University of East Anglia

2022, 8th GTWS symposium

PML Plymouth Marine Laboratory

Near-surface stratification for the Arctic and the temperature effects for the global air-sea CO_2 flux estimates

Yuanxu Dong[1,2], Mingxi Yang[2], Dorothee Bakker[1], Peter Liss[1], and Tom Bell[2]

[1]University of East Anglia, [2]Plymouth Marine Laboratory

Changing Arctic Ocean NERC

esa

CHINA SCHOLARSHIP COUNCIL

Contents

Session 1: Shallow stratification in the Arctic Ocean

- Sea-ice melt generates shallow stratifications
- Bias the Arctic Ocean CO_2 flux estimates

Session 2: Temperature effects for global ocean CO_2 flux estimates

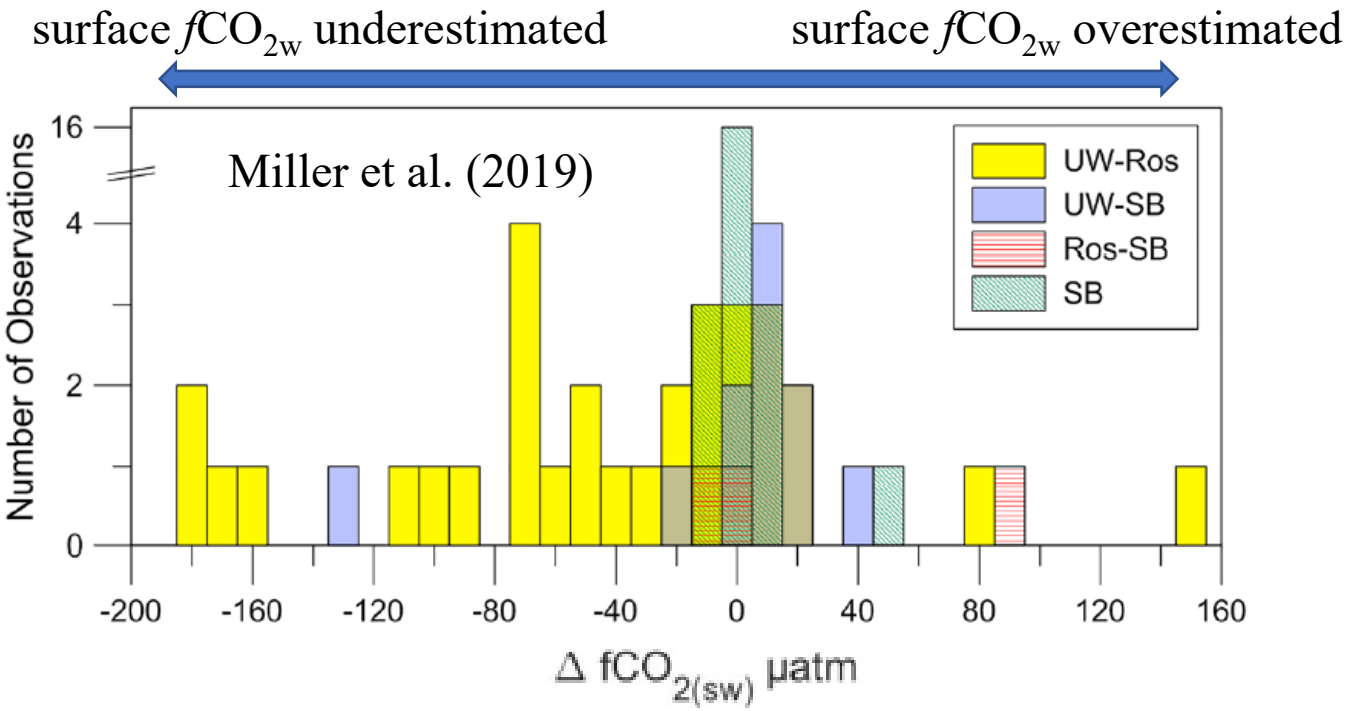
- Re-visit the warm bias in SOCAT SST?
- Re-visit the cool skin effect?

Shallow stratification in the Arctic Ocean

Why the shallow stratification matters

Indirect bulk flux:

