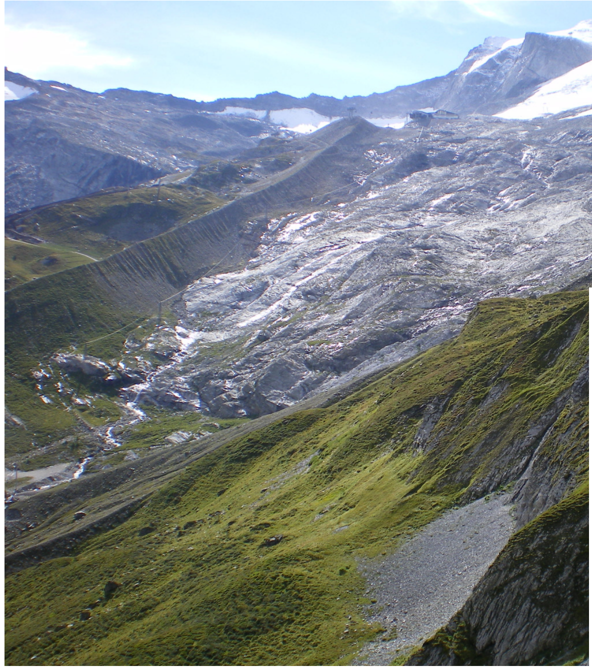
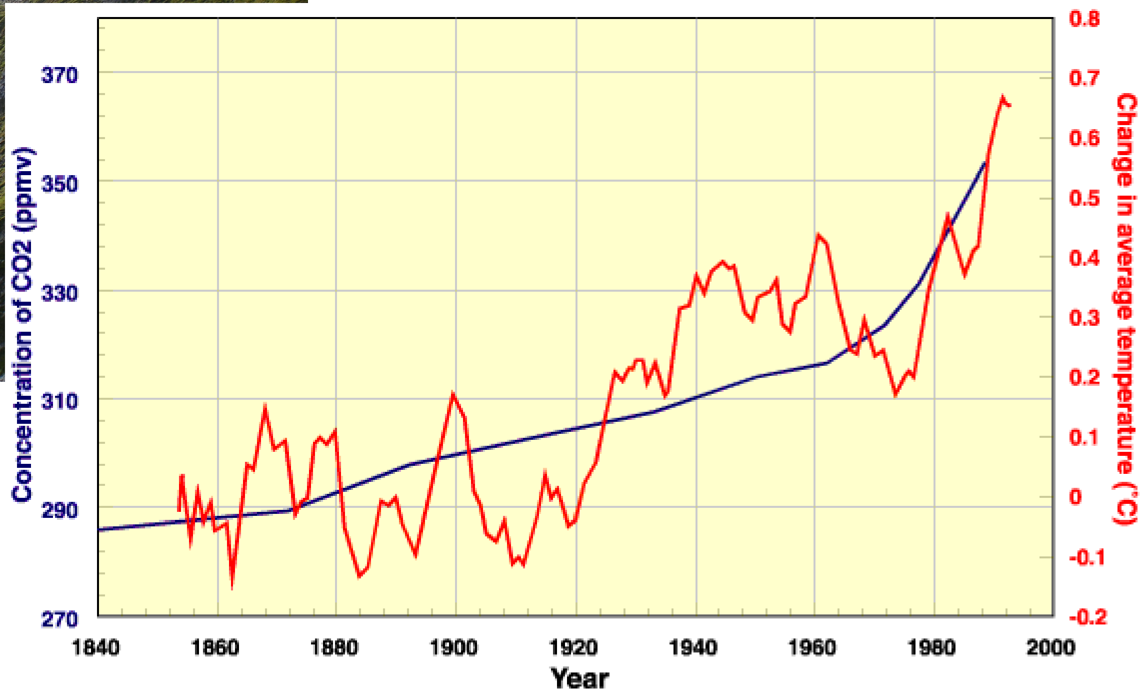
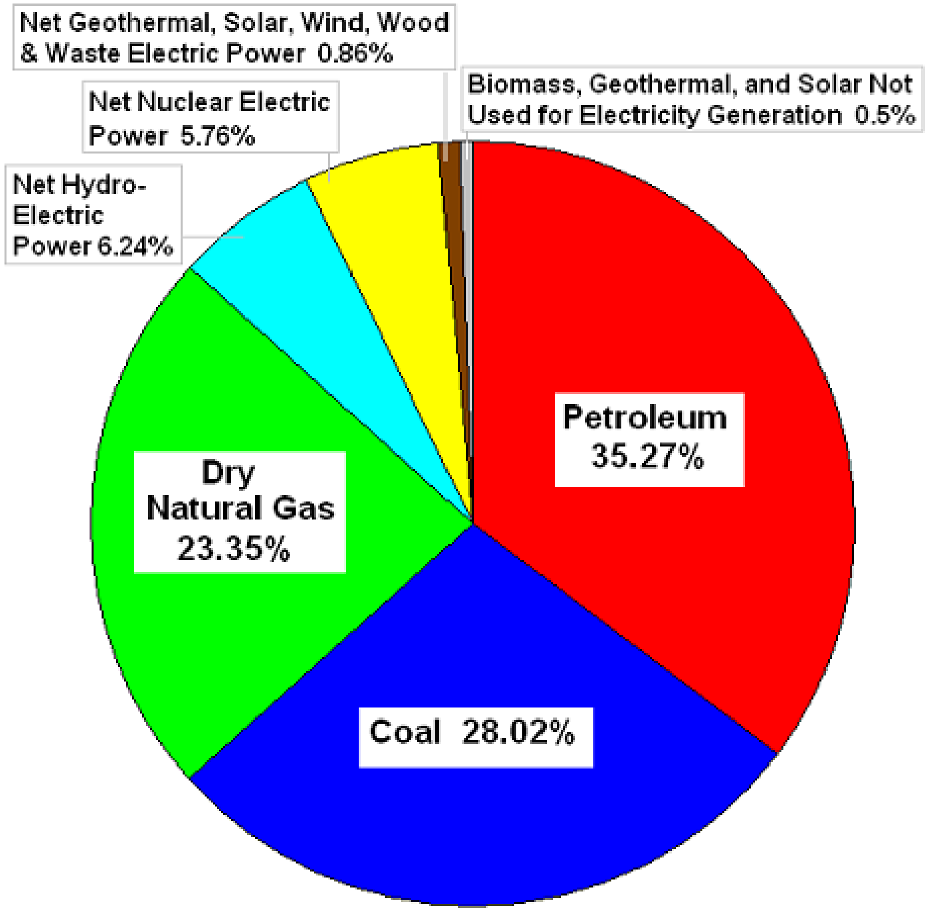
Global warming and greenhouse effect

Alps 2007

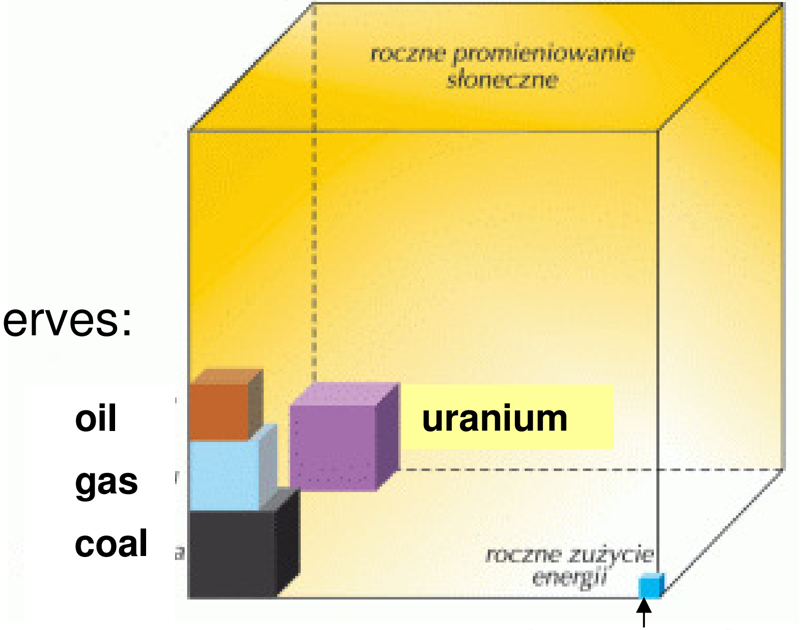






World Consumption 2006

Energetical resources:
fossil and nuclear fuels compared to the energy from the Sun



energy coming from the sun per year

total reserves:

oil

gas

coal

uranium

world consumption/year

Renewable energy

- ☐ hydro 5 TW=5x10^{12} W
- ☐ geotherm. – up to 20 TW
- ☐ wind – 50 TW (27 % area of Earth)
- ☐ biomass 20 TW (31% area of Earth)
- ☐ sun 600 TW

