LATE REQUEST FOR A SPECIAL PROJECT 2016–2018

MEMBER STATE: Germany

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Project Title:
Ice-supersaturation and cirrus clouds and their feedbacks to tropopause dynamics

Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2016-2018: (The project duration is limited to a maximum of 3 years, agreed at the beginning of the project. For late requests the project will start in the current year.)		**2016**	**2017**	**2018**
High Performance Computing Facility	(units)	100 000	200 000	200 000
Data storage capacity (total archive volume)	(gigabytes)	500	500	500

An electronic copy of this form ***must be sent*** *via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date): 5 January 2016

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[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

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Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

Motivation:

Clouds consisting exclusively of ice crystals, so-called cirrus clouds, occur quite frequently in the tropopause region. In the extratropics the cirrus cloud amount is quite high (up to 30%) over the storm track regions, whereas in the tropics in regions of deep convection cirrus clouds occur frequently (up to 50%, see e.g., Stubenrauch et al., 2010). In contrast to liquid clouds, which usually coincide with their saturated environment, cirrus clouds are usually embedded into a supersaturated environment, i.e. so-called ice supersaturated regions (see, e.g., Gierens et al., 1999; Spichtinger et al., 2003). Thus, the air in the tropopause region is very often in a state far away from thermodynamic equilibrium, i.e. in the status of ice supersaturation, containing ice crystals or even cloud free. Cirrus clouds do usually not have sharp boundaries. In contrast, there could be a continuous transition from clear air over thin cirrus clouds up to thick clouds with high ice crystal mass and number concentration. One reason for the occurrence of ice supersaturation in clear and cloudy air is given by the formation mechanisms of ice crystals. The formation of ice crystals usually requires high ice supersaturation; for homogeneous freezing of solution droplets (see, e.g. Koop et al., 2000) relative humidities (with respect to ice, RHi) in the range 140-170% are required, whereas heterogeneous nucleation still needs values of ~130%. Since diffusional growth is quite low at temperatures $T<235K$, ice supersaturation is slowly depleted by growing ice crystals, thus even inside cirrus clouds ice supersaturation can exist for quite a long time.

Cirrus clouds interact with radiation as all other clouds. They partly scatter incoming solar radiation (albedo effect) and also absorb and re-emit thermal radiation from Earth (greenhouse effect). However, both effects are of similar absolute value, thus the net radiation effect of cirrus clouds is not clear. The microphysical properties of ice crystals determine small order corrections of the radiation effects (e.g., Zhang et al., 1999), which might turn the radiation effect into a net warming or a net cooling, respectively. Here, ice crystal number concentration is an important variable, since in a first order approximation ice water content and ice crystal number concentration determines the size of crystals, which in turn controls the scattering and absorption of radiation, respectively.

Ice crystal number concentration is crucially depending on formation mechanism. For heterogeneous nucleation, the amount of available ice nuclei mostly control ice crystal number concentration (Hoose and Moehler, 2012). For homogeneous nucleation, local dynamics plays an important role; changes in vertical velocity might lead to variations in ice crystal number concentrations over several orders of magnitudes (e.g. Spichtinger and Gierens, 2009a).

In fact, at the moment the dominant mechanism forming ice crystals in the tropopause region is not known. Since the amount of aerosol particles acting as suitable ice nuclei is quite small, it is often assumed that homogeneous nucleation might be the dominant process; however, heterogeneous nucleation might modify subsequent homogeneous nucleation (e.g. Spichtinger and Cziczo, 2010; Joos et al., 2014). Thus, environmental conditions influence formation and evolution of cirrus clouds and their potential formation regions, i.e. ice-supersaturated regions (ISSRs, see e.g. Gierens et al., 1999).

