A statistical approach to the study of dynamical barriers in the stratosphere

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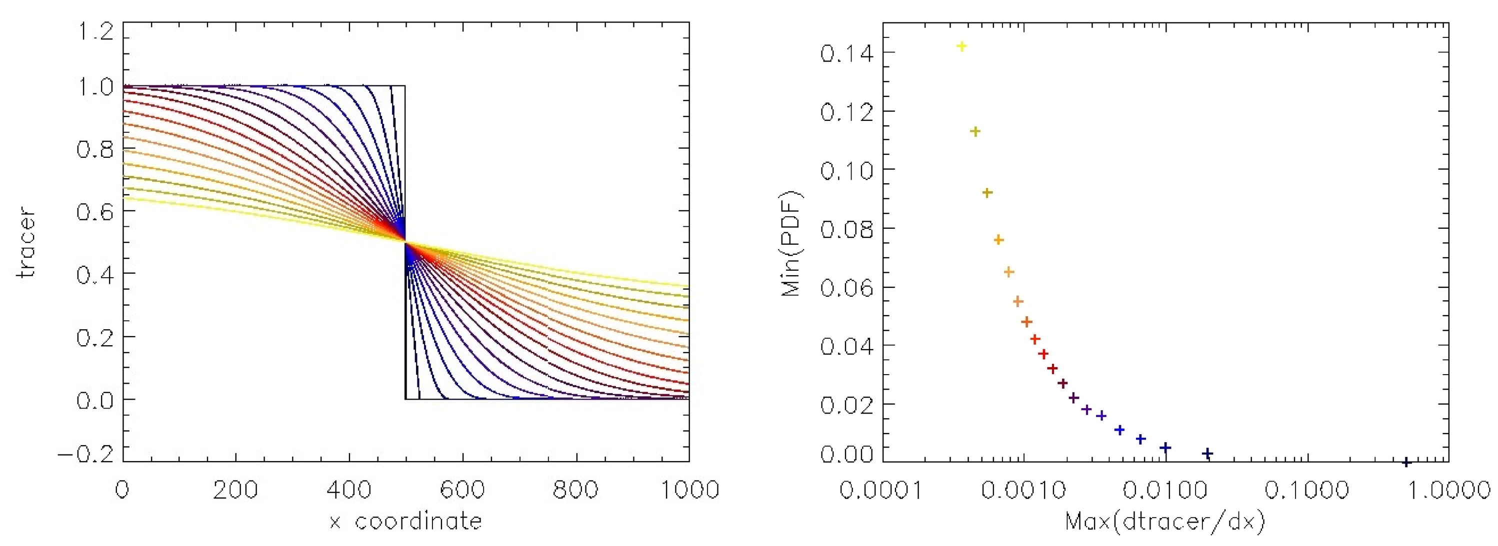
Introduction

Many studies have been conducted in the past to identify the position of dynamical barriers in the stratosphere, to quantify their permeability and thickness, and their spatial and temporal variability. Many of them have generally been of limited scope; this work has the aim to define in a more objective way the edge regions using probability density functions (PDFs) of long-lived tracers to infer information on the transport processes in the stratosphere and identify regions with different chemical/dynamical characteristics. This work is a bit an extension of the Sparling (2000) and Neu et al. (2003) framework focusing on the transition zones represented by the dynamical barriers. The methodology followed is twofold: (1) we will analyze the morphology of a tracer field (N2O from MLS) as a function of the equivalent latitude; (2) we will apply statistical diagnostics based on the construction of PDFs of N2O and the analysis of their statistical properties which are found to be strictly correlated with the tracer latitudinal gradients.

The methodology

In the atmosphere, strong meridional gradients of long-lived chemical tracers such as N2O as well as dynamical tracers like Potential Vorticity (PV) or winds and wind shears, indicate weak mixing (due to suppression of wave breaking activity) and the presence of sharp slope changes in the tracer mixing ratio fields. These regions correspond to the dynamical barriers.

