

Solar Energy Deployment in the UAE:

The role of the Masdar Institute

Laboratory for Energy and Nano Science , Masdar Institute Abu Dhabi

M. Chiesa



- Solar Resource Assessment
- The effect of CSR (Circum-Solar Ratio)
- Power Demand in the UAE
- Smart design of solar power plant: Shams 1
- The role of Masdar Institute

Solar Energy Deployment in the UAE:

The role of the Masdar Institute

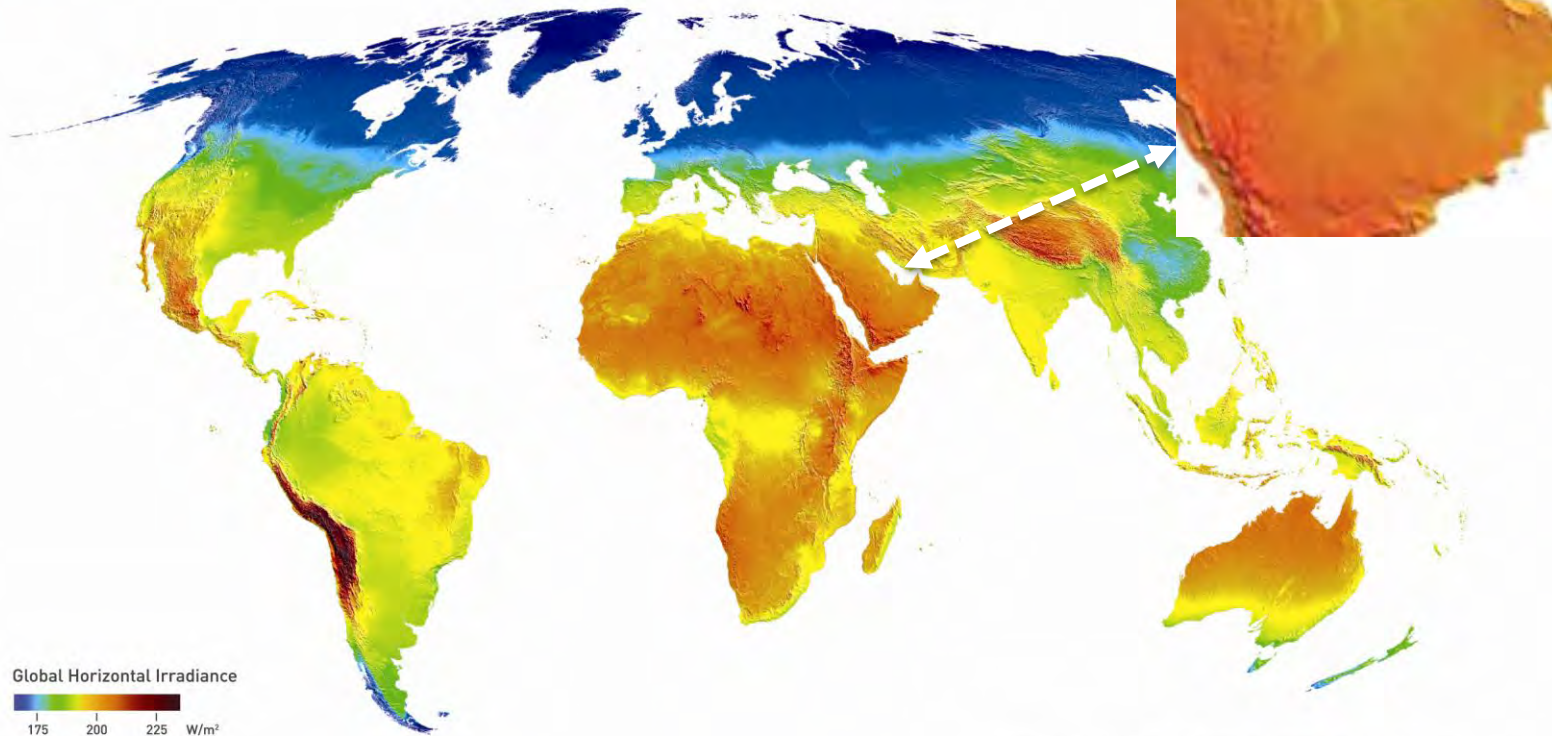


- **Solar Resource Assessment**
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- The role of Masdar Institute

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

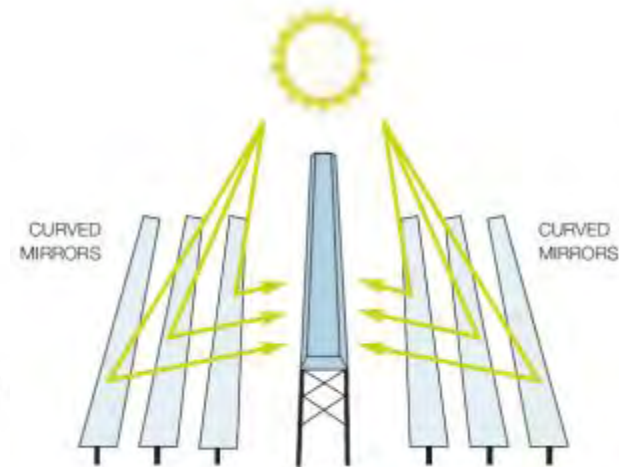
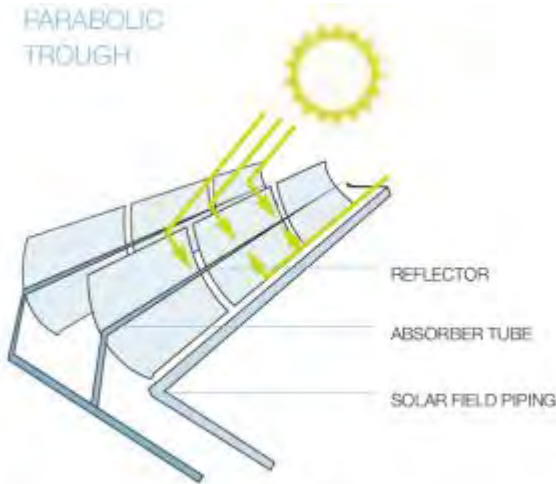
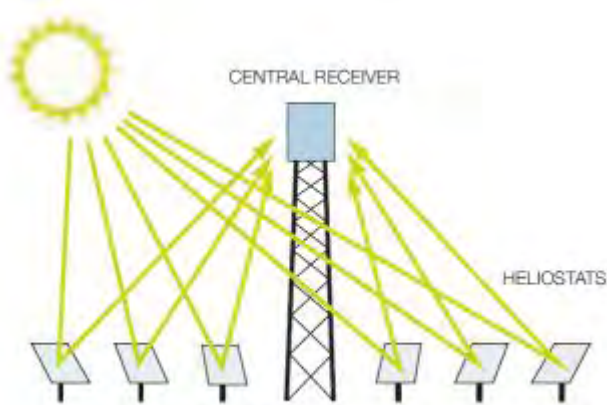


Global Mean Solar Irradiance



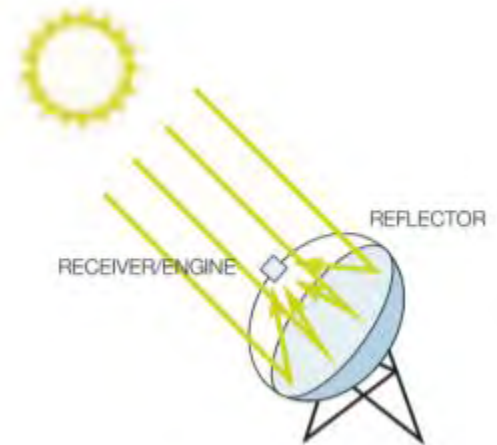
Map developed by 3TIER | www.3tier.com | © 2011 3TIER Inc.

Concentrated Solar Power (CSP)



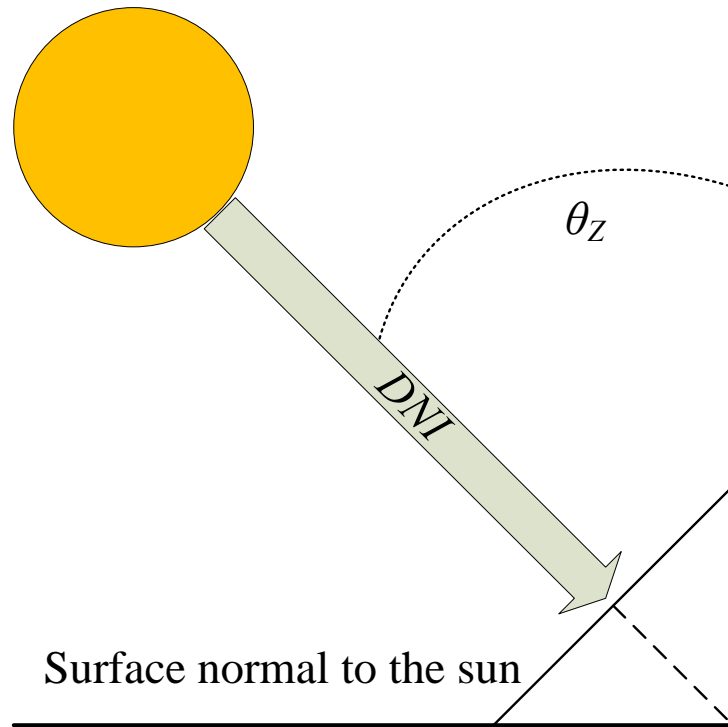
For concentrate solar power, the direct the Direct Normal Irradiance (DNI) is a more relevant measure of the solar resource.

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.

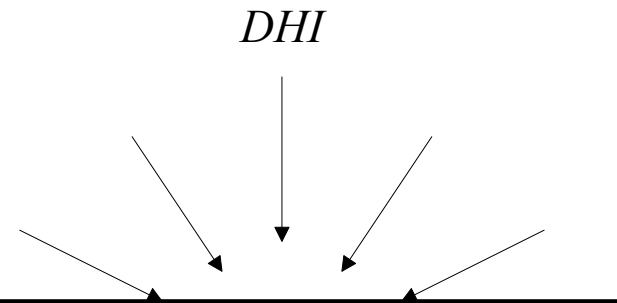


Concentrating Solar Thermal Technologies makes use of DNI

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



$$GHI = DHI + DNI \cos \theta_z$$



Surface

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

19 Feb 2012



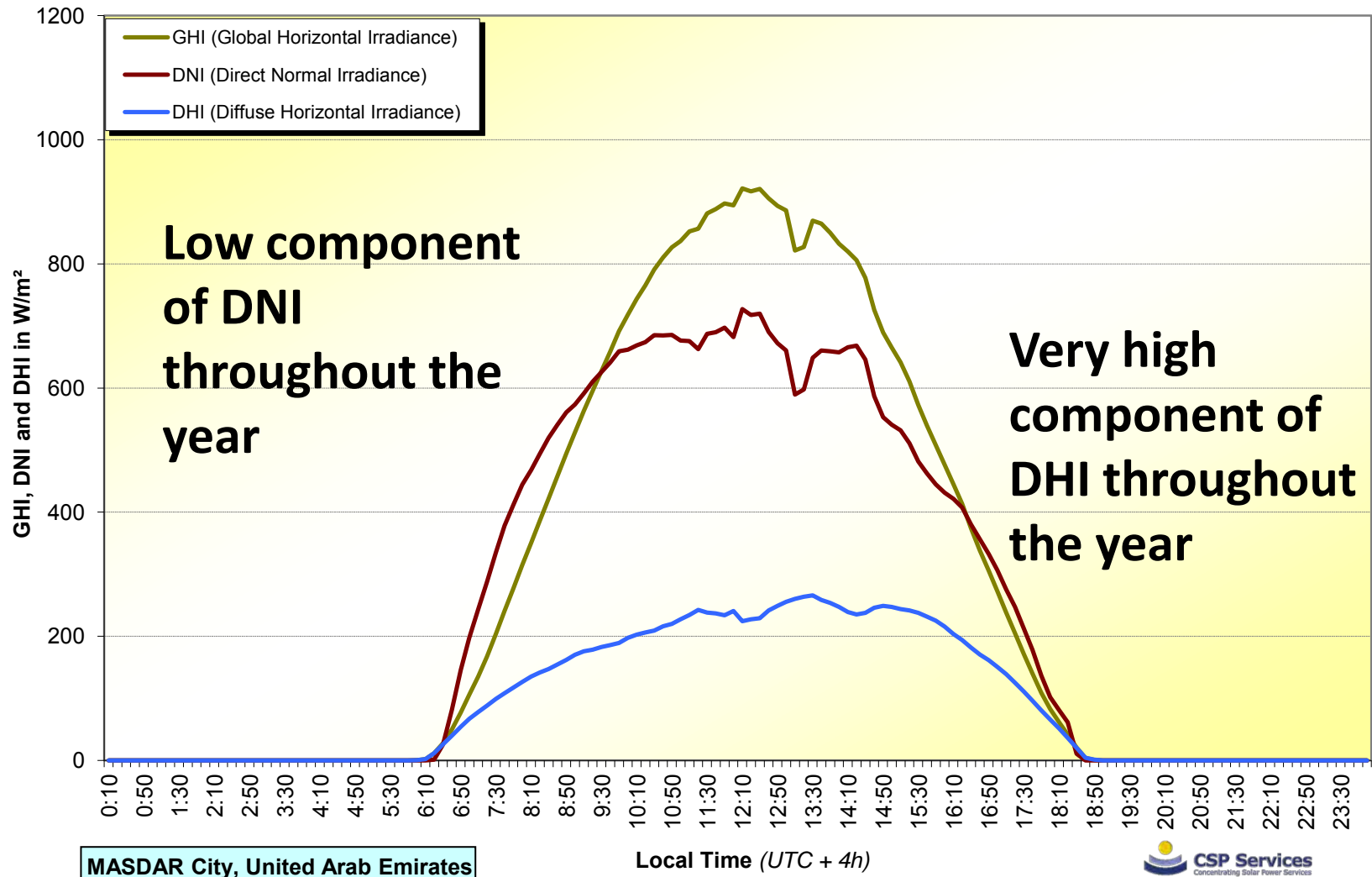
Yearly DNI in the UAE is only
1934 kWh/m²/yr.

