PHOTOVOLTAIC INSTITUTE BERLIN

Optical Simulation to Enhance PV Module Encapsulation

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Content

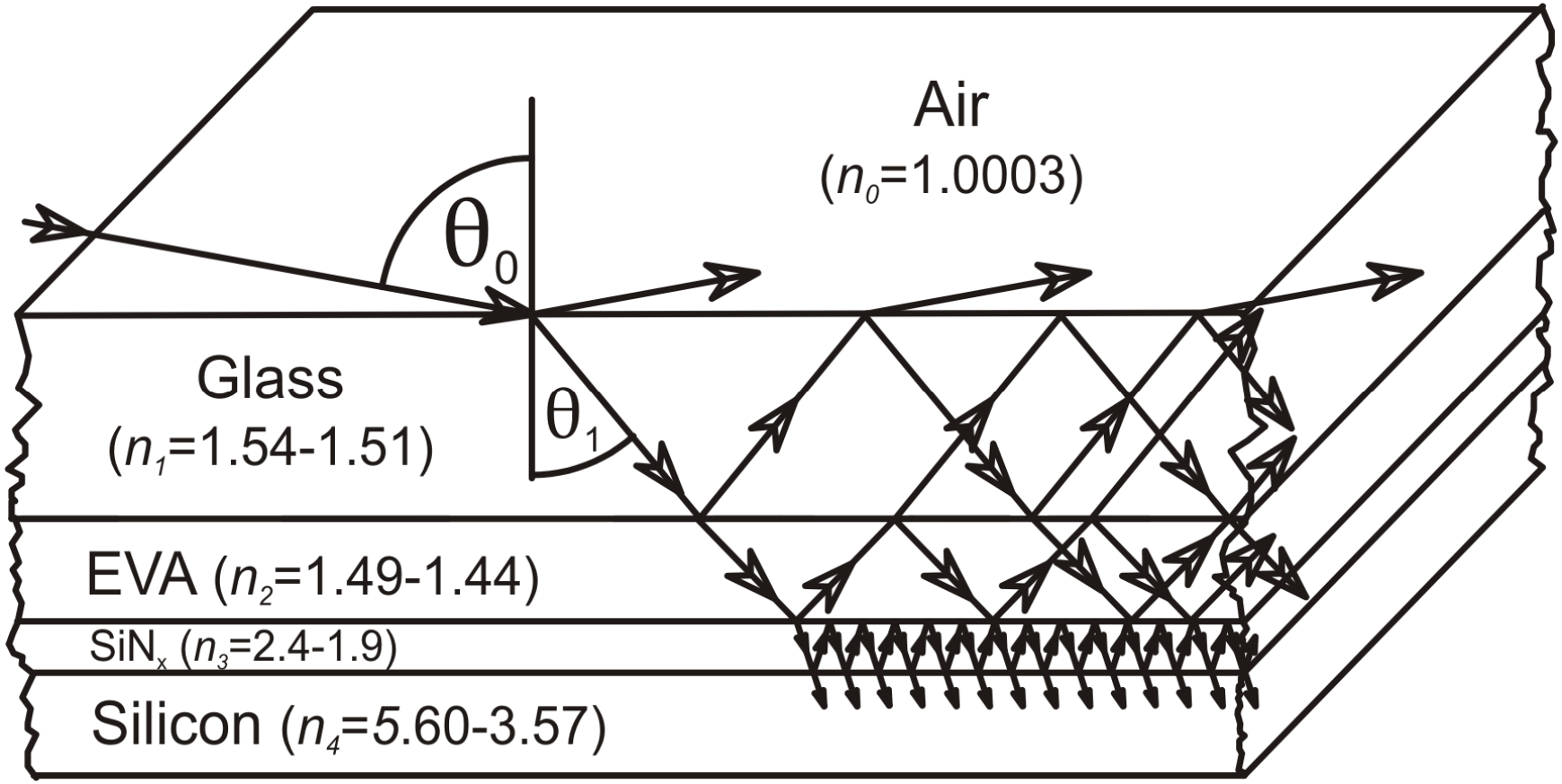
- Basics of optical simulation
- Modeling of real world conditions (non-perpendicular incidence, variable spectrum)
- Simulation of complete optical process
- Results, Enhancements
- Consequences (materials, energy yields at different conditions, suggestions for standardization and rating methods)

