Working group 4. Air pollution effects on ecosystems, materials and health in a changing climate
Effects from air pollution and how it may be influenced by climate change, including feedback mechanisms

Conclusions and recommendations

Acidification.
- There is a need to integrate ongoing monitoring work and initiate multi-factorial ecosystem experiments (ICPs F, W, IM, M&M).
- Models are essential to interpret and predict the direction and rate of air pollution and climate change effects (ICPs M&M, IM, JEGDM).

Nutrient N.
- Due to the complexity of response between the nitrogen and carbon cycles and soils and vegetation there is a strong need for improved integration of monitoring which combine receptor responses and development of ecosystem modelling
- Multi-factor experiments are needed to test and help develop models
- Access to datasets on changes in spatial patterns of landcover and agriculture practices
- There is a need to identify combinations of specific receptors that are unique to nitrogen effects.

Ozone.
- Complexity of interactions between climate, ozone, elevated CO2 and other pollutants require large-scale and long-term experiments to be resolved
- Monitoring changes in (semi-)natural vegetation at the ecosystem and regional scale, and multi-factor analysis to quantify ozone impacts
- Impacts of climate change on distribution of (semi-)natural vegetation, and on choosing crop and tree species and cultivars
- Further development of flux modelling methods needs to include CO2, prioritizing meteorological parameters and climate-dependent plant factors.
- Developing dynamic modelling of ozone interactions in a changing climate.
- Feedback mechanisms for climate (e.g. potential of reduced stomatal flux of ozone to increase ozone-induced radiative forcing, ozone-induced reduction in C sequestration etc)

Particulate matter.
- Increased wind speeds in Northern Europe will increase the importance of resuspension of surface derived aerosols. It will therefore increase suspended PM levels, thus making it harder to meet air quality guidelines with anthropogenic emission controls.
- The risk for boreal forest fire frequency is expected to increase (along with biomass fires at all latitudes), which increases human health risk through the exposure to higher PM levels.

Heavy metals and POPs.
- Reconcile heavy metals emission inventories and observed concentrations and deposition in Europe.
- Global cycle of mercury, which is a remaining problem, requires monitoring, modelling and understanding of underlying processes.
- There is a need to quantify the climate change feed backs in POP mobilization, transport and effects in the Arctic.

Materials.

- Trends in corrosion and pollution should continue to be monitored for selected materials.
- Corrosion and soiling of materials and the interaction with climate needs to be quantified by additional field studies and by combining and analysing data from existing field studies in Europe with data from subtropical and tropical regions.
- Laboratory studies on effects of organic acids should be initiated.

Health.

- More knowledge is necessary on health effects linked to specific sources and types of particles, in particular for prioritization of preventive action.
- More information is needed about health effects related to long-term exposure to ozone, as the yearly ozone background levels in Europe are increasing.
- The role of VOC emissions on health impacts, e.g. including direct effects and via formation of ozone and secondary organic aerosols, needs to be re-evaluated.
- Climate change: synthesize climate change interaction.

Feedbacks to climate change (in particular carbon cycle).

There are many important feedbacks between air pollution and greenhouse gases, radiative forcing and global carbon cycle. Of particular importance we highlight:

- Ozone reduces carbon sequestration in vegetation
- Climate change effects on ozone deposition are most likely to enhance ambient ozone concentrations through decreased stomatal uptake.
- Nitrogen deposition will increase carbon sequestration in vegetation and NO/N20 emissions in N-limited ecosystems.
- Climate change is expected to increase transport of black carbon (aerosols in general) into the Arctic, which affects albedo.
- There are direct effects of tropospheric ozone and particles on climate change. Ozone and soot are responsible fore regional warming while most areosoles are cooling, e.g. sulphate.
- Air pollution can modify methane release in wetlands.
- Climate change and higher CO2 levels can change the emission of NM-VOC from vegetation.
- Air pollution causes significant change in habitat structure, and this may change carbon cycle, release of greenhouse gas emissions and albedo.
- Coupling of air pollution emissions and effects into earth system models.

Countries outside UNECE regions.

Continue to enhance the exchange of knowledge between the researchers and policymakers across the continents. It is likely to achieve these goals to undertake impact assessment of air pollution and interaction with climate chabge. Better spatial coverage will be needed.

Annex

1. Introduction

The science of air pollution effects is well advanced in general, though uncertainties exist in specific areas. Interactions with climate change are expected due to climate-dependency of many biological processes. Here we describe the current status of impacts known interactive effects with some key recommendations.

2. Acidification

Acidification is still recognized a problem in acid-sensitive aquatic and terrestrial ecosystems of Europe (critical load exceedance for forests in Europe was 21% in 2000 and will be 6% by 2020).Climate change affects the chemical and biological recovery from acidification by a number of mechanisms both in short and long term. (See also Materials.)

Influence of climate change.

