Twelve years of Arctic ozone depletion observed by Odin/SMR

Kazutoshi Sagi, Donal P Murtagh and Joachim Urban

Department of Earth and Space Science
CHALMERS UNIVERSITY OF TECHNOLOGY

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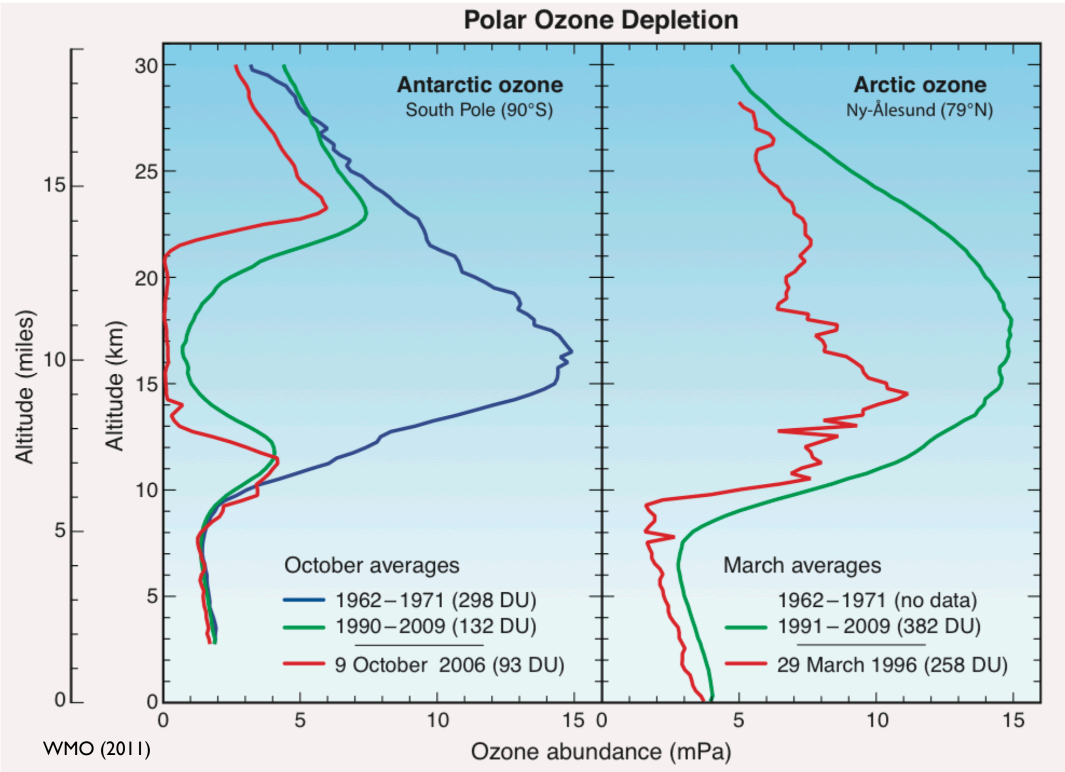
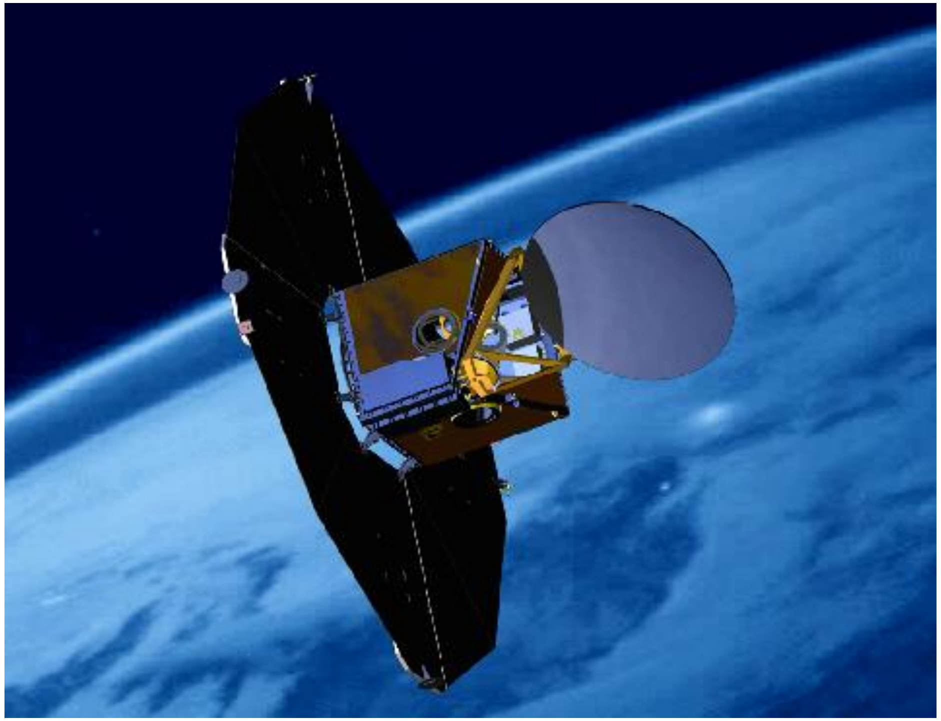
Polar Ozone Depletion



- Since the early 80's, large scale ozone depletion has been observed in the lower stratosphere in the early spring. (Farman et al., 1985)
- Polar ozone loss is caused by catalytic species, such as Cl, NOx and Br
- The process of depletion is also related to the formation of PSC
- Huge Ozone loss such as Antarctic ozone hall was observed in 2011 winter (Manney et al., Nature, 2011)