Purpose of work

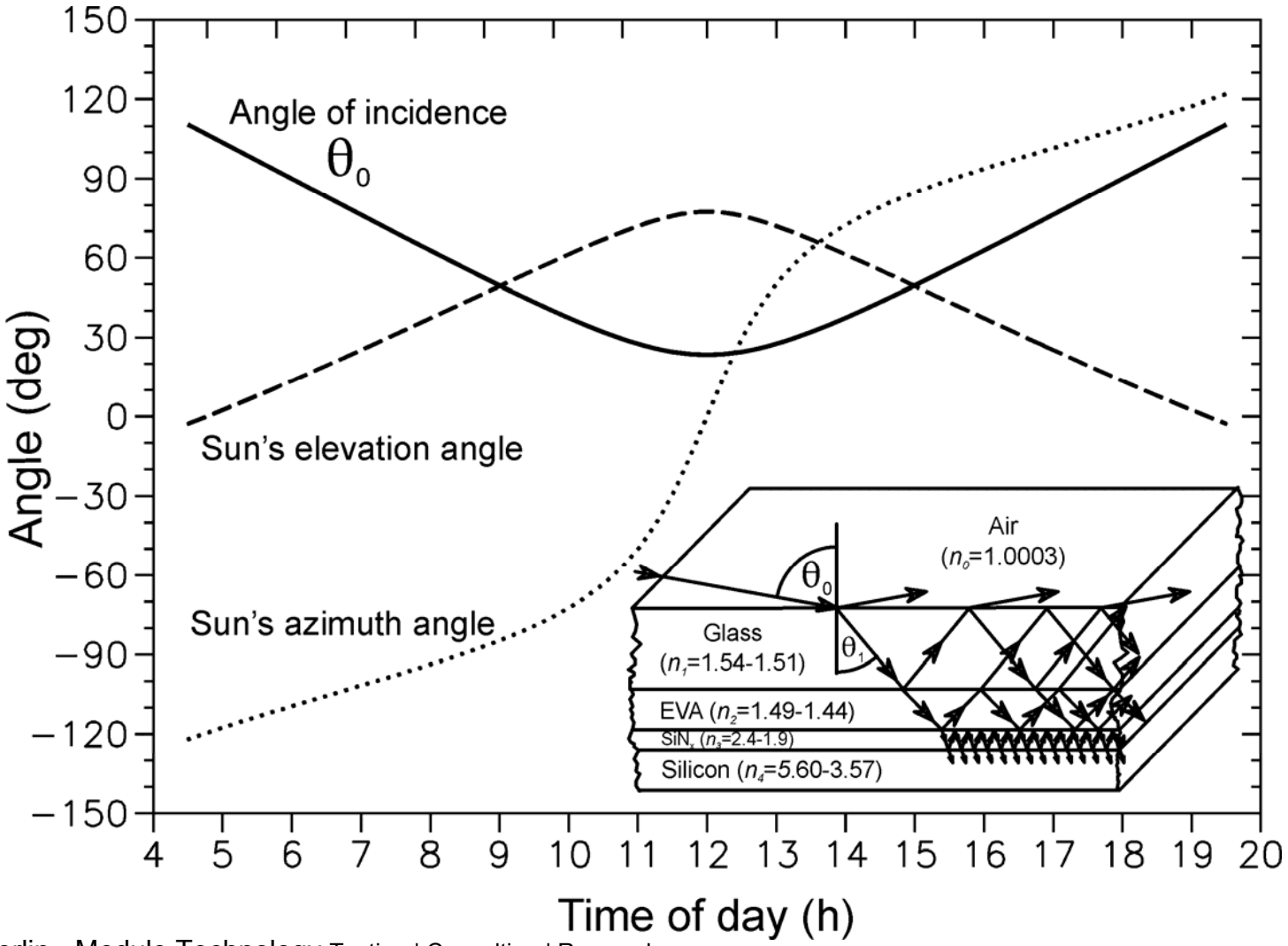
- Accurate prediction of electrical energy yield, incl. suggestions for energy rating methods

- Optimization of PV modules, incl. better optical matching cell and encapsulation

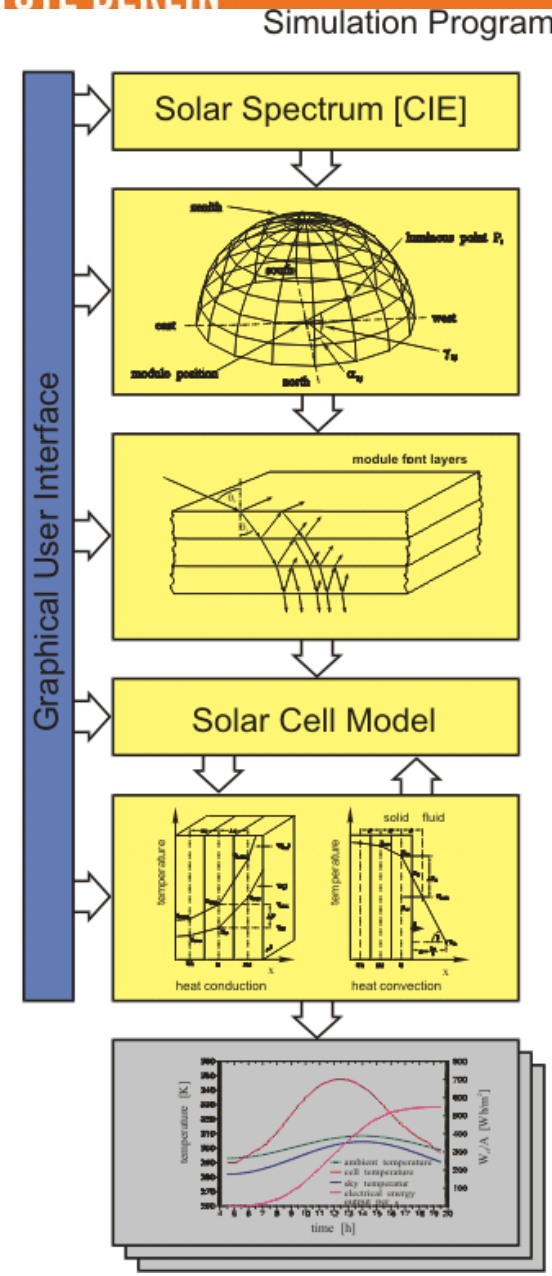
Ray-racing inside the PV module



Angle of incidence of direct irradiance during a day



Structure of simulation process



1. Radiation Model
   - solar spectrum according to CIE

2. Sky Model
   - spectral power density dependence as an interpolated function of the air mass
   - local distribution of diffuse radiation according to DIN

