Optimizing Umkehr Ozone Profile Retrievals

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1. Introduction.

NOAA Dobson Umkehr ozone profile records have been collected since the 1970s. Umkehr ozone profiles are used to monitor stratospheric ozone recovery predicted to occur by the 2050s. Current operational Dobson Umkehr profile algorithms produce data that have uncertainty on the order of ~ 5 % in the stratosphere. However, when large volcanic eruptions inject aerosols into the stratosphere, the errors can be as large as 70 %. In order to evaluate Umkehr records for aerosol-related and instrumental artifacts, we compare observations with a Hindcast simulation of the NASA Merra-2 Global Modeling Initiative (GMI) Replay (M2GMI, Orbe et al, 2017; Wargan et al, 2018) and Chemistry Transport Model (GMI CTM, Strahan et al, 2013, Strahan et al, 2016). The biases found between the models and observations are summarized for each Dobson calibration and volcanic eruption period, thus providing a reference tool for homogenization of the Umkehr time series and removal of volcanic aerosol errors.

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, $100 \cdot \log_{10}(I_{332.4}/I_{310.5})$. Large difference 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)

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 based on the forward (RT simulation) and inverse (Rodgers 2000) models. Independent zenith sky cloud detector data are used for screening of N-value measurements for interference of clouds in the zenith view. N-value is described as:

$$N(w,Z) = 100 * log_{10}\{\frac{I_{(w,z,Ls)}}{I_{(w,z,Ll)}} / \frac{F_{(w,z,Ls)}}{F_{(w,z,Ll)}}\} + k$$

Where I/F is zenith-sky intensity/Solar flux measured at 2 spectral channels.

Stray light correction (Standardized)

The operational Umkehr ozone profiles are biased relative to other ozone observations, i.e. satellite (Petropavlovskikh et al., 2011). The updated algorithm takes into account the standardized stray light correction (d*Nslc*).

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

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) (Figure 1).

