NREL
NATIONAL RENEWABLE ENERGY LABORATORY





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

Yu Xie and Manajit Sengupta

Solar 2016, July 11, 2016

San Francisco, California

NREL/PR-5D00-66756

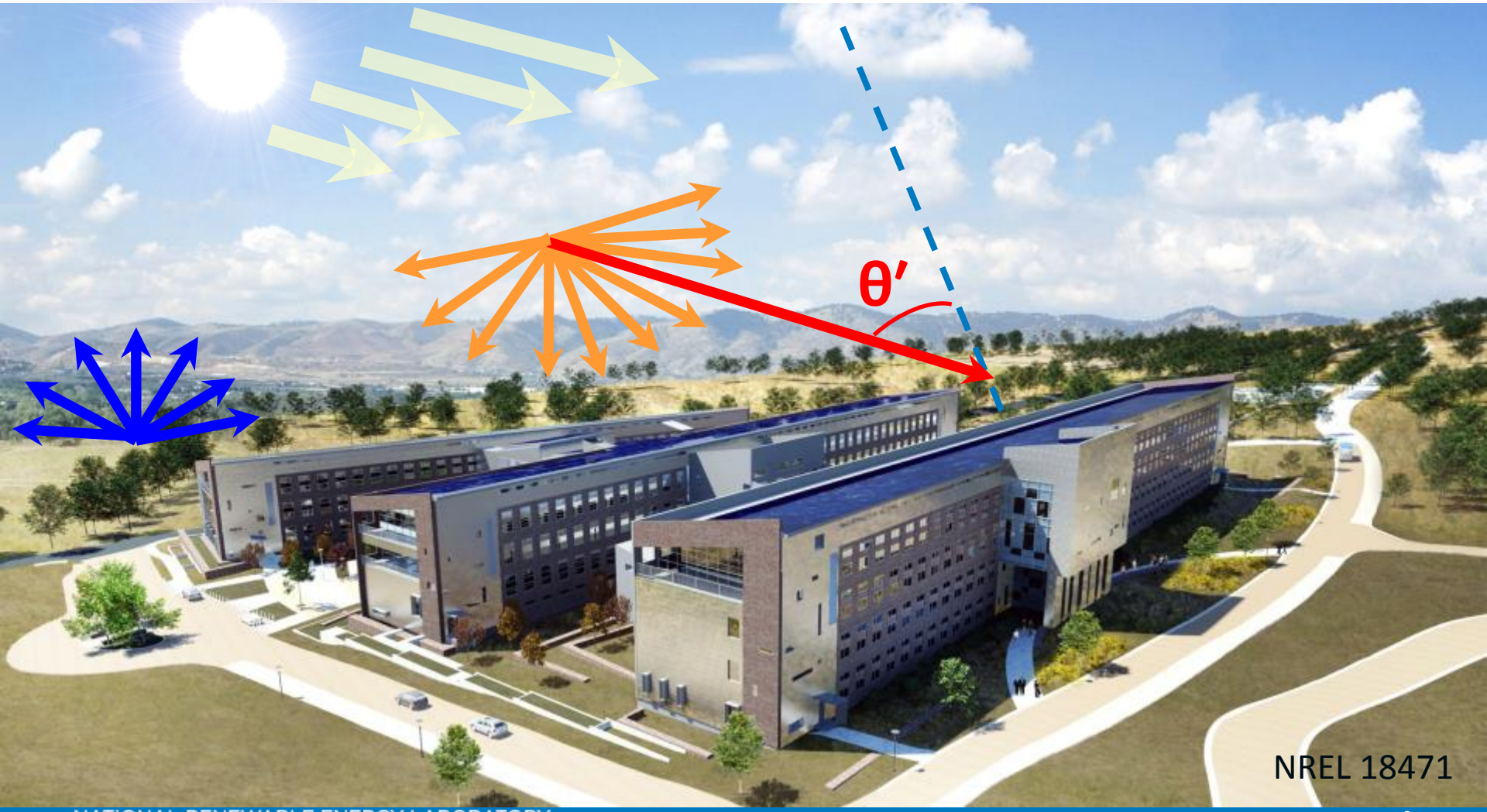
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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

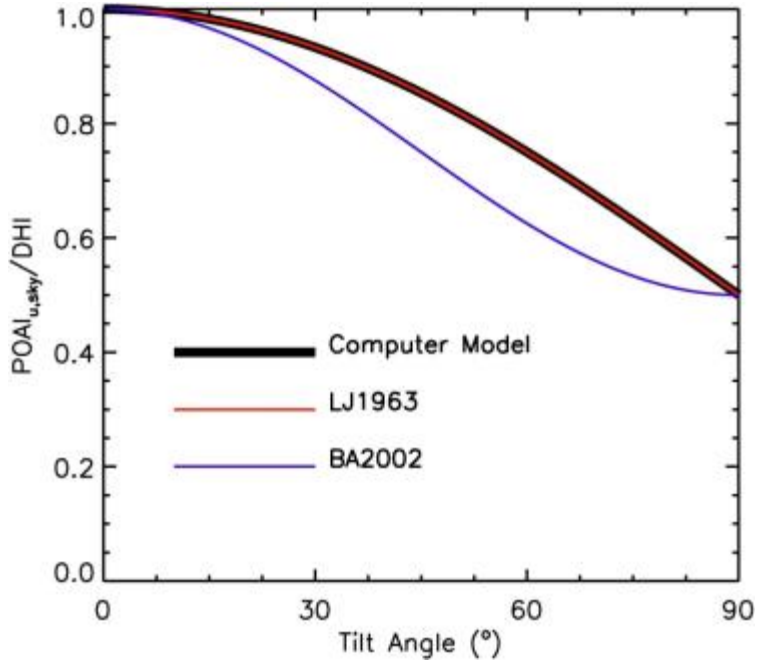
$$POAI = DNI\cos\theta' + GHI \times \sigma f + \int I\cos\theta' \, d\Omega$$

