IE290
Alternate Energy Course

Lecture #, 5

Energy and Power,
Solar Energy Resources

Solar Astronomy

Notion of the Cost per peak watt installed

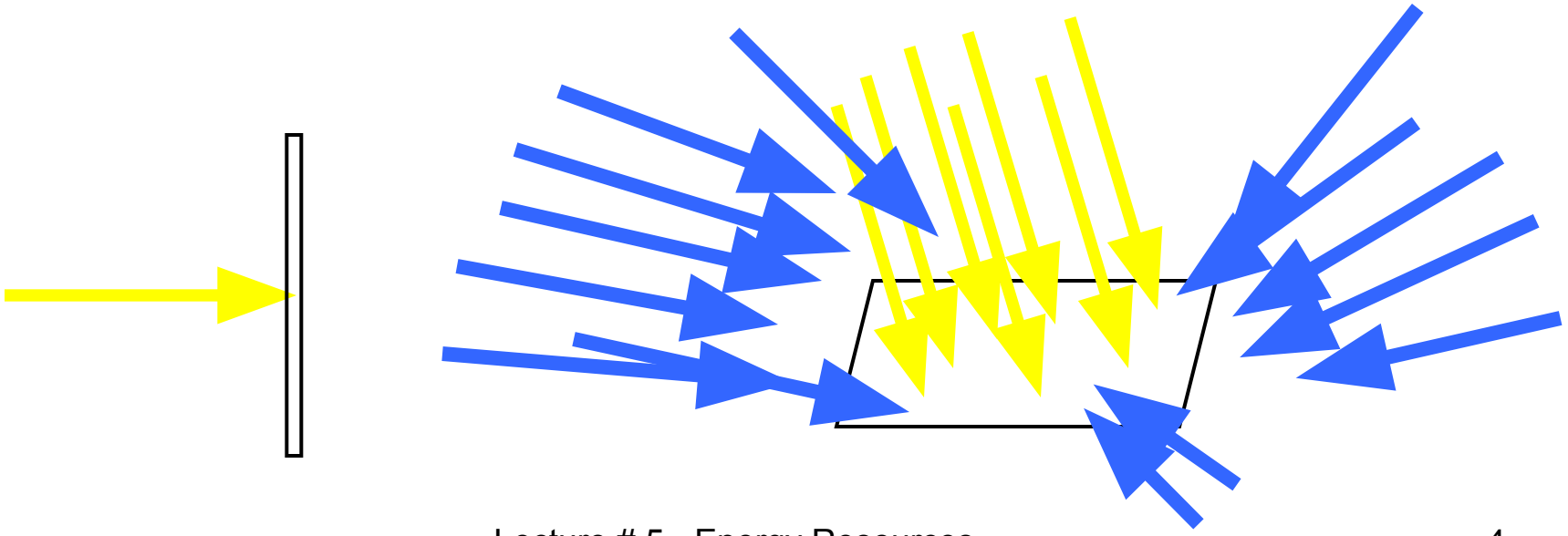
- “Peak Watt” = 1000W = 1kW
- Is the power produced at normal incidence of solar radiation @ 1000W/m^2.
- $/$W_p$ - Easy way to compare various solar conversion devices.
- Mostly useful for electric power generation devices, such as for: Hydro; PV; Wind, Solar Thermal Electric, etc.

Solar Monitoring

- However, each geographical location has its characteristic insolation.
- For that purpose we need to have a number of solar monitoring stations
- AUA has the first automated solar monitoring station in Armenia.
- There are >24 SMS-s in San Francisco

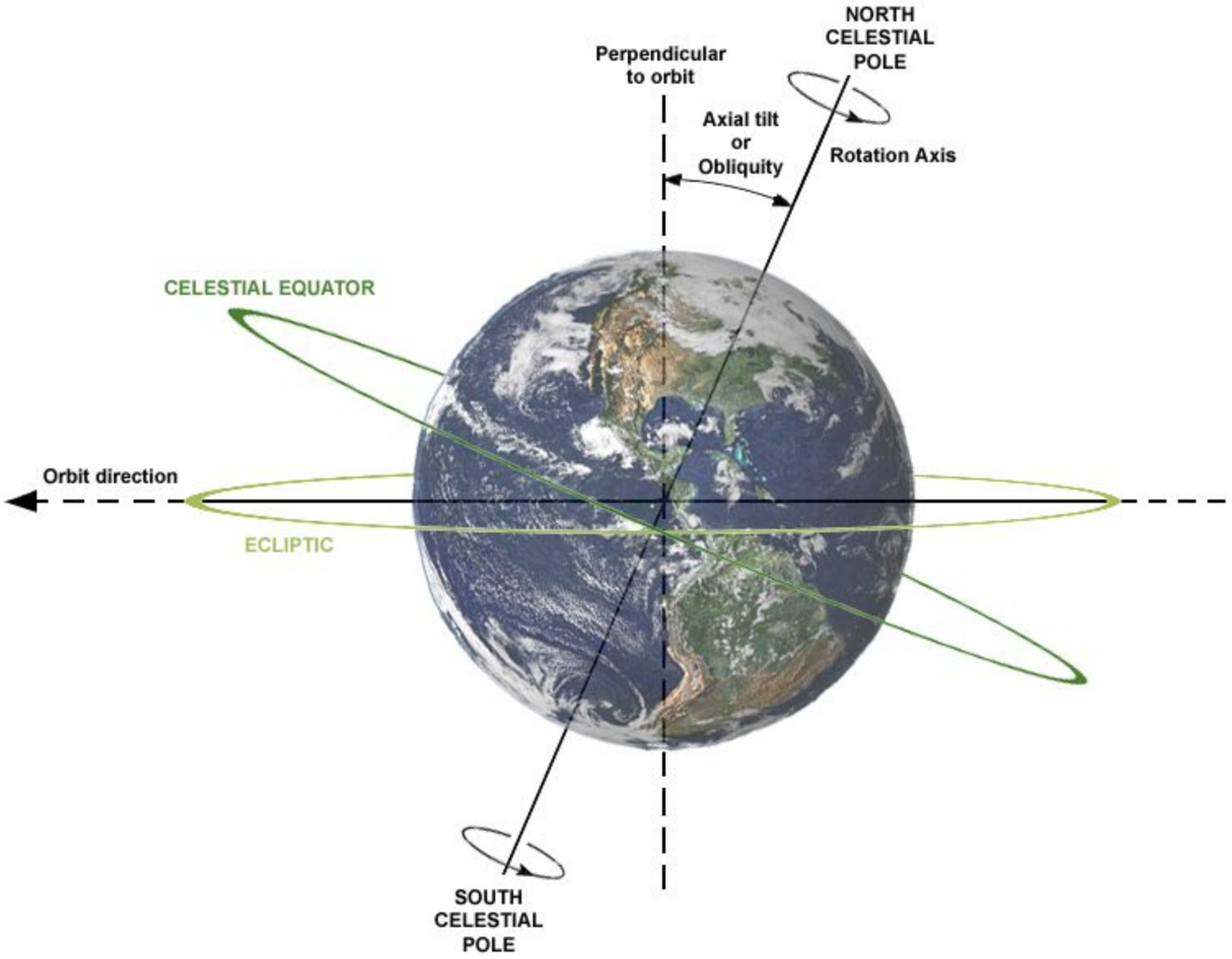
Components of Solar Radiation

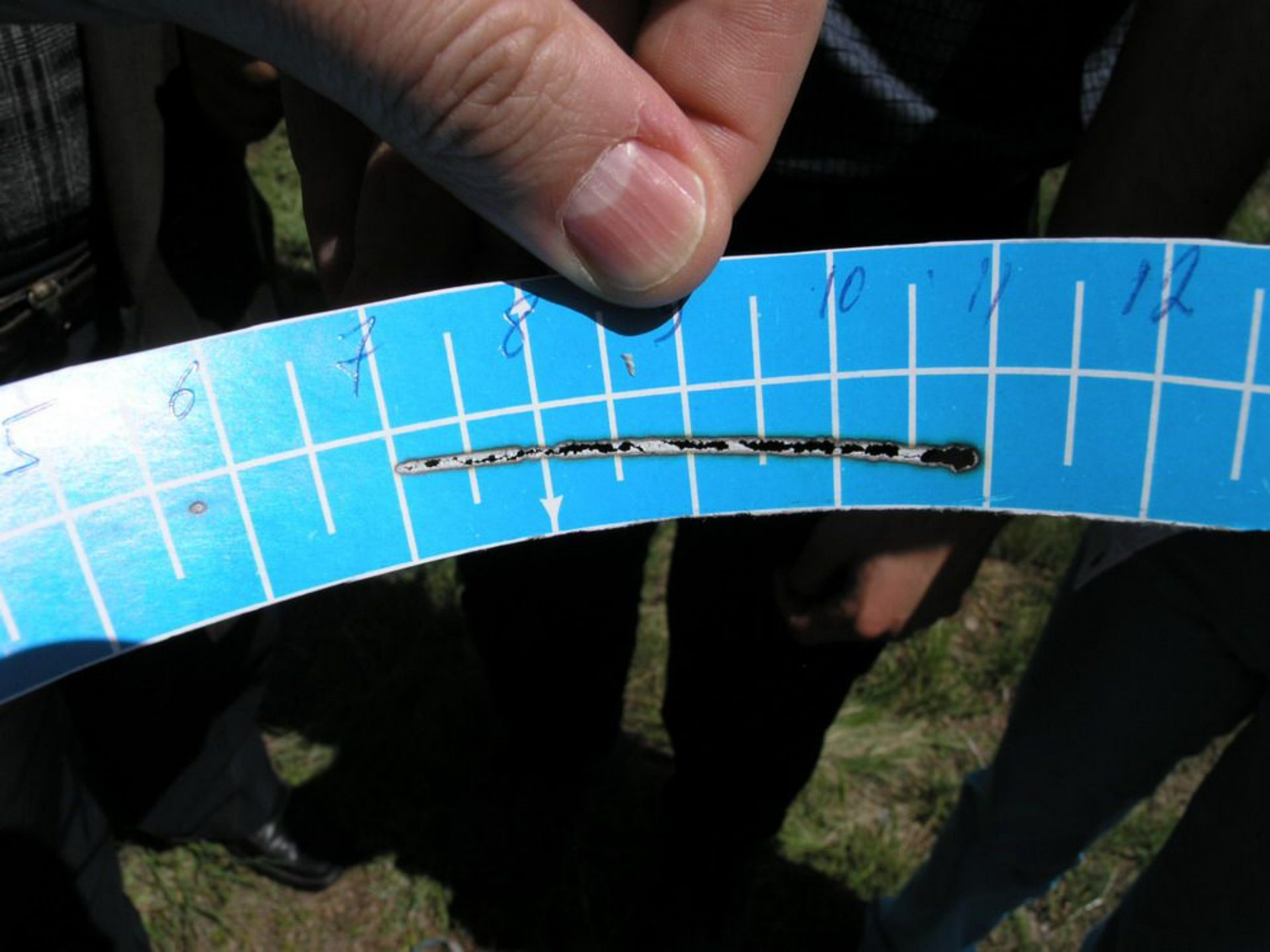
- Direct Normal, DN – pure direct sun rays that hit a surface, normal to the rays.
- Diffuse Horisontal, DH
- Global Horisontal, GH



