

# Photosynthesis under partial sea-ice cover

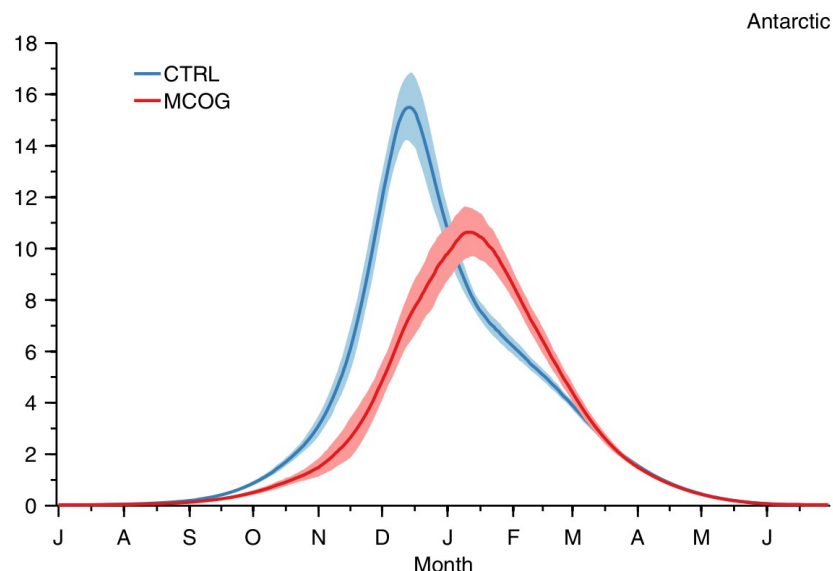
## Modeling photosynthesis in sea ice-covered waters

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### Citation:

Long, M. C., K. Lindsay, and M. M. Holland (2015), Modeling photosynthesis in sea ice-covered waters, *J. Adv. Model. Earth Syst.*, 7, 1189–1206, doi:10.1002/2015MS000436.

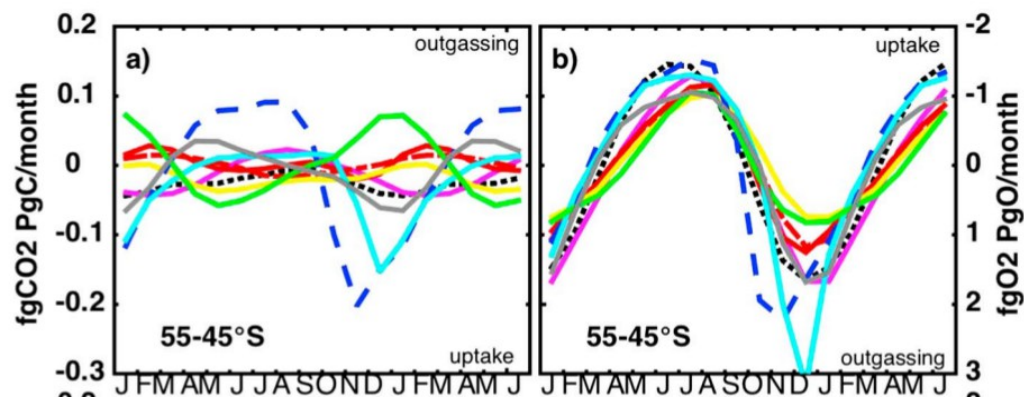


**Figure 6.** Annual net primary production in the (a) Arctic ( $>65.5^{\circ}\text{N}$ ) and (b) Antarctic region ( $>60^{\circ}\text{S}$ ) from CTRL (blue) and MCOG (red). Shading shows the standard deviation of interannual variability over 30 years of simulation.

### Key Points:

- Photosynthesis is nonlinear, computations on mean versus full fields will differ
- Sea ice drives spatial variability in light
- Accounting for nonlinearity improves accuracy of simulated primary productivity

Challenge in HAMOCC:  
Southern Ocean Seasonality  
(Nevison et al. 2016)



# Bulk phytoplankton

$$\frac{\partial \text{Phy}}{\partial t} = \underbrace{G_{\text{phy}}}_{\text{growth}} - \underbrace{F_{\text{pz}}}_{\text{grazing}} - \underbrace{M_{\text{phy}}}_{\text{mortality}} - \underbrace{E_{\text{phy}}}_{\text{exudation}}$$

$$G_{\text{phy}} = J(I, T) \frac{X}{K_X + X} \text{Phy}$$

$$f(T) = \mu_{\text{phy}} 1.066^{(T)}$$

$$g(I(z)) = \alpha I_0 \left( \sigma \exp(-zk_r) + (1-\sigma) \exp(-zk_w - k_{\text{chl}} \int_0^z R_{\text{C:Chl}} \text{Phy}) \right)$$

