Main Points

Clean conditions as a proxy for pre-industrial

We agree that a set of "clean" observations defined by a limit in the aerosol index may not be the perfect proxy for pre-industrial conditions, however we view our work as a frameowrk for how this could be done. In the future, combining more limits on other environmental parameters in order to define the "clean", pre-industrial proxy set could help set the clean conditions to better match the pre-industrial environment. If we limit the number of observations in our clean set, we do run the risk of having an unrepresentative "pre-industrial" set of observations as compared to the present day set. In causal inference, this would lead to a positivity assumption, whereby an unperturbed cloud does not have a perturbed proxy or vice versa. To avoid violating the positivity assumption in our work, we chose to only set one constraint to define our "clean", pre-industrial proxy, as other methods would require more abstract machine learning methods such as represenation learning that are less interpretable and more prone to error due to the model chosen (Tec et al. 2022).

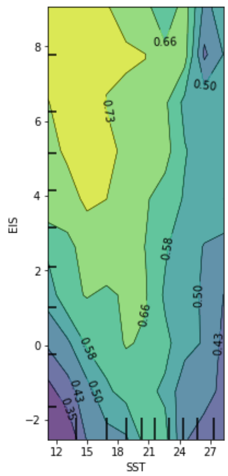
We have added as a caveat to our methods section: "It is likely that our clean set does not perfectly reflect the true nature of pre-industrial clouds. Creating counterfactuals requires us to not violate the positivity assumption, whereby the clean set of observations the models are trained on are representative of the possible conditions contained in the polluted scenes. In the future, representation learning similar to Tec et al. 2022 could be used to create a better representation of the pre-industrial environment without violating this base assumption."

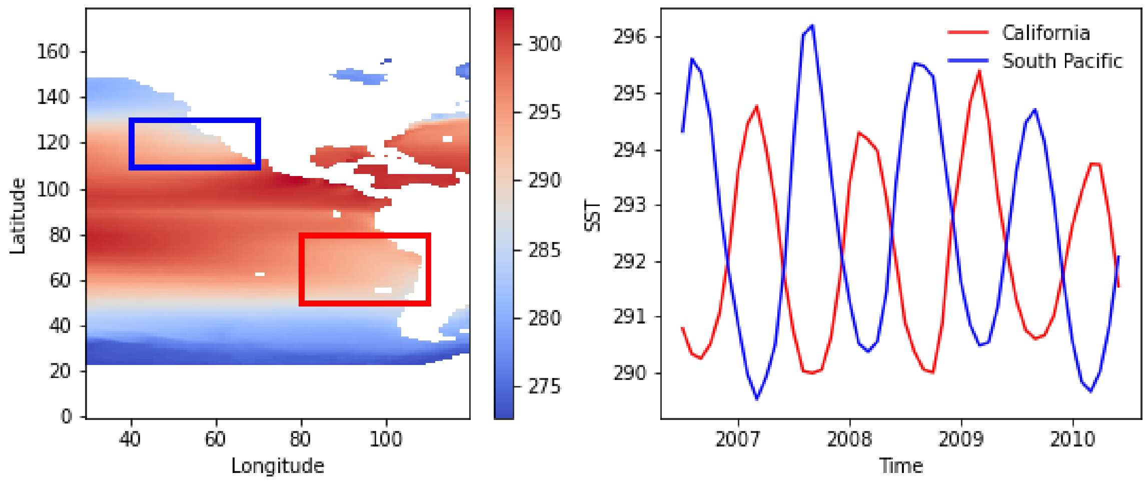
Southern hemispheric change

This is likely due to two factors:

1. Warm clouds are more likely in the southern hemispher and therefore have larger changes when weighted by their occurrence.
2. The regime of stability and sea surface temperatures of the southern atmosphere cloud decks leads to larger sensitivities.

