The authors thanks the referees for their interesting comments, which were very helpful to improve the discussion quality of the manuscript

Interactive comment on "Summertime tropospheric ozone variability over the Mediterranean basin observed with IASI" by C. Doche et al.

Anonymous Referee #1
Received and published: 4 June 2014

Six years of summertime tropospheric ozone observed by the IASI instrument are analysed in this manuscript in order to document the tropospheric ozone variability over this region. I recommend publication of the manuscript after considering the following comments.

Referee: a) The authors state that "the western ridge results from the spreading of the Azores anticyclone" (page 13023 at line 15). The western Mediterranean ridge may associated with the Azores high. However in Figure 1 the high pressure ridge over the western Mediterranean (referred in page 13023 at line 13) in fact extends over Central and Central-eastern Europe (or Balkans) which according to the current understanding is detached from the Azores anticyclone. Many researchers underline the differences between the anticyclonic center over Central and Central-eastern Europe (or Balkans) and the Azores high pointing to the importance of anticyclonic vorticity advection from Northwestern Africa (Prezerakos, Arch. Meteorol. Geophys. Bioclimatol. 1984; Tyrlis and Lelieveld, J. Atmos. Sciences, 2013; Anagnostopoulou et al., Clim. Dynam., 2014). Furthermore when looking Figures 6 and 10 of Geopotential Height at 850 hPa you may notice that the Azores anticyclone is detached from the anticyclone which extends from Northwestern Africa towards western Mediterranean and central to central-eastern Europe.

Authors: The authors agree that there are two different high pressure systems, one above Europe driven by the Azores Anticyclone, one above the Mediterranean driven by the Northern African Anticyclone (as shown in Figures 6 and 10 of the current version of the paper). In order to clarify this point in the manuscript, red lines indicating the position of the two different ridges will be added in Figure 1 and details with the recommended references will be given in the text as follow (P13023-L12): "<u>These summertime meteorological conditions are characterised by two high pressure ridges, one over the Central Europe and one over the Western Mediterranean basin, and a deep trough extending from the Persian Gulf to the Eastern Mediterranean basin (Fig.~1a). The Central Europe ridge results from the spreading of the Azores anticyclone and the Western ridge results from the spreading of the North African anticyclone, which leads to low winds, persistent clear sky conditions, and high solar irradiation \citep{prezerakos84,tyrlis13,anagnostopoulou14}</u>".

Referee: b) Concerning the discussion for the role of transport on the spatial ozone variability over Mediterranean (Section 3) it should be noted that the subsidence (in Figure 2c) actually takes place at the western flank of the high PV-streamer (Figure 2b) as would be theoretically expected from a dynamical point of view with anomalous subsidence upstream a positive PV anomaly (Hoskins et al., Q. J. Roy. Meteor. Soc., 111, 877–946, 1985).

Authors: This comment has been addressed in the revised manuscript as follow (P13031-L5): "[…] explain the enhancement of ozone over the eastern Mediterranean basin in the lower troposphere. <u>It should be noted that the downward vertical transport actually takes place at the</u>

western flank of the high PV-streamer (Fig.2b) as would be theoretically expected from a dynamical point of view \cite{hoskins85}"

Referee: c) Apart from the important role of subsidence it should also considered the high probability of tropopause folds over the area which feeds stratospheric air in the upper and middle troposphere. There is a recent article by Tyrlis et al., (JGR, 2014) indicating a global "hot spot" of summertime tropopause fold activity over a sector between the eastern Mediterranean and Afghanistan, in the vicinity of the subtropical jet. Mind also that according to a study of Sprenger et al. (J. Atmos. Sci., 2007), a maximum in stratosphere-to-troposphere transport (STT) is identified at the western flank of the stratospheric PV streamers which implies a co-location with the area of the strongest subsidence.

Authors: This discussion has been addressed in the revised manuscript as follow (P13031-L5): "Apart from the important role of subsidence it should also considered the high probability of tropopause folds over the area which feeds stratospheric air in the upper and middle troposphere. \cite{tyrlis14} indicates a global "hot spot" of summertime tropopause fold activity over a sector between the eastern Mediterranean and Afghanistan, in the vicinity of the subtropical jet. According to a study of \cite{sprenger07}, a maximum in stratosphere-to-troposphere transport (STT) is identified at the western flank of the stratospheric PV streamers which implies a co-location with the area of the strongest subsidence."

