Analysis of simultaneous aerosol and ocean glint retrieval using multiangle observations

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Moderate-resolution Imaging Spectroradiometer (MODIS) wide swath, many spectral channels

\+ **Multi-angle Imaging Spectroradiometer (MISR)** narrower swath and fewer spectral channels, but multi-angle observations

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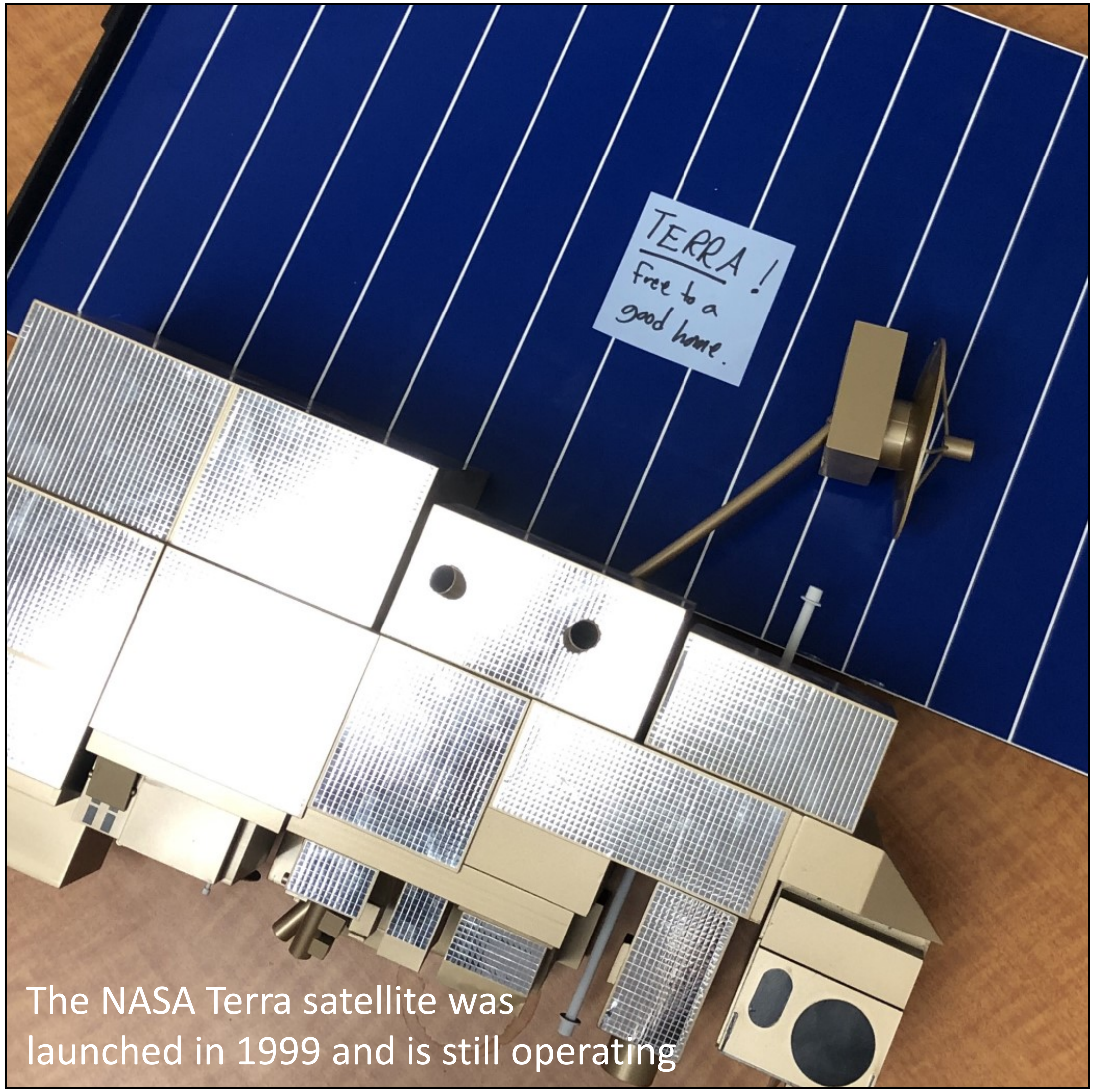
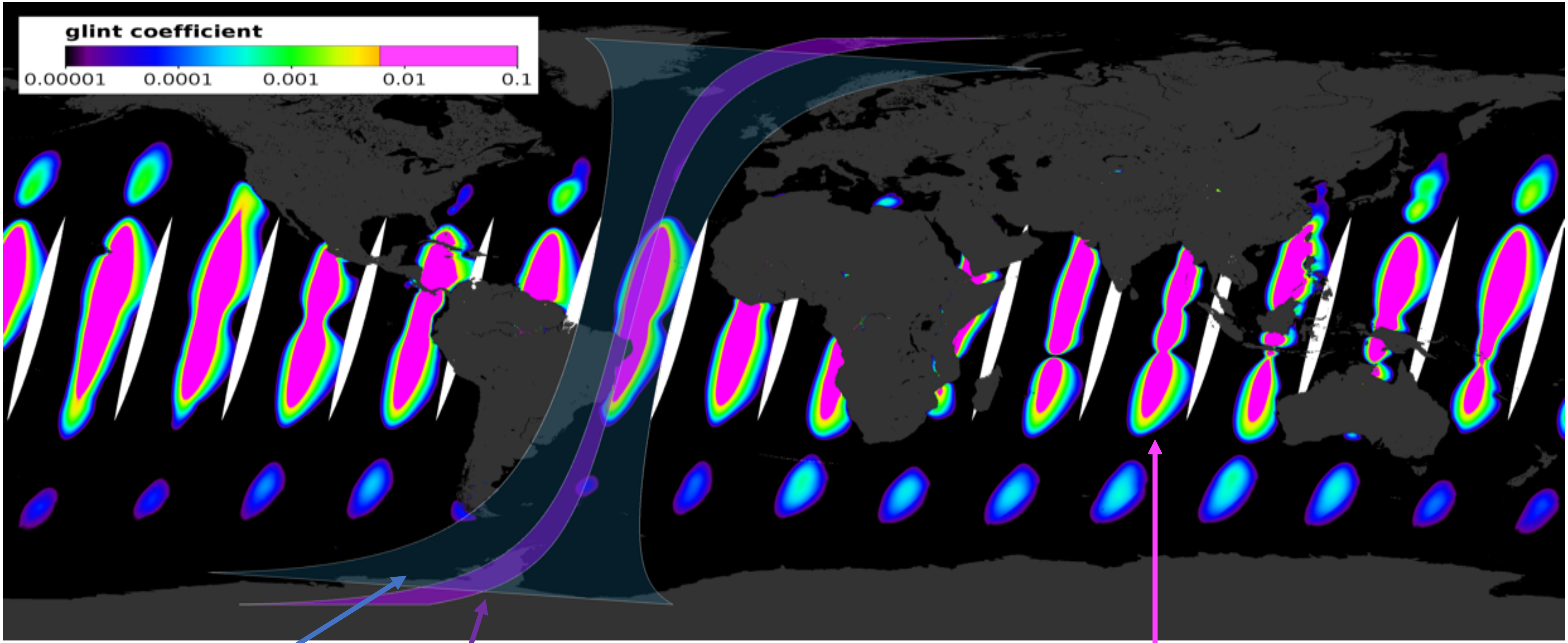
Improved retrieval of aerosol, ocean, and sun-glint parameters



The NASA Terra satellite was launched in 1999 and is still operating

Depending on your perspective…

…sun glint is either something to correct for, or utilize



MODIS swath

MISR swath

Ancillary wind speed predicted glint coefficient for a nadir view

Motivation:

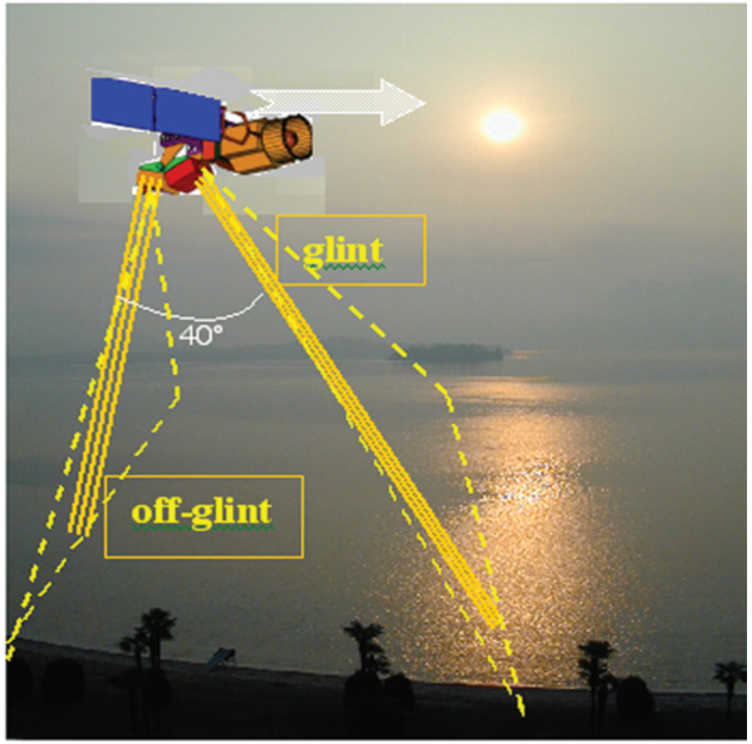
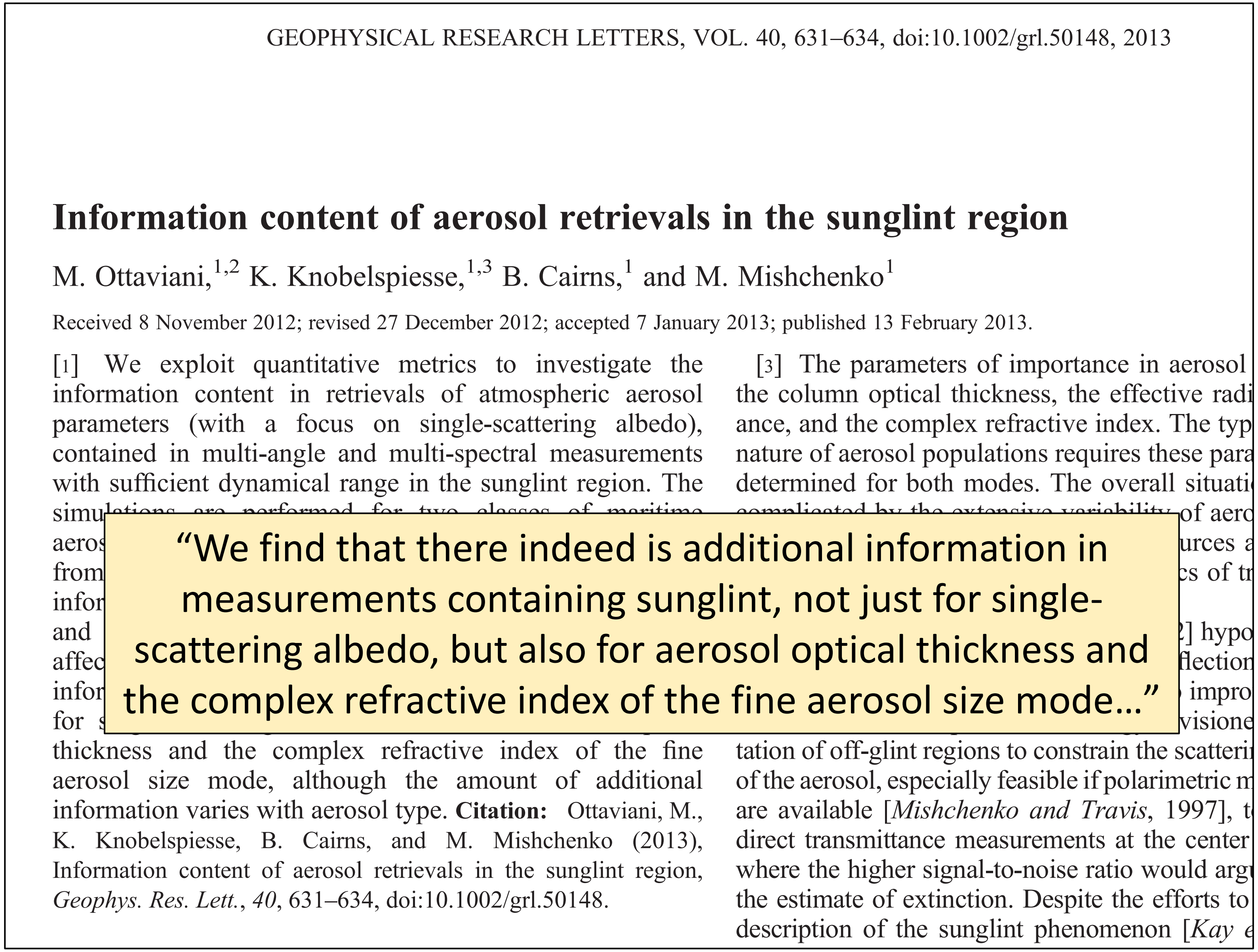


