Excessive Subsidence of the Southeast Atlantic Biomass Burning Aerosol Plume in the NASA Goddard Earth Observing System (GEOS) Model

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Background

- The Southeast Atlantic Ocean is characterized by a marine stratocumulus cloud system that interacts with plumes of biomass burning aerosol from southern Africa
- Models, including GEOS, struggle to accurately represent this complex regime
- NASA's Observations of Aerosols above Clouds and their interactions (ORACLES) campaign provided an opportunity to sample the environment and evaluate the meteorology and aerosols within GEOS

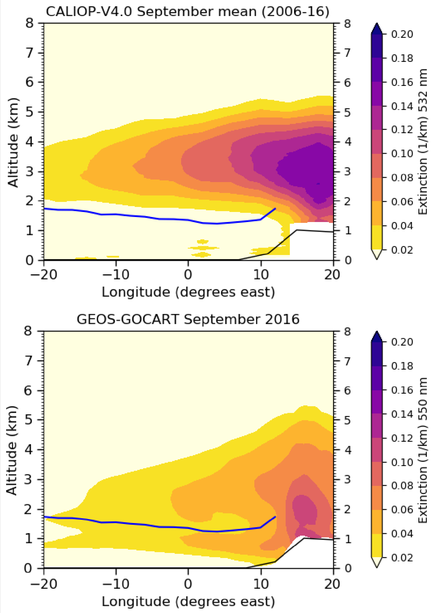

Figure 1: 532 nm aerosol extinction from CALIOP (top) and GEOS (bottom) during the month of September for 2006 through 2016, averaged over 0 °S to 20 °S. The blue contour in both panels is cloud top height from CALIOP.

Extinction is underestimated in the GEOS and aerosol descends much too rapidly.

- A modified version of the QG-omega equation is used to isolate model processes that may contribute to the excessive subsidence

$$\left(\nabla^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega$$

$$= \frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[\boldsymbol{v}_g \cdot \nabla(\zeta_g + f)\right] + \frac{1}{\sigma}\nabla^2\left[\boldsymbol{v}_g \cdot \nabla\left(-\frac{\partial \Phi}{\partial p}\right)\right] + IAU$$

~ vorticity advection + thermal advection + heating + "nudging"

- Please see the corresponding iPoster for a more detailed analysis and conclusions

Diabatic Heating Due to Biomass Burning Aerosol

- Metrology was free-running in two ensembles of 24 simulations using GEOS v10.22.0 in which a control ensemble was compared to an ensemble with radiatively inactive black and brown carbon
- Aerosol emissions included biomass burning emissions from QFED v2.5r1 and anthropogenic emissions from CEDS v2021_04_21

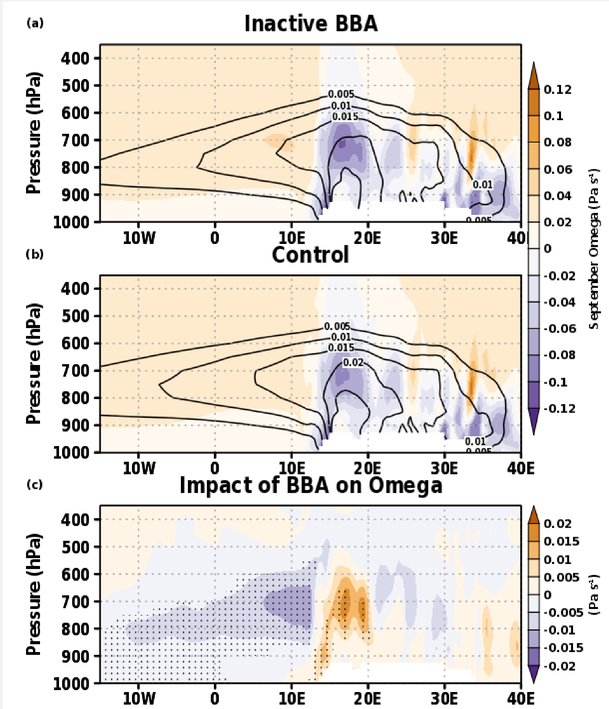

Figure 2: Omega during the month of September in the ensemble mean (a) with inactive biomass burning aerosol, (b) control, and (c) inactive minus control. Contours in (a) and (b) represent mixing ratio of brown carbon in units of mg kg^{-1} and dots in (c) indicate statistical significance in the difference.

