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Warming increases isoprene emissions from an arctic fen

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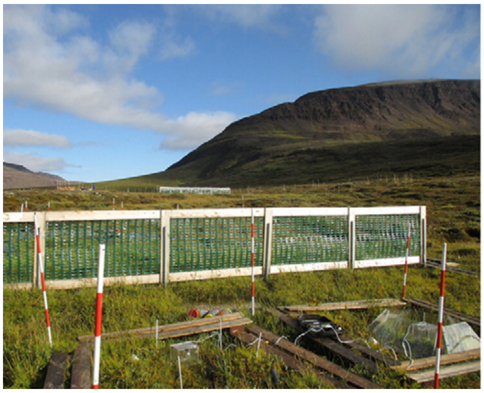
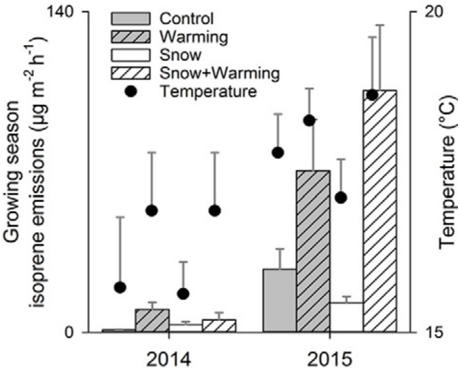
HIGHLIGHTS

- Biogenic volatile organic compounds (BVOCs) affect the biosphere and atmosphere.
- The effects of climate change on BVOC emissions from arctic wetland were examined.
- Isoprene was the dominant compound emitted and was strongly increased by warming.
- BVOC emissions from arctic wetlands strongly increase in a future warmer climate.

GRAPHICAL ABSTRACT





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ABSTRACT

Emissions of biogenic volatile organic compounds (BVOCs) from dry ecosystems at high latitudes respond strongly to small increases in temperature, and warm canopy surface temperatures drive emissions to higher levels than expected. However, it is not known whether emissions from wetlands, cooled by through-flowing water and higher evapotranspiration show similar response to warming as in drier ecosystems. Climate change will cause parts of the Arctic to experience increased snow fall, which delays the start of the growing season, insulates soil from low temperatures in winter, and increases soil moisture and possibly nutrient availability. Currently the effects of increasing snow depth on BVOC emissions are unknown. BVOC emissions were measured in situ across the growing season in a climate experiment, which used open top chambers to increase temperature and snow fences to increase winter snow depth. The treatments were arranged in a full factorial design. Measurements took place during two growing seasons in a fen ecosystem in west Greenland. BVOC samples collected by an enclosure technique in adsorbent cartridges were analysed using gas chromatography–mass spectrometry. Gross ecosystem production (GEP) was measured with a closed chamber technique, to reveal any immediate effect of treatments on photosynthesis, which could further influence BVOC emissions. Isoprene made up 84–92% of the emitted BVOCs. Isoprene emission increased 240 and 340% due to an increase in temperature of 1.3 and 1.6 °C in 2014 and 2015, respectively. Isoprene emissions were 25 times higher in 2015 than in 2014 most likely due to a 2.4 °C higher canopy air temperature during sampling in 2015. Snow addition had no significant effect on isoprene emissions even though GEP was increased by 24%. Arctic BVOC emissions respond strongly to rising temperatures in wet ecosystems, suggesting a large increase in arctic emissions in a future warmer climate.

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1. Introduction

Emission of biogenic volatile organic compounds (BVOCs) from arctic mesic and dry ecosystems has been reported to increase in response to small increases in temperature (Faubert et al., 2010a; Tiiva et al., 2008; Valolahti et al., 2015). Furthermore, arctic emission can exceed modelled emission rates due to warmer tundra surface temperature, compared to air temperatures (Rinnan et al., 2014; Schollert et al., 2014). A doubling in BVOC emissions were observed in a wet subarctic tundra heath due to a warming of 1.9–2.5 °C (Faubert et al., 2010a), and the emission was 2 fold higher after 11 and 13 years of warming treatment (Valolahti et al., 2015). However, it is not known whether warming produces a similar response to BVOC emissions in wetlands, where water through-flow and higher evapotranspiration causes generally cooler surfaces (Gordon, 2008). The amount of BVOCs emitted from arctic wetlands is likely to be of high importance since about half of global wetlands are located between 50 and 70°N (Matthews, 2000) and they constitute approximately half the arctic vegetated area (Matthews, 2000; Walker et al., 2005).

The estimated rate of BVOCs emitted to the atmosphere is 1–1.5 Pg carbon each year (Guenther et al., 2006); the most ubiquitous single compound is isoprene (Guenther et al., 2012; Sindelarova et al., 2014). In fact, isoprene represents 50% of the global budget of BVOCs emitted per year (Guenther et al., 2006). Both isoprene and monoterpenes along with sesquiterpenes belong to the terpenoids family of BVOCs, and monoterpenes make up a significant portion of global BVOC emissions. The largest source of BVOCs is terrestrial ecosystems, mainly plants, which emit BVOCs in order to communicate within and between trophic levels and to increase tolerance to biotic and abiotic stresses (Laothawornkitkul et al., 2009; Peñuelas and Staudt, 2010).

