Authors Reply to Referee 3 (R3)

General comments

This study investigates the dispersion of wildfire smoke across continental Europe and its contribution to the aerosol load. The analyses are performed for a five-year period i.e. 2002-2007. The location of wildfires is determined from MODIS fire counts, and the transport of smoke is estimated using a trajectory model (HYSPLIT). Authors show that wildfires have an impact mainly on Eastern and Central Europe, as well as the Scandinavia, whereas the impact is very limited over Western Europe and Western Mediterranean regions.

The results of the smoke dispersion are also qualitatively compared to the satellite observations of the aerosol optical thickness, with the objective of estimating their contribution to the submicron AOT. Authors conclude that 5 to 35% of submicron AOT in Europe is due to wildfires, with however a strong seasonal variability. The applied approach leads to interesting results although it is based on numerous assumptions and a very crude modeling, in particular the representation of the fires daily cycle is omitted. The methodology is well explained, and the study is relevant to ACP.

Therefore, I recommend its publications after the following questions have been fully addressed:

R3.1 - The horizontal resolution of trajectory computations was set to 2.5x2.5 degrees, which to my opinion is too coarse. Authors need to show that the results are not significantly impacted by this choice by repeating the calculations for a 0.5x0.5 degrees horizontal resolution. If this calculation is computationally demanding, a 2 months time period could be chosen e.g. summer 2003, and the resulting trajectories compared with the current results. An additional section for instance "3.3 Sensitivity analysis and comparisons to previous studies; 3.31. Effects of the horizontal resolution" need to be added to paper, and the new results described.

The original description of our methodology possibly led to a misunderstanding. We divided the domain into 2.5° cells and used these as starting point of the forward trajectories, but this is not the actual resolution of the Lagrangian model used to compute the trajectories themselves. This latter is only limited by the resolution of the meteorological data used, which in our case are NCEP analyses at 1° resolution. In the revised version of the manuscript we specified this aspect (Section 2.3) clarifying that: "*Trajectories are driven by the 1°-resolution NCEP analyses. We divide the domain in a regular 2.5°- resolution grid and start trajectories from those grid-cell centres, where and when fires are detected. This resolution is chosen as a compromise between good spatial resolution of sources and acceptable computing time, because it limits the number of trajectories to be calculated.*"

Unfortunately, due to limited computational resources at our disposal, we can't refine the trajectory starting point resolution down to 1° in the present study (note that the 0.5° resolution suggested is, in any case, not possible as the MODIS Fire Radiative Power dataset used in the analysis is given at 1° resolution). It is not only a matter of computing a larger number of trajectories (about 5 times larger, which translates into a 5-times-longer computational time), but rather a limitation in the ability to handle such a large number of data (matrices to be handled would increase from about 1 million points each to 5 million points each).

Actually, the starting points resolution refinement (as well as the use of other aerosol/fires datasets) is in our future plans but this will require a re-architecture of the entire data-analysis program.

From a scientific point of view, we do not expect this refinement to produce major differences in the simulated transport pattern, which is basically driven by the synoptic wind field, but it could lead to the inclusion of a larger number of small fires (now limited by the imposed fire count threshold of 25 fire counts/1000km^2/day in the 2.5°x2.5° pixel). This means

that the main message of the current study would be not compromised but rather 'reinforced' by this improvement.

Following the Reviewer's comment, these arguments are now included in the conclusion section where we now clearly state that '*the 2.5° horizontal resolution of starting points used in this study could be refined having at disposal higher computational resources. However, as the modelled atmospheric transport is not expected to be much affected by a finer resolution (it is basically driven by synoptic winds), the main effect of such improvement is likely a more careful evaluation of small fires*'.