Referee: d) The trough of high PV extending over SE Europe (Figure 3b) (thus inducing a deviation from a zonal distribution of PV) is not clearly represented in IASI 10 km ozone data. It could be possibly the selected colored scale that masks this feature in Figure 3a. It would interesting to show the similarity in the patterns of the ERA-interim PV and IASI O3 (e.g. by adding contour lines or modifying the colored scale). Mind that PV and O3 at the tropopuase level should show similar field structures.

Authors: In the current version of the manuscript, Fig. 3a and 3b were not given exactly on the same geographical domain. Figure 3b was more extended eastward. This explains most of the differences noticed by the referee. In the revised version of the manuscript the Figures will be provided on the same domain. Moreover ozone and PV isolines will be added to help with the readability of the map. General features are similar for both the ozone and PV distributions. The ozone distribution at 10 km remains noisier compared to the PV distribution due to significant errors in the IASI observations (about 25% at this level – see Dufour et al., 2012 for more details).

Referee: e) The authors refer to a correlation of 0.99 between ozone and PV (page 13023, line 17) . Is this correlation calculated from a number of 18 data points (6 years x 3 months) shown in Figures 4 and 5? Please clarify in the text.

Authors: Indeed, the correlation is calculated from a number of 18 data points (6 years * 3 months). This will be specified in the revised version of the manuscript.

Referee: f) The discussion of the case of June 2008 refers to a deeper low-pressure system over Eastern Mediterranean but it misses any discussion of the link with the Asian monsoon which controls this low pressure system. This discussion maybe even more relevant in comparison to the other case of June-July 2009.

Authors: The anomalies in the summertime convective activity of the Indian Monsoon can be describeb by the Indian Monsoon Index (IMI). We use the seasonal and daily IMI provided byhttp://apdrc.soest.hawaii.edu/projects/monsoon/seasonal-monidx.html to complete our analysis. The 2009 daily IMI shows that the monsoon activity was significantly smaller in

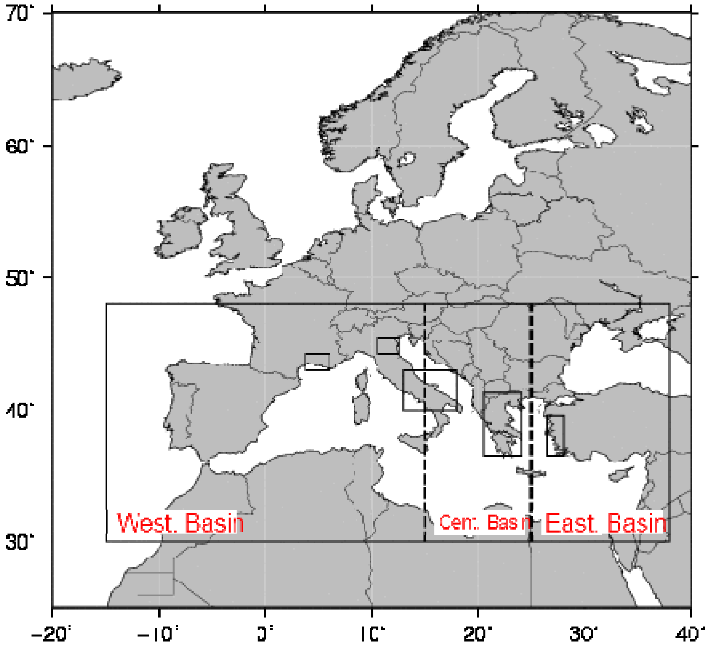
June and July compared to the climatology. This is in agreement with the negative ozone anomaly observed with IASI in June and July 2009. For 2008, the monsson activity is rather comparable to the climatology. However, some periods of June exhibit slightly more intense activity.

