Beyond TMYs, meteorological data for solar energy system simulations

Kristian Pagh Nielsen,

Danish Meteorological Institute,

ISES Webinar 2016-05-24

SolarPACES: BeyondTMY

IEA SHC Task 46: Solar resource assessment and forecasting

Department of Civil Engineering

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SolarPACES: BeyondTMY

Frank Vignola, Lourdes Ramírez, Philippe Blanc, Richard Meyer & Manuel Blanco

IEA SHC Task 46: Solar resource assessment and forecasting

Elsa Andersen, Janne Dragsted & Simon Furbo

WHY ARE METEOROLOGICAL DATA NEEDED FOR SOLAR ENERGY SYSTEM SIMULATIONS?

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- Specific uses: Solar District Heating, Concentrated Solar Thermal Electric, Photovoltaic, Architecture (Passive solar)

HISTORY OF METEOROLOGICAL DATA FOR SOLAR ENERGY APPLICATIONS

- Benseman and Cook (1969): The standard year
  - Select 12 typical solar months from a long-term data set…
  - … based on the cumulative clearness index distribution
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  - Includes 20 meteorological parameters
  - 12 months selected based on means and stdev. of GHI, temperature (2 m) and daily temperature maxima
- Typical meteorological years (Hall et al. 1978):
  - Select 12 typical meteorological months…
  - … based on cumulative distributions of several weighted meteorological variables (Finkelstein & Schafer 1971)

EXAMPLE OF 12 ”TYPICAL MONTHS”

January 2001, February 2014, March 2003,
April 2007, May 2009, June 2011,
July 2001, August 2001, September 2012,
October 2011, November 2009, December 2015.

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Issue: *The untypical months are excluded!*

METEOROLOGICAL DATA FOR SOLAR ENERGY APPLICATIONS USED TODAY

- The reference year developments
  - DRY (IEA SHC Task 9, Skartveit et al. 1994; Lund 1995)
    - … includes 5-minute resolution DrHI and GHI)
  - 12 months selected based on means and stdev. of GHI, temperature (2 m) and relative humidity (2 m)
  - Energy reference year (ERY) - ISO (15927-4) standard

- Typical meteorological years developments:
  - TMY2, TMY3, gridded data sets
  - TMY weights: http://rredc.nrel.gov/solar/pubs/tmy2/tabA-1.html

DEVELOPMENTS IN RECENT YEARS

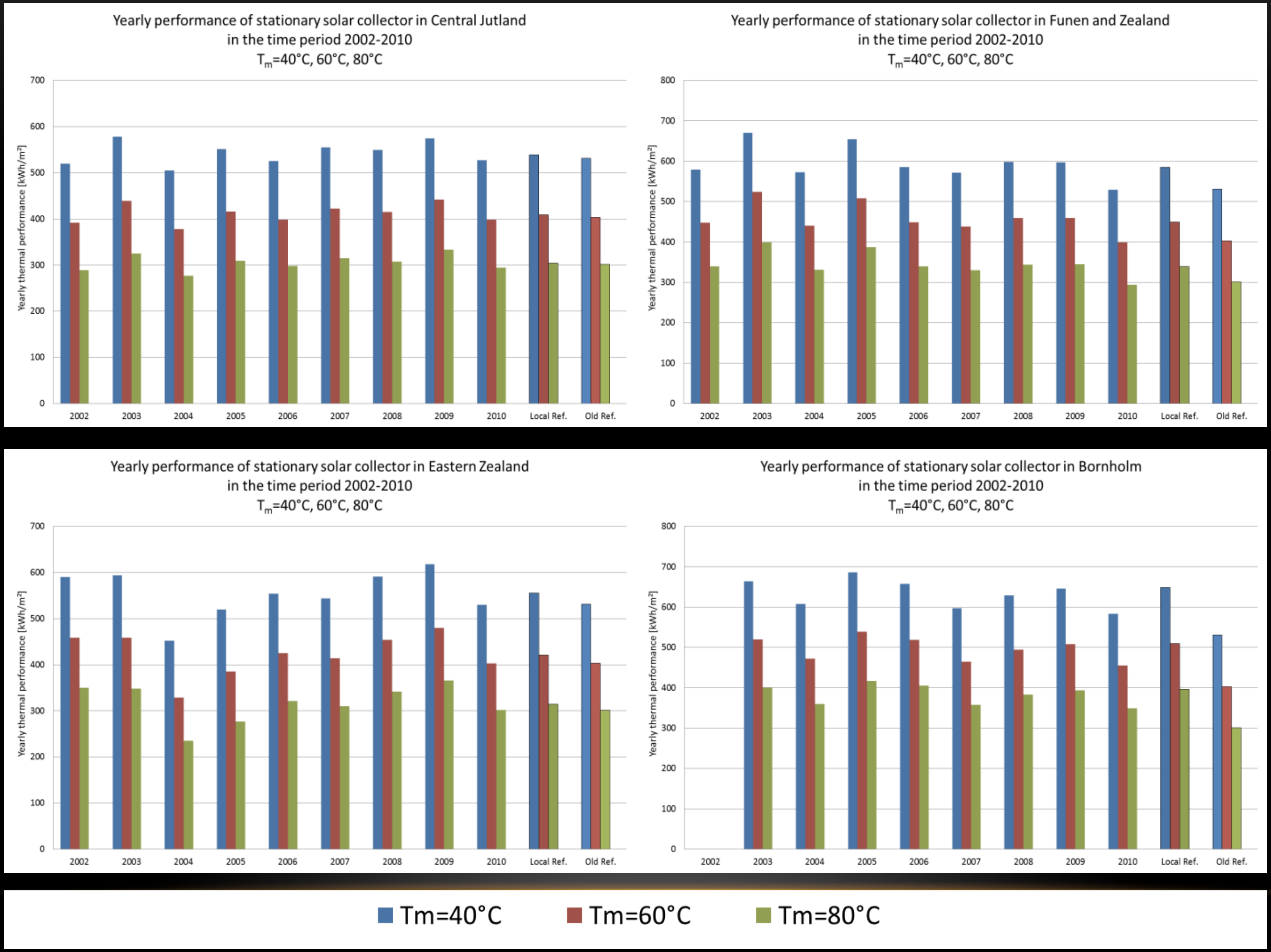
- **ENDORSE: Satellite derived TMY design with a driver:** *"<u>The driver</u> is a one-dimensional composite time series from the multidimensional meteorological long-term dataset more related (or more linearly correlated) to the energy production of the solar energy conversion system of interest (PV, CPV, CSP, etc...).*

- **IEC/TC117 PT62862-1-2: Procedure for generating a representative solar year (for CSP/STE)**
  - **Direct Normal Irradiance (DNI) is prioritized**

- **NREL: Gridded TMY, TDY (DNI-based), TGY (GHI-based)**
  - **Other satellite-based products (SolarGIS, …)**

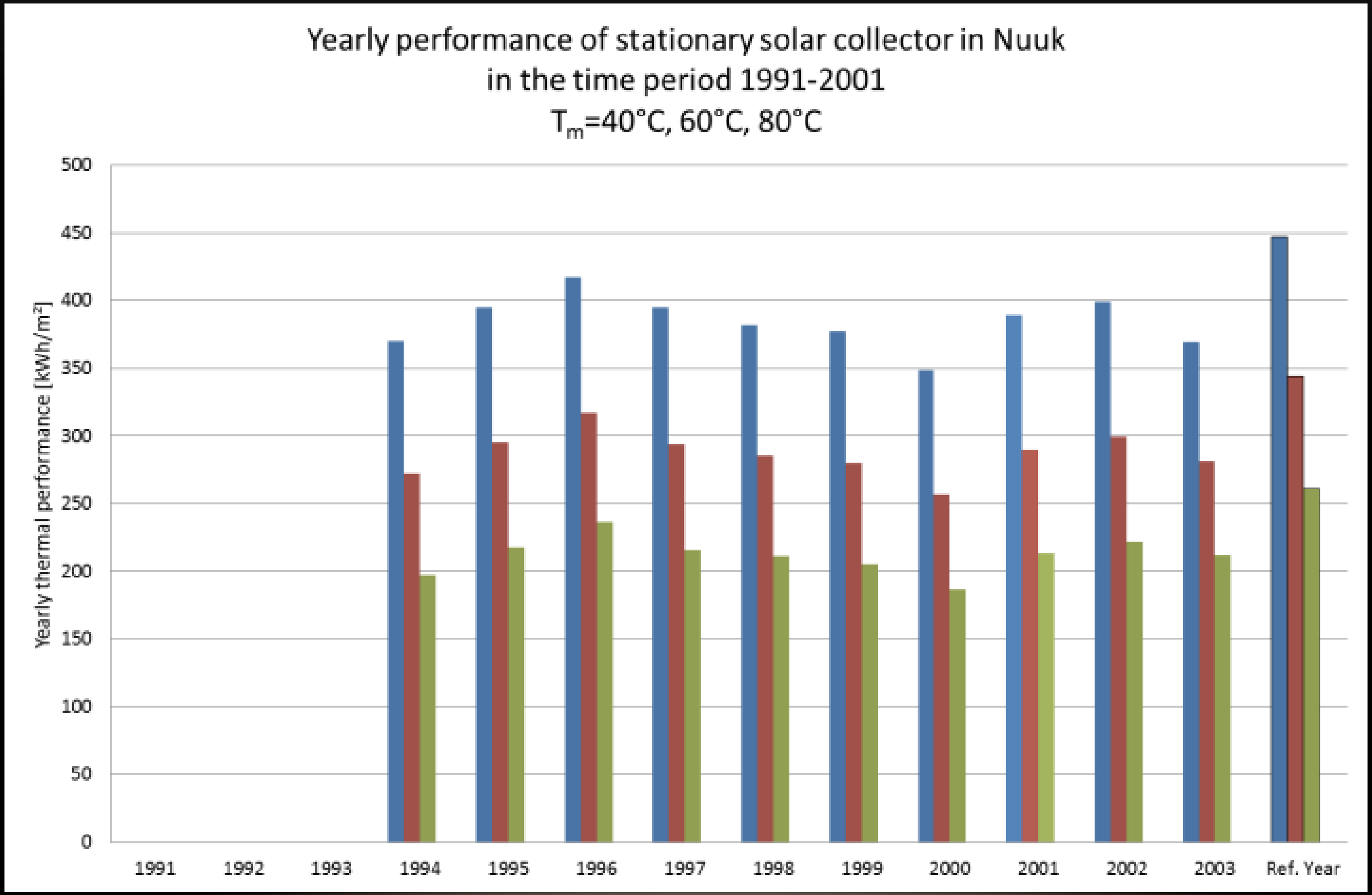
- **Concerns about overall resource trends due to dimming and brightening (Müller et al. 2013)**

