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EOS Microwave Limb Sounder Observations of the Antarctic Polar Vortex Breakup in 2004

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Abstract. Observations from the Microwave Limb Sounder (MLS) on NASA's new Aura satellite give an unprecedentedly detailed picture of the spring Antarctic polar vortex breakup throughout the stratosphere. HCl is a particularly valuable tracer in the lower stratosphere after chlorine deactivation. MLS HCl, N_2O, H_2O and O_3, analyzed with meteorological fields, show that the 2004 Antarctic vortex broke up in the upper stratosphere by early October, in the midstratosphere by early November, and in the lower stratosphere by late December. The subvortex broke up just a few days later than the lower stratospheric vortex. Vortex remnants persisted in the midstratosphere through December, but only through early January 2005 in the lower stratosphere. MLS N_2O observations show diabatic descent continuing throughout November, with evidence of weak ascent after late October in the lower stratospheric vortex core.

1. Introduction

The spring stratospheric polar vortex breakup is important to understanding transport, especially in the southern hemisphere (SH) where ozone-depleted air may disperse throughout the hemisphere [e.g., *Ajtić et al.*, 2004]. Previous observational studies of the SH vortex breakup have been limited by sparsity of data in time and/or in geographic and vertical extent [e.g., *Ajtić et al.*, 2004; *Orsolini et al.*, 2005]. The Microwave Limb Sounder (MLS) on NASA's Earth Observing System (EOS) Aura satellite, launched 15 July 2004, is a greatly enhanced follow-on to the Upper Atmosphere Research Satellite (UARS) MLS instrument [e.g., *Waters et al.*, 1999]. In addition to denser along-track sampling, better horizontal resolution, and better precision and/or vertical resolution, EOS MLS measures several species not available from UARS MLS. N_2O and HCl are of particular interest here as tracers of transport. We use measurements of N_2O, HCl, H_2O and O_3 from EOS MLS, along with meteorological analyses from NASA's Global Modeling and Assimilation Office's Goddard Earth Observing System 4 (GEOS-4) assimilation system, to detail the structure and evolution of the SH vortex breakup in 2004.

Results shown here are from preliminary data processing algorithms that were tested extensively using simulations. Limitations in computational resources preclude immediate reprocessing of data from the 2004 SH winter/spring with newer algorithms. Estimated accuracies for these preliminary data are given by *Santee et al.* [2005]; their quality is adequate to capture the morphology of the vortex evolution reported here. Computational limitations precluded processing every day of MLS observations; for timeseries plots, short data gaps are filled using a Kalman smoother, as in *Santee et al.* [2005].

2. The 2004 Antarctic Polar Vortex Breakup

Plots of N_2O, HCl and O_3 as a function of equivalent latitude (EqL, the latitude enclosing the same area as the potential vorticity, PV, contour on which a point lies) and potential temperature (Figure 1) give an overview of three-dimensional (3D) vortex evolution; strong PV gradients demark the vortex edge. In early September, N_2O gradients are strong across the vortex boundary throughout the stratosphere, and O_3 and HCl gradients are strong at altitudes where those species have large horizontal gradients. Between 3 and 27 September, the development of the "ozone hole" and chlorine deactivation are seen in lower strato-

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spheric O_3 and HCl, respectively, as described by *Santee et al.* [2005]. The vortex breakup progresses from the top down as is typical in the SH [e.g., *Manney et al.*, 1994; *Orsolini et al.*, 2005], with transport of low-latitude, high-N_2O air into the polar regions at increasingly lower altitudes. This transport is also reflected in HCl in the middle and lower stratosphere, where its horizontal gradients are large, and in O_3, where high values in the midstratospheric mixing ratio peak intrude progressively further poleward. By 27 September, the vortex has weakened in the upper stratosphere, and by 15 October it is apparent only below ~900 K. By 21 November, a significant transport barrier exists only below ~600 K, with both N_2O and HCl showing mid-EqL values transported to the pole near or below 700 K. Low N_2O values inside and along the vortex edge progress downward through late November, indicating continuing descent through this period. However, starting about 15 October, higher N_2O begins to appear in the lower stratospheric vortex center below ~600 K (and lower HCl appears at the lowest levels shown in late November), suggesting the beginning of weak ascent in the vortex core at some lower stratospheric levels; this is consistent with the calculations of *Manney et al.* [1994]. We show below how this 3D evolution appears in trace gas distributions in the middle and lower stratosphere.

Figure 2 shows timeseries at 850 K in the middle stratosphere of effective diffusivity (K_{eff}) calculated from GEOS-4 PV and MLS N_2O, H_2O and O_3. K_{eff}, expressed as log-normalized equivalent length, measures the complexity of tracer contours; high values indicate mixing regions and low values transport barriers [e.g. *Haynes and Shuckburgh*, 2000; *Allen and Nakamura*, 2001]. Very low K_{eff} values coincident with strong PV gradients show the transport barrier at the polar vortex edge. Sporadic increases in mid-EqL (extravortex) mixing in September are associated with minor warming events, common in the SH late winter [e.g., *Harvey et al.*, 2002], that have little effect on vortex strength. However, at the end of September, a large increase in mid-EqL mixing accompanied by a weakening polar vortex transport barrier (increasing K_{eff}, diverging PV contours) signals vortex erosion leading to the breakup. The vortex edge remains distinct until mid-October, when the isolated area rapidly retreats to the pole, accompanied by large mixing over a broad EqL range. By the beginning of November, the vortex has broken up and a distinct transport barrier is no longer apparent.

The timeseries of MLS N_2O (H_2O) shows episodic decreases (increases) in mid-EqL values during periods of stronger mixing, and the erosion of low (high) values characteristic of the vortex as that transport barrier dissipates. Also apparent in early September and again in early October are

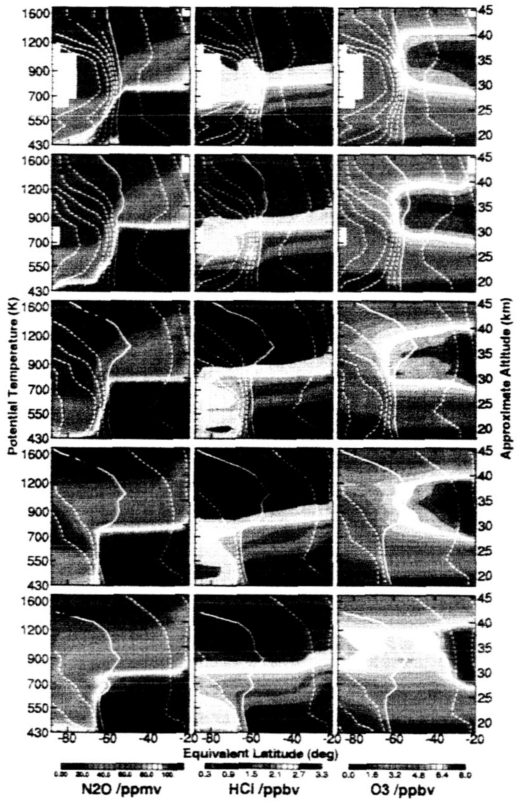

Figure 1. Equivalent Latitude (EqL)/potential temperature cross-sections of MLS N_2O, HCl, and O_3 during the 2004 SH vortex breakup. Overlaid contours are scaled potential vorticity (sPV, *Manney et al.* [1994]).