Evaluation of CMAQ boundary layer processes and air quality over the Chesapeake Bay and Maryland

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Goals:

1) Gain a better understanding of boundary layer processes and regional and local scale circulations on air quality in a polluted marine boundary layer.
2) Identify regional air quality model deficiencies for future work on improving model simulations.

Significance:

A bay, sea, or lake breeze can exacerbate air pollution levels. When the regional scale wind is offshore in the morning, onshore pollutants are transported offshore. After a bay breeze develops, the pollutants over the water are then transported back onshore and converge with more pollution over land near the bay breeze convergence zone contributing to high concentrations. In addition, pollutants are lofted upward at the bay breeze convergence zone. Pollutants lofted above the boundary layer have a longer lifetime than pollutants in the boundary layer, and can then more efficiently be transported downwind, having a larger impact on climate and air quality farther away from the source. Improving air quality model simulations near a coastline and over a polluted marine boundary layer will not only improve model results over the water, but also inland, near the coastline, and downwind of the region due to bay breeze effects.

Method:

The temporal and spatial distribution of air pollution and boundary layer height over the Chesapeake Bay is analyzed using ship- and aircraft-based observations obtained during the DISCOVER-AQ and GeoCAPE-CBODAQ field campaigns during July 2011 and the NOAA experimental WRF-NMM-CMAQ modeling system. Airborne High Spectral Resolution Lidar (HSRL) observations of boundary layer height from the NASA UC-12 aircraft; in-situ P-3B aircraft profiles of O_3, NO, and NOy mixing ratios; and ship-based in-situ O_3, NO, and NOy mixing ratios are analyzed alongside the NOAA experimental WRF-NMM-CMAQ modeling system. Model biases and future work on how to improve regional air quality model simulations near a coastline are identified.

Results:

July 11:

Figure 1: Ship track and observed and simulated surface O_3, NO, and NOy concentrations. CMAQ has high O_3, NO, and NOy biases compared with observations.

