Southern Ocean Storms - Zephyr

Joellen L. Russell[1], David G. Long[2], Nicole Lovenduski[3], Ernesto Rodriguez[4]

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ABSTRACT/BACKGROUND

Strong winds associated with Southern Ocean storms drive large air-sea fluxes of carbon and heat. These fluxes are an integral part of the global climate system. The speed of these winds is increasing. We demonstrate that the current scatterometer constellation, used to measure winds remotely, undersamples the wind speed and surface fluxes in the Southern Ocean, leading to systematic biases of unknown size in global flux budgets. We propose a carefully planned addition to the scatterometer constellation to increase the frequency of observations and better constrain high winds. More observations, in conjunction with higher spatial resolution, will reduce the uncertainty in estimates of the global carbon and heat budgets.

METHODS

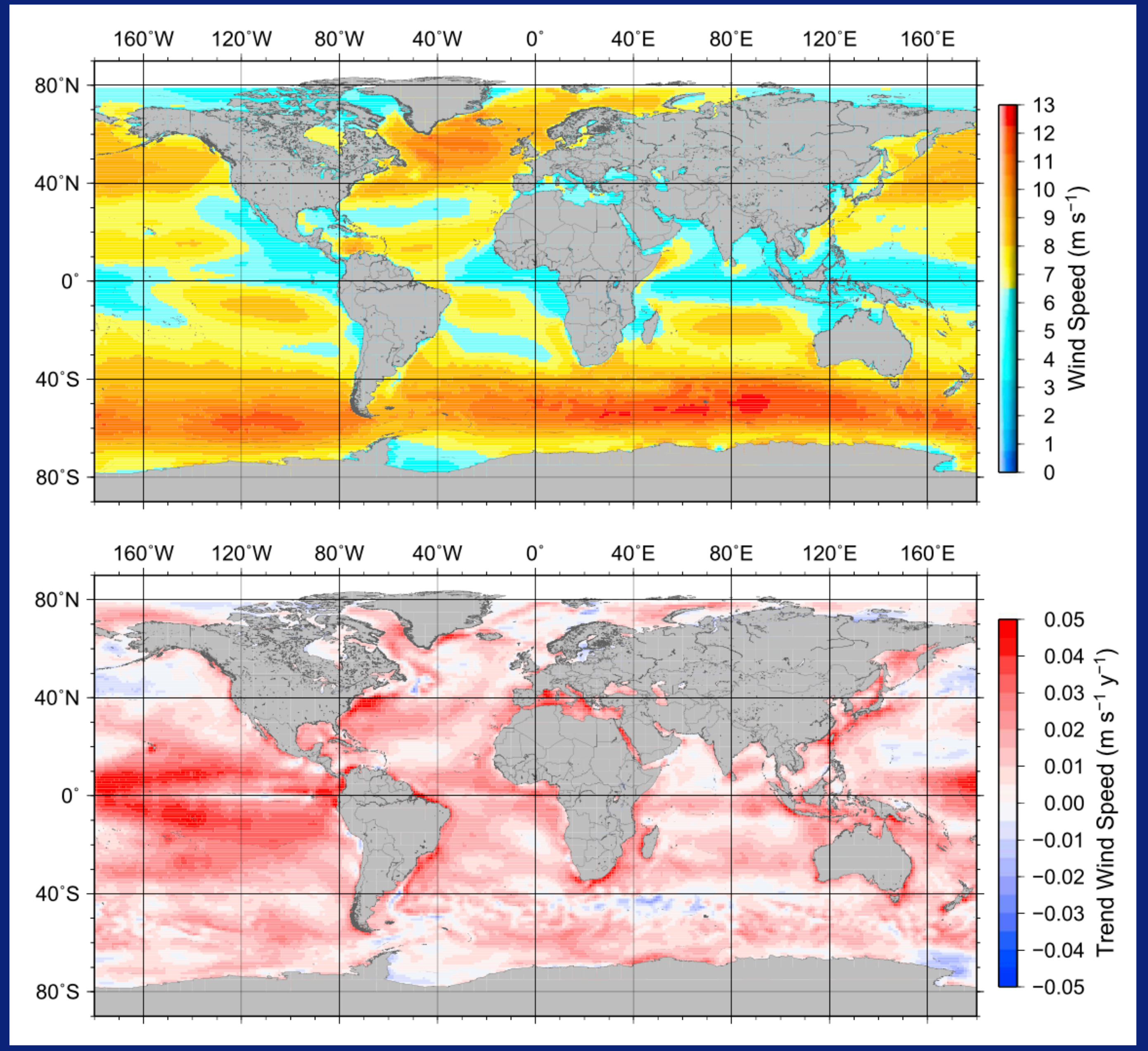
We assess how often per day and at what spatial resolution the existing wind observing constellation measures Southern Ocean winds.

Evidence from altimeters, the strength of Southern Ocean mesocyclones and wave power indicate that wind speeds and wind stresses over the Southern Ocean are increasing

We employ the Biogeochemical Southern Ocean State Estimate (BSOSE, Verdy & Mazloff, 2017), a coupled ocean, sea ice, biogeochemical model to assess the carbon fluxes consistent with the observed winds. We also use BSOSE to assess the fluxes consistent with 20% stronger winds.

Increasing Winds

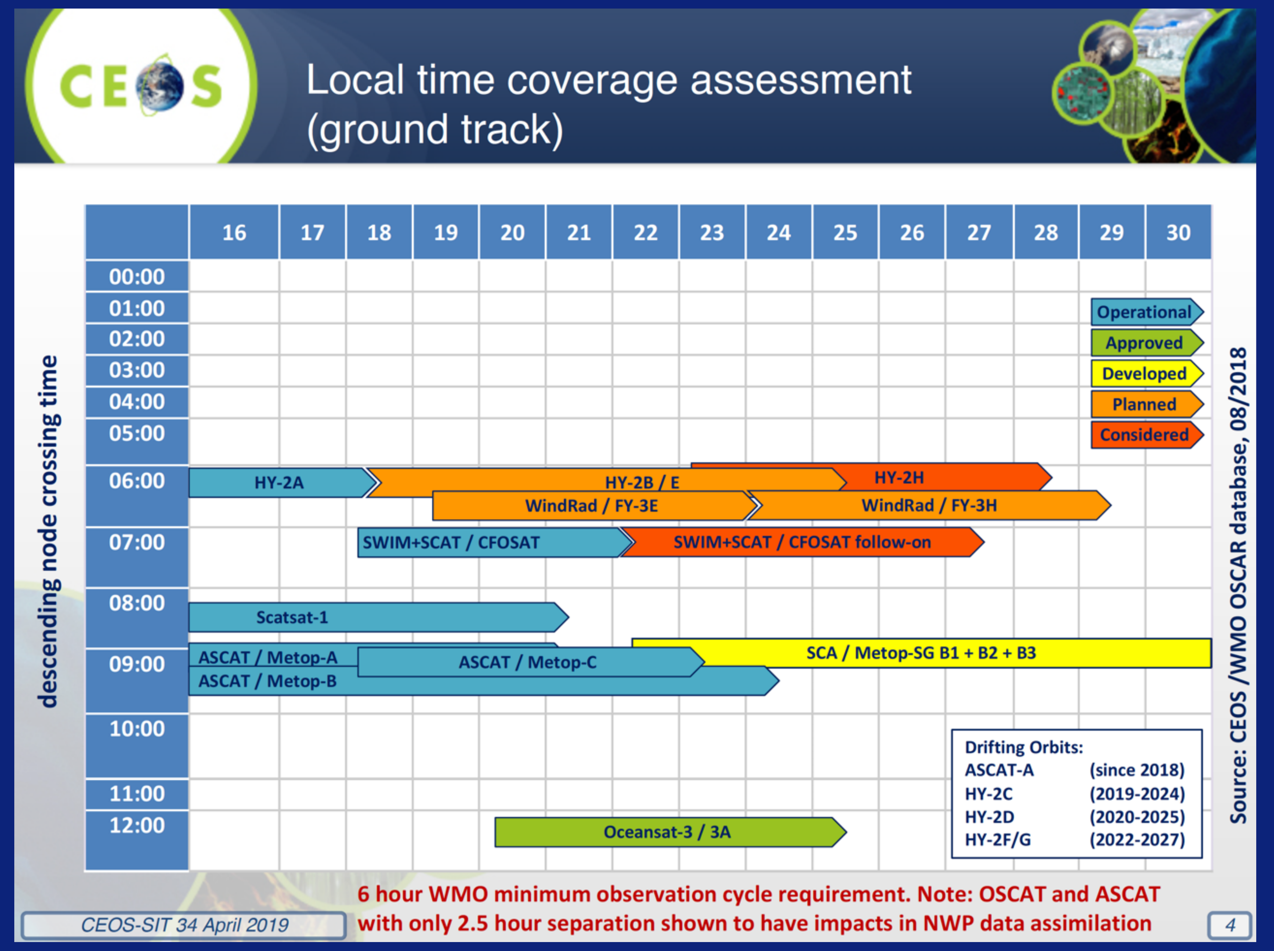
The Southern Ocean plays a significant role in the Earth's carbon budget, but its remoteness and isolation make it difficult to monitor changes, and its unique geography and circulation make it highly susceptible to global climate change, with resulting poorly understood feedbacks. We have observed that mid-latitude westerly winds are strengthening and slowly shifting poleward by several latitudinal degrees (Toggweiler and Russell 2008; Thompson et al. 2011). As these westerlies align with the Drake Passage, wind-driven divergence taps further into the deep ocean (>2000m), enhancing carbon and heat exchange between the deep ocean and atmosphere (Russell et al. 2006; Toggweiler et al. 2006).