$$F_{CO2} = K\,\alpha\,(fCO_{2w} - fCO_{2a})$$



Affected by the stratification issue

Direct flux by eddy covariance

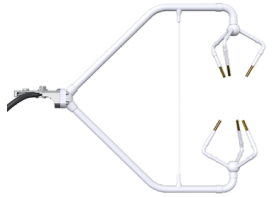
$$F_{CO2} = \rho\overline{c'w'}$$

Not affected by the stratification issue

Setup of ship-based eddy covariance (EC) system

Instruments

$$F_{CO2} = \rho \overline{c'w'}$$

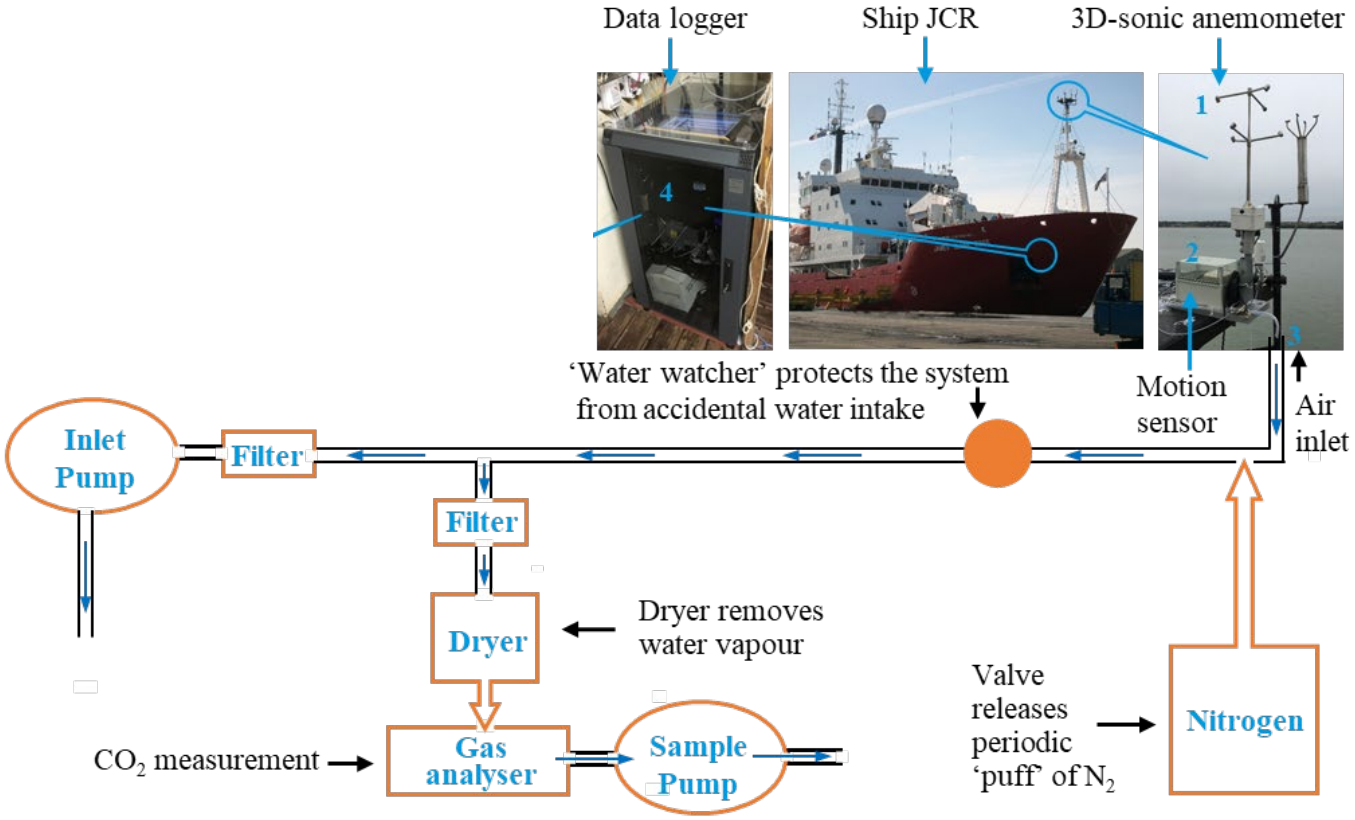
w'  + 

Sonic anemometer — Motion sensor

c'  + 

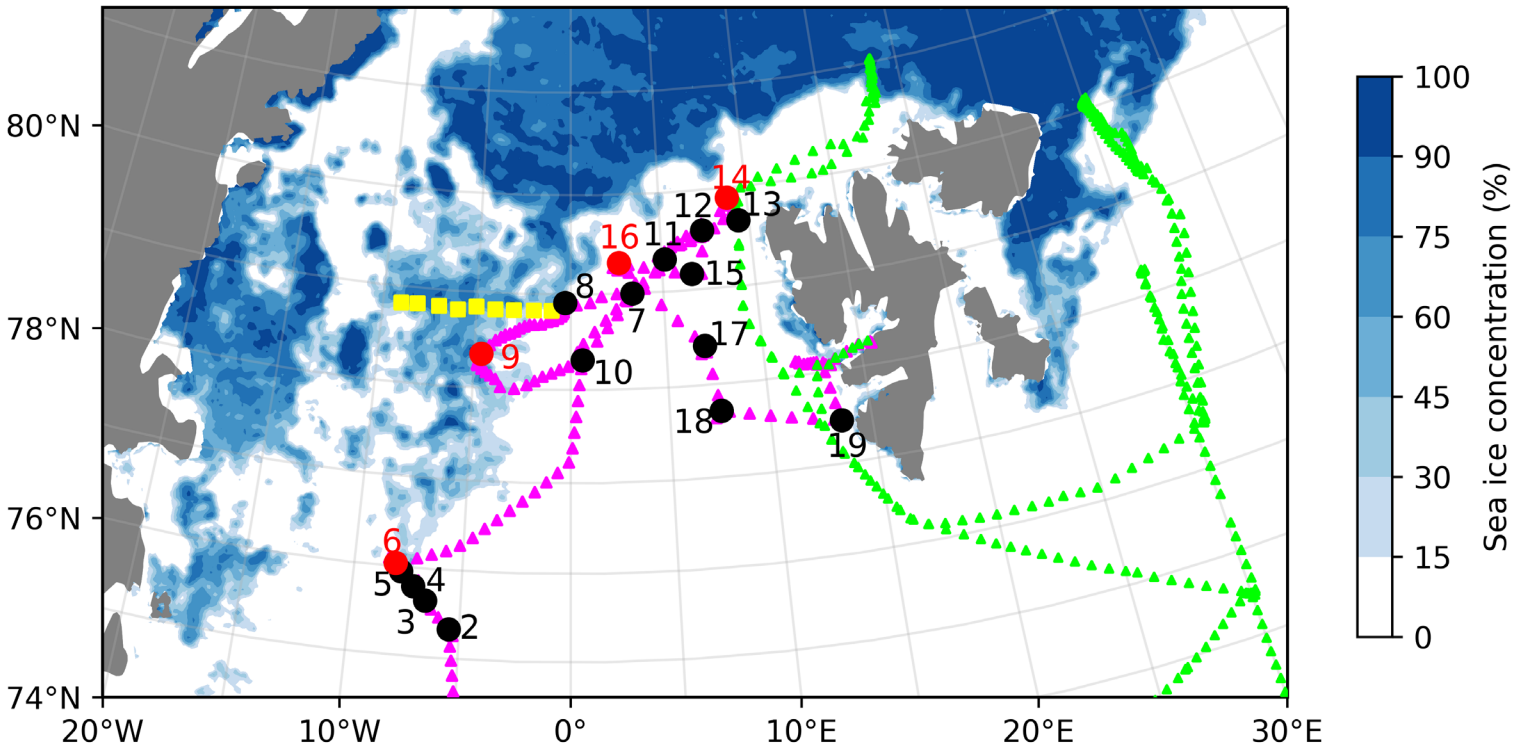
Dryer — Closed-path gas analyser

Setup



(Dong et al., 2021, ACP)

