The Value of Spectrally Resolved Measurements in Understanding Earth's Energy Flows

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Ehrhard Raschke
1936-2023

IRC business meeting in 1976 in Garmisch

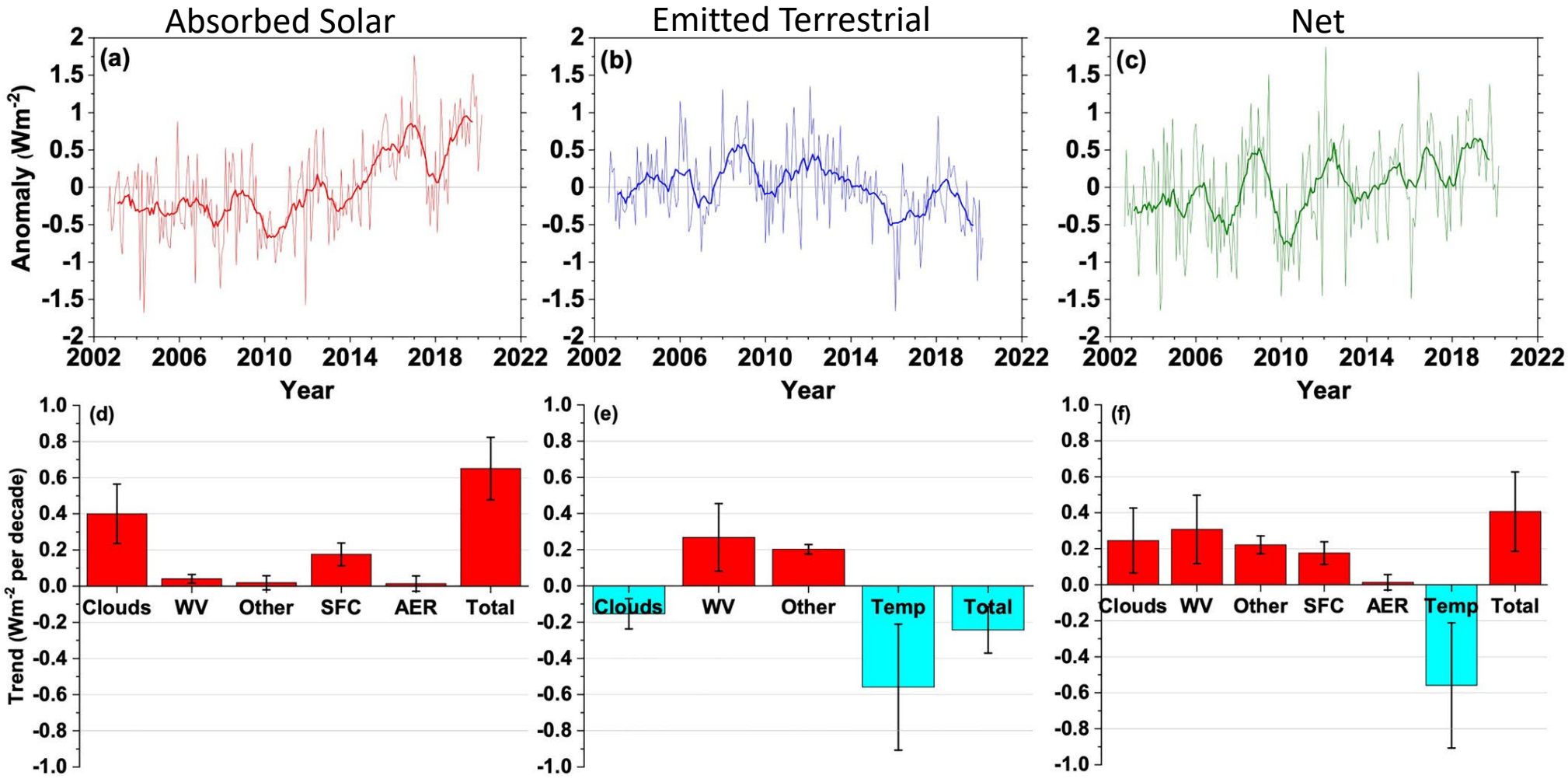
Summer 2021 in Hanau

CERES ERB Climate Data Record

Loeb et al., GRL, 2021, https://doi.org/10.1029/2021GL093047

Trend in absorbed solar: 0.65 W m^{-2}/decade

Trend in net: 0.42 W m^{-2}/decade



Early Satellite Observations of ERB

"We found that Earth was a warmer and darker planet than previously believed – especially in the Tropical Regions. We found that 40% more energy must be transported poleward by the atmosphere and ocean circulations!"
[*Vonder Haar and Suomi, 1969, 1971*]

Modern evidence that Earth is getting darker:
Current trend in albedo is approximately −0.002/decade or −0.7%/decade

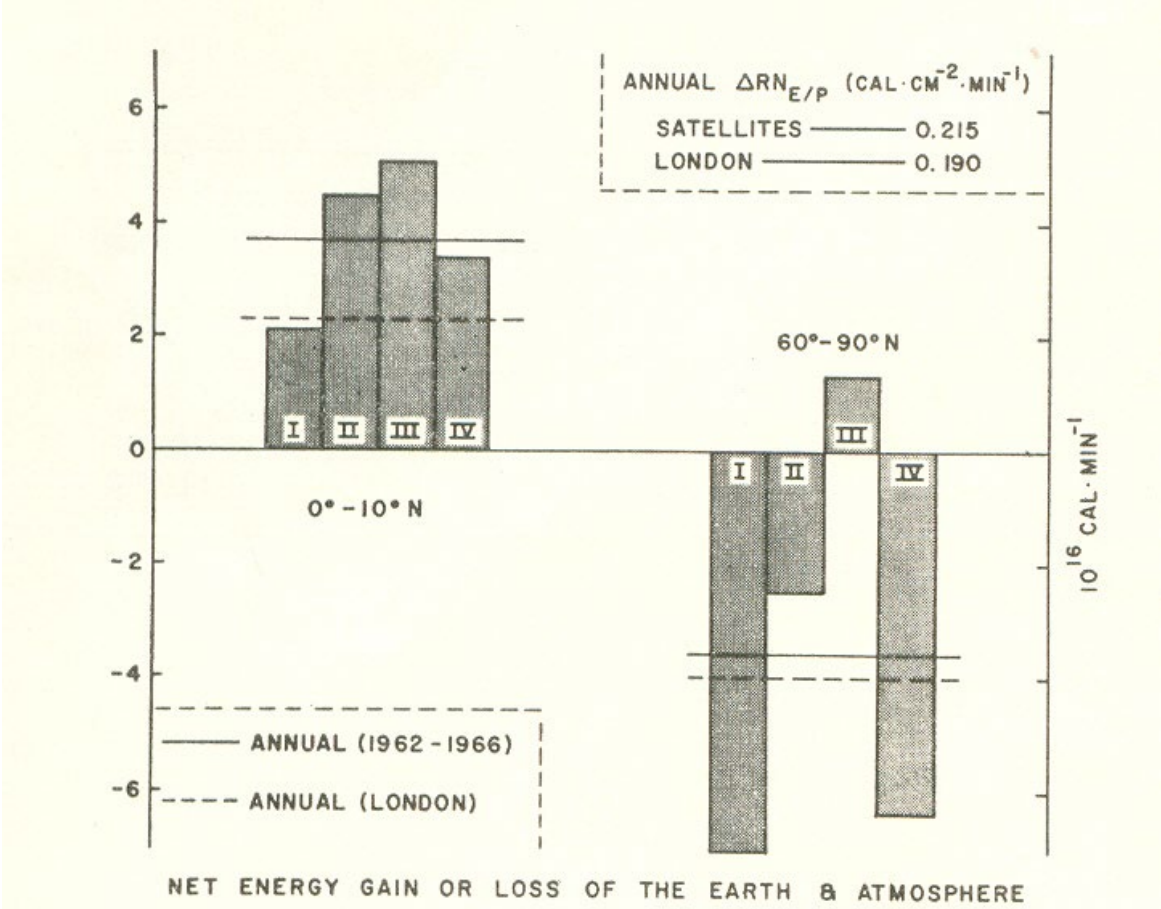
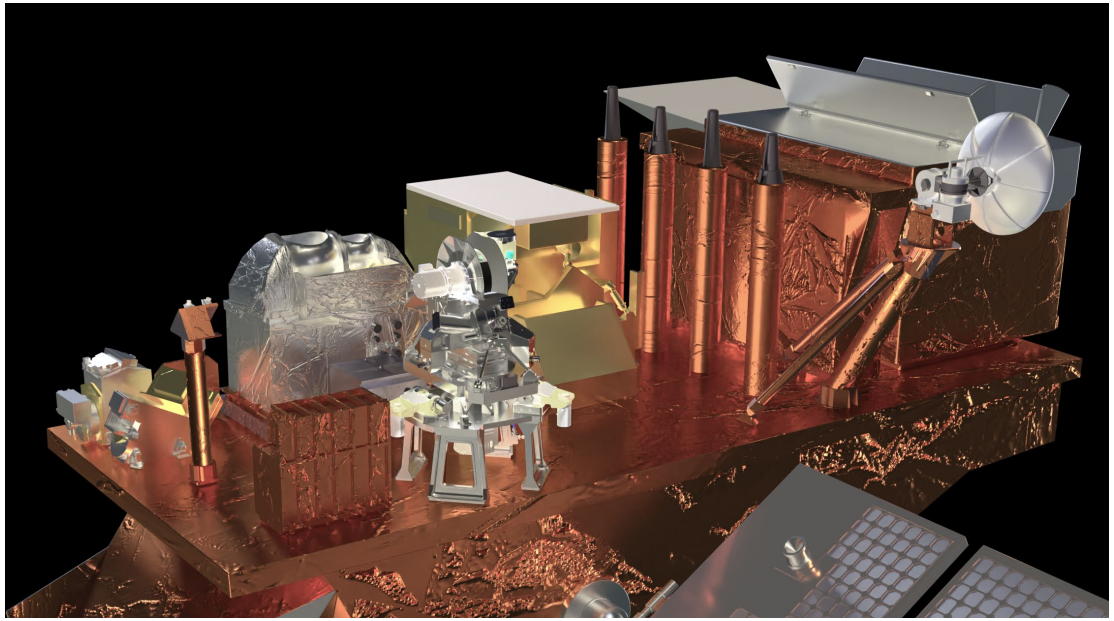


FIG. 2. Mean annual and seasonal energy exchange with space, measured from satellites during 1962–66, for two latitude zones. Bar graph represents seasonal values (I=Dec., Jan., Feb.; II=Mar., Apr., May; etc.). $\Delta RN_{E/P}$ is the net radiation gradient between equator and pole.

