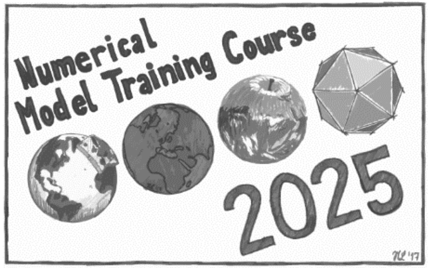
Getting Started with ICON

DWD ICON Course | July 2025 | Florian Prill, DWD

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Introduction



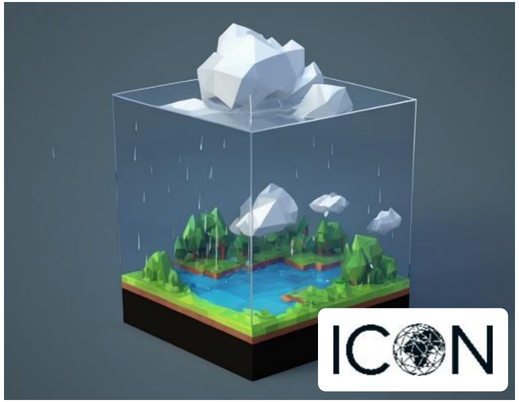
ICON

ICON-NWP

ICON is a modelling framework, consisting of various

- institutions: DWD, MPI-M, DKRZ, KIT, C2SM, MCH, ...
- communities: users and developers, MetServices, universities, CLM, natESM, ...

ICON is used with various computing platforms:
x86 clusters, GPUs, vector engines …



In this talk we move along a path called **ICON-NWP**, which is the numerical weather prediction (NWP) branch of the model, developed for operational and regional weather forecasting by the German Weather Service.

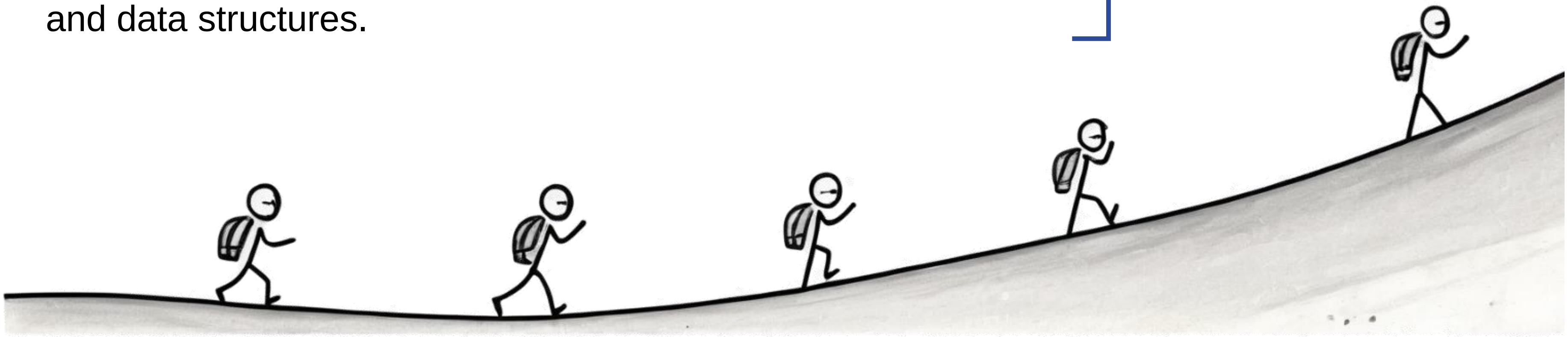
Unavoidable simplifications: we omit ICON's ocean model, wave model, …

Talk outline

We can get started with the ICON model in three different ways:

- We begin with the source code, the various subdirectories and libraries involved.
- We consider a model setup, and follow the flow of control of a typical model run.
- We have a closer look at some of the functional components and data structures.

~ 45 minutes



Building blocks of the ICON model

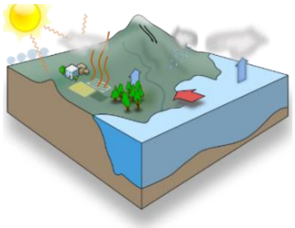
Many contents are dealt with in specific lectures…

`src/atm_dyn_iconam`

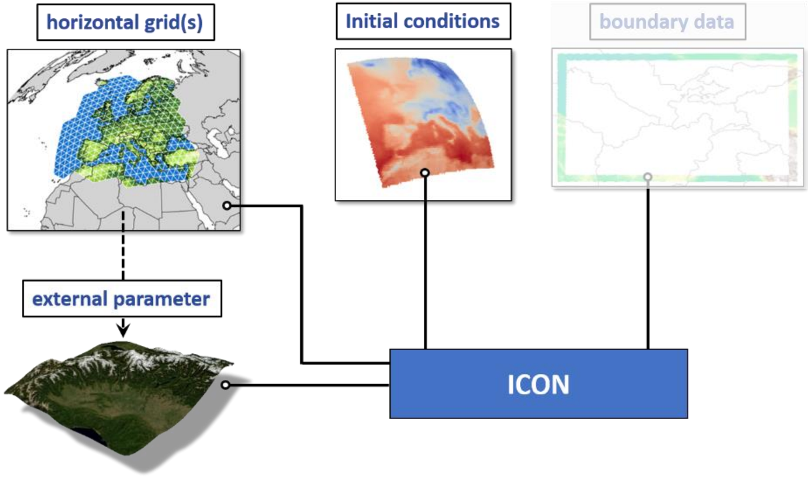
$$
\begin{aligned}
&\partial_t v_n \quad + (\zeta + f)\, v_t \quad + \ldots \\
&\partial_t w \quad + \mathbf{v}_n \cdot \nabla w \quad + \ldots \\
&\partial_t \rho \quad + \nabla \cdot (\mathbf{v}\rho) \quad = \ldots \\
&\partial_t (\rho\theta_v) + \nabla \cdot (\mathbf{v}\rho\theta_v) \quad = \ldots
\end{aligned}
$$

- **DyCore**
  see
  dedicated talk

`src/atm_phy_schemes`



- **Physics**
  see various
  talks this week



- **Input and boundary data**
  see dedicated talk

ICON Tutorial and further documentation

- **Users**: see https://docs.icon-model.org
and we also refer to the **Tutorial Book** (linked there)

⇨ chapters 0-2, 7-10

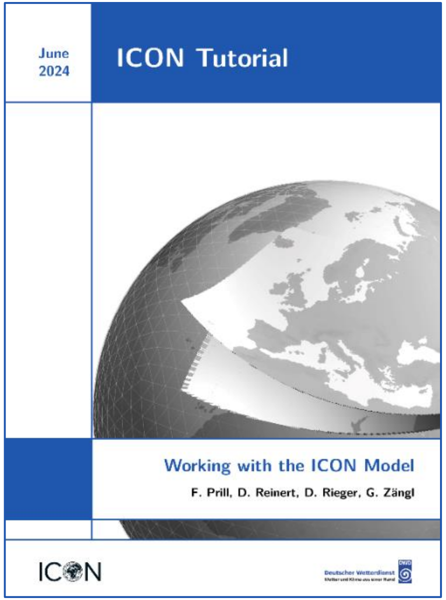
- **Scientific publications**, eg.,

  Zängl et al. (2015): The ICON modelling framework of DWD and MPI-M: Description of the nonhydrostatic dynamical core. Q. J. R. Meteorol. Soc., 141, 563-579.

  (see https://www.icon-model.org/publications/reference-publications for more)

- DWD's operational products are documented in the
DWD database manual

  www.dwd.de/SharedDocs/downloads/DE/modelldokumentationen/
  nwv/icon/icon_dbbeschr_aktuell.pdf



https://www.dwd.de/DE/leistungen/nwv_icon_tutorial/nwv_icon_tutorial.html

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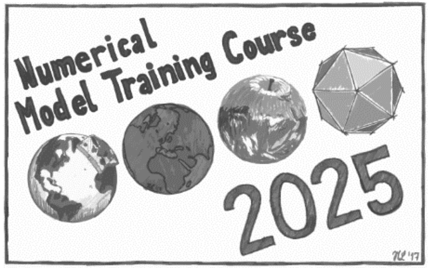
Part 1: Source Code



ICON source code

- Components: **weather, climate, ocean, land.**
- **Model source code - Fortran code (***F2003 compliant***)**
- **Auxiliary libraries**: written in C99

Root directory: **icon**

config	*platform configuration*
externals	*external submodules (ART, calendar etc.)*
run	*test scripts*
src	*Fortran sources*
support	*C99 support library and utility routines*
build	*build directory with sources and binary*