- The sensitivity of ecosystems to air pollution, the critical load, may change over time depending on climate (e.g. elevated dissolved organic carbon (DOC) increases the acid neutralizing capacity (ANC) in waters, sea-salt episodes increase soil base saturation, which may lead to delayed biological recovery). Climate change has potential to both enhance and slow down recovery from acidification.
- Climate change will affect ecosystem compartments differently, e.g. waters may improve but soils acidify further.

Recommendation.There is a need to integrate ongoing monitoring work and initiate multi-factorial ecosystem experiments (ICPs F, W, IM, M&M). Models are essential to interpret and predict the direction and rate of air pollution and climate change effects (ICPs M&M, IM, JEGDM).

3. Nutrient nitrogen

There is clear evidence of continuing chronic and acute effects of nitrogen as a nutrient on ecosystems. Nitrogen is causing species loss on land and in waters across Europe. Invasion by competitive nitrophilic (nitrogen-loving) species is observed, e.g. grass invasion of understorey of boreal forests, loss of peat-building moss species, confirming the ecosystem critical load exceedance across Europe both 2000 (57%) and in the future (33% by 2020).

Influence of climate change.

- Acceleration of the N cycle and thus increased release of N available to biota on land, freshwaters and marine systems. This will require a lowering of current critical loads for ecosystems where increased production is not desirable.
- Increased sensitivity of receptors under climate change conditions e.g. increased sensitivity to nitrogen in drought conditions. This may also require a lowering of current critical loads.
- Changes in location of species, habitats, land use and management will affect spatial patterns of critical load assessment and exceedance.
- Climate change may confound the attribution of changes due to N deposition.

Conclusions and recommendations

- Due to the complexity of response between the nitrogen and carbon cycles and soils and vegetation there is a strong need for improved integration of monitoring which combine receptor responses and development of ecosystem modelling
- Multi-factor experiments are needed to test and help develop models

- Access to datasets on changes in spatial patterns of landcover and agriculture practices
- There is a need to identify combinations of specific receptors that are unique to nitrogen effects.

4. Ozone (O3)

- Critical levels for crops exceeded in most Europe with estimated crop yield loss worth over 6 billion € in 2000.
- Reduction in productivity of natural vegetation – threat to biodiversity
- Economic losses via reduced crop and timber yield and crop quality. In extreme cases e.g. complete loss of salad crop following ozone episodes.
- "Early Autumn" in deciduous forests with long-term cumulative impacts

Influence of climate change.

- Background concentration is rising above known thresholds for damage to vegetation.
- Less ozone deposition to vegetation due to climate and elevated CO2 induced reduced uptake, feeds back into larger ambient ozone concentrations (climate feedbacks).
- Climate change induced changes in phenology (vegetation growth periods) may increase the risk for ozone damage.

Recommendations

Experimental and monitoring

- Complexity of interactions between climate, ozone, elevated CO2 and other pollutants require large-scale and long-term experiments to be resolved
- Monitoring changes in (semi-)natural vegetation at the ecosystem and regional scale, and multi-factor analysis to quantify ozone impacts

Land use mapping. Impacts of climate change on distribution of (semi-)natural vegetation, and on choosing crop and tree species and cultivars

Predictive modelling

- Further development of flux modelling methods needs to include CO2, prioritizing meteorological parameters and climate-dependent plant factors.
- Developing dynamic modelling of ozone interactions in a changing climate.
- Feedback mechanisms for climate (e.g. potential of reduced stomatal flux of ozone to increase ozone-induced radiative forcing, ozone-induced reduction in C sequestration etc)

5. Particulate matter (PM)

See also Health and Materials.)

Conclusions

- Increased wind speeds in Northern Europe will increase the importance of resuspension of surface derived aerosols. It will therefore increase suspended PM levels, thus making it harder to meet air quality guidelines with anthropogenic emission controls.
- The risk for boreal forest fire frequency is expected to increase (along with biomass fires at all latitudes), which increases human health risk through the exposure to higher PM levels.

6. Heavy metals and POPs

This group of pollutants, HM and POPs, is of concern, in particular in boreal and arctic regions. In particular Hg effects on human health remains in high priority, e.g. there is a ban to eat fish from half of Swedish lakes.

Influence of climate change.

- Increases in precipitation and temperature in boreal forest increase the inputs and mobilization of methyl mercury. Changes in forestry practice with increases in biomass production accelerate the process.
- Climate change is expected to increase transport of heavy metals and POPsinto the Arctic. The key effects of POPs in the arctic are endocrine disruption through food chain concentration).

Recommendations

- Reconcile heavy metals emission inventories and observed concentrations and deposition in Europe.
- Global cycle of mercury, which is a remaining problem, requires monitoring, modelling and understanding of underlying processes.
- There is a need to quantify the climate change feed backs in POP mobilization, transport and effects in the Arctic.