Figure 2. Solar glint over Lago Maggiore, Italy, June 27, 2001. The haze is urban pollution (optical thickness ~1) plus dust from the Sahara [*Gobbi et al.*, 2000]. A hypothetical spaceborne mission to measure aerosol absorption over the ocean consists of two pushbroom instruments that scan across-track as the spacecraft moves along track: one through the glint and one 40° off-glint.

From Kaufman, Y. J., Martins, J. V., Remer, L. A., Schoeberl, M. R., & Yamasoe, M. A. (2002). Satellite retrieval of aerosol absorption over the oceans using sunglint. *Geophysical Research Letters*, *29*(19).



GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 631–634, doi:10.1002/grl.50148, 2013

Information content of aerosol retrievals in the sunglint region

M. Ottaviani,[1,2] K. Knobelspiesse,[1,3] B. Cairns,[1] and M. Mishchenko[1]

Received 8 November 2012; revised 27 December 2012; accepted 7 January 2013; published 13 February 2013.

[1] We exploit quantitative metrics to investigate the information content in retrievals of atmospheric aerosol parameters (with a focus on single-scattering albedo), contained in multi-angle and multi-spectral measurements with sufficient dynamical range in the sunglint region. The simulations are performed for two classes of maritime
aeros
from
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thickness and the complex refractive index of the fine aerosol size mode, although the amount of additional information varies with aerosol type. **Citation:** Ottaviani, M., K. Knobelspiesse, B. Cairns, and M. Mishchenko (2013), Information content of aerosol retrievals in the sunglint region, *Geophys. Res. Lett.*, *40*, 631–634, doi:10.1002/grl.50148.

[3] The parameters of importance in aerosol
the column optical thickness, the effective radi
ance, and the complex refractive index. The typ
nature of aerosol populations requires these para
determined for both modes. The overall situati
complicated by the extensive variability of aero
urces a
cs of tr
] hypo
flection
impro
visione
tation of off-glint regions to constrain the scatteri
of the aerosol, especially feasible if polarimetric m
are available [*Mishchenko and Travis*, 1997], t
direct transmittance measurements at the center
where the higher signal-to-noise ratio would argu
the estimate of extinction. Despite the efforts to
description of the sunglint phenomenon [*Kay e*

"We find that there indeed is additional information in measurements containing sunglint, not just for single-scattering albedo, but also for aerosol optical thickness and the complex refractive index of the fine aerosol size mode…"

Also see recent review: Neukermans, G., Harmel, T., Galí, M., Rudorff, N., Chowdhary, J., Dubovik, O., Hostetler, C., Hu, Y., Jamet, C., Knobelspiesse, K., and others: Harnessing remote sensing to address critical science questions on ocean-atmosphere interactions, Elem Sci Anth, 6(1) , 2018. DOI: https://doi.org/10.1525/elementa.331

Further motivation

Expected launch: 2023

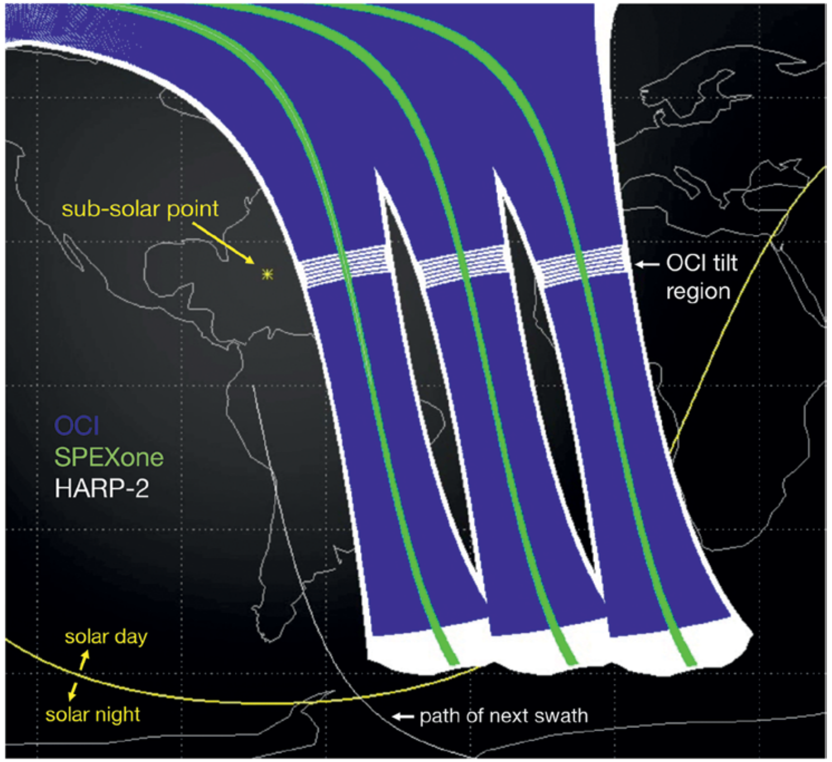


Fig. 4. Three example consecutive daytime orbits of the PACE observatory science data collection, showing the OCI (blue), SPEXone (green), and HARP-2 (white) swaths. The polarimeter swaths consider all along-track viewing angles (such that the HARP-2 swath width viewed at ±57° exceeds that of OCI, which is ±20°). The subsolar point and region of OCI aft-to-fore tilt are also shown.

P.J. Werdell, et al., 2019. The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission: Status, science, advances, *Bulletin of the American Meteorological Society*, 100 (9). DOI:10.1175/BAMS-D-18-0056.1

Plankton, Aerosol, Cloud, ocean Ecosystem

Advanced Measurements of Sea & Sky

PACE

NASA • Goddard Space Flight Center

https://pace.gsfc.nasa.gov

Merged observation plan, synthetic test data and other info:
https://oceancolor.gsfc.nasa.gov/data/pace

Ocean Color Imager (OCI): tilting imaging UV-SWIR spectrometer

Spectro-Polarimeter for Planetary Exploration (SPEXone): narrow swath, high accuracy, multi-angle VIS polarimeter/spectrometer

Hyper Angular Rainbow Polarimeter (HARP-2): wide swath, four channel, hyper-angle VIS polarimeter

As proposed

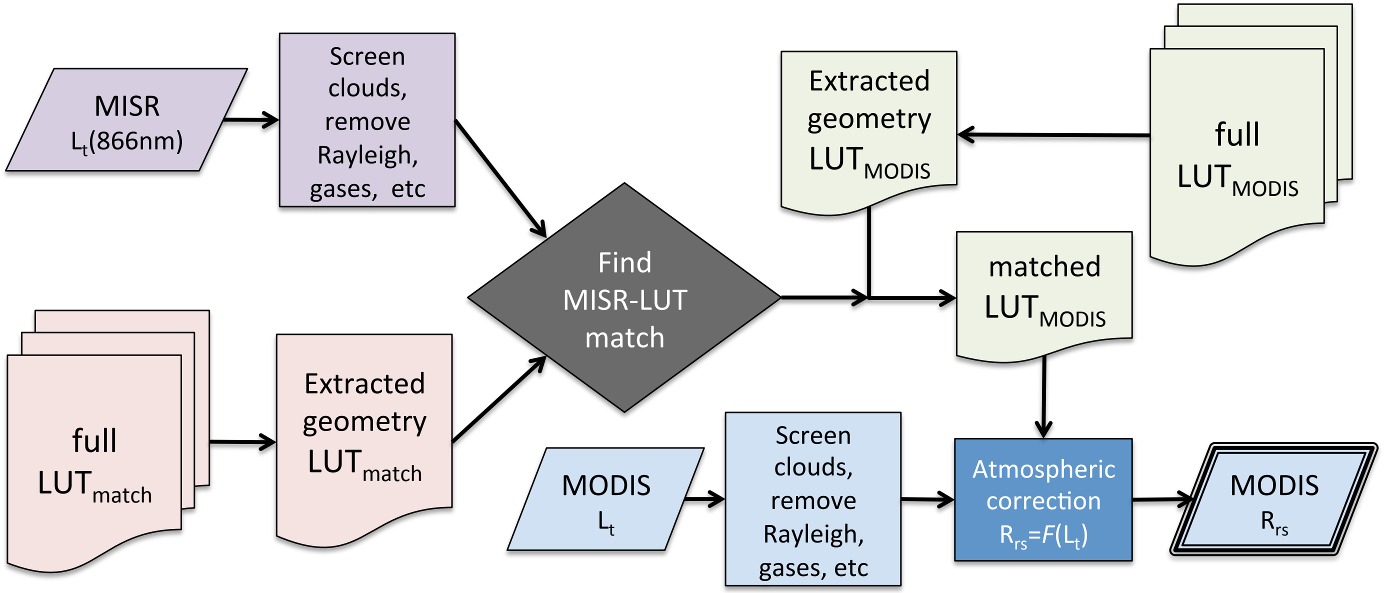
Oceanographer lingo for aerosol retrieval

Coincident MISR data will be used to benefit MODIS-Terra atmospheric correction by:

1. Improving aerosol model selection in the NIR with multi-angle observations
2. Refining reflected sun glint characterization with direct observations, and
3. Identification of aerosol absorption with multi-angle glint observation.

Leveraging combined atmospheric (GSFC, JPL), instrument (GSFC MODIS, JPL MISR) and ocean color (GSFC) experience, and utilize the infrastructure of the GSFC OBPG.

