River-Shelf Interactions During Spring and Summer in the Coastal Beaufort Sea*

*aka: Tasks 3 and 4.

John H. Trefry, Robert P. Trocine, Matthew B. Alkire, Carrie M. Semmler
Florida Institute of Technology

Mark A. Savoie, KLI, Anchorage

Robert D. Rember, IARC, UAF

cANIMIDA Meeting in Duxbury, MA May 1-2, 2007
Goal:

To adequately understand the background physical/biogeochemical setting for rivers and coastal waters in the cANIMIDA area so that we can detect perturbations due to industrial activities ....
Components of Study

Dissolved and particulate metals
(Fe, Al, Ba, Cd, Cu, Cr, Cu, Hg, MeHg, Mn, Ni, Pb, Zn)

Dissolved and particulate organic C

Nutrients, salinity, temperature, pH, some $\delta^{18}O$

Total suspended solids, turbidity, currents

...and more.

Sagavanirktok, Kuparuk and Colville Rivers

Sagavanirktok River salinity gradient

Coastal Beaufort Sea under ice and during open water
Coastal Beaufort Sea with 1.7-m thick ice

Sagavanirktok River SPRING flow
Water flow data from http://waterdata.usgs.gov/ak/nwis/dvstat/?format=sites_selection_links&search_site_no=15908000&amp;referred_module=sw
Flow for Sagavanirktok R. is from gauge ~100 km upstream of sampling site. Total flow is about 5X greater than shown on graph.

Flow for Kuparuk R. is from gauge near sampling site.

Water flow data from http://waterdata.usgs.gov/ak/nwis

Sagavanirktok River

Kuparuk River
Water flow data from
http://waterdata.usgs.gov/ak/nwis
The first day of the spring floods has moved by 5-8 days earlier in the spring over the past 40 years.

Annual increase of ~32 million m$^3$/yr

About 50% increase from mid-1980s to present.
Sagavanirktok River 2001

Total Suspended Solids (mg/L)

Water flow (m³/sec)

July-August TSS = <1 to 2 mg/L

Kuparuk River 2002

Total Suspended Solids (mg/L)
July-August TSS = <1 to 2 mg/L
Total Suspended Solids

Sagavanirktok River 2001

July-August TSS = <1 to 2 mg/L

Sagavanirktok River 2006
Sagavanirktok River 2006

- TSS
- Water flow

Kuparuk River 2006

- Water flow
- TSS
Why river and offshore TSS?

**Northstar Island**

800,000 yds\(^3\) sand & gravel \(\times\)
0.76 m\(^3\)/yd\(^3\) \(\times\) 2.6 metric tons/m\(^3\)

\[= 1.6 \times 10^6\] metric tons of sand & gravel

*Northstar, April 2000*

*Northstar, August 2000*
## Sediment Transport

(Northstar Island $1.6 \times 10^6$ metric tons of sand & gravel)

<table>
<thead>
<tr>
<th>River</th>
<th>Sediment Output</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagavanirktok</td>
<td>$0.3 \times 10^6$ metric tons/yr</td>
<td>~</td>
</tr>
<tr>
<td>Kuparuk River</td>
<td>$0.02 \times 10^6$ metric tons/yr</td>
<td>1.6 metric tons km$^{-2}$ yr$^{-1}$ (Kriet et al., 1992)</td>
</tr>
<tr>
<td>Colville River</td>
<td>$5^+ \times 10^6$ metric tons/yr</td>
<td>1.0 metric tons km$^{-2}$ yr$^{-1}$ (Arnborg et al., 1967)</td>
</tr>
</tbody>
</table>

... with >50% of annual sediment output in 2-3 weeks.
600 mg/L
390 mg/L
36 mg/L
33 mg/L
31 mg/L
Dissolved Organic Carbon (mg/L)

Dissolved Pb (0.4 µm filtered, ng/L)

Rivers carry highest concentrations of DOC and these metals during the period of greatest water flow.
Rivers carry highest concentrations of DOC and these metals during the period of greatest water flow.
Dissolved Fe

Sagavanirktok River

Dissolved Fe (µg/L, 0.4 µm)
Dissolved Fe

Sagavanirktok River

Dissolved Fe (µg/L, 0.4 µm)

- 2001
- 2004
- 2006
Dissolved Fe

Sagavanirktok River

Dissolved Fe (µg/L, 0.4 µm)

