AMT Annual Report 2022

The Atlantic Meridional Transect (AMT)

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1. Ongoing activities, in line with the IMBeR Grand and Innovation Challenges

(Among other uses, information will be used to update the IMBeR Annual Report to SCOR)

1.a. Grand Challenge I

Understanding and quantifying the state and variability of marine ecosystems - with focus on Research Objectives 1 to 3:

Research Objective 1*. Evaluate and predict the cumulative effect of multiple stressors*
Research Objective 2*. Integration of climate change and climate variability*
Research Objective 3*. Impacts on society – preparation for a changed future*

AMT has enabled extensive investigation of biodiversity and biogeochemical processes and provided the first Atlantic Ocean basin scale measurements of: Prochlorococcus and Synechococcus *abundance (Zubkov et al., 2000); plankton net community production (Serret et al., 2001), respiration (Robinson et al., 2002), nitrification (Clark et al. 2007), mixotrophy (Hartman et al., 2012) and distribution of calcifying coccolithophores (Balch et al 2019). By engagement with other global scale programmes AMT contributes to understanding of global metagenome diversity (Larkin et al 2021).*

AMT research has contributed to the quantitative understanding of key interactions and feedbacks between the ocean and the atmosphere *which have included the role of ammonium in climate control (Jickells et al., 2003); enabled global prediction and model-validation of climate-relevant dimethylsulphide (Bell et al., 2006); provided first ocean basin budget of the global marine sources of atmospheric N2O and CH4 respectively (Forster et al., 2009) and enabled estimates of pCO2 in seawater from net community production measurements (Ford et al 2021).*

AMT observations are a key component of the monitoring and detection of long-term changes in the ocean, *driven by both natural variability and anthropogenic change. Kitidis et al. (2017) quantify changes in surface ocean CO2 and the carbonate system revealing a basin wide ocean acidification. AMT inputs to the global carbon project and annual carbon budget assessment (https://www.globalcarbonproject.org/). Long-term deployments of ocean moorings have revealed the contribution of atmospheric dust to deep ocean carbon sequestration (Pabortsava et al 2017). Whilst the integration of AMT data with satellites observations and biogeochemical modelling has characterised spatial and temporal variability of dominant oceanic provinces (Smyth et al 2017).*

Engagement with other organisations *including NASA and ESA has been key to the origin and continuation of AMT. Early efforts provided first validation and calibration of SeaWiFS generation* *satellites (e.g. Aiken & Hooker 1997), recent highlights have included ESA supported projects (www.amt4oceansatflux.org) which continue this work for the current Sentinel Satellites (Tilstone et al 2021), enabling greater characterisation of ocean processes (Lange et al 2020) and ocean-atmosphere exchange of climatically important gases (Holding et al 2019).*

Cited references can be found at: Publications (amt-uk.org)

1.b. Grand Challenge II

Improving scenarios, predictions and projections of future ocean-human systems at multiple scales - with focus on Research Objectives 4 to 6:

***Research Objective 4**. Development of integrated data systems and approaches for predictions and projections*
***Research Objective 5**. Development of predictive models and projections for use at regional scales*
***Research Objective 6**. Development of alternative scenarios to bridge the gap between physical climate sciences and humanities*

***Rapid public availability of AMT data has enabled sophisticated model and machine learning outputs**: the use of neural networks has linked AMT and remote sensing observations to project accurate fields of pCO2 across the sparsely sampled South Atlantic (Ford et al 2022); AMT observations have validated the use of optical data in the improvement of biogeochemical models to further mechanistic understanding of phytoplankton diversity (Dutkiewicz et al 2015, 2021). Data assimilation methods are utilised to improve ecosystem simulations (Ciavatta et al 2018) and deep learning methods deployed to improve the resolution and accuracy of chlorophyll concentrations from high frequency optical measurements (Graban et al 2020).*

Cited references can be found at: Publications (amt-uk.org)

2. Selected highlights

2.a. Selected scientific highlights since last report (1-5)

Last report was submitted to SSC meeting, May/June 2021

As an ocean-going project AMT has suffered greatly due to ship unavailability since 2019 (COVID related plus loss of RRS James Clark Ross/current unavailability of RRS Sir David Attenborough. Planned for annual cruises). COVID has also impacted heavily on meeting attendance and outreach activities. Efforts in this reporting period have therefore focussed on preparation and publication of papers. Three listed below include 1) an ongoing collaboration with a US group revealed diel variability in algal nutrient signatures which sheds new light on the impact of ocean warming on phytoplankton growth; 2) collaboration with University of Lisbon enabled a comparative validation of observational and remote sensing measures of phytoplankton indices to establish a relationship between size class and functional group; 3) Early career researcher/ PhD student use of neural networks has linked AMT and remote sensing observations to project accurate fields of pCO2 across the sparsely sampled South Atlantic. Further to these publications the AMT community is currently working towards the publication of a special issue of Frontiers in Marine Science with deadline for manuscript submission of September 2022.

Garcia, N. S., Talmy, D., Fu, W.-W., Larkin, A. A., Lee, J., & Martiny, A. C. (2022). The diel cycle of surface ocean elemental stoichiometry has implications for ocean productivity. Global Biogeochemical Cycles, 36, e2021GB007092. https://doi.org/10.1029/2021GB007092

Brotas Vanda, Tarran Glen A., Veloso Vera, Brewin Robert J. W., Woodward E. Malcolm S., Airs Ruth, Beltran Carolina, Ferreira Afonso, Groom Steve B. (2022). Complementary Approaches to Assess Phytoplankton Groups and Size Classes on a Long Transect in the Atlantic Ocean. Frontiers in Marine Science, 8. https://doi.org/10.3389/fmars.2021.682621

Ford, D. J., Tilstone, G. H., Shutler, J. D., and Kitidis, V.: Derivation of seawater pCO_2 from net community production identifies the South Atlantic Ocean as a CO_2 source, Biogeosciences, 19, 93–115, https://doi.org/10.5194/bg-19-93-2022, 2022.

Further, AMT scientists have contributed the following:

1. ***Assessing the performance of the European Space Agency's Sentinel-3 mission.***

Due to their inaccessibility, the oligotrophic open-ocean gyres are under-sampled and therefore under-represented in global in situ data sets. The Atlantic Meridional Transect fills the sampling gap in the Atlantic Ocean. On AMT, PML is working closely with the European Space Agency (ESA) and the Mission Performance Centre (EUMETSAT), to evaluate the performance of range of satellite instruments launched under the Sentinel mission. In-water underway spectrophotometric measurements of Chlorophyll-a have been made on AMT26 to 29 at very high resolution to assess the performance of the ESA's Sentinel-3(S-3) Ocean and Land Colour Instrument (OLCI) and NASA Ocean Colour products. Three Chl a algorithms for S-3 OLCI were compared, including the recently released processing baseline (pb) 3. An alternative algorithm (POLYMER), that models both atmosphere and water reflectance to retrieve Chl a, performed best. The findings have been published in Tilstone et al. (2021). In parallel, long-track infrared Sea surface temperature Autonomous Radiometer (ISAR) and c-band radar measurements have also been made to assess the accuracy of the ESA S-3 Sea-Land Temperature Sensor and Sentinel-1 Sea Surface Roughness. The AMT provides a vital platform for ESA to evaluate the performance of multi-mission instruments and products in remote locations of the Atlantic.

2. ***Wind speed and mesoscale features drive net autotrophy in the South Atlantic Ocean.***

Measurements of Chlorophyll a, net primary production (NPP) and net community production (NCP) made on AMT since 2002 were used to evaluate the performance of ocean colour algorithms for these parameters using the NASA satellite MODIS-Aqua in the South Atlantic Ocean. The uncertainties in both the in situ measurements and satellite products were considered to determine which products are the most accurate for this region. A 16 year time series (2002 to 2018) of these parameters using MODIS-Aqua data was then used to assess climate and environmental drivers of NCP across the Atlantic basin. Positive correlations between wind speed and NCP anomalies were observed in the central South Atlantic Gyre and the Benguela Upwelling, indicating that autotrophic conditions are fuelled by local wind-induced nutrient inputs to the mixed layer. Sea Level Height Anomalies, as an indicator of mesoscale eddies, were negatively correlated with NCP anomalies offshore of the Benguela upwelling, in the Agulhas bank and Brazil-Malvinas confluence, suggesting autotrophic conditions are driven by mesoscale features in these regions. This study sheds new light on the large scale drivers of NCP over the south Atlantic Basin. The findings have been published in Ford et al. (2021).

3. ***New techniques deployed on AMT to quantify the variability in CO2 flux and ocean acidification in the Atlantic Ocean.***

Under the European Space Agency project AMT4OceanSatFlux on board the Atlantic Meridional Transect, a new technique, deploying cutting edge instrumentation to directly measure CO_2 flux, has been undertaken on AMT28 and 29. The technique uses an eddy covariance technique, where high frequency measurements of wind velocity are used to determine the vertical flux of gases, These measurements are in turn being used to assess the performance of state-of-the-art satellite estimates of CO_2 flux. These satellite estimates of CO_2 flux provide a global perspective of ocean sources and sinks of CO_2 from satellite data, to address large scale issues and scientific questions on the effects of climate change. Long-term absorption of atmospheric CO_2 is causing a gradual decrease in seawater pH, which is having an adverse effect on many important marine organisms. AMT4OceanSatFlux has developed and evaluated algorithms that estimate pH, CO_2 concentrations in the water and aragonite saturation state to identify areas of the ocean that are most at risk from acidification.

2.b. Publications since last report

Please add all publications since last report to the table below (see notes for details on "Class" and "Activity" fields).

***Publication** with DOI*	***Class 1, 2, 3***	***Activity****
Clark, D.R., A.P. Rees, C.M. Ferrera, L. Al-Moosawi, P.J. Somerfield, C. Harris, G.D. Quartly, et al. "Nitrite Regeneration in the Oligotrophic Atlantic Ocean." Biogeosciences 19 (2022): 1355-76. https://doi.org/10.5194/bg-19-1355-2022.	*3*	
Ford, D., G. Tilstone, J.D. Shutler, and V Kitidis. "Derivation of Seawater Pco2 from Net Community Production Identifies the South Atlantic Ocean as a Co2 Source." Biogeosciences 19 (2022): 93-115. https://doi.org/10.5194/bg-19-93-2022.	*3*	
Garcia, N.S., D. Talmy, W.-W. Fu, A.A. Larkin, J. Lee, and A.C. Martiny. "The Diel Cycle of Surface Ocean Elemental Stoichiometry Has Implications for Ocean Productivity." Global Biogeochemical Cycles 36, no. 3 (2022): e2021GB007092. https://doi.org/10.1029/2021GB007092.	*3*	
Brewin, R.J.W., W. Wimmer, P. Bresnahan, T. Cyronak, A.J. Andersson, and G. Dall'Olmo. "Comparison of a Smartfin with an Infrared Sea Surface Temperature Radiometer in the Atlantic Ocean." Remote Sensing 13, no. 5 (2021): 841. https://doi.org/10.3390/rs13050841.	*3*	
Tilstone, G., S. Pardo, G. Dall'Olmo, R.J.W. Brewin, F. Nencioli, D. Dessailly, E. Kwiatkowska, T. Casal, and C.J. Donlon. "Performance of Ocean Colour Chlorophyll a Algorithms for Sentinel-3 Olci, Modis-Aqua and Suomi-Viirs in Open-Ocean Waters of the Atlantic." Remote Sensing of	*3*	

the Environment 260 (2021): art:112444. https://doi.org/10.1016/j.rse.2021.112444.		
Smyth, T.J., G.A. Tarran, and S. Sathyendranath. "Sub-Micron Picoplankton Shape, Orientation and Internal Structure Combine to Preferentially Amplify the Forward Scatter." Optics Express 29, no. 2 (2021): 2014-24. https://doi.org/10.1364/OE.413576.	*3*	
Mekkes, L., G. Sepúlveda-Rodríguez, G. Bielkinaitė, D. Wall-Palmer, G.-J.A. Brummer, L.K. Dämmer, J. Huisman, et al. "Effects of Ocean Acidification on Calcification of the Sub-Antarctic Pteropod Limacina Retroversa." Frontiers in Marine Science 8 (2021): art:157. https://doi.org/10.3389/fmars.2021.581432.	*3*	
Larkin, A.A., C.A. Garcia, M.L. Brock, J.A. Lee, N. Garcia, L.J. Ustick, L. Barbero, et al. "High Spatial Resolution Global Ocean Metagenomes from Bio-Go-Ship Repeat Hydrography Transects." Scientific Data (2021). https://doi.org/10.1101/2020.09.06.285056.	*3*	
Ford, D., G. Tilstone, J.D. Shutler, V Kitidis, P. Lobanova, J. Schwarz, A.J. Poulton, et al. "Wind Speed and Mesoscale Features Drive Net Autotrophy in the South Atlantic Ocean." Remote Sensing of the Environment 260 (2021): art:112435. https://doi.org/10.1016/j.rse.2021.112435.	*3*	
[Add more rows if needed]		

**If appropriate, please list the IMBeR activity through / by / from / during which the publication arose*

*******Notes on publications*******

Publications are logged in the IMBeR Zotero library which is publicly accessible online –

Publications since 2019 | Publications prior to 2019

Publications are categorised by “Class” and linked to “Activities”:

Class 1 publications are specifically generated through/by/from/during ***IMBeR activities*** - for example, arising from IMBIZOs and IMBeR conferences such as the IMBeR open science meeting and the IMBeR West Pacific symposia and from the activities of the working groups, regional programmes and the SPIS scoping teams.

Class 2 publications are on topics relevant to the IMBeR Science Plan that benefitted from some interaction with IMBeR or ***IMBeR activities***, for example by IMBeR symposium attendees, past and present SSC members, working group, regional programme and endorsed project members, or national contacts.

Class 3 publications are on topics relevant to the IMBeR Science Plan but for which there is no direct link to or benefit from an IMBeR activity. These might include publications by SSC members, working group, regional programme or endorsed project members or members of the IMBeR international community that were written as part of the normal scientific activity of the authors and would have occurred irrespective of IMBeR's existence. You can report Class 3 publications, but they will no longer be logged in the IMBeR database.

[See "What is an IMBeR publication?" for further information]

Why list 'Class' and 'Activity'? This helps us to declare authentically which publications IMBeR has helped to generate, and it makes it easier for us to demonstrate the value of the Regional Programmes, the Working Groups, and IMBeR in general, and it helps us to justify support for IMBeR activities when we can list tangible outputs.

3. International collaboration and links

Since 2012, there have been >239,000 downloads of AMT data from BODC by users in 34 countries which include 168 unique users in the UK. AMT provides an inclusive platform for multi-disciplinary ocean research. AMT's 29 research cruises have involved 289 sea-going scientists from 77 institutes representing 29 countries, resulting in >350 refereed papers.

4. Planned activities

4.a. Upcoming papers (Community-Position-Review-etc)

The AMT community is currently working towards the publication of a special issue of Frontiers in Marine Science with deadline for manuscript submission of September 2022.