

Interactive comment on “Winter- and summertime continental influences on tropospheric O₃ and CO observed by TES over the western North Atlantic Ocean” by J. Hegarty et al.

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Anonymous Referee 2

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This paper by Hegarty et al. is a worthy attempt to employ TES observations of both O₃ and CO in an effort to discern the influence of continental sources from North America on the chemical composition of the free troposphere over the Western North Atlantic Ocean (WNAO). The paper is most successful in providing good evidence that TES captures realistic synoptic scale variability, and TES observations suggest transport patterns consistent with previous research based on airborne field campaigns. How-

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ever, the paper seems to try too hard to make their results match every element of earlier aircraft work. In fact, it would benefit the paper if the authors remained more focused on what can actually be observed with the data they have analyzed. The paper includes one novel result, illustrating the influence of shallow convective instability, driven by cold air outbreaks over the WNAO in the wake of cyclonic storms. The authors demonstrate that these events appear to redistribute boundary layer pollutants into the lower free troposphere, or possibly even up to 400hPa when the convection occurs over the warmer waters of the Gulf Stream. While these results are interesting, it is also important that the authors establish that there is no bias in the CO retrievals under these meteorological conditions as a result of low cold cloud fields.

Concern about a potential bias in CO retrievals over low clouds is certainly legitimate. Unfortunately, without access to the exact retrieval algorithm used to generate the retrievals it is not possible for us to absolutely rule out this possibility for these cases. However, simulations performed by the TES team have shown that clouds do not add substantial biases to trace gas retrievals. These simulations are documented in the following paper which is referenced in our manuscript.

Kulawik, S. S., Worden, J., Eldering, A., et al.: Implementation of cloud retrievals for Tropospheric Emission Spectrometer (TES) atmospheric retrievals: 1. Description and characterization of errors on trace gas retrievals, *J. Geophys. Res.*, 111, D24204, doi:10.1029/2005JD006733, 2006.

Furthermore, we did not universally observe high CO over low clouds over the ocean, rather mainly in locations that were directly downwind of the more populated areas of North America.

*I do think this paper warrants publication, but I believe it needs more than minor edits. There are two main points, scientific issues, that I raise in the next few paragraphs of this review. The first has to do with the change in the TES retrieval *a priori*, the second has to do with the misrepresentation of what can be reasonably inferred about*

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the atmosphere from plots of composite synoptic patterns like average mean sea level pressure. These need to be addressed. Then I have flagged a number of more minor problems in the text. These can be fixed more quickly, with an eye toward editing for clarity in language and brevity of exposition.

Overall, this paper is extremely difficult to read in the present form. It is too long, with numerous lengthy passages of imprecise language attempting to describe in words what is shown graphically in images. The paper is poorly organized, skipping back and forth between seasons and between static maps of mean synoptic patterns and then much later introducing plots of trajectories. The paper would benefit greatly from some judicious editing. This would presumably also lead to the correction of several grammatical errors. For example the very first sentence of the Abstract has grammatical errors, and should be recast, perhaps as follows: " The distribution(s) of tropospheric O3 and CO(,) and the (synoptic) factors regulating (these distributions) over the western North Atlantic Ocean during winter and summer, were investigated using profile retrievals from the Tropospheric Emission Spectrometer (TES) from 2004-2006." The corrections are indicated with parentheses. I suggest you define winter and summer later in the paragraph, to keep the main topic sentence clear.

We will attempt to reorganize the paper to make it shorter and more focused. We have also implemented your suggested changes to the abstract in the revised manuscript.

The scientific issues you bring up are addressed later in this response.

One of the main points, made right at the outset of this paper, is that the seasonal a priori biases the TES observations, and the authors even seem to suggest that if the a priori was not altered, they would produce unrealistic seasonal composites. This is rather confusing, and would seem to call many of the published TES results into question. Furthermore, the differences in the a priori profiles based on the Mozart model, and the universal a priori employed here are never shown. The authors should at least illustrate the range of the seasonally varying a priori versus the universal profile they

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used. Since the a priori was changed, this also raises the question of what happens to TES profiles if they didn't converge. This has the potential to be more likely since the extremes of any one season may be further from a universal a priori profile than from a seasonally variable mean profile. Does this lack of convergence ever happen as a result of switching to the universal a priori? Anyway, by not accepting the standard TES retrieval approach, the authors imply their own published results are in fact dependent on the approach they have chosen!

