Urban Climate 10 (2014) 801–814

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com/locate/uclim

A proxy for air quality hazards under present and future climate conditions in Bergen, Norway

Tobias Wolf *, Igor Esau

Nansen Environmental and Remote Sensing Center/Bjerknes Centre for Climate Research, Thormøhlensgt. 47, 5006 Bergen, Norway

ARTICLE INFO

Article history:
Received 31 January 2014
Revised 11 October 2014
Accepted 16 October 2014

Keywords:
Air quality
Climate change
Atmospheric blocking
Mountain meteorology

ABSTRACT

This study reports a statistical analysis of air quality observations in Bergen, Norway over 2003–2013. We linked high levels of air pollution (NO_2 concentrations >150 μg m^{-3}) to the regional atmospheric circulation through a meteorological proxy index. We used the proxy index to characterize the potential for air quality hazards in Bergen using: (i) ERA-Interim for the period 1979–2013; and (ii) climate change simulations with the Norwegian Earth System Model (NorESM) for the period 1950–2100. We found that the recent air quality hazards in 2009–2011 were rather exceptional in the historical reanalysis data and the climate simulations over the considered 150 years. The atmospheric conditions favourable to frequent air quality hazards on seasonal time scales were observed in ERA-Interim only for 7 (out of 34) winters. The climate simulations with NorESM do not project a significant change in the frequency and persistence of the potential air quality hazards until 2100. The NorESM simulations suggest a significant role of the decadal (10–15 years) variations in the regional atmospheric circulation. If the timing of those variations is controlled by the anthropogenic forcing, the simulations project on average less frequent air quality hazards up to the mid 2020s.

* Corresponding author.
E-mail address: tobias.wolf@nersc.no (T. Wolf).

http://dx.doi.org/10.1016/j.uclim.2014.10.006
2212-0955/

1. Introduction

Urban air quality is one of the concerns in the development of regional climate change adaptation strategies. The air quality scenarios include a product of two variables to be assessed and projected: (i) the change in frequency and persistence of certain atmospheric conditions, which favour the accumulation of atmospheric pollutants; and (ii) the change in the pollutant emission rates. In Bergen, Norway, air quality is mainly affected by emissions from road traffic. Therefore, this study is limited to the analysis of the air quality as expressed through concentrations of nitrogen dioxide (NO_2), μ_{NO_2} in the near surface air that is mostly emitted from road traffic.

Over the last decades, the Norwegian environmental policy has been predominantly focussed on the reduction of carbon emissions. This policy indirectly set preference to cars with diesel engines, which has resulted in raising NO_2 emission rates (Sundvor et al., 2012). Fig. 1 shows the gradual change in the number and fraction of cars with diesel engines in Hordaland county, where Bergen is located. The number of diesel cars on the roads has more than doubled since 2003. Despite such a change, the raising NO_2 emissions did not make a significant footprint in the measured μ_{NO_2} over several years (2003–2009) due to enhanced atmospheric storminess. The passing winter storms ventilated the Bergen valley preventing the accumulation of the air pollutants in the stably stratified boundary layer. The recent cold winter seasons 2009/10 and 2010/11 that created a demand for new research (Yang and Christensen, 2012) made this footprint visible. Fig. 1 shows that the meteorological variations in μ_{NO_2} are far larger than those due to the change in road traffic and engine types.

The winters 2009–2011 revealed a lack of knowledge about the dynamical and physical mechanisms controlling the air quality in the city (Esau, 2012). Moreover, these events revealed a lack of preparedness for proper action and the failure of air quality models to predict the air quality hazards. The subsequent debates in mass media have transformed into a societal request to assess meteorological conditions favourable to air quality hazards in a historical perspective and to project the related risks (probability of severe seasonal air quality hazards) in perspective till 2025 and till the end of the 21st century (e.g. Colette et al., 2012).

Bergen (located at 60.4°N, 5.3°E) is the second largest city in Norway. The central part of Bergen is located in a relatively deep and narrow valley at the Norwegian western coast. The city repeatedly experienced episodes of air quality hazards, defined in this study as $\mu_{NO_2} > 150\ \mu g\ m^{-3}$. The measured μ_{NO_2} is mostly determined by the emissions from road traffic and to a lesser degree from ships (Bergen Kommune and Statens Vegvesen, 2013). The measured μ_{NO_2} does not strictly follow the emission cycle, which peaks with the morning (07:00–09:00 local time) and the evening (15:00–17:00 local time) rush hours, but varies on a multitude of time scales (Fig. 2). Air quality hazards occur almost exclusively under low-level temperature inversions in connection with low cloudiness and weak winds during the extended winter season from November through February (Wolf et al., 2014). Under such

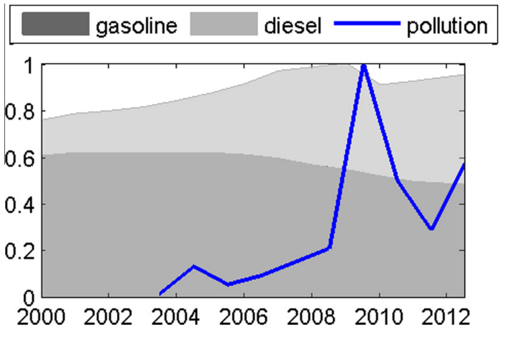

Fig. 1. The total number (normalized to unity) of registered vehicles in the Hordaland county (including Bergen) in 2000–2012 (Bergen Kommune and Statens Vegvesen, 2013). The gray shading shows fractions of vehicles with gasoline and diesel engines. The blue line shows the number of days per winter season in Bergen (normalized to unity) with at least one hourly measurement with $\mu_{NO_2} > 150\ \mu g\ m^{-3}$.