

Ozone X-sections in ground based measurements: Brewer at Mauna Loa

Peter Kiedron and Julian Groebner

CIRES/NOAA and PMOD-WRC

Data set from MLO 1998 (J. Groebner and J.B. Kerr, JGR, 2001)

UV-Scans of sun direct beam with BR119

92 useable Langley events that had up to 83 spectral elements
in 300nm-341nm

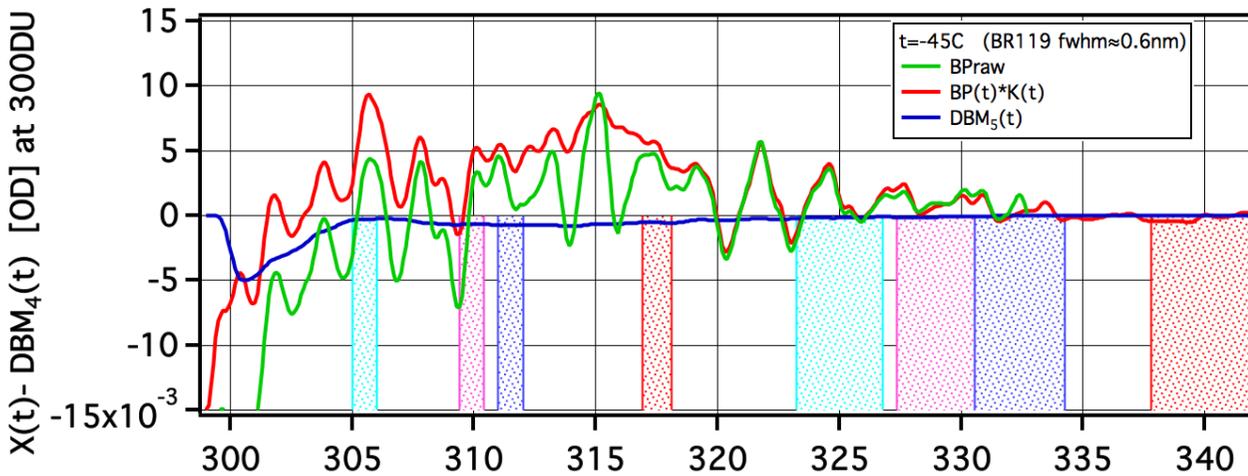
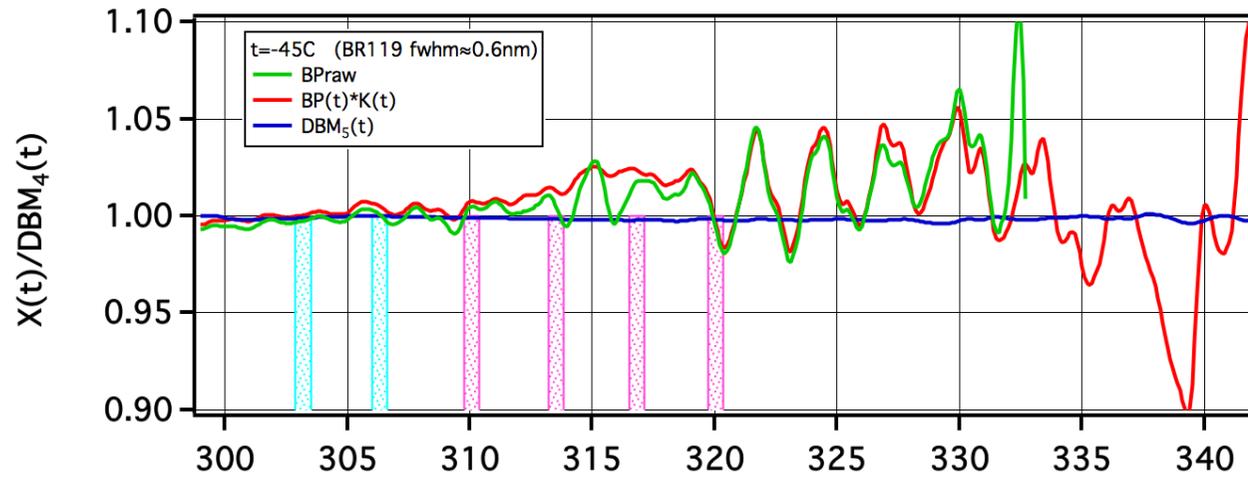
Optical depth from Langleys is used in retrievals. In principle, we do not
need to bother with airmass information

As many wavelengths as possible are used.

We look at residuals and ozone column for various X-sections

Effects of X-section error in retrievals

Four X-sections at -45°C at BR119 resolution, oversampled to 0.1nm grid: $DBM_4(t)$, $DBM_5(t)$, $BP(t)*K(t)$, BP_{raw} . $K(t)$ is Khomyr correction (1.00329 at -45°C). BP_{raw} does not use the correction. Marked channels of Brewer (on ratio) and Dobson (on difference) plots, respectively.



Ozone column retrieval from single wavelength:

$$\frac{c_R(O_3)}{c_A(O_3)} = \frac{X_A(\lambda)}{X_R(\lambda)}$$

A- actual (A= DBM_4 ?)
 R- used in retrieval

Ozone column retrieval with multi-wavelength differential method:

$$\frac{c_R(O_3)}{c_A(O_3)} = \frac{\sum w_i \cdot X_A(\lambda_i)}{\sum w_i \cdot X_R(\lambda_i)}$$

$$\sum w_i = 0$$

Dobson: $w = \{+1, -1, -1, 1\}$

Brewer: $w = \{+1, -0.5, -2.2, +1.7\}$

Retrieval from optical depth

$$\text{RMS}^2 = \min \sum_i \left(c_A(O_3) \cdot X_A(\lambda_i) - c_R(O_3) \cdot X_R(\lambda_i) - g(\lambda_i) \right)^2$$

The four “Methods”:

M1: $g(\lambda) = 0$

M2: $g(\lambda) = b$

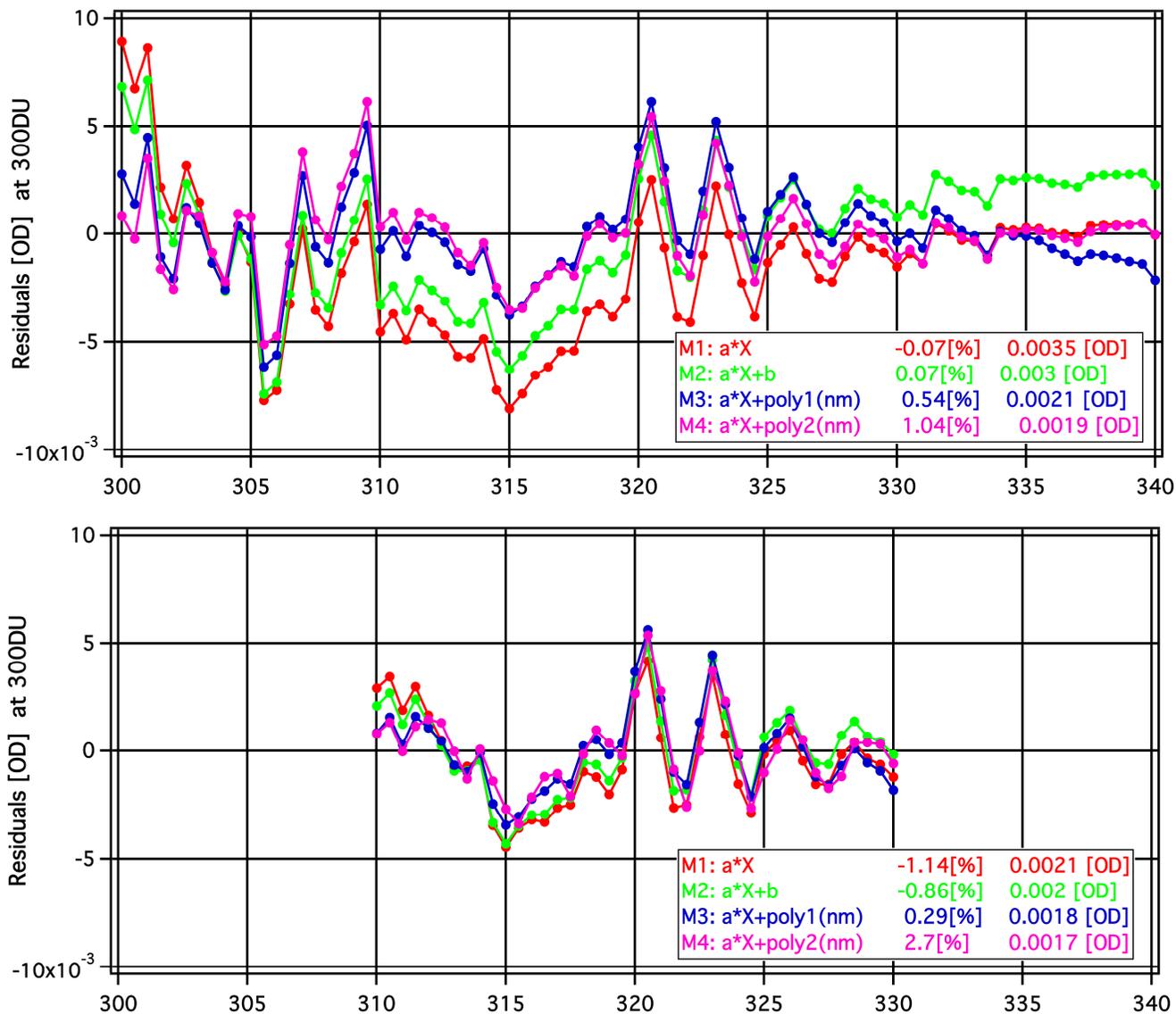
M3: $g(\lambda) = b + c \cdot \lambda$

M4: $g(\lambda) = b + c \cdot \lambda + c \cdot \lambda^2$

To test effects of g function and the fitting spectral range we simulate retrievals:

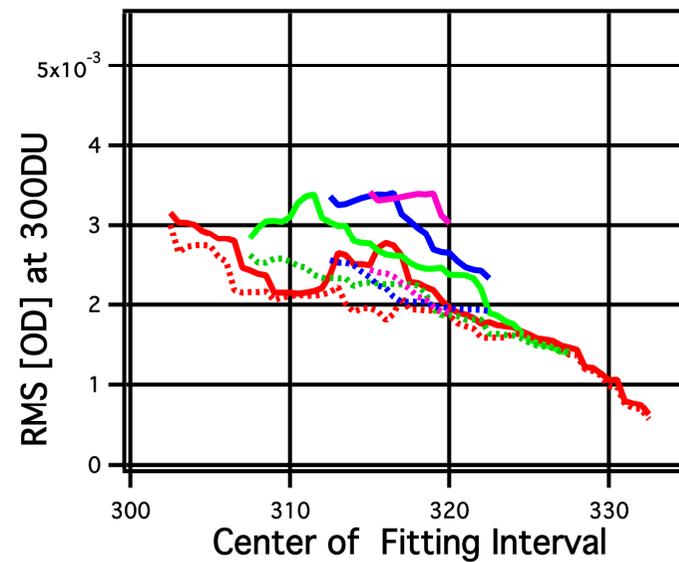
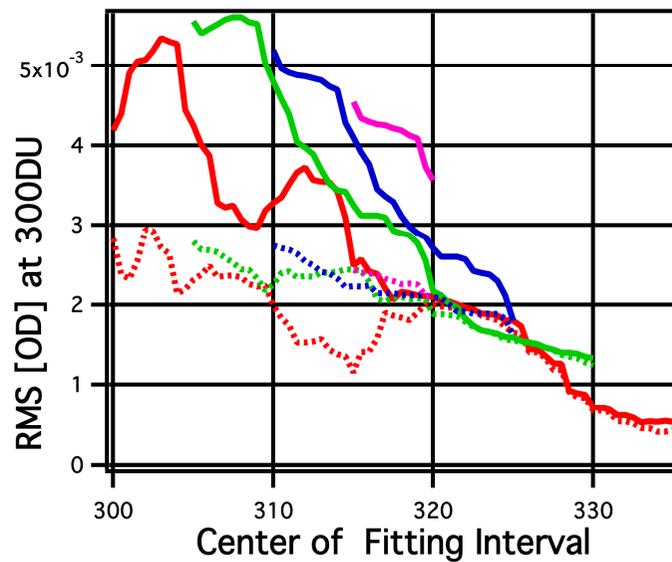
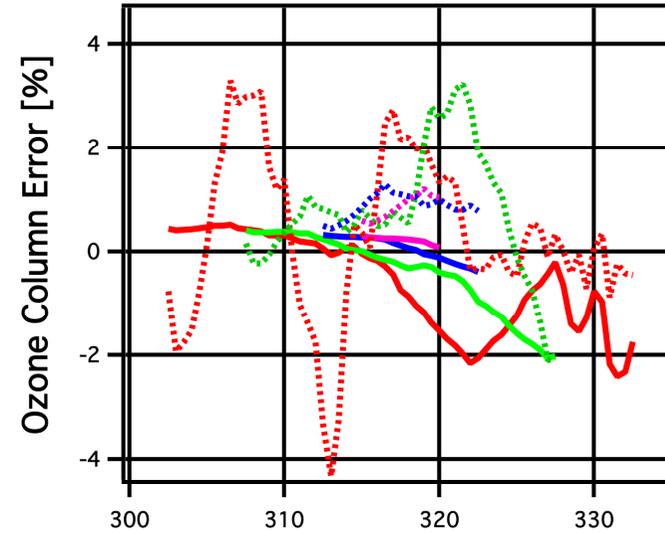
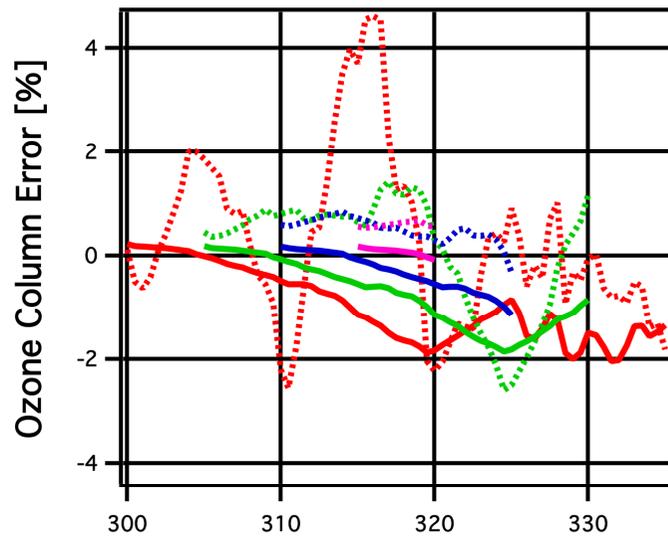
$$X_A = \text{DBM}_4(-45^\circ) \quad C_A(O_3) = 300 \text{ DU} \quad X_R = \text{BP}(-45^\circ) * K(-45^\circ)$$

Examples of residuals



Note that for M3 $\Delta c(\text{O}_3)/c(\text{O}_3) = +0.54\%$ and $+0.29\%$. Error in the same direction as in field data in this study and from RSS at Table Mt. using M3 method. Is this congruency meaningful?

Ozone column error as function of fitting interval and retrieval method



Interval: 10, 20, 30, 40 nm
Method1 and Method3 (dotted)

Interval: 15, 25, 35, 40 nm
Method2 and Method4 (dotted)

Ozone profile X-section: Is there ozone effective temperature?

Common definition of the effective temperature $T_{\text{eff}} = \langle T(z) \rangle$

Ozone profile X-section X_p :

$$X(T, \lambda) = c_0(\lambda) + c_1(\lambda)T + c_2(\lambda)T^2 \Rightarrow X_p(\lambda) = \langle X(T(z), \lambda) \rangle = c_0(\lambda) + c_1(\lambda)\langle T(z) \rangle + c_2(\lambda)\langle T^2(z) \rangle$$

$$X_p(\lambda) = c_0(\lambda) + c_1(\lambda)T_{\text{eff}} + c_2(\lambda)T_{\text{eff}}^2 + c_2(\lambda)\left[\langle T^2(z) \rangle - \langle T(z) \rangle^2\right] \Rightarrow X_p(\lambda) = X(T_{\text{eff}}, \lambda) + c_2(\lambda)\left[\langle T^2(z) \rangle - \langle T(z) \rangle^2\right]$$

