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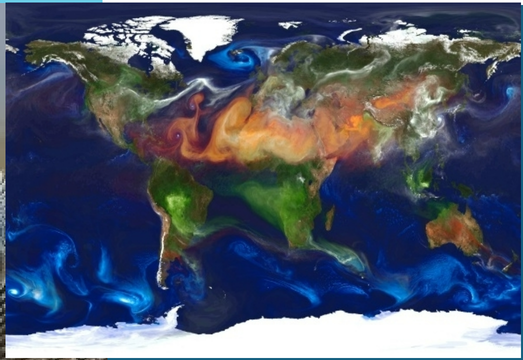
Sandia National Laboratories

Spectral Atmospheric Attenuating Effects for Heliostats and Receivers

SolarPACES 2022 - 25300



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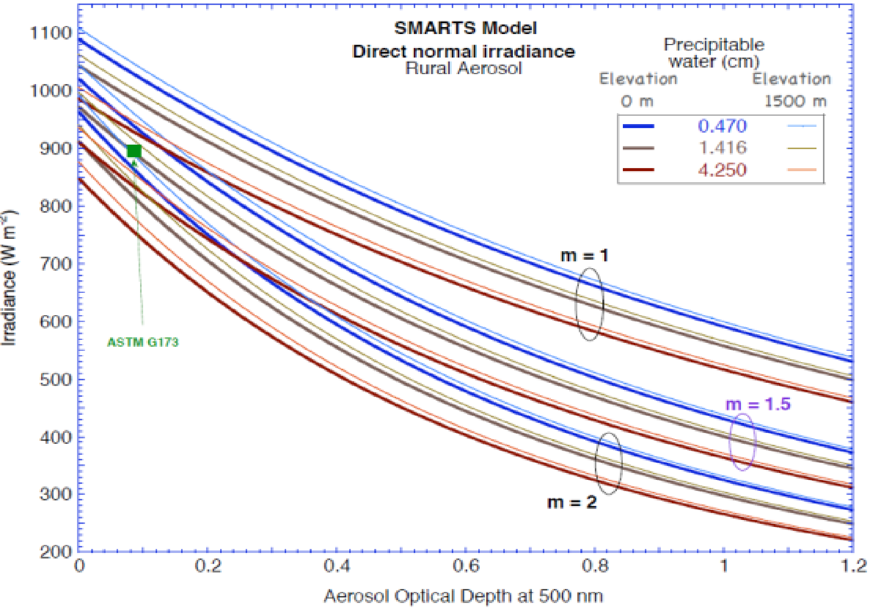
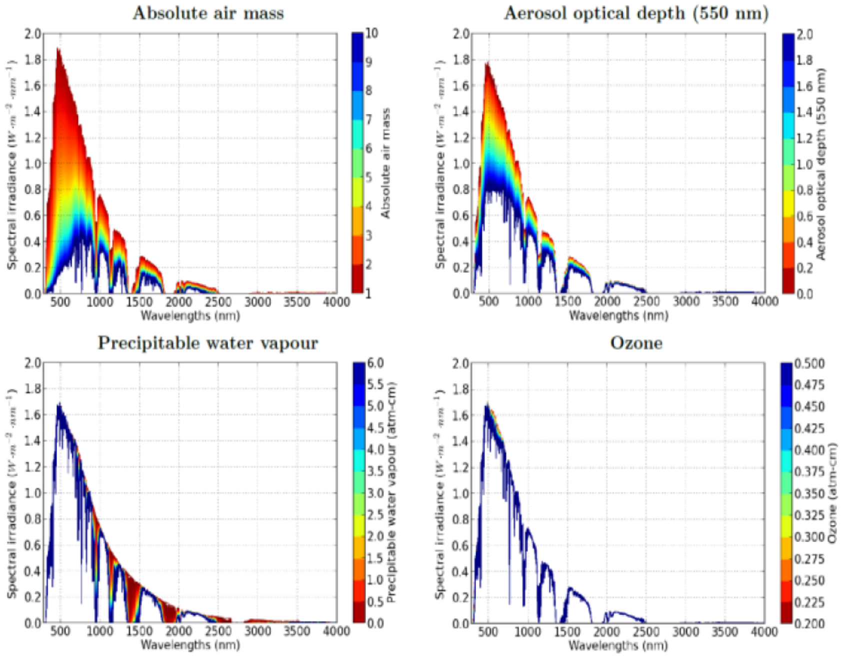
Irradiance Impacts of Water & Aerosols

