Response to Reviewer 1, S. Bauer:

We would like to thank the reviewer for the encouraging words and insightful comments. Our responses to the comments are listed below. The referee's comments are italicized and our responses are in normal print.

The paper presents a modeling study on the origin and forcing of black carbon in the Himalaya region using the GEOS-CHEM model and its adjoint modeling tool. The paper compares simulated and observed BC concentrations in the Himalaya region, estimates regional BC and snow albedo forcings and uses the adjoint model to track the origin of BC at different stations. The papers main findings are that emissions from India and China are the main source regions of BC to the Himalayas.

I want to congratulate the authors to this very interesting well presented paper, and I have only some minor improvements that I would like to suggest:

P 21618, L12: Hansen et al, 2005 is cited as most recent snow-albedo estimate. There are more recent papers on this, either change the word 'most recent' or include later studies.

The text was changed to:
"Some of the recent estimates of snow-albedo effect alone are +0.05Wm^{-2} globally (Hansen et al., 2005) and as high as +20Wm^{-2} during spring in parts of the Tibetan Plateau (Flanner et al., 2007)."

P21618 L: 17: BC forcing is directly compared to CO2 forcing. Comparing a short term forcing such as BC to a long term greenhouse gas forcing could be misleading. Please rewrite this sentence.

We agree with the reviewer that the sentence was misleading. We removed it.

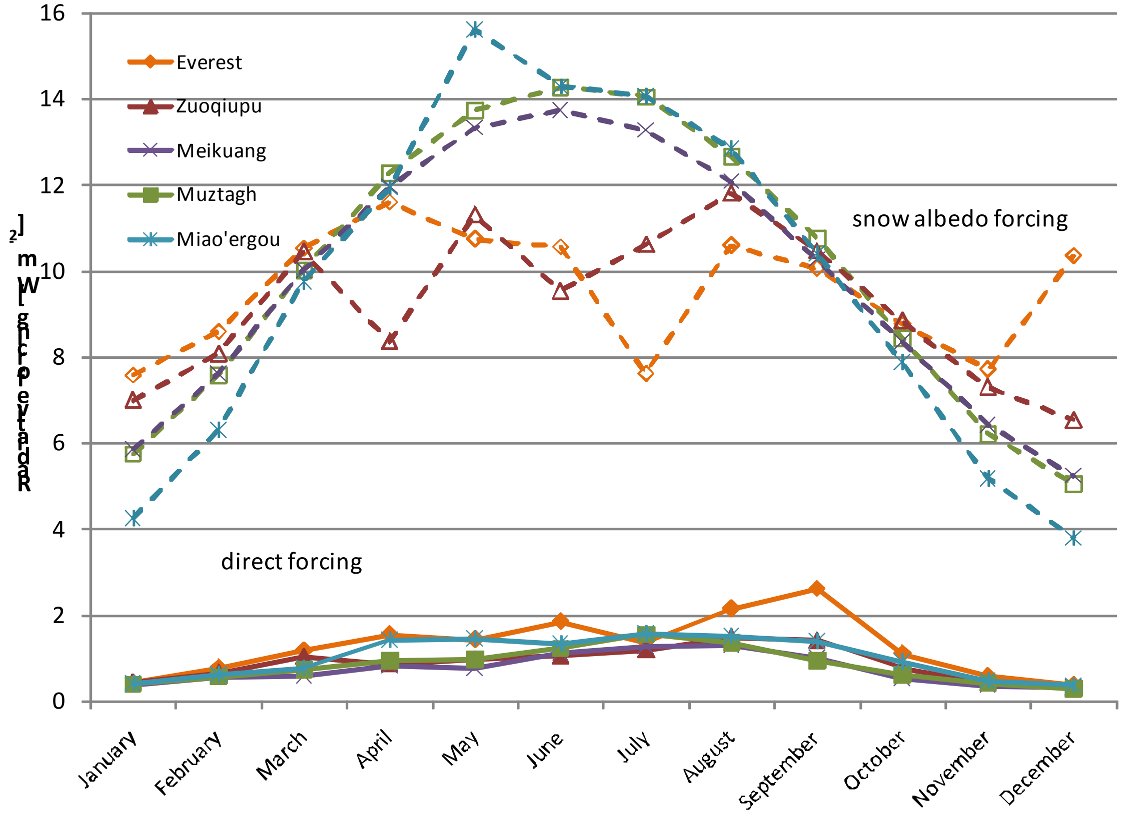
P21618 L 25: Could you summarize the findings of the cited papers, Menon et al 2010, Ramanathan and Carmichael, 2008, and Ming et al.