Heating due to biomass burning aerosol reduces upward vertical motion, and reduces the subsidence rate of the aerosol plume, over the Southeast Atlantic Ocean. There is no statistically significant change to horizonal winds.

"Replaying" Meteorology to Reanalyses

- A version of GEOS with updated model physics relative to MERRA-2 was run with meteorology "replayed" to MERRA-2 and ERA5.
- ERA5 has previously been shown to agree well with observations of specific humidity from ORACLES (Pistone et al., 2021).
- Comparisons are made to aircraft data collected as part of ORACLES-1 in 2016

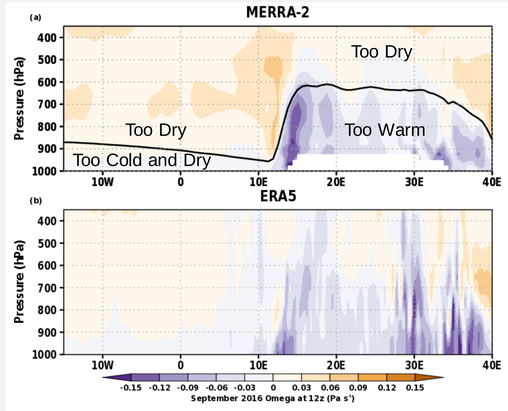

Figure 3: Omega at 12z during the month of September 2016 averaged from 5 °S to 20 °S in (a) MERRA-2 and (b) ERA5. The solid line in (a) is the height of the planetary boundary layer. Annotations in (a) are with respect to ERA5.

An anomalous circulation is present in MERRA-2 along the coastline of Angola such that upward motion is too strong over land and downward motion is too strong over the ocean. This is coupled with temperature biases.

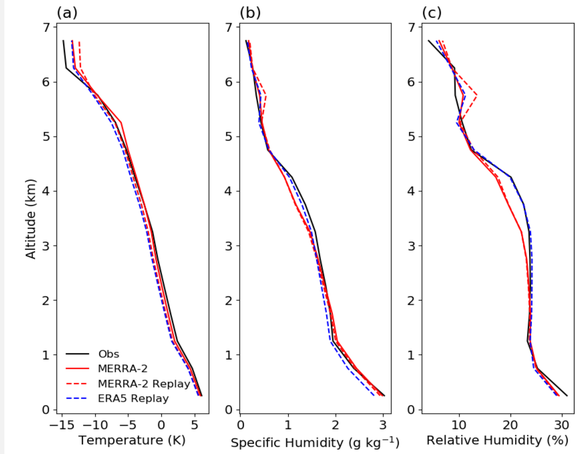

Figure 4: Vertical profiles of temperature, specific humidity, and relative humidity along the P3 flight tracks during ORACLES-1 from observations, MERRA-2, a replay to MERRA-2, and a replay to ERA5.

GEOS can match the vertical of profile of relative humidity, correcting a bias in cloud fraction, if meteorology is nudged to ERA5 however a cold bias is present in the lower troposphere.

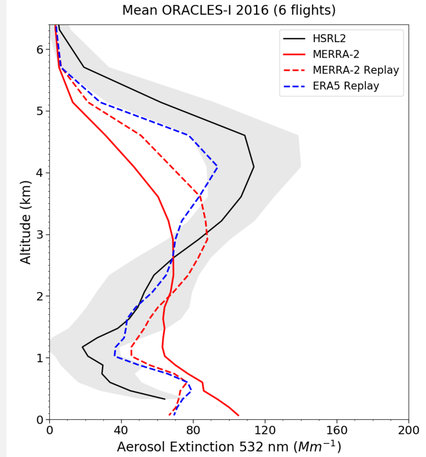

Figure 5: Aerosol extinction at 532 nm along the ER2 flight tracks during ORACLES-1 from observations, MERRA-2, MERRA-2 replay and ERA5 replay.

Using the analysis from ERA5 corrects the height of the aerosol plume in GEOS however extinction is still underestimated within plume.

References

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