Direct Normal realization

- Concentration
- Tracking: DN + inclined Diffuse (PV panel)


NORTH
CELESTIAL
POLE
Perpendicular
to orbit
Axial tilt
or
Obliquity
Rotation Axis
CELESTIAL EQUATOR
Orbit direction
ECLIPTIC
SOUTH
CELESTIAL
POLE

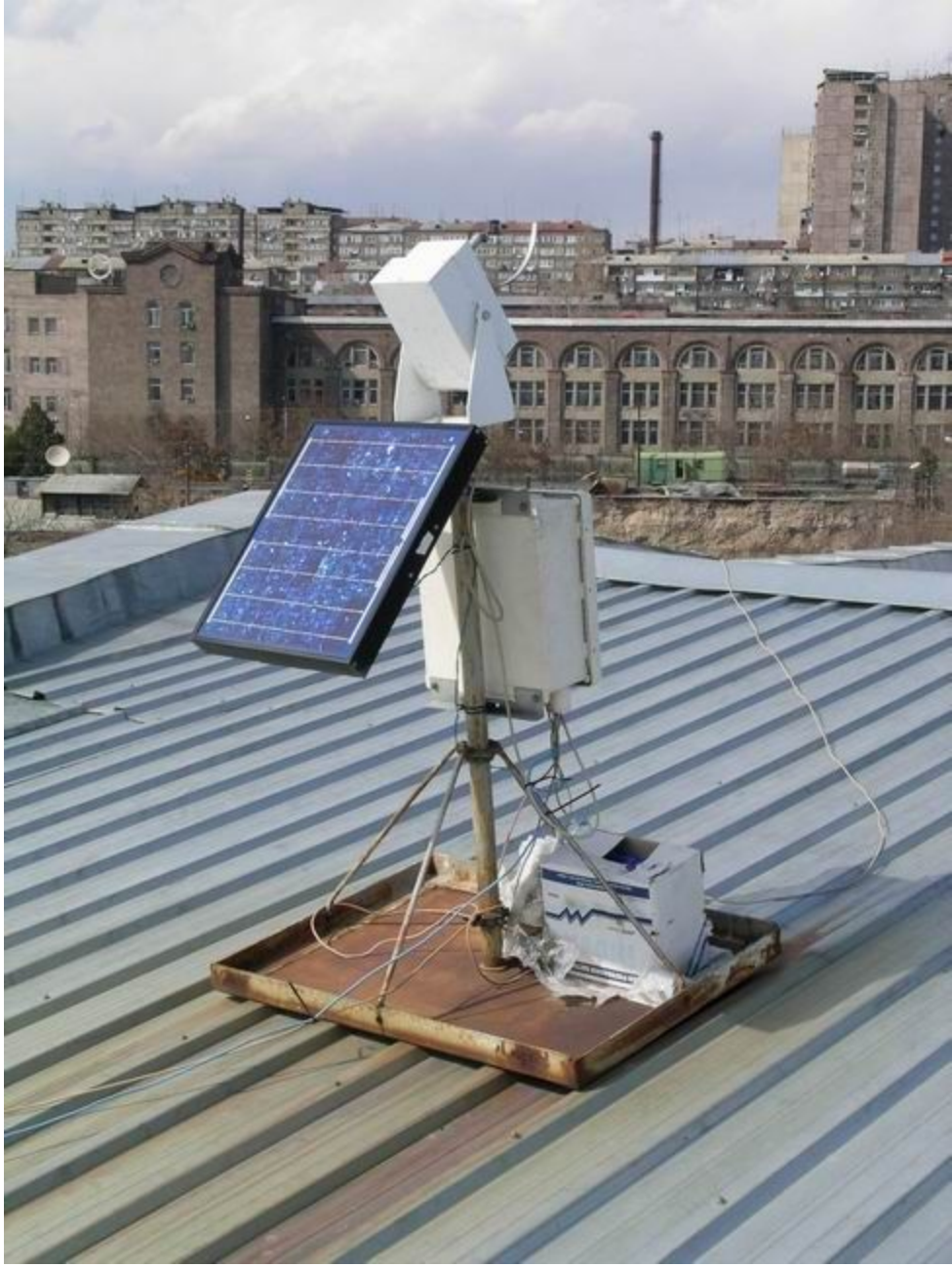

6
7
8
10
11
12


FUN
FOR
YOU

Solar position Calculator

- http://www.spectralcalc.com/solar_calculator/solar_position.php

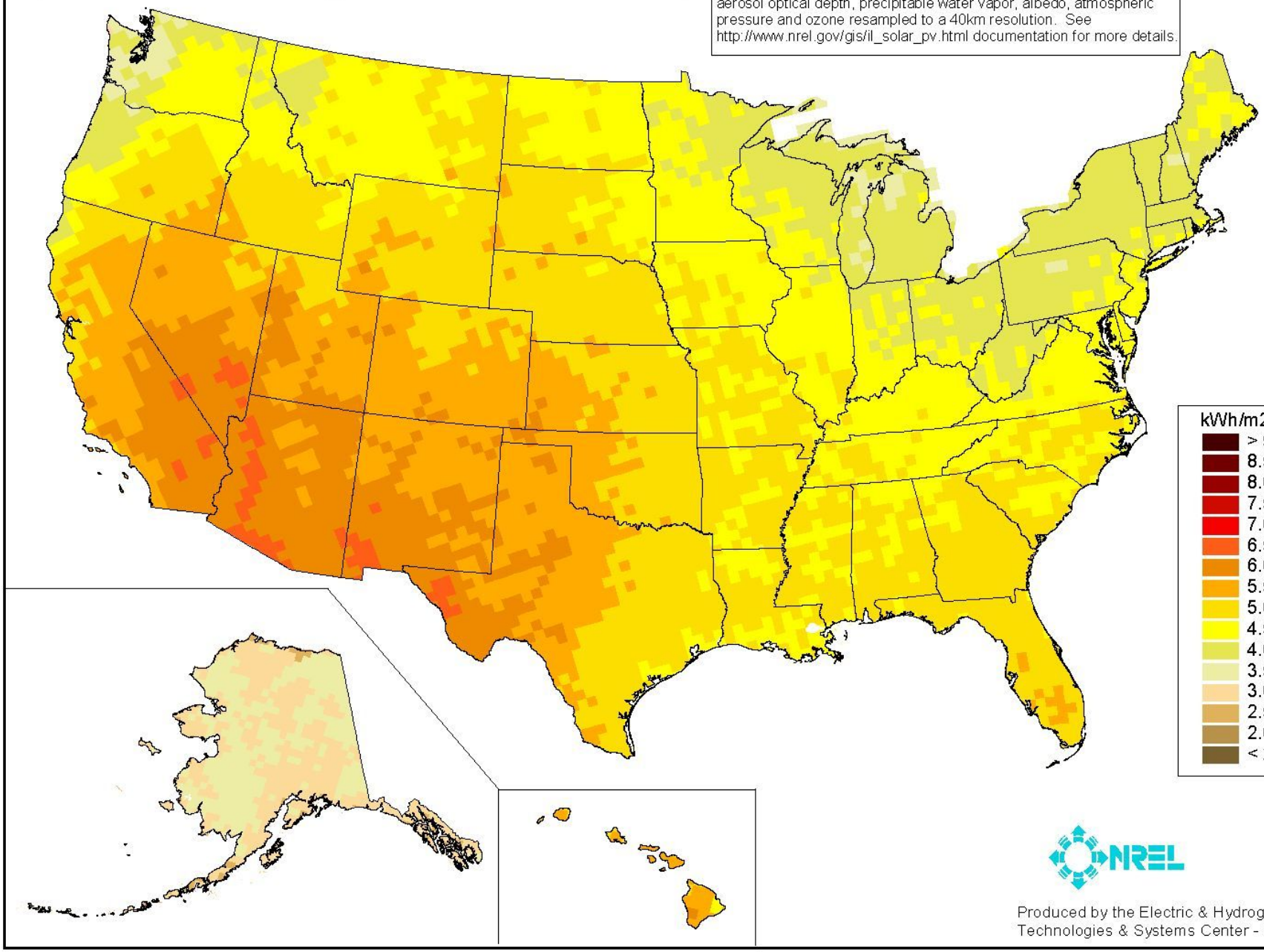
AUA Solar Monitoring Station Collecting data since 1995



PV Solar Radiation
(Flat Plate, Facing South, Latitude Tilt)

