Modelling of potential vorticity transport in the polar stratosphere during Spring and Summer 2005

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Context

The polar stratosphere remains largely unexplored in the summertime compared to polar winter ozone depletion issues. Former studies mainly focused on the summer chemical ozone loss processes. However, several significant gaps remain regarding :
1) the knowledge of the dynamical state and of the compound content characterizing the polar summer stratosphere
2) the ability of models to simulate properly the involved mechanisms. These uncertainties have an impact on the understanding of the processes controlling the ozone budget and consequently of the ozone-climate interactions.

In the frame of the International Polar Year the **STRAPOLETE** protect has started on January 2009 to study the Arctic stratosphere in the summertime for which a dynamical transition regime towards the conditions settling the winter stratosphere is expected. In the context of this project we study in detail past summer (year 2005) from March when the vortex breakdown to summer in order evaluate the ability of dynamical model to represent large scale transport and mixing processes occuring.

Introduction

The vortex break up takes place every spring. It is due to an **increase of wave activity** which cause a **major stratospheric warming**. During this warming, the temperature gradient between the equator and the poles is reversed. It generates the turn-around of the mean circulation ; the eastward mean flow of the polar vortex is converted to a strongless westward flow typical of summer polar stratosphere. The vigorous wave activity leads to the weakening of the polar dynamical barrier. As a result, an intense anticyclone comprising air drawn up from the tropics formed at high latitude : a **FrIAC** (« Frozen In Anticyclone »). This phenomeon has been reported using long-lived chemical tracers CH_4 and N_2O by MIPAS-ENVISAT (Lahoz and al., 2007) and MLS-AURA (Manney and al., 2006) satellites. After the vortex break-up, studies have shown that **vortex remnants** advected in the westward cirulation hold chemical and physical caracteristics typical of the polar winter (Orsolini, 2001 ; Konopka and al., 2003). Understanding evolution of remnants is essential because they have an important role on the distribution of ozone at global scale.
The purpose of this study is to use the high resolution model of advection of **potential vorticity** MIMOSA (Hauchecorne et al., 2002) and to compare the results with the MLS long-lived tracer N_2O data during the spring and summer period (2005), in order to understand mixing and transport mecanisms at fine scale.

MIMOSA model

MIMOSA : Modèle Isentropique de transport Mésoéchelle de l'Ozone Stratosphérique par Advection (Hauchecorne and al., 2002)

MIMOSA is a semi-Lagrangien high resolution model of advection of potential vorticty (PV). PV is advected on several isentropic levels [350 K; 950 K] by the horizontal wind components on a x-y grid centered at the North Pole with a resolution of either 3 or 6 points per degree. Initialisation and assimilation data come from winds, pressure and temperature fields of the European Center for Medium-Range Weather Forecasts (ECMWF). Grid of PV are advected then re-interpolate on the original grid every 6 hours in order to keep the distance between two adjacents points approximatively constant. The regridding process is based on a the preservation of the second order momentum of PV perturbation which allow to minimize the numerical diffusivity to 1350 $m^2.s^{-1}$. Relaxation and explicit diffusivity are insert :

Relaxation : in order to consider the diabatic effects on the PV, assimilation of ECMWF fields is done every 12 hours. It allows to correct the advected PV. More the relaxation time nh_{relax} will be high, more the PV will be corrected.

Explicit diffusion : this module allows to insert an additive diffusion to have a better representation of the reality.

Potential vorticity

The potential vorticity is a conserved physical quantity in adiabatic conditions in atmosphere during 10 days. It represents the product of an air mass vorticity by the vertical stability.

With
- ξ relative vorticity
- f Coriolis parameter
- θ potential temperature (in K)

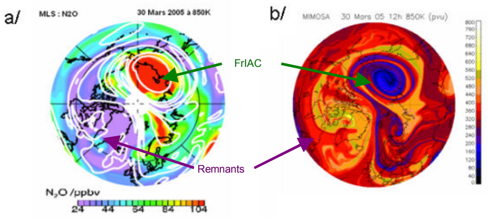
$$PV = \underbrace{(\xi + f)}_{\text{vorticity}} \underbrace{\left[-g \frac{\partial \theta}{\partial p} \right]}_{\text{Vertical stability}}$$

1 pvu = 1 K.kg^{-1}.m^2.s^{-1}

Specific dynamical structures : FrIAC & Vortex Remnants

Frozen-in Anticyclone (FrIAC) : high N_2O (vmr) and low H_2O. This air mass intrusion can be seen in long-lived tracers fields. Its chemical composition is typical of tropical signature. FrIAC's lifetime extends to the beginning of the mean flow transition in August (Manney and al., 2006).

