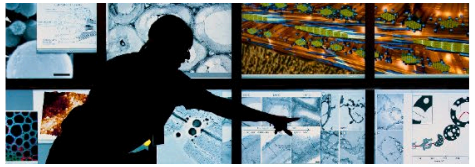
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

A Fast Radiative Transfer Model for Solar Resource Assessment and Forecasting

EU PVSEC, Munich, Germany

Yu Xie and Manajit Sengupta

June 20-24, 2016

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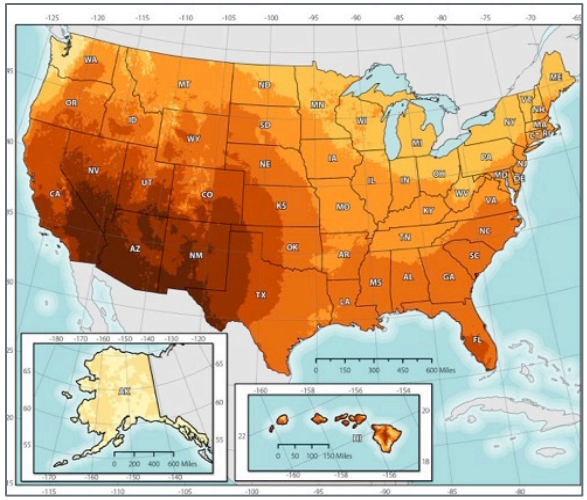
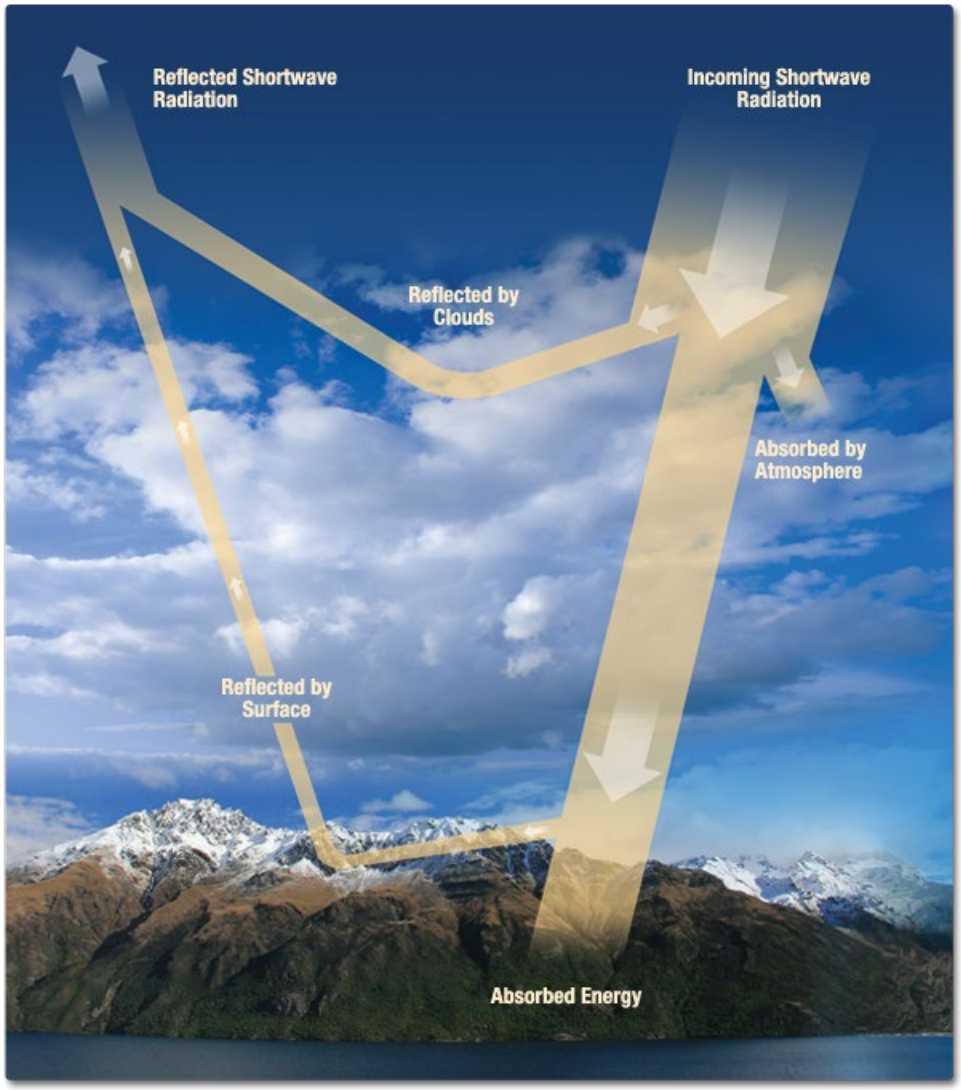
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Sensing, Measurement, and Forecasting

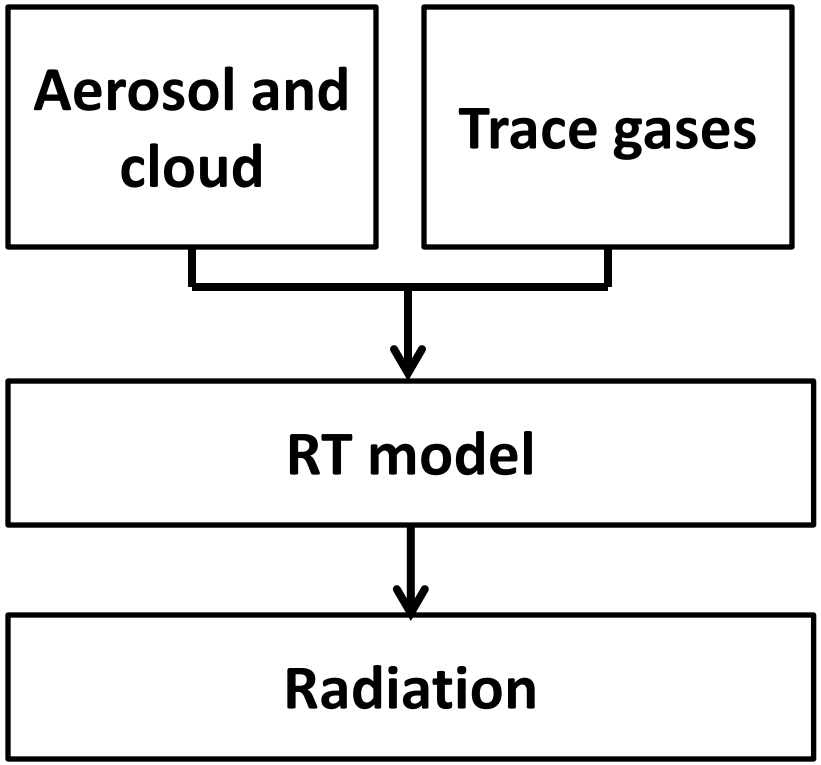
Provide high-quality meteorological and power data for energy yield assessment, resource characterization, and grid integration