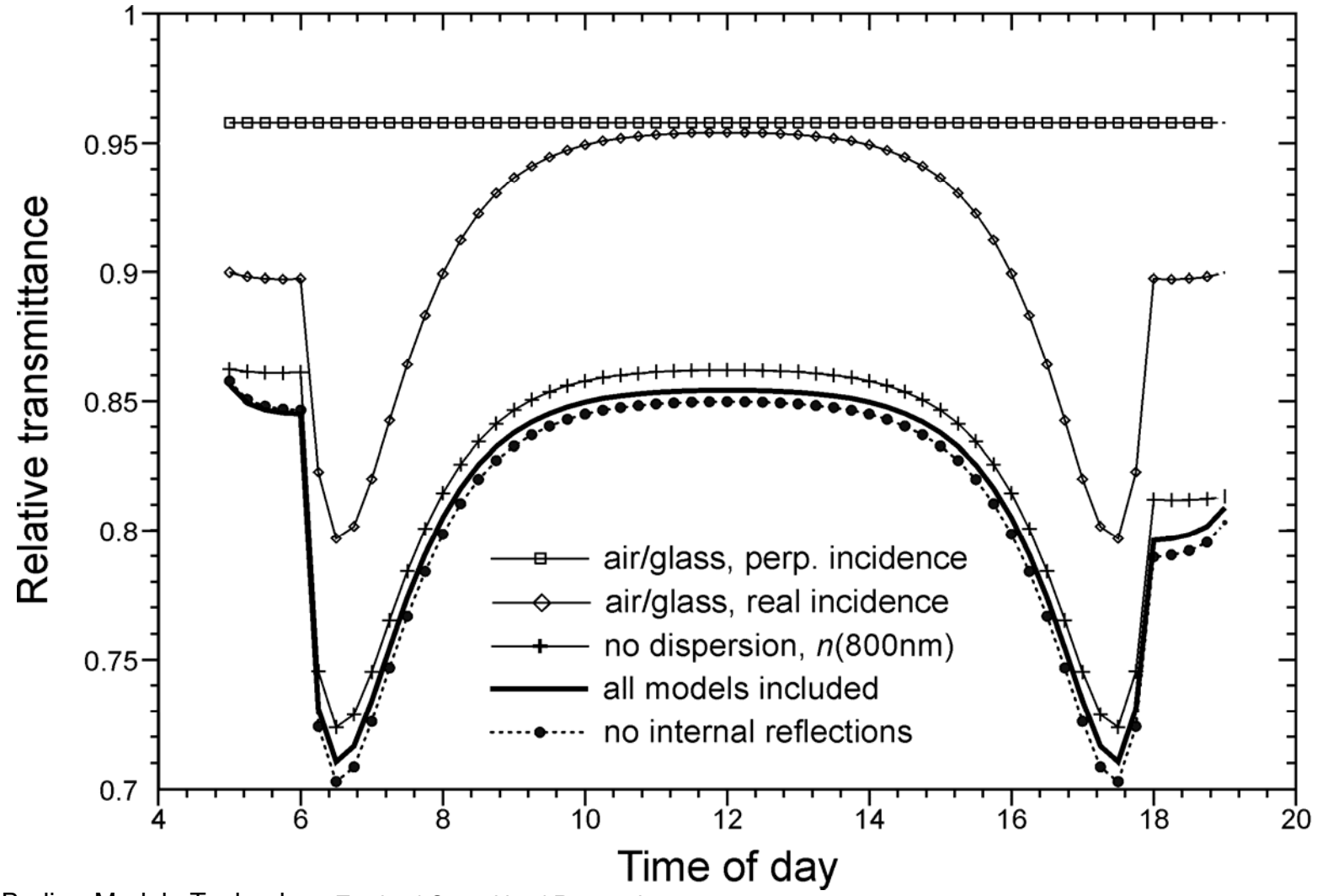
3. Optical Encapsulation Model
   - insolation through the front layers calculated seperatly for each wave band and direction

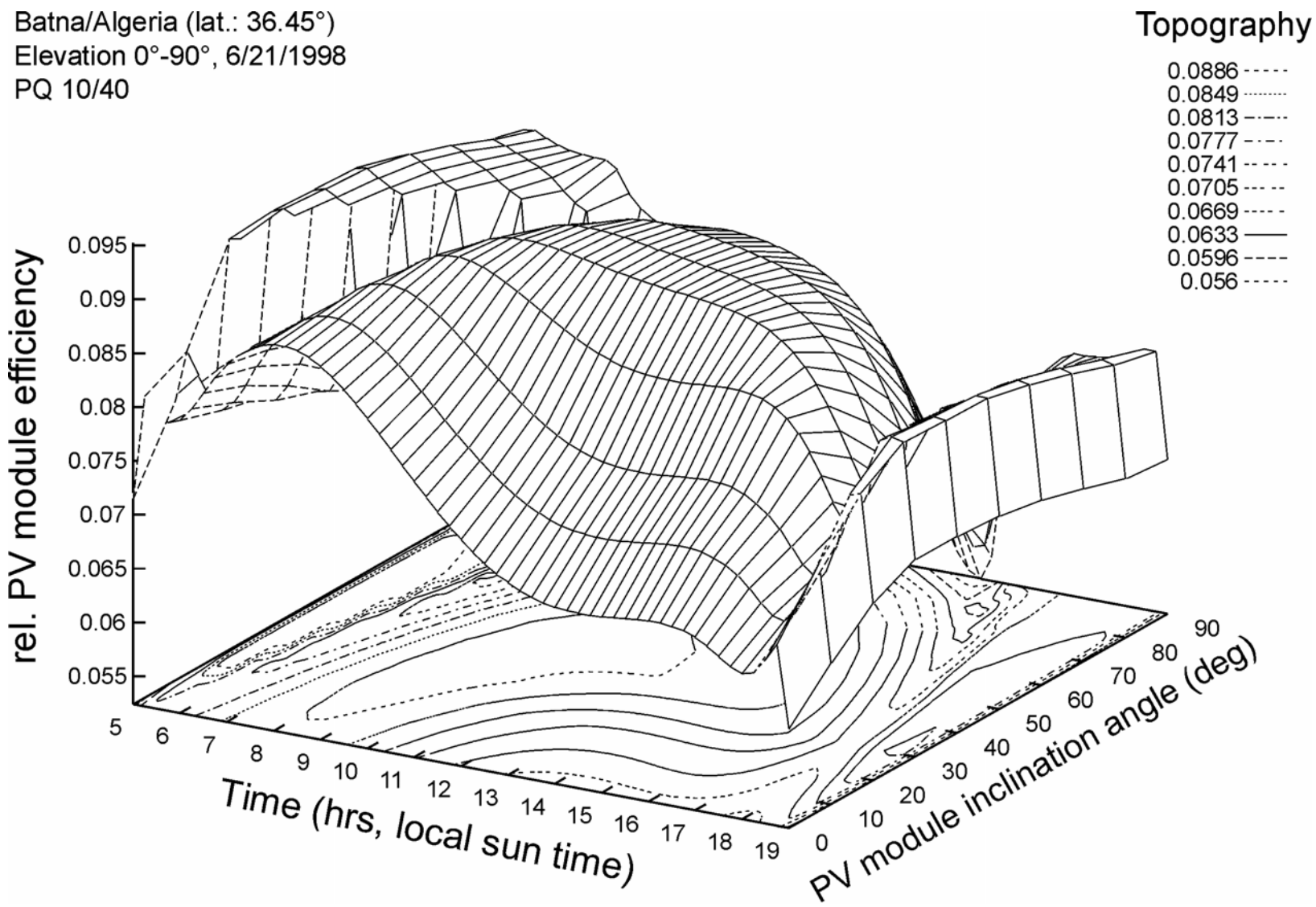
4. Solar Cell Model
   - wavelength and temperature dependent efficiency

