We thank the referees for helpful comments. Our responses to comments appear below in blue.

Anonymous Referee #1

Received and published: 5 July 2013

I have read the paper "Two hundred fifty years of aerosols and climate: the end of the age of aerosols" by Smith and Bond. The authors describe past and future aerosol emission scenarios and corresponding forcing pathways based on an uncertainty assessment. It provides a useful compilation of recent studies on uncertainty in aerosol forcing. The analysis of the relation between greenhouse gas and aerosol forcing is interesting and well presented. I have only some minor comments and questions.

Specific comments:

P6424 line 1-3: Does the carbon price also lead to higher energy efficiency and thus less energy consumption? This would further decrease fossil fuel use and thus aerosol emissions.

Yes, the carbon price leads to reduced energy consumption. This reduction is a combination of improved efficiency and reductions in service demands due to increases in prices. We have added the following sentence to the paper:

> *Energy prices increase, which induces both decreases in end-use service demands but also induces shifts to more efficient technologies.*

P6424 line 10: What exactly does "reversal of deforestation trends" mean? Is there only less deforestation or also afforestation? To which extent? Does this affect aerosol emissions?

We have edited the text to clarify:

> *The climate policy scenario also assumes that carbon in terrestrial ecosystems is valued at the same level as carbon emitted by fossil-fuel use (Wise et al. 2009), which results in a reversal of deforestation trends in the RCP4.5 scenario to net reforestation over the 21st century. This results in a net decreases in aerosol emissions from burning associated with deforestation.*

While the dominant effect is a reduction in deforestation-related burning, there are also changes in natural forest fires (due to changes in forest area, but not changes in climate) and changes in grassland and savannah burning (due to changes in grassland area).

P6427 line 15-17: It would be helpful to specify "climate implications". Does this relate only to temperature or also to e.g. precipitation?

We have edited the text to clarify:

> *climate implications, specifically temperature change, of.*

P6433 line 3-16: The considered studies seem to include sulfate, carbonaceous

aerosols, cloud indirect effects, nitrate, mineral dust, land-use albedo, and stratospheric water vapor changes. The authors chose to subtract nitrate and mineral dust, but not land-use albedo and strat. water vapor. This should be explained and justified.
We have edited the text to make note of this point:

> *Changes in other forcings over this period, such those associated with stratospheric water vapor and land-use changes, could also impact aerosol estimates. We have not attempted to take such changes into account, particularly given the different methodologies used in these works, and this might add additional uncertainty.*

It should also be clarified in the caption of Table 2 which forcing agents are included.
We agree that this is an important issue. Since it is not entirely clear how various forcings might have been included in each study, or not, in these studies we prefer to leave the reference to this material in the text. We have added a sentence in the text more explicitly calling attention to this point as:

> *A reanalysis of these literature results taking into account the slightly different boundary conditions in each study would be helpful, but is beyond the scope of this present work.*

P6436 line 5: “land-use emissions” -> include "aerosol", CO2 may have a larger effect.
Good point, done.

Technical comments:
P6437 line 14: “with is projected decrease” there seems to be a typo somewhere
Corrected, thank you.

Anonymous Referee #2
Received and published: 18 September 2013
In this manuscript, the authors have estimated the global emission of black carbon, organic carbon and sulphate aerosols from 1850 to 2100. They have concluded that aerosols will be a minor contributor to the radiative forcing by the end of the 21st century. This analysis is interesting and will be useful for policy makers who want to examine at the relative roles of greenhouse gases and aerosols in controlling global climate. The authors should provide clarification with regard to the following points

1. The authors state that "we also assume that the aggregate emission factor within each sector decreases, as incomes increase". This needs further elaboration
We have added some additional explanatory text, and a more explicit reference to where this is discussed in more detail.

> *As incomes increase, we also assume that the aggregate emission factor within each sector decreases, becoming similar at high-income levels. This decrease represents more stringent pollution control standards over time, given that GCAM does not represent individual pollution control technologies (although different energy supply and demand technologies are represented). This treatment captures expected behavior, consistent with historical evidence given the assumed growth in*

regional incomes. The representation in GCAM is further discussed in Smith, West, & Kyle (2011, Section S4).

