QEERI
معهد قطر لبحوث البيئة والطاقة
Qatar Environment & Energy Research Institute
جامعة حمد بن خليفة
HAMAD BIN KHALIFA UNIVERSITY

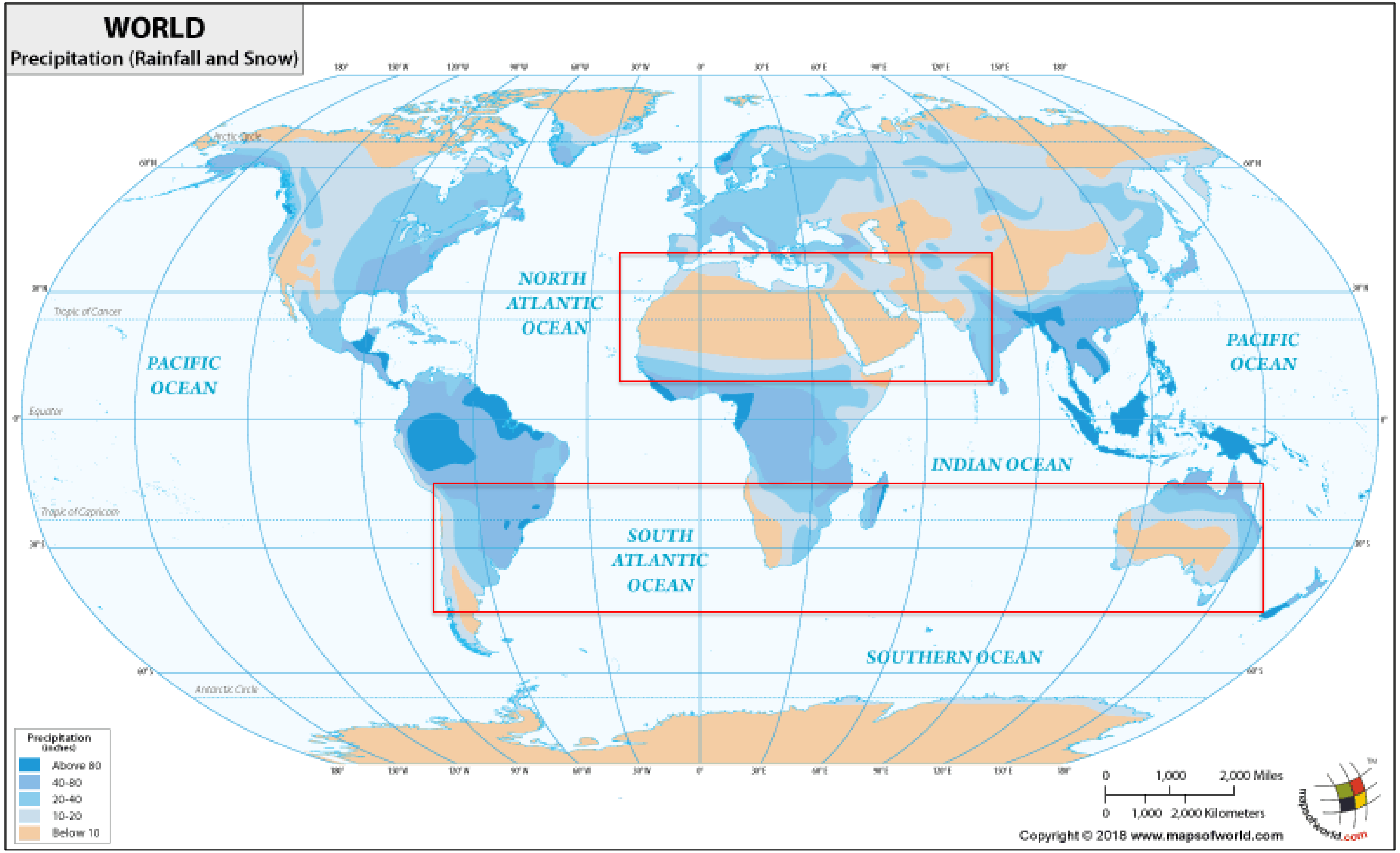
Bifacial Photovoltaics and Trackers in Desert locations – Environmental perspective

Research performed by the Energy Conversion team and Air Quality team of QEERI – Qatar Environment & Energy Research Institute

Presented by Dr. Cedric Broussillou - Research Program Director

July 7th 2020

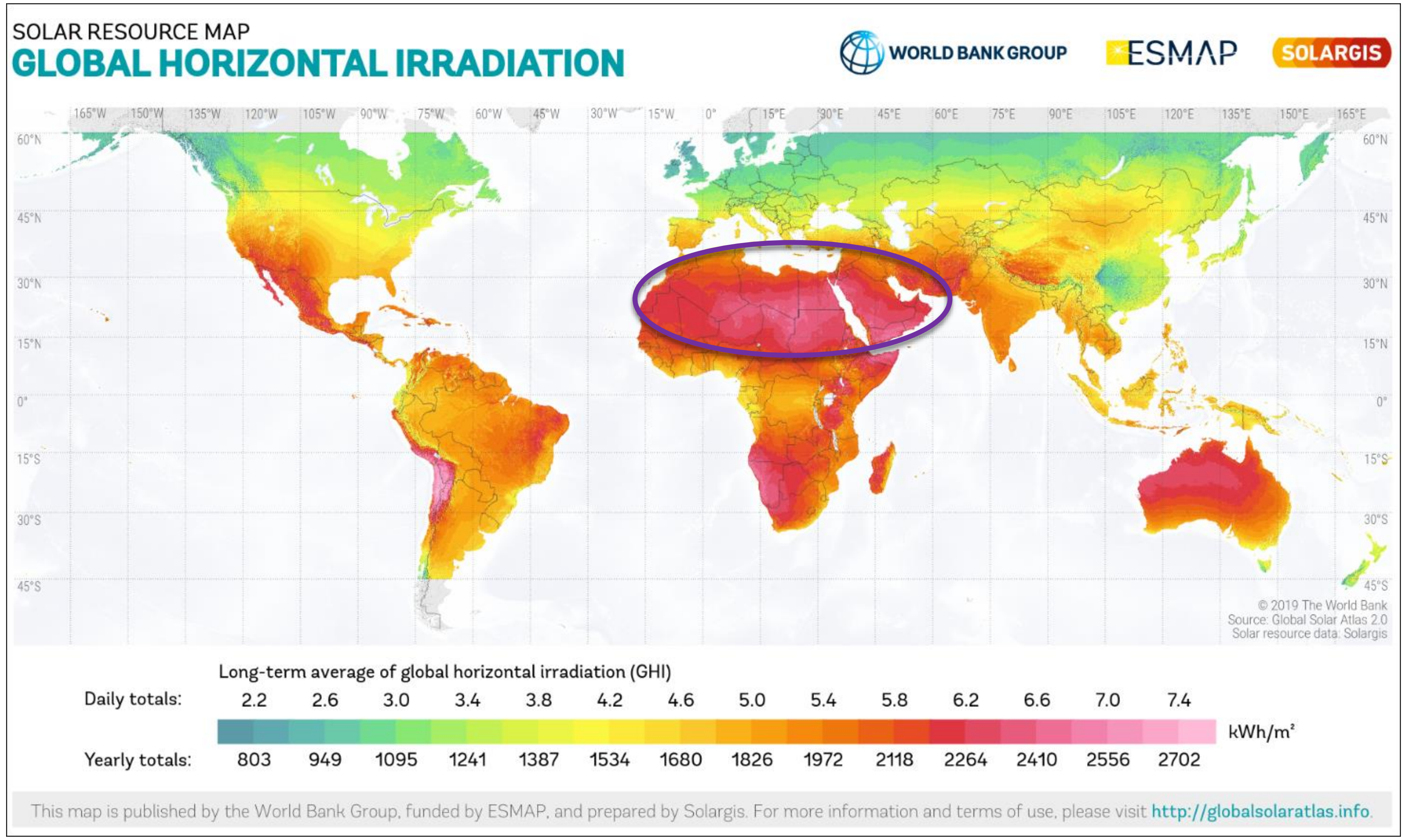
World precipitation map



https://www.mapsofworld.com/world-maps/precipitation-rain-and-snow-enlarge-map.html

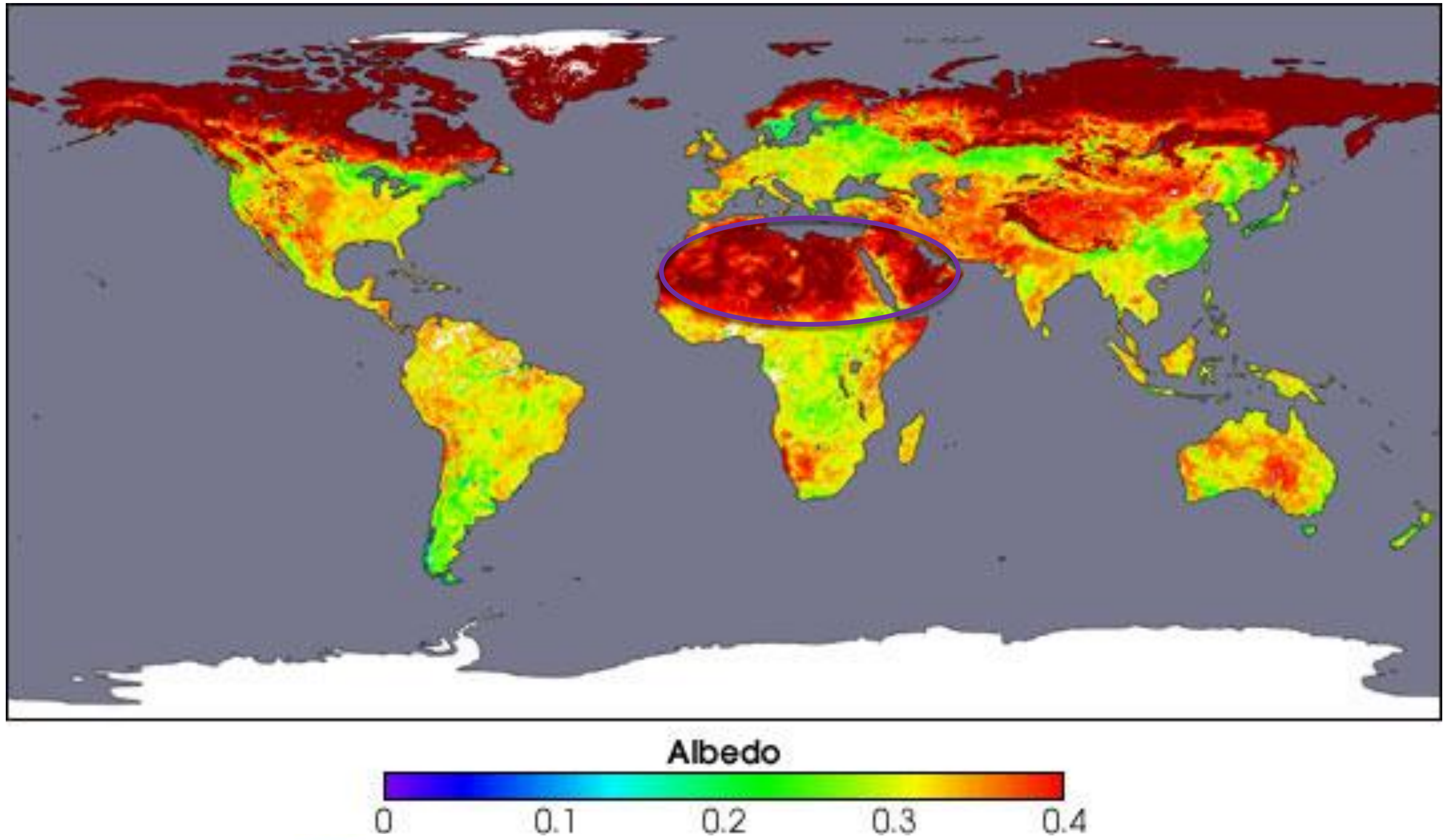
Correlation between High GHI and albedo in the MENA region

