Particles and soot connecting climate change and airpollution abatement

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1. Introduction

The climate abatement negotiations are based on the assumption that a doubling of the natural CO_2 concentrations ($2xCO_2$) will give 2°C increases in global temperature. In the debate concerning the uncertainties in the climate models concerns have been raised that the climate warming will be considerably larger at $2xCO_2$. On the other hand soot has been suggested to cause a considerable fraction of the observed global warming indicating that the climate sensitivity to higher CO_2 concentrations is lower than anticipated (Ramanathan and Carmichael, 2008). Another complicating factor is the climate cooling by atmospheric particles is still quite uncertain as indicated by IPCC (2007) giving a range of 0.5 to 2 W/m^2 for the total anthropogenic aerosol forcing. The climate cooling hides the actual warming by climate warming components as soot, ozone and other greenhouse gases. Further complications are the feedback processes in the interaction between e.g. the atmosphere, the hydrosphere and the biosphere.

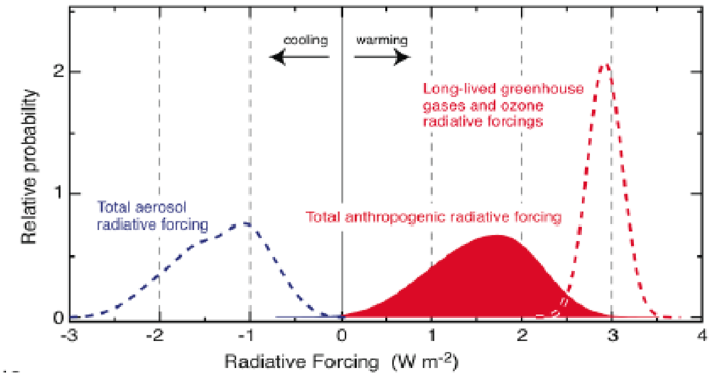

Figure 1. The radiative forcing of aerosol and greenhouse gases according to IPCC(2007).

The IPCC report (Solomon et al, 2007) summarize the present knowledge on how the total anthropogenic aerosol and the total green house gases influence the global radiative forcing, respectively (figure 1). The uncertainty in the estimates is illustrated in the width and height of the peaks. The concentrations of the green house and their influence on the present radiative forcing gases are well known equal to about 3 W/m^2. While the aerosol concentrations and their total influence on the radiative forcing is not well known and estimated to be somewhere between 0 and -3 W/m^2, most likely in the range -0.5 to -2 W/m^2, with a best estimate of -1.2 W/m^2.

Climate sensitivity can be defined as the global temperature response to a forcing of 1 W/m^2. Assuming the observed global temperature increase over the last 120 years of about 0.8 degrees to be the result of the total present anthropogenic forcing the climate sensitivity can be calculated. Knowing the climate sensitivity it is possible to calculate the global temperature in different future emission scenarios. The present total forcing is the sum of the forcing of the long lived greenhouse gases and ozone and the total aerosol forcing. Assuming a total aerosol forcing the climate sensitivity can be calculated. However is should be noted that such a calculation assume the present climate to be in equilibrium with the present forcing which is most likely not the case.

As shown in figure 2 the calculation of the climate sensitivity is strongly dependent on how well we know the present total global aerosol forcing. The uncertainty imposed by the aerosols on the total anthropogenic climate forcing progress into the climate projections at 2xCO_2. The total aerosol forcing is most likely in the range – 0.5 to -2 W/m^2 giving a range of 0.3 to 0.9 K m^2/W for the climate sensitivity. This uncertainty directly progress into the uncertainty of the projection at a 2xCO_2.

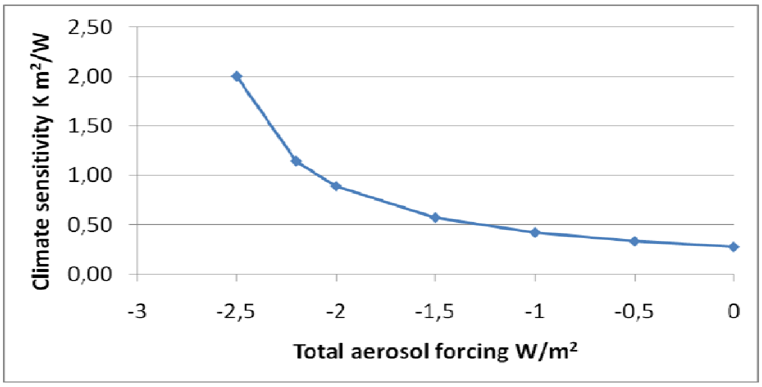

Figure 2. Climate sensitivity as determined by observed global temperature increase and present global forcing being the sum of total aerosol forcing and total greenhouse gas forcing, assumed to be 2.9 W/m^2.

