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Geographic Assessment of Photovoltaic Module Environmental Degradation Stressors

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Introduction

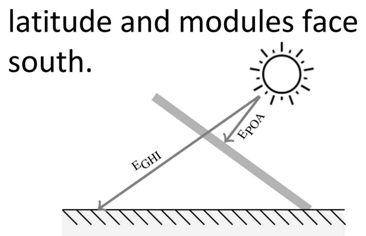
A detailed review of climate conditions in different geographic locations provides an overview of a photovoltaic (PV) module's potential exposure to environmental stressors. Exposure to extreme temperatures, humidity, thermal cycling, ultraviolet radiation, and others can stress and damage the bonds, packaging, and other components. This poster reviews **past work that modeled PV degradation based on environmental stressors, identifies the weather variables, and evaluates the ability of the Global Land Data Assimilation System (GLDAS) to map the stressors.**

Methodology

The assessment of weather variables (radiation, temperature, humidity) uses GLDAS, which provides spatial and temporal data for the entire Earth, to map known degradation stressors. However, the degradation and the GLDAS variables did not match exactly. Therefore, this poster assesses the need to translate GLDAS variables (e.g. ambient temperature to module temperature) to match with the PV degradation model variables.

Solar Radiation

POA estimate assumes that the tilt angle is equal to the latitude and modules face due south.



Module Temperature

Estimate and compare module temperature based on POA and GHI irradiance, wind, and ambient temperature provided by the GLDAS data set.

$$T_m = E[\exp(a + bW)] + T_a$$

Humidity

GLDAS provides specific heat (SH), however relative humidity (RH) is a common variable in past literature. This work calculated and compared SH and RH.

$$RH = 0.26(P)(SH)\left[\exp\left(\frac{17.67(T - T_o)}{T - 29.65}\right)\right]^{-1}$$

Background

Solar Radiation

Koehl, Michael, et al. "Development and application of a UV light source f PV-module testing." International Society for Optics and Photonics, 2009.

$$D_{uv}(t) = \int_a^b E(u)(0.05)\,\mathrm{d}u.$$

Module Temperature

Haillant, et al. "An Arrhenius approach to estimating organic photovoltaic module weathering acceleration factors." *Solar Energy Materials and Solar Cells* 95.7 (2011): 1889-1895.

$$D = \mathrm{T}_m \exp\left(\frac{-Q_a}{k_b \mathrm{T}_m}\right)$$

Kurtz, Sarah, et al. "Evaluation of high-temperature exposure of rack-mounted photovoltaic modules." *2009 34th IEEE Photovoltaic Specialists Conference (PVSC)*. IEEE, 2009.

$$\exp\left(\frac{-Q_a}{k_b \mathrm{T}_{eq}}\right) = \frac{1}{t_1 - t_2}\int \exp\left(\frac{-Q_a}{k_b \mathrm{T}(t)}\right)\mathrm{d}t.$$

Module Thermal Cycling

Vasudevan, Vasu, and Xuejun Fan. "An acceleration model for lead-free (SAC) solder joint reliability under thermal cycling." *2008 58th Electronic components and technology conference*. IEEE, 2008.

$$\mathrm{AF} = \left(\frac{f_{field}}{f_{test}}\right)^{-m}\left(\frac{\Delta T_{field}}{\Delta T_{test}}\right)^{-n} \exp\left(\frac{Q_a}{k}\left(\frac{1}{T_{\text{field}}} - \frac{1}{T_{\text{test}}}\right)\right)$$

Bosco, Nick, Timothy J. Silverman, and Sarah Kurtz. "Climate specific thermomechanical fatigue of flat plate photovoltaic module solder joints." *Microelectronics Reliability* 62 (2016): 124-129.

$$D = \mathrm{C}(\Delta\mathrm{T})^n(r(\mathrm{T}))^m \exp\left[\frac{-Q}{k_B \mathrm{T}_{max}}\right]$$

