Southern Ocean zonal scale summertime oxygen outgassing and carbon dioxide ingassing

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Overview: We made intensive and extensive observations of atmospheric O_2 and CO_2 distributions over the Southern Ocean adjacent to Drake Passage and the Antarctic Peninsula during January and February of 2016 as part of the O_2/N_2 Ratio and Carbon Dioxide Airborne Southern Ocean (ORCAS) Study. These measurements revealed consistent large scale patterns indicating strong O_2 outgassing and CO_2 ingassing over the previous several months, with distinct differences from climatological flux estimates and many Earth system models. The magnitudes and O_2:CO_2 ratios of these signals, and their broad spatial representativeness, provide valuable constraints on this biogeochemical and climate critical region.

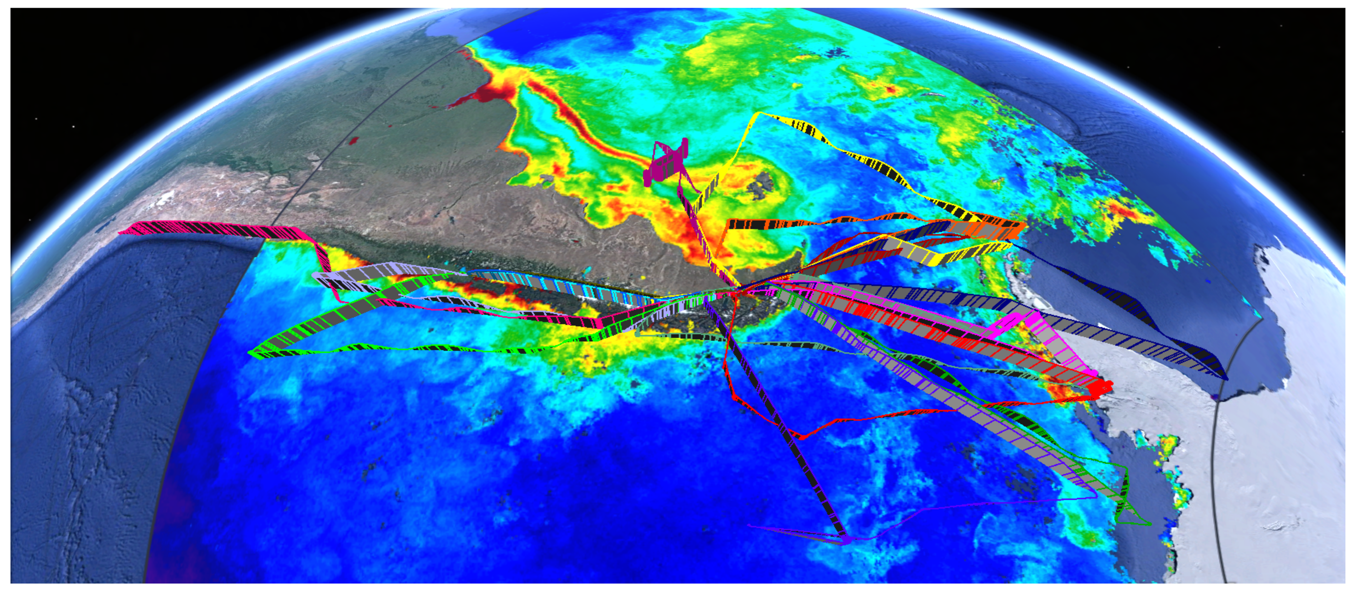


Figure 1. ORCAS flight tracks and altitudes colored by flights. Also shown is average chlorophyll during the campaign from the VIIRS satellite instrument.

The ORCAS Campaign

ORCAS used the NSF/NCAR Gulfstream V (GV) aircraft, based out of Punta Arenas, Chile, to target a range of diverse biogeochemical regions adjacent to the southern tip of South America and the Antarctic Peninsula (https://www.eol.ucar.edu/field_projects/orcas). The GV payload included continuous sensors and whole air samplers for O_2, CO_2, other greenhouse gases, industrial pollutants, and marine biogenic reactive gases; a hyperspectral ocean color remote sensor; and aerosol, liquid water, and cloud microphysics probes. In addition to the field component, the ORCAS project includes modeling activities which guided the observational effort, and are now providing a basis for synthesizing the observations to improve our understanding of key biogeochemical processes.

