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Ozone recovery as detected in NOAA Ground-Based and Satellite Ozone Measurements

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1. Introduction.

The 1987 Montreal Protocol and its 1990 amendments to the US Clean Air Act require NASA and NOAA to monitor ozone and the reduction of ozone depleting substances (ODS). The 2018 WMO/UNEP Ozone Assessment and the SPARC/WMO/IO3C Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) special report indicate that the extent of ozone recovery is geographically diverse. These studies focused on Multi-linear Regression analyses (MLR) optimized for broad latitudinal bands. NOAA's ground-based instruments (GB) include Dobson total column ozone observations, vertical distribution of ozone from Dobson Umkehr and ozonesonde profiling. Additionally NOAA's homogenized satellite record from SBUV, SBUV/2 and OMPS provide information on ozone vertical distribution globally allowing the study of large scale ozone variability. The meteorological models MERRA2, GFS and the GMI chemistry transport models allow the exploration of diurnal variability in the satellite records and the tracking of air parcels relevant to the representativeness of the GB data. This study aims to revise historical WMO GAW and NOAA Umkehr records with improved stray light corrections. Overpass data are generated for the NOAA GB sites using the combination techniques of the NOAA Cohesive (SBUV COH) zonal ozone product. This project is aimed at comparing ozone variability and trend in regional (i.e. GB station, satellite overpass) and zonally averaged data.

2. N-value correction optimized using the M2GMI simulation.

Dobson Umkehr measurements are made by tracking relative differences in zenith sky intensities from two UV wavelengths between the horizon and 70-degrees Solar Zenith Angle (SZA). The ratio of the zenith sky intensities are converted to N-values, $100*\log_{10}(I_{332.4}/I_{310.5})$. Large differences between the observed and modeled N-values are found in the volcanic eruption periods (1982-1984, 1991-1994). Modeled corrections are based on M2GMI model ozone profile data matched to the Umkehr observations.

Umkehr Retrievals (Operational) and Stray light corrections

Dobson Umkehr measurements are made using information from the C wavelength pair (311.5, 332.4 nm). The algorithm for ozone retrieval, UMK04 (Petropavlovskikh et al., 2005, is used for operational data processing (WinDobson).

The operational Umkehr ozone profiles are biased relative to other ozone observations, i.e. SBUV record (Petropavlovskikh et al., 2011). The updated algorithm takes into account the standardized stray light correction (dNslc):

$$N_{slc} = N(w, Z) + dNslc(O_3, P, Z)$$

where dN_{slc} is estimated from look-up tables that are dependent on latitude, altitude (p), solar zenith angle (Z), and total ozone (O_3).

Optimization with the M2GMI model

Re-alignment of Dobson optical system (wedge) and instrument replacements can create step changes in Umkehr data. The optimization process involves the use of empirical corrections to reduce differences between observed and simulated Umkehr data, and serves to homogenize the time series (Fig.1 and 2). The Umkehr simulations are based on ozone profiles from the independent datasets, i.e. NDACC ozonesonde, lidar, and MW, SBUV/OMPS COH record, and GMI CTM (Strahan et al, 2016) and M2GMI models (Wargan et al, 2018).

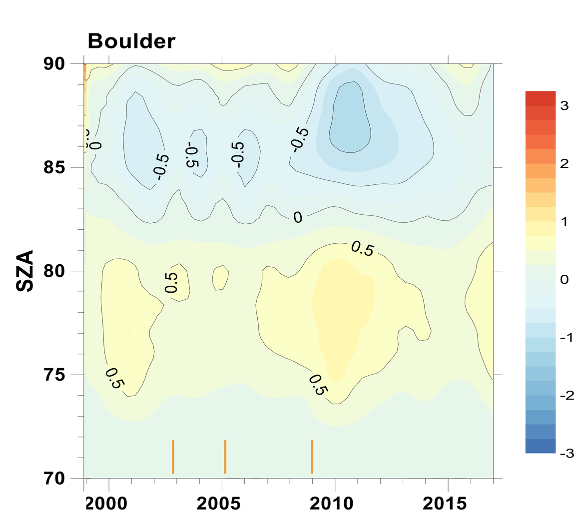

Figure 1. Optimized correction of Umkehr N value for Boulder (BDR, 40 N, 105 W) as function of time and SZA. The difference between observed N-values and those simulated based on M2GMI ozone porifles is shown as a function of time (monthly mean) and SZA.

