Break-detection and time series homogenization through joint observations from independent ozone observation systems: a case study for the Mauna Loa ozone records

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Abstract: The inference of ozone recovery by ground-based instruments is complicated by (1) the relatively short period of decline of ODS concentrations from their peak values in the late 1990s, (2) natural atmospheric variability, and (3) perturbations/discontinuities in observational records resulting due to changes in instrumental characteristics over time and instrument replacements. Here we focus explicitly on the latter by evaluating a series of comprehensive ozone measurements made with different observational systems at NOAA's observatory at Mauna Loa and at Hilo, Hawaii. The three main observational platforms are: (1) Umkehr measurements (starting 1982), (2) recently homogenized sonde measurements (available from 1991), and (3) microwave measurements (starting 1995). Here we assess time series properties, variability, and trends across the joint observational record. We assess variability and trends across the joint observational record at both discrete layers and integrated total column amounts to identify potential perturbations to observational records related to instrument degradation and replacement.
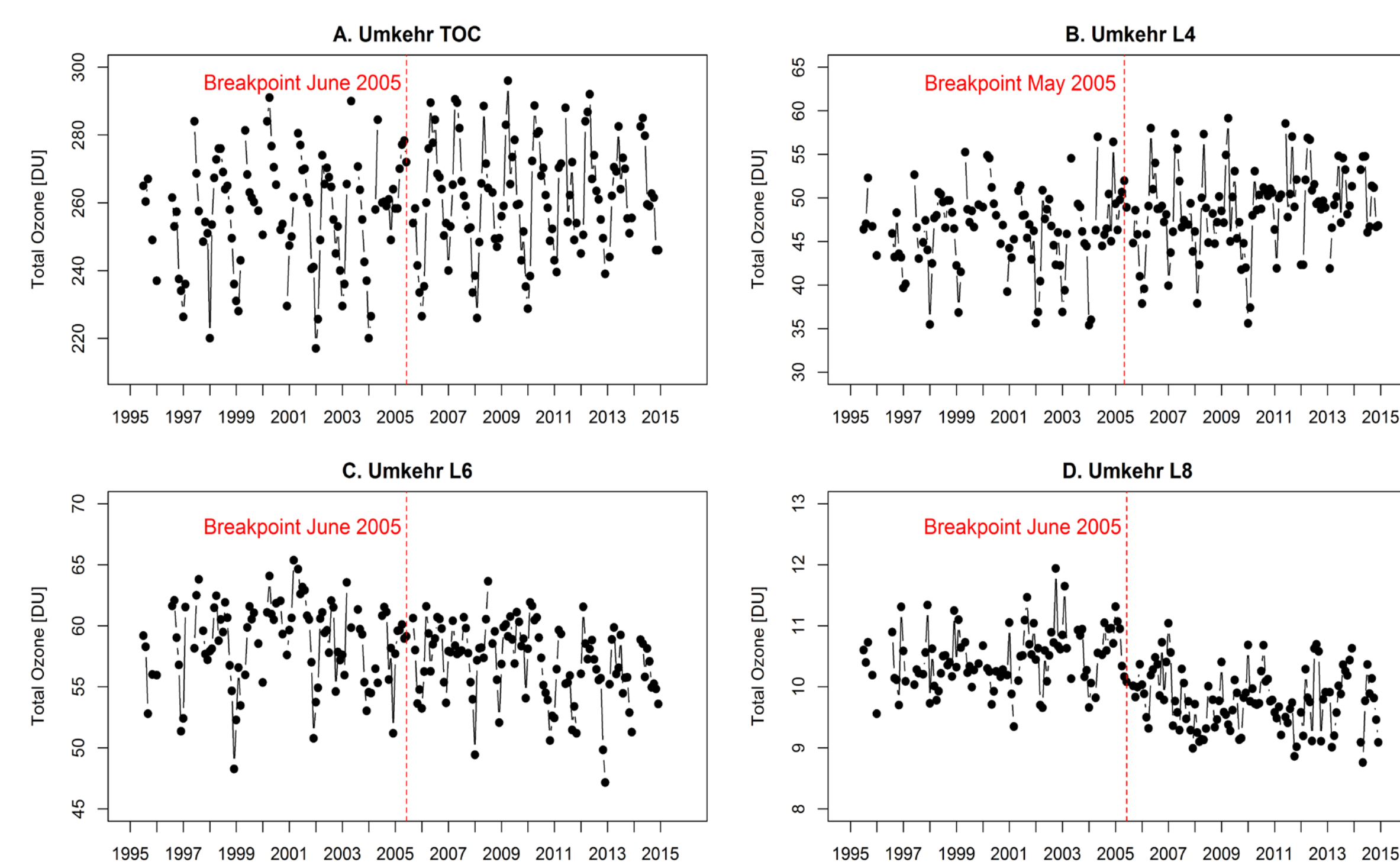
Figure 1. Umkehr monthly averaged time series of ozone in several Umkehr layers. Vertical dashed red line indicates the date of the break in time series.

