The Chemical Lagrangian Model of the Stratosphere (CLaMS)

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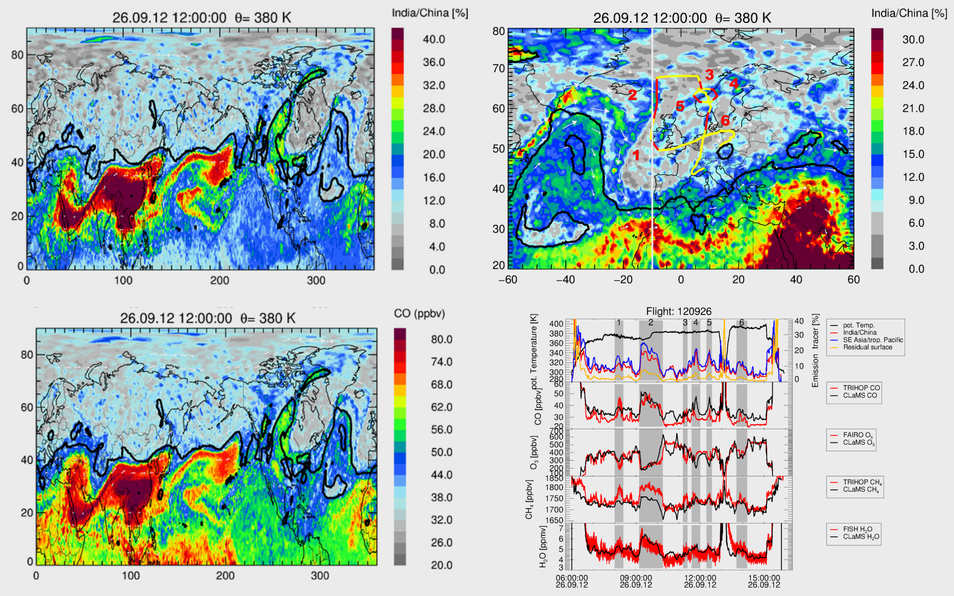
Introduction

The Chemical Lagrangian Model of the Stratosphere (CLaMS) has been developed in Jülich in the last two decades. Unlike most other atmospheric models it is based on the Lagrangian principle with an irregular adaptive grid that follows the trajectories of so-called air parcels. Together with a special anisotropic mixing scheme, CLaMS is especially able to properly simulate the tracer gradients at atmospheric transport barriers as the tropopause or the boundaries of the polar vortex and the Asian Monsoon Anticyclone. In this aspect, the common Eulerian models are often too diffusive. Besides a stand-alone simulation as a Chemistry Transport Model (CTM), also a coupling with a Chemistry Climate Model (CCM) was established through the MESSy interface. CLaMS simulations can be performed with different resolutions and different degrees of complexity either on LINUX workstations or on the parallel supercomputer facilities. Besides the presentation of the basic model concepts, some highlights of the scientific model results are presented including transport pathways from the Asian Monsoon Anticyclone to Northern Europe, polar ozone depletion and chlorine chemistry pointing to still open questions in stratospheric chemistry.