Arctic cruise JR18007 (Aug. 2019)

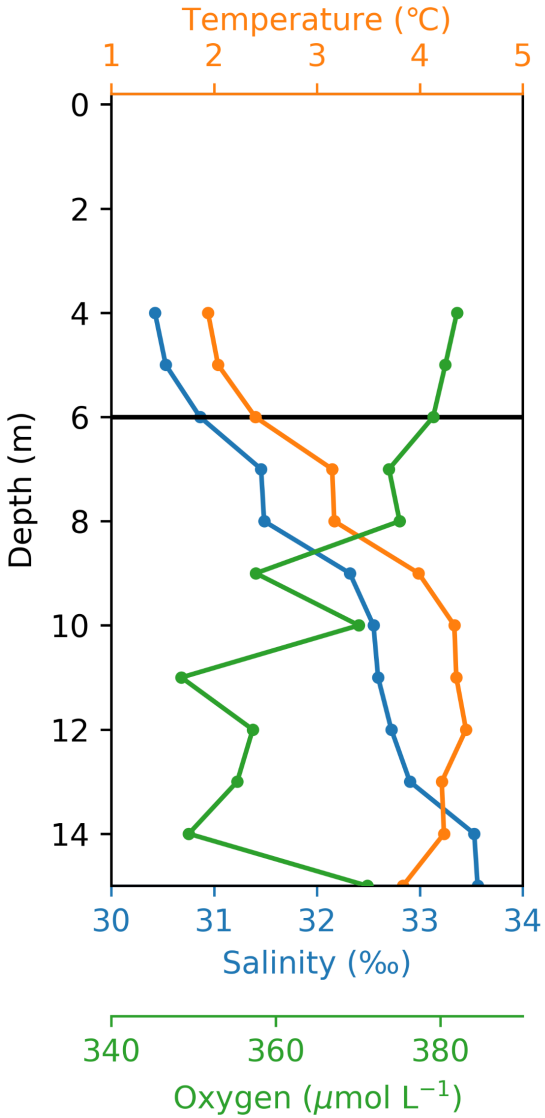


● Stratified station

▲▲▲ Cruise track

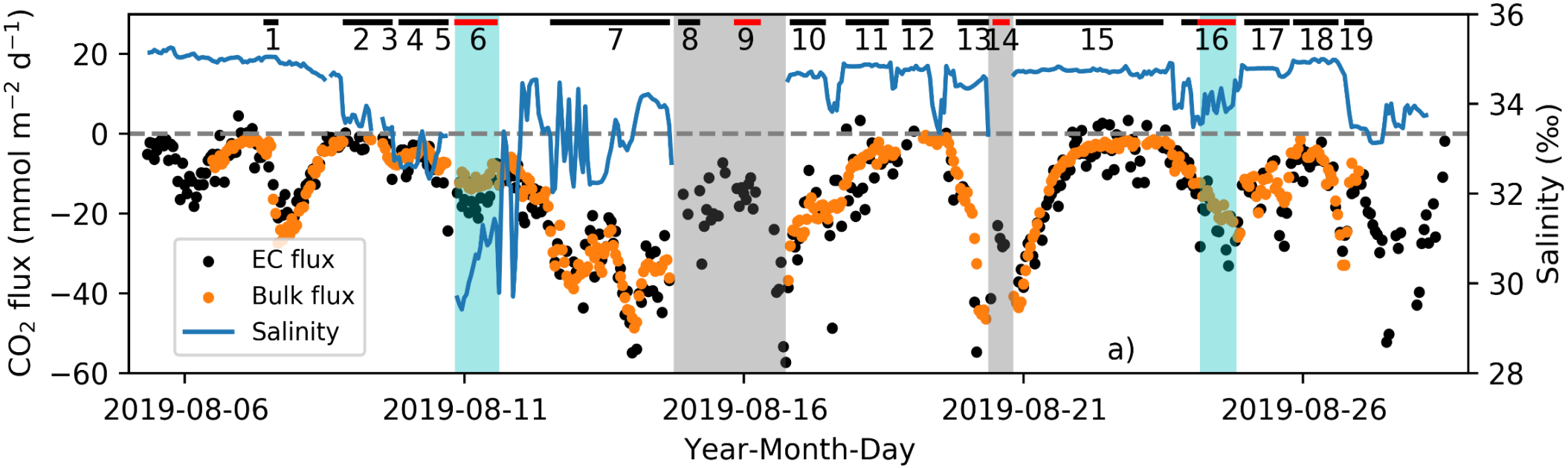
● Non-stratified station

Station 6



Use EC to detect the shallow stratification

The EC flux (black dots) is **consistently more negative** (more CO_2 uptake) than the bulk flux using fCO_{2w} measurements at ~5 m depth (orange dots) in the stratified stations (two light-blue shades).

