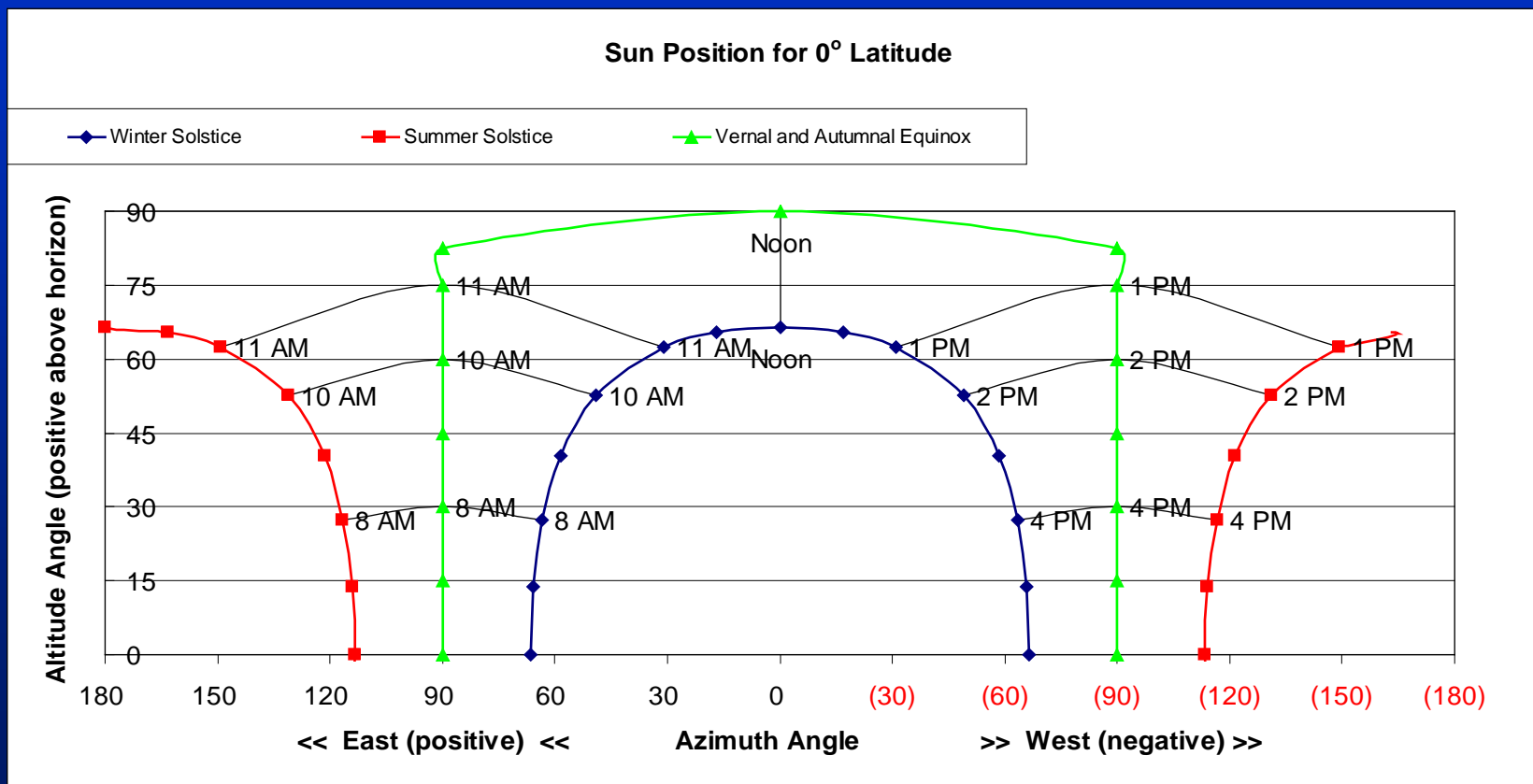Altitude at Solar Noon = 43°

Sun Path Diagrams at the Summer Solstice
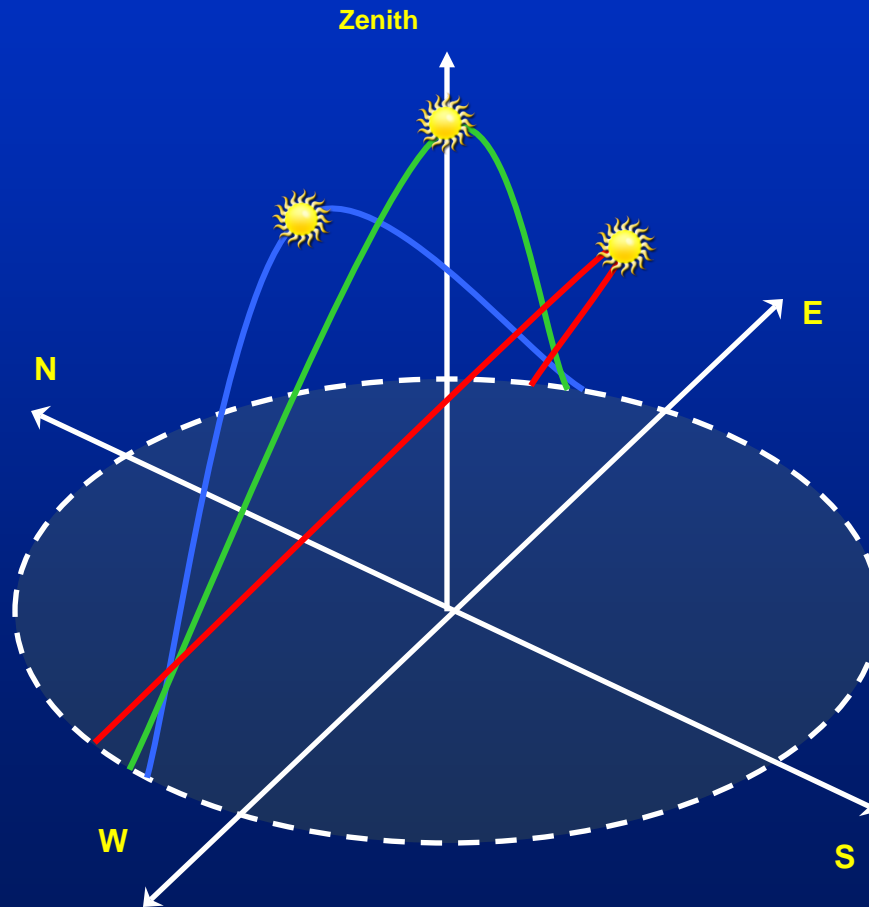
0° Latitude (Equator):
Altitude at Solar Noon = 66.5°
(Sun in Northern Sky)

23.5° N Latitude (Tropic of Cancer):
Altitude at Solar Noon = 90°
(Directly Overhead)

