Overview of the validation of POAM III version 4 retrievals

METHOD

A statistical analyses of comparisons between POAM III version 4.0 retrievals and measurements from HALOE (version 19) and SAGE II (version 6.2) and ozonesondes have been performed. In addition, when available, limited numbers of comparisons with aircraft-based instruments have been performed. For statistical analyses with correlative satellite data, coincidence criteria were 500 km and 2 hours unless too few coincidences were found, in which case the time criterion was relaxed to 12 hours. Comparisons for NO_2, however, included only measurements that occurred within 2 hours to avoid artifacts due to diurnal variations. Coincident measurements for satellite statistical analyses were also required to occur within 3 degrees in equivalent latitude.

Comparisons are performed separately for satellite sunrise ("r") and sunset ("s") occultations, since occultation instruments are known to often suffer from systematic errors related to the satellite occultation type. Note that all POAM sunrise occultations occur in the northern hemisphere (NH) whereas all POAM sunset occultations occur in the southern hemisphere (SH). HALOE and SAGE II spacecraft occultations occur as both sunrises and sunsets in each hemisphere. Local times for the POAM measurements correspond to local sunsets throughout the year in the NH, to local sunrise in the SH from ~April through August, and to local sunset in the SH from ~September through March.

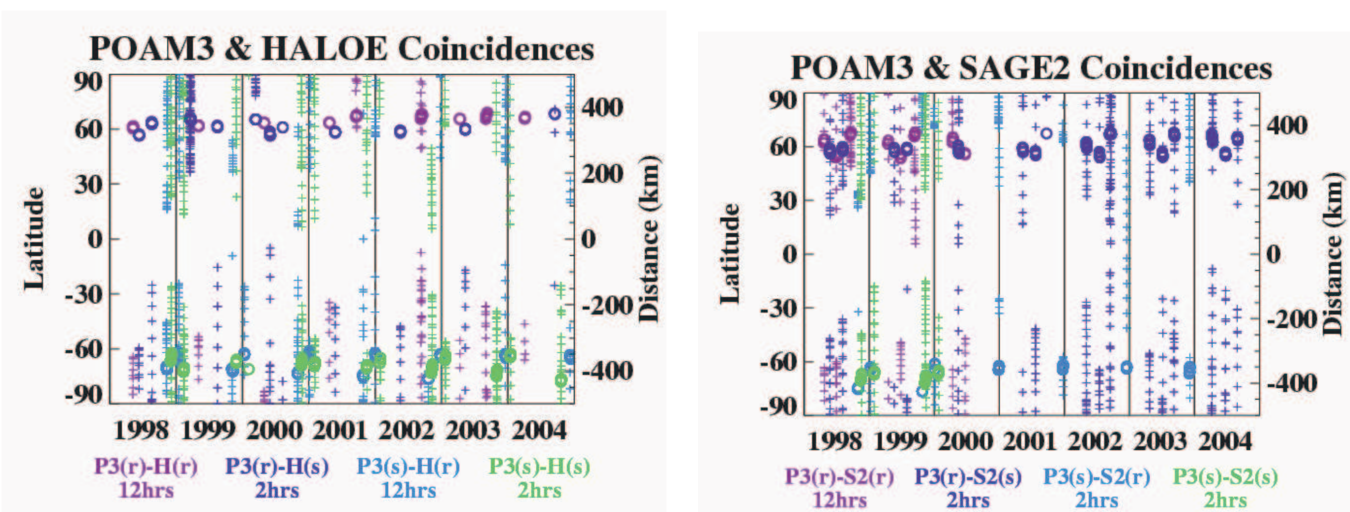

Figure 1: Coincidence latitudes and separation distances for all measurement pairs between POAM III and HALOE (left) or SAGE II (right). The "r" and "s" notations refer to sunrise and sunset spacecraft occultations, respectively. Plus marks denote separation distance (right axis) and circles denote latitudes. Distances are negative when POAM III was at a lower latitude than the correlative instrument. Coincidences with ozonesonde measurements are as described in Randall et al. [2003].

Both relative (P-C)/Avg (%) and absolute (P-C) (ppmv or ppbv) differences were calculated at each altitude for each coincidence pair. Here P refers to the POAM measurement, C refers to the correlative measurement, and Avg refers to the average of the two; for comparisons with in-situ data, the denominator in the relative difference was set equal to C. Before calculating the differences, correlative data were smoothed and interpolated to 1-km vertical resolution to match the vertical resolution and scale of the POAM data. For any given coincidence pair, P and/or C could have had missing data due to failed measurements, these are generally found at the high and/or low ends of the altitude range. Data were flagged as "bad", and thus not included in the analysis, if the stated errors on the measurements exceeded 100%. POAM data were further screened for sunspot or aerosol artifacts through a separate procedure that was developed empirically because the formal error analysis often did not catch all of these artifacts. This procedure is described by Lumpe et al. [2005]. HALOE data are operationally screened for cloud artifacts, so no cloud-contaminated data were included in the comparisons. SAGE II measurements of O_3, NO_2, or aerosol were not further screened. SAGE II H_2O measurements were screened according to Taha et al. [2004], whereby all measurements for which the 1020-nm aerosol extinction was greater than 2×10^{-4} km^{-1} were removed. The error analysis and screening process results in varying numbers of coincident comparisons at each altitude, with generally substantially lower numbers of comparisons in the top and bottom 5 km of the relevant altitude range for each constituent (10-60 km for O_3, 10-50 km for H_2O, 20-45 km for NO_2).

