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ASPECTS CONCERNING THE SPATIALISATION OF RADIATION BALANCE COMPONENTS

COST719 - Final Conference - Grenoble (France), 2-5 July 2006

<u>Different approaches</u>:

- *Statistical interpolation*

  ✓ applicable to global radiation, but the number of stations is relatively small for regional and local radiation assessment

  ✓ measurements are usually performed on horizontal surfaces

- *Satellite imagery*

  ✓ provide the most realistic spatialisation

  ✓ good especially for regional and local assessment, but give momentarly values, therefore the need for many time frames to derive mean values

- *Conceptual models*

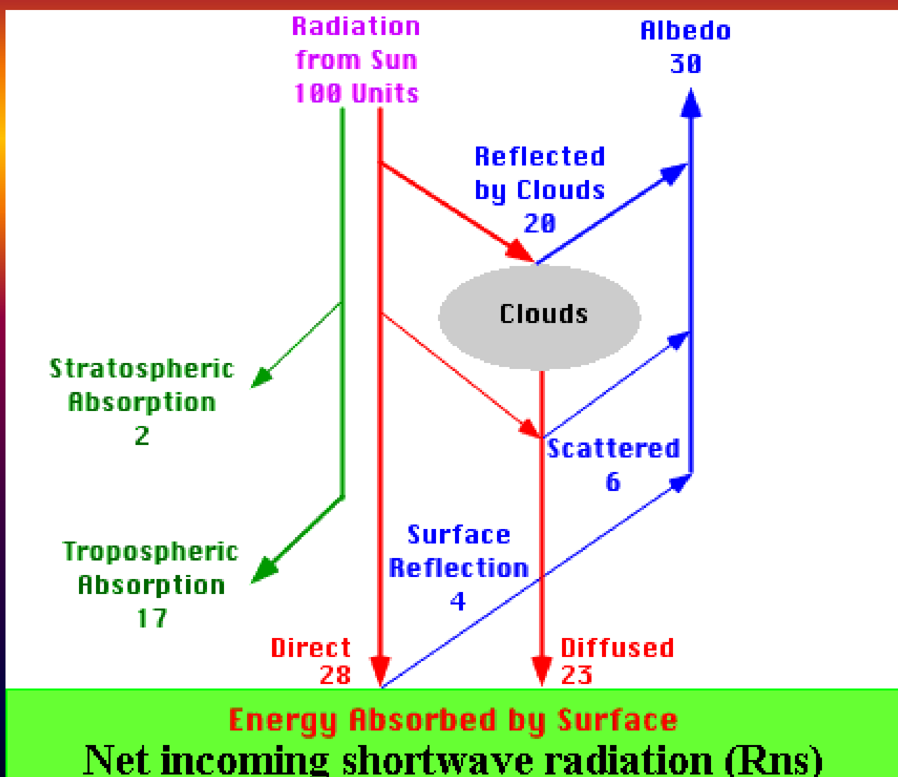
  ✓ provide algorithms for slope and aspect influence

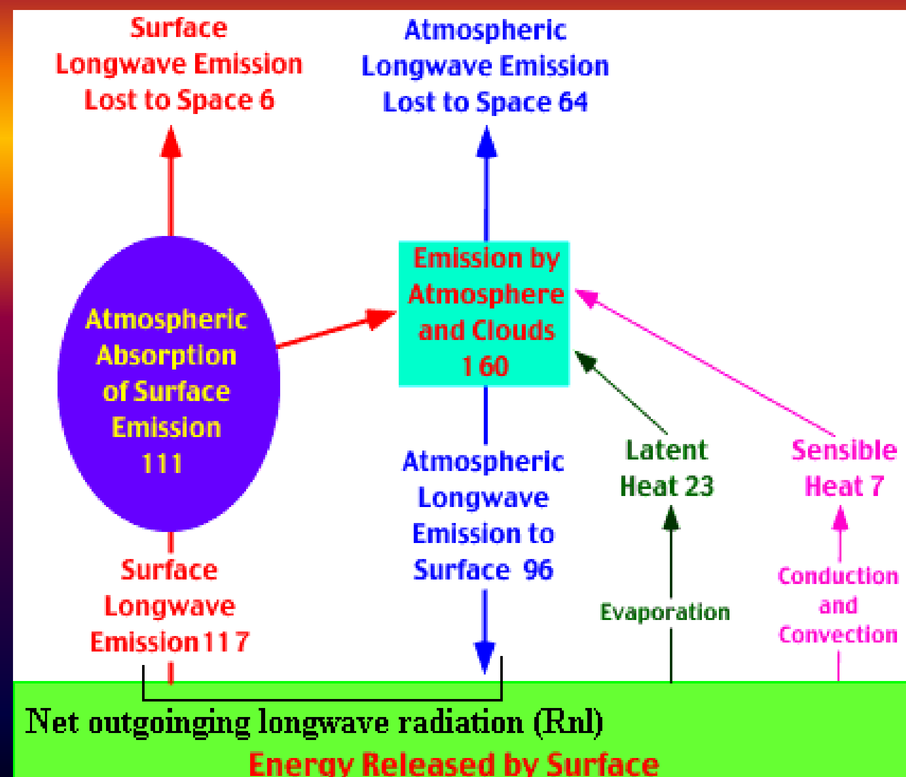
- *Combined models*

  ✓ most of the spatialisations are derived from combined models

Radiation balance components

- global radiation
- net incoming shortwave radiation
- net outgoing longwave radiation
- net radiation



