

# ESTIMATION OF THE EFFECTS OF SF<sub>6</sub> AND PFCs RESERVOIR TRACERS ON ATMOSPHERIC QUALITY IN THE NORTH SEA USING DATA FROM THE AEOLUS STUDY

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## ABSTRACT

The 3-D modelling studies of the effects of SF<sub>6</sub> and PFCs reservoir tracers during oil activities on atmospheric quality in the North Sea are presented. Two different domains have been examined under different meteorological fields. Firstly, two different emission scenarios have been applied, a scenario with maximum estimated emissions and a second one with average estimated emissions. As oil rigs emissions do not affect background concentrations under the previously mentioned scenarios, a third one has been applied. In the third scenario, oil rigs emissions are 10<sup>6</sup> times higher than the maximum estimated emissions. Only under these extreme as well as unrealistic emissions, oil rigs emissions affect the atmospheric background concentrations in the domains.

## INTRODUCTION

The oil exploration and production industry uses extensively and depends heavily on non-radioactive tracing substances like SF<sub>6</sub> and PFCs for several purposes related to reservoir characterisation and enhanced oil recovery. These compounds are potent greenhouse gases with very high global warming potential (GWP) and extremely long atmospheric lifetimes. In fact, the Intergovernmental Panel on Climate Change (IPCC) has evaluated them as the two most potent greenhouse classes of substances. Hence, emissions of PFCs and SF<sub>6</sub> are important anthropogenic contributors to global warming and long-term climate change. This document presents the 3-D modelling studies of the effects of SF<sub>6</sub> and PFCs reservoir tracers on atmospheric quality in the North Sea.

## METHODS

The Urban Airshed Model – Aerosols (UAM-AERO) [1] that we use in this study, is a gas/aerosol model that is based on the air quality model UAM version IV (UAM-IV) [2]. The procedures used in the UAM-AERO model to simulate gas-phase chemical reactions and dry deposition of gases are similar to those in the UAM-IV. For this simulation UAM-AERO was used with the SAPRC90 chemical mechanism. The SAPRC90 chemical mechanism comprises fifty chemical species (eleven fast reacting; thirty slow reacting; seven steady state and two constant species, CH<sub>4</sub>, H<sub>2</sub>O), solar radiation and one hundred thirty chemical reactions. Primary emissions of organic compounds are assigned to nine lumped classes. The specific mechanism is also designed to simulate the production of condensable organic species from the oxidation of

higher molecular weight gaseous VOCs. The physical processes considered are: advection, turbulent diffusion, condensation and evaporation, coagulation, emissions, nucleation and deposition. The 3-D model was applied in two areas of the North Sea, namely, North and South domains, with important emissions of SF<sub>6</sub> and PFCs under different meteorological conditions. The North domain on which UAM-AERO was applied was a 30x30 grid system, with horizontal grid increments of 10 km in both directions while the South domain was a 40x68 grid system with horizontal grid increments of 10 km in both directions (Figure 1).

In both domains, 10 vertical layers were used of variable thicknesses with elevation up to 10 km above sea or ground level, 4 under and 6 above the diffusion break. The domains were chosen in such way to include all the

oil-rigs allowing at the same time enough space for atmospheric dynamics to develop appropriately. The pollutant concentrations at the domain boundaries were assumed to be equal to the background concentrations. Data from hourly gridded emissions of NO, NO<sub>2</sub>, CO, CO<sub>2</sub>, SO<sub>2</sub>, C<sub>6</sub>F<sub>12</sub>, C<sub>7</sub>F<sub>14</sub>, C<sub>8</sub>F<sub>16</sub> and SF<sub>6</sub> were used as initial conditions in addition to pollutant concentrations data from the literature. Meteorological data from HIRLAM model available every six hours over a two year period were processed using a methodology developed in the framework of this work [3]. This manipulation of data has resulted in the determination of specific weather types characterising the region. The application of the proposed methodology on the North domain identified 11 representative days. We have focused our attention on the 2nd representative day, the 24th of May 2002. The Mean Sea Level pressure at midday was 1002.2 mb, and in a general decreasing pattern of 3.8mb in the 12 hour interval between 06.00

