Overview on the COSMO-Model System

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The COSMO-Model and its Users
The COSMO-Model

- The COSMO-Model System is a nonhydrostatic limited-area atmospheric prediction system.
- It has been originally developed by DWD and is now used by several communities for their special applications:
  - NWP: The COSMO consortium
  - Climate Mode: The CLM Community
  - ART: Aerosols and Reactive Trace Gases
The Consortium for Small-Scale Modelling

- Consists of national weather services (latest member Israel not yet visible in this picture)

- Uses the COSMO-Model for daily numerical weather prediction
CLM Community

- The CLM Community developed the COSMO-Model further for regional climate modeling (RCM),
- Applications are now
  - IPCC runs
  - various scientific purposes in the climate mode
- For these applications the model is called COSMO-CLM or CCLM
The CLM Community has more than 250 scientific members from 71 climate research institutions all over the world.

see: http://www.clm-community.eu
COSMO-ART

- The Karlsruhe Institute of Technology (KIT) extended the COSMO-Model by an online coupling of ART (Aerosols and Reactive Trace Gases)
- The online calculation of reactive trace substances and their interaction with the atmosphere is possible with this modeling system.
- COSMO-ART is used by about 15 research institutes and 7 national weather services
- ETH has added the M7 aerosol module that is usually used for global climate simulations
- See the presentation of Bernhard Vogel on Thursday!
In Switzerland it is used for operational forecasting of Pollen

In April 2010 DWD and KIT were able to produce simulations of the volcanic ash event of Eyjafjalla very soon after the eruption

At the United Arab Emirates (in Abu Dhabi) it is used daily to predict sandstorms

DWD uses COSMO-ART in case of volcanic eruptions and Saharan dust storms operationally on demand

Rosshydromet produces air quality forecast on a daily basis.
Operational Usage of the COSMO-Model in 2016
The COSMO-Model 
Software Package
The COSMO-Model is formed by the equations and the algorithms to solve them.

**Momentum**

\[
\begin{align*}
\frac{\partial u}{\partial t} + v \cdot \nabla u -\frac{uv}{a} \tan \varphi &= f v - \frac{1}{\rho \alpha \cos \varphi} \left( \frac{\partial p'}{\partial \lambda} - \frac{\sigma}{p^*} \frac{\partial p'}{\partial \lambda} \frac{\partial p'}{\partial \sigma} \right) - \left( \frac{\nabla \cdot F}{\rho} \right) e_\lambda \\
\frac{\partial v}{\partial t} + v \cdot \nabla v + \frac{u^2}{a} \tan \varphi &= -f v - \frac{1}{\rho \alpha} \left( \frac{\partial p'}{\partial \varphi} - \frac{\sigma}{p^*} \frac{\partial p'}{\partial \varphi} \frac{\partial p'}{\partial \sigma} \right) - \left( \frac{\nabla \cdot F}{\rho} \right) e_\varphi \\
\frac{\partial w}{\partial t} + v \cdot \nabla w &= \frac{g \rho_0}{\rho p^*} \frac{\partial p'}{\partial \sigma} + \frac{g \rho_0}{\rho} B - \left( \frac{\nabla \cdot F}{\rho} \right) e_z
\end{align*}
\]

**Pressure**

\[
\frac{\partial p'}{\partial t} + v \cdot \nabla p' - g \rho_0 w = -\gamma p D + \frac{\gamma p}{T} \left\{ \frac{Q}{c_p} + T \frac{d\alpha}{dt} \right\}
\]

**Temperature**

\[
\frac{\partial T}{\partial t} + v \cdot \nabla T = \frac{1}{\rho c_p} \left( \frac{\partial p'}{\partial t} + v \cdot \nabla p' - g \rho_0 w \right) + \frac{Q}{c_p}
\]

**Humidity**

\[
\frac{\partial q^k}{\partial t} + v \cdot \nabla q^k = -\frac{1}{\rho} \left( \nabla \cdot J^k + \nabla \cdot F^k \right) - \frac{1}{\rho} I^k
\]
Model, Grids and Software

- The equations are discretized on a model grid

- The COSMO-Model uses a rotated latitude-longitude grid
Model, Grids and Software

- For practical reasons the discretized equations must be implemented on computer systems.
- The corresponding software is, what we call the COSMO-Model Software Package.
The COSMO-Model Software Package

- The COSMO-Model Software Package consists of
  - **COSMO-Model**: the atmospheric simulation model
  - **INT2LM**: preprocessing program to deliver initial and boundary conditions
- In addition you need some external libraries for input / output of data
  - **GRIB**: a standard data format defined by the World Meteorological Organization (WMO) and is used by the weather services. You can use:
    - **DWD GRIB1 library** (only for GRIB1; available from DWD) and / or
    - **ECMWF grib_api** used for GRIB2 (available from ECMWF)
  - **NetCDF**: The Network Common Data Form is a set of software libraries and machine-independent data formats to support the creation, access, and sharing of array-oriented scientific data and is widely used by the climate community: http://www.unidata.ucar.edu/software/netcdf
- The NWP group uses **NetCDF** also for observation processing.
The COSMO-Model Software Package (II)

→ There is an optional component, that can be used to compute „synthetic satellite images“:

→ **RTTOV Library**: The Radiative Transfer Model can be used to compute radiances and brightness temperatures, as can be measured by certain satellites and their instruments.

