Lecture 16: Solar Radiation

Course: MECH-422 – Power Plants

Instructor: Kashif Liaqat

Term: Fall 2021

BUITEMS – DEPARTMENT OF MECHANICAL ENGINEERING

Solar Radiation and Geometric Relationship of the Sun and Earth

- So far, we learned about the variation of the energy released by the Sun and how the distance between Earth and the Sun impacts the irradiance outside Earth's atmosphere.
- The actual irradiance that a certain location on Earth receives depends on the following four factors:
  - Latitude of the location
  - Time of the day
  - Time of the year
  - Atmospheric conditions

Cosine emission law

- also known as Lambert's cosine law
- It states that the irradiance a surface actually receives is directly proportional to the cosine of the angle between the direction of the light and the direction perpendicular to the surface

$$I_s = I\cos\theta$$

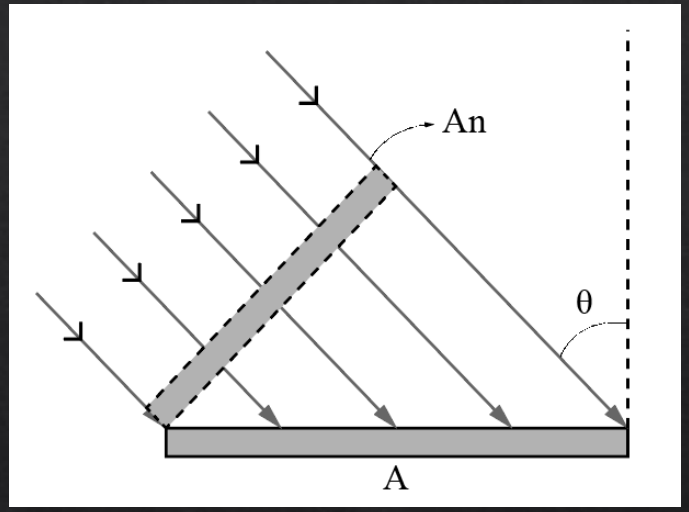
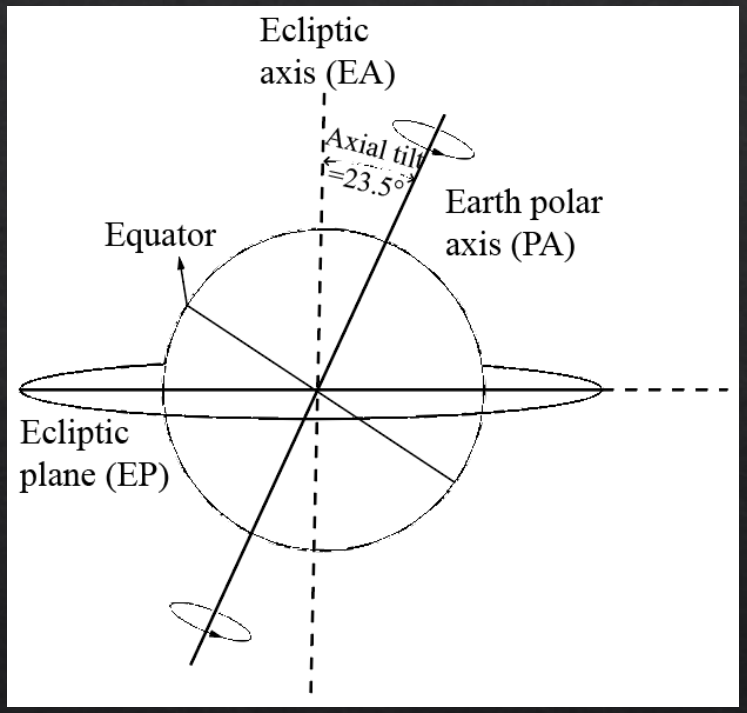


Illustration for the cosine emission law

It simply means when a surface is not normal to the direction of the light, the irradiance (radiation per unit of area) received by the surface reduces because the same amount of radiation will be distributed on a larger surface

