Using Lagrangian flights and modeling to study O_2 and CO_2 fluxes over the Southern Ocean during the O_2/N_2 Ratio and CO_2 Airborne Study (ORCAS)

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Abstract

The ORCAS (O_2/N_2 Ratio and CO_2 Airborn Southern Ocean Study) was designed to add new observational constraints on summertime fluxes and controlling processes for carbon dioxide and oxygen with unprecedented spatial coverage over the Southern Ocean. One approach unique to these air-sea gas exchange studies involved using Lagrangian modeling to determine flight paths for sampling different biogeochemical regions in the Southern Ocean and defined Lagrangian flights to sample the same air mass as it transits the Drake Passage and the Argentine basin. We will discuss the Stochastic Time-Inverted Lagrangian Transport (STILT) modeling system as used in planning and analyzing flights. We will show the sensitivity of the entire campaign to the Southern Ocean and combine with the Community Earth System Model (CESM) and climatologies of air-sea exchange to directly compare aircraft observations with simulated values and discuss reasons for discrepancies. We also will show results from a 24-hour Lagrangian experiment that tightly constrains short-term air-sea gas exchange over the Palmer Antarctic Long Term Ecological Research Network (PALTER) grid.

1 Introduction

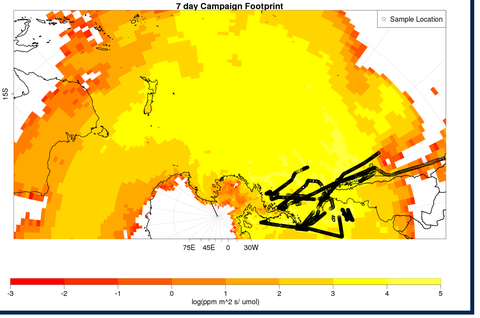
Successive flights intercept the same air mass to estimate the enclosed flux over the Southern Ocean and Argentine Basin.

- Current measures of air-sea gas exchange are poorly constrained
- To sample similar extents require long commitments of ship time (e.g. PALMER LTER)
- We plan successive flights to intercept the same air mass and estimate the enclosed flux over the Southern Ocean and Argentine Basin.
- We Forecast air parcel trajectories from flight plans
- Connect forward and backward forecast trajectories
- Fly Aircraft surveys of various gasses

2 Location

The ORCAS campaign consisted of a series of flights aboard the NSF/NCAR Gulfstream-V High-performance Instrumented Airborne Platform for Environmental Research

- Based out of Punta Arena, Chile
- 19 Flights from January 15th to February 29th 2016
- Span Drake Passage, Argentine Basin, and Chilean coast.
- Samples from $\sim$ 300m to $\sim$ 12000m

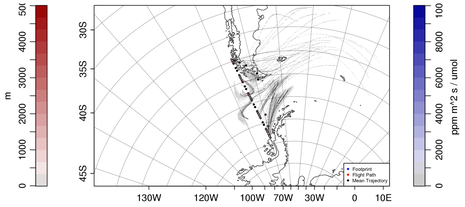


3 Flight Planning

The Stochastic Time-Inverted Lagrangian Transport (STILT) model was used to evaluate flight plans in the field. This limited the influence of terrestrial sources and allowed for re-sampling of air masses after they interacted with our region of study. The mode setup

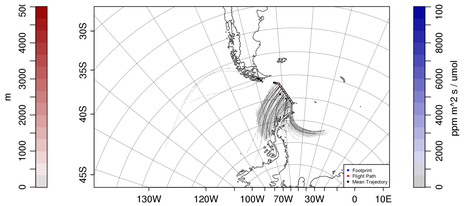
- Used Global Forecast System (GFS) winds 1° / 3 hour resolution
- Included a pre-dermined set of nine flights spanning Drake Passage, the Argentine Basin, and going as far west as the Ocean Observatories Initiative Global Southern Ocean Array.
- Nightly runs were added the the field catalog
  - 48 hour back trajectories
  - Particles were released ate $\sim$ 200 locations throughout the flight path, 128 particles per release
  - Calculated $\sim$ 2 days before the flight
- Special cases were run to refine proposed flights.

