Ozone enhanced layers in the Antarctic ozone hole

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1. Summary

After reaching the maximum area on September 24, the Antarctic ozone hole in 2003 gradually recovered and disappeared on December 8 [cf. Sato et al., submitted]. In this study, ozone enhanced layers observed inside the ozone hole during its recovery period are investigated using ozonesonde data at Syowa and Neumayer Antarctic Stations. Our analysis shows that the ozone enhanced layers inside the ozone hole are induced by intrusion of ozone rich air from the polar vortex boundary region. A contribution of the ozone enhanced layers to the ozone hole recovery is estimated at ∼4DU, which is much smaller than the total recovery.

2. Data and Method

2.1 Data

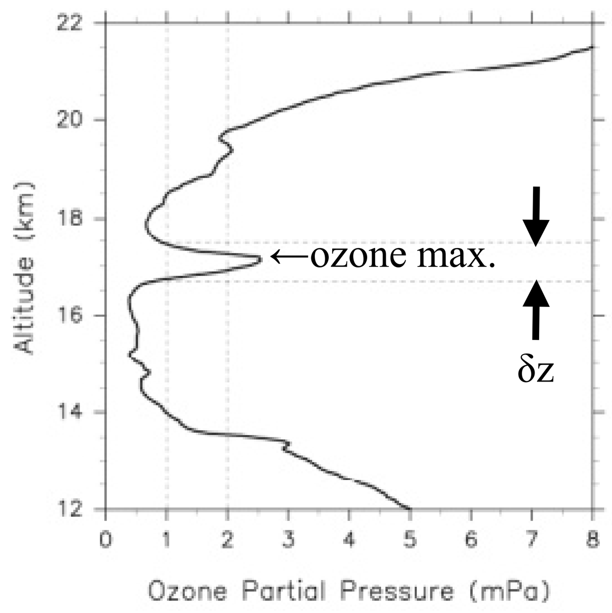
- Ozonesonde data at Syowa Station (69S, 39.6E) during September 26 to October 24 in 2003 (10 profiles)
- Ozonesonde data at Neumayer Station (70.65S, 8.25E) during September 26 to October 24 in 2003 (12 profiles)
- ECMWF objective analysis data

2.2 Definition of ozone enhanced layers

Ozone enhanced layers are defined when satisfying following conditions

- Maximum of ozone partial pressure higher than 2mPa between 12 and 20km
- Minima of ozone partial pressure lower than 1mPa above and below the maximum

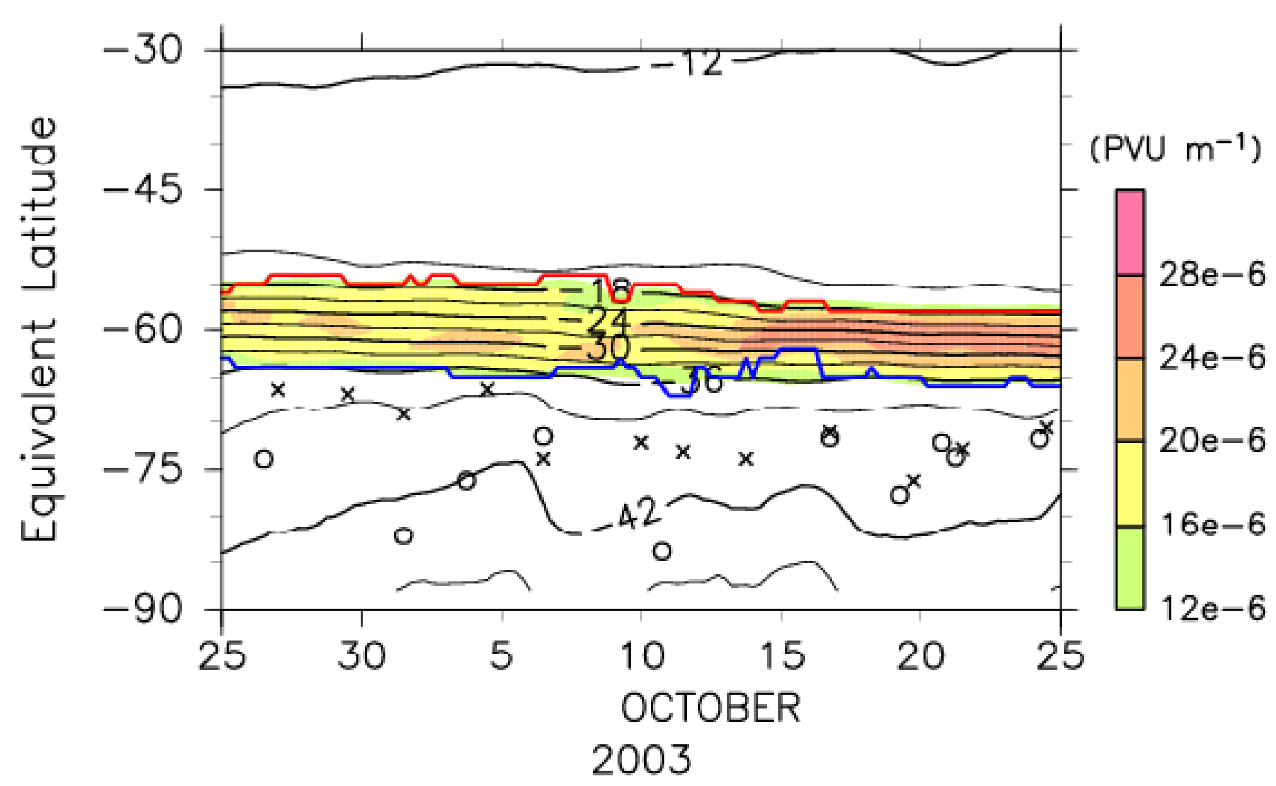
(See right figure)