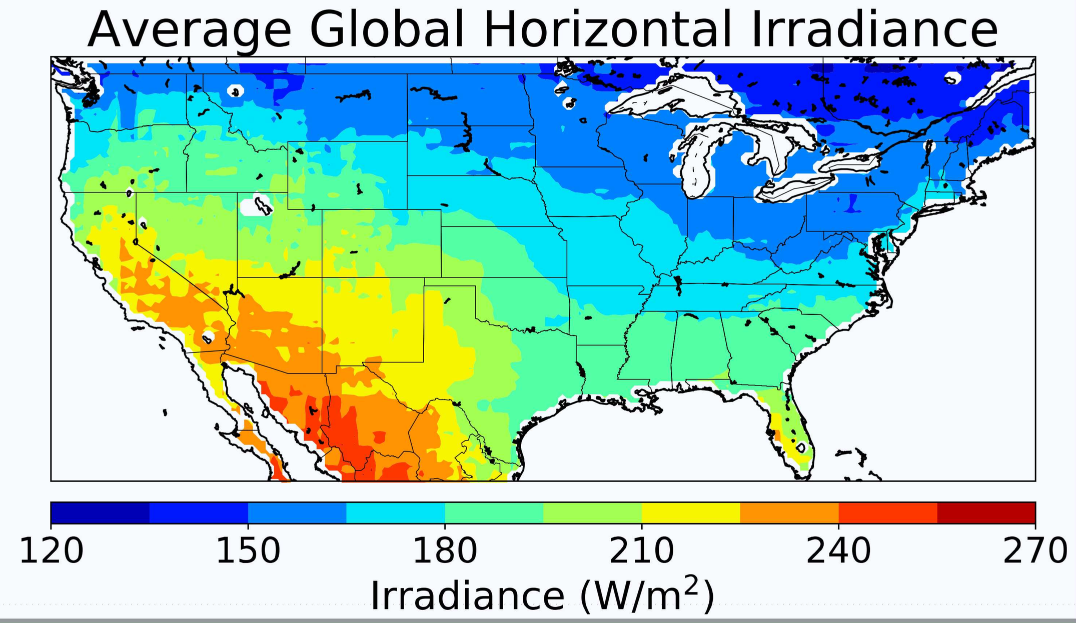
Humidity

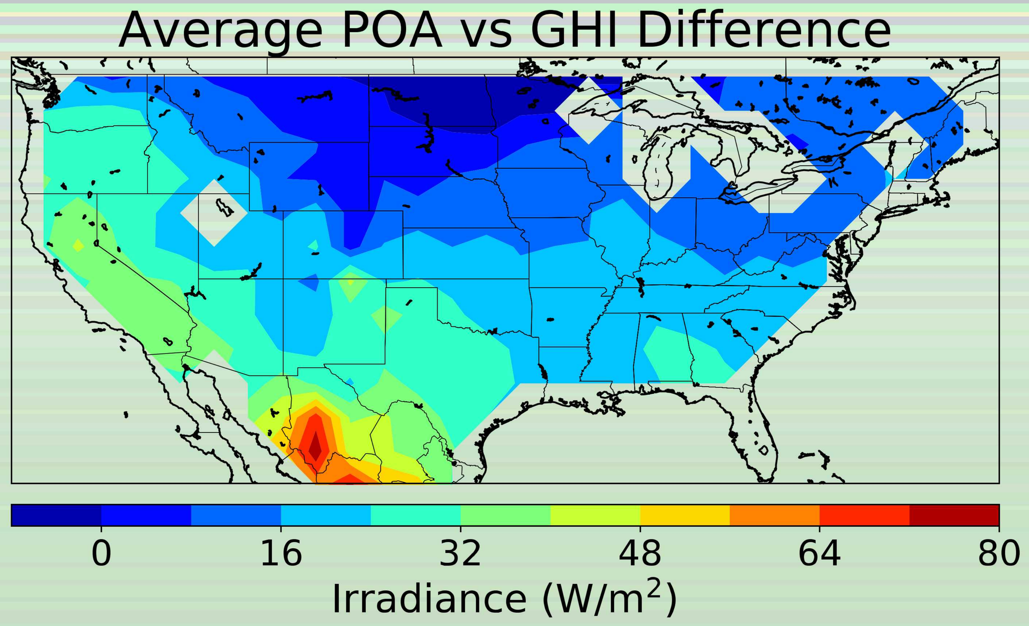
Park, N. C., W. W. Oh, and D. H. Kim. "Effect of temperature and humidity on the degradation rate of multicrystalline silicon photovoltaic module." *International Journal of Photoenergy*2013 (2013).

