The El Niño Impact Process on Tropical Aerosols and Trace Gases

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INTRODUCTION

MOTIVATION:

In 2015, emissions from widespread fires in Indonesia caused over 500,000 cases of acute respiratory infection.[1] The 2015 biomass burning—and similar events in 1982 and 1997—share a common driver: abnormally strong El Niño-Southern Oscillation (ENSO) signals. Understanding this ENSO-driven causal process could help enable future prediction and prevention of uncontrolled Indonesian fires.

BACKGROUND:

- ENSO, the irregularly periodic warming across the central and eastern Pacific, drives numerous large-scale changes in atmospheric and ocean dynamics.
- One such change is a reversal in the Walker circulation anomaly which negatively impacts precipitation in the western Pacific rim.
- **Combined with agricultural burning in the area, decreased precipitation and soil moisture contribute to widespread burning of the Indonesian peat-land.**
- This study highlights fire emissions of black carbon (BC) aerosol and carbon monoxide gas (CO), which both lower air quality, using data from the Modern Era Retrospective Analysis for Research and Applications – version 2 (MERRA-2).

DATA AND METHODS

- Sea surface temperature, total land precipitation, soil moisture, and BC and CO column data obtained from MERRA-2.
- Aerosol emissions obtained from the Quick Fire Emissions Dataset (QFED), derived from Moderate Resolution Imaging Spectroradiometer (MODIS).
- CO comparisons from the MERRA-2 Global Modeling Initiative (GMI) replay simulation and the Measurement of Pollution in the Troposphere (MOPITT) daytime CO product (V6).
- Relevant data fields examined to determine correlations.
- Existing literature used as comparison for calculated values from MERRA-2.

1 – EL NIÑO

- ENSO is the primary driver behind variability in the tropics.[2]
- The ENSO events of 1982/83, 1997/98, and 2015/16 registered a temperature anomaly of greater than +2 °C (above 0.5 °C is considered an El Niño) based on the commonly-used Niño-3.4 index.

