The air-sea flux of oxygen

Raymond Najjar

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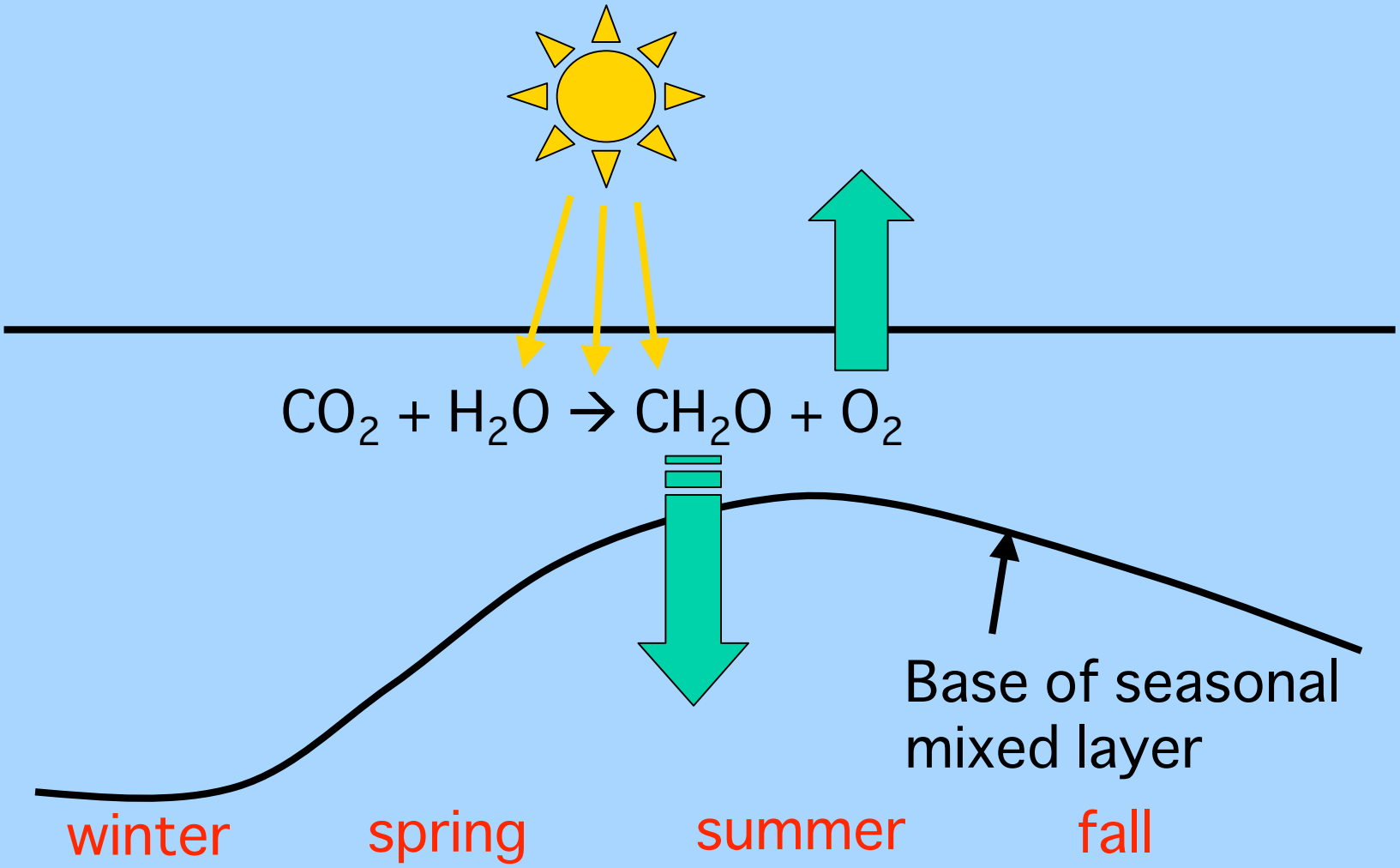
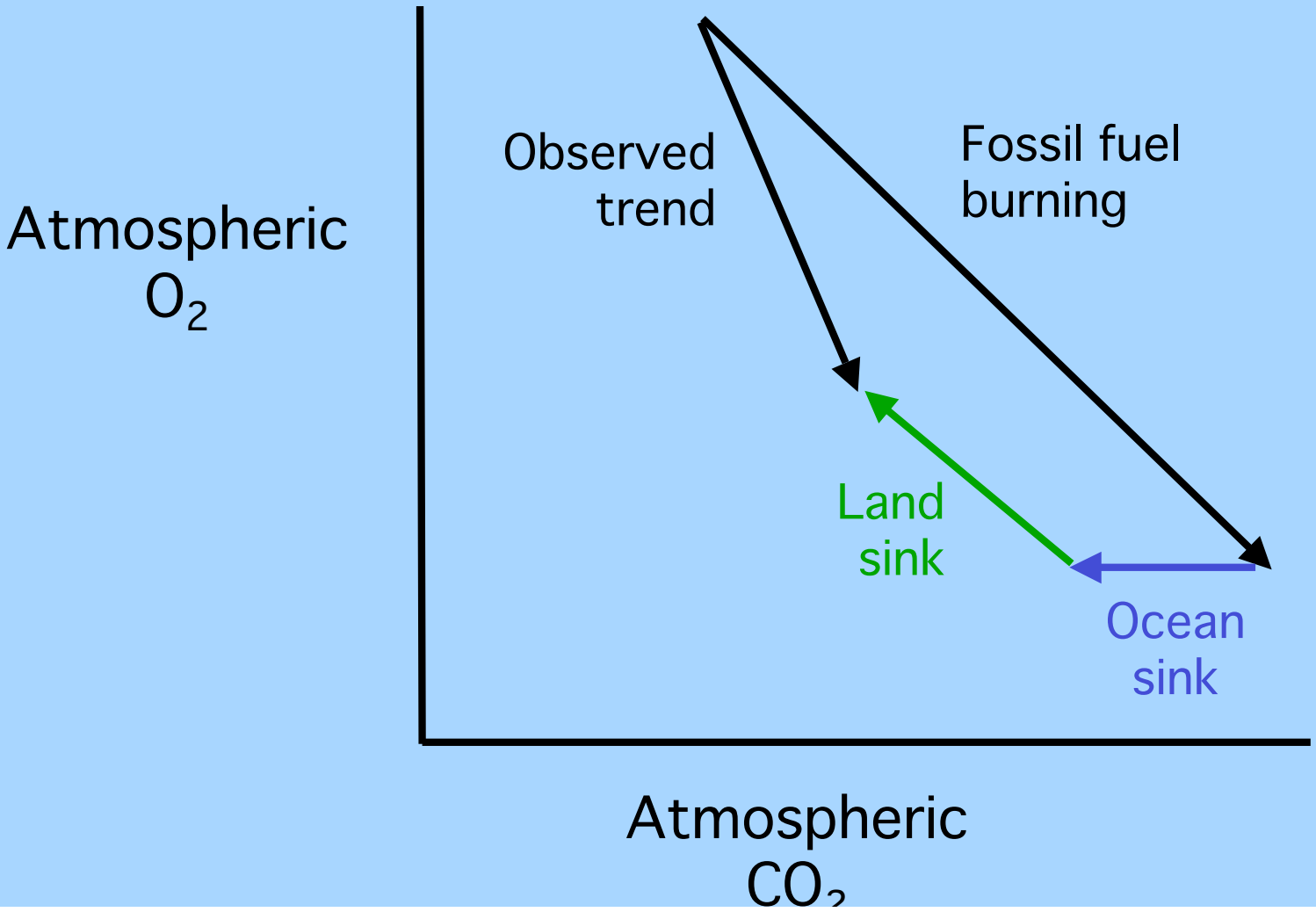
Motivation

1. Export production



Motivation

2. Anthropogenic CO_2 sink



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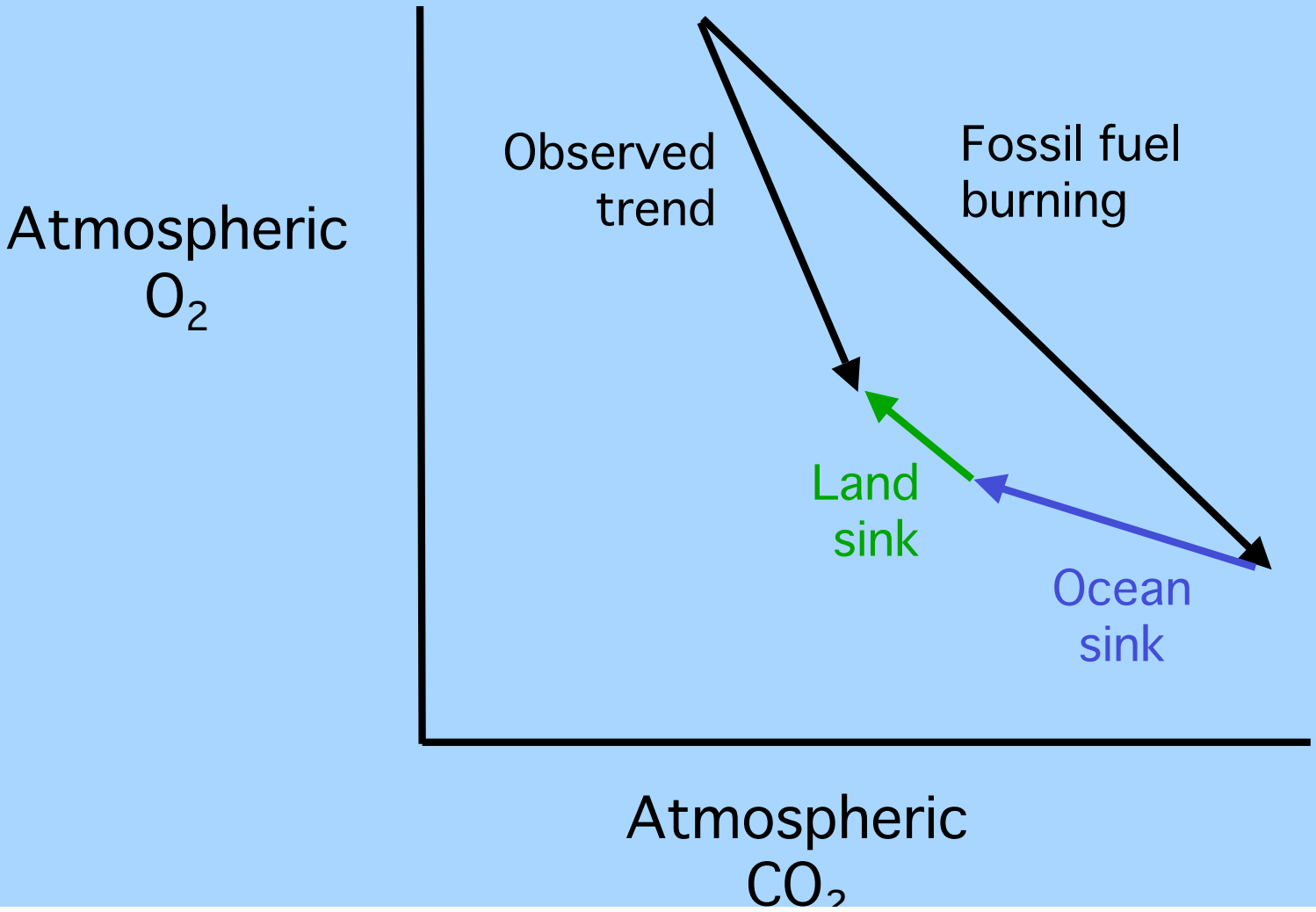
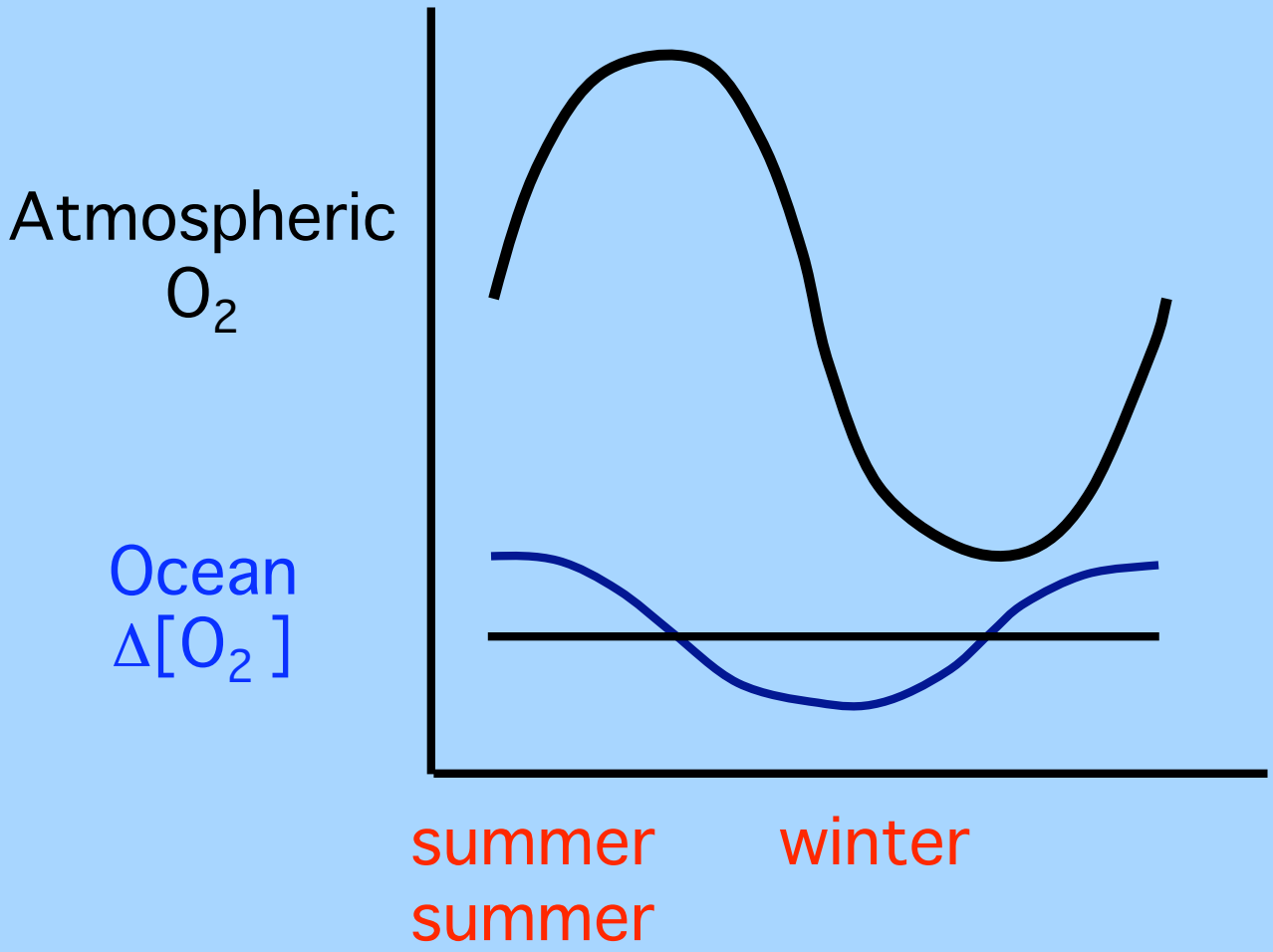