5. Thermal Encapsulation Model
   - instationary ther mal conduction
   - different convection models

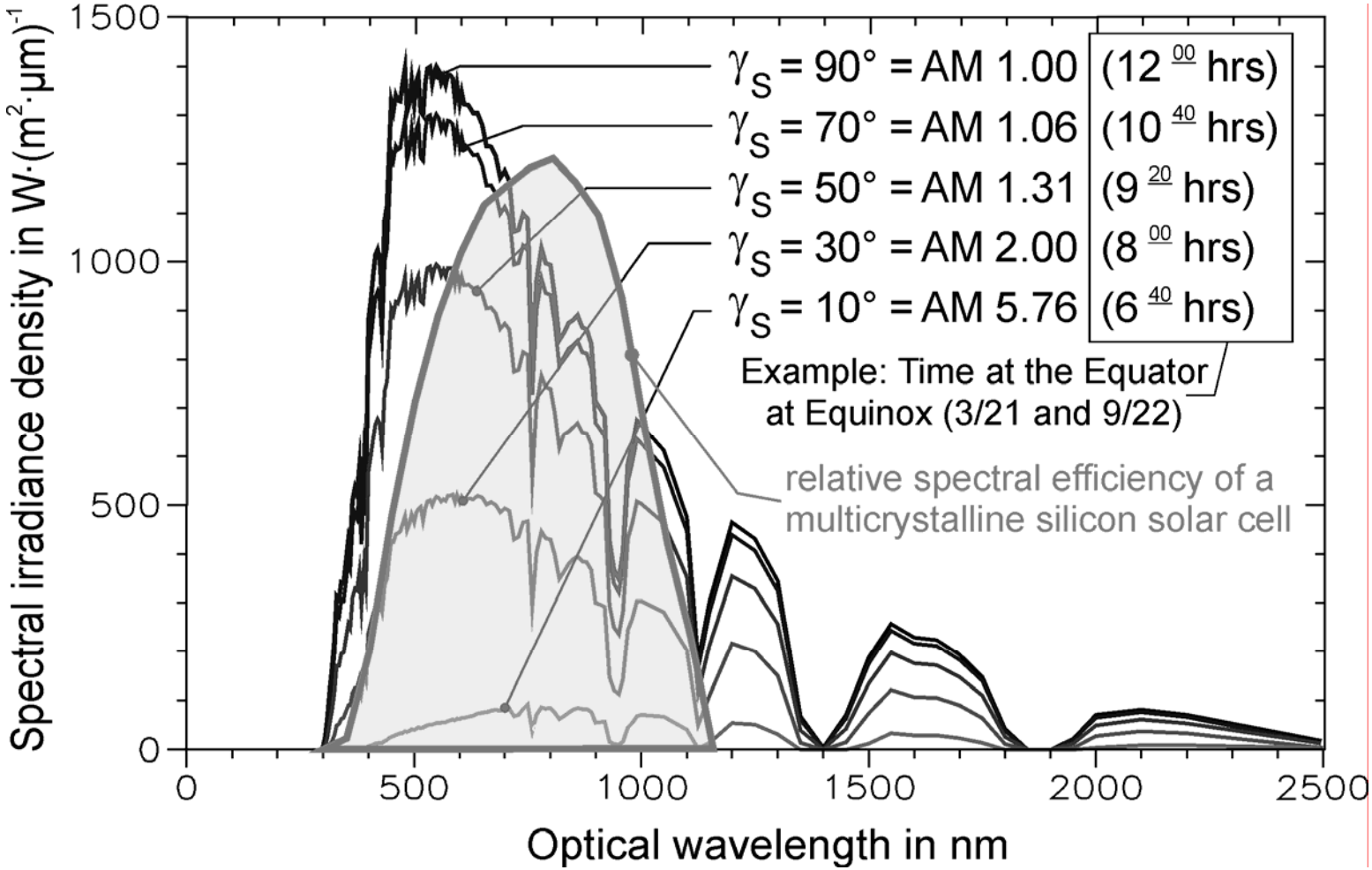
6. Data Output
   - output of several ASCII-data files for prediction and optimization:
     - cell temperature
     - electrical energy output
     - solar cell efficiency
     - module efficiency