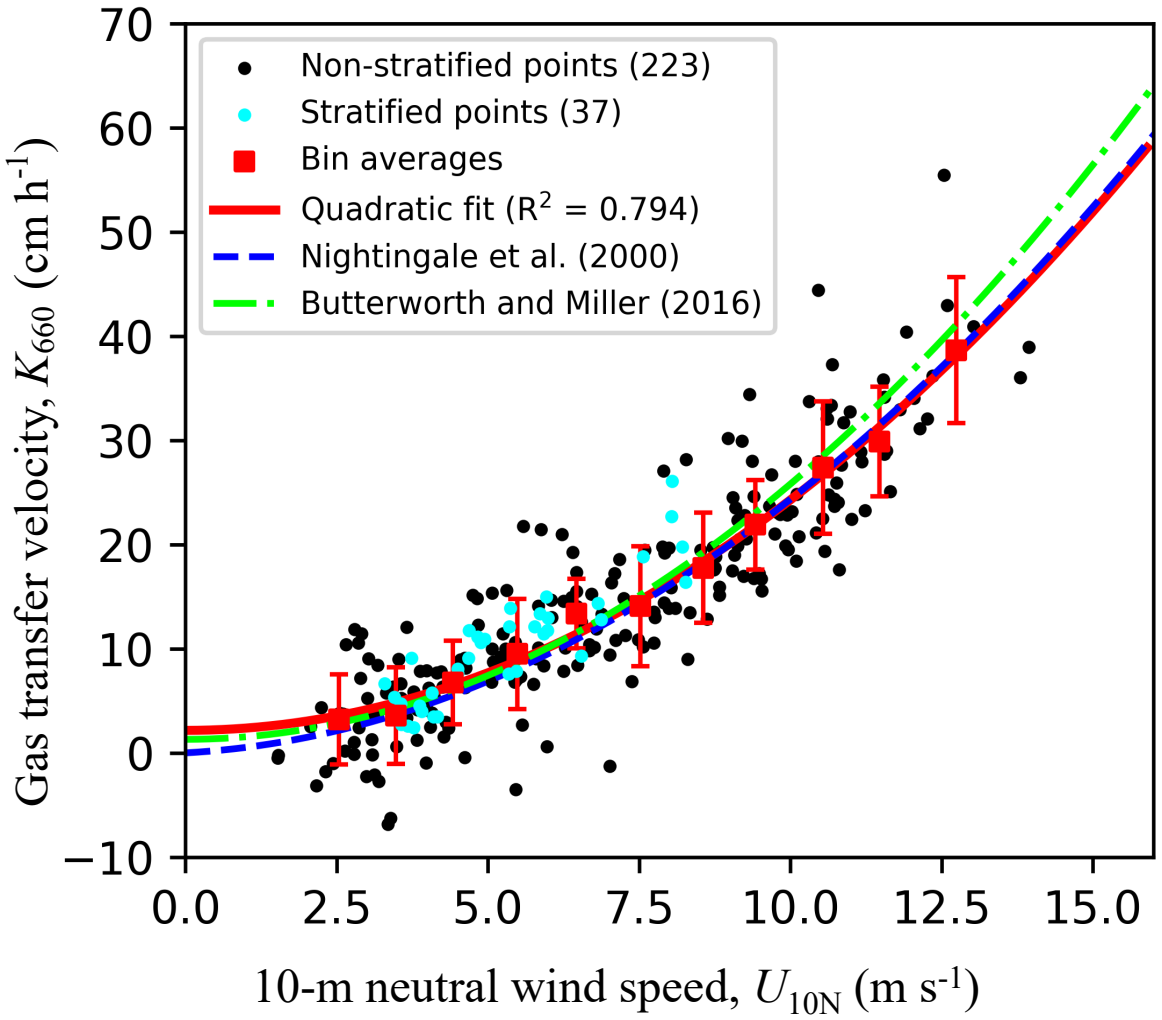


Neglecting the summertime shallow stratification due to the sea-ice melt could potentially underestimate the Arctic Ocean CO_2 uptake by 10%!

(Dong et al., 2021, GRL)

Implications for studies of gas transfer velocity

K_{660} derived from EC measurements during JR18007



Be careful with the study in the polar and coastal oceans!

The data affected by stratification should be removed.

(Dong et al., 2021, GRL)

Re-visit the temperature bias and cool skin effect

Based on Woolf et al. (2016) and Watson et al. (2020)

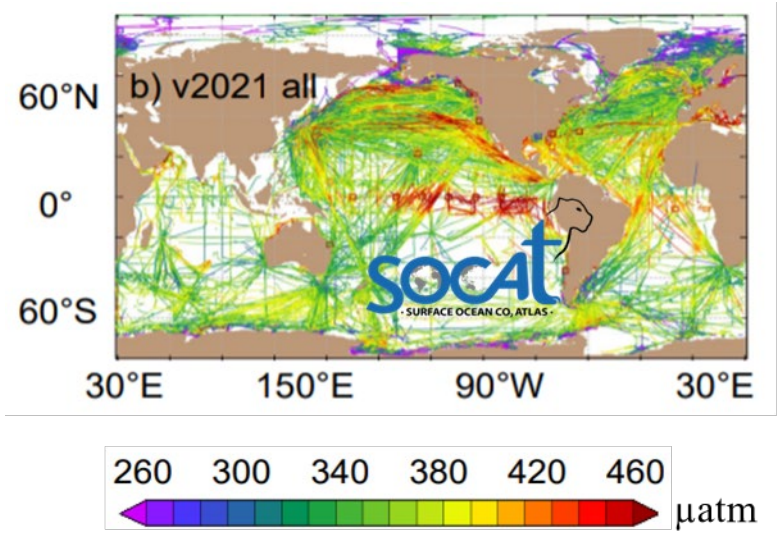
Temperature issues for global air-sea CO_2 flux estimates

0.1 K temperature bias could result in a 15% change in the global air-sea CO_2 flux

We generally use the Surface Ocean CO_2 Atlas (SOCAT) data for the global air-sea CO_2 flux estimate

$$F_{CO2} = K\,\alpha\,(fCO_{2w} - fCO_{2a})$$

$$F_{CO2} = K\,(\alpha_{subskin}\,fCO_{2w} - \alpha_{skin}\,fCO_{2a})$$



- There is a potential warm bias in SOCAT SST – **warm bias issue**
- Skin is generally cooler than the subskin– **cool skin effect**

