Decoupling of carbon and heat uptake rates of the global ocean over the 21st century

Eric Mortenson[1]

Andrew Lenton[1], Elizabeth Shadwick[1], Xuebin Zhang[1], Matt Chamberlain[1]

[1]CSIRO-Hobart

Motivation

- Global oceans are a major sink of anthropogenic CO_2 and heat.

- Air-sea exchange of heat and carbon are driven by similar mechanisms (e.g. air-sea difference, winds).

- How does the air-sea exchange of these two quantities evolve through the century? Do they follow similar or divergent pathways?

- Does an eddy-resolving (0. 1°) model better capture air-sea exchange of heat and carbon than a coarse resolution (1°) model, such as CMIP5 simulations?

Deciphering Patterns and Drivers of Heat and Carbon Storage in the Southern Ocean

Haidi Chen[1], Adele K. Morrison[2], Carolina O. Dufour[3], and Jorge L. Sarmiento[1]

Similar work:

Deciphering Patterns and Drivers of Heat and Carbon Storage in the Southern Ocean

Haidi Chen[1], Adele K. Morrison[2], Carolina O. Dufour[3], and Jorge L. Sarmiento[1]

- Southern Ocean is a big player in ocean C and H storage

- Passive effect due to increased uptake due to anthropogenic C and H uptake

- Also, substantial effect due to ‘natural’ or ‘preindustrial’ ocean concentrations advected by anthropogenic changes to ocean circulation.

Air-sea-land carbon system

-Global ocean reservoirs:

from a budgetary perspective, the global ocean is a key reservoir in determining the atmospheric concentration of CO_2 (and surface temperature)

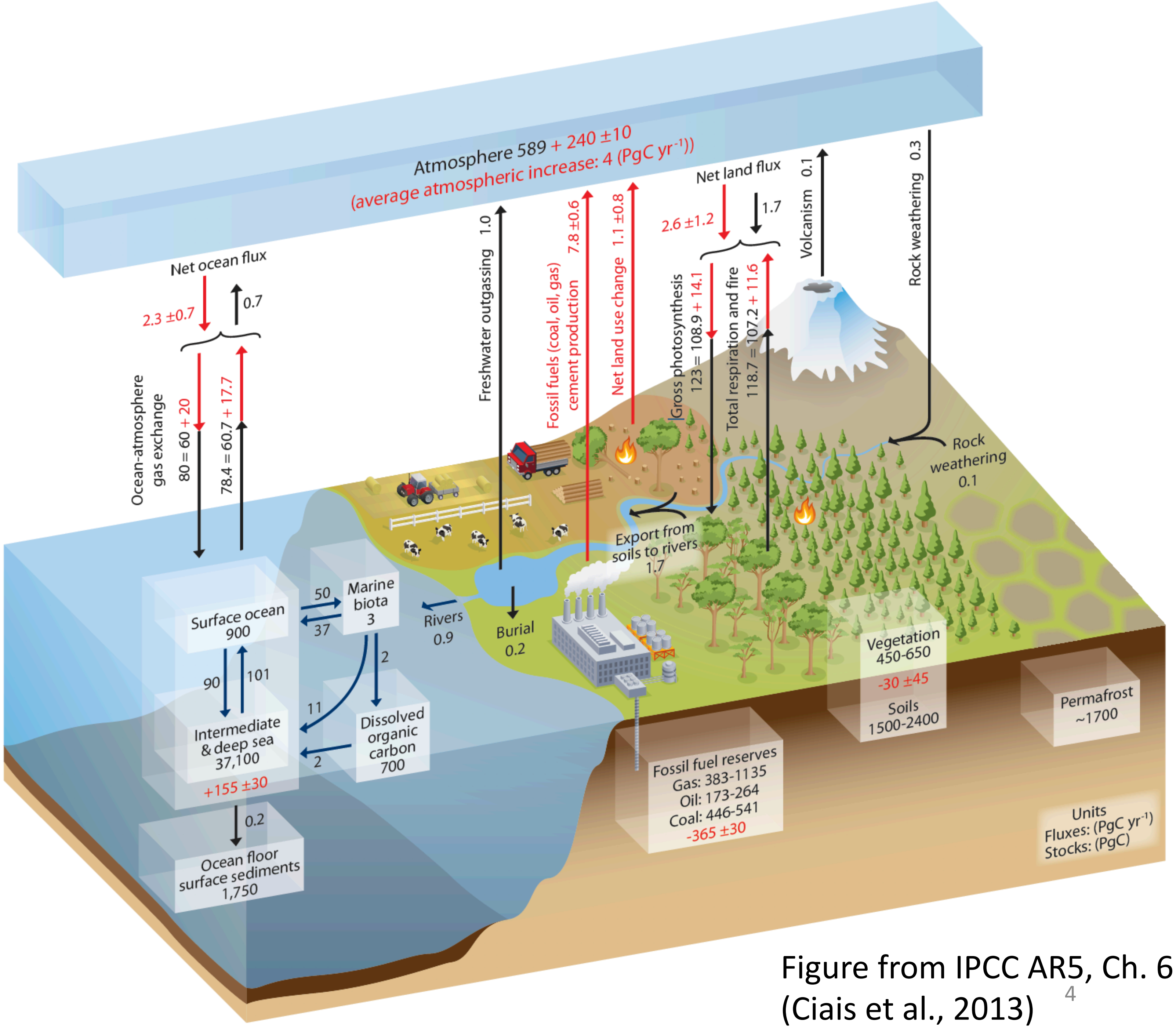


Figure from IPCC AR5, Ch. 6 (Ciais et al., 2013)

Air-sea-land carbon system

-Global ocean reservoirs:

from a budgetary perspective, the global ocean is a key reservoir in determining the atmospheric concentration of CO_2 (and surface temperature)

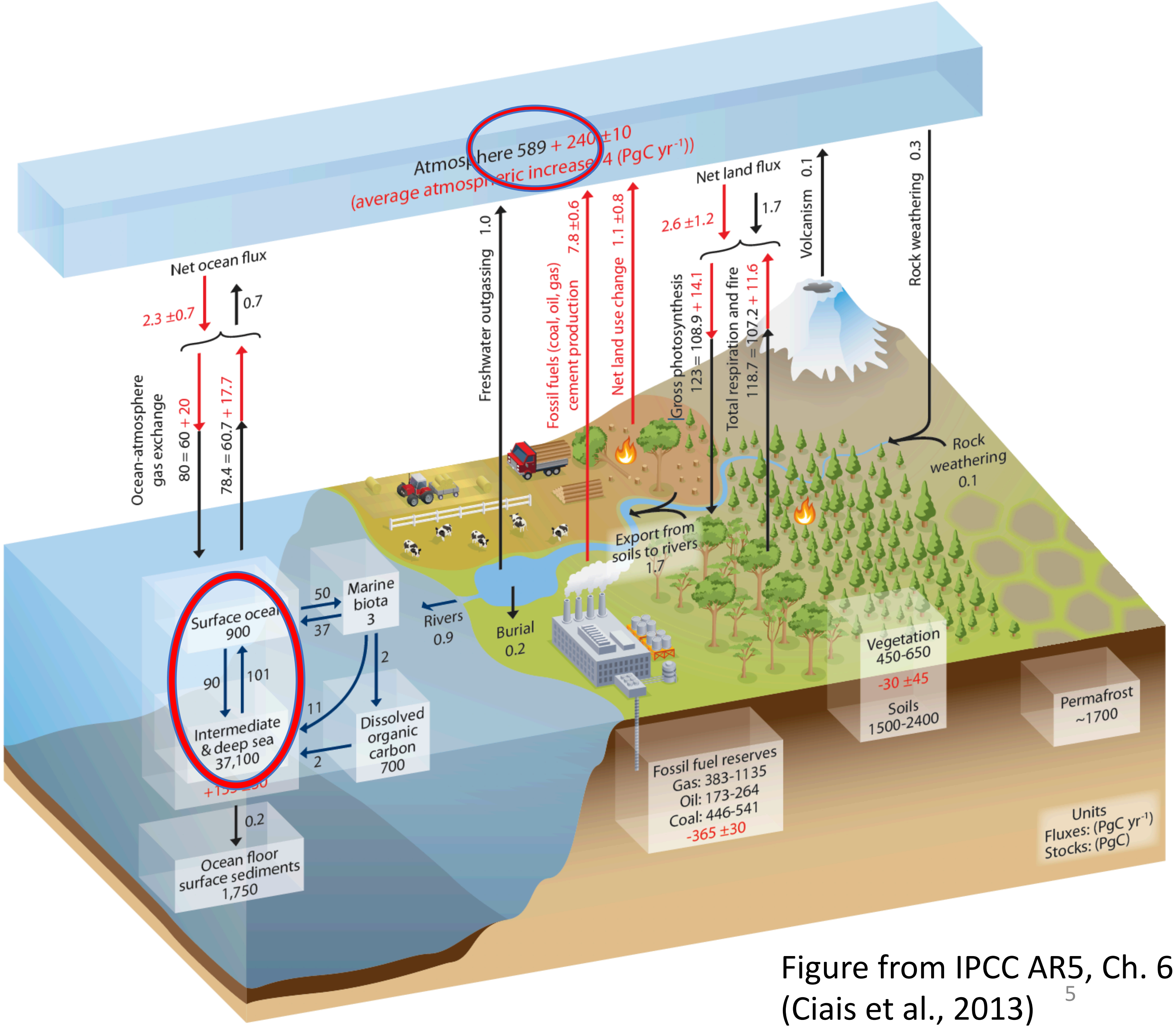
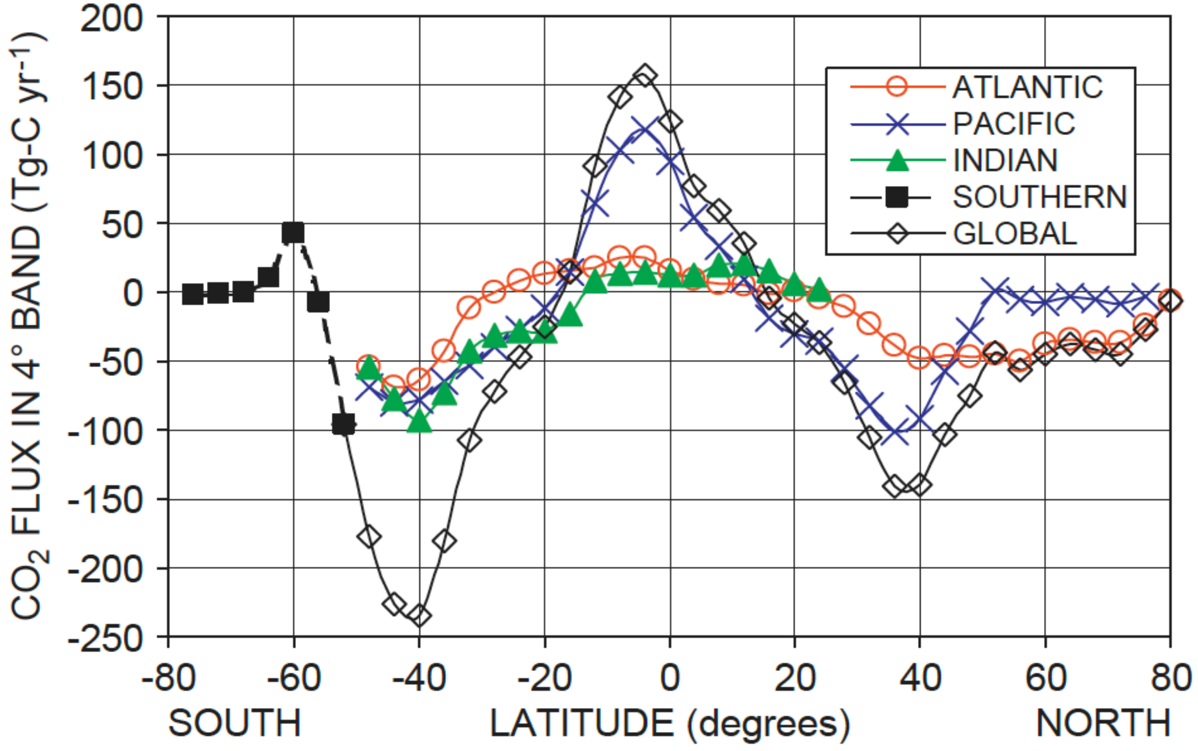


