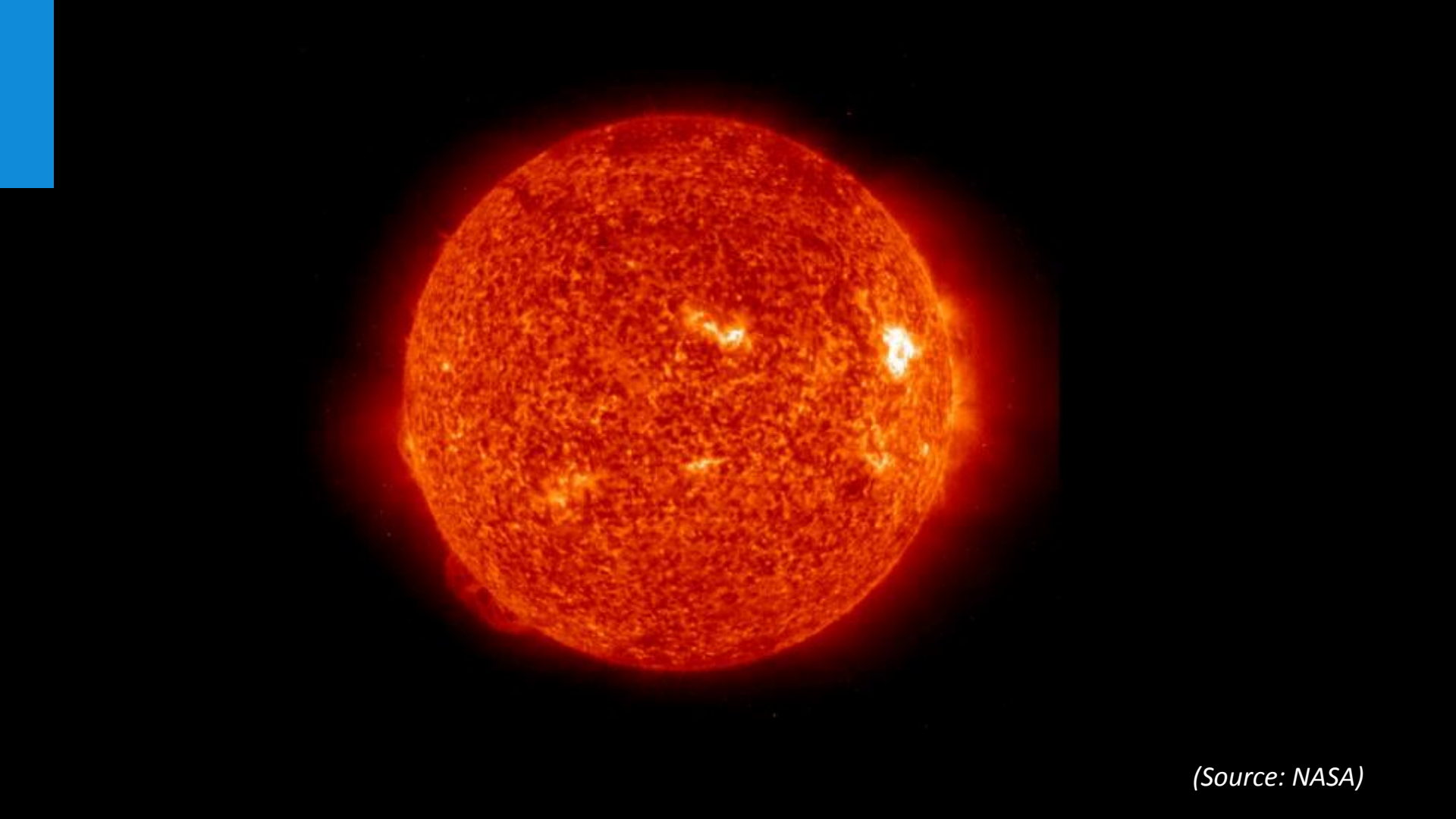


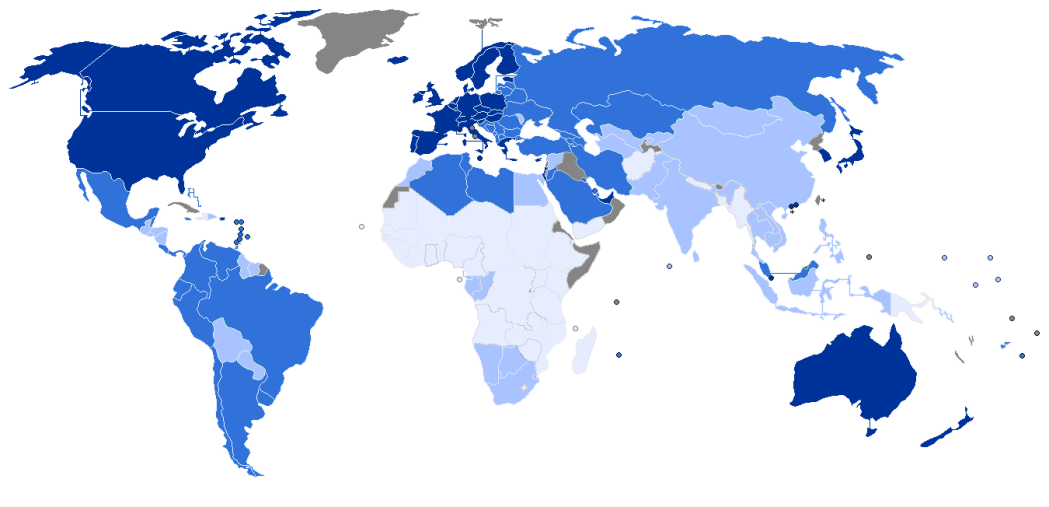
(Source: NASA)

The Energy Problem

Growing world population

The Energy Problem Energy Shortage

Increasing living standard:



Energy consumption per capita

(Source: Wikipedia)

Energy → Joules (J)

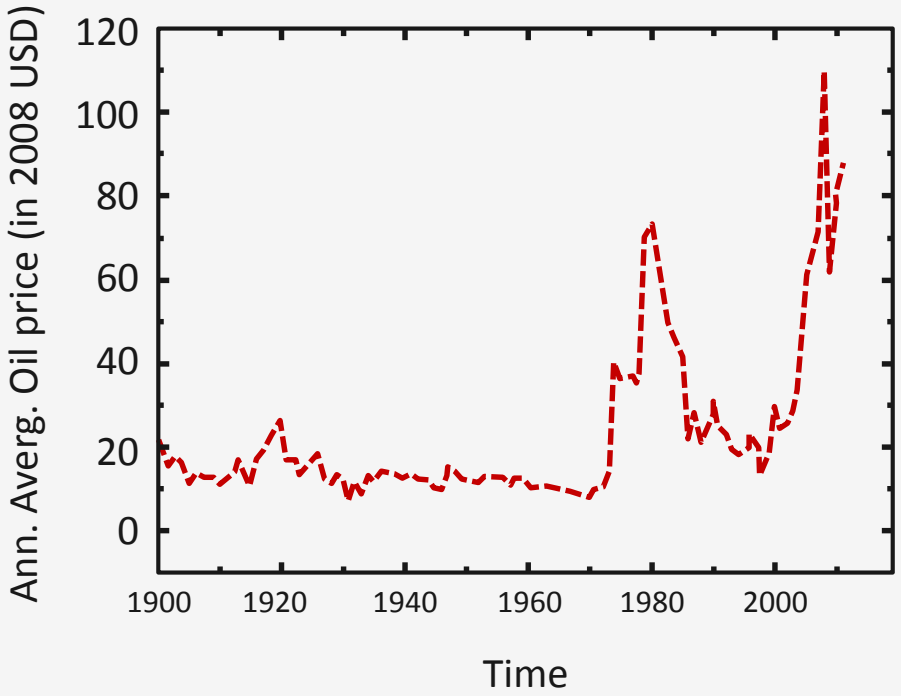
Power = Energy/Time → Watts (W)