2001
2002
2004
2006


2002 Refreeze event
Dissolved Fe

Sagavanirktok River

Dissolved Fe (µg/L, 0.4 µm)

- 2001
- 2002
- 2004
- 2006

July-August
Peak DOC  Sagavanirktok R. = 8-9 mg/L  Kuparuk R. = 14-15 mg/L

Dissolved Fe (µg/L)

Kuparuk River

Sagavanirktok River

Peak dissolved Fe
Sagavanirktok River

**Copper in river suspended sediment**

**Lead in river suspended sediment**

**Zinc in river suspended sediment**

**Iron in river suspended sediment**

**Barium in river suspended sediment**

**POC in river suspended sediment**
Distribution Coefficient

\[ K_d = \frac{\text{(particulate metal in ng/g)}}{\text{(dissolved metal in ng/g)}} \]

\[ \text{Particle}^{(-n)} + \text{Ba}^{2+} = \text{particle-Ba}^{(2-n)} \]

\[ K_d = 24000 \pm 5000 \]

\[ \log K_d = 4.38 \pm 0.10 \]
Spring 2006
Under Ice

2004 Under Ice
28 stations

Kuparuk R.

Sagavanirktok R.

-149
-148.8
-148.6
-148.4
-148.2
-148
-147.8

70.3
70.4
70.45
70.5

Pt. McIntyre

STP

Gwydyr Bay

Stump Island

Long Island

Kuparuk River

Prudhoe Bay

Sagavanirktok River

Stefansson Sound

Beaufort Sea

Spring 2006 Under Ice
Mooring SOND1 - Temperature, Salinity, & Turbidity Time-Series

Date

Salinity (psu) & Turbidity (ntu)

Temperature

Salinity

Turbidity

5.44 mgL

05/22/06 05/23/06 05/24/06 05/25/06 05/26/06 05/27/06 05/28/06 05/29/06 05/30/06 05/31/06
% Sagavanirktok River Water at 1 m

Sagavanirktok R.

Kuparuk R.

% Kuparuk River Water at 1 m
Kuparuk River

Spring Discharges

- 0.64 km³
- 0.74 km³
- 0.94 km³
- 0.68 km³

Water flow (m³/sec)

- 0
- 400
- 800
- 1200
- 1600
- 2000

Kuparuk River

- 40K ft³/s
- 20K ft³/s

Map showing locations K5, K4, K3, K2, K1, SK9, SK8, SK7, SK6, SK5, SK4, SK3, SK2, SK1, S1, S2, S3, S4, S5, S6, S7, S8, S9, and labels for Kuparuk River, Sump, Stump, & Midway Island.
Salinity

Dissolved As (µg/L)

May-June 2004 Under Ice

Y = 0.032X + 0.030
r = 0.98; n = 73
Salinity

Dissolved Ba (µg/L)

Sagavanirtok River plume under ice
(May-June 2004)

River end-member a moving target

200 nM
100 nM
Sagavanirktok River plume under ice
May-June 2004

Salinity

Dissolved Si (µM)

Dissolved Organic Carbon (mg/L)

0 5 10 15 20 25 30 35

0 2 4 6 8 10 12 14

800 µM

400 µM

Salinity
Sagavanirktok River plume  May-June 2004

Salinity

TSS (mg/L)

Sag. River
SW Transect
S Transect
SE Transect
Surface water sample collection near flow ice

Suspended Sediments as indicators of metal contamination

Carrie Semmler
Surface water sample collection near flow ice

Suspended Sediments as indicators of metal contamination and biogeochemical processes

Carrie Semmler
Are metals in suspended particles a more sensitive indicator of contamination than sediments?
Offshore Suspended Sediment

- Summer 2000
- Summer 2001

As (µg/g) vs. Al (%)
Offshore Suspended Sediment

Al (%)

As (µg/g)

Summer 2000
Summer 2002
Summer 2004
Spring 2004
Summer 2001
Summer 2005
Phyto, Zoo Amp

As (μg g⁻¹, dry wt.)

