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Volatile organic compound emission profiles of four common arctic plants

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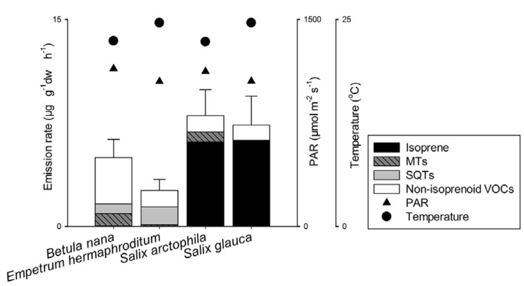
HIGHLIGHTS

- Arctic plants significantly emit volatile organic compounds into the atmosphere.
- Emission profiles differ between species and are affected by phenology.
- *Betula nana* had highest emissions in early summer.
- *Salix* spp. and *Empetrum hermaphroditum* had highest emissions in late summer.
- Future vegetation alterations are critical for the BVOC impact on the atmosphere.

GRAPHICAL ABSTRACT



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ABSTRACT

The biogenic volatile organic compound (BVOC) emissions from plants impact atmosphere and climate. The species-specific emissions, and thereby the atmospheric impact, of many plant species are still unknown. Knowledge of BVOC emission from arctic plants is particularly limited. The vast area and relatively high leaf temperature give the Arctic potential for emissions that cannot be neglected. This field study aimed to elucidate the BVOC emission profiles for four common arctic plant species in their natural environment during the growing season. BVOCs were sampled from above-ground parts of *Empetrum hermaphroditum, Salix glauca, Salix arctophila* and *Betula nana* using the dynamic enclosure technique and collection of volatiles in adsorbent cartridges, analyzed by gas chromatography-mass spectrometry. Sampling occurred three times: in late June/early July, in mid-July and in early August. *E. hermaphroditum* emitted the least BVOCs, dominated by sesquiterpenes (SQTs) and non-isoprenoid BVOCs. The *Salix* spp. emitted the most, dominated by isoprene. The emissions of *B. nana* were composed of about two-thirds non-isoprenoid BVOCs, with moderate amounts of monoterpenes (MTs) and SQTs. The total *B. nana* emissions and the MT and SQT emissions standardized to 30 °C were highest in the first measurement in early July, while the other species had the highest emissions in the last measurement in early August. As climate change is expected to increase plant biomass and change vegetation composition in the Arctic, the BVOC emissions from arctic ecosystems will also change. Our results suggest that if the abundance of deciduous shrubs like

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Betula and *Salix* spp. increases at the expense of slower growing evergreens like *E. hermaphroditum*, there is the potential for increased emissions of isoprene, MTs and non-isoprenoid BVOCs in the Arctic.

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1. Introduction

Vegetation impacts the atmosphere by emitting biogenic volatile organic compounds (BVOCs). The global BVOC emissions from the terrestrial biosphere to the atmosphere are, with large uncertainties, estimated to be between 700 and 1000 $\times$ 10^{12} g C per year (Laothawornkitkul et al., 2009). Many BVOCs are highly reactive and their chemical degradation processes influence air quality and climate (Laothawornkitkul et al., 2009), contributing to complex climate feedback mechanisms in the atmosphere associated with global climate change (Peñuelas and Staudt, 2010).

Information on BVOC emissions in all regions is needed to improve the understanding of global BVOC emissions. Emissions from the Arctic have been considered negligible because of low temperatures, short summers and low vegetation biomass (Guenther et al., 1995). BVOC emissions are highly temperature dependent, often showing an exponential relationship with increasing temperature (Laothawornkitkul et al., 2009). Low-statured vegetation canopies in high latitude ecosystems have been observed to have canopy temperatures up to 15 °C warmer than the ambient air temperature and reach temperatures above 30 °C (Helliker and Richter, 2008; Scherrer and Körner, 2009; Rinnan et al., 2014). Due to the temperature dependence of BVOC emissions, arctic plants might therefore be of greater importance than previously expected despite the low air temperatures. Indeed, the Arctic is vast, and the first ecosystem-level measurements suggest significant emissions from this poorly studied region (Potosnak et al., 2013; Schollert et al., 2014).