Vortex remnants : low N_2O (vmr) and high H_2O. Remnants come from vortex break-up. Their lifetime can extend until the end of summer. This phenomeon has always been modelisated in Orsolini (2001)



MLS data (Manney et al., 2006) MIMOSA (PV) (nh_{relax} = 240 h or 10 d)

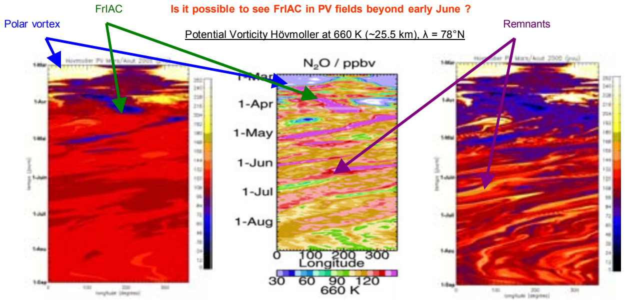
« The formation and persistence through late May of the anticyclone are seen in PV fields […] but the PV feature disappears in early June. Although, this may be partly related to the differing effect of diabatic processes on PV and chemical tracers, the inability of transport calculations to preserve FrIAC suggests that it may also be related to deficiencies in summer high-latitude horizontal winds » (Manney et al., 2006)

Vortex remnants and FrIAC are **well correlated** in the PV and N_2O fields. The high resolution of MIMOSA allows to see **fine scales structures** like residus of tropical air mass intrusion and vortical aspect of FrIAC ; a better understanding of mecanisms appears.

Sensivity test : relaxation

Is it possible to see FrIAC in PV fields beyond early June ?

Potential Vorticity Hövmoller at 660 K (~25.5 km), λ = 78°N



nh_{relax} = 240 h & $diff_{expl}$ = 2000 $m^2.s^{-1}$ N_2O-MLS (Manney et al., 2006) nh_{relax} = ∞ & $diff_{expl}$ = 2000 $m^2.s^{-1}$

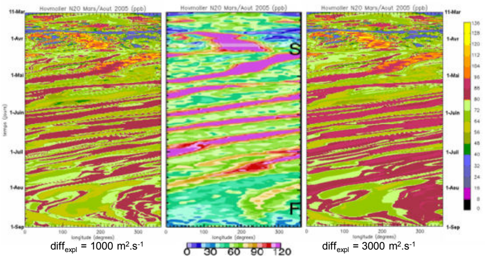
- ➢ **On left-side**, the diabatic effects on PV are taken into account in the same order of magnitude that the PV conservation time in atmosphere. As in Manney and al, 2006, correlation between PV and N_2O are in good agreement until mid-May.
- ➢ **On right-side**, the diabatics effects are not taken into account during the run ; here it's not the true PV but a « quasi-passive » tracer call « advected PV » (APV). APV field is very well correlated with N_2O until the end of June.

Sensivity test : explicit diffusion

What is the influence of explicit horizontal diffusion ?

N_2O-MIMOSA Hövmoller at 850 K (~31 km), λ = 78°N, nh_{relax} = ∞.

MIMOSA Manney et al. (2006) MIMOSA



$diff_{expl}$ = 1000 $m^2.s^{-1}$ $diff_{expl}$ = 3000 $m^2.s^{-1}$

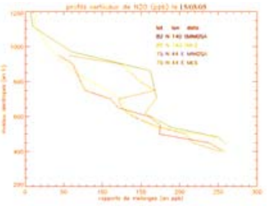
Good Correlation between N2O-MLS (middle) and N_2O-MIMOSA.

- ➢ **On left-side**, with a weak explicit diffusion, respectively, **the structures – FrIAC, remnants - keep their - high, low – N_2O values**.
- ➢ **On right-side**, with a mean diffusion in stratosphere, N_2O values decrease in FrIAC and increase in remnants due to mixing.

The diffusion, according to N_2O fields, seems high during the stratospheric warming until mid-April and increases again in August which corresponds to the summer/winter winds transition. Diffusion is weak between May and July. It's necessary to modify explicit diffusion parameter during a run in order to improve the correlation between satellite and model data.

Conclusions

The high resolution model MIMOSA is an efficient tool to study dynamical process associated with air mass exchanges between tropics midlatitudes and polar region. Using Advected PV and advected N_2O from MIMOSA, it's possible to follow the evolution of thin structures such as FrIAC and vortex remnants. As a result :
✓ An infiny relaxation time allows to follow structures in Advected PV and advected N_2O fields until Summer with an initialisation of the MIMOSA run in March.
✓ The diffusion processes seems to be seasons dependent due to variability of waves activities.



Exemple of N_2O-MLS and N_2O-MIMOSA vertical profils (in process).

Perspectives

- •Direct comparison between N_2O MLS vertical profils and Advected N_2O in order to quantify in detail the spatial and temporal distribution.
- • Time evolution of FrIAC area.
- • Quantification of waves activites as a function of the seasons to constraint the diffusion coefficient.

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Acknowledgments

This study is conduced in the framework of the STRAPOLETE project supported by the "Agence Nationale de la Recherche ANR (STRAPOLETE project ANR 08 BLAN 0300), the "Institut Polaire Paul Emile Victor" (IPEV) and the "Centre National d'Etudes Spatiales (CNES)".
We thanks the ETHER database (Pôle thématique du CNES).