# Photosynthesis under partial sea-ice cover

## Modeling photosynthesis in sea ice-covered waters

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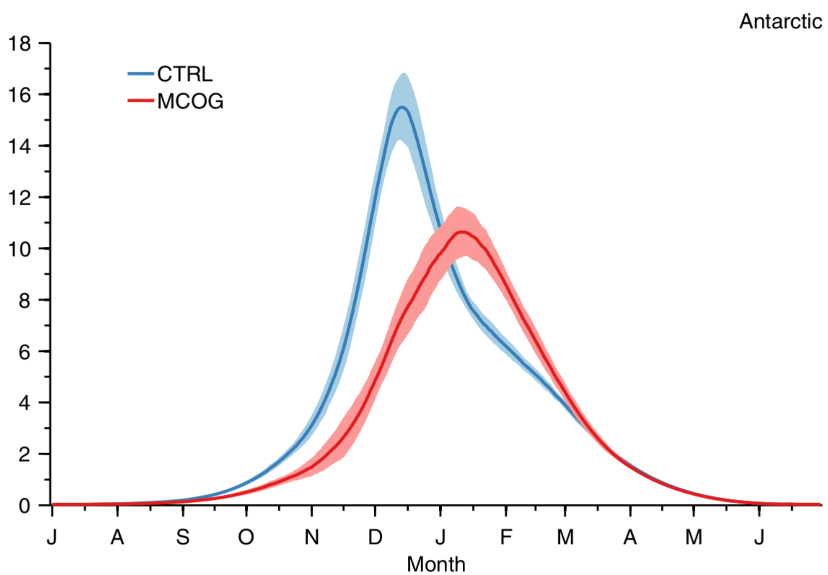
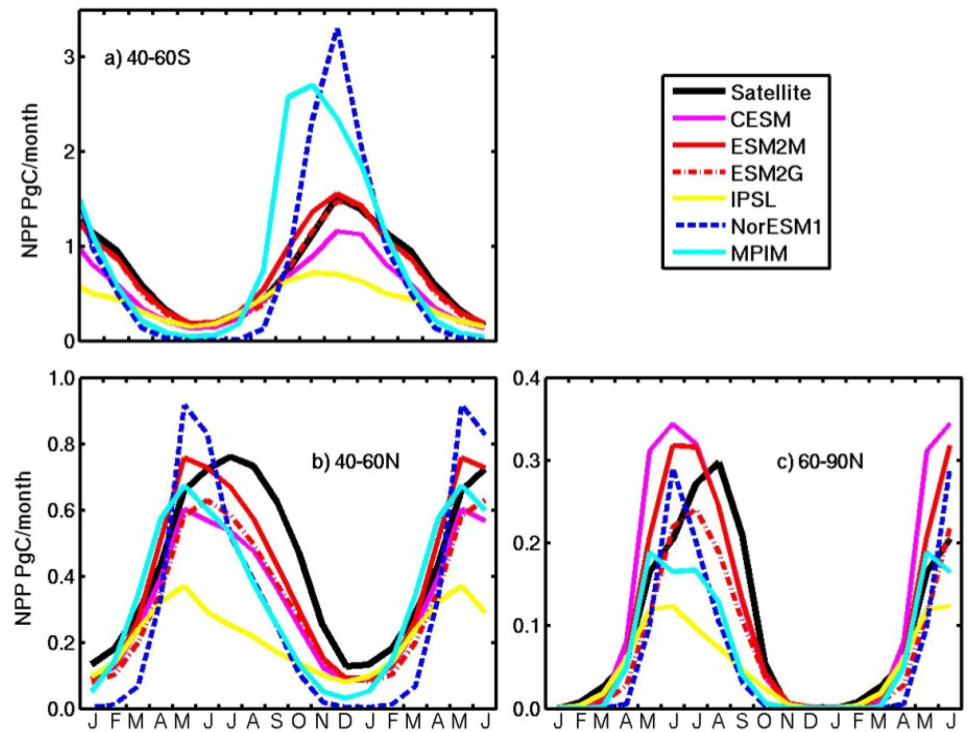



**Figure 6.** Annual net primary production in the (a) Arctic (>65.5°N) and (b) Antarctic region (>60°S) from CTRL (blue) and MCOG (red
Shading shows the standard deviation of interannual variability over 30 years of simulation.

