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Research paper

The UK22/4b blowout 20 years on: Investigations of continuing methane emissions from sub-seabed to the atmosphere in a North Sea context

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ABSTRACT

The 22/4b blowout occurred in the UK sector of the North Sea in November 1990, but during a survey in September 2011 strong gas emissions still were occurring. This manuscript summarizes the findings of the 2011 survey and subsequent studies, considering them in the context of previous investigations, and the regional geologic and oceanographic environments.

The seabed crater formed during the initial event is still there, as is a previously-undiscovered secondary crater. Seabed bubble flux estimates indicate methane emission rates of 90 L s^{-1} at the time; however, this methane's fate(s) remains unclear. The very strong thermocline that persists for more than half the year acts as an effective barrier to upward migration, despite the presence of strong upwelling flows around the bubble plume. Clearly a large proportion of the methane is advected away from the site to be either oxidized microbially in the water column, or released to the atmosphere as a result of normal sea:air gas exchange processes. Nevertheless, a significant atmospheric methane anomaly persists in the vicinity of the blowout site. This has been constrained to likely less than 0.72 Mscfd (5 kTon yr^{-1}) and possibly less than 0.36 Mscfd (2.5 kton yr^{-1}).

During the late-fall to early spring months (when there is no thermocline), direct methane emissions to the atmosphere are expected to increase significantly. Also, long-term monitoring has shown that periodic eruptive events occur, which likely expel great quantities of methane. These demonstrate the dynamic nature of the system and suggest that migration pathways in and between the deep sub-seabed and seabed remain active.

The *22/4b Study* resulted in the development and adaptation of novel techniques that are applicable to other studies of seabed seepage and the development of a number of critical hypotheses with application to megaplume seepage by natural migration pathways or from the result of anthropogenic intervention.

1. Prologue

1.1. Shallow gas blowout

On 20 November 1990, Mobil North Sea Ltd. (MNSL) encountered shallow gas at 360 m below seabed while drilling in the Quaternary section of exploration well UK22/4b-4 in the UK sector of the North Sea. The well blew out, creating a massive bubble plume (Fig. 1) that rapidly diminished after several days. Remotely Operated Vehicle (ROV) inspection showed gas escaping from a deep crater in the seabed and that the short section of well casing installed to start the drilling had sunk below the seabed level. It was concluded that neither plugging the well nor drilling a relief well were possible, and might lead to secondary uncontrolled leakage to the seabed via new pathways.

The gas plume's vigor was monitored by survey ships and ROVs (remotely operated vehicle) from 1990 to 1998 over which time period; qualitative observations indicated a slow and continuous decrease in strength. Although 22/4b emissions were not deemed a nautical hazard, the site was marked on Admiralty charts.

The first scientific expedition that assessed methane, CH_4, emissions associated with the 22/4b plume in a North Sea context was undertaken in 1994 and found highly elevated CH_4 concentrations in near-surface waters (Rehder et al., 1998; Schneider von Deimling et al., 2015). Rehder et al. (1998) estimated the 1994 blowout emissions were ~25% of the entire North Sea atmospheric methane

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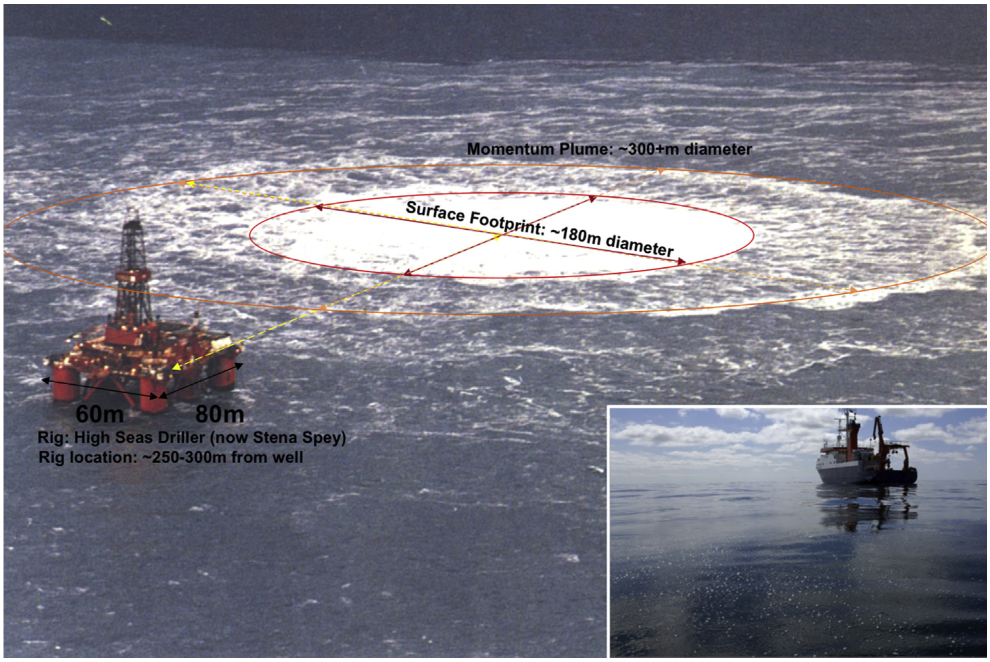

