Exploring the potential of off-the-shelf spectral shortwave instrumentation for ground-based networks

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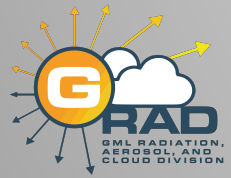
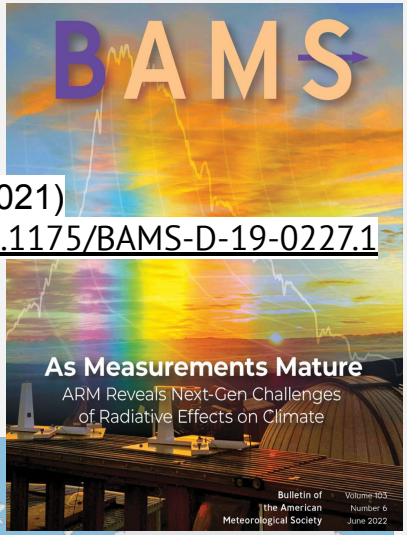
Kelly Balmes, Davide Rezzonico, John Augustine, Connor Flynn, Charles Wilson, John Wood, Steve Jones, Hagen Telg, Emiel Hall, Gary Hodges, Kathy Lantz, Logan Soldo, Scott Stierle

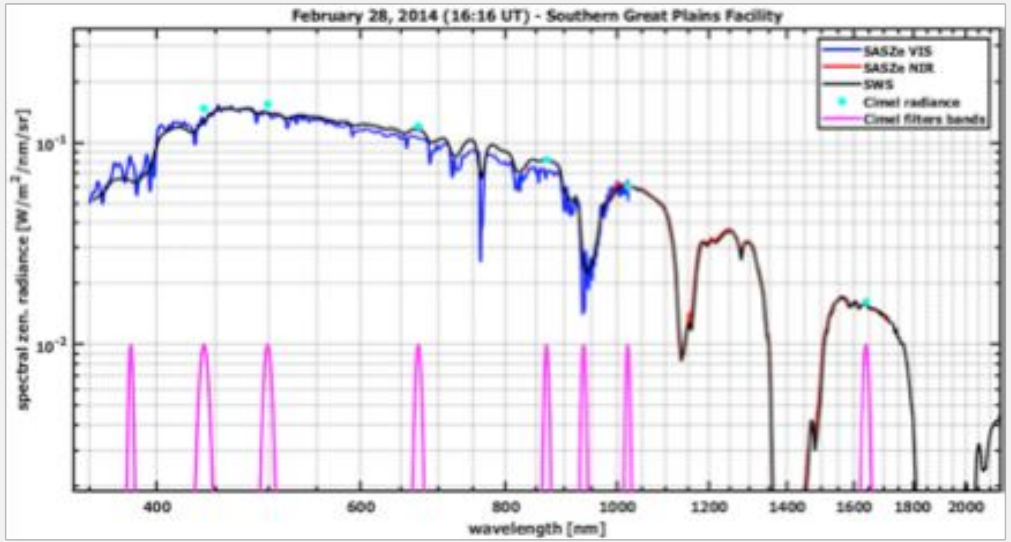


ARM Workshop in 2019 focused on use of SW spectral measurements to derive cloud and aerosol properties for understanding atmospheric processes

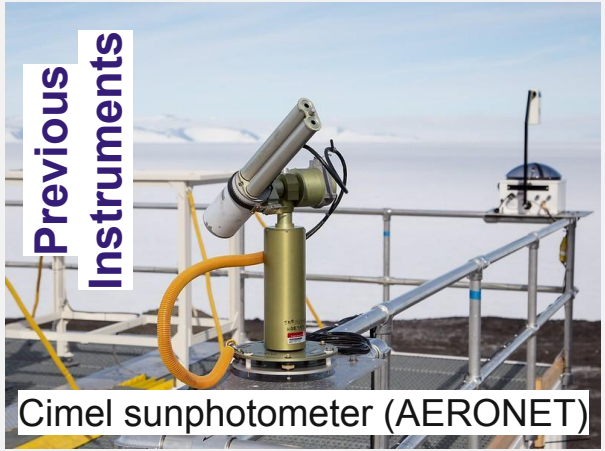
- Over 15 years of hyperspectral radiation measurements
- Hemispheric irradiance and zenith radiance measurements.
- Filter-based and full spectral



Riihimaki et al (2021)
https://doi.org/10.1175/BAMS-D-19-0227.1



Previous Instruments



Cimel sunphotometer (AERONET)

Multifilter Rotating Shadowband Radiometer (MFRSR)

Shortwave Array Spectroradiometer (SASHe)

New Instruments

Peak Design Ltd. HSR1

EKO MS 711

AERODYNE TWST

GRAD
GML RADIATION, AEROSOL, AND CLOUD DIVISION

Scientific Motivation for SW Hyperspectral Measurements

1. Next generation of radiative closure experiments with new satellites

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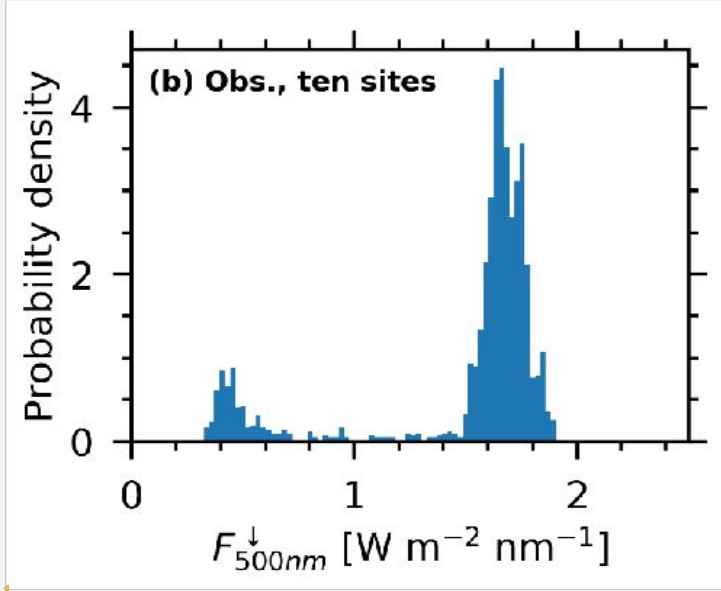
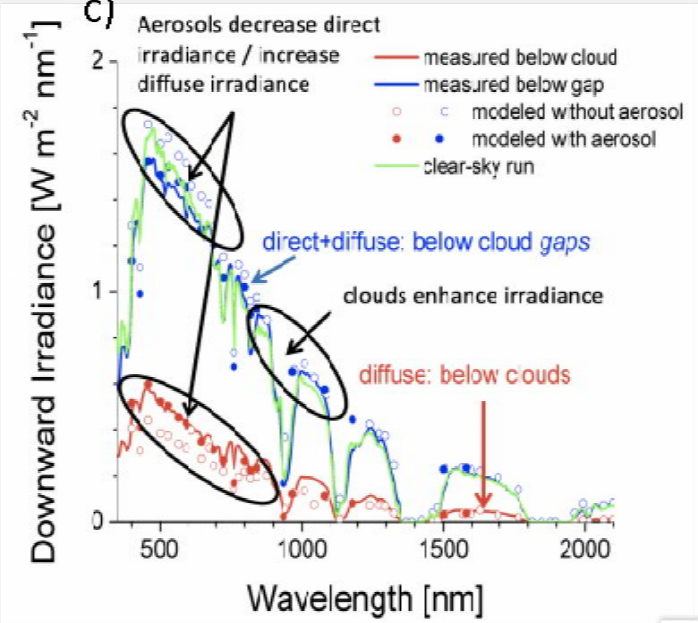
2. Quantifying cloud & aerosol radiative effects in complex scenes





