Response to Reviewer #1

We thank the reviewer for the objective evaluation of our work. Below, we give our detailed responses to each of the concerns raised by the reviewer. Reviewer's comments are in regular font and our replies are in bold font.

General Comments

The paper of Kumar et al. investigate the relative contribution of black carbon (BC) from different emission sources, sectors and regions to total surface BC concentrations in South Asia and surrounding regions. This is done with WRF-Chem model, evaluated by information from ICARB campaign. While the authors address the topics listed in the paper, it is not immediately clear how significant the results actually are.

First, surface BC concentrations in source regions are closely related to the emissions. The relative contributions from different emissions sources and sectors could be inferred by the emissions inventories. It would be helpful if the authors also provide relative contribution from different sources and sectors to total emissions and give a discussion if there exists large difference when compared with current model results.

The reviewer brings up an excellent point to discuss whether the emission sources and sectors have the same contribution to the total BC emissions as the BC concentration categorized by different sources and sectors. These different sources and sectors contributing to surface BC concentrations in a region will be similar to their contribution to BC emissions only if transport processes are insignificant. We have shown in section 4.3 that regional transport plays an important role in distributing anthropogenic BC emissions over the model domain. To examine further how transport processes can affect the relationship between BC emissions and surface mass concentrations, we compare the contributions of anthropogenic and biomass burning emissions to the total BC emissions as well as to the surface BC mass concentrations in different regions of South Asia. We estimate that anthropogenic emissions contribute about 90%, 90%, 45%, 75% and 3% to the total BC emissions in North, West, East and South India, and Burma respectively, while their contributions to surface BC mass concentrations are 93%, 95%, 69%, 90% and 18%, respectively. Similarly, the biomass burning emissions contribute about 10%, 10%, 55%, 25% and 97% of the total BC emission in North, West, East and South India, and Burma respectively, while the contributions of biomass burning emissions to the surface BC mass concentrations in these regions are 4%, 3%, 30%, 8% and 81% respectively. The sources located outside the model domain are the remaining contribution (less than 3%) in these regions. These results show that surface BC concentrations cannot be inferred directly from the emission inventories.

We further examine the contributions of residential, industrial, transport and power generation sectors to total anthropogenic emissions as well as to the surface anthropogenic

BC mass concentrations in North, West, East and South India, and Burma (Table R1). It is interesting to note that the contribution of BC emissions from different sectors to the total anthropogenic BC emissions as well as to the surface anthropogenic BC mass concentration are very similar in North, West, East and South India despite a significant contribution (up to 25%) of regional transport to surface total anthropogenic BC mass concentration in these regions (see Table 3 of the manuscript). This is likely because of the fact that these geographical regions do not differ significantly in terms of the relative contribution of different sectors to total anthropogenic BC emissions, and these relative contributions are maintained during transport of BC from one region to the other.

Table R1: Percent contributions of residential (RES), industrial (IND), transport (TRA) and power generation (POW) sectors to the total anthropogenic emissions and to the surface anthropogenic BC mass concentrations in North (NI), West (WI), East (EI) and South India (SI), and Burma (BR).

Region	**Percent contribution to anthropogenic BC emissions**				**Percent contribution to surface anthropogenic BC mass concentration**			
	RES	**IND**	**TRA**	**POW**	**RES**	**IND**	**TRA**	**POW**
NI	**62**	**23**	**14**	**1**	**62**	**22**	**15**	**1**
WI	**56**	**33**	**11**	**1**	**55**	**33**	**12**	**1**
EI	**70**	**19**	**10**	**1**	**68**	**20**	**11**	**1**
SI	**64**	**23**	**12**	**1**	**61**	**26**	**12**	**1**
BR	**79**	**3**	**18**	**1**	**69**	**17**	**14**	**1**