Libera, NASA Earth Venture Continuity-1 Mission

'Li-be-ra, named for the daughter of Ceres in ancient Roman mythology



JPSS-4 Instruments

***Libera* – Earth Radiation Budget**

ATMS - Advanced Technology Microwave Sounder

CrIS - Cross-track Infrared Sounder

VIIRS – Visible Infrared Imaging Radiometer Suite

OMPS – Ozone Mapping and Profiler Suite

Successful Critical Design Review 27-29 June 2023

Provides continuity of the Clouds and the Earth's Radiant Energy System (CERES) Earth radiation budget (ERB).

- Measures integrated shortwave (0.3–5 µm), longwave (5–50 µm), total (0.3–100+ µm) and ***(new) split-shortwave (0.7–5 µm) radiance*** over 24 km nadir footprint; ***uncertainty ~ 0.3%***
- ***Includes a wide FOV camera for scene ID and simple ADM generation to pave way for future free-flyer ERB observing system***

Innovative technology:

- ***Electrical substitution radiometers (ESRs) using vertically-aligned carbon nanotube (VACNT) detectors***

Primary operational modes:

- Cross-track and azimuthal scanning; on-board calibrators; solar and lunar viewing.

Flight:

- **JPSS-4, 2027 launch; 5-year mission**

Partners:

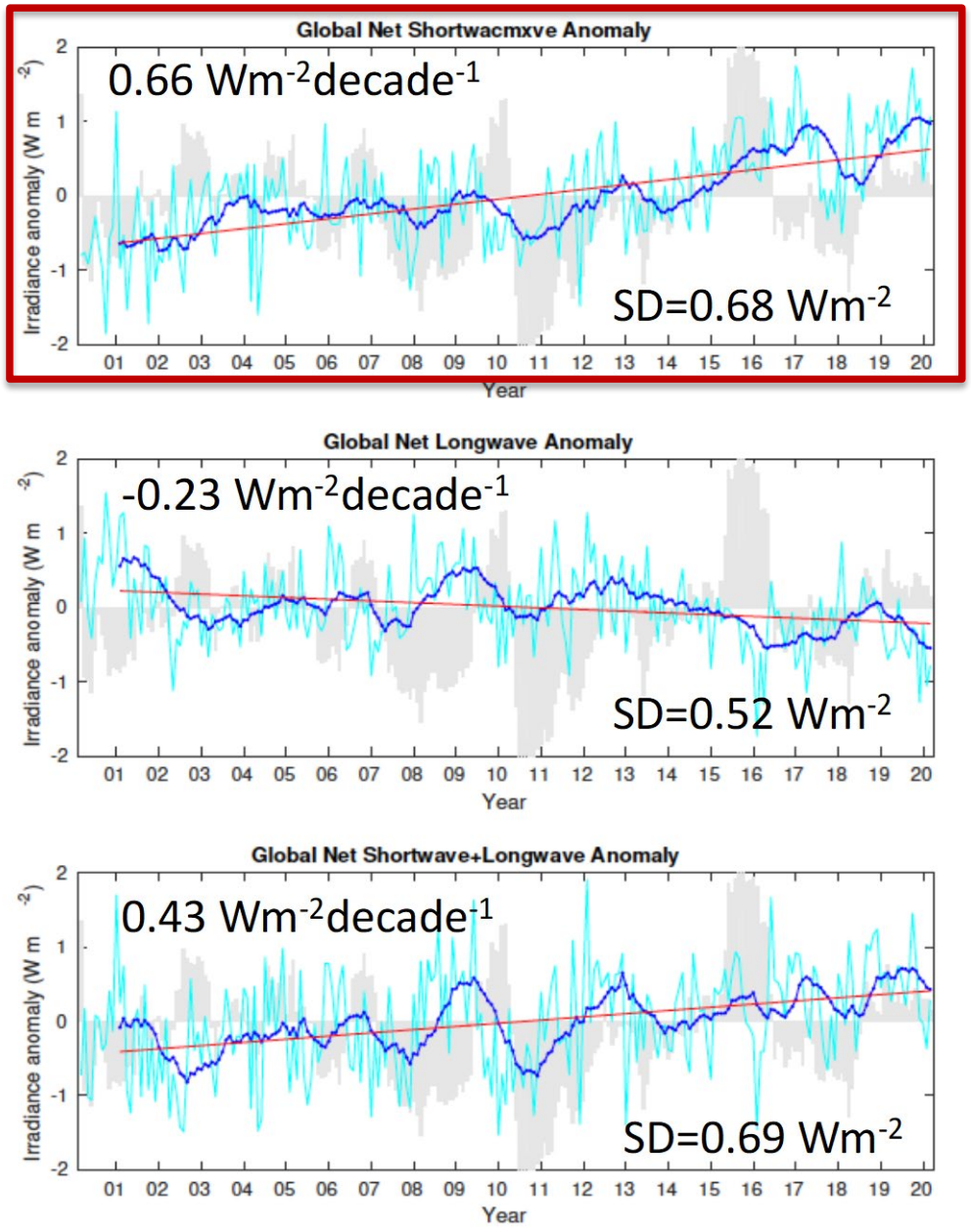
- LASP, Ball Aerospace, NIST Boulder, Space Dynamics Lab; CU, JPL, CSU, UA, UM, LBL

Libera's Split-shortwave Channel

NIR & VIS signature of processes controlling the absorption of solar radiation & climate feedbacks.

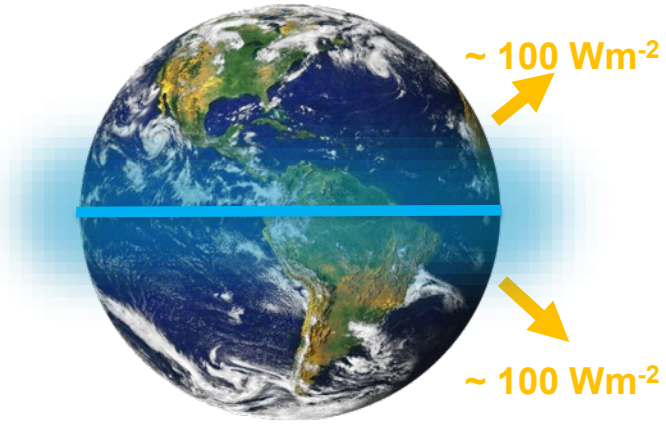
- *In CERES observations, a positive trend in ASR is the main reason for increase in EEI*
- *Climate models suggest that global warming is sustained by the increase in ASR on decadal to centennial time scales (positive SW feedbacks)*
- *Libera's fourth channel measures near-IR radiances (0.7-5 μm) at the same accuracy as the total SW radiance (~0.2%).*

