surface.ocean solas lower.atmoshpere.study

solas event report

Report 18 I January 2021

SOLAS Indian Ocean online meeting

30 September 2020

A Surface Ocean - Lower Atmosphere Study (SOLAS) sponsored event focusing on the Indian Ocean was held on 30 September 2020. The event was conducted online, with participants attending via two different streaming platforms.

The Indian Ocean has been highlighted as an important region for SOLAS science and is included in the list of key environments under the Integrated Studies of High Sensitivity Systems of the SOLAS science mission. The main aim of this workshop was to present and discuss current, ongoing, and planned SOLAS research and initiatives taking place in the Indian Ocean and help forge collaborations between different institutions. Another aim of the workshop was to reinvigorate the Indian SOLAS community and develop community actions and strategies supported by SOLAS.

Due to the travel restrictions in place because of the ongoing pandemic, the meeting was conducted online. In total 350 people from 35 countries registered for the event, which has been viewed by approximately 650 people across two streaming platforms. This shows that the online meeting was very well received, and it enabled a

In this report

Figure 1: Participants of the SOLAS Indian Ocean meeting, from upper left to lower right: Anoop S. Mahajan, Lisa Miller, Hermann Bange, Parvadha Suntharalingam, Susann Tegtmeier, N. Anilkumar, Christa Marandino, Manish Naja, Nidhi Tripathi, Swapna Panickal, Roxy Koll, Yoav Lehahn, Sheryl O. Fernandes, Arvind Singh, Michal Strzelec, Liselotte Tinel, Carolin Löscher, Peter Burkill, Katye Altieri, P. N. Vinayachandran.

large number of early career scientists to attend, suggesting that an online stream should become a standard feature of future meetings to help reduce the carbon footprint and increase attendance.

The meeting was divided into four scientific sessions after an introductory talk. The sessions were designed to cover the latest in SOLAS research in the Indian Ocean and were: (i) The air-sea interface and boundary-layer exchange of trace gases in the Indian Ocean; (ii) Air-sea exchange and monsoons; (iii) Impacts of the atmosphere on the Indian Ocean (including pollution); and (iv) Impacts of ocean biogeochemistry and microbiology on the atmosphere over the Indian Ocean. Each session was comprised of two talks of 15 minutes each. A poster session was also organised between the four sessions, with posters available for comments online before the event, and one-minute flash presentations from 21 presenters showing the latest in Indian Ocean research from groups across the world.

In addition to the four sessions, two keynote talks were also organised, with the first focusing on consolidating the air-sea exchange research in the Indian Ocean, and the second focused on the Second International Indian Ocean Expedition (IIOE-2), which is one of the largest scientific program to take place in the Indian Ocean in recent years. At the end, a panel discussion was also conducted with the aim of identifying what research is needed in the Indian Ocean.

A few important take home messages from the meeting were:

- The Indian Ocean is rapidly changing. It is the fastest heating ocean aside from the Arctic Ocean, which has large implications on biogeochemistry and its impact on SOLAS science. However, the situation is compounded by the Indian Ocean being a dynamically complex and highly variable system under monsoonal influence.
- A holistic approach in the Indian Ocean is encouraged, with linkages between the atmosphere, ocean, coastal and deep sea research both in the northern Indian Ocean and the southern Indian Ocean. These studies need to be interdisciplinary and focus on the temporal and spatial scale because many uncertainties remain in terms of how oceanic and atmospheric processes affect climate, extreme events, marine biogeochemical cycles, atmospheric chemistry, meteorology, ecosystems, and human populations in and around the Indian Ocean.
- There is a large community interested in Indian Ocean SOLAS research but currently the efforts are disjointed and need consolidation in order to increase the impact of the research activities.
- There is a distinct need of focused field campaigns and long-term observations in the Indian Ocean, which is one of the least sampled oceans in the world.
- A public data repository on the observations made in the Indian Ocean as well as synthesis papers highlighting the SOLAS related studies that have hitherto been conducted in the Indian Ocean would be hugely important for understanding the current state of SOLAS science in the Indian Ocean and to identify missing gaps for future research.
- Further collaborations with other international projects, such as the Scientific Committee on Oceanic Research (SCOR), the International Global Atmospheric Chemistry (IGAC), and the Indian Ocean Observing System (IndOOS), are encouraged.
- A white paper on SOLAS research in the Indian Ocean should be written to create a baseline for future SOLAS research.

Along with the SOLAS Indian Ocean meeting, a side meeting for the SOLAS India community was organised on the same day. The workshop included a presentation from another national community and discussions on the structure and future of SOLAS India and increasing collaborations with ongoing programs in India.

The outcomes of the meeting contribute to the Cross-Cutting Theme ‘Integrated Topics’ (Indian Ocean) of the SOLAS 2015-2025: Science Plan and Organisation.