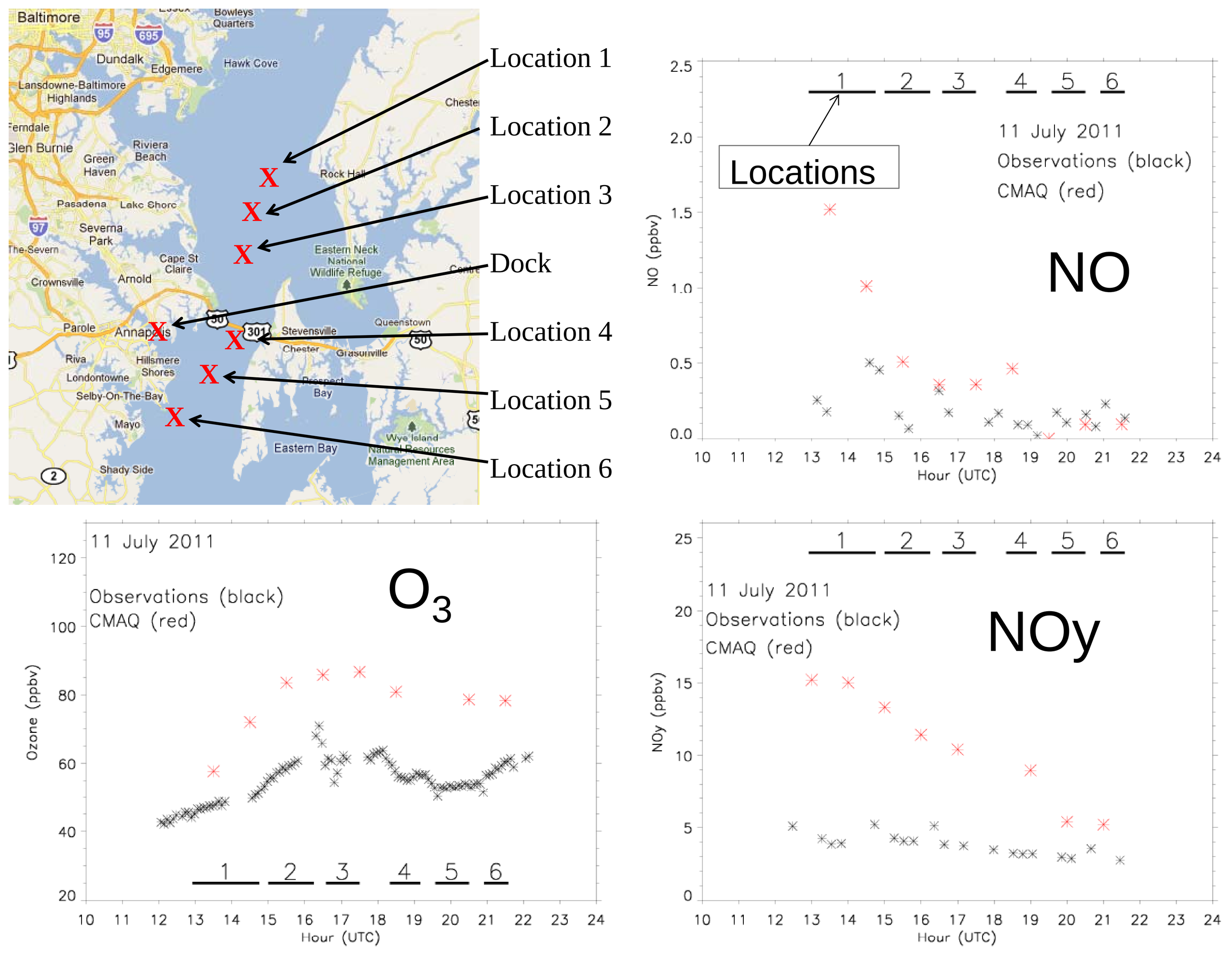
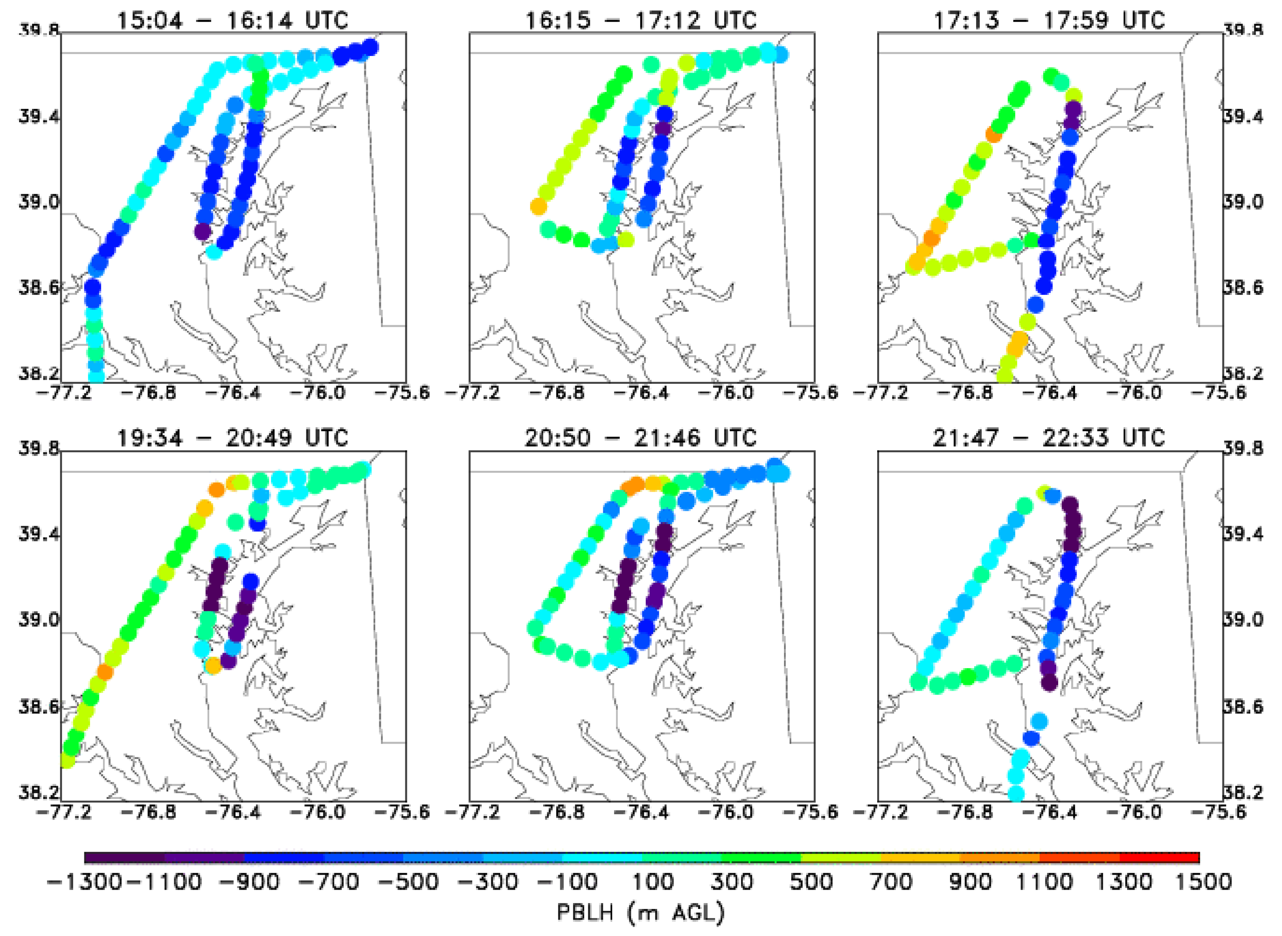