Natan Lewis, Caltech

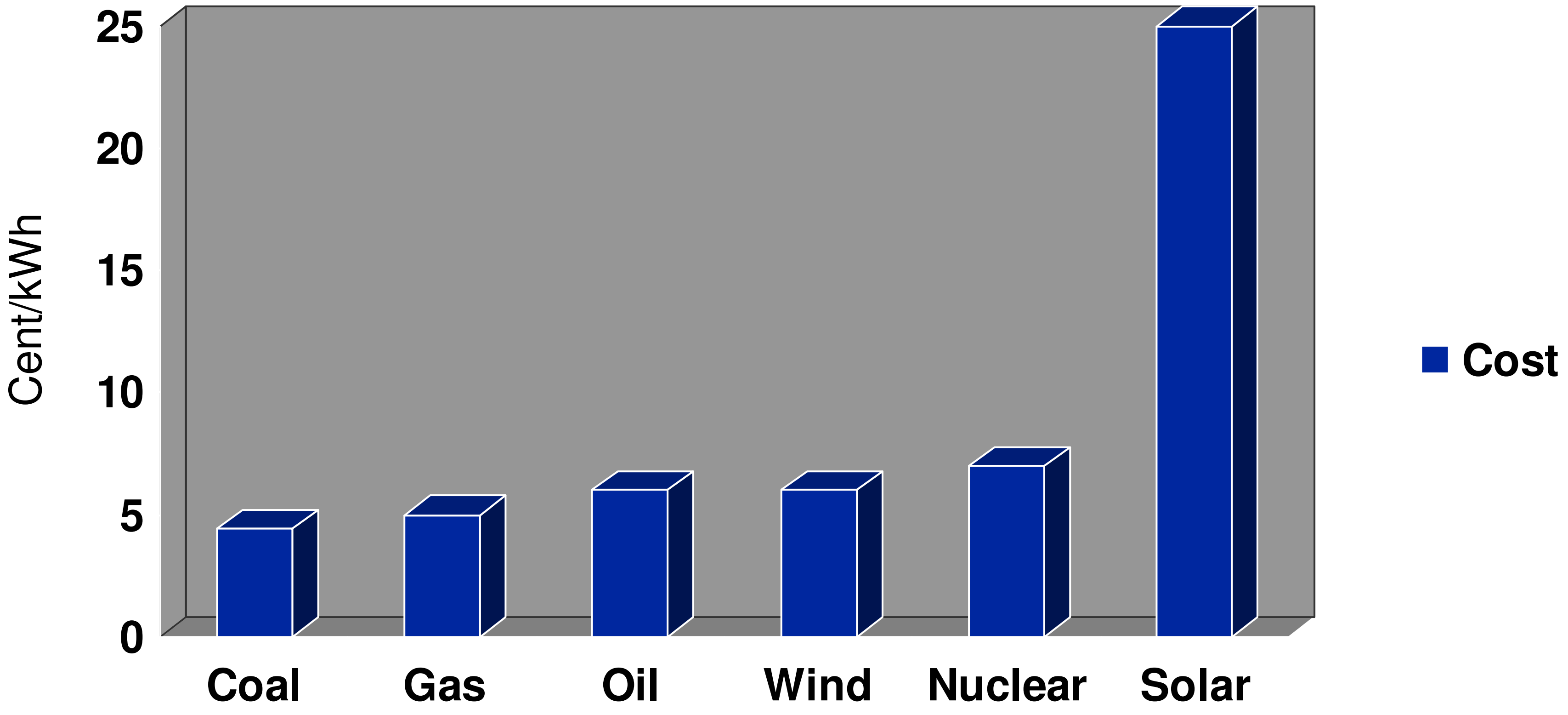
Present and expected energy demand

2010: 15 TW

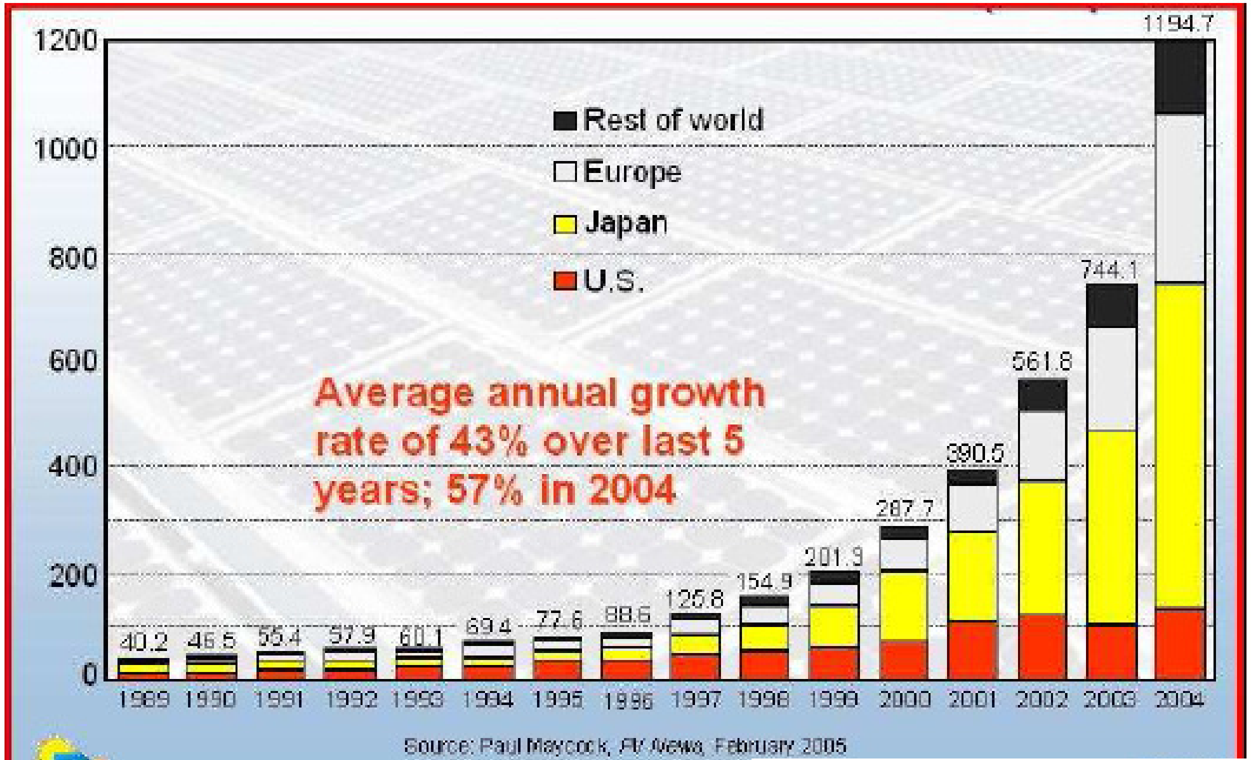
2050: 28 TW

generation of 20 TW at 10 % eff.
requires 8.8 % area of USA

Electricity - production costs (USA, 2002)

