Karlsruhe Institute of Technology

Institute for Meteorology and Climate Research - Atmospheric Trace Gases and Remote Sensing

Investigating convective tropospheric transport processes and large scale stratospheric dynamics with ICON-ART

Roland Ruhnke, Jennifer Schröter, Christian Stassen, Daniel Rieger, Ingeborg Bischoff-Gauss, Heike Vogel, and Bernhard Vogel

Introduction

We have extended the global ICON (ICOsahedral Nonhydrostatic) modelling framework. ICON is a joint development by the German Weather Service (DWD) and the Max-Planck-Institute for Meteorology (MPI-M). We added modules for gas-phase chemistry and aerosol dynamics (ART, Aerosols and Reactive Trace gases) [1]. ICON allows a regional grid refinement with two-way interactions between the different horizontal grids. It is used by DWD for numerical weather predictions and will be used by MPI-M for climate projections [2].

The extended modelling framework ICON-ART is developed in an analogous way to its predecessors COSMO-ART [3], so that aerosol and chemical composition feedbacks can be considered in a comprehensive way. Up to now, ICON-ART accounts for volcanic ash tracers, radioactive tracers, sea salt and mineral dust aerosols. Additionally, several gaseous tracers have been introduced. For the dynamics (transport and diffusion) of aerosol and gaseous tracers, the original ICON tracer framework is used. For the model physics, numerical time integration follows a process splitting approach separating physical processes. Each process is called independently via an interface module. Currently, the processes of emission, dry and wet deposition, sedimentation, and first order chemical reactions are included.

Simulation of very short-lived Ozone depleting brominated substances

Bromoform ($CHBr_3$) and Dibrommethane (CH_2Br_2) contribute significantly to stratospheric inorganic bromine, which is involved in Ozone destroying catalytic cycles, although they have short chemical lifetimes (24 and 123 days, respectively). In a multi month simulation initialized at June 1st 2012 with IFS data ICON-ART is used in a R02B06 (about 40 km) resolution with 90 levels up to 75 km to investigate the fast convective vertical transport of these very-short lived substances (VSLS) in the tropical troposphere.

