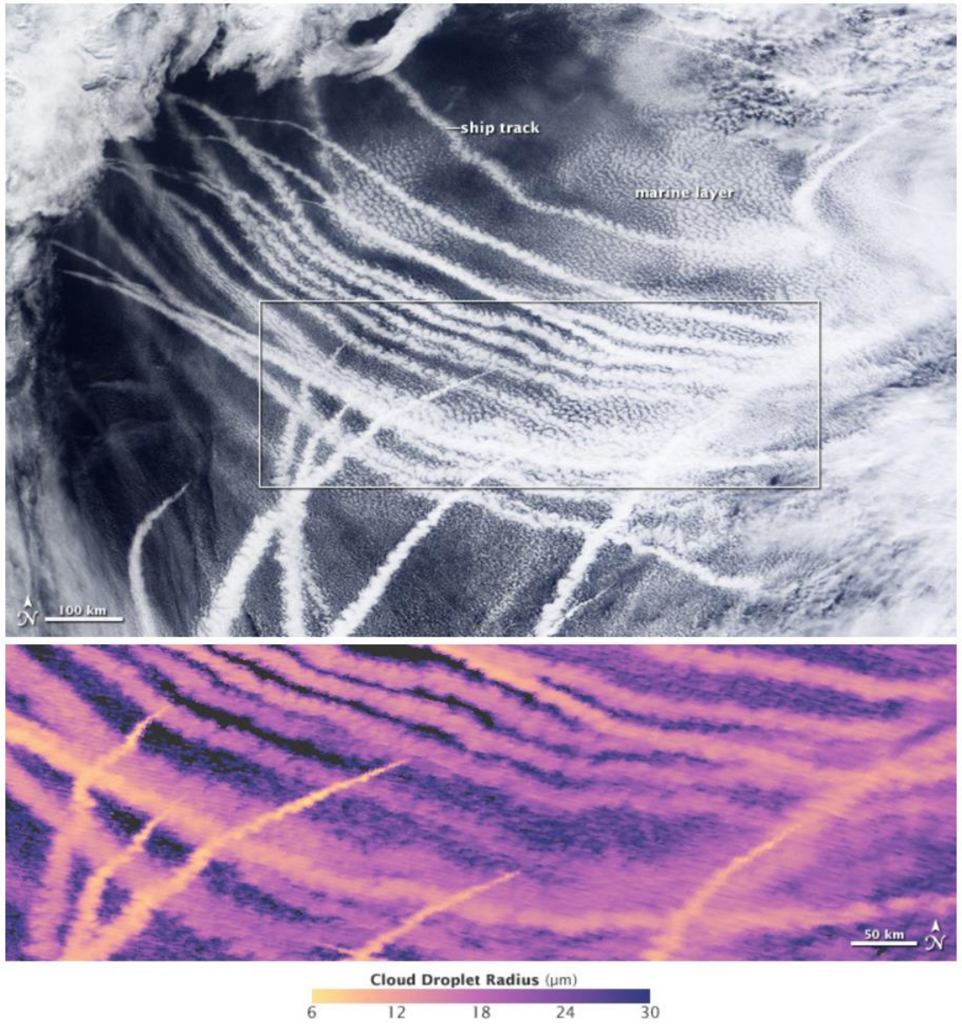
Distinguishing Aerosol Effects from Meteorological Impacts on Low Cloud over the Global Ocean

(work in progress)

Joel Norris

Spring 2021 CERES-Libera Science Team Meeting

Aerosol Effects on Low Clouds



Potential aerosol effects:

- Higher droplet concentration
- Reduced droplet radius
- Enhanced optical depth
- Greater cloud fraction

Challenging to assess at large scales due to complex interaction between microphysics, turbulence, and meteorology

Credit: NASA Earth Observatory

What’s New in this Presentation?

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Observed Sensitivity of Low-Cloud Radiative Effects to Meteorological Perturbations over the Global Oceans

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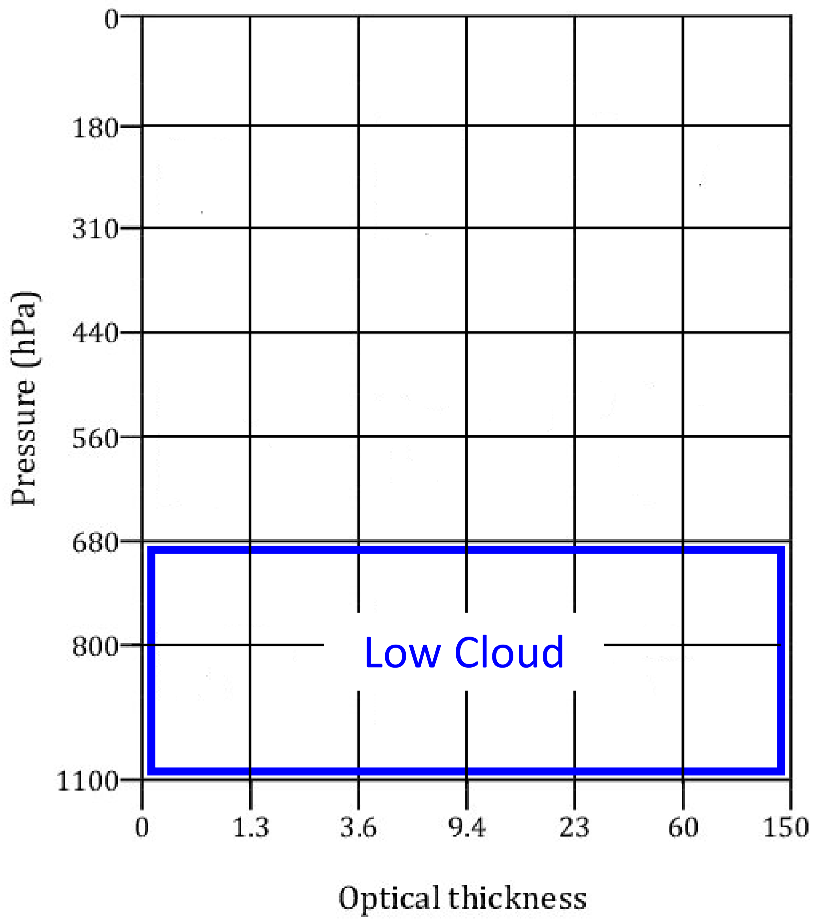
Constraints on Low Cloud Feedbacks from Observed Climate Variability