Global Horizontal irradiation

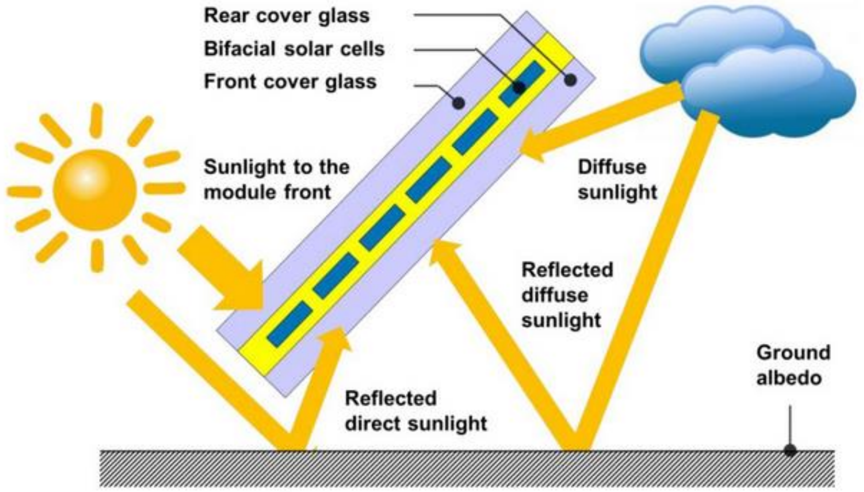


https://solargis.com/maps-and-gis-data/download/world

Albedo (proportion of incident radiation that is reflected by the ground)



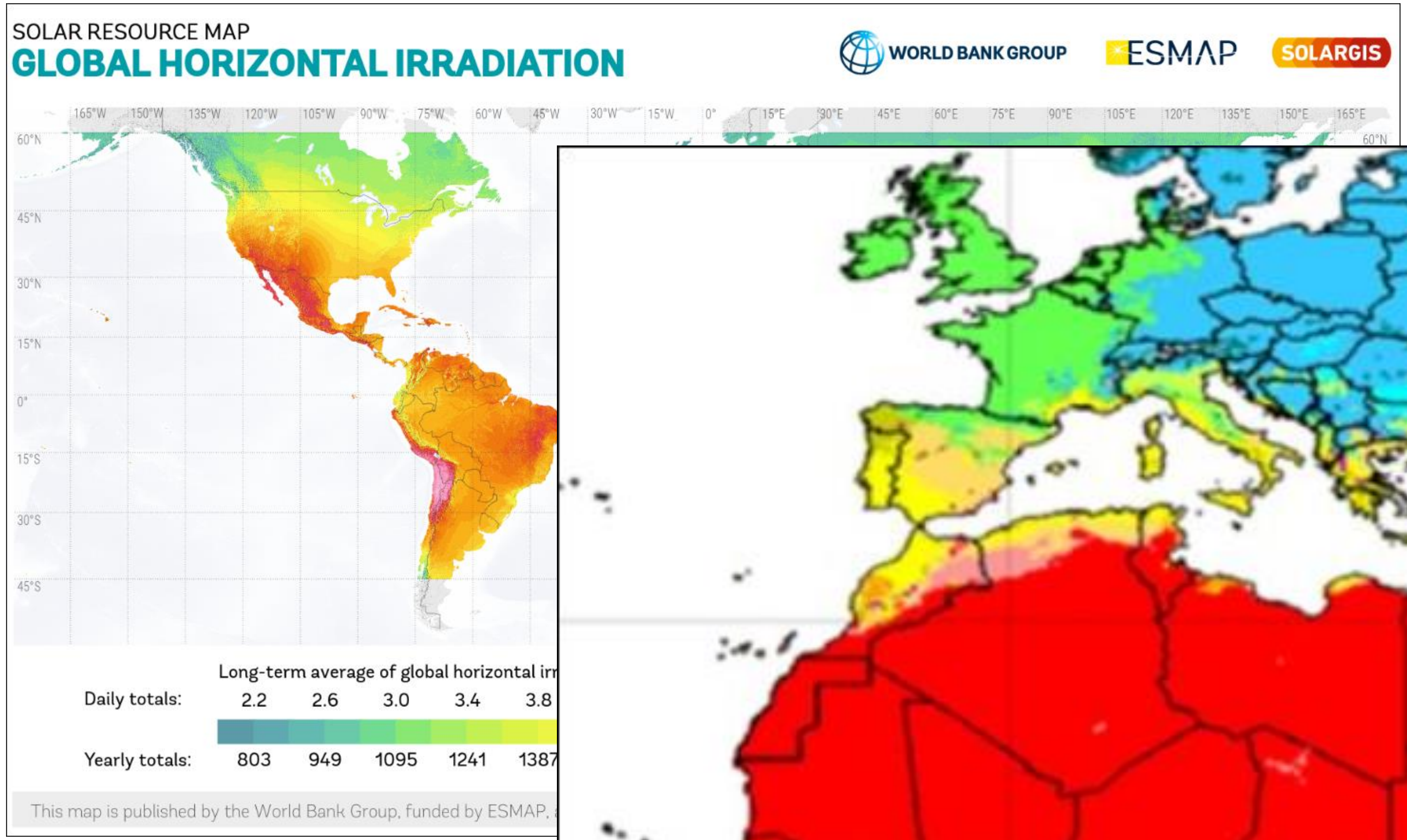
https://visibleearth.nasa.gov/images/60636/global-albedo



picture: TÜV Rheinland

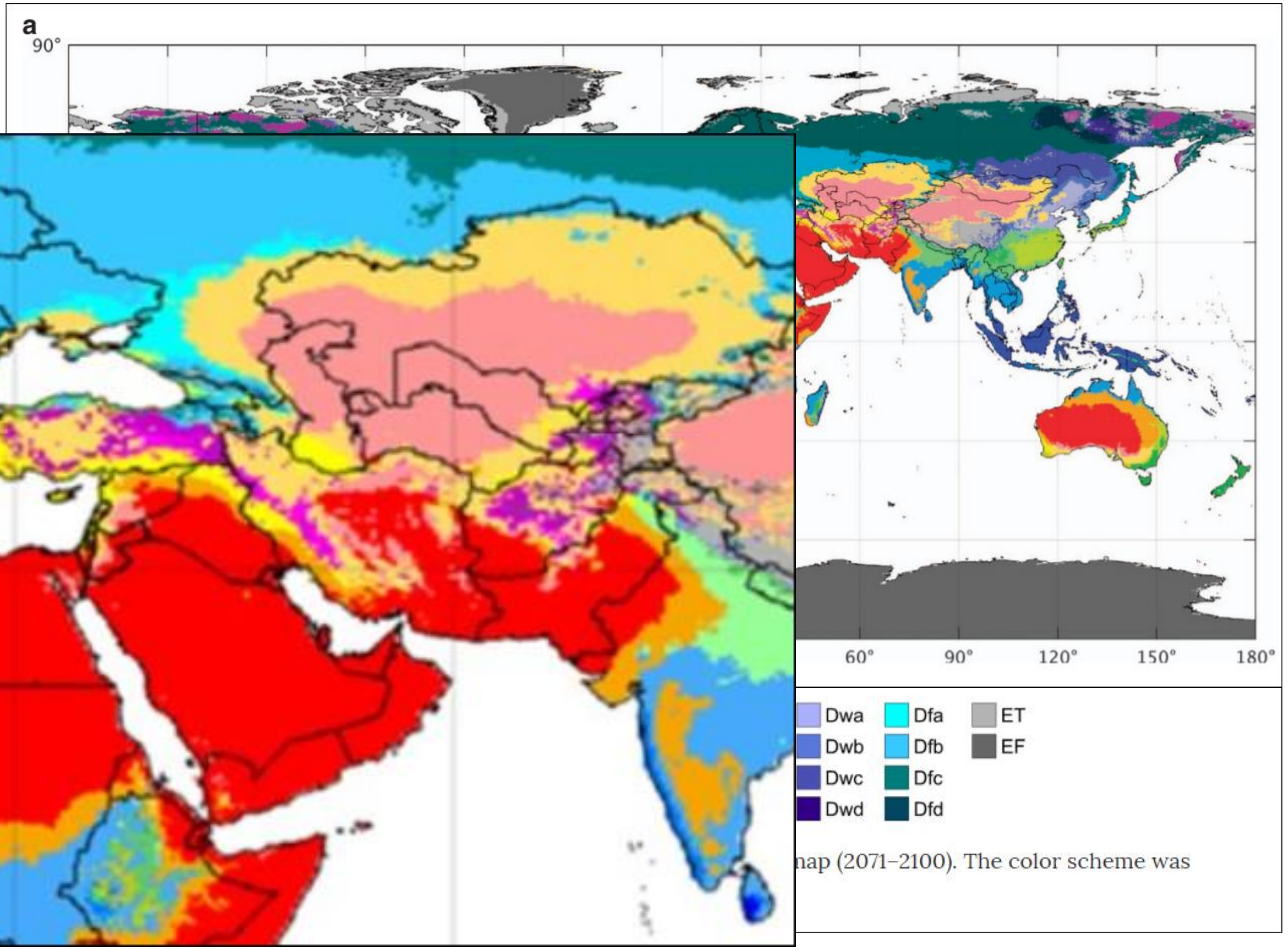
Correlation between Arid climate and Irradiation

Global Horizontal irradiation



https://solargis.c

Climatic zones (Köppen-Geiger classification)