Scatterometer Winds

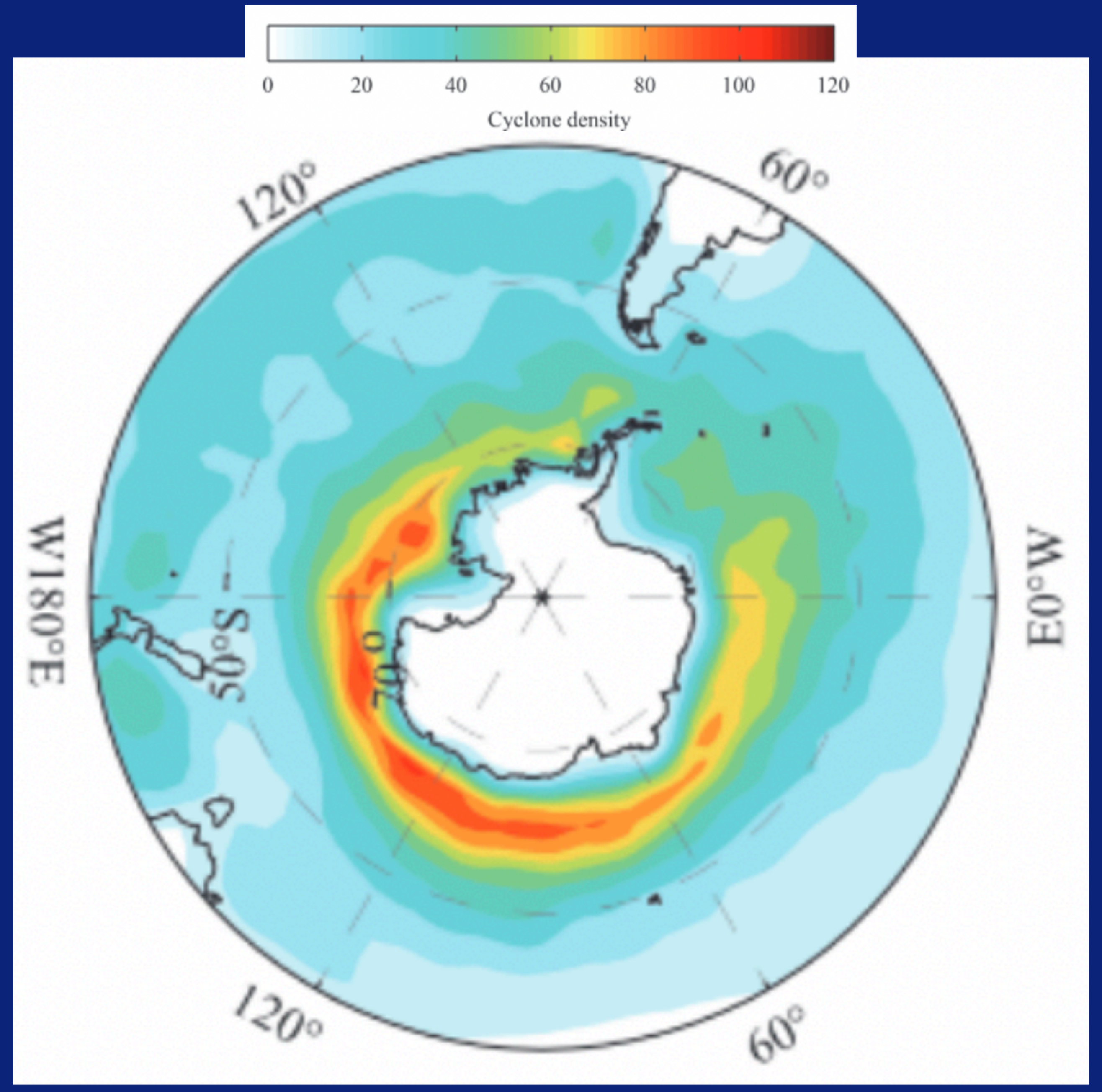
The ASCAT scatterometers are sun-synchronous, in a tandem orbit. This configuration dictates that successive swaths do not overlap each other except at very high latitudes; in effect, they cover a wider area (~3100km side-to-side, with two 725 km gaps in the middle), but only produce one "independent" observation per hour at each location and are therefore little different from a single satellite with respect to assessment of the carbon cycle. The constellation returns to most locations every 12 hours or longer.

The size and timing of the SOS-Zephyr ground track will decrease the average time between return visits to less than 6 hours south of 65°S (4 per day at most longitudes) and less than 8 hours south of about 50°S (3 or more per day). The orbital node is at 90° from the existing constellation.



Southern Ocean Storms

The World Meteorological Organization (WMO) recognizes the need for global wind sampling every 6 hours at a minimum (4 times per day) and preferably every 3 hours for ocean and climate applications; which is not achieved by the existing scatterometer constellation. This undersampling is acute in the Southern Ocean where fast-moving storms drive an increase in carbon exchange. These storms are frequent but infrequently sampled (usually only 1-2 times per day at any location), limiting independent assessment of model-based wind reanalyses. The derived carbon flux is very sensitive to the imposed wind speed and a small negative bias could affect the sign of the net carbon flux over the Southern Ocean.



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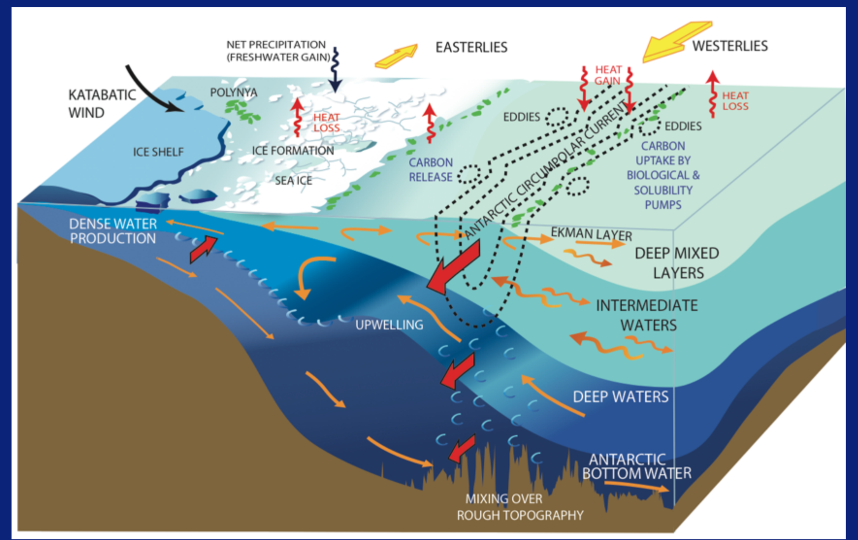
What is the role of the Southern Ocean in the global climate system?

1
It accounts for 67-98% of the excess heat that is transferred from the atmosphere into the ocean yearly.

2
It accounts for up to half of the annual oceanic uptake of anthropogenic carbon dioxide from the atmosphere.

3
Vertical exchange in the Southern Ocean is responsible for supplying nutrients that fertilize three-quarters of the biological production in the global ocean north of 30°S.