Research algorithm for Section 2.2 of TASNPP call “Algorithms – New Data products” as part of the Ocean Biology and Biogeochemistry Measurements Science Team



1st & 2nd year accomplishments

1. MISR data into Ocean Biology Processing Group (OBPG) “l2_gen”
2. 1st generation MISR LUT generated with Ahmad-Frasier RT (AFRT) code. Dimensions: aerosol model, AOT, wind speed + geometry
3. Benchmark comparison (2) to GISS Doubling-Adding RT code
4. l2_gen modification to handle glint and other changes
5. Ported AFRT to OBPG data processing system for increased speed
6. 2nd generation MISR LUT created with (5), with additional aerosol models (varying humidity as a proxy for aerosol properties)
7. Initial tests of applying OBPG vicarious calibration to MISR data. Limited by narrow instrument swath
8. Information content assessment to determine appropriate parameterization (GENRA), 1st publication
9. Initial tests of MISR retrieval

GENRA (Generalized Nonlinear Retrieval Analysis)

Coddington, O., Pilewskie, P., and Vukicevic, T.: The Shannon information content of hyperspectral shortwave cloud albedo measurements: Quantification and practical applications, J. Geophys. Res, 117(D4), D04205 , 2012. doi:10.1029/2011JD016771

Posterior

Prior

Data + uncertainty

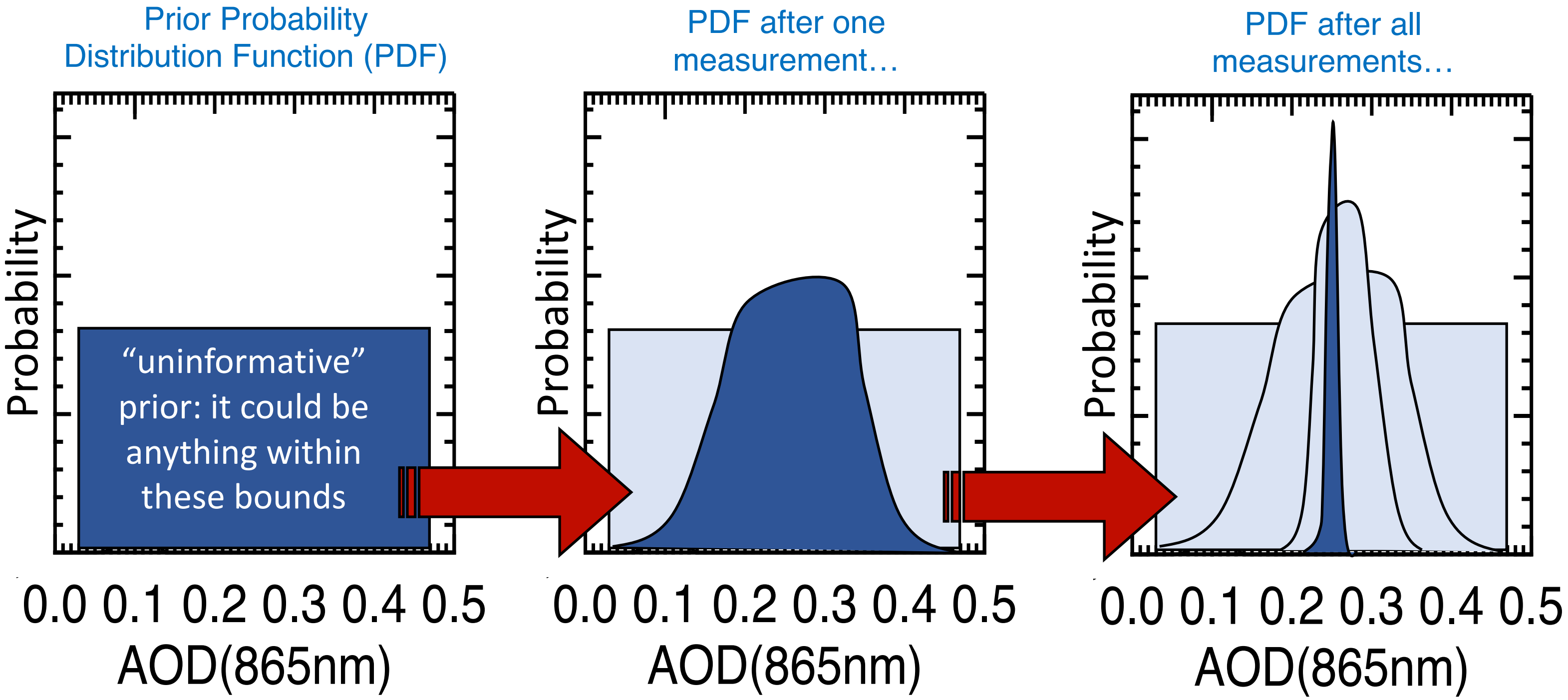
Forward model / LUT

$$p_o(\mathbf{m}) = \frac{1}{\gamma^*}\int_D \left[p_r(\mathbf{m})\,p_d(\mathbf{y})\,p_l(F(\mathbf{m})|\mathbf{m})\right] d\mathbf{y}$$

Measurement space

Normalization constant

Theory (likelihood function)



Goal - determine the best parameterization scheme

Input: MISR (865nm) 9 views

Output:

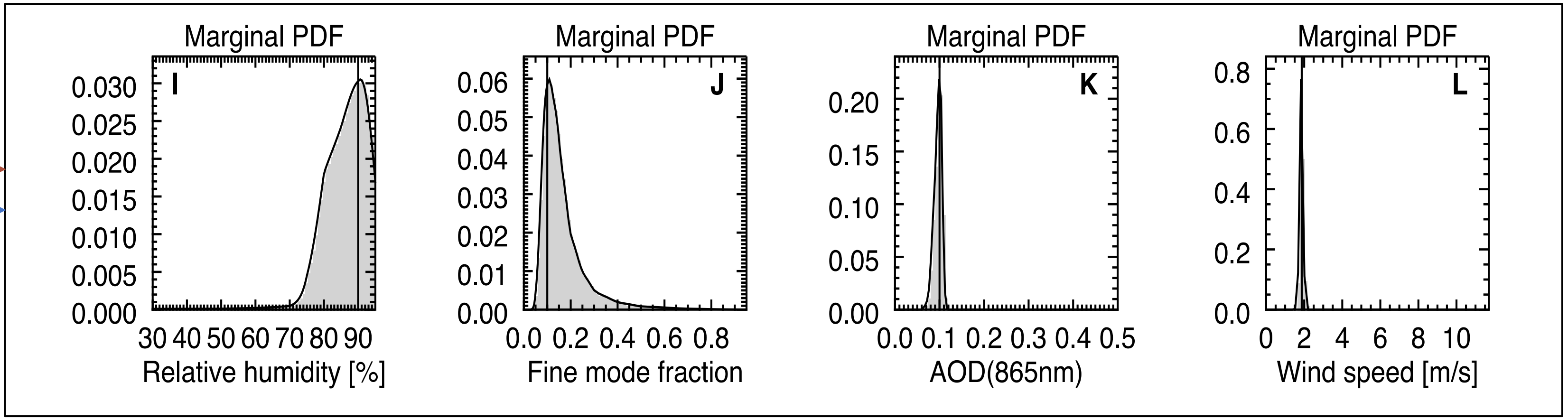
- AOD(865nm)
- scalar surface wind speed
- 2 parameter aerosol model (fine coarse mode concentration, relative humidity)

+ tests of model errors

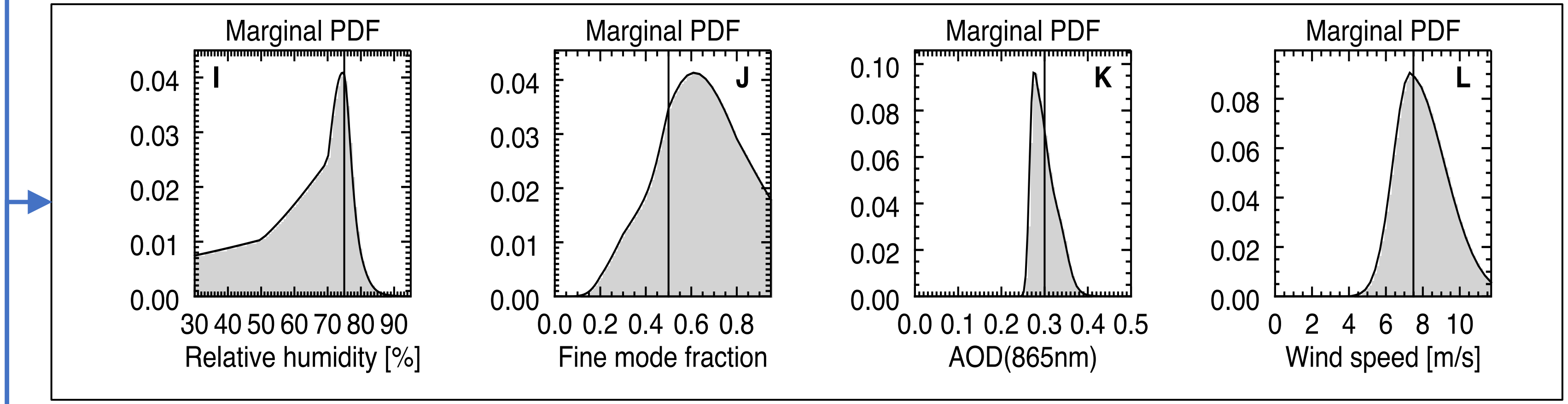
Some Results

(thousands of cases for different parameters and geometries)

Marginal Probability Distribution function: what a retrieval on one node in our simulation dataset would be like



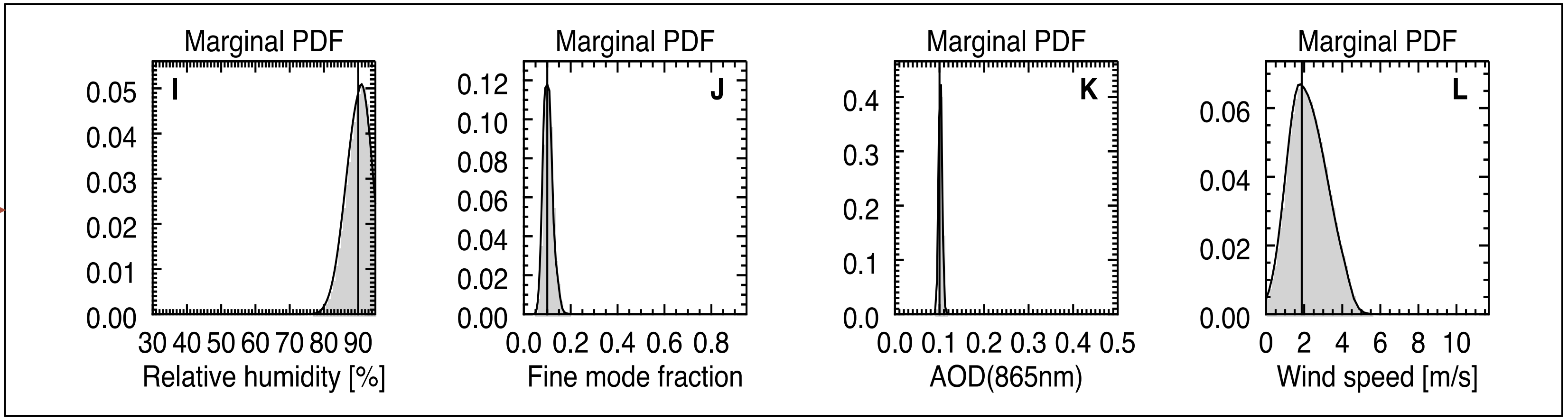
Solar zenith angle: 43.9°
Relative humidity: 90 %
Fine mode fraction: 0.10
AOD(865nm): 0.10
Wind speed: 1.87 [m/s]



Solar zenith angle: 43.9°
Relative humidity: 75 %
Fine mode fraction: 0.50
AOD(865nm): 0.30
Wind speed: 7.49 [m/s]

Same geometry, different geophysical state

Same geophysical state, different geometry



Solar zenith angle: 69.7°
Relative humidity: 90 %
Fine mode fraction: 0.10
AOD(865nm): 0.10
Wind speed: 1.87 [m/s]

