surface ocean solas lower atmosphere study

Report for the year 2019 and future activities

SOLAS *'Germany'*
compiled by: 'Christa Marandino and Hartmut Herrmann'

This report has two parts:

- Part 1: *reporting of activities in the period of January 2019 - Jan/Feb 2020*
- Part 2: *reporting on planned activities for 2020 and 2021.*

The information provided will be used for reporting, fundraising, networking, strategic development and updating of the live web-based implementation plan. As much as possible, please indicate the specific SOLAS 2015-2025 Science Plan Themes addressed by each activity **or specify an overlap between Themes or Cross-Cutting Themes.**

1 Greenhouse gases and the oceans;
2 Air-sea interfaces and fluxes of mass and energy;
3 Atmospheric deposition and ocean biogeochemistry;
4 Interconnections between aerosols, clouds, and marine ecosystems;
5 Ocean biogeochemical control on atmospheric chemistry;
Integrated studies of high sensitivity systems;
Environmental impacts of geoengineering;
Science and society.

IMPORTANT*: This report should reflect the efforts of the SOLAS community in the* ***entire country*** *you are representing (all universities, institutes, lab, units, groups, cities).*

First things first...Please tell us what the IPO may do to help you in your current and future SOLAS activities. ?
Better communication between researchers performing field and laboratory investigations. Need for more communication **across** the disciplines. A new SOLAS summer school in 2020/2021 would be appreciated. A support for community building nationally would be great.

PART 1 - Activities from January 2019 to Jan/Feb 2020

1. Scientific highlight

*Describe one scientific highlight with a title, text (**max. 300 words**), a figure with legend and full references. Please focus on a result that would not have happened without SOLAS, and we are most interested in results of international collaborations. (If you wish to include more than one highlight, feel free to do so).*

Sea-Surface Microlayer - Its global role in ocean and climate science (O. Wurl, Themes 1 and 2)

Our main objective has been to provide a better understanding on how the ocean absorbs CO_2 as a critical component for predicting climate change. In this context, we have focused on the role of the sea-surface microlayer (SML) in the air-sea CO_2 exchange.

We have evaluated in situ data from the SML and CO_2 fluxes from several cruises in the western Pacific, North Atlantic and Baltic Sea. We found an abrupt reduction of air-sea CO_2 exchange if the SML contains surfactants at concentrations exceeding 200 µg/L (Mustaffa et al., 2020). This implies that an error of 20% in air-sea CO_2 fluxes is induced if the computation includes typical wind-based parameterizations not developed within a low-surfactants region (i.e., the western Pacific). Overall, we found that the SML reduces global CO_2 fluxes by 19%, and that slicks, a sea surface phenomenon characterized by wave-dampening, exhibit the strongest suppression (Figure 1). Furthermore, cooler and saltier SMLs, i.e. denser SMLs, are hold at the surface due to interfacial tension until density anomalies exceeds the prevailing interfacial tension, and the denser SML sinks and is replaced with underlying bulk water (Wurl et al., 2019). Such buoyancy fluxes may explain the anomalously high gas transfer velocities not following generalized wind-based parameterization. We used our data to suggest improvements of wind-based parameterizations by introducing a non-zero intercept (Ribas-Ribas et al. 2019) and including near-surface turbulence as additional driving force (Banko-Kubis et al., 2019). For example, our global analysis shows that ignoring a nonzero intercept may bias the oceanic CO_2 uptake by 0.73 Gt C yr^{-1}. This work was completed with collaborations from Prof. Zappa (Columbia University), Propf. Landing (Florida State University) Dr. Battaglia (University of Bern), Dr. Humphreys (University of East Anglia), and with support from the Schmidt Ocean Institute (USA).