47° Latitude (Seattle, WA):
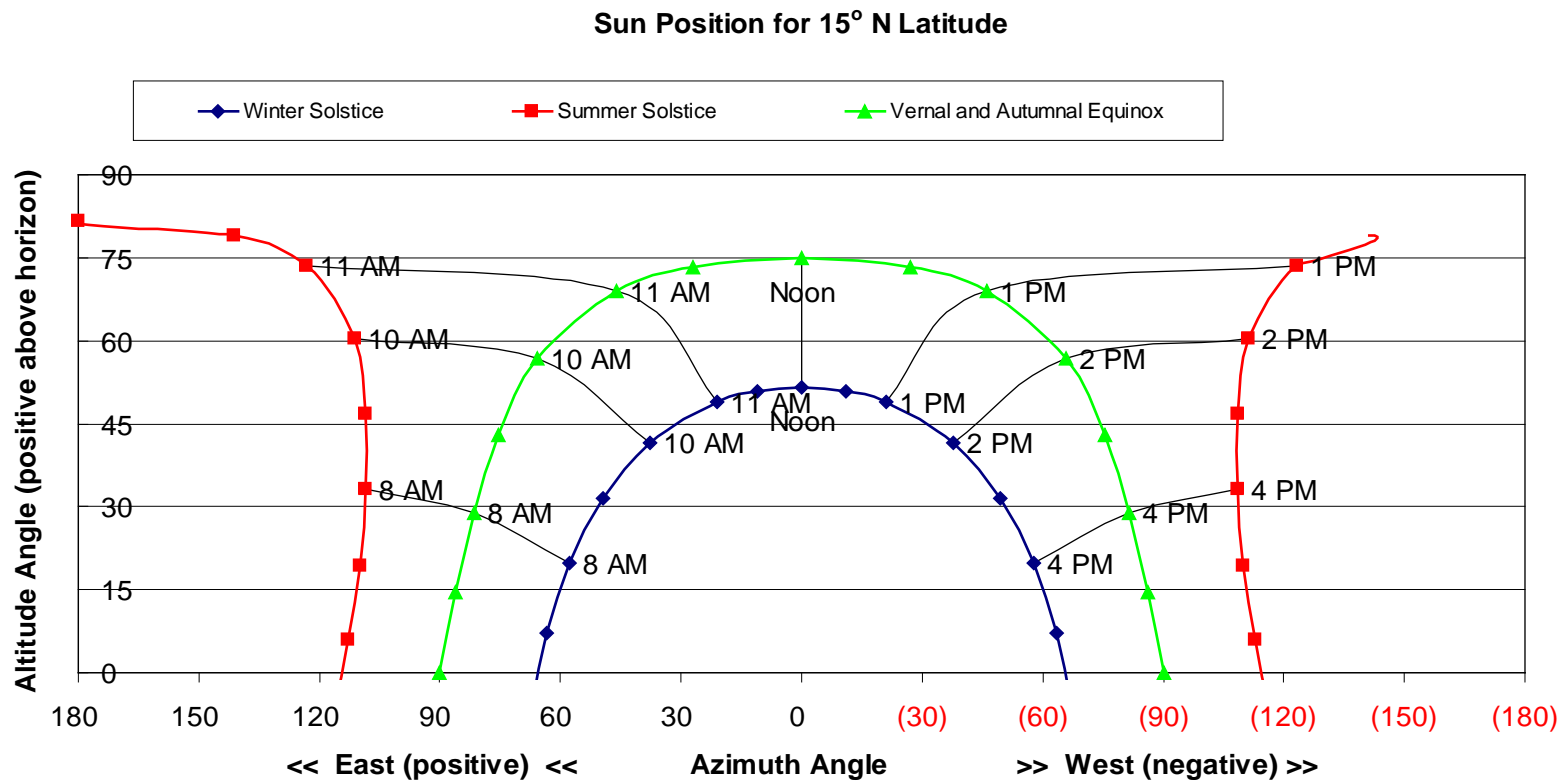Altitude at Solar Noon = 66.5°
(Sun in Southern Sky)
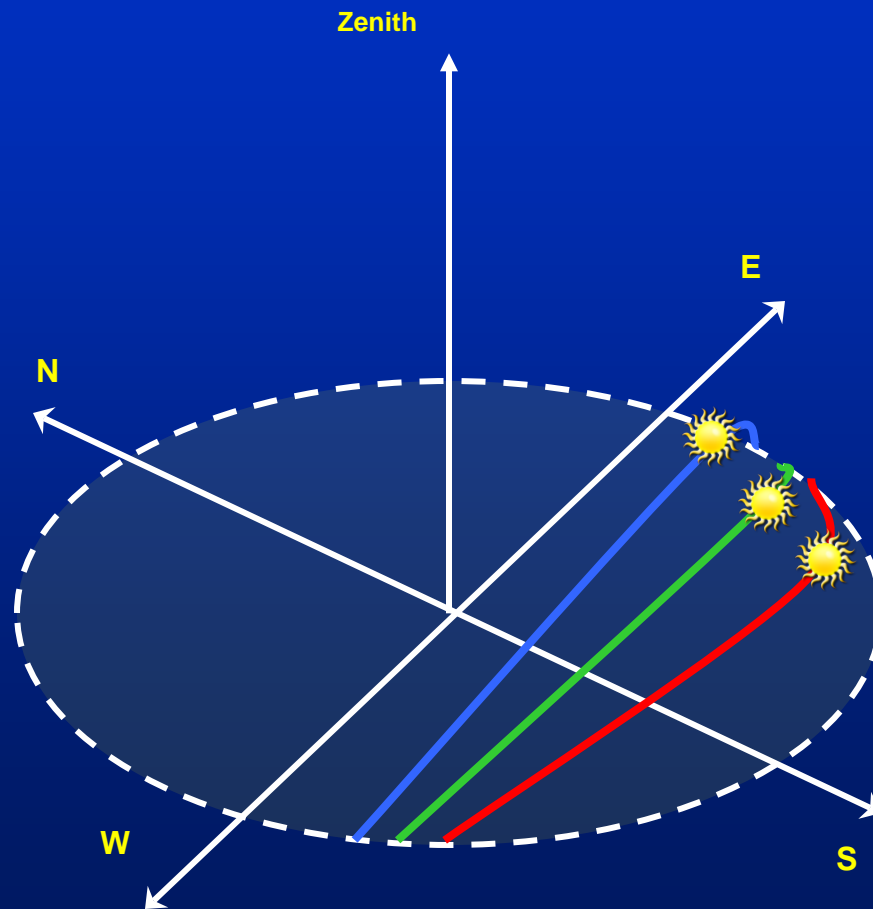
0° Latitude (Equator):
Altitude at Solar Noon = 66.5°

