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Implications for mitigation strategies on air pollution under climate change

We have first estimated the impact of climate change on the chemical composition of the troposphere due to changes in climate from current climate (2000-2010) looking 20 to 40 years ahead, and then investigated the impact of mitigation of emissions of ozone precursors for ozone formation under current as well as future climate. Two sets of calculations have been performed, one by FZJ/UiO and the other one by met.no.

In the FZJ/UiO calculation, to be described in section 1, the climate projection was made by the ECHAM5 model for 2040-2050 and was followed by chemistry-transport modelling using a global model, Oslo CTM2. The second calculation, performed by met.no and presented in section 2, was done with the HIRHAM model and the chemical transport model of EMEP/Meteorological Synthesizing Centre West. The latter calculation focused on a shorter time horizon, 2025-2035 and additional emission scenarios.

In this report we look at carbon monoxide (CO), surface ozone (O_3), and particulate matter, which all are measures of primary and secondary air pollution.

1) The FZJ/UiO calculation with ECHAM5/OsloCTM2

Changes in climate from 2000-2010 to 2040-2050 predicted by the ECHAM5 model

ECHAM5 has been run for this study in CityZen from year 2000 to year 2050. It was run using pre-calculated sea surface temperatures (SST) from a coupled climate model run with ECHAM5/MPIOM from the IPCC AR4 assuming emissions of greenhouse gases and aerosols according to scenario A1B. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system, where A1B assumes a balance across all energy sources. The change in climate parameters has been reviewed in Deliverable Report 2.3.1 and is only briefly mentioned here. Temperatures increase in the 40-year period from 2000-2010 to 2040-2050 in the troposphere and decrease in the stratosphere, in agreement with known impacts of greenhouse gases. The warming, in Northern Hemisphere summer, was in general larger over continents than oceans, and with marked warming at high latitudes. There are also regions with cooling, most noticeably over the North Atlantic Ocean. In parts of Europe and China regional cooling from aerosols is evident, opposing the large scale warming due to the greenhouse gases. As expected, a warmer troposphere in 2040-2050 has a higher specific moisture. The pattern of moistening to a large extent follows the pattern of warming, so that e.g. Europe will gain less. Other parameters in the water cycle that impact the atmospheric chemistry are precipitation and cloud cover, regulating wet deposition of water soluble chemical species and thus radiative transfer and photo-dissociation rates respectively. Changes in these two parameters are clearly related to atmospheric moisture and also to each other. At low and mid latitudes, the fraction of mid and high level clouds decreases, whereas there is an increase in the fraction of low level clouds. The low level clouds increase their fraction in parts of Europe, whereas they decrease their fraction in other parts. Over India there is a noticeable decrease in precipitation as well as in cloud fraction. In China precipitation increases in the central and southern parts, whereas there is a drying in the north. Low level clouds follow the same pattern, with increased cloudiness in the south and decreased in the north.

Emission scenarios for 2050

We have estimated the changes in chemistry due to changes in anthropogenic emissions, adopting two scenarios where certain mitigation measures represent the only difference. We have selected the HIGH-CLE and the HIGH-FROZEN scenarios for this purpose. The HIGH-FROZEN scenario assumes that there is no change in future pollution policies relative to 2005. The combustion technologies/abatement measures are assumed not to change beyond the year 2005 technologies for the entire period 2000-2050. While for OECD countries, this implies a continuation of current high levels of control, for many developing countries where air quality legislation are only very recently becoming implemented, this could mean a continuation of low legislation levels as in the past. There is also no implementation of policies on energy access, although increasing economic growth leads to a slowly declining use of dirty solid fuels for cooking and heating in developing regions. As a result pollution levels in this scenario are the highest among the scenarios described.

The HIGH-CLE scenario is identical to the case described above in terms of energy structure and no specific policies on climate change and energy access. However, it assumes full implementation of all current and planned air pollution legislation world-wide until 2030. Thus this scenario provides a measure of the impact of current and planned air pollution policies in the absence of any specific climate or energy access policy.

The anthropogenic emissions of CO and NOx in the two scenarios are shown in Figures 1 and 2 along with the difference between the two. We see that in Europe emission legislation will result in reductions in emissions of CO as well as NOx in the mitigation case. All across Europe CO (Figure 1) and NOx (Figure 2) emissions are lower in HIGH-CLE than in HIGH-FROZEN. Naturally, this is the case all over the globe. In absolute terms, the difference between the two, and thus the impact of mitigation, is largest in Asia, most notably in large parts of India and China where the emissions before mitigation are clearly highest.

