Atmospheric Constraints on Southern Ocean Carbon Uptake

Yuming Jin
NSF/NCAR Earth Observing Laboratory

2025 US CLIVAR Summit
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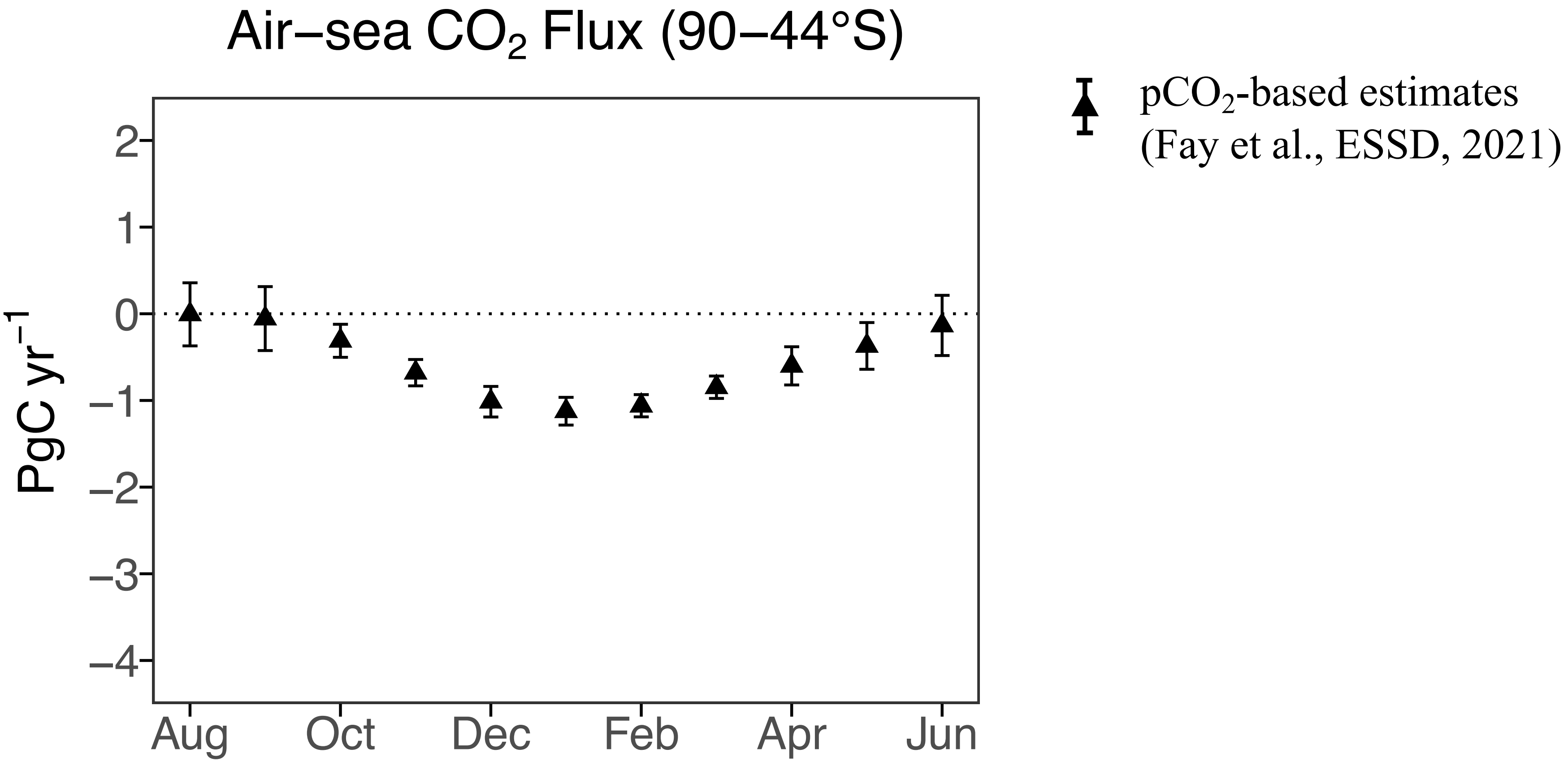
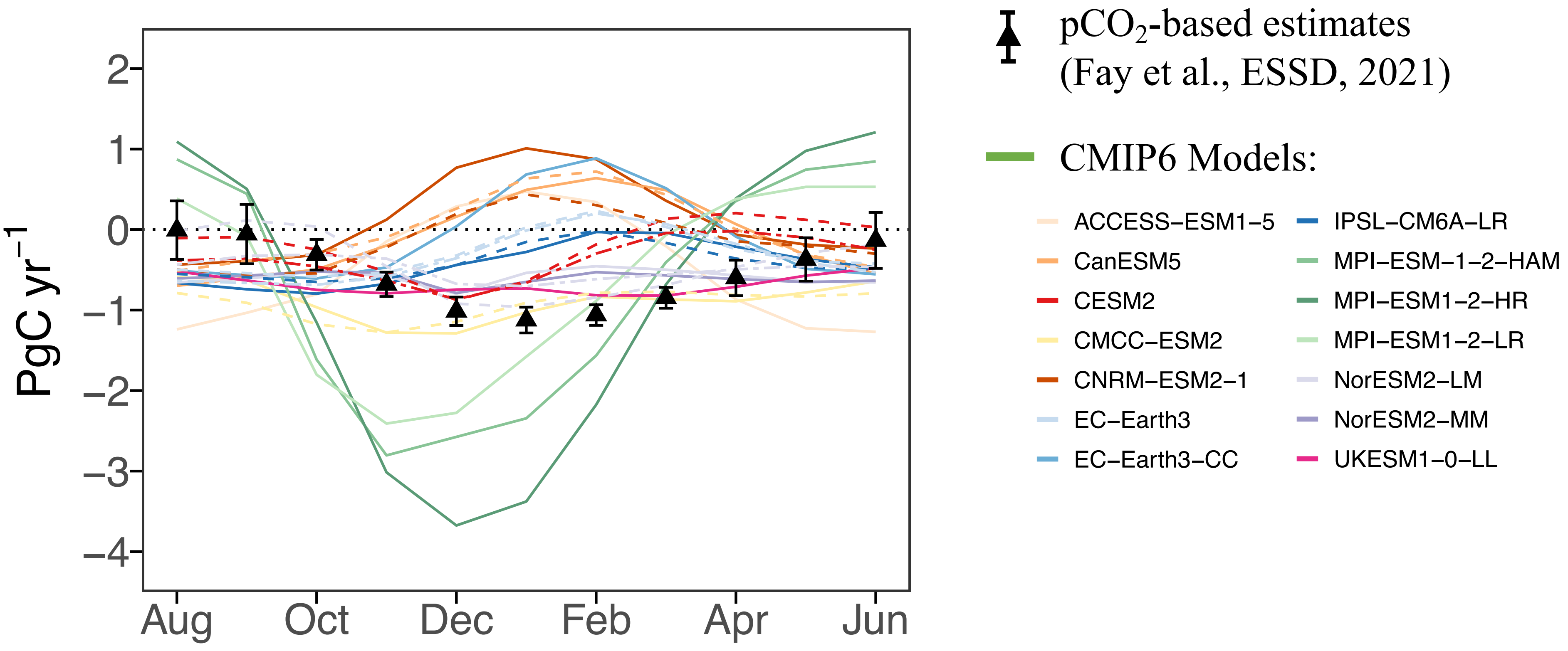
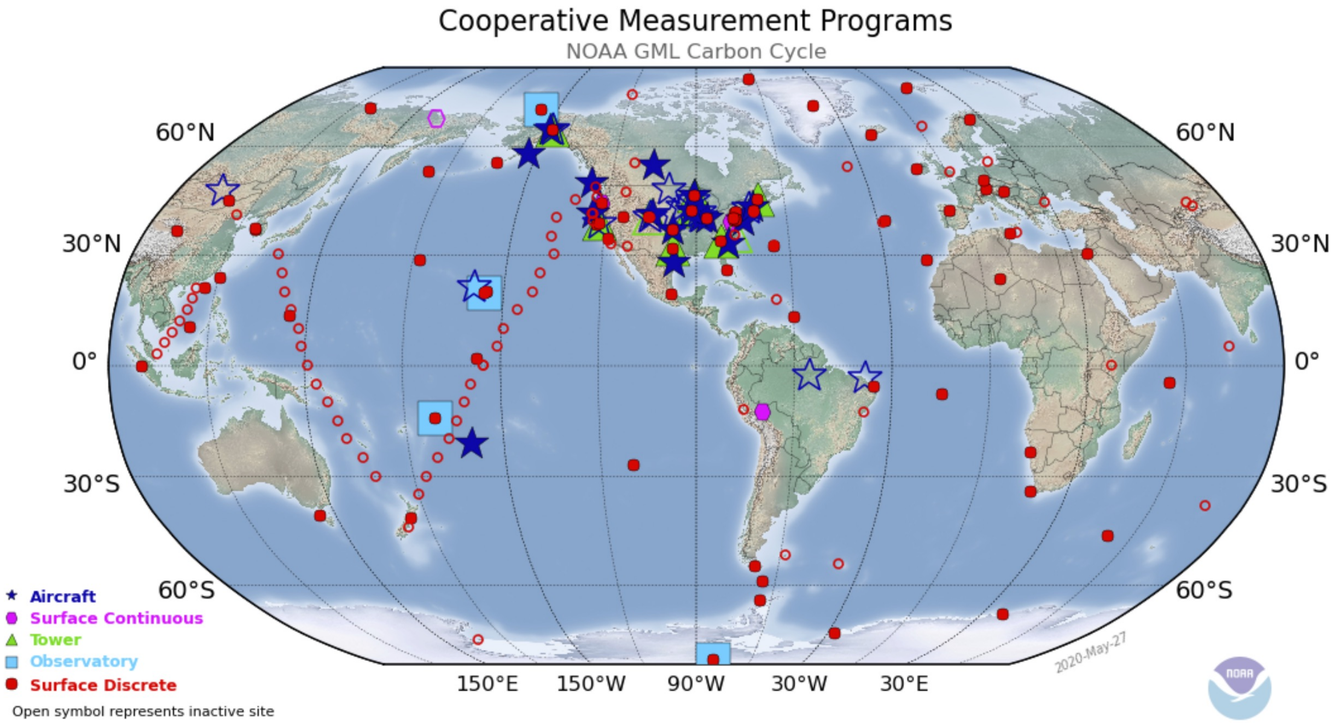
Photo Credit: Dr. Jonathan Bent
ORCAS Campaign



