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The influence of future non-mitigated road transport emissions on regional ozone exceedences at global scale

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HIGHLIGHTS

- Regional trend studies regarding NO_x emissions across all transport and industrial sectors between 2000 and 2050.
- Assessment of global air quality for the year 2000 using the EC recommendation for exceedence limit.
- Identification of the most sensitive world regions in terms of a policy failure for road traffic emissions.
- Assessment to whether mitigation of road traffic emissions is crucial for meeting future air quality standards.

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ABSTRACT

Road Transport emissions (RTE) are a significant anthropogenic global NO_x source responsible for enhancing the chemical production of tropospheric ozone (O_3) in the lower troposphere. Here we analyse a multi-model ensemble which adopts the realistic SRES A1B emission scenario and a "policy-failure" scenario for RTE (A1B_HIGH) for the years 2000, 2025 and 2050. Analysing the regional trends in RTE NO_x estimates shows by 2025 that differences of 0.2–0.3 Tg N yr^{-1} occur for most of the world regions between the A1B and A1B_HIGH estimates, except for Asia where there is a larger difference of ~1.4 Tg N yr^{-1}. For 2050 these differences fall to ~0.1 Tg N yr^{-1}, with shipping emissions becoming as important as RTE. Analysing the seasonality in near-surface O_3 from the multi-model ensemble monthly mean values shows a large variability in the projected changes between different regions. For Western Europe and the Eastern US although the peak O_3 mixing ratios decrease by ~10% in 2050, there is an associated degradation during wintertime due to less direct titration from nitric oxide. For regions such as Eastern China, although total anthropogenic NO_x emissions are reduced from 2025 to 2050, there is no real improvement in peak O_3 levels. By normalizing the seasonal ensemble means of near-surface O_3 (0–500 m) with the recommended European Commission (EC) exposure limit to derive an exceedence ratio (ER), we show that ER values greater than 1.0 occur across a wide area in the Northern Hemisphere for boreal summer using the year 2000 emissions. When adopting the future A1B_HIGH estimates, the Middle East exhibits the worst regional air quality, closely followed by Asia. For these regions the area of exceedence (ER > 1.0) for 2025 is ~40% and ~25% of the total area of each region, respectively. Comparing simulations employing the various scenarios shows that unmitigated RTE increases the area of exceedence in the Middle East by ~6% and, for Asia, by ~2% of the total regional areas. For the USA the area of exceedence approximately doubles in 2025 as a result of un-mitigated RTE, with the most exceedences occurring in the southern USA. The effects across the various

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regions implies that unmitigated RTE would have a detrimental effect on regional health for 2025, and potentially offset the benefits introduced by mitigating e.g. international shipping emissions. By 2050 the further mitigation of non-transport emissions results in much cleaner air meaning that mitigation of RTE is not critical for achieving the defined limits in many world regions.

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1. Introduction

High concentrations of tropospheric ozone (O_3) near the Earth's surface has a range of detrimental effects including increased mortality (Bell et al., 2004), decreased crop production (Hollaway et al., 2012) and impaired visibility (Sillman, 2003). Recently, it has been shown that nitrogen oxide emissions (NO_x) from road transport have been an important contributor towards tropospheric O_3 mixing ratios in the lower troposphere at the beginning of this century (Hoor et al., 2009). Estimates in the SRES A1B emission scenarios (Nakicenovic et al., 2000) predict a reduction in global Road Transport Emissions (RTE) of NO_x from $\sim$9 Tg N yr^{-1} (2000) to $\sim$7 Tg N yr^{-1} (2025), followed by a further reduction to $\sim$2 Tg N yr^{-1} (2050), assuming the efficient application of mitigation technologies. It is estimated that A1B SRES has provided the most realistic emission estimates to date from the different SRES scenarios, where the integrated global anthropogenic emissions are thought to have exceeded the A1B estimates up to 2008 (Garnet et al., 2008). More recently there has been a decline in anthropogenic NO_x emissions associated with the global economic crisis, where trends observed from space have shown there has been a significant impact of economic activity on regional emission trends (e.g. Lin and McElroy, 2011). The assumed reduction in global RTE for future decades means that their influence on atmospheric composition could diminish (Koffi et al., 2010). However, there is the possibility that the estimated reductions in RTE are not attained, resulting in a so-called 'policy-failure' scenario (A1B_HIGH). Given the ubiquitous use of road transport in many world regions such a 'policy-failure' has the potential to prolong the time-scale needed in achieving air quality targets, which have been legislated for in future decades.