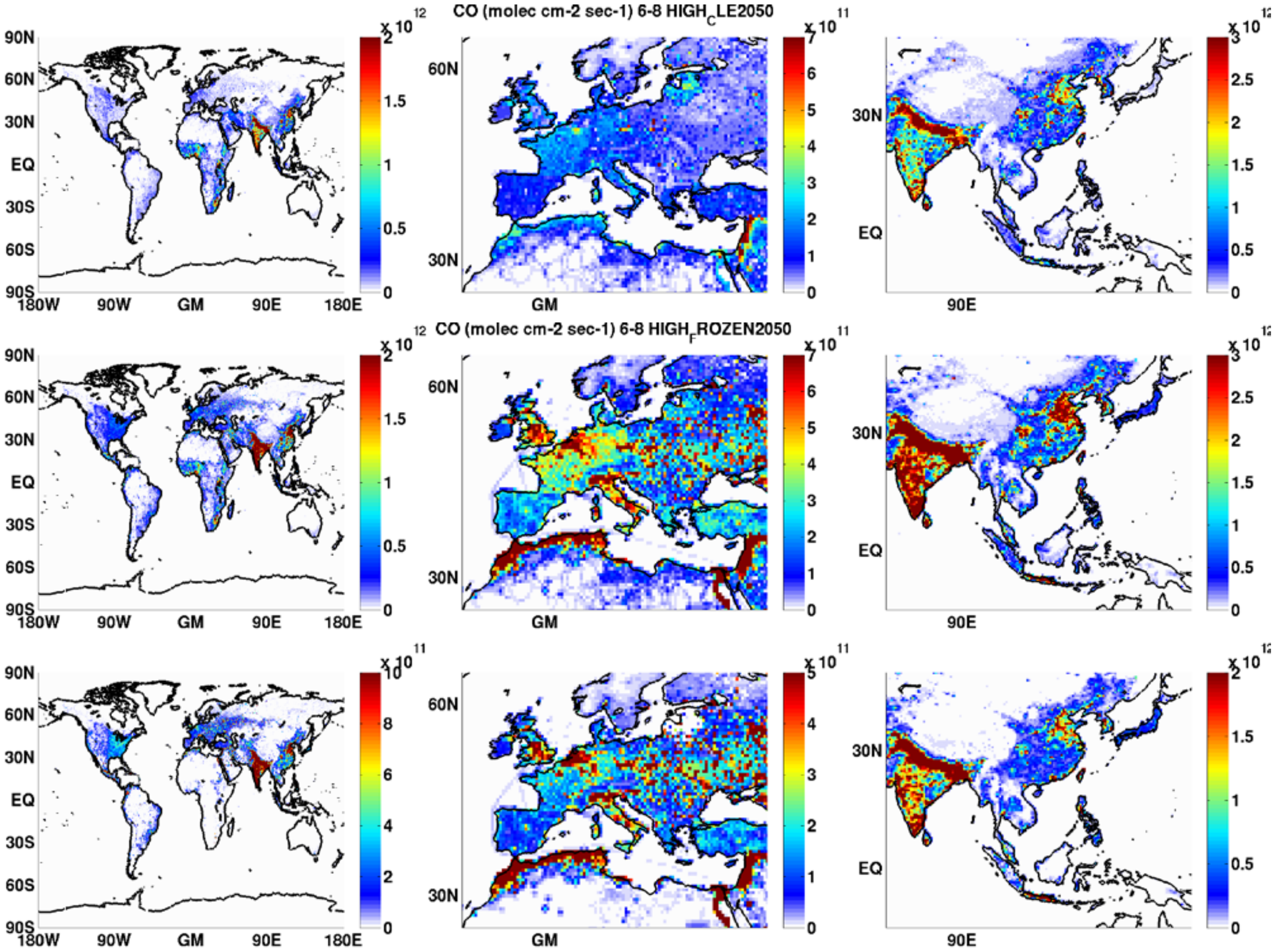


Figure 1: Anthropogenic emissions of CO (molec cm^{-2} s^{-1}) in the period June-August for the 2050 HIGH CLE (top) and HIGH FROZEN (middle) scenarios, and as differences between the two scenarios (bottom). Note that the scales are different.