4 Connecting Successive Flights



24 hour forward trajectory forecast of the final plan of the upwind flight

- Particle trajectories were forecast for various flight plans
- Forward trajectories gave a target region for a followup flight
- Backwards trajectories further refine the receptor flight



24 hour backward trajectory forecast of the final flight plan of the down wind flight

5 Post-Flight Analysis

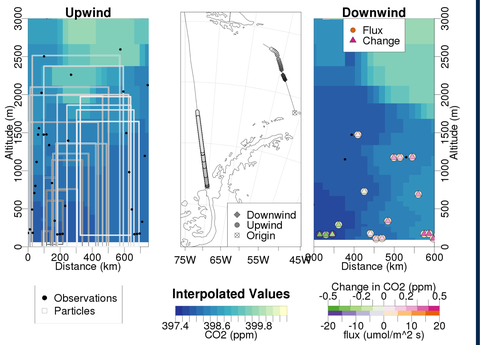
Reran STILT trajectories

- 0.5° Global Data Assimilation System (GDAS) winds
- Sample coincident with Trace Organic Gas Analyzer data
- 4096 particles released
- 7 day back trajectories

Can Aircraft Measure Southern Ocean Air-Sea Exchange?

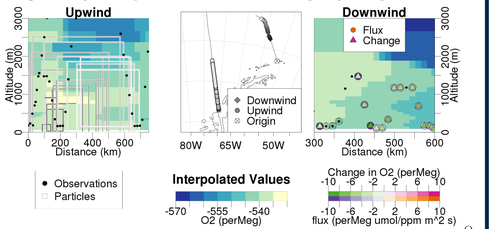
- *What did we do?* Used a model to guide Lagrangian flights to sample 4-24 hour fluxes in the Southern Ocean
- *Why?* Novel synoptic scale measurement of fluxes to inform process-based understanding
- *What was found?* Successfully observe and quantify fluxes of CO_2, O_2, DMS & others on 4-24 hour time frames. Suggest of spatially heterogeneous and intense fluxes comparable to model predictions.

6 DrakePassage



CO_2 Over Drake Passage. Trajectory intersections are marked with a grey bounding boxes. Shading links observations on the downwind leg and their extents on the upwind curtain (left) and on the map (center). Change and flux calculated using the STILT model connections and footprints.

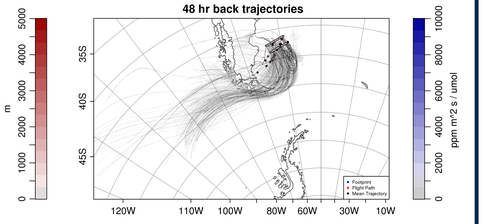
- Δ = downwind − intercepted upwind observation values (using STILT model connections).
- Flux is calculated using Δ and the STILT footprint
- CO_2 flux changes from uptake near Antarctica to weak out gassing crossing to South America



O_2 Over Drake Passage. Trajectory intersections are marked with a grey bounding boxes. Shading links observations on the downwind leg and their extents on the upwind curtain (left) and on the map (center). Change and flux calculated using the STILT model connections and footprints.

