Review of the Gothenburg Protocol: Hemispheric Transport

Topic 1: Contribution of hemispheric transport to observed trends in air quality and its impacts, and future projections

1. The hemispheric contribution to ground-level ozone is larger than the hemispheric contribution to PM or its components due to ozone's longer atmospheric lifetime. The concentration of ozone experienced at any given location is the combination of ozone and ozone precursors transported from distant sources on hemispheric to regional scales and, depending on the photochemical regime, local photochemical ozone production or local ozone loss due to titration with NO. Reduction in emissions of ozone precursors in the UNECE region has led to a reduction in peak, short-term ground-level ozone concentrations associated with local photochemical production, especially in the summertime. Reduction of NO_x emissions has also led to a reduction in the titration of ozone by NO, leading to higher concentrations of ground-level ozone, especially between autumn and spring, at nighttime, and in Europe. Both effects have increased the relative influence of background ozone, including ozone from hemispheric transport, on local concentrations of ozone experienced in urban areas of the UNECE region, but especially in Europe.
2. Peak ground-level ozone levels in Europe and North America have decreased strongly since 2000, but trends for annual average ozone levels are mixed, with increases at some sites and decreases at others. Average ozone levels in the free troposphere above Europe and North America, as measured by aircraft, have continued to increase, In other parts of the world, both peak levels and annual average levels of ground-level ozone have continued to increase, as have ozone levels aloft as measured by aircraft.
3. The mixed or weak trends in annual average ozone levels belie opposing trends in different seasons. In Europe, in winter (DJF) and spring (MAM) some sites have experienced weak increasing trends and others weak decreases. In summer (JJA), however, most European sites have had strong decreases over the period 2000-2014. In autumn (SON), most sites have seen no trend or a weak decrease. In North America, winter (DJF) ground-level ozone levels strongly increased over the period 2000-2014 and summer (JJA) levels strongly decreased. Trends in spring and autumn were mixed with many sites showing no significant trends. (Chang 2017).
4. This observed trend in ground-level ozone and its impacts cannot be explained completely by precursor emission trends in Europe and North America. Downward trends of ozone precursor emissions in Europe and North America since around 1990 appear to be at least partially offset by increasing NO_X and VOC emissions outside the UNECE region and increasing CH_4 emissions globally. .
5. The contribution of anthropogenic emission sources outside the UNECE region to PM species and their associated impacts within the UNECE region is negligible compared with the impact of local anthropogenic sources. Wildfires and wind-blown dust emanating from outside the UNECE, however, do influence PM levels and deposition in the UNECE region and are sensitive to changes in climate.

6. The absolute contribution of NO_X and VOC emissions outside the UNECE region to annual average ground-level ozone in Europe and North America is not expected to change significantly under a business as usual scenario to 2050. Expected increases in global CH_4 are expected to more than offset projected reductions of NO_X and VOC emissions in Europe and at least partially offset reductions of NO_X and VOC emissions in North America.
7. If NOx and VOC emissions were reduced everywhere by the same percentage, the emission reductions outside of Europe would have a bigger impact on European ozone levels than the emission reductions within Europe. In North America, equal percentage emission reductions of NO_X and VOC outside of North America would contribute significantly to decreases of ozone in North America, but not more than the equal percentage emission reductions in North America itself.

Topic 2: Projected trends in methane, contribution to ground-level ozone, and mitigation potential

8. Projected trends in anthropogenic methane emissions span a very wide range, between a factor of two smaller or a factor of two larger than present-day emissions by the end of the century, depending on assumptions made about economic development and the use of emission control technology.
9. Ozone formation is strongly influenced by the atmospheric methane burden, with model studies consistently showing that higher mixing ratios of methane lead to higher background mixing ratios of ground-level ozone.
10. Due to the long lifetime of methane in the atmosphere, methane is well mixed. Decreases in surface ozone arising from methane emission control are largely independent of source location, but the local response to global methane reduction is stronger in locations where local NOx emissions are high. Equal emission reductions in any given regions will lead to the same reductions in global background ground-level ozone.
11. The fossil fuel (production and distribution) and waste sectors have the highest technical potential for reduction of methane emissions. The agricultural sector is a major source of methane emissions but has a low technical potential for reductions in methane emissions.
12. Outside the UNECE region there is currently potential for reducing methane emissions from the waste sector in China and the fossil fuel sector in the Middle East.

Topic 3: Projected trends in international shipping, contribution to ground-level ozone and N deposition, and mitigation potential

13. NOx emissions from international shipping on the global seas are projected to remain approximately constant or decrease slightly in absolute terms over the 21st century, depending on assumptions about growth in international trade and the use of emission control technology. The share of global shipping NOx as a proportion of global anthropogenic NOx emissions (currently at about 30%) is projected to vary between 10% and 60%, by the end of the century depending on the effectiveness of land-based NOx emission control.

14. Projections of the future effects of shipping on air quality in Europe has focused on the human health impact of PM2.5 from SOx and NOx emissions over European seas. Projections of the impact of global shipping NOx on baseline ground level ozone and N deposition in the UNECE region are currently lacking. Models show low agreement on the present-day effects of shipping NOx on ground-level ozone, but do agree that extra-regional sources account for up to half of N deposition in coastal regions, strongly indicating a role for shipping NOx.
15. Due to the short lifetime of NOx, it seems likely that reduction of emissions of ship NOx near coastlines has a high potential to reduce N deposition. There are some indications that the global springtime maximum in intercontinental transport of ozone is influenced by shipping NOx emitted over the high seas, but further model studies are needed to determine the strength of this influence.

Topic 4: Sufficiency of atmospheric modelling for understanding hemispheric transport of air pollution, and the main requirements for improving simulation of hemispheric transport

16. Multi-model intercomparisons show a very large spread in simulated surface ozone, which has not improved over the last decade despite higher spatial resolution and other model developments. As an ensemble, global models tend to overestimate available surface observations.
17. The source/receptor relationships for ground-level ozone from the HTAP2 multi-model exercise were not significantly different from those of the HTAP1 exercise, despite developments in individual models and closer harmonisation of the model inputs.
18. Global models disagree strongly on the magnitude of the pre-industrial to present-day trend in ground-level ozone, and tend to underestimate the magnitude of the observed trend. Projection of the contribution of hemispheric background ozone to the attainment of future targets using current models remains highly uncertain.
19. Regional ozone models generally performed better in comparison to observations than did global ozone models, which generally have lower spatial resolution than regional models. However, the best performing global models compared better to observations than did the worst performing regional models.
20. Technical challenges for improved global simulations of ground-level ozone for the UNECE region include more accurate simulation of the global methane lifetime, better resolution of the NOx chemistry of ship exhaust plumes, and better representation of ozone deposition to vegetation.
21. Model intercomparison studies such as HTAP, CCMI, and AerChemMIP exercises play a vital role in assessing the adequacy of state-of-the-art emission inventories, global models, and measurement data for informing the Convention on the impacts of extra-regional emission sources on ozone impacts in the UNECE region.
22. In addition to model development, ongoing provision of high-quality emission inventories and expansion of the global network of ozone observations for model evaluation are required