Locations in Spain have DNI from
2,000-2,300 kWh/m²/yr, and the
best location in the U.S. Southwest
have DNI of **2,800 kWh/m²/yr**



19 Feb 2012

Ground Data Measurements

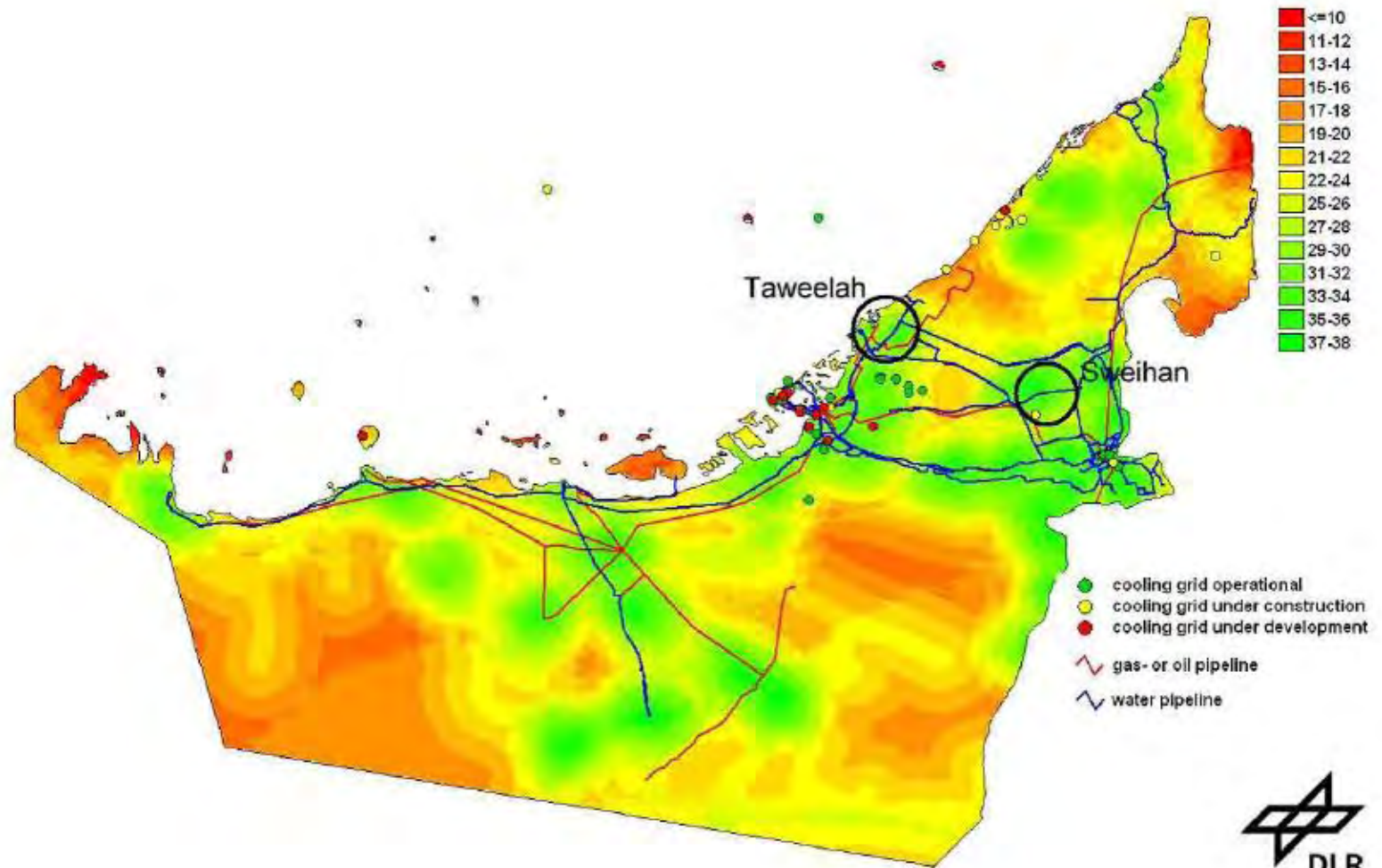


MASDAR City, United Arab Emirates

CSP Services
Concentrating Solar Power Services



Utilities Mapping added on solar assessment by DLR



Ground data Measuring equipment



K+Z alt-azimuth tracker



EKO tracker



Radiometer Platform

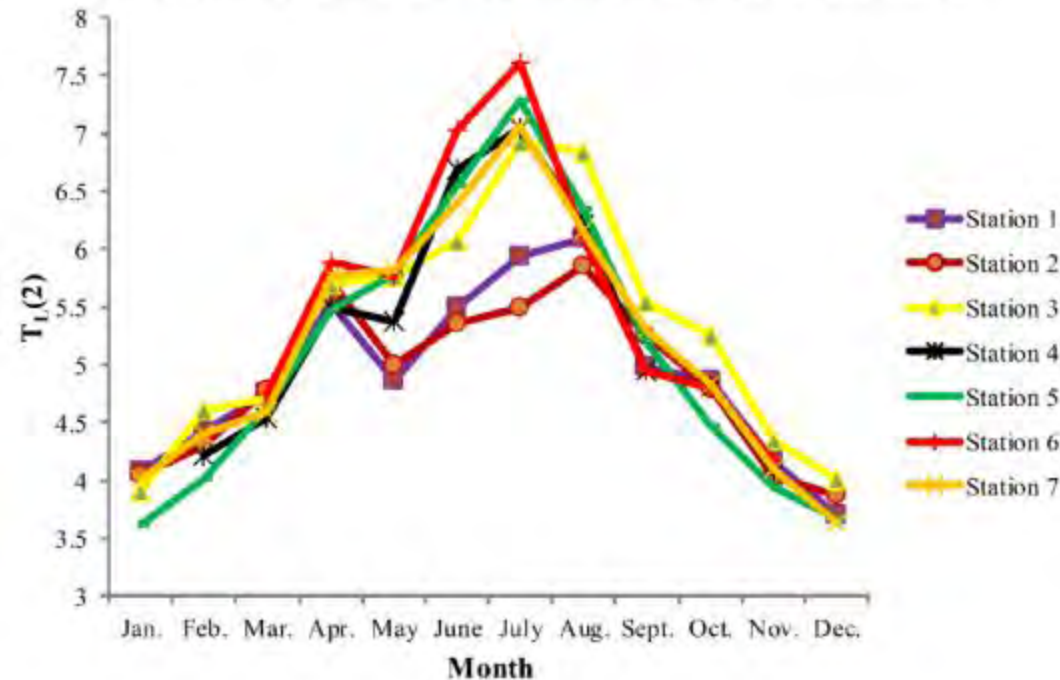


SAM

Satellite Solar Maps vs. Ground Data Measurements



Linke Turbidity Factor Variance Throughout the Year Over the UAE



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 aerosol 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

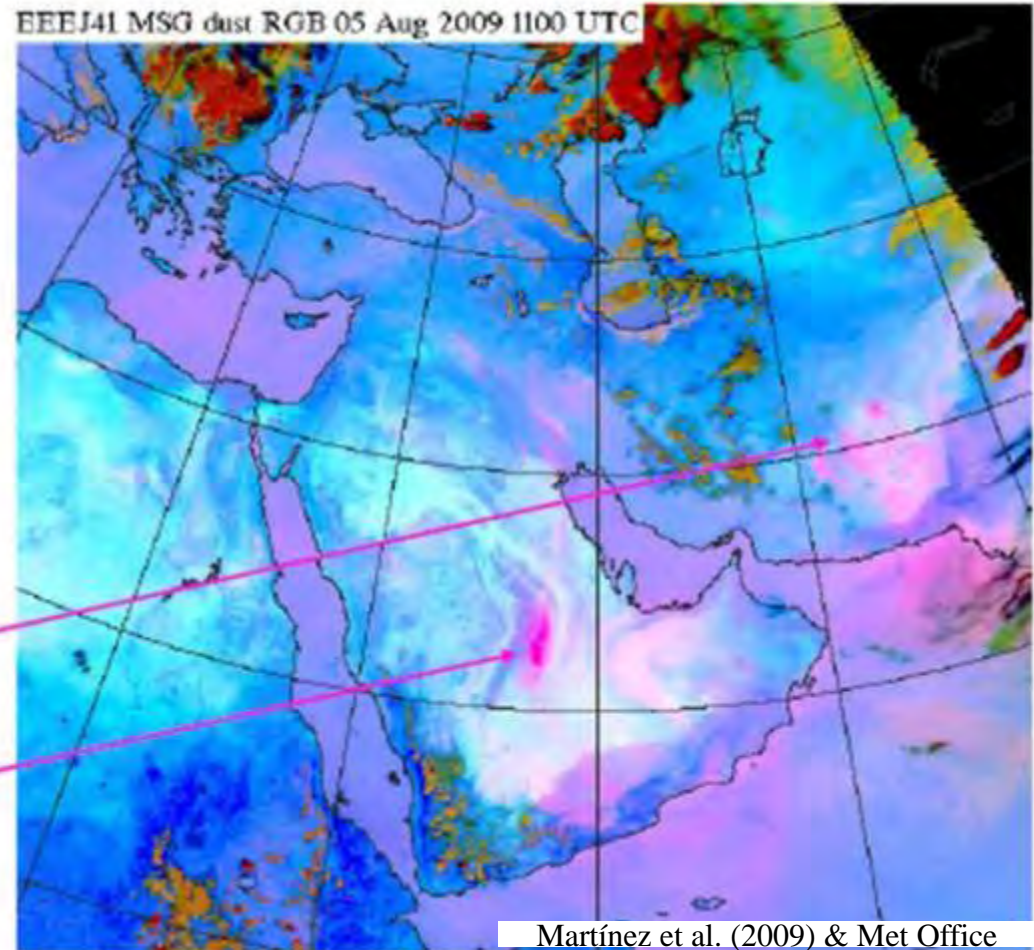
Colour composite

RED = $T_{10} - T_{09}$

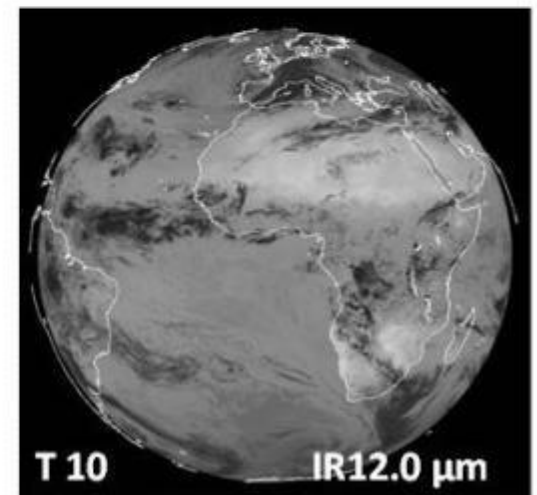
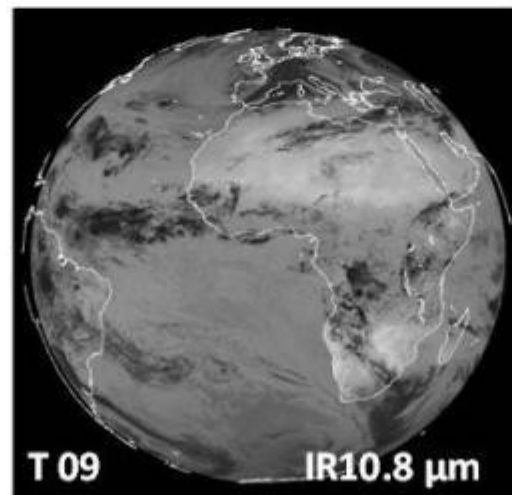
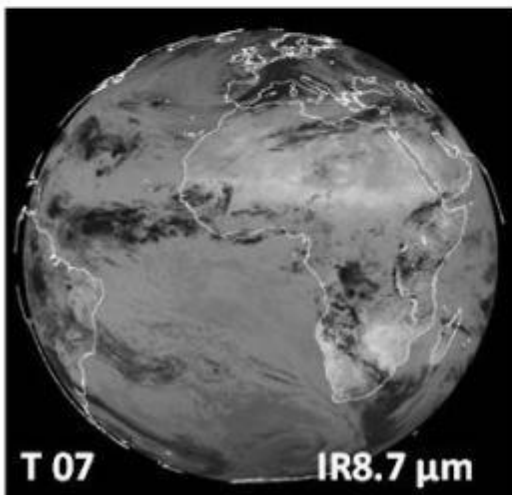
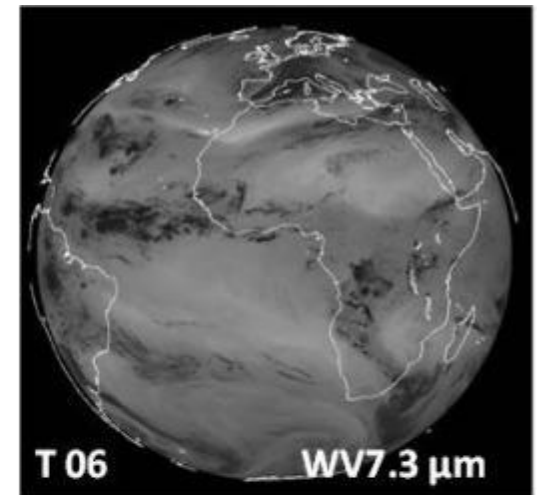
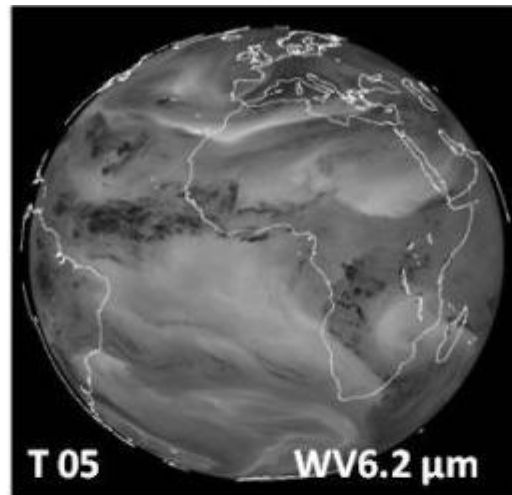
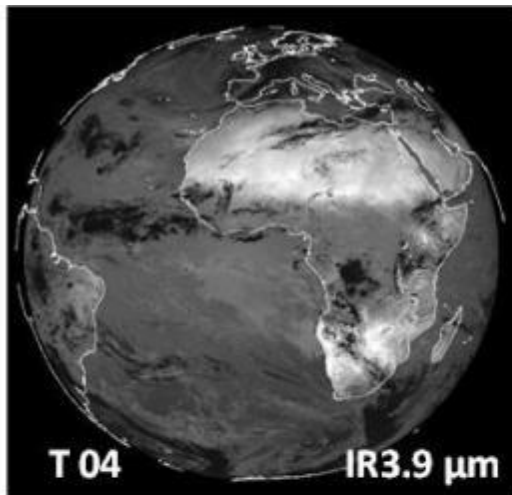
GREEN = $T_{09} - T_{07}$

