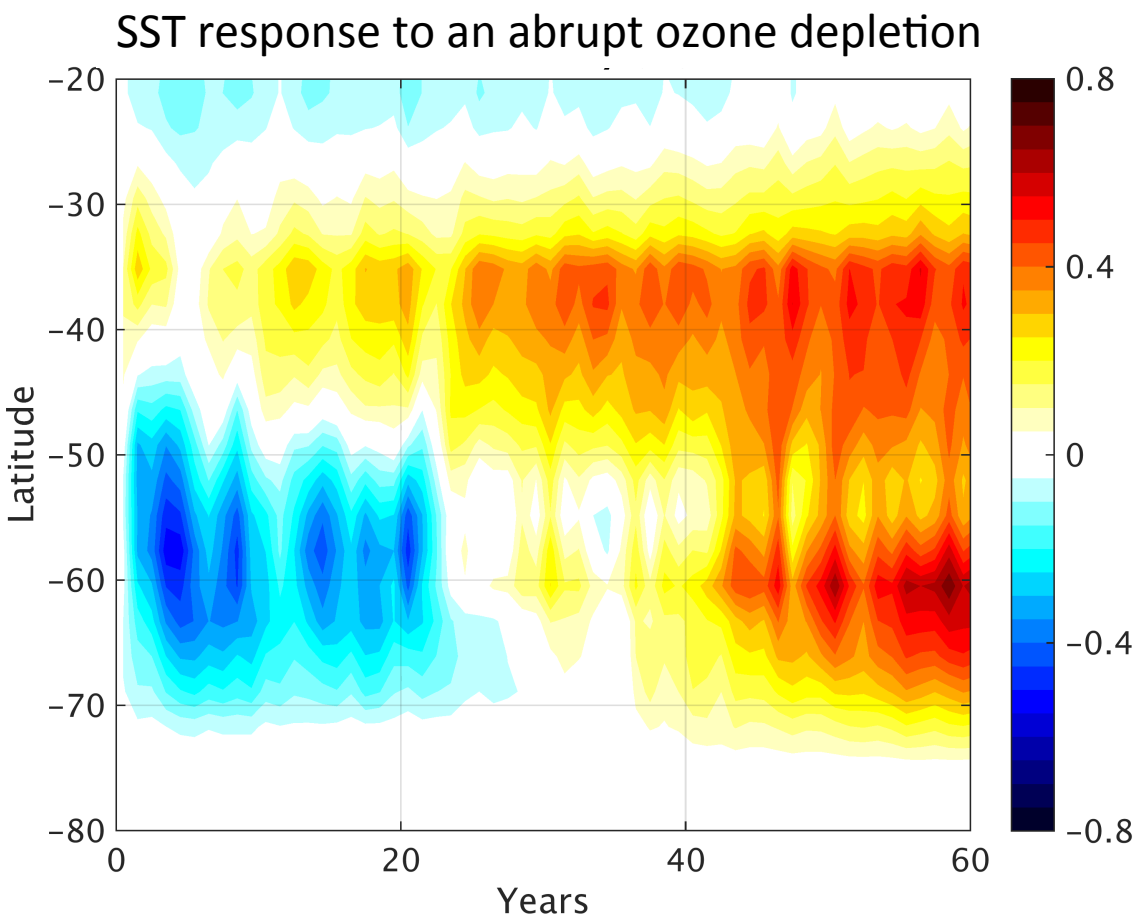
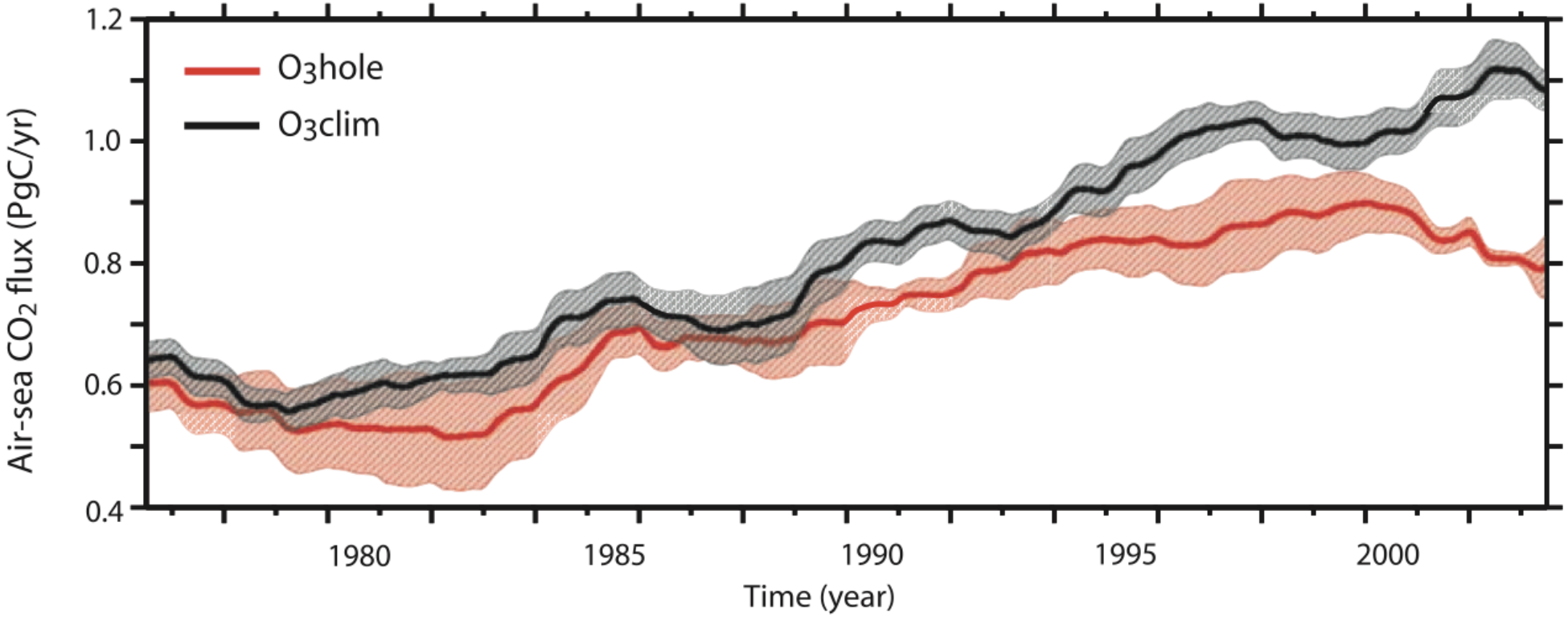
The two-timescale of the carbon cycle: it's not just like SST

David Ferreira, University of Reading



CO2 uptake in the Southern Ocean

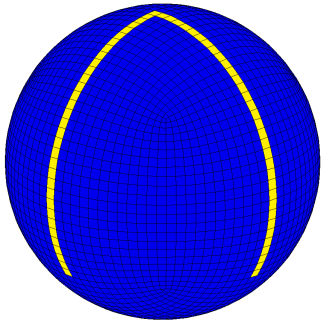
Lenton et al. 2009



- Slow down of CO_2 uptake in the Southern Ocean
  → LeQuere et al. 07, 09, but Landschutzer et al. 2015

- Carbon cycle response to Southern Hemisphere wind changes:
  → Kickfeld et al. 2007, Menfield et al. 2008, and d'Orgeville et al. 2010