Stephens et al., 2022

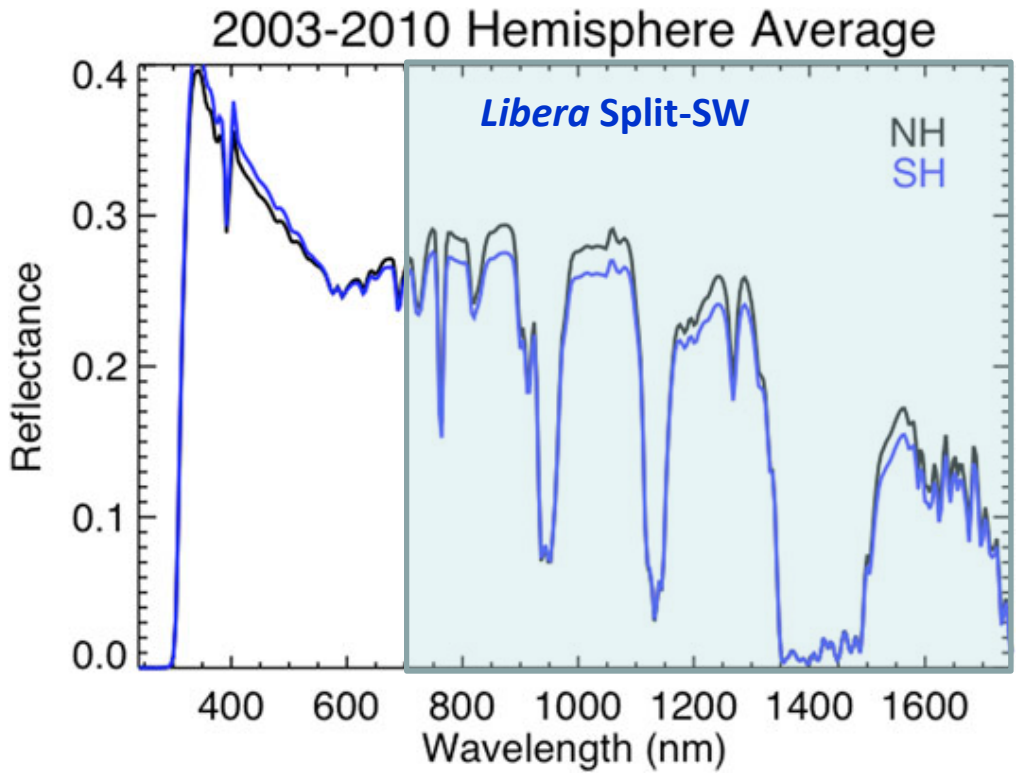


Libera's Split-shortwave Channel

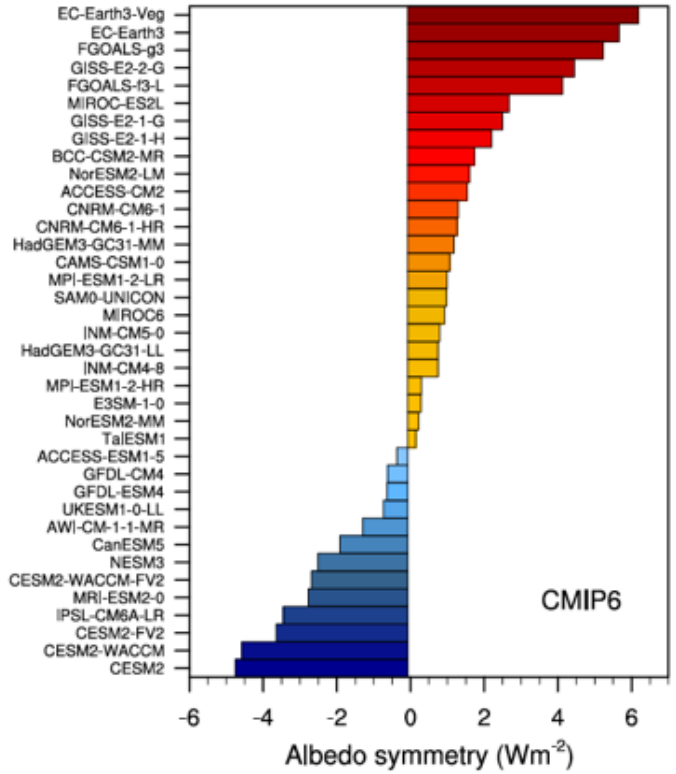
Better understanding of the hemispheric symmetry of planetary albedo