Authors

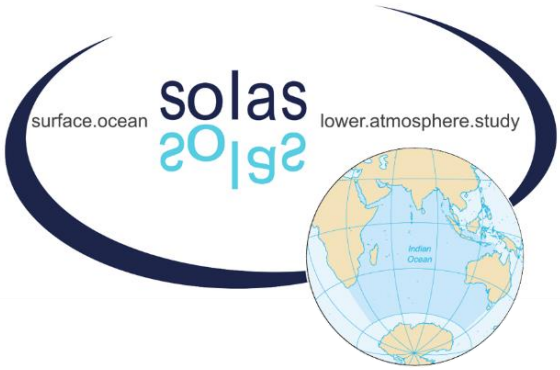
Anoop Mahajan, Indian Institute of Tropical Meteorology, Pune, India. anoop@tropmet.res.in

Hermann Bange, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany. hbange@geomar.de

Jessica Gier, SOLAS International Project Office, GEOMAR, Kiel, Germany. jgier@geomar.de

Lisa Miller, Institute of Ocean Sciences, Victoria, Canada. Lisa.Miller@dfo-mpo.gc.ca

Parvadha Suntharalingam, University of East Anglia, Norwich, United Kingdom. P.Suntharalingam@uea.ac.uk



Swaleha Inamdar completed her master's degree in physics in 2014 and switched to research in atmospheric chemistry in 2016. Her PhD study at the Indian Institute of Tropical Meteorology (IITM), Pune, India and Banaras Hindu University (BHU) is centred around investigation of atmospheric iodine precursors and estimating its impact on the chemical composition of atmosphere over the Southern and Indian Ocean.

Exploring iodine chemistry in the Indian and Southern Ocean marine boundary layer

Inamdar, S. [1*], Tinel, L. [2], Mahajan, A. S. [1]

[1] Indian Institute of Tropical Meteorology, India
[2] University of York, UK

[*] swaleha.inamdar@tropmet.res.in

In the last 40 years, research around halogen-based trace gases has evolved with increased observations, laboratory experiments, and modelling studies. However, there are still uncertainties around the source and transport pathways of iodine-based compounds in the atmosphere. The ocean is the primary source of reactive iodine compounds; the presence of iodine monoxide (IO) in the atmosphere is an indicator of active iodine chemistry in the marine boundary layer (MBL). About 75 % of the detected IO over the tropical Atlantic Ocean is accounted to the inorganic emissions of hypoiodous acid (HOI) and molecular iodine (I_2) via the reaction of seawater iodide with atmospheric ozone (O_3) (Carpenter *et al*., 2013).

To investigate iodine chemistry in the marine environment, our studies over the Indian and Southern Ocean waters involve ship-based observations of IO using the state-of-the-art, multi-axis differential optical spectroscopy (MAX-DOAS) technique (Hönninger *et al*., 2004). Simultaneously, along the cruise track, O_3 concentrations are observed using a photometric UV analyser. Surface seawater iodide (SSI) concentration was measured during one of our expeditions, the 9th Indian Southern Ocean Expedition (ISOE-9) in 2017 contributing to the first concomitant observation of SSI, IO, and O_3 in the Southern Ocean. Additionally, SSI observations in the northern Indian Ocean were also obtained from two expeditions; namely, the Sagar Kanya-333 cruise (SK-333) and the Bay of Bengal Boundary Layer Experiment (BoBBLE) conducted during June-July and September 2016, respectively (Chance *et al*., 2020). Between 2015 - 2017, in the three (8th Indian Southern Ocean Expedition (ISOE-8), 2nd International Indian Ocean Expedition (IIOE-2), and ISOE-9) field experiments, we have observed the ubiquitous presence of IO with levels of 1 to 1.5 pptv in the Indian and Southern Ocean MBL (Mahajan *et al*., 2019; Inamdar *et al*., 2020).

To understand the sources of IO in this region, we estimated the inorganic HOI and I_2 fluxes using the Carpenter *et al*. (2013) algorithm which is based on SSI, O_3, and wind speed. Since the SSI observations are sparse and difficult to automate,