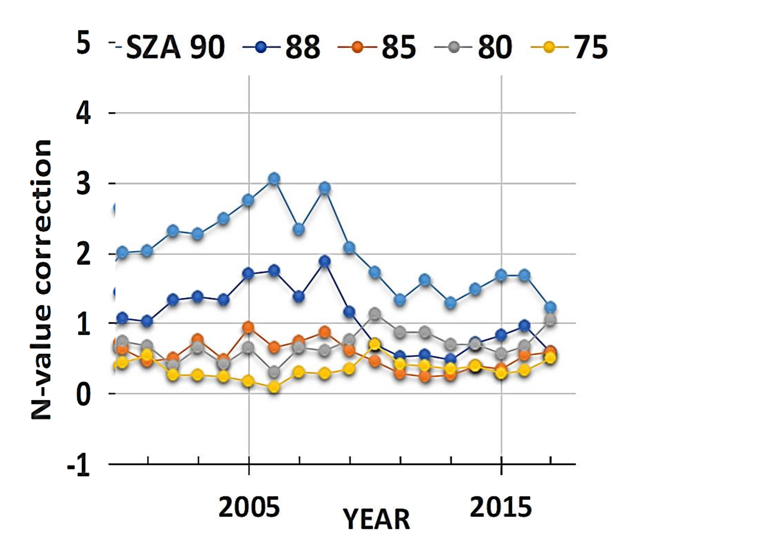

Figure 2. Optimized correction of Umkehr N value for Boulder is shown as function of time at several solar zenith angles (SZA). Umkehr empirical correction for volcanic aerosol period shows strong dependence on SZA

2. SBUV COH time series and overpass data.

The Solar Backscatter Ultraviolet (SBUV and SBUV/2) instrument onboard NASA and NOAA satellites have provided 40 years of continuous ozone profile data (1978 – present). OMPS on Suomi National Polar-orbiting Partnership (S-NPP), NOAA-20 and successor satellites continues this series using a retrieval algorithm similar to SBUV. The SBUV&OMPS COH dataset combines data from these instruments removing small residual differences by examination of overlap periods. The resulting profile product is a set of daily or monthly zonal means publically available at ftp.cpc.ncep.noaa.gov/SBUV_CDR. The corrections to remove the instrumental differences are determined by an examination of the overlap period for each zone and level (or layer). An overpass SBUV&OMPS COH has been produced by applying the adjustments for the relevant zone to SBUV and OMPS profiles extracted within proximity to the ground measurement site. For this study, we collect satellite profiles within 2° latitude and 20° longitude of the site.

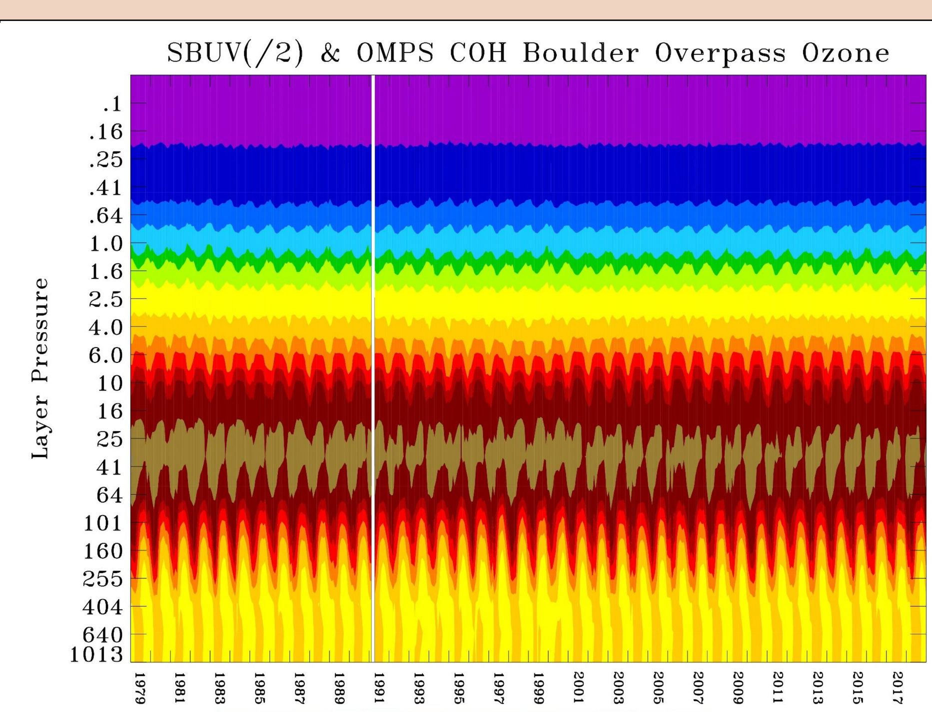

Figure 3. A contour plot of the COH ozone profile time series selected for the overpass criteria: a monthly average of all data within the +-2 degree latitude, and +- 20 degree longitude, centered at Boulder, CO station (40 N, 105 W).