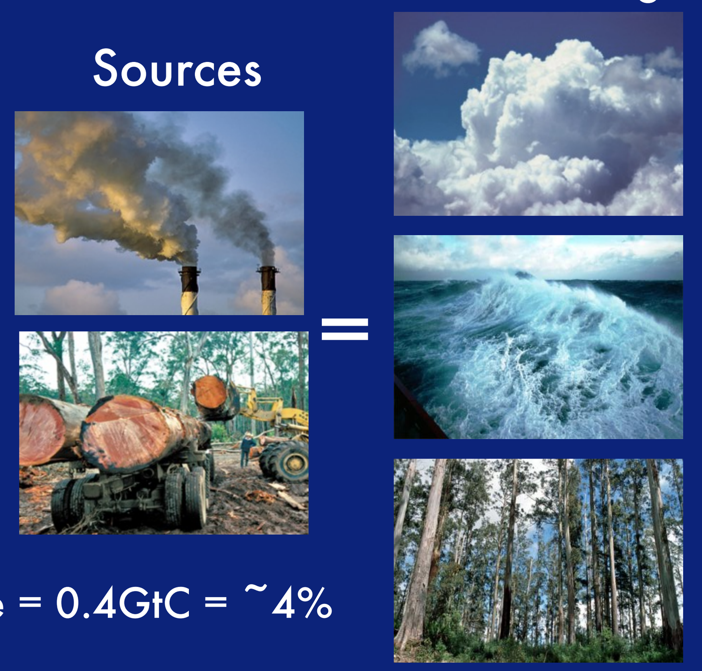
Why is the Southern Ocean so important?



"Window to the deep ocean"

Southern Ocean is the only place where there is direct upwelling from very deep waters to the sea surface over a very large region

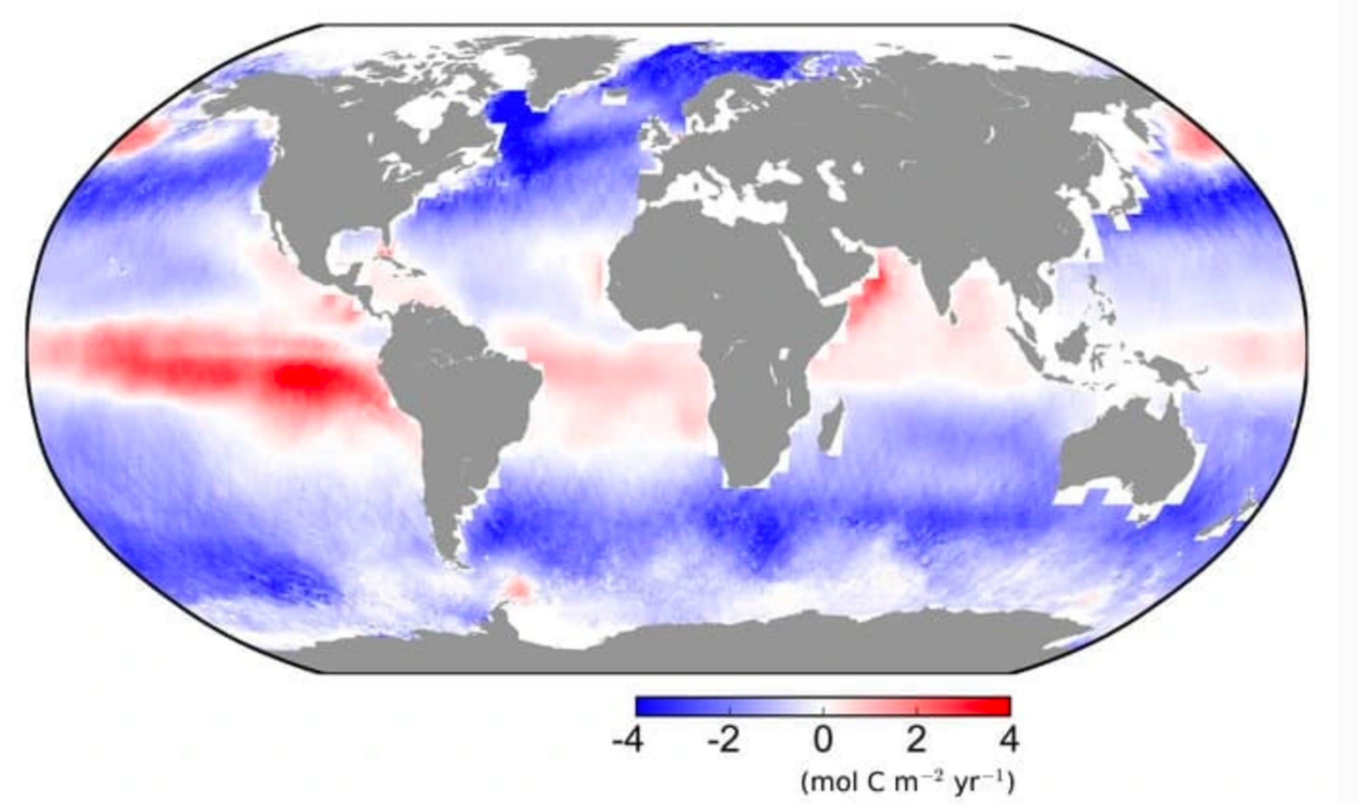
Fate of Anthropogenic CO_2 Emissions (2009-2018 average)



Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Friedlingstein et al 2019; Global Carbon Budget 2019

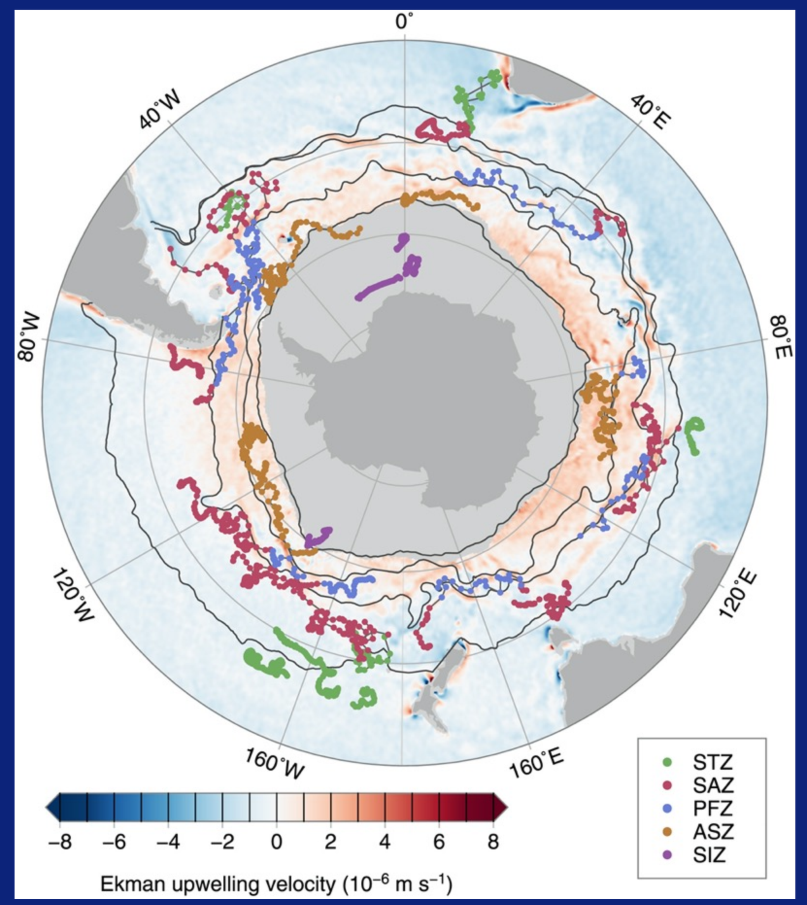
Air-Sea Carbon Flux

(annual, mol/m2/yr)



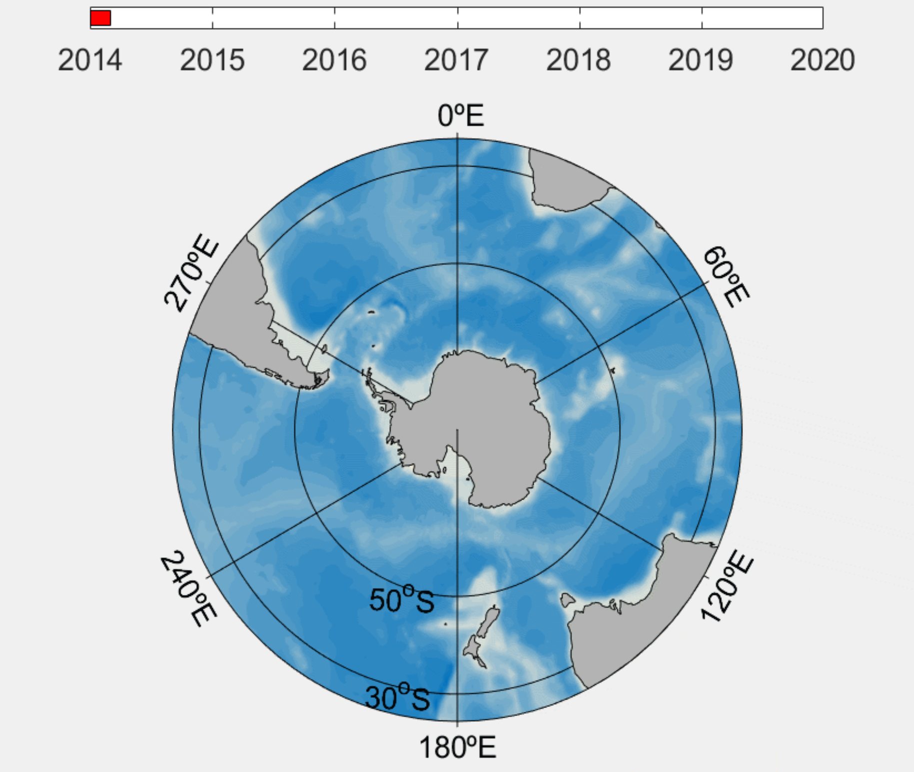
Annual-mean carbon flux: blue is into the ocean and red is out of the ocean. The Southern Ocean takes up a significant fraction of the global total

Annual mean upwelling velocity



Wind-induced upwelling velocity calculated from the scatterometer climatology, along with several float tracks (from Gray et al. 2018). Upwelliing coincides with outgassing to the atmosphere.