BLUE = T_{09}

striking magenta
indicates dust



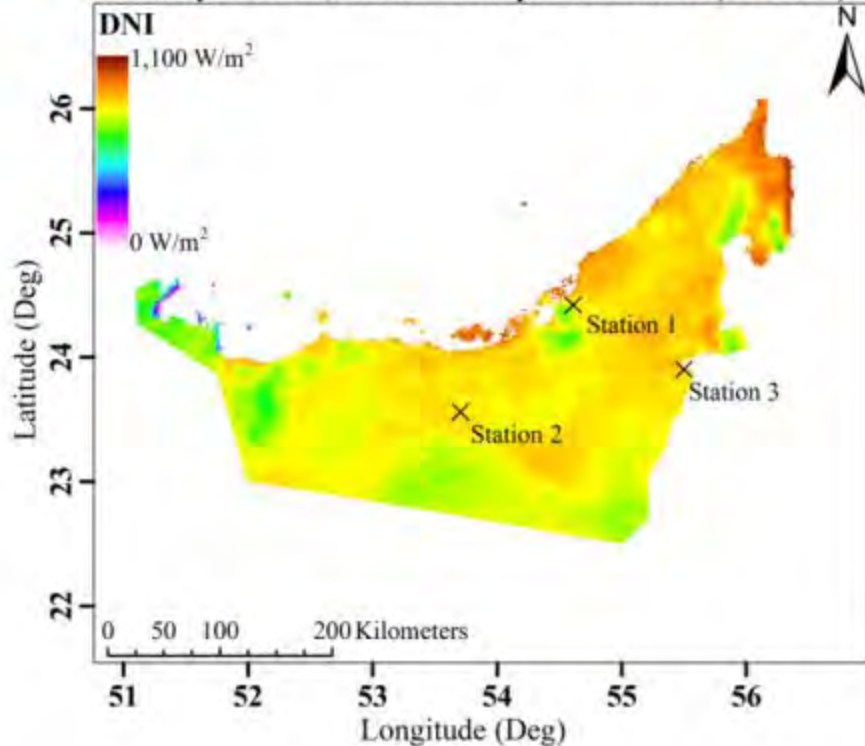
Choice of Thermal Channels



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

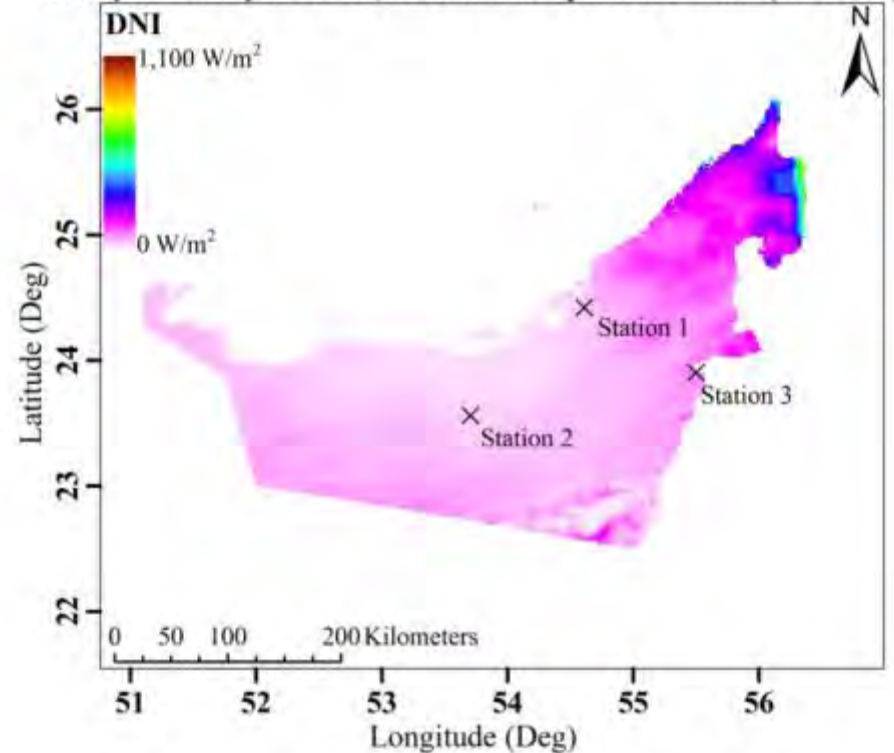
DNI Map over the UAE

Clear Day: Feb. 05, 2009 at 12:15pm UAE Time (+4 GMT)



DNI Map over the UAE

Heavy Dust Day: Feb. 12, 2009 at 12:15pm UAE Time (+4 GMT)

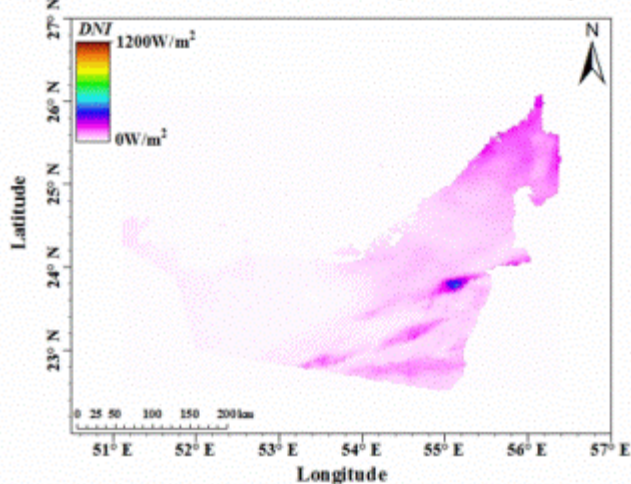


Spatial Variations: Heavy Dusty Day

9:00AM

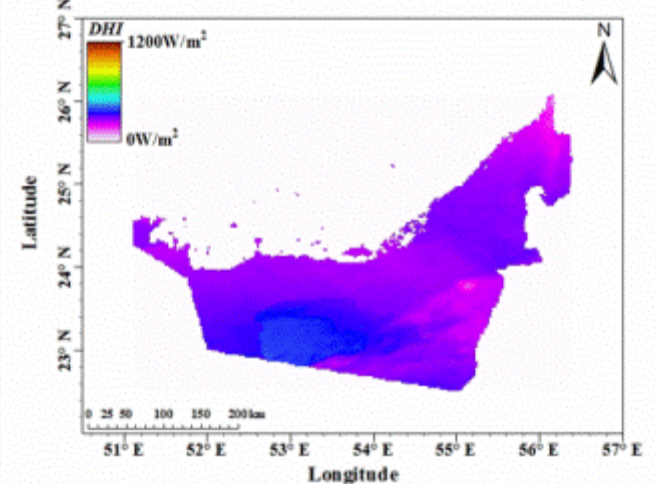
DNI Map on Heavy Dusty Day: Feb. 12, 2009

8:45AM - 4:15PM UAE Time (15-min resolution)



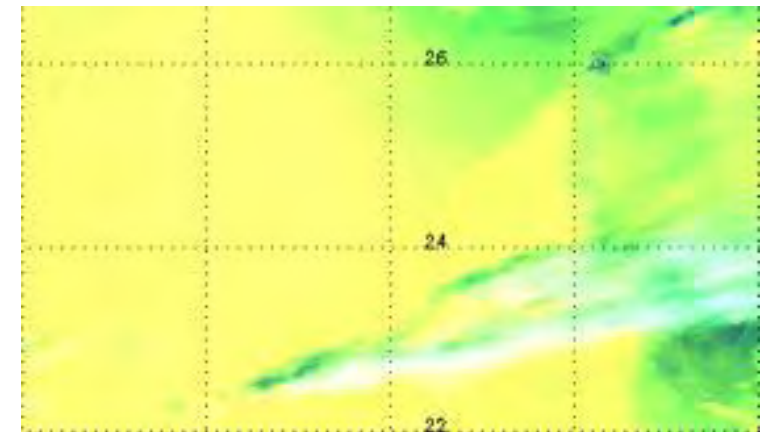
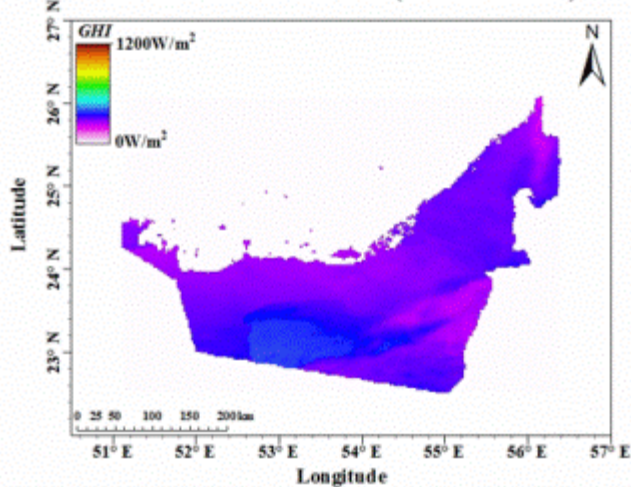
DHI Map on Heavy Dusty Day: Feb. 12, 2009

8:45AM - 4:15PM UAE Time (15-min resolution)



GHI Map on Heavy Dusty Day: Feb. 12, 2009

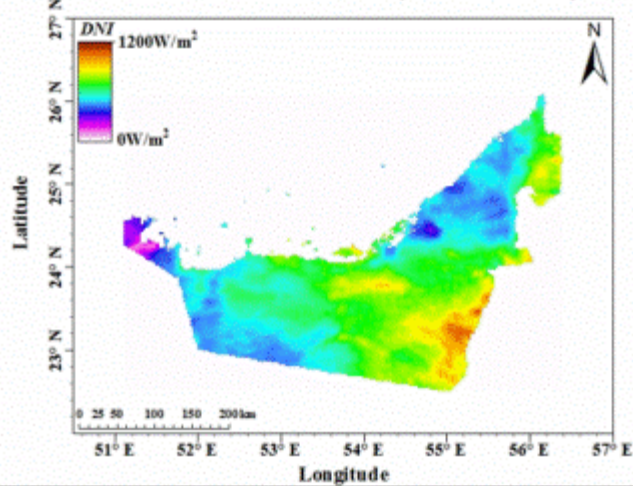
8:45AM - 4:15PM UAE Time (15-min resolution)



Spatial Variations: Moderate Dusty Day

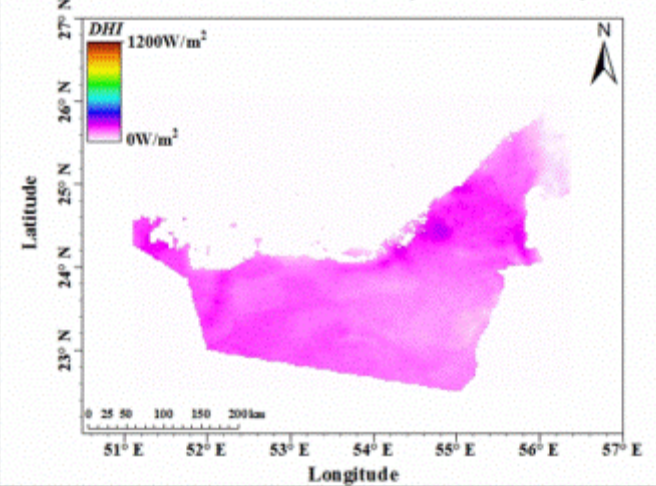
DNI Map on Moderate Dusty Day: Feb. 28, 2009

8:30AM - 5:00PM UAE Time (15-min resolution)



DHI Map on Moderate Dusty Day: Feb. 28, 2009

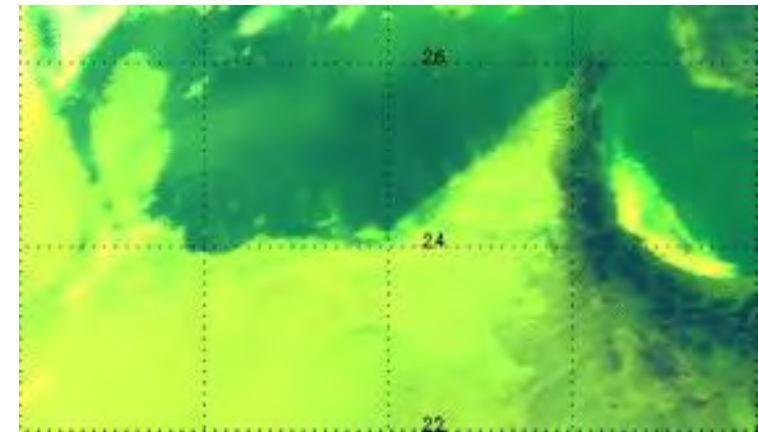
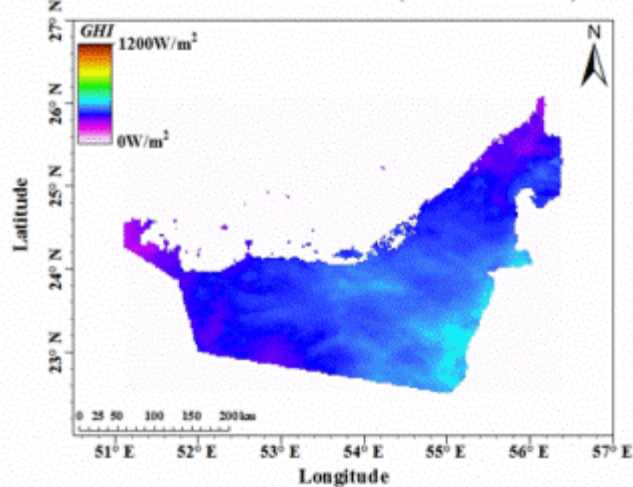
8:30AM - 5:00PM UAE Time (15-min resolution)



8:45AM

GHI Map on Moderate Dusty Day: Feb. 28, 2009

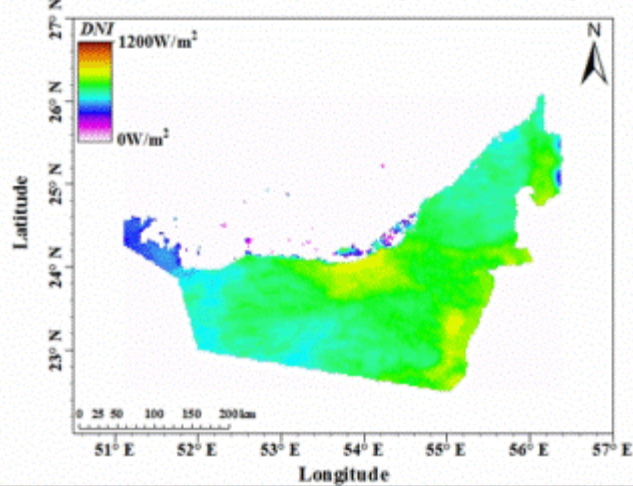
8:30AM - 5:00PM UAE Time (15-min resolution)