Research by Sebastian Schmidt, Jake Gristey, & colleagues (figs in Riihimaki et al 2021)

Scientific Motivation for SW Hyperspectral Measurements

1. Next generation of radiative closure experiments with new satellites
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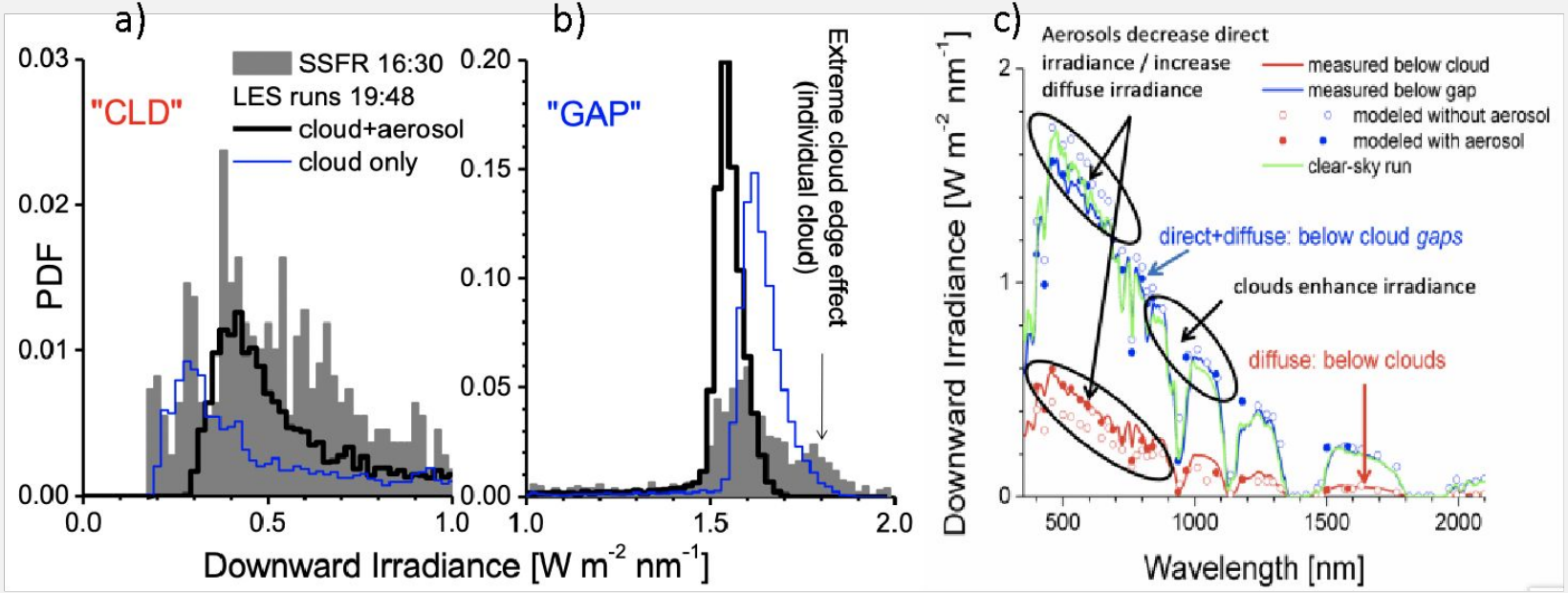

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Instrument Evaluations

Test hemispheric irradiance measurements against AOD measurements (MFRSR, CIMEL)


Peak Design Ltd. HSR1


EKO MS 711

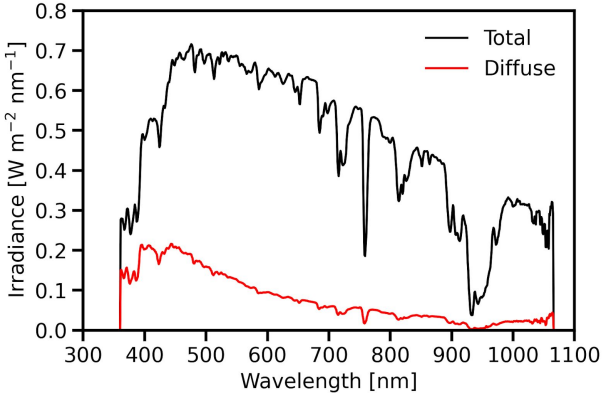
Zenith radiance tested against cloud retrievals from multiple ground/GOES products

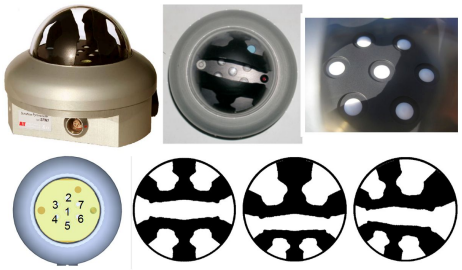
AERODYNE TWST

HSR1 comparison

Balmes et al. (2024), *AMT,* https://doi.org/10.5194/amt-17-3783-2024

- HSR1 prototype developed by John Wood measures total and diffuse with a shadow pattern and seven sensors (following SPN1 design)
- 2 month intercomparison at SGP from mid-May to mid-July 2022
- Low diffuse bias which translates into acceptable AOD retrieval on average, but could be improved
- No moving parts made instrument very easy to use, flexible deployment

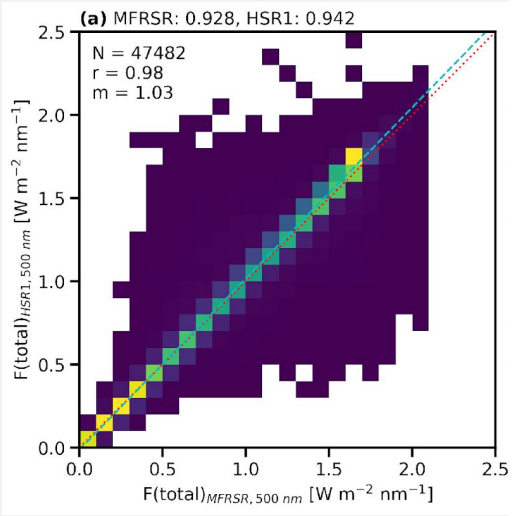


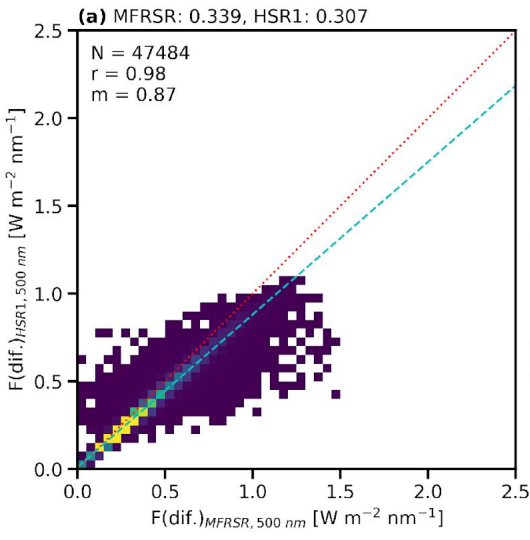


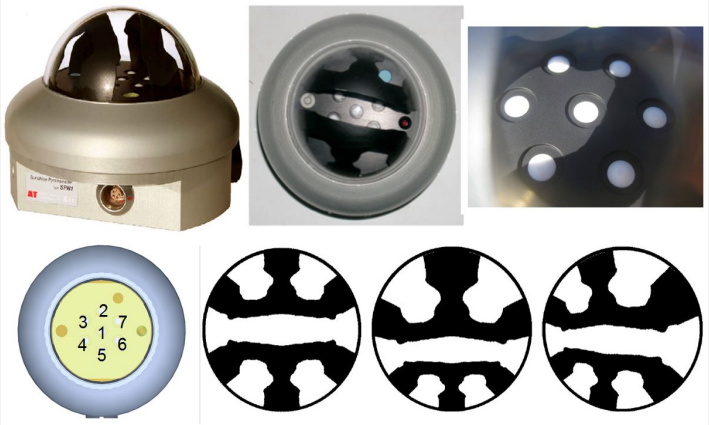
Wood et al. (2017, AMT)