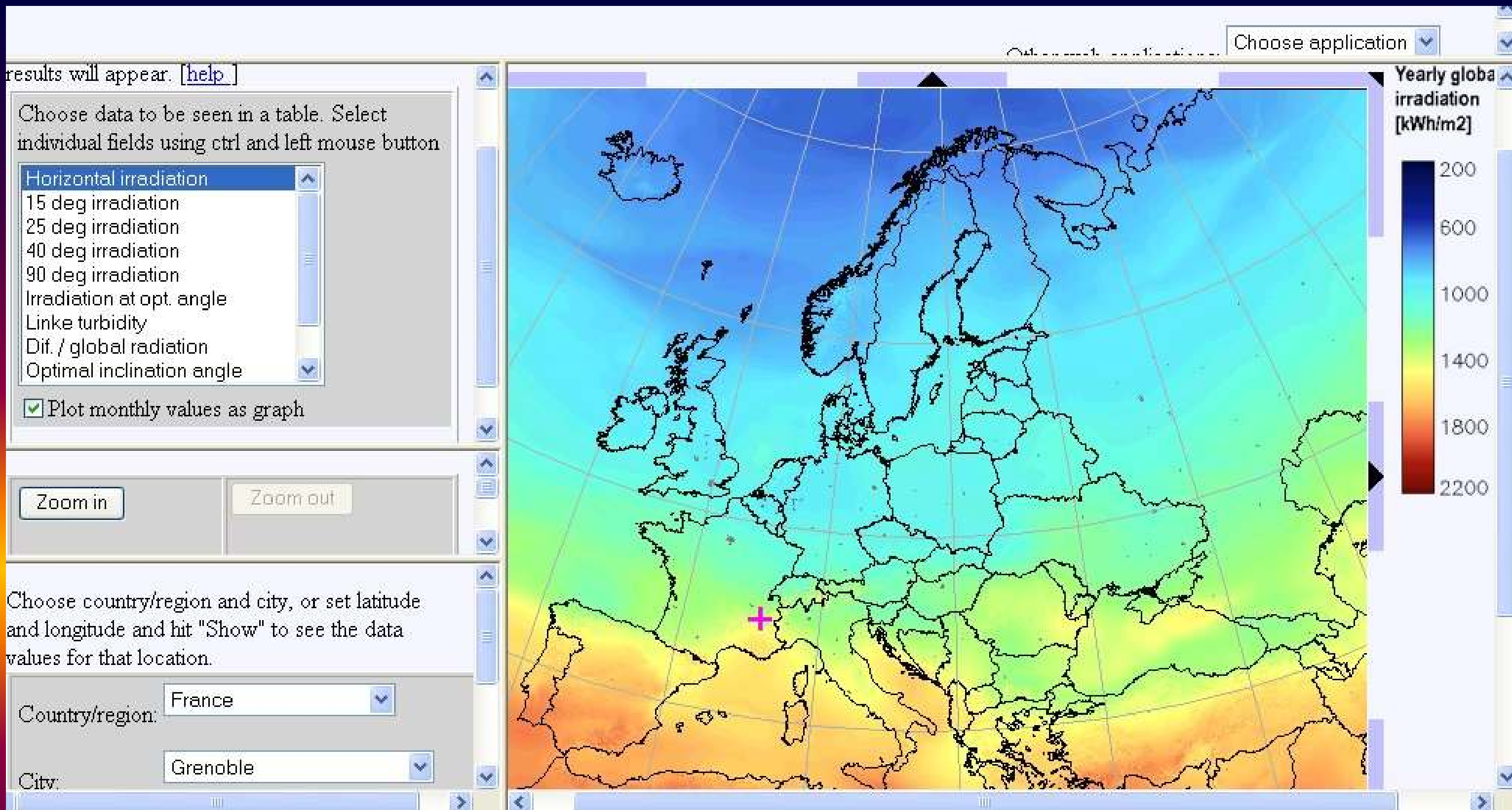


Source: http://www.physicalgeography.net/fundamentals/7i.html, © 1999-2006 Michael Pidwirny

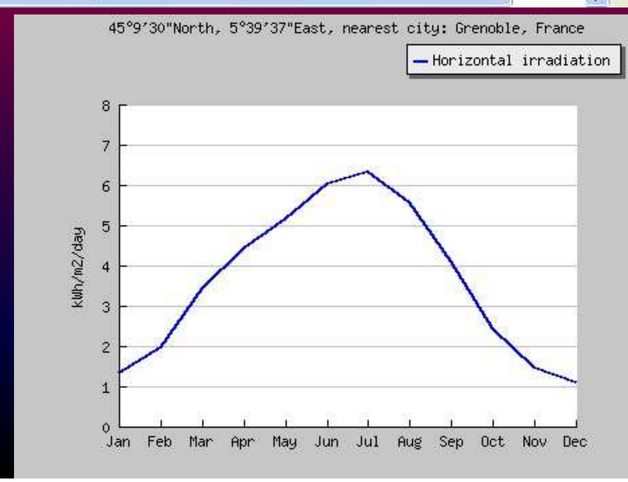
Overview of conceptual models and softwares

- *Horizontal global radiation*
  - ✓ Angström formula
  - ✓ parameterization of clear and cloudy skies radiation
    - o **SolarAnalyst**, an ArcView GIS extension module (Fu and Rich, 2000);
    - o **Solar Radiation** module form SAGA GIS (System for Automated Geoscientific Analyses), developed by O. Conrad;
    - o **r.sun** module from PVGIS (PhotoVoltaic Geographical Information System), an open source GIS developed by Dunlop, Šúri, Huld, Cebecauer, based on the database from the European Solar Radiation Atlas (ESRA, Scharmer and Greif, 2000)
- *Accounting for slope and aspect influence*
  - ✓ sinus ratio using mean daily sun angle for Angström formula
  - ✓ Kaempfert-Morgen nomogram
  - ✓ SAGA GIS ray tracing module

Overview of conceptual models and softwares



PVGIS output example: spatialization of the mean annual horizontal global radiation and the mean annual regime at Grenoble



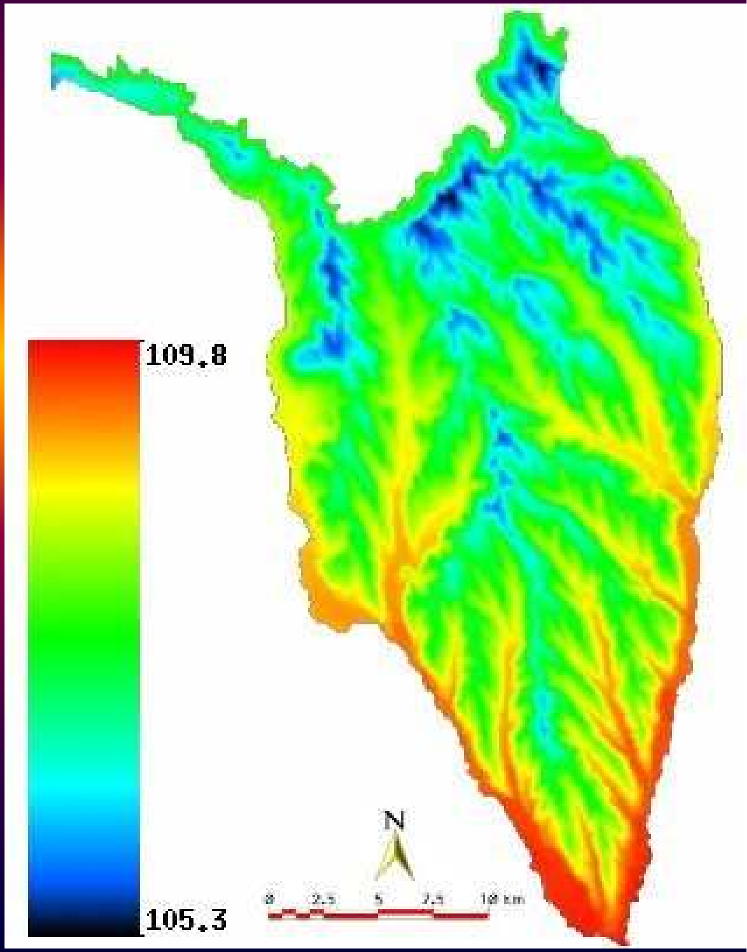
The Angström formula:

$$R_g = R_a\,[a + b(n/N)]$$

where:

- R_g: global radiation;
- R_a: extraterrestrial radiation, received at the upper limit of the atmosphere, on a surface parallel with the horizon of the determination point;
- n/N: relative sunshine duration, representing the ratio of the actual duration of sunshine (n), to the maximum possible duration of sunshine (N);
- a, b: coefficients, expressing the qualitative structure of the global radiation (direct and diffuse radiation).

The Central Moldavian Plateau: estimated mean annual global radiation on horizontal surface (kcal/cm^2, resolution 20m) (*Patriche C.V.*, 2005)



Sinus ratio correction

(*Patriche C. V.*, 2005):

$$R_g = R_a \left[a + b \frac{n}{N} \frac{\sin(h_m \pm \alpha)}{\sin(h_m)} \right]$$

where:

- α : slope angle of land surface;
- h_m : mean daily sun angle estimated using latitude (φ) and number of day in the year (J) (*Allen et al.*, 1998):