3. Satellite and model comparisons.

Validation of optimized Umkehr RT.

The optimized Umkehr ozone processing includes multiple N-value adjustments for each of instrument calibration periods as in Figure 4 where arrows at the bottom indicate dates of the applied corrections and during volcanic eruptions shown as yellow colored periods.

The changes in the Umkehr Boulder record are assessed through comparisons to M2GMI, GMI CTM and several satellite datasets (Aura MLS, aggregated SBUV series and JPSS OMPS V8PRO).

Figure 4 also shows comparisons of optimized Umkehr data and the M2GMI model where seasonal to sub-seasonal biases are +/-2 % and the long-term mean bias is 0%. Figure 5 shows comparisons with other datasets.

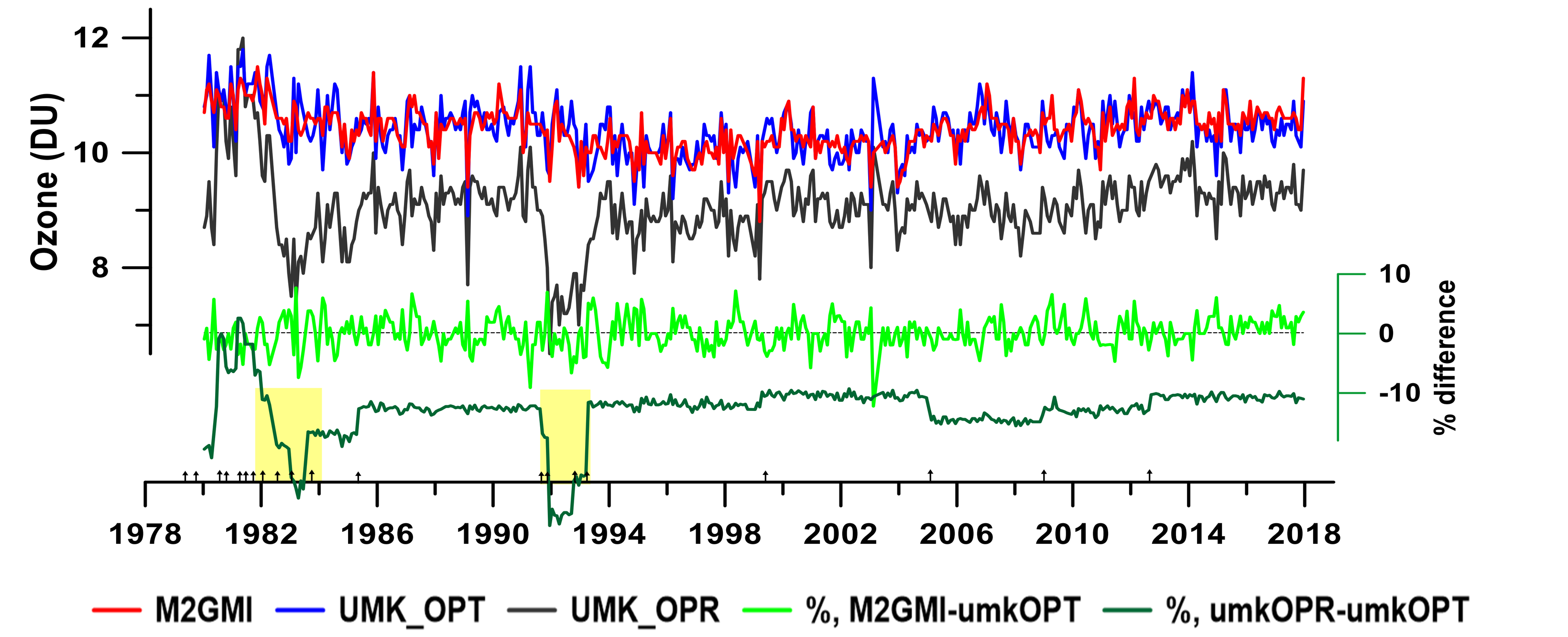

Figure 4. The time series of ozone at Boulder in Umkehr layer 8 (2-4 hPa). Operational Umkehr (black), Optimized Umkehr (blue) and M2GMI (red) data are shown as monthly averages. Difference between Optimized and Operational Umkehr data is shown as a dark green line. The percent difference between optimized Umkehr and M2GMI model is shown as a light green line. The arrows at the bottom indicate dates of Dobson calibrations and instrument replacements.