Measurements	Modeling	Standards
		
The right observations of wind and solar resource	Targeted predictions of resources and plant performance	Raising everyone to the same level and enabling dialog

RT model and solar applications

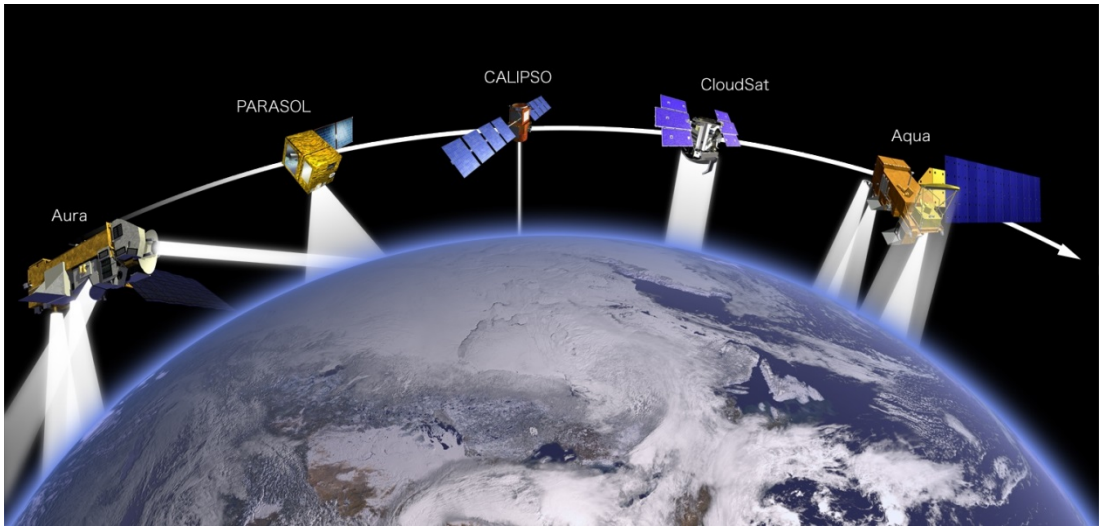


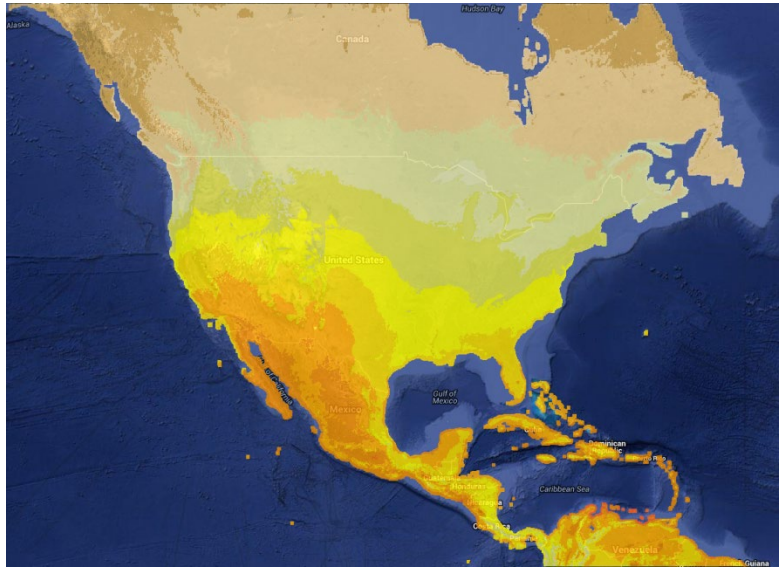
An atmospheric RT model numerically solves the electromagnetic radiation in the Earth's atmosphere



RT model and solar applications

- Simulate upwelling radiance and retrieve aerosol, cloud, and other atmospheric properties.
- Provide solar resource at specific locations.
- Understand the radiative budget of the Earth and develop GCMs and NWP models.
- Forecast solar radiation when cloud motions are predicted by NWP, satellite or surface measurements.





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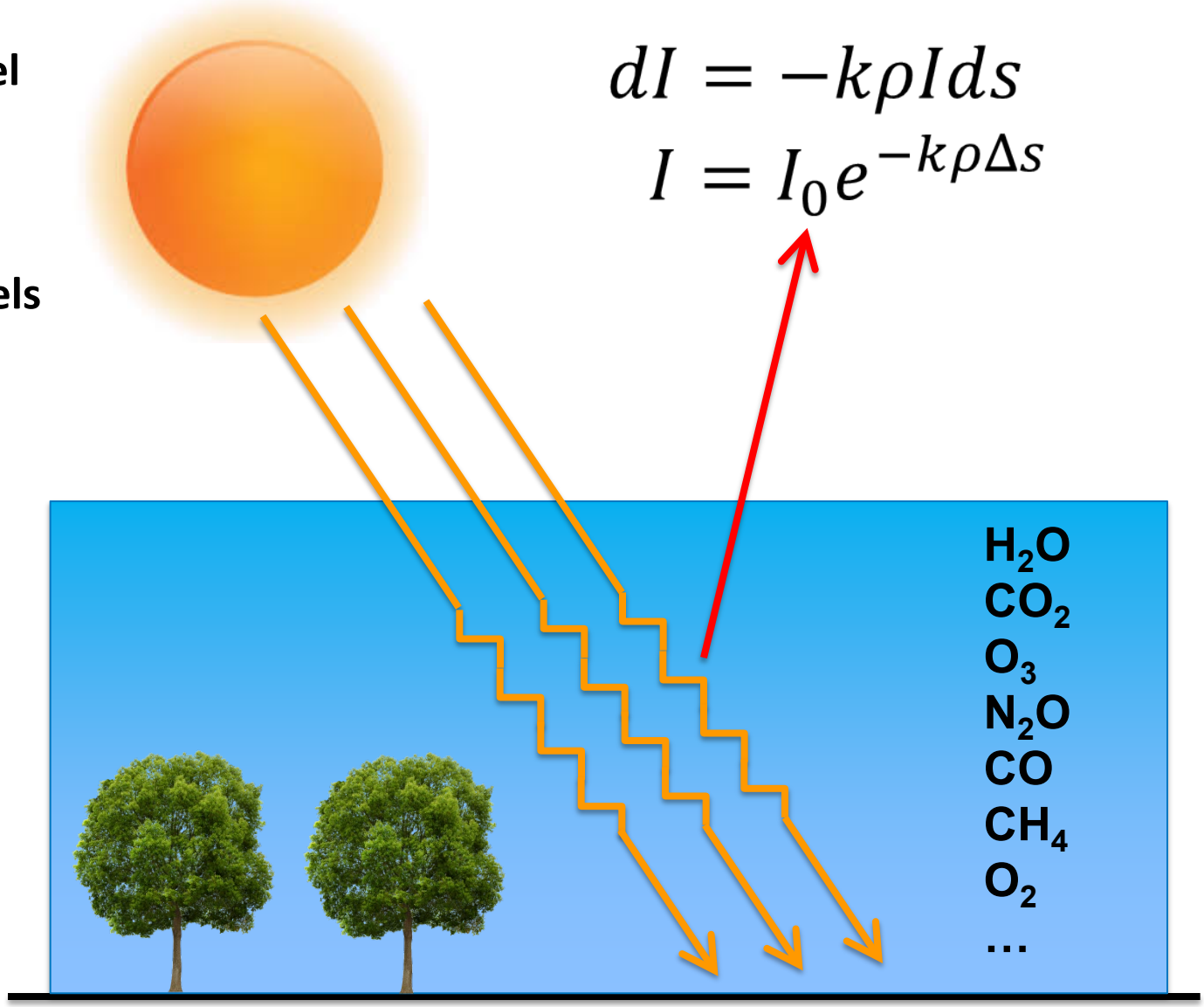
Clear-sky RT models