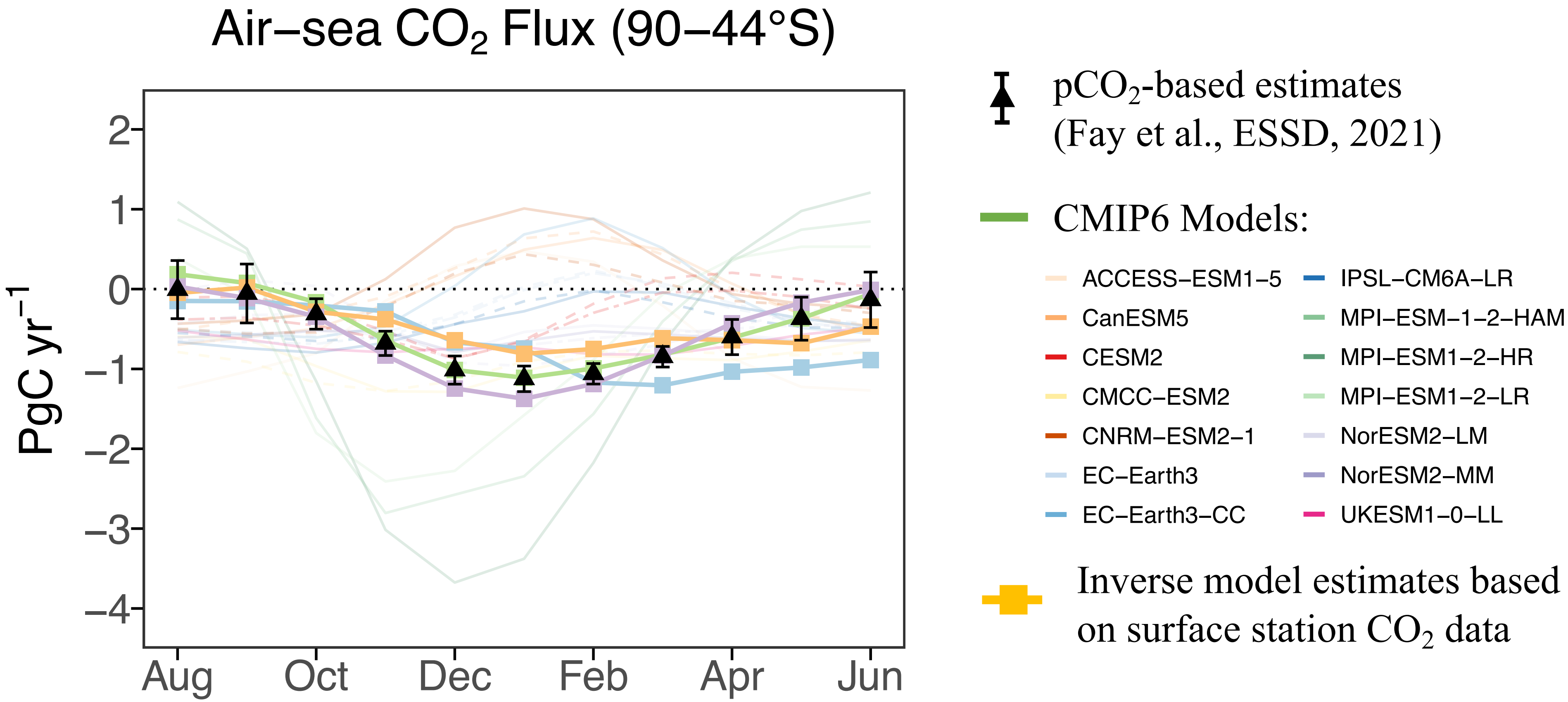
Air–sea CO_2 Flux (90–44°S)
2
1
0
−1
−2
−3
−4
$PgC\ yr^{-1}$
Aug
Oct
Dec
Feb
Apr
Jun
pCO_2-based estimates
(Fay et al., ESSD, 2021)

Air–sea CO_2 Flux (90–44°S)





Cooperative Measurement Programs
NOAA GML Carbon Cycle
60°N
30°N
0°
30°S
60°S
150°E
150°W
90°W
30°W
30°E
2020-May-27
Aircraft
Surface Continuous
Tower
Observatory
Surface Discrete
Open symbol represents inactive site



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pCO_2-based estimates
(Fay et al., ESSD, 2021)
CMIP6 Models:
ACCESS–ESM1–5
CanESM5
CESM2
CMCC–ESM2
CNRM–ESM2–1
EC–Earth3
EC–Earth3–CC
IPSL–CM6A–LR
MPI–ESM–1–2–HAM
MPI–ESM1–2–HR
MPI–ESM1–2–LR
NorESM2–LM
NorESM2–MM
UKESM1–0–LL
Inverse model estimates based
on surface station CO_2 data

HIAPER
Pole-to-Pole
Observations

Global and seasonal survey of CO_2, O_2, CH_4, CO, N_2O (over 90 species).