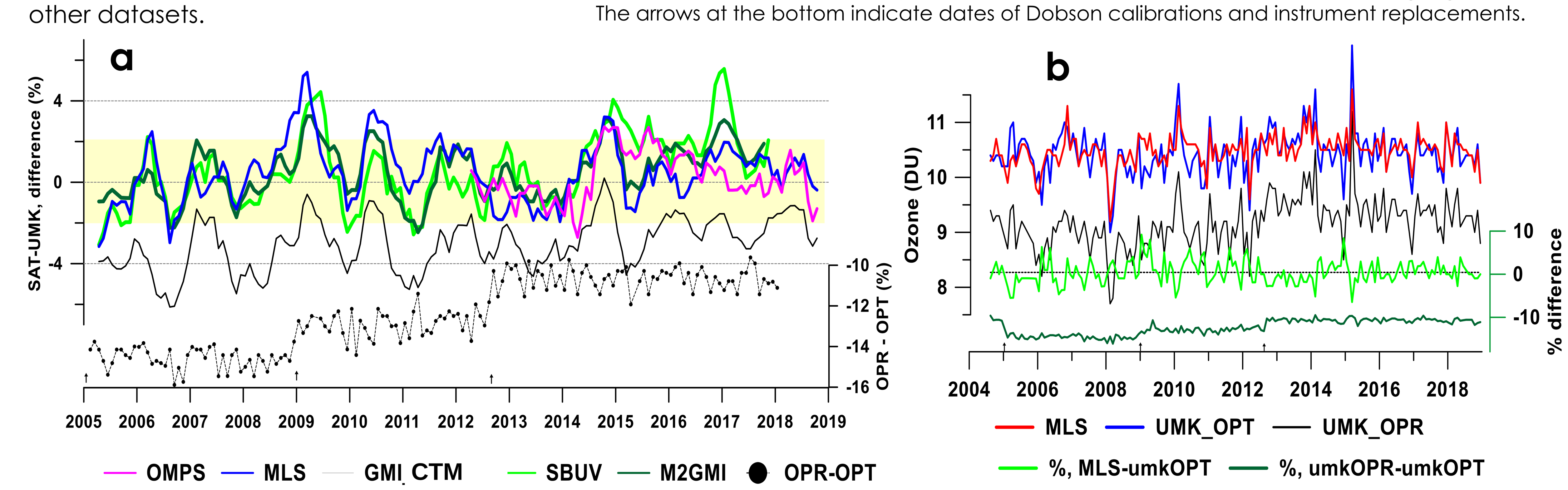

Figure 5. a) The 5-month smoothed difference of optimized Umkehr and measured/modeled ozone over Boulder, Umkehr layer 8 (2-4 hPa). The difference is calculated relative to the optimized Umkehr data. The data sets include: M2GMI simulated ozone (dark green), GMI CTM (black), Aura MLS (blue), SBUV aggregated (light green) and JPSS S-NPP OMPS (pink). The difference between optimized (UMK_OPT) and operational (UMK_OPR) data is shown with dotted-dashed black line. **b)** similar to **a)**, but focused on Aura MLS 2004-2018 comparisons with operational and optimized Umkehr data.