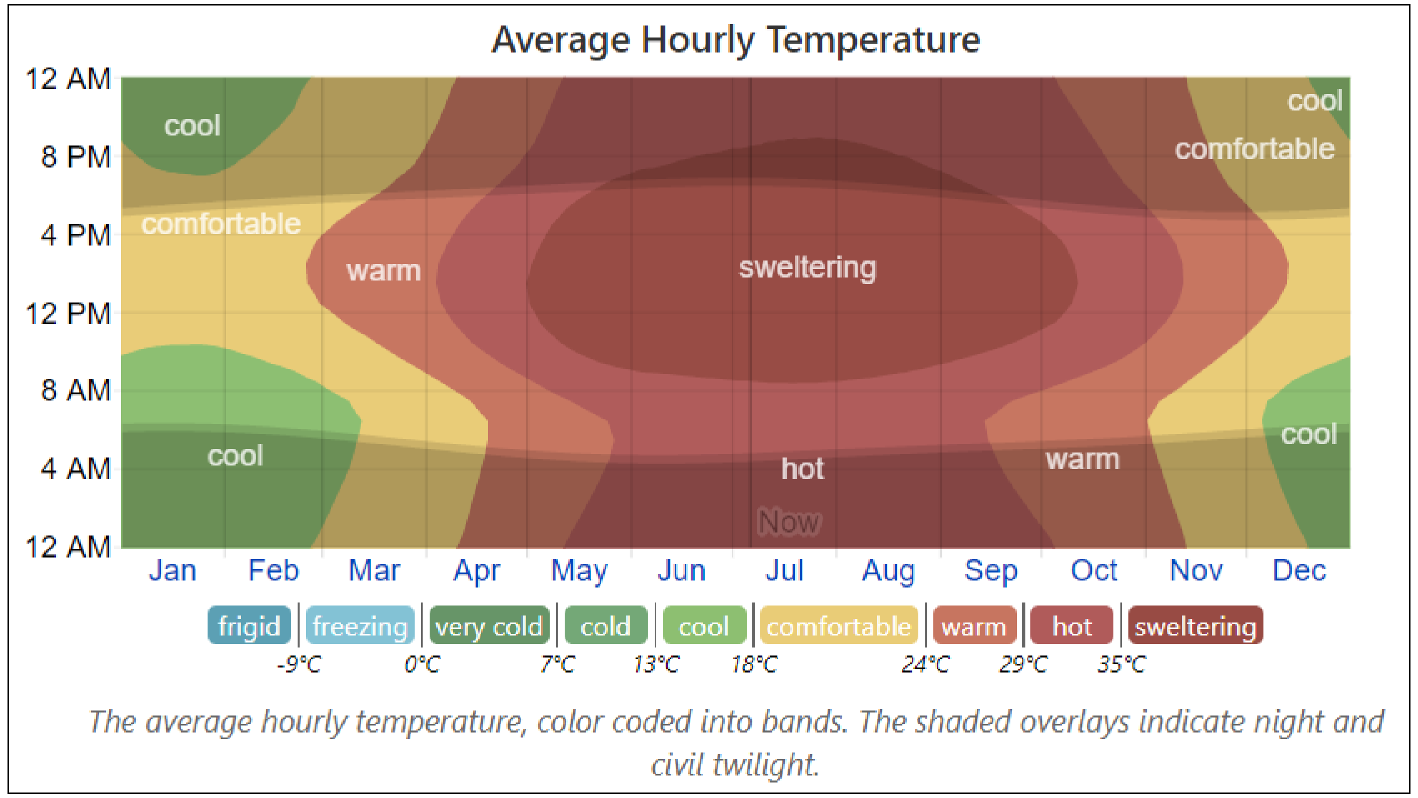


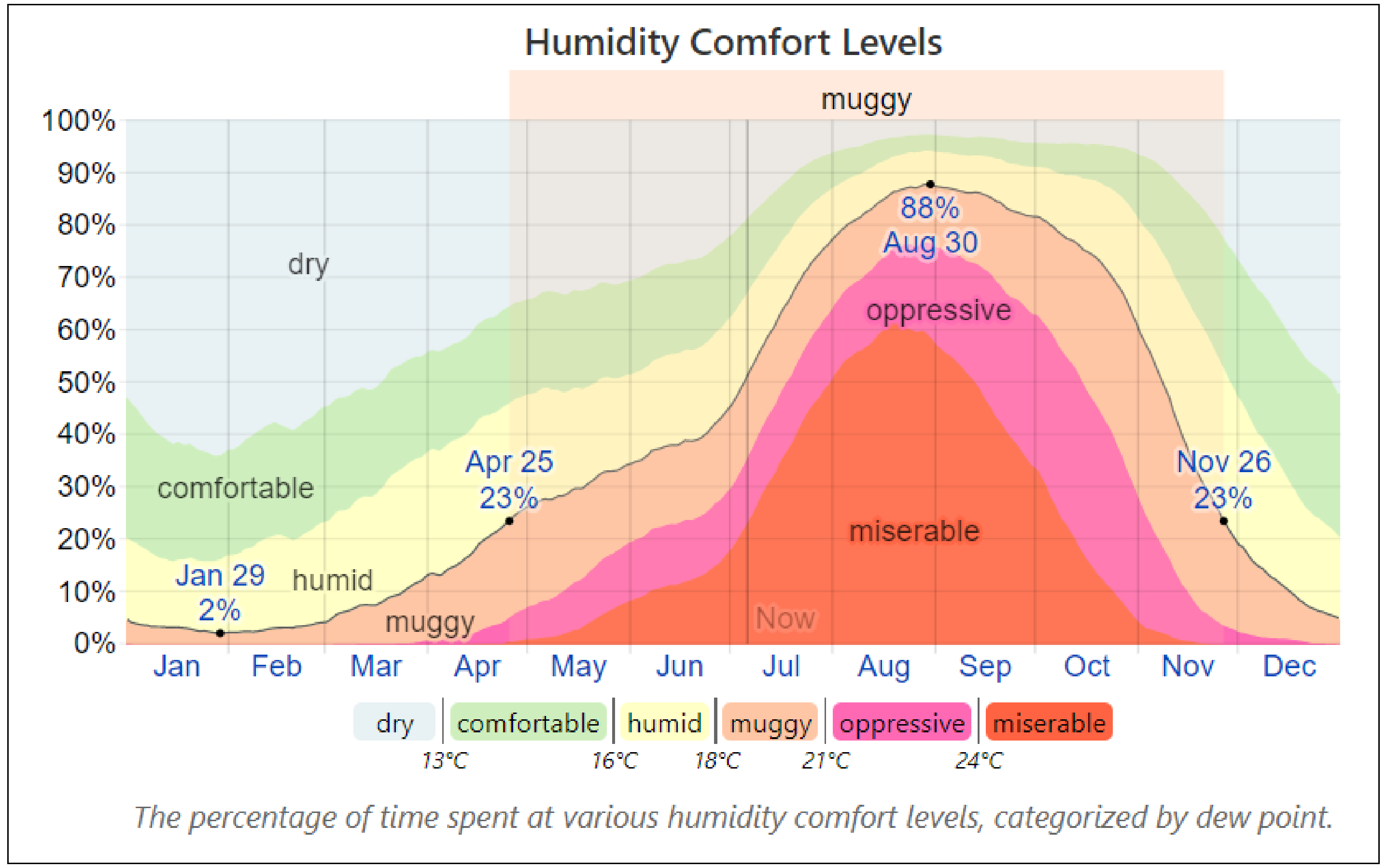
H. E. Beck, N. E. Zimmermann, T. R. McVicar, N. Vergopolan, A. Berg, and E. F. Wood, "Present and future Köppen-Geiger climate classification maps at 1-km resolution," *Sci Data*, vol. 5, no. 1, p. 180214, Dec. 2018, doi: 10.1038/sdata.2018.214.

M. C. Peel, B. L. Finlayson, and T. A. McMahon, "Updated world map of the Koppen-Geiger climate classification," *Hydrol. Earth Syst. Sci.*, p. 12, 2007.