1 W = 1 J/s

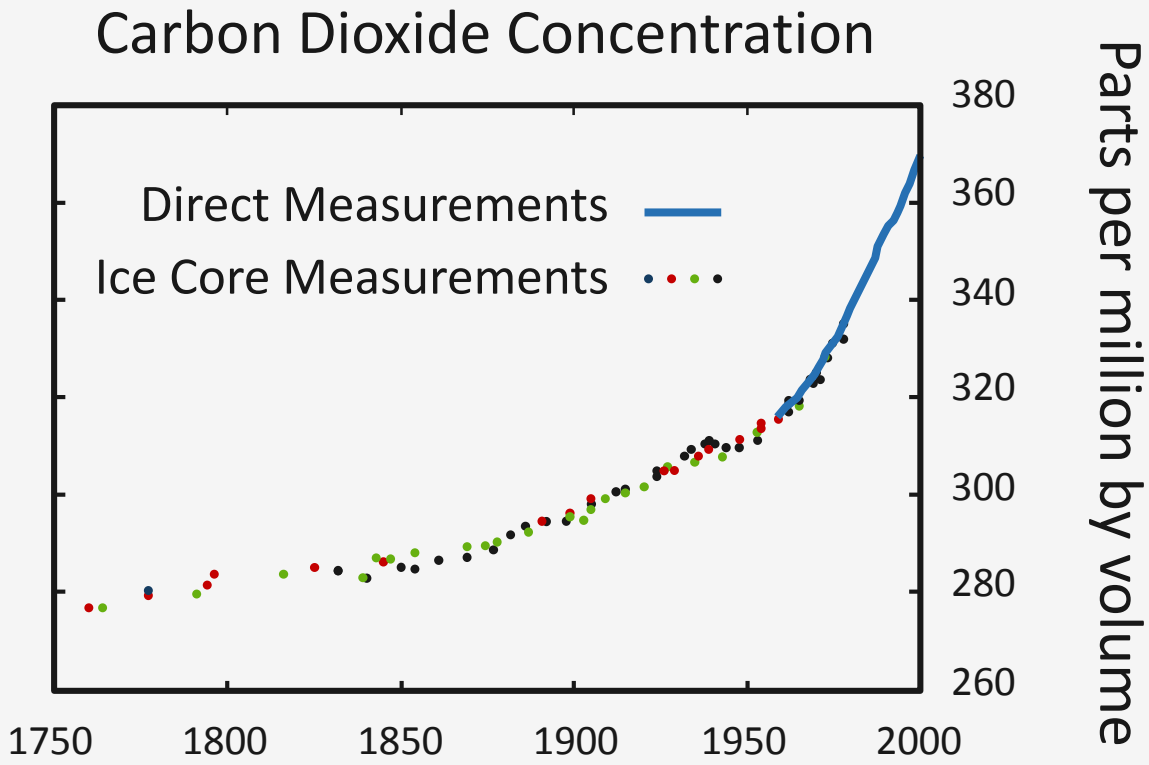
1 kWh = 1kW x 1h = 3.6 MJ

The Energy Problem

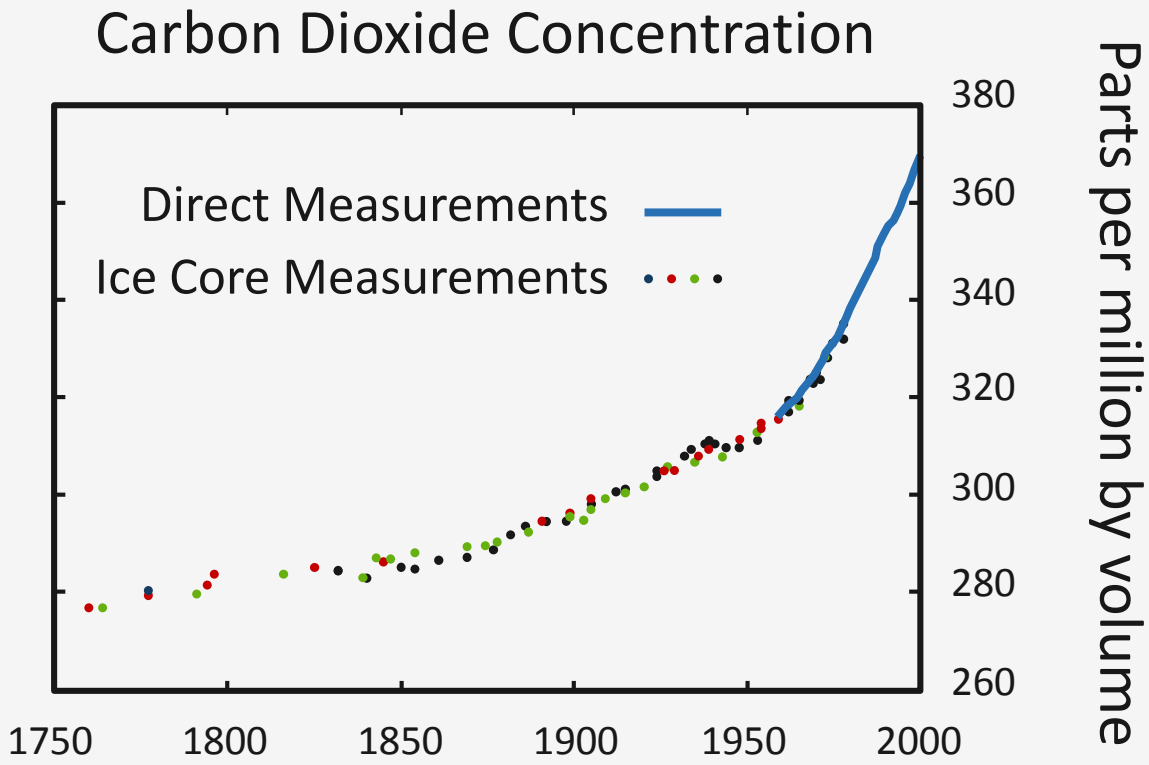
Energy Shortage



Source: BP workbook of historical data



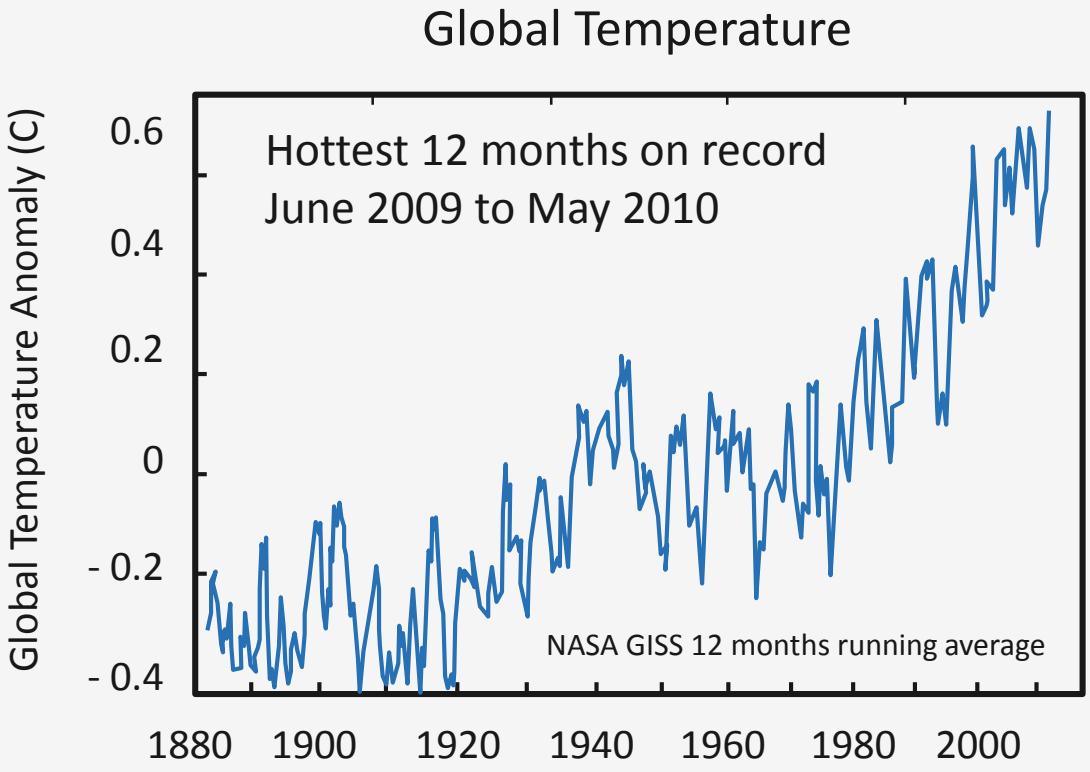
Source: Trends in atmospheric CO_2 ESRL-GMD