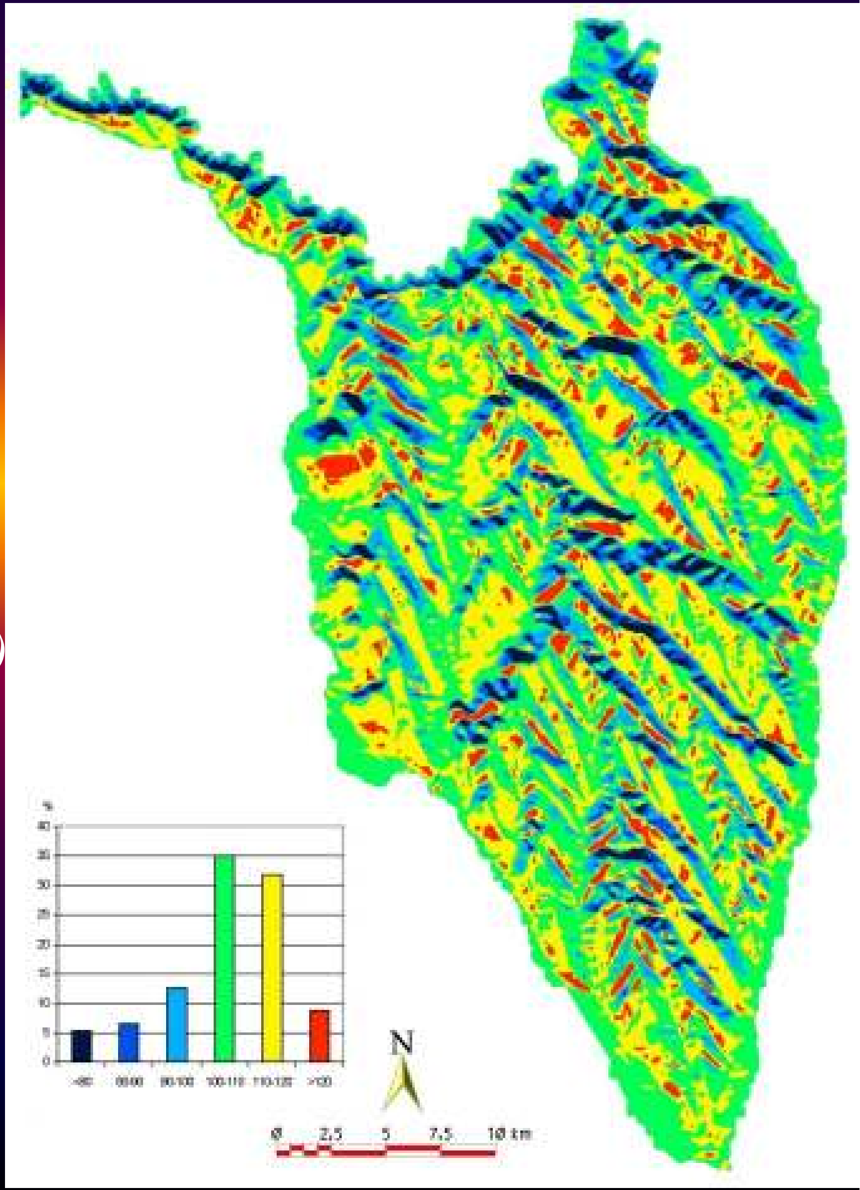
$$\sin(h_m) = \sin[0{,}85 + 0{,}3\ \varphi\ \sin(2\pi\ J/365 - 1{,}39) - 0{,}42\ \varphi^2]$$

$$R_g = R_{g\text{-}N} + c\ (R_{g\text{-}S} - R_{g\text{-}N})$$

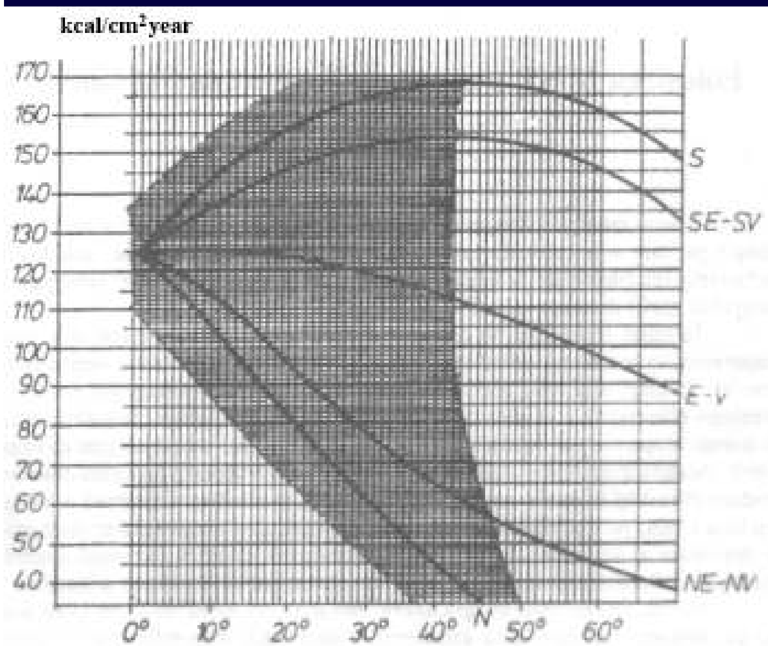
where:

- $R_{g\text{-}S}$, $R_{g\text{-}N}$: the global radiation for southern and northern orientations

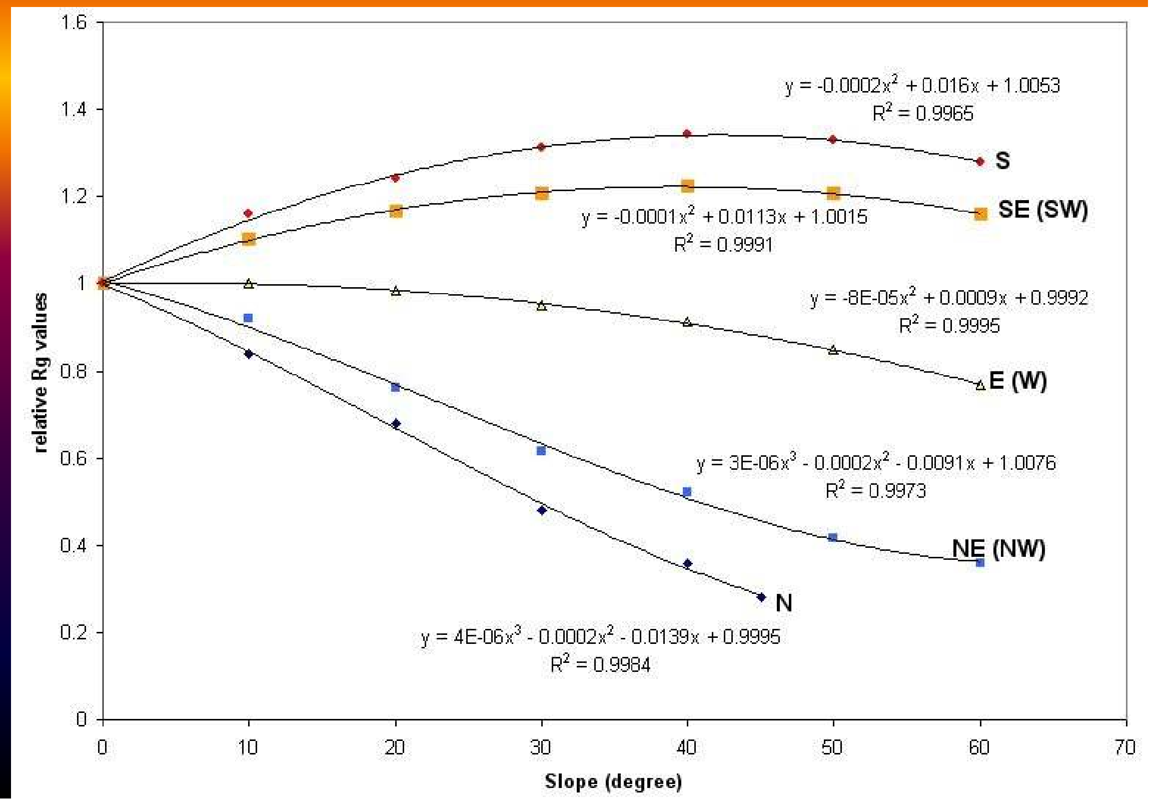
The Central Moldavian Plateau: estimated mean annual global radiation on real terrain (kcal/cm^2, resolution 20m) (*Patriche C.V.*, 2005)



<u>Kaempfert-Morgen nomogram</u> for annual global radiation values



Relative values



linear variations of the global radiation can be applied between N – NE (NW), NE (NW) – E (W), E (W) – SE (SW) and SE (SW) – S expositions in order to improve the spatialisation