Spatial Variations: Clear Day

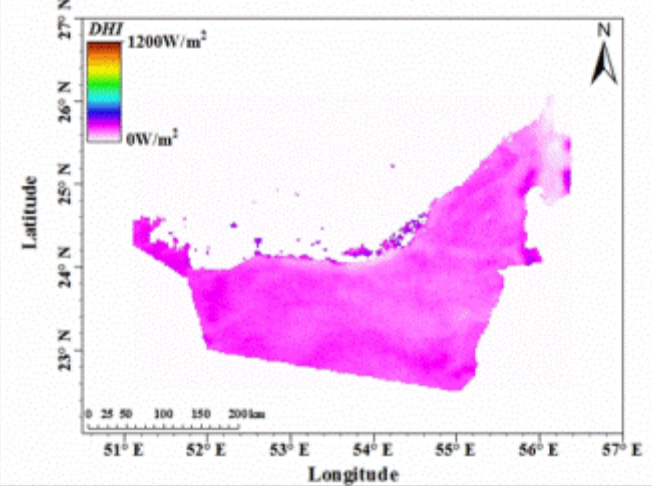
DNI Map on Clear Day: May 28, 2009

7:15AM - 5:15PM UAE Time (15-min resolution)



DHI Map on Clear Day: May 28, 2009

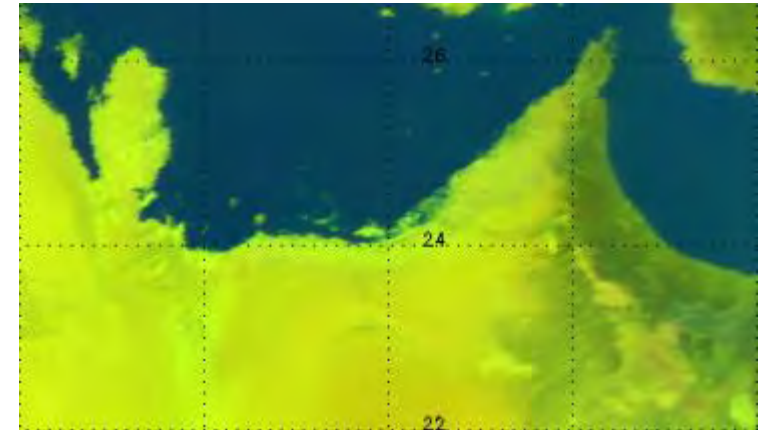
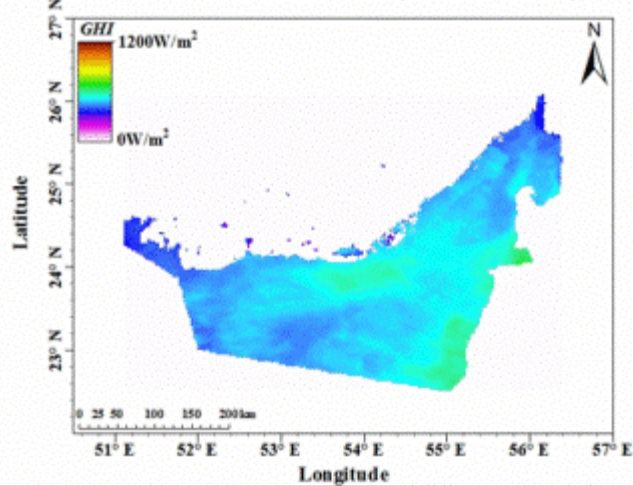
7:15AM - 5:15PM UAE Time (15-min resolution)



8:15AM

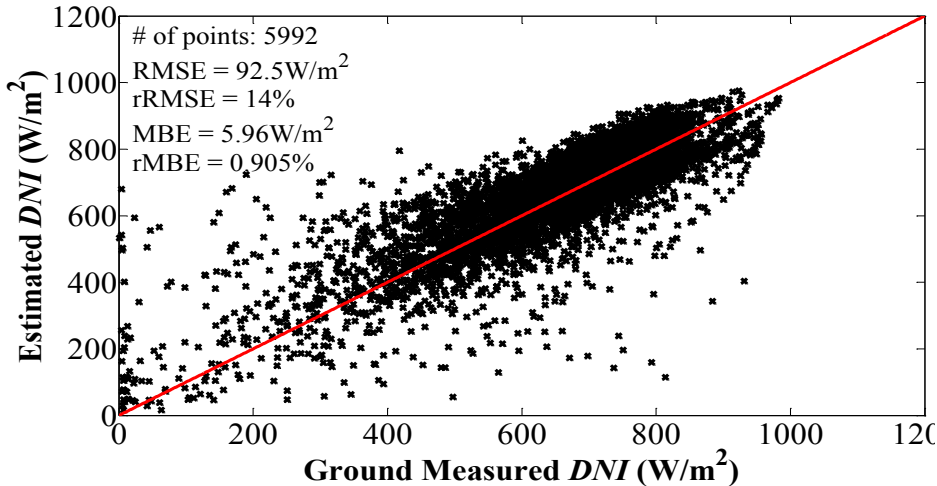
GHI Map on Clear Day: May 28, 2009

7:15AM - 5:15PM UAE Time (15-min resolution)

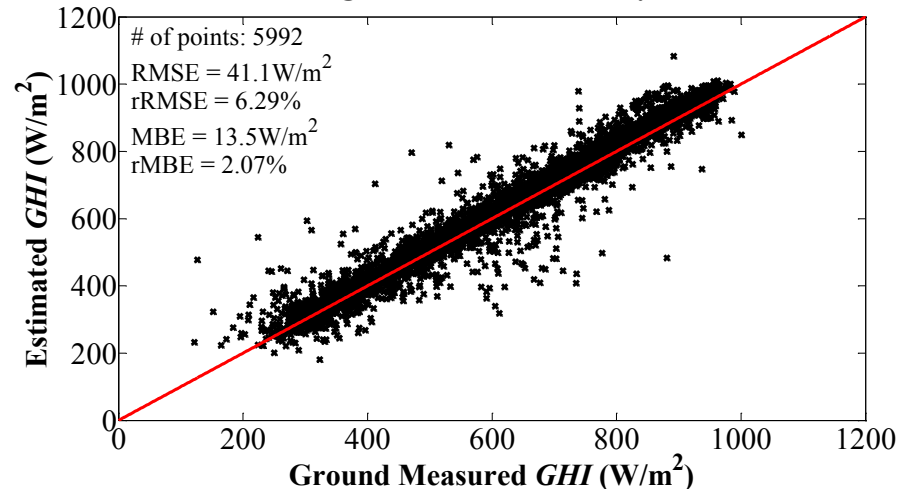


DNI & GHI Estimation Scatter Plots

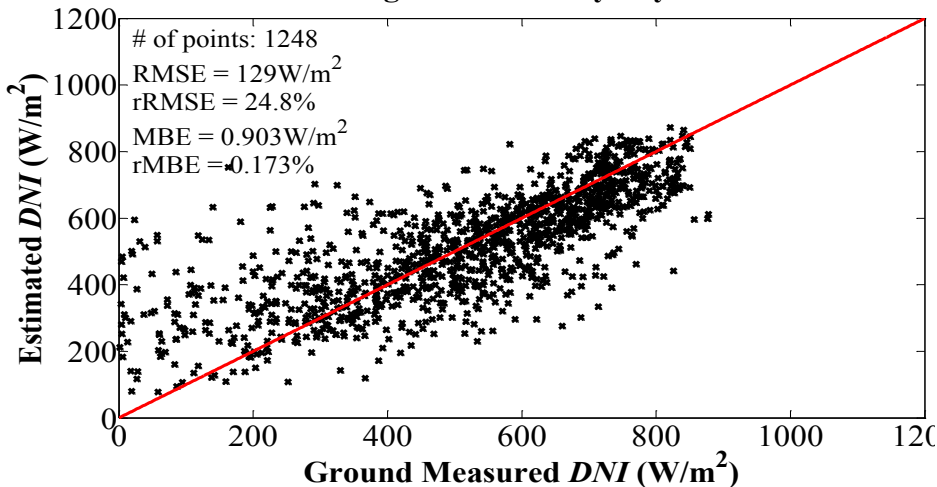
a) Estimated versus Measured DNI
Testing Set for Cloud-free Sky Case



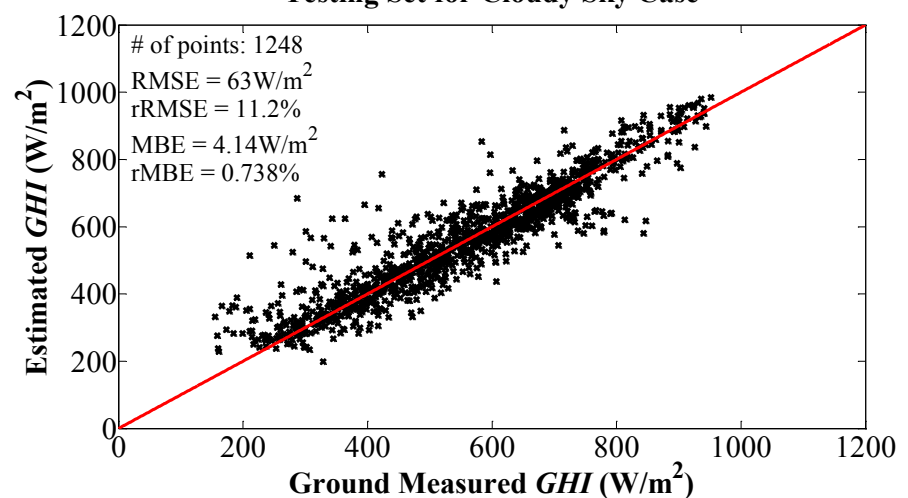
a) Estimated versus Measured GHI
Testing Set for Cloud-free Sky Case



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



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



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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.



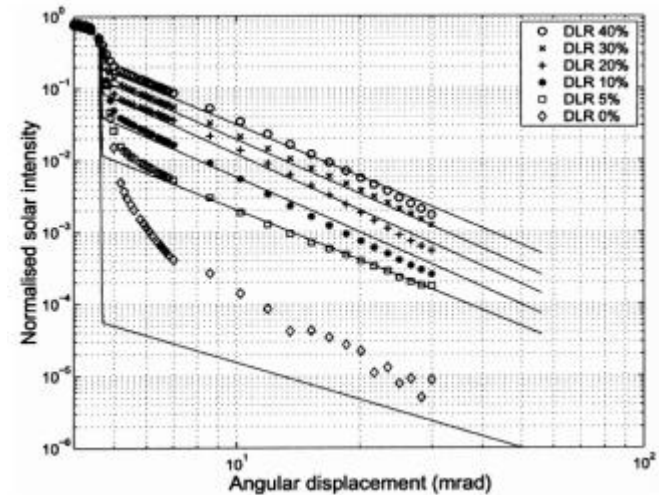
The SAM is a tracking camera in which the circumsolar image is captured by a CCD camera. This gives a measure of atmospheric scattering of direct solar radiation.

Effect of Sun Shape on CSP Technology



$$CSR = \frac{\Phi_{Circumsolar}}{\Phi_{SolarDisk} + \Phi_{Circumsolar}}$$

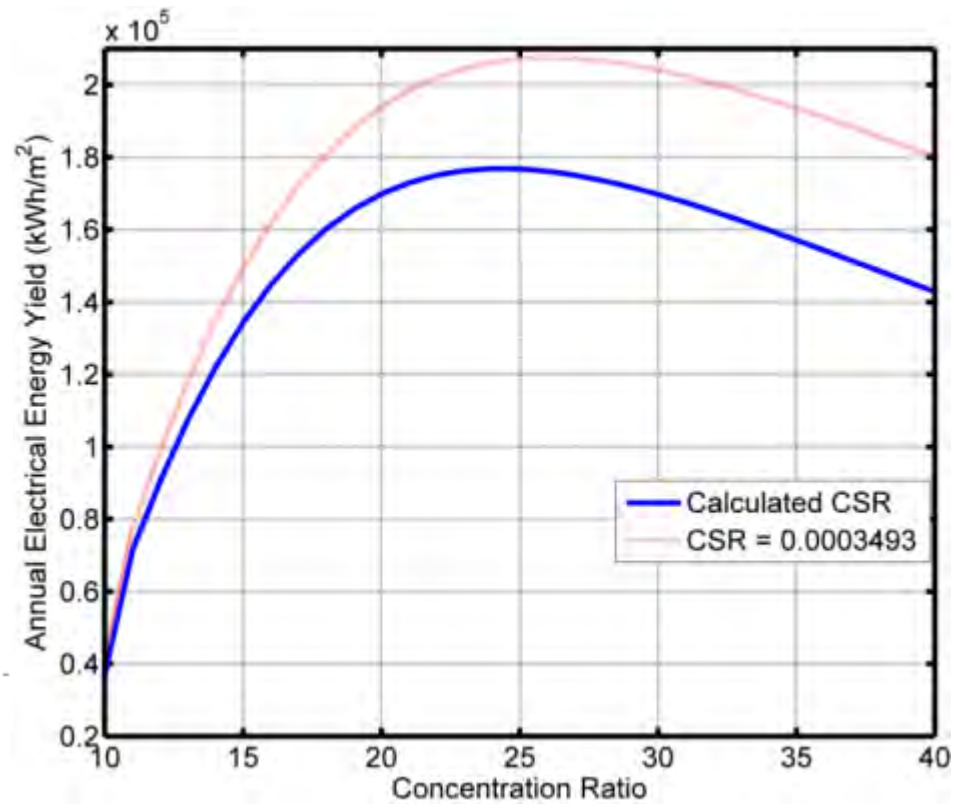
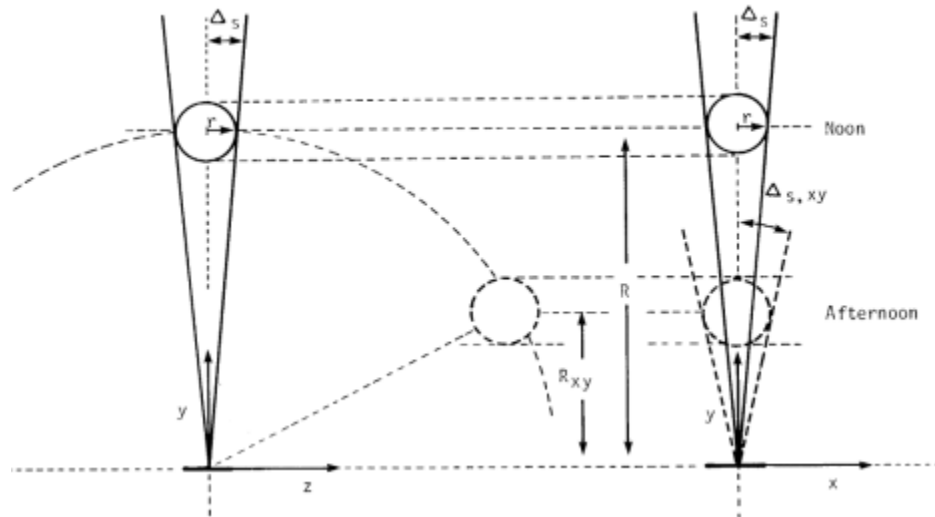
Sun Edge Angle: $0.266^\circ \approx 4.64 \text{ mrad}$
 Aureole Extends till: $3^\circ - 4^\circ \approx 52 - 70 \text{ mrad}$