Solar Radiation and Geometric Relationship of the Sun and Earth

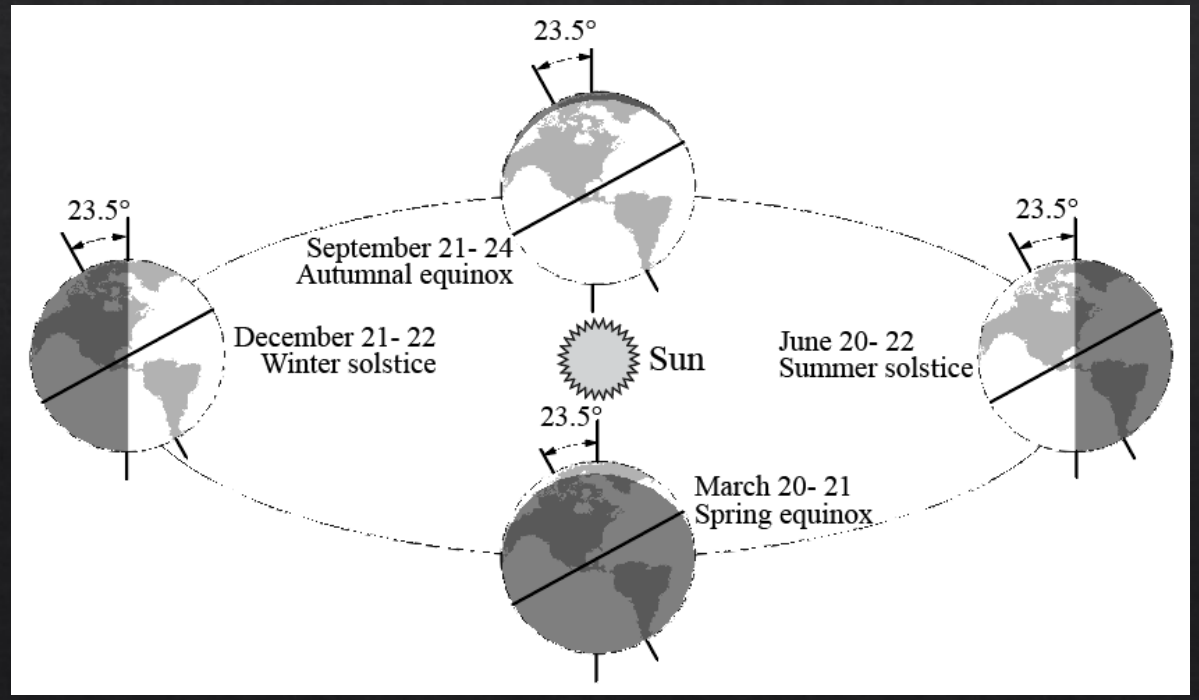
- Earth orbits around the Sun, which takes 365.256 days for every complete rotation.
- Also, Earth rotates around its own axis every 86,400
- (=24 × 60 × 60) seconds, which results in the day and night cycle.



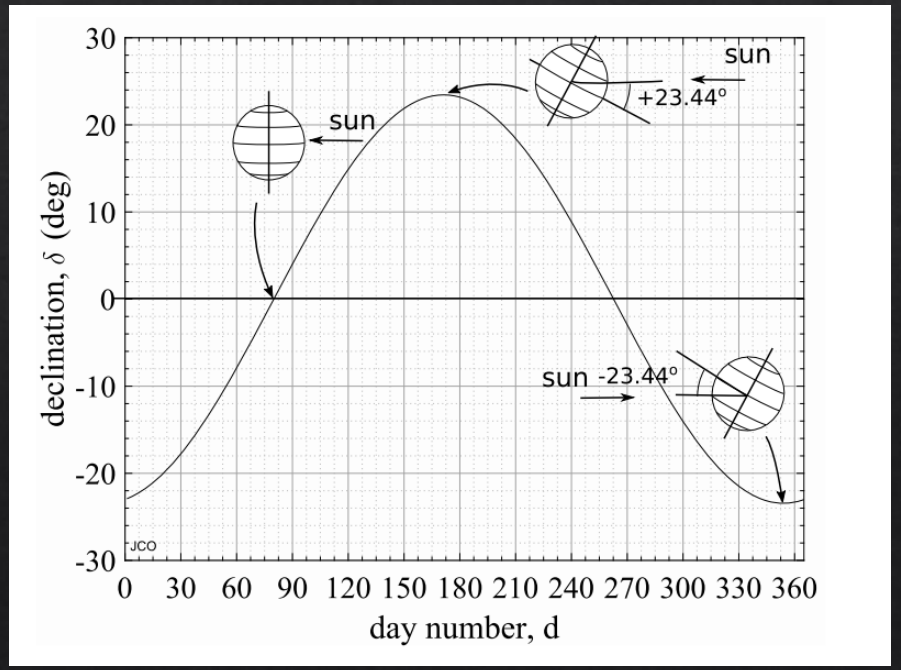
Rotation of Earth around itself and the Sun

Solar Radiation and Geometric Relationship of the Sun and Earth

Solar declination is the angle between the Sun's rays and the plane of the Earth's Equator. An equinox occurs when the declination is 0° that day (March 21 and September 22, currently). A solstice occurs when the declination is ±23.5° (June 21 and December 21, currently).