<u>Parameterizations for clear skies</u> (I_{clear}) and **<u>cloudy skies</u>** (I_{cloudy}) solar radiation (*Entekhabi D.*, 1997):

$$I_{clear} = I_0 \, e^{-n \, \alpha 1 \, m}$$

$$I_{cloudy} = I_{clear} \, (1\text{-}0.65N^2)$$

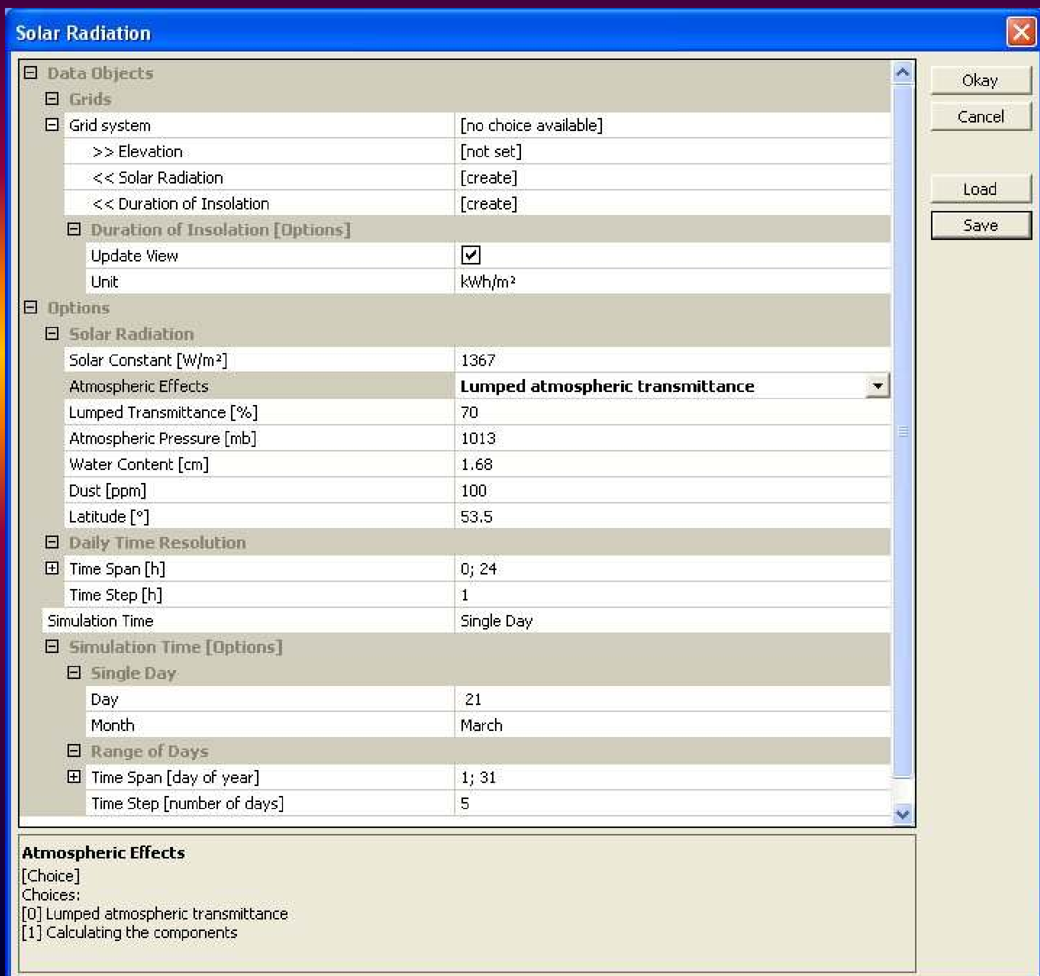
where:

- I_0: extraterrestrial radiation, received at the upper limit of the atmosphere, on a surface parallel with the horizon of the determination point;
- n: atmospheric turbidity (n = 2 for very clean and clean air, n = 5 for thick smog conditions;
- α_1: molecular scattering coefficient parameterized as $\alpha_1 = 0.128\text{-}0.054 \log_{10}(m)$
- m: optical air mass (approximately $1/\sin(\alpha)$, where α is the mean sun angle);
- N: fractional cloud cover.

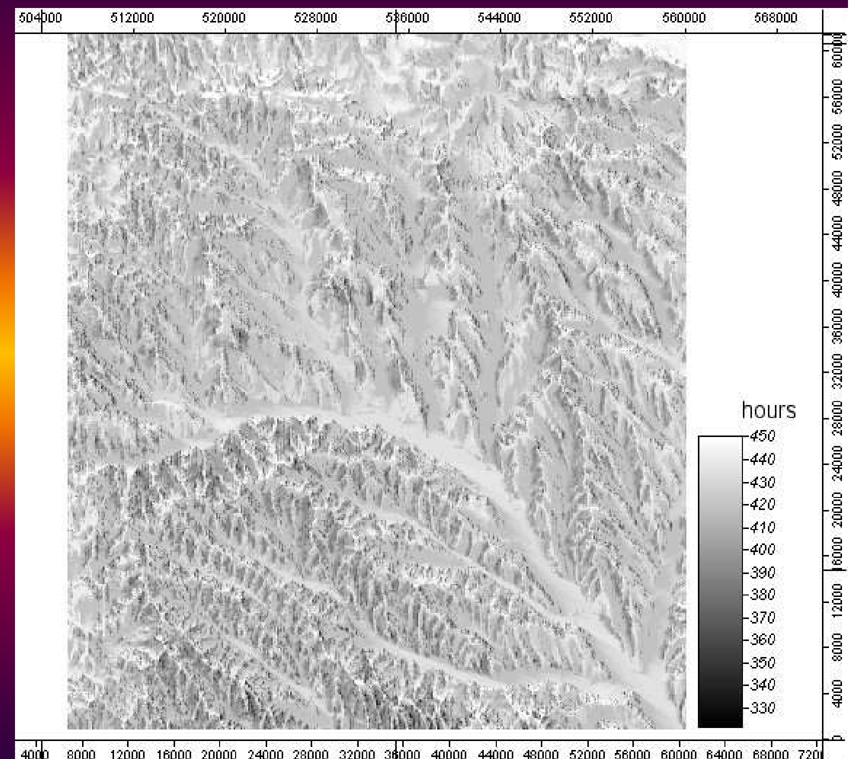
<u>SAGA GIS software</u> (System for Automated Geoscientific Analyses)

- developed by *O. Conrad* - http://www.saga-gis.uni-goettingen.de/html/index.php