OZONE COMPARISONS

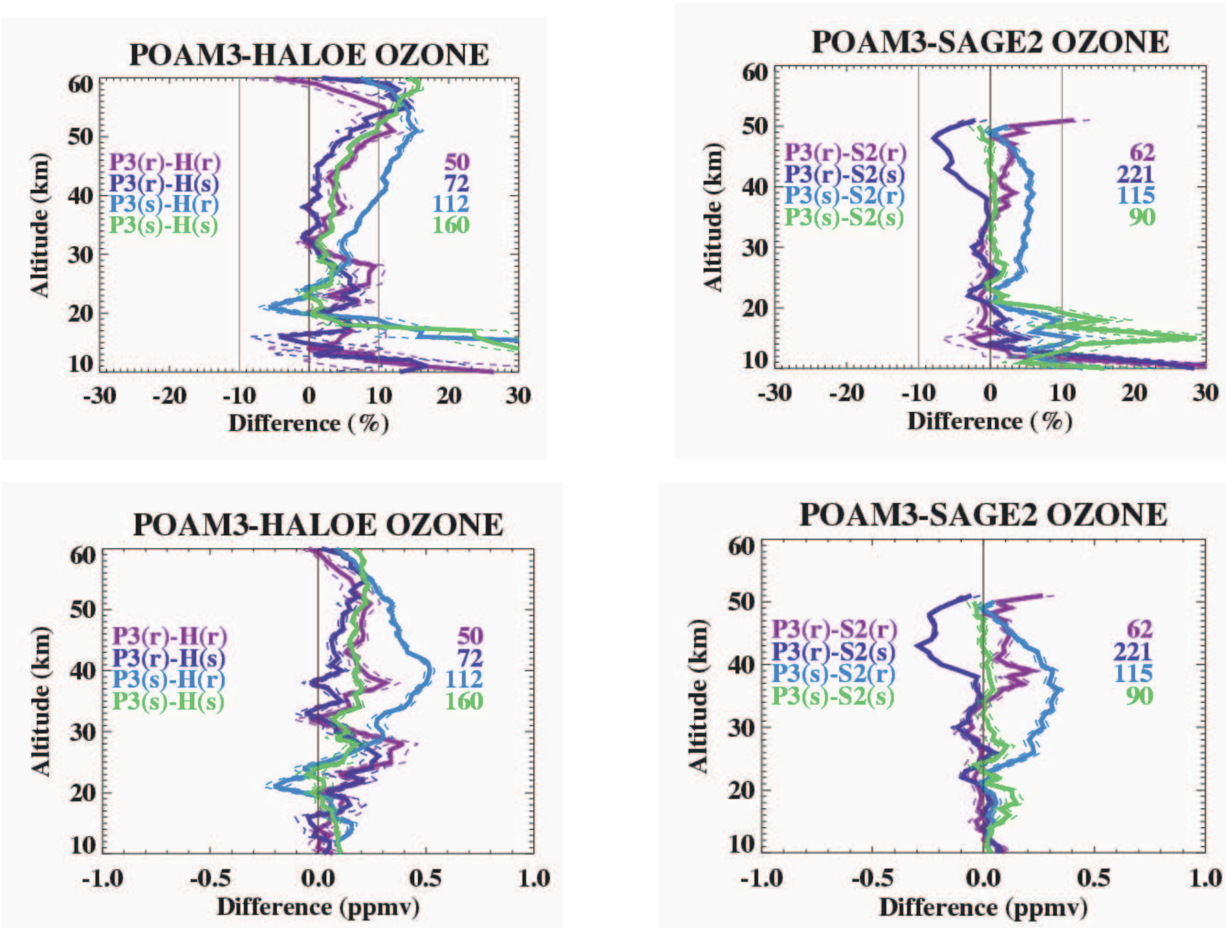

Figure 2: Comparisons between POAM III and HALOE (left) or SAGE II (right) ozone profiles for the coincidences described above. Average relative (%) differences are shown in the top row, and absolute differences (in units of ppmv) are shown in the bottom row. Dashed lines represent the uncertainty in the mean difference profiles, given by the standard deviation of the distribution of differences at each altitude divided by the square root of the number of coincident comparisons at that altitude. The maximum number of coincidences for each type of comparison is denoted in each panel (see method section).