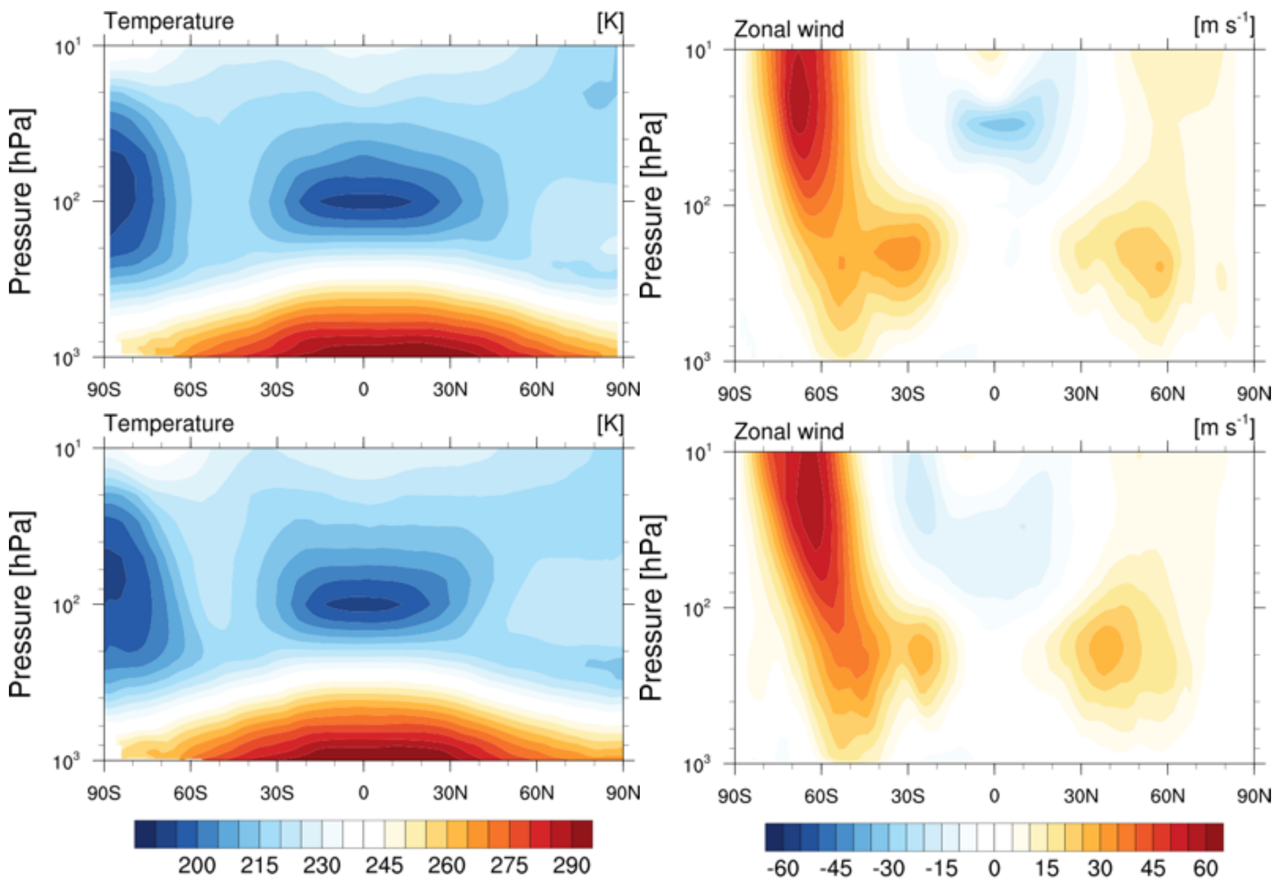

Figure 1: Zonal mean of temperature (left column) and zonal wind (right column) at 1 October 2012 as given by ERA-Interim reanalysis (top row) and ICON-ART (bottom row).

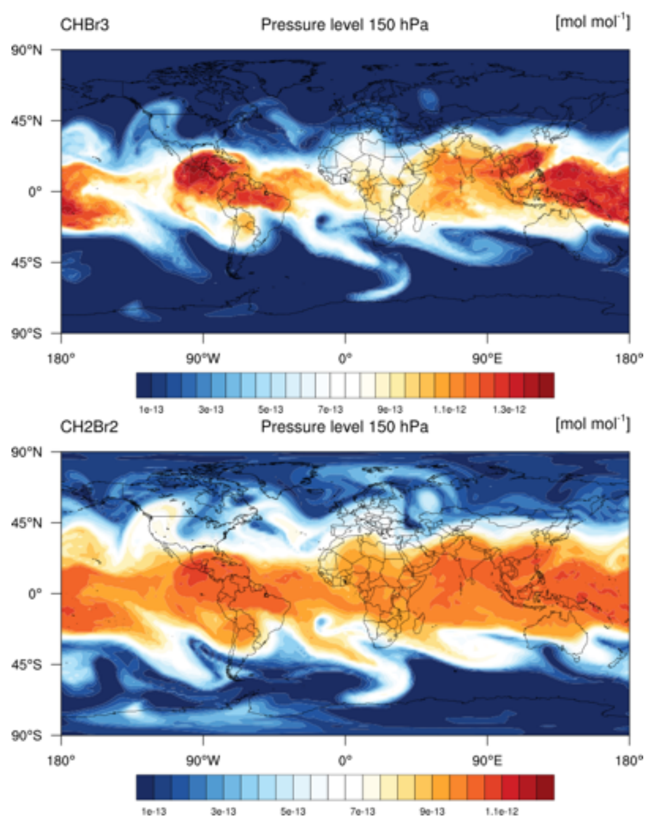

Figure 2: Simulated distribution of $CHBr_3$ (top) and CH_2Br_2 (bottom) volume mixing ratio at 150 hPa at 1 October 2012. Please note the different color scales.