2. There is a need for more discussion regarding assumptions about aerosol emissions in 1850.

We have added the following paragraph.

While anthropogenic SO_2 emissions in 1850 are small (2% of year 2000 emissions), BC and OC emissions are more significant, 20% and 40% of year 2000 emissions in the inventory used here. 1850 anthropogenic BC and OC emissions are largely emissions from biomass used in the residential sector for heating and cooking (Bond et al. 2007). Building biomass consumption is estimated using per-capita consumption assumptions (Fernandes et al. 2007). Both biomass consumption and emissions factors at this point in the past are uncertain, although there is more confidence in the trends from 1850-1900 than the absolute magnitudes.

3. The global emissions of SO2 and BC reach a maximum in different years. How sensitive is this result to the assumptions made in the paper.

The peak in global SO2 is in the past, so this is a function of the historical inventories used. The peak in SO2 is fairly well defined, given that global SO2 emissions uncertainty is relatively small (Smith et al. 2011). Inventories indicate BC emissions are still increasing, but BC emissions are much more uncertain and, while it is likely that the BC emissions peak is somewhere past 1990 or 2000, we can't entirely rule out an emissions peak in earlier years given the large uncertainties in these emissions (Bond et al. 2007).

Even with the uncertainties in BC emissions and forcing, this does not change the overall conclusion that aerosol forcing will become relatively small in comparison with greenhouse gas forcing in the future.

4. In a recent paper Bond et al., (2013) have shown that global mean BC forcing is 1.1 W/m2 m-2. This is substantially higher than the values used in the present manuscript(figure 5). This difference has to be discussed in greater detail.

We will add a discussion of the results from the Bond et al. assessment to the paper. The higher forcing from BC in Bond et al. is due to two effects: a higher forcing per unit emission, and an assumption of higher overall emissions (a conclusion based on comparisons to observations). Because we use here forcing per unit emission, we focus only on this portion of the difference. Although the total BC forcing in Bond et al. (2013) is much greater than earlier assumptions because of scaling to observations, OC and other products of incomplete combustion, including their effects on clouds, was also scaled along with BC, producing a smaller net change in forcing. Of course, the net forcing of BC versus OC depends upon the dominant emission sector, which will evolve in the future. Nevertheless, the scaling in Bond et al. (2013) has a smaller effect on net aerosol forcing in present-day and future trajectories, compared with the doubling effect on BC-only forcing.

As stated in the paper emissions uncertainty for BC is large and we did not address that in this paper. New text is below.

Bond et al. (2013), hereinafter "Bounding-BC," recently assessed carbonaceous aerosol forcing. High and central BC values of direct forcing per emission used here (Table 1) are similar while the Bounding-BC lowest value is smaller, which would lead to a slightly larger range of overall forcing in our sensitivity studies below. The direct forcing-per-emission values in Bounding-BC were also drawn from AeroCom models; they differ from the values used in this work mainly because Bounding-BC employed emission scaling, and emissions were increased in regions where aerosol had shorter lifetimes.

The central OC direct forcing value in Bounding-BC is 40% more negative than that used here, and the low/high range is also slightly (20-30%) wider in the Bounding-BC report. The net effect is a potentially lower overall forcing from BC+OC. This could change some of the details of our results, however, since organic carbon forcing is very small compared to BC and SO2 forcing (Figure 3), altering the forcing-per-emission for OC makes a small difference in overall forcing trajectories.

A large part of the reason for higher black carbon forcing in Bond et al. is the finding that BC burden needs to be increased to match atmospheric observations. Bond et al. also increased the OC burden proportionately, resulting in smaller increase in net forcing. The implications of emissions uncertainty in residential building and road transport sectors the near-term climate impact of BC reductions have been examined by Smith and Mizrahi (2013).

5. Figures 4 and 5 are confusing. What do the various colors signify?
The colors are somewhat arbitrary, and simply indicate the different cases. We have clarified this in the Figure 4 legend by noting that these indicate "different colors for each forcing combination". Results are also given in table form as ranges.