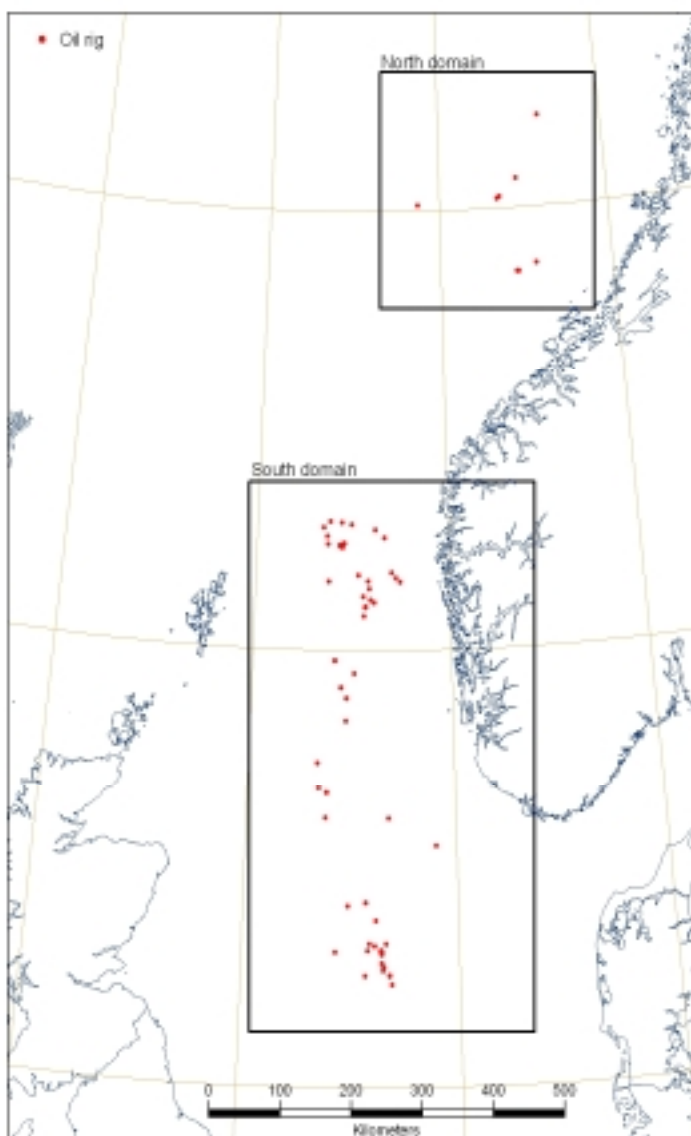


Figure 1: Map of the domains

and 18.00. This weather presents all the major characteristics exhibited by a cold front. Wind was blowing from North at a speed of 3 m/s and the air temperature was ~ 8 degrees. Only few clouds were present. For the South domain 10 representative days were identified. We have also examined the date of the 27th of May 2001. The Mean Sea Level pressure at midday was 1013.6 mb, and in a general decreasing pattern of 2.1mb in the 12 hour interval between 06.00 and 18.00. This weather corresponds to the warm part of a front. Wind was blowing from the south west at a speed of 5 m/s and the temperature was ~ 9.8 degrees. Scattered clouds were present. The 3-dimensional meteorological fields have been calculated using appropriate UAM pre-processors. The UAM-AERO model was applied for 24 hours simulating all cases of characteristic weather types. It should be noted that while the distributions vary significantly under the different weather types, the maximum concentrations of tracers remain similar.

