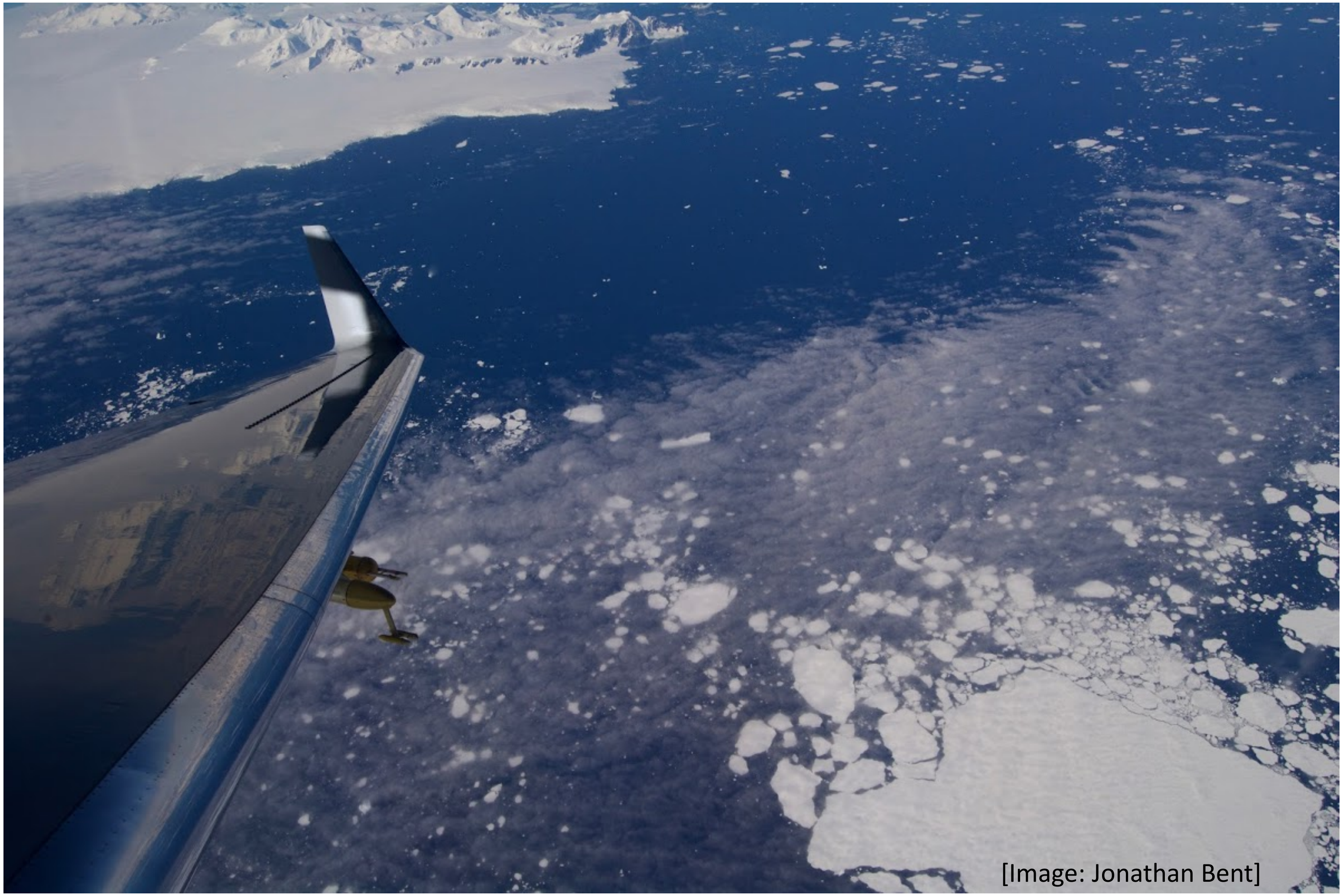
Recent NSF Supported Airborne Oceanography Campaigns and Future Directions



Britton Stephens, NCAR Earth Observing Laboratory / Research Aviation Facility

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

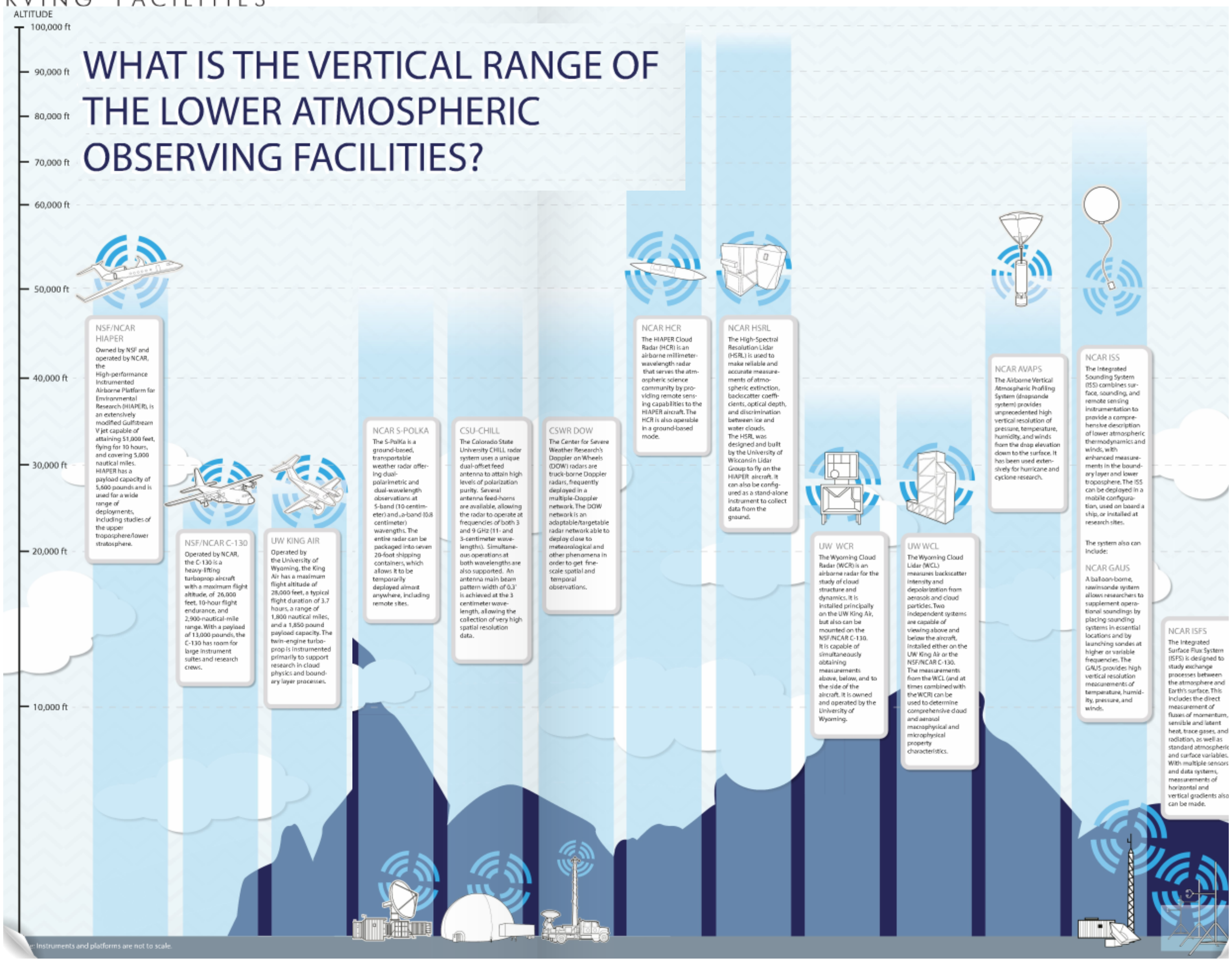
NSF

Outline:

1) NSF Lower Atmospheric Observing Facilities
   - NCAR C-130
   - NCAR GV
   - Request process
2) Past campaigns
3) O_2/N_2 Ratio and Southern Ocean (ORCAS) Study
4) Future Plans

LAOF
LOWER ATMOSPHERIC OBSERVING FACILITIES

Digital Guide: https://www.eol.ucar.edu/laof



C130 Research Aircraft

- 10 Hours Endurance
- 23,000 lb (13,000 with max fuel) payload
- Range 3100 nautical miles
- 26,000 ft max altitude (7.9 km)

Photo courtesy of Tony Clarke, Univ. of Hawaii

NSF/NCAR G-V Aircraft

- Six under-wing hardpoints
- Up and down co-aligned 21-inch optical viewports
- Multiple aperture/inlet locations

- 6000 lb science payload
- 6000 nautical miles
- 51,000 ft max altitude (15.5 km)

EARTH OBSERVING LABORATORY
Airborne Instruments

https://www.eol.ucar.edu/aircraft-instrumentation

I.State Parameters Including Temperature, Wind and Position
- A. Temperature, Ambient Air
- B. Humidity, Ambient Air
- C. Pressure, Ambient Air
- D. Winds
- E. Water vapor isotopes

II.Properties of Clouds and Hydrometeors
- A. Liquid Water Content
- B. Cloud Droplet Spectrometers
- C. Ice, Drizzle, and Precipitation Probes
- D. Remote Sensors

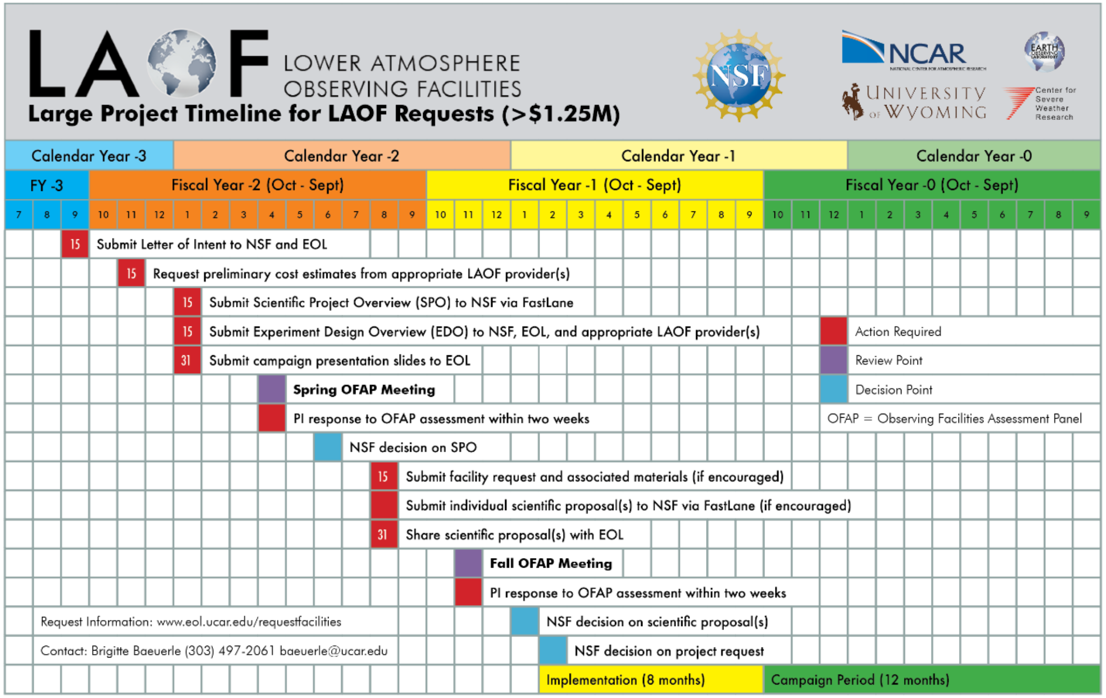
III.Gas Concentrations
- A. Ozone
- B. Carbon Dioxide, Methane, Carbon Monoxide, Nitrous Oxide
- C. Oxygen
- D. Flask Sampling Systems