$$R_{D,Peck} = A\,\exp\left(\frac{-Q_a}{k_b \mathrm{Tm}_{max}}\right)\mathrm{RH}^n$$

$$R_{D,Eyring} = A\,\exp\left(\frac{-Q_a}{k_b \mathrm{Tm}_{max}} - \frac{b}{\mathrm{RH}}\right)\mathrm{RH}^n$$

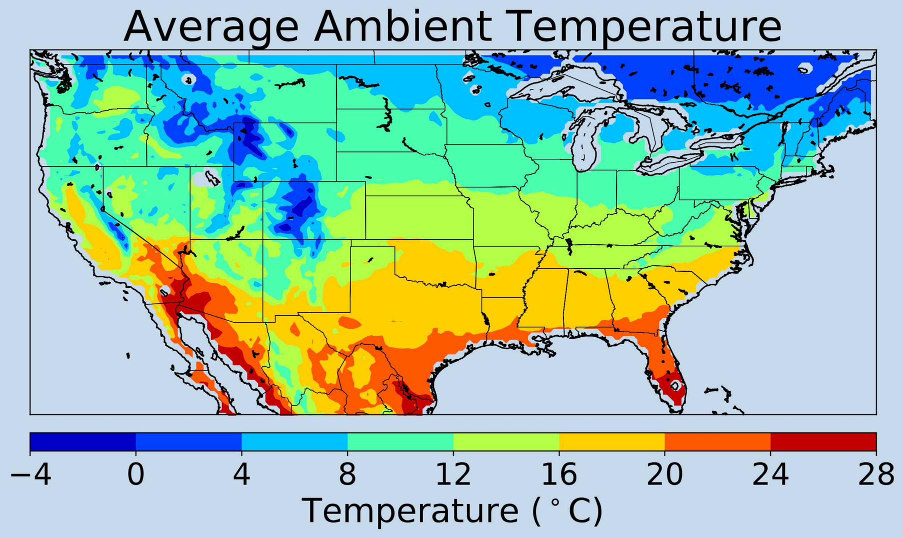
Solar Radiation



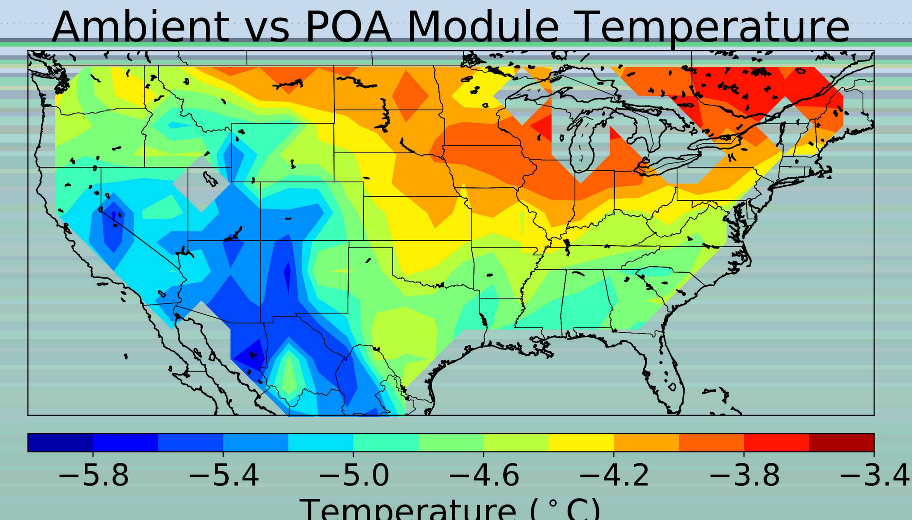


The difference between GHI and POA irradiance ranged between -2 to 80W/m² across the U.S. Largest differences are in the south and are lower in the north part of the country. In higher latitudes the difference between POA and GHI became negative (i.e. POA is higher than GHI in norther latitudes and the opposite is true in the more southern latitudes).