↑  
depth dependent

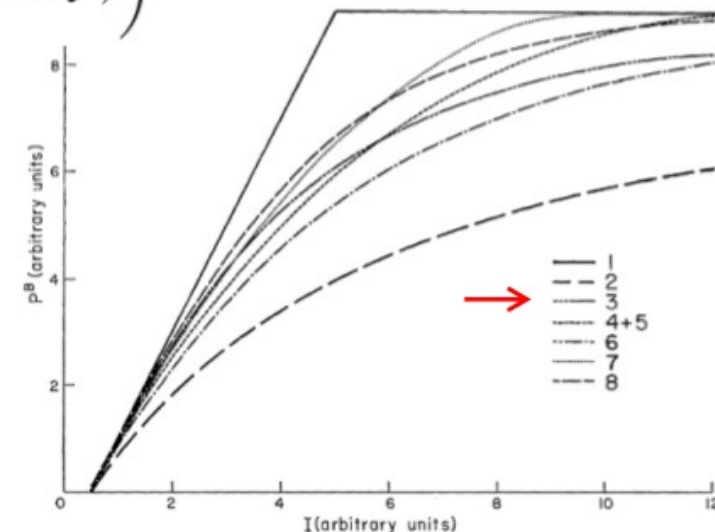
$$J(I, T) = \frac{g(I(z))f(T)}{\sqrt{g(I(z))^2 + f(T)^2}}$$

Smith (1936)

$$P^B = P_m^B \alpha I / [ (P_m^B)^2 + (\alpha I)^2 ]^{\frac{1}{2}}$$

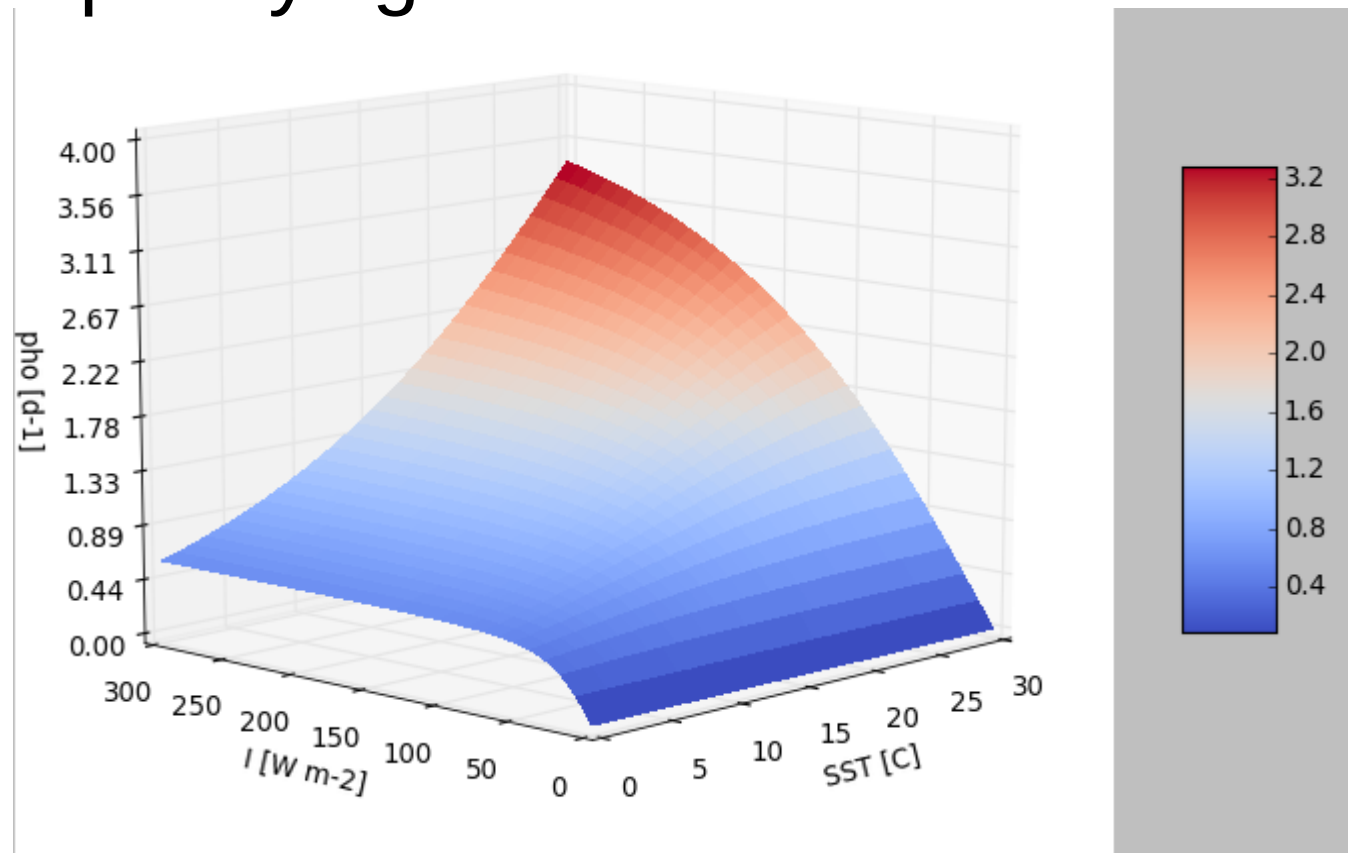
## Growth

- Limitation by: light, temperature, nutrients
- Temperature: Eppley curve
- Light: P-I saturation curve (Smith, 1936) with light provided by MPIOM: vertical light field Zielinski et al. (2002) (exponential profile, clear water and self shading effect of Phy with constant C:Chl conversion factor)