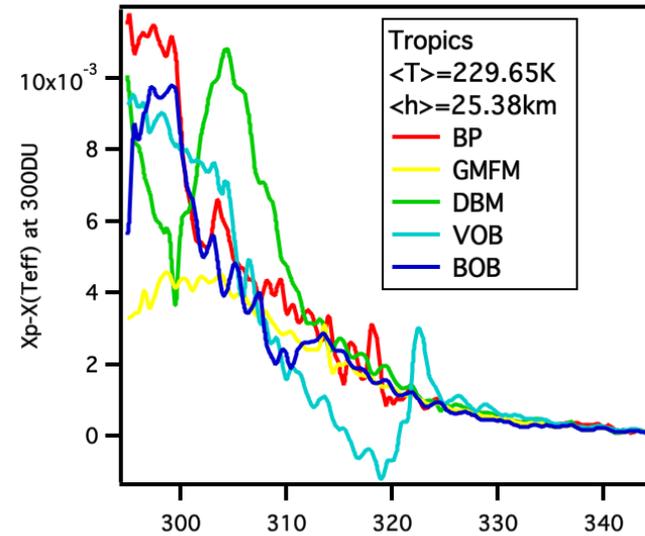
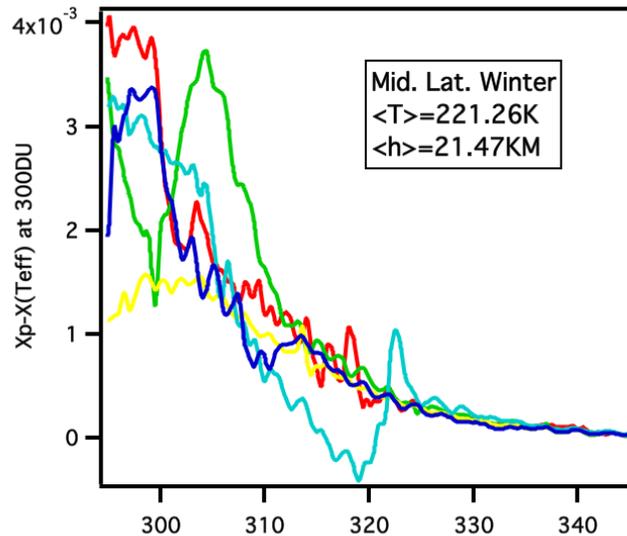
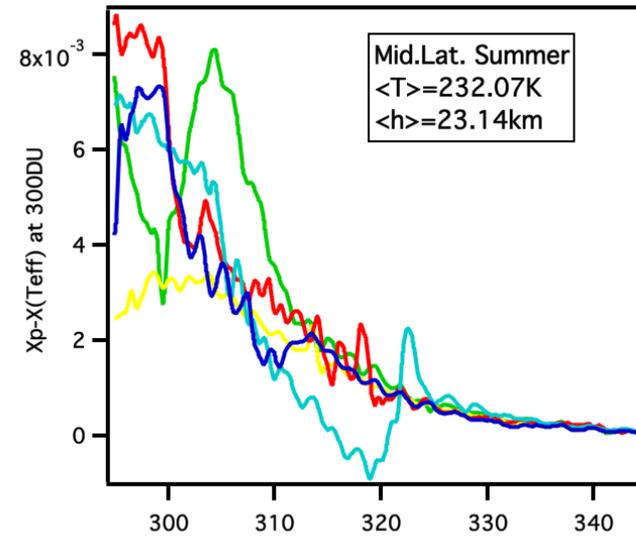
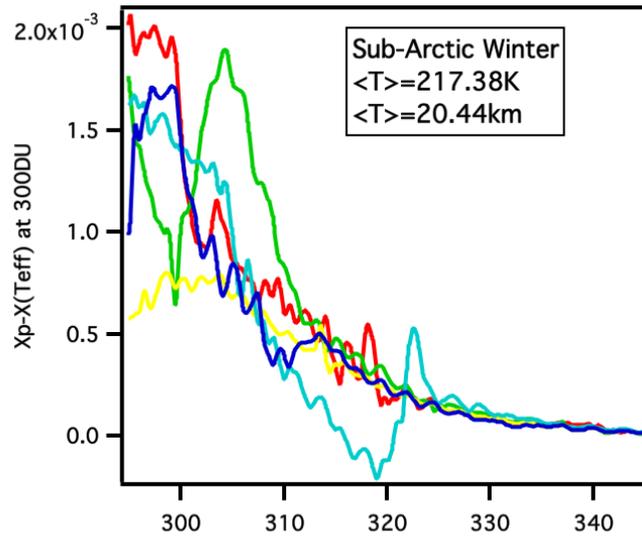
T_{eff} usually ($c_2 > 0$) underestimates ozone profile X-section: $X_p(\lambda) \geq X(T_{\text{eff}}, \lambda)$

Profile X-section temperature is strongly λ dependent: $X_p(\lambda) = X(T, \lambda) \Rightarrow T_p(\lambda)$

A good definition, but it necessitates O_3 retrieval: $\min_T \|X_p(\lambda) - X(T, \lambda)\| \Rightarrow T_{\text{eff}}(\lambda_1, \lambda_2)$