We have applied three different emission scenarios (Table 1). The first two scenarios are realistic scenarios using calculated values for the maximum and average emissions from the oil rigs. Due to the low tracer concentrations in the area, a third emission scenario is applied. It is named worst case scenario with very high and totally unrealistic values. According to this scenario, the released to the atmosphere tracers are determined by assuming that their mass was released over a smaller window of time (approximately one and a half years) compared to the more realistic case (of a few years). This window has been defined as the time of maximum release of the tracers according to the in-situ measurements.

Scenarios	PDMCH [C <sub>8</sub> F <sub>16</sub> ] (mg/day)		PMCH [C <sub>7</sub> F <sub>14</sub> ] (mg/day)		PMCP [C <sub>6</sub> F <sub>12</sub> ] (mg/day)		SF <sub>6</sub> (mg/day)	
	<i>North Domain</i>	<i>South Domain</i>	<i>North Domain</i>	<i>South Domain</i>	<i>North Domain</i>	<i>South Domain</i>	<i>North Domain</i>	<i>South Domain</i>
<b>Maximum</b>	2.62E-01	1.35E+00	1.57E-01	5.95E+00	1.81E+00	5.75E-01	0.00E+00	1.09E+00
<b>Average</b>	9.03E-02	4.20E-01	6.70E-02	4.56E-01	5.81E-01	9.21E-02	0.00E+00	1.10E-01
<b>Worst case</b>	2.84E+05	5.77E+05	2.92E+05	5.36E+05	5.73E+05	1.40E+05	0.00E+00	1.49E+06

Table 1: SF<sub>6</sub> and PFCs tracers emissions

## RESULTS AND DISCUSSION

Figures 2 and 3 present the spatial distributions of tracers for the time that their maximum concentrations are calculated, for North and South domains, respectively. Moreover, the vertical profiles for a specific grid cell where the maximum concentration are predicted by the model are presented. In order to make these plots, the model was firstly applied with both the background concentrations and the emissions. But due to the high background concentrations and the low emissions of the tracers from the oil rigs the impact of the emissions of PFCs and SF<sub>6</sub> on the atmospheric background concentrations weren't visible. Thus the model was applied once more but considering only the background concentrations without taking into consideration the tracer's emissions. By ignoring the application of the model with the background concentrations and the emissions, the estimated concentrations and the net impact of the oil rigs is calculated, and is presented in the figures below.