On the other hand, cirrus clouds and ISSRs might feed back to dynamics on different scales. In recent case studies using ECMWF data and in situ measurements, we found that in potentially unstable layers close to the tropopause shallow cirrus convection, i.e. formation of small convective cells might occur (Spichtinger, 2014). Due to latent heat release via phase changes small scale convection on scales in order of few kilometres was triggered. These cells lead also to enhanced mixing and turbulence in the tropopause region. Thus, we expect that shallow cirrus convection is able to change environmental conditions in the tropopause region, leading to changes in dynamic processes at the tropopause.

Finally, in recent investigations using radiosonde data (Peinke, 2012) and ECMWF analysis data we found strong correlations between enhanced water vapour in the tropopause region and the so-called tropopause inversion layer (TIL, Birner et al., 2002). This inversion is characterised by a strong maximum in static stability (i.e. Brunt-Vaisala frequency) just above the thermal tropopause. A connection between water vapour and the TIL was already conjectured (Randel et al., 2007); in fact, radiative cooling of the water vapour might lead to sharpening of the TIL. However, it is still unclear how water vapour, cirrus clouds and (local) dynamics interact for forming or even destroying the TIL. Especially the role of cirrus clouds is completely unclear.

Strategy:

In the proposed special project we want to investigate the interaction between cirrus clouds and their supersaturated environment with (local) tropopause dynamics. We want to address the following research questions:

- What are the dominant formation mechanisms for ice crystals in the tropopause region under certain environmental conditions?
- What is the radiative impact of cirrus clouds in the tropopause region in terms of net contribution and vertical profiles of heating rates?
- How often does shallow cirrus convection occur and how does it determine exchange processes at the tropopause?
- How are enhanced water vapour and tropopause inversion layer correlated? What is the role of cirrus clouds for the tropopause inversion layer?

To answer these questions we plan different investigations, combining data analysis and high-resolution numerical simulations. We will investigate ECMWF analysis and reanalysis data in terms of correlations between water vapour, cirrus clouds and tropopause characteristics.
In a first step we will investigate long time series of data in order to determine possible correlations in a robust statistical sense. For connecting the meteorological analysis/reanalysis data with in situ measurements we will additionally use data from the European MOZAIC/IAGOS project (see, e.g., http://www.iagos.org/). During this analysis, we will also be able to compare ECMWF data with in situ measurements; thus, we can also evaluate the quality of ECMWF water vapour/cirrus data in the tropopause region. In a second step, we will carry out some case studies in order to investigate the dominant processes for interaction of water vapour, cirrus clouds and tropopause dynamics in more detail. Since ECMWF data only cover scales larger than about 10 kilometres, we additionally use high-resolution modelling in order to resolve small scale processes.

For this purpose the anelastic non-hydrostatic model EULAG (Prusa et al., 2008) together with a recently developed ice microphysics scheme (Spichtinger and Gierens, 2009a) will be used for high-resolution simulations (dx~100m, dz~10-50m). This model was used for several investigations of cirrus clouds in different meteorological situations; these data sets can be used for first investigations (e.g. Spichtinger and Gierens, 2009b; Joos et al., 2009). However, we will have to study some effects in detail, thus we will carry out new simulations. The EULAG model is currently running on the HPC system of ECMWF. The model itself can be run highly parallelized on many hundreds to thousands CPUs without losing its scaling properties.

Finally, we will use a radiative transfer model based on work by Fu and Liu (1993) in order to investigate the radiative feedback of water vapour and cirrus clouds on tropopause dynamics as well as the radiative impact of cirrus clouds as retrieved from either ECMWF data or from high-resolution modelling (see e.g. Joos et al., 2014). This single column model will be ported to ECMWF HPC system in order to investigate many vertical profiles efficiently.

Our proposed work has strong connections to other research fields, namely the life cycle of cirrus clouds in the upper troposphere, stratosphere-troposphere exchange and diabatic mixing processes in the atmosphere.