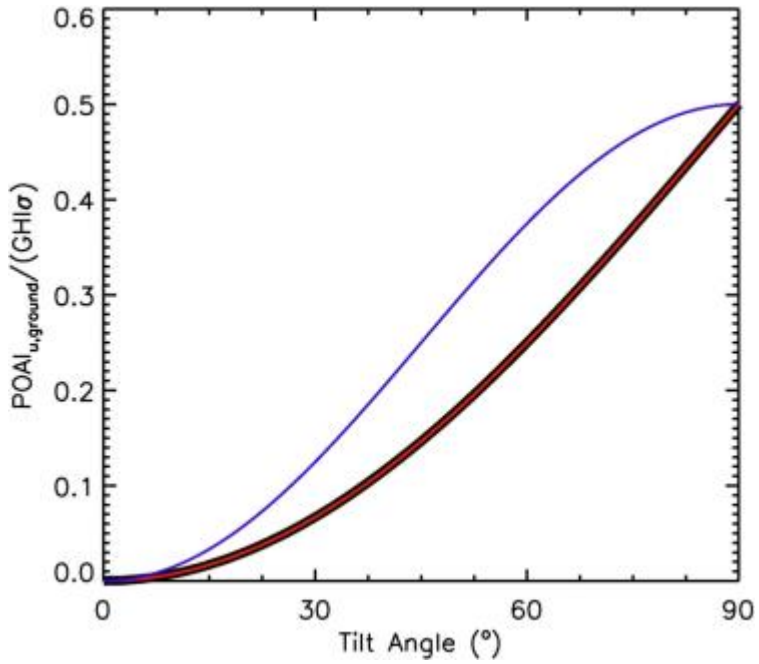


NREL 18471

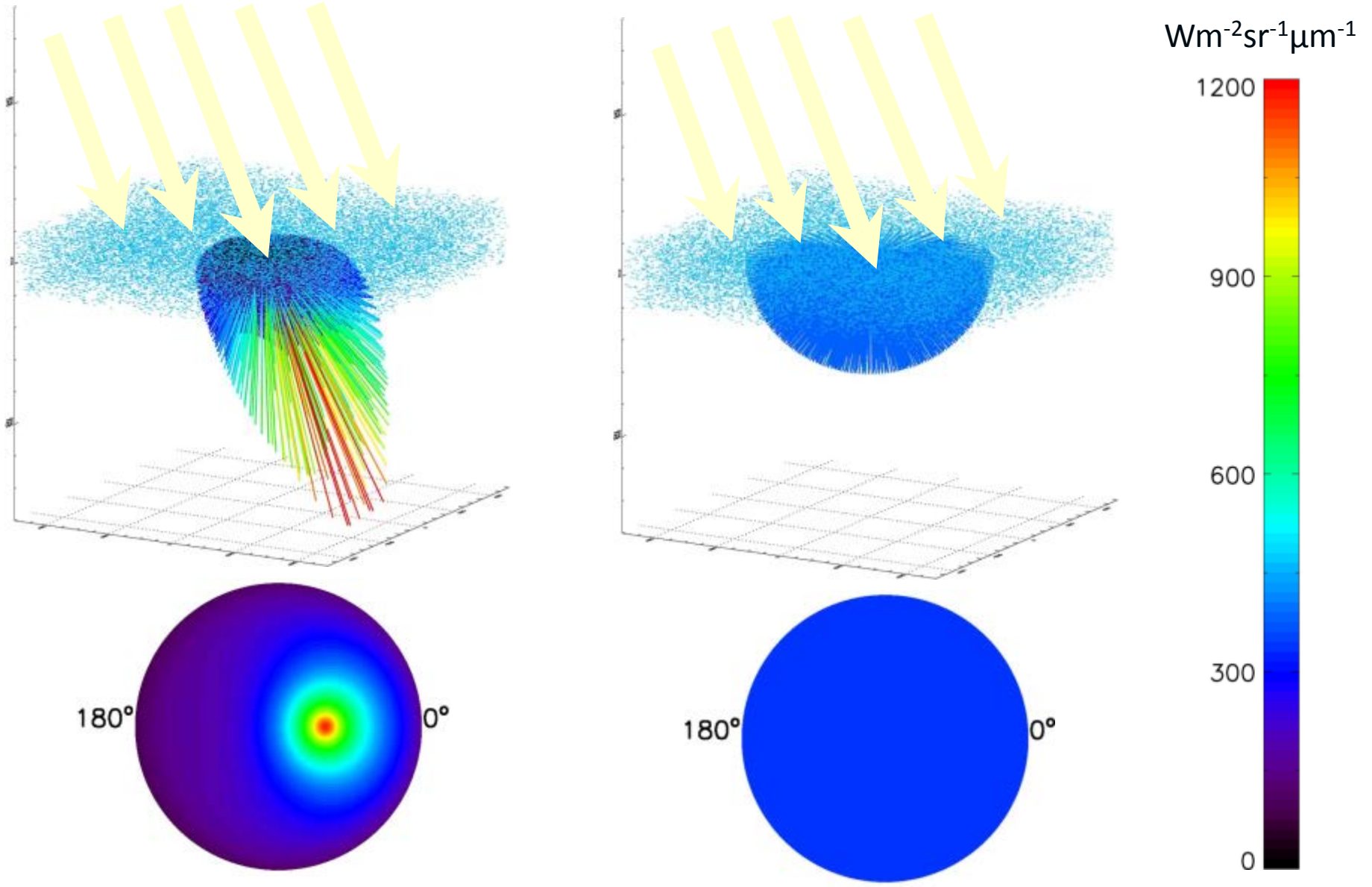
Isotropic approximation

- **Liu and Jordan (1963):** $$POAI_{diffuse} = DHI \times \frac{1+\cos\beta}{2}$$
- **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),Loutzenhiser, et al.(2007)).**