## 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




Challenge in HAMOCC:
Southern Ocean Seasonality
(Nevison et al. 2015)

# Bulk phytoplankton

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

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

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

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

↑ depth dependent

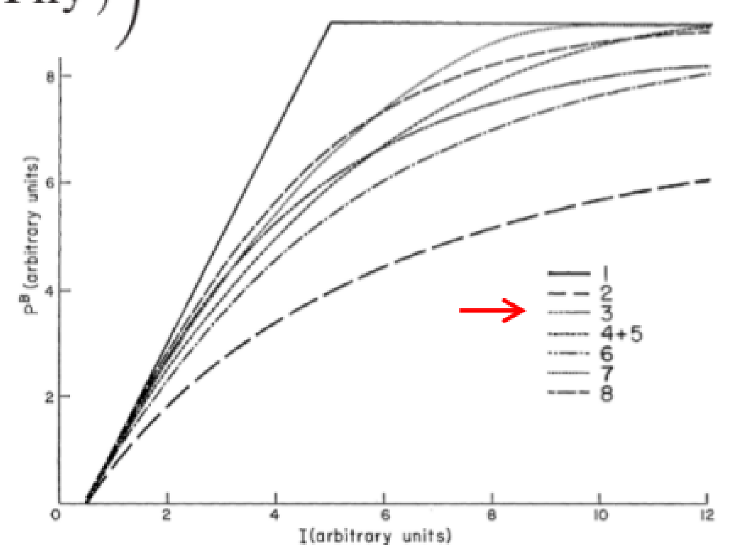
$$J(I,T) = \frac{g(I(z))f(T)}{\sqrt{g(I(z))^2 + f(T)^2}}$$

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)

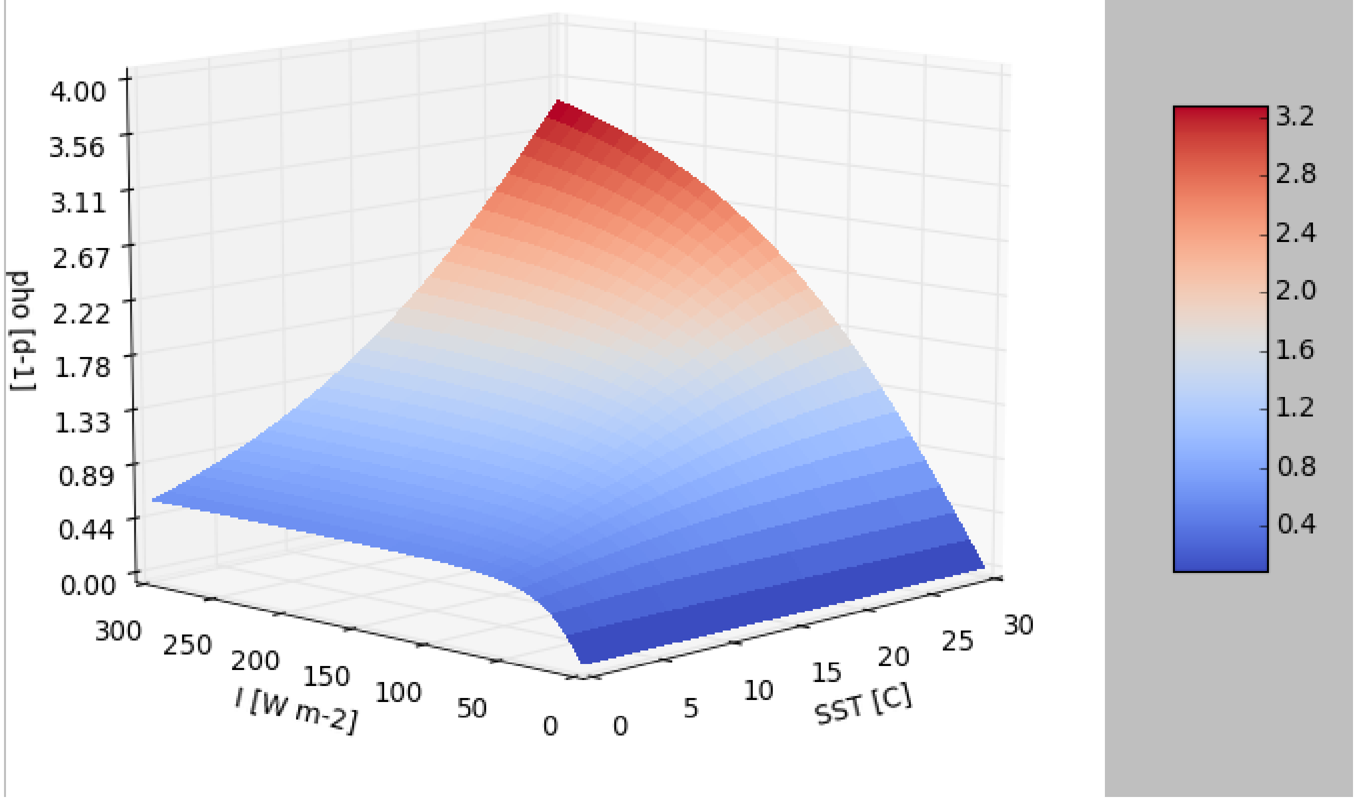
Smith (1936)

