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UARS MLS O_3 soundings compared with lidar measurements using the conservative coordinates reconstruction technique

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Abstract. A technique based on conservative properties of certain meteorological fields is used to compare ozone measurements from the Microwave Limb Sounder (MLS) on the Upper Atmosphere Research Satellite (UARS) with soundings from a lidar system operated at midlatitudes by the University of L'Aquila, Italy. A few typical cases are analyzed in connection with the position of the vortex relative to the observing station, and it is shown that in general lidar observations taken within the vortex compare well with the UARS data, regardless of whether they are coincident with a satellite overpass. It is shown that such analysis may be useful for comparing measurements of the same quantity taken at different sites using different measurement techniques.

Introduction

Conservation properties of potential vorticity (PV) and potential temperature (θ) in the middle atmosphere allow a Lagrangian approach to the study of tracer transport, under a "Modified Lagrangian Mean" theory [*Andrews and McIntyre*, 1978; *McIntyre*, 1980]. These quantities are conserved under adiabatic frictionless motion [e.g. *Hoskins et al.*, 1985] so they can be used as coordinates which are preserved following such motion. This suggests a method of reconstructing long-lived chemical constituents ($t \geq 15$ days): using coincident meteorological field values, constituent measurements are mapped into the (PV, θ) coordinate space [*Schoeberl et al.*, 1989, 1991; *Redaelli et al.* 1992]. The resulting two-dimensional field can be considered relatively unaffected by the natural meteorological variability associated with, for example, the movement of the vortex.

Given a set of gridded meteorological analyses of PV and θ, the two-dimensional distribution of constituent data in (PV, θ) space may be used as a lookup table to supply constituent values at the analysis gridpoints. That is, the 2D constituent field can be inversely mapped back into any region of real (longitude, latitude, height) space for which the PV and θ fields are known. As its principal application, then, reconstruction allows for the production of large-scale distributions of trace gases from relatively sparse measurements taken by single or multiple instruments.

Alternatively, data from one instrument may be mapped onto the sampling loci of another, allowing data comparisons between different instruments at different times and locations, for example along aircraft or balloonsonde paths [*Schoeberl et al.*, 1989; *Lait et al.*, 1990, 1992], or simulating vertical soundings from satellites or ground-based instruments. Such an approach could potentially be a powerful technique for instrument intercomparison. In this paper, this potential is tested, reconstructing UARS MLS ozone onto the vertical line-of-sight path of a lidar over a number of days.

The basic requirement for applying the reconstruction technique, aside from conservation of potential vorticity and potential temperature, is that fluid tubes bounded by two isentropic surfaces and by two surfaces at constant PV (a so called "Lagrangian Tube") should show little constituent variation along their lengths. This assumption appears to be good for most long-lived tracers within and on the edge of the polar vortex, where the strong meridional wind shear produces rapid constituent mixing within a tube [*Leovy et al.*, 1985]. Outside the polar vortex, mixing along the length of a tube is less pronounced, gradients of PV and θ are not as strong, and the assumption of uniformity is less valid. The constituent must be long-lived enough to be well mixed along the tube; species which are chemically active on short time scales (e.g., diurnally varying species) will almost certainly be quite nonuniform along the fluid tube. (The reconstruction technique might, however, be applicable to conserved families of species.)

The principal differences between the technique used for this analysis and the one described in the references cited above are an improved transformation and averaging procedure, and the use of a "Modified Potential Vorticity", Π, as a conservative coordinate instead of PV [*Lait*, 1993]. Π is PV scaled to remove its exponential variation with altitude and is calculated as :

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$$\Pi = \mathrm{PV} \cdot (\frac{\theta}{\theta_0})^{-9/2}$$

where θ_0 is a constant reference θ value (420 ^{0}K here). Π exhibits conservation properties similar to those of PV, but its more more manageable scale of values allows a better mapping of the constituent data to the 2D (Π, θ) space.

Lidar and UARS observations

O_3 lidar data are obtained as described in *D'Altorio et al.*, [1993]. The differential absorption lidar (DIAL) instrument in its most recent version can obtain an ozone profile up to 45 km in about two to three hours at night. Vertical profiles of ozone number density are then converted to volume mixing ratios by using radiosonde soundings taken about 300 km north of the observing station in L'Aquila. Notice that the data used in this paper refer to early lidar operations, when profiles were obtained up to about 10 mb.

