Technical Note: A fully automated purge and trap GC-MS system for quantification of volatile organic compound (VOC) fluxes between the ocean and atmosphere

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Abstract. The oceans are a key source of a number of atmospherically important volatile gases. The accurate and robust determination of trace gases in seawater is a significant analytical challenge, requiring reproducible and ideally automated sample handling, a high efficiency of seawater–air transfer, removal of water vapour from the sample stream, and high sensitivity and selectivity of the analysis. Here we describe a system that was developed for the fully automated analysis of dissolved very short-lived halogenated species (VSLS) sampled from an under-way seawater supply. The system can also be used for semi-automated batch sampling from Niskin bottles filled during CTD (conductivity, temperature, depth) profiles. The essential components comprise a bespoke, automated purge and trap (AutoP & T) unit coupled to a commercial thermal desorption and gas chromatograph mass spectrometer (TD-GC-MS). The AutoP & T system has completed five research cruises, from the tropics to the poles, and collected over 2500 oceanic samples to date. It is able to quantify > 25 species over a boiling point range of 34–180°C with Henry’s law coefficients of 0.018 and greater (CH$_2$I$_2$, $k_{HC}$ dimensionless gas/aqueous) and has been used to measure organic sulfurs, hydrocarbons, halocarbons and terpenes. In the eastern tropical Pacific, the high sensitivity and sampling frequency provided new information regarding the distribution of VSLS, including novel measurements of a photolytically driven diurnal cycle of CH$_2$I$_2$ within the surface ocean water.

1 Introduction

The ocean covers > 70% of the Earth’s surface and is an important natural source of a wide range of trace gases, notably those containing sulfur, nitrogen and halogens. These play critical roles in global biogeochemical cycling and in a wide range of atmospheric processes including marine aerosol formation and modification, tropospheric ozone formation and destruction, and stratospheric ozone loss (Davis et al., 1998; von Glasow et al., 2004; Yang et al., 2005; Read et al., 2008; McFiggans et al., 2010; Montzka et al., 2011; Saiz-Lopez et al., 2012; Santos and Rast, 2013).

A number of ocean biological and chemical processes are responsible for the production of marine gases. Very short-lived halogenated species (VSLS), which deliver ozone-depleting reactive halogens to the troposphere and lower stratosphere, can be released from marine macro algae, from phytoplankton, from marine bacteria and detritus and via photochemical breakdown of dissolved organic matter (DOM) in the surface ocean (Sturges et al., 1993; Schall et al., 1994; Tokarczyk and Moore, 1994; Happell and Wallace, 1996; Goodwin et al., 1997; Carpenter et al., 2000; Carpenter and Liss, 2000; Richter and Wallace, 2004; Hughes et al., 2008; Chance et al., 2009; Asare et al., 2012; Ordoñez et al., 2012; Leedham et al., 2013).

Water bodies may also contain anthropogenic components such as trihalomethanes (THMs), aromatic hydrocarbons, pesticides and waste pharmaceuticals which must be closely monitored and have legally enforceable limits (DEFRA, 2000). These contaminants are a direct concern for human health and as such are often targeted by established
developed for the analysis of VSLS in seawater. This allows for the analyst to concentrate on the upkeep of the instrument and reduces the amount of time required to prepare samples. Automation of a method removes sources of human error, and trap systems (Quack et al., 2007; Raimund et al., 2011). Manual water sampling is still commonly used for purge and trap gas chromatography methods (e.g. Ledyard and Dacey, 1994; Quack et al., 2004; Jones et al., 2009) or via online equilibrator techniques with analysis by pre-concentration GC-MS or chemical ionisation mass spectrometry (Saltzman et al., 2009; Beale et al., 2011; Kameyama et al., 2014). Equilibrator techniques include Weiss-type (Johnson, 1999; Butler et al., 2007; Kameyama et al., 2010), which employs direct contact between the liquid and gas phases, or membrane-type (Groszko and Moore, 1998; Loose et al., 2009; Yang et al., 2014), which physically separates the phases, with the analytes able to pass through the gas permeable membrane. The latter offers the advantage of reduced water vapor in the gas phase, especially if a hydrophobic membrane is used. A disadvantage of the equilibrator technique is that it is limited to analytes with quite high volatilities. Purge and trap samples however can be heated and extensively purged to remove the analytes, such that compounds with boiling points greater than 180 °C can be efficiently sampled. However, this often introduces a large amount of water vapor into the instrument, is aggressive toward any biological life in the sample and requires sample preparation and constant operator attention. An automated purge and trap system involves mechanical handling of the sample and requires mechanisms to prevent salt, biological life and debris from blocking valves and fouling tubing.