Figure 2 shows comparisons between POAM III and HALOE or SAGE II ozone profiles, since ozone measurements from these satellites have been validated previously for prior retrieval versions [e.g., Bhatt et al., 1999; Brühl et al., 1996; Morris et al., 2002; Wang et al., 2002]. Differences at most altitudes are within 10% and often within 5%. POAM sunrise/sunset biases would appear as differences between the purple and light blue curves, or between the dark blue and green curves. HALOE (SAGE II) sunrise/sunset biases would appear as differences between the purple and dark blue curves, or between the light blue and green curves, in the left (right) panels. The main such difference that appears systematically is that the light blue curve is displaced higher than all three other curves in all sets of comparisons, between about 25 and 50 km. This could be interpreted as a POAM high bias at sunset, a HALOE high bias at sunrise, or a SAGE high bias at sunrise. The other comparisons do not suggest systematic sunrise/sunset biases in any of the three instruments, however, so the analysis is inconclusive as to whether any of the instruments exhibit a statistically significant sunrise/sunset bias. The primary exception to this is altitudes below 20 km, where POAM sunset measurements are 10-30% (or more) higher than sunrise measurements. Note, however, that this translates to mixing ratio differences on the order of only ~0.1 ppmv. Also, although not shown, this apparent sunrise/sunset bias is reduced substantially if ozone "hole" events (e.g., November at high southern latitudes) are removed from the comparisons.

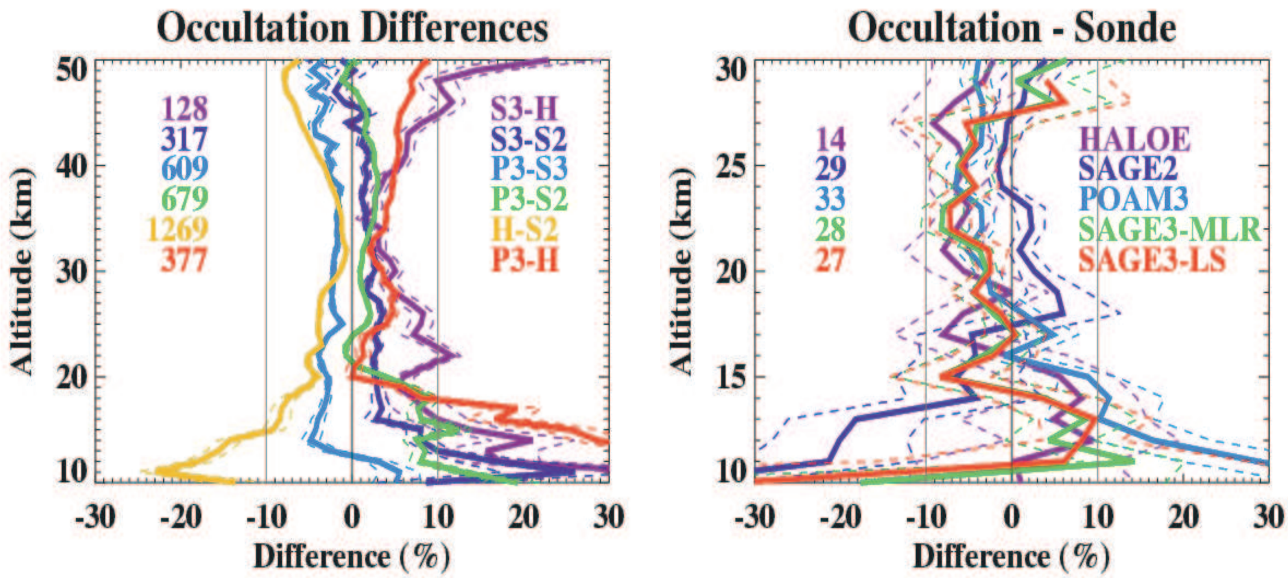

Figure 3: Summary of ozone comparisons between different occultation instruments (left) and between the occultation data and sonde measurements (right). Satellite occultation sunrise and sunset data have been averaged together, and coincidence criteria were 12 hrs, 500 km, and 3 deg in equivalent latitude.

Figure 3 summarizes differences between the various occultation instrument measurements of ozone (left) and between the occultation data and ozonesonde data (right). From this analysis, any potential sunrise/sunset biases were ignored, and SAGE III data are also included. Two separate ozone retrievals for SAGE III are performed, referred to here as the MLR (Multiple Linear Regression) and LS (Least Squares) inversions. In all of the comparisons, differences below 15 km are quite variable, but at higher altitudes are generally within ±10%, and often within ±5%.

