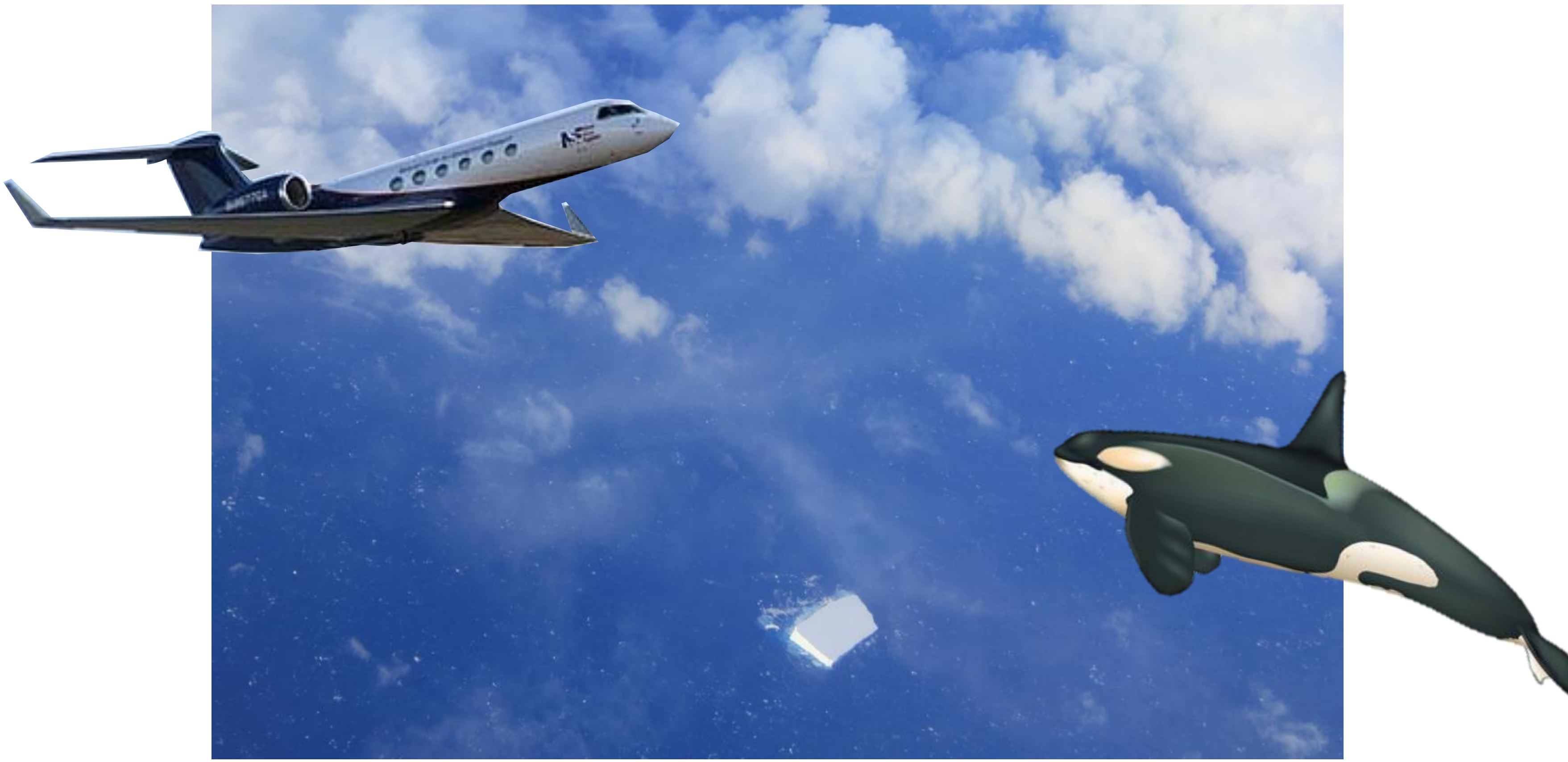
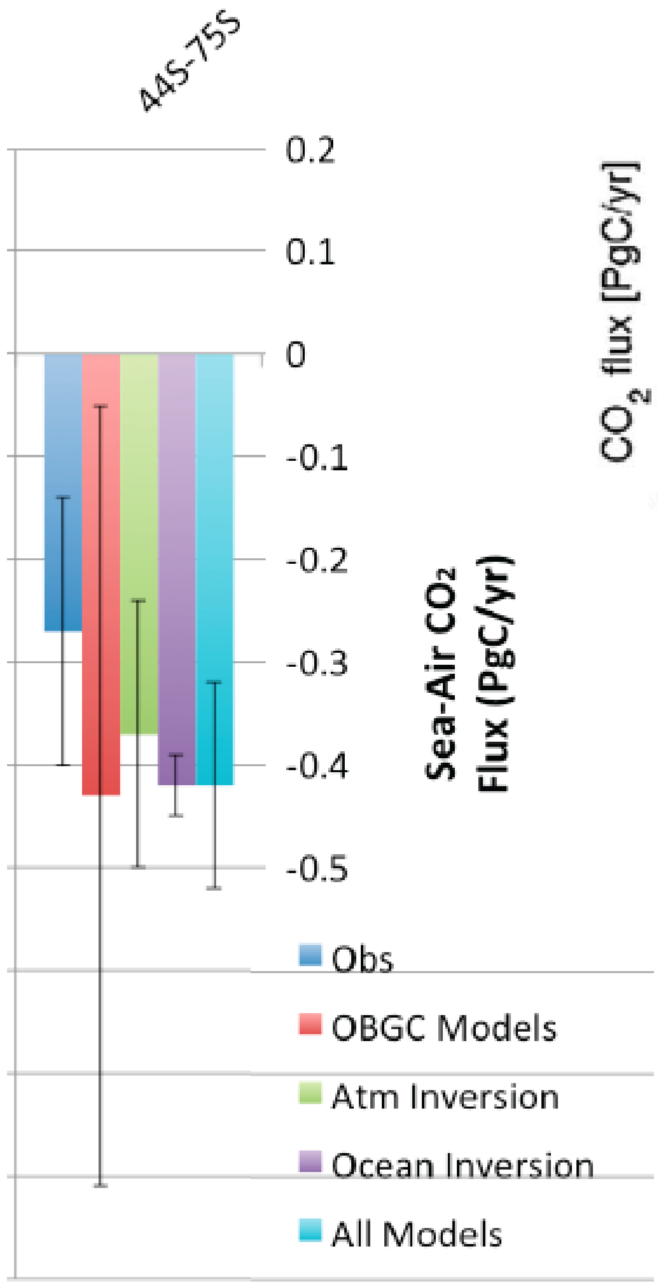
The O_2/N_2 Ratio and CO_2 Airborne Southern Ocean (ORCAS) Study

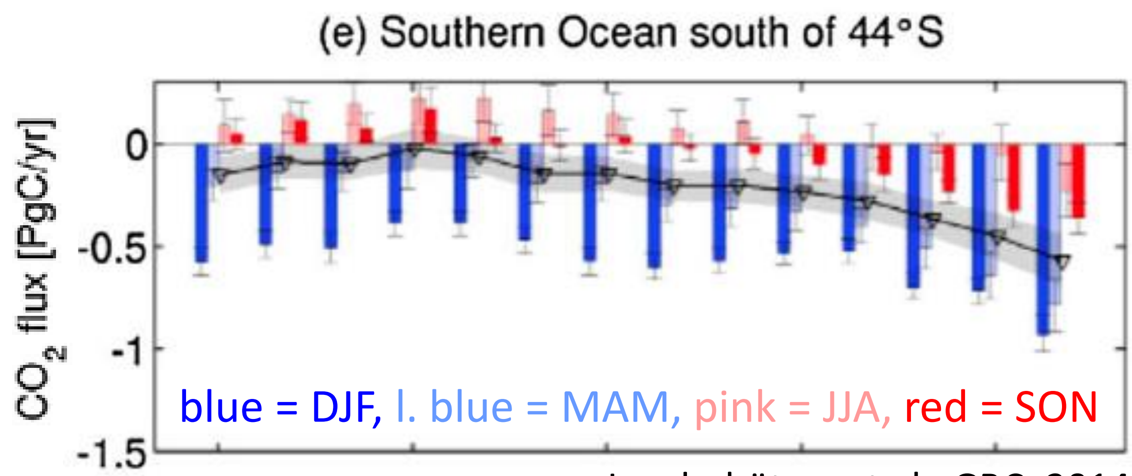


Collaborative Science Team representing:
NCAR (EOL, CGD, ACD, MMM), Scripps, U. Michigan, U. Colorado, NOAA, JPL, U. Connecticut, LDEO, WHOI, Duke, Rutgers, Princeton, U. Miami, NASA GMAO

