Ice formation pathways in Warm Conveyor Belts

HD(CP)²
High definition clouds and precipitation for advancing climate prediction

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Introduction

Warm conveyor belts (WCB) cause the formation of large cirrus clouds in the upper troposphere. However, the contribution of the different formation processes and the resulting micro- and macrophysical properties of the cirrus are still poorly understood. We want to especially address the question of in situ vs. liquid origin ice formation. Therefore we implemented a new microphysics scheme in the atmospheric model ICON to investigate dominant formation pathways of the cirrus in the upper troposphere.

We present a case study of the 30 January 2009 which features a WCB that ascends from the boundary layer over the Northern Atlantic to the upper troposphere over Scandinavia.

Model description

Common microphysic bulk schemes consider only a single ice class which includes sources from multiple formation mechanisms.
We developed and implemented a new two-moment microphysics scheme in ICON that distinguishes between different ice modes of origin:

- Homogeneous freezing of solution droplets
- Deposition nucleation
- Homogeneous freezing of cloud droplets
- Immersion freezing
- Secondary ice production

The homogeneous (hom) and deposition mode (dep) contribute to in situ formation of cirrus where as homogeneous freezing of cloud droplets (frz) as well as immersion freezing (het) and secondary ice production from rime splintering (sec) occur at water saturation and hence are of liquid origin.

Each ice mode is described by its individual size distribution, prognostic moments and unique formation mechanism but else subject to the same parameterizations and sinks.

Homogeneous nucleation triggers above a temperature-depended critical supersaturation and grid-scale vertical velocity. Heterogeneous nucleation is constrained by the availability of ice-nucleating particles (INP) which relaxes back to a prescribed INP background profile in a cloud-free environment. Homogeneous freezing of cloud droplets follows a temperature-depended freezing rate and secondary ice is a byproduct of riming.
Other cloud particle classes are cloud droplets, rain, snow, graupel and hail.

References

Joos, H. and Wernli, H. (2012). "Influence of microphysical processes on the potential vorticity development in a warm conveyor belt: a case-study with the limited-area model COSMO". In: *Quarterly Journal of the Royal Meteorological Society* 138.663, pp. 407–418.

Wernli, H., Boettcher, M., Joos, H., Miltenberger, A. K., and Spichtinger, P. (2016). "A trajectory-based classification of ERA-Interim ice clouds in the region of the North Atlantic storm track". In: *Geophysical Research Letters* 43.12, pp. 6657–6664.

