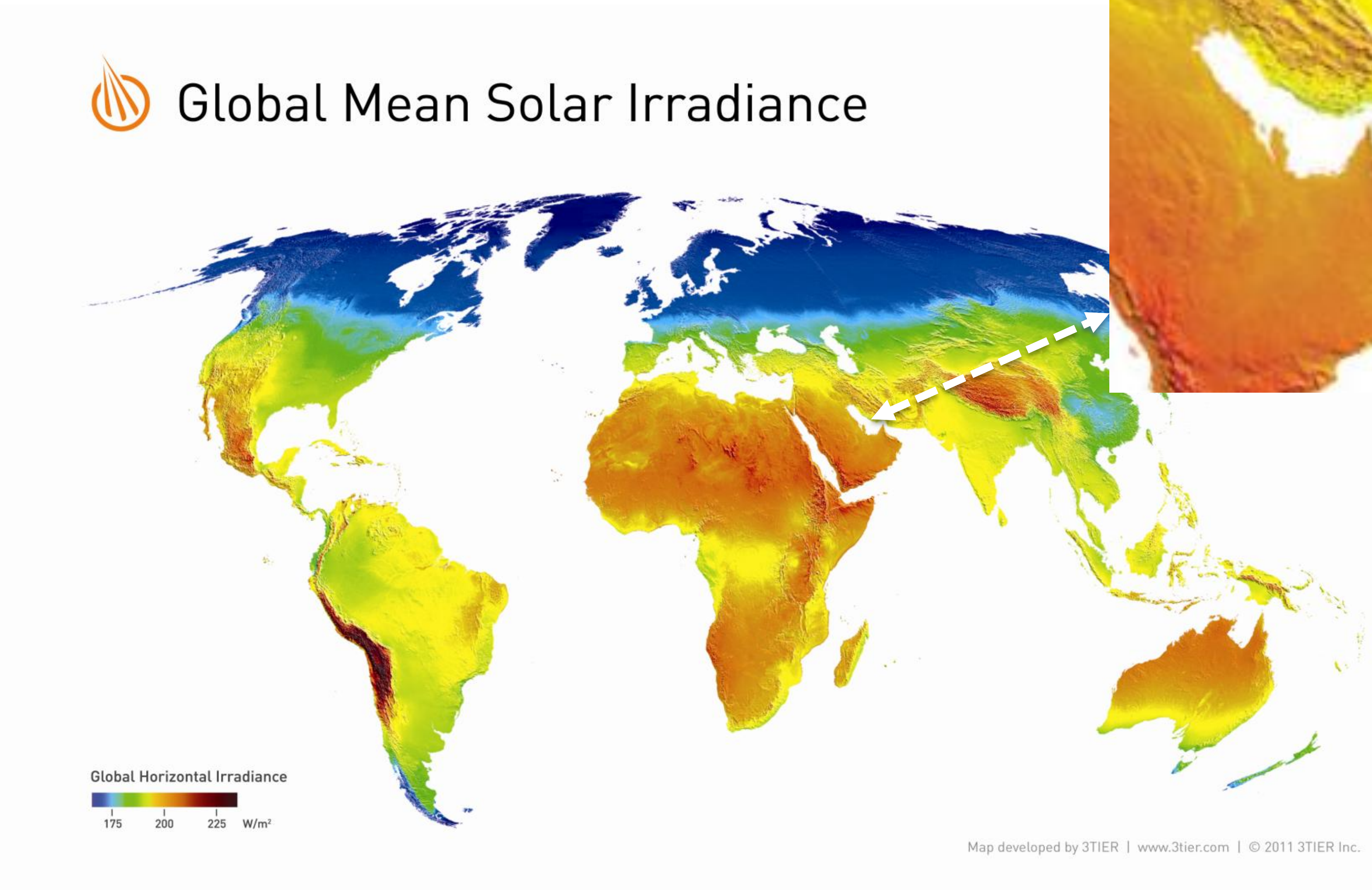
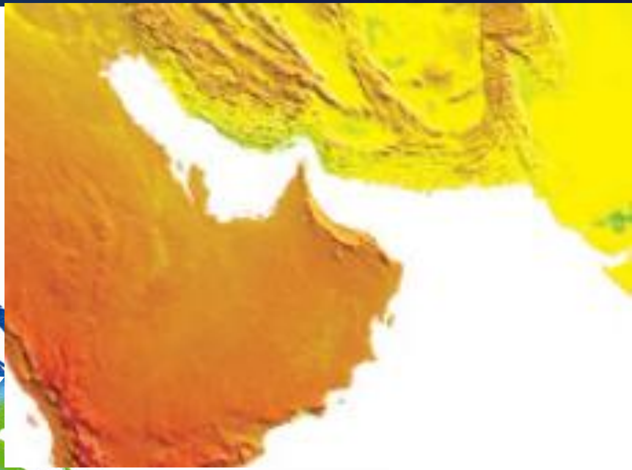
Solar Energy Deployment in the UAE: The role of the Masdar Institute

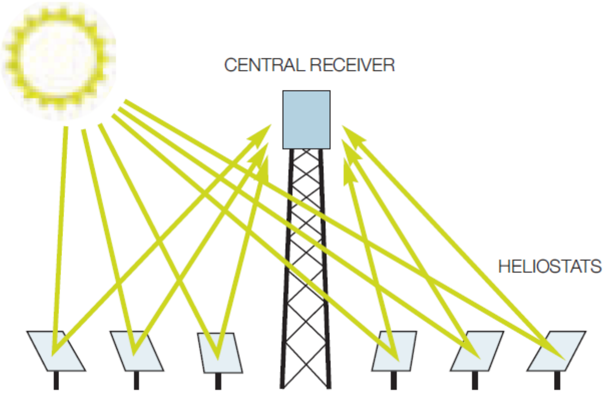
- Solar Resource Assessment
- The effect of CSR (Circum-Solar Ratio)
- The role of dust in the UAE
- Power Demand in the UAE
- Research projects

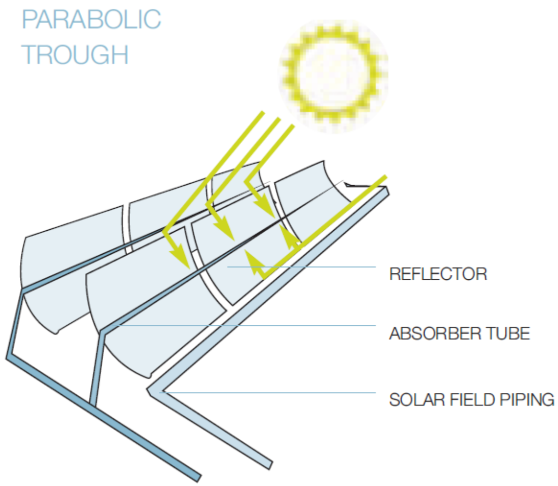
Solar is a good idea in the Middle East and even better in Australia

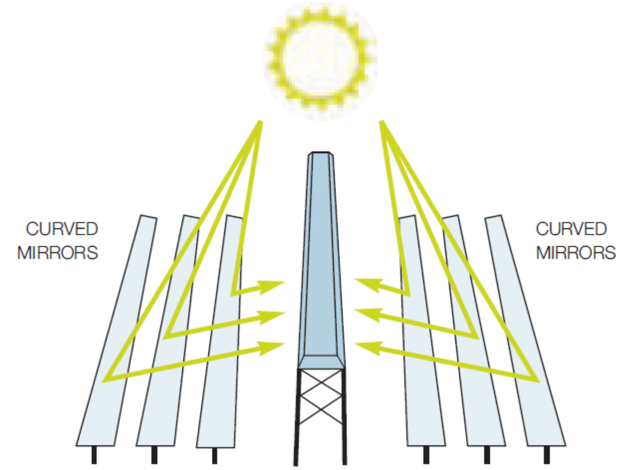




Concentrated Solar Power (CSP)

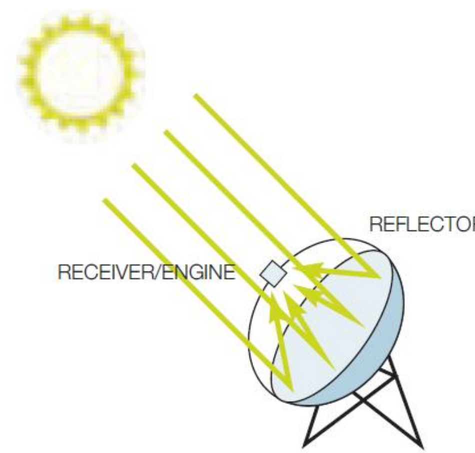






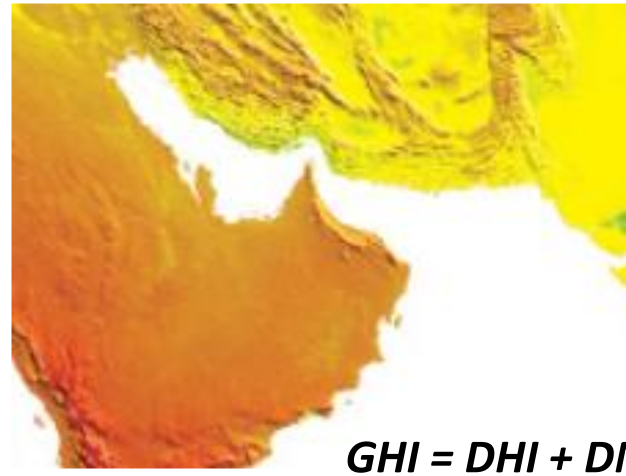
For concentrate solar power, the direct the Direct Normal Irradiance (DNI) is a more relevant measure of the solar resource.

Concentrating solar technologies can only focus sunlight coming from one direction, and use tracking mechanisms to align their collectors with the direction of the sun.

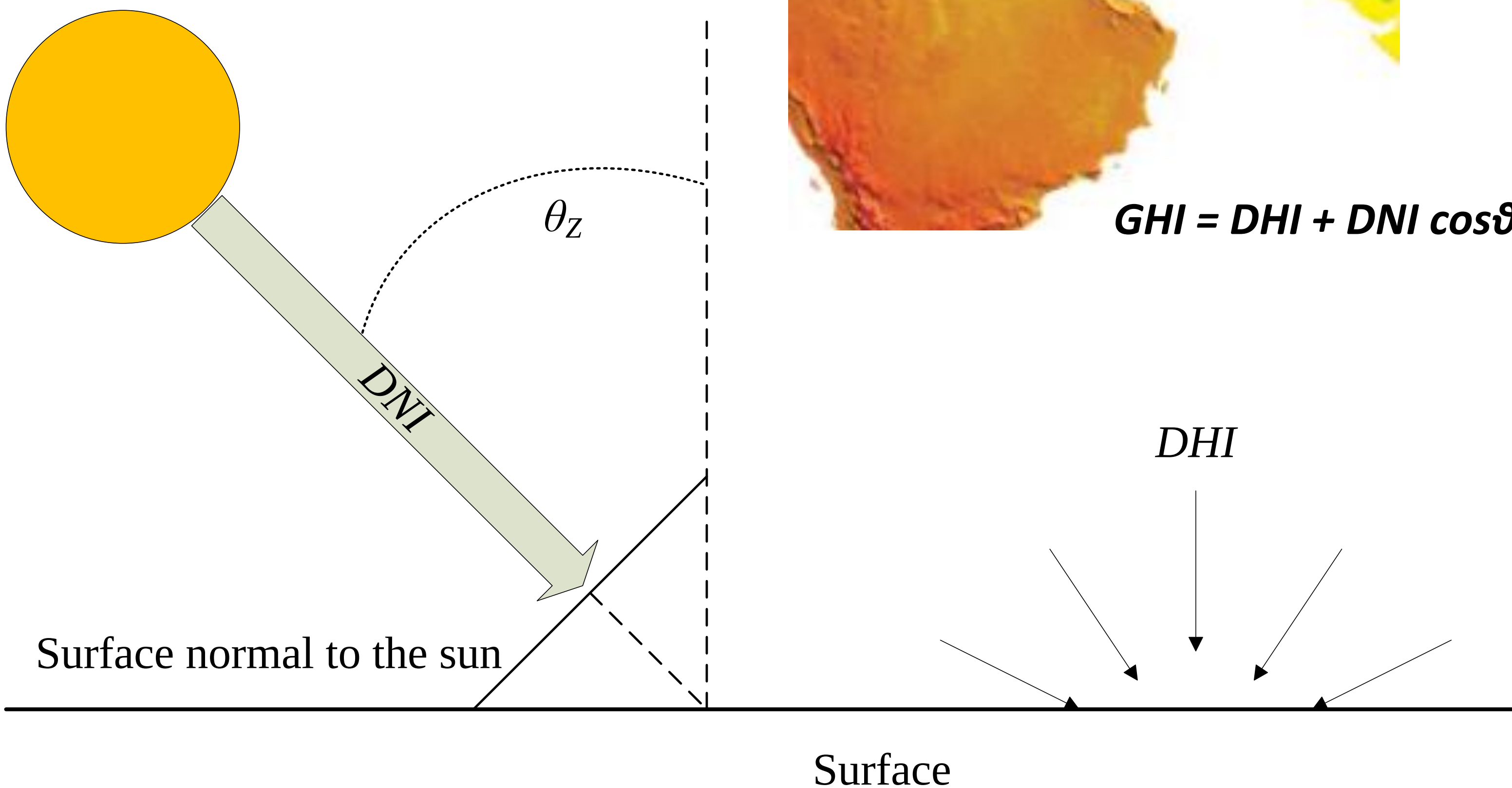


Concentrating Solar Thermal Technologies makes use of DNI

DNI is the solar radiation measured at a given location on earth with a surface element perpendicular to the sun ray.



GHI = DHI + DNI cosϑ_z

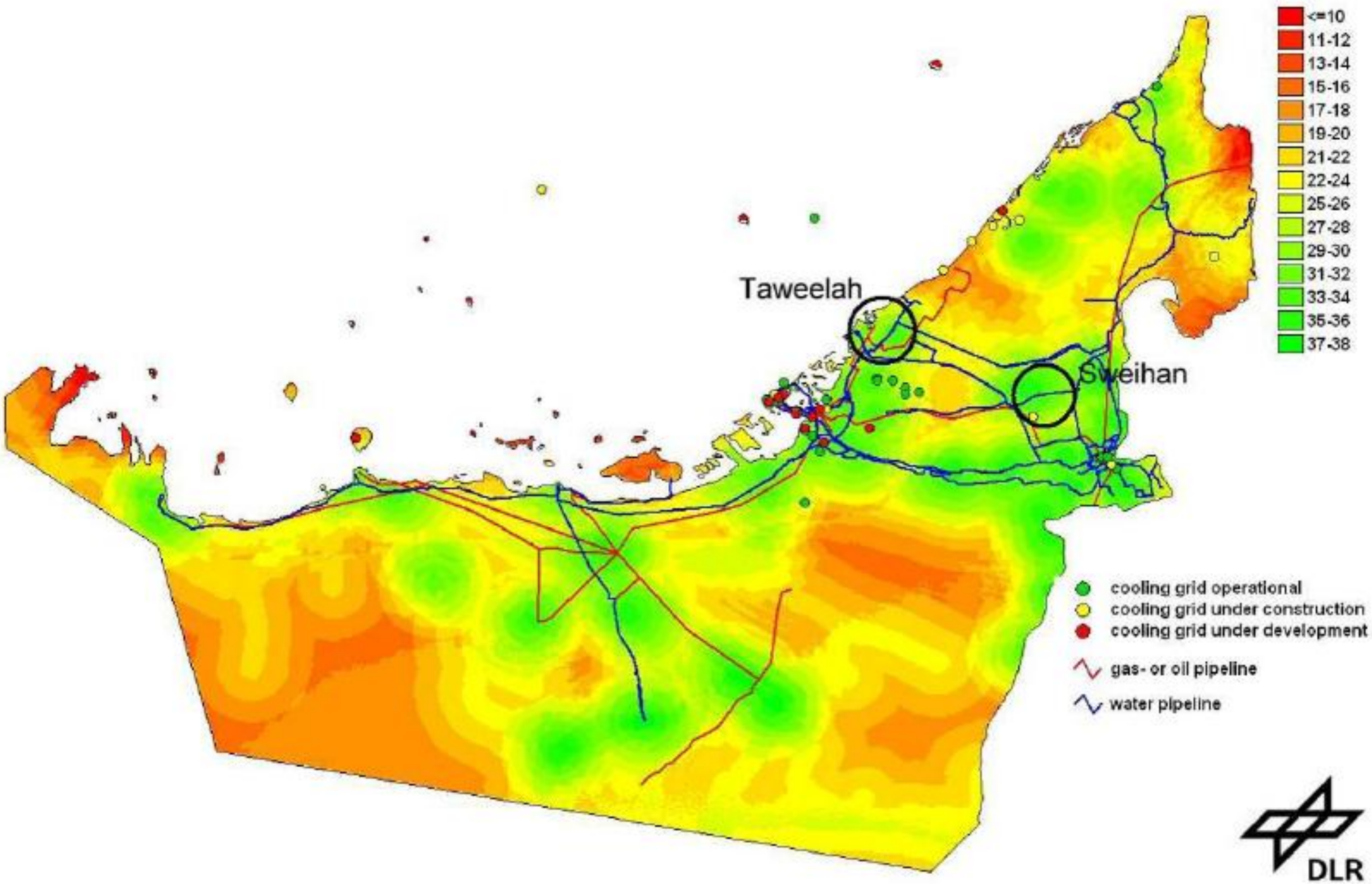


Sometimes it's not so clear… and the yearly DNI is not so great

Yearly DNI in the UAE is only **1934 kWh/m^2/yr.**

Locations in Spain have DNI from **2,000-2,300 kWh/m^2/yr**, and the best location in the U.S. Southwest have DNI of **2,800 kWh/m^2/yr**

Utilities Mapping added on solar assessment by DLR



Ground data Measuring equipment

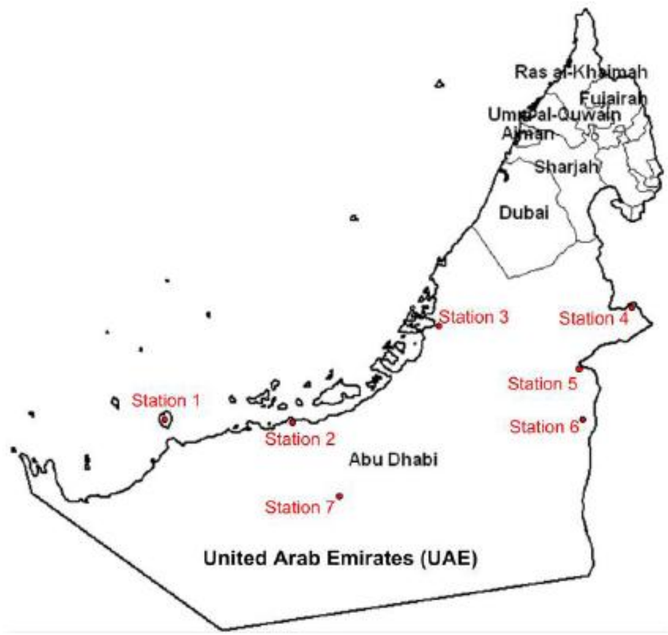
K+Z alt-azimuth tracker

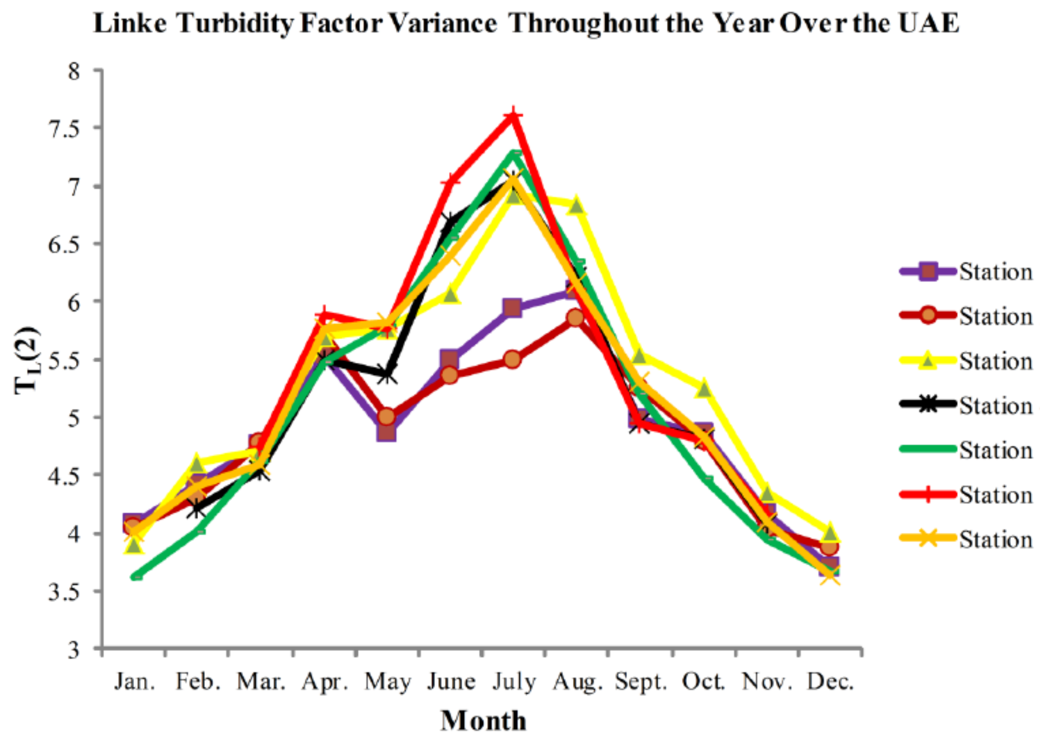
Radiometer Platform

EKO tracker

SAM

Satellite Solar Maps vs. Ground Data Measurements





Satellite data overestimates the measured DNI of more than 15% throughout the year due to the fact that the model used to interpret the data do not account for high aereosol loading in the atmosphere. (bankability of shams 1)

