Project: 688 Project title: Zirren in der Tropopausenregion Principal investigator: Peter Spichtinger Report period: 2018-01-01 to 2018-12-31 Text: maximum of two pages including figures.

## **Progress report:**

Normal progress as expected.

## (1) Gravity waves and cirrus clouds at the tropopause (CIRRUS-GW)

In this project (DFG research group MSGWaves, project GW-TP) we investigate the feedbacks between tropopause dynamics and gravity waves and their feedbacks on cirrus clouds. For this purpose we conducted 2D and 3D simulations of gravity waves propagating vertically from the troposphere through the tropopause into the stratosphere. We investigate different scenarios, changing background stratification, environmental wind conditions and wavelengths in the prescribed waves.

One study that was conducted in order to examine the propagation of gravity waves through a socalled tropopause inversion layer (TIL). This sharp peak in stability is often observed in the tropopause region in the mid-latitudes. We looked at two parameters defining the characteristics of the TIL, its strength and its depth. Mathematically, this can be expressed in terms of the Brunt-Väisälä frequency, using a hyperbolic function with parameters d and c:

$$N^{2}(z;c,d,ztp) = \left(N_{0}^{2} + \frac{3N_{0}^{2}}{2} \cdot \left[1 + \tanh\left(\frac{z - ztp}{d}\right)\right]\right) \cdot \left(1 + (c-1) \cdot \operatorname{sech}^{2}\left(\frac{z - ztp}{d}\right)\right)$$

Multiple high-resolution simulations were made, using orographic wave excitation in the model with different wavelengths and scanning through the parameter space of the TIL strength c and depth d.



Figure 1: Experiments of vertical wave propagation through the tropopause inversion layer

Panel a) in figure 1 shows a grid of various realizations of the N<sup>2</sup>-profile. Panels b), c) and d) show the corresponding amplitude ratio of the wave above and below the tropopause for each grid segment. This ratio is highest for the smoothest transition in the upper right corner of the field in b) and c) where waves with equal horizontal and vertical wavelength are used. The transmission of larger wavelengths in c) is generally weaker than the one of smaller wavelengths in b), but reveals a very similar pattern. Panel d) shows the behavior of a wave with small vertical wavelength but larger horizontal wavelength. The transmission is significantly higher in the upper part of the grid than in for the case of smaller wavelengths in b).

The dependency on the tropopause depth d vanishes for weak TIL settings (c=1), but is distinct for strong TIL settings (c=6).

The transmission in panel d) is weakest for large d and large c, indicating that the horizontal wavelength is more relevant when it comes to large waves traveling through a small disturbance that they don't "see".

These results were compared with two other models, a multi-layer model with an asymptotic calculation of transmission coefficients using a step-wise constant N<sup>2</sup>-profile and a ray-tracing model that uses Wentzel-Kramer-Brilloin (WKB) theory in order to calculate gravity wave-mean flow interaction.

The models generally agree, but show some differences which gives important information on how the various assumptions and simplifications that are used in the models make them suitable for studying different scientific questions. A manuscript is in preparation.

## (2) Inhomogeneities and structures in cirrus clouds (CIRRUS-INH)

In this project the impact of instabilities in the tropopause region on the formation and evolution of cirrus clouds has been investigated. We investigated several idealized cases of shear and convective instabilities triggering cirrus cloud formation. This is still work in progress, since it is only a small part of the computing project, and progress depends on the amount of free time of the main PI.