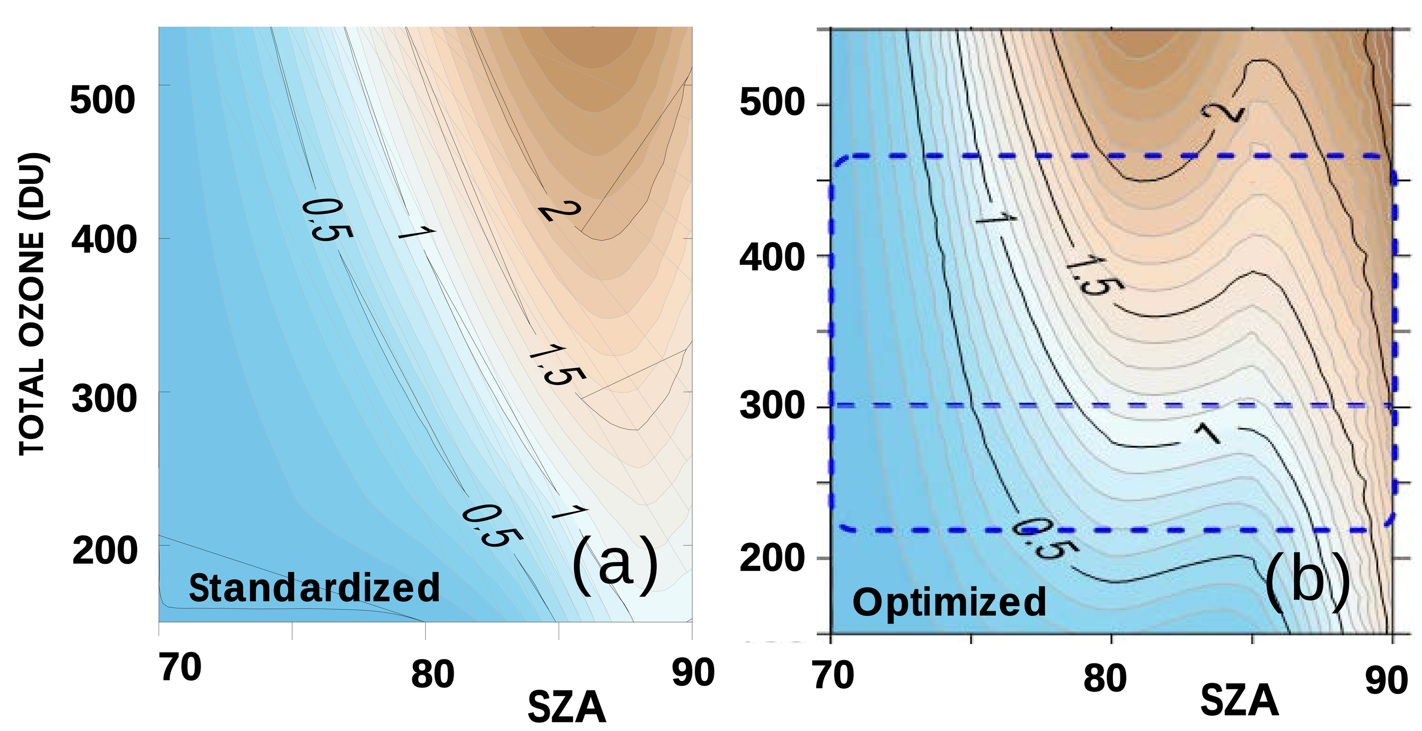


Figure 1. Stray light correction (N-value) is shown as a function of solar zenith angle. (a) Standardized stray light correction, (b) Optimized stray light correction. The dashed lines shows range of total ozone measurements in Boulder.

Optimization with the M2GMI model

Calibration of Dobson instruments and instrument replacements can create bias in Umkehr observations due to changes in the optical characterization of the instrument. Additional atmospheric scattering due to volcanic aerosols (Fig. 2) is not accounted for in present Umkehr operational data processing and also results in biases.

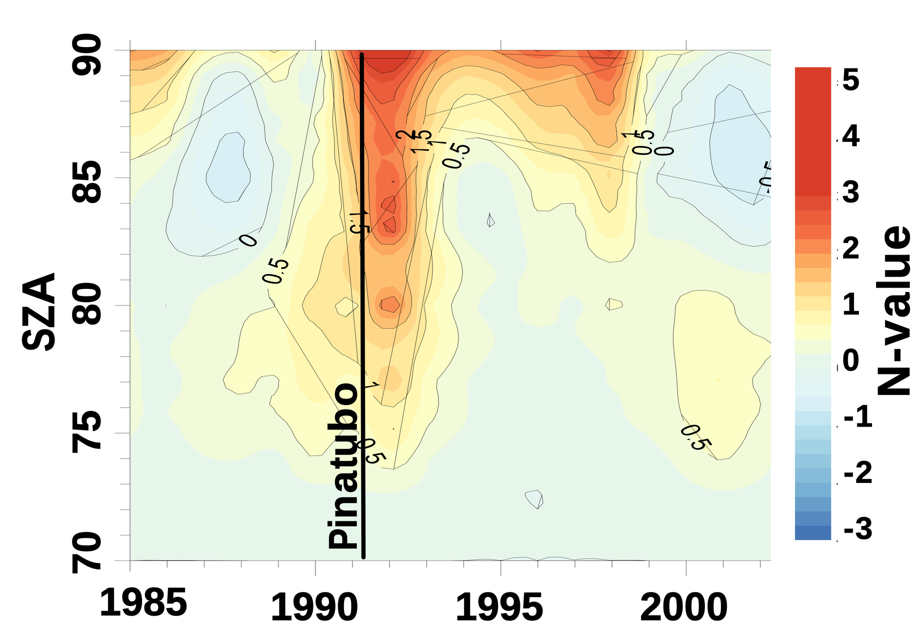


Figure 2. Optimized correction of Umkehr N value for Boulder (BDR, 40 N, 105 W). The difference between M2GMI simulated and observed N values is shown as a function of time (monthly mean) and SZA. The Umkehr empirical correction for the volcanic aerosol period (1991-1993) shows strong dependence on SZA.