Y. Eissa, M. Chiesa and H. Ghedira "**Assessment and Recalibration of the Heliosat-2 Method in Global Horizontal Irradiance Modeling over the Desert Environment of the UAE**" *Solar Energy* Volume 86, Issue 6, June 2012, Pages 1816–1825

Choice of Thermal Channels

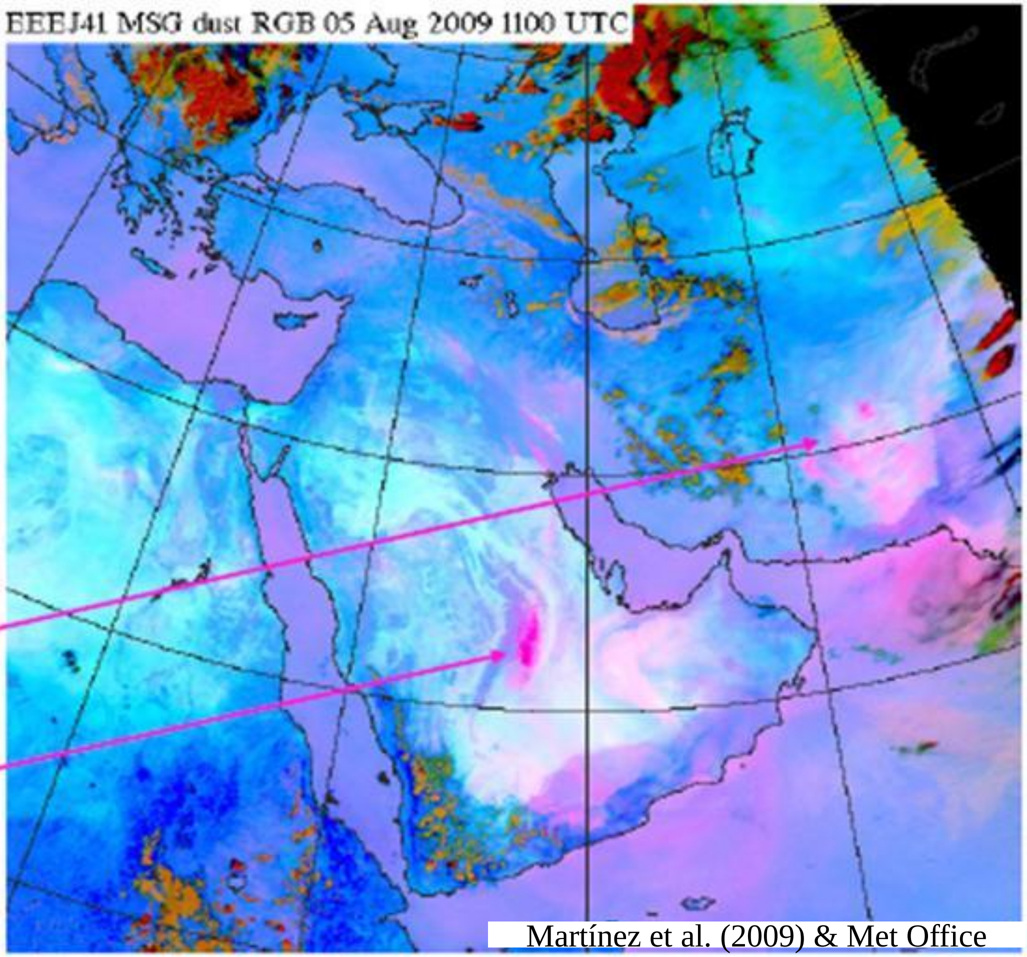
Colour composite

RED = T10 – T09

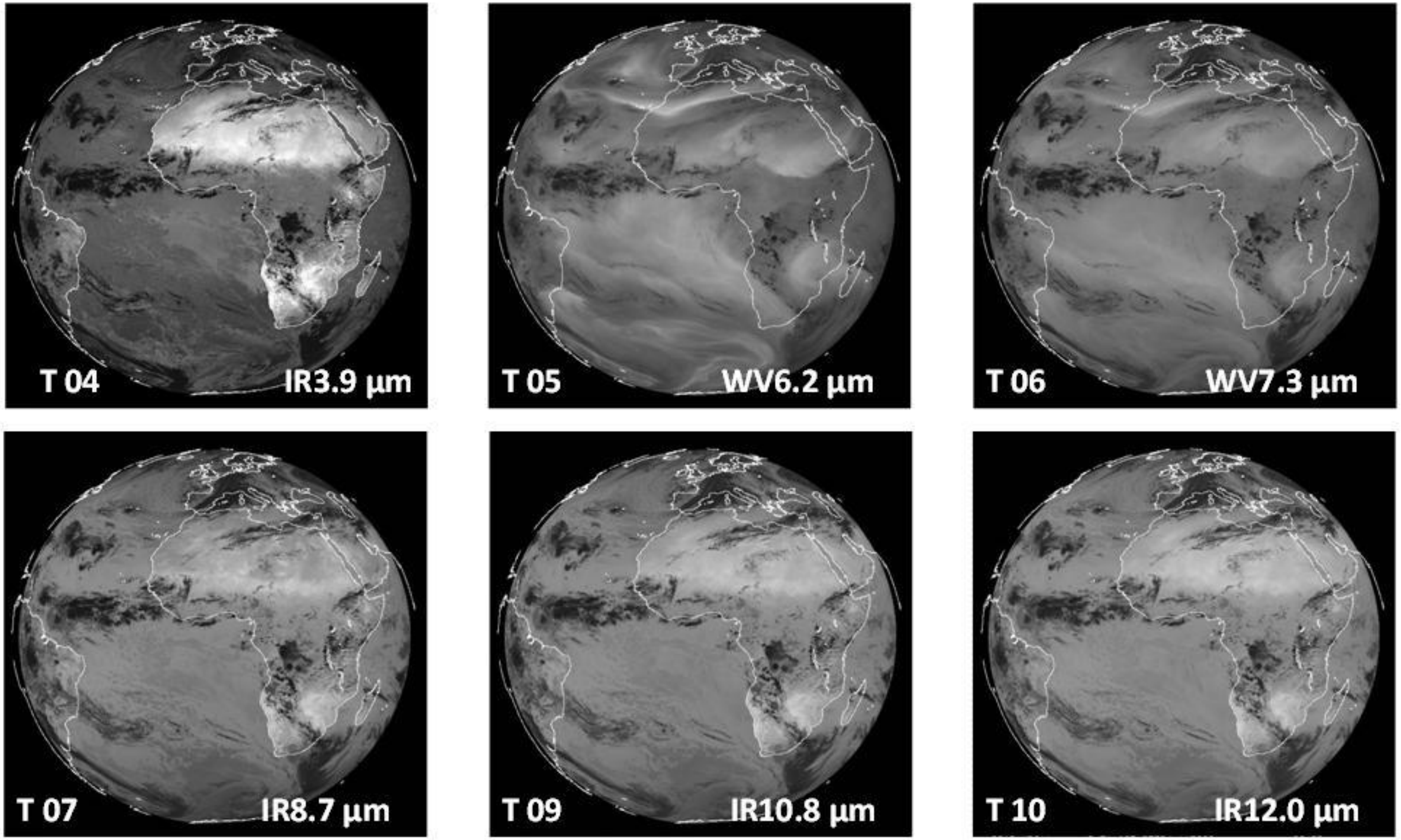
GREEN = T09 – T07

BLUE = T09

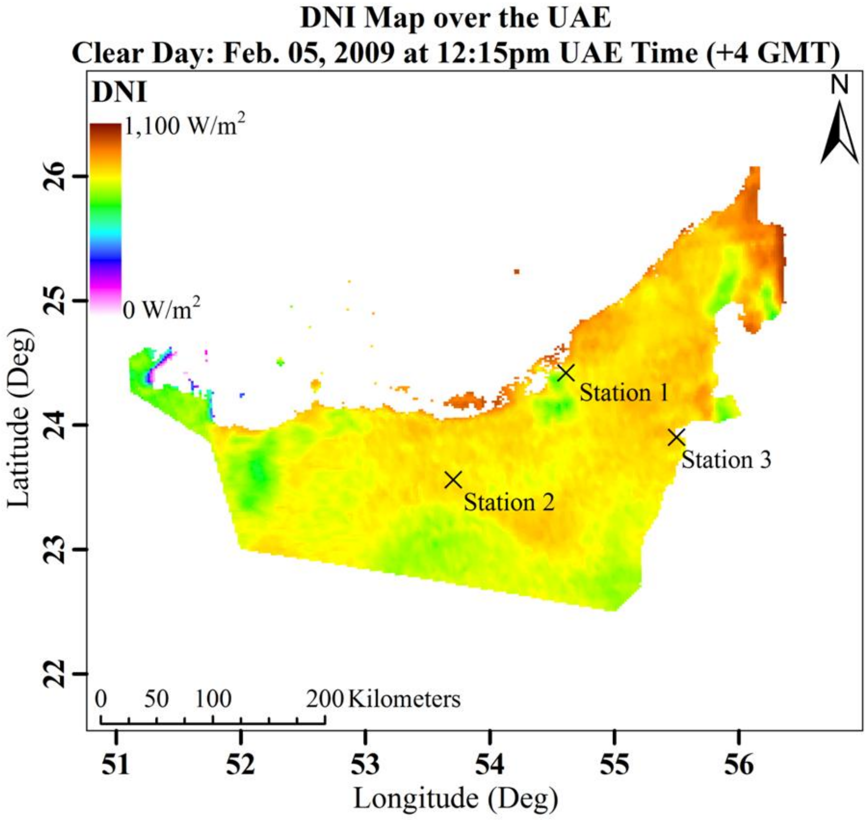
striking magenta indicates dust

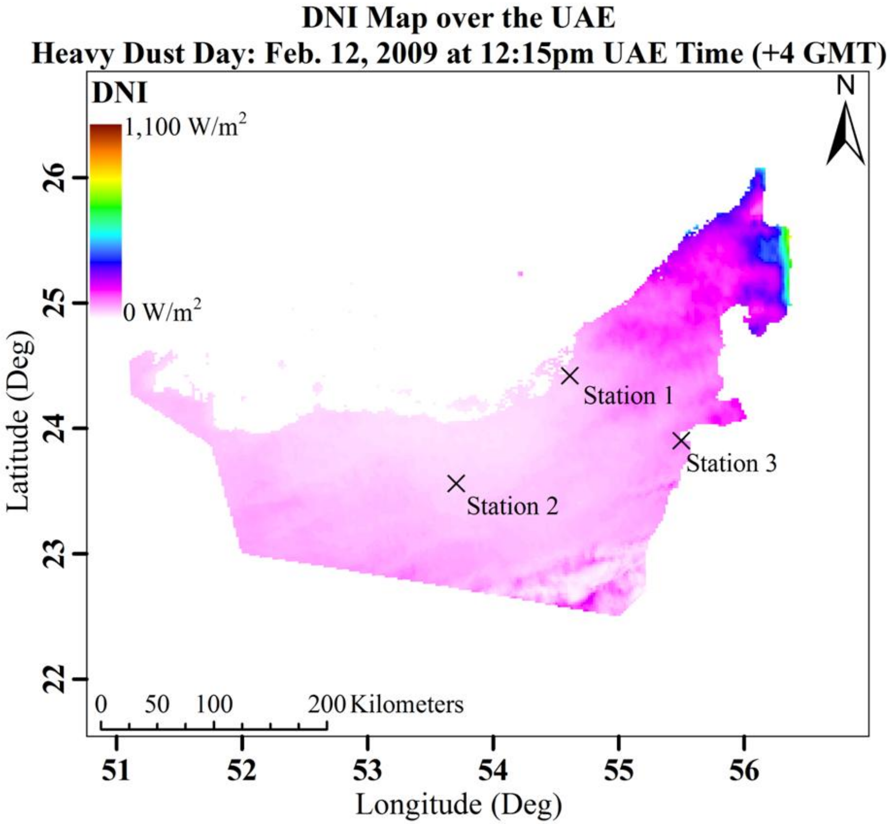


Choice of Thermal Channels



Solar Assessment usually based on satellite data, that is not that easy





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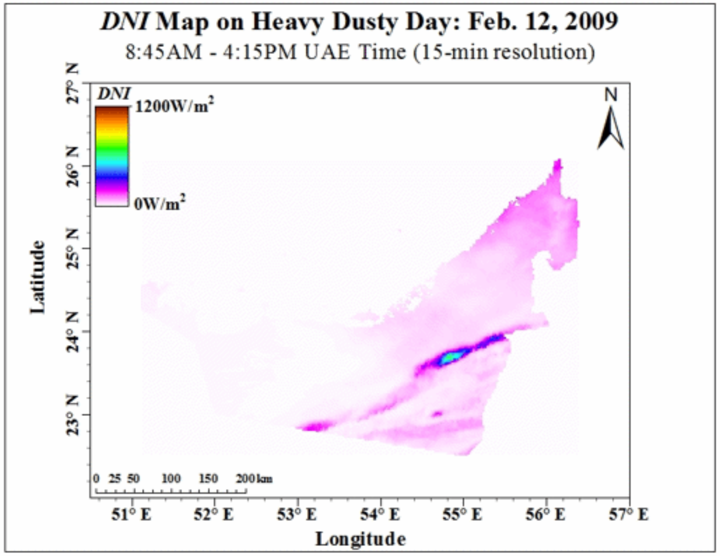
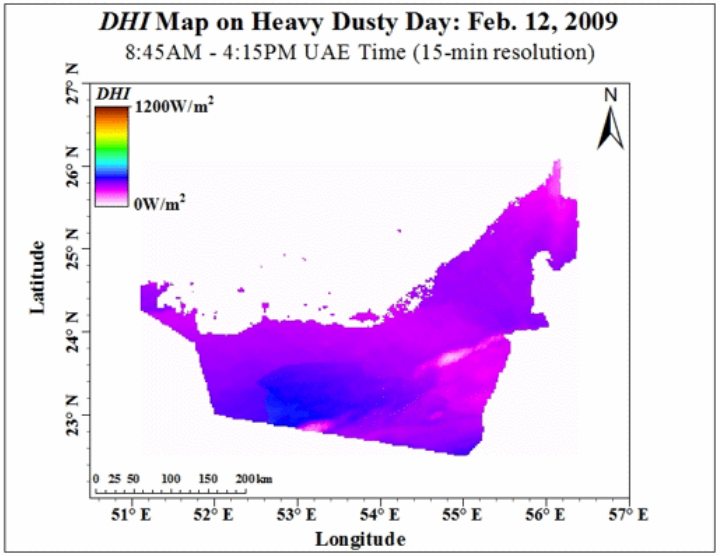
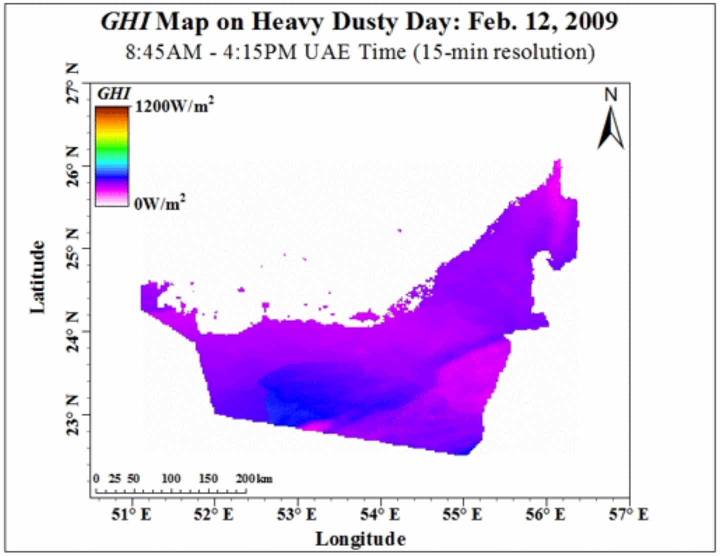
Spatial Variations: Heavy Dusty Day







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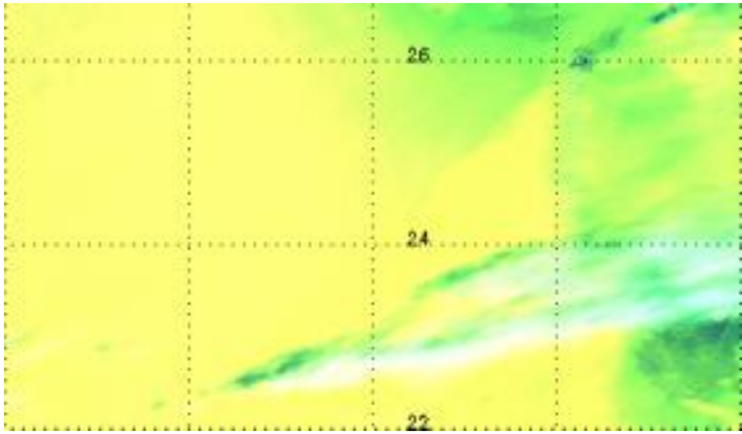

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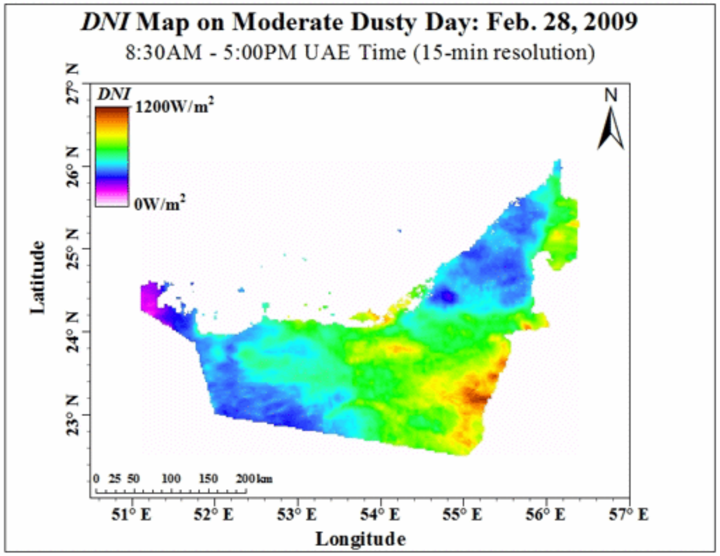
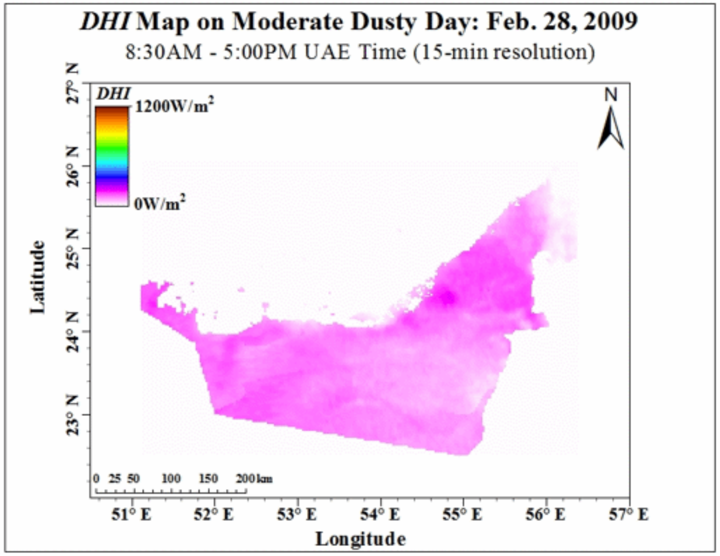
Spatial Variations: Moderate Dusty Day