<table>
<thead>
<tr>
<th></th>
<th>Phyto</th>
<th>Zoo</th>
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<tr>
<td></td>
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<td>4</td>
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<td>8</td>
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<td>12</td>
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<td>16</td>
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<td>20</td>
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### Phytoplankton

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<tr>
<th>Station(s)</th>
<th>To 4B July 31</th>
<th>L17 - L17A July 31</th>
<th>L01B - L01A Aug. 3</th>
<th>4A - L18 Aug. 3</th>
<th>L01A - 4A Aug. 3</th>
<th>4A - L18 Aug. 5</th>
<th>BP01 - 4A Aug. 5</th>
<th>4B - L17A Aug. 5</th>
<th>STP1 - STP2 Aug. 8</th>
<th>5(1) Aug. 11</th>
</tr>
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<tr>
<td><strong>Ciliates (Phylum Ciliophora)</strong></td>
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<tr>
<td><em>Tintinnopsis loricae</em></td>
<td>24% (933)</td>
<td>24% (200)</td>
<td>19% (9660)</td>
<td>18% (8060)</td>
<td>17% (9450)</td>
<td>18% (6530)</td>
<td>30% (3300)</td>
<td>30% (5280)</td>
<td>53% (3960)</td>
<td>49% (3150)</td>
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<tr>
<td><strong>Dinoflagellates (Phylum Dinoflagellata)</strong></td>
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<tr>
<td><em>Ceratium</em></td>
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<td></td>
<td>21% (1350)</td>
</tr>
<tr>
<td><em>Dinoflagellates (Peridinium-like)</em></td>
<td>15% (120)</td>
<td>21% (10970)</td>
<td>29% (12980)</td>
<td>16% (8820)</td>
<td>23% (8620)</td>
<td>26% (2880)</td>
<td>10% (1680)</td>
<td>47% (3460)</td>
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<tr>
<td><strong>Diatoms (Phylum Bacillariophyta, Class Coscinodiscophyceae)</strong></td>
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<tr>
<td><em>Odontella</em></td>
<td>13% (516)</td>
<td>61% (500)</td>
<td>18% (9310)</td>
<td>10% (1140)</td>
<td>0.3% (20)</td>
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<tr>
<td><em>Biddulphia</em></td>
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<tr>
<td><em>Coscinodiscus</em></td>
<td>31% (1200)</td>
<td>5% (2790)</td>
<td>16% (5980)</td>
<td>35% (6120)</td>
<td>30% (1900)</td>
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<tr>
<td><em>Thalassiosira</em></td>
<td>12% (483)</td>
<td>22% (11360)</td>
<td>33% (14620)</td>
<td>33% (18585)</td>
<td>25% (9410)</td>
<td>34% (3780)</td>
<td>26% (4600)</td>
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</tr>
<tr>
<td>Unidentified chain diatom</td>
<td>20% (783)</td>
<td>20% (10650)</td>
<td>21% (9240)</td>
<td>30% (17235)</td>
<td>18% (6580)</td>
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<tr>
<td><strong>Total organisms per 30 mL vial</strong></td>
<td>3915</td>
<td>820</td>
<td>52250</td>
<td>44900</td>
<td>56880</td>
<td>37120</td>
<td>11100</td>
<td>17680</td>
<td>7440</td>
<td>6400</td>
</tr>
</tbody>
</table>
**Phylum Arthropoda, Subphylum Crustacea**

