TWELVE YEARS OF ARCTIC OZONE LOSS OBSERVED BY THE ODIN SATELLITE

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ABSTRACT

Odin, the Swedish-led satellite project in collaboratation with Canada, France and Finland, was launched on 20 February 2001 and continues to produce profiles of chemical species relevant to understanding the middle and upper atmosphere. The long-term observation of stratospheric ozone can be useful for trend analysis of chemical ozone loss. This study concerns ozone loss over the northern pole utilizing the 12 years of ozone data from Odin/SMR. In order to quantify the chemical loss, it is necessary to clearly understand the contribution of dynamics in ozone changes. We have applied the data assimilation technique described in Rösevall et al. [13] with a number of improvements to study the inter-annual variability during the entire Odin period.

Key words: Stratosphere; Arctic; O_3; Odin/SMR.

1. INTRODUCTION

The ozone (O_3) hole is the phenomenon of removing more than 80% of ozone from the inside of the antarctic polar vortex in the lower stratosphere in early spring. This is related to catalytic destruction by species such as Cl, Br and NO_x and also the formation of Polar Stratospheric Clouds (PSCs) [16].

Chemical loss is also observed in the northern hemisphere. Whereas in general the arctic O_3 loss is relatively weaker than the O_3 hole over Antarctica, many groups reported dramatic ozone depletion over the arctic polar region approaching that of the antarctic ozone hole in 2011 [e.g. 1, 7, 15]. Meanwhile, the total O_3 depletion in the arctic winter has been found to be linearly dependent on the volume of air having temperature below the threshold for PSC formation [10]. The fact that the arctic lower stratosphere has been getting colder over the past decades [11] predicts that arctic O_3 loss may become worse if the cooling trend continues.

It is important to have continuous observations and trend analysis of the arctic O_3 depletion. Several studies have quantified the arctic loss using a variety of techniques based on different assumptions and instruments

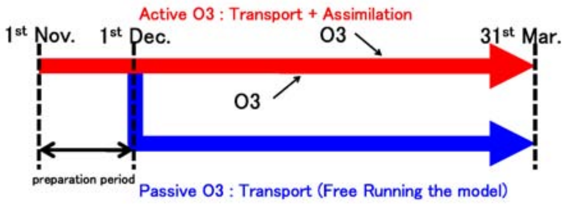

Figure 1. Schematic diagram of the study.

[e.g. 3, 5, 10, 14, 18, 19] . However, the unstable nature of the arctic vortex due to the propagation of planetary waves excited by the complex topography of northern hemisphere makes quantifying chemical ozone loss in the arctic more difficult.

2. METHODOLOGY

We applied the assimilation technique using a transport model to estimate the O_3 loss as demonstrated earlier [13]. Data assimilation is used to combine the measurements and the numerical model, is well known as a tool for weather prediction. This method allows us to separate the dynamical and chemical changes in the ozone amount. We used two O_3 fields derived from the model. One is the active O_3, which is modeled O_3 modified by the data assimilation of Odin/SMR measurements. The other O_3 field is passively transported in the advection model. The specific process of our calculations is shown in figure 1. The chemical O_3 depletion can be derived by subtracting passive O_3 from active O_3.

3. MODEL AND DATA

3.1. DIAMOND model

The original DIAMOND (Dynamic Isentropic Assimilation Model for OdiN Data) model is an off-line wind driven isentropic transport and assimilation model designed to simulate horizontal ozone transport in lower stratosphere with low numerical diffusion [12]. Horizontal advection employing the Prather transport scheme [9] has been performed on separate layers with constant

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potential temperature (PT) from 400K to 1000K in 25K intervals. The ECMWF operational winds were used in the advection scheme. The assimilation scheme in DIAMOND is described as a variant of the Kalman filter. The details of the assimilation scheme can be found in [12].