IV. Aerosol Particles
- A. Condensation Nucleus Counter (Water or Butanol) (CN)
- B. Aerosol-Particle Spectrometers
- C. Chemical, Optical, or Other Properties of Aerosols
- D. Remote Sensors
- E. Special Inlet: Solid Diffuser Aerosol Inlet (SDI)

V. Radiation
- A. Upwelling and Downwelling Irradiance
- B. Actinic Flux
- C. Remotely Sensed Surface Temperature

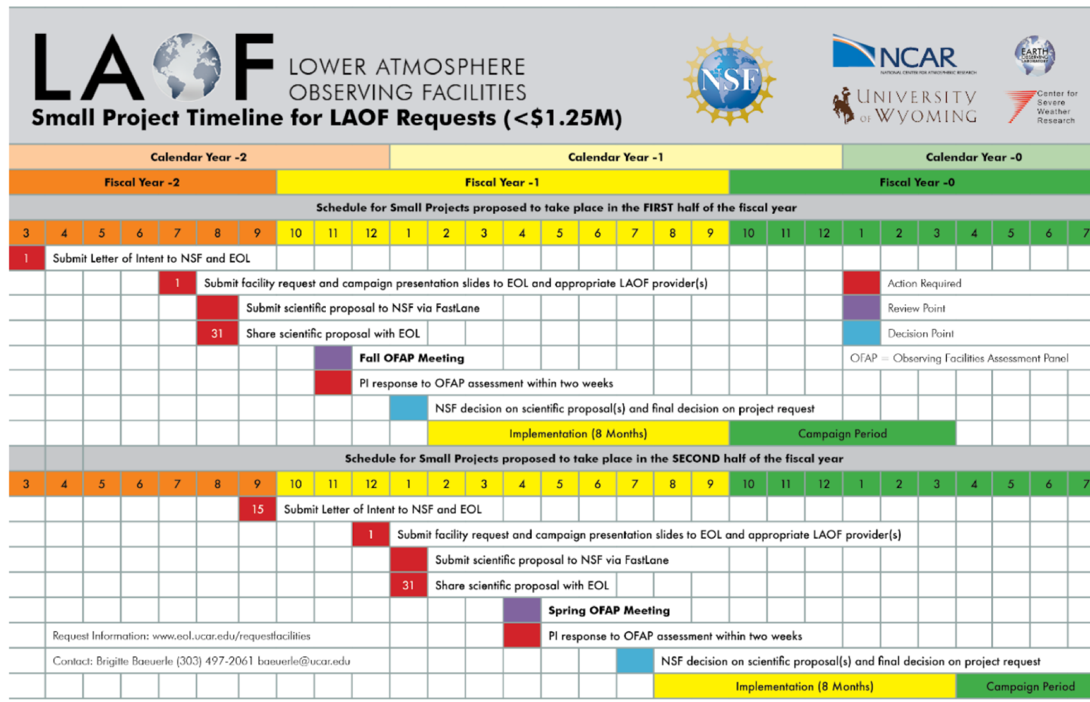
VI. Other
- A. HIAPER Modular Inlet (HIMIL; "HIMIL" inlets)
- B. Digital Imagery (camera or video)
- C. Satellite Communications System (SATCOM)
- D. Optical viewports
- E. Dropsondes

Large project request timeline



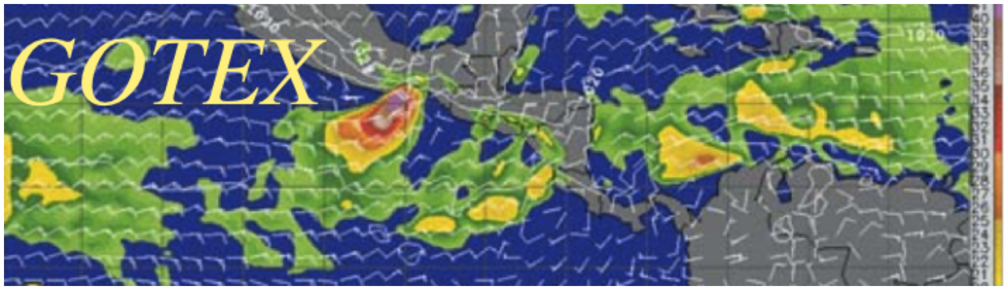
https://www.eol.ucar.edu/request-lower-atmosphere-observing-facilities

Small project request timeline



Example NCAR C-130 Campaigns

Gulf of Tehuantepec Experiment - 2004



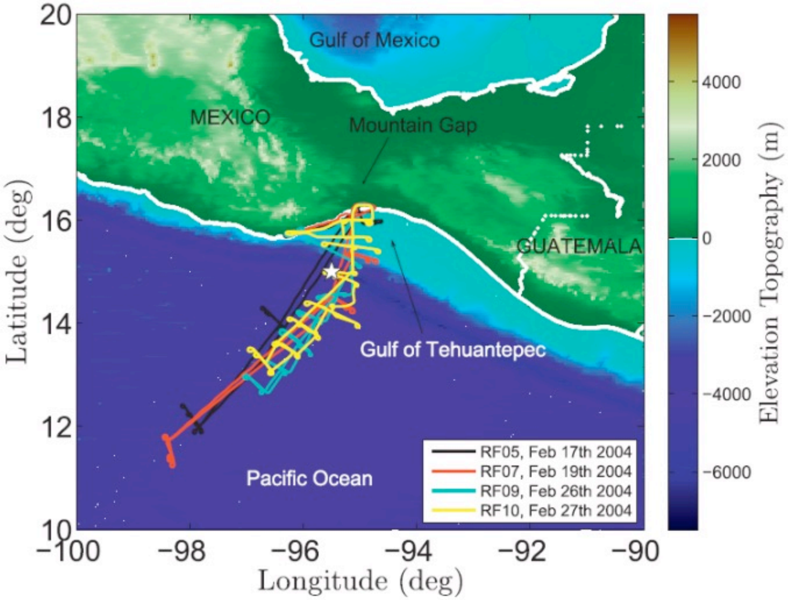
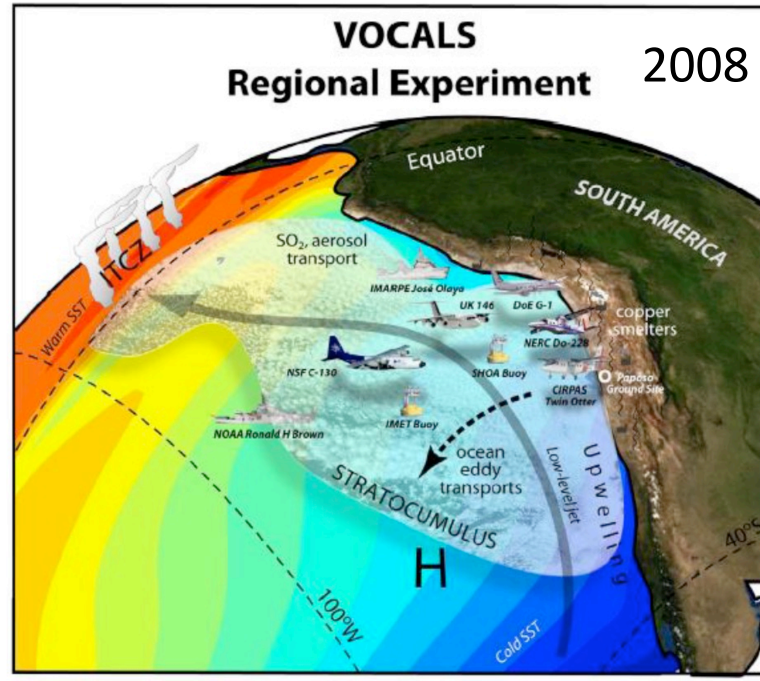
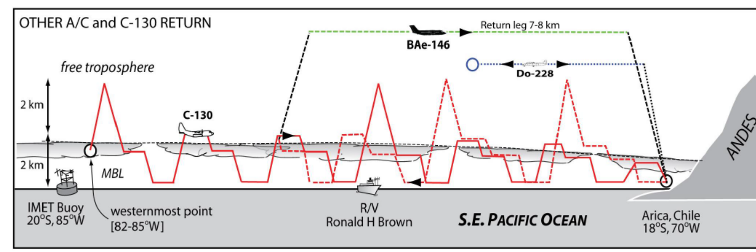


FIG. 2. GOTEX flight tracks from research flights 05, 07, 09, and 10. The white star corresponds to the location of wind time series shown in Fig. 3.