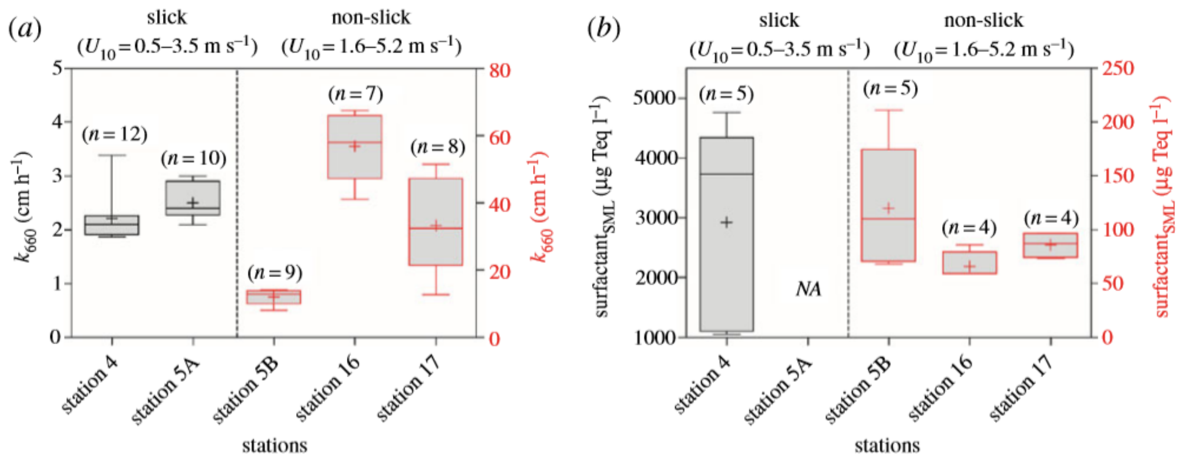

Figure 1: (a) Gas transfer velocity k_{660} for CO_2 and (b) surfactant concentrations in the SML in the Western Pacific (FK161010) with and without the presence of slicks. Error bars represent 5–95% median values. Lines represent 50% median and cross symbols represent mean values. Letter n represents number of observations. Please note different scales of primary and secondary y axis. (from Mustaffa et al., 2020)

REFERENCES

Banko-Kubis, H. M., Wurl, O., Mustaffa, N. I. H., & Ribas-Ribas, M. (2019). Gas transfer velocities in Norwegian fjords and the adjacent north Atlantic waters. Oceanologia, 61(4), 460-470.

Mustaffa, N. I. H., Ribas-Ribas, M., Banko-Kubis, H. M., & Wurl, O. (2020). Global reduction of in situ CO2 transfer velocity by natural surfactants in the sea-surface microlayer. Proceedings of the Royal Society A, 476(2234), 20190763.

Ribas-Ribas, M., Battaglia, G., Humphreys, M. P., & Wurl, O. (2019). Impact of nonzero intercept gas transfer velocity parameterizations on global and regional ocean–atmosphere CO2 fluxes. Geosciences, 9(5), 230.

Wurl, O., Landing, W. M., Mustaffa, N. I. H., Ribas-Ribas, M., Witte, C. R., & Zappa, C. J. (2019). The ocean's skin layer in the tropics. J. Geophys. Res. Oceans, 124(1), 59-74.

2. Activities/main accomplishments in 2019 (e.g., projects; field campaigns; workshops and conferences; model and data intercomparisons; capacity building; international collaborations; contributions to int. assessments such as IPCC; collaborations with social sciences, humanities, medicine, economics and/or arts; interactions with policy makers, companies, and/or journalists and media).