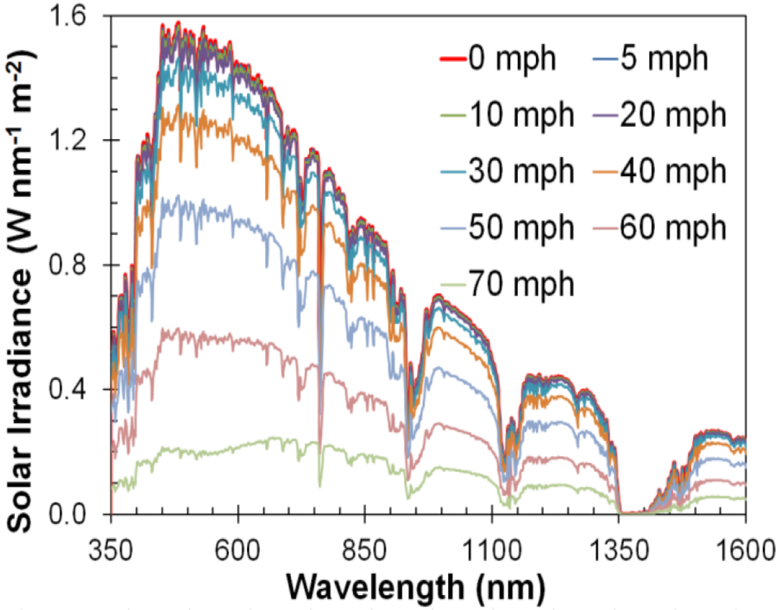
- CSP design decisions pertaining to appropriate receiver design and heliostat field layout to optimize power generation for a respective site can have a significant impact on ROI and bankability.
- Ultimate energy absorption into receiver HTF with subsequent electric generation is influenced by spectral distribution of sunlight & daily/seasonal variability, impacting radiation losses at receiver & heliostat mirrors.
- Photons undergo scattering from air molecules (Rayleigh scattering) and suspended particulate matter (aerosol scattering), absorption by molecules or aerosols, and reflections from the ground



(Gueymard, 2009)



(Litjens, 2013)

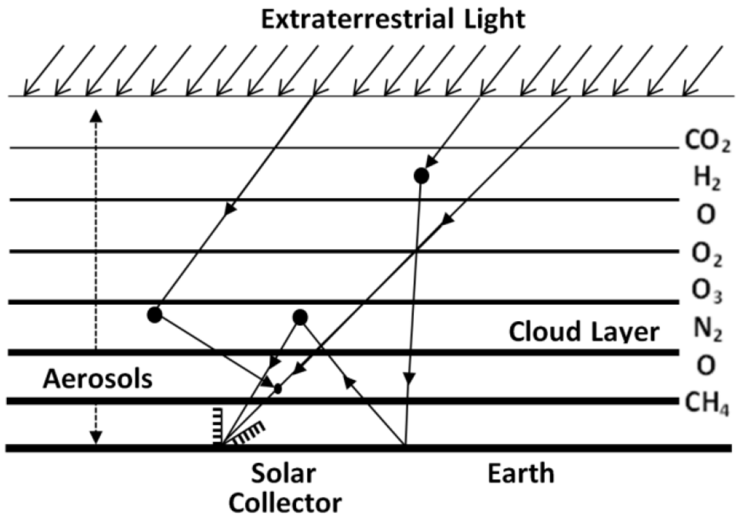


(Armijo et. al., 2014)

Spectral Attenuation Project Scope

- Unlike PV systems, which are more spectrally selective & beams only between sun and module normal, attenuation in CSP tower facilitates can be found between sun, heliostats & tower receiver.
- For heliostat fields larger than a few kilometers in radius, atmospheric attenuation losses can be significant.
- CSP plant aerosol concentrations with smoke (forest fires or smog), dust & humidity, can have notable impact on direct normal irradiance (DNI) resource potential.
- Scale of influence for changing spectrum on CSP receiver performance may vary significantly depending on receiver & heliostat mirror composition/coatings being employed.
- Few models to date have considered the complex interplay between aerosol atmospheric attenuation with respective heliostat and receiver spectral losses