NSF / NCAR Gulfstream V

HIPPO-1: 12 January to 30 January 2009

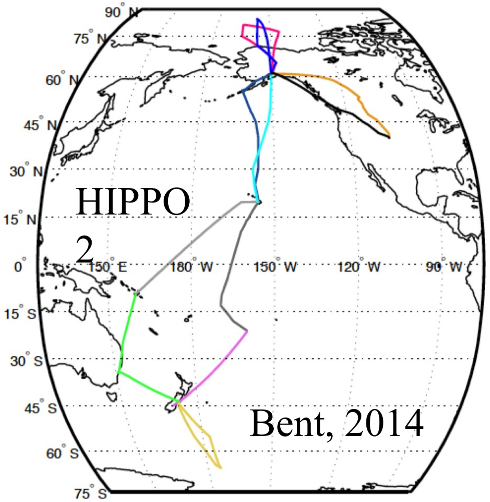
HIPPO-2: 2 November to 22 November 2009

HIPPO-3: 26 March to 16 April 2010

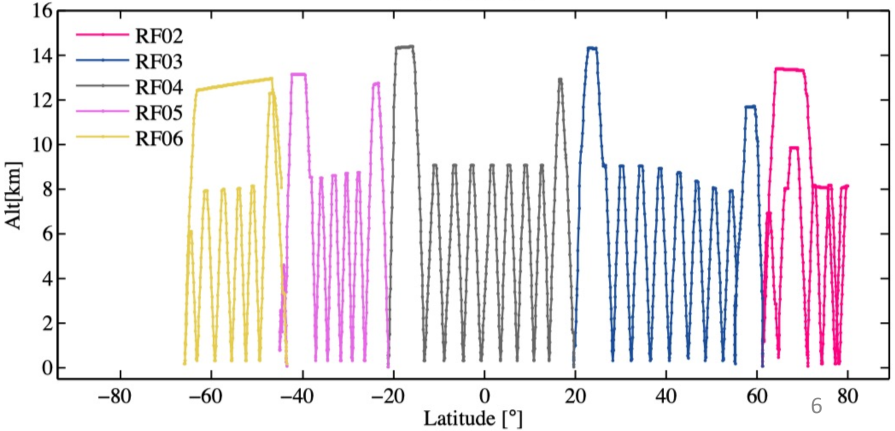
HIPPO-4: 16 June to 11 July 2011

HIPPO-5: 19 August to 8 September 2011

lasting ~3 weeks each

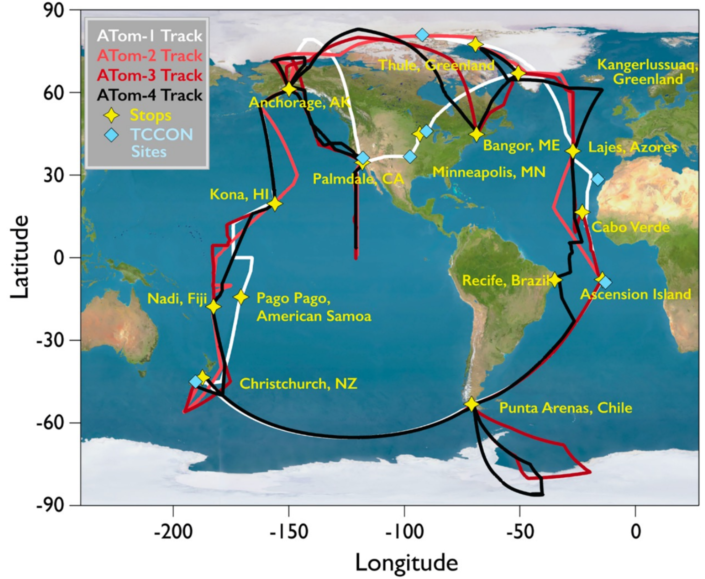


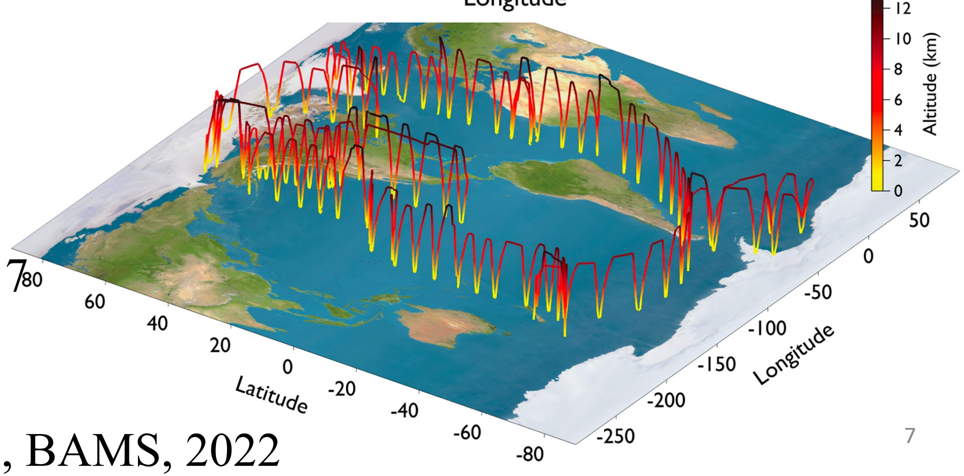
HIPPO2 Southbound



NASA DC-8 aircraft

ATom-1: 28 July to 22 August 2016
ATom-2: 26 January to 22 February 2017
ATom-3: 28 September to 26 October 2017
ATom-4: 24 April to 21 May 2018
lasting ~28 days each