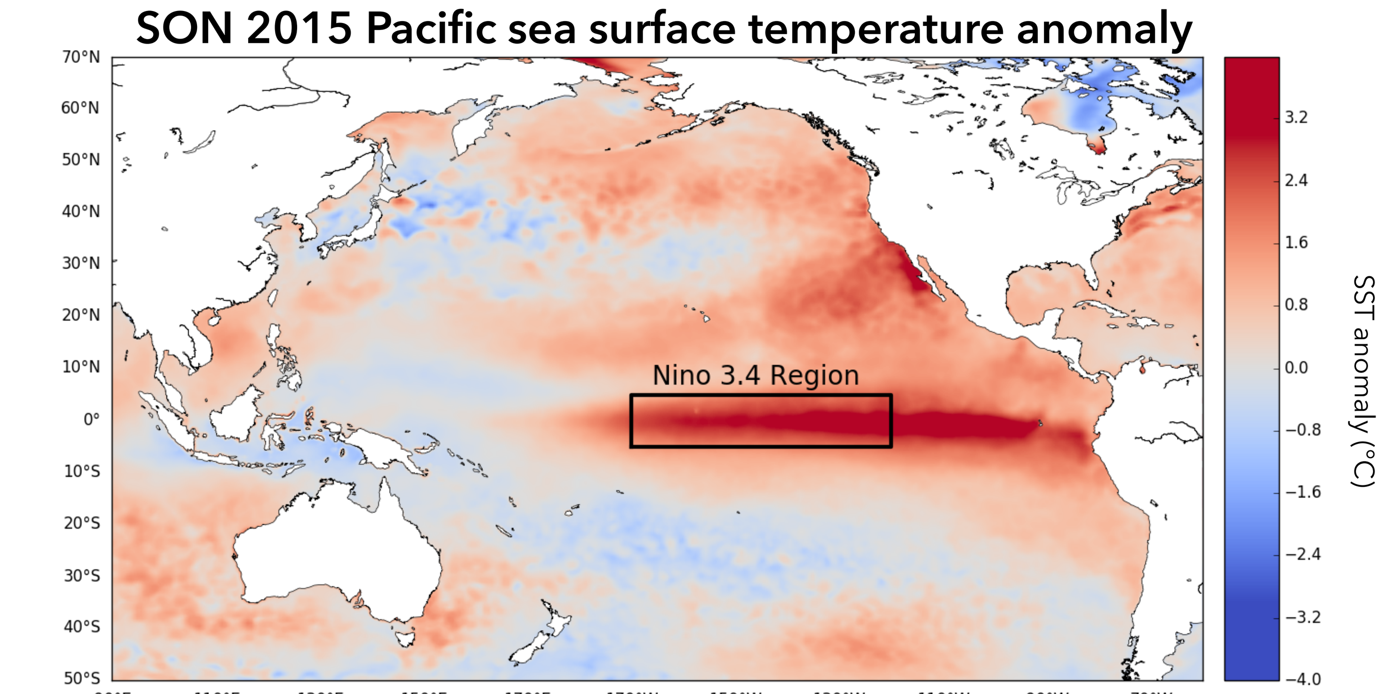


FIGURE 1. September-October-November average. The Niño 3.4 region extends from 5°S – 5°N and from 170°W – 120°W. Data from MERRA-2 skin temperature.

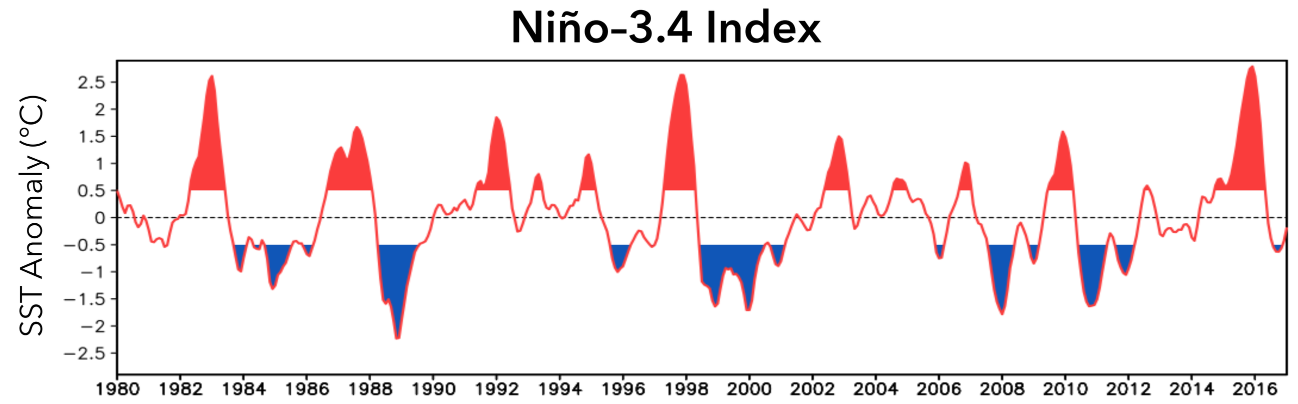


FIGURE 2. Niño-3.4 Index smoothed with a 3-month running average. Shaded above and below 0.5 °C (note the large positive anomalies in 1982, 1997, and 2015). Data obtained from NOAA/Climate Prediction Center.