Optimization involves the use of empirical corrections to reduce differences between observed and simulated Umkehr data, and serves to homogenize time series (Fig.3). The Umkehr simulations are based on ozone profiles from the independent datasets, i.e. M2GMI. Ozone profile data from the M2GMI are selected for the Boulder location and matched to the date of Umkehr observations. Data are available from 1980 to 2017.

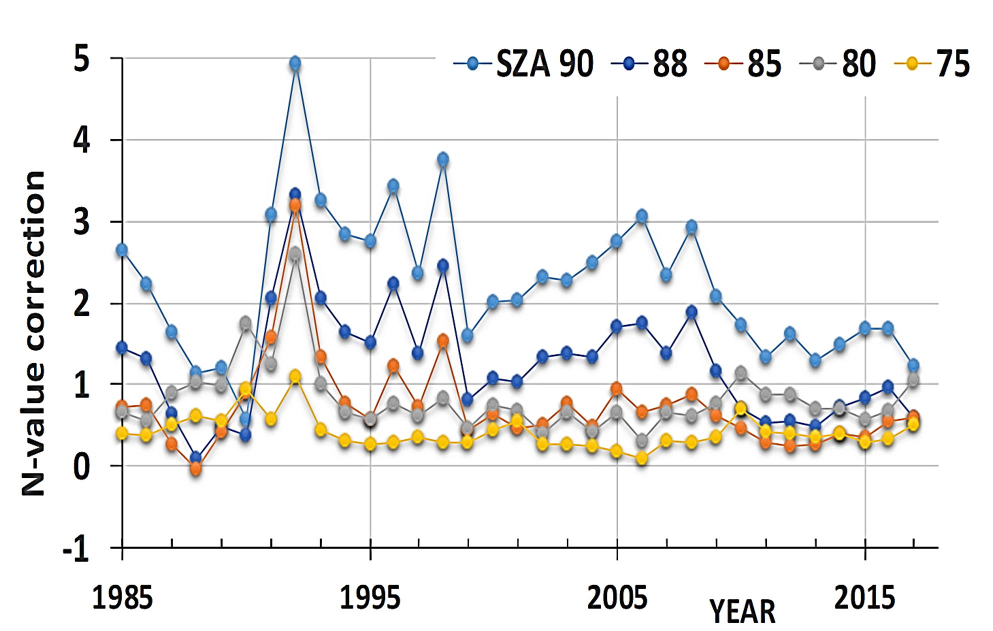


Figure 3. Optimized correction of Umkehr N value for Boulder is shown as function of time at several solar zenith angles (SZA). Umkehr empirical correction for volcanic aerosol period shows strong dependence on SZA

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 (Audra 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.