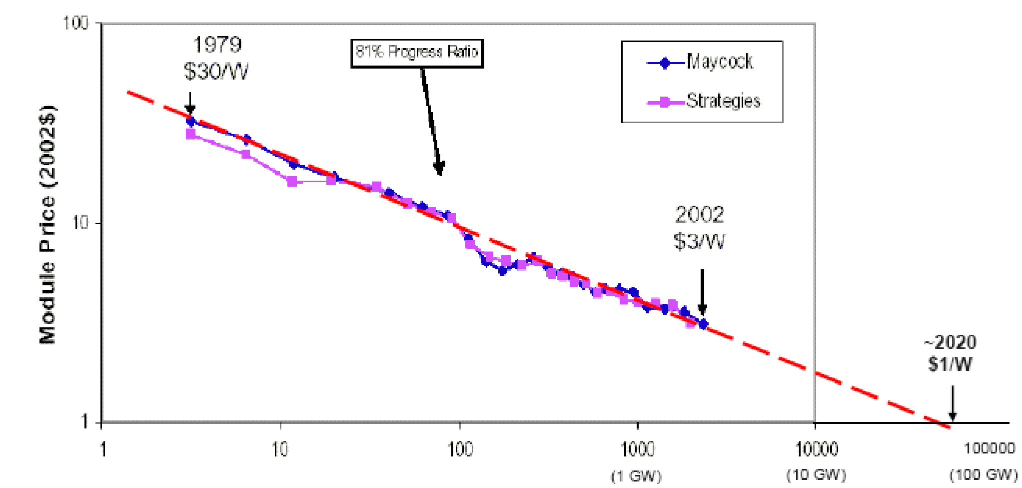


Growth of photovoltaic industry



Average annual growth rate of 43% over last 5 years; 57% in 2004

Source: Paul Maycock, *PV News*, February 2005



1979
$30/W

2002
$3/W

~2020
$1/W

Photovoltaics – energy from the sun

Topics

1. The characteristics of sunlight
2. Electrons and holes in semiconductors: band model, doping, current transport, absorption of light, defects and recombination
3. Junctions: pn, heterojunction
4. Principles of solar cell: photovoltaic effect, conversion efficiency, basic design, efficiency limits and photovoltaic losses
5. Simulation of solar cells performance
6. Monocrystalline solar cells: silicon, GaAs
7. Thin film solar cells: amorphous silicon, heterojunction cells (CIGS, CdTe)
8. Other concepts: Graetzel cell, organic etc
9. 3rd generation photovoltaics, new ideas
10. Modules: design, problems & solutions
11. Light management: concentration, light confinement
12. Photovoltaic systems: stand-alone, grid-connected, concentrator

Literature

J. Nelson „The physics of solar cells”

S.R.Wenham „Applied photovoltaics”

R.H. Bube „Photovoltaic materials”

A. Rockett „The materials science of semiconductors”

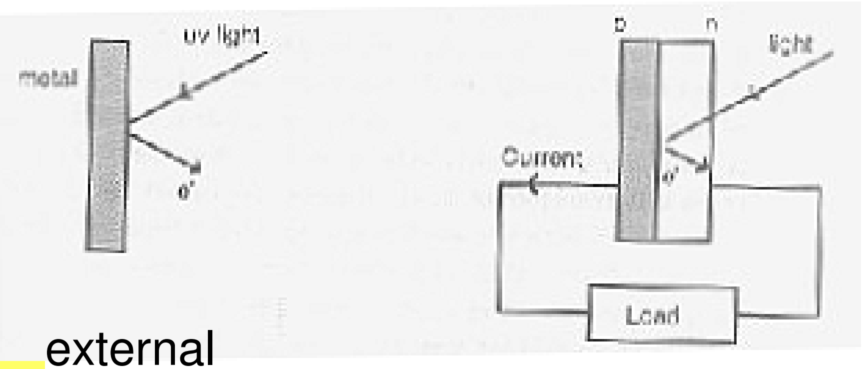
P. Wurfel „Physics of solar cells”

PV CDROM

History

- Becquerel 1834 electrolyte
- Adams & Day 1877 Se
- Chapin, Fuller, Pearson 1954 Si 6%
- CdS pn junction 6% 1954
- Vanguard 1, 1958

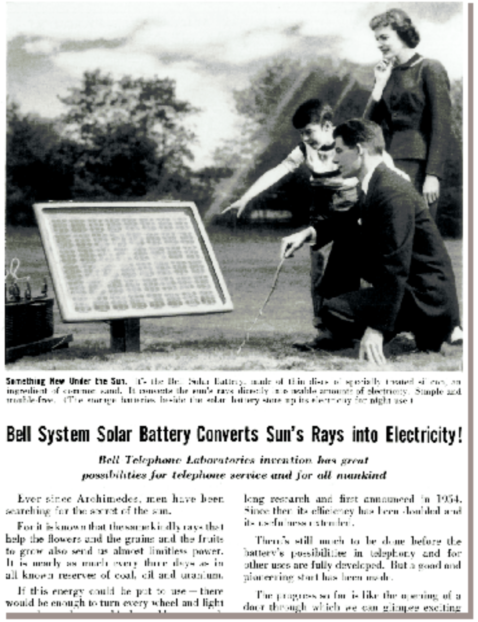
Photovoltaic effect



external

internal

The First Practical Solar Cell-1954



Something New Under the Sun. It's the Bell Solar Battery, made of thin discs of specially treated silicon, an ingredient of common sand. It converts the sun's rays directly into usable amounts of electricity. Simple and trouble-free. (The storage batteries beside the solar battery store up its electricity for night use.)

Bell System Solar Battery Converts Sun's Rays into Electricity!

Bell Telephone Laboratories invention has great possibilities for telephone service and for all mankind

Ever since Archimedes, men have been searching for the secret of the sun.

For it is known that the same kindly rays that help the flowers and the grains and the fruits to grow also send us almost limitless power. It is nearly as much every three days as in all known reserves of coal, oil and uranium.

If this energy could be put to use — there would be enough to turn every wheel and light

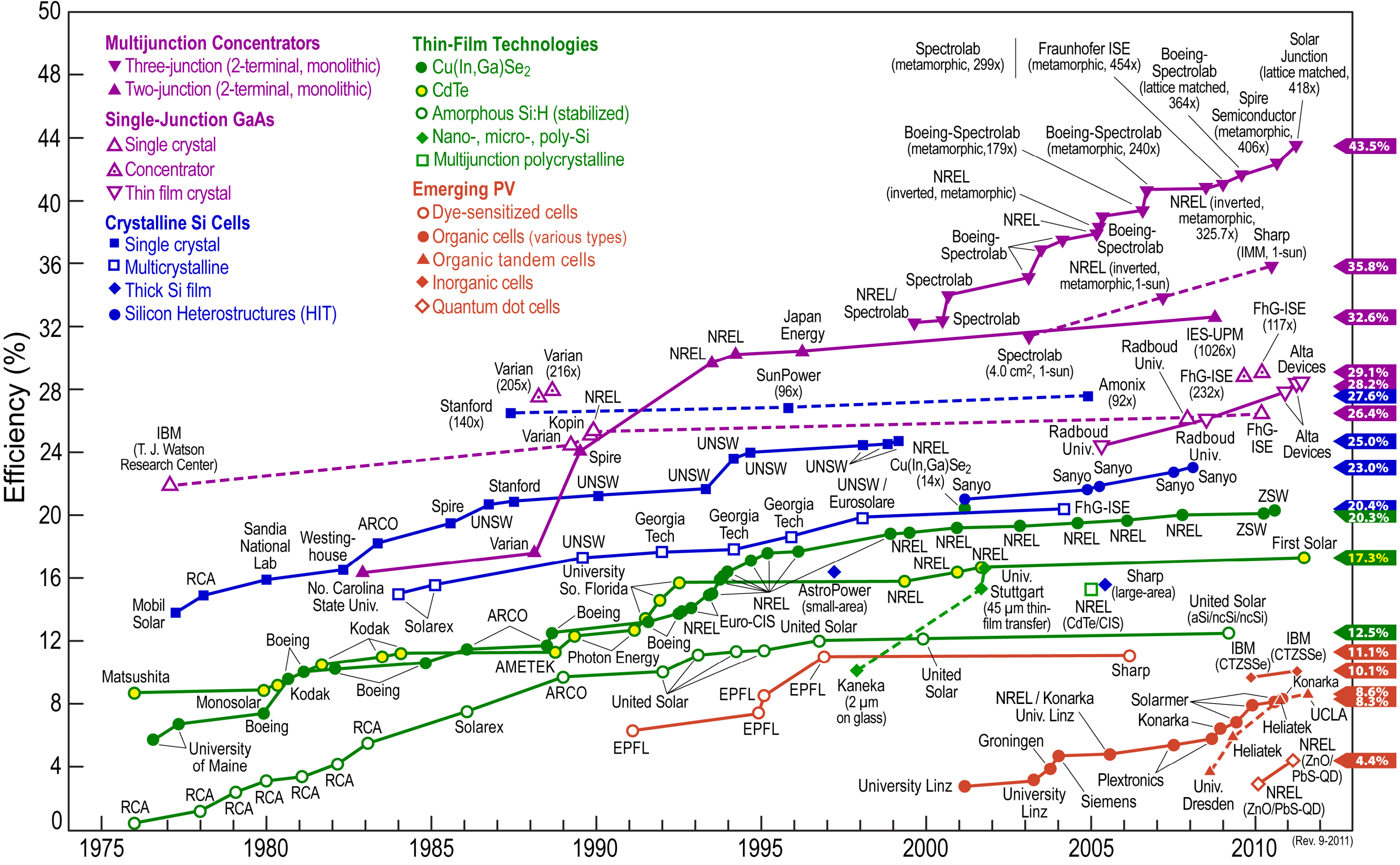
long research and first announced in 1954. Since then its efficiency has been doubled and its usefulness extended.