Schematic of the Sun and Earth relative positions during solstices and equinoxes



Solar Radiation and Geometric Relationship of the Sun and Earth

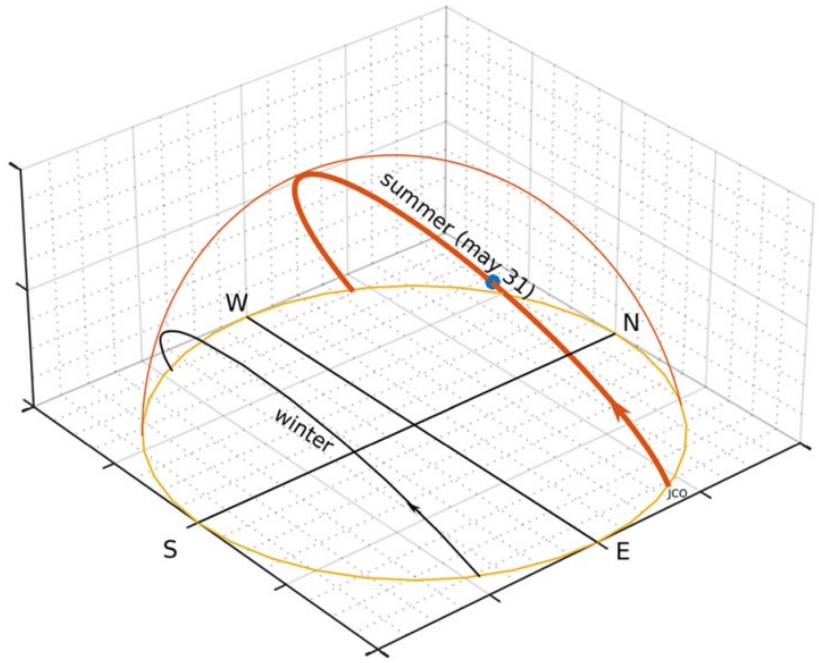
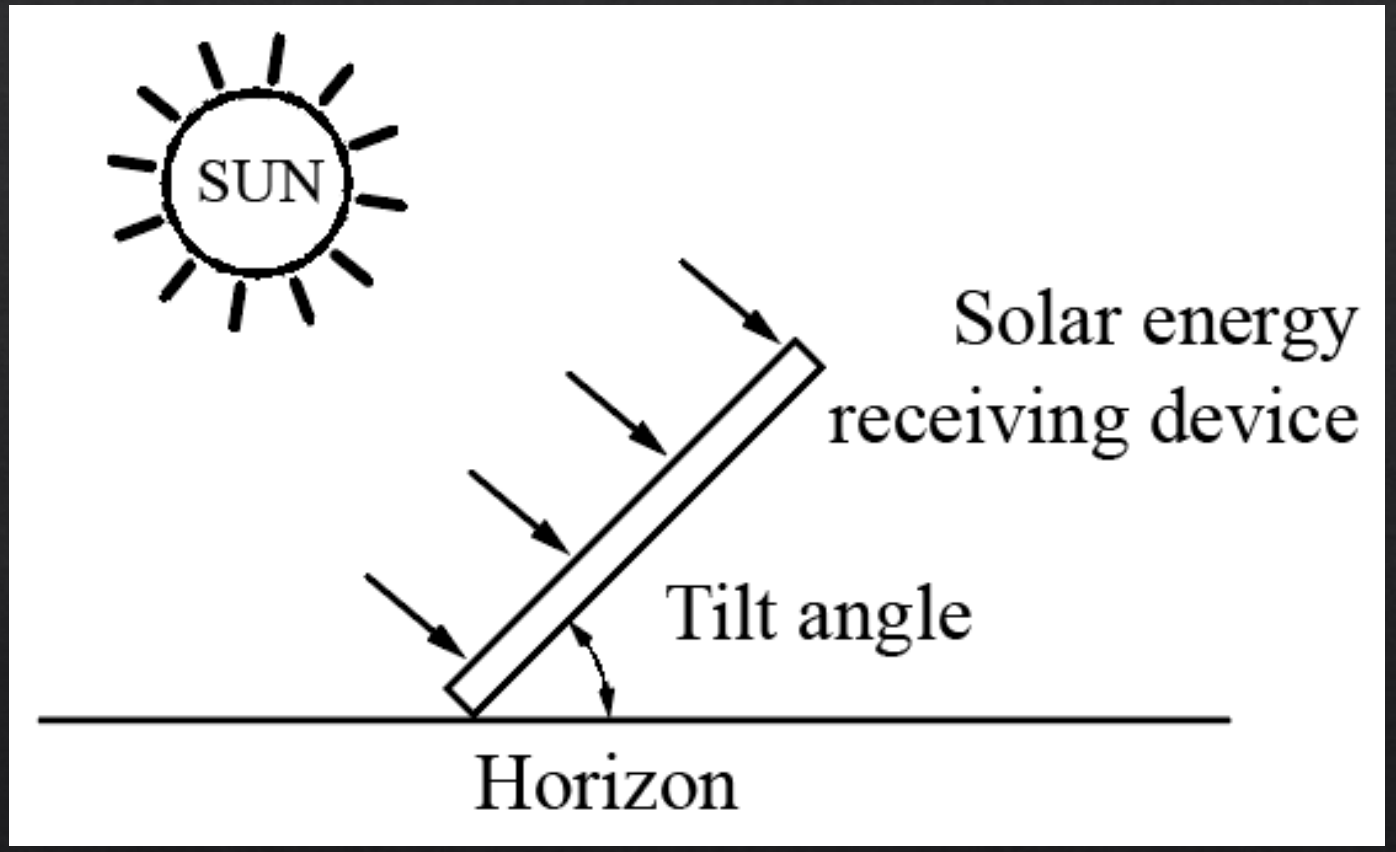