- High-spectral-resolution RT model provides rigorous solutions for clear sky.
- Fast clear-sky models using surface observations or model simulations.
  - Lacis and Hansen (1974)
  - Atwater and Ball (1978)
  - Hoyt (1978)
  - Bird and Hulstrom (1981)
  - Gueymard (1989, 2003, 2008)

$$dI = -k\rho I ds$$

$$I = I_0 e^{-k\rho\Delta s}$$

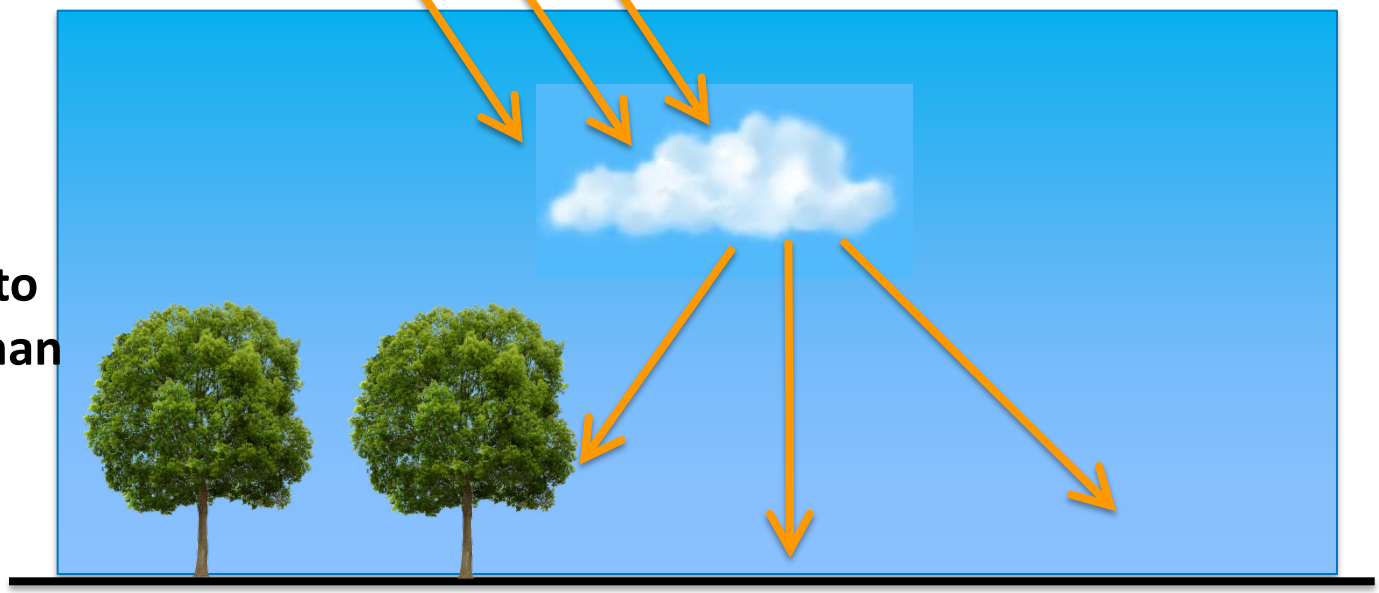


Cloudy-sky RT models

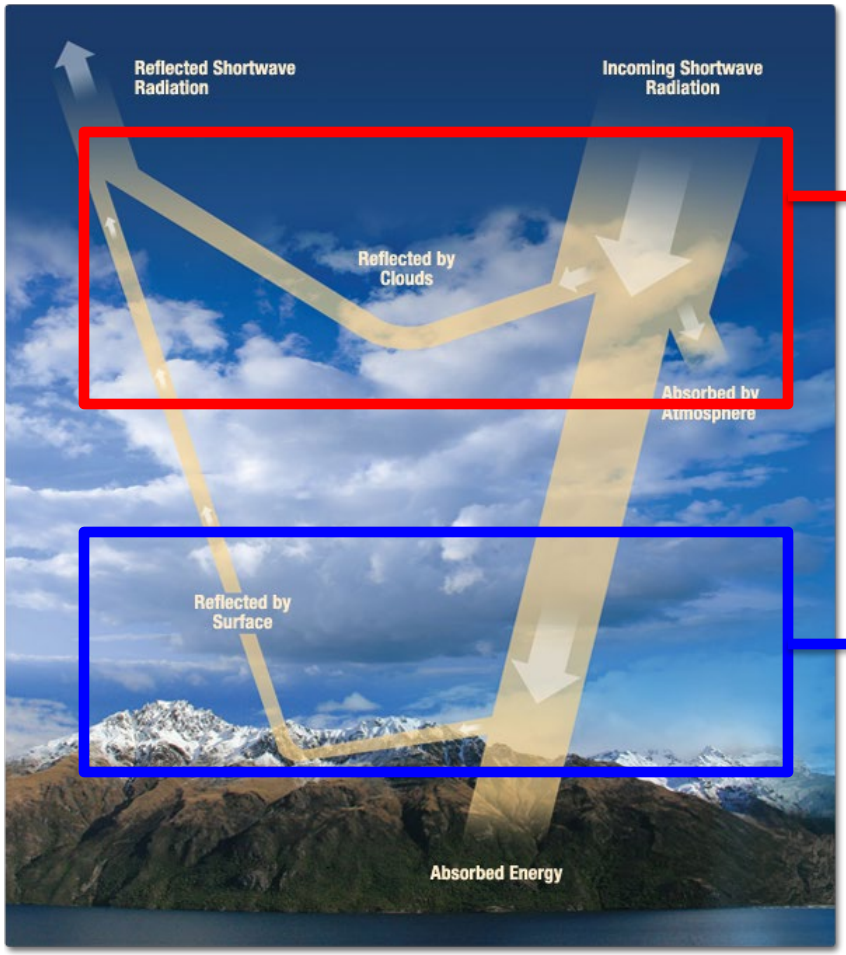
- **Reducing the computational burden from high resolutions of satellite data and NWP demands RT models with a better efficiency than two stream approximation.**
- **Expansion of discrete ordinate streams can lead to better accuracy than two stream.**

$$\mu \frac{dI(\tau,\mu)}{d\tau} = I(\tau,\mu) - \frac{\omega}{2}\int_{-1}^{1} P(\mu,\mu')I(\tau,\mu')d\mu' - \frac{\omega F}{4\pi} P e^{-\tau/\mu_0}$$

$$\mu_i \frac{dI_i}{d\tau} = I_i - \frac{\omega}{2}\sum_j I_j a_j - \frac{\omega F}{4\pi} P e^{-\tau/\mu_0}$$



Forward RT models for radiance in cloudy skies



Cloud transmittance and reflectance for radiance

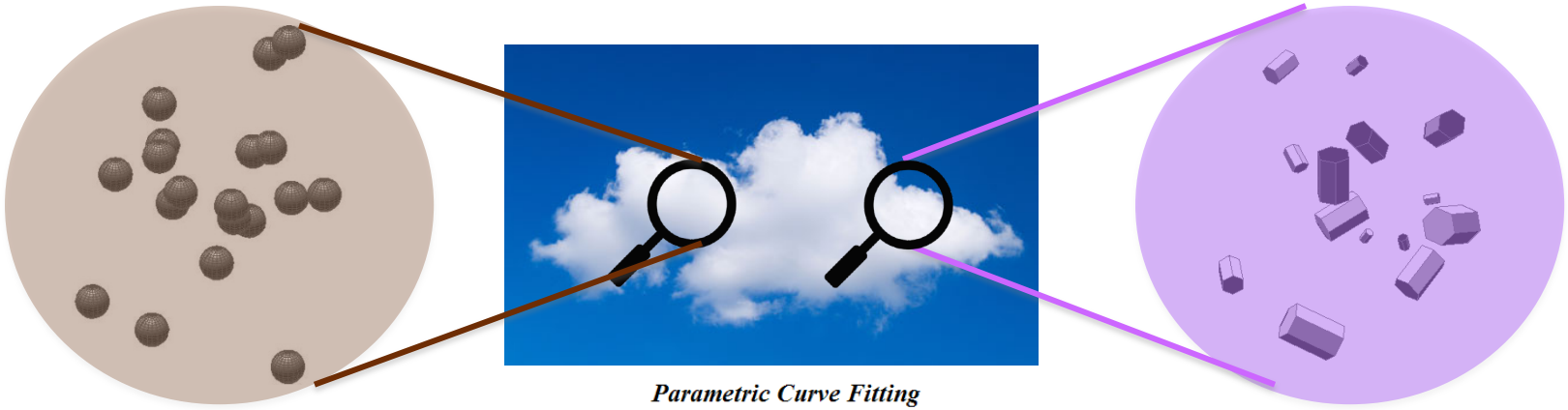
Radiative transfer in clear skies

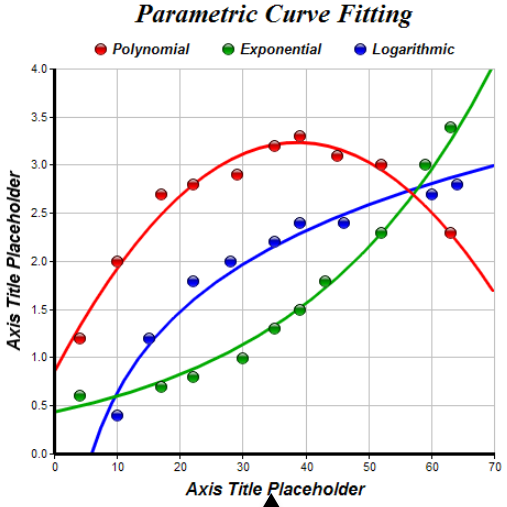
However, they are not favorable candidates for solar energy because:

- **Designed for satellite channels**

- **Need much more computational time to compute radiances and get irradiance.**
- **Downwelling radiation is more dependent on the computation for clear skies.**

Fast All-sky Radiation Model for Solar applications (FARMS)