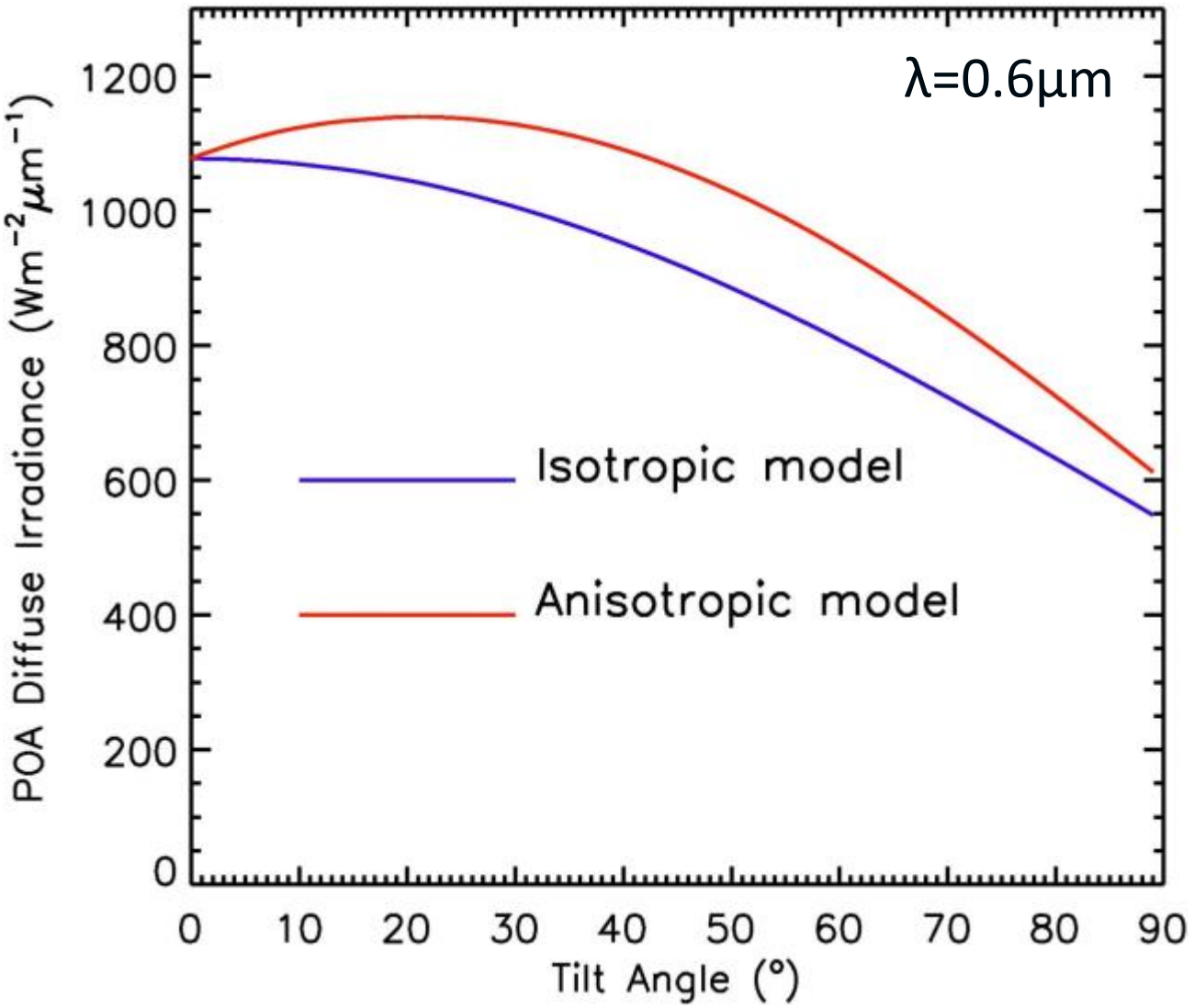


Isotropic *vs.* anisotropic models



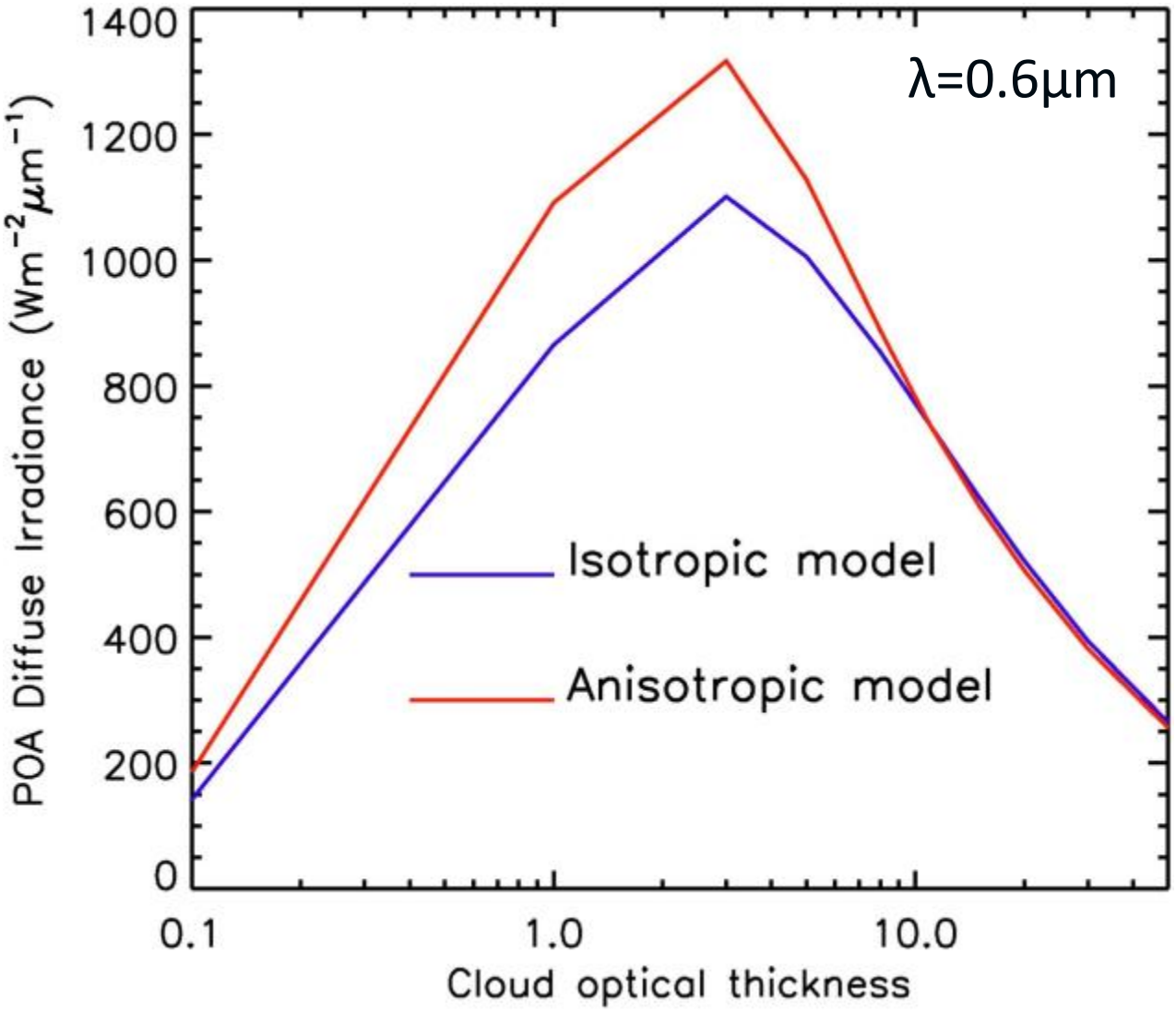
Isotropic *vs.* anisotropic models

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



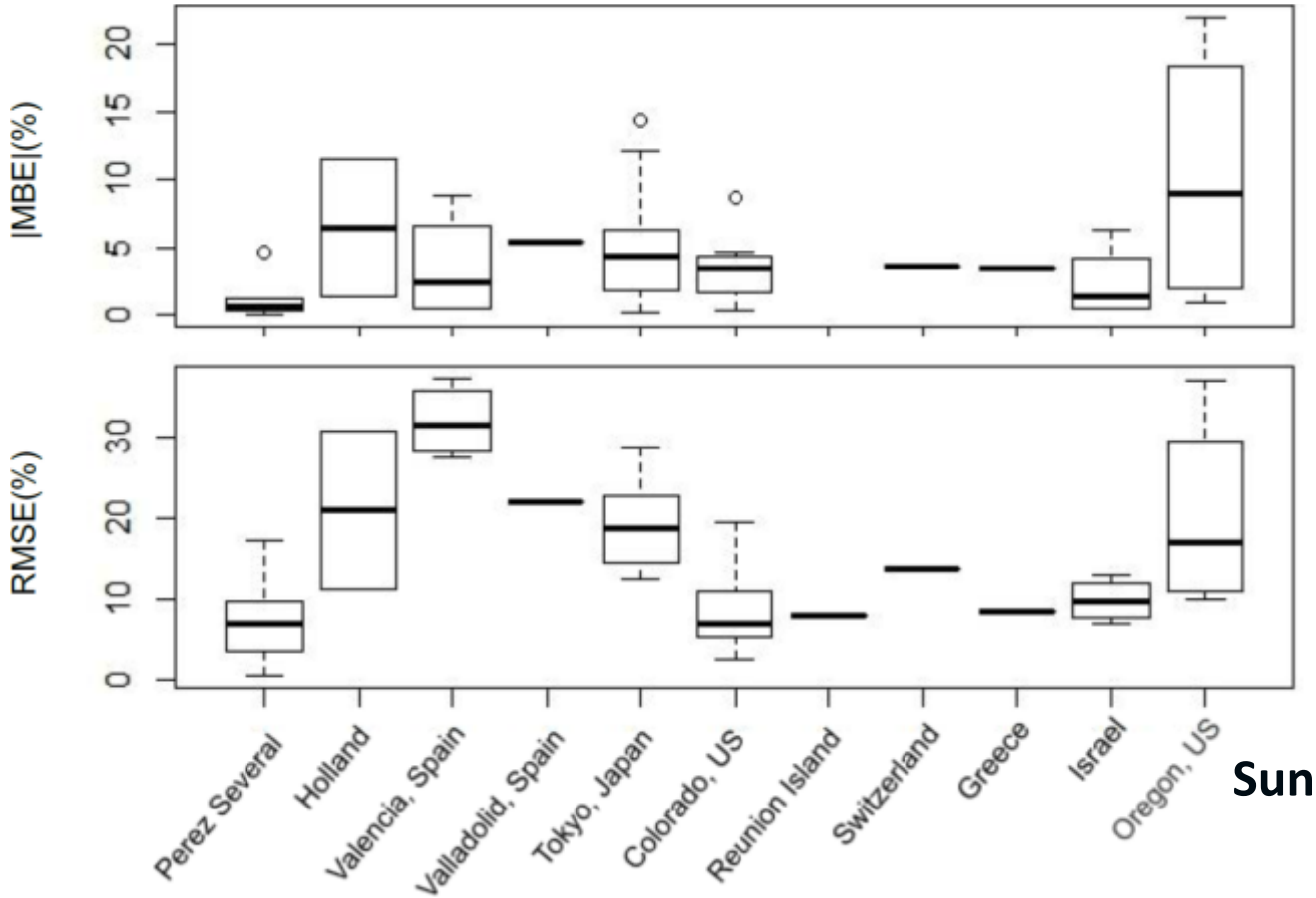
Isotropic *vs.* anisotropic models

- **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).**



Empirical transposition models show bias