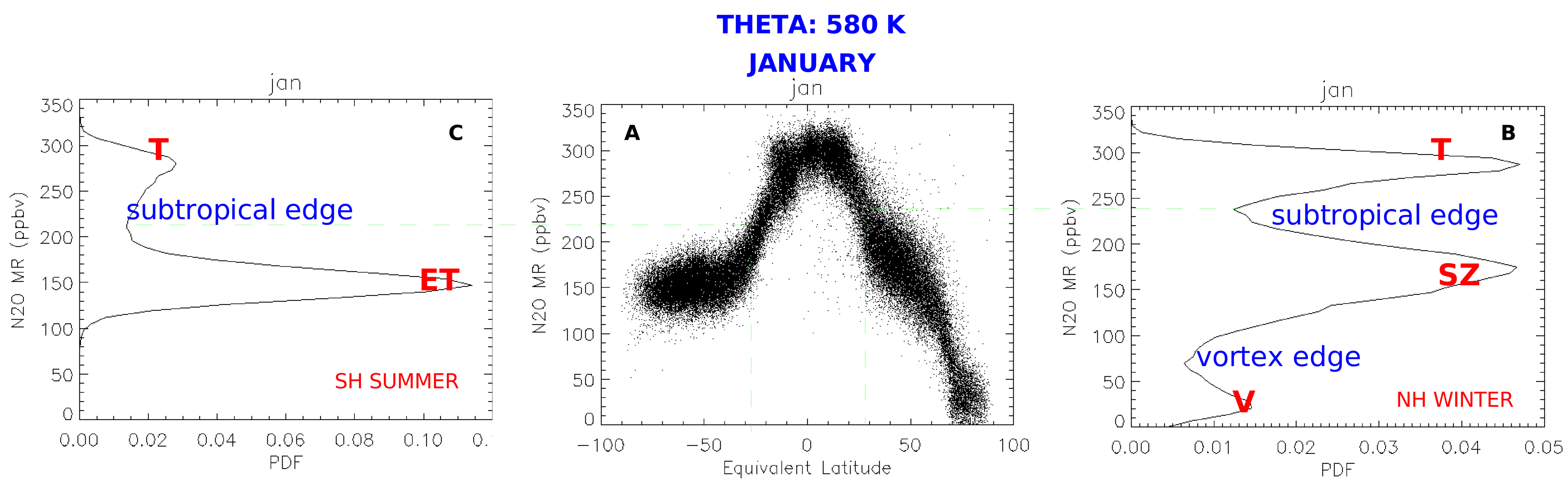


1) Figure 1 shows, on the left, the 1-D distributions of an ideal tracer (obtained by recursive linear smoothing of an initial step function).
2) The probability density function (PDF) of the tracer, i.e., the tracer value normalized frequency distribution, for each distribution has been computed resulting in:
- a correspondence between the point where the tracer gradient takes its maximum value and the location of the minimum in the normalized frequency;
- a proportionality between the PDF minimum and the tracer gradient maximum: the higher the PDF minimum the lower the tracer gradient maximum (see Fig. 1 on the right).

Figure 1. Left: idealized smoothed 1-D mixing ratio distribution of a tracer as a function of an arbitrary coordinate (in the stratosphere, this coordinate would be equivalent latitude typically and the tracer field on an isentropic surface would be averaged along this coordinate to produce 1-D mixing ratio distribution). The initial distribution is a step function (black line). Right: the figure shows the relationship between the ideal tracer gradient maximum and PDF minimum.

Application to the study of stratospheric barriers

In this work we have used the Microwave Limb Sounder (MLS) level 2 N2O mixing ratio vertical profiles accumulated over **2006.** MLS measurements have a vertical resolution of about 3 km, and their spatial coverage is near-global (about -82° to +82°) and characterized by a sampling pattern which is homogeneous with respect to the latitude ranges and dense enough to perform a statistical analysis.



WINTER HEMISPHERE: the PDF is trimodal, with peaks corresponding to weak N2O gradients in the tropics (T), surf zone (SZ) and polar vortex (V) and valleys corresponding to the strong N2O gradients at the subtropicaledge and the polar vortex edge.
SUMMER HEMISPHERE: the PDF is bimodal with peaks corresponding to the tropics (T) and the summer extratropics (ET) air masses; the valley correspond to the summer subtropical barrier.