Thank you for the suggestion. The text now reads:
"Several studies attempted to link the Asian BC emissions to their impact on Asian glaciers. Menon et al. (2010) used two recent BC emission inventories for India to assess the effect of BC aerosols on snow cover. Ramanathan and Carmichael (2008) studied the impact of biofuel BC emissions in India on regional radiative forcing, while Ming et al. (2008, 2009) employed back trajectory analysis to map the regions from which BC in the Third Pole snow was transported. We use an adjoint model approach that improves on these approaches by providing both the exact location (model grid box) from which BC is emitted and the quantity of emissions from each grid box that arrived at the receptor grid box."

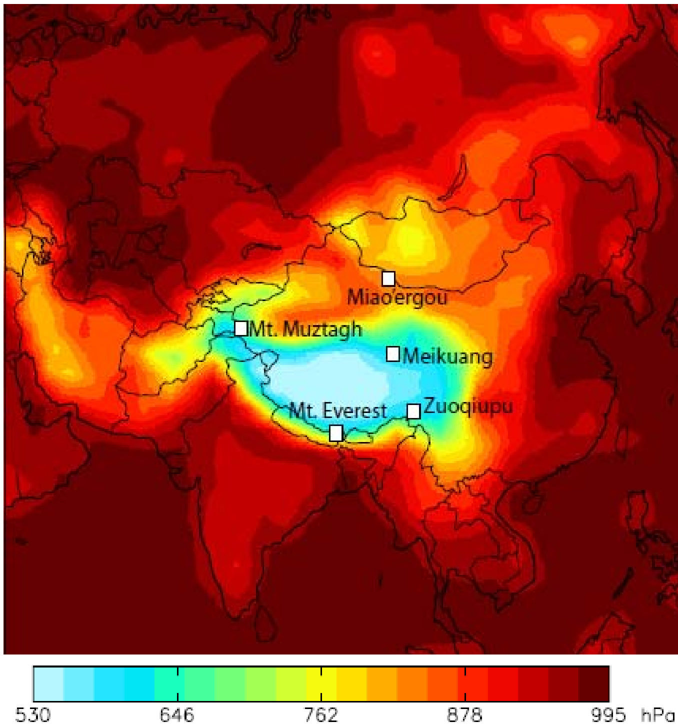
P21622 L 6: You assume doubled absorption in order to account for internal mixing of BC aerosol, but later in the paper (P 21627 L3) you also double the forcing numbers of your calculations. First of all I think doubling of the absorption is a bit to high, a factor of 1.5 seems more appropriate, but if you already altered absorption in your radiative calculations you *should not double your forcing numbers after that. L8: Can you please explain in more detail how the snow-albedo calculation is done?*

The description of the methodology was confusing. In our calculations we did not assume doubled absorption numbers and thus we remove the sentence referring to doubling of absorption. We only doubled the resulting direct forcing amount (following Kopp and Mauzerall 2010). We agree with the reviewer that a factor 1.5 would also be appropriate and we adjust the text as well as Figure 4 accordingly. We add the following text at the end of Section 2 (Radiative Transfer Model) to elaborate on snow-albedo calculations:

"To compute snow-albedo radiative forcing, we first compute radiative forcing with MODIS-derived surface albedo. We then add the albedo change we computed to have resulted from BC deposition, and again calculate radiative forcing. The difference between the two forcing calculations is our linear approximation to the radiative forcing due to snow-albedo effect."



P21624 and Fig1: Maybe Fig. 1 would be more insightful if you would zoom more into the region and plot the model grid over the graph.



As per Reviewer's suggestion, we made the figure more regionally focused. More than gridlines, however, we tried to emphasize the geopolitical location of the studied region.

P21629 whole paragraph: Maybe this is just personal preference, but why do you suddenly use the phrase 'Third pole'. You still discuss the same region as before, why not stick to the same terminology.

In fact, we use the compact phrase "Third Pole" throughout the manuscript, including wherever appropriate for the headings and several preceding pages. We find it a compact way to refer to glaciers in both the Himalayas and the Tibetan Plateau. We refer to the individual regions when discussing individual results. We introduce this terminology on p21618, in the first section of the paper.

P21635 L1: Was biomass burning especially strong during that year in Africa? Discussion: Following your study could you write a section in your discussion about the quality of emission data in China and India.