Annual

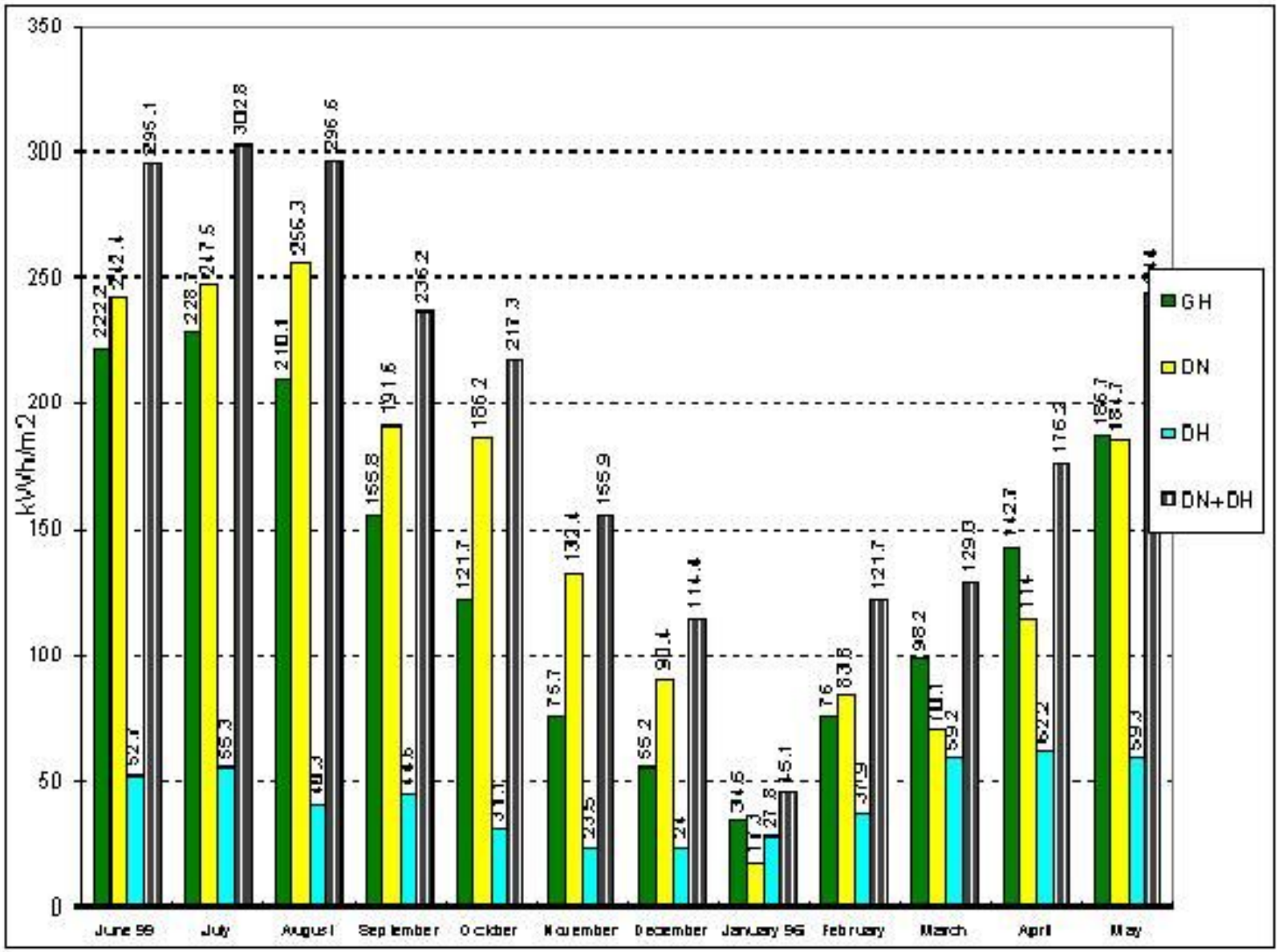
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_solar_pv.html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



