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Atmospheric Composition Forecast Model Evaluation Using Ozone Measurements Collected by the Langley Mobile Ozone Lidar

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1 Introduction

The Langley Mobile Ozone Lidar (LMOL) is a mobile ground based lidar system based at NASA Langley in Hampton, Virginia. Between 2022 and 2024, LMOL collected over 2500 hours of ozone measurements for a range of different atmospheric conditions, including calm days, stratospheric intrusions, surface frontal passages, and long-range transported wildfire smoke plumes. Here, the data is used to evaluate the forecast accuracy of NASA's Global GEOS Composition Forecasting (GEOS-CF) model. GEOS-CF makes daily three-dimensional forecasts of trace gases and aerosol species. Overall, for calm periods, the forecast model predicts lower tropospheric ozone at NASA Langley with reasonable accuracy (within 20%). The model best predicts the timing and extent of stratospheric intrusions but often vary in the magnitude of the ozone mixing ratio. Among the other types of atmospheric conditions, there is more variability in the model forecasts. Based on this analysis, model forecasts are utilized to determine future data acquisition opportunities with the goal of providing feedback to the modeling teams, thereby enabling them to better understand the model biases and improve the model forecasts of ozone during these different atmospheric conditions.

2 Langley Mobile Ozone Lidar (LMOL)

- A mobile ground-based O_3 differential absorption lidar (DIAL) system.
- Can simultaneously measure O_3, SO_2, and aerosols.
- O_3 vertical profiles range from 0.1-4 km during the daytime and up to 8 km at night with a 5-minute temporal resolution.
- LMOL is a part of the Tropospheric Ozone Lidar Network (TOLNet), a network of 7 operational ozone lidar systems across North America.

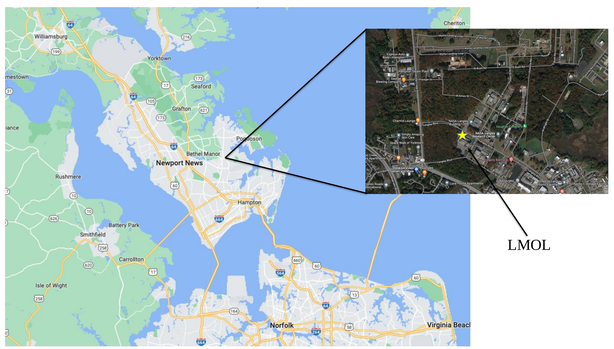


QR code to TOLNet webpage

LMOL parked behind the Atmospheric Science building at NASA Langley Research Center

2.1 LMOL Site Location

- LMOL is located at NASA Langley Research Center in Hampton, Virginia (37.095 N, -76.389 W).
- The Newport News/Hampton peninsula is bordered by the James River to the west and south, and Chesapeake Bay to the east, creating a land-sea gradient which impacts local meteorology and atmospheric composition.
- Major sources of pollution in neighboring cities include:
  - $PM_{2.5}$ and coal emissions from the shipyard and ship traffic in Norfolk and Newport News
  - Emissions from the airports in Newport News and Norfolk
  - Vehicular emissions from the surrounding populated areas.



3 GEOS-CF Model Configuration

- Global 5-day forecasts of atmospheric composition
- 25-km horizontal resolution
- 72 hybrid eta levels, output as 3D fields on pressure levels regridded to altitude
- Physics package comparable to MERRA-2
- GEOS-Chem version 12 chemistry
- Physics coupled to GOCART aerosols
- HTAP anthropogenic emissions

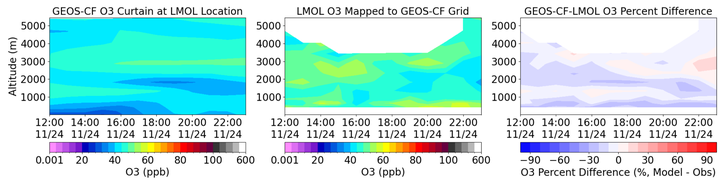
4 Model Forecast Evaluation at LMOL Location

LMOL has been routinely collecting data over the past 3 years (with some target data acquisition events) and has observed several different types of atmospheric events:

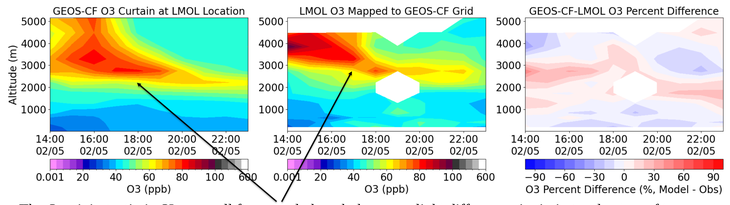
1. **Clear/calm days**: no other atmospheric event occurring.
2. **Stratospheric intrusions**: O_3-rich, stratospheric air extending into the mid-troposphere.
3. **Surface frontal passages**: passage of a surface boundary marked by a wind shift and distinct gradients in temperature and moisture.
4. **Long-range smoke transport**: presence of an elevated O_3 layer linked to a smoke plume.

We utilize this data to evaluate the performance of the GEOS-CF forecasts. To do so, the LMOL profiles are mapped onto the model's vertical grid and then we calculate the percent difference in the O_3 profiles. We present four example events below.