→ To use this library, you need a special licence, which can be acquired by nwpsaf@metoffice.gov.uk

→ But the source code for RTTOV you should take from DWD, because we did some technical modifications

→ To run the COSMO-Model package, you also need **DATA**.
Software and Data

- Utilities for preprocessing
  - EXTPAR (DWD) / PEP (CLM): to prepare external parameters for the COSMO-Model
  - INT2LM: Interpolation program which reads data from a driving model and interpolates them to the COSMO-Model grid

- Input data for the COSMO-Model
  - External parameters to describe the surface of the earth:
    - Constant data (orography, land-sea-mask, soil type)
    - (Not so constant) data, e.g.: plant characteristics

- Data from a driving model
Software and Data

- The simulation model itself
  - COSMO-Model

- Postprocessing tools that are necessary to understand the results
  - for visualization
  - for verification
  - for evaluation of climate runs

- The simulation model itself
  - Needs initial and boundary data

- Output data of the COSMO-Model
Components of the COSMO-Model
Structure of the COSMO-Model

- Input / Output
- Framework
- Fortran 90/95/2003
- MPI Parallelization
- Assimilation
- Utilities
- Chemistry (COSMO-ART)
- Memory Management
- Physics
- Dynamics
- Diagnostics
Basic Framework

- The basic organization of the COSMO-Model is done in the main program `lmorg.f90`.
- The first task is the setup, to define the configuration
  - namelist input for the setup
  - definition of the model domain
- memory management
- parallelization by domain decomposition
- computation of basic constants and fields
I/O and Postprocessing

- For practical simulations, it is necessary to get data into and out of the model. For idealized test cases, input can be switched off.

- The COSMO-Model supports three different data formats:
  - Grib, Version 1 and Version 2; Version 2 only used at DWD up to now
  - NetCDF
  - Binary data (only for Restarts)

- During the Output, additional fields can be computed, if wanted (Postprocessing)
Dynamics

- The Dynamics solves the set of differential equations, that define the COSMO-Model.

- Two different dynamical cores are offered, the Leapfrog-scheme (old scheme, used since the beginning) and the Runge-Kutta (or 2-timelevel) scheme (implemented in the last years). For both schemes there are several variants.

- The Runge-Kutta scheme was mainly intended for high-resolution (< 3km) runs, but is now also used for coarser resolutions. At DWD, the Leapfrog scheme has been replaced also in the 7 km application.

- It is recommended not to use the Leapfrog dynamical core any more.
Physical Parameterizations

- The COSMO-Model uses several sub-components for the physical parameterizations. For most sub-components, different variants are offered.
- Note: Not all variants are fully tested!
- The sub-components are:
  - Microphysics
  - Radiation
  - Moist convection
  - Turbulent diffusion and parameterization of surface fluxes
  - Soil Processes
  - Lake and sea ice schemes
  - Subgrid Scale Orography Scheme
Diagnostics

- In the Diagnostics, additional meteorological fields are computed, that are not present in the basic equations.
- Also, some ASCII output is produced for a quick monitoring of the forecast: Meteographs, mean values for several variables, etc.
Assimilation

- An Assimilation scheme is implemented in the COSMO-Model, which has been used in NWP-mode up to last Thursday (21.03.2017): the Nudging

- Using nudging in the assimilation mode, the model-state is continuously nudged against available observations.

- Therefore it provides the analysis for the initial state of a forecast.

- In the last years, DWD and the COSMO consortium developed a new assimilation method based on the LETKF: Local Ensemble Transform Kalman Filter. The code name for this development is KENDA (Kilometer based ENsemble Data Assimilation). See the (NWP) presentation by Christoph Schraff on Wednesday for more information.
Chemistry

- Interfaces have been implemented into the COSMO-Model for an online coupling of
  - COSMO-ART: Aerosols and Reactive Tracers
  - a Pollen module.
- This work has been done by the Karlsruhe Institute of Technology (KIT).
- Note: The source code for COSMO-ART and the Pollen module is not distributed by COSMO or the CLM-community, but can be obtained directly from KIT.
Preprocessing
Necessary Data

To run the COSMO-Model, several fields have to be provided (Depending on the chosen configuration)

External parameters: Constant or slowly varying fields for:
- HSURF (FIS), FR_LAND, SOILTYP, Z0, FR_LAKE, DEPTH_LK, FOR_E, FOR_D, constant
- PLCOV, LAI, ROOTDP, annual cycle
- VIO3, HMO3 annual cycle