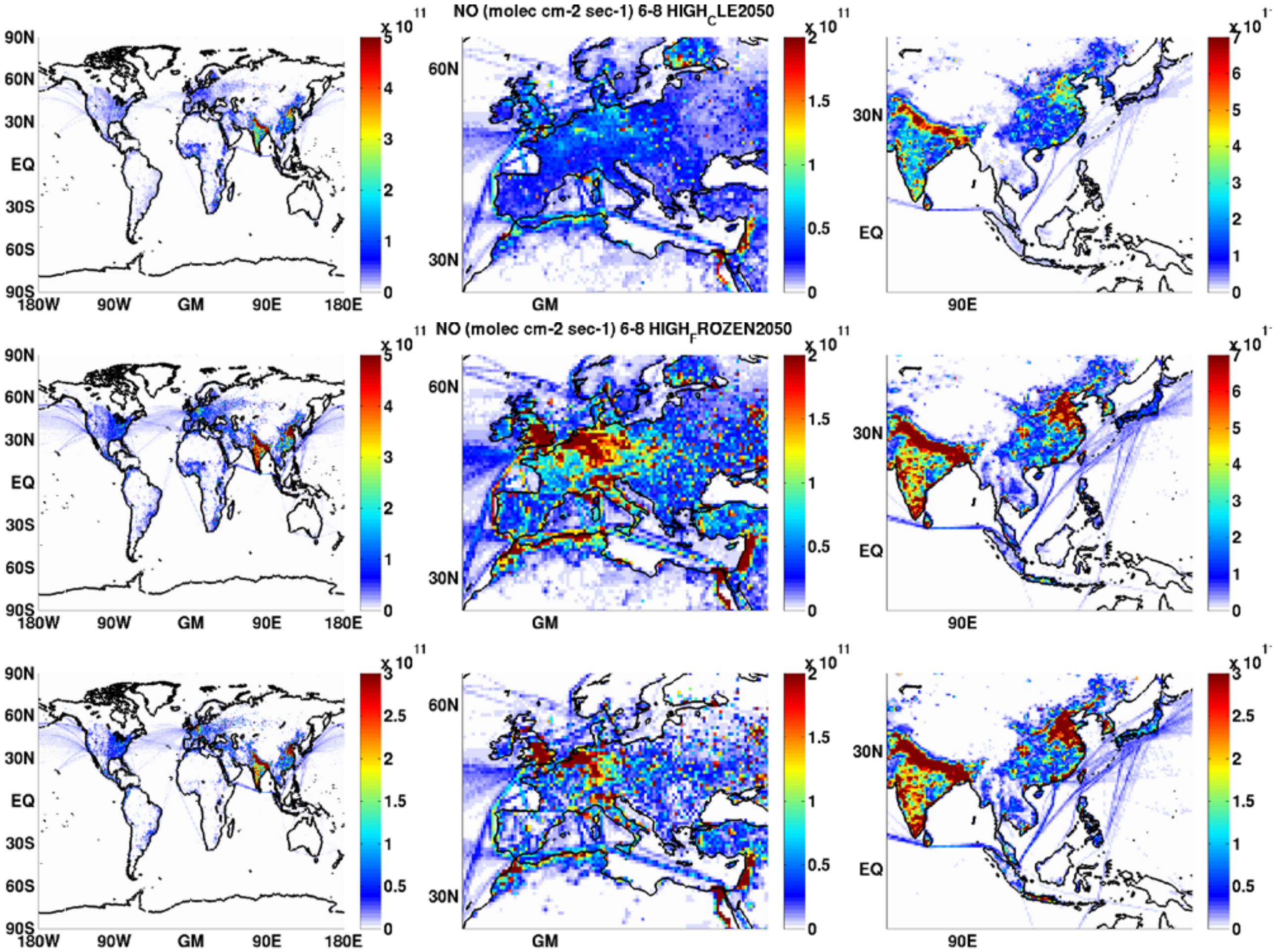


Figure 2: Anthropogenic emissions of NO_X *(molec* cm^{-2} s^{-1}*) in the period June-August for the 2050 HIGH CLE (top) and HIGH FROZEN (middle) scenarios, and as differences between the two scenarios (bottom). Note that the scales are different.*

Implications of mitigation strategies on near-surface CO predicted by the OsloCTM2 model

CO concentrations resulting from anthropogenic emissions retain a pattern which is similar to the emission pattern, although somewhat smeared out due to transport of CO some distance away from the sources (Figure 3). Mitigation of CO emissions is seen most clearly over the UK, in Central Europe and in the Mediterranean region, most notably along the southern and eastern boundaries of the Mediterranean Sea. However, in relation to the focus of this report, it is worth noticing that the effects of mitigation on the CO distribution in much of Europe are only moderately impacted by the change in meteorology due to climate change from 2000-2010 to 2040-2050 (Figure 3). However, over the Mediterranean region the impact exceeds 15 µg m^{-3} in certain areas, which is not negligible. The same size impact is seen over larger parts of India, where climate change is rather important for the atmospheric chemistry. Over China the impact is somewhat weaker but very wide spread, up to about 5 µg m^{-3}.

Implications of mitigation strategies on daily maximum near-surface ozone predicted by the Oslo CTM2 model

Ozone concentrations resulting from anthropogenic emissions are impacted by emissions of all the ozone precursors, thus following the emission patterns of both CO and NOx as shown in Figures 1 and 2. Mitigation of ozone precursor emissions are seen most clearly over the Mediterranean region, but also in Central Europe. However, as for CO, it is worth noticing that the effects of mitigation on the ozone distribution in Europe is only modestly impacted by the change in meteorology due to climate change from 2000-2010 to 2040-2050 (Figure 4), even though the impact is slightly stronger than for CO. The geographical distribution across Europe is roughly like the one for CO, and the largest impacts exceed 10 µg m^{-3} or 5 ppb. A similar effect is seen over much of India, where climate change is rather important for the atmospheric chemistry. All in all, the conclusion of this work, given the climate scenario and emission scenarios that we have adopted, is that the climate change impacts results of mitigation of ozone precursor emissions on air pollution are relatively moderate, but clearly not negligible. Thus mitigation strategies may not need to be drastically altered. However, the effects are large enough to call for further investigation, including also other climate change and emission scenarios.

