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

42nd session
Agenda item 4

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

Report of the Co-Chairmen of Working Group 38

History of WG 38

1 Recognition continues to grow concerning the impact of the atmospheric input of both natural and anthropogenic substances on ocean chemistry, biology, and biogeochemistry as well as climate. In the 1980s GESAMP formed a working group sponsored by WMO, UNESCO/IOC, and UNEP that developed a comprehensive review of the input of atmospheric trace species to the global ocean (GESAMP, 1989). That benchmark effort led to a scientific publication in *Global Biogeochemical Cycles* in 1991 that for more than 15 years was the state-of-the-art reference in this area, leading to over 1300 citations in the literature. That paper is now 25 years old, and a new overall look at this issue was needed.

2 For this reason Working Group 38 was formed during 2008 and it held its first meeting at the University of Arizona, Tucson, AZ, in December, 2008. Subsequent meetings were held at IMO in London in 2010, and Malta in 2011. Sponsors of those WG 38 efforts have included WMO, IMO, SCOR, SIDA, the European Commission Joint Research Centre, the University of Arizona, and the International Environment Institute at the University of Malta.

3 Following the initial terms of reference, as a result of the first working group meetings and follow-up activities five scientific papers have been published in the scientific literature. These are:

- Okin, G., A. R. Baker, I. Tegen, N. M. Mahowald, F. J. Dentener, R A. Duce, J. N. Galloway, K. Hunter, M. Kanakidou, N. Kubilay, J. M. Prospero, M. Sarin, V. Surapipith, M. Uematsu, T. Zhu, "Impacts of atmospheric nutrient deposition on marine productivity: roles of nitrogen, phosphorus, and iron", Global Biogeochemical Cycles, 25, GB2022, doi:10.1029/2010GB003858, (2011).

- Hunter, K.A., P. S. Liss, V. Surapipith, F. Dentener, R. A. Duce, M. Kanakidou, N. Kubilay,, N. Mahowald,, G. Okin,, M. Sarin,, I. Tegen, M. Uematsu, and T. Zhu, "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).

- Kanakidou, M., R. Duce, J. Prospero, A. Baker, C. Benitez-Nelson F. J. Dentener, K.A. Hunter, N. Kubilay, P. S. Liss , N. Mahowald, , G. Okin, M. Sarin, K. Tsigaridis, M. Uematsu, L.M. Zamora, and T. Zhu, "Atmospheric fluxes of organic N and P to the ocean", Global Biogeochemical Cycles, 26, GB3026,doi:10.1029/2011GB004277, (2012).

- Schulz, M., J. M. Prospero, A. R. Baker, F. Dentener, L. Ickes, P. S. Liss, N. M. Mahowald, S. Nickovic, C. Pérez García-Pando, S. Rodríguez, M. Sarin, I. Tegen, R.A. Duce, "The atmospheric transport and deposition of mineral dust to the ocean

- Implications for research needs", Environmental Science and Technology, 46, 10,390-10,404 (2012).

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

More recent activities of WG 38

4 The US National Science Foundation, through the ICSU Scientific Committee on Oceanic Research (SCOR), also has supported the newest work by WG 38. During GESAMP 39 additional terms of reference for continued work of GESAMP WG 38 were approved to address issues related to the impact of the atmospheric deposition of anthropogenic nitrogen to the ocean. As a reminder, the additional tasks added were as follows:

.1 Update the geographical estimates of anthropogenic nitrogen deposition to the global ocean made in the 2008 paper in *Science* (Duce, R.A., et al., "Impacts of atmospheric anthropogenic nitrogen on the open ocean", *Science, 320*, 893-897, 2008), which were based on data from 2005 or earlier. This would utilize newer and more geographically distributed data on anthropogenic atmospheric nitrogen concentrations and deposition over the global ocean as well as improved models of these processes and impacts;

.2 Considering issues related to Task 1 above, re-evaluate the impact of atmospheric nitrogen deposition on marine biogeochemistry, including re-estimating the amount of CO_2 that could be drawn down from the atmosphere into the ocean as a result of the increased productivity in the ocean derived from the additional anthropogenic nutrient nitrogen deposited. This would allow an update on the impact of the atmospheric nitrogen deposition on atmospheric radiative properties outlined in the 2008 *Science* paper;

.3 Provide a more reliable estimate of the impact of atmospheric anthropogenic nitrogen deposition on the production of additional nitrous oxide in the ocean and its subsequent emission to the atmosphere. This was one of the greatest uncertainties in the 2008 *Science* paper;

.4 Evaluate the extent to which anthropogenic nitrogen delivered to the coastal zone via rivers, atmospheric deposition, etc. is transported to the open ocean, in which regions this may happen, and what its impact is there. In the 2008 *Science* paper it was assumed that all nitrogen delivered to the coastal zone was sequestered there and did not reach the open ocean, but this may not be true in all locations; and

.5 Make a more detailed estimate of the input and impact of anthropogenic nitrogen in the area of the Northern Indian Ocean (Arabian Sea, Bay of Bengal) and the South China Sea - the areas that are expected to show the greatest increase of anthropogenic nitrogen deposition over the next few decades.