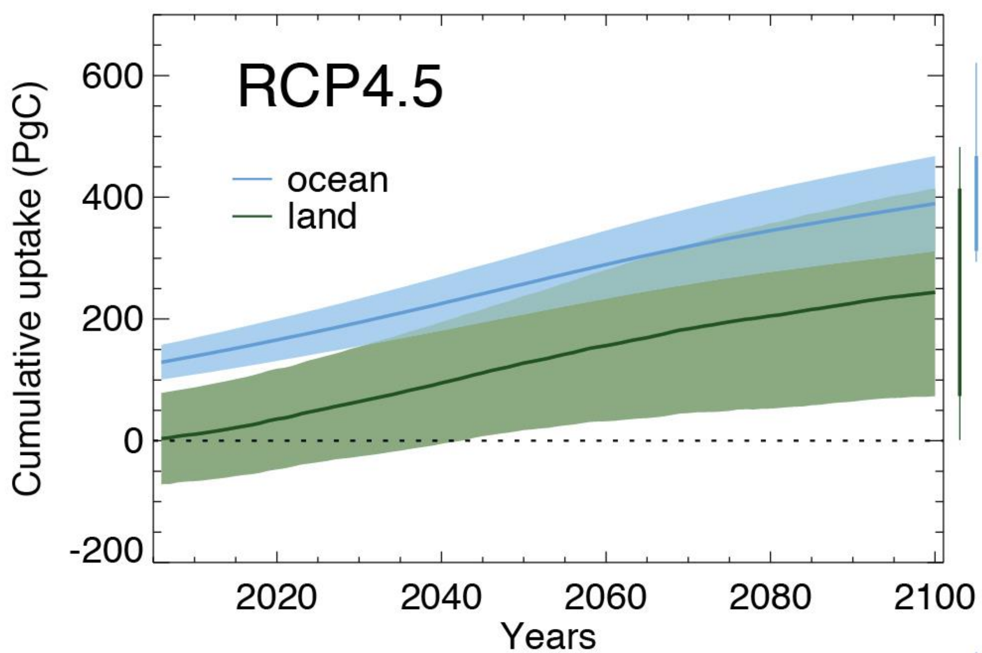
The evolving Southern Ocean carbon sink



Lenton et al., BG, 2013



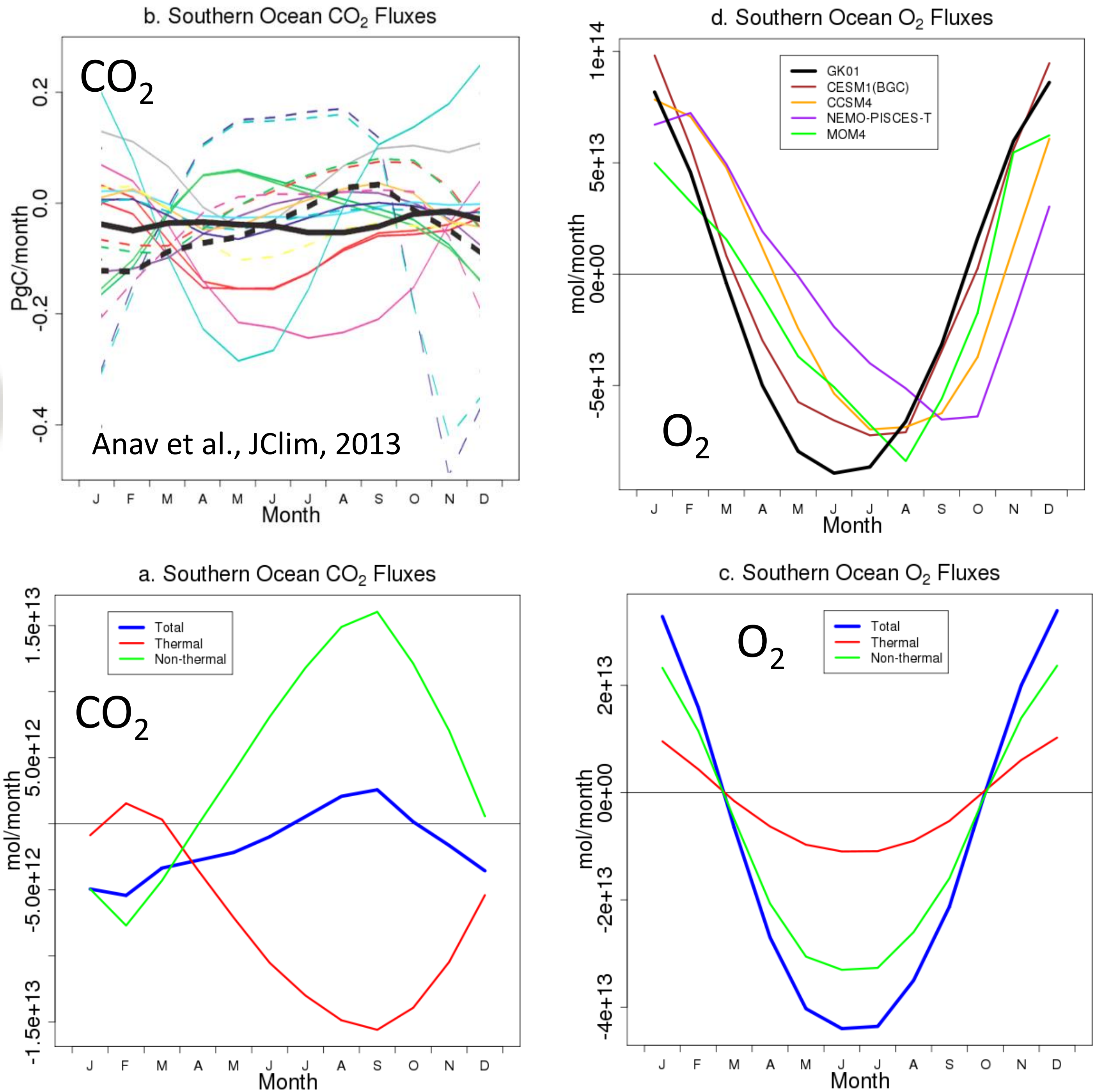
Landschützer et al., GBC, 2014



IPCC AR5, 2013

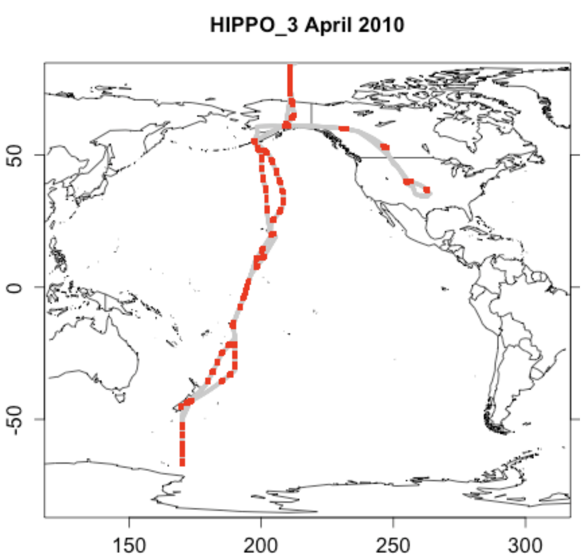
Seasonal CO_2 and O_2 forcings

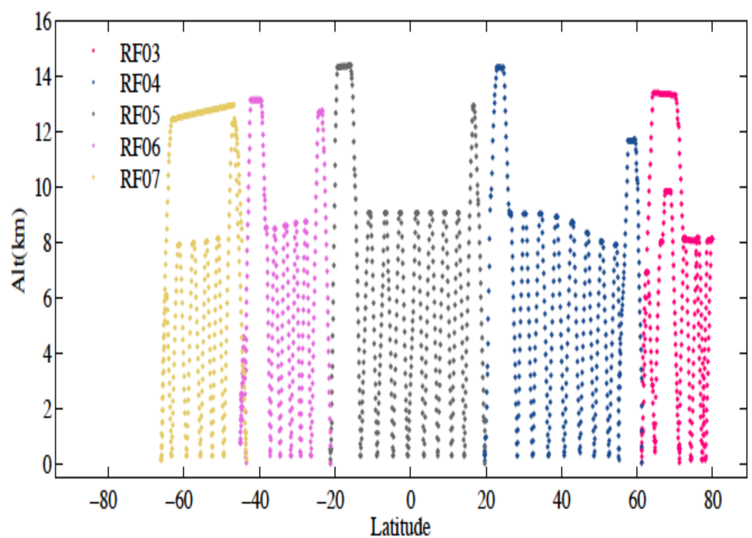
Total
Thermal
Non-thermal

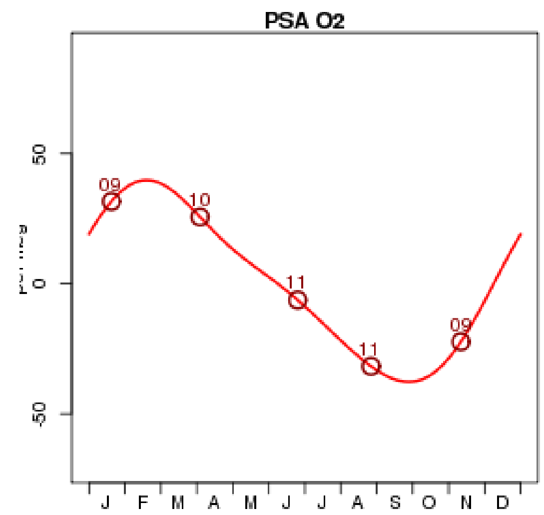


HIAPER Pole-to-Pole Observations

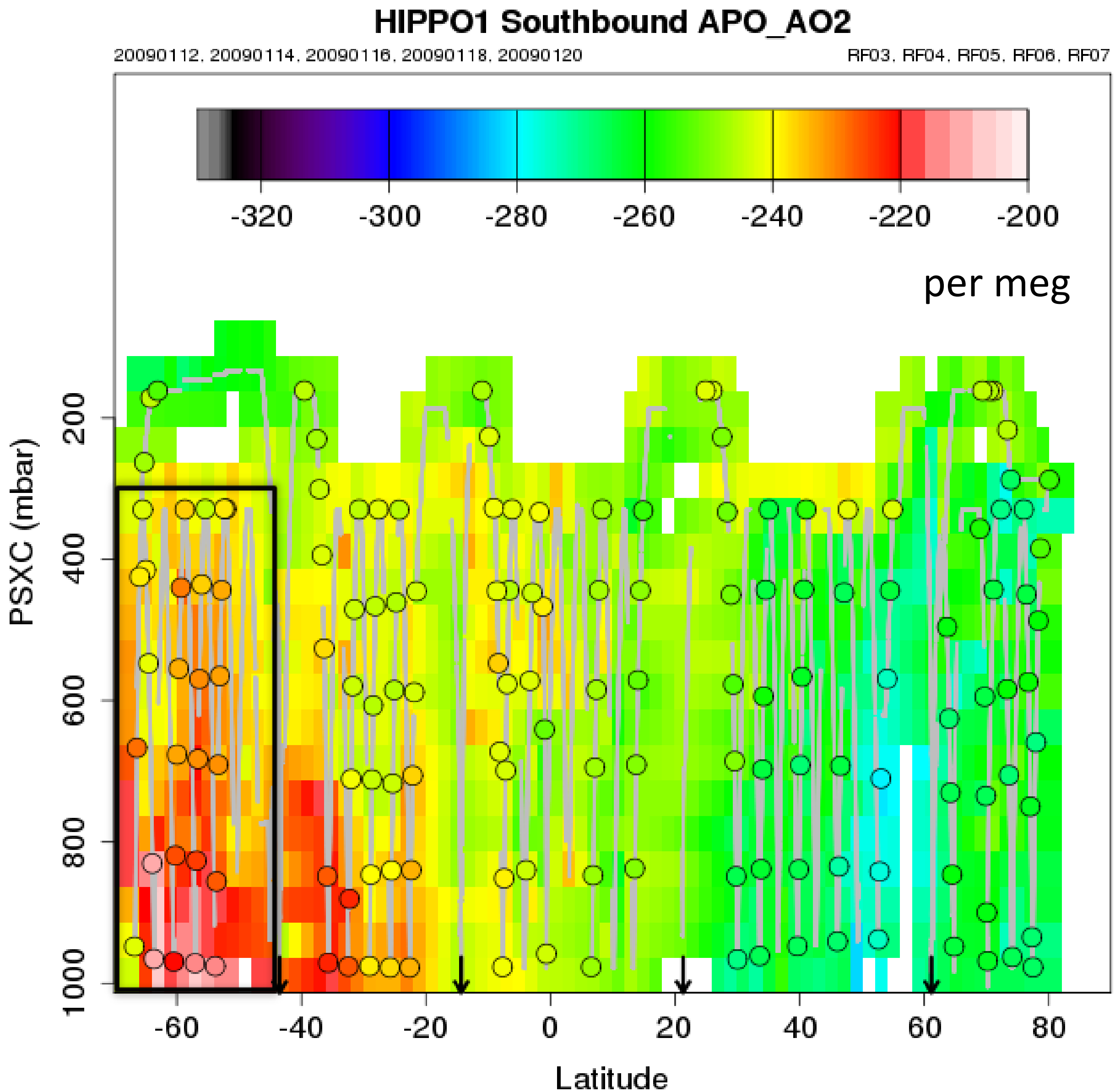
- PIs: Harvard, NCAR, Scripps, NOAA
- Global and seasonal survey of CO_2, O_2, CH_4, CO, N_2O, H_2, SF_6, COS, CFCs, HCFCs, O_3, H_2O, CO_2 isotopes, Ar, black carbon, and hydrocarbons (over 90 species).
- NSF / NCAR Gulfstream V
- Five 3-week campaigns over 3 years, across Pacific between 87 N and 67 S
- Continuous profiling between surface and 10-14 km
- 64 flights, 787 profiles, 434 hours in situ data + 4235 flasks
- hippo.ucar.edu, www.eol.ucar.edu/hippo, hippo.ornl.gov