2 – PRECIPITATION

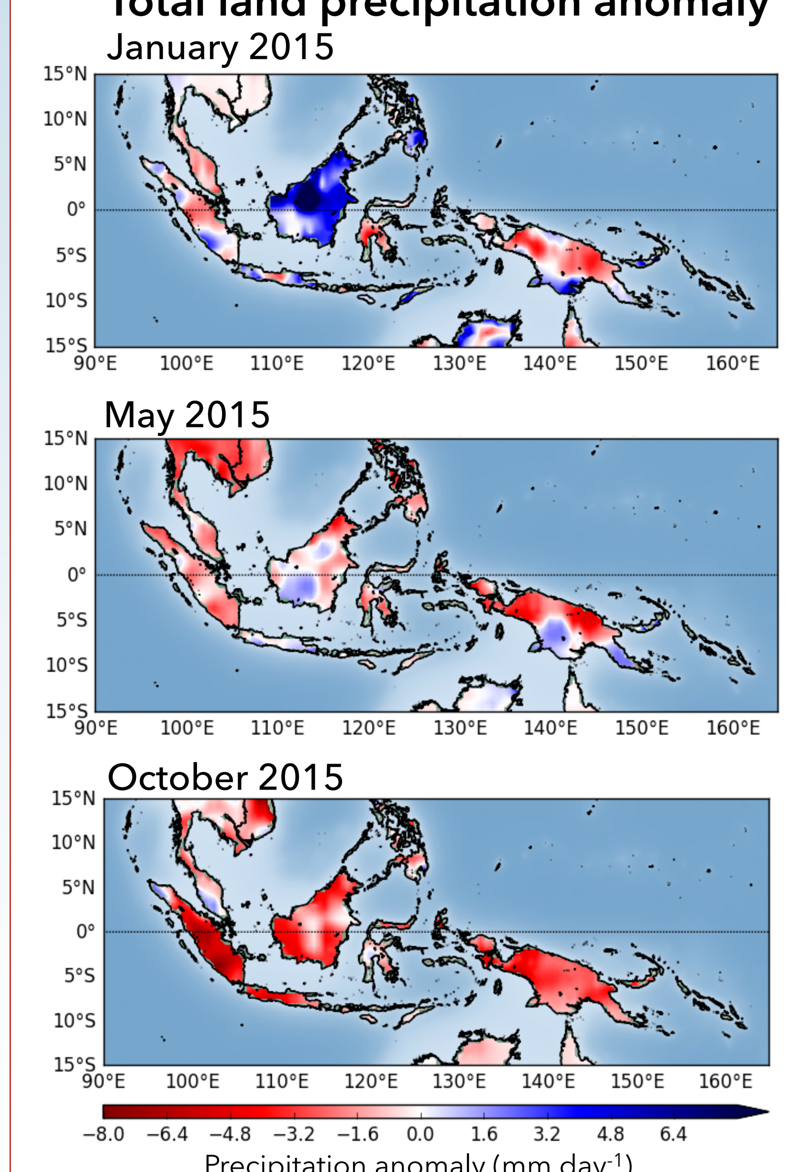


FIGURE 3. As the 2015 El Niño progressed, rainfall deficits increased across Indonesia and Malaysia. From MERRA-2 land precipitation (bias corrected).

- The ENSO-induced Walker circulation reversal results in decreased western Pacific convection.[2]
- Weaker convection inhibits vertical moisture transport from the lower troposphere, lessening precipitation over Indonesia.
- Field *et al.* (2016) showed that severe burning years occur when rainfall drops below 4 mm day^{-1} for an extended period.[3]
- Analysis of MERRA-2 precipitation agreed with Field *et al.*, as severe burning events occurred only during 3+ month periods of sub-3 mm day^{-1} monthly averaged rainfall.
- Lessened precipitation led to a 6-11% reduction in top-meter soil moisture across the three burning seasons (not shown).

3 – FIRE AND EMISSIONS

- As a result of decreased precipitation, Indonesia saw colossal biomass burning events in September/October of 1982, 1997, 2006, and 2015 (2006 event was not driven by strong ENSO).
- **The low-heat smoldering of peat fires is difficult to detect remotely.**
- QFED uses MODIS Fire Radiative Power (FRP) measurements, which are heavily biased with respect to peat fires.
- Agricultural fires are generally smaller and more scattered than forest fires, presenting another challenge for MODIS.