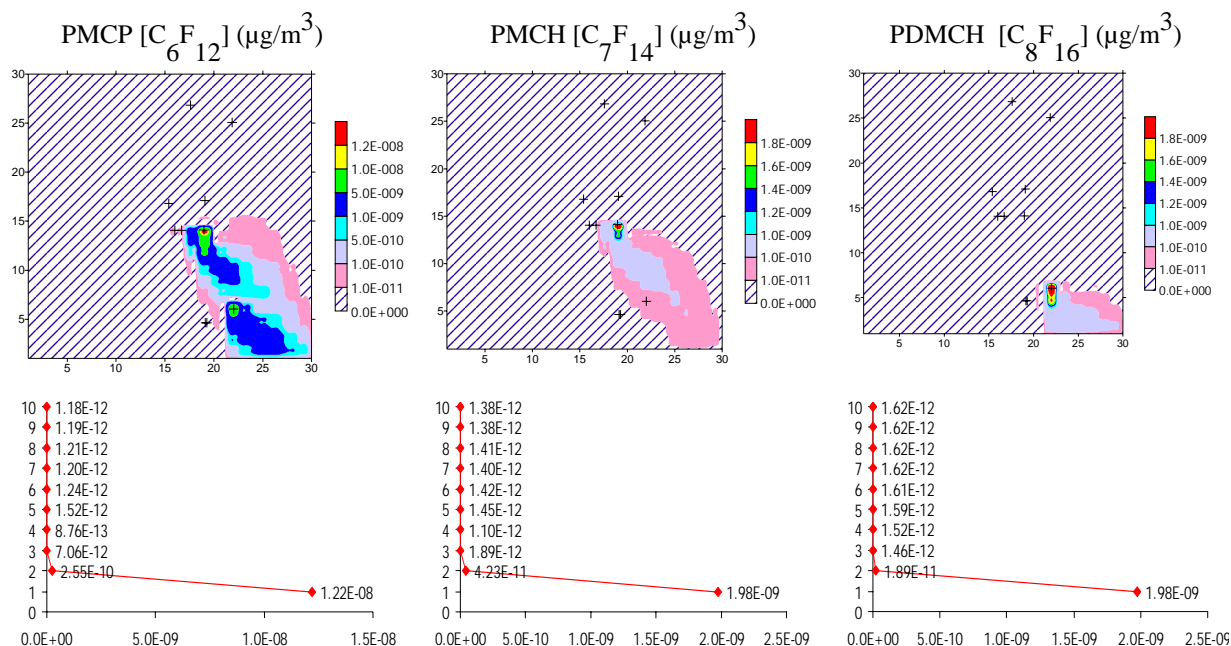


Figure 2a: PFCs concentration based on maximum emissions scenario (North Domain)

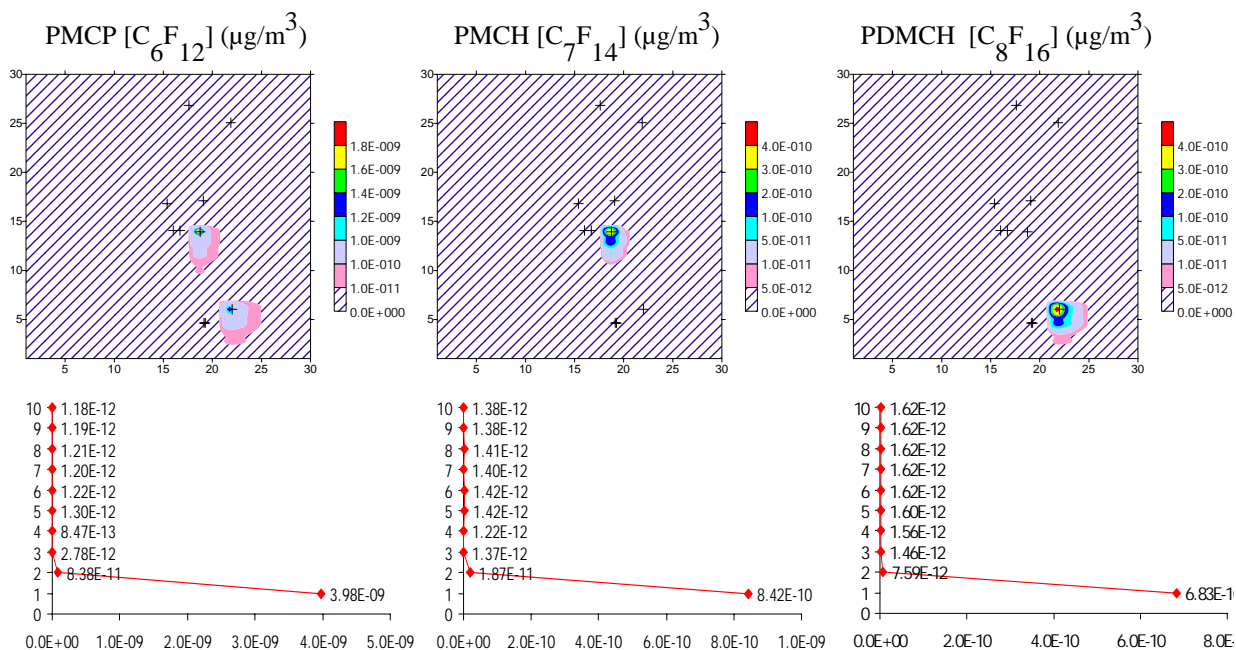


Figure 2b: PFCs concentration based on average emissions scenario (North Domain)