Motivation

3. Air-sea gas exchange: $F = k_w \Delta[O_2]$



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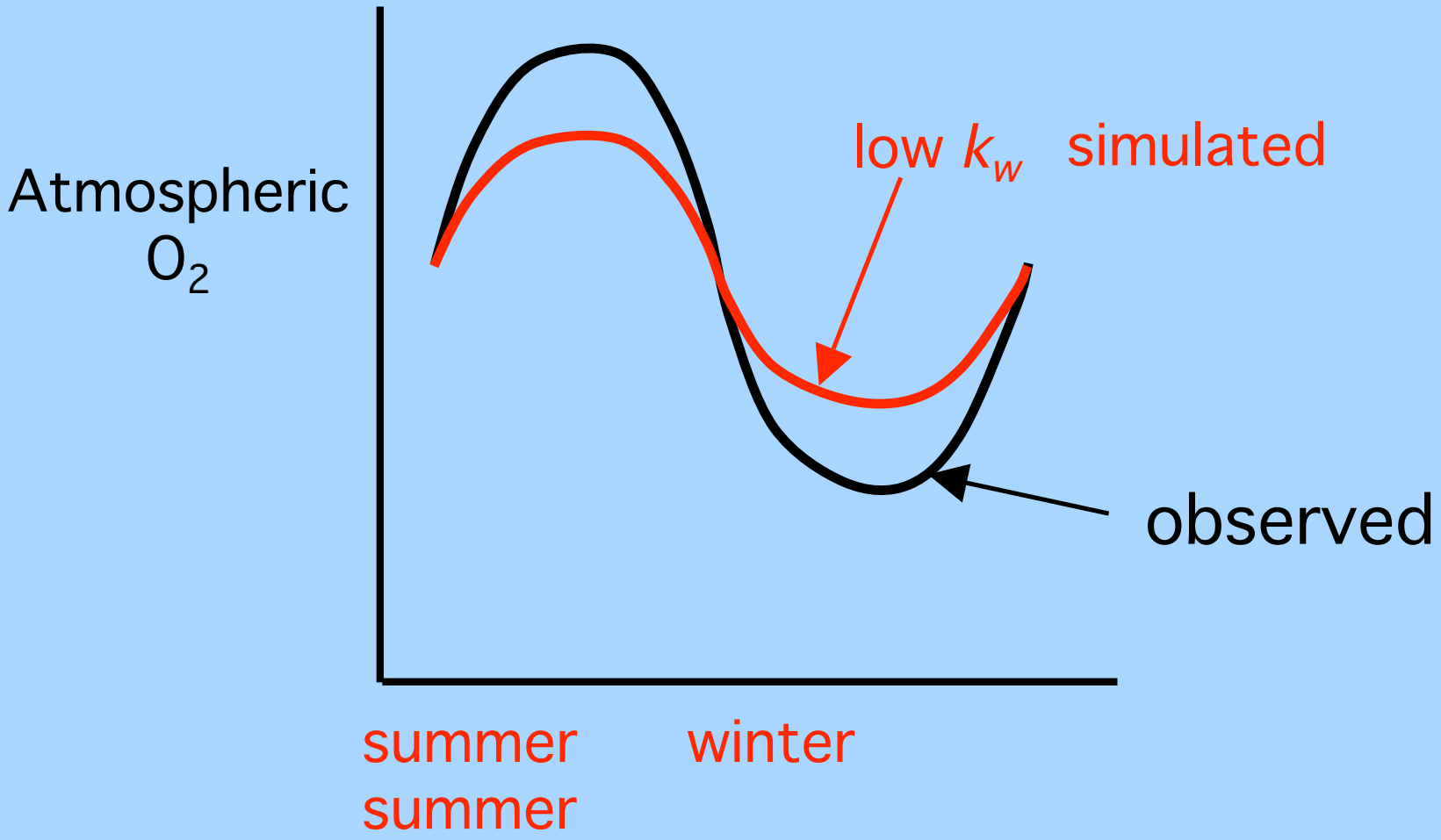

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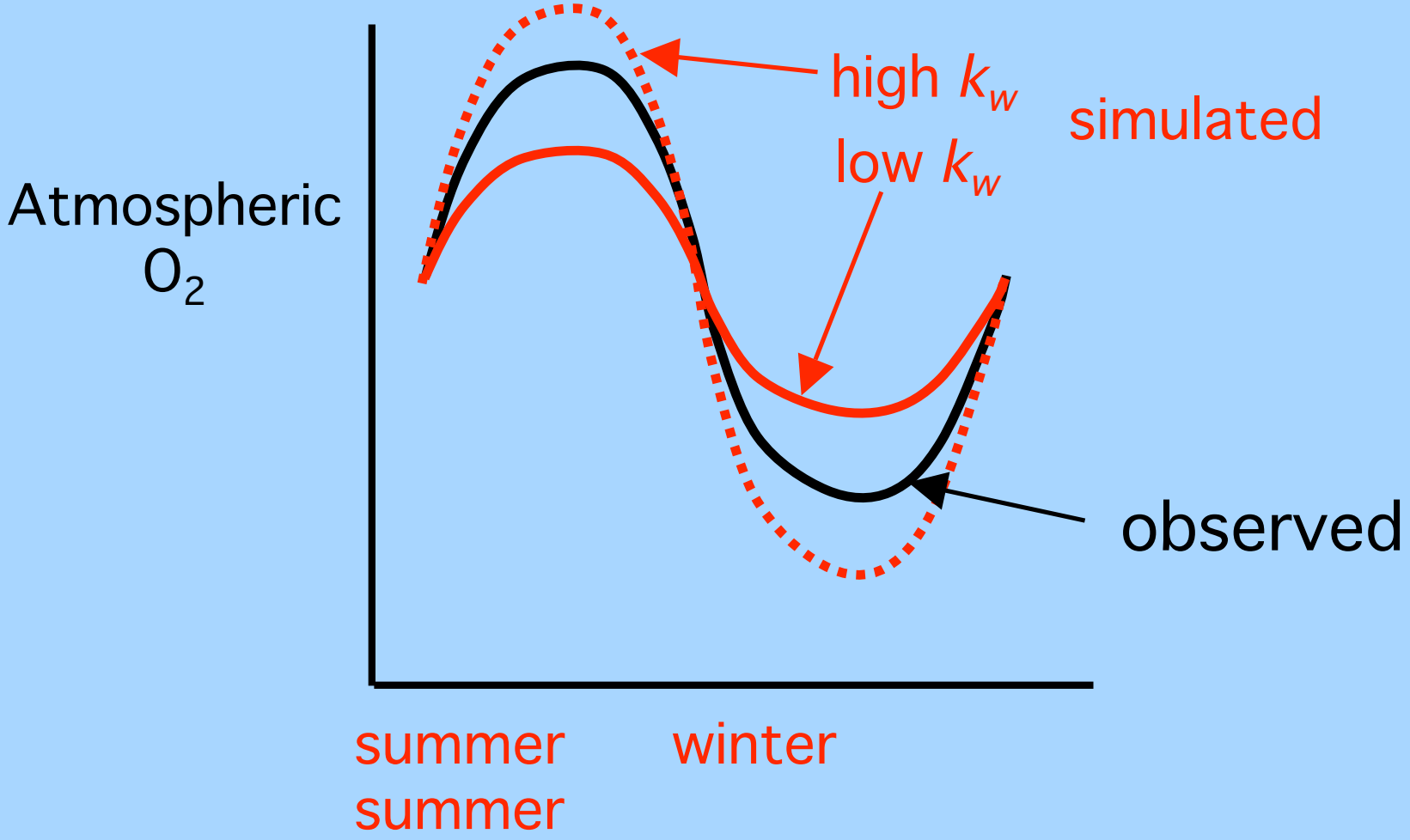
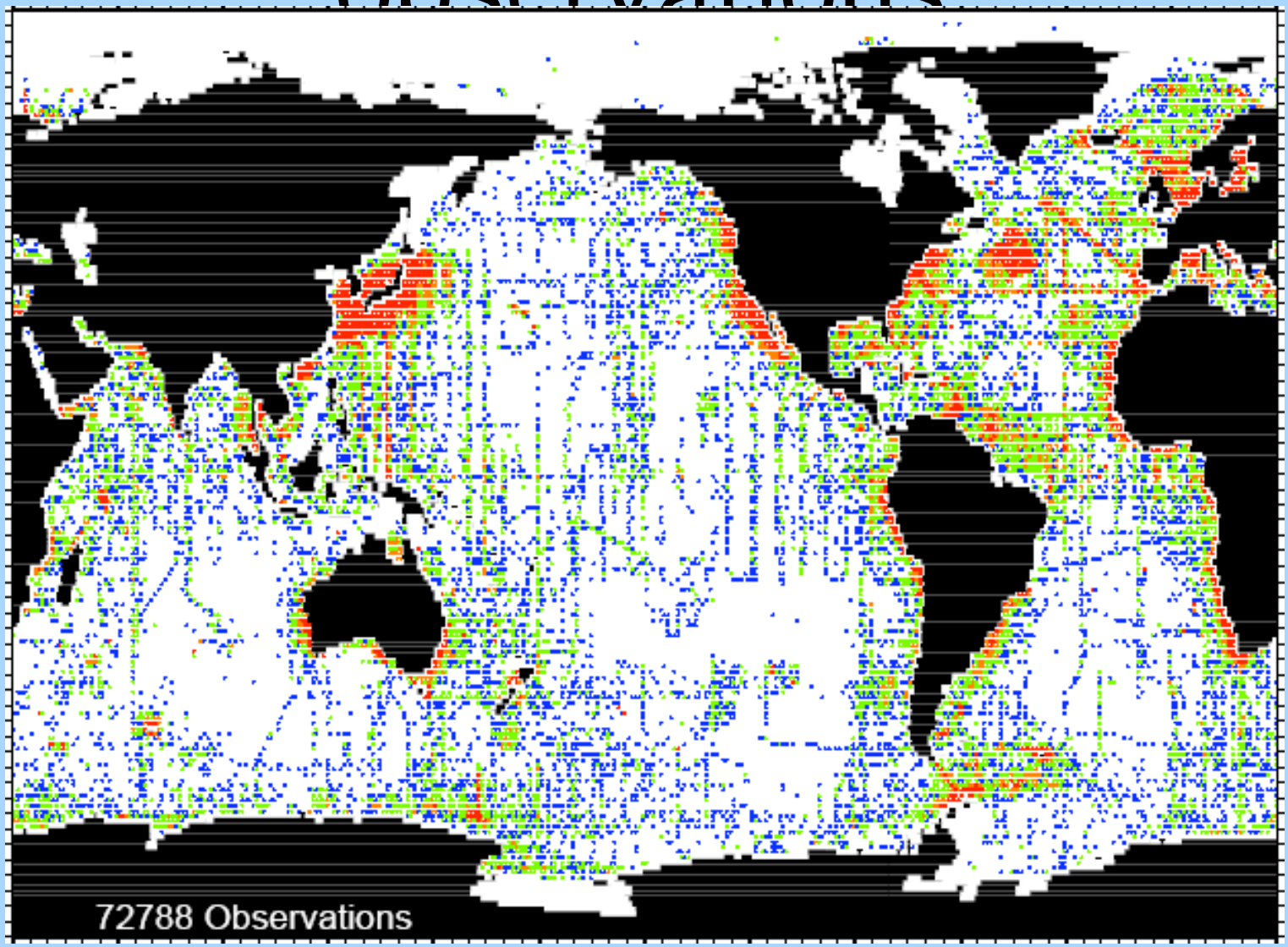


An old subject

Redfield, A. C. 1948. The exchange of oxygen across the sea surface. *Journal of Marine Research, 7,* 347-361.