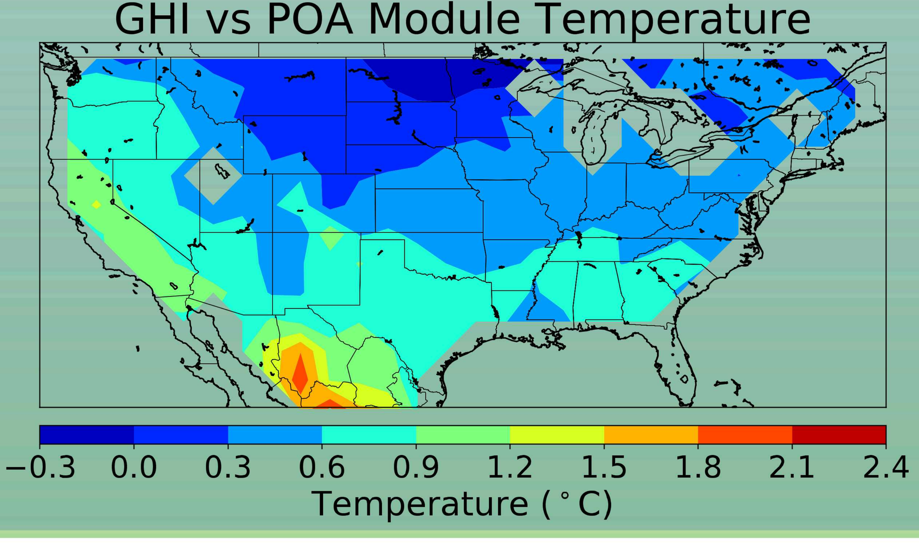
Module Temperature



The average annual ambient temperature in the U.S. range from -4℃ to 28℃. The hottest temperatures are are in the Gulf Coast and the Death Valley region. The coldest areas are in the high altitudes and extreme latitudes.

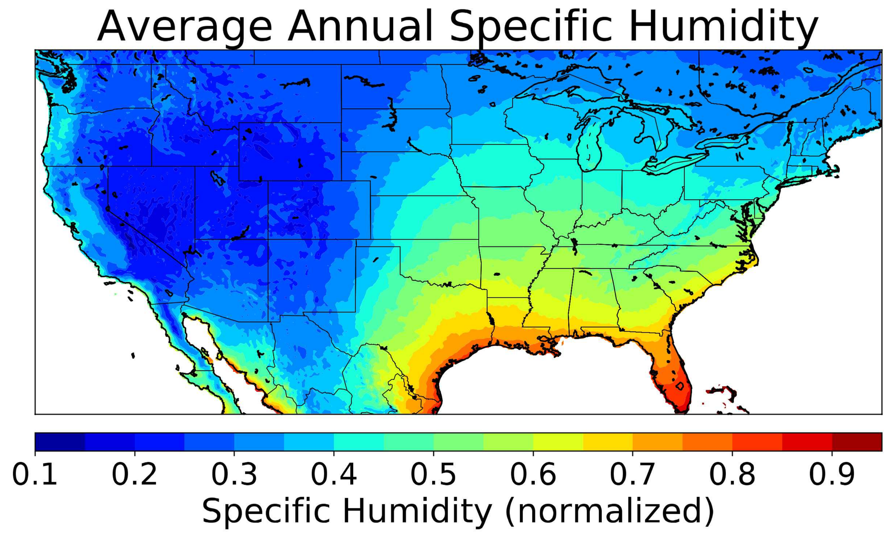


The difference between the ambient and module POA temperature is maximum in the southwest region where there is significant radiation and smaller in the northeast where radiation does not have as much of an impact.

