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Atmospheric Chemistry and Physics
Discussions

# *Interactive comment on* "Summertime free tropospheric ozone pool over the Eastern Mediterranean/Middle East" *by* P. Zanis et al.

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Reply to Reviewer #1 We would like to thank Reviewer #1 for the constructive and helpful comments. Reviewer's contribution is recognized in the acknowledgments of the revised manuscript. It follows our response point by point.

1) The Reviewer notes: "I would suggest the citation Kalabokas et al., 2007 to be transferred to line 13 "but also tropospheric subsidence (. . .. . .. . ." as it is more relevant to tropospheric subsidence." Done as suggested.

2) The Reviewer notes: "Is there any explanation about the geographical shift (several hundred of kms to the west) of the maximum in ozone anomalies, when ERA-Interim and TES data are compared? This might differentiate some space details on the is-



sue of lower troposphere-boundary layer interaction over the area, as the discussion of the paper is based only on ERA-Interim data." Even though we are satisfied that both datasets capture the general picture in Figure 3, we agree with the reviewer that there is a slight geographical shift of the ozone anomalies between ERA-Interim and TES data. This might related to the much coarser grid resolution of TES data (4o x 2o) compared to ERA-interim (0.75o x 0.75o). The following sentence was added in the revised manuscript at page 9, lines 267-271. "A geographical shift of the maximum ozone anomalies between ERA-Interim and TES data could be attributed to the coarser grid resolution of TES data (4o x 2o) compared to ERA-interim (0.75o x 0.75o) and limitations of the simplified ozone chemistry scheme in the ECMWF model, which misses part of the photochemical ozone buildup over the EM. " We also added more technical details about the TES data in page 7, lines 200-212. See below: " At Level 2 (L2) processing step, TES calibrated spectral radiances derived from the observed interferograms at Level 1B (L1B) are used to retrieve vertical profiles 0–32 km of atmospheric temperature and chemical species such as carbon monoxide, ozone, methane, and water vapor on a global scale every other day. These L2 data at the observation geolocations and times are used as the inputs to produce the TES Level 3 (L3) data that fill with horizontal interpolation the spatial gaps in global scale of the L2 orbital data (http://tes.jpl.nasa.gov/uploadedfiles/Level3_UserGuide_v1.0.pdf). The TES L3 ozone data provides information for mapping the global distribution of tropospheric ozone with special focus on understanding the factors that control ozone concentrations (Osterman et al., 2008; Voulgarakis et al., 2011). The TES data used in the current analysis include daily L3 ozone values for the period 2005-2009 with grid spacing 4o x 2o in longitude and latitude."

3) The Reviewer notes: "Fig. 4 and also related text: The humidity and the vertical velocity seem to be more effective tracers of transport than potential vorticity as they are better associated with corresponding ozone changes (see Fig. 4). This might be due to the fact that that the subsidence from the upper troposphere to the lower troposphere might be the most crucial factor on local scale if compared to the strato-

spheric intrusions occurring over the area. I would suggest that stratospheric dry air, rich in ozone, entering the upper troposphere at other geographical locations, even remote, it could influence as well the lower troposphere and eventually the boundary layer over the Eastern Mediterranean, through the strong and very persistent regional subsidence. It has also to be mentioned that the upper tropospheric ozone reservoir might be additionally enriched by the accumulated ozone production from tropospheric photochemical processes on hemispheric scale during the warm period of the year." We agree with the reviewer that a main transport mechanism affecting the lower tropospheric levels is the subsidence. However it can be also important that shallow STT events feed upper tropospheric levels with stratospheric air at a frequent rate. This is what we point in the conclusions: " Taking into account the above results we infer that STT processes feed stratospheric ozone into the upper troposphere, and subsequently these air masses (rich in ozone) are transported to lower free tropospheric levels through the characteristic strong summertime EMME subsidence at the western flank of the higher PV streamers extending southwards and in association also with the persistent northwesterly to northerly flow for the whole tropospheric column." We think that all parameters including, PV, fit well each other in Fig. 4. This is more clearly illustrated in the cross-sections of Figure 5 verifying that O3, PV, water vapour and vertical velocities, all fit well together. The structure of PV fields in Figure 4 is a typical streamer structure with relatively higher values of PV entraining the southern latitudes from the north. The maximum subsidence is located at the western flank of the higher PV-streamer in accordance with the studies of Hoskins et al. (1985) and Spenger et al. (2007). A similar PV streamer structure is illustrated in Figure 3 of Traub and Lelieveld (2003). Furthermore similar PV streamer structures are also typical in cases studies of stratospheric intrusions (see e.g. Zanis et al., Atmos Chem. Phys., 2003). We also agree with the reviewer that upper tropospheric ozone reservoir might be additionally enriched by accumulated ozone production from tropospheric photochemical processes on hemispheric scale. The following sentence were added: In page 10, lines 290-297. "It is interesting to note in Figures 4e and 4k (at 500hPa) as well as in



