Net and gross production in the Southern Ocean mixed layer

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Determining net community production in the mixed layer

\[ \text{Photosynthesis} \]
\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2 \]

\[ \text{Respiration} \]
\[ \text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

\[ \text{P - R = O}_2 \text{ NCP} \]
\[ = \text{O}_2 \text{ efflux to atmosphere} = \]
\[ ([O_2] - [O_2]_{\text{sat}}) \times \text{gas exch. coeff.} \]

Base of the mixed layer

- \([O_2] > [O_2]_{\text{sat}}, \text{ lost to atmosphere} \]
  - \(\text{O}_2 \text{ efflux} = ([O_2] - [O_2]_{\text{sat}}) \times \text{gas exchange coefficient} \)
- Net community \(\text{O}_2\) production = flux to atmosphere
- Complication: \([O_2] > [O_2]_{\text{sat}}\) because of warming and bubble entrainment
- Measure \(\text{Ar}\) as inert analog to \(\text{O}_2\) to correct for physical supersaturation (Jenkins, Quay, Emerson, Luz…)
Determining gross photosynthesis in the mixed layer

- 2 sources of O\textsubscript{2} to surface water:
  - Gross photosynthesis and gas exchange
- Determine fraction of photosynthetic O\textsubscript{2} from \textsuperscript{17}Δ (Luz and Barkan)
  - \textsuperscript{17}Δ of dissolved O\textsubscript{2} from air = 0
  - \textsuperscript{17}Δ of dissolved O\textsubscript{2} from photosynthesis = + 0.25 %
- Measure \textsuperscript{17}Δ of dissolved O\textsubscript{2}; calculate fraction and conc. from photosyn.
- Apply gas exchange coefficient to calculate GPP

\textit{Base of the mixed layer}

\textbf{Determining the fraction of photosynthetic O\textsubscript{2} from \textsuperscript{17}Δ (Luz and Barkan)}

\textbf{Photosynthesis}

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2 \]

\textbf{Dissolved O\textsubscript{2} pool}

\[ \text{O}_2 \]

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2 \]
What is $^{17}\Delta$ of $O_2$?

- $^{17}\Delta$ of $O_2 \approx \delta^{17}O - 0.5 \delta^{18}O$
- Normally $^{17}O$ is fractionated $0.5 \times ^{18}O$ and $^{17}\Delta$ is the same for “everything”
- $O_2$ is an exception (work of Thiemens, Boering, Luz and Barkan)
  - Isotope exchange reaction between $O_2$ and $CO_2$ in stratosphere
  - $^{17}O$ is fractionated $1.7 \times ^{18}O$
- Consequence:
  - $^{17}\Delta$ of $O_2$ is different from $^{17}\Delta$ of $H_2O$ (and photosynthetic $O_2$)
Southern Ocean studies of net and gross production: sampling sites as of fall, 2006 (25 crossings)
Distribution of summertime net community production

- Colors: Southern Ocean summertime chl
- Lines: frontal positions
- Filled circles: $O_2$ flux to atmosphere
  - NCP>0
  - Calculate magnitude assuming steady state NCP, observed winds, constant MLD, no mixing from below
- Open circles: $O_2$ flux into oceans
  - Ventilation or net heterotrophy?
Distribution of net community production in summer

- General pattern of NCP decreasing to the south, then rising again near the coast
- High NCP coincides with high chl around STF and close to Antarctic coast
- Origin of southward decrease in open ocean:
  - Not SiO$_2$
  - Not ss PAR or MLD
  - Grazing?
  - Not upwelling iron
- Possibly aerosol iron input
Fan et al. (2006) model for input of soluble iron by aerosols

- Dust entrained in dry continental areas
- Fe progressively solubilized as dust is attacked by $\text{H}_2\text{SO}_4$ and $\text{HNO}_3^-$
- Dust settles out by gravity
- Soluble Fe ranges from about 5-35 % of total
- Soluble Fe distribution delivery is very different from constant solubility model
  - Less delivery near sources
  - More delivery in farfield
- Surely uncertainties are large

Model-data comparison
NCP and GPP vs. latitude and season

NCP, GPP and iron deposition all are highest in the north, decrease to the south

NCP, GPP, and iron deposition all are highest in spring, lower in summer, lowest in fall
NCP vs. aerosol deposition of soluble iron

Climatological summer Fe input

NCP increases with soluble iron deposition

Scatter decreases with averaging

Last 2 weeks’ Fe input

Single sample (+)

Avg. by zone, crossing (○)

Avg. by zone (∆)
NCP vs. aerosol deposition of soluble iron

Climatological summer Fe input

NCP increases with soluble iron deposition

Why so much scatter?
Variations in light, SiO$_2$, grazing, other influences
Analytical errors and uncertainty in gas exch. coeff.

Other sources of iron

Last 2 weeks’ Fe input

Single sample (+)
Avg. by zone, crossing (o)
Avg. by zone (∆)
Links between chlorophyll, productivity, and enhanced iron sources in the Southern Ocean: Contributions of many authors
Chlorophyll, productivity, and iron sources: shallow sediments (coastal areas around Antarctica)
Chlorophyll, productivity, and iron sources: deep water upwelling (Polar Front)
Chlorophyll, productivity, and iron sources: deep mixing induced by topography (Scotia Sea, Kerguelen Plateau)
Chlorophyll, productivity, and iron sources: aerosols

Summer climatology of dissolved iron supply

Modeled Iron Deposition (modified from Fan et al. 2006)
Low chlorophyll, productivity, and iron sources: southern deep waters overlying abyssal plains
Can we scale NCP in the Southern Ocean?

- $O_2 \text{ GPP} / O_2 \text{ NCP} \sim 0.15$ in the AZ, PFZ, and SAZ
- $\Rightarrow f$ ratio of about 0.3
  - New/ total N uptake
  - 6.6 New N/$^{14}$C
- If net/gross $\sim$ constant, we can scale local results with $^{14}$C production from ocean color
Conclusions

• NCP (and GPP) characterized over a wide reach of the Southern Ocean
• We hope that these data will be used for validating models

• Productivity is highest in the northern reaches
• NCP increases with recent or climatological Fe input
• Various sources of Fe input can explain variations in Southern Ocean chlorophyll and productivity
• Scaling NCP values assuming constant NCP/productivity may be possible
Conclusions

• NCP (and GPP) characterized over a wide reach of the Southern Ocean
• These data can be used to test and validate algorithms and models
• Higher values linked to chl and $^{14}$C productivity (VGPM)
• NCP increases with recent or climatological Fe input
• Various sources of Fe input can explain variations in Southern Ocean chlorophyll and productivity
• Scaling NCP values assuming constant NCP/productivity may be possible
Modeled Iron Deposition (modified from Fan et al. 2006)