Romero and Melville, JPO, 2010

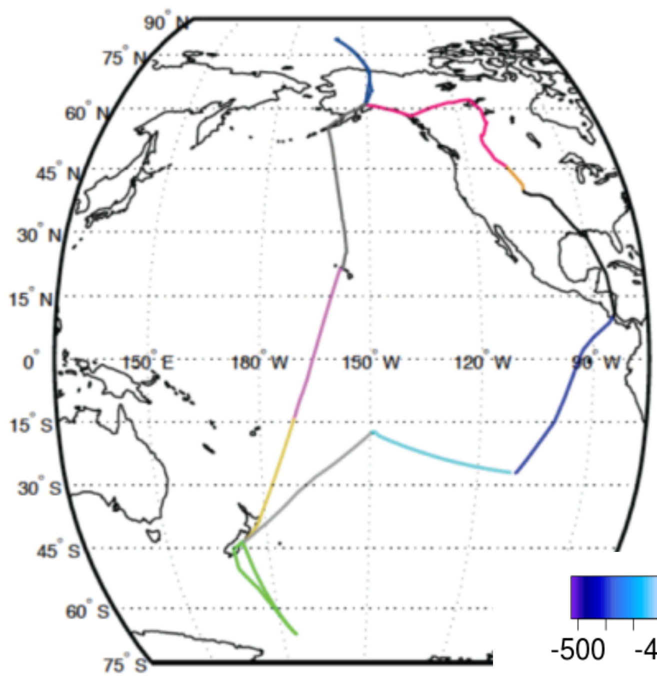




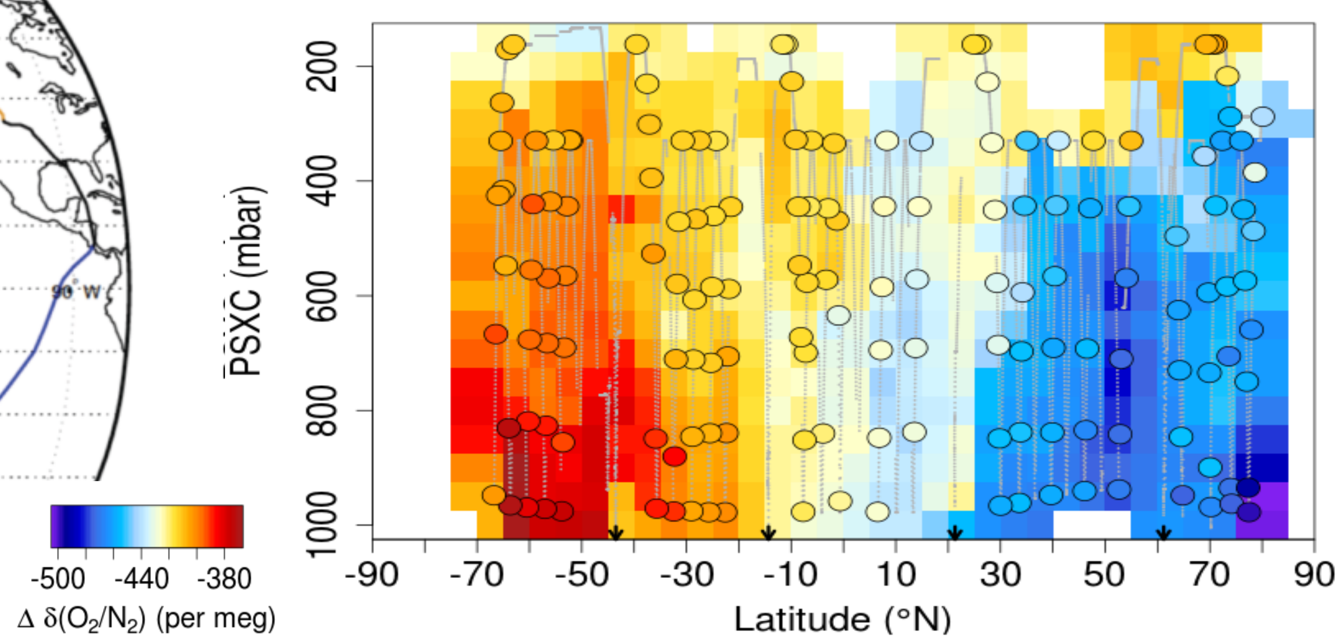
HIAPER Pole-to-Pole Observations (HIPPO)

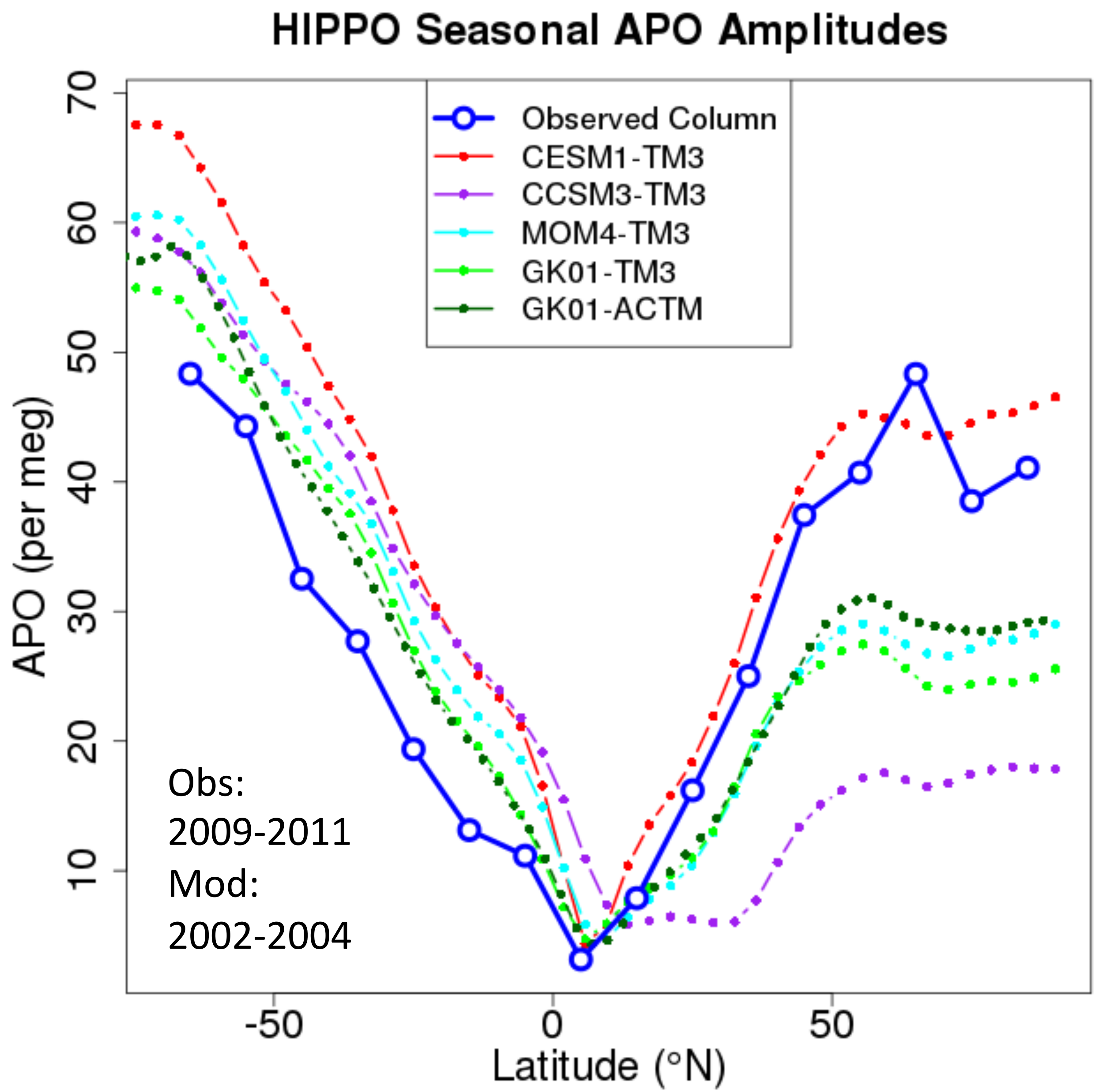
2009-2011

- 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
- www.eol.ucar.edu/field_projects/hippo



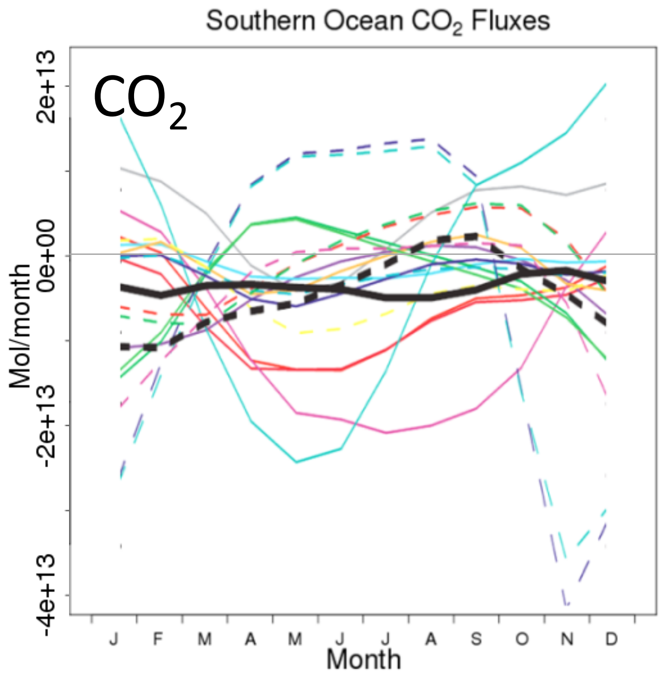
HIPPO1 January 2009 Atmospheric O_2

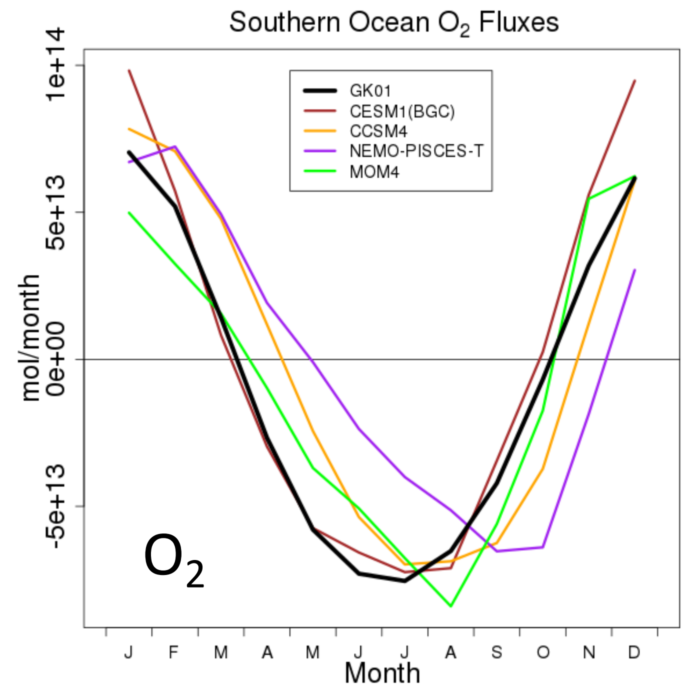




APO = O_2 + CO_2 = "oceanic oxygen"

Seasonal CO_2 and O_2 fluxes (S of 44 S)