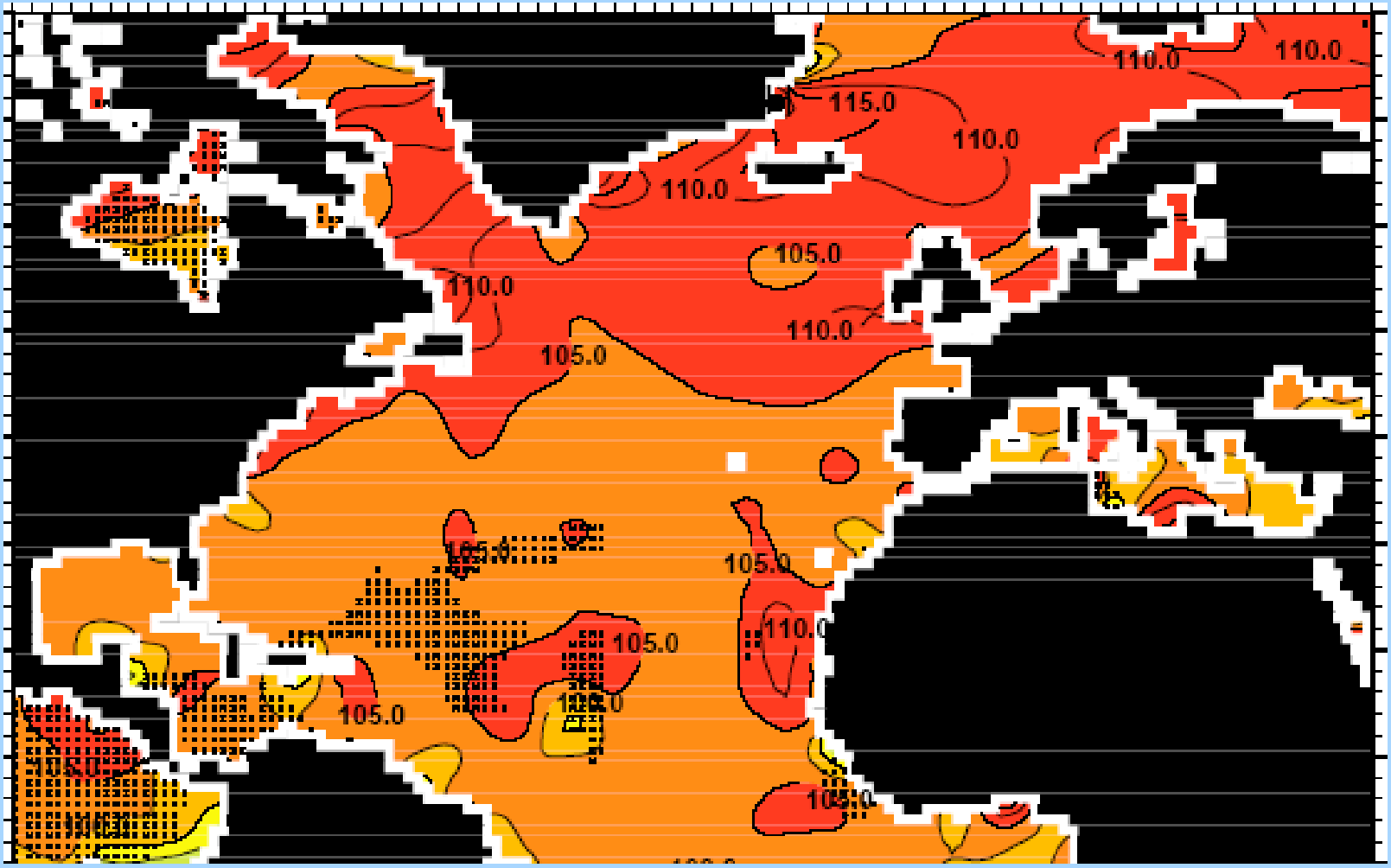
(On the annual cycle of dissolved O_2 in surface waters of the Gulf of Maine)

Surface ocean O_2 observations



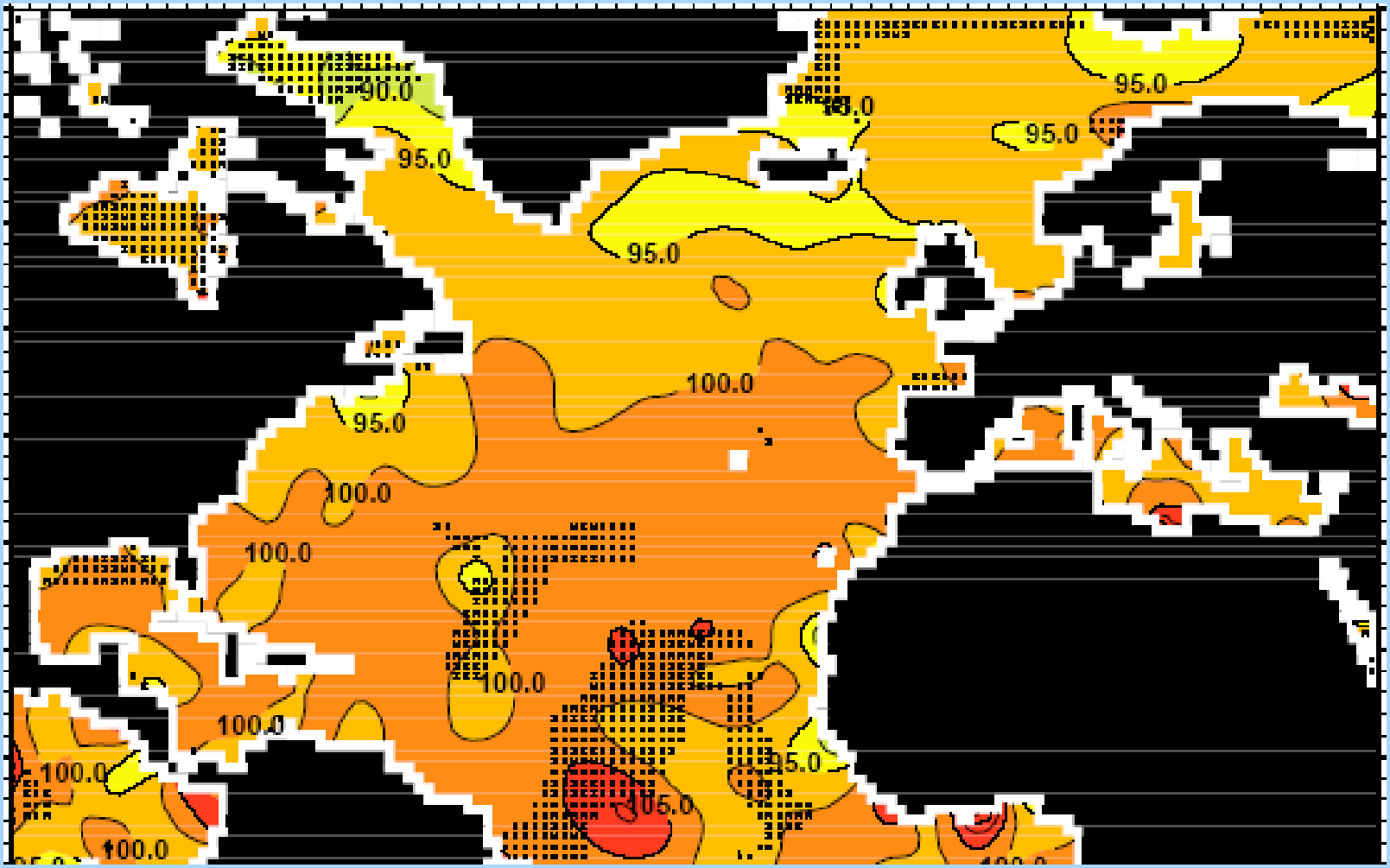
Source: World Ocean Atlas 2001, Ocean Climate Laboratory of NODC

O_2 % saturation in June



Source: World Ocean Atlas 2001, Ocean Climate Laboratory of NODC

O_2 % saturation in December



Source: World Ocean Atlas 2001, Ocean Climate Laboratory of NODC

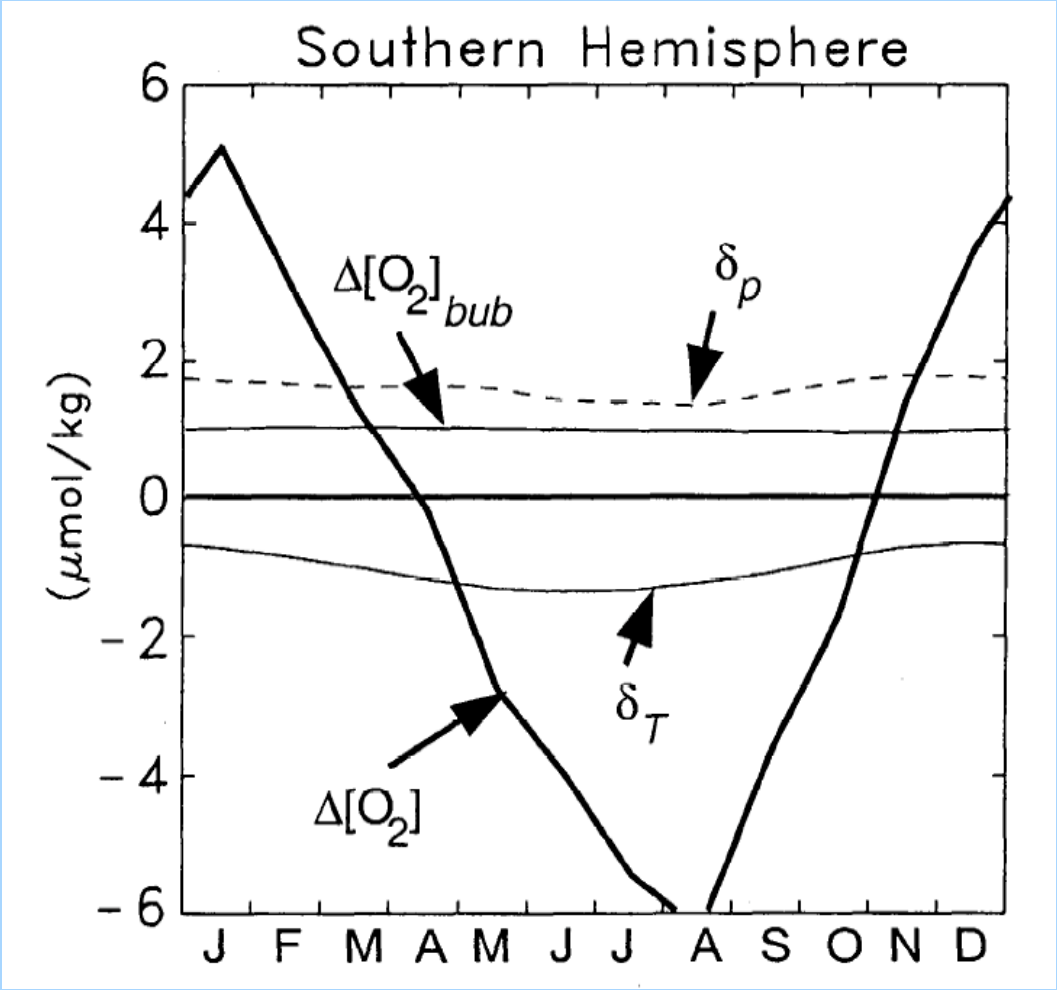
Inferred flux from surface ocean O_2 observations