(yesterday’s invited presentation by Tim Myers)

- Low cloud and radiative properties distinguished from upper cloud properties using Flux-by-Cloud-Type
- Actual changes in low cloud fraction distinguished from that due to changes in obscuration by upper clouds
- Meteorological impacts on low cloud distinguished from aerosol effects following method of *Scott et al.* (2020) and *Myers et al.* (2021)

Low Cloud Radiative Properties from Flux-by-Cloud-Type



Average cloud properties and radiation flux across all bins with pressure > 680 hPa

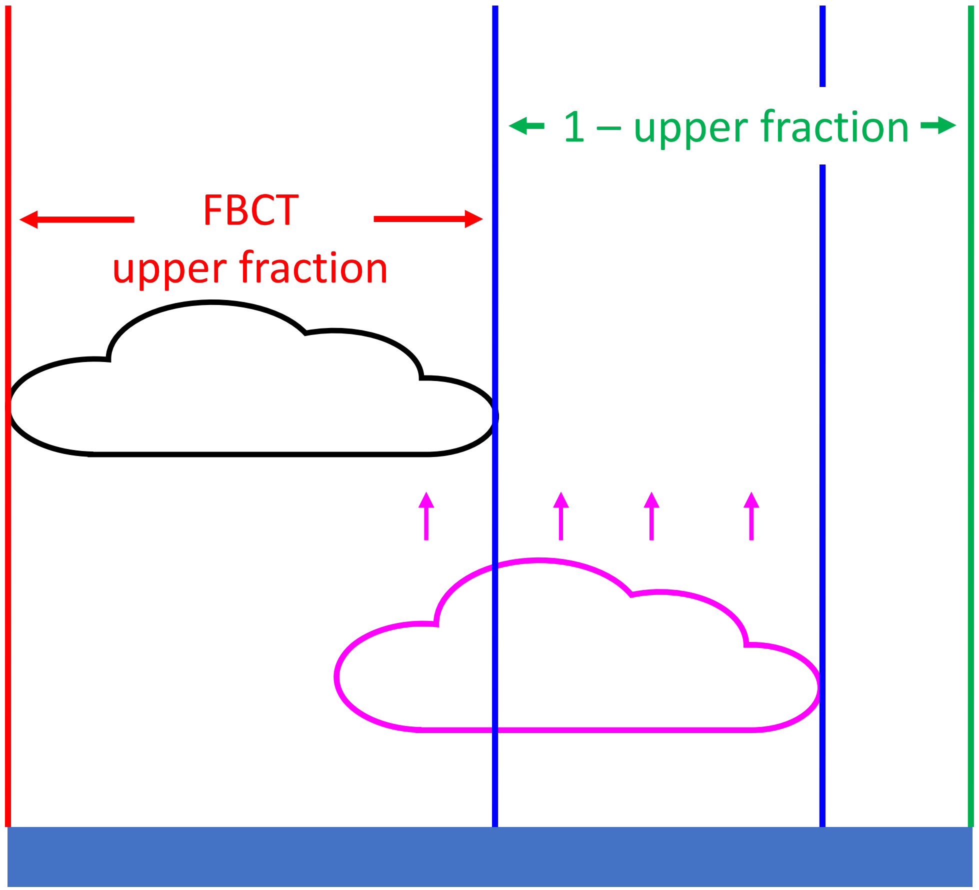
Low cloud SW = Low fraction · SW_{low}

Contribution from cloudy-sky flux = Low $fraction_{clim}$ · $(SW_{low})_{anom}$

Contribution from cloud fraction = Low $fraction_{anom}$ · $(SW_{low})_{clim}$

Radiation flux is defined as positive upward!

Adjusting for Obscuration by Upper Clouds



Assume random overlap between low fraction and upper fraction

Actual low fraction =

FBCT low fraction / (1 – upper fraction)

Scale radiation anomalies by climatological fraction not overlapped by upper cloud

Scaled low cloud SW =

$\text{low cloud SW}_{\text{anom}} \cdot (1 - \text{upper fraction})_{\text{clim}}$

Distinguishing Meteorological Impacts from Aerosol

Approximate low cloud SW anomalies as response to variability in meteorological and aerosol conditions

$$\Delta SW \approx \sum_i \frac{\partial SW}{\partial m_i} \Delta m_i + \frac{\partial SW}{\partial A} \Delta A$$

low cloud radiative response to variations in meteorological conditions m_i

low cloud radiative response to variations in aerosol conditions A

Apply multilinear regression using same predictors as *Scott et al.*, *Myers et al.*:

SST, EIS, near-surface temperature advection, ω_{700}, RH_{700}, surface wind speed

How to Represent Aerosol?

- We want measurements of number concentration of CCN going into cloud

  … but we have only measurements of scattering by aerosol outside of cloud

- Relative humidity increases aerosol particle size and scattering cross section

  … use RH_{850} and RH_{925} as additional predictors to mitigate this effect

- MODIS AOD retrievals may be contaminated by cloud (e.g., *Loeb and Manalo-Smith* 2005, *Zhang et al.* 2005)