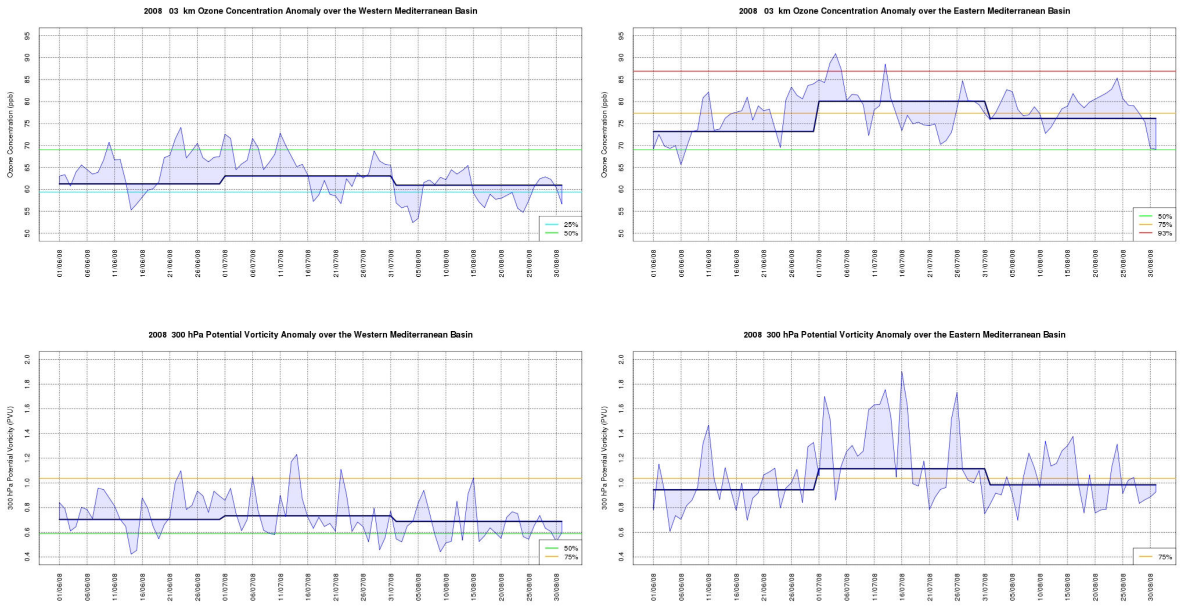
We propose to add the followed sentences in the revised version of the manuscript (P13034-L15): "This is confirmed by the analysis of the daily Indian Monsoon Index (IMI, http://apdrc.soest.hawaii.edu/projects/monsoon/seasonal-monidx.html) which indicates positive anomalies events of the diabatical convective activity over the Indian Ocean during the month of June 2008."
P13035-L11: "Indeed, the IMI daily variation shows strong negative anomalies, indicating a lower diabatical convective activity than the climatological mean during June and July 2009."

Referee: g) The analysis of the case of June 2008 uses an averaging over the whole Mediterranean Sea for IASI ozone and ERA-interim PV thus loosing the distinction of the circulation patterns between western and eastern Mediterranean. Maybe a differentiation between west and east could emphasize even more the controlling role of downward transport over the eastern part.

Authors: Ozone and PV time series have been studied separately for the Western and Eastern part of the Mediterranean basin. In summer 2008, the ozone concentrations and the PV values reach larger quantiles levels on the Eastern basin (up to 75% and sometimes up to 93%) than on the Western Mediterranean basin (under the median and sometimes under the first quartile).

The followed sentence will be added in the revised version of the manuscript (P13034-L10): "Studying separately the Eastern and the Western basin show as expected that the Eastern basin is the most affected. Ozone concentrations exceed 80 ppb during these periods and even exceeds the 93% quartile for some days, whereas the ozone concentrations remain smaller than 70 ppb on average on the Western basin (not shown)."





Referee: h) Mind please an analogous study which is under discussion in Atmospheric Chemistry and Physics (Atmos. Chem. Phys. Discuss., 14, 12377–12408, 2014).

Authors: The reference has been inserted in the conclusion. The last sentence has been change into: "Recently, \cite{safieddine14} investigated this point using IASI ozone observations and regional WRF-CHEM simulations."

Interactive comment on "Summertime tropospheric ozone variability over the Mediterranean basin observed with IASI" by C. Doche et al.

