LASSO: Lagrangian study of marine trace gas Air-Sea exchange over the Ocean (CP 1617)

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Global emission estimates of marine halocarbons show large discrepancies, possibly due to an underestimation of localized coastal sources. Investigating the trace gases at the coastal interface gave novel and quantitative insights in the biogeochemical cycling of marine trace gases from an airborne perspective. For the “Lagrangian study of marine trace gas Air-Sea exchange over the Ocean (LASSO)” we planned to sample marine trace gases across the oceanic surf zone and in the water up to about 500 m offshore with a medium size drone, to differentiate between advective and near-coastal sources.

In the project the drone and additional equipment needed to be bought, flight school needed to be attended and many permissions for the sampling, planned for the North Westcoast of Sylt needed to be obtained. The sampling plan was according to Figure 1:

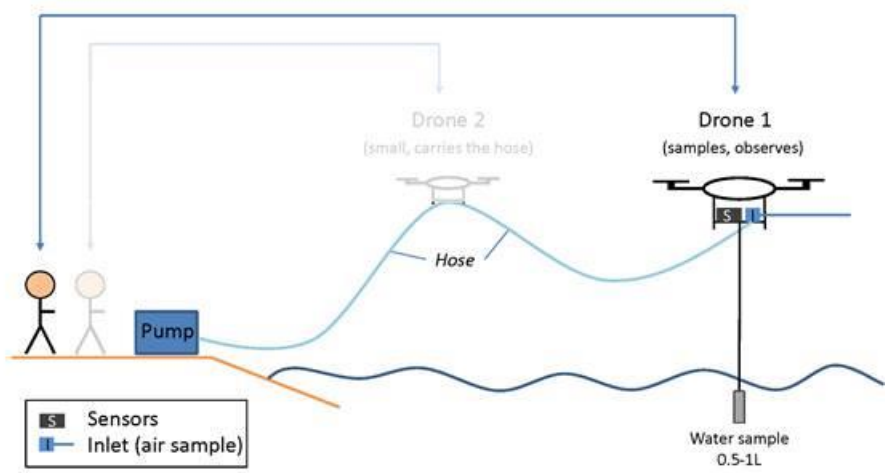


Figure 1: Initial sampling plan for LASSO. A hose should be attached to an air pump at the beach and to a medium, size drone over water in order to sample marine air of different heights. An additional drone should carry the hose (<2 kg). In addition the drone should take a water sample (up to 1L) and carry a variety of additional sensors.

After an intense investigation phase in the rapidly evolving drone market, with many medium sized drones for hobby and professional purposes on the market, we decided to obtain a hexacopter from the world leading drone company DJI, a Matrice 600 which was new on the market at that time and outstanding (weight: 9 kg) with good flight time (40 min, empty) and a good pay load (6 kg) and great flight stability, as it was built for professional film makers. The price range was enormous between different manufacturers (Aerialtronics, Airbornerobotics, DJI, Vespadrones, Walkera) and prices > 20.000 Euros for similar performances were normal. And even the Matrice 600 price ranged from 6.000 and >10.000 Euros between several German retailers and finally we obtained it from AF Marcotec. In order to obtain the drone, we needed to write operating instructions for a multicopter use at GEOMAR, a risk assessment and an investment plan. The Matrice 600 was a perfect tool and extraordinary in payload, flight time and price, making it a powerful, cost effective research tool. We got the DJI Matrice 600 in parts and Steffen Fuhlbrügge assembled it according to instructions. The accessories: camera, gimbal, additional batteries, additional chargers, transport case, GPS upgrade for increased stability and accuracy when flying and a sensor package for measuring temperature, humidity, air pressure, CO_2, O_3, wave height in connection with a single board computer "Raspberry Pi" was purchased. With this, the first project goal to spend under 15.000 Euros for the drone, including necessary battery packs and chargers, camera and video equipment was met, as it was possible to stay below 10.000 Euros for everything.