Optical transmission of encapsulation during a day

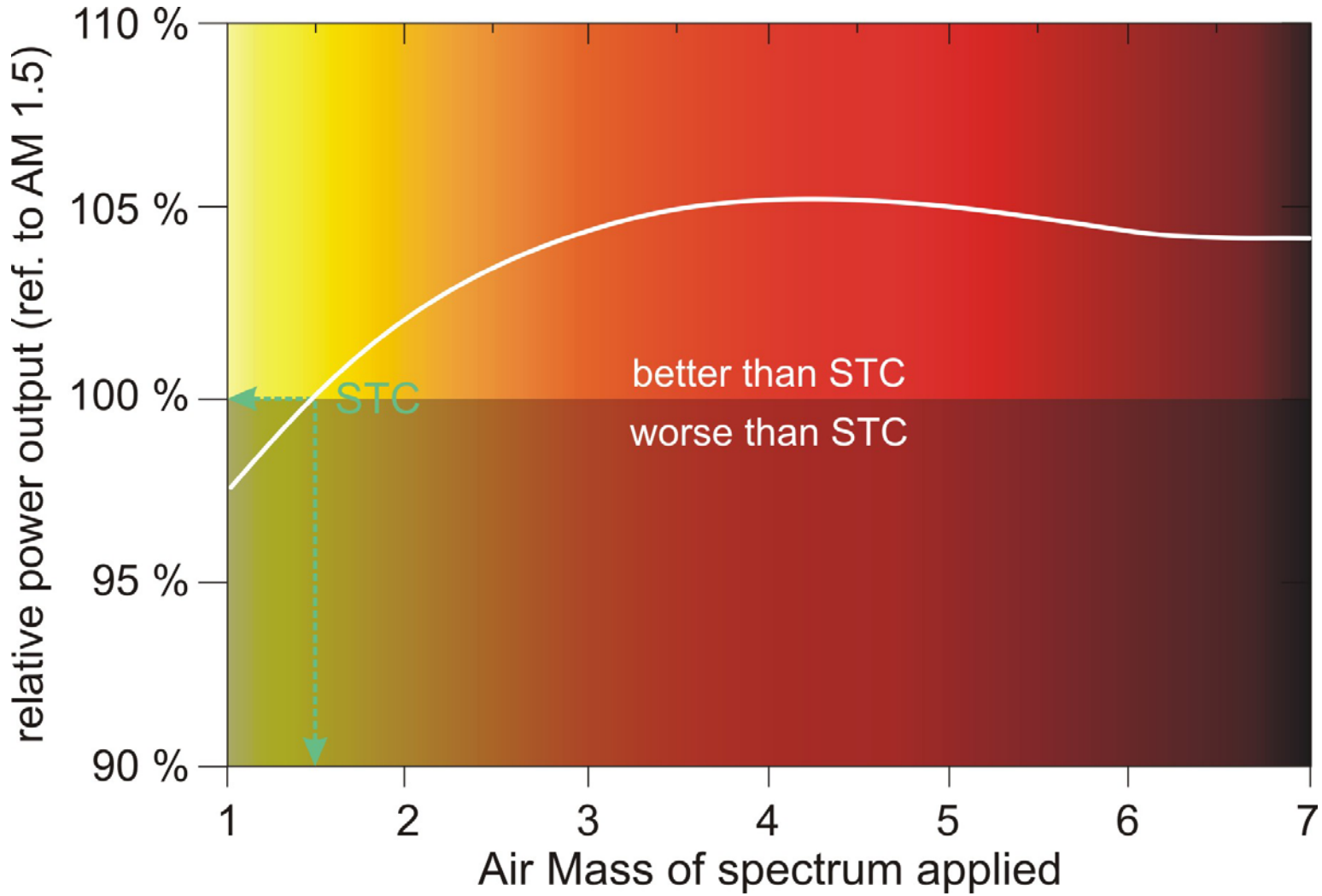



Batna/Algeria (lat.: 36.45°)
Elevation 0°-90°, 6/21/1998
PQ 10/40
Topography
0.0886
0.0849
0.0813
0.0777
0.0741
0.0705
0.0669
0.0633
0.0596
0.056
rel. PV module efficiency
0.095
0.09
0.085
0.08
0.075
0.07
0.065
0.06
0.055
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Time (hrs, local sun time)
0
10
20
30
40
50
60
70
80
90
PV module inclination angle (deg)