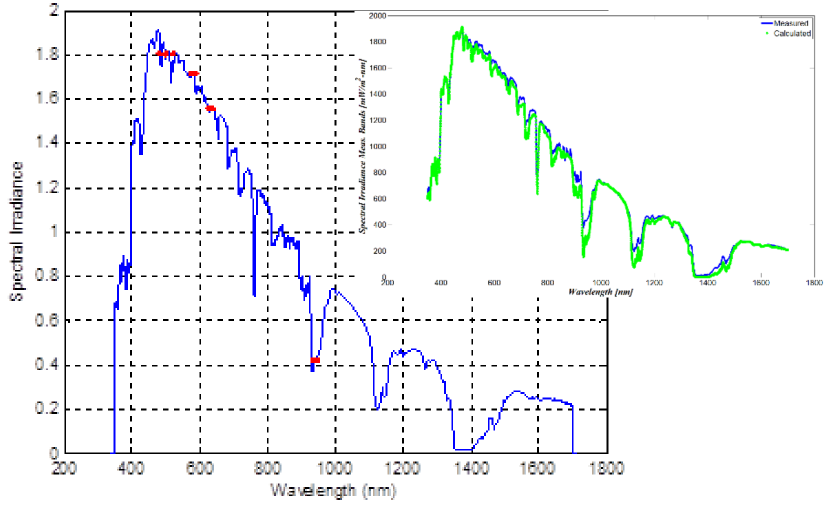
https://www.renewableenergyworld.com/
- Crescent Dunes



(Bird et. al., 1993)

Experimental Setup

- Sandia National Solar Thermal Test Facility (NSTTF) with mounted spectrometer and tracker assembly.
  - 35-42 heliostats used (of 218 total)
  - ~200 ft tall tower with 6 MW_{th} potential
- Low-cost custom spectrometer used to recreate the spectrum within less than 1% RMS error.
  - Calibrated photodiode measurements (red) of 500nm 580nm 630nm and 940nm bands, with EKO spectrometer data (blue)
- Several experiments collecting data within +/- 1 hr. from solar noon between March and June 2022.
- Reflectance measured using handheld Solar 410 SOC reflectometer (Surface Optics, Model# 0410-0004) with solar-weighted reflectivity of a surface over 6 spectral bands: 0.30-2.5 µm.
- Total solar absorptance obtained by subtracting total solar hemispherical reflectance from one.



(Armijo et al., 2015)

Reflectivity Meas. & Transmission

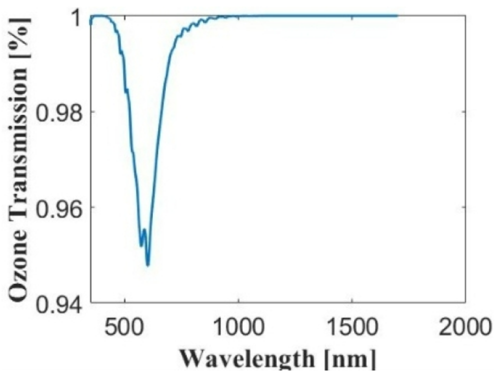
- Receiver tubes from two CSP plants evaluated (Solar One & Solar Two) with appreciable degradation assessed with reflectivity meas.
- Meas. Clean heliostat mirrors had ~92-97% reflectance though had small losses due to soiling.
- High attenuation from water between 350-1,700 μm.
- Transmission for CH_4, CO_2, O_2 & N_2 found to have less attenuation, though with impacts at more discrete bandwidths.
-

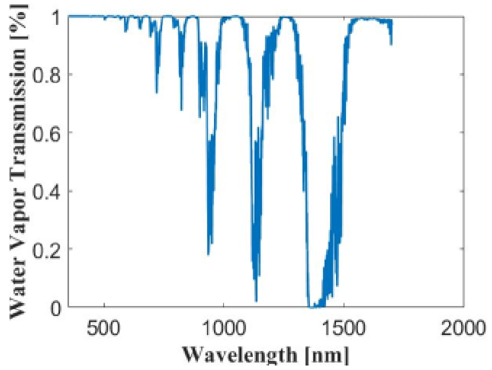
Absorptivity for Investigated Receiver Tubes

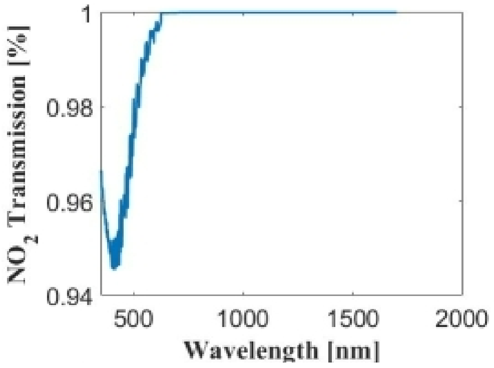
Sample	335-380nm	400-540nm	480-600nm	590-720nm	700-1100nm	1000-1700nm
Receiving Tubes 1	0.961	0.960	0.961	0.960	0.958	0.952
Receiving Tubes 2	0.897	0.897	0.895	0.891	0.855	0.877