Solar angle

Optical thickness

Particle size

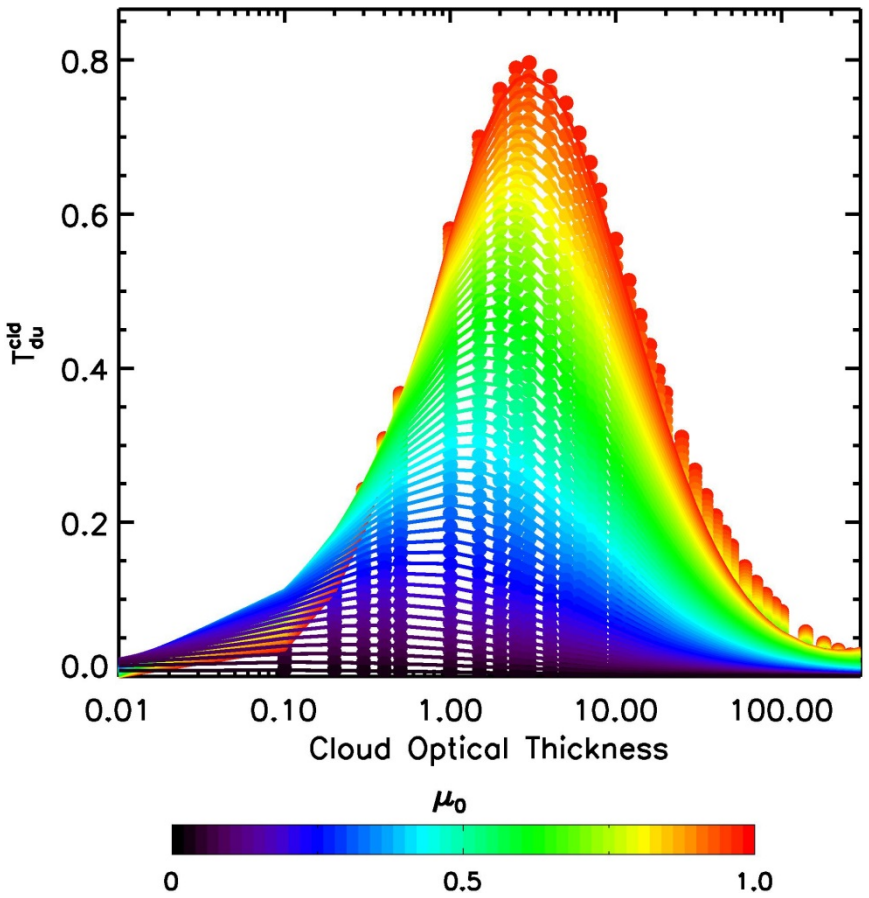
Solar angle

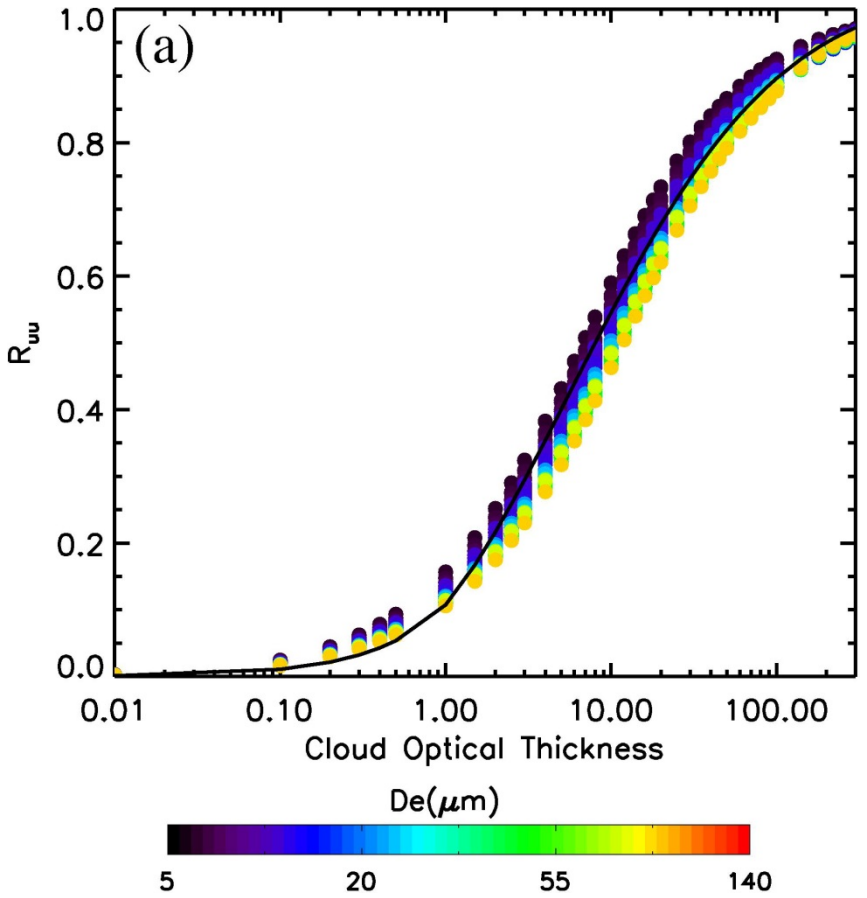
Optical thickness

Particle size

Cloud transmittance and reflectance of irradiance

Fast All-sky Radiation Model for Solar applications (FARMS)

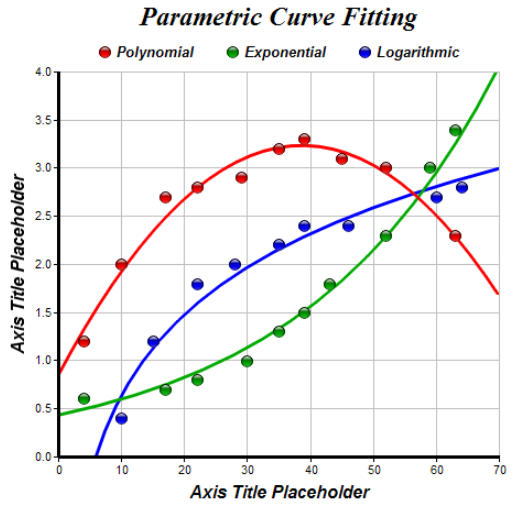




- **Cloud transmittance for diffuse radiation can be parameterized as exponential functions of cloud optical thickness and solar zenith angles.**
- **Cloud reflectance for diffuse radiation can be parameterized using simple equations of cloud optical thickness with a good accuracy.**

Fast All-sky Radiation Model for Solar applications (FARMS)

Cloud transmittance and reflectance of irradiance



AOD, θ, g, ω, PWV, P, ozone,…

↓

REST2 (Gueymard, 2008)

