Response to Reviewer #1 for manuscript ACP-2013-133
(A decadal satellite analysis of the origins and impacts of smoke in Colorado)

We thank the reviewer for her/his comments. Our responses to these comments (in italics) are given below.

In this manuscript, the authors investigate the impact of fires on aerosol loading in Colorado through both the total column aerosol optical depth (AOD) and observations of surface PM2.5 in Colorado. The manuscript is clearly written on an interesting topic that is certainly of relevance to the ACP audience. I would, however, recommend several changes, some of the major, prior to acceptance.

<u>Major Comments:</u>

As described by the abstract, this paper investigates the impact of both local and transported smoke from fires on air quality in Colorado. Looking at Table 2, it was unclear to me why some major events, such as the Wallow Fire, were included as a part of the low fire impact years. Were these considered low impact simply because the fires themselves were not within the borders of Colorado? If so, doesn't this limit the study's investigation to local transport events during the high fire impact years and bias the low-impact baseline with long-range transport events?

The reviewer is correct stating that we classified high and low fire years based on the area burned over Colorado. We understand the reviewer's concern about biasing our results due to this classification. However, we divided the data analysis in three periods (2002, 2012 and 2000-01/03-11) for clarity and identified potential fire events for all 13 years studied. For Table 2, we considered potential fire events when daily MODIS AOD levels were above 0.5. We feel that we clearly identified the main local and transported fire events independently of our high/low fire year classification. We have clarified our classification in the text to address this concern.

Section 3.1 (Page 8 Line 20)

> For clarity, we separately show daily area burned for two high active fire seasons (2002 and 2012) and the minimum and maximum range reported *for all other seasons with low fire activity (2003-2011) over Colorado.*

Section 3.1 (Page 9 Line 14)

> Figure 2 shows average MODIS AOD over the western US for the fire seasons of 2002, 2012, and 2000-01/03-11*, i.e., the two high-active fire and the low-active fire years identified over Colorado, respectively.*

Section 3.2 (Page 10 Line 9)

> Periods when AOD levels were above 0.5 were classified as key fire events and identified in Figure 3a.

The use of MODIS AOD over western North America can be quite challenging. The author shave applied filtration based upon Zhang and Reid (2006), but this approach was developed for oceanic regions, and is likely not applicable here. Figure 2, for example, shows significant and unrealistic enhancements over parts of Nevada, questioning the filter's effectiveness. The removal of AOD above 1.5 as a part of this filter (p. 8237, L7) may also remove some important peaks during fire events. I would suggest the authors rather adopt the methods of Hyer et al., AMT, 2011, which extends the earlier work of Zhang and Reid to over land.

We carefully considered this comment and revisited the MODIS AOD screening method. We compared our screened AOD values with those obtained from the basic screening proposed by *Hyer et al*. (2011) over western US in 2002. We also included in the analysis Deep Blue 550 nm AOD over land corrected by the quality assurance flag (*Hsu et al.,* 2004) provided within the MODIS Terra L3 Collection 5.1 data files.

We agree with the reviewer than the screening method is important when analyzing MODIS AOD: all three AOD methods return similar AOD distributions over western US, although Deep Blue and Hyer el al. (2011) AOD smooth the very high AOD values over Nevada; the daily AOD variability is very similar with the three AOD approaches over the Colorado Front Range in the 2002 fire season, although our screening method slightly overestimates the background AOD over the Colorado Front Range.

However, we would like to highlight that the basic screening method of Hyer et al. (2011) removes about 65% of the AOD data over Colorado, and unfortunately Deep Blue MODIS Terra AOD is only available from 2000 to 2007 due to known calibration issues (*Shi et al.*, 2013). Therefore, we decided to maintain our screening method in the paper as our intention is to preserve as much data as possible for the analysis as well as include the 13 year record of MODIS Terra AOD data.

We would also like to note that our MODIS AOD screening method followed the work of *Zhang and Reid* (2006) over ocean and the work of *Ridley et al.,* (2012) over land, which is slightly different than that proposed by *Zhang and Reid* (2006).

Finally, the purpose of this work is not to validate MODIS AOD with other observations, but rather use the long-term record of MODIS AOD to investigate qualitatively the number of fire smoke events, from local and out-of-the state fires, independently of the magnitude of the AOD levels. Therefore, the exact quantification of AOD is not critical to our analysis. We, however, acknowledge that our filtering method may not be very effective over bright surfaces, such as Nevada, and added a discussion in the text on this issue. We also corrected the description of our MODIS screening method.