50% increase in the global air-sea CO_2 flux estimate**?**

(Woolf et al., 2016; Watson et al., 2020; Bakker et al., 2021)

Re-visit the warm bias in SOCAT SST

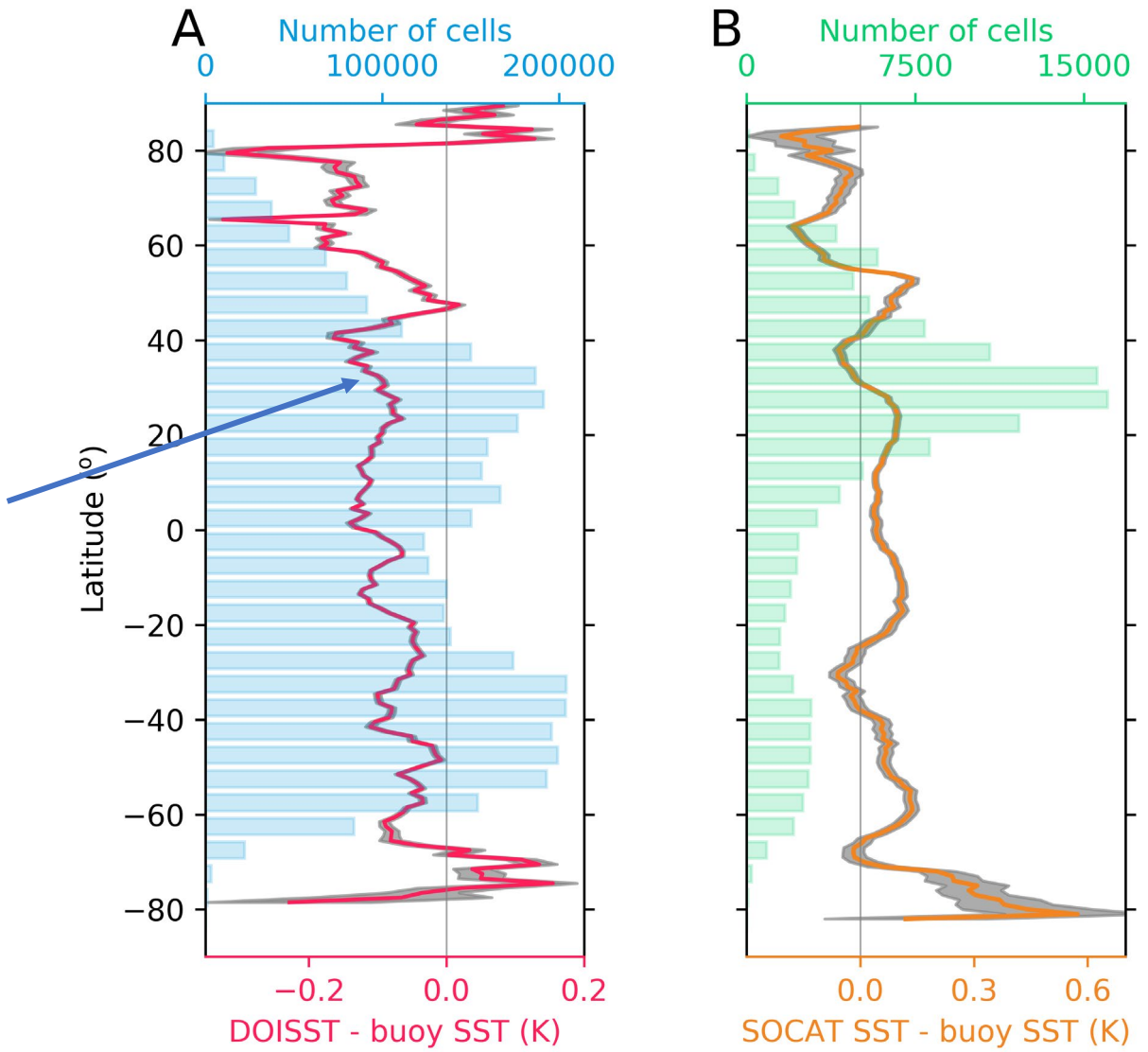
Watson et al., 2020:

- DOISST v2.0 (a satellite SST) replaces the SOCAT SST
- Huang et al, 2021:
  - ➢ *For* DOISST *v2.0, the cold bias against Argo was about -0.14 °C on global average and -0.28 °C in the Indian Ocean.*
  - ➢ *By updating v2.0 to v2.1, the biases are reduced to -0.07 °C and -0.14 °C in the global ocean and Indian Ocean, respectively.*

This study:

- The drifting buoy SST dataset is used as the reference temperature to assess the bias in the SOCAT SST

A small warm bias in SOCAT SST (< 0.1 K)



(Bakker et al., 2021; Xu & Ignatov, 2014; Huang 2021 et al., 2021)