MULTI-YEAR ANALYSIS OF SOLAR COLLECTOR PERFORMANCE



Analysis and figure by Janne Dragsted (DTU Civil Engineering)

MULTI-YEAR ANALYSIS VS REFERENCE YEAR



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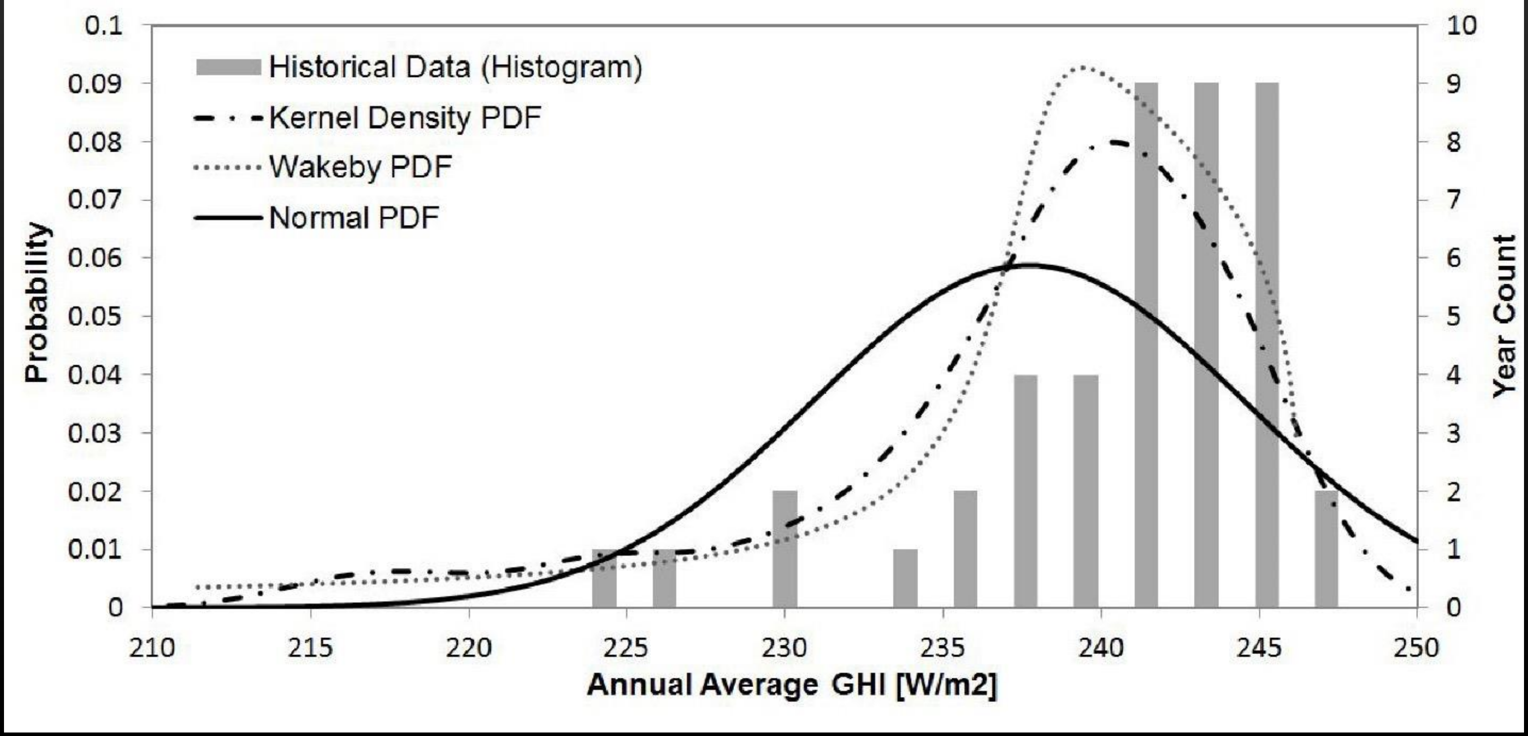
YEARLY VARIABILITY



Histogram of 43 years of annual Global Horizontal Irradiance (GHI) data from Phoenix, Arizona. Different statistical distributions that have been fitted to the data are also shown (Vignola et al. 2013).The black curve ("Normal PDF") is a fit of a Gaussian distribution.

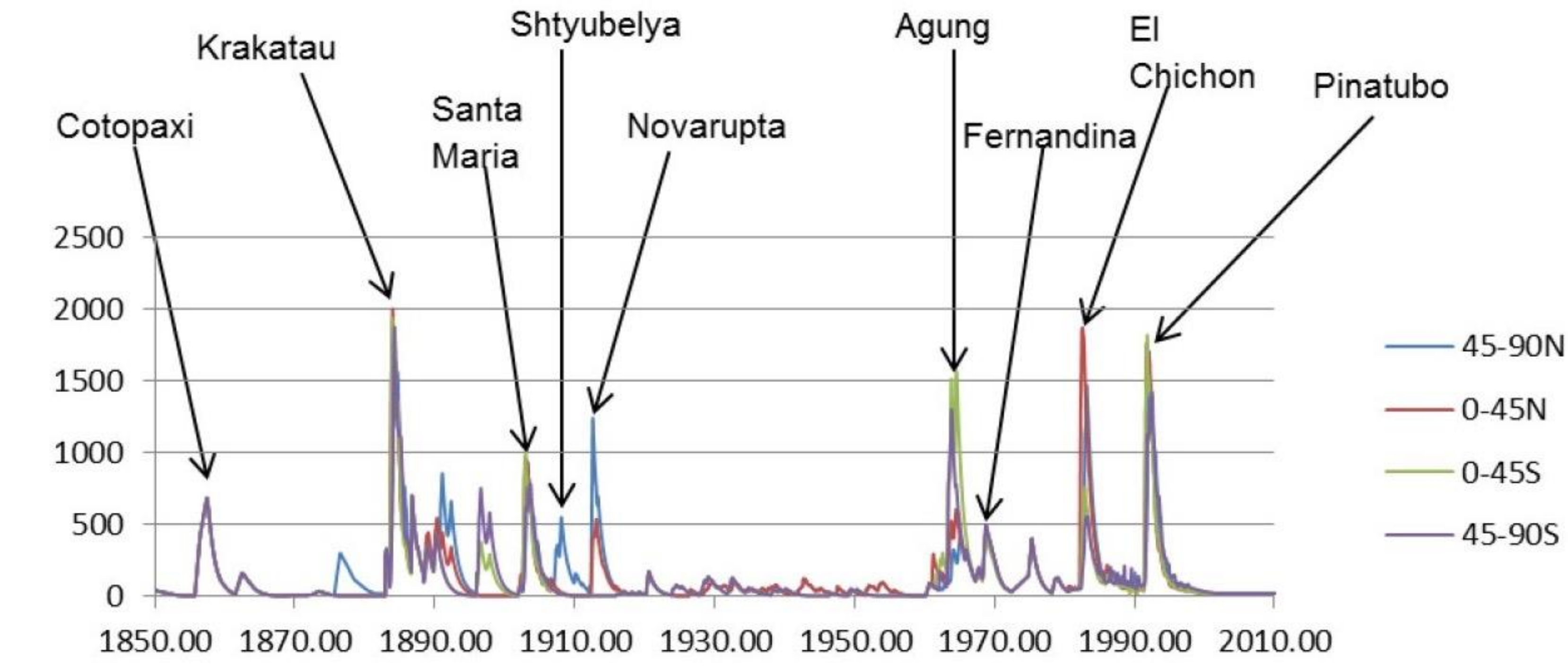


Figure S.2 Perturbations to aerosol optical depth at 0.55 μm (x10000) based on *Sato et al.* [1993] and the nine eruptions used to simulate explosive volcanic eruptions during 2011-2099.

Method of Jackson et al. (2014): Monte Carlo based selection of years from 150 years of volcanic data in 4 laditudinal bands used for for future simulation.