$$Fk = \Delta_w \quad [O_2]$$

$$\Delta[O_2] = [O_2] - [O_2]^0 \quad \delta\delta_{TPbub}$$

$$\Delta[O_2] = [O_2] - [O_2]^0(,1\ \text{atm})_{satbulk} \quad Tp$$

Corrections are non-trivial



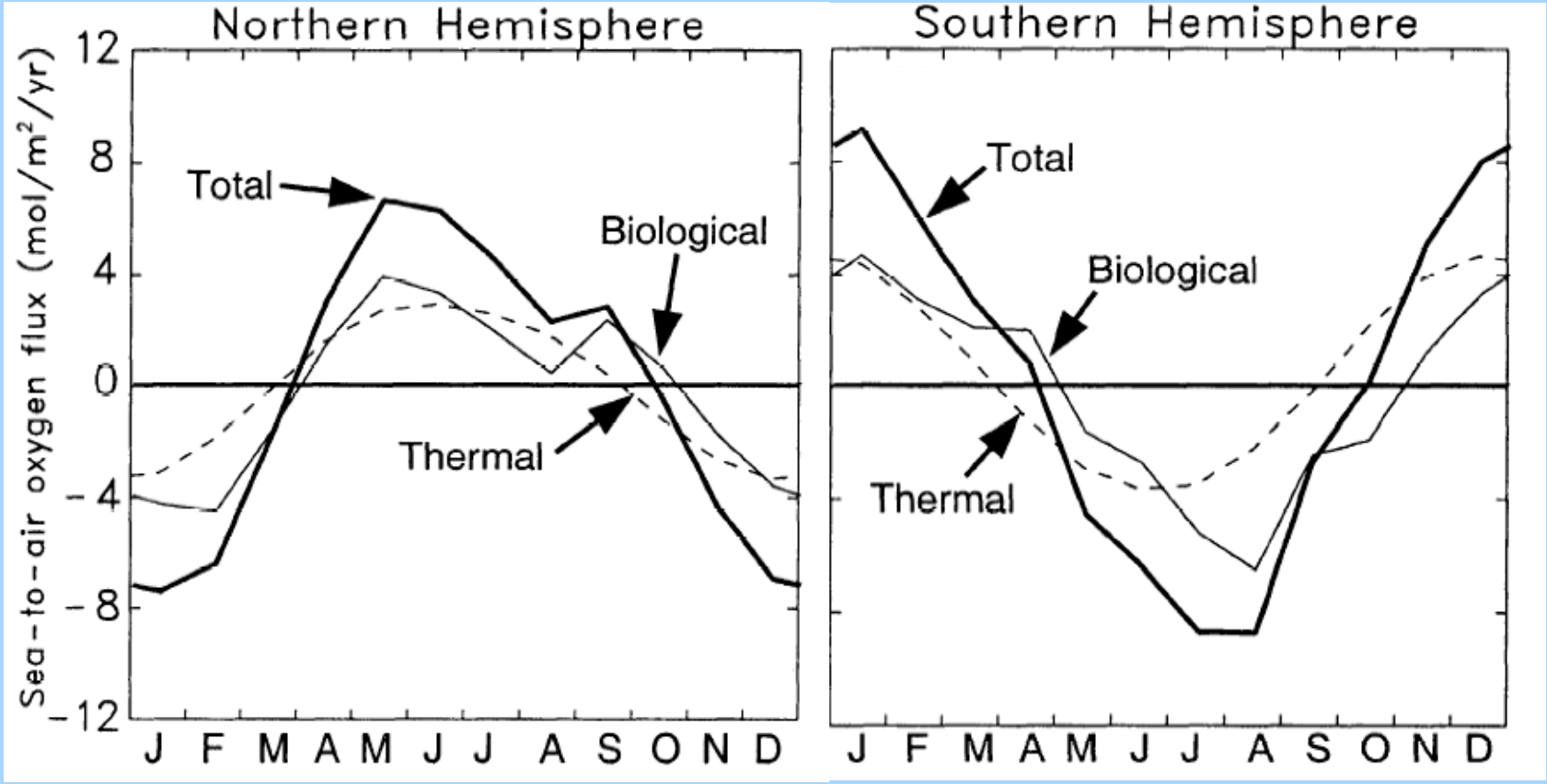
Source: Najjar and Keeling (2000)

Thermally-induced O_2 flux

$$F_T = -\frac{Q}{C_p T}\frac{\partial [O_2]^{O}_{sat}}{\partial}$$

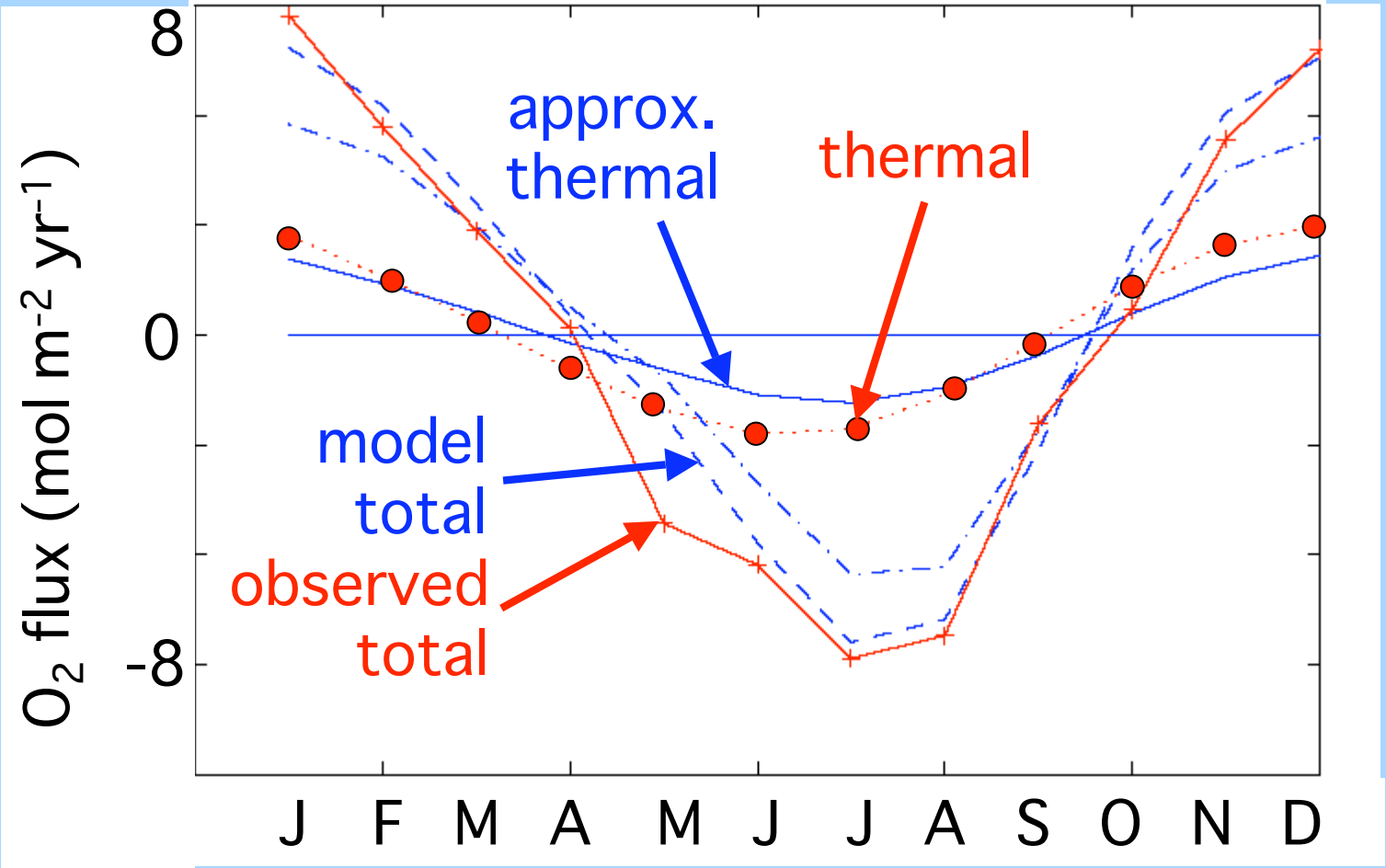
Reasonable if residence time of water in mixed layer is greater than gas equilibration time

Seasonality in air-sea O_2 flux



Source: Najjar and Keeling (2000)

Ocean model simulation of annual cycle

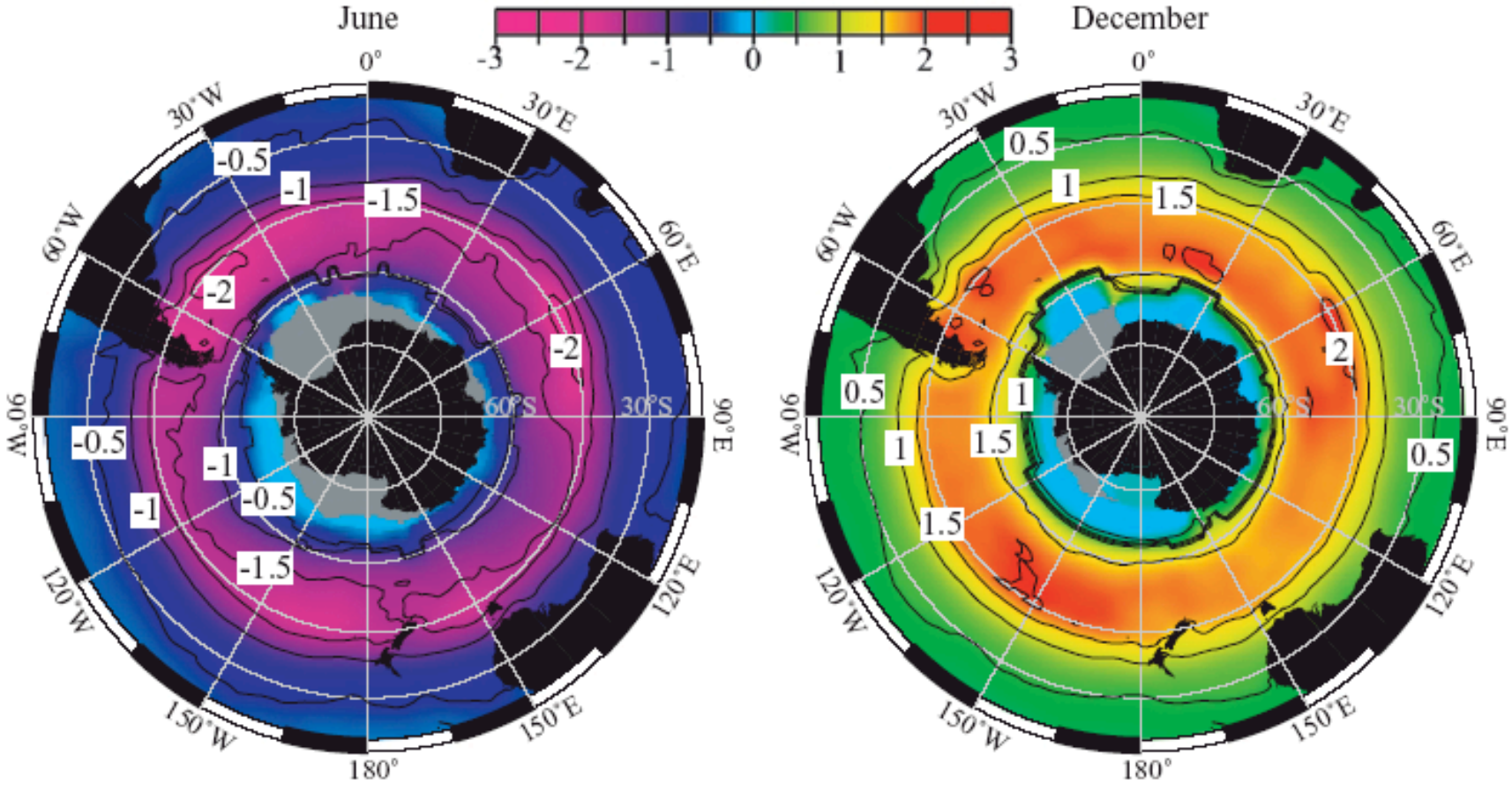


Source: Jin et al. (in prep.)

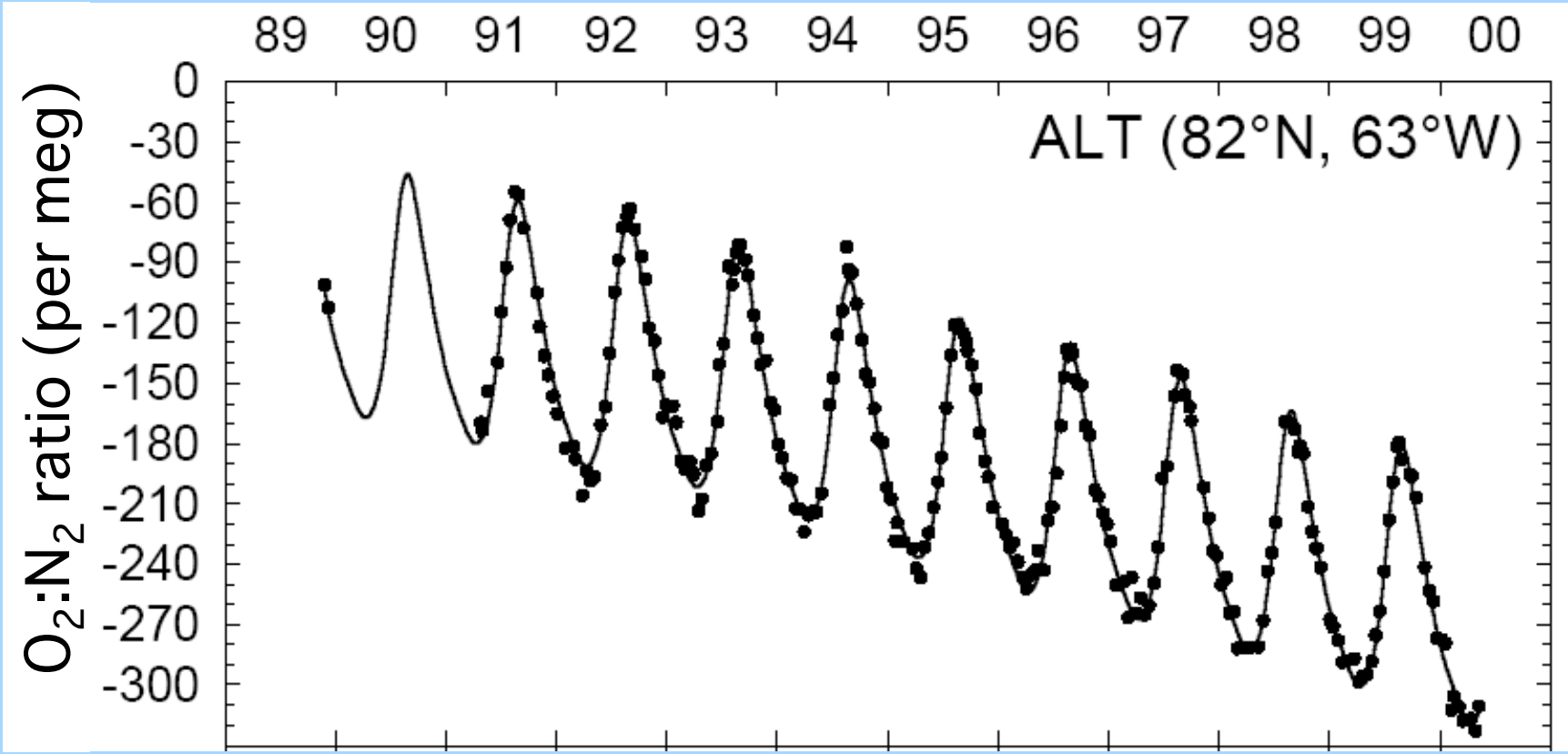
Garcia and Keeling (2001) global climatology

