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OBSERVATIONS FROM MACPEX OF ENHANCED CHEMICAL PLUMES AND PERTURBATIONS IN TROPOPAUSE STRUCTURE IN REGIONS WITH DEEP CONVECTION

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1. INTRODUCTION[1]

Deep convection is an efficient method of the transport of gases from the boundary layer to the UTLS (upper troposphere/lower stratosphere) region. However, the chemical reactions and dynamics, more specifically the updraft characteristics, within deep convection are still not fully understood (e.g. Mullendore et al. 2005). Characteristics of the updraft that are important to redistribution of tracers include vertical extent, distribution of velocities, magnitude and longevity. The updraft itself is impacted by several variables, such as the storm environment, morphology and microphysics. This study focuses on how one part of the storm environment, the tropopause structure, impacts updraft depth and cloud top mixing and thus transport within deep convection.

2. METHODOLOGY

During the Mid-latitude Airborne Cirrus Properties Experiment (MACPEX) campaign aircraft flights sampled the environment over central North America (NASA-ESPO 2015). Although many chemical and hydrometeor concentrations were sampled in situ (Figure 1), carbon monoxide (CO) measurements are focused on for this study as representative of a non-reactive tracer. Vertical profiles from the campaign are catalogued from ascents and descents comprising a change in aircraft altitude of at least 6 km (Figure 2). Subsequently, CO plumes are identified as regions of CO enhancements in the vertical profiles (e.g., 12 km in Figure 3). The location and time of the maximum concentration of the plumes from each ascent and descent is considered a single case.

Back trajectories using the National Oceanic and Atmospheric Administration Air Resources Laboratory Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) trajectory model (Draxler and Rolph 2015) are initialized from the location of the CO plume. The back trajectories are generated using the EDAS 40 km dataset. The model is run for 72 hours generating hourly locations. If these back trajectories come into contact with convection, the structure of the UTLS is then analyzed for that case using temperature data acquired from the aircraft. 12 UTC and 00 UTC soundings are also utilized if they are near either the plume or convective locations.

The thermal tropopause structure is determined using the temperature data from the operational flights as well as the 12 and 00 UTC soundings. The thermal tropopause is defined using the World Meteorological Organization's definition. The definition states that "the tropopause is the lowest altitude where $\Gamma < 2$ K/km, provided that the average lapse rate from this level to any point within 2 km above also has $\Gamma < 2$ K/km. The definition permits multiple tropopauses to be defined, if a tropospheric lapse rate of $\Gamma > 3$ K/km for 1 km occurs above the first tropopause and the first criteria is met again." (Gettelman et al. 2011)

Deep convection is determined using National Center for Atmospheric Research/Earth Observing Laboratory (NCAR/EOL) 4km gridded stage IV precipitation data (NCAR/EOL 2015). More specifically, hourly accumulation totals are used to determine convective activity. A conservative threshold of 8 mm/hr is used to determine if an area of precipitation is convective or not.

Determining if back trajectory locations come into contact with convective activity is accomplished using the nearest neighbor method. The latitude and longitude coordinates are determined for every back trajectory point. These coordinates are matched up with the nearest longitude/latitude coordinates on the precipitation grid. If the precipitation totals of the nearest grid point met the convective threshold requirements, then the back trajectory is said to have come into contact with a convective source (Figure 4).

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3. RESULTS AND DISCUSSION

27 enhanced CO plumes were initially identified from the MACPEX data. However, only four cases were determined to have been from a recent convective source. It should be noted that while the back trajectory may have crossed a recent source of convection, that does not necessarily mean that the plume is from that particular convective event. For all four cases a double tropopause structure was evident in the thermal profiles. Both Figures 5 and 6 show the thermal profiles in the right-hand panels, with green dots indicating a point where the average lapse rate is tropospheric (> 3 K/km) and red dots indicating average lapse rate is stratospheric (< 2 K/km). In cases where there the initial tropopause showed a strong inversion there is a single enhancement of CO (Figure 5), at the LMD (level of maximum detrainment) (Bigelbach et al. 2014). Cases that showed a weak inversion above the first tropopause showed a double peak in CO concentrations (Figure 6). Currently, it is not certain why the double peak exists. The secondary peak could be a result of convective updrafts penetrating into colder air aloft, or it could be a different air mass that has advected into the region.