Conclusions, briefly…

- **High dependence on BOTH geometry and AOD**
- **Marginal PDF's are not always Gaussian** Simple +/- uncertainty bounds may not tell the whole story. This gets worse as parameter retrieval is less well determined and prior state has a larger impact.
- **Higher AOD =** good aerosol retrievals, worse wind/glint, **lower AOD =** worse aerosol, better wind/glint
- **We could do actual retrievals this way!** But it may not be computationally feasible.
- **Many more results in the backup slides**

Analysis of simultaneous aerosol and ocean glint retrieval using multi-angle observations

Kirk Knobelspiesse[1], Amir Ibrahim[1,2], Bryan Franz[1], Sean Bailey[1], Robert Levy[1], Ziauddin Ahmad[1,3], Joel Gales[1,3], Meng Gao[1,2], Michael Garay[4], Samuel Anderson[1,2], and Olga Kalashnikova[4]

[1]NASA Goddard Space Flight Center, Greenbelt, MD, USA
[2]Science Systems and Applications, Inc., Lanham, MD, USA
[3]Science Applications International Corp., Greenbelt, MD, USA
[4]JPL, California Institute of Technology, Pasadena, USA

Correspondence: Kirk Knobelspiesse (Kirk.Knobelspiesse@nasa.gov)

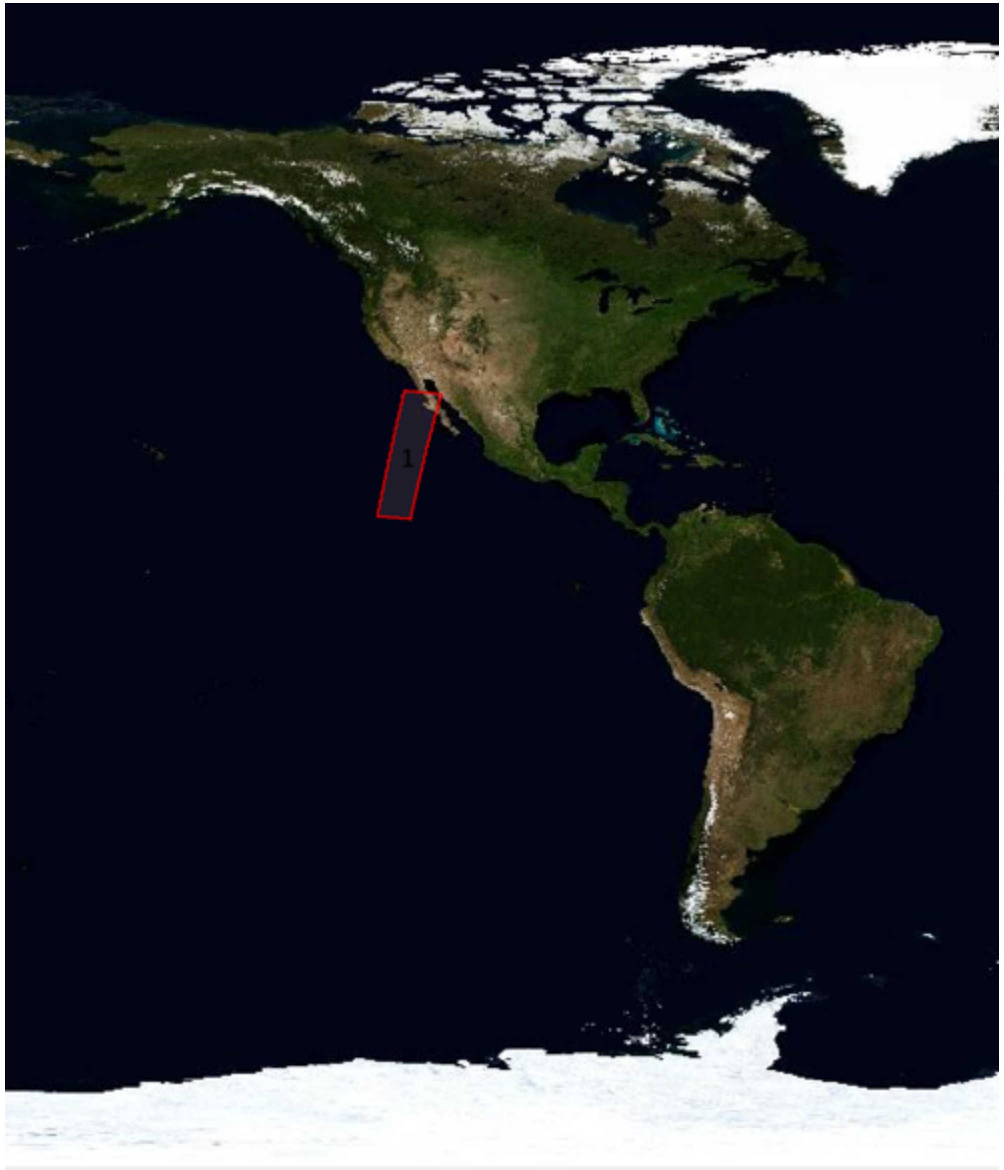
Abstract.
Since early 2000, NASA's Multi-angle Imaging Spectro-Radiometer (MISR) instrument has been performing remote sensing retrievals of aerosol optical properties from the polar orbiting Terra spacecraft. A noteworthy aspect of MISR observations over the ocean is that, for much of the Earth, some of the multi-angle views have contributions from solar reflection by the ocean surface (glint, or glitter), while others do not. Aerosol retrieval algorithms often discard these glint influenced observations because they can overwhelm the signal and are difficult to predict without knowledge of the (wind speed driven) ocean surface roughness. Other algorithms directly use the sun glint to determine the ocean surface roughness, and by extension wind speed, but may not simultaneously retrieve aerosol optical properties. However, theoretical studies have shown that multi-angle observations of a location at geometries with and without reflected sun glint can be a rich source of information, sufficient to support simultaneous retrieval of both the aerosol state and the wind speed at the ocean surface.

We are in the early stages of creating such an algorithm. In this manuscript, we describe our assessment of the appropriate level of parameterization for simultaneous aerosol and ocean surface property retrievals using sun glint. For this purpose, we use Generalized Nonlinear Retrieval Analysis (GENRA), an information content assessment (ICA) technique employing Bayesian inference, and simulations from the Ahmad-Fraser iterative radiative transfer code. We find that a suitable parameterization for the retrieval algorithm includes four parameters: aerosol optical depth (τ, which is the atmospheric column aerosol optical extinction), particle size distribution (expressed as the relative contribution of small particles in a bimodal size distribution, or fine mode fraction, f), surface wind speed (w, scalar/non directional) and relative humidity (r, as a means to define the aerosol water content and complex refractive index). None of these parameters define ocean optical properties, as we found that the aerosol state could be retrieved with the nine MISR near-infrared views alone, where the ocean body is black in the open ocean. We also found that retrieval capability varies with observation geometry, and that as τ increases so does the ability to determine aerosol intensive optical properties (r and f, while it decreases for w). Increases in w decrease the ability to determine the true value of that parameter, but have minimal impact on retrieval of aerosol properties. We explored the benefit of excluding the two most extreme MISR view angles (view zenith angles of 70.5° fore and aft of nadir), which may be subject to inaccurate radiative transfer calculations for models that make plane parallel approximations. So long as the retrieval algorithm accounts for increased uncertainty due to this for those view angles, it is best to use all nine views. Finally, the impact of treating wind speed as a scalar parameter, rather than as a two parameter directional wind, was tested. While the simpler scalar model does contribute to overall aerosol uncertainty, it is not sufficiently large to justify the addition of another dimension to parameter space.

The long term goal of this project is to use the aerosol retrieval from MISR to perform an atmospheric correction for coincident ocean color (OC) observations by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, also on the NASA Terra spacecraft. Unlike MISR, MODIS is a single view angle instrument, but it has a more

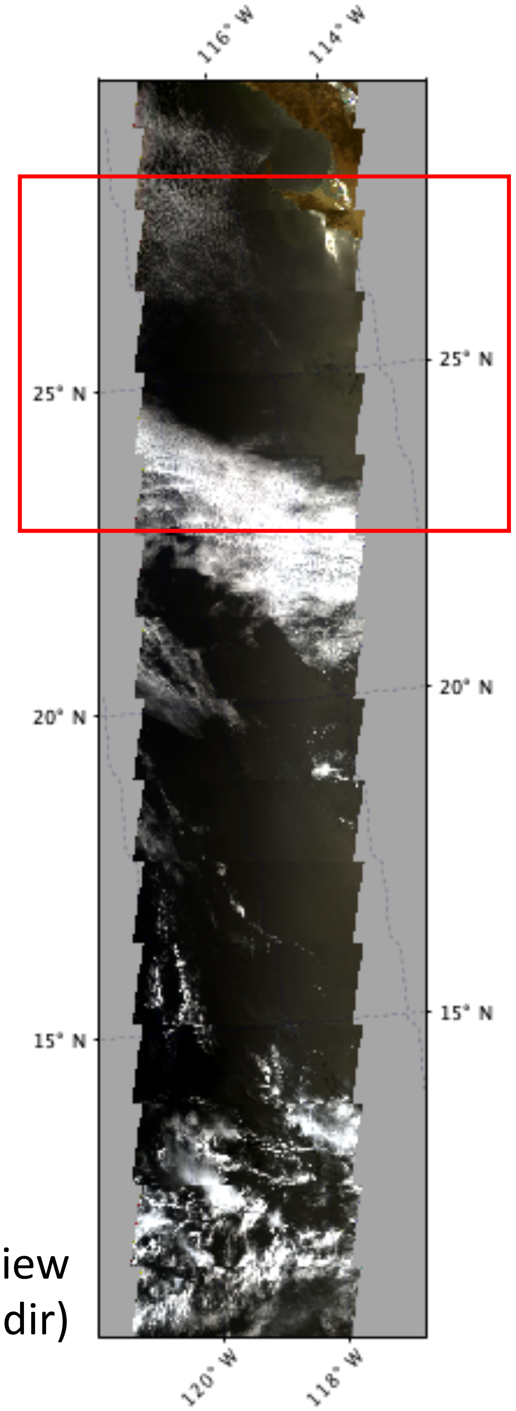
Almost ready to submit to Atmospheric Measurement Techniques

Initial MISR retrieval using 865nm band



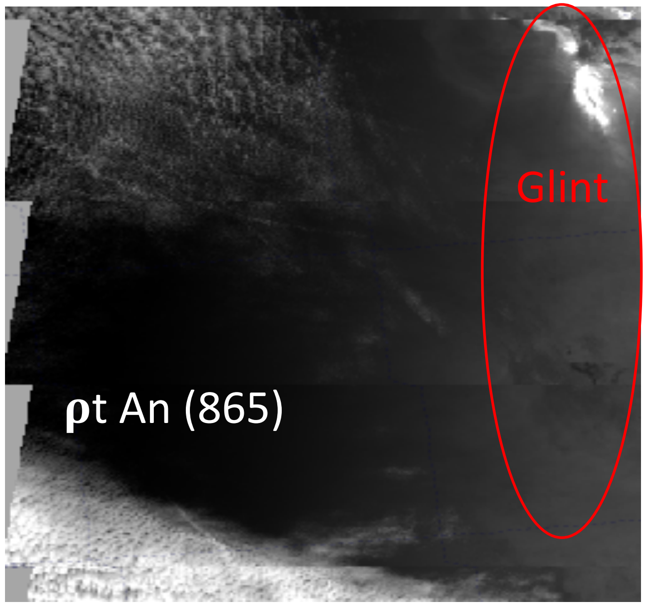
We tested a maximum likelihood (non-Bayesian) retrieval using the same aerosol simulations.