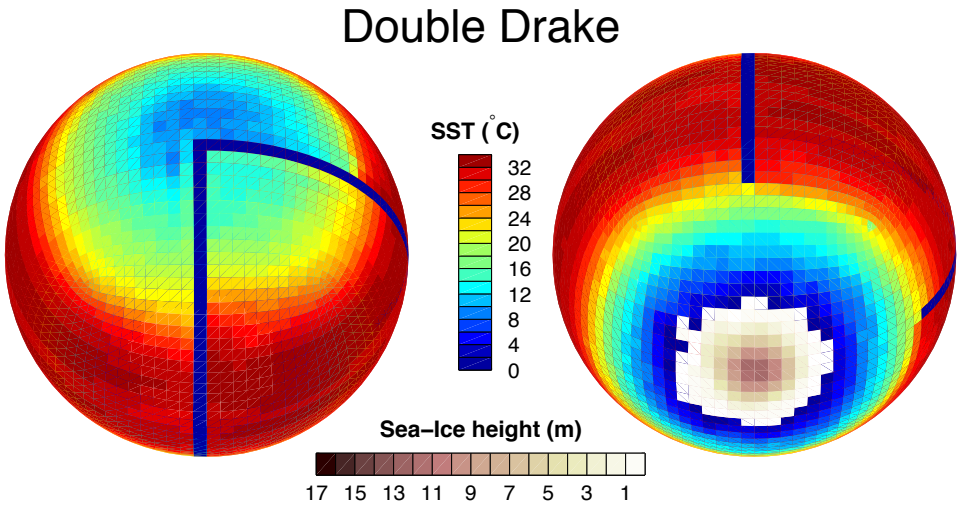
Coupled Ocean-Atmosphere-Sea ice MITgcm



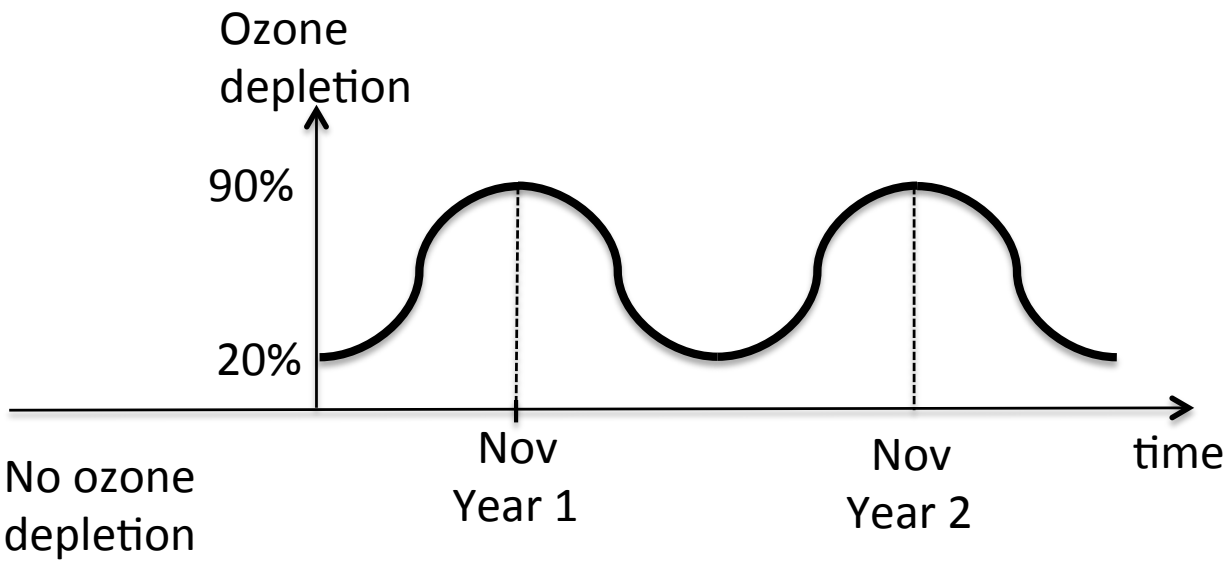
Response to a step "Ozone-depletion" in Double-Drake

- Simplified 5-layer atmosphere:

-> effect of lower stratosphere ozone is parameterized

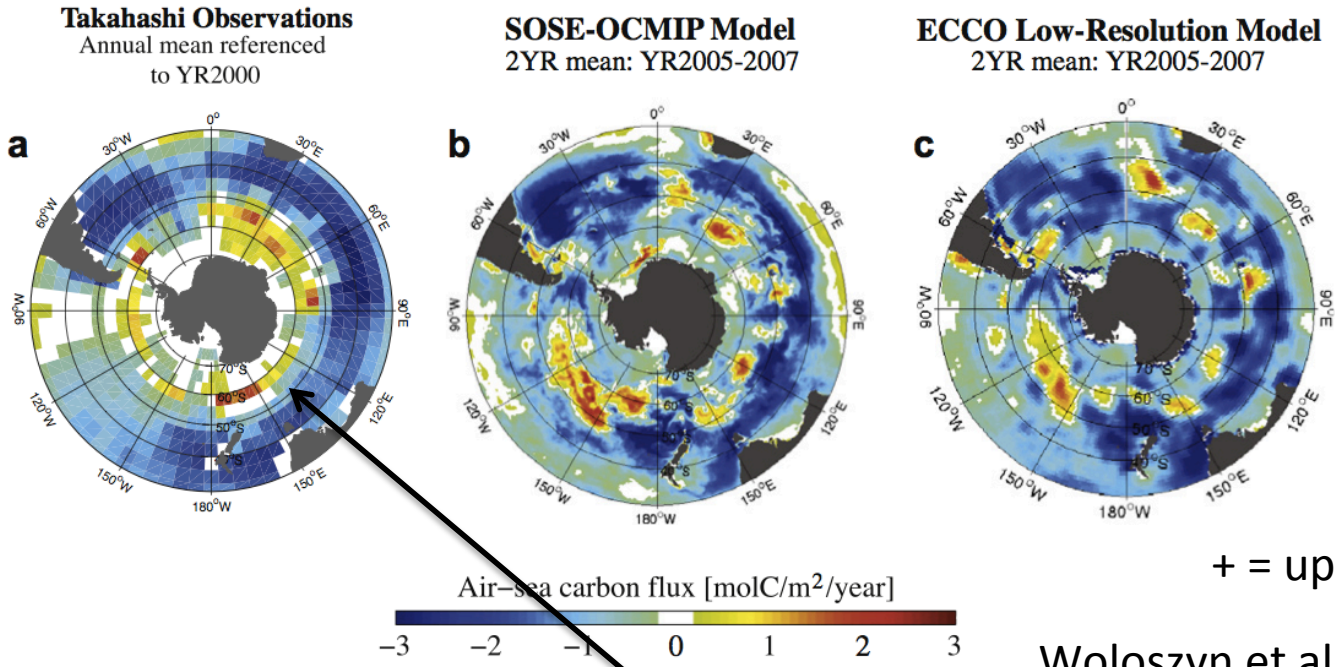


A repeated mid 90s Ozone hole:



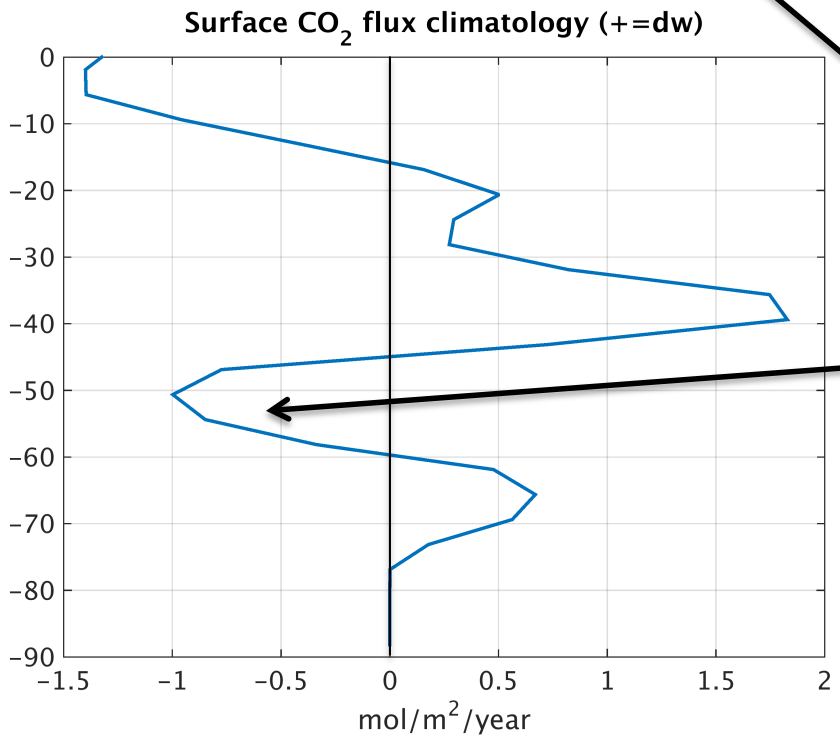
- a minimum 20% depletion
- increasing to 90% in Oct/ Nov
- 20 realizations, 40-y runs