FIGURE 12.9

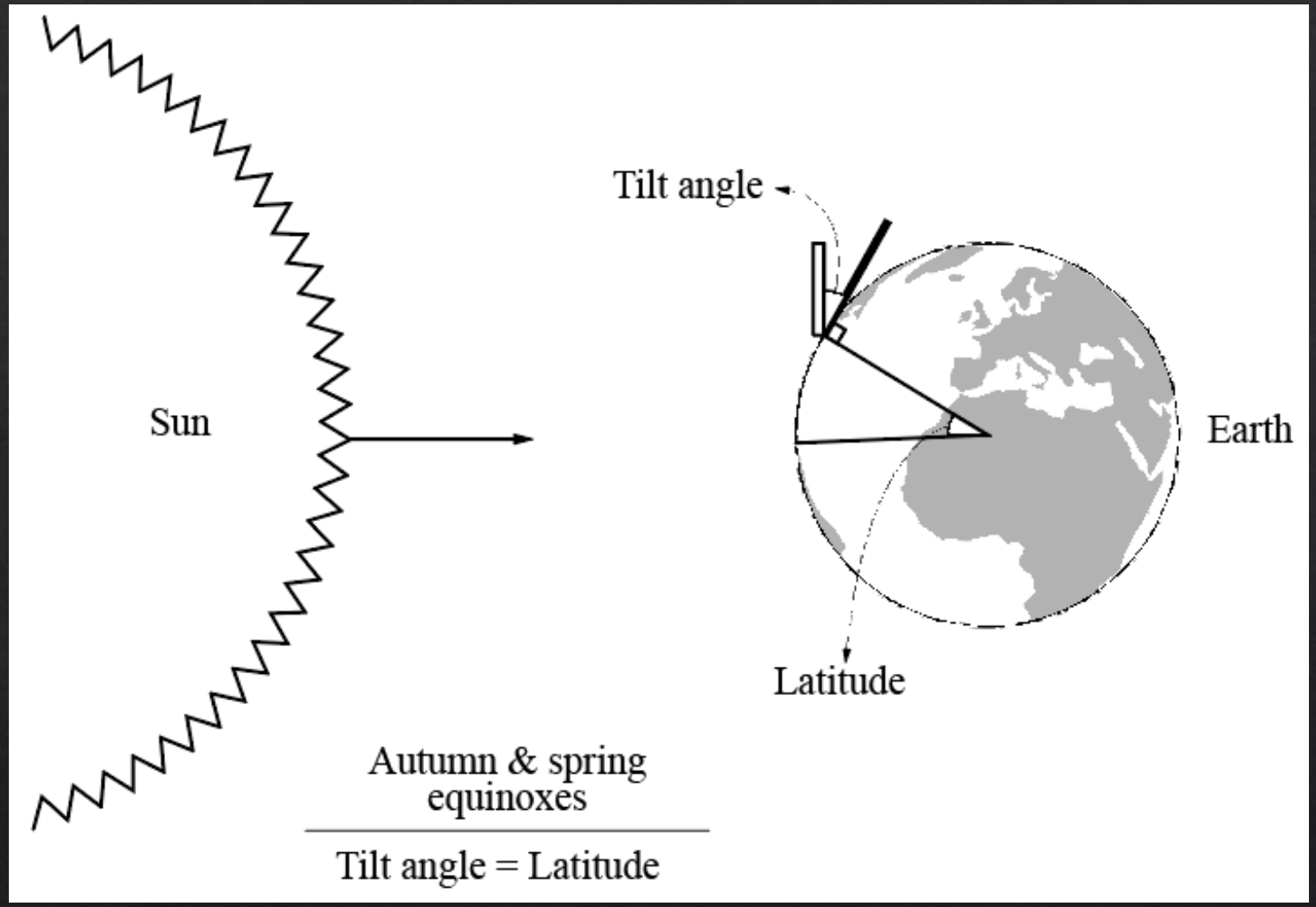
Solar motion in the sky as seen from a location in the Northern Hemisphere ($\lambda = 30.43$ degrees). In summer, the Sun appears higher in the sky than in winter.