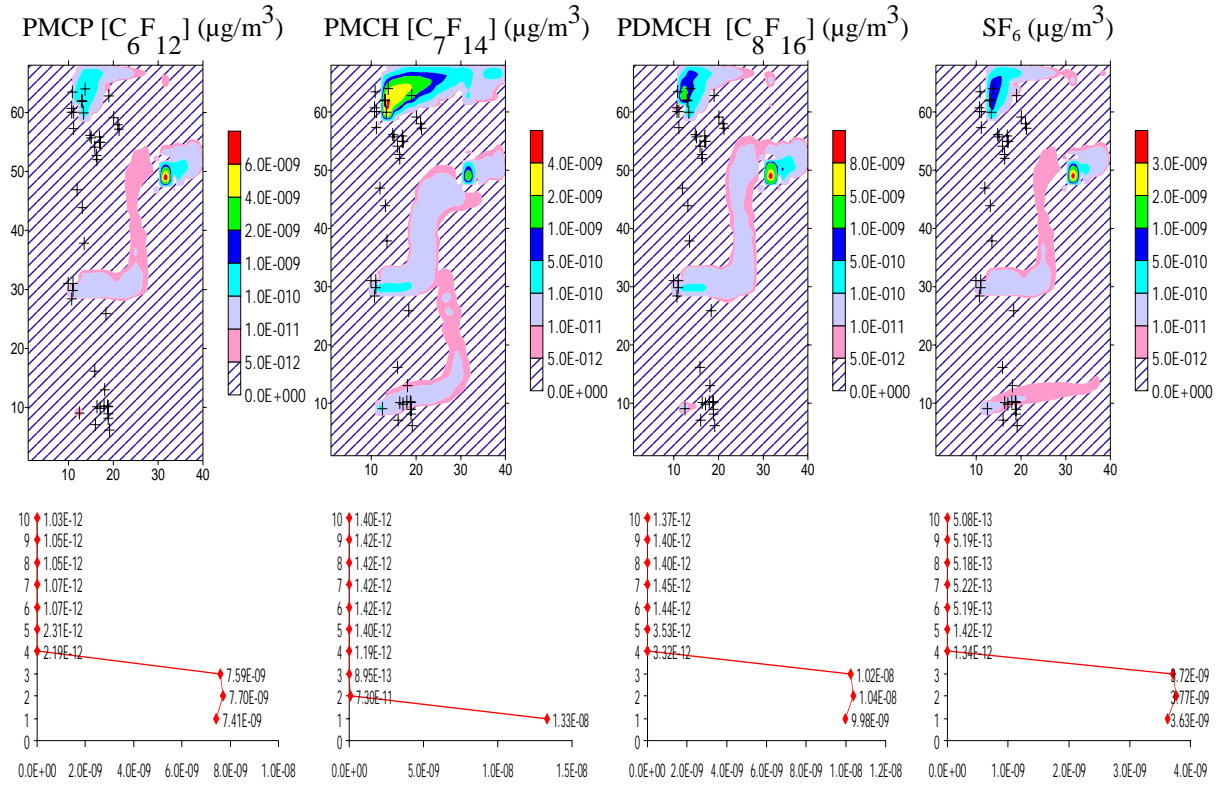


Figure 3a: PFCs and  $\text{SF}_6$  concentration based on maximum emissions scenario (South Domain)