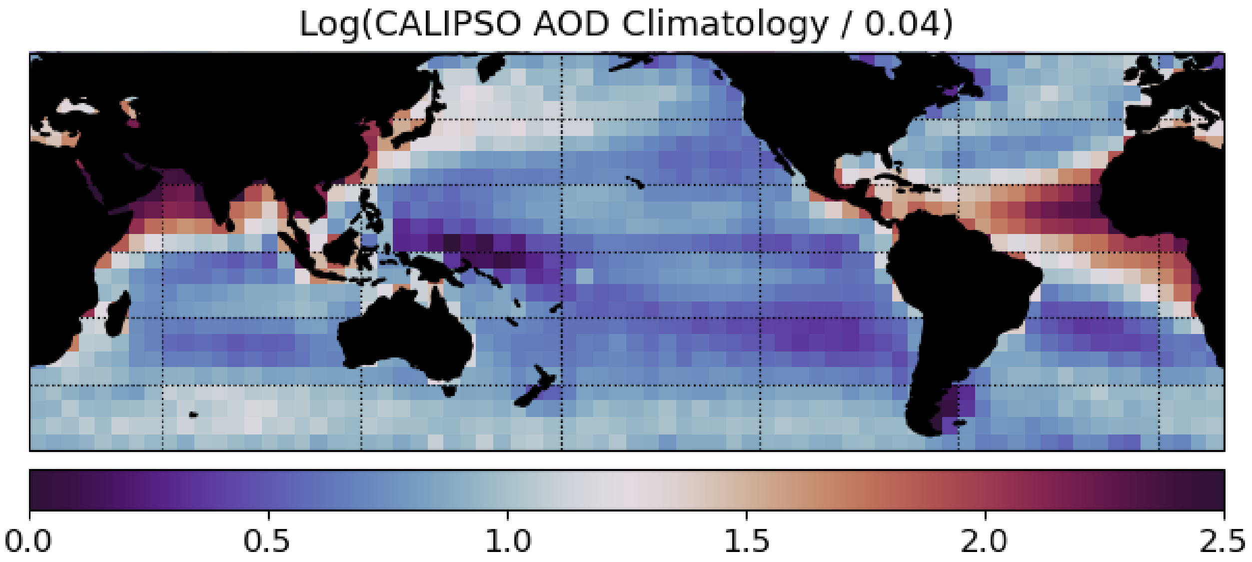
  … use CALIPSO AOD from nighttime cloud-free columns

How Has Aerosol Changed since Pre-Industrial Times?

- Estimate as the ratio between the 2006-2020 AOD climatology and a “clean” ocean background value

  … Smirnov et al. (2002) measurements suggest AOD_{clean} = 0.07

  … CALIPSO AOD is around 0.04 over some areas of the ocean

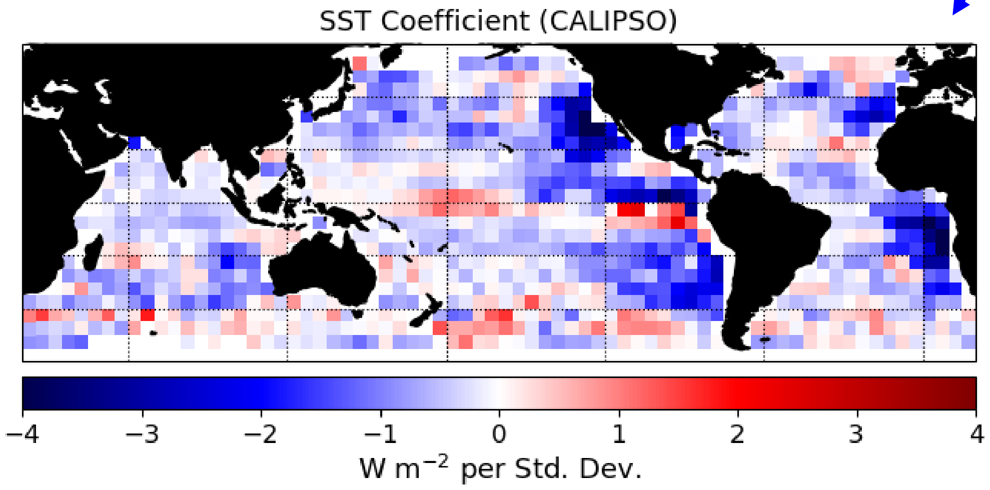


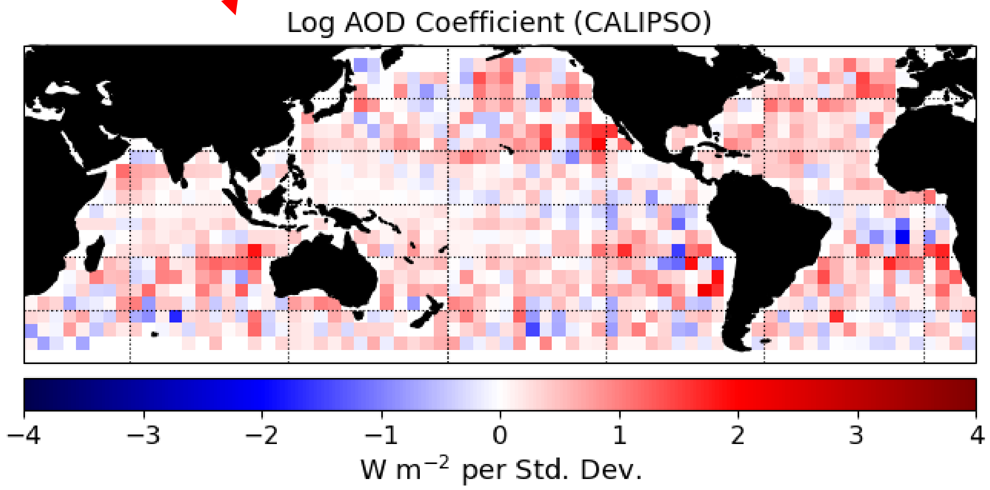
Analysis Details

- All data are averaged to 5°×5° monthly values and then deseasonalized
- Long-term trends are removed from each anomaly time series to avoid artifacts
- Meteorological and aerosol predictors are standardized to remove dimensionality
- Time period is July 2006 – June 2020
- Spatial domain is ocean equatorward of 55° latitude
- Use log(AOD) as aerosol predictor for sensitivity at low concentration

Low Cloud SW Radiative Response Coefficients

$$\Delta SW \approx \sum_i \frac{\partial SW}{\partial m_i} \Delta m_i + \frac{\partial SW}{\partial A} \Delta A$$