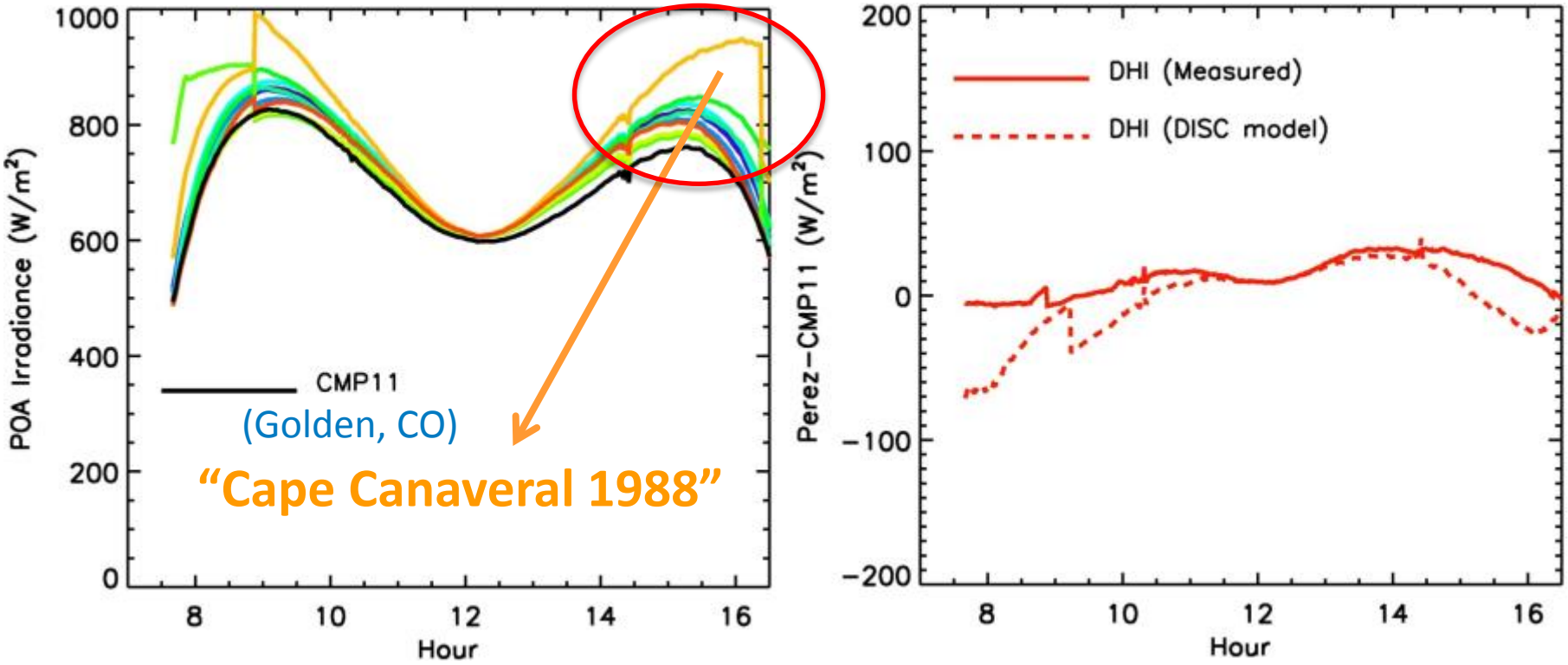
- Empirical transposition models consider a more detailed analysis of the downwelling diffuse solar radiation by using empirically derived coefficients.
- Perez model is one of the models (in 21 models) with consistently best performance (Hay, 1988).
- Sun et al. (2014) showed bias of Perez model depending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



Sun et al.(2014)