Air-sea CO_2 flux climatology



+ = up

Wolosyzn et al. 2011

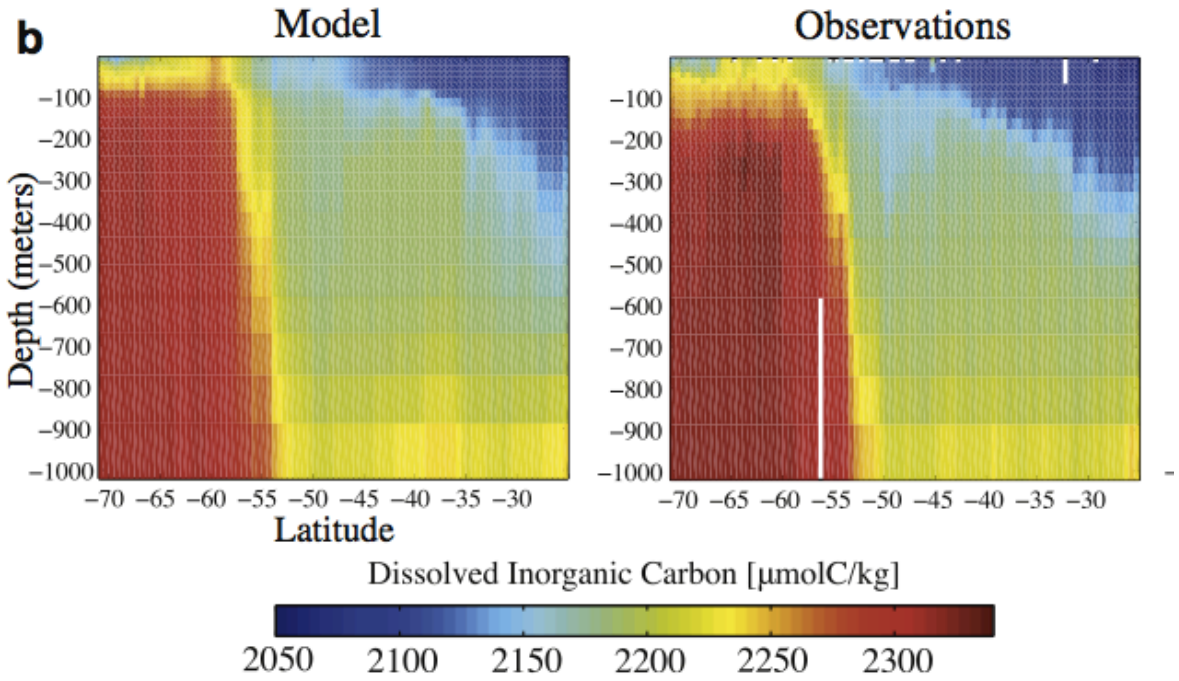


Latitude

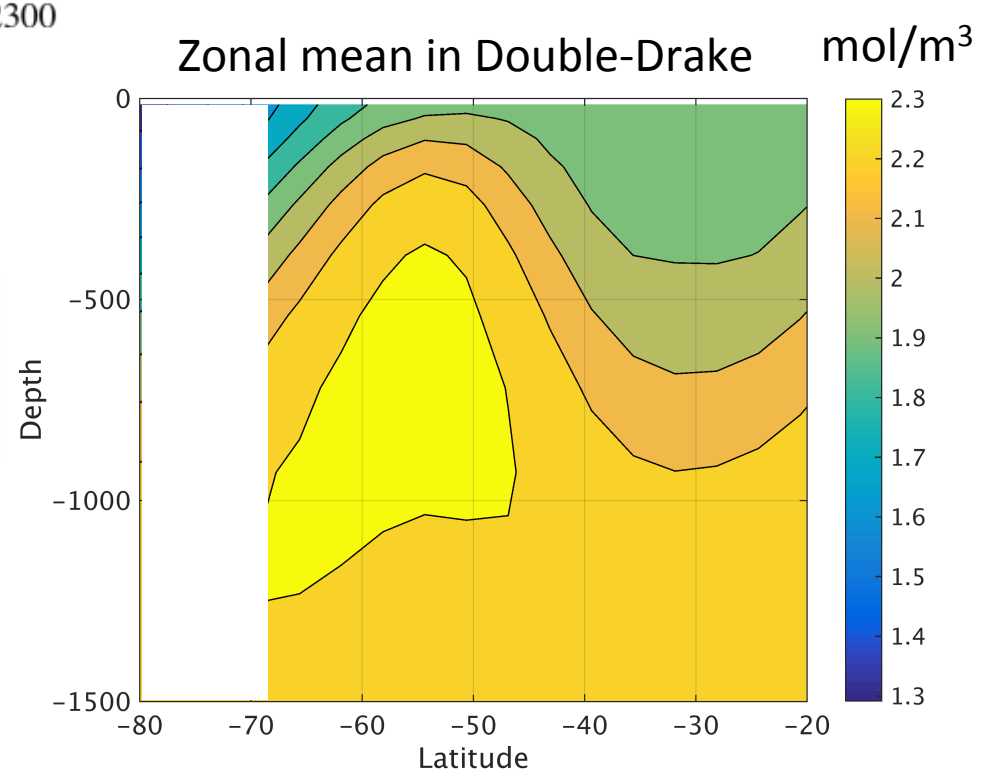
Outgassing

Pacific section

Woloszyn et al. 2011

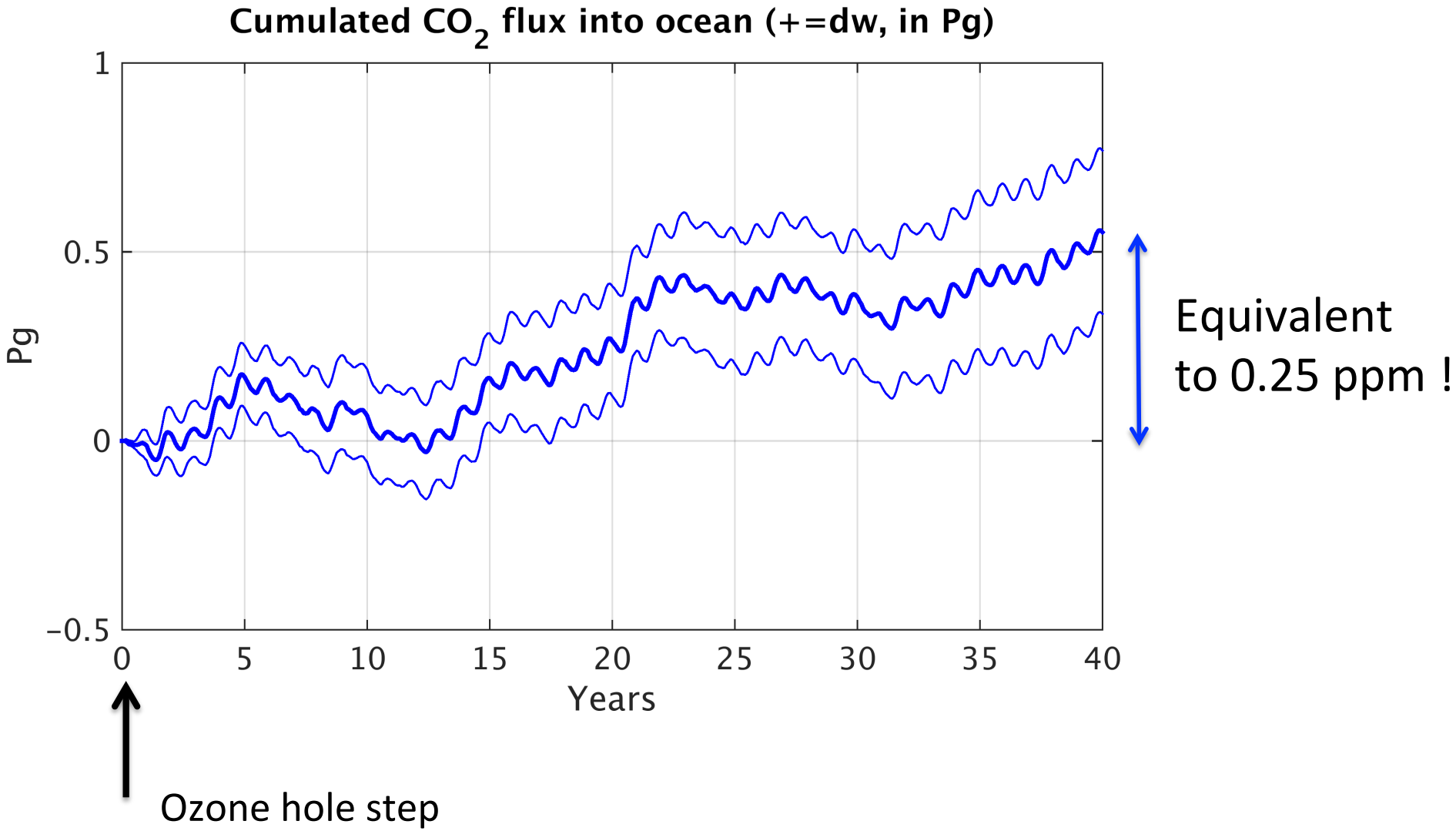


Dissolved inorganic carbon (DIC) distribution



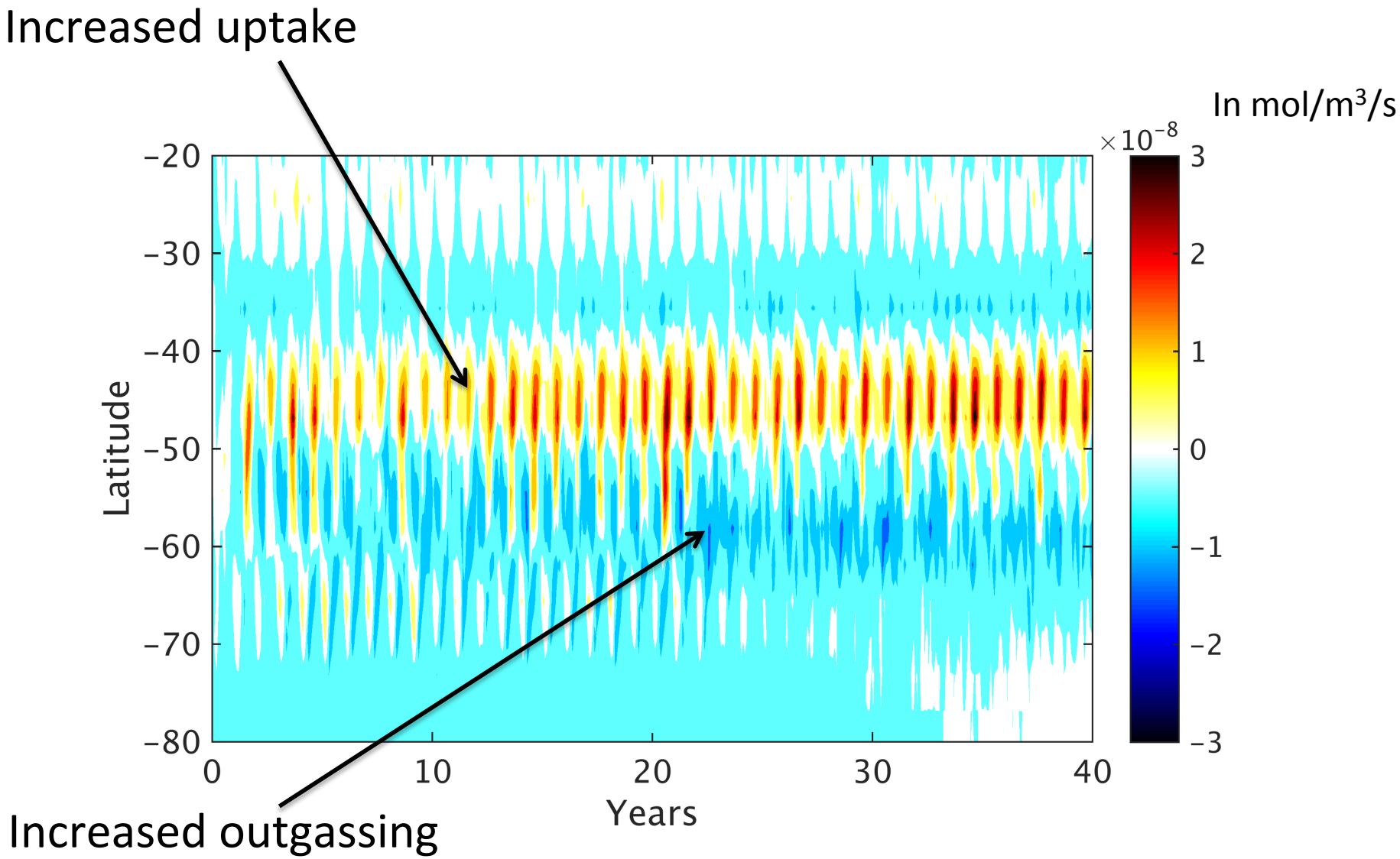