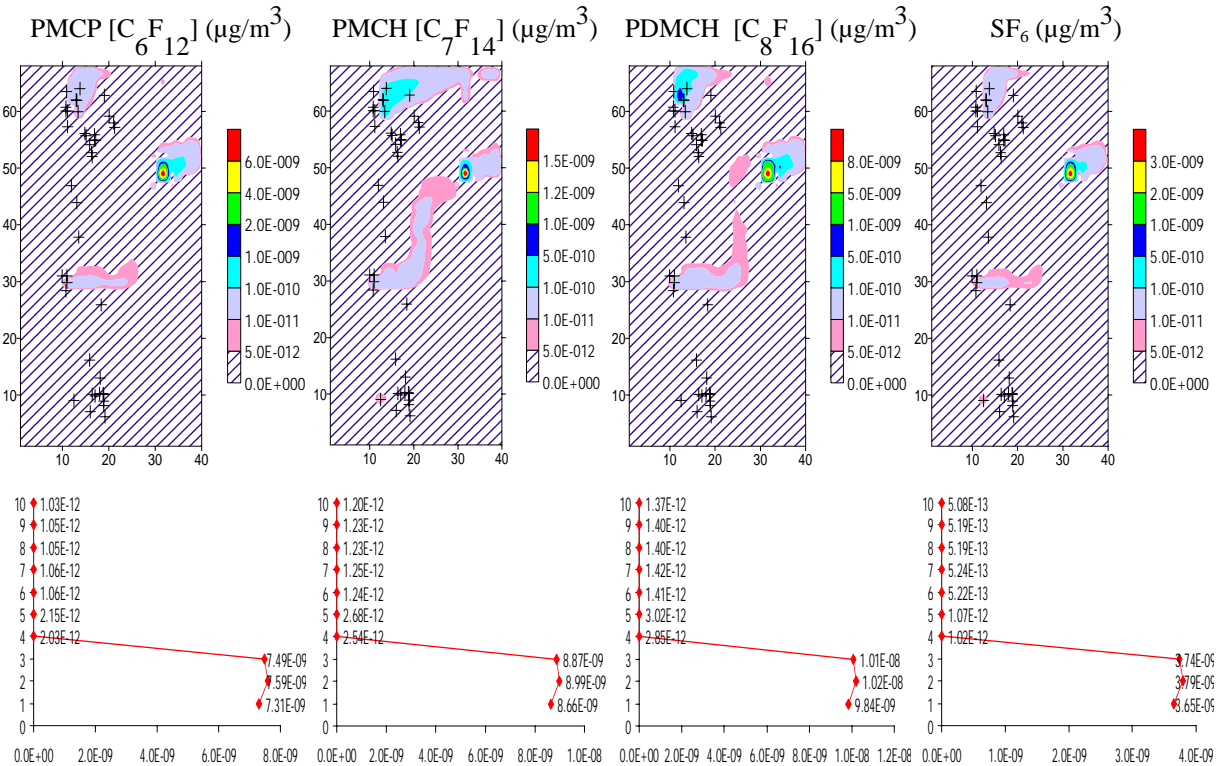


Figure 3b: PFCs and  $\text{SF}_6$  concentration based on average emissions scenario (South Domain)

The reported background atmospheric concentrations for the tracer of interest are:  $56 \times 10^{-6} \mu\text{g}/\text{m}^3$  for PMCP [ $\text{C}_6\text{F}_{12}$ ],  $66 \times 10^{-6} \mu\text{g}/\text{m}^3$  for PMCH [ $\text{C}_7\text{F}_{14}$ ],  $99 \times 10^{-6} \mu\text{g}/\text{m}^3$  for PDMCH [ $\text{C}_8\text{F}_{16}$ ] and  $21 \times 10^{-3} \mu\text{g}/\text{m}^3$  for  $\text{SF}_6$  [4, 5]. So, the net impact of oil rigs tracers' emissions on both domains concentrations are at least  $10^{-2}$  times lower for PFCs and  $10^{-6}$  times lower for  $\text{SF}_6$ , even in the maximum emission scenario. Moreover, in the vertical profile modified concentrations appear up to the 4<sup>th</sup> layer. As these compounds are potent greenhouse gases with very high global warming potential (GWP) and extremely long atmospheric lifetimes, emissions of PFCs and  $\text{SF}_6$  should be considered regarding their impact on global warming. Thus, the current level of emissions from the North Sea oil fields seem to have not noticeable direct radiative effect on regional climate forcing. But they should be carefully used, as the global long-term effect of the cumulative concentrations of the tracer gases may, however, be significant due to the extremely long atmospheric lifetimes.