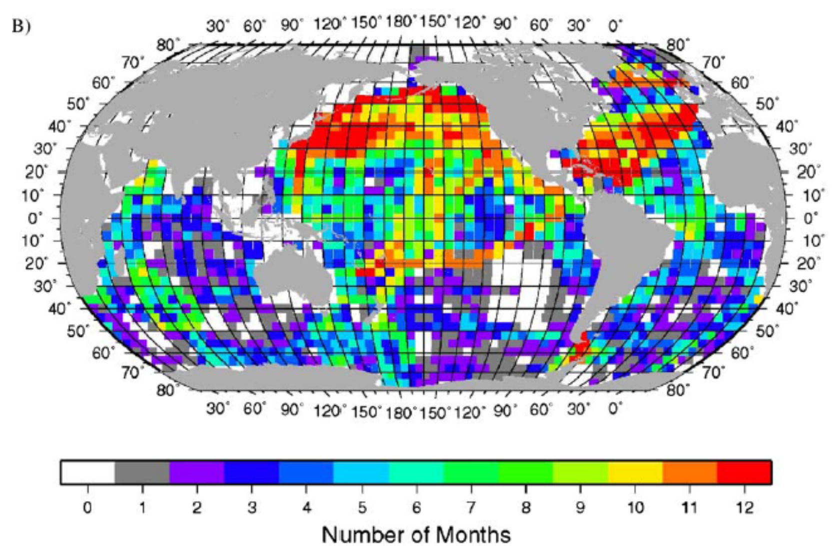




Models: Anav et al., J.Clim., 2013 M. Long, S. Doney, C. Le Quéré, J. Dunne

Obs: dash = Takahashi et al. DSR, 2009 black = Garcia and Keeling, JGR 2001

pCO_2 coverage

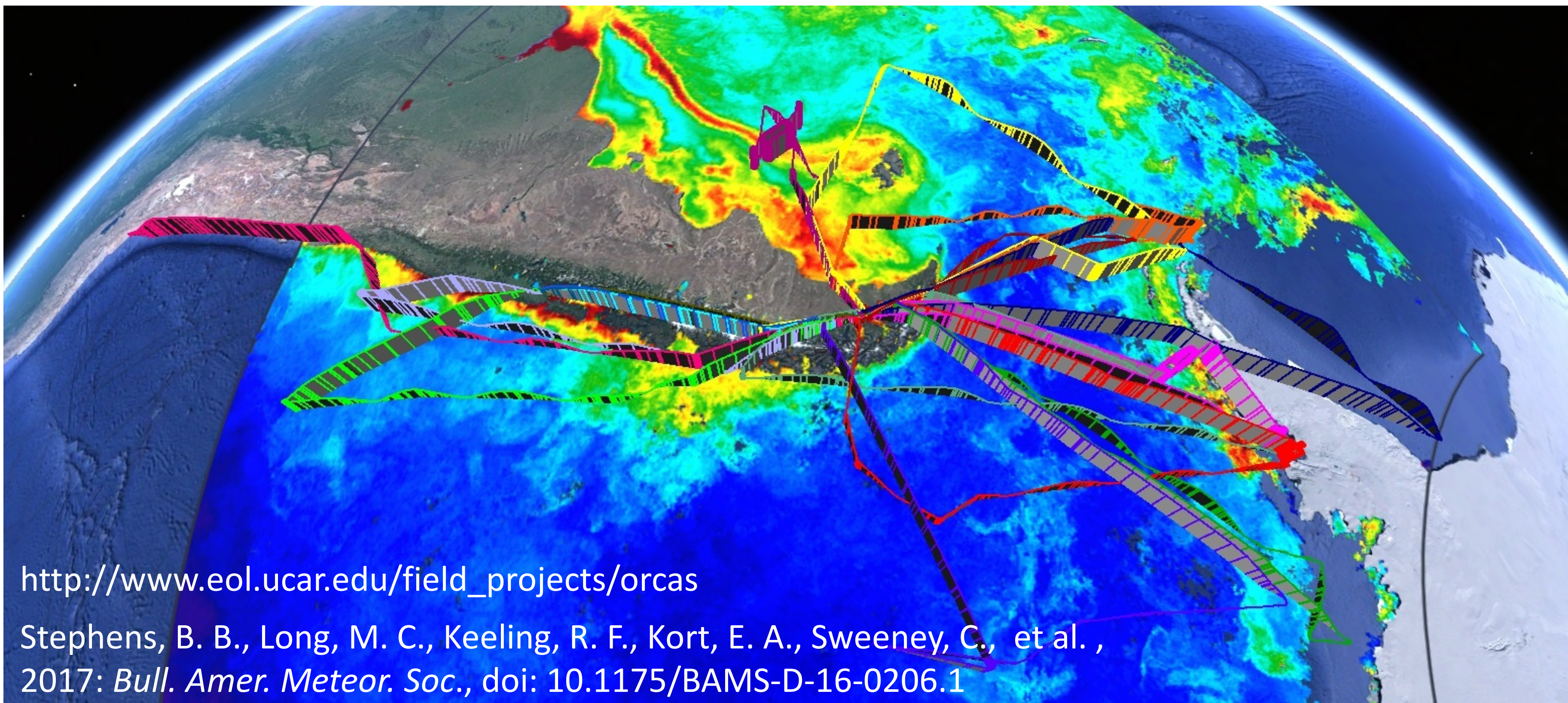


Takahashi et al., DSR, 2009

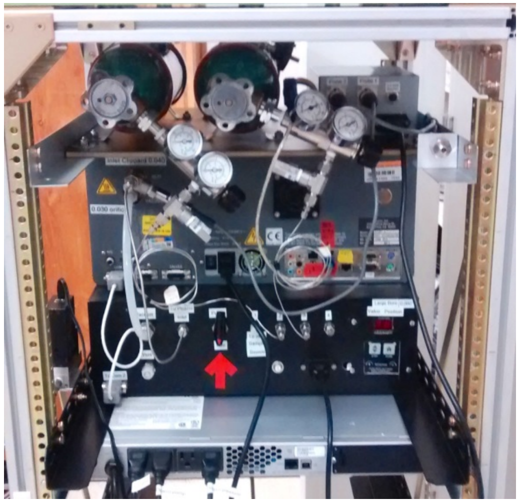
ORCAS

2016 O_2/N_2 Ratio and CO_2 Airborne Southern Ocean Study

NSF/NCAR GV
Punta Arenas, Chile
15 Jan to 29 Feb 2016

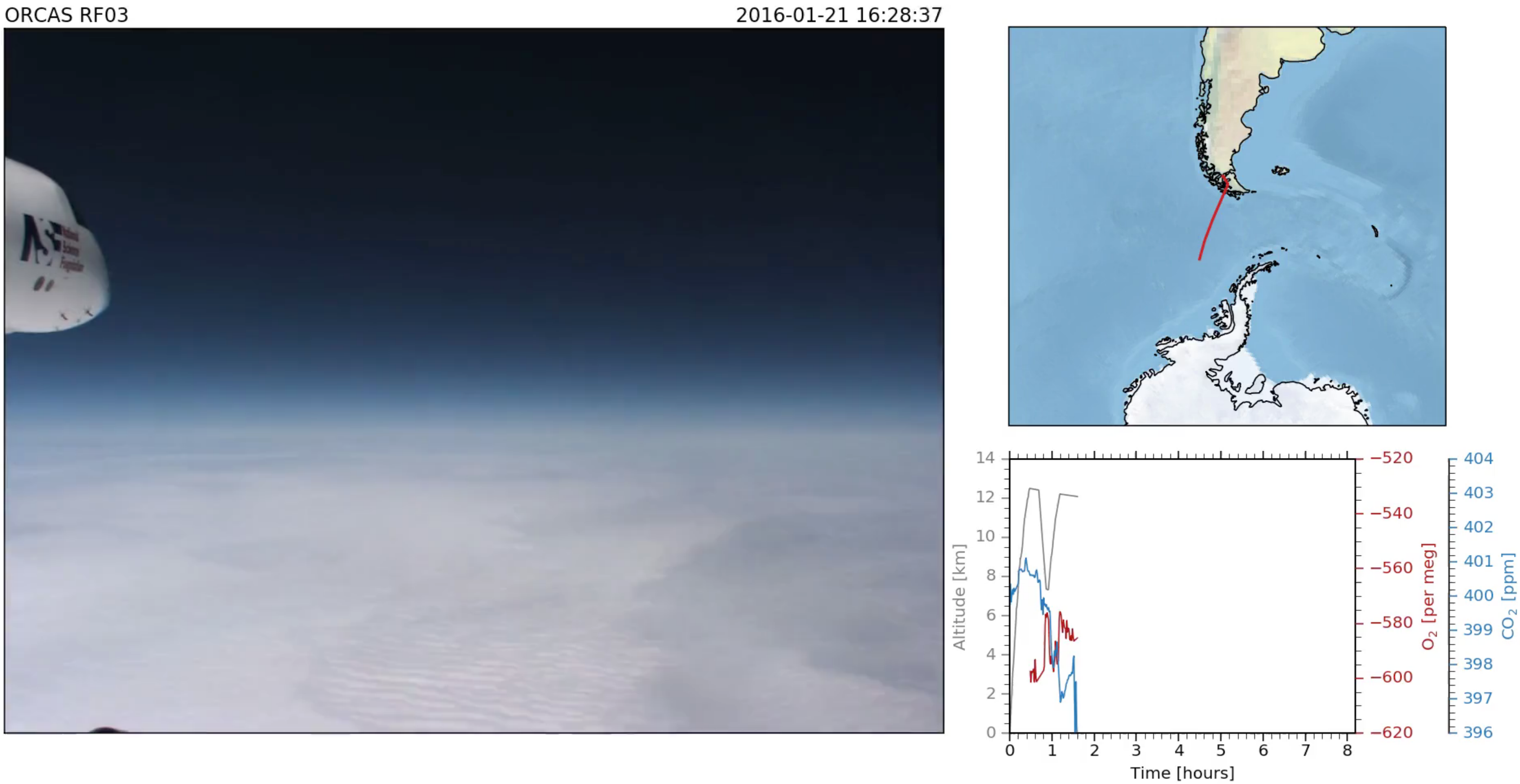


GV Scientific Payload:



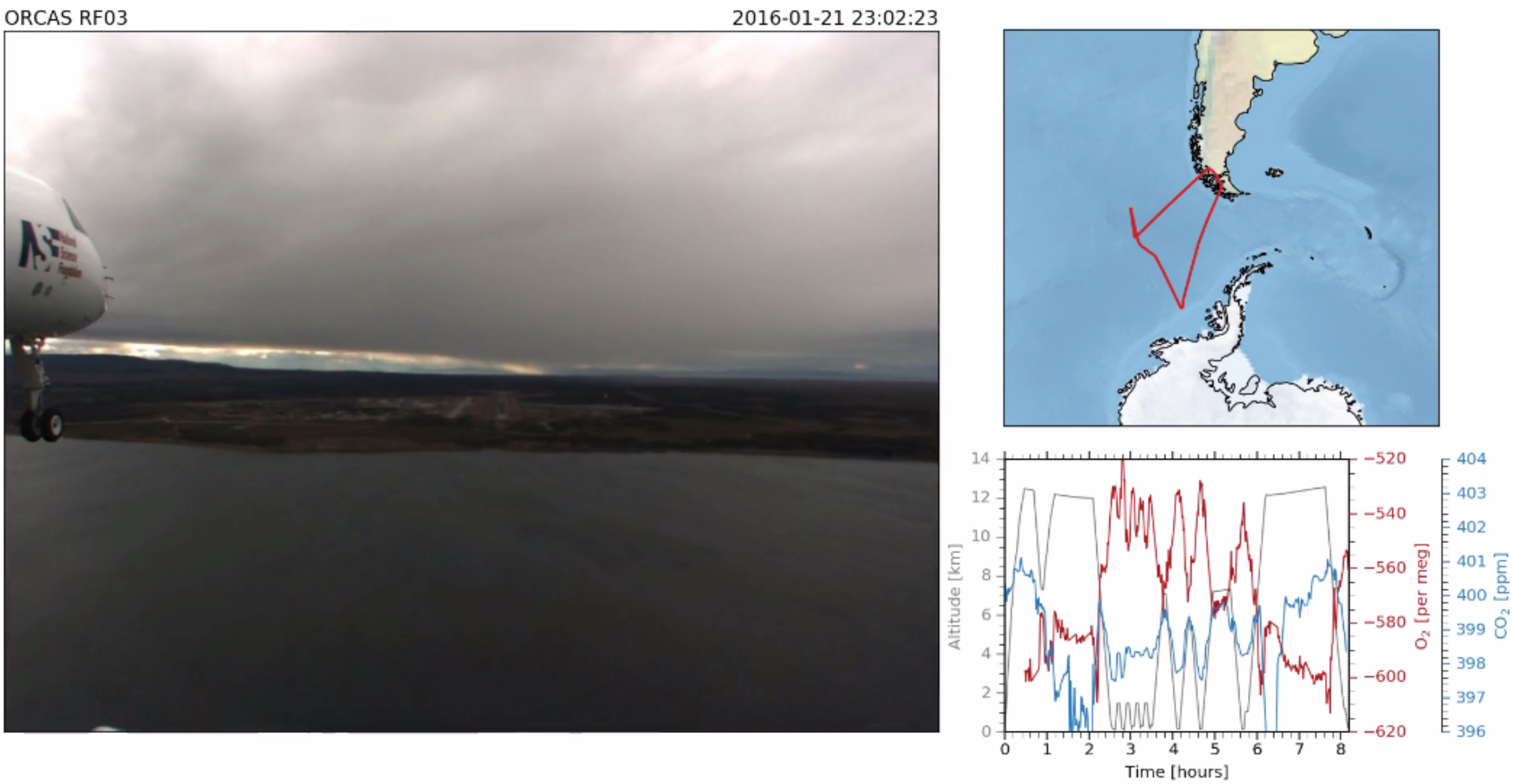
Instrument	Measurement	Institution
Airborne Oxygen Instrument (AO2)	$\delta(O_2/N_2)$, CO_2	NCAR EOL
Medusa Flask Sampler	$\delta(O_2/N_2)$, CO_2, $\delta(Ar/N_2)$, $\delta^{13}C$, $\delta^{18}O$, and $\Delta^{14}C$ of CO_2	NCAR/Scripps
Quantum Cascade Laser Spectrometer (QCLS)	CO_2, CH_4, N_2O, CO	Harvard/Aerodyne/NCAR
Picarro	CO_2, CH_4, H_2O	NOAA/CU
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 Research Flight 3