It is perhaps unfortunate that we chose the term reprocessed, based on previously published papers, to refer to the procedure performed on the TES retrievals using the universal a priori, since post-processed is more accurate. To be clear we did not re-run the retrieval algorithm with a new a priori. Instead we applied a post-processing procedure to all of the already converged retrievals to remove the seasonal and geographic variability that was contributed by the a priori rather than the radiance measurements. For the profiles in which the TES signal is strong the post-processing has little impact, but where the TES signal is weak the retrieval will reflect an average profile rather than one with seasonal and geographic variability. In this way the real measured TES variability is emphasized. This procedure has been applied in Zhang et al., (2006) cited in our manuscript and validated by Kulawik et al., (2008) which is cited in our revised manuscript.

Kulawik, S. S., K. W. Bowman, M. Luo et al.: Impact of nonlinearity on changing the a priori of trace gas profile estimates from the Tropospheric Emission Spectrometer (TES), *Atmos. Chem. Phys.* 8(12), 3081-3092, 2008.

We will include a plot of the universal a priori along with selected a priori profiles within our study region for each season in the revised manuscript.

The authors establish two goals, the first seems almost trivial, to characterize the seasonal distributions of TES derived O3 and CO over the WNAO.

Many of the papers published about TES distributions so far have focused on the de-

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piction of rather extreme seasonal events such as biomass burning. We felt it was important to show that TES could accurately depict more subtle seasonal changes such as those over the western North Atlantic Ocean to give context to the rest of our analysis of the relationship with synoptic patterns.

However, the second goal is somewhat muddled. Stated more succinctly, it appears the goal is to associate chemical variability (in TES O3 and CO) with synoptic scale variability that controls transport and dispersion. The problem with this approach is that rather than group the TES observations according to transport patterns derived from trajectories, the authors are intent on identifying "synoptic circulation patterns". This is a non-standard meteorological term, and it gets used along with other terms, such as map types, and synoptic-scale circulation activity, in a way that implies the authors are talking about the three-dimensional atmospheric flow. In reality, it is misleading to refer to circulation when the authors have used spatial correlation of meteorological data to identify mean synoptic conditions, specifically, they have classified TES data into groups of days with similar mean sea level pressure.

The problem is, the authors make some very dangerous over-simplifications regarding the transport, or as they often refer to it, the circulation, represented by these composite synoptic maps. A mean meteorological map, the average of several days that have a high degree of correlation, does not represent a "circulation". In fact, the circulation, or movement of air, associated with a synoptic pattern is a complex three dimensional description of flow. The conceptual model of airstreams in a cyclonic system, referred to in the text and figures, considers that you hold the system stationary, or that you move with the cyclone, that is, they represent storm relative motion. If you want to understand the origin of an air parcel within a specific location of an actual specific synoptic pattern, you really need to calculate trajectories. Not every cyclone will have a strong warm conveyor belt, or dry airstream, or they will not always be present in the same location. These features are a function of the dynamics of specific events. By the way, the representation of airstreams drawn over figure DJF1, even in the conceptual

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sense, is inaccurate. The WCB should be delivering air from well ahead of where one would analyze a surface cold front; it represents the adiabatic ascent of air in the warm sector rising up over a warm frontal boundary. Similarly, the other airstreams are off in their representation of conceptual, storm relative motion, as drawn in this figure. In addition to a mean synoptic patterns not representing circulation, neither does it describe a "storm track". These are all confusing terms that the authors use when really all they are talking about are mean synoptic patterns.

To address some of these problems of misrepresentation, Table 1a should be dropped completely. Figure 1 should simply refer to DJF mean synoptic patterns. The meteorological characteristics attributed to these patterns, which suggest knowledge of movement, or evolution of conditions, can only be determined from back trajectories. For instance, Table 1a includes a description for DJF1: "Subsiding northwest flow around back of cyclone center covering much of northeastern US and southeastern Canada". In fact, much later in the paper, in Figure 6, there is finally a presentation of back trajectories for at least one sub-region of synoptic pattern DJF1, and it clearly represents some transport that is subsiding from the northwest, however, it shows a number of other transport patterns, or air parcel origins as well. Obviously transport path, or correspondingly, source regions for material are not in fact well characterized by a single synoptic pattern. By definition, these maps represent an average snap shot. DJF1 shows a cyclone over the WNAO east of Newfoundland, with high pressure centered over the central east coast of the US. However, the temporal evolution of this pattern is not illustrated from a simple representation of mean sea level pressure. It is not even reasonable to assume a storm track from a static composite map. This might be at least partially justified if there was a corresponding mean upper-air pattern associated with the surface MSL, but this is not referred to in the discussion of these surface composites.