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<th>To STP1 Aug. 8</th>
<th>5(1) Aug. 11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crustacean Nauplius</strong></td>
<td>22% (2880)</td>
<td>18% (800)</td>
<td>6% (120)</td>
<td>27% (17360)</td>
<td>13% (760)</td>
<td>15% (19850)</td>
<td>18% (850)</td>
<td>25% (140)</td>
<td>19% (850)</td>
<td>14% (15455)</td>
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<tr>
<td><strong>Copepods (Class Maxillopoda, Subclass Copepoda)</strong></td>
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</tr>
<tr>
<td><strong>Cyclopid Copepods (Order Cyclopoida)</strong></td>
<td>47% (2100)</td>
<td>24% (15360)</td>
<td>1% (80)</td>
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<tr>
<td><strong>Calanoid Copepods (Order Calanoida)</strong></td>
<td>35% (4520)</td>
<td>33% (720)</td>
<td>14% (9040)</td>
<td>30% (1720)</td>
<td>36% (46800)</td>
<td>44% (2100)</td>
<td>53% (300)</td>
<td>36% (1600)</td>
<td>15% (16665)</td>
<td></td>
</tr>
<tr>
<td><strong>Copepod Metanauplius</strong></td>
<td>16% (2120)</td>
<td>10% (450)</td>
<td>11% (240)</td>
<td>13% (8560)</td>
<td>18% (1040)</td>
<td>18% (22800)</td>
<td>16% (750)</td>
<td>23% (130)</td>
<td>13% (600)</td>
<td>9% (10725)</td>
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<tr>
<td><strong>Euphausids (Class Malacostraca, Superorder Eucarida, Order Euphausiacea)</strong></td>
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<tr>
<td><strong>Euphausid Nauplius</strong></td>
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<td>7% (400)</td>
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<tr>
<td><strong>Euphausid Protozoa</strong></td>
<td>13% (1640)</td>
<td>21% (13360)</td>
<td>31% (1800)</td>
<td>25% (31750)</td>
<td>10% (500)</td>
<td>25% (1100)</td>
<td>62% (70235)</td>
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<tr>
<td><strong>Euphausid Zoea</strong></td>
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<td>2% (100)</td>
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<tr>
<td><strong>Amphipods (Class Malacostraca, Superorder Peracarida, Order Amphipoda)</strong></td>
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<tr>
<td><strong>Gammarid Amphipod (Suborder Gammaridea)</strong></td>
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<td>2% (100)</td>
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<tr>
<td><strong>Phylum Annelida</strong></td>
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<tr>
<td><strong>Polychaete Metatrocophore (Class Polychaeta)</strong></td>
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<td>4% (200)</td>
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</tbody>
</table>

**Phylum Chordata, Subphylum Vertebrata**
Excess As and Fe
Excess Fe (%)

Excess As (μg g⁻¹)

$y = 11.8x + 2.2$

$r = 0.67$
Data for Dissolved As along salinity gradient

Conservative mixing line
\[ y = 0.024x + 0.10 \]

Sagavanirktok River  
\([\text{As}] = 110 \pm 40 \text{ ng/L } (2001-2006)\)
Data for (Dissolved As + Excess Particulate As)

Salinity

Dissolved + Excess Particulate As (μg/L)

Dissolved As (μg/L)

r = 0.98
**Chart 1: Salinity vs. Diss. Reactive Phosphate**

- **Conservative mixing line:**
  \[ y = 0.014x + 0.050 \]

**Chart 2: Diss. As vs. Diss. Reactive Phosphate**

- **Equation:**
  \[ \text{Dis As} = 0.023(\text{Dis P}) + 0.0003 \]
  \[ r = 0.99 \]
2006 Sampling Stations

Y = 1.3X + 4.4
r = 0.53, n = 194

Also Fe, Cr and V
Trend lines from data for bottom sediment

Al (%) vs. Pb (µg/g)
Linear regression line and 99% prediction interval based on 1999-2002 data.
## Dissolved Hg

<table>
<thead>
<tr>
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<th>Dissolved Hg (ng/L)</th>
<th>Dissolved Methyl Hg (ng/L)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Sagavanirktok R.</td>
<td>0.8</td>
<td>0.5 - 1.1</td>
</tr>
<tr>
<td>Kuparuk R.</td>
<td>1.0</td>
<td>0.7 – 1.3</td>
</tr>
<tr>
<td>Lena R.</td>
<td>1.0</td>
<td>0.9 – 1.1</td>
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<tr>
<td>St. Lawrence R.</td>
<td>2.4</td>
<td>-</td>
</tr>
<tr>
<td>Coastal Beaufort</td>
<td>0.7</td>
<td>0.5 - 0.9</td>
</tr>
<tr>
<td>North Atlantic</td>
<td>0.23</td>
<td>0.1 – 0.5</td>
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<tr>
<td>Arctic Ocean</td>
<td>-</td>
<td>-</td>
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<td>820</td>
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<td><strong>Phylum Arthropoda, Subphylum Crustacea</strong></td>
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<tr>
<td><strong>(Order Cyclopoida)</strong></td>
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<td><strong>Calanoid Copepods</strong></td>
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</tr>
<tr>
<td><strong>Copepod Metanauplius</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Euphausids (Class Malacostraca, Superorder Eucarida, Order Euphausiacea)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Euphausid Nauplius</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Euphausid Protozoea</strong></td>
<td>13% (1640)</td>
<td></td>
</tr>
<tr>
<td><strong>Euphausid Zoea</strong></td>
<td></td>
<td>2% (40)</td>
</tr>
<tr>
<td><strong>Amphipods (Class Malacostraca, Superorder Peracarida, Order Amphipoda)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gammarid Amphipod</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(Suborder Gammaridea)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Phylum Annelida</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Polychaete Metatrochope</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(Class Polychaeta)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Phylum Chordata, Subphylum Vertebrata</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary/Conclusions