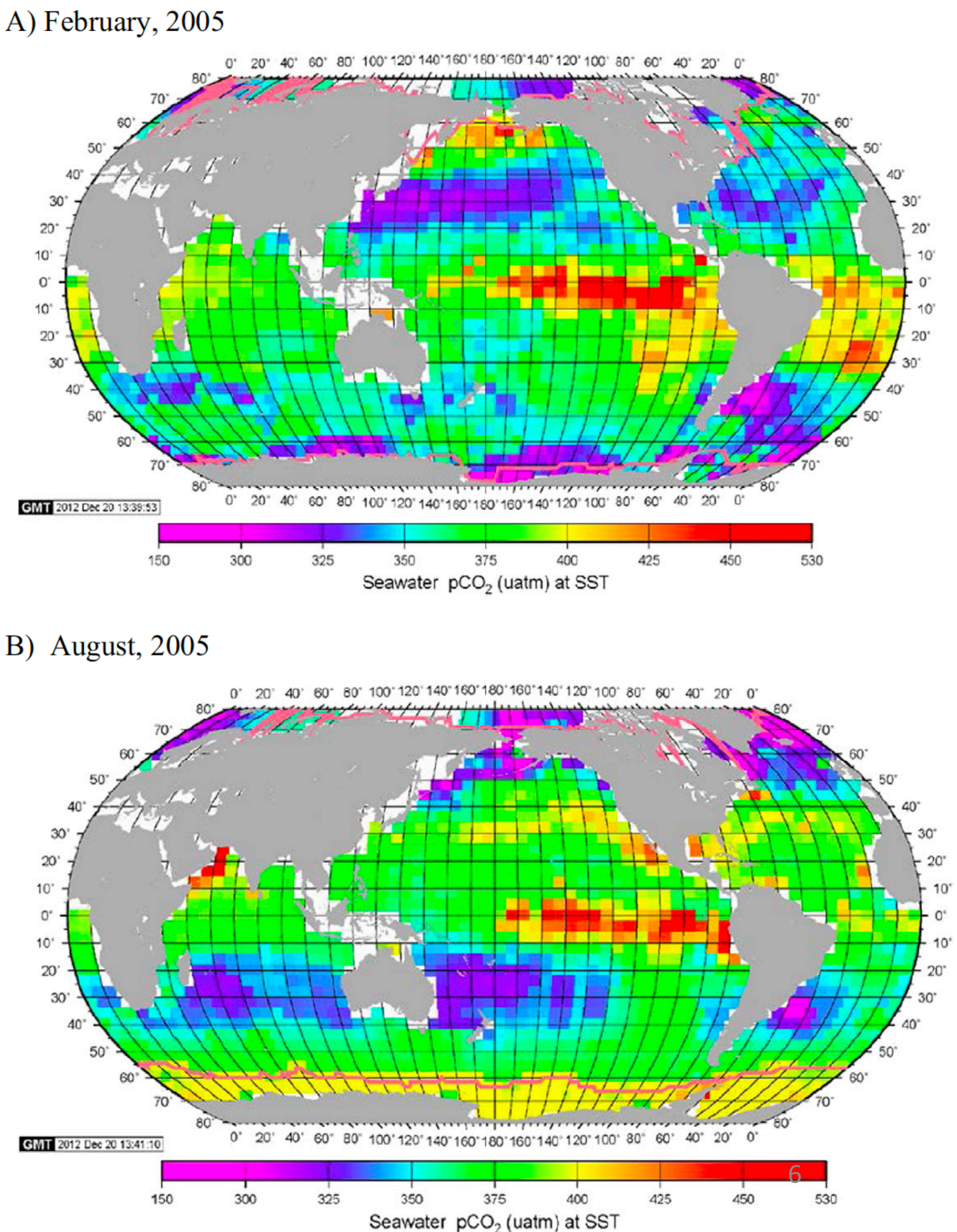
Figure from IPCC AR5, Ch. 6 (Ciais et al., 2013)

Air-sea CO_2 exchange

Subpolar oceans play an important role in ocean-carbon exchange



Takahashi et al., 2009 (above), and 2014 (right)



Global heat balance

-Long and short wave radiation

-Latent and sensible heat

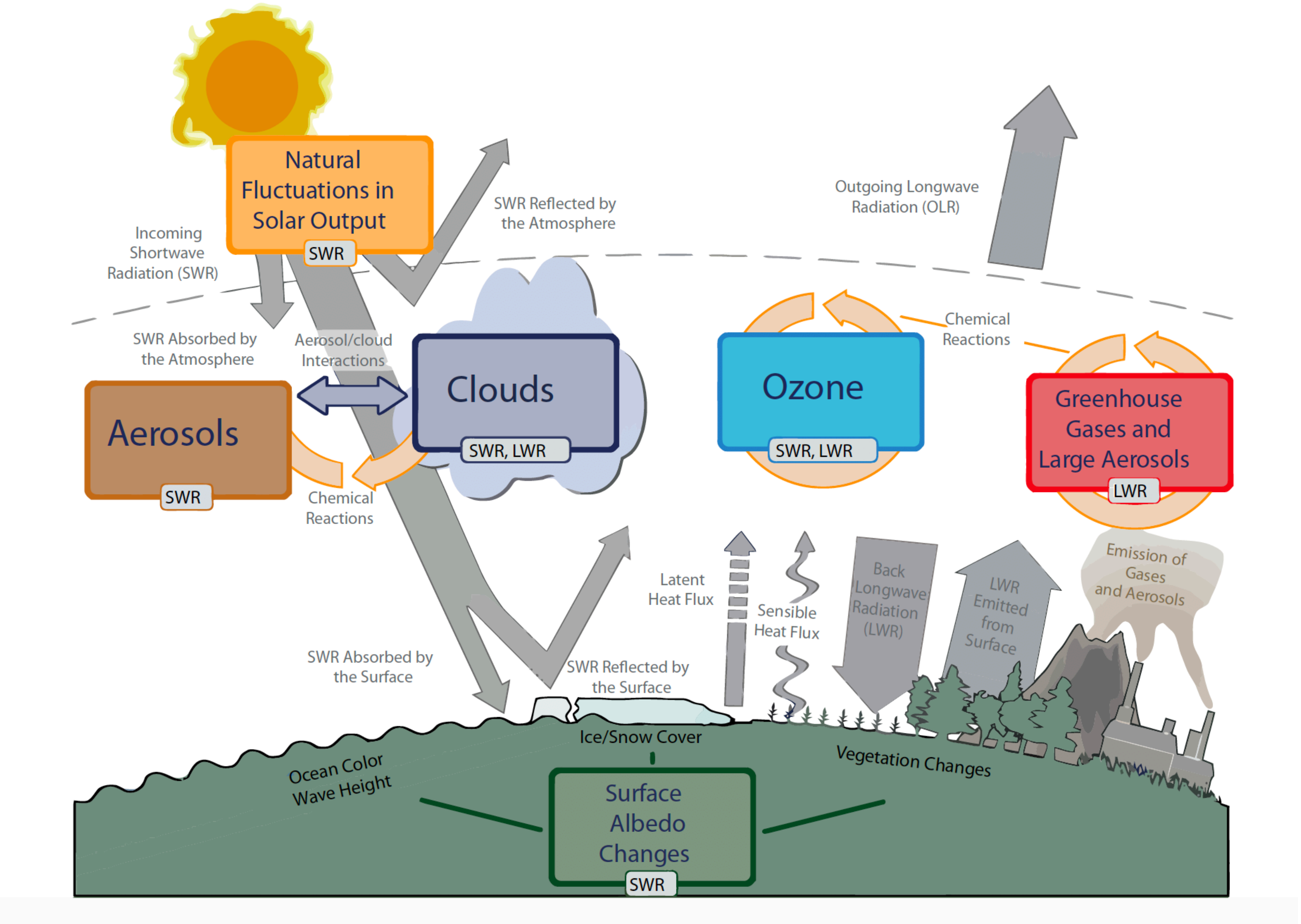


Figure from IPCC AR5, Ch.1 (Cubasch et al., 2013)