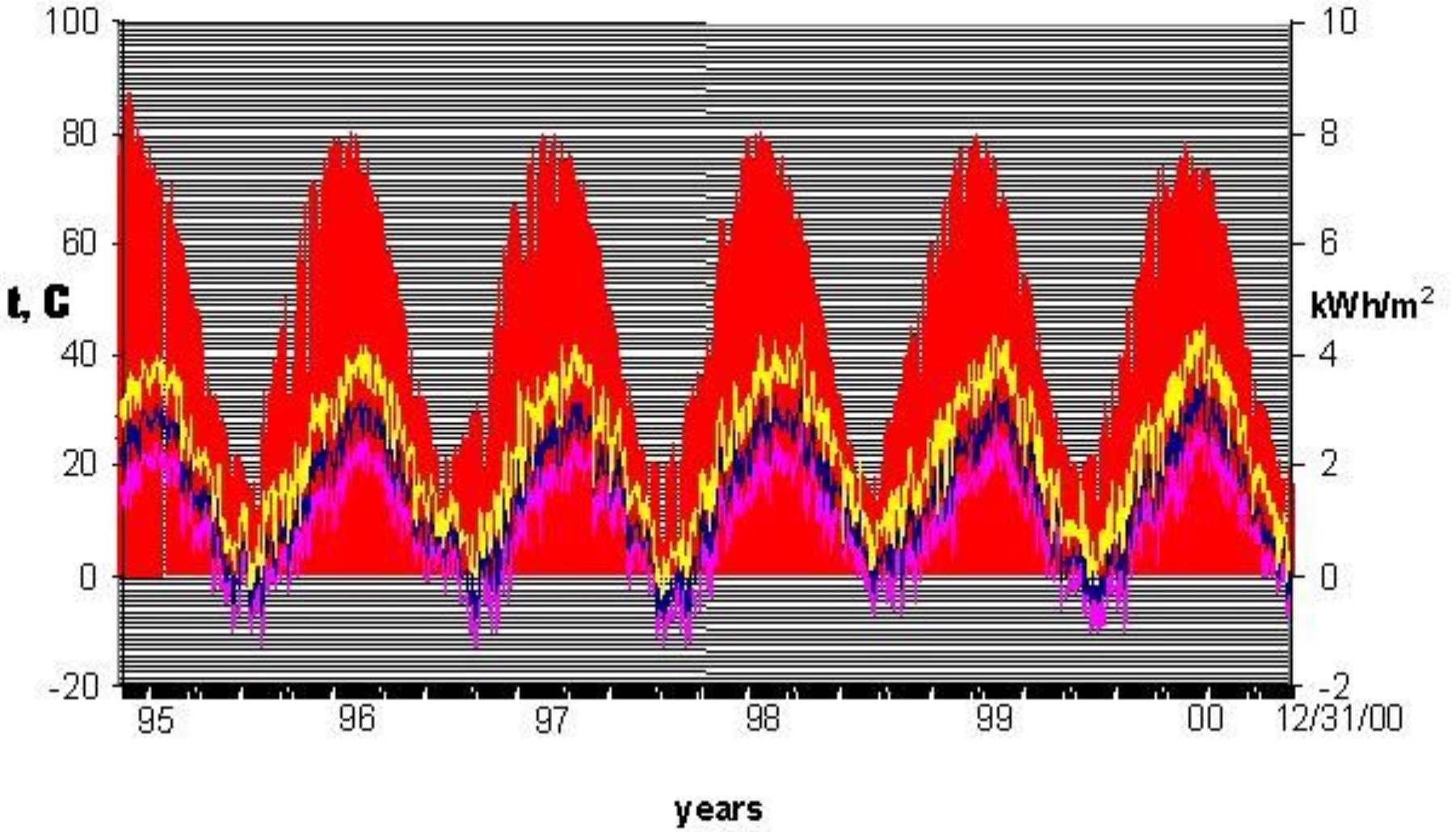
NREL

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

AUA Solar Monitoring Station



AUA Solar Monitoring Station

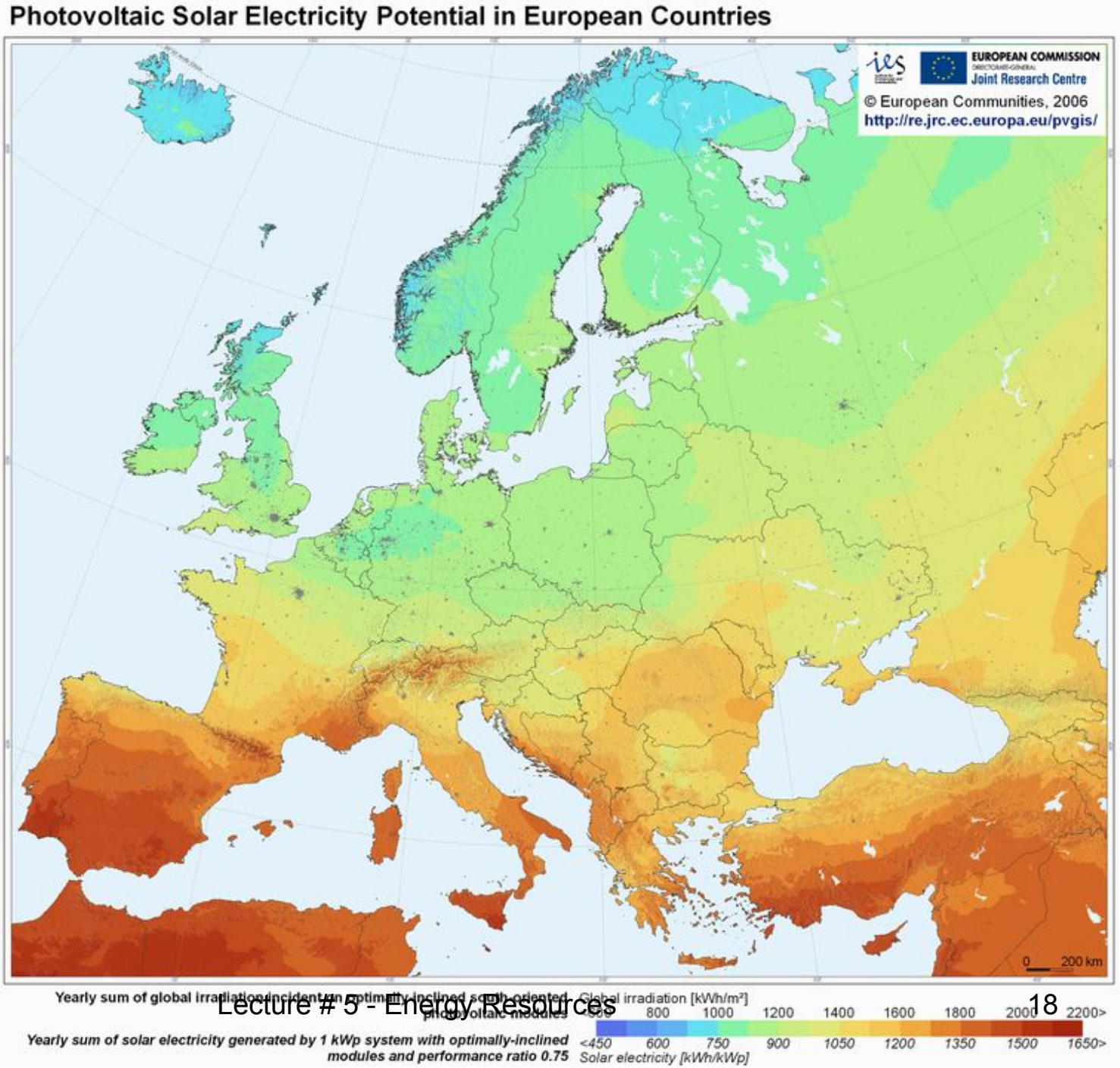


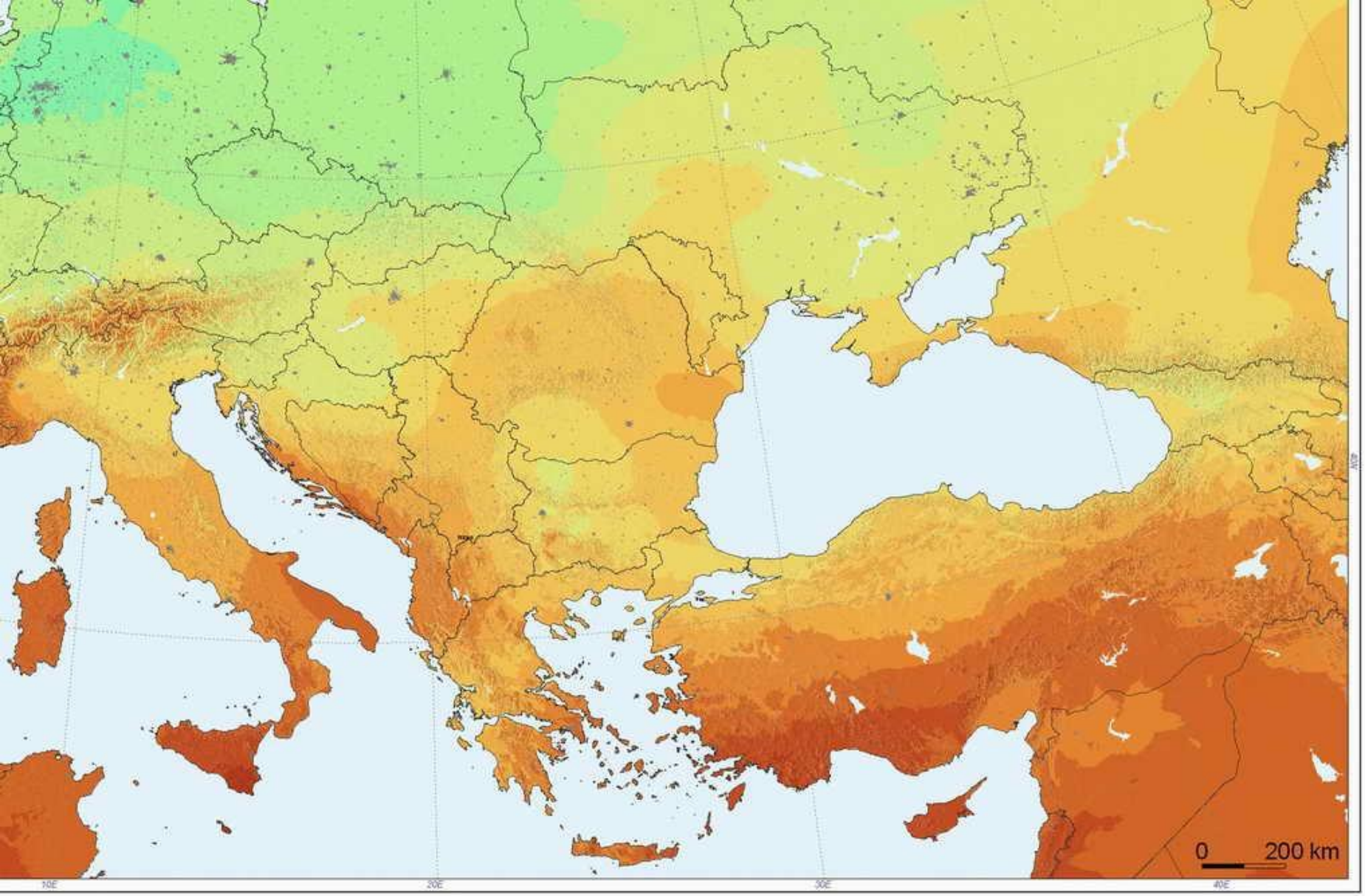
AUA SMS RESULTS

- Total Annual Global horizontal: 1720kWh/m^2.
- Average of 4.7 kWh/m^2 per day across years (DN+DH).
- January about 6.6 times less than in June:
- January: ≈ 1.1 kWh/m^2 per day.
- June: ≈ 8.3 kWh/m^2 per day.