↓

Clear-sky transmittance and reflectance

↓

Cloudy-sky irradiances

↑

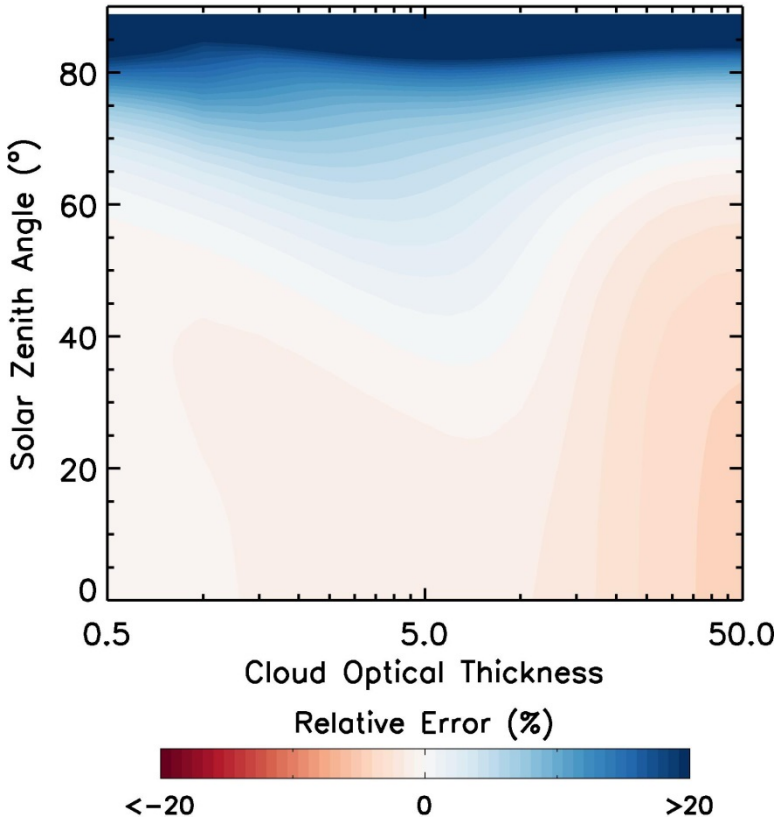
Surface albedo

Fast All-sky Radiation Model for Solar applications (FARMS)

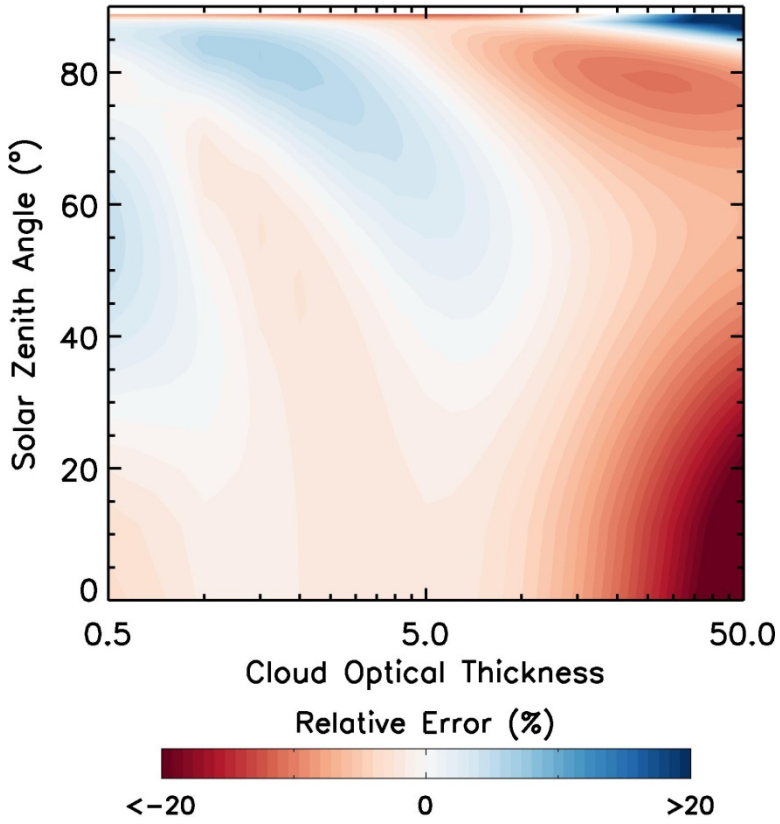
	RRTM/RRTMG	FARMS
RT scheme	2-16 stream	Parameterization from REST2 and a LUT using 16-stream
Channel	14 channels from 0.2 to ~4 μm	1 broadband channel for the solar region