2.3 Definition of vortex boundary region

Equivalent latitude (ϕ_e) is employed as a coordinate relative potential vorticity (PV) contours. An edge of polar vortex is defined by a maximum of isentropic PV gradients with respect to ϕ_e. Inner and outer edges of vortex boundary region are defined by local maximum and minimum of second-order differential of PV with respect to ϕ_e. A region poleward of the inner edge of vortex boundary region is called a vortex core.

A figure below shows a time- ϕ_e section of PV and PV gradient during the analysis period. A region of ϕ_e=55∼65 deg. is corresponding to the vortex boundary region throughout the period. Syowa and Neumayer Stations (○ and ×, respectively) are always located in the vortex core.



Time- ϕ_e section of PV (contours) and PV gradients with respect to ϕ_e (colors) at 435K. Blue and red lines represent inner and outer edges of the vortex boundary region. ○ and × are equivalent latitudes of Syowa and Neumayer Stations, respectively.

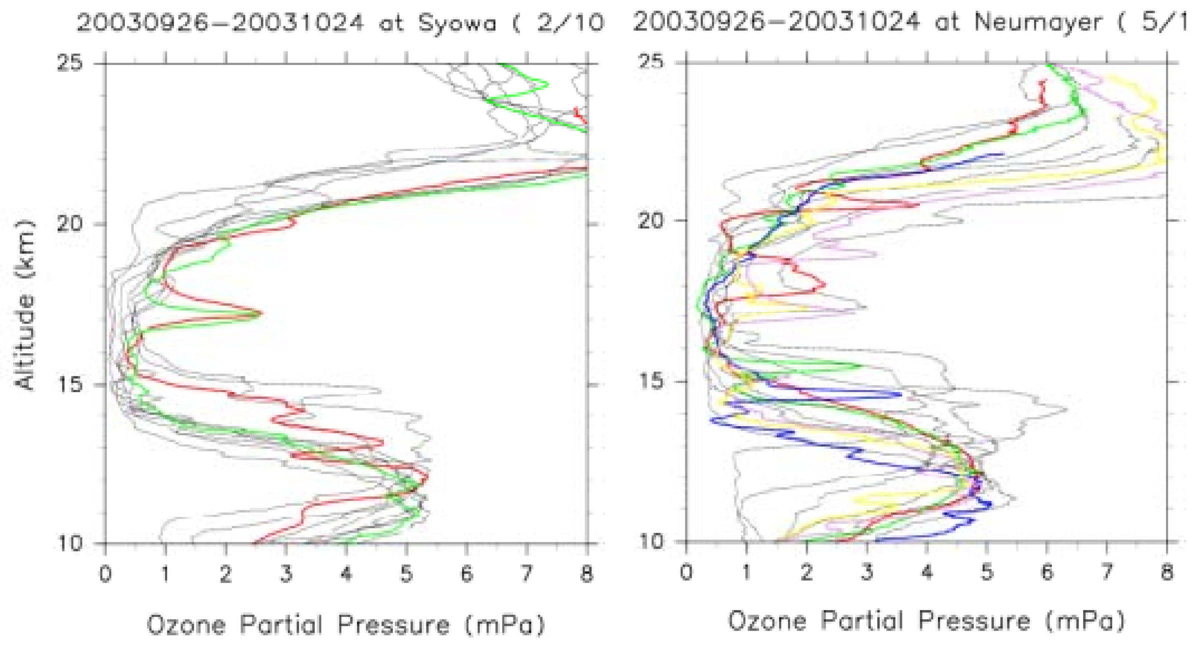
2.4 Reverse Domain Filling (RDF) method

