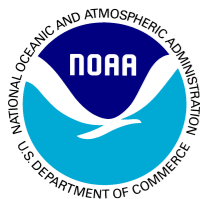




Southern Ocean Gas Exchange Experiment

David T. Ho

Department of Oceanography, University of Hawaii at Manoa





Southern Ocean Gas Exchange Experiment

- Scientific Goals
- Experiment Details
- Projects

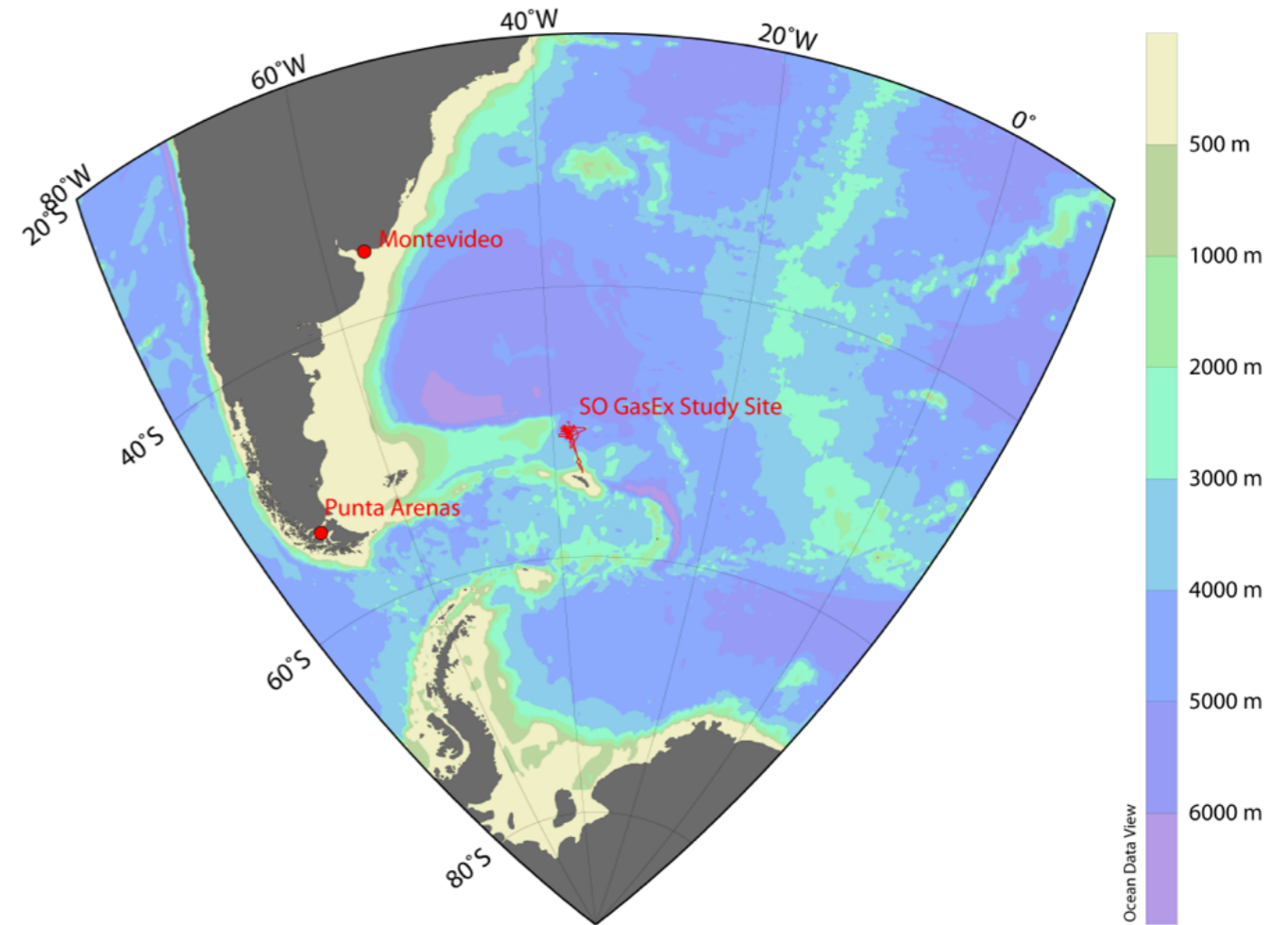


SO GasEx Research Questions

- What are the gas transfer velocities at high winds?
- What is the effect of fetch on the gas transfer?
- How do other non-direct wind effects influence gas transfer?
- How do changing $p\text{CO}_2$ and DMS levels affect the air-sea CO_2 and DMS flux, respectively in the same locale?
- Are there better predictors of gas exchange in the SO than wind?
- What is the near surface horizontal and vertical variability in turbulence, $p\text{CO}_2$, and other relevant biochemical and physical parameters?
- How do biological processes influence $p\text{CO}_2$ and gas exchange?
- Do the different disparate estimates of fluxes agree, and if not why?
- With the results from Southern Ocean GasEx, can we reconcile the current discrepancy between model based CO_2 flux estimates and observation based estimates?



SO GasEx



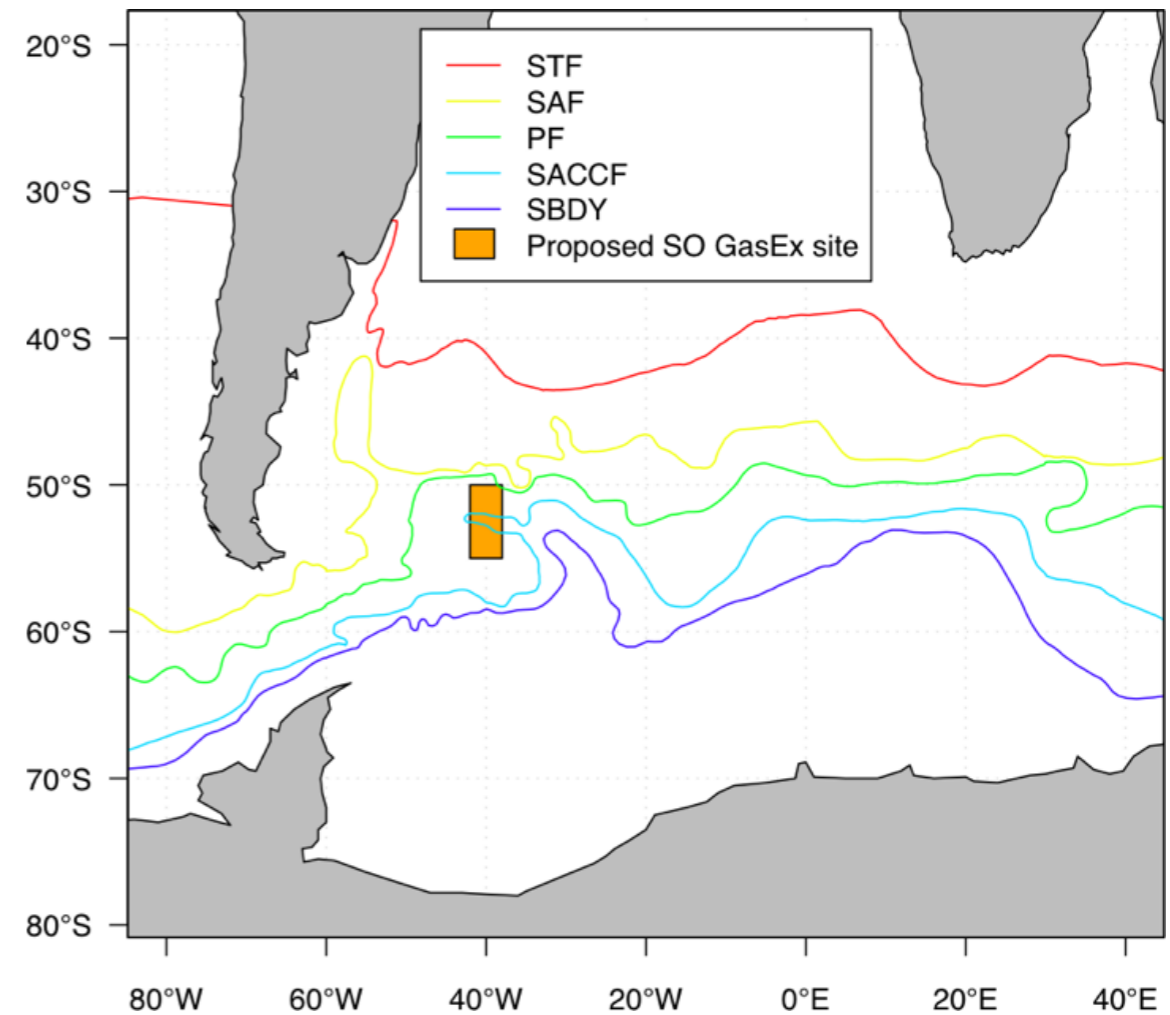
- NOAA SHIP RONALD H BROWN
- Atlantic sector of Southern Ocean
- Austral Fall (February 29 to April 12, 2008)
- 31 Scientist
- 16+ Projects funded by NOAA, NASA, NSF, and NERC



SO GasEx Study Site

The study location should capture the germane aspects of the Southern Ocean forcing and biogeochemistry while providing a suitable environment to perform the study.

The South Atlantic sector of Southern Ocean was chosen based on the following criteria...



- **Delta pCO₂** of at least 40 μatm to ensure a large enough signal to noise for direct eddy-covariance measurements of CO₂.
- Relatively **stable water mass** (i.e., relatively weak currents and low mesoscale eddy variability) to allow ³He/SF₆ patch to be followed for up to 25 days.
- **Mixing layer depth** less than 50 to 70 m.
- Relatively high **wind speeds**, long fetch and large **waves**.
- Proximity to Punta Arenas and Montevideo to minimize transit time.



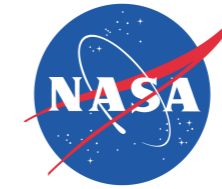
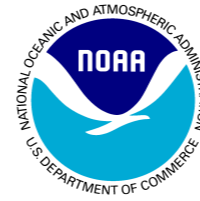
Categories of Projects

Table 1: Categories of research projects on SO GasEx.

	Research Projects	Method
1	Direct Flux Measurements (CO ₂ , ozone and DMS)	Air-sea CO ₂ (NDIR), Ozone and DMS (APIMS) flux systems
2	Bulk Meteorology and Turbulent Fluxes (winds, momentum, water vapor, temp, IR, Solar radiation, etc.)	Sonic anemometer, thermometer, pyranometer, pyrgeometer, MicroSAS
3	Integrated Gas Transfer Velocities with Deliberate Tracers (SF ₆ and ³ He)	Continuous and discrete SF ₆ systems (GCs) and He isotope mass spec
4	Surface and Subsurface variability (CO ₂ , nutrients, calcite, DMS, chlorophyll)	Shipboard underway systems, NDIR CO ₂ systems, GC, EcoVSF, IC-POES, fluorometer, ACS, ISUS, SuperSoar/TOMASI
5	Autonomous Platforms	MAPCO ₂ , SAMI, ASIS, surface drifters, SOLO floats
6	Surface and near-surface ocean processes (wave spectra, white capping, currents)	Shipboard radar; microwave altimeter, video camera, ADCP
7	Water column hydrography, carbon and related tracers (DIC, pCO ₂ , Talk, temp, sal, O ₂ , nutrients, DOC, CDOM, PIC, O ₂ /Ar/N ₂ , DMS, particles, TSM, Chl., POC)	SOMMA, NDIR, titration, CTD, Winkler, nutrient auto-analyzer, spectrophotometer, mass spec., GC, HPLC, fluorometer
8	Primary production/new production	¹⁴ C and ¹⁵ N incubations, O ₂ /Ar, spectral absorption, radial photosynthetron
9	Ocean Optics	PAR sensor, FRRF, IOP cage, HTSRB, MVSM


































Funded Projects



<p>Gas Exchange</p>	<p>Quantifying air-sea gas exchange at high wind speeds using a dual gas tracer ($^3\text{He}/\text{SF}_6$) technique during the Southern Ocean Gas Exchange Experiment, (David Ho, Peter Schlosser, Rik Wanninkhof)</p> <p>Southern Ocean air-sea carbon dioxide exchange, (Wade McGillis, Chris Zappa, Jim Edson, Penny Vlahos)</p> <p>Measurement and parameterization of air-sea DMS transfer over the Southern Ocean in GasEx-III, (Barry Huebert, Byron Blomquist)</p> <p>Measurement and parameterization of air-sea gas transfer over the Southern Ocean in GasEx-III, (Chris Fairall, Detlev Helmig)</p> <p>Quantifying the surface physical controls on CO_2 transfer during the Southern Ocean Gas Exchange Experiment, (Will Drennan)</p> <p>Gas tracers of productivity and bubble-mediated gas exchange during the SO GasEx Experiment (Roberta Hamme, Michael Bender, Steve Emerson)</p>
<p>Biogeochemistry</p>	<p>CO_2 and hydrographic measurements during the GasEx-III Experiment, (Dick Feely, Chris Sabine, Greg Johnson, Rik Wanninkhof, Molly Baringer)</p> <p>Closing the mixed layer carbon budget during Southern Ocean GasEx, (Burke Hales, Pete Strutton, Dave Hebert, David Ullman)</p> <p>Autonomous multi-parameter measurements from a drifting buoy during the SO GasEx Experiment, (Chris Sabine, Mike DeGrandpre, Wade McGillis, Chris Zappa)</p> <p>Measurement of seawater DMS during SO GasEx (Steve Archer)</p> <p>Measurement of nutrients during the Southern Ocean Gas Exchange Experiment (GasEx III), (Jia-Zhong Zhang)</p> <p>On the distribution of colored dissolved organic matter in the Southern Ocean and the potential for photoproduction of CO_2 and CO, (Carlos del Castillo, Rick Miller, Watson Gregg, Tom Haine, Francis Monaldo, Donald Thompson)</p>
<p>Remote Sensing</p>	<p>Phytoplankton absorption and carbon dioxide drawdown in the Southern Ocean: A consortium of observations, (John Marra, Bob Vaillancourt, Ajit Subramaniam)</p> <p>Optical properties in the Southern Ocean: In situ and satellite observations in support of Southern Ocean Carbon Program, (ZhongPing Lee, Alan Weidemann, Paul Martinolich, Wesley Goode)</p> <p>Optical properties in the Southern Ocean: In situ measurements of phytoplankton absorption using the pFPT-TR instrument in support of the Southern Ocean Carbon Program, (Bruce Hargreaves)</p> <p>Differentiating sources of backscattering in the Southern Ocean: Calcite, bubbles, and other optical constituents, (Heidi Dierssen, Barney Balch, Michael Twardowski, Penny Vlahos)</p>



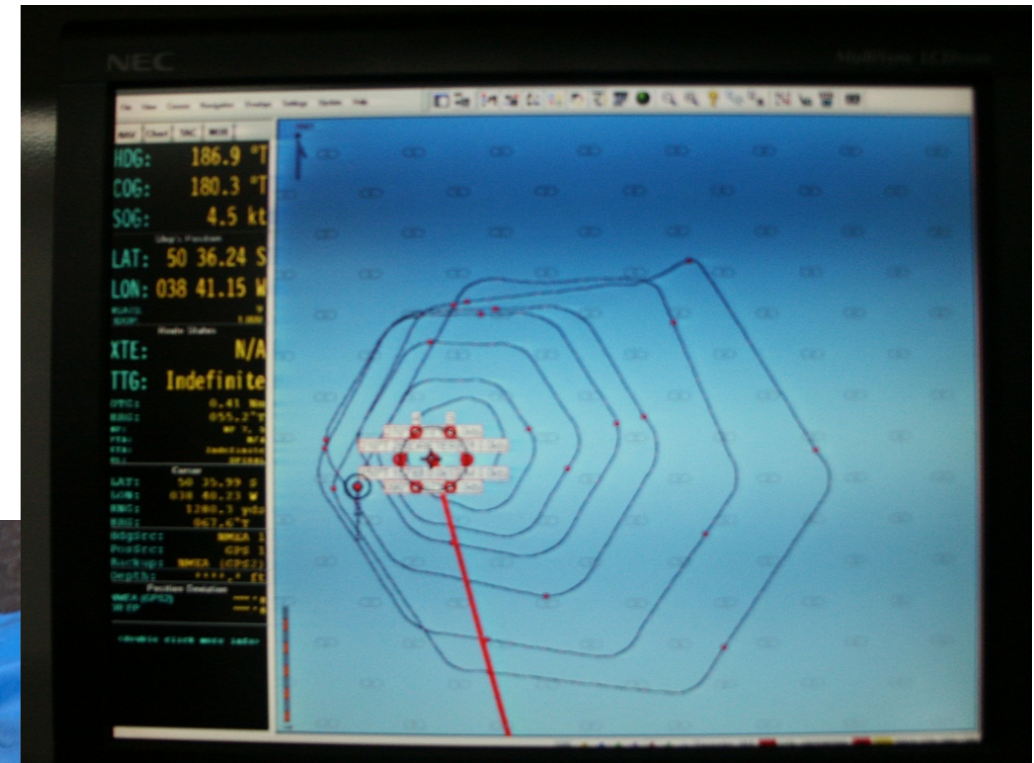
Participants

-  **Steve Archer** (Plymouth Marine Lab.), DMS
-  **Ludovic Bariteau** (NOAA/ESRL), Micromet
-  **Byron Blomquist** (Univ. of Hawaii), DMS Flux
-  **Chris Buonassisi** (Univ. of Connecticut), HTSRB/LISST
-  **Bob Castle** (NOAA/AOML), Discrete pCO₂
-  **Paul Covert** (Univ. of Washington), TALK
-  **Juan de Abelleyra** (Servicio de Hidrografía Naval), Observer
-  **Carlos Del Castillo** (Johns Hopkins Univ.), CDOM
-  **David Drapeau** (Bigelow Lab), HTSRB/LISST
-  **Charlie Fisher** (NOAA/AOML), Nutrients
-  **Scott Freeman** (WET Labs), HTSRB/LISST
-  **Burke Hales** (Oregon State Univ.), SuperSoar chem/optics
-  **Roberta Hamme** (Univ. of Victoria), O₂/inert gases
-  **Bruce Hargreaves** (Lehigh Univ.), pFPT-TR
-  **Dave Hebert** (Univ. of Rhode Island), Turbulence/mixing
-  **David Ho** (LDEO), Chief Sci
-  **Dale Hubbard** (Oregon State Univ.), SuperSoar chem/optics
-  **Veronica Lance** (LDEO), FRRF
-  **Goeff Lebon** (Univ. of Washington), DIC/drifting pCO₂
-  **Alejandro Cifuentes** (Univ. of Connecticut), CO₂ Flux
-  **Bertrand Lubac** (Naval Research Lab.), MVSM/LISST
-  **Rick Miller** (NASA Stennis), CDOM
-  **Sarah Purkey** (Univ. of Washington), CTD/O₂
-  **Mike Rebozo** (Univ. of Miami), ASIS
-  **Matt Reid** (LDEO), Underway SF₆
-  **Chris Sabine** (NOAA/PMEL), Co-Chief Sci
-  **Paul Schmieder** (LDEO), ³He
-  **Pete Strutton** (Oregon State Univ.), SuperSoar chem/optics
-  **Kevin Sullivan** (NOAA/AOML), Discrete SF₆
-  **Bob Vaillancourt** (LDEO), FRRF
-  **Chris Zappa** (LDEO), Waves/Turbulence