The evolution and development of these cyclonic systems is discussed in Section 3.1. This is indeed why trajectories are often used to categorize chemical data, instead

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of synoptic maps: evolution of the pattern matters as much as the pattern. What happened in each case captured by this mean synoptic pattern, did the low push SW to NE, or more directly from W to E, or in fact did it track from NW to SE as the ridge builds in behind it? This will make a significant difference in discerning the transport, and therefore the location or type of continental influence being delivered over the WNAO. Using only mean surface pressure, there is simply no way to consider the evolution of the pattern, or the speed of transition, or effectively, the storm track. This information can be identified, to some extent, by looking at the three dimensional motion of back trajectories. These can help to capture the actual evolution of the synoptic pattern. This is why trajectories were used in previous work (cited by the authors), for example the papers of Cooper, Parrish and Kiley. Depending where you sample a cyclone (where you fly an aircraft for instance), your relative position within the cyclone may determine the type of airstream you sample, but the specific transport is a function of the evolution of conditions, as well as the relative location of the cyclone. Therefore, it is very dangerous to refer to a mean synoptic pattern and use it to say where the air on a given day is originating, or where it goes next. The strength and precise location of a descending dry air stream, or the adiabatic ascent of air in a warm conveyor belt is not predetermined by a general synoptic condition, but is determined by the specifics of the wind and temperature fields and gradient magnitudes on a specific day.

By grouping the events using synoptic patterns in MSL, it is apparent that the trajectories will not all be the same, and therefore the inferred source region or continental influence is not some distinct location, but a composite of various influences. Again, this is why it doesn't really make sense to refer to the "meteorological characteristics" that are listed in Tables 1 a and 1b. Furthermore, since these synoptic patterns represent a composition of many individual days, it is also clear that the composite of associated chemical observations may result in the cancellation of high and low values over some parts of the domain of consideration, the WNAO. This may confound the interpretation of the composite chemical fields. The authors oversimplify or ignore this issue as well. Previous work, as cited, has shown that trace gas signatures within

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different parts of a cyclone may vary according to the origin and the evolution of the component airstreams. However, while the composite mean sea level may be used to represent the synoptic conditions, only trajectories can be used to discern the three dimensional motion of air parcels. This is much more clearly illustrated when the trajectories shown in figure 6 are finally introduced.

The authors should not refer to circulation patterns, but to synoptic patterns. For example Section 3.1 would become Winter Synoptic Patterns and 3.2 Summer Synoptic Patterns. Dropping Table 1 (a and b), the frequency of occurrence of days described by each mean pattern should be included as a label on Figures 1 and 2. The authors should also explain why in each season, over 30 percent of the days are not classified (the frequency figures do not total 100 percent).

These are all very good points that we will attempt to address in the revised manuscript.

We can remove Table 1a and 1b and include the frequencies on the plots. The frequencies do not add up to 100 percent because we examined only the synoptic patterns that had a minimum number of cases equal to 5 percent of the total. Retaining all of these less frequent patterns would lead to a number that had too few data points to create composites. The minimum group size cutoff is an input to the synoptic classification scheme arrived at by trial and error. This information was inadvertently left out of the original manuscript and will be included in the revised version.

We will refer to mean synoptic patterns rather than circulation patterns in the section headings and text. However, we would like to point out that in literature the synoptic patterns identified by correlation techniques are often referred to as circulation patterns. For an example see the book "Synoptic Climatology in Environmental Analysis" by Brent Yarnal published in 1993. Furthermore, Iver Lund himself refers to the synoptic patterns as map types in his 1963 paper that we cite in our manuscript.