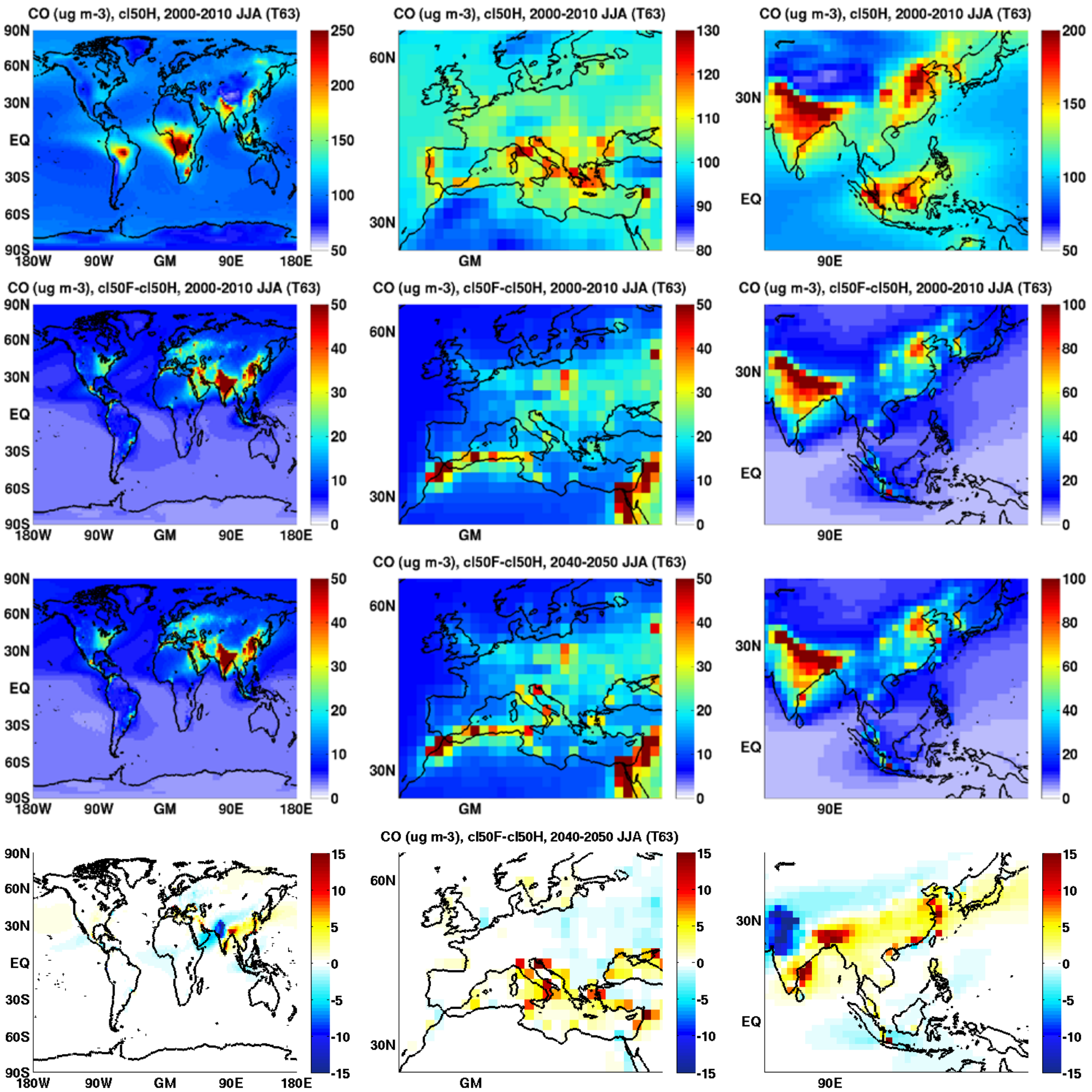


Figure 3: 11-year average of near-surface CO (µg m^{-3}) for the northern hemisphere summer (June, July, August) shown (i) for the simulations with current climate (2000-2010) and 2050 HIGH CLE emissions (top), (ii) as difference between simulations with 2050 HIGH FROZEN and 2050 HIGH CLE emissions (2nd row), (iii) for future climate as difference between simulations with 2050 HIGH FROZEN and 2050 HIGH CLE emissions (3rd row), and (iv) for differences between the two latter cases (ii and iii; bottom row). Note that the scales are different.