PVGIS - Europe

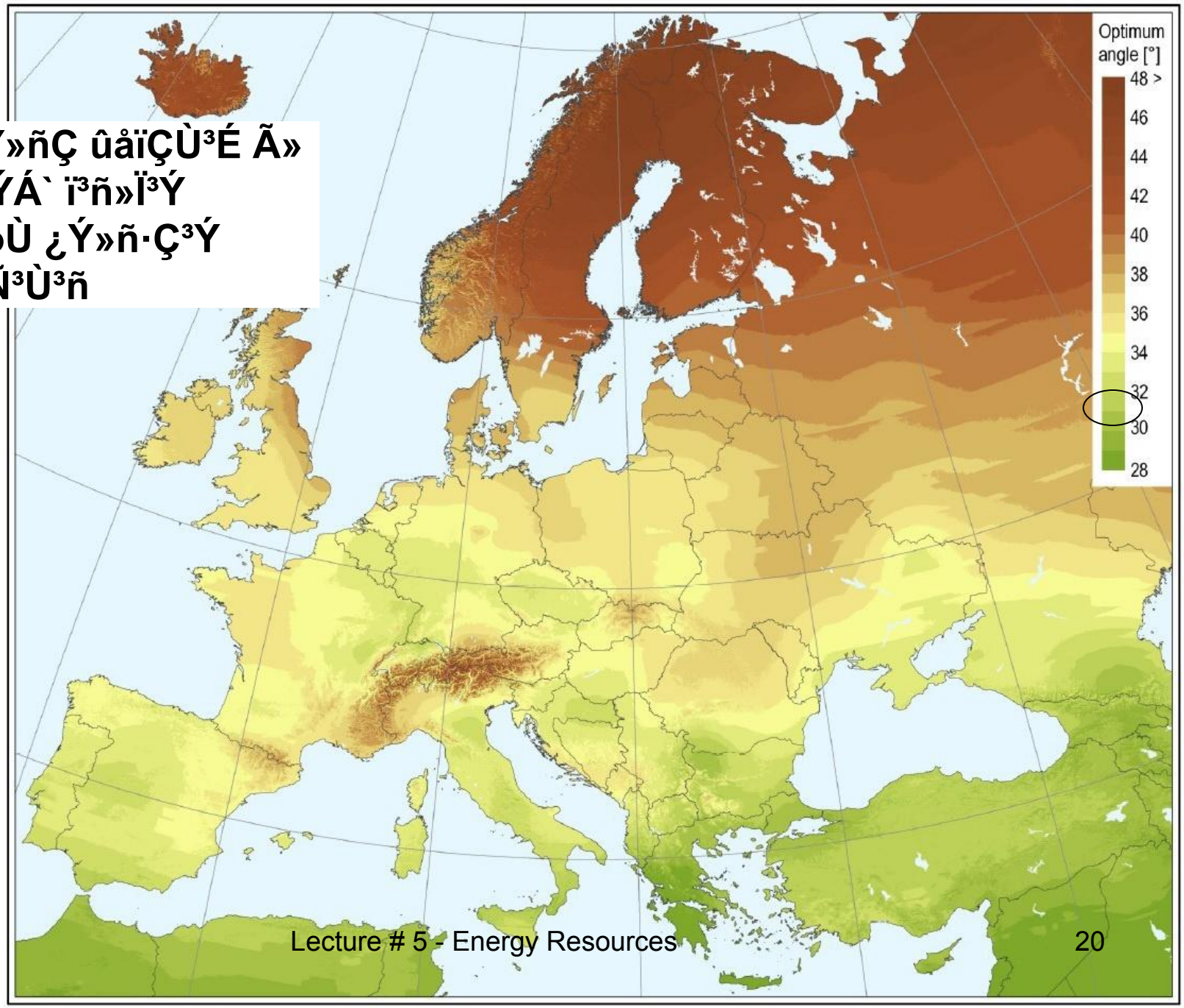
http://re.jrc.ec.europa.eu/pvgis

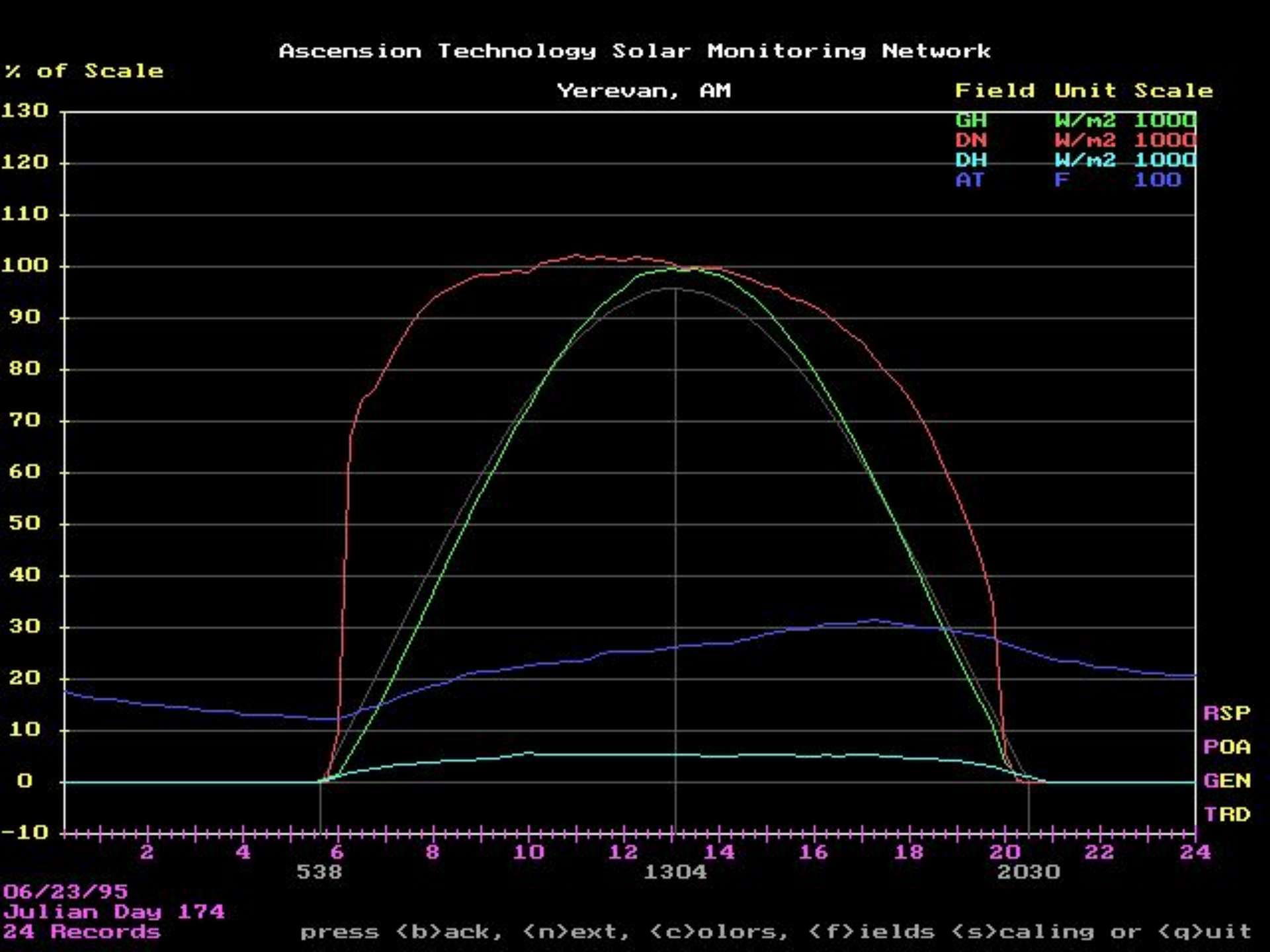


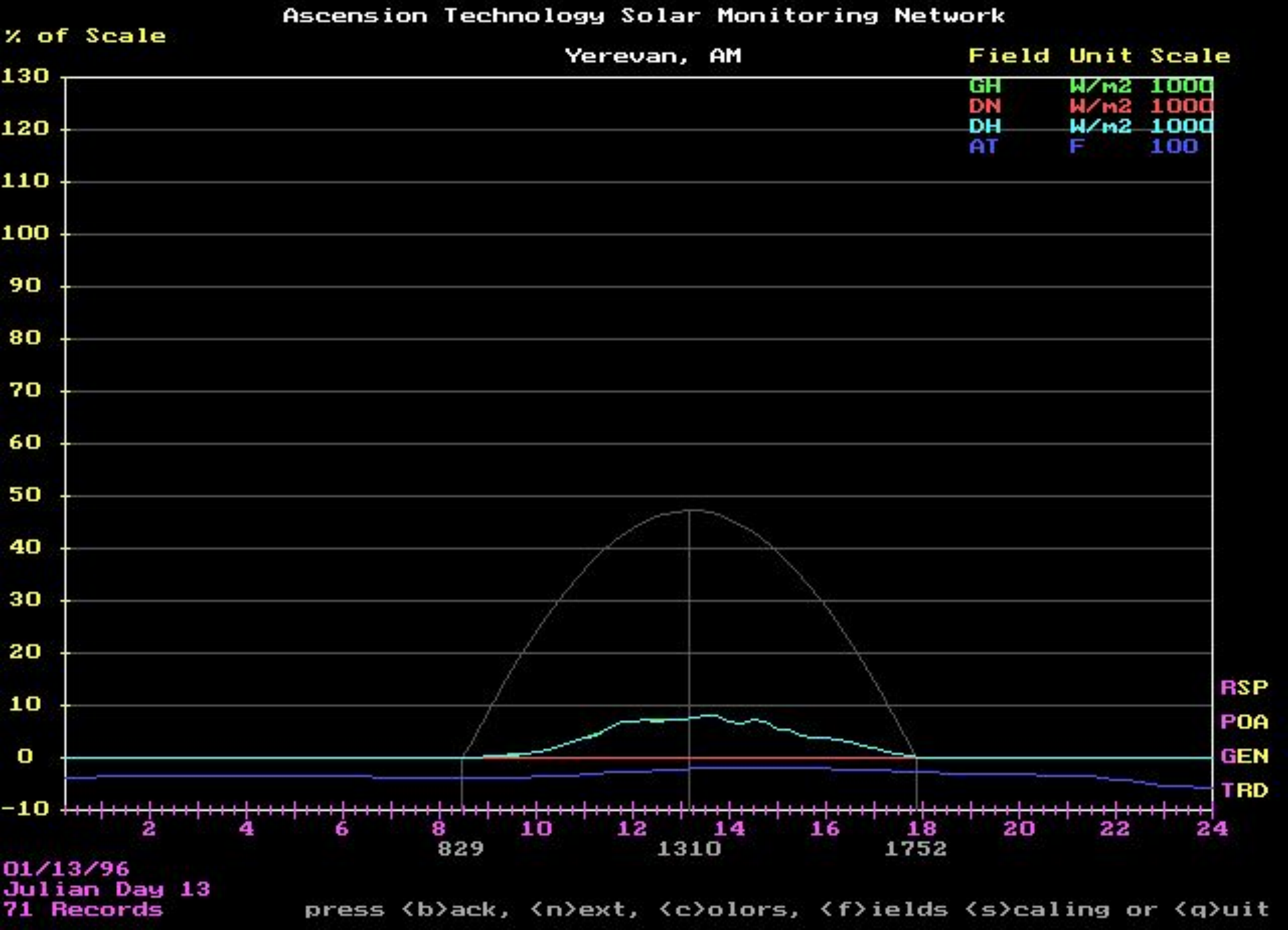

0 200 km
timally-inclined south-oriented photovoltaic modules
system with optimally-inclined les and performance ratio 0.75
Global irradiation [kWh/m²]
<600 800 1000 1200 1400 1600 1800 2000 2200>
<450 600 750 900 1050 1200 1350 1500 1650>
Solar electricity [kWh/kWp]

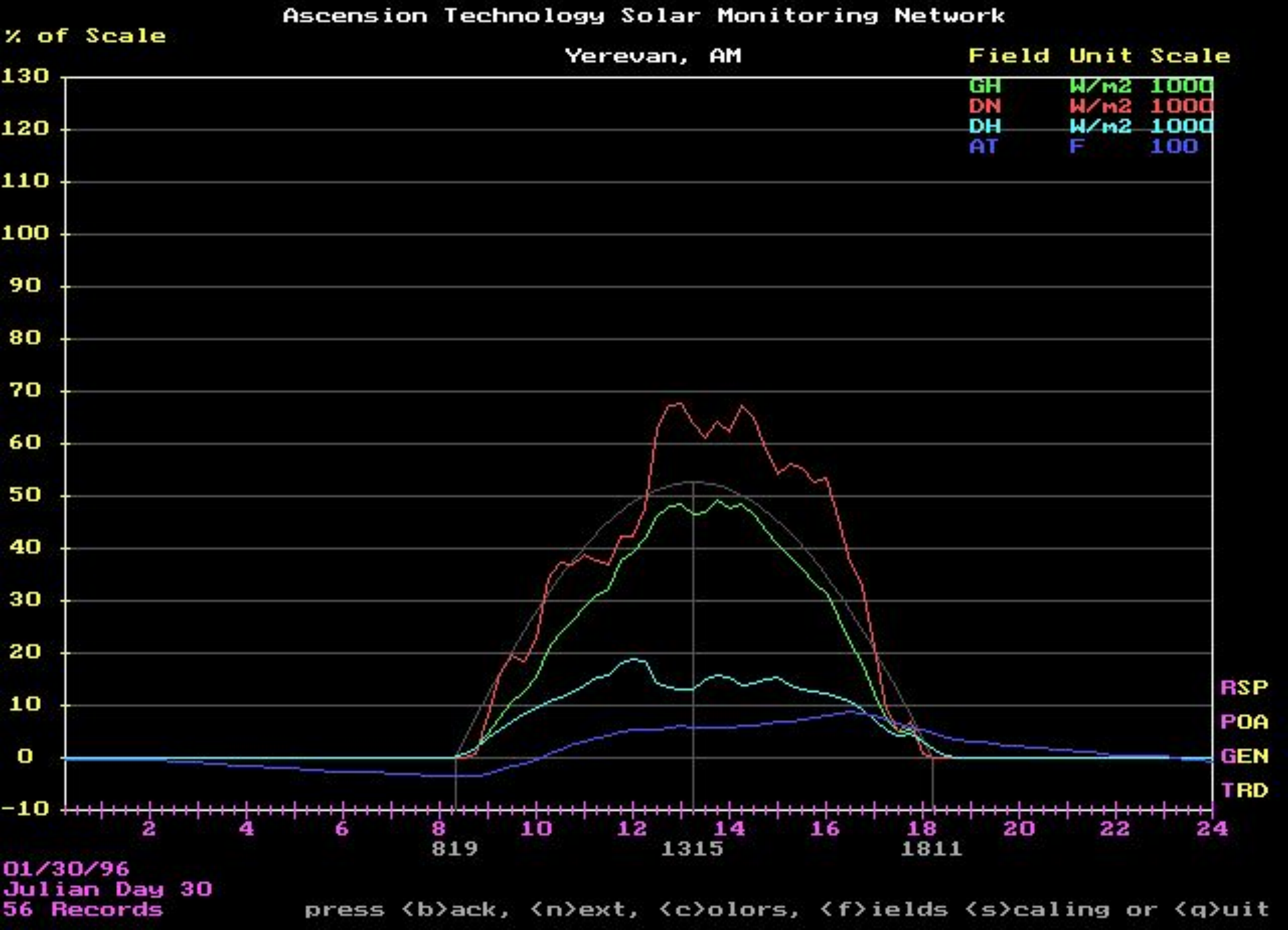
Optimum inclination of PV modules to maximize yearly energy yield