YEARLY VARIABILITY

What must be accounted for:

- Uncertainty in the measurements or satellite-derived data must be documented and accounted for (Röttinger *et al.* 2015)
- Separate analysis of volcanic years
- Do the non-volcanic data have a Gaussian distribution?
- Are adjacent years correlated?

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- Separate analysis of volcanic years
- Do the non-volcanic data have a Gaussian distribution?
- Are adjacent years correlated? P. Blanc: *Hurst coefficient*

What could be accounted for:

- Future trends cannot be forecast, but scenario analyses can be made.

DIRECTIONAL VARIABILITY

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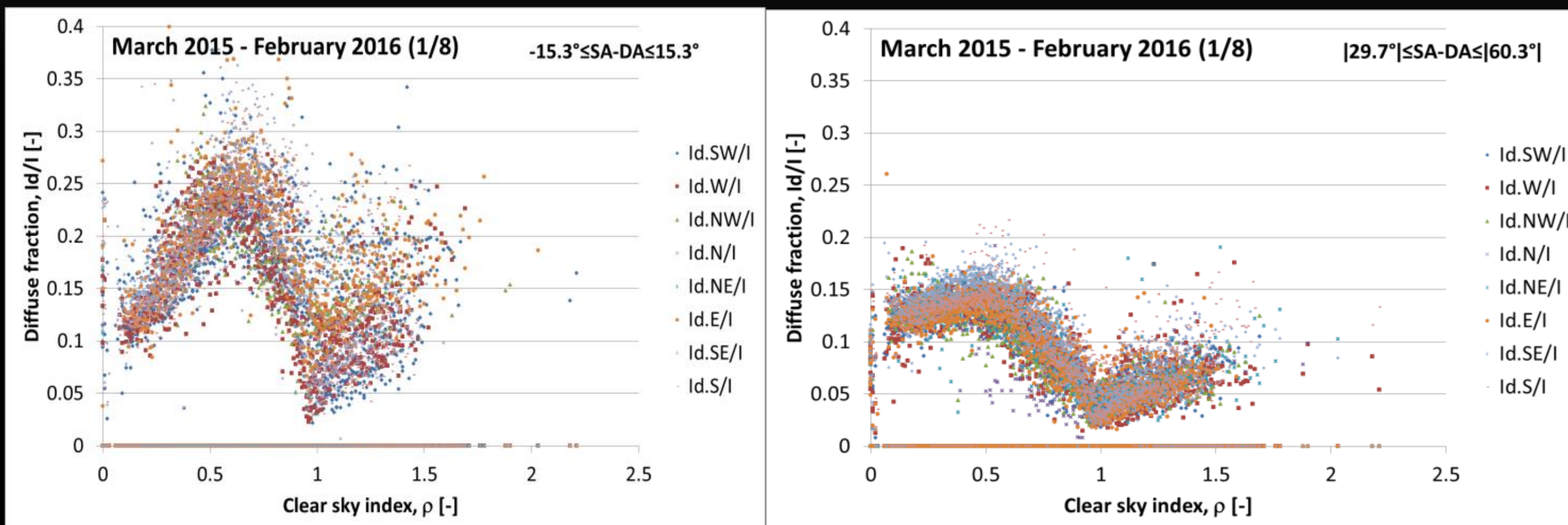
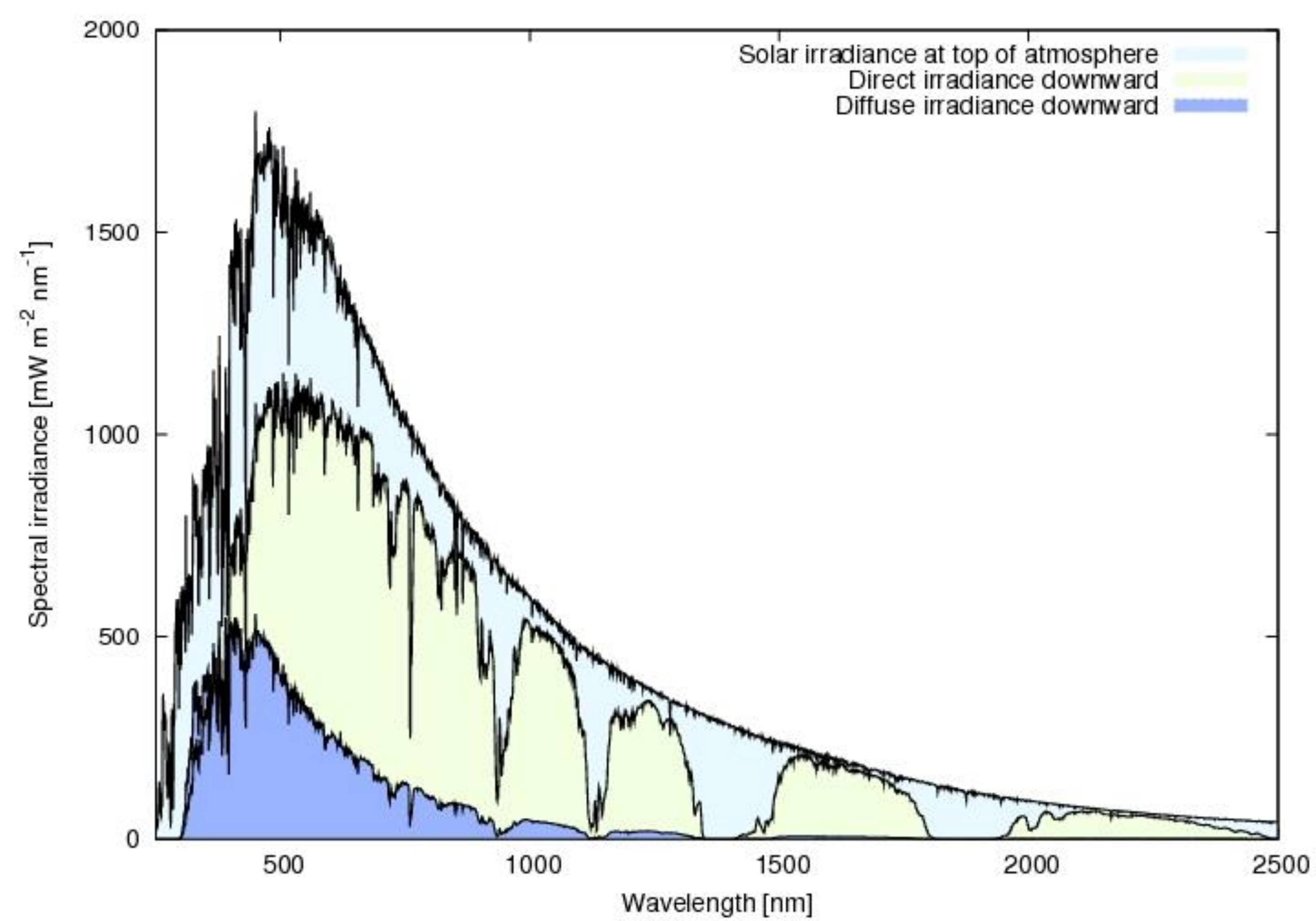


- Empirical relations between the directional diffuse irradiances and the clear sky index (i.e. the global irradiance normalized against clear sky irradiances).
- Analysis and figures by Elsa Andersen *et al.*, DTU Civil Engineering.