I have a real problem with Tables 2 and 3. For each season, the authors calculate the slope of the O₃-CO relationship under different synoptic patterns. However, of the

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18 slopes calculated during summer, only 5 are statistically significant at 0.01, and another 3 are significant at 0.05. Even though the other 10 values are not significant, the authors go on to compare these values, and discuss the relative relationship of O3 to CO between regions, or under different synoptic patterns. If a slope is not significant, it should probably not be reported, and its magnitude should certainly not be compared with other slopes. Similar issues arise with Table 3 where only 5 out of 15 slopes are statistically significant.

We can fill the table with NS (for not significant) for cases with slopes that are not statistically significant at the p=0.05 level or better and note that in the table captions.

Section 5 begins to address the variation within a season, the goal is to correlate the composition with the synoptic conditions. Again, I would remove the word circulation. What is really being considered is: "Transport influences on O3 and CO distributions in winter". This absolutely depends on the use of back trajectories. However, as is obvious from the spaghetti plots of trajectories shown, classifying days according to their mean sea level pressure does not capture one dominant source region or transport pattern. The composite distributions of chemistry, again may have confounding cancellations of high and low values averaged over the same location, and it gets attributed as a lack of transport to this location. You might address this by calculating the variance or standard deviation of the chemical pattern, this would highlight regions that observed a lot of variability in composition, variability that has been averaged away in the production of the composite.

We will attempt to show the variability for each synoptic pattern as suggested by calculating the variance or standard deviation. However, since the composites use a Gaussian function weighted by distance between the observations and grid points, the calculation may not be as meaningful as if the composite averages were calculated as a simple mean within a square box.

On page 23222, it is noted that O3 and CO distributions were different between dif-

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ferent synoptic patterns. The meaning of synoptic pattern is clearer than referring to map type. In general, the synoptic patterns (not circulation types) could be grouped into two main types, one representing the relative position and strength of a cyclone, which seemed to enhance continental export, and the other representing an off shore anticyclone, which seemed less conducive to continental export. (Remove references to storm track). It is quite difficult to follow the main idea of the text on pages 23223. Which seems to be trying to address the origin of enhanced CO.

We will make these changes to the manuscript.

The authors cite evidence of enhanced CO at 681hPa as evidence that warm conveyor belt transport is lofting boundary layer air into the free troposphere. However, when one looks at the trajectories plotted in figure 6 there is no strong evidence of the WCB which should provide lift from around 800 to 300 hPa. The authors describe a warm conveyor belt "transports air masses within an ascending stream". In fact, it would be better to suggest that air parcels are transported within an ascending stream. The works of Cooper et al., cited in the manuscript, report the movement of airstreams based on backward and forward trajectories from the location of specific aircraft observations. It is not analogous to simply plot a composite synoptic map based on correlations of mean sea level pressure, and then assume that there is a corresponding mean vertical structure. Again, if all the trajectories for each TES overpass have been calculated, why not identify specific airstreams, defining each observation based on its location relative to each real (specific) cyclone for each date, and the representative forward and backward trajectories. This would be a more analogous approach to the published work by Cooper et al, as well as Kiley et al. If this extra effort is not made, at the minimum, the current paper should be reorganized such that the trajectory results for winter synoptic patterns are included with the introduction of the synoptic pattern (Section 3.1), and not folded in after the discussion of summer patterns. Find a way to combine sections 3.1 and all of section 5, and then combine section 3.1 and all of section 6. This seems like it would make more sense, and it's the only way it makes any sense to talk about

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transport or circulation.

In the aircraft studies cited they could count on a comparatively large number of in situ observations over a concentrated area directly within the relevant airstreams for a small number of specific cyclonic events. Unfortunately, with TES the data density is much less and furthermore the core of the warm conveyor belt is typically associated with unbroken thick clouds making TES retrievals unavailable. Therefore we had to rely on our compositing methods utilizing a number of cases over broad areas often with only a few trajectory samples per case that were not always ideally situated with respect to the cyclonic airstreams. Therefore it is probably not suitable to use the same methods used in the aircraft studies.