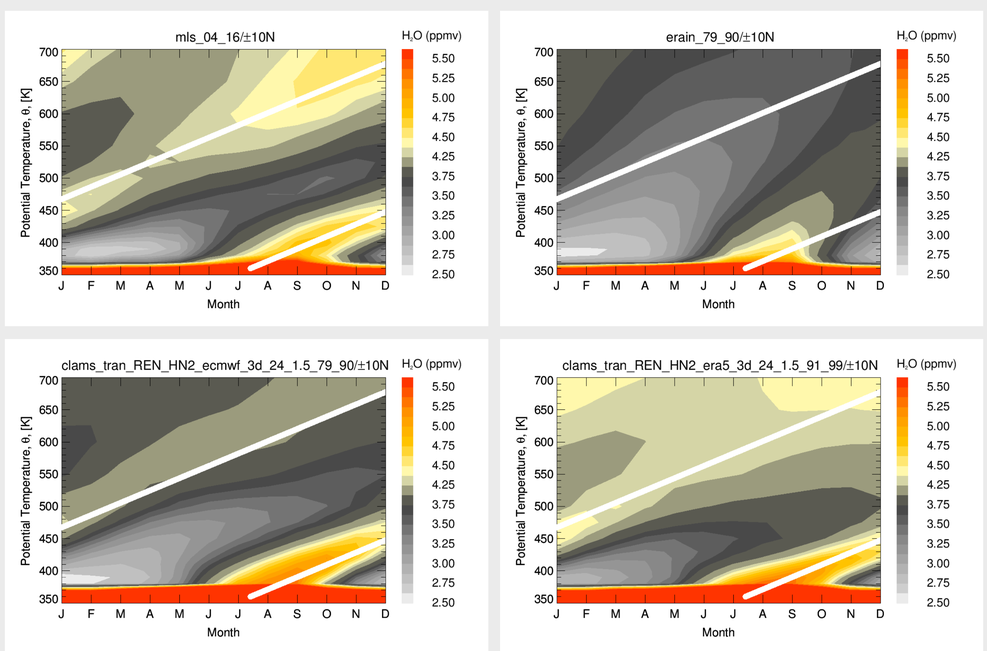
Outflow from Asian Monsoon



The Asian Monsoon Anticyclone (AMA) plays an important role for the transport of polluted air masses into the stratosphere. These figures show a CLaMS simulation that includes an artificial surface origin tracer from the region of India and China which fills the AMA (top left). The simulation of CO shows very similar patterns (bottom left). Comparisons were made with observations of the HALO aircraft measurement campaign TACTS/ESMVAL. The top right panel shows the same surface origin tracer in the region of the campaign including the location of a flight path. The bottom right panel shows in situ measurements and corresponding model results along the flight path. Several small-scale filaments marked by numbers were reproduced well.

Vogel et al., Atmos. Chem. Phys., 16, 15301-15325, doi:10.5194/acp-16-15301-2016, 2016.

Vertical Transport in the Tropical Stratosphere

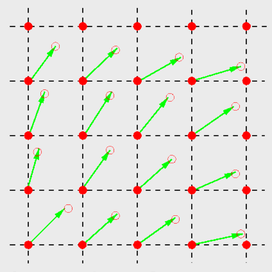


One measure of the quality of the vertical transport in the tropical stratosphere is the reproduction of the so-called tape-recorder effect. The entry of water vapour is modulated by the tropopause temperature and this pattern is transported by the slow vertical ascend. The top left panel shows the satellite observations by MLS. The top right panel shows the water vapour transport in the (Eulerian) re-analysis ERA-Interim itself. The bottom panels show the CLaMS results with the vertical velocity derived from the re-analyses ERA-Interim (left) and the new ERA-5 (right) with higher vertical resolution. The over-plotted white line in all plots shows the observed vertical ascent of the water vapour maximum.

Konopka et al., in preparation, 2020.

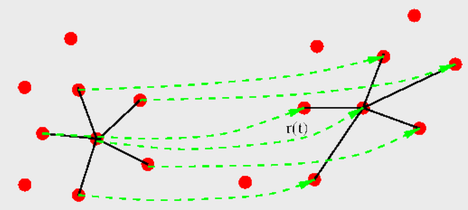
Lagrangian Model Formulation

Eulerian Models



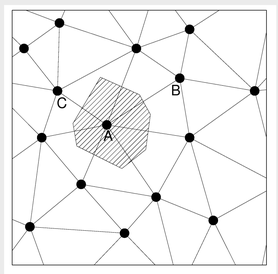
- Regular grid uniform in time
- Regridding after each time step
- Mixing by permanent numerical diffusion

Lagrangian Models



- Irregular grid changing in time
- Coordinates follow air parcels
- Quantities conserved in air parcels
- Mixing formulated explicitely

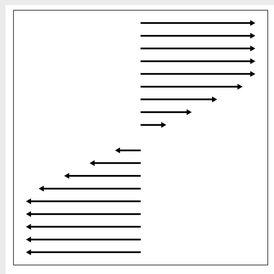
Lagrangian Mixing in CLaMS



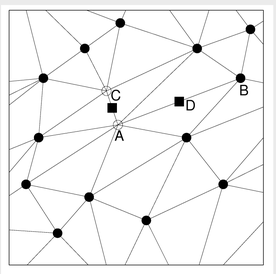
About uniform air parcel distribution in each layer