There's still much to be done before the battery's possibilities in telephony and for other uses are fully developed. But a good and pioneering start has been made.

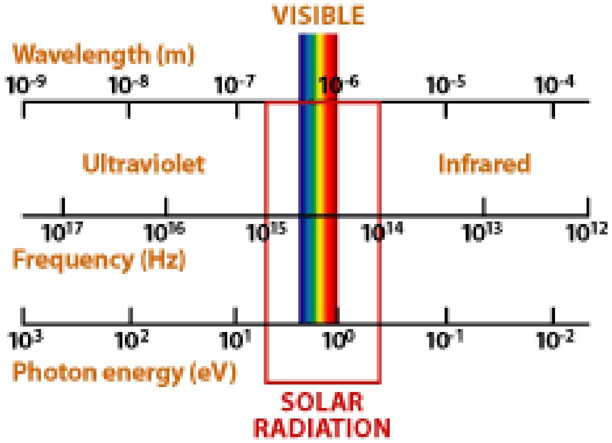
The progress so far is like the opening of a door through which we can glimpse exciting

Vanguard, 1st terrestial satelite, 1958

Best Research-Cell Efficiencies

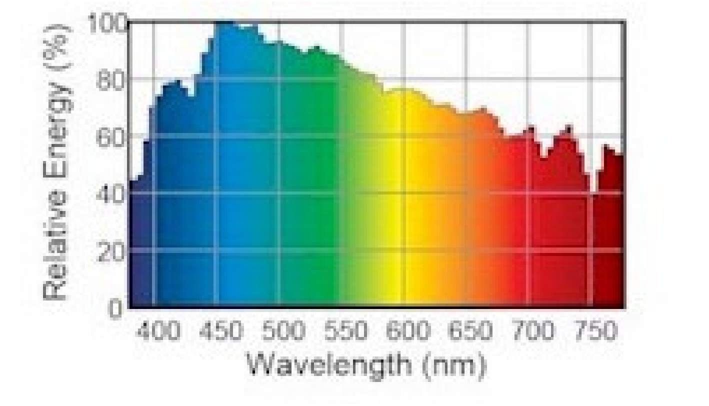


Electromagnetic radiation

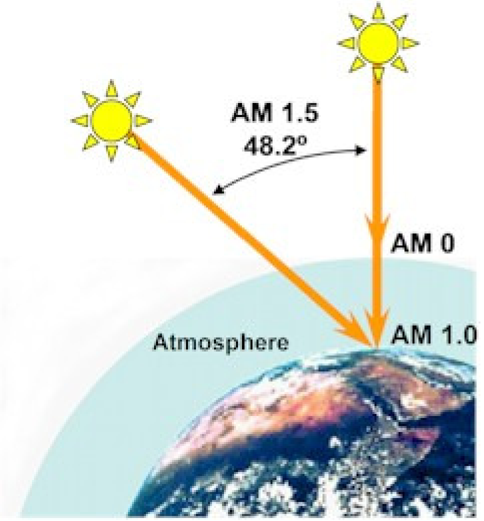


AM - air mass
AM0: just outside the atmosphere
1.3661 kW/m^2 (solar constant)
Per year: 1.188 kWh/cm^2

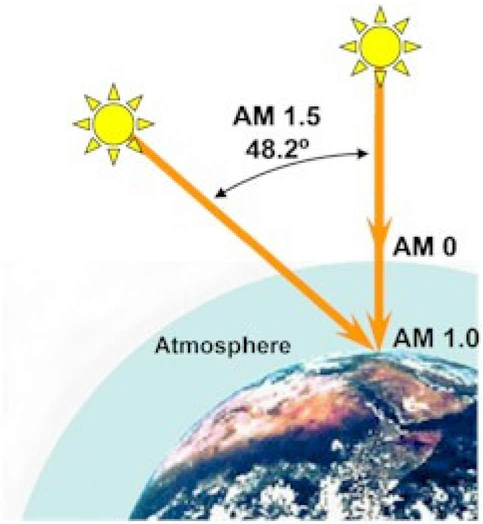
AM1=after 1 atmosphere thickness
AMX=AM1/cosϕ
A.M1.5 $\cong 1$ kW/m^2 $\phi \cong 48.2^o$
(it corresponds to ~42^o latitude on equinox)



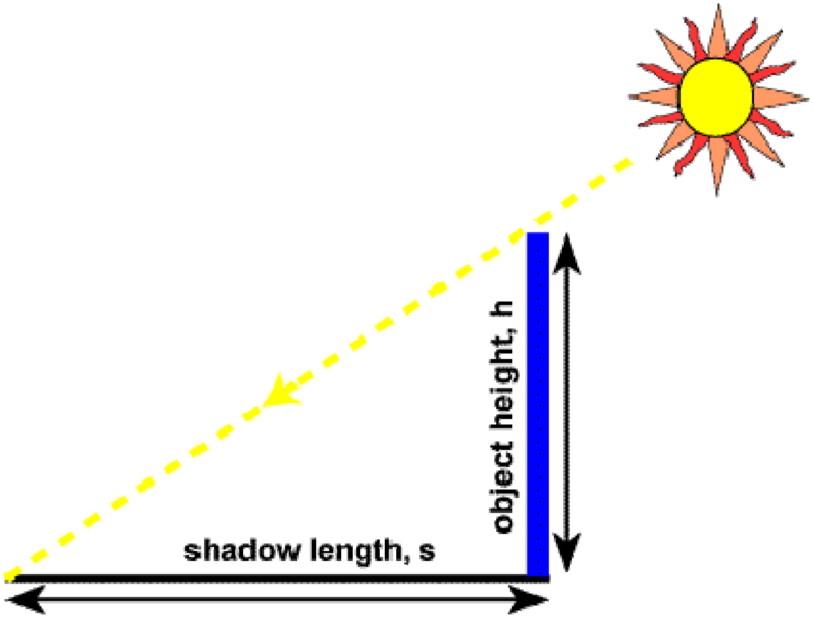
Solar spectrum in visible light



How to measure Air Mass coefficient



AMX=AM1/cosϕ



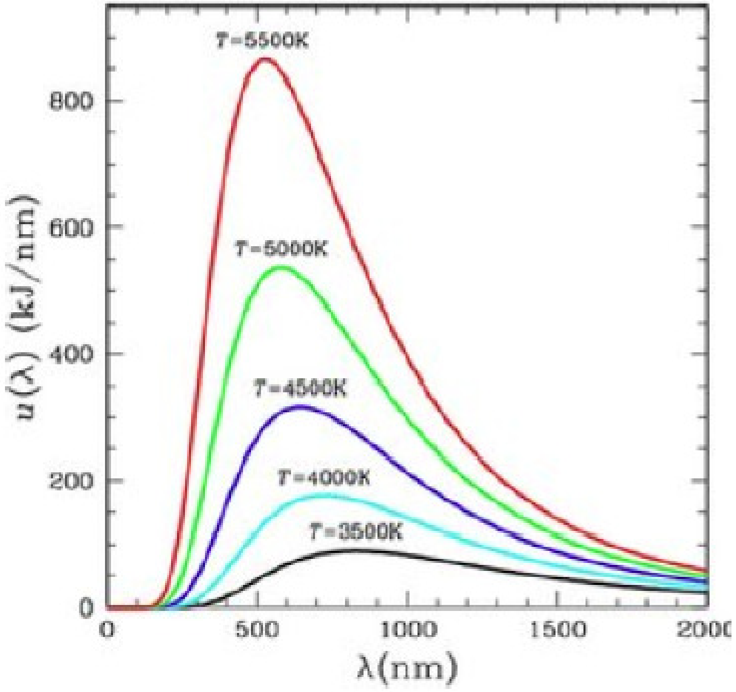
$$AM = \sqrt{1 + \left(\frac{s}{h}\right)^2}$$

Black-body radiation

Planck's distribution

$$\mathbf{E}(\lambda,\mathbf{T}) = \frac{2\pi\mathbf{hc}^2}{\lambda^5[\mathbf{e}^{\frac{\mathbf{hc}}{\lambda\mathbf{kT}}} - 1]}$$

photons:
E = hν=**hc**/λ
λ = c/ν



Stephan-Boltzmann law

$$\int_0^\infty \mathbf{E}(\lambda,\mathbf{T})d\lambda = \sigma\mathbf{T}^4 \quad [\mathbf{W/m^2}]$$

