Mixing in the upper troposphere/lower stratosphere observed by simultaneous radar and satellite observations.

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Abstract

The upper troposphere /lower stratosphere (UTLS) is a region of key interest for understanding global change and chemistry-climate coupling. However, this region is generally poorly understood because of the lack of quantitative knowledge on Stratosphere-Troposphere Exchange (STE). One of the key difficulties in quantifying Stratosphere-Troposphere Exchange (STE) in the extratropics is the identification and characterization of the extratropical tropopause. Recent studies by Pan et al. (2004) have examined how well the thermal and dynamical tropopauses identify the chemical transition from troposphere to stratosphere by using relationships between stratospheric (O_3) and tropospheric (CO and H_2O) tracers. Relationships between these tracers identify a mixed transition layer centred around the thermal tropopause where the observations of chemical concentrations display a mixture of stratospheric and tropospheric signatures. This study aims to intercompare localised high-resolution MST radar observations with lower-resolution global satellite observations to examine whether MST radar can observe the mixed transitional layer and therefore provide useful information on the time variation of this layer. Satellite observations of O_3 and H_2O from the Atmospheric Infrared Sounder (AIRS) instrument onboard the Aqua satellite will be used to identify the mixed transitional layer and STE on a global scale. High-resolution MST radar observations will be made using the NERC MST radar facility at Aberystwyth, UK.

Introduction

Pan et al. (2004) have examined how well the thermal and dynamical tropopause definitions identify the chemical transition between the troposphere and stratosphere. They considered the relationship between the concentrations of a tracer such as water vapour, which is typically high throughout the troposphere but low in the stratosphere, and ozone, which is low in the troposphere but high in the stratosphere. Tracer-tracer diagrams, such as the ideal one shown in Figure 1, often indicate a transition layer, around the altitude of the tropopause, which exhibits tracer concentrations which are intermediate between those of the troposphere and stratosphere for both species. Figure 1 indicates that the depth of the mixed transition layer (blue dashed line) increases as the data moves away from the intercept between the lines associated with tropospheric (green line) and stratospheric (red line) tracers. Figure 2 shows the tracer-tracer relationship between ozone and water vapour mixing ratios for a single ozonesonde flight. The colours in Figure 2 indicate the altitude relative to the thermal tropopause level.

Work by a number of authors has indicated that VHF radar are sensitive to the thermal tropopause (Gage and Green, 1982; Hopper et al., 2004). Previous work has also suggested that the static stability impacts the form of the signal power independent of the type of reflections observed. The aim of this study is to intercompare localised high-resolution MST radar observations with lower-resolution global satellite observations to examine whether MST radar can observe the mixed transitional layer and therefore provide useful information on the time variation of this layer. Satellite observations of O_3 and H_2O mixing ratios from the Atmospheric Infrared Sounder (AIRS) instrument onboard the Aqua satellite are used to identify the mixed transitional layer on a global scale.

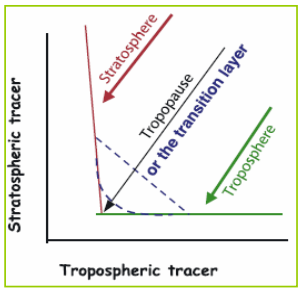

Figure 1: Tracer-tracer relationship between a stratospheric, such as ozone, and a tropospheric (such as water vapour) tracers. The red line displays the form of a stratospheric tracer in this parameter space, the green line shows the from of a tropospheric tracer in this parameter space and the blue line shows the form observed for a mixed transition layer.

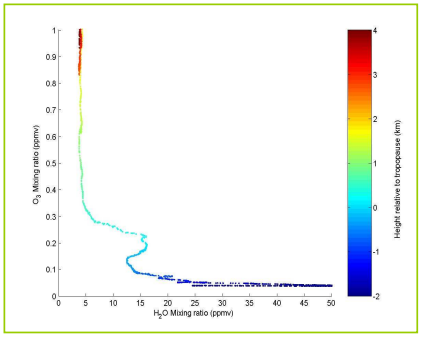

Figure 2: Tracer-tracer relationship between the H_2O (a tropospheric tracer) and O_3 (a stratospheric tracer) mixing ratio measured by an ozonesonde. The colours indicate the altitude relative to the thermal tropopause. Note that the transition layer is slightly offset from the tropopause altitude in this case.

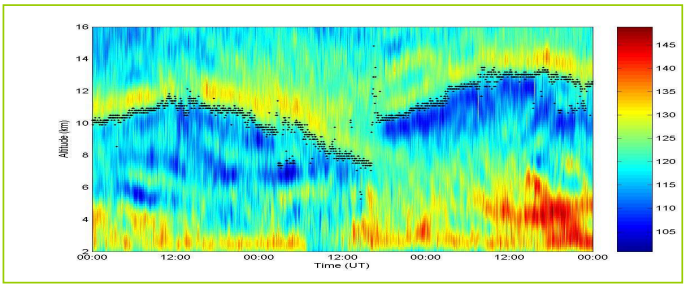

Figure 3: Time-Altitude contour plot of the range squared corrected vertical signal power observed by the NERC MST radar. Black dots indicate the altitude of the radar derived tropopause level.