Warm Conveyor Belt

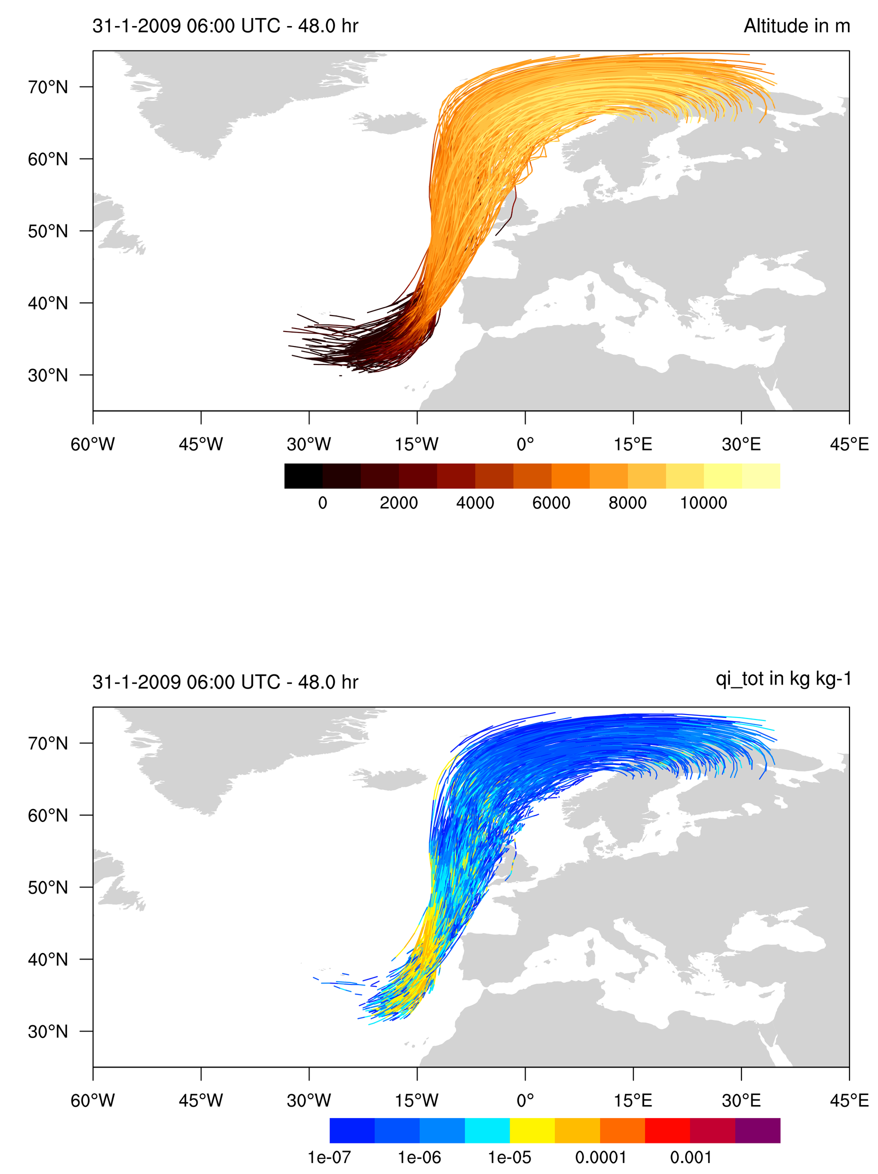

Figure 1: Warm Conveyor Belt trajectories temporal evolution of altitude on the top and total ice mass content, the sum of all ice modes, on the bottom.

- WCB case which has been thoroughly investigated by Joos and Wernli (2012)
- ICON simulation of the North Atlantic domain with 2.5 km resolution
- Trajectory selection criteria: start below 2 km and ascend by at least 7 km within two days
- Figure 1 shows compactly packed trajectories which form a distinct WCB
- Formation of vast cirrus cloud in outflow region