BVOC emissions affect atmospheric chemistry and have implications on air quality and climate. Some BVOCs have double bounds and do not carry oxygen atoms (Loreto and Fares, 2013) which causes them to readily react with reactive oxygen species, for example the hydroxyl radicals (•OH), which leads to a lowered oxidation capacity in the atmosphere. This process may in turn prolong the atmospheric lifetime of the greenhouse gas methane (Carlton et al., 2009; Laothawornkitkul et al., 2009).BVOCs can also form aerosols, leading to a higher concentration of cloud condensation nuclei (CCN) that scatter sunlight and may cool the climate (Claeys et al., 2004; Ehn et al., 2014). The latter process is a more important driver for the regional climate in northern remote areas where the atmosphere is cleaner than in urban areas where anthropogenic volatile organic compound sources play a larger role (Paasonen et al., 2013). Thus, the amount of BVOCs released to the atmosphere affect the regional climate, and since the production and emission of BVOCs is temperature dependent, the emissions will increase as the climate continuous to warm (Laothawornkitkul et al., 2009; Peñuelas and Staudt, 2010).

The rate of the climate change-driven temperature increase in the Arctic is twice the global average (ACIA, 2005). A warmer climate in the Arctic leads to changes in vegetation cover, plant species distribution and an increased plant biomass (Elmendorf et al., 2012a; Elmendorf et al., 2012b; Myers-Smith et al., 2011), which increases BVOC emissions (Rinnan et al., 2014; Valolahti et al., 2015). Climate change also affects the total amount and pattern of precipitation, with a large part of the Arctic receiving more snow fall (Callaghan et al., 2011), leading to deeper snow which insulates the soil from cold air temperatures during winter (ACIA, 2005; Morgner et al., 2010). The resulting warmer soil temperatures in winter can support higher mineralization rates, which might increase nutrient availability for plants in the soil (Semenchuk et al., 2015). Also, deeper snow leads to later snow melt and a delayed start of growing season (ACIA, 2005), which may decrease total BVOC emissions. However, in wet ecosystems, deeper snow and a later snowmelt may increase BVOC emissions from anaerobic processes in the waterlogged soil, due to a later drawdown of the water table and the maintained activity of anaerobic bacteria (Faubert et al., 2011; Tiiva et al., 2009).

The aim of this study was to determine the immediate effect of experimental warming and snow addition – both applied individually and in concert – on BVOC emissions across the growing season from whole ecosystem plots in an arctic graminoid-dominated fen. We also investigated if surface temperature plays a role in BVOC emissions in wet ecosystems as previously reported from drier tundra (Schollert et al., 2014). Measurement of BVOCs were performed in situ after one and two years of treatments and this short term experiment allowed us to investigate the effect of warming and snow-addition before any treatment-induced vegetation changes had occurred. We expected isoprene to be the single most emitted compound, similarly to subarctic wetlands with graminoid-dominated vegetation (Faubert et al., 2010b; Holst et al., 2010). We also expected, based on previous high latitude studies (Faubert et al., 2011; Tiiva et al., 2008) a clear increase in isoprene emissions due to warming by open top chambers. The short term effect of snow addition was hypothesized to decrease emissions due to a delayed start of the growing season. Furthermore, gross ecosystem production (GEP) was measured with a closed chamber technique during the first growing season to investigate how photosynthesis may be affected by the short term treatments and how it varies during the season. This was done as GEP may influence production of some BVOCs, for example isoprene, through its control on substrate metabolism (Laothawornkitkul et al., 2009; Sharkey et al., 2008).

2. Materials and methods

2.1. Experimental site

Measurements took place during two growing seasons in a fen in low arctic western Greenland (69°18′40.9″N/53°30′40.9″W), situated on the southern part of the Disko Island, approximately 500 m from the coast. The yearly mean air temperature is −3 °C and annual precipitation sum 436 mm, whereof 42% falls as snow. The maximum snow depths were approximately 80 and 100 cm for 2014 and 2015, respectively, and the field site was snow-free on the 16 June 2014 and 25 June 2015. The field site is surrounded by hills which allow inflow of water during snowmelt and rain events and the water table fluctuates from 20 cm below to 15 cm above the surface. The peat layer is approximately 20 cm deep with a glacially sediment of volcanic basalt underneath. The ecosystem was dominated by the graminoids *Carex rariflora* (Wahlenberg) J.E. Smith and *Eriophorum angustifolium* Honck., the common horsetail *Equisetum arvense* L. and the moss *Tomentypnum nitens* (Hedw.) Loeske. The vegetation cover was analysed by a point-intercept method (Jonasson, 1988) the 25–26 August 2014.

2.2. Treatments

A snow accumulation and warming experiment, similar to that employed in Blok et al. (2015), was set up in July 2013. The snow accumulation was achieved by putting up 14.7 m wide and 1.5 m high snow fences (N = 6), which protect one side of the fence from wind, and thus allow the snow to accumulate in the lee side during winter (hereafter called "snow addition"; see Supplementary Fig. S1). During both winters, the snow depth was on average 30 cm deeper in the snow addition treatment compared to ambient snow conditions (Supplementary Fig. S2). On each side of the fence four plots (2 × 2 m) were installed, of which two were used in this study, one with and one without an open top chamber (OTC; warming treatment; Supplementary Fig. S1). The OTCs were hexagon shaped Plexiglas chambers (3 mm thick, 35 cm tall and 150 cm in diameter at the base and 85 cm in diameter at the top) which increased the air temperature and lowered the wind speed (Marion et al., 1997). The OTCs were kept on the plots the whole year. In total, there were four plots: control, warming, snow