Difference in climate in Arabian Peninsula

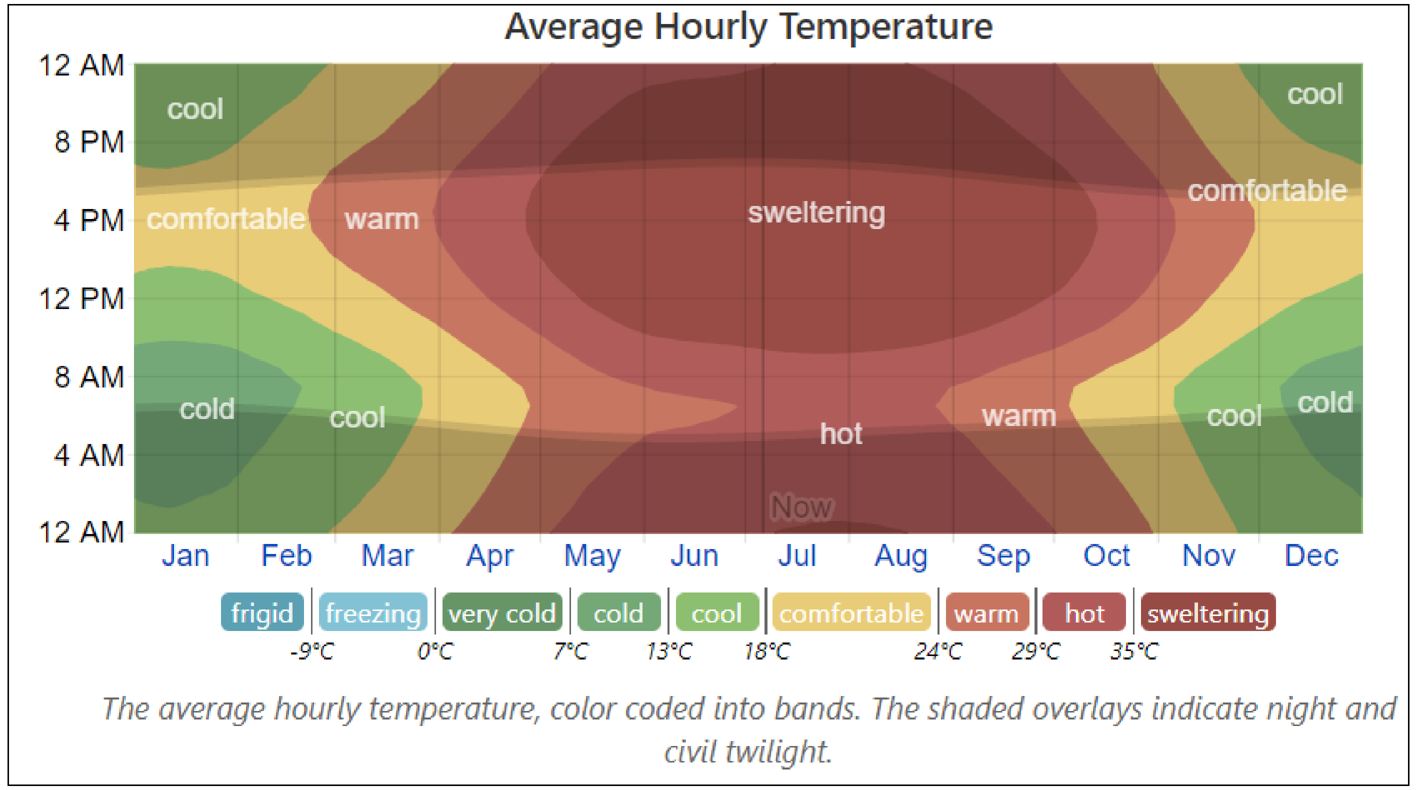
Doha

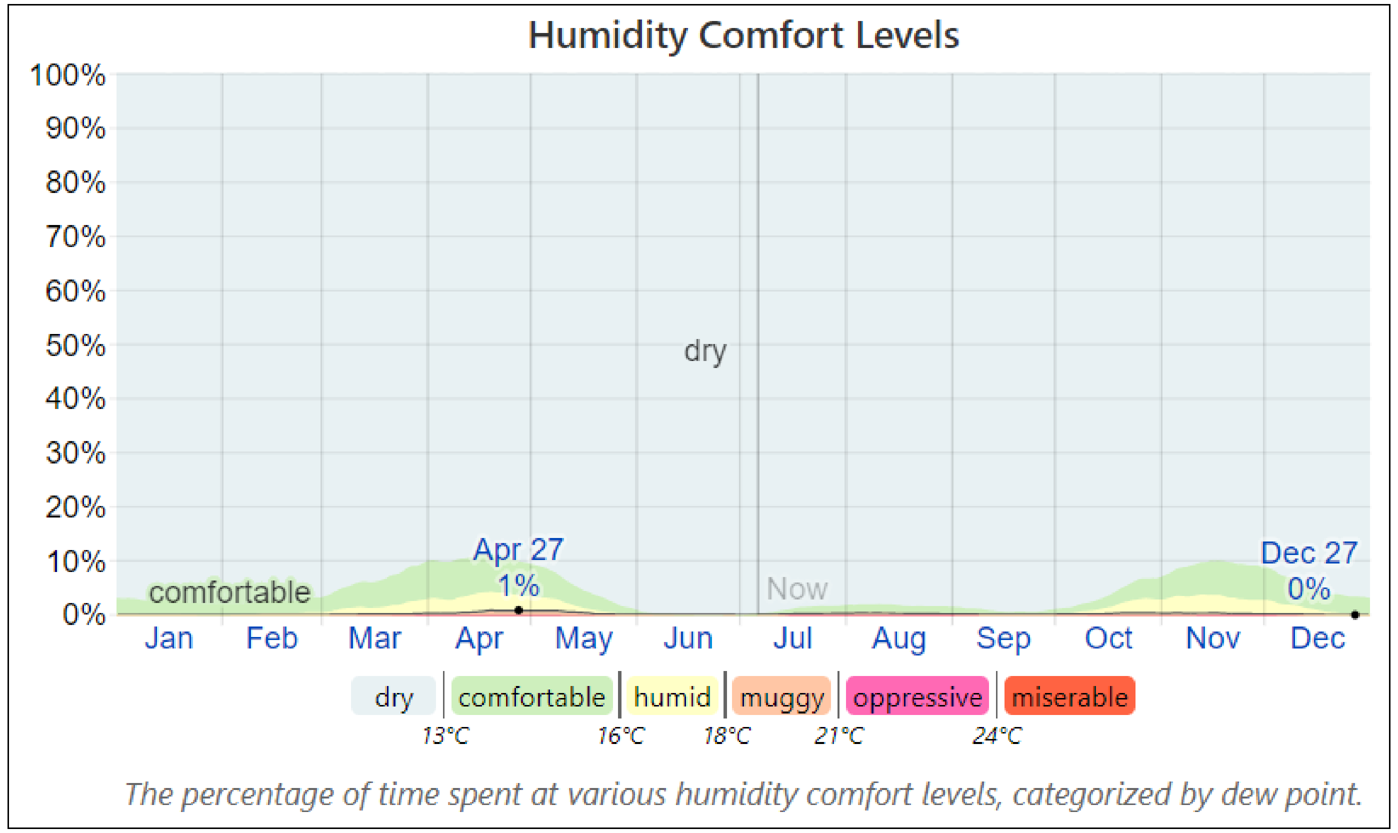




https://weatherspark.com/y/105083/Average-Weather-in-Doha-Qatar-Year-Round

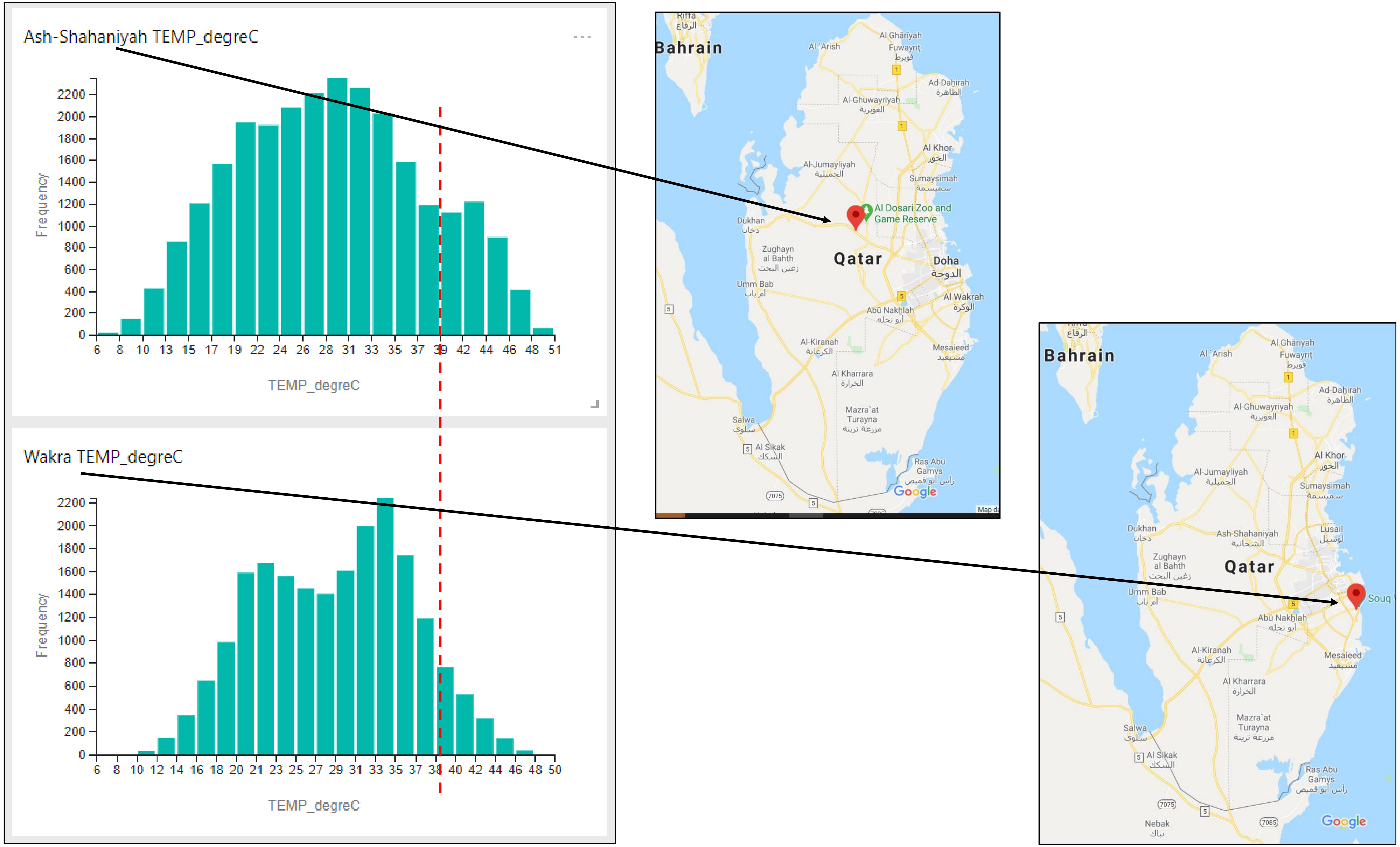
Riyadh





https://weatherspark.com/y/104018/Average-Weather-in-Riyadh-Saudi-Arabia-Year-Round

Difference in temperature coast vs inland in Qatar



Credit: Adam Skillern for data preparation

Measurements provided by QEERI's Air Quality Group led by Mohammed Ayoub

New classification of climate stressors for PV modules

Photovoltaic Degradation Climate Zones

Todd Karin *, C. Birk Jones †, Anubhav Jain *

*Lawrence Berkeley National Laboratory, Berkeley, CA, U.S.A
†Sandia National Laboratory, Albuquerque, NM, U.S.A

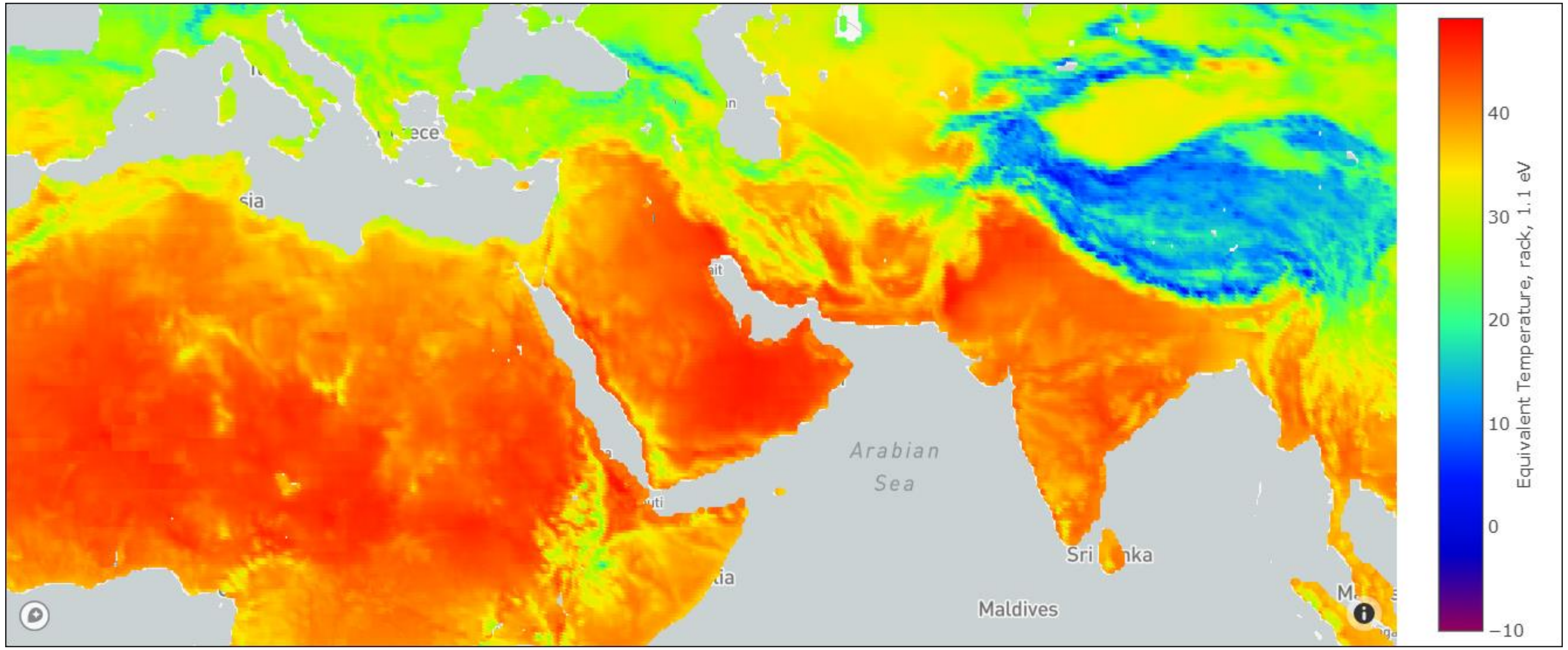
TABLE I
Stressor thresholds for photovoltaic climate zones. Zone T2 comprises sites with module temperature between 14 and 19 C. Zone T1 comprises sites with module temperature lower than 14 C. Only 5 zones are defined for specific humidity and wind, a dash is used to signify "not applicable."

		Threshold								
Description	Symbol	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Module Temperature (°C)	T	14	19	24	29	34	39	44	49	54
Specific Humidity (g/kg)	H	3.0	4.1	5.9	10.5	-	-	-	-	-
Wind, 25-year MRI (m/s)	W	1	33	36	39	-	-	-	-	-

Since the rate of many degradation processes such as solder bond degradation or encapsulant browning follows an Arrhenius dependence [13], [14], [15], an Arrhenius-weighted equivalent temperature T_{eq} has been identified [6], [7] for quantifying the amount of temperature-activated stress present at each location, defined by

$$\exp\left(-\frac{E_a}{k_B T_{\mathrm{eq}}}\right) = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \exp\left(-\frac{E_a}{k_B T_m(t)}\right) dt \quad (1)$$

- **Degradation mechanisms are activated by high temperatures and large temperature cycles amplitude**
- **Combined stressors (humidity, temperature, UV, wind load, corrosive atmosphere) are the most detrimental**
- **Those parameters can vary significantly throughout climate zones which are considered similar and during the year**