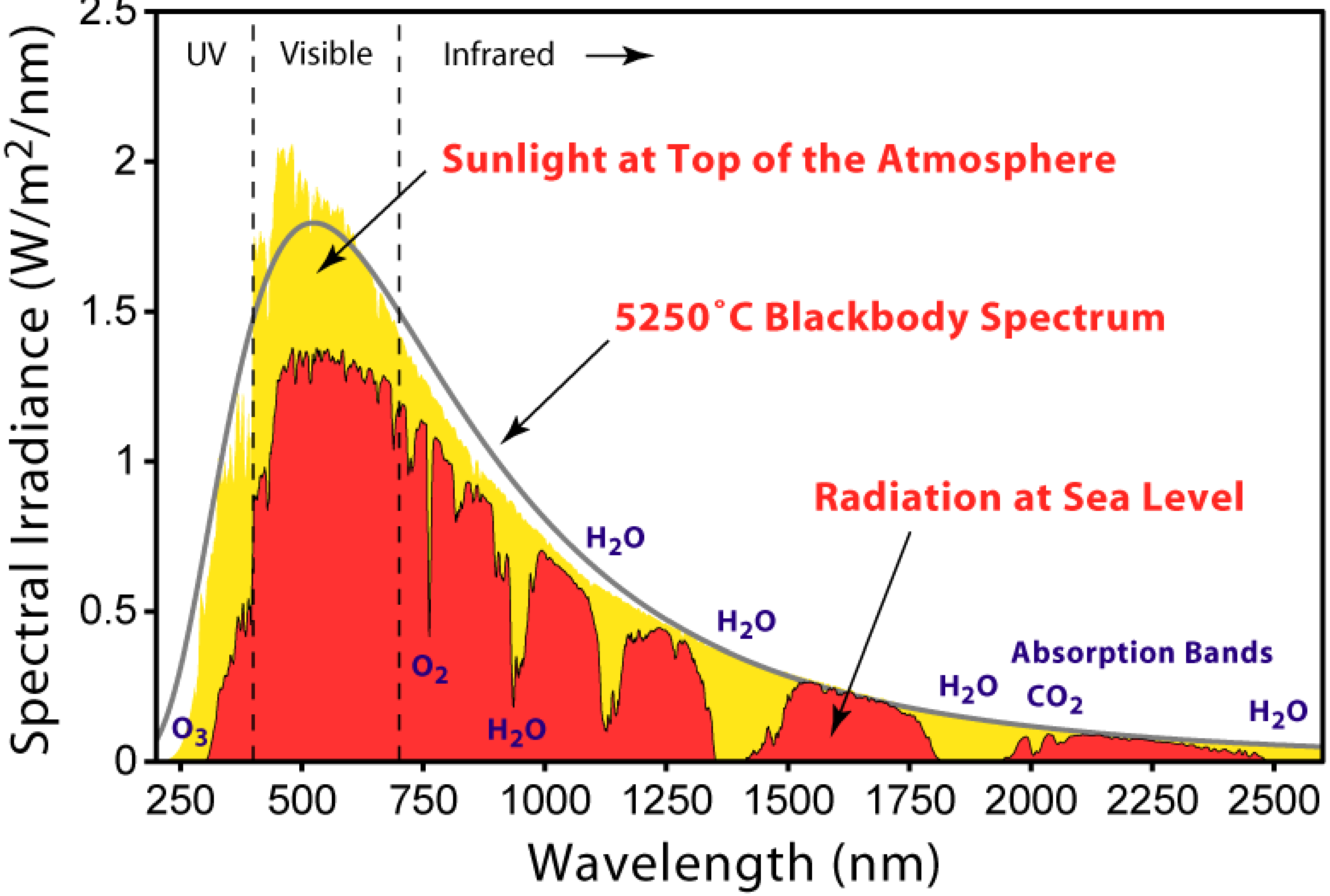
h=6.6x10^{-34} Js Planck's constant
k=1.38x10^{-23} J/K Boltzmann's constant

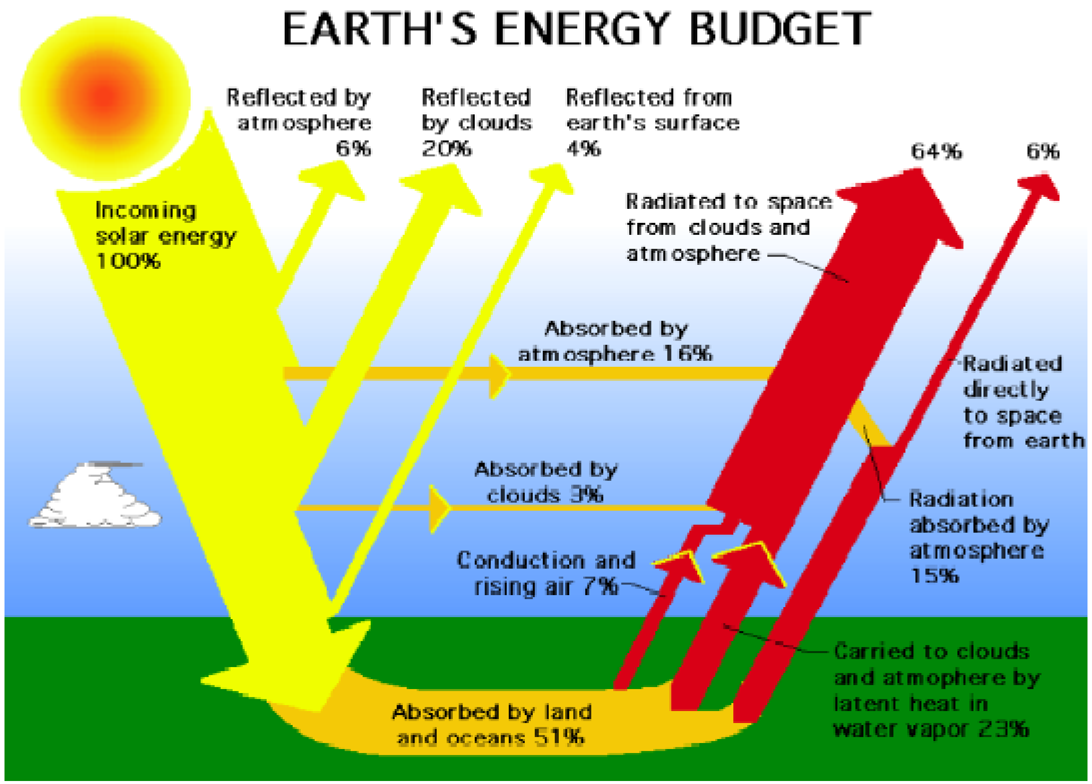
Wien law:

$$\lambda_{\max} = \frac{b}{T}$$

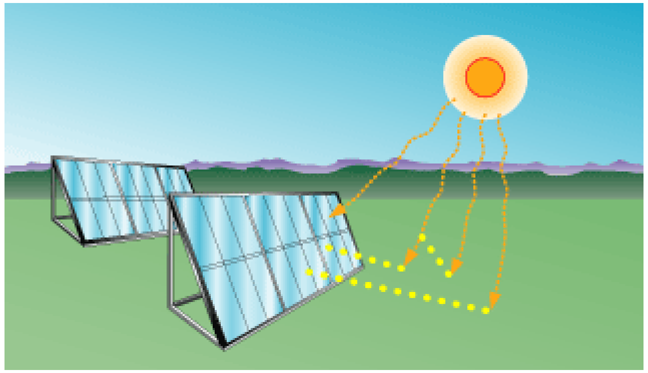
$$b = 2.9 \bullet 10^{-3}\ \mathrm{mK}$$