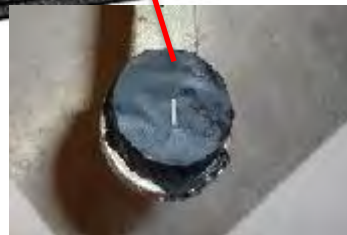
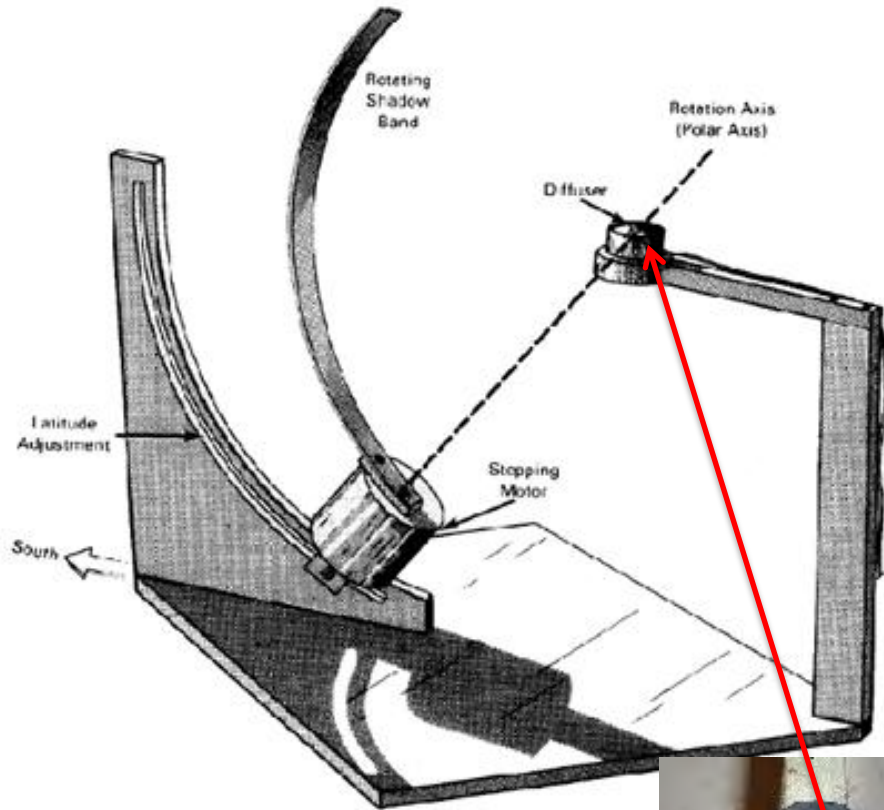
- ❑ Concentrating solar collectors are designed with angular acceptance angles which are relatively close to the angular size of the solar disk 0.266° . (maximization of the capture radiation and minimization of the thermal radiation from the receiver)
- ❑ Concentrated technology make use of the direct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

Effect of CSR on power output of euro troughs

$$CSR = \frac{\Phi_{Circumsolar}}{\Phi_{SolarDisk} + \Phi_{Circumsolar}}$$



Sunshape Profiling Irradiometer



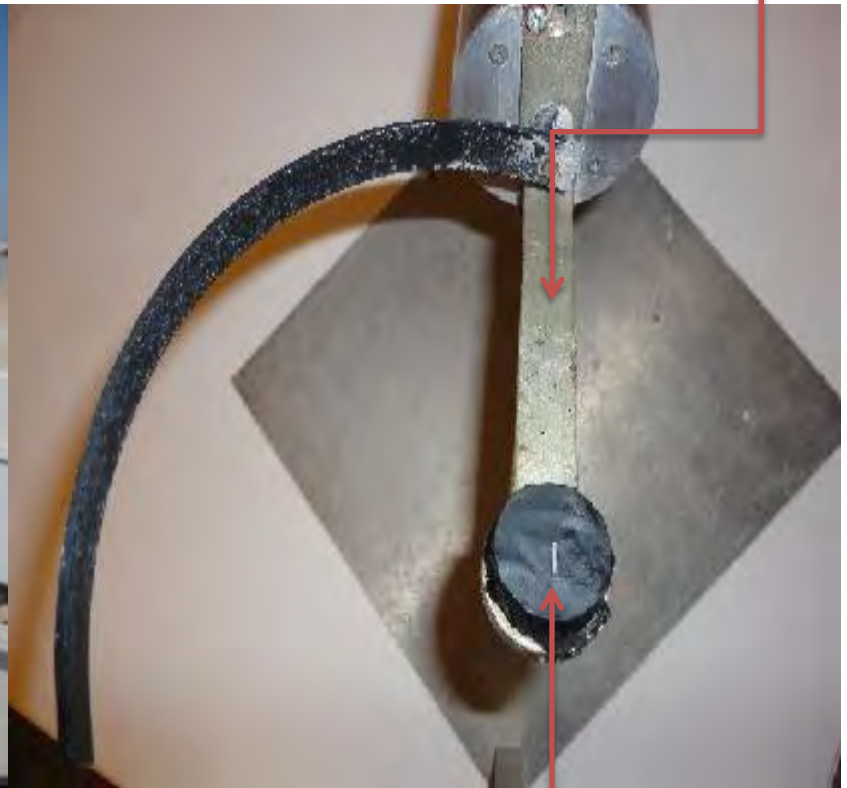
- Low cost (like RSB)
- Reliable unattended operation (like RSB)
- Simple alignment and operation
- (Aerosol optical depth in several wavelength bands)
- (Circumsolar radiation profile in several wavelength bands)

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

Sunshape Profiling Irradiometer

Shadowband

Bracket holding the Receiver



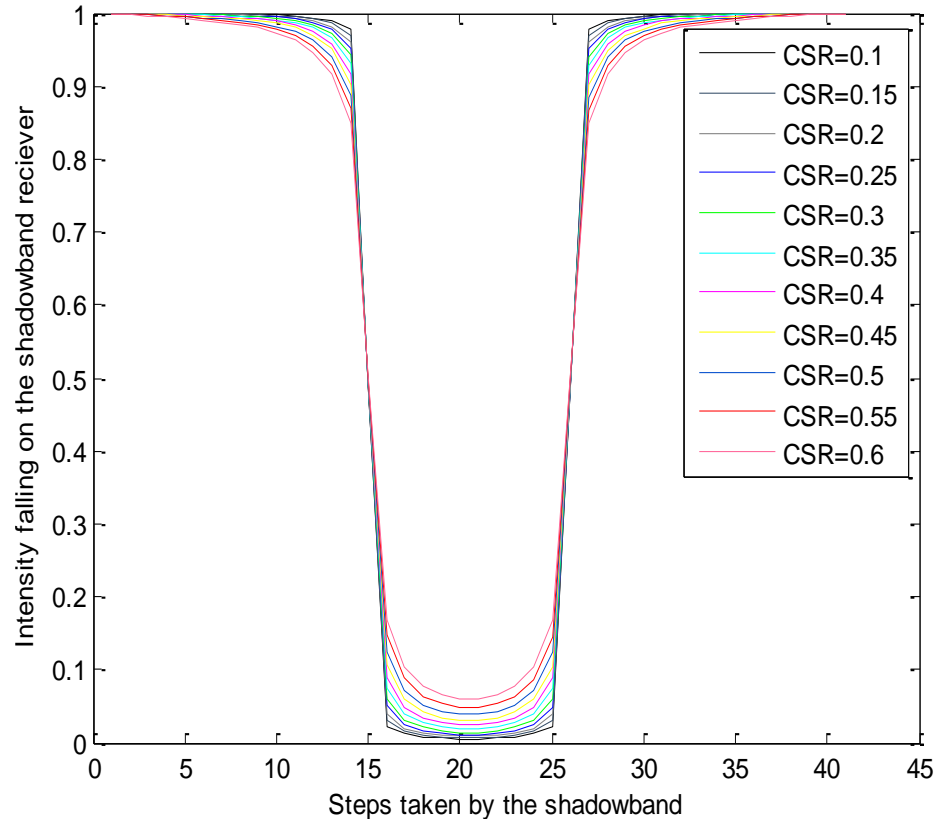
Stepper Motor

Latitude Adjustment Bracket

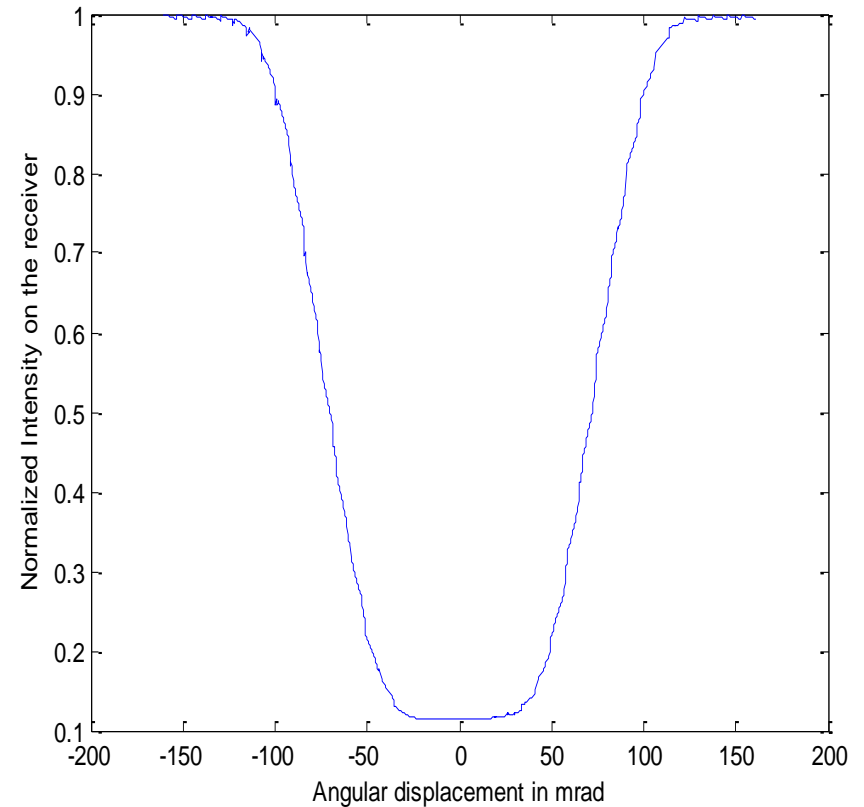
Licor's Receiver

Sunshape Profiling Irradiometer: Preliminary Results

Simulated Shadowband Signal



Slit Receiver Measured Results for all the 27 sweeps and 41 steps



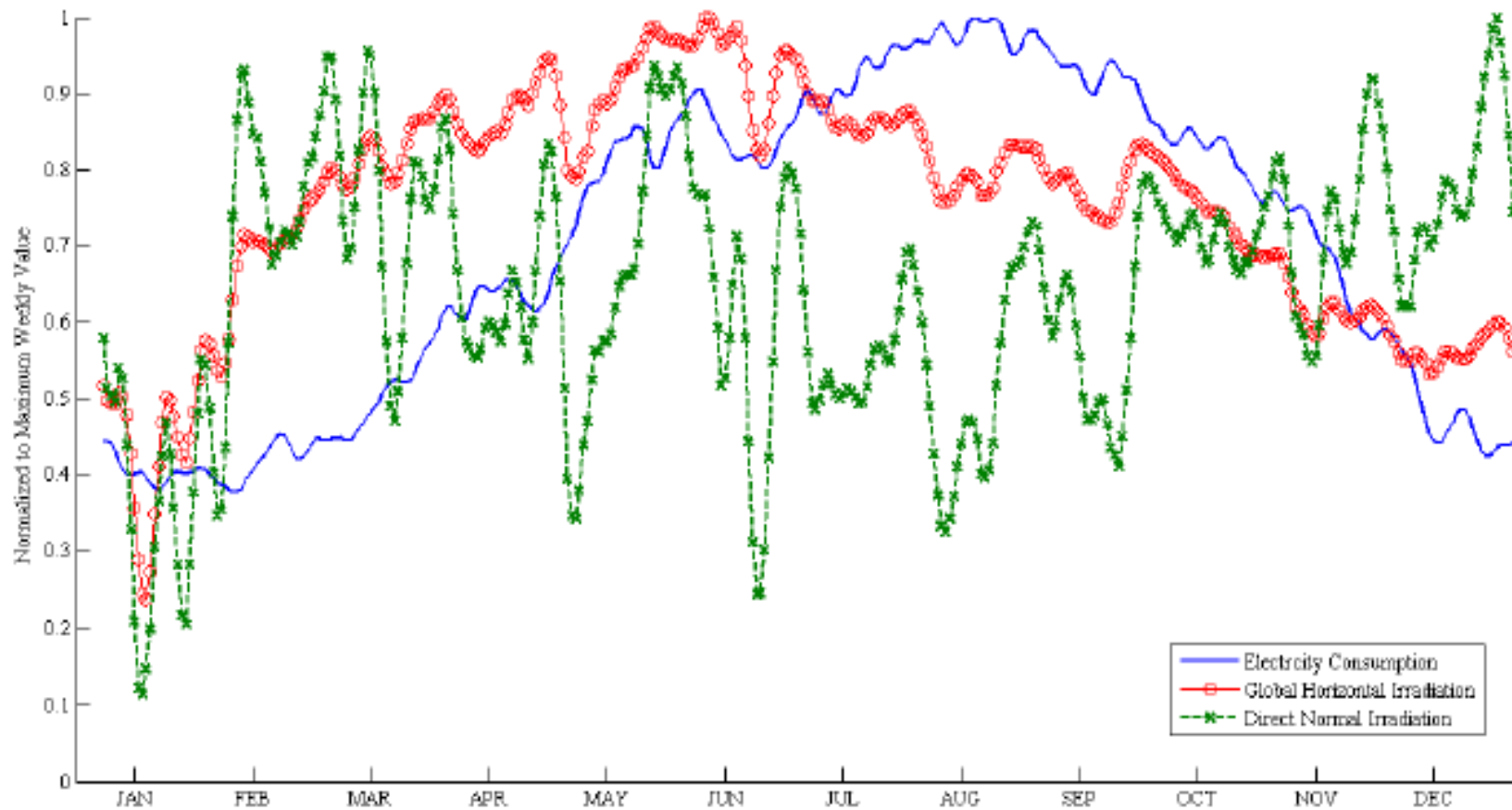
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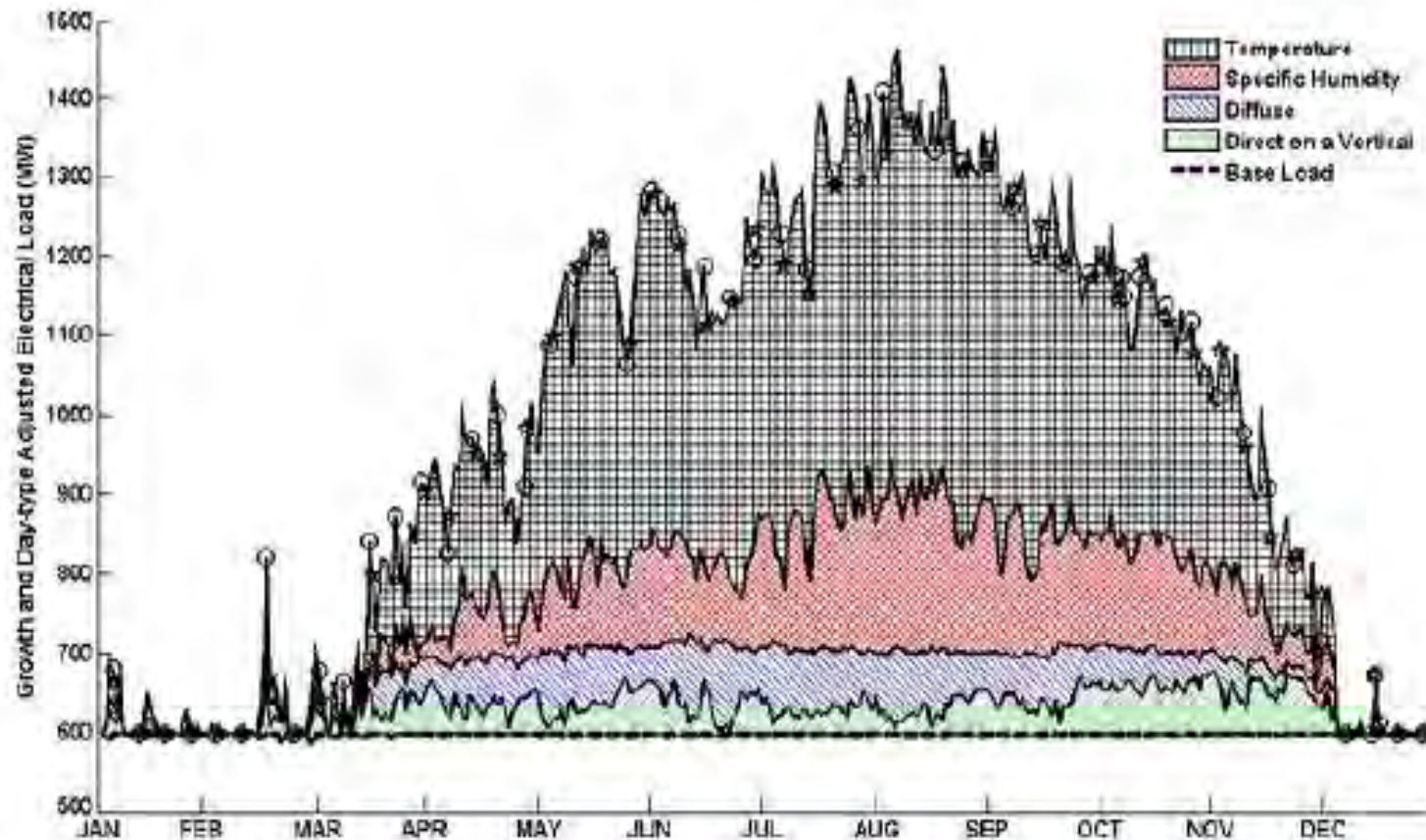