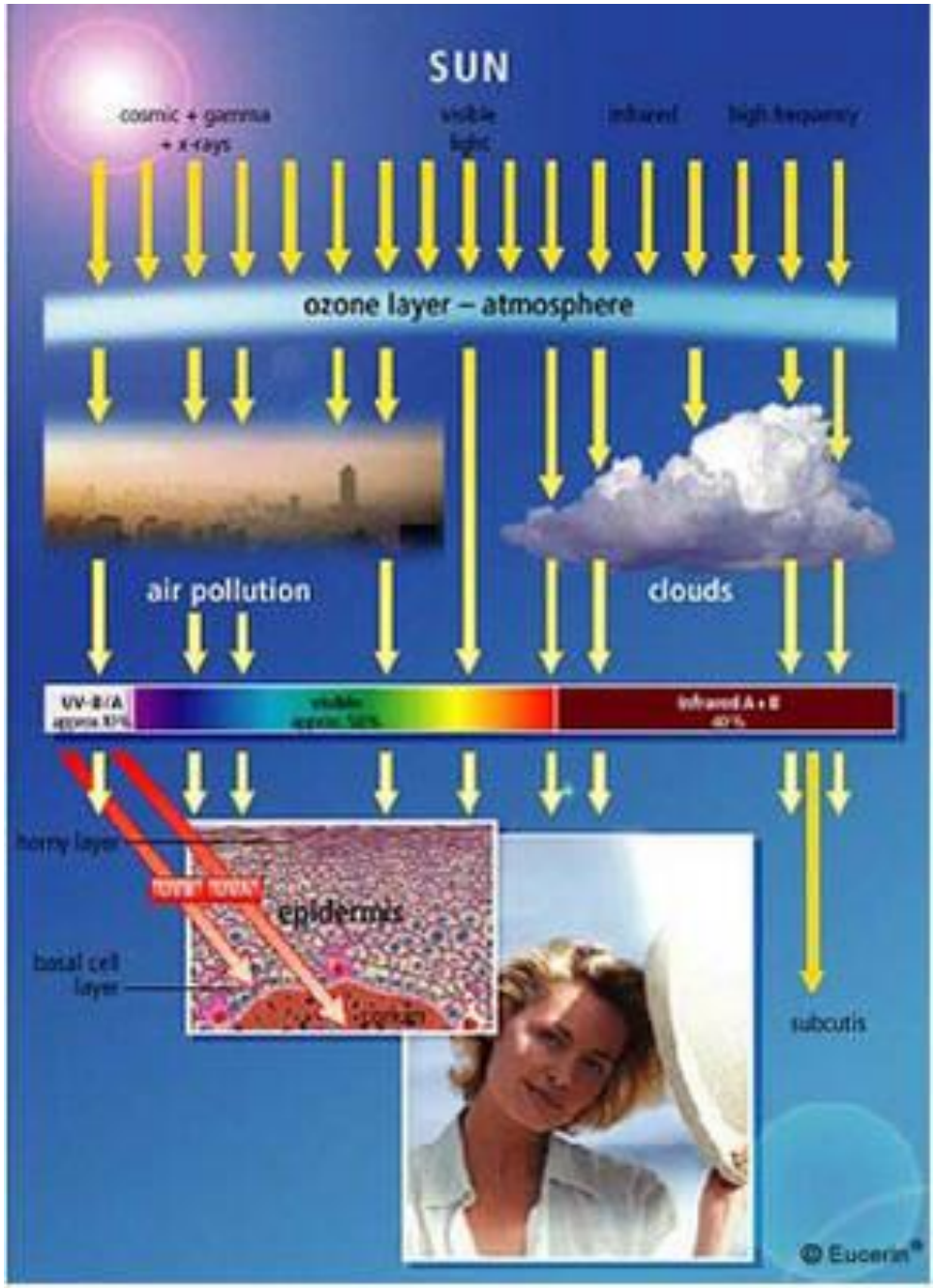
Source: Trends in atmospheric CO_2 ESRL-GMD