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



# 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

  → <u>CHANGE IN TIMING</u>
- No change if no ice (f=0)
- No change if J(I,T) linear

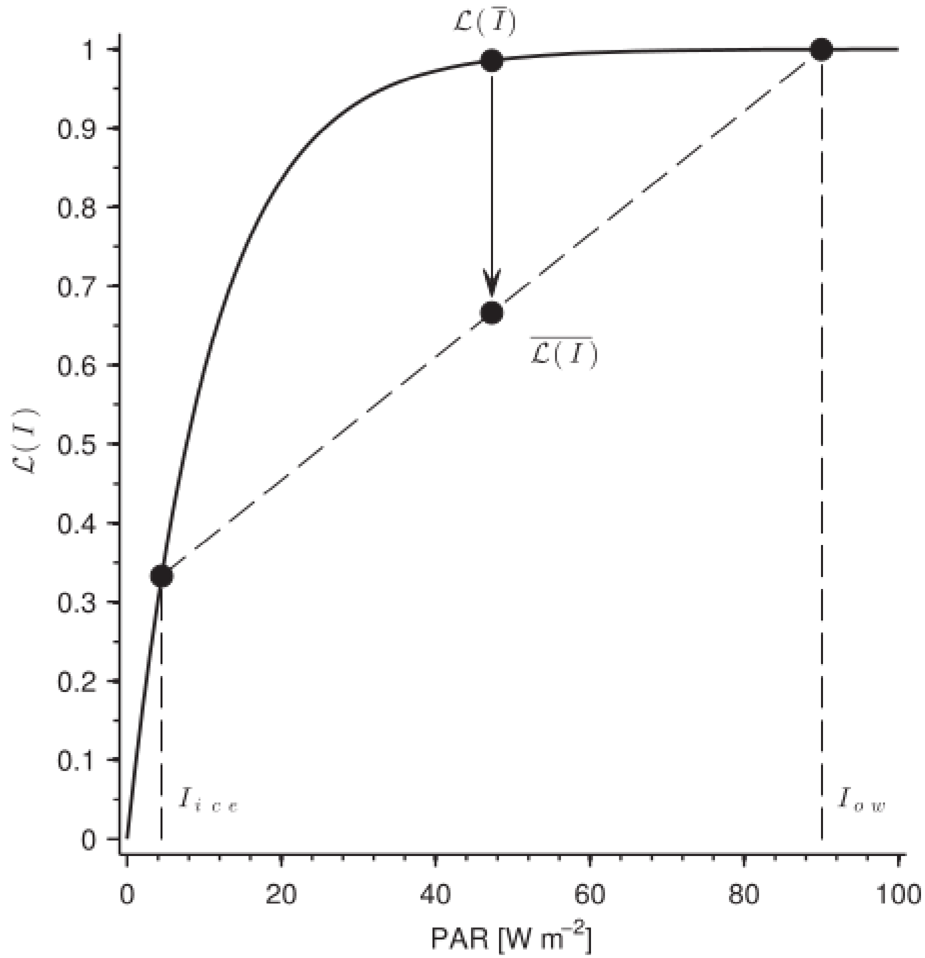
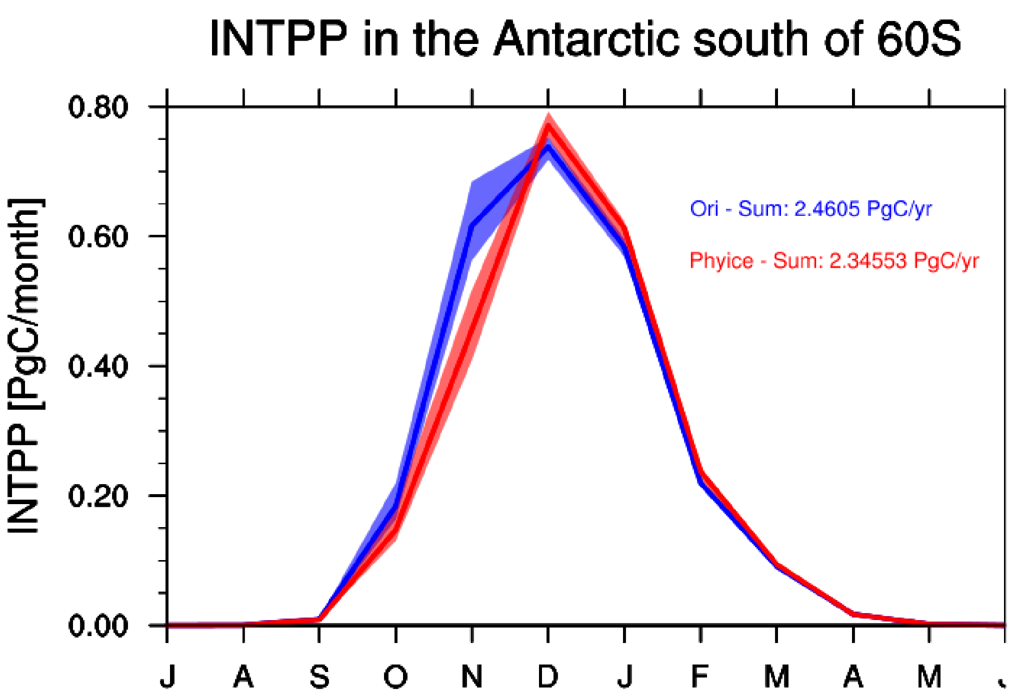
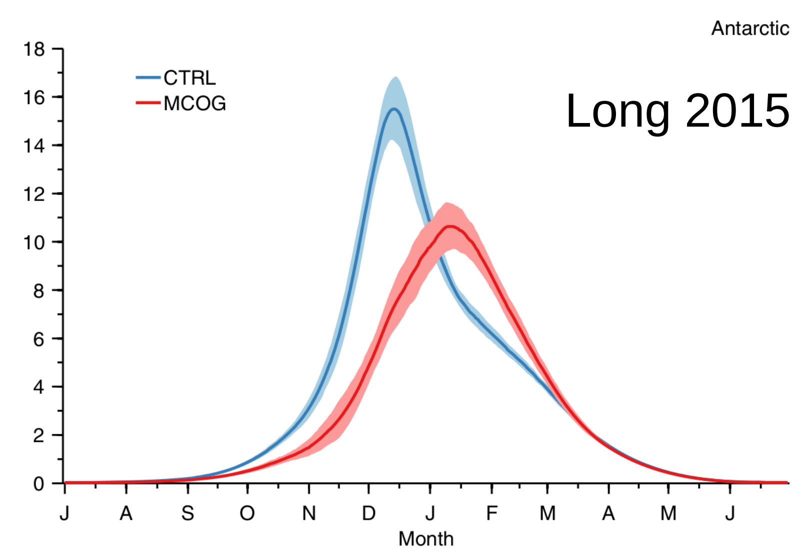



**Figure 1.** Relative rate of photosynthesis (equation (1)) plotted as a function of irradiance (photosynthetically available radiation [PAR]) under constant temperature (2°C), nutrient replete conditions, and a chlorophyll:carbon ratio of 0.025 g Chl (g C)$^{-1}$ ($P^C_{max}$ = 4.8 day$^{-1}$, representative 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