Ozone Summary: Version 4.0 ozone has changed little from version 3.0, so conclusions are similar to those drawn by Randall et al. [2003] for version 3.0. On average, POAM III O_3 profiles agree to within ±5% with correlative data from 13 to 60 km. There is a suggestion that the POAM III sunrise data are biased low by less than 5% relative to sunset data from 25-50 km, but this is not definitive. There is evidence that POAM III has a high bias of up to about 0.1 ppmv from 10-12 km.

NO_2 COMPARISONS

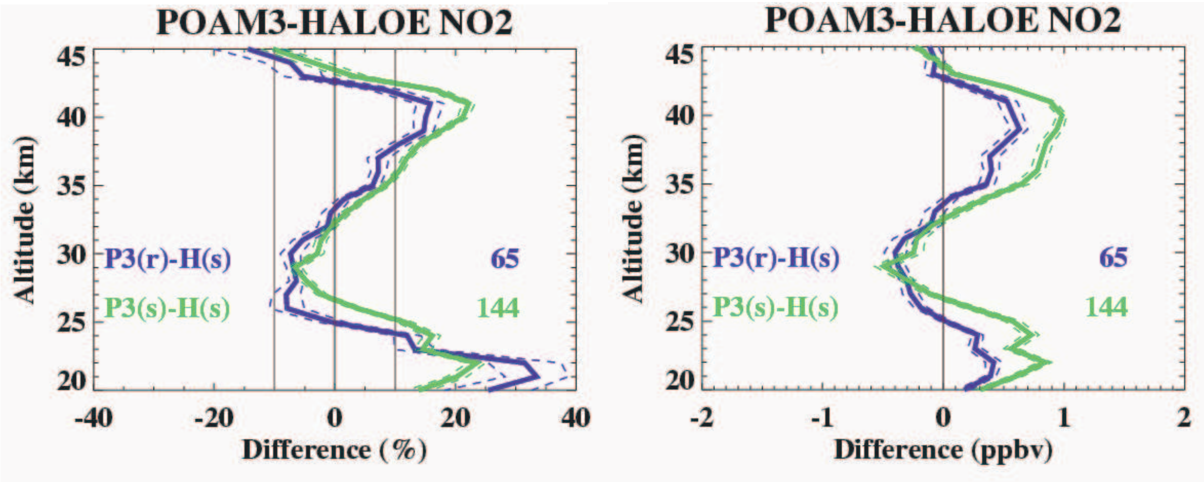

Figure 4: Relative (left) and absolute (right) comparisons of POAM III and HALOE NO_2, for all coincidences that occurred within 2 hours in local time. Plots are analogous to those in Figure 2.

Figure 4 shows NO_2 comparisons between POAM III and HALOE. Differences are within ±10% from 25-35 km, but approach 20% or higher (POAM higher than HALOE) near 20 km and 40 km. There is no indication of a significant systematic sunrise/sunset bias in the POAM measurements. These results are similar to the results in Randall et al. [2002] for version 3.0, but reflect the fact that the version 4.0 NO_2 data are lower than version 3.0 NO_2 data by about 5% near 30 km. The number of comparisons is smaller because here we limit comparisons to those measurements that occurred within 3 degrees in equivalent latitude, whereas Randall et al. [2002] had no such limitation. As discussed by Randall et al. [2002], differences near 40 km are decreased by about 5% after accounting for a recently discovered error in the HALOE retrievals. Differences below 25 km are difficult to interpret because the HALOE retrievals include a correction for diurnal variations along the line-of-sight, whereas POAM retrievals do not; this correction varies with season and latitude.

Although not shown, comparisons have also been made with SAGE II and SAGE III, neither of which have yet been formally validated. POAM III NO_2 agrees with SAGE III at the 5% or better level from 25-40 km in the NH (no coincidences exist in the SH), providing a mutual verification of both data sets. Comparisons with SAGE II indicate a substantial sunrise/sunset bias in the SAGE II data set; agreement between POAM III sunrise or sunset data and SAGE II sunset data is within ±10% from 25-35 km. Comparisons with SAGE II sunrise data, however, suggest a SAGE II sunrise low bias of more than 15%.

NO_2 Summary: Results are similar to those in Randall et al. [2002], except that version 4.0 NO_2 near 30 km is lower than version 3.0 by about 5%. This leads to larger disagreements with HALOE at this altitude (POAM lower than HALOE by up to 5-8%).

