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Spatial distribution of hydrogen sulfide from two geothermal power plants in complex terrain

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HIGHLIGHTS

- High air stability, low wind speed and low precipitation increased H_2S concentration.
- Plumes were narrower with higher concentration over smoother terrain, such as lakes.
- Plumes were observed to be trapped alongside a mountain range.
- H_2S plumes were observed to be guided by the terrain during stable conditions.
- Plumes converged due to spatial variability in the wind field.

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ABSTRACT

Concerns have arisen about the health impact and odor annoyance of hydrogen sulfide (H_2S) emissions associated with geothermal power production. Measurements have been made at stationary measuring stations in inhabited areas but little is known about the spatial behavior of the H_2S plumes. This study presents field measurements of the spatial distribution of the ground concentration of H_2S within a 30 km radius of two geothermal power plants during 20 distinct events spanning one year. The results showed that high H_2S concentration was correlated with high air stability, low wind speed and absence of precipitation. The odor threshold (11 μg m^{-3}) was exceeded in all events. The instantaneous measurements exceeded the 24-h average national health limit (50 μg m^{-3}) up to 26 km from the power plants. The shape of the measured plumes at the same location was similar between events, indicating repeated patterns in plume distribution. Convergence of plumes was observed due to spatial variability in wind direction. Plumes were found to follow mountain passes and accumulate alongside a mountain range. AERMOD modeling demonstrated that narrower plumes with higher concentration can be expected for smoother terrain, such as lakes, consistent with measurements.

1. Introduction

Development of geothermal energy as a clean and sustainable energy source is growing worldwide. Some concerns have been raised with regard to environmental and health impacts, such as hydrogen sulfide (H_2S) emissions to the atmosphere (Kristmannsdottir and Armannsson, 2003; Ermak et al., 1980).

For the past two decades geothermal utilization has been increasing in southwest Iceland in close proximity to the capital of Reykjavik, rural settlements and recreational areas. In 2010 local authorities established a health limit of 50 μg m^{-3} for a 24-h running average (Ministry for the Environment and Natural Recourses, 2010) which represents over four times the mean odor threshold of 11 μg m^{-3} (WHO, 2003). Prior research has established the connection between H_2S concentration in nearby towns and cities and weather conditions. Olafsdottir and Gardarsson (2013) reported a correlation between H_2S concentration and wind speed, air temperature and increasing air stability. Kristmannsdottir et al. (2000) reported a negative correlation with precipitation. Thorsteinsson et al. (2013) found occurrence of high H_2S concentration with low atmospheric exchange and autochthonous weather. Field measurements of H_2S include stationary measuring stations (Kourtidis et al., 2008; Susaya et al., 2011) and passive samplers (D'Alessandro et al., 2009; Horwell et al., 2005). Latos et al. (2011) used a hand held device for multiple measurements. To the authors' knowledge, large scale measurements of H_2S, up to 30 km distance from the source, have not been reported before.