1) Eastern boundary upwelling ecosystems (EBUES) are well-known sites for intense cycling and emission of climate-relevant trace gases to the atmosphere. The air-sea gas exchange of such long-lived greenhouse gases (LLGHG) like CO_2, N_2O and CH_4 is highly variable both spatially and temporally due to the sporadic nature of upwelling events. Hence, accurate estimation of the overall (annual) magnitude and sign of the fluxes as well as their zonal extent is challenging if only short-term field campaigns are considered. In the absence of sustained ocean-based observatories for LLGHG in most EBUES, top-down methods, which use atmospheric measurements to infer gas fluxes at the ocean's surface using simple models are a promising alternative. In this study, two years of continuous observations from a ground-based atmospheric observatory for greenhouse gases, the Namib Desert Atmospheric Observatory (NDAO), were used to compute top-down estimates of the air–sea flux densities of the above-mentioned LLGHG and O_2 from the Lüderitz and Walvis Bay upwelling cells in the northern Benguela upwelling ecosystem during upwelling events. The resulting estimates were compared with contemporaneous ship-based observations on board the R/V Meteor during the cruise M99 in July-August 2013. Upwelling events were net sources of CO_2, N_2O, and CH_4 to the atmosphere. N_2O fluxes were fairly low in comparison with other EBUS. Conversely, surface ocean CH_4 release was quite high, suggesting a large sedimentary source of this gas off Walvis Bay area. These results highlight the suitability of atmospheric time series for characterizing the temporal variability of upwelling events and their influence on the overall marine emissions of LLGHG from the northern Benguela region.

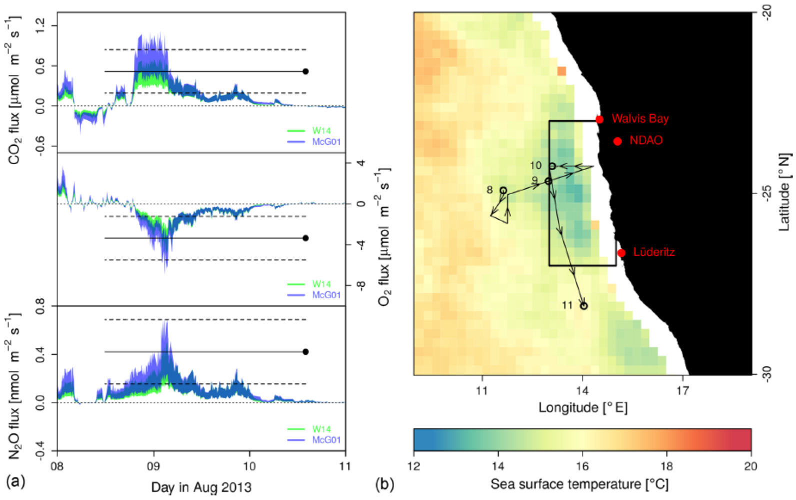

Figure: Air–sea flux densities for CO_2, O_2, and N_2O using bottom-up methods (a), with a shaded envelope depicting the estimated surface flux and its uncertainty. W14 and McG01 refer to two different gas transfer velocity parameterizations. Positive values indicate net evasion to the atmosphere. The top-down flux density estimate is plotted as a dot at the time of the peak of the associated atmospheric anomaly. The horizontal line extending from each dot represents the time period during which the flux density associated with the anomaly was estimated to have occurred. Dotted lines indicate the uncertainty of the top-down estimate. Grid-cell average satellite SST data for the three-day period are overlain with a cruise track and the Lüderitz–Walvis Bay domain (b). The days in August 2013 are marked with labels and open circles on the cruise track.

Citation: Morgan, E. J., Lavric, J. V., Arévalo-Martínez, D. L., Bange, H. W., Steinhoff, T., Seifert, T., and M. Heinmann: Air–Sea Fluxes of Greenhouse Gases and Oxygen in the Northern Benguela Current Region During Upwelling Events, Biogeosciences, 16 (20), 4065-4084, https://doi.org/10.5194/bg-16-4065-2019.