Also we would like to emphatically state that trajectory analysis alone cannot be considered ground truth, especially in representing sub-grid scale mixing processes, for which all hypotheses concerning the origin of the observed features in an analysis of measurements can be based. Though airstreams such as the WCB are sometimes described as a regions with gradually ascending air from the boundary layer to the middle and upper troposphere in a general southwest to northeast direction, in reality much of the ascent takes place in relatively short intense bursts within fairly narrow bands separated by areas of little or no ascent. However, ascent in trajectory models is based on vertical velocity on a grid scale that is typically too coarse (i.e. 1 x 1 degree for GDAS) to accurately represent all the vertical motions. NWP modelers have long recognized that vertical mixing is not well represented at the grid scale and therefore incorporate sophisticated cumulus and boundary layer parameterizations often optimized for a particular region or synoptic situation to represent the redistribution of heat, moisture, and momentum throughout the model's domain.

While eventually such modeling techniques might be employed to help prove or disprove our hypotheses the purpose of our study in this manuscript was to analyze the TES trace gas distributions with respect to synoptic patterns common in each of the seasons and postulate relationships between the two which we hope will inspire future

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more quantitative approaches applied to the more important albeit preliminary findings.

We do agree that the manuscript could be reorganized to make our presentation clearer.

We will attempt to combine Sections 3.1 and Section 5 and Section 3.2 and Section 6 in the revised manuscript.

The reorganized manuscript will have the following general structure.

Section 1 : Introduction; Section 2: TES Data: Section 3: Meteorological Analysis (including Data and Synoptic Classification sub-sections); Section 4: Seasonal Distributions; Section 5: Synoptic Influences on O3 and CO Distributions in Winter (combination of former Section 3.1 and Section 5); Section 6: Synoptic Influences on O3 and CO Distributions in Summer (combination of former Section 3.2 and Section 6); Section 7: Summary;

For the discussion of summer synoptic patterns, their variability and associated chemistry, why establish five distinct synoptic patterns , when later you collapse them into only three unique groups? Just introduce the three main patterns from the outset. Again, there are at over 30 percent of the days that appear to remain unclassified, (based on frequencies reported in Tables 1a and 1b), and yet this never seems to be mentioned in the text! By combining data into larger groups, you may find that statistical tests of the slope between O3 and CO observations may result in more significant results.

The synoptic classification scheme identified them as distinct patterns, but since they are so similar it does make sense to combine them in the revised manuscript. Again, the frequencies will not add up to 100 percent because we only show the patterns that had a minimum group size greater than or equal to 5 percent of the total group size. These patterns are considered to be the most common. This additional information will be included in the revised manuscript.

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Suggested changes to figures:

Figures 1 and 2, plot the maps (continental and state outlines) in grey, this will allow the isobars to stand out more clearly. Since only three summer patterns are discussed, simply collapse the patterns at the outset, and describe three main JJA synoptic conditions. As noted in the discussion, this figure appears to misrepresent the location of conceptual airstreams.

We will combine the original 5 JJA synoptic patterns into 3.

We will adjust the depiction of the WCB to reflect flow contributions from further ahead of the cold front and review the positions and orientations of the other airstreams on Figure 1.

Figure 4. In the discussion of the spatial correlation of highest CO and O3, to my review of Figure 4, these do NOT correlate, the highest O3 is south of Kentucky and Virginia, while the highest CO is north of Kentucky and Virginia, peaking in Ohio?!

The correlation referred to the scatter plots in Region 1 where on a case-by-case basis O3 and CO mixing ratios were somewhat correlated ($r=0.20$). Also the scatter plots were for Region 1 which did not extend inland as far as Ohio and Kentucky. Still you bring up a good point about the lack of spatial correlation in the composite plots. While we don't fully understand the reason for this occurrence at this point we think it may be due in part to the differences in lifetimes of O3 and CO.

Figure 5. Again, it might be helpful to overlay the synoptic MSL pattern in light grey, since you are trying to relate the spatial pattern of the chemical data to the spatial pattern of the high and low pressure centers. I constantly found myself flipping back to Figure 1. Since it was stated at the outset that TES profiles that were flagged as cloudy were removed, it is not at all clear how representative these plots of chemical observations may be. Is there any artifact of cloud cover in these images?

There would be fewer retrievals available in regions of thick or unbroken cloud cover

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which is typical near the cyclone centers and along the core of the warm conveyor belt. Therefore the artifact in the composites would be an under representation of the contribution of continental export transported in the ascending airstreams. The white spaces in the composites for DJF3 and DJF4 roughly correspond to these regions.