Ocean heat uptake

- Air-to-sea flux of heat is particularly strong around 40°S, with less pronounced peaks at the equator and 40°N

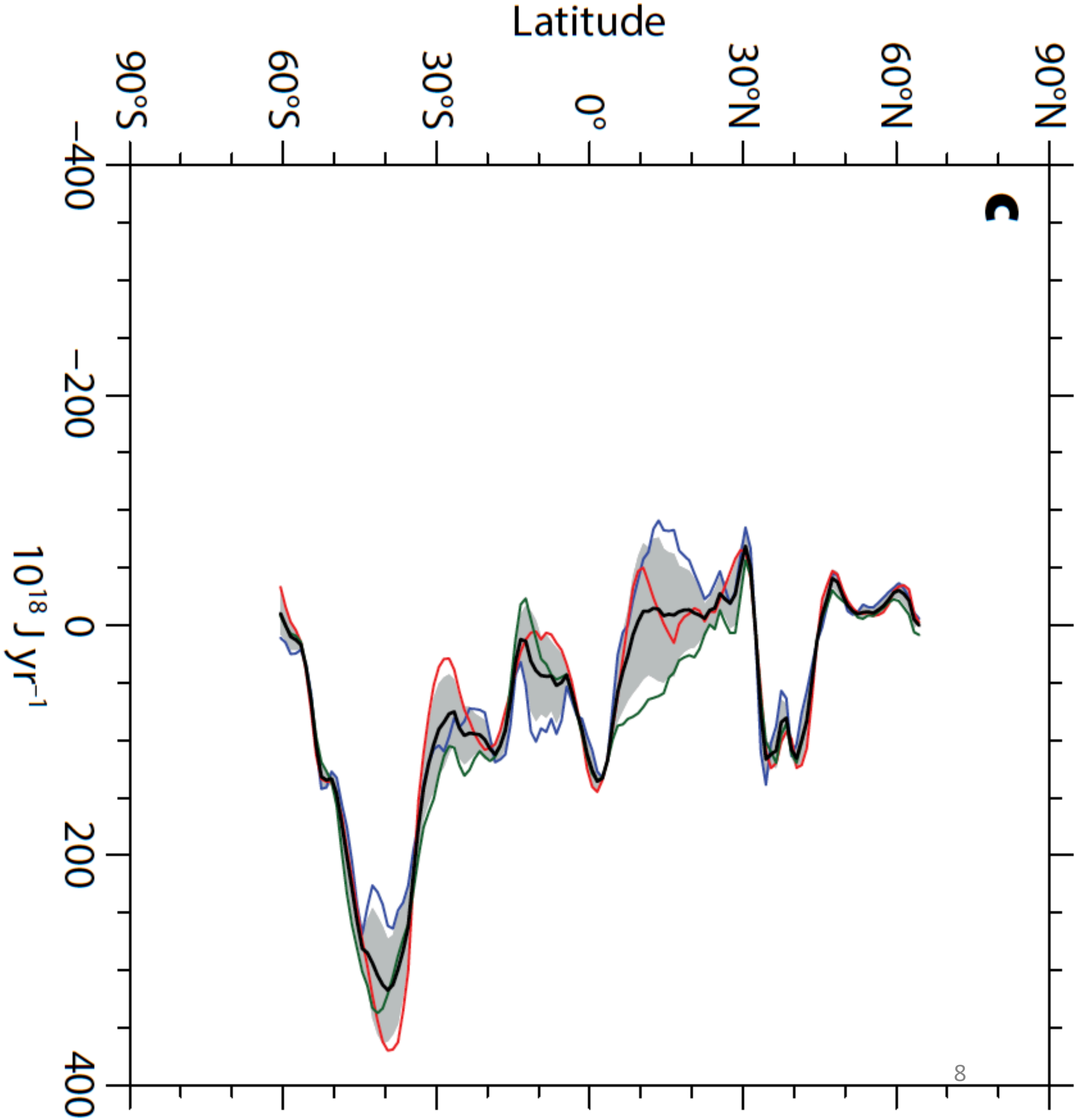
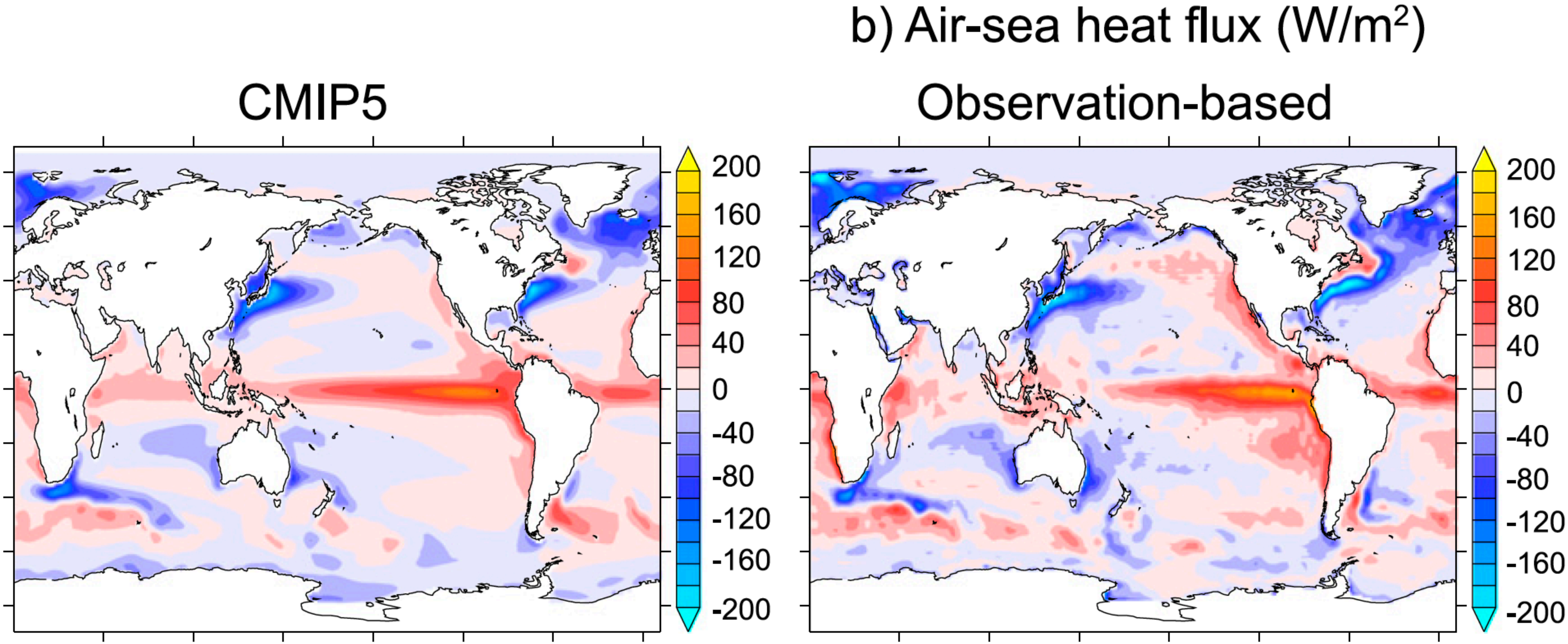


Figure adapted from Sallee et al., 2018

Figure adapted from:
Froelicher et al., 2015



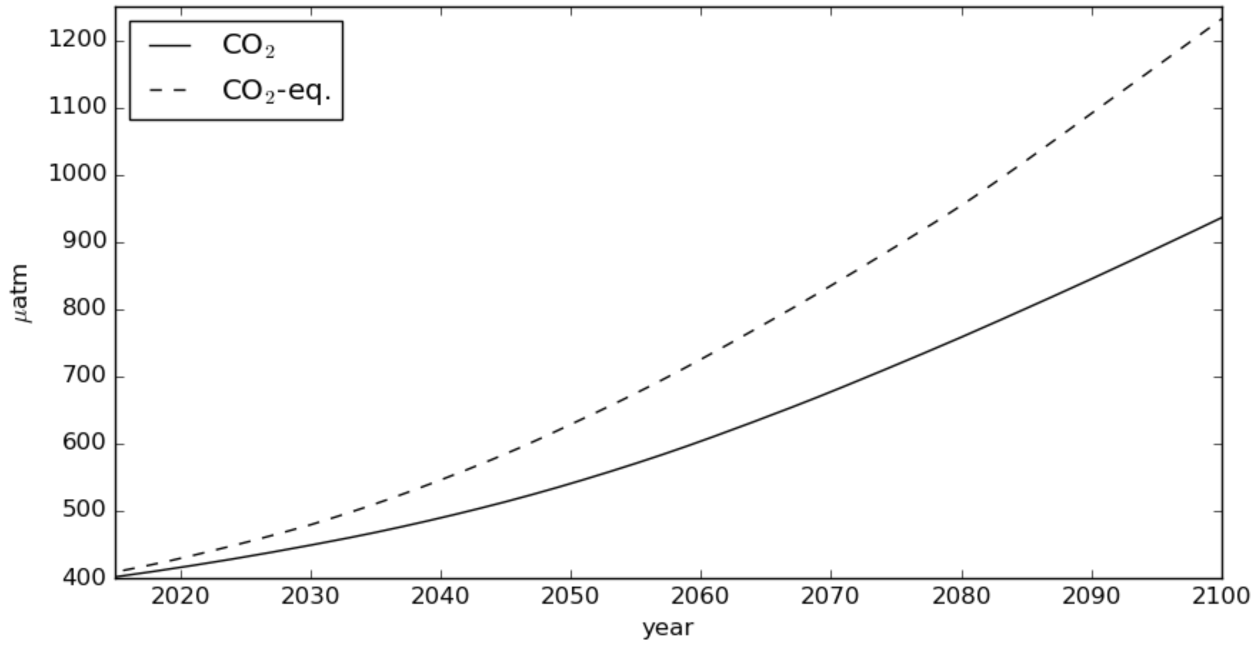
Ocean Forecasting Australia Model, vs. 3 (OFAM3)

