SCOR Working Group Proposal

(max. 5000 words, excluding Appendix)

Title: Translation of Optical Measurements into particle Content, Aggregation & Transfer

Acronym: TOMCAT

Summary/Abstract (max. 250 words)

Sinking particles transport organic carbon to the deep sea, where they form the base of life. The magnitude of particle export and the rate at which particles are consumed determine carbon sequestration in the oceans, and directly influence atmospheric carbon dioxide concentrations and global climate. Traditionally, sinking particles have been collected using sediment traps. However, the limited spatial and temporal coverage of sediment traps have led to new technologies that focus on optical measurements to allow the collection of large data sets describing both frequencies and types of sinking particles. These can be used from ships or installed on remote platforms, promising greater spatial and temporal coverage. Yet, whilst technologies to image particles have advanced greatly during the last two decades, techniques to analyze the often immense data sets have not. One short-coming is the translation of optical particle properties (e.g. the image) into particle characteristics such as carbon content and sinking speed. Moreover, different devices often measure different optical properties, leading to difficulties in comparing results. This working group aims to bring together experts in observation, experimentation, theoretical modelling, and data analyses to systematically improve the process of converting in-situ particle measurements to global export estimates. Final outcomes will include publications detailing intermediate steps and a framework outlining the most efficient way of converting large volumes of particle measurements into export estimates. The output of this working group should have high impact on future ocean research by enabling efficient use of the rapidly developing field of optical sensors.

Scientific Background and Rationale (max 1250 words)

The oceans play a critical role in controlling the climate by storing large quantities of carbon dioxide (CO_2) in the interior. The interaction between atmosphere and deep ocean storage is driven in large parts by the biological processes associated with production, sinking and remineralization of organic matter in the ocean. These processes, collectively known as the biological carbon pump, keep atmospheric CO_2 concentrations ~200 ppm lower than if the oceans were abiotic (Parekh et al. 2006). The size of ocean carbon storage is determined by the amount of organic matter exported and the rate at which sinking organic matter is reworked and respired in the mesopelagic zone (region between 100-1000 m depth) (Kwon et al. 2009). Accurate estimates of these two processes (export and remineralization of sinking organic matter) are therefore key to understanding the ocean carbon cycle and how it regulates atmospheric CO_2 concentrations.

One of the big challenges in estimating export and remineralization is the accurate measurement and characterization of sinking particle fluxes. Traditionally, export flux is collected using sediment traps, which collect particles at a certain depth over a period of several days to months. Owing to the limited spatial and temporal coverage of sediment traps, characterization of export flux is restricted. Shortcomings include the inability to resolve variations in export flux over short time periods and across space. Moreover, particles are pooled in the sediment traps, making it hard to characterize the origin and composition of the individual particles. Rather, sediment traps give bulk estimates only and no information on the individual particles making up the bulk flux. Especially particle size is an important parameter determining how and how fast it sinks, how much material an object contains, and who can find and eat it. Knowing the sizes and abundance of the settling particles is the starting point for understanding how they interact with the marine environment.

As an alternative to sediment traps, most current large-scale assessments on the role of sinking particles in the marine carbon cycle focus on measuring dissolved biogeochemical tracers such as nutrients, oxygen or pH. These tracers reflect the net processes of particle transport and the circulation. Major observational programmes that use dissolved tracers include GO-SHIP (Global Ocean Ship-Based Hydrographic Investigations Program) and SOCCOM (Southern Ocean Carbon and Climate Observations and Modeling), which uses biogeochemical sensors on profiling floats. The focus on dissolved tracers is partly driven by two advantages; the sensor techniques are relatively advanced, and estimated rates are integrated over space and time thus reducing observational needs. However, these observations are unlikely to deliver any predictive understanding of how particle fluxes will respond to environmental change as they fail to identify the processes that control the sinking and transformation of particles.

Recent developments in in situ optical sensors may offer the opportunity to overcome some of these problems. Optical sensors use in situ photography ('imaging') or information on light transmission ('non-imaging') combined with automatic particle recognition to estimate particle type, size and distribution. Commonly used devices include the Video Plankton Counter (VPR, Davis et al. 1992), the Underwater Video Profiler (UVP, Gorsky et al. 1992), Laser Optical Plankton Counter (LOPC, Herman et al. 2004), and backscattering sensors. Optical devices can be used from ships or installed on remote platforms (e.g. Argo floats), allowing greater spatial and temporal coverage than sediment traps. They provide high-resolution descriptions of particle frequencies and types and can inform about particle origin. Information about the particle transformation mechanisms can be inferred from observations of particle abundance and size-distributions at different water depths. Lastly, the use of optical devices has become increasingly attractive as they are becoming constantly more affordable.

The translation of optical particle properties into export flux estimates is, however, difficult due to missing information on carbon content and sinking speed. To understand the functioning of the ocean's biology and chemistry, it is necessary to determine how much mass is contained in each particle, their sinking velocity, and the summed contribution of all particles at different depths through the water column. The interpretation of optical measurements is further complicated as different optical devices often measure different optical properties leading to difficulties in comparing results.

The challenge now is to systematically improve the use of optical devices for understanding particle dynamics and export. This includes the comparison and inter-calibration of the outputs of available optical particle devices, as well as collation and distribution of knowledge on how to efficiently convert such optical information into particle export estimates. The working group would advance the processing of data from both imaging and non-imaging instruments, with a strong emphasis on comparing results from field programmes that have deployed both types of systems simultaneously. This will allow for optimization of information gained from already collected data (e.g. non-imaging sensors on profiling floats) and is expected to lead to recommendations on how to enhance current and future programmes by using optical devices. One of the most important aspects of the working group would be to assess which optical properties (e.g. backscattering, transmission or spectral information) and which processing techniques can best provide information on particle densities and chemical compositions, as this - along with sinking rates - is one of the weakest links between obtaining images and estimating material fluxes.

This working group would tackle an extremely timely challenge as the volume of data from optical sensors is steadily increasing, but much of the data are not worked up. This effort thus relies heavily on international collaboration and knowledge exchange, not least as it requires the collection of data from a broad range of ocean environments.

Terms of Reference (max. 250 words)

This working group will focus on converting optical particle information into sensible characterization of particle flux and export. It aims to

(1) compare current devices that optically measure particles and document the advantages and disadvantages of each device.
(2) inter-calibrate the outputs of different devices and/or highlight calibration difficulties.
(3) define key parameters to use for interpretation of the optical information and decide which measurements are most important for characterizing particle export.
(4) improve techniques/algorithms for the conversion of optical observation into fluxes.
(5) decide on how to best analyse the increasingly larger data sets.
(6) develop software examples and codes, placed on a public repository.
(7) deposit optical particle data in an internationally-recognised database that can be actively added to as new data is collected (to allow for large scale analysis and future data exchange)
(8) advise on future methods to maximize data collection and interpretation.

Working plan (logical sequence of steps to fulfil terms of reference, with timeline. Max. 1000 words)

The working group would be comprised of individuals with a wide range of expertise (observation, experimentation and theoretical modelling), which will help to facilitate discussion and problem solving. The working group will focus on four stepping stones to fulfill the terms of reference. The starting point for each stepping stone is the initial workshop that will bring together the experts and share the current state of knowledge. The working group will then identify sub-groups (where considered sensible), leaders, and will finalize a timeline for data analysis, synthesis and publication. The working group will meet once a year to ensure timely progress.

The first step would be the technology analysis, which will focus on optical instruments that have been deployed in various regions of the world's oceans and have collected an extensive database on particles. The working group will compare the outputs of these instruments. The main questions will address

- What data format is produced?
- Are the data comparable between instruments?
- Are there products that could be produced/recorded, but are not currently produced, which would facilitate either data analysis and/or data comparison between instruments?

- Is there a technology which seems to excel and appears particularly promising?

This step will further focus on validation and inter-calibration of the different devices. The working group would develop recommendations for standard methods to calibrate any of the instruments across different size ranges of particles. Subsequently, the working group would coordinate field programmes in different oceanic regions to cross-calibrate different optical sensors, taking particular focus on comparing imaging (UVP/LOPC/VPR) and non-imaging (backscatter/beam attenuation) techniques. We have identified three cruises across the Atlantic (40°N, 20°S, and 54°S; lead by the National Oceanography Centre, Southampton, UK) that will provide the opportunity for inter-calibration throughout the mesopelagic zone (the region between 100-1000 m depth).

Next, the working group will discuss information on how optical properties correspond to particle characteristics such as sinking speed and carbon content, which are key to estimating export fluxes. Special emphasize will further be put on identifying the type and source of the particles, and how particles change with depth. This step aims to discuss our current knowledge and hypotheses, and drive the community to focus research on filling the knowledge gaps. The final product should be a quantitative relationship between the optical properties of particles (whatever appears to be the most sensible in view of the available technologies) and particle characteristics (sinking speed and biochemical contents).

The third step will be to test the proposed relationship with the large data sets that have been collected so far. One of the outcomes should include a sensitivity analysis of how good optical measurements translate into real fluxes. If more research is needed, the details should be highlighted in this phase. An important outcome will be a better understanding of the frequency and resolution that is needed for reasonable export estimates. Overall, the resulting synthesis should greatly advance our understanding of spatial and temporal patterns of particle export.

Finally, a framework will be written that recommends the most efficient way of converting large-volume optical measurements into export estimates. This framework should have high impact on future ocean research as it will enable efficient use of the fast-developing field of optical sensors on remote platforms.

Deliverables (state clearly what products the WG will generate. Should relate to the terms of reference. Max 250 words). A workshop is not a deliverable. Please note that SCOR prefers that publications be in open-access journals.

(1) Review paper prioritizing research to fill identified knowledge gaps
(2) Publication on inter-calibration of currently used optical devices
(3) Sensitivity analysis of how good optical measurements translate into real fluxes
(4) Framework of how to convert optical measurements into export fluxes and how to cope with large data sets
(5) Data synthesis showing spatial and temporal patterns of particle export globally (high-impact publication)
(6) Development of software examples and codes, placed on a public repository such as GitHub
(7) Deposition of optical particle data in a common database that can be actively added to as new data is collected

Table 1. Time line of activities related to Terms of Reference

TOR		2016				2017				2018				2019			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	Meetings																
1	Review paper																
2	Inter-calibration efforts																
2.1	Fieldwork/cruises		40°N				20°S		54°S								
2.2	Publication & recommendation																
3	Key parameters for conversion																
4	Improve algorithms																
5	Tackling large data sets																
6	Code repository																
7	Database																
8	Framework																

Capacity Building (How will this WG build long-lasting capacity for practicing and understanding this area of marine science globally. Max 500 words)

Only a few nations use optical devices to measure in situ particles, a fact which is reflected in the composition of the list of proposed Full Members. We hope that the outcomes of this working group will highlight the benefits of optical measurements and encourage both collaboration as well as increased investment into their application, which may be especially attractive as optical devices are becoming increasingly more affordable. To realize these goals, the working group will seek funding to organize a summer school/training course on use of optical particle counters and how to access and analysis data from these instruments. The group will also develop and release example codes (e.g. in R and Matlab) on a public repository (such as GitHub) thereby allowing other researchers access to the codes for their own research. The group will also encourage students from developing countries to apply for the POGO-SCOR Fellowship Program for Operational Oceanography to transfer technology to developing countries.

We will further recommend standardized data documentation (i.e. units, etc.) and encourage submission of data on optical particles to a common database. We would encourage that every deployment of an optical instrument would be registered, so that even if the data is not available, details of the deployment are recorded to facilitate data sharing, data synthesis and collaboration.

The database will be supported by the British Oceanographic Data Centre (BODC). BODC is a UK national facility for looking after and distributing data concerning the marine environment. BODC has 26 years' experience in making high-quality data readily available to UK research scientists in academia, government and industry. They play an active role in the international exchange and management of oceanographic data, sitting on panels such as the International Oceanographic Data and Information Exchange (IODE). BODC will contribute to the working group by

- advising on best data practices and help formulate metadata standards to facilitate the collation of data into a database and its re-use in the wider scientific community, ensuring knowledge exchange. This will not only ensure the longevity of these important and valuable data but will help make them interoperable with other knowledge bases.
- using their experience of working on a wide range of national and international projects to help develop a suitable data policy.
- using their expertise in data-basing to develop a central inventory of deployments and will make data accessible through a central repository, hosted at BODC.

Working Group composition (as table). Divide by Full Members (10 people) and Associate Members, taking note of scientific discipline spread, geographical spread, and gender balance. (max. 500 words)

Full Members (no more than 10, please identify chair(s))

Name	Gender	Place of work	Expertise relevant to proposal
1 Sari Giering (chair)	F	United Kingdom	Biological carbon pump, particle export measurements using sediment traps and Marine Snow Catcher, measuring optical properties of particle characteristics
2 Klas Ove Möller	M	Germany	Video Plankton Recorder (VPR), expertise in automatic particle recognition and characterization from photos, large volume data acquisition
3 Sünnje Basedow	F	Norway	Laser Optical Plankton Counter (LOPC), expertise in particle recognition from transparency and size, size spectra, large data acquisition
4 Lionel Guidi	M	France	Underwater Video Profiler (UVP), expertise in automatic particle recognition and characterization from images, large volume data acquisition and analysis
5 Morten Iversen	M	Germany	In situ and ex situ photogrammetry of particles, connecting optical properties of particle characteristics
6 Andrew McDonnell	M	USA	Marine particle dynamics, in situ imaging of particles and zooplankton
7 Adrian Burd	M	USA	Theoretical modelling of particle dynamics
8 Catarina R Marcolin	F	Brazil	Automatic particle recognition LOPC and Zooscan, size spectra, large data acquisition and analysis
9 Sandy Thomalla	F	South Africa	Linking Southern Ocean optical property measurements and biogeochemistry to characterize plankton community and particle export
10 Tom Trull	M	Australia	Southern Ocean particle flux measurements, In situ measurement of particle sinking rates, use of gel traps to collect and characterize sinking particles, deployment and interpretation of optical sensor equipped moorings and Bio-Argo profiling floats.

Associate Member (no more than 10)

Name	Gender	Place of work	Expertise relevant to proposal
1 Emma Cavan	F	United Kingdom	Observations of dynamics of slow and fast sinking particles, correlation between particle images and sinking speed
2 Uta Passow	F	USA	Combination of lab-based experiments, mesocosm studies and field work to better understand particle dynamics and processes
3 George Jackson	M	USA	Modelling coagulation processes and sedimentation in marine ecosystems. Analyzing particle distribution data taken with multiple instruments. Comparing observations of particle size distribution with model predictions.
4 Nathan Briggs	M	France	Use of backscatter and fluorescence data to estimate large particle concentration, chlorophyll content, and export, esp. from autonomous platforms.
5 Dhugal Lindsay	M	Japan	In situ imaging, trophic level interaction
6 Lou Darroch	F	United Kingdom	Data management, collating data from research cruises and physical data repositories, standardising metadata from in-situ marine sensor networks

Working Group contributions (max. 500 words)

Detail for each Full Member (max. 2 sentences per member) why she/he is being proposed as a Full Member of the Working Group, what is her/his unique contribution?

Sari Giering (Researcher at the National Oceanography Centre, Southampton, UK):

Sari is a marine biogeochemist with research focus in carbon export, zooplankton ecology and particle dynamics. She has extensive expertise in using a combination of field measurements, models and data synthesis to better constrain the ocean carbon cycle.

Morten Iversen (Head of Helmholtz Young Investigator Group SeaPump at the Alfred Wegner Institute, Germany):

Morten's research focuses on understanding how food web composition influences particle export dynamics, specifically how particle size and composition determine sinking speed and particle remineralization. His group is developing several new camera systems and new in situ methods to collect intact marine particles.

Andrew McDonnell (Associate Professor at the University of Alaska Fairbanks, USA):

Andrew’s research focuses on assessing the biogeochemical role of various particle processes such as particle formation, sinking, lateral transport and remineralization. He uses a wide range of laboratory and field methods including sediment traps, in situ photography and particle incubations.

Adrian Burd (Associate Professor at the University of Georgia, USA):

Burd’s research focuses on mathematical and computer modeling of marine particles and their transformations relevant to biogeochemical cycling. His work has shown how particle aggregation and disaggregation are important for interpreting particle measurements and in understanding and predicting export flux, biogeochemical cycles, and trace metal cycling in the oceans.

Klas Ove Möller (Researcher at the University of Hamburg, Germany):

Klas’ expertise is in optical sampling methods (e.g. Video Plankton Recorder) and automatic image classification. He further looks at biological and physical forcing on plankton and particle distribution patterns from small- to mesoscale as well as patchiness structures.

Sünnje Basedow (Researcher at the University of Nordland, Norway):

Sünnje uses the laser optical plankton counter (LOPC) to look at spatial distributions and size spectra of zooplankton and particles. She has compared the LOPC to the VPR and Multinet for intercalibration of instruments and currently focuses on calculating energy flow and trophic linkages within the pelagic community based on size spectrum theories.

Lionel Guidi (Researcher at Laboratoire d'Océanographie de Villefranche sur Mer, France):

Lionel’s expertise is optical sampling measurements (especially the Underwater Vision Profiler, UVP), automatic particle recognition, large data compilation and analysis, and conversion of imaging data into flux estimates. Recent efforts included a global synthesis of particle size distribution and related estimate flux profiles as calculated from the UVP.

Catarina Marcolin (Researcher at University of São Paulo, Brazil):

Catarina uses optical systems such as the LOPC and ZooScan to automatically detect and measure plankton and particles in situ and ex situ. Her expertise includes coding for large data set analysis.

Sandy Thomalla (Senior Scientist at Southern Ocean Carbon and Climate Observatory, South Africa):

Sandy's research focuses on linking optical property measurements (scattering, absorption, attenuation) with the biogeochemistry (species composition, carbon content, size structure, photophysiology) in order to optically characterize the plankton community and predict carbon export potential. She further uses bio-optics floats with upward facing transmissometers to estimates particle flux.

Tom Trull (Professor of Marine Biogeochemistry at the Antarctic Climate and Ecosystems Cooperative Research Centre University of Tasmania, and Senior Principal Research Scientist CSIRO Oceans and Atmosphere Flagship Hobart, Australia)

Tom is an expert in Southern Ocean particle flux measurements, including in situ measurement of particle sinking rates, use of gel traps to collect and characterize sinking particles, deployment and interpretation of optical sensor equipped moorings and Bio-Argo profiling floats. He further aims to expand the global use of biogeochemical and bio-optical sensors on Argo floats to measure ocean ecosystem productivity and export.

Relationship to other international programs and SCOR Working groups (max. 500 words)

To our knowledge the only SCOR working group that focused on particle export was WG116 'Sediment Trap and ^{234}Th Methods for Carbon Export Flux Determination' (approved 1999). As outlined above, the development of optical sensors would complement sediment-trap-based export estimates and help to understand the biological carbon pump. This working group would further complement WG134 'The Microbial Carbon Pump in the Ocean' (approved 2008) in the effort of understanding the ocean carbon cycle.

Key References (max. 500 words)

Davis CS, SM Gallager, MS Berman, LR Haury & JR Strickler (1992) The Video Plankton Recorder (VPR): Design and initial results. Archiv für Hydrobiologie–Beiheft Ergebnisse der Limnologie 36:67-81.

Gorsky G, C Aldorf, M Kage, M Picheral, J Garcia & J Favole (1992) Vertical distribution of suspended aggregates determined by a new Underwater Video Profiler. Annales de l’Institut Oceanographique de Paris 68:13-23.

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Kwon EY, F Primeau & JL Sarmiento (2009) The impact of remineralization depth on the air–sea carbon balance. Nature Geoscience 2:630-635.

Parekh P, MJ Follows, S Dutkiewicz & T Ito (2006) Physical and biological regulation of the soft tissue carbon pump. Paleoceanography 21:PA3001.

Appendix

For each Full Member, indicate 5 key publications related to the proposal.

Basedow:

Basedow SL, KS Tande, MF Norrbin & SA Krisitiansen (2013) Capturing quantitative zooplankton information in sea: performance test of laser optical plankton counter and video plankton recorder in a *Calanus finmarchicus* dominated summer situation. Progress in Oceanography 108:72-80.

Basedow SL, KS Tande & M Zhou (2010) Biovolume spectrum theories applied: spatial patterns of trophic levels within a mesozooplankton community at the polar front. Journal of Plankton Research 32:1105-1119.

Gaardsted F, KS Tanke & **SL Basedow** (2010) Measuring copepod abundance in deep-water winter habitats in the NE Norwegian Sea: intercomparison of results from laser optical plankton counter and multinet. Fisheries Oceanography 19:480-492.

Basedow SL, M Zhou & KS Tande (2014) Secondary production at the polar front, Barents Sea, August 2007. Journal of Marine Systems 130:147-159.

Trudnowska E, **SL Basedow**, & K Blachowiak-Samolyk (2014) Mid-summer mesozooplankton biomasss, its size distribution, and estimated production within a glacial Arctic fjord (Hornsund, Svalbard). Journal of Marine Systems 137:55-66.

Burd:

Jackson GA & **AB Burd** (2015) Simulating aggregate dynamics in ocean biogeochemical models. Progress in Oceanography 133:55-65.

Burd AB (2013) Modeling particle aggregation using size class and size spectrum approaches. Journal of Geophysical Research Oceans 118:3431-3443.

Burd AB, DA Hansell, DK Steinberg, TR Anderson, J Arístegui, F Baltar, SR Beaupré, KO Buesseler, F DeHairs, GA Jackson, DC Kadko, R Koppelmann, RS Lampitt, T Nagata, T Reinthaler, C Robinson, BH Robison, C Tamburini, T Tanaka (2010) Assessing the Apparent Imbalance Between Geochemical and Biochemical Indicators of Meso- and Bathypelagic Biological Activity: What the @$#! is wrong with present calculations of carbon budgets? Deep-Sea Research II 57:1557-1572.

Burd AB & GA Jackson (2009) Particle aggregation. Annual Reviews of Marine Science 1:65-90.

Burd AB, GA Jackson & SB Moran (2007) The role of the particle size spectrum in estimating POC fluxes from ^{234}Th/^{238}U disequilibrium. Deep-Sea Research I 54:897-918.

Giering:

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SLC Giering, R Sanders, AP Martin, Möller KO, C Lindemann, C Daniels, D Mayor & M St. John (in revision) High export before the onset of the spring bloom. Biogeosciences.

Guidi:

Boss E, **L Guidi**, MJ Richardson, L Stemmann, W Gardner, JKB Bishop, RF Anderson & RM Sherrell (2015) Optical techniques for remote and in-situ characterization of particles pertinent to GEOTRACES. Progress in Oceanography 133:43-54.

Guidi L, PHR Calil, S Duhamel, KM Björkman, SC Doney, GA Jackson, B Li, MJ Church, S Tozzi, ZS Kolber, KJ Richards, AA Fong, RM Letelier, G Gorsky, L Stemmann & DM Karl (2012) Does eddy-eddy interaction control surface phytoplankton distribution and carbon export in the North Pacific Subtropical Gyre? Journal of. Geophysical Research 117(G2):G02024.

Picheral M, **L Guidi**, L Stemmann, DM Karl, G Iddaoud & G. Gorsky (2010) The Underwater Vision Profiler 5: An advanced instrument for high spatial resolution studies of particle size spectra and zooplankton. Limnology and Oceanography Methods 8:462–473.

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Iversen:

Iversen MH, Robert ML (2015) Ballasting effects of smectite on aggregate formation and export from a natural plankton community. Marine Chemistry doi:10.1016/j.marchem.2015.04.009.

Nowald N*, **Iversen MH***, Fischer G, Ratmeyer V & Wefer G (2014) Times series of in-situ particle properties and sediment trap fluxes in the coastal upwelling filament off Cape Blanc, Mauritania. Progress in Oceanography doi:10.1016/j.pocean.2014.12.015. *equal contribution.

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Marcolin:

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McDonnell:

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Möller:

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Möller KO, M St John, A Temming, J Floeter, AF Sell, JP Herrmann & C Möllmann (2012) Marine snow, zooplankton and thin layers: indications of a trophic link from small-scale sampling with the Video Plankton Recorder. Marine Ecology Progress Series 468:57-69.

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Thomalla:

Thomalla SJ, MF Racault, S Swart & PMS Monteiro (2015) High-resolution view of the spring bloom initiation and net community production in the Subantarctic Southern Ocean using glider data. ICES Journal of Marine Science doi: 10.1093/icesjms/fsv105.

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Trull:

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