HSR1 Comparison to MFRSR/CIMEL

- HSR1 total irradiance slightly larger than MFRSRs by 1-2%
- HSR1 diffuse irradiance is smaller than MFRSRs by 10%



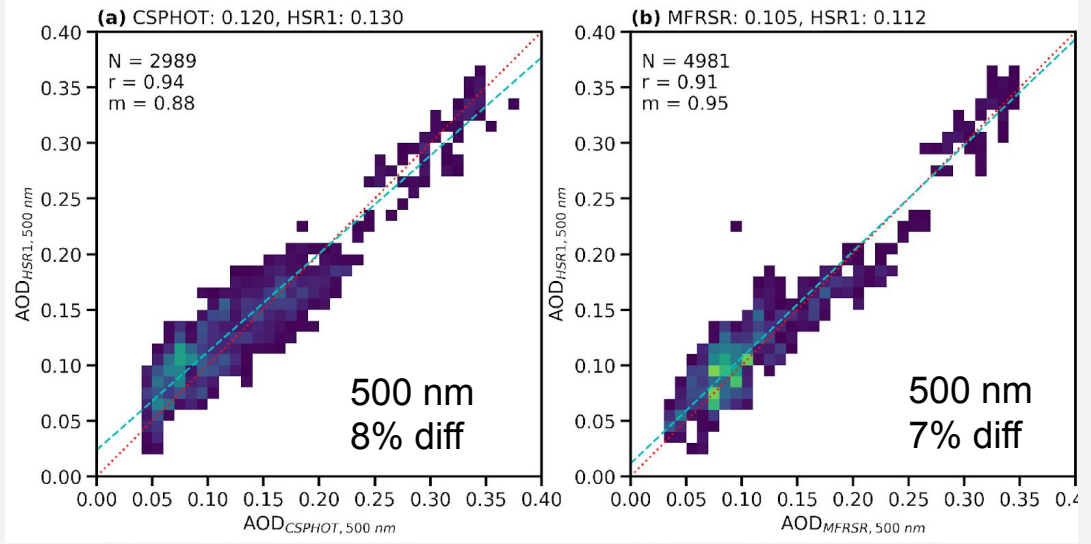




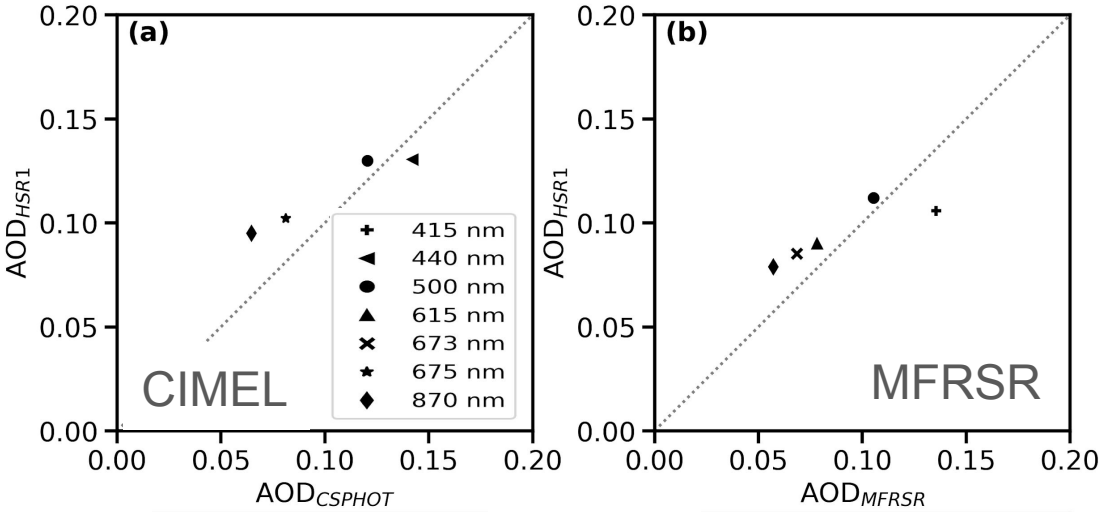
Low diffuse due to a combination of spectral response and the effective field of view of the shade mask (additional circumsolar radiation).

HSR1 Comparison to MFRSR/CIMEL

- HSR1 AOD is larger than the CSPHOT and MFRSRs AOD by 0.007-0.017 (6-18%)
  - HSR1 mean AOD is within 0.01 of CSPHOT mean AOD
- CSPHOT and MFRSR AODs agree well with each other, 0.01 (10%) or less



HSR1 AOD



EKO MS 711

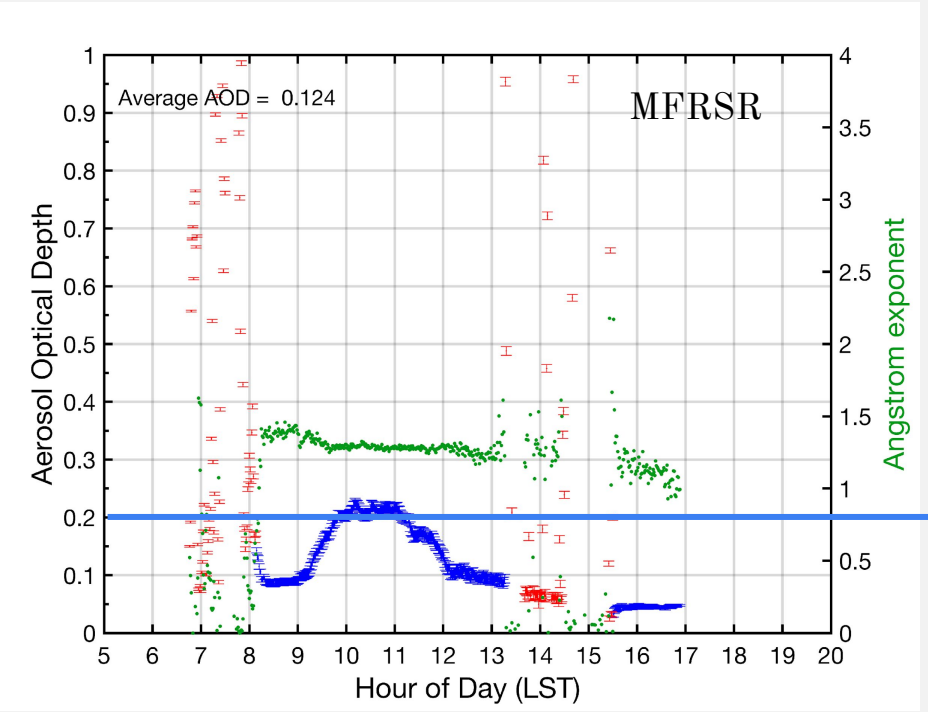
Key points:

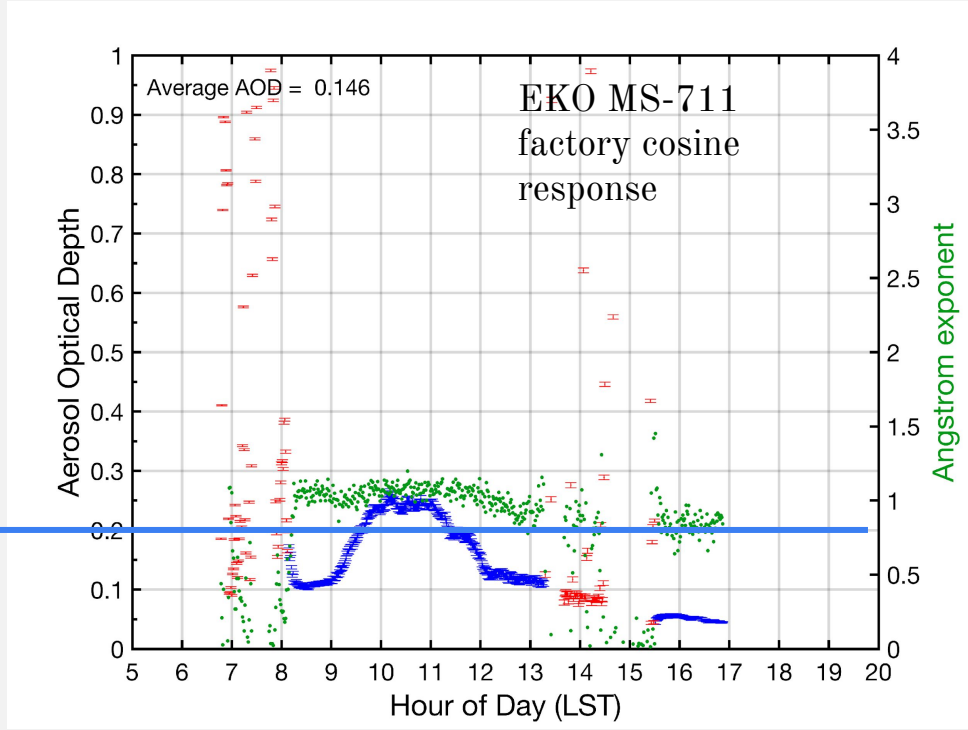
- Tested EKO MS 711 with shadowband for two months (Sep-Oct 2023) at Table Mt site in Colorado
- Did experiment in a period with very low AOD
- Were able to get an acceptable level of difference (PMOD levels of 0.01) for most wavelengths when we measured the cosine correction of the instrument in the laboratory. The manufacturer provided cosine correction was insufficient.
- Still significant challenges in using the shadowband consistently in the field

- 300-1100 nm wavelength range
- Spectral resolution < 7 nm

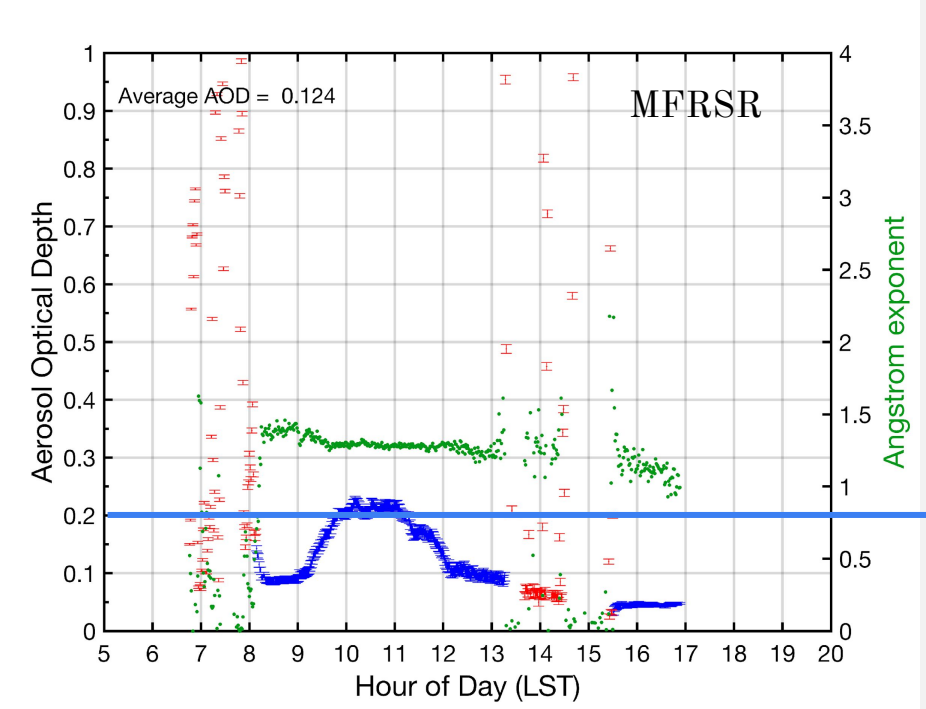
Results from Master's Thesis of Davide Rezzonico, ETH

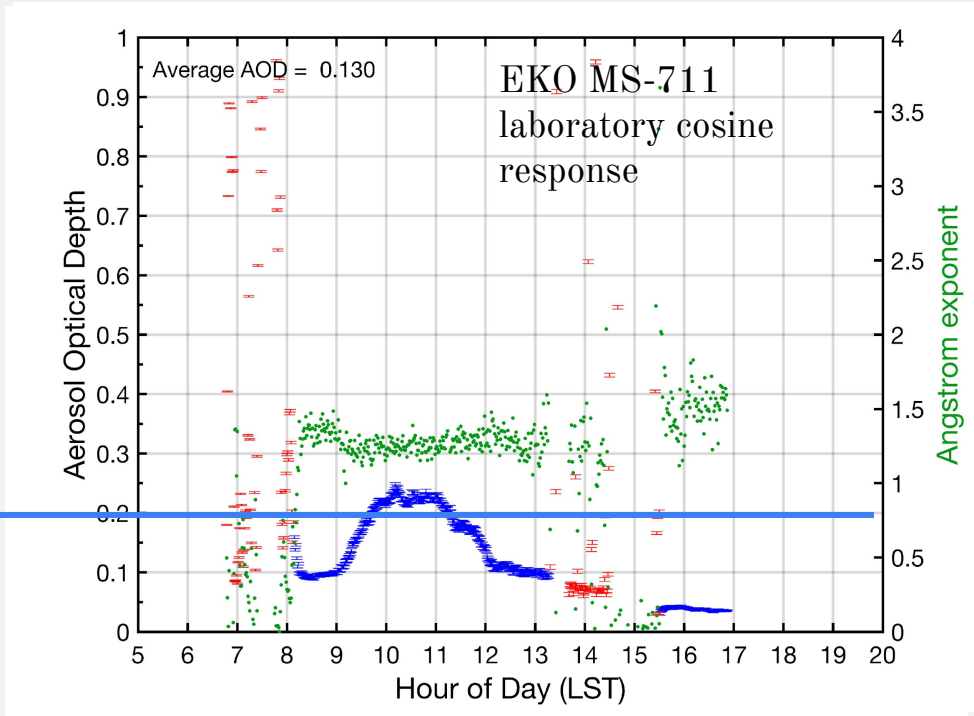
Using only the factory provided cosine response correction, we get a ~18% high bias in 500 nm AOD for this day.