- RCP8.5 scenario (2015-2100)
- 1/10 degree (eddy-rich)

resolution

- Biogeochemistry through WOMBAT
  - NPZD; nutrients = P, Fe
- Forcing through JRA55
- Historical analysis:

Atm. Forcing in RCP8.5



Evaluation of a near-global eddy-resolving ocean model

P. R. Oke, D. A. Griffin, A. Schiller, R. J. Matear, R. Fiedler, J. Mansbridge, A. Lenton, M. Cahill, M. A. Chamberlain, and K. Ridgway

A near-global eddy-resolving OGCM for climate studies

X. Zhang[1], P. R. Oke[1], M. Feng[2], M. A. Chamberlain[1], J. A. Church[1], D. Monselesan[1], C. Sun[2], R. J. Matear[1], A. Schiller[1] and R. Fiedler[1]

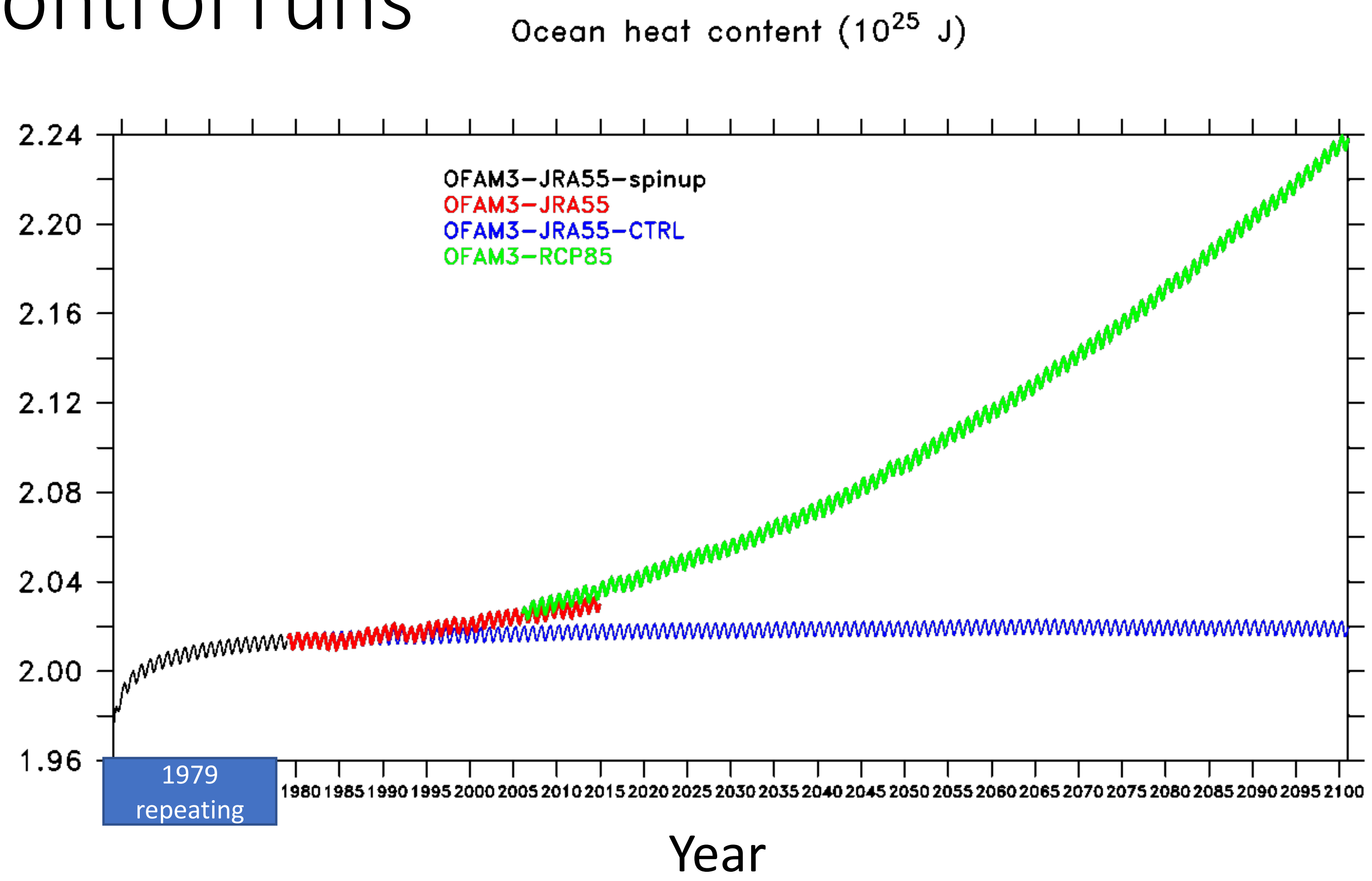
Downscaling with a global 1/10^{o} ocean model

- ***<u>Methodology</u>*** - ***<u>Dynamical downscaling</u>*** ***<u>(Giorgi et al. 2001; Flato et al. 2013):</u>***

How does the OGCM respond to climate change "perturbation" derived from CMIP climate models.

  - Derive present ocean climate: integrate a near-global 1/10^{o} OGCM (based on MOM4p1) over 1979 to 2014 with JRA-55 atmospheric reanalysis product $\mathbf{F_{present}}$
  - Estimate climate change signals $\mathbf{\Delta F_{CMIP5}}$ under RCP8.5 from 17 CMIP5 climate models for 9 atmospheric & oceanic variables.
  - Derive future ocean climate in the 21st Century by integrating the ocean model with merged future forcing $\mathbf{F_{future} = F_{present} + \Delta F_{CMIP5}}$.
  - The "downscaled" ocean changes are derived by comparing future and present ocean states.
  - A control run with repeating 1979 year forcing is run in parallel to quantify any artificial drifts.