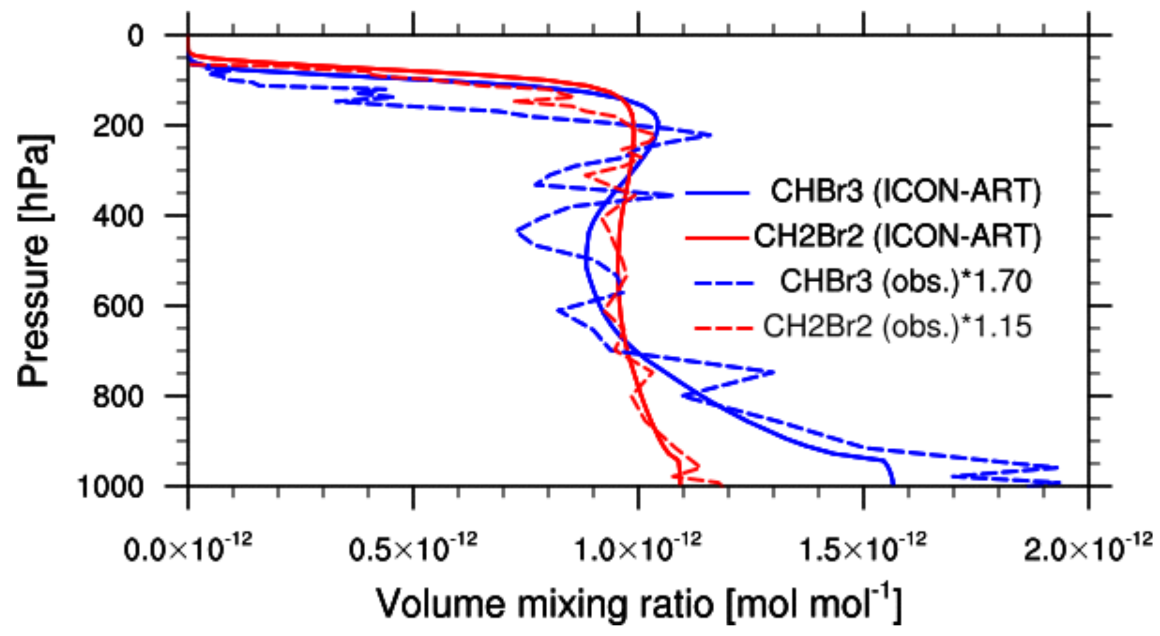

Figure 3: Mean vertical profiles between 20° S and 20° N of $CHBr_3$ (blue) and CH_2Br_2 (red) volume mixing ratio simulated by ICON-ART for 1 October 2012 (solid lines) and observed during different campaigns (dashed lines). Please note that, the observed mean tropical profiles have been multiplied by 1.70 for $CHBr_3$ and 1.15 for CH_2Br_2 for an easier comparison with the modelled profiles.

The simulated temperature agrees well with the ERA-Interim data in absolute temperature values in the tropical lower stratosphere as well as in the minimum temperatures within the stratospheric polar vortex in the southern hemisphere (Fig. 1). A good agreement with ERA-Interim is also found for the wind fields revealing that ICON-ART in the NWP mode is suitable for the investigation of the tracer transport of the VSLS from the surface into the UTLS region.

The simulated fast convective transport into the lower stratosphere occurs mainly in the tropical West Pacific region (Fig. 2), which is in agreement with previous studies as the preferred region of the transport of VSLS into the lower stratosphere. For $CHBr_3$ the distribution at 150 hPa is more inhomogeneous than for CH_2Br_2 due to its shorter life time pointing to the regions of fast vertical transport into the lower stratosphere. Consequently, the advection into the mid-latitudes is more visible in the longer lived CH_2Br_2.

The simulated zonal mean profiles in the tropical region of both brominated substances exhibit the characteristic C-shape profile form and more pronounced for the short-lived $CHBr_3$ than for CH_2Br_2, both also being observed (Fig. 3). The volume mixing ratio of about 1 pptv at about 200 hPa (about 11 km) for the longer-lived CH_2Br_2 is in good agreement with the mean observations as well as other model studies which are in the range of about 0.9 pptv. For the shorter-lived $CHBr_3$ the observations are in the range of 0.3 to 1.1 pptv with a mean of about 0.6 pptv, and thus slightly lower than the simulated volume mixing ratio. This discrepancy might be caused to a possible sampling bias of the highly variable $CHBr_3$ in that altitude region due to its short lifetime.

Comparison with aircraft measurements and global EMAC simulation

For the TACTS / ESMVAL campaign of the German High Altitude and Long Range Research Aircraft (HALO) in September 2012 an ICON-ART simulations in R03B07 (about 13 km) resolution has been performed and compared to a EMAC simulation.