Anonymous Referee #2
Received and published: 20 June 2014

This paper reports on the summer ozone maximum in the Mediterranean region within the 2007-2012 period and two ozone anomalies (positive in June 2008 whereas negative in June-July 2099), using the thermal infrared space-borne instrument IASI. To understand how the ozone variability is driven, this study examines ECMWF meteorological analysis. The authors found the meteorology is a major key factor to explain both variability and anomalies in the lower troposphere.
The paper, on a very interesting topic, is well in the scope of ACP. The manuscript is clear, well written and documented. I suggest this manuscript to be published in ACP after few corrections and address the following recommendations to the authors:

Referee: Why do you provide the figure 1 on June-July over 1979-2012 and not over June-July-August, the summer period you study? Please check and revised if necessary.

Authors: The figure has been changed in order to include the month of August. It doesn't change the interpretation of the figure.

Referee: Do you make your IASI validation with the WOUDC ozonesondes from coincident and collocated measurements? Could you provide more details on that? Could you suggest hypothesis to explain the negative bias around 3km and a positive bias around 10km as shown on Table 1?

Authors: The Mediterranean validation performed in this study has been done using the same coincidence criteria than the ones used in Dufour et al., 2012: +/- 1° and 7 hours.
The following sentence have been added in the revised version of the manuscript (P13028-L14): "<u>The same coincidence criteria (+/- 1° in lon gitude and latitude and 7 hours) as Dufour et al. (2012) have been used.</u>"
Concerning the positive bias observed at 10km and representative of the UTLS region, it has also been noticed by Dufour et al., 2012. Several hypotheses have been discussed in Dufour et al. First of all, the coarse vertical resolution of IASI observations with about one degree of freedom or less in the UTLS region does not allow one to reproduce correctly the strong ozone gradient between the troposphere and the stratosphere. Recent studies about the evaluation of the next generation of IASI satellite (IASI-NG) have shown that the improved spectral and radiometric noise of IASI-NG leads to a better vertical resolution, then reducing the bias in the UTLS region (Sellitto et al., AMT, 2013).
Other hypotheses given by Dufour et al. concern the impact of spectroscopic uncertainties on ozone line intensities and possibly systematic problems in the radiative transfer. Concerning the negative bias at 3 km, it has to be compared to the estimated errors of the observations (3% versus 16%). Its significance is then questionable. The negative sign of the bias might reflect a slightly compensation effect of the positive bias reported in the UTLS region (one have to recall that the ozone retrieved in the lower and in the upper troposphere are not fully independent). This has been extensively discussed in Dufour et al., 2012 paper, we would more clearly refer the reader to this paper concerning the bias discussion. The following sentence has been added in the revised version of the manuscript (P13028-L19): "<u>Several hypotheses (coarse vertical resolution, spectroscopic and radiative transfer uncertainties) have been discussed by Dufour et al. (2012) to explain this bias. We refer the reader to this paper for more details.</u>"

Referee: P13024 L19-22 : I would suggest to add a reference and to replace by "These studies are mainly based on accurate in-situ observations – ozonesondes or MOZAIC/IAGOS vertical profiles and surface stations - (Kalabokas et al., 2013, 2008; Zbinden et al. 2013) but their specific geographic and temporal sampling provide an incomplete vertical tropospheric description over the entire basin."

Authors: This suggestion has been taken into account in the new version of the paper.

Referee: P 13024 L24 : "Coarse", please evaluate P 13025 L4-6 : "offer a maximum of sensitivity in the mid-troposphere with an effective vertical resolution of about 6–7km". Please clarify what you meant by (IASI) "effective vertical resolution of about 6–7km". Text could be improved, I am not sure "vertical resolution" is here the correct expression

Authors: In atmospheric inverse method, the vertical resolution of the retrieved profile is given by the full width of the half maximum of the averaging kernel of the profile (Rodgers, C. D.: Inverse methods for atmospheric sounding: Theory and practice, vol. 2, World Scientific Publications, Series on Atmospheric, Ocean, Planet. Phys., Singapore, 2000.). In the case of thermal infrared sounders like IASI and TES, the vertical resolution estimate ranges between 6 and 7 km. The expression "vertical resolution" is the one commonly used in inverse approaches for atmospheric sounding.

Referee: P 13025 L26 : I suggest "lower free troposphere" instead of "lower part of the free troposphere".

Authors: This suggestion has been taken into account in the new version of the paper.