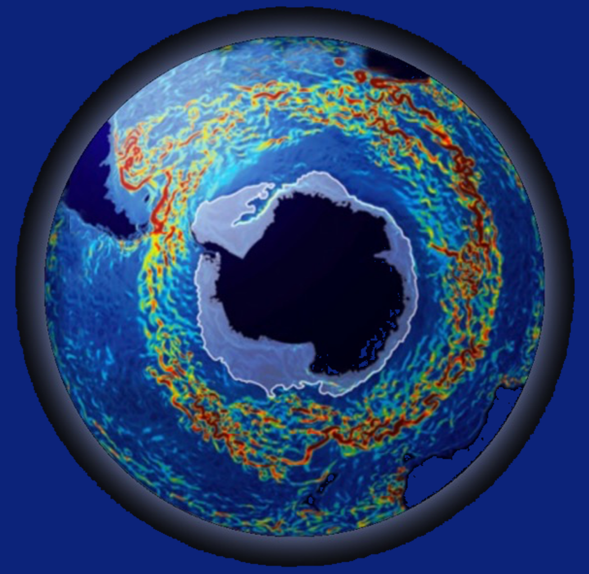
Biogeochemically-Sensored Float Array



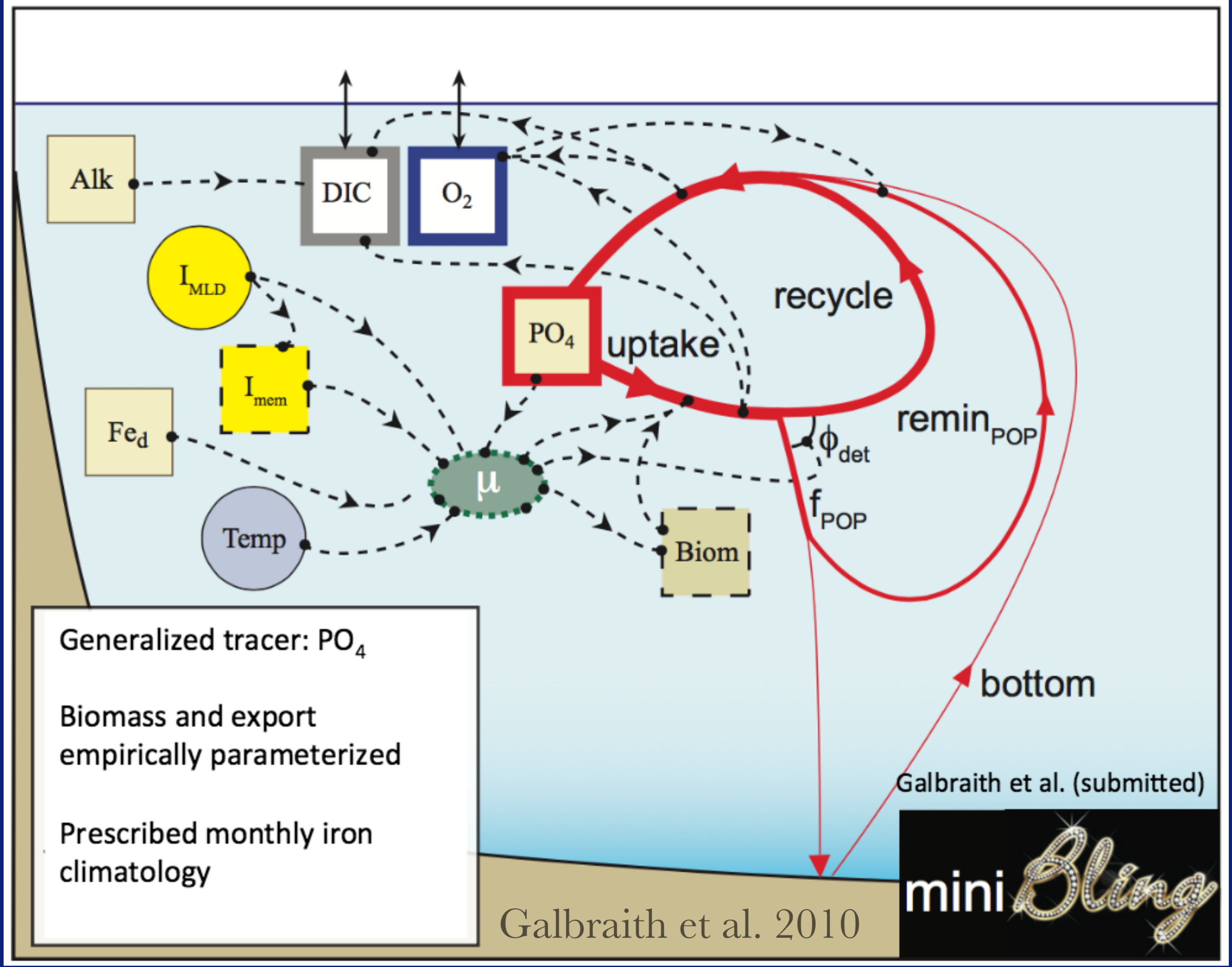
BGC-Argo floats deployed by the SOCCOM initiative measure temperature, salinity, pH, oxygen, nitrate and other carbon system parameters

The Biogeochemical Southern Ocean State Estimate (BSOSE)

A modern general circulation model, the MITgcm, is a least squares fit to all available ocean observations.
Nominal Resolution is 1/6°
(Verdy and Mazloff, 2017)



Mini-BLING (reduced Biology Light Iron Nutrient and Gas model



BSOSE incorporates mini-BLING, a reduced biogeochemical module in order to determine the state of the carbon system consistent with the assimilated observations