Solar Radiation and Geometric Relationship of the Sun and Earth



Schematic of the tilt angle of a solar energy receiving device

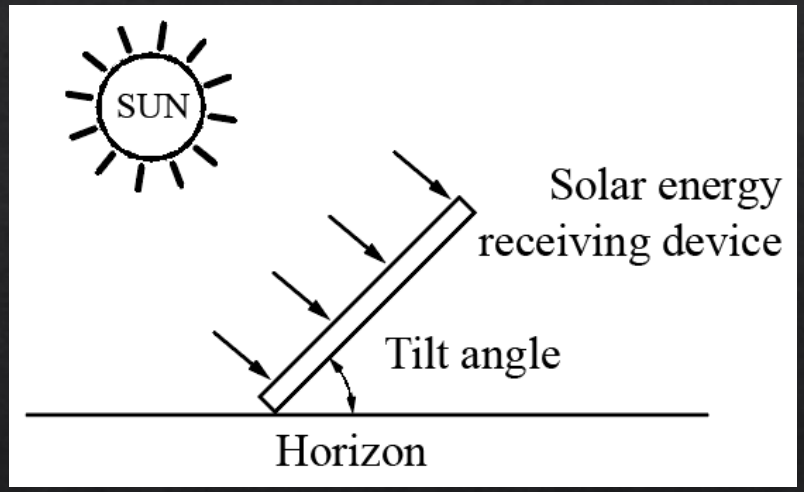
Tilted solar panels in a solar farm (Image by Andreas Troll from Pixabay, https://pixabay.com/photos/ solar-field-solar-photovoltaic-191683/)



When the tilt angle is equal to the latitude of the site, the surface of the device will be perpendicular to Sun's rays on the two equinoxes

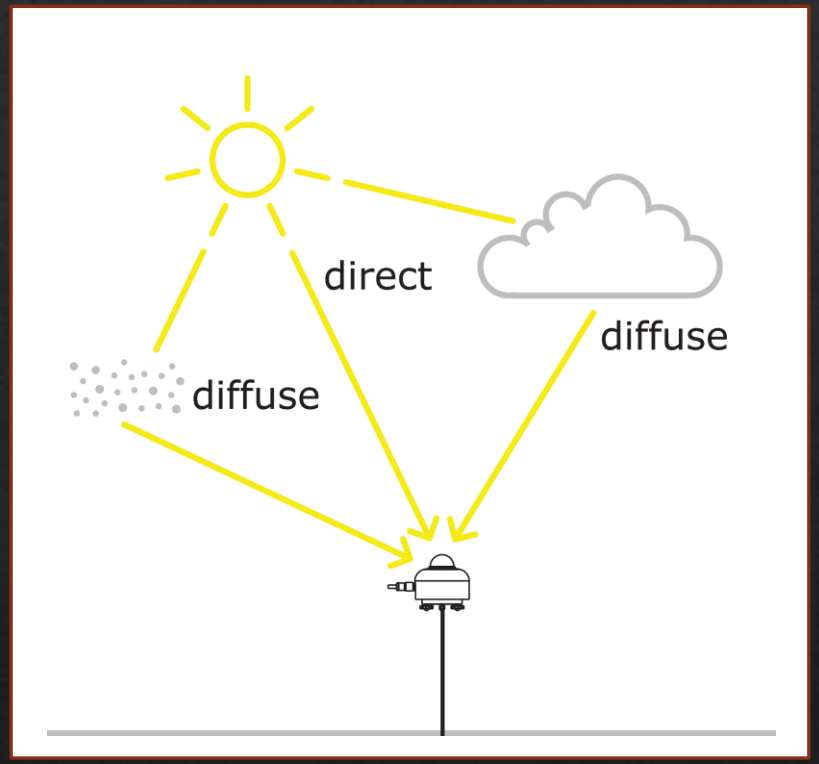
Solar Radiation and Geometric Relationship of the Sun and Earth

- If the objective is to maximize the annual intercepted solar energy, the best tilt angle is equal to the latitude of the site.
- if it is desired to have more energy in summer, for example, for photovoltaic panels installed in a hot region where the peak load happens in summer
  - the tilt angle of the device should be smaller than the latitude.
- On the contrary, if more energy is required in winter, for example, for a solar water heater in a cold region where more thermal energy is required in winter
  - the tilt angle should be greater than the latitude.