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Demand vs Solar Resources



Power Demand in the UAE: The Abu Dhabi island case

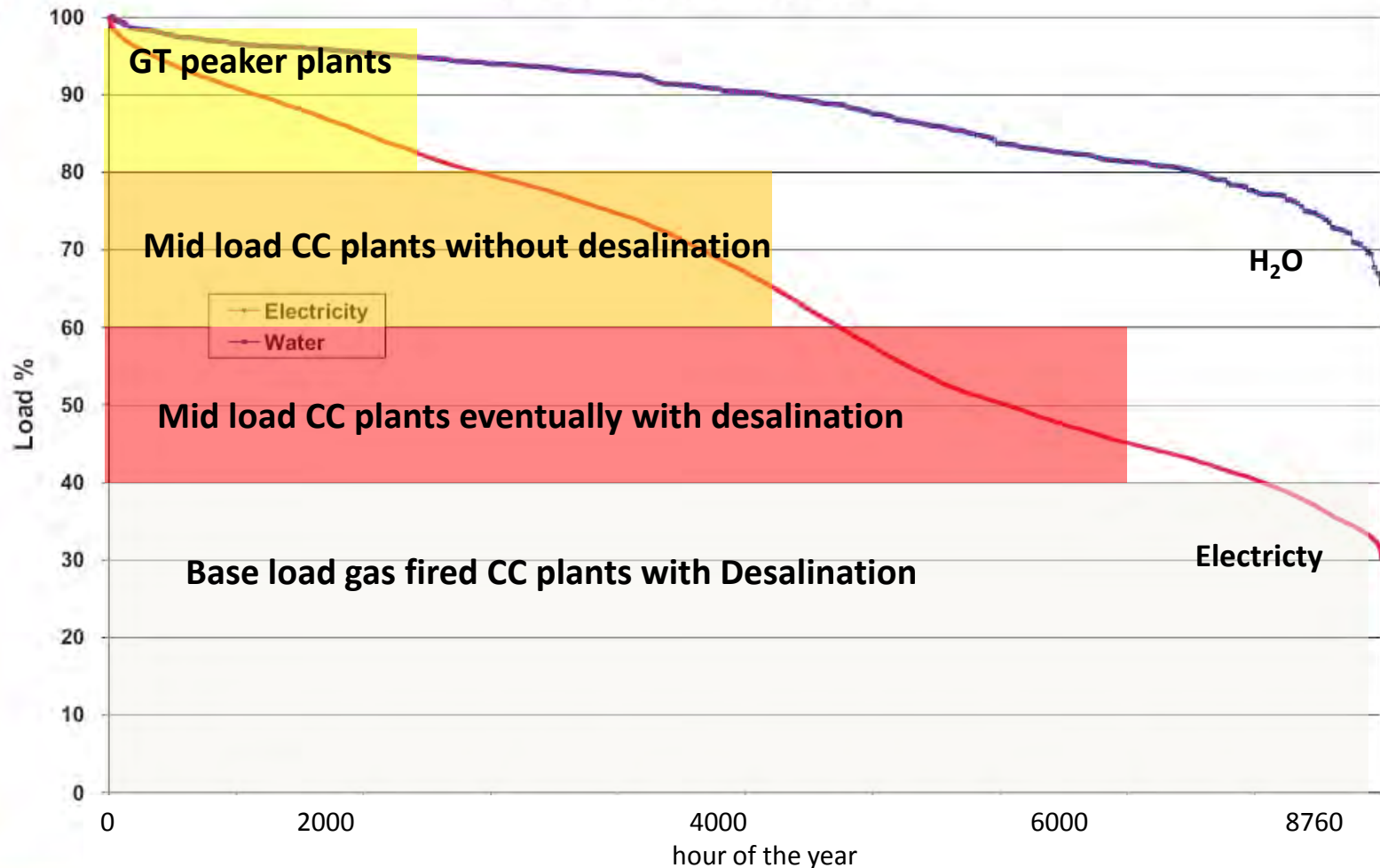


Muhammad Tauha Ali³, Marwan Mokhtar¹, Matteo Chiesa, Peter R Armstrong “[A cooling change-point model of community-aggregate electrical load](#)” *Energy and Buildings* Vol. 43 Issue 1 Pages 28-37, 2011

Today's Power Plant Park to Satisfy the Load Curve

100% = 5 GW in yr 2008.

منحنى الأحمال الزمني للعام ٢٠٠٦
2006 Load Duration Curves



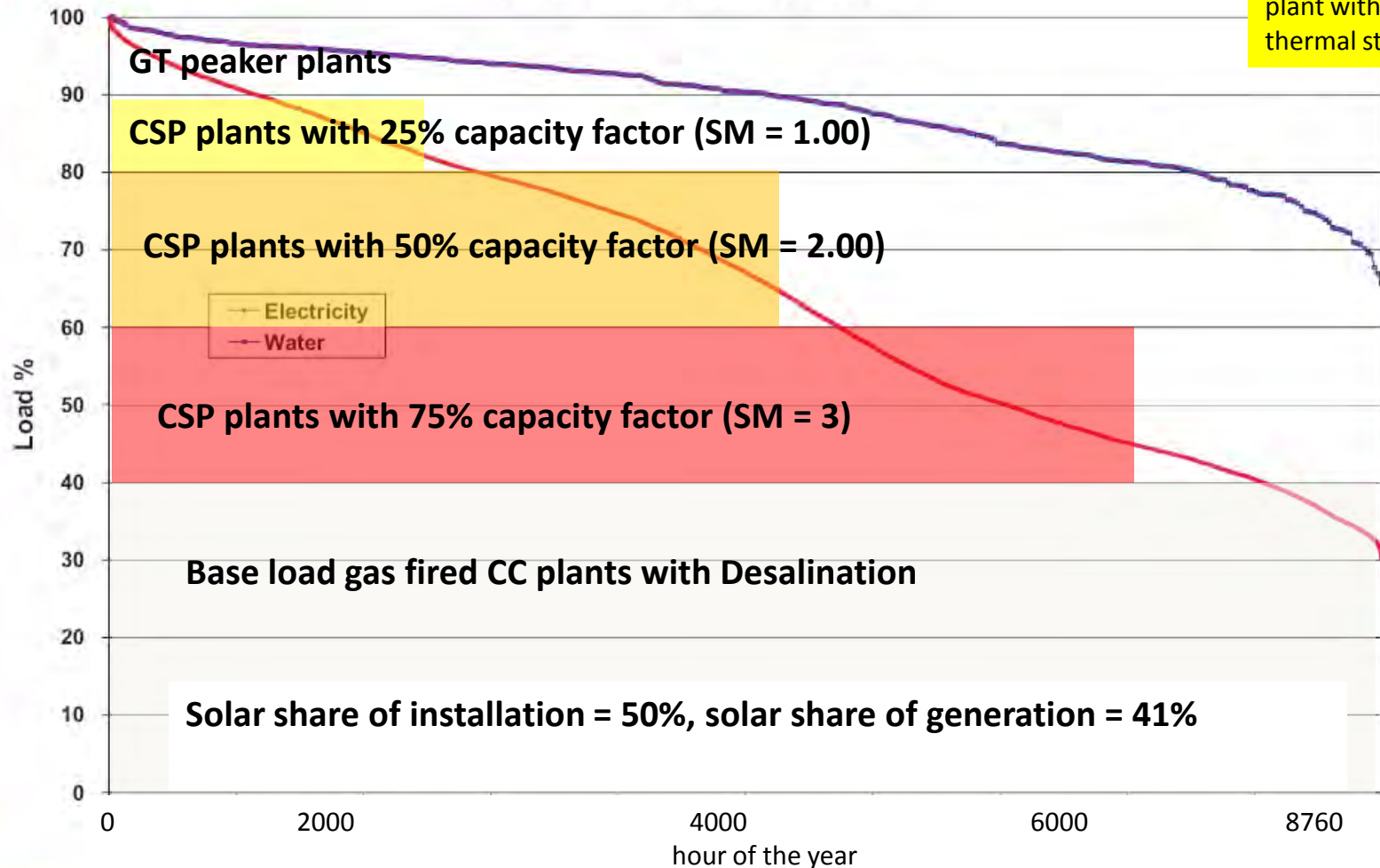
Possible CSP final penetration (beyond 2030)

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

منحنى الأحمال الزمني للعام ٢٠٠٦

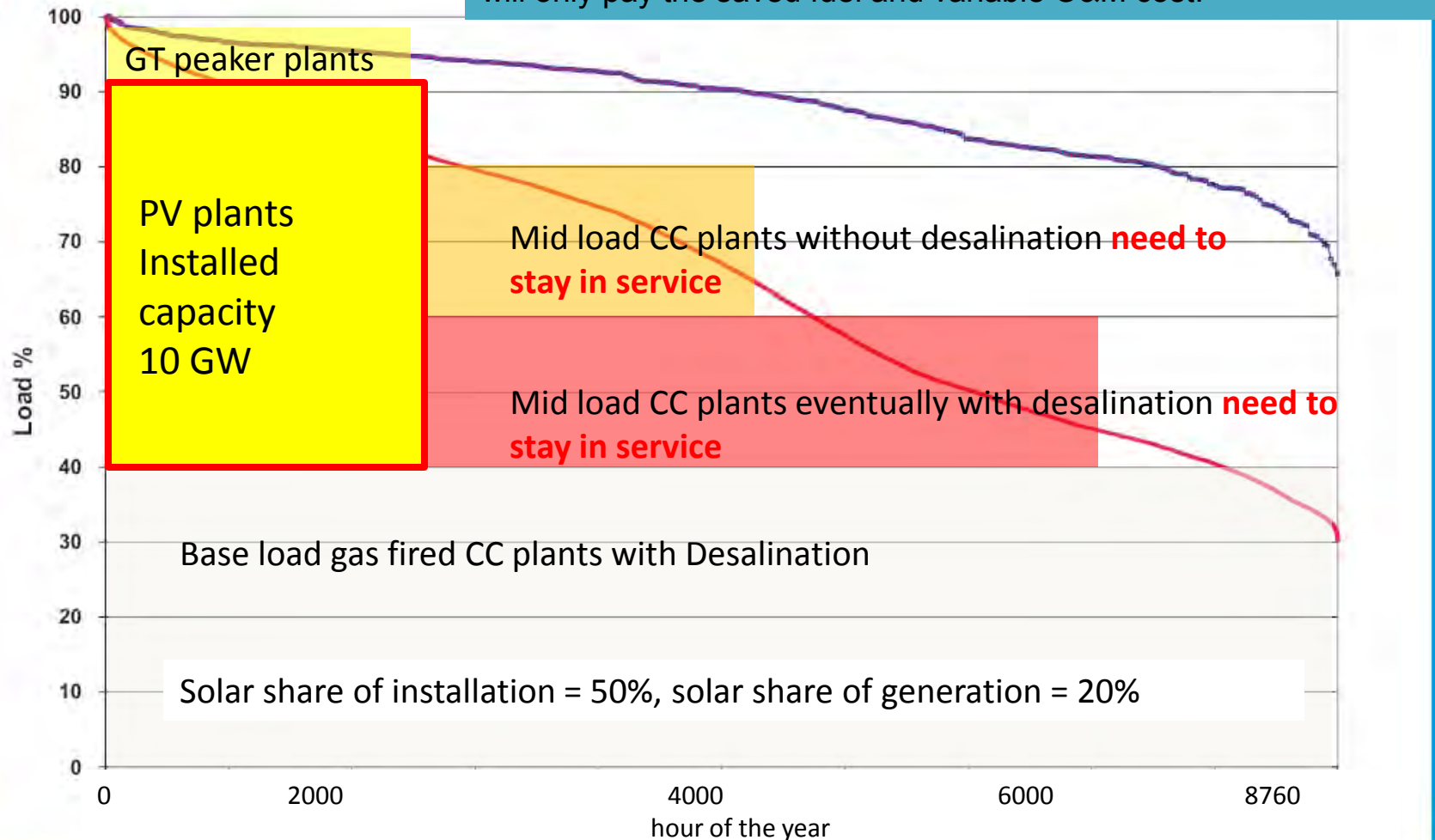
Load Duration Curves



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.