R3.2 - It is not clear in the paper how the diurnal cycle of the fires has been treated. According to p.2324 l.9-11: "One trajectory per day was computed. . . starting at 10:30LT. ", it seems that the results are based on a singe calculation per day. If this is true, this is an important shortcoming of the paper that needs to be addressed and fixed. The transport of the fire plume will strongly depend on the time of the day when the fires were injected, as the boundary layer mixing and atmospheric stability considerably change during the day. The end result of trajectory calculations is likely to be very different if the fire plume gets injected at 10:30am LT or e.g. 4:30pm LT due to diurnal changes in the boundary layer mixing. In addition, fires have also a strong diurnal cycle with more active burning during the mid-day and slower burning (smoldering fires) during night. Injection of the fires at 10:30LT is not representative of this cycle in anycase. This time dependence needs to be introduced in the Equation 1, and the calculations repeated for at least 1 year time period, if not the entire paper. To my opinion including this dependence is critical to the paper, and its results.

This study is based on satellite data. These give unique opportunities to investigate phenomena on a large scale but, of course, they also have several drawbacks among which the relatively low spatial and temporal resolution. In particular the fire and AOT data used in our study are from instruments onboard the NASA polar satellite Terra. Polar satellites overpass the same region twice per day (day and night overpasses) but the AOT can only be retrieved in daylight. The diurnal cycle of fires, but also of AOT, cannot thus be followed by such type of instruments. It is true that some more information on both fire and AOT daily cycles could be obtained using data from the MODIS instrument onboard the Aqua platform (daytime overpass at about 14.30 LT). However the MODIS Team has recently recommended not to use the MODIS fine fraction AOT for scientific purposes (*Levy, R. C., L. A. Remer, R. G. Kleidman, S. Mattoo, C. Ichoku, R. Kahn, and T. F. Eck Global evaluation of the Collection 5 MODIS dark-target aerosol products over land, Atmos. Chem. Phys., 10, 10399-10420, 2010*). Conversely, the MISR sensor is not available on Aqua. Also, global analysis of multiyear records of MODIS Terra and Aqua active fire data by Giglio et al. (2006) has indicated that the diurnal fire cycle in central Eurasia is insignificant.

We now comment on this point in Section 4: '*Some simplifications have been made in this preliminary assessment, the effect of which will be further investigated in future work, as well as the use of other available AOT and fires/burned area datasets, to reach more definitive conclusions. …….omissis……. Also, due to the use of data from a single, polar satellite we neglected here possible effects of fire diurnal cycles. Nonetheless, this approximation is expected to have a minor impact on our results due to the weak diurnal cycle of fires generally observed in the Eurasia region with respect to other areas of the world (Giglio et al., 2006)*'.

R3.3 - Authors assume that the fine fraction AOT should follow a sinusoidal behavior during the year based as found in unperturbed regions. Can Europe be considered as unperturbed region is absence of widlfires? In Europe aerosols are both directly emitted from many anthropogenic sources, but also chemically formed from anthropogenic precursors. This anthropogenic fraction contributes, and one would expect also dominate, the AOT signal in Europe. Therefore, is it reasonable to consider their signal as unperturbed sinusoidal one? This point needs to be further JUSTIFIED and discussed. The

inability of this paper to treat the anthropogenic AOT fraction is another weak point of this paper that needs to be explained and highlighted in the conclusion.

We never considered Europe as an unperturbed region. On the contrary in the Introduction we clearly state that "*Over Europe and the Mediterranean, the AOT is typically build up by a complex mixture of different components of both natural and anthropogenic origin. Marine particles from the surroundings seas and desert dust advected from the nearby Sahara desert mix, in variable proportions, with local and/or long-range transported pollution produced by human activities*". Possibly, this misunderstanding comes from the use of the term 'regional background' for the sinusoidal curves. This term is not used to mean 'pristine conditions' in the text but rather to represent the typical AOT without the fires contribution. This 'regional background' may coincide with 'unperturbed' conditions in the Atlantic control regions but obviously not in Europe, where anthropogenic aerosols play a major role. Therefore, by using this curve we do not neglect the important anthropogenic contribution over Europe but rather assume that its yearly cycle behaves similarly over each year of the dataset, an assumption supported by the low inter-annual variance associated to those months unaffected by fires.