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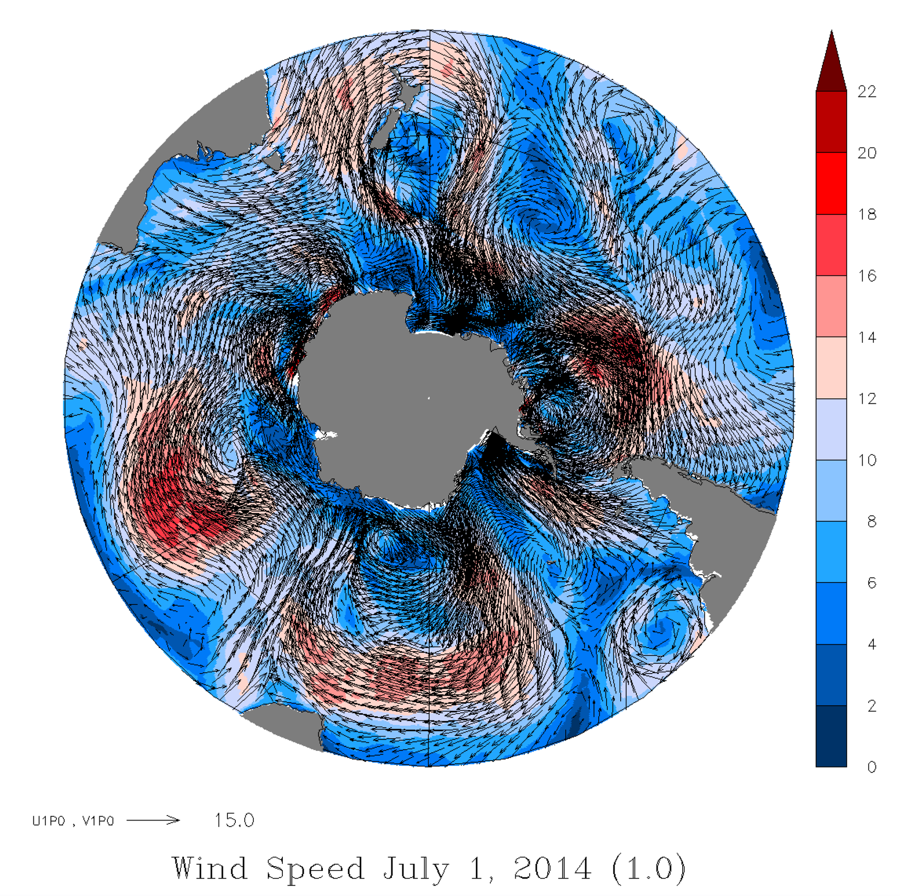
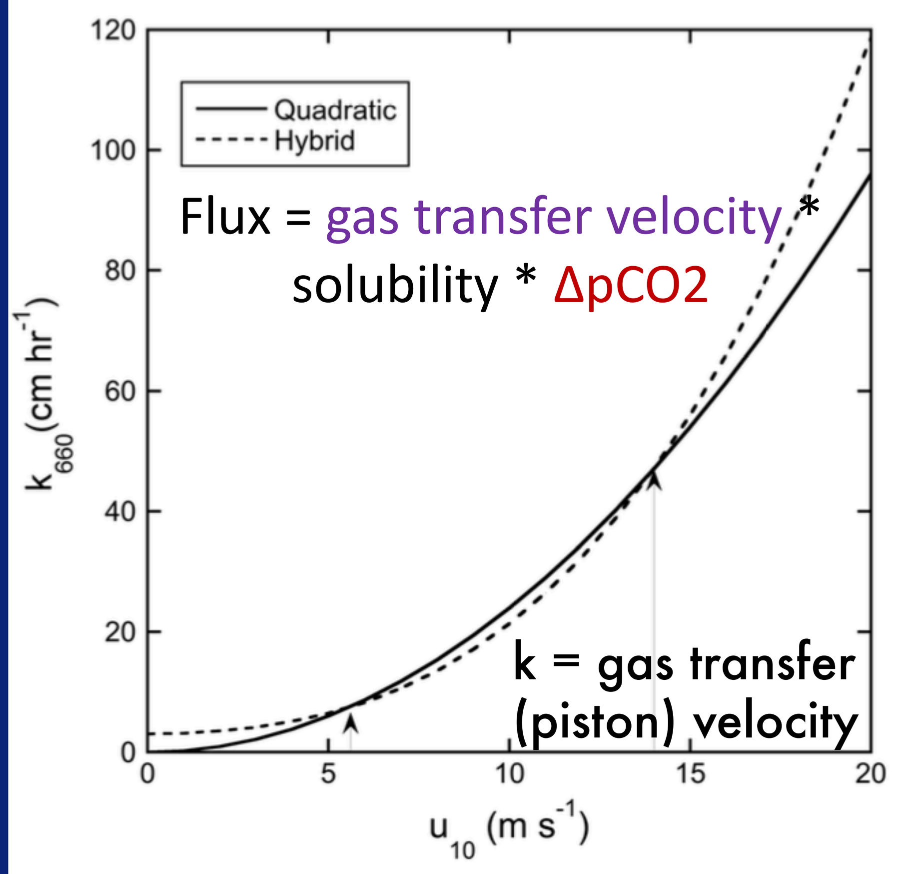
Surface Winds and Wind Speed



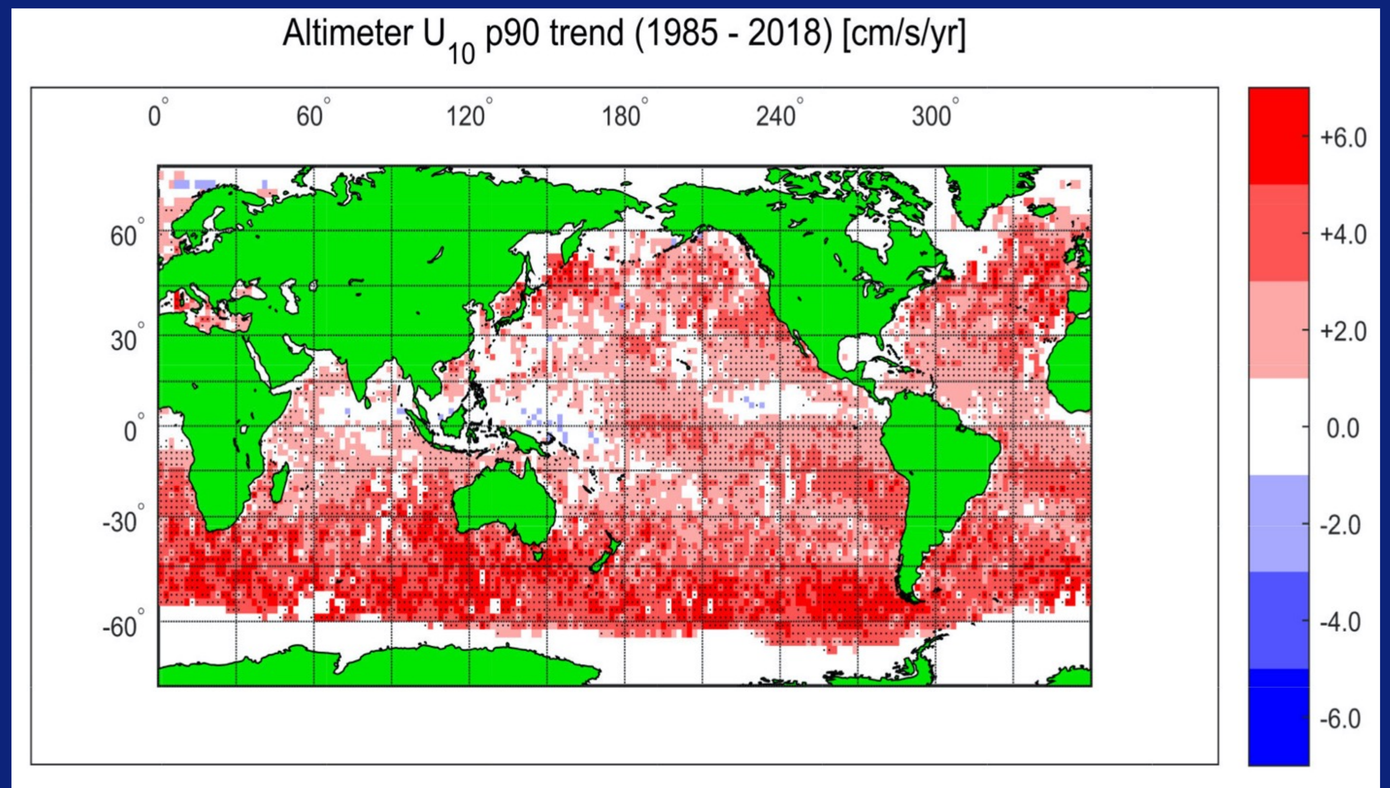
Hourly wind data from ERA5 is assimilated into BSOSE. These are the average winds on July 1, 2014. Several large mesocyclones (storms) are visible.