ICON model code

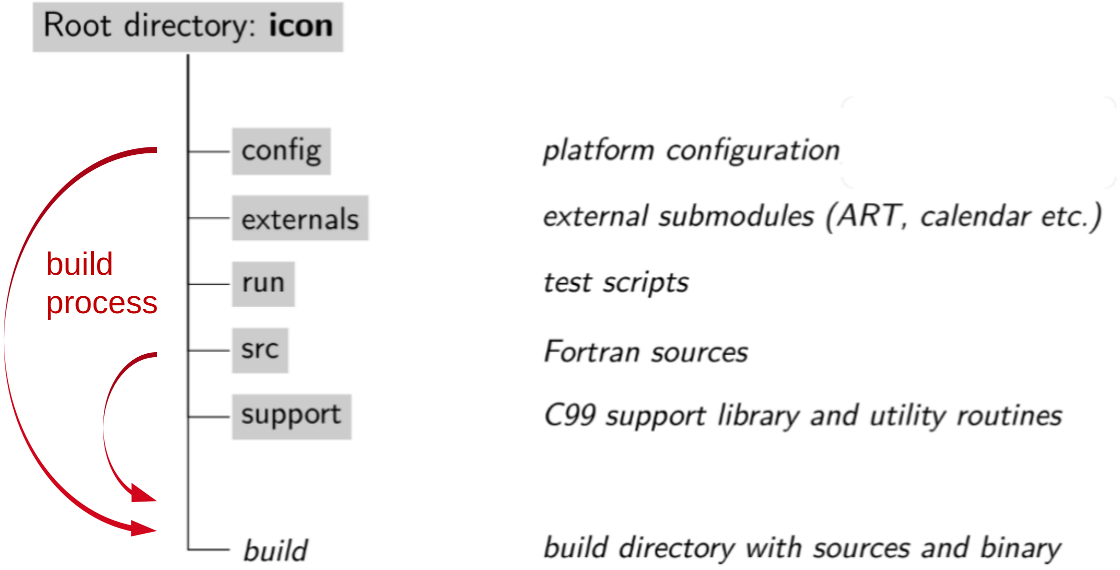
spring release 2025.04

Releases can be found under

gitlab.dkrz.de/icon/icon-model

ICON versions are named
using the scheme \`icon-yyyy.mm\`
where \`yyyy\` is the year
and \`mm\` is the month
of the release

Build process: configure & compile



Configure options:

`configure -h`

Parallel build:

`make -j4`

List of tested compilers
see Tutorial book, Section 1.3

GNU, Cray, Intel, NAG, NEC, NVIDIA

- see **`https://docs.icon-model.org/buildrun/buildrun_building.html`**:
how to configure, build and run ICON.

Build process: configure & compile

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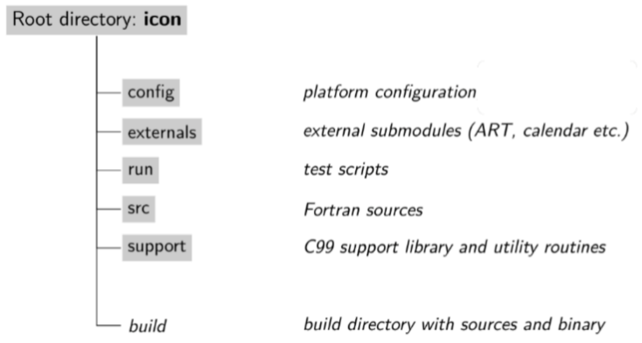
The configuration step is typically executed by running the **`configure`** script with command-line arguments[1].

Instead of running the generic **`configure`** script directly, it is recommended to use a platform-specific configuration wrapper.
The wrappers can be found in the **`config`** subdirectory.



[1] … see Autoconf: https://www.gnu.org/software/autoconf/

ICON source code

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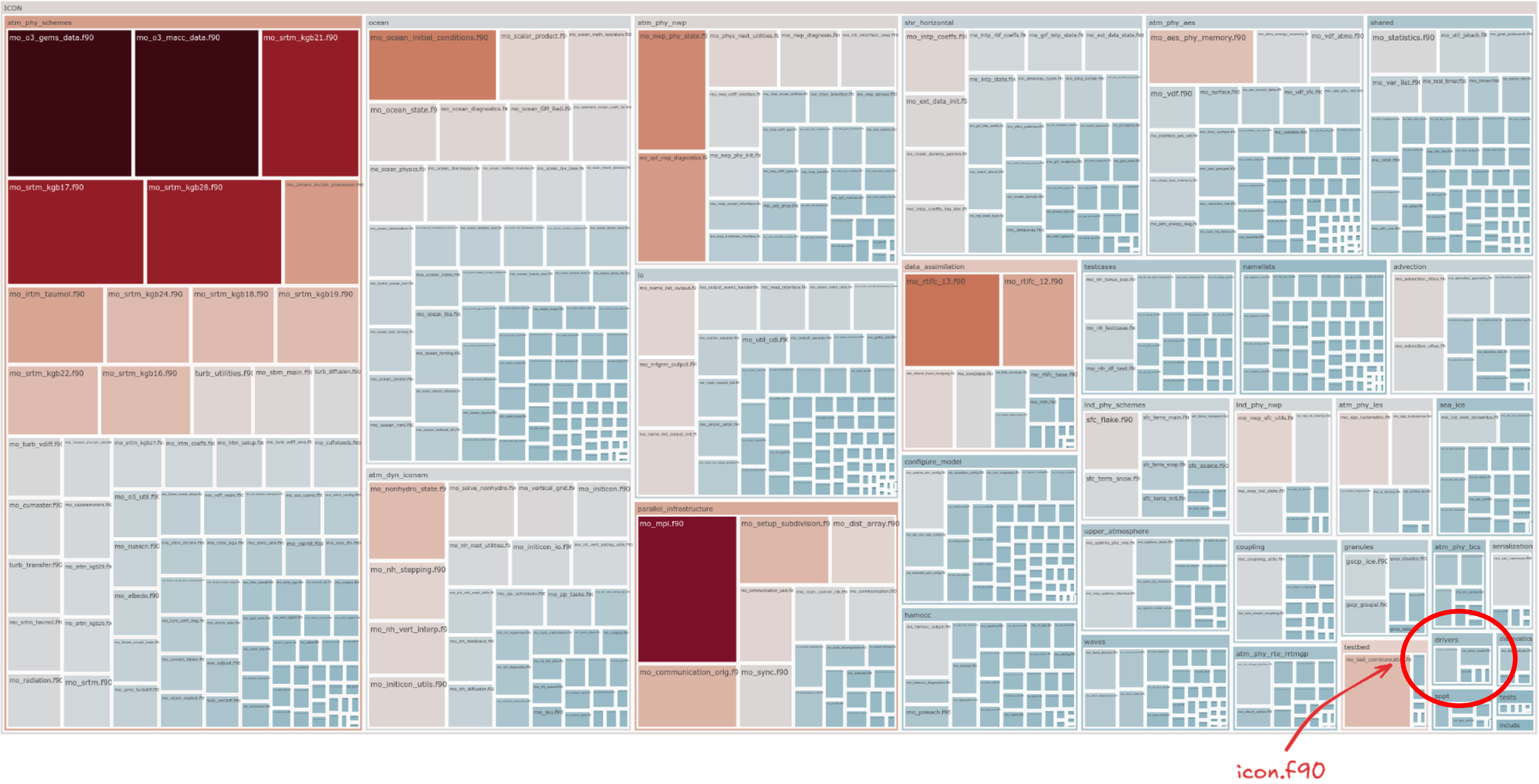
Release ICON 2025.04

Fortran and C code: 1,168,413 lines of which 523,853 are in `icon/src`[1]



[1] SLOC count

Subdirectory **`icon/src`**

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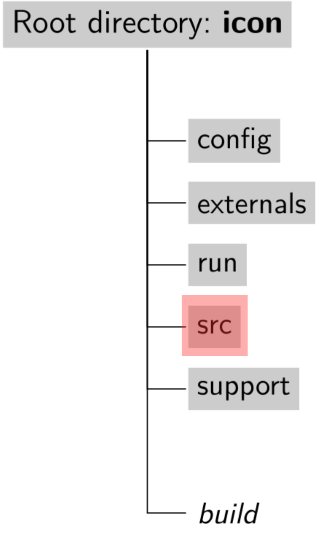
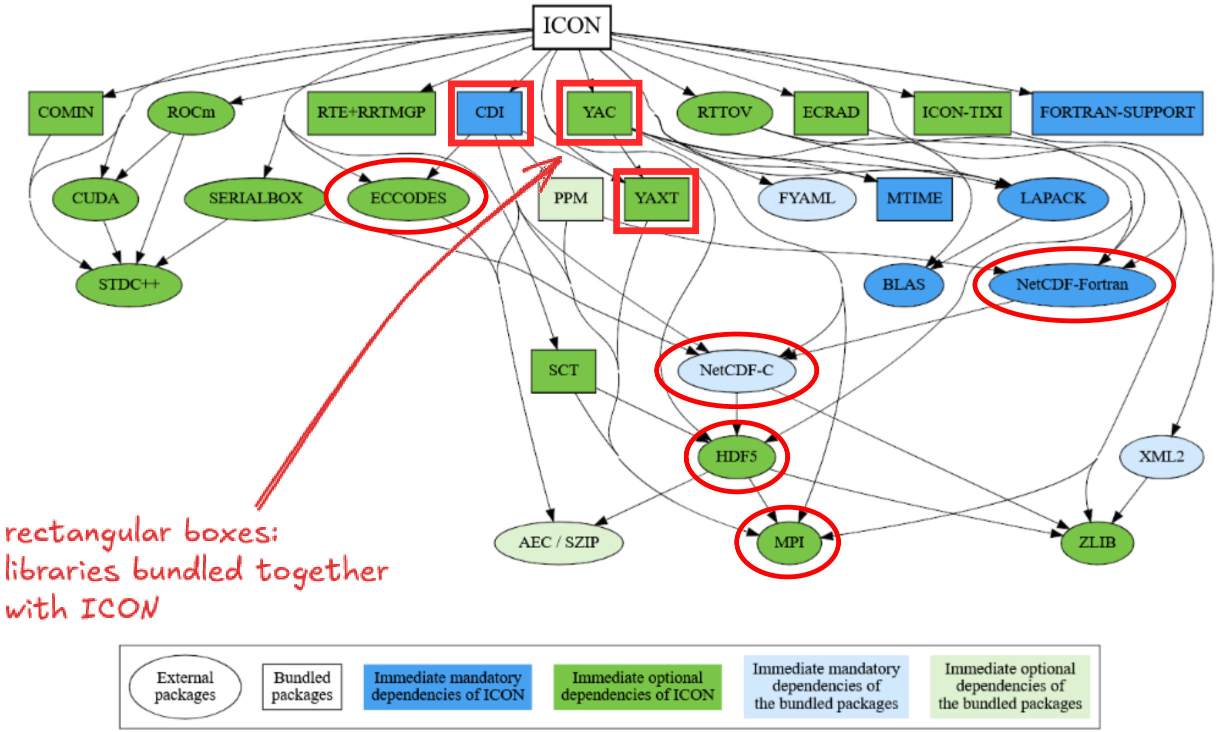
- Subdirectory **`src/drivers`**
  main program and nonhydrostatic setup
- Subdirectory **`src/atm_dyn_iconam`**
  dynamics implementation
- Subdirectory **`src/atm_phy_nwp`** and **`src/lnd_phy_nwp`**
  physical parameterizations
- Subdirectories **`src/configure_model`** and **`src/namelists`**
  configuration of run-time settings
- Subdirectories **`src/shared`** and **`src/shr_horizontal`**, and **`src/parallel_infrastructure`**
  shared infrastructure modules
- Subdirectory **`src/io`**
  Input and output modules



Software libraries

The ICON model package integrates a whole variety of external libraries.