Field campaigns:
- Cruise Transarktika 2019 (Barents Sea, March-April, SOLAS Theme 1)
- Cruise MSM85 (Southeastern Greenland, July-August, SOLAS Theme 1)
- Cruise M158 (Southeast Atlantic, September-October, SOLAS Theme 1)
- PETRA-NERC/BMBF CAO Program Cruise JCR 18007 to the Fram Strait, Aug 2019 (SOLAS Theme 1)

-BONUS INTEGRAL cruises to the central and northern Baltic Sea in Feb./Mar. and Aug. 2019

2) Gas transfer velocities were measured in two high-speed wind-wave tanks (Kyoto University and the SUSTAIN facility, RSMAS, University of Miami) using fresh water, simulated seawater and seawater for wind speeds between 7 and 85 m/s. Using a mass balance technique, transfer velocities of a total of 12 trace gases were measured, with dimensionless solubilities ranging from 0.005 to 150 and Schmidt numbers between 149 and 1360. This choice of tracers enabled the separation of gas transfer across the free interface from gas transfer at closed bubble surfaces. The major effect found was a very steep increase of the gas transfer across the free water surface at wind speeds beyond 33 m/s. The increase is the same for fresh water, simulated seawater and seawater. It is obvious that a new regime is established, which is governed by the intense turbulent mixing and permanent rapid disruption of the surface. The detailed mechanisms causing the steep increase of the gas transfer velocity at high wind speeds are still unclear and require further investigations. It can be explained as either significantly enhanced turbulence at the water surface, or a significantly enlarged surface area for the exchange processes, or a combination of both. Bubble-induced gas transfer played no significant role for all tracers in fresh water and for tracers with moderate solubility such as carbon dioxide and dimethyl sulfide (DMS) in seawater, while for low-solubility tracers bubble-induced gas transfer in seawater was found to be about 1.7 times larger than the transfer at the free water surface at the highest wind speed of 85 m/s. There are indications that the low contributions of bubbles are due to the low wave age/fetch of the wind-wave tank experiments, but further studies on the wave age dependency of gas exchange are required to resolve this issue.