1. Spring melt delivers >80% of suspended sediment and >50% of many dissolved chemicals to Beaufort Sea in 2-3 weeks.

2. Spring melt of river water has been traced offshore, under-ice to show transport pathways for freshwater, suspended sediment and dissolved chemicals.
Summary/Conclusions (continued)

3. Rivers are key source for dissolved Ba, Cu, Fe, DOC and TSS

4. Offshore, subsurface waters are the key source for dissolved As, Cd, as well as P and N

5. Adsorption and coprecipitation control concentrations of most trace metals.

6. River water and coastal seawater essentially pristine.
JOURNAL PUBLICATIONS


REVIEWED and PUBLISHED TECHNICAL REPORTS


**JOURNAL PUBLICATIONS**


**THESES and DISSERTATIONS**


<table>
<thead>
<tr>
<th>Task Order</th>
<th>MMS Issue Addressed</th>
<th>Monitoring Hypotheses</th>
<th>Methods</th>
<th>Key Monitoring Result or Parameter for Decision Making</th>
</tr>
</thead>
<tbody>
<tr>
<td>004</td>
<td>Will offshore oil development and production at Northstar and potential development at Liberty result in increased or chronic loadings of dissolved contaminant metals or hydrocarbons?</td>
<td><strong>H1:</strong> Concentrations of dissolved and particulate metals and selected organic substances in waters near offshore oil- and gas-related activities in the coastal Beaufort Sea are not significantly different than in more remote, coastal waters of the Beaufort Sea. <strong>H2:</strong> Concentration of dissolved metals behave <strong>conservatively</strong> across the freshwater/seawater mixing zone. <strong>H3:</strong> Concentrations of dissolved and particulate metals and selected organic substances in waters of the coastal Beaufort Sea follow measurable and <strong>predictable distribution coefficients</strong> ($K_d$).</td>
<td>Discrete sampling of rivers and the coastal Beaufort Sea during the ice-covered and open-water periods with analysis of water for metals and petroleum hydrocarbons.</td>
<td>Annual interpretative report with tabulated data on suspended sediments will be provided, with statistical tests of potential interannual significant differences. Contractor will alert MMS COTR of any important trends or changes.</td>
</tr>
<tr>
<td>Task Order</td>
<td>MMS Issue Addressed</td>
<td>Monitoring Hypotheses</td>
<td>Methods</td>
<td>Key Monitoring Result or Parameter for Decision Making</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
</tr>
</tbody>
</table>
| 004        | Will offshore oil development and production at Northstar and potential development at Liberty result in increased or chronic loadings of dissolved contaminant metals or hydrocarbons? | **H4:** Bioaccumulation of trace metals by mussels, kelp and plankton is directly proportional to levels of dissolved metals in the water.  
**H5:** Added amounts of dissolved metals or selected organic substances to Beaufort Sea water are taken up by suspended sediments as predicted by $K_d$. | Discrete sampling of rivers and the coastal Beaufort Sea during the ice-covered and open-water periods with analysis of water for metals and petroleum hydrocarbons. | Annual interpretative report with tabulated data on suspended sediments will be provided, with statistical tests of potential interannual significant differences. Contractor will alert MMS COTR of any important trends or changes. |
Final Report plus ~3 more papers

(a) River metals - trends – time series

(b) Under Ice 2 (The moorings and more)