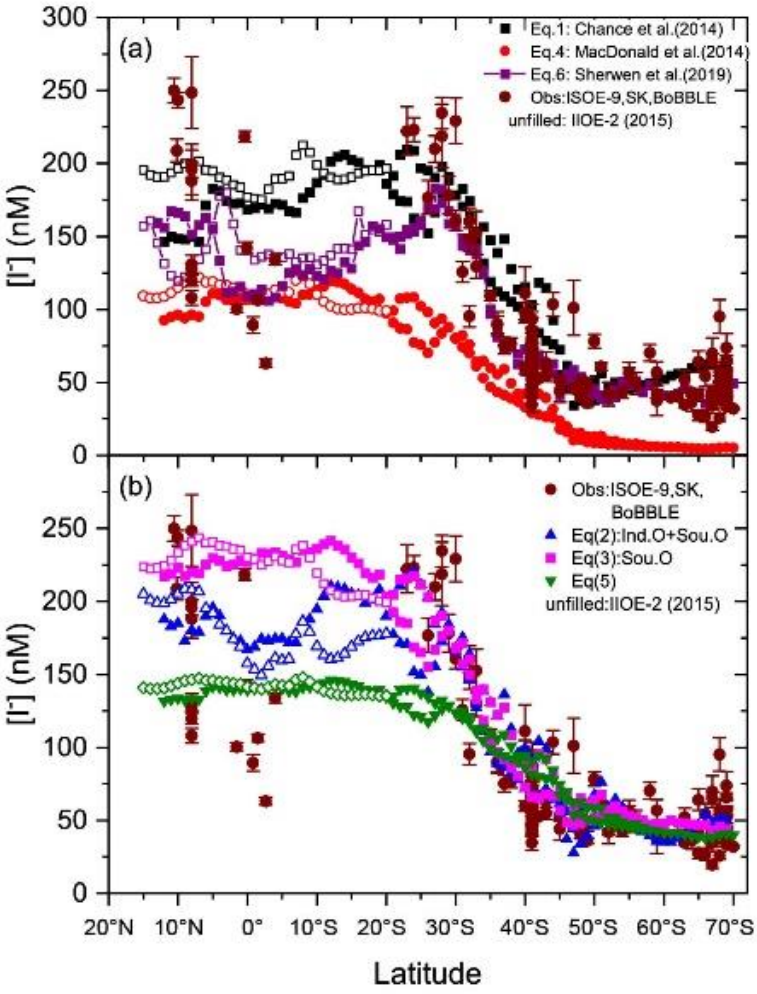


Figure 2: Latitudinal averages of calculated sea surface iodide (SSI) concentrations for each campaign using (a) existing, (b) new parameterisation tools and observations from the ISOE-9, SK-333, and BoBBLE field campaigns. Filled markers represent combined SSI from ISOE-8 and ISOE-9, unfilled markers represent SSI from IIOE-2 campaign.

Chance *et al*. (2014) and MacDonald *et al*. (2014) devised parameterisations to estimate the seawater iodide concentration. We used similar methods to form a region-specific parameterisation for the Indian and Southern Ocean region using the observed SSI concentration from ISOE-9, SK-333, and BoBBLE. Figure 2a shows a comparison of SSI calculated from existing parameterisation (Chance *et al*., 2014; MacDonald *et al*., 2014) and SSI concentration obtained from machine-learning-based global model output (Sherwen *et al*., 2019) with observations for the Indian and Southern Ocean region. In Figure 2b, we compare the SSI concentration from region-specific parameterisation for the Indian and Southern Ocean with observations. It is evident that the region-specific parameterisation performs well for the Indian and Southern Ocean region as they are derived using the data they are tested on. However, the existing parameterisation (Figure 2a) fails to match the observed SSI concentration in the northern Indian Ocean region. This is mostly because the existing parameterisation are based on little to no observations from the Indian and Southern Ocean region, thus making them unsuitable for this region.

Figure 3 shows the latitudinal variation in IO mixing ratios, inorganic iodine emissions (HOI and I_2), chlorophyll-a (Chl-a) and ozone mixing ratios for the entire dataset comprising of the three campaigns (IIOE-2, ISOE-8 and 9). The inorganic fluxes estimated using iodide from different parameterisation and observation did not show a large variation in values and followed a similar latitudinal trend (Figure 3c and 3d). This is indicative that the inorganic iodine flux parameterisation is not highly sensitive to the SSI concentration. The estimated inorganic iodine fluxes do not explain iodine chemistry, as indicated by IO levels (Figure 3a), in the atmosphere above the Indian and Southern Ocean (Indian Ocean sector) regions. Modelled atmospheric IO concentrations in Figure 3b match the observations but with a large offset suggesting that the inorganic fluxes drive some part of the chemistry. Chl-a shows a positive correlation with IO for the north of the polar front. This was also reported by Mahajan *et al*. (2019), suggesting that biologically emitted species could also play a role in addition to ozone and iodide derived inorganic emissions of HOI and I_2. This study suggests that the fluxes of iodine in the MBL are more complex than considered at present and