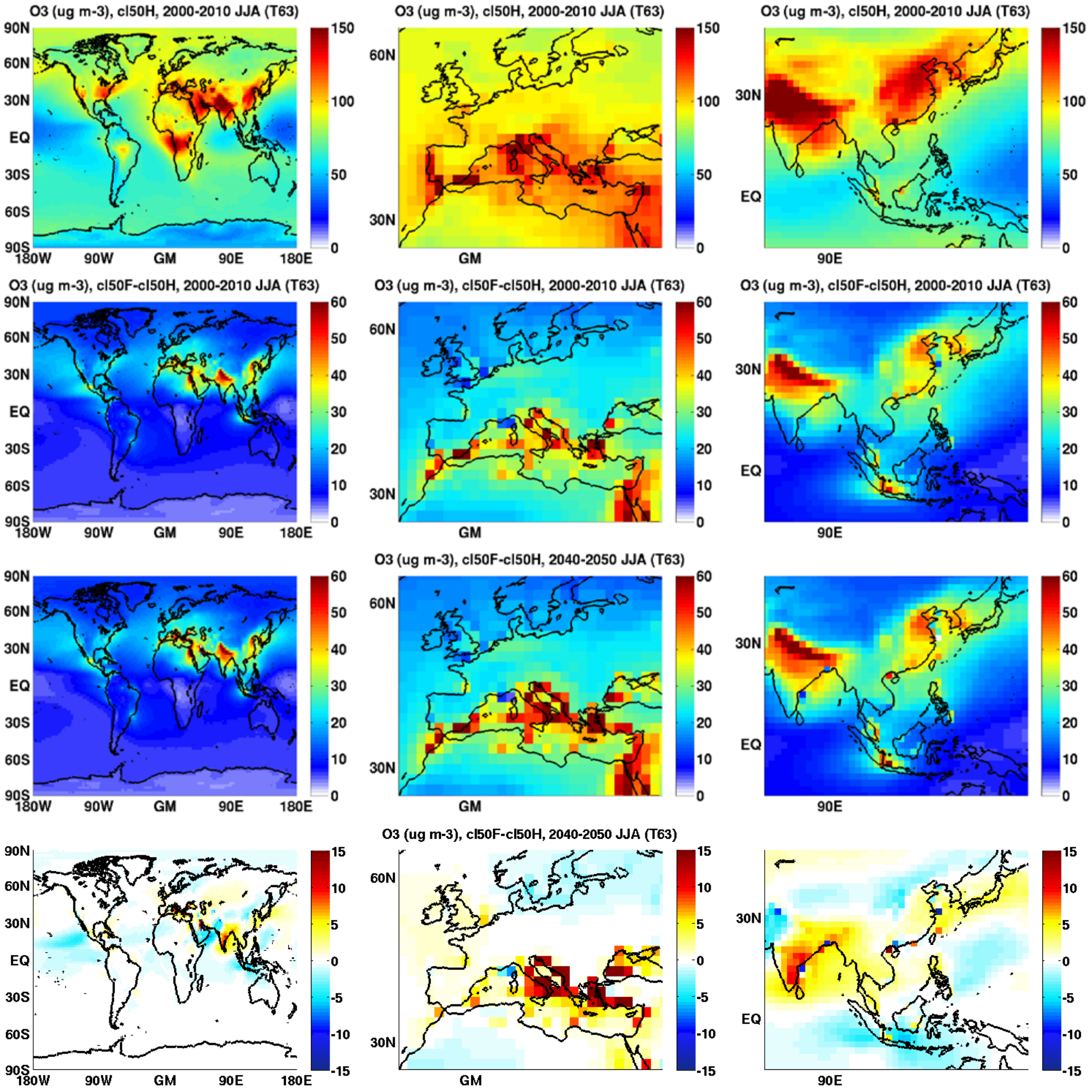


Figure 4: Same as Figure 3, but for average of daily maximum near-surface ozone.

2) The met.no calculation with HIRHAM/EMEP

Similar to the FZJ/UiO study described in the previous section, the set of calculations performed at met.no is an offline coupling between a climate model and a chemical transport model. The scale is regional, i.e. the output from a global climate model had to be downscaled, and the data were used to drive a state-of-the-art regional CTM, the EMEP/MSC-W model (European Monitoring and Evaluation Programme / Meteorological Synthesizing Centre – West), herafter referred to as 'EMEP model'. The period considered was the decade centered around 2030.

Changes in climate from 2000-2010 to 2025-2035 predicted by the HIRHAM model

The change in climate parameters, as modeled by HIRHAM, is reviewed in Deliverable Report 2.3.1 and is only briefly outlined here. Meteorological input data to the EMEP model for this experiment were generated by the HIRHAM RCM (Haugen and Haakenstad 2006, Haugen and Iversen 2008). This HIRHAM run was forced by data from the Hadley Centre global climate model HadCM3. The HadCM3 data was run at the Hadley Centre on 3.75º (lat) × 2.5º (lon) resolution with emissions from SRES A1B (Nakicenovic and Swart 2000). The HIRHAM RCM was run on a rotated spherical projection with 0.22º × 0.22º horizontal resolution for the period 1950-2050. All meteorological parameters required by the EMEP model were extracted from this 101-year HIRHAM data set, interpolated into the vertical grid of the EMEP model and converted into netCDF format.