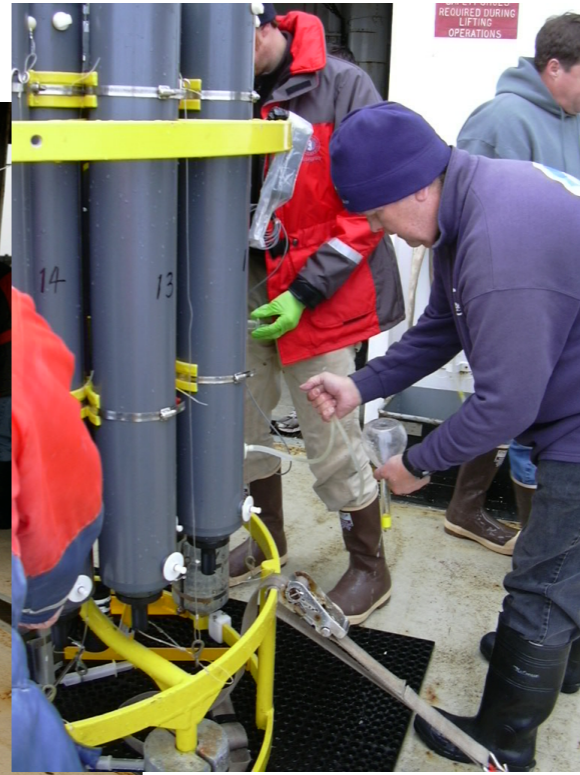
Atmospheric Flux Measurements



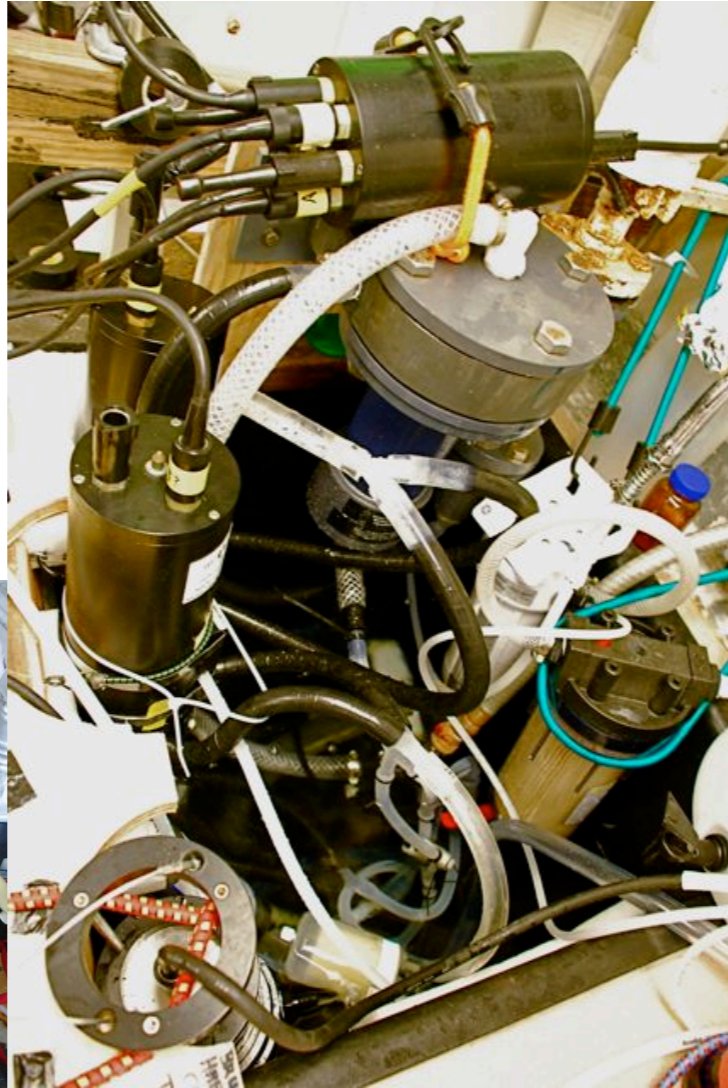
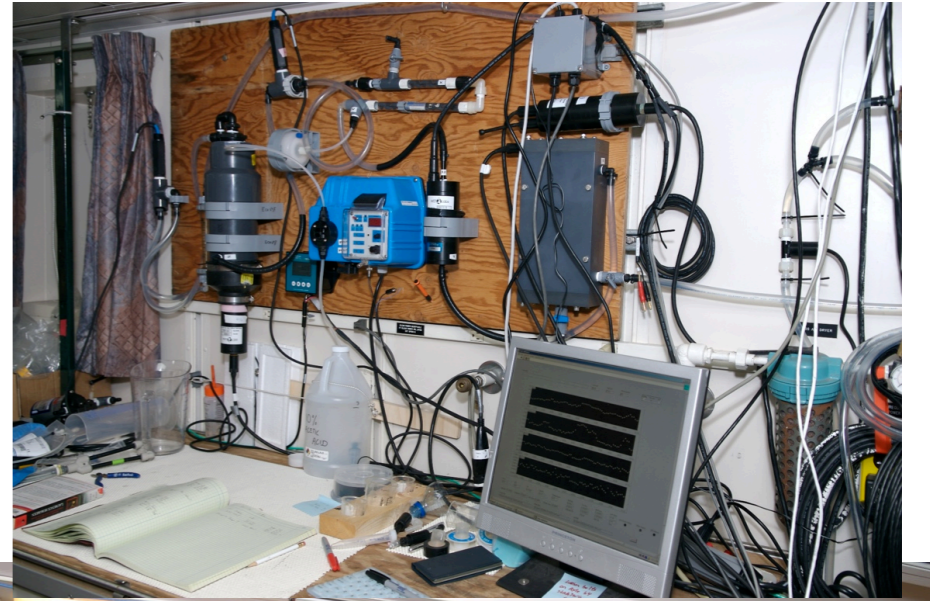
$^3\text{He}/\text{SF}_6$ Lagrangian Experiment



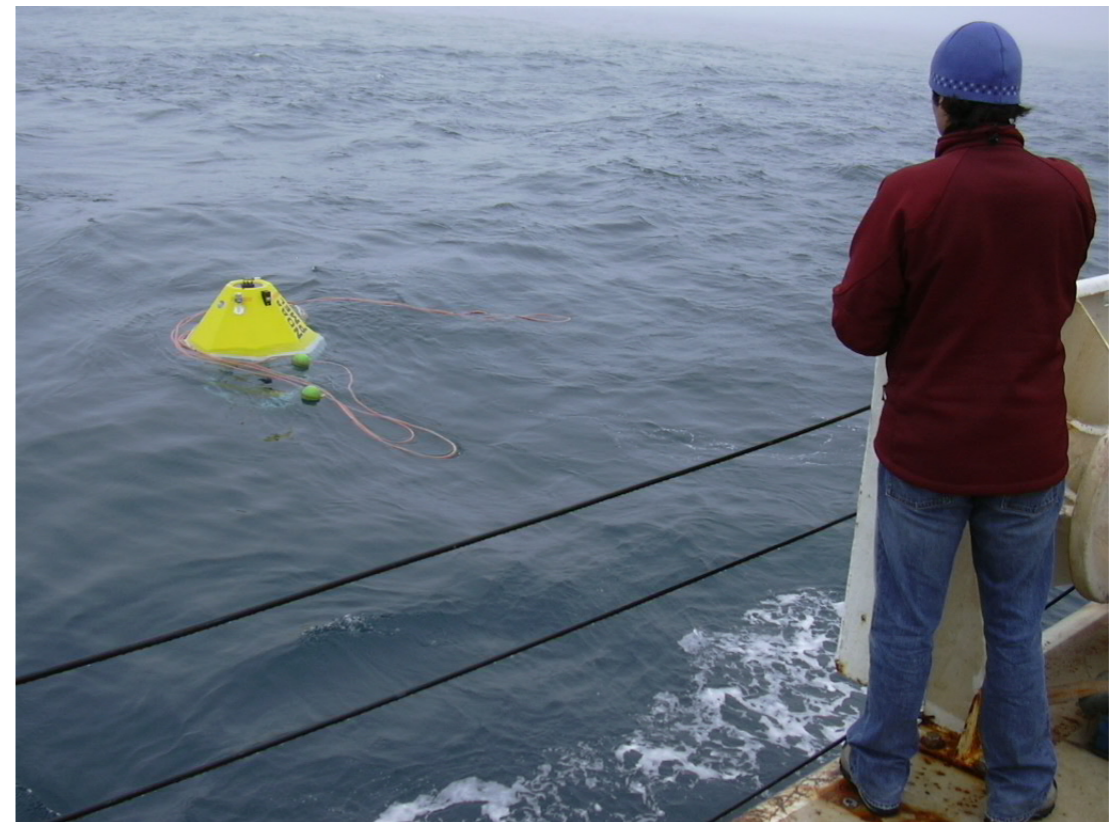
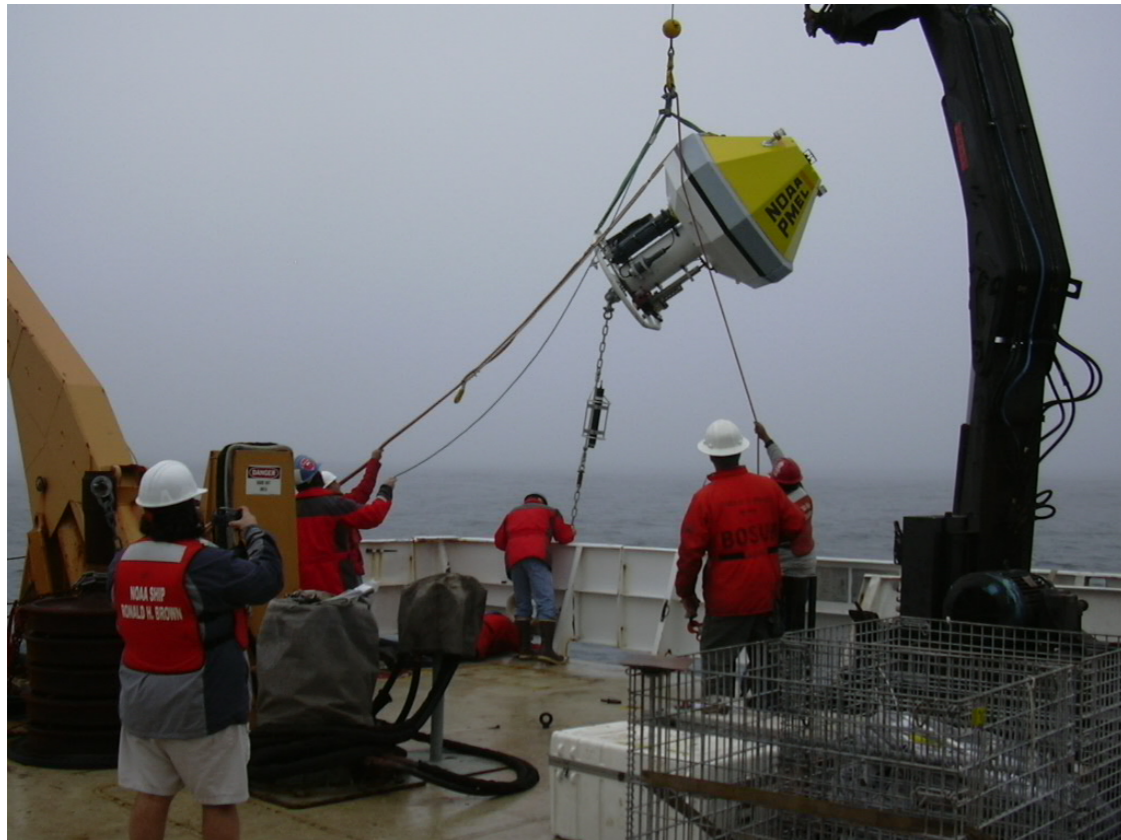
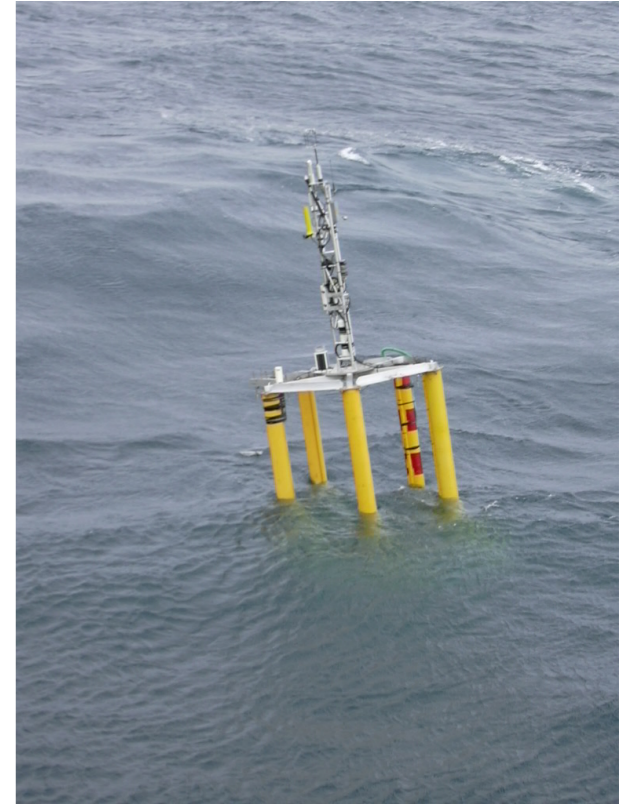
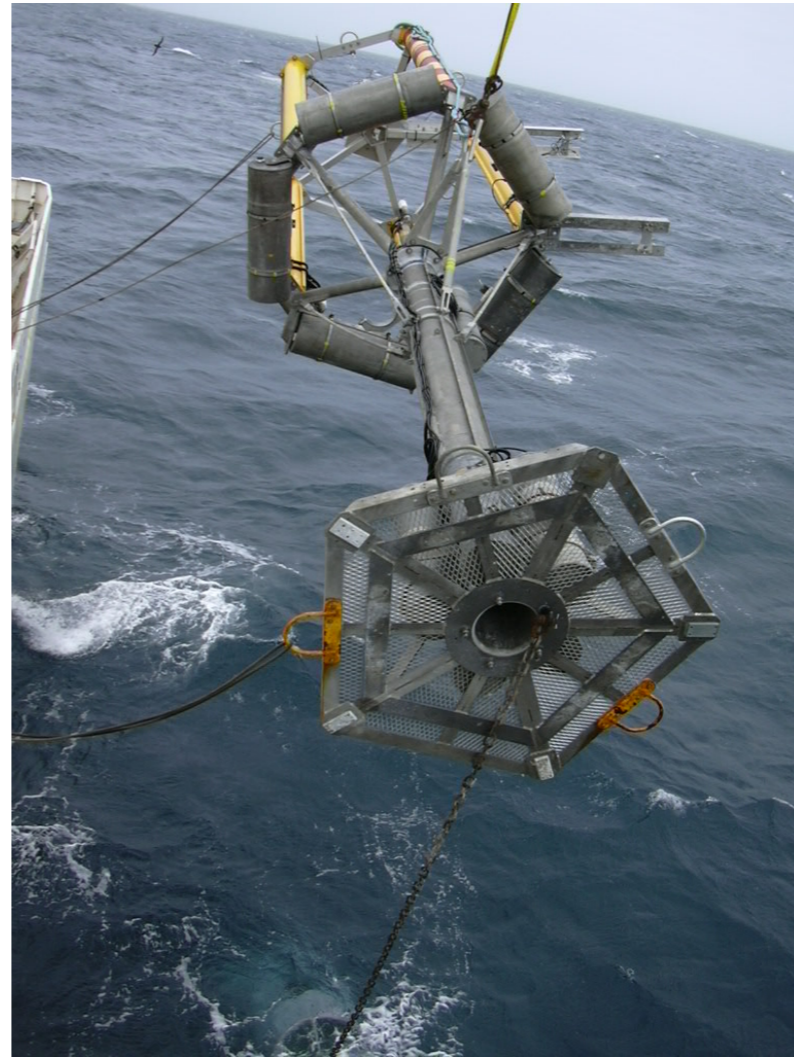
Biogeochemical Measurements