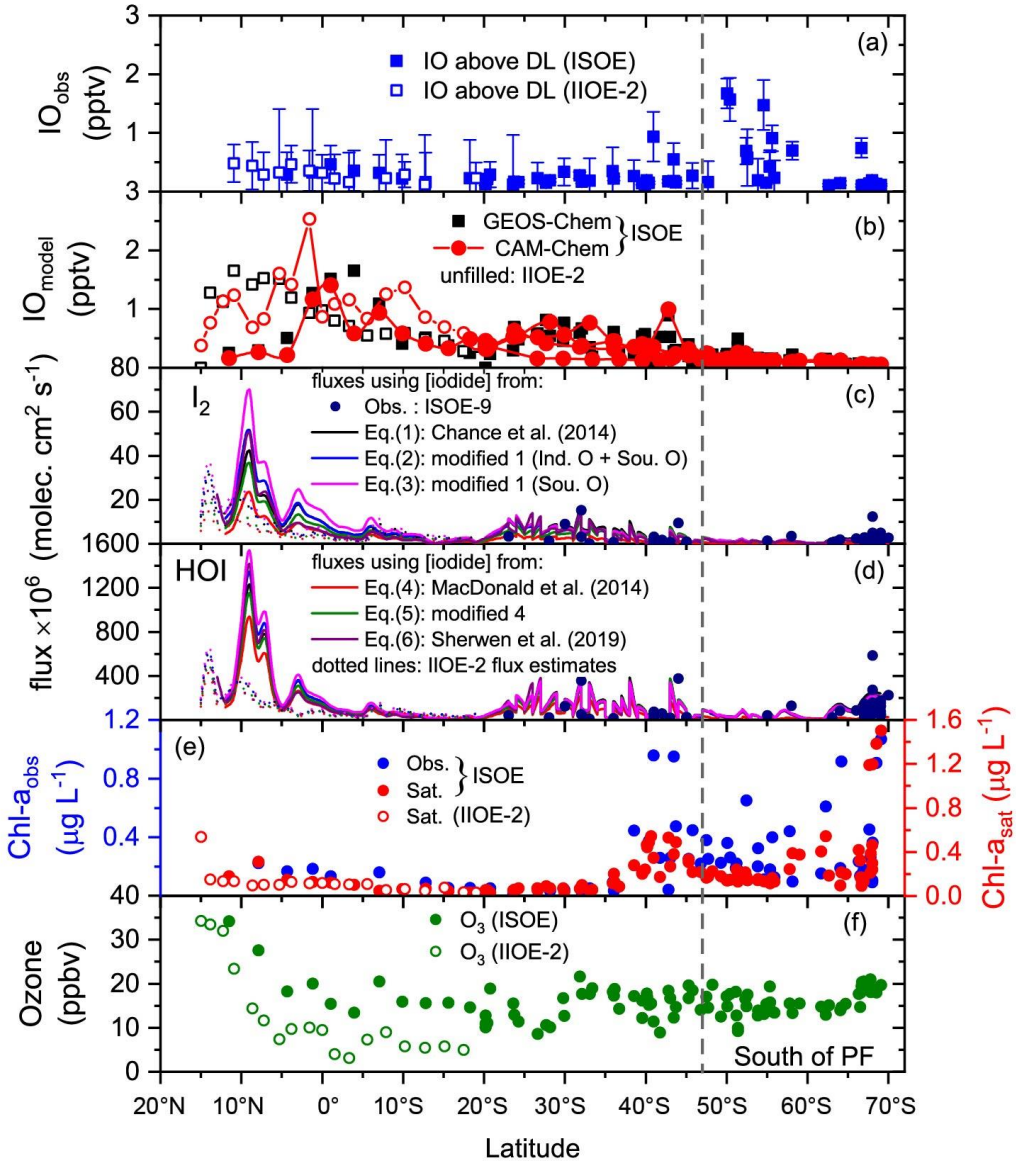


Figure 3: Daily averaged atmospheric and oceanic parameters combined from ISOE-8, IIOE-2, and ISOE-9 field campaigns. (a) IO above detection limit from ISOE-8, ISOE-9 and IIOE-2. (b) Surface IO values from GEOS-Chem and CAM-Chem models. (c) and (d) comprise of estimated HOI and molecular I_2 fluxes (e) Chl-a observations from ISOE-8 and ISOE-9 (blue circles) and satellite data for all campaigns (red circles). (f) O_3 mixing ratios from campaigns ISOE and IIOE-2. Observational plots for ISOE-8 and IIOE-2 were adapted from Mahajan *et al*. 2019 a & b. The vertical dashed line through the figure indicates the Polar Front at 47º S.

further studies are necessary in order to parameterise accurate inorganic and organic fluxes that can be used in atmospheric models.

References

Carpenter, L. J., MacDonald, S. M., Shaw, M. D., *et al*. (2013) Atmospheric iodine levels influenced by sea surface emissions of inorganic iodine, *Nat. Geosci.*, 6(2), 108-111, doi:10.1038/ngeo1687.

Chance, R., Baker, A. R., Carpenter, L., *et al*. (2014) The distribution of iodide at the sea surface, *Environ. Sci. Process. Impacts*, 16(8), 1841-1859, doi:10.1039/C4EM00139G.

Chance, R., Tinel, L., Sarkar, A., *et al*. (2020) Surface Inorganic Iodine Speciation in the Indian and Southern Oceans From 12°N to 70°S, *Front. Mar. Sci.*, 7, 621, doi:10.3389/fmars.2020.00621.

Hönninger, G., von Friedeburg, C., Platt, U. (2004) Multi Axis Differential Optical Absorption Spectroscopy (MAX-DOAS), *Atmos. Chem. Phys. Discuss.*, 3(6), 5595–5658, doi:10.5194/acpd-3-5595-2003.