7. Materials

Corrosion and soiling of materials still exceeds tolerable levels by air pollutants (SO_2, HNO_3, O_3 and PM). For example, based on a tolerable soiling level and a time between cleaning a tolerable PM_{10} level of 15 µg m^{-3} has been calculated.

Influence of climate change.

- Acidifying pollutants interact with temperature, relative humidity and precipitation for metallic materials and stone.
- Particulate deposition influences soiling of materials and is affected by humidity and precipitation.
- Ozone may interact with temperature and radiation for some polymeric materials.
- The use of alternative fuels will result in new pollutants (e.g. use of ethanol in vehicles producing aldehydes and organic acids) with potential impacts on a wide range of materials.

Recommendations.

- Trends in corrosion and pollution should continue to be monitored for selected materials.
- Corrosion and soiling of materials and the interaction with climate needs to be quantified by additional field studies and by combining and analysing data from existing field studies in Europe with data from subtropical and tropical regions.
- Laboratory studies on effects of organic acids should be initiated.

8. Health

Current and proposed target values and emission ceilings within the European Union and under the Convention, for particulate matter and ozone as the main issues, do not fully protect against adverse health effects. (See also health effects under HM and POPs.)

Climate change influence. Climate change may have many interaction effects influencing the health impact of air pollution, e.g. affecting particle characteristics and chemistry, and more frequent episodes of combined effects of high temperatures and ozone.

Conclusions and recommendations

- More knowledge is necessary on health effects linked to specific sources and types of particles, in particular for prioritization of preventive action.
- Recommendation. More information is needed about health effects related to long-term exposure to ozone, as the yearly ozone background levels in Europe are increasing.

- The role of VOC emissions on health impacts, e.g. including direct effects and via formation of ozone and secondary organic aerosols, needs to be re-evaluated.
- Climate change: synthesize climate change interaction.

9. Feedbacks to the climate change, in particular the carbon cycle

There are many important feedbacks between air pollution and greenhouse gases, radiative forcing and global carbon cycle. Of particular importance we highlight:

- Ozone reduces carbon sequestration in vegetation
- Climate change effects on ozone deposition are most likely to enhance ambient ozone concentrations through decreased stomatal uptake.
- Nitrogen deposition will increase carbon sequestration in vegetation and NO/N20 emissions in N-limited ecosystems.
- Climate change is expected to increase transport of black carbon (aerosols in general) into the Arctic, which affects albedo.
- There are direct effects of tropospheric ozone and particles on climate change. Ozone and soot are responsible fore regional warming while most areosoles are cooling, e.g. sulphate.
- Air pollution can modify methane release in wetlands.
- Climate change and higher CO2 levels can change the emission of NM-VOC from vegetation.
- Air pollution causes significant change in habitat structure, and this may change carbon cycle, release of greenhouse gas emissions and albedo.

Recommendation. Coupling of air pollution emissions and effects into earth system models.

10. Issues in countries outside UNECE region

There are many issues of concern related to air pollution in countries outside UNECE region, which are increasing in contrast to many trends observed in Europe. Examples of these include:

- Acid rain is enhancing soil acidification due to increased base cation leaching in already highly leached soils, in particular in South-Eastern Asia.
- The expected ozone concentration increases may adversely affect food production and food security.
- Health effects due to indoor and outdoor air pollution are of concern.
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Key recommendation. Continue to enhance the exchange of knowledge between the researchers and policymakers across the continents. It is likely to achieve these goals to undertake impact assessment of air pollution and interaction with climate chabge. Better spatial coverage will be needed.

NOTE TO WORKING GROUP: Analysis for each pollutant is a guess only at the moment – if you think it useful – please indicate high, medium or low, ? or not applicable for your pollutant and whether direction of feedback or interaction is + or -. There is probably not space for explanation in italics but I give a few examples to explain the entries.

Table 1 Importance of different processes underlying interactions between individual air pollutants and climate change (+/- indicates direction of change)

High= high importance; Medium= medium importance; Low= low importance
? – unknown; N/A – not applicable

Process	**Acidity**	**Nutrient-N**	**Ozone**	**HM**	**POPs**	**Particles**
Change in precursors and/or deposition load	Low (+) *e.g. Increase in sea salt due to increased storms*	High (-) *e.g. Increased deposition of NHy due to warming*	High (+)		High	High (+)
Change in form of pollutant	Low	High	N/A	Low		High
Change in release, transfers and/or flows of pollutant	Medium (+/-)	Medium (+)	High (-)	Medium (+)	Medium (+)	High (+)
Change in uptake	Medium (+)	Medium (+)	High (-) *e.g. Reduced stomatal conductance due to droughts*			
Change in sensitivity / susceptibility of receptor	Medium (+)	Medium	High			High
Change in location of receptor	Medium	Medium	Medium			
Feedbacks to climate change and C cycle	Low	High	High	?		
Others?						