Figure 2. A) the scatter plot of the MLS N2O measurements at theta = 580 K during January 2006. The number of measurements are 34,937 in the NH and 35,860 in the SH, for the chosen theta interval. B) the PDF of the N2O measurements in the northern (winter) hemisphere, with the normalized frequency along the x-axis and the N2O mixing ratio along the y-axis. C) the PDF of the N2O measurements in the Southern (summer) hemisphere

Statistics of a Support Region

In general, a **support region** can be identified as a region in space over which the field of the variable we are interested in takes a certain value or in which a certain condition is satisfied (Sparling, 2000). In this study, **the statistics of the support can be applied to identify the characteristic (equivalent) latitude where the transport barriers are located.**
In Fig. 2, each subtropical minimum and the vortex edge minimum in the PDF occur at a certain value of the tracer, namely, N2O*, which is called "**tracer boundary**". The support of the tracer boundary can be quantitatively determined calculating the **conditional probability PDF(ϕ|N2O*)** of the equivalent latitudes ϕ of observations that have mixing ratios near N2O*. The most probable value of PDF(ϕ|N2O*) gives the characteristic equivalent latitude of the tracer boundary. In the example shown in Fig. 3, the SH and NH subtropical edges are found at -28° and 24° equivalent latitude respectively, while the polar vortex edge at 68° equivalent latitude.

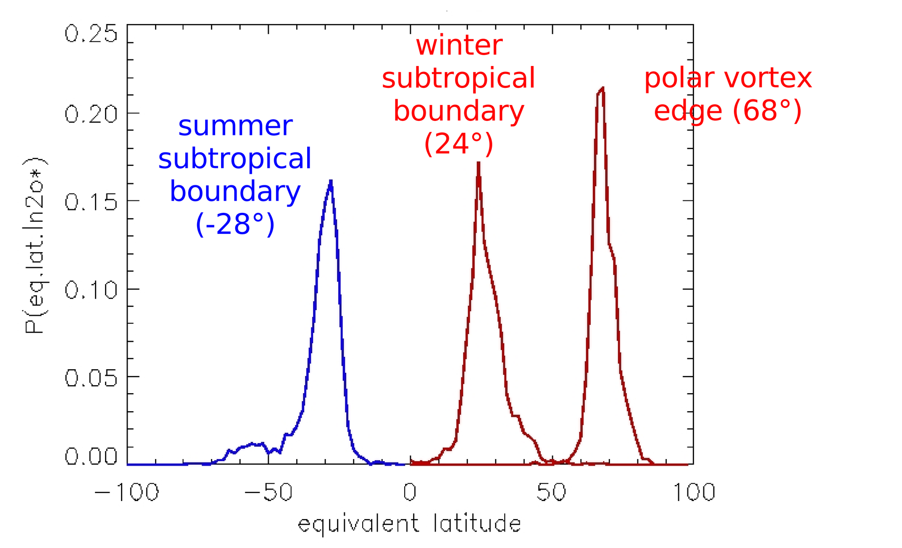


Figure 3. The PDF of the latitudes of the observations within the northern and southern subtropical valleys and the vortex edge valley.