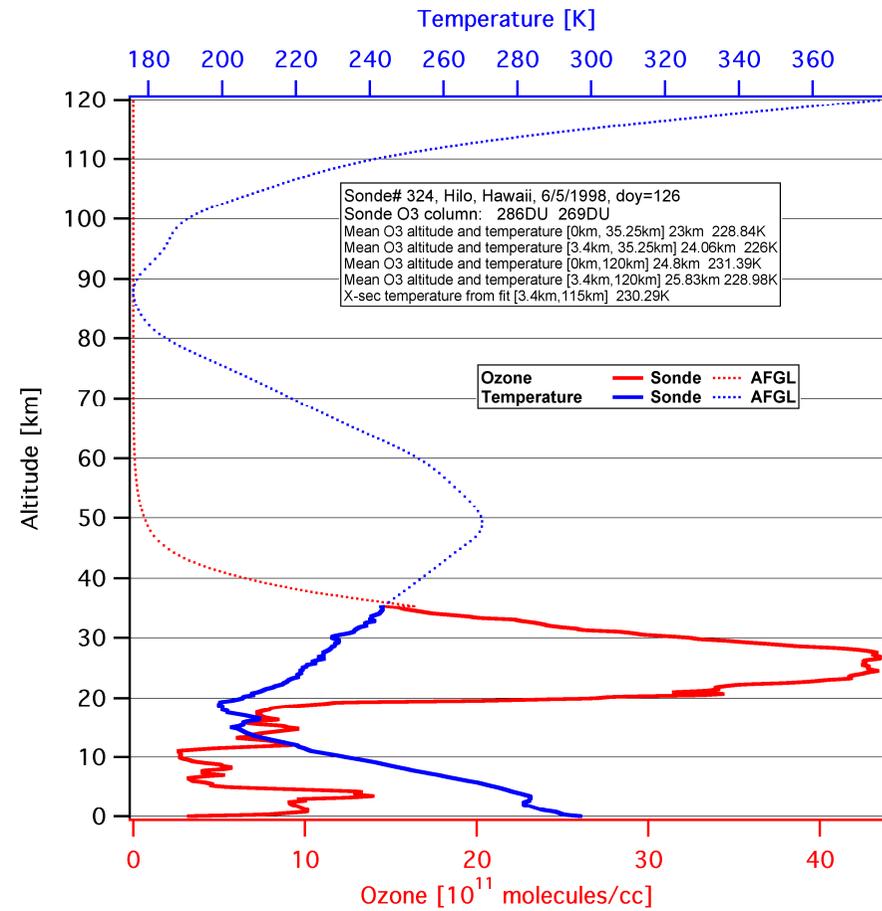
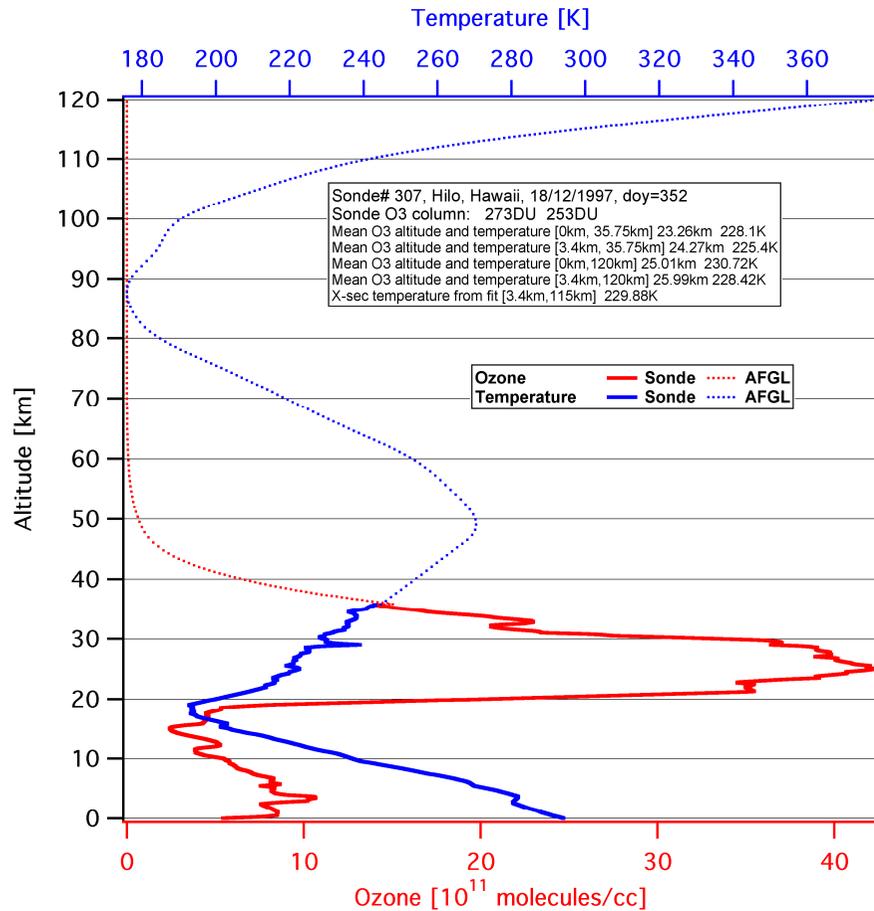
No effective temperature can substitute the actual profile X-section!

Difference between $X_p(\lambda)$ and $X(T_{\text{eff}}, \lambda)$



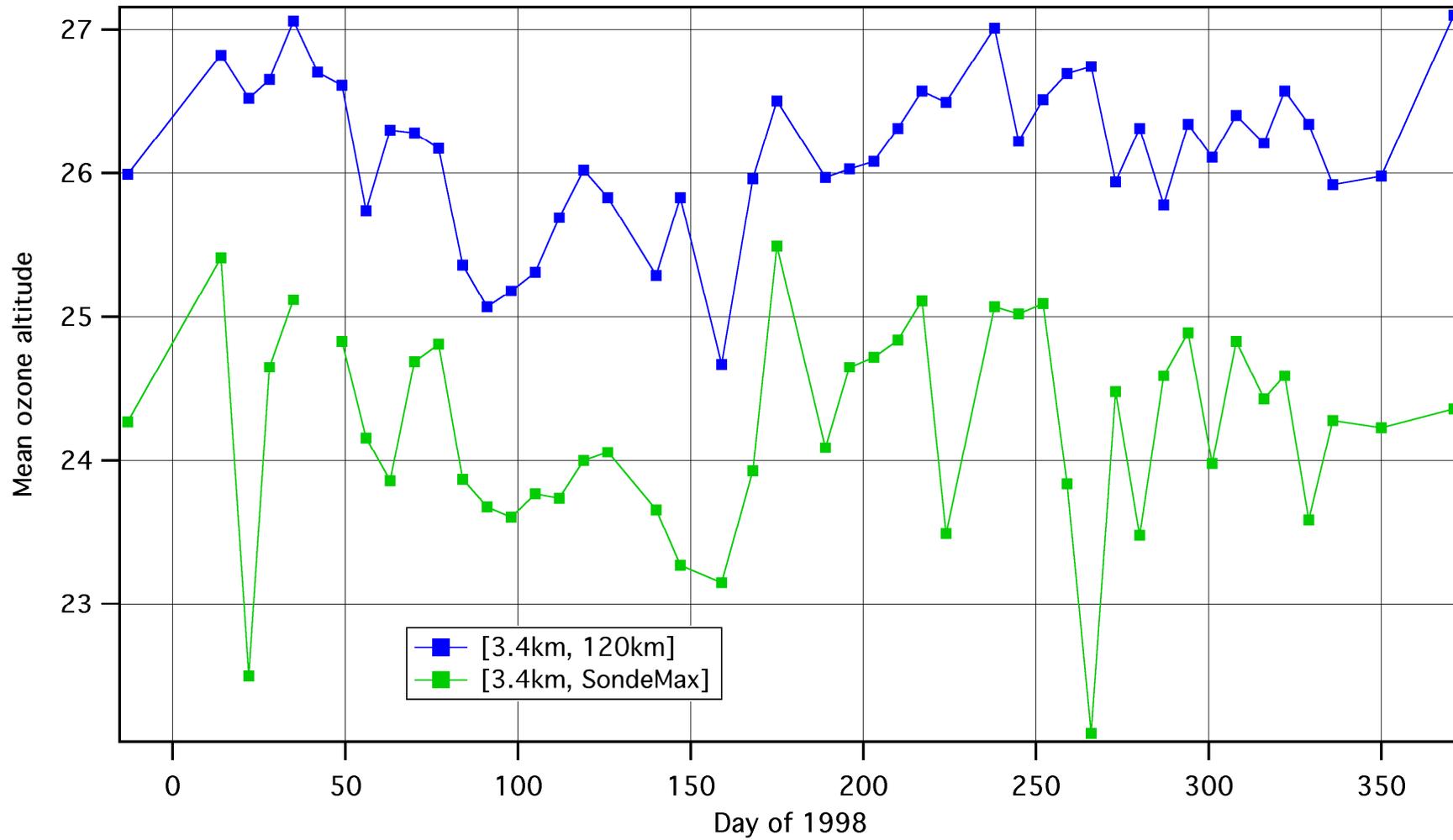
When using DBM's X_p for tropics and $X(T=229.65\text{K})$ in retrieval $\Delta c(\text{O}_3)/c(\text{O}_3)$ changes between -0.4% to +0.7% depending on spectral range and method.