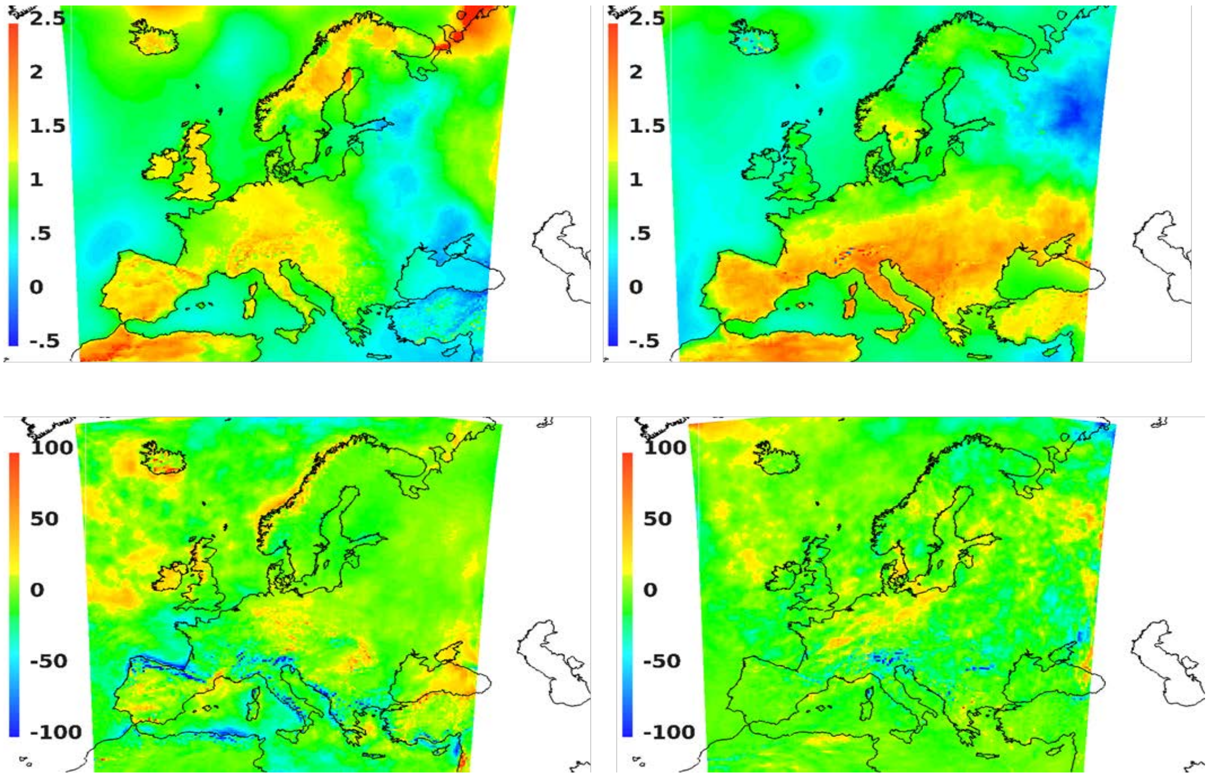


Figure 5: Change in T (upper panels) and surface precipitation (lower panels) between the 2000s and the 2025-2035 period for the DJF (left) and the JJA (right) seasons. Units: Kelvin for temperature and mm/year for surface precipitation.

What is written in the D2.3.1 report for the 2040-2050 period (D2.3.1 report, their Figure 11) is qualitatively true for the 2025-2035 period as well, except that the changes are less significant, see Figure 5. Temperature increases from the 2000s to the 2030s are clearly seen in nearly all parts of Europe, North Africa and the European Arctic. The highest temperature increase occurs during winter in high latitudes, while in mid-latitudes the warming is most pronounced during summer. Precipitation is reduced mainly in coastal regions of the Mediterranean, the Bay of Biscay and some regions in the Alps. Largest increases in precipitation are seen during winter in Western Scandinavia and the Eastern part of the North Atlantic.

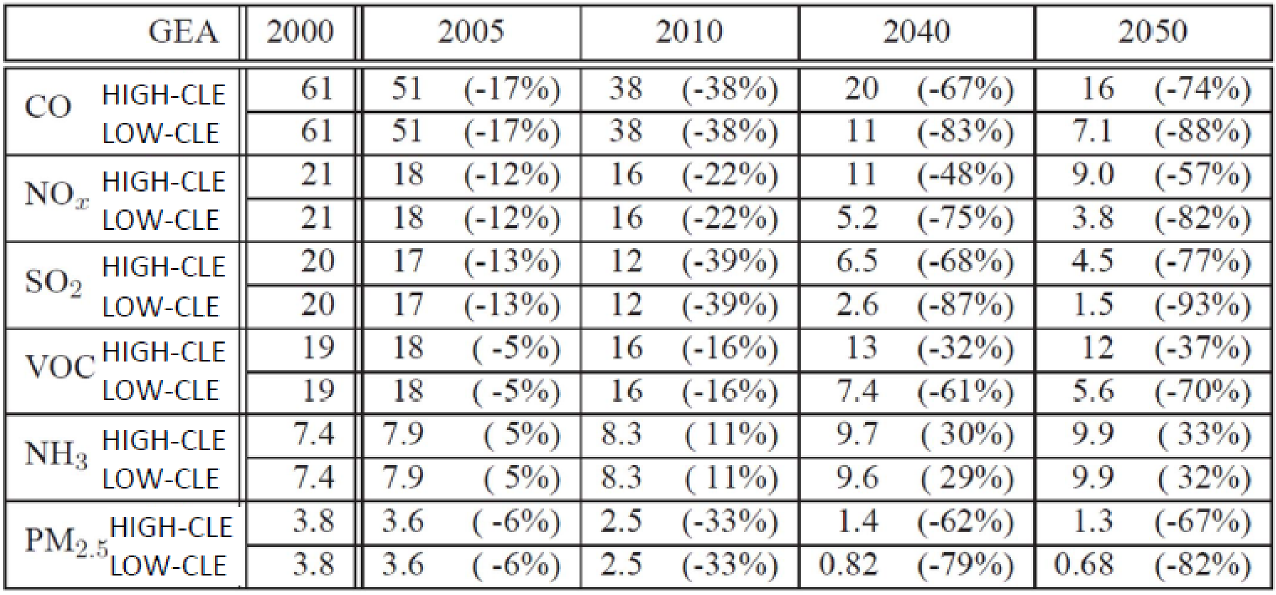
Emission scenarios for 2030

In this study, two sets of emission data are in focus, which were derived from two global emission scenarios both developed by IIASA. The first one, HIGH-CLE, is the same as was used by UiO in the calculation described in Section 1:

HIGH-CLE. No specific policies on climate change and energy access are implemented in this scenario. However, it assumes full implementation of all current and planned air pollution legislation world-wide until 2030. Thus, this scenario provides a measure of the impact of current and planned air pollution policies in the absence of any specific climate or energy access policy.

In addition, a more optimistic emission scenario was used, LOW-CLE, that also assumes a stringent climate policy:

LOW-CLE. In this scenario a stringent climate policy corresponding to a 2-degree global temperature target is implemented. In addition, it assumes a moderate energy access policy corresponding to microfinance and 20% fuel subsidy, as well as full implementation of all current and planned air quality legislation until 2030, similar to the reference case described above. Thus, this scenario explicitly provides an indication of the co-benefits of combining policies on climate change, energy access and air pollution.