Inamdar, S., Tinel, L., Chance, R., *et al*. (2020): Estimation of reactive inorganic iodine fluxes in the Indian and Southern Ocean marine boundary layer, *Atmos. Chem. Phys.*, 20(20), 12093-12114, doi:10.5194/acp-20-12093-2020.

MacDonald, S. M., Gómez Martín, J. C., Chance, R., *et al*. (2014) A laboratory characterisation of inorganic iodine emissions from the sea surface: Dependence on oceanic variables and parameterisation for global modelling, *Atmos. Chem. Phys.*, 14(11), 5841–5852, doi:10.5194/acp-14-5841-2014.

Mahajan, A. S., Tinel, L., Hulswar, S., *et al*. (2019) Observations of iodine oxide in the Indian Ocean Marine Boundary Layer: a transect from the tropics to the high latitudes, *Atmos. Environ.* X, 1(January), 100016, doi:10.1016/j.aeaoa.2019.100016.

Sherwen, T., Chance, R. J., Tinel, L., *et al*. (2019) A machine learning based global sea-surface iodide distribution, *Earth Syst. Sci. Data Discuss.*, 1-40, doi:10.5194/essd-2019-40.

Amit Sarkar is a marine biogeochemist, who received a PhD from the National Institute of Oceanography (NIO), Goa, India. He worked as a project scientist at the Earth System Science Organization-National Centre for Polar and Ocean Research (ESSO-NCPOR), Goa, and currently works as an associate research scientist at the Kuwait Institute for Scientific Research (KISR), Kuwait. His expertise involves studying nutrient and carbon cycling in the northern Indian Ocean and the Indian sector of Southern Ocean. His present research involves studying biogeochemistry of climatically important gases over the northwestern Persian/Arabian Gulf.

Revising the reductive nitrogen loss processes over the western Indian continental shelf during seasonal deoxygenation

Sarkar, A.

Kuwait Institute for Scientific Research, Kuwait

amitsarkar81@gmail.com

The equatorward surface currents along the western Indian continental shelf (WICS) during summer (southwest) monsoon induces slow but steady upwelling of water derived from the upper part of the mesopelagic oxygen minimum zone (OMZ) of the Arabian Sea in the northern Indian Ocean. Intense rainfall in coastal zones facilitates water column stratification by forming cold and low saline water lens at the surface. The cumulative effects of these processes transform this shelf into a seasonal OMZ, which occupies a geographical area of ~ 200,000 km^2, the largest of its kind around the globe (Naqvi *et al*., 2000). Elevated biological productivity, chronic deoxygenation, extremely high nitrous oxide (N_2O), methane (CH_4) and dimethyl sulphide (DMS) production in conjunction with frequent sulphidic events make this system an ideal natural laboratory to study fixed nitrogen (N)-loss/transformation processes. Naik (2003) estimated a denitrification rate of 0.84 µmol L^{-1} d^{-1} based on changes in nitrate (NO_3^-) + nitrite (NO_2^-) concentration over time at a fixed station along WICS. In another study, Devol *et al.*, (2006) reported 0.03 µmol N L^{-1} d^{-1} as the denitrification rate from this region by incubating samples spiked with $^{15}NO_3^-$. However, these measurements suffered from several uncertainties as the first report did not envisage replenishment of the NO_3^- pool or removal by the dissimilatory nitrate reduction to ammonium (DNRA). Additionally, none of the studies considered the possibility of N-loss through the anaerobic ammonium oxidation (Anammox) process.

We employed modified isotope pairing techniques (Holtappells *et al*., 2011) using various combinations of ^{15}N-labelled substrates to identify and quantify the potential of multiple reductive N-processes operating in the water column over the WICS during the anaerobic period (Figure 4). The experiments were conducted for three consecutive years occupying multiple locations to provide an insight into the magnitude of the inter-annual and spatial variability. Denitrification was the dominant N-loss pathway over the WICS with an average rate of 2.45±0.6 µmol N L^{-1} d^{-1} with extreme

