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Performance Analysis of Transposition Models Simulating Solar Radiation on Inclined Surfaces

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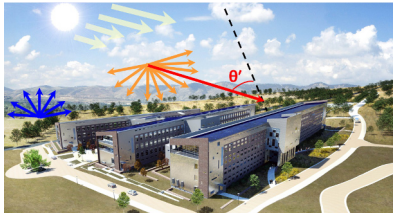
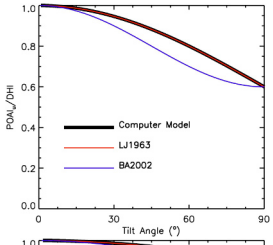
1. Overview

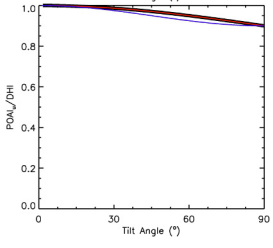
Transposition models have been widely used in the solar energy industry to simulate solar radiation on inclined photovoltaic panels. Following numerous studies comparing the performance of transposition models, this work aims to understand the quantitative uncertainty in state-of-the-art transposition models and the sources leading to the uncertainty. Our results show significant differences between two highly used isotropic transposition models with one substantially underestimating the diffuse plane-of-array (POA) irradiances when diffuse radiation is perfectly isotropic. In the empirical transposition models, the selection of empirical coefficients and land surface albedo can both result in uncertainty in the output. This study can be used as a guide for the future development of physics-based transposition models and evaluations of system performance.

$$POAI = DNI\cos\theta' + GHI \times \sigma f + \int I\cos\theta' d\Omega$$



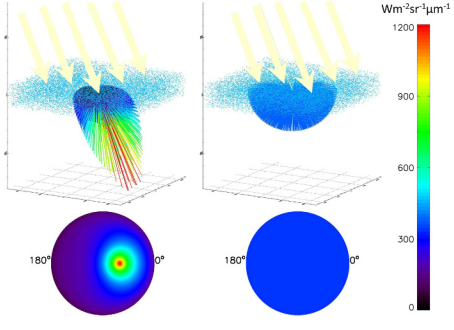
2. Isotropic Approximation



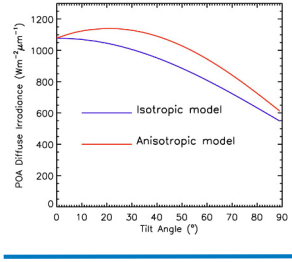


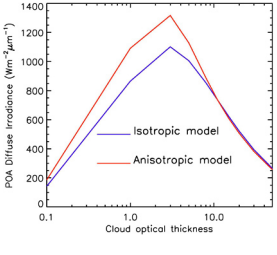
- Liu and Jordan (1963; LJ1963) analytically solved diffuse POA irradiance with an isotropic approximation.
- Badescu (2002; BA2002) provided the solution of isotropic approximation following a 3D geometry.

A computer model imitating isotropic diffuse radiation and numerically simulating diffuse POA irradiance suggests that BA2002 substantially underestimates diffuse POA irradiance.



A radiative transfer model with typical cloud properties suggests that diffuse radiation is more pronounced in the forward direction. Thus, isotropic approximation may dramatically underestimate POA irradiance.

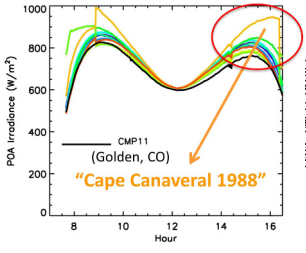


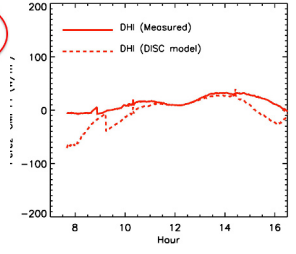


- The underestimation can reach >20% (200 W/m^2).
- For thick clouds, the uncertainty of POA irradiance from isotropic approximation is ~5% (8–15 W/m^2)

3. Empirical Transposition Models

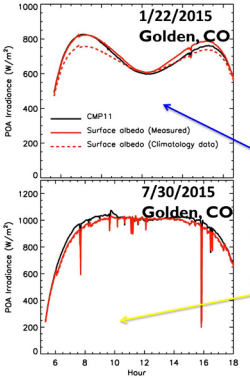
- One-minute POA irradiances from 1-axis tracking measurements at NREL suggest that empirical transposition models generally have better accuracy than isotropic models.

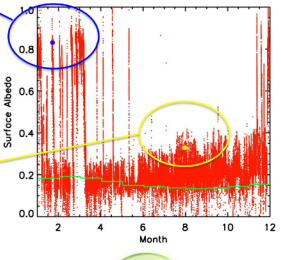




- The accuracy of empirical transposition models varies with the use of the coefficients.
- Decomposition models give additional uncertainty in the POA irradiance.

4. Other Uncertainties

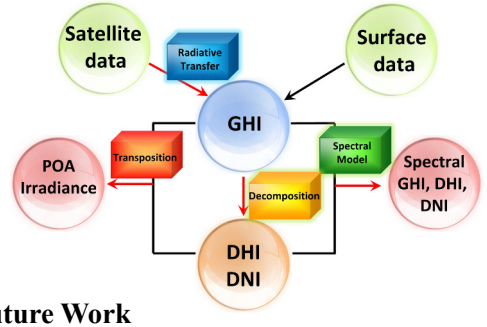




- Many transposition models use surface albedo from climatology/TMY data to estimate surface reflection.
- The uncertainty becomes much larger in winter because of snow.

The solid lines associated with LJ1961 and PEREZ are simulations using surface albedo measurements at NREL. The dashed lines are those from surface albedo based on a climatology using NASA's MERRA data.

- Current models use multiple steps to derive POA irradiance and spectral GHI, DHI and DNI.
- The uncertainties from individual models/steps can accumulate and lead to higher uncertainties in POA irradiance and spectral GHI, DHI and DNI.
- Current models suffer the risk in double counting the uncertainties in multiple steps.



5. Conclusions and Future Work

- POA irradiance can be analytically solved using an isotropic approximation.
- Isotropic models 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 should benefit from the development of satellite remote sensing.
- The risk of accumulated uncertainties can be reduced by using a physics model.

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