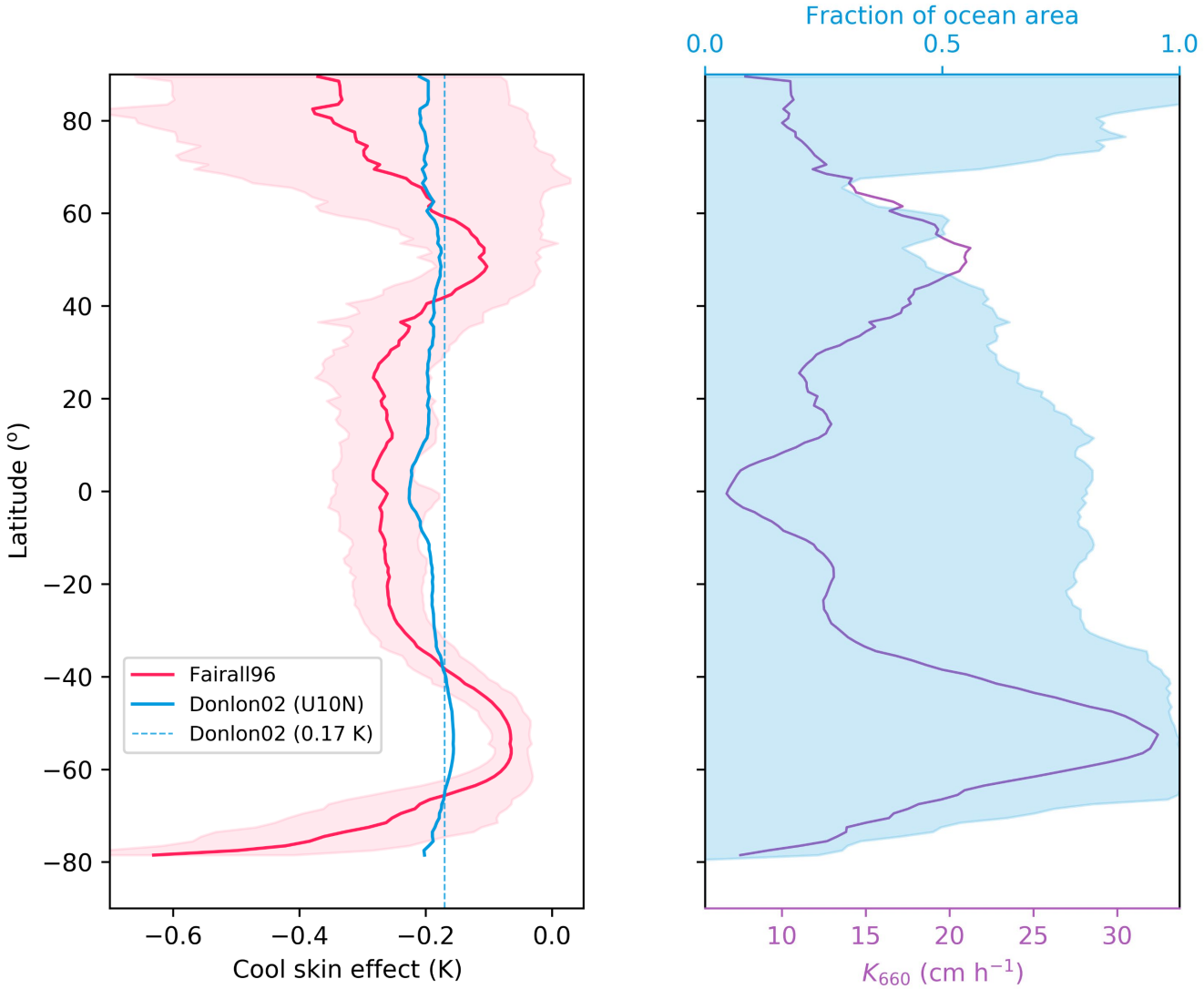
Re-visit the cool skin effect

Watson et al., 2020:

- Constant cool skin effect (-0.17 K, Donlon et al., 2002)
- Wind speed-dependent

This study:

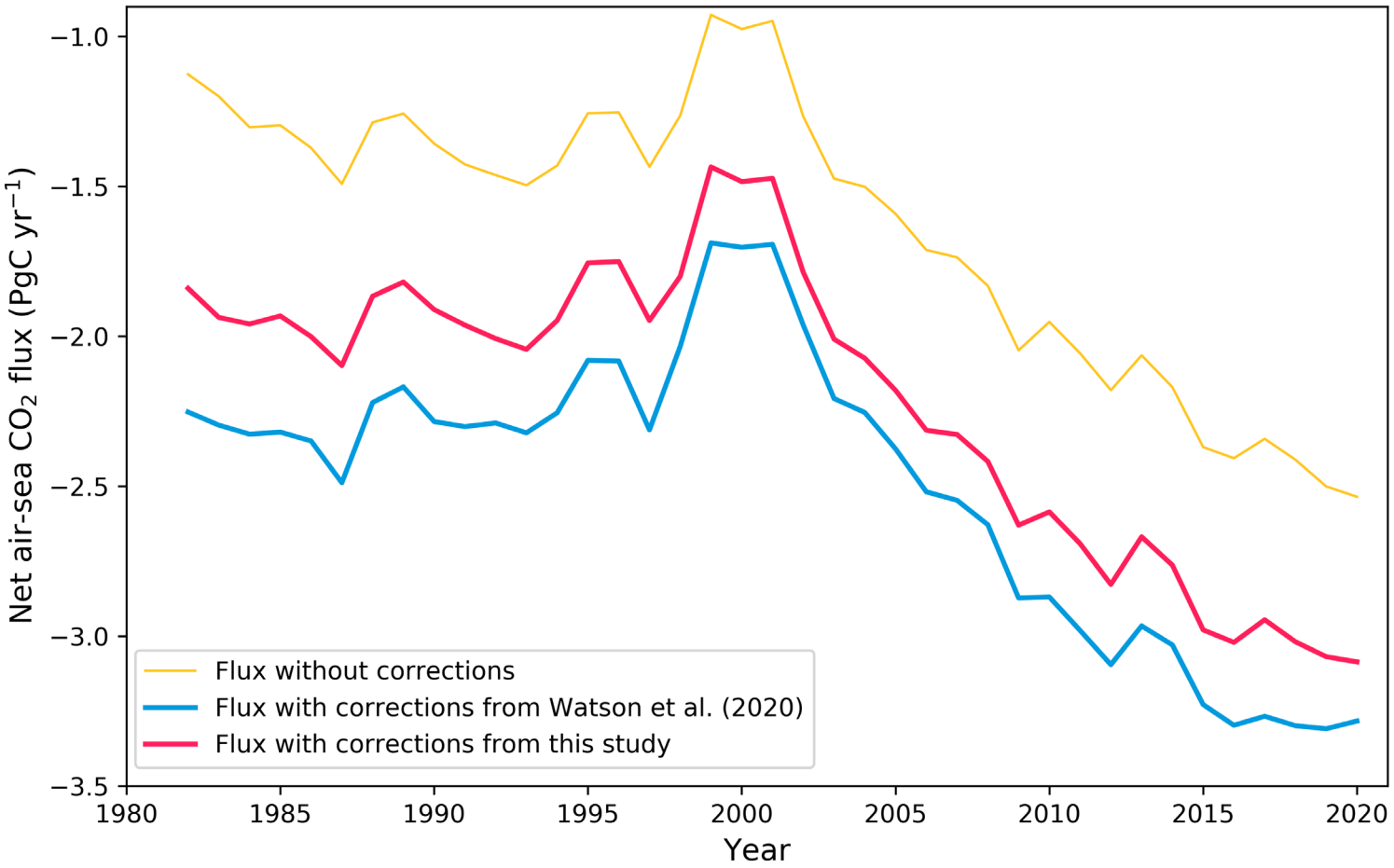
- Fairall et al., (1996) physical model
- Consider wind speed, longwave/solar radiation, heat flux