BVOCs play key roles in plant reproduction and in protection against abiotic and biotic stressors (Loreto and Schnitzler, 2010; Holopainen and Gershenzon, 2010). The emissions are thus important for plant survival and are regulated in interaction with the surrounding environment (Laothawornkitkul et al., 2009). The quality and the quantity of BVOC emissions (i.e. the BVOC emission profiles) are species-specific, and depend on plant phenology and environmental factors, most importantly temperature and photosynthetically active radiation (PAR) (Laothawornkitkul et al., 2009; Niinemets et al., 2010; Llusia et al., 2013). Our overall aim was to obtain an estimate of the *in situ* emission rates and profiles of common arctic shrub species *Betula nana*, *Empetrum hermaphroditum*, *Salix arctophila* and *Salix glauca* in low arctic Greenland. *B. nana* (dwarf birch) is a common circumboreal-polar shrub, and it can be dominant on both dry and wet tundra (Bliss and Matveyeva, 1992; Elven, 2014). *E. hermaphroditum* (black crowberry) is a common circumboreal-polar dwarf shrub in the Northern Hemisphere and also occurs in the Southern Hemisphere (Anderberg, 1994; Tybirk et al., 2000; Popp et al., 2011). *S. arctophila* (arctic marsh willow) is a common dwarf shrub found on mires and along streams in Canada, Alaska, and Greenland (Elven, 2014). *S. glauca* (greyleaf willow) is a common circumboreal-polar shrub species (Böcher et al., 1968; Elven, 2014).

The objectives of the work were to 1) compare the emission rates, diversity and the relative contribution of the BVOCs emitted from the studied species and 2) assess changes in emission profiles over the growing season. This information will aid in assessment of how climate change-related vegetation changes, including altered relative abundance of evergreen and deciduous species, will alter the BVOC emissions of the arctic region. The region is under a rapidly proceeding climate change (IPCC, 2013) and the arctic shrubs, especially deciduous species, are increasing in abundance (Tape et al., 2006; Elmendorf et al., 2012; Walker et al., 2014).

2. Materials and methods

2.1. Study area

The field study was conducted from late June to early August 2013 in the bottom of Kobbefjord (Kangerluarssunguaq), South Western Greenland (64°07′N, 51°21′W). The climate is characterized as low arctic with a mean annual precipitation of 752 mm (1961–1990) (Aastrup et al., 2009). In 2013, the mean annual temperature was 0.2 °C which is the same as for 2008–2013, and the frost-free period lasted from 9 June to 14 September (Jensen and Christensen, 2014).

The BVOC sampling was conducted *in situ* in an unfenced tundra heath with wet and dry areas. The wet area had sporadically occurring wet depressions. The vegetation was heterogeneous; it had spots of *Sphagnum* moss spp. and the vascular vegetation was dominated by *B. nana* (~35% coverage) and *S. arctophila* (~25% coverage) occasionally together with high growing graminoids. The dry area was overall more homogeneous with spots of bare ground. The vegetation was dominated by *E. hermaphroditum* (~50% coverage) with *S. glauca* (~40% coverage) as a subdominant species.

2.2. BVOC sampling

Shoots from six individuals of *B. nana* and *S. arctophila* were measured in three campaigns, on July 5, July 23 and August 4 (from here on out early July, mid-July and early August). Six individuals of *E. hermaphroditum* and *S. glauca* were also measured in three campaigns, on June 30-July 1, July 15–17 and August 2–3 (from here on out early July, mid-July and early August). The vegetation greenness (normalized difference vegetation index, NDVI) for a plot with *S. glauca* cover was high from early July through September, with a peak on August 6 (Jensen and Christensen, 2014). The bud burst of *S. glauca* occurred from June 3 onwards, and the first flowering male and female catkins were observed on June 13 and 18, respectively (Jensen and Christensen, 2014).

Polyethylene terephthalate (PET) bags (Rul-Let, Abena A/S, Aabenraa, Denmark), pre-heated at 120 °C for 1 h, were used as enclosures in the dynamic enclosure measurements (Niinemets et al., 2011; Ortega and Helmig, 2008; Stewart-Jones and Poppy, 2006). A new PET bag was used for each sample. The PET bag with a volume of 1 L was gently attached around the plant shoot and a teflon tube, supplying an air inflow of 500 ml min^{-1} was connected. The incoming air was purified by a charcoal filter to remove particles and VOCs present in the ambient air, and by a Manganese oxide (MnO_2) scrubber to remove ozone (Ortega and Helmig, 2008). After running for 5 min to reach steady state conditions, sampling was started by attaching a stainless steel cartridge filled with Tenax TA (150 mg) and Carbograph 1TD (200 mg) (Markes International, Llantrisant, UK) through a hole in the bag. Air was

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