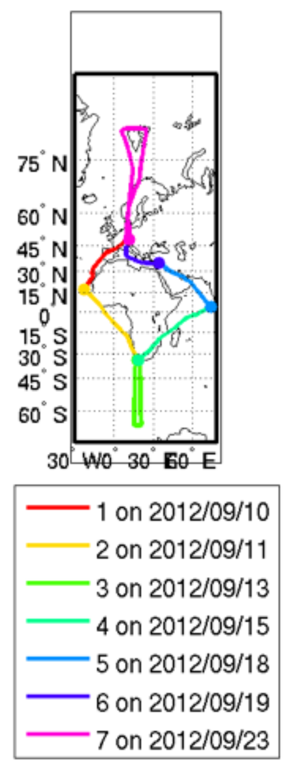

Figure 4: Flight tracks during the TACTS/ESMVAL campaign.

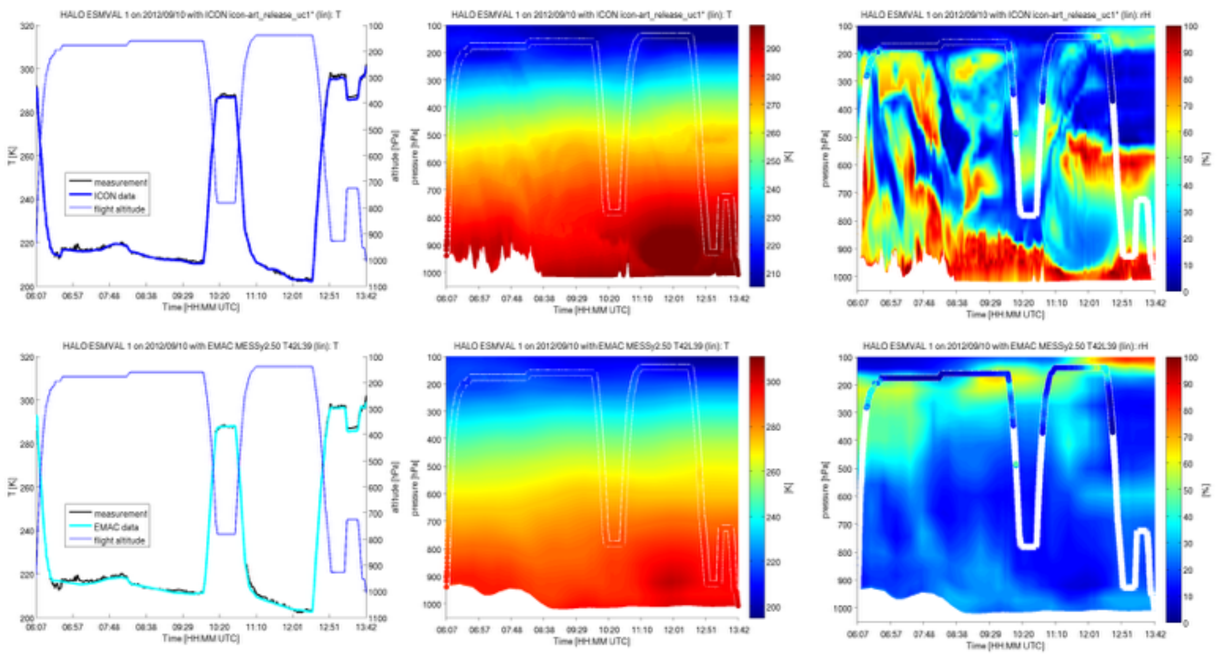

Figure 5: Measurements and simulation results for HALO flight #1 (2012/09/10). Top: ICON-ART results, bottom: EMAC results. Left: Comparison of temperature at flight level, mid: temperature profiles, right: profiles of relative humidity. The measurements for temperature and relative humidity are sumperimposed.