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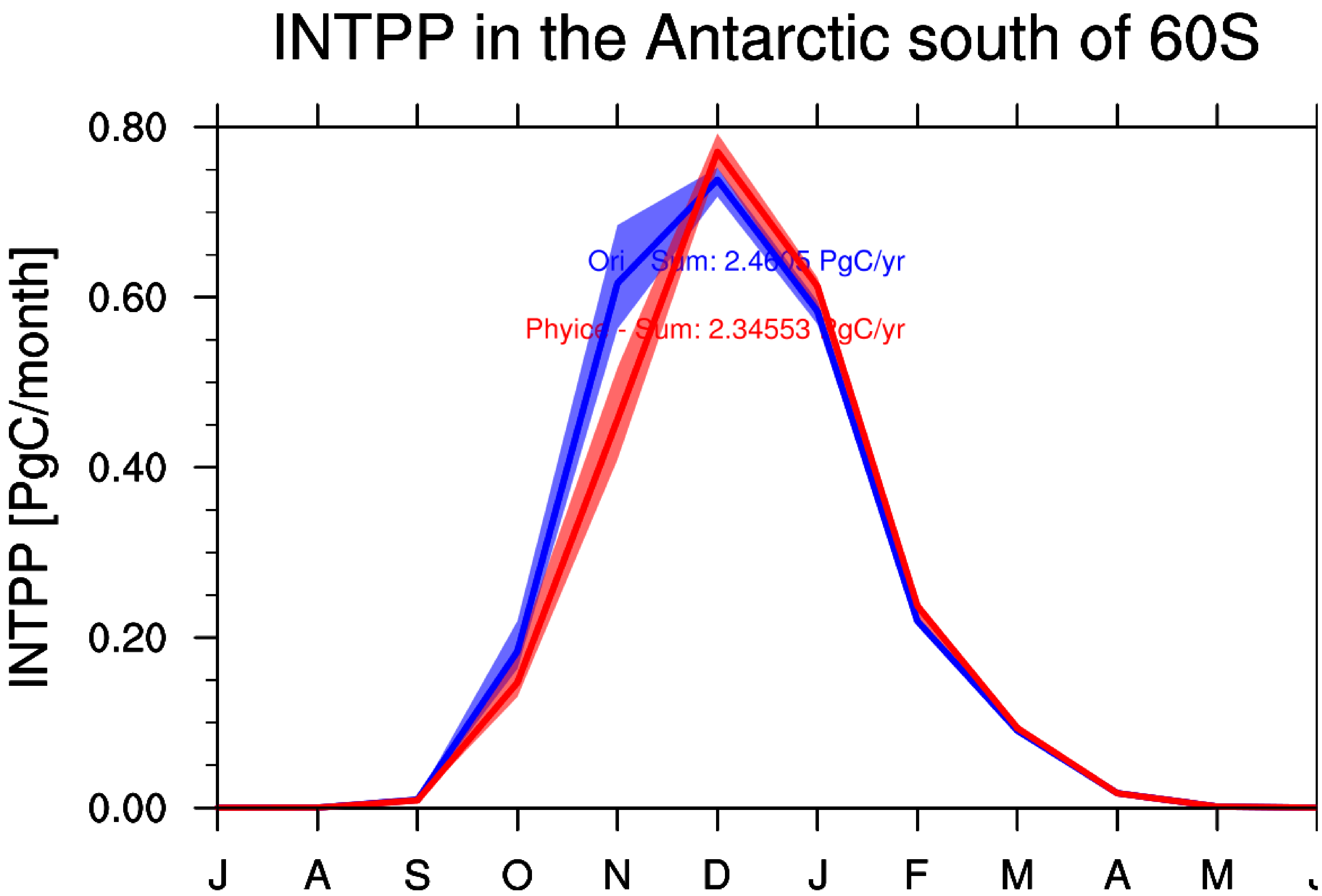
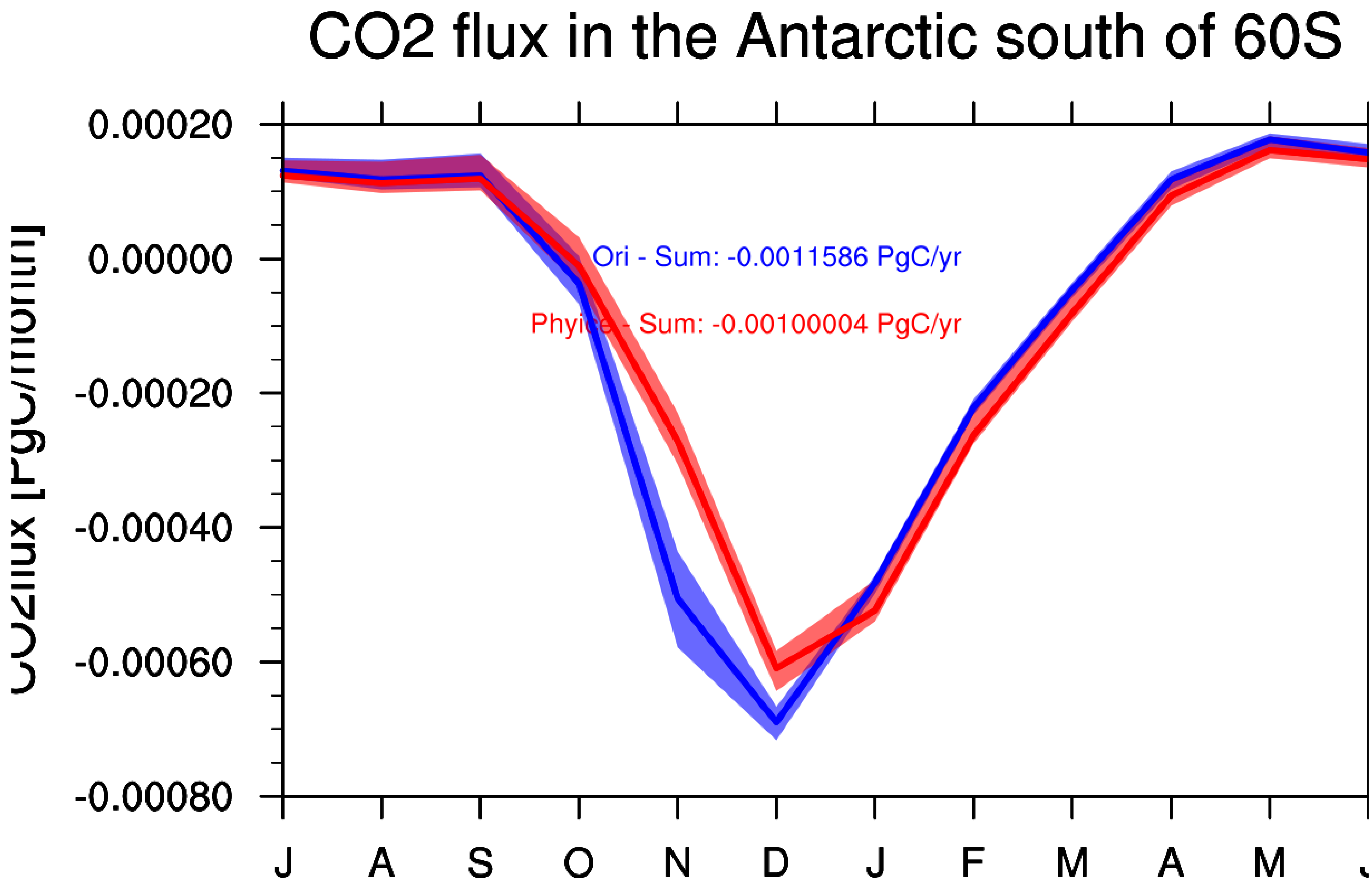