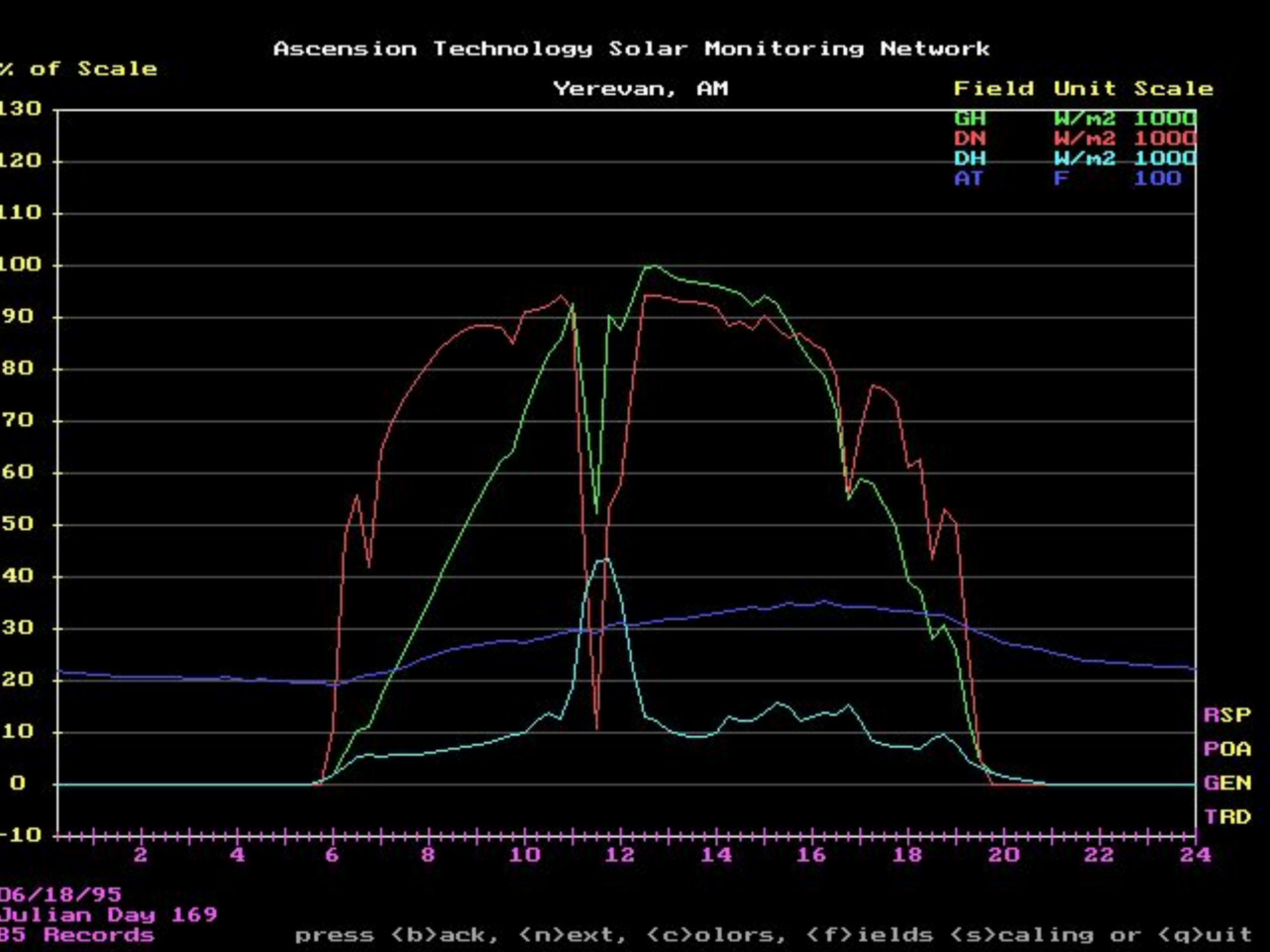
üì Ñ³ñÃ³ÏÝ»ñÇ ûåïÇÙ³É Ã»
ùáõÃÛáõÝÁ` ï³ñ»Ï³Ý
Ù³ùëÇÙáõÙ ¿Ý»ñ·Ç³Ý
ëï³Ý³Éáõ Ñ³Ù³ñ

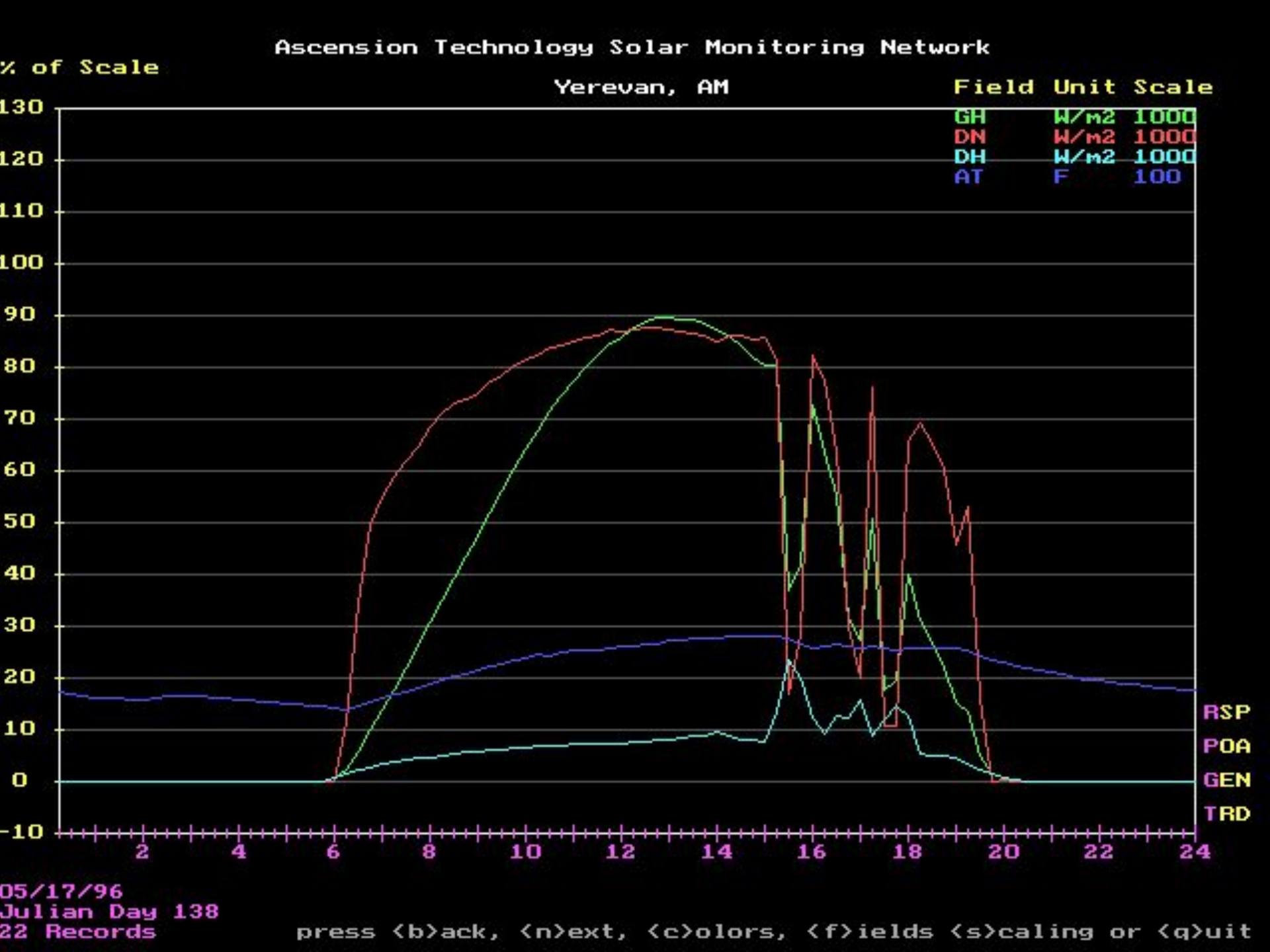



Ascension Technology Solar Monitoring Network
% of Scale
Yerevan, AM
Field Unit Scale
GH W/m2 1000
DN W/m2 1000
DH W/m2 1000
AT F 100
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
2
4
6
8
10
12
14
16
18
20
22
24
538
1304
2030
RSP
POA
GEN
TRD
06/23/95
Julian Day 174
24 Records
press <b>ack, <n>ext, <c>olors, <f>ields <s>caling or <q>uit


Ascension Technology Solar Monitoring Network
% of Scale
Yerevan, AM
Field Unit Scale
GH W/m2 1000
DN W/m2 1000
DH W/m2 1000
AT F 100
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
RSP
POA
GEN
TRD
2
4
6
8
10
12
14
16
18
20
22
24
829
1310
1752
01/13/96
Julian Day 13
71 Records
press <b>ack, <n>ext, <c>olors, <f>ields <s>caling or <q>uit

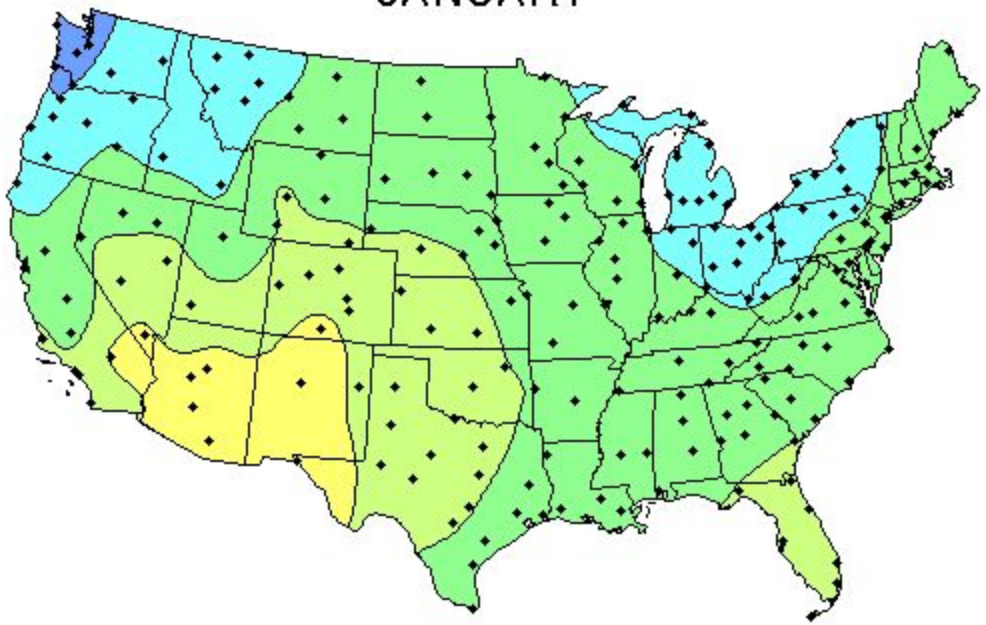

Ascension Technology Solar Monitoring Network
% of Scale
Yerevan, AM
Field Unit Scale
GH W/m2 1000
DN W/m2 1000
DH W/m2 1000
AT F 100
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
2
4
6
8
10
12
14
16
18
20
22
24
819
1315
1811
RSP
POA
GEN
TRD
01/30/96
Julian Day 30
56 Records
press <b>ack, <n>ext, <c>olors, <f>ields <s>caling or <q>uit


Ascension Technology Solar Monitoring Network
Yerevan, AM
% of Scale
Field Unit Scale
GH W/m2 1000
DN W/m2 1000
DH W/m2 1000
AT F 100
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
2
4
6
8
10
12
14
16
18
20
22
24
RSP
POA
GEN
TRD
06/18/95
Julian Day 169
85 Records
press <b>ack, <n>ext, <c>olors, <f>ields <s>caling or <q>uit


Ascension Technology Solar Monitoring Network
Yerevan, AM
% of Scale
Field Unit Scale
GH W/m2 1000
DN W/m2 1000
DH W/m2 1000
AT F 100
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
2
4
6
8
10
12
14
16
18
20
22
24
RSP
POA
GEN
TRD
05/17/96
Julian Day 138
22 Records
press <b>ack, <n>ext, <c>olors, <f>ields <s>caling or <q>uit

Average Daily Solar Radiation Per Month

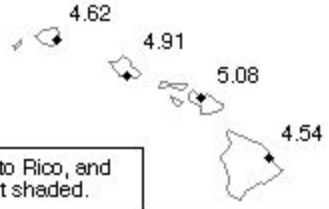
JANUARY



Flat Plate Tilted South at Latitude

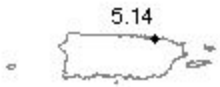
Alaska

Hawaii



Hawaii, Puerto Rico, and Guam are not shaded.