Measuring the cosine response in our laboratory, improves AOD agreement to within 5% (<0.01) for this case

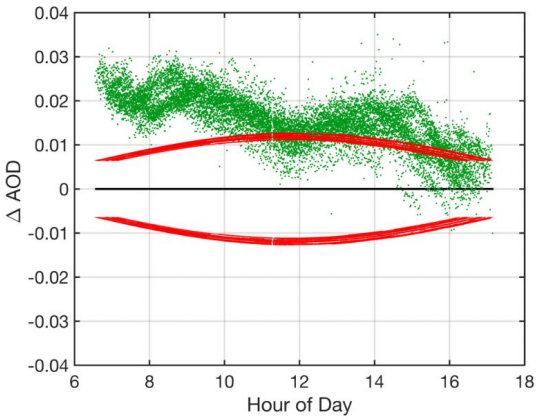




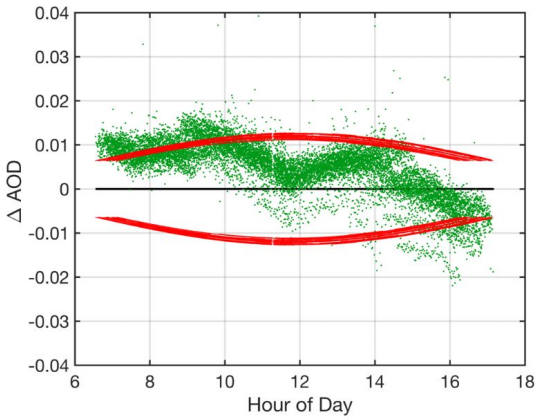
PMOD STANDARDS

- EKO is mostly accepted
- Not for 415 nm

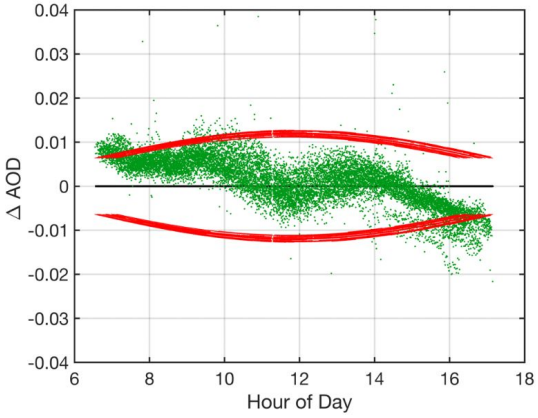
- 2 main effects:
  - Shape – likely an impact of additional cosine response errors
  - Tilt – could be due to MFRSR leveling



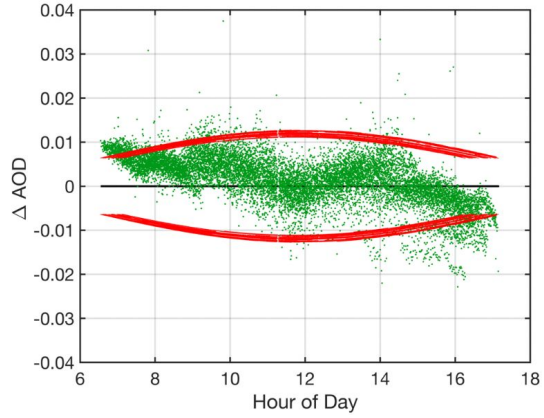
(a) 415 nm.



(b) 499 nm.



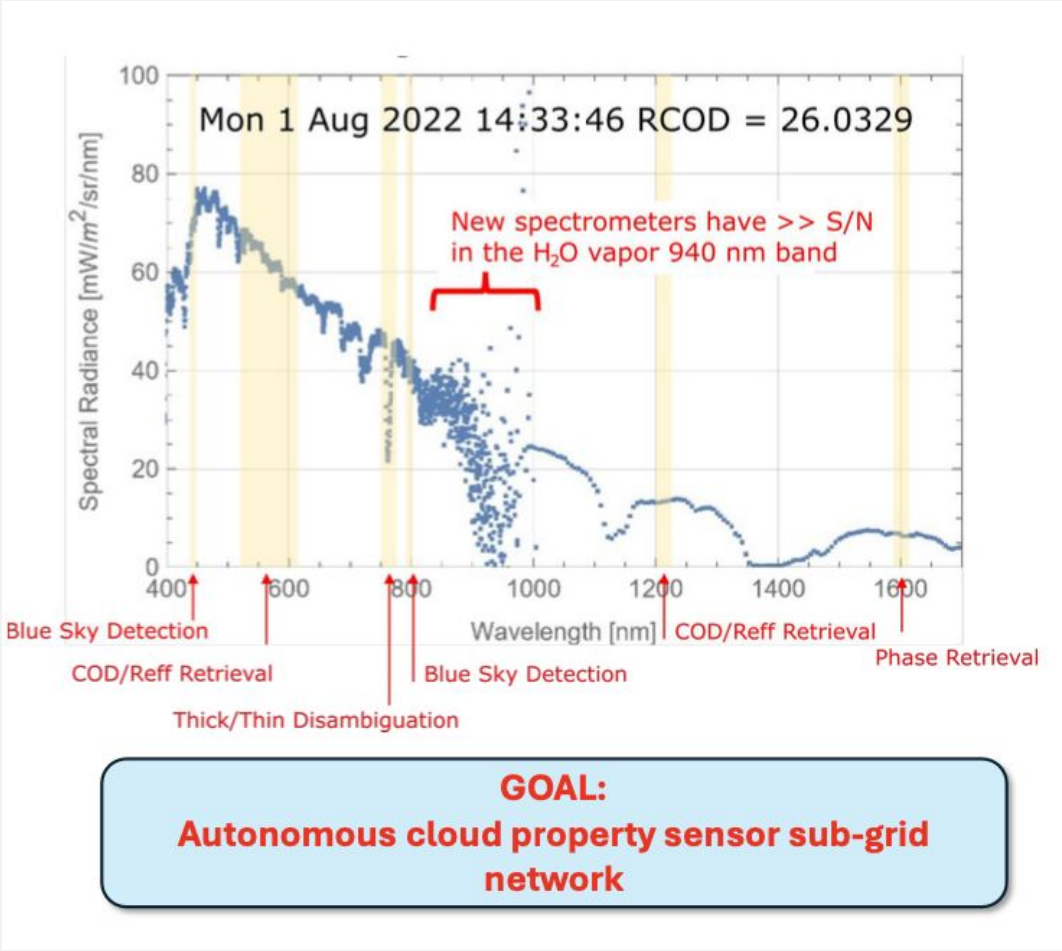
(c) 674 nm.



(d) 868 nm.