Example trajectory

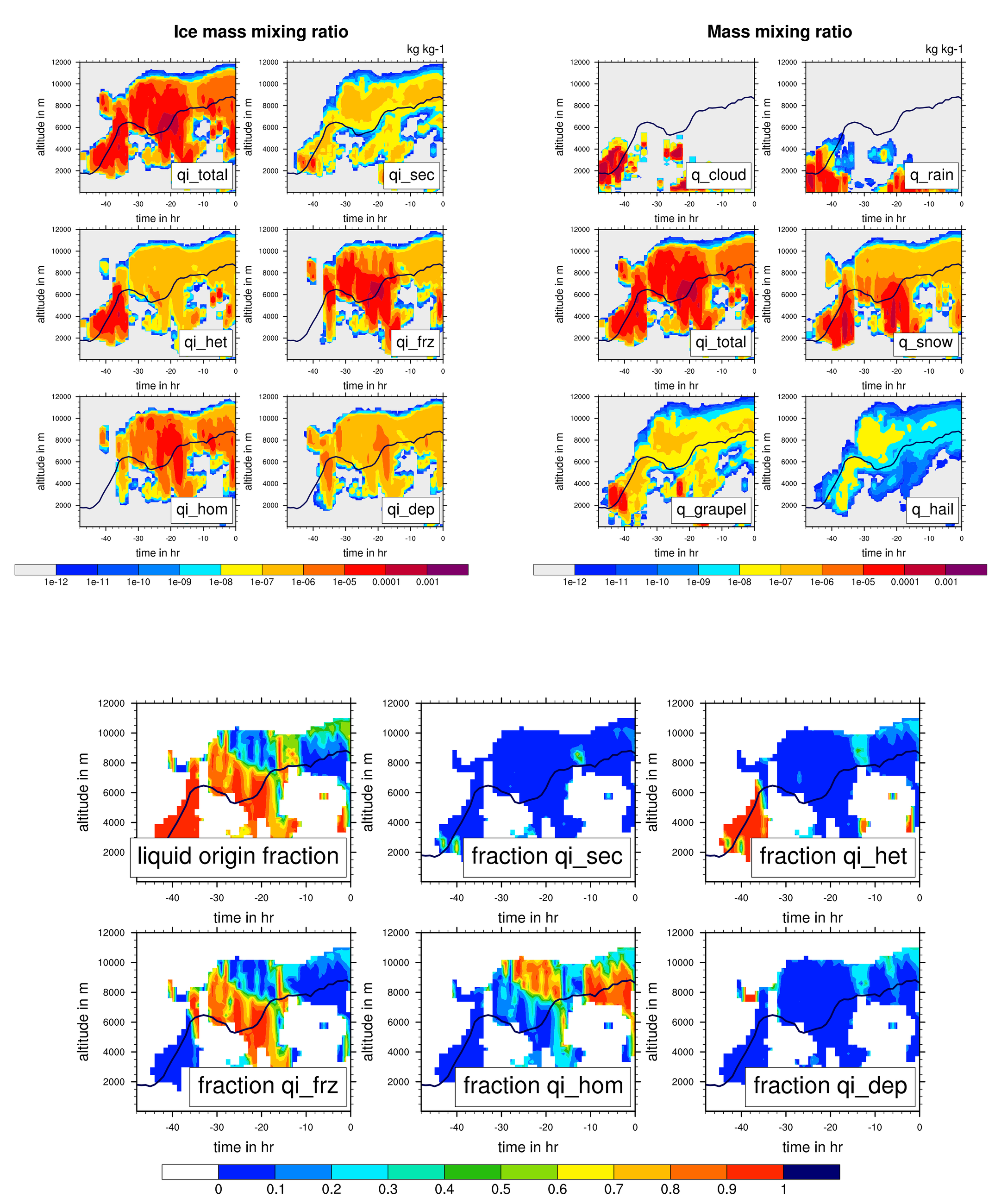

Figure 2: Vertical slice following a trajectory with mass mixing ratio of ice and other cloud particles on the top panels and ice mode fractions on the bottom panel. The black line indicates the altitude of the trajectory.

- Immersion freezing (het) and secondary ice production (sec) dominate early development
- The remaining cloud droplets freeze homogeneously (frz), liquid origin fraction remains high
- Late stage WCB shows strong homogeneous nucleation events and in situ formed cirrus

In situ vs liquid origin

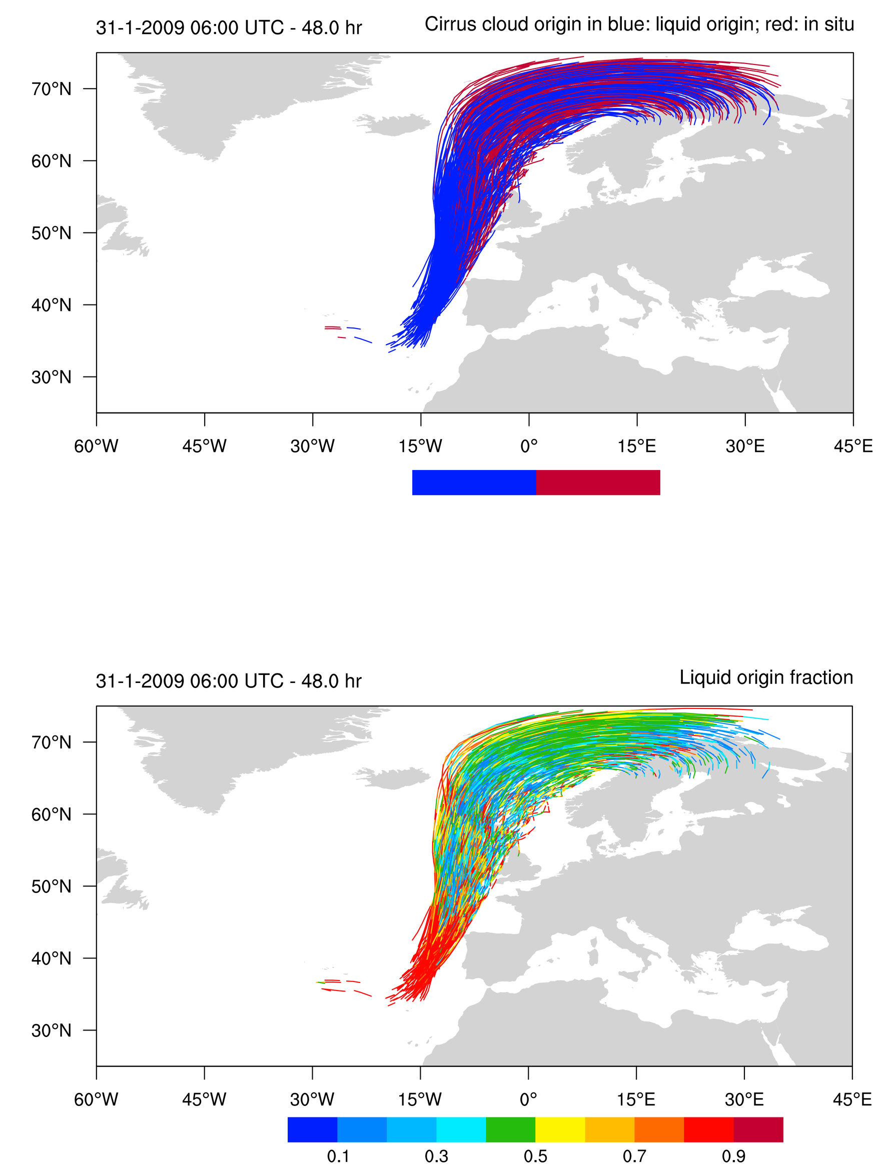

Figure 3: Top: cirrus cloud origin following Wernli et al. (2016) classification. Bottom: liquid origin fraction of the ice modes scheme.