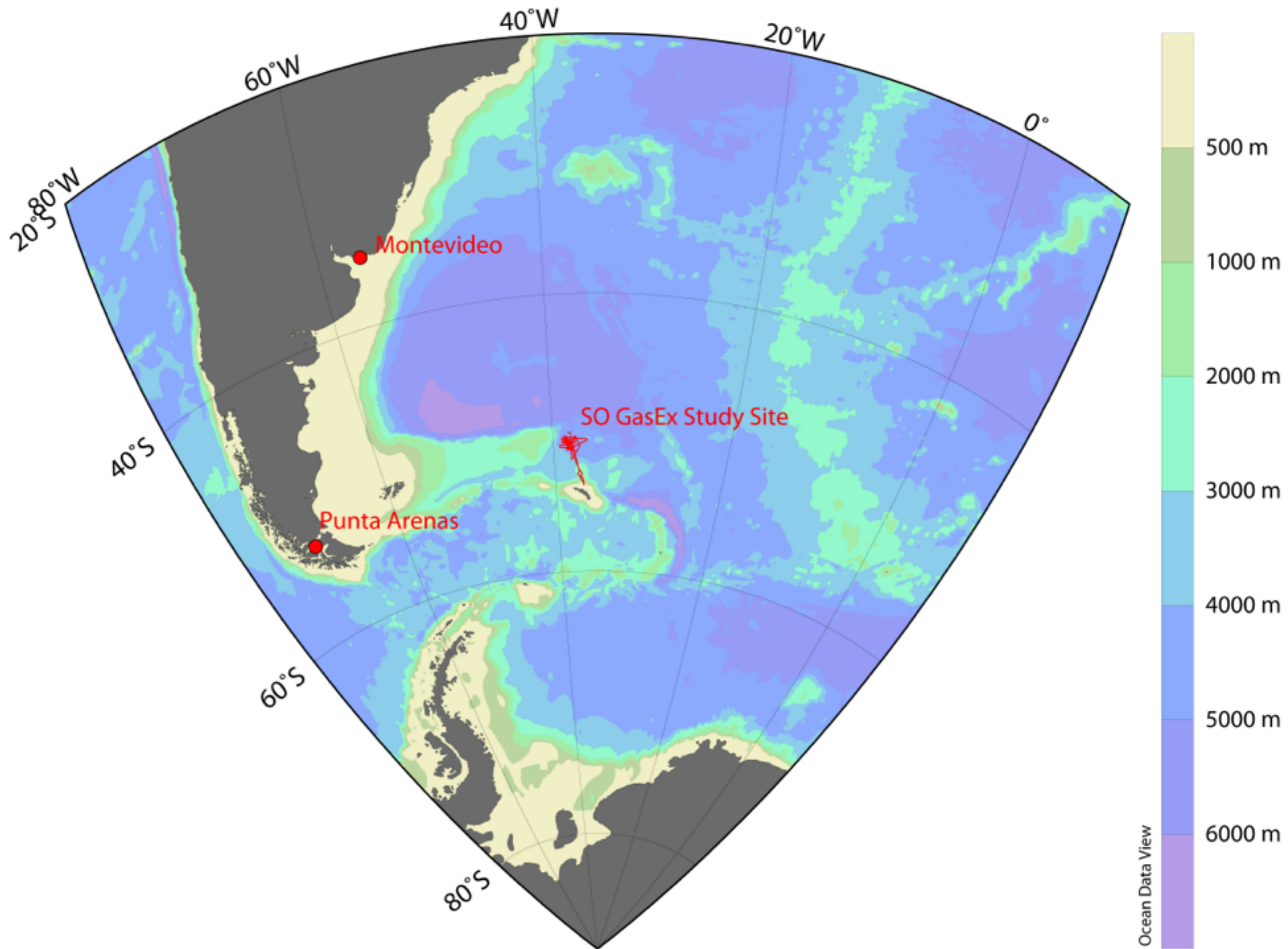


Optics/ Productivity

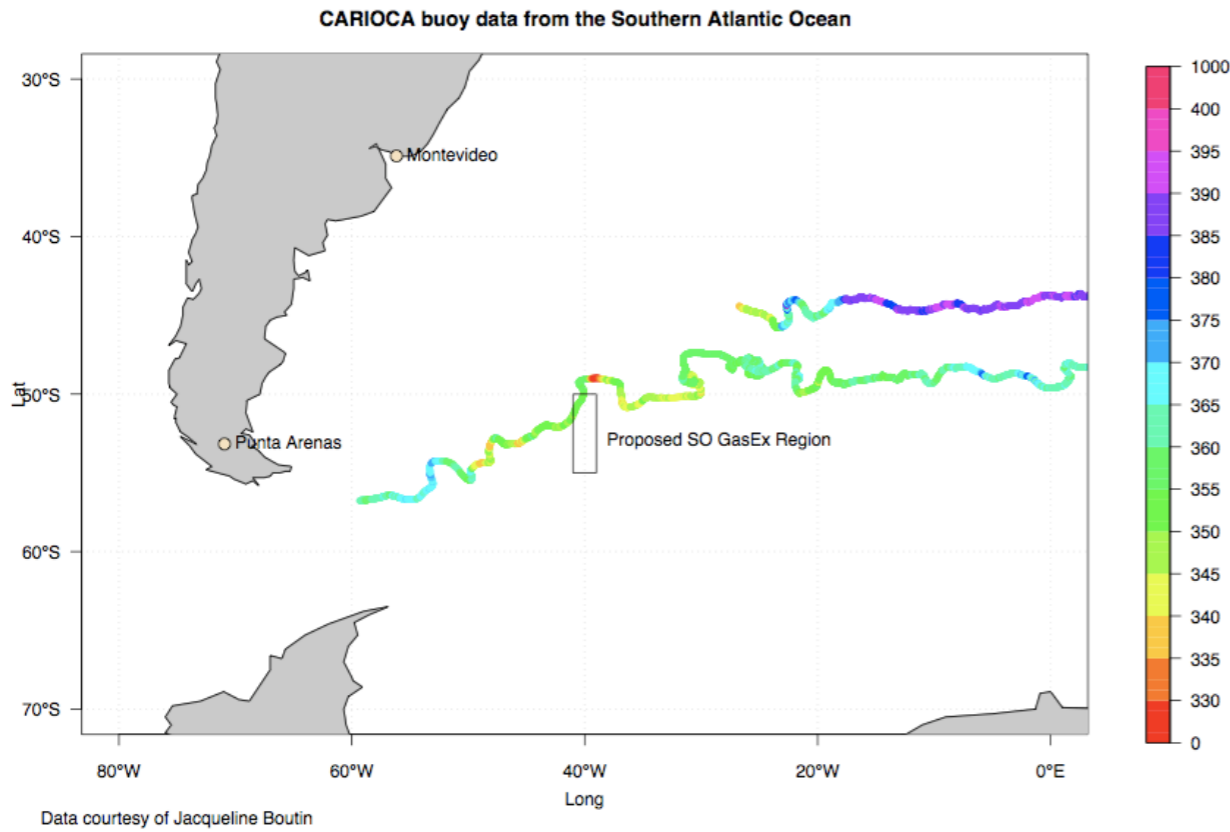
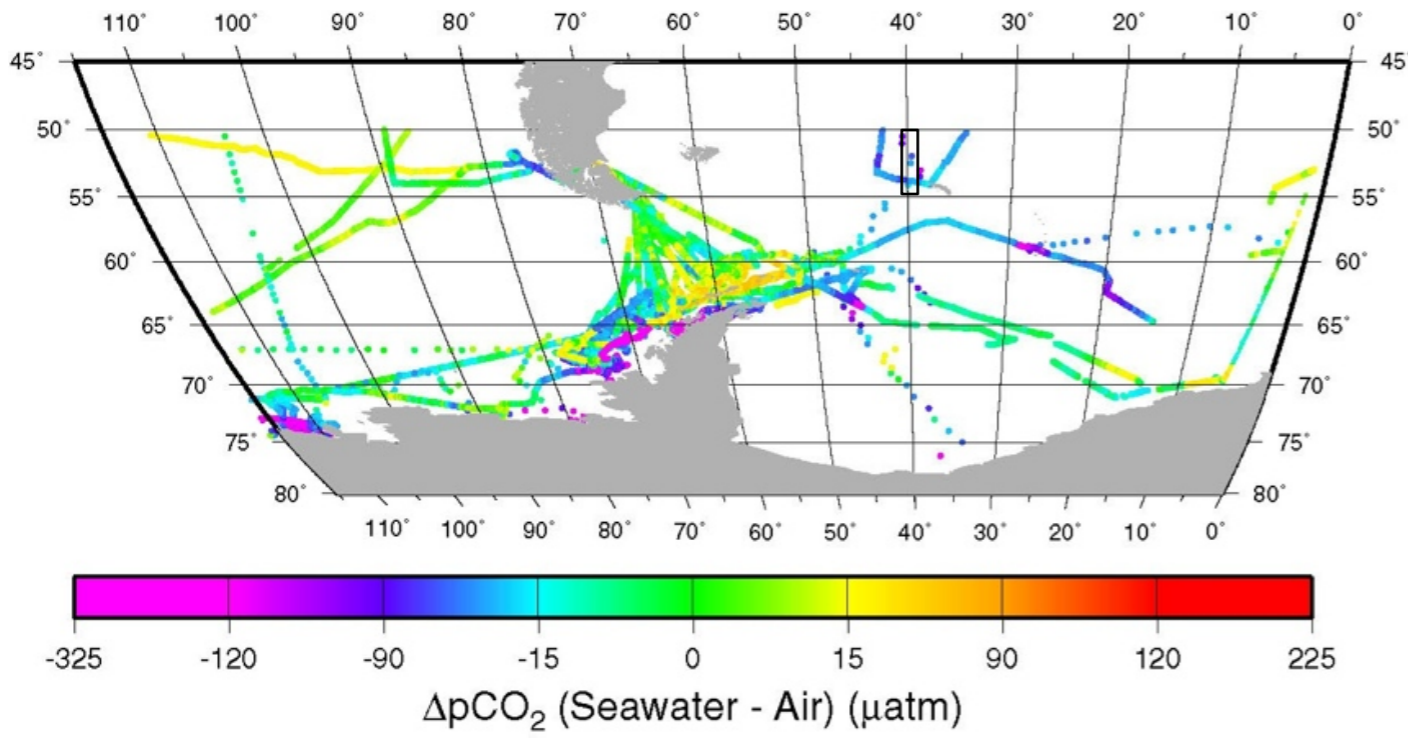


Buoys/Drifters



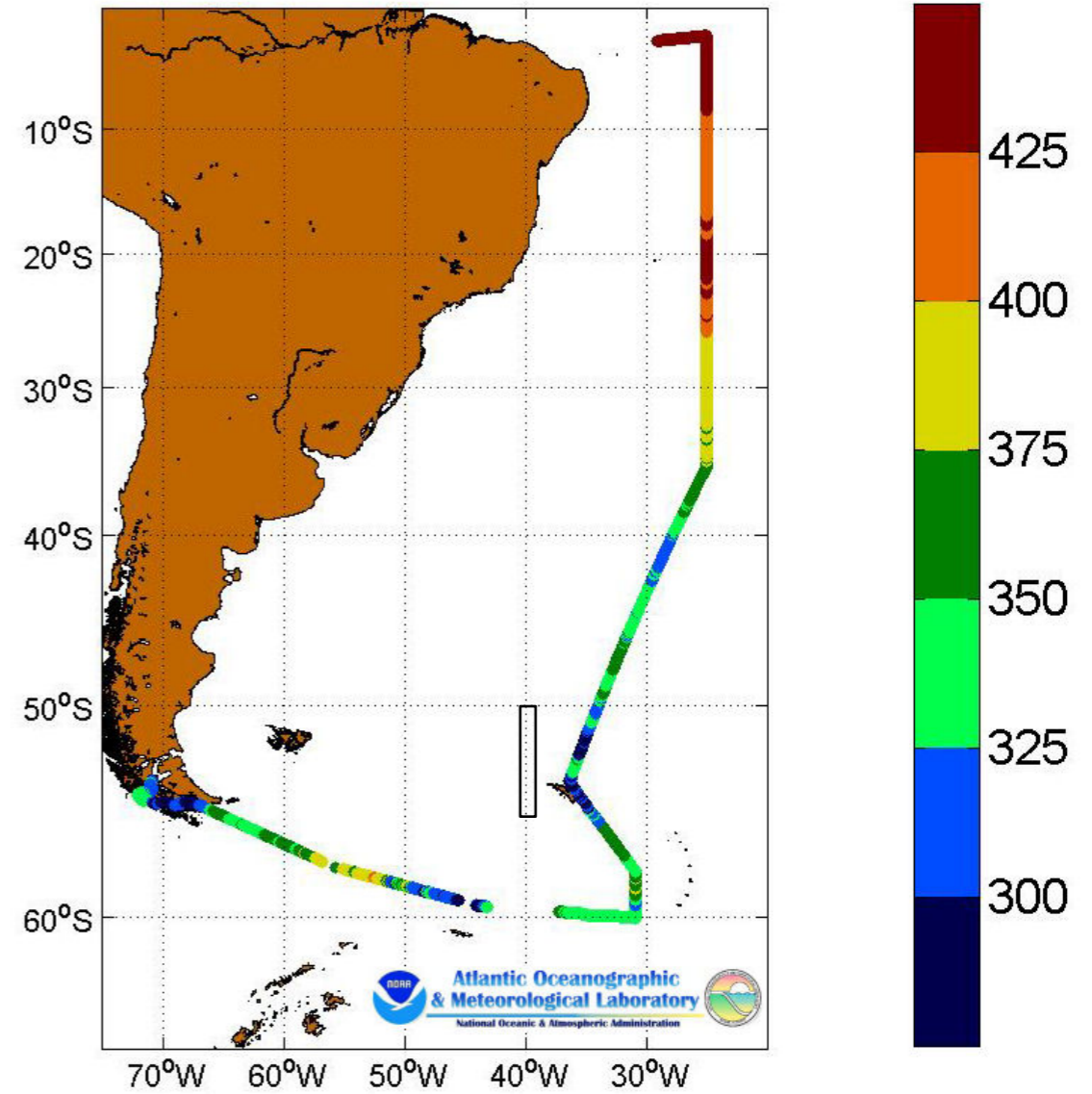


LDEO Database Feb, Mar, & Apr Only

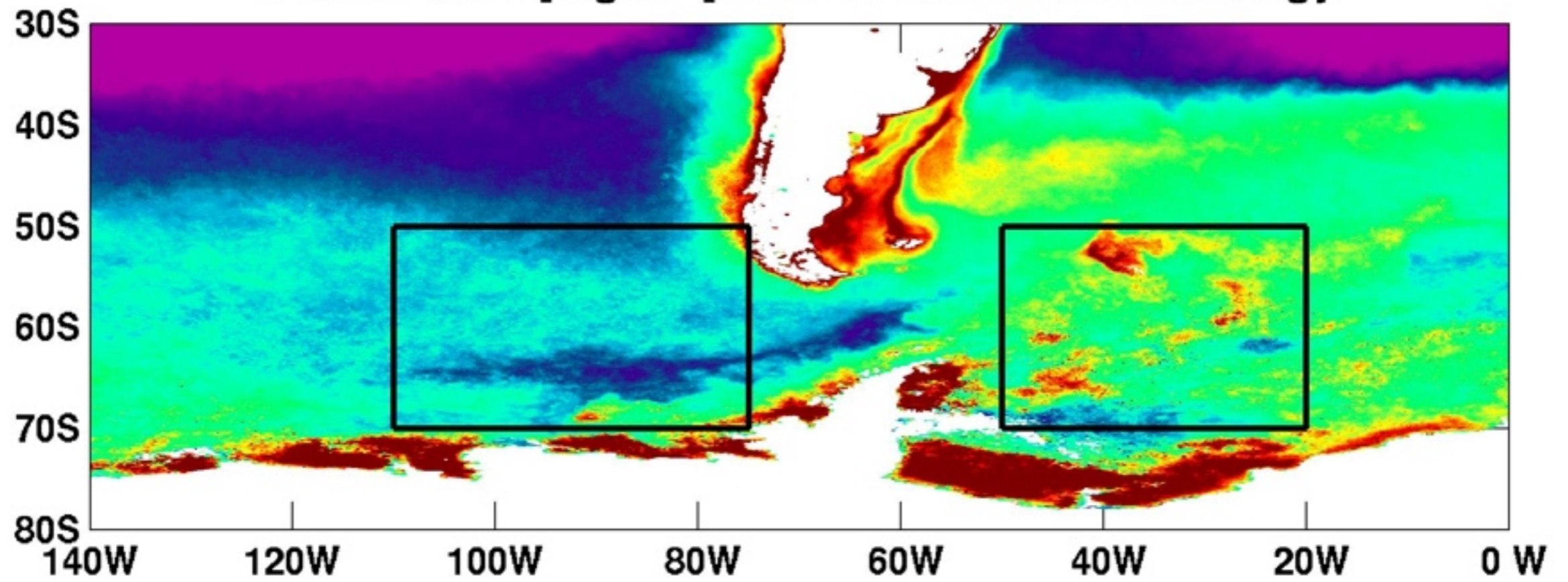


$\Delta p\text{CO}_2$

RB0501B CLIVAR A16S Leg 2 Water $x\text{CO}_2$



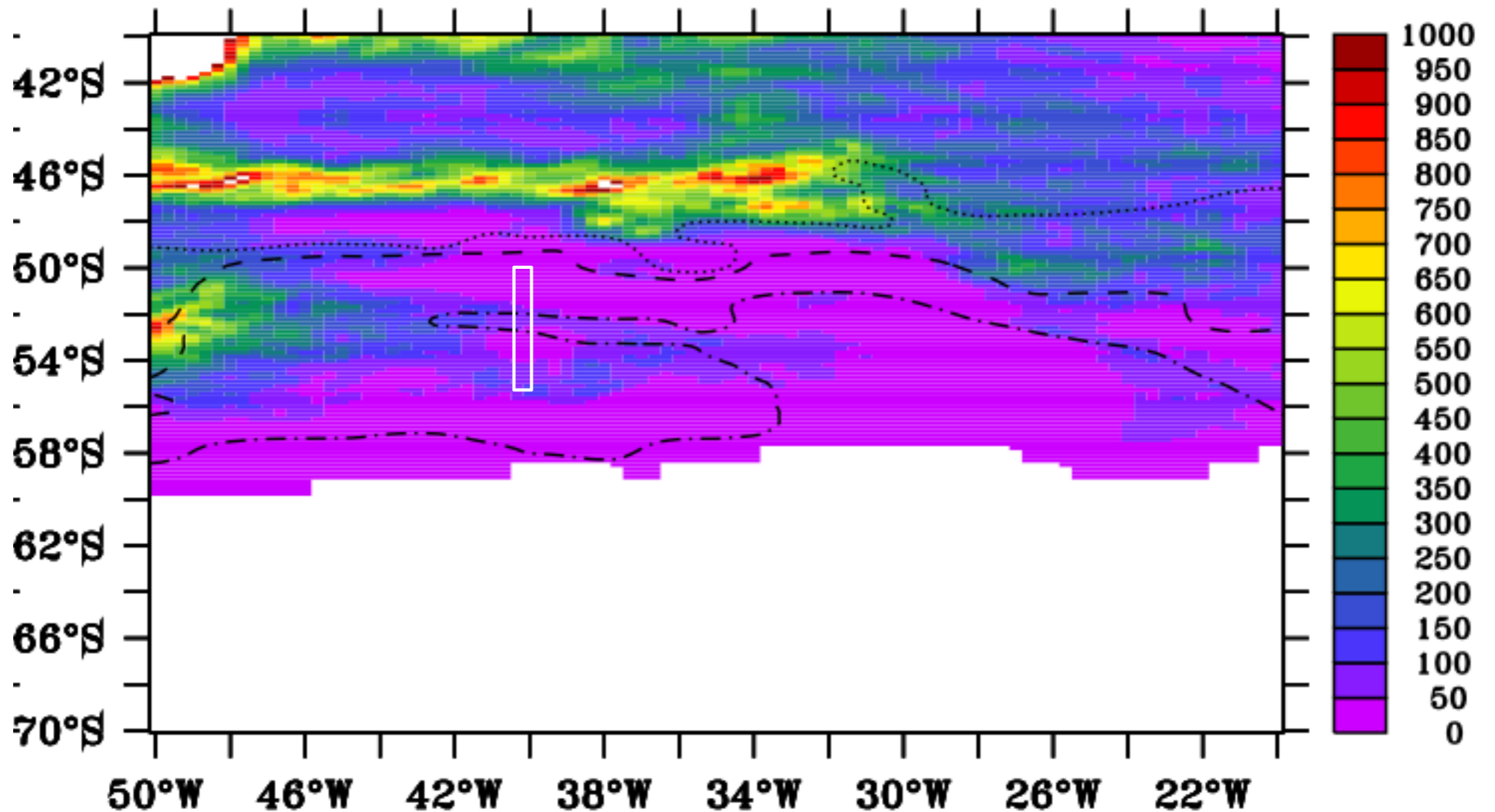
SeaWiFS chl [mg m^{-3}] Austral Summer climatology



Sub-mesoscale variability

MAR

Eddy Kinetic Energy ($\text{cm}^2 \text{s}^{-2}$)

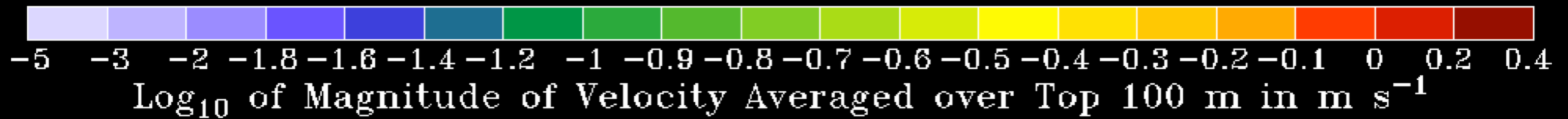
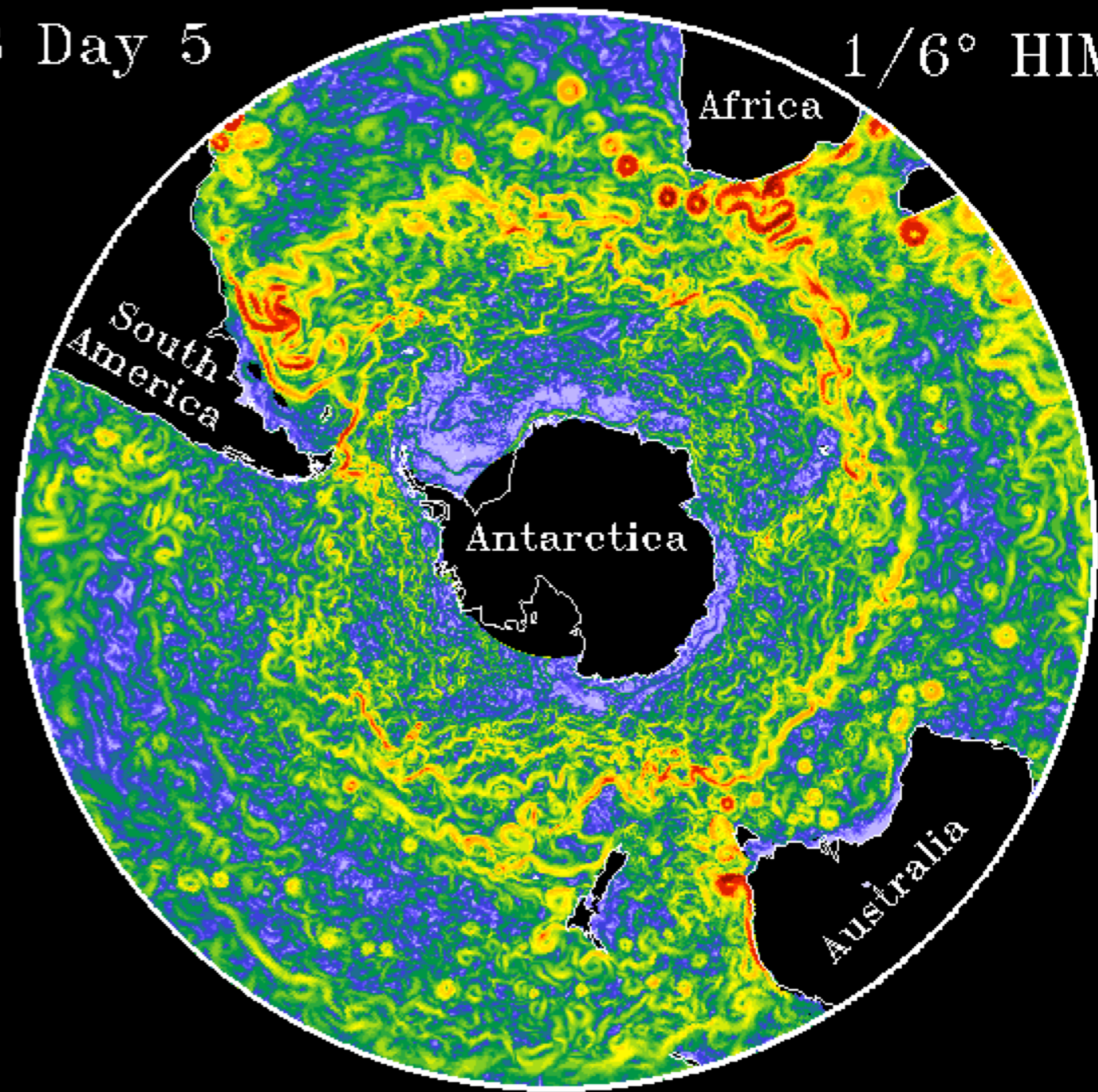
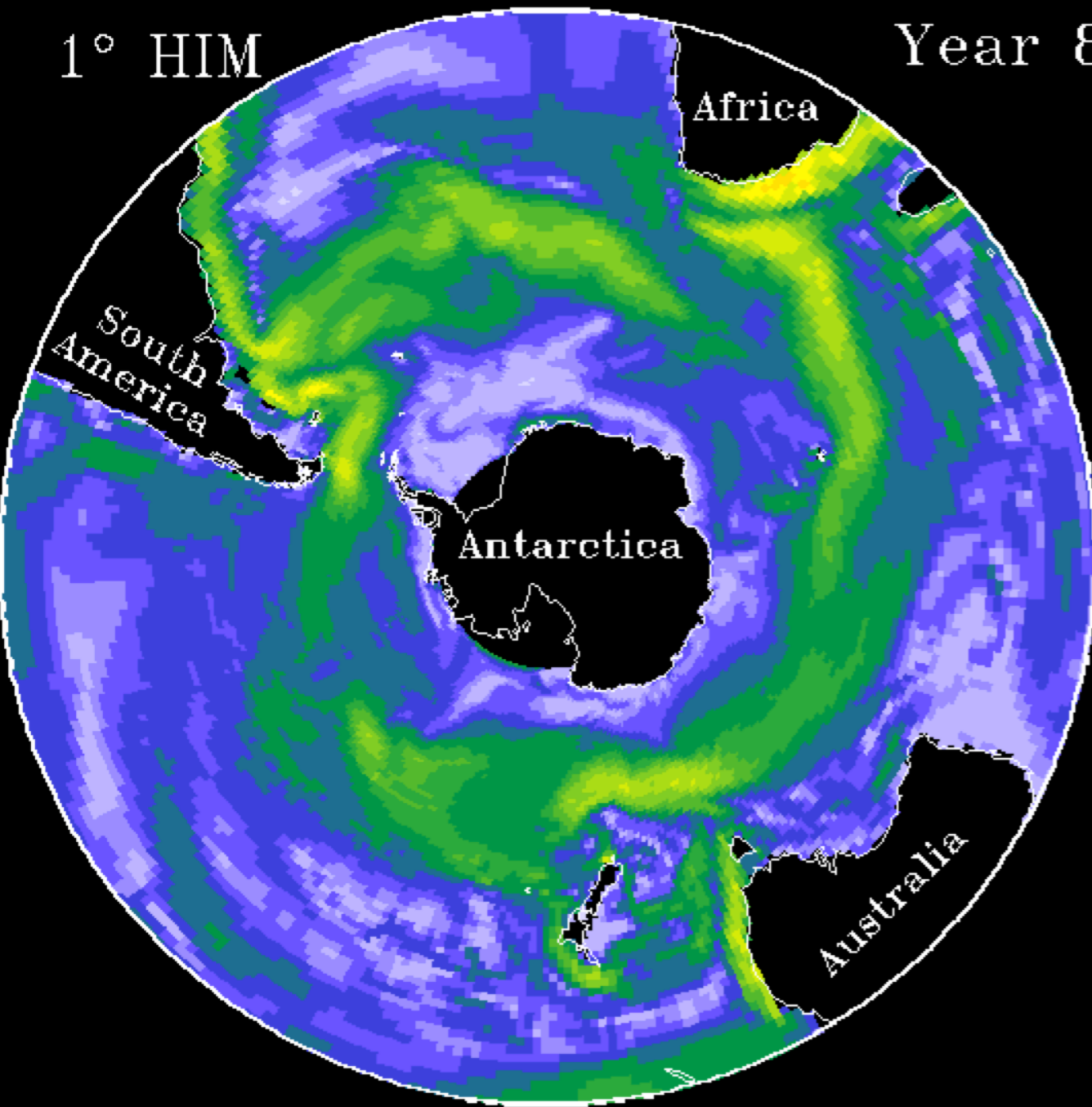