Uses relationship between fluxes of heat and oxygen (r^2 ~ 0.8 poleward of 20_)

Upward flux anomaly (mol m^{-2} mon^{-1})



Atmospheric O_2 measurements



Source: R. Keeling's Atmospheric Oxygen Group

Isolating the ocean influence on atmospheric O_2

- Atmospheric potential oxygen

  $APO \equiv O_2 + CO_2$
- APO is only weakly dependent on fossil fuel burning and terrestrial carbon cycling

Seasonality in APO

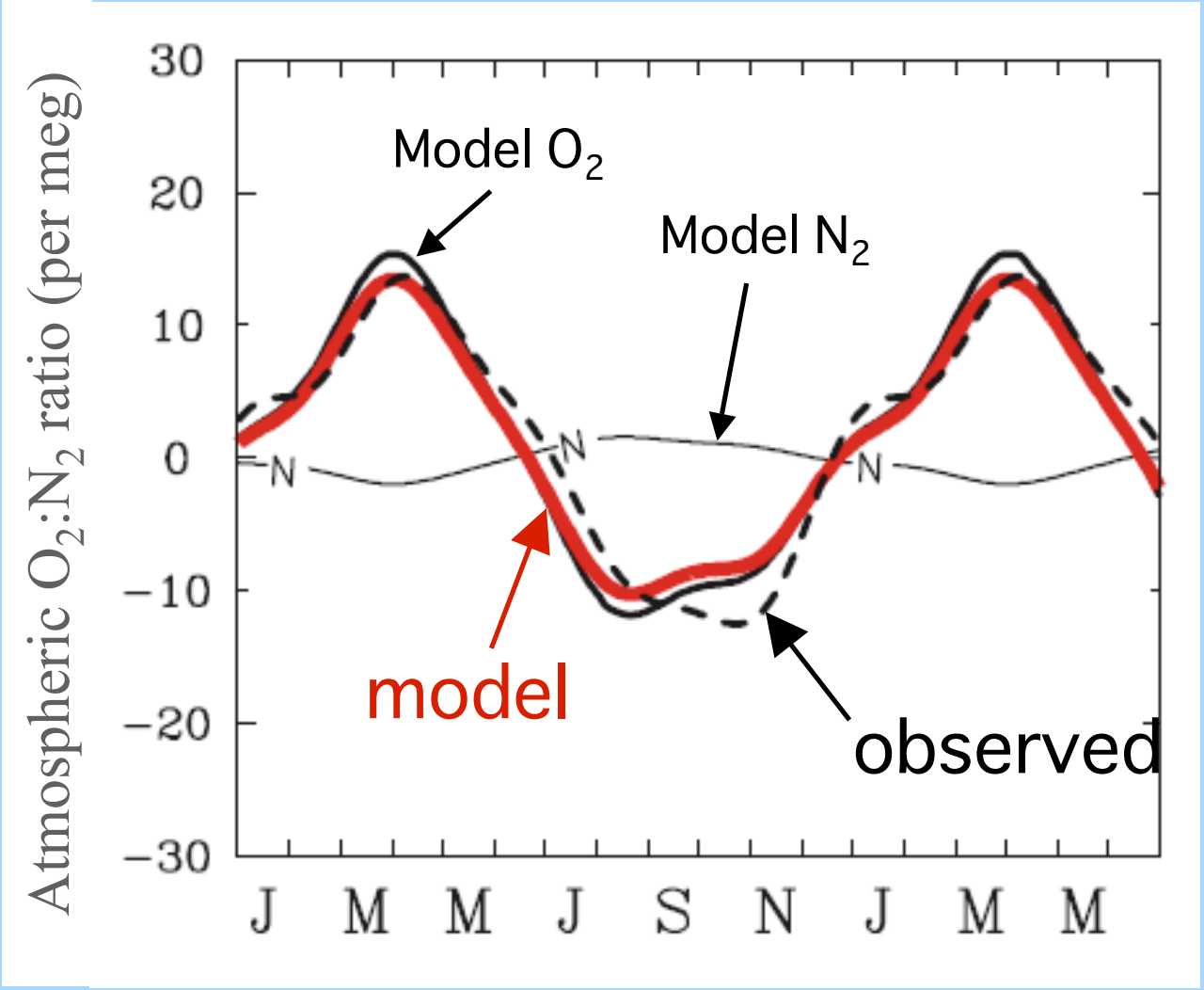
- Gas exchange equilibration time scale for O_2:

  $\sim MLD/k_w \sim$ (50 m)/(3 m d^{-1}) ~ 20 days.
- For CO_2, about 20 x longer
- So annual cycle in atmospheric APO depends mainly on air-sea O_2 flux.

Annual O_2 cycles in ocean and atmosphere as a constraint on gas transfer velocity

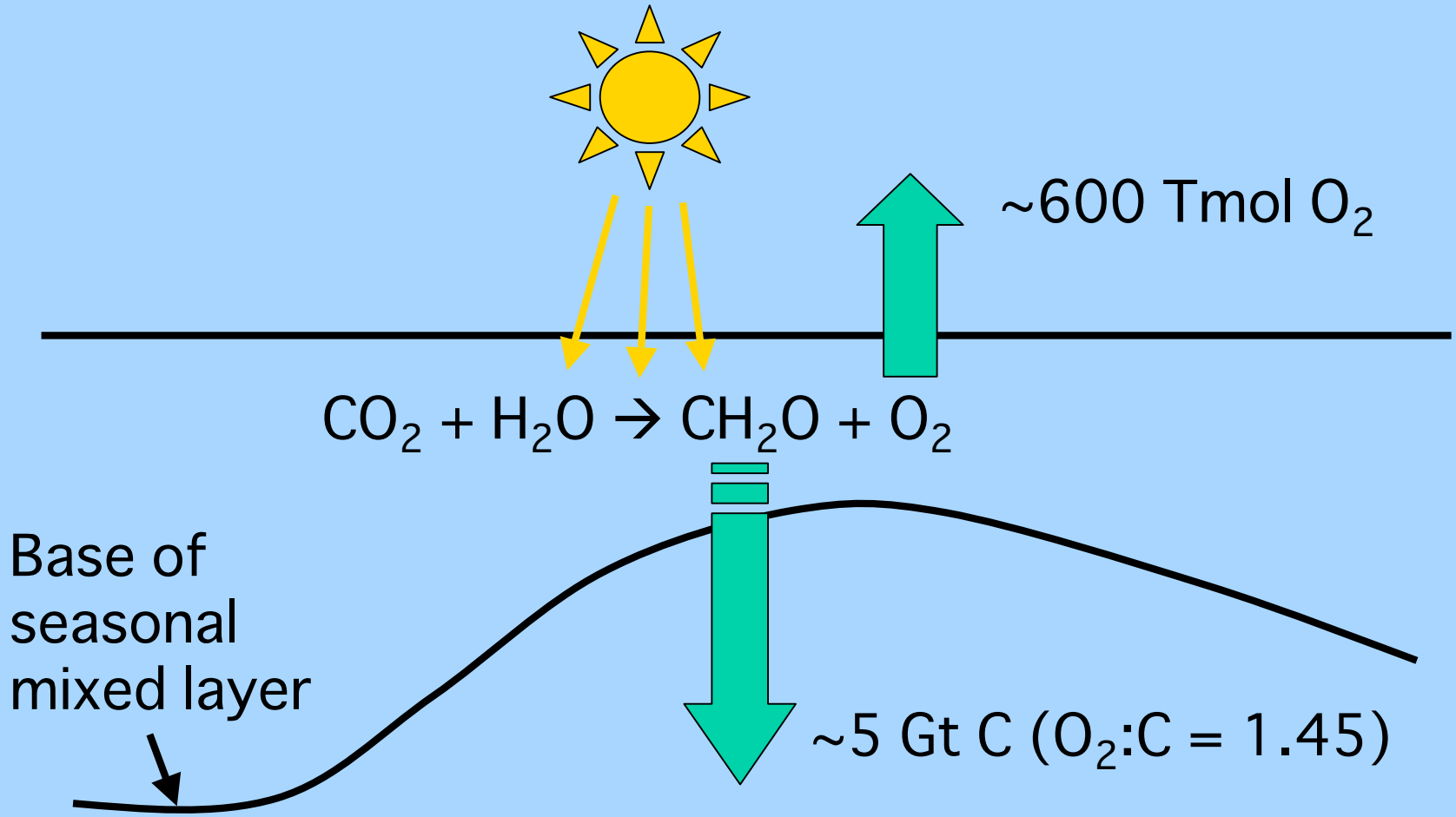
Site:
American
Samoa

(14S, 170W)



Source: Garcia and Keeling (2001)

Annual O_2 cycles as a constraint on extratropical spring-summer new production

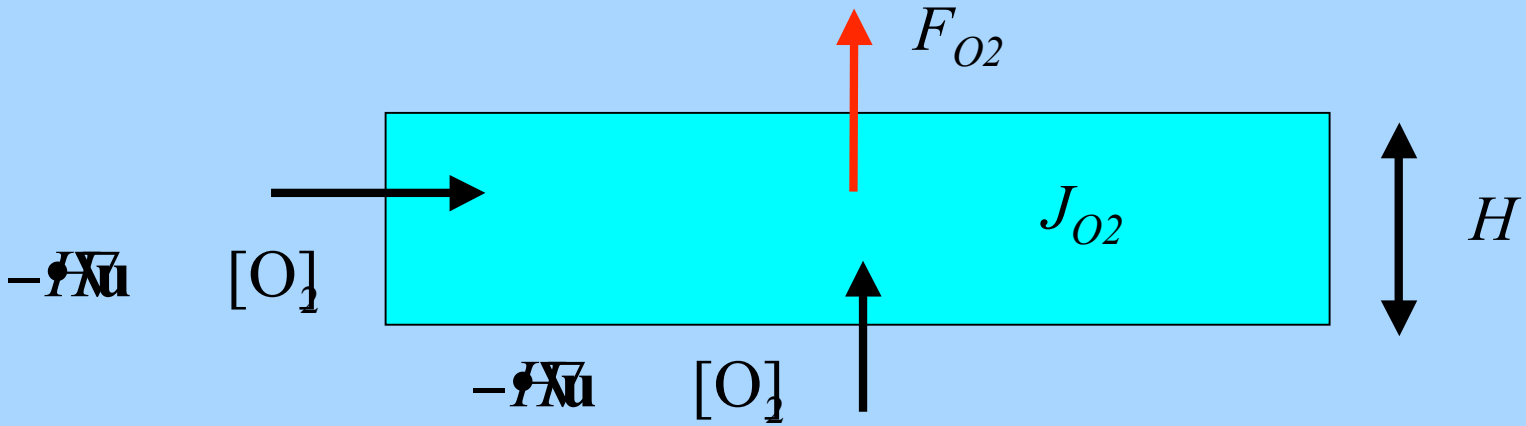


Source: Najjar and Keeling (2000)

Annual mean fluxes

- Difficult to determine accurately from $k_w \Delta[O_2]$
- Current methods invert ocean O_2 data
- Requires knowledge of ocean circulation and nutrient-oxygen stoichiometry