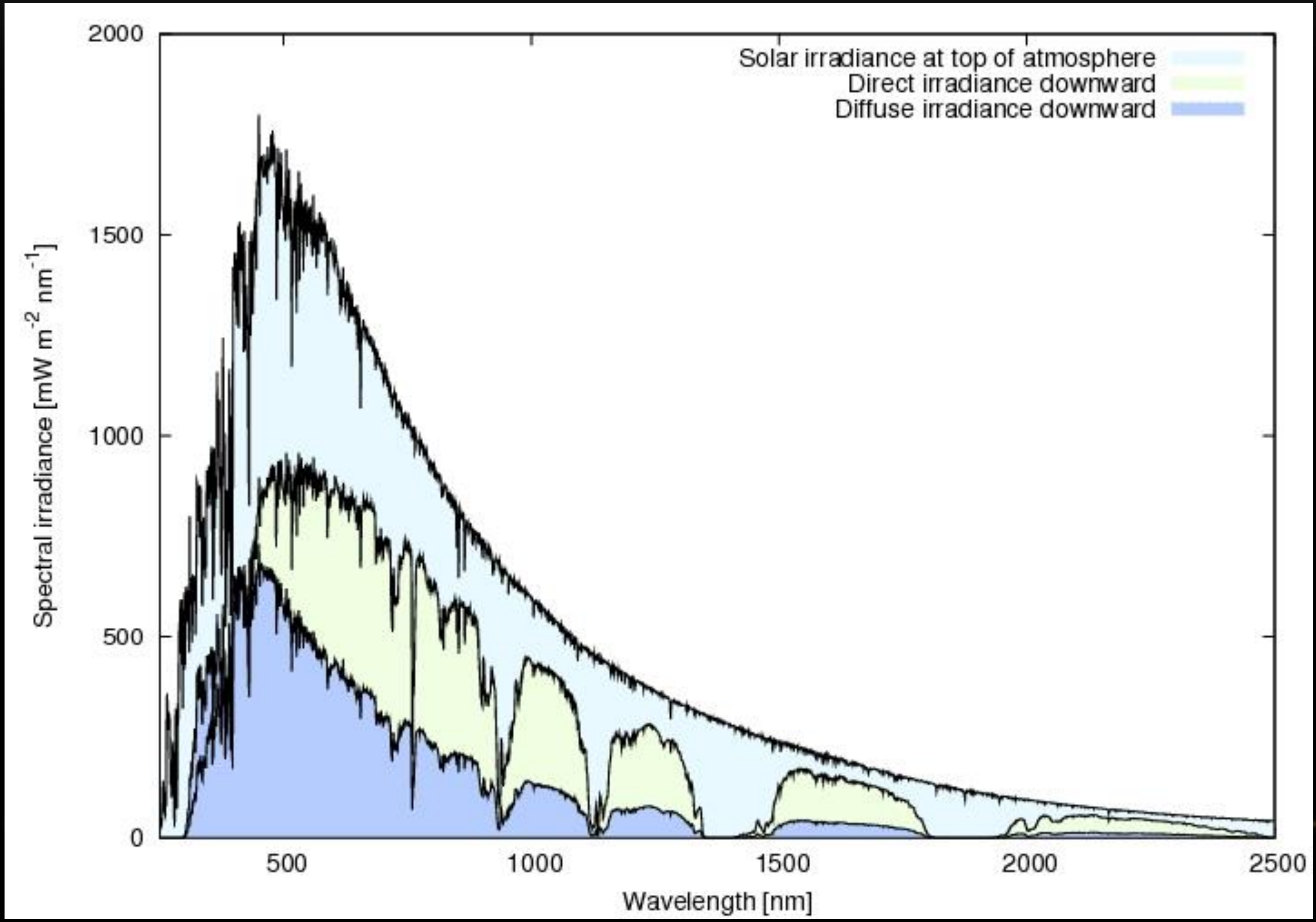
SPECTRAL VARIABILITY



0.0 kg/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

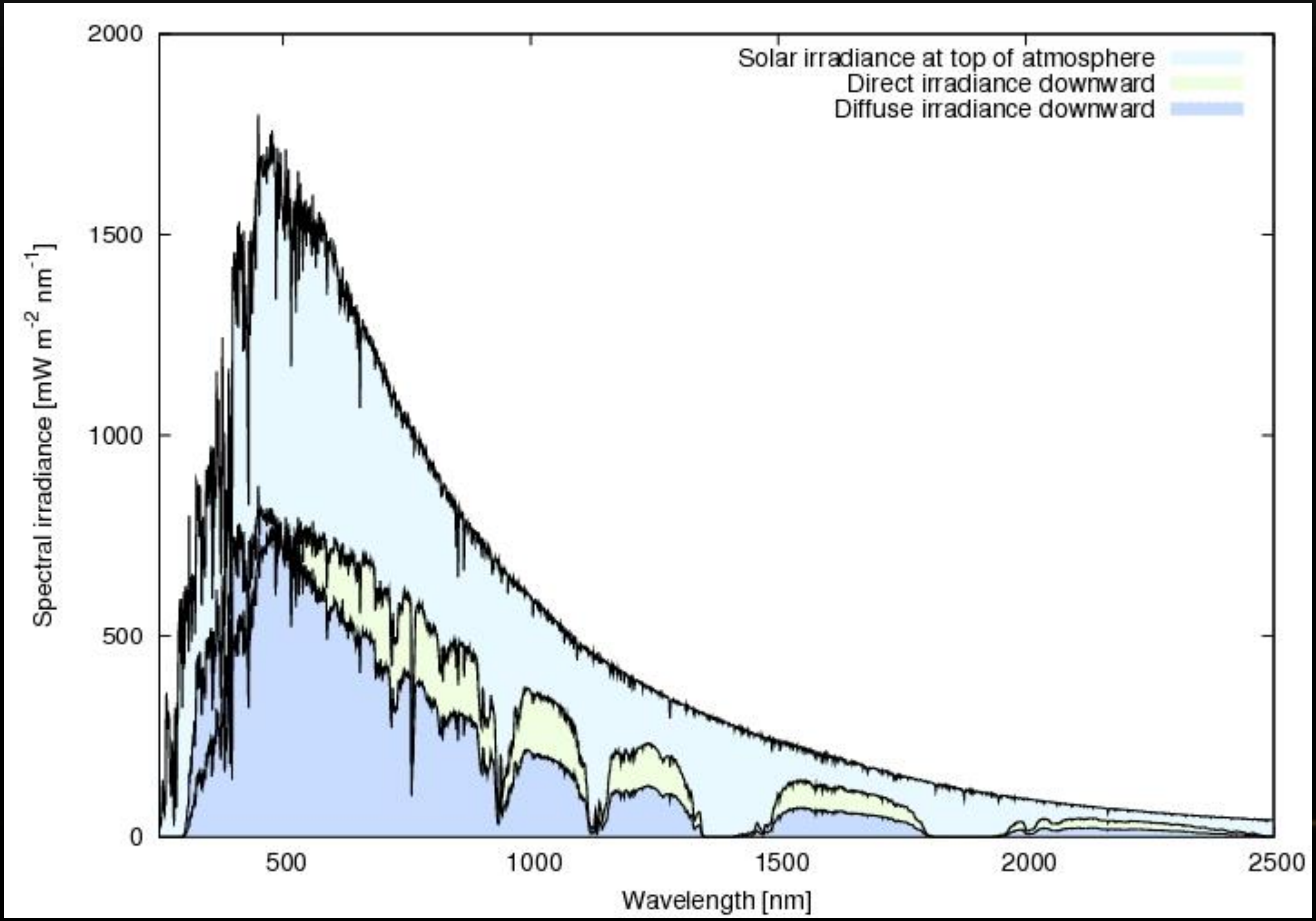
SPECTRAL VARIABILITY



1.0 g/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

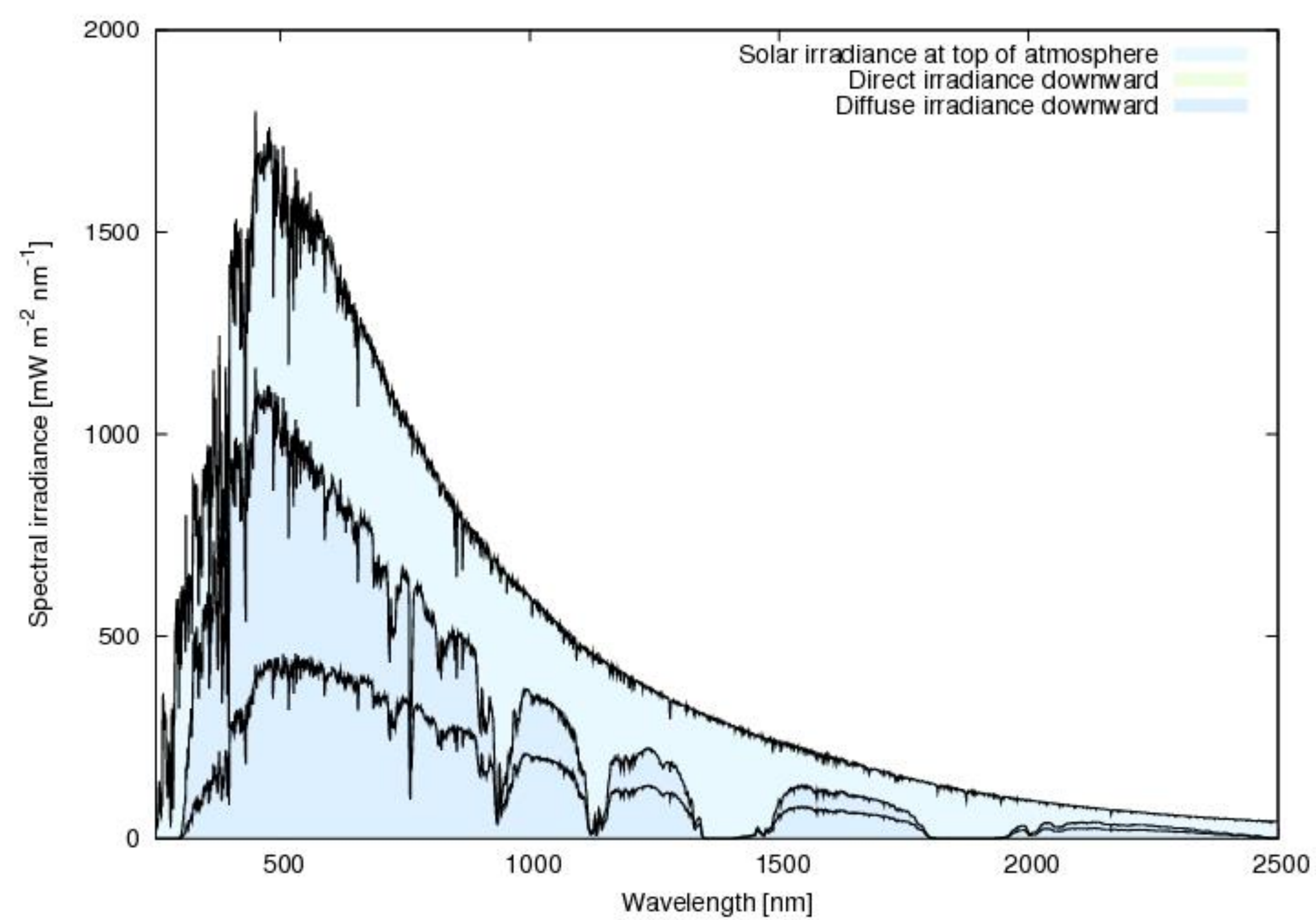
SPECTRAL VARIABILITY



2.0 g/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

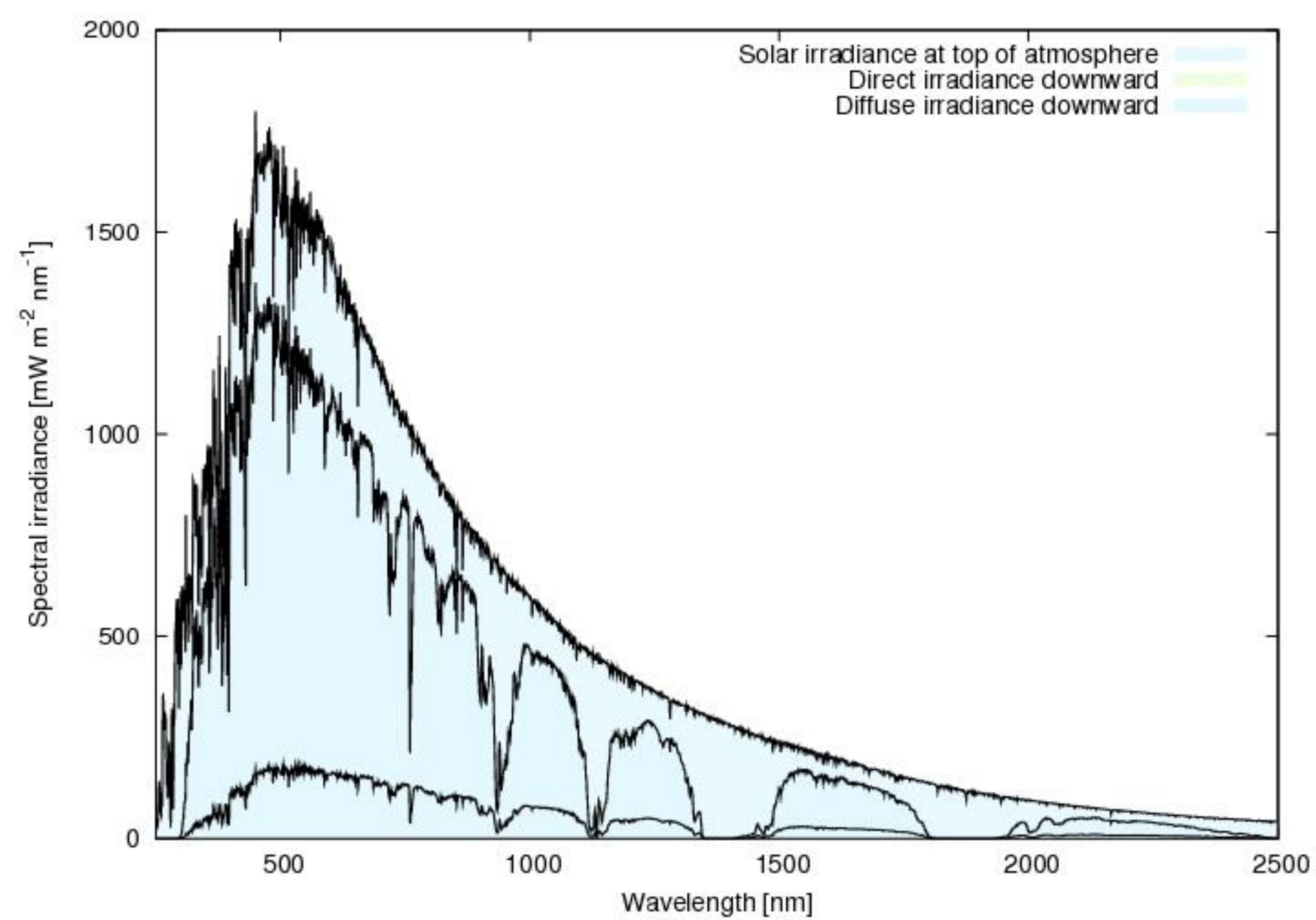
SPECTRAL VARIABILITY