Data from 44 Sonde Launches in Hilo, HI, 1998



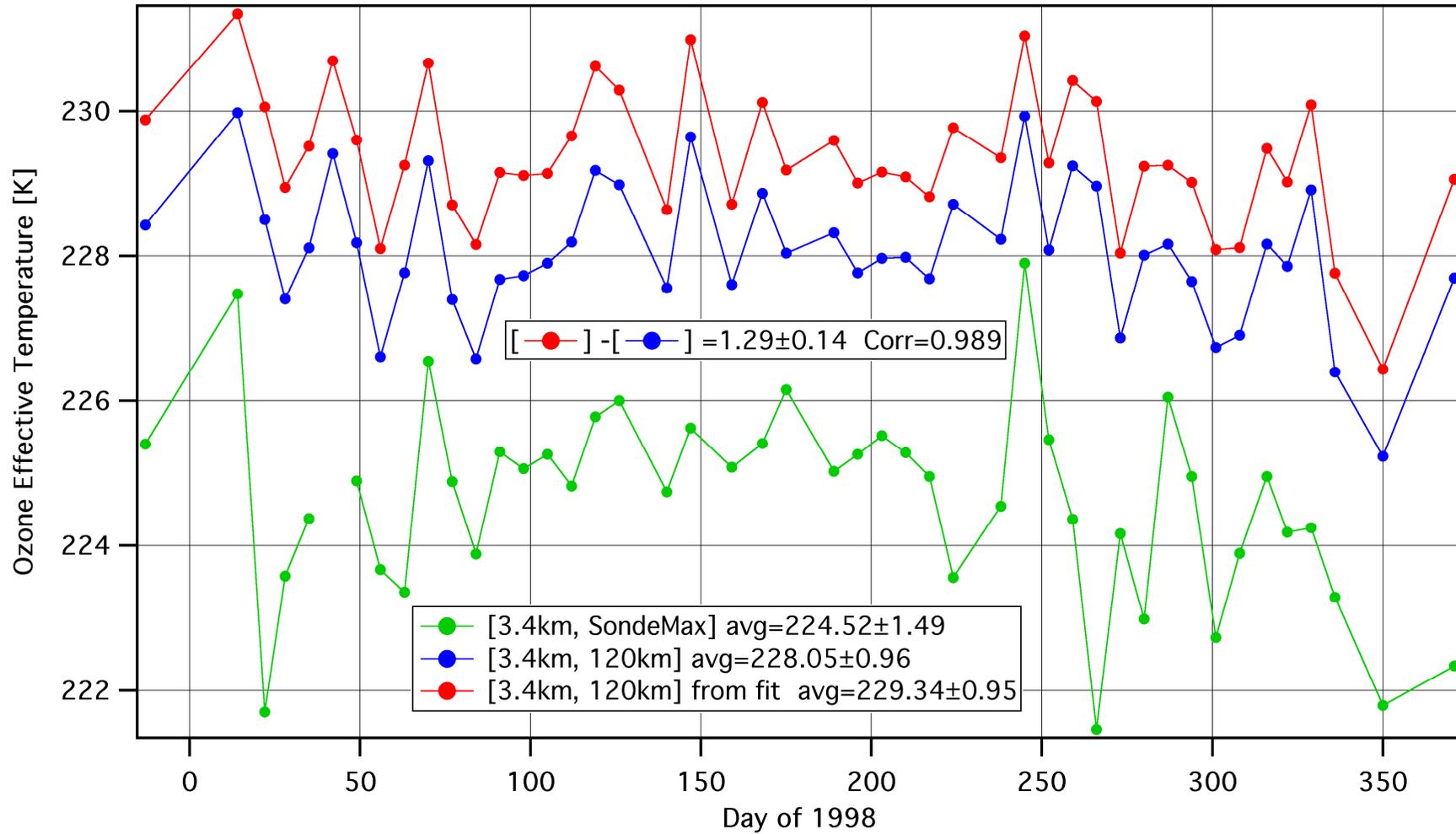
Note: We extrapolated profiles to 120km and then used their X-sections (the nearest in time) in retrievals