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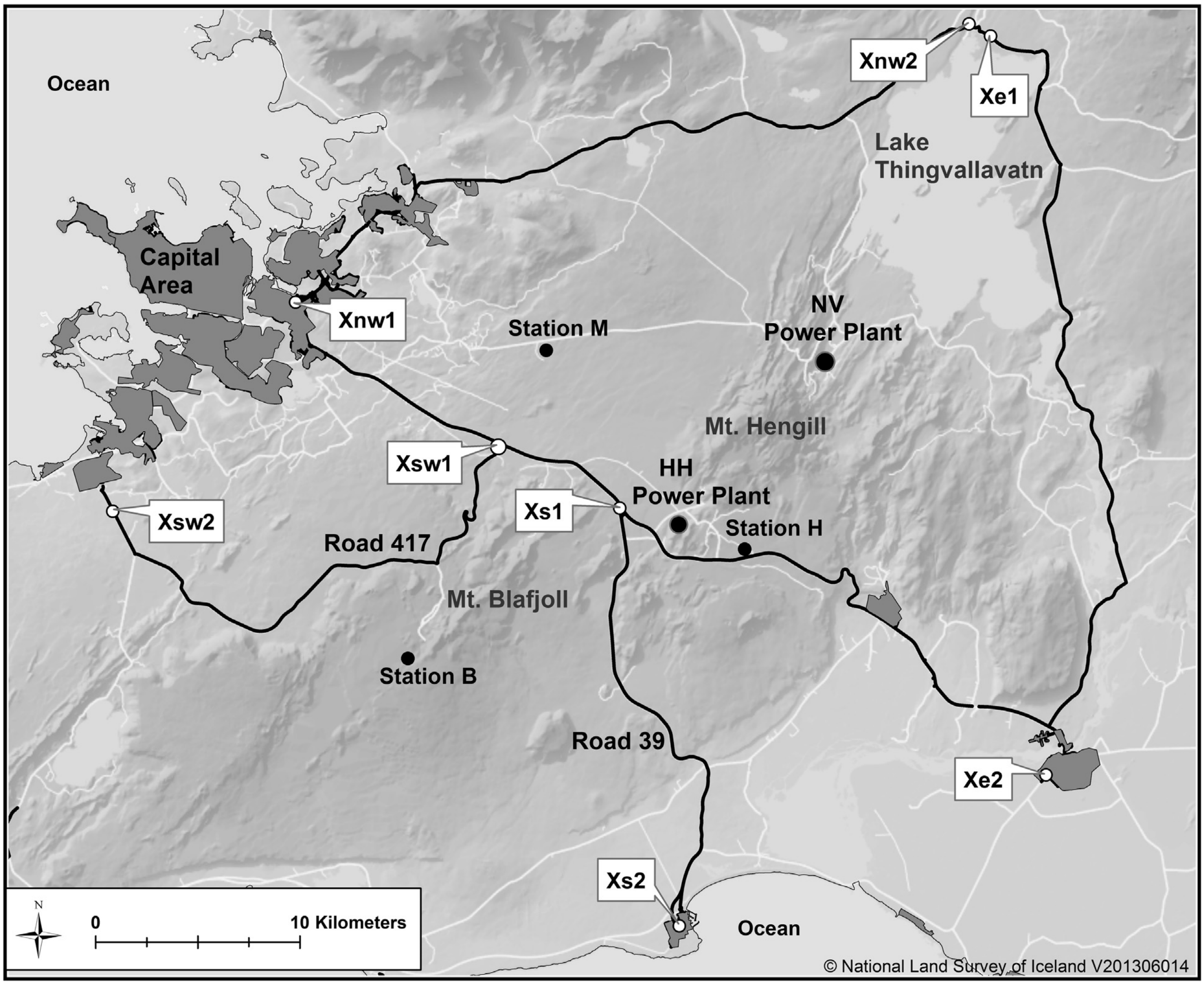

Fig. 1. The study area. Black lines show the measurement roads. Dark shaded areas are the locations of local towns and/or inhabited areas.

Modeling air pollution is an important tool to devise strategies to manage pollution. AERMOD, the recommended model by the US EPA, has been used to model the distribution of various air pollutants including mercury (Heckel and LeMasters, 2011), SO_2, NO_x and PM_{10} (Zhang et al., 2008), and VOC's (Venkatram et al., 2009). The model has also been used to determine H_2S emission rates, based on measurements (O'Shaughnessy and Altmaier, 2011). AERMOD has been found to perform well for modeling buoyant tall stacks in moderate to complex terrain, where samplers were generally between 2 and 8 km from the source (Perry et al., 2005). Seangkiatiyuth et al. (2011) reported that the performance of the model for complex terrain and wind field was problematic for locations more than 5 km from the source. Peralta et al. (2013) found that AERMOD results compared well with measurements when wind direction and speed were stable.

This paper presents results from field measurements of near surface H_2S concentration levels within about 30 km distance of two geothermal power plants situated in a mountainous terrain. Spreading, directionality and strength of plumes were analyzed under different weather conditions and in relation to topological ground features. Selected characteristic events were modeled in AERMOD to identify the importance of meteorology and topography. The analysis provides an enhanced understanding of the behavior of H_2S plumes in complex terrain and therefore a base for predicting H_2S concentration.

2. Methods

2.1. Site description

The study encompasses area up to 30 km from the two geothermal power plants in the Hengill volcanic system. The geothermal power plants Hellisheidi (HH, 260 m.a.s.l.) and Nesjavellir (NV, 180 m.a.s.l.) are 10 km apart, located on each side of Mt. Hengill (max 805 m.a.s.l., Fig. 1). Northeast of the mountain is Iceland's largest natural lake, Lake Thingvallavatn (84 km^2). The NV Power Plant is located near the lake shore in a small valley, with ridges rising 200 m to the west and 100 m to the east. The HH Power Plant is located at the southwest base of Mt. Hengill with Middalsheidi Heath to the west sloping towards the capital of Reykjavik. In the southern part of the area are volcanic fissures with crater rows (Gunnlaugsson et al., 2010). Four local towns are located in the area, in addition to the capital (dark shaded in Fig. 1), as well as a few farms and summer houses. Most of the land is uninhabited, characterized by moss, grass and small shrubs.