Solar Radiation is the electromagnetic energy emitted by the sun that reaches Earth. It is the **primary driver of Earth's climate, weather, and renewable energy systems** (like solar PV and thermal). Measuring it accurately is critical for solar energy projects, agriculture, climate science, and architecture.

I. Key Solar Radiation Components

Solar radiation is categorized based on its direction and composition:

Term	Definition	Formula/Relationship
Extraterrestrial Radiation (G_{ext})	Solar flux *above* Earth's atmosphere (~1367 W/m², the "solar constant").	$G_{ext}=1367\cdot(1+0.033\cos\frac{360n}{365})$ *(n = day of year)*
Direct Normal Irradiance (DNI)	Radiation traveling in a straight line from the sun (beam radiation).	Critical for concentrated solar power (CSP).
Diffuse Horizontal Irradiance (DHI)	Radiation scattered by atmosphere, clouds, and particles.	—
Global Horizontal Irradiance (GHI)	Total radiation on a horizontal surface: **GHI = DNI · cos(θ) + DHI** *(ϑ = solar zenith angle)*	Primary metric for PV system sizing.
Global Tilted Irradiance (GTI)	Radiation on a tilted surface (e.g., solar panels).	GTI = DNI · cos(θ_i) + DHI_{tilt} + reflected radiation

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II. Factors Affecting Solar Radiation

1. **Atmospheric Effects**:
   - **Absorption**: By O_2, O_3, H_2O, CO_2.

    - **Scattering**: Rayleigh (gases, blue sky) + Mie (aerosols/particles, haze).
2. **Geometric Factors**:
    - **Solar Zenith Angle** (θ): Higher θ → longer atmospheric path → more attenuation.
    - **Air Mass (AM)**: AM = 1/cos(θ). *AM1.5* (θ=48°) is the standard spectrum for solar panel testing.
3. **Weather**: Clouds reduce DNI drastically; DHI increases under light clouds.
4. **Albedo**: Surface reflectivity (snow: 80%, grass: 20%) boosts GTI via ground reflection.

III. Solar Radiation Measurement Instruments

1. Pyranometers

- **Function**: Measure GHI or GTI.
- **Principle**: Thermopile sensor converts *temperature difference* (black surface vs. reference) to voltage.
- **Accuracy**:
    - *Secondary Standard*: ±3% (high-cost research).
    - *Class A/B/C*: ±5–10% (commercial use).
- **Key Brands**: Kipp & Zonen, Hukseflux.

2. Pyrheliometers

- **Function**: Measure DNI (mounted on sun-tracking "solar trackers").
- **Design**: Tube with thermopile at the base; aperture limits field of view to 5°.
- **Standard**: ISO 9060:2018 (Class A/B/C).

3. Sunshine Duration Sensors

- **Function**: Record hours with DNI > 120 W/m² (e.g., Campbell-Stokes recorder, digital sensors).

4. Reference Cells

- **Function**: Measure irradiance using calibrated PV cells.
- **Use**: Quick surveys, PV performance monitoring (less accurate than thermopiles).

IV. Satellite & Model-Based Estimation

When ground sensors are unavailable:

1. **Satellite Data**:
    - Geostationary satellites (e.g., GOES, Meteosat) provide GHI maps every 5–15 mins.
    - Sources: NASA POWER, ECMWF, Copernicus.
2. **Numerical Weather Models**:
    - Predict GHI/DNI using atmospheric physics (e.g., WRF, GFS).
3. **Empirical Models**:
    - Estimate GHI from sunshine duration (Ångström-Prescott model).

V. Key Metrics for Solar Energy

Term	Formula/Description	Application
Peak Sun Hours (PSH)	Hours equivalent to 1000 W/m² irradiance. Daily PSH = Daily GHI (kWh/m²) / 1 kW/m².	Sizing PV systems (e.g., 5 PSH → 5 hrs @ 1000 W/m²).
Solar Irradiation	Cumulative energy over time (kWh/m²/day).	Energy yield calculation.
Clearness Index (Kt*Kt*)	Kt=GHIExtraterrestrial GHI*Kt* =Extraterrestrial GHIGHI	Quantifies atmospheric clarity (0–1).