OHC from spin-up, historical, future and control runs



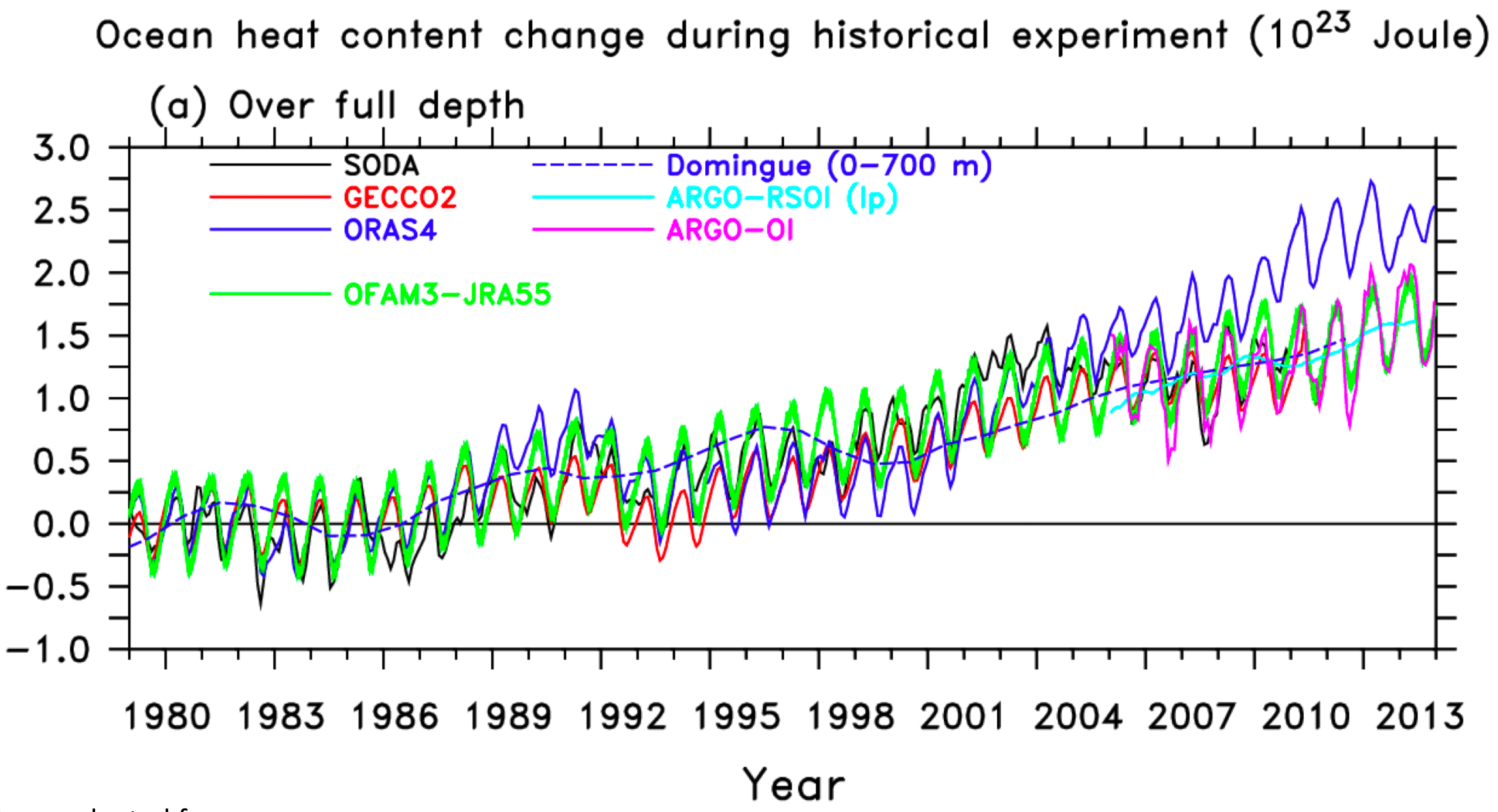
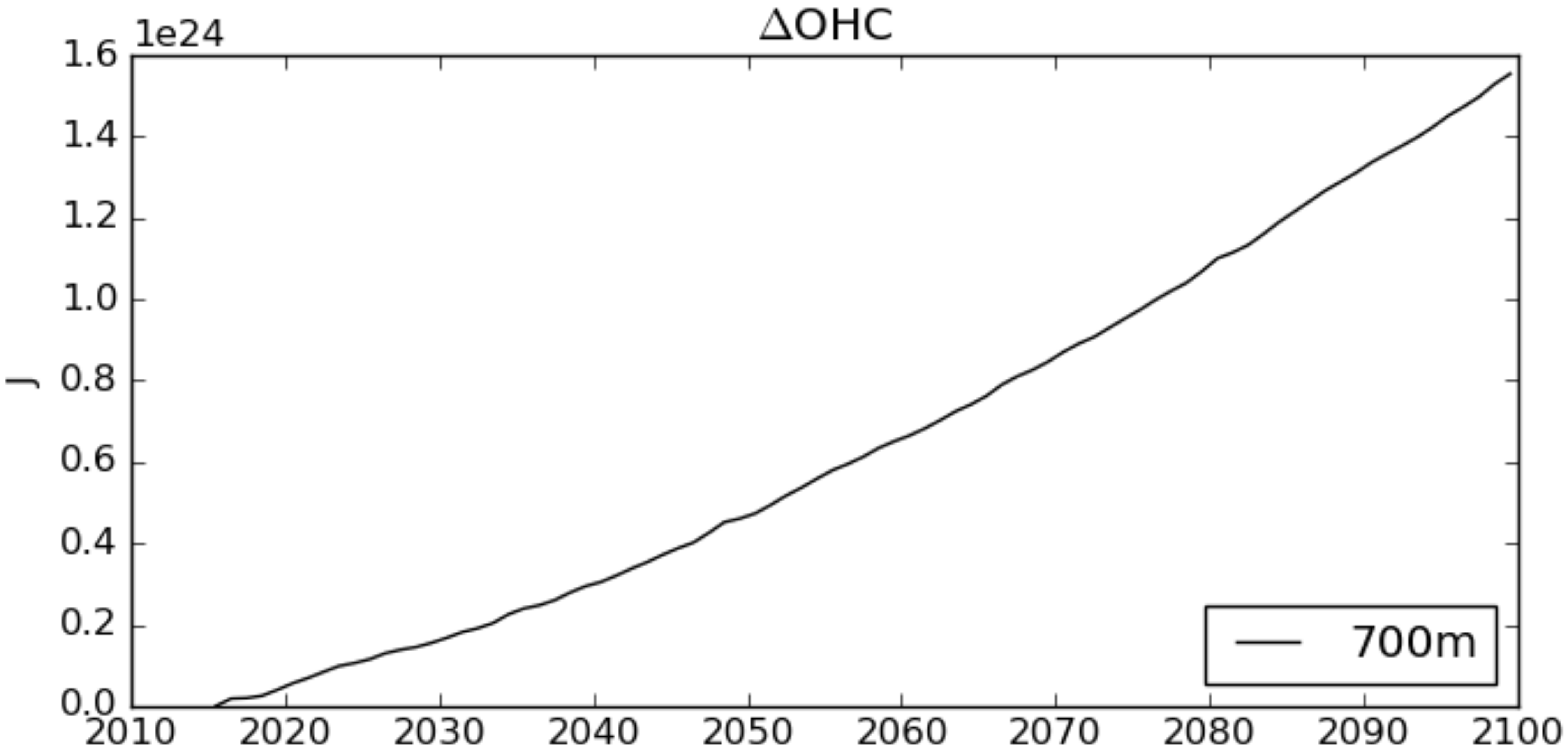


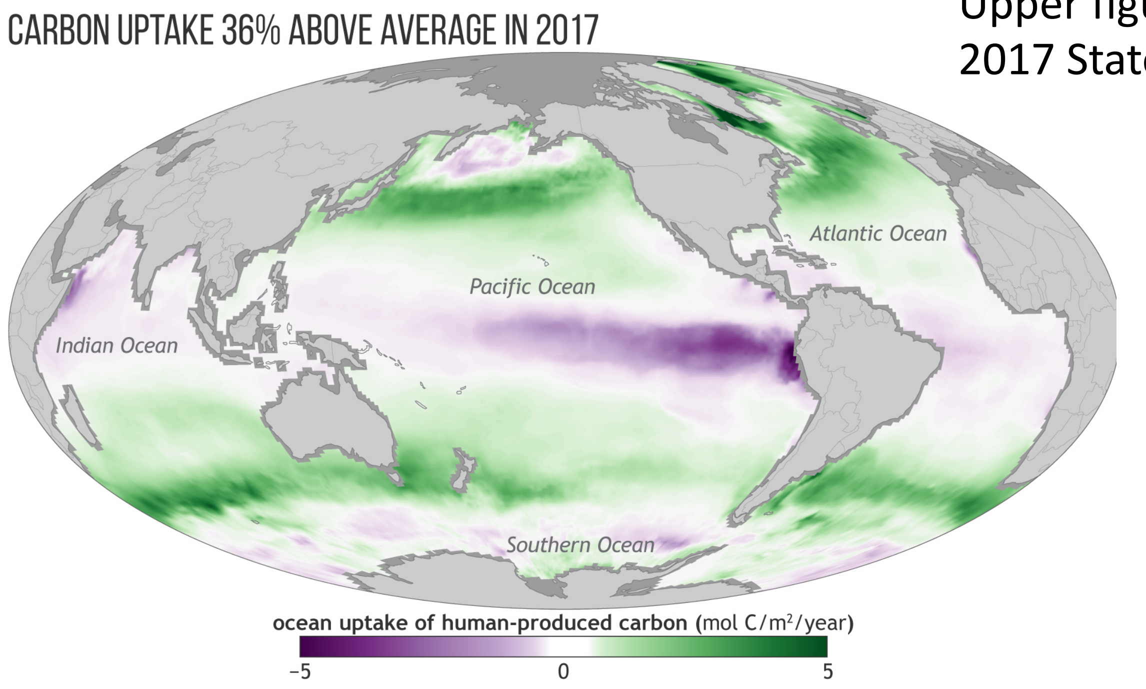
Figure adapted from:
Zhang et al., 2016

Historical change in OHC (previous slide):
ΔOHC = 15*10^{22} J over the period 1980-2010, or
~ 4*10^{22} J /decade

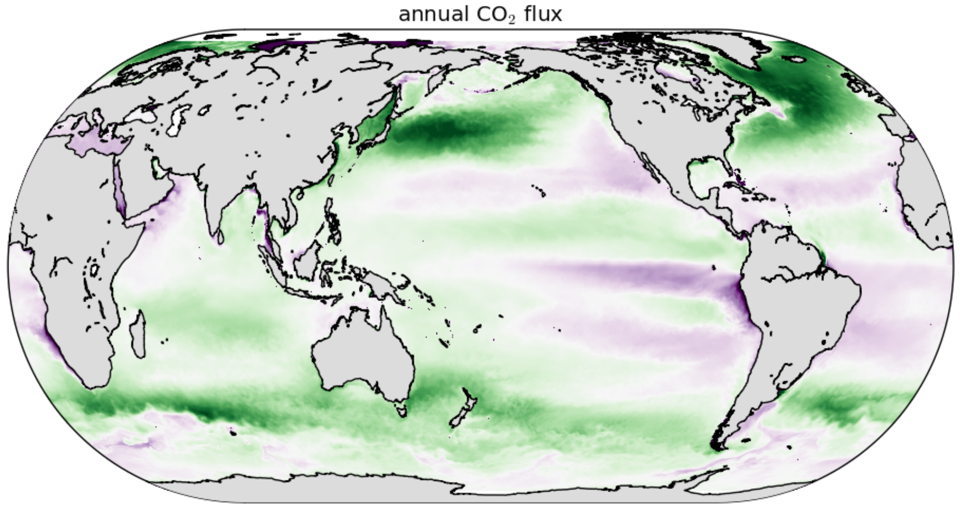
Projected change in OHC (below):
ΔOHC = 150*10^{22} J over the period 2015-2100 for RCP8.5, or
~ 17*10^{22} J /decade