Total CO_2 uptake by ocean

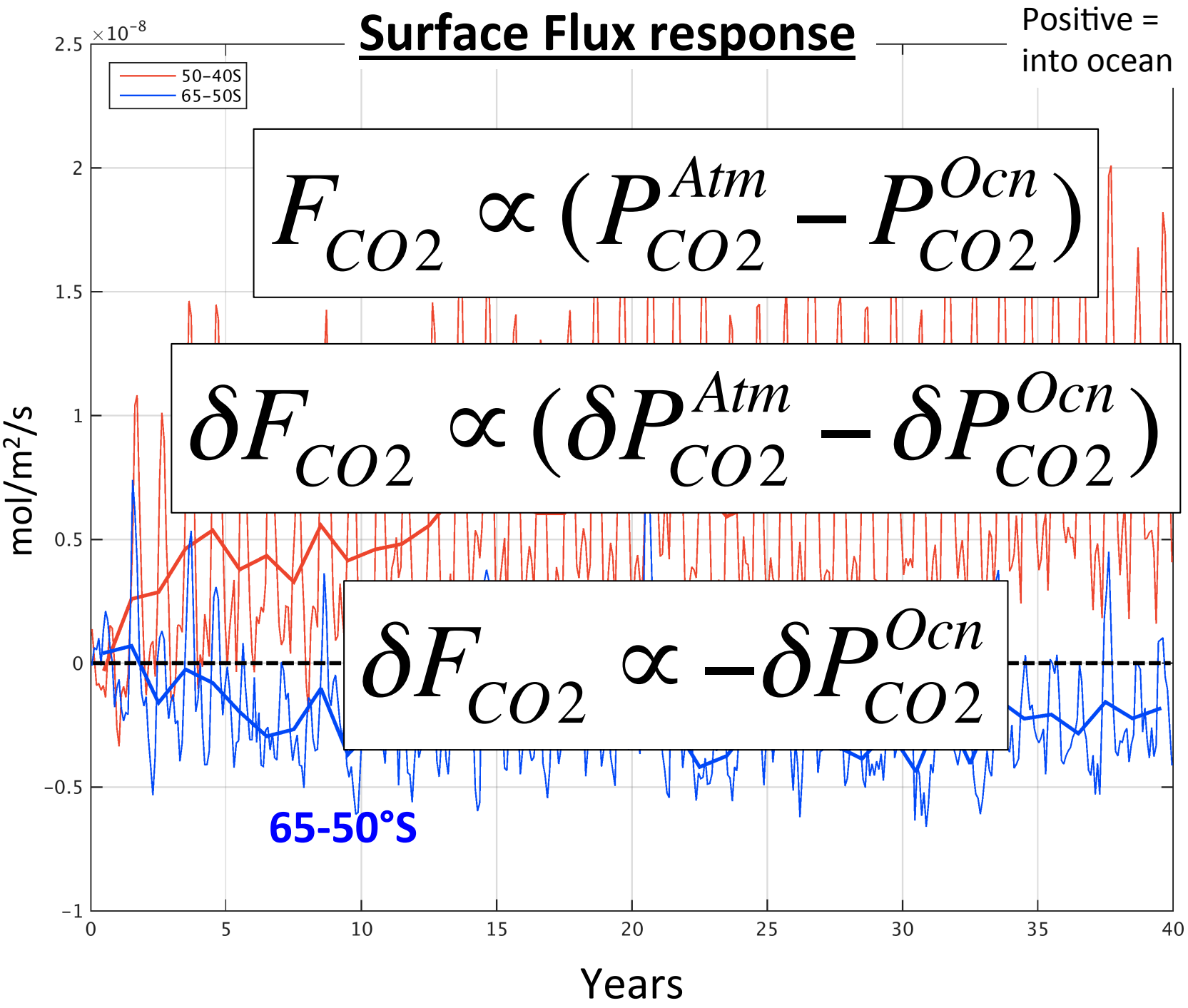
CO_2 in Atmosphere
690 PgC or 325 ppm

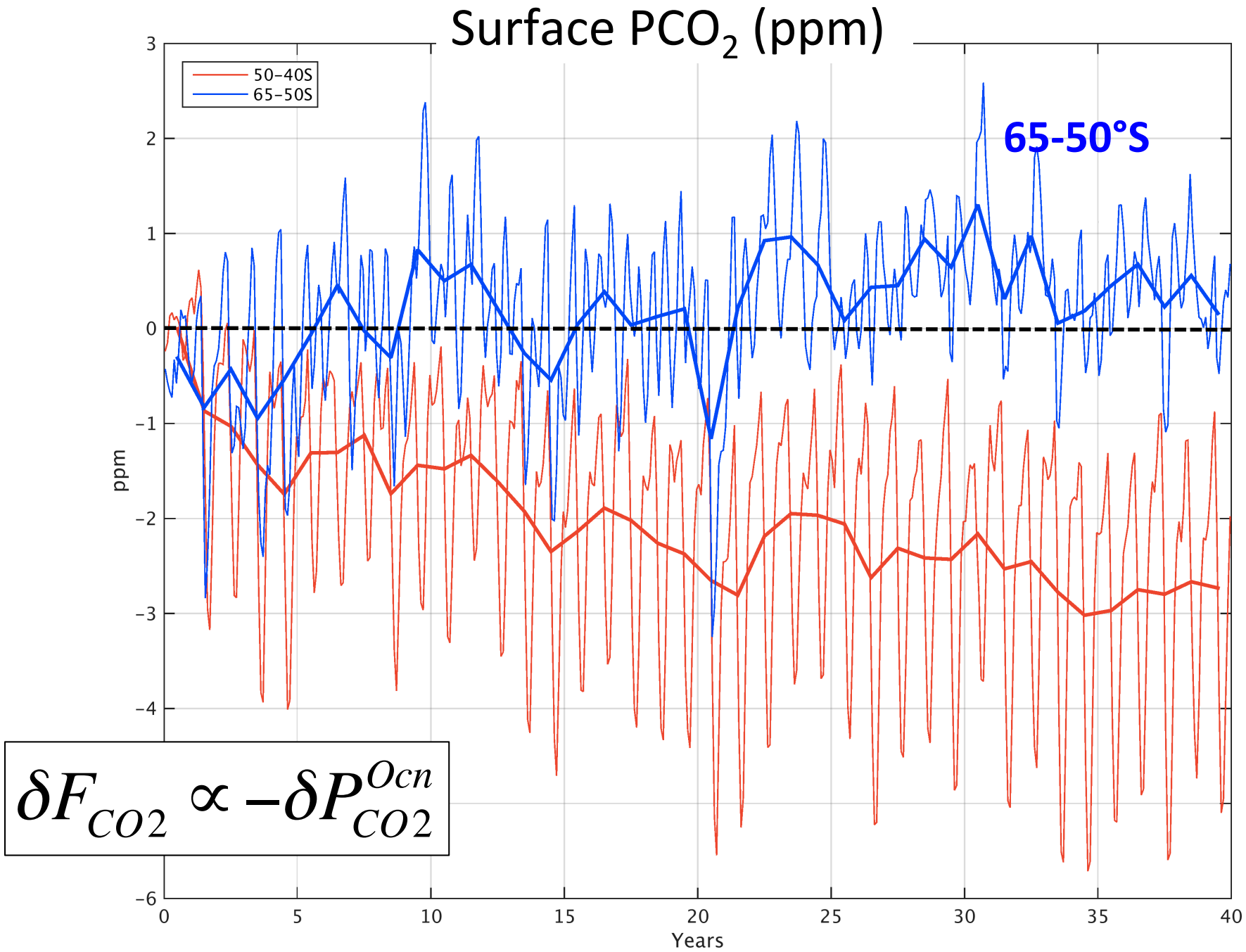


Surface CO_2 flux to abrupt Ozone depletion

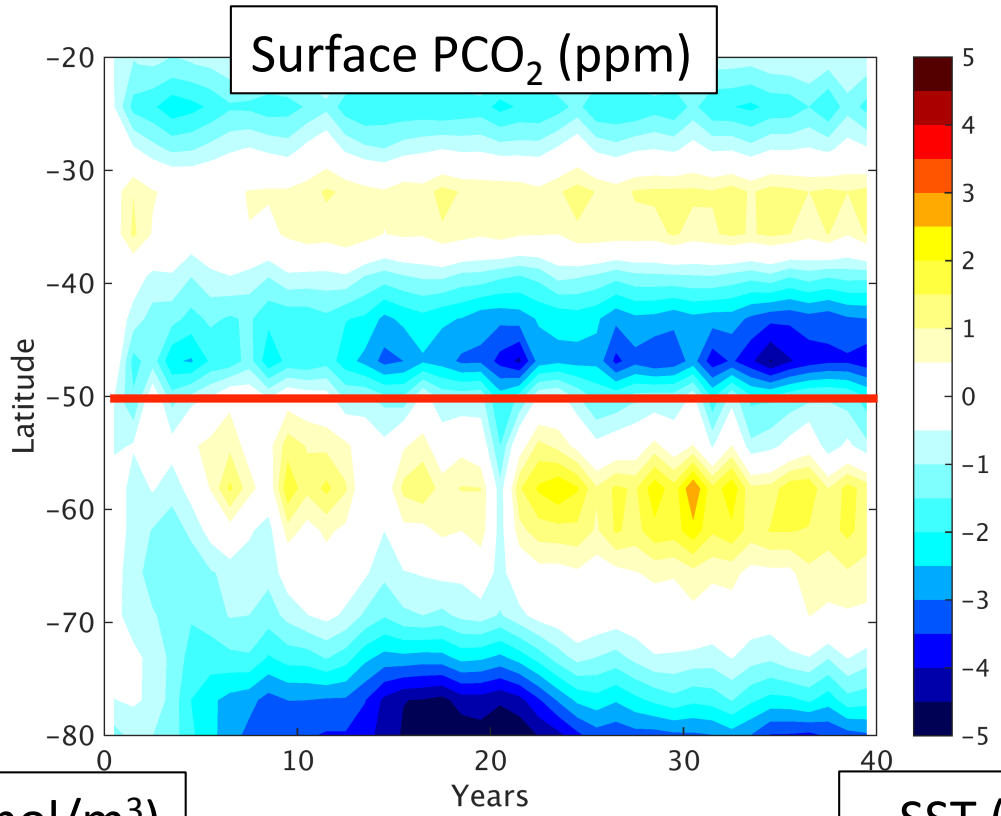
Positive = into ocean



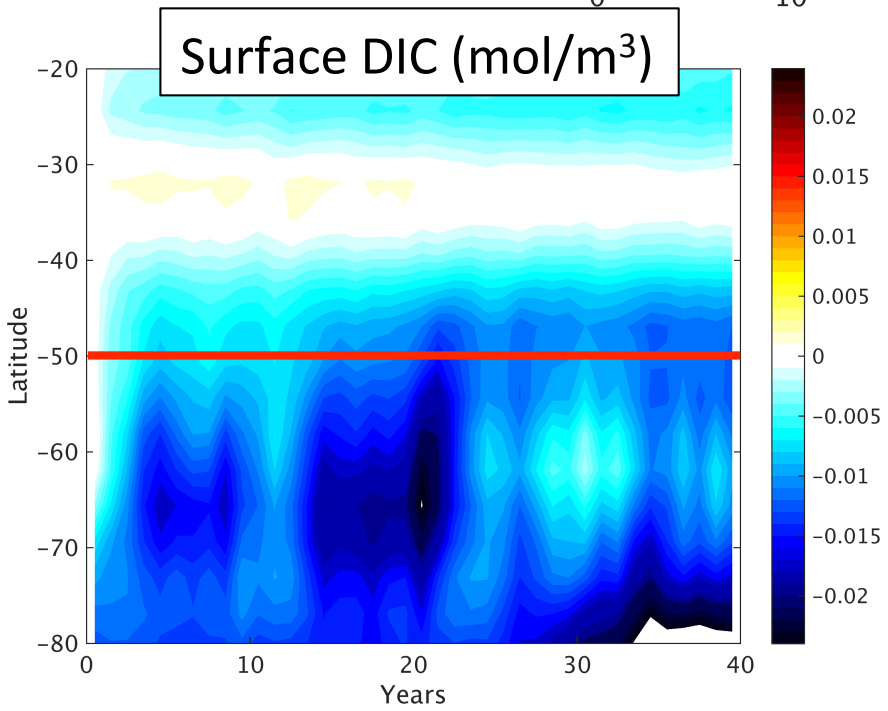

Surface Flux response
Positive = into ocean
$\times 10^{-8}$
50–40S
65–50S
$F_{CO2} \propto (P_{CO2}^{Atm} - P_{CO2}^{Ocn})$
$\delta F_{CO2} \propto (\delta P_{CO2}^{Atm} - \delta P_{CO2}^{Ocn})$
$\delta F_{CO2} \propto -\delta P_{CO2}^{Ocn}$
65-50°S
mol/m²/s
Years
2.5
2
1.5
1
0.5
0
-0.5
-1
0
5
10
15
20
25
30
35
40