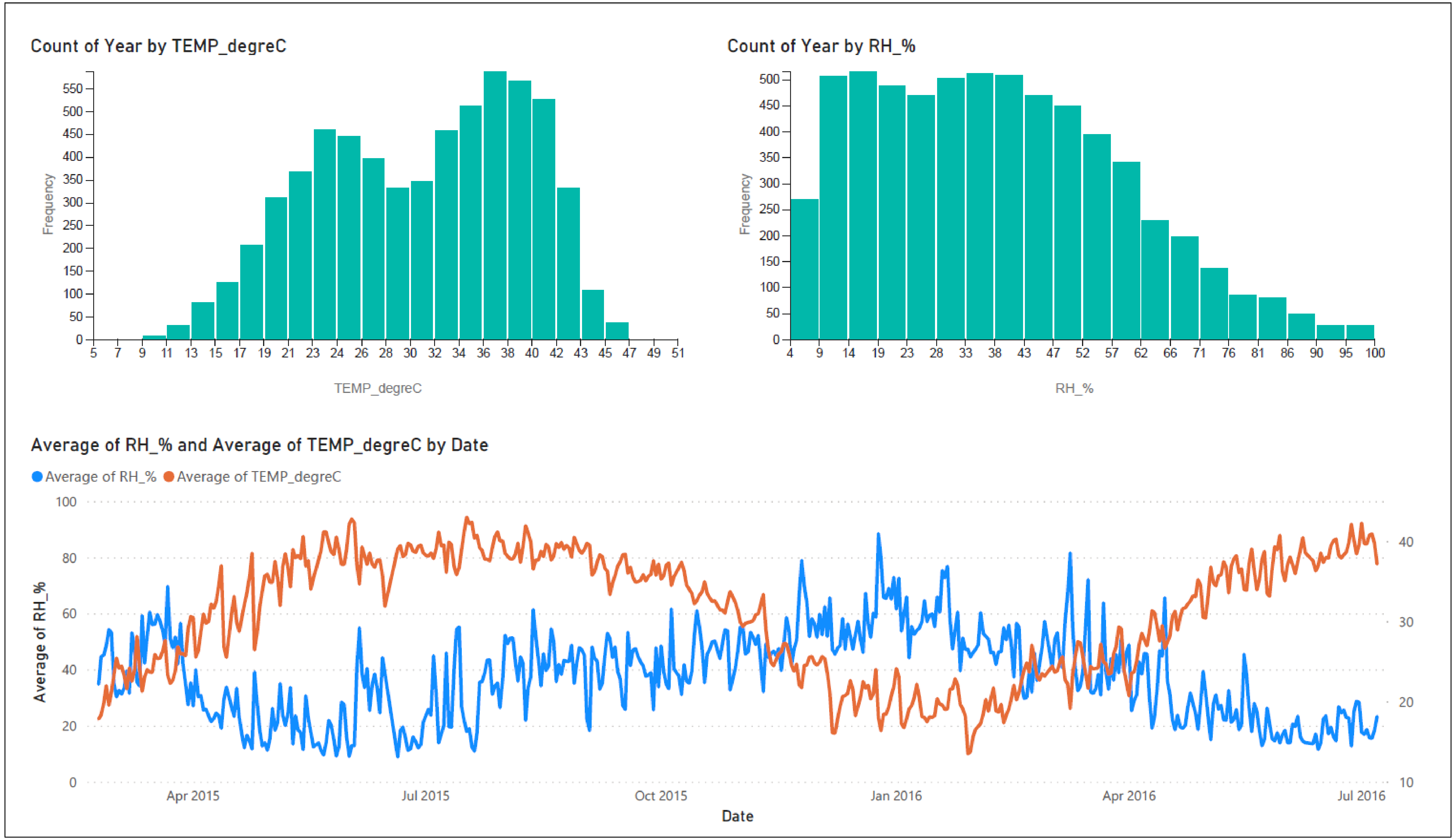


https://pvtools.lbl.gov/pv-climate-stressors

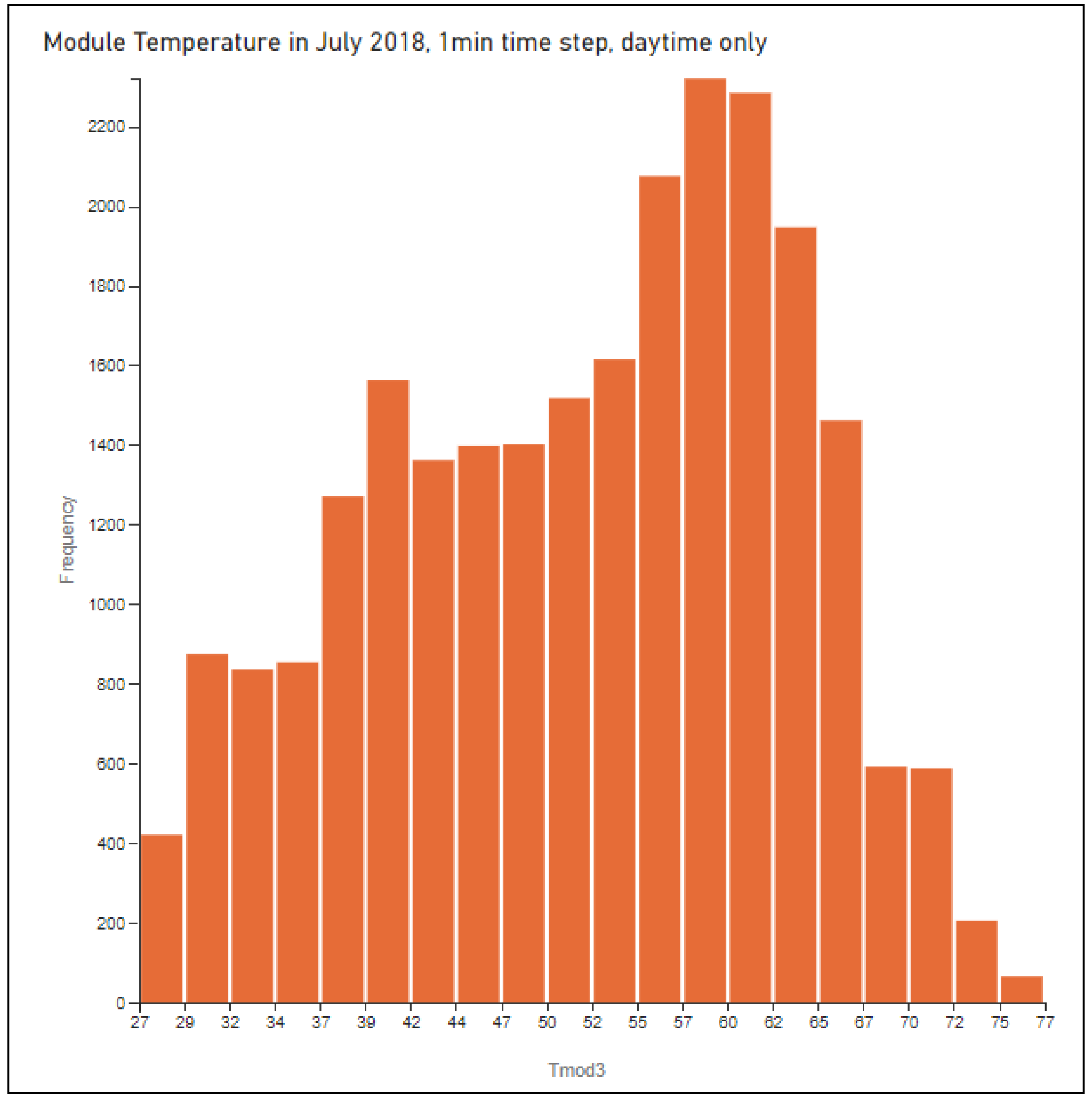
T. Karin, C. B. Jones, and A. Jain, "Photovoltaic Degradation Climate Zones," in *2019 IEEE 46th Photovoltaic Specialists Conference (PVSC)*, Jun. 2019, pp. 0687–0694, doi: 10.1109/PVSC40753.2019.8980831.