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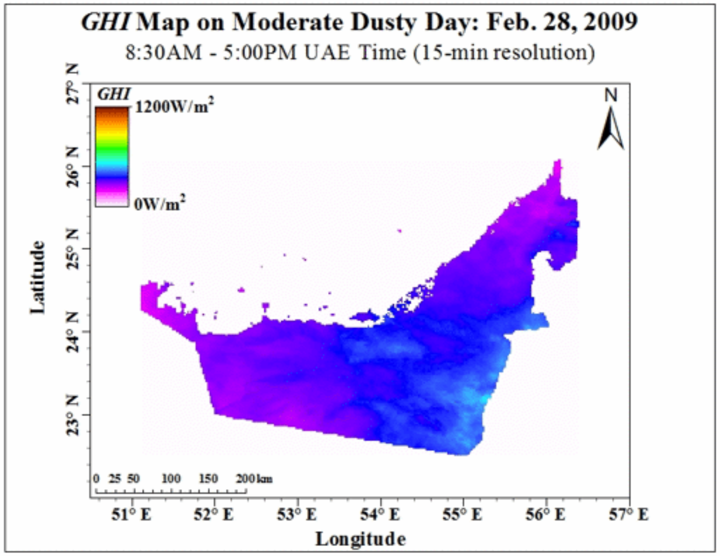

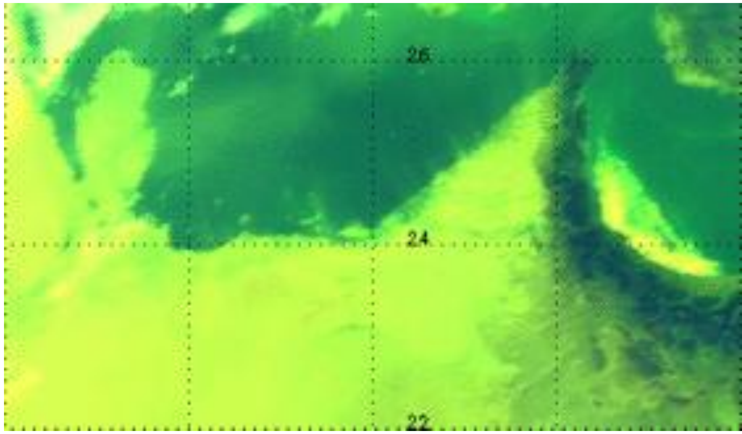

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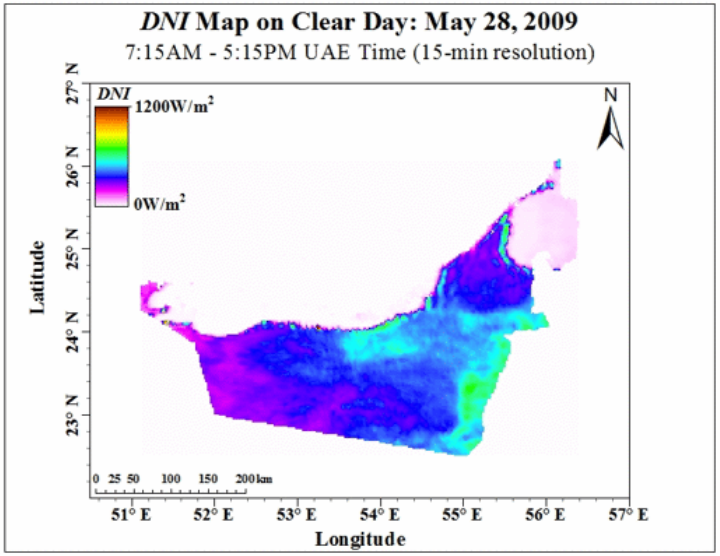
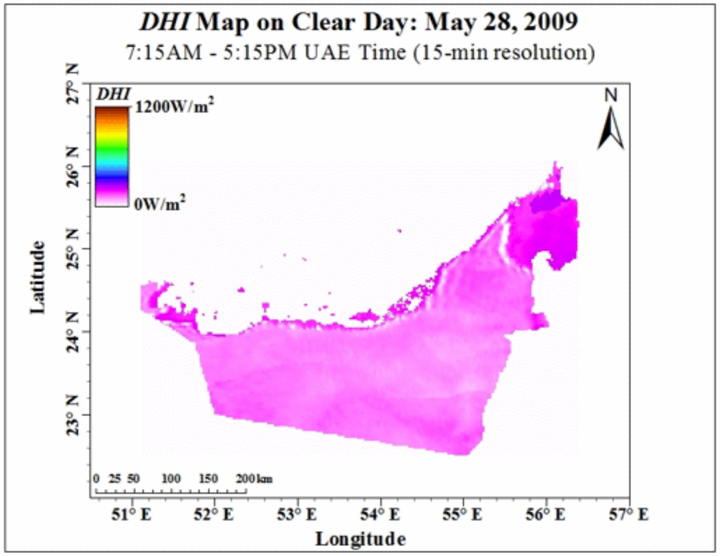
Spatial Variations: Clear Day





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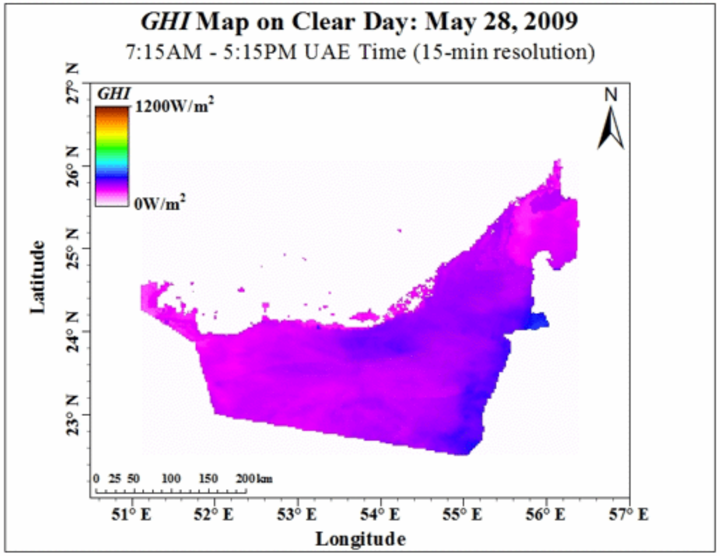

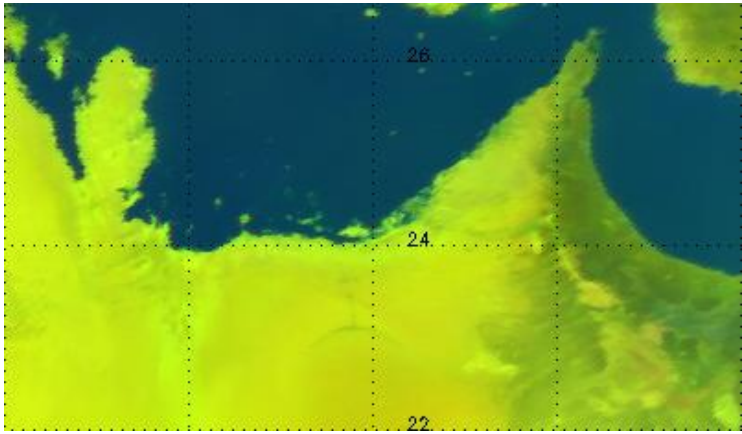

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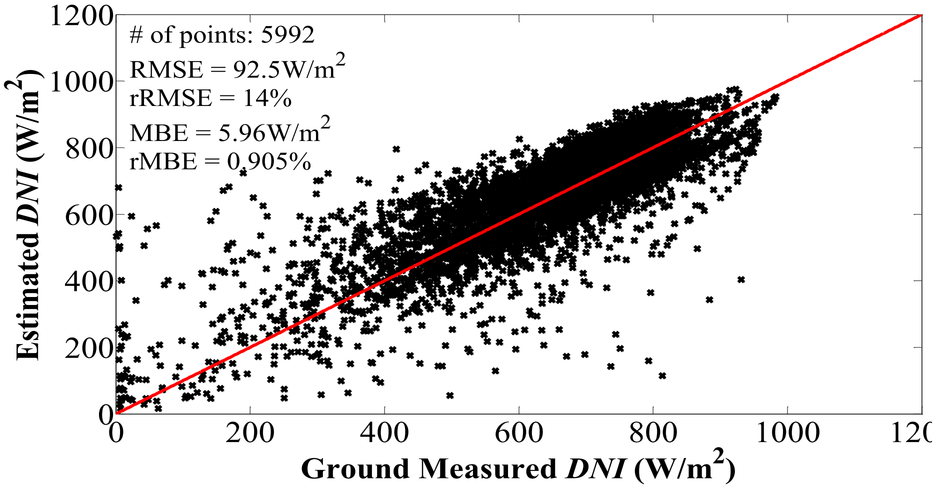
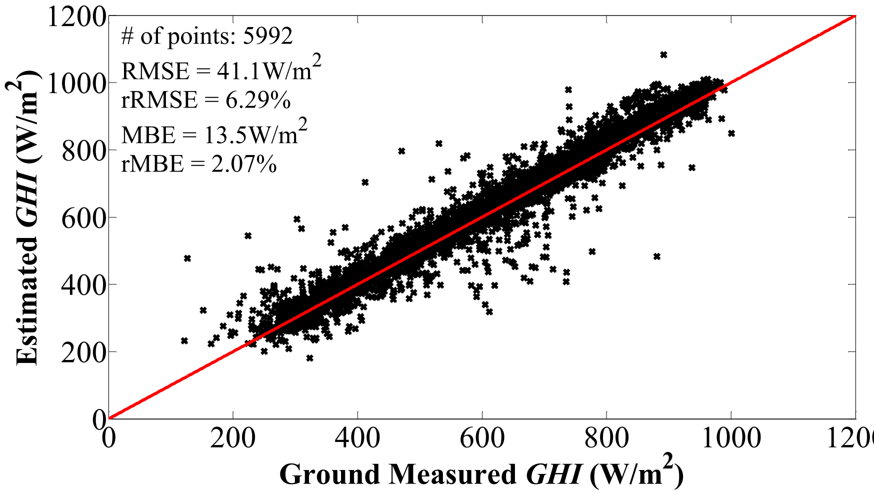
DNI & GHI Estimation Scatter Plots

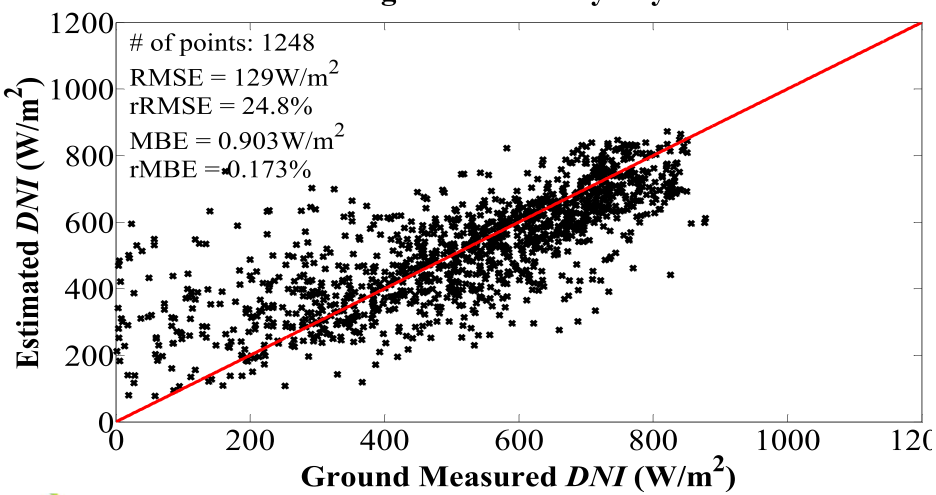
a) Estimated versus Measured *DNI*
Testing Set for Cloud-free Sky Case



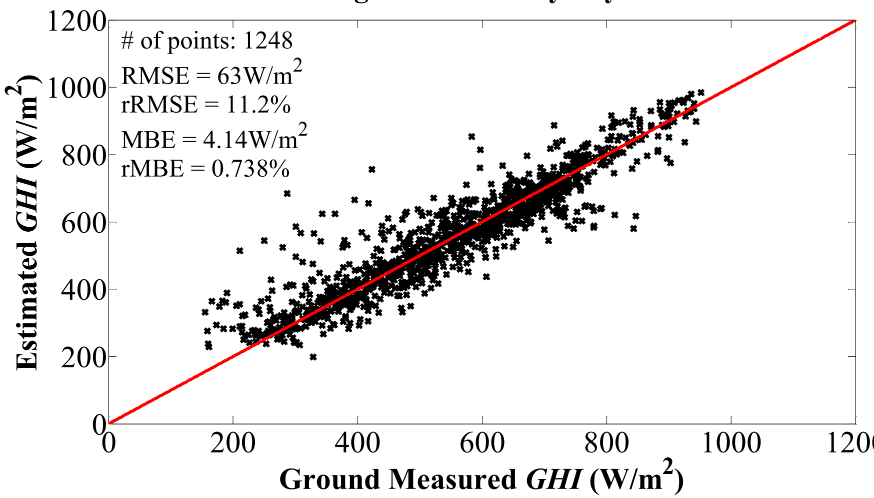
a) Estimated versus Measured *GHI*
Testing Set for Cloud-free Sky Case



b)Estimated versus Measured *DNI*
Testing Set for Cloudy Sky Case

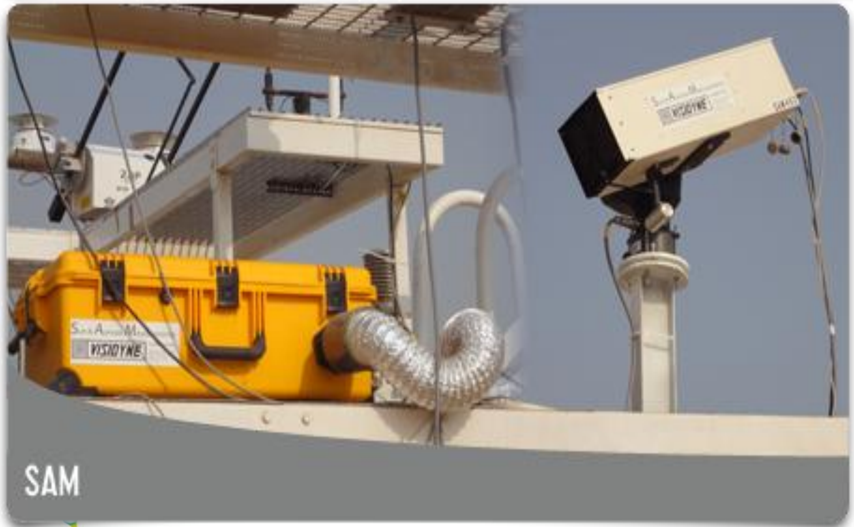


b) Estimated versus Measured *GHI*
Testing Set for Cloudy Sky Case



Y. Eissa, P. R. Marpu, I. Gherboudj, H. Ghedira, T. B. M. J. Ouarda and M. Chiesa "**Estimation of direct normal irradiance from Meteosat S 1 EVIRI thermal channels using a neural network ensemble**" Under Review *Solar Energy*

Measuring equipment: dust focused tools



CIMEL is a tracking, multi-filter radiometer used primarily for inferring aerosol concentrations from atmospheric extinction coefficients by performing Langley analysis in 13 bands of the solar spectrum.

The SAM is a tracking camera in which the circumsolar image is captured by a CCD camera.This gives a measure of atmospheric scattering of direct solar radiation.

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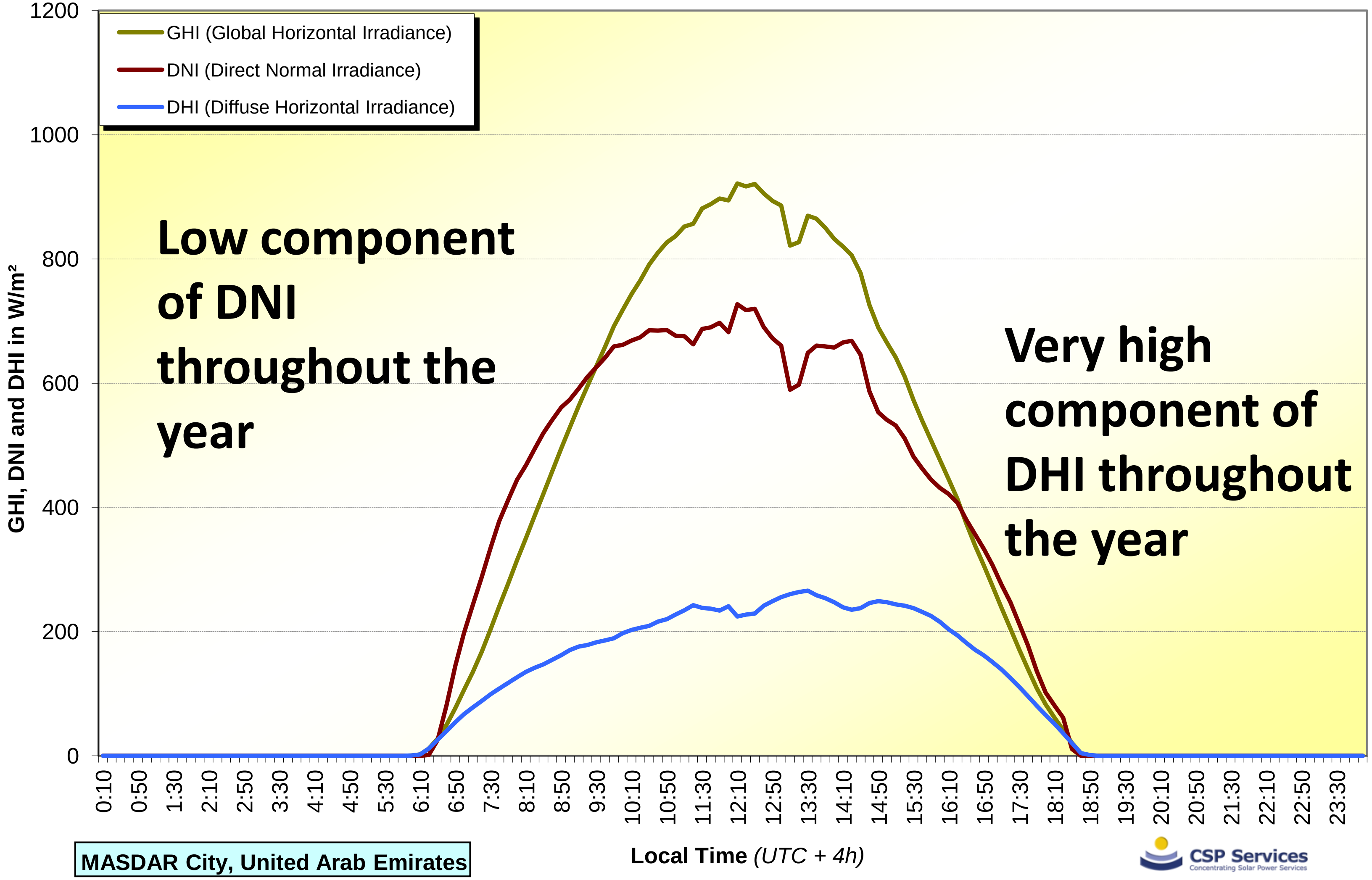
Ground Data Measurements



CSP Services
Concentrating Solar Power Services

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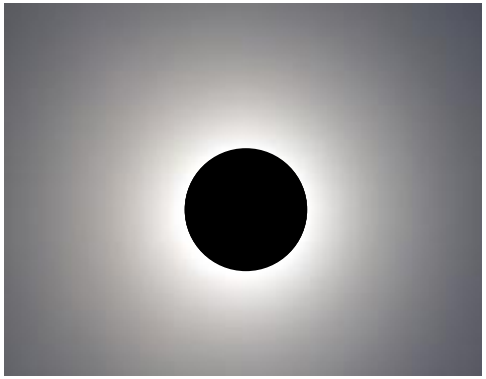
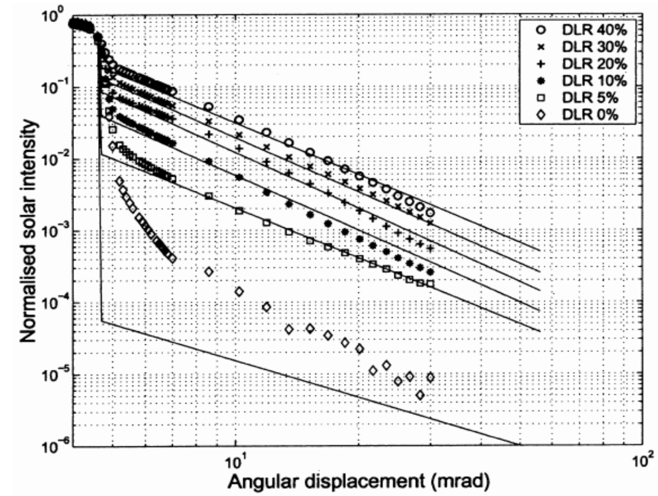
Effect of Sun Shape on CSP Technology



$$CSR = \frac{\Phi_{Circumsolar}}{\Phi_{Solar\ Disk} + \Phi_{Circumsolar}}$$



Sun Edge Angle: **0.266º =~ 4.64 mrad**
Aureole Extends till: **3º-4º = ~ 52-70 mrad**

- ❑ Concentrating solar collectors are designed with angular acceptance angles which are relatively close to the angular size of the solar disk 0.266º. (maximization of the capture radiation and minimization of the thermal radiation from the receiver)

- ❑ Concentrated technology make use of the direct component of the incoming radiation, but the DNI measurements instruments have angular acceptance angle which is ten times greater than the size of the solar disk.