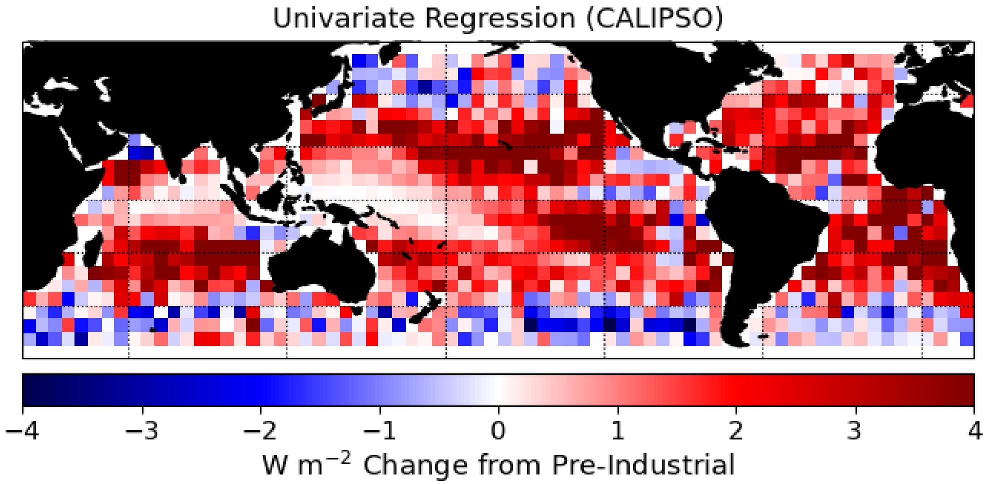


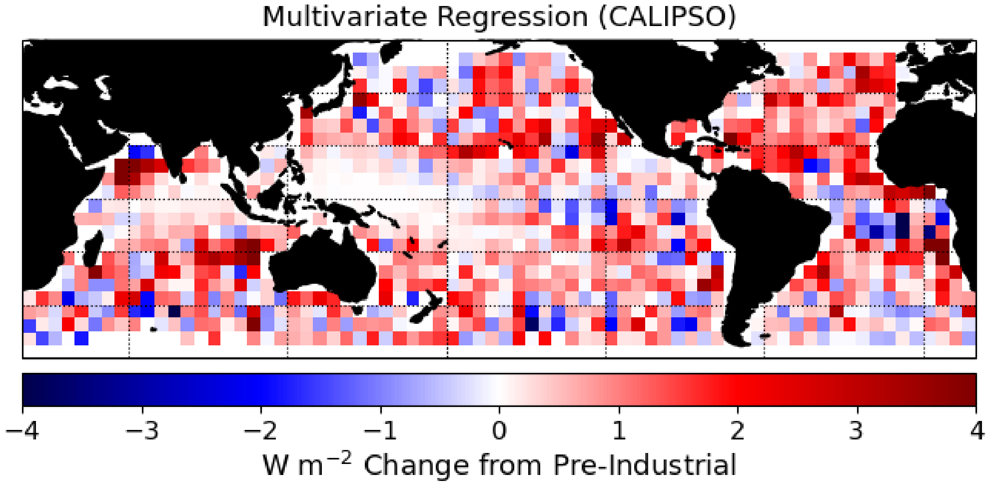
Low Cloud SW Radiative Response to Aerosol Change