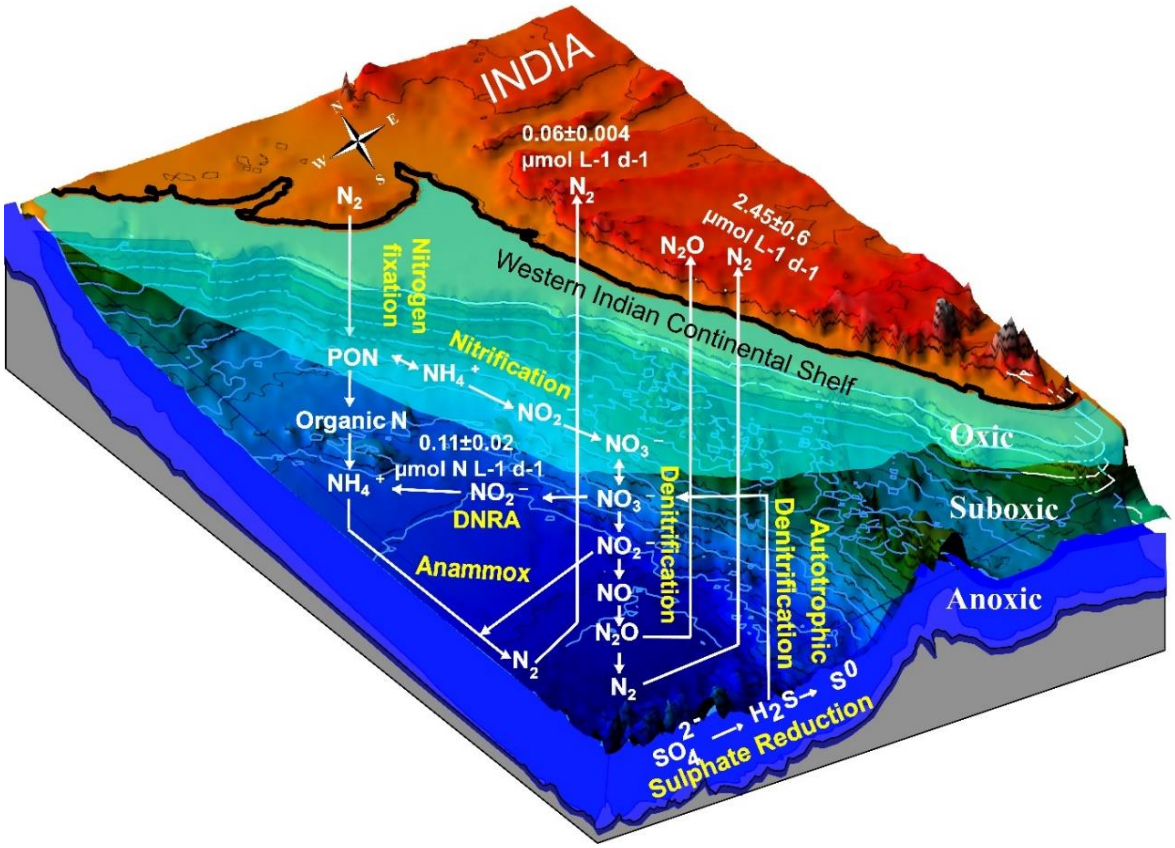


Figure 4: Schematic diagram of reductive nitrogen cycling over the western Indian continental shelf during seasonal anoxia. The rates of multiple reductive N-transformation processes are specified after Sarkar *et al*., (2020).

potential over the inner shelf and at the interface of the oxic-suboxic/anoxic layers. This rate is two orders of magnitude higher than the earlier estimates. Anammox was also observed but at a lower rate (0.06±0.004 µmol N L^{-1} d^{-1}) compared to denitrification. DNRA activities were however sporadic and at a much lower rate (0.11±0.02 µmol N_2 L^{-1} d^{-1}). Intriguingly, we noticed very high denitrification rates (reaching up to ~10 µmol N_2 L^{-1} d^{-1}) to be associated with sulfidic events. It is not unlikely that these high rates of denitrification may arise at least in part from chemolithoautotrophic denitrification by sulphide-oxidising microbes. From our study, the overall N removal via denitrification over the WICS is estimated to range between 3.70±0.91 and 11.1±2.72 Tg annually. This corresponds to as much as 20-60% of the total annual fixed N-loss in the perennial OMZ of the Arabian Sea. In comparison, anammox contributes only 0.09±0.01 - 0.27±0.03 Tg to the N-loss per year. This work is published in Frontiers in Marine Science (Sarkar *et al*., 2020).

References

Devol, A. H., Uhlenhopp, A. G., Naqvi, S. W. A., *et al*. (2006) Denitrification rates and excess nitrogen gas concentrations in the Arabian Sea oxygen deficient zone, Deep *Sea Res. Part I Oceanogr. Res. Pap.*, 53(9), 1533-1547, https://doi.org/10.1016/j.dsr.2006.07.005

Holtappels, M., Lavik, G., Jensen, M. M., *et al*. (2011) ^{15}N-labelling experiments to dissect the contributions of heterotrophic denitrification and anammox to nitrogen removal in the OMZ waters of the ocean, *Methods Enzymol.*, 486, 223-251, doi: 10.1016/B978-0-12-381294-0.00010-9.

Naik, H. (2003) Benthic nitrogen cycling with special reference to nitrous oxide in the coastal and

continental shelf environments of the eastern Arabian Sea, Dissertation thesis, Marine Science Department, Goa University, Taleigao Plateau, Goa, India.

Naqvi, S. W. A., Jayakumar, D. A., Narvekar, P. V., *et al*. (2000), Increased marine production of N_2O due to intensifying anoxia on the Indian continental shelf, *Nature*, 408(6810), 346-349, doi: 10.1038/35042551.

Sarkar, A., Naqvi, S. W. A., Lavik, G., *et al*. (2020) Massive Nitrogen Loss over the Western Indian Continental Shelf during Seasonal Anoxia: Evidence From Isotope Pairing Technique, Frontiers in Marine Science, 7, p.678.