Ocean Surface Speed in NOAA/GFDL Southern Ocean Simulations

1° HIM

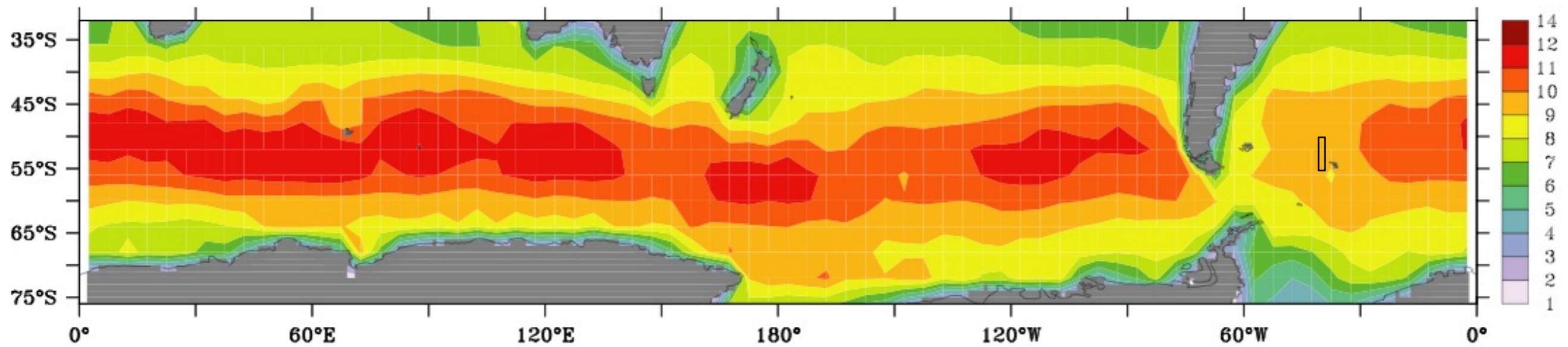
Year 8 Day 5

1/6° HIM



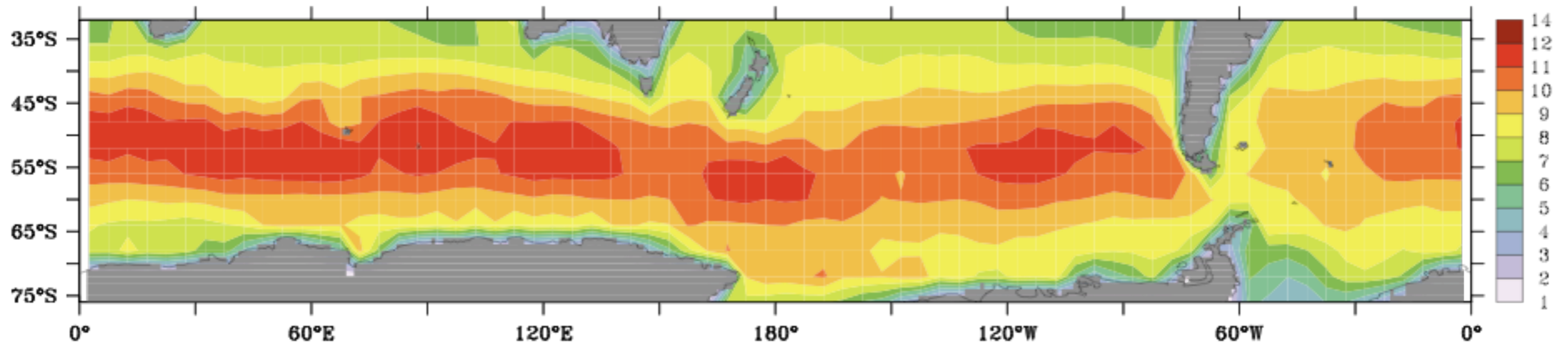
Wind speeds

March

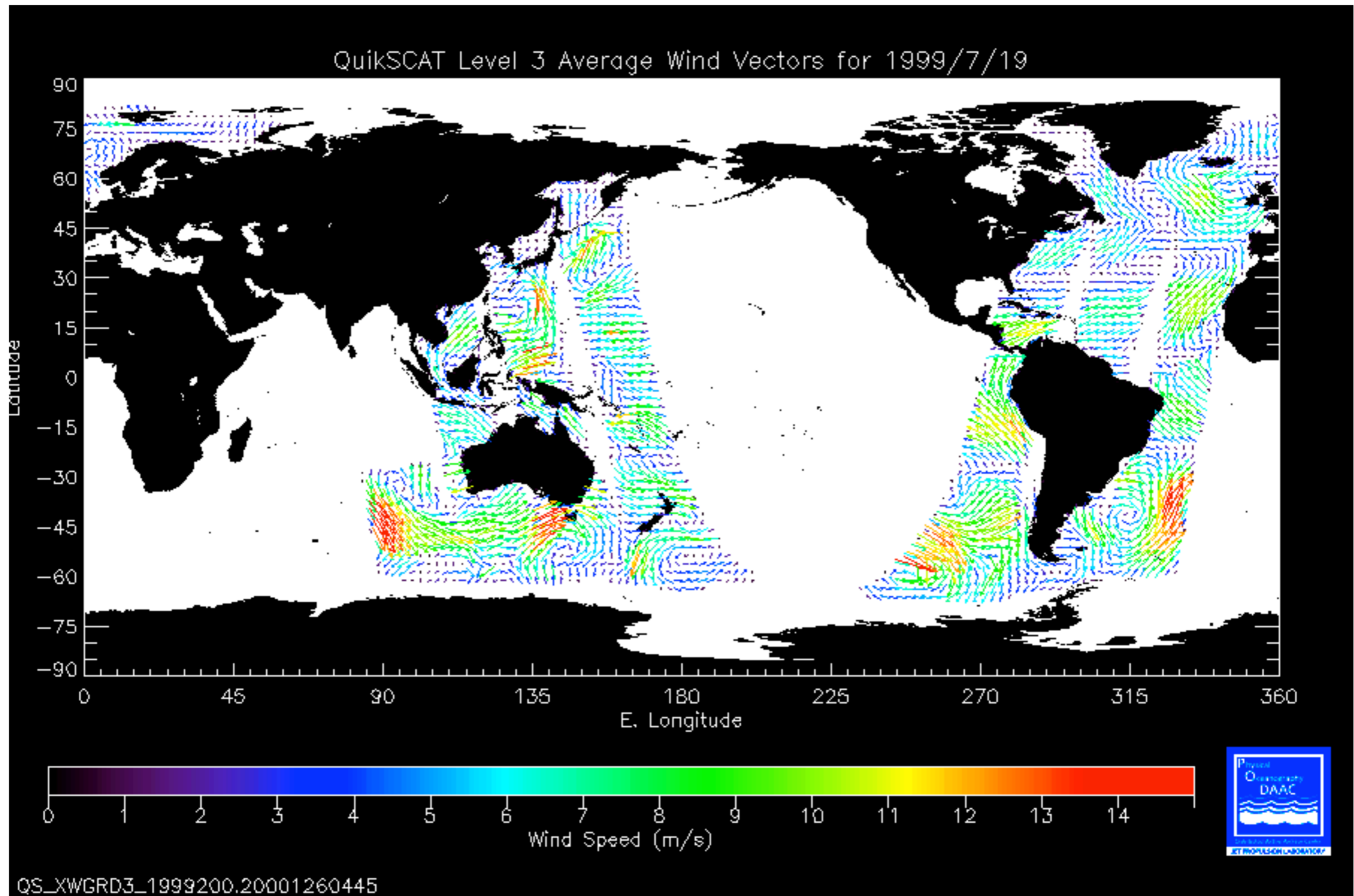


Wind speeds (m s^{-1})

March



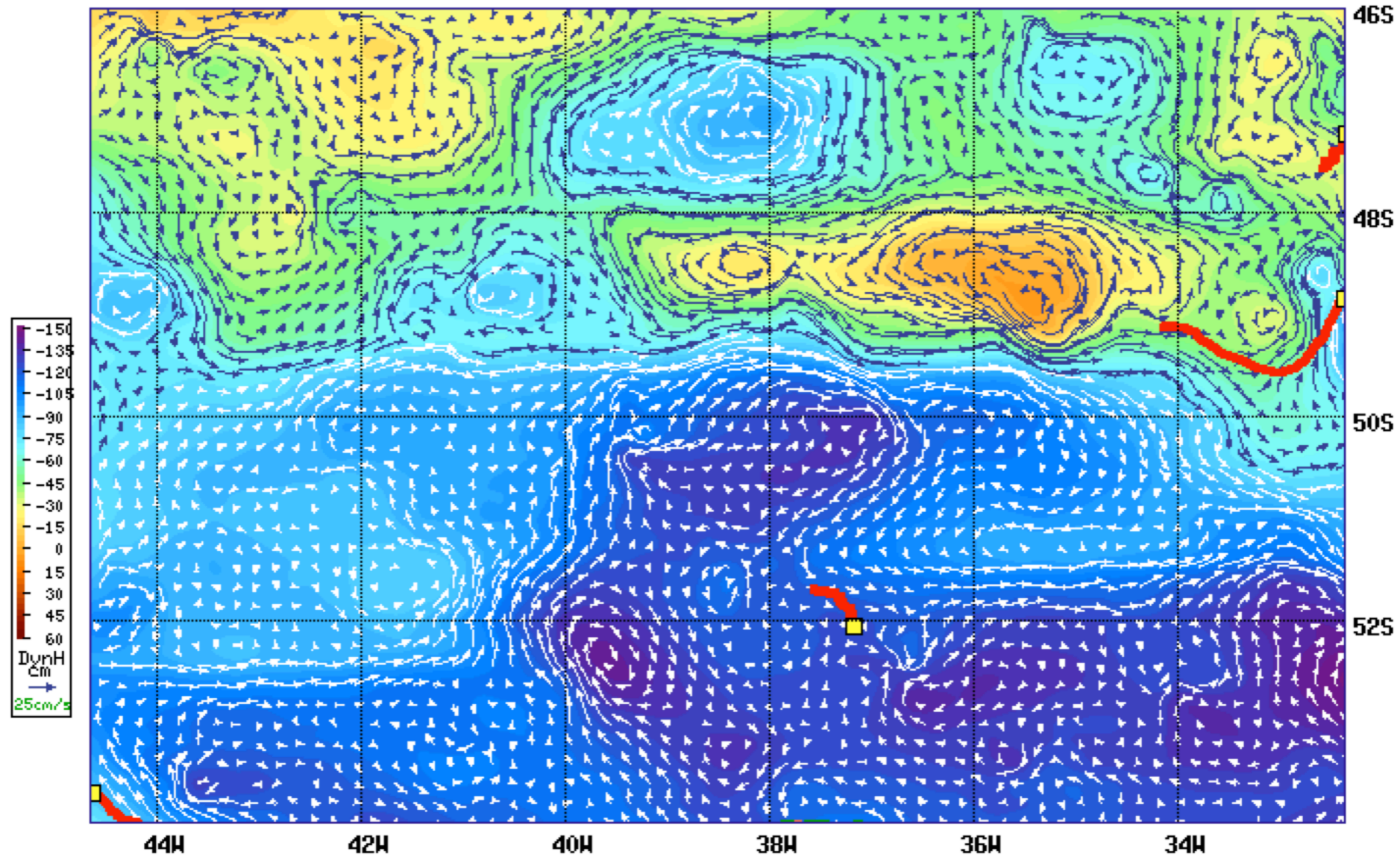
QSCAT Level 3 Average Wind Vectors (m s^{-1})



Surface Velocities Calculated from Altimeter

FEB-17-2008

GOOS/CoastWatch NOAA/AOML
Altimeter/GTS Interface



Developed by Joaquin A. Trinanes

O_2/Ar Productivity ($mmol\ C / m^2 / d$)

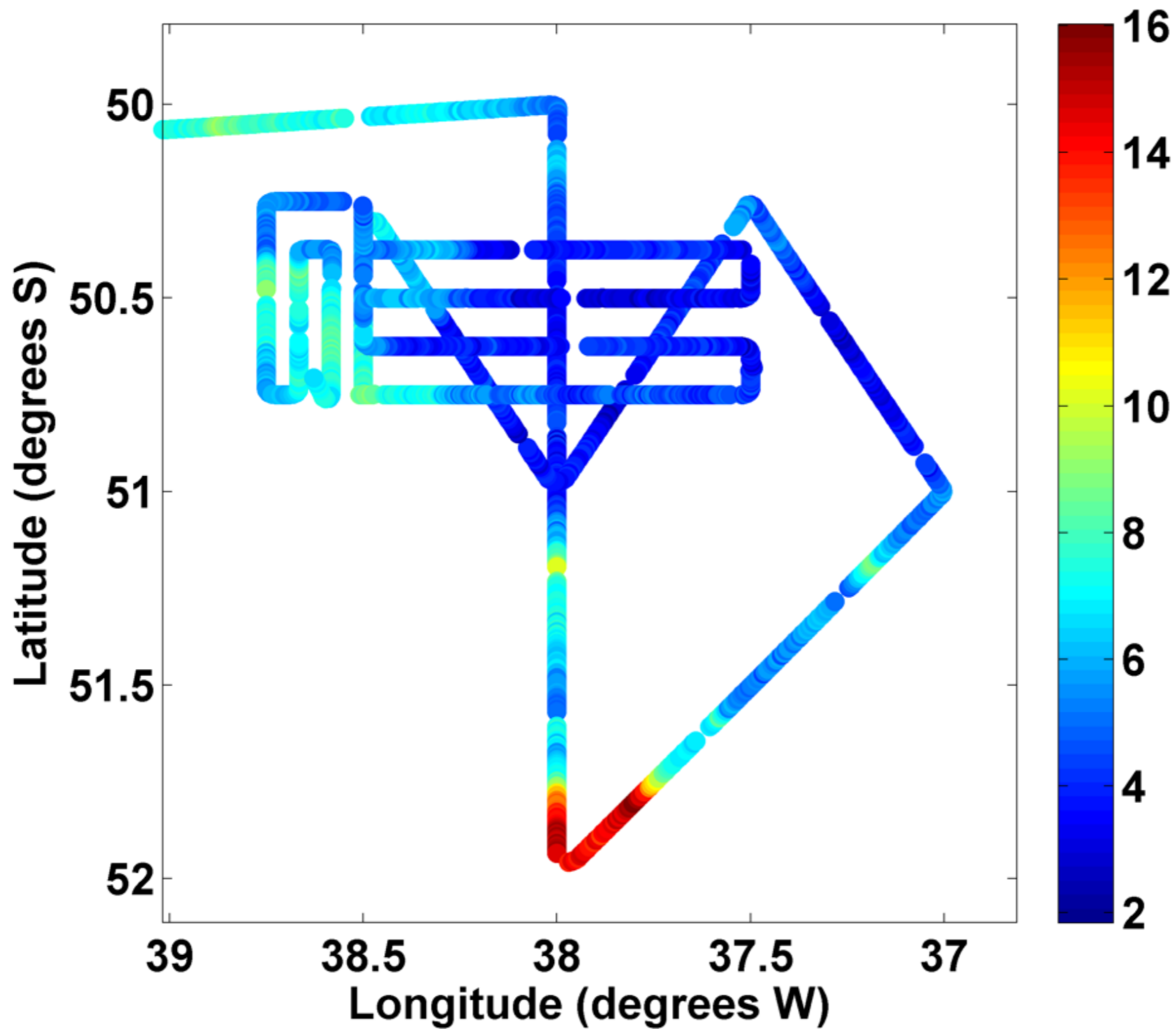


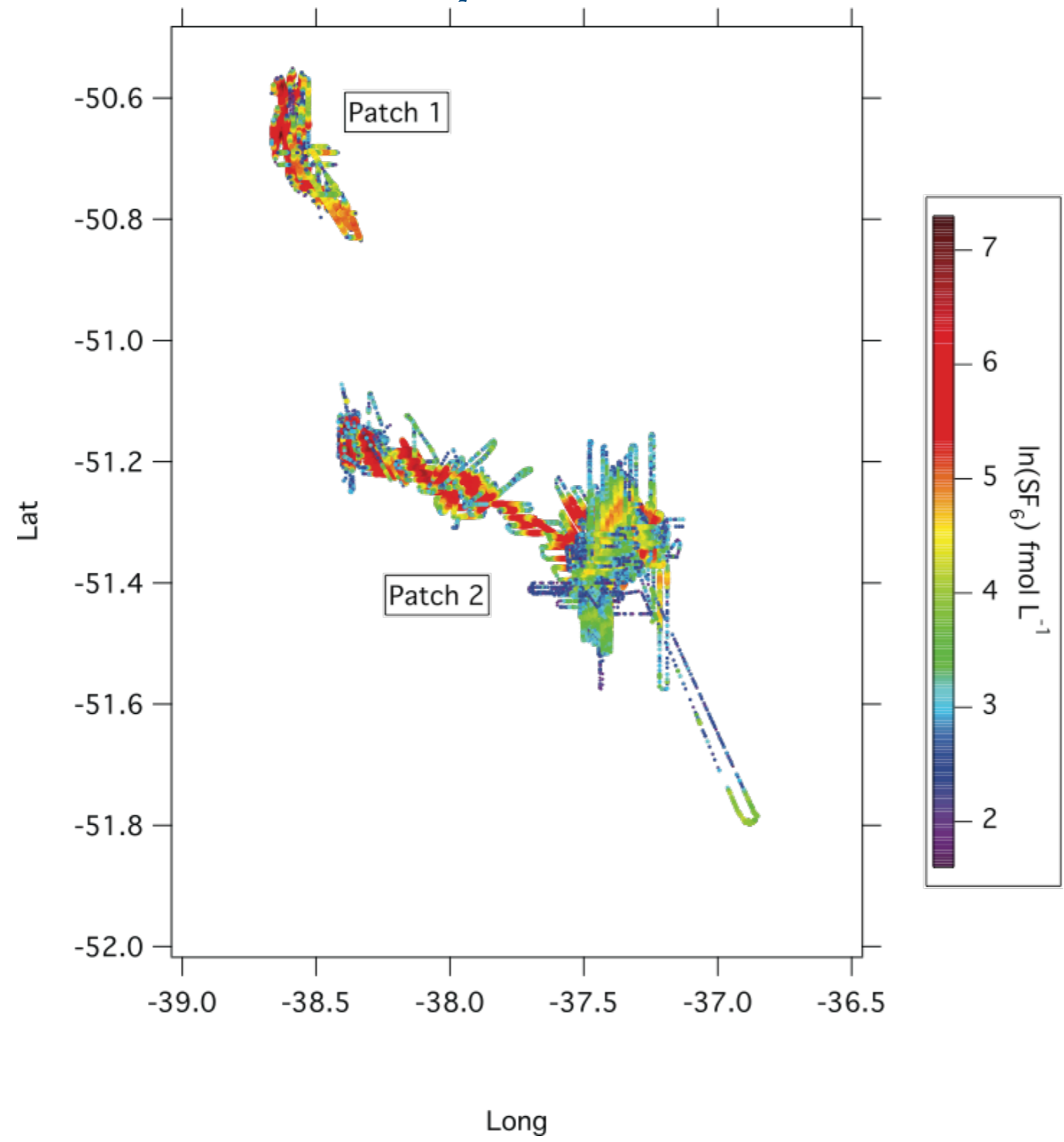
Table 3: Southern Ocean Air-Sea Gas Exchange Experiment