Figures 4f and 4l (at 250 hPa) that the region with the highest subsidence is located to the western flank of the higher PV streamers extending southwards as would be expected from a dynamical perspective with anomalous subsidence upstream a positive PV anomaly (Hoskins et al., 1985). Taking into account the study of Sprenger et al. (2007) that identified a STT maximum on the western flank of the stratospheric PV streamers it is implied a coincidence of the region with the strongest subsidence and that of maximum STT." In page 14, lines 524-527. "Furthermore, it should be pointed that upper and middle tropospheric ozone levels can be additionally enriched by accumulated ozone production from tropospheric photochemical processes on hemispheric scale during summertime over the Middle East and North Africa (Liu et al., 2009). "

4) The Reviewer notes: "Figs. 6-7 and also related text: Regarding the tropospheric influence to the boundary layer and to the surface, which is the most crucial point of ozone pollution regarding policy implications, I think that it should to be added that according to the presented modeling results at the top of the boundary layer (850-900 hPa) the stratospheric contribution is only around 10 ppb with total levels over the examined region of 80-90 ppb. I think that the remaining tropospheric ozone levels (70 – 80 ppb, after subtracting the direct stratospheric influence), are already sufficient in principle, to create ozone pollution problems in the region given the strong and characteristic regional subsidence." We agree with the reviewer that photochemical processes dominate over stratospheric over the lower free troposphere and hence photochemically produced tropospheric ozone (from regional to hemispheric scales) can be more important for affecting near surface ozone than ozone of stratospheric origin. Nevertheless the O3s helps us to identify the transport pathway and quantify the process. The following lines were added in the text, in page 12, lines 361-369: ". At the top of the boundary layer (at 850 hPa) O3s contributes over the EMME around 16%-20% of the tropospheric ozone (not shown). The model results indicate the important contribution of stratospheric ozone to the pool of high ozone values over the EMME down to the lower free troposphere. Nevertheless it should be pointed that photochemical processes dominate for the control of ozone in the lower free troposphere and hence

photochemical produced ozone in the free troposphere can be more important than ozone of stratospheric origin for affecting near surface ozone."

5) The Reviewer notes: “I would suggest that the description of the characteristics of ambient measurements (Fig. 8e) should be done independently and before doing the comparison with the modeling, as I think that they deserve priority when dealing with so complicated situations. An interesting characteristic of these measurements is that the Finokalia station in Crete shows significantly higher summer average ozone values in comparison to Cyprus and Malta, which verifies the tendency already reported but based only on the first 4-years of ozone measurements at the same stations (Kalabokas et al., 2008). An additional interesting point, which I think that it deserves discussion here, is that based on several years of measurements, long term rural ozone averages from other stations in central Greece and also at the periphery of Athens (upwind) show comparable high levels with Finokalia (Kalabokas et al., 2008). These comparable high ozone levels seem to extend throughout the Aegean sea up to the north, as it has been reported from an intensive ship campaign (Kouvarakis et al., 2002). In my opinion, the points mentioned above are helpful to the argumentation of the paper on the importance of large scale subsidence occurring during summertime over the area. It has just to be considered that during summertime with the characteristic northern flow occurring over the Aegean Sea, comparable (usually high) levels of ozone are recorded, thus minimizing the role of local and regional photochemistry on ozone levels in comparison to transport (especially in the vertical direction), despite the favorable summertime conditions for photochemistry prevailing over the Mediterranean." We thank the reviewer for the suggestion but we selected to start the discussion in Section 3.4 with EMAC model for reasons of continuity and coherency with Section 3.3. Following the other comment of the reviewer we added in page 16, lines 531-535, the sentence: " Several years of ozone records at different Greek stations as well as ozone measurements along the Aegean sea from an intensive ship campaign showed spatial homogeneity with comparable high ozone levels to Finokalia during summer (Kouvarakis et al., 2002; Kalabokas et al., 2008), thus indicating the importance of



large scale subsidence for the near-surface ozone over the area. "

6) Figure 2 was revised with the mutual exchange of Fig.2j and Fig.2i.

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 22025, 2013.