Wernli et al. (2016) cirrus origin classification:

- Calculate backwards trajectory of cirrus
- If liquid water was present then classification as liquid origin, otherwise as in situ cloud
- Figure 3 top: liquid origin fraction 69 % and in situ fraction 31 %

Ice modes classification:

- The statistics in Figure 4 show that liquid origin cirrus dominates during the early WCB development ($T > 230$ K)
- Strong tendency towards in situ formed ice for $T < 230$ K and liquid origin fraction maximum of around 55 %
- Homogeneous nucleation and freezing (hom, frz) are more prominent than heterogeneous nucleation (het, dep)

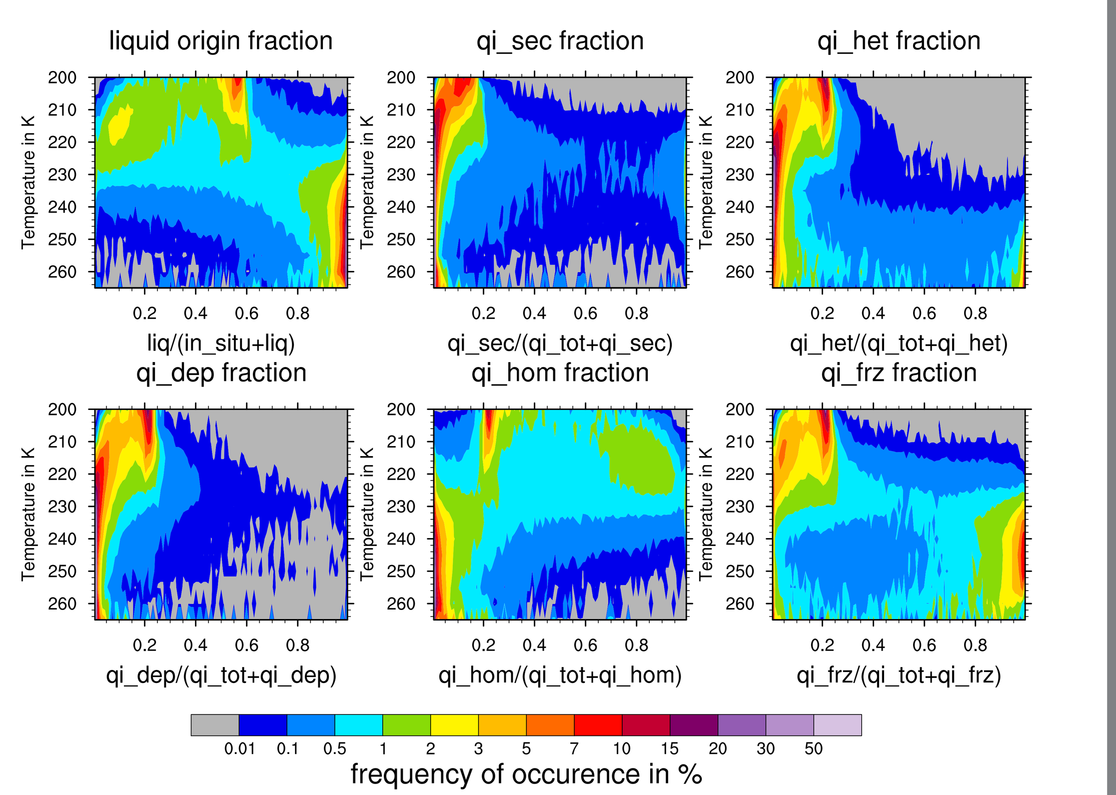

Figure 4: Frequency of occurrence of liquid origin fraction and ice mode fractions as a function of temperature for all WCB trajectories.

Summary

- Cirrus outflow formed by a contribution of all ice modes
- Immersion and homogeneous freezing of cloud droplets dominate early WCB
- Deposition nucleation is weak but highly sensitive to heterogeneous nucleation scheme
- Early cirrus is of liquid origin but strong homogeneous nucleation events form in situ cirrus later that lower liquid origin fraction below 55 %