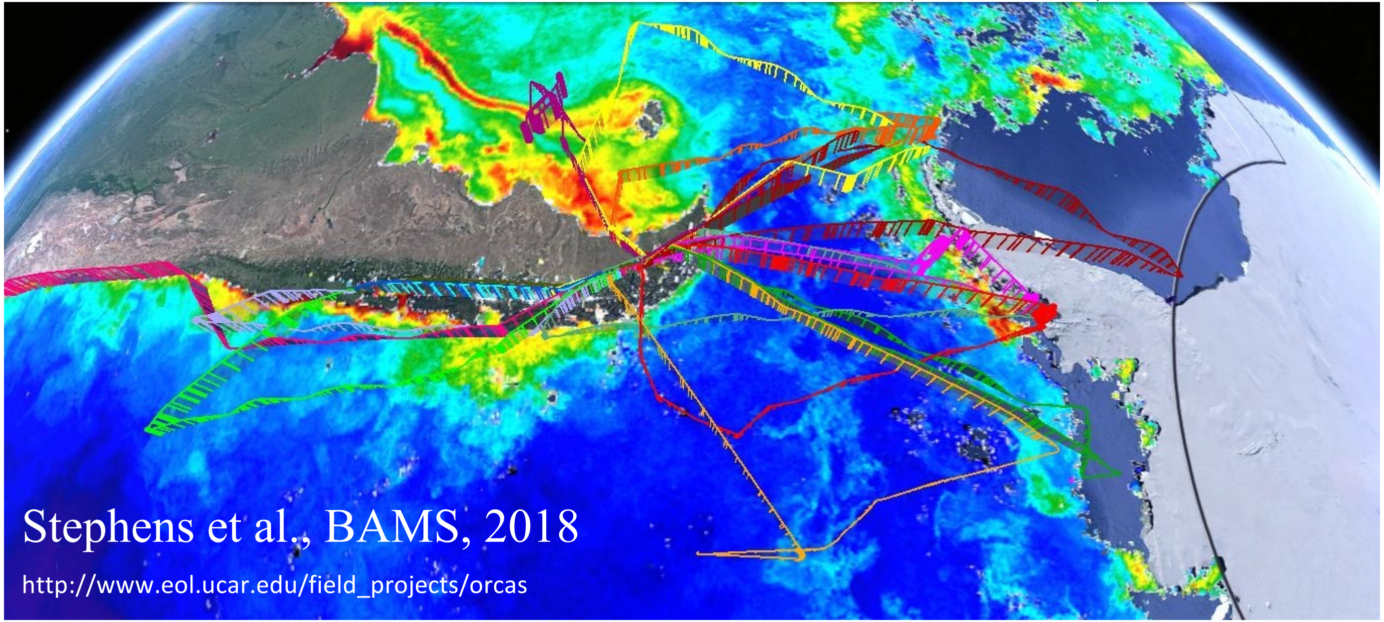


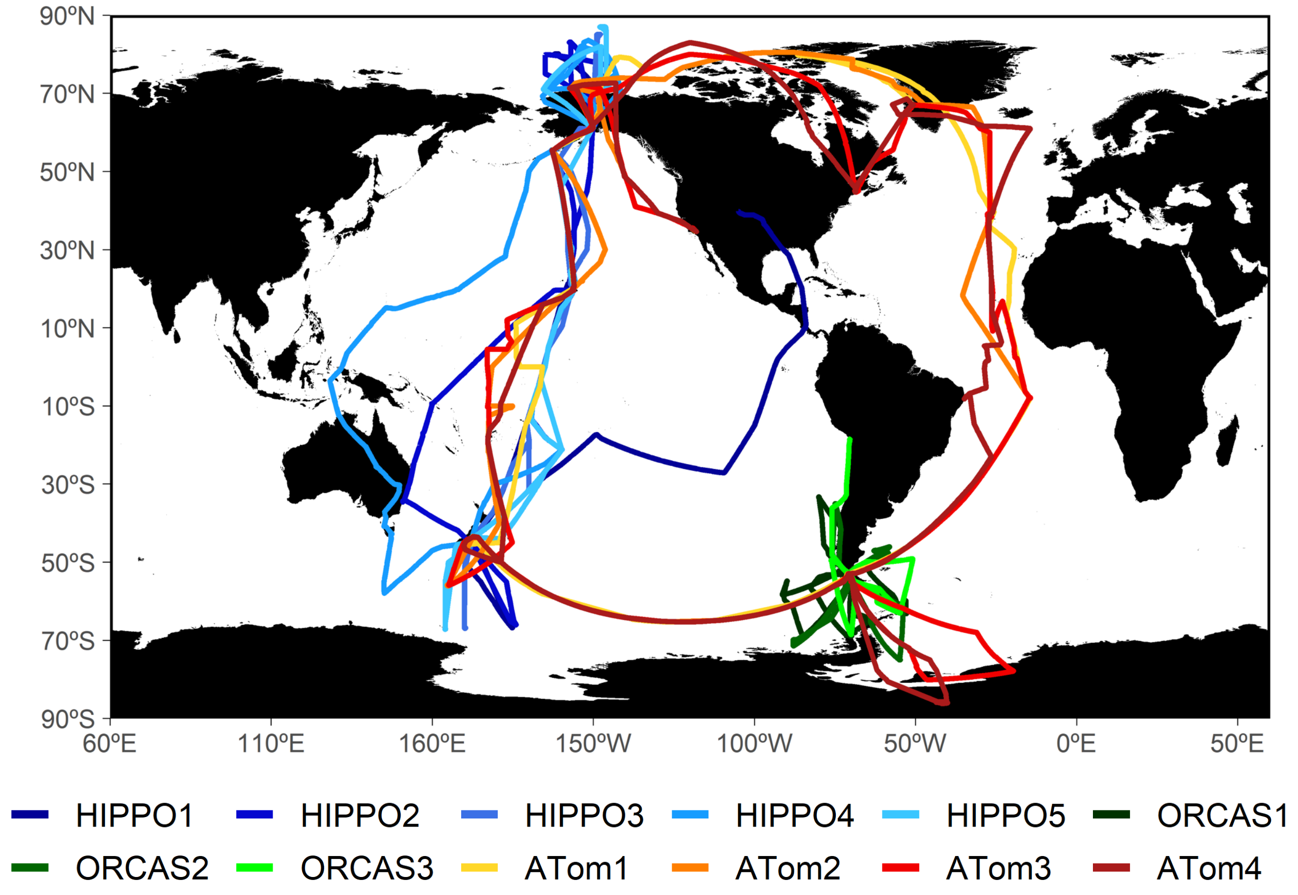
Thompson et al., BAMS, 2022

ORCAS

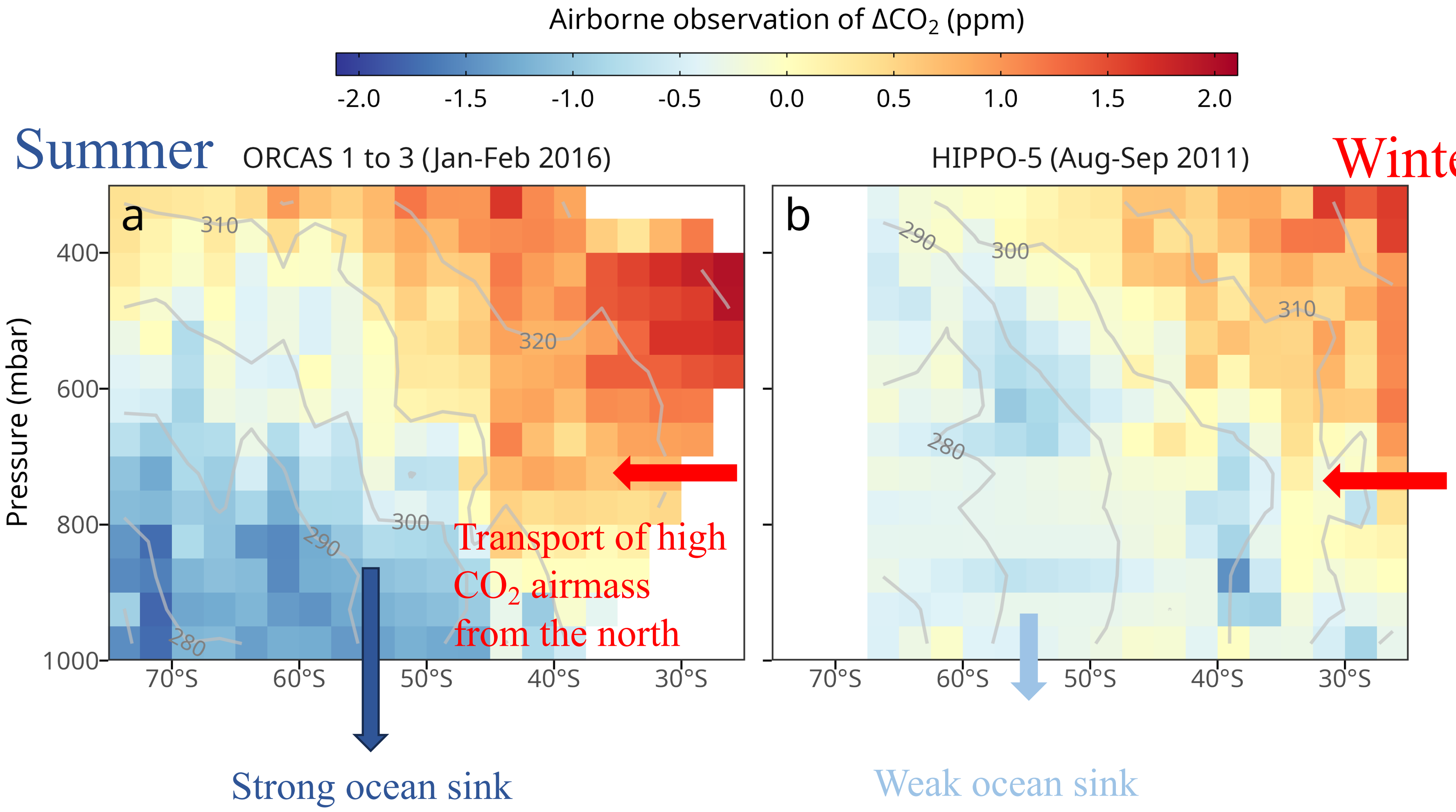
2016 O_2/N_2 Ratio and CO_2 Airborne Southern Ocean Study

NSF/NCAR GV
Punta Arenas, Chile
15 Jan to 29 Feb 2016
(~6 weeks)

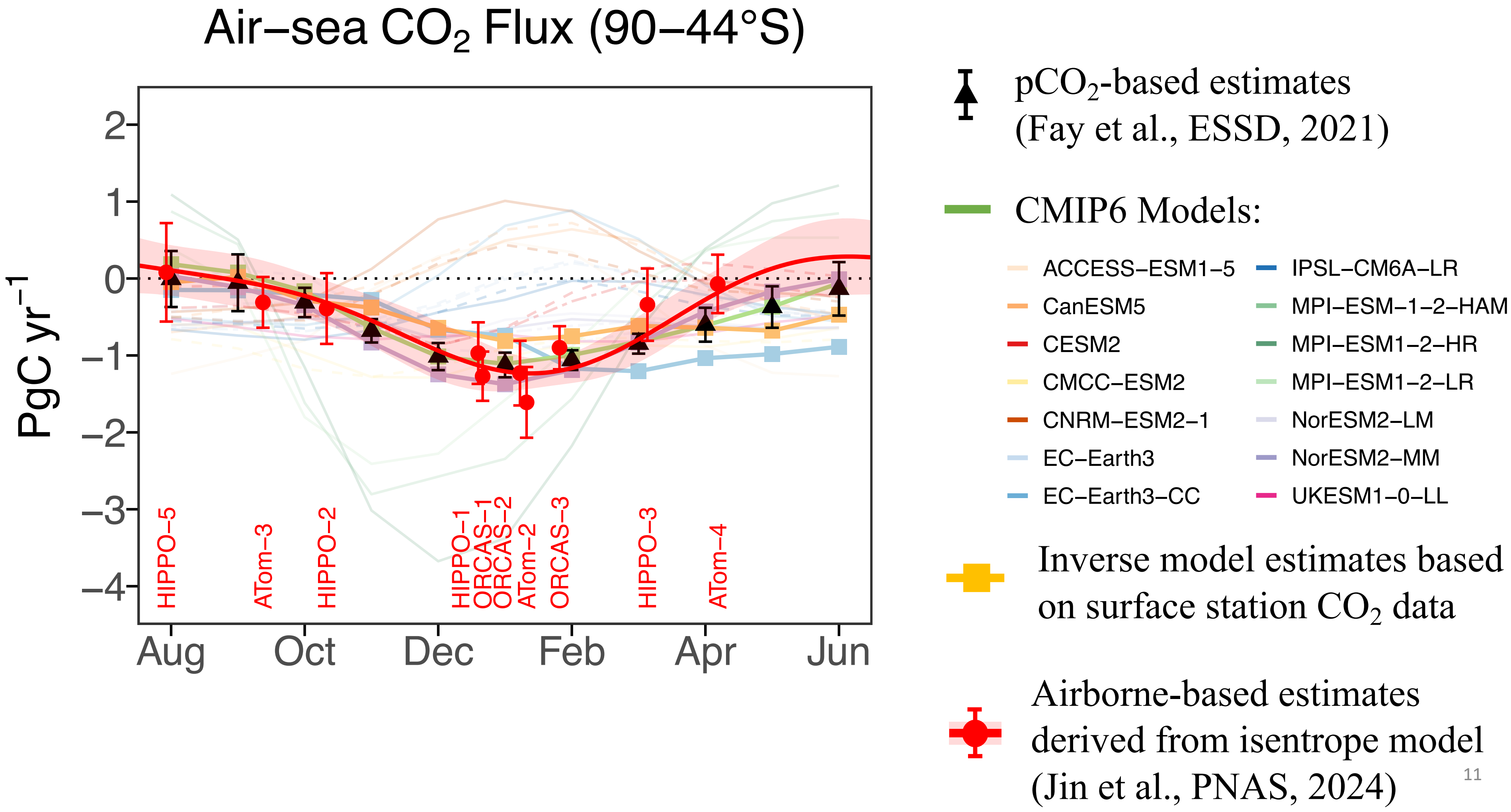




90ºN
70ºN
50ºN
30ºN
10ºN
10ºS
30ºS
50ºS
70ºS
90ºS
60ºE
110ºE
160ºE
150ºW
100ºW
50ºW
0ºE
50ºE
HIPPO1
HIPPO2
HIPPO3
HIPPO4
HIPPO5
ORCAS1
ORCAS2
ORCAS3
ATom1
ATom2
ATom3
ATom4



Airborne observation of ΔCO_2 (ppm)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
Summer
ORCAS 1 to 3 (Jan-Feb 2016)
HIPPO-5 (Aug-Sep 2011)
Winter
a
b
Pressure (mbar)
400
600
800
1000
310
320
300
290
280
70°S
60°S
50°S
40°S
30°S
Transport of high CO_2 airmass from the north
Strong ocean sink
Weak ocean sink