In earlier versions of these figures we overlaid the synoptic patterns on the composite plots and the appearance seemed too busy. We will consider putting the contours back on in light grey as you suggest.

Figure 11. Again, is it possible that the patterns in seasonal ozone are influenced by where TES retrieved cloud free pixels? This would result in lower frequency of reporting at the center of the mean cyclone for example (please address this issue).

Yes this is true. Please see the response to a previous comment. We will explicitly address this in the revised manuscript.

Figures 7-10. Although I think this is a very nice analysis of the influence of a cold air outbreak on the mixing of the lower troposphere, it makes good meteorological sense, I would still like the authors to address the role of these low level clouds on the TES retrieval. In addition, I have suggested soundings that could better illustrate the conditions indicative of the hypothesized convection. In both cases, I believe there is a better sounding, based on time and/or location. You should use the closest soundings to the TES over pass, this would be Yarmouth, Nova Scotia rather than Grey Maine. For the Wallops case, the 00UTC sounding is more conducive to the observed CO profiles reaching nearly 400hPa. If one lifted saturated air from near the warm ocean surface (see red line above), and it followed a moist adiabatic lapse rate, the parcel would be warmer than the environment, the air blowing off the continent, as represented by Wallops Island, all the way up to about 450hPa. The area between the red parcel profile and the ambient environment temperature is a measure of the convective available potential energy (CAPE) and there is no convective inhibition to overcome. This seems quite plausible. I have included these figures for reference.

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The role of the clouds and how they adversely affect the retrievals is discussed in the manuscript on page 23225, lines 17-26. We have also addressed this issue in response to a comment above.

Thank you very much for providing the additional soundings. We will replace the soundings with these in the revised manuscript and change the text accordingly.

The discussion on page 23255 has a few confusing statements, perhaps they include typos? First, the authors state that "the CO level decreased dramatically over ...Rhode Island... This may be evidence that subsidence inhibited any lofting of pollutants to altitudes to which thermal instruments such as TES are less sensitive to CO". The authors then go on to note: "To the south the profile showed no CO enhancement...possibly due to the dispersion of the pollutant plume since surface winds near the Florida coast were backing to the east and while further to the northeast they remained west-erly." Again, this is very poorly worded, and leads to confusion. Perhaps you mean to say "winds near the Florida coast were becoming on shore, or northeasterly, although further north along the east coast, they still had a northwesterly component"? However, this may not be the most relevant piece of information regarding the origin of the air that TES sampled. For these individual profiles, why not just look at the back trajectories for this specific case, and not infer the different source region for different parts of this individual TES orbit, particularly since transport differences are what you seem to be trying to explain.

The clause "instruments such as TES are less sensitive to CO" is indeed a typo and should be "instruments such as TES are more sensitive to CO". It has been corrected in revised manuscript.

Unfortunately the back trajectories, which do not resolve sub-grid scale processes, do not show any vertical mixing from near the surface, only descending motion from the middle and upper troposphere, which is not consistent with the satellite photos and soundings which suggest convective lofting over the ocean. So it is difficult to say for

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certain what the exact source regions were from the back trajectories.

The following is a list of grammatical and typographical errors, and or suggested additions to text. Parentheses, (), represent additions, [] represent deletions. This is not an exhaustive list of all errors, but a sampling of the kinds of changes that should be made, for example, in addition to removing all references to synoptic circulations, I would suggest that all references to ozone or CO "levels", be changed to refer specifically to mixing ratios (or volume mixing ratios). I cite specific examples below, but other instances can be found throughout the document.

We will change all the references of O3 and CO levels to mixing ratios and all the references of synoptic circulations to synoptic patterns in the revised manuscript. We will also make all of the suggested changes listed below and check for additional errors once the manuscript reorganization is complete.

Page 23214, line 16...more frequent(ly); line 18, ozone [levels] (mixing ratios); line 21 further(more); end of paragraph, you should consider a reference to the role of lightning production of ozone (add Cooper et al., 2007, reference included below).

These changes have been made to the revised manuscript. I added the reference to Cooper et al., 2007 as the penultimate sentence in the paragraph since it is related to tropospheric ozone production, and that was the subject of the previous sentence.