WATER VAPOR COMPARISONS

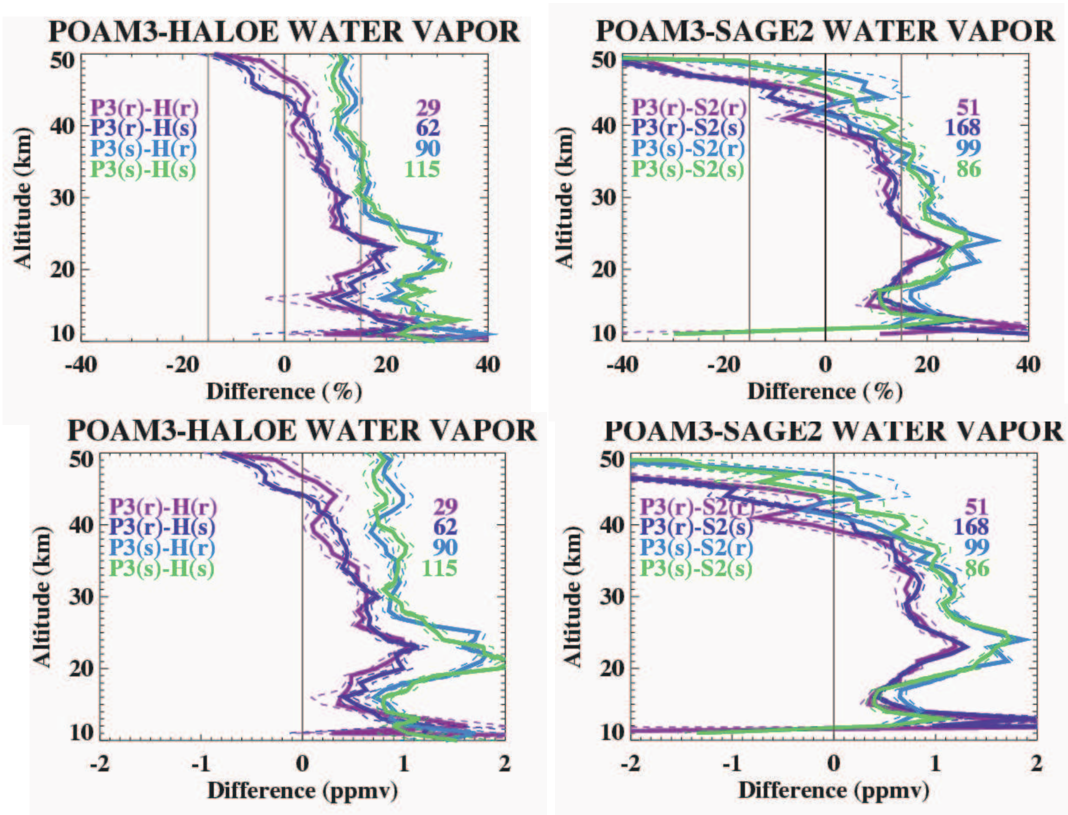

Figure 5. Relative (top) and absolute (bottom) differences between POAM III and HALOE (left) or SAGE II (right) water vapor for all coincidences as defined in Figure 1. Plots are analogous to those in Figure 2.

The core of the POAM III version-4 water vapor validation analysis consists of statistical comparisons using coincident measurements from HALOE V19 and SAGE II V6.2. In addition, a number of coincidences exist between POAM III and both aircraft and balloon measurements made in the Northern Hemisphere, primarily during the two SOLVE missions. Since a validation of version 3.0 water vapor has not been published, we include here a more comprehensive analysis of version 4.0 than for the other constituents. Figure 5 shows the comparisons between POAM III and HALOE or SAGE II. POAM III data are higher than both HALOE and SAGE II below 40 km by about 10-30%, with a POAM sunrise/sunset bias of about 5-10% (sunset higher than sunrise).

Figure 6 shows water vapor comparisons between POAM III v4.0 and two *in-situ* instruments onboard the ER-2 during the SOLVE-1 campaign. Contrary to the high bias seen in the HALOE and SAGE II comparisons, these results show agreement to within about ±10%. Comparisons with the NOAA CMDL frost point hygrometer during SOLVE-1 and with MkIV occultation profiles during SOLVE-1 and SOLVE-2 are similar, suggesting a POAM sunrise (NH) high bias of up to 10% (Figures 7 and 8).