Simulation of the Antarctic stratospheric vortex split 2002

To test the ability to forecast large scale stratospheric dynamics, ICON-ART has been used in a R02B06 (about 40 km) resolution to simulate the unprecedented event of the Antarctic stratospheric vortex split in September 2002. Therefore, an Ozone chemistry based on the linearization scheme from McLinden et al. (J. Geophys. Res., 2000) has been included in the model and initialized with Ozone data from the GEMS climatology. The simulation results show that ICON-ART can predict the stratospheric vortex split about one week in advance and that the simulated Ozone agrees well with TOMS data.

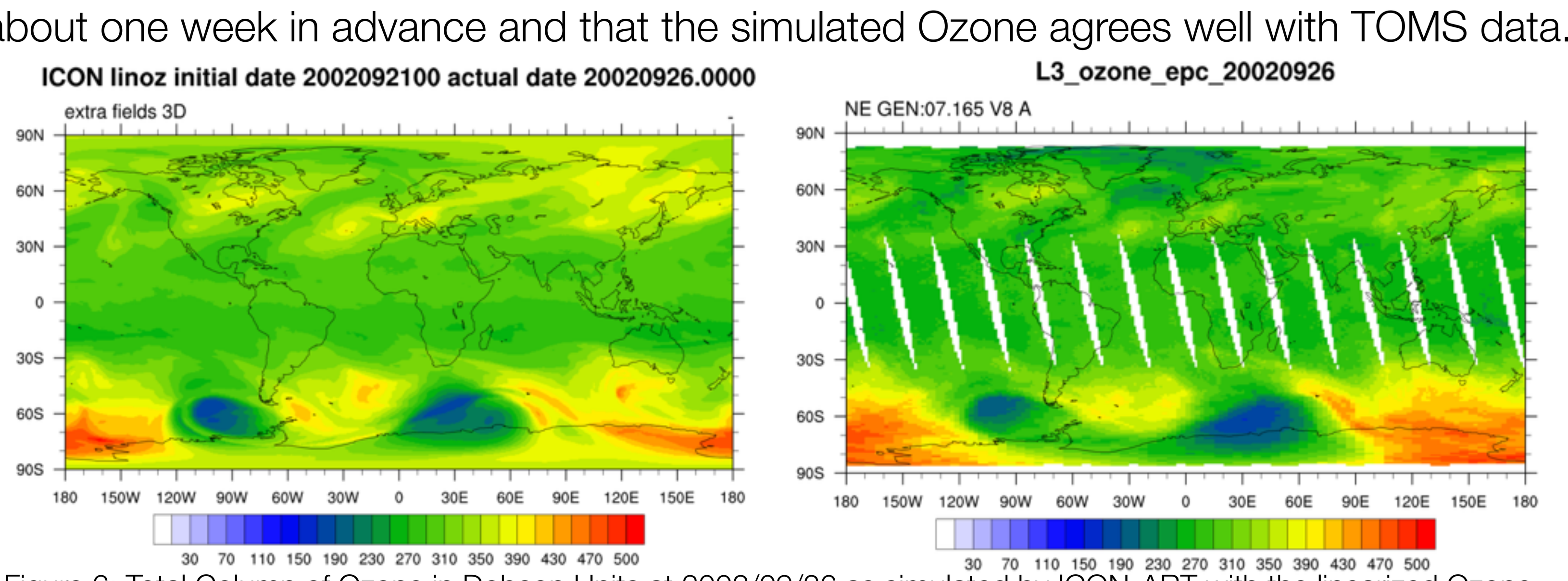

Figure 6: Total Column of Ozone in Dobson Units at 2002/09/26 as simulated by ICON-ART with the linearized Ozone chemistry scheme of McLinden et al. (2000) initialized at 2002/09/21 (left) and measured by the Total Ozone Mapping Spectrometer (TOMS) (right).

References

[1] Rieger, D., et al. (2015), ICON-ART - A new online-coupled model system from the global to regional scale, Geosci. Model Dev. Discuss., 8, 567-614
[2] Zängl, G., et al. (2014), The ICON (ICOsahedral Non-hydrostatic) modelling framework of DWD MPI-M: Description of the non-hydrostatic dynamical core. Q.J.R. Meteorol. Soc., doi:10.1002/qj.2378
[3] Vogel, B., et al. (2009), The comprehensive model system COSMO-ART - Radiative impact of aerosol on the state of the atmosphere on the regional scale, Atmos. Chem. Phys., 9, 8661-8680