Initial fields:
- Atmosphere: U, V, W, T, PP, QV, QC, QI, QR, QS, QG
- Soil and surface: T_SNOW, W_SNOW, W_I, QV_S, T_S, T_SO, W_SO, FRESHSNOW, RHO_SNOW

Boundary fields:
- Atmosphere: U, V, W, T, PP, QV, QC, QI, QR, QS, QG
- Soil and surface: T_SNOW, W_SNOW, QV_S
EXTPAR / PEP

- The external parameters have to be provided for a special application (domain, grid size and resolution) of the COSMO-Model.
- They are derived from (global / regional) raw data sets like GLOBE, ASTER, GLOBCOVER, etc.
- DWD developed a program, to process these raw data (EXTPAR)
- The CLM Community developed a web-tool, to create these parameters for a chosen domain: [http://www.clm-community.eu → Tools → WebPEP](http://www.clm-community.eu)
- EXTPAR / WebPEP are NOT distributed with the COSMO-Model package!
- Because without the raw data it does not make sense. And the raw data are several hundreds of GBytes!
- If you need a special set of external parameters, you can
  - contact DWD or
  - go to the CLM web page to use WebPEP
INT2LM

- The INT2LM does the final preprocessing of all input data for the COSMO-Model. Despite the name, this is more than just an interpolation.
- The constant external parameters are taken as provided by EXTPAR/WebPEP.
- The varying external parameters are taken from EXTPAR/WebPEP and processed for the special day of the year.
- The variables for ozone (VIO3, HMO3) are not provided by EXTPAR/WebPEP, but are computed by INT2LM, depending on the special day of the year.
- All other initial and boundary fields are taken from a coarse grid model and processed for the COSMO-Model domain.
- This involves (mainly) a horizontal interpolation, a vertical interpolation and a special treatment in the boundary layer.
Working with the COSMO-Model Software Package
Necessary Steps to Run the Models

- 3 steps are necessary to run the models
  - Installation of the models on a computer
  - Setting the proper Namelist Input
  - Starting the jobs on the computer
- All these steps are part of the practical exercises during this week
- In addition you will also
  - visualize your results
  - learn about idealized test cases
  - do some trouble shooting
Additional Courses

- In (optional) additional courses next week you will also
  - learn about the features of COSMO-ART
  - learn about the implementation of a new dynamical core for ACCelerators
    - The Swiss COSMO colleagues run the COSMO-Model on a machine using GPU (Graphical Processing Units)
    - To implement the COSMO-Model on GPUs they re-wrote the dynamical core and implemented a „domain specific language“
    - The rest of the model still uses Fortran with „OpenACC“ directives
    - The development of this GPU version took several years and is not yet supported officially. Only the dynamical core is ready to use now.
Namelist Input

- For both, the INT2LM and the COSMO-Model, you have to specify a certain configuration.
- This defines, what you want to run: which variant of the dynamics, which versions for the physical parameterizations, etc.
- To specify the configuration, both programs use NAMELIST input.
- The COSMO-Model has more than 500 (!) Namelist variables, the INT2LM has about 200.
- It is not necessary to know all of them. Perhaps only 10 % of them are really important.
- You will learn about the important ones in the Practical Exercises.
## Namelist Groups

<table>
<thead>
<tr>
<th>COSMO</th>
<th>INT2LM</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUNCTL</td>
<td>CONTRL</td>
<td>Specifying the basic configuration</td>
</tr>
<tr>
<td>LMGRID</td>
<td>LMGRID</td>
<td>Specifying the COSMO-Model domain</td>
</tr>
<tr>
<td></td>
<td>GRID_IN</td>
<td>Specifying the input model domain</td>
</tr>
<tr>
<td>IOCTL,</td>
<td>DATA</td>
<td>Specifying I/O characteristics</td>
</tr>
<tr>
<td>GRIBIN,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRIBOUT,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DYNCTL</td>
<td></td>
<td>To choose the dynamical core variant</td>
</tr>
<tr>
<td>PHYCTL</td>
<td></td>
<td>To choose the physical parameterizations</td>
</tr>
<tr>
<td>DIACTL</td>
<td></td>
<td>To choose the diagnostics</td>
</tr>
</tbody>
</table>
User Support
User Support

⇒ In case of problems with the COSMO-Model Software Package, you are not alone!

⇒ If something is not working with
  ⇒ the installation,
  ⇒ the basic setup of your application or
  ⇒ running the programs

⇒ you can contact:
  ⇒ for NWP: cosmo-support@cosmo-model.org
  ⇒ for CLM: information will be given during the exercises
Coming to an END

➤ This presentation should have given you an overview on the different parts and components of the COSMO-Model System.

➤ During this week you will learn more on the theoretical aspects for the dynamics, physics and additional components.

➤ You will also get some practical experience for installing the source code and running the necessary programs during the „Tutorials“.

➤ We are happy to take your comments and suggestions!
Thank you very much for your attention.