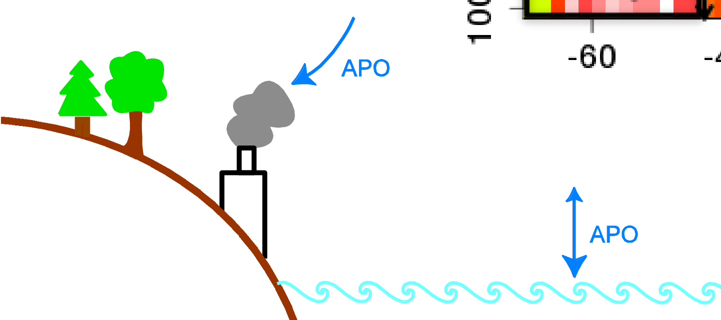






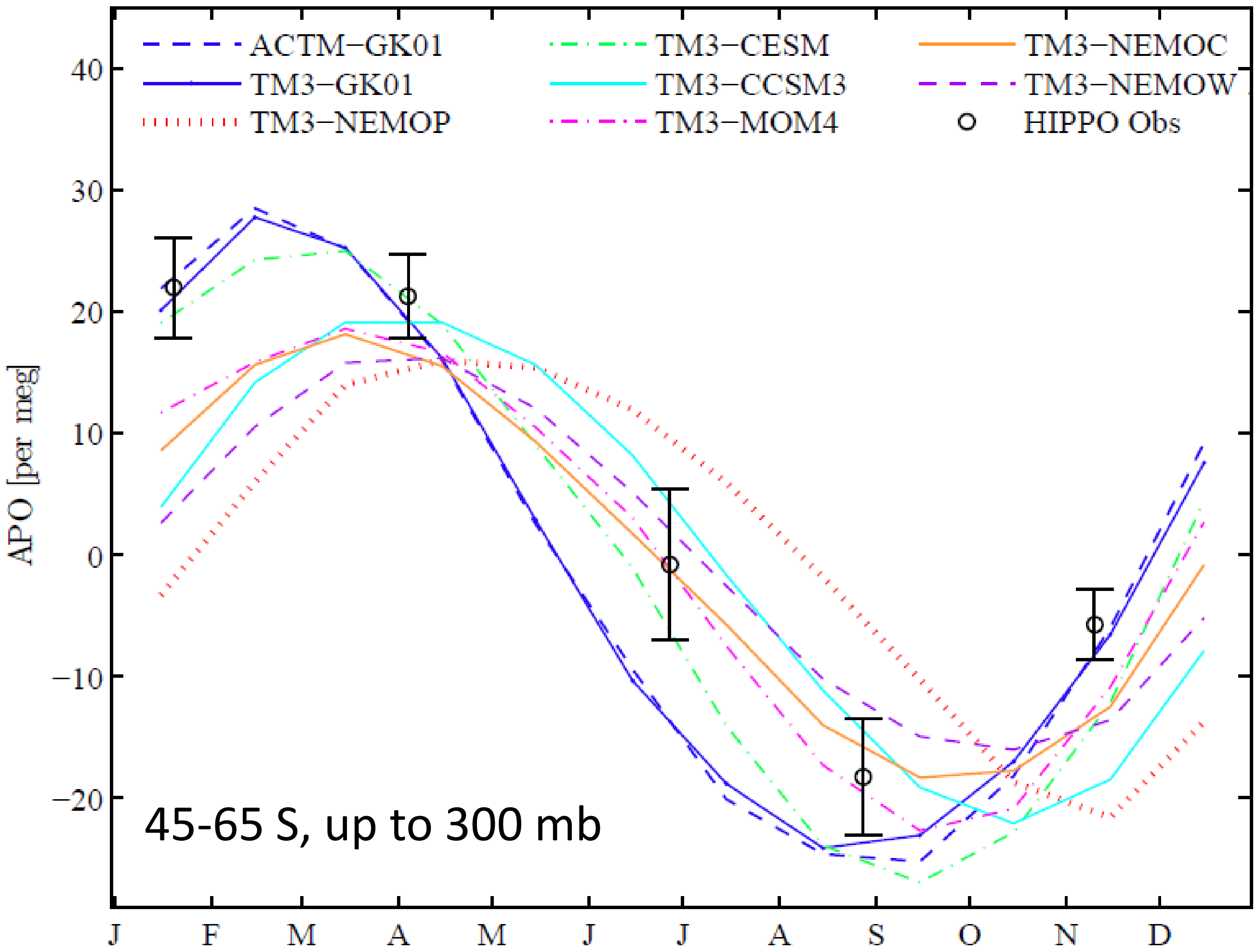
January, 2009





Atmospheric Potential Oxygen:
$APO = O_2 + 1.1*CO_2$

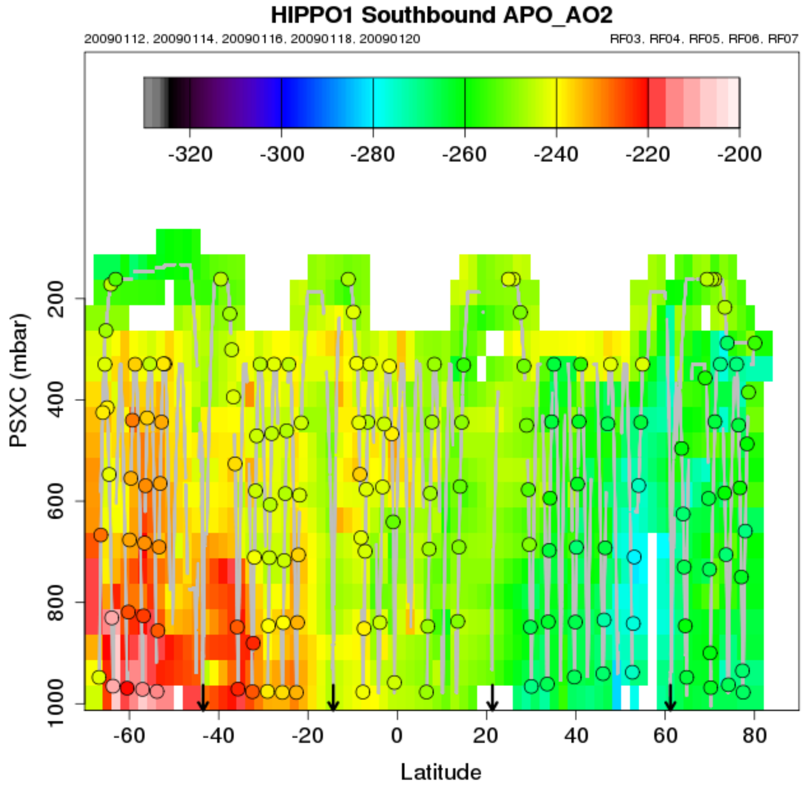
HIPPO Southern Ocean Curtain Averages

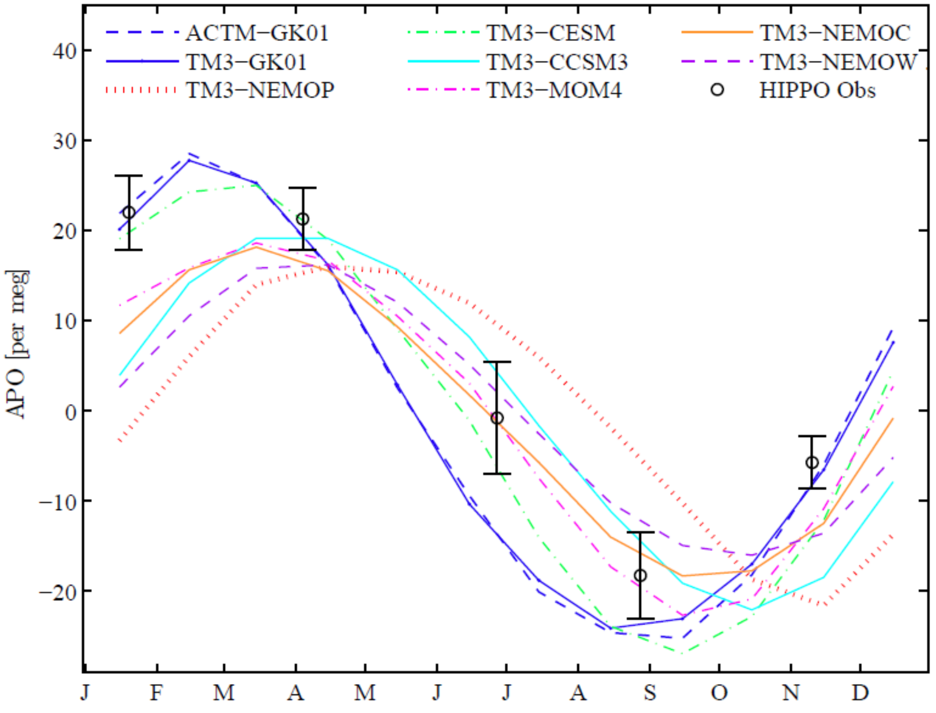


J. Bent, Dissertation, 2014

ORCAS Measurement Objective #1:

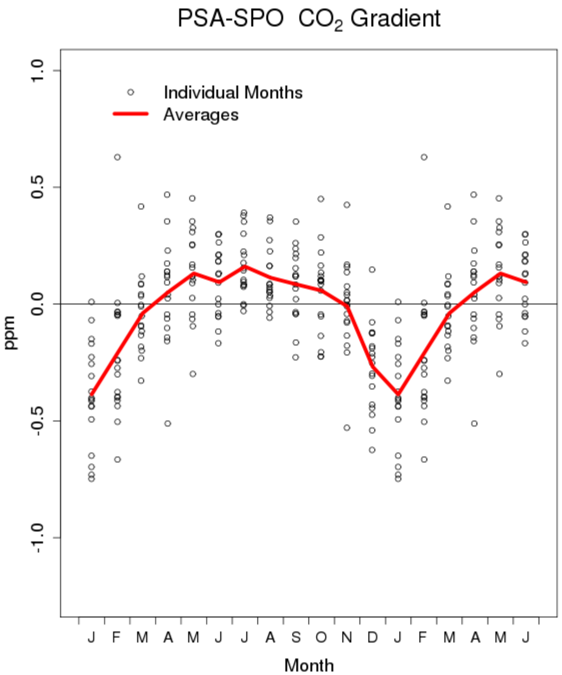
Large scale (50-70 S, 0-14 km altitude) atmospheric O_2 and CO_2 distributions, characterizing the size and temporal growth of the zonal atmospheric O_2 plume, and constraining zonal fluxes on monthly to seasonal time scales.