23.5° N Latitude (Tropic of Cancer):
Altitude at Solar Noon = 43°
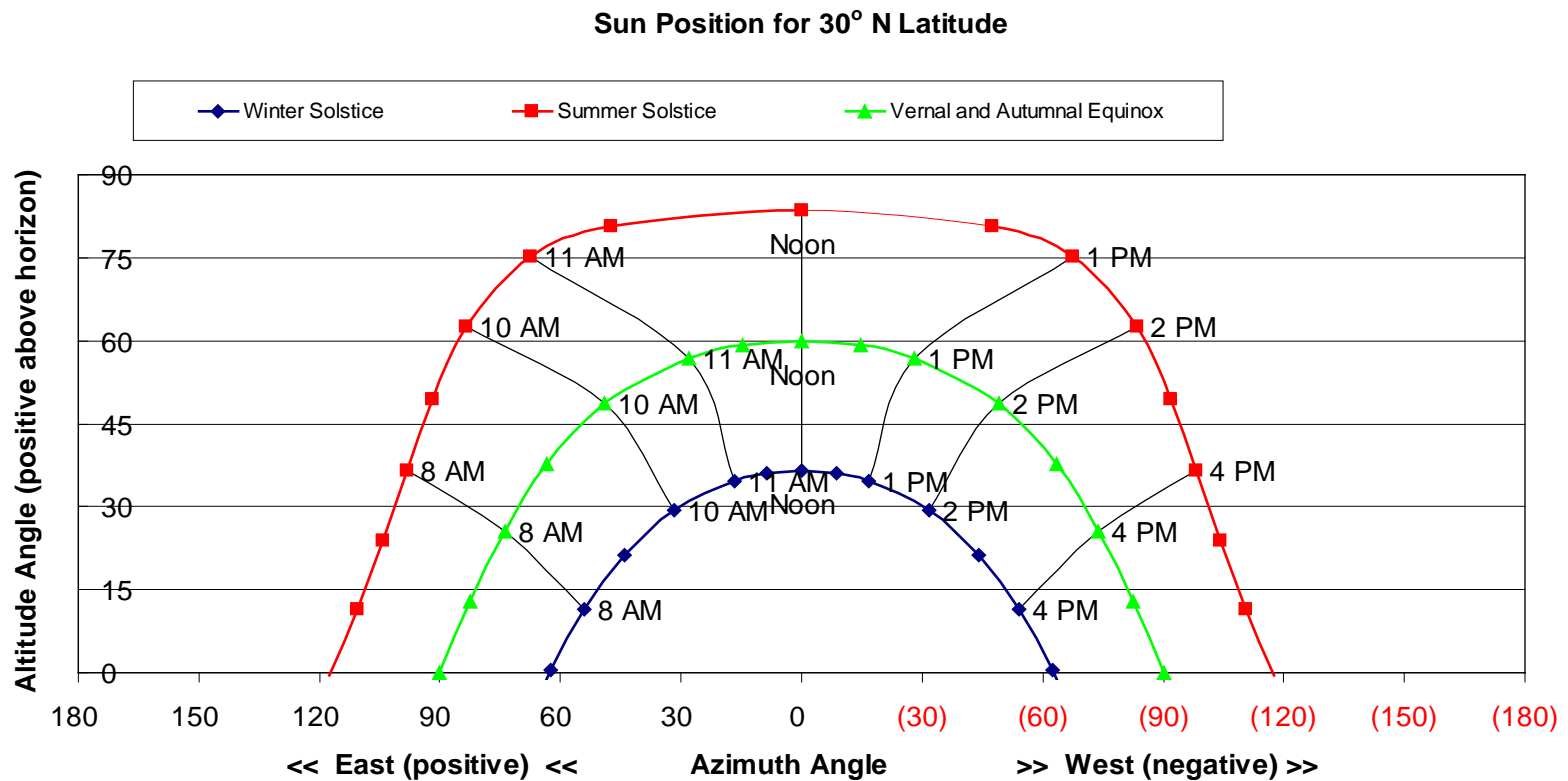
47° Latitude (Seattle, WA):
Altitude at Solar Noon = 19.5°
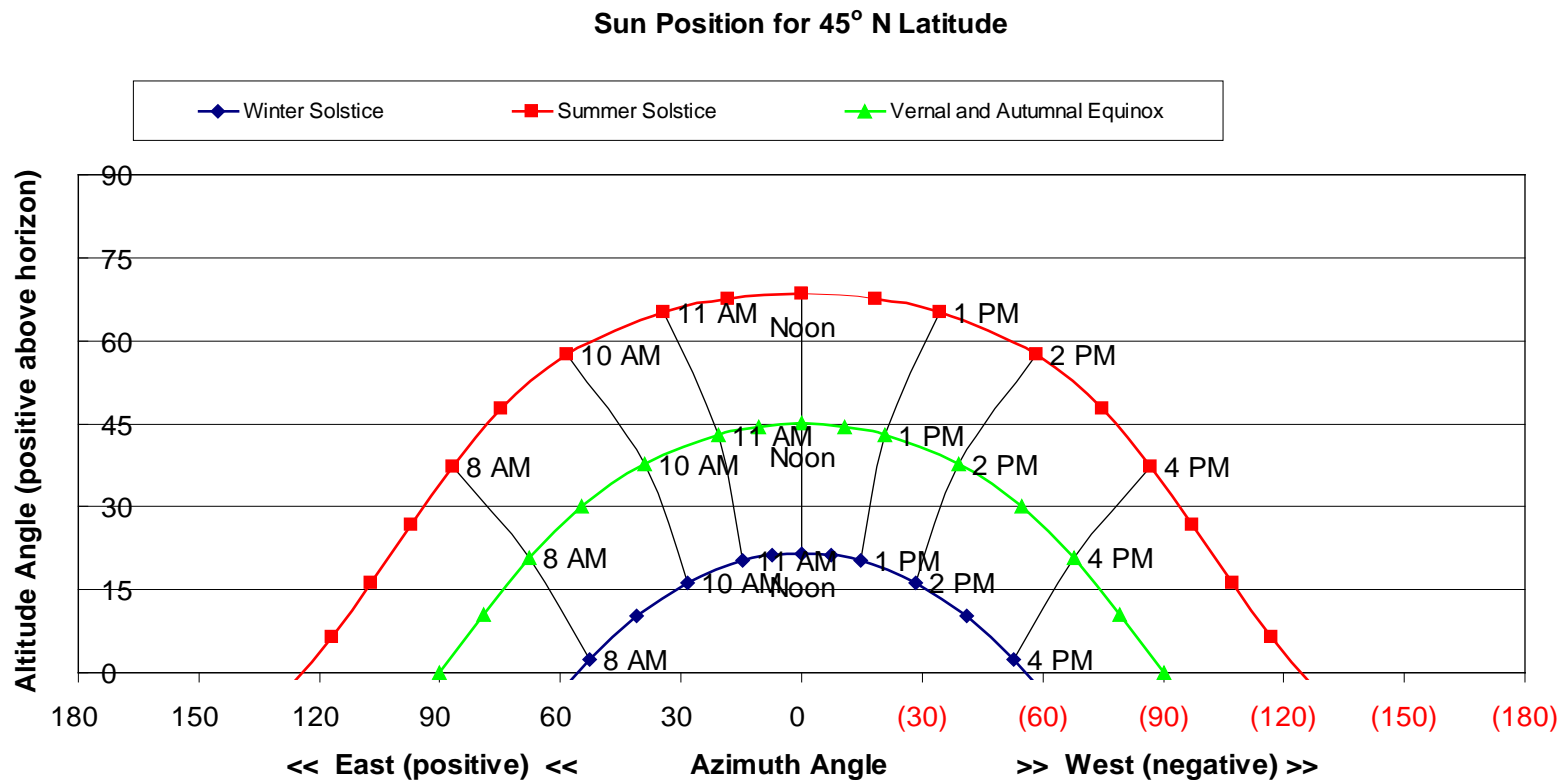
Sun Position on the Equator

Sun Position for 0° Latitude
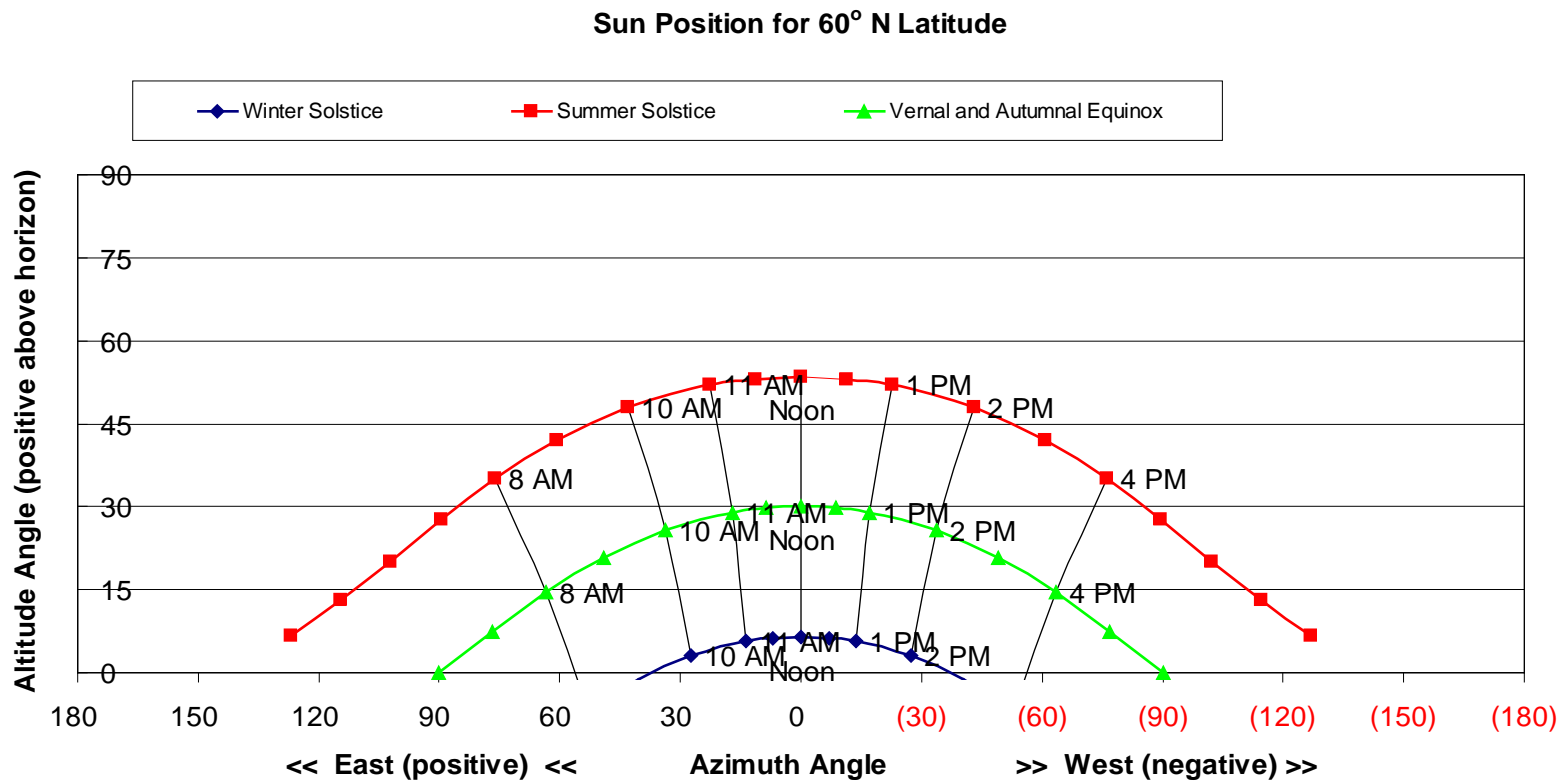
Sun Position for 15°N

Sun Position for 30°N

Sun Position for 30° N Latitude

Legend: Winter Solstice · Summer Solstice · Vernal and Autumnal Equinox

Altitude Angle (positive above horizon)