Ocean inversion



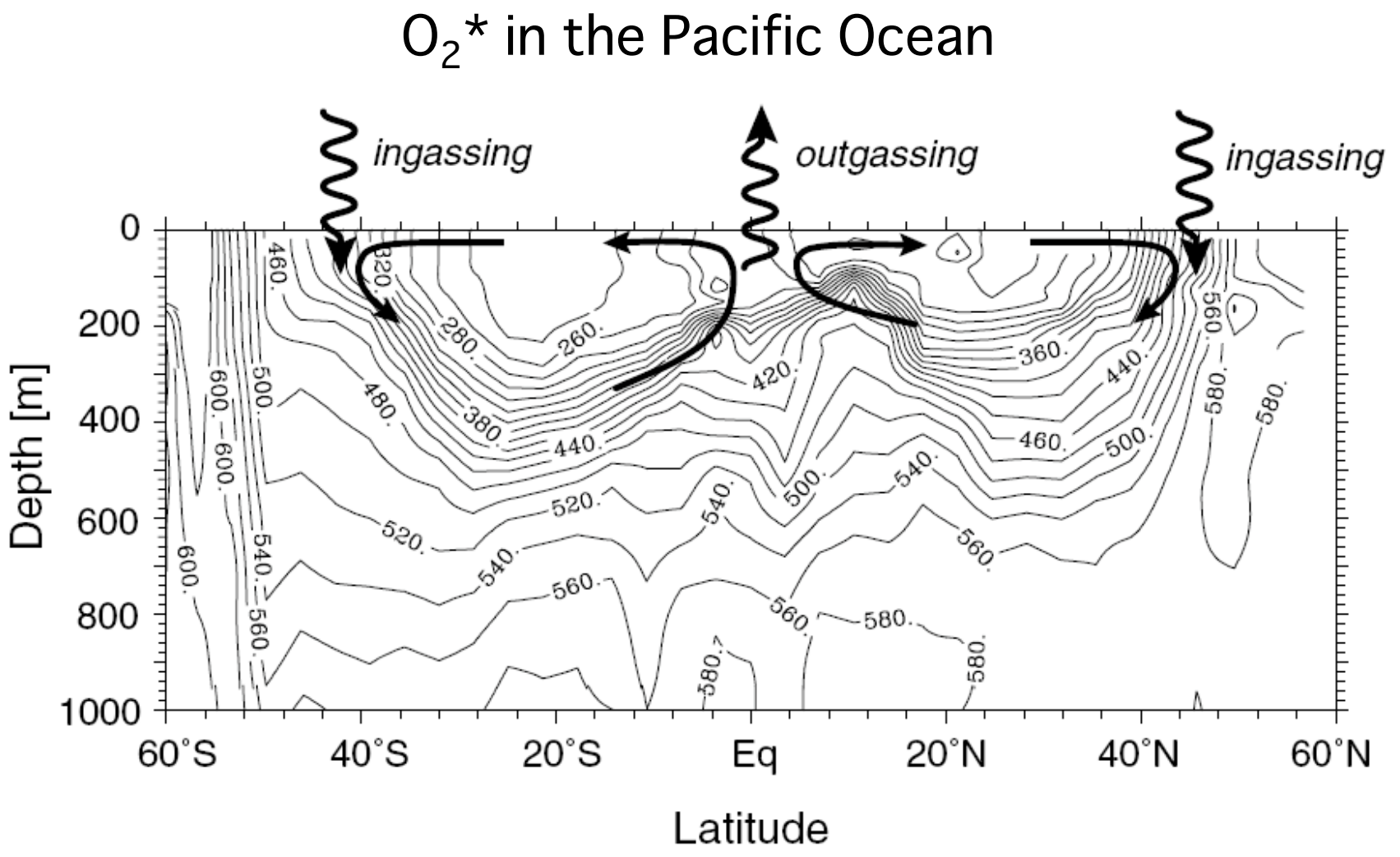
$$\frac{\partial [O]}{\partial t} = -\mathbf{u} \cdot \nabla [O]$$

$$0 = -\mathbf{u} \cdot \nabla [PO_4] + r_{O2:P} J_{PO4}$$

$$\frac{\partial [O]}{\partial t} = -\mathbf{u} \cdot \nabla [O] + r_{O2:P} \left(-\mathbf{u} \cdot \nabla [PO] \right)$$

$$= -\mathbf{u} \cdot \nabla [O]^* H_2$$

O_2* conservation

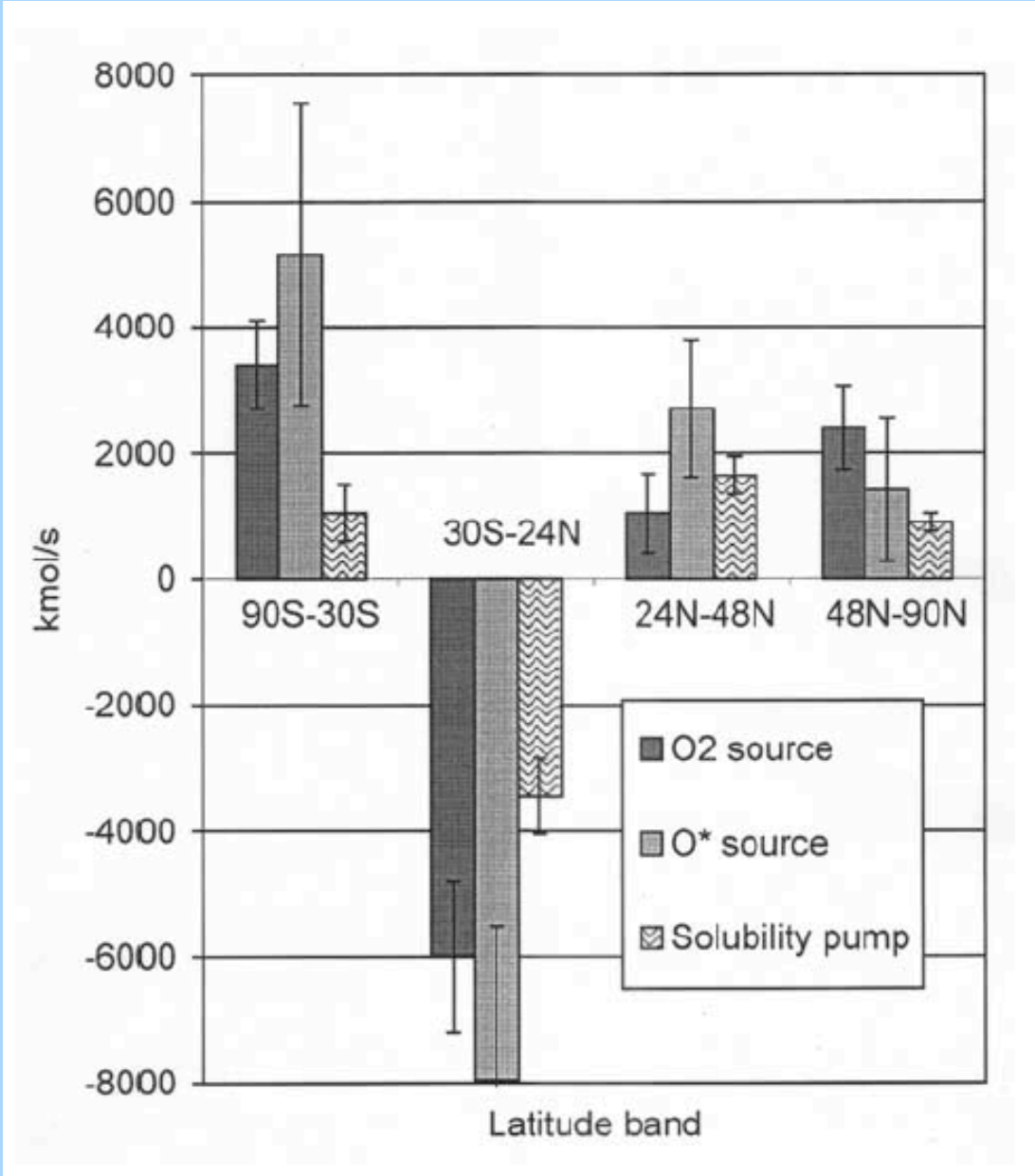


Source: Gruber et al. (2001)

Annual mean fluxes

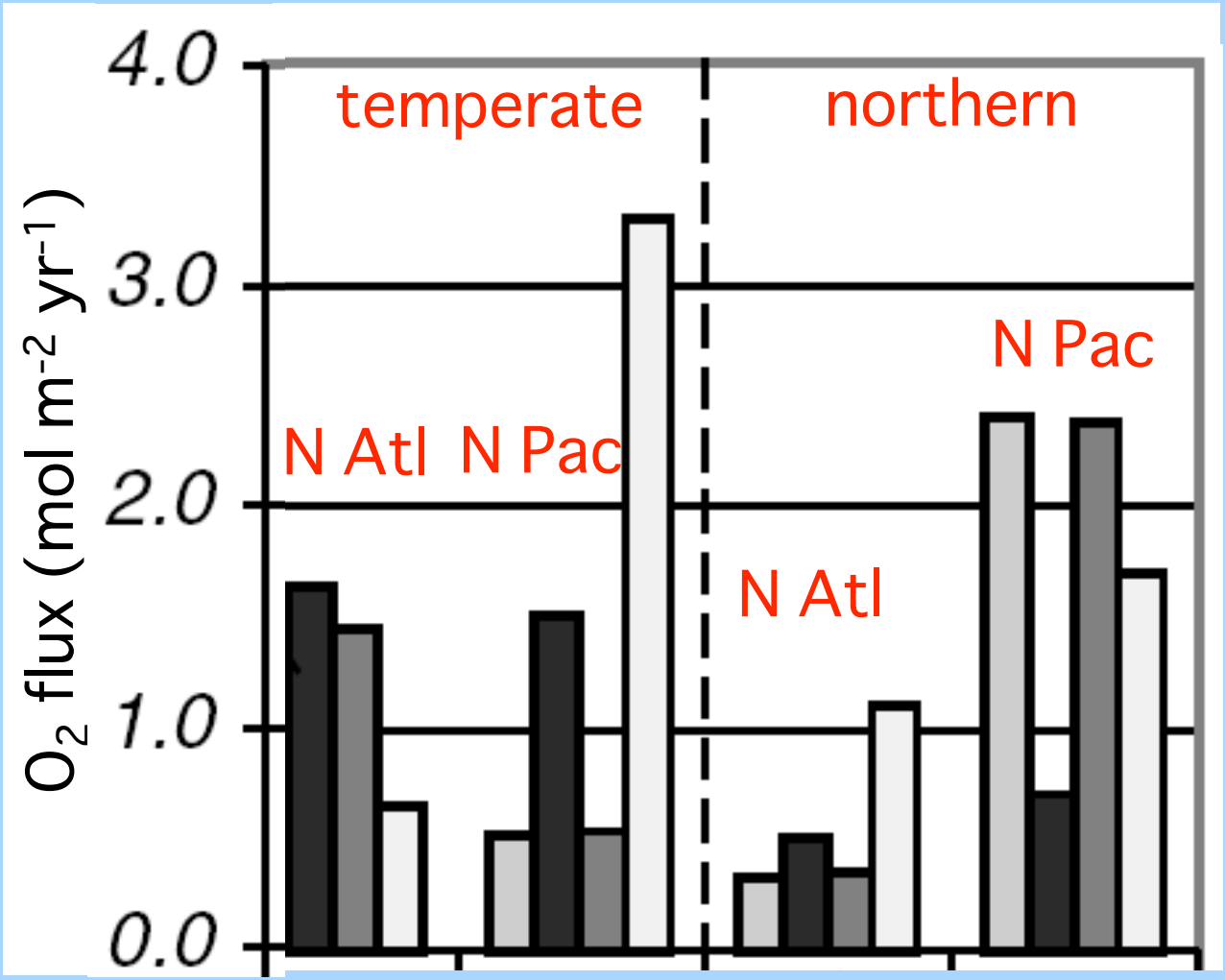
influx

efflux



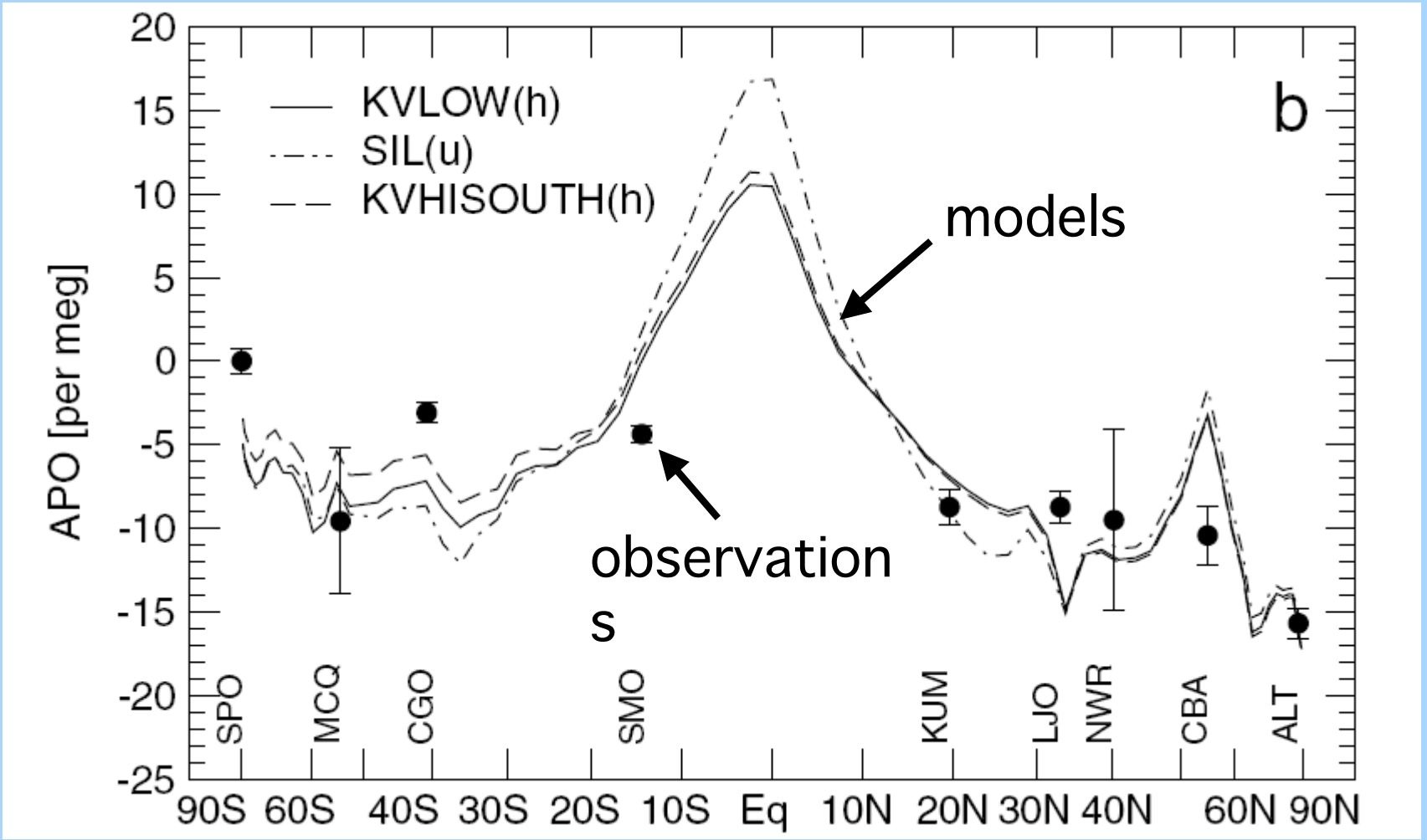
Source: Ganachaud and Wunsch (2002)