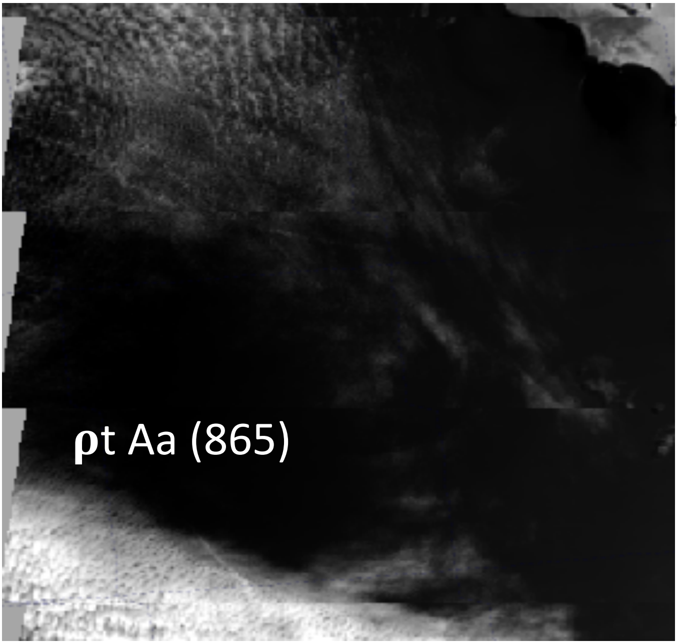
Scene: 2018-07-01, south of Baja California

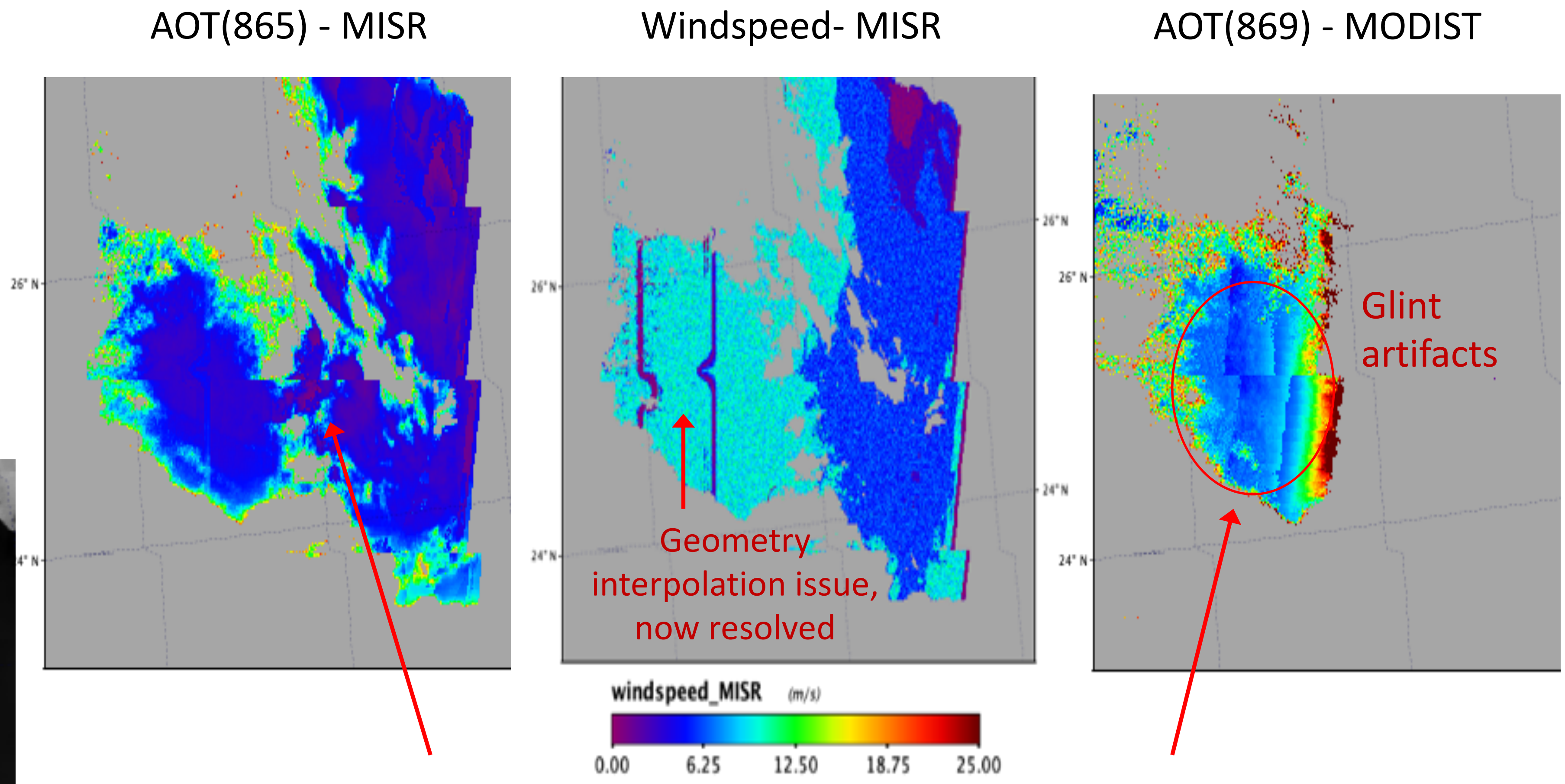


An view
(nadir)

Initial MISR retrieval using 865nm band







Very preliminary: we can retrieve reasonable (?) aerosol properties in regions too contaminated by glint to be useful in MODIS (ocean color) retrievals

Thank you!

↑Kirk.Knobelspiesse@nasa.gov

Backup slides and more information…

GENRA objectives

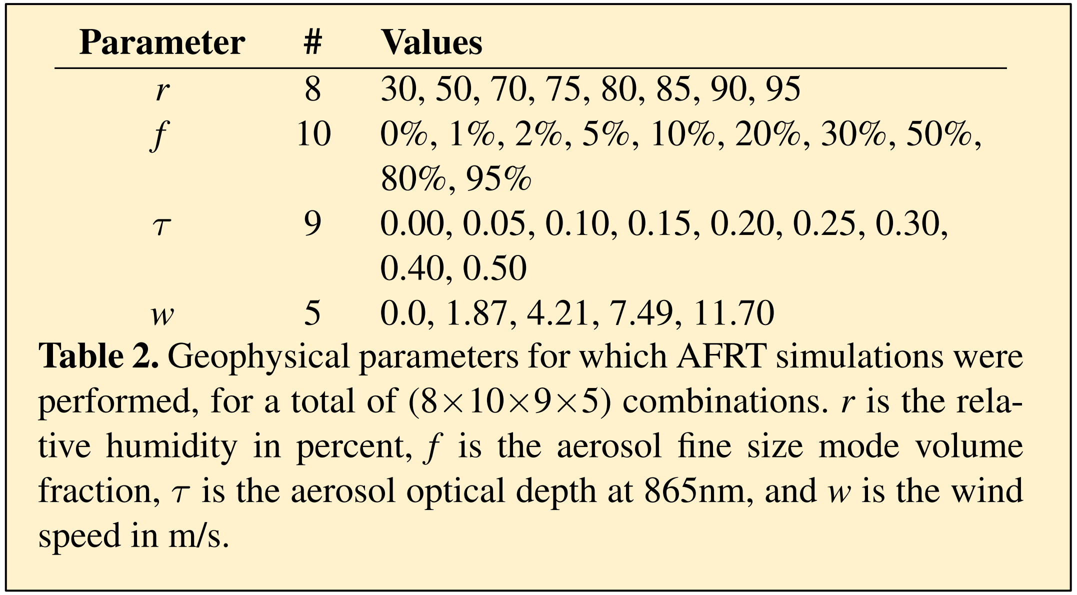
We want to retrieve four parameters from the 9 MISR 865nm views. Is this feasible?

What retrieval uncertainty can we expect? How does this depend on geometry? How does it depend on conditions?

Tests of model error:

How sensitive are we to plane parallel radiative transfer uncertainty for large zenith angles?

Better to use scalar or vector winds to parameterize sun glint?



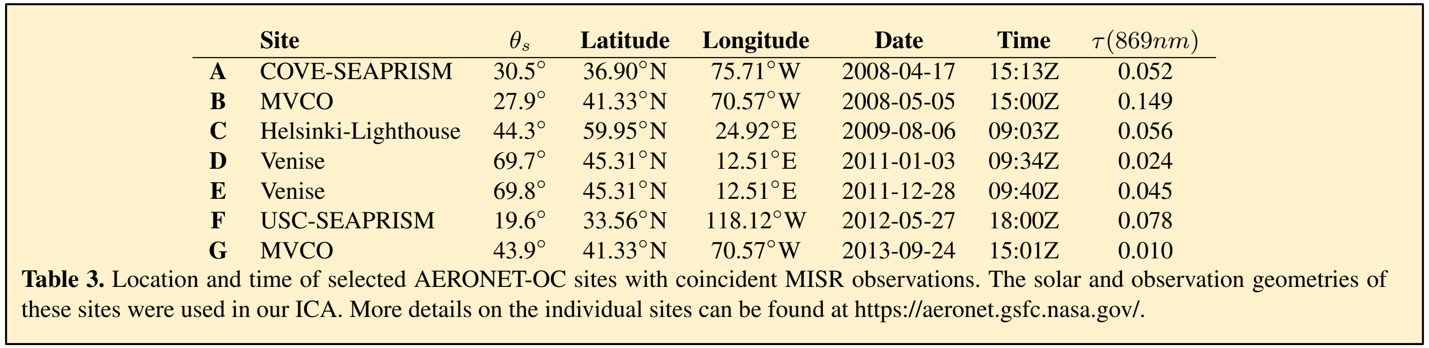
Parameter	#	Values
r	8	30, 50, 70, 75, 80, 85, 90, 95
f	10	0%, 1%, 2%, 5%, 10%, 20%, 30%, 50%, 80%, 95%
τ	9	0.00, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50
w	5	0.0, 1.87, 4.21, 7.49, 11.70

Table 2. Geophysical parameters for which AFRT simulations were performed, for a total of ($8\times10\times9\times5$) combinations. r is the relative humidity in percent, f is the aerosol fine size mode volume fraction, τ is the aerosol optical depth at 865nm, and w is the wind speed in m/s.

Test scenes

To find a set of reasonable MISR measurement conditions, performed a SeaBASS search on AERONET-OC / MODIS-Terra matchups, where MODIS zenith angle maximum is 15˚

Found 906. Picked 7 @ low, medium and high solar zenith angles.



	Site	θ_s	Latitude	Longitude	Date	Time	$\tau(869nm)$
A	COVE-SEAPRISM	30.5°	36.90°N	75.71°W	2008-04-17	15:13Z	0.052
B	MVCO	27.9°	41.33°N	70.57°W	2008-05-05	15:00Z	0.149
C	Helsinki-Lighthouse	44.3°	59.95°N	24.92°E	2009-08-06	09:03Z	0.056
D	Venise	69.7°	45.31°N	12.51°E	2011-01-03	09:34Z	0.024
E	Venise	69.8°	45.31°N	12.51°E	2011-12-28	09:40Z	0.045
F	USC-SEAPRISM	19.6°	33.56°N	118.12°W	2012-05-27	18:00Z	0.078
G	MVCO	43.9°	41.33°N	70.57°W	2013-09-24	15:01Z	0.010

Table 3. Location and time of selected AERONET-OC sites with coincident MISR observations. The solar and observation geometries of these sites were used in our ICA. More details on the individual sites can be found at https://aeronet.gsfc.nasa.gov/.