Solar Radiation module interface in SAGA GIS software

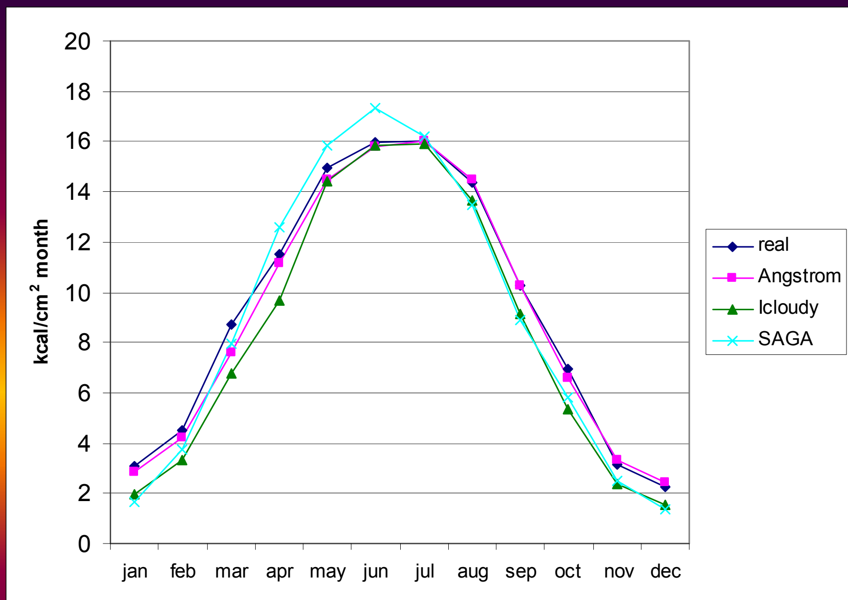


Astronomically sunshine duration in July

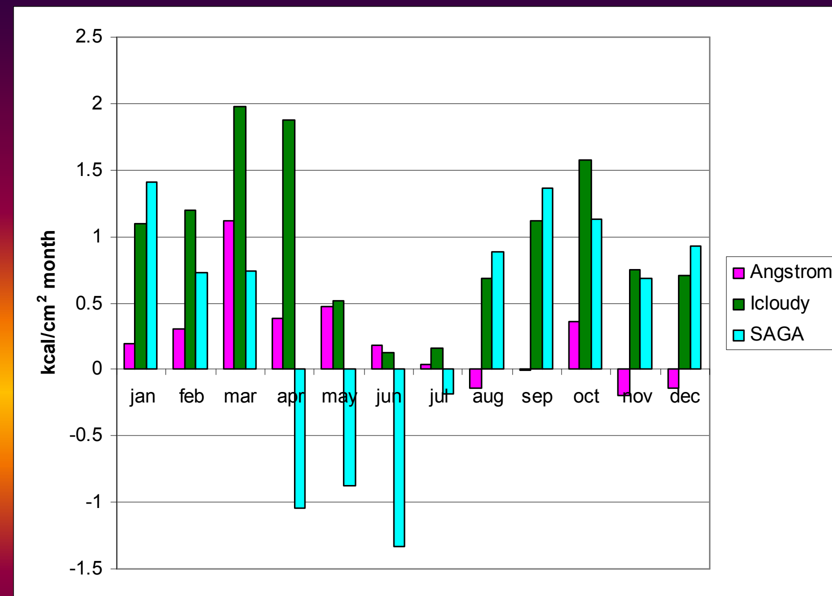


Comparison of the models

Comparison of real and estimated global radiation values on horizontal surface for Iasi meteorological station (eastern Romania, 46.17° latitude, 102m altitude)



Real and estimated annual regime



Differences between real and estimated values

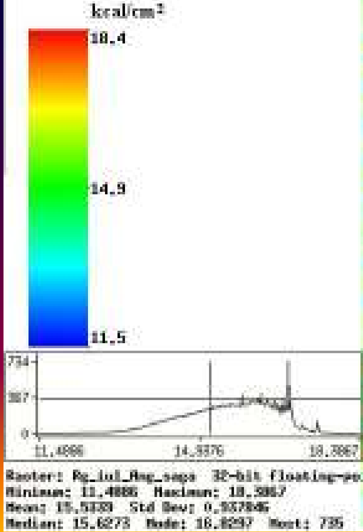
Error parameters for the global radiation models

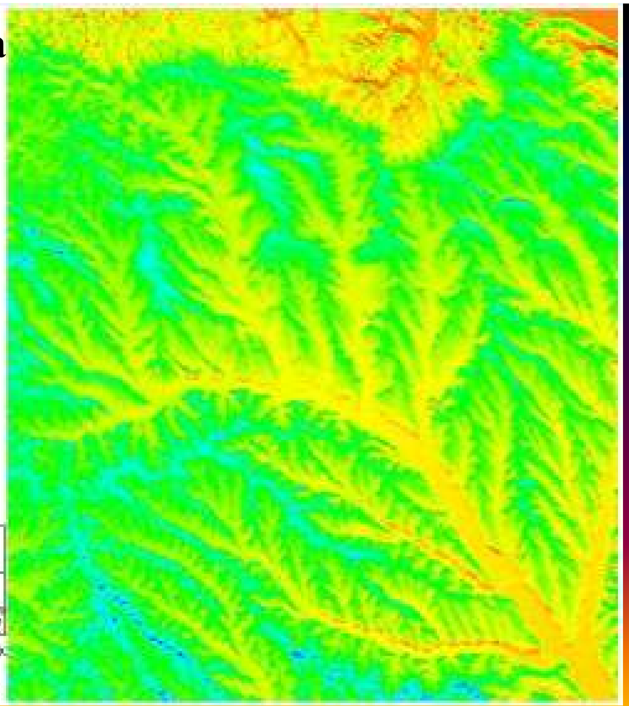
Models	Maximum error		Minimum monthly error	Mean annual error	Root mean annual square error
	Highest monthly overestimation	Highest monthly underestimation			
Angström	-0.192	1.115	-0.006	0.215	0.407
I_{cloudy}	-	1.973	0.130	0.981	1.140
SAGA	-1.334	1.403	-0.180	0.368	0.998

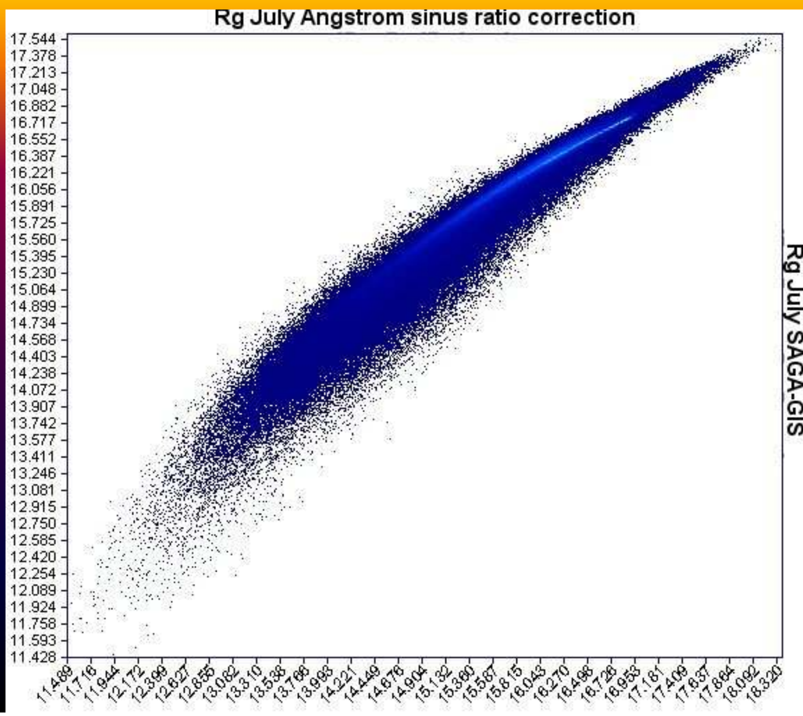
Comparison of the models

Comparison of global radiation spatialisation using the Angström formula with sinus ratio correction and SAGA model for July (eastern Romania, 90m resolution)

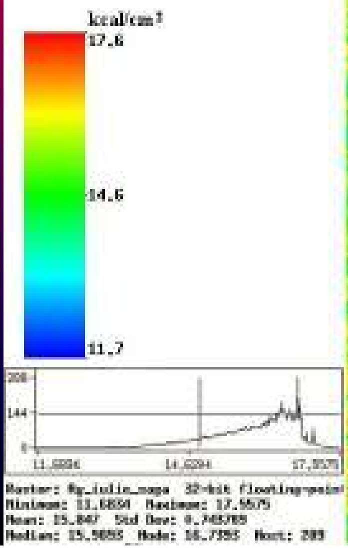
Angström formula with sinus ratio correction