Azimuth Angle

<< East (positive) <<   >> West (negative) >>

Sun Position for 45°N

Sun Position for 45° N Latitude

Legend: Winter Solstice · Summer Solstice · Vernal and Autumnal Equinox

Altitude Angle (positive above horizon) vs Azimuth Angle

<< East (positive) <<   Azimuth Angle   >> West (negative) >>
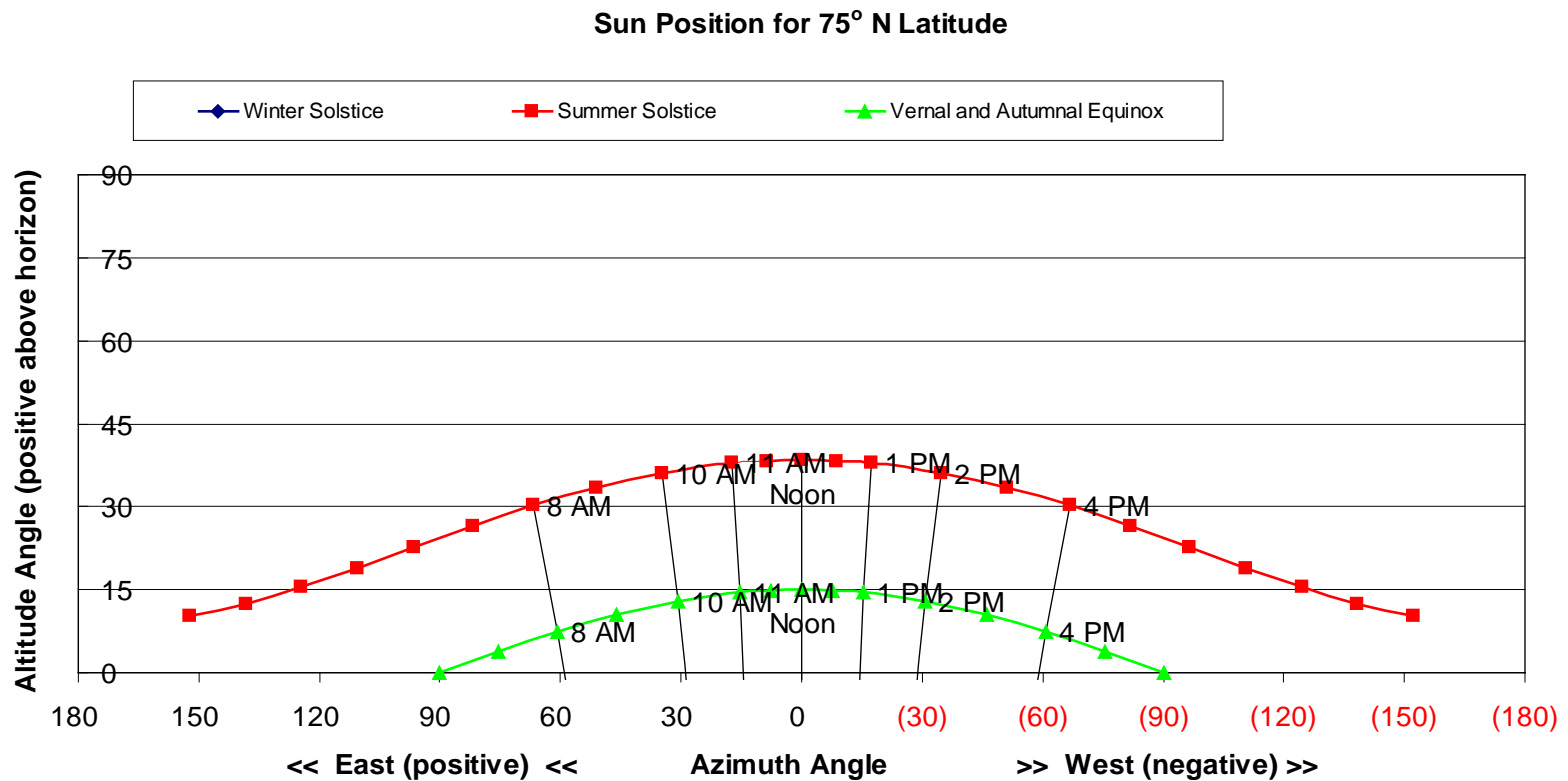
Sun Position for 60°N

Sun Position for 60° N Latitude

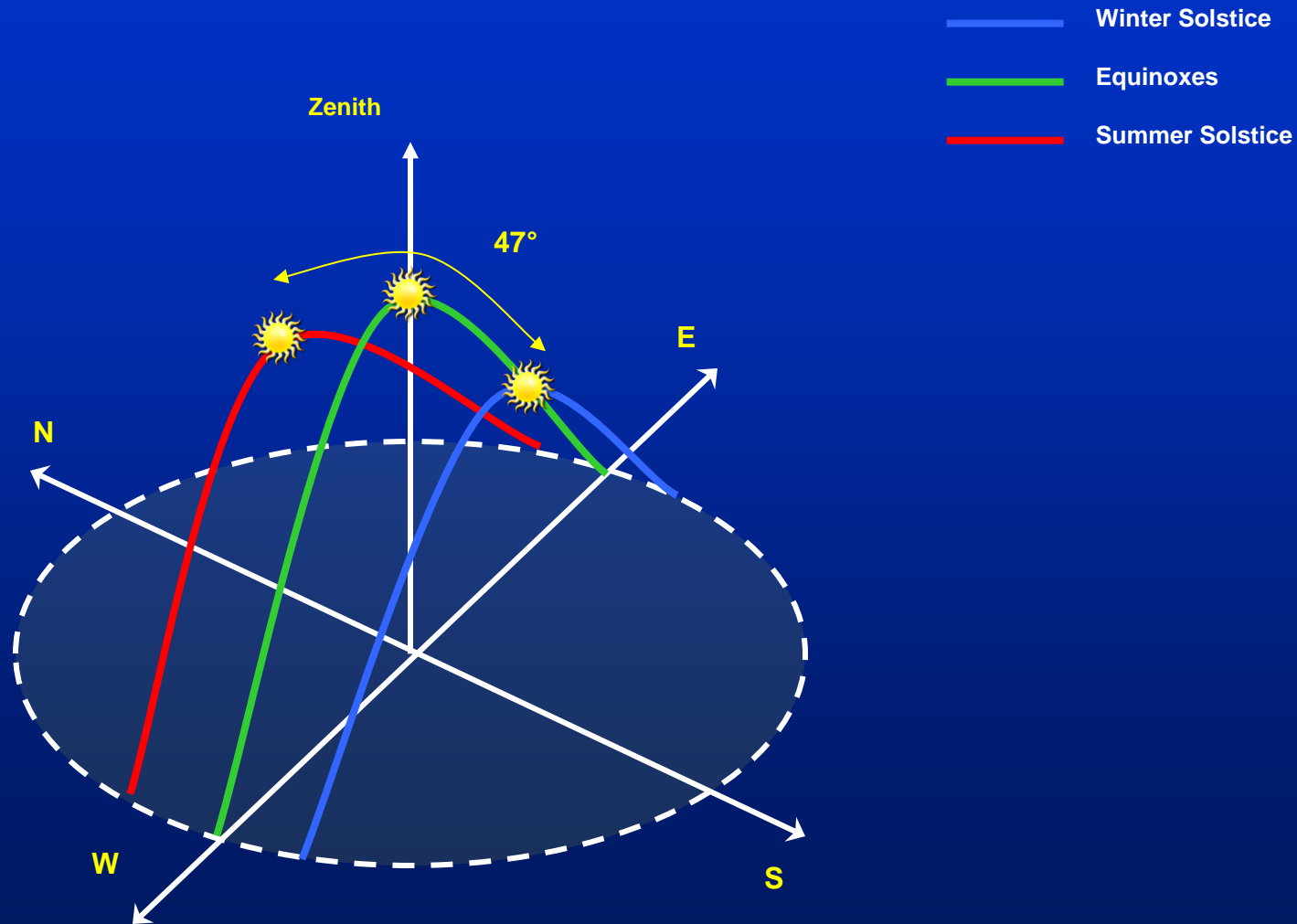# Sun Position for 75°N

Sun Position for 75° N Latitude

The Solar Window

▶ **The *solar window* represents the range of sun paths for a given latitude between the winter and summer solstices.**

▶ **As latitudes increase from equator:**
  ♦ The solar window is inclined at a closer angle with the southern horizon.
  ♦ Sun path and days are longer during summer; shorter during winter.