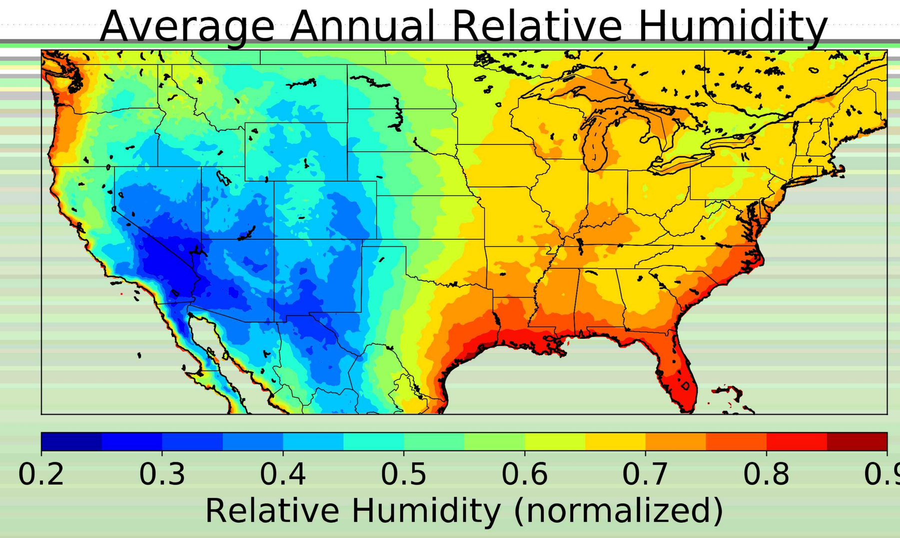


The difference in module temperature using the GHI or POA irradiance input varied between -0.3℃ and 2.4℃. The most significant difference is in the south and is near zero in the norther latitudes.

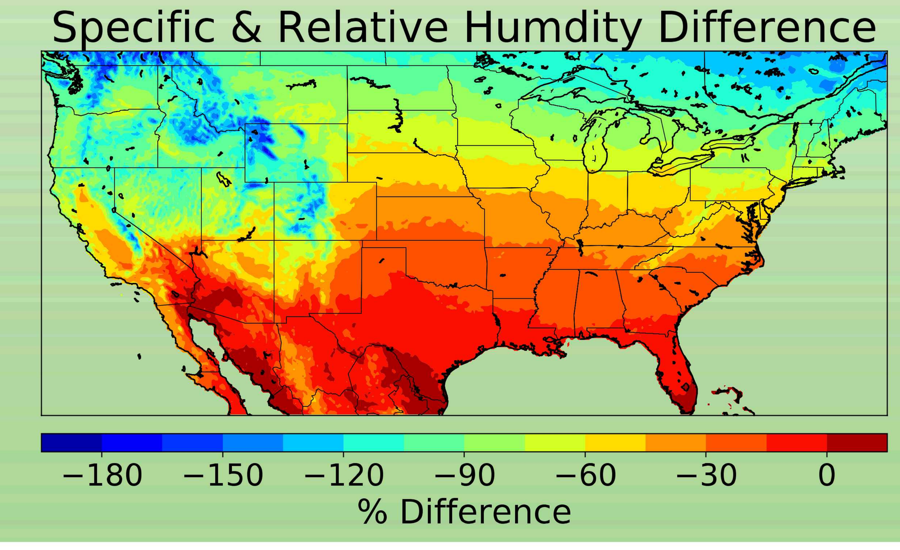
Humidity



The specific humidity (SH), which is the mass of water vapor in a unit of moist air, is highest in the Gulf Coast region and decreases to the north and west. The western states all experience low SH that is at a similar magnitude.



Relative humidity (RH) is the amount of water vapor present in air depending on the ambient temperature. The highest RH is in the eastern part of the U.S., especially in the southeastern states. The southwestern region has low RH in comparison with the eastern states. The four corners area has the lowest RH.



The difference between the specific and relative humidity is smallest in states east of New Mexico and south of Kentucky. The differences are also small in the Death Valley area. The most significant differences are in the high elevation areas like the Rocky Mountains.

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