Due to the minor impact of oil rigs emissions on air quality, a third emission scenario was examined. According to this scenario, the amount of tracers in gas phase was released to the air from the production wells during a specific window in time, which was rather narrow compared to reality. Figures 4 and 5 present the spatial distributions of tracers for the time that their maximum concentrations were calculated, for North and South domains respectively, using the worst case emission scenario. Moreover, the vertical profiles for a specific grid cell where the maximum concentration were predicted by the model are presented.

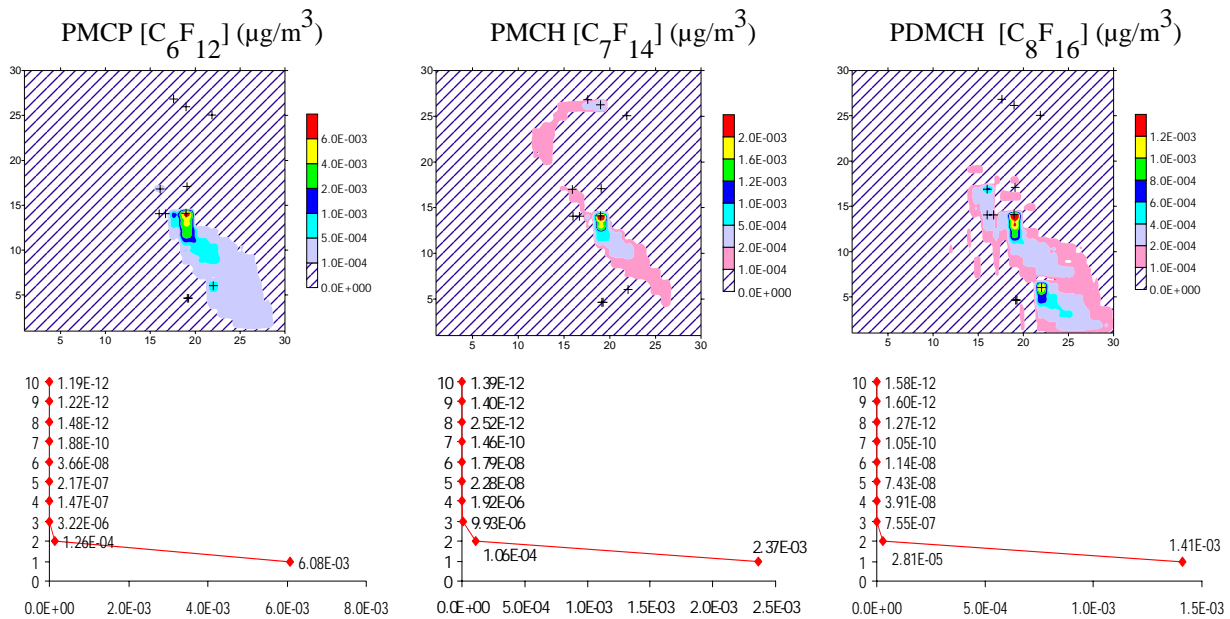


Figure 4: PFCs concentration based on worst case emission scenario (North Domain)