Acknowledgements

The Council of Scientific & Industrial Research and Ministry of Earth Sciences, India along with the European Commission (Marie Curie International Incoming Fellowship) and Max-Planck Society, Germany supported this research.

Follow us on twitter
@SOLAS_IPO

Liselotte Tinel did her PhD in Lyon, France, under the supervision of Dr. George, on photochemistry at atmospheric surfaces, including the sea-air interface. She then moved to York, U.K., as a post-doctoral researcher in the group of Prof. Carpenter to further the work on air-sea exchanges, in particular of iodine species.

The influence of the sea surface microlayer on oceanic iodine emissions

Tinel, L. [1]*, Adams, T. J. [2,3], Hollis, L. D. J. [2], Inamdar S. [4], Mahajan, A. S. [4], Chance, R. [1], Ball, S. M. [2], Carpenter, L. J. [1]

[1] Department of Chemistry, University of York, York, U.K.
[2] School of Chemistry, University of Leicester, Leicester, U.K.
[3] Now at Ricardo Energy & Environment, Harwell, Oxfordshire, U.K.
[4] Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune, India

* liselotte.tinel@imt-lille-douai.fr

The reaction of ozone (O_3) with iodide (I^-) at the ocean's surface is one of the main drivers for iodine emissions into the marine troposphere and an important sink for ozone through dry deposition. Recent studies in the Indian Ocean showed differences between observed and modelled iodine oxide in the marine boundary layer, pointing out an incomplete understanding of iodine emissions (Mahajan *et al*., 2019a; Mahajan *et al*., 2019b; Inamdar *et al*., 2020). In particular, the different global models overestimated the formation of iodine oxide. This is likely caused by an overestimation of I^- concentrations at the sea surface. The I^- climatology has recently been updated, incorporating extended global I^- observations, especially in the Indian Ocean, using a machine learning approach (Chance *et al*., 2019; Sherwen *et al*., 2019; Chance *et al*., 2020). However, uncertainties on the estimations of iodine fluxes from the O_3 + I^- reaction, mainly un-

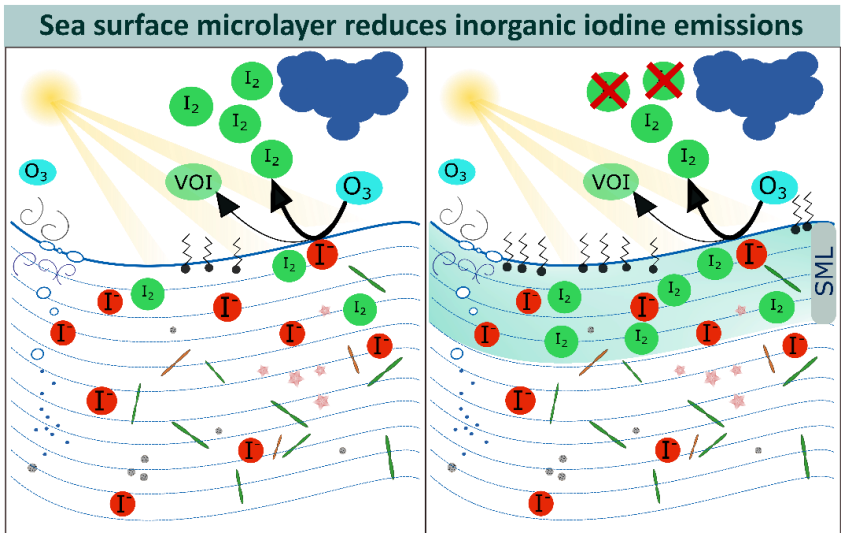


Figure 5: Schematic representation of the reaction of O_3 and I^- at the sea surface, leading to I_2 emissions.

der the form of hypoiodous acid (HOI) and molecular iodine (I_2), at the sea surface remain (illustrated in Figure 5). In particular, the influence of organic matter on these fluxes, and more specifically the influence of the surface microlayer (SML), is not well understood. Therefore, in a recent series of laboratory experiments, gas phase iodine (I_2) was measured using broadband cavity enhanced absorption spectroscopy (BBCEAS) over a range of I^- and O_3 concentrations (Tinel *et al*., 2020). The I_2 emitted was measured directly above the surface of 4 different types of solutions exposed to O_3: buffered potassium iodide (KI) solutions, artificial seawater, natural subsurface seawater and, for the first time, surface microlayer samples. Compared to I_2 emissions over buffered KI solutions, emissions over artificial seawater were reduced, but the strongest reductions were observed over natural seawater samples, as shown in Figure 6. The I_2 flux observed over SML was in average 65% lower than over subsurface samples. These lower emissions could be caused by the reaction of products of the $O_3 + I^-$ reaction with organics present in the natural seawater samples, leading to the formation of e.g. volatile organic iodine (VOI) and hence lowering I_2 (and HOI) emissions. Therefore, in a parallel set of experiments, emissions of 11 halocarbons in the gas phase were monitored over the same types of solution in presence of O_3 in the gas phase, using thermo-desorption gas chromatography coupled to a mass spectrometer (TD-GC-MS). Although some volatile organic iodine production was observed over the natural samples, mainly as iodomethane (CH_3I), and higher production was observed over the SML sample, this production was very low and could not explain the reduction in emissions of I_2 observed. Using a modified version of the interfacial model proposed by Carpenter *et al*. (2013), other reasons behind the reduction of iodine fluxes were explored. The model matched the observations best when using an increased solubility of the products (HOI and I_2), as can be seen in Figure 6. Hence, we propose that the organic enriched SML leads to higher solubility of