4. Summary and Discussion

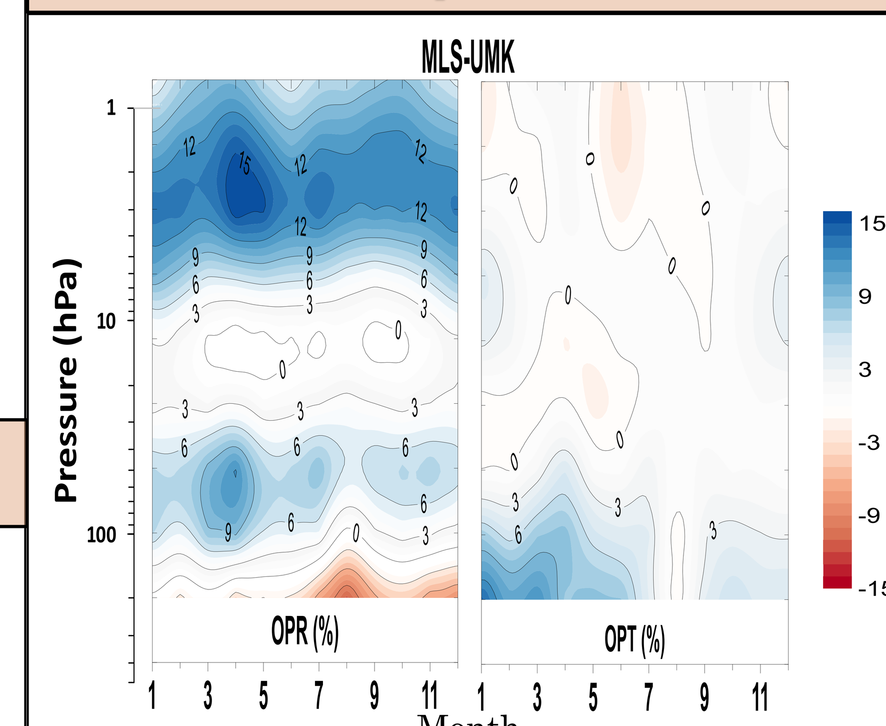

Figure 6. Seasonal biases between the Umkehr measurements in Boulder and the Aura MLS satellite overpass record. Two panels show results for Umkehr retrievals: operational (left), Optimized correction (right). The biases are significantly reduced after the Optimized Umkehr correction.

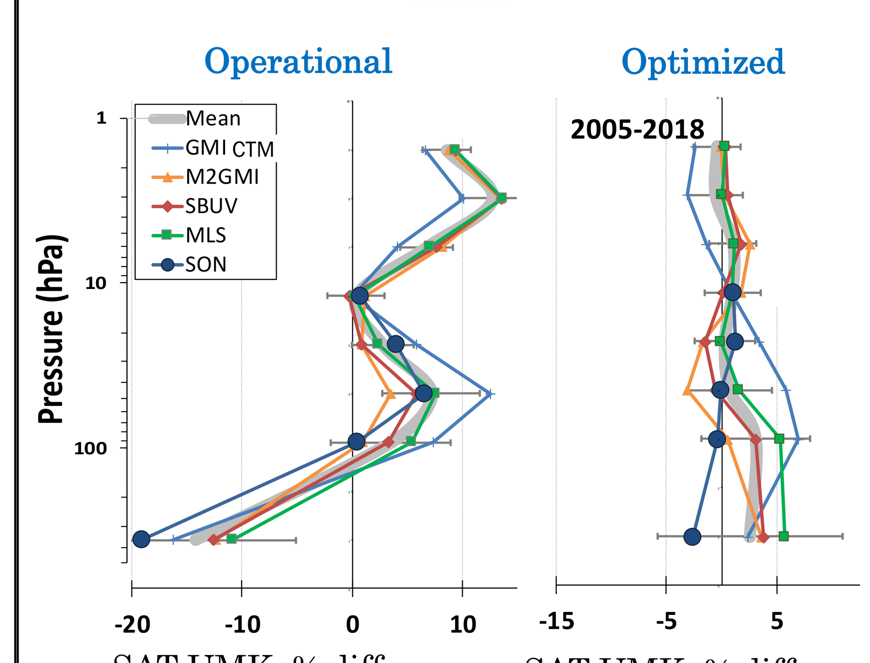

Figure 7. Biases in M2GMI, GMI CTM, SBUV, Aura MLS, and ozonesondes are shown with respect to the operational (left panel) and optimized (right panel) Umkehr profiles at Boulder, CO. Averages are done for 2005-2018. The mean bias is shown with light grey thick line.

Findings

- Umkehr mean bias is reduced after optimization (Figs. 6 & 7).
- Seasonal biases are still present and need to be investigated (Fig. 6).
- Mean bias of 5 % is found between M2GMI and GMI CTM in the stratosphere (Fig. 5a & Fig. 7)
- Very similar models (MERRA2 winds and chemistry), biases in the upper stratosphere need to be understood better (Fig. 7, i.e. Stauffer et al, 2019).

Nest Steps

- Residuals of the Umkehr retrieval (delta N-value) need evaluation to verify improvement in the Umkehr measurement fit.
- Other Umkehr stations will be optimized and verified against other instruments including lidar, FTIR and Microwave.
- Examine variability of SBUV COH overpass and GB records in the context of overpass selection criteria, atmospheric dynamics, and representation in Equivalent Latitude
- Optimize the LOTUS statistical trend model for GB and overpass datasets testing the need to include additional proxies