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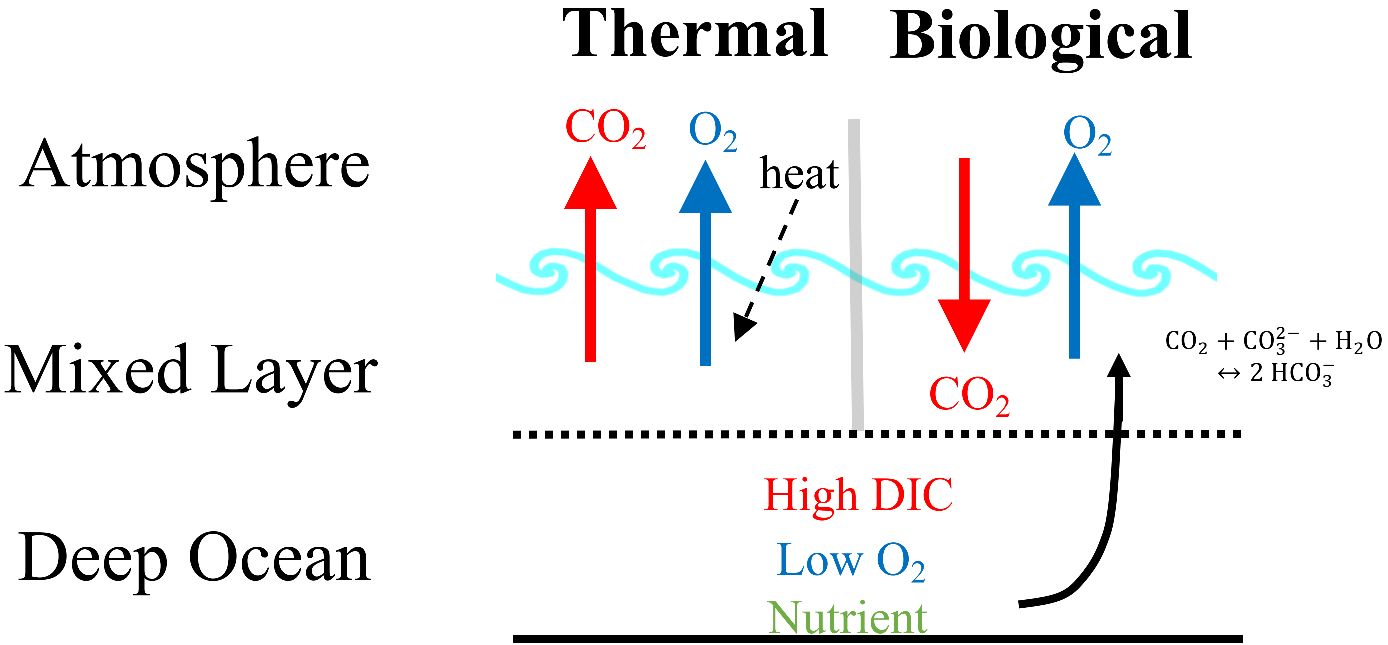
Inverse model estimates based on surface station CO_2 data
Airborne-based estimates derived from isentrope model
(Jin et al., PNAS, 2024)

Summer:



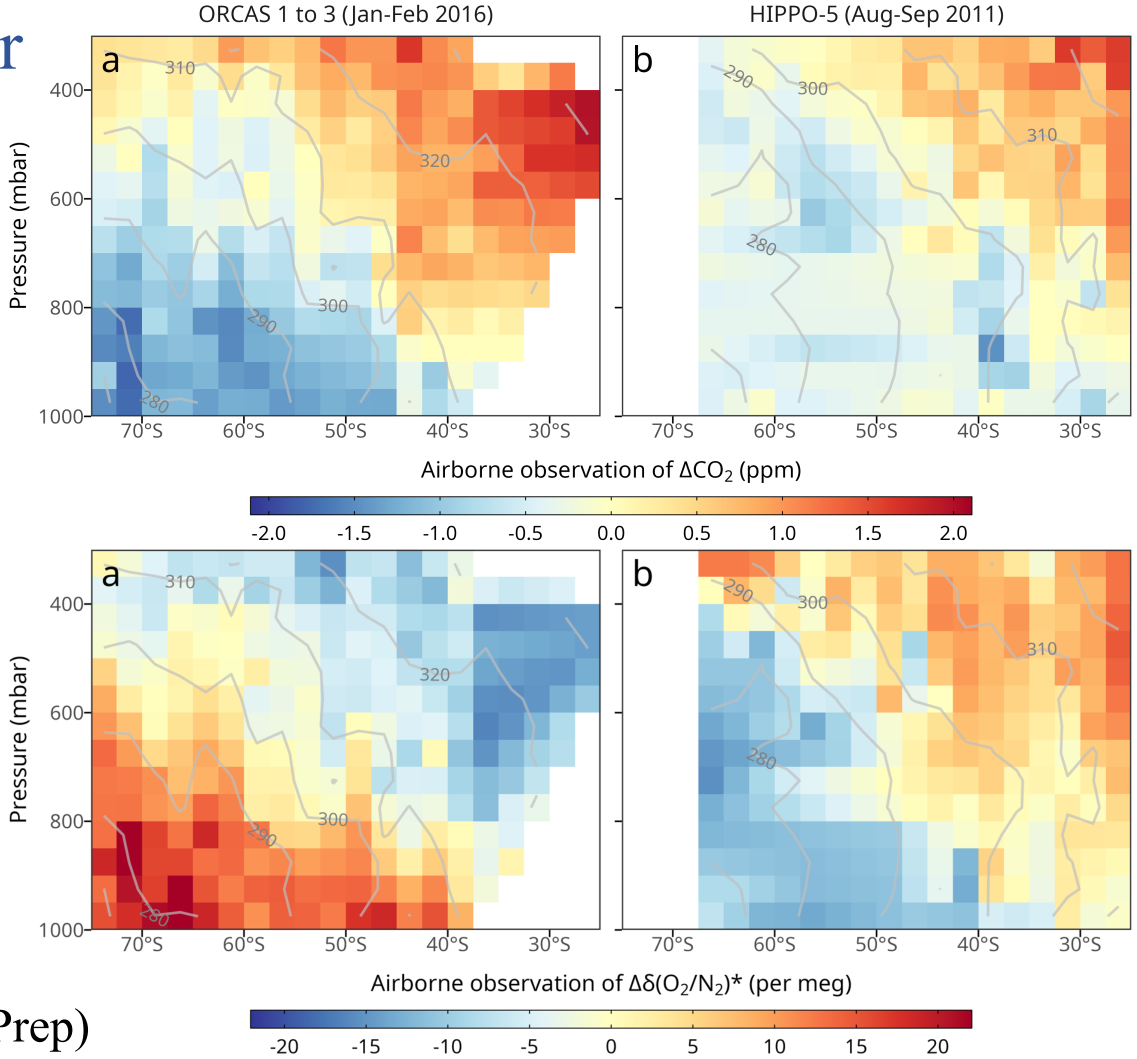
Thermal
Biological
Atmosphere
Mixed Layer
Deep Ocean
CO_2
O_2
heat
O_2
CO_2
$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2\ HCO_3^-$
High DIC
Low O_2
Nutrient

Summer

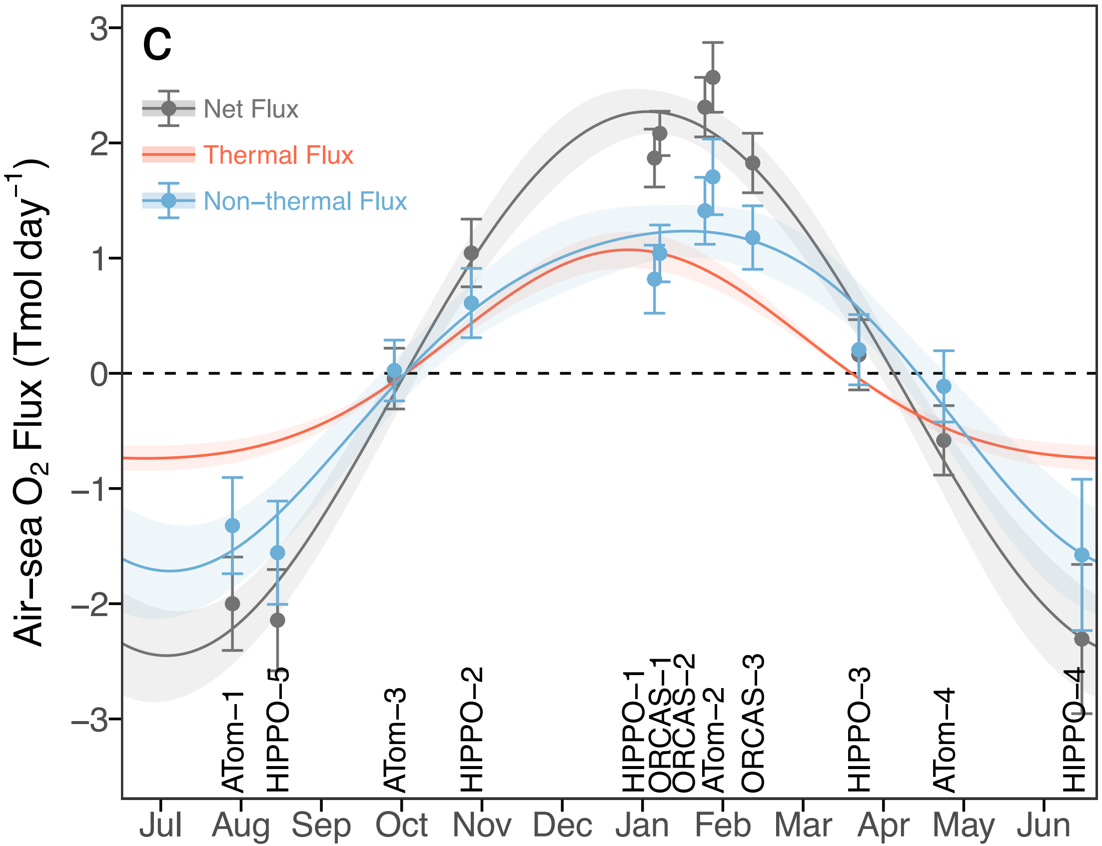
Winter

CO_2

O_2/N_2



(Jin et al., In Prep)