▶ **For any location, the maximum altitude of the sun at solar noon varies 47° between the winter and summer solstice.**

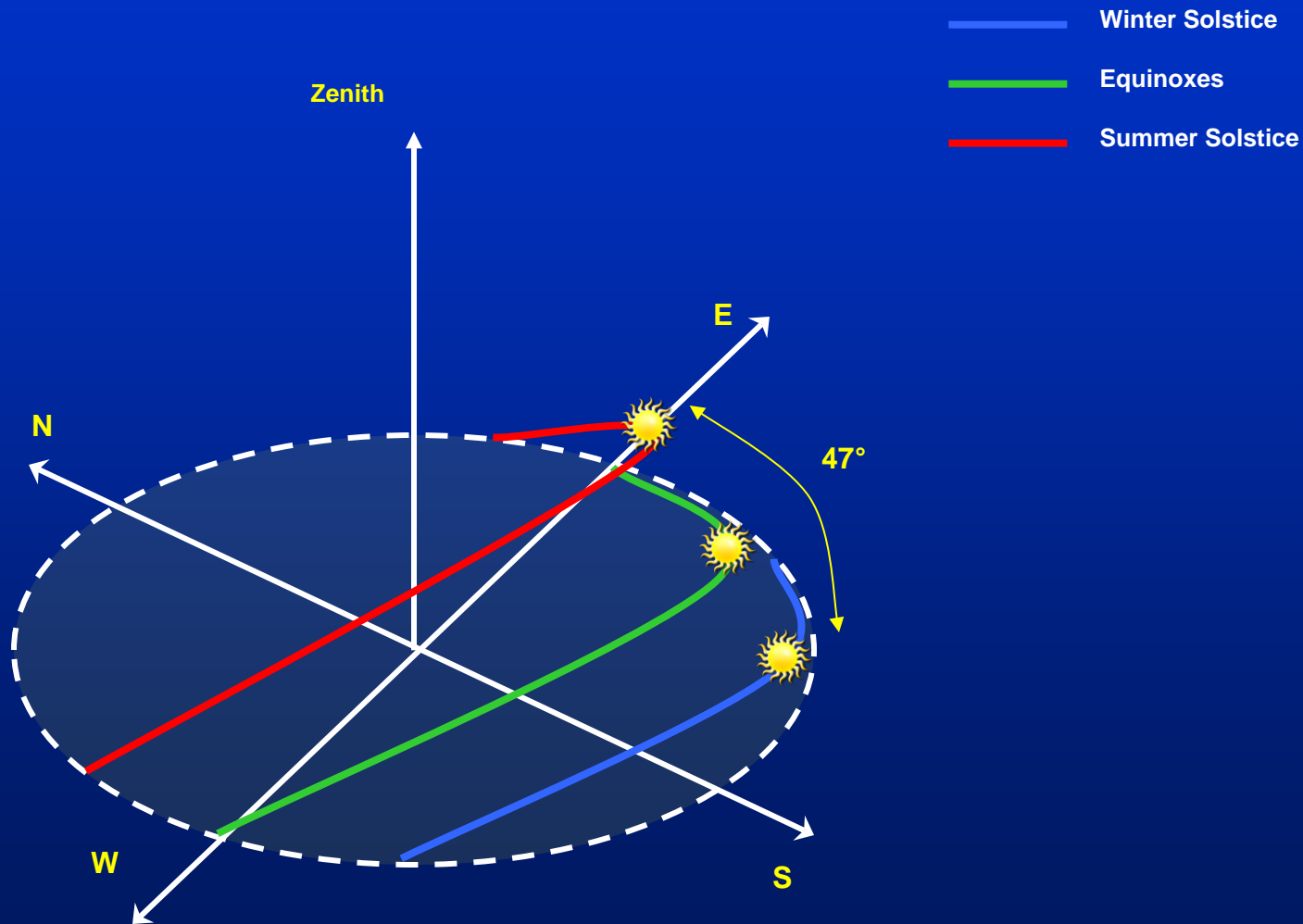▶ **PV arrays should be oriented toward the unobstructed solar window for maximum solar energy collection.**

Solar Window on the Equator

Winter Solstice

Equinoxes

Summer Solstice

Zenith

E

47°

N

W

S
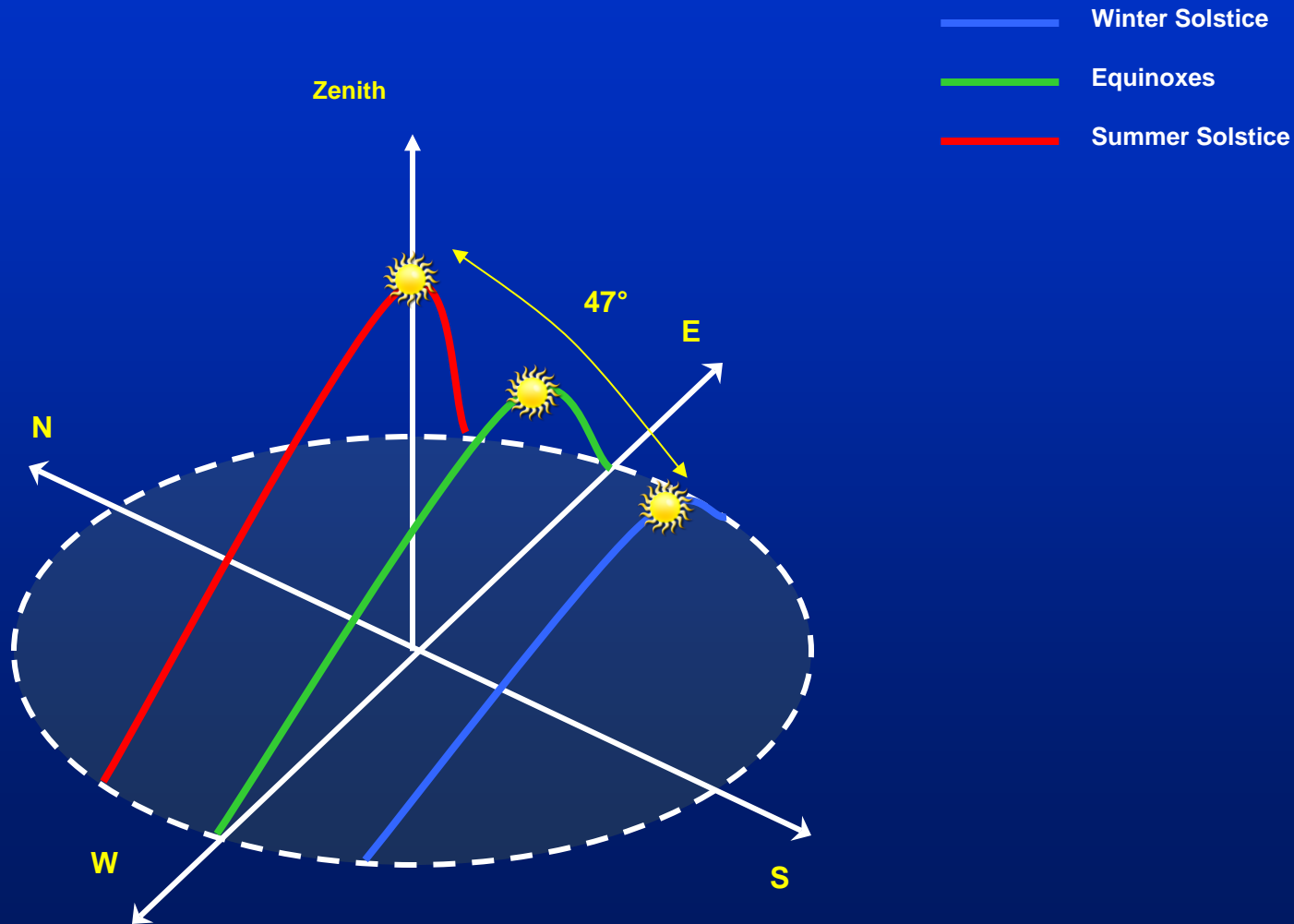
Collector Orientation

▶ **The orientation of PV arrays and other solar collectors is defined by two angles with respect to the earth's surface.**

▶ **The *collector azimuth angle* represents the angle between due geographic south and direction the collector faces.**

▶ **The *collector tilt angle* represents the angle the array surface makes with the horizontal plane.**