Odin/SMR

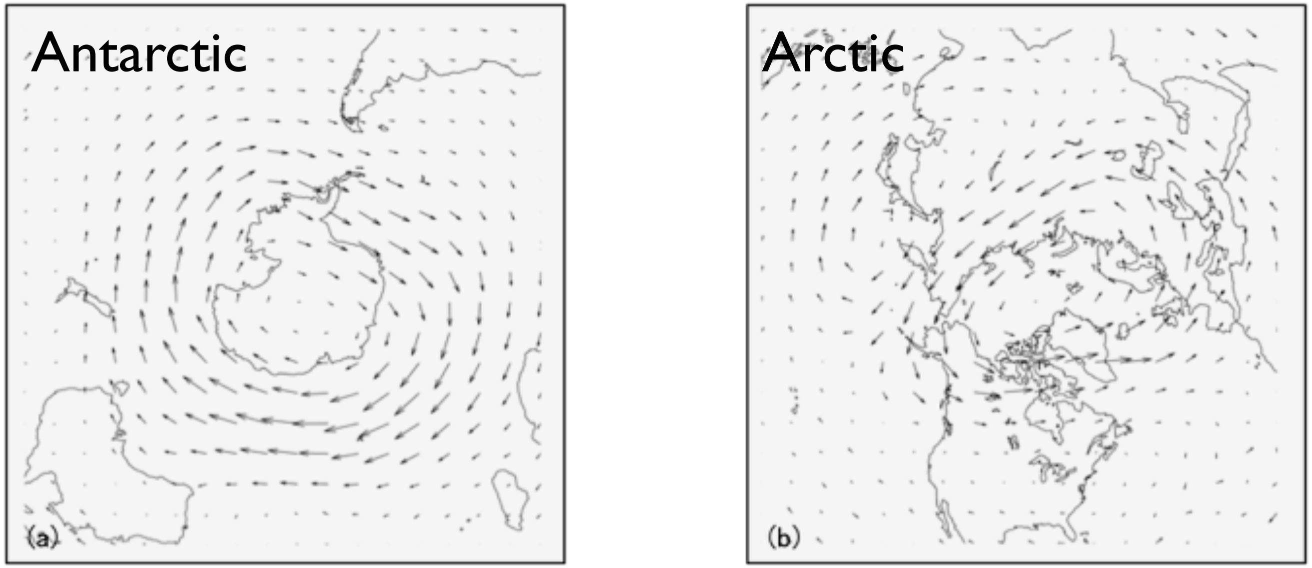
- Swedish-led satellite, collaborated with Canada, France and Finland
  - OSIRIS (Optical Spectrograph and Infrared Imaging System)
  - SMR (Sub-Millimetre Radiometer)
- launched on February 20, 2001



Long-term observation of stratospheric ozone can be used for trend study

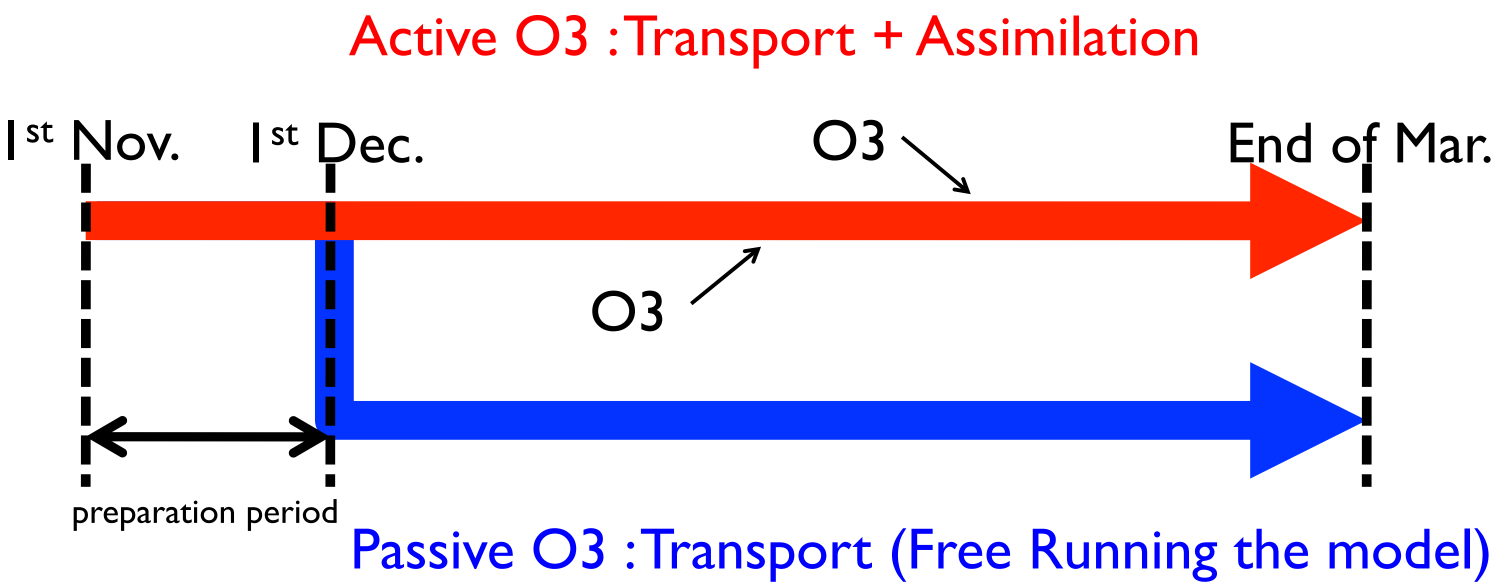
Arctic Ozone depletion

- difficult to quantify the ozone depletion over arctic region due to instability of the polar vortex



Stratospheric wind patterns over the winter poles. (a) Antarctic winds on 2006-07-01. (b) Arctic winds on 2007-01-01. The wind data have been obtained from the European Centre for Medium-range Weather Forcasts, ECMWF [John, 2007]

Methodology



$$O_{3loss} = O_{3active} - O_{3passive}$$

Possible to separate into "transport" and "chemical process" on Ozone VMR variation