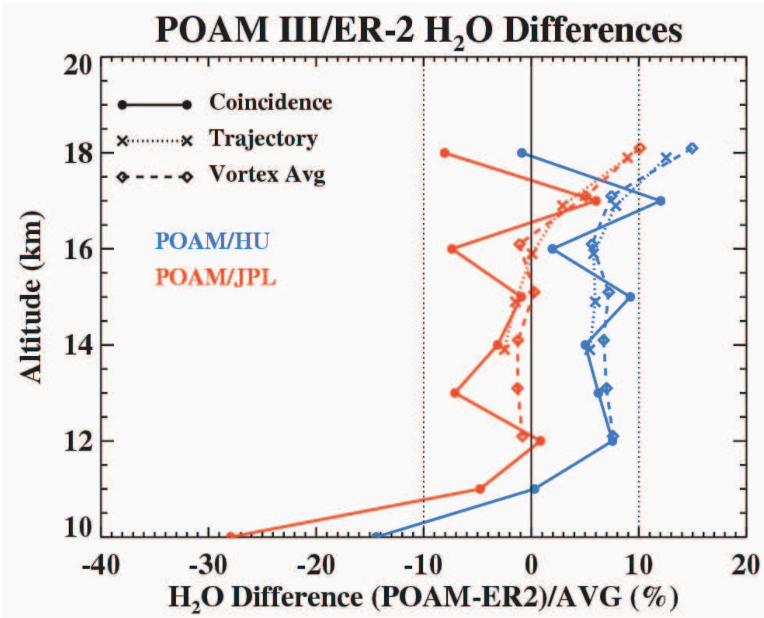

Figure 6. POAM/ER-2 differences using 3 methods: direct coincidence, vortex-average, and trajectory matching [see Lumpe et al.,. 2003]. SOLVE I ER-2 *in situ* measurements are from the Harvard Lyman-α hygrometer and JPL TDL spectrometer, during 11 aircraft flights.

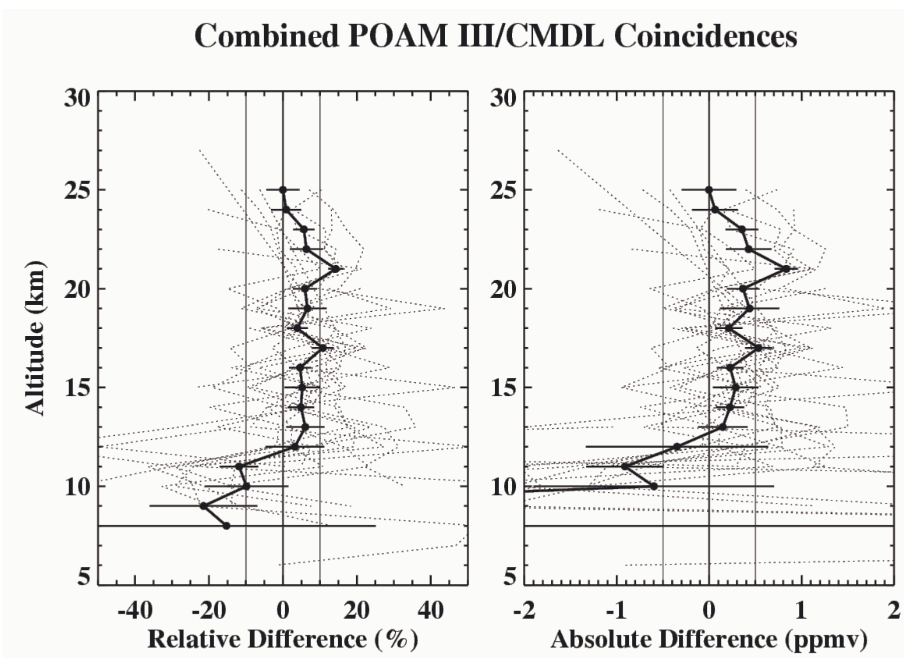

Figure 7. Mean difference for 18 coincidences with the balloon-borne NOAA CMDL frost point hygrometer during SOLVE I.

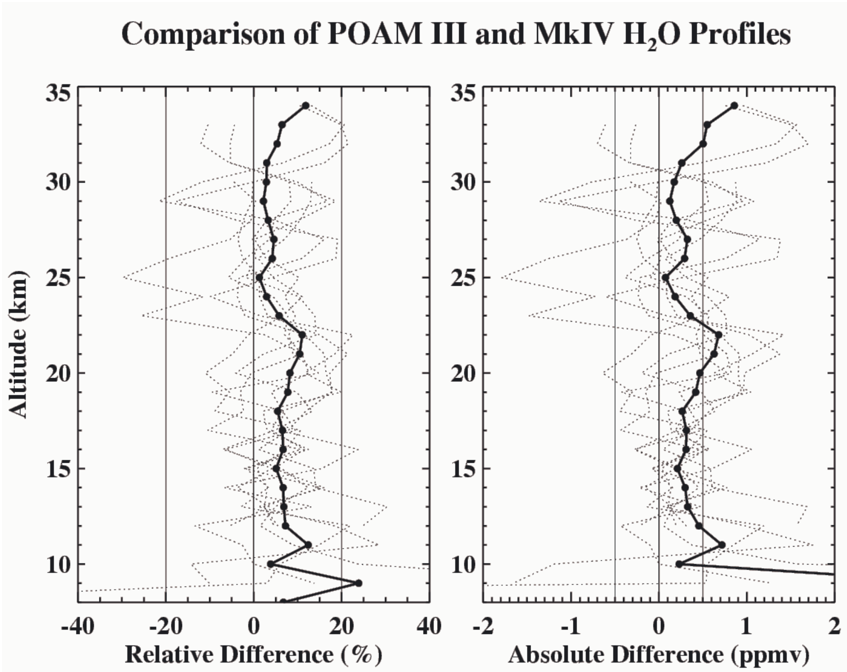

Figure 8. Comparisons between POAM and MkIV balloon measurements during SOLVE I & II. MkIV measurements were made near latitudes of 63-68 N on 12/3/1999, 3/15/2000, 12/16/2002, and 3/31/2003.