- ❑ The solar profile in the UAE has never been investigated, but due to the high aerosols concentration characterizing the climate in the UAE, we expect high CSR

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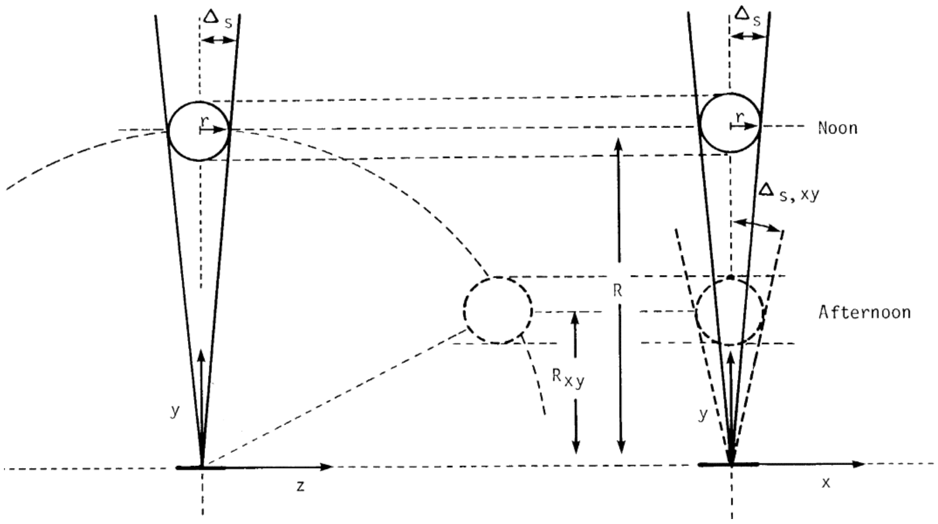
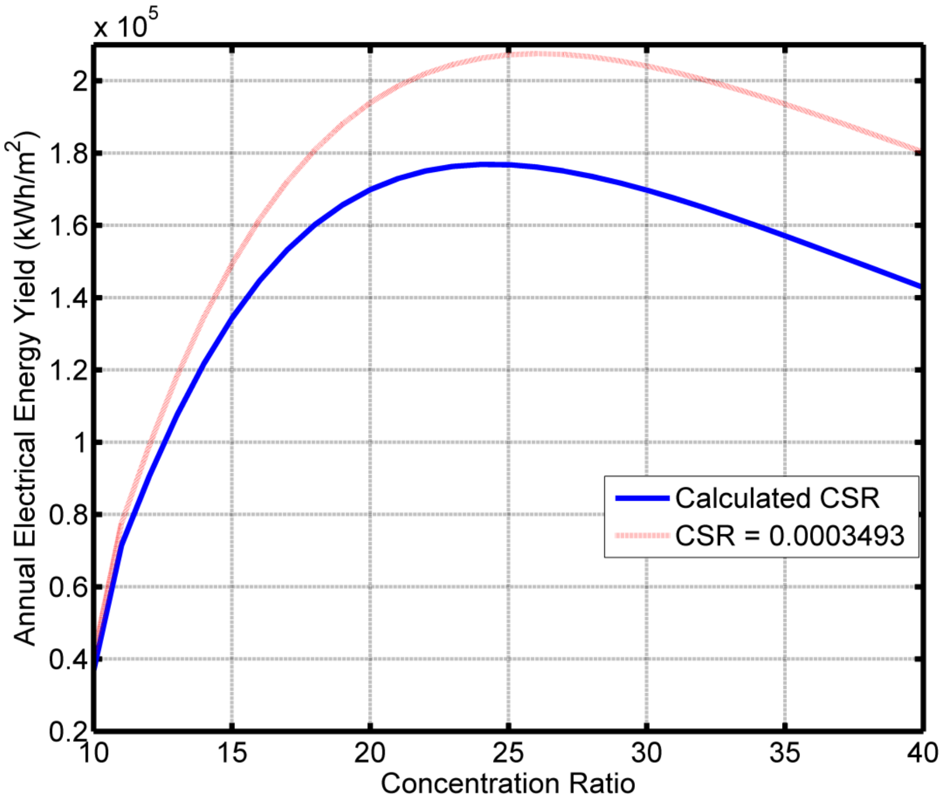
Effect of CSR on power output of euro troughs

$$CSR = \frac{\Phi_{Circumsolar}}{\Phi_{Solar\ Disk} + \Phi_{Circumsolar}}$$





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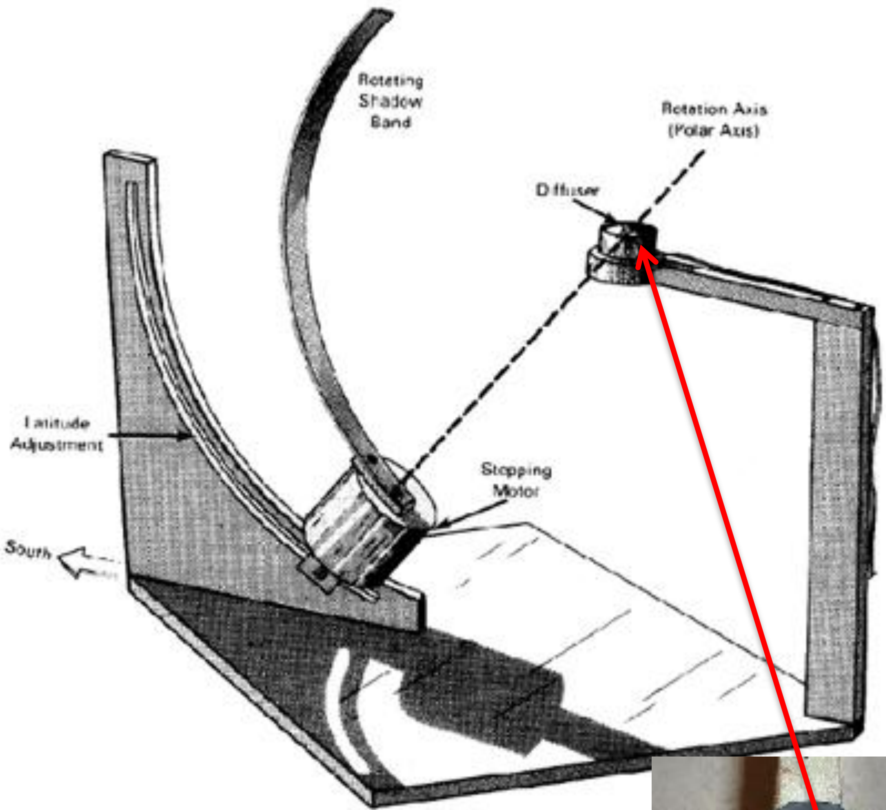
Sunshape Profiling Irradiometer



- Low cost (like RSB)
- Reliable unattended operation (like RSB)
- Simple alignment and operation
- (Aerosol optical depth in several wavelength bands)
- (Circumsolar radiation profile in several wavelength bands)

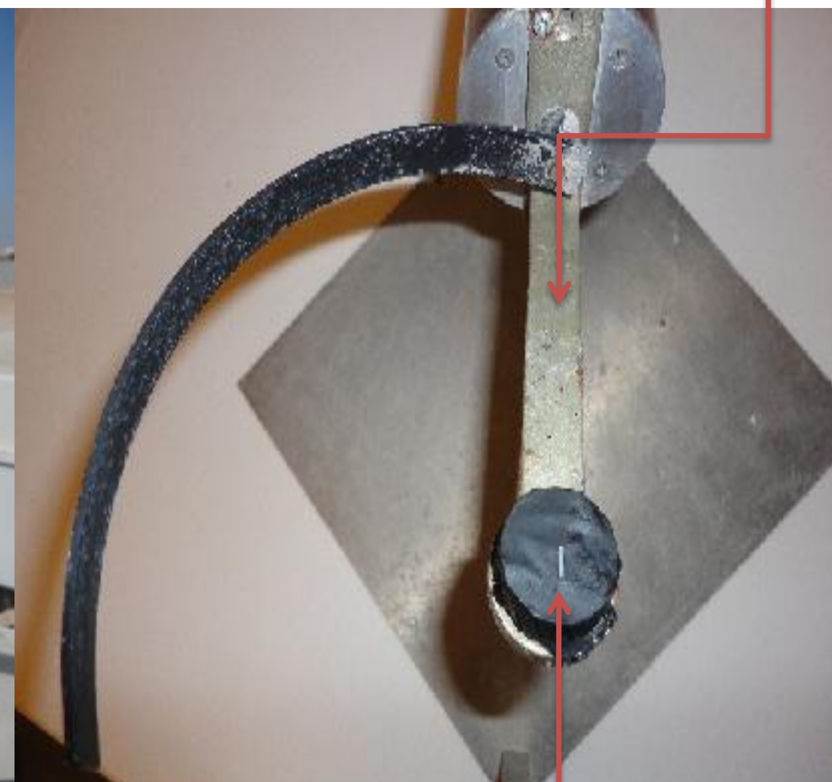
The shadow of the rotating shadowband covers, progressively, larger portions of the sun allowing to calculate the "sunshape" effect of atmospheric light scattering.

Kalapatapu, R., Armstrong, P., & Chiesa, M. (2011). Rotating Shadowband for the Measurement of Sunshapes. Solar Paces. Granada

Sunshape Profiling Irradiometer

Shadowband

Bracket holding the Receiver



Stepper Motor

Latitude Adjustment Bracket

Licor's Receiver

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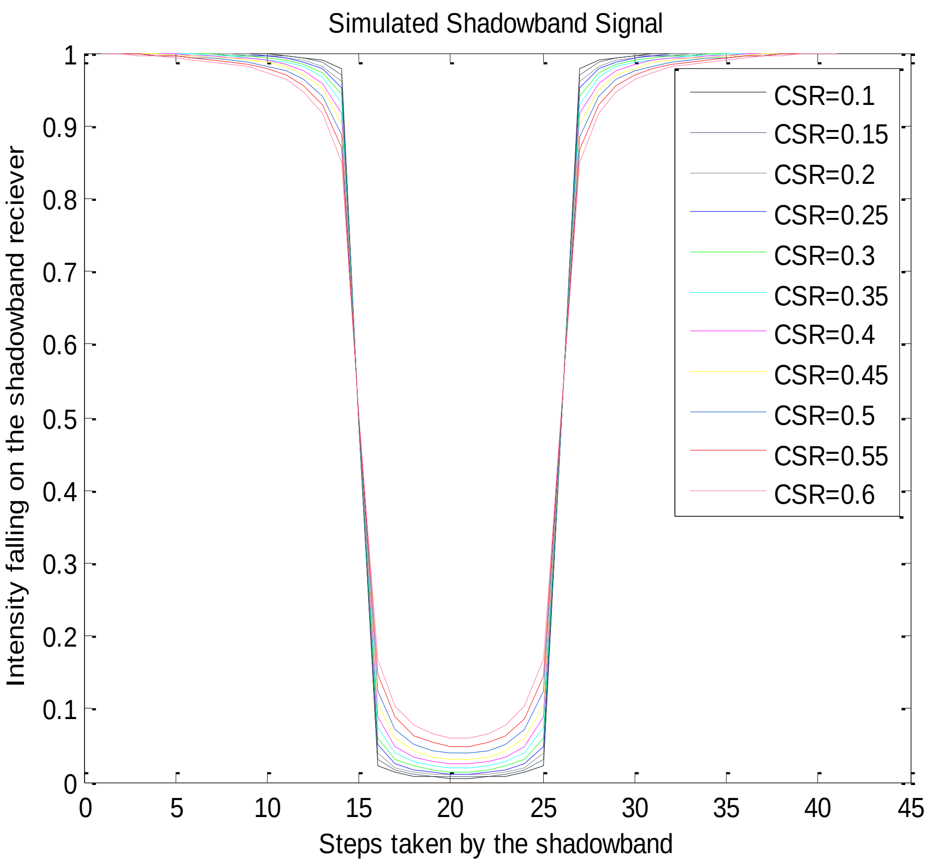
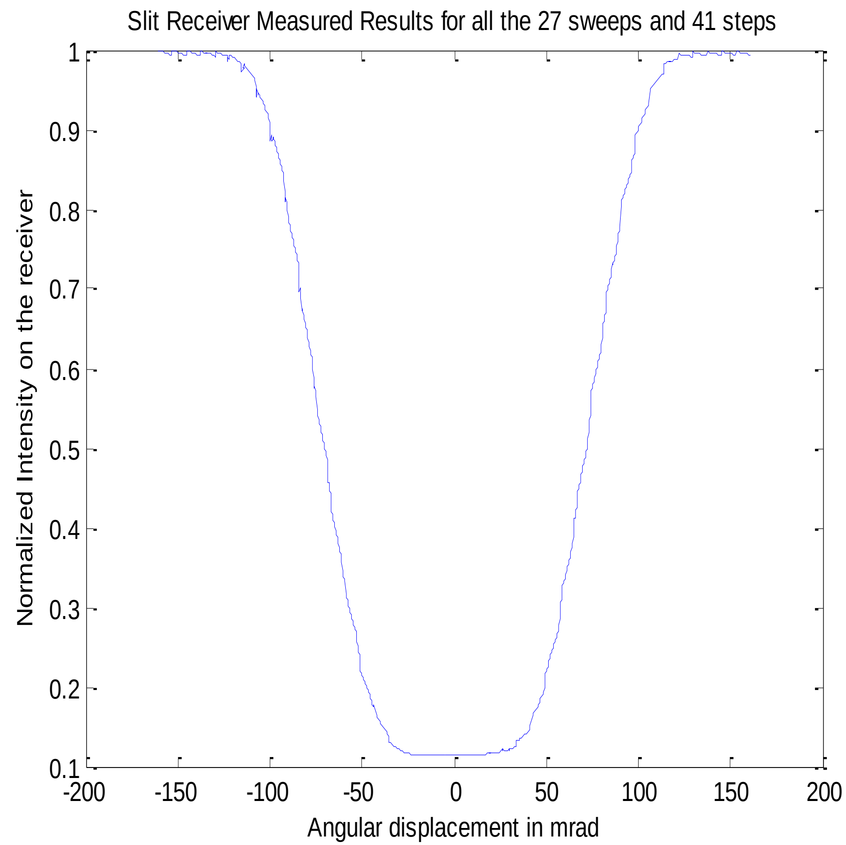
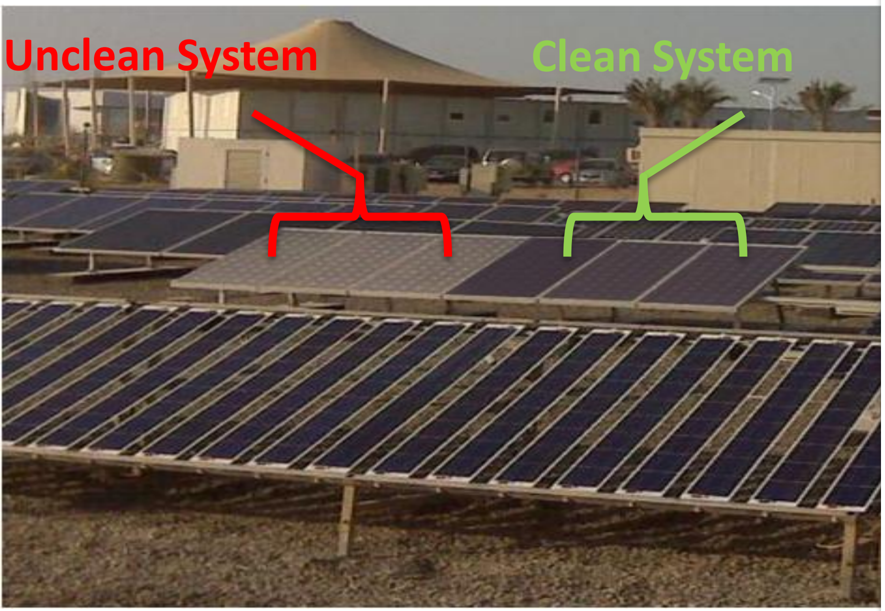
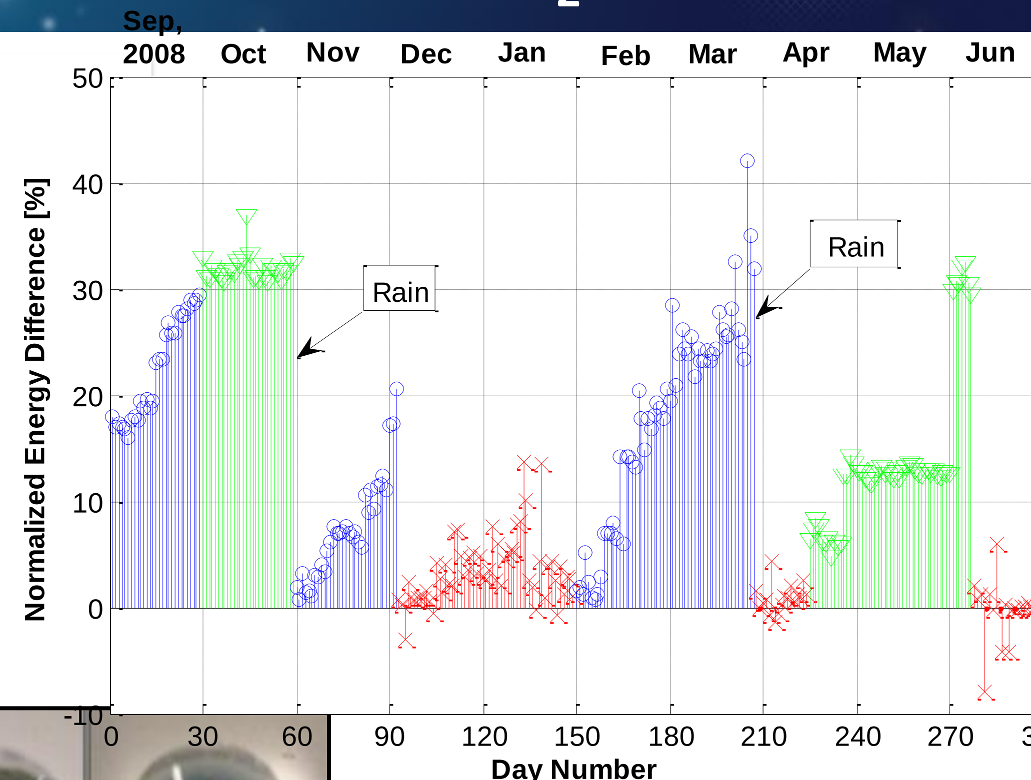
Sunshape Profiling Irradiometer: Preliminary Results