Gas exchange vs wind speed



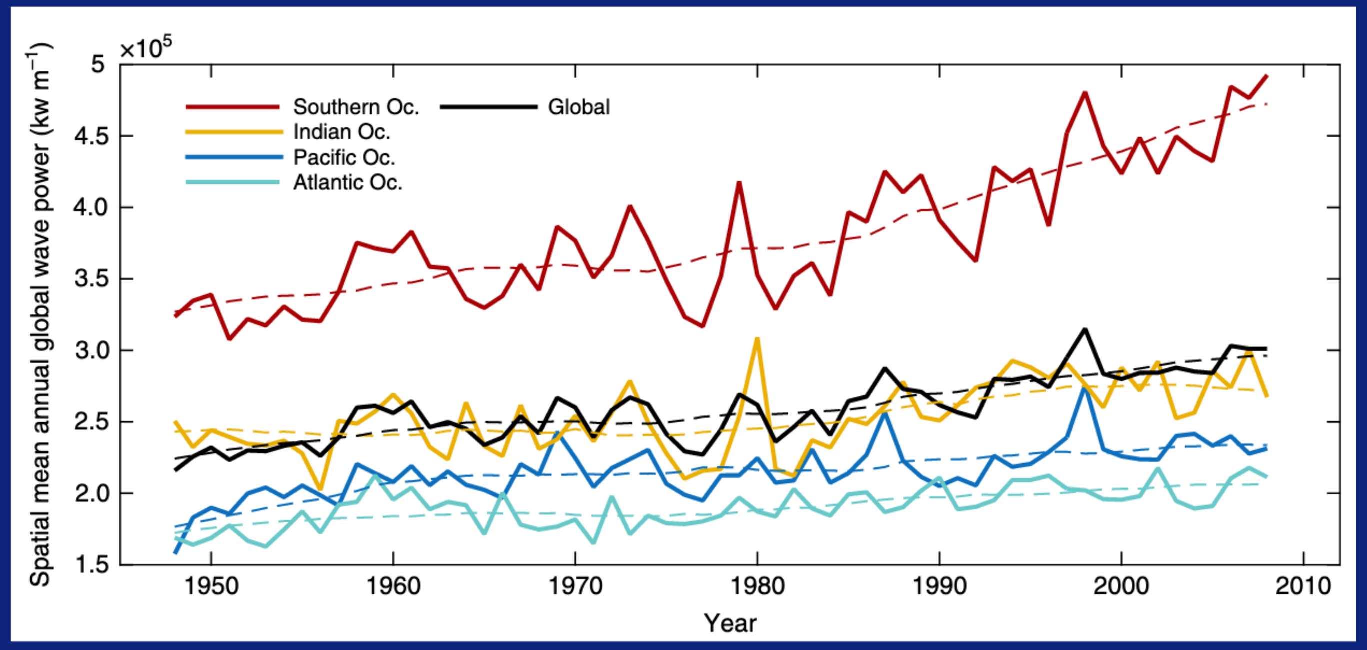
The rate of exchange of gases across the air-sea interface is a non-linear function of the wind speed. (from Wanninkhof & Triñanes, 2017)

Upward Trend in the Speed of the Fastest Winds



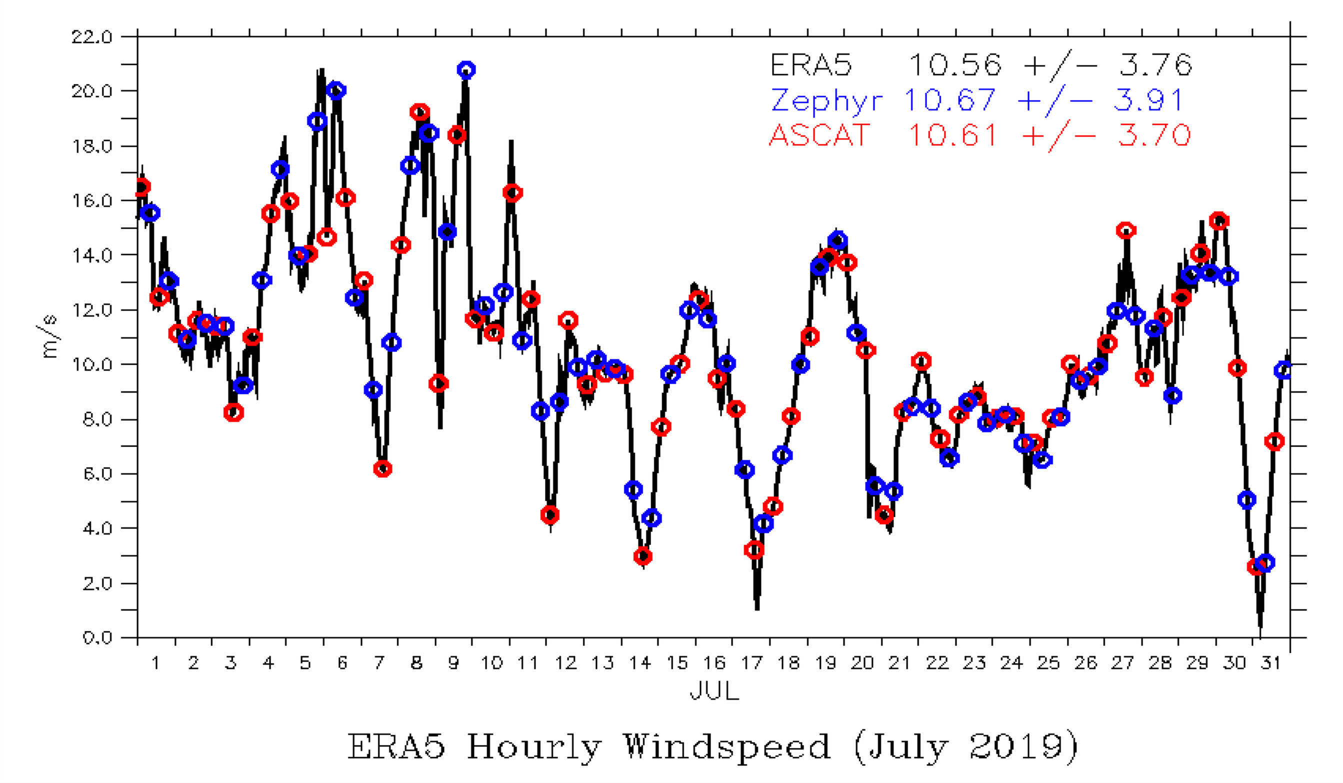
Altimeter data indicate that wind speeds in the 90th percentile in the SO are increasing there at the fastest rate (from Young & Ribal, 2019)

Wave Power in the SO is Increasing



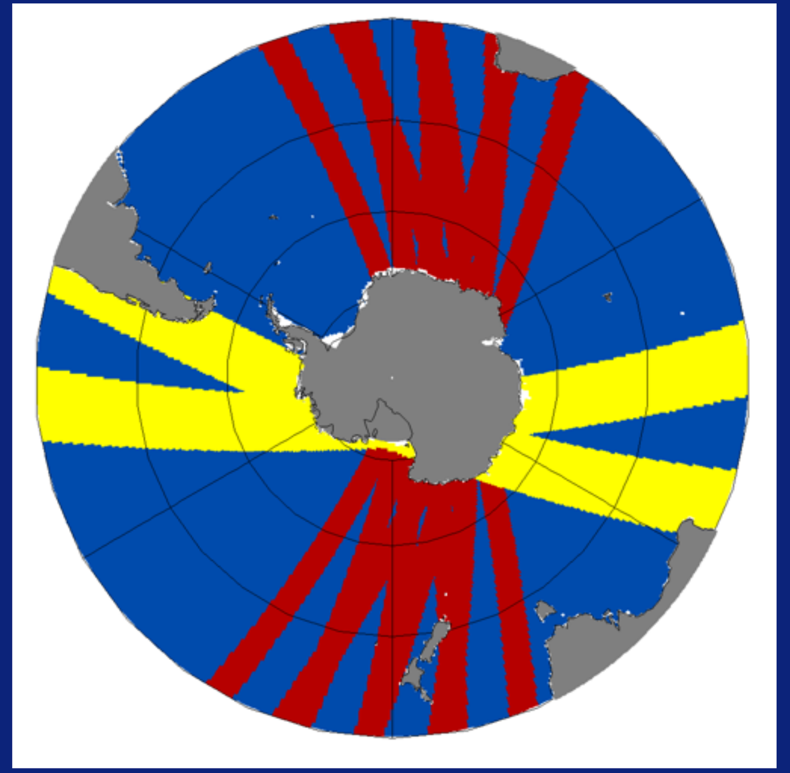
Ocean waves get their energy from the wind, and the total power of the waves in the SO are increasing faster than everywhere else. (from Reguero et al. 2019)

Winds are sampled infrequently



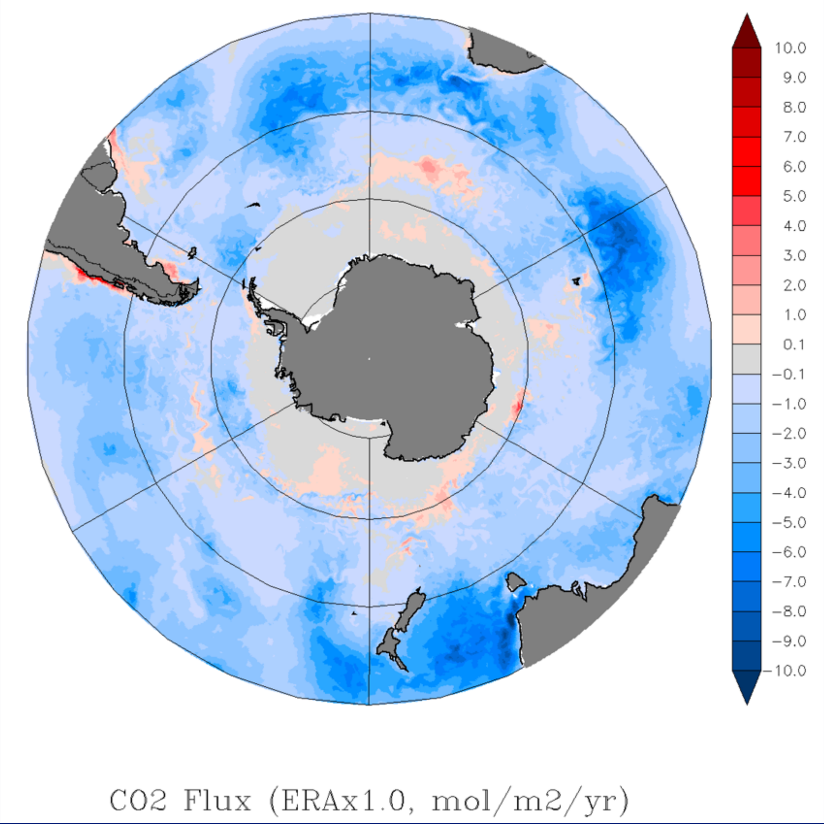
The data show the hourly wind speed at a typical point in the SO from ERA5. The red circles indicate hours where this location is observed by either of the ASCAT satellites and are ~12 hours apart. The blue circles indicate hours when this location is observed by SOS-Zephyr.