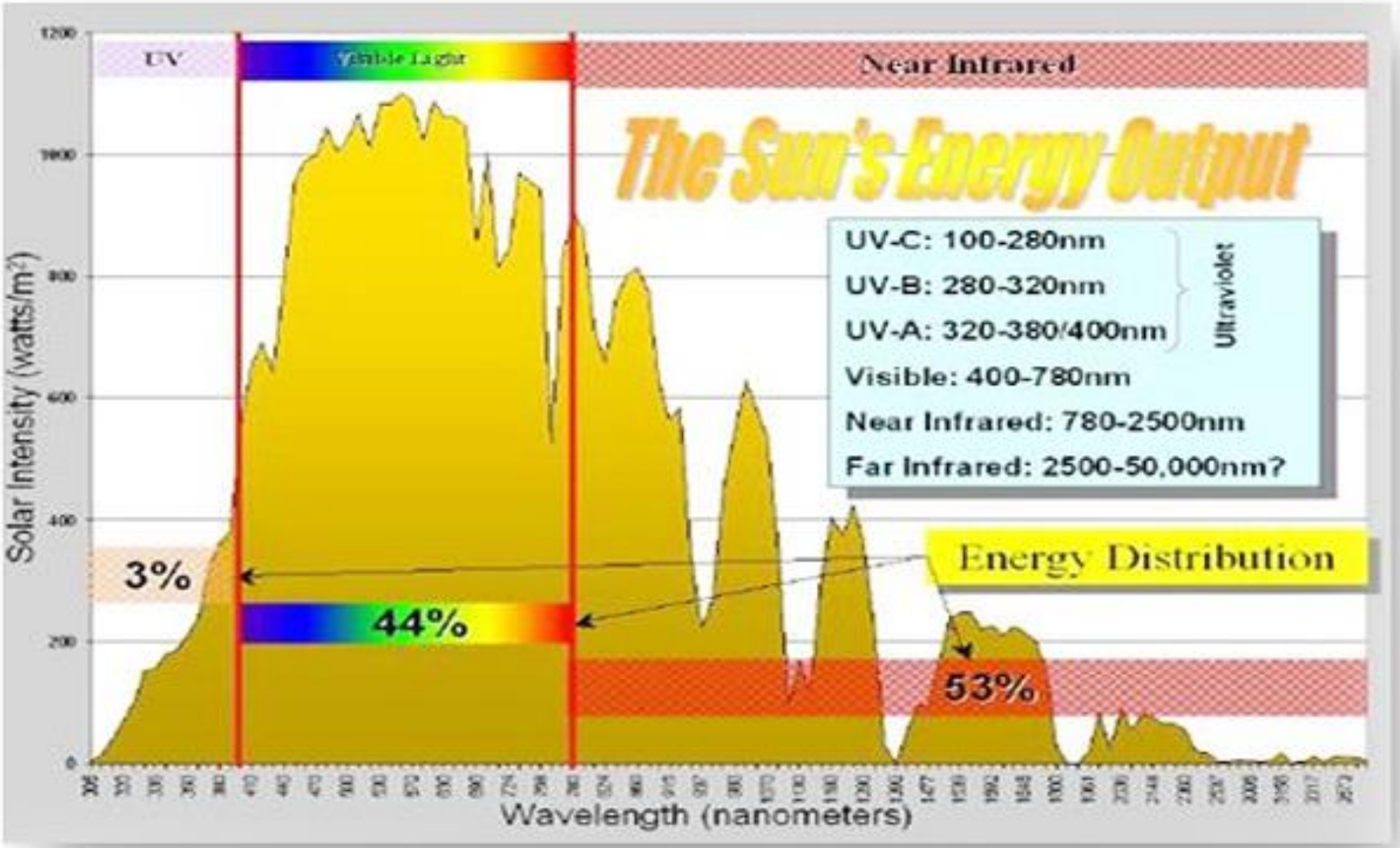
The Energy Problem

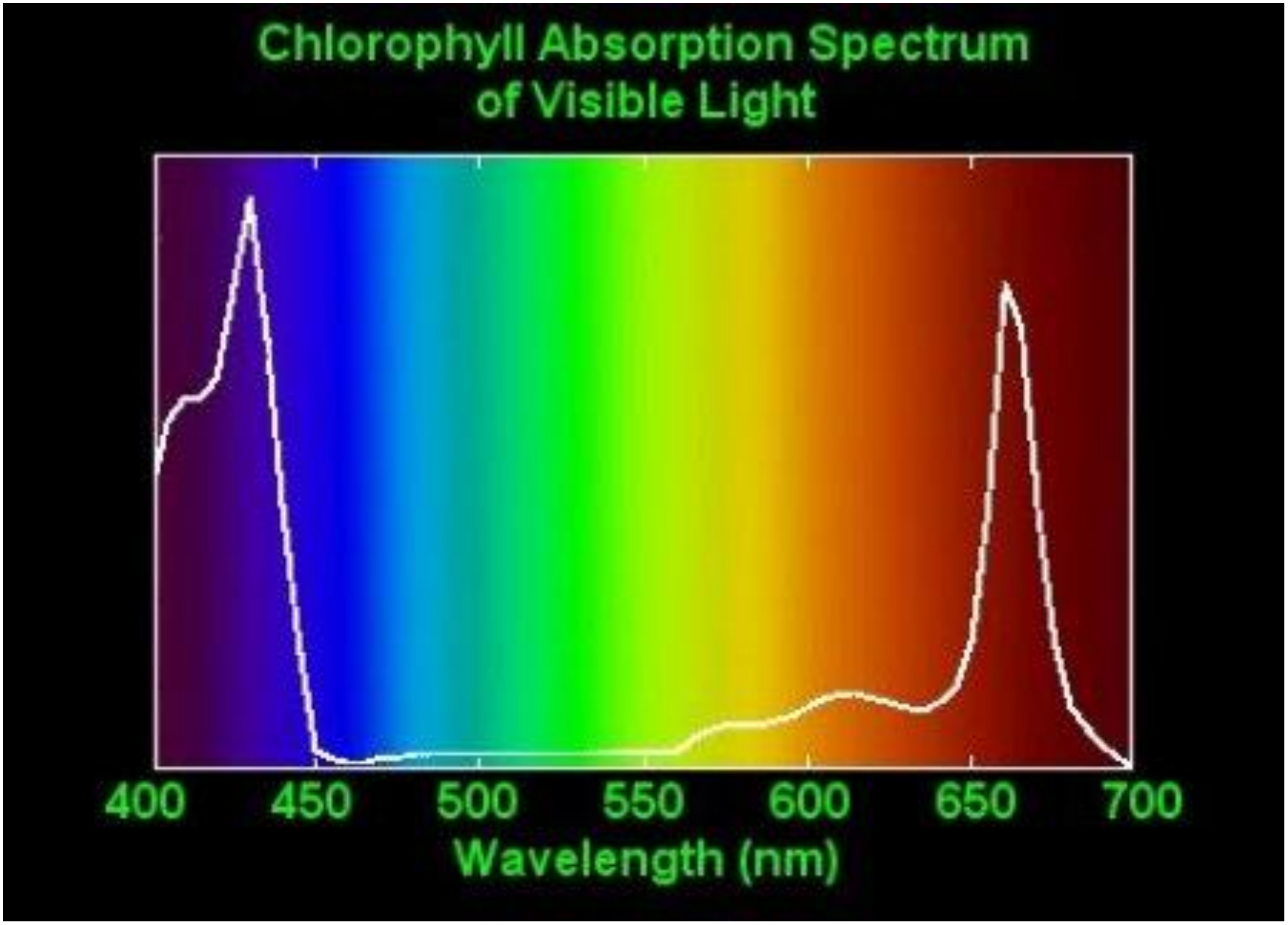
Climate change



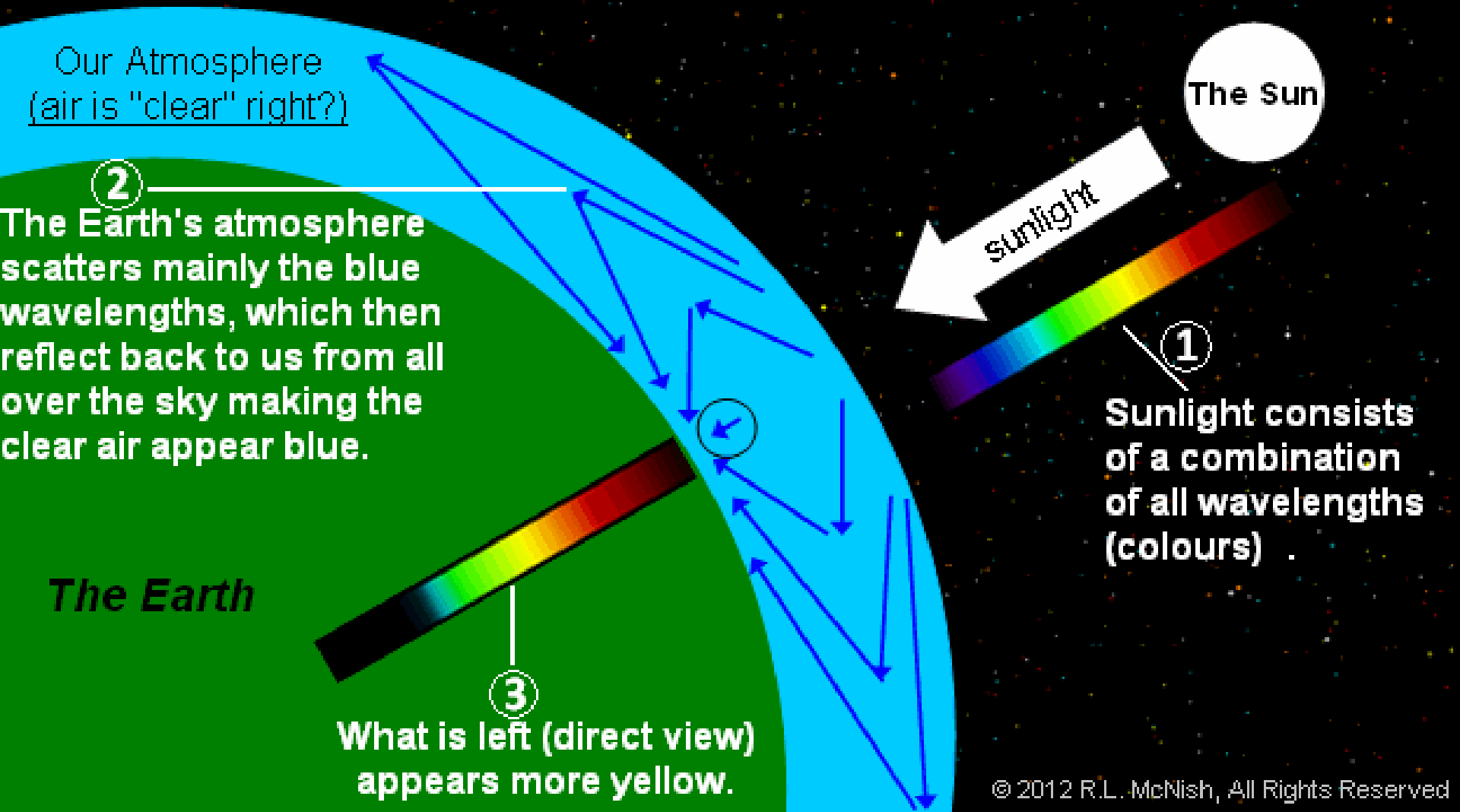

Newton


SUN
cosmic + gamma + x-rays
visible light
infrared
high frequency
ozone layer – atmosphere
air pollution
clouds
UV-B/A
Infrared A + B
horny layer
epidermis
basal cell layer
subcutis
© Eucerin®