Knowing the climate sensitivity and its dependence of total aerosol forcing facilitate making projections assuming different emission scenarios. It is also possible to investigate how uncertainties in different forcing estimates influence how the future global temperature will evolve.

2. Results and discussion

The climate forcing of soot has lately been discussed extensively. IPCC estimated the forcing of soot to be in the range 0.2 – 0.6 W/m2. Ramanathan and Carmichael (2008) propose the forcing to be as large as 0.8 W/m^2. The climatic importance of soot compared to CO_2 and how the uncertainty in the climate forcing of soot influence this comparison was investigated by assuming constant particle concentrations, a continuation of increasing concentrations of CO_2 of about 10% per decade and decreasing soot concentrations with 20% per decade from 2010 and on. Figure 3 show how the temperature evolve with time with a high soot forcing of 1.2 W/m^2 giving a total aerosol forcing of -0.2 W/m^2 and with a low soot forcing of 0.2 W/m^2 giving a total aerosol forcing of -1.2 W/m^2. Further all other forcing are assumed according to best estimate as given by IPCC (2007).

It should be noted that in the atmosphere the soot is mixed with other particulate components, both organic and inorganic. Already in the emissions the particles are mixed, e.g. soot and organic carbon are mixed in the same particles in most combustion emissions. However in this analysis soot is kept separate and is treated as a separate particle fraction to investigate its maximum potential influence in an abatement strategy.

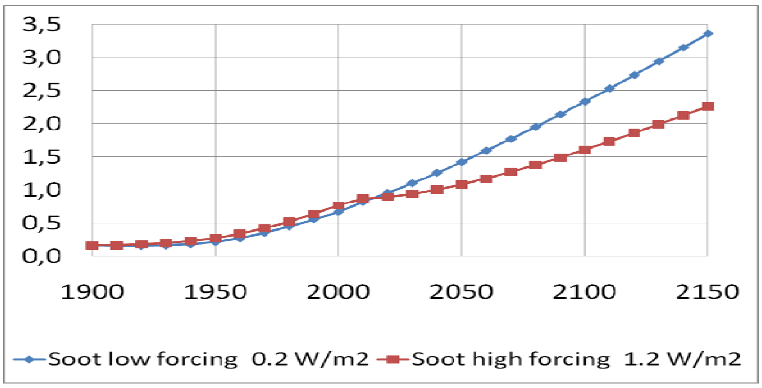

Figure 3. Temperature response to increasing CO_2 concentrations, 10% per decade, assuming a high and low soot forcing scenario. For soot an abatement scenario of -20% per decade from 2010 and on is assumed.

At a the very high soot forcing abatement of soot gives an clear effect on the temperature however it is mainly due to a lower climate sensitivity than in the low soot forcing case. The trend of increasing temperature is in both cases unbroken depending on increasing CO_2-concentrations, showing the importance of CO_2 abatement to break the temperature increase.

A smooth increase of atmospheric CO_2 concentrations peaking at 550 ppm (about $2xCO_2$) around year 2130 was used to investigate how climate forcing of air pollutants, i.e. short lived climate forcing components, will influence how climate evolve. By comparing the CO_2 forcing with the forcing of the other climate forcing components as ozone, particles and methane, as estimated by IPCC, their influence in a changing climate can be visualized.

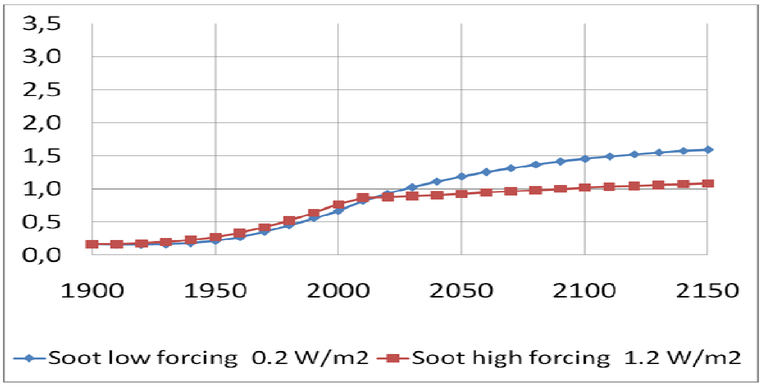

Figure 4. Temperature response with decreasing CO_2 emissions, about 10% per decade, assuming a high and low soot forcing scenario. For soot an abatement scenario of 20% per decade from 2010 and on is assumed.

Figure 4 show how strongly the CO_2 abatement influences the temperature trend. Soot abatement gives a clear positive effect however still mostly due to the lower climate sensitivity. The lower climate sensitivity is due to the lower total forcing with high soot forcing giving less masking of the warming CO_2 forcing. Further CO_2 has a much longer residence time in the atmosphere compared to soot which makes abatement actions on CO_2 most urgent.