Solar Radiation Spectrum

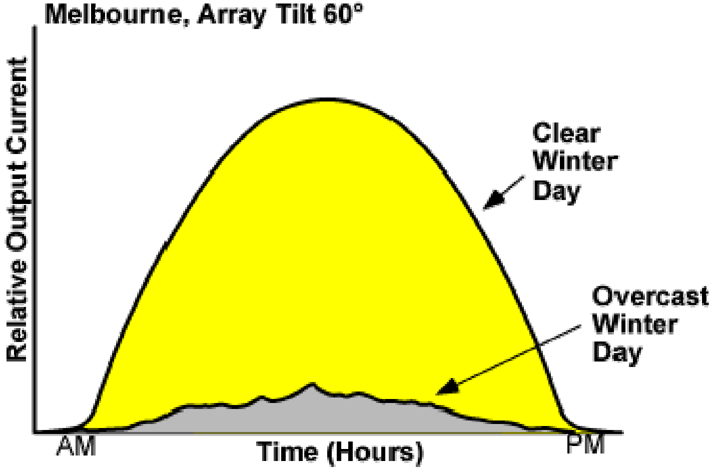


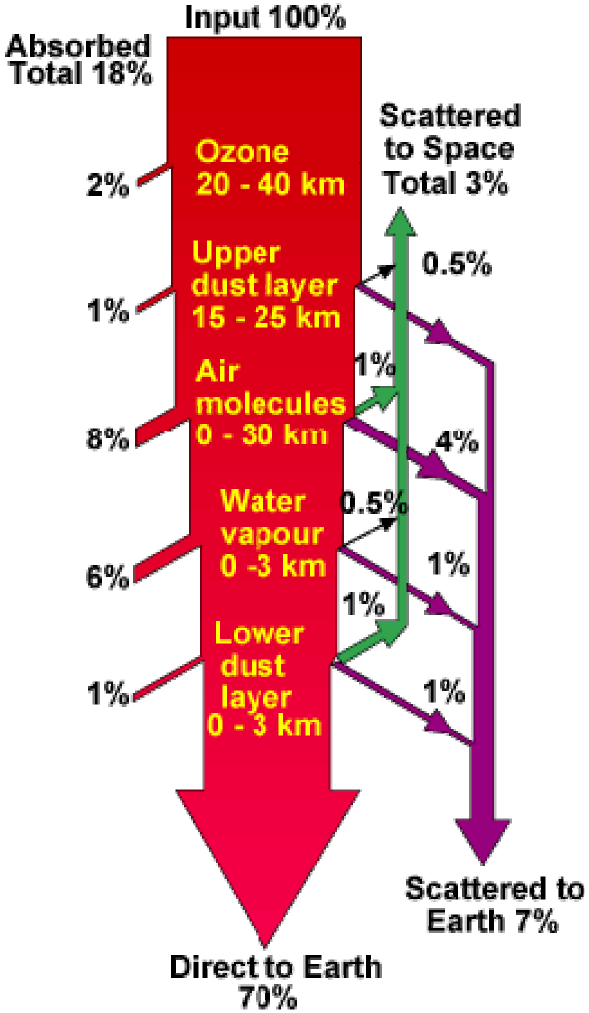

EARTH'S ENERGY BUDGET
Reflected by atmosphere 6%
Reflected by clouds 20%
Reflected from earth's surface 4%
64%
6%
Incoming solar energy 100%
Radiated to space from clouds and atmosphere
Absorbed by atmosphere 16%
Radiated directly to space from earth
Absorbed by clouds 3%
Radiation absorbed by atmosphere 15%
Conduction and rising air 7%
Carried to clouds and atmophere by latent heat in water vapor 23%
Absorbed by land and oceans 51%

Direct and Diffuse radiation



10% diffuse component at clear skies, AM1



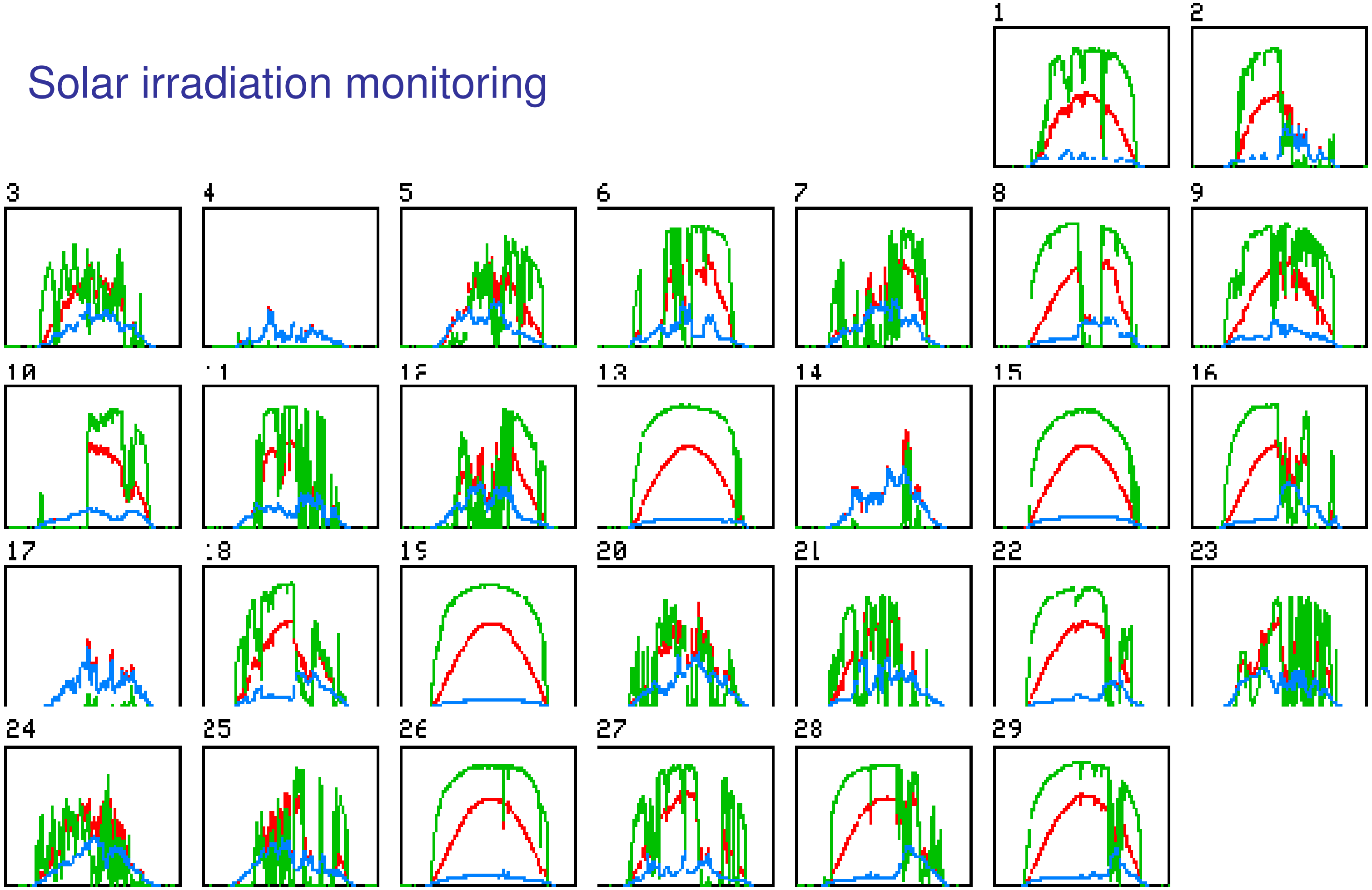


Typical clear sky absorption and scattering of incident sunlight

Solar Radiation Research Laboratory (BMS)

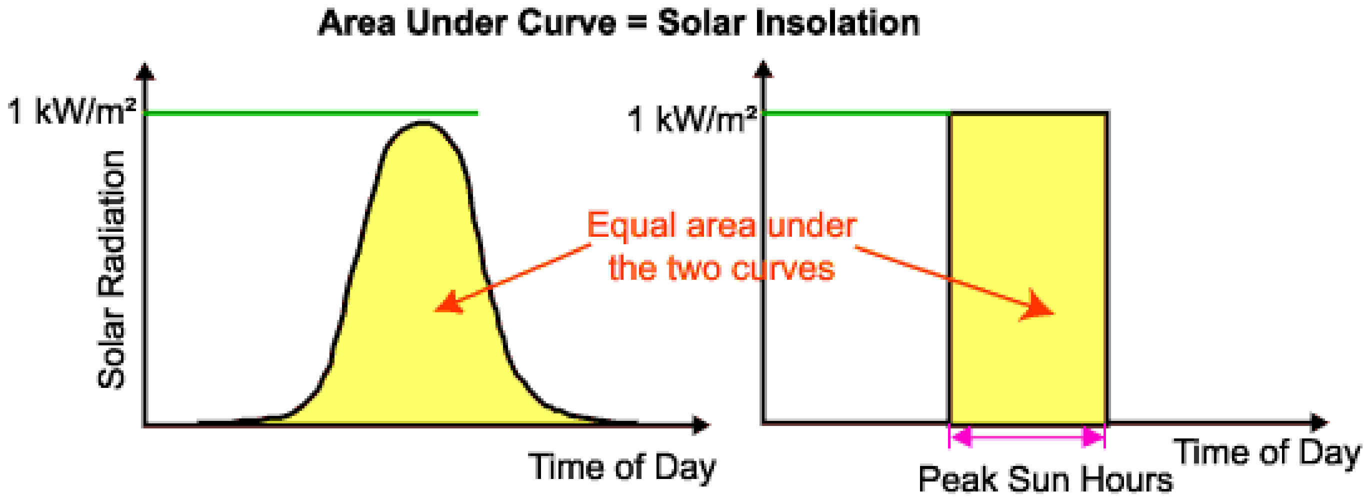
February 2008 Solar Calendar (NREL)