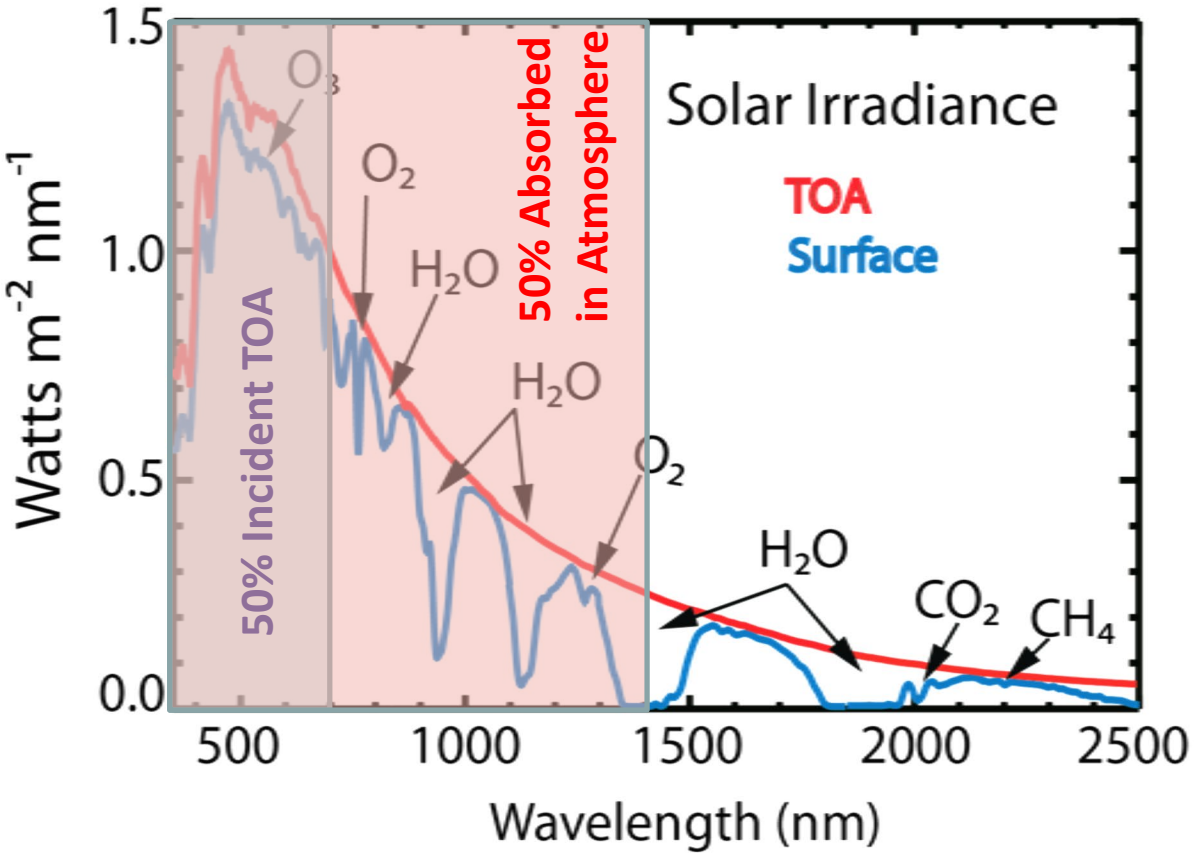
Stephens et al., 2015

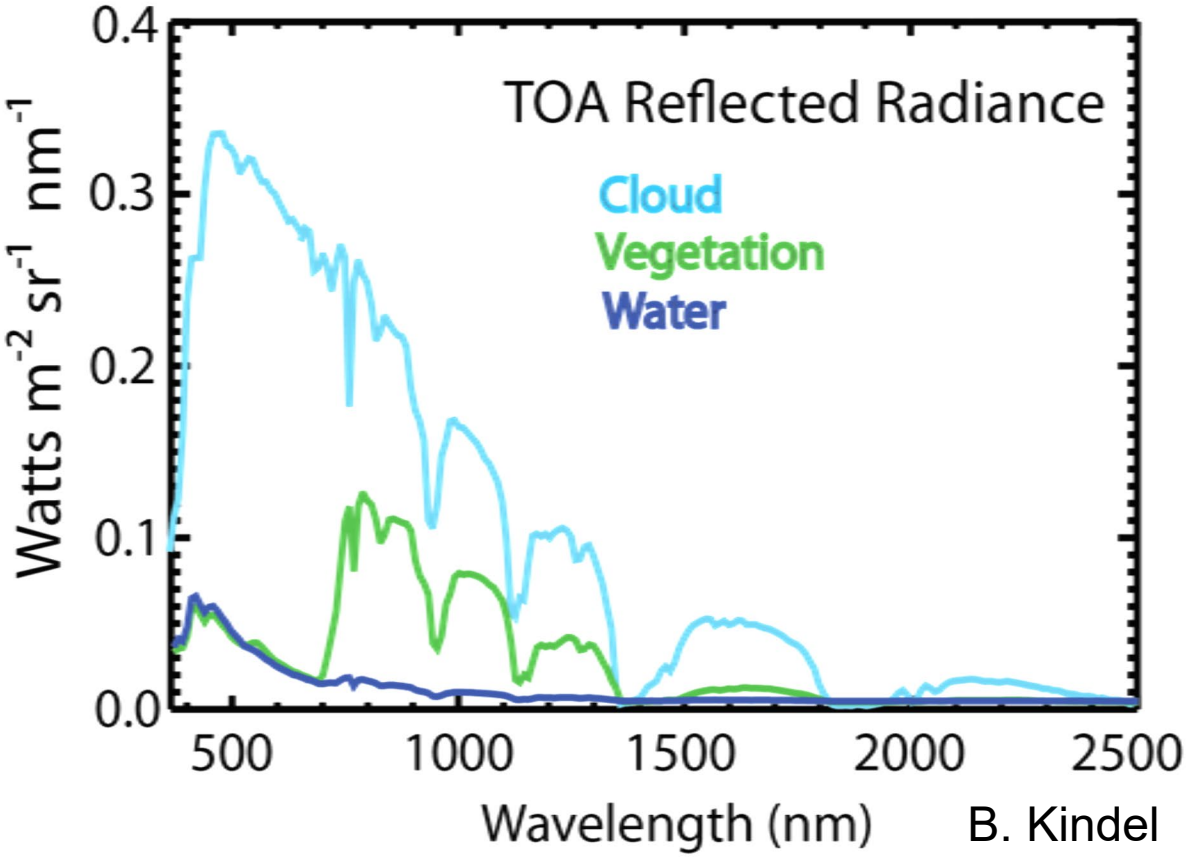


Rugenstein & Hakuba, 2023



Spectral Signatures of Solar Radiation



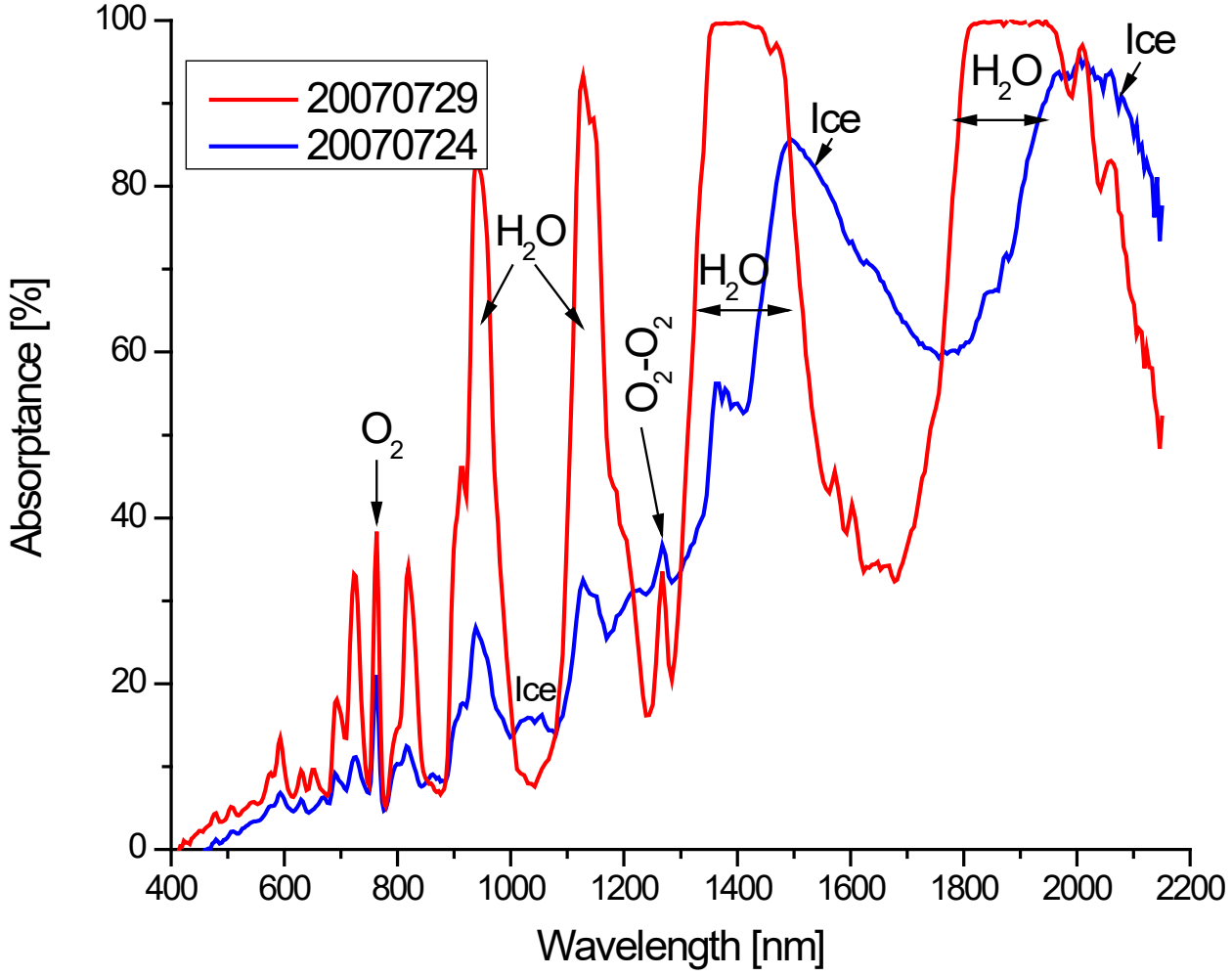


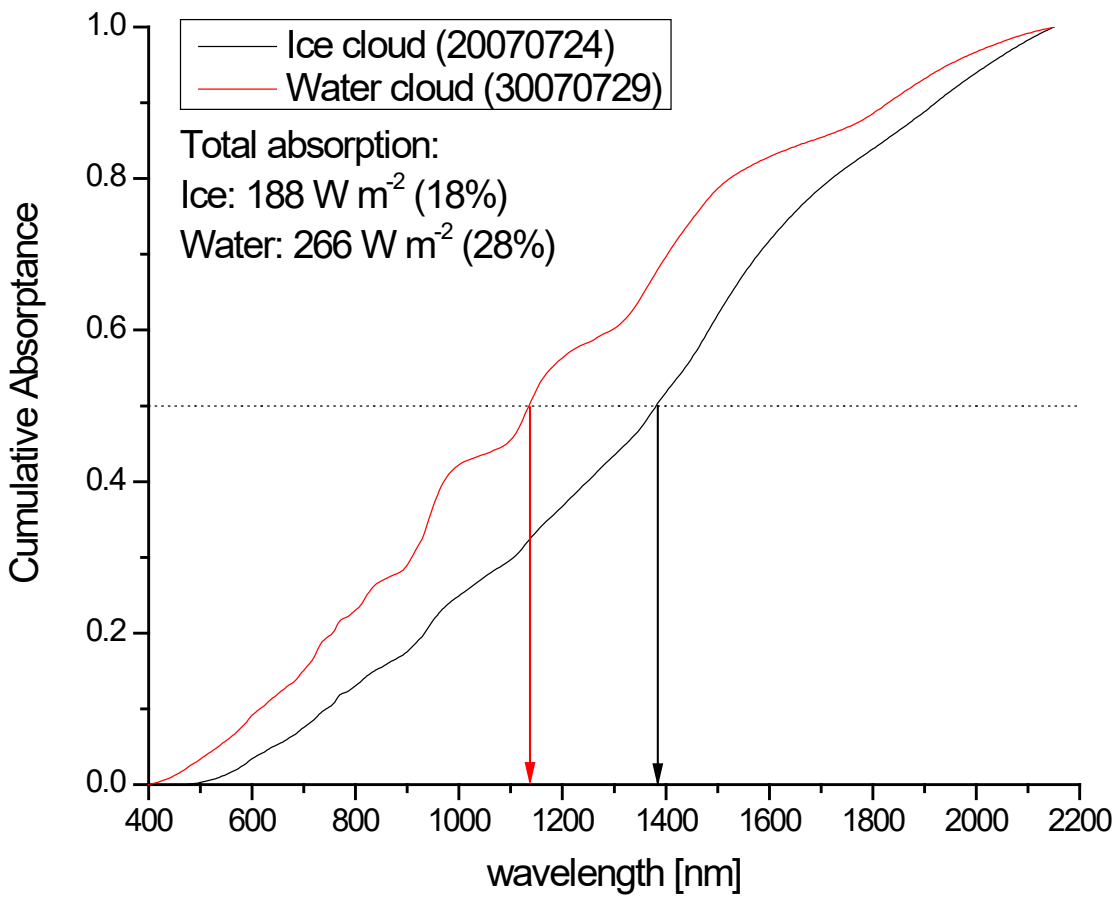
B. Kindel

Shortwave spectral information - clouds

Water Cloud vs. Ice Cloud Column Absorption Derived from Measurements

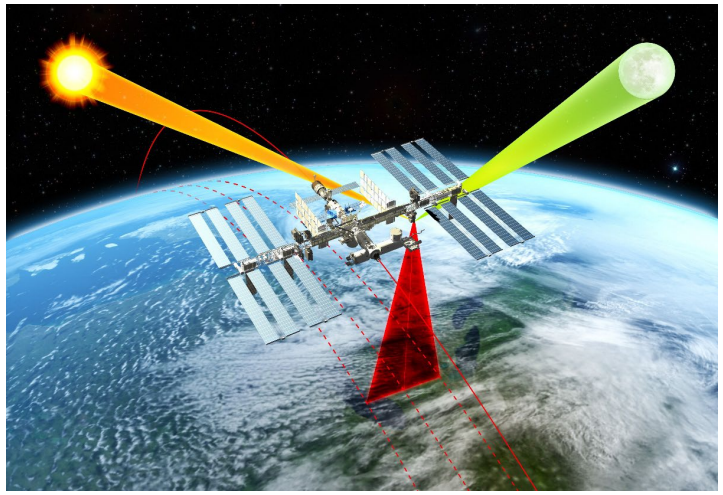
Schmidt and Pilewskie, 2012





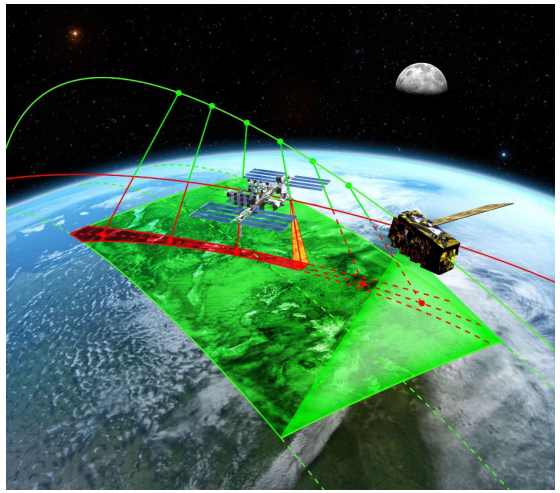
CLARREO Pathfinder

High Accuracy SI-Traceable Shortwave Reflectance



Demonstrate on-orbit calibration ability to reduce reflectance uncertainty by a factor of ***5-10 times*** compared to the best operational sensors on orbit.