The assumption of adiabatic conditions break down during polar winter when there is strong radiative cooling of the air masses inside the polar vortex. Thus, we implemented a simple vertical transport scheme into DIAMOND. This scheme is based on the one dimensional first-order upstream method. The vertical velocity ω is calculated as,

$$\omega = \left(\frac{\Theta}{T}\right) \cdot Q \tag{1}$$

there, Θ and T are potential and absolute temperature, respectively. Q is the diabatic heating rate [K/sec] derived from SLIMCAT calculations [2].

3.2. Odin/SMR

Odin is a Swedish satellite mission in association with Canada, Finland and France, which was designed for radio astronomy and limb sounding of the Earth's middle atmosphere [8]. It carries two different limb sounding instruments, OSIRIS (Optical Spectro graph/InfraRed Imaging System) and SMR (Sub-Millimetre Radiometer). The SMR instrument is described in Frisk et al. [4].

The dataset of O_3 from Odin/SMR used in this study was retrieved from the emission line at 501.5GHz, using the Chalmers version 2.1 retrieval scheme. The O_3 profiles cover the altitude range ~17-50 km with an altitude resolution of 2.5-3.5 km and an estimated single-profile precision of ~1.5 ppmv [20]. Odin/SMR v2.1 O_3 data has been validated against balloon sonde measurements as described in detail by [6].

4. RESULTS

4.1. The arctic losses during the Odin period

The chemical O_3 losses derived from our method can be categorized in 3 types, which are "cold winter", "warm winter" and intermediates between cold and warm. Figure 2 shows the time evolutions of the O_3 losses for the arctic winters 2004/2005, 2008/2009 and 2010/2011, corresponding to intermediate, warm and cold winters, respectively. The significant loss starts at the beginning of March for all winters. The characteristic difference appears in the altitudes having maximum depletion. The maximum depletion in cold winters took place in the lower stratosphere below 500K as in the antarctic O_3 hole. On the other hand, in warm winters, O_3 loss has the peak at around 650K. Those features are obviously seen in the monthly mean of chemical loss for March (see in figure 3). We consider that, although it is still unclear that this feature is real or an artifact caused by the method, the enhancement of O_3 loss is related to the Sudden Stratospheric Warming (SSW) in some way.

To evaluate our results, we compared the loss in 2004/2005 winter to the losses estimated from other methods and instruments. The details of other losses can be found in figure 14 in Sonkaew et al. [17]. We found the loss in 2004/2005 winter quantified from the DIAMOND is slightly smaller, but in agreement with the others within the error range. This underestimation of the loss from our method also applies in all winters. Several reason have been considered, and the main reason is the low sensitivity of the O_3 retrieved from 501GHz below 500K. Unfortunately, the measurement response which shows the quality of the measurement becomes rapidly worsen under 18km [20, Fig. 3].