Solar irradiation monitoring



Red = Global, Green = Direct, Blue = Diffuse

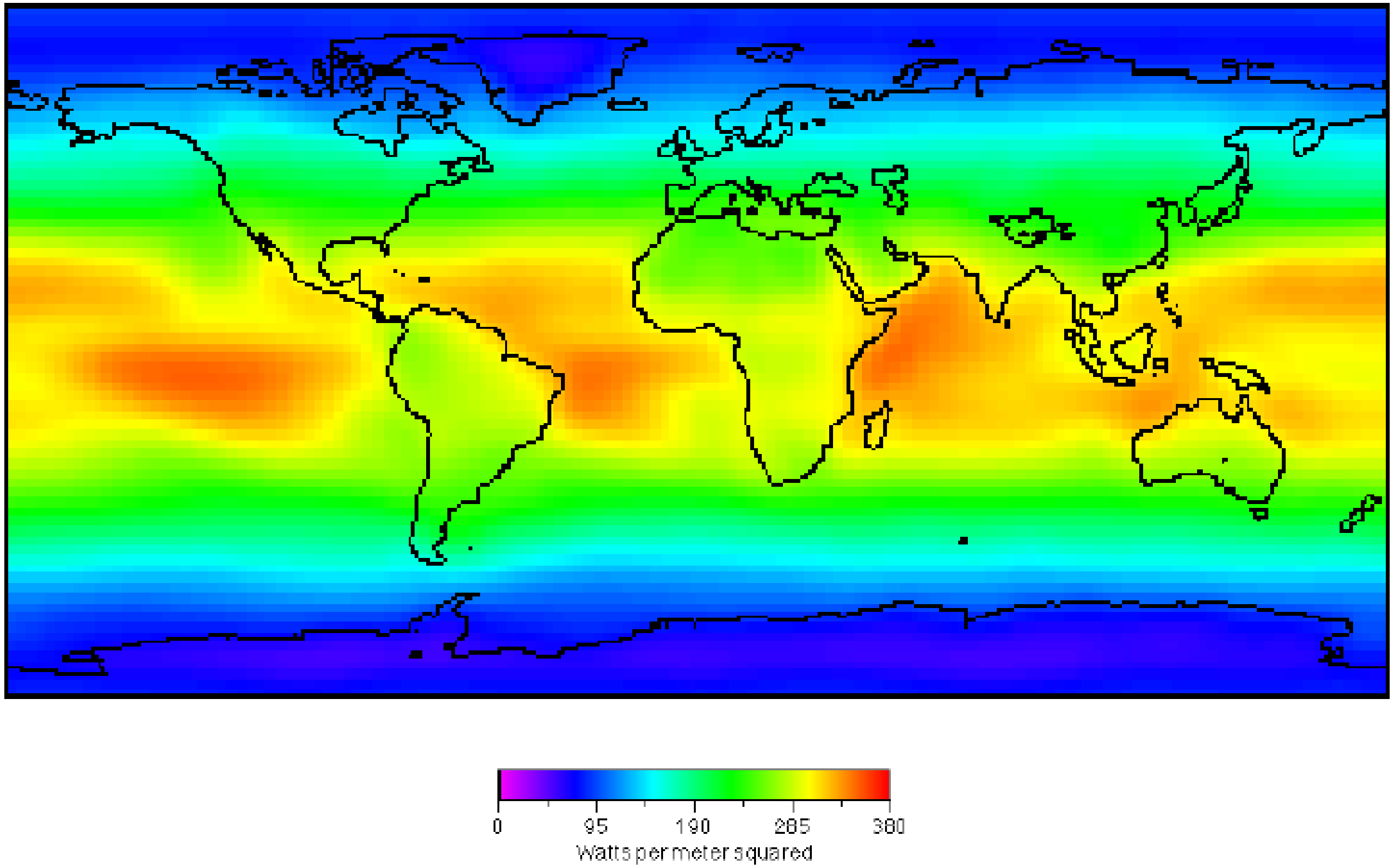
Peak Sun Hours



Peak sun hours = solar insolation if the sun were shining at its maximum value for a certain number of hours

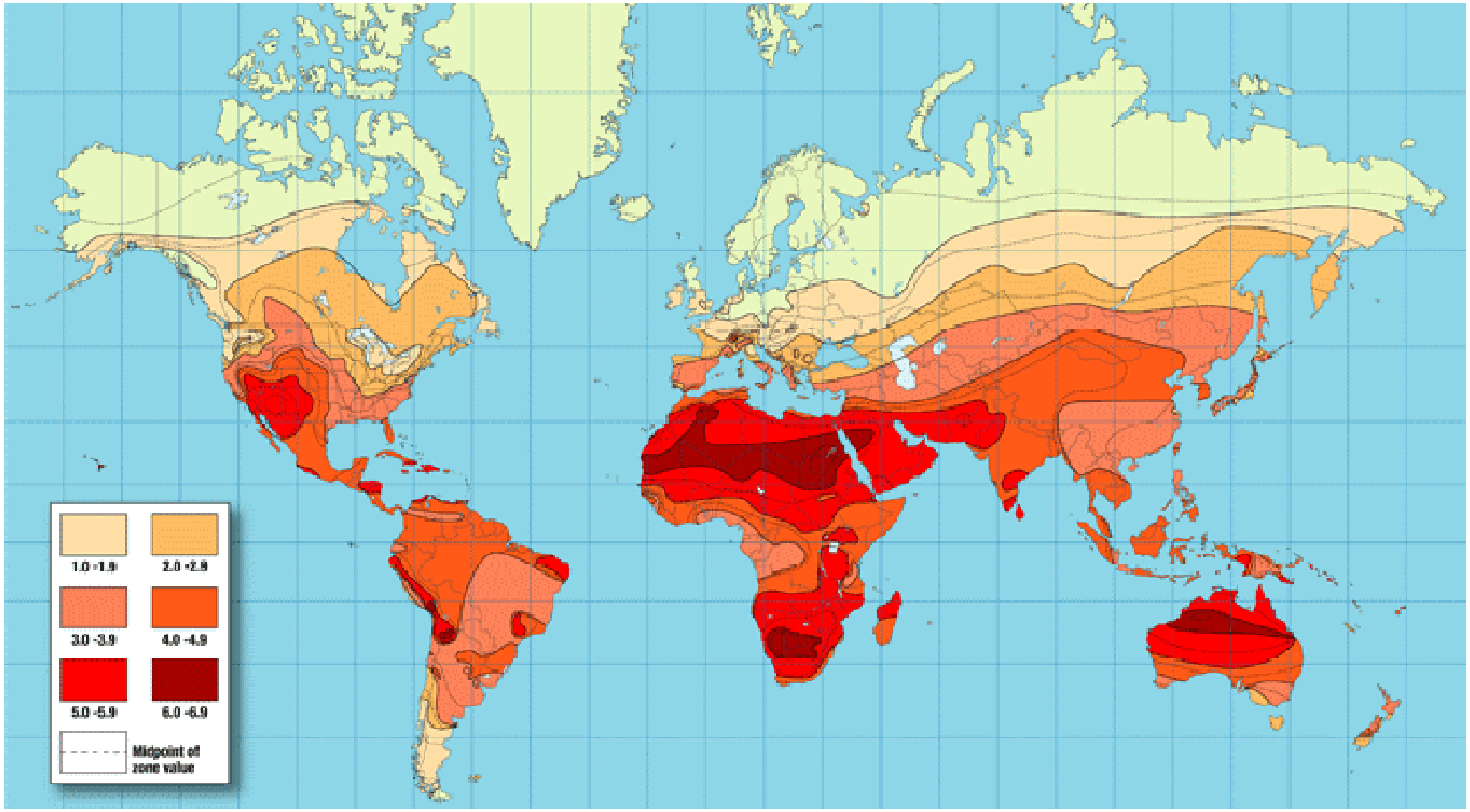
8 kWh/m^2 per day = 8 hours of sun at 1 kW/m^2 per day