5.0 g/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

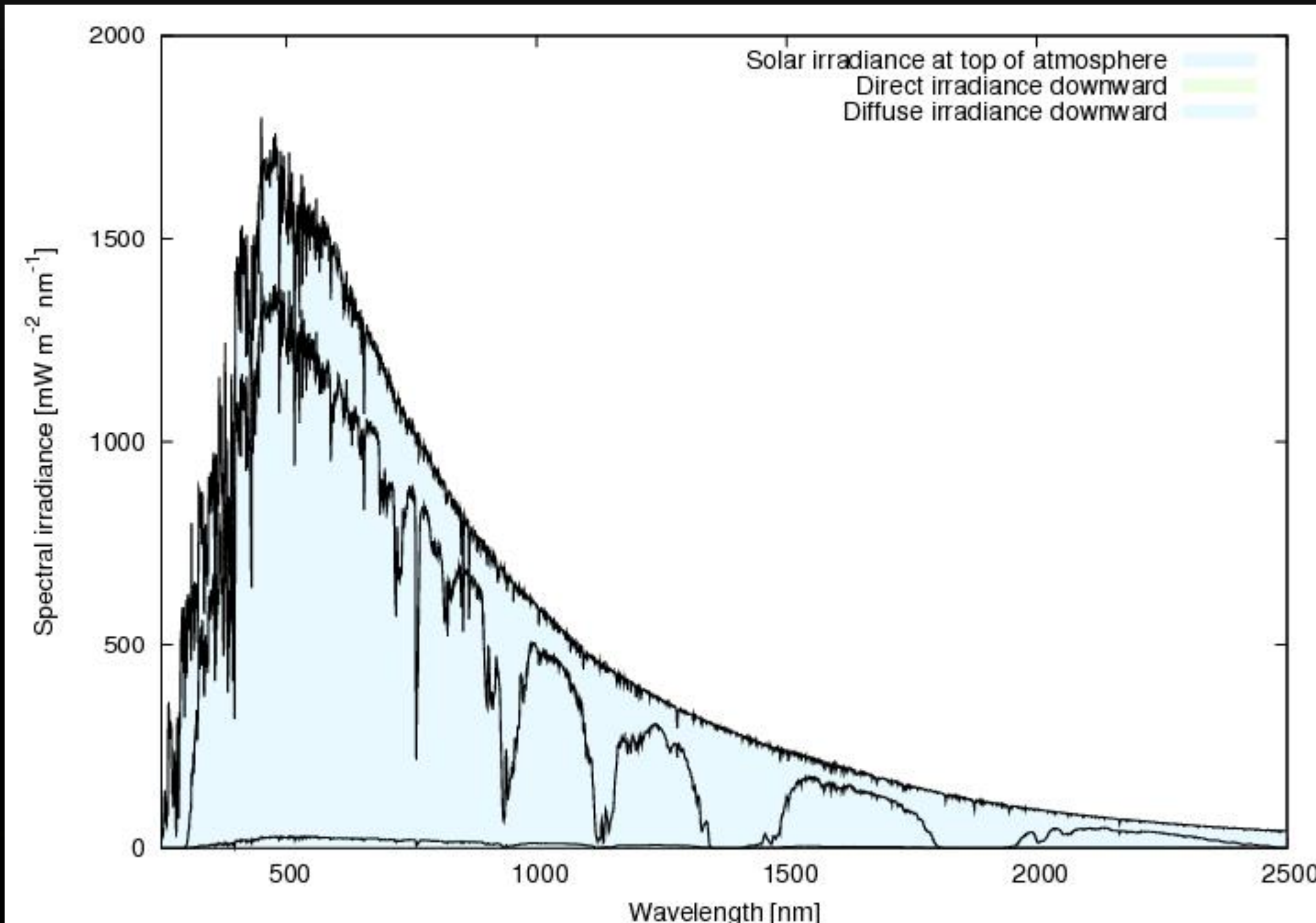
SPECTRAL VARIABILITY



10.0 g/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

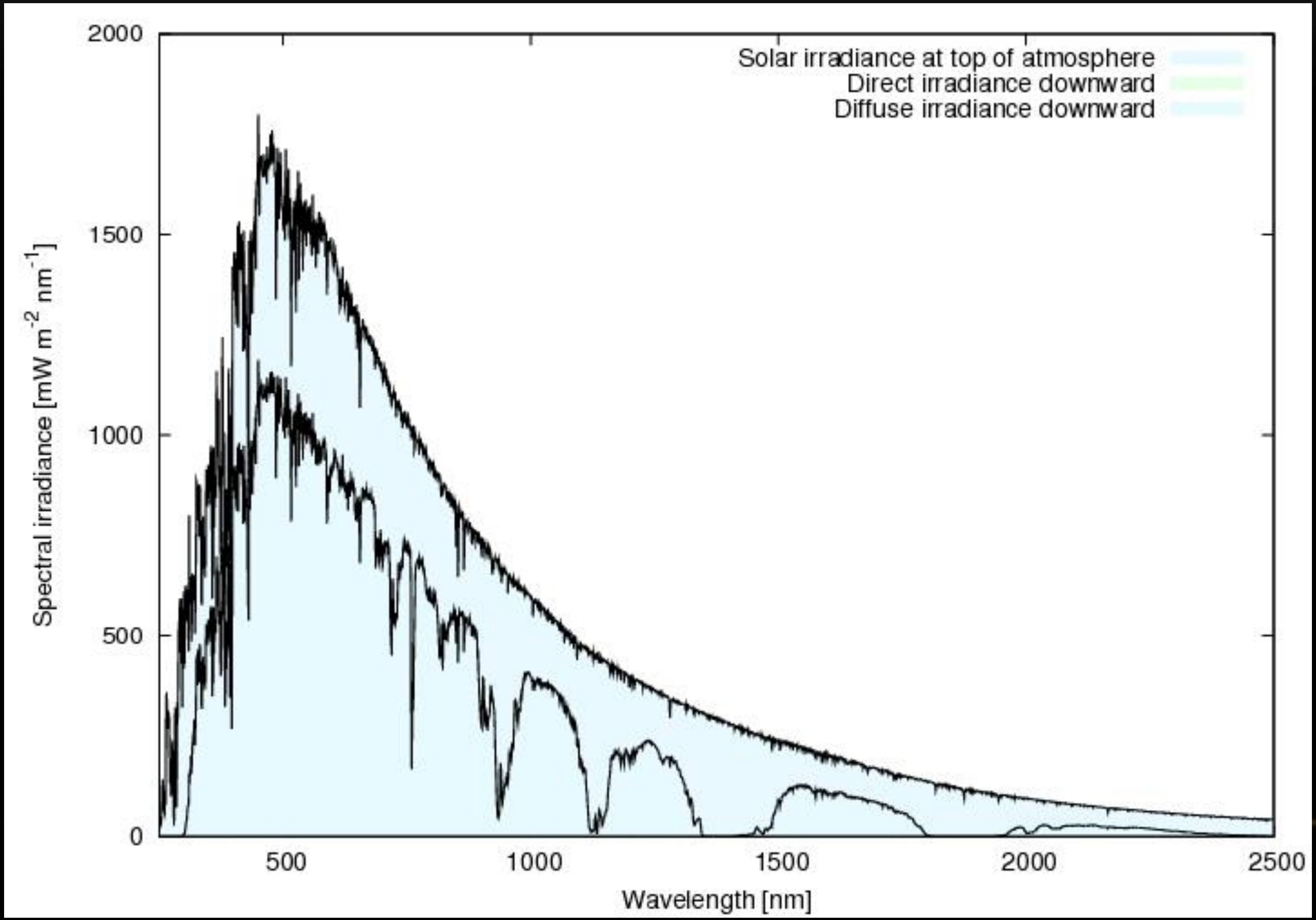
SPECTRAL VARIABILITY



20.0 g/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

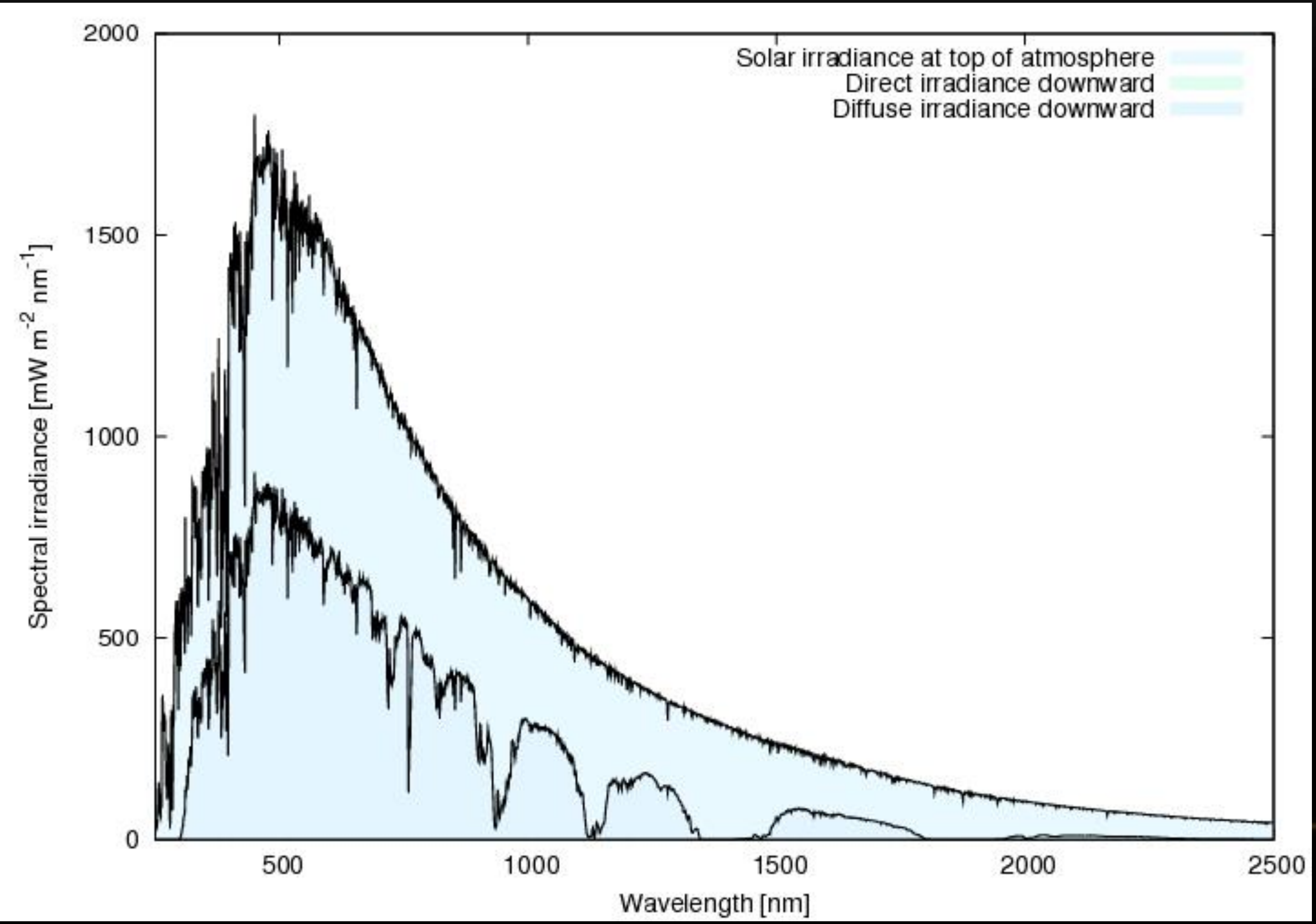
SPECTRAL VARIABILITY



50.0 g/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