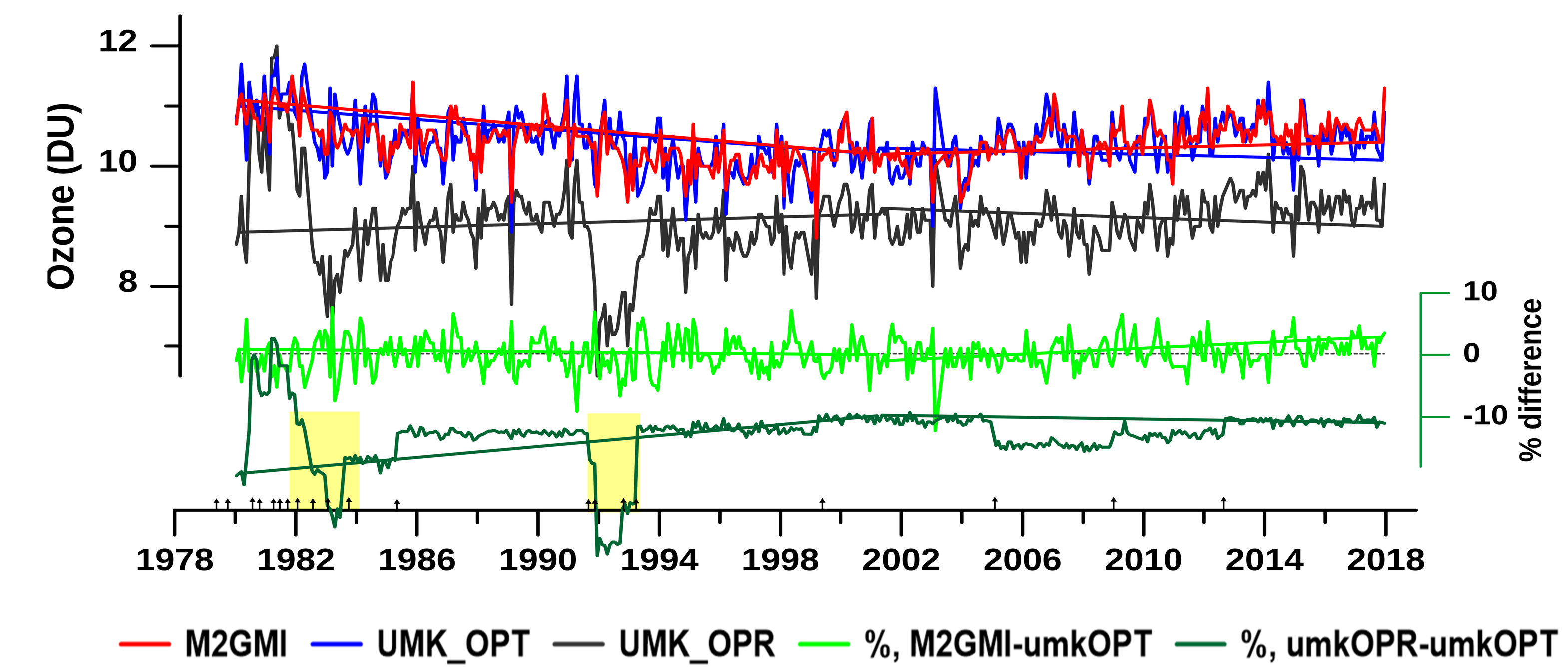


Figure 4. The time series of ozone at Boulder in Umkehr layer 8 (2-4 hPa). Operational Umkehr (black), Optimized Umkehr (blue) and M2GMI (red) data are shown as monthly averages. Difference between Optimized and Operational Umkehr data is shown as a dark green line. The percent difference between optimized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