Sensitivity to ocean circulation



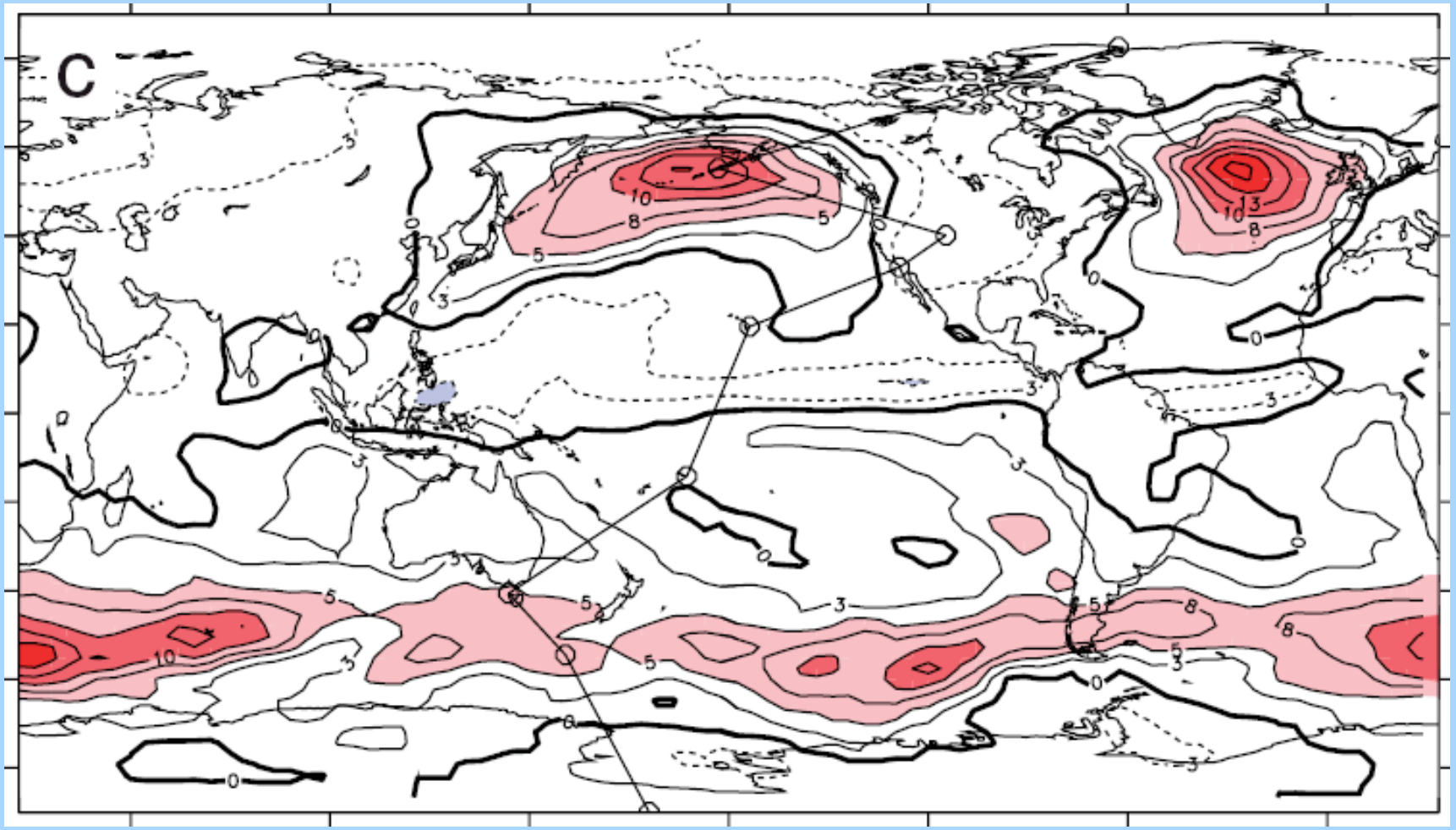
Source: Gruber et al. (2001)

Annual mean APO distribution



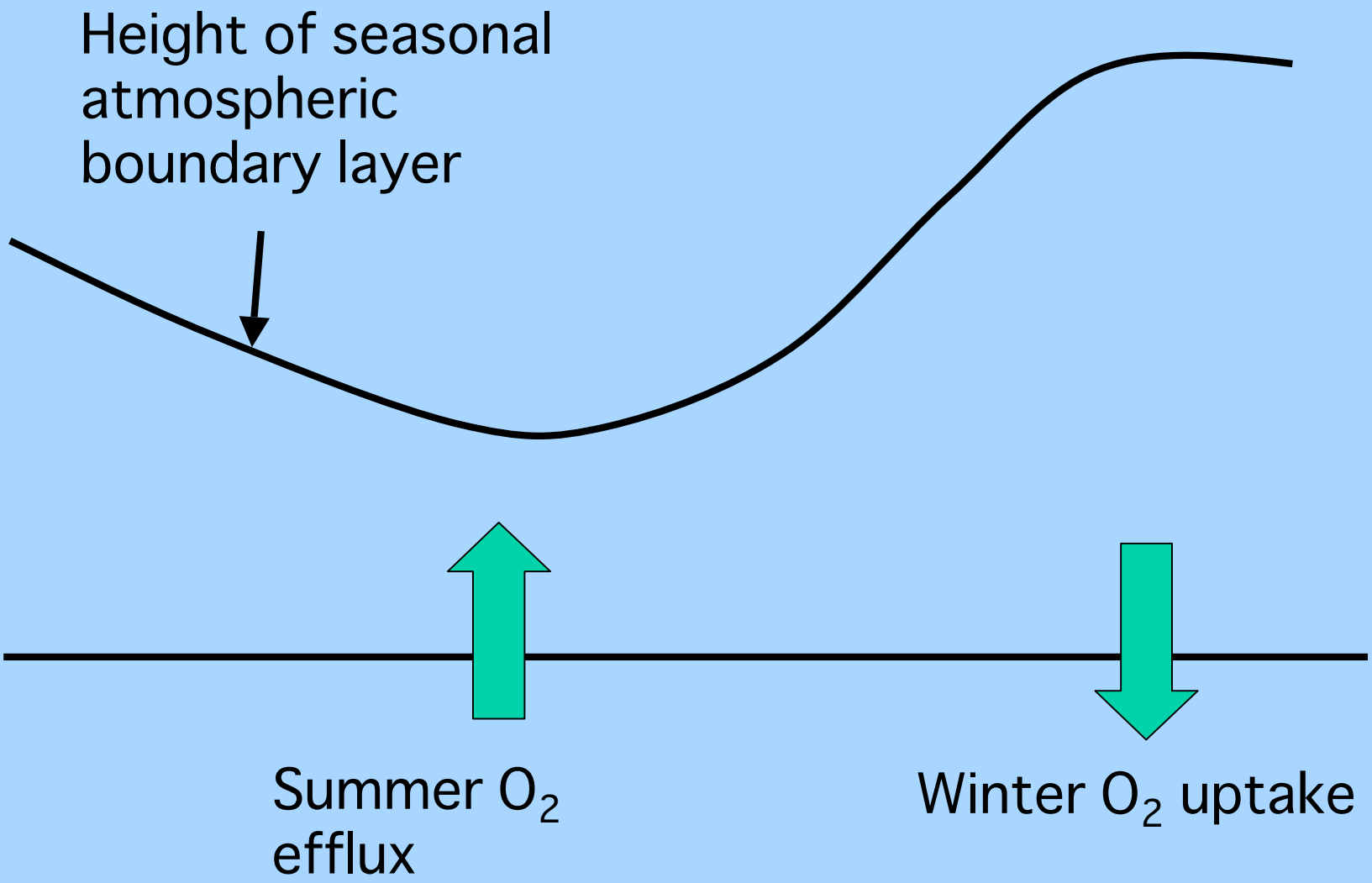
Source: Gruber et al. (2001)

Simulated seasonal rectifier effect on APO



Source: Gruber et al. (2001)

Seasonal rectification of O_2 flux



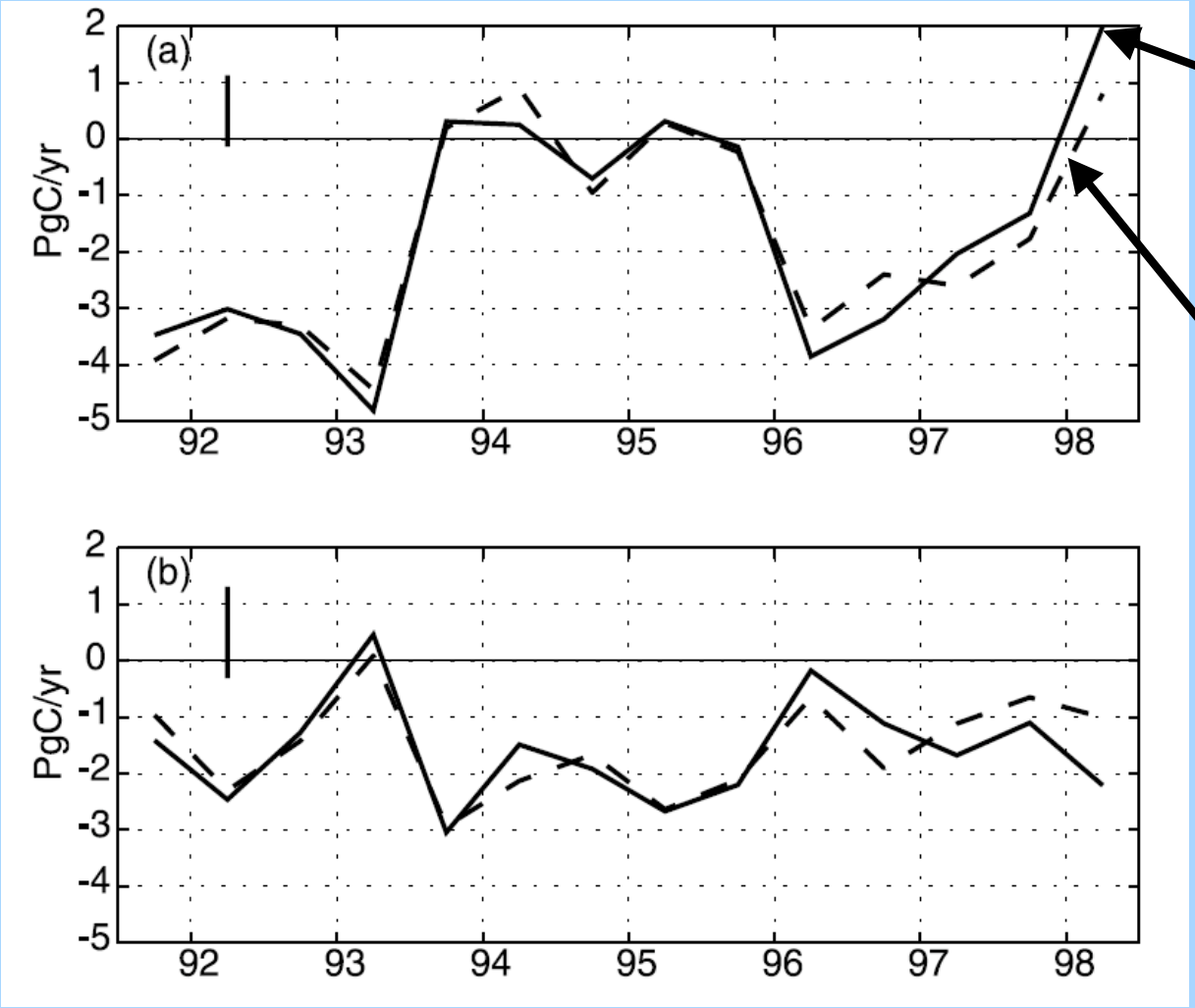
Interannual variability

- Few data
- Some models
- Models suggest significant impact on anthropogenic CO_2 sink
- Variability is related to heat flux