GEA		2000	2005	2010	2040	2050
CO	HIGH-CLE	61	51 (-17%)	38 (-38%)	20 (-67%)	16 (-74%)
	LOW-CLE	61	51 (-17%)	38 (-38%)	11 (-83%)	7.1 (-88%)
NO_x	HIGH-CLE	21	18 (-12%)	16 (-22%)	11 (-48%)	9.0 (-57%)
	LOW-CLE	21	18 (-12%)	16 (-22%)	5.2 (-75%)	3.8 (-82%)
SO_2	HIGH-CLE	20	17 (-13%)	12 (-39%)	6.5 (-68%)	4.5 (-77%)
	LOW-CLE	20	17 (-13%)	12 (-39%)	2.6 (-87%)	1.5 (-93%)
VOC	HIGH-CLE	19	18 (-5%)	16 (-16%)	13 (-32%)	12 (-37%)
	LOW-CLE	19	18 (-5%)	16 (-16%)	7.4 (-61%)	5.6 (-70%)
NH_3	HIGH-CLE	7.4	7.9 (5%)	8.3 (11%)	9.7 (30%)	9.9 (33%)
	LOW-CLE	7.4	7.9 (5%)	8.3 (11%)	9.6 (29%)	9.9 (32%)
$PM_{2.5}$	HIGH-CLE	3.8	3.6 (-6%)	2.5 (-33%)	1.4 (-62%)	1.3 (-67%)
	LOW-CLE	3.8	3.6 (-6%)	2.5 (-33%)	0.82 (-79%)	0.68 (-82%)

Table 1: Changes in emissions over the EMEP model domain (numbers in brackets give the relative change with respect to year 2000).

Table 1 lists emissions for different chemical species. In order to put the 2030 change into context, also other times are given, e.g. the years 2040 and 2050. In both emission scenarios reductions of all pollutants are foreseen, except (NH_3). The LOW-CLE scenario features larger emission reductions than the HIGH-CLE scenario.

In addition to these two scenarios, model runs were made for mitigation scenarios based on the ‘IIASA ratios’, which are described in more detail elsewhere (CityZen deliverable D3.3.4). The IIASA ratios mimic so-called ‘climate-friendly air quality mitigation measures’. Such measures are designed to improve air quality, while not contributing to climate change. They thus target reductions of the climate forcers CH_4 and BC (black carbon). In CityZen, these measures were applied on top of the HIGH-CLE scenario by multiplying the emissions of the HIGH-CLE scenario by the IIASA ratios in the target regions, either in megacity regions only, or country-wide. A list of model runs performed with the EMEP model in this study is given in Table 2.

Acronym	Emission scenario	IIASA ratios applied	Climate
2005_HC	High CLE	No	2000-2010
2030_HC	High CLE	No	2000-2010
2030_HC_Clim	High CLE	No	2025-2035
2030_LC	Low CLE	No	2000-2010
2030_HC_2	High CLE	In megacities	2000-2010
2030_HC_3b	High CLE	Country-wide	2000-2010
2030_HC_3b	High CLE	Country-wide, but keeping the total emission change per country as in ‘2030_HC_2’	2000-2010

Table 2: List of EMEP model runs performed for this study.

Implications of mitigation strategies on air pollution predicted by the EMEP model

Figure 6 presents European and annual averages. The blue line represents the situation of the present run with HIGH-CLE emissions (2005_HC). It is a 10-year run with climate that is typical of the present (2000-2010 decade), see Table 2. The dark green line shows results for the same climate, but with the HIGH-CLE emissions for 2030 (2030_HC). The reduction in ozone due to the reduction in ozone precursors is clearly seen, demonstrating the success of the mitigation measures foreseen in HIGH-CLE. The benefit is even larger in the LOW-CLE scenario (red line), which considers stringent climate policy in addition. The black line shows results for a run where HIGH-CLE emissions were used as in 2030_HC (green line), but with climate data for the future (typical of the 2025-2035 decade). In other words, the difference between the dark green and the black lines shows the effect of climate change only. The 10-year average of the black line is slightly higher than that of the green line, i.e. ozone increases due to climate change. This is mainly due to increases in temperature, which accelerate ozone photochemistry, reduce the uptake of ozone on soil and vegetation, and make PAN (an important ozone-precursor reservoir gas) less stable. Also biogenic emissions of isoprene and terpene are increased in a warmer climate, leading to an increase in ozone.

