MARS gliders in the Arctic

DAVID WHITE
MARINE AUTONOMOUS AND ROBOTIC SYSTEMS
NOC
Marine Autonomous and Robotic Systems Facility at NOC
The MARS glider fleet

- 8 Seagliders -1000m, 6 months
- 13 Deep Slocums – 1000m, 3-5 months
- 10 shallow Slocums – 200m, 3-5 months
- Includes 4 Slocum OMGs with Rockland Microrider turbulence probe
- All gliders carry Seabird CTD, Aanderaa O2 optode, WetLabs triplet puck with Chlorophyll, CDOM and 650nm or 700nm backscatter.
- Extra sensors include ES853 echosounder, PAR, ADCP(Slocum) and NOC wet nutrient (Seaglider)
The MARS surface fleet

- **Waveglider SV3**
  - CTD, ADCP, cameras, meteorology, acoustic modem.
  - Wave-driven, solar power, large platform, limited power. Limited thruster, 8m draft

- **Autonaut**
  - On-board sensors: meteorology,
  - Towed sensors – array, CTD, PAM
  - Wave-driven, solar power, small platform, long endurance

- **C-Enduro**
  - CTD, Sidescan, ADCP, meteorology, PAM, BB2FL
  - Propeller driven large platform, solar and wind, drop keel, winch.
What Gliders can do

All gliders:

• Slow – not good in currents.
• Poor navigation – magnetic compass not good.
• Simple ice-front crossing away from magnetic pole is do-able. Preferred ops Spring-Autumn.
• Seagliders under ice if we collaborate with UW.
• Low energy budget – low power sensors or short duration.
"Churchill" track 1-10 October – not a straight line
What we can do now - Slocums

Slocum:
• May be less prone to icing
• Can fit extra battery packs – 4 increases to 5-6 months?
• Ice avoidance software can be run but Rafos not implemented.
• Sensors in the dry science bay
• Thruster will allow level or gently undulating flight.
What we can do now - Seagliders

Seaglider:

- Vulnerable in icing conditions
- Standard battery packs – 5-6 months?
- Rafos not implemented, requires liaison with UW but may be possible.
- Sensors in the wet fairing.
Waveglider and other USVs:

- Vulnerable in ice
- Solar charged battery – great in summer, not in winter.
- Wave powered – not good inside pack ice.
- Limited thruster capability.
- Big platform for instruments
- Certainly vulnerable to icing – unknown quantity.
The Seaglider found with the Argos goniometer in February 2014. A block of ice had formed on the sea glider’s antenna, stopping communication with the Iridium system.
What improvements could we undertake by 2017?

- Improved compass for Slocum?
- Extra power modules for the Slocum
- Improved ice avoidance and detection for Slocum – upward looking altimeter.
- Berg avoidance for the Waveglider?
- Seaglider Rafos – with University of Washington.
Slocums – used in the Antarctic
Seaglider and Waveglider
Waveglider and Autonaut
Costs

• Typical glider deployment of up to 90 days ~£35k-£40k excluding ship and freight costs.

• Typical waveglider deployment of 90 days ~£75k-£100k

• The main costs are Iridium, batteries and piloting – 1 pilot to many vehicles.
# NOC National Marine Facilities AUVs Available for Arctic Operations

Steve McPhail : Head of AUV Development, NOC. 

[mailto:sdm@noc.ac.uk](mailto:sdm@noc.ac.uk)

## Summary Specifications

<table>
<thead>
<tr>
<th>AUV</th>
<th>Range</th>
<th>Endurance</th>
<th>@ Speed</th>
<th>@ Typical Payload Power</th>
<th>Max Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autosub3</td>
<td>300 km</td>
<td>60 hrs</td>
<td>5 km/hr</td>
<td>120 W</td>
<td>1600 m</td>
</tr>
<tr>
<td>Autosub6000</td>
<td>150 km</td>
<td>30 hrs</td>
<td>5 km/hr</td>
<td>120 W</td>
<td>6000 m</td>
</tr>
<tr>
<td>ALR 6000</td>
<td>2000 km</td>
<td>1 month</td>
<td>2.7 km/hr</td>
<td>5 W</td>
<td>6000 m</td>
</tr>
<tr>
<td>ALR 1500</td>
<td>5000 km</td>
<td>2.5 month</td>
<td></td>
<td></td>
<td>1500 m</td>
</tr>
</tbody>
</table>
Autosub3 / 6000

- Can track the underside of the ice (upwards/downwards ADCP)
- Navigation ~ 0.1 % of distance travelled when DVL lock (400 m Asub3, 200m Asub6000)
- Very wide range of sensor possible. Lots of power and space.
- Our NOC team have world leading experience of under sea ice and ice shelf operations

**However:** They do need a research ship and have insignificant range vs the Arctic basin.

Mapping the underside of the Pine Island Glacier - Palmer 2009, 2013

Darwin Mounds (Rockall)
Cruise JC060 [2011]
Altitude 15 – 50 m
Summary Specifications

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</tr>
<tr>
<td>ALR 1500</td>
<td>5000 km</td>
<td>2.5 month</td>
<td>2.7 km/hr 5 W</td>
<td>1500 m</td>
</tr>
</tbody>
</table>
Autosub Long Range

- Autosub Long Range (ALR) is perhaps better suited to the requirements
- Has adequate space for a wide range of sensors
- ALR2 – 6000 and ALR3 -6000 recently passed commissioning trials in Portland Harbour
- Much lower cost than large Autosubs
- Has adequate range to cross Arctic Basin.
- Is shore launched / recovered
- Navigation is not as good as larger AUVs – when bottom tracking - but that might not be relevant …
- 1500 m version (under development) has 2.5 x energy payload capability.
ALR : Future projects

• 2017: Deep deployment in the southern ocean to 4000 m (DynOPO) to investigate mixing processes.

• 2017: Demonstration of the carbon capture storage monitoring system in the North Sea.

• 2018: 7 day deployments under the Fimbull Ice Shelf in the Weddell sea.
But what is exciting is the prospect of:
(e.g.) Svalbard to Barrow, Alaska: 3200 km, 50 days

Range is not the issue for ALR.

Main technical issue is **Navigation**.

But (I think) a tractable problem:

- e.g. Terrain matching (TERCOM) navigation, possibly with acoustic beacon (RAFOS principle) aiding at edges of basin.
Other NERC AUV assets which are available for the NERC ARCTIC call:
AUV Remus 600

Propeller-driven vehicle
~3m long, 200kg
Depth rating: 600m
Speed: 4.5 knots (~2.5m/s)
Endurance: 15h, >100km
Wet payload section (with power)

Equipped with:

- CTD
- Wetlabs triplet
- RDI 600 kHz ADCP (up and downward looking)
- RSI micro-structure sensing package

Contact: Estelle.Dumont@sams.ac.uk
Gavia AUV

configuration

- Offshore Surveyor base vehicle (500m depth rating)
- High-precision DVL aided Inertial Navigation System
- Swath Bathymetry & side-scan Kongsberg 500kHz GeoSwath+
- Colour Camera & strobe
- Sound Velocity Meter, Obstacle Avoidance Sonar,

REMUS and GAVIA Available for Changing Arctic

Contact:
Estelle.Dumont@sams.ac.uk

Gavia AUV
80kg
2.7m long
9 boxes for transport
4hr endurance
~10-15 km² area per mission
Context of ALR Filchner Ice shelf Missions
British Antarctic Survey
Arctic Science and logistics

Randolph Sliester, Ship Operations Manager
Current BAS ship operations

- BAS operates two vessels, RRS *James Clark Ross* and RRS *Ernest Shackleton*. *The Ernest Shackleton is not available during the northern summers due to commercial charter work.*

- RRS James Clark Ross has completed a three year £ 11 million pound life extension program. This should see the vessels working life well into 2025, with some investment to make the ship compliant with the Polar Code.
RRS James Clark Ross: Science and logistics

• Built by Swan Hunter in Scotland
• Launched 1990
• World class polar science and logistics platform
• Completed more than 300 science cruises
The James Clark Ross is an ice strengthened vessel, it can easily deal with 1 meter of ice at three knots. The vessel can deal with ice greater than 1 meter with backing and ramming, but should not be considered as having the same capability of a heavy icebreaker.

Endurance is approximately 57 days @ 12 knots open water steaming, we typically operate the RRS JCR @ 10 knots on transit to minimize fuel usage and carbon footprint, this extends the endurance for open water work. Overall endurance will depend on sea ice and sea state conditions.
Science capabilities of RRS JCR

Scientific/Expedition Accommodation

15 Single berth (with Pullman Berth) (14 Available on Science Cruise)
4 x 4 berth
Chief Scientist Suite (2 Single berths available)
Maximum Science Complement 31

Working Deck

Aft Deck 20m long, full deck width (370m2)
Starboard Deck 5m wide to midships (150m2)
Forward Deck Starboard Side of Main deck (130m2)
All working deck areas covered by Matrix of 1 Tonnes capacity Bolt-down sockets at 1m centres (0.5m in some areas)
Facilities for 5 Laboratory Containers (ISO 20 ft. [4 aft, 1 fwd])
Science capabilities of RRS JCR

Gantries

<table>
<thead>
<tr>
<th>Location</th>
<th>Equipment</th>
<th>SWL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midships</td>
<td>Articulated ‘A’ Frame</td>
<td>15 Tonnes</td>
</tr>
<tr>
<td>Aft</td>
<td>Articulated ‘A’ Frame ‘A’ frame</td>
<td>10 Tonnes</td>
</tr>
</tbody>
</table>

Winches

<table>
<thead>
<tr>
<th>Winch Type</th>
<th>Equipment</th>
<th>SWL/Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Traction Winch</td>
<td>Superaramid Deep Coring Warp</td>
<td>8000m 10,000kgf</td>
</tr>
<tr>
<td></td>
<td>Standard Coring Warp</td>
<td>7000m 7.84 Tonnes</td>
</tr>
<tr>
<td></td>
<td>Tapered Trawl Warp</td>
<td>15000m 5.24 Tonnes</td>
</tr>
<tr>
<td></td>
<td>Conducting Cable</td>
<td>10000m 4,500kgf</td>
</tr>
<tr>
<td>CTD/Hydro graphic Traction Winch</td>
<td>Hydrographic Wire</td>
<td>9000m 0.8 Tonnes</td>
</tr>
<tr>
<td></td>
<td>Conducting Cable (CTD)</td>
<td>7000m 3,220kgf</td>
</tr>
<tr>
<td></td>
<td>Spare Drum</td>
<td></td>
</tr>
</tbody>
</table>

Inboard and outboard motion compensator systems are fitted to both traction winch systems

<table>
<thead>
<tr>
<th>Winch Type</th>
<th>Equipment</th>
<th>SWL/Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological Drum Winch</td>
<td>Conducting cable</td>
<td>3000m 2,948kgf</td>
</tr>
</tbody>
</table>

Gilson Winches x 2 SWL 5 Tonnes
# Science capabilities of RRS JCR

## Gantries
- **Midships**: Articulated ‘A’ Frame SWL 15 Tonnes
- **Aft**: Articulated ‘A’ Frame ‘A’ frame SWL 10 Tonnes, Articulating Arm SWL 7.5 Tonnes

## Winches
**Main Traction Winch** (Serving Midships and Aft Gantries)
- **Storage Drums**: Superaramid Deep Coring Warp 8000m SWL 10,000kgf
- Standard Coring Warp 7000m SWL 7.84 Tonnes
- Tapered Trawl Warp 15000m SWL 5.24 Tonnes
- Conducting Cable 10000m SWL 4,500kgf

**CTD/Hydrographic Traction Winch**
- **Storage Drum**: Hydrographic Wire 9000m SWL 0.8 Tonnes
- Conducting Cable (CTD) 7000m SWL 3,220kgf
- Spare Drum

Inboard and outboard motion compensator systems are fitted to both traction winch systems
**Biological Drum Winch**: Conducting cable 3000m SWL 2,948kgf

**Gilson Winches x 2** SWL 5 Tonnes
# Science capabilities of RRS JCR

## Laboratories

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Laboratory</td>
<td>23.5m²</td>
</tr>
<tr>
<td>Main laboratory</td>
<td>44.2m²</td>
</tr>
<tr>
<td>Rough Workshop</td>
<td>25.9m²</td>
</tr>
<tr>
<td>Scientific Workshop</td>
<td>19.6m²</td>
</tr>
<tr>
<td>Water bottle Annex</td>
<td>18.1m²</td>
</tr>
<tr>
<td>Chemistry Laboratory</td>
<td>18.1m²</td>
</tr>
<tr>
<td>Preparation Laboratory</td>
<td>16.3m²</td>
</tr>
<tr>
<td>Biochemistry Laboratory</td>
<td>10.6m²</td>
</tr>
<tr>
<td>Microbiology/Radioactive Lab</td>
<td>10.7m²</td>
</tr>
</tbody>
</table>

## Computer Electronic and Control Spaces

<table>
<thead>
<tr>
<th>Space</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underway Instrument and Control Room</td>
<td>66.8m²</td>
</tr>
<tr>
<td>(Incorporating Winch Control Room)</td>
<td></td>
</tr>
<tr>
<td>Swath Bathymetry and TOPAS Control Area</td>
<td>7.4m²</td>
</tr>
<tr>
<td>(Incorporated in the U.I.C. Room)</td>
<td></td>
</tr>
<tr>
<td>Electronic Workshop</td>
<td>7.2m²</td>
</tr>
<tr>
<td>Data Preparation Room</td>
<td>16.5m²</td>
</tr>
<tr>
<td>Computer Room</td>
<td>19.5m²</td>
</tr>
<tr>
<td>Paper and Magnetic Tape Ready Use Store</td>
<td>4.6m²</td>
</tr>
</tbody>
</table>

## Other Scientific Spaces

<table>
<thead>
<tr>
<th>Space</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity Meter Room</td>
<td>5.2m²</td>
</tr>
<tr>
<td>Cool Specimen Room</td>
<td>13.0m³</td>
</tr>
<tr>
<td>Scientific Freezer -20°C</td>
<td>25.0m³</td>
</tr>
<tr>
<td>Scientific Chest Freezers -80°C x2</td>
<td></td>
</tr>
<tr>
<td>Scientific Hold</td>
<td>267m³</td>
</tr>
<tr>
<td>Explosives Store</td>
<td>35m³</td>
</tr>
<tr>
<td>Hazardous Chemical Lockers x3</td>
<td></td>
</tr>
<tr>
<td>Storm Clothing Annex</td>
<td>Main deck Aft</td>
</tr>
</tbody>
</table>
Science capabilities of RRS JCR

Scientific Data Acquisition
Local Area Network system with back up is installed for cruise instrumentation and equipment. Instrumentation continuously logged on the central computing system. Facilities are available for data transmission via satellite to and from the ship.

Scientific Instrumentation

Echo Sounders
- Simrad EM 122 Multi Beam Echo Sounder
- Simrad TOPAS Parametric Sub-Bottom Profiler
- Simrad EK 600 Fish Finding Sounder

- Simrad EK 6000 38kHz, 200kHz and 120kHz Transducers
- Precision Echo Sounder 10kHz
- Furuno CSH5D Directional Sonar

Logs
- Sperry SRD 421S Dual Axis Doppler log
- Chernikeef Aquaprobe Mk 5 EM Log

Ships Motion Monitor/Compensator
- Heave - Pitch - Roll Monitor / Compensator

Navigation and Oceanography
- Ships ARCS Navigation System (Displayed in UIC Room and Main laboratory)
- Trimble 400D Surveyor DGPS (Thales Geosolutions)
- Ashtec GPS3DF linked to ADCP
- Acoustic Doppler Current Profiler RD1 type RD-VDM 150
- PC-Based Ocean Logger
BAS Vessel availability

- The RRS JCR will be able to undertake Arctic cruises summer 2017/18/19/20/21 and onward (if government wants to continue operating the vessel).

- New Polar Vessel will be conducting sea trials starting in summer 2018 and should not be considered for planning purposes until summer 2019.
New Polar Vessel

- Helicopter deck with Hanger
  This design specs as follows.
  - 124.90m LOA
  - Breadth 24.00 m
  - Draught 7.00m
  - Draught Scantling 7.50m
  - Dead Weight 4400 Lt.
  - Polar Research Vessel ice classed +100A1
  - DP (AA)
  - 90 Berths total
  - 28 crew
  - 55 Science
  - 7 support staff
  - Cargo 2800 m3
  - 600 m3 Aviation fuel
  - 1690 tonnes MGO ships fuel
  - Open water transit speed 13kts
  - Ice Breaking speed 3kts in 1m ice
  - Modularized Lab vans
The Changing Arctic Ocean Research Programme

NMF-Sea Systems RRS *James Cook* and RRS *Discovery* are designed to carry scientists to some of Earth’s most challenging environments, from tropical oceans to the edge of the ice sheets giving potential for exploration within the Arctic Region.

**James Cook:**
- Marine crew ...........22 officers & ratings
- Scientists & technicians ..... 32
- Average operating speed.....11 knots
- Operational endurance ...... 50 days

  - Single & multibeam echosounder surveys
  - Integrated data logging
  - Seismic surveys
  - Clean seawater sampling
  - Remotely Operated Vehicle operations
  - CTD surveys
  - Deepwater coring, trawling, and towing

**Discovery:**
- Marine crew ..................... 24 officers & ratings
- Scientists & technicians ..... 28
- Average operating speed ... 11 knots
- Operational endurance ...... 50 days

  - Single & multibeam echosounder surveys
  - Integrated data logging
  - Seismic surveys
  - Clean seawater sampling
  - Remotely Operated Vehicle operations
  - CTD surveys
  - Deepwater coring, trawling, and towing

noc.ac.uk
James Cook is Lloyds Ice Notation Class 1C provides \textit{strengthening for ships intending to navigate in first year ice conditions equivalent to unbroken level ice with a thickness of 0.4m}.)

Class C instructions to Master's for Operations in Ice do not allow entry into pack ice unless absolutely necessary and intended operations should be planned for summer only. James Cook - There is one projection beyond the hull for the non-toxic inlet. NMFSS is currently evaluating Polar Code compliance and cost implications \textit{(Discovery Lloyds Ice Class 1D which facilitates operations in light ice)}

RRS James Cook and Discovery are the most effective and compatible platforms to deploy National Marine Equipment Pool. An example being AUV that have carried out missions under ice in the Arctic and Antarctica since 1999

Both vessels multi role –can undertake ROV/AUV/CORING Operations and can compliment this with seismic and multibeam work from each vessel’s acoustic array.
MEDUSA is an “intermediate complexity” model of ocean ecosystems and biogeochemistry [Model of Ecosystem Dynamics, nutrient Utilisation, Sequestration and Acidification] embedded into Global ocean circulation model NEMO (including sea-ice model)

Examples of the output:
- Surface velocity
- SST+ice
- Phytoplankton
- pH
MEDUSA is a component model of UK ESM

Delivers improved climate modelling capability in support of NERC strategy

Ice Sheets/Shelves

Atmosphere

UK ESM

Ocean

Sea-Ice

Land Surface

Marine Biogeochemistry
Coupled ocean - sea-ice - biogeochemistry system (NEMO-MEDUSA) is available to the Arctic Biogeochemistry program through NC.
MEDUSA-2.0: an intermediate complexity biogeochemical model of the marine carbon cycle for climate change and ocean acidification studies

A. Yool, E. E. Popova, and T. R. Anderson
National Oceanography Centre, University of Southampton Waterfront Campus, European Way, Southampton SO14 3ZH, UK

Correspondence to: A. Yool (a.yool@noc.ac.uk)

Received: 31 January 2013 – Published in Geosci. Model Dev. Discuss.: 21 February 2013
Revised: 5 September 2013 – Accepted: 10 September 2013 – Published: 29 October 2013

Abstract. MEDUSA-1.0 (Model of Ecosystem Dynamics, nutrient Utilisation, Sequestration and Acidification) was developed as an “intermediate complexity” plankton ecosystem model to study the biogeochemical response, and especially that of the so-called “biological pump” to autho...
MEDUSA’s simplicity is driven by high computational cost of the global/regional high resolution realisations.

Capacity of adding new state variables is limited but new elements can be added “off-line”.

<table>
<thead>
<tr>
<th>What’s in?</th>
<th>What needs to be in to facilitate Challenge 2?</th>
<th>What is out?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>On-line: Sea-ice algae</td>
<td>e.g. Phosphorous</td>
</tr>
<tr>
<td>Silicon</td>
<td></td>
<td>Coccolithophorids</td>
</tr>
<tr>
<td>Iron</td>
<td>Off-line: Higher trophic levels</td>
<td>N2-fixers</td>
</tr>
<tr>
<td>Diatoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-diatoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro-Zooplankton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meso-Zooplankton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POC</td>
<td></td>
<td></td>
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<tr>
<td>Carbon system</td>
<td></td>
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</tbody>
</table>
MEDUSA and higher trophic levels

- Size-spectrum models can be coupled to NEMO-MEDUSA off-line

- NEMO-MEDUSA comes with off-line lagrangian particle tracking system which is designed to facilitate:
  
  - Lagrangian models of zooplankton life stages (i.e. colonisation of Arctic by Atlantic zooplankton under warming climate)
  
  - Biological connectivity (invasive and non-native species, i.e. pacific diatoms in the NA- fig)
  
  - Pathways of nutrients and pollution (including pollution (i.e. oil) impact on ecosystems services)
MEDUSA and optimisation of observational strategies

Use of the model as a “virtual reality” for optimisation of the proposed field work including AUVs (with “artificial intelligence”)

Upscaling the field work to complete season and pan-Arctic scale

1/12° run is available now with excellent representation of the MIZ, stratification, under ice and ice-edge blooms, sub-surface Chl-a maximum
NEMO-MEDUSA proven capability in the Arctic

Physical mechanisms controlling regional aspects of present-day Arctic productivity (Popova et al., 2010; Popova et al., 2012)

Future change in ocean productivity: Is the Arctic the new Atlantic? (Yool et al., in press)

Nutrient pathways, mechanisms of nutrient supply, role of advection (Popova et al., 2013)

Future projections of Arctic CO2 fluxes and acidification (Popova et al., 2013)

Subsurface Chl-a maxima, mechanisms of formation and future projections (Lawrence et al., in press)

Ice-edge blooms (Perette et al., 2011)

Regional AO model (Luneva et al., 2015)
Regional vs Global NEMO-MEDUSA

- Better underpinned by NC (a lot of NC projects are using it)
- Direct links to ESM
- Long history of well published AO research

- Higher risk option (less NC, needs more supplement from the program)
- Has tides and cascading (better for shelf-basin exchange)
- Cheaper for ensemble runs
- MEDUSA coupling is ongoing work
What will be made available to the program?

1/4° global NEMO-MEDUSA run 1980-2099 – Available now, NC

1/12° global NEMO-MEDUSA run 1990-2014 – Available now, NC

1/12° global NEMO-MEDUSA run 1980-2099 – Might become available later in the program, NC + extra development (i.g. sea ice algae) by Arctic SPA

1/4° Arctic regional NEMO run 1990-2014 - Available now, NC

1/4° Arctic regional NEMO-MEDUSA run 1990-2014 - Might become available if needed by this program, NC + extra development (i.g. sea ice algae) by Arctic SPA
Logistics of NC support to the program

1. All existing model runs are publically available
   • please do not underestimate amount of work and skills involved in processing, visualisation, interpretation – you will need NOC participation. We will support all projects which need NEMO-MEDUSA. This effort is not huge but will need to be costed (contact: K.Popova, NOC ekp@noc.ac.uk)

2. Links to UK ESM: “An important consideration in the proposed modelling activities will be how, overall, they can contribute to the development of the ecological component of UK ESM”
   • Please contact UK ESM Ocean Biogeochemistry PIs: (K.Popova, NOC and I.Allen PML)

3. Coordination with other NC funded MEMO-MEDUSA activities
   We are happy to run a PI workshop on cross-proposal modelling coordination, integration and any other issues if such a request is made (There is an option of 23rd Nov in London, MRC, 12-5pm. 10 spaces – requests to K.Popova ekp@noc.ac.uk).
**AO in the global model:**

Yool, A., E. E. Popova, and A. C. Coward. Future change in ocean productivity: Is the Arctic the new Atlantic? JGR in press.


**AO Regional model:**

FRAM and MOSAIC
two milestones of the Arctic programme of AWI

Torsten Kanzow, Ian Salter, Maria Nielsdottier, Klaus Dethloff
FRAM | FRontiers in Arctic Marine Monitoring: Aim and key tasks

Sustained multidisciplinary, year-round surface to seafloor observations of physics – ecosystem coupling in the changing Arctic
FRAM | FRontiers in Arctic Marine Monitoring: Aim and key tasks

Sustained multidisciplinary, year-round surface to seafloor ecosystem observations in the changing Arctic

- HGF 'Strategic Investment' to implement a distributed observatory infrastructure in Fram Strait and the central Arctic
- 25 million Euro, mid 2014 – mid 2021
- Coordination: Antje Boetius, Torsten Kanzow (deputy)
- Integrate existing AWI time series components (Hausgarten, HAFOS), extend scientific scope and spatial and temporal coverage
- Develop and implement cutting edge technologies (sensors, samplers, moored, mobile, and drifting platforms)
- Establish procedures for data dissemination and products generation
FRAM activities

Fram Strait
FRAM | FRontiers in Arctic Marine Monitoring:
Contributing sections, work packages and project teams

- Climate Dynamics
- Polar Biological Oceanography
- Observational Oceanography
- Planktosens (YIG)
- Phytochange (YIG)
- Seapump (YIG)
- Deep Sea Ecology & Technology
- Ocean Acoustics
- Sea Ice Physics
- Phytooptics

*AWI*
FRAM | FRontiers in Arctic Marine Monitoring: Contributing sections, work packages and project teams

WP 1: Coordination, management, dissemination

Observational Oceanography

Ocean Acoustics

Sea Ice Physics

Phytooptics

Deep Sea Ecology & Technology

Polar Biological Oceanography

Planktosens (YIG)

Phytochange (YIG)

Seapump (YIG)

FRAM coordination

Data management
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WP 2: Physical oceanography observations

- Observational Oceanography
- Backpack Oceanography
- Profiling winches
- Floats, gliders, satellite comm.
- AUV platform
- Active & passive hydroacoustics
- Climate Dynamics
- Polar Biological Oceanography
- Planktosens (YIG)
- Phytochange (YIG)
- Seapump (YIG)
- Deep Sea Ecology & Technology
- Ocean Acoustics
- Sea Ice Physics
- Phytooptics
SWIPS underwater winch – developed under ICOS-D WP. 2.2

Subsea Winched Profiling System – SWIPS

Profiling measurements of various physical and biogeochemical parameters in the upper part of the water column (approx. 200m to surface)

Profiler equipped with:
- CTD Sensor Sea-Bird SBE 52-MP
- $O_2$ Sensor Sea-Bird SBE 63
- $CO_2$ Sensor CONTROS HydroC
- Fluorometer Wet-Labs ECO Triplet-w
- Altimeter Valeport VA500
- IRIDIUM Modem

Specifications:
- Profiling speed: configurable (currently 10m per minute)
- Profiling interval: configurable (currently one profile per day)
- Sample frequency: one dataset per second (1Hz)
- Data storage in profiling unit and winch unit

The system is still a prototype and subject to ongoing development.
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WP 3: Sea-ice based observations

Ice-tethered platforms
Ice tethered platforms

Liquid freshwater

Rabe et al. (2011, DSR-I)
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WP 4: Biological and ecological observations

- Water col. biogeo. sampling & sensing
- DNA sampling
- Water and seafloor imaging systems
- Particle sampling & sensing
- Benthic observatories
- Crawler systems
- Remote sensing

Climate Dynamics
Observational Oceanography
Ocean Acoustics
Sea Ice Physics
Planktosens (YIG)
Phytochange (YIG)
Seapump (YIG)
Deep Sea Ecology & Technology
Phytooptics
Particle Flux Observatory (Ian Salter, Evi Noethig, Edi Bauerfeind, Morten Iversen)

New long-term sediment trap deployments in the Arctic Ocean


Existing time-series (2004-2016)

- Salter, Bauerfeind, Noethig et al in prep

Gel traps and bio-optical arrays
Aggregate samplers
Large volume particle samplers
Microbial Observatory (Katja Metfies, Ian Salter, Antje Boetius)  

**Surface Ocean**  
Water and particles

**Ice**

**Meso/Bathypelagic**  
Water column  
Suspended particles  
Sinking particles

**Coring**

**Sediment Coring**

**Autonomous sampling**

**Underway sampling**  
Automated sampling, extraction, and hybridisation

**Standard sampling**

**NMDS relative abundance**

**Water samplers**  
**Sediment traps**  
**Particle samplers**

**Pelagophyceae**  
**Dictyochophyceae**  
**Diatoms**  
**Stramenopiles MAST**  
**Rhizaria**  
**Cercozoa**  
**Syndinales**
Research themes of Nutrient Biogeochemistry

1. Seasonal estimates of gross and net community production beneath the ice

2. Spatial variation in surface nutrient concentrations in relation to ice / water masses

3. Carbonate system chemistry and ocean acidification

4. Regional Nutrient Biogeochemistry in Fram Strait as Arctic-Atlantic deep-water connection

**FIXO3 Collaboration**
- Sinhue Torres-Valdez (NOC)
- Sheldon Bacon (NOC)
- Alex Beaton (NOC)
- Ian Salter (AWI)
- Maria Nielsdottir (AWI)
Autonomous water samplers

- 2 x Hausgarten Bio-Moorings
- Central Arctic Bio-mooring
- 2x Svalbard Fjords: Kongsfjorden (open water) and Van Mijen Fjorden (Ice covered)

- Test two separate lab-on-a-chip sensors (nitrate) developed by Mowlem group at NOC (FIXO3)

  (i) to use the 48 discrete water samples collected by the samplers to ground-truth the sensor performance over a 1 yr deployment and

  (ii) to provide some temporal context for the weekly water samples in the sensor dataset which has much higher temporal resolution ~3 measurements per day.
Sensor testing TRANSARC  Summer 2015

Contros pCO$_2$
Alkalinity sensor

Seafet pH

Water IN

Water OUT

ISUS V3
SUNA Deep

SAMI pH and pCO2
MIMS: Membrane Inlet Mass Spectrometer-Summer 2016

Björn Rost, Klaus-Uwe Richter
Integrated time-series work

(Soltwedel et al., in press)
Summary FRAM

- FRAM is currently being implemented as an infrastructure for Arctic Ocean monitoring
- physical, biogeochemical, biological time series
- collaborations and use of infrastructure is highly welcome
Leading Science Question:
“What are the causes and consequences of an evolving and diminished Arctic sea ice cover?”

Sea-ice Lifecycle as a Theme.
Use a sea-ice “Lagrangian” perspective, where ice processes integrate forcings from atmos and ocean.
MOSAIC
Multidisciplinary drifting Observatory for the Study of Arctic Climate

Transpolar Drift track

Objectives:
• Observe full sea-ice “life cycle,” starting in new ice.
• Trajectory that will last for at least (more than) 1 year
• Observe an understudied region

Challenges:
• Central Arctic is isolated
• First year ice will be difficult
Measurements

atmospheric profiling, BL, & dynamics

gases, aerosols, clouds & precip.

ice thermodynamics, optics

ocean state, profiling, BL, & dynamics

aircraft + UASs

buoys, AUVs, gliders

ocean and ice biogeochem
Measurements

D = Deep Ocean Profile
M = Mid Ocean Profile
U = Upper Ocean Profile
O = Ocean Flux
I = Ice Profile
A = Atmos Flux
B = BGC Sampling

= GPS array
= Glider
(BGC, ocean survey)
= UAS
(ice, atmos survey)
= Radar

2-5 km  
20 km
50-70 km
MOSAIC: Multidisciplinary drifting Observatory for the Study of Arctic Climate

- life cycle of sea ice
- multiple grid approach
- one year drift of R/V Polarstern along transpolar drift
- envisioned to start in summer 2019
- coordinated by Klaus Dethloff (AWI) with Mathew Shupe (U. Colorado)
- large international science team
- funding not yet fully secured
Arctic Science and Impact at Cefas
Stephen.Dye@cefas.co.uk
@stephendye

Cefas Marine Climate Change Centre (MC3)

Deep Sea Sponge
Ernest Holt 1949-1970

Station locations 1930 to 1959


- ‘Cefas’ Arctic fisheries and hydrography work 1940s-1970s
- W. Barents Sea, W. Greenland, later on Iceland, East Greenland.
- Digitised up to 1959
- Catch Composition
- Length Distribution
- Stomach Contents
- Not all digitised or exploited
Barents Sea Physics to Fish (Whales)

- Existing Ecopath foodweb
- Lower Trophic Levels Modelling
  GOTM-ERSEM-BFM

Ecosystem Modelling

Centre for Environment
Fisheries & Aquaculture
Science
Marine climate change impacts

The 2013 MCCIP Report Card provides the very latest updates on our understanding of how climate change is affecting UK seas. Over 150 scientists from more than 50 leading science organisations contributed to the report card covering a wide range of topics ensuring that the information is timely, accurate and comprehensive.

- MCCIP
- OSPAR & NEAFC
- Fisheries assessment
- ICES, NAFO, Southern Ocean
- Developing new methods of integrated ecosystem and fisheries assessment
- Vulnerability of deep water habitats vs activities
Arctic Workshop

Tim Clarke

Dstl (Defence Science and Technology Laboratory) – Maritime Environment

NERC – Attachment to exploit and initiate research

tclarke@dstl.gov.uk 01980 658515
Interest Areas

• Understanding Physical, Biological, Chemical Oceanography and Sea Bed

• Novel Sensing and Vehicles (faster, cheaper, smaller)

• Forecasting

• Information Fusion

70% of our Research Budget is spent with Academia and Industry
Opportunities (1)

Use of RN equipment

MASSMO: MARINE AUTONOMOUS SYSTEMS IN SUPPORT OF MARINE OBSERVATIONS

Possible use of planned submarine science trials under the ice (ICEX)
Opportunities (2)
Previous/Current CASE awards and PhDs
https://www.gov.uk/guidance/phd-research-funding

Remote sensing of turbidity

Holographic camera: classify and count marine particles

Swimming efficiency of southern elephant seals

Underwater navigation using a quantum based gravitometer

Marine Bioluminescence

Photon counting for underwater depth imaging

Localisation of unmanned vehicles in unknown environments

Novel sensors for gliders

Whisker sensor array for operating in close proximity to the seabed

Remote sensing of turbidity
NOAA’s Arctic Research Program: Priorities for the Future

Jeremy T. Mathis, Ph.D.
Director – Arctic Research Program
Climate Program Office
How the Arctic system is changing on time scales of weeks to decades, particularly with respect to the consequences that the loss of sea ice may have on both Arctic ecosystems and northern hemisphere severe weather events.
Ocean Acidification

OA Indicator
(Aragonite Saturation State)

Mathis et al., 2015
A Pan-Arctic Approach
Research Cruises in the Pacific Arctic Region, 2004-2014

Japan: RV Mirai

China: RV Xuelong

Korea: RV Araon

Russia-USA: RV Khromov

Canada: CCGS Sir Wilfrid Laurier, Louis St. Laurent

USA: Healy, RV Aquila, Brown etc.
The Distributed Biological Observatory (DBO)
Underwater Profilers
New Mooring Configurations

#1
- Humidity, AT, PAR, Pressure
- LW/SW Radiation Sensor, Wind Speed / Direction, GOPRO3+ Camera, Light
- Lab on a Chip (Nitrate)
- SBE 37, Eco-Fluorometer, SUNA (Nitrate), Accelerometer
- Prowler stopper
- Prowler (T, S, O₂)
- 5 m
- 25 m
- 27 m
- 29 m
- 31 m
- 33 m
- 35 m
- Microcat, Eco Fluorometer
- Acoustic Release
- 42 m
- Anchor

#2
- LARA surfaced
- LARA submerged
- Sensor unit
- Prowler stopper
- Microcat, Eco Fluorometer
- T
- 27 m
- 29 m
- T
- 31 m
- T
- 33 m
- T
- 35 m
- Microcat, Eco Fluorometer
- Acoustic Release
- Underwater winch
- Acoustic release
- Anchor weight

#3
- Prototype
- Hard Hat
- Satellite Tag
- Trawl Float
- Counter-Weight
- Weight
- Release #2
- Release #1
- Anchor
The Wave Glider
The Sail Drone
International Collaborations
The Pacific Arctic Group (PAG)

• The Pacific Arctic Group (PAG) is an informal group of organizations and individuals having a Pacific perspective on Arctic science. PAG is now an independent affiliate of the IASC and has as its mission to serve as a Pacific Arctic regional partnership to plan, coordinate and collaborate on science activities of mutual interest.

• PAG shares information on annual field activities in the Pacific Arctic region

• PAG continues to develop and implement long-term monitoring activities such as the Distributed Biological Observatory (DBO)

• PAG undertakes Pacific Arctic regional, multidisciplinary syntheses of scientific findings in the marine region relevant to ongoing scientific objectives at the core of the PAG

• PAG is engaged in project development and sampling in the Pacific Arctic region to investigate climate, oceanography, air-sea ice interactions, physical oceanography, and modeling
Questions