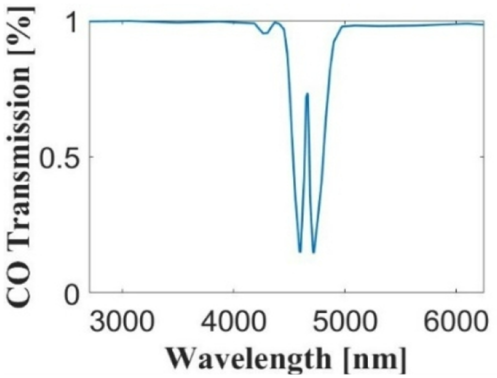
Reflectivity for a clean and soiled heliostat after snowing

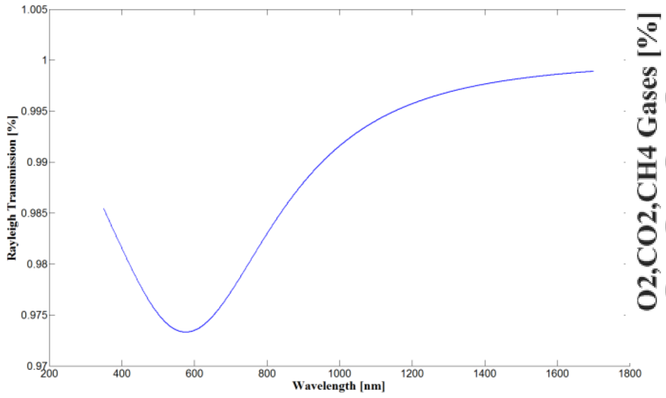
Sample	335-380nm	400-540nm	480-600nm	590-720nm	700-1100nm	1000-1700nm
Clean Heliostat	0.809	0.940	0.953	0.955	0.938	0.961
Soiled Heliostat	0.788	0.929	0.942	0.946	0.932	0.956

