Characteristics of Double Tropopause Layers Observed during TORERO

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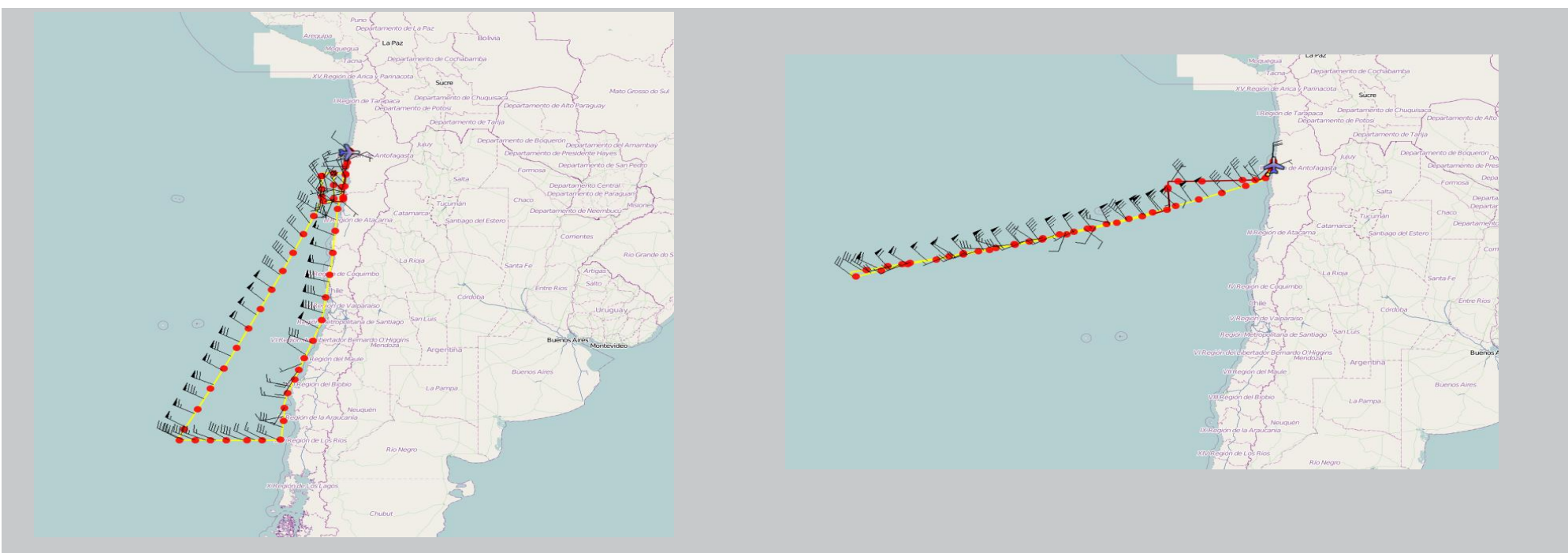
Introduction

TORERO Field Campaign

The Tropical Ocean tRoposphere Exchange of Reactive Halogen and Oxygenated VOC (TORERO) experiment was designed to study the release, transport, and fate of reactive halogen gases and oxidized volatile organic compounds. Specifically, their effect on the atmospheric oxidation capacity in the Eastern Tropical Pacific Ocean during the season of high biological ocean productivity was observed from airborne and ship platforms. The NSF/NCAR Gulfstream V (GV) aircraft collected remote and in situ data during flights based in Antofagasta, Chile and San Jose, Costa Rica (TORERO, 2012).



Flight track of the NSF/NCAR Gulfstream V on 27 Jan 2012 (left) and 29 Jan 2012 (right). Both flights originated in Antofagasta, Chile.

Double Tropopause Conditions

The Upper Troposphere Lower Stratosphere (UTLS) is a region where chemical constituents are redistributed. Stratosphere Troposphere Exchange (STE) processes for ozone, water vapor and other trace gases are of interest due to their influence on radiative forcing and chemistry-climate interactions.

Double tropopauses, as defined using the temperature lapse rate, were observed during TORERO flights from Antofagasta. Such conditions tend to exist near a characteristic break in the thermal tropopause associated with the subtropical jet. In these regions the tropical tropopause extends to higher latitudes, overlying the lower tropopause (Randel et al., 2007). It has been shown that double tropopauses tend to form above strong cyclonic circulation and may be associated with areas of reduced ozone concentration due to tropospheric intrusion in the lower stratosphere (Pan et al, 2009). Global analyses of double tropopause distribution shows a high frequency of occurrence over the Andes Mountains (Peevey et al., 2012).

Data Sets

Various airborne measurements from the GV define and characterize the transition layer at the UTLS:

- Remote vertical temperature profiles (Denning et al., 1989)
- In situ ozone mixing ratio (Proffitt and McLaughlin,1983)
- In situ carbon monoxide mixing ratio (Gerbig et al., 1996)
- In situ water vapor mixing ratio (Zondlo et al., 2010)

Model profiles of temperature and trace gases were also generated by the Real-time Air Quality Modeling System (RAQMS) during TORERO (Pierce et al., 2003).