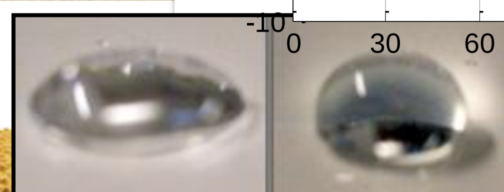


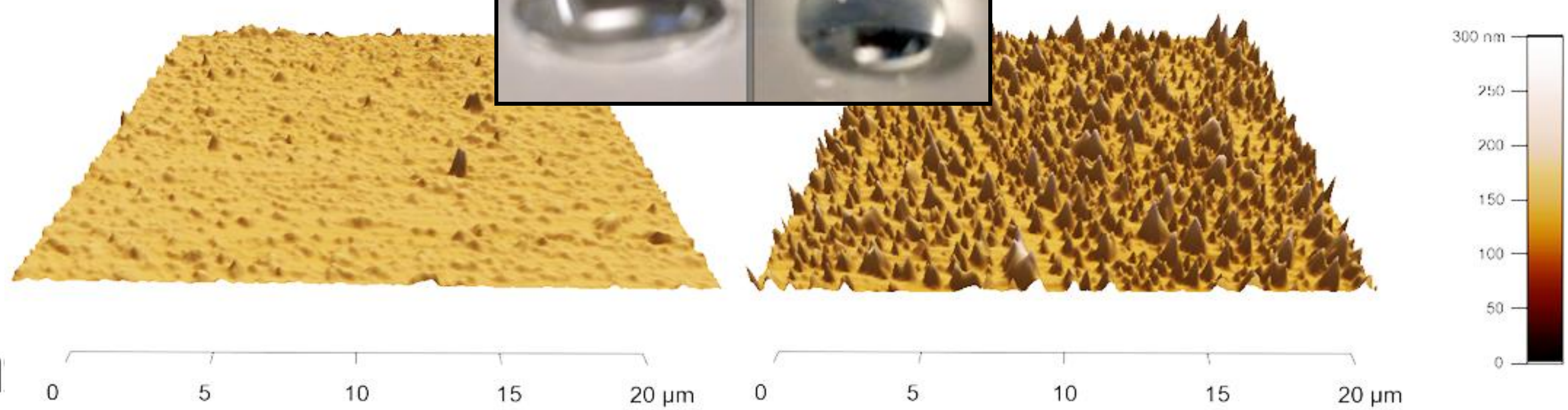


Surface Treatment to Reduce H_2O Needs

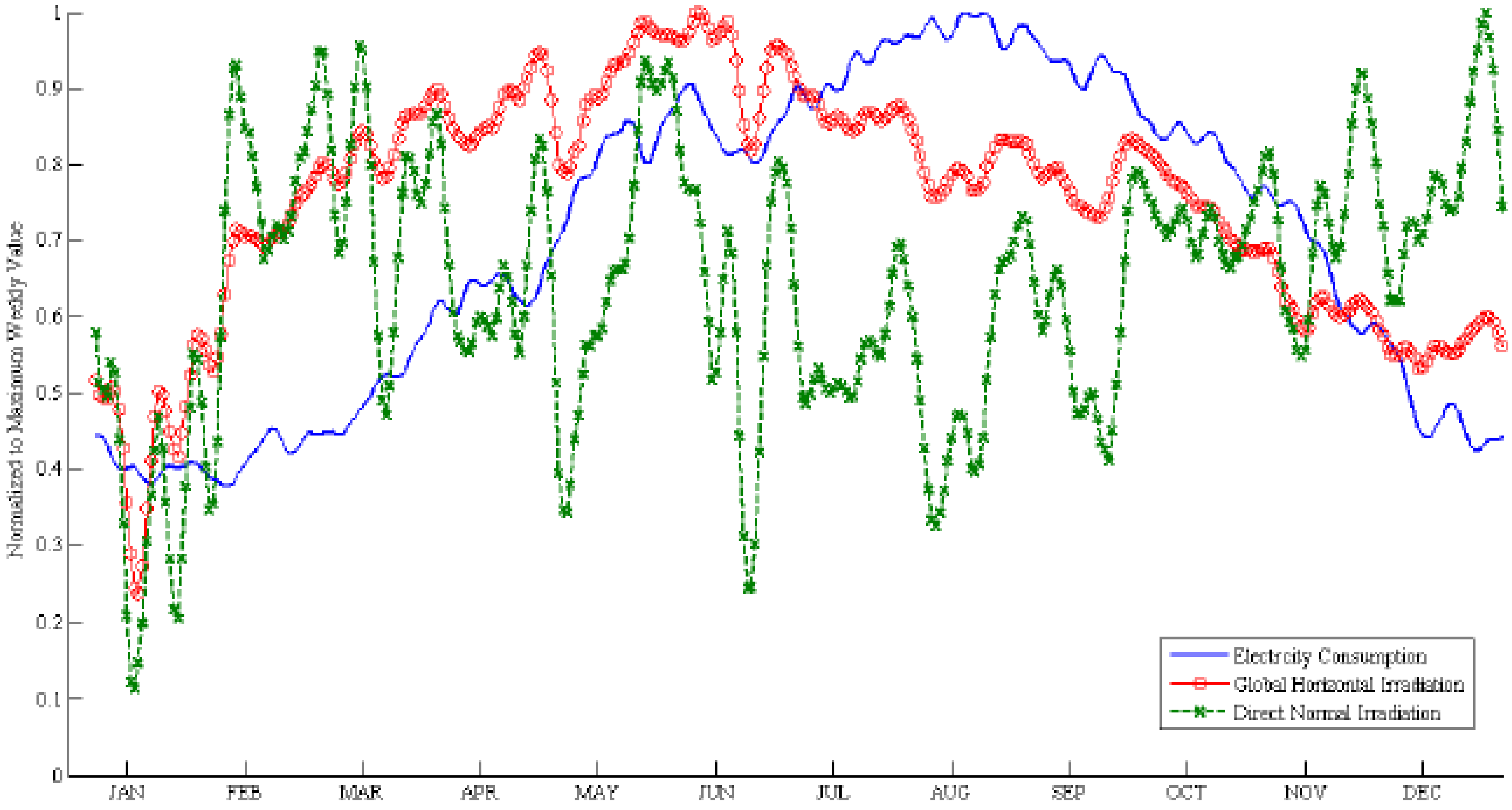








Demand vs Solar Resources



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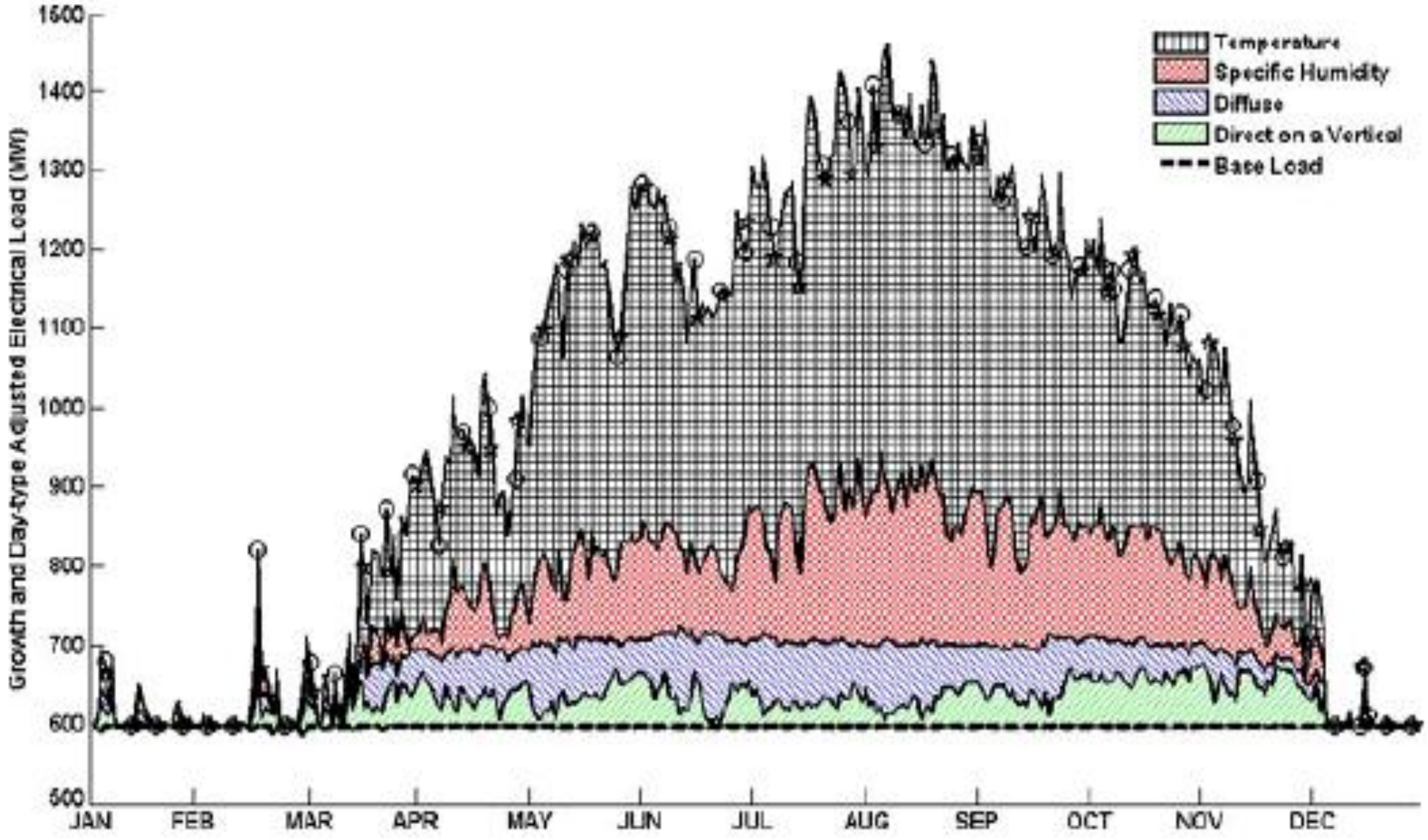
Power Demand in the UAE: The Abu Dhabi island case



Muhammad Tauha Ali[3], Marwan Mokhtar[1], Matteo Chiesa, Peter R Armstrong "A cooling change-point model of community-aggregate electrical load" *Energy and Buildings* Vol. 43 Issue 1 Pages 28-37, 2011

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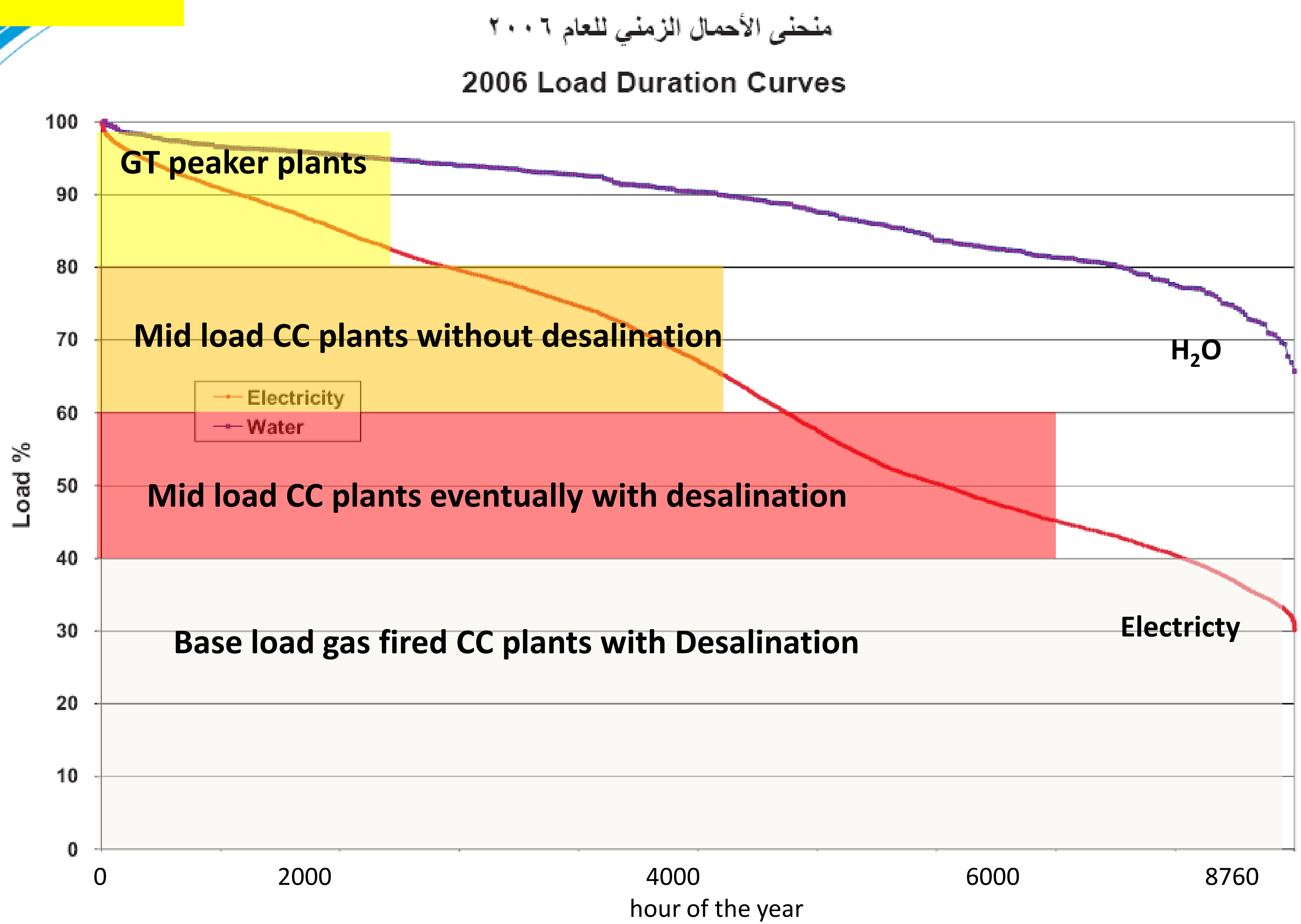
Today's Power Plant Park to Satisfy the Load Curve

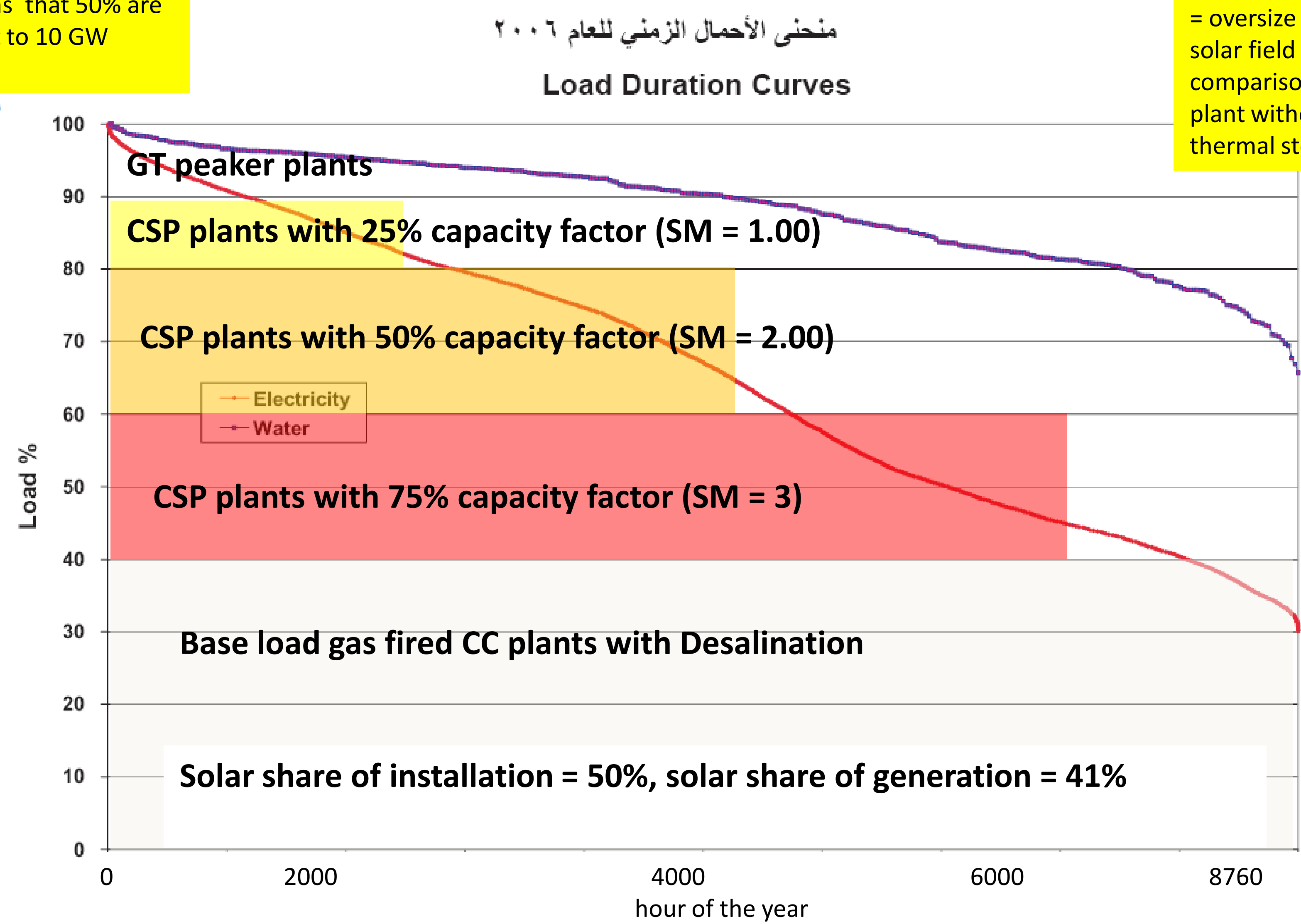
100% = 5 GW in yr 2008.