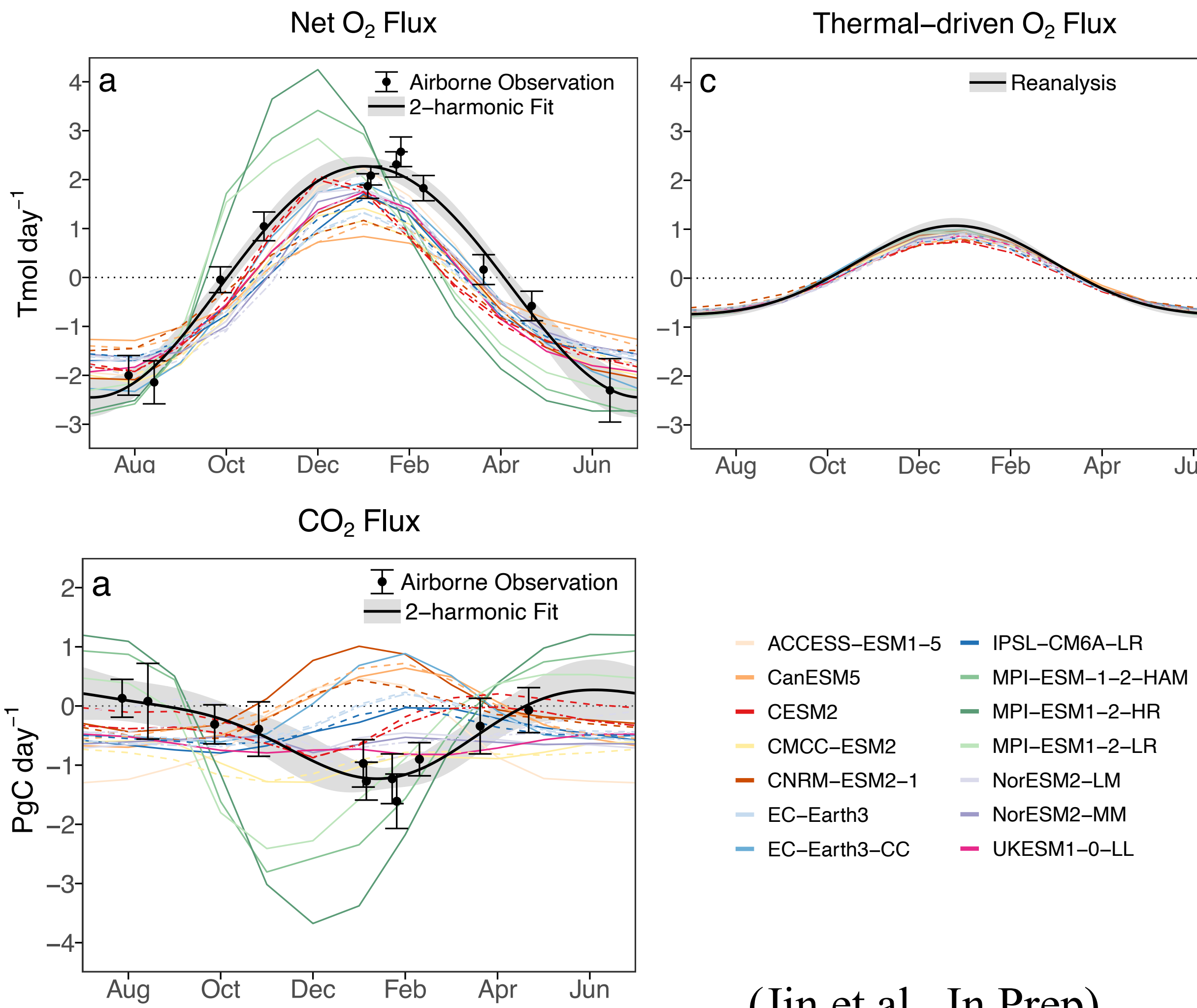


Net O_2 flux is resolved from airborne data

Thermal O_2 flux is calculated by scaling ocean heat flux (adapted from Keeling & Shertz, Nature, 1992)

Non-thermal O_2 flux is the residual, representing mainly biological activities and circulation.

(Jin et al., In Prep)



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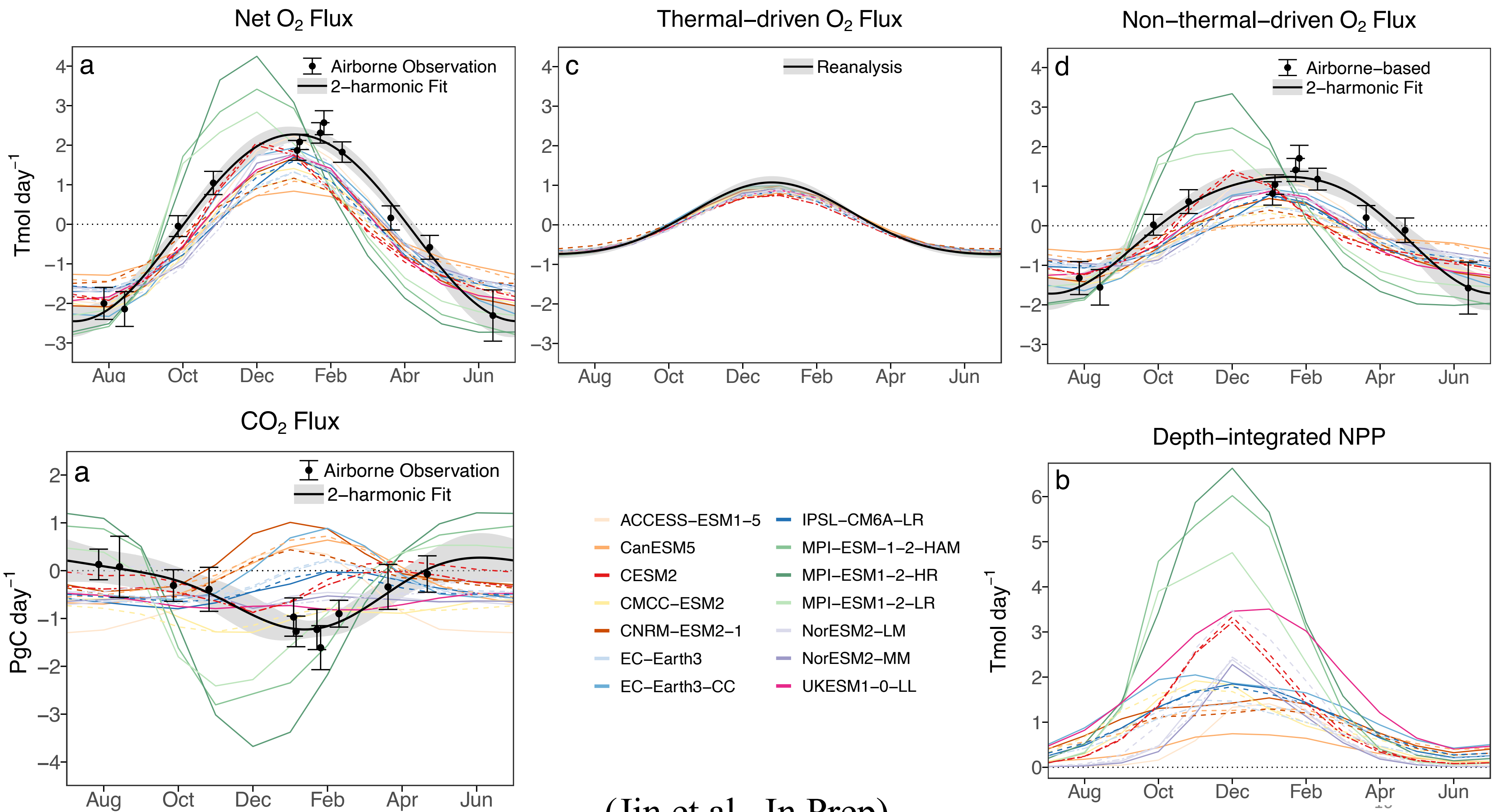