Section 2.1 (Page 5 Line 13)

> We use *corrected* land optical depth retrievals and filter the MODIS data to include only grid boxes with cloud fractions below 0.8 and aerosol optical depths less than 1.5, following the work of *Ridley et al.,* (2012). Our results do not change if we use all the data from the standard MODIS AOD product. For example, monthly average AOD over Colorado in June 2012 is 0.2 and 0.23 from the standard and filtered data, respectively. *This screening method may not be the most effective over bright surfaces (Hsu et al., 2004, Hyer et al., 2011). However, it preserves a large fraction of the data and allows for the complete use of the 13 year record of MODIS Terra AOD data (Shi et al., 2012).*

In light of the regional uncertainty in MODIS AOD, I would suggest that AERONET observations from Boulder should be incorporated into this study alongside MODIS. This station has been operational since 2001 and resides within the Front Range Corridor defined by the authors, so it could be an excellent source of validation.

We thank the reviewer for pointing out the availability of AERONET AOD data from Boulder. As suggested by the reviewer, we analyzed these data and included the results in the manuscript.

Section 3.1 (Page 9 Line 23)

> As an additional source of AOD observations over Colorado, we analyzed aerosol optical depth obtained in Boulder as a part of the AERONET global aerosol monitoring network (Holben et al., 1998). AERONET AOD values were slightly lower than MODIS AOD (not shown). However, they showed an increase of about 20-30% in AOD in 2002 and 2012 with respect to 2001/03-11, with average values of 0.18, 0.15 and 0.12, respectively.

My understanding of Figure 2 from Omar et al, 2009, is that the CALIOP retrieval over land distinguishes polluted continental aerosol from biomass burning aerosol based solely upon whether or not an aerosol layer is elevated. If this is the case, can this algorithm truly distinguish whether or not biomass burning plumes were impacting the surface, as suggested from Figure 5? Some further discussion is needed.

We agree with the reviewer that the CALIOP algorithm cannot truly distinguish biomass burning from polluted continental aerosols near the surface. We addressed this issue in the text

Section 3.4 (Page 13 Line 27)

> It is important to note that although Figure 5b identifies smoke aerosols near the surface, CALIOP algorithm cannot truly distinguish smoke from polluted continental aerosols (Omar et al., 2009, Winker et al., 2013).

Section 3.4 (Page 15 Line 20)

> Unlike MISR, CALIOP did not identify smoke aerosols at surface level (<1 km) during the High Park fire in part because its algorithm *does not distinguish smoke aerosols near the surface (Omar et al., 2009, Winker et al., 2013),* and in part […]

The paper would benefit from a better characterization of non-fire conditions, as compared to those observed during high active fire seasons. For example, how often do Colorado PM2.5 levels exceed national health standards in the absence of fire influence? Are fires effectively responsible for all the non-compliance days? Half of them? Background levels are briefly mentioned to be below 10 g/m3, but I feel the paper could be much more effective if fire-related enhancements could be clearly placed in context.

We thank the reviewer for suggesting including a discussion on $PM_{2.5}$ background levels and exceedances in Colorado. As also suggested by reviewer # 2, we added this discussion in the Introduction.

Section 1 (Page 4 Line 9)

> Fire smoke has an important impact on air quality in Colorado during the summer. Typical summertime background $PM_{2.5}$ levels are below 10 µg/m^3, with a contribution of about 60% from carbonaceous aerosols (Hand et al., 2012). Since $PM_{2.5}$ started being monitored in Colorado in 1999, the daily $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS; 35 µg/m^3, based on the 98th percentile, averaged over 3 years) has never been violated during the summer, although exceptionally fire events have been responsible of increases in $PM_{2.5}$ concentrations above the daily NAAQS (CDPHE APCD, 2012).

Minor comments:

p. 8245, L26-27 – For comparison purposes, it would be quite helpful if Figure 6 and Figure 5 provided consistent vertical units of pressure and/or altitude.

Modified the yaxis in Figure 5 as indicated. We also modified any reference to CALIOP pressures in the text accordingly.

p. 8247, L2 – ": : :swath is 4000 narrower: : :" Do you mean "4000x"?

Added 'times' as indicated.

Figure 3b – The use of "/" to indicate a range of years could be confusing. I would suggest using "-"instead.

Modified as suggested.