Possible CSP final penetration (beyond 2030)

100% = 20 GW in yr 2020 . That means that 50% are equivalent to 10 GW capacity

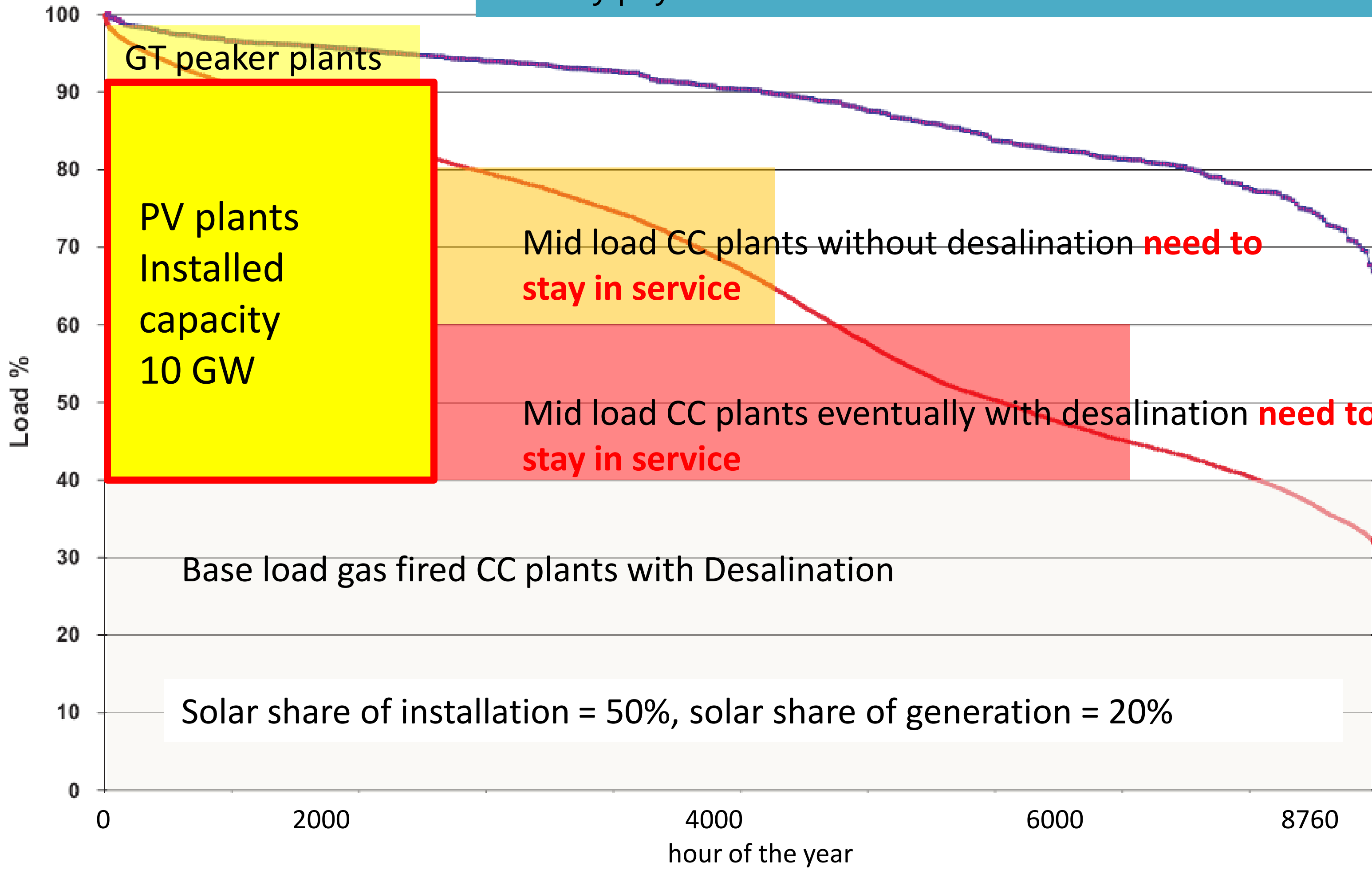
SM = Solar Multiple = oversize factor of solar field in comparison to a plant without thermal storage



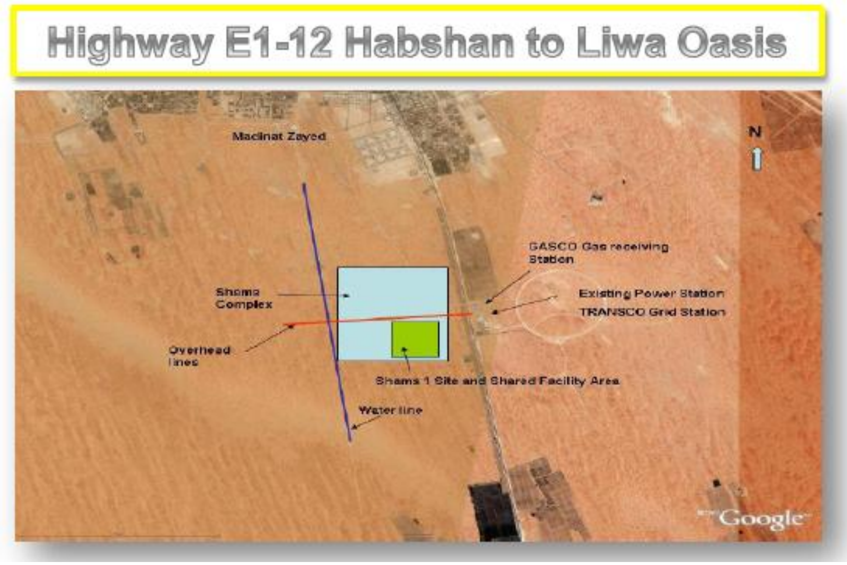
Max. possible PV penetration

100% = 20 GW in yr 2020 .

The mid load plants, which would be fully replaced by CSP plants need to be maintained by the utility, because the PV plants can only run when the sun shines, and do not replace capacity. Therefore the utility will only pay the saved fuel and variable O&M cost.



Shams 1: 110 MW CSP plant



- Parabolic Trough Solar Power Plant with gas fired booster
- Booster power share: 18% of heat input
- HTF Heater: 150 MW_{th} => 50 Mw_{el} (Firm Output)
- Nominal net Capacity: 110 MW_{el} (@ 730 W/m^2)
- Area required: 2.6 km^2
- Cooling: Dry Cooling (ACC)
- Annual power generation: Approx. 210 GWh
- Location: Madinat Zayed (Western Region)
- DNI at site: 1934 $kWh/m^2/a$
- Soil Condition: Desert with sand dunes
- Power export @: 220 kV

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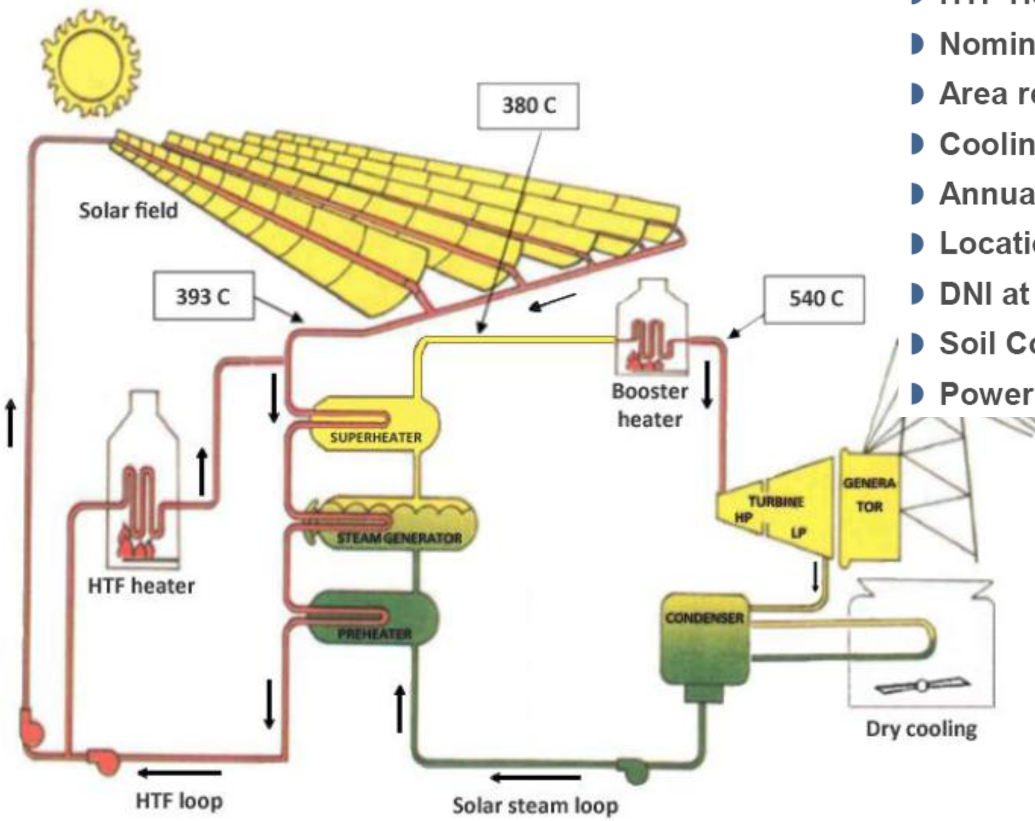
Shams 1: 100 MW CSP plant



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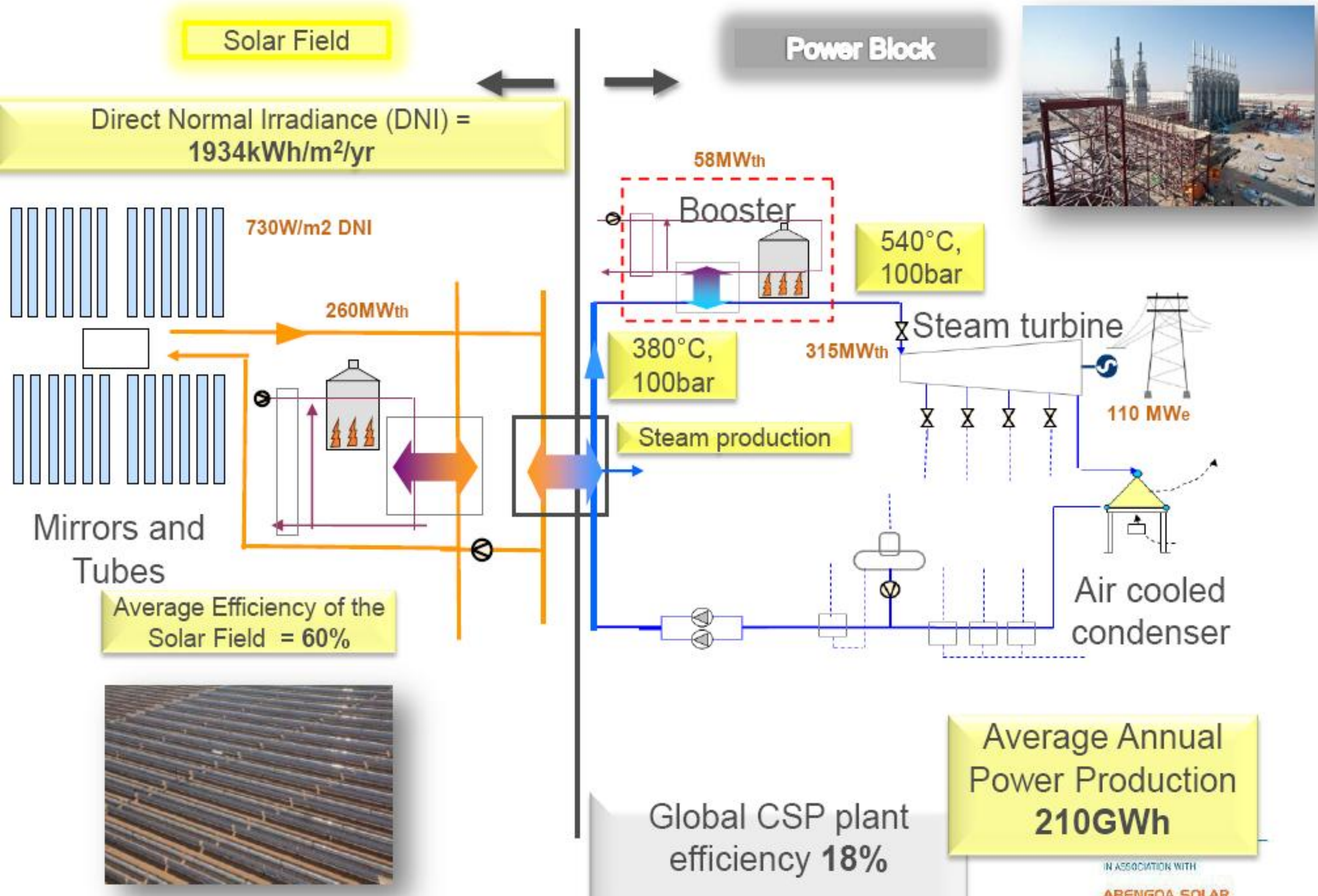
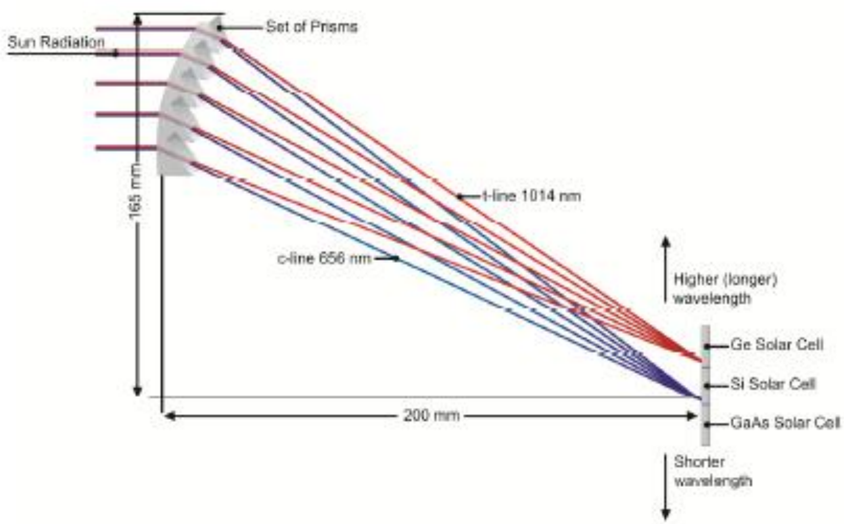
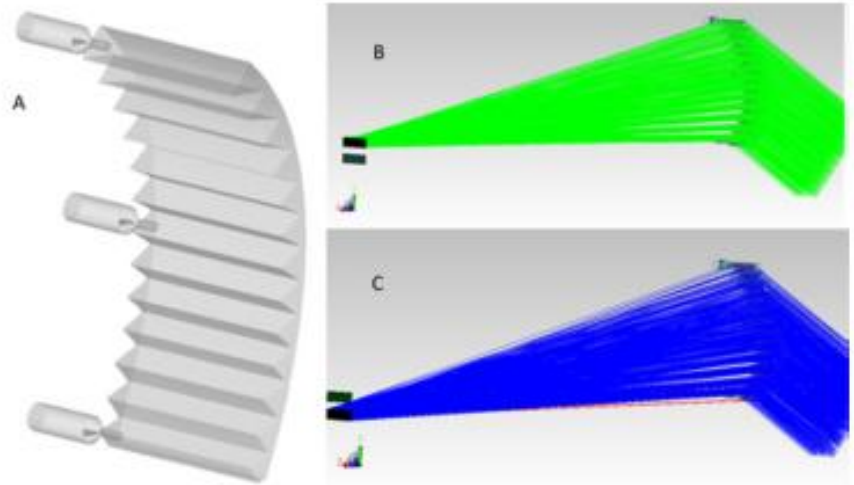
Plant Process



Shams One project

Beam Splitting concept for new PV architecture





M. Stefancich, A Zayan, S. Rampino, D. Roncati, L. Kimerling, J. Michel and M. Chiesa "**Single element spectral splitting solar concentrator for multiple cells CPV system**" Optics Express, Vol. 20, Issue 8, pp. 9004-9018 (2012) http://dx.doi.org/10.1364/OE.20.009004

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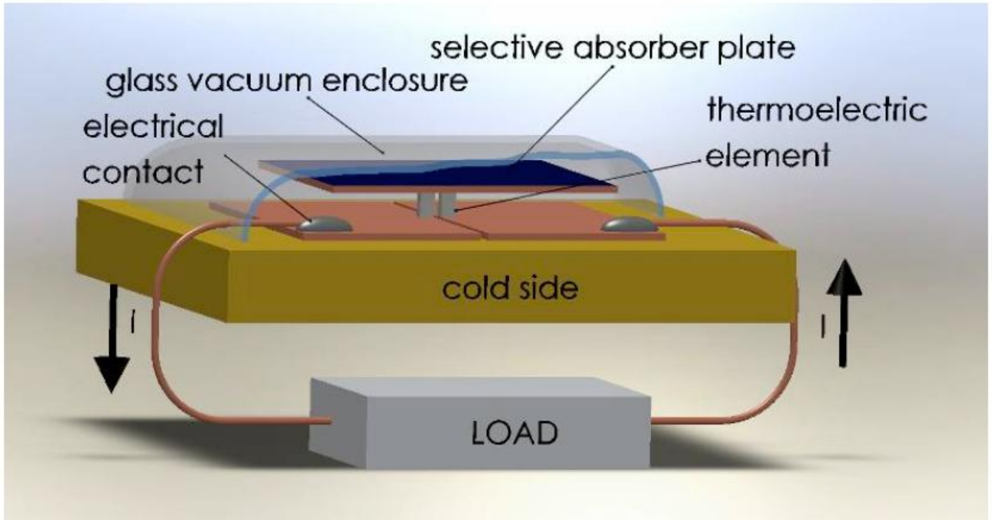
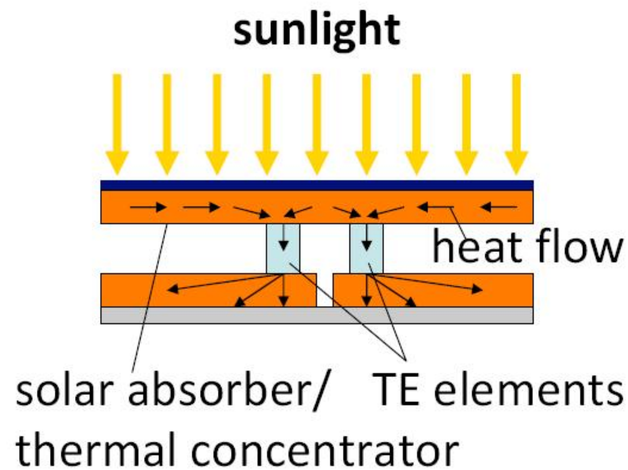
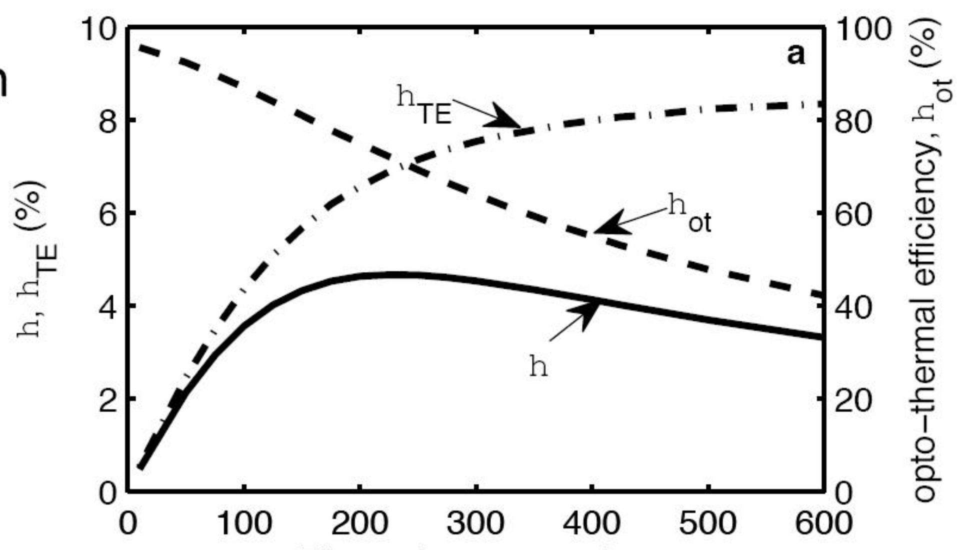
Solar Thermoelectric Power Generator



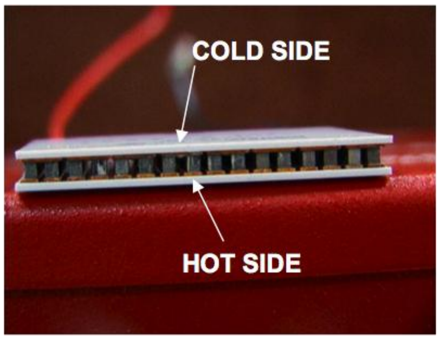


- Solid state solar-to-electric power conversion based on Seebeck effect
- Vacuum STEG design enables large optimum thermal concentration
- Minimum usage of thermoelectric material

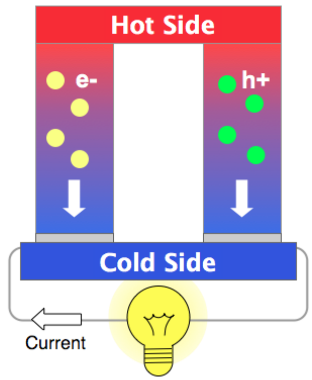


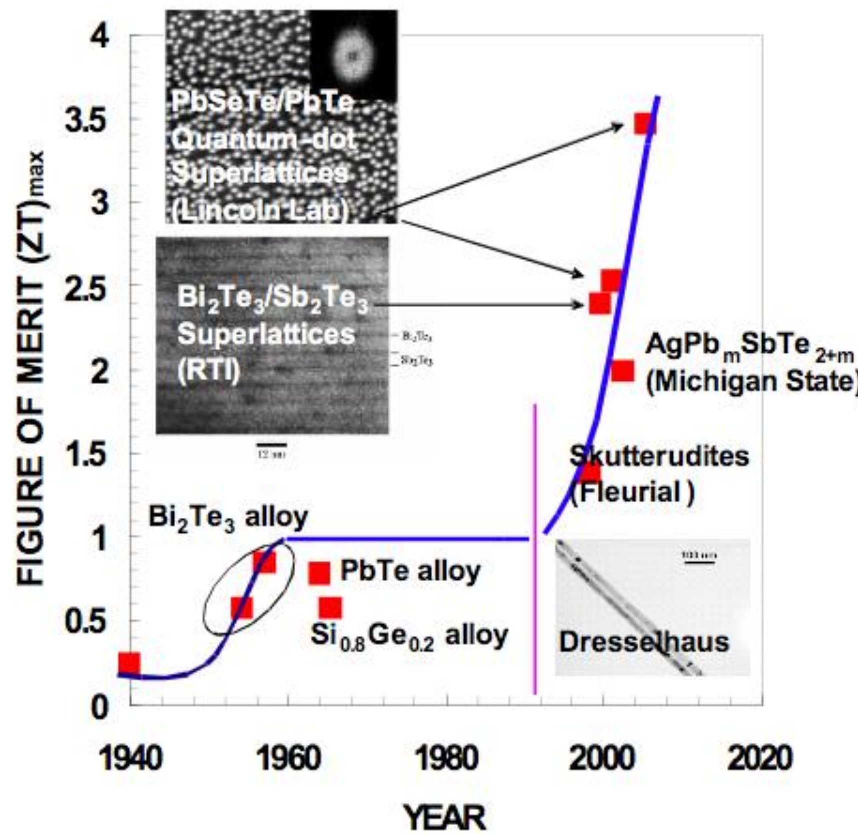
Energy Transport in Nanostructures: Thermo-Electric Energy Conversion