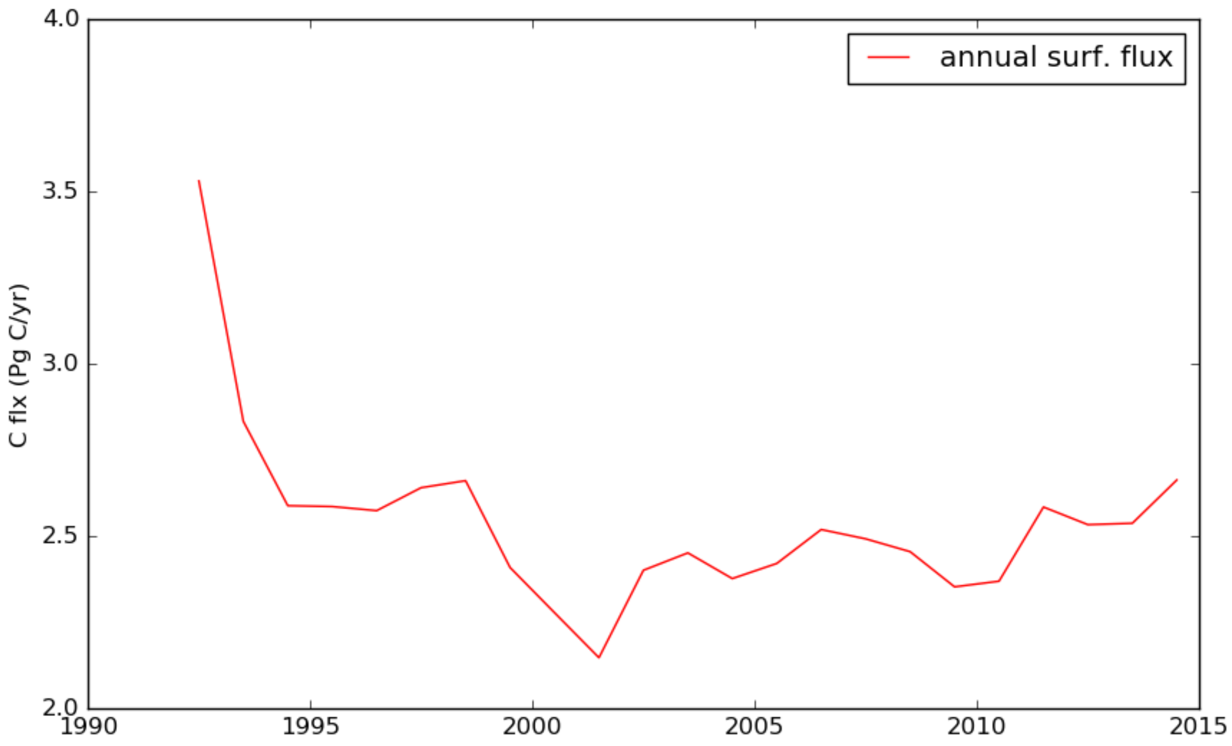
Upper figure adapted from:
2017 State of the Climate; Feely et al., 2018



Lower figure from OFAM, year 2017

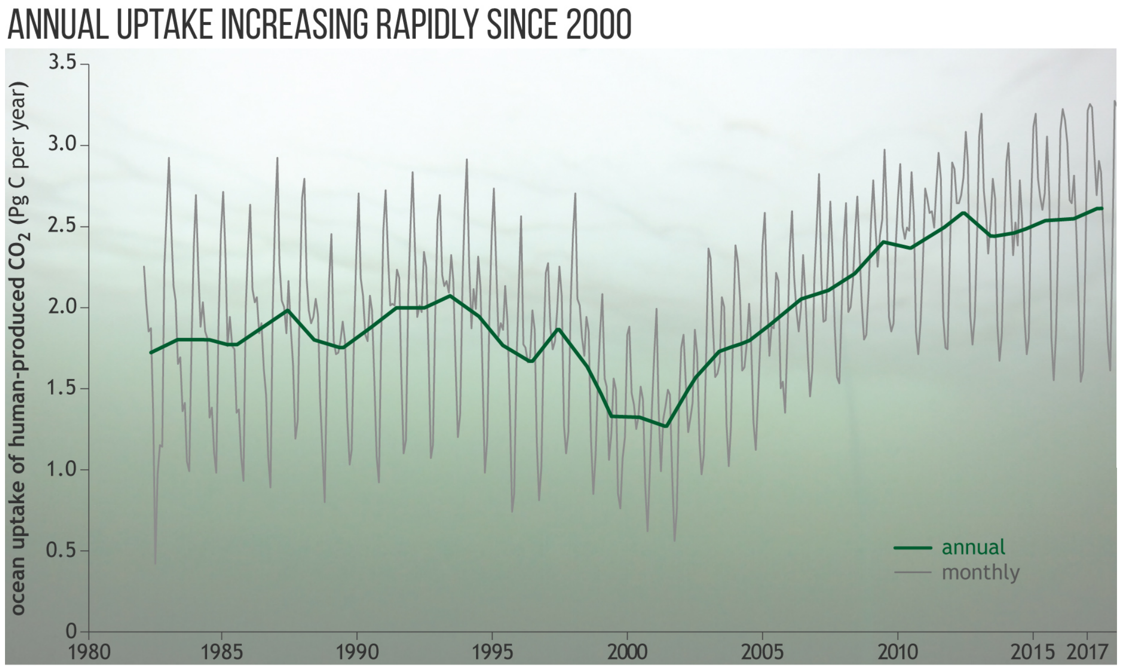


Carbon system spun up since early 1990's, with annual surface uptake in reasonable agreement with observations by the 2000's.

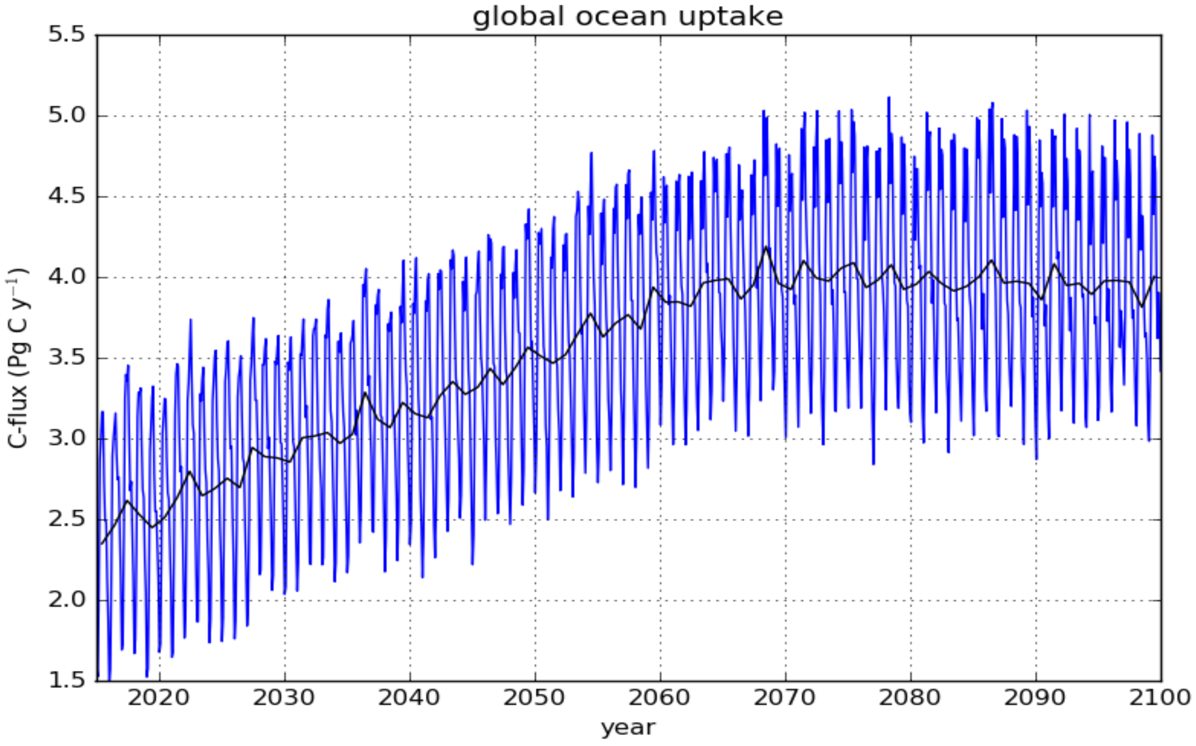


RCP8.5 scenario

The projected ocean uptake of carbon starts near observed present-day uptake rate, and increases until around 2070, after which it levels off.



NOAA Climate.gov, adapted from State of the Climate 2017



Seasonal range is consistent with recent observed range.