Figure 2: WRF-NMM minus HSRL-observed PBL heights. CMAQ PBL heights have a high bias over land and a large low bias (500-1,300m) over the Chesapeake, which contributes to CMAQ's high surface O_3, NO, and NOy biases.



July 20:

Figure 3: Ship track and observed and simulated surface O_3, NO, and NOy concentrations. Better agreement between observed and simulated O_3 and NO than on July 11. However, CMAQ's high NOy bias persists throughout the field campaign

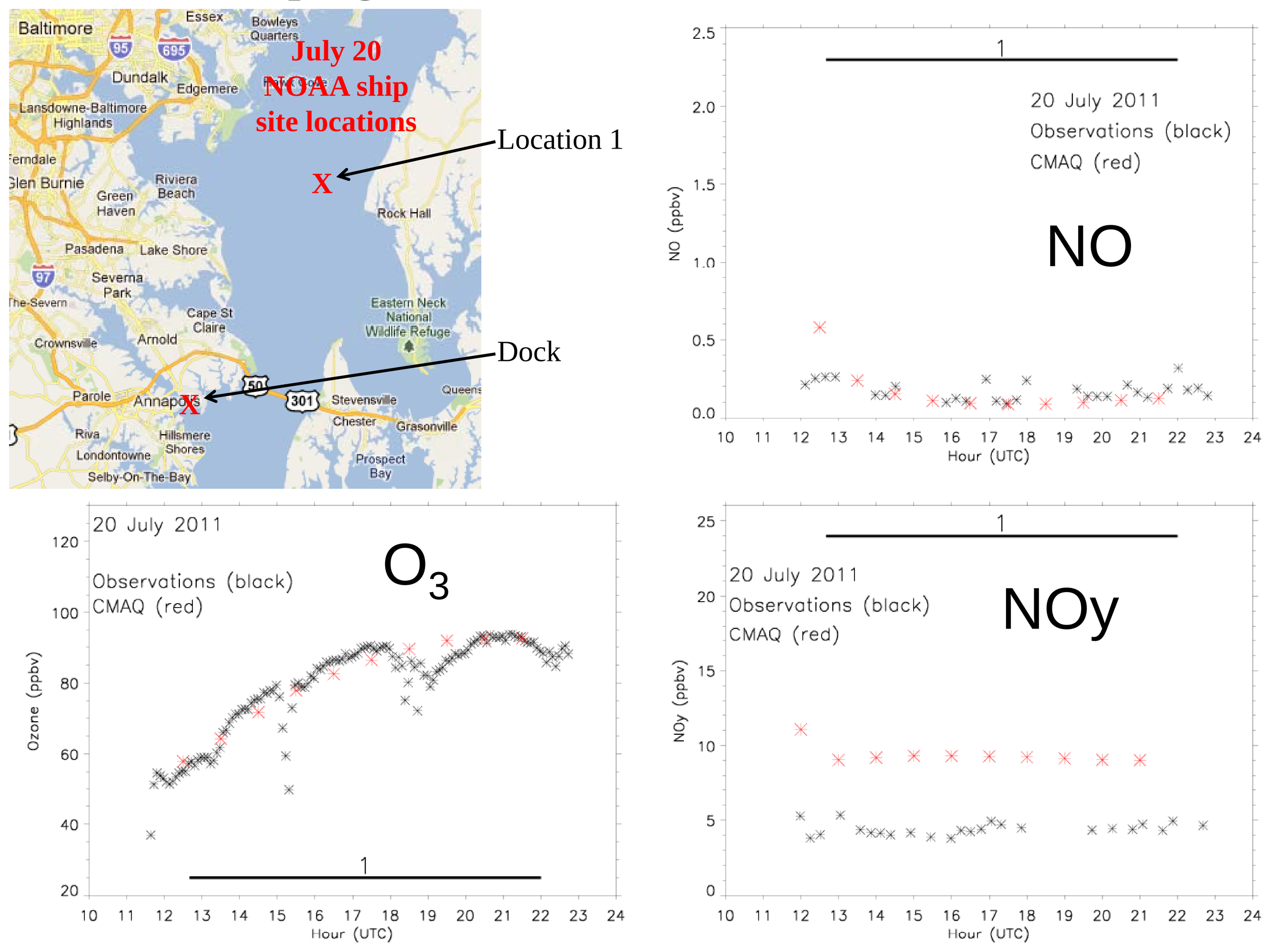


Figure 4: WRF-NMM minus HSRL-observed PBL heights. CMAQ PBL heights have a smaller low bias (100-500m) than on July 11 over the Chesapeake, which coincides with better agreement between observed and simulated surface O_3 and NO concentrations.