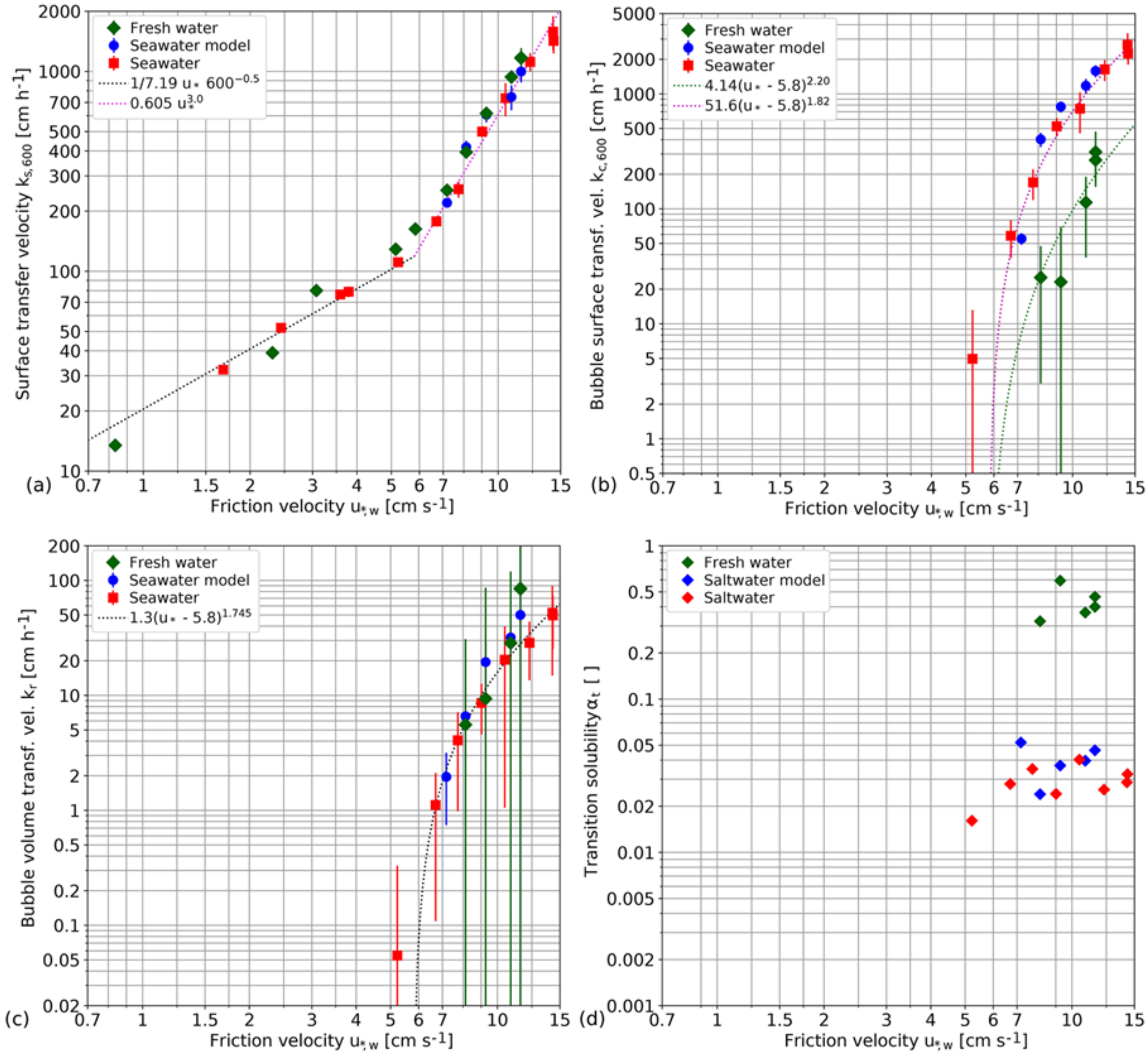

Figure: Fitted contribution of the different components to the gas transfer velocity: (a) surface transfer velocity (b) bubble surface transfer velocity (low solubility limit) and (c) the bubble volume transfer velocity (high solubility limit) as a function of the water-side friction velocity in double-logarithmic presentations. Please note the different vertical scales. The graphs include error bars of the fitted parameters. In addition, the transition solubility is shown in panel (d) without error bars.

Citation: K. E. Krall, A. W. Smith, N. T. Takagaki and B. Jähne, *Air-sea gas exchange at wind speeds up to 85 m/s*, 2019, Ocean Sci., 15, 1783-1799, https://doi.org/10.5194/os-15-1783-2019
SOLAS Theme 2

3) The export of organic matter (OM) from the oceans into aerosol particles establishes a significant carbon flux in the Earth system; however, functional OM relationships in the water column via the Sea Surface Microlayer (SML) to the atmosphere are still poorly understood. A better knowledge of the origin and evolution of marine aerosols, in particular of the organic content, is a challenging topic and requires expertise from a wide range of disciplines. The project MarParCloud (marine biological production, organic aerosol particles, marine clouds: a process chain) aimed at achieving a better understanding of the biological oceanic production of OM, its export into marine aerosol particles and finally its ability to act as ice and cloud condensation nuclei (INP and CCN). To this end, a field campaign was performed at the Cape Verde Atmosphere Observatory (CVAO), employing a variety of chemical, physical, biological and meteorological approaches. Measurements of the bulk water, the SML, ambient aerosol particles on the ground (30 m) and in mountain heights (744 m) as well as cloud water were carried out (Figure 1). First results are summarized in an overview paper (van Pinxteren et al., 2019) and show the proof of concept of the connection between OM emission from the ocean to the atmosphere up to the cloud level. A link between the ocean and the atmosphere was clearly observed as (i) the particles measured at the surface were well mixed within the

marine boundary layer up to cloud level and (ii) ocean-derived compounds were found in the (submicron) aerosol particles at mountain height and in the cloud water. From a perspective of particle number concentrations, the marine contributions to both CCN and INP were, however, rather limited. Further studies are currently performed to elucidate the abundance and cycling of OM within the marine environment