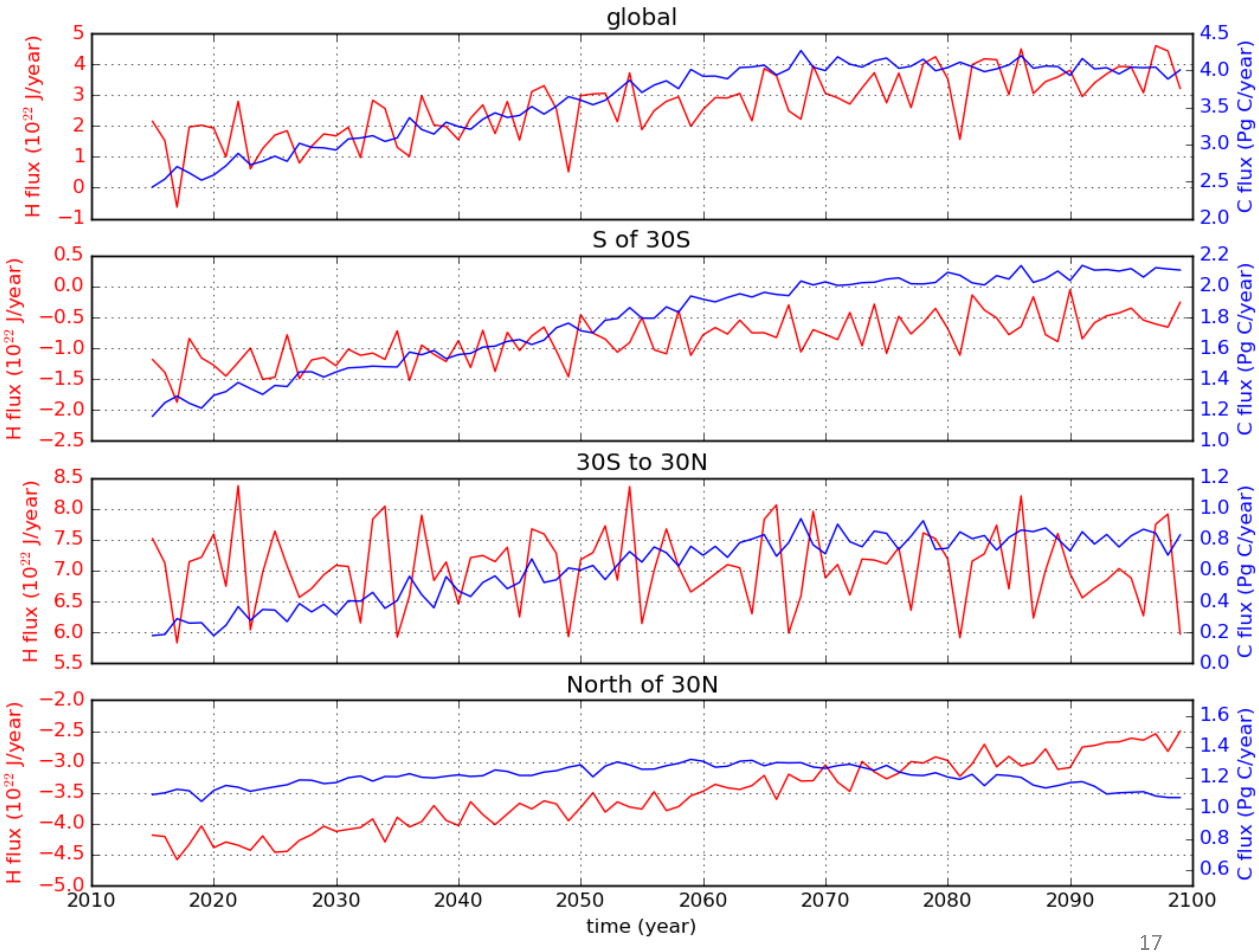
Global heat and carbon uptake, and zonal divisions.

-<u>Global:</u>
Steady increase in H uptake, but flat rate for C uptake after 2070

-<u>Southern zone:</u>
More marked increase in uptake of C than H

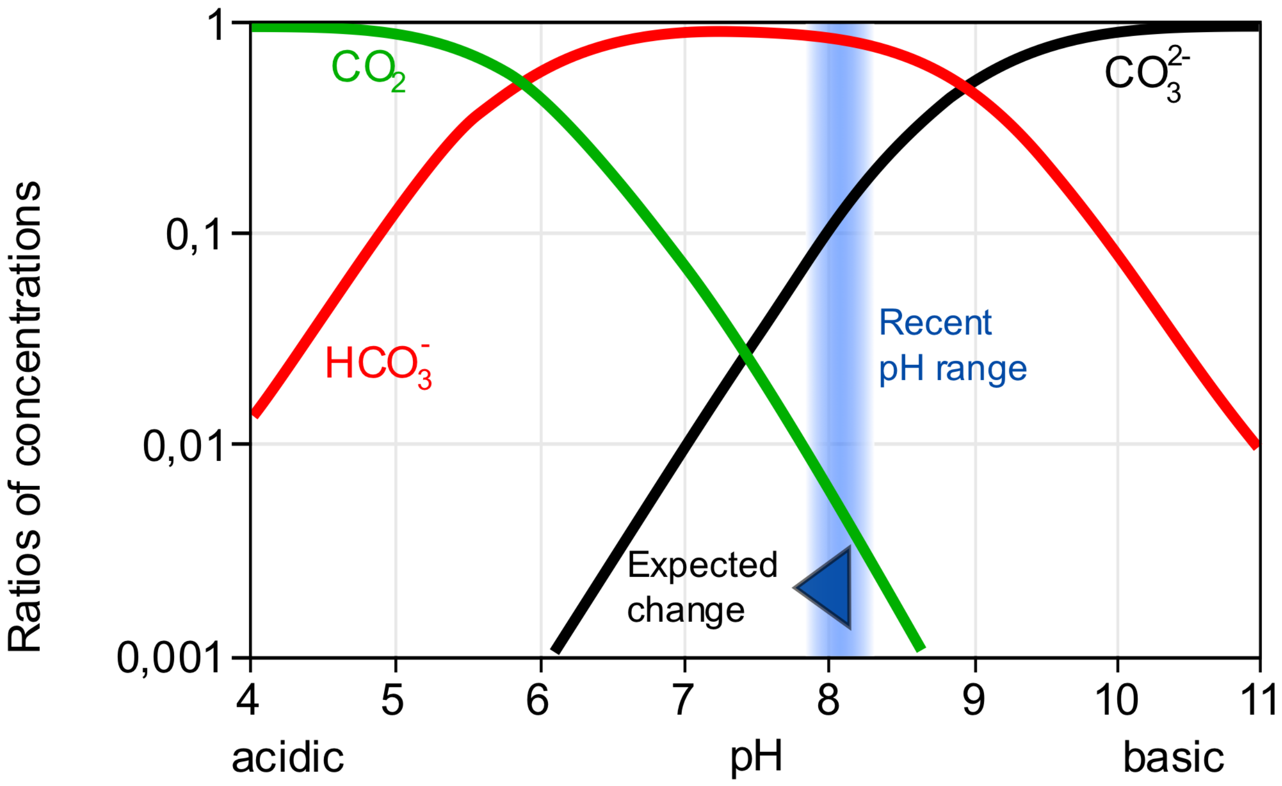
-<u>Equatorial zone:</u>
No increase in H uptake, slight increase in C uptake

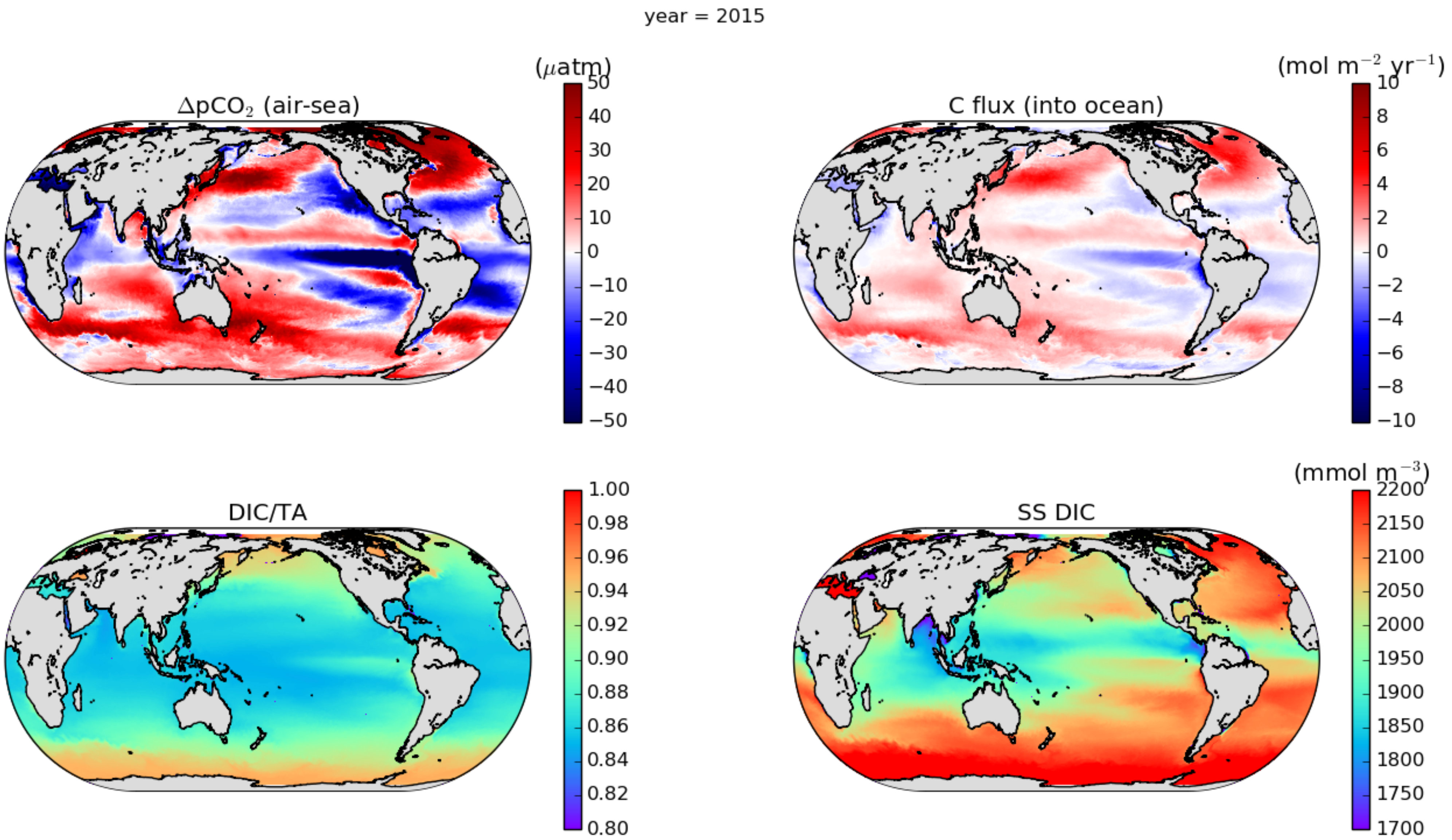
-<u>Northern zone:</u>
Steady increase in H uptake, and decrease in C uptake with a reduction in C-uptake after 2070