▶ **The *solar incidence angle* represents the angle between the sun's rays and the normal (perpendicular) to a collector surface.**
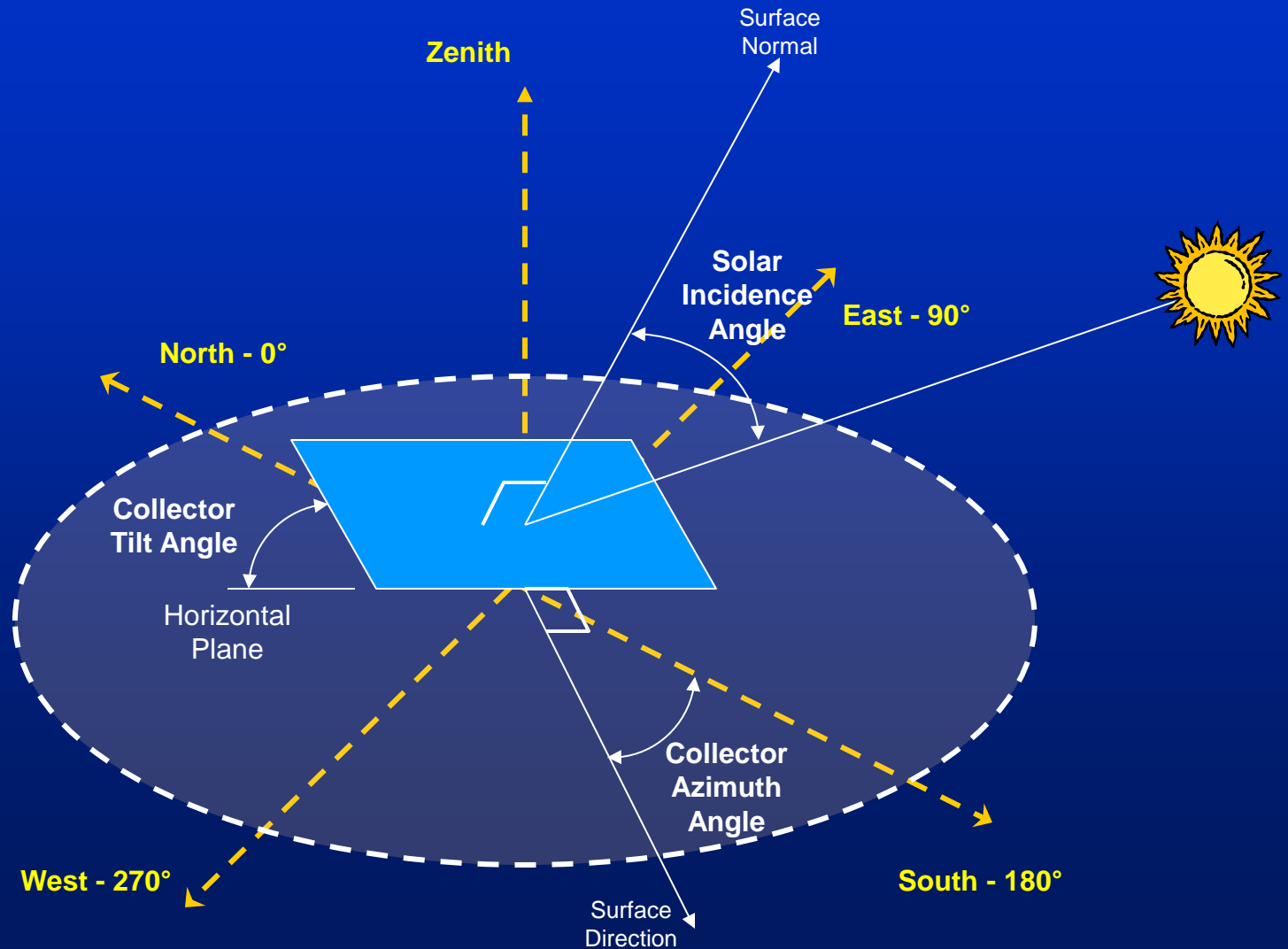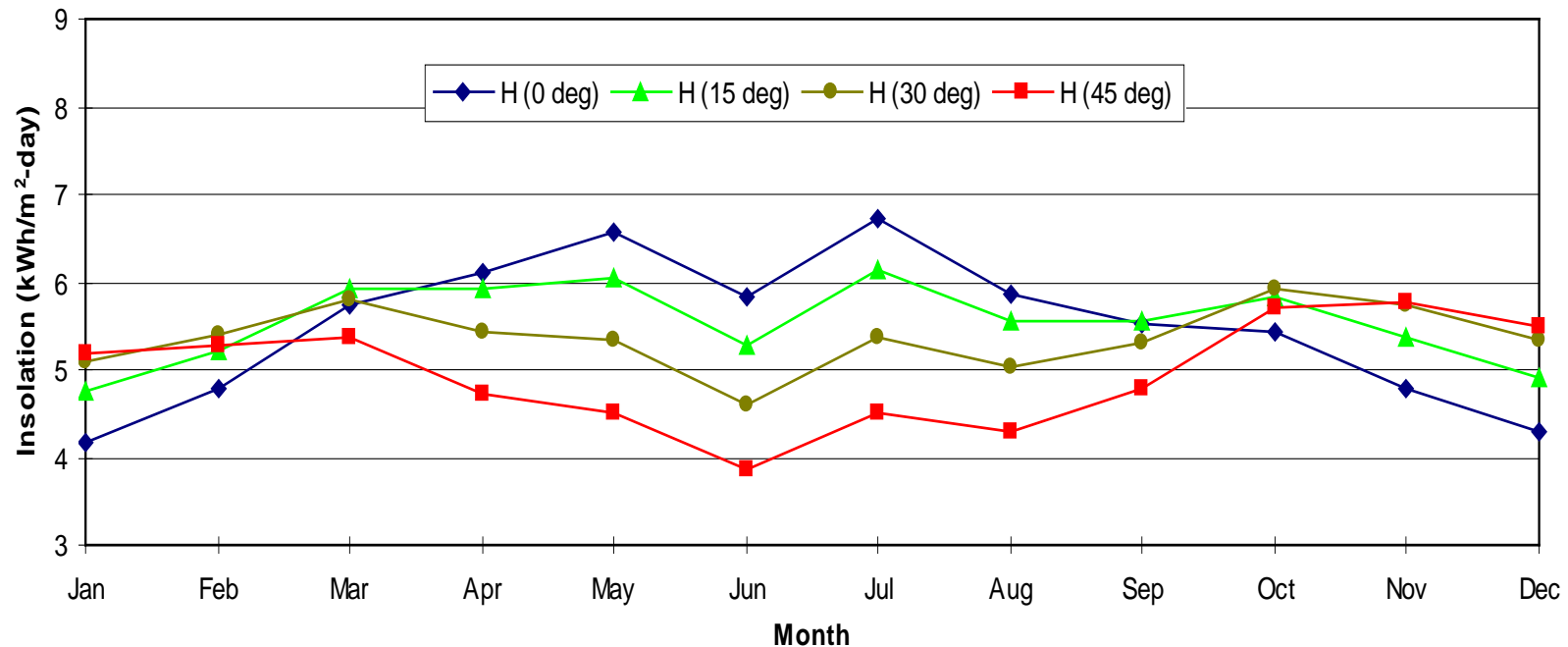
Optimal Collector Orientation

▶ **Maximum annual solar energy is received on a fixed surface that faces due south, and is tilted from the horizontal at an angle slightly less than local latitude.**

◆ Fall and winter performance is enhanced by tilting collectors at angles greater than latitude.

◆ Spring and summertime performance is enhanced by tilting collectors at angles lower than latitude.

▶ **For the central and southern U.S., latitude-tilt surfaces with azimuth orientations of ± 45 degrees from due south and with tilt angles ± 15 of local latitude will generally receive 95 % or more of the annual solar energy received on optimally-tilted south-facing surfaces.**

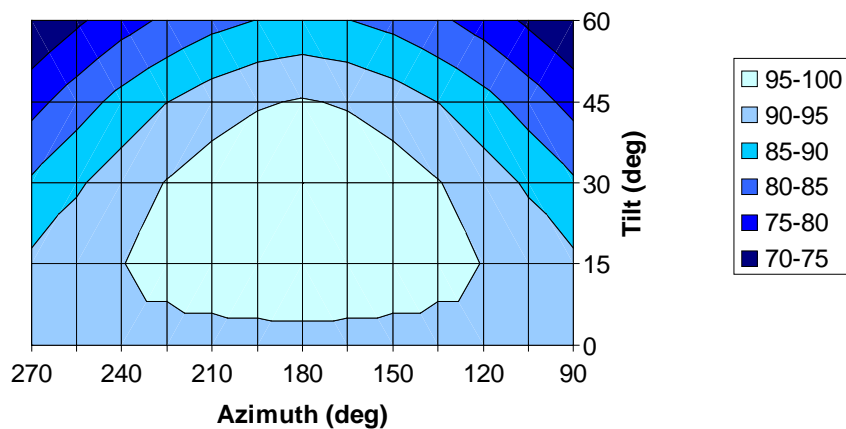# Effect of Collector Tilt Angle on Solar Energy Received