As shown in Figure 10 (right), there is a large regime of cool sea surface temperatures and high stabilities that exhibits the largest cloud fractions. This regime most likely coincides with the clouds of the California stratocumulus, the region of most frequent warm clouds in the northern hemisphere. These clouds are likely less sensitive as their cloud fractions are already extremely high and in that sense they are at a "saturated" point of cloudiness. Though their difference in sea surface temperature is only a few degrees (see map and trends of two regions below), this few degree difference shifts the California region to a more cloudy regime that is less sensitive to aerosol even at the same stability.





Uncertainty Range

We agree that it is optimal to be transparent about our uncertainty range, as it is not the same as an uncertainty range from an Earth system model or sensitivity analysis that then compounds uncertainty. We have repeated our uncertainty limitations in the forcing section of the results:

"Not measured within this uncertainty range is how our technique, and the imperfect use of AI limits as a proxy for pre-industrial esque versus present day clouds, leads to either an over or underestimation of the effect. This type of epistemistic knowledge is difficult to quantify; in the future, applying "uncertainty aware" models that quantify how unknown factors may alter the prediction could remedy this fault (Jesson et al. 2020)."

Minor points

L12: Updated to include newest IPCC report section on Short-lived Climate Forcers.

L28: Removed Rosenfeld and replaced with opportunistic/natural labs reference as that demonstrates the spread in LWP estimates better than two conflicting papers.

L28-31: Rephrased to "Similarly, although increased cloud extent should in theory be an obvious to observe, due to confounding relationships it remains difficult to isolate the change in cloudiness due anthropogenic aerosol from environmental changes."

L40: Added: "Andersen et al. 2017 set some groundwork in using a simple artificial neural network (ANN) to understand cloud properties, but was limited by the shallow depth of the network (2 layer ANN) in fully capturing and translating the global drivers... Our ML models differ from an ANN as decision tree models can have variable depths dependent on the data itself, allowing for better representation of multivariate, non-linear interactions like those between clouds and the environment."

L70: Rephrased to "a majority of the uncertainty" as our methodology itself is the main source of uncertainty, not the use of AI/AOD/Nd as a proxy for anthropogenic aerosol.

L75: Fixed to subsection.

L80: Fixed to only have AI defined as an acronym once.

L143: A higher resolution version of SST from AMSR-E is available as a CloudSat auxillary product. Added: "...available from the AMSR2-AUX CloudSat product." to clarify the source of the data.

L156: Yes, we have clarified this definition of SW CRE.

L229: Reworded to: "We quantify only the changes for scenes which were already cloudy, as we believe delineating how cloud fraction may have increased is different in nature than how cloud occurrence may have changed due to anthropogenic aerosols."

L267: This was included due to feedback that SPRINTARS results may differ from other models' results.

Figure 4 Caption: These results have been weighted by the occurrence of warm clouds within each 15° x 15° region.

L287: Yes, Gryspeerdt et al. 2019 used a joint distribution, but ultimately found a sensitivity by fitting two linear relationships depdent upon "low" and "high" values of Nd. (https://acp.copernicus.org/articles/19/5331/2019/#section2)

L305-308: Reworded to: "If our hypothesis had been wrong, and aerosol's significance to cloudiness was greater than the environment's, the explained variance scores would be lower as variation due to aerosol would not be learned by the models. Instead, we see that our simple ML models do exceedingly well at learning the patterns of cloudiness associated with the clean environments (Figures 6, 7)."

L322: Rephrased to: "Changes in cloud occurrence, i.e. whether aerosol or climate change lead to more or less clouds developing, are difficult to quantify and remove from our estimates. In the future, finding a way to evaluate how cloud occurrence itself may have change would be invaluable to understanding ACI."

Fig 11: This was an error (96 vs 12 written in Latex) and has been corrected. The two images are now correct, though they do look alike.

References

Tec, M., Scott, J., & Zigler, C. (2022). Weather2vec: Representation Learning for Causal Inference with Non-Local Confounding in Air Pollution and Climate Studies. arXiv preprint arXiv:2209.12316.