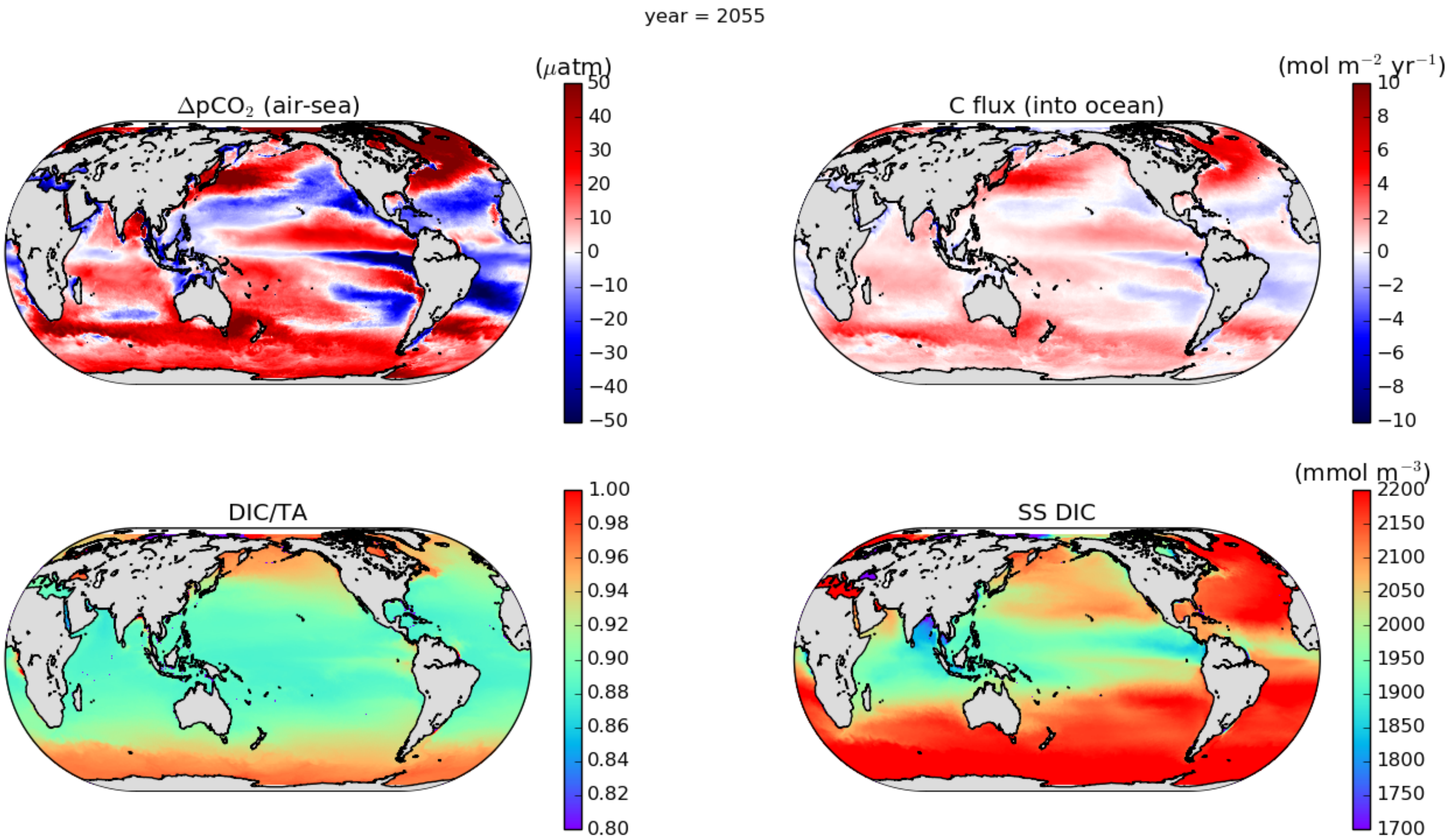
Possible reasons for weakening C uptake

- Increasing ocean temperature
  (of about 2.5 C over the century)
- Revelle factor:
  $(\Delta pCO_2 / \Delta DIC) / (pCO_2 / DIC)$
  I.e., the uptake capacity of the oceans decreases with lowering pH (due to C uptake).
- Decreased in rate of increase for prescribed atm CO_2
- Decreased mixing in regions of carbon uptake
  (but not where heat is taken up)

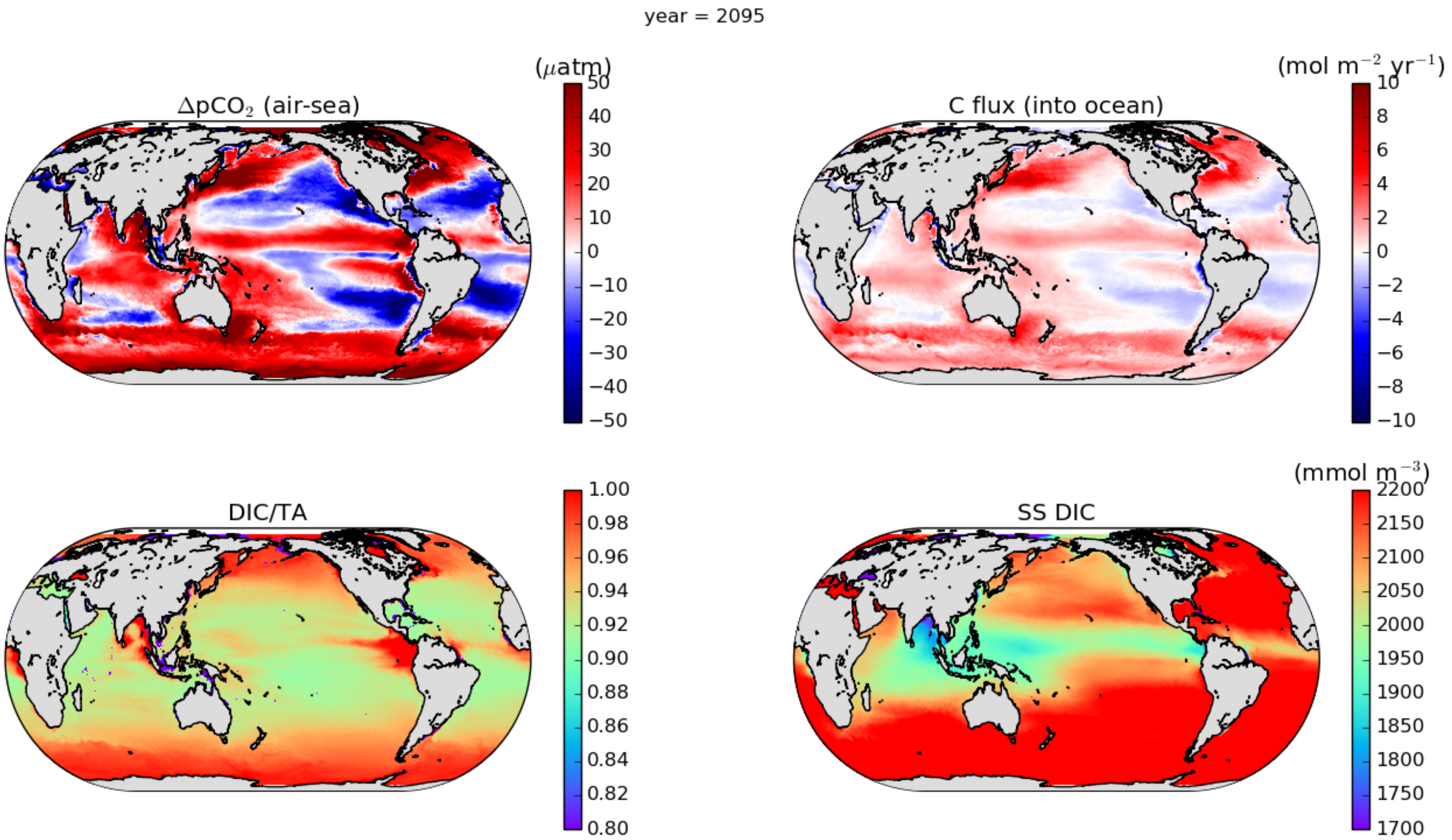




DIC/TA = proxy for Revelle factor



DIC/TA = proxy for Revelle factor



DIC/TA = proxy for Revelle factor

Future work:
Identifying the roles of heat and carbon

Anthropogenic radiative forcing RCP8.5 atm pCO_2	Anthropogenic radiative forcing Preindustrial atm pCO_2
Preindustrial radiative forcing RCP8.5 atm pCO_2	Preindustrial radiative forcing Preindustrial atm pCO_2

Conclusions

- Changes to annual heat and carbon content of the ocean are consistent with observations.
- Oceanic carbon is spun up from the early 1990’s, and consistent with observations by the beginning of the RCP8.5 run.
- Projected global ocean budgets of carbon and heat increase through the 21st century, but the rate of carbon increase levels off by the end of the century.
  - Why the leveling off? Revelle factor? Increase SST? Rate of atm pCO_2 increase? Mixing?
- As in the past, a large proportion of the increase in both occurs in the Southern Oceans, with a peak around 40°S