Referee: P 13026 L19-21 :"Concerning ozone, the vertical information is sufficient to study eparately different atmospheric layers within the troposphere". Suppress "atmospheric" and give something more accurate than "different" (may be 2 or 3 layers???).

Authors: The sentences will be replaced by (P13026-L19): "Concerning ozone, between 3 and 4 pieces of information are available for the overall profile depending on the thermal conditions. In the troposphere, up to 1.5 degrees of freedom are observed in favourable thermal conditions. In particular, Dufour et al. (2010) have shown the ability to capture separately the variability of ozone at the lower and the upper troposphere in summer conditions, making possible air quality studies in largely polluted region".

Referee: P 13028 L23-26 : "Due to the vertical sensitivity and resolution of IASI, the 10km level is used to describe the variability of ozone at the upper troposphere and lower stratosphere whereas the 3km level for the lower to middle troposphere. Ozone concentrations retrieved at 3km capture the ozone concentration and variability roughly from 2 to 8 km and retrievals at 10 km are sensitive to ozone changes approximately between 5 km and 14km". Condense, it will be clearer, this is important is the frame of your study.

Authors: The sentences will be rephrased like this (P13028-L23): "Due to the coarse vertical resolution of IASI, ozone concentrations retrieved at 3 km describe the ozone concentration and variability roughly from 2 to 8 km and ozone concentrations retrieved at 10 km the ozone concentration and variability from 5 to 14 km."

Referee: P13029 L10-11 : "A land/sea mask has been applied to calculate the averages only over the Mediterranean sea." Could you explain more, it is not clear enough… You did not exclude land from your study. Furthermore the Fig 2a shows white areas on some continental regions that the caption does not describe. Could you explain and provide also a short information on that on Fig2a.

Authors: The land/sea mask has been applied on IASI dataset in order to calculate the ozone averages just over the sea, where the measurement is not perturbed by land emissivity patterns which may lead to systematic ozone overestimation, in particular over the Northern Africa (sand emissivity). For figures, this mask has been kept just over this area which is the most affected by this phenomenon.

Referee: P13029 L15-17 : May be add the number of layers relevant to the 0-14km you are studying?

Referee: P13030 L11-12 : Better to specify in the title your study is on the summer variability, may be replace by "Ozone spatio-temporal variability in summer from IASI on a 2007-2012 period"?

Authors: This suggestion has been included in the new version of the manuscript.

Referee: P13030 L 22-26: I suggest to condense and replace may be by : "At this altitude over the basin, a steep horizontal west/east ozone gradient is observed, with greater concentrations eastward of 15E (by about 20ppbv) than westward".

Authors: This suggestion has been included in the new version of the manuscript.

Referee: Figure 3a : Please change the ppm into ppb in order to be consistent with your text.

Authors: This suggestion has been included in the new version of the manuscript.

Referee: P13031 L 20-21 : "This comparison shows that the ozone concentrations retrieved from IASI at 3 km and at 10 km". I can find out the 3km ozone concentrations on that figure 3.

Authors: This comparison shows that the ozone concentrations retrieved from IASI at 3 km (Fig2a) and at 10 km (Fig3a)...

Referee: P13032 L2-5 : Better to suppress "origin of" and replace by "the mixed stratospheric-tropospheric characteristics of air masses at this pressure level." Revised the following sentence also.

Authors: This suggestion has been included in the new version of the manuscript.

Referee: Figure 4 : Please provide an Y axis scaled to the minimum and maximum and not only between [62-70ppb]. Same for fig 5,6,7 and on fig 7 provide ppb instead of ppm. P 13034 L 7 : Please keep constant the ozone units : it is sometime ppm, ppb and ppbv.

Authors: This suggestion has been included in the new version of the manuscript.

Referee: Take into account and refer to a study submitted recently to acpd "Summertime tropospheric ozone assessment over the Mediterranean region using the thermal infrared IASI/MetOp sounder and the WRF-Chem Model" by Safieddine et al, Atmos. Chem. Phys. Discuss., 14, 12377–12408, 2014.

Authors: The reference has been inserted in the conclusion. The last sentence has been change into: “Recently, \cite{safieddine14} investigated this point using IASI ozone observations and regional WRF-CHEM simulations.”