Average insolation intensity

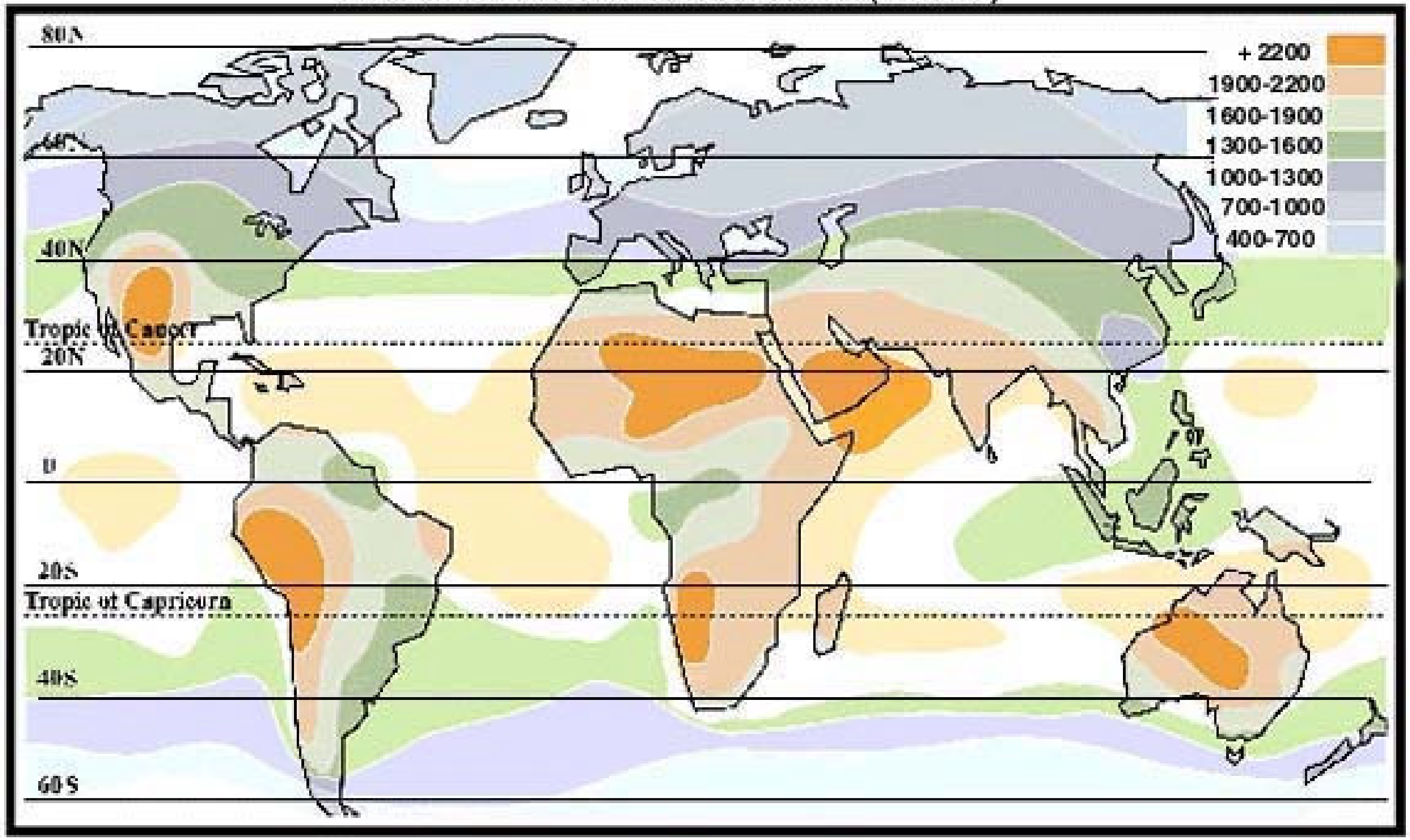


World insolation chart – energy (kWh/m^2) during winter day

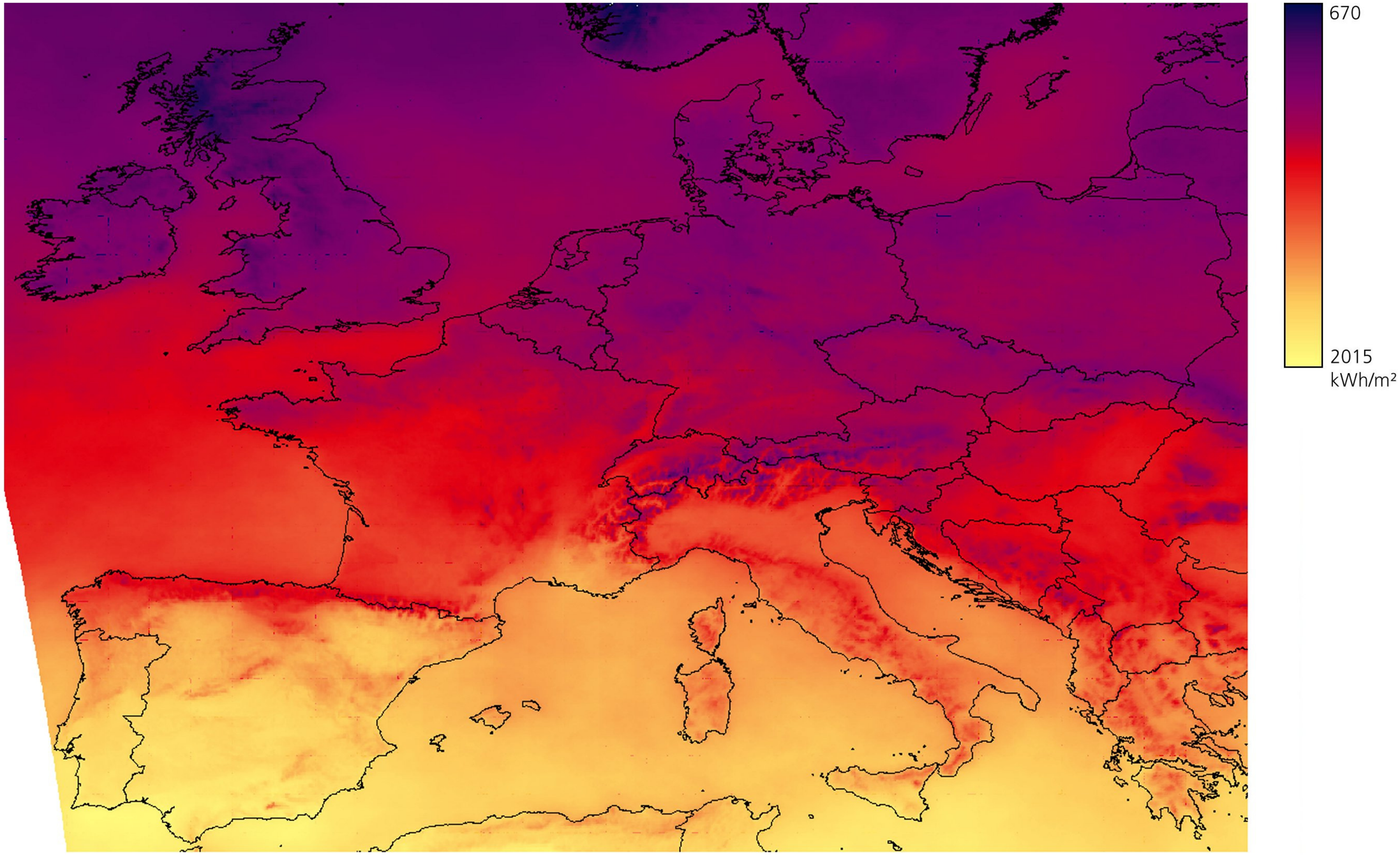
peak sun hour data= total daily insolation kWh/m2



WORLD SOLAR ANNUAL RADIATION (kWh/m2)



Annual Sum of Global Irradiance 2004



MINES PARIS

CARL VON OSSIETZKY universität OLDENBURG

DLR **Deutsches Zentrum für Luft- und Raumfahrt** e.V.
in der Helmholtz-Gemeinschaft