Use of natural-series radionuclides to understand particle dynamics and carbon flux in the NW Mediterranean Sea

J.-C. Miquel¹, B. Gasser¹, S.W. Fowler¹,²

¹ IAEA Environment Laboratories, Monaco
² School of Marine and Atmospheric Sciences, Stony Brook, USA
Outline

DYFAMED site, a unique field lab in the Mediterranean

$^{230}$Th, a tracer to calibrate trap data

$^{234}$Th, a tracer for particle export

$^{210}$Po, a tracer for organic carbon flux

$^{210}$Po and $^{234}$Th in particles and biota
DYFAMED site
DYFAMED site

Unique open sea station in the Mediterranean Sea with a 20yrs time series (hydrodynamic, bio-optics, biogeochemical and biological observations)

- Northern current and associated geostrophic front: relatively well isolated from land masses

- Hydrological cycle: winter convection and summer stratification

- Biological cycle: spring plankton bloom

- Atmospheric inputs are important, in particular Saharan dust

Since Jan 2010, Dyfamed is integrated in a large Med network called MOOSE
Flux seasonality

200 m depth

1000 m depth

biweekly means (1988-2005)

(Miquel et al., PiO in review)
Phytoplankton and POC flux

(Marty et al., DB 2010)
Zooplankton and POC flux

(Gasser, 1995)
Zooplankton fecal pellets and POC flux

FP flux (mg C m$^{-2}$ d$^{-1}$) and POC flux (mg m$^{-2}$ d$^{-1}$) over different months. Biweekly means (1988-2005) are shown.

(Carroll et al., 1998)
Ocean carbon cycle, The biological pump

238U → 234Th

Physical mixing

Dissolved Organic Carbon

CO2

Phytoplankton
Carbon uptake

Grazing

Aggregate Formation

Faeces

Zooplankton migration

Respiration

Excretion

Sinking particles

Decomposition

Bacteria

Particulate carbon flux

Consumption

Zooplankton

Respiration

Excretion

Sediment trap

210Po → 210Pb

230Th
$^{230}$Th, a tracer to calibrate trap data
\[ ^{234}\text{U}_{\text{dissolved}} \rightarrow ^{230}\text{Th}_{\text{dissolved}} \leftrightarrow ^{230}\text{Th}_{\text{particulate}} \]

\[ ^{230}\text{Th}_{\text{litho}}, ^{232}\text{Th}_{\text{litho}} \]

Sinking particles
$^{234}\text{U}_{\text{dissolved}} \rightarrow ^{230}\text{Th}_{\text{dissolved}} \rightleftharpoons ^{230}\text{Th}_{\text{particulate}}$

$^{230}\text{Th}_{\text{litho}},^{232}\text{Th}_{\text{litho}}$
Calculation of trap collection efficiency using $^{230}$Th

\[ E = \frac{F}{P \times h} \]

- \( E \): collection efficiency
- \( F \): trap flux of $^{230}$Th$_{xs}$, year-averaged
- \( P \): $^{230}$Th production rate
  - (0.65 fg/l/y in the salty Mediterranean Sea)
- \( h \): depth
Calculation of trap collection efficiency using $^{230}\text{Th}$

\[ E = \frac{F}{P \times h} \]

- $E$: collection efficiency
- $F$: trap flux of $^{230}\text{Th}_{\text{xs}}$ year-averaged
- $P$: $^{230}\text{Th}$ production rate
  - (0.65 fg/l/y in the salty Mediterranean Sea)
- $h$: depth

Collection efficiency of traps at Dyfamed:

<table>
<thead>
<tr>
<th>Year</th>
<th>200m</th>
<th>1000m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999-2000</td>
<td>187 ± 85%</td>
<td>87 ± 11%</td>
</tr>
</tbody>
</table>

(Roy-Barman et al., 2009)
Calculation of trap collection efficiency using $^{230}$Th

\[ E = \frac{F}{P \times h} \]

E: collection efficiency

F: trap flux of $^{230}$Th$_{xs}$, year-averaged

P: $^{230}$Th production rate
   (0.65 fg/l/y in the salty Mediterranean Sea)

h: depth

Collection efficiency of traps at Dyfamed:

<table>
<thead>
<tr>
<th>Year</th>
<th>200m</th>
<th>1000m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999-2000</td>
<td>187 ± 85%</td>
<td>87 ± 11%</td>
</tr>
<tr>
<td>2005</td>
<td>136 ± 47%</td>
<td>96 ± 10%</td>
</tr>
<tr>
<td>2006</td>
<td>46 ± 36%</td>
<td>30 ± 5%</td>
</tr>
</tbody>
</table>
$^{234}$Th, a tracer for particle export
Radioactive Equilibrium

238U - 234Th disequilibria

• 234Th is highly particle reactive (t_{1/2} = 24 d); 238U is conservative in seawater

• 234Th is removed by scavenging, its activity is low in surface ocean (particle scavenging) and increases with depth.

• 238U activity varies as a function of salinity.