2 Methods

In situ VOC seawater measurements are typically made using manual purge and trap gas chromatography methods (e.g. Ledyard and Dacey, 1994; Quack et al., 2004; Jones et al., 2009) or via online equilibrator techniques with analysis by pre-concentration GC-MS or chemical ionisation mass spectrometry (Saltzman et al., 2009; Beale et al., 2011; Kameyama et al., 2014). Equilibrator techniques include Weiss-type (Johnson, 1999; Butler et al., 2007; Kameyama et al., 2010), which employs direct contact between the liquid and gas phases, or membrane-type (Groszko and Moore, 1998; Loose et al., 2009; Yang et al., 2014), which physically separates the phases, with the analytes able to pass through the gas permeable membrane. The latter offers the advantage of reduced water vapor in the gas phase, especially if a hydrophobic membrane is used. A disadvantage of the equilibrator technique is that it is limited to analytes with quite high volatilities. Purge and trap samples however can be heated and extensively purged to remove the analytes, such that compounds with boiling points greater than 180 °C can be efficiently sampled. However, this often introduces a large amount of water vapor into the instrument, is aggressive toward any biological life in the sample and requires sample preparation and constant operator attention. An automated purge and trap system involves mechanical handling of the sample and requires mechanisms to prevent salt, biological life and debris from blocking valves and fouling tubing.

2.1 Instrument design

Manual water sampling is still commonly used for purge and trap systems (Quack et al., 2007; Raimund et al., 2011). Automation of a method removes sources of human error, allows continuous 24 h sampling and can improve reproducibility. Just as important and often overlooked is the reduction in workload that automation can bring, allowing time for the analyst to concentrate on the upkeep of the instrument and the interpretation of the data.

An automated purge and trap system (AutoP & T) was developed for the analysis of VSLS in seawater. This allows for the measurement of trace gases, not limited to VSLS, in any liquid sample, but was designed predominantly for operation on-board research ships sampling seawater from pumped underway supplies and discrete samples taken directly from the ocean. The AutoP & T was coupled to a commercial thermal desorption unit (TD, Markes Unity2-CIA8), and an Agilent 6850 gas chromatograph (GC) with a 5975C mass selective detector (MSD), but can be used with any TD-GC instrument.

The system employs the commonly used glass purge tube design with a nitrogen or helium carrier gas for sparging dissolved gases from the liquid sample. The purge tube is thermostatic at 50 °C using PID (proportional-integral-derivative) controlled high temperature heating rope (Omega, FGR). As is the case for direct air analysis, the gas sample is pre-concentrated onto the cooled (~30 °C) absorbent trap (Tenax TA) of the TD unit. All analytes were quantitatively trapped during breakthrough tests using sample volumes up to 3 L with these conditions. The sample was desorbed at 250 °C onto the GC column (60 m 320 µm Internal Diameter (I.D.) 1 µm 5 % phenyl film, SGE). The column was held at 40 °C for 2 min, ramped at 20 °C min⁻¹ to 207 °C, then at 100 °C min⁻¹ to 250 °C. The MSD was operated in SIM/SCAN mode with 19 selected ion windows monitoring a total of 46 ions, and a qualifier and quantifier per analyte. The MSD source and quadrupole temperatures were increased to 250 and 200 °C, respectively, and an enlarged 6 mm draw out plate was fitted to counter MSD sensitivity stability issues associated with water sampling.

2.2 Ship-borne installation and automation

The pumped underway water supply varies with research vessel but usually consists of an inlet positioned at the bow around 6 m below sea level to allow for pitching and rolling of the ship without introduction of air to the inlet. For the RSS James Clark Ross (JCR), in which the AutoP & T has been fitted on two occasions, the water is pumped at a high flow rate into the laboratories (~200 L min⁻¹). From this a proportion was diverted to the AutoP & T via a stainless steel mesh filter (400 µm) to remove small particulate matter, drawn by a peristaltic pump (Watson Marlow, 1208/DV). The remaining supply was allowed to flow to waste.