2001 was a rather typical year for biomass burning in Africa. We state that with the following addition on p 21620, line 9:

"Biomass burning emissions in Africa can be characterized as typical, with standard deviation of only 10% in 1997-2004 years (van der Werf et al. 2006), thus the interannual variability of BC emissions from Africa to Third Pole depends mostly on the change in meteorology."

We added the following text to the discussion, which brings more attention to the current uncertainties:

"(…) These source regions are also places where reducing the uncertainty in BC emissions is most critical. Currently, a lot of uncertainty exists in both emission factors and activity rates, especially in India and China. Though very difficult to quantify, the 95% confidence interval for emission estimates can include a range that varies by more than a factor of four (Bond et al. 2004)."

Figures: I have problems to see the arrows in Fig3. maybe it's just the printer version, but the arrows are tiny.

The arrows in the surface wind plot are much smaller than the winds they are in the plots of 550mb winds. We kept the same wind vector scale for both plots.

Response to reviewer #2 comments:

We would like to thank the reviewer for the encouraging comments and helpful suggestions. Our responses to the comments are listed below. The referee's comments are italicized and our responses are in normal print.

This well-written manuscript presents an interesting study on the origin and radiative forcing (direct and snow-albedo) of black carbon in the Himalayan and Tibetan Plateau region. The study estimate BC concentrations in snow using modeled BC deposition and precipitation rates from GEOS-Chem and compared them to observational data for 16 sites. BC direct and snow-albedo radiative forcing were calculated. The most exciting part of the study is the use of the adjoint of the GEOS-Chem model to identify the origin of BC for five sites. While emissions from India and China are found to be the main source of BC to the Third Pole, the study also finds biomass-burning emissions from Africa contributed non-negligible amounts for the modeled year (2001). I recommend this manuscript for publication in ACP, with minor improvements suggested below.

P21622, L6: Doubling of absorption to account for internal mixing is too high. A factor of 1.5 is more appropriate (Bond et al., 2006).

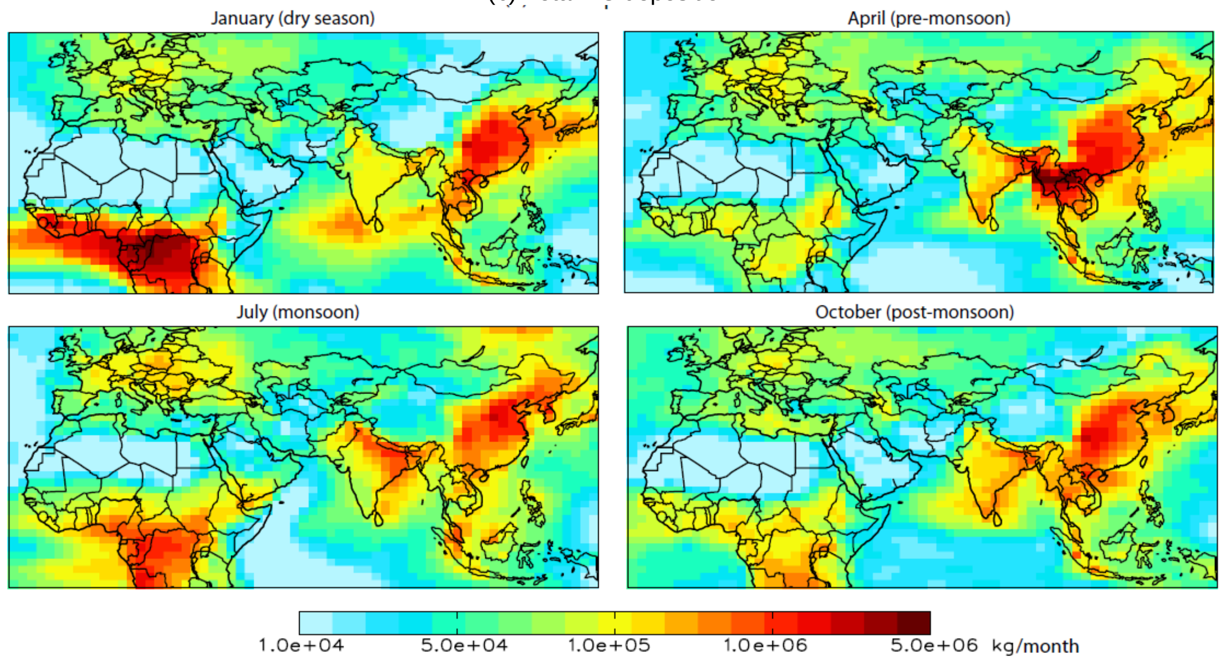
We appreciate the Reviewer's comment and instead of a factor of 2 apply a factor of 1.5. This change was made in the text and in Figure 4.