San Juan, PR



Guam, PI

Collector Orientation

Flat-plate collector facing south at fixed tilt equal to the latitude of the site: Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site's latitude.

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

National Renewable Energy Laboratory
Resource Assessment Program

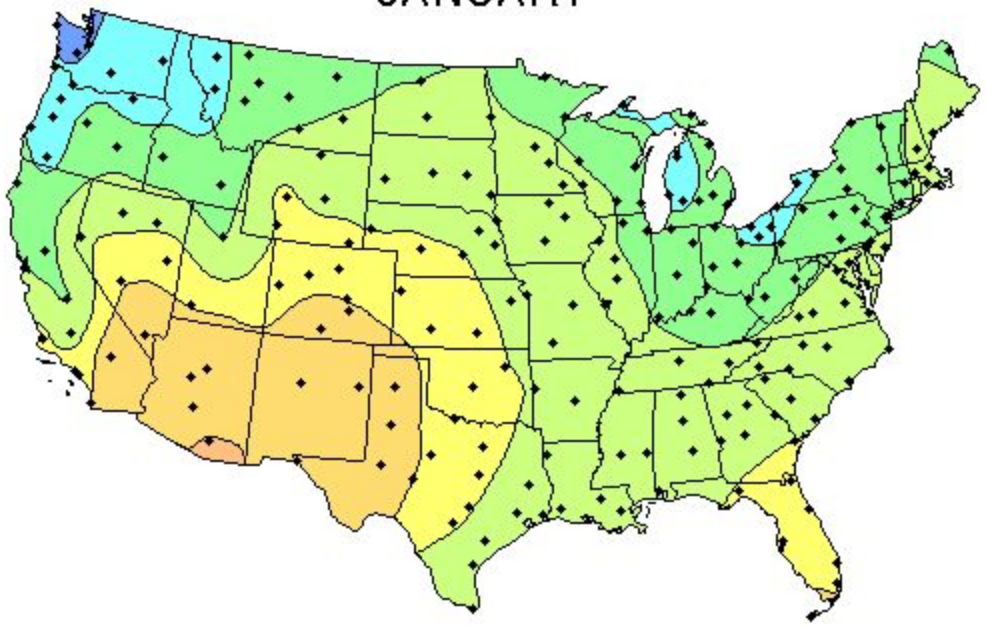
kWh/m^2/day

- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

FLATA01-196

Average Daily Solar Radiation Per Month

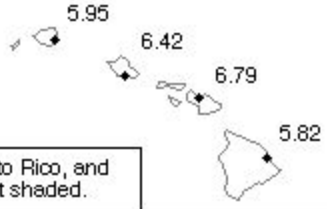
JANUARY



Two-Axis Tracking Flat Plate

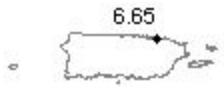
Alaska

Hawaii



Hawaii, Puerto Rico, and Guam are not shaded.

San Juan, PR



Guam, PI

Collector Orientation

Two-axis tracking flat-plate collector: Data used to generate this map represent the maximum solar radiation at a site available to a collector. Tracking the sun in both azimuth and elevation, these collectors keep the sun's rays perpendicular to the collector surface.

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

NREL

National Renewable Energy Laboratory
Resource Assessment Program

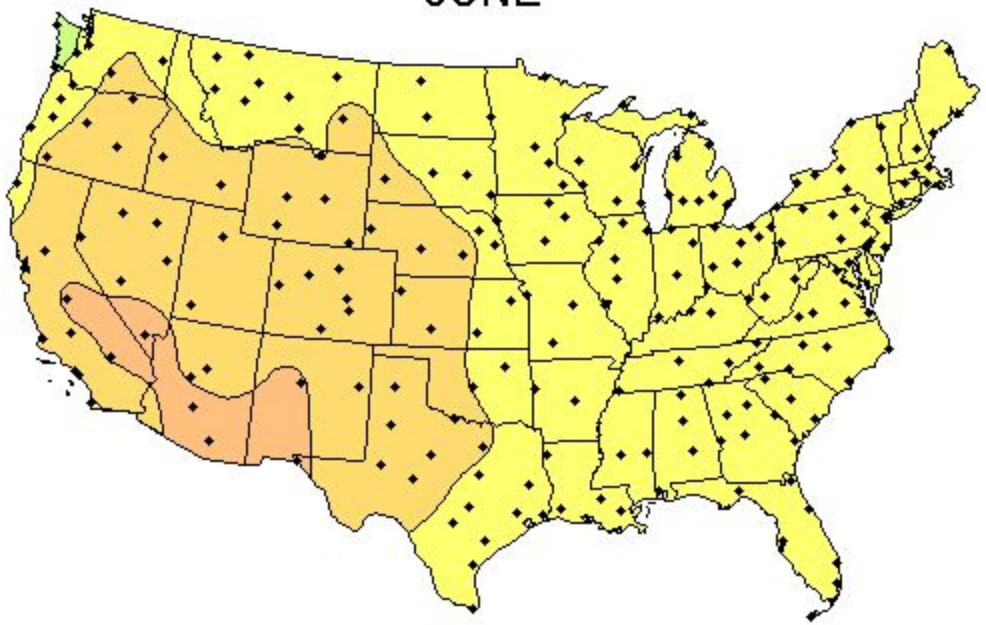
kWh/m^2/day

	10 to 14
	8 to 10
	7 to 8
	6 to 7
	5 to 6
	4 to 5
	3 to 4
	2 to 3
	0 to 2
	none

P2XXA01-157

Average Daily Solar Radiation Per Month

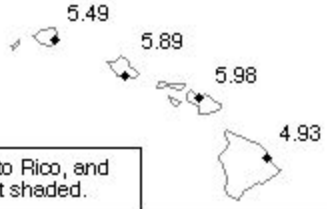
JUNE



Flat Plate Tilted South at Latitude

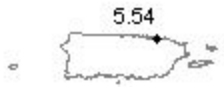
Alaska

Hawaii



Hawaii, Puerto Rico, and Guam are not shaded.

San Juan, PR



Guam, PI

Collector Orientation

Flat-plate collector facing south at fixed tilt equal to the latitude of the site: Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site's latitude.

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

NREL

National Renewable Energy Laboratory
Resource Assessment Program

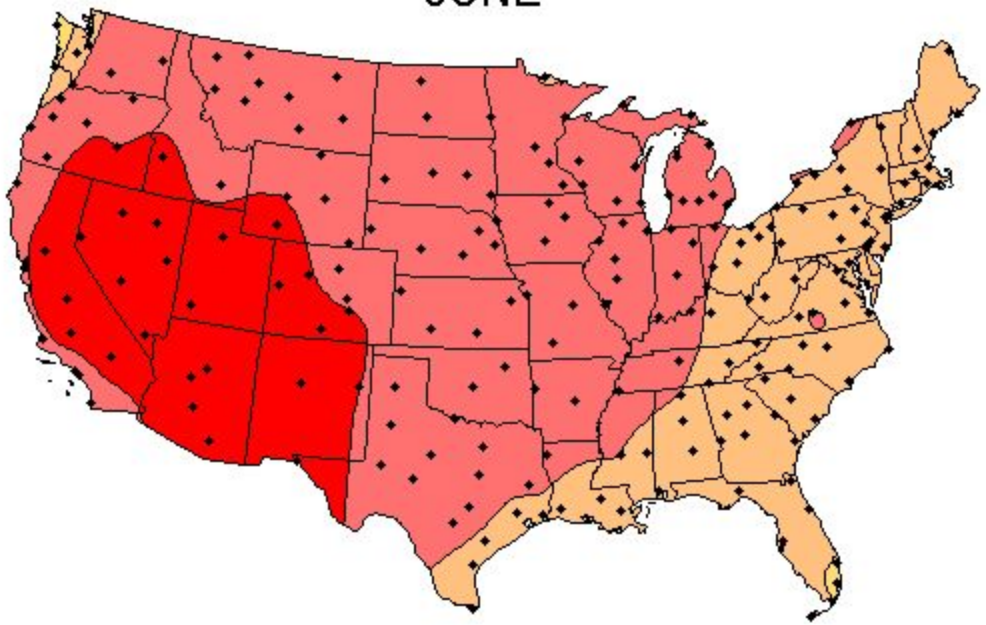
kWh/m^2/day

	10 to 14
	8 to 10
	7 to 8
	6 to 7
	5 to 6
	4 to 5
	3 to 4
	2 to 3
	0 to 2
	none

FLATA06-201

Average Daily Solar Radiation Per Month

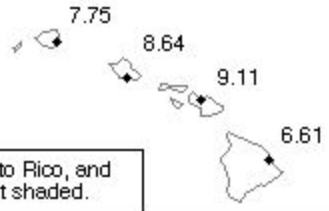
JUNE



Two-Axis Tracking Flat Plate

Alaska

Hawaii



Hawaii, Puerto Rico, and Guam are not shaded.

San Juan, PR

Guam, PI

Collector Orientation

Two-axis tracking flat-plate collector: Data used to generate this map represent the maximum solar radiation at a site available to a collector. Tracking the sun in both azimuth and elevation, these collectors keep the sun's rays perpendicular to the collector surface.