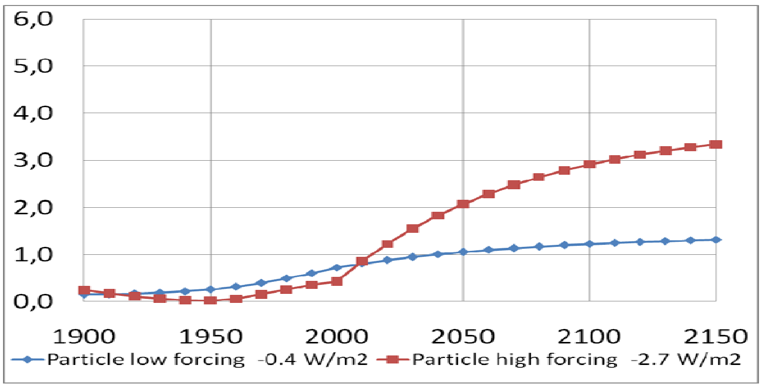

Figure 5. Temperature response with decreasing CO_2 emissions, about 10% per decade, assuming a high and low particle forcing scenario.

The influence of assuming a high or low particle forcing, i.e. the sum of the lowest or highest estimates on the direct and the indirect particle climate forcing as given by IPCC (2007), will have on temperature projections was investigated by assuming a high particle forcing of 2.7 W/m^2 giving a total aerosol forcing of -2.3 W/m^2 and with a low particle forcing of -0.4 W/m^2 giving a total aerosol forcing of 0 W/m^2. Further all other forcing are assumed according to best estimate as given by IPCC (2007). Figure 5 shows the temperature trends keeping all forcing constant besides the forcing by CO_2, which were kept as in Figure 4. The large difference in trends for the high and the low estimates of particle forcing is due to the difference in climate sensitivity. With a high particle forcing cooling the climate a major fraction of the warming by CO_2 is masked and thus the response to increasing CO_2 concentration is much larger than with a less masking. The response to concentration changes of components having the same magnitude of forcing as CO_2 will then be equally strong. Introducing decreasing concentrations of ozone and soot will decrease the temperature increase while decreasing the particle concentrations will strongly enhance the temperature increase. The cause is that ozone and soot warms the climate while particles cool. As the particles in the high forcing case is assumed to have a large climate forcing abatement will have equally large climate effect (see figure 6).

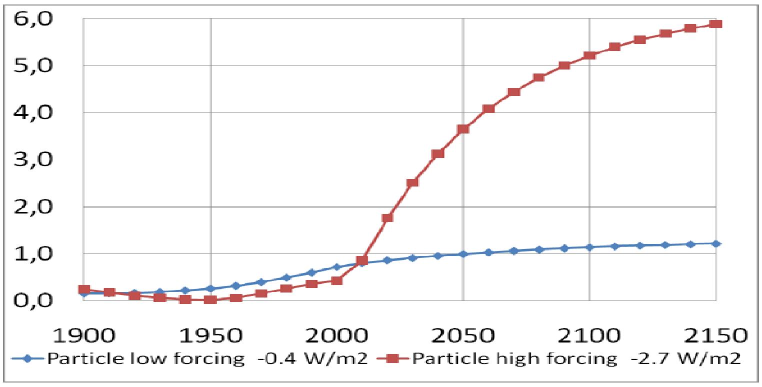

Figure 6. Temperature response with decreasing CO_2 emissions, about 10% per decade, assuming a high and low particle forcing scenario. For soot, ozone and particles an abatement scenario of 20% per decade from 2010 and on is assumed.

3. Conclusions

Investigating the influence of soot on the climate the following conclusions can be drawn;

- A high present climate forcing of soot implies low climate sensitivity.
- Abatement of soot will lower the temperature increase at 2xCO_2 proportional to soot forcing /total forcing

- Abatement of soot even at the highest soot forcing scenario will have a limited global effect and as CO2 emission have a much longer residence time in the atmosphere the abatement actions on CO_2 are most urgent.

Similarly using the IPCC results to investigate the particle effect the following could be concluded;

- High present particle climate forcing implies very high climate sensitivity giving very high temperature increase at $2xCO_2$.
- Total abatement of soot and ozone in this scenario will reduce this while abatement of particles will increase the temperature increase.
- This is a direct reflection on the assumed relation between the magnitude of the climate forcing for soot, ozone and particle, respectively.
- It is crucial to determine the total aerosol effect to get a better estimate of the climate sensitivity and thus a better estimate of the temperature at $2xC0_2$

From these conclusions the following policy recommendations follows;

- Start CO_2 abatement now!
- Air quality abatement should include particles, soot, ozone and methane and be climate neutral using a balanced abatement strategy on a regional scale.
- Climate and air quality abatement should focus on combustion as the main source of anthropogenic CO_2, particles, soot and ozone.
- Determine climate sensitivity, i.e. the total climate forcing of aerosols to establish target CO_2 concentration.

4. Acknowledgement

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References

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