(c) Offshore metals – nutrients – plankton
## Phytoplankton

<table>
<thead>
<tr>
<th>Station(s)</th>
<th>To 4B</th>
<th>L17 - L17A</th>
<th>L01B - L01A</th>
<th>4A - L18</th>
<th>L01A - 4A</th>
<th>4A - L18</th>
<th>BP01 - 4A</th>
<th>4B - L17A</th>
<th>STP1 - STP2</th>
<th>5(1) Aug. 11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phytoplankton</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Ciliates (Phylum Ciliophora)</strong></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tintinnopsis loricae</em></td>
<td>24% (933)</td>
<td>24% (200)</td>
<td>19% (9960)</td>
<td>18% (8060)</td>
<td>17% (9450)</td>
<td>18% (6530)</td>
<td>30% (3300)</td>
<td>30% (5280)</td>
<td>53% (3960)</td>
<td>49% (3150)</td>
</tr>
<tr>
<td><strong>Dinoflagellates (Phylum Dinoflagellata)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ceratium</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21% (1350)</td>
</tr>
<tr>
<td><em>Dinoflagellates (Peridinium-like)</em></td>
<td>15% (120)</td>
<td>21% (10970)</td>
<td>29% (12980)</td>
<td>16% (8820)</td>
<td>23% (8620)</td>
<td>26% (2880)</td>
<td>10% (1680)</td>
<td>47% (3460)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diatoms (Phylum Bacillariophyta, Class Coscinodiscophyceae)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Odontella</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10% (1140)</td>
</tr>
<tr>
<td><em>Biddulphia</em></td>
<td>13% (516)</td>
<td>61% (500)</td>
<td>18% (9310)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Coscinodiscus</em></td>
<td>31% (1200)</td>
<td></td>
<td></td>
<td>5% (2790)</td>
<td>16% (5980)</td>
<td></td>
<td>35% (6120)</td>
<td></td>
<td></td>
<td>30% (1900)</td>
</tr>
<tr>
<td><em>Thalassiosira</em></td>
<td>12% (483)</td>
<td>22% (11360)</td>
<td>33% (14620)</td>
<td>33% (18585)</td>
<td>25% (9410)</td>
<td>34% (3780)</td>
<td>26% (4600)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unidentified chain diatom</td>
<td>20% (783)</td>
<td>20% (10650)</td>
<td>21% (9240)</td>
<td>30% (17235)</td>
<td>18% (6580)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total organisms per 30 mL vial</td>
<td>3915</td>
<td>820</td>
<td>52250</td>
<td>44900</td>
<td>56880</td>
<td>37120</td>
<td>11100</td>
<td>17680</td>
<td>7440</td>
<td>6400</td>
</tr>
<tr>
<td>Phylum Arthropoda, Subphylum Crustacea</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crustacean Nauplius</td>
<td>22% (2880)</td>
<td>18% (800)</td>
<td>6% (120)</td>
<td>27% (17360)</td>
<td>13% (760)</td>
<td>15% (19850)</td>
<td>18% (850)</td>
<td>25% (140)</td>
<td>19% (850)</td>
<td>14% (15455)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Copepods (Class Maxillopoda, Subclass Copepoda)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclopoid Copepods (Order Cyclopoida)</td>
</tr>
</tbody>
</table>

| Calanoid Copepods (Order Calanoida) | 35% (4520) | 33% (720) | 14% (9040) | 30% (1720) | 36% (46800) | 44% (2100) | 53% (300) | 36% (1600) | 15% (16665) |

| Copepod Metanauplius | 16% (2120) | 10% (450) | 11% (240) | 13% (8560) | 18% (1040) | 18% (22800) | 16% (750) | 23% (130) | 13% (600) | 9% (10725) |

<table>
<thead>
<tr>
<th>Euphausids (Class Malacostraca, Superorder Eucarida, Order Euphausiacea)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euphausid Nauplius</td>
</tr>
</tbody>
</table>

| Euphausid Protozoa | 13% (1640) | 21% (13360) | 31% (1800) | 25% (31750) | 10% (500) | 25% (1100) | 62% (70235) |

| Euphausid Zoea | 2% (40) |

<table>
<thead>
<tr>
<th>Amphipods (Class Malacostraca, Superorder Peracarida, Order Amphipoda)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gammarid Amphipod (Suborder Gammaridea)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phylum Annelida</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polychaete Metatrocophere (Class Polychaeta)</td>
</tr>
</tbody>
</table>

| Phylum Chordata, Subphylum Vertebrata |
### Offshore in the coastal Beaufort Sea