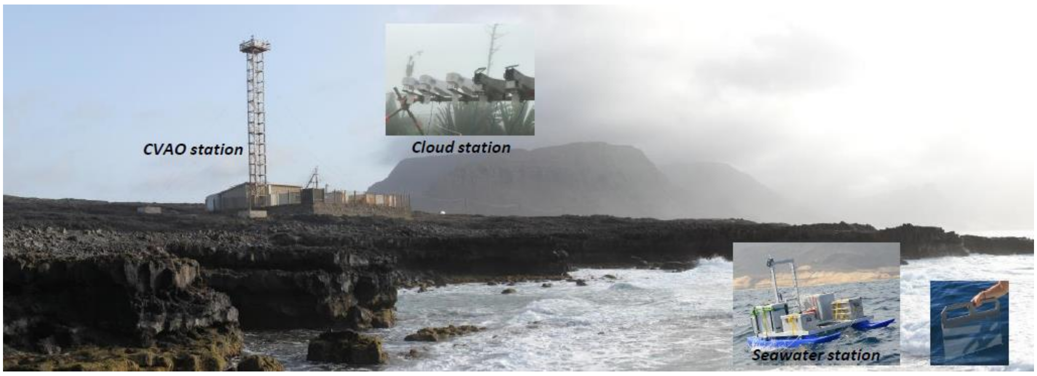

Figure1: The different sampling sites during the campaign: the Cape Verde Atmospheric Observatory (CVAO), the seawater station and the cloud station at the Mt. Verde.

Citation: M. van Pinxteren et al. Marine organic matter in the remote environment of the Cape Verde Islands – An introduction and overview to the MarParCloud campaign, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2019-997, in review, 2019.
SOLAS Theme 4

4) Volatile organic compounds (VOC) were measured in the marine boundary around the Arabian Peninsula using a research vessel during the AQABA campaign (Air Quality and Climate Change in the Arabian Basin) from June to August 2017. Measurements were made from the south of France, through the Suez canal, through the Red Sea, Arabian Sea and Arabian Gulf (and returning on the same route). In 2019 we published results stemming from this campaign of interest to the SOLAS community. The campaign was of particular interest to atmospheric chemists as it crossed regions pristine and polluted regions. Hydrocarbon distributions from the oil and gas industry were documented by Bourtsoukidis et al. 2019 (Atmos. Chem. Phys., 19, 7209–7232, 2019). The OH reactivity in the region was reported by Pfannerstill et al. 2019 (Atmos. Chem. Phys., 19, 11501–11523, 2019). A new marine emitted VOC methyl sulphonamide containing sulphur and nitrogen atoms was discovered and reported by Edtbauer et al. 2019 (https://doi.org/10.5194/acp-2019-1021) and it´s OH rate coefficient determined by Berasategui et al. 2019 (https://doi.org/10.5194/acp-2019-1030). Finally we discovered an important new deep sea source of ethane and propane to the atmosphere in the northern Red Sea. The submarine emission rates of this source rival some middle east countries. This result was published this year in Nature communications Bourtsoukidis et al. 2020 (https://www.nature.com/articles/s41467-020-14375-0).
SOLAS Themes 3 and 5

5) **Arévalo-Martínez, D. L.**, Löscher, C. R., Brown, I. J., Rees, A. P., Kitidis, V. and **Bange, H. W.** (2019) Nitrous Oxide Cycling in the Fram Strait. [Talk] In: 27th IUGG General Assembly, 08-18.07.2019, Montreal, Canada.

3. Top 5 publications in 2019 (only PUBLISHED articles) and if any, weblinks to models, datasets, products, etc.

Arévalo-Martínez, D. L., Steinhoff, T., Brandt, P., Körtzinger, A., Lamont, T., Rehder, G., and H. W. Bange: N_2O emissions from the northern Benguela upwelling system, Geophysical Research Letters, 46, 2019, https://doi.org/10.1029/2018GL081648.