The UARS MLS remotely measures vertical profiles of temperature, ozone and other trace gases every 65 seconds [*Barath et al.*, 1993; *Waters et al.*, 1993]. In this work, MLS ozone and temperature data version 3 are used.

The meteorological data used in this paper are derived from the National Meteorological Center's (NMC) analyzed fields, with PV and winds calculated from the NMC temperature and geopotential height. The calculation procedure, which uses the balanced wind equation, is described by *Newman et al.* [1989].

Analysis and discussion

To perform a valid test of the reconstruction technique, one must maintain non-coincidence of the data from UARS and the lidar. Therefore, UARS soundings falling within a 10° longitude by 10° latitude boundary around the lidar site at L'Aquila (13.2 E, 42.2 N) were excluded from the analysis.

For each day analyzed, 24 hours of MLS O_3 soundings are mapped into (Π, θ) space using MLS θ and NMC Π which has been interpolated in time and space to each MLS profile. The area between the measurement points in (Π, θ) space is filled in by performing a Delaunay triangulation of the points and using linear interpolation within each triangle. The result, shown in Figure 1 for 11 January 1992 , shows the ozone distribution in (Π, θ) for a single day from MLS.

Similarly, data from a single lidar sounding for the same day are shown in Figure 2a, where local balloonsonde temperatures have been used for θ and interpolated NMC analyses for Π. Note that the lidar image covers a smaller portion of the 2D conservative coordinate space; this is to be expected, considering the limited range of Π and θ encountered by a single vertical sounding.

These two images can be now compared; Figure 2b shows the percentage differences between the two images.

The 2D MLS constituent field from Figure 1 can then be mapped back into real space using the NMC analyses to reconstruct the MLS measurements onto a vertical profile coincident with the lidar measurements. (The reconstruction is done at approximately the same vertical resolution as the lidar, yielding data points about 300 meters apart). The comparison of the reconstruction with the original is shown in Figure 3a. Also shown are MLS values from a nearby profile (with error bars indicating the uncertainties). Also shown are data reconstructed from a 2D (Π, θ) field of lidar measurements mapped back onto the lidar profile. This illustrates the magnitude of errors introduced in creating the 2D field (i.e. transforming data from real space to (Π, θ) space). The reconstructed profiles in Figure 3a show reasonable agreement with the lidar measurements (especially in comparison with the nearby MLS profile).

This confirm that the reconstructed profile can contain more informations than the nearest MLS sounding.

Other cases in which comparison is good are shown in Figures 3(b,c,d), for January 2 , January 3, and March 19 of 1992. While there is good agreement on these days, this does not always hold. Figure 3e shows a comparison for January 9; the lidar and the reconstructed UARS data show some important differences. Such cases are by no means rare, and it is important to determine their likely causes.

First of all, accurately determining a measurement's coordinates in (Π, θ) space may be difficult. At the rim of the polar vortex, for example, where there are strong gradients and vortex edge erosion, Π may not be adequately resolved by the meteorological data. In addition, the lidar site may also occasionally be too far outside the polar vortex, where the assumption of uniformity of lagrangian tubes is not as good. One should be able, however, to isolate such cases through inspection of the meteorological fields.

Another possible source of error is artifacts of the triangulation procedure used to fill in between the data points in the 2D space. For example, the triangulation will of course miss features in regions of the 2D space which were not sampled. To lessen the influence of such interpolated data, weights can be assigned to each point in (Π,θ) space based on the distance to the nearest actual data point. Using these weights, one can chose to reconstruct only points in the 2D constituent field that have greater significance. (Note that a point may be close to an actual data point in the 2D field while being far away from it in real 3D space.) While the reconstructions filtered by means of these weights tend to be at reduced spatial resolution, they should be more reliable.