$$\frac{dSW}{dA}\Delta A$$

Estimated change from pre-industrial conditions

$$\frac{\partial SW}{\partial A}\Delta A$$

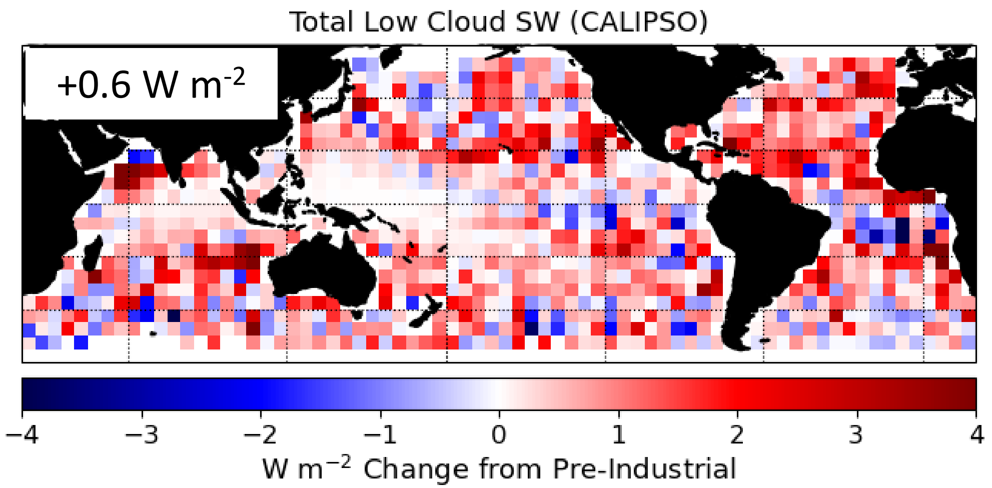


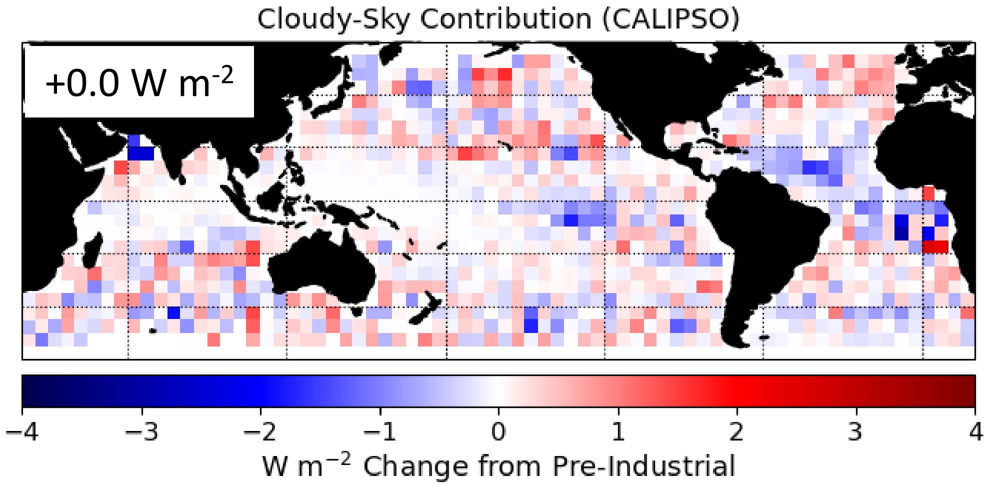


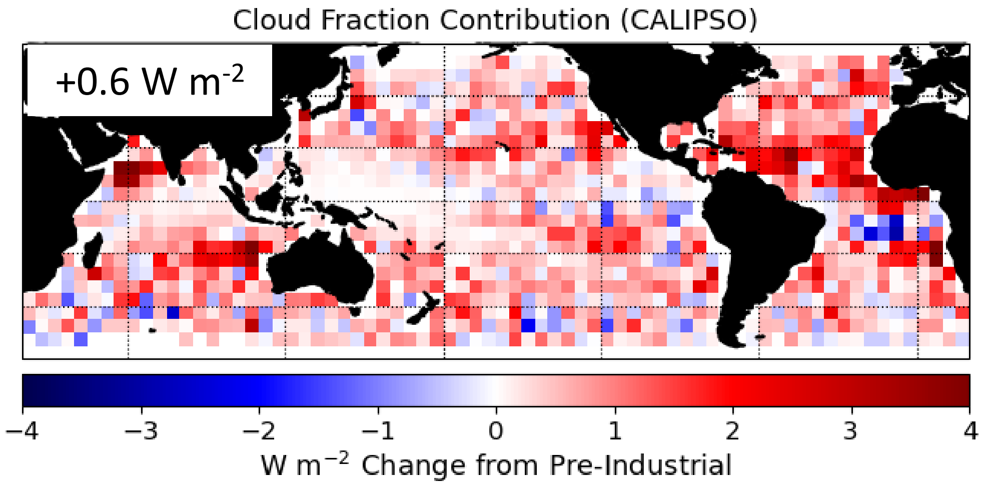
Univariate 55°S–55°N ocean average:
+1.4 W m^{-2} change from pre-industrial

Multivariate 55°S–55°N ocean average:
+0.6 W m^{-2} change from pre-industrial

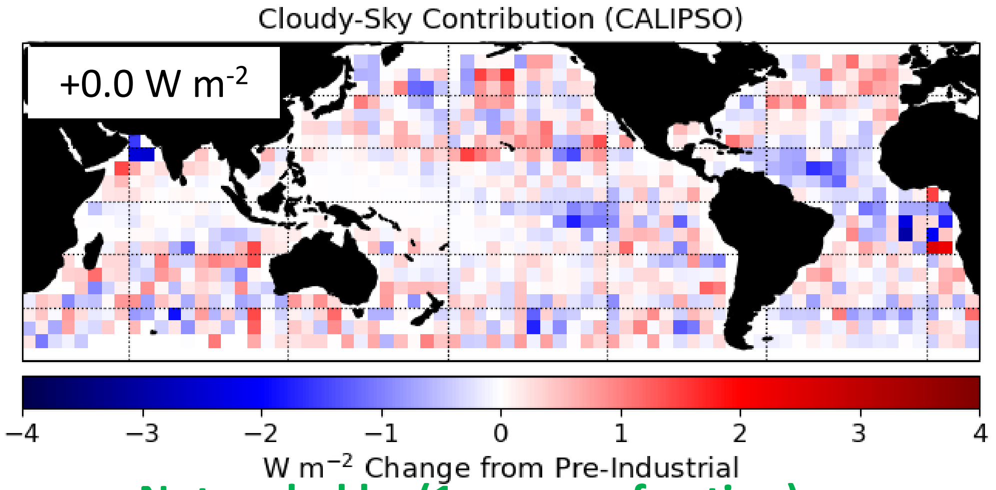
Cloudy-Sky and Cloud Fraction Radiative Contributions