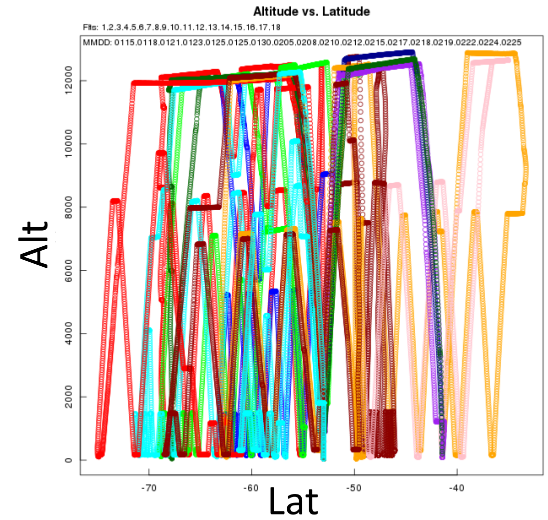
https://youtu.be/Df2peaFxUAM

ORCAS Research Flight 3

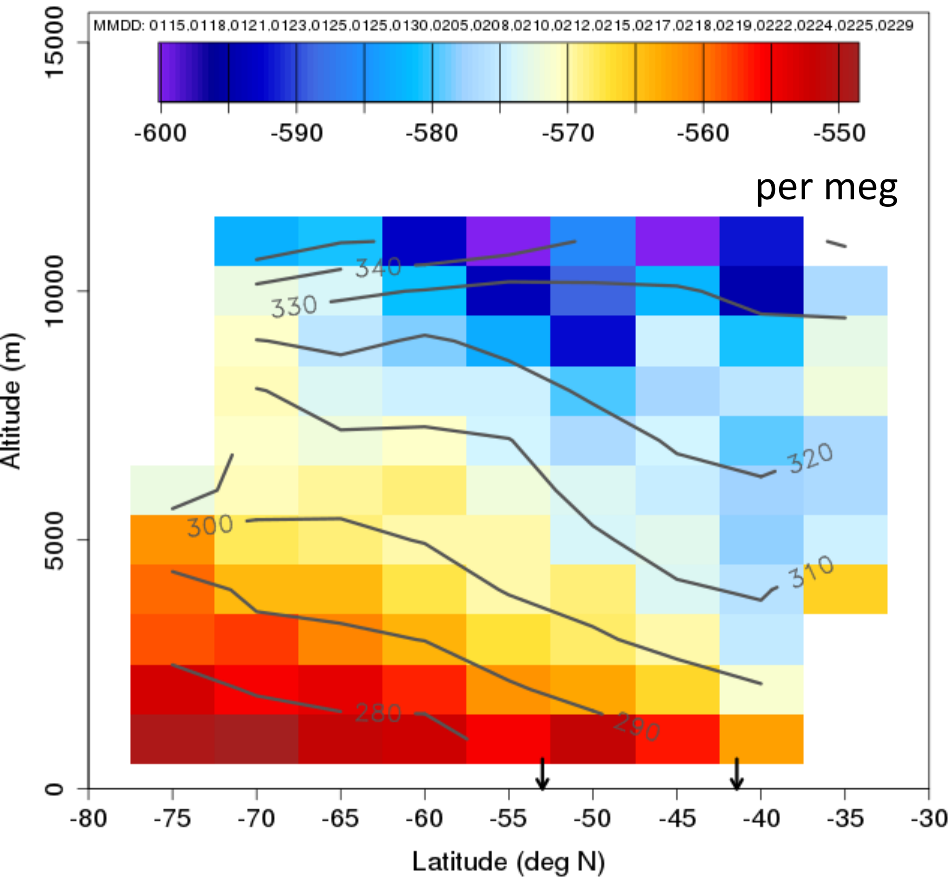


https://youtu.be/Df2peaFxUAM

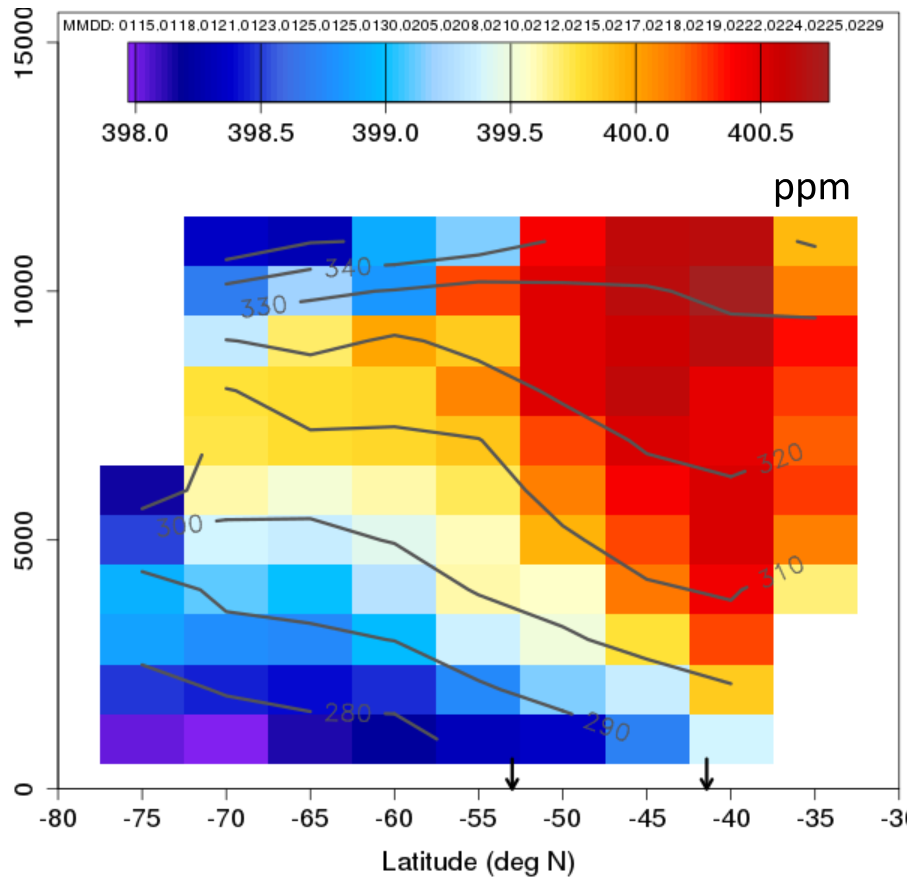
Whole campaign latitude /altitude bin averages



O_2



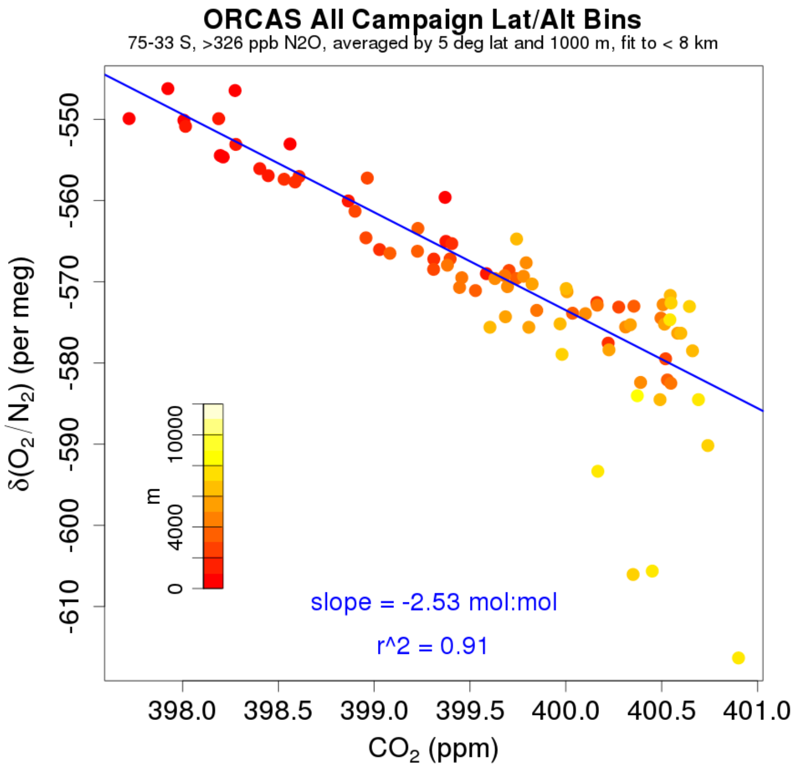
CO_2



ORCAS Highlights

- Negative O_2:CO_2 correlations revealed the dominance of biological drivers on summertime CO_2 fluxes
- O_2:CO_2 ratio and mean O_2 and CO_2 gradients suggest CESM overestimates summertime O_2 outgassing and climatologies underestimate summertime CO_2 ingassing
- Halogenated VOCs correlate with O_2 indicating biogenic source and providing new model tests
- ESM evaluation of supercooled liquid cloud distributions
- Development of methods for remotely sensing depth-resolved chlorophyll fluorescence

Whole campaign bin averaged O_2:CO_2 relationship



Southern Ocean Carbon Gas Observatory (SCARGO)

- NSF Polar Programs funded project
- B. Stephens / M. Long PIs
- "Roll-on / roll-off" rack and inlet
- Initially measuring CO_2, CH_4, CO, and H_2O
- 139th EAS LC-130s operating between Christhurch, McMurdo Station, South Pole, and north from McMurdo, Nov-Feb
- To quantify gradients, and trends in CO_2 and CH_4