The automated control of the system is achieved using just three solenoid valves. A two-way PEEK diaphragm valve (valve C, Fig. 1, BioChem 100T2N24-62-SP) allows purge gas to flow through the system to waste. Two pinch valves, one dual-channel three-way (BioChem 100PD3MP24-02S) and one single-channel three-way (BioChem 100P3MP24-02S), are used to control the multiple water flow paths through the system and are configured to allow a flow at all times to ensure a fresh sample (Fig. 1). The three valves allow the user to filter the sample, fill/empty the glass purge tube, de-gas a liquid to waste, de-gas and trap the analytes for analysis, or to flush the purge tube with carrier gas. Pinch
valves are used as they have no wetted parts, and so are robust and the tubing can easily be replaced if contaminated. Early iterations of the instrument used polytetrafluoroethylene (PTFE) diaphragm valves (BioChem 150L3MP24-156). However, the soft PTFE diaphragm was easily damaged by flow path debris, causing leaks, and microbial growth could not easily be cleaned from inside of the valve.

The valves, heated lines and the temperature of the purge tube are controlled by an open-source microprocessor (Arduino Uno) and the programming code is available in the Supplement. A glass water trap is incorporated after the purge tube as an overflow safety and any condensation is emptied by valve C at the end of each run. Water removal is necessary and is incorporated before and after the CIA8 unit of the TD (Fig. 4 and Sect. 2.3).

The system can run in one of two modes, inline or discrete. Inline mode refers to sampling from the underway supply. Discrete samples are introduced manually directly into the purge tube or semi-automated via the offline sample inlet (Fig. 1). In either scenario, sampling is started by a trigger from the TD unit, which in turn waits for the GC system to become ready. The timing of the system is shown in Fig. 3. Purge gas passes through the purge tube, water removal system, TD and out to waste. During this time the water sample is diverted through the filter (0.45 micron PTFE or grade glass fiber filter (GF/F) application dependent), which has a maximum pore diameter of 0.45 micron, capturing any phytoplancton (larger than 0.45 micron, Bouteiller et al., 1992) and also retaining smaller species such as picoplankton in its smaller pores. Biological matter removal is important as it can produce VOC within the heated purge tube. The carrier gas is then diverted onto the pre-concentration trap and the water sample stream diverted to fill the purge tube. Any VOCs de-gassed during the purge tube filling stage are trapped for analysis. During filling, the power available for the temperature control of the purge tube is increased to allow rapid equilibration (≈ 0.5°C deviation) of the water sample to the purge temperature set point. Once the purge tube is filled the sample is purged for the remaining time and the sample flow is diverted to waste. After the sample is completely de-gassed, the flow through the purge tube stops and the pressure increases. This pressure is then used to empty the contents of the purge tube out to waste in preparation for the next sample.

In order to calculate ocean-atmospheric fluxes, air samples were acquired between each water sample. Air was drawn from a bow inlet through 1/2” (12.7 mm) PFA tubing at approx. 35 L min⁻¹ using a diaphragm pump (KNF, N035.1.2AN.18). Before the air reached this pump it was drawn through a clean stainless steel bellows pump (Senior Aerospace, MB-158) and pressurised into the thermal desorption unit at 70 kPa (10 psi) with the majority of flow vented via a proportional relief valve.

2.3 Water removal

The purging of water at elevated temperatures produces a large amount of water vapour that must be removed before entering the GC-MS. If the absorbent pre-concentration trap is cooled to below the dew point of the sample gas, a drying step is required pre-trapping. This was done us-
Figure 2. Example Atlantic Ocean seawater chromatogram obtained using the AutoP& T with extracted ions individually scaled. Compound names of peak labels are listed in Table 1.

ing two different techniques, depending upon which analytes were being monitored. For halocarbons, non-oxygenated satu-
rated hydrocarbons, DMS and isoprene, an ME™-series Nafion® moisture exchanger and a counter-flow MD™-
series Nafion® gas drier (Permapure™) were used in series.

For oxygenated, unsaturated hydrocarbons and monoter-
penes, in addition to the species mentioned previously, a glass cold trap ("coldfinger") was used to selectively re-
move the water whilst maintaining sample integrity in com-
parison with the Nafion, through which these species are lost
or transformed. This type of trap has previously been used for
hydrocarbon and DMS analyses (Ledyard and Dacey, 1994;
Lidster et al., 2014). The analyte recovery using the two sam-
ple drying techniques, Nafion and “coldfinger”, is listed in
Table 1.