5 To address these new terms of reference, a highly successful workshop on The Atmospheric Deposition of Nitrogen and Its Impact on Marine Biogeochemistry was held at the University of East Anglia in Norwich, United Kingdom, from 11 to 14 February 2013. Twenty-three scientists participated in the workshop, one participating by Skype. The first day of the workshop was devoted to discussions of the five tasks identified above as the foci of the workshop. Two participants were asked to summarize the issues in each of these task areas and to lead the discussions that followed. On the basis of the task area discussions above the workshop participants broke up into sub-groups on the second through fourth days of the workshop. These sub-groups began the development of a number of different scientific papers covering the task

areas above. This newest work by WG 38 has been supported by WMO, IMO, the University of East Anglia and the US National Science Foundation through SCOR.

6 Since the Norwich workshop one paper has been published:

- 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", Geophys. Res. Lett., DOI: 10.1002/2014GL059665 (2014).

7 Two additional papers have been submitted for publication:

- Sharples, J., J.J. Middelburg, K. Fennel, and T.D. Jickells, "Physical controls on riverine delivery of nutrients and carbon to the open ocean", under revision, Nature Geosciences (2015).

- Somes, C.J., A. Landolphi, W. Koeve, and A. Oschlies, "Ocean biogeochemical feedbacks limit the impact of atmospheric nitrogen deposition on marine productivity", Submitted to the Proceedings of the National Academy of Sciences (2015).

8 Four additional papers are still in preparation, but all should be submitted before the end of the year. This includes a major summary paper on our current understanding of the impact of atmospheric nitrogen deposition on marine biogeochemical cycling, led by Tim Jickells, and a paper comparing observation and model-based estimates of atmospheric nitrogen deposition to the ocean, led by Dr. Alex Baker.

9 Following its successful 2014 session at the European Geosciences Union (EGU) meeting, WG 38 again organized a session on atmospheric input of chemicals to the ocean for the 2015 EGU meeting, held in Vienna, Austria in April, 2015. Papers at this session were presented by a combination of WG 38 members and other scientists. The co-chairs; several members of WG 38; Dr. Alexander Baklanov, WMO Technical Secretary for GESAMP; and Dr. Oksana Tarasova, Chief, Atmospheric Environment Research Division, World Meteorological Organization, met at the 2015 EGU meeting and began to discuss possible additional tasks for WG 38. Since then WG members have developed two possible proposals for future WG 38 activities, and they are as follows:

Potential future activities of WG 38

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

10 Oceanic uptake of atmospheric CO_2 has increased over the past 200 years, driven by intensifying fossil fuel combustion and cement production. The resulting acidification of the world's oceans, characterized by reductions in pH and increased pCO_2 of surface waters, has potentially significant consequences for marine ecosystem function, oceanic biogeochemical cycles, and ocean emissions of climatically- and chemically-active species

11 Earlier investigations on the impact of ocean acidification (OA) have primarily focused on changes in oceanic uptake of anthropogenic CO_2, the resulting shifts in carbonate chemical equilibria and the consequences for marine calcifying organisms. Very little attention has been paid to the direct impacts of OA on the ocean sources of a range of other gaseous and aerosol species that are influential in regulating radiative forcing, atmospheric oxidising capacity (via OH and O_3 cycling) and atmospheric chemistry. These species include greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4); atmospheric aerosol precursors such as dimethylsulfide (DMS); and marine volatile organic compounds (VOCs) and a range of halocarbons important in tropospheric chemistry and atmospheric particle formation. The oceanic processes governing emissions of these species are frequently sensitive to the changes in pH and ocean pCO_2 accompanying ocean acidification. These processes include, for example, metabolic rates of

microbial activity, levels of surface primary production, ecosystem composition and photochemical and microbially mediated production/loss pathways for individual species. The direct and indirect influences of these factors on oceanic fluxes of non-CO_2 trace-gases and aerosols and the subsequent feedbacks to climate remain highly uncertain.

12 The dearth of information on the direct influences of OA on marine fluxes of the climate- and chemistry active species discussed above, highlights the need for a comprehensive and coordinated set of laboratory studies, measurement campaigns, and modelling investigations to identify and quantify these impacts. WG38 is in an excellent position to bring together observational scientists and marine modelling groups to address these issues.