QEERI Proprietary

Hourly temperature & Relative humidity measurements

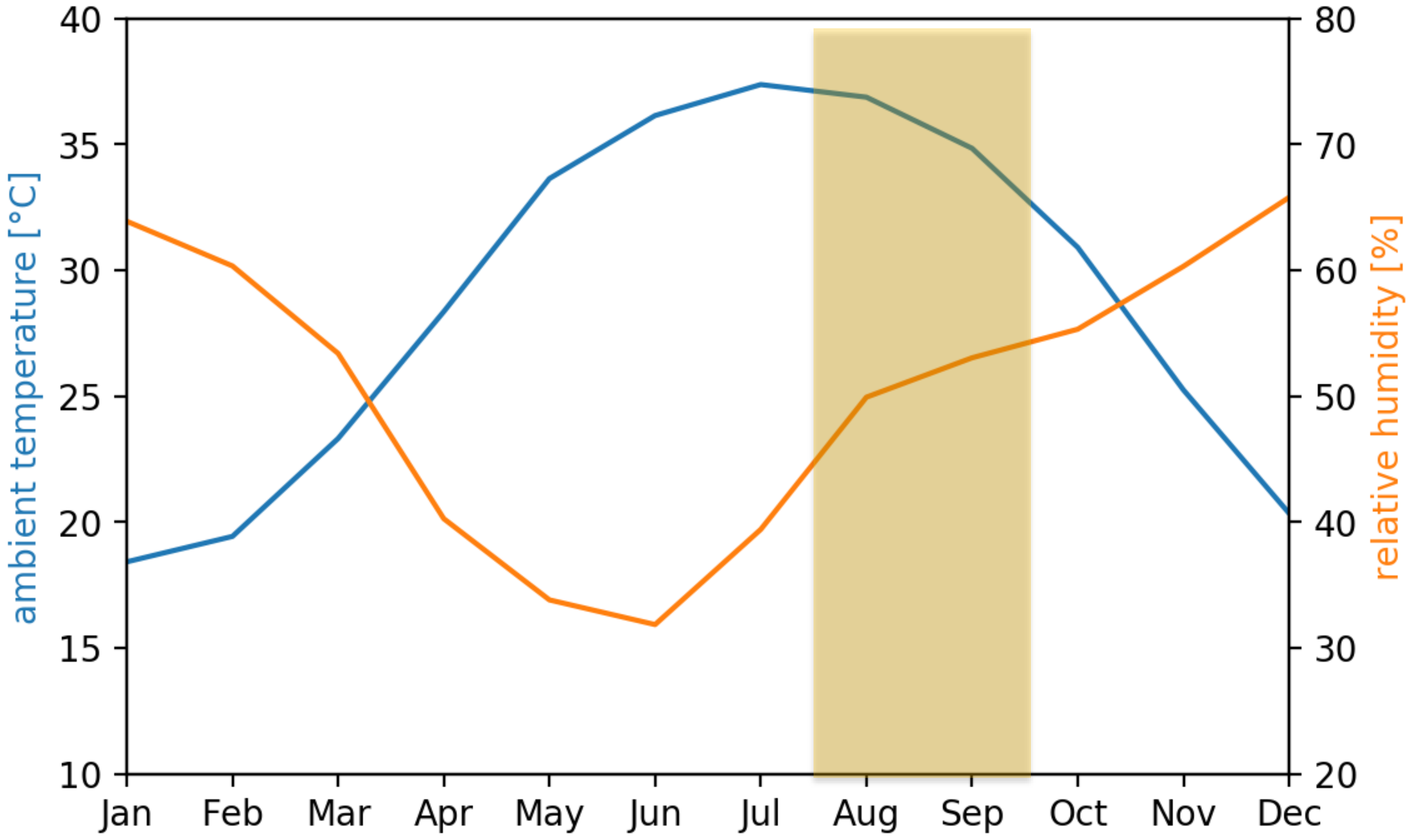


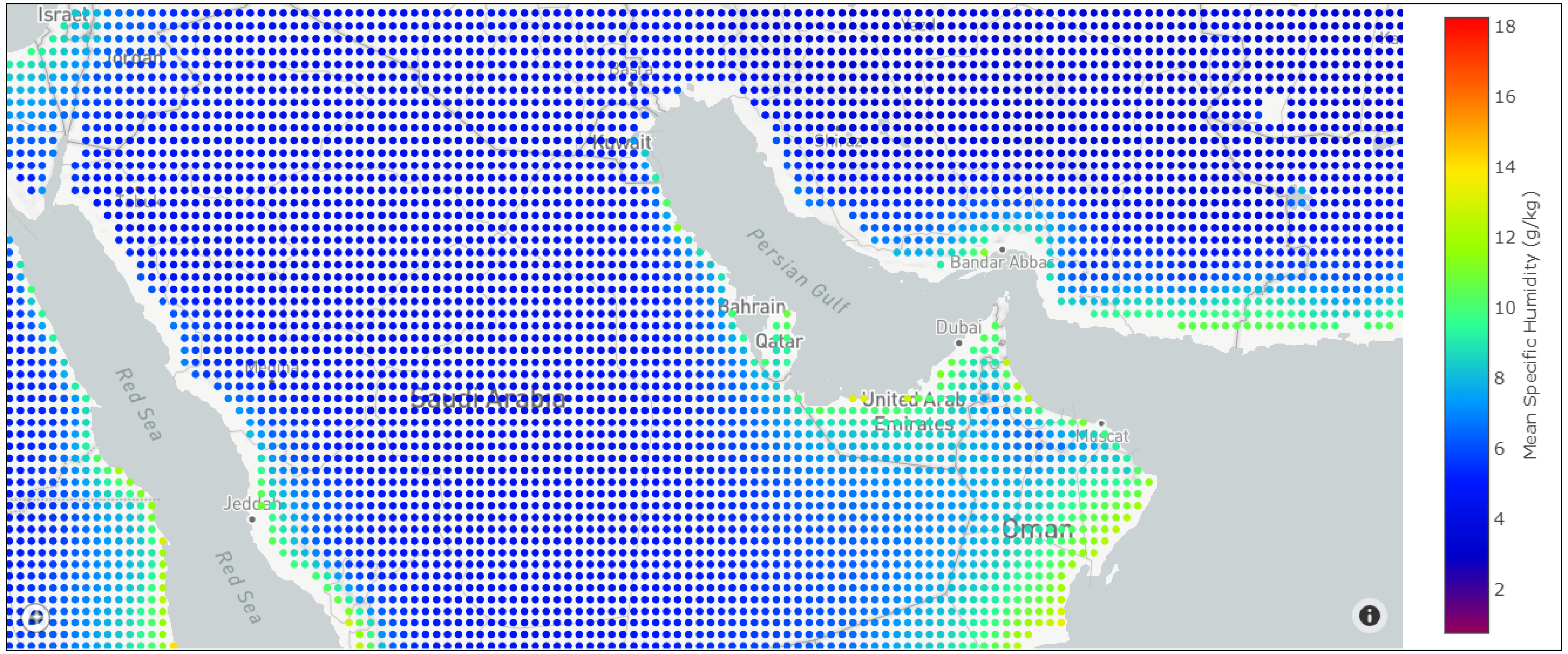
1min time step module temperature measurements (July 2018)



- **Ambient air temperature or daily average module temperature measurements are not sufficient to describe the temperature stressor**
- **Detailed measurements throughout the day provide a better assessment of the worst case conditions likely to affect the module (e.g module temperatures above 70°C while ambient is 45°C, no hot spot considered here)**

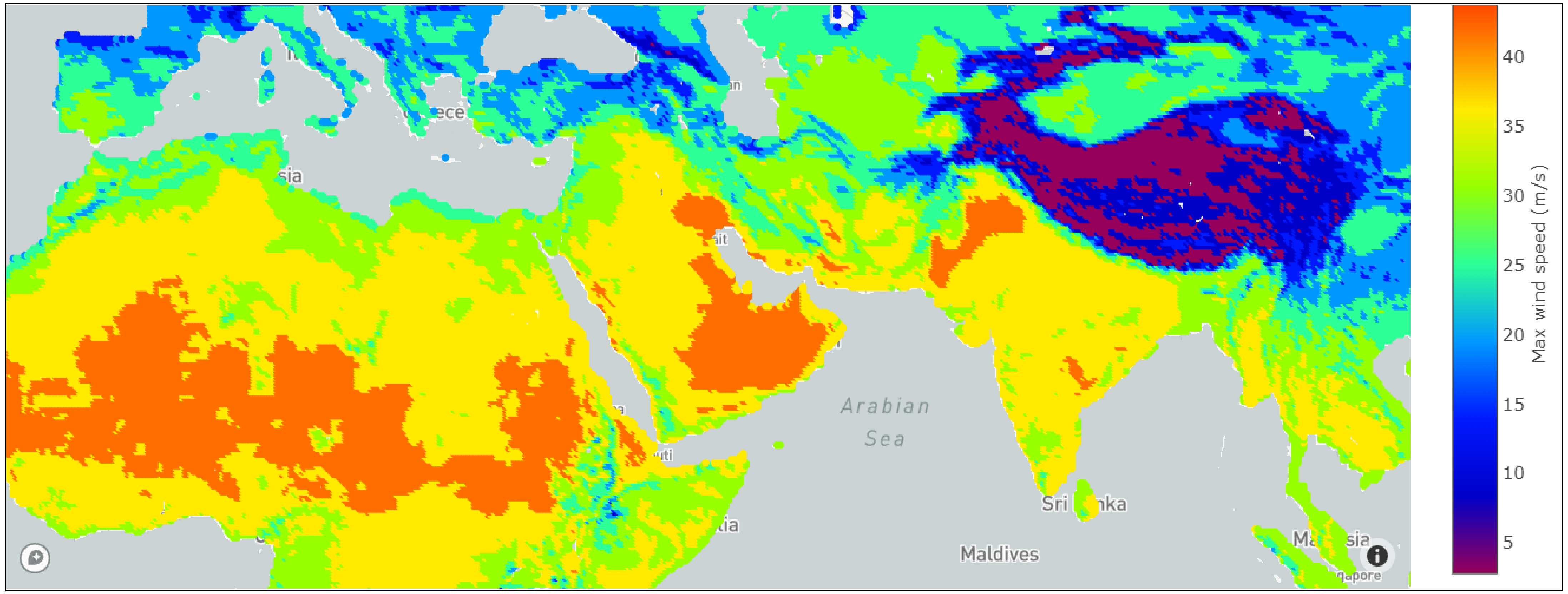
Other climate stressors : Humidity, Wind speed, Corrosion





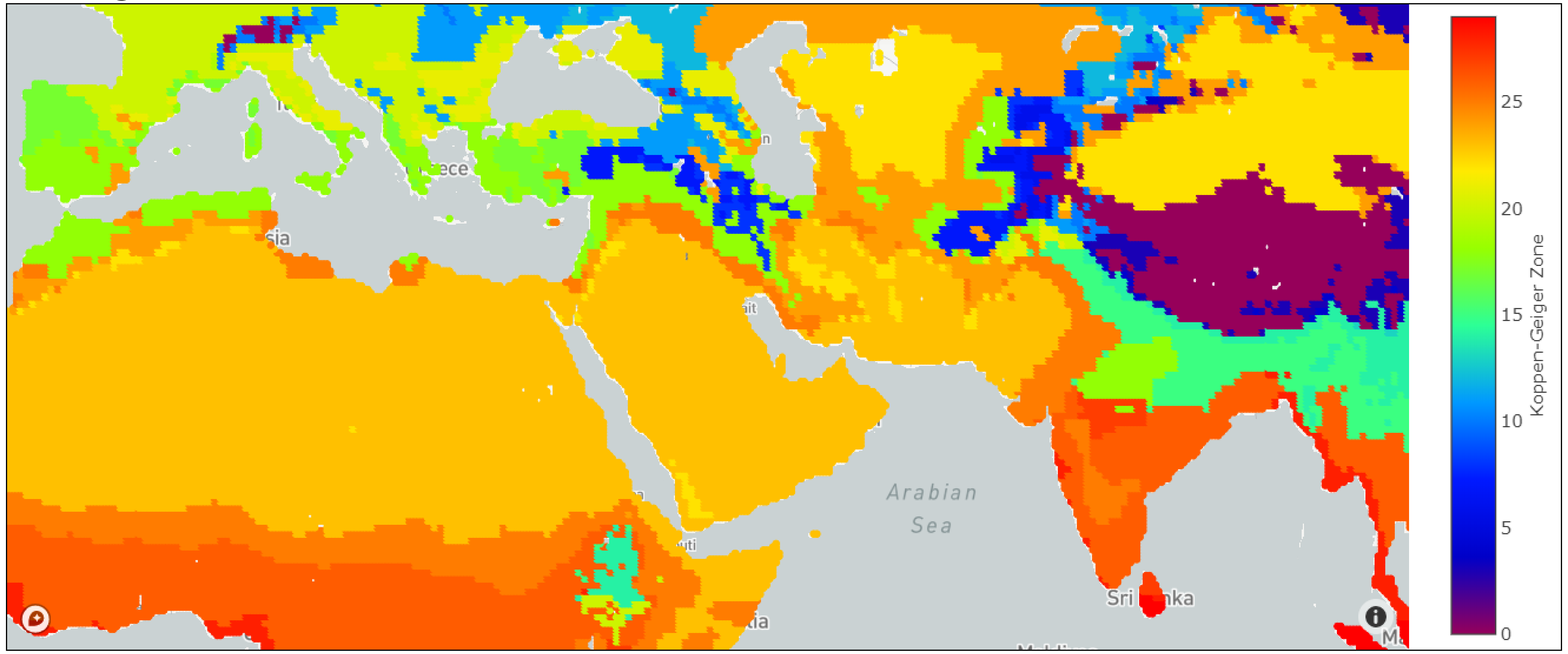
https://pvtools.lbl.gov/pv-climate-stressors

- Highest relative humidity seen in winter in Qatar but the true factor to be considered is the specific humidity which is worst in August and September
- Specific humidity of more than 20g/kg can be observed throughout the summer
- High wind speed especially during dust storms
- High corrosivity due to saline atmospheric content that deposits on modules and no rain to wash it off



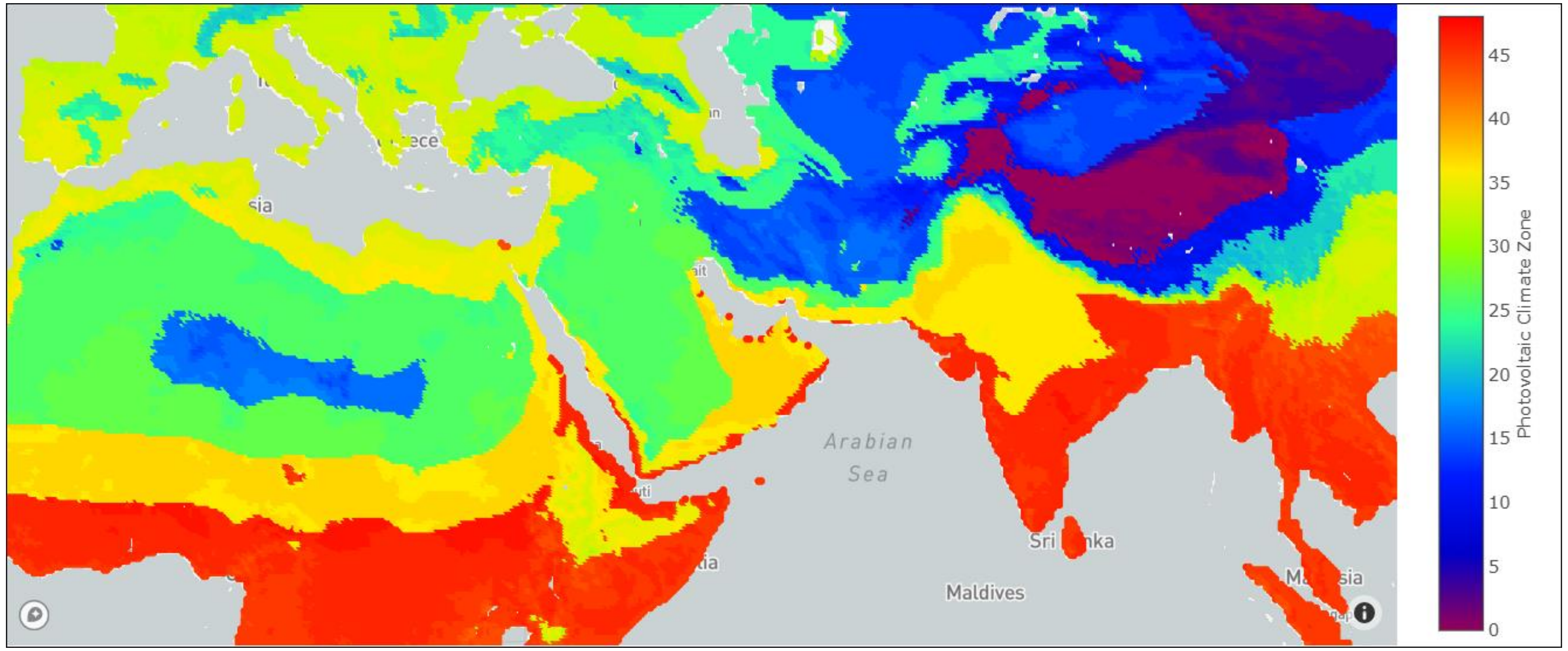
Climate stressors need to be assessed locally