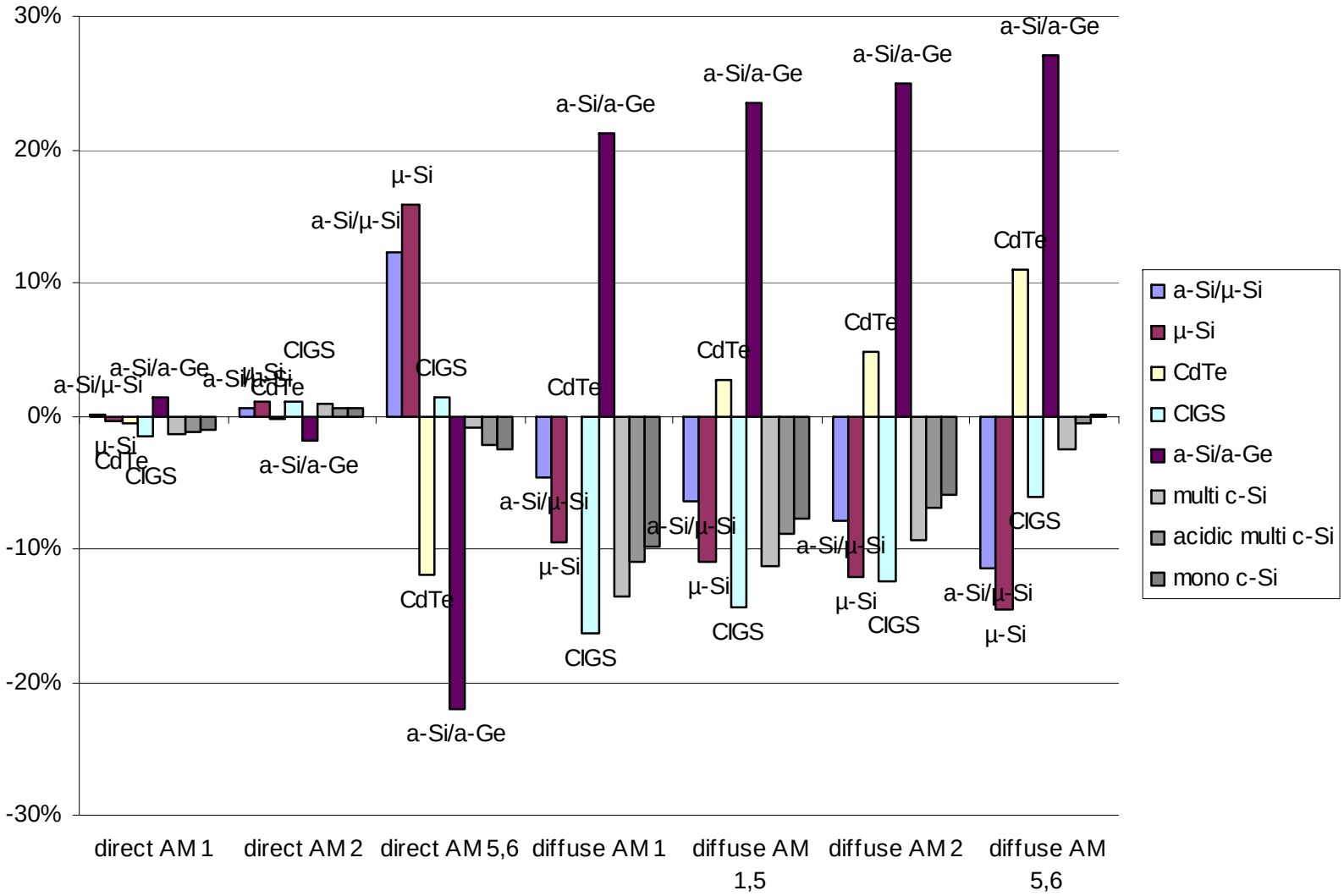
Matching of spectral response with the actual spectrum



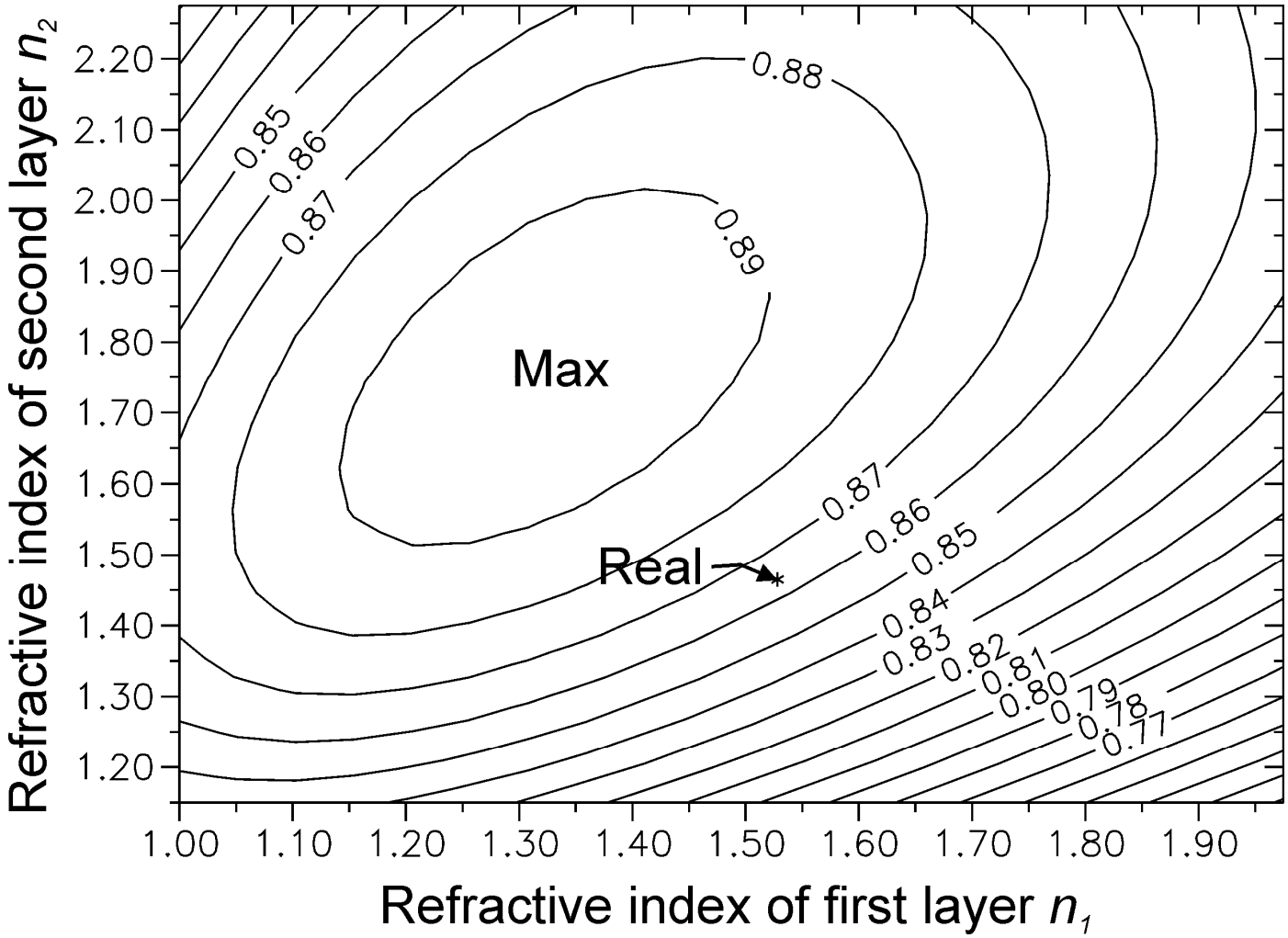
Effect of actual spectrum on electrical power output