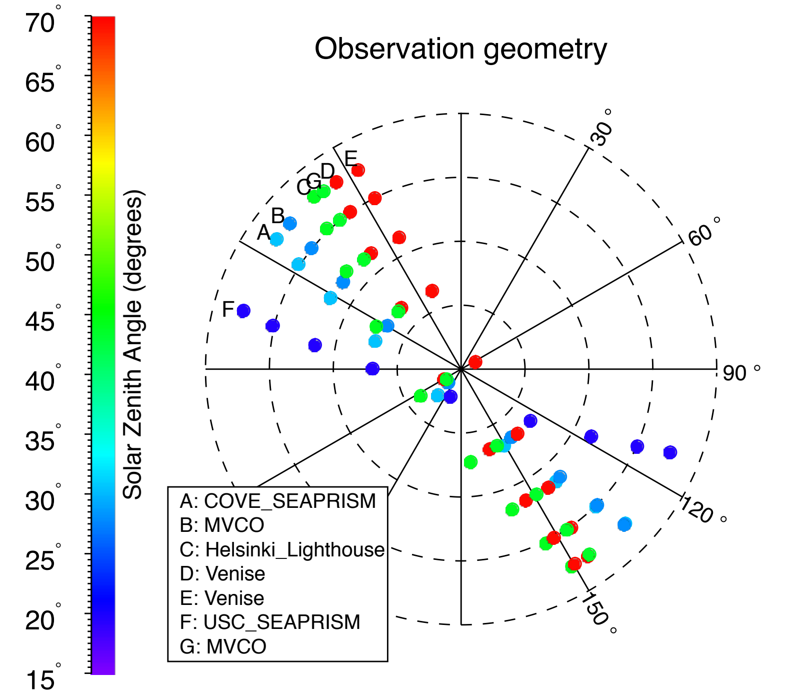


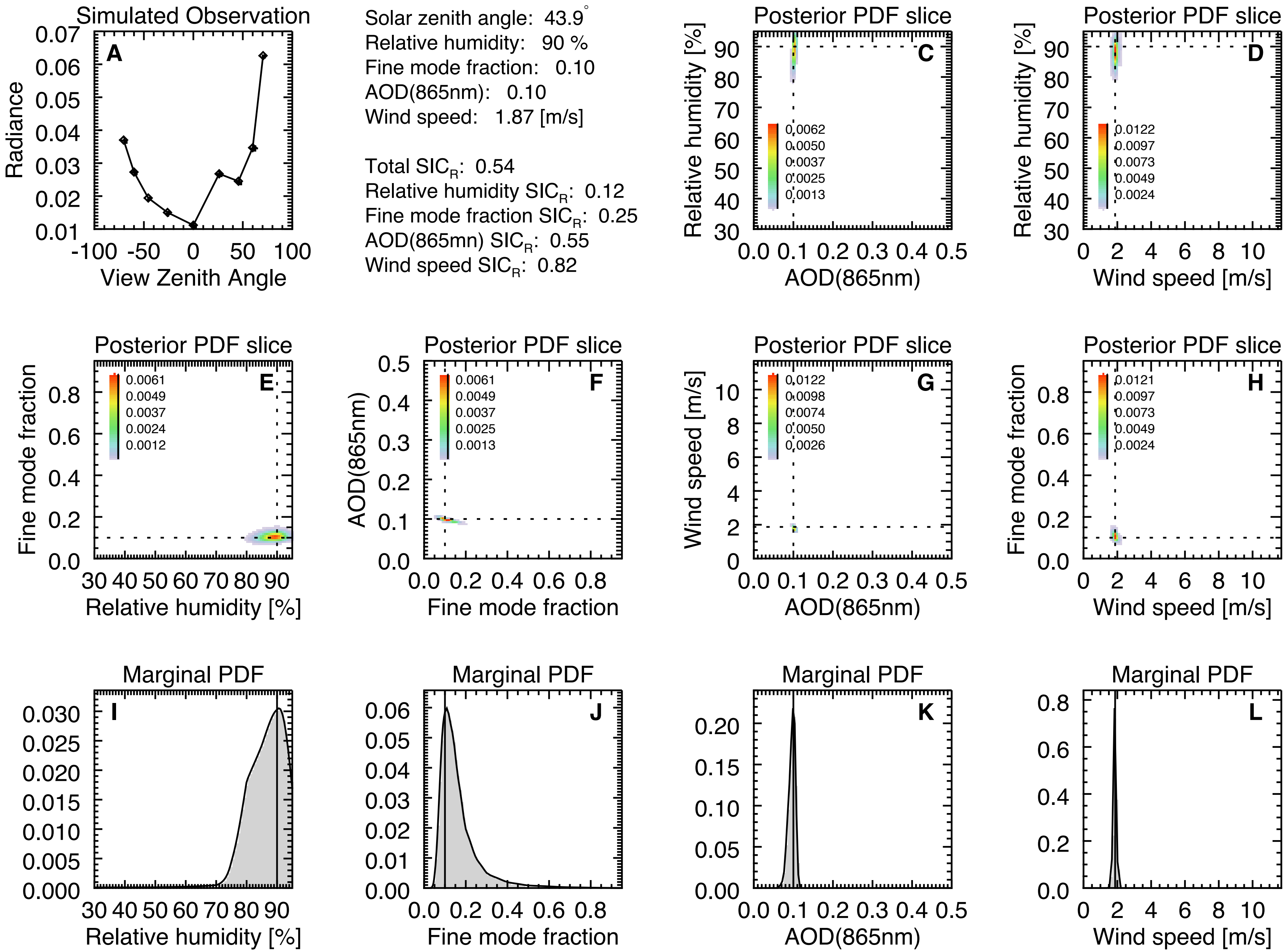
Figure 1. Polar plot of the observation geometries used in the ICA, corresponding to AERONET-OC and MISR coincident observations. The angular coordinate indicates ϕ, while the radial coordinate indicates θ_v (each dashed concentric circle represents 20°). θ_s is indicated by color.

Results

for one LUT node and test case G

We’re best at retrieving AOD and wind speed

Aerosol property PDF’s are non-Gaussian



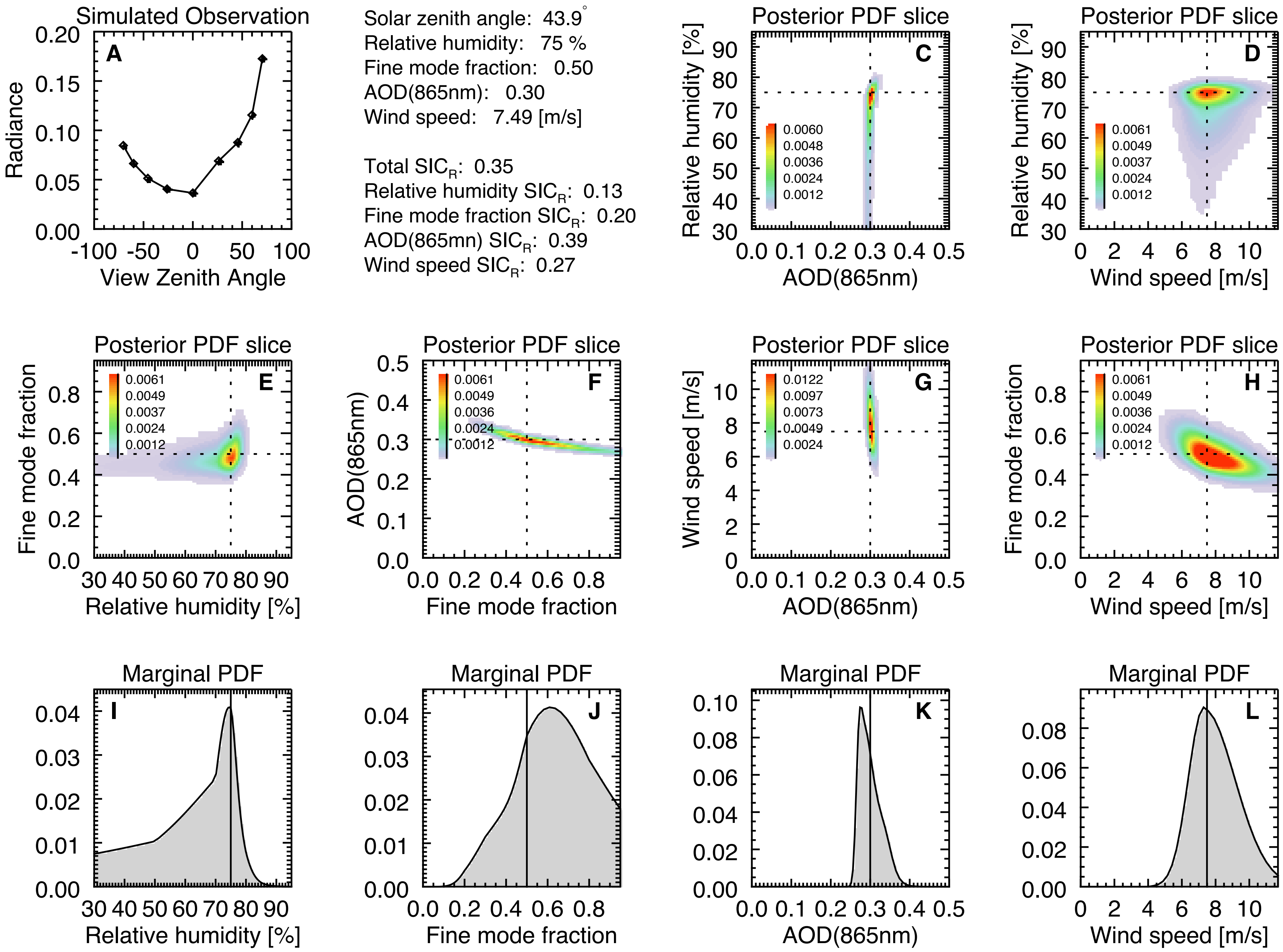
Solar zenith angle: 43.9°
Relative humidity: 90 %
Fine mode fraction: 0.10
AOD(865nm): 0.10
Wind speed: 1.87 [m/s]

Total SIC_R: 0.54
Relative humidity SIC_R: 0.12
Fine mode fraction SIC_R: 0.25
AOD(865mn) SIC_R: 0.55
Wind speed SIC_R: 0.82