Data homogenization

Given the identified break in the Umkehr record we apply a two step correction procedure to adjust/homogenize the Umkehr record with Microwave and Sonde data. The adjustment aims to preserve the observed relative (%) offset between individual time series observed during the 2000-2004 time period. To this aim we:

1) Calculate the average relative difference between Umkehr and Microwave (or Sonde) records for monthly means in 2000-2004. (C1)
2) Calculate the average relative difference between Umkehr and Microwave (or Sonde) records for monthly means in 2006-2010. (C2)
3) Adjust individual monthly mean values of Umkehr data in 2006-2014 by C2 to obtain an initially adjusted Umkehr record that matches closely with observed Microwave/Sonde data
4) Adjust the data set obtained in (3) by C1 to obtain an adjusted Umkehr time series that preserves the offset observed among instruments in 2000-2004.
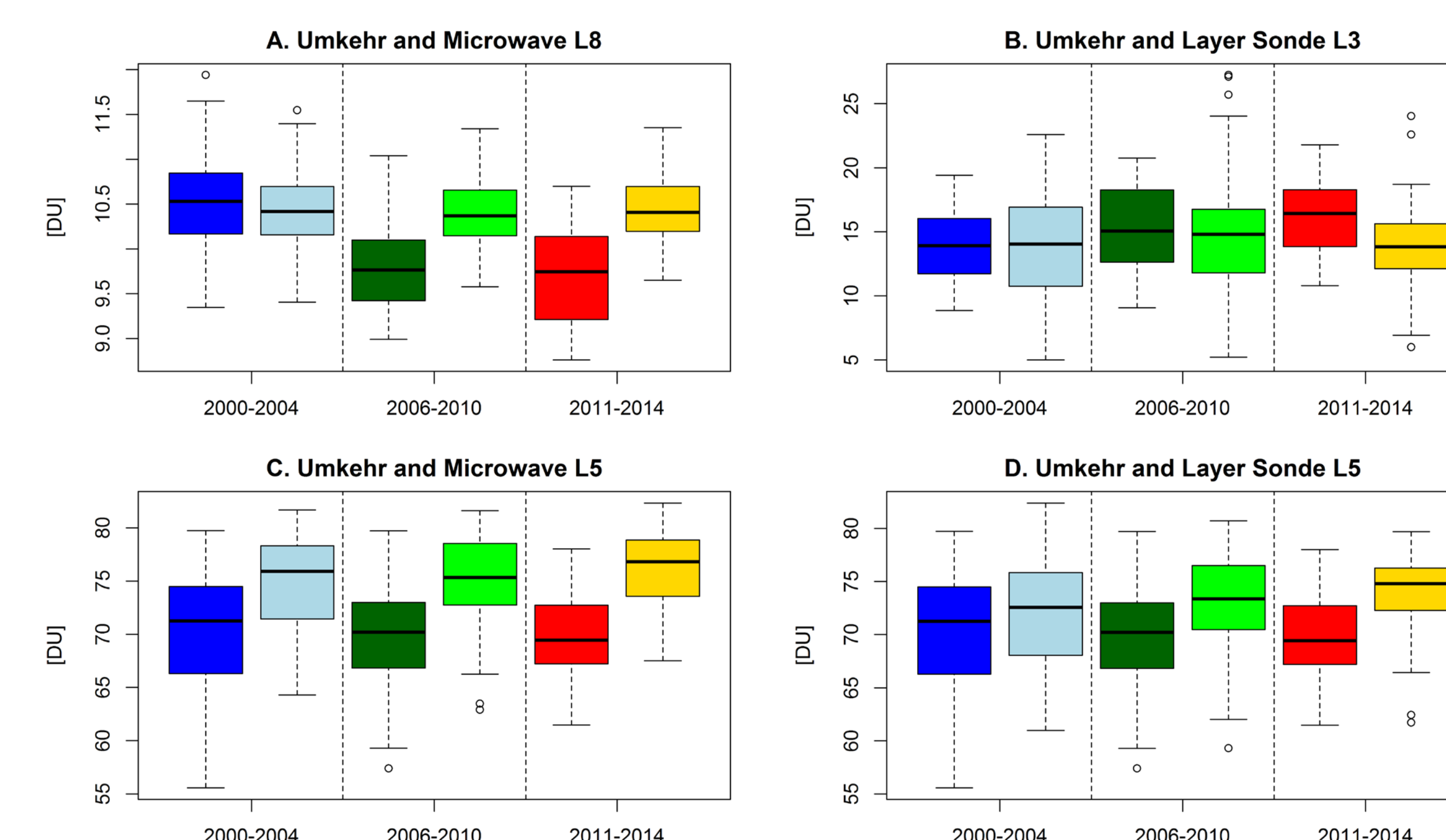