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Shams 1: 110 MW CSP plant

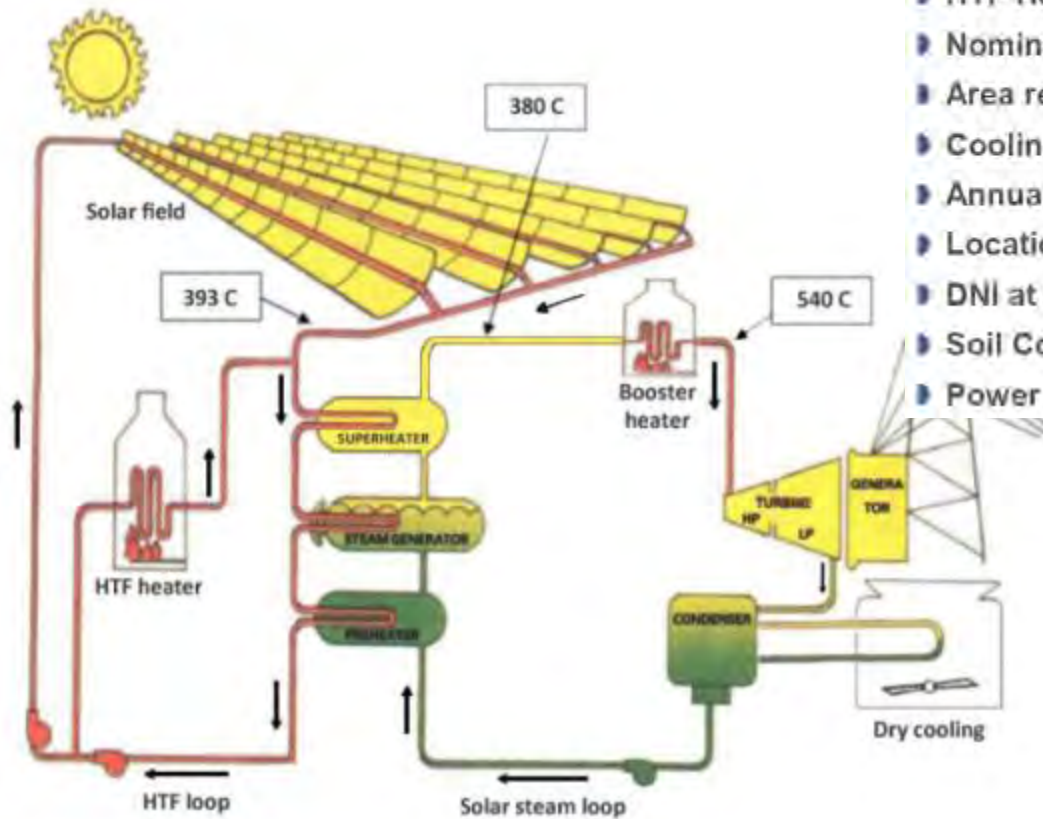


Highway E1-12 Habshan to Liwa Oasis



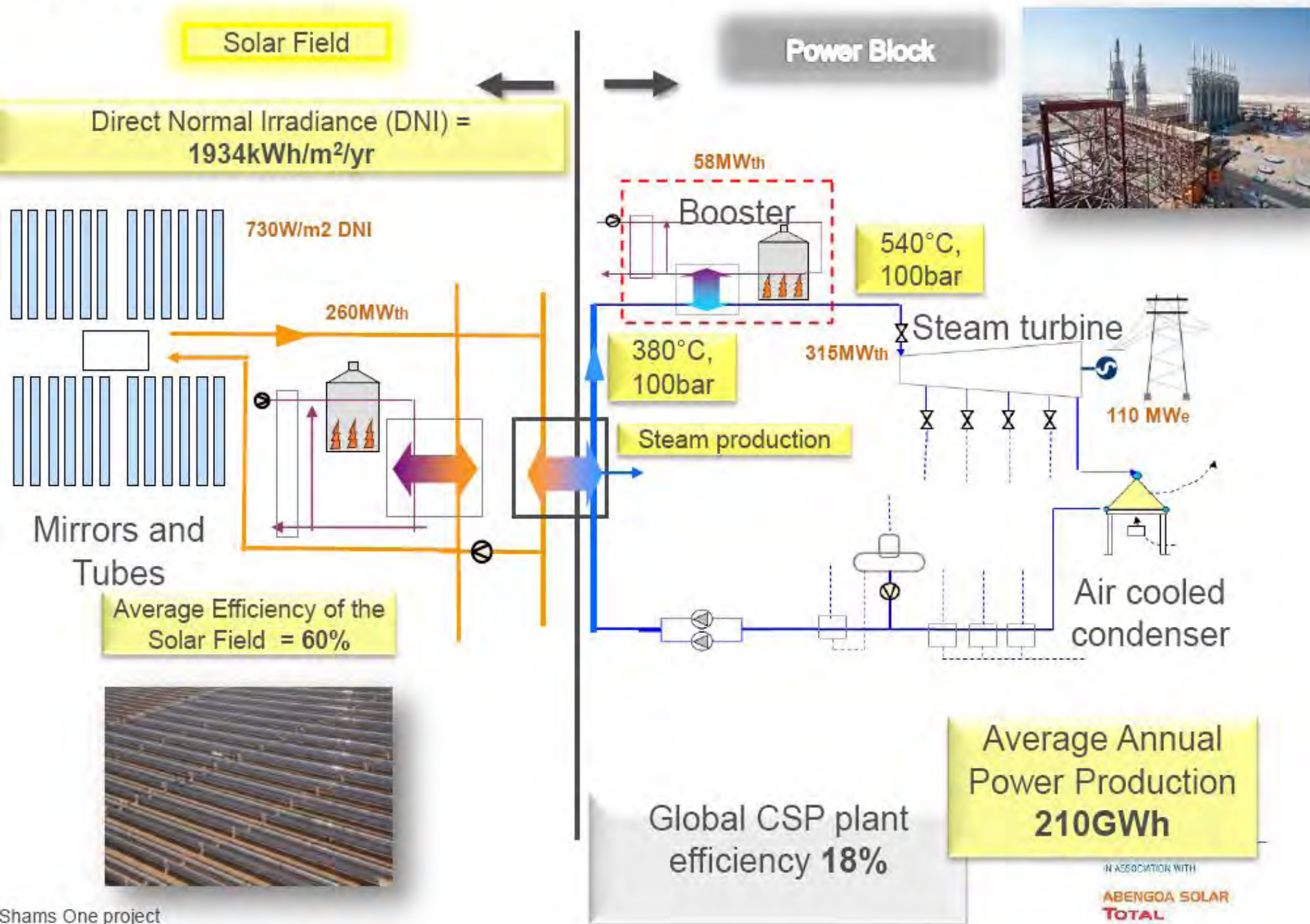
- ▀ Parabolic Trough Solar Power Plant with gas fired booster
- ▀ Booster power share: 18% of heat input
- ▀ HTF Heater: $150 \text{ MW}_{th} \Rightarrow 50 \text{ MW}_{el}$ (Firm Output)
- ▀ Nominal net Capacity: 110 MW_{el} (@ 730 W/m^2)
- ▀ Area required: 2.6 km^2
- ▀ Cooling: Dry Cooling (ACC)
-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

Shams 1: 110 MW CSP plant



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Plant Process



Take home message



- Local conditions requires local expertise to implement smart design
- Progress in renewable energy requires an holistic approach to the energy challenges.

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Ready For the Next Challenge?



Towards a knowledge-based society

- ✿ Global platform to search for solution to energy security and climate change
- ✿ Development of human expertise in sustainability
- ✿ To position Abu Dhabi as a world-class research and development hub for new energy technologies

***First to occupy Masdar City is
Masdar Institute!***





Masdar Institute's Sustainable Campus

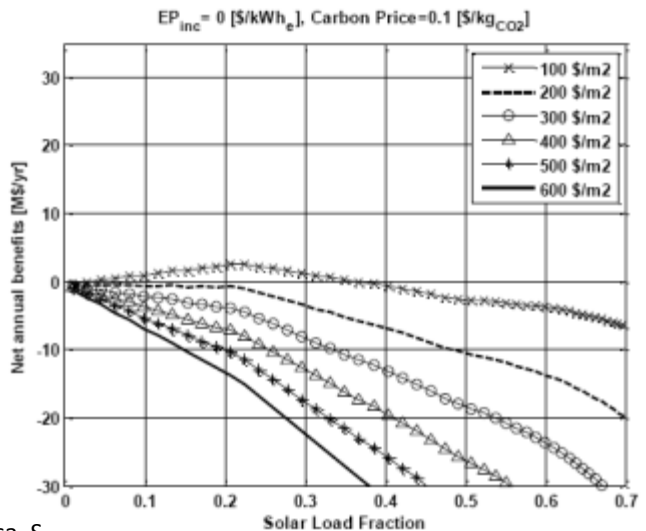
- ☼ Independent, private, non-profit research university
- ☼ Graduate level (MSc)
- ☼ Focused on sustainable technology and clean energy
- ☼ In collaboration with Massachusetts Institute of Technology (MIT)



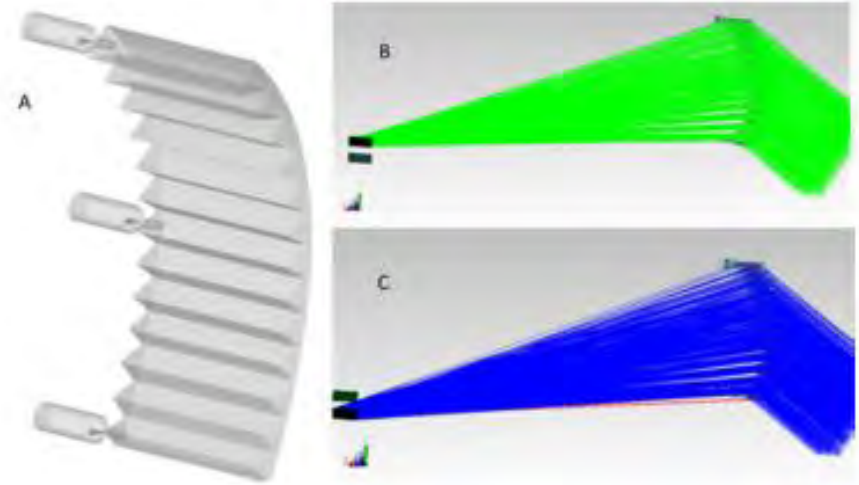
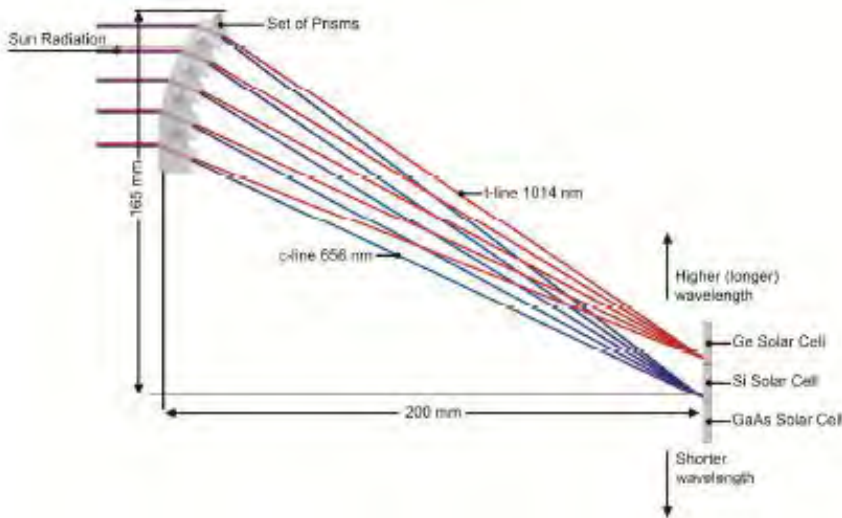


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M. Mokhtar, M.T. Ali, R. K., A. Abbas, N. Shah, A. Al Hajaj, P. Armstrong, M. Chiesa, S. Sgouridis **"Solar-Assisted Post Combustion Carbon Capture Feasibility Study"** Accepted with minor changes in *Applied Energy* 2011



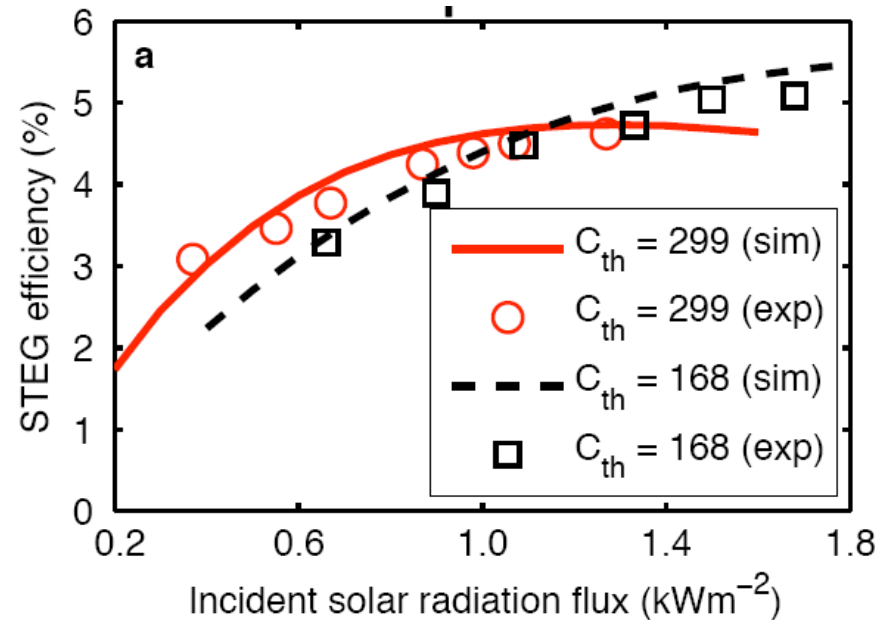
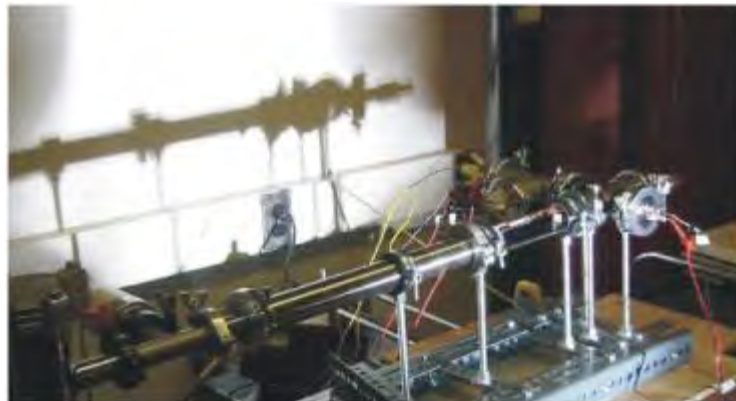
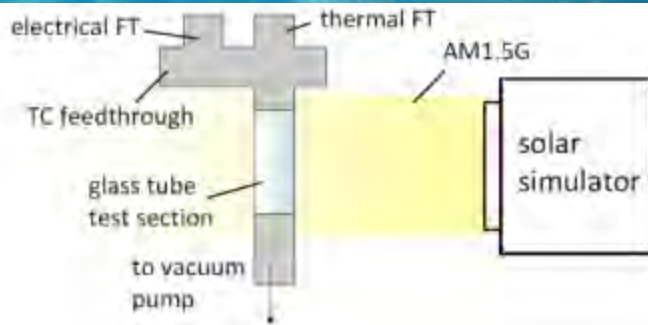
Beam Splitting concept for new PV architecture