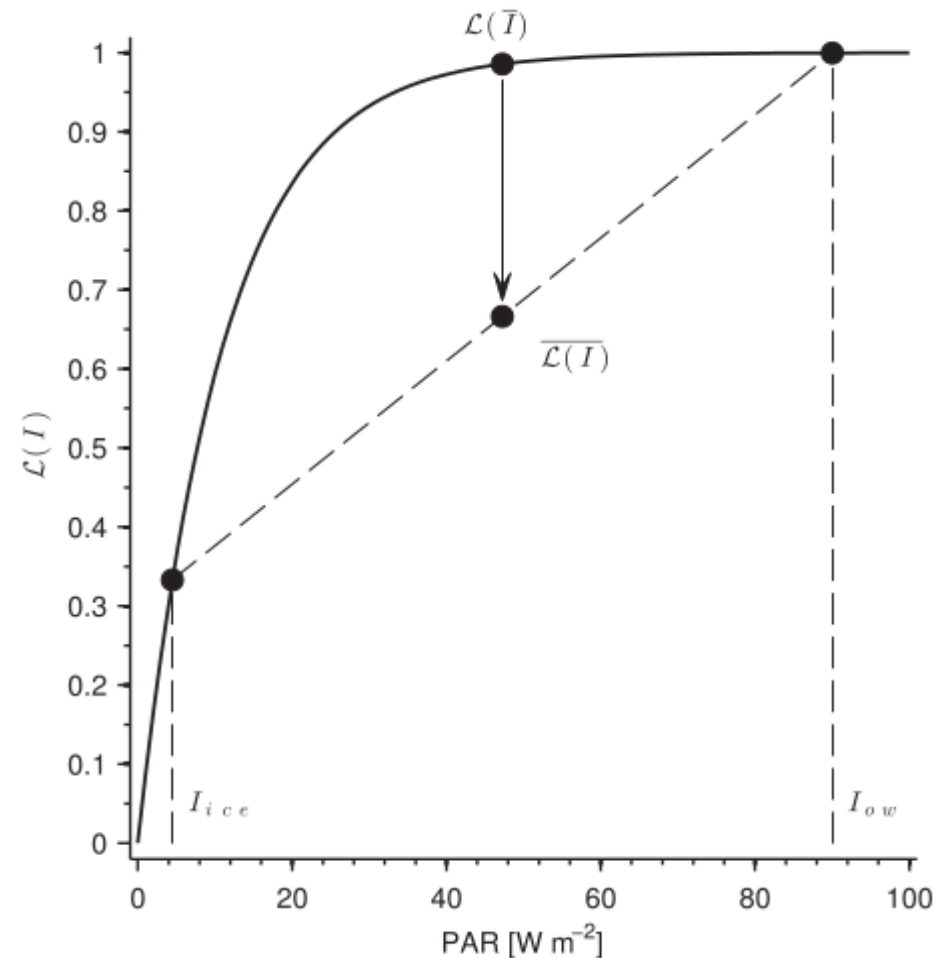
# Photosynthesis in HAMOCC

- Combined temperature- and light-limitation
- Non-linear
- For cold waters quickly light-saturated



# Proposal: Fix for PAR

- Now: If grid cell is sea-ice covered, then strahl is attenuated
- Proposal: ..., then PAR for grid cell is calculated for sea-ice free area ( $f$ ) and sea-ice covered area ( $1-f$ ) separately
- No change if no ice ( $f=0$ )
- No change if linear



**Figure 1.** Relative rate of photosynthesis (equation (1)) plotted as a function of irradiance (photosynthetically available radiation [PAR]) under constant temperature ( $2^{\circ}\text{C}$ ), nutrient replete conditions, and a chlorophyll:carbon ratio of  $0.025 \text{ g Chl (g C)}^{-1}$  ( $P_{max}^C = 4.8 \text{ day}^{-1}$ , representative of diatoms in BEC). A thought experiment is illustrated in which a grid-cell is half covered with sea ice that has uniform transmittance properties, passing 5% of incident solar radiation such that  $I_{ice} = 0.05 I_{ow}$ , where  $I_{ow}$  is the PAR value of open water.