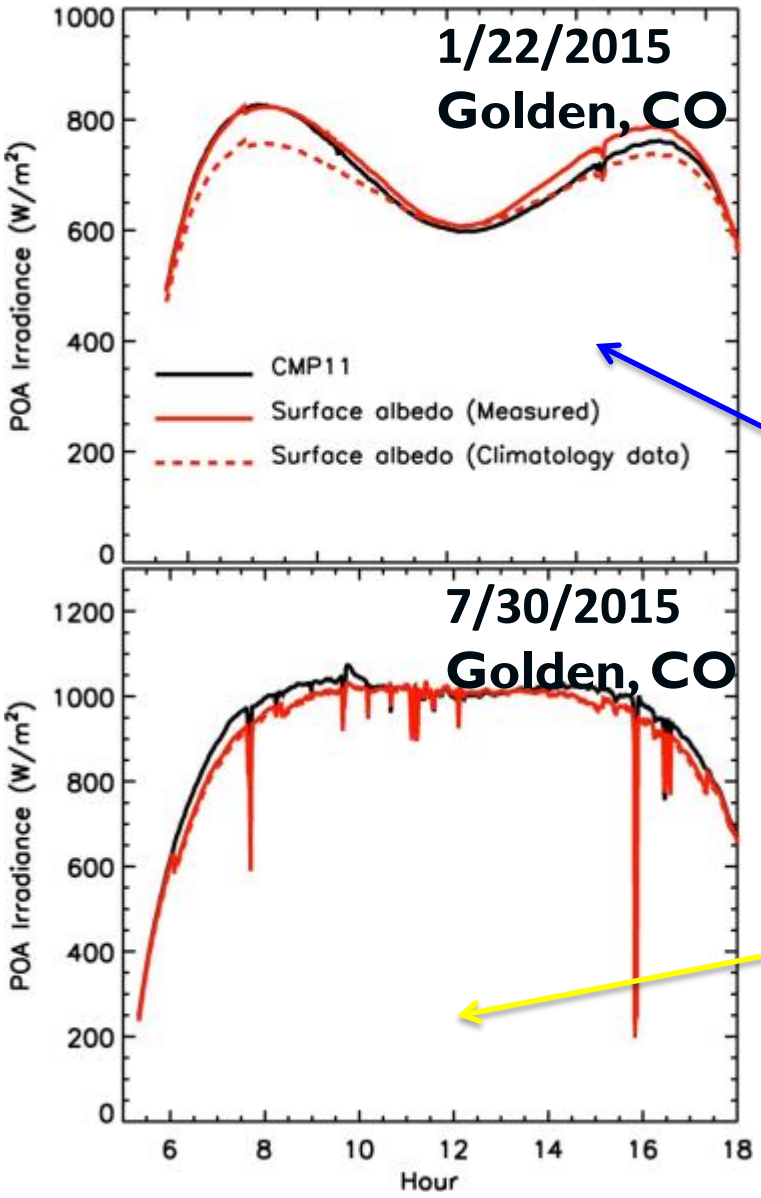
Uncertainties in transposition models

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

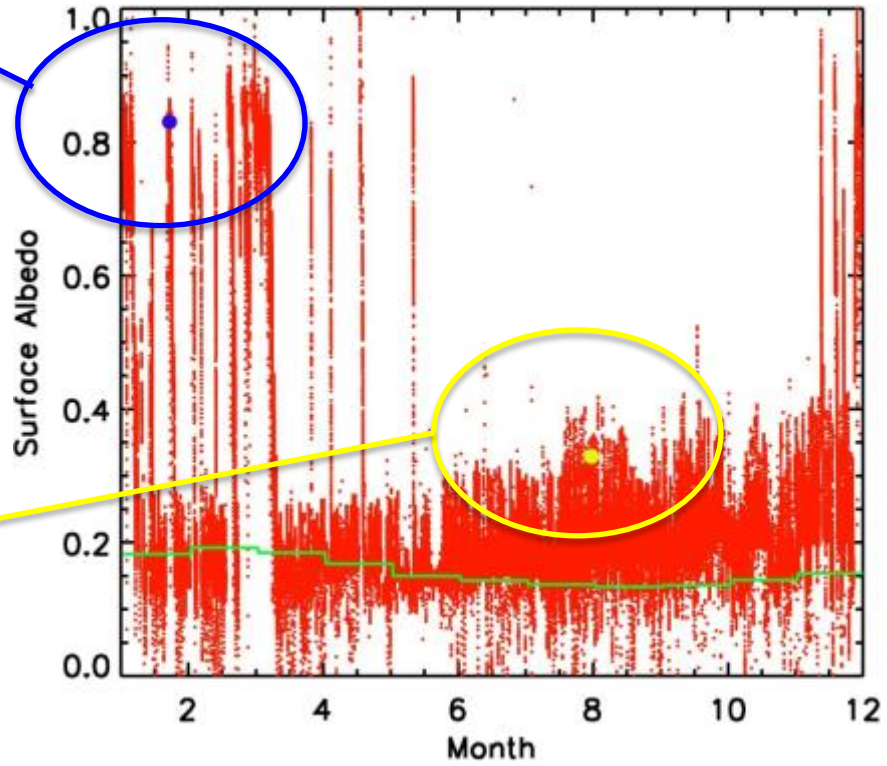


1-minute POA irradiances from 1-axis tracking measurements on 1/22/2015.