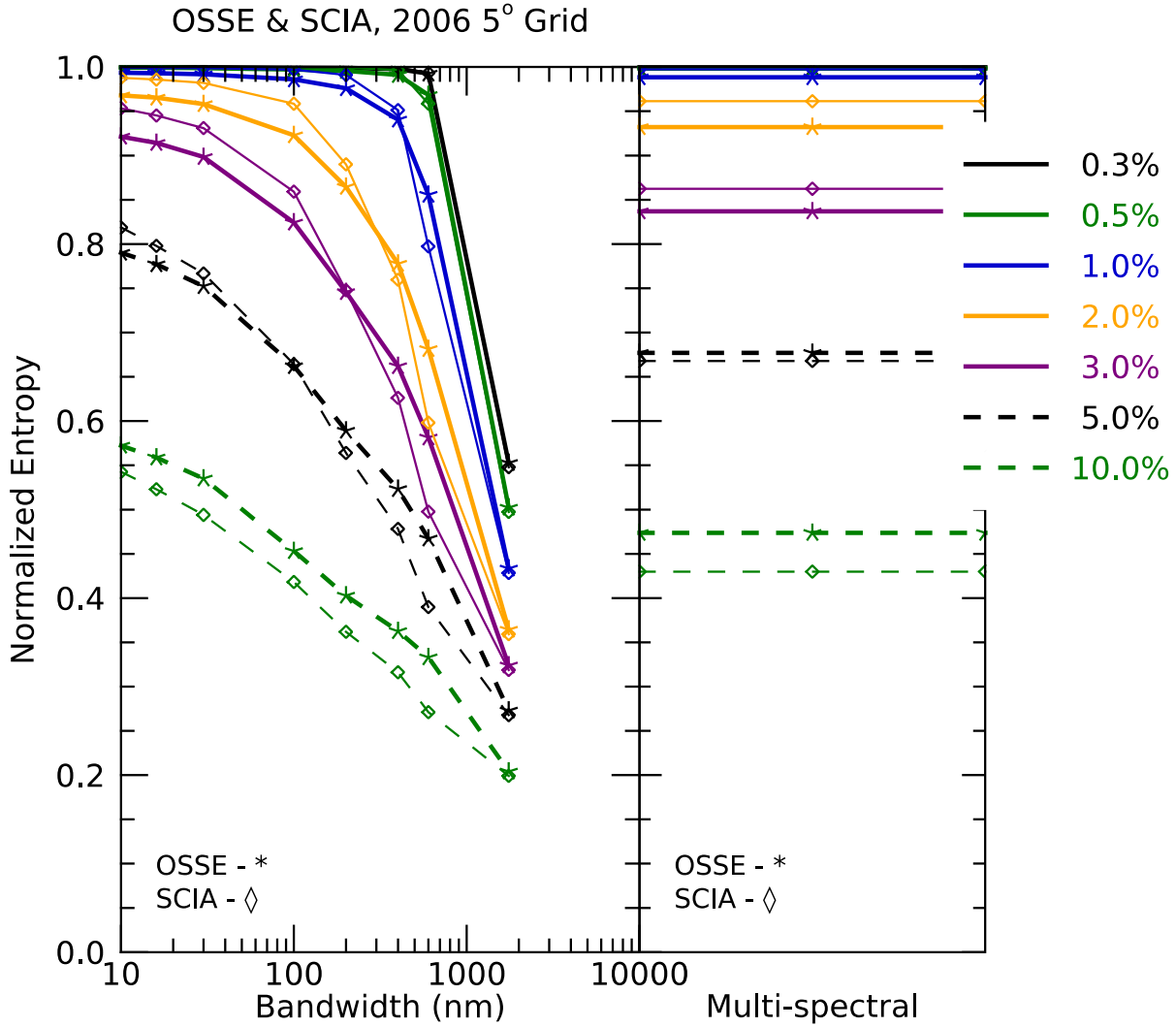
Reference Inter-Calibration



Demonstrate calibration transfer to other satellite sensors by inter-calibrating with CERES & VIIRS.

	Objective #1	Objective #2
Uncertainty	Spectrally & broadband reflectance: ≤0.3% (1σ)	Inter-calibration Sampling Difference: ≤0.3% (1σ)
Data Product	Level 1A: Highest accuracy, best for inter-cal, lunar obs Level 1B: Approx. consistent spectral & spatial sampling, best for science studies using nadir spectra	Level 4: One each for CPF-VIIRS & CPF-CERES inter-cal. Merged data products including all required info for inter-cal analysis

High Information Content is critical for climate change attribution.
High Accuracy is critical for climate change detection.



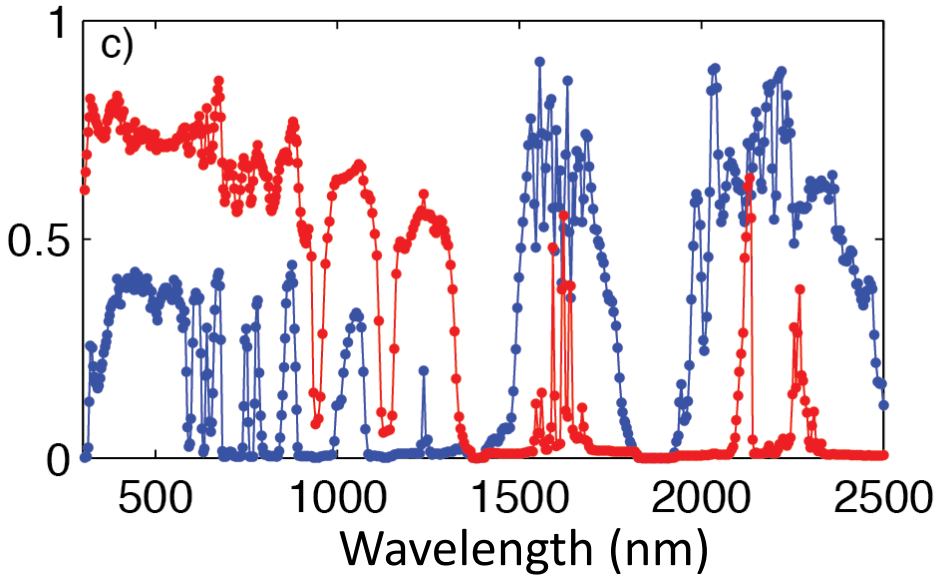
Shea et al., 2022

Normalized Information Content

Cloud Optical Thickness Droplet Effective Radius

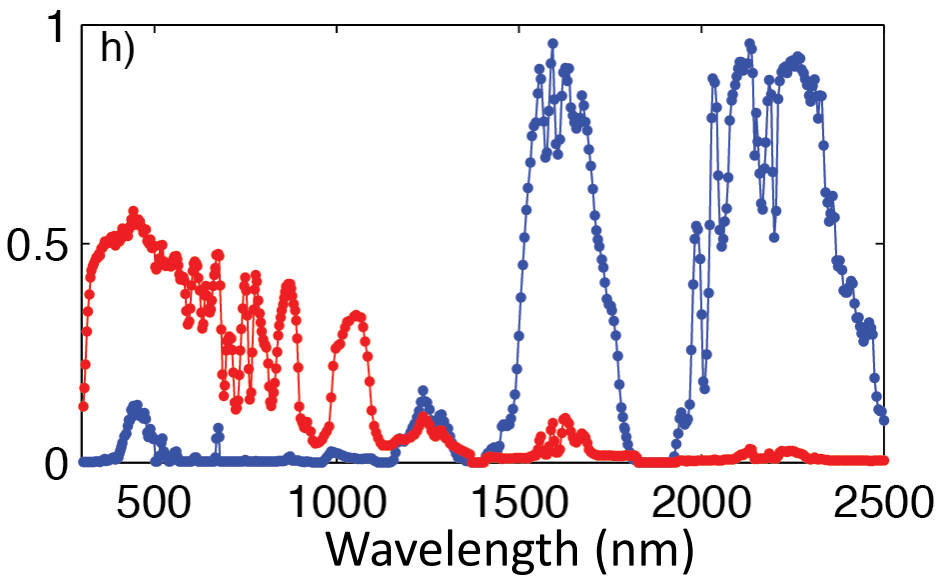
Moderately Thick Cloud

($\tau = 15$, $r_e = 14$ μm)



Thick Cloud

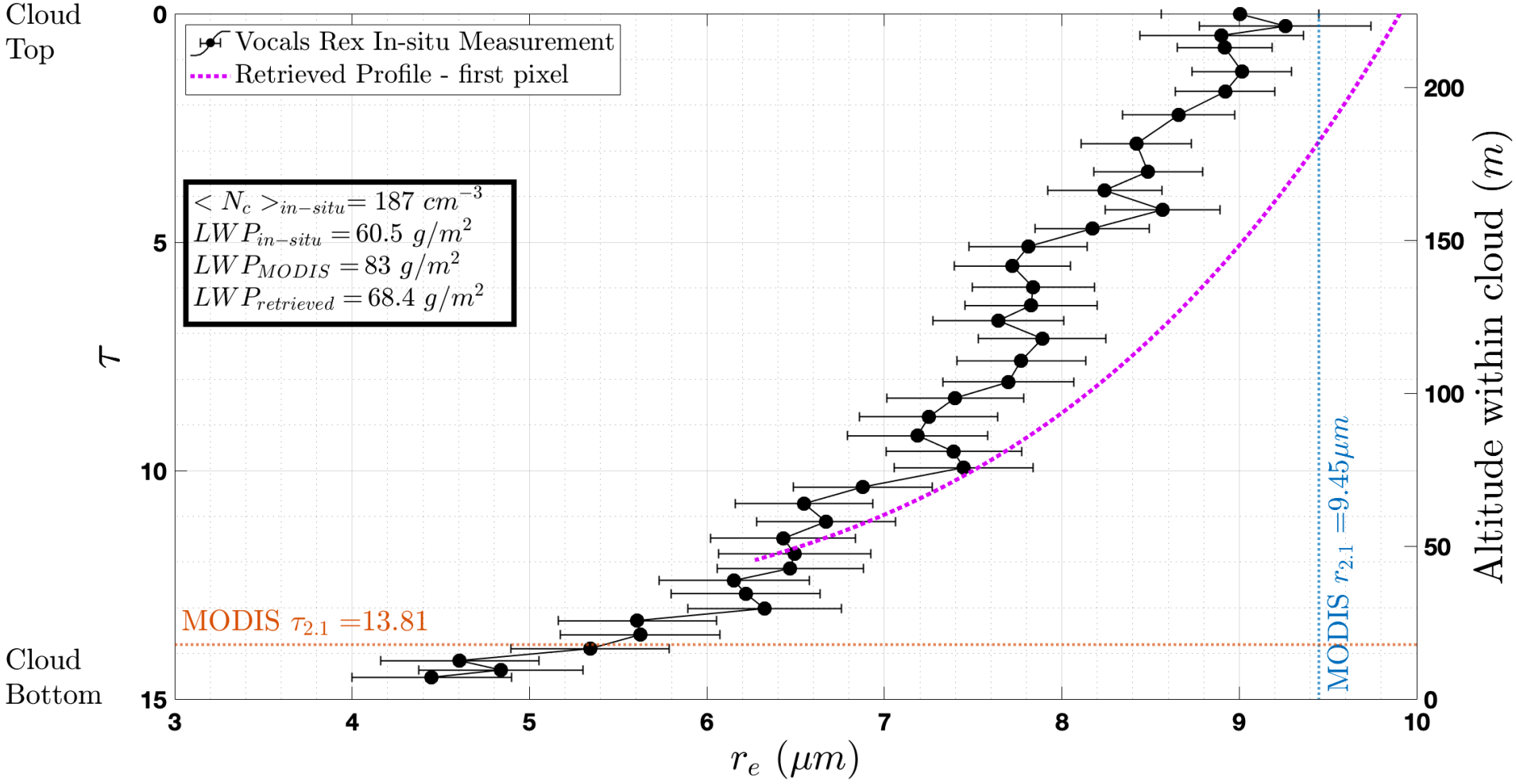
($\tau = 60$, $r_e = 20$ μm)