Uncertainties in two stream and FARMS

Two stream



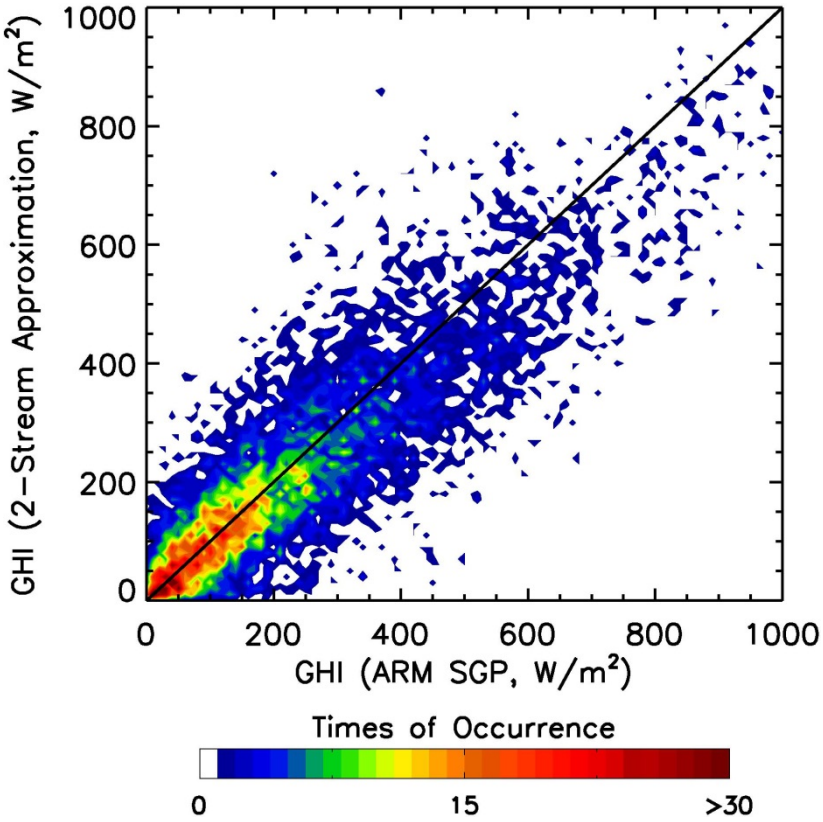
FARMS



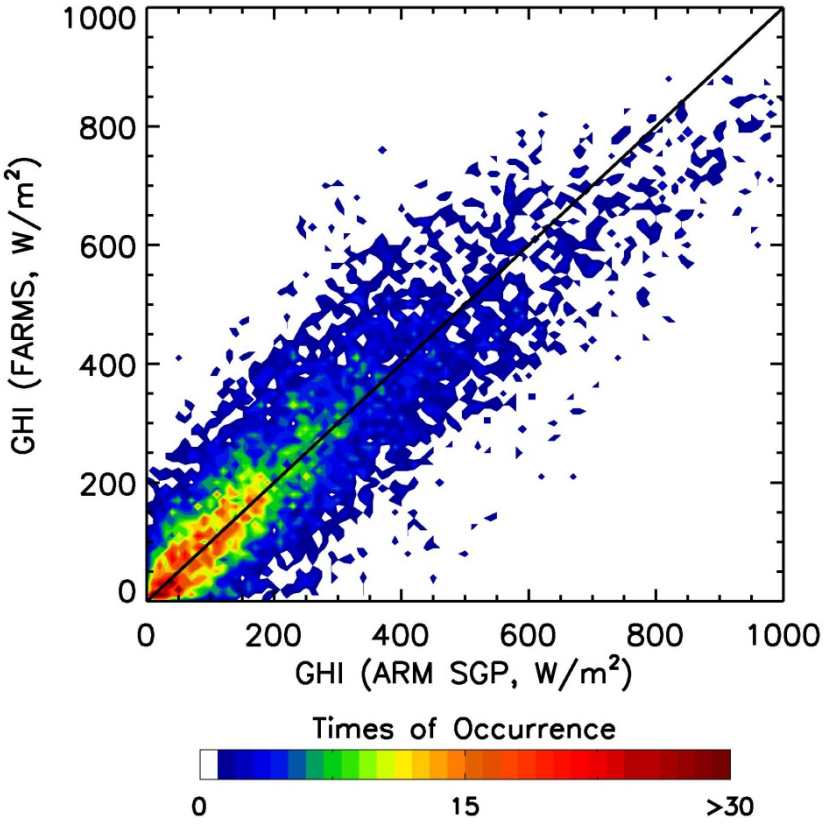
RRTM with 16 stream is used as a benchmark to compute the LUTs of cloud transmittance and compare with 2 stream and FARMS. Two stream overestimates transmittance for large solar angles. FARMS underestimates transmittance for thick clouds.