Köppen-Geiger climate zones

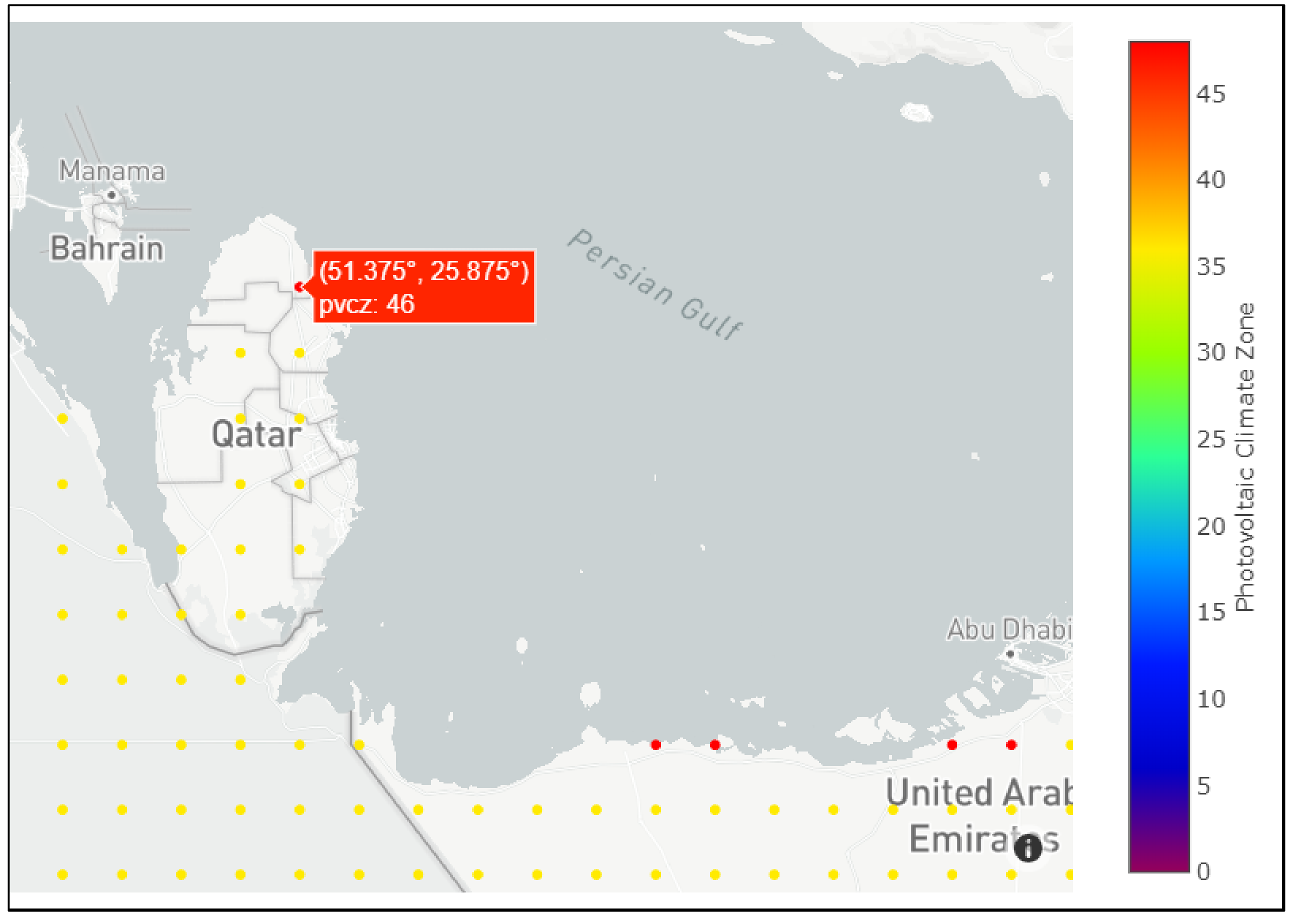


Photovoltaic Degradation climate zones

https://pvtools.lbl.gov/pv-climate-stressors



- **Based on Köppen – Geiger climate zones all Arabian peninsula would be considered homogeneous**
- **This is far from being correct and the new Photovoltaic zones provides a better assessment of these differences**
- **North of Qatar is already identified in PVCZ 46 and some stressors are underestimated based on satellite analysis ➔ Challenge for PV systems operation but opportunity to test under real worst-case conditions**

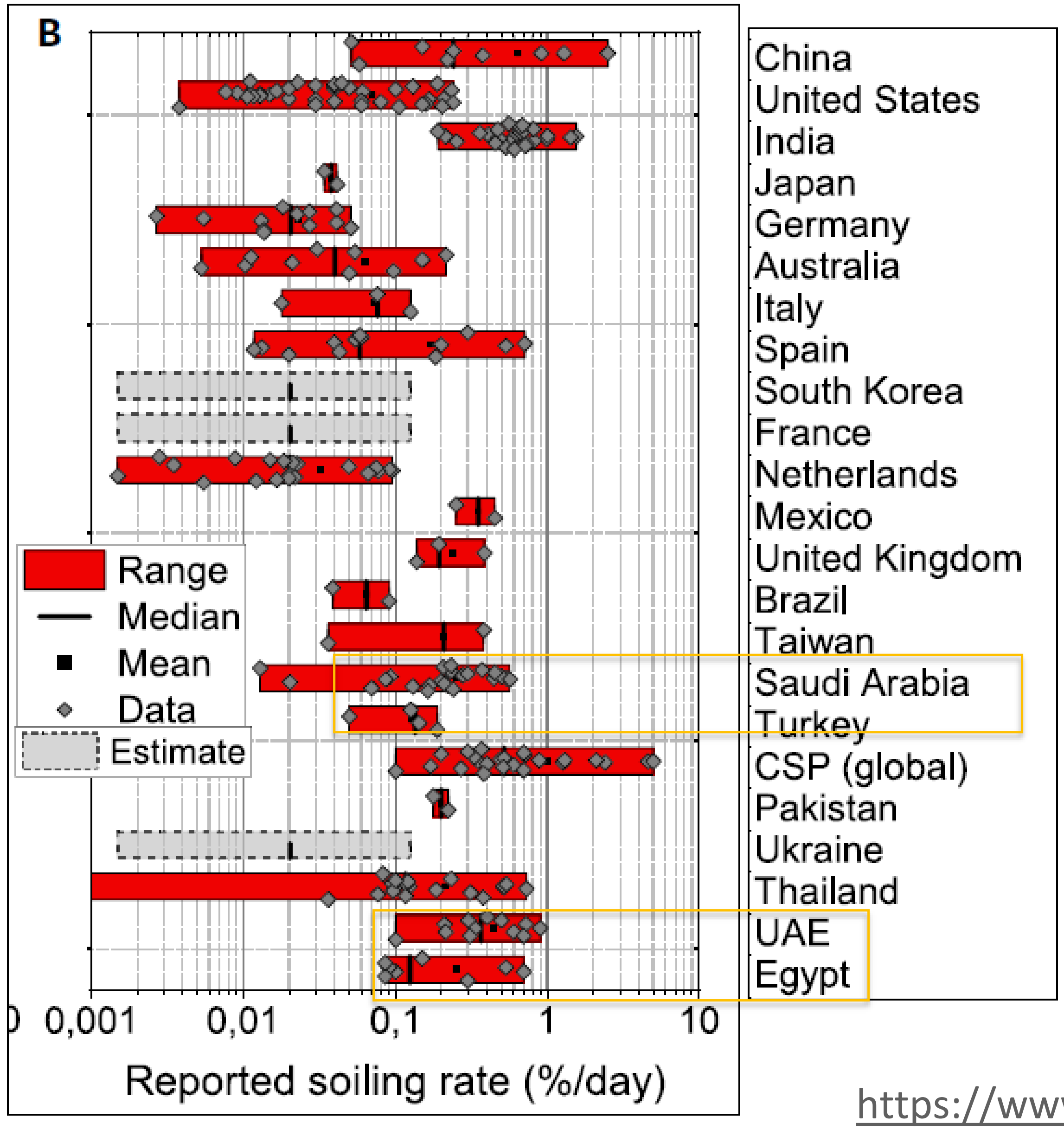


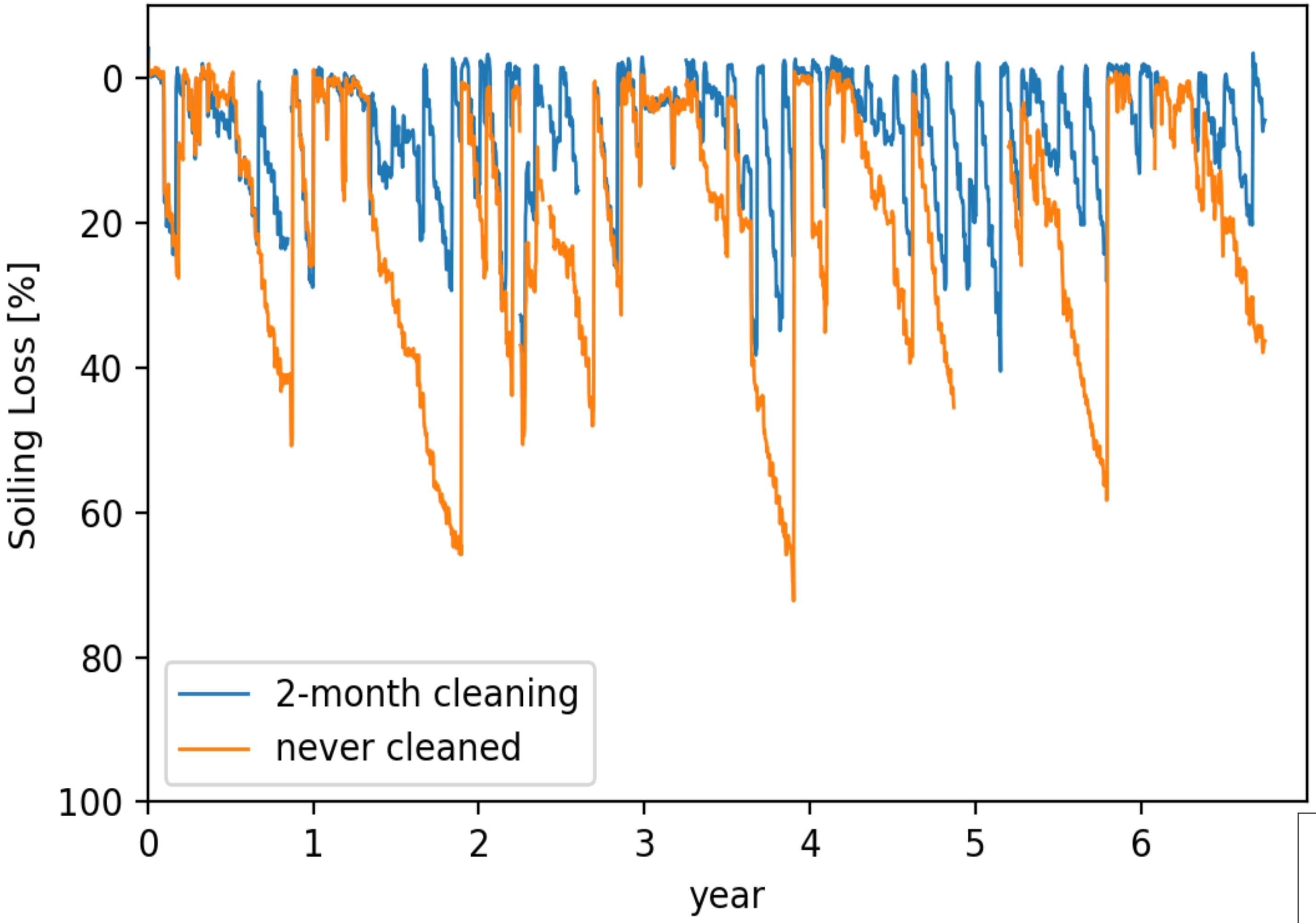
Soiling losses in desert environment

COVER STORY Soiling and cleaning

PV soiling in dry climates: causes, impacts and solutions

O&M | In arid regions soiling can greatly impact the energy yield of PV systems and drive up their O&M costs. Benjamin Figgis, Amir Abdallah, Maulid Kivambe, Brahim Aissa, Kamran Ali, Cédric Broussillou and Veronica Bermudez of the Qatar Environment & Energy Research Institute, and Klemens Ilse of the Fraunhofer Center for Silicon Photovoltaics, review the main challenges associated with soiling of PV plants globally, and the most promising techniques for dust prevention and cleaning in dry climates, drawing on research results from six years of PV performance and soiling studies at QEERI's Outdoor Test Facility in Doha