[Adapted from *Coddington et al.*, 2012]

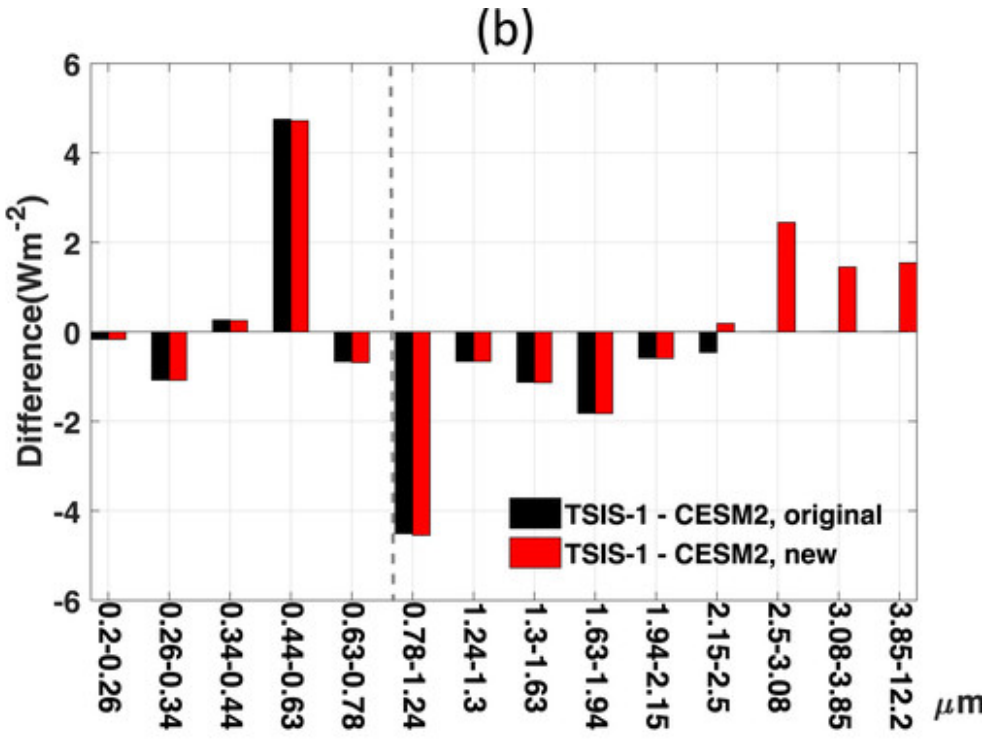
Retrieved Cloud Droplet Size Profile

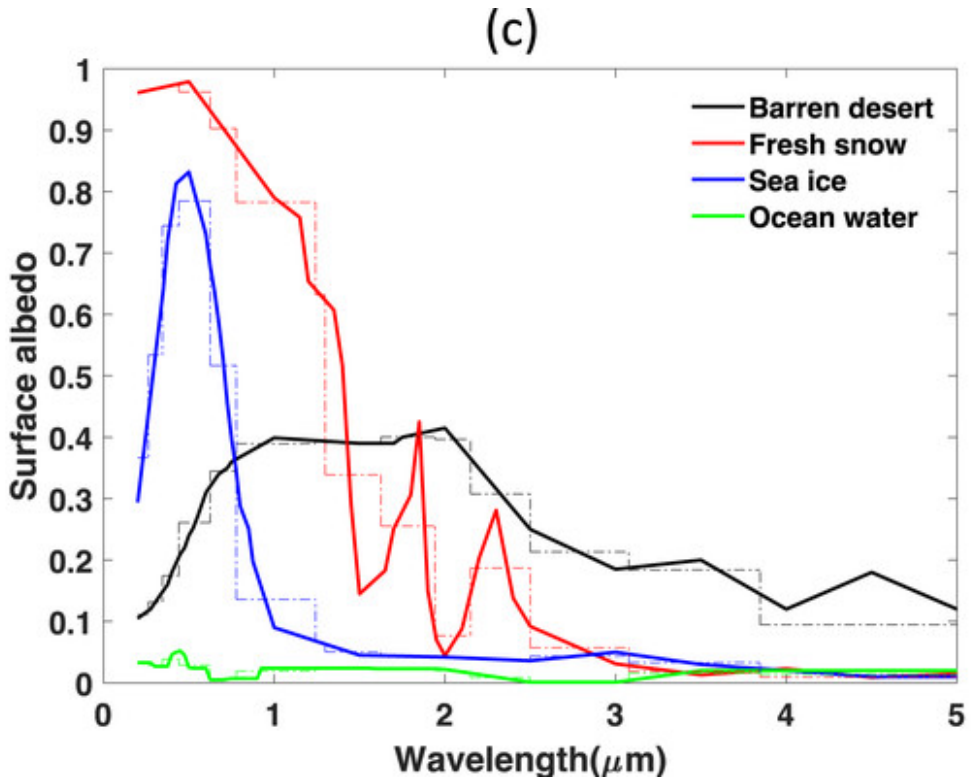
Buggee and Pilewskie, 2023



There's Only One Sun…

Jing et al., *Journal of Climate* 34, 10; 10.1175/JCLI-D-20-0743.1





"Our results show that indeed such SSI partitioning difference can cause discernible differences in the simulated high-latitude surface climate, primarily through a bottom-up mechanism due to the changes in surface SW absorption caused by the VIS and NIR surface albedo contrasts in the high latitudes."

Summary

1. Libera split-shortwave band separates the spectral region where shortwave energy deposition occurs in the atmosphere (near-infrared) from that where the atmosphere is nearly transparent (visible).
   - Help identify the sources that are driving recent trends in ERB
   - Provide insight into albedo symmetry
2. Increases information from spectrally resolved measurements has been well-established
   - Improves climate change detection and attribution
   - Enhances remote sensing capabilities, improves climate process studies
3. Climate models are sensitive to the spectral distribution of incident solar irardiance