**Trends in Total Suspended Sediment (TSS)**

<table>
<thead>
<tr>
<th>Condition</th>
<th>TSS Typically</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Under ice</strong></td>
<td>0.1 – 0.5 mg/L</td>
</tr>
<tr>
<td><strong>Open Water</strong></td>
<td></td>
</tr>
<tr>
<td>Winds calm to 5 knots</td>
<td>1-4 mg/L</td>
</tr>
<tr>
<td>(2.5 m/sec)</td>
<td></td>
</tr>
<tr>
<td>Winds 5-10 knots</td>
<td>3-8 mg/L</td>
</tr>
<tr>
<td>(2.5-5 m/sec)</td>
<td></td>
</tr>
<tr>
<td>10-20 knots</td>
<td>5-15 mg/L</td>
</tr>
<tr>
<td>(5-10 m/sec)</td>
<td></td>
</tr>
<tr>
<td>&gt;20 knots</td>
<td>50 - &gt;100 mg/L</td>
</tr>
<tr>
<td>(10 m/sec)</td>
<td></td>
</tr>
</tbody>
</table>
APPENDICES
>80% of the annual loads of suspended sediment (as well as POC and particulate metals) from the Sagavanirktok and Kuparuk Rivers are carried to sea during the 2-3 weeks of the spring melt.

>50% of the dissolved organic carbon, dissolved metals from the Sagavanirktok and Kuparuk Rivers are carried to sea in 2-3 weeks.

We have a very large data base for the North Slope rivers.
Regression line and prediction interval are based on sediment data.

May-June 2004 Under Ice

(a)

Particulate Fe (%)

0 2 4 6 8

Particulate Al (%)

0 2 4 6 8

(b)

Ba (%)

0 200 400 600 800 1000 1200

12 10 8 6 4 2 0
Distribution Coefficient

\[ K_d = \frac{\text{(particulate metal in ng/g)}}{\text{(dissolved metal in ng/g)}} \]

\[ \text{Particle}^{(-n)} + \text{Ba}^{2+} = \text{particle-Ba}^{(2-n)} \]
Data for (Dissolved As + Excess Particulate As)
Dissolved Ba (µg/L)

- Sag: 31.7 ± 2.0 µg/L
- Sag-g
- Kup
- Col
Dissolved Ba (µg/L)

Sag  Sag-g  Kup  Col

Particulate Ba (µg/g)

Sag  Sag-g  Kup  Col

31.7 ± 2.0
Kuparuk River

Spring Discharges

<table>
<thead>
<tr>
<th>Year</th>
<th>DOC</th>
<th>Fe</th>
<th>Pb</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>15.8</td>
<td>232</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>13.7</td>
<td>171</td>
<td>66</td>
<td>8.1</td>
</tr>
<tr>
<td>2004</td>
<td>166</td>
<td>23</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>2006</td>
<td>67</td>
<td>37</td>
<td>7.8</td>
<td>7.8</td>
</tr>
</tbody>
</table>
## River Transport as Dissolved Metal

<table>
<thead>
<tr>
<th>Metal</th>
<th>Sag</th>
<th>Kup</th>
<th>Col</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba</td>
<td>10 - 73%</td>
<td>34 – 97%</td>
<td>12 – 50%</td>
</tr>
<tr>
<td>Pb</td>
<td>0.9 – 1.9%</td>
<td>5 – 76%</td>
<td>~1%</td>
</tr>
</tbody>
</table>
TSS = 1.3(Turbidity) - 2.3
r = 0.95

2005 TSS under ice, no river flow
0.16 ± 0.06 mg/L

TSS range 1999-2002
0.1-0.5 mg/L
Regression line and prediction interval are based on sediment data.
May 23, 2004

Station K1
Distribution Coefficient

\[ K_d = \frac{\text{particulate metal in ng/g}}{\text{(dissolved metal in ng/g)}} \]

\[ \text{Particle}^{(-n)} + \text{Ba}^{2+} = \text{particle-Ba}^{(2-n)} \]
Dissolved Ba (µg/L)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sag</td>
<td>31.7 ± 2.0</td>
</tr>
<tr>
<td>Sag-g</td>
<td></td>
</tr>
<tr>
<td>Kup</td>
<td></td>
</tr>
<tr>
<td>Col</td>
<td></td>
</tr>
</tbody>
</table>
# River Transport as Dissolved Metal

<table>
<thead>
<tr>
<th>Metal</th>
<th>Sag</th>
<th>Kup</th>
<th>Col</th>
</tr>
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</tr>
<tr>
<td>Pb</td>
<td>0.9 – 1.9%</td>
<td>5 – 76%</td>
<td>~1%</td>
</tr>
</tbody>
</table>
Endmember Matrix for Optimum Multiparameter Analysis (OMP)