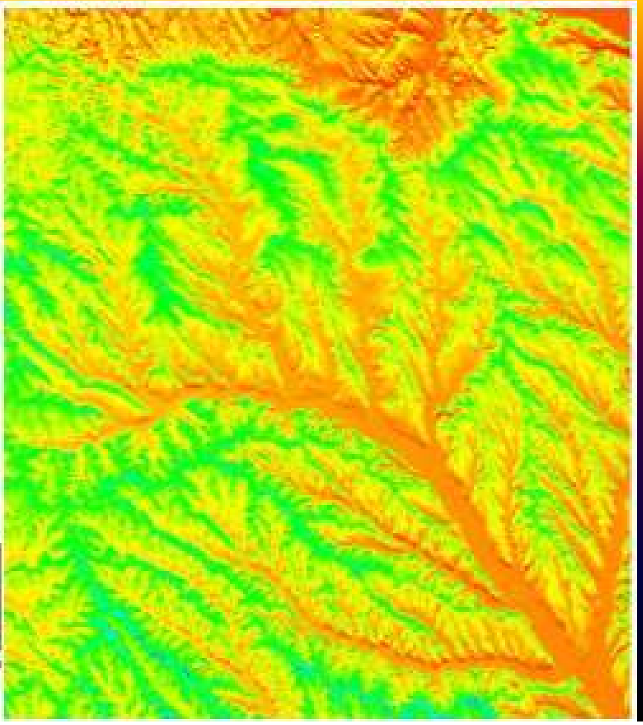






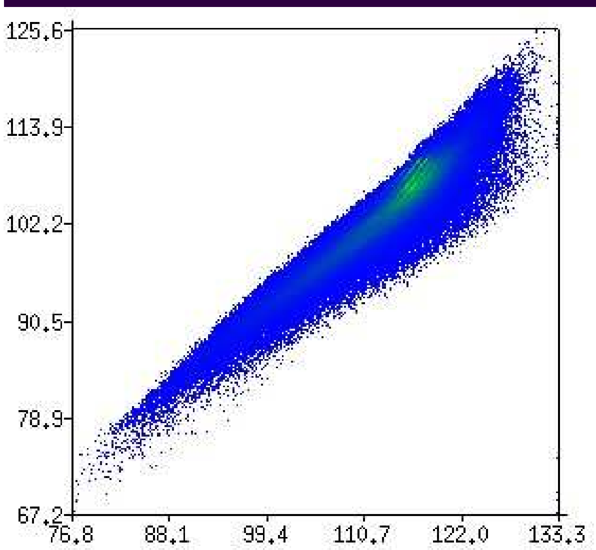
SAGA model



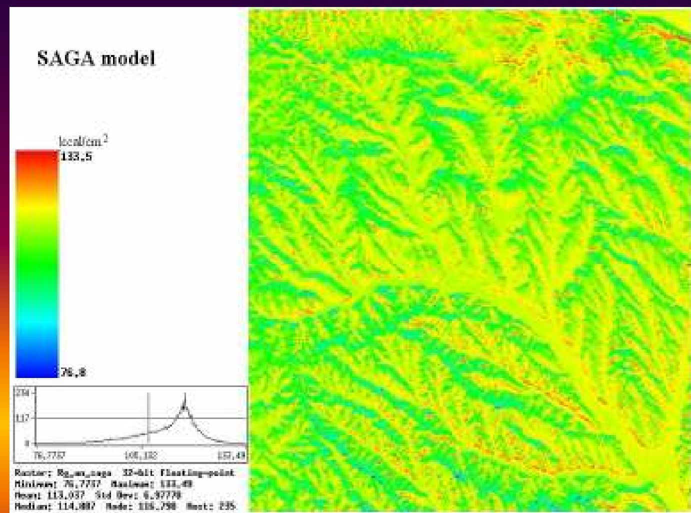


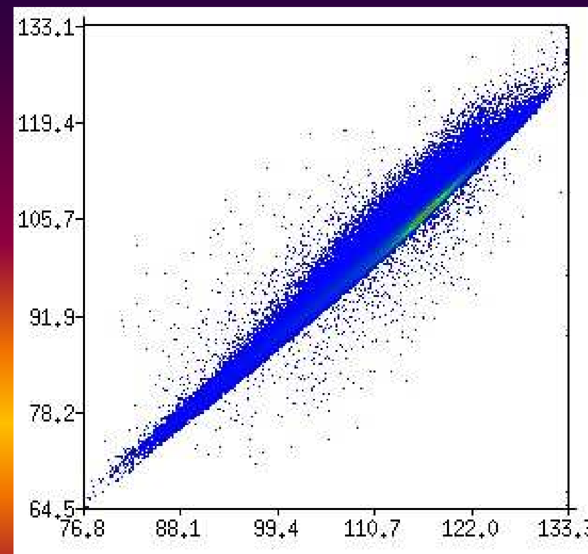
Comparison of the models

Correlation between annual global radiation spatialisations using different methods of accounting for slope and aspect influence (eastern Romania, 90m resolution)

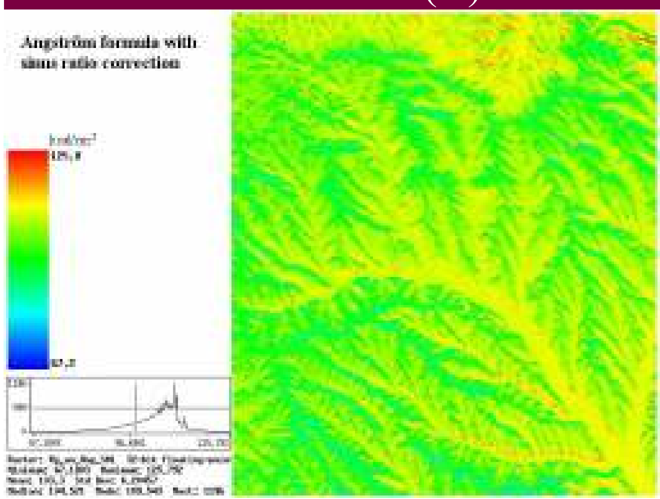


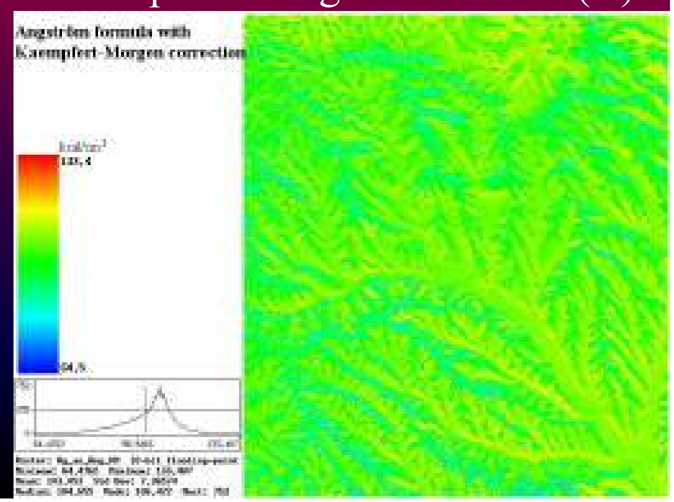
SAGA (X) – Angström with sinus ratio correction (Y)





SAGA (X) – Angström with Kaempfert-Morgen correction (Y)





Comparison of the models. Conclusions

• The **Angström formula** (a=0.25, b=0.5) gives the best estimate of the horizontal global radiation in our case

• The **SAGA ray tracing model** is the best because it actually generates the solar incidence angles for successive hours within a day, from which the daily global radiation sums are further calculated

• The **Kaempfert-Morgen nomogram** correction is more generalized. Even if we overcome the disadvantage of using exposition classes instead on numerical exposition values, we still have a degree of generalization due to the fact that it was designed for middle latitudes

• The **sinus ratio correction** has several shortcomings:

✓ It does not sum the hourly radiation values

✓Potential problems for steep slopes:

o *South-facing surfaces*: if the maximum sun angle (h_{max}, at noon) plus the slope is greater than 90 ($h_{max}+\alpha > 90$), the radiation derived from sinus ratio correction will be greater than the real one, because the sinus ratio uses the mean sun angle and $h_m+\alpha < 90$.

o *North-facing surfaces*: if $h_m<\alpha$ the direct component of the global radiation must be set to zero, but in fact there is a small amount of direct radiation reaching these surfaces corresponding to the time when solar angle is between h_m and h_{max}.