# My runs

- From Fabrice pre-industrial control restart file
- Ori (CTRL) = 30 yrs control run
- Phyice (MCOG) = 30 yrs phyice fix

INTPP in the Antarctic south of 60S

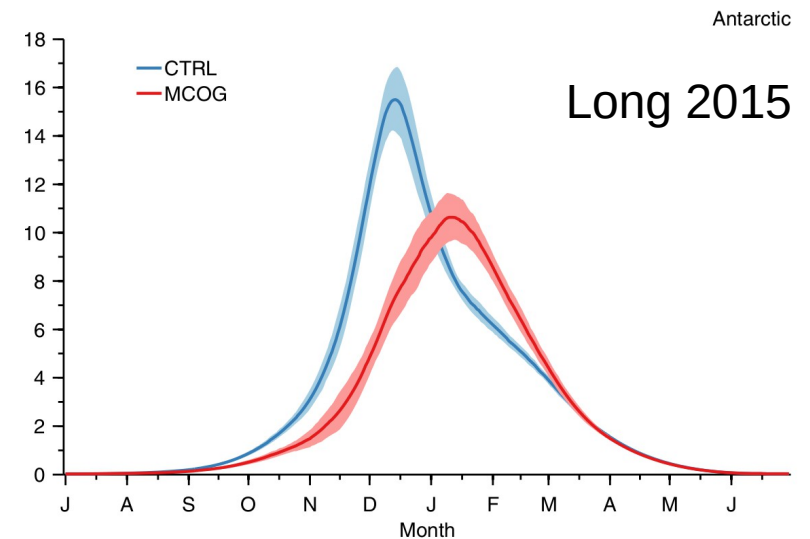
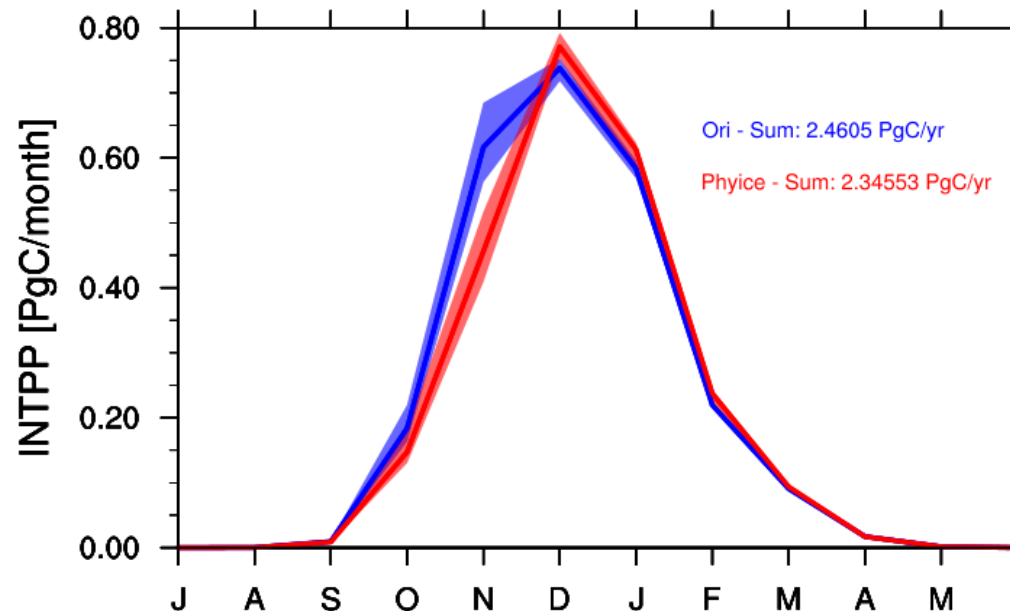
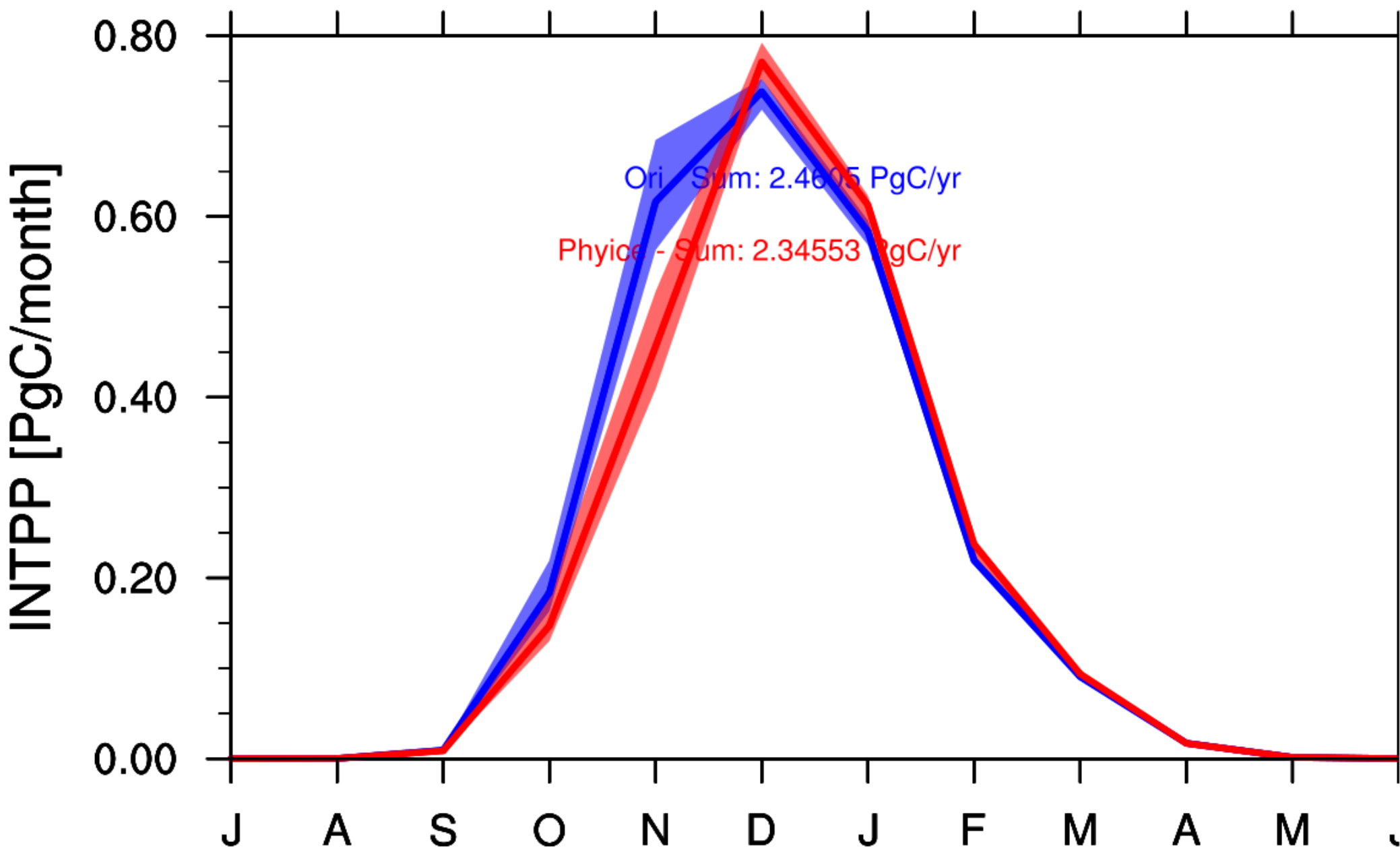
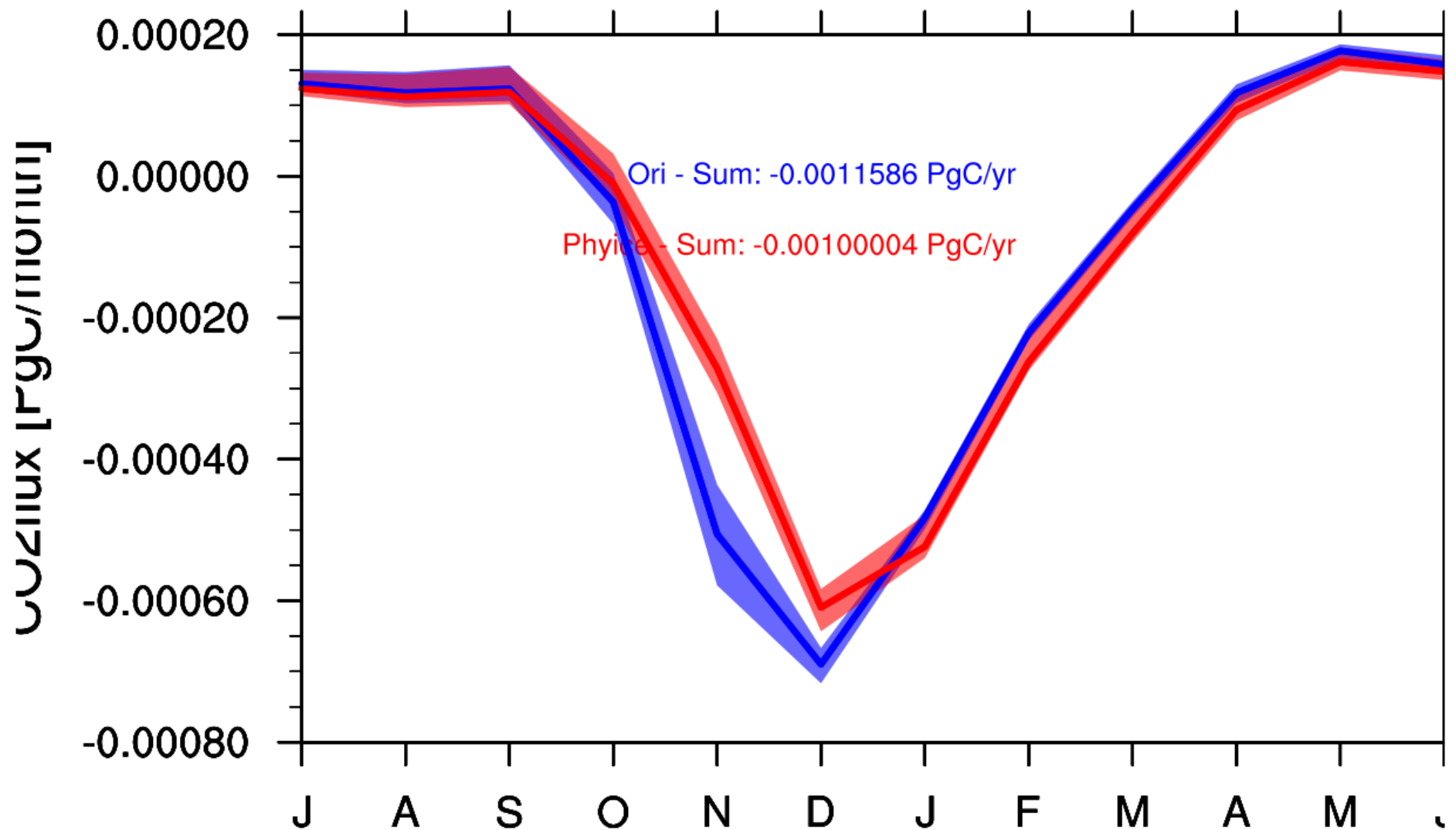