- **Extensive work in QEERI on soiling published as cover story of PV Tech Power vol.21**
- **Losses of up to 0.4-0.5%/day excluding sandstorms**
- **>50% of power lost after high soiling due to sandstorm**
- **Low precipitation and low water availability in desert**

POWER PVTECH
Volume 21 PV POWER PLANT TECHNOLOGY AND BUSINESS November 2019

https://www.pv-tech.org/news/pv-tech-power-21-now-available-to-download

QEERI’s Outdoor Test Facility 35,000m²

- Since 2013: Testing of all PV Systems technologies : polycrystalline, monocrystalline, heterojunction, thin films (tandem u-Si-a-Si, CdTe, CIGS), concentration PV
- Fixed tilt and trackers compared : Older Horizontal Single axis tracker technology has shown the interest and applicability of tracking the Sun to increase Energy yield in Qatar→ Innovation to optimize also the energy to be converted from the rear side

QEERI Proprietary

A Consortium with international companies and local stakeholders

Consortium members: DSM, Hanwha Q-Cells, Nice Solar Energy, and Total, as well as Qatar’s Ministry of Energy & Industry, Kahramaa + **SOLTEC**

Conclusions

- Degradation of photovoltaic systems is due to higher value stressors not to average conditions

- Typical Köppen-Geiger climatic zones do not provide a full picture of the climate stressors

- Environmental conditions in the Middle East and in desert locations are diverse and can stress selectively part or all of the PV components
  ➔ Photovoltaic Systems planned to be used in Desert locations must be designed for and tested in such locations to really assess the effect of combined stressors

- It is preferable to test & demonstrate the technology at small scale to support large investment for GWp PV plants

- QEERI is glad to welcome Soltec as the new member of the Solar Consortium

- PV Systems that « can make it here can make it anywhere »
  Space is available for future collaborations

Satellite view of QEERI's 35,000m²
Outdoor Test Facility

Thank you

For further requests and information:

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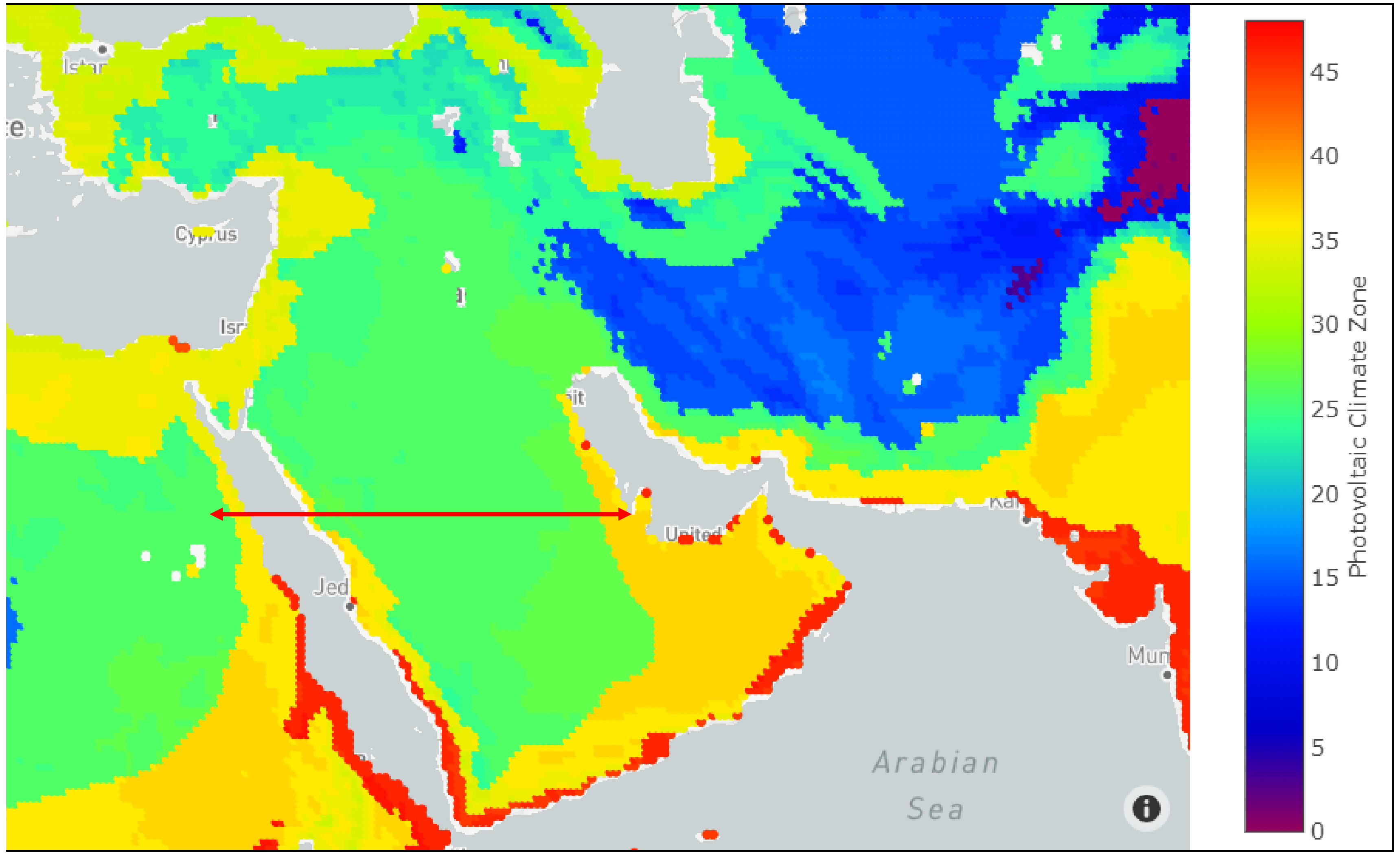
QEERI at a glance

Key metrics

- 160+ headcount / 120+ permanent staff.
- Approaching 200 headcount by end 2020.
- > 4000 m^2 laboratory space

Back-up slides

Site specific conditions can cause reliability issues

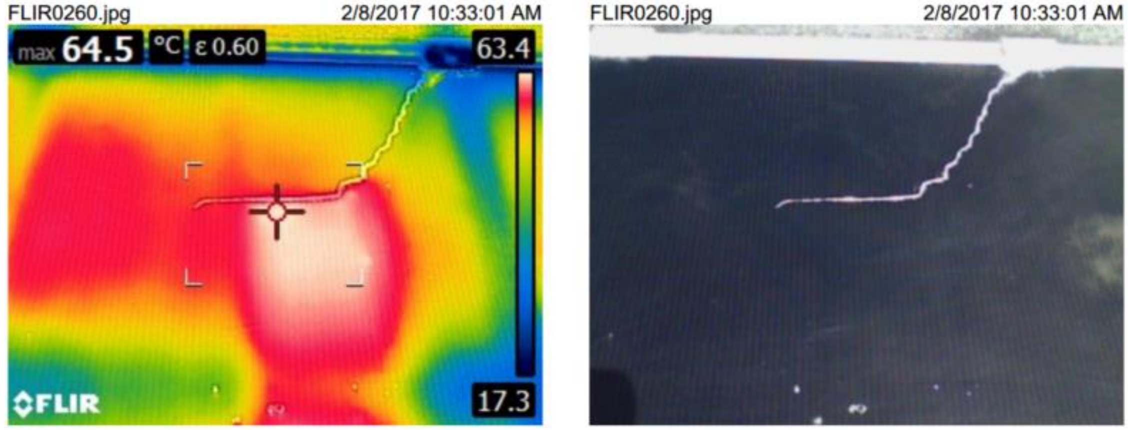


https://www.middleeastmonitor.com/20191217-egypt-giant-solar-park-in-the-desert-jump-starts-renewables-push/

QEERI's Outdoor Test Facility

- Various failure modes were observed in PV modules installed in a desert climate

- High temperatures and high UV irradiation caused earlier failure than in other climates

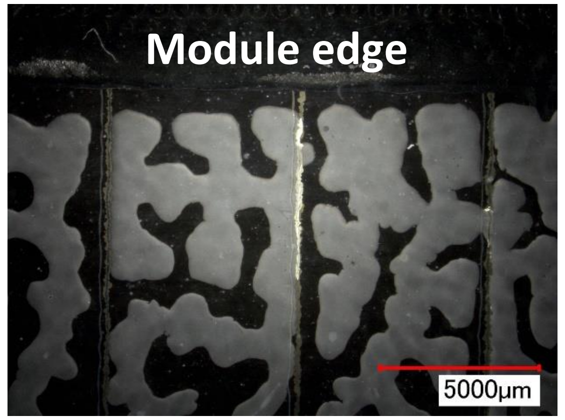


Thermo-mechanical loading: Glass breakage

Thermo-mechanical loading: Solar cell micro-cracks

Discoloration of antireflective coating

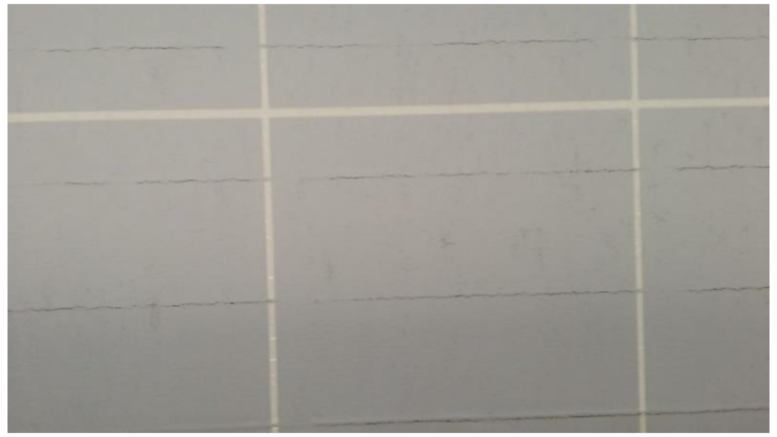
Water ingress: Ribbons corrosion



Thin film delamination (CIGS)

Back sheet yellowing: polyester

Back sheet wrinkles & folds: PVF



Back sheet cracking: Polyamide