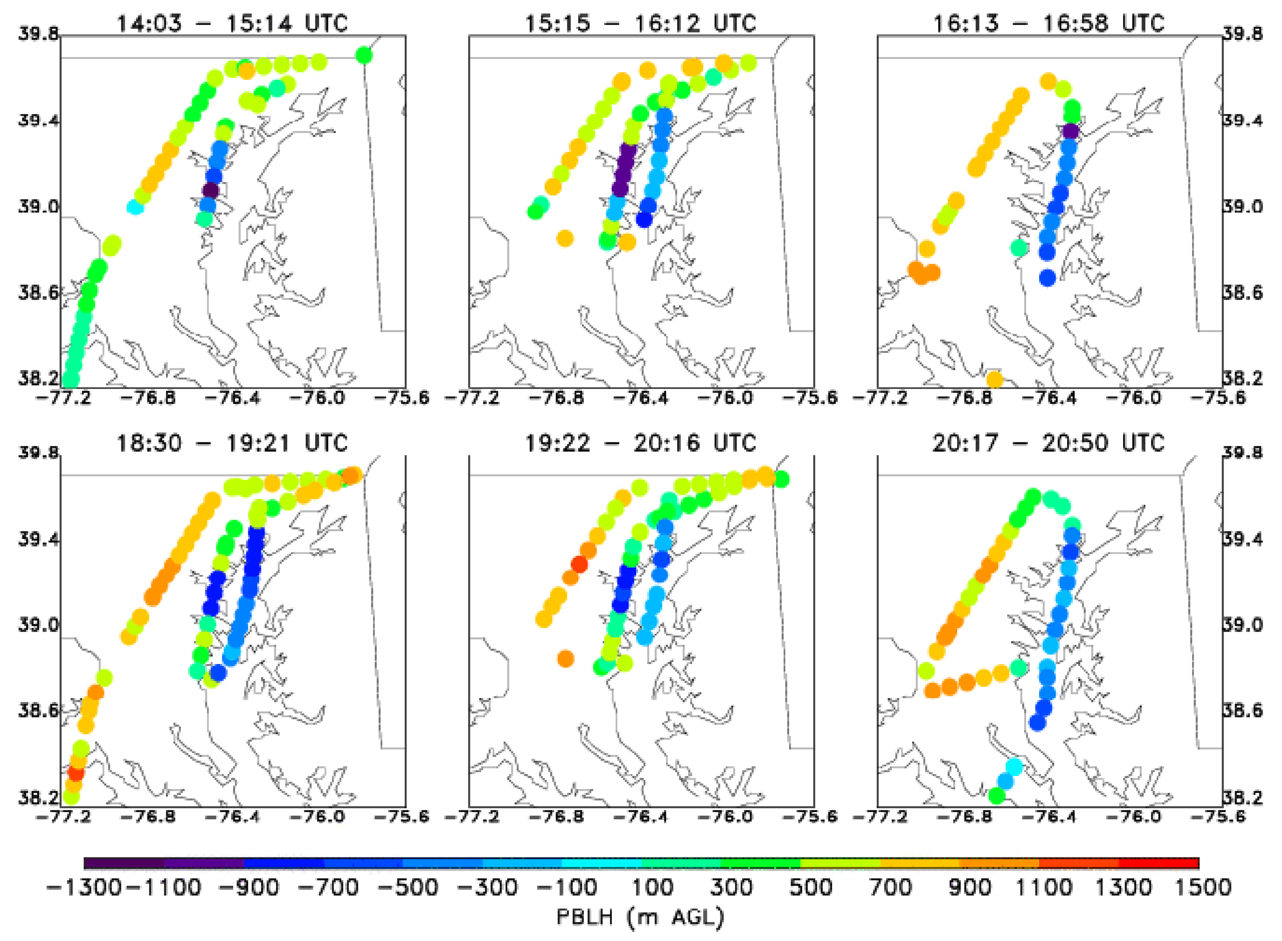
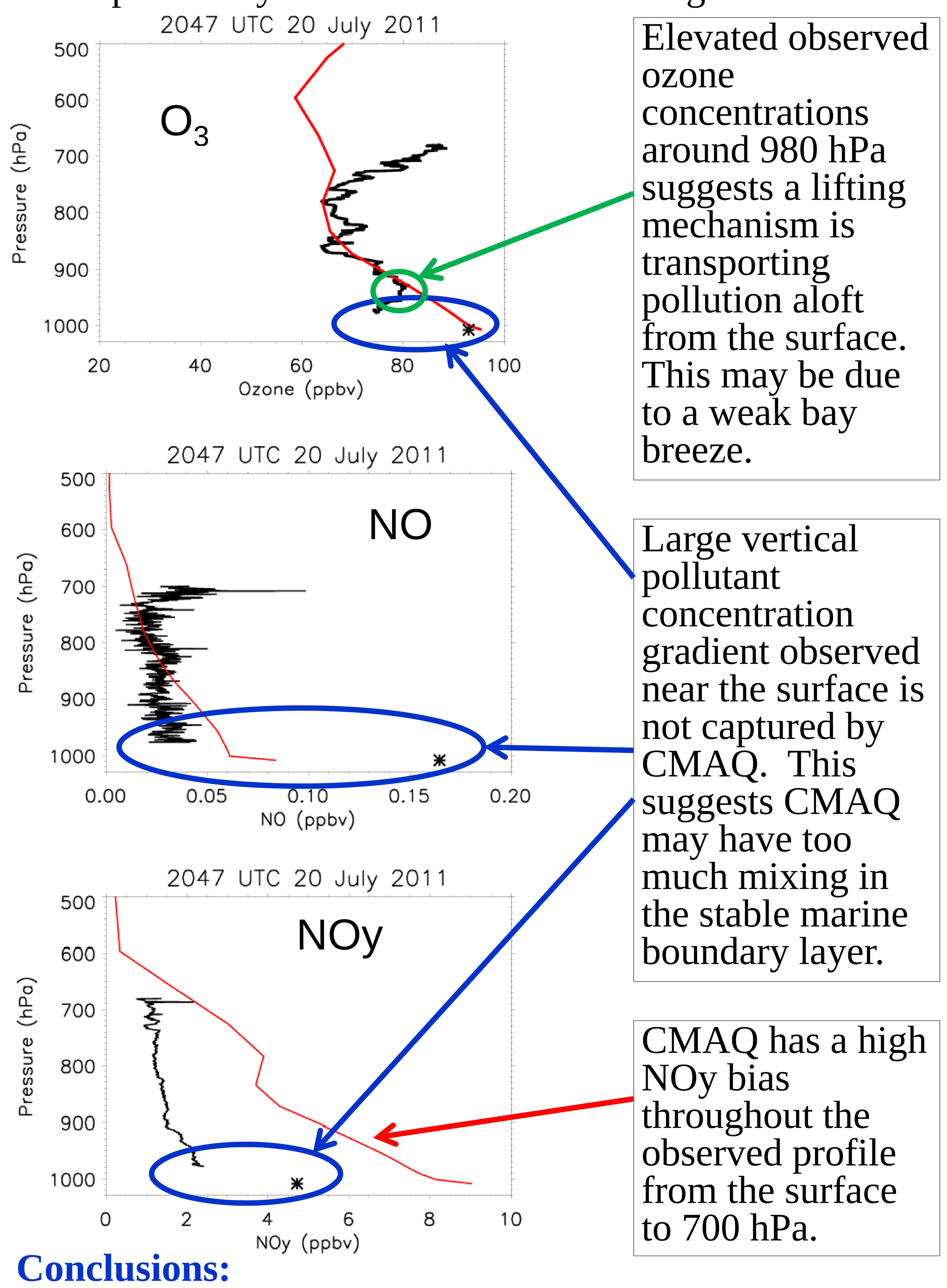


Figure 5: O_3, NO, and NOy observed (aircraft in-situ profiles and ship in-situ surface concentrations; black) and CMAQ (red) simulated profiles over the ship in the Chesapeake Bay at Location 1 shown in Figure 3.



Conclusions:

CMAQ-simulated surface O_3, NO, and NOy have high biases when model PBL heights have a large low bias. When model PBL heights improve, simulated surface O_3 and NO come into agreement with observations. However, profiles over the Chesapeake Bay show that the model does not capture the shape of observed profiles of O_3, NO, and NOy. The profiles show elevated ozone aloft, which may be due to a weak bay breeze transporting pollution aloft. The observed profiles also show a larger vertical gradient near the surface than CMAQ, which suggests the mixing in the model is too strong in the stable marine boundary layer. CMAQ-simulated NOy concentrations have a large high bias compared to observations throughout the observed profile.