Delaunay triangulation

⇒ next neighbours



Wind shear



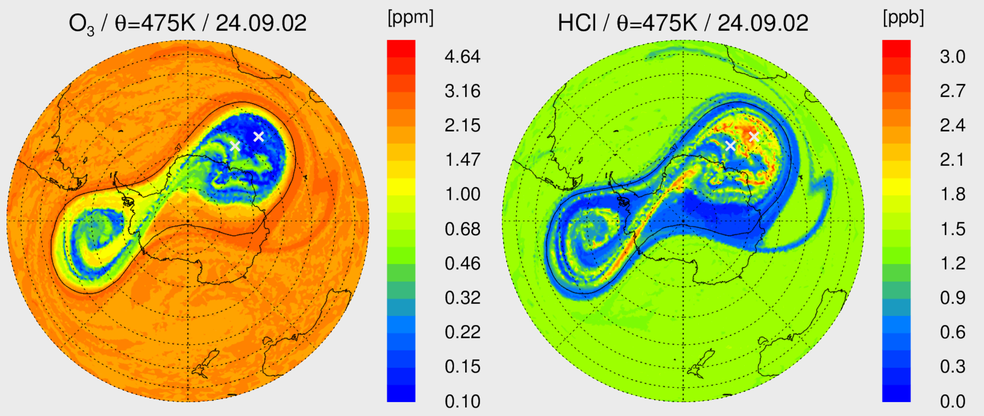
Grid adaption:

Added air parcels (D)

Combined air parcels (A+C)

Konopka et al., J. Geophys. Res., 109, doi:10.1029/2003JD003792, 2004.

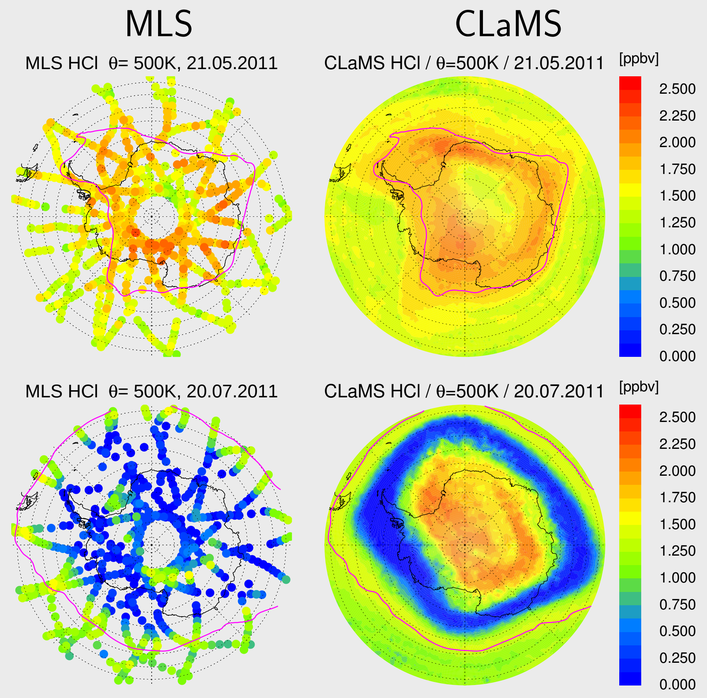
Ozone-dependent Chlorine Deactivation



In 2002, the Antarctic vortex that is typically very stable in winter and spring experienced a quite unusual "major warming" event with the consequence that is split into two parts. This unusual event triggered a series of studies including this CLaMS model study looking an the deactivation of chlorine species into HCl that is known to be dependent on ozone. Due to the Lagrangian non-diffusive formulation of the model, the small-scale structure of chlrone deactivation into HCl where ozone is low is visible.

Grooß et al., J. Atmos. Sci., 62, 860-870, doi:10.1175/JAS-3330.1, 2005.

Discrepancy in Polar Chlorine Chemistry



The accuracy in the CLaMS transport scheme also allows for investigations in stratospheric chemistry. In this study, a major discrepancy in chlorine chemistry has been discovered that indicates a missing process in the stat-of-the art models. The left panels show satellite observations by MLS for 21 May and 20 July 2011 and the right panel show the corresponding CLaMS results. In early winter the model does show no significant depletion of HCl in the polar vortex core, which, however, was observed. Other Eulerian models do also show this effect to a lesser extent because of the higher diffusivity.

Grooß et al., Atmos. Chem. Phys., 18, 8647-8666, doi: 10.5194/acp-18-8647-2018, 2018.