Several of them are <u>mandatory</u> for parallelization, coupling, and model I/O!



Software libraries (cont'd)

- **MPI - Message Passing Interface**
  distributed-memory parallelization
- **OpenMP**
  multi-threading, part of your compiler
- **NetCDF and ecCodes/GRIB-API**
  read/write data

wrapper scripts with flags and library paths for various platforms

`icon/config/`

… append your additional options

Infrastructure libraries distributed together with the ICON model:

Climate Data Interface (CDI) - https://code.mpimet.mpg.de/projects/cdi

YAC (ICON coupler software, German Climate Computing Centre DKRZ)

and others

NEC SX-Aurora rack mount model

External packages - `icon/externals`

YAC is an example of a switchable external package.

Further examples:

- ComIn
  plugin mechanism (e.g. Python scripts)
- ecRad
  atmospheric radiation scheme
- JSBACH
  ICON-LAND
- YAXT
  parallel communication library

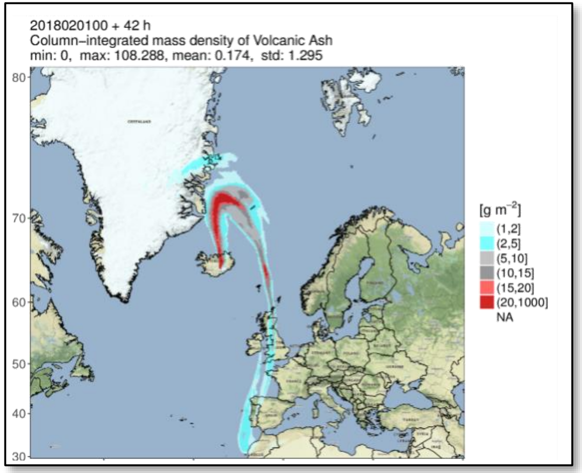
Note: Not all modules that can be switched via **`configure`** are available in the Open Source Release.

ICON-ART

The ICON-ART package enables ICON to simulate gases, aerosol particles and related feedback processes in the atmosphere.

- "ART" stands for
  Aerosols and **R**eactive **T**race gases.
- ICON-ART requires additional source code, which is provided by the **Karlsruhe Institute of Technology**.
- ICON-ART is a good example for a model extension, which consists of the **adapter source code** (externals/art/interface) and the **module code** (externals/art) itself.

Karlsruhe Institute of Technology



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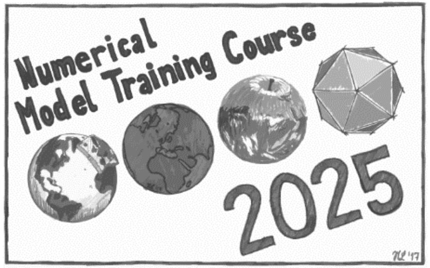
Part 2: Typical model run



ICON

ICON’s namelists

In general, the ICON model is controlled by a parameter file which uses the Fortran NAMELIST syntax.

```
! --- parallel_nml: MPI parallelization ---
&parallel_nml
 nproma                       =              8         ! loop chunk length
 num_io_procs                 =              1         ! number of I/O processors
 num_restart_procs            =              0         ! number of restart processors
 iorder_sendrecv              =              3         ! sequence of MPI send/receive calls
/
```

- During the setup phase, the ICON model reads ~600 namelist parameters
  … most namelist parameters are not set explicitly, but use a default value!

Complete table with ICON namelist parameters:

icon/doc/Namelist_overview/Namelist_overview.pdf

most important namelist parameters see Tutorial book index!

`master_nml` and NWP namelists

For NWP simulations: Use the prepared exercises as “best practice settings”.

Bootstrap namelist file **`icon_master.nml`**

- initializes the ICON setup
- handles restart from saved model state: namelists are read from the **restart** file to override the default namelist settings, before reading new namelists from the run script
- specifies the “component namelist” for NWP in which the lion’s share of the parameters is defined **(often) named NAMELIST_NWP**

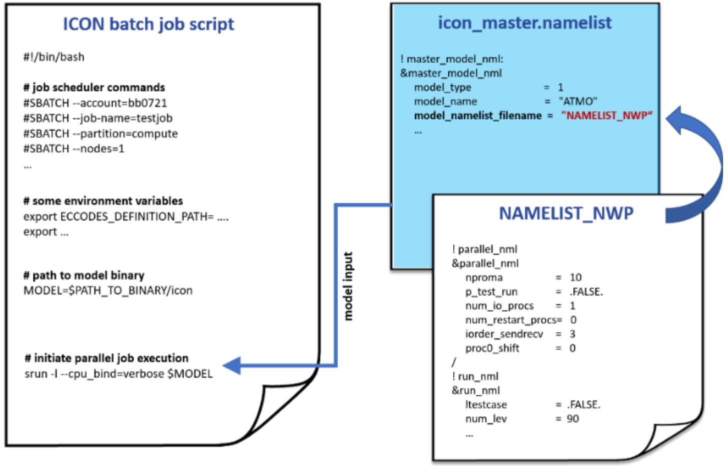
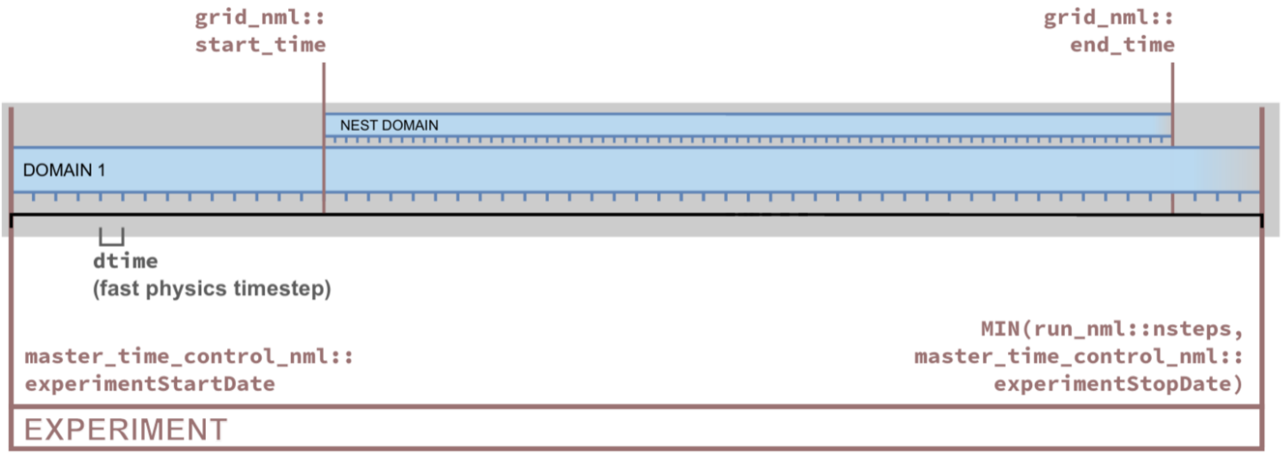


Illustration: D. Reinert, DWD

Namelist: setting start and end date

… and parameters for switching computational domains on and off during the simulation.