A vertical resolution of PV distribution depends on the resolution of analysis data (∼ 4km). In order to obtain "high resolution" PV field, a reverse domain filling (RDF) method is used here. In the RDF method, air parcels are arranged on a 0.5deg.×1deg. latitude and longitude mesh. A PV value of each air parcel is replaced by that at the position of the parcel 7days before, which is computed using the NIPR trajectory model. Since the PV is conserved for 1-2 weeks and a spatial scale of the PV anomaly decreases exponentially with the typical e-folding time of 4days in the lower stratosphere, the reconstructed PV field is supposed to have a vertical resolution of about 0.7 km.

3. Results

3.1 Characteristics of ozone enhanced layers

Based on the definition, ozone enhanced layers were detected twice out of 10 observations at Syowa and 5 times out of 12 observations at Neumayer (see right figure).



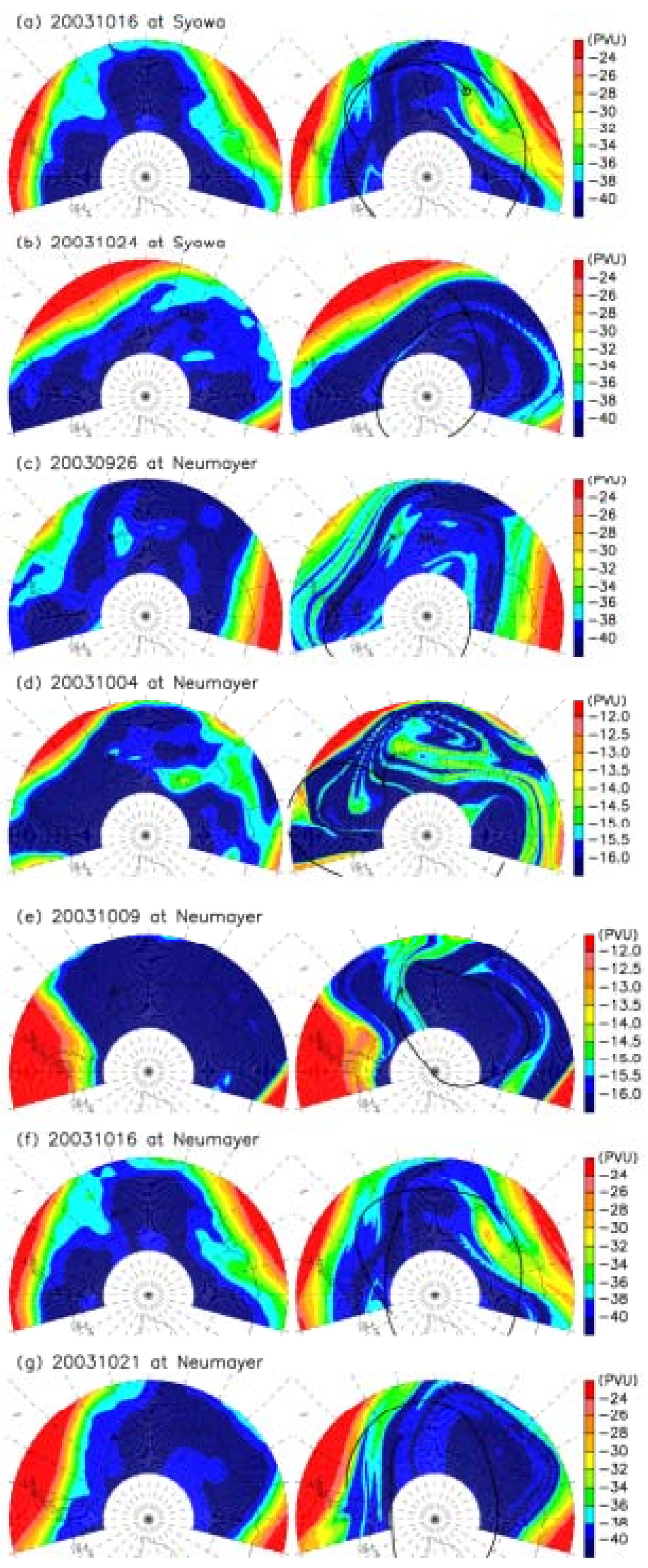
Vertical profiles of ozone partial pressure at (left) Syowa and (right) Neumayer Stations. Color lines represent ozone profiles with ozone enhanced layers.