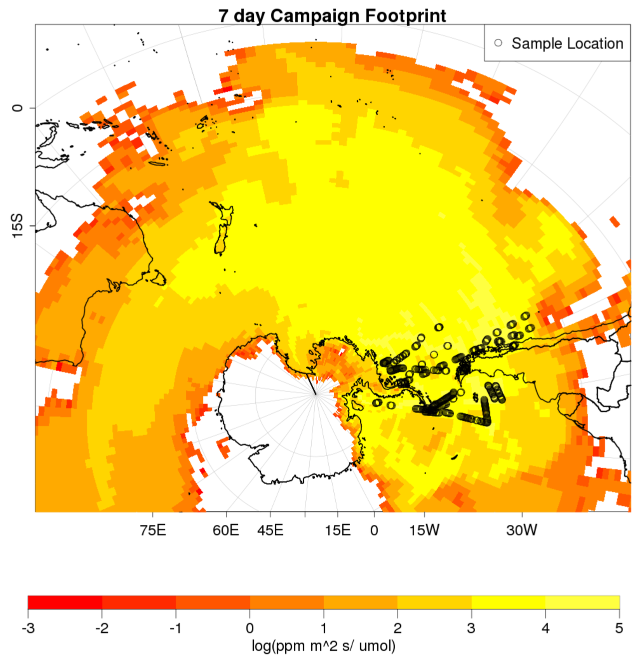


Figure 2. 7-day area of surface influence (footprint) for the whole campaign using GDAS re-analysis winds, and receptors every ~ 30 seconds of flight with 4096 particles run backwards in time.

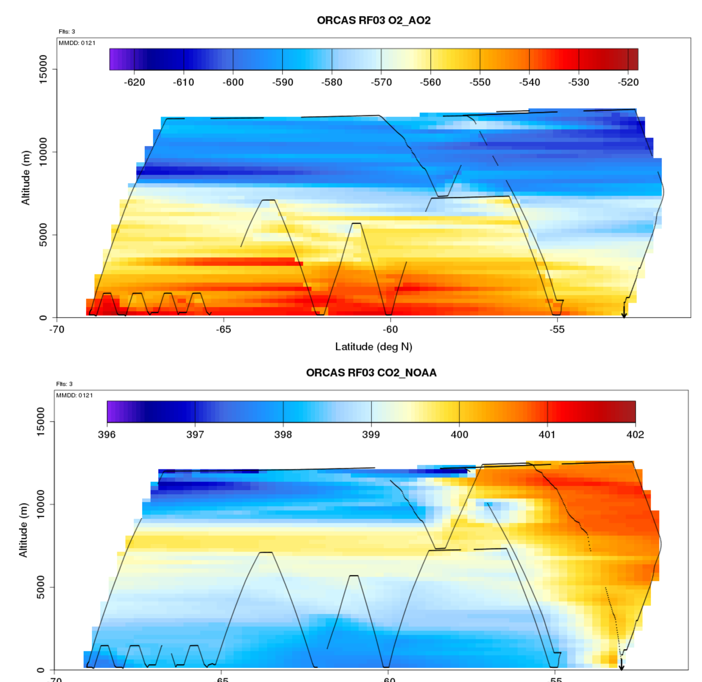
ORCAS included 19 research flights; 10 flights departed from and returned to Punta Arenas, Chile, conducting research over the Southern Ocean, 3 flights surveyed along the western coast of Chile, and 6 flights were for the purpose of ferrying the GV to a more northern location to avoid high wind events in Punta Arenas. In total, 98.2 research flight hours were used, collecting 117 full profiles from the near surface (150 m) to 7-12 km and 43 lower altitude profiles from the near surface to 1.5-5 km.