ICON Tutorial book - Section 5.1

Namelist: setting restart option

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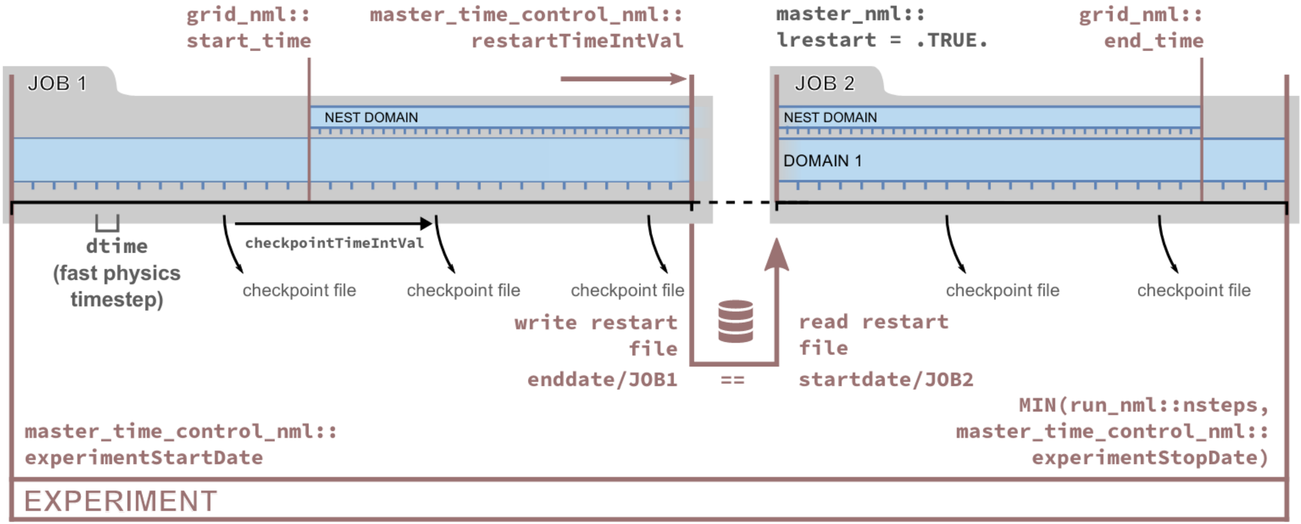
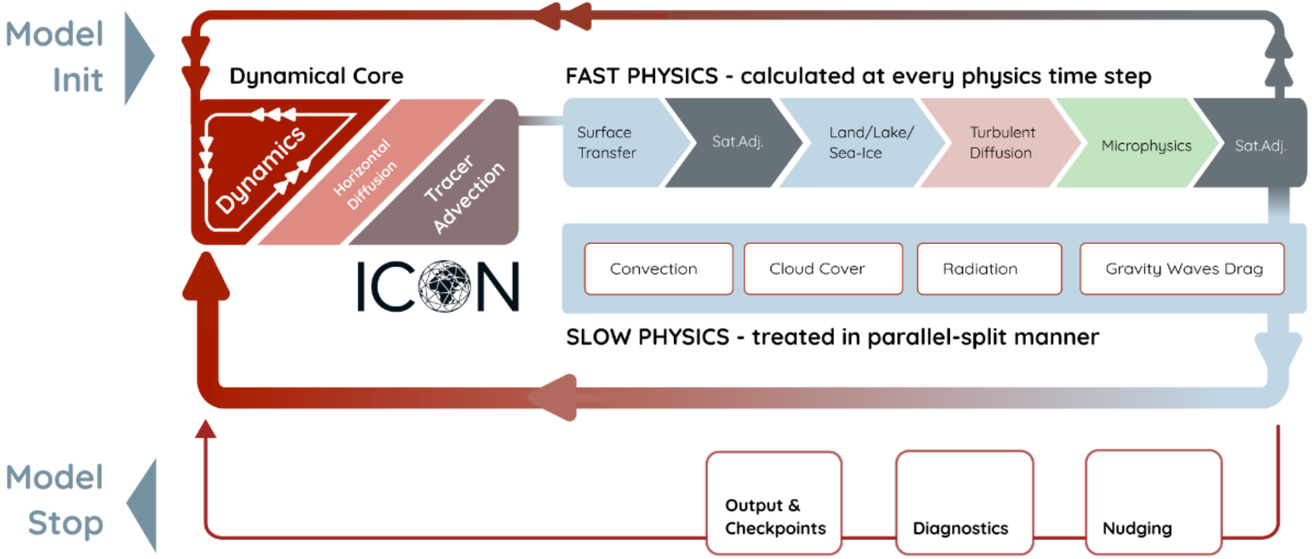
Restart option: allows to restart the execution from a pre-defined point using a checkpoint file.



ICON Tutorial book - Section 7.2

Flow of control



For efficiency reasons, different integration time steps are applied depending on the process.

Δt : basic time step (tracer, diffusion, fast physics) ; $\Delta\tau$: DyCore time step ; $\Delta t_{i,slow}$: slower processes

Grids and nested domains

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Many multi-domain namelist parameters:

```
&run_nml
  num_lev = 90, 60
```
number of vertical levels

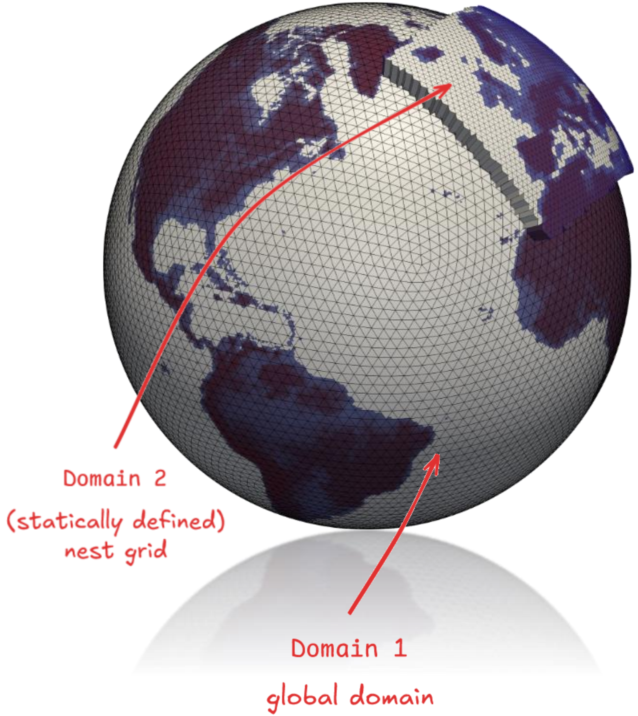
ICON has the capability for running

- global simulations on a single global grid
- global simulations with "nests" (= refined domains)
- regional simulations (ICON-LAM)