In contrast, Burma is different from the Indian regions as contributions of different sectors to total anthropogenic BC emissions and to the surface anthropogenic BC mass concentrations are not similar. The percent contributions of different sectors to the surface anthropogenic BC mass concentrations in Burma are more similar to the Indian regions, i.e. the highest contribution is from the residential sector followed by the industrial and transport sectors. This is likely because of the fact that regional transport of BC from the Indian regions is the main source (71%) of surface anthropogenic BC mass concentrations in Burma (see Table 3 of the manuscript) and anthropogenic BC emissions in India are much stronger compared to Burma (see Figure 1 of the manuscript). These results show that it is important to account for the contribution of regional transport while relating surface BC concentrations to emissions but the relationship between surface BC concentrations and local emissions may be preserved if emissions in the source region are weaker compared to the receptor region and relative contributions of different sectors to total emissions are similar in the source and receptor regions. These results have been included in Section 4.3 of the revised manuscript.

Second, this study investigates the relative contribution of local versus regional anthropogenic sources. It is confusion why the authors do not provide any information about the meteorology and its implication for regional transport. How will the Indian Monsoon current affect the results? What is the meteorological condition during the modeling period (Mar-May) compared with other seasons?

Our previous studies have provided a detailed description of the meteorological conditions during the ICARB period (Nair et al., 2008) and comparison of March-May meteorology with other seasons (Kumar et al., 2012a) and we did not want to repeat that information here. However, we have added the following brief description of meteorological conditions in Section 2 of the revised manuscript. "The meteorological conditions prevailing during the ICARB comprised mainly of calm synoptic conditions with weak winds, clear skies and absence of precipitation (except for 9 April). The ship did not face any major weather system or cyclonic depression during the whole campaign. Analysis of synoptic scale wind patterns showed the presence of weak westerly winds in the northern BoB associated with a low-level anticyclonic circulation centered at (88°E, 15°N), and weak easterly winds south of 12°N in the BoB. During the AS segment of the campaign, the synoptic winds were strong westerlies in the northern AS, which turned sharply to northerlies close to the peninsular India due to the presence of a strong anticyclone centered at (60°E, 16°N)."

We agree that the seasonal change in regional meteorology will affect the regional transport making the results presented in this paper applicable to only the March-May time frame. We have since conducted a yearlong simulation of BC over South Asia. These results are presented in a separate paper (Kumar et al., 2015) in order to evaluate whether WRF-Chem could adequately represent the BC seasonal cycle. Regarding the impact of Indian monsoon currents on the results, we find that the contribution of regional transport to anthropogenic BC loadings does not change seasonally in the West and East India; however there is a clear seasonality of regional BC transport in South and North India. The regional transport makes a small contribution to anthropogenic BC loading in South India during the monsoon season (June-September), while it is small in north India outside the monsoon season. Further details are presented in Kumar et al. (2015).

Last, the increasing trend of emissions in South Asia (also mentioned in the paper) is of great concern. This study is done for the year 2006. Could the results be used to extrapolate the situation in more recent years?

We conducted the simulations for the year 2006 to utilize the high resolution ICARB data for evaluating the model's ability in simulating observed BC over South Asia. However, the yearlong simulations referred to above were conducted for the year 2011 and we can gain some insight into how changes in emissions between the two simulations affect the source contribution analysis by comparing the 2006 simulation with the 2011 simulation. It should be noted that anthropogenic emissions in these two simulations are taken from two different emission inventories, SEAC^{4}RS + MACCity emissions, which are appropriate for the 2006 (MACCity shipping emissions and emissions due west of India) to 2012 (SEAC^{4}RS