TWST

Zenith radiance, 400-1700 nm

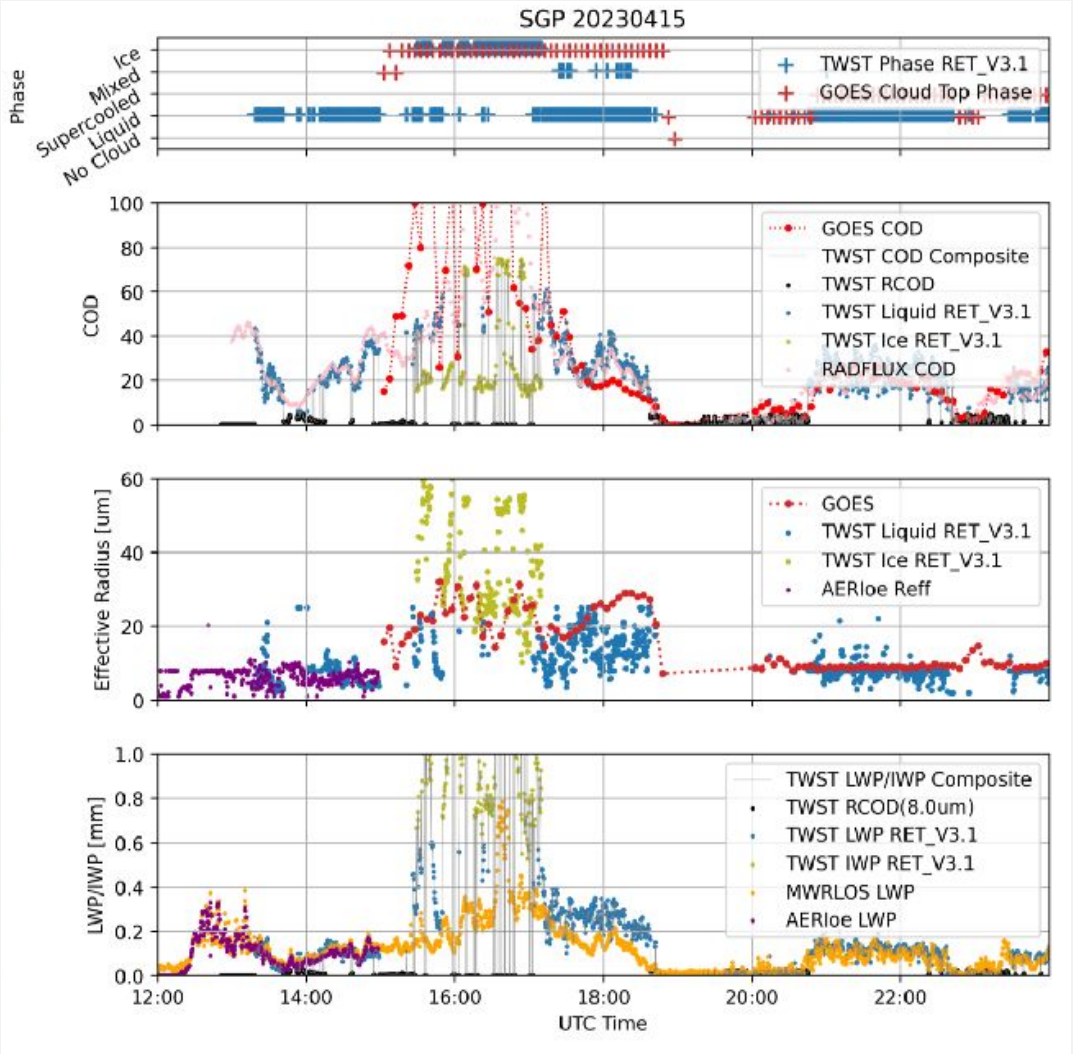


Study courtesy of Zachary Payne and Stephen Jones

Instrument includes operational cloud retrievals

Microphysical retrievals compared to various surface and satellite based measurements with good results

- Cloud phase
- Cloud Optical Depth
- Effective Radius
- LWP/IWP

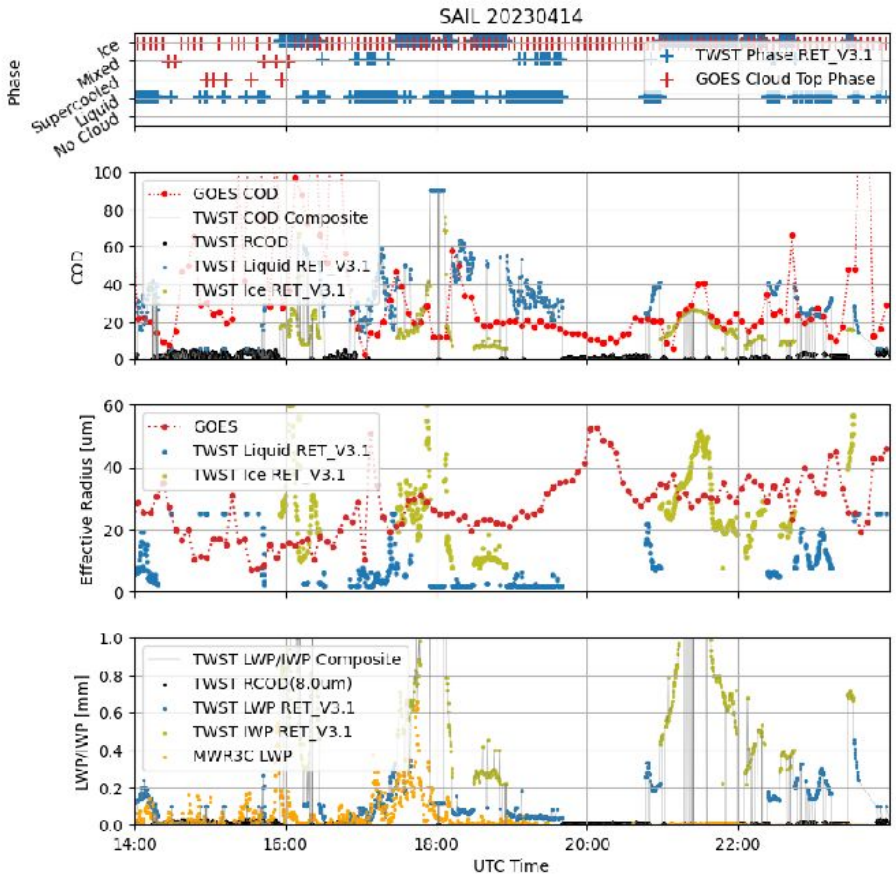


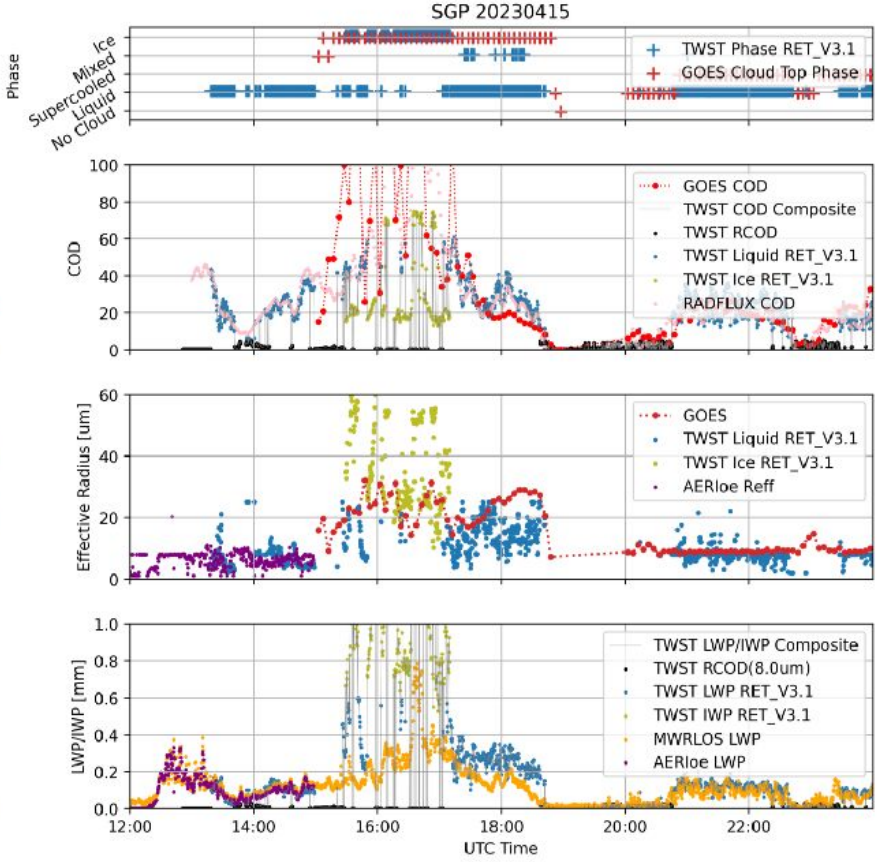
Summary: Ground-based hyperspectral shortwave measurements have potential for next-gen radiative effects

- Off-the-shelf hemispheric spectral instruments give relatively good total irradiance values, but more work is needed to get sufficient diffuse measurement quality to match filter-based instruments.
  - AOD comparisons are used because of known good quality comparison datasets, but not highest strength of hyperspectral instruments.
  - Hyperspectral measurements may be more suited to using features in the shape of the spectrum for retrieving atmospheric constituents/quantifying radiative effects.
  - Planning to set up a multi-instrument intercomparison in the future to better assess accuracies and inter-operabilities of different instrumentation.
- TWST – narrow field of view designed for cloud retrievals even in broken cloud conditions. New features under development like cloud retrieval properties may make this an easy-to-use instrument for cloud retrievals in many networks.