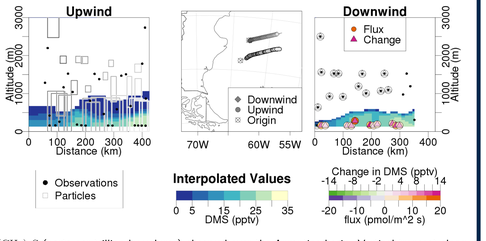
7 Single Flight Re-Sampling

- The Argentine basin was a target of opportunity as it is a local productivity maximum
- Forecast trajectories avoided continental air and optimized flight orientation



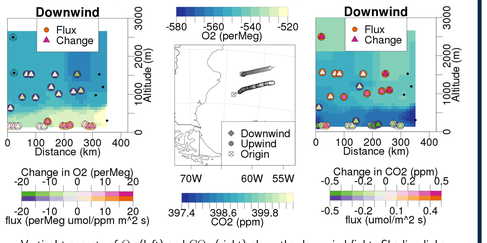
Flight plan and trajectories for flight over Argentine Basin

8 Argentine Basin



$(CH_3)_2S$ (parts per trillion by volume) observed over the Argentine basin. Vertical transect along the upwind (left) and downwind (right) fights. Grey bounding boxes mark trajectory intersections. Shading links observations on the downwind leg and the extent on upwind curtain (left) and map (center). Change and flux (right) calculated using the STILT model connections and footprints.

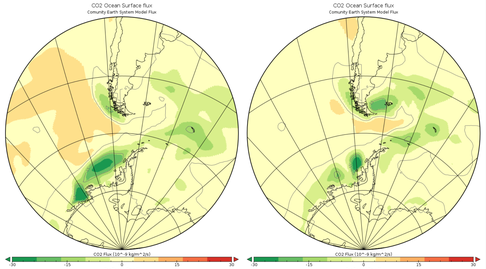
- Near the ocean surface there is CO_2 uptake and and O_2 out gassing
- Measurable out gassing of in the Argentine Basin of Dimethysulfide (DMS)



Vertical transects of O_2 (left) and CO_2 (right) along the downwind fight. Shading links observations on the downwind leg and their extents on the map (center).

9 Flux Estimates

- Community Earth System Model (CESM) estimates of CO_2 flux
- Consistent with the spatial pattern seen over Drake Passage
- Similar magnitudes as observed by aircraft and in model
- Poor agreement during the Argentine basin flight



CESM flux estimates of CO_2 during the Argentine basin (left) and Drake Passage (right) flights ($30\ 10^{-9}$kg $CO_2 \sim 0.7\mu$mol CO_2)

10 Summary

- Operation Forecasting of Aircraft Sampling
  - Plan flights 2 days ahead
  - Avoid unwanted (Terrestrial) influence
  - Connect observation curtains
- Estimate Air-Sea gas Exchange
  - Drake Passage Exchange
    - $\Delta CO_2 \sim 0.5$ppm $\Rightarrow 10\mu$mol/m^2 s flux
    - CO_2 Meridional variability consistent with CESM
    - $\Delta O_2 \sim 5$perMeg $\Rightarrow$ 5perMeg μmol/ppm m^2 s flux
  - Argentine Basin Exchange
    - $\Delta(CH_3)_2S \sim 5$pptv $\Rightarrow$ 10pmol/m^2 s flux
    - $\Delta CO_2 \sim 0.5$ppm $\Rightarrow 0.3\mu$mol/m^2 s flux
    - $\Delta O_2 \sim 10$perMeg $\Rightarrow$ 10perMegμmol/ppm m^2 s flux

ORCAS Related Things @AGU

OS41D Recent Advances in Ocean Biogeochemical Observations and Modeling I
OS42A Recent Advances in Ocean Biogeochemical Observations and Modeling II
OS43B Recent Advances in Ocean Biogeochemical Observations and Modeling III Posters
A42F-07 Microphysical and macrophysical characteristics of ice and mixed-phase clouds compared between in-situ observations from the NSF ORCAS campaign and the NCAR Community Atmospheric Model
A42F-04 Comparisons of mixed-phase clouds and relative humidity distributions between in-situ observations and multi-resolution CAM5 simulations
A43A-0170 Comparison of CAM-Chem with Trace Gas Measurements from Airborne Field Campaigns from 2009-2016
A41F-0119 An Update on Validation of OCO-2 XCO2 Observations

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