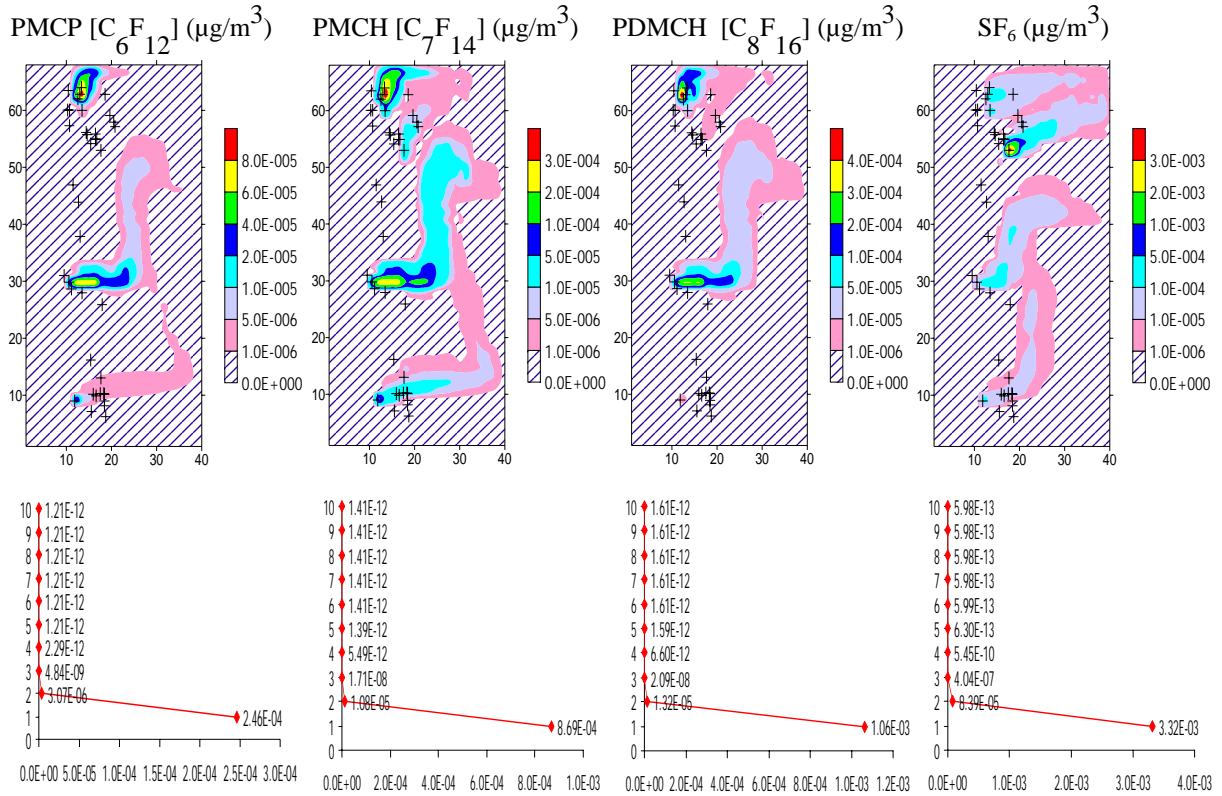


Figure 5: PFCs and SF<sub>6</sub> concentration based on worst case emission scenario (South Domain)

In the worst-case scenario a significant impact of oil rigs emissions was calculated on the air quality of both domains. In particular, PFCs concentration due to oil rigs emissions was increased up to  $10^3$  times although SF<sub>6</sub> was found at the same order of magnitude compared to the background concentrations. The emissions of SF<sub>6</sub> and PFCs were seen to affect large parts of the domains, depending on the prevailing weather conditions. In most cases studied, emissions of SF<sub>6</sub> and PFCs affect large areas over the Norwegian land. In the vertical, the model predicted modified concentrations of the emitted constituents up to the 7<sup>th</sup> layer.

## CONCLUSIONS

Atmospheric background concentrations of PFC's and SF<sub>6</sub> are not affected by the emissions of the oil rigs in the scenarios compiled with realistic emissions. In the vertical, modified concentrations appear up to the 4<sup>th</sup> layer. Thus, it is expected that the current level of emissions in the North Sea oil fields not to have noticeable direct radiative effect on regional climate forcing. But, they should be carefully used as the global long-term effect of the cumulative concentrations of the tracer gases may, however, be significant.

## **ACKNOWLEDGMENTS**

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