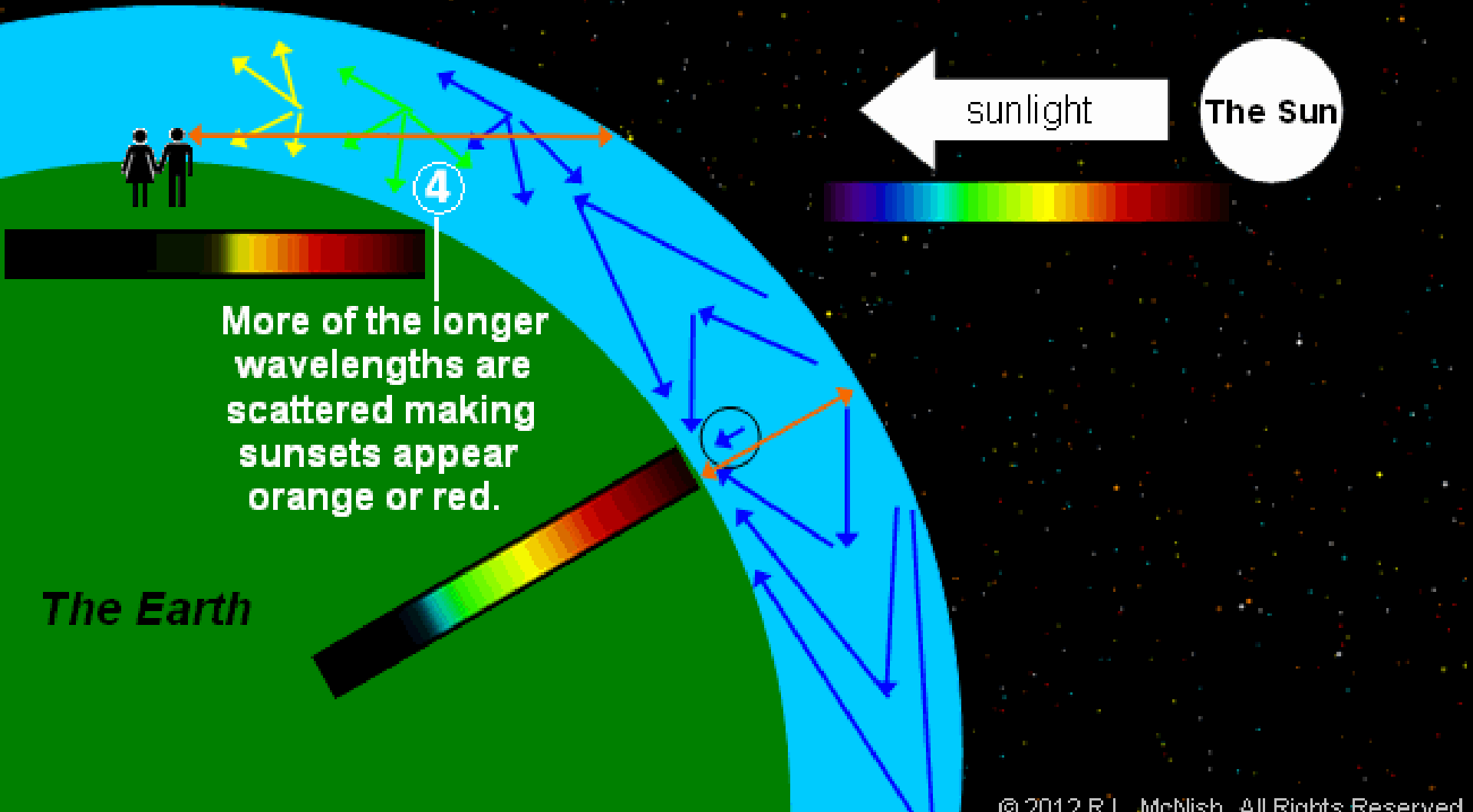

UV
Visible Light
Near Infrared
The Sun's Energy Output
UV-C: 100-280nm
UV-B: 280-320nm
UV-A: 320-380/400nm
Ultraviolet
Visible: 400-780nm
Near Infrared: 780-2500nm
Far Infrared: 2500-50,000nm?
Energy Distribution
3%
44%
53%
Solar Intensity (watts/m²)
Wavelength (nanometers)

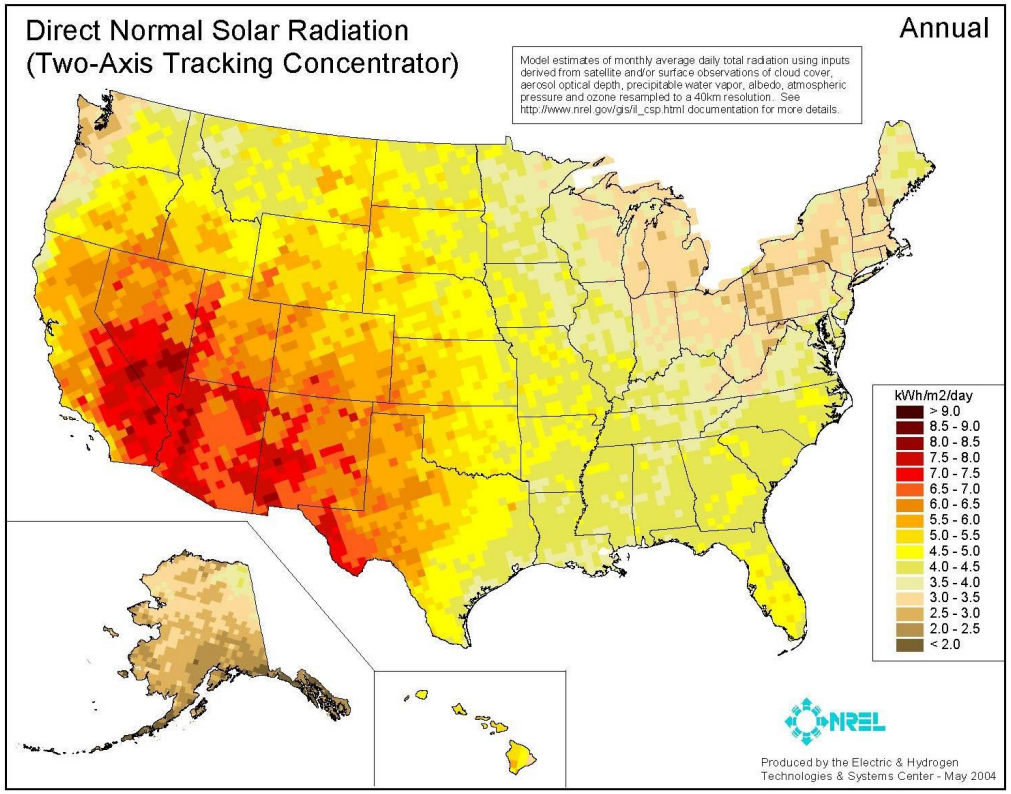

Chlorophyll Absorption Spectrum
of Visible Light
400
450
500
550
600
650
700
Wavelength (nm)

The Sun is not yellow (or orange or red), - it's white.



This effect is even more pronounced at sunset.