The coldfinger trap was cooled to −30 °C using either an
ethylene glycol chiller (Grant R3) or a free piston Stirling
cooler (Twinbird, SC-UD08 FPSC). The latter was imple-
mented for use aboard the research ships, as it does not con-
tain liquid and the power consumption is only around 30 W
at −30 °C. The glass cold trap system was tested for losses
by the analysis of dry standard gas passed through or by-
passing the water trap whilst ice from previous samples was
present in the trap. No significant losses were observed for
any of the analytes of interest. For monoterpenes and halocar-
bon integrity it is important that the sample lines are heated
as physically close as possible to the cooled water trap and
that the transition between hot and cold is very rapid. This
minimises the amount of liquid water into which the analytes
can partition. It was found that, below −40 °C, monoterpenes
and xylenes began to be lost in the coldfinger trap.

2.4 Reproducibility

In order to reduce the amount of water vapour entering the
system, decrease purge time and maximise purge efficiency,
the lowest volume of a sample should be used that provides
a signal above the system’s limit of detection (LOD, Table 1).
This becomes an important consideration when designing the
purge tube, as the out-gassing of analytes from the sample
is dependent upon partitioning between the liquid and gas
phases. Assuming the carrier gas is never saturated, the rate
of removal of analyte from the sample is dependent upon four
factors: the total surface area of all the bubbles that sparge
the sample, its temperature, the time in which the gas con-
acts the sample and the Henry’s law constant of the analyte.
Therefore the purge tube was designed long and thin so that
the sample filled the tube, allowing for a longer gas–liquid
contact time. The carrier gas enters the tube through a quartz
frit (porosity 3), which produces numerous small bubbles to
maximise surface area.

The subtleties of the sparging method can have a signifi-
cant influence on reproducibility. Bubbles reach terminal ve-
locity shortly after formation (Leifer et al., 2000). This ter-

inal velocity is determined by a combination of the bub-
ble’s drag and its buoyancy. Whereas buoyancy is relative to
the gas that forms the bubble, drag is dependent upon bub-
ble size and viscosity of the liquid. Water becomes less vis-
cous at higher temperatures, increasing velocity. Increasing

temperature also results in oscillation of the bubble, increas-
ing its velocity but reducing its rise time. For bubbles larger
than 2 mm, rise time is independent of temperature (Leifer
et al., 2000). Bubbles should be small and numerous to en-
sure maximum surface area. Bubble size generated in this
system is dependent upon sparge gas pressure and the poros-
ity of the quartz frit, which are both kept constant. However,
due to its effect upon the analytes Henry’s law constant, the
bubble’s trajectory and the viscosity of the water, it becomes
increasingly apparent that accurate temperature control is vi-
tal if de-gassing is to be reproducible.
Table 1. Individual compound purge efficiencies using AutoP & T, associated data, water removal analyte recoveries and limits of detection (LOD).

<table>
<thead>
<tr>
<th>Label</th>
<th>Compound</th>
<th>Retention time</th>
<th>$k_{d}$</th>
<th>B. pt. (K)</th>
<th>% purge eff. 84 mL</th>
<th>% RSD 84 mL</th>
<th>% purge eff. 20 mL</th>
<th>% RSD 20 mL</th>
<th>% coldfinger recovery</th>
<th>% Nafion recovery</th>
<th>LOD (pmol L$^{-1}$)</th>
</tr>
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<td>1</td>
<td>Isoprene</td>
<td>219.4</td>
<td>1.461$^a$</td>
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<td>307</td>
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<td>1.7</td>
<td>0.7</td>
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<td>105</td>
<td>92</td>
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<td>0.292$^a$</td>
<td></td>
<td>316</td>
<td>92</td>
<td>5.4</td>
<td>9.4</td>
<td>100</td>
<td>95</td>
<td>0.05</td>
</tr>
<tr>
<td>4</td>
<td>CH$_2$BrCl</td>
<td>303.5</td>
<td>-</td>
<td></td>
<td>341</td>
<td>85</td>
<td>4.5</td>
<td>100</td>
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<td>104</td>
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</tr>
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<td>5</td>
<td>CHCl$_3$</td>
<td>304.9</td>
<td>0.151$^a$</td>
<td></td>
<td>334</td>
<td>91</td>
<td>2.9</td>
<td>83</td>
<td>6.9</td>
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<td>1.076$^a$</td>
<td></td>
<td>350</td>
<td>93</td>
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<td>100</td>
<td>0.2</td>
<td>104</td>
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<td>0.044$^a$</td>
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<td>370</td>
<td>68</td>
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<td>378.1</td>
<td>0.102$^a$</td>
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<td>3.3</td>
<td>89</td>
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$^a$ Where available, Henry’s law constants reproduced from the compiled list by Sander (1999).