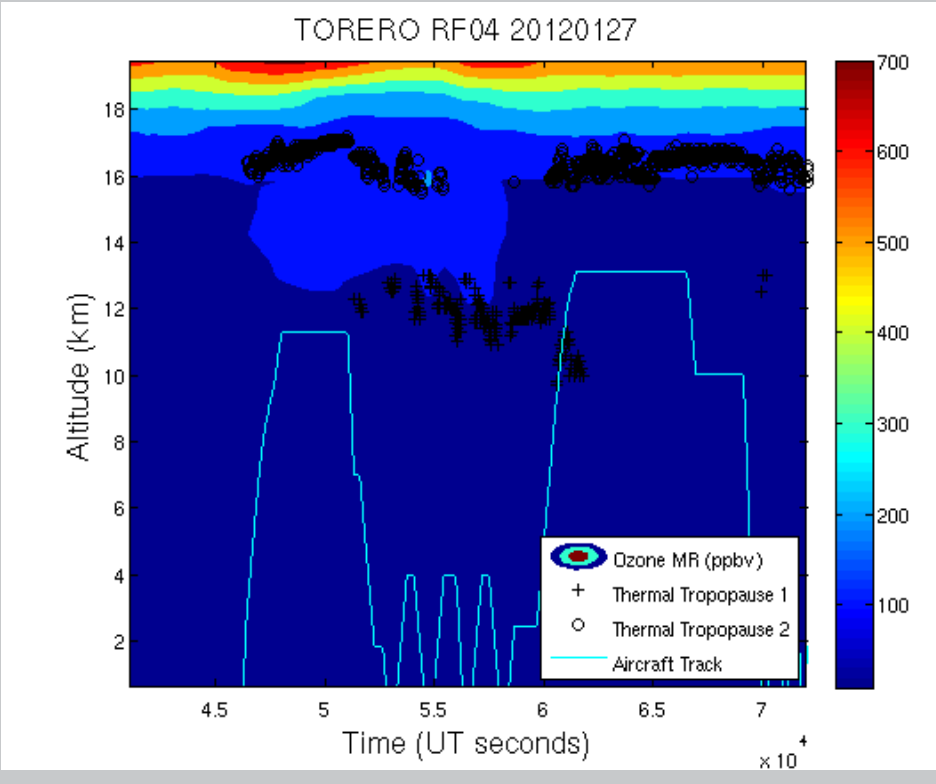
Objective

Identify double tropopause occurrences using thermal lapse rate and in situ measurements of ozone, carbon monoxide and water vapor. Compare these various metrics of tropopause height with RAQMS-generated fields of each quantity to locate areas of STE.