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>



Solar Thermoelectric Power Generator

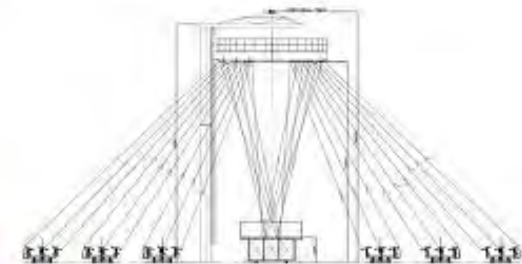
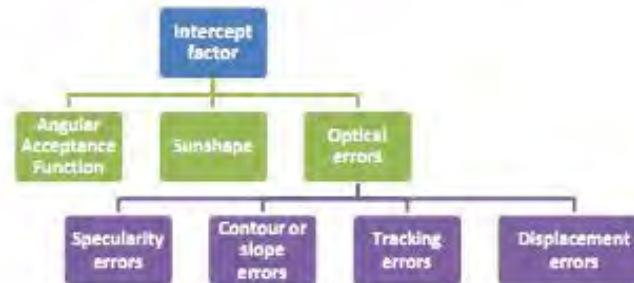


- ❑ thermoelectric material: nanostructured Bi₂Te₃ bulk elements
- ❑ solar absorber: $\alpha = 0.944$, $\epsilon = 0.04-0.08$ (100-230°C)
- ❑ n-/p-type TE element dimensions: 1.35x1.35x1.6 mm
- ❑ optimal thermal concentration: $C_{th} = A_{abs}/A_{te} = 300$
- ❑ STEG cell is mounted inside a glass vacuum chamber ($\tau = 0.94$)
- ❑ light source: solar simulator with AM1.5G filter

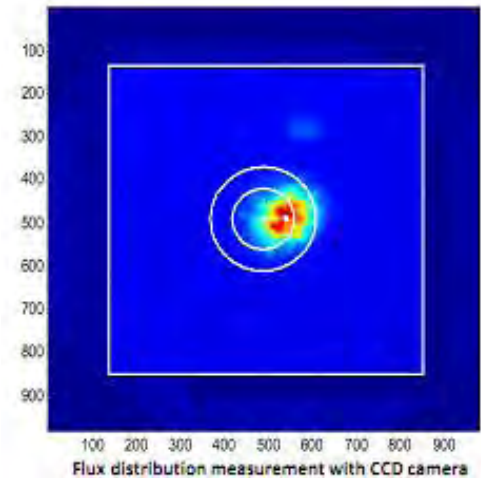
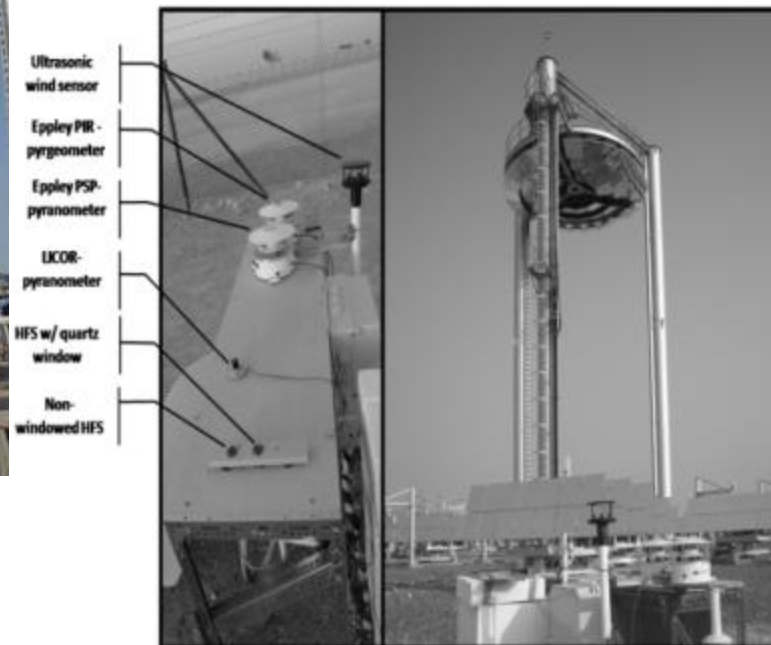
Solar -Thermal Design and Testing Beam- Down Pilot Plant



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



Schematic diagram of the Beam-Down plant



Geometrical Optical Model and Error Analysis of Beam Down Concentration

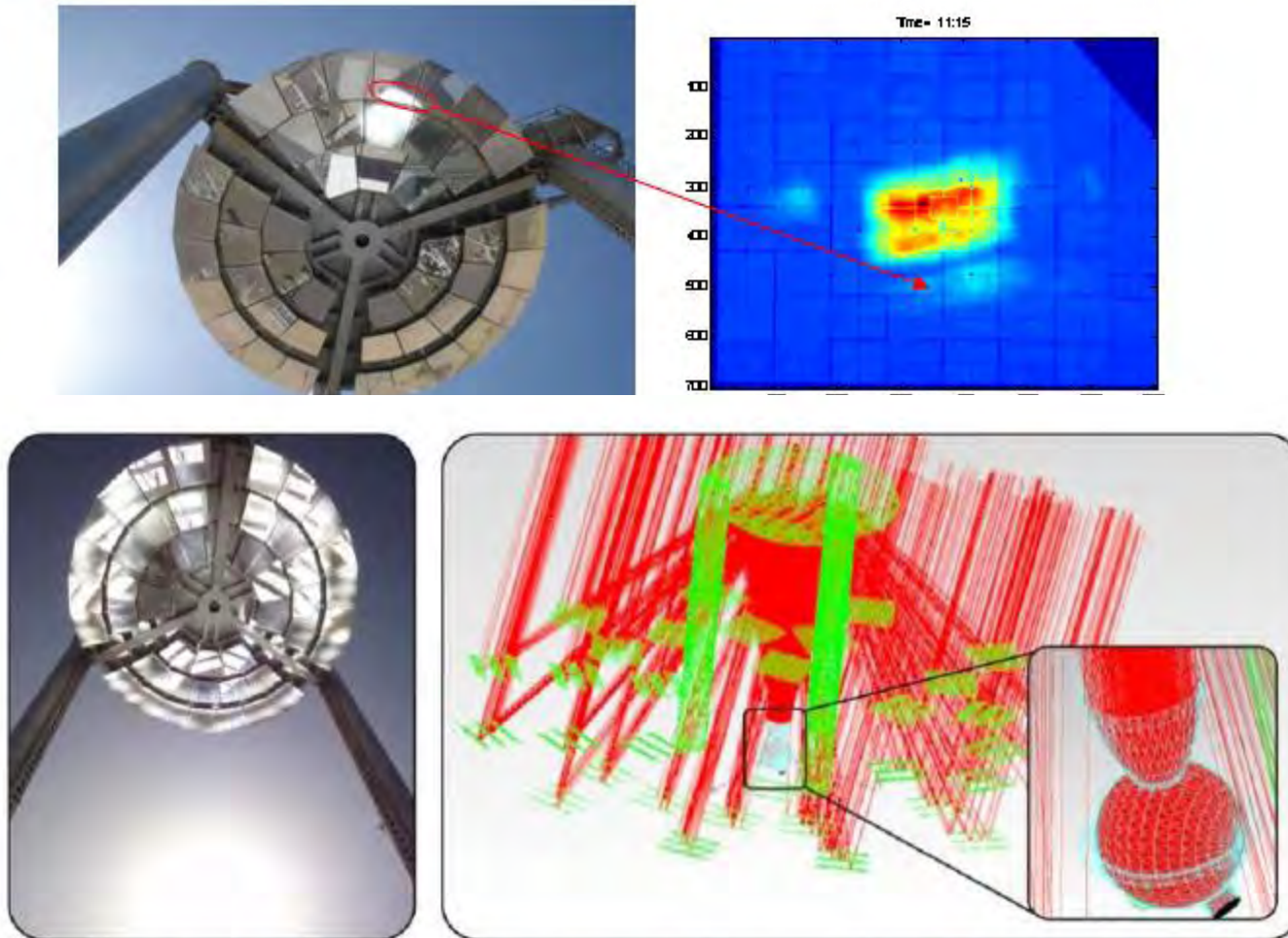
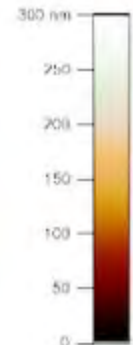
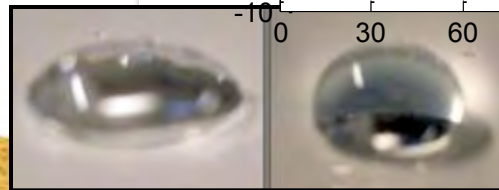
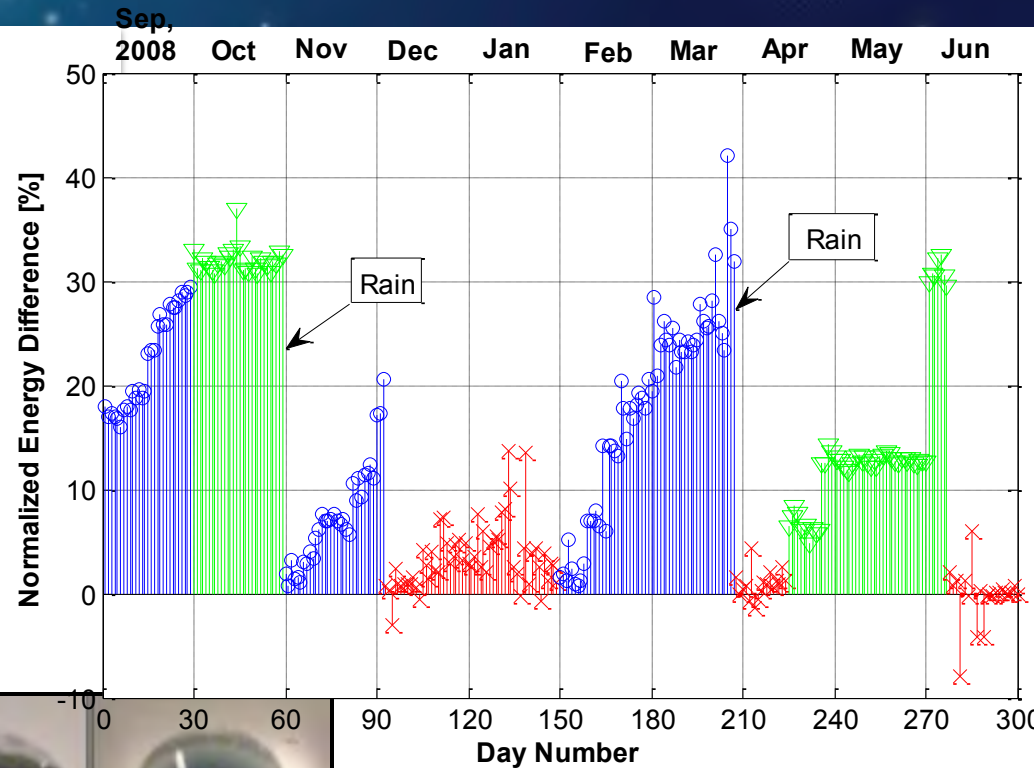
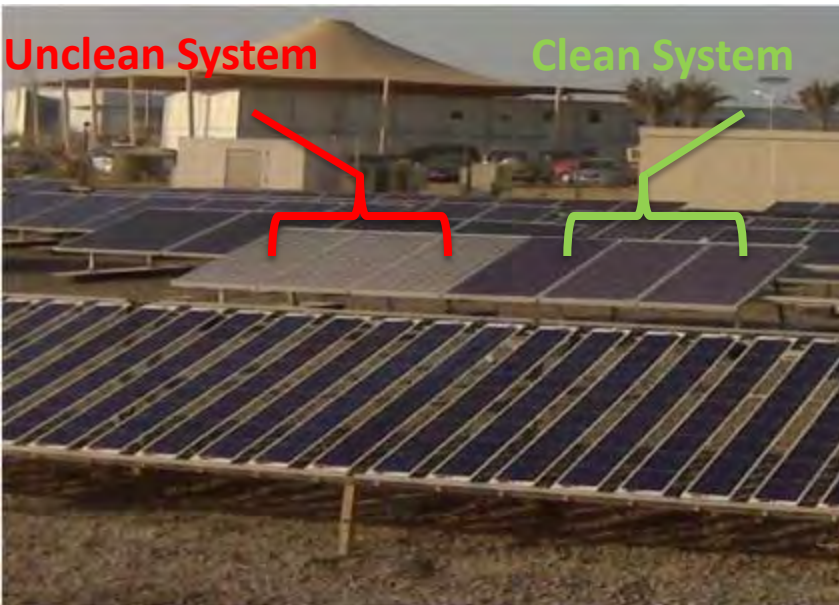


Figure 4: The solar energy is collected by a large array of sun-tracking heliostats, and through a secondary “beam down” mirror concentrates it at the entrance of a Compound Parabolic Concentrator (CPC). This element, in turn, feeds radiation into a cavity beam homogenizer as shown above.

Surface Treatment to Reduce H₂O Needs During Cleaning





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