DIAMOND model

(Dynamical Isentropic Assimilation Model for Odin Data)

- designed to simulate ozone horizontal transport in lower stratosphere (Rösevall et al., 2008)
- Square grid dedicated for the poles

- Horizontal Advection
  - Transport on isentropic surfaces
  - Prather transport scheme (Prather, 1986)
  - ECMWF operational winds

- Vertical Transport
  - 1st order upwind scheme
  - vertical motions calculated using SLIMCAT diabatic heating rate

- Assimilation
  - Statistical interpolation
  - Modified Kalman Filtering
  - Transported analysis errors

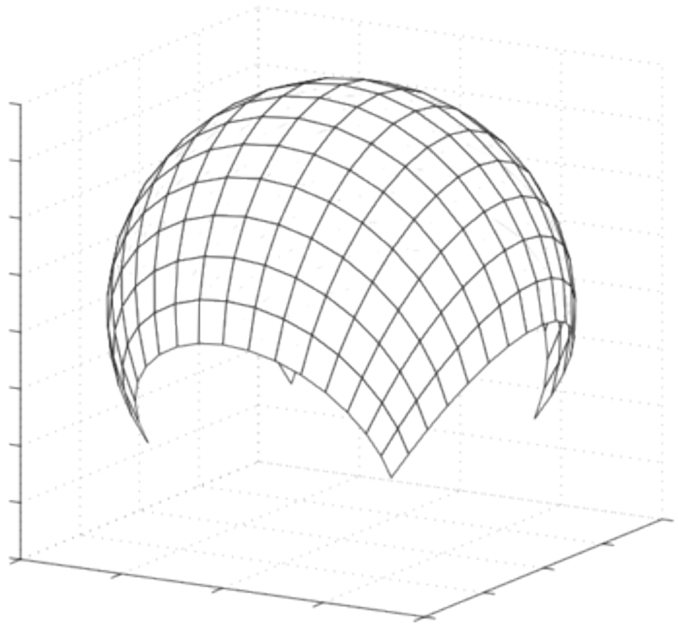
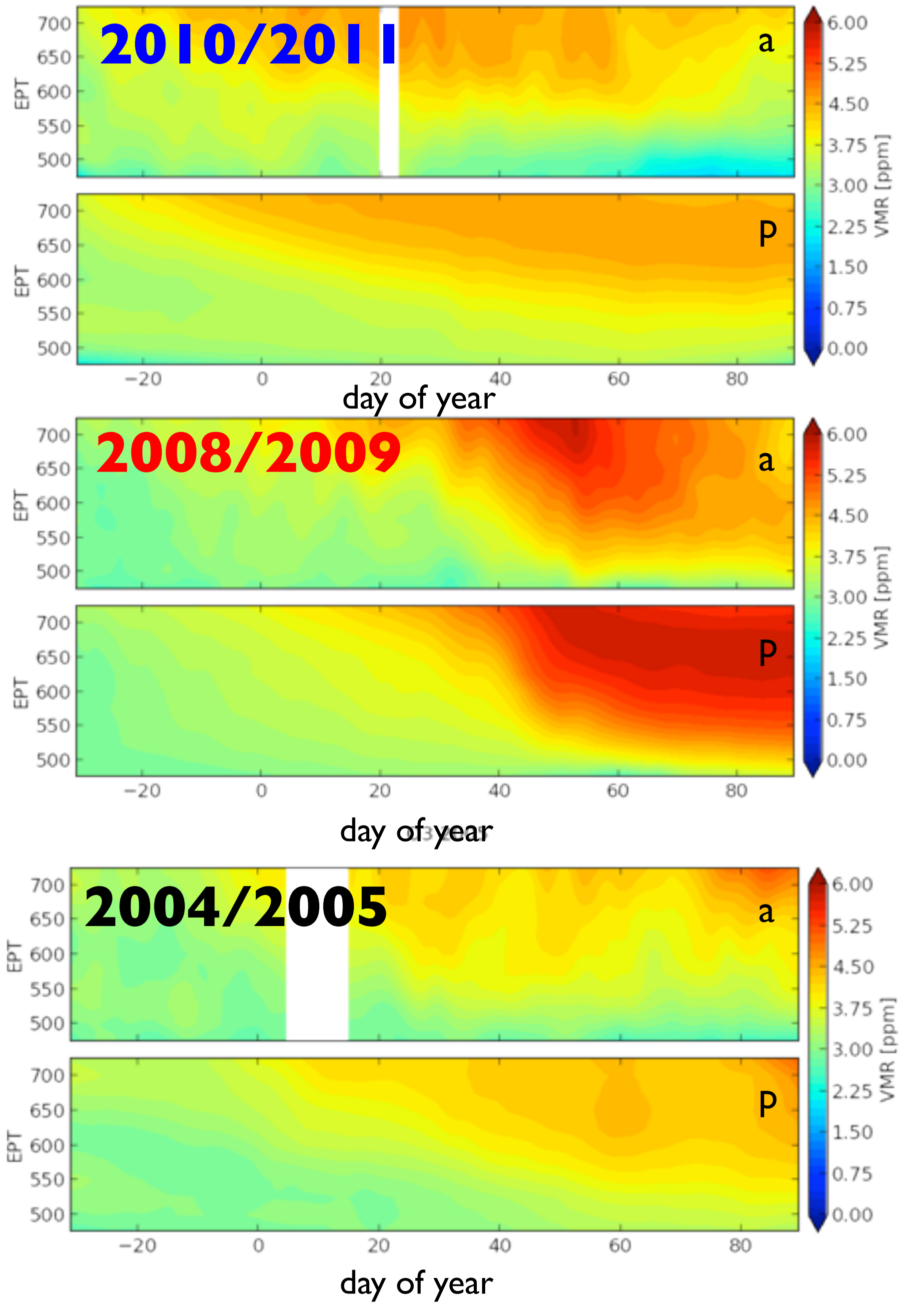


Fig. 2. The shape of the grid used in the DIAMOND model.