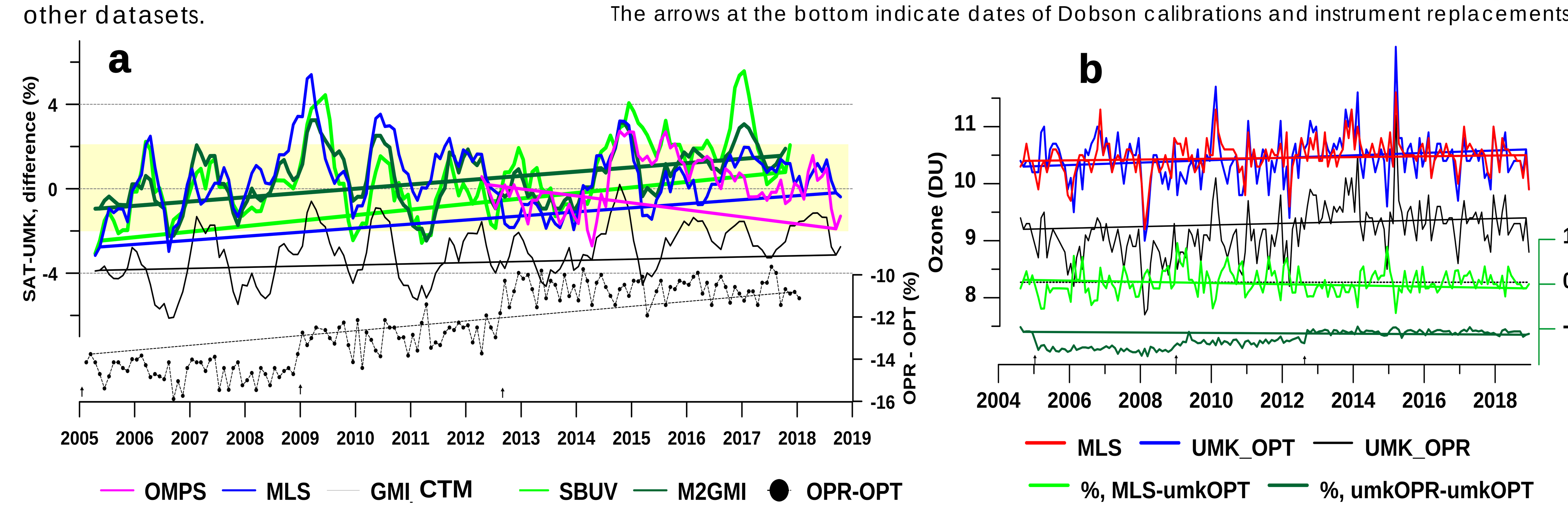


Figure 5. a) The 5-month smoothed difference of optimized Umkehr and measured/modeled ozone over Boulder, Umkehr layer 8 (2-4 hPa). The difference is calculated relative to the optimized Umkehr data. The data sets include: M2GMI simulated ozone (dark green), GMI CTM (black), Aura MLS (blue), SBUV aggregated (light green) and JPSS S-NPP OMPS (pink). The difference between optimized (UMK_OPT) and operational Umkehr (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