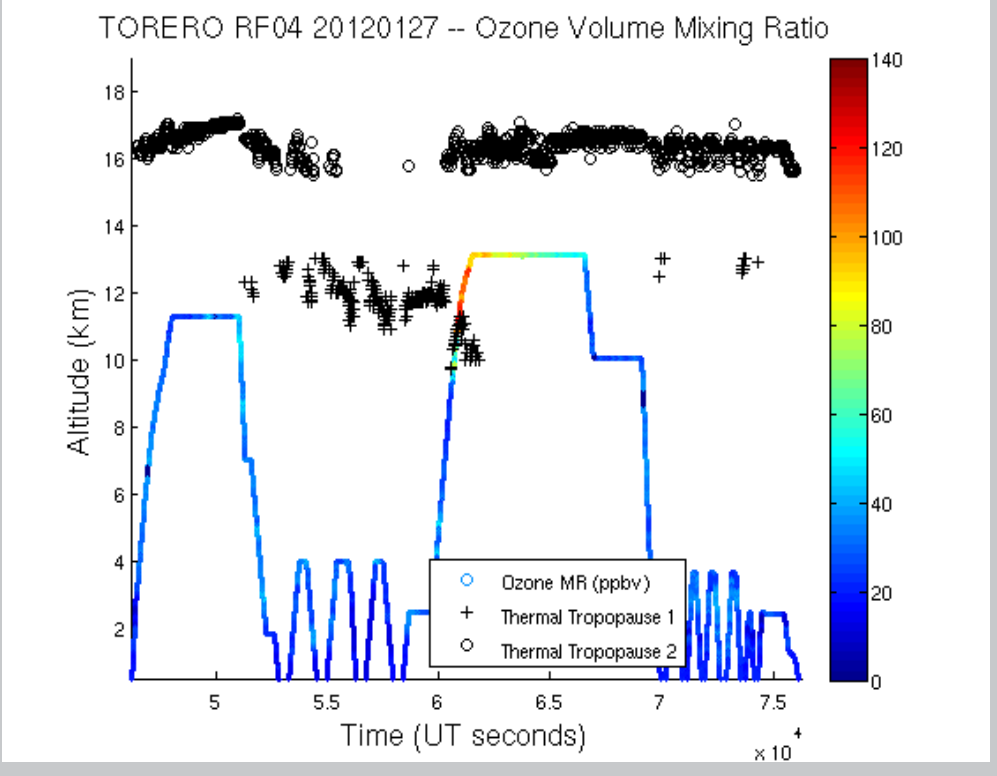
Case Studies

I. 27 Jan 2012 (TORERO flight RF04)

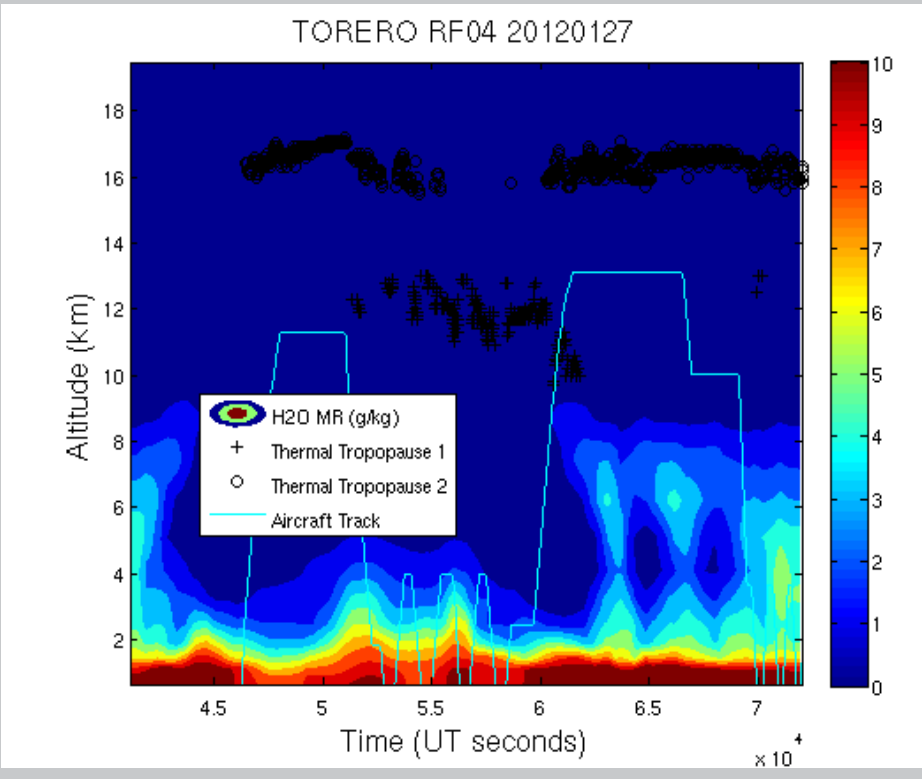
- Southbound flight along Chilean coast to observe upwelling and deep convective outflow
- Double tropopauses encountered at latitude range 33-40° S



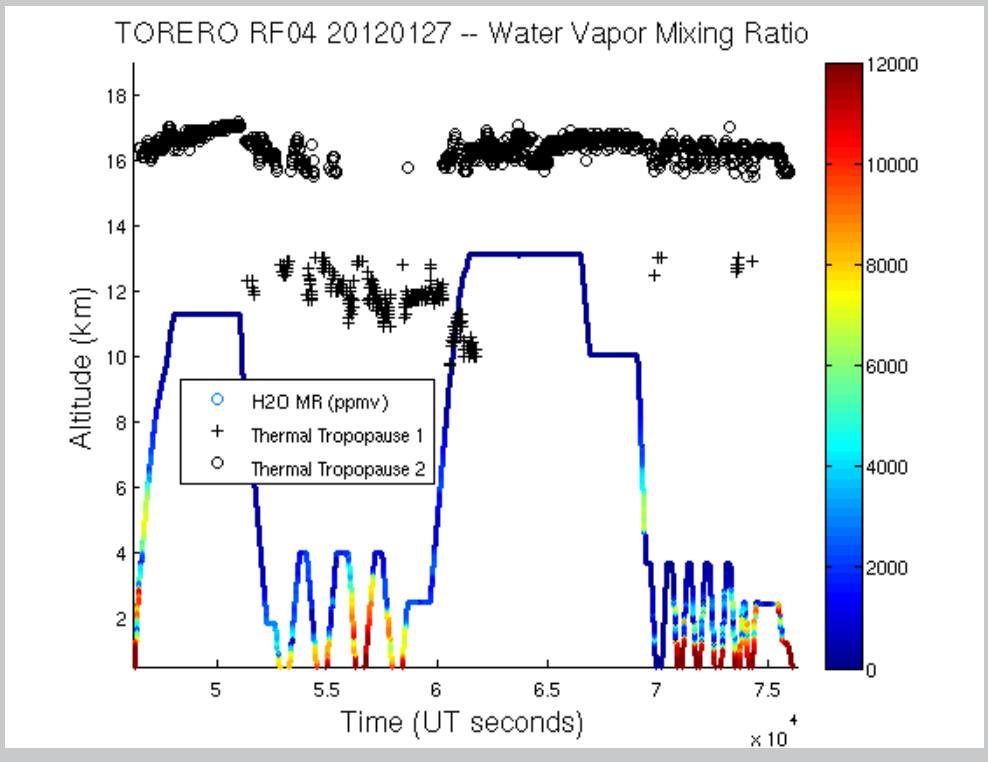
RAQMS ozone cross section along GV flight track suggests elevated ozone in layer between lower and upper thermal tropopause observed by the Microwave Temperature Profiler.



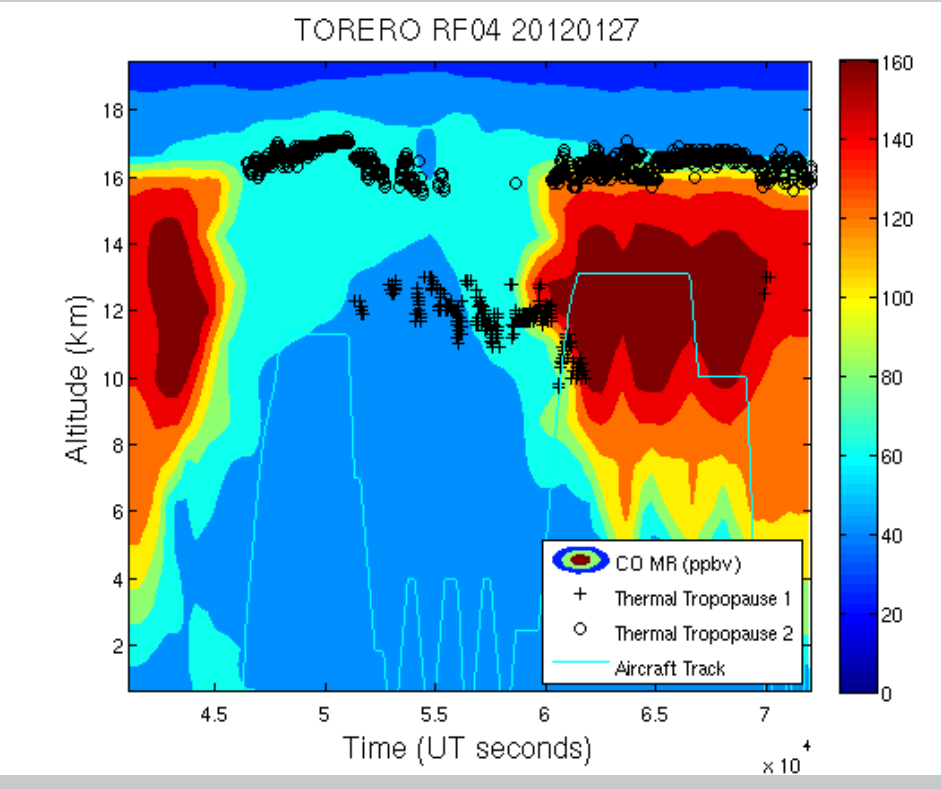
A reduction in the lower tropopause height to ~10 km is accompanied by elevated levels of ozone as measured by the UV-absorption ozone photometer, showing intrusion of stratospheric air between 60-65 ksec (UTC).