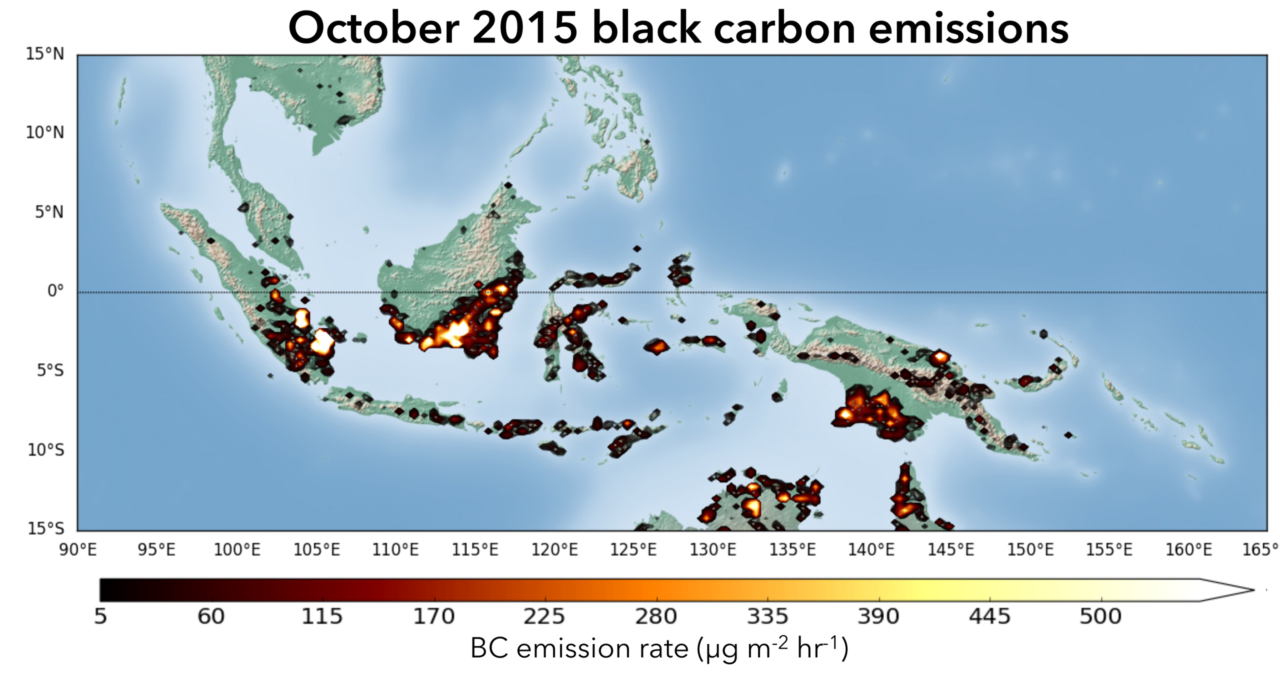


FIGURE 4. Emissions from QFED during the 2015 burning season.

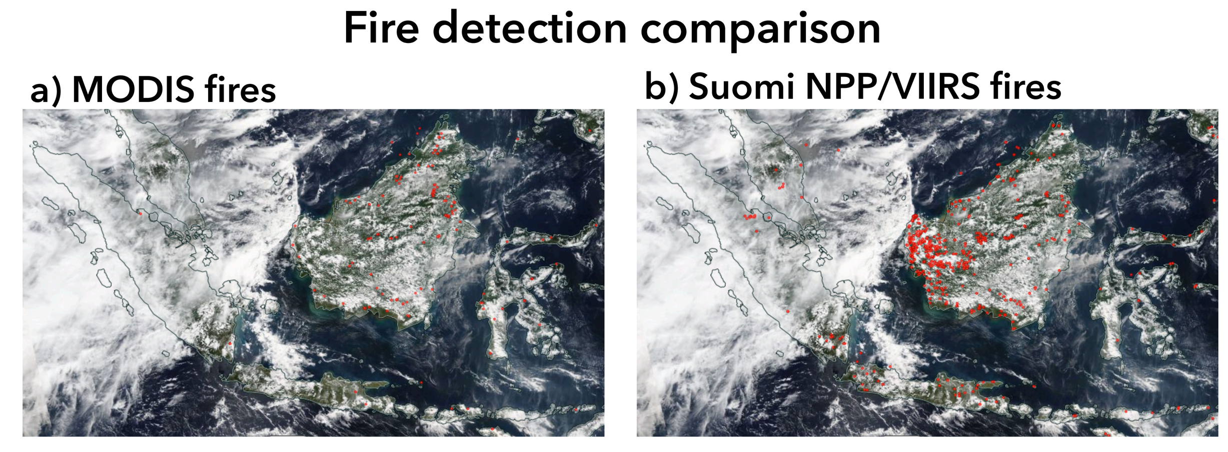
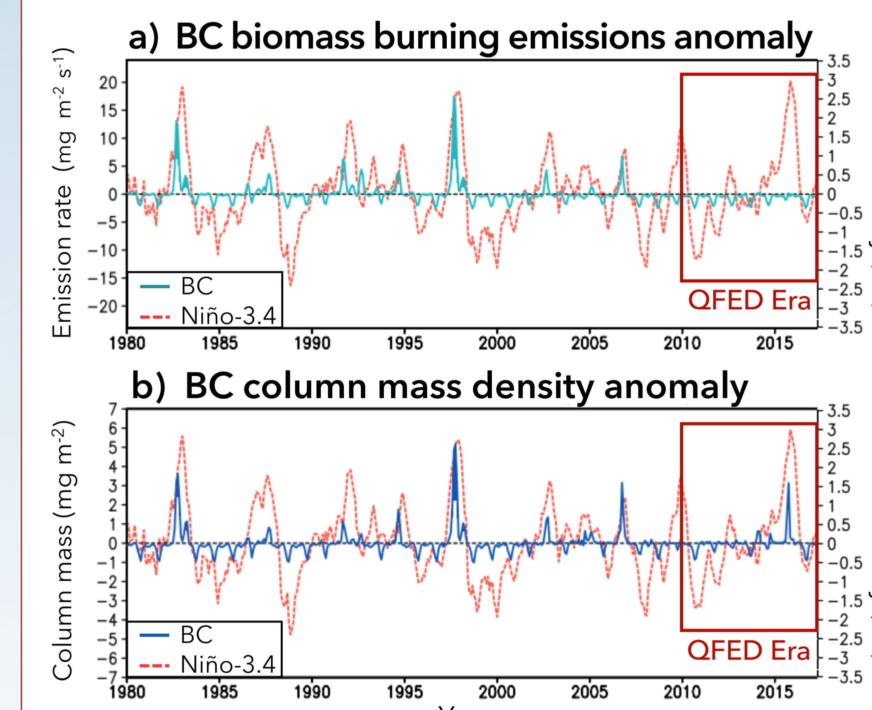