Time evolution of the dynamical barriers

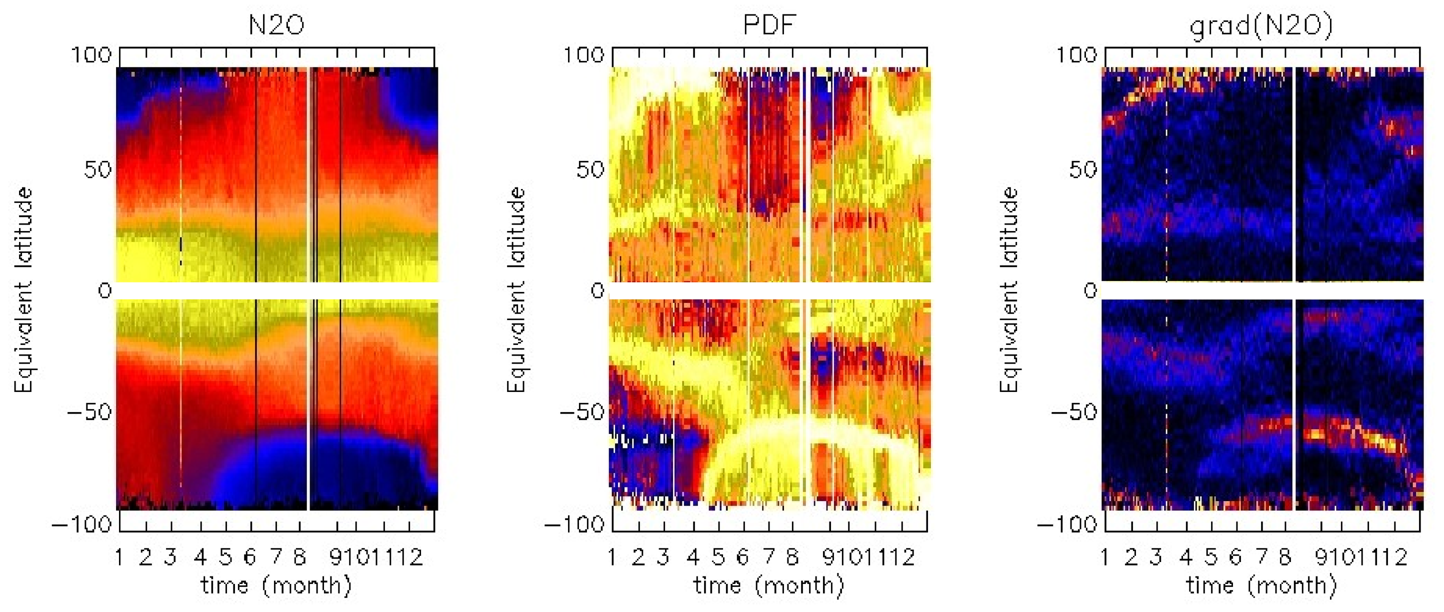


Figure 4. Time evolution of the N2O mixing ratios (left, from black to yellow increasing values), PDF(N2O) (middle, from black/blue to yellow/white decreasing values) and N2O gradient (right, from black to yellow increasing values) vs equivalent latitude.

- The time evolution of PDF(N2O) and N2O gradient allows to study the temporal variability of the dynamical barriers in the stratosphere. The strength and persistence of the SH polar vortex edge, for example, is visible in the middle and right plots of Fig. 4. The lowest PDF(N2O) values and highest N2O gradients indicating the polar vortex barrier are found from August to November. The shape of the vortex is moreover well described by both the diagnostics.

- In analogy with what seen in Fig. 1 (right), we can also relate the **absolute value of the PDF minimum with the maximum in the tracer gradient resulting in a strict relationship with the barrier permeability**.

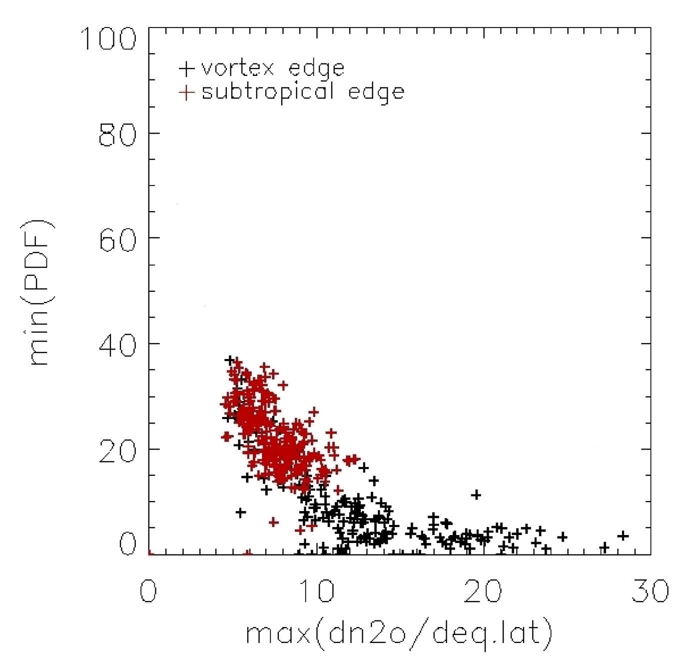


Figure 5. The same as Fig. 1, for the Southern Hemisphere MLS N2O dataset of 2006.

This is shown in Fig. 5 for the SH subtropical and polar vortex barriers: the polar vortex barrier is less permeable (lower values of the PDF minimum, higher values of the N2O gradient maximum) than the SH subtropical barrier (higher values of the PDF minimum, lower values of the N2O gradient maximum).

References

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Neu, J. L., Sparling, L. C., and Plumb, R. A.: Variability of the subtropical "edges" in the stratosphere, J. Geophys. Res., 4482, doi:10.1029/2002JD002706, 2003.

Conclusions

In this study we have applied a statistical diagnostics based on the construction of probability density functions of a the long-lived species N2O to study the characteristics of the dynamical barriers in the stratosphere (position, permeability, strength). These PDFs are calculated as a function of equivalent latitude, which is suitable since it filters out many of the short term reversible atmospheric motions, leaving a clearer picture of the significant tracer distribution.

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