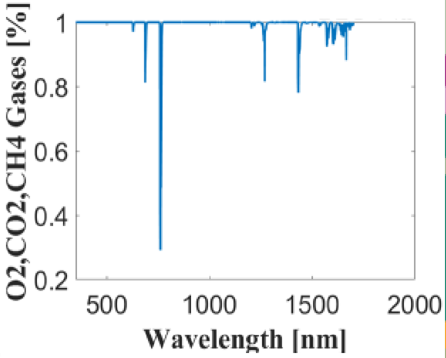






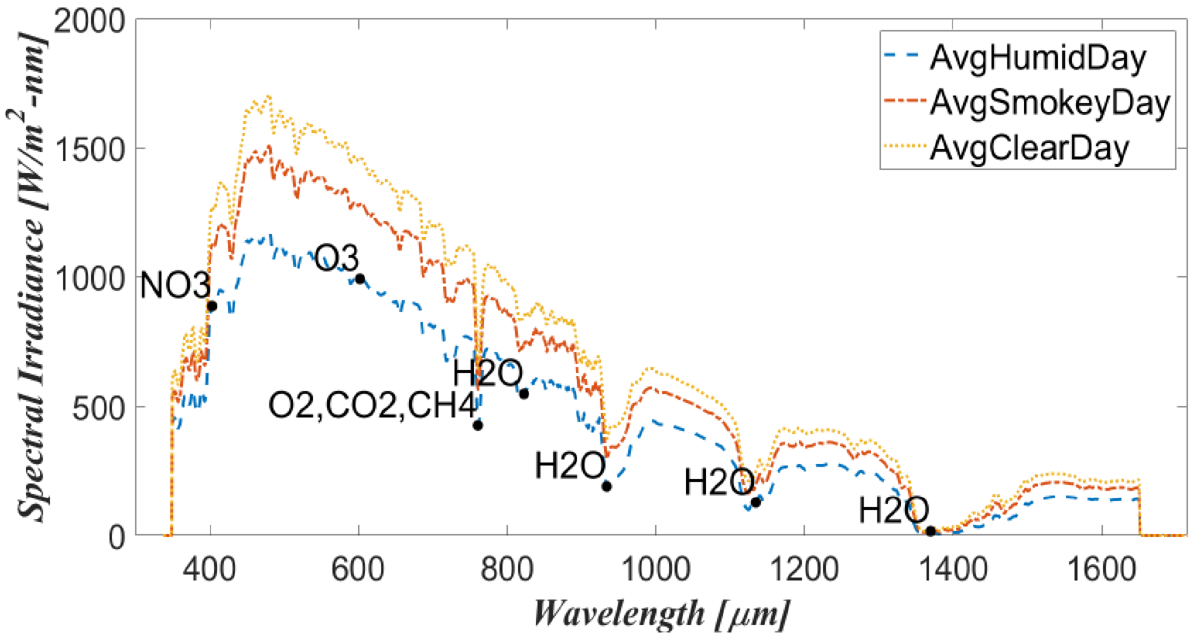






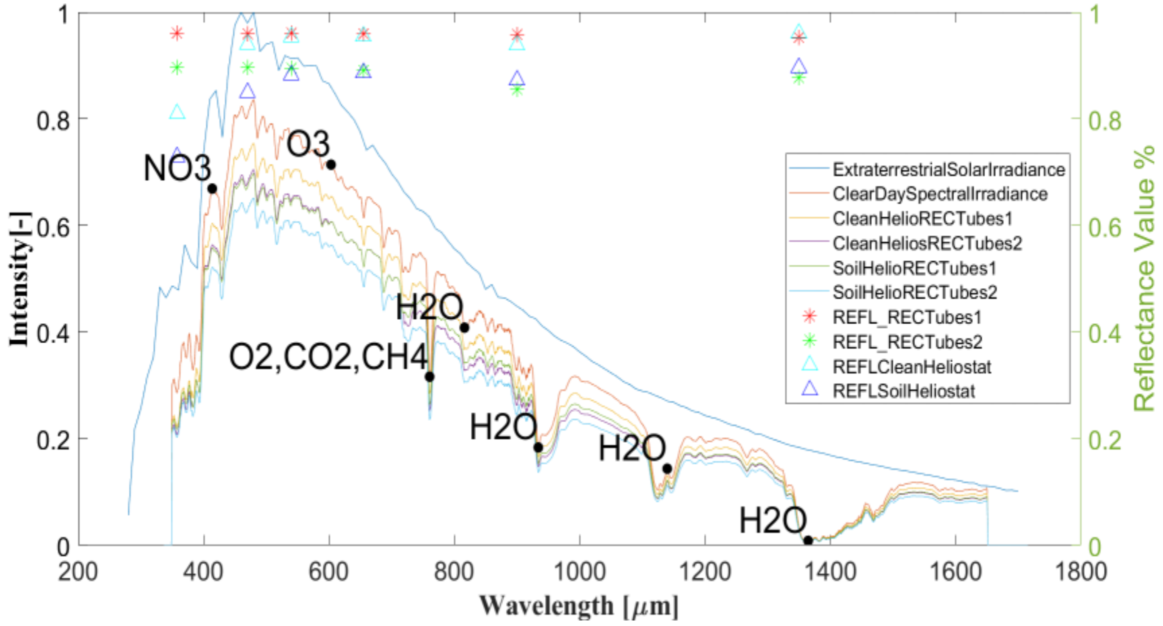
DNI Aerosols Attenuation Impacts

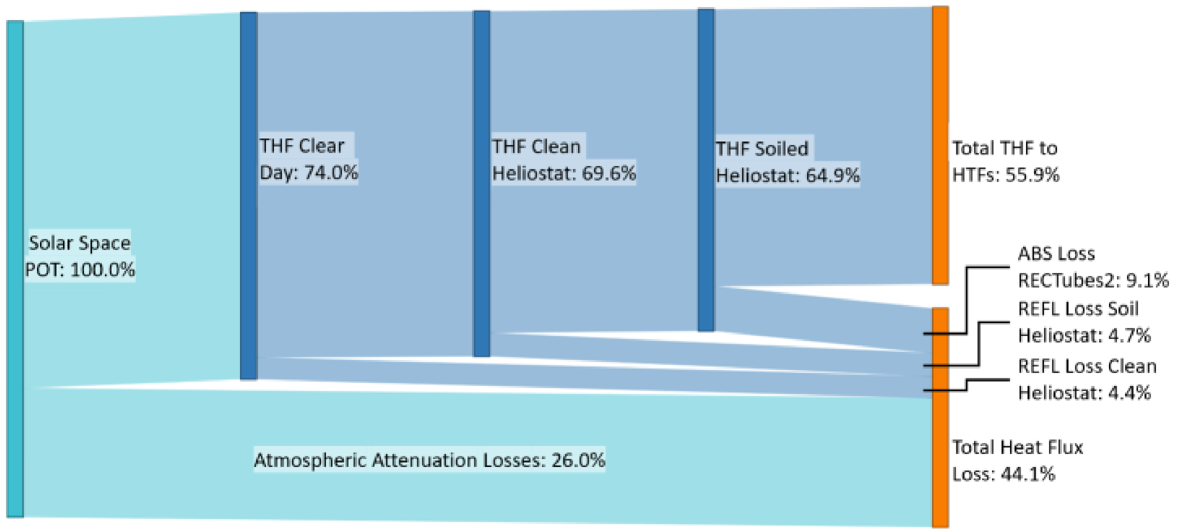
- Spectral data was collected from the top of the solar tower using the customer spectrometer, which tracked the sun +/- 1 hr. from solar noon on the respective experimental evaluation days.
- Data convolved with U.S. EPA air-quality index data to identify smokiest and humid days while having DNI >900 W/m^2
- Results suggest that humidity impacted the overall spectrum more so than for smokey days by an average wavelength difference of 35.2% and 13.7% respectively.
- Particulate matter (PM) 2.5 and PM 10 data collected for days based on relative level of haze while not having any clouds present.