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

NREL

National Renewable Energy Laboratory
Resource Assessment Program

kWh/m^2/day

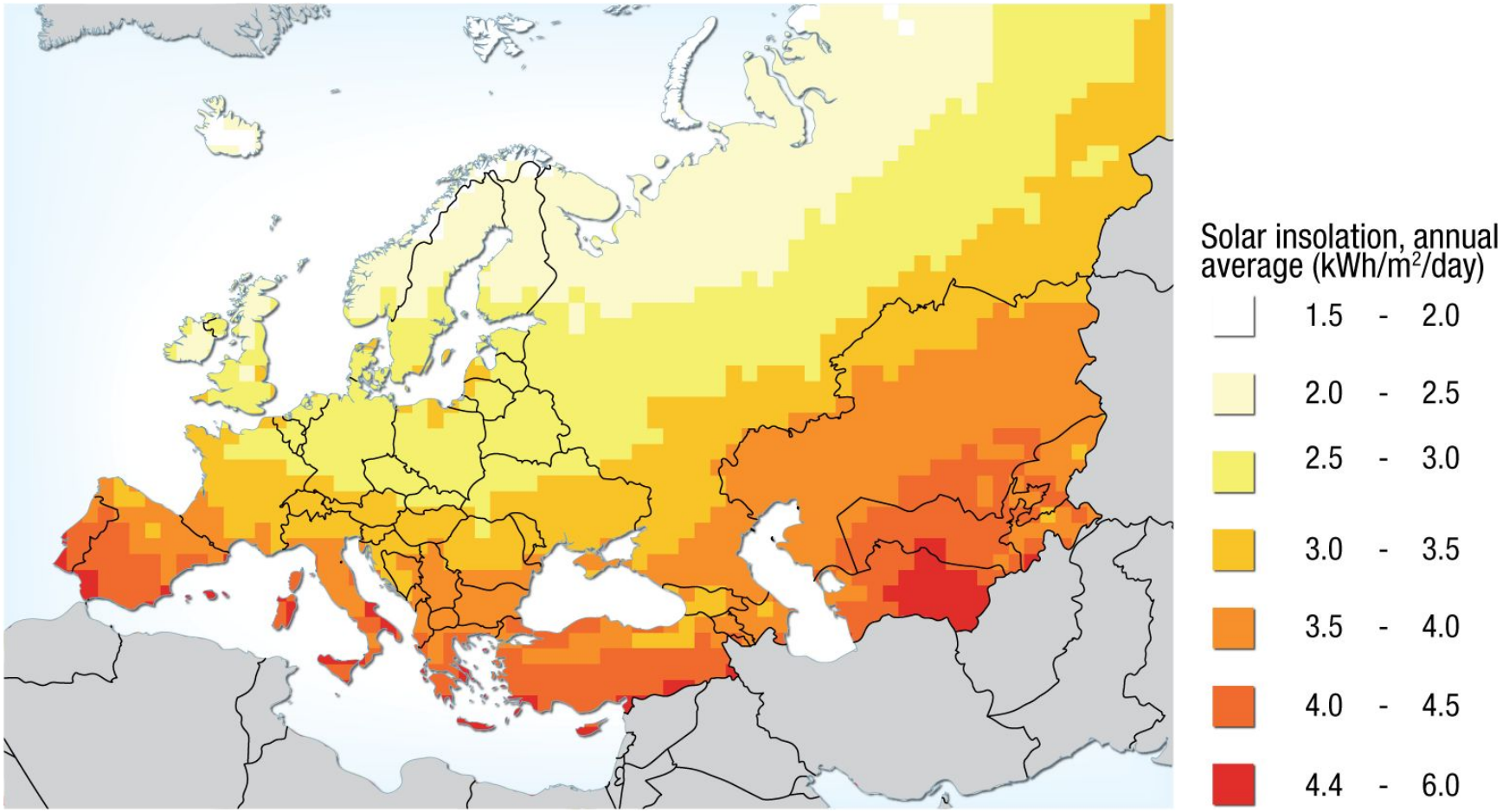
- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

P2XXA06-162

This info is available @:

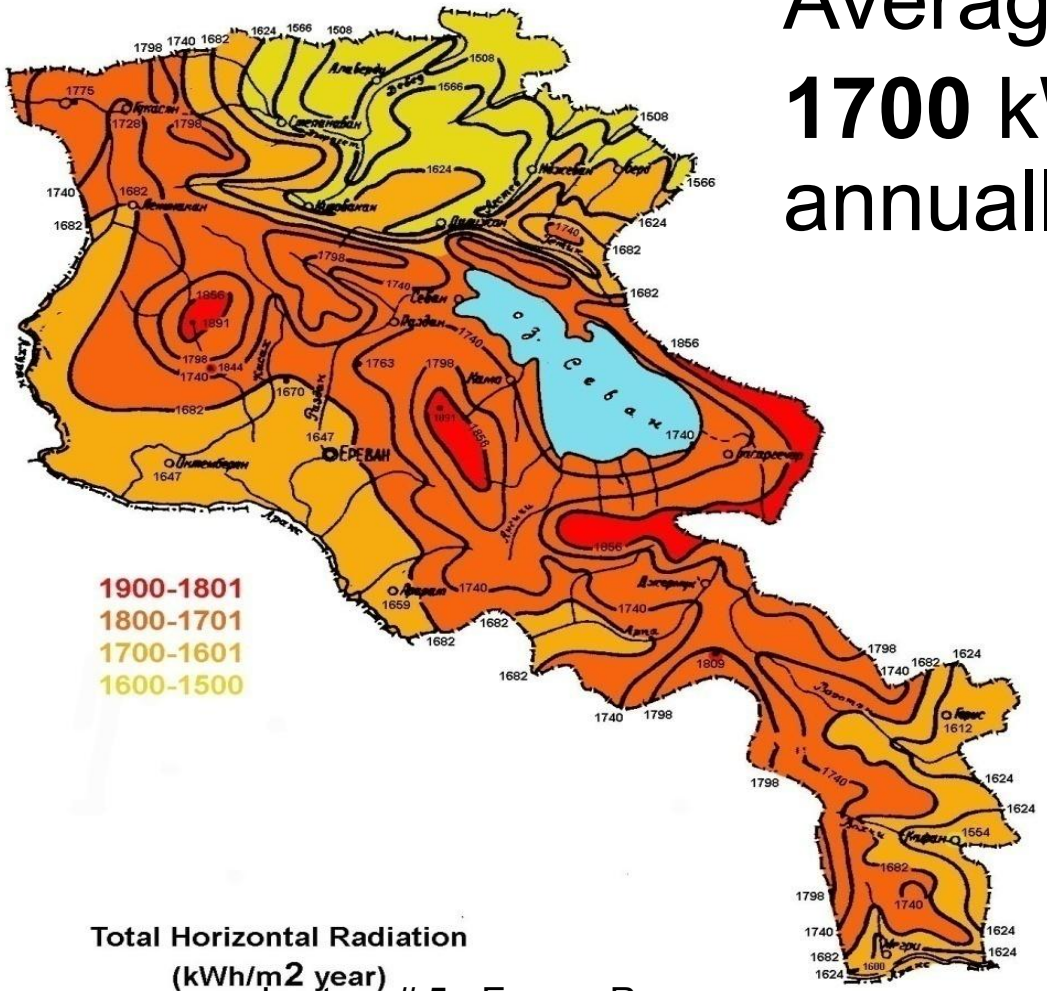
http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/

European Global Horizontal



ØÇçÇÝ »íñáå³Ï³ÝÁ ßaõñç 1000 ïíÁ/(Ù².ï³ñÇ)

Global Horizontal in Armenia



Average:
1700 kWh/m^2
annually

Solar Radiation in Armenia

- ÐáñÇ½áÝ³Ï³Ý Ù³Ï»ñµáõÛÃÇ **³é³í»É³·áõÛÝ** ·áõÙ³ñ³ÛÇÝ Ö³é³·³ÛÃáõÙÁ ÙÇçÇÝ ³Ùå³Ù³ÍáõÃÛ³Ý å³ÛÙ³ÝÝ»ñáõÙ` 1740-1770 ÏìïÅ/(Ù²·ï³ñÇ) êÇëÇ³Ý, æ»ñÙáõÏ, Â³ÉÇÝ µ ³ÛÉÝ,
- ÜáõÛÝÁ **Ýí³½³·áõÛÝÁ**` 1230-1240 ÏìïÅ/(Ù²·ï³ñÇ) ì³Ý³Óáñ, î³ßÇñ, êï»ɳÝ³í³Ý, ¸ÇÉÇç³Ý µ ³ÛÉÝ,
- ØÃÝáÉáñïÇ ÙÇçÇÝ ï³ñ»Ï³Ý “Ã³ɳÝó»ÉÇáõÃÛáõÝÁ”` 0.73-0.78,
- ºñµ³ÝáõÙ ÑáõÉÇëÇÝ ` 0.94, ÑáõÝí³ñÇÝ` 0.62,
- ì³Ý³ÓáñáõÙ ÑáõÉÇëÇÝ ` 0.51, ÑáõÝí³ñÇÝ` 0.67,
- êµ³ÝáõÙ ÑáõÉÇëÇÝ` 0.78, ÑáõÝí³ñÇÝ` 0.72

Solar Radiation in Armenia

- ºñu³ÝáõÙ ÑáõÉÇëÇÝ ÑáñÇ½áÝ³Ï³Ý Ù³Ï»ñuáõÛÃÇ ûñ³Ï³Ý ·áõÙ³ñ³ÛÇÝ ¢³é³·³ÛÃ³Ñ³ñáõÙÁ` 8.14 ÏïïÅ/(Ù².ûñ),
- ÜáõÛÝÁ ÑáõÝí³ñÇÝ ÑáõÉÇëÇ ÝÏ³ïÙ³Ùµ` 20-22% or less,
- ú·ï³Ï³ñ ç»ñÙ³ÛÇÝ ¿Ý»ñ·Ç³Ý ¹»åÇ Ñ³ñ³í ÏáÕÙ-Ýáñáßí³Í u 30⁰-Ç Ã»ùáõÃÛ³Ùµ Ù³Ï»ñuáõÛÃÇÝ` ÙÇÝãu ßáõñç 900 ÏïïÅ/(Ù².ï³ñÇ),
- ú·ï³Ï³ñ ç»ñÙ³¿Ý»ñ·Ç³ÛÇ ù³Ý³ÏÝ ¿³å»ë Ï³Ëí³Í ¿ Ñ³ñÃ ÏáÉ» ÏïáñÇ ß³Ñ³·áñÍÙ³Ý é»ÅÇÙÝ»ñÇó u ÁÝÏÝáÕ ¢³é³·³ÛÃ³ÛÇÝ ÑáëùÇ ËïáõÃÛáõÝÇó:

Homework 5

1. calculate the maximum theoretical difference between direct normal (DN) and direct horizontal (DH) for 12 hour daytime period on a location at equator @ March 21 equinox. Assume AM0.
2. Go to

   http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/.

   Explain why radiation values decrease with "**Two Axis Tracking Concentrator**" compared to "**Two Axis Tracking Flat Plate**". Illustrate by maps.