Nomenclature for icosahedral grids: RnBk

initial subdivision of icosahedral edges

subsequent edge bisections



Namelist specifications for the output

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```
! output_nml: specifies an output stream --------------------------------------
!
&output_nml
 filetype                  =                      4         ! output format: 2=GRIB2, 4=NETCDFv2
 dom                       =                     -1         ! write all domains
 output_bounds             =   0., 10000000., 10800.        ! output: start, end, increment
 steps_per_file            =                      2         ! number of output steps in one file
 mode                      =                      1         ! 1: forecast mode (relative t-axis)
 output_filename           =                  'NWP'         ! file name base
 output_grid               =                 .TRUE.         ! flag: grid information in output?
 !
 ml_varlist                =  'u', 'v', 'w', 'temp', 'pres','topography_c', 'pres_msl', &
                              'qv', 'qc', 'qi', 'qr', 'qs', 'tke',                      &
                              'tkvm', 'tkvh', 'group:pbl_vars',                         &
                              'group:precip_vars',  'group:additional_precip_vars',     &
                              'group:land_vars', 'group:land_tile_vars',                &
                              'group:multisnow_vars,
/
```

- Multiple namelists **`output_nml`** are allowed.
- Model prints a detailed tabular summary at start-up.

List of output fields and variable groups

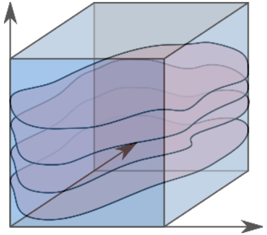
Variable Name	GRIB2 Name	Description
acdnc	ndcloud	Cloud droplet number concentration
adrag_u_grid		Zonal resolved surface stress mean since model start
adrag_v_grid		Meridional resolved surface stress mean since model start
aer_bc	aer_bc	Black carbon aerosol
aer_du	aer_dust	Total soil dust aerosol
aer_or	aer_org	Organic aerosol
aer_ss	aer_ss	Sea salt aerosol
aer_su	aer_so4	Total sulfate aerosol
aercl_bc		Black carbon aerosol c
aercl_du		Total soil dust aerosol
aercl_or		Organic aerosol climat
aercl_ss		Sea salt aerosol climat
aercl_su		Total sulfate aerosol cl
alb_dif	alb_dif	Shortwave albedo for d
alb_si	alb_seaice	Sea ice albedo (diffuse

List of available output fields and variable groups

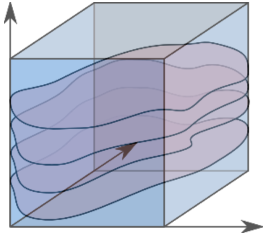
See Tutorial book, Appendix A

Internal post-processing

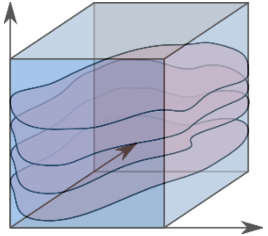
Vertical Grid



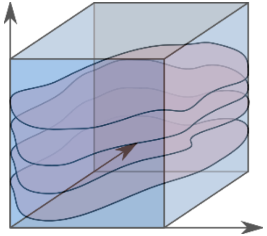
model levels



pressure levels



height levels

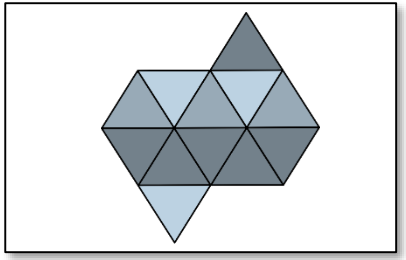


isentropic levels

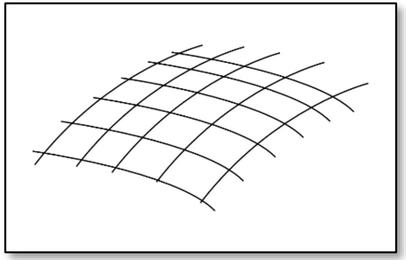
`output_nml::hl_varlist & h_levels`

X

Horizontal Grid



triangular grid



regular grids

`output_nml::remap`

GRIB2 data format

- GRIB Data Format: Defined by the World Meteorological Organization (WMO).
- The European Centre for Medium-Range Weather Forecasts (ECMWF) has developed a GRIB application programmers interface: ecCodes library (previously: GRIB-API).
- ICON supports only GRIB edition 2.

Model output in ICON accesses the ecCodes API through the CDI library.

DWD ecCodes Definition Files

ecCodes consists of two parts: The library and a definitions directory.

In particular, the variable name (string) is stored in the definitions but **not** in the data files!

To recognize GRIB2 variable names, you need to install DWD definition files

https://opendata.dwd.de/weather/lib/grib/

NetCDF data format

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The NetCDF storage format can also be used for model output:

- storage format for data arrays and attributes, structured and unstructured
- self-describing, machine-independent

Many tools interfacing NetCDF are available:

dataset info/modification:	**`ncdump`, `nco`, `cdo infov`**
visualization:	**`ncview`**, NCL, Python

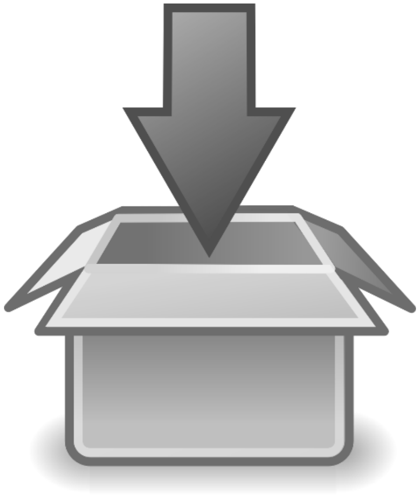
NetCDF-4/HDF5: permits storing files as large as the file system supports.

Typical file sizes

Example: global R2B6 grid with
327 680 triangular cells

40 km grid spacing, 90 vertical levels

- Storage size of a single 2D layer:
  - NetCDF: 1.38 MB
  - GRIB2: 641 KB
- GRIB2 storage format:
  ~ 50% file size compared to NetCDF
- additional 22 MB grid topology data
  in NetCDF file



I/O Libraries

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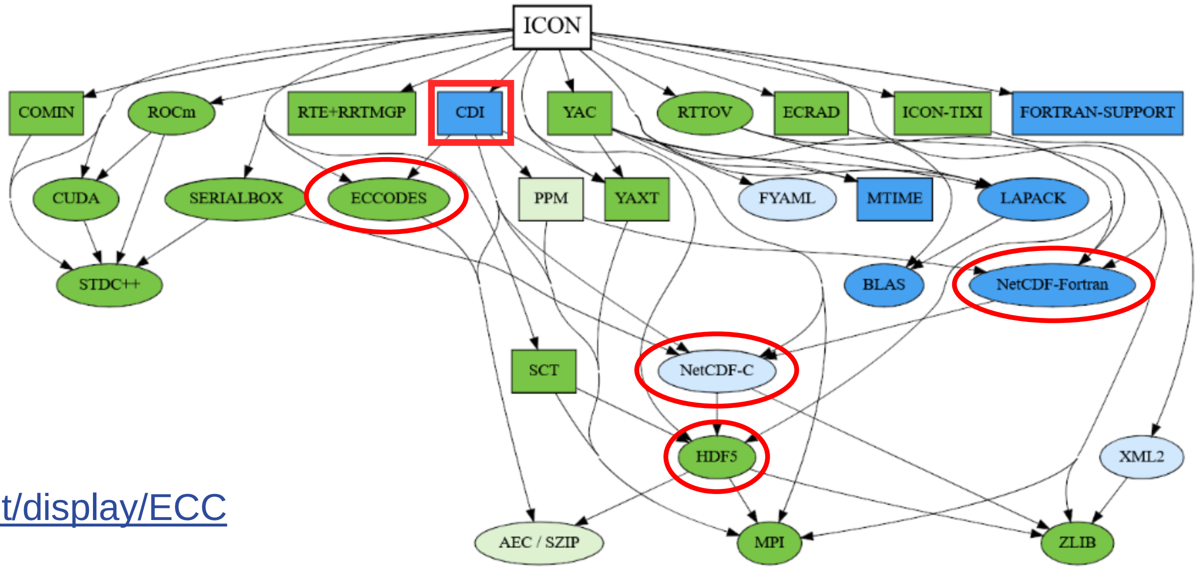

- ecCodes
  https://confluence.ecmwf.int/display/ECC

- NetCDF
  https://www.unidata.ucar.edu/software/netcdf/

Complicated details: file name keywords

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File name parameters for init data & output & boundary often use placeholders.

… the user specifies a list of file names through wildcards (“keywords”).

Example: Lateral boundary conditions, **`latbc_filename`** may contain:

<nroot>	grid root division Rx (single digit)
<nroot0>	grid root division Rxx (two digits)
<jlev>	grid bisection level Byy (two digits)
<dom>	domain number (two digits)
<y>	year (four digits)
<m>	month (two digits)
<d>	day in month (two digits)
<h>	hour (UTC) (two digits)
<min>	minutes (UTC) (two digits)
<sec>	seconds (UTC) (two digits)
<ddhhmmss>	elapsed days, hours, minutes and seconds since `ini_datetime_string` or `experimentStartDate` (each two digits)
<dddhh>	elapsed days and hours since `ini_datetime_string` or `experimentStartDate` (three digits day, two digits hours).

Namelist setting (example):

```
extpar_filename = 'extpar_DOM<idom>.nc'
```

Complicated details: dictionaries

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Field names that are internally used by the ICON model are not necessarily identical to the GRIB2 field names or the names in your NetCDF input file.

Dictionary files: two-column text files; translate between ICON variable names and GRIB2 or other external name schemes.

```
# internal name      GRIB2 shortName
#
temp                 T
pres                 P
pres_sfc             LNPS
rho                  DEN
…
```

Namelist parameters: **ana_varnames_map_file**, **latbc_varnames_map_file**, **var_names_map_file**, …

Error handling

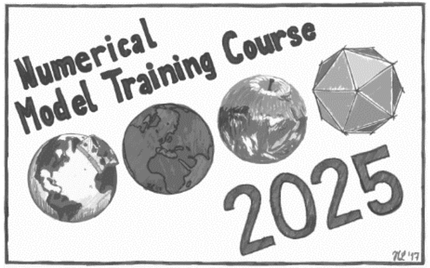
Fortran does not offer built-in support for exceptions and exception handling.

- **Exception handling in software: not implemented**
  The functions and subroutines in the ICON model do not return special error codes.
- **On error, the ICON model simply aborts:**
  When
  - an input argument is invalid
    (e.g. value is outside of the domain of a function), or
  - when a resource it relies on is unavailable
    (like a missing file),

  routines simply raise an exception with a hopefully meaningful message:

```
CALL finish(subroutine,"my_process_component is unknown")
```

Runscript and job execution



Runscript and job execution

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To run ICON it is necessary to create a runscript that sets required environment variables and calls the executable.

Slurm scheduler basics: The Slurm workload manager mediates between the ICON software and the HPC cluster, ie. the management of a job queue and the allocation of cluster nodes.

Slurm directives (may) appear as header lines in a runscript:

```
#SBATCH --partition=compute
#SBATCH --job-name=icon-lam
#SBATCH --nodes=16
#SBATCH --ntasks-per-node=48
#SBATCH --cpus-per-task=2
```

Most of your jobs will be submitted this way:

- sbatch <your_batch_script>

- srun <executable> is the task launcher for slurm
- squeue is used to show the queue
- scancel is used to cancel (i.e. kill) a job.

DWD's NEC: PBS batch system, qstat, qsub, …

Distributed-memory parallelization: MPI

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Model performance is determined by balance of workload, communication and memory consumption.

Domain decomposition

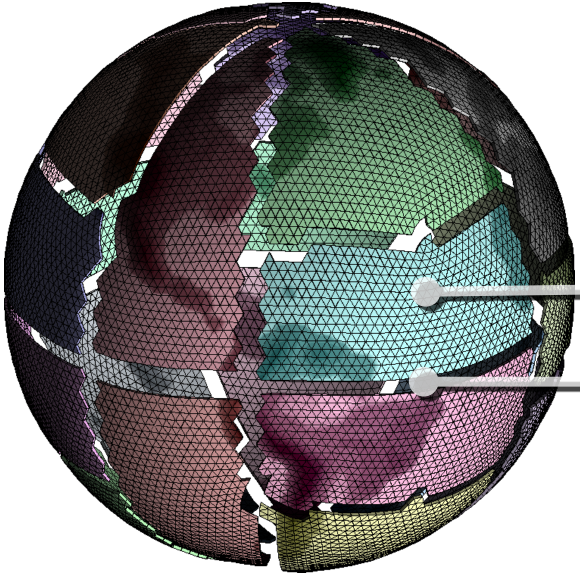
Each MPI task operates on a separate partition

Static load balancing

Partitioning fixed at start-up

Geometric subdivision

Recursive latitude/longitude bisection



Interior of partition

Halo region

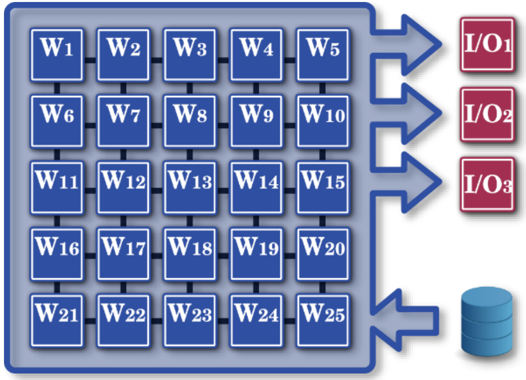
Finite difference stencils require communication

ICON

Splitting of the MPI process pool

Processors (PEs) are divided into

- **Worker PEs** majority of MPI tasks, doing the actual work
- **Output PEs** dedicated I/O server tasks
- **Restart PEs** for asynchronous restart writing
- **Prefetch PE** for ICON-LAM boundary data



ICON namelist settings for MPI

`num_io_procs`, `num_restart_procs` `num_prefetch_proc`

Asynchronous output: Some MPI processes run exclusively for writing data. Computation and output overlap.

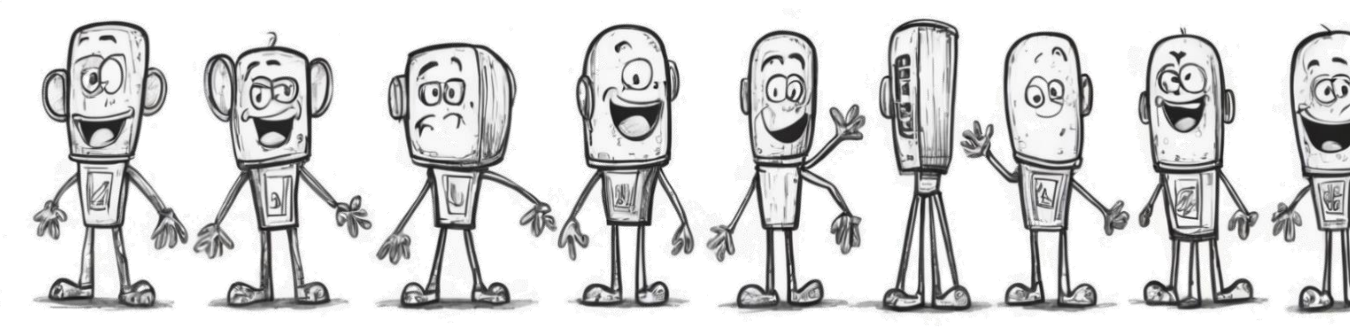
ICON-LAM: One MPI process runs exclusively for reading boundary data. Boundary data is linearly interpolated between two boundary data samples.

Levels of parallelism, target platforms

Besides distributed-memory computing other modes of parallel execution are possible:

- multi-core processors - OpenMPI — shared memory, multiple register sets
- classical vector computers — operate efficiently of large one-dimensional arrays
- Graphics Processing Units (GPUs) — compute kernels run on thousands of cores.

Not mutually exclusive; hybrid approaches are possible.



ICON on GPUs (Graphics Processing Units)

OpenACC is an API for offloading programs from a host CPU to an accelerator device.
ICON-Atmosphere has been gradually ported to GPUs using OpenACC.

ICON-CH on GPUs operational since May 28, 2024.

Critical settings:

- **`nproma`** ≫ number of arithmetic units on the accelerator
  (explanation will follow later)
- data transfers between CPU and GPU must be avoided.

Tutorial Book
Section 8.5

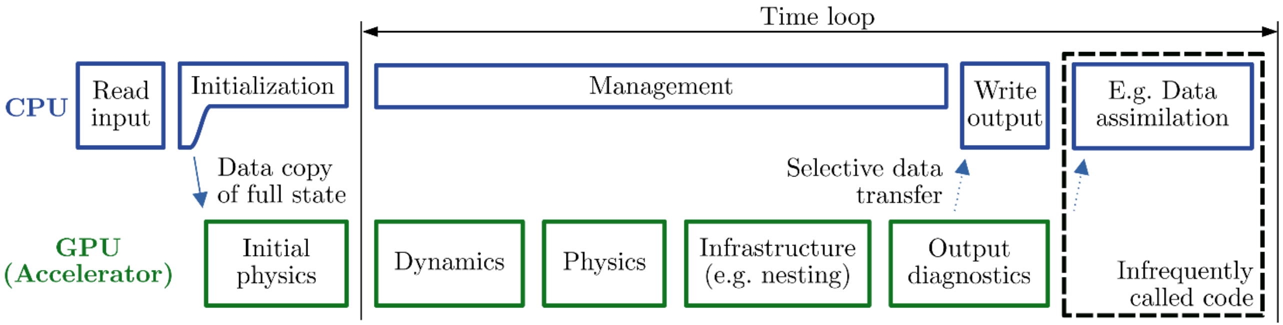


Illustration: M. Jacob, DWD

Performance measurement

The ICON code contains internal routines for performance logging for different parts (setup, physics, dynamics, I/O) of the code.

These may help to identify performance bottlenecks.

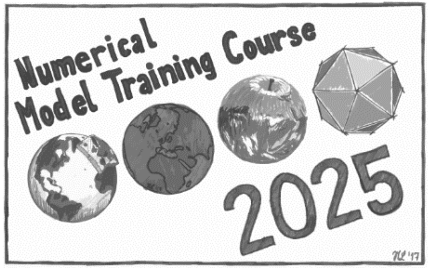
```
----------------------------  -------             -------------  -------------
name                          # calls             total min (s)  total max (s)
----------------------------  -------             -------------  -------------
total                         118         ...          272.564        272.637
 L integrate_nh               247800      ...          255.208        270.596
    L transport               49560       ...           33.409         35.791
       L adv_horiz            49560       ...           22.849         24.663
       L adv_vert             49560       ...            6.280          7.698
physics                       49678       ...          103.107        104.759
 L nwp_radiation              10030       ...           40.402         42.985
    L radiation               220674      ...           31.845         34.963
…
```

Caveat: Sometimes defined inconsistently by module developers!
For example, “total” does not contain ICON’s initialization.

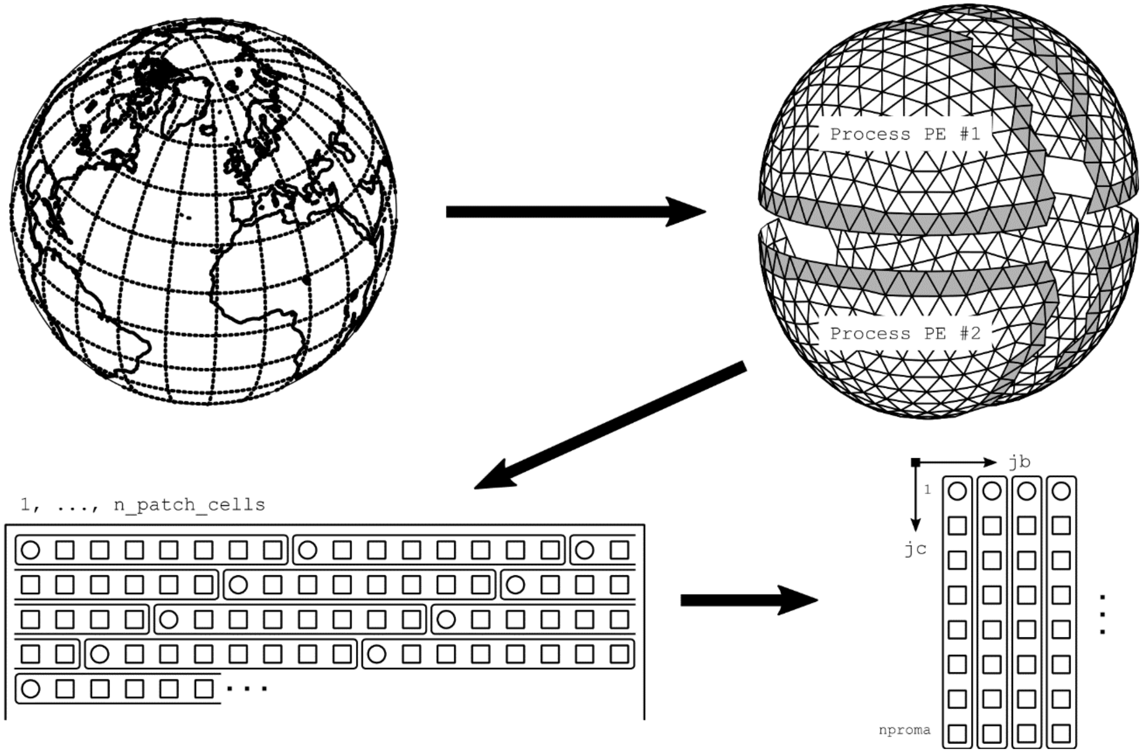
ICON namelist parameters

`run_nml::ltimer, timers_level`

Part 3: Code parts



Representation of 2D and 3D fields



Loop tiling: Arrays are logically two-dimensional in ICON

ICON namelist
`parallel_nml`
`nproma`

abbreviation **`nproma`** (probably) stands for
<u>n</u>ombre de <u>pro</u>fondeurs <u>ma</u>ximal
- maximum of maximal depths.

Physics and dynamics variables

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Prognostic and diagnostic fields are collected in **`t_nh_prog`** and **`t_nh_diag`**.
Elements of **`t_nh_prog`** are allocated for each time slice.

`t_nh_prog`

w	orthogonal vertical wind $[\mathrm{m\,s^{-1}}]$
vn	orthogonal normal wind $[\mathrm{m\,s^{-1}}]$
rho	density $[\mathrm{kg\,m^{-3}}]$
exner	Exner pressure
tke	turbulent kinetic energy $[\mathrm{m^2\,s^{-2}}]$
tracer	tracer concentration $[\mathrm{kg\,kg^{-1}}]$
