Global scale airborne and ship based observations of atmospheric potential oxygen

Britton Stephens, NCAR Earth Observing Laboratory

**Observations:** Jonathan Bent, Ralph Keeling (Scripps), Andrew Watt, Steve Shertz (NCAR), Colm Sweeney (CIRES), HIPPO Science Team, NCAR RAF Staff, ARSV LMG Staff

**Models:** Sara Mikaloff-Fletcher (NIWA), Prabir Patra (JAMSTEC), Matt Long (NCAR), Ivan Lima, Scott Doney (WHOI), John Dunne, Anand Gnanadesikan (GFDL)
Testing global ocean carbon cycle models using measurements of atmospheric O$_2$ and CO$_2$ concentration

Britton B. Stephens, Ralph F. Keeling, Martin Heimann, Katharina D. Six, Richard Murnane, and Ken Caldeira

Speculated that global ocean biogeochemistry models underestimated the southward transport of O$_2$ and CO$_2$ (too much equatorial outgassing and not enough S. Ocean outgassing), and that this was caused by excessive penetration of heat at low latitudes.
• PIs: Harvard, NCAR, Scripps, NOAA
• Global and seasonal survey of CO₂, O₂, CH₄, CO, N₂O, H₂, SF₆, COS, CFCs, HCFCs, O₃, H₂O, CO₂ 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
NCAR Airborne Oxygen Instrument (AO2)

NCAR/Scripps Medusa Flask Sampler
January, 2009

HIPPO1 Southbound APO_AO2

per meg – MLO trend
August, 2011

HIPPO5 Southbound APO_AO2

per meg – MLO trend
HIPPO Annual APO Means

from single harmonic fits to binned and detrended observations
Mid-latitude uptake

Tohjima et al., GBC, 2012
from single harmonic fits to binned and detrended observations
HIPPO Seasonal APO Amplitudes

APO (per meg)

Latitude (°N)

Column (>300)
Surface (>900)

hemispheric parity
NSF ARSV L.M. Gould Atmospheric O$_2$ / CO$_2$ installed in June of 2012
NSF ARSV L.M. Gould Atmospheric $O_2 / CO_2$ timeseries

Hourly Means at PSA

$\delta(O_2/N_2)$ (per meg)

$CO_2$ (ppm)

2012 2013 2014 2015
Ship clean air sector = W
SIO flask clean air sector = E
High $O_2$ variability reflects atmospheric signals related to synoptic transport and local exchange.

Low instrument noise of < 5 per meg evident on high latitude June cruise.
Averaged in 1-degree latitude bins, detrended, and fit with 1 harmonic. Observations while docked at Palmer Station binned separately.

Annual mean decrease in O₂ and APO to the south follows hemispheric gradient but deeper than western Pacific.

Agreement with station flasks remarkable but partly by luck.
NSF ARSV L.M. Gould latitudinal gradients in seasonal amplitude

- APO amplitude peaks near 80 per meg from 60-65 S
- APO amplitude at Palmer Station much lower – local effect or continuing further south?
- Potentially large zonal differences in amplitude in Southern Ocean
NSF ARSV L.M. Gould Atmospheric APO seasonal amplitudes

1-Harmonic Seasonal Amplitude

APO (per meq)

Latitude °S

LMG
CESM1-TM3
CCSM3-TM3
MOM4-TM3
GK01-TM3
GK01-ACTM
The O$_2$/N$_2$ Ratio and CO$_2$ Airborne Southern Ocean (ORCAS) Study

CSIRO R/V Investigator O$_2$ / CO$_2$ System to be installed in Mar. 2016


NASA Atmospheric Tomography Mission (ATom 1) (2-4 TBD)
Conclusions

• Column average airborne measurements are effective at eliminating atmospheric transport uncertainty in model-data comparisons
• The equatorial mid-Pacific APO bulge is vertically homogeneous, smaller than some early estimates at approximately 5 per meg, and shifted south of the Equator
• The interhemispheric APO gradient is approximately 11 per meg (lower in the north), consistent with strong northward heat transport (Resplandy presentation)
• North Pacific APO dip / bulge previously seen in W. Pacific (Tohjima presentation) is also evident in HIPPO data (Mikaloff-Fletcher presentation)
• Several models that match seasonal APO amplitudes over the Southern Ocean (Bent presentation) do poorly over the North Pacific, and vice versa
• The seasonal APO amplitude in the mid Pacific is very similar between the two hemispheres, despite the disparity in ocean area (Nevison presentation)
• The seasonal APO cycle in Drake Passage is bigger than adjacent station observations, and the latitudinal peak is sharper than represented in coarse resolution models
• At Palmer Station, annual mean agreement with station flask measurements is very good, but with opposing seasonal differences reflecting significant sector effects
• We now have extensive observations of the latitudinal and vertical distribution of atmospheric oxygen within the Pacific Basin, and we encourage others to use them