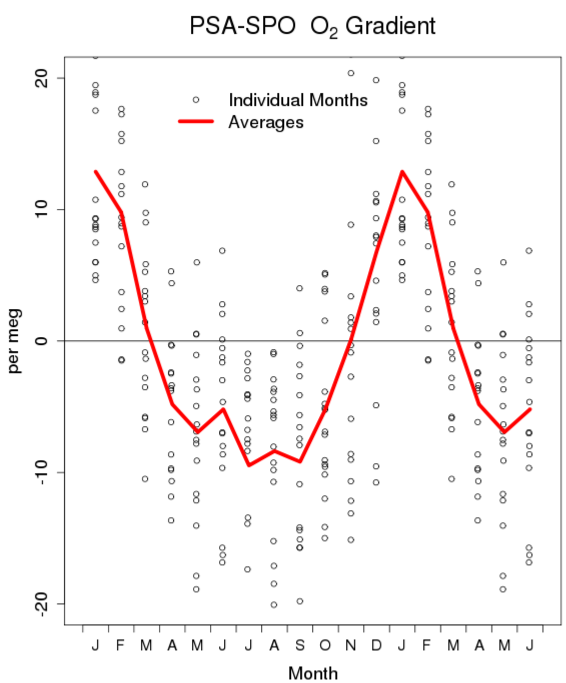


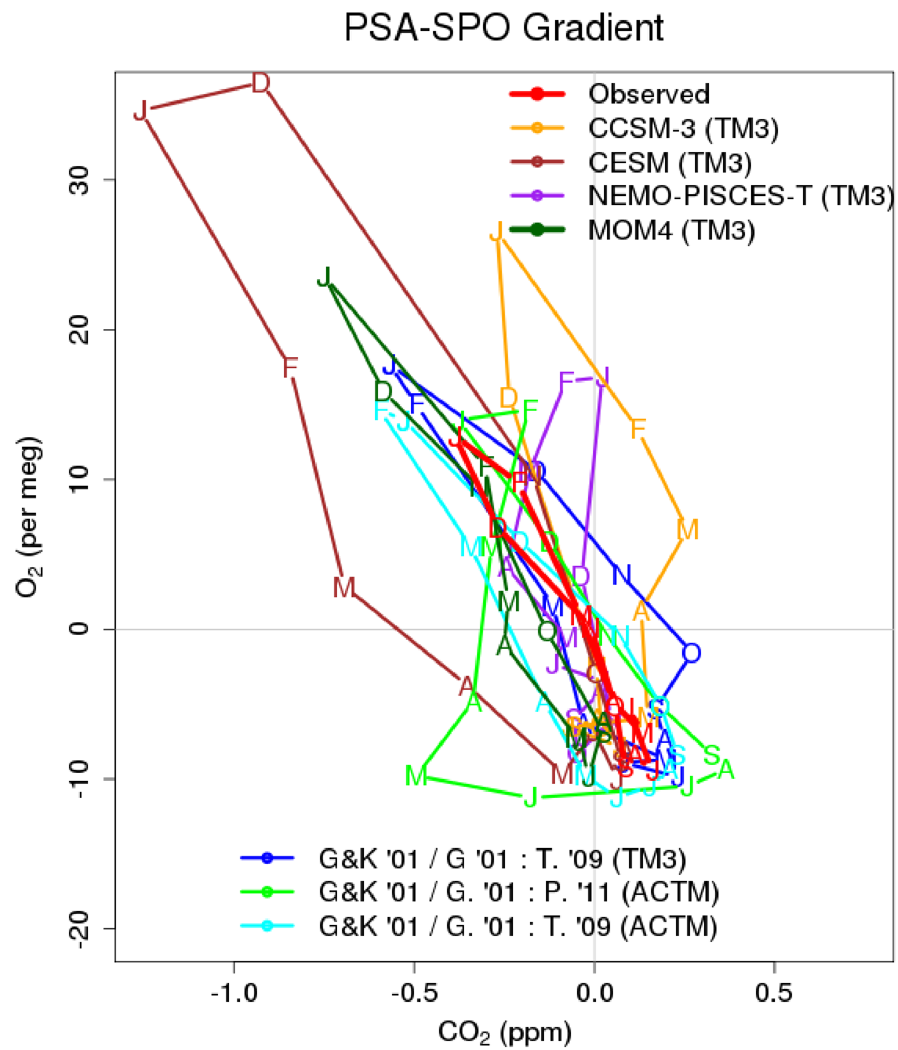


Scripps Oxygen Network

Palmer Station and South Pole Flasks

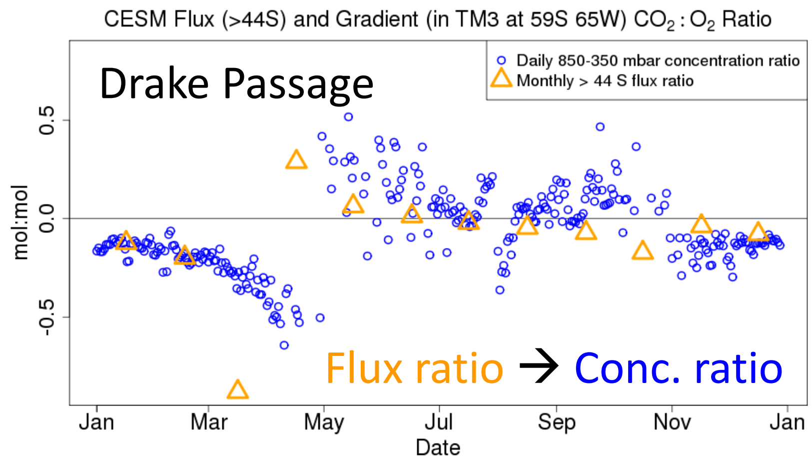


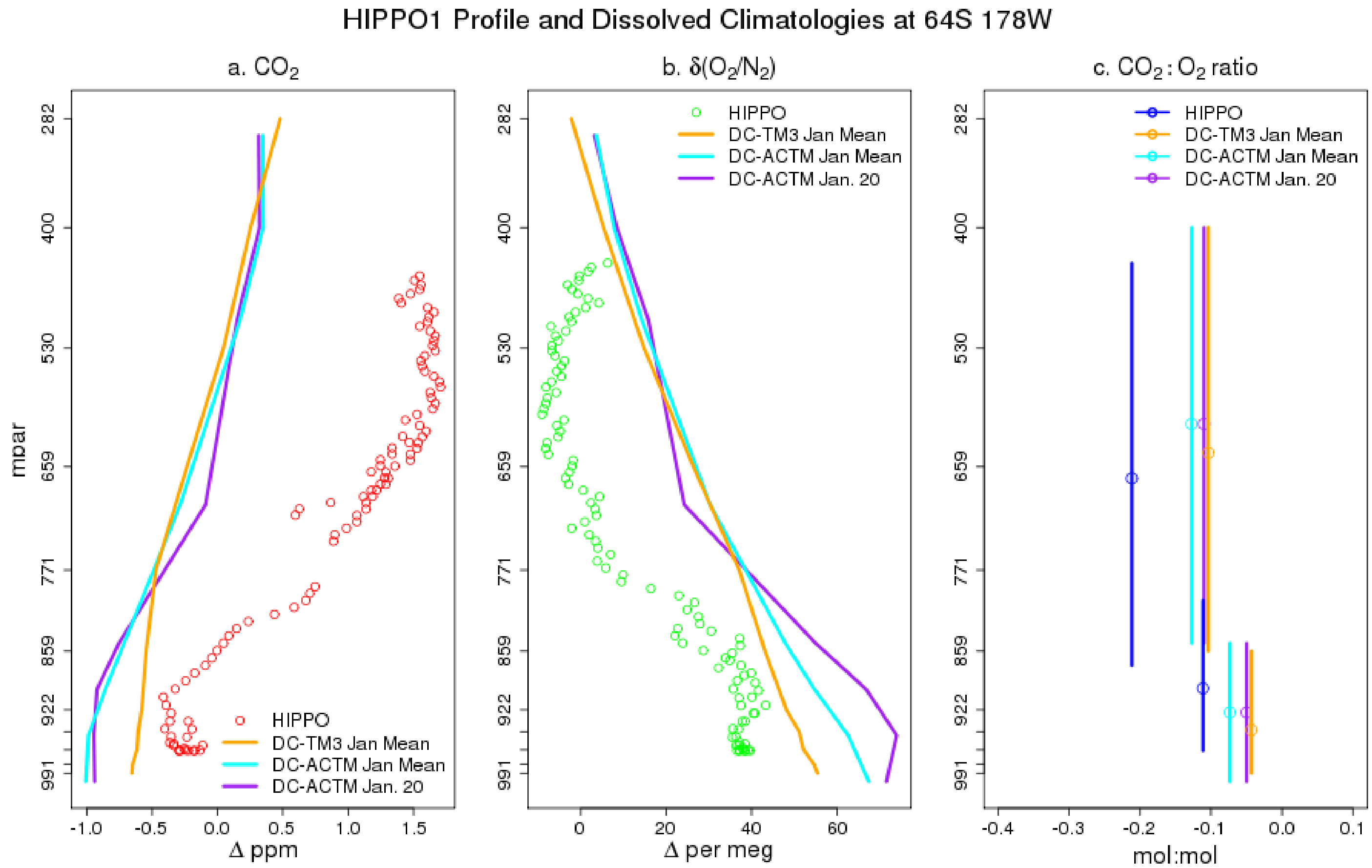




Jan = 0.15 mol CO_2 : mol O_2

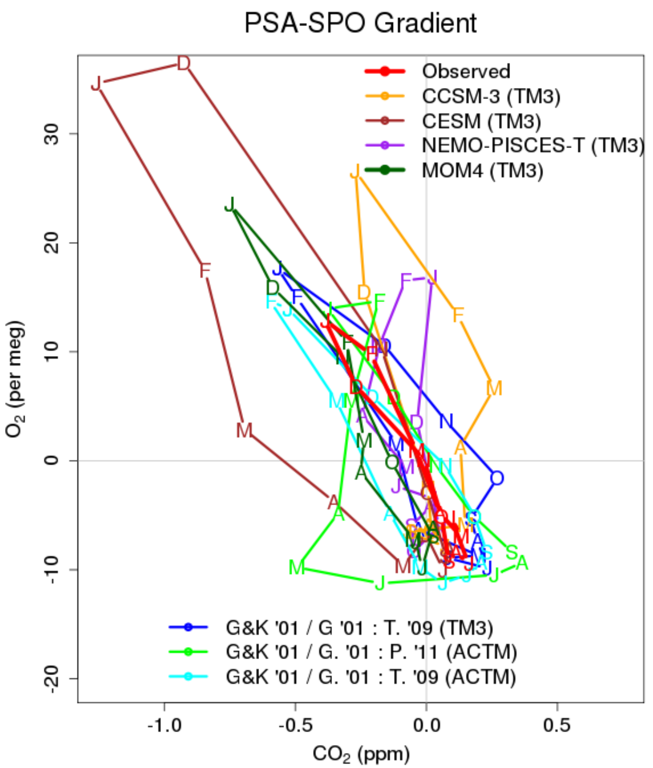
$CO_2 : O_2$ ratios from correlation over vertical profiles