Commercial Module



Unit



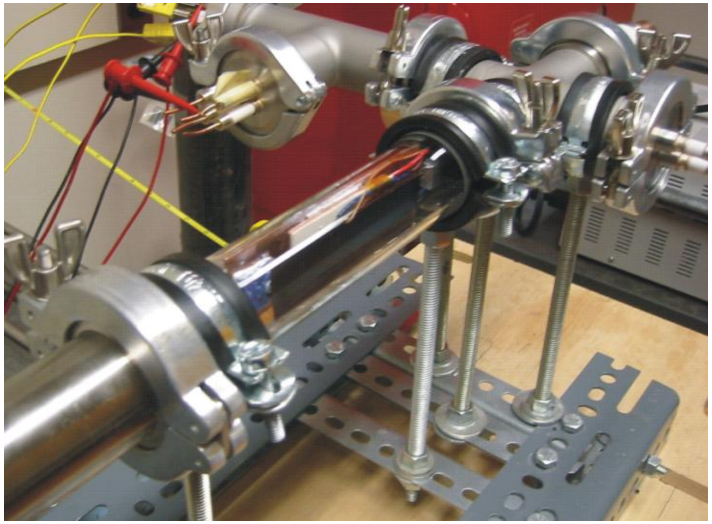


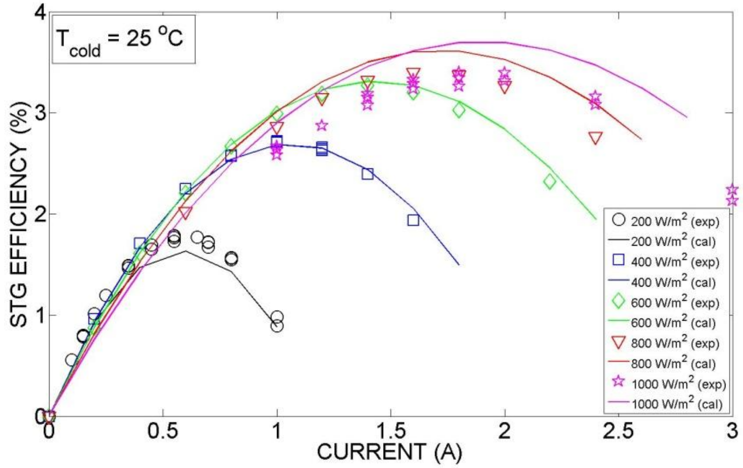
Performance:

$$ZT = \frac{S^2 \sigma T}{k}$$

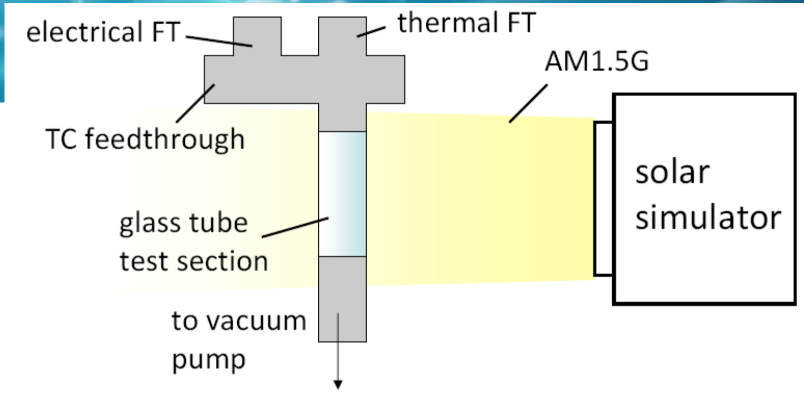
Thermal conductivity

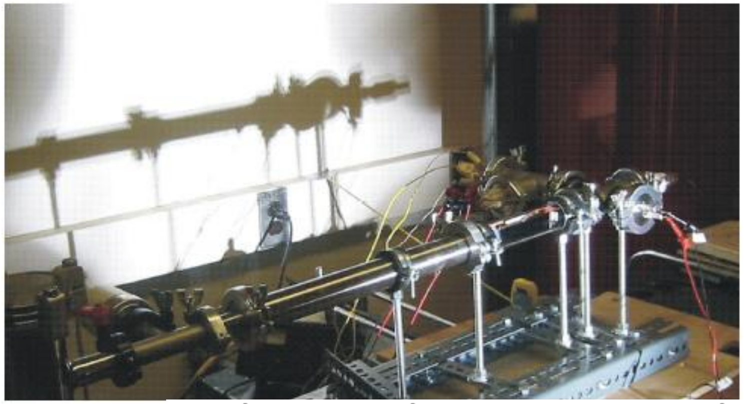
Solar Thermoelectric Power Generator

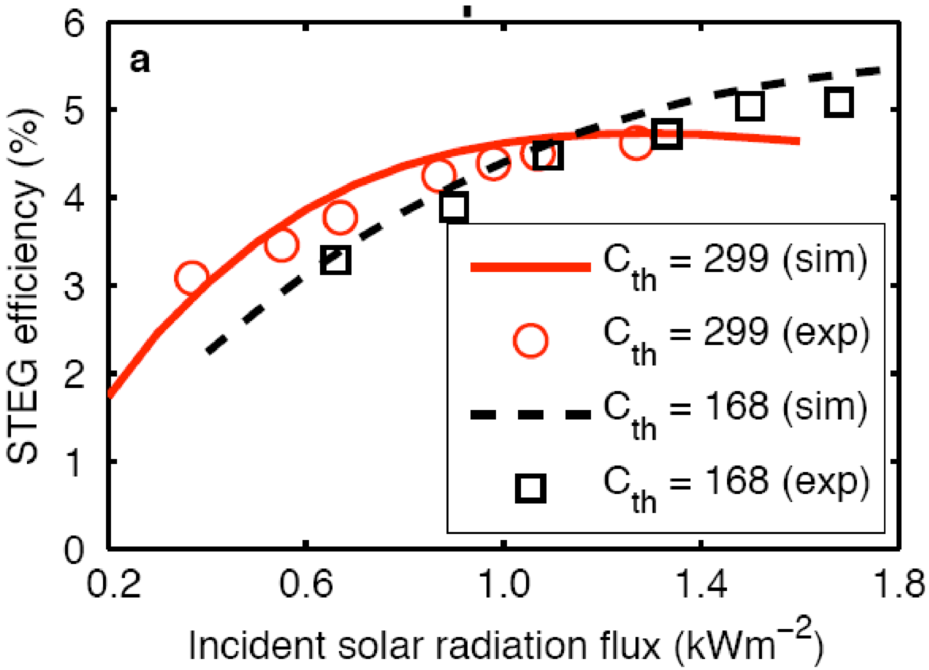




Solar Thermoelectric Power Generator







- thermoelectric material: nanostructured Bi_2Te_3 bulk elements
- solar absorber: α = 0.944, ε = 0.04-0.08 (100-230°C)
- n-/p-type TE element dimensions: 1.35x1.35x1.6 mm
- optimal thermal concentration: $C_{th} = A_{abs}/A_{te} = 300$
- STEG cell is mounted inside a glass vacuum chamber (τ = 0.94)
- light source: solar simulator with AM1.5G filter

LENS

D. Kraemer, B. Poudel, H.-P. Feng, J. C. Caylor, B. Yu, X. Yan, Y. Ma, X. Wang, 3 D. Wang, A. Muto, K. McEnaney, M. Chiesa, Z. Ren, and G. Chen **Solar thermoelectric generators with flat-panel thermal concentration** Accepted for publication in *Nature Materials* 2011

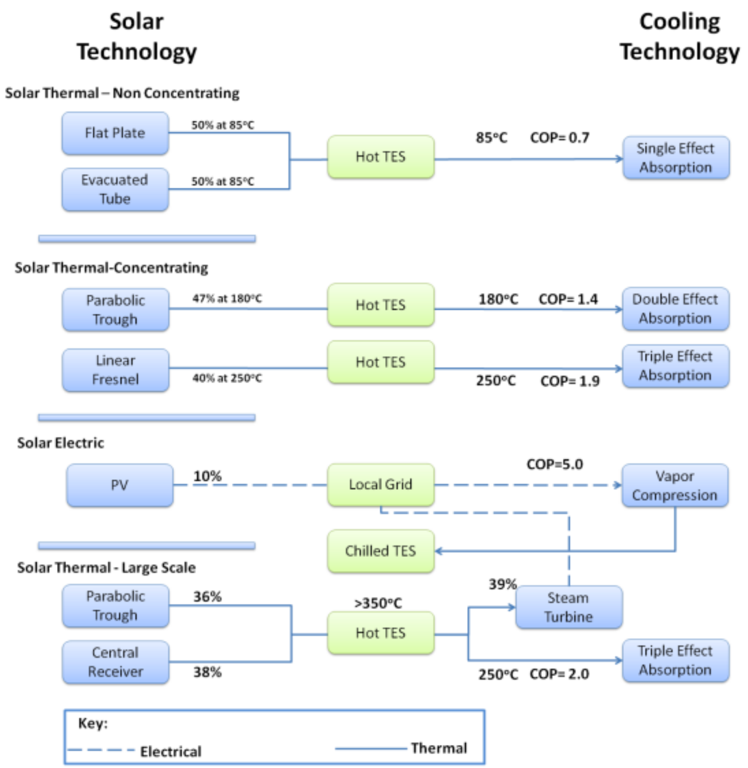
Masdar INSTITUTE معهد مصدر

Assessment of Solar Cooling Technologies

Research Objectives

- Assessment of the feasibility of using different solar cooling technologies for replacing conventional cooling.

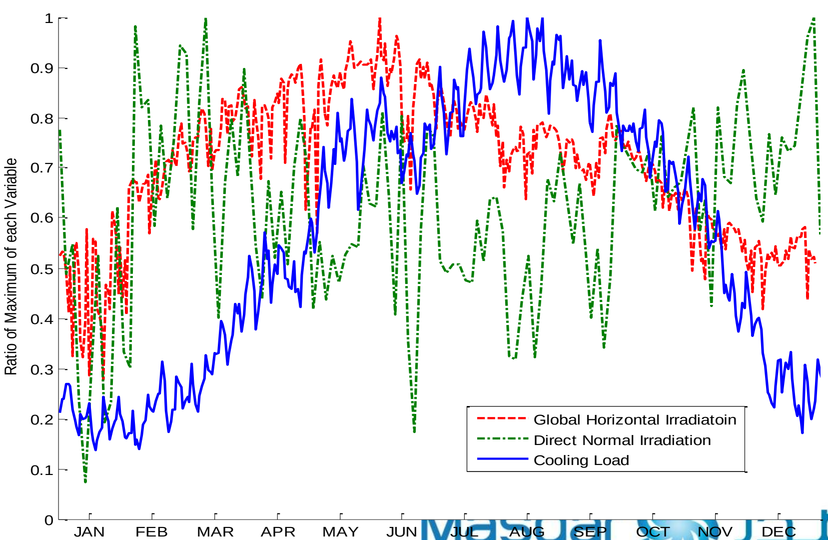
Solar Cooling Paths



Accomplishments

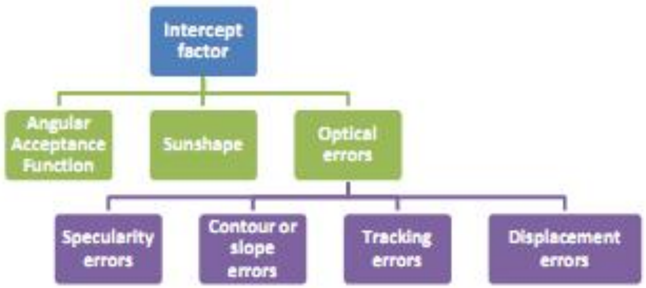
- A methodology for the assessment of solar cooling technologies was proposed.
- A study on the feasibility of several solar cooling was performed.
- A model for the prediction of cooling demand from electricity consumption

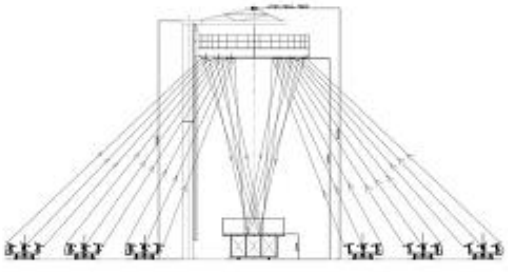
Solar Cooling Challenges



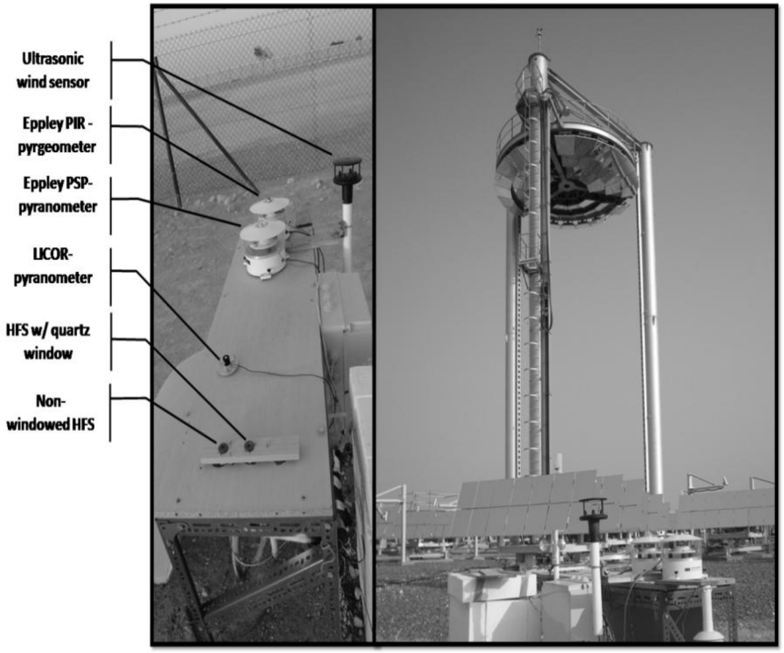
Solar -Thermal Design and Testing
Beam- Down Pilot Plant

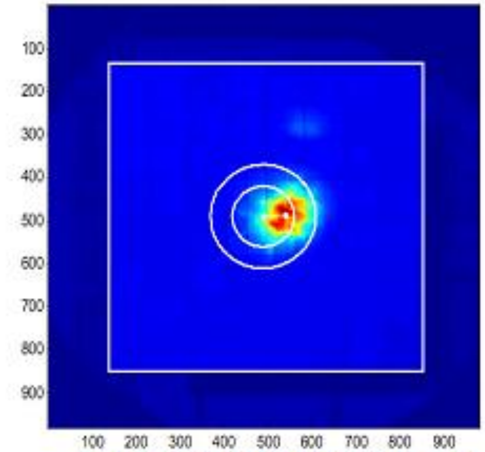
Optical modeling, characterization and experimental validation of Beam Down CSP pilot plant





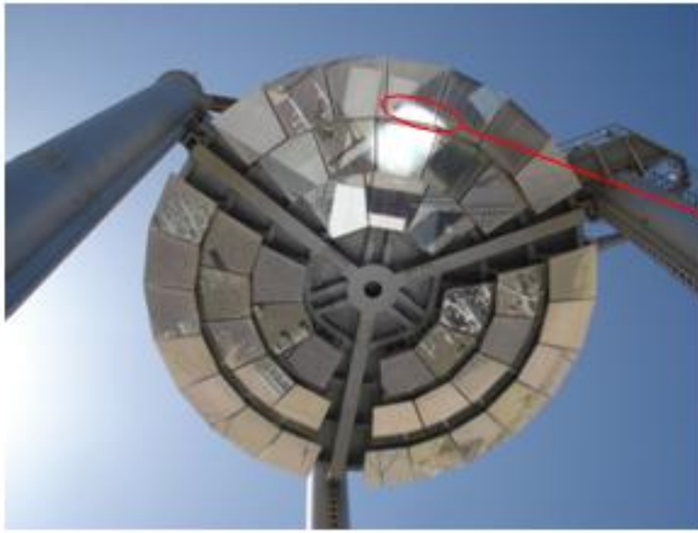
Schematic diagram of the Beam-Down plant

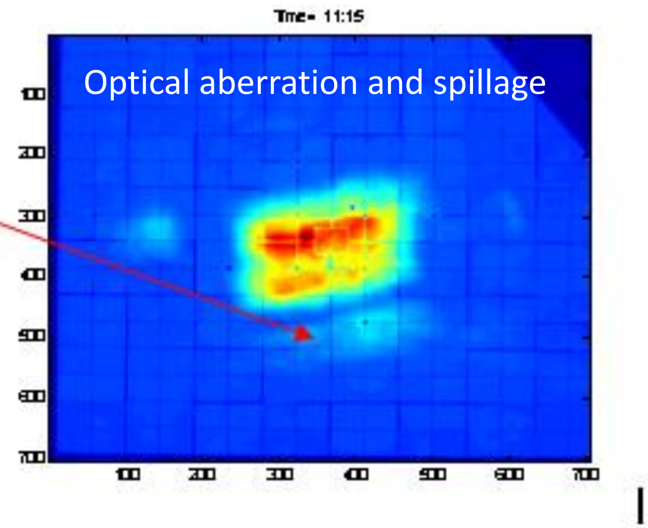




Flux distribution measurement with CCD camera

Geometrical Optical Model and Error Analysis of Beam Down Concentration





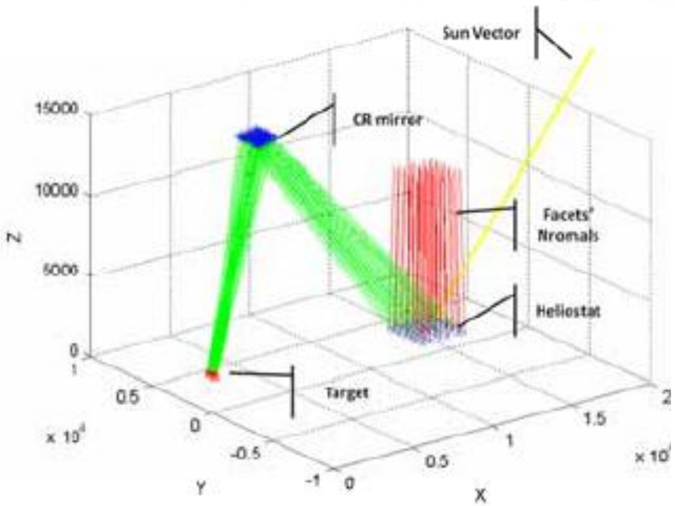
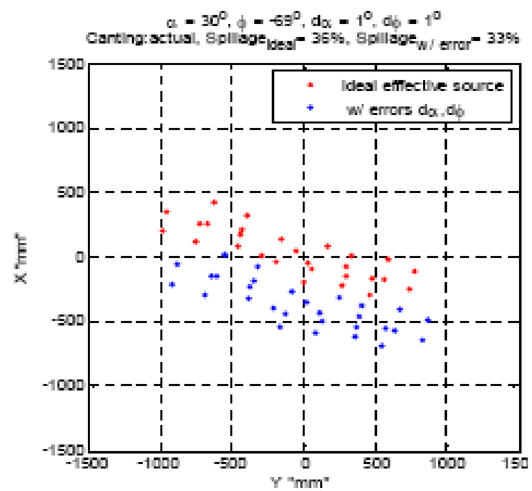
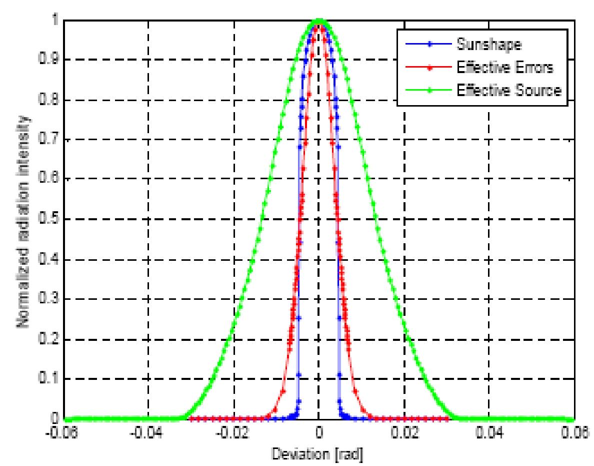


Illustration of model application on heliostat B8 in the reference position (i.e zero azimuth, 90° elevation)



Facet centers on target plane deviated from ideal location at origin (0,0).