The net incoming shortwave radiation (Rns)

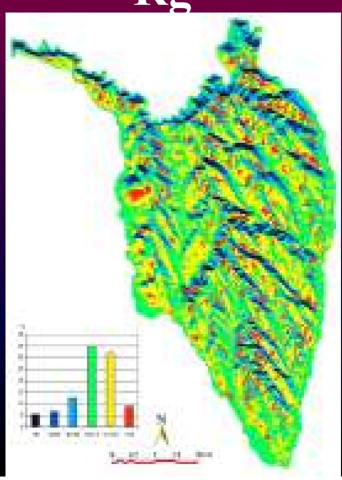
$$R_{ns} = (1 - a)\, R_g$$

Approaches for albedo spatialisation:

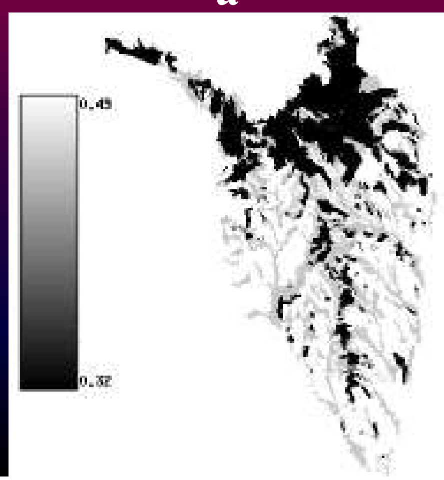
- Attachment of *predefined values* to land cover polygons in a land cover map (the case of the joined figure): easier way, but more general due to rigid albedo values which, in reality, vary within certain limits.

- Derivation of the albedo values from *satellite images*: more precise, but far more difficult and time consuming.

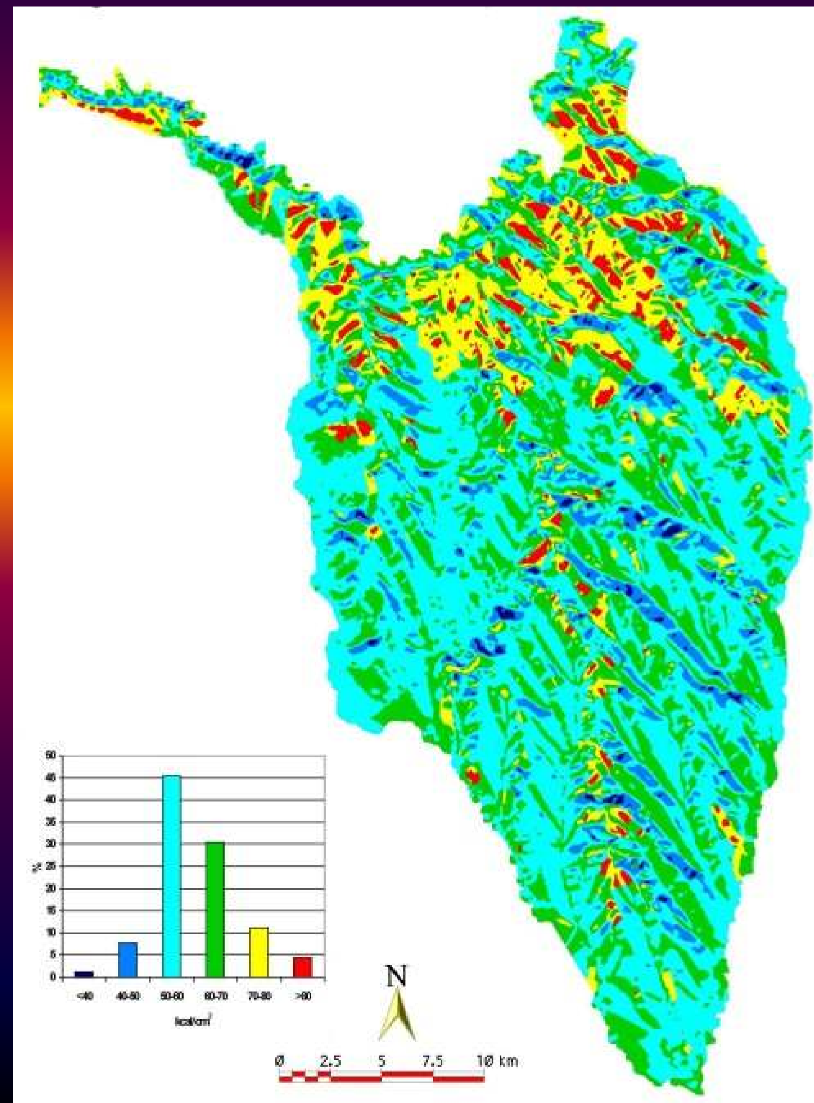
Rg



a



The Central Moldavian Plateau: estimated mean annual net incoming shortwave radiation (kcal/cm^2, resolution 20m) (*Patriche C.V.*, 2005)



Satellite-based albedo computation

Computation methods depend on the satellite sensor (Landsat – TM/ETM, NOAA – AHVRR, METEOSAT etc.).

Basic steps for obtaining the albedo using Landsat images (Goita K., Royer A., 1992):

• Transformation of the digital numbers (DN) in radiance values, using the sensor's calibration parameters (gain, offset):

$$L = \text{Offset} + (\text{Gain} \times DN)$$

• Calculation of apparent reflectance (ρ) for each spectral band:

$$\rho = \pi L d^2 / E \cos(\theta_s)$$

where: L – spectral radiance, d - Earth-Sun distance correction, E - mean solar exoatmospheric irradiance, θ_s – sun zenith angle.

• Calculation of albedo for the whole visible (TM1,2,3; ETM1,2,3), near (TM4; ETM4) and middle infrared (TM5,7; ETM5,7) spectrum:

$$a = \sum \rho_i E_i / \sum E_i$$

An example of albedo derivation from Landsat TM optical data for Doon Valley, India (*Saha, Pande*, 1995)

The net outgoing longwave radiation (R_{nl})

- Estimation according to *Stefan – Boltzmann* law:

$$R_{nl} = \sigma T^4 \left(0.56 - 0.079\sqrt{e_{act}}\right) \cdot \left(0.1 + 0.9\, n/N\right)$$

where: σ: *Stefan – Boltzmann* constant ($4{,}903 \cdot 10^{-9}$ $MJ/m^2 K^4$ day); T: absolute temperature (K); e_{act}: actual water vapor pressure (mb); n/N: relative sunshine duration.

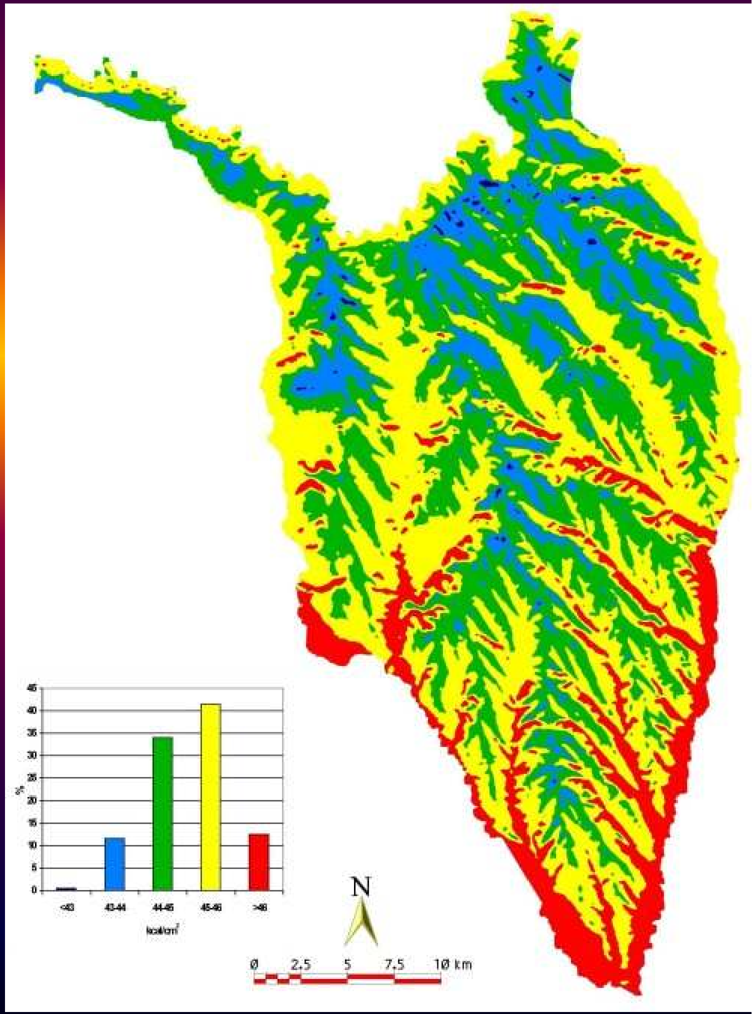
The actual water vapor pressure can be estimated using air temperature and relative humidity (*FAO*, 1998):

$$e_{act} = e_{sat}(r/100) = 6{,}1078e^{[17.27t/(t+237.3)]}(r/100)$$

where: e_{sat}: saturation vapor pressure (mb); r: relative humidity (%); t: air temperature (°C).