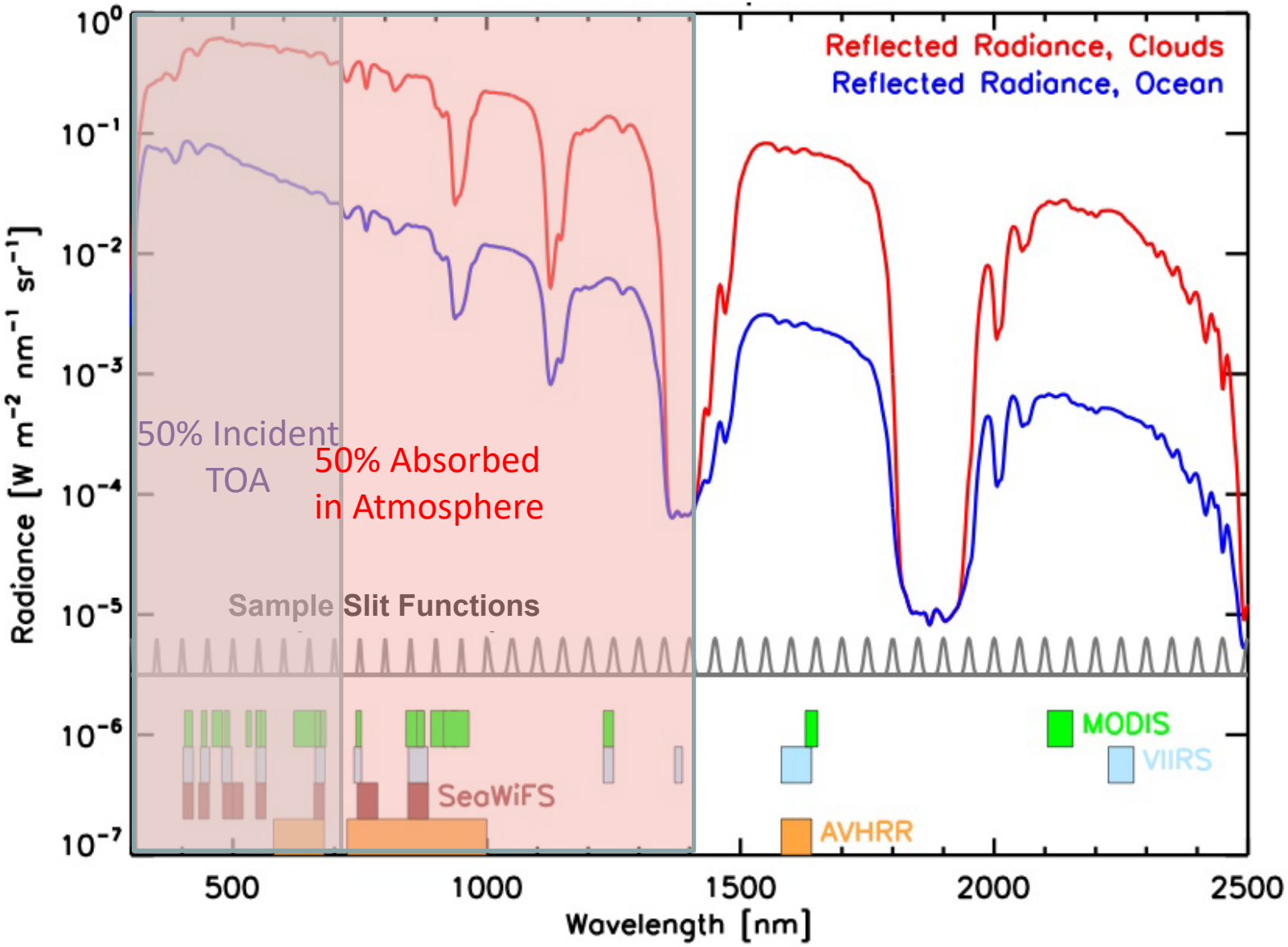
INTERNATIONAL RADIATION SYMPOSIUM

INTERNATIONAL RADIATION SYMPOSIUM 2024

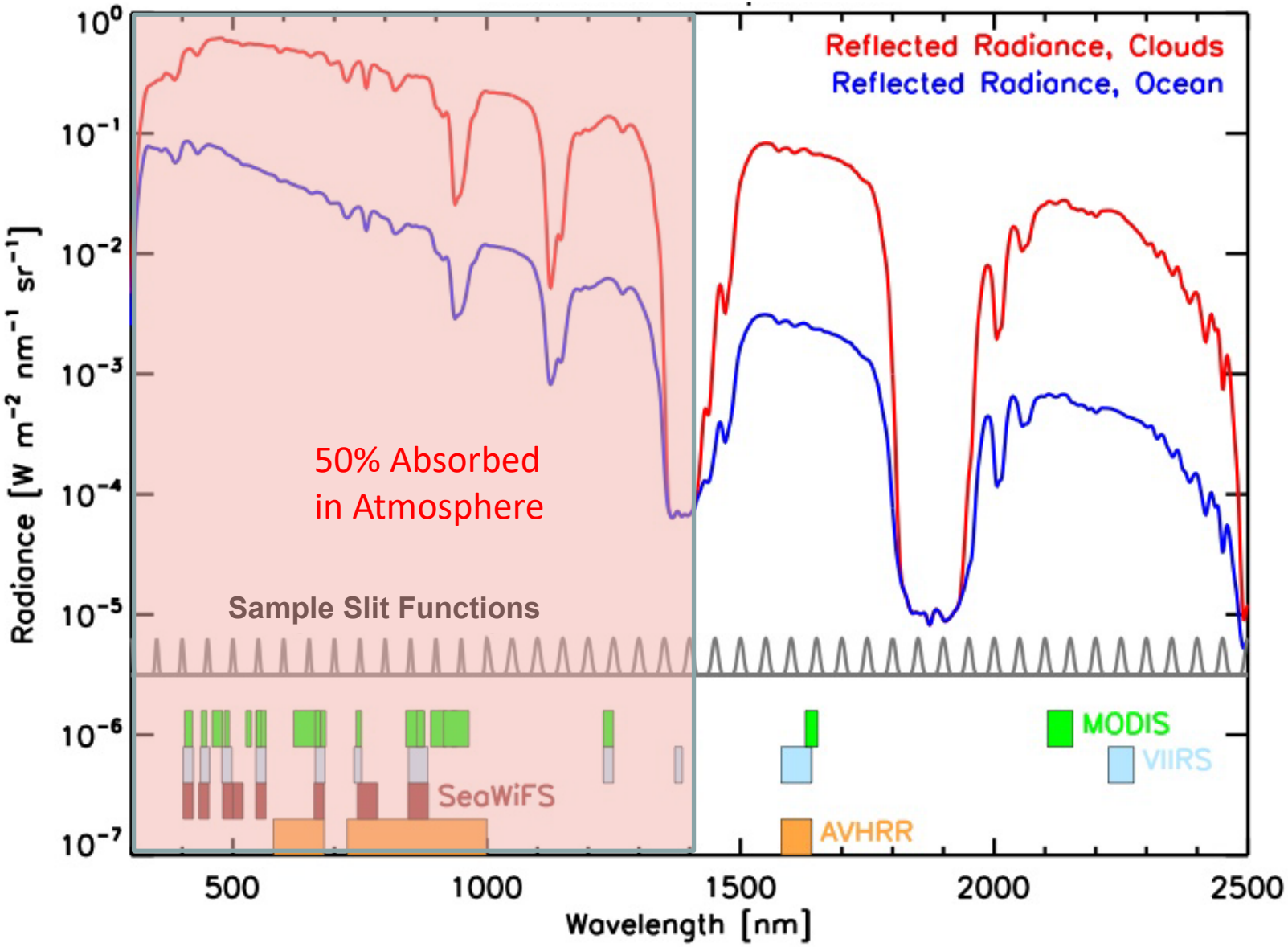
17-21 June 2024 Hangzhou, China

http://www.irs2024.org

Cumulative Incident and Absorbed Solar Radiation



Cumulative Incident and Absorbed Solar Radiation

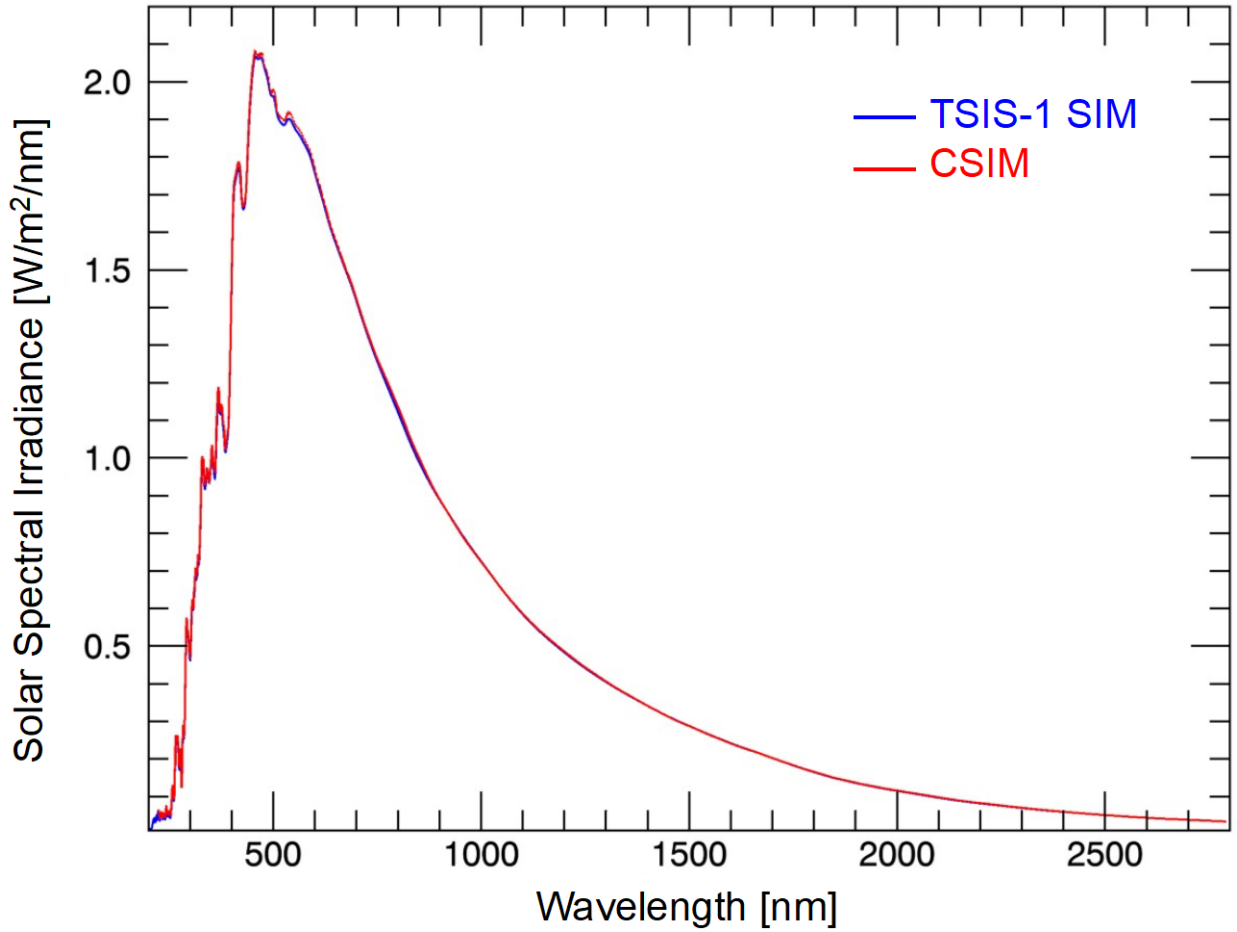


Conclusions

- Libera carries a fourth “shortwave split channel”
- Split at 700 nm to distinguish between solar radiation that is absorbed by the clear atmosphere (NIR) and in which vegetation is bright vs. radiation for which the clear atmosphere is mostly transparent (VIS) and snow is bright
- Albedo symmetry is an accumulation of processes that differ per hemisphere and affect the NIR/VIS ratio; UKESM1: Clouds balance clear-sky asymmetries in total SW AND in NIR/VIS especially over the Southern Ocean
- The increase in solar absorption with “climate change” in UKESM1 occurs both in the VIS (surface albedo + clouds) and NIR (water vapor), while NIR slightly dominates (adds to surface absorption). More models to assess NIR/VIS fingerprints!
- Libera will serve to quantify relevant sensitivities & to evaluate climate models