$^b$ Calculated assuming vapour pressure of 0.003 atm and using the AIOMFAC model (http://www.aiomfac.caltech.edu, Zuend et al., 2008, 2011).

Figure 3. Graphical representation of the AutoP & T cycle (purple shading) beginning with the trigger from the thermal desorption cycle (blue shading) and its subsequent triggering of the GC-MS run (green shading).

3 Results

3.1 AutoP & T performance

The reproducibility of the system was tested in the laboratory pre-, during and post-research cruises. Obtaining blank samples for laboratory tests was difficult due to the ubiquitously high concentrations of VOCs, especially halogenated species, in domestic and laboratory water supplies (Milli-Q, Fisher Scientific Optima LC-MS, etc.). It was noted during fieldwork that the first few seawater samples collected from the ship’s continuous supply were usually higher than average – these data points were discarded. Continual system operation with underway seawater resulted in a “conditioning” of the AutoP&T and/or the ship’s underway water supply, as suggested by the stabilisation of concentrations after 2–3 h. Duplicate analysis of underway samples from unproductive oceanic regions showed very good reproducibility (7% RSD for CCl$_4$, 24 h sampling, 7 February 2012, eastern tropical Pacific). This is due to the system being optimised to trace levels far below those present in commercially available water, and for this reason it is likely that reproducibility is actually better during shipboard deployment than during laboratory-based trials, and system performance testing should be carried out in the field. For post-cruise performance testing, seawater was collected from 3000 m depth in the Arctic Ocean, filtered, sparged with N$_2$ and used as a blank matrix spiked with each compound of interest at mid-high ocean representative levels (0–50 pmol L$^{-1}$). The reproducibility of the AutoP&T ranged from between 0.1 and 20% RSD, depending on the method (see Table 1), but was <2% RSD for the majority of compounds in 20 mL sample volumes.
3.2 Purge efficiencies

Purge efficiencies were determined using multiple purges of spiked, blank seawater collected at 3000 m depth (Table 1). Water samples were run as per a usual analysis but not emptied from the purge tube at the end of the sampling time. The degassed sample was held within the tube and repeatedly analysed until no measurable difference between consecutive samples was observed. The purge efficiency was then calculated using

\[
\% \text{ purge eff.} = \frac{[\text{analyte}]_{n1} \times 100}{\sum_{n=1}^{N} [\text{analyte}]_n}. \tag{1}
\]

where \(n\) is the number of consecutive purges of the same water sample. Two set-ups were tested for purge efficiency with either 20 or 84 mL sample volumes, depending on the target analytes; the results are shown in Fig. 5. The 20 mL volume was optimised for VSLS and used during the Tropical Ocean ROPosphere Exchange of Reactive halogen species and Oxygenated VOC (TORERO) campaign in the eastern tropical Pacific. As halocarbons were present in seawater at a high enough concentration to be quantified in 20 mL samples, this smaller volume was used as it could be efficiently degassed in 20 min. Halocarbon purge efficiencies were lower than 100 % in the larger, 84 mL sample volume. Monoterpene concentrations observed in seawater were very low. This, combined with higher limits of detection compared to the halocarbons, prompted the use of an 84 mL sample sparged for 30 min. The relatively high Henry’s law coefficients of the monoterpenes resulted in near 100 % purge efficiency even at this large water volume. Where the analytes were not purged completely, their purge efficiencies decreased with decreasing Henry’s law coefficients, as expected (Fig. 5).