• The shift in 234Th from secular equilibrium with its parent 238U gives us an idea of particle flux.

\[ 2^{34}\text{Th flux} = \lambda_{\text{Th}} \int (A_U - A_{\text{Th}}) \, dz \]

\[ C \text{ flux} = 2^{34}\text{Th flux} \times [C/2^{34}\text{Th}]_{\text{sinking particles}} \]

(assumes steady state and minimal physics)
Depth profiles of $^{234}$Th activity at Dyfamed site (1994)

(Schmidt et al., 2002)
Depth profiles of $^{234}$Th activity at Dyfamed site (2003)

(Stewart et al., 2007)
(Cochran et al., 2009)
$^{210}\text{Po}$, a tracer for organic carbon flux
$^{210}\text{Pb} - ^{210}\text{Po}$ disequilibria

- $^{210}\text{Pb}$ and $^{210}\text{Po}$ are both particle reactive elements, removed by scavenging.

- Water column $^{210}\text{Pb}$ ($t_{1/2} = 22$ y) activities are a function of in situ $^{226}\text{Ra}$ decay (conservative) and atmospheric deposition.

- $^{210}\text{Po}$ ($t_{1/2} = 138$ d) is slightly more particle reactive than $^{210}\text{Pb}$. Also, $^{210}\text{Po}$ is removed preferentially from the water column through biological activity.

- This enables to examine particle export on timescales of months.
Depth profiles of total $^{210}$Po and $^{210}$Pb activity at Dyfamed site (2003)

(Stewart et al., 2007)
POC export fluxes at Dyfamed site (2003)

(Verdeny et al., 2009)
- Differences in half-lives
- $^{234}\text{Th}$ tracks all particles
- $^{210}\text{Po}$ tracks only the labile POC pool
$^{210}\text{Po}$ and $^{234}\text{Th}$ in particles and biota
RN specific activities and particle size at Dyfamed site (March 2005)

\[ ^{234}\text{Th} = 50 + 890 \ e^{-0.0238s} \]

\[ R^2 = 0.93, \ p < 0.0001 \]

(Rodriguez-y-Baena et al., 2007)
RN specific activities and surface:volume ratio in particles (March 2005)
POC : RN ratios and particle size (March 2005)
$^{234}$Th uptake driven by adsorptive processes

$^{210}$Po uptake driven by internal bioaccumulation processes
Zooplankton Fecal Pellets

Salps

Pteropods (Gymnosomata and Thecosomata)

Euphausiids

Copepods
C flux vs. fecal pellet flux
(Miquel et al., 1994)

\[ Y = 0.32X + 7.52 \]
\[ r = 0.83 \]

\(^{234}\text{Th} \text{ flux vs. fecal pellet flux}
(Schmidt et al., 1990)

Dyfamed-Calvi site, 1986-1988
### Fecal Pellets

<table>
<thead>
<tr>
<th>Organism</th>
<th>n</th>
<th>POC %</th>
<th>Th-234 (dpm/g)</th>
<th>POC/Th-234 (μmol/dpm)</th>
<th>Po-210 (dpm/g)</th>
<th>POC/Po-210 (μmol/dpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salps</td>
<td>3</td>
<td>6.20</td>
<td>1980</td>
<td>2.61</td>
<td>49.0</td>
<td>104</td>
</tr>
<tr>
<td>Euphausiids</td>
<td>3</td>
<td>15.3</td>
<td>1270</td>
<td>10.0</td>
<td>37.9</td>
<td>291</td>
</tr>
<tr>
<td>Gymnosomes</td>
<td>3</td>
<td>6.36</td>
<td>1920</td>
<td>2.76</td>
<td>39.1</td>
<td>137</td>
</tr>
<tr>
<td>Thecosomes</td>
<td>3</td>
<td>13.0</td>
<td>646</td>
<td>18.0</td>
<td>52.6</td>
<td>187</td>
</tr>
<tr>
<td>Copepods</td>
<td>2</td>
<td>16.5</td>
<td>1030</td>
<td>13.4</td>
<td>36.4</td>
<td>377</td>
</tr>
</tbody>
</table>

### Zooplankton

<table>
<thead>
<tr>
<th>Organism</th>
<th>n</th>
<th>POC %</th>
<th>Th-234 (dpm/g)</th>
<th>POC/Th-234 (μmol/dpm)</th>
<th>Po-210 (dpm/g)</th>
<th>POC/Po-210 (μmol/dpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salps</td>
<td>2</td>
<td>1.87</td>
<td>12.8</td>
<td>121</td>
<td>1.14</td>
<td>1360</td>
</tr>
<tr>
<td>Euphausiids</td>
<td>3</td>
<td>39.7</td>
<td>3.14</td>
<td>13900</td>
<td>3.38</td>
<td>11500</td>
</tr>
<tr>
<td>Gymnosomes body</td>
<td>3</td>
<td>20.4</td>
<td>36.9</td>
<td>527</td>
<td>20.5</td>
<td>762</td>
</tr>
<tr>
<td>Gymnosomes cart.</td>
<td>3</td>
<td>4.63</td>
<td>1.62</td>
<td>6660</td>
<td>ND</td>
<td>-</td>
</tr>
<tr>
<td>Thecosomes</td>
<td>2</td>
<td>17.3</td>
<td>38.6</td>
<td>377</td>
<td>144</td>
<td>109</td>
</tr>
<tr>
<td>Copepods</td>
<td>3</td>
<td>40.5</td>
<td>12.9</td>
<td>2660</td>
<td>9.10</td>
<td>3600</td>
</tr>
</tbody>
</table>
Thanks

the end