P21624, L4: ": : :the likely reason for lower BC concentrations during the monsoon is that during the rainy season aerosols are scavenged close to source regions. As a result, less BC is transported to the remote mountains." It seems to me that concentration and deposition results from GEOS-Chem can be analyzed to give a definitive statement on this instead of resorting to an inconclusive statement using the word "likely."

After a closer inspection of deposition amounts, we revised the second part of the sentence to read:
"… for the Everest site, the highest amount of BC deposited occurs during monsoon, reflecting scavenging near the source regions, whereas deposition of BC in other sites peaks in other seasons."

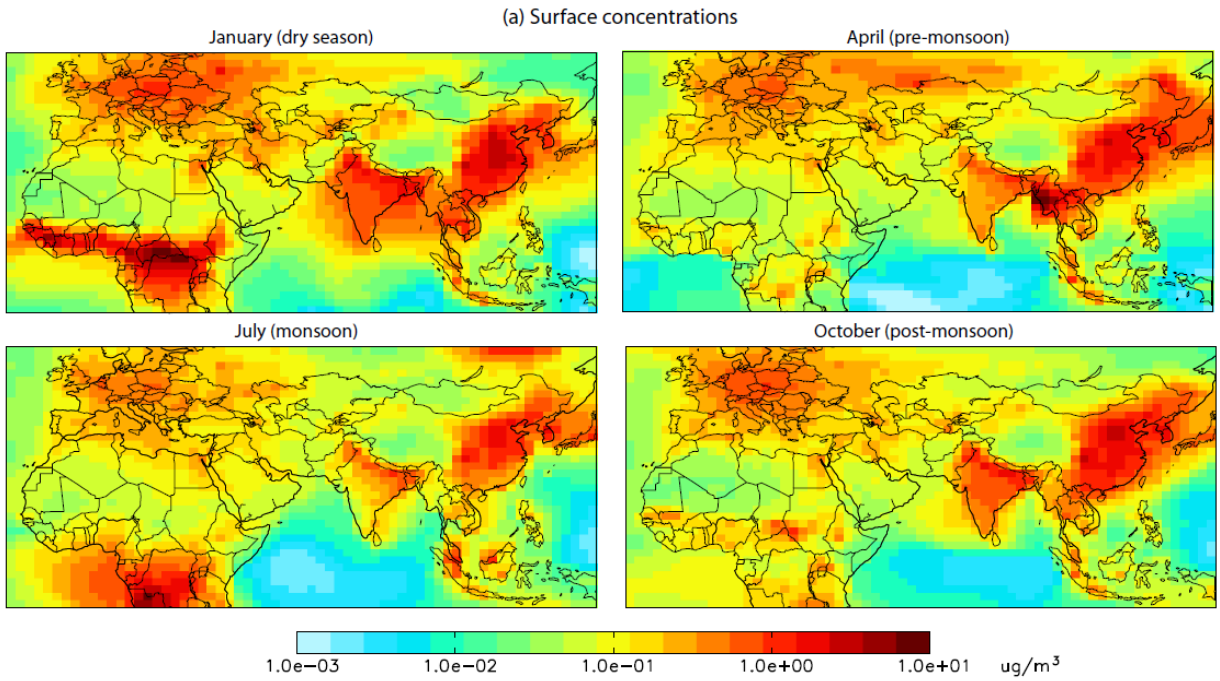
We also modified Figure 2 to now also include maps of BC deposition.

(b) Total BC deposition



P21625, L4: "Figure 2 shows that air concentrations are also lower during the monsoon season: : :" It is actually impossible to tell from Figure 2 because: 1) Figure 2 shows results of Jan, Apr, Jul, & Oct, not monsoon versus non-moonson seasons; and 2) the figure shows the whole globe, making it difficult to see the Himalayan region. It would be more useful if Figure 2 is zoomed into the Himalaya and Tibetan Plateau region (similar to Figure 1, but zoomed in even more). In addition to surface concentrations, it would also be more insightful if deposition rates are shown.