- Thermal infrared satellite images

The Central Moldavian Plateau: estimated mean annual net outgoing longwave radiation (kcal/cm^2, resolution 20m) (*Patriche C.V.*, 2005)

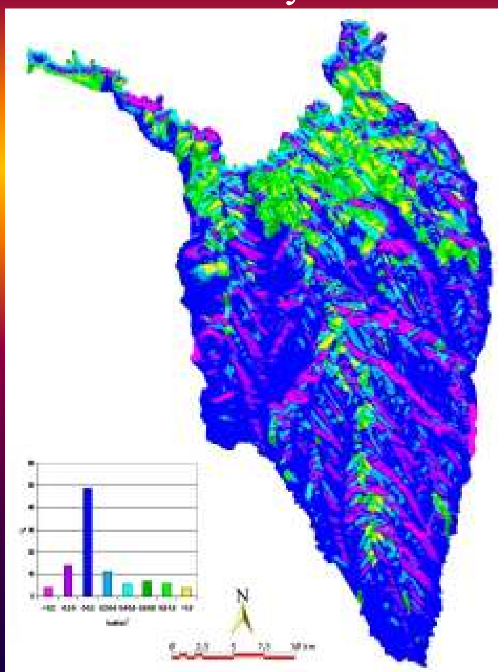


The net radiation (radiation balance) (R_n)

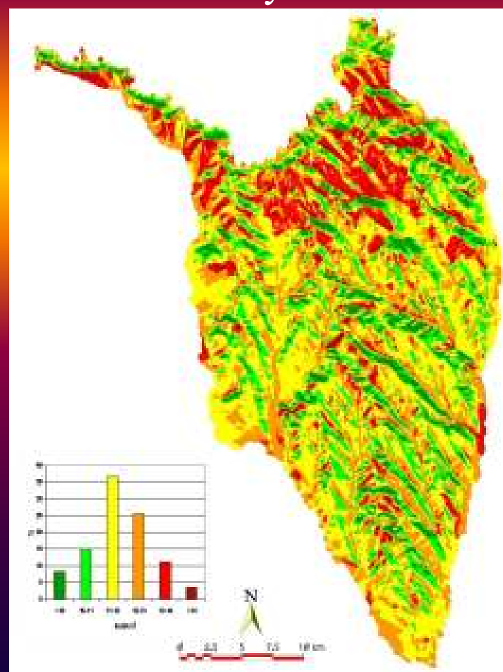
$$R_n = R_{ns} - R_{nl}$$

The Central Moldavian Plateau: estimated net radiation (kcal/cm², resolution 20m) (*Patriche C.V.*, 2005)

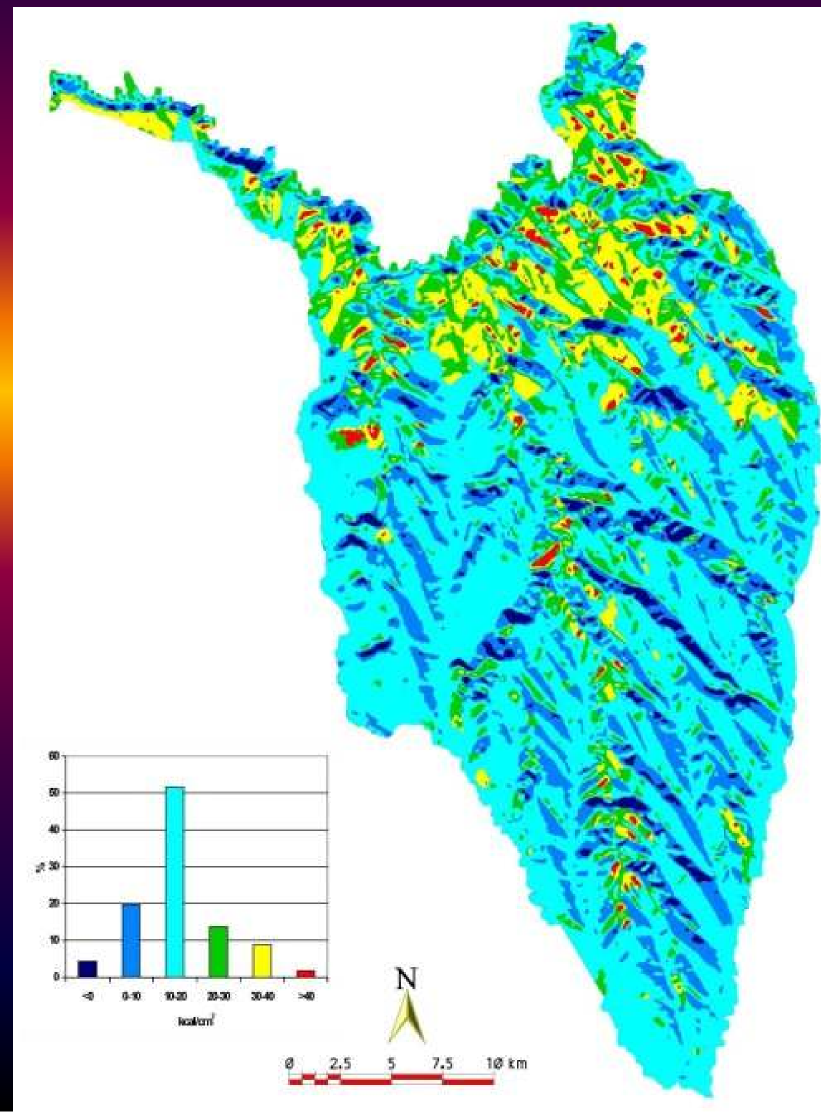
January



July



Mean annual



Some usefull websites concerning solar radiation

PVGIS (PhotoVoltaic Geographical Information System) - http://re.jrc.cec.eu.int/pvgis/pv/index.htm

HelioClim - http://www.helioclim.org/index.html, Centre Energétique et Procédés of Ecole des Mines de Paris

Surface meteorology and Solar Energy *(release 5.1) -* http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?na+s01#s01

METEONORM 5.x - Global Meteorological Database for Solar Energy and Applied Meteorology - http://www.meteotest.ch/en/mn_home?w=ber

THE EUROPEAN SOLAR RADIATION ATLAS - http://www.ensmp.fr/Fr/Services/PressesENSMP/Collections/ScTerEnv/Livres/atlas_tome1.htm

The Global Energy Balance Archive (GEBA) - http://bsrn.ethz.ch/gebastatus/geba_main_frame_set.html

SoDa:: Services for Professionals in Solar Energy and Radiation - http://www.soda-is.com/eng/index.html

Satel-Light – The European Database of Daylight and Solar Radiation - http://www.satel-light.com/indexgS.htm

WRDC Online Archive - World Radiation Data Centre - http://wrdc-mgo.nrel.gov/ , http://wrdc.mgo.rssi.ru/

Renewable Resource Data Center - Solar Radiation Resource Information - http://rredc.nrel.gov/solar/