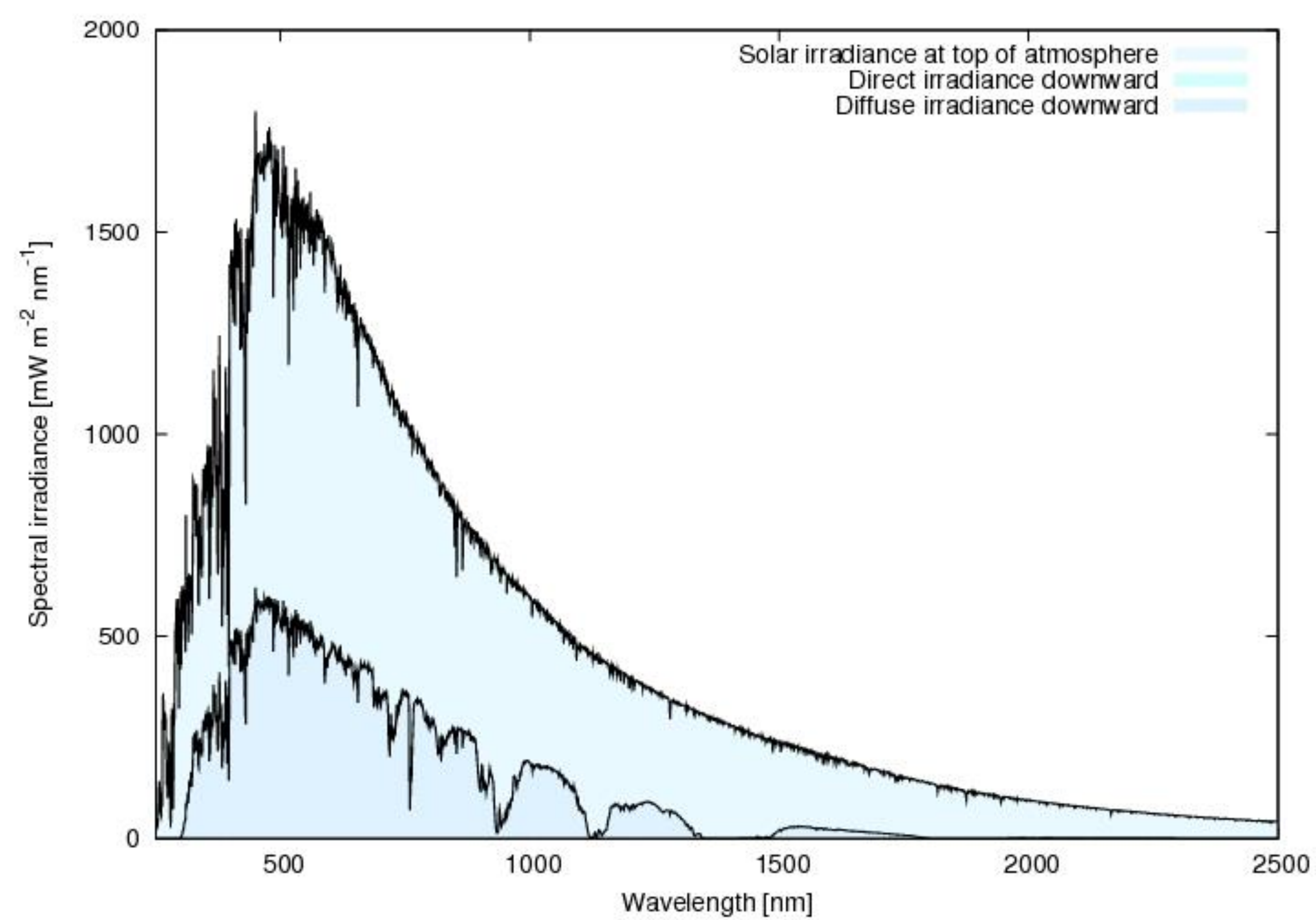
SPECTRAL VARIABILITY



0.1 kg/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

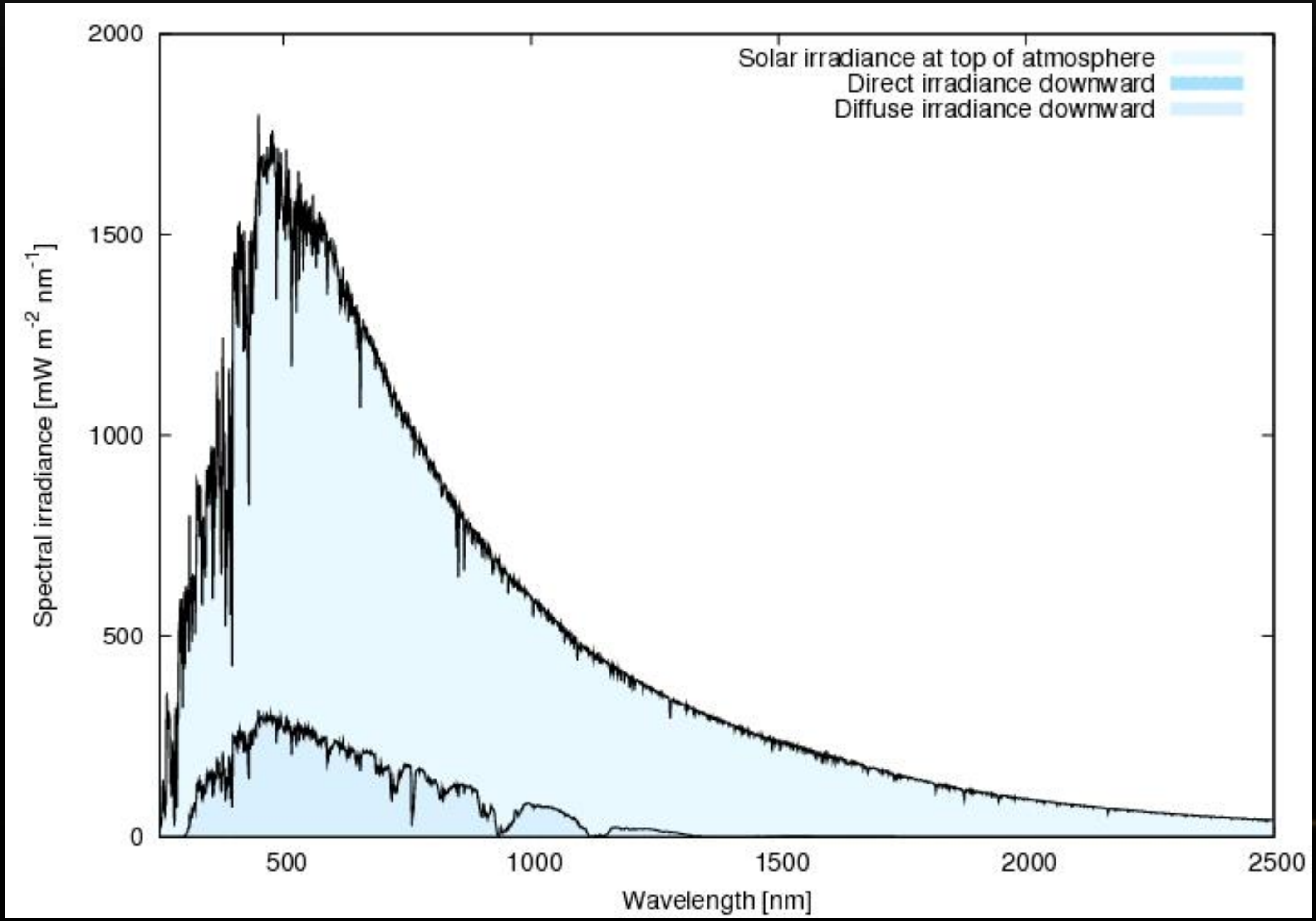
SPECTRAL VARIABILITY



0.2 kg/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

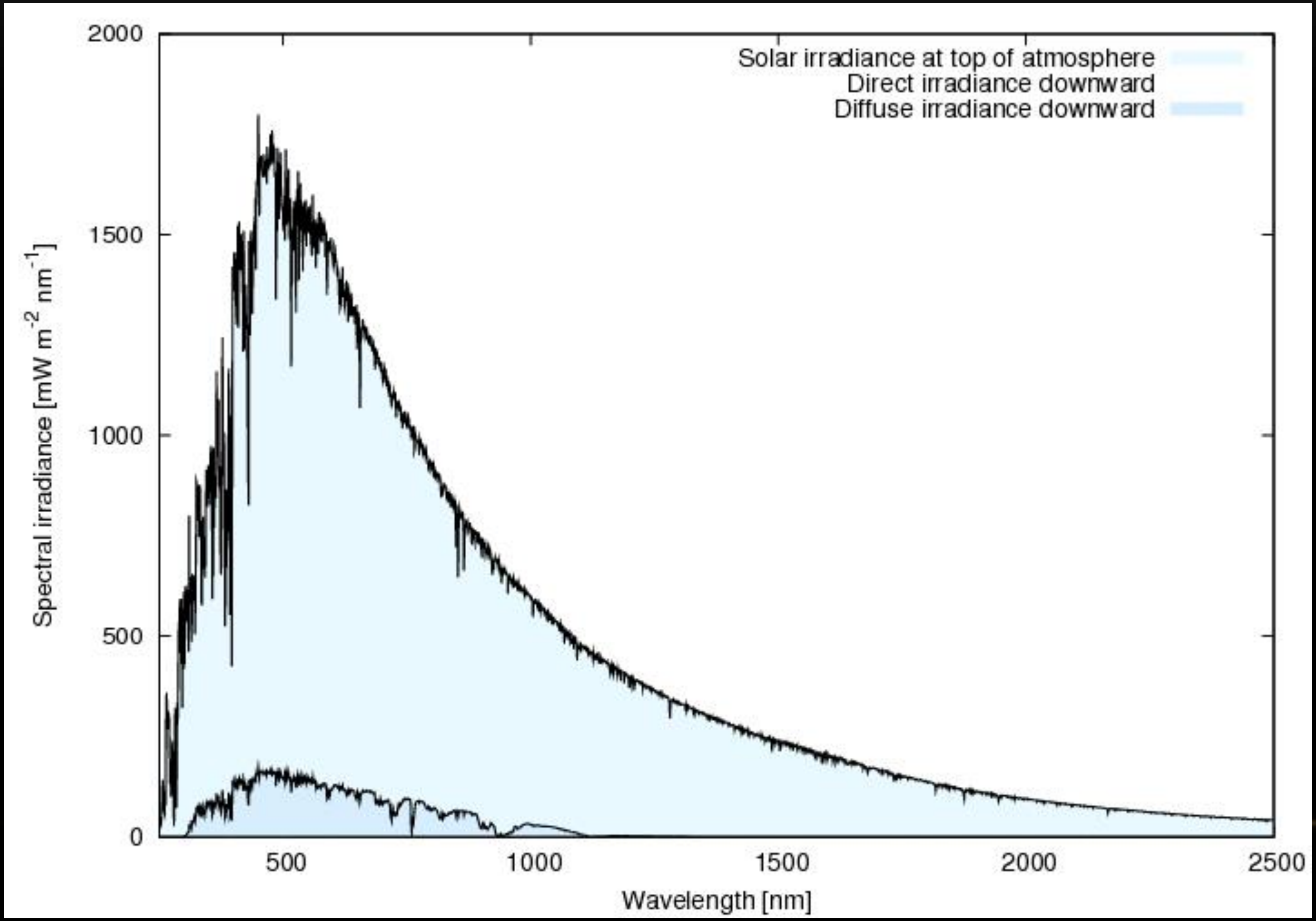
SPECTRAL VARIABILITY



0.5 kg/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

SPECTRAL VARIABILITY



1.0 kg/m^2 Cloud water load

libRadtran/DISORT (Emde et al. 2016; Mayer & Kylling 2005; Stamnes et al. 1988, …)

FUTURE PROSPECT: GENERATION OF REALISTIC MULTI-YEAR DATA

- Carlos M. Fernández-Peruchena, Martín Gastón, Marcelino Sánchez, Javier García-Barberena, Manuel Blanco, Ana Bernardos. “MUS: A multiscale stochastic model for generating plausible meteorological years designed for multiyear solar energy yield simulations”. Solar Energy (2015). Vol 120. Pages 244-256.