Results

Same test case geometry, more difficult scene

Large optical thickness is obscuring sun glint



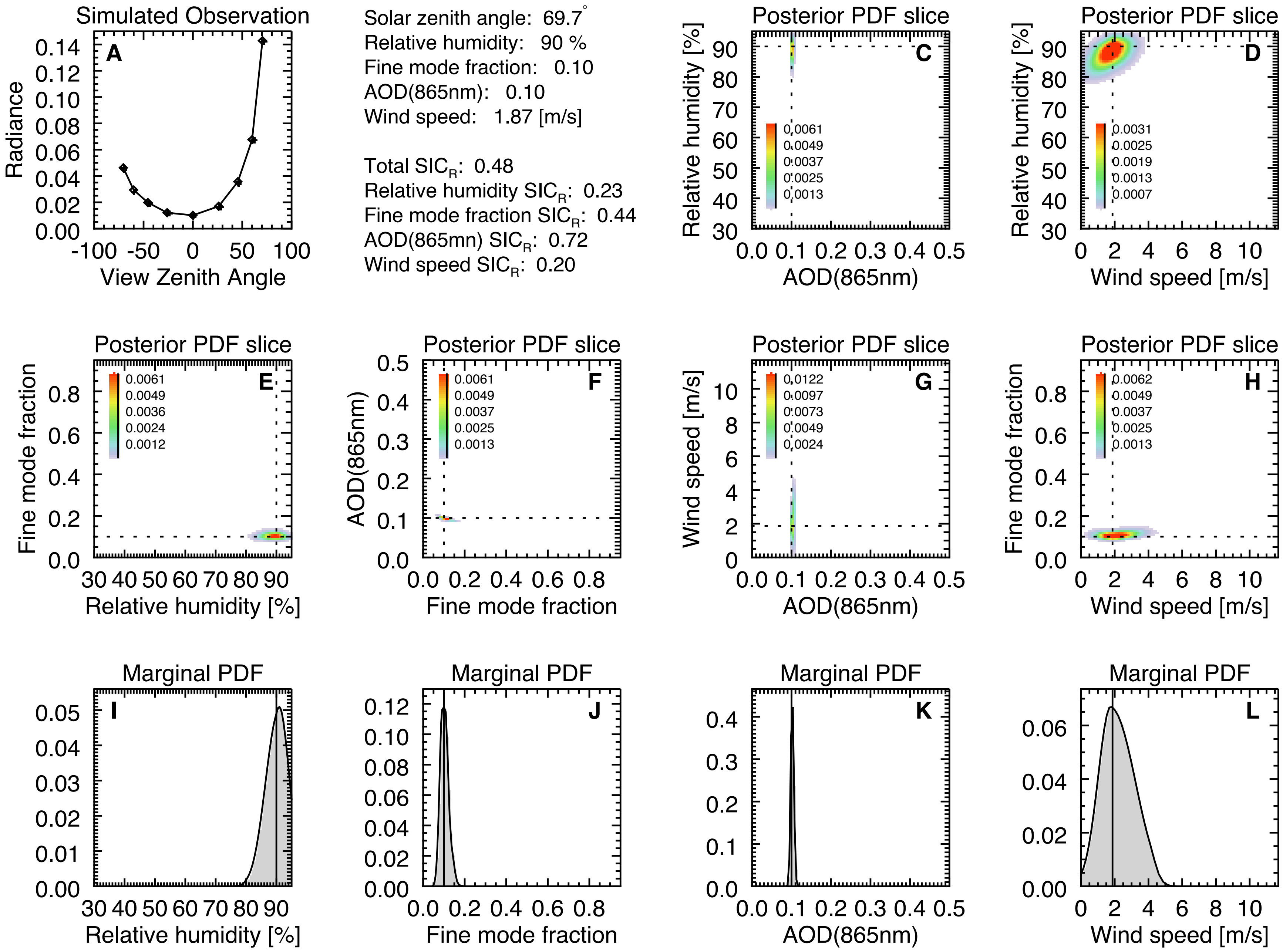
Solar zenith angle: 43.9°
Relative humidity: 75 %
Fine mode fraction: 0.50
AOD(865nm): 0.30
Wind speed: 7.49 [m/s]

Total SIC_R: 0.35
Relative humidity SIC_R: 0.13
Fine mode fraction SIC_R: 0.20
AOD(865mn) SIC_R: 0.39
Wind speed SIC_R: 0.27

Results

What happens if there is no sun glint at this geometry?

Worse for wind speed determination, but there is still skill



Solar zenith angle: 69.7°
Relative humidity: 90 %
Fine mode fraction: 0.10
AOD(865nm): 0.10
Wind speed: 1.87 [m/s]

Total SIC_R: 0.48
Relative humidity SIC_R: 0.23
Fine mode fraction SIC_R: 0.44
AOD(865mn) SIC_R: 0.72
Wind speed SIC_R: 0.20

Results

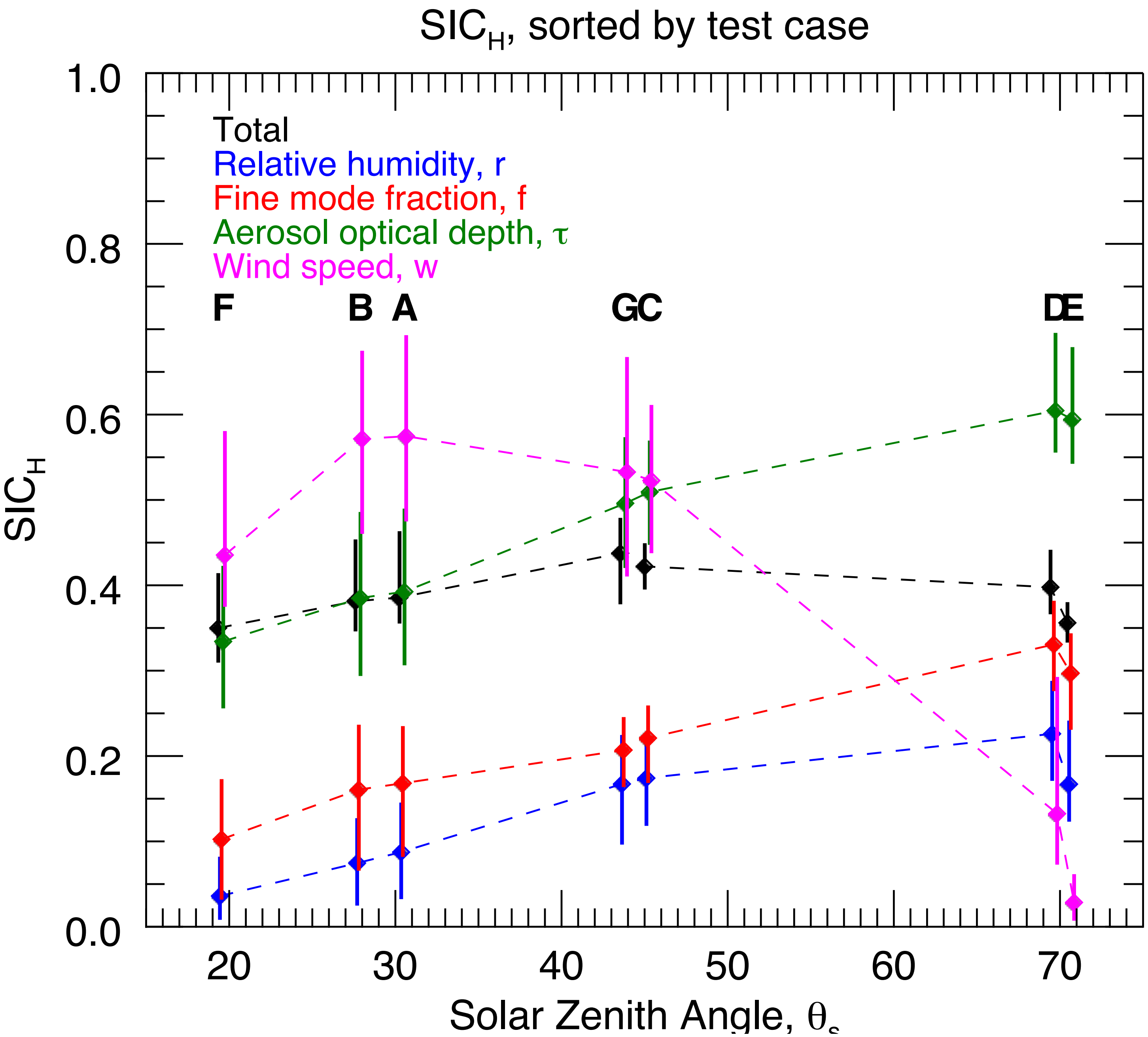
Shannon Information Content is a more compact representation

Aerosol properties increase with solar zenith angle (less glint)

Wind speed decreases

Total SIC relatively insensitive (trade off)

Special case for SZA=20˚



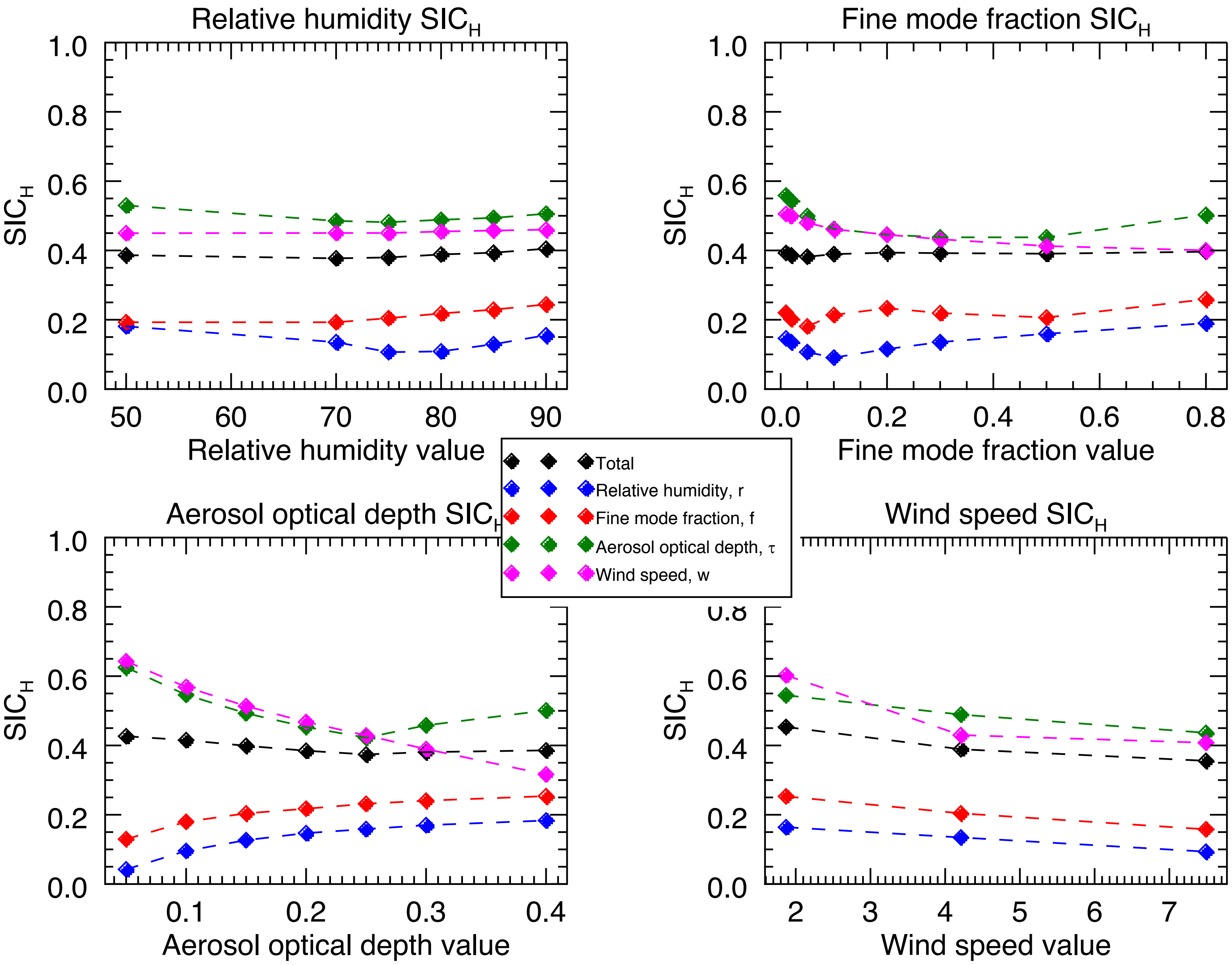
Results

How sensitive are we to parameter value?