Ozone data

- Odin/SMR
  - Retrieved from 501.5 GHz (Chalmers Retrieval Scheme v2.1, Urban et al., 2005)
  - Altitude range and resolution : 18 ~ 50 km, 2.5-3.5 km
  - Systematic Error : < 0.3 ppmv

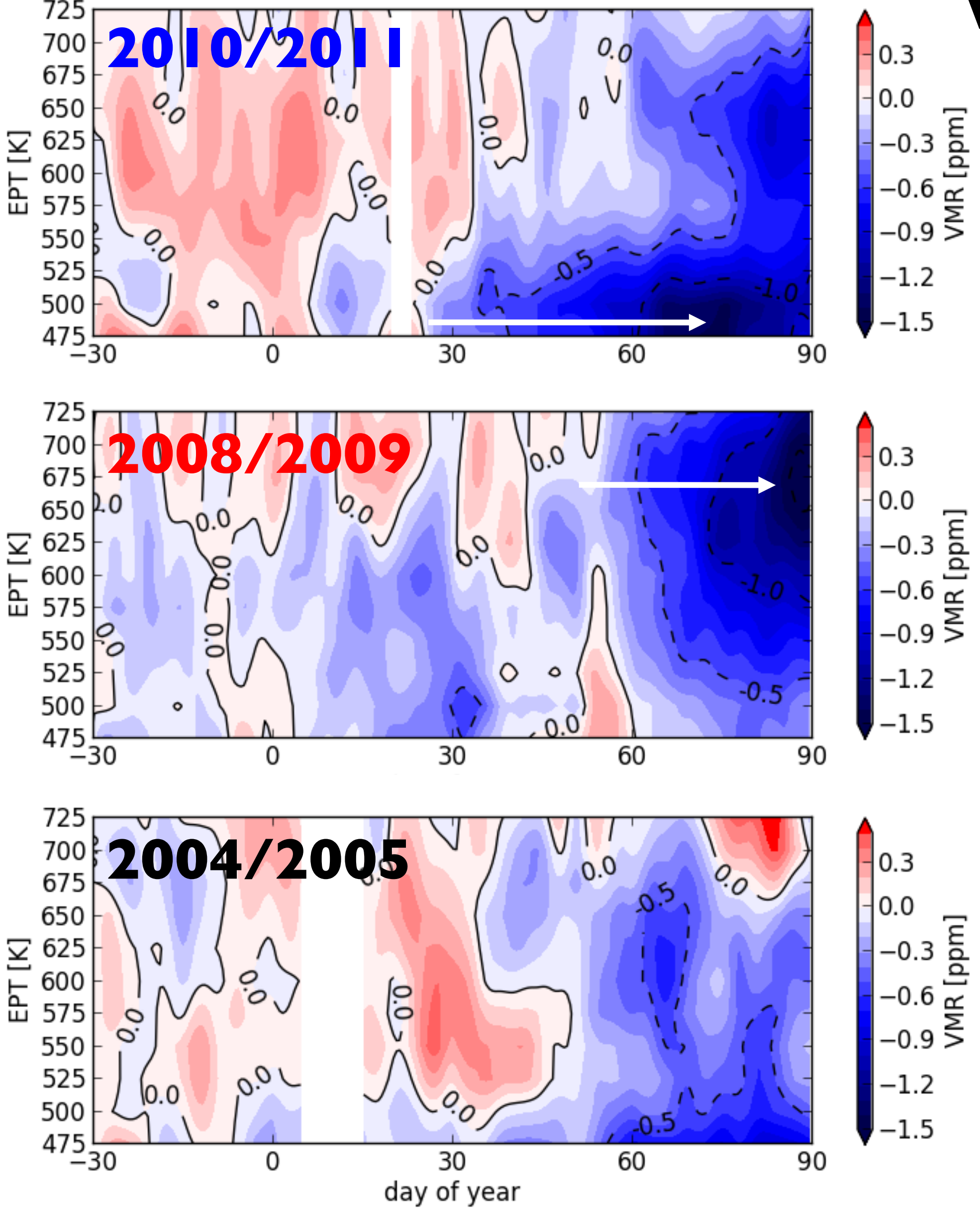
Vortex Mean of Ozone



- Diabatic descent inside vortex is visible
- All ozone distributions can be categorized in 3 types