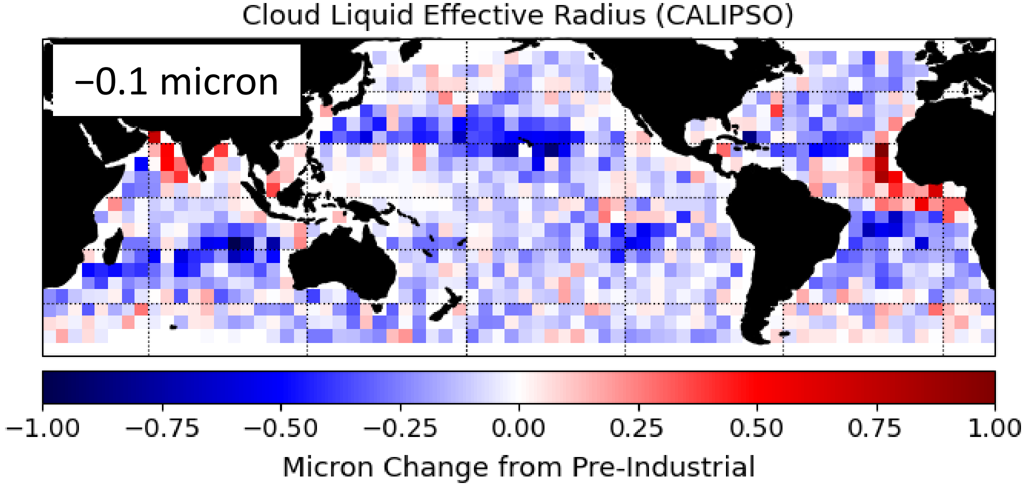


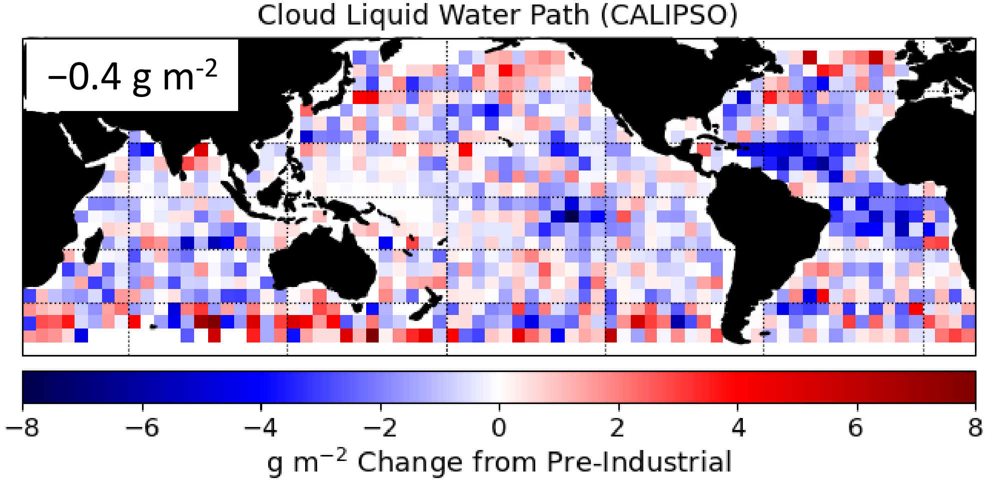


Interpreting the Cloudy-Sky Contribution

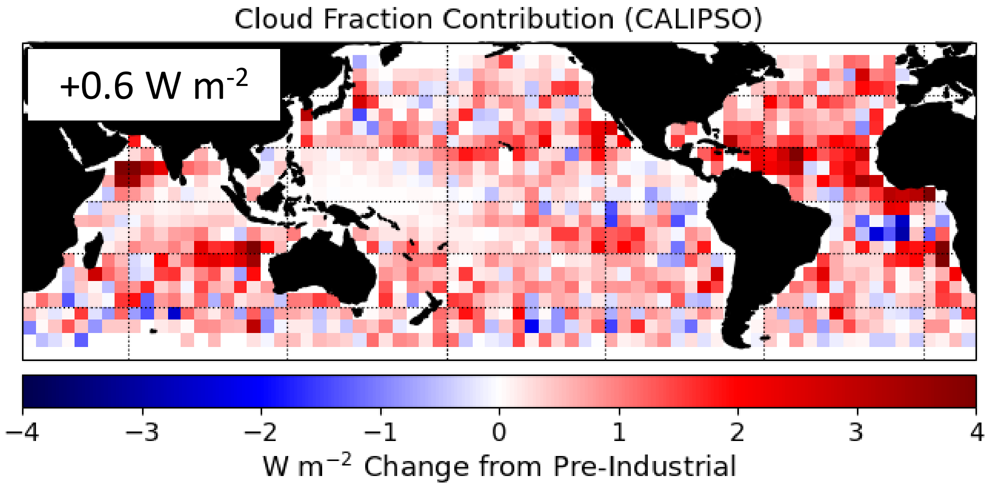


Not scaled by (1 – upper fraction)$_{clim}$

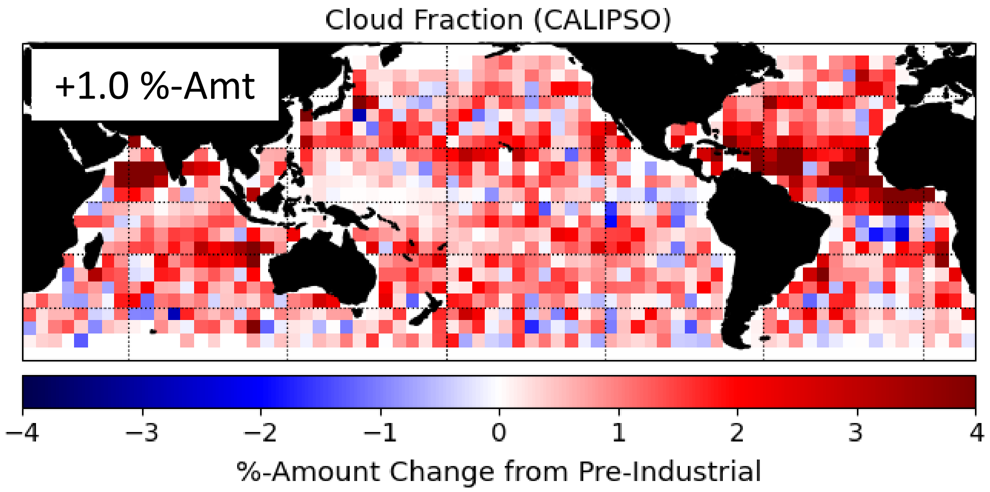




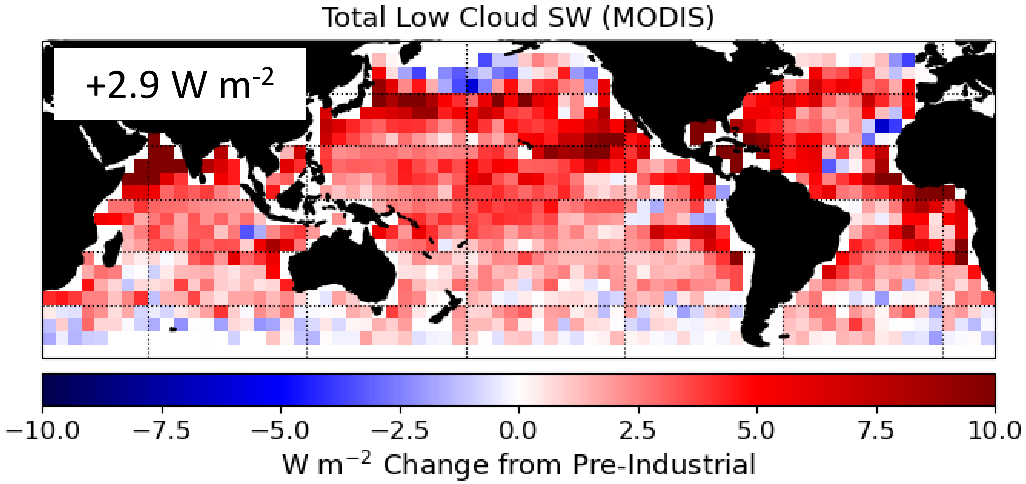
Interpreting the Cloud Fraction Contribution