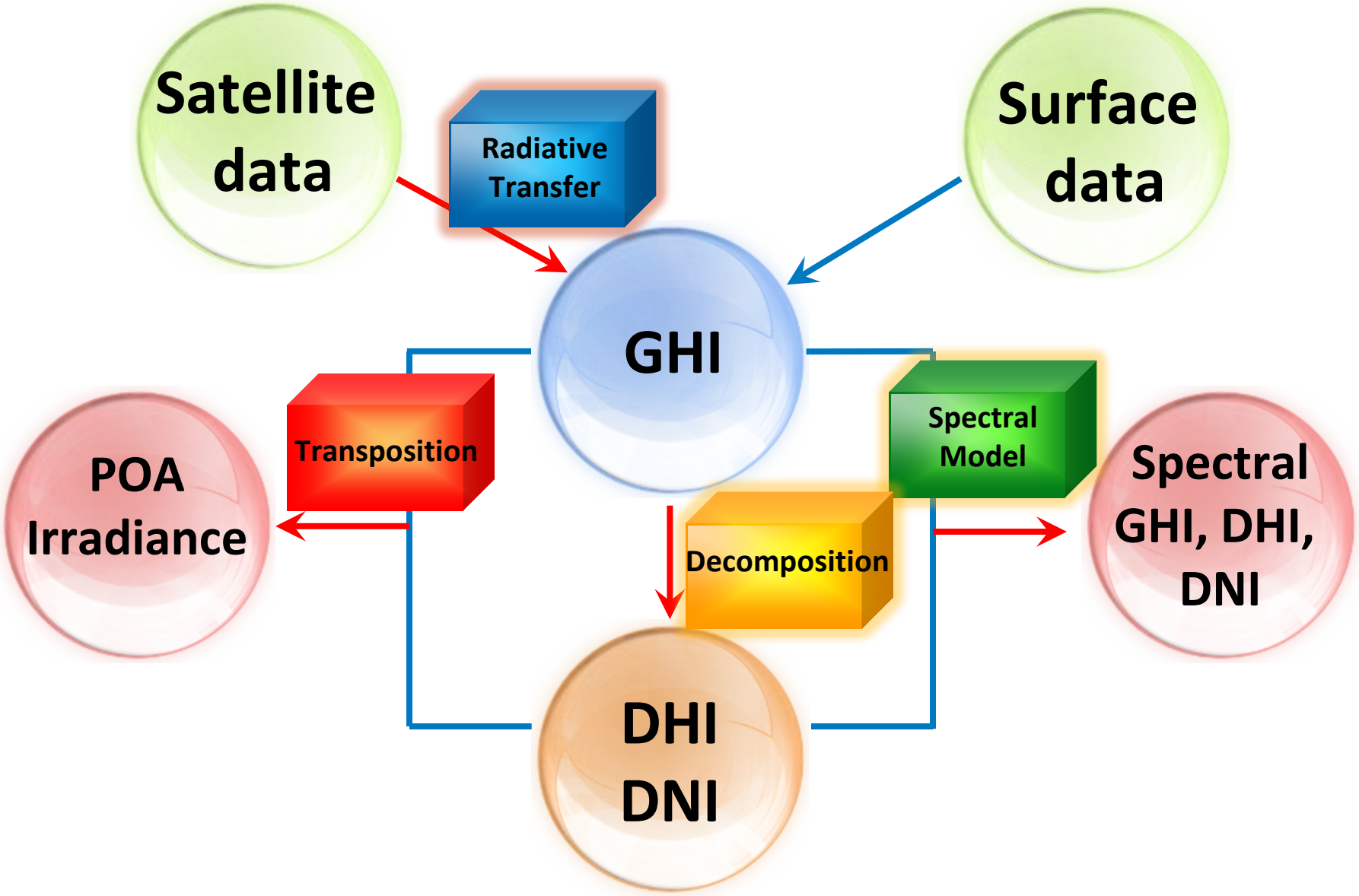
Uncertainties in surface albedo



- 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

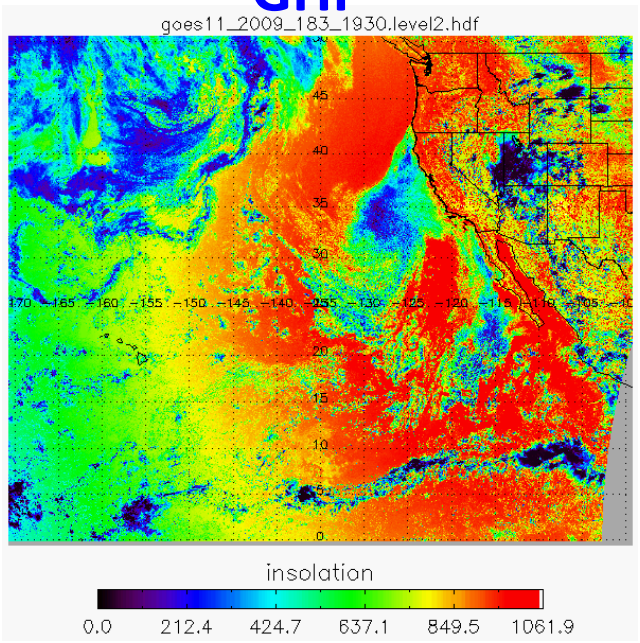


Future opportunities

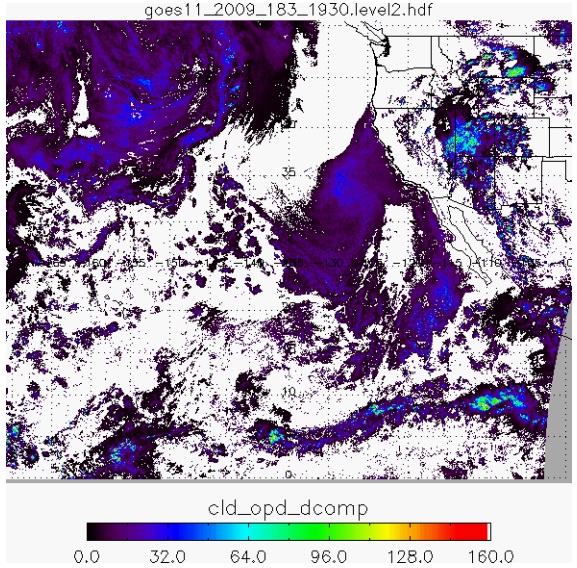
www.lockheedmartin.com

- 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