ECMWF will benefit from our proposed work in the following ways:

- We will hopefully improve our understanding of processes, which are dominant for the formation and evolution of cirrus clouds. This might help to improve cloud parameterisations for coarse models as IFS
- We will obtain a better understanding of the interaction of cirrus clouds, water vapour and tropopause dynamics. This will probably help to improve the representation of tropopause characteristics in coarse grid models
- We will investigate the quality of ECMWF analysis (re-analysis) in terms of representing key features of cirrus clouds and tropopause dynamics.

The project would be a successor of the former special projects SPDEISSR and SPDEFLUC.

References:

- Birner A. Doernbrack, U. Schumann., 2002: How sharp is the tropopause at midlatitudes? Geophys. Res. Lett., 29, 1700.
- Fu, Q. and K. Liou, 1993: Parameterization of the Radiative Properties of Cirrus Clouds, J. Atmos. Sci., 50, 2008–2025.
- Gierens, K., U. Schumann, M. Helten, H.G.J. Smit, A. Marenco, 1999: A distribution law for relative humidity in the upper troposphere and lower stratosphere derived from three years of MOZAIC measurements. Ann. Geophys. 17, 1218-1226.
- Joos, H., P. Spichtinger, U. Lohmann, 2009: Orographic cirrus in a future climate. Atmos. Chem. Phys., 9, 7825-7845.
- Joos, H., P. Spichtinger, P. Reutter, F. Fusina, 2014: Influence of heterogeneous freezing on the microphysical and radiative properties of orographic cirrus clouds. Atmos. Chem. Phys., 14, 6835-6852.
- Hoose, C. and O, Moehler, 2012: Heterogeneous ice nucleation on atmospheric aerosols: a review of
- results from laboratory experiments. Atmos. Chem. Phys., 12, 9817-9854.
- Kaluza, T., 2015: Korrelationen zwischen dem Wasserdampf in der UT/LS und der Tropopauseninversionsschicht. Diploma Thesis, Institute for Atmospheric Physics, Johannes Gutenberg University Mainz, Germany.
- Koop, T., B. Luo, A. Tsias, T. Peter, 2000. Water activity as the determinant for homogeneous ice nucleation in aqueous solutions. Nature. 406, 611-614.
- Peinke, I., 2012: Tropopauseninversionsschicht und eisübersättigte Regionen. Bachelor Thesis, Institute for Atmospheric Physics, Johannes Gutenberg University Mainz, Germany
- Prusa, J., P. Smolarkiewicz, A. Wyszogrodzki, 2008: EULAG,a computational model for multiscale flows. Comput. Fluids. 37, 1193-1207.
- Randel, W., F. Wu, P. Forster, 2007: The Extratropical Tropopause Inversion Layer: Global Observations with GPS Data, and a Radiative Forcing Mechanism. J. Atmos. Sci., 64, 4489-4496.
- Spichtinger, P. and Cziczo, D. J. 2010. Impact of heterogeneous ice nuclei on homogeneous freezing events in cirrus clouds. J. Geophys. Res. 115, D14208.

- Spichtinger, P. and K. Gierens, 2009a: Modelling Cirrus Clouds. Part 1a: Model description and validation. Atmos. Chem. Phys., 9, 685-706.
- Spichtinger, P. and K. Gierens, 2009b: Modelling Cirrus Clouds. Part 1b: Structuring cirrus clouds by dynamics. Atmos. Chem. Phys., 9, 707-719.
- Spichtinger, P., 2014: Shallow cirrus convection - a source for ice supersaturation.Tellus A, 66, 19937.
- Stubenrauch, C., S. Cros, A. Guignard, N. Lamquin, 2010: A 6-year global cloud climatology from the Atmospheric Infra Red Sounder AIRS and a statistical analysis in synergy with CALIPSO and CloudSat. Atmos. Chem. Phys., 10, 7197-7214
- Zhang, Y., A. Macke, F. Albers, 1999: Effect of crystal size spectrum and crystal shape on stratiform cirrus radiative forcing. Atmos. Res., 52, 59-75.