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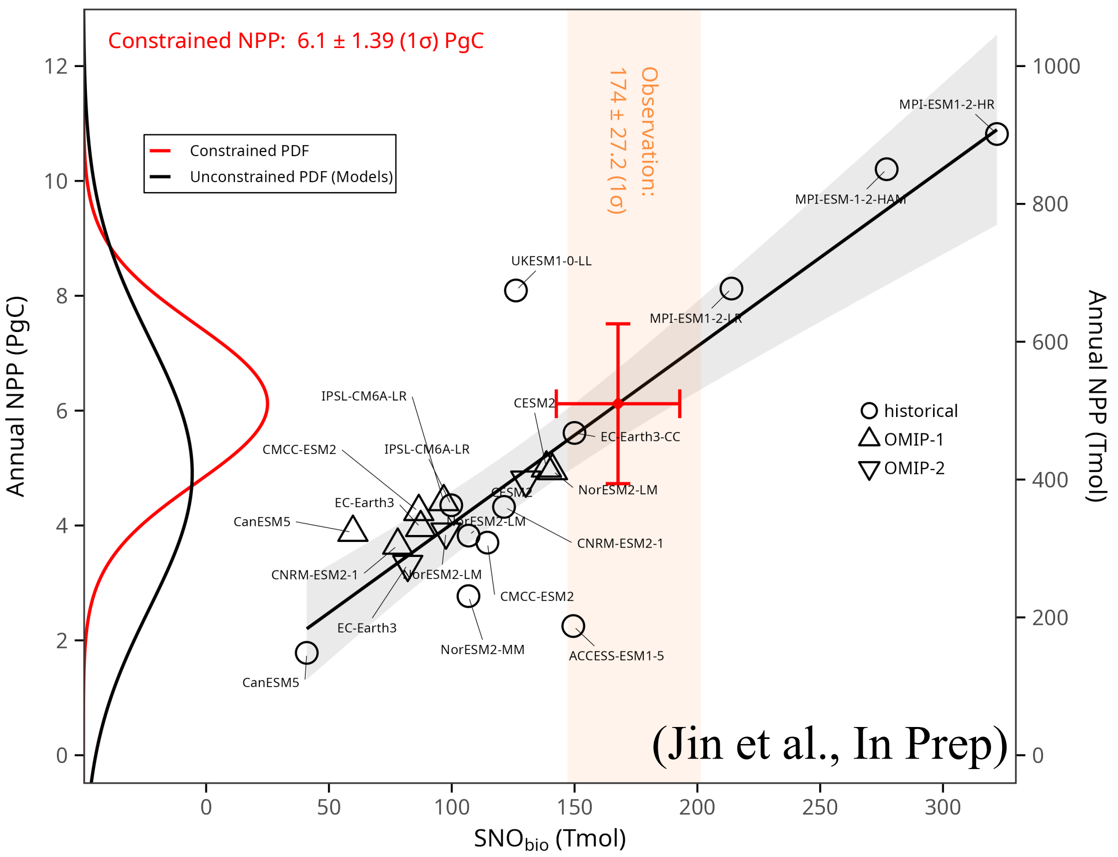
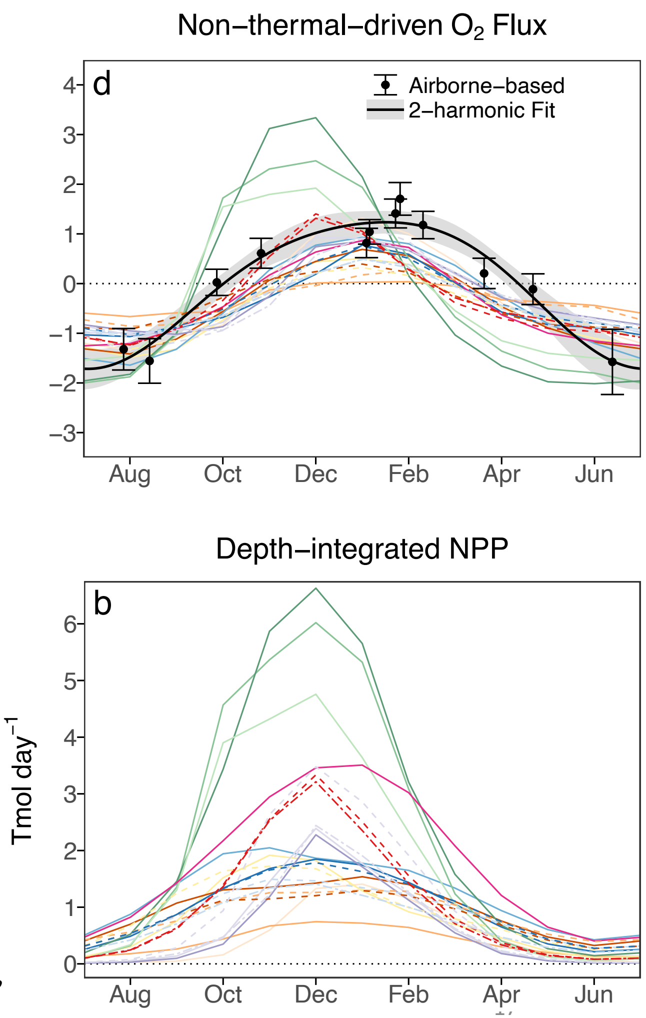
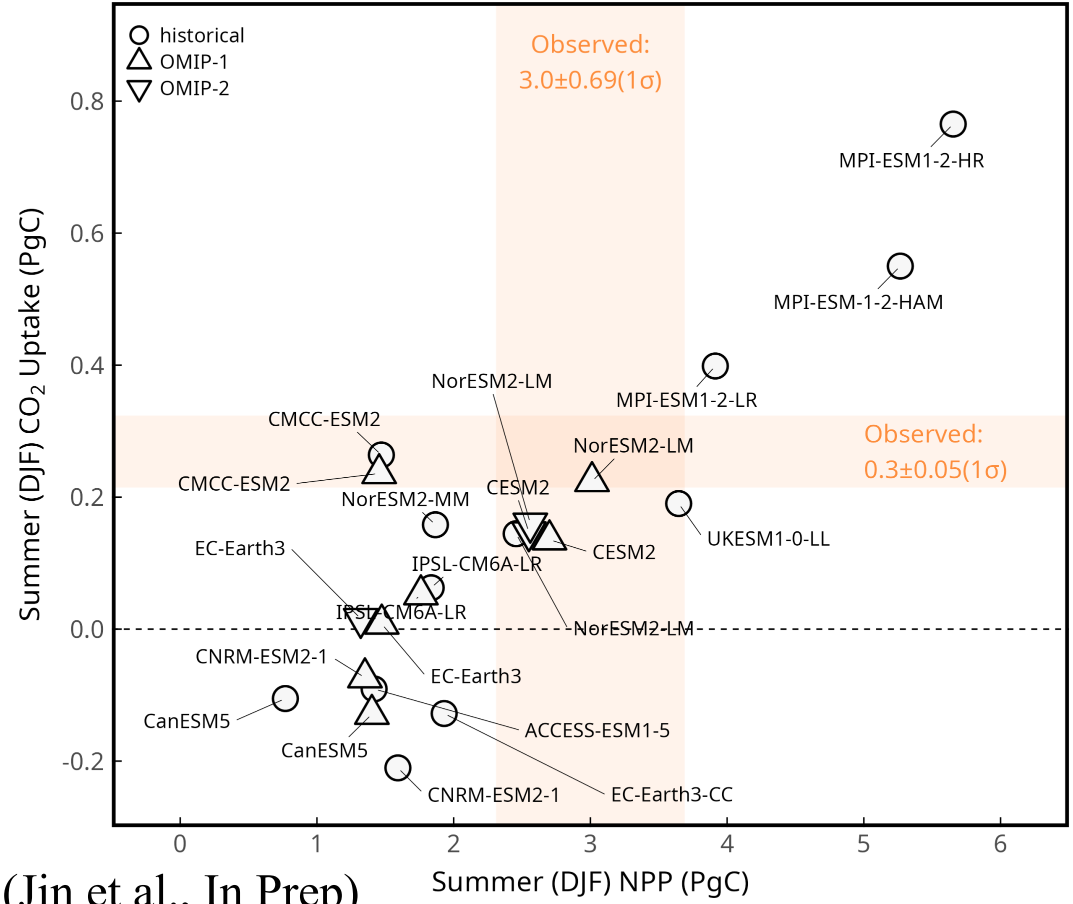