FIGURE 5. True-color images from Aug. 24, 2016. The 250m resolution of VIIRS (Visible Infrared Imaging Radiometer Suite) more effectively detects Indonesian fire signals, as MODIS's 1km resolution does not record as many observations.

4 – AEROSOLS AND GASES



- Dark aerosols contribute to surface cooling and tropospheric warming, creating a drought feedback loop by further decreasing convection.[2]
- MERRA-2 column aerosol assimilation partially corrects low-biased QFED BC emissions.
- MERRA-2 GMI atmospheric chemistry replay more accurately represents observed CO conditions from MOPITT.

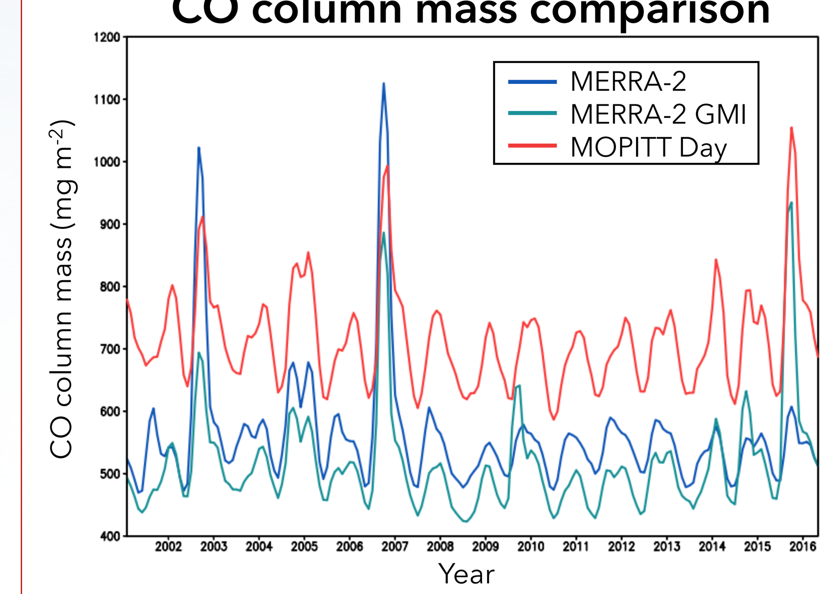


FIGURE 6. (Top) MERRA-2 switched its emissions input data from homogenized monthly means (HFED) to QFED in 2010. BC column mass in **b)** partially preserves the expected emissions rise in 2015. Both shaded above monthly mean + two standard deviations (visible in 1997).
FIGURE 7. (Left) The GMI + chemistry replay switched to daily emission inputs in 2000. All smoothed with a 3-month running average.

All from 10°S – 7°N and 90°E – 165°E.