Impact on CO_2 sink estimate

Land uptake

Ocean uptake



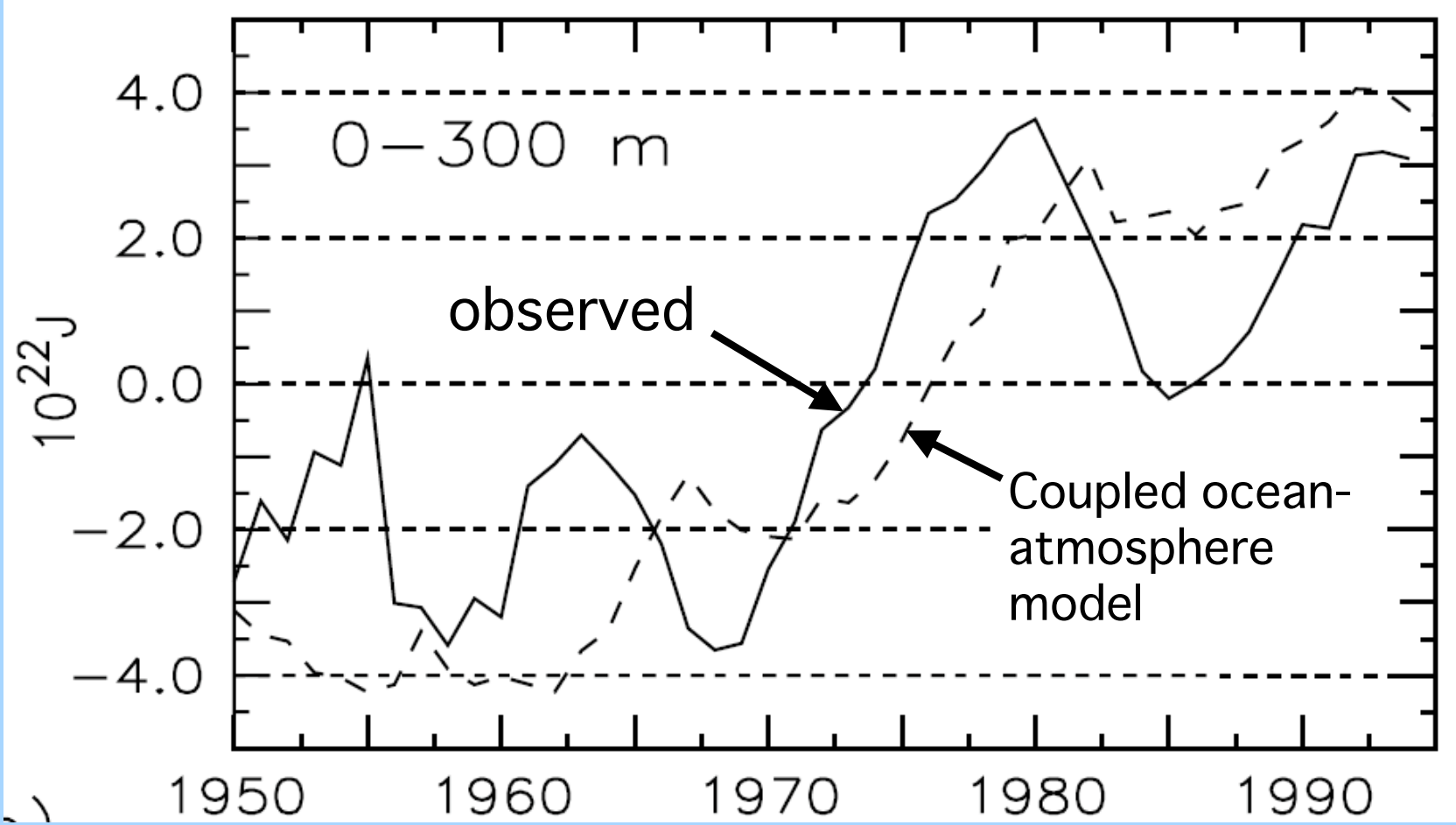
Assumes no air-sea O_2 flux

Includes correction for air-sea O_2 flux

RMS Correction ~ 0.5 Gt C yr^{-1}

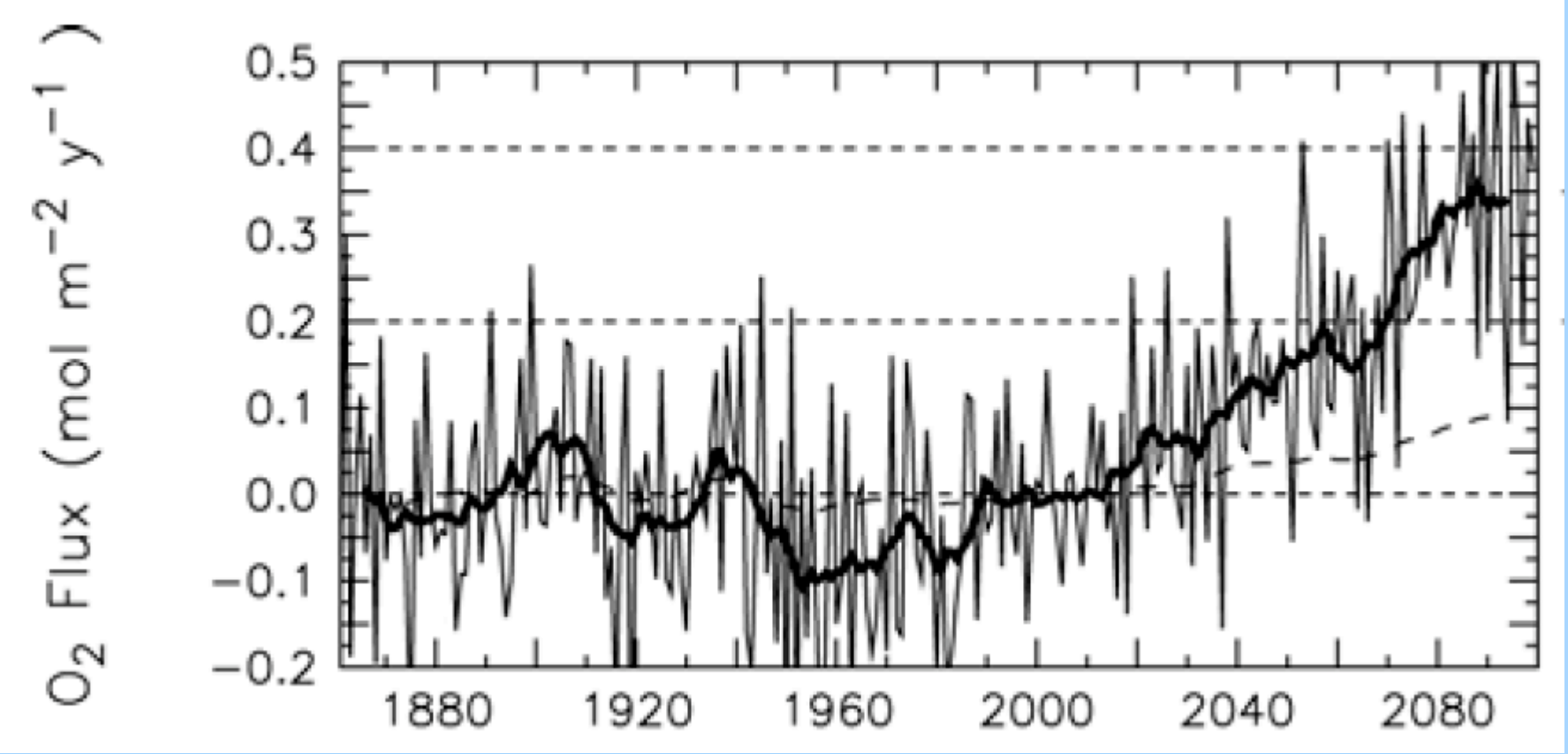
Source: McKinley et al. (2003)

Trend in ocean heat content



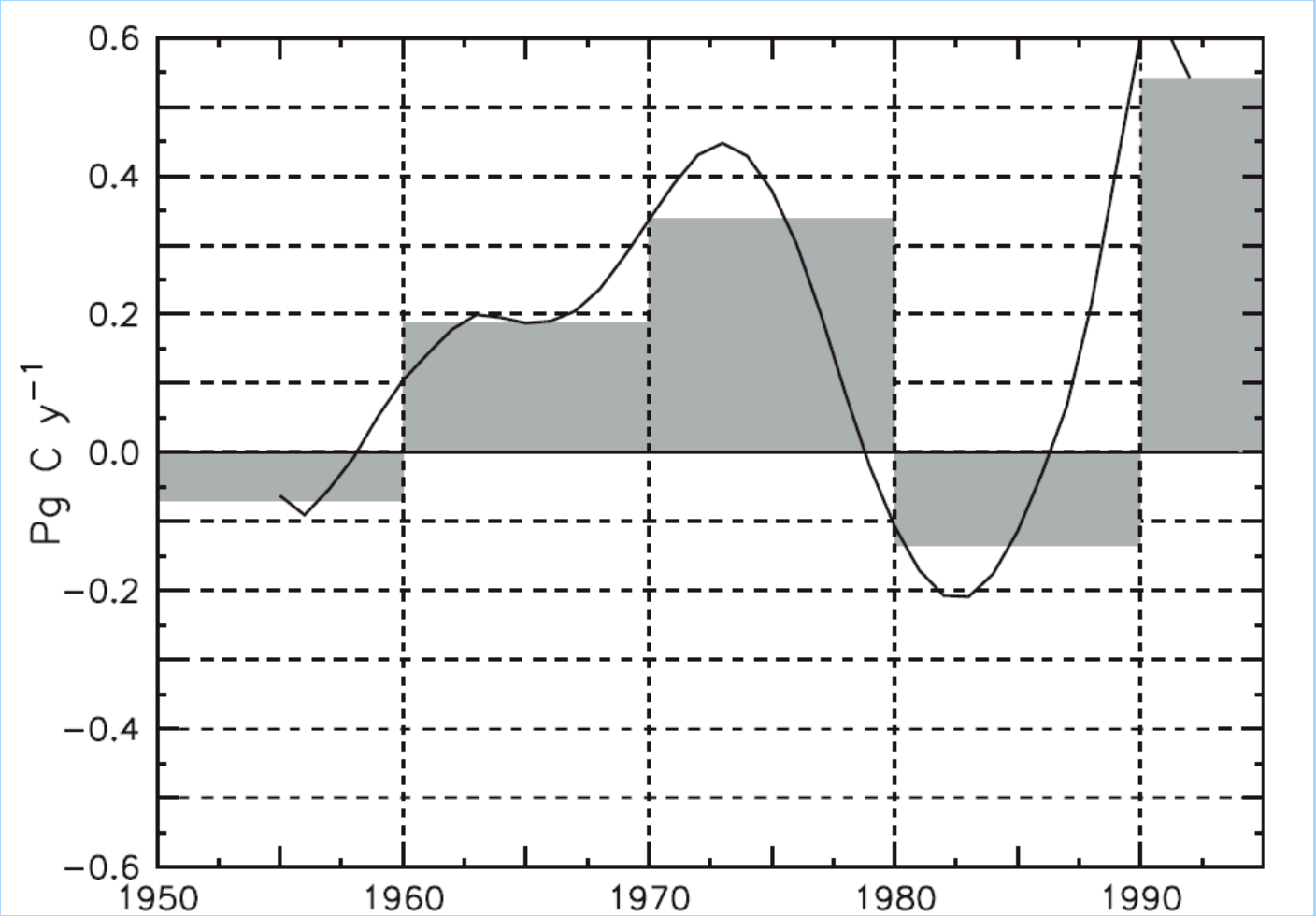
Source: Bopp et al. (2002)

Climate change impact on O_2 flux



Source: Bopp et al. (2002)

Correction to ocean sink



Source: Bopp et al. (2002)

Direct measurement?

- Stephens *et al.* (2003) developed ship-board atmospheric O_2 measurement technique based on absorption of UV
- Precision ~1 ppm for discrete 10 s measurement, 0.2 ppm for 5-min average
- O_2 flux variability generally ≧ that of CO_2

Early insights

Richards (1957) on Redfield (1948):

"The general ideas of Redfield must apply to the sea as a whole, with oxygen entering the sea surface for most of the year in polar regions and in regions where upwelling brings oxygen-deficient waters to the surface, and leaving the sea surface most of the year in the tropics, where photosynthesis and high temperatures favor excesses of oxygen."

Early insights

Richards (1957) on Redfield (1948):

"Seasonally alternating periods of oxygen exchanges in opposite directions would be expected in the temperate zones."

Summary of air-sea oxygen flux

- Air-sea O_2 flux relevant for a variety of phenomena in the SOLAS domain

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- Direct measurements may be within reach

References

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