Extra Slides

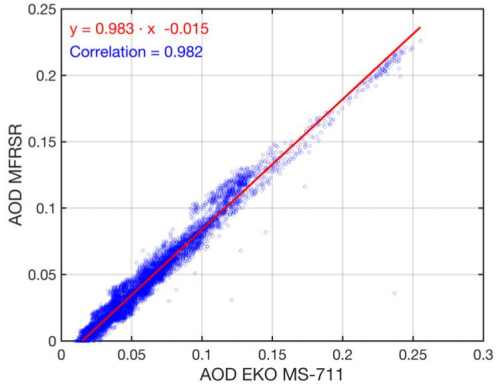
Cloud Properties Retrievals and Method





CORRELATION

- Good correlation
- BUT: offset, especially at 415 nm



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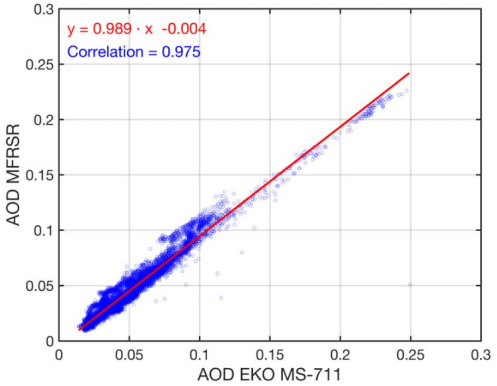

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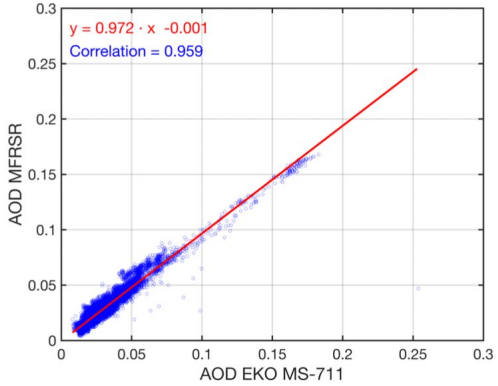

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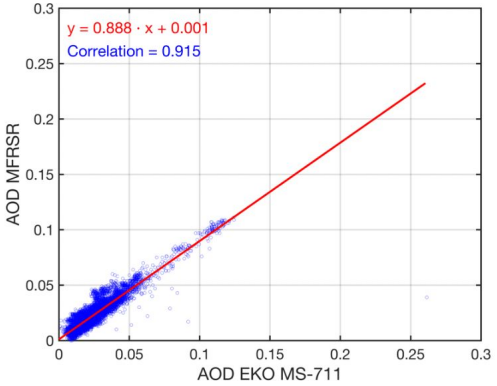

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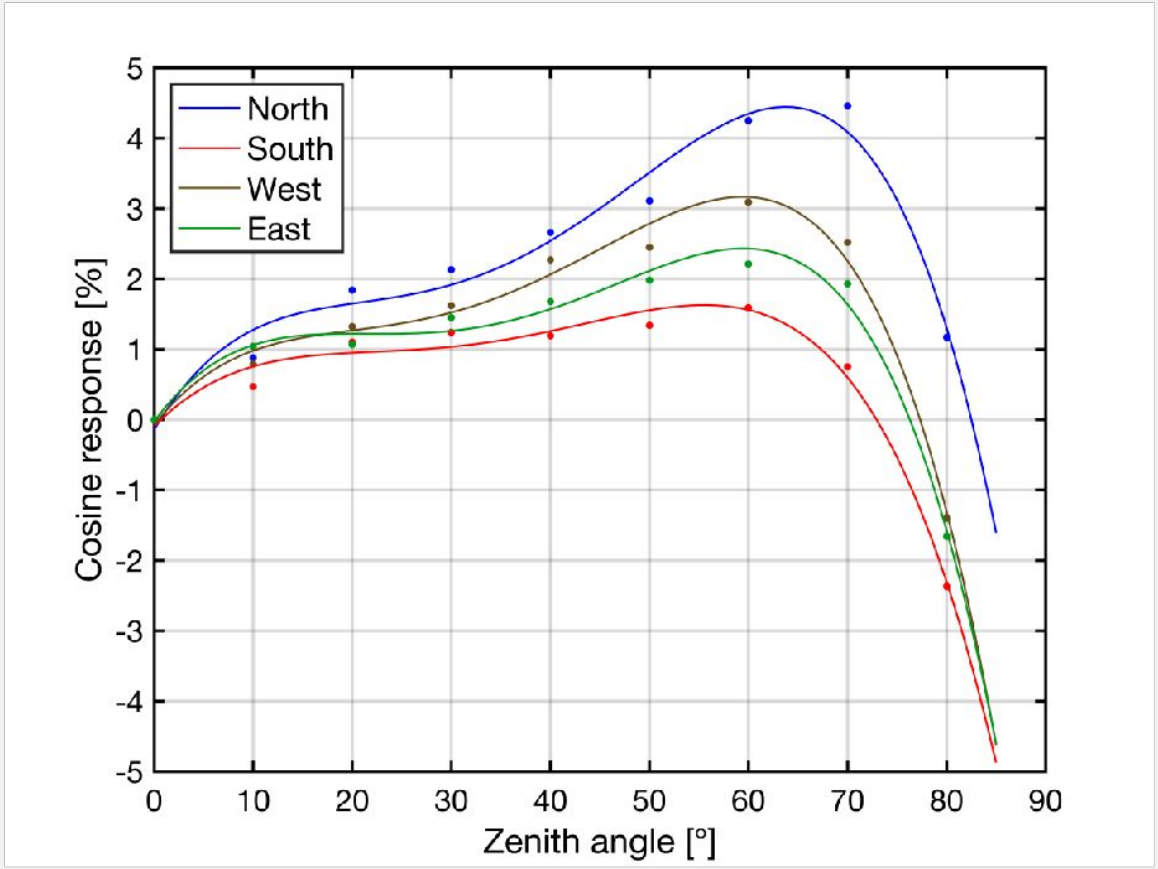
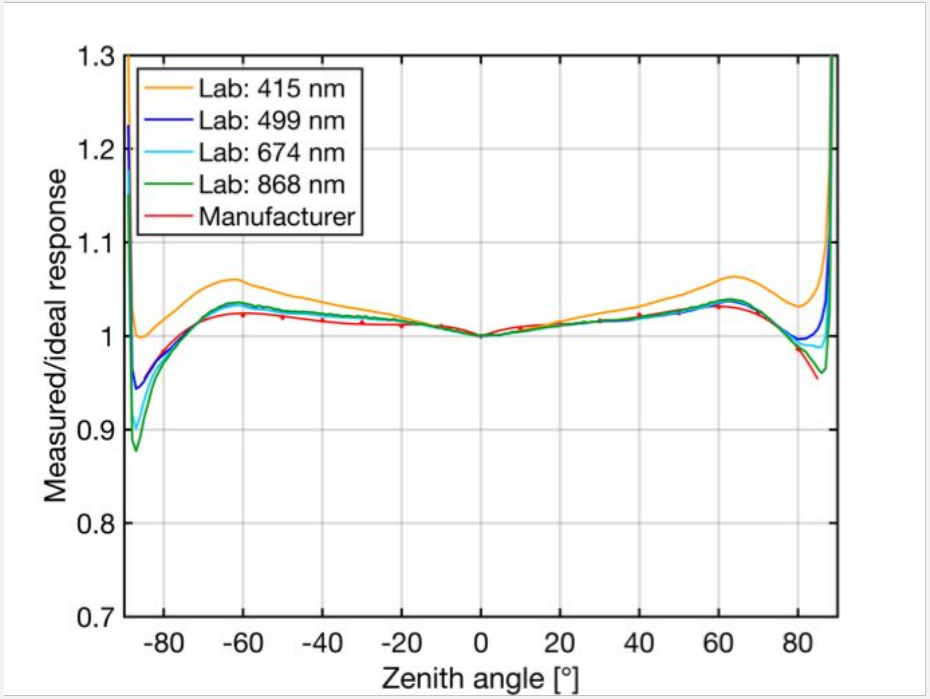
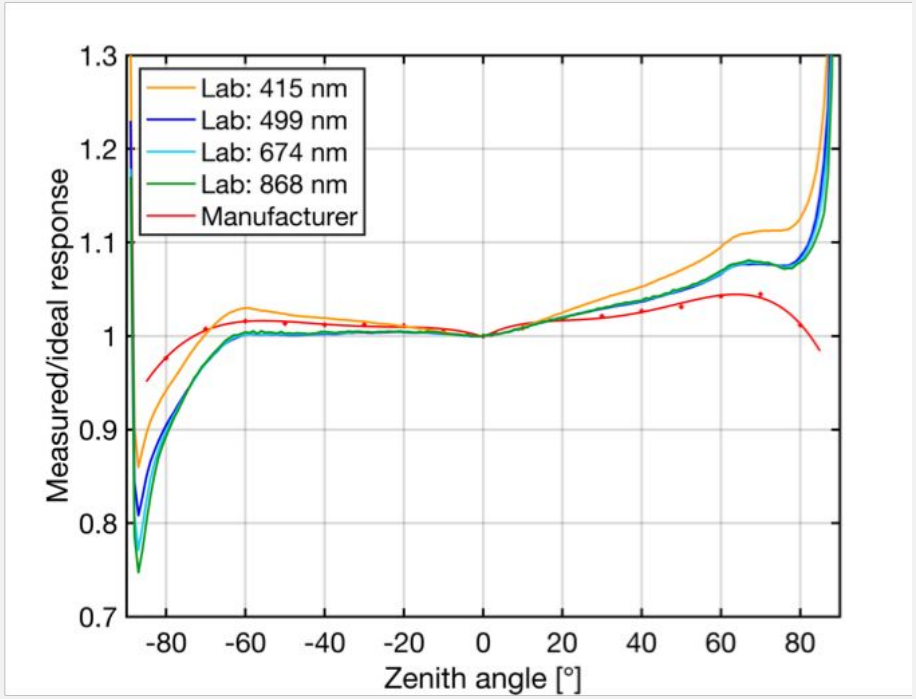