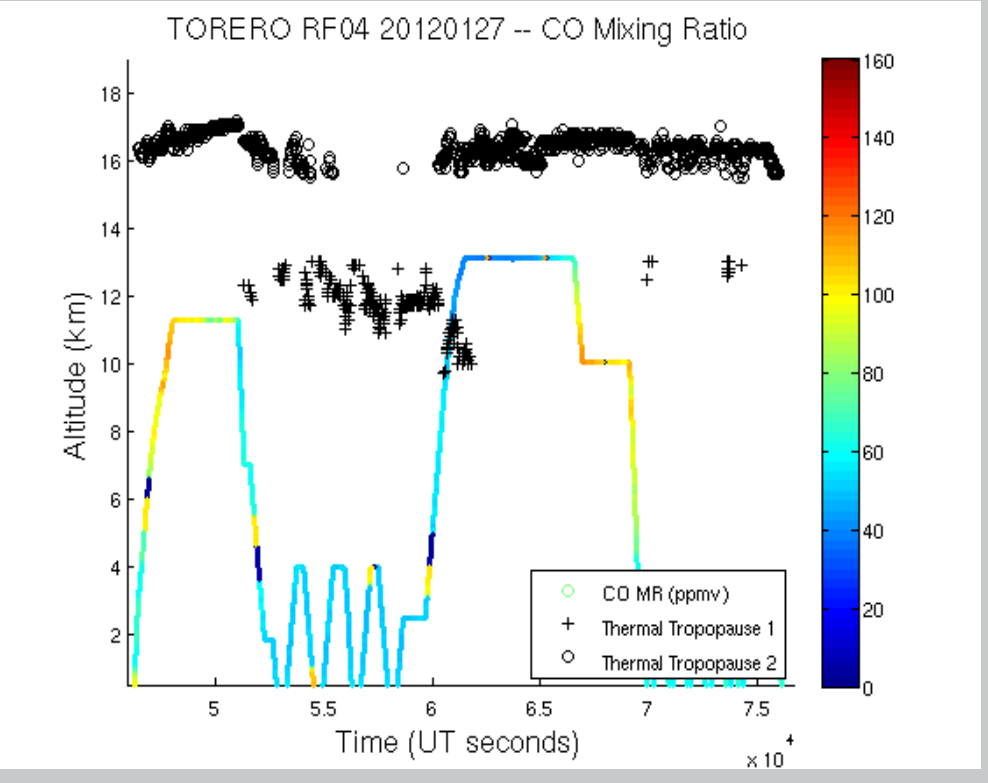
RAQMS water vapor cross section shows vertical gradients consistent with in situ measurements and dry air in the UTLS region.



Water vapor mixing ratio measurements from the Vertical Cavity Laser Hygrometer show a similar vertical distribution.



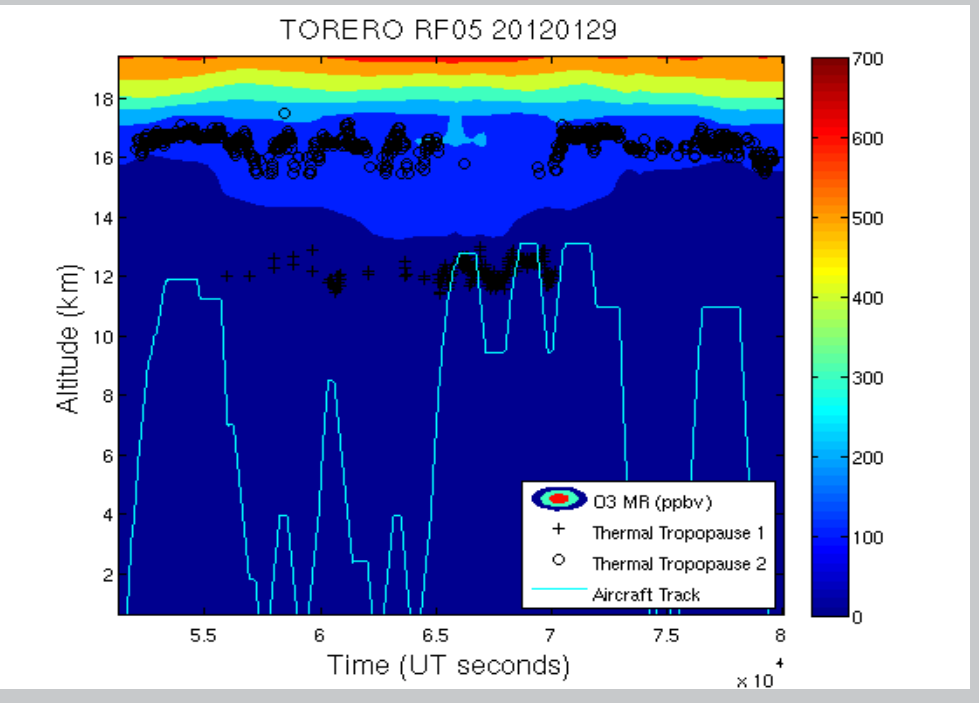
RAQMS carbon monoxide mixing ratio shows elevated levels associated with continental outflow