  - For a 107 PM2.5 and 298 PM10 the average spectral irradiance deviation from a clear sky day was found to be 9.4%.



Clear-Sky Conditions Analysis

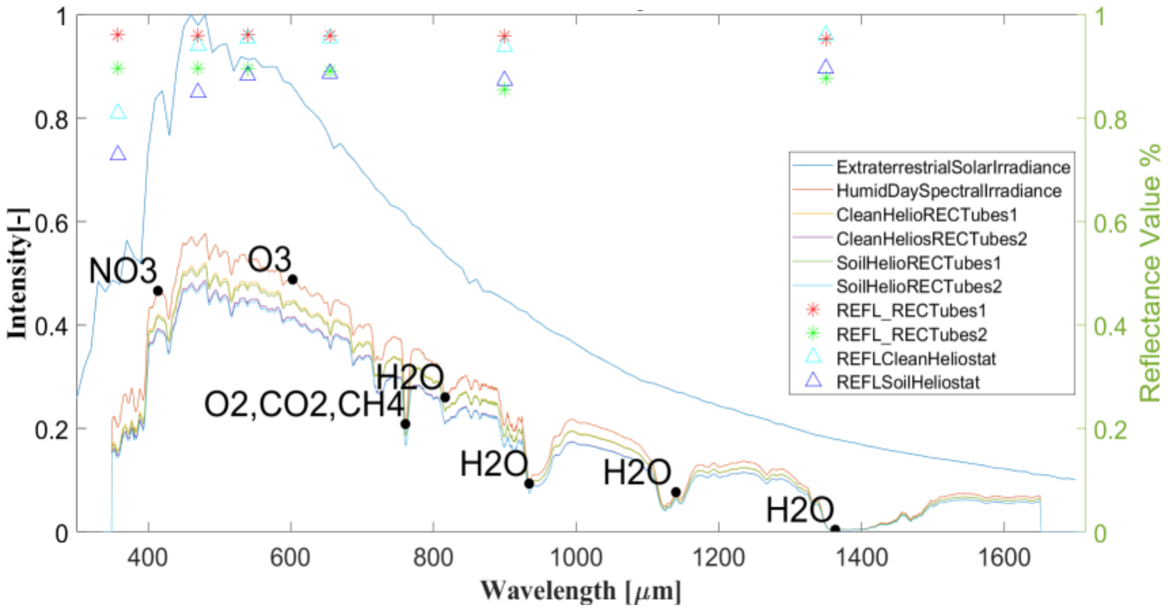
- Heliostat & receiver tube reflectance losses factored into averaged data for varying levels of operational degradation per the reflectance measurements, & as prescribed in the convolved losses.
- Results indicate soiled heliostat & set 2 receiver tubes (most degradation), had greater reflectance losses from clean heliostat and more pristine first receiver tube set.
- Spectrally reflectance losses for clean & soiled heliostats more pronounced for wavelengths < 485 nm.
- Sankey analysis results suggest 26% heat flux loss due to aerosol attenuation, while reflectance losses due to soiled heliostat of 4.7% of total.
- Total reflectivity losses from receiver tubes found to be 9.1% for an overall 55.88% total heat flux (THF).