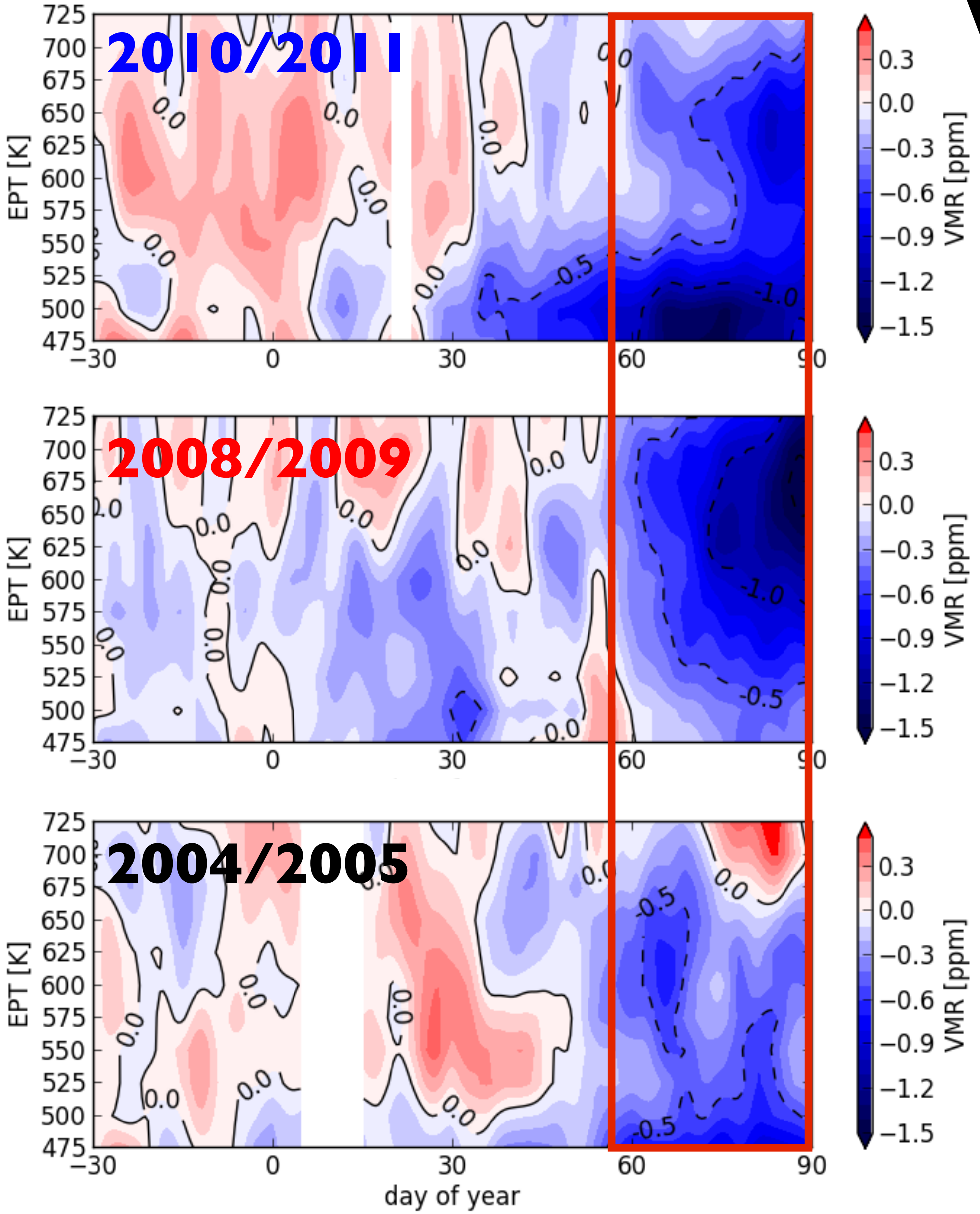
1) Cold Winter
2) Warm Winter
3) intermediate

Vortex Mean of loss



- Cold Winter
  - Ozone loss starts from beginning of February below 500K
- Warm Winter
  - major loss starts from beginning of March