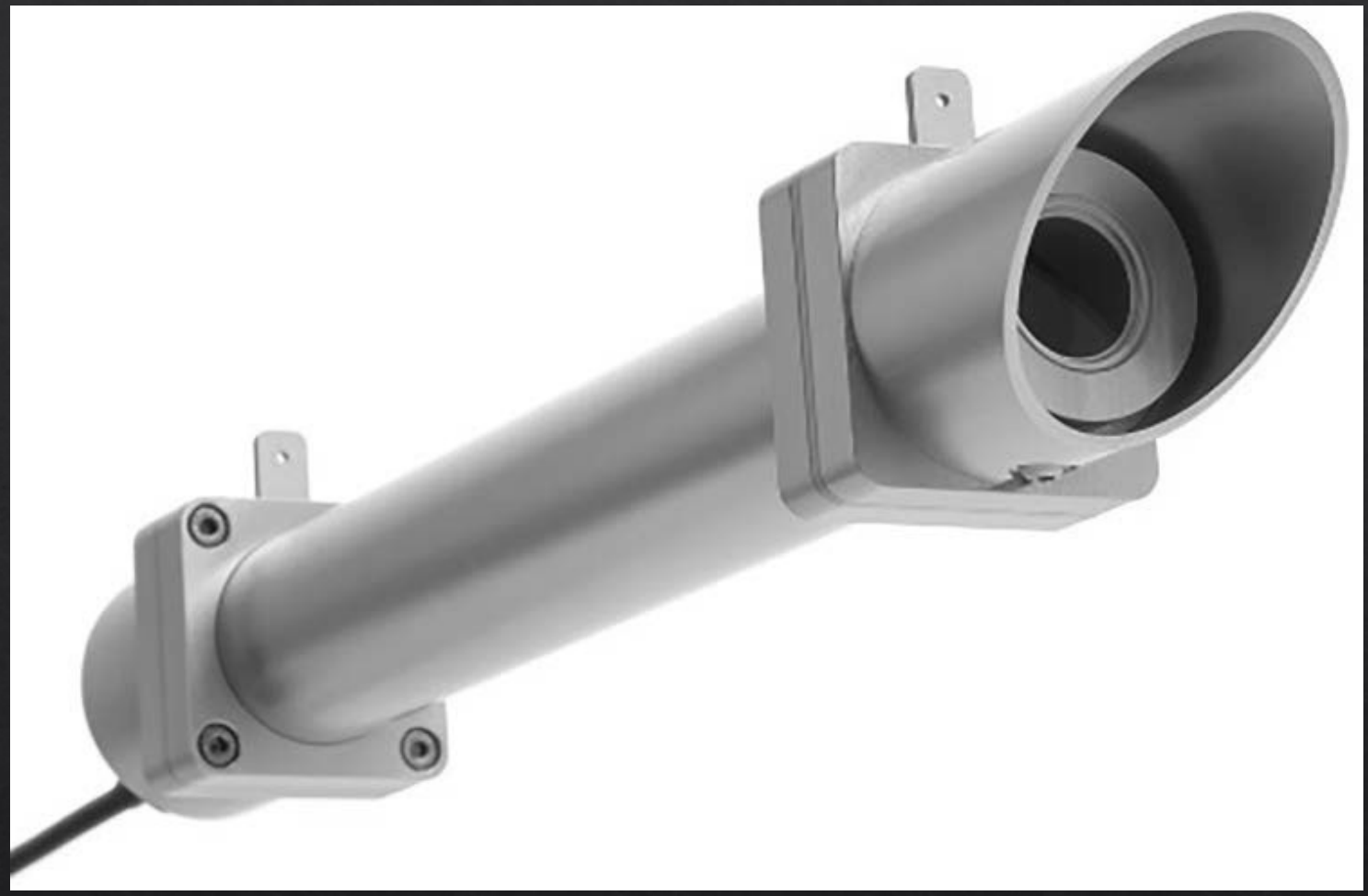
What's the difference between DNI, DIF and GHI?

- The term solar irradiance represents the power from the sun that reaches a surface per unit area.
- Direct irradiance (DNI) is the part of the solar irradiance that directly reaches a surface;
- Diffuse irradiance (DHI) is the part that is scattered by the atmosphere;
- global irradiance (GHI) is the sum of both diffuse and direct components reaching the same surface.