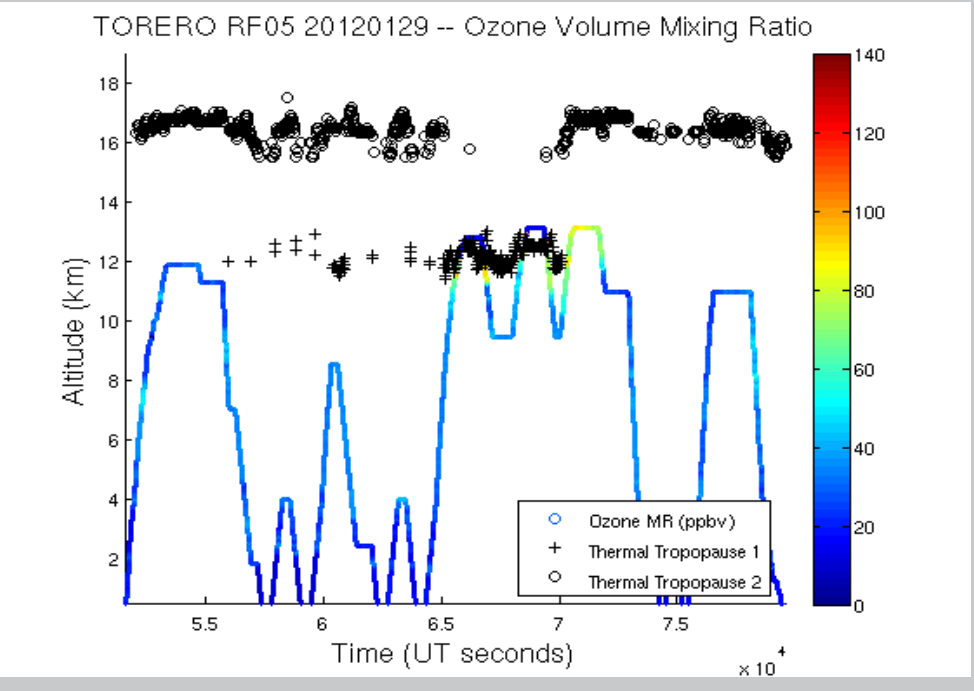
Carbon monoxide mixing ratio measurements detect elevated levels associated with continental outflow.

II. 29 Jan 2012 (TORERO flight RF05)

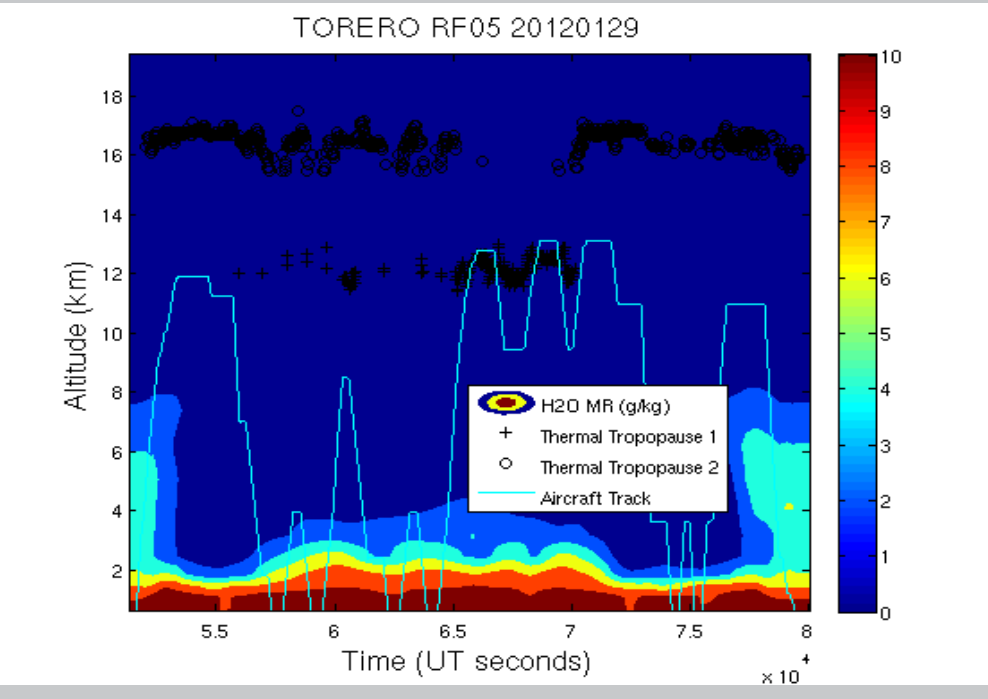
- Westbound flight from Antofagasta, Chile to observe oligotrophic ocean region
- Double tropopauses observed in latitude range 29-31° S