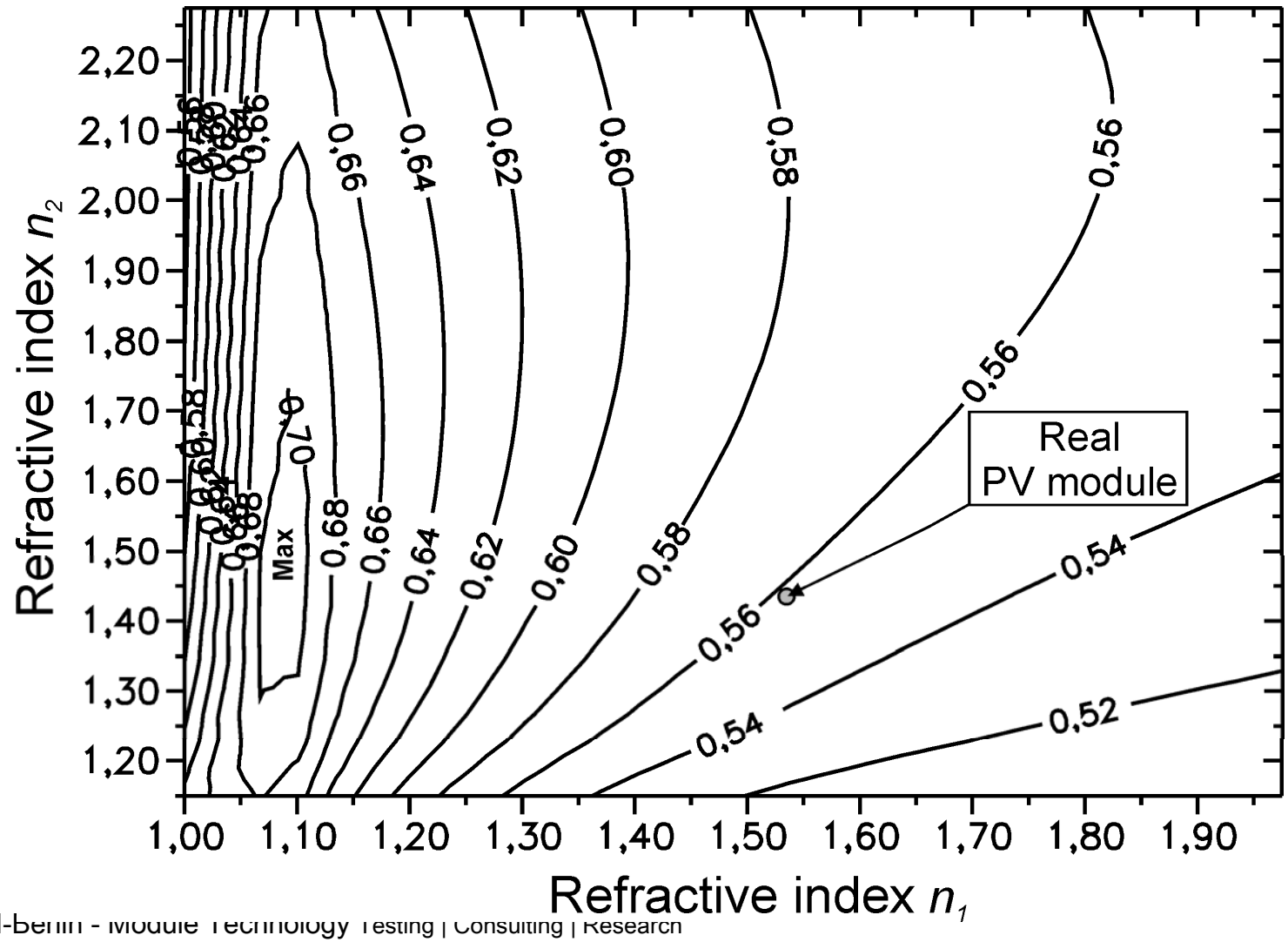
Performance deviations for several materials at different spectra (I_{SC} rel. to AM 1.5)



Optical transmittance at perpendicular incidence for variation of refractive indices



Optical transmittance at an incidence of 80° for variation of refractive indices



Effect of an anti-reflection layer (n=1.33) on top of the cover-glass on the annual electrical energy yield

Performance of a PV module with mono-crystalline silicon solar cells (module elevation angle 30°):

Berlin (lat=52.5° N): + 1.95%

N-Africa (lat=30°N): + 1.45%

Further measures for yield increase:

- Decrease of operating cell temperature:
- Cover glasses with ARC and infrared IR reflection capabilities, thinner cover materials.