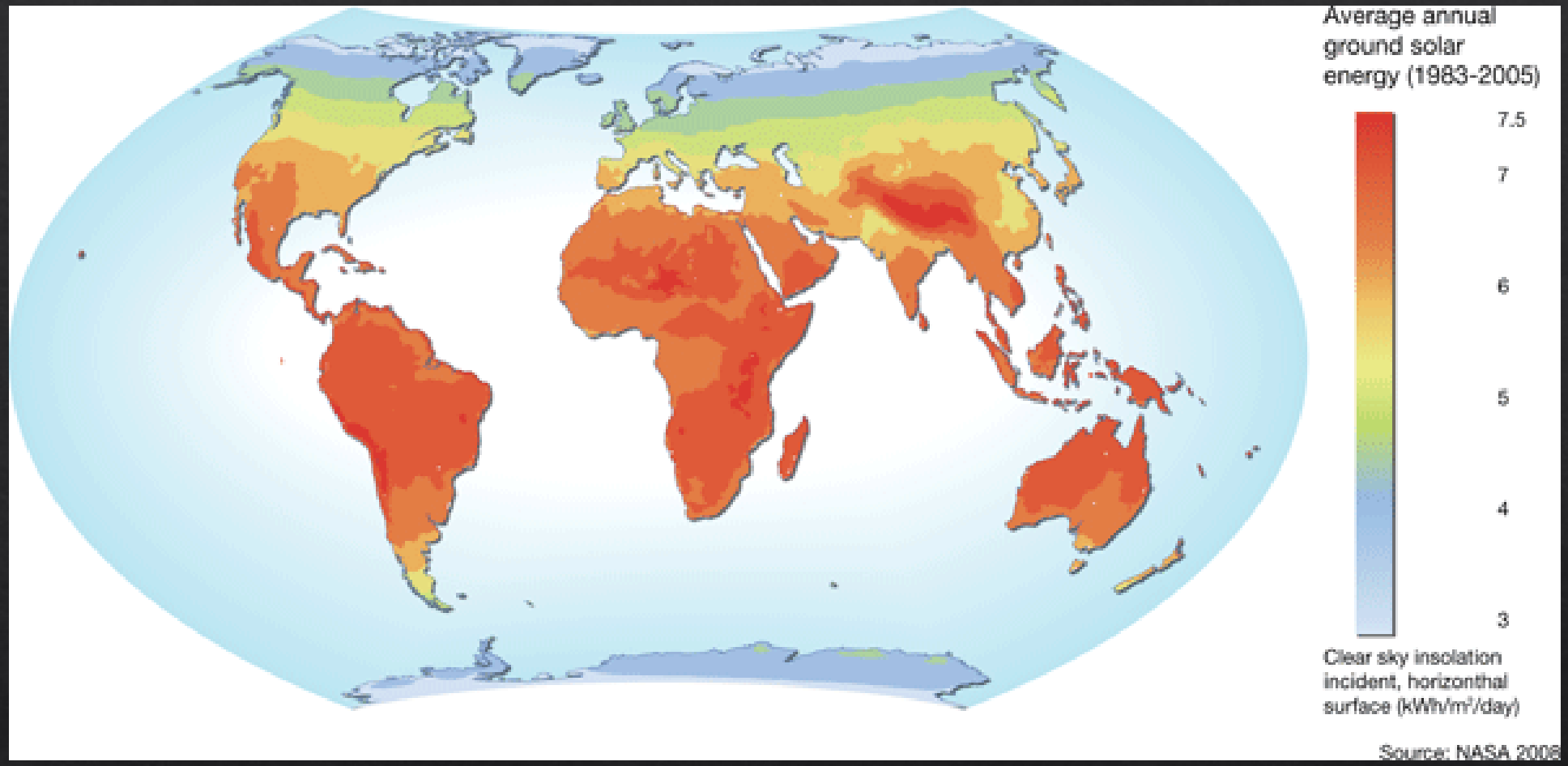


GHI, Global Horizontal Irradiation
DNI, Direct Normal Irradiation
DHI, Diffuse Horizontal Irradiation