It should be noted the results presented are strictly preliminary. Only four cases were analyzed and a larger dataset will need to be analyzed to provide more conclusive results. One objective of this presentation is to present a methodology that would garner the interests of the scientific community and thus offerings of data for a more robust data set and further analysis. Another step being taken to increase the dataset is improving the method in which convection is detected. Instead of looking for trajectory points that fall on grid points that contain precipitation accumulations that meet the convective threshold, the new method would look at all precipitation values that lie on a line between two hourly trajectory points, as well as precipitation points some given distance from that line (accounting for uncertainty in trajectories). Since the precipitation is accumulated over an hour, it stands to reason that any point that lies between two trajectory points could have potentially come into contact with a convective source. This should allow for the detection of more cases that have come into contact with deep convection.

4. CONCLUSIONS

Data from the MACPEX campaign is used to investigate observed CO plumes from recent sources of convection in relation to tropopause structure. The locations of CO plume maximums are used as a starting for point for the HYPSLIT model back trajectory calculations. If the back trajectory came into contact with a recent source of convection – which is determined using NCAR Stage IV gridded hourly precipitation data – then that particular case is analyzed.

Using this methodology four cases are analyzed. Preliminary results show that the thermal profile for each case showed a double tropopause. Given that the data was collected in April this is to be expected. Double tropopause structures are more prevalent in the winter/spring time in the northern hemisphere (e.g., Randel et al. 2007). For cases that showed a weak initial thermal inversion a double peak in CO maximums are observed. Cases that have strong initial thermal inversions show a single peak in CO concentrations.

5. FUTURE WORK

Going forward with this research it will be imperative to analyze more cases to form more robust conclusions. Currently, the main focus of the analysis is on the main, or maximum, CO plume for each case. It will be important to determine the origin of the CO plumes that aren't as large in magnitude. The methodology will need to be refined in such a way that allows for the determination of the origin of the secondary CO plumes. Continuation of this work in the form of a modeling study would most likely be the best approach to this problem as it will be extremely difficult to determine its origin for the aforementioned reasons in the results section.

6. REFERENCES

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7. FIGURES

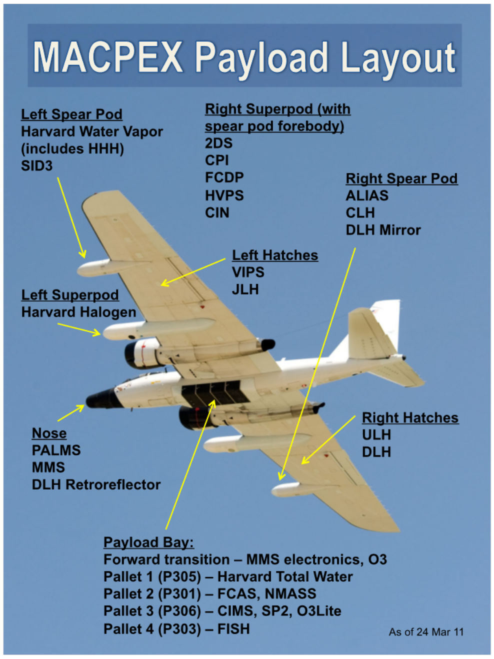

Figure 1. Image of the NASA WB-57 aircraft used during the MACPEX field campaign. This image shows the instruments used during the field campaign. For this study, measurements taken from the ALIAS instrument and MMS electronics are used.

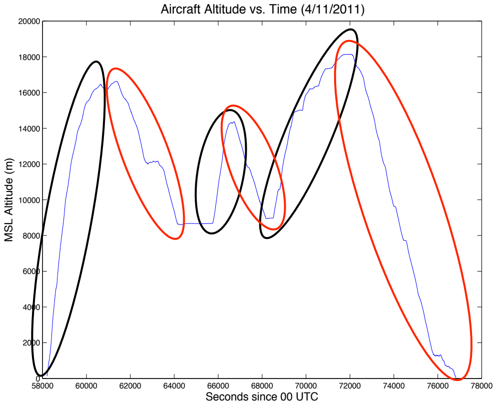

Figure 2. Figure showing the descent profile of a flight on 04/11/11. Ascents are represented by black ovals and descents are represented by red ovals. Each ascent/descent represents a change in altitude of at least 6 km.