Figure 6. Annual net primary production in the (a) Arctic ( $>65.5^{\circ}\text{N}$ ) and (b) Antarctic region ( $>60^{\circ}\text{S}$ ) from CTRL (blue) and MCOG (red). Shading shows the standard deviation of interannual variability over 30 years of simulation.

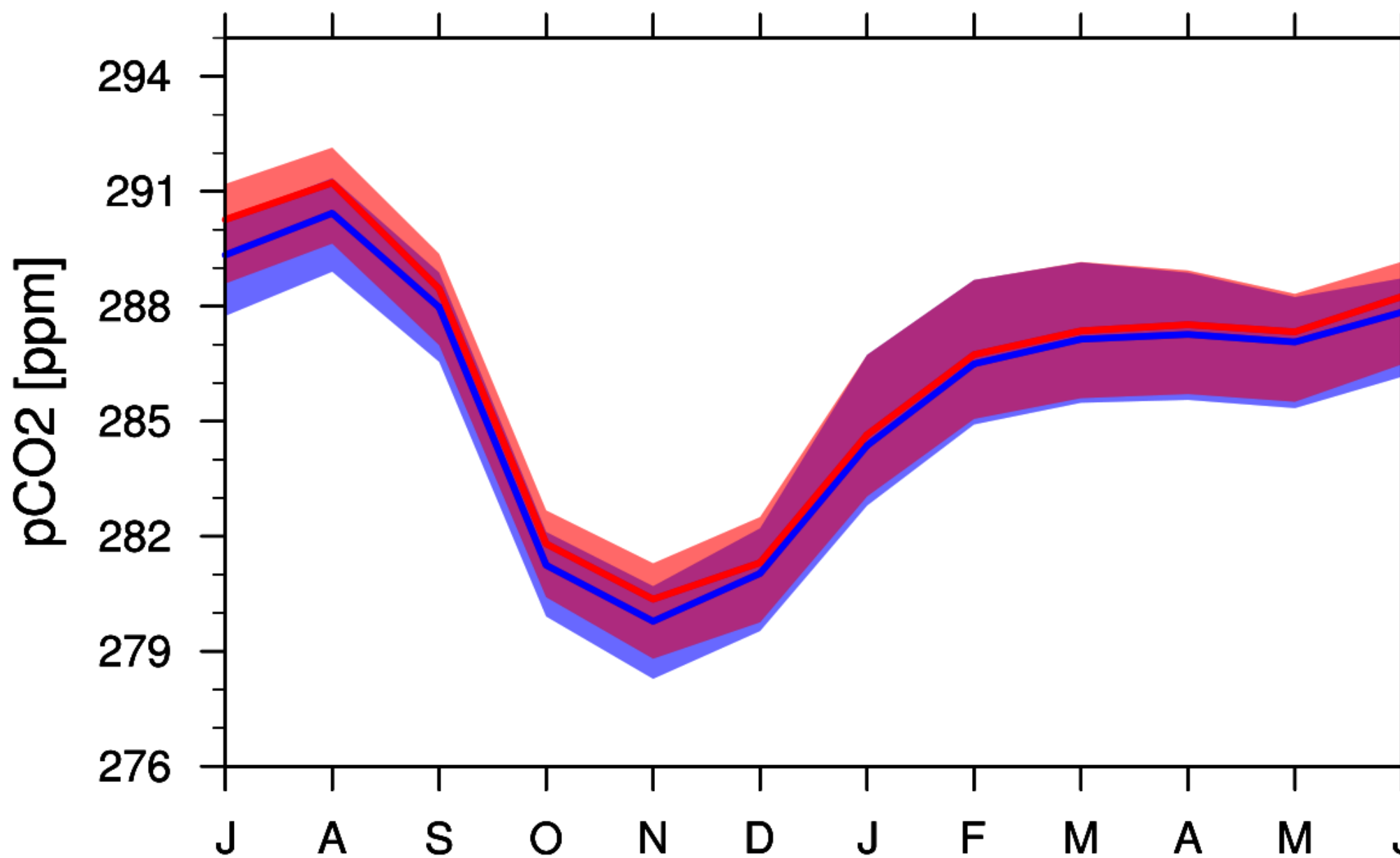
# INTPP in the Antarctic south of 60S



# CO2 flux in the Antarctic south of 60S

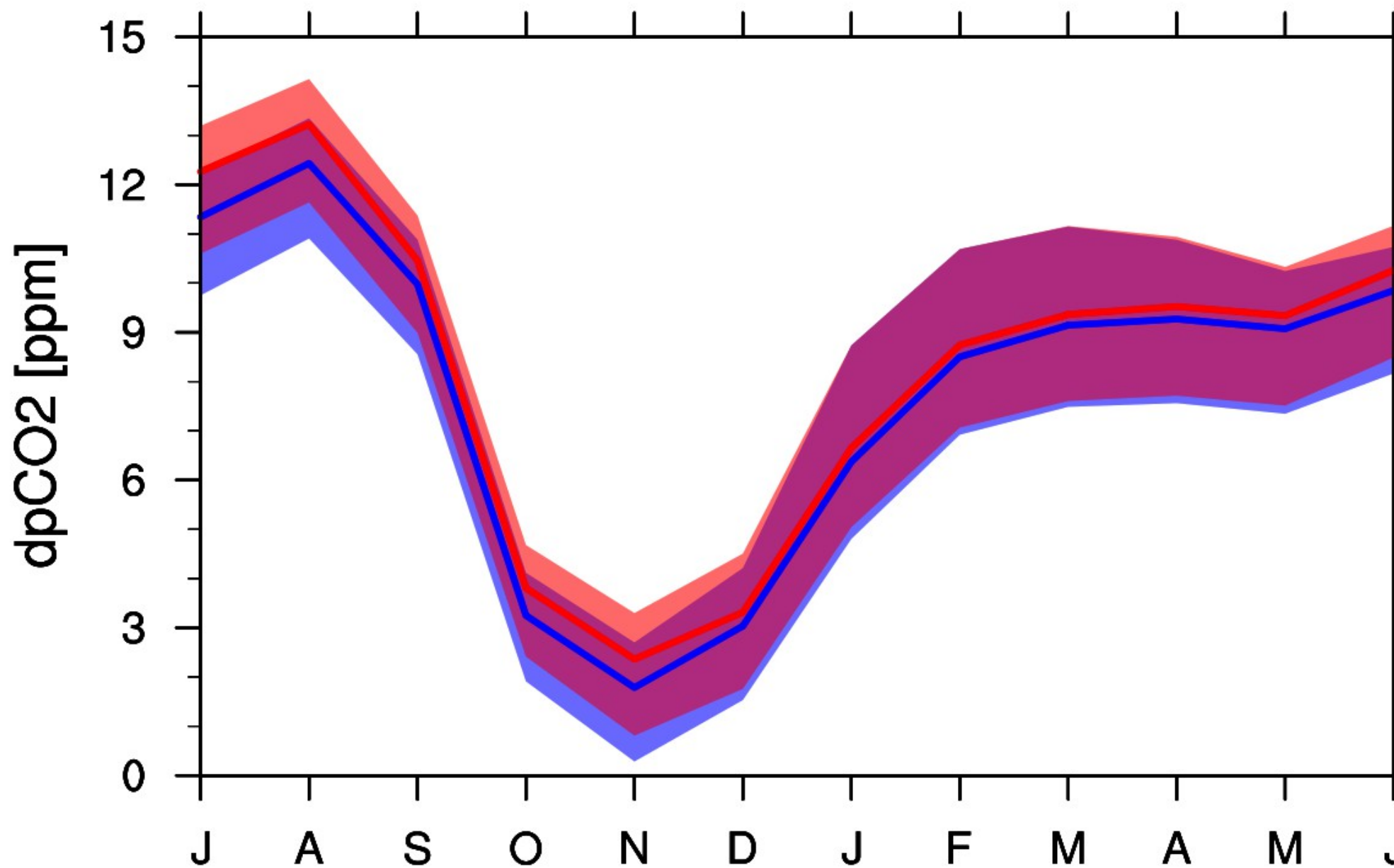


# pCO<sub>2</sub> in the Antarctic south of 60S



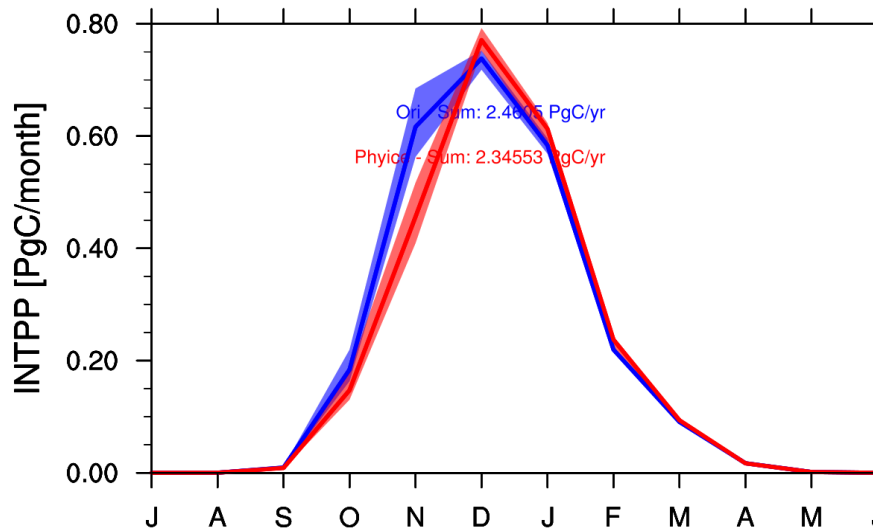