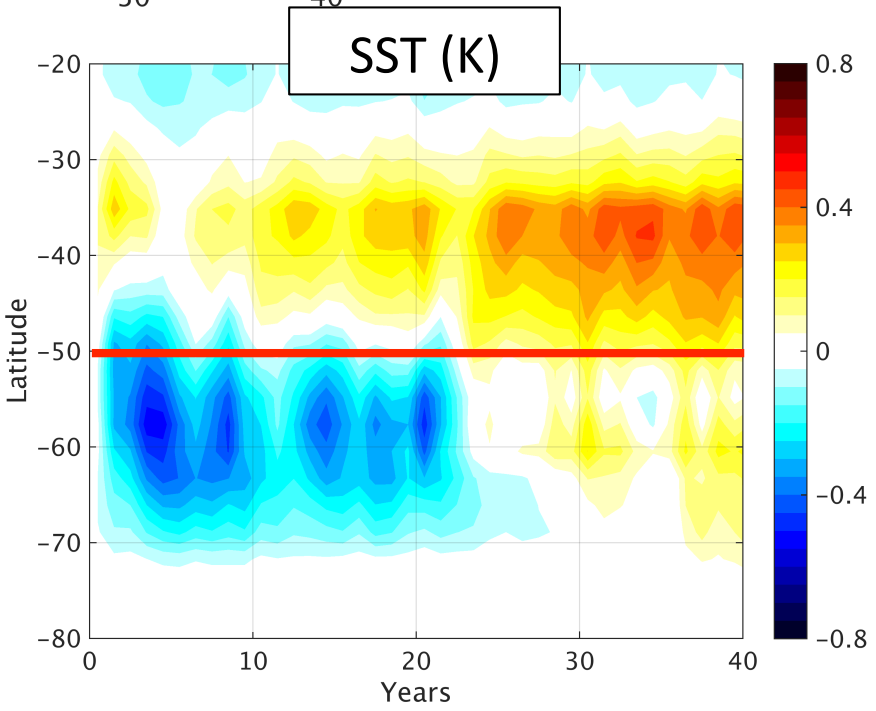

Surface PCO2 (ppm)
50-40S
65-50S
65-50°S
ppm
Years
3
2
1
0
-1
-2
-3
-4
-6
0
5
10
15
20
25
30
35
40
$\delta F_{CO2} \propto -\delta P_{CO2}^{Ocn}$

Two different regimes north and south of 50°S



$$P_{CO2}^{Ocn} = \frac{[CO_2^*]}{K_O}$$





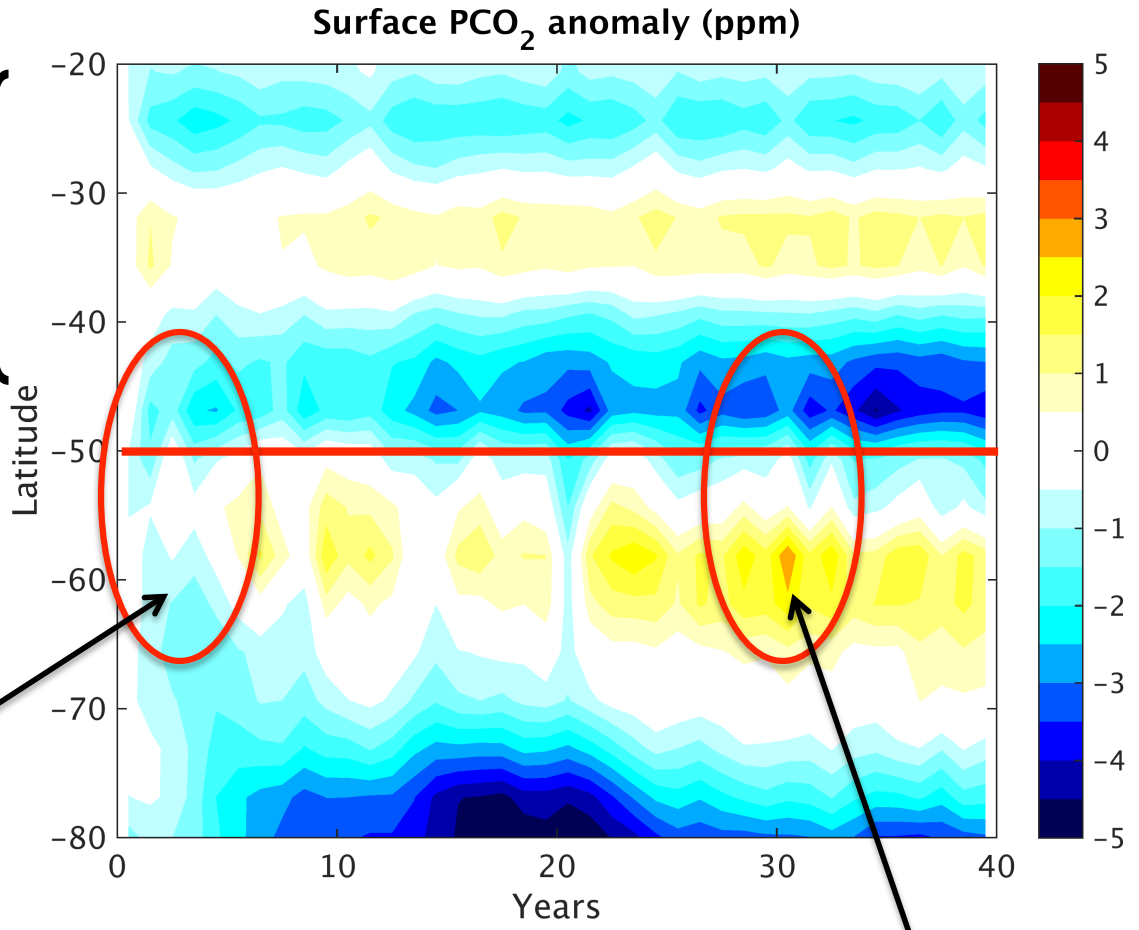
$$P_{CO2}^{Ocn} = \frac{[CO_2^*]}{K_O}$$

Dominated by

$$\delta[CO_2^*] \propto \delta DIC$$

Temp effect:

$$\delta T > 0 \Rightarrow \delta K_o < 0$$

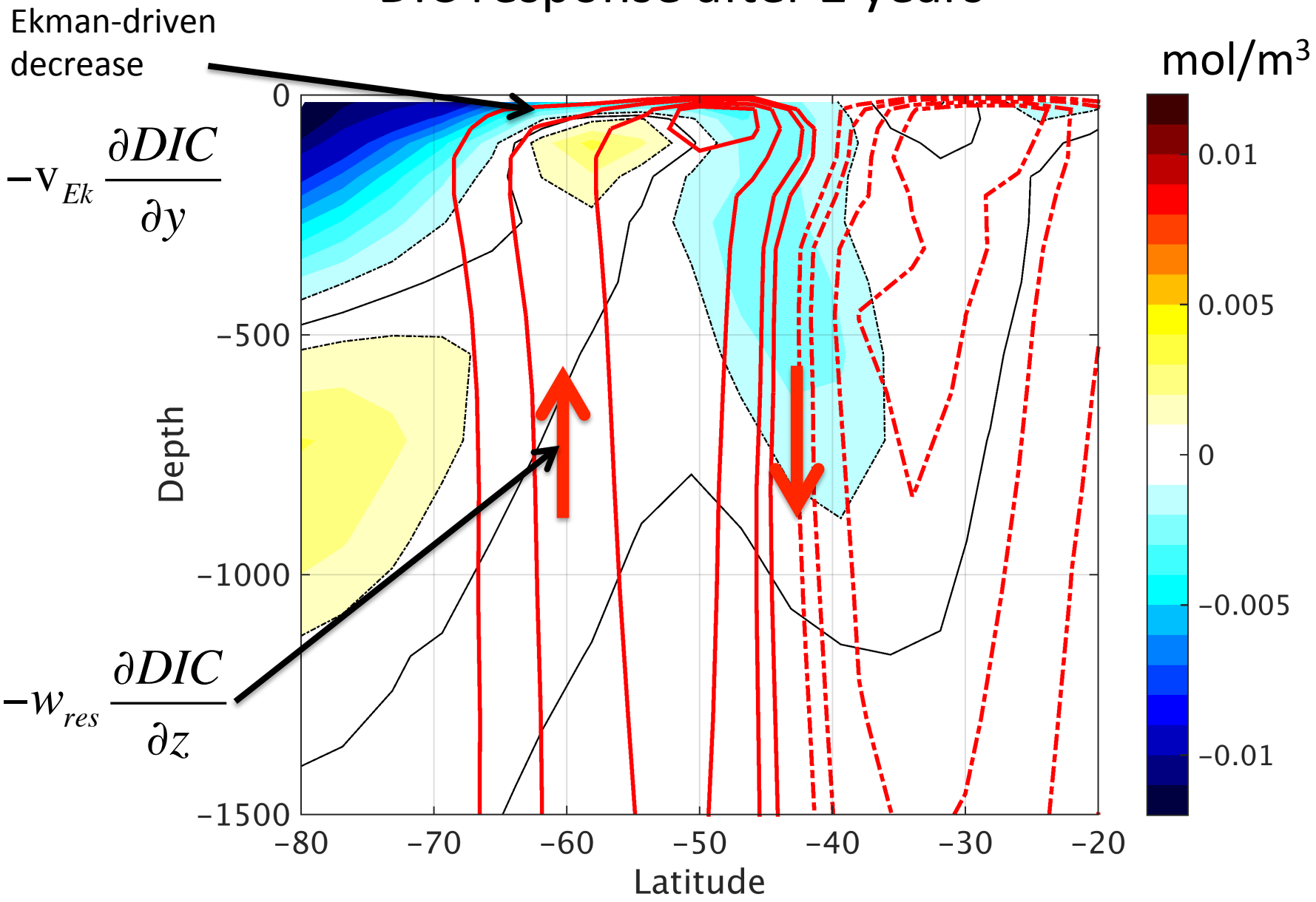


$$\delta[CO_2^*] \approx \delta DIC < 0$$

$$\delta T < 0 \Rightarrow \delta K_o > 0$$

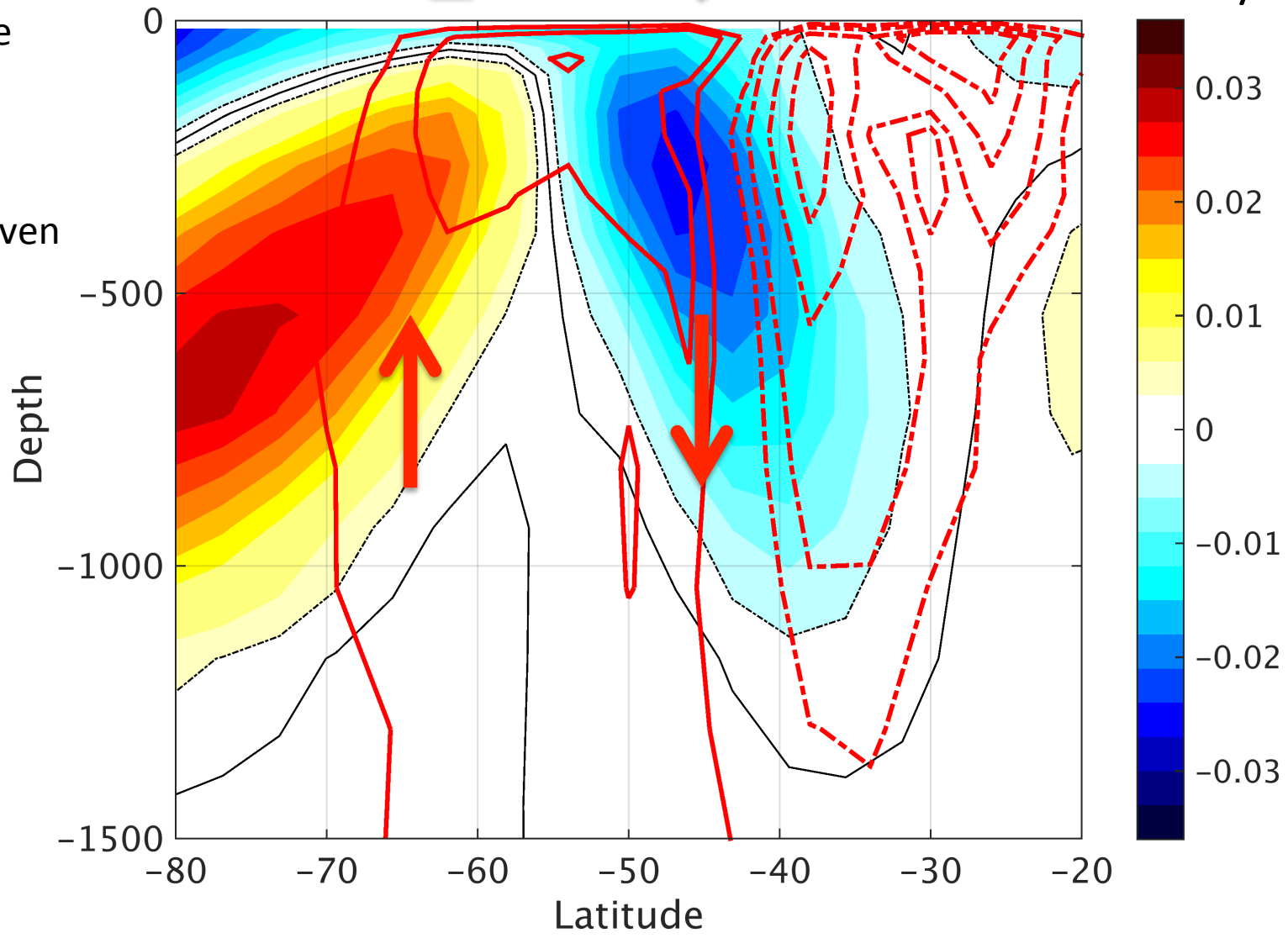
$$\delta T > 0 \Rightarrow \delta K_o < 0$$

DIC response after 2 years



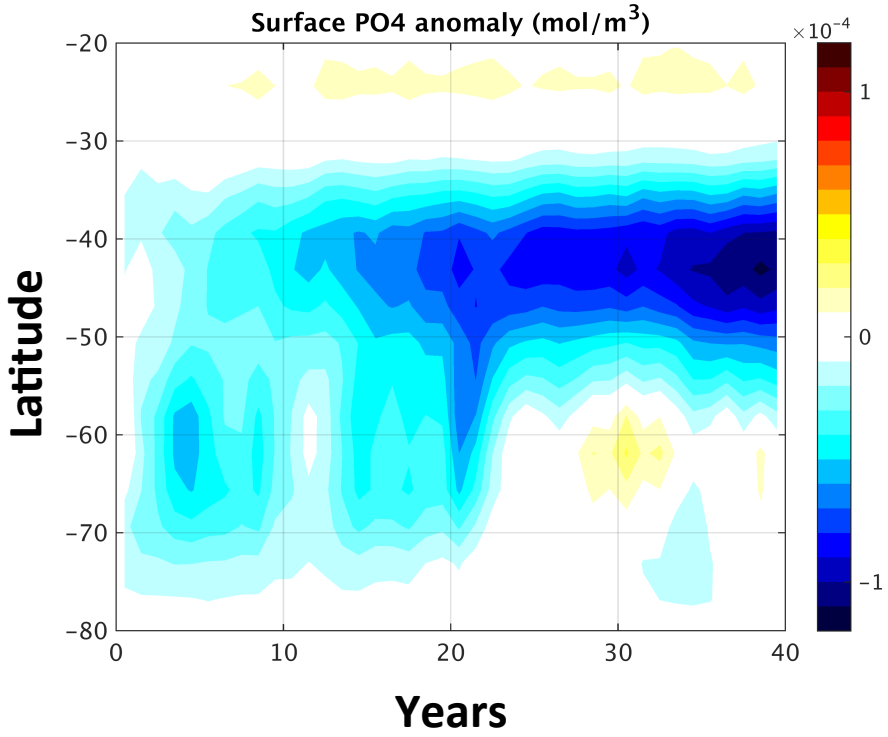
Flux out: positive feedback

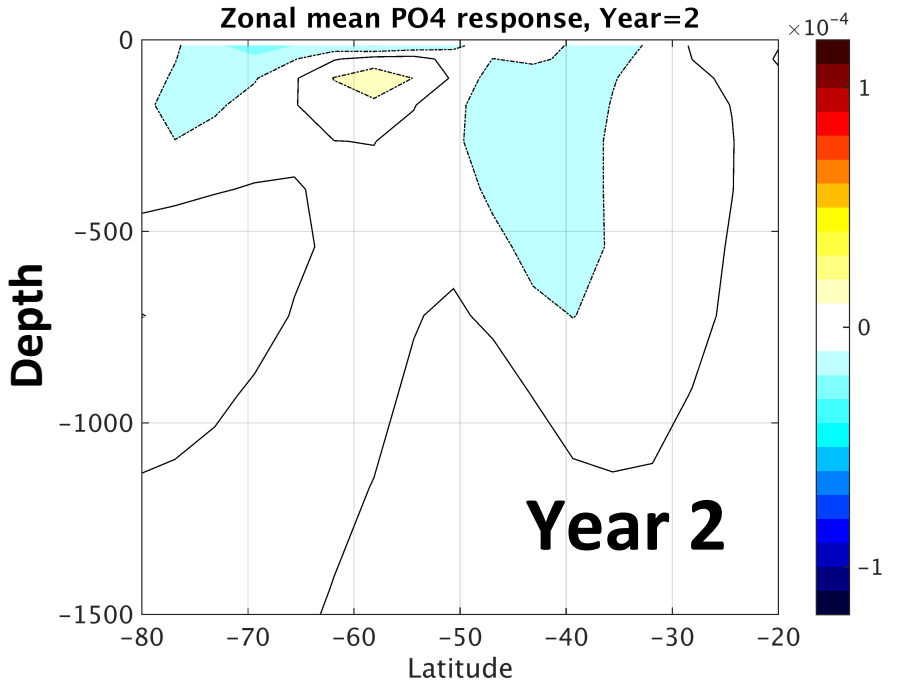
Subsurface increase does not overcome Ekman-driven decrease