UAS Activities

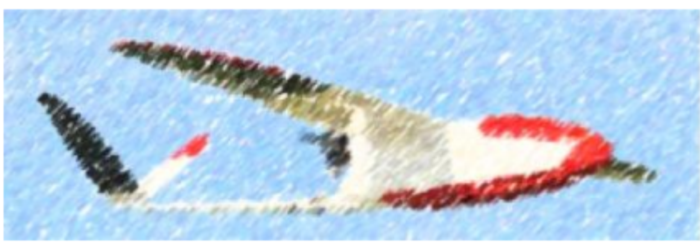
THE NCAR/EOL COMMUNITY WORKSHOP ON UNMANNED AIRCRAFT SYSTEMS FOR ATMOSPHERIC RESEARCH

21-24 February 2017
Boulder, Colorado, USA
Final Report 6 February 2018

Senior Editor:
Holger Vömel (NCAR/EOL)

Workshop Report Authors:
B.M. Argrow (CU), D. Axisa (DMT), P. Chlson (OU), S. Ellis (NCAR/EOL), M. Fladeland (NASA/AMES), E.W. Frew (CU), J. Jacob (OSU), M. Lord (NCAR/EOL), J. Moore (NCAR/EOL), S. Oncley (NCAR/EOL), G. Roberts (UCSD), S. Schoenung (BAERI), C. Wolff (NCAR/EOL)

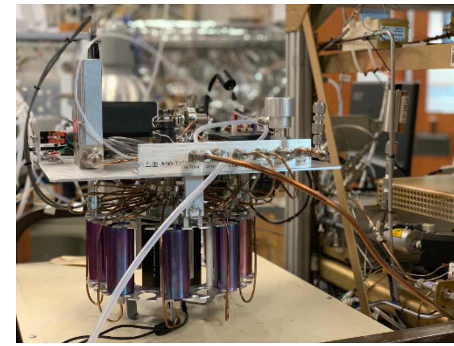
Download the Final Workshop Report



Reference:
H. Vömel, B.M. Argrow, D. Axisa, P. Chlson, S. Ellis , M. Fladeland, E.W. Frew, J. Jacob, M. Lord, J. Moore, S. Oncley, G. Roberts, S. Schoenung, C. Wolff, 2018: NCAR/EOL Community Workshop on Unmanned Aircraft Systems for Atmospheric Research, UCAR/NCAR Earth Observing Laboratory, https://doi.org/10.5065/D6X9292S

Whole-air Airborne Sampler - Pilotless (WASP)

Developed by Lizzy Asher



- Collects 8 air canisters per flight (may collect ≤15)
- Measured on the NCAR TOGA fast GCMS instrument
- VOC measurements range <10 ppt - ~50 ppb
- 1Hz T, RH, P, 2D winds, system P and flow
- Computer programed or piloted flights

Summary

- NSF aircraft have been used for past and ongoing oceanographic campaigns
- NSF aircraft are requestable by the community and come with a wide array of instrumentation
- Engineering, flight planning, data management, outreach, and logistical support are also available
- The ORCAS campaign provided insights into the biogeochemical drivers of Southern Ocean air-sea gas exchange not possible from shipboard measurements

[Image: Jonathan Bent]

- NCAR EOL is interested in pursuing further synergies and eager to provide future support to the oceanographic research community


Courtesy of Alec Chin (ARSV L.M. Gould)

ORCAS Science Team

Principle Investigators: Britton Stephens (NCAR/EOL), Matt Long (NCAR/CGD), Ralph Keeling (Scripps), Eric Kort (U. Mich.), Colm Sweeney (CU/NOAA), Elliot Atlas (U. Miami), Michelle Gierach (JPL)

Carbon Cycle Instruments: Jonathan Bent (NCAR/EOL), Bruce Daube (Harvard), Kathryn McKain (CU), Eric Morgan (Scripps), Tim Newberger (NOAA), Mackenzie Smith (U Mich.), Andy Watt (NCAR/EOL), Steve Wofsy (Harvard)

Biogenic Reactive Gas Instruments: Eric Apel (NCAR/ACOM), Nicola Blake (UC Irvine), Valeria Donets (U. Miami), Alan Hills (NCAR/ACOM), Becky Hornbrook (NCAR/ACOM), Rich Lueb (NCAR/EOL), Sue Schauffler (NCAR/ACOM), Joanna Casey (CU)

PRISM Remote Sensing: Ernesto Diaz (JPL), Heidi Dierssen (U. Conn.), Robert Green (JPL), Justin Haag (JPL), Ian McCubbin (JPL), Pantazis Mouroulis (JPL), Scott Nolte (JPL), David Thompson (JPL), Byron Van Gorp (JPL), Kate Randolph (U. Conn.), Kat Smith (CU)

Aerosol and Cloud Microphysics Instruments: Minghui Diao (San Jose State), Andrew Gettleman (NCAR/CGD), Jorgen Jensen (NCAR/EOL), Bryan Rainwater (CU), Jeff Stith (NCAR/EOL), Darin Toohey (CU)

Forecasting support: Jim Bresch (NCAR/MMM), Shawn Honomichi (NCAR/ACOM), Jordan Powers (NCAR/MMM)

Atmosphere and Climate Modeling: Abhishek Chatterjee (GMAO), Martin Hoecker-Martinez (U. Mich.), Jean-Francois Lamarque (NCAR/CGD/ACOM), Francis Vitt (NCAR/ACOM/CGD)

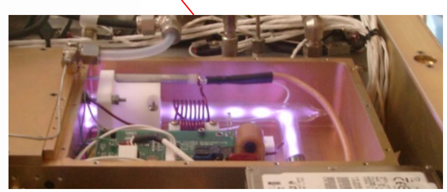
Education and Outreach: Alison Rockwell (NCAR/EOL), Teri Eastburn (UCAR), Nikki Lovenduski (CU)

External Collaborators: Nicolas Cassar (Duke), Scott Doney (PALTER), Hugh Ducklow (PALTER), Oscar Schofield (PALTER), Jorge Sarmiento (SOCCOM), Lynne Talley (SOCCOM)

ORCAS was primarily supported by NSF Polar Programs and LAOF. Additional support from NSF Atmospheric Chemistry and NASA Ocean Biology and Biogeochemistry

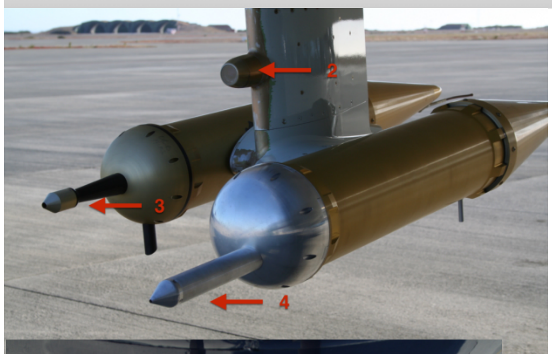
NCAR Airborne Oxygen Instrument (AO2)