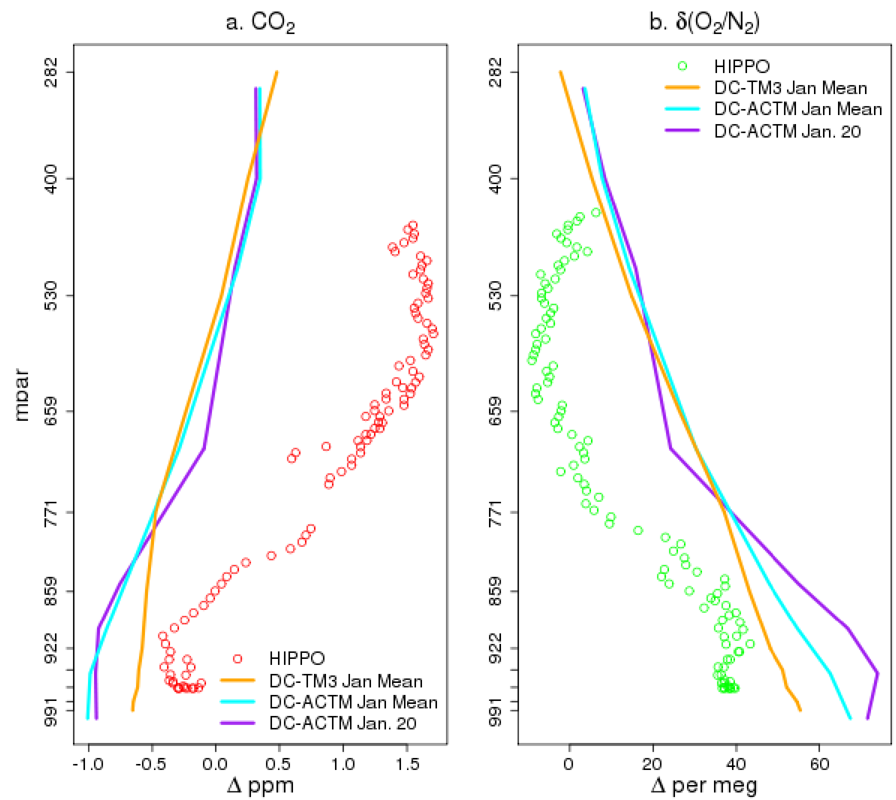




ORCAS Measurement Objective #2:

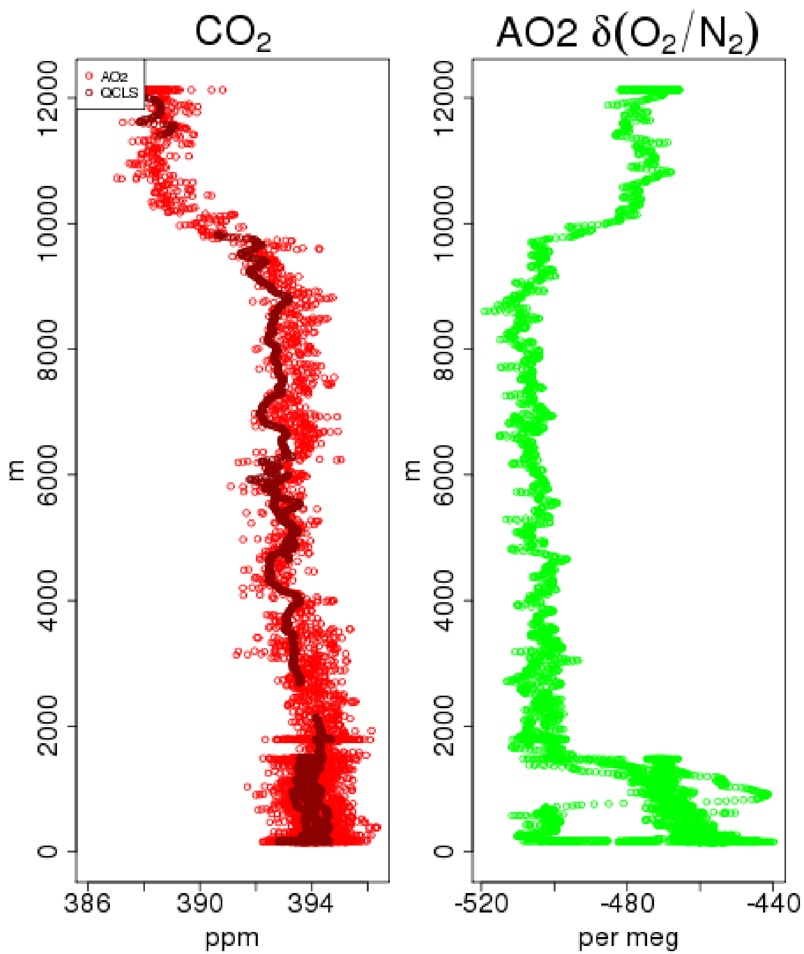
Basin scale vertical atmospheric O_2 and CO_2 gradient ratios through the mid-troposphere and spatial distributions to support estimation of flux ratios and magnitudes over full campaign time period and spatial extent.