Orlando, FL

Predicted Insolation on South-Facing Tilted Surfaces

Legend: H (0 deg), H (15 deg), H (30 deg), H (45 deg)

Y-axis: Insolation (kWh/m²-day), ranging from 3 to 9

X-axis: Month (Jan through Dec)

Effects of Collector Tilt and Azimuth on Annual Solar Energy Received
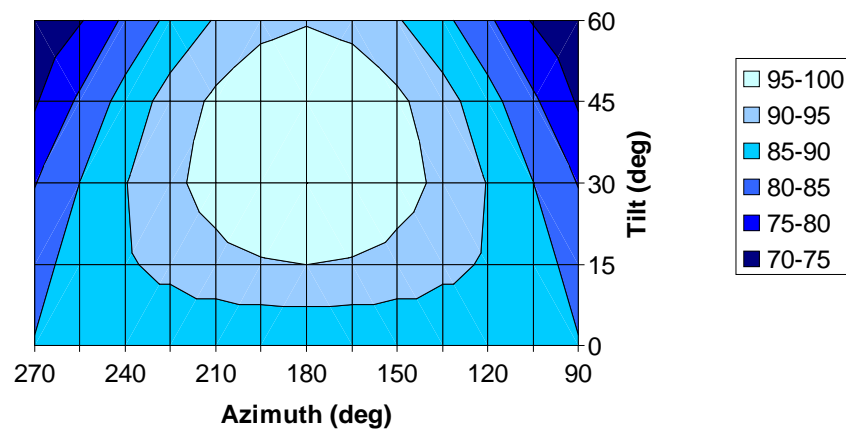
Solar Radiation Resource Data

▶ **Available from National Renewable Energy Laboratory (NREL) - Renewable Resource Data Center (RReDC):**
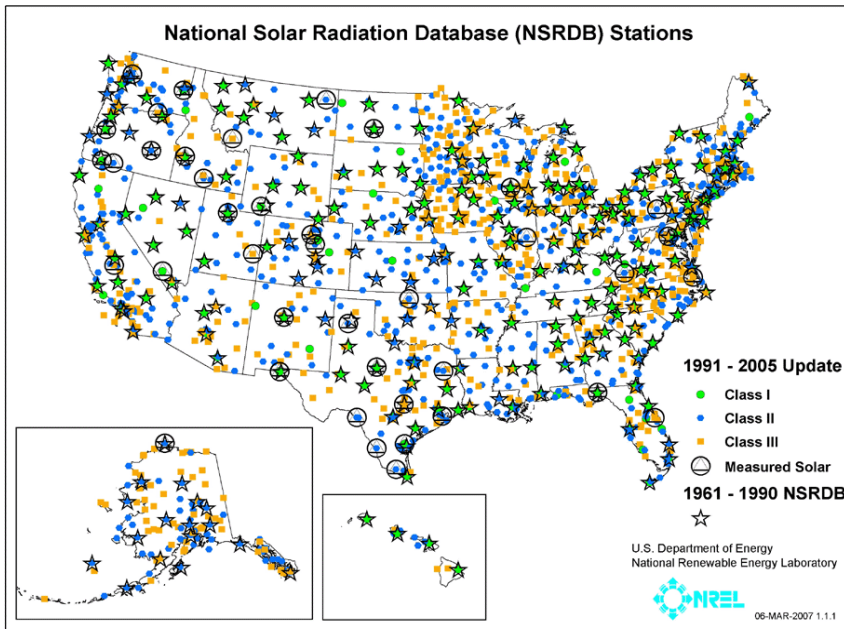
    ♦ http://www.nrel.gov/rredc/

▶ **Includes extensive collection of renewable energy data, maps, and tools for using biomass, geothermal, solar, and wind resources.**

▶ **Solar resource data is used for sizing and estimating the performance of solar energy utilization systems.**

National Solar Radiation Database

National Solar Radiation Database (NSRDB) Stations

NREL

▶ **NSRDB 1961-1990**

- ♦ 30 years of solar radiation and meteorological data from 239 NWS sites in the U.S.
- ♦ TMY2 hourly data files

▶ **NSRDB 1991-2005 Update**

- ♦ Contains solar and meteorological data for 1,454 sites.
- ♦ TMY3 hourly data files

Solar Radiation Data Tables

▶ **Standard format spreadsheets provide minimum and maximum data for each month and annual averages for:**

- ♦ Total global solar radiation for fixed south-facing flat-plate collectors tilted at angles of 0°, Lat-15°, Lat, Lat+15° and 90°.

- ♦ Total global solar radiation for single-axis, north-south tracking flat-plate collectors at tilt angles of 0°, Lat-15°, Lat and Lat+15°.

- ♦ Total global solar radiation for dual-axis tracking flat-plate collectors.

- ♦ Direct beam radiation for concentrating collectors.
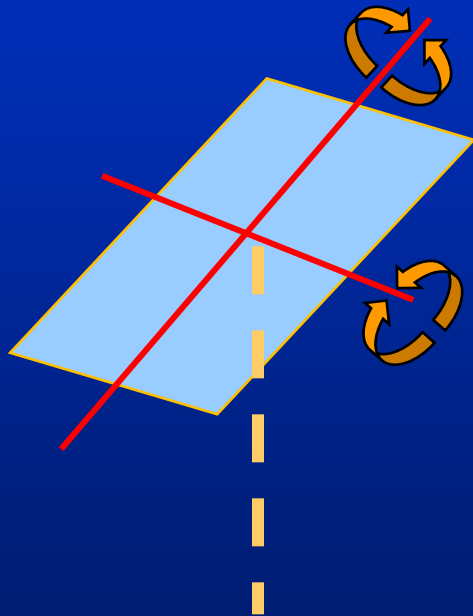
- ♦ Meteorological data.

Solar Radiation Data Tables

City:	**DAYTONA BEACH**												
State:	FL												
WBAN No:	12834												
Lat(N):	29.18												
Long(W):	81.05												
Elev(m):	12												
Pres(mb):	1017												
Stn Type:	Primary												
SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9													
Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	3.1	3.9	5.0	6.2	6.4	6.1	6.0	5.7	4.9	4.2	3.4	2.9	4.8
	Minimum	2.7	3.2	4.2	5.6	5.3	5.4	5.5	4.8	4.3	3.5	2.9	2.4	4.6
	Maximum	3.7	4.4	5.5	6.8	7.0	7.0	6.6	6.3	5.5	4.8	3.7	3.3	5.1
Lat - 15	Average	3.8	4.5	5.5	6.4	6.4	6.0	5.9	5.8	5.2	4.7	4.1	3.6	5.2
	Minimum	3.2	3.7	4.5	5.8	5.3	5.3	5.4	4.8	4.5	3.8	3.4	2.8	4.8
	Maximum	4.6	5.2	6.1	7.1	7.0	6.8	6.4	6.5	6.0	5.5	4.6	4.1	5.5
Lat	Average	4.3	4.9	5.7	6.3	6.0	5.5	5.5	5.6	5.3	5.0	4.6	4.1	5.2
	Minimum	3.6	4.0	4.6	5.7	5.0	4.9	5.1	4.6	4.5	4.0	3.8	3.1	4.9
	Maximum	5.4	5.8	6.3	7.0	6.6	6.3	6.0	6.3	6.1	5.9	5.2	4.9	5.7
Lat + 15	Average	4.6	5.1	5.6	5.9	5.4	4.8	4.9	5.1	5.1	5.1	4.8	4.4	5.1
	Minimum	3.8	4.1	4.5	5.3	4.5	4.3	4.5	4.2	4.3	4.0	3.9	3.3	4.7
	Maximum	5.8	6.0	6.3	6.5	5.8	5.5	5.3	5.7	5.9	6.0	5.6	5.3	5.5
90	Average	3.9	3.8	3.6	2.9	2.1	1.8	1.9	2.4	3.0	3.6	4.0	3.9	3.1
	Minimum	3.1	3.1	2.9	2.7	2.0	1.6	1.8	2.0	2.5	2.7	3.1	2.8	2.8
	Maximum	5.1	4.7	4.0	3.1	2.2	1.9	2.0	2.6	3.4	4.3	4.7	4.7	3.3