Consider the latitudinal variation is important!

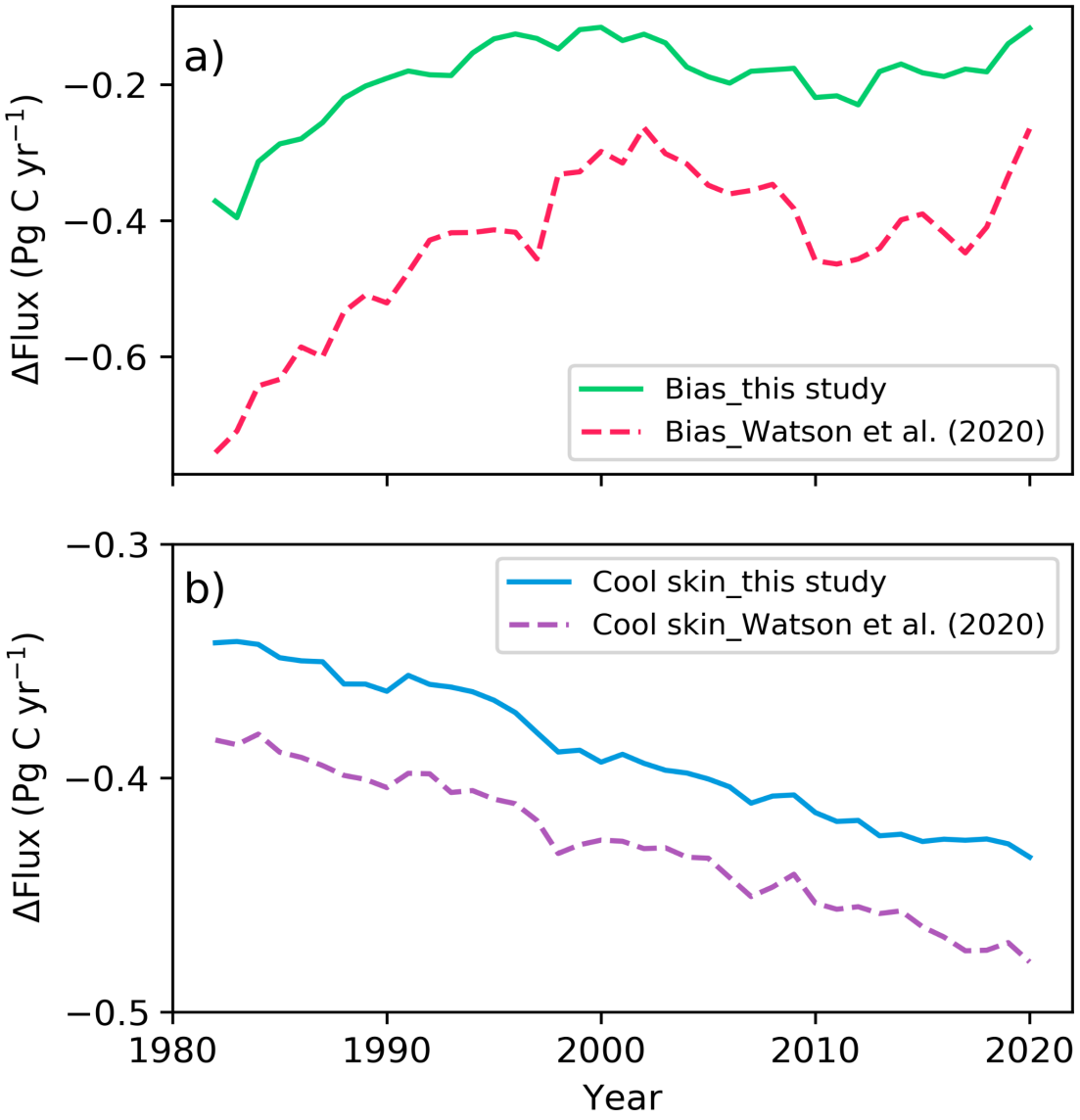
(Fairall et al., 1996; Donlon et al., 2002; Hersbach et al., 2020)

From 0.9 (50%) to 0.6 Pg C yr^{-1} (35%)