  - around 650K

Vortex Mean of loss



- Cold Winter
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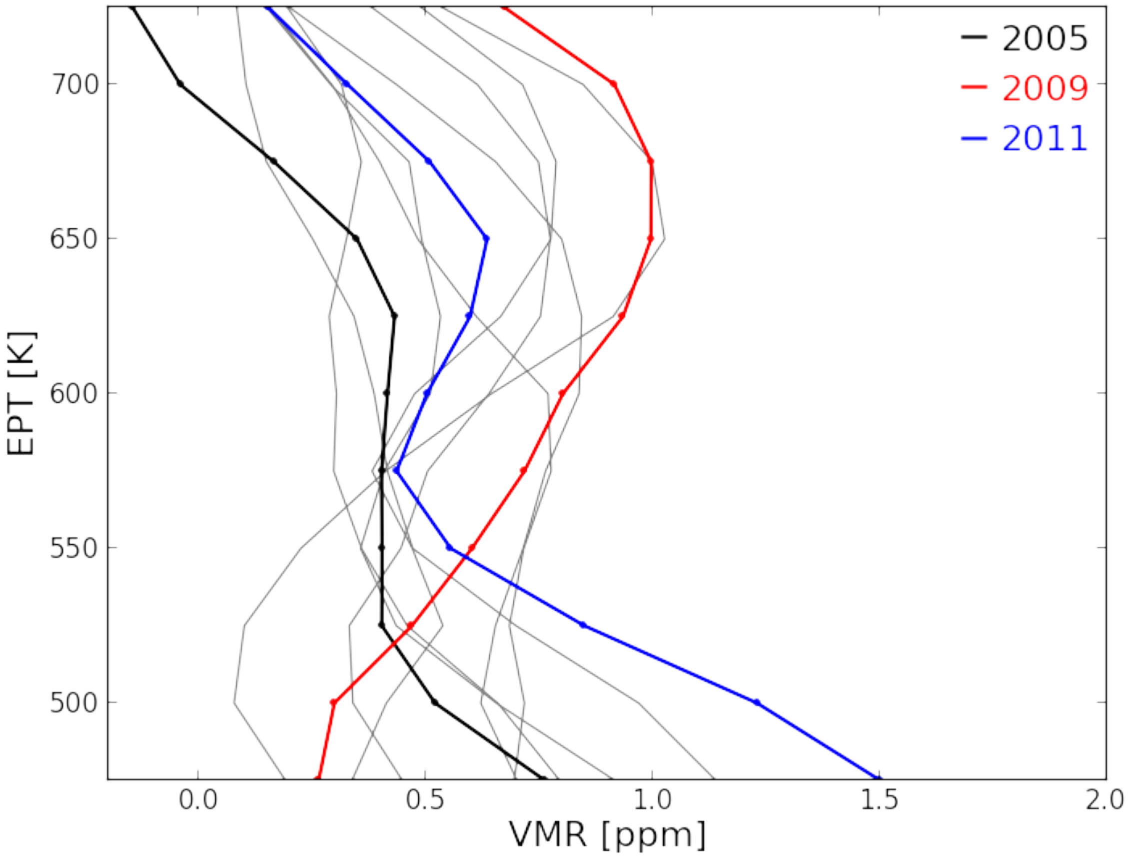
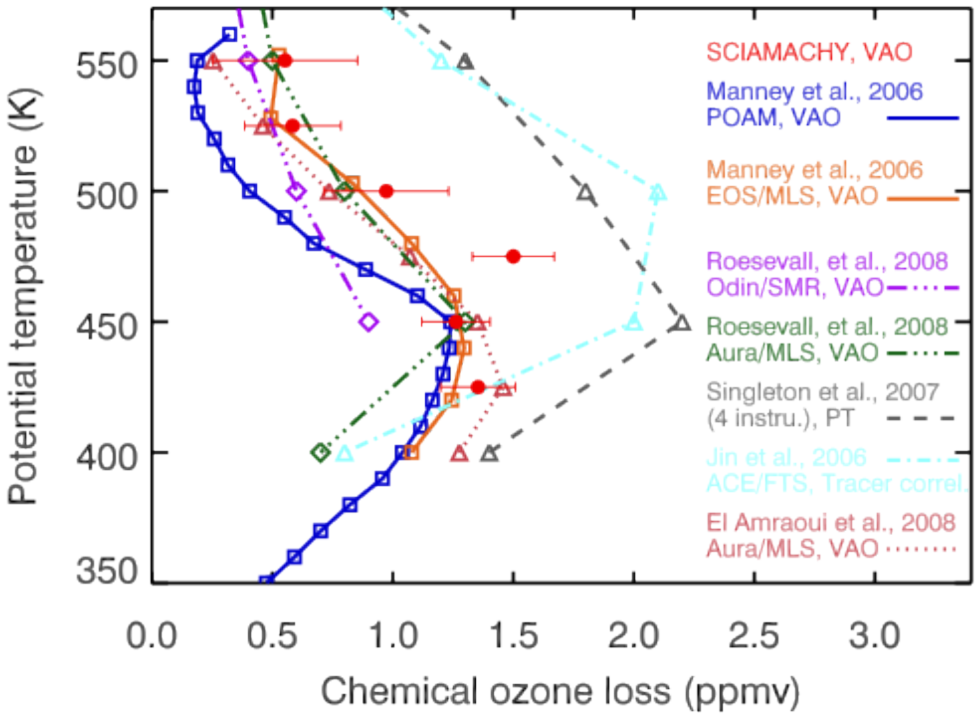
Monthly Average of Chemical ozone depletion for March