	$\vdots$

Array dimensions:

[nproma, nlev, nblks_c]

`t_nh_diag`

u	zonal wind $[\mathrm{m\,s^{-1}}]$
v	meridional wind $[\mathrm{m\,s^{-1}}]$
temp	temperature $[\mathrm{K}]$
pres	pressure $[\mathrm{Pa}]$
	$\vdots$

src/atm_dyn_iconam/
mo_nonhydro_types.f90

Data structures: model domain

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The **t_patch** data structure contains all information about grid coordinates and topology as well as parallel communication patterns and decomposition info.

t_patch

grid_filename	character string, containing grid file name
ldom_active	indicator if current model domain is active, see Section 5.2
parent_id	domain ID of parent domain
child_id(1:n_childdom)	list of child domain ID's
n_patch_cells/edges/verts	number of locally allocated cells, edges ...
n_patch_XXXX_g	global number of cells, edges and vertices
nblks_c/e/v	number of blocks
npromz_c/e/v	chunk length in last block
cells / edges / verts	lower-level data structures, see below
comm_pat_c/e/v	halo communication patterns, see Section 9.2.4
	⋮

src/shr_horizontal/
mo_model_domain.f90

Index ordering and loop blocking

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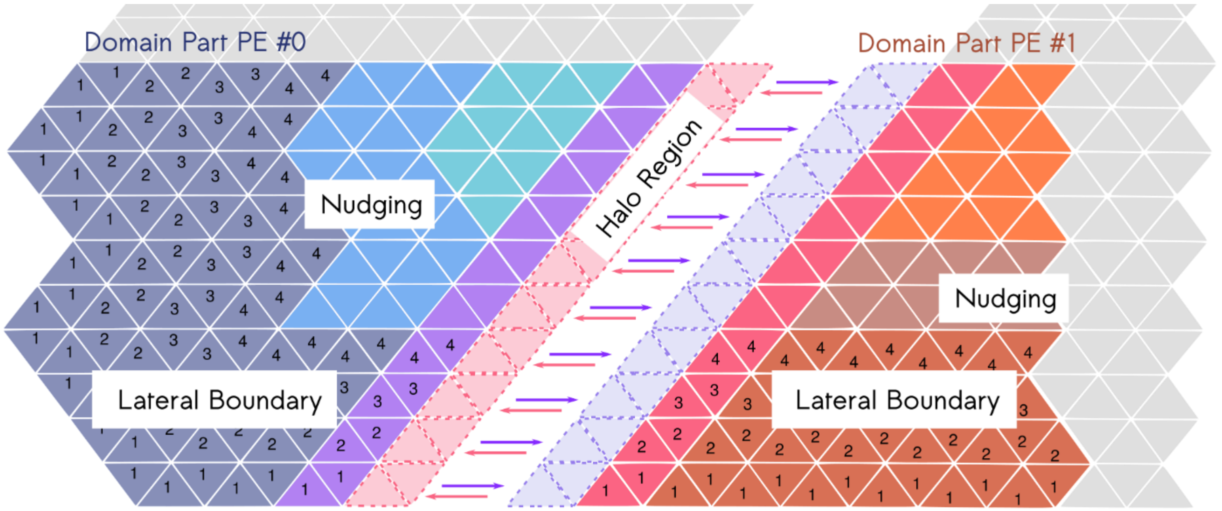
Each PE performs a sorting of its local cells.

array portions for

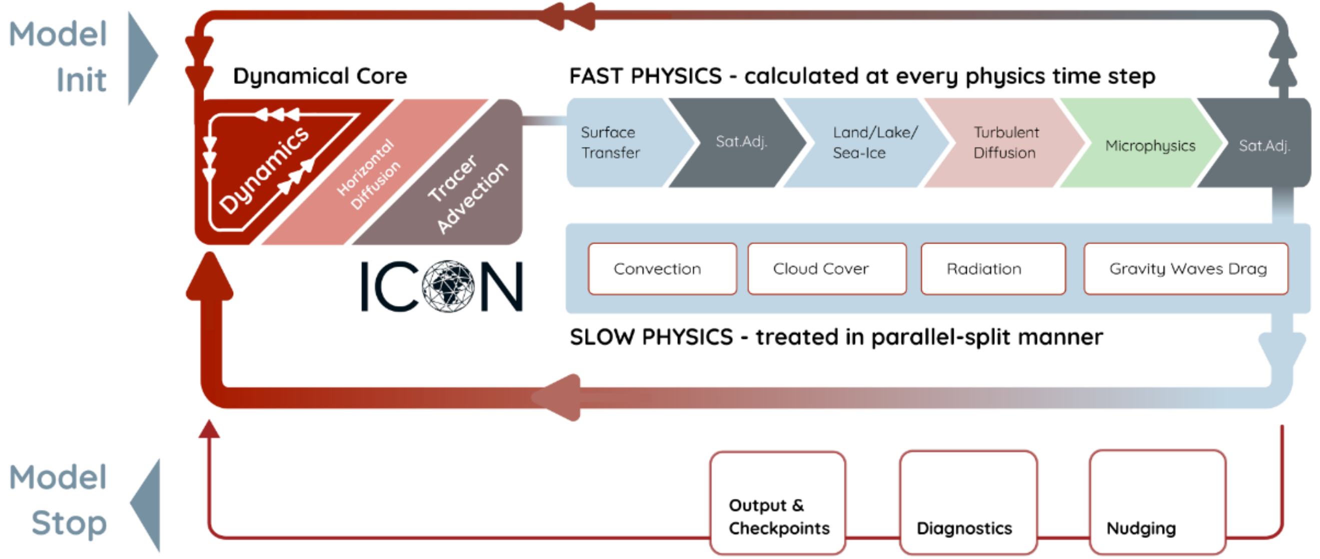
- lateral boundary and
- prognostic cells



`refin_c_ctrl(cell)` array:

Used to identify the nest boundary zone: cell rows are numbered starting from the grid boundary

Flow of control (revisited)



For efficiency reasons, different integration time steps are applied depending on the process.

Δt : basic time step (tracer, diffusion, fast physics) ; $\Delta\tau$: DyCore time step ; $\Delta t_{i,slow}$: slower processes

Physics-dynamics coupling

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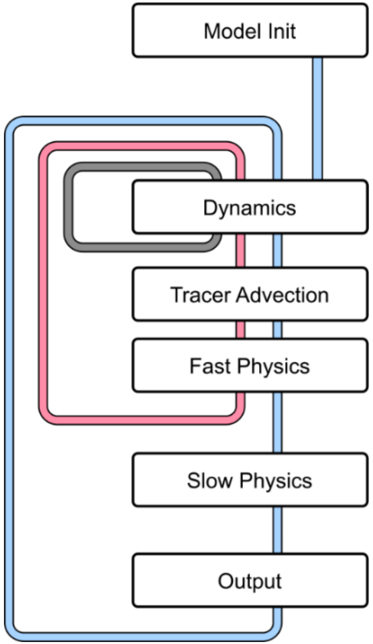
schematic



different integration
time steps applied:

dry NSE

act sequentially on
the atmospheric state

calculation of
independent tendencies

actual implementation

Physical parameterizations

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Process	Scheme	Settings
Radiation	RRTM (Rapid Radiative Transfer Model) Mlawer et al. (1997), Barker et al. (2003)	inwp_radiation=1
	ecRad Hogan and Bozzo (2018)	inwp_radiation=4
Non-orographic gravity wave drag	Wave dissipation at critical level Orr et al. (2010)	inwp_gwd=1
Sub-grid scale orographic drag	Lott and Miller scheme Lott and Miller (1997)	inwp_sso=1
Cloud cover	Diagnostic PDF *M. Köhler et al. (DWD)*	inwp_cldcover=1
	All-or-nothing scheme (grid-scale clouds)	inwp_cldcover=5

Process	Scheme	Settings
Microphysics	Single-moment scheme Doms et al. (2011), Seifert (2008)	inwp_gscp=1, 2
	Double-moment scheme Seifert and Beheng (2006)	inwp_gscp=4
Convection	Mass-flux shallow and deep Tiedtke (1989), Bechtold et al. (2008)	inwp_convection=1
Turbulent transfer	Prognostic TKE (COSMO) Raschendorfer (2001)	inwp_turb=1
	EDMF-DualM (Eddy-Diffusivity/Mass-Flux) Köhler et al. (2011), Neggers et al. (2009)	inwp_turb=3
	3D Smagorinsky diffusion (for LES)	inwp_turb=5
Land	Tiled TERRA Schrodin and Heise (2001), Schulz et al. (2016)	inwp_surface=1
	Flake: Mironov (2008)	llake=.TRUE.
	Sea-ice: Mironov et al. (2012)	lseaice=.TRUE.

- see physics lectures this week

ICON

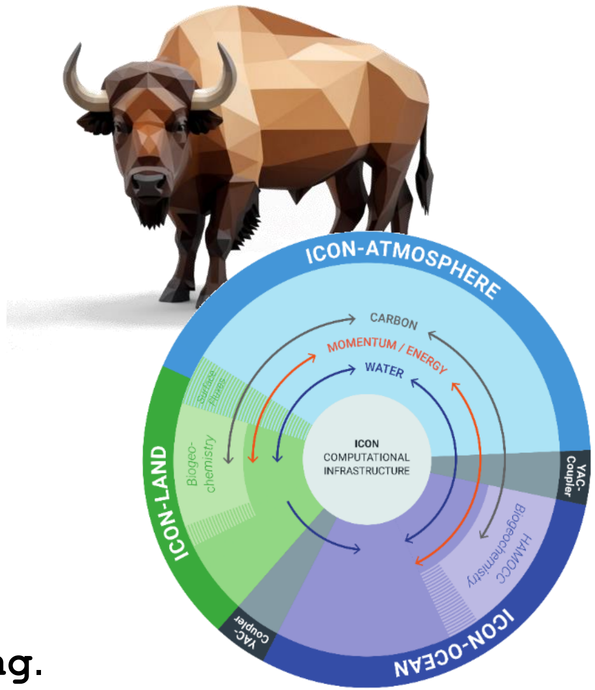
YAC coupler library

YAC (Yet Another Coupler) is used internally to exchange data between ICON's components, e.g.

- atmospheric model
- ocean model
- wave model
- hydrological discharge model
- CLEO microphysics
- alternative output writing

Implementation: see **`externals/yac`** and **`src/coupling`**.

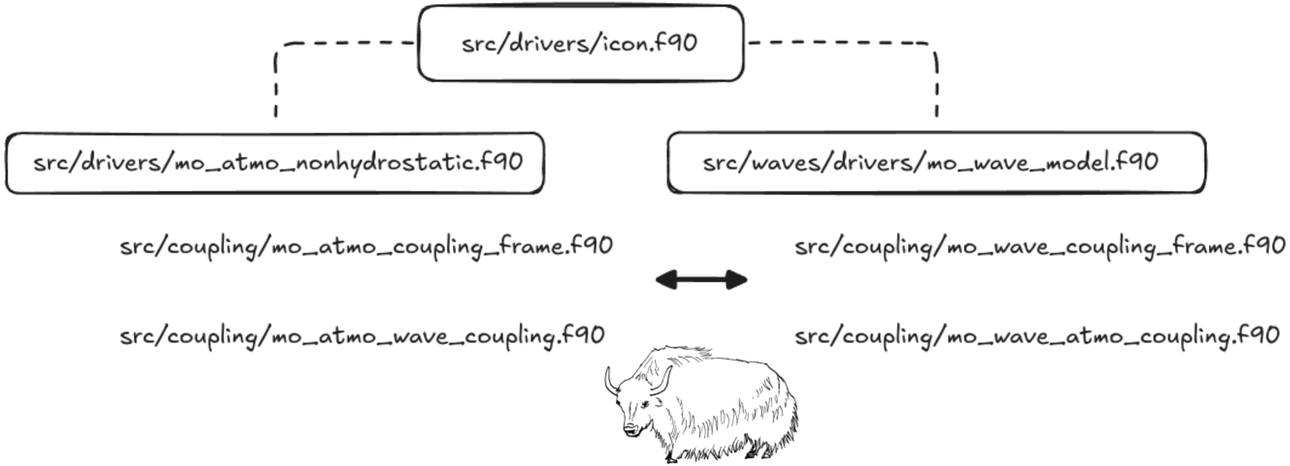
Developed and maintained by DKRZ, currently v3.6.2.



Source: D. Klocke, MPI-M

Coupler implementation

Example: Interface between ocean surface waves and atmosphere, through a coupler.
Coupling implemented in pairs of modules:



See also: Dobrynin, M., & co-authors. (2025, April 28). ICON-waves, a new ocean surface waves component of the ICON modeling framework [presentation]. EGU General Assembly 2025, Vienna, Austria.

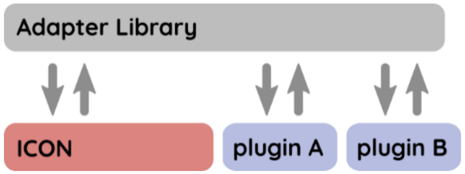
ComIn: ICON Community Interface

A plugin mechanism which

- connects 3rd party modules to the ICON host model
- plugin functions are called at pre-defined events
- access and creation of model variables

Shared libraries for Fortran or C/C++ plugins.

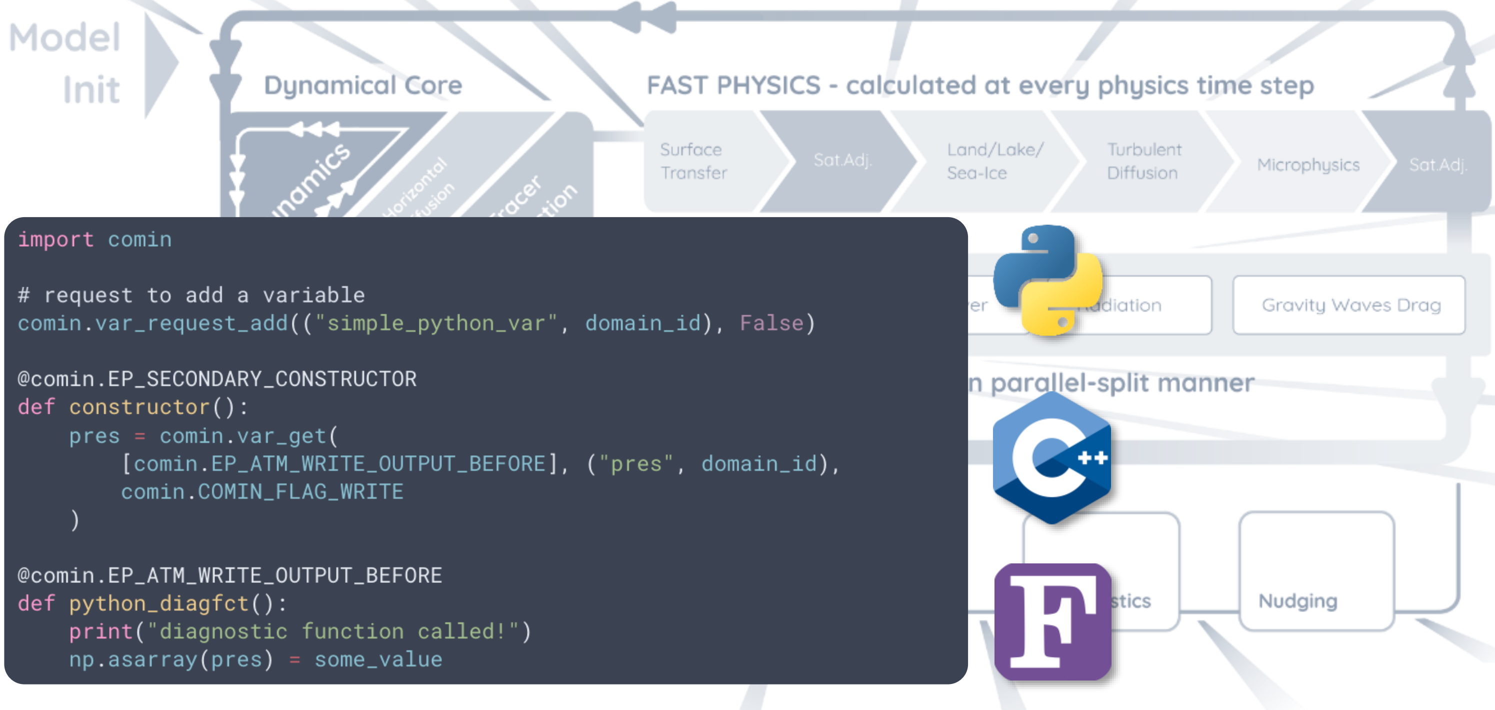
Python plugins do not need any compilation process at all.



Project started 2022 as a collaboration between
DWD, **DLR-IPA** and **DKRZ**.

ComIn is now part of the Open Source Release of ICON

ComIn: ICON Community Interface