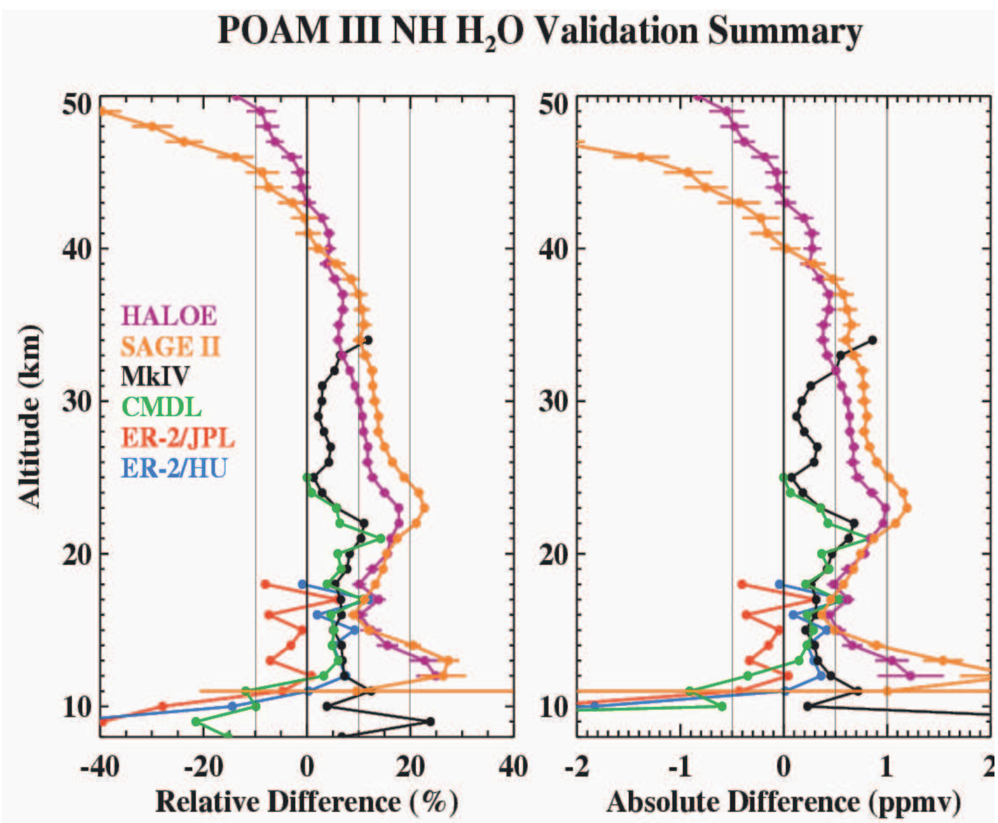

Figure 9. Summary of the NH comparisons shown in Figures 5-8.

Figure 9 compares NH POAM differences with all datasets used in this study. The results indicate a clear POAM high bias in the stratosphere, but the magnitude varies. The balloon and aircraft comparisons are very consistent, indicating a 5-10% bias from 12-34 km. The satellite comparisons show larger differences, from 10-20% below 35 km. At ~ 40 km and above POAM becomes drier than both SAGE II and HALOE. Overall, the POAM-SAGE II differences are larger than POAM-HALOE by about 5%. Interpretation of the HALOE and SAGE II comparisons is complicated, however, by the fact that the SAGE II V6.2 H_2O has been constrained to fit the HALOE climatology in a gross sense and so is not completely independent.

H_2O Summary: The results of this analysis show that Northern Hemisphere POAM Version 4.0 water vapor generally agrees with HALOE and SAGE II to within 10-20 % from 10 to 45 km. The balloon and aircraft comparisons show smaller NH differences of 5-10%. In all cases, POAM is biased high relative to the correlative data. There is also evidence of a 5-10% hemispheric bias in the POAM data (NH < SH), so that SH differences with HALOE and SAGE II increase to ~ 25 % at 20 km.