Figure 2. Detection of shifts in Umkehr ozone data. The median levels and interannual ozone variability (box and whiskers) are shown in each panel for three periods: 2000-2004 (left), 2006-2010 (middle), and 2011-2014 (right). The MLO Umkehr record (dark blue, dark green, red) is compared to Hilo ozonesonde or MLO Microwave radiometer data (light blue, light green, orange). Panels A and C show comparisons of Umkehr ozone against MW data in layers 8 and 5. Panels B and D show Umkehr ozone comparisons relative to ozonesonds data in Umkehr layers 3 and 5.

Both MW and ozonesonde comparisons in layer 5 show similar results.

Time series decomposition based on LOESS (STL)

The Seasonal Trend decomposition of the time series is based on LOESS (Locally wEighted Scatterplot Smoothing) and derives a seasonality, trend and residual component from the observational records (Cleveland et al, 1990, Rieder et al., 2010). Here we apply STL to compare trend components of Umkehr (black), Microwave (blue) and ozonsonde (green) observations after the year 2000 (Figure 4). The curve provides the STL trend component from adjusted Umkehr data at the respective levels, which by design of our homogenization method matches instrument offsets observed in 2000-2004.
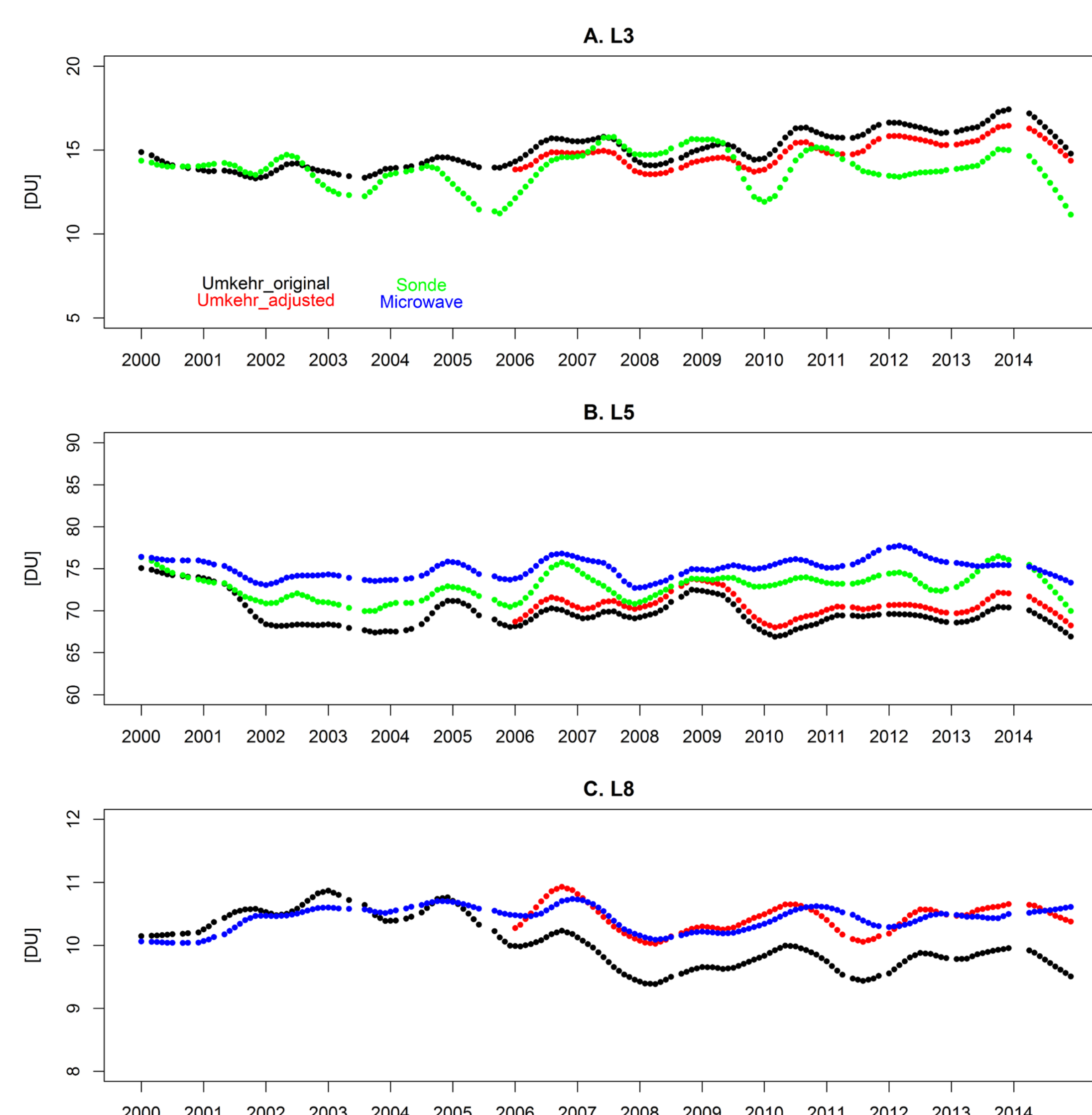