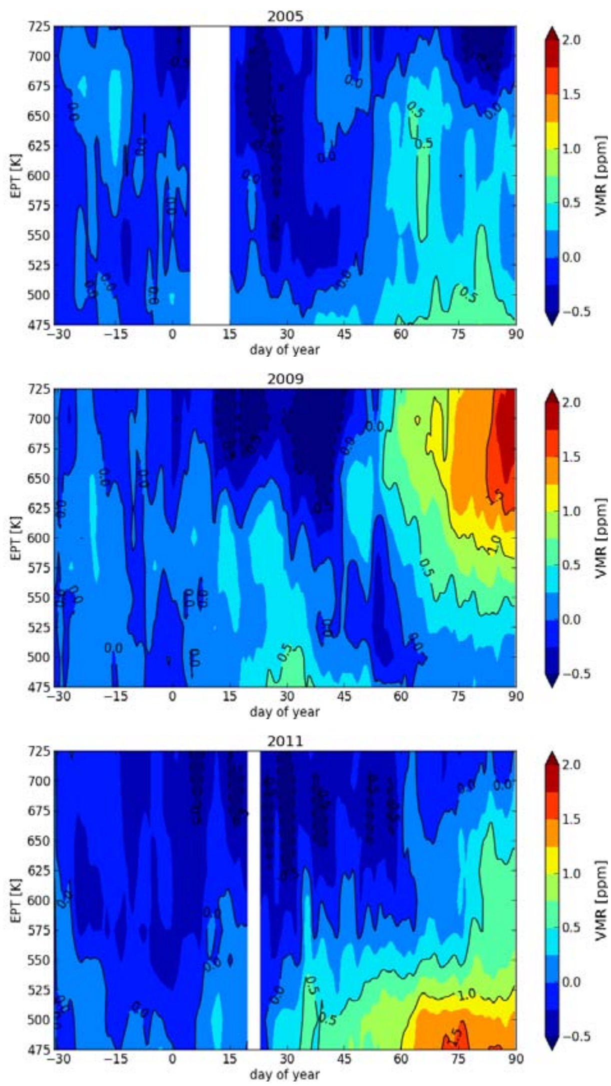

Figure 2. Vortex mean of O_3 as a function of time (days from 1 Jan.) and isentropic levels between 475K to 725K for selected winters, 2005, 2009 and 2011.

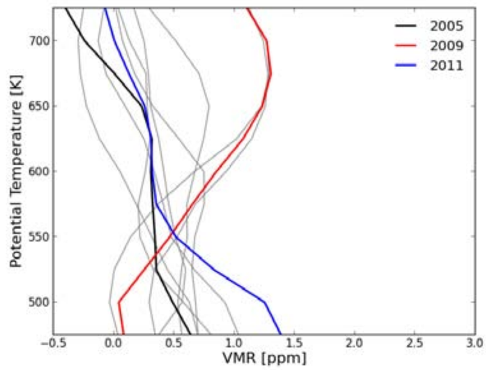

Figure 3. Monthly mean of chemical O_3 *loss for March for all winters from 2002 to 2012. The colored solid lines correspond to the winters in figure 2.*

4.2. The QBO effect on the loss

In figure 4, we show the temporal variation of monthly mean of O_3 for March and its anomaly. Apparently the anomaly has a similar pattern to the Quasi-Biannual Oscillation (QBO) in equatorial zonal winds. The calculated cycle of the anomaly was 2.73, this is close to the cycle of 2.42 estimated from ECMWF zonal winds. Progress study to reveal this behavior is undergoing.

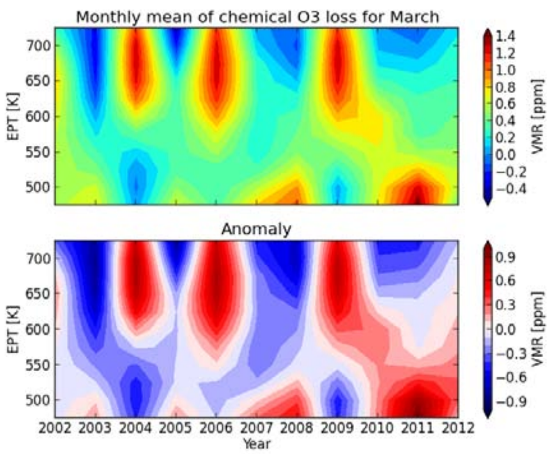

Figure 4. Time series of monthly O_3 *losses for the winters from 2002 to 2012 (top panel) and its anomaly (bottom).*

5. SUMMARY

Odin/SMR has been observing stratospheric ozone since 2001. Arctic chemical ozone losses during the northern winters from 2002 to 2012 were quantified by using the DIAMOND model. Comparison of derived O_3 loss in 2004/2005 winter agreed with the other methods within the error ranges. On the other hand, losses from our method for all winters are smaller than for other instruments. This underestimation is probably caused by the low sensitivity of the O_3 retrieved from 501Ghz below 500K. The peak of ozone loss is shown to be below 500K in cold winters, while it appears at higher altitudes in warm winters. Variation of O_3 depletions of each winters seems to have similar pattern to the QBO.

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