Page 23215, line 5, ...grouped TES observations by synoptic (weather patterns) [circulation type] and created composite O3 and CO distributions ... to identify the average chemistry associated with each synoptic pattern to postulate factors regulating the composition. [the salient characteristics and their causal mechanisms].

Change made to revised manuscript.

Page 23216, line 11 : :we used: : :which (removed) [removes]

Change made to revised manuscript.

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Page 23216, line 17, of [the] each element of the true state vector

Change made to revised manuscript.

Page 23215, line 15, which is a post-processing diagnostic (that) [which] defines

Change made to revised manuscript.

Page 23218, remove references to “circulation”, replaced with synoptic pattern, or composite mean sea level pattern.

Changes made to revised manuscript.

Page 23218, line 21, the warm conveyor belt transports air [masses] (parcels in the warm sector, lifting air from) the boundary layer: : :

Change made to revised manuscript.

Page 23219, line 15, from (the) continental boundary layer : : : was possibly restricted; the authors have the trajectories to evaluate whether large scale subsidence under the high was restricting vertical transport.

Change made to revised manuscript with reference to trajectory figure for DJF2 included.

Page 23220, line 17, they typically developed as migrating upper level [synoptic waves] (troughs or short waves) approached the coastline.

Change made to revised manuscript.

Page 23221, line 16, This is not an “export pathway”! (The northward shift of the highest composite CO mixing ratios relative to the winter chemical pattern suggests a correlation with the northward shift in the mean sea level pressure pattern.)

Change made to revised manuscript.

Page 23221, line 27, To identify possible sources for [types of] the [higher] (enhanced)

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O3 and CO [levels] (mixing ratios) at [the] 681hPa we [applied the correlation] calculated the correlation between O3 and CO

Change made to revised manuscript.

Page 23222, line 6, Slopes do not “take place”, similar slopes were derived from observations in the lower free troposphere

Change made to revised manuscript.

Page 23227, line 29, one of the striking features was the [high levels] (enhanced mixing ratio) of CO

Change made to revised manuscript.

Page 23229, line 17, the five original [map types] (synoptic patterns) for summer could be grouped in three more general [flow patterns] sets of synoptic conditions.

Change made to revised manuscript.

Page 23230, These passages make very misleading analogies of flow, referring the the synoptic pattern as if it was a stationary, persistent feature, and not simply a average of several days of similar mean sea level pattern. Again, this is very dangerous and wrongheaded. All of this discussion, and on page 23231, 23232, makes these same interchangeable statements about transport, derived as if the synoptic pattern was fixed in space.

We can replace the references to circulation with synoptic pattern to be consistent with your suggestions from earlier comments. However, we feel that your criticism of our discussion is overstated and not entirely correct. We do not treat the synoptic patterns as static features. We reference trajectory analyses on page 23230, line 6, satellite images (which were actually loops over several days) on page 23230, line 27 and discuss the evolution of the synoptic patterns over several days on page 23231 lines 18-27, and page 23232, lines 14-15. Throughout the discussion we point out how the

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evolution of the pattern over several days influences the trace gas distributions. Aside from being careful with the use of phrases such as “circulation” and “export pathway”, we do not think that there is much more that can be done to revise these sections without undertaking a completely different analysis.

Once these recommended changes have been made, I am confident the paper will be much stronger, and ready for publication.

*Additional Reference suggested: Cooper, O. R., M. Trainer, A. M. Thompson, S. J. Oltmans, D. W. Tarasick, J. C. Witte, A. Stohl, S. Eckhardt, J. Lelieveld, M. J. Newchurch, B. J. Johnson, R. W. Portmann, L. Kalnajs, M. K. Dubey, T. Leblanc, I. S. McDermid, G. Forbes, D. Wolfe, T. Carey-Smith, G. A. Morris, B. Lefter, B. Rappenglück, E. Joseph, F. Schmidlin, J. Meagher, F. C. Fehsenfeld, T. J. Keating, R. A. Van Curen and K. Minschwaner (2007), Evidence for a recurring eastern North America upper tropospheric ozone maximum during summer, *J. Geophys. Res.*, 112, D23304, doi:10.1029/2007JD008710.*

Thank you for your suggestions. We will do our best to implement as many of them as possible.

Interactive comment on *Atmos. Chem. Phys. Discuss.*, 9, 23211, 2009.

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