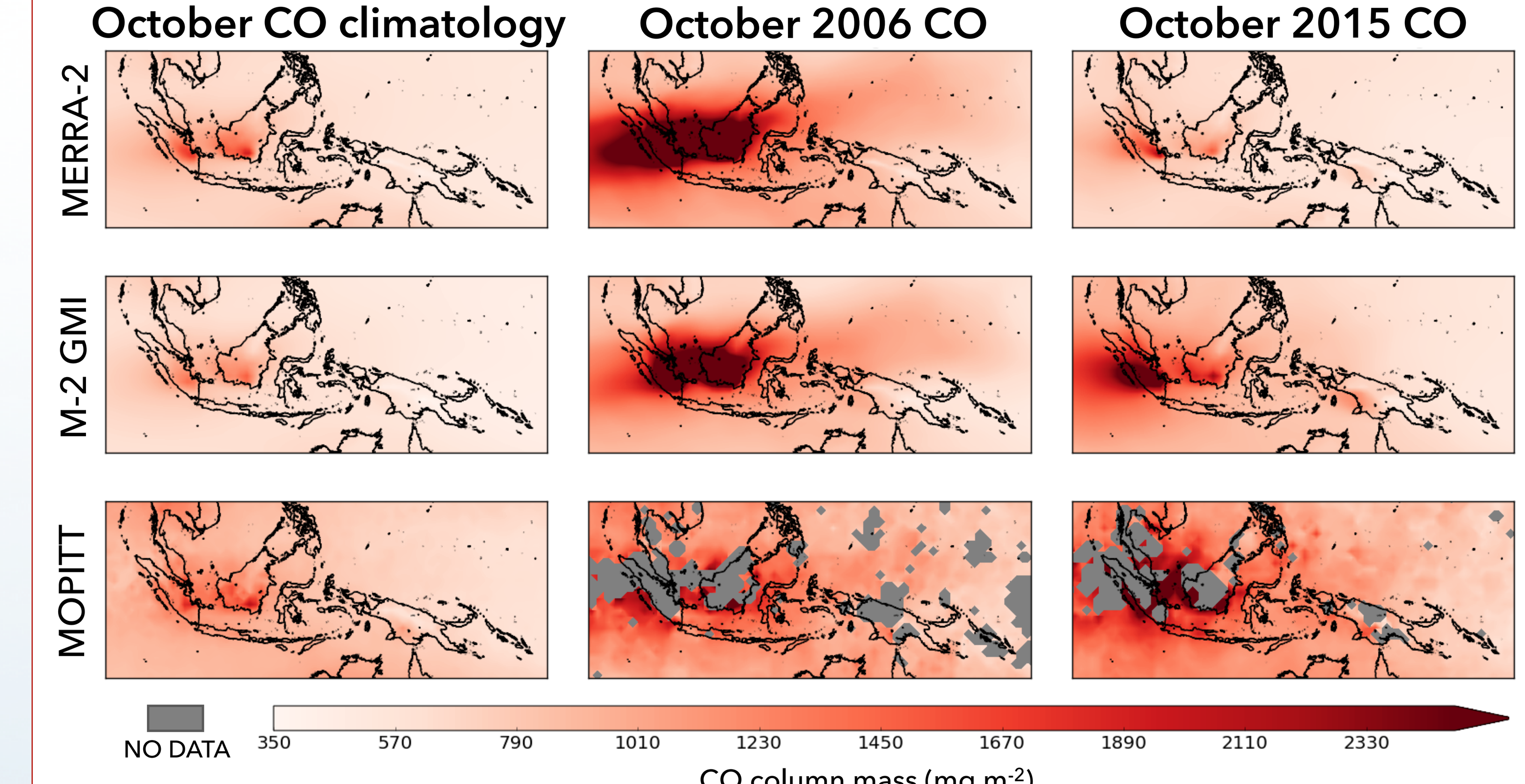


FIGURE 8. 2001-2015 October climatology compared to a high emission year (2006) and the ENSO-driven 2015 season.

CONCLUSIONS

- MERRA-2 data agreed with the expected ENSO–drought–fire impact process.
- The unique burnings in Indonesia make emissions observations difficult, suggesting the need for bias correction.
- **MERRA-2's assimilation of emissions with column aerosol partially preserves expected signals, but continued optimization is necessary.**
- Further research: other bias-correction methods for emissions, such as in-situ visibility observations or finer remote sensing resolution.

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