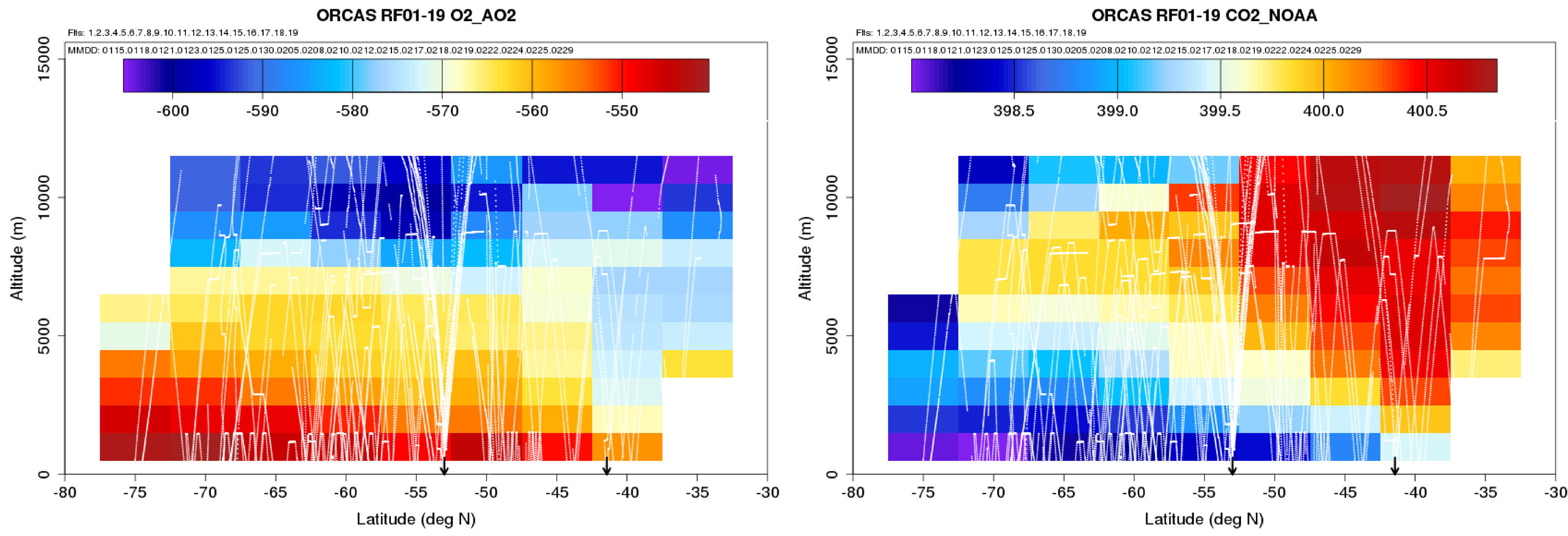
ORCAS
O_2/N_2 Ratio and CO_2 Airborne Southern Ocean Study
2016

O_2 and CO_2 Cross Sections

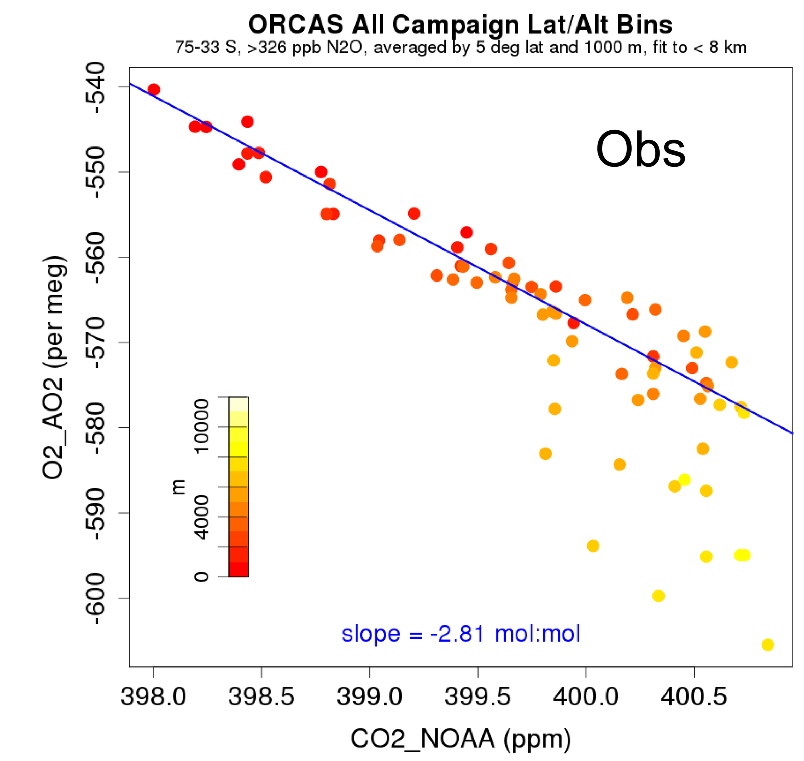
Figure 3 (right). Interpolated cross sections from an example research flight (RF03) for O_2 (top) in per meg on the Scripps O_2 scale, and CO_2 (bottom) in ppm. The flight track is shown as a black line. O_2 is from the NCAR AO2 instrument while CO_2 is from the NOAA/CU Picarro instrument.