Ozone enhanced layers always had a thickness thinner than 2km (see table below). Their maximum ozone mixing ratio was between 0.3 and 0.5ppmv. An ozone mixing ratio was mostly smaller than 0.2ppmv inside the ozone hole and larger than 0.5ppmv in midlatitude. Thus it is inferred that they originated from the vortex boundary region.

		Ozone maximum					Ozone enhanced layer			
Site	Date	z (km)	P (hPa)	θ (K)	P_{O3} (mPa)	χ_{O3} (ppmv)	δz (km)	$\delta\theta$ (K)	δO_3 (DU)	Total ozone (DU)
S	10/16	17.2	65.5	431	2.60	0.397	1.360	35.0	3.0	166
S	10/24	17.1	67.4	437	2.55	0.378	0.761	14.1	1.8	145
N	9/26	18.1	55.1	438	2.30	0.417	1.345	28.8	3.5	126
N	10/4	15.5	87.2	385	2.90	0.333	0.431	7.4	1.3	131
N	10/9	14.6	98.7	375	3.57	0.362	1.010	15.3	2.6	130
N	10/16	17.3	63.6	434	2.00	0.314	0.712	15.7	1.3	134
N	10/21	17.2	66.7	435	2.79	0.418	1.533	36.8	3.4	146

Characteristics of the ozone enhanced layers observed at Syowa (S) and Neumayer (N) Stations.

3.2 Formation mechanism of ozone enhanced layers



Polar projection maps of PV at 435K (a-c, f-g) and 380K (d-e) computed by the ECMWF data (left) and reconstructed by the RDF method (right) when the ozone enhanced layers were observed at Syowa (a-b) or Neumayer (c-g). Regions with -18∼-36 PVU in (a-c, f-g) and -11∼-15 PVU in (d-e) are corresponding to the vortex boundary region. Black lines show the 7-days backward trajectories.

In the ECMWF data, Syowa and Neumayer Stations are always located in the vortex core region (left panels). On the other hand, PV filaments with values of the vortex boundary region reach near Syowa and Neumayer Stations in the reconstructed PV field (right panels).

Backward trajectories are not always circumpolar, although eastward advection due to the polar-night jet is dominant. Trajectories are perturbed by transient planetary waves with s=1 (e), 2 (b, g) and 3 (d). While trajectories are determined by planetary-scale waves, tracer distributions have horizontal and vertical scales much smaller than the planetary scale. This is a characteristic of the chaotic advection.

4. Discussion

- Appearance frequency of ozone enhanced layers (= total area occupied by ozone enhanced layers) ≤ 50%
- Lifetime of ozone enhanced layers ≈ 2 weeks [cf. Reid et al., 1998]
- Column ozone amounts in the layer ≤ 4DU

Ozone recovery due to ozone enhanced layers ≤ 4DU/Month
(if photochemical sources and sinks are negligible)

A contribution of ozone enhanced layers to the ozone hole recovery is negligibly small compared to the total recovery (∼100DU)