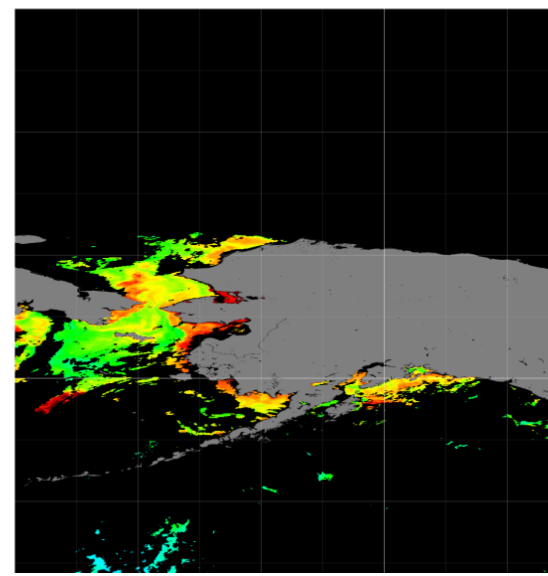




Boundary layer O_2 enhancements over summertime Arctic

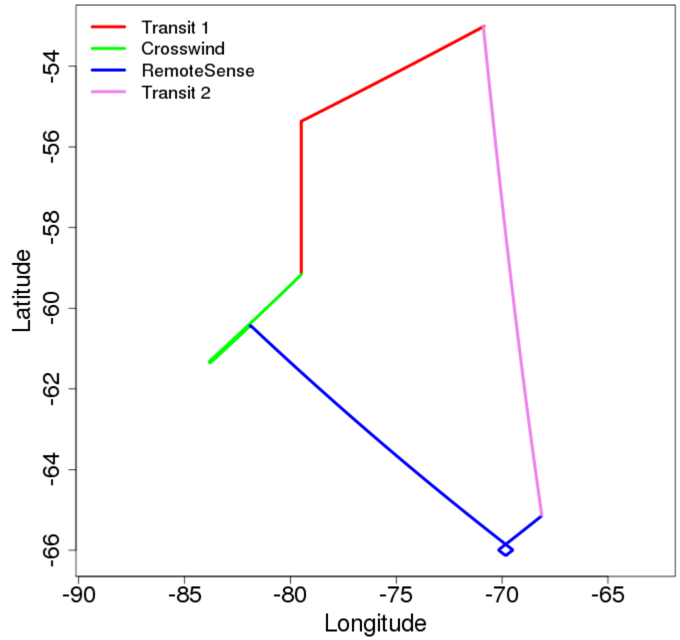
HIPPO4 RF02, 16 June 2011



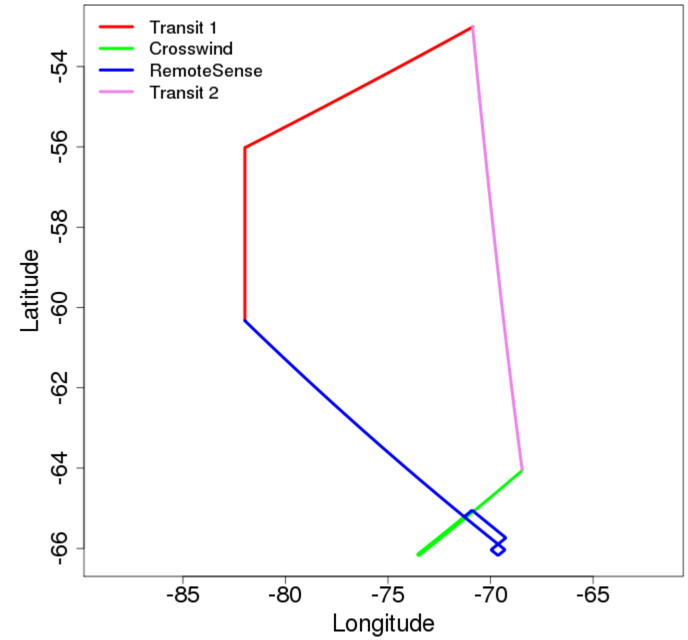


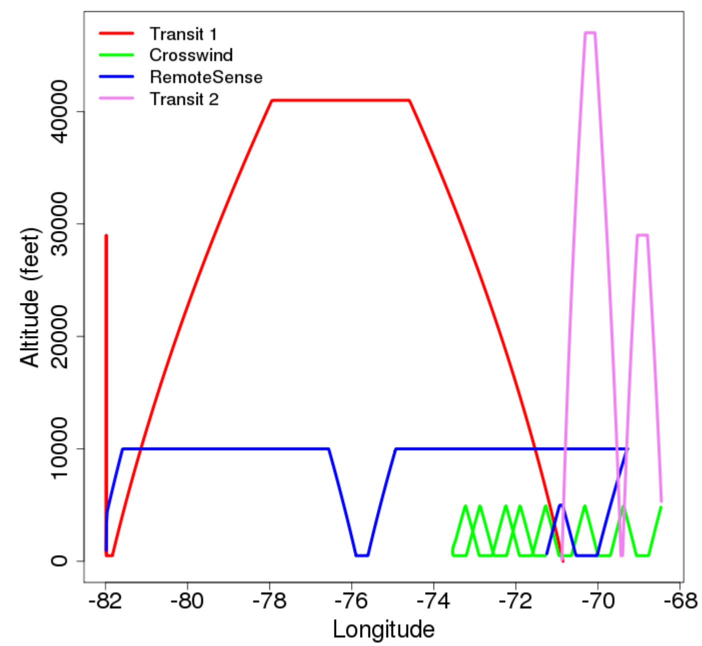
Pseudo-lagrangian sampling strategy

Day 1



Day 2





<u>1-σ SE on repeated sampling of BL gradients</u>

± 1.0 per meg O_2 and ± 0.03 ppm CO_2

<u>1 km ABL venting over 3 days flux precisions</u>

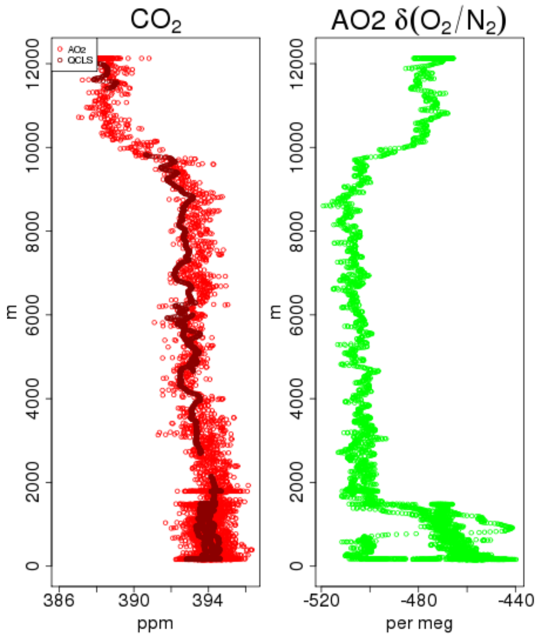
± 3 mmol O_2 $m^{-2}d^{-1}$ and ± 0.4 mmol CO_2 $m^{-2}d^{-1}$

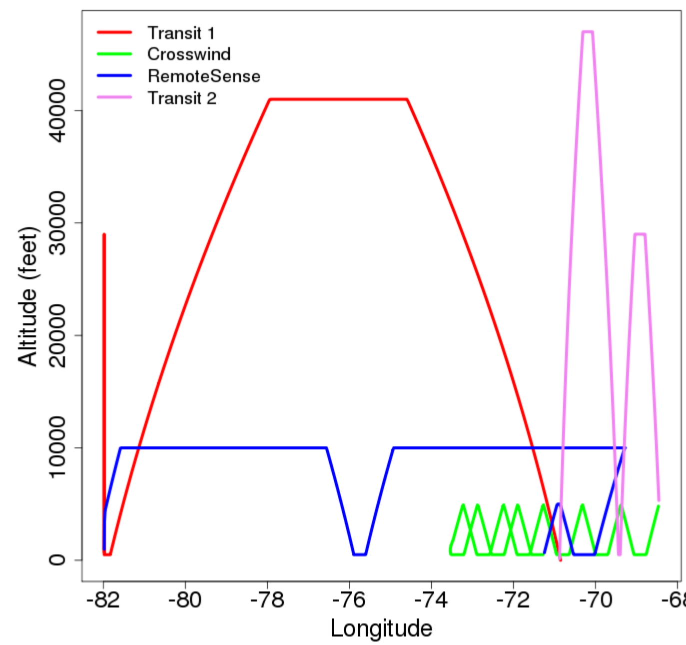
<u>Expected Jan/Feb Southern Ocean fluxes</u>

0-100 mmol O_2 $m^{-2}d^{-1}$ and -15 to 5 mmol CO_2 $m^{-2}d^{-1}$

ORCAS Measurement Objective #3:

Regional scale pseudo-Lagrangian flights for localized daily flux estimates and O_2 and CO_2 gradient ratios across the top of the ABL.