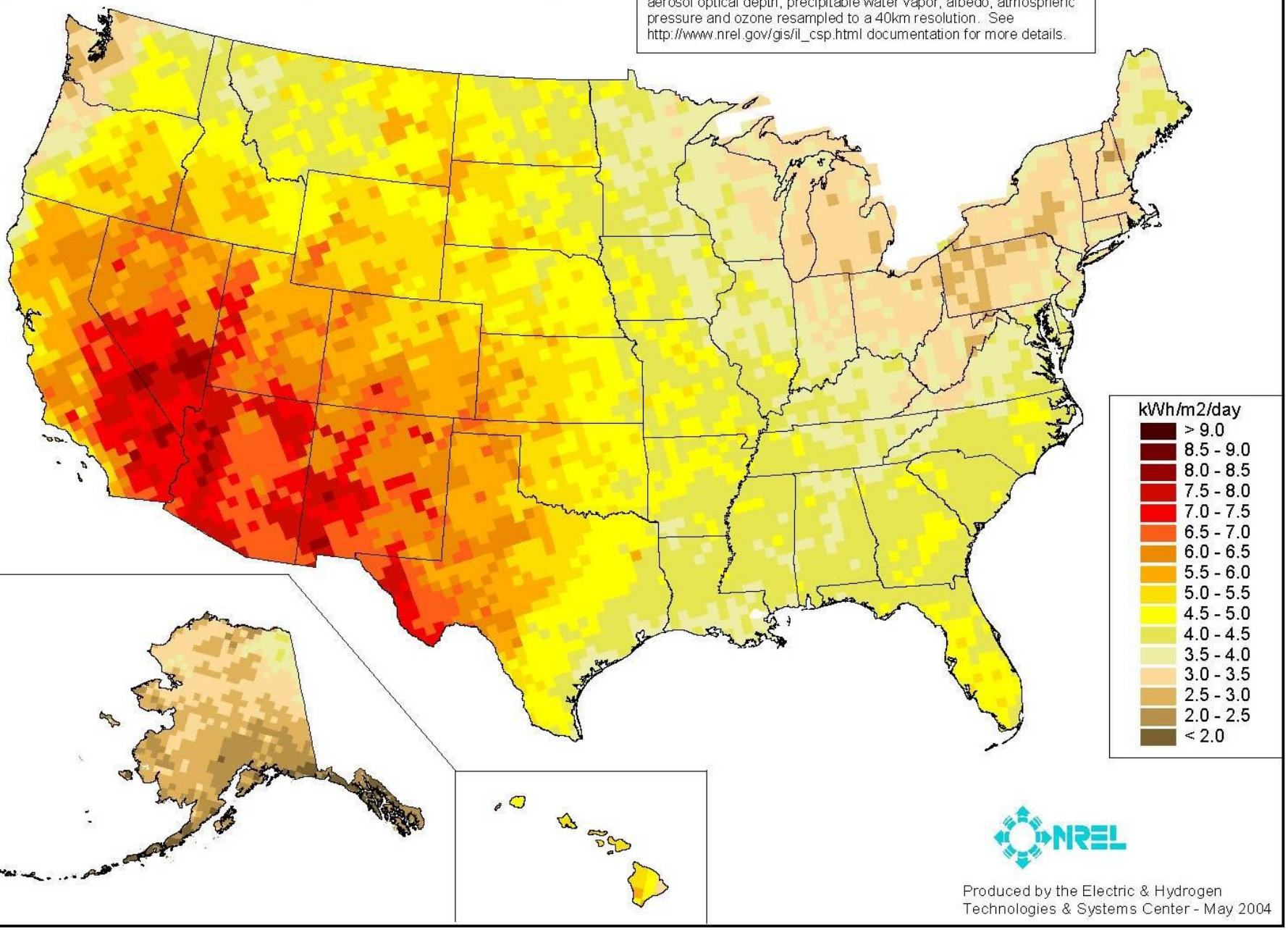


- Irradiance – power density - W/m^2
  - instantaneous
- Irradiation – energy density - kWh/m^2
  - Power integrated over time, psh (peak sun hours)

Direct Normal Solar Radiation (Two-Axis Tracking Concentrator)

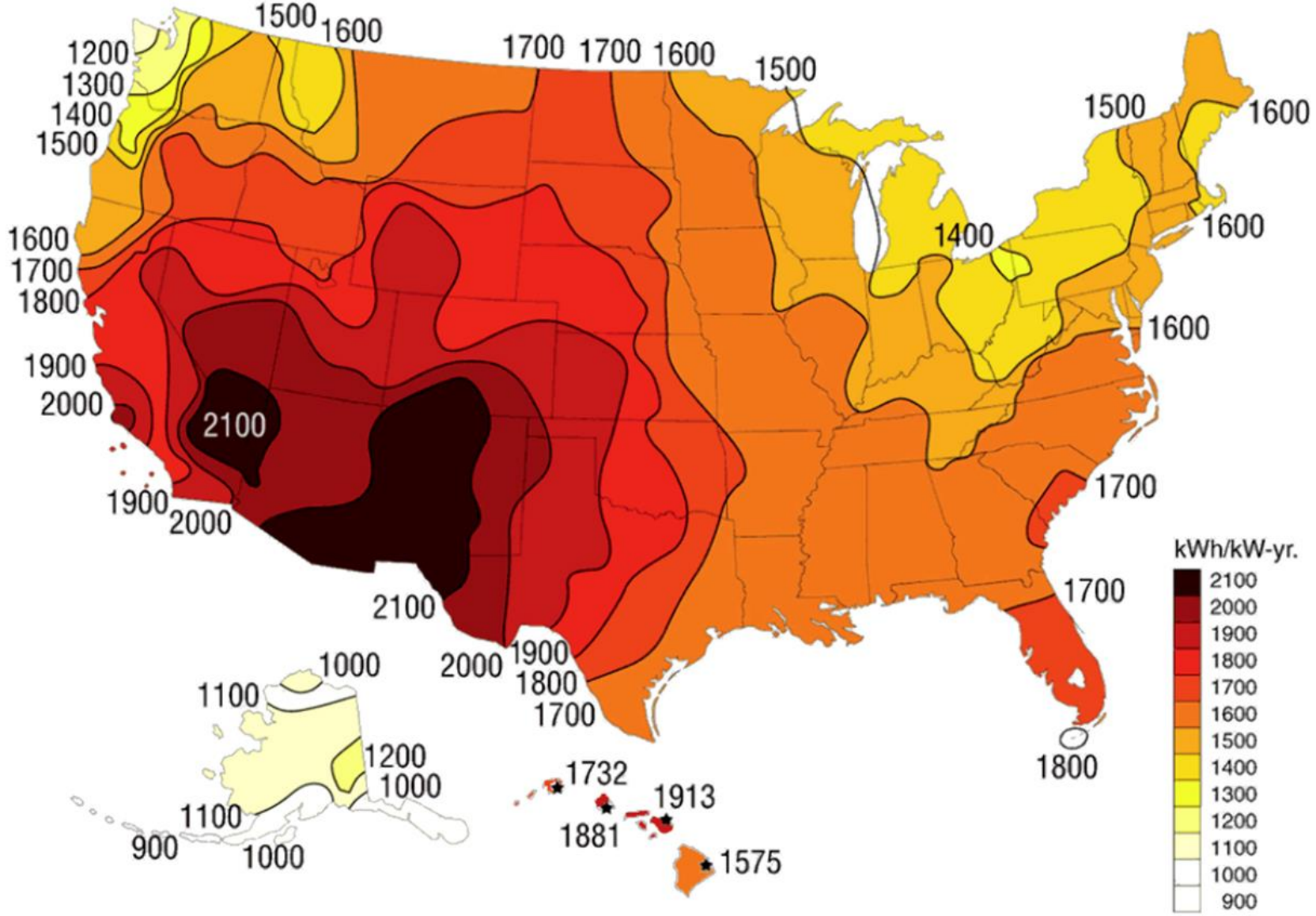
Annual

Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_csp.html documentation for more details.



NREL

Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004


1500
1600
1700
1700
1600
1500
1200
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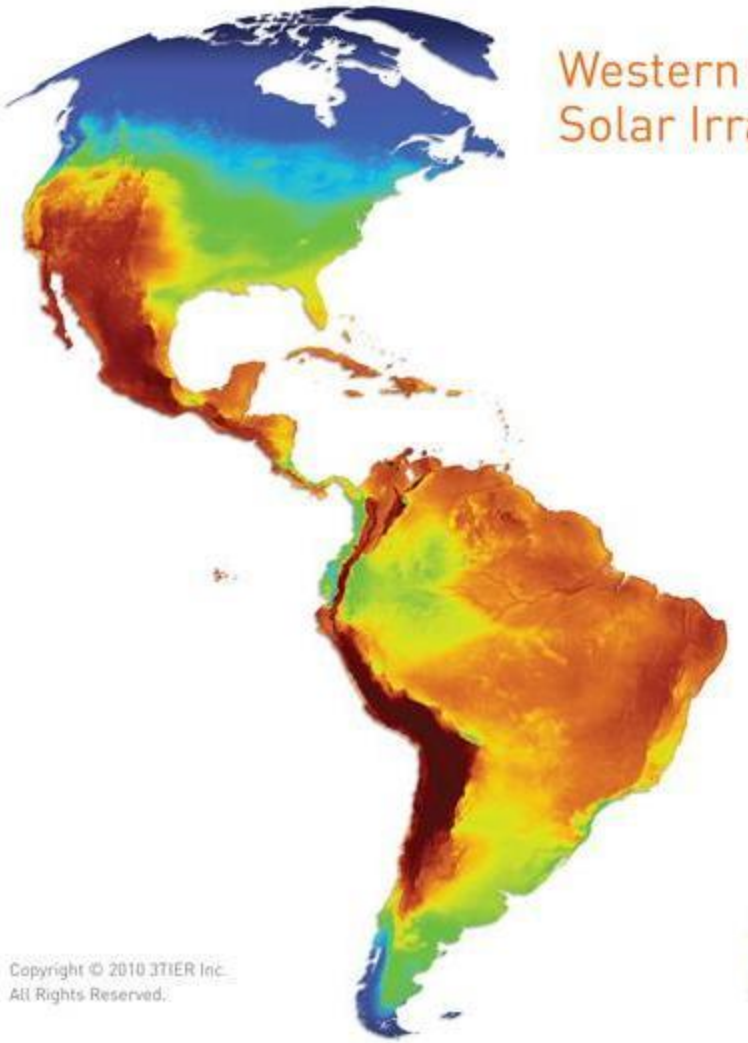
1800
1900
2000
2100
1600
1900
2000
1700
2100
1700
1000
1900
2000
1800
1700
1100
1200
1000
1732
1913
1100
1881
900
1000
1575
1800
kWh/kW-yr.
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900