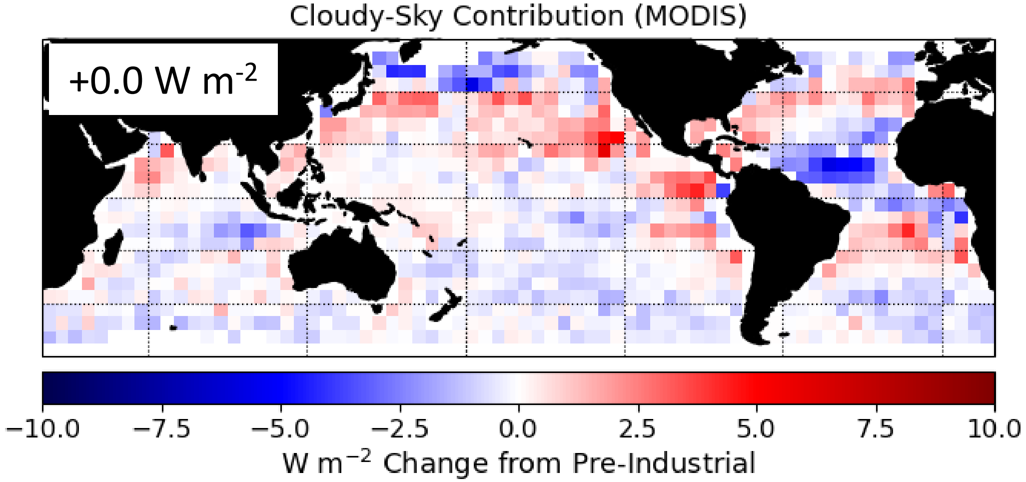
Not scaled by (1 – upper fraction)$_{clim}$

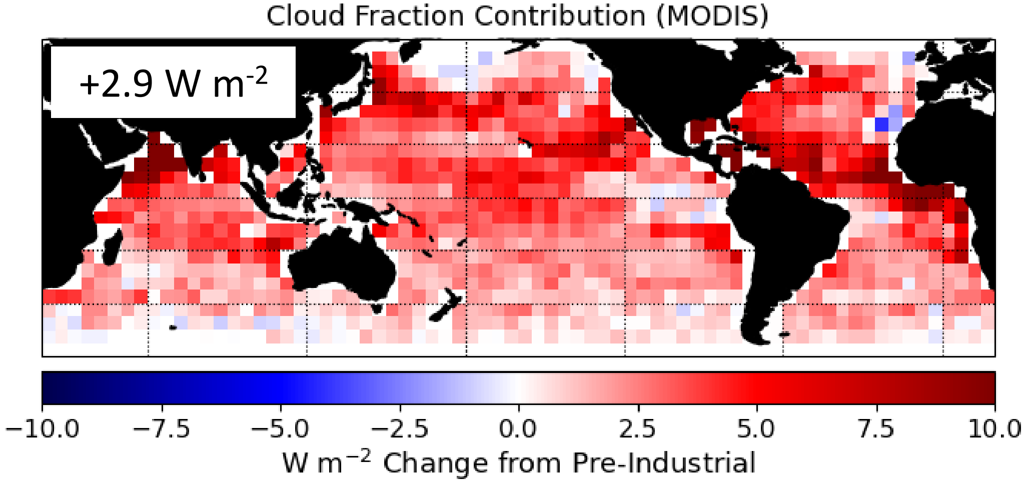


MODIS Cloudy-Sky and Cloud Fraction Contributions



$AOD_{clean} = 0.07$





Summary

- Low cloud SW response to CALIPSO AOD is approximately halved when co-variations with meteorology are taken into account
- Low cloud SW response to CALIPSO AOD is almost entirely caused by changes in cloud fraction rather than cloudy-sky radiation flux
- A very rough estimate suggests that changes in aerosol since pre-industrial times increased average oceanic low cloud SW reflection by 0.6 W m^{-2}
- Results obtained using MODIS AOD are five times larger than results obtained using CALIPSO AOD

Questions

- Is there a physical process by which aerosol would both reduce water content and increase the horizontal extent of low clouds?
- Are cloud effects more likely to influence CALIPSO AOD retrievals when clouds have lower LWP and greater horizontal extent?
- Is AOD (or extinction within an atmospheric layer) a poor measure of the aerosol that influences on low cloud?
- If a real and substantial aerosol effect were present, would it be larger than what is seen with CALIPSO AOD?

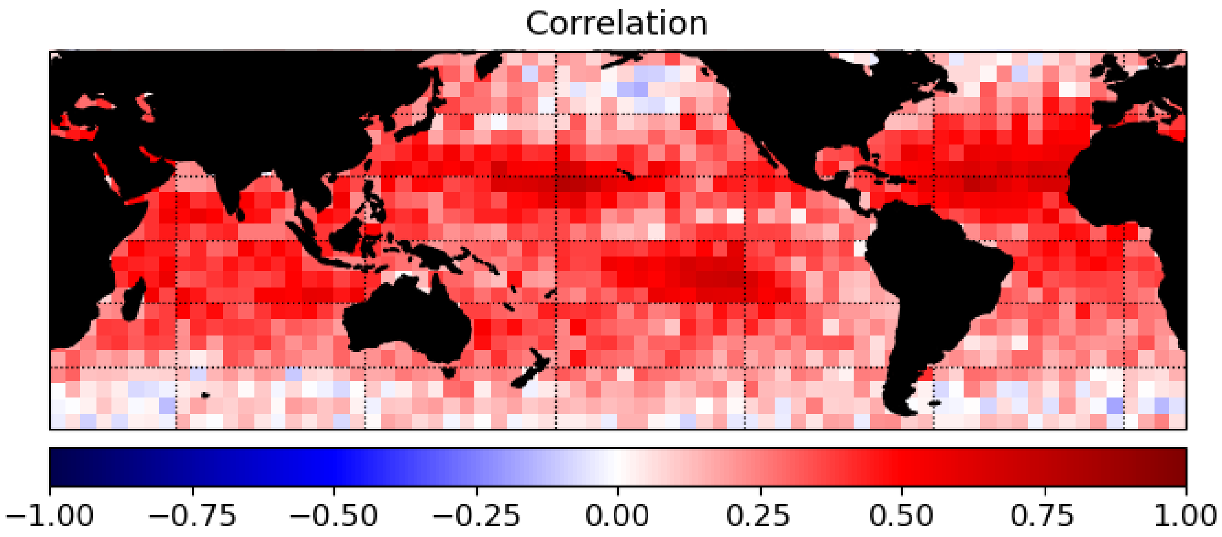
Conclusions

- Meteorology is likely to be not the only confounding factor in observational estimates of the low cloud SW response to aerosol
- Estimating the low cloud SW response to aerosol will require a careful approach to mitigate retrieval artifacts and sampling biases

Thank you!