Ground Swaths "Seen"

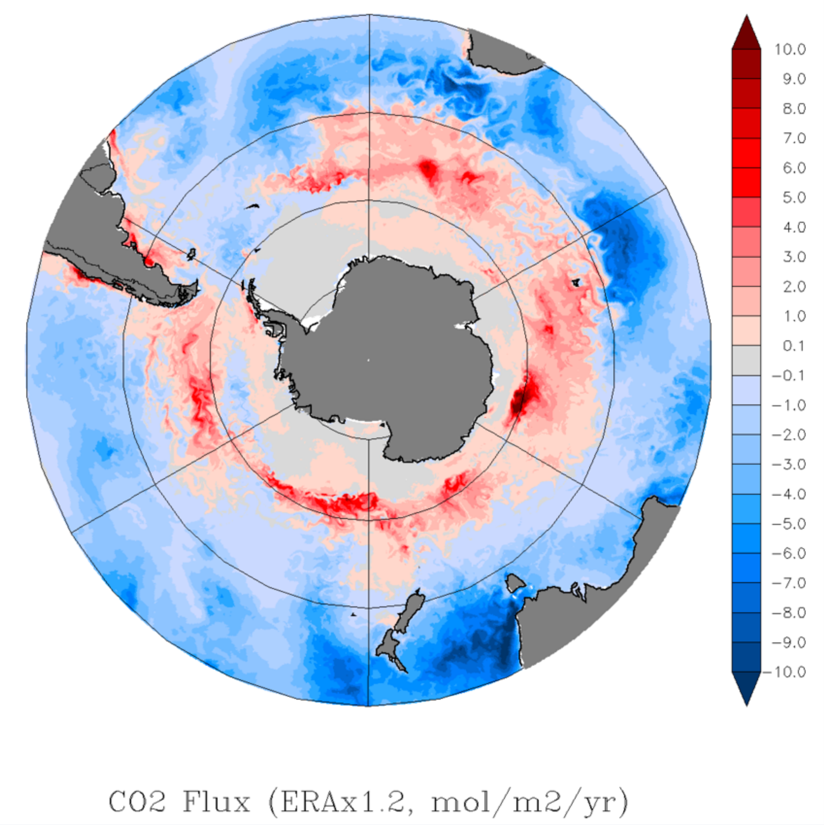


Locations of ground swaths during a "typical" 3-hour period (3-6am GMT) for ASCAT-2 and ASCAT-3 (red) and Zephyr (yellow). Note the separation in space that provides the ~6-hour separation in time.

Carbon Flux for July 2014 under standard winds (ERA5x1.0)



Carbon Flux for July 2014 under enhanced winds (ERA5x1.2)



The surface flux of carbon consistent with standard winds has a net uptake of 0.179 PgC, Increased winds under the SO storms enhance the outgassing in the ASZ and reduce the net uptake by ~60% to 0.107 PgC consistent with the evidence from the BGC-Argo floats (Gray et al. 2018)

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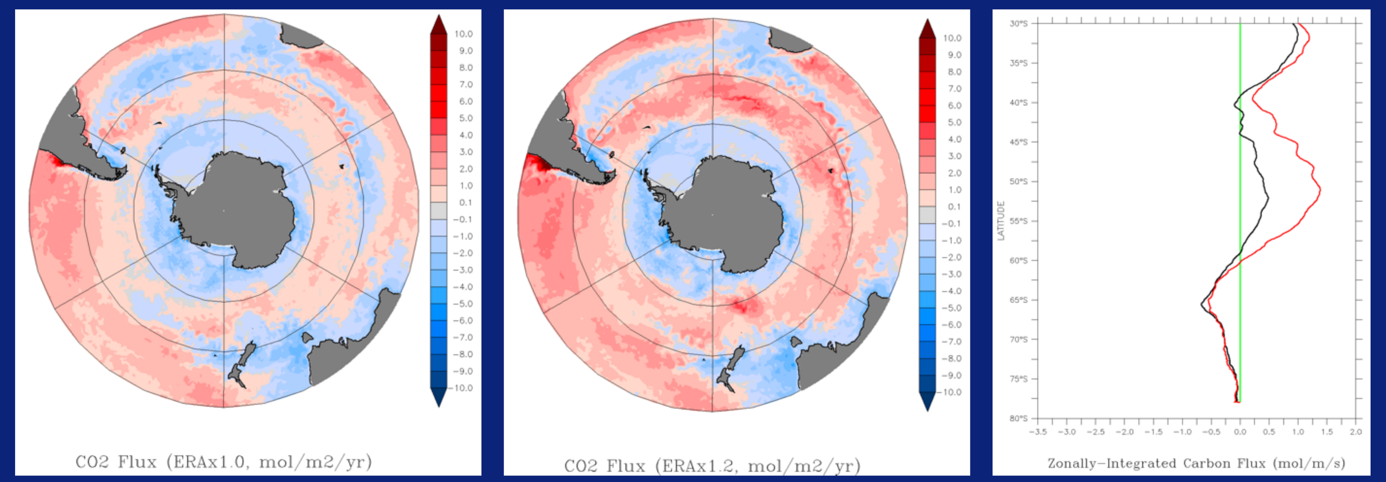
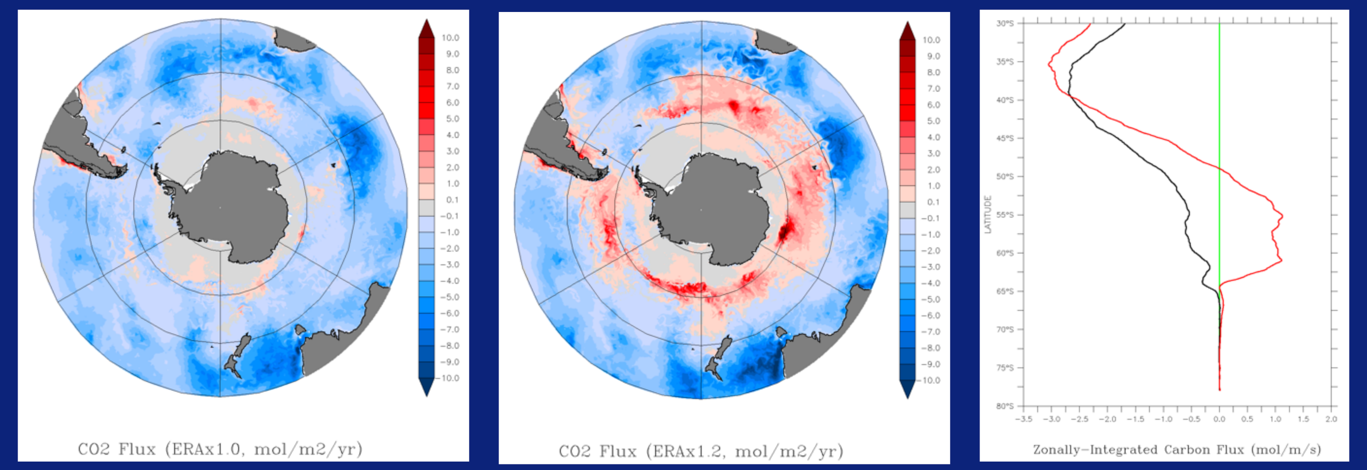
Carbon Fluxes (Summer – January)