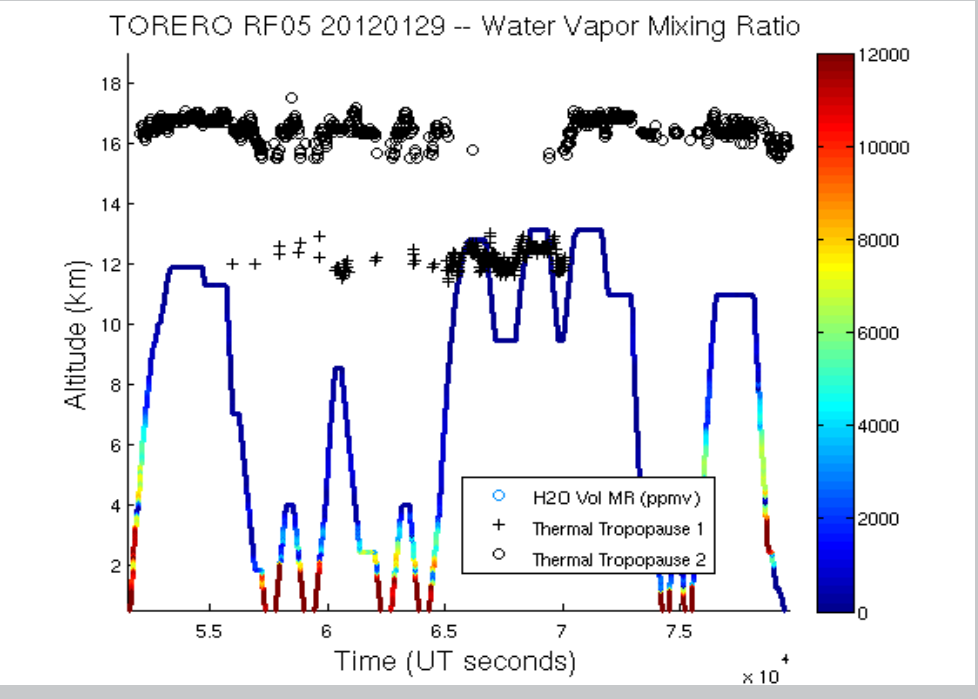
RAQMS ozone cross section shows elevated ozone in layer between lower and upper thermal tropopause.



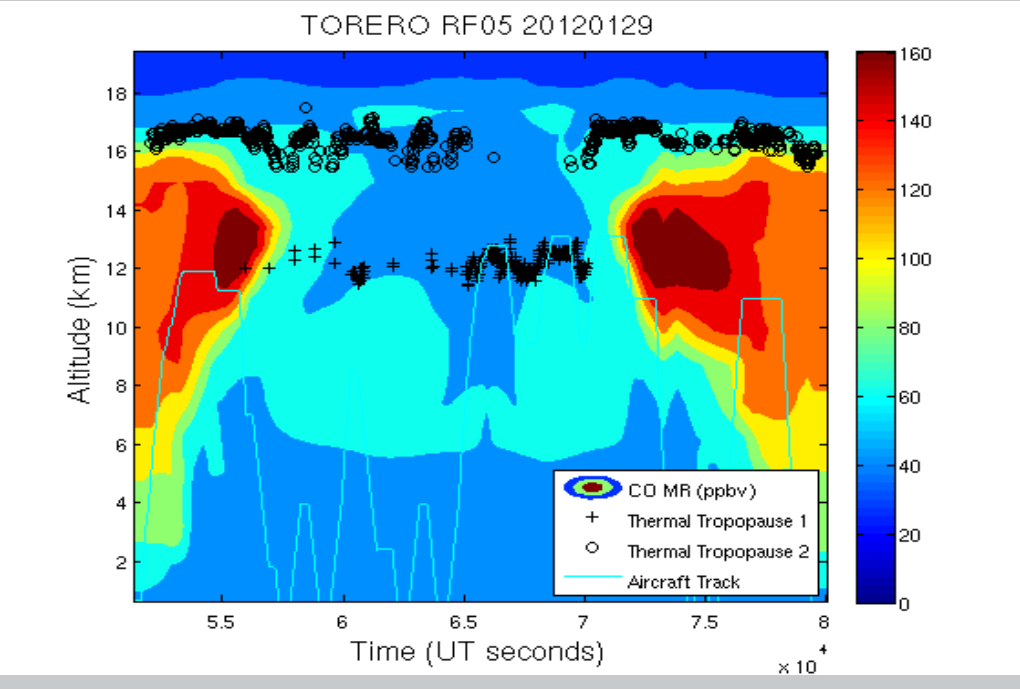
Airborne observations of ozone at the lower thermal tropopause exhibit elevated mixing ratio.



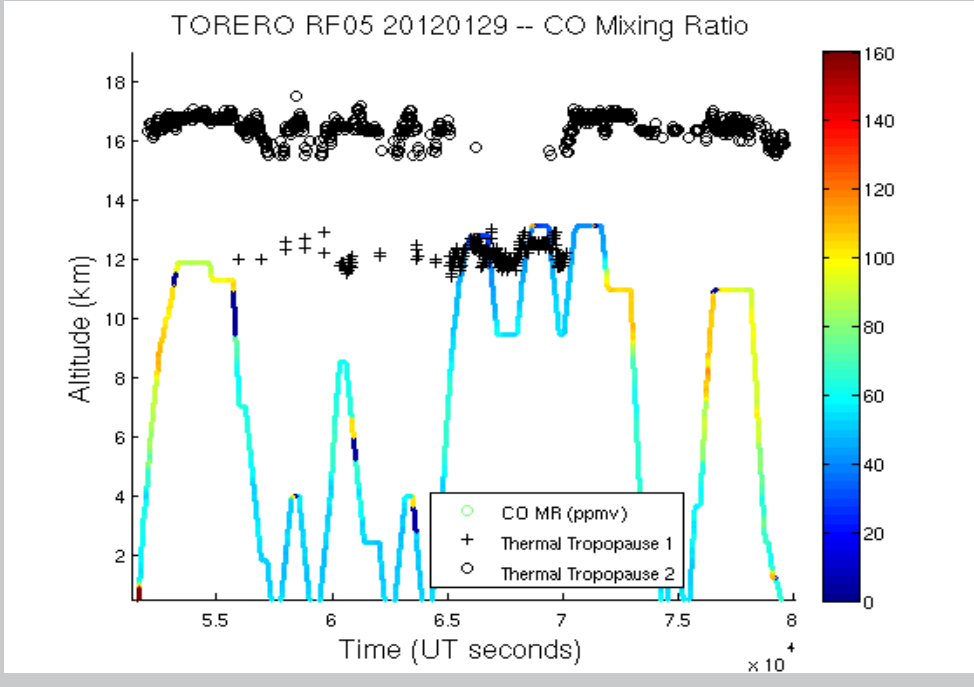
RAQMS water vapor cross section shows vertical gradients consistent with in situ measurements and dry air in the UTLS region.