Aerosol intensive properties don’t change SIC much

More aerosols (higher AOD) means better aerosol retrievals, worse wind retrievals

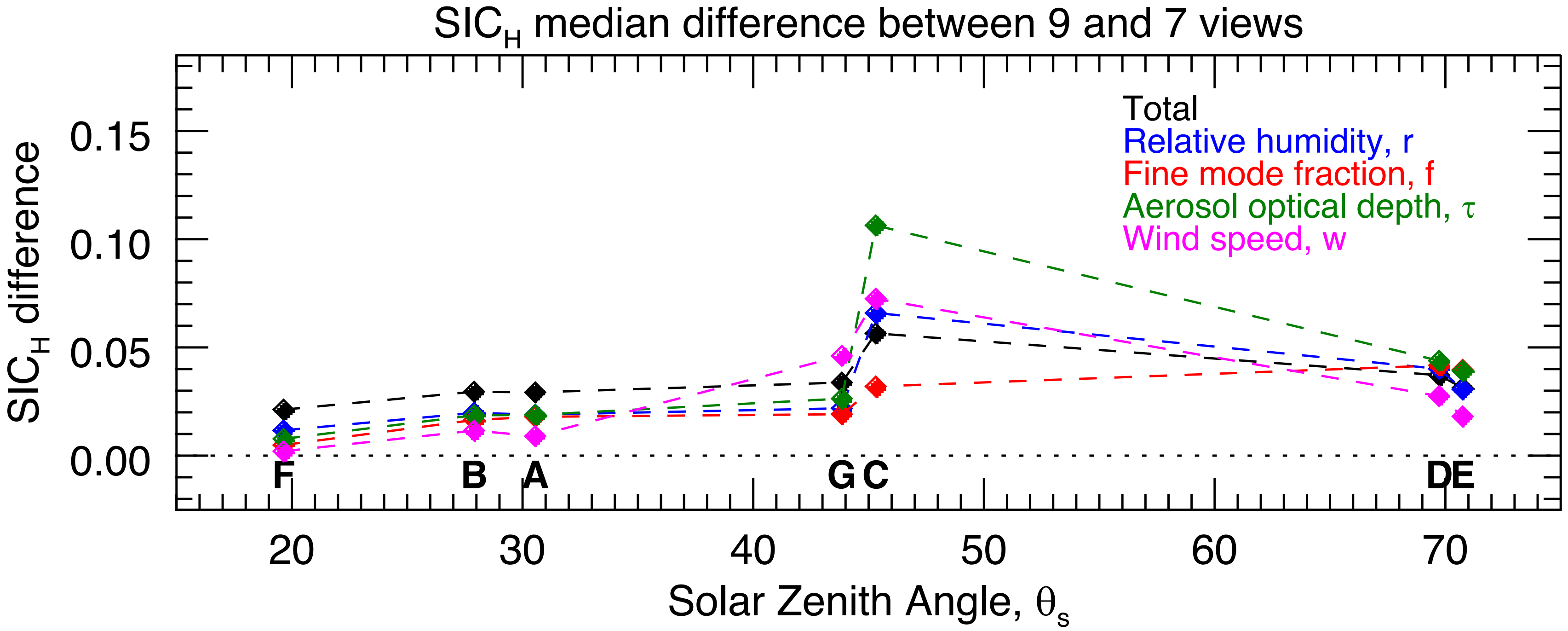
Minor decrease in SIC as wind speed grows



Results

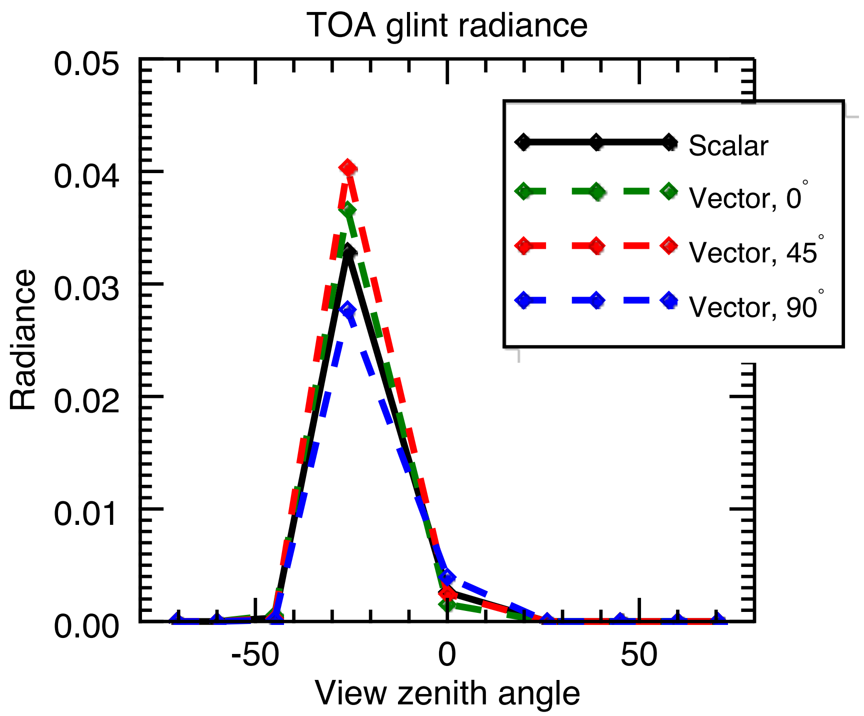
Is it better to discard most extreme (view zenith = 70.5˚) MISR views because of plane parallel radiative transfer error? **No**

Plot is of SIC for the 9 view case (incorporating expectations of error) vs 7 view case. Positive values mean 9 view has higher SIC.

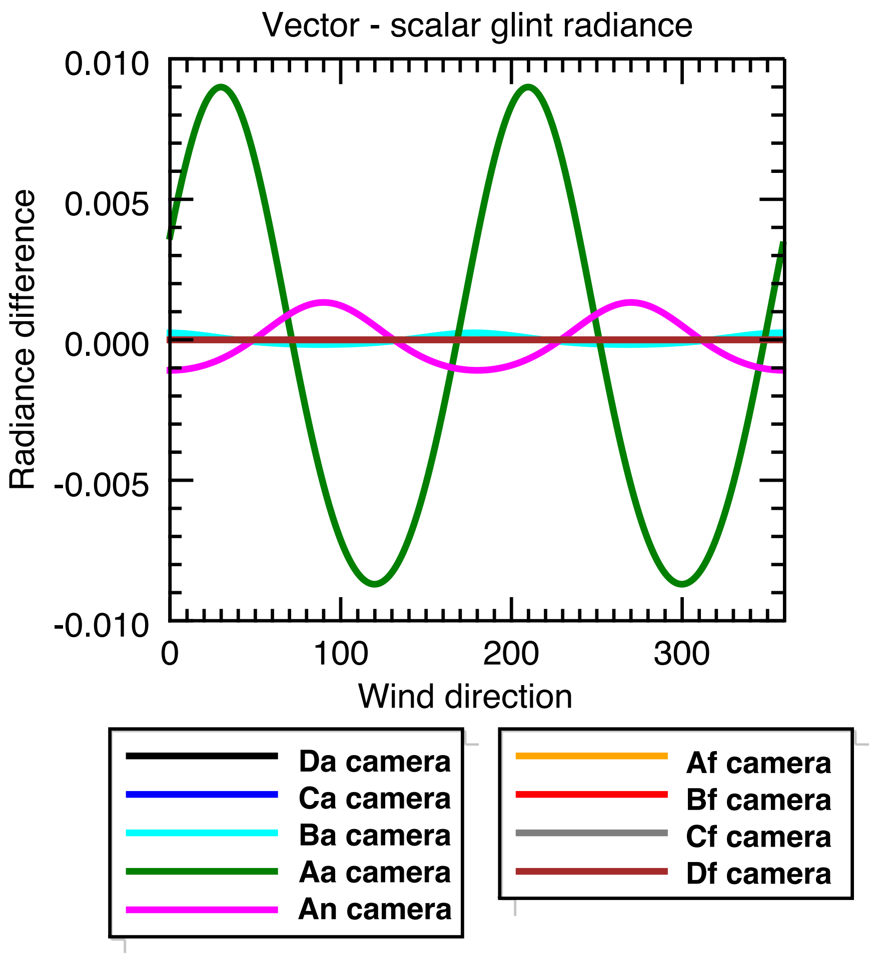


Results

We model sun glint as depending on a single (scalar) wind speed
A more complex model uses speed and direction. What is the model error due to this?

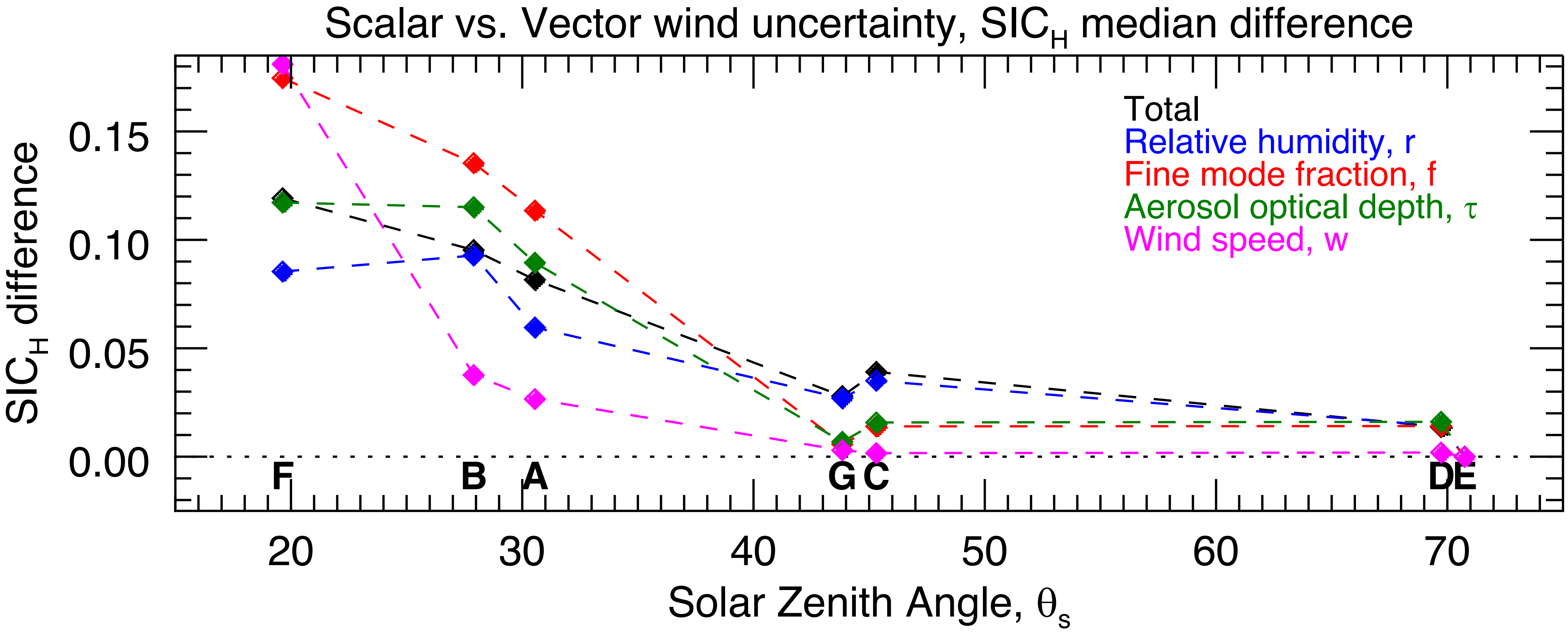


Solar Zenith Angle: 29.3°
Forward Relative Azimuth Angle: 44.2°
AOT(865nm): 0.05
Wind speed: 1.68 [m/s]



Results

Plot is SIC without – SIC with this model uncertainty
Impacts are greatest for low solar zenith angles. But what is the impact on parameter uncertainty?



Results

Plot is SIC without – SIC with this model uncertainty

Impacts are greatest for low solar zenith angles. But what is the impact on parameter uncertainty?

Here is one example of marginals for one node in LUT. We can see that impact is only for aerosol intensive parameters at lowest SZA, and not worth the additional parametrization complexity and RT expense