Bange, H. W., Arévalo-Martínez, D. L., de la Paz, M., Farias, L., Kaiser, J., Kock, A., Law, C. S., Rees, A. P., Rehder, G., Tortell, P. D., Upstill-Goddard, R. C., and S. T. Wilson: A harmonized nitrous oxide (N_2O) ocean observation network for the 21st century, Frontiers in Marine Science, 6(157), 2019 https://doi.org/10.3389/fmars.2019.00157.

Nagel, L., Krall, K. E., and Jähne, B.; Measurements of air-sea gas transfer velocities in the Baltic Sea, Ocean Science, 15, 2019, https://doi.org/10.5194/os-15-235-2019, data set: https://doi.org/10.1594/PANGAEA.899774

van Pinxteren, M. et al.: Marine organic matter in the remote environment of the Cape Verde Islands – An introduction and overview to the MarParCloud campaign, Atmospheric Chemistry and Physics Discussions, 2019, https://doi.org/10.5194/acp-2019-997, in review.

Zavarsky, A., and Marandino, C. A.: The influence of transformed Reynolds number suppression on gas transfer parameterizations and global DMS and CO_2 fluxes, Atmospheric Chemistry and Physics, 19 (3), 2019, DOI 10.5194/acp-19-1819-2019.

4. Did you engage any stakeholders/societal partners/external research users in order to co-produce knowledge in 2019? If yes, who? How did you engage?

German Commission on Sustainability Research (*DKN*) Ship Emissions Group (C. Marandino co-chair) - stakeholder meeting (http://www.dkn-future-earth.org/community/arbeitsgruppen/arbeitsgruppen/shipping-emissions.html): Climate and shipping pollution: piecemeal regulation for different objectives? Health, climate, environmental, and socioeconomic implications and challenges for green shipping propulsion Hamburg, 12. / 13. March 2019 at KlimaCampus Hamburg - We invited people from NGOs, Hamburg Ports, ship building companies, MCN, the IMO, and research organizations to participate.

PART 2 - Planned activities for 2019/2020 and 2021

1. Planned major national and international field studies and collaborative laboratory and modelling studies (incl. all information possible, dates, locations, teams, work, etc.).

Mariana Ribas-Ribas (ICBM, Uni Oldenburg), Oliver Wurl (ICBM, Uni Oldenburg), Sanja Frka Milosavljević (Ruđer Bošković Institute, Croatia) and their co-workers will conduct a joint field study in the Adriatic Sea to investigate diurnal changes of the sea-surface microlayer (May 2020).

H. Herrmann et al.:
Summer 2020: Participation in the MOSAiC Cruise with the project: Marine sugars in the Arctic environment (H. Herrmann et al.), SOLAS Theme 2, 4 and 5
Field campaign 2021, *DUSTRISK,* Cape Verde Atmospheric Observatory, SOLAS Theme 3 and 4,
Field campaign *Phosdmap*, October 2020, Namibia, SOLAS Theme 3 and 4

H. Bange lab:
-GLACE (Circumnavigation around Greenland, July-September 2021, SOLAS Theme 1)
- ODEN cruise 2020 (Northwest Greenland, June-August 2020, SOLAS Theme 1)
- Cruise SO276 (GEOTRACES, Southern Indian Ocean, July-August, 2020, SOLAS Theme 1)
- Cruise SO279 (Arabian Sea, December 2020, SOLAS Theme 1)
- Cruise SO280 (BIOCAN-IIOE2; Arabian Sea, December 2020-January 2021, SOLAS Theme 1)
- Cruise SO282 (BIOCAT-IIOE2; Bay of Bengal, March-April 2021, SOLAS Theme 1, includes the work groups of H. Herrmann/M. van Pinxerten-SOLAS Theme 4 and C. Marandino-SOLAS Theme 3)
- Meteor/Merian cruise (Equatorial Atlantic, Benguela region, 2021 (proposed), SOLAS Theme 1)
- Meteor/Merian cruise (Benguela region, 2021 (proposed), SOLAS Theme 1)

Summer 2021 - Baltic GasEx second round of campaigns aboard R/V EMB in central Baltic, led by G. Rehder, includes C. Marandino lab group, international participation (SOLAS Themes 1 and 2)

2. Events like conferences, workshops, meetings, summer schools, capacity building etc. (incl. all information possible).