<table>
<thead>
<tr>
<th>Water Mass</th>
<th>Temp (°C)</th>
<th>Salinity</th>
<th>$\delta^{18}$O (per mil)</th>
<th>Si (µM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kupark R.</td>
<td>0.3</td>
<td>0.1</td>
<td>-23.0</td>
<td>14</td>
</tr>
<tr>
<td>Sagavan. R.</td>
<td>0.2</td>
<td>0.2</td>
<td>-21.7</td>
<td>25</td>
</tr>
<tr>
<td>Sea Ice Melt</td>
<td>0.0</td>
<td>5.0</td>
<td>-0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Coastal Beaufort Seawater</td>
<td>-1.8</td>
<td>32.1</td>
<td>-3.4</td>
<td>8</td>
</tr>
</tbody>
</table>

...also use weighting matrix and analysis of error (residuals).
Salinity vs $\delta^{18}O$ for all under ice samples (2004)

$r = 0.998$
... add end-member values.
May 23, 2004, $z = 10$ m, 3.7 cm/s (274°)

May 23, 2004, $z = 1$ m, 15.4 cm/s (51°)

May 25, 2004, $z = 1.5$ m, 7.5 cm/s (24°)
May 25, 2004, $z = 1.5$ m, 7.5 cm/s (24°)

May 30, 2004, $z = 1.5$ m, 8.3 cm/s (18°)

...apply model information to offshore transport of freshwater, suspended sediment and to under-ice spill scenarios.
Sagavanirktok River
Conductivity (μS) over the course of June for Sag and Col, Kup locations.
Kuparuk River
Total Suspended Solids (mg/L)

- 2001
- 2002
Water flow data from
http://waterdata.usgs.gov/ak/nwis

Sagavanirktok River

Kuparuk River
Under Ice
Total Suspended Solids (mg/L)

May 25, 2004

Ice, average depth = 1.7 m

Depth Below Ice (m)

Offshore → Near shore

May 25, 2004

S1 May 25
S2 May 25
S3 May 25
S4 May 25
S5 May 25
S7 May 25
Ice, average depth = 1.7 m

May 25 and 28, 2004

Total Suspended Solids (mg/L)
Sagavanirktok River delta and offshore (2004)

Period of re-cooling

TSS (mg/L) vs. Salinity

Turbidity (NTU) vs. Time

Sagavanirktok River delta and offshore (2004)
TSS follow apparent non-conservative behavior along freshwater-seawater mixing zone.
Dissolved and particulate metals – pathways to the biota

Dissolved Hg = 0.6 ng/L
Dissolved Pb = 7 ng/L
Dissolved Cu = 0.5 µg/L
Dissolved Cd = 28 ng/L
Sagavanirktok River 2001

Conductivity (μS)

June

- Sag PBOC
- Sag USGS Gauge
- Sag Dalton Hwy Mile 401
River water and suspended sediment are carried offshore *under* and *over* ~2-m thick *ice*.
2004 Under Ice
- 28 stations
Prudhoe Bay
Sagavanirktok River
Stefansson Sound
Beaufort Sea
Kuparuk River
Pt. McIntyre
Endicott

Long Island
Simpson Lagoon
Gwydyr Bay
Egg Island
Stump Island

SE1
SE2
SE3
SE4

S1
S2
S3
S4

SW1
SW2
SW3
SW4
SW5

SK1
SK2
SK3
SK4
SK5
SK6
SK7
SK8
SK9
SK10

K1
K2
K3
K4
K5

3.8 km
Mooring SOND34 - Temperature, Salinity, & Turbidity Time-Series

<table>
<thead>
<tr>
<th>Date</th>
<th>Salinity (psu)</th>
<th>Turbidity (ntu)</th>
<th>Temperature (deg. C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/30/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/31/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/01/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/02/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/03/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/04/06</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Fraction of Sagavanirktok River water

May 27, 2004

Spring 2006 Under Ice
Mooring SOND3 - Temperature, Salinity, & Turbidity Time-Series

Date

05/22/06 05/24/06 05/26/06 05/28/06 05/30/06 06/01/06 06/03/06

Salinity

-1.8  -1.5  -1.3  -1.0  -0.8  -0.5  -0.3  0.0

Temperature

Turbidity (ntu)

0.08 mgL

2.34 mgL

2.91 mgL

Salinity (psu)

Temp (deg. C)