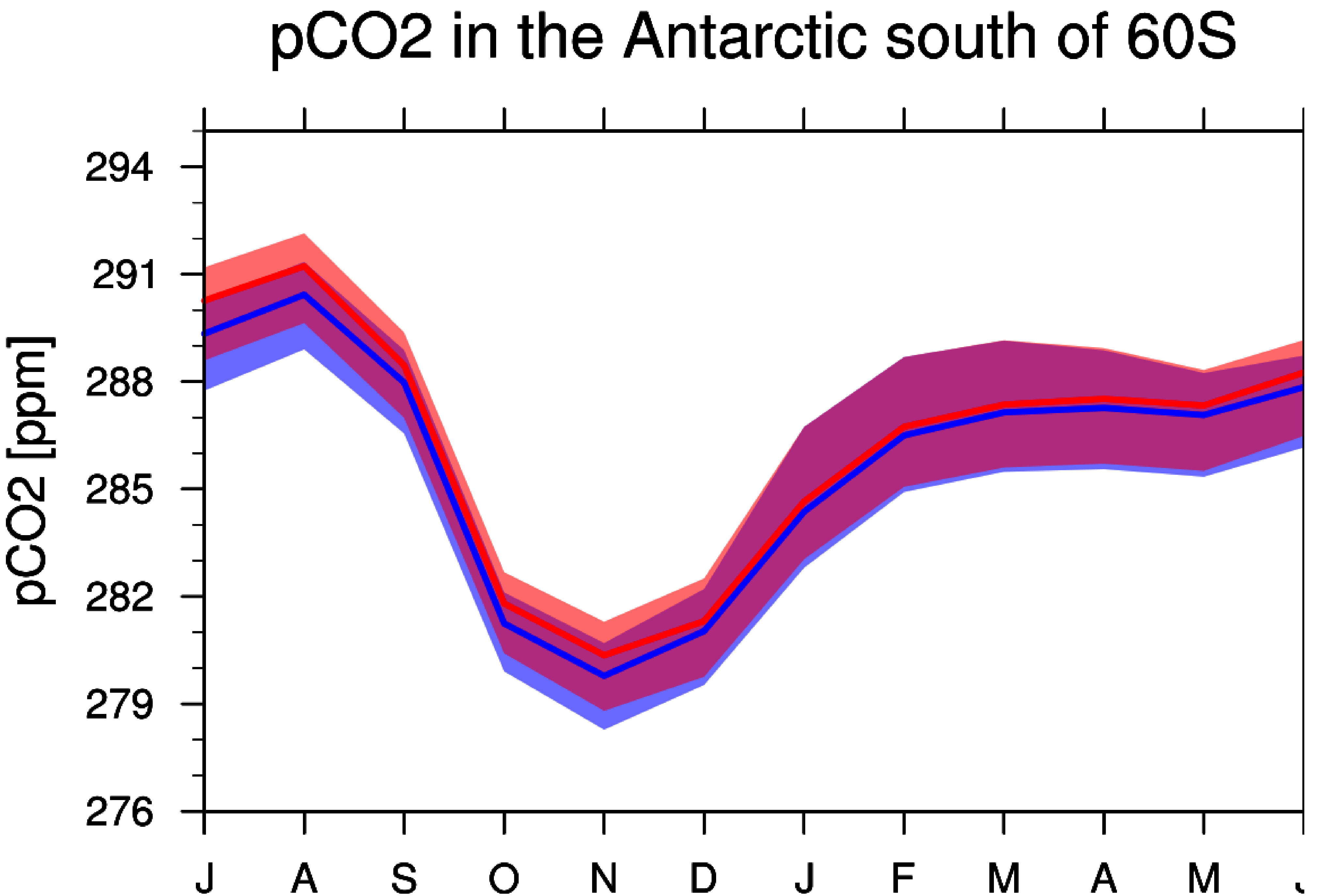
INTPP in the Antarctic south of 60S
INTPP [PgC/month]
0.80
0.60
0.40
0.20
0.00
J
A
S
O
N
D
J
F
M
A
M
J
Phyice - Sum: 2.34553 PgC/yr