Marandino, C. A., Lennartz, S. T., von Hobe, M. (2020) A database for carbonyl sulfide (COS) and carbon disulfide (CS_2) measurements in seawater and the marine boundary layer, (*Talk requested by session conveners)*, Ocean Sciences Meeting, San Diego, United States. The database and request for input will be featured in the SOLAS newsletter.

The lab group of B. Jähne and C. Marandino were supposed to participate in the 8th Int. Symposium on Gas Transfer at Water Surfaces, Plymouth, UK in May 2020. C. Marandino was invited to present a keynote talk. However, this meeting has been cancelled and rescheduled for 2021.

June 2021 – 8th SOLAS Summer School in Cape Verde, led by C. Marandino

Arévalo-Martínez, D. L., Löscher, C. R., Brown, I. J., Rees, A. P., Kitidis, V. and **Bange, H. W.** (2019) Nitrous Oxide Cycling in the Fram Strait. [Talk] In: 27th IUGG General Assembly, 08-18.07.2019, Montreal, Canada.

The final meeting of MarParCloud took place in June 2019.

M. van Pinxteren and H. Herrmann will present the main results of MarParCloud in a talk at EGU 2020.

3. Funded national and international projects/activities underway.

MATE (Maritime Traffic Emissions) with focus on oil films, soot deposition and floating plastic (funded by MarTera and awaiting formal approval by BMWi; expected from June 2020 to May 2023). Coordinator: O. Wurl (ICBM, University of Oldenburg, SOLAS Theme 3)

From the H. Bange lab group (SOLAS Themes 1, 3, 5, Integrated studies of high sensitivity systems):
- TRACE: TRace gAses (N_2O, CO) Cycling in the Arctic marine Ecosystem
- PETRA: Pathways and emissions of climate-relevant trace gases in a changing Arctic Ocean
- NITROSO: Effects of ocean acidification on the emission and production pathways of NITRous Oxide in the Southern Ocean (Antarctic)

Integrated carboN and TracE Gas monitoRing for the bALtic sea (EU BONUS INTEGRAL)

Global Shipping: Linking policy and economics to biogeochemical cycling and air-sea interaction (ShipTRASE) Belmont Forum CRA on ocean sustainability call; Coordinator A. Rutgersson (Sweden), German coordinator – C. Marandino, Other PIs – N. Matz-Lück (Germany), L. Recuero-Virto (France), funded from June 2020 to May 2023 (SOLAS Theme 3 and Science and Society)

4. Plans / ideas for future national or international projects, programmes, proposals, etc. (please indicate the funding agencies and potential submission dates).

O. Wurl (ICBM, University of Oldenburg) and H. Bange (Geomar) coordinate a proposal for a DFG research unit with the involvement of 18 PIs from Germany and Austria. Submission of preproposal by March 2020 and, if approved, submission of full proposal before the end of 2020. (SOLAS Themes 1, 2, 4, 5)

Further air-sea gas transfer measurements in the Annular Air-Sea Interaction Facility, the Heidelberg Aeolotron (B. Jähne, SOLAS Theme 2), with focus on
- fetch and wave age dependency including the influence of varying wind speeds
- influence of monomolecular surface films with varying physico-chemical properties

5. Engagements with other international projects, organisations, programmes, etc.

- 2nd International Indian Ocean Expedition: HW Bange is member of the steering committee and co-chairing WG1 ‘Science and Research’
- SCOR WG #143: HW Bange and ST Wilson (U Hawaii) are co-chairs
- CAO program by NERC/BMBF: HW Bange and AP Rees (PML, UK) are co-PIs of the PETRA project
- Belmont Forum/Future Earth CRA on ocean sustainability – C. Marandino

Comments