Uncertainties in two stream and FARMS

Two stream

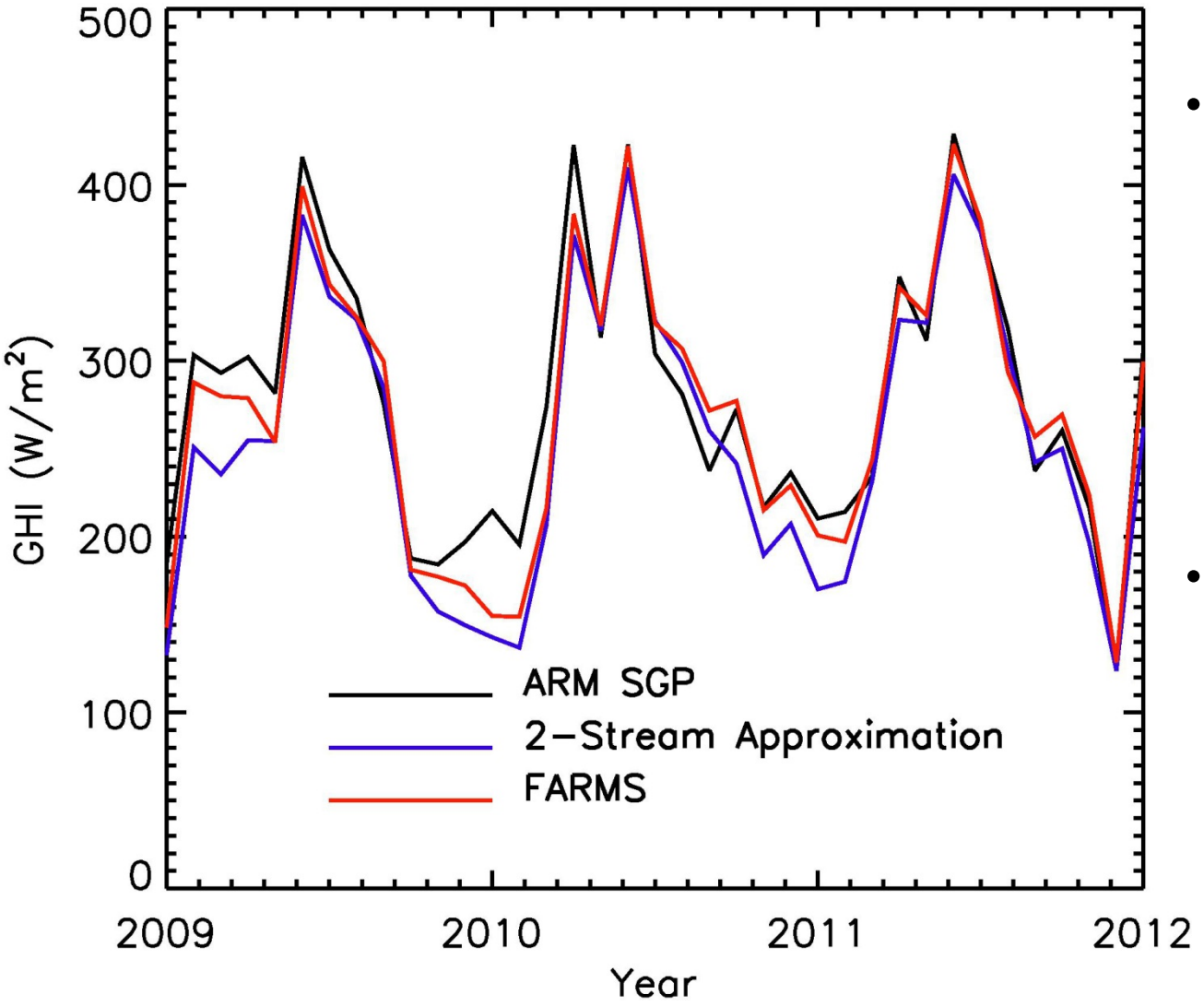


FARMS



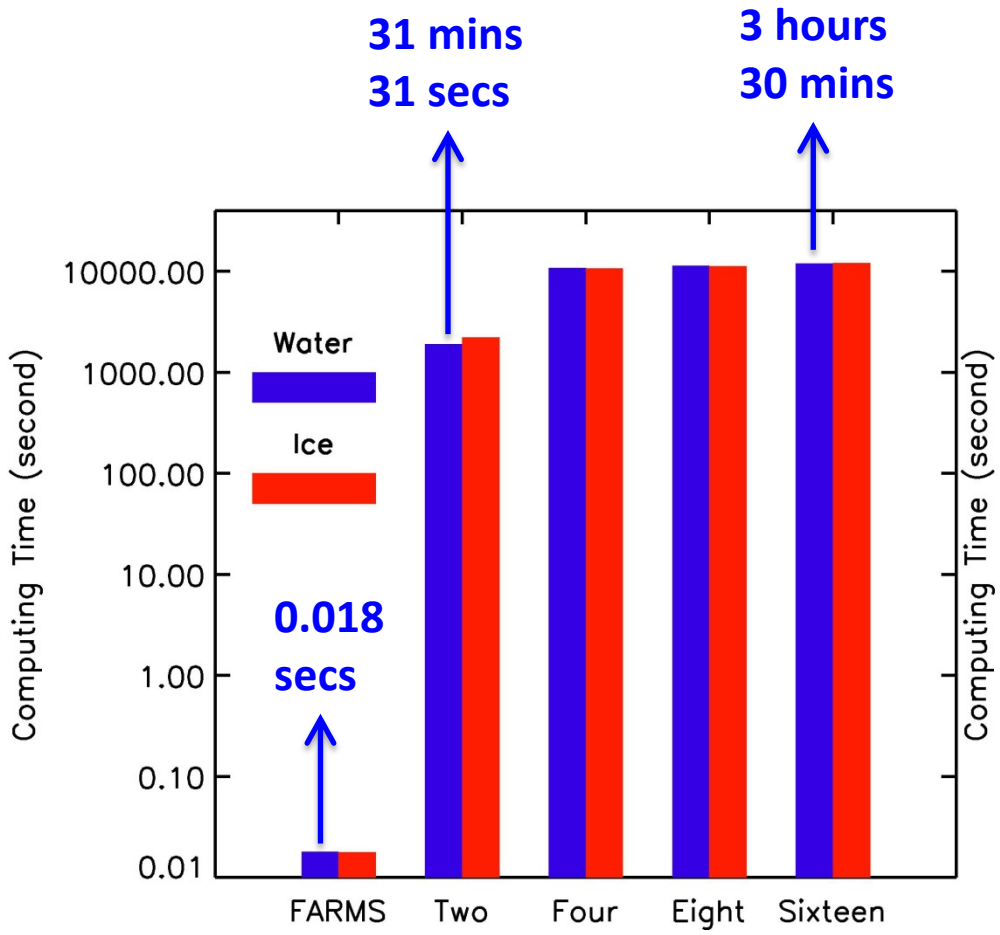
GOES satellite data is collocated to ARM SGP site. The satellite-based retrievals of cloud properties are used as inputs of two stream and FARMS. A total number of 9669 scenarios associated with cloudy-sky are selected during 2009-2012.

Uncertainties in two stream and FARMS

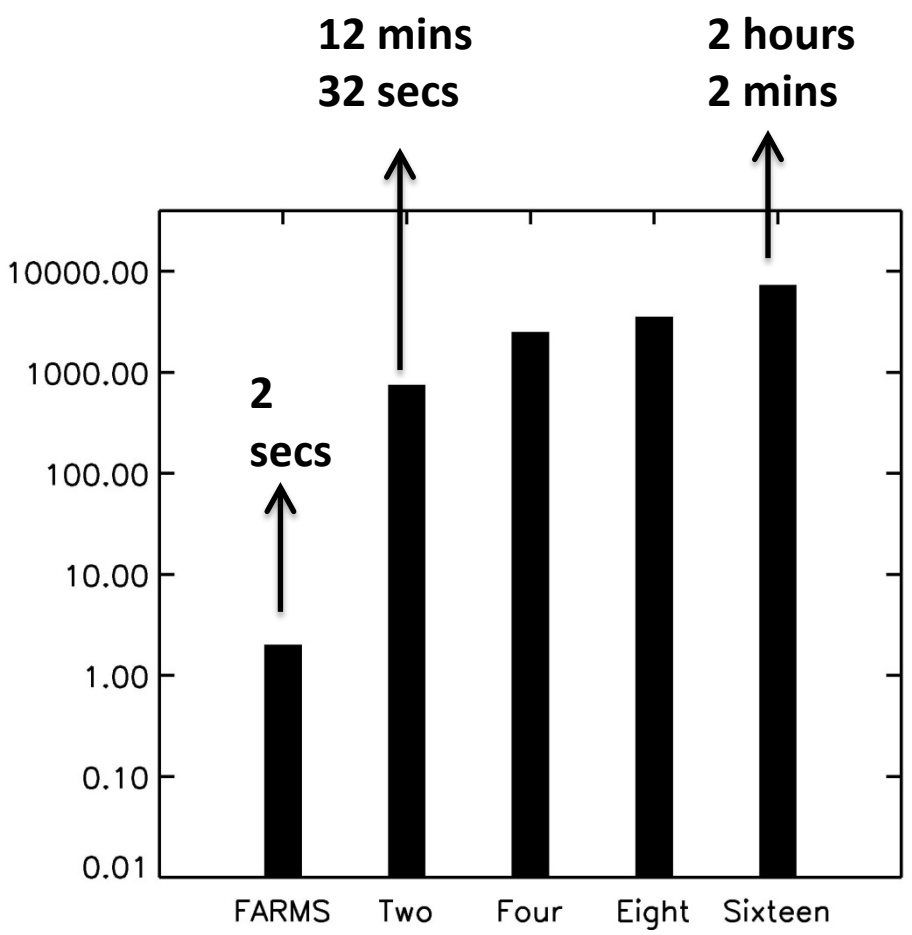


- **FARMS and REST2 can apply the measurements of the total amount of PWV while 2 stream uses standard atmospheric profiles.**
- **It takes more computational time to scale PWV in RRTM.**

Computational efficiency



Computation of cloud T for 39 cloud optical thicknesses, 28 particle sizes, and 50 solar zenith angles.



Computation of solar radiation for 9669 scenarios of cloudy sky conditions over ARM SGP.

Conclusions and future work

- FARMS is developed using REST2 and RRTM
- Computational efficient and accurate
- Available in Fortran90, IDL, and Python
- Yu.Xie@nrel.gov or Manajit.Sengupta@nrel.gov
- Parallel computing
- Spectral model and reducing uncertainty
- Update NREL's NSRDB
- Application in solar forecasting