Here we analyse the results of a multi-model ensemble study performed using large scale atmospheric chemistry-transport models as part of the recent EU-QUANTIFY project (Quantifying the Climate Impact of Global and European Transport Systems; http://www.pa.op.dlr.de/quantify/) where the focus was on the effects of Transport Emissions (TE) on global atmospheric composition. First we analyse the regional trends in NO_x emissions between 2000 and 2050 as estimated in the A1B and the "policy-failure" scenario regarding RTE. Then we investigate the consequences A1B_HIGH would have on regional air quality in terms of tropospheric O_3 for a number of important world regions over the coming decades. By using exposure recommendations provided by the EC regarding safe air-quality standards for O_3, we subsequently determine which world regions exhibit the highest sensitivity towards unmitigated RTE and assess the extent to which this affects exceedences above the defined threshold that is deemed safe.

2. Trends in regional NO_x emission estimates between 2000 and 2050

By examining the global trends in NO_x emissions from each of the different transport sectors defined in the SRES A1B and A1B_HIGH scenarios (Nakicenovic et al., 2000; Hodnebrog et al., 2011) it has been shown that A1B_HIGH estimates that the road sector will release the highest global NO_x emissions across all transport sectors by 2025 (equal to $\sim$9.5 Tg N yr^{-1}) and will be the second most important by 2050 after shipping (equal to $\sim$3 Tg N yr^{-1}). Fig. 1 shows the global surface distribution of RTE annual NO_x emissions for the year 2000. The RTE NO_x from Europe, the US and Taiwan/Korea/Japan are an order of magnitude larger than those estimated for either India or China.

Here we decompose the global trends in RTE NO_x for a number of world regions containing large urban centres, namely: Europe (20°W–30°E, 37–70°N), the USA (60–140°W, 30–54°N), Asia (60–140°E, 10°S–60°N), South America (30–90°W, 40°S–10°N), Africa (20°W–50°E, 14°N–36°S) and the Middle East (16–60°E, 14–40°N). Each of these regions is clearly defined in Fig. 1 and shown as the solid lines. The smaller sub-regions shown within the black dashed lines are used for analysis in Section 4.

Fig. 2 shows the emission trends across the timeline 2000–2050 for both the A1B and A1B_HIGH. For clarity the trend in the absolute differences in RTE between the A1B and A1B_HIGH are shown. in the upper right panel in Tg N yr^{-1}. Also shown are the corresponding regional NO_x trends for shipping, aircraft (scaled up five-fold) and the cumulative emissions from industrial/domestic/biomass burning sectors (hereafter referred to as the non-transport sector (NTS)). Although the largest regional NO_x emissions come from the NTS, integrating the contribution across all transport sectors shows that the total contribution approaches $\sim$50% of that from the NTS in 2025. As for the global emission trends shown in Hodnebrog et al. (2011), the contribution to regional NO_x from RTE in the A1B_HIGH scenario dominates the other transport sectors in 2025. This dominance of RTE is in spite of the rapid increase in air transport, which introduces a rather low regional NO_x emission. For 2050, the NTS is either equal to or lower than that in 2025 due to mitigation and the implementation of technological developments. For RTE NO_x emissions become either comparable to (e.g. South America) or lower than (e.g. Asia) those from the shipping sector.

Analysing the regional NO_x emission trends shown in Fig. 1 reveals that the Asian region has the largest RTE of NO_x across the entire timeline, with the annually integrated RTE being approximately double those of Europe and the USA for future decades. For A1B_HIGH, this results in an extra emission of $\sim$1.4 Tg N yr^{-1} from Asia by 2025, which decreases to $\sim$0.4 Tg N yr^{-1} by 2050. For the Middle East (ME), A1B_HIGH results in this region becoming the second most important region for RTE by 2050 and for South America, A1B_HIGH results in the trend in RTE exhibiting a modest increase by 2025 (equating to differences of $\sim$0.2–0.3 Tg N yr^{-1}). For most of the world regions shown the additional NO_x from RTE A1B_HIGH falls to $\sim$0.1 Tg N yr^{-1} by 2050 when compared to A1B, thus being negligible in terms of total global N emissions.

3. Methodology

3.1. Multi-model ensemble

The multi-model ensemble used here is similar to that used to assess the present-day and future impact of TE on tropospheric composition and oxidative capacity (Hoor et al., 2009; Hodnebrog et al., 2011, 2012). For the purpose of this study the ensemble includes five independent members, these being: TM4, OSLO CTM-2,

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