Finally, large uncertainties in the original data would obviously affect the reconstructed profiles, as would inaccurate Π and θ coordinates. Such problems can be partly solved by averaging together in some manner data from several days, instead of data from a single day's 2D field. Care must be taken, however, to limit

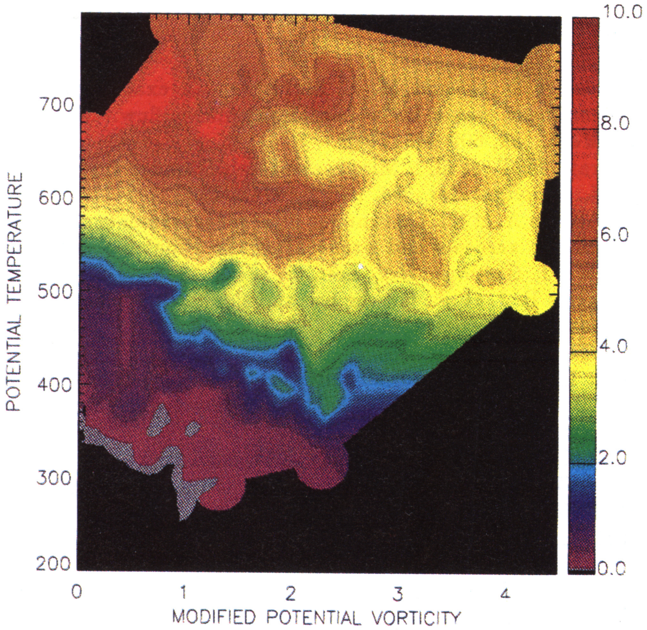

Figure 1. False colors image of a single day's UARS MLS O_3 field in ppmv, as it appears in the Π-θ 2D space. The space is filled with the UARS data using 24 hours of soundings, collected outside a ± 5^o latitude/longitude range from the L'Aquila lidar site. The vertical axis is θ in K^o, with Π in $10^{-5}\ {}^0Km^2Kg^{-1}s^{-1}$ on the horizontal axis.

the time period to one over which Π and θ are approximately conserved.

Thus, applying these considerations to the reconstruction technique, one can often improve the quality of the profiles obtained, while continuing to use data from non-coincident sites.

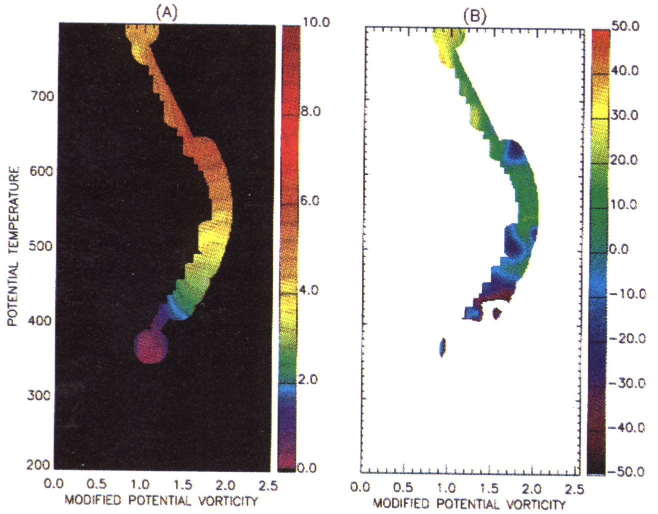

Figure 2. (A) As in Figure 1, but for lidar data. Note that a smaller portion of the Π-θ space is covered, because data came from a single sounding. (B) False colors image showing percentage differences between UARS MLS and lidar O_3 mixing ratio, in the Π-θ space.