Figure 7. STL trend components in 2000-2014 for Umkehr layers 3 (125-63 hPa, 5 (32-16 hPa), and 8 (4-2 hPa) and total column ozone. Original (black) and adjusted (red, as of 2006) data are fitted as time series of monthly averages. STL components for co-sampled ozonesonde (green) and MW (blue) time series are also shown for reference.
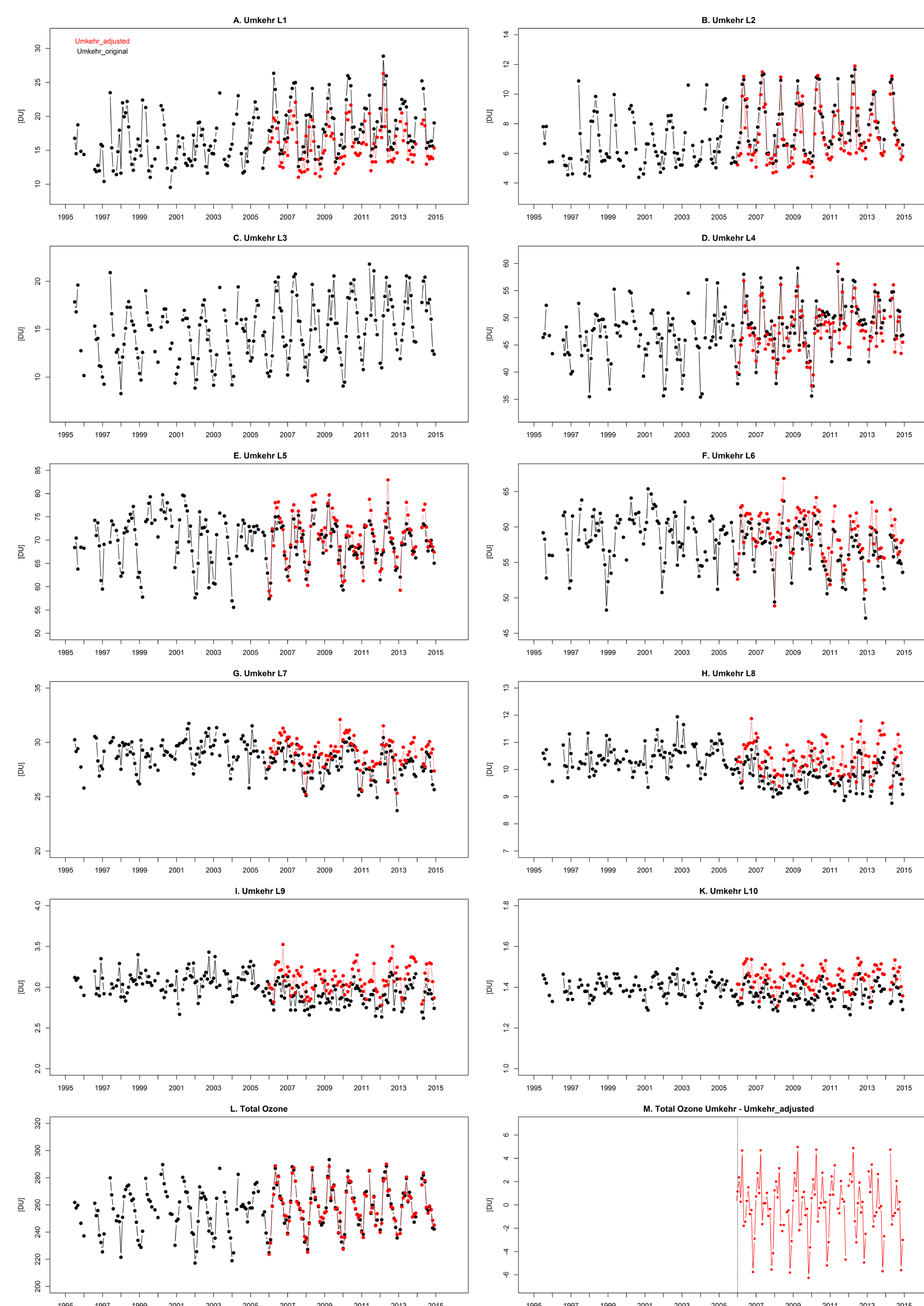

Figure 3. Panels for Umkehr layers 1 through 8 show monthly averaged time series of ozone time series before (black) and after correction (red). The bottom two panels show total ozone from the original (black) and adjusted (red) Umkehr record (left) and the difference between original and adjusted monthly mean total ozone (right). Adjustments range between -6.3 DU and + 4.9 DU. The largest adjustments are found for April (positive) and November (negative)."

Summary of Results

1) A shift (break) in the Dobson #076 Umkehr ozone profile record has been identified after 2005 instrument repairs.
2) The level of the shift was verified against co-located Microwave radiometer ozone time-series available for comparisons in Umkehr layers 5-10 (above 32 hPa pressure level). In addition, ozone-sonde profiles from Hilo were used to determine ozone shifts in the bottom 6 layers (below 8 hPa).
3) A two-step procedure was developed to homogenize the Umkehr time series.
4) Results of the shift corrections in Umkehr layer 5 are consistent between MW and ozone-sonde data.
5) STL analyses show changes in the trend components in all Umkehr layers after 2005 as the result of homogenization. Impacts are largest in layers 7 and 8.