Ozone Mean Altitude



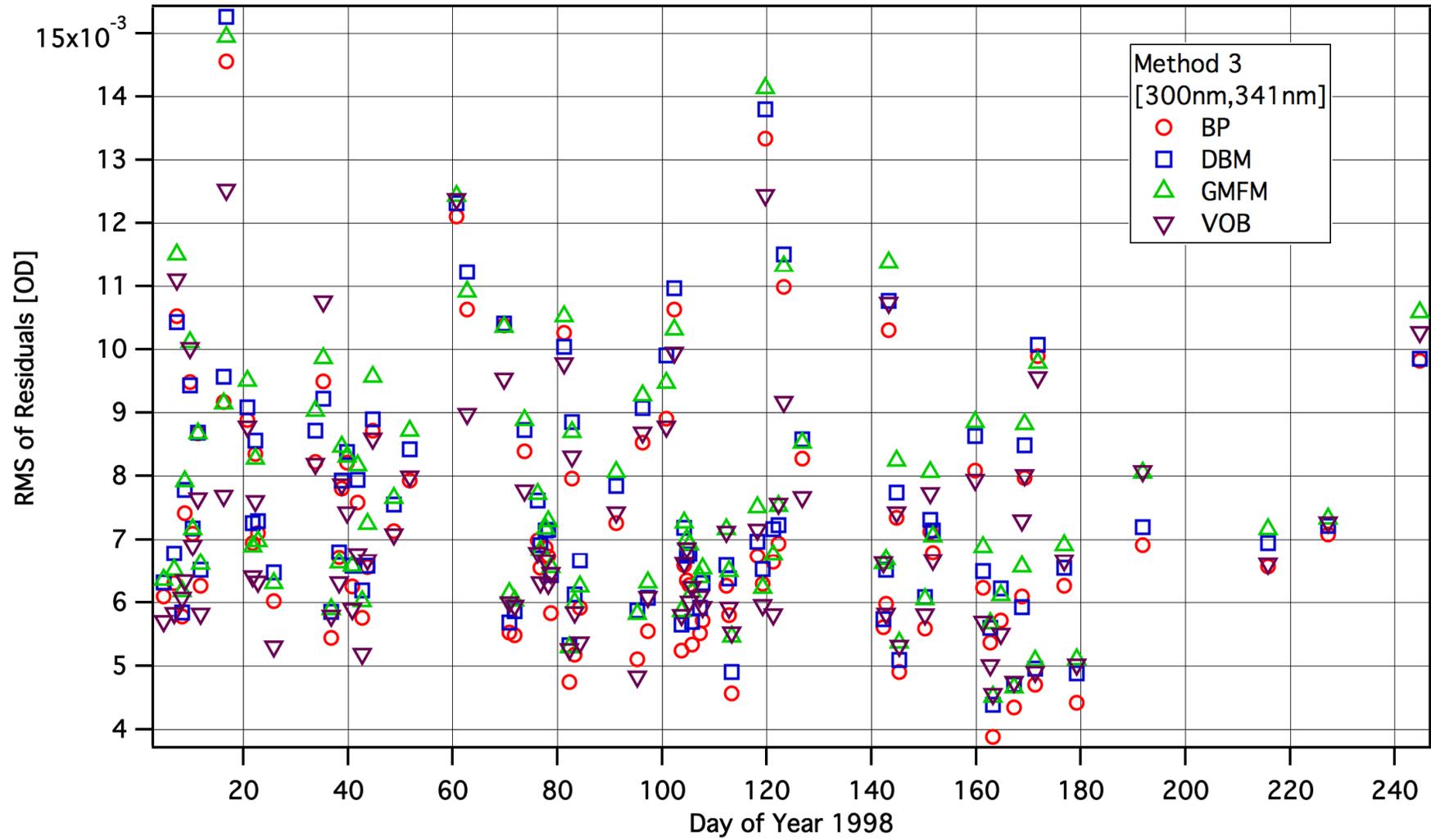
For illustration only. We did not use this information.

Ozone "Effective" Temperatures



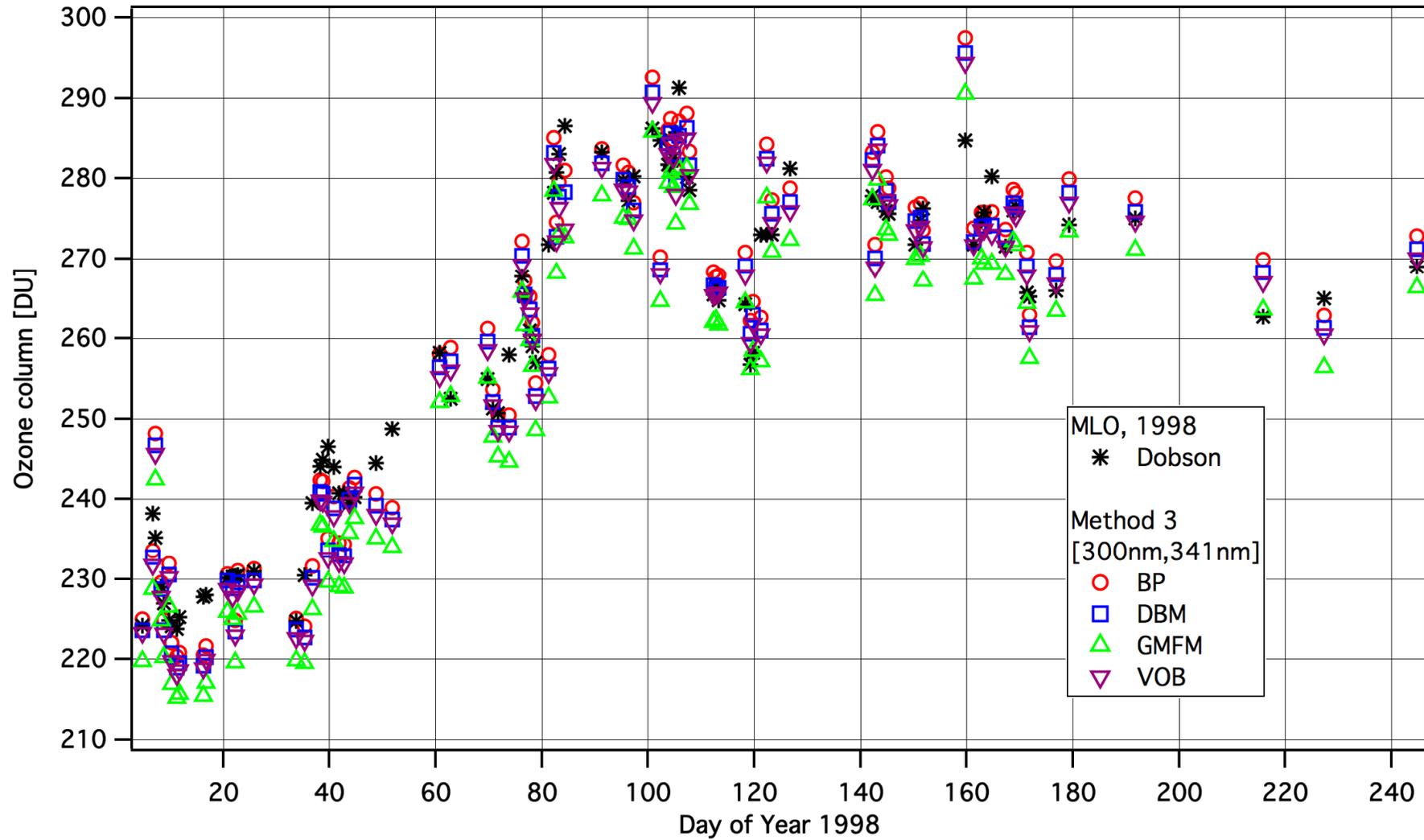
For illustration only. We did not use this information.