Figure 4 (below). Cross sections for O_2 (left) and CO_2 (right) obtained by averaging all ORCAS data by 5 degree latitude and 1000 m bins. Flight tracks shown as white lines.





O_2 vs CO_2 Relationship



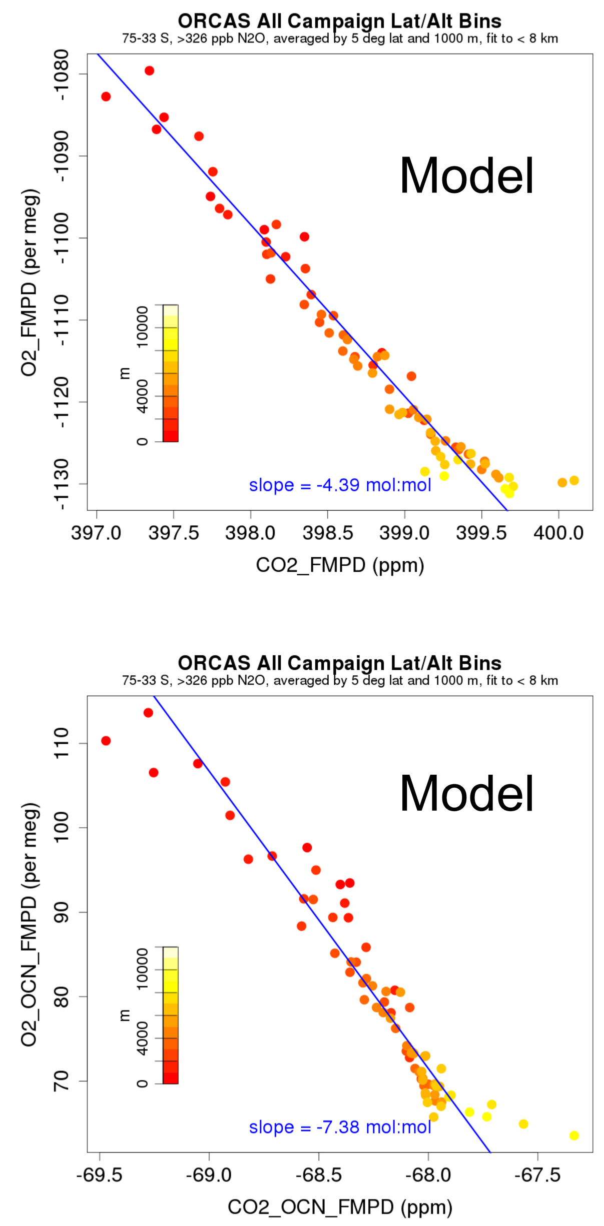


Figure 5. Whole campaign relationship between tropospheric O_2 and CO_2, obtained by bin averaging all data by 5 degrees of latitude and 1000 m altitude and coloring by altitude, for the observations (top left), a forecast configuration of the Community Earth System Model (CESM, top right), and the ocean component of the CESM forecast (bottom right). Lines and slopes are from fits to data below 8 km.