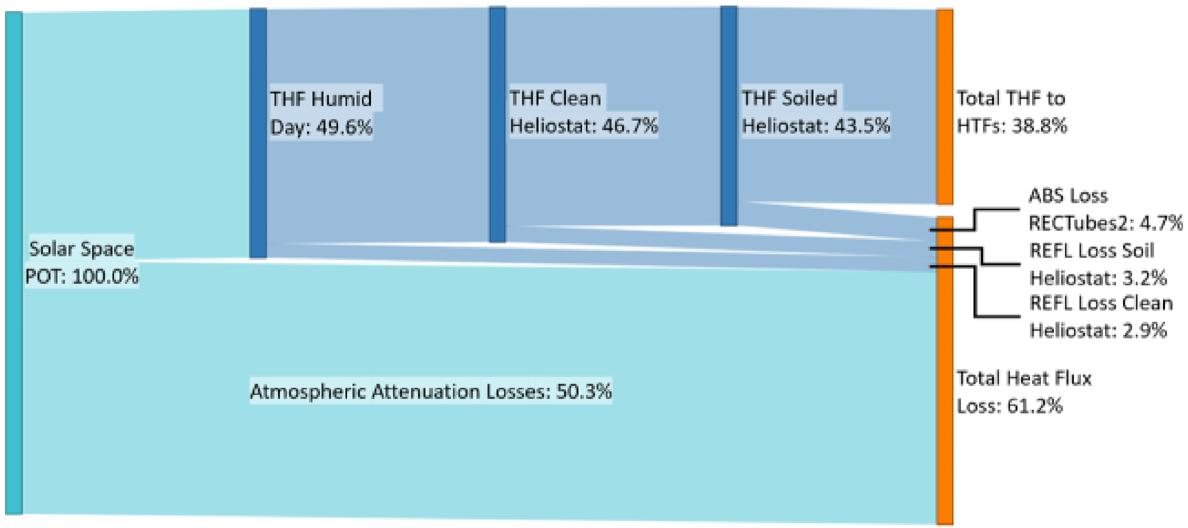




Humidity Conditions Analysis

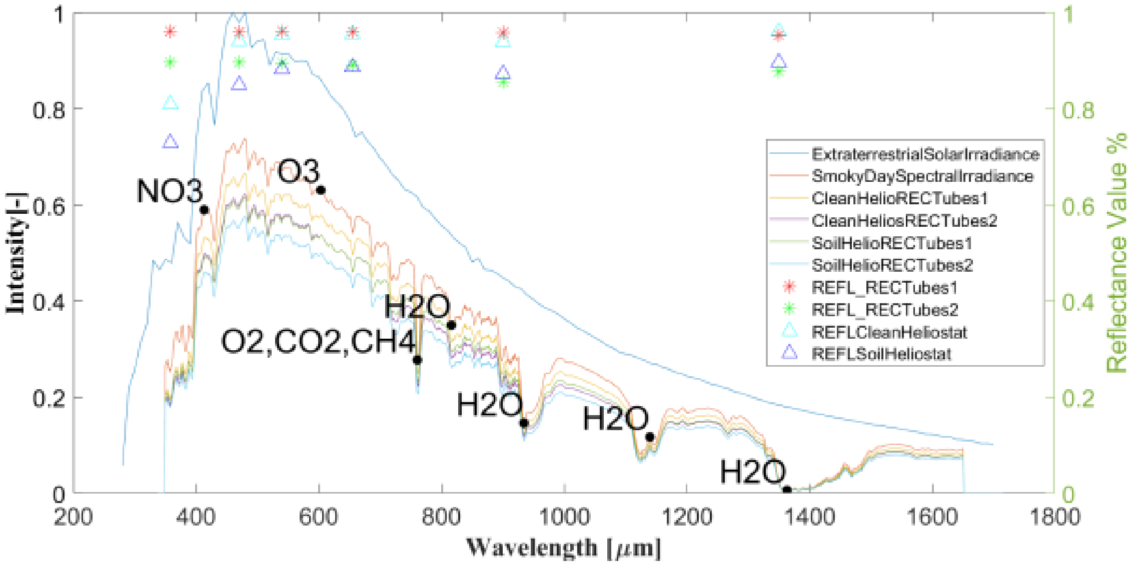
- Attenuation from extraterrestrial irradiance to averaged spectral irradiance was ~49%.
- In comparison to a dry clear day, final overall flux was reduced by approximately 24.4%.
- Sanky results suggest a total atmospheric attenuation of 50.3%.
- When reflectivity losses from heliostats and receiver tubes were factored in, THF into receiver found to be 38.8% with total heat flux loss of 61.2%.

