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Final Report

SAGE II/Umkehr Ozone Comparisons and Aerosol Effects: An Empirical and Theoretical Study

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The objectives of this research were to 1) To examine empirically the aerosol effect on Umkehr ozone profiles using SAGE II aerosol and ozone data, 2) To examine theoretically the aerosol effect on Umkehr ozone profiles, 3) Examine the differences between SAGE II ozone profiles and both old- and new- format Umkehr ozone profiles for ozone-trend information, 4) Re-examine SAGE I-Umkehr ozone differences with the most recent version of SAGE I data, and 5) Contribute to the SAGE II science team. During the first year, Drs. Newchurch/UAH and Cunnold/Georgia Tech were funded on this project. During the second and third years, Drs. Allen and Herman are also funded.

During the first year (FY94) of this research, we constructed a substantial database of available SAGE and Umkehr ozone measurements (540 SAGE I coincidences over 24 stations, and 7448 SAGE II coincidences over 34 Umkehr stations from 1979 to 1995). *Newchurch and Cunnold* [1994] reported some results of the aerosol effect on Umkehr ozone profiles. A preliminary look at coincidences from a reasonable sample of stations [*Newchurch* et al., 1995a and *Newchurch*, 1993] indicated substantial differences between the 1964 Umkehr algorithm results and the 1992 Umkehr algorithm results. Because the most important aspect of the Umkehr record is multi-decadal length for trend analysis [*WMO*, 1988; *Reinsel et al.*, 1989, *Stolarski et al.*, 1992], we must understand how these differences between new and old Umkehr reduction algorithms propagate into the ozone trends. From inspection of the differences in the SAGE-Umkehr comparisons, we predicted [*Newchurch*, 1994] ozone trend estimates from new Umkehrs would be dissimilar to those previously deduced from old Umkehrs.

Analysis of trends from 12 northern hemisphere stations using the new Umkehr inversion vary from 0% to -13% per decade at 40 km and -4% to +6% per decade at 20 km [*Reinsel et al.*, 1994]. These results represent a very large variance between stations and in the lower stratosphere are uncertain even in the sign of the trend. Furthermore, the mean trends from the new Umkehr differ from the mean trends of the old Umkehrs. These trends derive from pre-Pinatubo observations, thereby avoiding the aerosol effect on the Umkehr observations. To extend the trend analysis further requires accurate correction for the Pinatubo aerosol in addition to accounting for the inter-station variability. Our SAGE/Umkehr comparisons also show large variances between stations where there should be none [*Newchurch and Cunnold*, 1995].

The objective of this research for the second year (FY95) was to examine the differences between the satellite-borne SAGE I and II ozone and aerosol profiles and the ground-based Umkehr ozone profiles for aerosol effects and trend information. Further analysis of the database produced the following results: 1) SAGE I altitude registration is low by approximately 1/2 km; adjustment for this offset reconciles SAGE I/II and old Umkehr trends in the upper stratosphere [*Newchurch et al.,* 1995b]; 2) SAGE/Umkehr differences vary among stations indicating

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significant station differences; 3) SAGE II total ozone is 5-10% higher than New (1992-algorithm) Umkehr; 4) New Umkehr significantly redistributes ozone in nearly all layers compared to the old algorithm; 5) Differences between SAGE and the Umkehr a priori distributions indicate that, while the new-algorithm a priori distributions are superior to the old-algorithm distributions, significant artifacts (e.g., seasonal) related to the a priori distributions remain. (cf. *Newchurch and Cunnold*, 1995; *Newchurch*, 1995 for points 2-5).

Because of the paucity of Umkehr data after 1990 (post-Pinatubo), and indications that the data would not be available in time for this research, we established a collaboration with Dave Hofmann (Acting Director of NOAA/CMDL) to investigate the Umkehr data from the six NOAA stations so that those measurements would be available for our analyses. We also established collaborations with Dr. J. Staehelin at Arosa, Dr. Krzyscin at Belsk, with the World Ozone Data Center to obtain the Umkehr data from other global stations (post-Pinatubo), and with Dr. Carl Mateer (author of the new Umkehr algorithm, with co-author John DeLuisi) to investigate the scientific implications of the new ozone reductions.

Newchurch et al., [1997] conclude from comparisons of 3403 coincidences of SAGE I and II ozone measurements against Umkehr[92] ozone profiles that SAGE ozone columns in Umkehr layers 4-10 are 5.0±1.3% (2σ) larger than the Umkehr[92]-measured column amounts (and by implication, the Dobson total-ozone column). These differences varied from 1.3 to 9.8% over the 15 Umkehr sites studied. The coincidence criteria were typically 1000 km and 12 hours; however, by analyzing the ozone differences as a function of latitudinal separation, and restricting that separation at some stations, we have based all the quoted mean differences on regression to zero latitudinal separation. The retrieved Umkehr[92] profiles have all been corrected for (small) aerosol effects. The primary reason for the ozone differences is suspected to be discrepancies in the ozone absorption cross-sections in the ultraviolet and visible bands. The difference between SAGE and the Dobson measurements should have relevance for the estimation of tropospheric ozone values from TOMS-SAGE differences. There is a substantial broad vertical structure to the SAGE-Umkehr[92] differences superimposed on the 5% mean difference, ranging from a maximum Umkehr deficit in layer 8 of about 10% from the mean bias to a maximum Umkehr excess of about 5% (relative to the mean bias) in layer 4. Except for Belsk and Sapporo, there is good consistency from site to site in the vertical structure of the ozone differences. Previously noted consistency between the vertical structure observed by SAGE and many other independent measurements has been cited. Nevertheless, the vertical structure in the Umkehr[92] retrievals is more consistent with the SAGE profiles than is the vertical structure of the previous Umkehr[64] retrievals. Significant improvement in the lower-stratospheric a priori climatology is also evident in the new retrievals.

Comparisons between SAGE and Umkehr[92] profiles after subtraction of the Umkehr[92] a priori profiles from both sets of measurements suggest that, on average, the Umkehr[92] profiles possess a correlation between 0.3 and 0.5 with the SAGE-measured ozone in the individual layers 4 to 8. Some stations, however, possess significantly higher correlations in some layers. The limited vertical resolution of the Umkehr method and sampling differences are likely contributors to the correlations being less than unity. The Umkehr[92] a priori climatology contains less ozone in layers 4-5 and somewhat more than SAGE in layers 7-8. However, changes in the a priori climatology will not affect the broad-scale pattern of the SAGE-Umkehr layer-ozone differences.

Time series of both the SAGE and Umkehr[92] measurements, with the Umkehr[92] a priori profiles subtracted, indicate a close correspondence between the Umkehr[92] and the SAGE ozone trends. There is, however, evidence of discontinuous changes at Kagoshima and Mauna Loa that could affect the calculated trends.

The principal investigator contributed to the DOE/ACP annual meetings [Newchurch et al., 1994a,b; 1995c], to the SAGE II science team meetings [*Newchurch*, 1993, 1994], to NOAA/CMDL meetings [*Newchurch,* 1995], POAM science team meetings [*Newchurch and Yang*, 1997a], and a number of international science meetings [*Newchurch and Cunnold*, 1995; *Newchurch et al.*, 1995a; *Newchurch,* 1996; *Newchurch and Yang*, 1996; *Newchurch et al.*,1996; *Newchurch and Yang*, 1997b; *Newchurch et al.* 1997b]

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