13 If such a task were undertaken by WG 38, the additional terms of reference would be to:

.1 Review and synthesize the current science on the direct impacts of ocean acidification on marine emissions to the atmosphere of key species important for climate and atmospheric chemistry;

.2 Identify the primary needs for new research to improve process understanding and to quantify the impact of ocean acidification on these marine fluxes (i.e. provide recommendations on the specific laboratory process studies, field measurements and model analyses needed to support targeted research activities on this topic);

.3 Publish the results of this activity in the open peer-reviewed scientific literature; and

.4 Provide input to and interact with national and international research programs on ocean acidification (e.g. UKOA, NOAA-OAP) and with relevant WMO programmes (e.g. Global Atmosphere Watch (GAW)) to build on their recent relevant activity in achieving the above objectives.

Changing atmospheric nutrient solubility

14 Atmospheric deposition of nutrients to the ocean is known to play a significant role in regulating marine productivity and biogeochemistry. This deposition therefore has potential impacts on the drawdown of carbon dioxide from surface seawater (and hence the global carbon cycle) as well as the production of other climate-active gases, such as nitrous oxide and dimethyl sulphide. The specific impact of such deposition is dependent on the identity of the nutrient in question (e.g. N, P, Fe, Co, Zn, Ni, Cd), the location of the deposition (because atmospheric input probably only has a significant, immediate impact in waters where a particular nutrient is in short supply) and the bioavailability of the deposited nutrient (because non-available nutrients are not taken up by marine microorganisms and do not therefore influence the carbon cycle).

15 Bioavailability is largely governed by the chemical speciation of a nutrient and, in general, insoluble species are not bioavailable. For Fe and P (and perhaps the other nutrient trace metals) solubility increases during transport through the atmosphere. The causes of this increase are complex, but interactions of aerosol particles with acids appears to play a significant role.

16 Emissions of acidic (SO_2 and NO_x) and alkaline (NH_3) gases have increased significantly since the Industrial Revolution, with a net increase in atmospheric acidity. This implies that Fe and P solubility may also have increased over this time period, potentially resulting in increased marine productivity. More recently, pollution controls have decreased emissions of SO_2 from some regions and further reductions in SO_2 and NO_x are likely in the future. Emissions of NH_3 are much more difficult to control however, and are projected to stabilize or increase slightly to the end of this century. Future anthropogenic emissions are therefore likely to change the acidity of the atmosphere downwind of major urban/industrial centres, with potential consequences for the supply of soluble nutrients to the ocean. Concurrent with this change in acidity, there are likely to be other changes (in the magnitude and species composition of atmospheric nitrogen supply to

the oceans, and in the stoichiometric ratios of the nutrients – N:Fe, N:P, P:Fe), which may also impact marine productivity rates and microbial species population composition.

17 WG38 is in an excellent position to bring together observational scientists (large amounts of new data on nutrients and trace metals in the atmosphere and ocean are becoming available through the GEOTRACES and SOLAS programmes) and atmospheric modeling groups to address these issues.

18 If such a task were undertaken by WG 38, the additional terms of reference would be to:

.1 Review and synthesize the current scientific information on solubility of key biogeochemical elements, their pH sensitivity and the biogeochemical controls on the pH sensitivity. Consider the likely future changes in solubility of key species into the future and the potential biogeochemical consequences of such changes;

.2 Identify the key future research needs that are necessary to reduce uncertainties in predictive capability in this area;

.3 Publish the results of this activity in the open peer-reviewed scientific literature; and

.4 Interact with, and provide information to, leading relevant international groups including the IGBP/Future Earth core projects SOLAS, IGAC and IMBER, SCOR particularly its GEOTRACES programme and WMO programmes such as GAW.

One or two workshops?

19 We are considering whether WG 38 should attempt to undertake only one of these possible activities or both. If approval is given by GESAMP, we would expect that this effort would be initiated by one or two workshops, followed by subsequent interactions by phone and e-mail to satisfy the terms of reference. The expertise needed would be very different for the two activities, and thus it is likely that there would be very little overlap in personnel if there were two workshops. Whether there are one or two workshops, timing becomes important due to funding issues. We do not believe that we could get together sufficient funding to do this work within the next year. The next year should be used to finally finish all the papers from the nitrogen workshop, but also to begin to work actively to develop one (or two) workshop(s) on the new selected topic(s), identify who would participate, where and when it (they) would be held, etc. We expect that no workshop(s) would be held within the next 12 months. This would also give us time to seek additional funding for the workshop(s), e.g. from other UN agencies as well as possibly SCOR and the US National Science Foundation, which gave us significant funds for the nitrogen workshop. We seek advice from GESAMP on these possible two new activities for WG 38.

New Co-Chair of WG 38

20 Prof. Peter Liss has served as an outstanding co-chair of WG 38 since its inception. He has now asked to step down from that position. We believe that an excellent replacement for Peter as co-chair would be Prof. Timothy Jickells, who is also at the University of East Anglia. He is an internationally renowned atmospheric and marine chemist. Tim has been involved with WG 38 activities for many years and is the lead author on the primary nitrogen paper that is coming out of the current WG 38 work on nitrogen deposition to the ocean and its impacts.

Action requested of GESAMP

21 GESAMP is invited to consider the information provided and take action as appropriate.