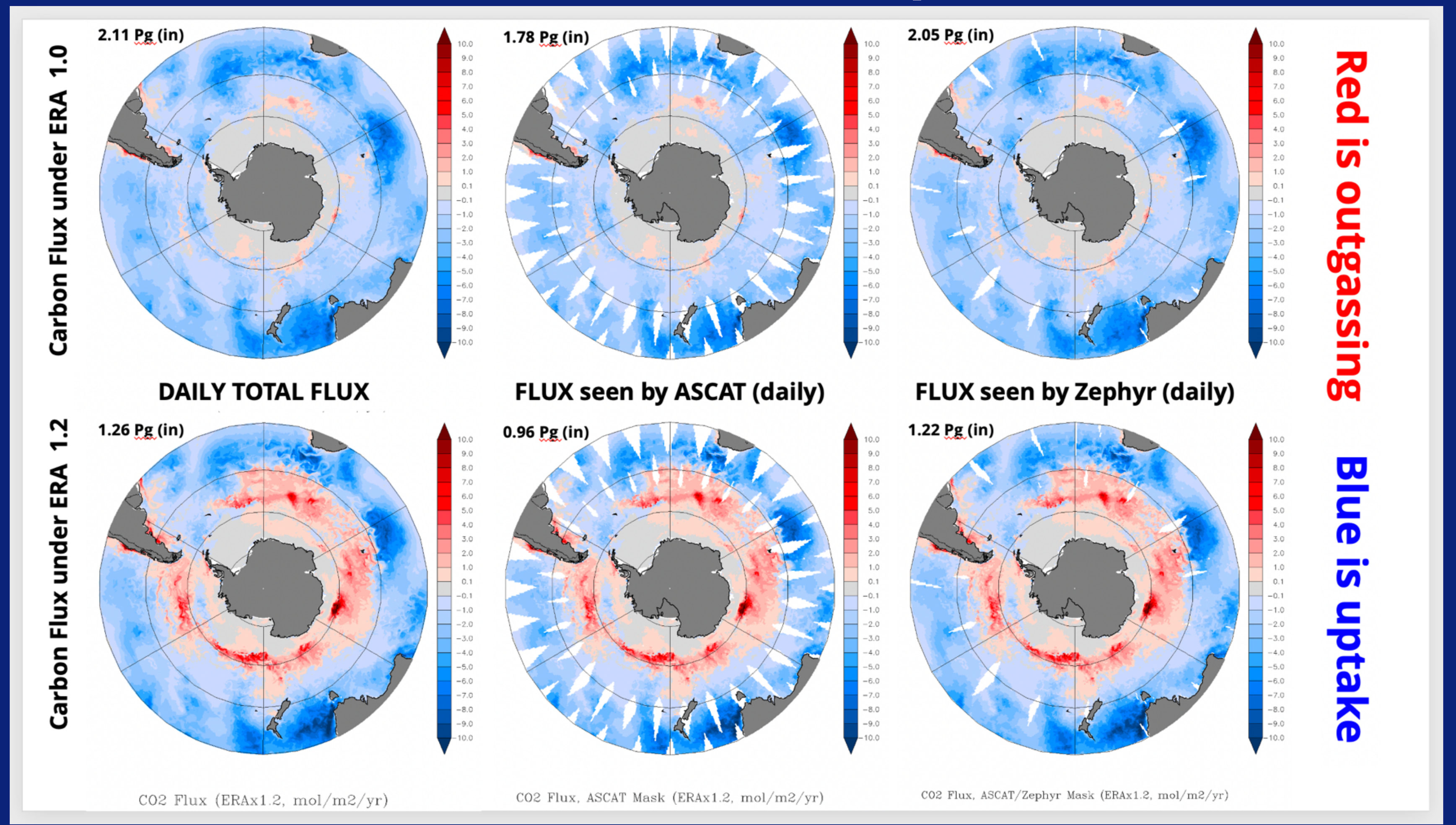
Positive flux (red) is out of the ocean. During summer where there is little sea ice, the coastal region of Antarctica is a moderate uptake region, while most of the SO is outgassing, due to decreased solubility as the surface warms. When the winds are increased (middle), the mixed layer depth and the rate of outgassing increase (right).

Carbon Fluxes (Winter – July)



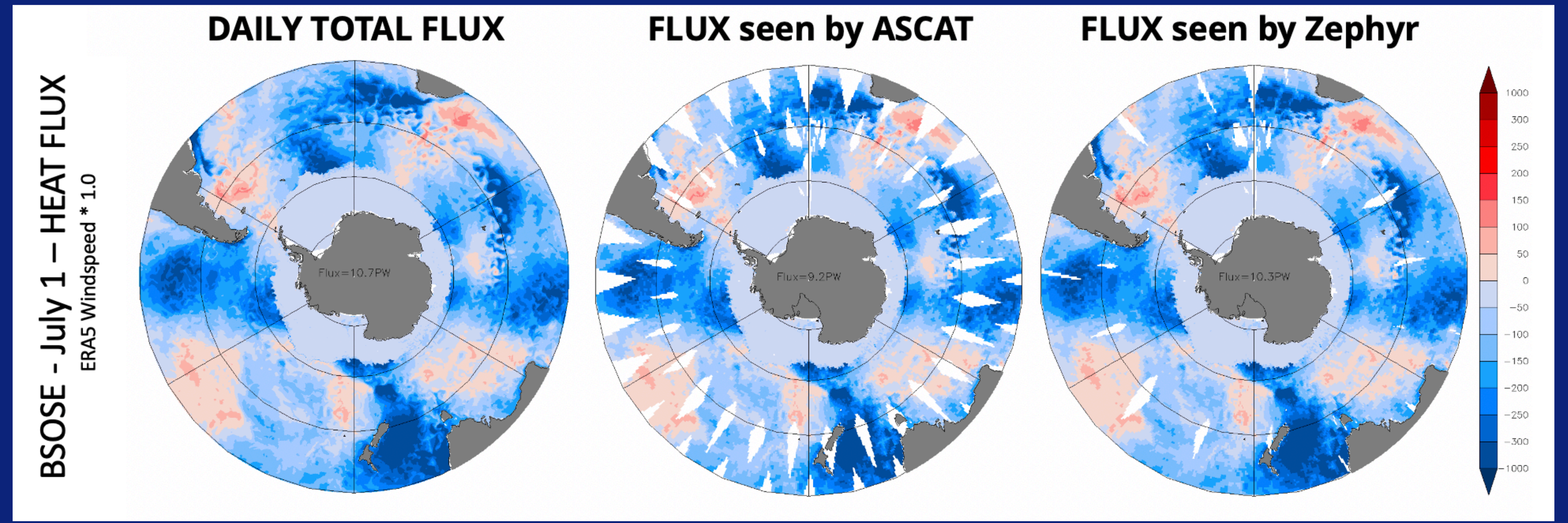
During winter, increased solubility as the surface cools causes most of the SO to take up carbon (left). Increased winds (center), however, cause greater divergence leading to a significant increase in the outgassing, especially at the edge of the sea ice zone. This causes the latitudes of Drake Passage to change from a net uptake region (black, right) into a net outgassing region (red, right).

Carbon Flux Capture



BSOSE (July 1, 2014) simulates a net monthly uptake of 0.179 PgC under the standard winds: the ASCAT constellation captures 84% of this, but the addition of SOS-Zephyr increases the capture rate to 97%. Under higher winds, ASCAT only "sees" 76% of the carbon flux, while SOS-Zephyr brings that back up to 97%.

Heat Flux Capture



The heat flux from BSOSE (July 1, 2014) is out of the ocean (cooling) and ASCAT captures 86% of the flux, while SOS-Zephyr captures 96%. Increased winds (not shown) slightly increase the magnitude of the local flux, but don't change the sine anywhere.

Conclusions

- Southern Ocean winds are the strongest surface winds on Earth, but are distinctly heterogeneous in both space and time due to the presence of long-lasting (~3-5 day) but fast-moving storms. These winds stir the surface ocean and drive strong carbon and heat fluxes between the atmosphere and ocean, especially in winter.
- Our current wind observing system for the Southern Ocean samples these storms infrequently, only once or twice per day, and is unlikely to directly observe the highest winds and variability.
- We need to know if our wind "data" from the reanalyses are reliable.
- A constellation of spacecraft is required to validate the wind speed range and variability provided by our reanalyses and to thereby reduce the uncertainty in our carbon flux calculations.
- Increasing the number of wind observations over the SO to better capture the high winds in SO storms from less than 2 per day to 4 per day will be transformative.
- SOS-Zephyr will reduce uncertainty in the global carbon budget by focusing on the Southern Ocean where quantifying air-sea exchange of carbon has the greatest impact on reducing uncertainty.
- Evidence from BGC-Argo biogeochemical floats are consistent with our enhanced wind experiment that the SO just north of the sea ice zone is likely a source of carbon in winter, rather than a sink. This could indicate a weakness in our current reanalysis winds

References

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Acknowledgments

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