4.1 Clear/Calm Days

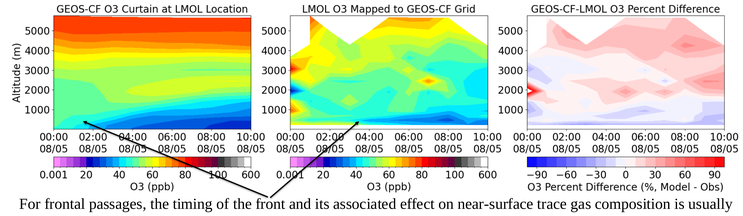


4.2 Stratospheric Intrusions



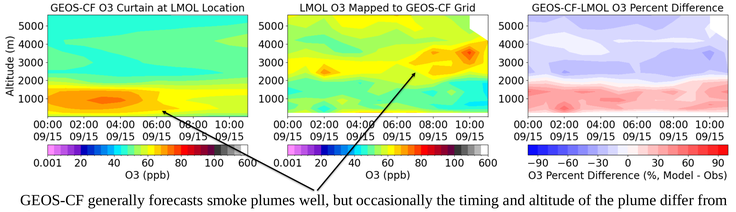
The O_3 mixing ratio in SIs are well forecasted, though there are slight differences in timing and extent of transport.

4.3 Frontal Passages



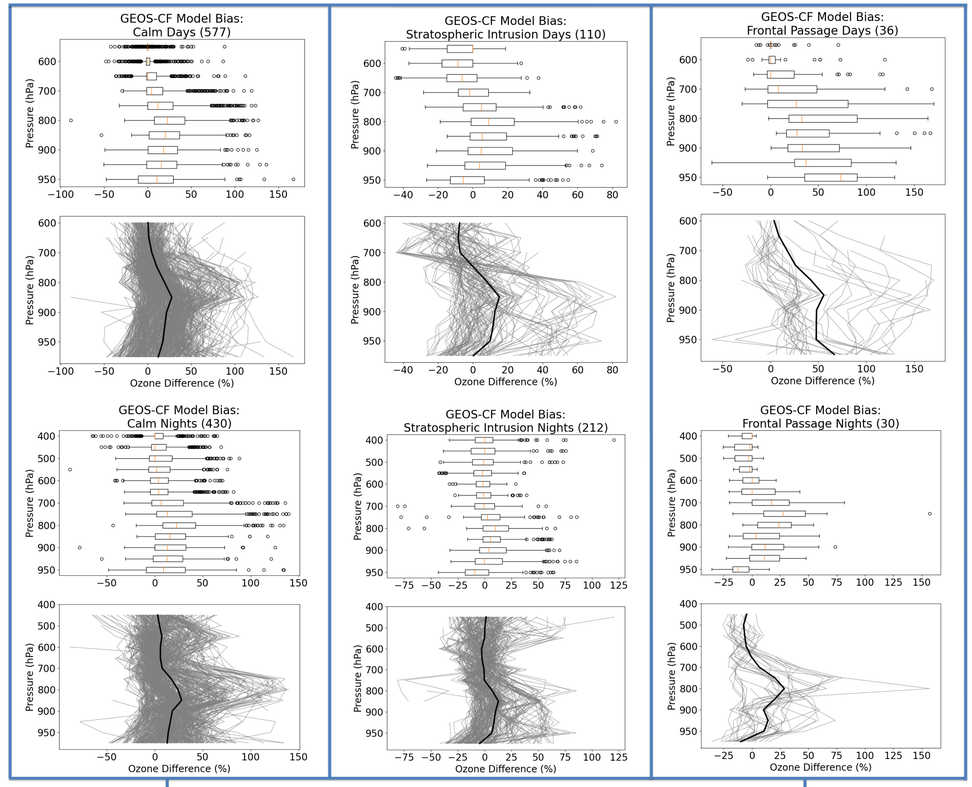
For frontal passages, the timing of the front and its associated effect on near-surface trace gas composition is usually within 1-2 hours.

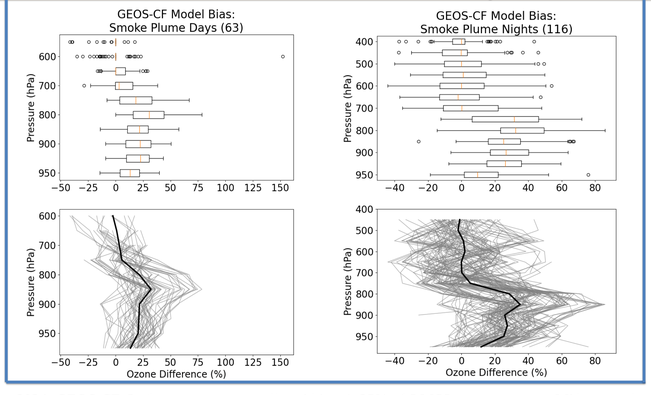
4.4 Long Range Smoke Transport



GEOS-CF generally forecasts smoke plumes well, but occasionally the timing and altitude of the plume differ from observations.

5 Summary of Events





For data collected in 2022 – 2024, GEOS-CF O_3 forecasts are generally within +/- 25% of LMOL measurements. Mid-troposphere O_3 (above 800 hPa) is forecasted with high accuracy (+/- 10%). GEOS-CF often overestimates O_3 between 900-850 hPa, potentially due to changes in the model's vertical resolution and older anthropogenic emissions, resulting in a high NO_X and O_3 bias, though we also note that there is a 10% uncertainty LMOL's retrievals. Future work will involve assessing any seasonal variation in the model biases and using GEOS-CF forecasts to select data acquisition days for further model evaluation. This collection of measurements also demonstrates LMOL's ability to observe a range of atmospheric features which may be used to validate other models and to compare with observations (e.g., ozonesondes, in-situ measurements, and satellite retrievals).

Acknowledgments

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