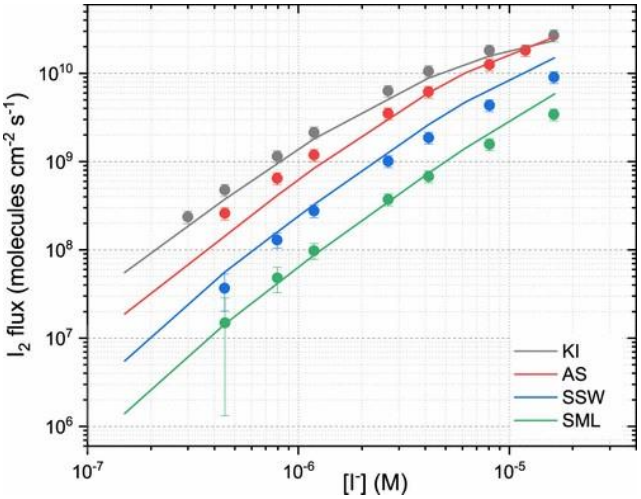


Figure 6: Observations (symbols) and modelling (lines) of I_2 emissions at 17 °C as a function of I^- concentration from buffered KI solutions (gray), artificial seawater (red), subsurface seawater (green), and surface microlayer (blue) for O_3 concentrations of 22.7, 34.7, 38.6, and 38.5 ppbv, respectively. The error bars reflect the overall uncertainty on the measurements. The plot extends the calculation of the modelled I_2 emissions back to an iodide concentration of 1.5×10^{-7} M, typical of natural oceanic surface iodide concentrations.

the I_2 produced, leading to the lower emissions observed. Our results highlight the importance of using environmentally representative concentrations in studies of the $O_3 + I^-$ reaction, due to the non-linearity of the emissions, and demonstrate that the SML exerts a strong influence on emissions of iodine, and potentially other volatile species.

References

Carpenter, L. J., MacDonald, S. M., Shaw, M. D., *et al*. (2013). Atmospheric iodine levels influenced by sea surface emissions of inorganic iodine, *Nat. Geosci.*, 6(2), 108-111, https://doi.org/10.1038/ngeo1687

Chance, R. J., Tinel, L., Sherwen, T., *et al*. (2019) Global sea-surface iodide observations, 1967–2018. *Sci. Data*, 6(1), 286. https://doi.org/10.1038/s41597-019-0288-y

Chance, R., Tinel, L., Sarkar, A., *et al*. (2020) Surface Inorganic Iodine Speciation in the Indian and Southern Oceans from 12o N to 70o S, *ESSOAr*, 7, 36, https://doi.org/10.1002/essoar.10502894.1

Inamdar, S., Tinel, L., Chance, R., *et al*. (2020) Estimation of Reactive Inorganic Iodine Fluxes in the Indian and Southern Ocean Marine Boundary Layer, *Atmos. Chem. Phys.*, 20, 12093-12114, https://doi.org/10.5194/acp-2019-1052

Mahajan, A. S., Tinel, L., Hulswar, S., *et al*. (2019a) Observations of iodine oxide in the Indian Ocean marine boundary layer: A transect from the tropics to the high latitudes, *Atmospheric Environ. X*, 1, 100016, https://doi.org/10.1016/j.aeaoa.2019.100016

Mahajan, A. S., Tinel, L., Sarkar, A., *et al*. (2019b) Understanding Iodine Chemistry over the Northern and Equatorial Indian Ocean. J. Geophys. Res. Atmos., 124(14), 8104-8118. https://doi.org/10.1029/2018JD029063

Sherwen, T., Chance, R. J., Tinel, L., *et al*. (2019) A machine-learning-based global sea-surface iodide distribution. *Earth Syst. Sci. Data*, 11, 1239-1262, https://doi.org/10.5194/essd-11-1239-2019

Tinel, L., Adams, T. J., Hollis, L. D. J., *et al*. (2020) The influence of the sea surface microlayer on oceanic iodine emissions, *Environ. Sci. Technol.*, 54, 20, 13228-13237, https://doi.org/10.1021/acs.est.0c02736

SOLAS Sponsors

Contact

SOLAS International Project Office

GEOMAR Helmholtz Center for Ocean Research Kiel, Germany
State Key Laboratory of Marine Environmental Science, Xiamen University, China

solas@geomar.de

Editors:
Jessica Gier and Li Li