Figure 6: Cosine response of the EKO MS-711 for the 4 azimuth orientations as provided by the manufacturer. For each data set, a curve is fitted to the data.



(a) E-W axis

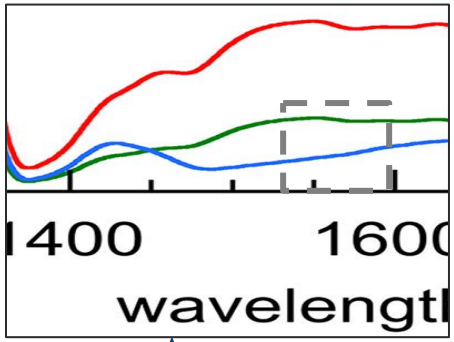


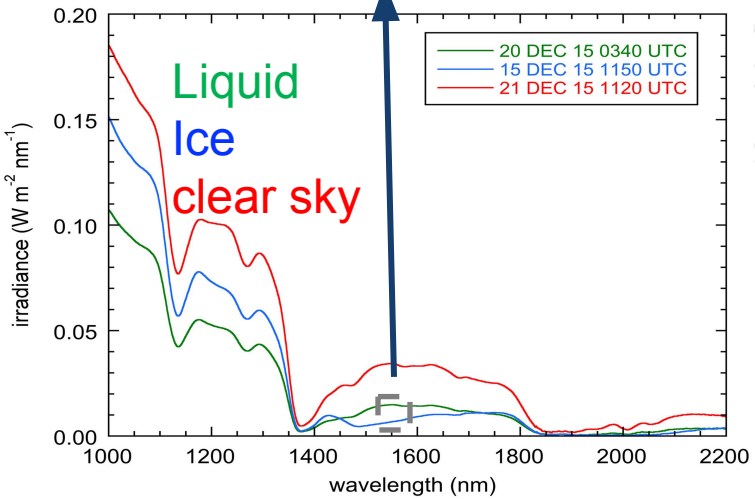
(b) N-S axis

Figure 13: Cosine correction, as provided by the manufacturer (red) and measured in the laboratory of NOAA (4 channels distinctly).

1. Spectral shape used to identify supercooled liquid clouds in Antarctica.

From Wilson al (2018)





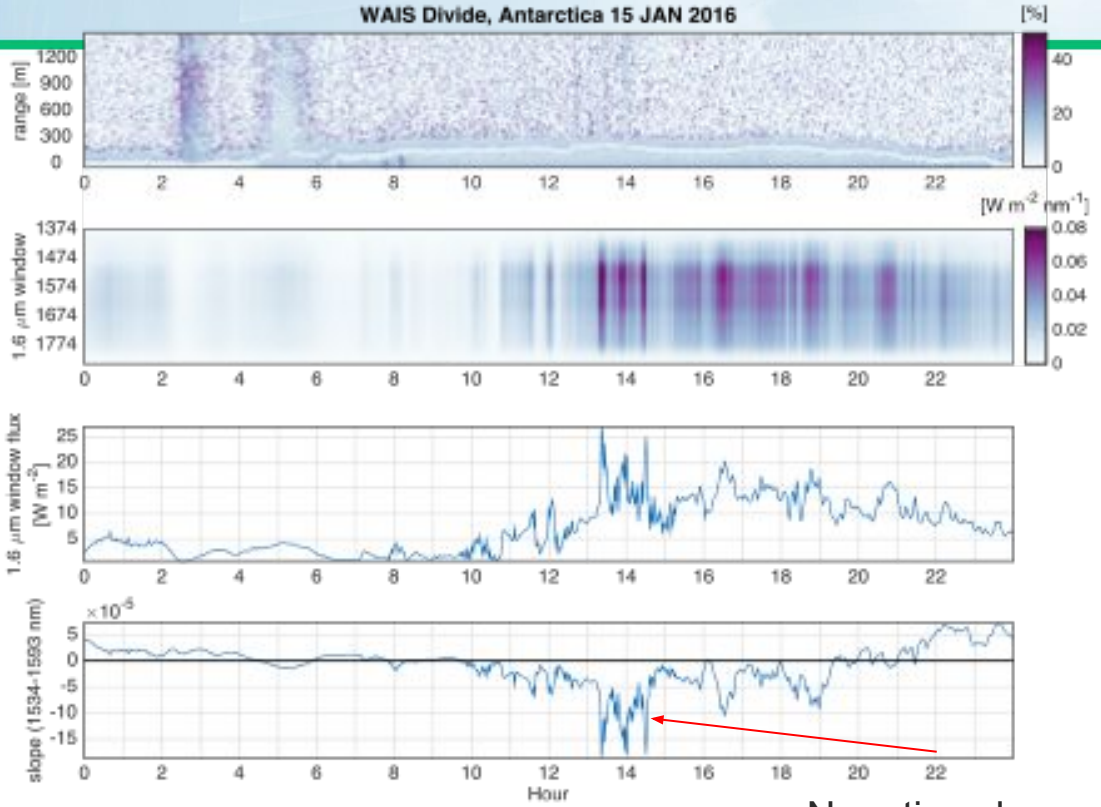


Figure by Dan Lubin (Riihimaki et al 2021)

Negative slope indicates liquid