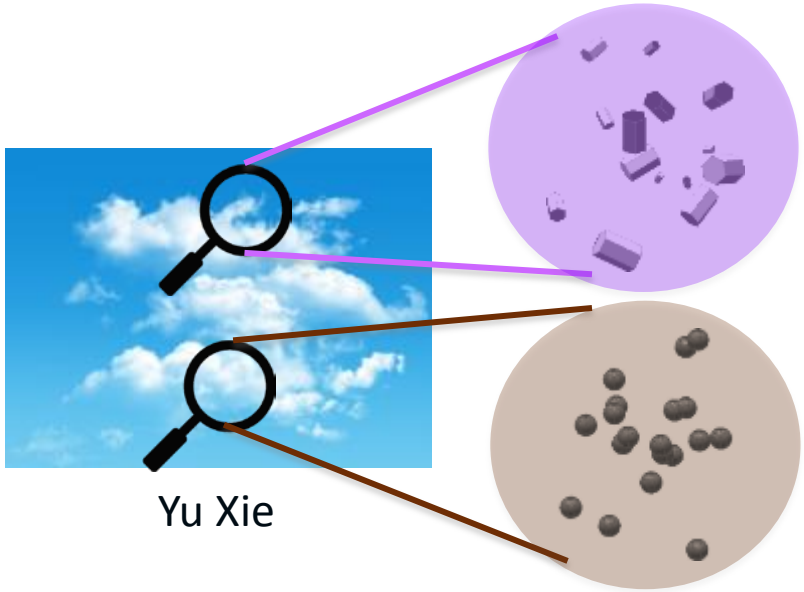


Cloud optical thickness



http://nsrdb.nrel.gov

FARMS



Cloud transmittance and reflectance of irradiance

AOD, θ, g, ω, PWV, P, ozone,…

REST2

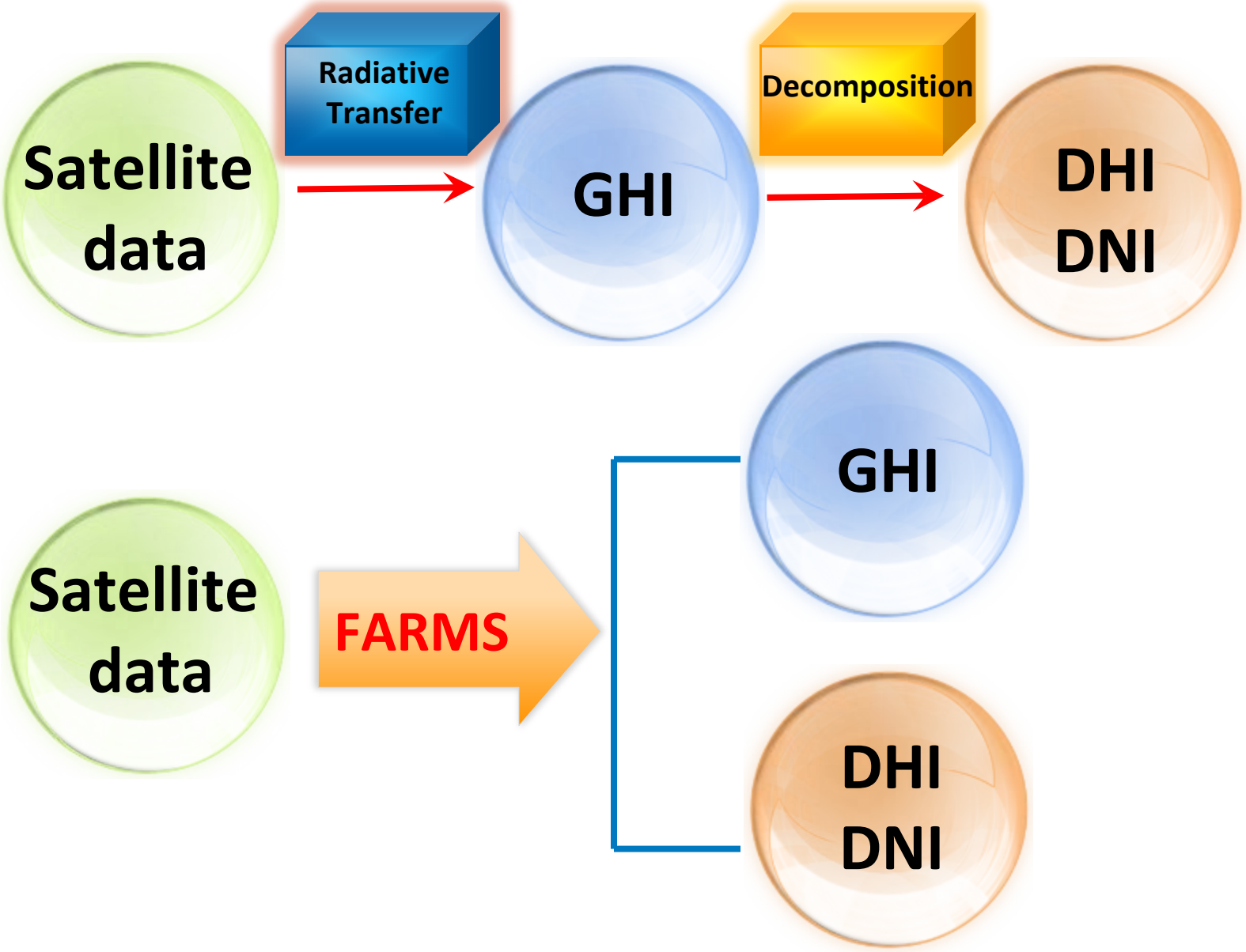
Clear-sky transmittance and reflectance

All-sky broadband irradiances

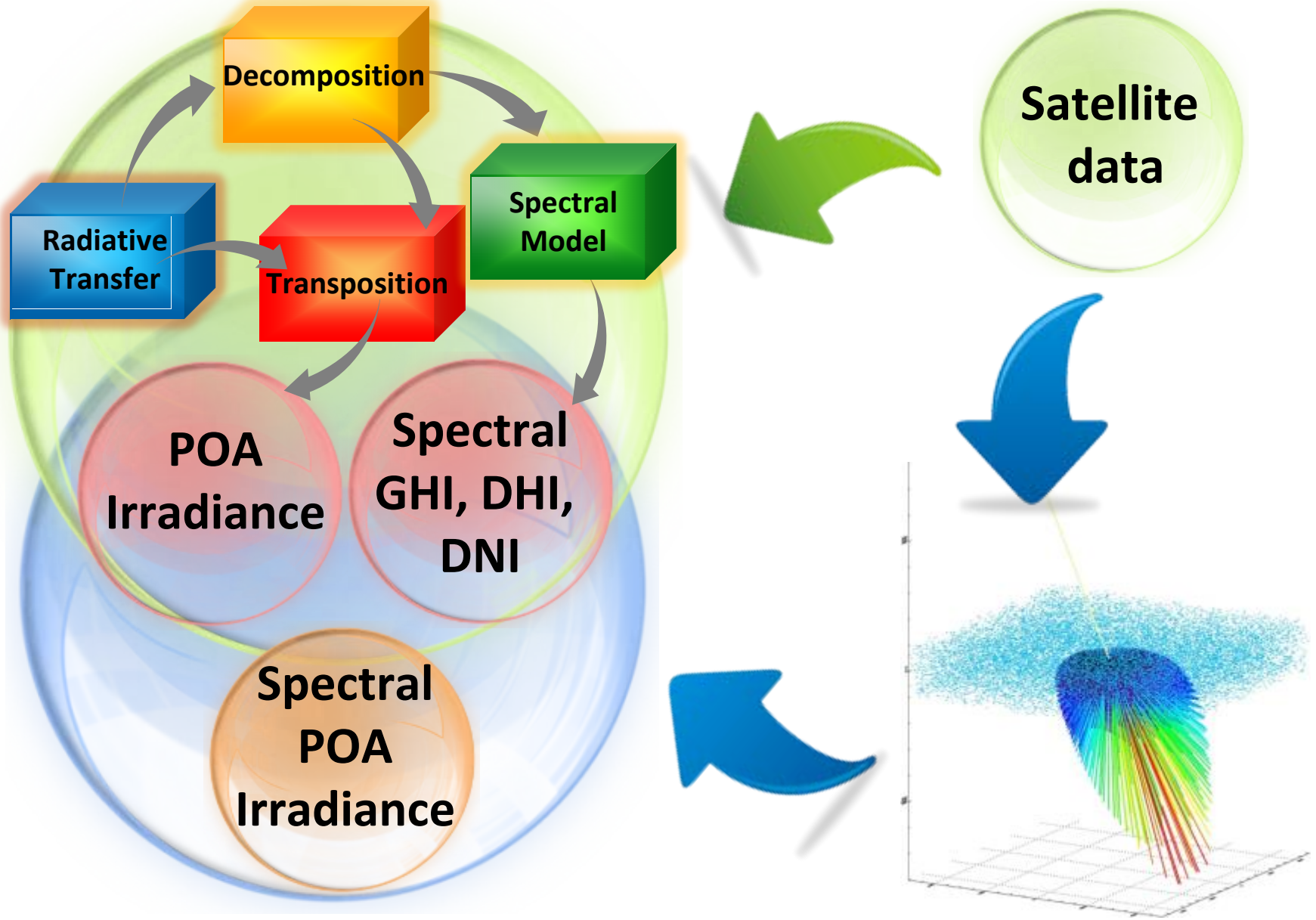
Surface albedo

Xie et al., *Solar Energy (2016)*

Empirical *vs.* physics models



Future models



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!

yu.xie@nrel.gov
manajit.sengupta@nrel.gov
andrew.clifton@nrel.gov

The Energy Systems Integration Facility
Golden, CO. Image by Dennis Schroeder, NREL