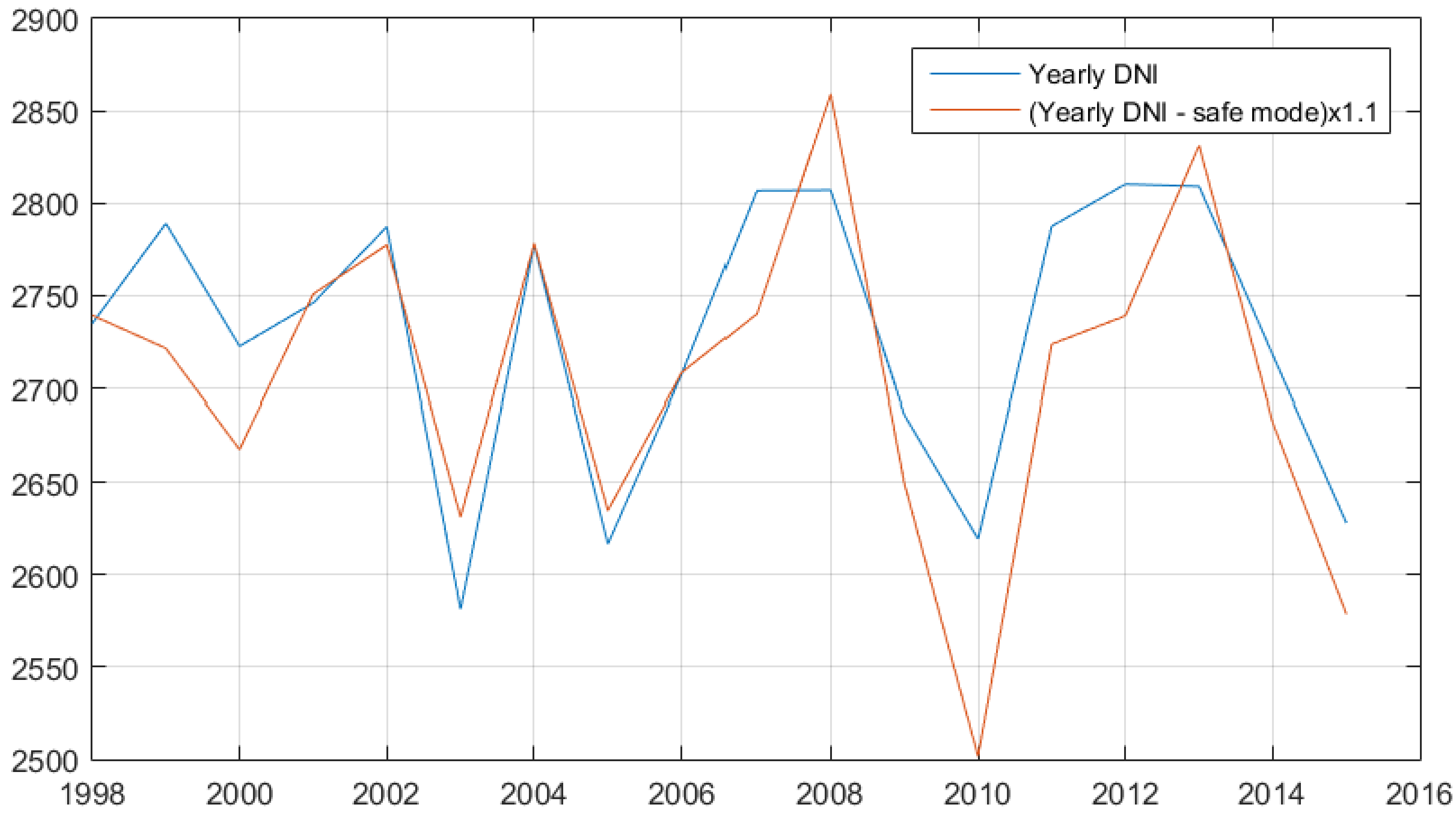
CONCLUDING REMARKS

- Yearly meteorological data sets (TMY, DRY, TRY, ERY, …) should be chosen with care, as can be optimized for different technologies!
- If multi-year meteorological data are available, these should be used in stead.
- When using satellite-derived data, it is important to use data for which proper site-adaptation – for at least 1 year – has been performed.
- Data uncertainty must be documented – and should be based on blind testing.

Thank you for your attention!

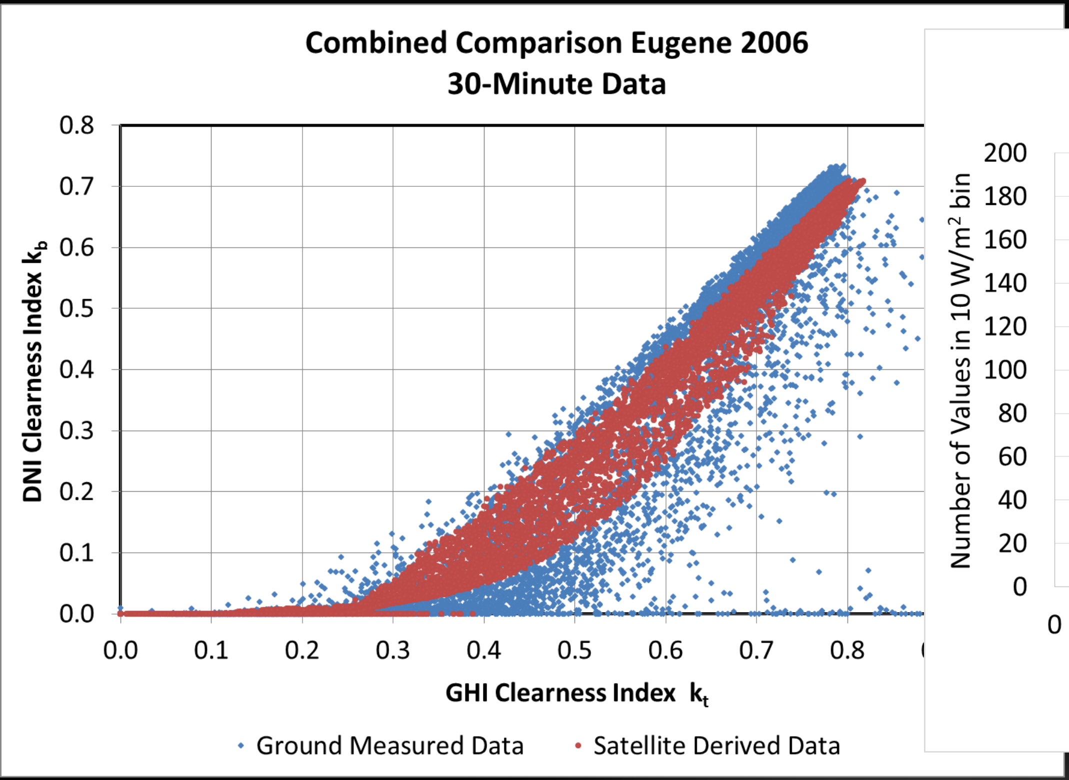
Contact: Kristian Pagh Nielsen, kpn@dmi.dk

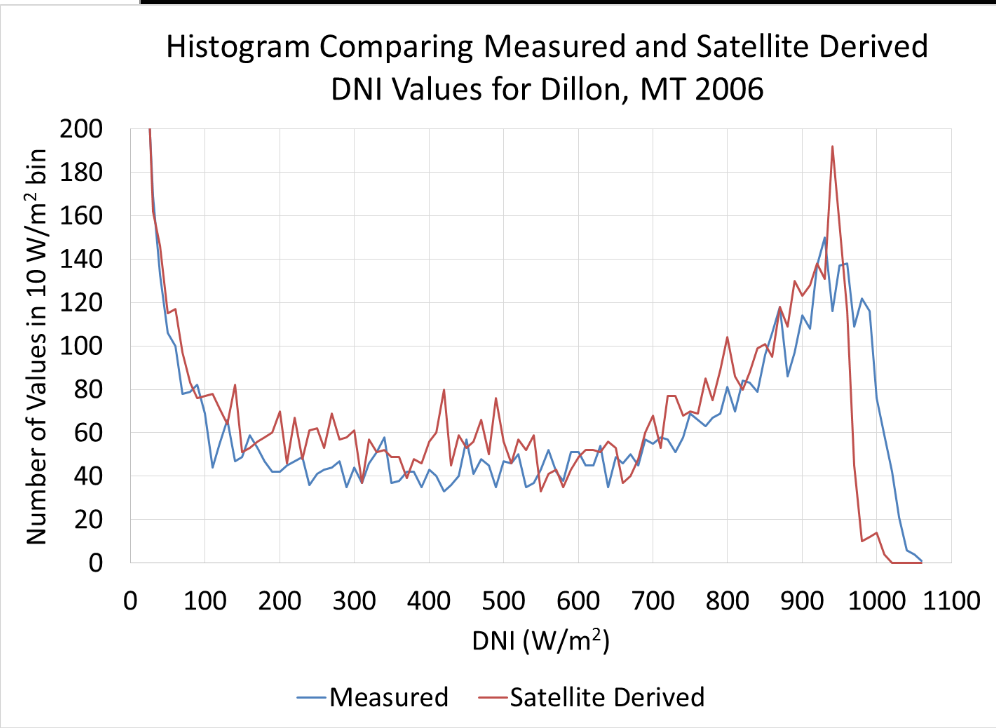
EFFECT ON THE YEARLY RESOURCE WHEN STRONG WINDS ARE ACCOUNTED FOR



Analysis and figure by Philippe Blanc

INDEPENDENT TESTING OF SATELLITE-DERIVED DATA





Analysis and figure by Frank Vignola