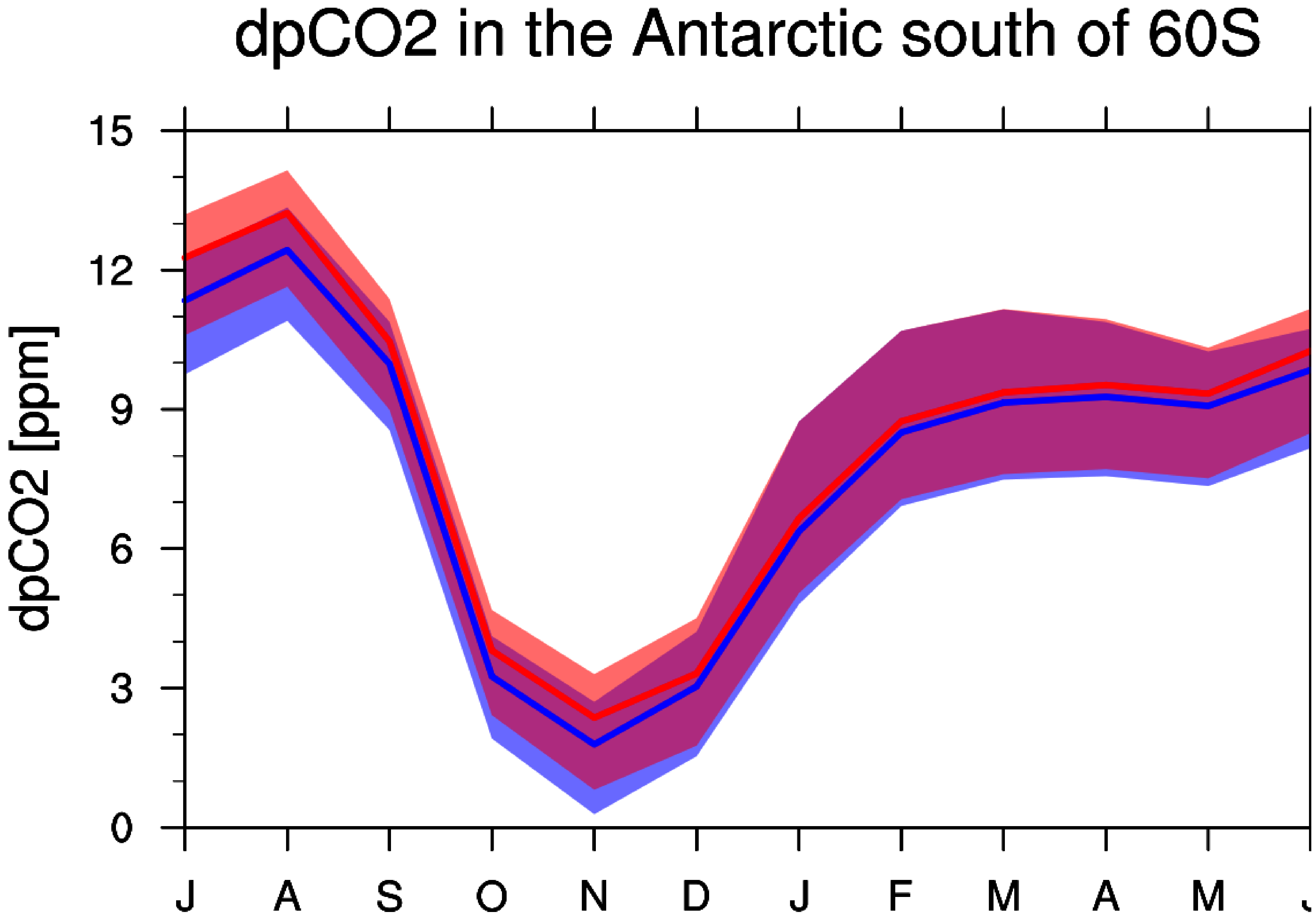


CO2 flux in the Antarctic south of 60S
0.00020
0.00000
-0.00020
-0.00040
-0.00060
-0.00080
CO2flux [PgC/month]
Ori - Sum: -0.0011586 PgC/yr
Phyice - Sum: -0.00100004 PgC/yr
J
A
S
O
N
D
J
F
M
A
M
J

# Effects

- Little less primary production
- Bloom little later
- Sea-ice under-estimated in MPIOM
- Only checked for 60-90S in pi-control
- Adaptable for under-ice phytoplankton growth


pCO2 in the Antarctic south of 60S
pCO2 [ppm]
294
291
288
285
282
279
276
J
A
S
O
N
D
J
F
M
A
M
J


dpCO2 in the Antarctic south of 60S
dpCO2 [ppm]
15
12
9
6
3
0
J
A
S
O
N
D
J
F
M
A
M
J

# Summary Seasonality