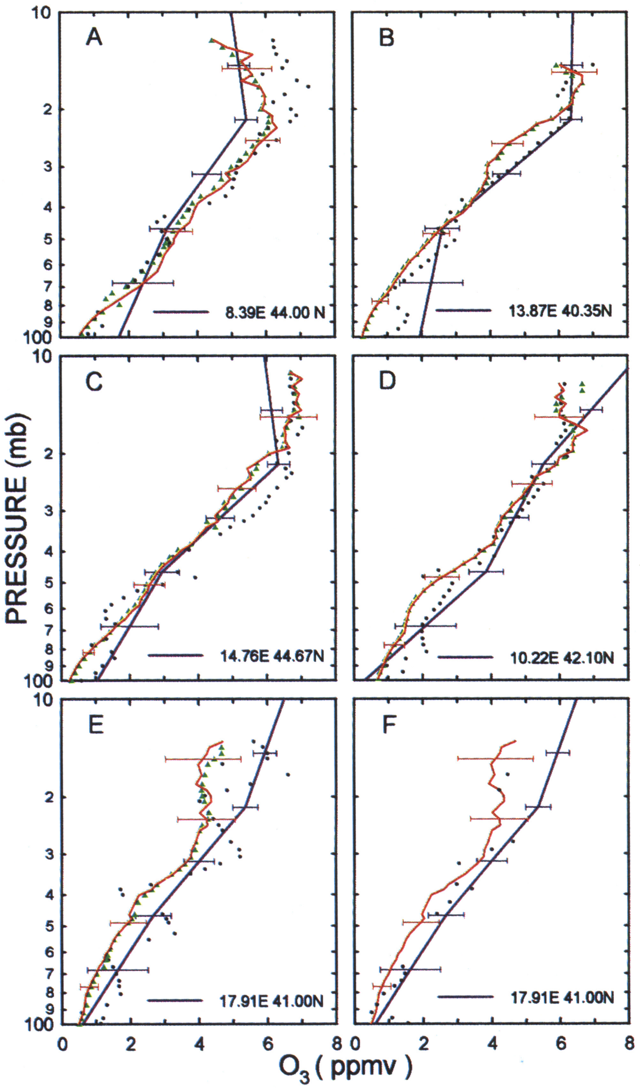

Figure 3. The UARS MLS soundings (blue line with horizontal error bars) compared with lidar soundings (red line with $\pm 1\sigma$ error bars) during overpass events. On the same graphs, the UARS MLS and the lidar soundings reconstructed over L'Aquila site at 13.2 E-42.2 N (black solid dots and empty green triangles, respectively). Latitude and longitude of each UARS sounding are indicated inside the graph. Profile comparison are shown for: (A) 11 January 1992, (B) 2 January 1992, (C) 3 January 1992, (D) 19 March 1992, (E) 9 January 1993 (note in this case the poorer correspondence between the UARS reconstruction and the lidar sounding; see text for discussion), (F) 9 January 1993, but the reconstruction is this time performed using a 2D averaged and weighted ozone field.

On 9 January, for example, the MLS ozone measurements show strong differences with those from 8 or 11 January in those regions of (Π,θ) space sampled by the lidar on 9 January. Averaging over 8–11 January, and using points in the 2D field which are weighted by distance to actual data points, the results in Figure 3f are obtained. The reconstructed profiles are much improved.

Conclusions

We have reported preliminary results of the comparison between ozone lidar measurements and UARS data using fields reconstructed from (Π,θ) space. The comparison is carried out only with data which are not coincident in real space; UARS MLS data are not used for reconstruction if they fall within a 10° longitude by 10° latitude boundary around the lidar site. Thus it is demonstrated that correlative measurement comparisons can be made in the absence of satellite overpasses.

The method seems to give satisfactory results in most cases examined. Large discrepancies observed in some cases can be explained in part in terms of the characteristics of the meteorological fields. For this reason meteorological maps should be checked daily with particular regard to the position of the polar vortex relative to the lidar site.

The triangulation procedure used here can also generate problems, filling in where satellite data are not available. Weighting constituent values near actual measurements in (Π,θ) space more strongly than heavily interpolated points can be used to limit this effect. In addition, reconstructing from time averaged (Π,θ) constituent images can help improve comparisons.

The results presented seem to indicate that comparison of data taken at different sites is feasible, assuming careful examination of the meteorological fields and (Π,θ) constituent fields. Furthermore, given data gathered over a widely varying set of meteorological conditions, a single site's measurements could potentially be reconstructed into tracer concentration maps extending well away from the measurement site.

Day-to-day differences in constituent profiles may be better characterized by considering their locations in (Π,θ) space [*Schoeberl et al.*, 1989]. Whether inspected in this 2D space or through comparison of reconstructed profiles, one should be able to ascertain more readily the relative influences of chemical and dynamical effects.

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