Research Project Component	Process and Method Components
Biological Measurements	New Production Primary Production
Bulk Meteorology and Turbulent Fluxes	Atmospheric Boundary Layer Physics and Meteorology IR Heat Flux Solar Temperature Turbulent Fluxes of Momentum Water Vapor
Core CO ₂ and Hydrographic Measurements	Conductivity, Temperature, and Density (CTD) Equipment Dissolved Inorganic Carbon (DIC) pCO ₂ Spatial and Temporal CO ₂ Flux Footprint
Deliberate Tracers	SF ₆ and He
IR Remote Sensing	Active Infrared Techniques Microbreaking Processes Ocean Skin Temperature
Nutrients	Nutrients O ₂
Sea Surface Roughness	Buoybased Small Scale Waves Shipboard Radars
Shipboard CO ₂ DMS Fluxes	Air-sea Gas Flux Systems Ship Mats
Surface Ocean Processes	Aerosols Atmospheric CO ₂ Gradients Bubbles Currents Directional wavefield Langmuir Cells Large Waves Oceanic Shear Oceanic Saturation Oceanic Surface Turbulence
Surface CO ₂ Variability	Carbon Interface Ocean Atmosphere (CARIOCA) buoy Carbon Modeling Free Rising Temperature Profiler Submersible Autonomous Moored Instrument (SAM) Surface CO ₂ and O ₂ Variability



Underway SF₆

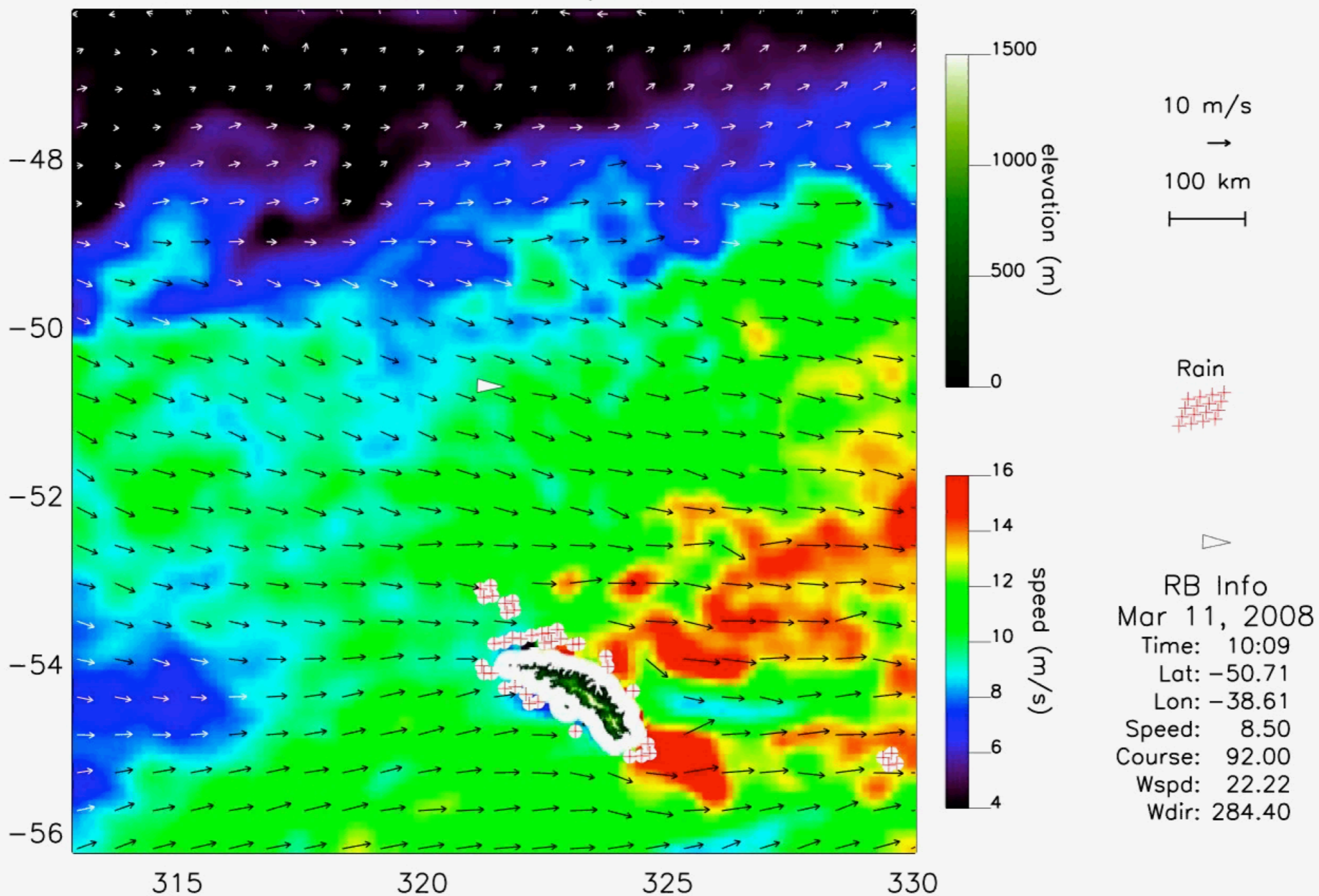
- 4741 SF₆ measurements from Patch 1
- 11175 SF₆ measurements from Patch 2





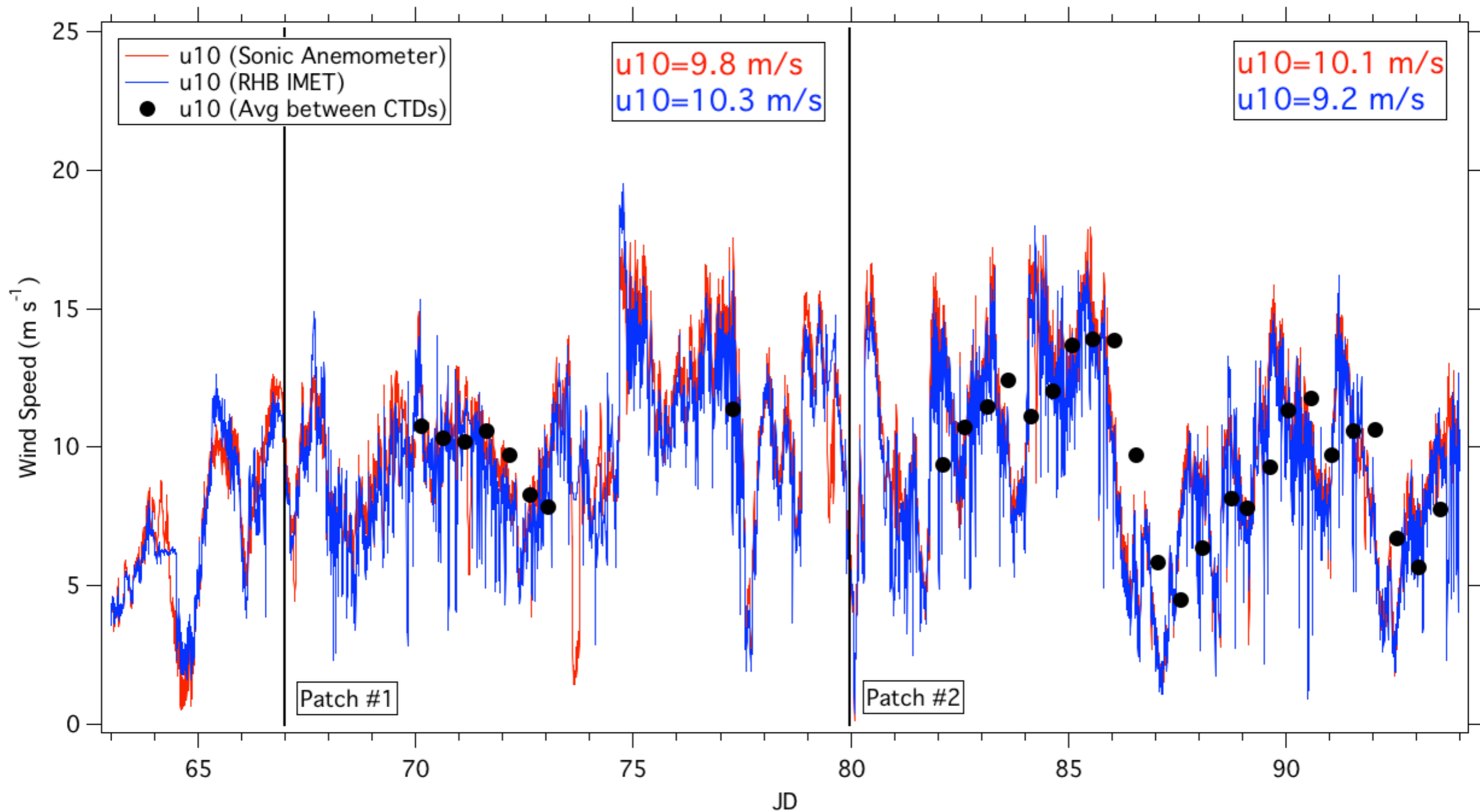
QuikSCAT Wind Speeds

QuikSCAT Winds : Mar 11, 2008 10:52z

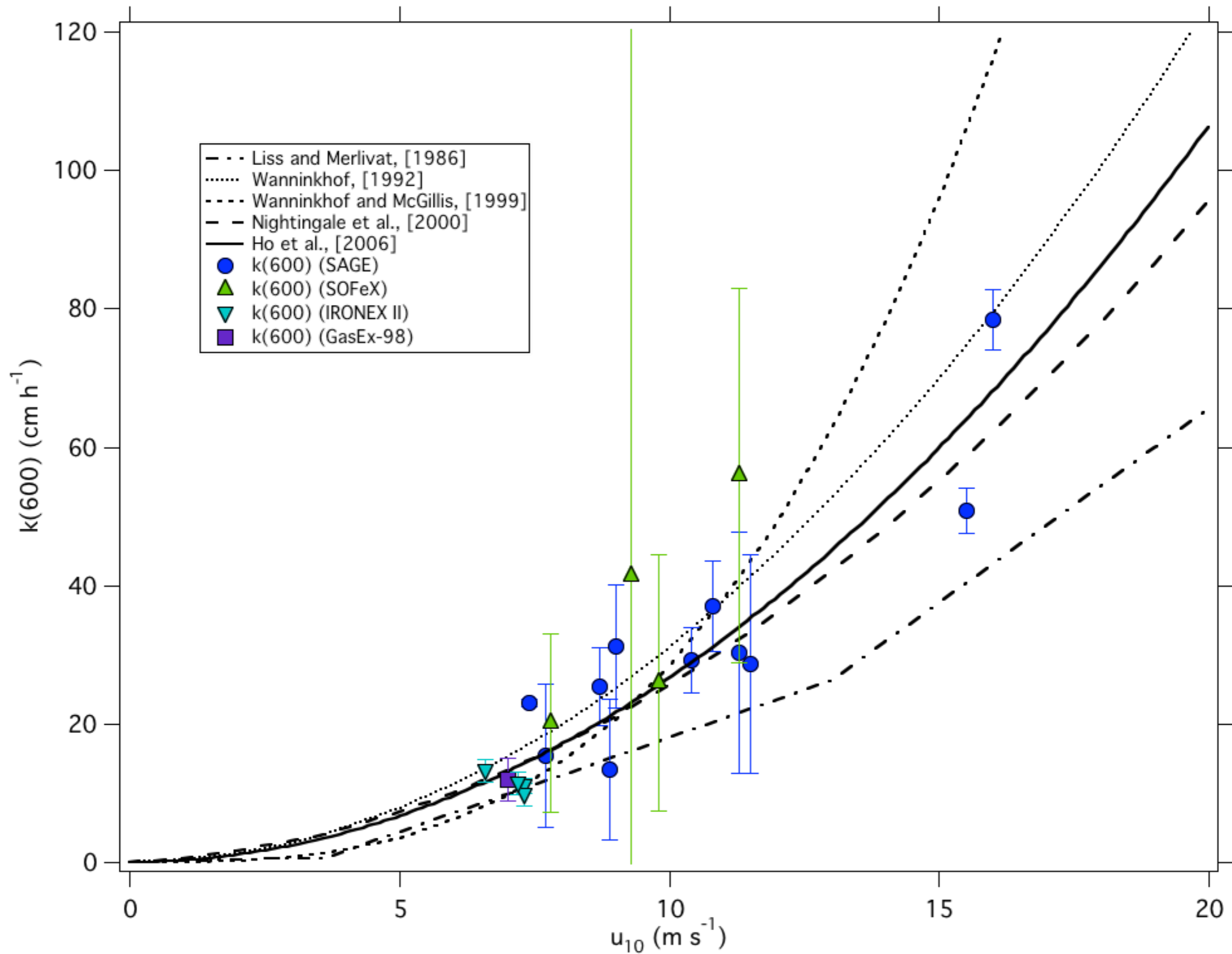




Wind Speeds

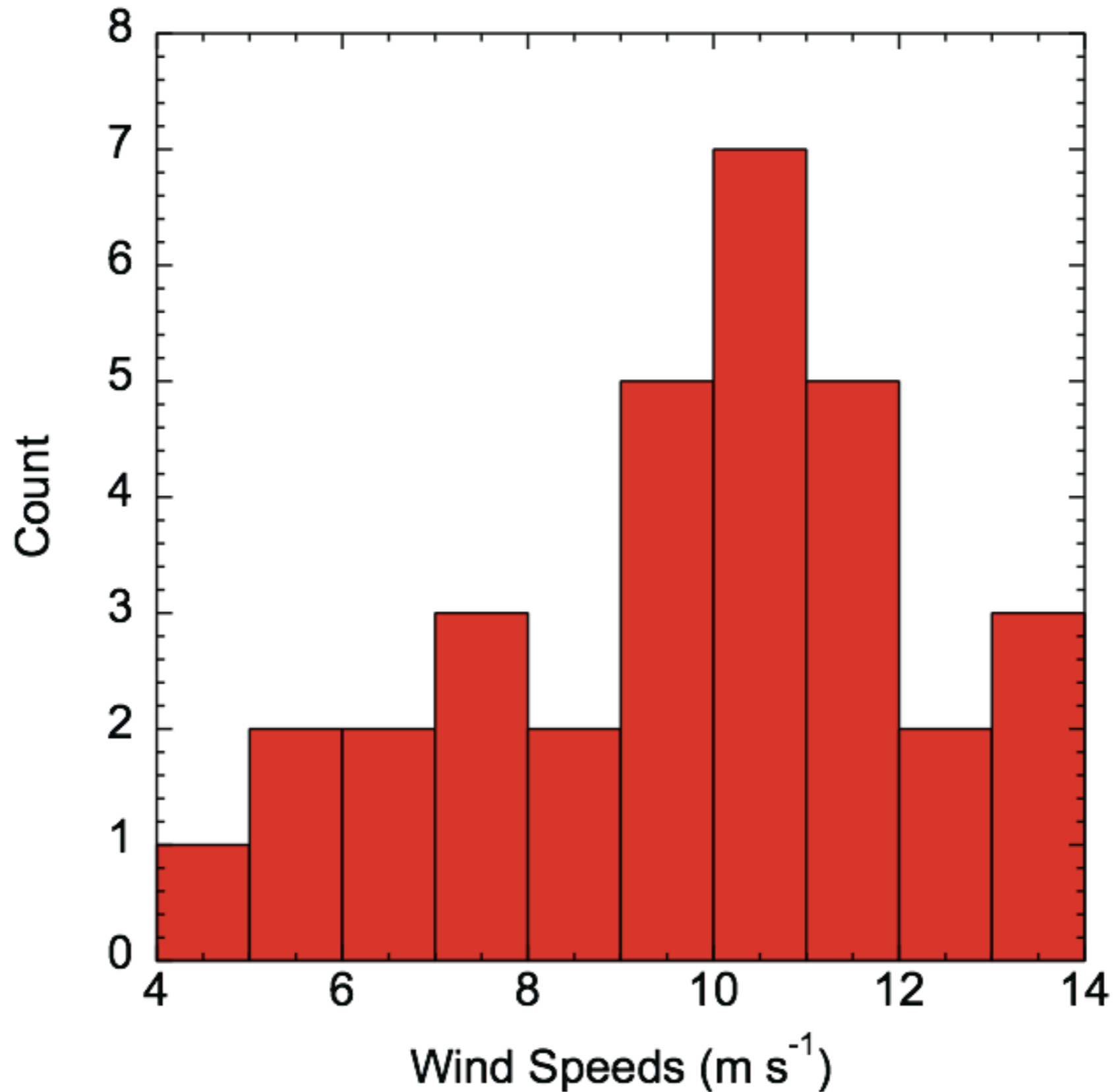


Gas transfer velocities from $^3\text{He}/\text{SF}_6$ Experiments (Open Ocean)