RMS of residuals from 92 retrievals



VOB denotes Voigt et al. X-sections

Ozone column from 92 retrievals



Summary: RMS & Ozone

RMS of fit residuals in optical depth: Mean \pm Std.Dev. for 92 cases.

	Method 3	Method 4
BP	0.00722 \pm 0.00199	0.00695 \pm 0.00177
DBM	0.00757 \pm 0.00198	0.00724 \pm 0.00173
GMFM	0.00772 \pm 0.00198	0.00749 \pm 0.00178
VOB	0.00717 \pm 0.00178	0.00661 \pm 0.00172

Ozone column minus interpolated Dobson's ozone at MLO in DU:
Mean \pm Std.Dev. (Correlation).

	Method 3	Method 4
BP	+0.31 \pm 5.52 (0.958)	-1.05 \pm 7.11 (0.942)
DBM	-1.27 \pm 5.48 (0.958)	-3.40 \pm 6.98 (0.943)
GM-FM	-5.56 \pm 5.30 (0.958)	-6.08 \pm 6.85 (0.943)
VOB	-2.18 \pm 5.45 (0.958)	+0.26 \pm 7.26 (0.940)

Note: RMS differences not statistically meaningful!

Comparison with earlier works

2010: Current work

DATA: MLO, 1998, Brewer 119, N=92: Optical depth from Langley's

Retrievals: [300nm,341nm] $n \leq 83$ spectral elements, linear aerosols

RMS ≈ 0.007 OD for all X-sections

Ozone: -0.6% DBM vs. BP and -2.2% GMFM vs. BP

2006: P. Kiedron et al. Proc. SPIE 6362.

DATA: Table Mt., CO, 2003-2006, UV-RSS, N=5000, Langley calibrated spectra

Retrievals: [310nm,330nm] $n=196$ spectral elements, linear aerosols

RMS ≈ 0.0048 OD for all X-sections

Ozone: -0.8% DBM vs BP -2.4% GMFM vs BP

2007: X. Liu et al., Atmos. Chem. Phys.

DATA: GOME, several orbits

Retrievals: [289nm, 307nm] & [326nm,337nm], profile and column

RMS up to 60% lower for DBM

Ozone: around +1.5DU DBM vs BP around -5DU GMFM vs BP

Note that for BP and DBM Liu et al. $\Delta c(O_3)/c(O_3)$ not congruent with Brewer and RSS results

Conclusions, questions and statements/conjectures

Neither Brewer (this study) nor RSS could demonstrate that RMS of optical depth differ between BP and DBM, but we are still working on DOAS method with MLO 1998 Brewer UV-scan data and will revisit RSS data set for DOAS study.

Is there any ground based measurement study that showed optical depth RMS difference?

Retrievals' results are dependent on spectral range and aerosol model. Using some aerosol model is unavoidable. There is a danger of over determining aerosols (too many parameters). This applies to satellites based retrievals as well.

Is the congruency of the sign of ozone errors for DBM and BP between simulations and field data retrievals (RSS and Brewer) of any meaning?

Neither Dobson nor Brewer (differential retrieval method, in general) can educate us about which X-section is more correct.

Both Dobson and Brewer use single layer ozone model: fixed temperature and fixed formula for ozone airmass.

If satellite retrievals use ozone climatology and “validate” their results against Dobsons and Brewers, shouldn't ground based results use exactly the same ozone climatology?

Conclusions, questions and statements/conjectures

Is there a systemic drift toward convergence among different ozone column measurements?

Authors, authors?

Quote 1: “We recommend for SCIAMACHY total ozone retrieval in the classical spectral window of 325-335 nm to use the SCIAMACHY FM cross-section (Bogumil et al. 2003) differentially scaled by 1.038 (+3.8%) and wavelength shifted by +0.016 nm. [...] The main driver here is to **provide consistency** between GOME and SCIAMACHY total ozone retrieval when GOME FM and SCIAMACHY FM spectra are used with their respective instruments.”

Quote 2: “In the northern hemisphere, the average difference between TOMS V7 and a network of Dobson and Brewer stations was 1.55%. In version 8, this offset dropped **to -0.03%**.”

Is Dobson the benchmark of ozone column?

Extra Slides

Profile X-section depends on SZA and wavelength and airmass depends on wavelength

$$X_P(\lambda) = \frac{1}{m_P(\theta_\lambda, \lambda)} \int_{z_0}^{\infty} X(T(z), \lambda) \cdot P_{O_3}(z) \left(1 - \left(\frac{z_0 \cdot n(z_0, \lambda)}{z \cdot n(z, \lambda)} \sin \theta_\lambda \right)^2 \right)^{-1/2} dz \stackrel{\text{Notation}}{=} \langle X(T(z), \lambda) \rangle$$

$$m_P(\theta_\lambda, \lambda) = \int_{z_0}^{\infty} P_{O_3}(z) \left(1 - \left(\frac{z_0 \cdot n(z_0, \lambda)}{z \cdot n(z, \lambda)} \sin \theta_\lambda \right)^2 \right)^{-1/2} dz$$

$X_P(\lambda) = g(\theta_\lambda, \lambda) \cdot \int_{z_0}^{\infty} X(T(z), \lambda) \cdot P_{O_3}(z) dz$ $g(\theta_\lambda, \lambda) \approx 1 \leftarrow \theta_\lambda < 75^\circ$
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