During research vessel expeditions, we have sampled marine boundary layer air in stainless steel canisters, by pressurizing air, which was sampled from a long pole at the front of the ship, through a metal bellow pump into the canisters. Thus the plan for this project was to also pressurize air samples into stainless steel canisters through a lightweight, inert and long hose, and send them for analysis as usually to the lab of Prof. Dr. Elliot Atlas at RSMAS in Miami. Thus we bought 100 m long ultra-light tubing of the inert material PEEK. In addition we got two generators to deliver the necessary power for pump and battery recharge operations at the coastline and long cables to install them away from the flight operations. We bought a second small drone to hold the tubing above the surf zone and flight simulator for PC to learn the controls. We obtained liability insurance for both drones from the company Allianz and performed flight school in Hamburg at the Copter College, and four pilots obtained the certificate of competence on November 2 in .2016. We also obtained the general rising permission for Schleswig-Holstein for all pilots and both drones from the „Landesbetrieb Straßenbau und Verkehr Schleswig-Holstein".

In winter we developed the sampling procedure and planned our field experiment during one week in April for Sylt at the northwest coast in front of List, where we planned to obtain air from the open North West Atlantic, reaching the coast from a remote environment and water samples uninfluenced from local sources. We obtained approvals for the sampling campaign on Sylt and special rising permission from the Landesbetrieb Straßenbau und Verkehr Schleswig-Holstein, an approval from Nationalparkverwaltung Wattenmeer and the „untere Naturschutzbehörde (UNB) des Kreis Nordfriesland".

We received the air canisters from Miami (RSMAS) for taking air samples in March 2017, while the sensor package was not ready for use, since the field campaign had to be shifted to the beginning of April instead /June. The campaign was planned after the intense test and setup phase, to be performed at the coast during moderate steady northwesterly winds. These conditions were thought to be ideal to account for contaminant-free air from the sea and also safe operation of the drone.

We then indeed had a successful expedition at the northwest coast of List from the 3rd to 7th April 2017, where we got help from colleagues at the AWI- Station in List (biological analysis, and logistic help) and beach workers from the public services of List, who helped us carrying the equipment through the dunes to the beach with their tractors, which was very much appreciated, as pumps, generators and air canisters had a weight of > 200 kg and the beach access was not easy (Figure 2).

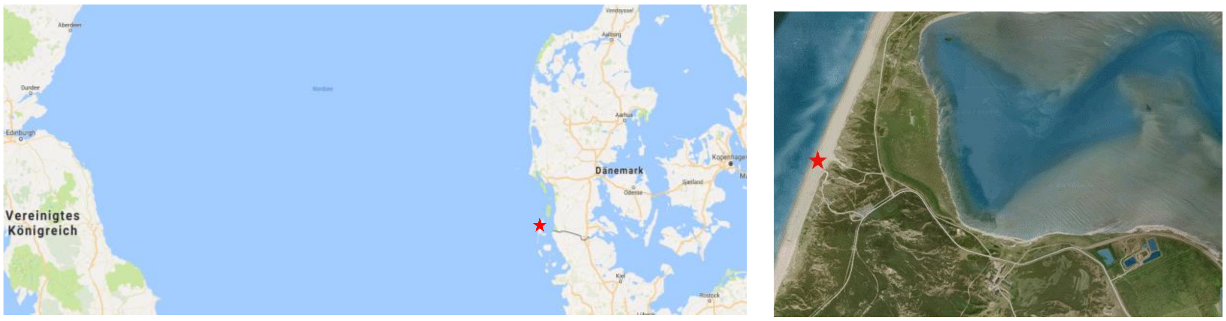


Figure 2: Sampling location at the North West coast of Sylt across List from 4 to 6 April 2017.

Then, the LASSO team (B. Quack, S. Fuhlbrügge, C. Marandino, and M. Paulsen) successfully performed the drone field deployment on the northwestern beach of Sylt (Figures 2 and 3).

Figure 3: Drone camp on Sylt at List beach

The goal of the field project was to better understand the role of coastal waters as sources of reactive trace gases important for tropospheric/stratospheric chemistry and climate. The DJI Matrice 600 drone was used to perform air sampling for both horizontal and vertical gradients over the costal surf zone. And also the drone obtained water samples in a horizontal gradient from the coast (Figure 4). During all flights, the drone imaged the sea surface for the presence of whitecaps, which significantly enhance air-sea gas exchange.

Figure 4: Water sampling with the drone.