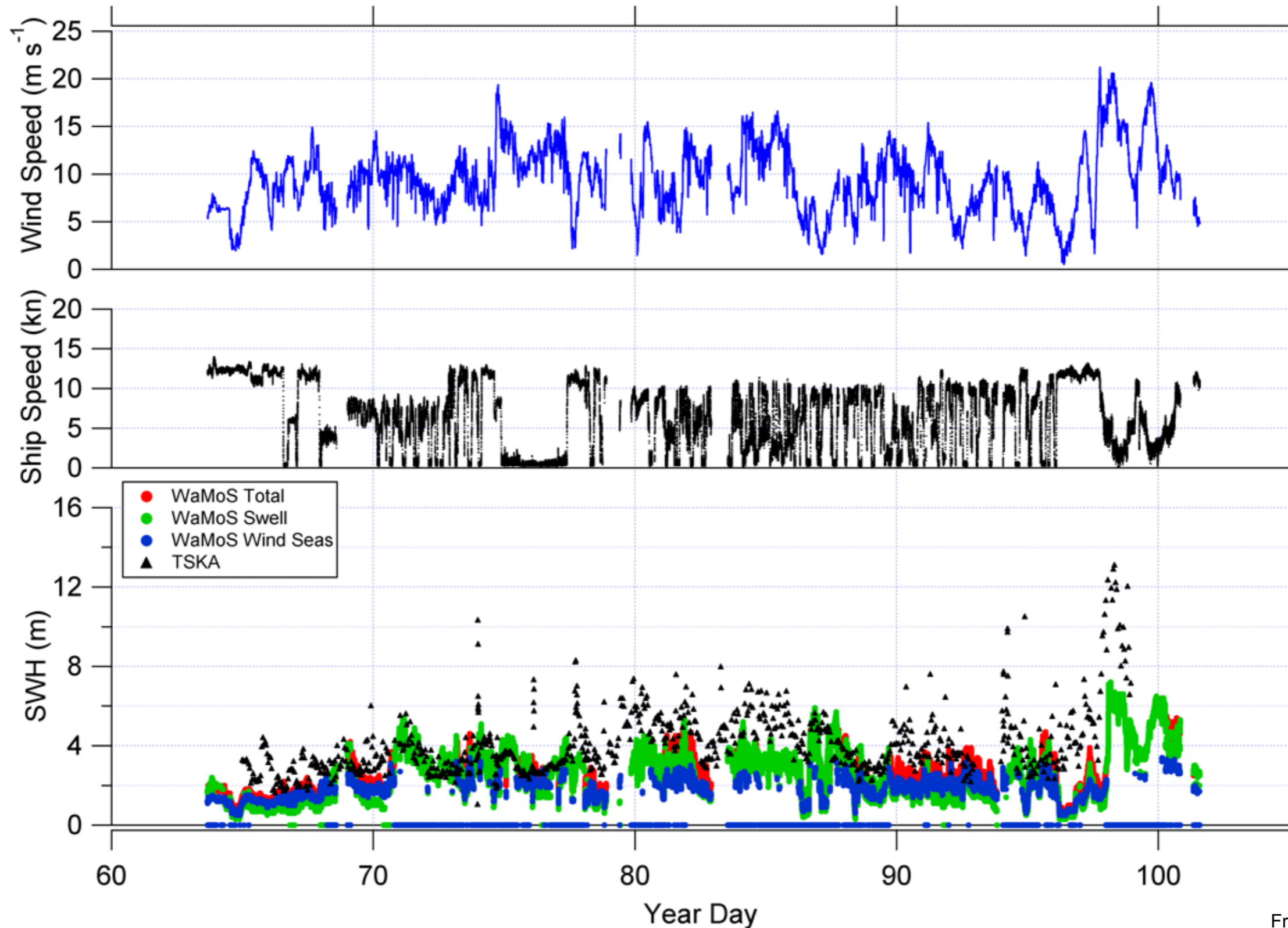


Wind Speeds Distribution



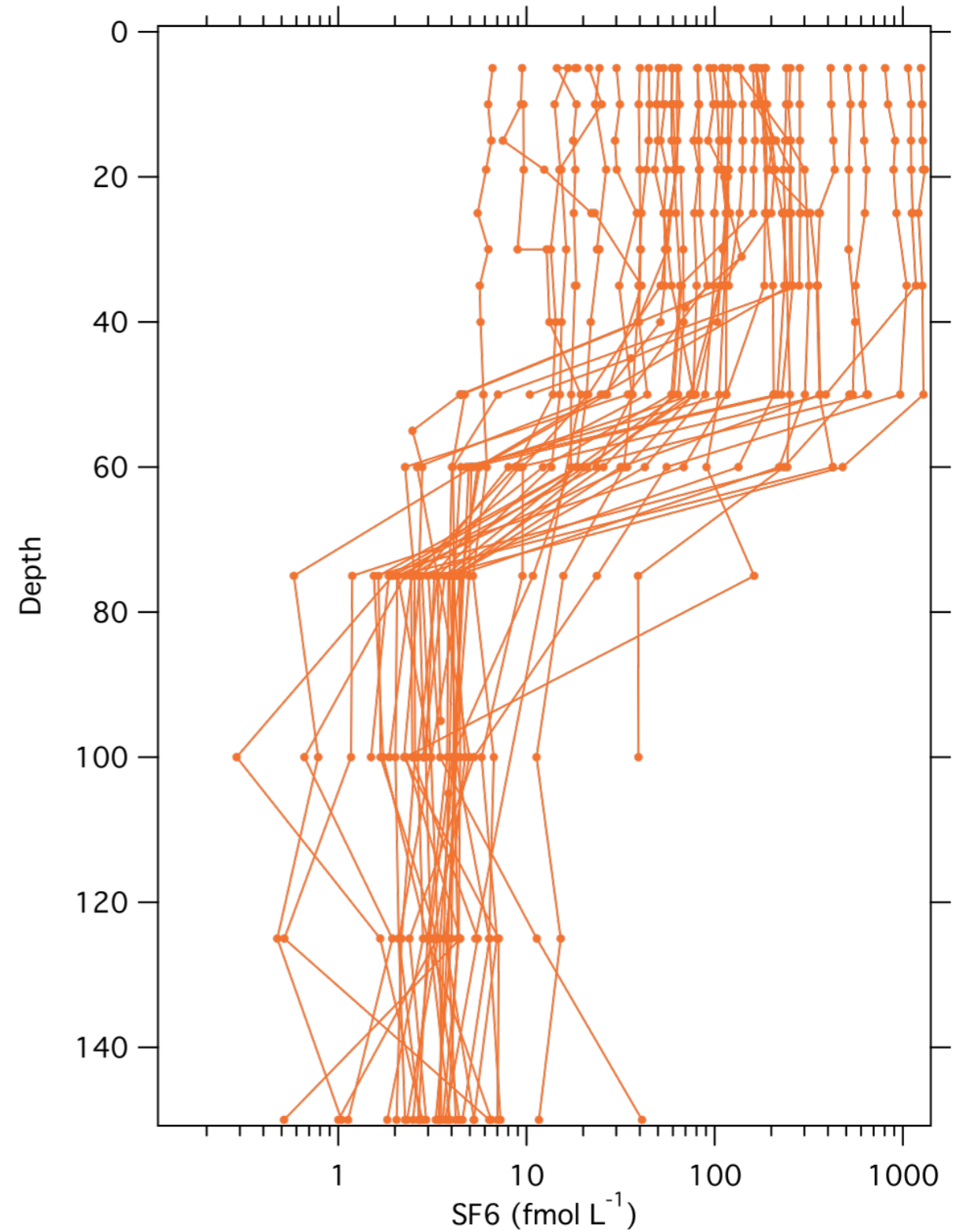
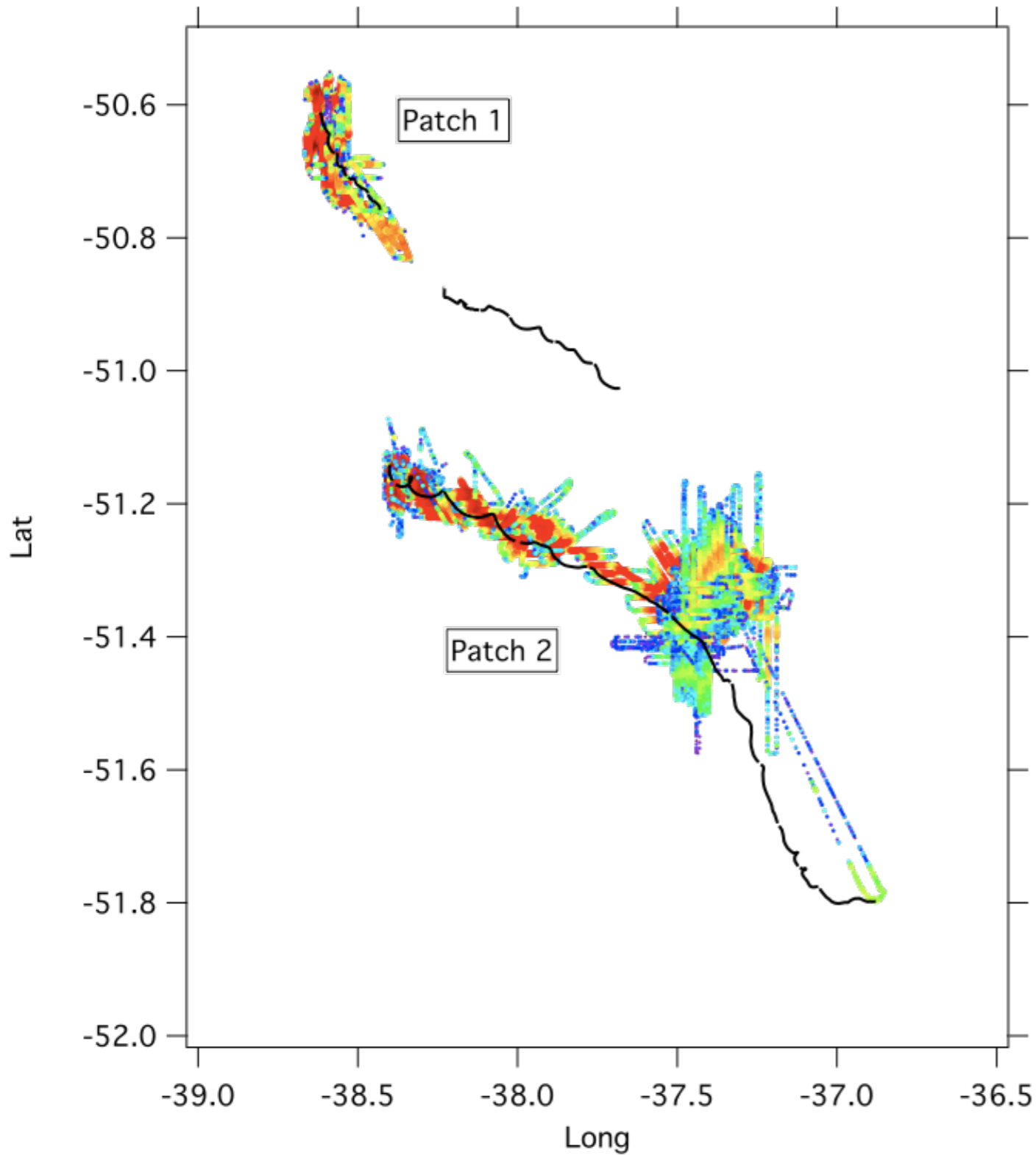


Wind speed, ship speed, and significant wave height



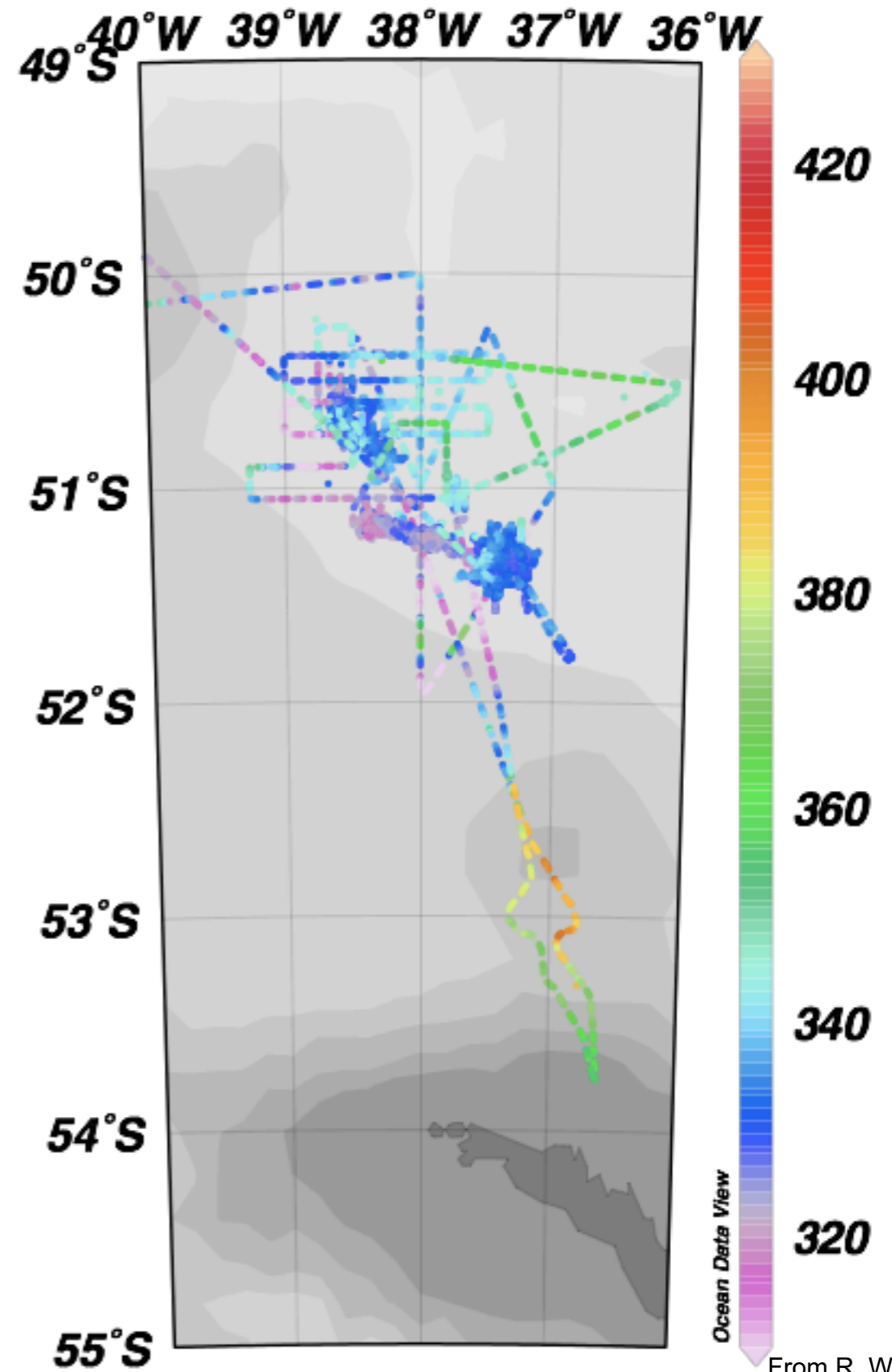
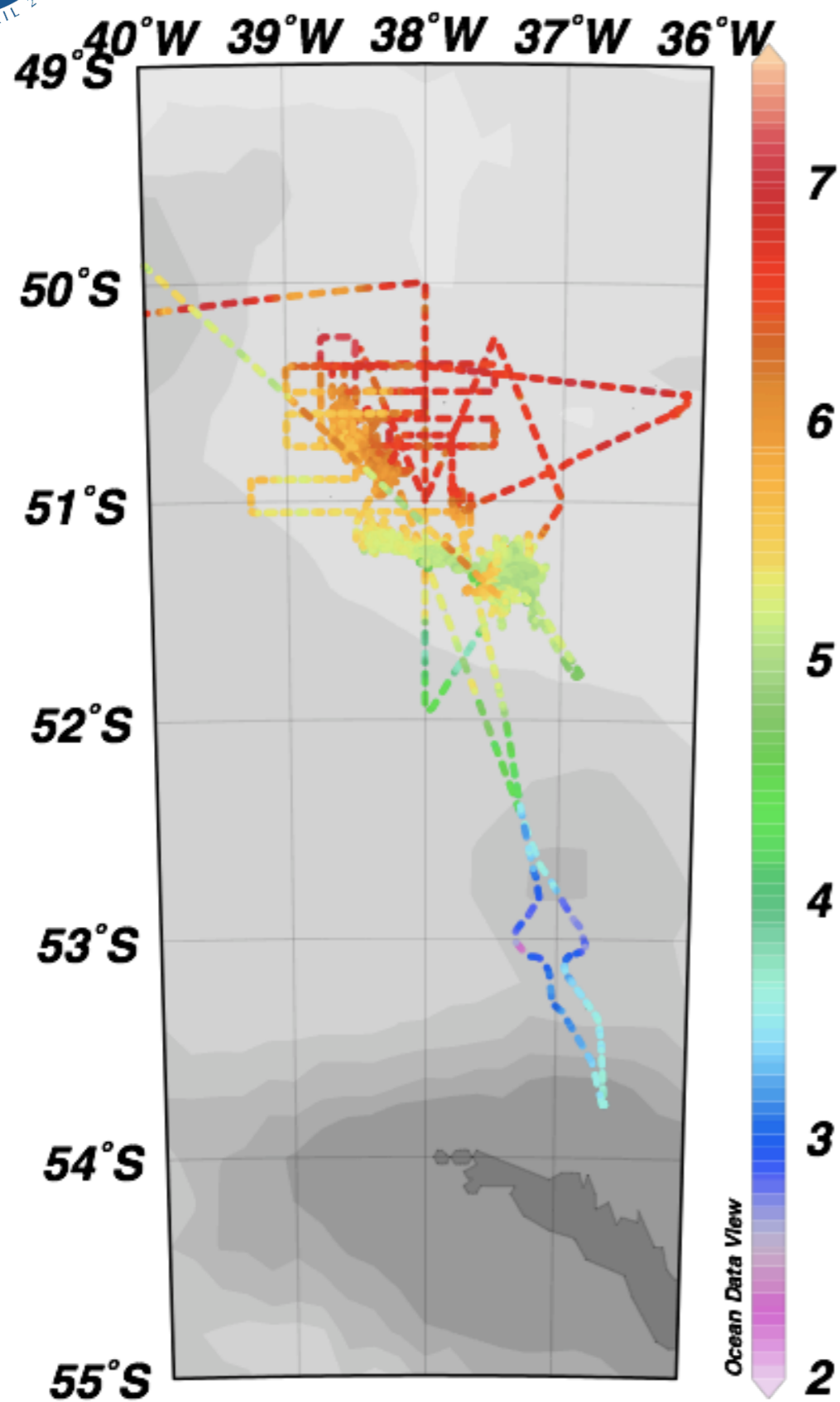