O_2 Curtain Averages

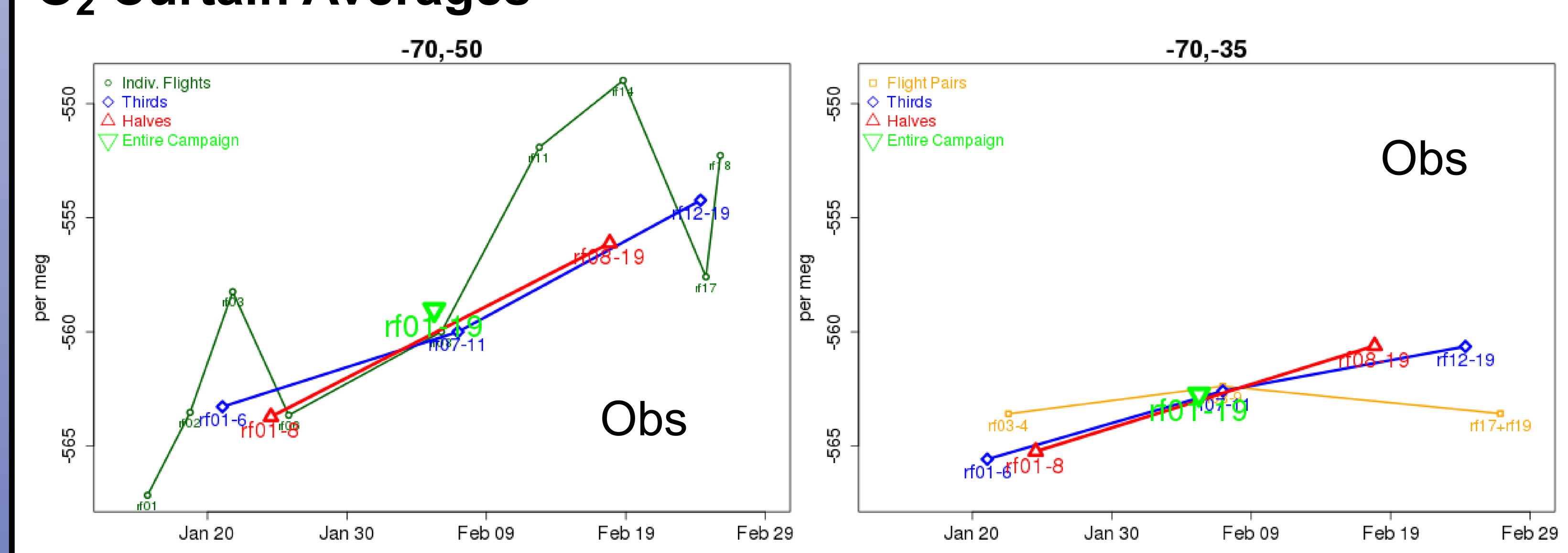
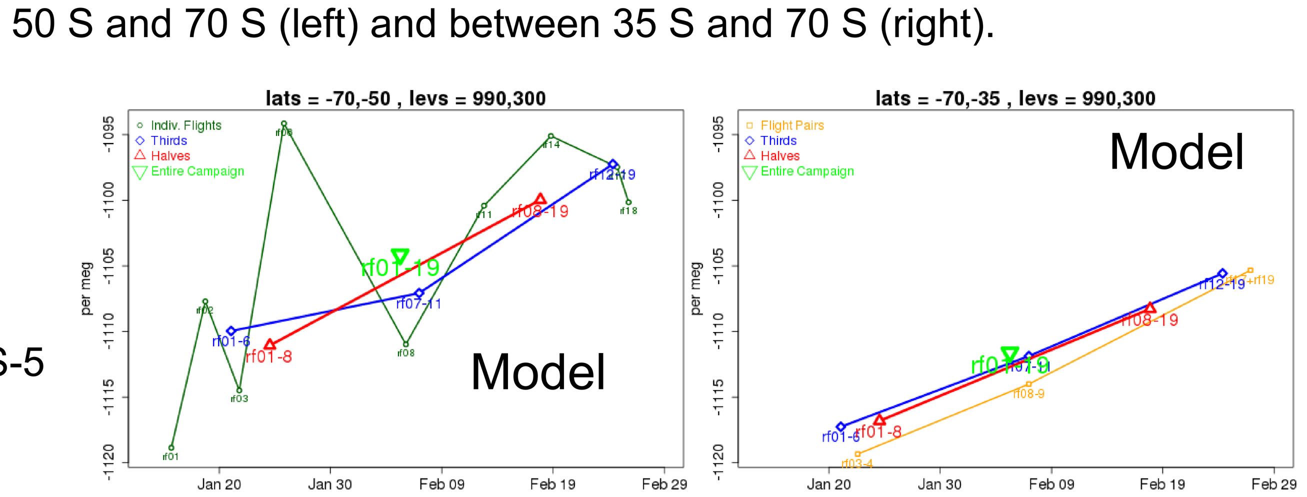


Figure 6 (top). Latitude and pressure weighted average values for O_2 from the surface to 300 mb between 50 S and 70 S (left) and between 35 S and 70 S (right).