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Sun-Tracking Arrays

Two-Axis Tracking

Vertical-Axis Tracking

East-West Tracking

Optional seasonal adjustment
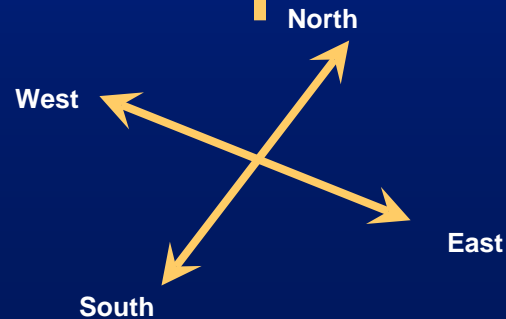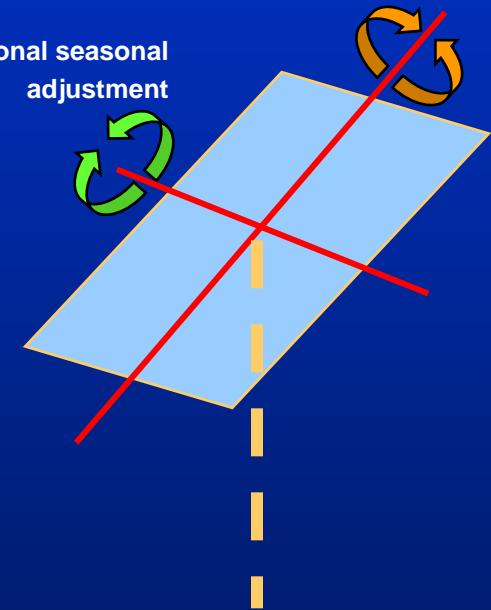
Optional seasonal adjustment

North

West

East

South

Solar Radiation Data Tables

City:	DAYTONA BEACH
State:	FL
WBAN No:	12834
Lat(N):	29.18
Long(W):	81.05
Elev(m):	12
Pres(mb):	1017
Stn Type:	Primary

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage Uncertainty = 9

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	4.3	5.2	6.6	8.1	8.2	7.5	7.4	7.1	6.2	5.5	4.6	3.9	6.2
	Minimum	3.5	4.2	5.2	7.1	6.3	6.5	6.6	5.8	5.0	4.2	3.8	3.0	5.7
	Maximum	5.4	6.2	7.6	9.5	9.2	8.9	8.3	8.3	7.3	6.6	5.3	4.7	6.8
Lat - 15	Average	4.8	5.7	7.0	8.3	8.2	7.4	7.4	7.2	6.5	5.9	5.1	4.4	6.5
	Minimum	3.8	4.6	5.5	7.3	6.3	6.4	6.5	5.9	5.2	4.5	4.1	3.3	6.0
	Maximum	6.1	6.8	8.0	9.7	9.2	8.8	8.2	8.4	7.6	7.1	5.9	5.4	7.1
Lat	Average	5.2	6.0	7.2	8.3	7.9	7.1	7.1	7.0	6.5	6.1	5.5	4.9	6.6
	Minimum	4.1	4.8	5.6	7.2	6.1	6.1	6.2	5.8	5.2	4.6	4.4	3.6	6.0
	Maximum	6.7	7.3	8.3	9.7	8.9	8.4	7.9	8.3	7.7	7.4	6.4	5.9	7.2
Lat + 15	Average	5.4	6.1	7.1	8.0	7.4	6.6	6.6	6.7	6.4	6.2	5.7	5.1	6.4
	Minimum	4.3	4.9	5.5	6.9	5.7	5.7	5.8	5.5	5.0	4.6	4.5	3.7	5.9
	Maximum	7.0	7.4	8.2	9.3	8.4	7.8	7.4	7.9	7.5	7.5	6.7	6.3	7.1

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	5.5	6.1	7.2	8.4	8.2	7.5	7.5	7.2	6.5	6.2	5.7	5.2	6.8
	Minimum	4.3	4.9	5.6	7.3	6.3	6.5	6.6	5.9	5.2	4.6	4.5	3.7	6.2
	Maximum	7.1	7.5	8.3	9.8	9.3	9.0	8.4	8.4	7.7	7.5	6.8	6.4	7.5

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Solar Radiation Data Tables

City:	DAYTONA BEACH
State:	FL
WBAN No:	12834
Lat(N):	29.18
Long(W):	81.05
Elev(m):	12
Pres(mb):	1017
Stn Type:	Primary

DIRECT BEAM SOLAR RADIATION FOR CONCENTRATING COLLECTORS (kWh/m2/day), Percentage Uncertainty = 8

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1-X, E-W	Average	3.1	3.3	3.6	4.2	3.9	3.3	3.3	3.1	2.8	3.1	3.2	3.0	3.3
Hor Axis	Minimum	2.1	2.4	2.4	3.3	2.2	2.4	2.4	2.1	1.7	1.8	2.2	1.8	2.9
	Maximum	4.5	4.4	4.6	5.5	4.8	4.6	4.2	4.0	3.6	4.1	4.1	4.1	3.9
1-X, N-S	Average	2.7	3.4	4.4	5.5	5.1	4.3	4.2	4.0	3.5	3.3	3.0	2.5	3.8
Hor Axis	Minimum	1.9	2.5	2.9	4.3	2.9	3.1	3.2	2.8	2.1	2.0	2.0	1.5	3.3
	Maximum	4.0	4.5	5.6	7.3	6.3	5.8	5.3	5.3	4.6	4.5	3.8	3.5	4.5
1-X, N-S	Average	3.5	4.1	4.8	5.6	4.9	4.0	4.0	4.0	3.7	3.9	3.7	3.3	4.1
Tilt=Lat	Minimum	2.4	3.0	3.2	4.4	2.8	2.9	3.0	2.8	2.2	2.3	2.5	1.9	3.5
	Maximum	5.1	5.4	6.1	7.4	6.0	5.4	5.0	5.3	4.8	5.2	4.7	4.6	4.8
2-X	Average	3.7	4.2	4.8	5.7	5.2	4.3	4.3	4.1	3.8	3.9	3.9	3.6	4.3
	Minimum	2.6	3.0	3.2	4.4	2.9	3.1	3.2	2.9	2.2	2.3	2.7	2.1	3.7
	Maximum	5.4	5.6	6.1	7.6	6.4	5.9	5.3	5.4	4.8	5.3	5.0	4.9	5.0

AVERAGE CLIMATIC CONDITIONS

Element		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temp.	(deg C)	14.2	15.0	17.9	20.7	23.7	26.3	27.3	27.2	26.3	23.0	18.8	15.6	21.3
Daily Min	(deg C)	8.3	9.1	12.2	14.8	18.3	21.6	22.5	22.7	22.2	18.4	13.5	9.8	16.1
Daily Max	(deg C)	20.0	20.8	23.8	26.7	29.2	31.1	32.1	31.7	30.4	27.5	24.2	21.3	26.6
Record Lo	(deg C)	-9.4	-4.4	-3.3	1.7	6.7	11.1	15.6	18.3	11.1	5.0	-2.8	-7.2	-9.4
Record Hi	(deg C)	30.6	31.7	32.8	35.6	37.8	38.9	38.9	37.8	37.2	35.0	31.7	31.1	38.9
HDD,Base:	18.3C	157	114	62	12	0	0	0	0	0	0	46	115	505
CDD,Base:	18.3C	28	21	50	83	167	240	279	276	240	147	61	31	1622
Rel Hum	percent	75	72	71	69	72	77	78	80	79	75	76	76	75
Wind Spd.	(m/s)	3.8	4.1	4.2	4.1	3.8	3.4	3.2	3.0	3.5	4.0	3.7	3.6	3.7

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PVWATTS Performance Calculator

▶ **Used to evaluate solar energy collected and the performance of grid-tied PV systems for any array azimuth and tilt angles.**

▶ **User selects state and city from map, and enters size of PV system, array orientation and derating factors.**

▶ **Results give monthly and annual solar energy received and PV system AC energy production.**

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PVWATTS Output

Summary

▶ **The solar radiation received on earth is affected by the earth's movements and atmospheric conditions.**

▶ **Solar irradiance (power) is expressed in units of W/m² or kW/m², and measured with a pyranometer.**
 ♦ Typical peak values are around 1000 W/m² on a surface at sea level facing the sun around solar noon; used as the rating condition for PV modules and arrays.

▶ **Solar irradiation (energy) is solar power integrated over time, expressed in units of kWh/m²/day.**
 ♦ Solar energy resource data are used in sizing and estimating the performance of PV systems, and varies location and with collector orientation.

▶ **The solar window defines the range of sun paths between the winter and summer solstices for a specific latitude.**
 ♦ PV arrays are oriented toward the solar window for maximum energy gain.