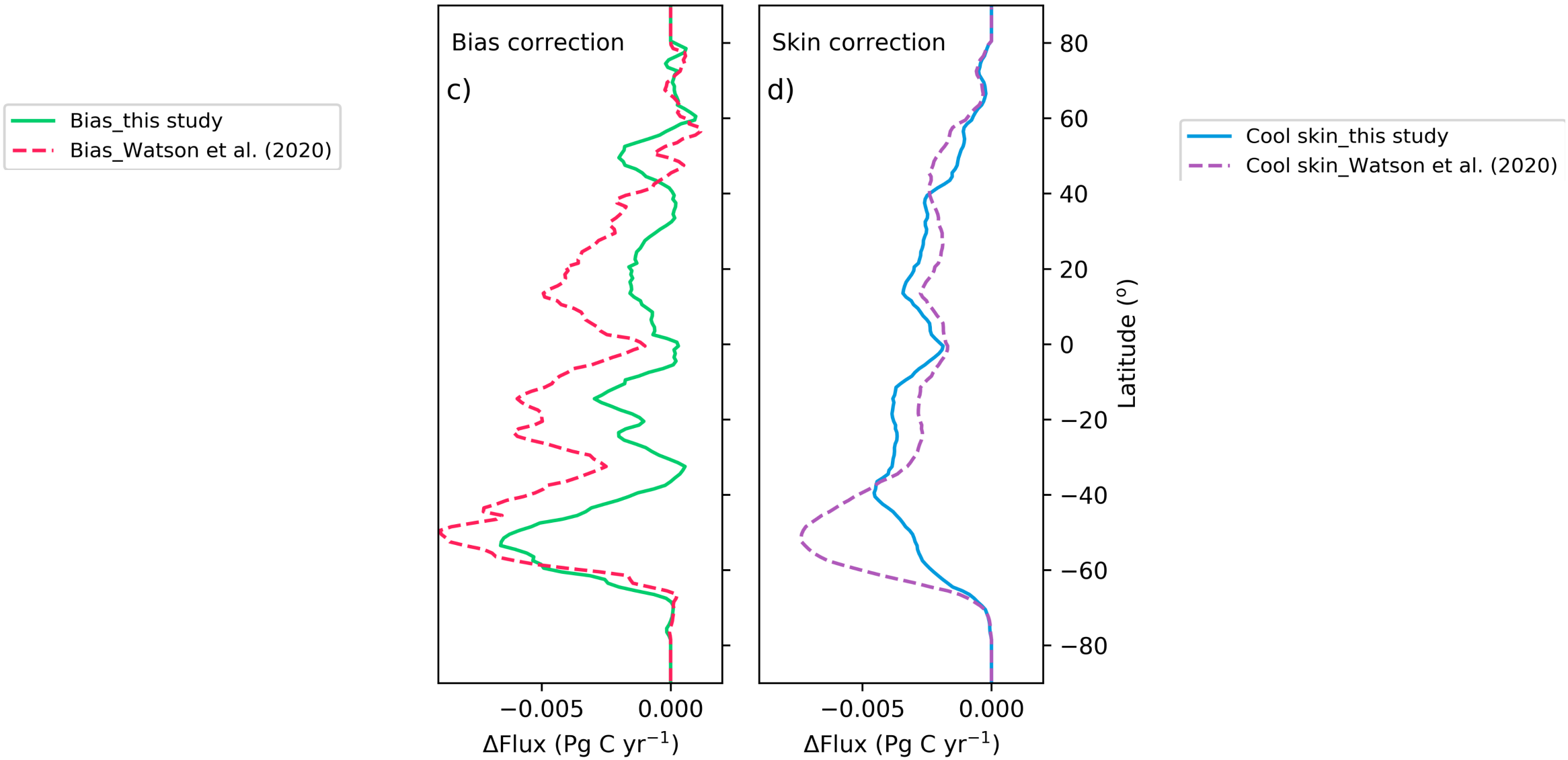
(Watson et al., 2020; Dong et al., 2022, GBC, accepted)

Inter-annual variation of the flux corrections



(Watson et al., 2020; Dong et al., 2022, GBC, accepted)

Latitudinal variation of the flux corrections



(Watson et al., 2020; Dong et al., 2022, GBC, accepted)

Caveat

- The temperature bias and the cool skin effects are only related to the **surface fCO_2 observation-based** air-sea CO_2 flux estimates, available from the 1982 onwards.

- **Cool skin effect**
  - Does not be included in the parameterized K_{660} (i.e., Wanninkhof, 2014)
  - Does not conflict with the pre-industrial air-sea CO_2 equilibrium assumption

$$F_{CO2} = K\,\alpha\,(fCO_{2w} - fCO_{2a})$$

$$F_{CO2} = K\,(\underbrace{\alpha_{subskin}\,fCO_{2w}}_{C_w} - \underbrace{\alpha_{skin}\,fCO_{2a}}_{C_i})$$

Equilibrium assumption has included the cool skin effect:

× $\Delta fCO_2 = fCO_{2w} - fCO_{2a} = 0$

√ $\Delta C = C_w - C_i = 0$

- Lack of strong observational evidence, eddy covariance method might help

Take-home message

- Summertime sea-ice melt generated stratification could bias the bulk air-sea CO_2 flux in the stratified regions.
- Be careful with the stratification in the polar oceans for the study of flux and $K_{660.}$

- A re-visit of the SOCAT SST bias and the cool skin effect suggests a 35% (0.6 Pg C yr^{-1}) increase in the global air-sea CO_2 flux.
- Urge the community to confirm the impact of the cool skin effect on CO_2 flux estimates by observation.

Acknowledgments:

- **Co-authors**: Vassilis Kitidis (PML), Ian Brown (PML), Melissa Chierici (Fram Centre, University Centre in Svalbard), Agneta Fransson (Fram Centre), Peter Landschützer (Max Planck Institute for Meteorology), Boyin Huang (National Oceanic and Atmospheric Administration, NOAA)

- H. Beggs (Bureau of Meteorology, Australia), B. Butterworth (University of Calgary), J. Kennedy (Met Office Hadley Centre), C. Merchant (University of Reading), D. Phillips (PML), J. Shutler (University of Exeter), T. Smyth (PML), R. Wanninkhof (NOAA), H. Zhang (NOAA), S. Zhou (British Antarctic Survey), captains and crew of the RRS James Clark Ross.