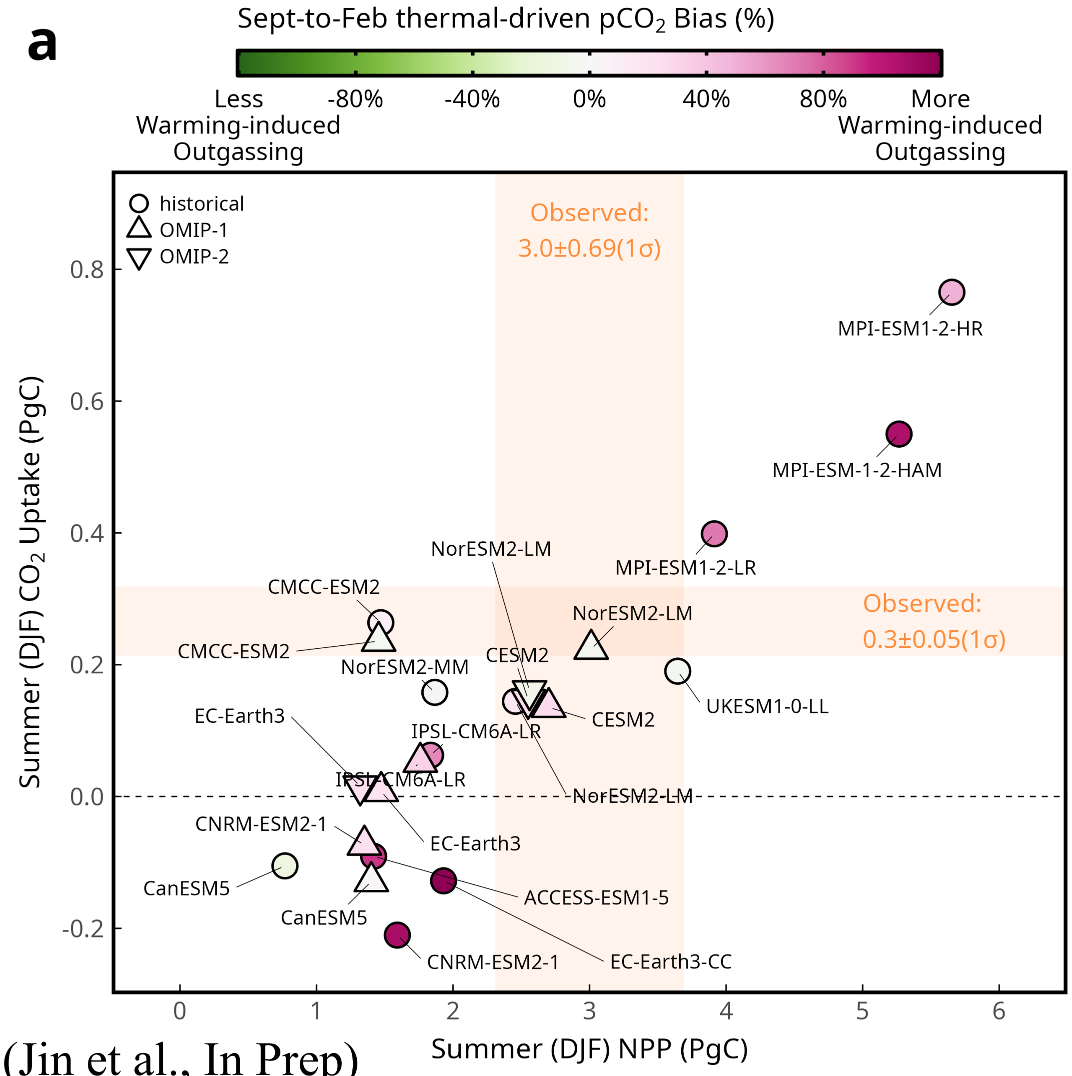


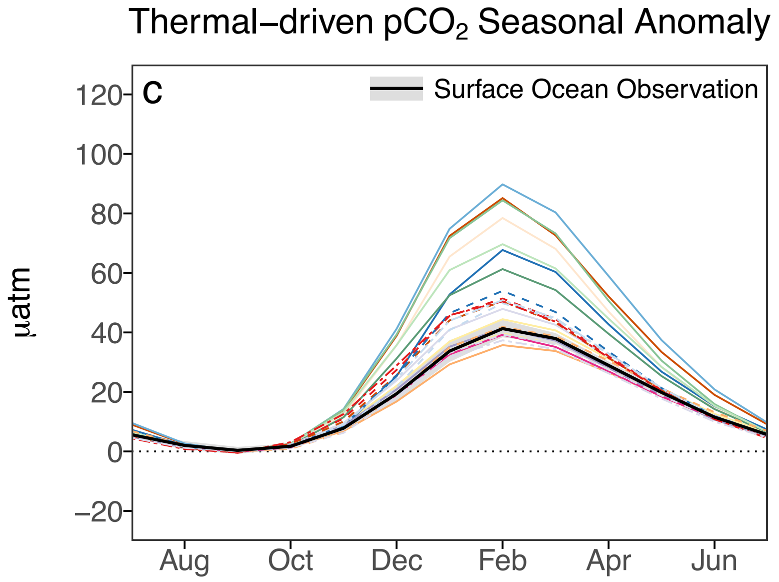
The constrained NPP (6.1 PgC) is consistent with *Johnson & Bif, NG, 2021* (~6.3), which was based on the diel cycle of O_2 from Argo.



(Jin et al., In Prep)

Most CMIP6 models underestimate NPP, and underestimate summertime CO_2 uptake.

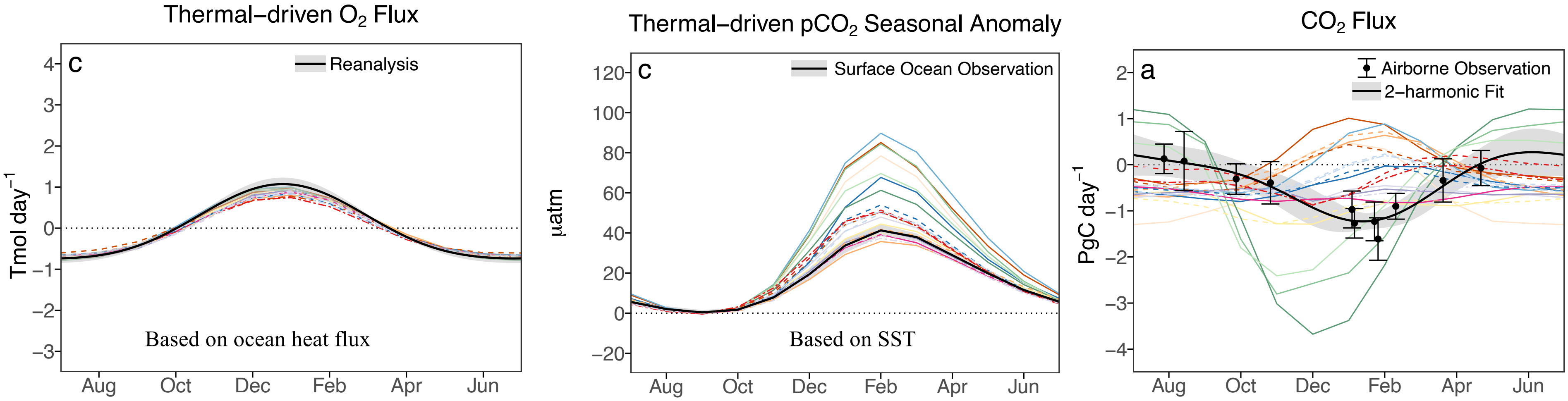




Most CMIP6 models underestimate NPP, and underestimate summertime CO_2 uptake.

Most models also overestimate thermal-driven CO_2 outgassing

(Jin et al., In Prep)



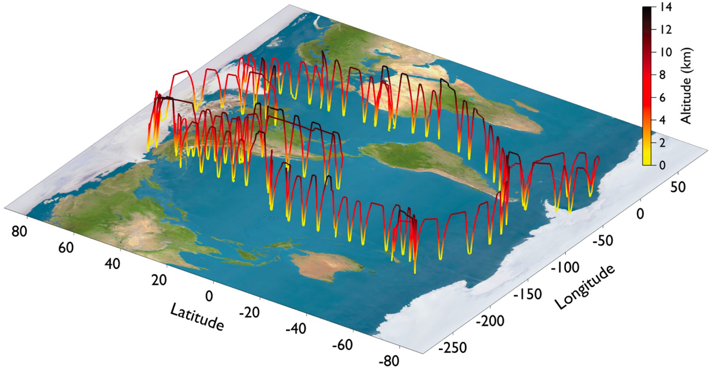
Biases in modeled Southern Ocean CO_2 uptake might relate to **circulation and other physical biases**, which affect heat redistribution, SST, and nutrient that determine the thermal and biological controls of CO_2 uptake.

(Jin et al., In Prep)

Next?

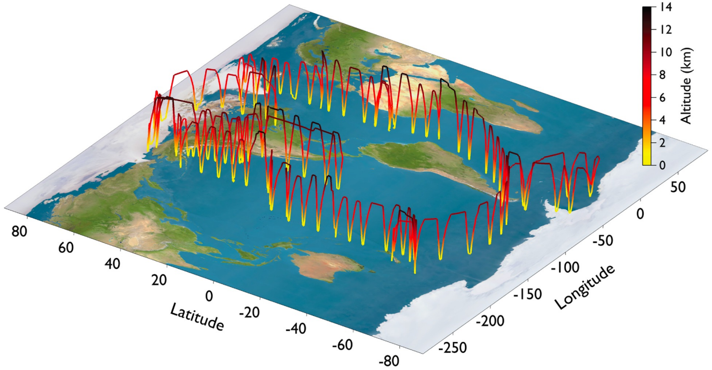
1. Repeating airborne campaign 2-4 weeks per year has the potential to constraint trend and IAV.

- 2 transects per campaign
- As many vertical profiles as possible



Contact: yumingjin@ucar.edu

Next?



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    - Atmospheric data provide better spatial integration at large scales
    - Oceanic data provide better spatial resolution at small scales

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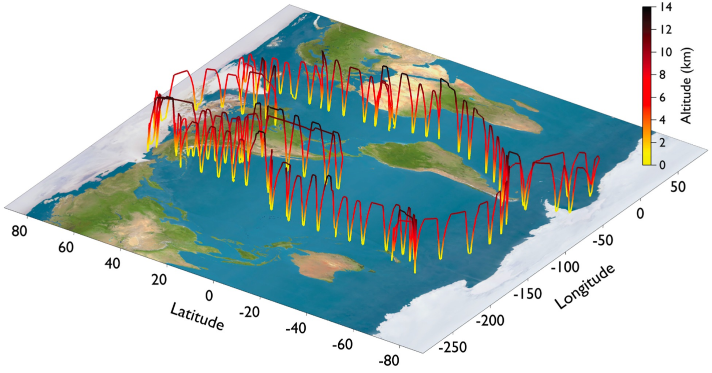

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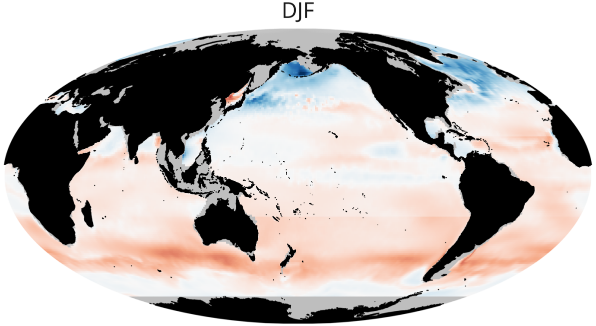

Air-sea O_2 flux derived from ML-interpolated DO data (GOBAI, Sharp et al., ESSD, 2023) and various gas exchange schemes that include bubble effects suggests a consistent seasonal flux cycle compared to airborne estimates.

(Jin et al., In Prep)

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