3.3 Seawater measurements

The AutoP&T was run continuously as an automated online instrument sampling underway surface seawater from NOAA ship Ka’iminoa during the TORERO campaign in January–February 2012. For the first 2 weeks the ship was in transit between Hawaii and the 110° W TAO (Tropical Atmosphere Ocean) buoy line. Afterward the underway sampling was interspersed with CTD depth profiles. To illustrate the performance of the instrument, Fig. 6 shows chloroiodomethane (CH\(_2\)ICl) and diiodomethane (CH\(_2\)I\(_2\)) concentrations measured simultaneously in seawater and air. These compounds are important components in global cycling of iodine, with combined emissions comparable to that of methyl iodide (CH\(_3\)I) (Jones et al., 2010). Air abundances

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**Figure 4.** Schematic of the free piston Stirling cooler (FPSC) water trap. Glass water traps are cooled to −30 °C via a billet aluminium interface insulated using milled expanded polyurethane foam.

**Figure 5.** Purge efficiencies for 20 mL (top) and 84 mL (bottom) water samples. Blue bars represent the % purged from the sample in the first purge. Error bars show the run to run reproducibility of the system. For the 84 mL samples \(K_H^C\) is plotted as red circles and decreases with purge efficiency.
two weeks the ship was in transit between Hawaii and the 110°W TAO buoy line. Afterward the underway sampling was interspersed with CTD depth profiles. The fixed heading, constant speed and consistent wind direction whilst transiting through a fairly homogeneous water body resulted in coupled air and water concentrations driven by wind speed and photolysis (figures x and x). This is consistent with expectations, since the lifetime of CH$_2$I$_2$ is approximately 1 month, and very little sample-sample carrier over of the AutoP & T system. This is the first time that a CH$_2$I$_2$ diurnal cycle has been measured in water.

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and CH$_2$I$_2$ble for this cylinder (34 L Essex Cryogenics) were measured as stable for >4 years from filling. Air concentrations of CH$_2$I$_2$ were at least partly driven by wind speed and photolysis during the cruise, showing strong diurnal cycles (night-time maxima) and with higher abundances at higher wind speeds (Fig. 6). This is consistent with their short atmospheric lifetimes (Montzka et al., 2011) and the fact that their main source is (largely wind-driven) air–sea exchange. In seawater, CH$_2$I$_2$ also showed a clear diurnal cycle in synchrony with the air observations. This is the first time that a VSLS diurnal cycle has been measured in seawater, but it is also consistent with expectations, since the lifetime of CH$_2$I$_2$ in surface seawater is only a few minutes (Jones and Carpenter, 2005). This observation of diurnal cycling was only possible with high temporal resolution, a low background signal and very little sample carry-over of the AutoP & T system.

4 Conclusions

The AutoP & T’s low cost and simplicity make it a feasible addition to any TD-GC-MS system and it has been shown to be robust (using pinch valves in later iterations) throughout extended ship-borne sampling campaigns. Filtration of the sample was found to be a large source of potential error. Whereas halocarbons appeared robust toward filtration, DMS was more sensitive (Kiene and Slezak, 2006; Saltzman et al., 2009) and required new filter media per water sample to avoid production occurring on the filter between samples. A further modification to improve the system would be an automated system for filter changing and the addition of an optical sensor for measuring the purge tube fill volume. Other instrumental issues encountered using this system were largely a result of water vapour ingress beyond the water removal steps. Salt was found to block narrow bore tubing and mass spectrometer sensitivity decreased as water accumulated in the TD-GC system. This highlights that complete water removal is imperative for robust system operation.

The AutoP & T approach of this study is not meant to indicate that this is necessarily the best method for seawater analysis. Equilibrator systems have advantages, such as reduced mechanical and thermal stress on the sample, and do not require extensive filtration. However, equilibrators often require more method validation and rely upon the system reaching equilibrium, whereas the AutoP & T method can be set up and tested relatively easily, provides an absolute concentration measurement and can be applied to a large range of analytes greater than within the scope of this work.

The AutoP & T system described here has proven capable of determining low levels of atmospherically important trace gases in the ocean. It has been successfully applied to the quantification of ocean–atmosphere fluxes with a 50 min temporal resolution, fast enough to capture gradients in diurnal cycling whilst maintaining a low limit of detection for short-lived gas species. Purge efficiencies were tested at >80% for all analytes (within SD) using 20 mL sample volumes at 50°C and purging with 50 mL min$^{-1}$ N$_2$ for 20 min.

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