Sunshape, effective errors and the resulting distribution

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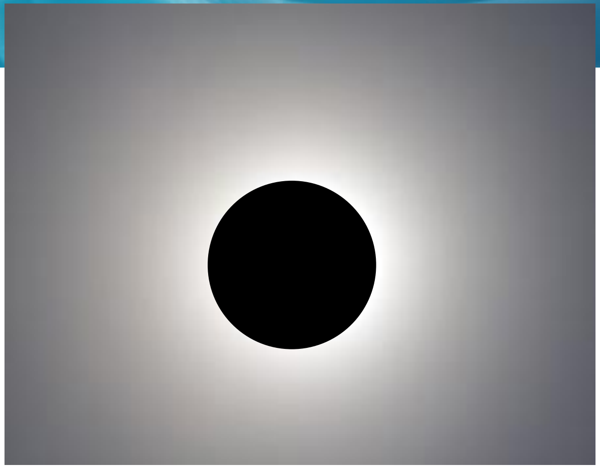
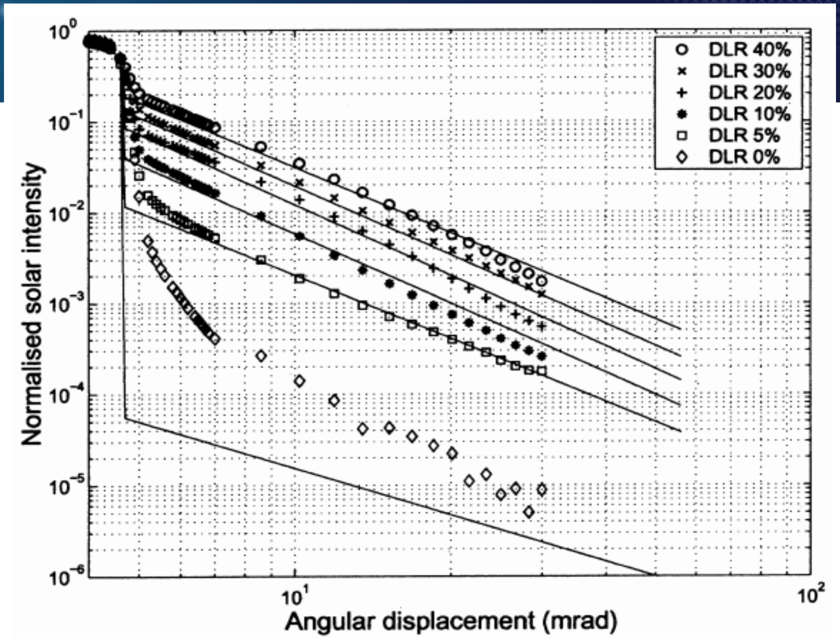
Effect of Sun Shape on Solar Concentrating-Technology





Sun Edge Angle: **0.266º =~ 4.64 mrad**

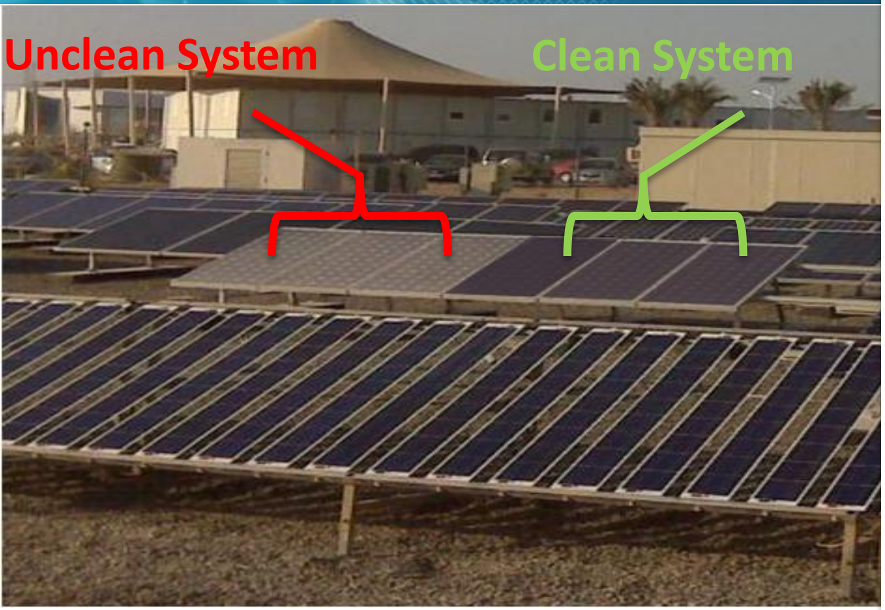
Aureole Extends till: **3º-4º = ~ 52-70 mrad**

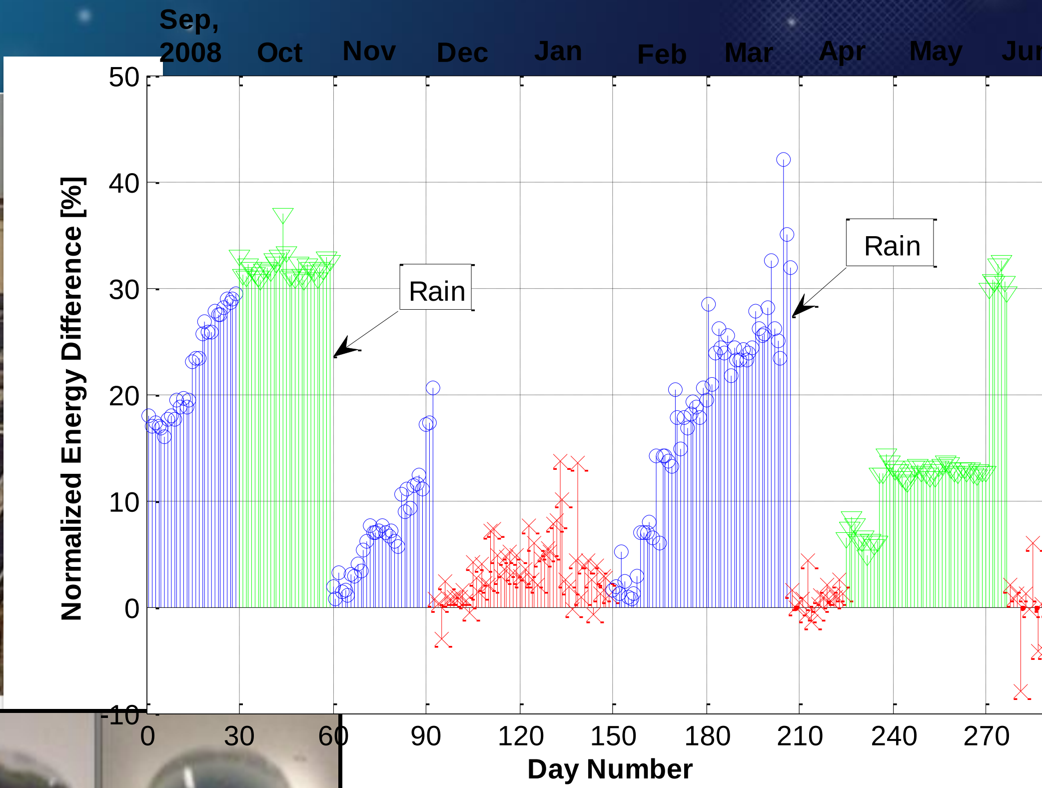
- Concentrating solar collectors are designed with angular acceptance angles which are relatively close to the angular size of the solar disk 0.266º. (maximization of the capture radiation and minimization of the thermal radiation from the receiver)

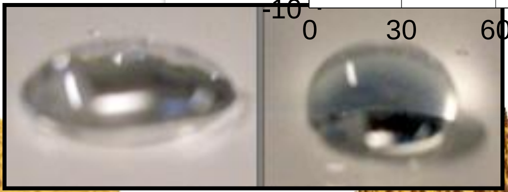
- Concentrated technology make use of the direct component of the incoming radiation, but the DNI measurements instruments have angular acceptance angle which is ten times greater than the size of the solar disk.

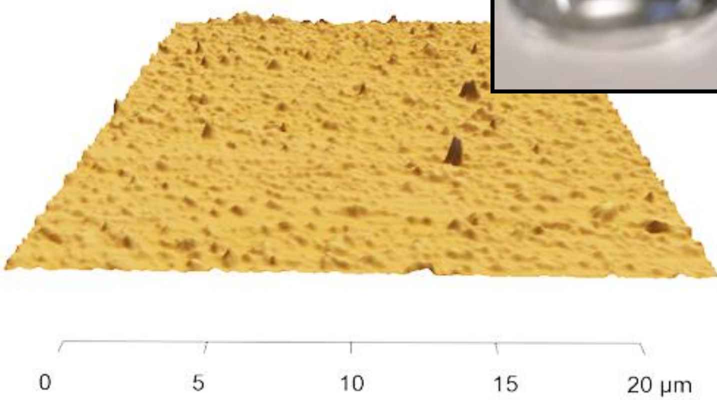
- The solar profile in the UAE has never been investigated, but due to the high aerosols concentration characterizing the climate in the UAE, we expect high CSR

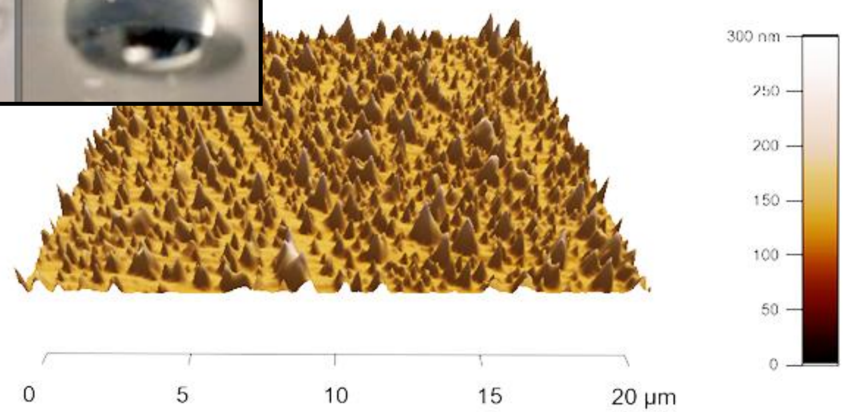
Surface Treatment to Reduce H_2O Needs During Cleaning











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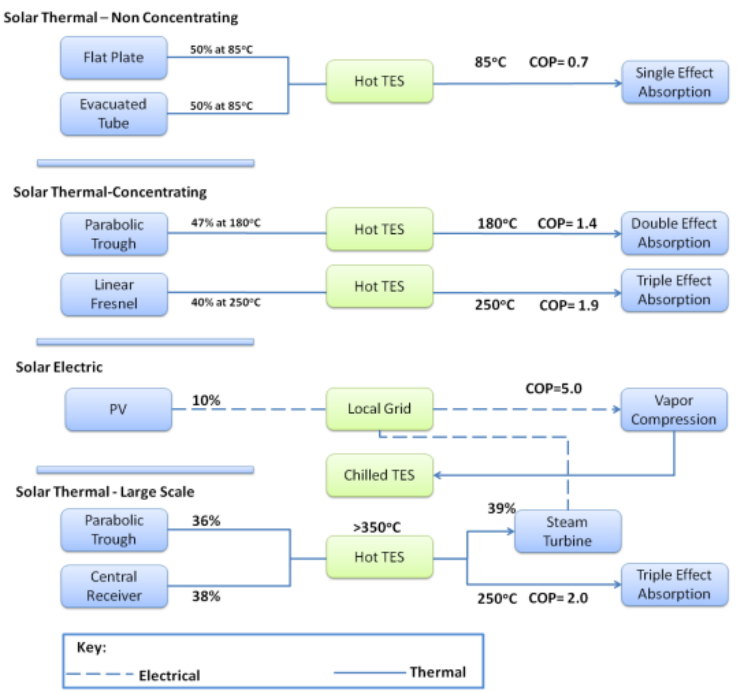
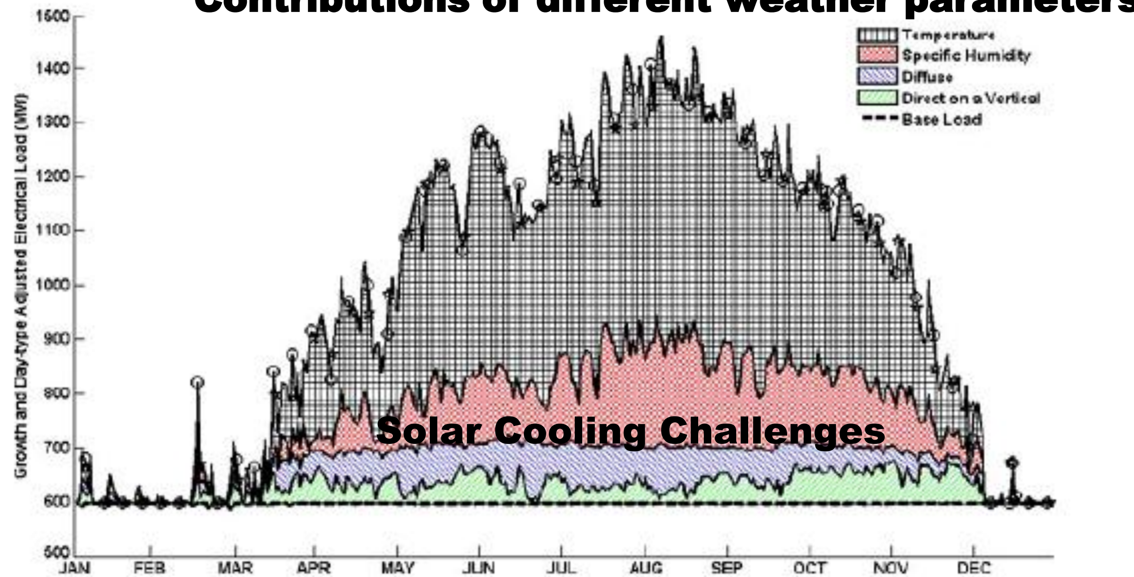
Assessment of Solar Cooling Technologies

Solar Cooling Paths



Contributions of different weather parameters



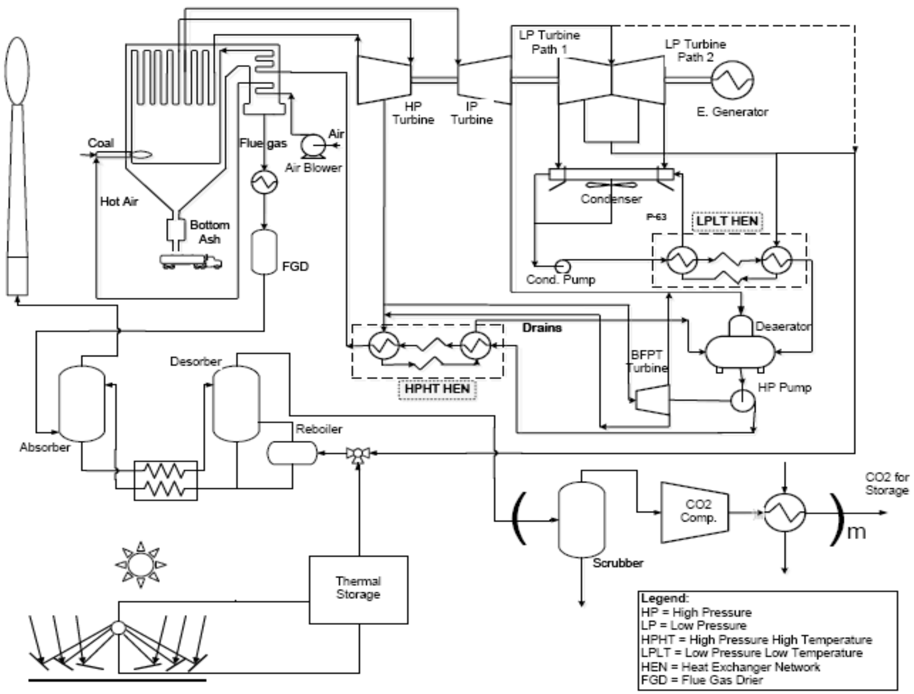
Accomplishments

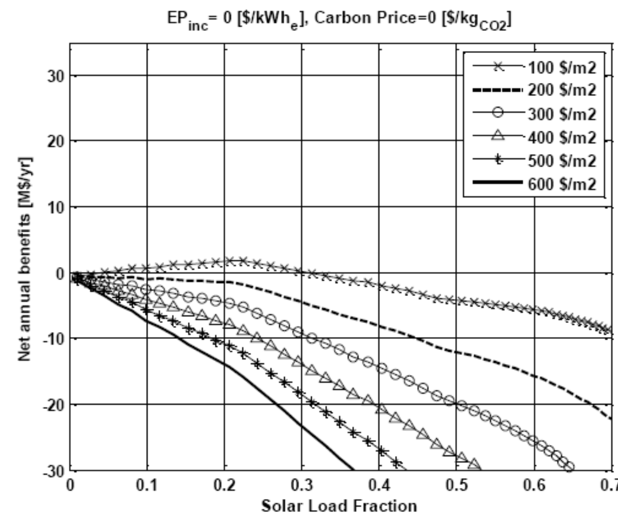
- A methodology for the assessment of solar cooling technologies was proposed.
- A study on the feasibility of several solar cooling was performed.
- A model for the prediction of cooling demand from electricity consumption

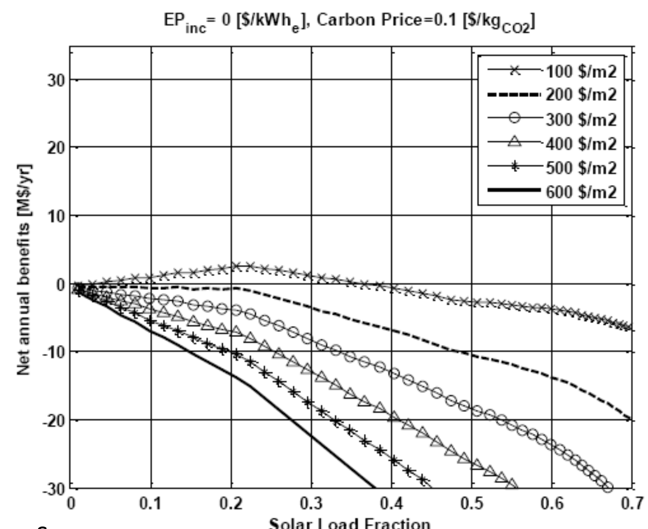
M. T. Ali, M. Mokhtar, M. Chiesa, P. R Armstrong "Weather Driven Multivariate Regression Modeling for Estimation of Electrical Cooling Load" Accepted for Publication in *Energy and Buildings* (2010)

M. Mokhtar, M. T. Ali, S. Braeuniger, A. Afshari, S. Sgouridis, P. R Armstrong and M. Chiesa, "Economic and Technical Assessment of Solar Cooling Technologies Case Study of Abu Dhabi, UAE" *Applied Energy* (2010), doi:10.1016/j.apenergy.2010.06.026

Solar-Assisted Post-Combustion Carbon Capture







- Obstacle in widely deploying PCCC is the power plant load reduction
- We propose and evaluate a system to reduce the output energy penalty by providing part of the PCC energy input using solar thermal energy.

M. Mokhtar, M.T. Ali, R. K., A. Abbas, N. Shah, A. Al Hajaj, P. Armstrong, M. Chiesa, S. Sgouridis "**Solar-Assisted Post Combustion Carbon Capture Feasibility Study**" Accepted with minor changes in *Applied Energy 2011*

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