The Future of Transposition Models: *From Isotropic Approximation to Physics Models*

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Options in quantifying solar resource

Thermopile on a horizontal surface providing horizontal irradiance

Reference cell or thermopile on inclined surfaces: more closely correlate with system performance

Transpose horizontal irradiance to POA irradiance: horizontal data are easier to document
Computation of POA irradiance

\[ POAI = DNI \cos \theta' + GHI \times \sigma_f + \int I \cos \theta' \, d\Omega \]
Isotropic approximation

- Liu and Jordan (1963):
  \[ POAI_{\text{diffuse}} = DHI \times \frac{1 + \cos \beta}{2} \]

- Koronakis (1986), Tian et al. (2001), Badescu (2002), etc.

- Models after 1963 may have a better agreement to surface measurements (Noorian et al. (2008), Jakhrani et al. (2012), Loutzenhisier, et al. (2007)).
Isotropic vs. anisotropic models

\[ W \text{m}^{-2} \text{sr}^{-1} \mu \text{m}^{-1} \]
Isotropic vs. anisotropic models

- Radiative transfer models can simulate radiances.
- For each tilt angle, POA irradiance can be computed.
- Isotropic model may dramatically underestimate POA irradiance.

$\lambda=0.6 \mu\text{m}$
Isotropic vs. anisotropic models

- The underestimation increases with cloud optical thickness, but rapidly decreases when cloud is thick.
- The underestimation can reach >20% (>200W/m²).
- For thick clouds, isotropic model overestimates POA irradiance by ~5% (8-15W/m²).

λ=0.6μm
Empirical transposition models show bias

- Empirical transposition models consider a more detailed analysis of the downwelling diffuse solar radiation by using empirically derived coefficients.
- Perez model is one of the models (in 21 models) with consistently best performance (Hay, 1988).
- Sun et al. (2014) showed bias of Perez model depending on site.

Sun et al.(2014)
Uncertainties in transposition models

- The accuracy of empirical transposition models varies with the use of the coefficients.
- Decomposition model gives additional uncertainty in the POA irradiance.

1-minute POA irradiances from 1-axis tracking measurements on 1/22/2015. "Cape Canaveral 1988"
Uncertainties in surface albedo

- Transposition models use surface albedo from climatology/TMY to estimate surface reflection.
- The uncertainty becomes much larger in winter because of snow.
Current models lead to higher uncertainties

Satellite data

Surface data

Radiative Transfer

POA Irradiance

Transposition

Spectral GHI, DHI, DNI

Spectral Model

Decomposition

GHI

DHI

DNI
Future opportunities

- The spectral channels with better temporal and spatial resolutions will lead to more accurate cloud and land surface products.
- Current models are hard to benefit from future development of satellite techniques.

GHI

http://nsrdb.nrel.gov

www.lockheedmartin.com
Cloud transmittance and reflectance of irradiance

AOD, \( \theta \), g, \( \omega \), PWV, P, ozone, ...

REST2

Clear-sky transmittance and reflectance

All-sky broadband irradiances

Surface albedo

Xie et al., Solar Energy (2016)
Empirical vs. physics models

Satellite data → Radiative Transfer → GHI → Decomposition → DHI, DNI

Satellite data → FARMS → GHI → DHI, DNI
Future models

Satellite data

POA Irradiance

Spectral POA Irradiance

Spectral GHI, DHI, DNI

Radiative Transfer

Decomposition

Transposition

Spectral Model
Conclusions and future work

• POA irradiance can be analytically solved using an isotropic approximation.
• Isotropic model can underestimate POA irradiance by 5-20%.
• The accuracy of empirical transposition models depends on empirical coefficients, decomposition models, and surface albedo.
• Future transposition models can benefit from the development of satellite remote sensing.
• The risk of accumulated uncertainties can be reduced by using a physics model.
Let’s talk!
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The Energy Systems Integration Facility
Golden, CO. Image by Dennis Schroeder, NREL