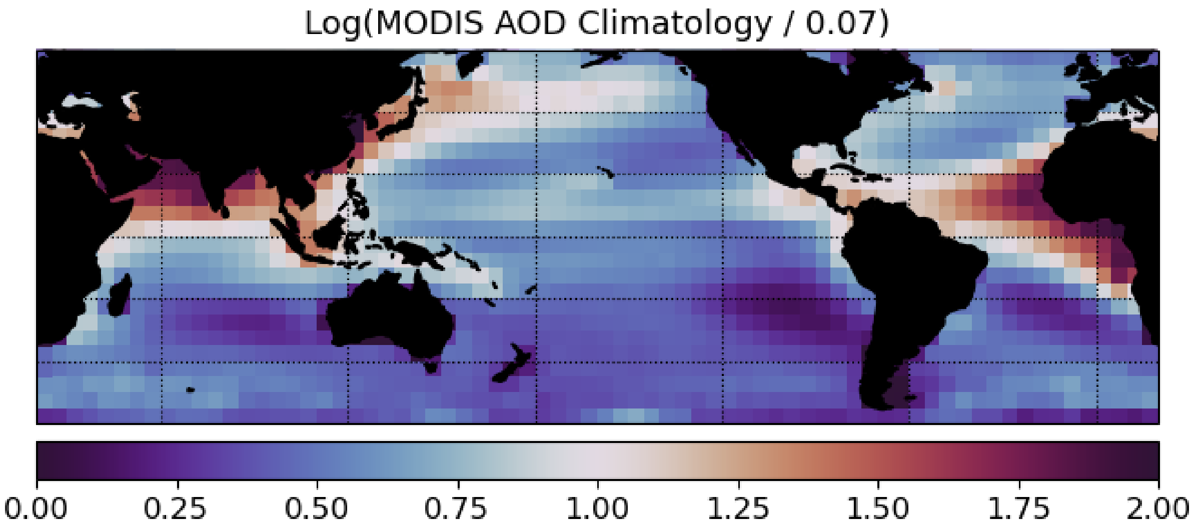
Extra Slides

CALIPSO–MODIS Correlation

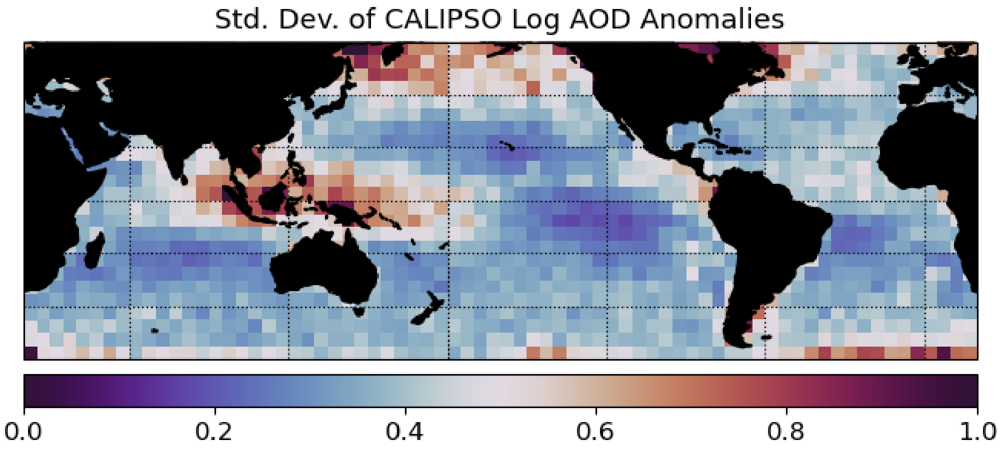


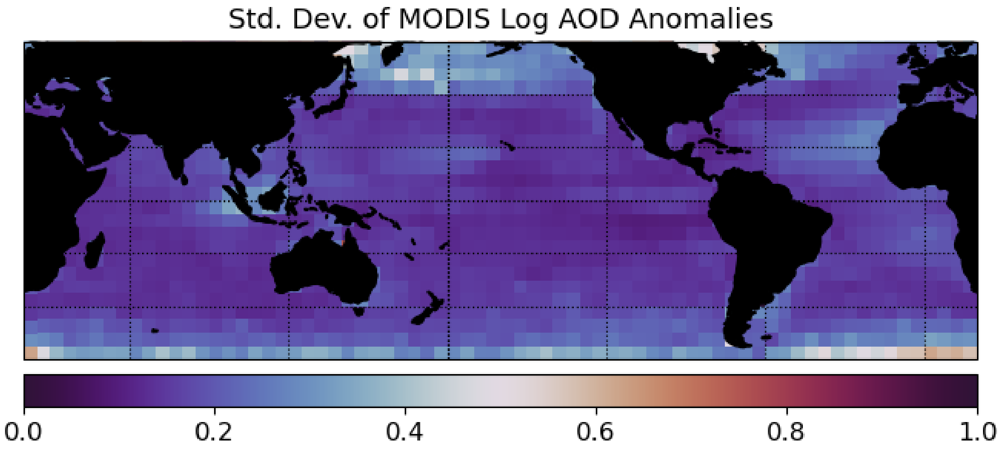
log(MODIS AOD) anomalies
log(CALIPSO AOD) anomalies

MODIS Climatology Ratio



Standard Deviation of Anomalies





MODIS Cloud Fraction