SO GasEx SF₆ Patches and Profiles

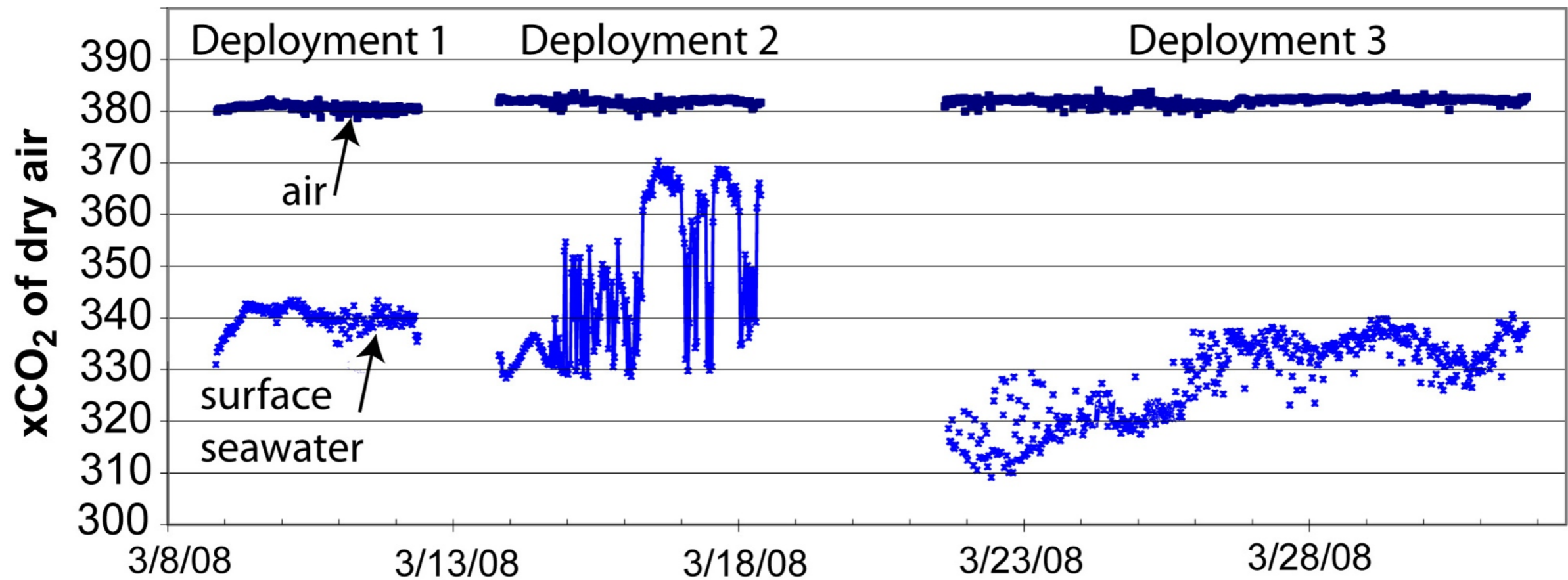




SST & xCO₂



xCO₂ from PMEL MAPCO₂ Buoy





SO GasEx-related Presentations

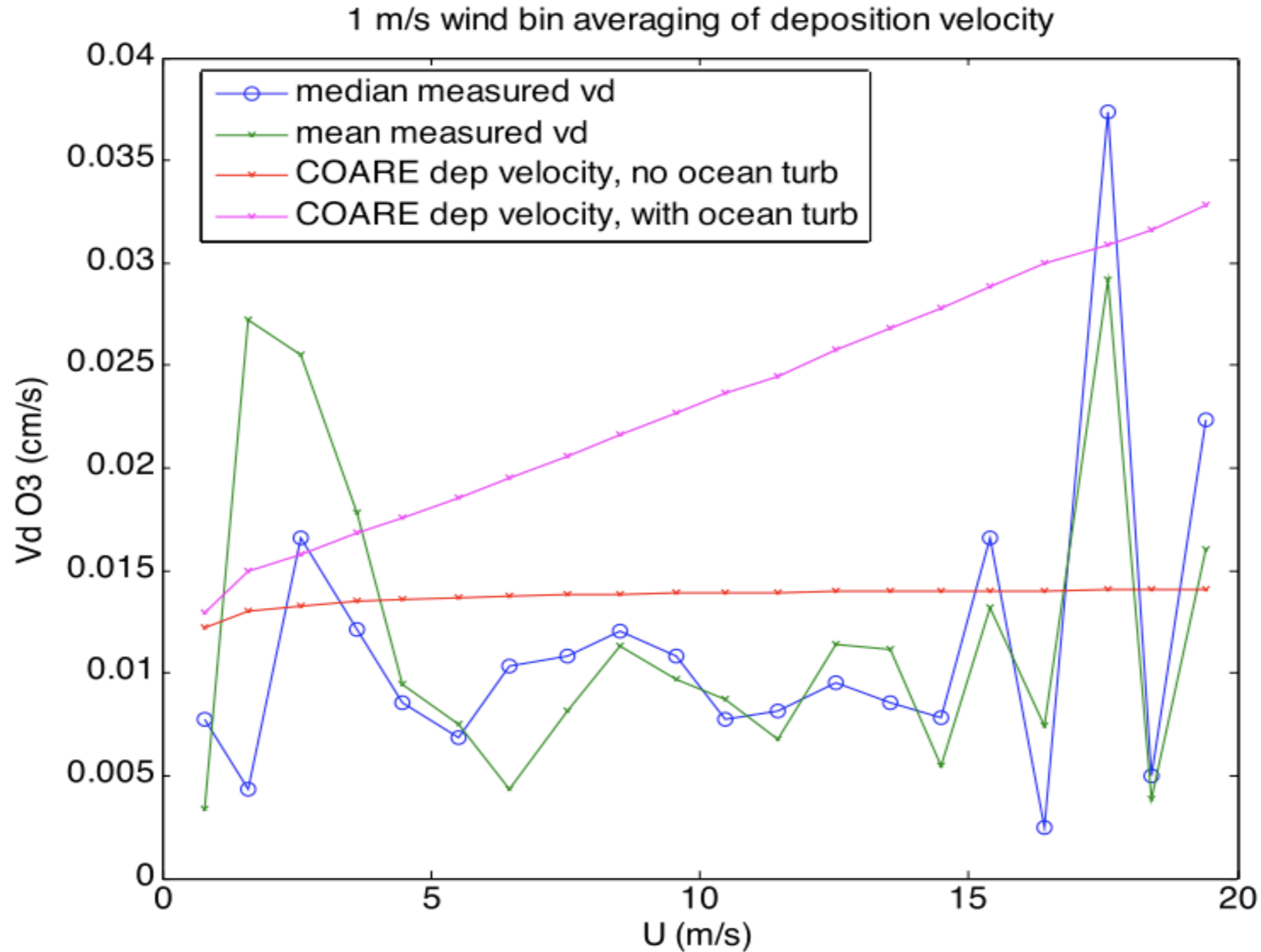
OS22B (This Session)

- Parameterization of Gas Exchange from the Southern Ocean Gas Exchange Experiment (A Cifuentes, C J Zappa, L Bariteau, J B Edson, W R McGillis, C W Fairall)
- DMS transfer velocities above 10 m/s (B J Huebert, B W Blomquist, S Archer, M X Yang, C Fairall)
- Air-sea fluxes from drifting buoys during two recent open-ocean gas exchange experiments (W Drennan, E Sahlee, M DeGrandpre)

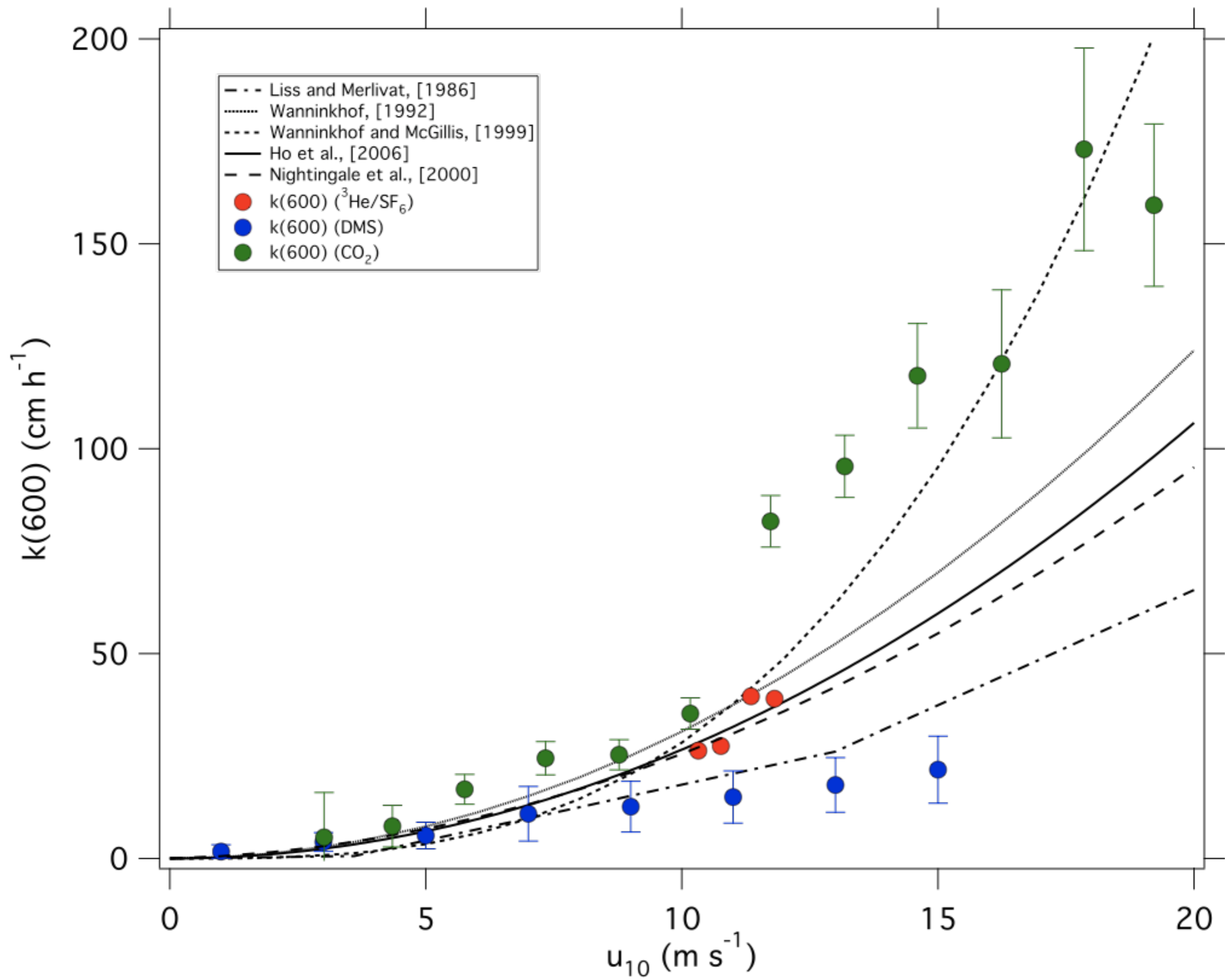
OS31B (Wednesday; MC Hall D)

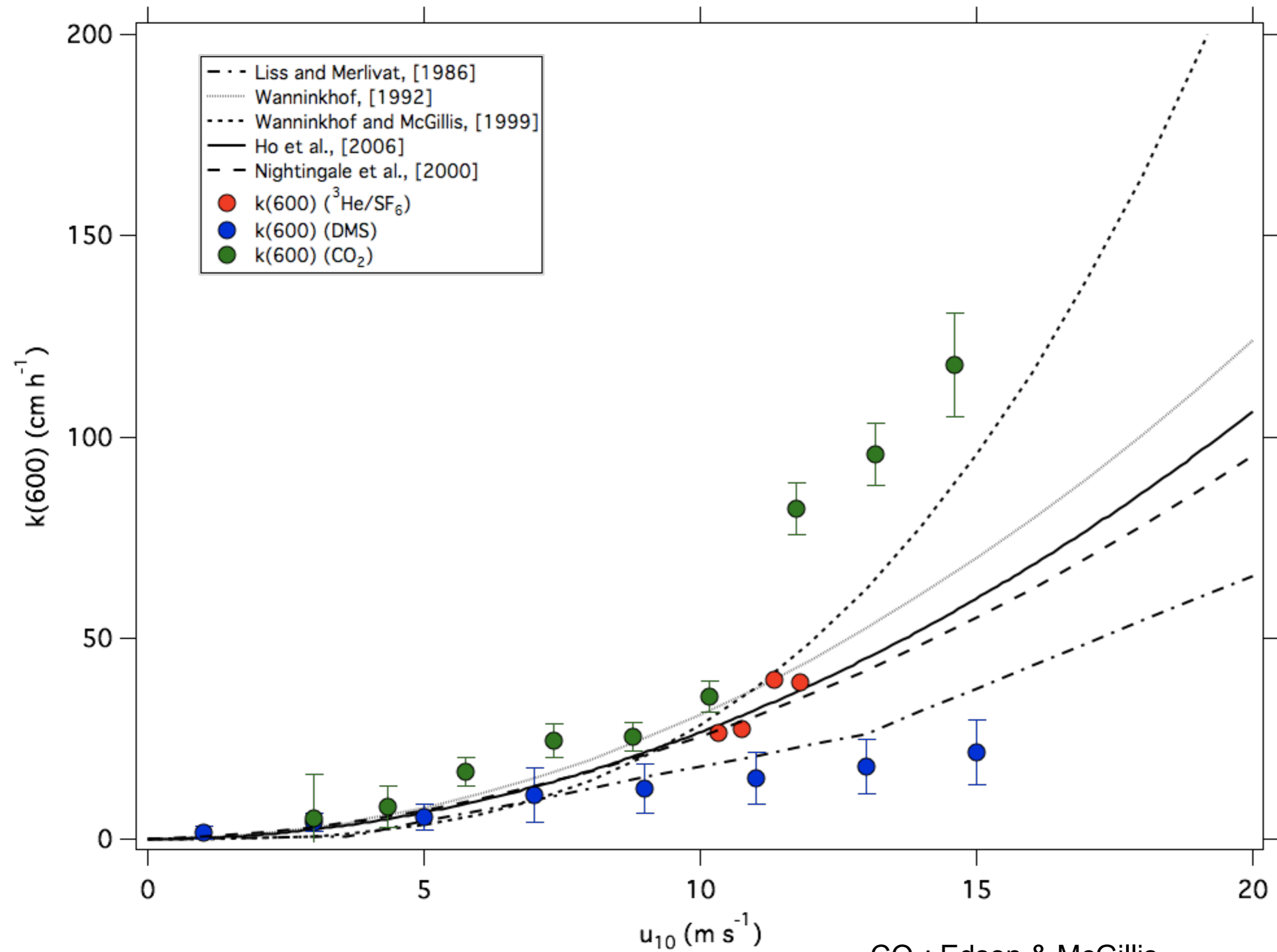
- Satellite Estimation of Air-Sea Gas Transfer During GasEx-3 Using QuikSCAT and Jason-1 Microwave Radars (N M Frew, *D M Glover, M J Caruso)
- Direct measurements of momentum and latent heat transfer coefficients during the GasExIII 2008 field program in the Southern Ocean: Comparisons with the COARE3.0 bulk flux algorithm (C Fairall, L Bariteau, J Hare, S Pezoa, J Edson, A Cifuentes-Lorenzen, W McGillis, C Zappa)
- Influence of Waves, Whitecaps, and Turbulence on the Gas Transfer during the Southern Ocean Gas Exchange Experiment (C J Zappa, A Cifuentes-Lorenzen, J B Edson, W R McGillis, L Bariteau, C W Fairall)
- Optical Measurements of Bubble Injections in the Southern Ocean (K L Randolph, H M Dierssen, C Buonassissi, S Freeman, M S Twardowski)
- Measurements of the air-sea flux of ozone from the Ronald H. Brown (J Hare, L Bariteau, C Fairall, D Helmig, L Ganzeveld, K Lang, J Hueber)
- Tracking the SO-GasEx tracer patch with ADCP and high-resolution surface data (D Hebert, B Hales, P Strutton, D T Ho)
- Air-Sea Gas Exchange Measured with $^3\text{He}/\text{SF}_6$ during SO GasEx (D T Ho, R Wanninkhof, P Schlosser, K F Sullivan)
- Water Column Carbon Trends During the SO Gas Exchange Experiment (C L Sabine, R A Feely, C Zappa, W McGillis, M DeGrandpre, G C Johnson, S M Jones, G Lebon)
- Low Net Community Production from Oxygen/Argon Mass Balance during the Southern Ocean Gas Exchange Experiment (R C Hamme, N Cassar)
- Primary Productivity and Carbon Export During the Southern Ocean Gas Exchange (SOGasEx) Lagrangian Tracer Experiments (V P Lance, P G Strutton, J F Marra)
- Depth-resolved water column spectral absorption of sunlight by phytoplankton during the Southern Ocean Gas Exchange (SOGasEx) Lagrangian tracer experiments (B R Hargreaves)
- Particle Populations in the Southern Ocean During the Southern Ocean Gas Exchange Experiment (C J Buonassissi, H Dierssen)

Measurements of the air-sea flux of ozone from the Ronald H. Brown (J Hare, L Bariteau, C Fairall, D Helmig, L Ganzeveld, K Lang, J Hueber)

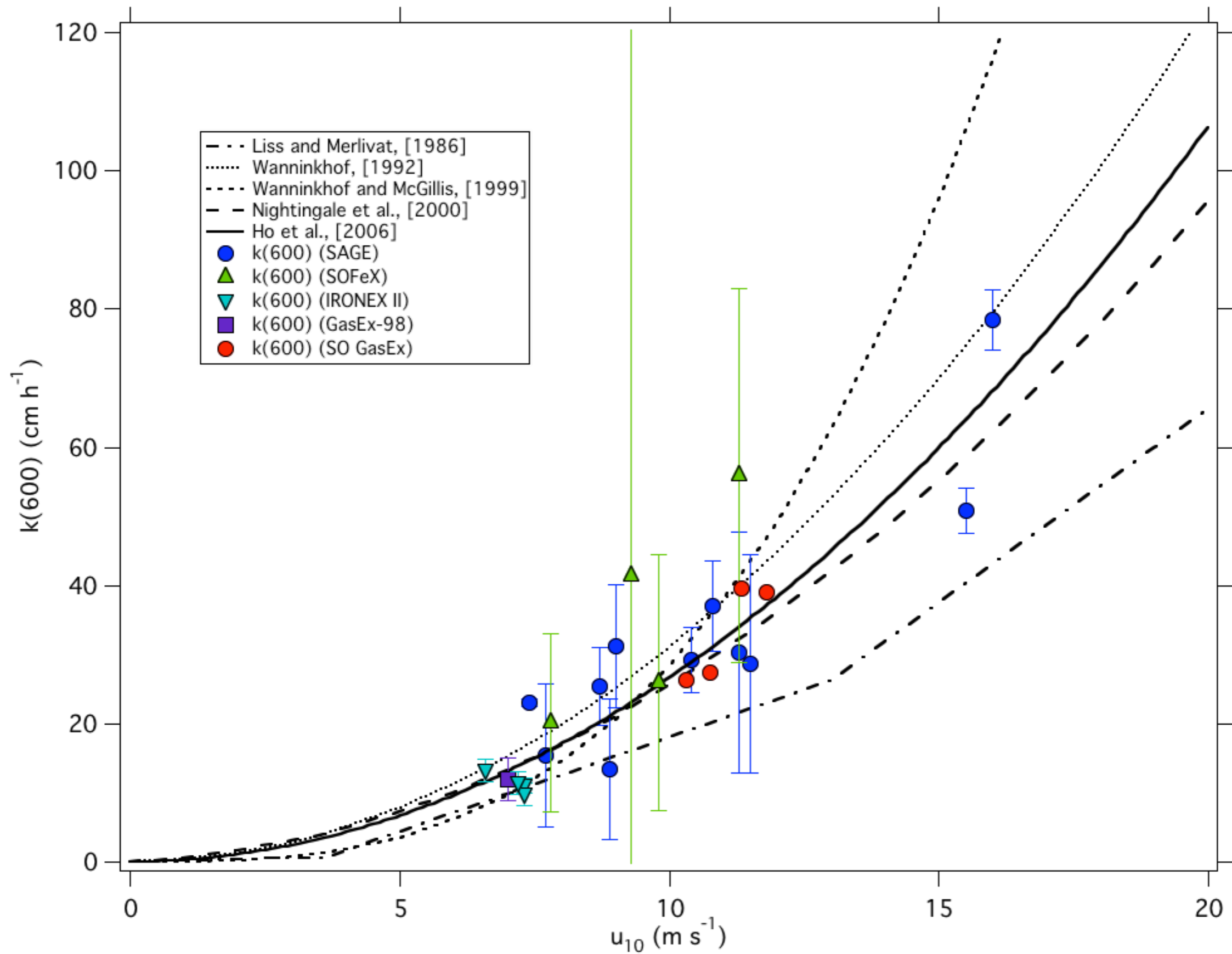


- Parameterization of oceanic turbulence dependency (Fairall et al., 2007).
- Ozone variable used in model are : solubility for ozone in ocean of 0.1, reactivity of 10^3 s^{-1} and Schmidt number of 500 for ozone in water.