Comparison with other Instruments and Methods

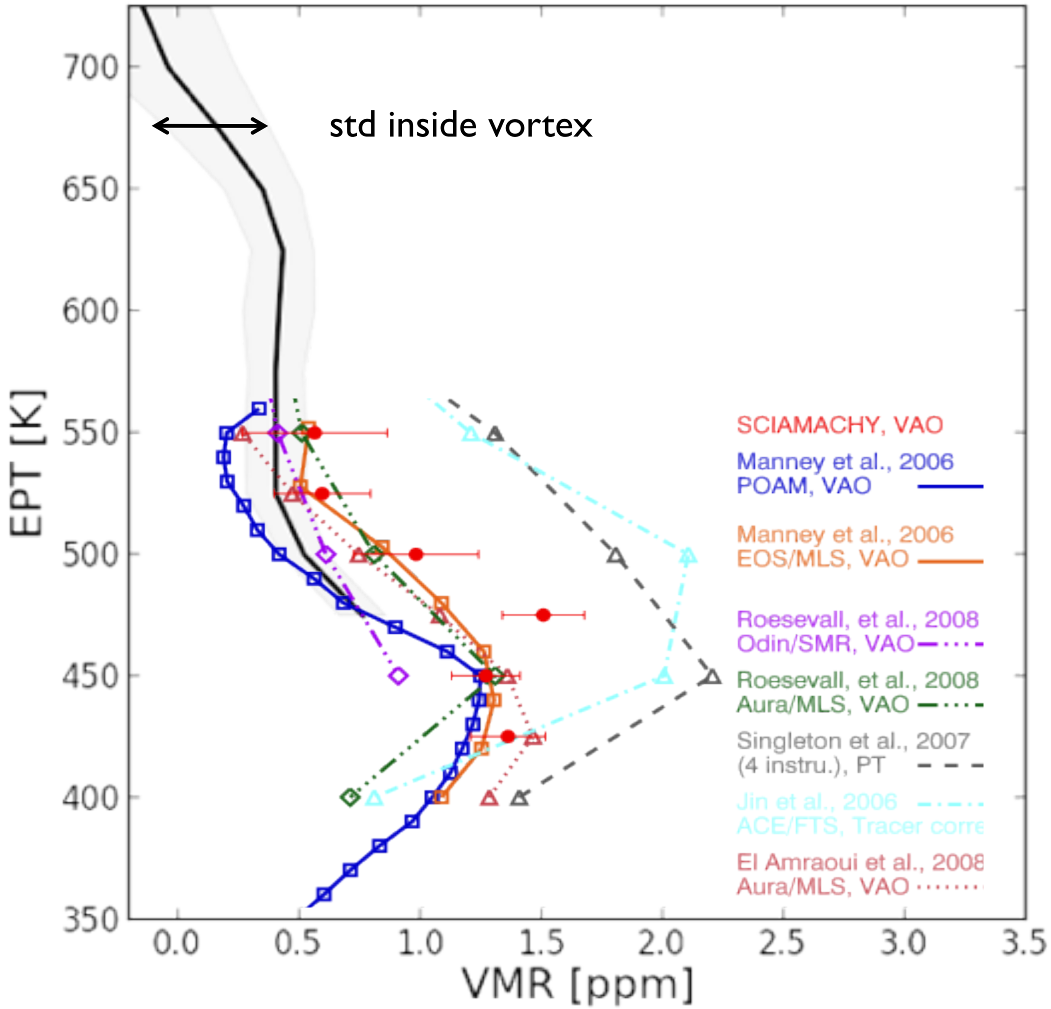
Chemical Ozone loss 2004/2005



T. Sonkaew et al., ACP, 2013

Ref	Instrument	Technique
T. Sonkaew et al., 2013	SCIAMACHY	Vortex Average
Manney et al., 2006	POAM	Vortex Average
Manney et al., 2006	EOS/MLS	Vortex Average
Rösevall et al., 2008	Odin/SMR	Original DIAMOND
Rösevall et al., 2008	Aura/MLS	Original DIAMOND
Singleton et al., 2007	POAM III, SAGE III, EOS MLS, ACE-FTS, and MAESTRO	Passive Subtraction
Jin et al., 2006	ACE/FTS	4 different techniques
El Amraoui et al. 2008	Aura/MLS	Vortex Average

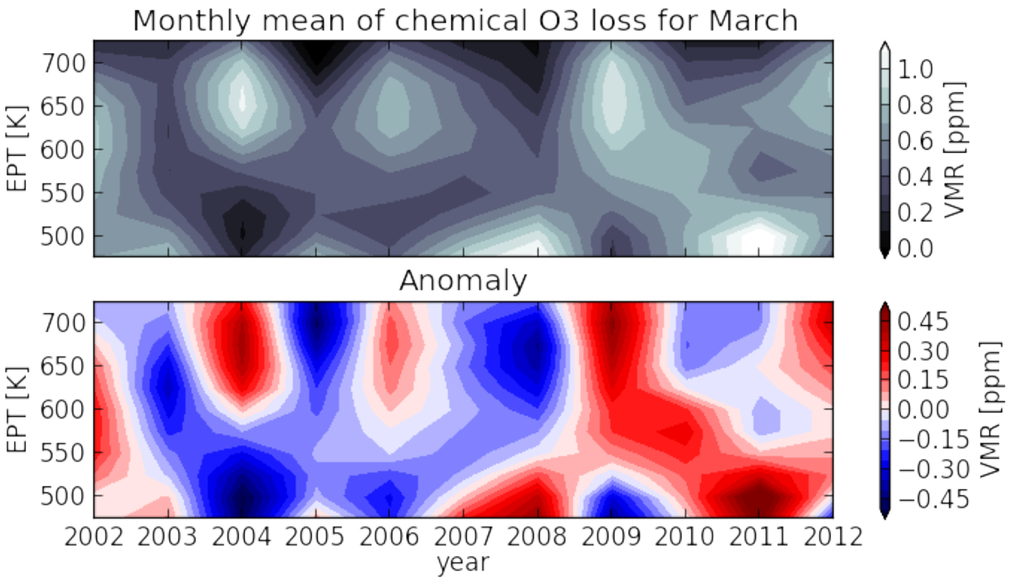
Comparison with other Instruments and Methods

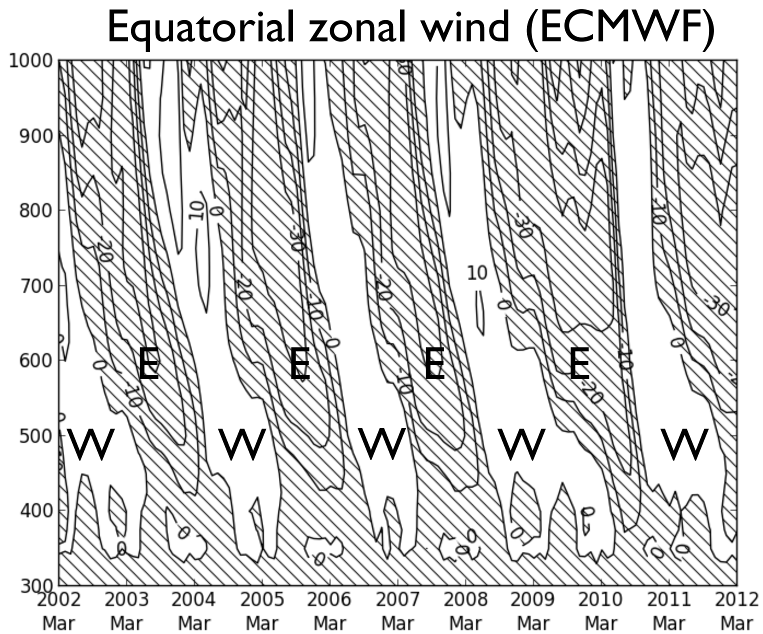


Under estimate the loss

- Odin/SMR Ozone biased?
- Due to the under estimate of diabatic descent inside vortex?