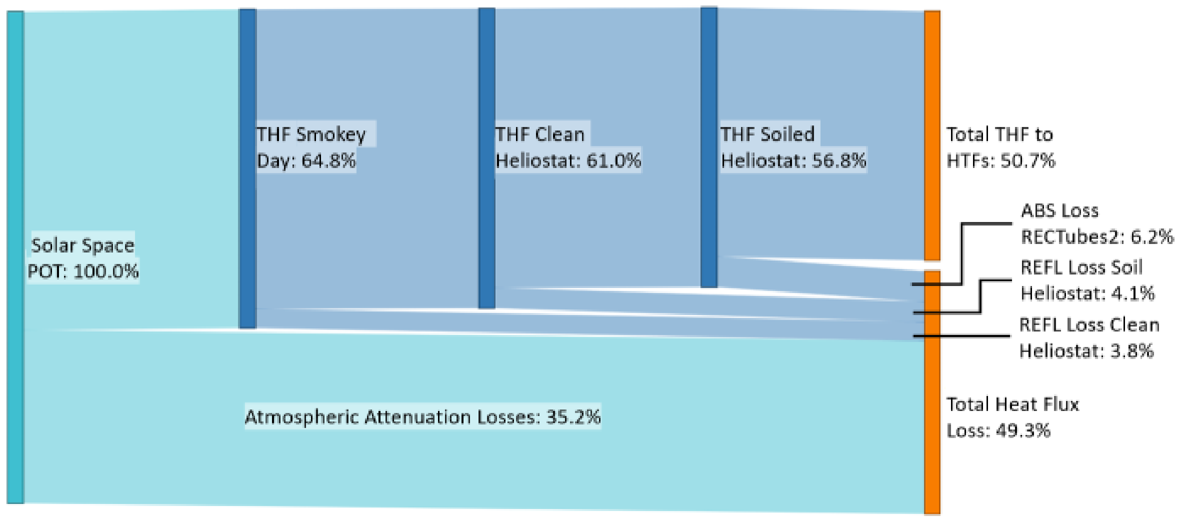




Smokey Conditions Analysis

- Smokey conditions found higher overall non-dimensionalized irradiance values compared to humid days.
  - Water vapor absorbing more within the three longer-wave IR bands.
- Flux lost at more discrete, lower-wavelength bands due to CO_2, O_2, NO_2, and CO.
  - CO mostly absorbed at much higher wavelengths in the far infrared spectrum.
- Attenuation from extraterrestrial spectral irradiance for averaged smokey days was 35%.
- Results indicate that days with high PM 2.5 and PM10 values, spectral irradiance absorbed in receiver was less than for days with low levels of smoke, by as much as 9.4%.
- Sanky results suggest THF into receiver found to be 50.7%, & total atmospheric attenuation of 49.3%.





Conclusions & Future Work

- Spectral attenuation investigation was performed to assess the impacts of atmospheric components in the atmosphere as a function of air mass and reflected light from heliostats that are positioned in front of CSP receivers.

- Data collected during dry clear sky, humid and smokey weather conditions, and convolved with measured reflectivity values of clean and soiled heliostats as well as two CSP receivers.

- Results indicate that soiled heliostats and set 2 receiver tubes had more environmental wear, & greater reflectance losses from that of the clean heliostat and first set of receiver tubes respectively.

- Reflectance losses for clean and soiled heliostats more pronounced for wavelengths less than 485 nm.
  - Convolved spectral results suggest for a dry clear sky day a 26% heat flux loss only due to ambient aerosol attenuation, while reflectance losses due to soiled heliostat found with 4.7% total losses respectively.

- Higher humidity conditions reduced THF by ~24.4%.

- Smokey conditions lost solar flux at more discrete, lower-wavelength bands due to CO_2, O_2, NO_2, and CO, where conditions with high PM 2.5 and PM10 values, absorbed in receiver less than for days with low levels of smoke, by as high as 9.4%.

Acknowledgements

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Thank you.