## THE SOUTHERN OCEAN AND ANTARCTIC SEA



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Photo by Cassandra

#### Global distribution of Air-Sea CO<sub>2</sub> flux



 $P_{\Delta} p \in \mathcal{O}_2^s \Delta p C O_2$ 

$$k = k (U_{10n}, \ldots)$$

Takahashi et al.

#### k vs U



## Global air-sea CO<sub>2</sub> flux



Cubic 60% greater uptake than quadratic
Impact is larger in high latitudes Wanninkhof and McGillis

## Question 1

# What is the dependence of k on wind speed in open water?

### Question 2

# What is the effect of sea ice on gas exchange?

## Eddy Covariance Methods $F_c = \overline{\rho_a} \, \overline{w'c'} = k \, s \, \Delta p \, CO_2$ Takahashi

Mast CSAT3 sonic anemometers Motion sensors sample air inlet Bosun's Locker LI-7200 (dried airstream) Pump, compressor, etc.

Raw data – 20 Hz Tux averages – 10 minutes







#### Cameras



- Port and starboard cameras
- 1 image/ sec
- Roughly 2.5 million/ per

#### Sea Ice Concentration (SIC)











#### Hall et al. (2002)

#### Open water and sea ice zone



#### Gas transfer velocity (open water)



#### Gas transfer velocity (open water)



 $k_{open} = 0.245 \ U_{10n}{}^2 + 1.3$ 

#### Air-sea-ice gas exchange model

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#### A parameter model of gas exchange for the seasonal sea ice zone

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#### Air-sea-ice gas exchange model



#### Requires: U, SST, T<sub>air</sub>, ice speed, salinity, sea ice concentration

Loose et al. (2014)

#### Gas transfer velocity (sea ice zone)



## ? $k_{eff} / k_{open} = fraction of open water$



## Evaluation of air-sea-ice gas exchange model



#### Evaluating the Loose et al. (2014) model (open water limit)



#### Evaluating the Loose et al. (2014) model (open water limit)



## Conclusions

- First unattended eddy covariance CO<sub>2</sub> fluxes in Southern Ocean and Antarctic sea ice zone
- Quadratic dependence of open ocean gas transfer velocity on wind speed
- Gas exchange in sea ice zone proportional to fraction of open water

## Papers

- Butterworth, B. J., and S. D. Miller, 2016: Air-sea exchange of carbon dioxide in the Southern Ocean and Antarctic marginal ice zone. Geophys. Res. Lett., 43, 7223–7230.
- Butterworth, B. J., and S. D. Miller, 2016: Automated underway eddy covariance system for air-sea momentum, heat, and CO2 fluxes in the Southern Ocean. J. Atmos. Ocean. Technol., 33, 635–652.
- Supplemental Information Geophysical Research Letters
- Marine Geosciences Data System
   www.marine-geo.org (NBP-1210, NBP-1402)

## Future Work



- Icebreaker-based (CCGS Amundsen) flux station
- 4 months of planned cruises next spring/summer





- Island flux station near Cambridge Bay, Nunavut
- Continuous through ice break-up/freeze-up starting next spring

## Thank You.

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