AEROSOL COMPARISONS

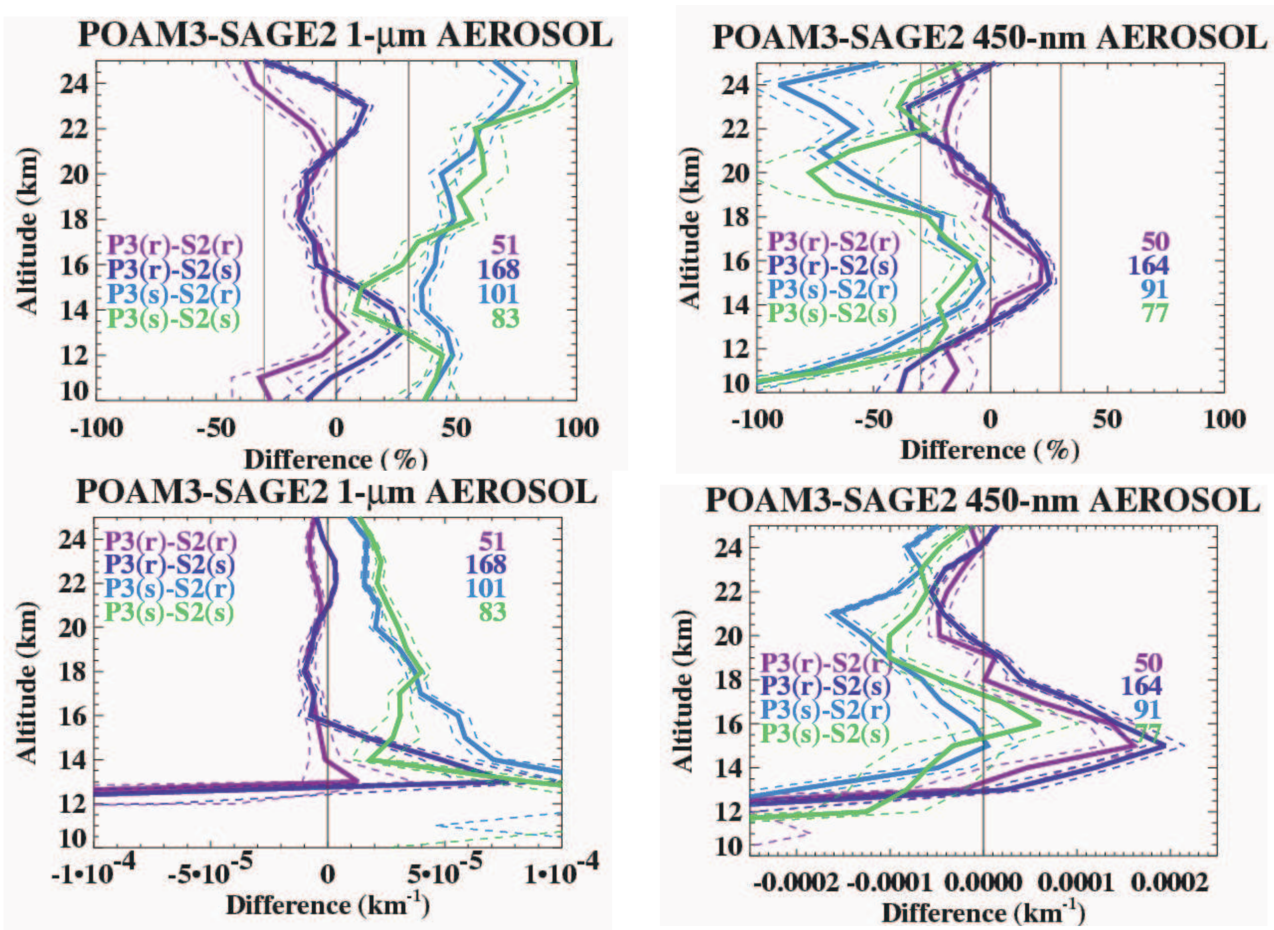

Figure 10. Comparisons between POAM III and SAGE II aerosol extinction at 1.02 μm (left) and 450 nm (right) as relative (%, top) and absolute (km^{-1}, bottom) differences. Plots are analogous to those in Figure 2.

POAM III vs. SAGE II comparisons of aerosol extinction at 1.02 μm and 0.45 μm are shown in Figure 10. These comparisons are substantially different from the comparisons shown in Randall et al. [2001] because there were major changes in the aerosol retrieval versions for both the POAM III (v3.0) and SAGE II (v6.0) data since that paper was written. There is a systematic bias in the POAM sunrise vs. sunset aerosol retrievals such that the sunset aerosol extinction at 1.02 μm is higher than the sunrise extinction, while the opposite is true for 0.45 μm. Based on the SAGE II comparisons, the bias is on the order of 20-50% at 1.02 μm, and about half that magnitude at 0.45 μm. Agreement between POAM III sunrise data and SAGE II data is generally within ±30% at both wavelengths, which is quite reasonable given the very low aerosol levels that have pertained since the launch of POAM III in 1998.

Aerosol Summary: POAM III satellite sunrise (NH) aerosol extinction measurements at both 1.02 μm and 0.45 μm are within ±30% of SAGE II, with no obvious systematic bias. However, POAM III exhibits a significant sunrise/sunset bias in its extinction measurements that leads to poorer agreement between SAGE II and the POAM III sunset data. Satellite sunset (SH) aerosol extinction at 1.02 μm exhibits a high bias with respect to SAGE II that is on the order of 50%; satellite sunset extinction measurements at 0.45 μm agree with SAGE II near 15 km, but exhibit an increasing low bias below and above this altitude.

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