- Better performance at non-perpendicular incidence via encapsulation structures.

- Consequent matching of refractive indices at: *Cell-ARC-EVA-Glass-Air* assembly
- (typically cell manufactures are optimizíng cells to perform best at a *Cell-ARC-Air* assembly).

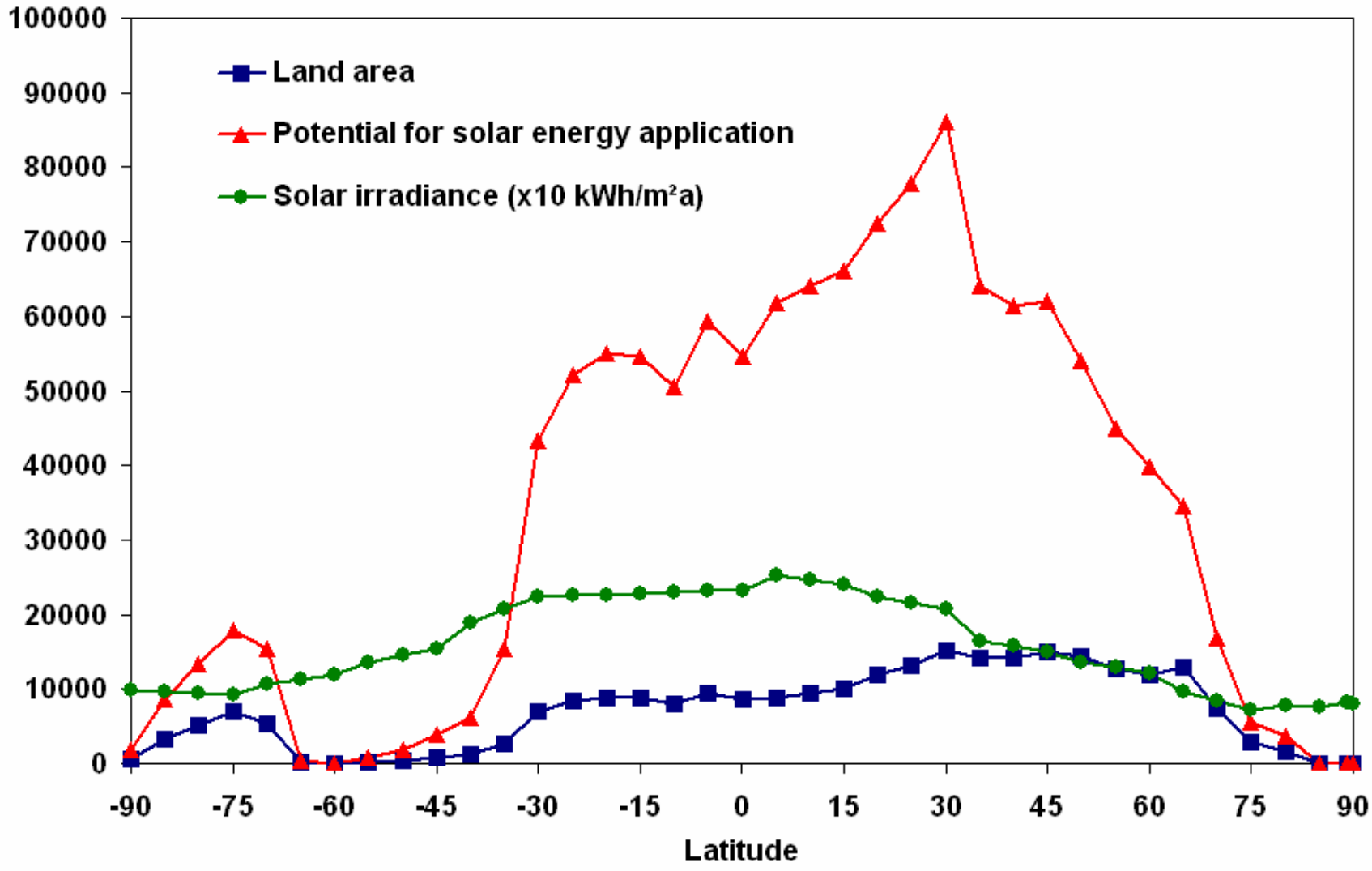
Suggestions for improved yield prediction and module enhancements:

Additional data-sheet information: performance at different locations (spectral conditions, incidence angles, operation temperatures), via correction factors or better standardizations:

IEC 61853: Performance testing and energy rating of terrestrial PV modules

IHT (High irradiance, high temperature) – hot dessert day.
HILT (High irradiance, low temperature) – spring day in alpine region.
MIMT (Medium irradiance, medium temperature) – cloud covered autumn day.
MIHT (Medium irradiance, high temperature) – hot, humid summer day with coverage
LILT (Low irradiance, low temperature) – covered winter day in northern regions
NICE (Normal irradiance, cool environment) – summer day at cool costal area

Solar energy potential as a function of latitude



Conclusions

Optical simulation via ray-tracing from the sun via the different optical interfaces into the photo-active material allows

- Quantitative yield considerations: actual converted irradiance
- Qualitative energy considerations: matching of actual spectrum, refractive indices, locations
- Integrated considerations: electrical energy yield, incl. all interface
- Enhancements of PV modules considering the issues above

Vielen Dank

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