Water vapor mixing ratio measurements show a similar vertical distribution.

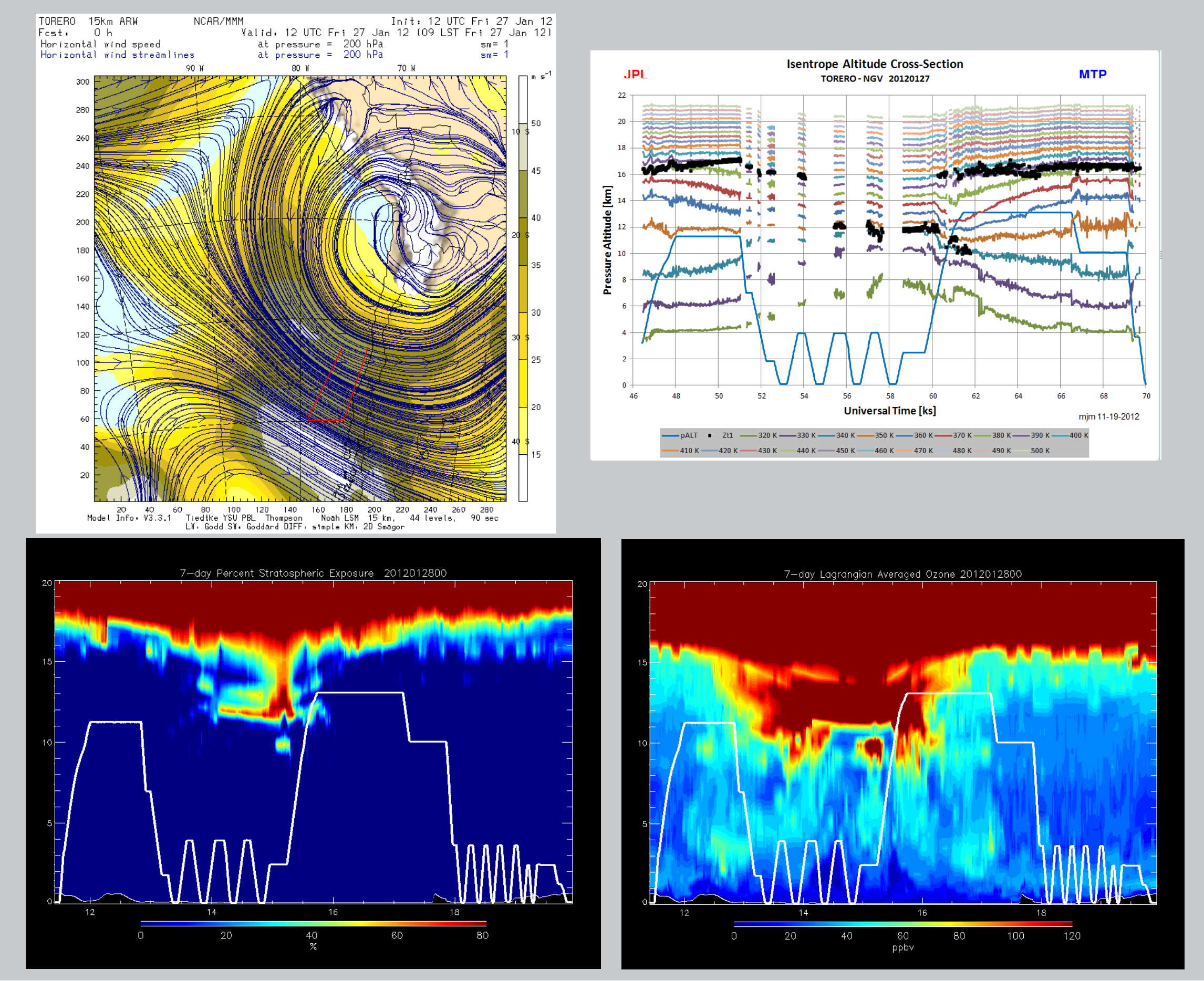


RAQMS carbon monoxide mixing ratio shows elevated levels associated with continental outflow



Carbon monoxide mixing ratio measurements detect elevated levels associated with continental outflow.