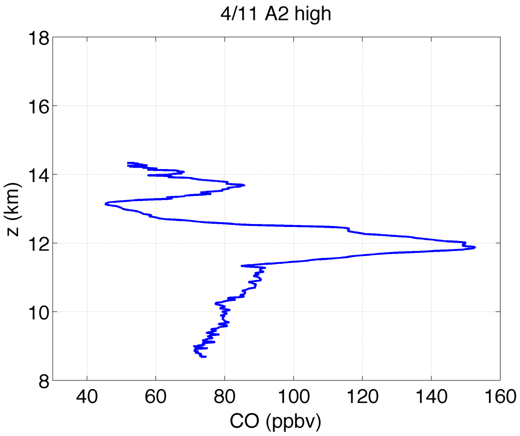

Figure 3. Example of an observed carbon monoxide plume from the 04/11/11 flight.

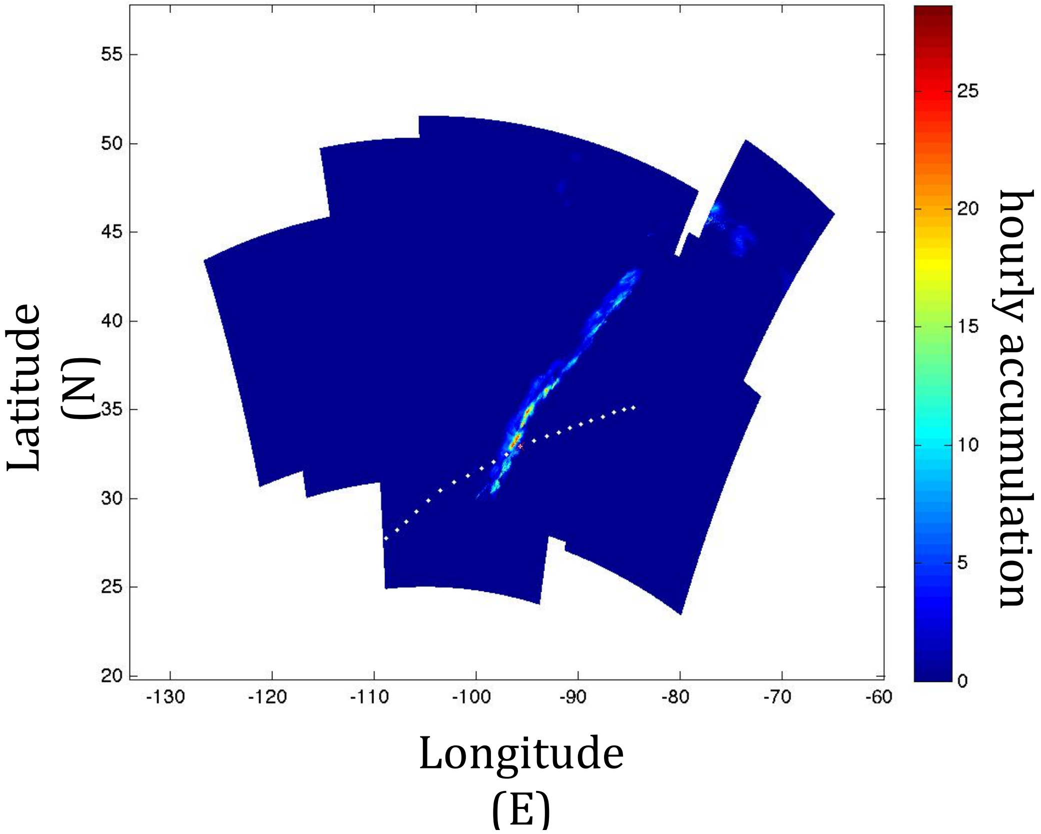

Figure 4. Example of a back trajectory overlaid on hourly precipitation accumulations. Each white dot represents the location of the trajectory model after each hour. The red dot represents the current location of the trajectory.