emissions over rest of the domain) time period, for the 2006 simulation and EDGAR-HTAP emissions, which are appropriate for the 2010 time period, for the 2011 simulation. (The EDGAR-HTAP inventory was released after we conducted the 2006 simulation.) Therefore, differences in anthropogenic emissions between the simulations do not represent temporal changes in anthropogenic emissions appropriate for the two modeled years. The biomass burning emissions are based on the Fire Inventory from NCAR (FINN) in both the simulations and thus differences between the two simulations represent actual changes in the biomass burning emissions over this region between 2006 and 2011. In comparing the emissions from the 2006 simulation to the 2011 simulation, the anthropogenic emissions changed from about 203 Gg to about 201 Gg, while the biomass burning emissions changed from about 327 Gg to 285 Gg for the ICARB period (18 March-11 May). Consequently, the contribution of BC-ANT, BC-BB and BC-BDY to the total surface BC concentrations in the 2011 simulation are estimated as 65%, 28% and 7% respectively, while the corresponding contributions in the 2006 simulations are 60%, 37% and 3% respectively. This comparison shows that changes in the strength of emission sources can potentially affect the source contribution analysis, but differences in meteorology between the two years can also play a role. Thus, multi-year simulations accounting for temporal variability in the strength of different emission sources and variability in meteorology must be conducted before these results can be applied to design BC mitigation strategies in South Asia. This information is included in the Summary section of the revised manuscript.

In summary, this paper is generally well written. It describes what they did and is easy to follow along. It is worthy of publication in ACP subject to addressing these and specific comments below.

We thank the reviewer for the positive recommendation

Specific Comments

p. 30729, line 25 – p. 30730, line 9, there are more recent studies (e.g. Wang et al., 2014, Global budget and radiative forcing of black carbon aerosol: Constraints from pole-to-pole (HIPPO) observations across the Pacific and Hodnebrog et al., 2014, How shorter black carbon lifetime alters its climate effect) suggesting shorter lifetime of BC (around 4 days rather than one week), which reduces the direct aerosol effect closer to the lower range of AeroCom Phase II models.

Thanks. These studies are cited in the revised version.

p. 30731, line 17, what is “BoB” And “AS”

They represent the Bay of Bengal and the Arabian Sea, and are spelled out in the revised version.

p. 30733, line 17-21, does the emission inventory account for the seasonality in emissions? How is emission during Mar-May compared with other seasons?

The SEAC4RS-MACCity emission inventory does not have a seasonal variation. If one examines the recently released EDGAR emission inventory (http://edgar.jrc.ec.europa.eu/htap_v2/index.php?SECURE=123) there is not a significant seasonality in BC emissions.

p. 30736, line 6-7, What is the possible reason for the large differences seen in the northern coastal BoB? There is also large difference in the southern costal of BoB in Figure 4, any explanation?

The time series of BC source tracers shown in Figure 3b provides insight into possible cause for these larger differences. The ship was sailing in the northern coastal BoB during 18-21 March 2006 and in the southern coastal BoB during 10-13 April 2006. According to our analysis (Figure 3b), anthropogenic emissions were the main source of BC during both of these periods. Thus, uncertainty in BC emissions from anthropogenic sources is likely responsible for these larger differences. Further analysis of region-specific tracers of BC showed that these sources were located in East and South India.

p. 30738, line 27 – p. 30739, line 2, there is eastward increase due north of 13◦N of BoB in BC-ANT concentrations (not affected by biomass burning) from Figure 5e, any explanation?

The eastward increase in BC-ANT mass concentrations due north of 13^{o}N in the BoB is due to outflow of pollutants from the eastern Indo-Gangetic Plain which enters into the northern BoB through Kolkata and Bangladesh (see Figure 6).

p. 30739, line 28-29, it is hard to tell from the figure that southern parts of the AS have higher contribution of transport sector than the northern parts.

We agree and have rephrased this part.

p. 30754, the yellow lines for the ship tracks are hard to see in the figure.

Sorry about this. We have increased the thickness of the yellow line and changed its style from solid to dashed line so that it can now be distinguished from the boundaries of the defined geographical regions.

References

Kumar, R., Barth, M. C., Pfister, G. G., Nair, V. S., Ghude, S. D. and Ojha, N.: What controls the seasonal cycle of BC in India?, J. Geophys. Res., submitted manuscript, 2015.