We have improved Figure 2 based on the reviewer's suggestions, zooming in on the same region as in Figure 3 (which also shows emissions) and relabeling the plots with seasons based on precipitation, ie. January (dry season), April (pre-monsoon season), July (monsoon), October (post-monsoon). Similarly, in the text we augmented monsoon/non-monsoon labels with months for which we show plots. As mentioned above, we also added a second part to Figure 2 showing total deposition rates of BC during the same months and over the same domain.



P21630, L5: "The Miao'ergou site atmospheric column, for example, receives about half as much BC as the Everest grid box, although the fraction deposited at that site is about a factor of five larger, resulting from lower precipitation at Miao'ergou than at Everest." Why would deposition rate at Mioa'ergou be higher if there its atmospheric column receives less BC and it has lower precipitation rate than at Everest?

We incorrectly used the word "deposition" when in fact the text was referring to BC mass fraction in snow. While there is less BC deposited at Miao'ergou than at Everest, there is even less precipitation, leading to larger relative concentration of BC in snow at Miao'ergou. We revised this and preceding sentences in the following way:

"The GEOS-Chem adjoint model indicates that 3–4 times as much BC is transported to the atmospheric column at the Mt. Everest receptor grid box as at the sites in the Tibetan Plateau. However, the observed BC mass fraction in the Everest grid box tends to be less than in the Tibetan Plateau, due to much larger precipitation, and the model generally overestimates that deposition fraction. The Miao'ergou site atmospheric column, for example, receives about half as much BC as the Everest grid box, although the relative snow concentration (BC mass fraction) at that site is about a factor of five larger, resulting from lower precipitation at Miao'ergou than at Everest."

P21635, L1: Please add discussion on biomass burning in 2001 in comparison to other years and what it means for contribution of this source of BC to the Third Pole. Was 2001 a typical, low, or high fire year in Africa? What is the range of variability in contribution of biomass burning emissions from Africa to the Third Pole?

We chose the year 2001 for our simulation partly because the biomass burning was quite typical that year. We now add the following text in our description of emission inventories, p21620, line 9:

"Biomass burning emissions in Africa can be characterized as typical, with standard deviation of only 10% in 1997-2004 years (van der Werf et al. 2006), thus the interannual variability of BC emissions from Africa to Third Pole depends mostly on the change in meteorology."

Tables 2 & 3: I don't understand why these results are split into two tables with seasonal results shown for only two sites. Why not show seasonal results for all five sites (and remove Table 2 because the annual results are simply the average of the seasonal results)?

The tables are now consolidated as suggested by the reviewer. Table 2 was removed. Consolidated table is the new Table 2 and includes all sites.

Table 2. National/regional origin of BC reaching the atmospheric column above the grid box containing a glacier site for each month of simulation and an annual average. Units are kg per country or region per day.

Site	Month	China	India	Pakistan	Nepal	Middle East	Africa	Russia
Mt. Everest	January	11,500	6,850	241	10,300	162	923	2
	April	12,200	29,500	3,200	17,400	954	260	13
	July	15,000	12,900	79	5,120	95	48	1
	October	11,000	11,700	486	9,000	74	4	3
	Annual	12,500	15,200	1,000	10,500	321	140	5
Zuoqiupu	January	4,620	4,400	131	1,310	117	419	2
	April	5,890	11,400	1,800	3,460	721	133	49
	July	7,640	1,990	86	80	38	5	2
	October	5,210	2,590	213	542	23	2	1
	Annual	5,820	5,100	558	1,350	225	140	13
Meikuang	January	3,640	608	532	56	318	18	22
	April	3,250	336	382	19	926	135	360
	July	15,160	599	177	87	247	1	46
	October	8,460	3,520	2,070	325	241	6	43
	Annual	7,600	1,270	791	122	433	40	118
Mt. Muztagh	January	2,490	232	902	1	552	7	19
	April	5,030	2,740	3,920	6	2,260	175	239
	July	13,000	151	1,370	5	2,870	3	161
	October	7,000	640	3,320	0	1,760	6	150
	Annual	6,880	941	2,380	3	1,860	48	142
Miao'ergou	January	4,540	6	7	0	379	4	493
	April	4,270	12	38	0	908	49	5,269
	July	13,400	38	226	1	1,770	2	1,493
	October	38,800	838	1,570	12	972	1	626

	Annual	15,300	223	459	3	1,000	14	1,970

Reference Bond, T. C., G. Habib, and R. W. Bergstrom (2006), Limitations in the enhancement of visible light absorption due to mixing state, J. Geophys. Res., 111, D20211, doi:10.1029/2006JD007315.