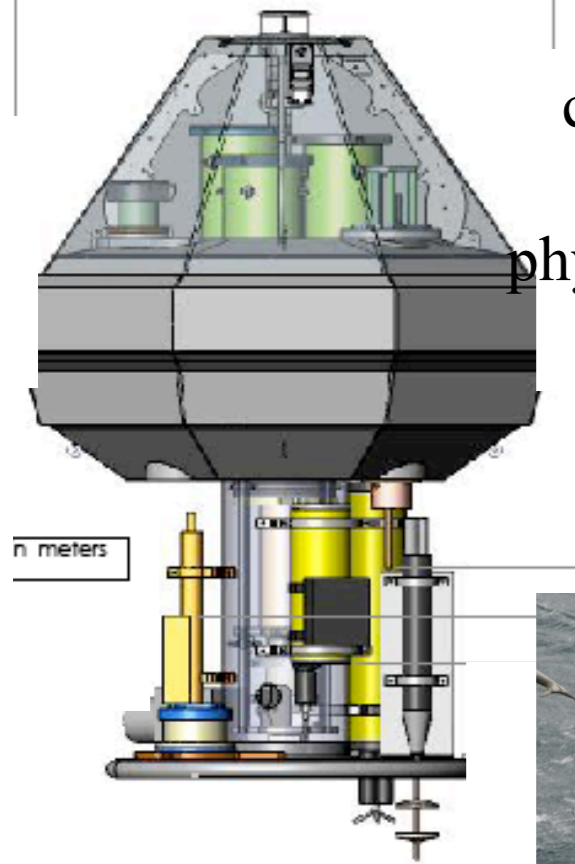


CO₂: Edson & McGillis
 DMS: Blomquist & Huebert
³He/SF₆: Ho, Schlosser & Wanninkhof



(D T Ho, R Wanninkhof, P Schlosser, K F Sullivan)

Water Column Carbon Trends During the SO Gas Exchange Experiment (C L Sabine, R A Feely, C Zappa, W McGillis, M DeGrandpre, G C Johnson, S M Jones, G Lebon, R Wanninkhof, D Ho)

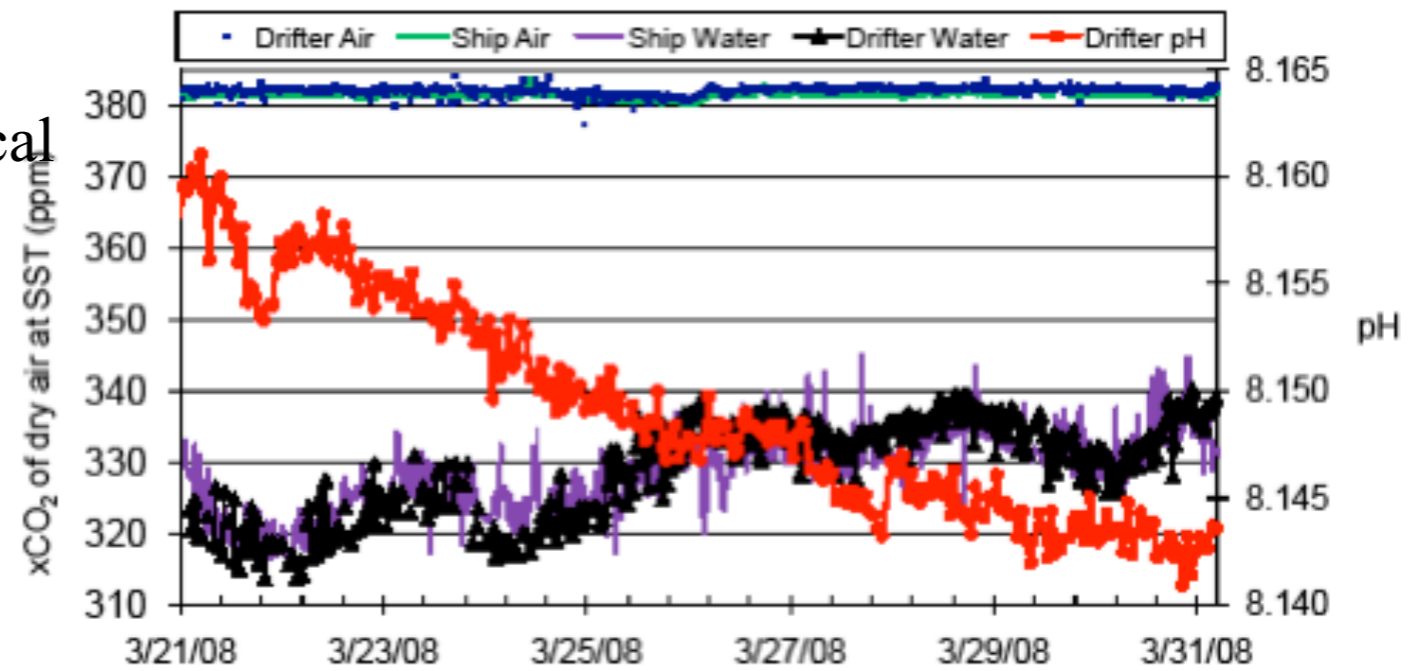


An autonomous drifter collected high resolution surface and subsurface physical and biogeochemical measurements

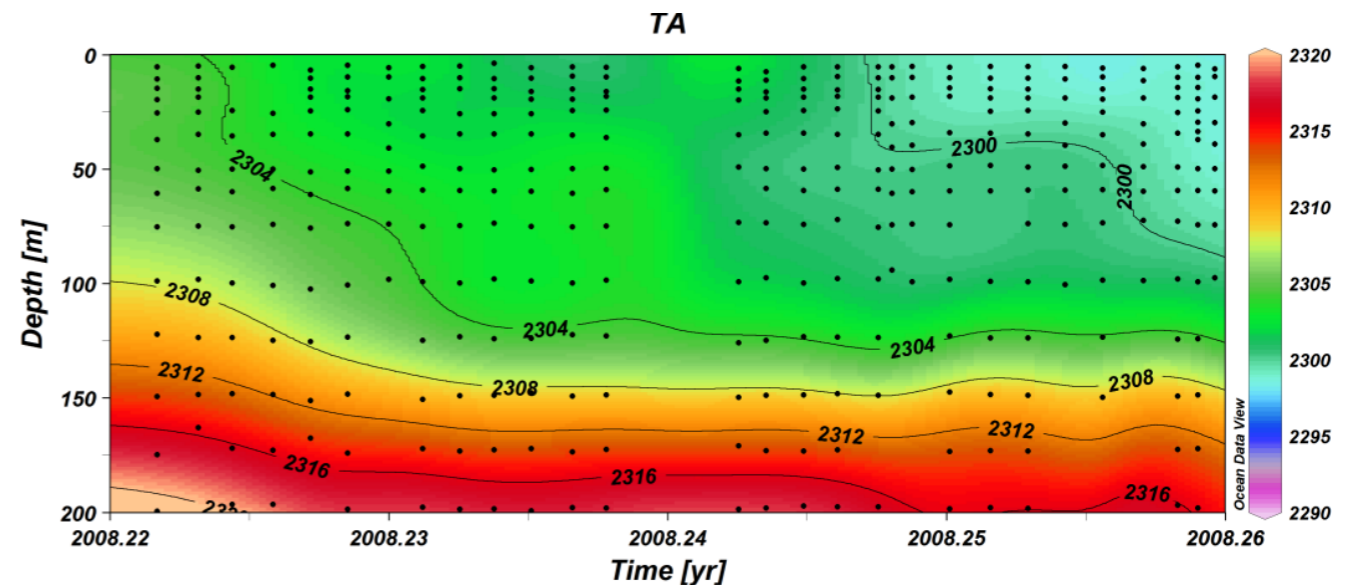


A 24-bottle CTD/rosette package was used to make a suite of measurements every 12 hours during the two tracer patch studies

Trends in surface $x\text{CO}_2$ and pH during 2nd tracer patch as measured by the drifter

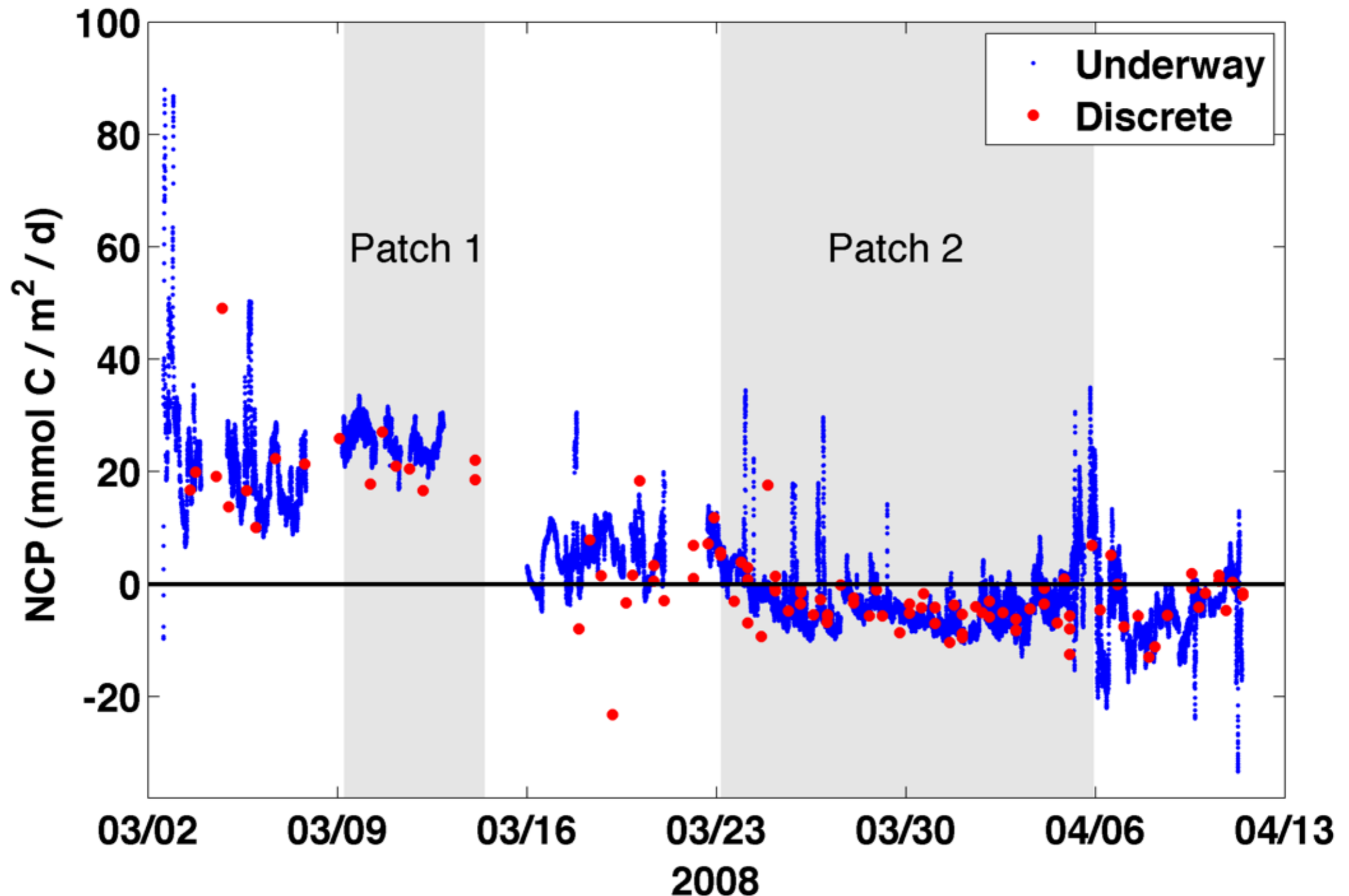


CTD/Rosette sampled showed a drop in mixed layer alkalinity during the 2nd tracer patch

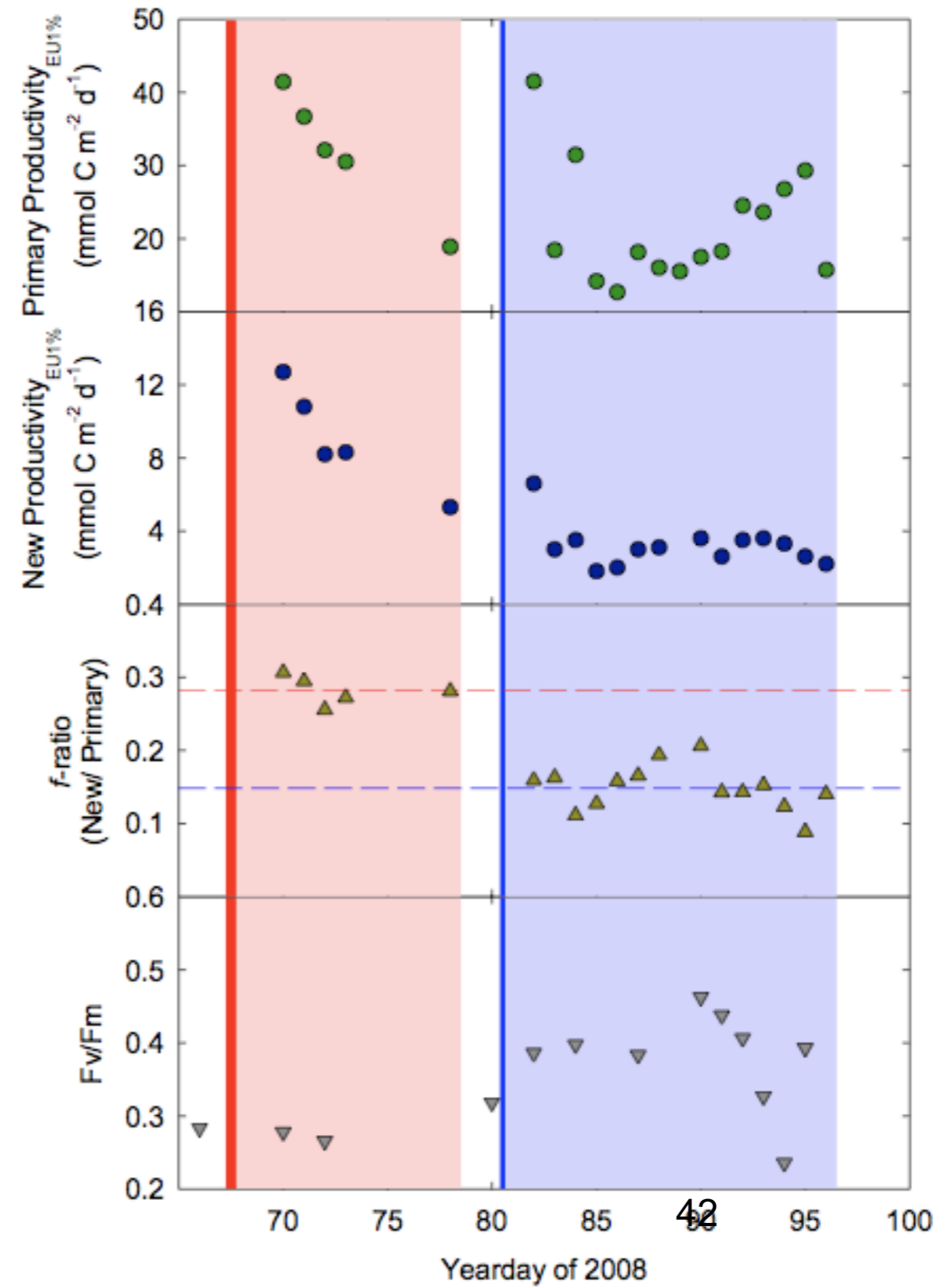
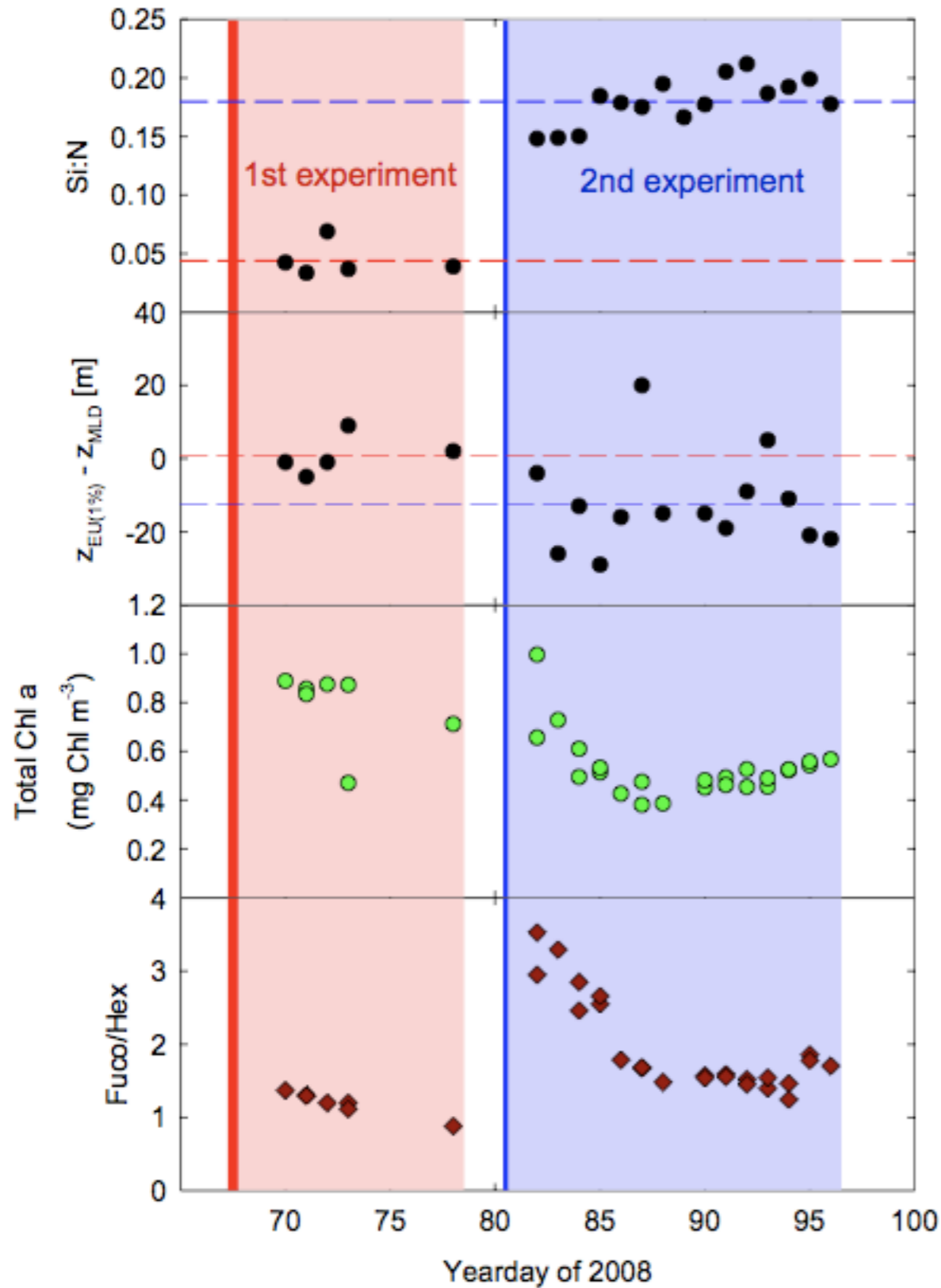


Low Net Community Production from Oxygen/Argon Mass Balance during the Southern Ocean Gas Exchange Experiment (R C Hamme, N Cassar)

Net Community Production from O_2/Ar ratios



Primary Productivity and Carbon Export During the Southern Ocean Gas Exchange (SOGasEx) Lagrangian Tracer Experiments (V P Lance, P G Strutton, J F Marra)





Summary - Gas Dynamics

- Most number of $^3\text{He}/\text{SF}_6$ samples ever taken in a gas exchange experiment.
 - More hours of eddy covariance CO_2 and DMS measurements than any other previous experiments.
 - Ancillary measurements of waves, turbulence, and bubbles.
 - Detailed carbon system (DIC, pCO_2 , TAlk), DMS, and productivity measurements.
- ✓ Results should allow us to:
- Elucidate mechanisms controlling air-sea gas exchange in the Southern Ocean;
 - Examine factors controlling CO_2 and DMS dynamics in the Lagrangian tracer patches.





To find out more...

<http://so-gasex.org>

Southern Ocean Gas Exchange Experiment

Home The Science Blog Discussion Science Team Data Media

SO GasEx » Home page

Announcements:
The SO GasEx cruise has concluded. Check out the [blog](#) for updates from the field.

Welcome to the information site for Southern Ocean GasEx...

...also known as GasEx III. The experiment took place in the Southern Ocean in austral fall of 2008 (February 29-April 12, 2008) on the **NOAA SHIP RONALD H. BROWN**. The research objectives for Southern Ocean GasEx are to answer the following questions:

- What are the gas transfer velocities at high winds?
- What is the effect of fetch on the gas transfer?
- How do other non-direct wind effects influence gas transfer?
- How do changing pCO₂ and DMS levels affect the air-sea CO₂ and DMS flux, respectively in the same locale?
- Are there better predictors of gas exchange in the Southern Ocean other than wind?
- What is the near surface horizontal and vertical variability in turbulence, pCO₂, and other relevant biochemical and physical parameters?
- How do biological processes influence pCO₂ and gas exchange?
- Do the different disparate estimates of fluxes agree, and if not why?
- With the results from Southern Ocean GasEx, can we reconcile the current discrepancy between model based CO₂ flux estimates and observation based estimates?

Site info:
This site will be continually updated as new information becomes available.

Links:
[GasEx I](#)
[GasEx II](#)
[SAGE](#)
[DOGEE-SOLAS](#)
[U.S. SOLAS](#)
[Intl. SOLAS](#)

Funding for SO GasEx is being provided by:

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