Fig. 1. The 22/4b blowout, November 1990. Approximate diameters of bubble surfacing footprint and momentum plume, shown. Inset. 22/4b surface bubble plume expression during 2005 Alkor Cruise. Inset photo courtesy Peter Linke.

budget – between 1.5×10^9 and 3.1×10^9 mol yr^{-1} (0.024–0.031 Tg yr^{-1}).

In 2000, the UK Dept. of Trade and Industry (DTI) determined that further monitoring was not required as there was no perceived health and safety threat, and no evidence of environmental harm. However, contrary to expectations that it would slowly decrease to negligible magnitude, surveys with the *R/V Alkor* in 2005 (Fig. 1. Inset) found significant bubbles escaping the seabed. A return cruise with the manned submersible JAGO in 2006 documented in sonar and visual observations strong emissions continuing rather than waning, with a visible bubble plume at the sea surface (Schneider von Deimling et al., 2015). A more recent aerial survey in Spring 2010 found bubbles still surfacing in a 10–20 m diameter footprint (Gerilowski et al., 2015).

1.2. The 22/4b *study*

In 2010, the UK Dept. of Environment and Climate Change (DECC, the successor to DTI) initiated the *22/4b Study*, described in a series of papers in this special issue. This large, interdisciplinary, and multi-institutional study included a field campaign, conducted in 2011–2012, and subsequent laboratory studies. The *22/4b Study* sought to assess the current status of the *22/4b* site in order to understand better the nature of the gas discharge and its overall impact on local and regional scales; principally to quantify greenhouse gas emissions to the water column and to the atmosphere. It is the first-ever effort to quantify emissions from such a massive shallow bubble plume, and to collect long-term monitoring data, and is arguably the most comprehensive study of its kind, as revealed by the depth and breadth of manuscripts in this special issue. Furthermore, it led to the development of novel approaches to study seabed bubble emissions, plume processes, and the fate of the emitted gases with standard and novel oceanographic instrumentation.

This special issue presents the findings of the *22/4b Study* and places them within the wider North Sea oceanographic and CH_4 context, comparing them to other efforts to study CH_4 emissions from 22/4b and other North Sea sources. The manuscripts presented herein demonstrate a template for future seep emission investigations, as well as blowout response and monitoring. Significantly, these contributions provide important insights into the role of geologically-sourced CH_4 to atmospheric budgets in a larger North Sea context.

2. Introduction

On a century time-scale, CH_4 is the second strongest greenhouse gas after carbon dioxide, CO_2; however, on a twenty-year (i.e. political) time-scale, its radiative impact is larger than that of CO_2 (IPCC, 2014; Shindell et al., 2012). Furthermore, this estimate likely understates indirect warming contributions from CH_4 (Shindell et al., 2009). In this light, the current, large uncertainties in many CH_4 sources (IPCC, 2014) and greater uncertainty in future trends argues that informed policy decisions require decreasing these uncertainties. This is particularly true given that future trends suggest warmer climate scenarios (Rigby et al., 2008) and future anthropogenic activities (Kirschke et al., 2013; Wunch et al., 2009) likely will increase emissions.

Fossil fuel industrial (FFI) emissions are the largest anthropogenic source (Brandt et al., 2014), releasing thermogenic or "ancient" CH_4; however, so do natural seeps of thermogenic origin. The total global natural geologically-sourced CH_4 budget has been estimated at 45 (Kvenvolden and Rogers, 2005), and 42–64 Tg yr^{-1} (Etiope et al., 2008), but remains poorly constrained at best. The total ancient CH_4 budget has been estimated at 118–175 Tg yr^{-1} (Denman et al., 2007; Lassey et al., 2007). Thus, natural geologic contributions (not-regulatable) comprise 20% or 30% of total ancient emissions, a role discussed in Leifer (2015). The natural marine seepage contribution to atmospheric budgets remains largely unknown because of a paucity of observations and the uncertainty of losses to the water column. In this regard, megaplume seepage – massive bubble plumes releasing more than a million liters per day (Leifer, 2015) – contributes potentially significantly to global budgets, but remains unknown. Given the uncertainties in the "marine