The meteorological conditions during the campaign were variable. Over the course of the 32 hours of sampling, the weather varied between mild and stormy conditions. Winds started on Tuesday (4 April) from the SW and gradually moved to W/NW over the next days, with seas ranging from mild to stormy and mostly white-capped. 120 air samples and 40 water samples were taken over the course of the three days up to 90 m heights and 500 m distance from the coast. The drone performed very well even in wind speeds above 10 m/s. The drone team had to learn that the second small drone for holding the hose was useless, as it could not fly in the strong winds, but the Matrice 600 performed very well without the hoseholding drone by just carrying the hose through the water itself. However, when reversing the drone, the hose which was attached to a 10m long rope beneath the drone, dipped into the water two times, as the tension on the rope slipped and elongated the rope and the team had to clean the hose with distilled water and dry it. The water samples (Figure 4) were taken with a 2l plastic bottle and the samples were filled in 250ml brown glass bottles and the trace gases from the surface water were measured directly afterwards in Kiel, using a purge and trap GC-MS (combined gas chromatography and mass spectrometry) system, which measured brominated, chlorinated and iodinated, and mixed halogenated compounds as CH_3I, $CHCl_3$, CH_2Br_2, CH_2ClI, CH_2BrI, $CHBr_2Cl$, $CHBr_3$, and CH_2I_2.

Figure 5: Air sampling with hose attached to drone (left), pressurizing air form different coastal distances and heights into stainless steel canisters (right)

The air samples (Figure 5) were sent to the lab of Prof. Dr. Elliot Atlas at RSMAS in Miami and were analyzed for more than fitfty marine and anthropogenic trace gases, including CH_3I, CH_2ClI, CH_3Cl, CH_3Br, CH_2BrCl, CH_2Br_2, $CHBrCl_2$, $CHBr_2Cl$, $CHBr_3$, OCS, DMS, CFC11, CFC12, CFC112, CFC113, CFC114, HFC134a, HCFC22, HCFC142b, HCFC141b, Halon1211, Halon2402, alkylnitrate, alkanes and alkenes. The data from these analyses were used for the calculation of air-sea exchange and the powerful parallel analysis of so many trace gases elucidates the sources, transport, and transformation of atmospheric trace gases from oceanic and coastal sources. The concept of vertical and horizontal air and water sampling with a drone proved successful in the coastal environment. First results show, that the ocean was, despite the still cold water temperature, a source of varying strength of iodinated, brominated and sulfur compounds for the atmosphere, visible in the air-sea fluxes of the compounds and different intensities of vertical gradients and variations during the three sampling days (Figures 6). Different relationships of the compounds and gradients during the three days reveal at least three different source regions of the compounds, which possibly include the Wadden Sea on the first day, the Scottish coast on the second day and the open North Atlantic on the third day.