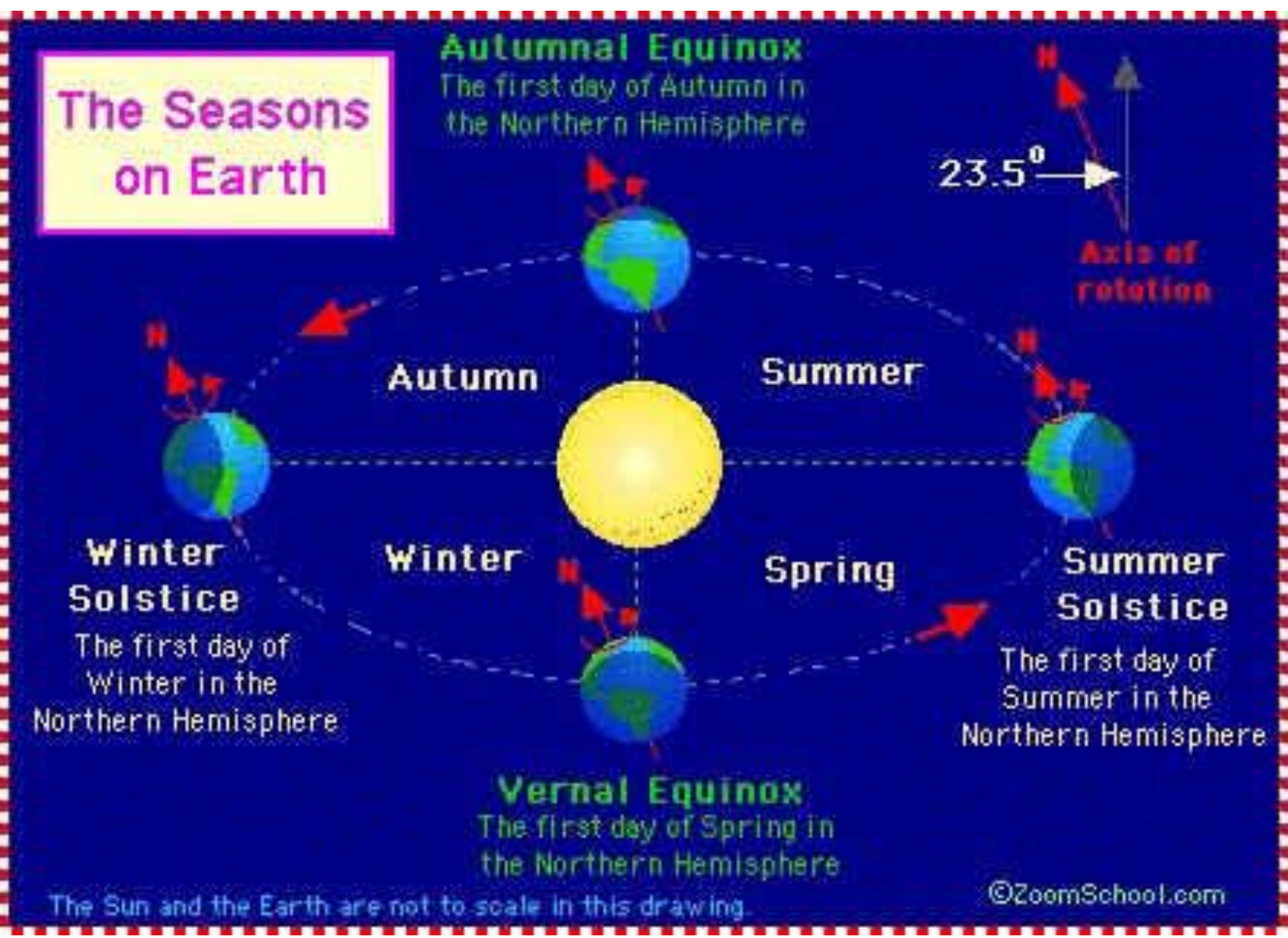
Western Hemisphere Solar Irradiance

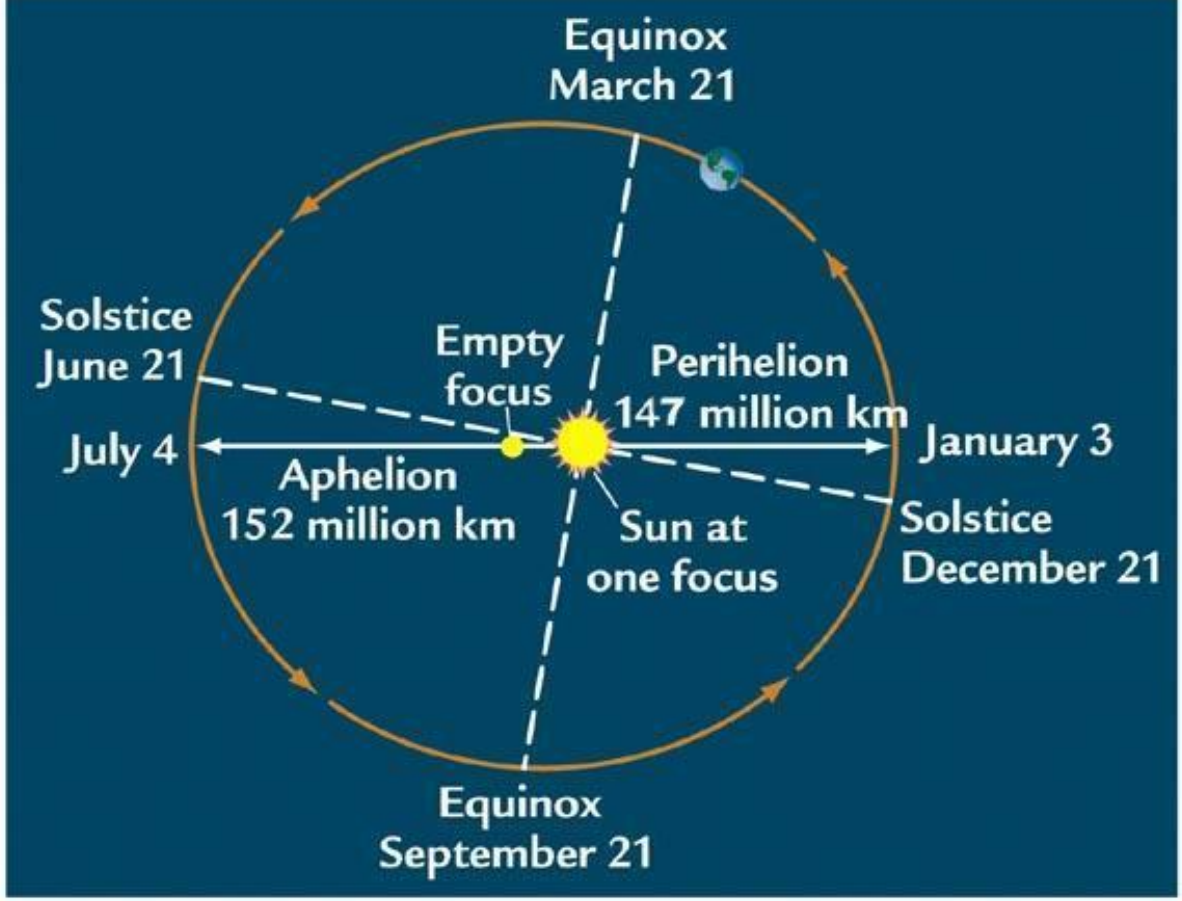
3TIER



Global Horizontal Irradiance

2 4 6 8 kWh/m²/day

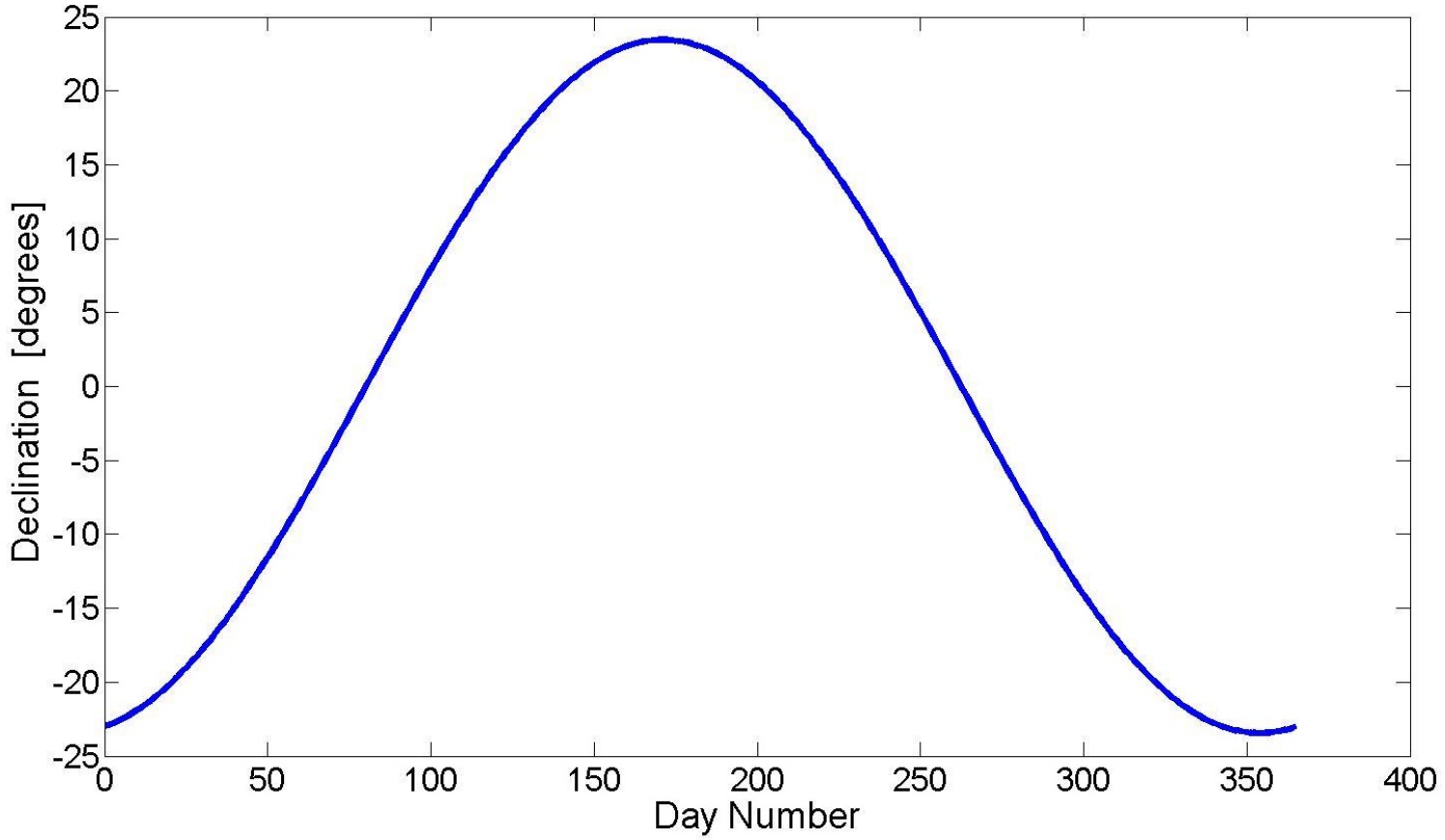

The Seasons on Earth
Autumnal Equinox
The first day of Autumn in the Northern Hemisphere
23.5°
Axis of rotation
Autumn
Summer
Winter
Winter Solstice
The first day of Winter in the Northern Hemisphere
Spring
Summer Solstice
The first day of Summer in the Northern Hemisphere
Vernal Equinox
The first day of Spring in the Northern Hemisphere
The Sun and the Earth are not to scale in this drawing.
©ZoomSchool.com

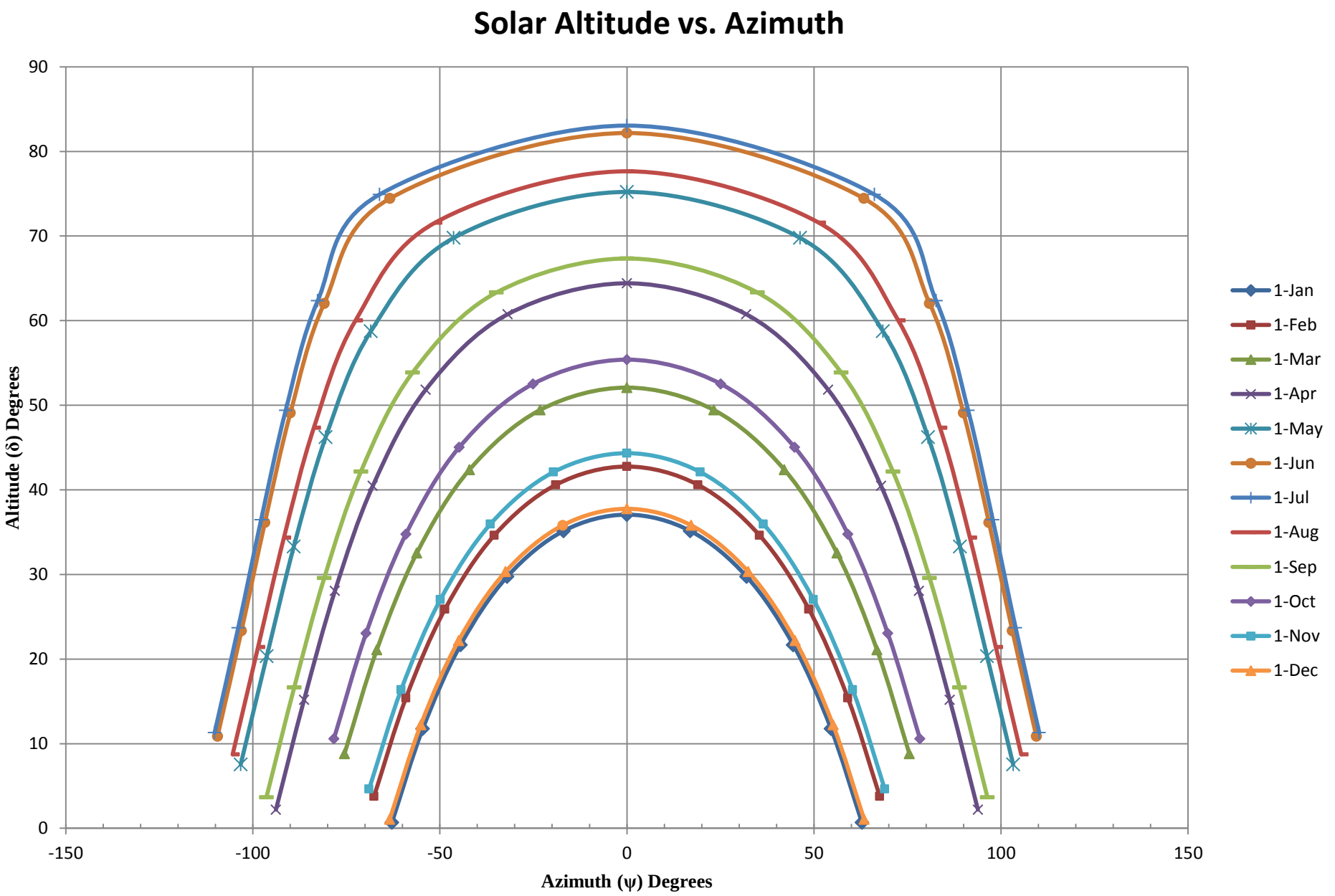


- Perihelion – point in orbit where a planet is nearest the sun (Earth ~ January 3 147 million km)
- Aphelion – point in orbit where a planet is furthest from the sun (Earth ~ July 4 - 152 million km)
- Seasons caused by tilt and not distance from sun (since southern hemisphere tilted towards sun when closest – receives slightly more energy from sun than Northern hemisphere)

Earth Declination

$$\delta = 23.45\sin\left[\frac{360(\mathrm{n}-80)}{365}\right]\ [degrees]$$




Solar Altitude vs. Azimuth
Altitude (δ) Degrees
Azimuth (ψ) Degrees
90
80
70
60
50
40
30
20
10
0
-150
-100
-50
0
50
100
150
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec