GESAMP
Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

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Agenda item 4

PLANNING OF GESAMP ACTIVITIES: ATMOSPHERIC INPUT OF CHEMICALS TO THE OCEANS

Report of the Co-Chairs of Working Group 38

History, early meetings and their results

1 Working Group 38 was first formed in 2008 because of growing concern about the impact of atmospheric deposition of both natural and anthropogenic substances on ocean chemistry, biology, and biogeochemistry as well as climate. It has held meetings at the University of Arizona, Tucson, Arizona, United States, in 2008, at IMO in London in 2010, in Malta in 2011, and at the University of East Anglia, Norwich, UK in 2013 and 2017. Sponsors of those WG 38 efforts have included WMO, IMO, SCOR, SIDA, the European Commission Joint Research Centre, the University of Arizona, the International Environment Institute at the University of Malta, the University of East Anglia, and the US National Science Foundation. Following the initial terms of reference and the meetings through 2011, five scientific papers were published in the peer-reviewed scientific literature. These were as follows:

[1] Okin, G., A. R. Baker, I. Tegen, N. M. Mahowald, F. J. Dentener, R A. Duce, et al., "Impacts of atmospheric nutrient deposition on marine productivity: roles of nitrogen, phosphorus, and iron, Global Biogeochemical Cycles, 25, GB2022, doi:10.1029/2010GB003858, (2011).

[2] Hunter, K.A., P. S. Liss, V. Surapipith, F. Dentener, R. A. Duce, M. Kanakidou, et al., "Impacts of anthropogenic SO_x, NO_x and NH_3 on acidification of coastal waters and shipping lanes", Geophysical Research Letters, 38, L13602, doi:10.1029/2011GL047720 (2011).

[3] Kanakidou, M., Kanakidou, M., R. Duce, J. Prospero, A. Baker, et al., "Atmospheric fluxes of organic N and P to the ocean", Global Biogeochemical Cycles, GB3026, doi:10.1029/2011GB004277 (2012).

[4] Schulz, M., J. M. Prospero, A. R. Baker, F. Dentener, L. Ickes, P. S. Liss et al., "The atmospheric transport and deposition of mineral dust to the ocean - Implications for research needs", Environmental Science and Technology, 46, doi:10.1021/es30073ul, 10,390-10,404 (2012).

[5] Hagens, M., K. A. Hunter, Peter S. Liss, and Jack J. Middelburg, "Biogeochemical context impacts seawater pH changes resulting from atmospheric sulfur and nitrogen deposition", Geophysical Research Letters, 41, doi:10.1002/2013GL058796 (2014).

Nitrogen workshop in Norwich, United Kingdom, 2013

2 New Terms of Reference for continued work of GESAMP WG 38 were approved in 2011 to address issues related to the impact of the atmospheric deposition of anthropogenic nitrogen to

the ocean. A highly successful workshop on "The Atmospheric Deposition of Nitrogen and its Impact on Marine Biogeochemistry" was held by WG 38 at the University of East Anglia in February, 2013 to address the new terms of reference. 23 scientists participated in the workshop. As a result of the Norwich nitrogen workshop several papers have been published in the peer reviewed scientific literature on this nitrogen issue. These include:

[6] Kim, T.-W., K. Lee, R.A. Duce and P.S. Liss, "Impact of atmospheric nitrogen deposition on phytoplankton productivity in the South China Sea", Geophysical Research Letters, 41, 3156-3162, doi: 10.1002/2014GL059665 (2014).

[7] Somes, C., A. Landolfi1, W. Koeve1, and A. Oschlies, "Limited impact of atmospheric nitrogen deposition on marine productivity due to biogeochemical feedbacks in a global ocean model, Geophysical Research Letters, 43, 4500–4509, doi:10.1002/2016GL068335 (2016).

[8] Kanakidou, M., S. Myriokefalitakis, N. Daskalakas, G. Fanourgakis, A. Nenes, A.R. Baker, K.Tsigaridis, and N. Mihalopoulos, "Past, Present, and Future Atmospheric Nitrogen Deposition", Journal of the Atmospheric Sciences, 73, 2039-2047, doi:10.1175/JAS-D-15-0278.1. (2016).

[9] Sharples, J., J. J. Middelburg, K. Fennel, and T. D. Jickells, "What proportion of riverine nutrients reaches the open ocean", Global Biogeochemical Cycles, 31, 39–58, doi:10.1002/2016GB005483. (2017).

[10] Jickells, T.D., E. Buitenhuis, K. Altieri, A.R. Baker, et al., "A re-evaluation of the magnitude and impacts of anthropogenic atmospheric nitrogen inputs on the ocean", Biogeochemical Cycles, 31, 289–305, doi:10.1002/2016GB005586. (2017).

[11] Baker, A.R., M. Kanakidou, K. E. Altieri, et al., "Observation- and model-based estimates of particulate dry nitrogen deposition to the oceans", Atmospheric Chemistry and Physics, 17, 8189-8210, (2017).

One final nitrogen paper will be submitted this fall:

[12] Suntharalingam, P., L. M. Zamora, H.W. Bange, S. Bikkina, E. Buitenhuis, A. Landolfi, L. Resplandy, M. M. Sarin, S. Seitzinger and A. Singh, "Increasing inputs of anthropogenic nitrogen to the Northern Indian Ocean and impacts on oceanic N_2O fluxes: the need for a nitrogen observation and modelling network", To be submitted to Deep Sea Research II, special issue on the Second Indian Ocean Expedition

3 Following the completion of the publication of the papers resulting from the 2013 workshop on the impacts of atmospheric nitrogen deposition to the ocean, WG 38 prepared a synthesis of the results from the scientific papers derived from that workshop. That report was reviewed by GESAMP and published by WMO in early 2018 as GESAMP Reports and Studies No. 97, The Magnitude and Impacts of Anthropogenic Atmospheric Nitrogen Inputs to the Ocean.

The primary conclusions of R&S 97 were as follows:

3.1 This synthesis by GESAMP WG 38 provides new current best estimates of nitrogen inputs to the ocean from the atmosphere (39 TgN y^{-1}), and for context synthesises comparable estimates of inputs from rivers (34 TgN y^{-1}) and natural biological nitrogen fixation (164 TgN y^{-1}). Most of the atmospheric nitrogen input reaches the open ocean beyond the shelf break, while a substantial part of the riverine input is trapped on the shelf. Both the riverine and atmospheric nitrogen inputs have been substantially increased by human activity, with the atmosphere now the main vehicle by which anthropogenic nitrogen reaches the open ocean.

The atmospheric input of nitrogen is estimated to now be almost 4 times that in 1850, and even in 1850 conditions were not pristine.

3.2 Atmospheric deposition of nitrogen to the oceans involves several distinct chemical components, each of approximately the same magnitude; oxidised nitrogen, primarily nitrate aerosol and nitric acid; reduced nitrogen, primarily ammonium aerosol and ammonia; and a poorly characterised organic nitrogen component. Identification of sources is important for the effective management of nitrogen inputs to the ocean. The main anthropogenic source of oxidised nitrogen is fossil fuel combustion on land plus an increasingly important source from fuel combustion on ships, while for reduced nitrogen the primary anthropogenic emission source is from intensive agriculture. There is also an important but poorly understood natural recycling of ammonia and organic nitrogen between the atmosphere and the oceans. The quantification of the net magnitude of atmospheric nitrogen inputs to the ocean and their impact is sensitive to the uncertainties in the magnitude of this recycling.

3.3 Atmospheric nitrogen emissions come predominantly from areas of high fossil fuel combustion and high rates of intensive agriculture. The largest emission sources are in North America, Europe, India and South East Asia. Models based on future emission scenarios suggest that total nitrogen inputs to the oceans will change little between now and 2050, but that emissions are likely to increase over southern Asia and decline over North America and Europe. The largest inputs of nitrogen to the oceans occur downwind of these large emission sources over the North Atlantic, Northern Indian and north-west Pacific Oceans. Impacts of this atmospheric deposition on the marine environment have been previously suggested for the north-west Pacific, and impacts in this region and the northern Indian Ocean are likely to increase in the future, based on the emission scenarios considered. Such impacts may include increases in phytoplankton production, and in the north-western Indian Ocean this may lead to increases in the emissions of the greenhouse gas N_2O from the low oxygen waters that occur naturally at depth in this region.

3.4 More generally the impact of nitrogen deposition to the ocean will be an increase in primary production in regions that are currently nitrogen limited, which include the surface waters of tropical ocean gyres. The increase in ocean production at the present day compared to 1850 levels is estimated to be about 0.4%, with an associated increase in the ocean uptake of CO_2 of 0.15Pg C y^{-1}. This estimate is very sensitive to assumptions about feedbacks that involve atmospheric nitrogen deposition suppressing nitrogen fixation. There is also, on a longer time scale, a sensitivity to feedbacks in which increasing nitrogen inputs to the ocean increase primary production and organic matter inputs to the deep ocean, increasing denitrification and anammox and leading to increased emissions of N_2 and N_2O gas.

Current Activities of Working Group 38

4 For the fifth year in a row WG 38 organized a session on atmospheric input of chemicals to the ocean for the 2018 European Geosciences Union meeting, held in Vienna, Austria in April – “Air-sea Exchanges: Impacts on Biogeochemistry and Climate”. A number of oral and poster papers at this session were presented by a combination of WG 38 members and other scientists.

5 Tim Jickells attended the INMS International Nitrogen Management System annual meeting in Edinburgh UK 16-19 April to represent WG 38 and supported by INMS. At the meeting he informally presented the work of WG 38 to relevant leaders of INMS activity, particularly those leading initiatives in SE Asia, and he presented them with details of our synthesis report. He made clear the enthusiasm of WG 38 to work with the INMS initiatives if they felt that would be useful and we await their responses.

6 One response has been that Tim Jickells has been invited to attend and participate in the 2nd East Asia Nitrogen Conference in Tsukuba, Japan from 19 to 22 November 2018. He will be giving a keynote talk on the atmosphere/ocean aspects of the nitrogen cycle on behalf of WG 38,

and he will participate in a subsequent workshop. We hope that this effort will increase our interactions with the INMS activity.

7 WG 38 proposed the following activity to be considered for the OceanObs'19 ocean observing community conference: "Ocean observations to estimate atmospheric nutrient and trace metal inputs to the oceans". This has been adopted and will be incorporated as part of a whitepaper that is currently being prepared for a special issue of Frontiers in Marine Science in advance of the conference. Alex Baker is taking the lead on this effort by WG 38.

8 At the meeting of GESAMP 42 at IOC in Paris in September, 2015, GESAMP approved two new workshops for WG 38. These two simultaneous workshops were related to the changing acid/base character of the global atmosphere and ocean and the impact of these changes on certain air/sea chemical exchange processes. Funding was obtained for these workshops from the US National Science Foundation (through SCOR), from WMO, and from IMO. SOLAS also sponsored these workshops. The workshops took place at the University of East Anglia (UEA) in Norwich, United Kingdom from February 27 through March 2, 2017.
The topics of the two workshops were as follows:

Impact of Ocean Acidification on Fluxes of Atmospheric non-CO_2 Climate-Active Species

Changing Atmospheric Nutrient Oceanic Solubility

9 The workshops took the form of rather informal presentations from experts followed by very lengthy discussion sessions exploring multiple issues and feedbacks evident in these complex air-sea interaction issues. The invited scientists were selected for their expertise and interest in these areas, and also to provide a wide spectrum of expertise from modellers to experimentalists. 34 scientists from 16 countries and also from a wide range of career stages, from senior scientists through to graduate students, participated in the workshops. At the present time the following papers have been published, are in press, have been or shortly will be submitted, or are still in preparation from the workshop discussions:

Published:

[13] Kim, J.-M, K. Lee, Y.-S. Suh, and I.S. Han, "Phytoplankton do not produce carbon-rich organic matter in high CO2 oceans", Geophysical Research Letters, 45, 4189–4197. https://doi.org/10.1029/ 2017GL075865 (2018).

In Press:

[14] Kanakidou, M., S. Myriokefalitakis, and K. Tsigaridis, "Aerosols in atmospheric chemistry and biogeochemical cycles of nutrients, In press, Environmental Research Letters (2018).

Submitted:

[15] Ito, A., S. Myriokefalitakis, M. Kanakidou, N.M. Mahowald, R.S. Scanza, D.S. Hamilton, A.R. Baker, T.D. Jickells, M. Sarin, S. Bikkina, Y. Gao, R.U. Shelley, C.S. Buck, W.M. Landing, A.R. Bowie, M.M.G. Perron, C. Guieu, N. Meskhidze, M.S. Johnson, Y. Feng, J.F. Kok, A. Nenes, and R.A. Duce, "Constraints on attribution of labile iron in aerosols to combustion and mineral dust sources from observations and models", Submitted to Nature Communications, (2018).

[16] Myriokefalitakis, S., A. Ito, M. Kanakidou, A. Nenes, M. C. Krol, N. M. Mahowald, R. A. Scanza, D. S. Hamilton, M. S. Johnson, N. Meskhidze, J. F. Kok, C. Guieu, A. R. Baker, T. D. Jickells, M. Sarin, B. Srinivas, M. M. G. Perron, and R. A.

Duce,"The GESAMP atmospheric iron deposition model intercomparison study", Submitted to Biogeosciences (2018)

To Be Submitted Shortly:

[17] Hopkins, F.E., P. Suntharalingam, M. Gehlen, O. Andrews, S.D. Archer, L. Bopp, E. Buitenhuis, I. Dadou, R.A. Duce, N. Goris, T.D. Jickells, M. Johnson, F. Keng, C.S. Law, K. Lee, P.S. Liss, M. Lizott, G. Malin, C. Murrell, H. Naik, A. Rees, J. Schwinger, and P. Williamson, "Changing ocean acidity as a modulator of atmospheric biogeochemistry and climate", To be submitted to Proceedings of the National Academy of Sciences (2018).

[19] Baker, A.R., M. Sarin, R.A. Duce, T.D. Jickells, M. Kanakidou, A. Nenes, S. Myriokefalitakis, A. Ito, D. Turner, N.M. Mahowald, R. Middag, C. Guieu, Y. Gao, P. Croot, R. Shelley, and M.M.G. Perron, **"**Changing Atmospheric Acidity and the Oceanic Solubility of Nutrients**",** To be submitted to Proceedings of the National Academy of Sciences (2018).

In Preparation:

[20] Peter Croot, lead author, "Controls and impacts of atmospheric nutrient solubility in the ocean".

[21] Peter Croot, lead author, "Impacts of the episodic atmospheric deposition on ocean biogeochemistry".

[22] Steve Archer, lead author, "A synthesis of the DMS response to ocean acidification observed in mesocosm experiments".

Future Activities of Working Group 38

10 The goal of WG 38 for the next year is to complete the submission and publication of all papers resulting from the 2017 workshop at the University of East Anglia.