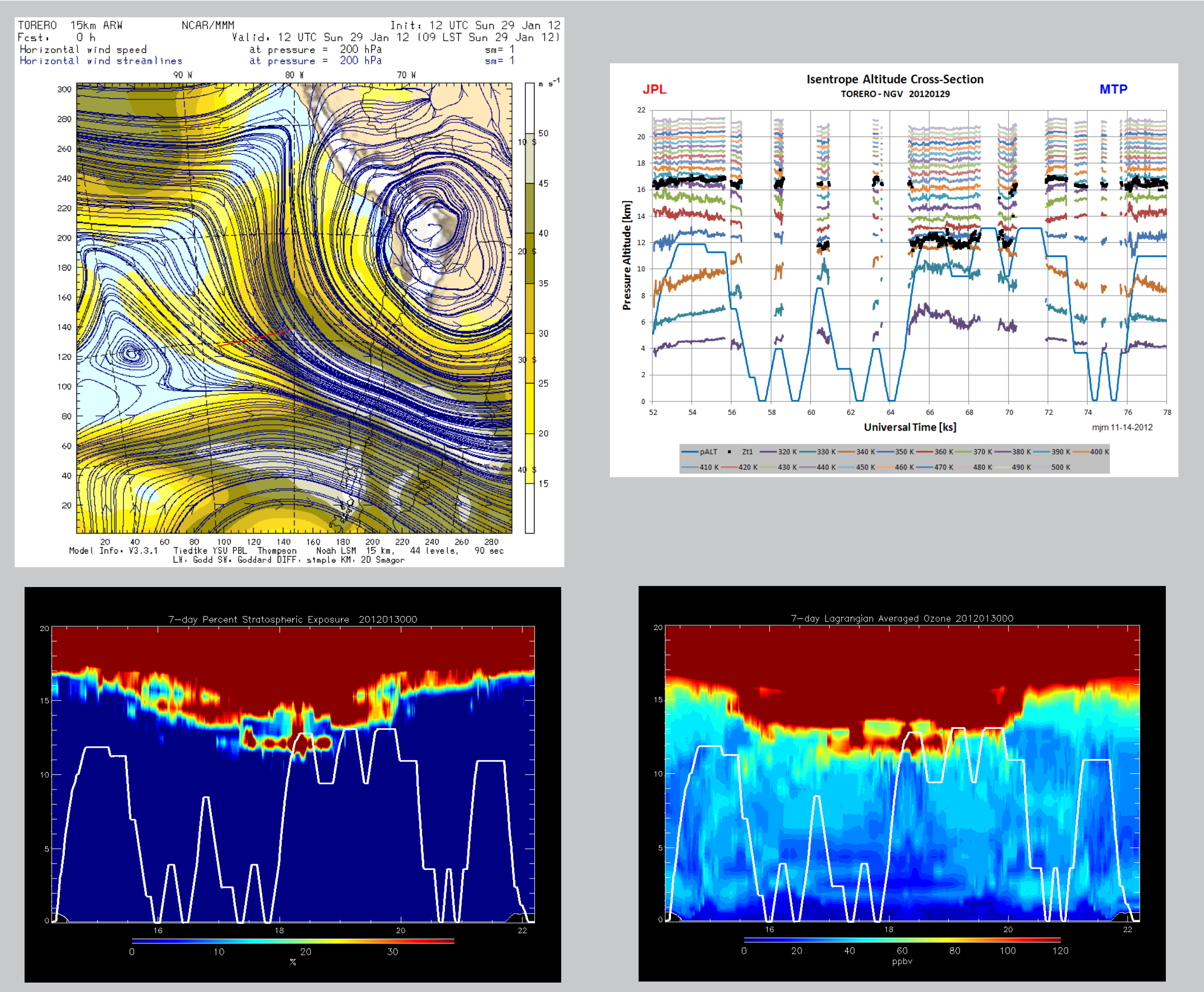
Results



I. 27 Jan 2012 (TORERO flight RF04)

The existence of double tropopauses during this coastal flight and associated Stratosphere Troposphere Exchange are indicated by the data shown above. The 200 mb wind field and streamlines from the Weather Research and Forecast (WRF) model (upper left) show evidence of a jet centered between 30-45 °S. The portion of the flight track where double tropopauses were encountered is shown as a red line, coinciding with the position of the jet stream. Isentropes along the flight track (upper right), derived from Microwave Temperature Profiler measurements, suggest stratospheric air down to altitudes of 10-12 km in the region of double tropopause observations (note closely spaced isentropes in the middle portion of the flight). Isentropes separate outside of this region indicating that the aircraft remained in tropospheric air at those times.

RAQMS back trajectory calculations are consistent with these observations. The 7-day Stratospheric Exposure field (lower left) places a feature with high percentage of stratospheric exposure at the approximate location of double tropopause observations. This intrusion of stratsopheric air extends from the level of the upper thermal tropopause (16 km) down to the lower thermal tropopause (11-12 km). Associated with this stratospheric intrusion are high levels of 7-day Lagrangian average ozone along the back trajectory (lower right). The 7-day Lagrangian average ozone field is better able to resolve thin filaments of higher ozone within the strong shear zones near the jet core than the RAQMS model instantaneous ozone field, revealing a substantial intrusion of stratospheric air that is only partially evident in the RAQMS ozone cross section at the time of this flight.



II. 29 Jan 2012 (TORERO flight RF05)

Data from this westbound flight show similar indications of double tropopauses and STE. The flight track appears to have crossed a portion of the jet stream (upper left). Isentropes (upper right) give evidence of stratospheric air down to the level of the lower thermal tropopause. RAQMS back trajectories show high percentages of stratospheric exposure and elevated ozone mixing ratio in the layer between thermal tropopauses.

Conclusion

Flights conducted during the TORERO experiment provide observations of double tropopause layers. Two cases analyzed demonstrate consistency between various metrics of tropopause height including thermal lapse rate and ozone vertical variations. RAQMS output along the flight tracks along with RAQMS back trajectory calculations provide context for the in situ measurements.

Continuing work will examine additional indicators of the tropopause such as potential vorticity and potential temperature lapse rate. Additional TORERO flights with double tropopauses remain to be analyzed. Results of this analysis will assist with interpretation of halogen oxide radicals and oxidized organic carbon measurements (Volkamer et al., 2012), and aerosol size distribution measurements (Wang et al., 2012) in the UTLS region during TORERO.

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