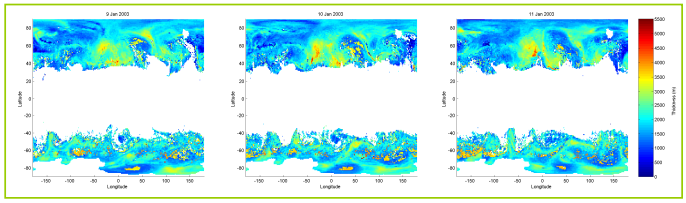

Figure 4: Latitude-Longitude diagrams of the mixed transition layer depth derived from AIRS measurements of ozone (stratospheric tracer) and water vapour (tropospheric tracer) for the 19th, 20th and 21st January 2003.

Results

Figure 3 displays the range squared corrected vertical signal power observed by the NERC MST radar (52.4º N, 4.0º W) between the 9th and 11th January 2003. This diagram shows clear variations in the tropopause altitude (identified by black dots). Close examination of Figure 3 also indicates that the region of enhanced signal power above the tropopause altitude varies significantly from roughly 2 km at the start of the period to 3 to 4 km at 12:00 UT on 10th January 2003.

Figure 4 displays latitude-longitude diagrams of the transition layer depth outside of the tropics based on AIRS measurements of ozone and water vapour mixing ratios. Comparison of the thicknesses in Figure 3 and Figure 4 is complicated by the differences in the horizontal scale of sampling and the fact that the MST radar measurements have a high temporal resolution. While the AIRS maps in Figure 4 are based on data collected over a whole day. However, close examination of the region around Aberystwyth (52.4º N, 4.0º W) does show that the thickness derived from the AIRS satellite and the thickness derived from the radar have a negative correlation.

This negative correlation is better displayed in Figure 5 which shows the transition layer thickness based on radar (red line) and AIRS data (blue line) over Aberystwyth for every day during 2003. This negative correlation (with correlation coefficient of -0.65 which is significant at the 99% confidence level) is at first glance rather unexpected. However, simple modelling of the form of the variation in signal power close to the tropopause for different forms of the temperature profile suggests that this relationship can be explained.

Figure 6 shows the modelled temperature profile (left) and the signal power (right) derived for two different situations. The signal power is derived using the fact that the returns observed by the VHF radar are proportional to the square of the mean vertical gradient of generalized radio refractive index divided by the range squared. The mean vertical gradient of the generalized radio refractive index assuming a dry atmosphere, which is a good assumption around the tropopause level, is defined as:

$$M_D = -77.6 \times 10^{-6} \frac{p}{T} \frac{\partial \ln \theta}{\partial z}$$

where z is the altitude (m), p (hPa) is pressure, T (K) is absolute temperature and θ (K) is potential temperature. In the first situation (dotted lines) the lapse rate varies smoothly from -6 K/km in the troposphere to 0 K/km in the stratosphere. In the second situation, an inversion occurs with a value of +2 K/km slightly above the tropopause. It should be noted that these inversions are often observed in high-resolution temperature profiles (Birner, 2006) and would provide a strong barrier to mixing. Examination of Figure 6 therefore suggests that the largest radar derived transition regions would be observed in regions of low mixing. However, it should be noted that under certain conditions, such as during active STE, this simple relationship is unlikely to hold true.

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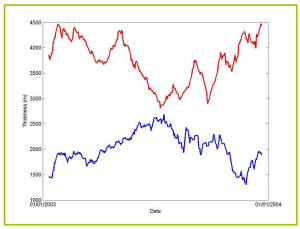

Figure 5: Transition layer depth determined from MST radar data (red line) and AIRS satellite chemical composition data (blue line) for 2003.

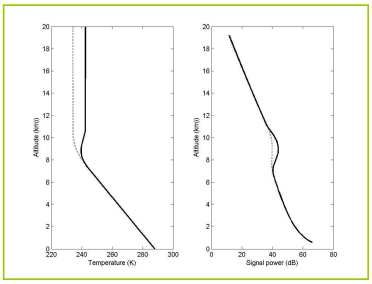

Figure 6: Simulated temperature profiles (left) with (full line) and without (dotted line) an inversion above the tropopause level. Simulated signal power (right) for the temperature profiles with and without an inversion.

Conclusions and Further work

This very initial work suggests that VHF6 radar returns are sensitive to mixing in the Upper troposphere/ Lower stratosphere. In particular, examination of the transition depth at the tropopause derived from VHF radar and AIRS satellite observations shows a negative correlation which can be explained by the presence of inversions in temperature profiles. It should be noted that significant extra work is needed to define methods to more clearly intercompare satellite and radar observations which have very different spatial and temporal scales.

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