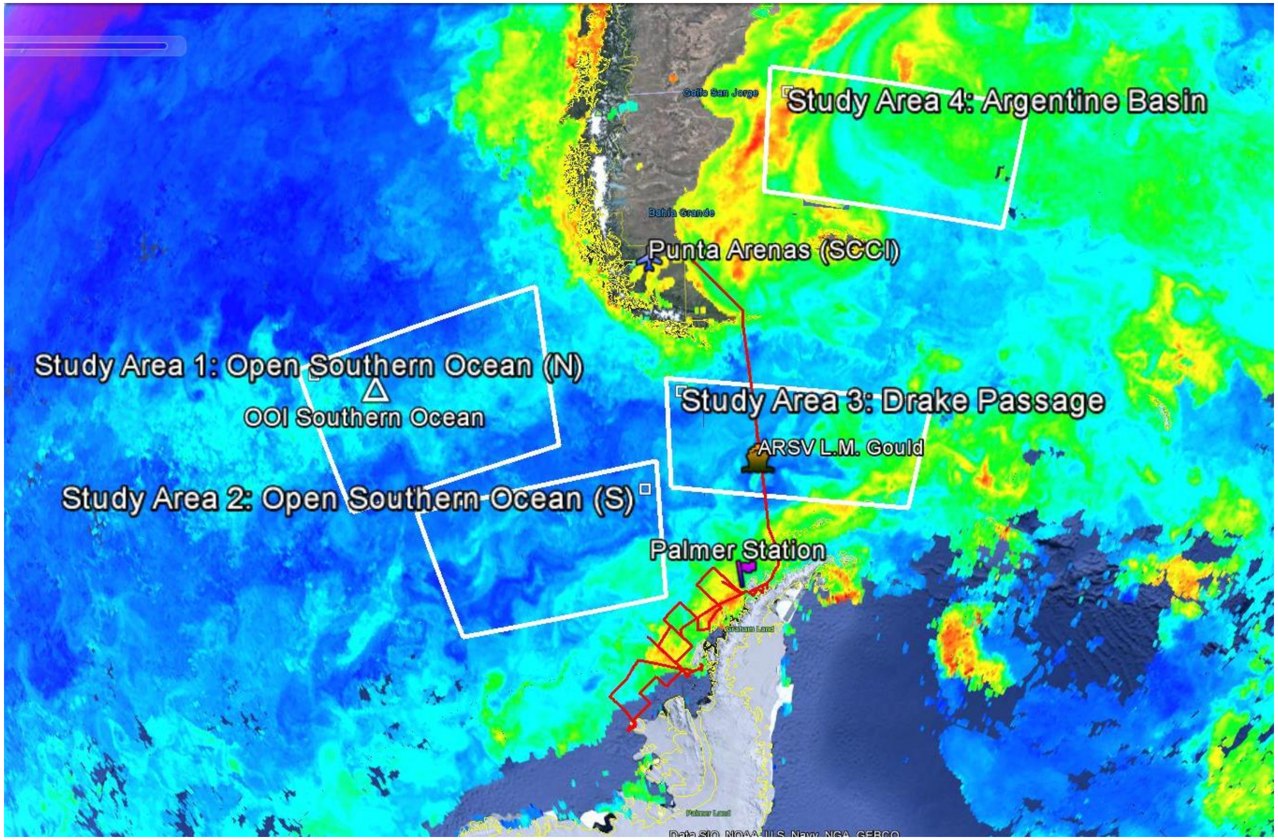


ORCAS Measurement Objectives #4 and #5:

Remote sensing of hyperspectral ocean color over daily flux influence regions and along the Antarctic Peninsula.

Biogenic reactive gas measurements to quantify emissions of chemically and radiatively important species.

ORCAS Preliminary Study Areas:



Study Area	Unique Features
Open Southern Ocean (north)	Representative of much of the low-iron, relatively warm, subantarctic Southern Ocean. Contains OOI Southern Ocean Node.
Open Southern Ocean (south)	Relatively cold polar frontal and Antarctic zone. Adjacent to LTER grid allowing additional constraints from Gould atmospheric O_2 and CO_2 measurements.
Drake Passage	Compressed frontal region with enhanced eddy activity. Overlaps decadal time-series from underway Gould crossings.
Argentine Basin	Region of high iron input and high productivity.
Palmer LTER Grid	Coastal region of high productivity. Coincident with long-term ecological study locations and planned location of the Gould during the ORCAS campaign.

ORCAS Project Overview:

- **Dates:** six weeks from mid January to end February, 2016, to coincide with high productivity and peak atmospheric O_2 conditions and to overlap with the 2016 Palmer LTER cruise
- **Synergistic observations:** Palmer LTER cruise and DO_2/Ar sampling aboard the NSF ARSV L.M. Gould; pCO_2, DIC, nutrients, and atmospheric CO_2 and O_2 on the Gould; NSF OOI Southern Ocean node; SOCCOM biogeochemical profiling floats; biogeochemical gliders
- **Operations:** 14 × 7-hour flights for a total of 98 research flight hours, plus 10 hours of test flights and ferry time, allowing 3-4 large-scale survey flights, 2-3 flights per study area, 1-2 dedicated Antarctic Peninsula remote sensing flight, and 1 dedicated student flight

GV Scientific Payload:

Instrument	Measurement	Institution
Airborne Oxygen Instrument (AO2)	$d(O_2/N_2)$, CO_2	NCAR EOL
Quantum Cascade Laser Spectrometer (QCLS)	CO_2, CH_4, N_2O, CO	Harvard/Aerodyne/NCAR
Picarro	CO_2, CH_4, H_2O	NOAA/CU
Medusa Flask Sampler	$d(O_2/N_2)$, CO_2, $d(Ar/N_2)$, $d^{13}C$, $d^{18}O$, and $D^{14}C$ of CO_2	NCAR/Scripps
Portable Remote Imaging Spectrometer (PRISM)	Hyperspectral water-leaving radiance	JPL
Advanced Whole Air Sampler (AWAS)	Over 80 trace gases, including DMS, OCS, halocarbons, $MeONO_2$, isoprene	NCAR/U. Miami
HIAPER Trace Organic Gas Analyzer (TOGA)	Over 60 VOCs, including nitrate species, DMS, and VSL halocarbons	NCAR
VCSEL, King Probe, RICE, CDP, 2DC, CN, UHSAS, GNI, CLH-2	Cloud microphysics and aerosol size distributions	NCAR, CU

ORCAS Motivation:

- The Southern Ocean is a large sink for anthropogenic CO_2 with particular sensitivity to climate change.
- State-of-the-art Earth System Models diverge for seasonal Southern Ocean air-sea CO_2 and O_2 fluxes, and for Southern Ocean climate-carbon feedbacks.
- Atmospheric O_2 (reported as deviations in the O_2/N_2 ratio) provides unique constraints on the biological, thermal, and anthropogenic drivers of Southern Ocean CO_2 exchange.

ORCAS Measurement Objectives:

- **Large scale** (50-70 S, 0-14 km altitude) atmospheric O_2 and CO_2 distributions, characterizing the size and temporal growth of the zonal atmospheric O_2 plume, and constraining zonal fluxes on monthly to seasonal time scales.
- **Basin scale** vertical atmospheric O_2 and CO_2 gradient ratios through the mid-troposphere and spatial distributions to support estimation of flux ratios and magnitudes over full campaign time period and spatial extent.
- **Regional scale** pseudo-Lagrangian flights for localized daily flux estimates and O_2 and CO_2 gradient ratios across the top of the ABL.
- **Remote sensing** of hyperspectral ocean color, **biogenic reactive gas** measurements, and **cloud microphysics and aerosol** observations