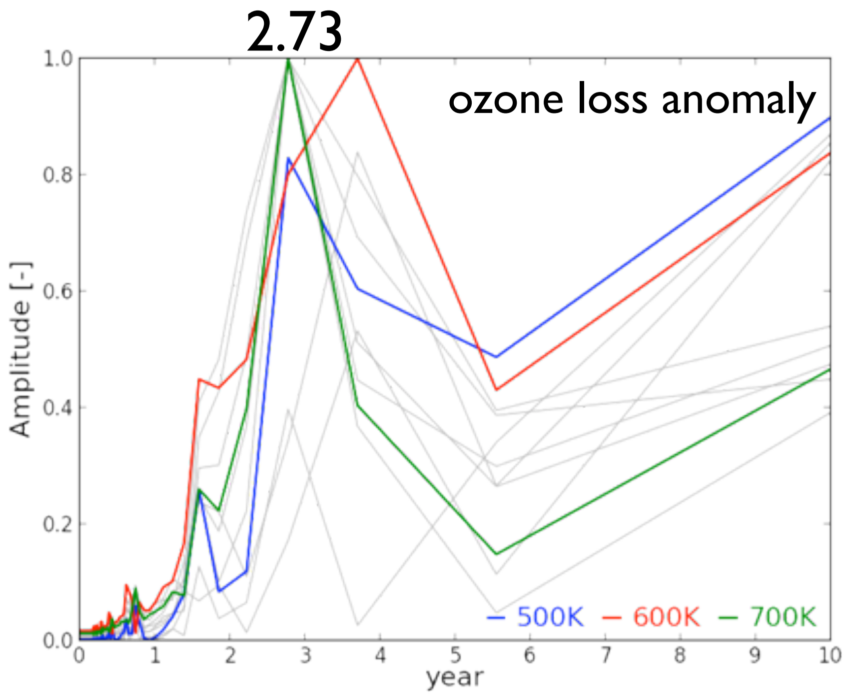
Variation of loss

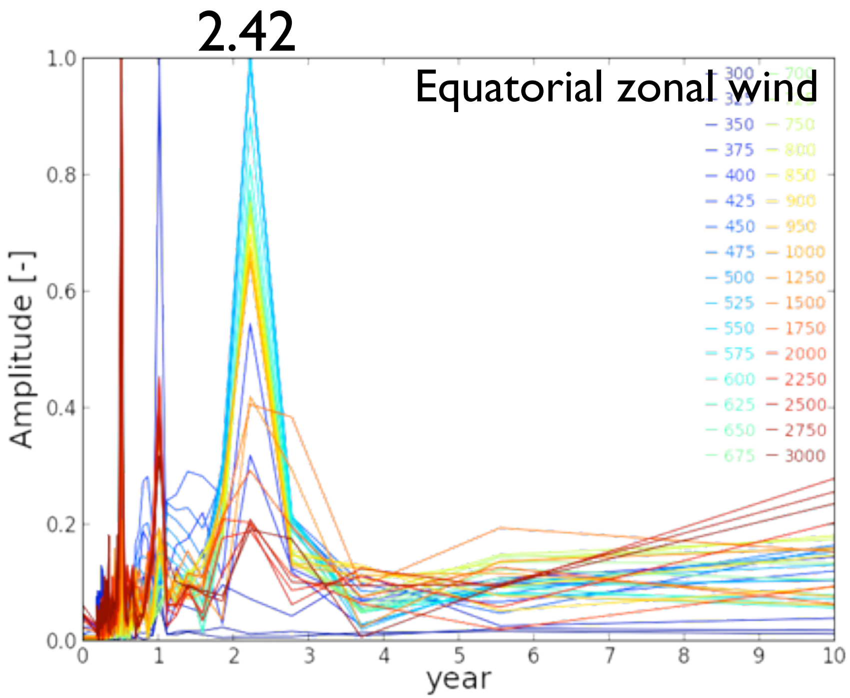




Periodic pattern is similar to QBO in equator

Spectrum of Ozone loss anomaly





Summary

- Odin/SMR is observing stratospheric ozone from 2001
- Arctic chemical ozone losses of Northern winters from 2002 to 2012 were quantified by using DIAMOND model
- Comparison of derived ozone loss in 2004/2005 winter agreed with the other methods in error range
- Losses from our method for all winters are lower than other instruments
- The peak of ozone loss is shown below 500K in cold winter, while it appears higher in warm winter
- Variation of ozone depletions of each winters seems to have similar pattern with QBO

Appendix

How to combine model and measurement ?

- Assimilation is usually used for meteorological prediction
- Measurement ingested into numerical model to estimate the optimal state

- Estimated ozone VMR and assimilation error are given as

$$\hat{x} = \left(\frac{1}{\sigma^2_{model}} + \frac{1}{\sigma^2_{meas}}\right)^{-1} \left(\frac{x_{model}}{\sigma^2_{model}} + \frac{x_{meas}}{\sigma^2_{meas}}\right)$$

$$\sigma = \left(\frac{1}{\sigma^2_{model}} + \frac{1}{\sigma^2_{meas}}\right)^{-1}$$

- Linear growth of error with time can be used to approximate the uncertainties due to the imperfection of transport model and chemical processes in Stratosphere

$$\sigma\left(t + \Delta t\right) = \sigma\left(t\right) + k_\sigma \cdot \Delta t$$

Chemical process of Ozone depletion

(1) Cl2 and HOCl are released by heterogeneous reactions on the surface of PSCs.

(2) Cold winter (<-80oC) required to form PSCs

(3) In early spring, Cl and ClO are produced by the photo-dissociation of Cl2 and HOCl

(4) Cl catalytic destruction cycle

(5) The cycle stops by reactions to CH4 or NO2

1.

$$ClNO_3 + HCl \xrightarrow{PSC} Cl_2 + HNO_3$$

$$ClNO_3 + H_2O \xrightarrow{PSC} HOCl + HNO_3$$

$$HOCl + HCl \xrightarrow{PSC} Cl_2 + H_2O$$

3.

$$Cl_2 + h\nu \longrightarrow 2Cl$$

$$HOCl + h\nu \longrightarrow OH + Cl$$

4.

$$Cl + O_3 \longrightarrow ClO + O_2$$

$$ClO + ClO \longrightarrow Cl_2O_2 + M$$

$$ClOOCl + h\nu \longrightarrow Cl + ClOO$$

$$ClOO + M \longrightarrow Cl + O_2 + M$$

$$\text{Net}: 2O_3 \longrightarrow 3O_2$$

5.

$$Cl + CH_4 \longrightarrow HCl + CH_3$$

$$ClO + NO_2 + M \longrightarrow ClNO_3 + M$$

Vertical transport

$$\psi\left(z,t+\Delta t\right)=\psi\left(z,t\right)\left(1-\omega\frac{dt}{dz}\right)+\psi\left(z-\Delta z,t\right)\omega\frac{dt}{dz}$$