Figure 7 (right). Same but for CESM run in forecast mode nudged to GEOS-5 meteorology.



Vertical CO_2 Gradient

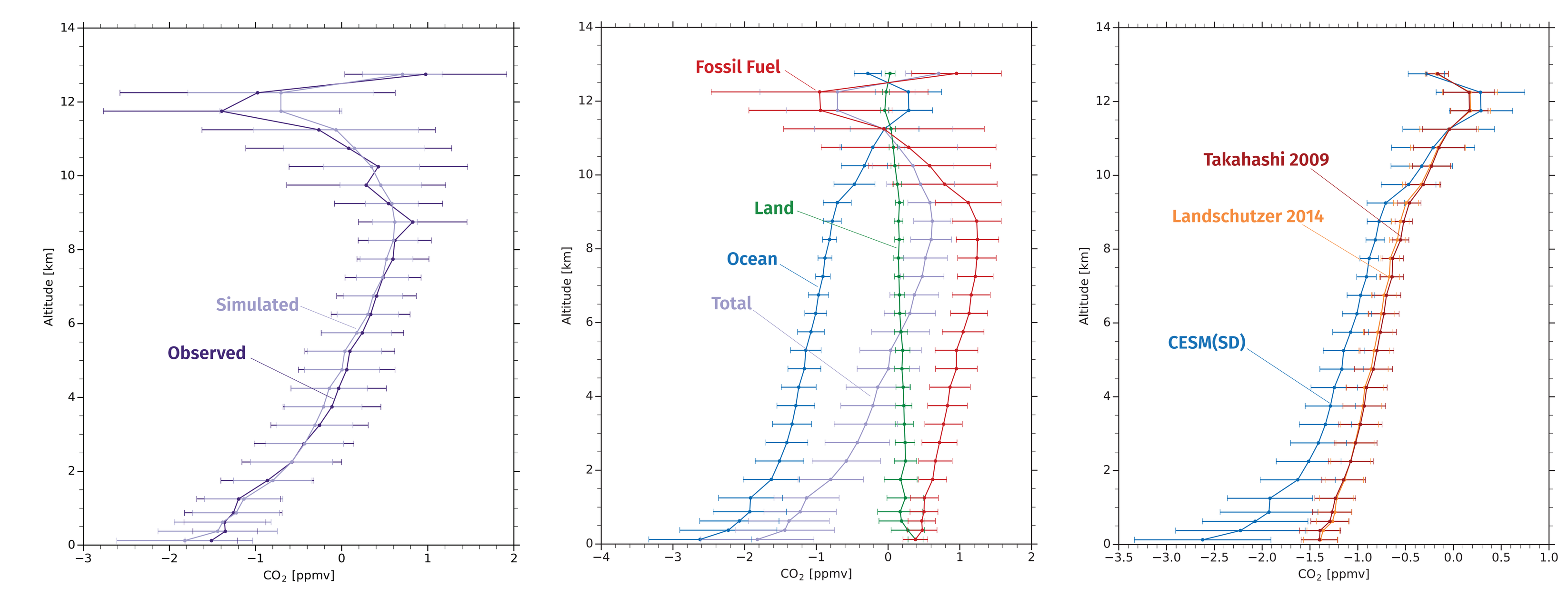


Figure 8. Campaign averaged vertical CO_2 profiles from observations and the CESM forecast (left), and broken down by individual contributions in the model (middle). Right panel: modeled ocean contribution compared to climatological fluxes run through CAM.

Summary: Negative O_2:CO_2 ratios reflect the dominance of biological drivers on summertime CO_2 fluxes. The CESM forecast product overestimated observed O_2 signals but showed remarkable agreement with CO_2 gradients, which were themselves much stronger than climatological estimates.