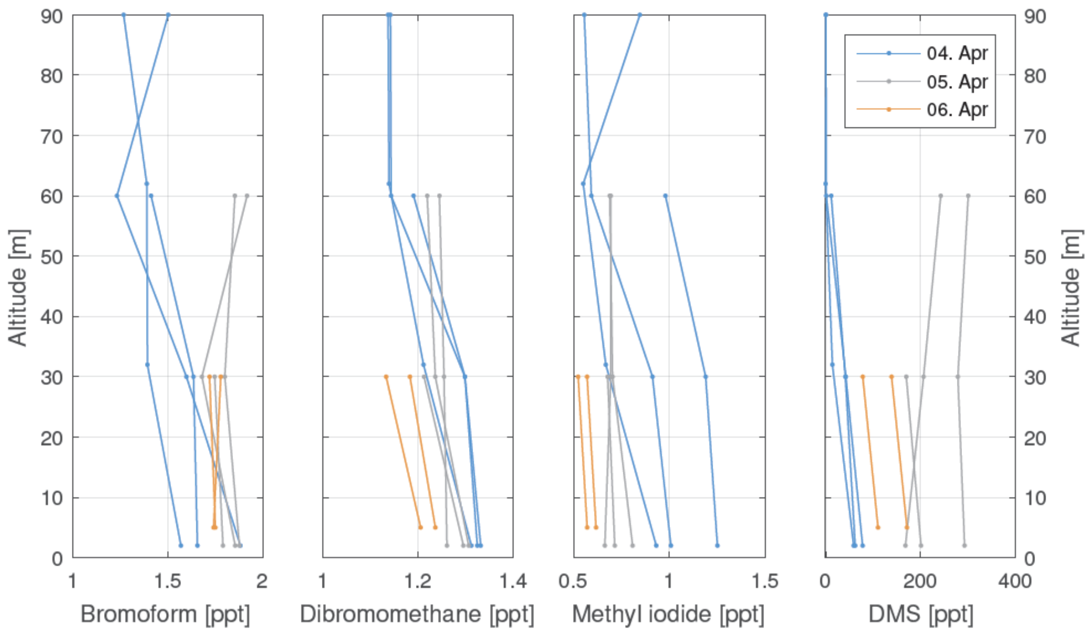
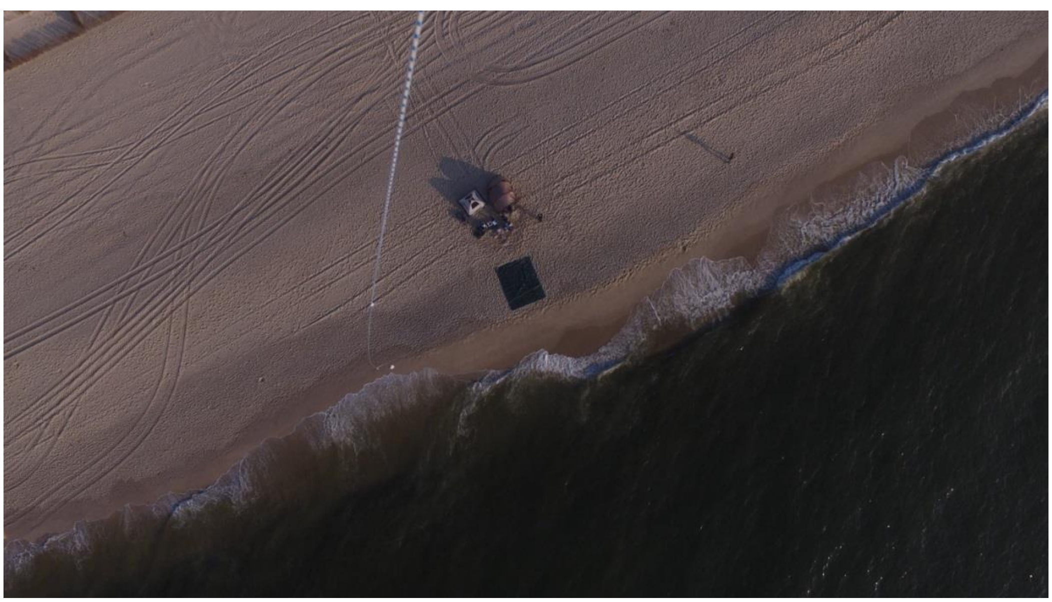


Figure 6: Vertical trace gas profiles during the LASSO field campaign from 4. to 4 April 2017.

Halocarbon concentrations in sea water declined towards the coast, showing an increased emission of the compounds, which was however not visible in the atmospheric gradient across the surf zone. This couldn't be expected during the encountered meteorological conditions, as the relatively narrow surf zone extension and strong wind speed both lead to a strong dilution of the possibly signal, below detection limit of the analytical system.

Further analysis of the data will better define the sources of reactive trace gases along the coastline of Sylt. The different gradients and properties of the trace will be used to extend process level models of the air- sea exchange and biogeochemical cycling of marine derived trace gases from an airborne perspective. The application of drones at and on the sea as a new tool for ocean research will further be developed. So far, the flight performance, deployment of different payloads, and the endurance and stability of the drone DJI Matrice 600 under different and even adverse conditions was very successful (Figures 7 and 8) and we will built on this drone for further ocean going projects and developments. We will try to deploy the drone directly from a ship, which may be tricky as the steel of the vessels strongly influences the compass and the drone's performance including start and landing. In future projects we will analyze the coastal air sea flux under warmer temperatures and the vertical gradients across the marine boundary layer in order to identify the pollution sources and air sea fluxes of natural and anthropogenic trace gases in different oceanic regions. Future plans include especially optimizing the air and water sampling to obtain a larger range with more flexibility and to incorporate sensors (e.g met data) on the drone package. Currently several proposals are in progress, which include the ultimate goal of bringing the entire setup on ocean-going cruises.

Figure 7: Drone camp on Sylt at List beach from the drone.



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