NCAR/Scripps Medusa Flask Sampler

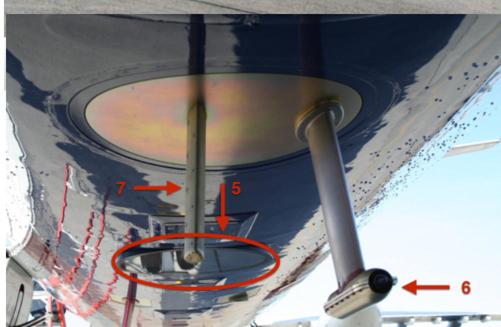


NSF/NCAR HIAPER Right-side

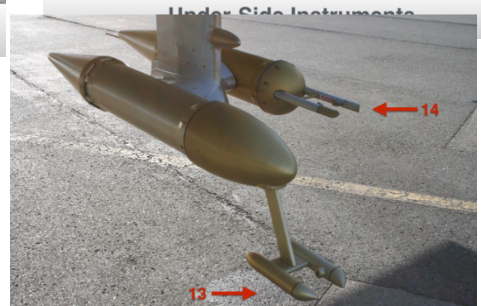
NSF/NCAR HIAPER Left-side



Under-Side Instruments

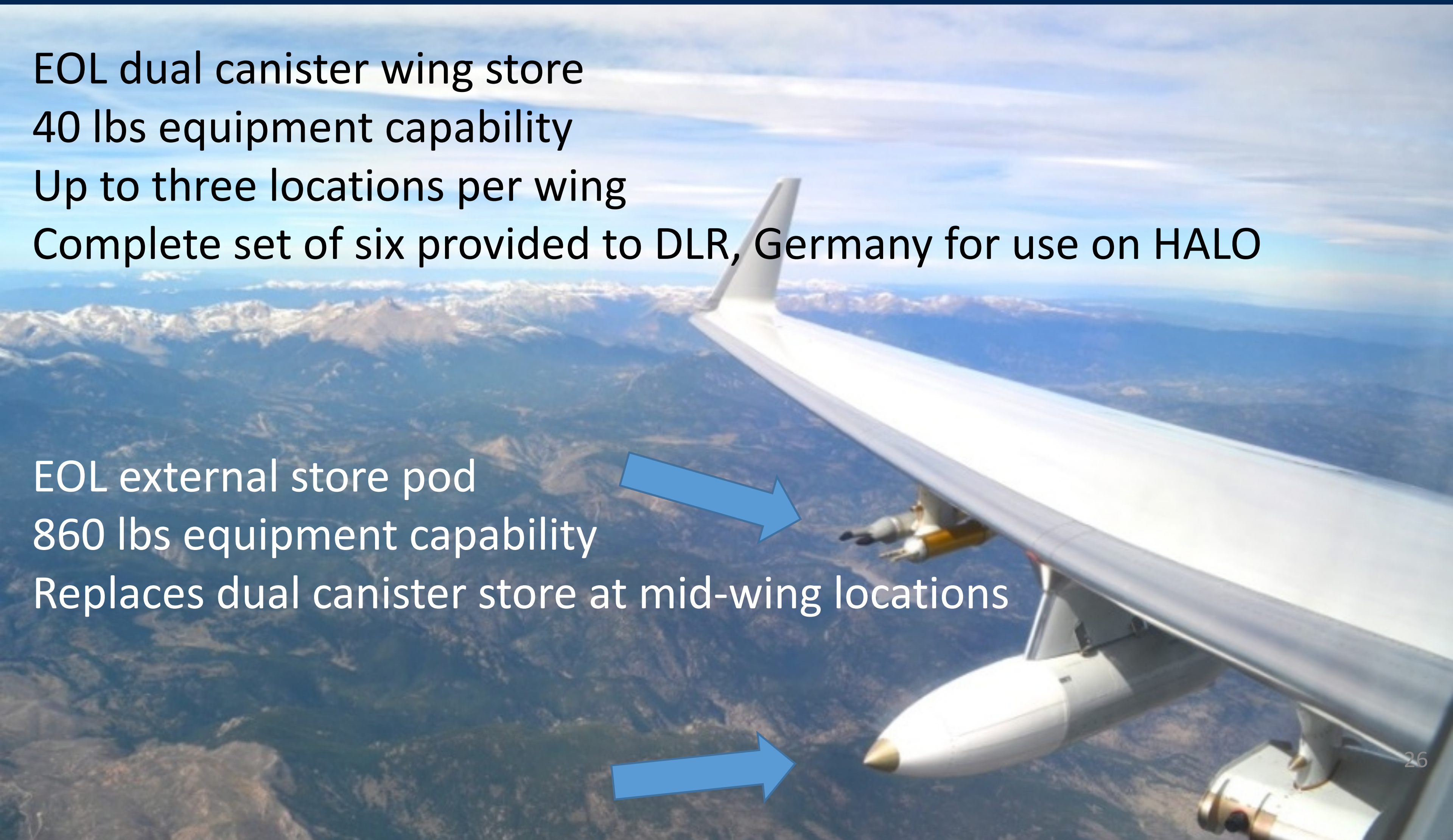


Under-Side Instruments



Left Wing-Mounted Instruments

EOL-developed, FAA-certified Wing Pylons and External Stores

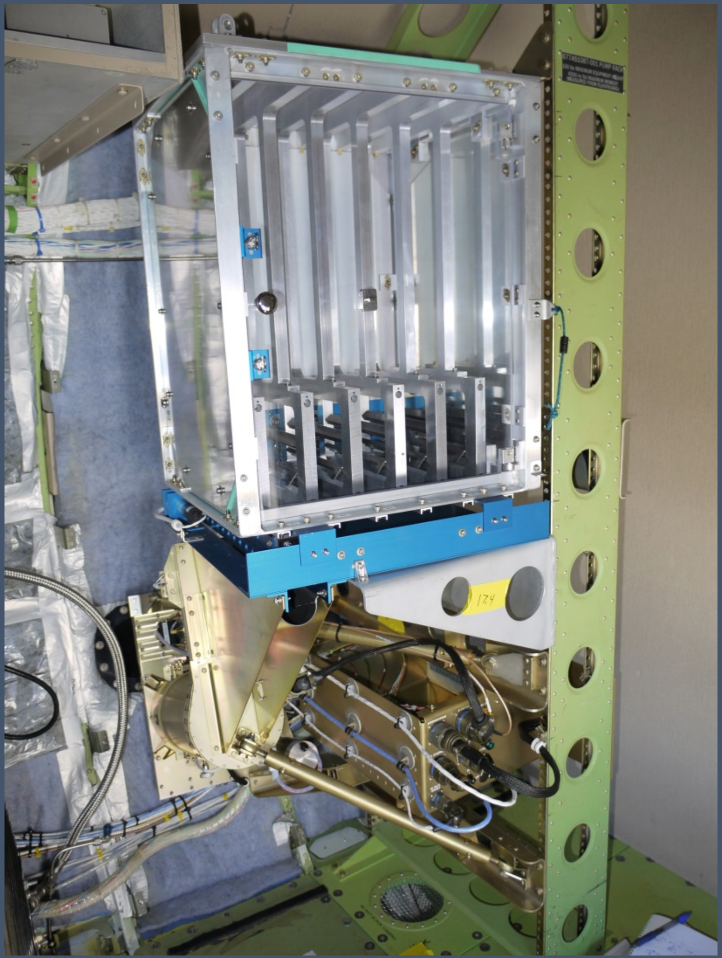


EOL dual canister wing store
40 lbs equipment capability
Up to three locations per wing
Complete set of six provided to DLR, Germany for use on HALO

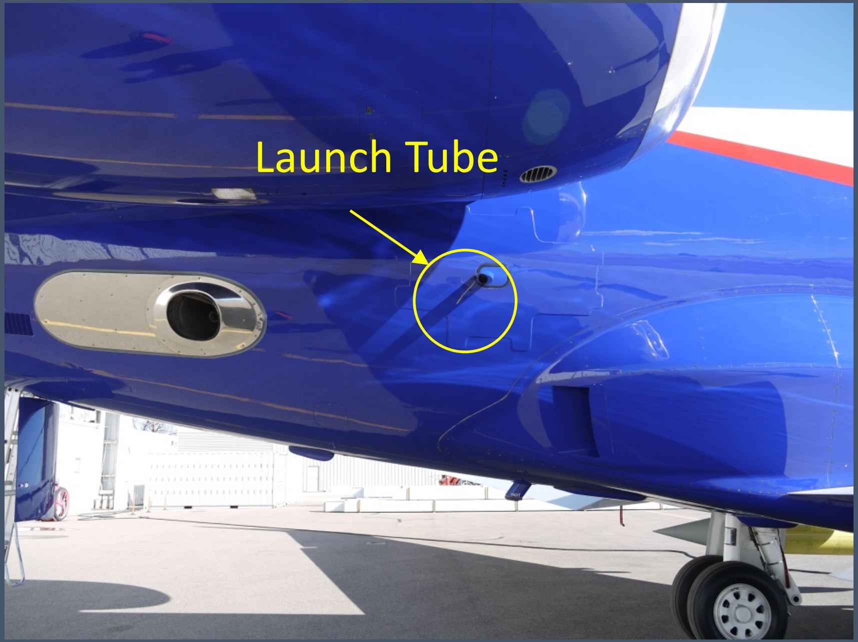
EOL external store pod
860 lbs equipment capability
Replaces dual canister store at mid-wing locations

NSF/NCAR GV Automated Dropsonde System

G-V Automated Dropsonde Launcher



AVAPS ®
Data System



https://www.eol.ucar.edu/aircraft-instrumentation

NCAR UCAR EOL Earth Observing Laboratory

NCAR is sponsored by National Science Foundation

Search

Files & Brochures

HAIS_brochure_2017.pdf

Aircraft Instrumentation

INSTRUMENTS AVAILABLE ON NCAR-OPERATED RESEARCH AIRCRAFT

I. State Parameters Including Temperature, Wind and Position
- A. Temperature, Ambient Air
  1. Heated (Deiced) Total / Ambient Temperature Sensor (ATHx-TTHx)
  2. High Rate Ambient Temperature Sensor (RTF1-ATF1)
  3. Radiometric Sensors
     - a. OPHIR-III Air Temperature Radiometer (Ophir) Decommissioned
     - b. In-Cloud Air Temperature Radiometer (ITR)
  4. Remote Sensors
     - a. Microwave Temperature Profiler (MTP)
     - b. GNSS Instrument System for Multi-static and Occultation Sensing (GISMOS)
     - c. AVAPS Dropsonde (AVAPS)
- B. Humidity, Ambient Air
  1. Thermo-electronic Dew Point Sensor (DPx)
  2. Buck Instruments Model CR-2 Cryogenic Hygrometer (CR2)
  3. Ultraviolet Absorption Hygrometer (UVH)
  4. Vertical Cavity Surface-Emitting Laser Hygrometer (VCSEL)
  5. Open-Path Laser Hygrometer (OPLH) Decommissioned
- C. Pressure, Ambient Air
  1. Ambient Static Pressure (PSFx)
- D. Wind

  Obtained from the addition of the relative-wind vector and aircraft-velocity vector using the following sensors:
  1. Gust Measurements (Wind Relative to the Aircraft)
     - a. Dynamic Pressure (QCx; at pitot-tube inlet)
     - b. Radome Gust Probe for 3-D Wind Measurements (ADIFR-BDIFR-QCRC)
     - c. All Weather Wind Gust Pod (TASX; anti-iced for all-weather capability)
     - d. Laser Air Motion Sensor (LAMS; remote measurement ahead of disturbed airflow)
  2. Aircraft Motion Relative to the Earth
     - a. Inertial Navigation System, A.K.A Inertial Reference Unit (IRU)
     - b. Global Positioning Systems
       - i. Research Global Positioning System (GPS; standard)
       - ii. Differential GPS Ground Station (DGPS; highest accuracy, depends on a reference station)
  3. Position of the aircraft
     - a. Inertial Navigation System, A.K.A Inertial Reference Unit (IRU)
     - b. Global Positioning Systems
       - i. Research Global Positioning System (GPS; standard)
       - ii. Differential GPS ground station (DGPS; highest accuracy, depends on a reference station)
     - c. Radar Altimeter (RALT; height above the surface underlying the aircraft)
- E. Time
  1. Time Server (Time)
- F. Other Related Measurements
  1. Cabin Pressure (PCAB)
  2. Cabin Temperature at ADS Rack Location (TCAB)
  3. Instrument Exhaust Gas Dump Pressure (PDump; pressure in the gas-dump manifold, this outlet is used a outlet for sampling lines)

II. Properties of Clouds and Hydrometeors
- A. Liquid Water Content
  1. King Probe Liquid Water Sensor (CSIRO)
  2. Gerber Liquid Water Probe (PVM-100 or XGLWC) Decommissioned
  3. Rosemount Icing Detector (RICE; supercooled liquid water sensor)
  4. (also obtained as a derived quantity from distrometers listed below)
- B. Cloud Droplet Spectrometers
  1. Forward Scattering Spectrometer Probe, Model 100 (FSSP-100) Decommissioned
  2. Forward Scattering Spectrometer Probe, Model 300 (FSSP-300) Decommissioned
  3. Cloud Droplet Probe (CDP)
  4. (see also the SID2H, 2DC, and 3V-CPI)
- C. Ice, Drizzle, and Precipitation Probes
  1. Two-Dimensional Optical Array Cloud Probe (2DC or 2D-OAP)
  2. Two-Dimensional Optical Array Precipitation Probe (2DP) Decommissioned
  3. Small Ice Detector, Version 2 for HIAPER (SID2H) Decommissioned
  4. Three-View Cloud Particle Imager (3V-CPI) Decommissioned
  5. Holographic Detector for Clouds (HOLODEC)
  6. Two-Dimensional, Stereo, Particle Imaging Probe (2D-S)
- D. Remote Sensors
  1. HIAPER cloud radar (HCR)
  2. (see also HSRL below and MTP above)