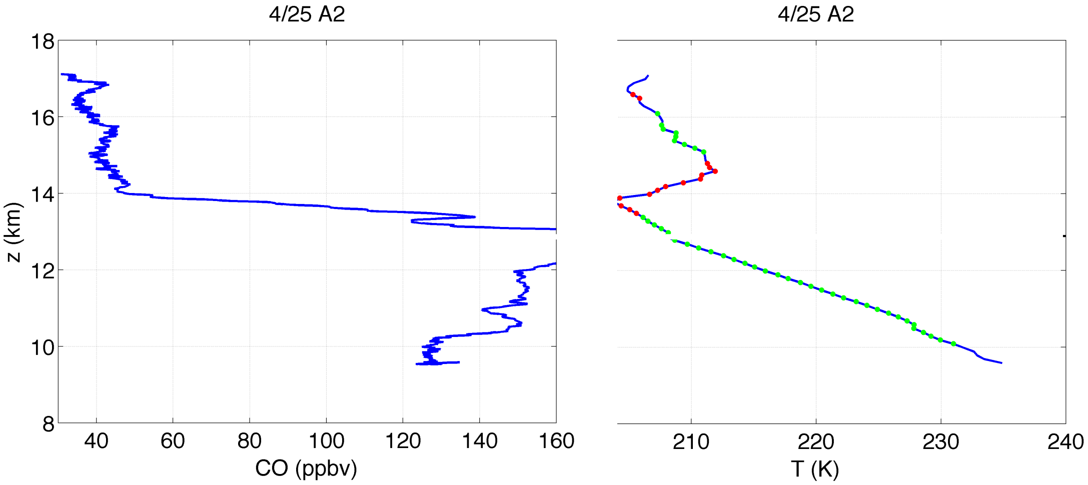

Figure 5. Example of a case that shows a strong inversion in the tropopause structure. The strong inversion is evident at about 14 km with a large enhancement of carbon monoxide located just below that at about 13km. No secondary maximum in CO is noted above the initial inversion. Green dots indicate tropospheric lapse rate and red indicate stratospheric lapse rate.

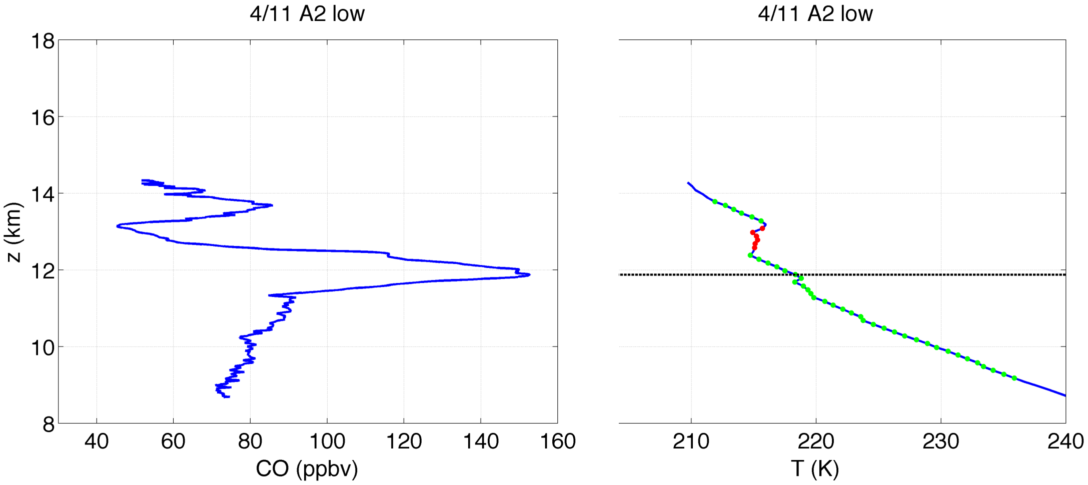

Figure 6. Example of a case that shows a weak inversion in the tropopause structure. The inversion is evident at about 12.5 km. A maximum in carbon monoxide concentrations is marked on the temperature profile by the dotted black line. There is also a secondary maximum in carbon monoxide located just above 14 km. Green dots indicate tropospheric lapse rate and red indicate stratospheric lapse rate.