# dpCO<sub>2</sub> in the Antarctic south of 60S

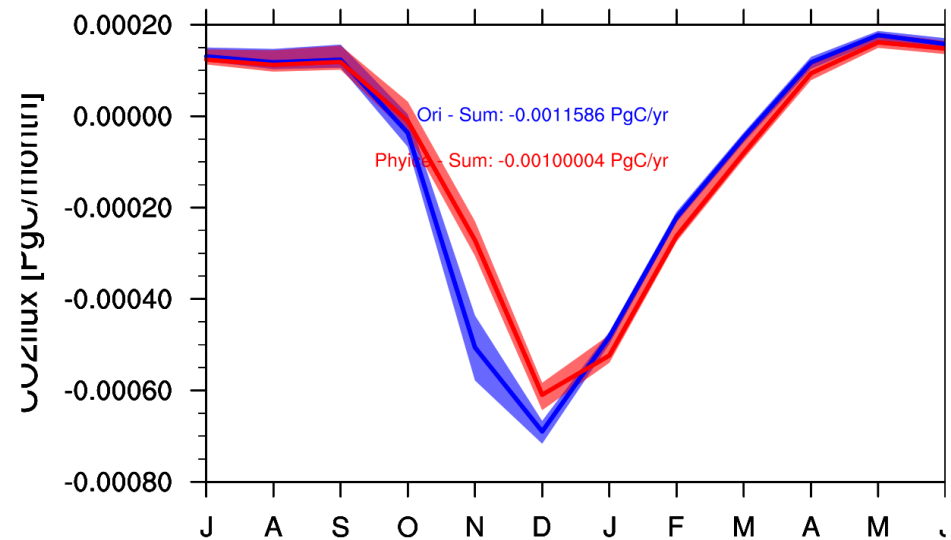


# Summary Seasonality

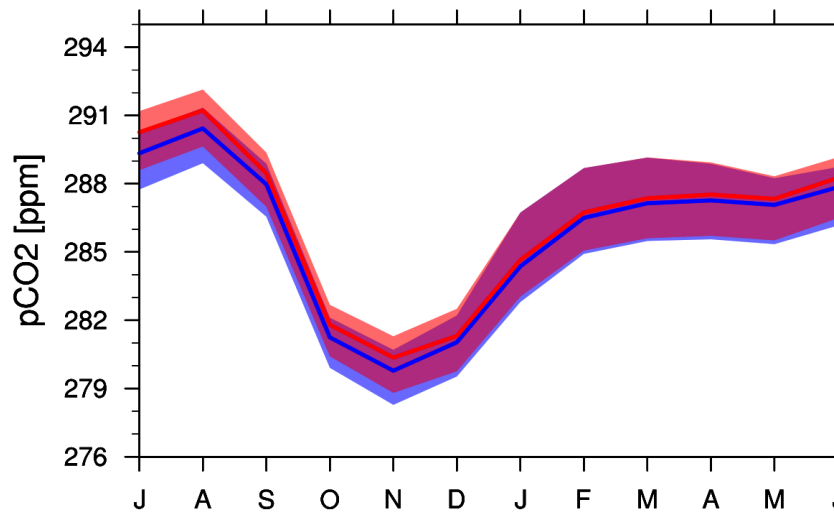
INTPP in the Antarctic south of 60S



CO2 flux in the Antarctic south of 60S



pCO2 in the Antarctic south of 60S



dpCO2 in the Antarctic south of 60S