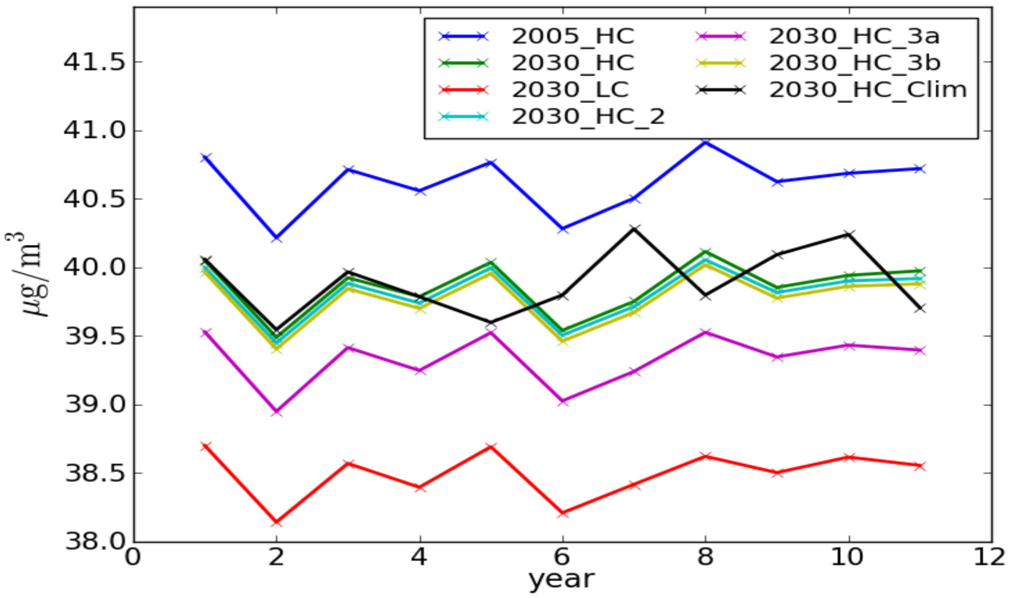


Figure 6: Annually averaged surface ozone concentrations over Europe (EMEP model domain), during a 10-year period and different mitigation options.

However, the signal of climate change is smaller than the effect of the emission reduction, both in the HIGH-CLE and LOW-CLE scenarios. Nevertheless, climate change should be taken into account when devising future mitigation measures, as, according to these model results, climate change will weaken the effect of the mitigation measures to some extent, albeit small. (The results of the other simulations are described in deliverable report D3.4.1, where the focus is on mitigation options rather than climate change effects.)

Figure 7 shows similar results for particulate matter. Again, the difference between the dark green and the black lines shows the effect of climate change only. It shows a slight increase, mainly related to a reduction in precipitation in areas with high PM load (e.g. Mediterranean region).

It is also noted that inter-annual variability as visualized by the 10-yr curves in Figures 6 and 7 is quite large and in some instances masks all other effects. E.g. some of the ‘future’ years may have similar ozone concentrations as some of the ‘present’ years, if meteorology is unfavorable.

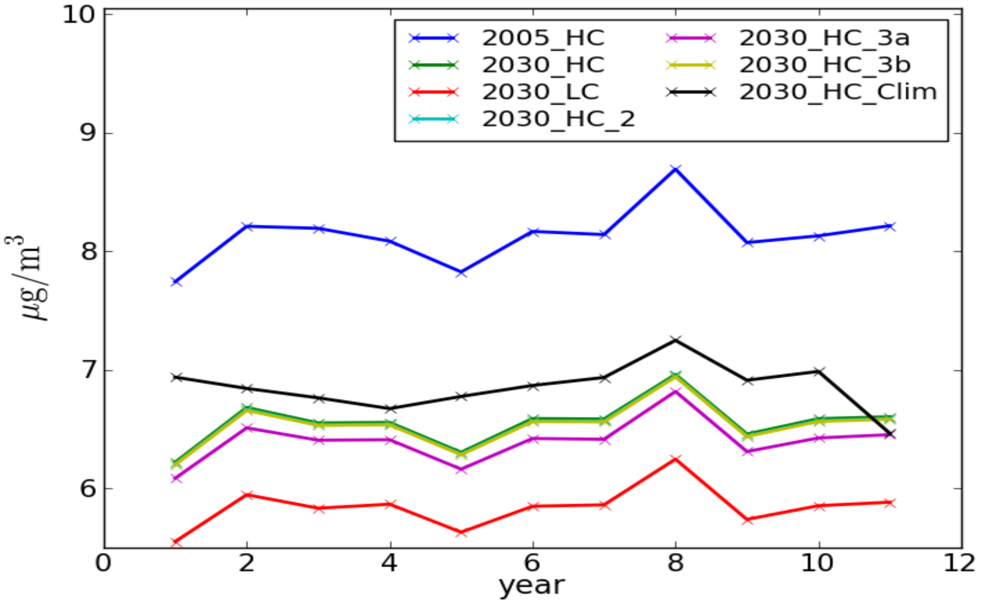


Figure 7: As Figure 6, but for $PM_{2.5}$.

3) Conclusions and future work

Offline calculations with chemical transport models using climate data from general circulation models have been performed. Changes in air quality due to climate change are clearly visible from the model runs performed in CityZen. IIASA has provided emission scenarios for the time period 2000-2050.

In addition to the work presented in D2.3.1, additional emission scenarios were run, namely the HIGH-FROZEN scenario (UiO), and the implementation of climate-friendly air quality mitigation measures (met.no).

From our calculations it seems that the effects from emission changes are larger than those due to climate change. For example in Europe, climate change alone will lead to an increase in ozone and particulate matter, mainly related to changes in temperature and precipitation. However, these changes are overwhelmed by emission reductions assumed in the IIASA scenarios. Nevertheless, climate change has to be taken into account when devising emission reduction policies for the future.

It has to be noted that the design of this experiment only allows investigation of effects from climate change on air pollution. For this purpose, CTMs, being computationally efficient, are useful tools as they can include, e.g. much more comprehensive chemistry modules than what is common in fully coupled chemistry-climate models.

4) References

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