To avoid this misunderstanding, we added the following sentence in Section 3.1: '*As over Europe the 'regional background' also includes an important anthropogenic contribution, the $FFAOT_{RB}$ absolute values vary depending on the region, with lowest values observed in the Western sectors as well as in Scandinavia*'.

R3.4 - Authors show that AOT display a clear bimodality, which they attribute to the wildfire emissions. Given their crude modeling approach, it is not clear to me if this bimodality could also be due to meteorology, and changes in e.g. relative humidity, precipitations (AOT are very sensitive to RH). Could authors also plot the corresponding yearly cycles for some of the meteorological parameters, and discuss this dependence?

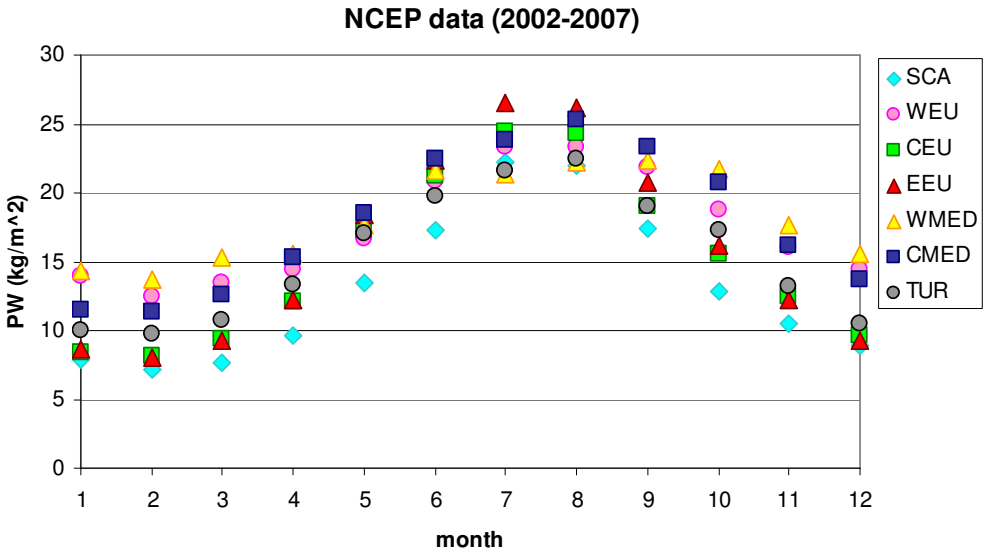
We had already investigated this aspect before submitting the manuscript and found that the AOT bimodality is not observed in any of the meteorological parameter which could impact the AOT. Rather, the main AOT modulating factors, either aerosol-source (e.g., radiation) or aerosol-removal (e.g., rain) factors exhibit a sinusoidal yearly cycle.

This was indicated in the text by the following sentence in the Introduction: '*the* (European) *AOT yearly cycle typically shows a winter minimum and a spring/summer maximum (e.g., Yu et al., 2003; Edwards et al., 2004; Papadimas et al., 2008, Chubarova, 2009), with some inter-annual and spatial variability. This annual AOT behaviour is mainly driven by in-phase annual cycles of major aerosol-source factors (e.g., radiation, which favours secondary aerosol formation, and convection, which facilitates particles and gases injection and mixing into the atmosphere), and opposite cycles of major aerosol removal agents as wind speed and precipitation (e.g., Koelemeijer et al., 2006; Mehta and Yang, 2008; Papadimas et al., 2008; Chubarova, 2009).*'

Following the Reviewer remark, we now further specify in the Results (Section 3) that '*the AOT follows a clear bimodal yearly cycle, with maxima in April and July-August. We could not find any similar seasonality in any of the meteorological parameters investigated (P, T, Radiation, Precipitable Water, Precipitation)*'.

As an example, we report below yearly cycles (2002-2007 average) of the Precipitable Water (PW) for each of the seven target regions addressed (NCEP reanalysis data).

The PW shows a clear sinusoidal behaviour with winter minima and summer maxima. Note that the PW refers to the whole column. To investigate possible correlations with AOT it is therefore more appropriate to use PW rather than RH, which is altitude dependent.