DIC response after 40 years

Phosphate behaves as we expect





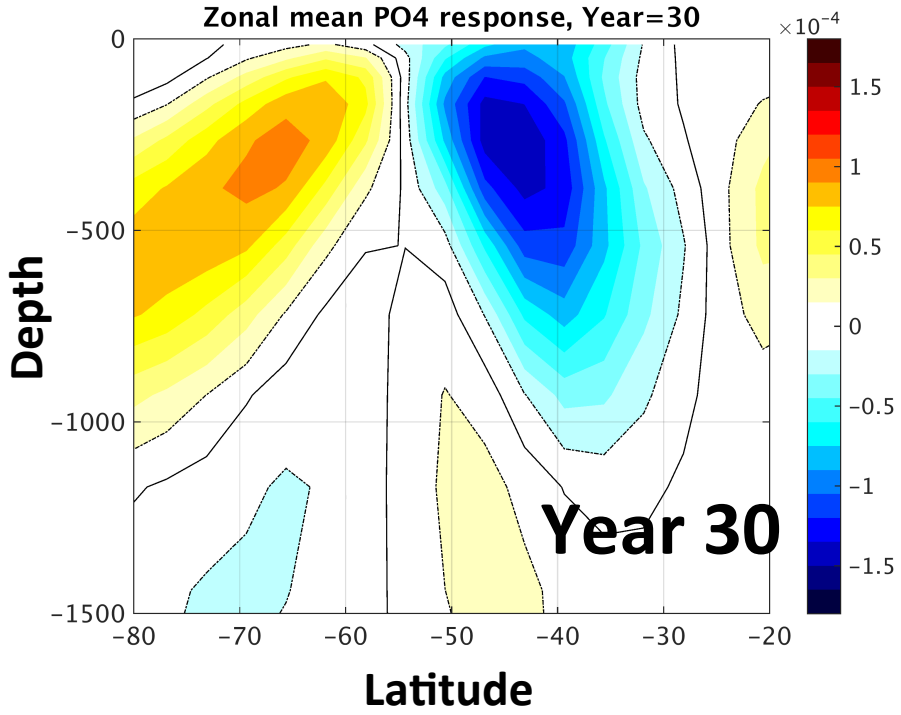
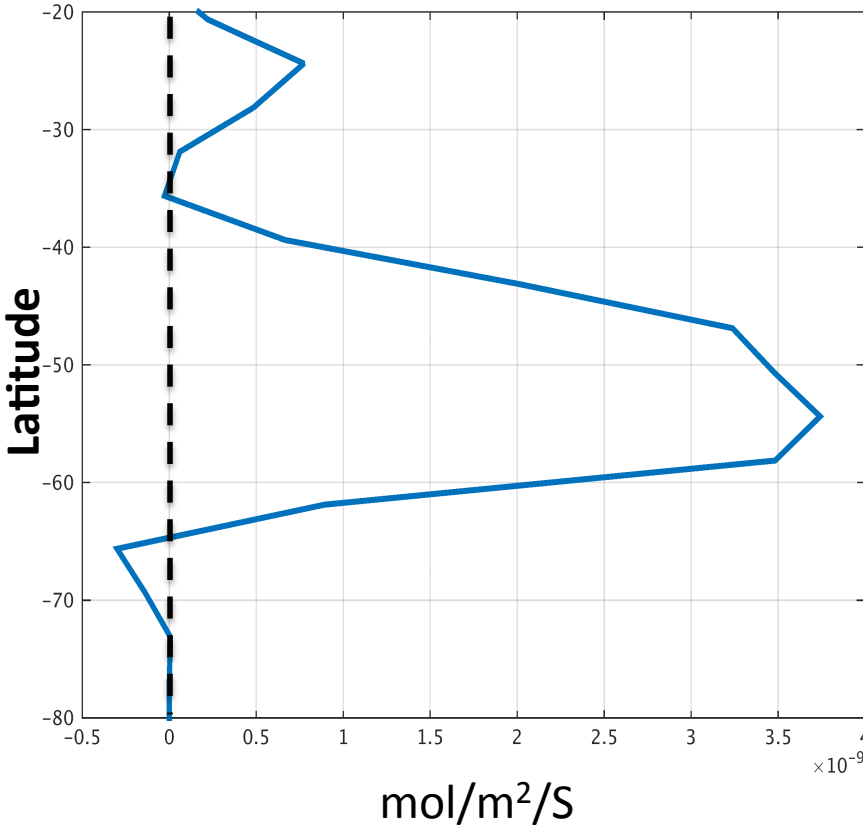
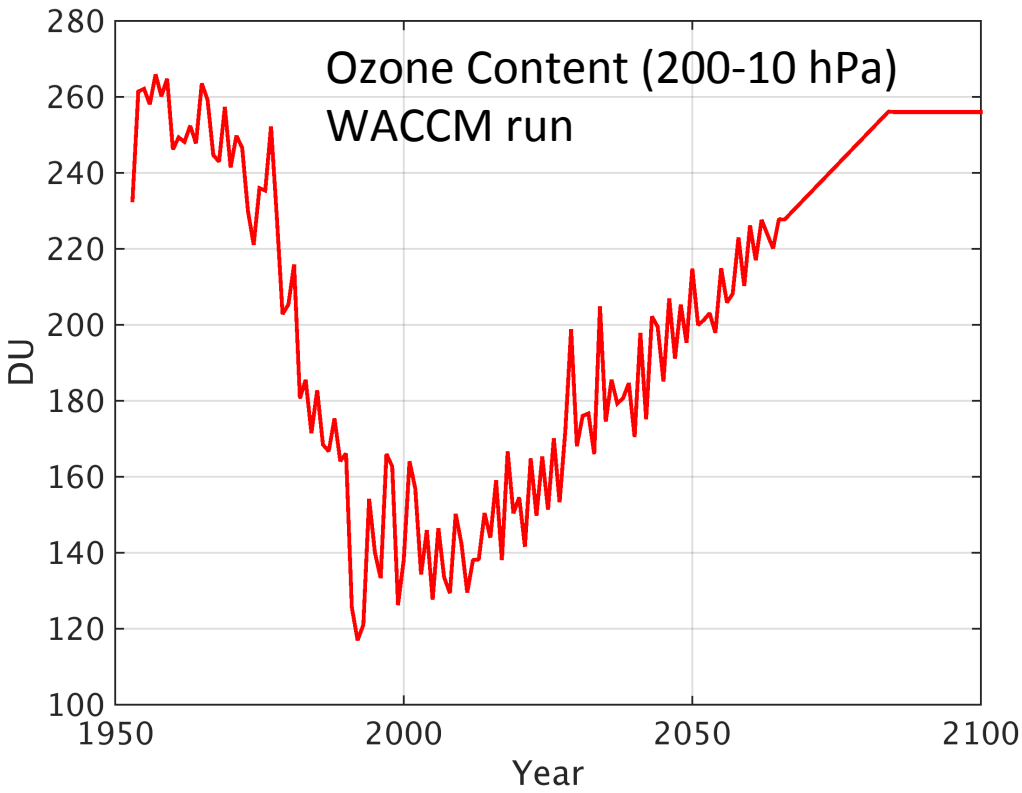


Illustration of the two-timescales in action

Surface CO_2 flux regressed on SAM (control run)



Surface CO_2 flux anomaly



Conclusion:

- Net effect of Ozone depletion on atmospheric CO_2 is weak
- But hides large compensating fluxes in the Southern Ocean
- There are multiple timescale involved in the adjustment of the carbon cycle to the changing winds
- Mechanisms (mostly) similar to those seen for temperature (Ekman, upwelling)
- Adjustment timescales are different: carbonate chemistry which is coupled to SST
- Multiple timescales play a role for different configurations/forcings