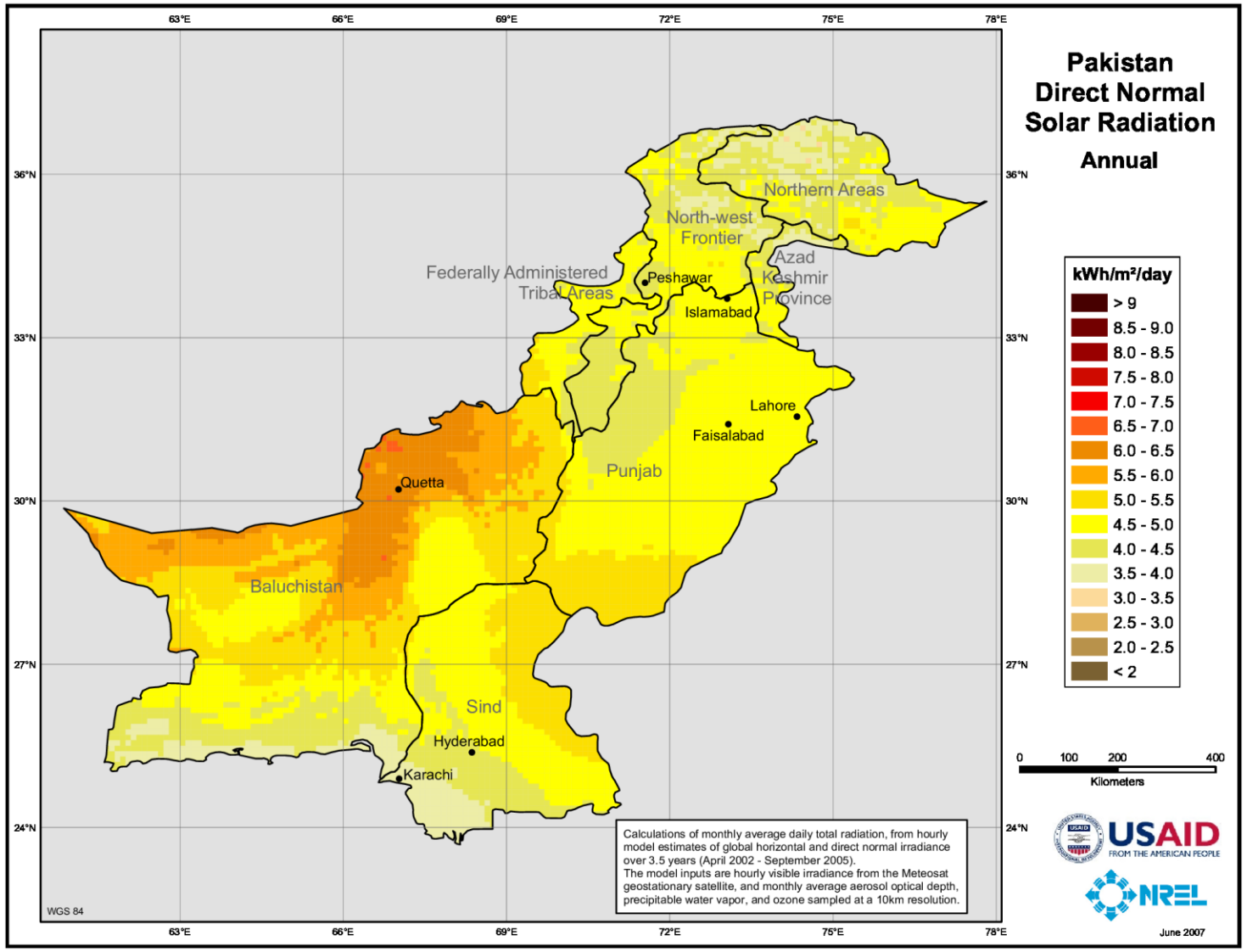
A pyranometer to measure GHI. (By Hukseflux Thermal Sensors – Hukseflux Thermal Sensors, CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=59851751)



A pyrheliometer to measure DNI. (By Hukseflux Thermal Sensors – Hukseflux Thermal Sensors, CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=59851747)



Global solar insolation map. (Source: The U.S. Energy Information Administration, https://www.eia.gov/energyexplained/solar/where-solar-is-found.php)


Pakistan
Direct Normal
Solar Radiation
Annual
kWh/m²/day
> 9
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2
Northern Areas
North-west Frontier
Federally Administered Tribal Areas
Azad Kashmir
Province
Peshawar
Islamabad
Lahore
Faisalabad
Punjab
Quetta
Baluchistan
Sind
Hyderabad
Karachi
63°E
66°E
69°E
72°E
75°E
78°E
36°N
33°N
30°N
27°N
24°N
0 100 200 400
Kilometers
Calculations of monthly average daily total radiation, from hourly model estimates of global horizontal and direct normal irradiance over 3.5 years (April 2002 - September 2005).
The model inputs are hourly visible irradiance from the Meteosat geostationary satellite, and monthly average aerosol optical depth, precipitable water vapor, and ozone sampled at a 10km resolution.
WGS 84
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June 2007

End of Lecture!