TSIS-1: A New Solar Irradiance Reference Spectrum

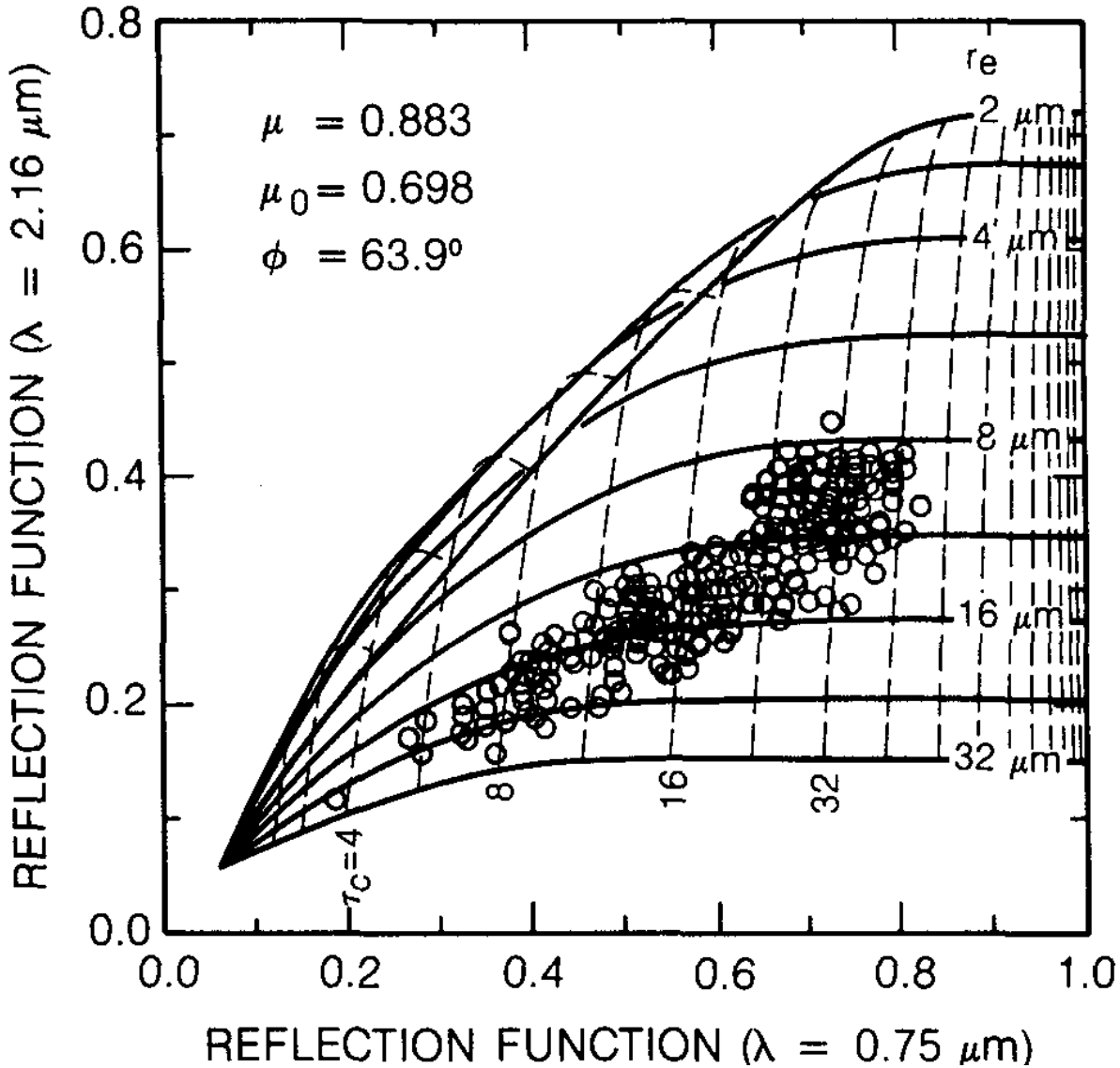
Reference Spectrum	205-2390 (W/m²)	+ 52 (W/m²)*	TIM TSI (W/m²)	% Diff.
ATLAS-3	1333	1386	1362-1360	+1.76-1.88
SIRS-WHI	1323	1375	1362-1360	+0.95-1.1
TSIS SIM	**1307.6**	**1359.6**	**1360.6**	**-0.08**



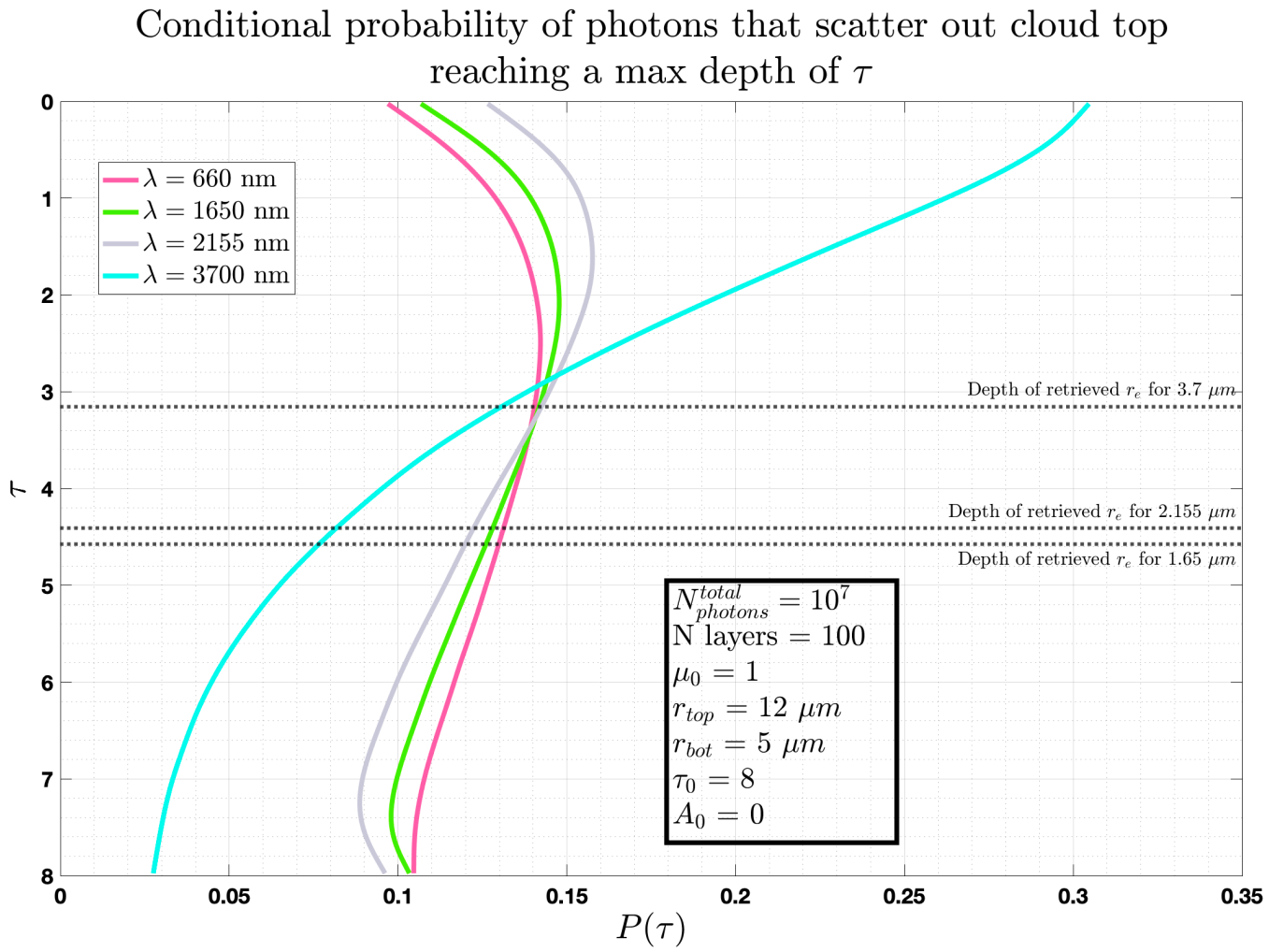
Achievements

- 0.2% uncertainty in TSIS-1 SIM is a factor of 10 improvement over most of the spectrum.
- A new reference spectrum is already improving retrievals of geophysical variables variables from space- and ground-based assets.
- Agreement <0.5% between TSTS-1 SIM and the Compact SIM (CSIM), an InVEST 6U CubeSat.

[*Nakajima and King*, 1990]



Compute Average Penetration Depth using Weighting Functions



Changes in reflectance due to a change in r_{bot}

$$\frac{\partial F_\lambda(\vec{x})}{\partial r_{bot}}$$