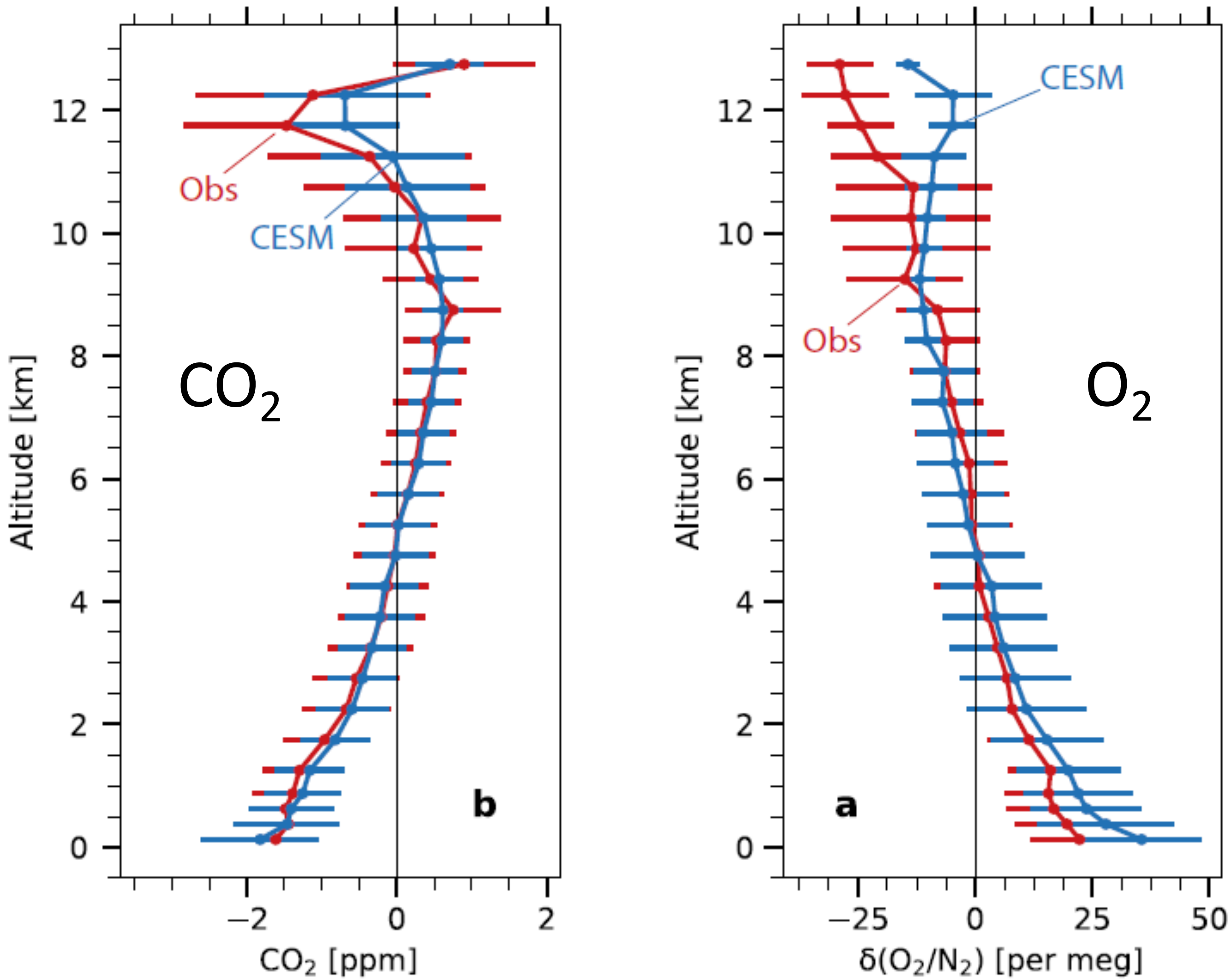
III. Gas Concentrations
- A. Ozone
  1. Nitric Oxide Chemiluminescence Ozone Instrument (FO3_ACD)
  2. RAF Ozone Photometer (OP-1 or OP-2; Photometric Ozone)
  3. Thermo Environmental Instruments Model 49 Ozone Analyzer (TECO) Decommissioned
- B. Carbon Dioxide
  1. Picarro Instrument for Airborne Measurement of CO2 and CH4 (CO2_PIC, CH4_PIC)
  2. Quantum Cascade Laser Spectrometer (QCLS; also measures CO, CH4, N2O) Decommissioned
  3. (see also AO2 and flask-sampling systems below)
- C. Whole Air Sampling Systems
  1. Advanced Whole Air Sampler (AWAS)
  2. NCAR/Scripps Medusa Flask Sampler (Medusa)
- D. Other Gases
  1. Aero-Laser VUV Resonance Fluorescence Carbon Monoxide (COMR_AL; See also QCLS above) Decor
  2. 2-Channel Chemiluminescence (NO-NO2)
  3. Airborne Oxygen (AO2)
  4. Georgia Tech Chemical Ionization Mass Spectrometer (GTCIMS; nitric acid and other species)
  5. Trace Organic Gas Analyzer (TOGA; many organic species)

IV. Aerosol Particles
- A. Condensation Nucleus Counter (Butanol) (CN)
- B. Aerosol-Particle Spectrometers
  1. Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)
  2. Signal Processing Package - 200 for Passive Cavity Aerosol Spectrometer Probe (SPP-200 or PCASP-1
  3. Radial Differential Mobility Analyzer (RDMA) Decommissioned
  4. Scanning Mobility Particle Spectrometer (SMPS) Decommissioned
  5. HIAPER Aerosol Spectrometer Probe, Optical Particle Counter (OPC, HASP)
- C. Chemical, Optical, or Other Properties of Aerosols
  1. Time-of-Flight Aerosol Mass Spectrometer (TOF-AMS; composition) Decommissioned
  2. Counter-flow Virtual Impactor (CVI; samples selected for size)
  3. Integrating Nephelometer (Neph; wet and dry, radiative properties) Decommissioned
  4. Giant Nuclei Impactor (GNI; collector of giant/ultra-giant particles on slides for analysis)
- D. Remote Sensors
  1. High Spectral Resolution Lidar (HSRL)
- E. Special Inlet: Solid Diffuser Aerosol Inlet (SDI)

V. Radiation
- A. Upwelling and Downwelling Irradiance
  1. HIAPER Airborne Radiation Package (HARP)
  2. Broadband Radiometers (Pyrgeometers and Pyranometers)
- B. Actinic Flux
  1. HIAPER Airborne Radiation Package (HARP)
- C. Remotely Sensed Surface Temperature
  1. Heimann Infrared Radiation Pyrometer (KT19)

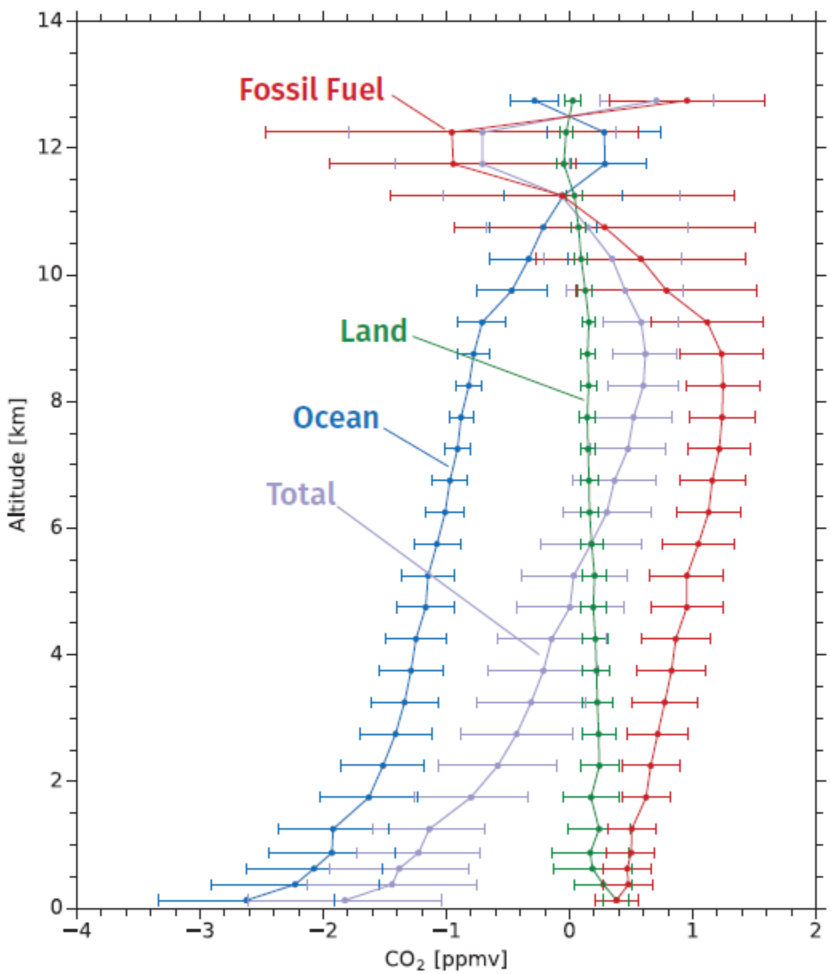
VI. Other
- A. HIAPER Modular Inlet (HIMIL; "HIMIL" inlets)
- B. Digital Imagery (camera or video)
- C. Satellite Communications System (SATCOM)

CESM(SD) Compared to Observations

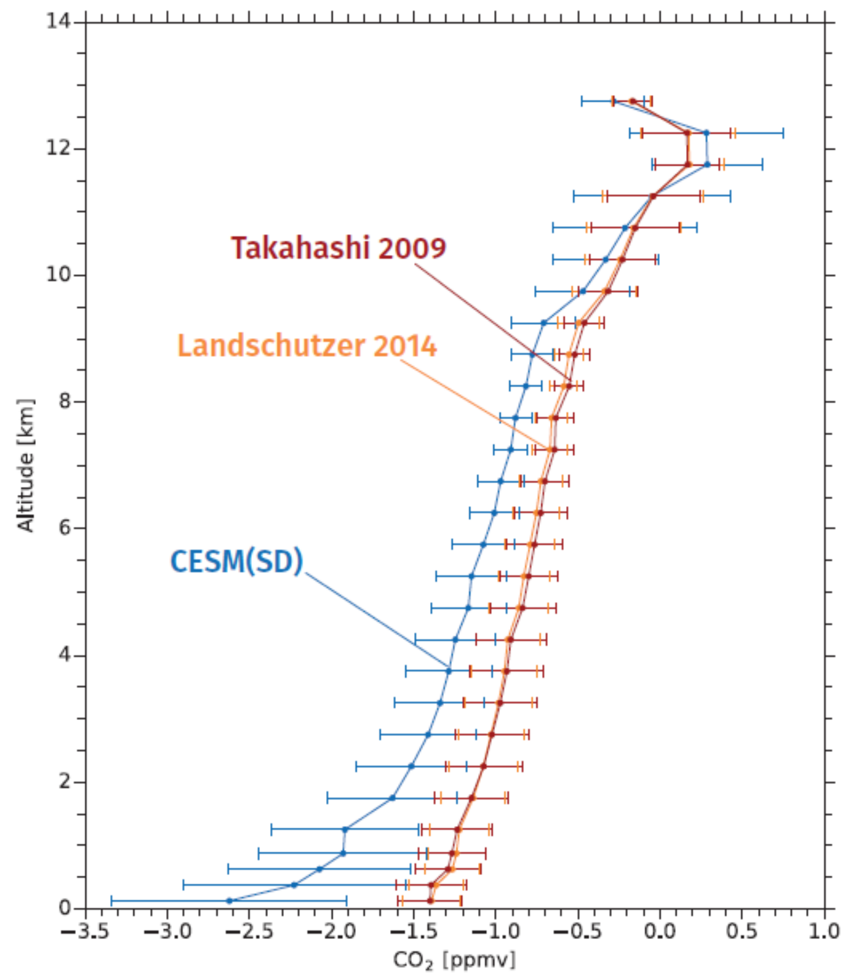


- Model matches CO_2 gradient but overestimates O_2 gradient from 5 km by 50%
- Implies CO_2 right for wrong reason, such as compensating overestimates of both biological and thermal forcing

CESM(SD) CO_2 Components



CESM(SD) Ocean CO_2 Comparison



ORCAS take-home points:

a) strong negative O_2:CO_2 correlation, but with relatively small slope
b) CESM(SD) matches CO_2 but not O_2 gradients
c) CAM vertical CO_2 gradients ~ 2X larger than expected from pCO_2 flux estimates

o