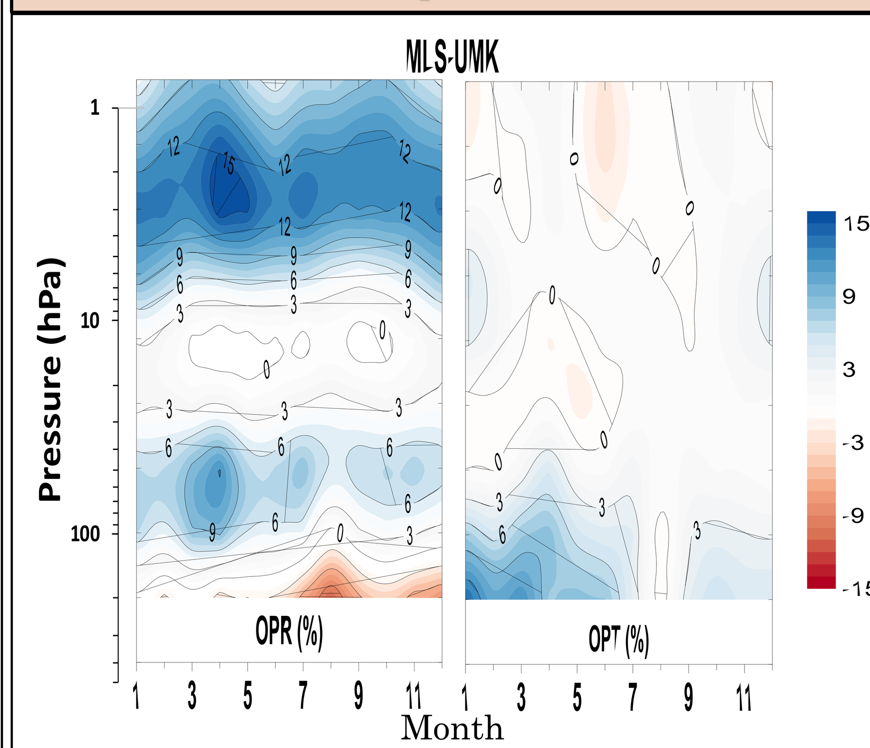
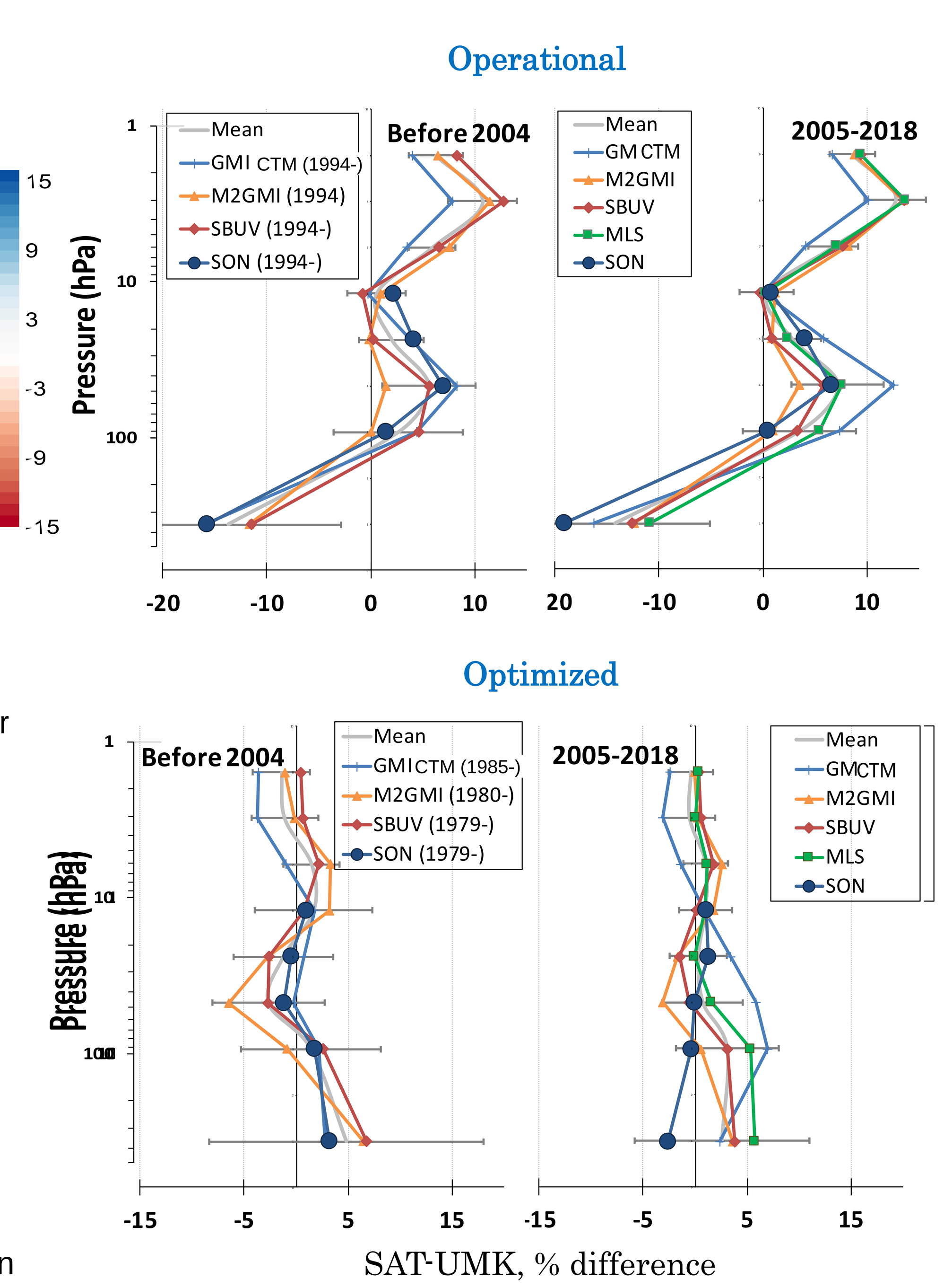


Figure 6. Seasonal biases between the Umkehr measurements in Boulder and the Aura MLS satellite overpass record. Two panels show results for Umkehr retrievals: operational (left), Optimized correction (right). The biases are significantly reduced after the Optimized Umkehr correction.

Figure 7 (to the right). Top: bias in operational Umkehr profiles relative to M2GMI, GMI CTM, aggregated SBUV, Aura MLS, OMPS and ozonesonde. Two period s are used for comparisons: before 2004 (left) and 2005-2018 (right). **Bottom**: the same as above, but for Optimized Umkehr. The averaged 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).
- **Next step**: residuals of the Umkehr retrieval (delta N-value) need evaluation to verify improvement in the Umkehr measurement fit.
- **Next step**: Other Umkehr stations will be optimized and verified against other instruments including lidar, FTIR and Microwave.