R3.5 - Several parts of the manuscript need to be clarified as suggested below. Authors need to clearly state in the conclusion the uncertainties associated with the results.

Several parts of the text have been clarified as detailed below. Also, we added the following sentence in the conclusion section: '*Some simplifications have been made in this preliminary assessment, the effect of which will be further investigated in future work, as well as the use of other available AOT and fires/burned area datasets, to reach more definitive conclusions*'.

Abstract:

R3.6 - p.2318, l1-8: this general description is too long for the abstract (30%). Here be more specific and just explain that the fires impact over Europe has not been assessed although smoke particles largely contribute to the aerosols load worldwide.

The sentence has been partially rephrased and shortened. However, we still believe this introductive sentence to be important to guide the less familiar reader into the topic of the paper.

R3.7 - p.2318, l13: replace: "atmospheric transport model" by "atmospheric trajectory model"**.**

Done

R3.8 - p.2318, l.13: replace: "to attempt unraveling the wildfires contribution" by "in the attempt to estimate the wildfires contribution"**.**

Done

R3.9 - p.2318, l25: replace the beginning of the sentence by" Our results suggest that the continent-wide smoke haze is expected to. . . ."

Done

Introduction:

R3.10 - p2319, l.26-28: Do not use the Chernobyl example here as it is not relevant to the paper. Instead, in this sentence provide the typical location of the anticyclone and low pressure systems during these events.

The Chernobyl example has been removed.

R3.11 - p.2320: l.7-12 and p.2321, l.14-19: these two paragraphs describe the results of the paper, which is a bit too soon. Authors should state the goals of the paper instead, and also provide its outline.

The two paragraphs have been removed from the Introduction. In the revised version we now more clearly state that '*In this study we aim at investigating the impact of wildfires on the European 'aerosol optical thickness' (AOT)….*' and provide its outline trough the following sentence: '*Here we use long term (2002-2007) satellite aerosol and fires observations coupled to atmospheric transport modelling (Section 2) and set up a methodology to derive monthly-resolved quantitative estimates of the wildfires contribution to the fine fraction AOT in Europe (Section 3). Our results provide evidences that, over the whole continent, wildfires play a major role in modulating the AOT yearly cycle, and particularly its fine mode fraction*'.

R3.12 - p.2321, l.1: replace "from a regular" by "from a typical".

We would prefer to keep the term 'regular' which, to our opinion, is more appropriate in this context.

MISR AOT data

R3.13 - p. 2322, l.25: convert the radius to the diameter, and specify which type of diameter this is.

Since the aerosol effective radius (not diameter) is commonly used in the MISR documents and literature (e.g., Kahn et al., 2010), we prefer to refer to it in our study.

MODIS fires data

R3.14 - p.2323, l3: change this title to "MODIS fire counts"

In this study, in addition to fire counts, we also use Fire Radiative Power data. Therefore the original title 'MODIS fires data' is more correct.

R3.15 - p.2323, l22: "rate of aerosols" is misused in this sentence, use "amount of aerosols" instead.

We prefer to keep the term 'rate' as more appropriate to describe the 'amount per unit time' as necessary in this case.

Forward trajectory calculations

R3.16 - p.2324: indicate what meteorological model is used to drive HYSPLIT calculations.

The Hysplit model is driven by NCEP analysis data at 1° resolution. We added this information into the text (Section 2.3).

Results:

R3.17 - p.2326, l.8: change "The so derived" into "The resulting".

Done

R3.18 - p.2326, l.25: write s.d. as "standard deviation".

Done

Conclusions:

R3.19 - p.2333, l.15-20: This sentence is too long and difficult to read.

The sentence has been rephrased.

R3.20 - p.2334, l.1: omit "intricate" from this sentence.

Done.

R3.21 - p.2334-2335: some sentences are repeated from the introduction and abstract, please rephrase them.

The introduction has been modified (see our reply to your point R3.11).