```python
import comin

# request to add a variable
comin.var_request_add(("simple_python_var", domain_id), False)

@comin.EP_SECONDARY_CONSTRUCTOR
def constructor():
    pres = comin.var_get(
        [comin.EP_ATM_WRITE_OUTPUT_BEFORE], ("pres", domain_id),
        comin.COMIN_FLAG_WRITE
    )

@comin.EP_ATM_WRITE_OUTPUT_BEFORE
def python_diagfct():
    print("diagnostic function called!")
    np.asarray(pres) = some_value
```

Example: Create and access model variables.

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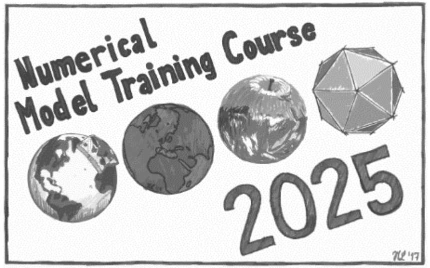
Visualization and data processing



ICON

DWD ICON Tools

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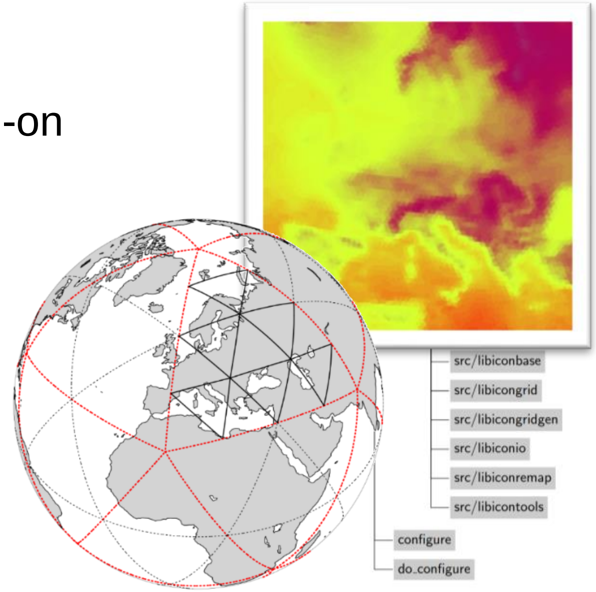
The ICON Tools are a set of command-line utilities
for remapping, extracting and querying data files.

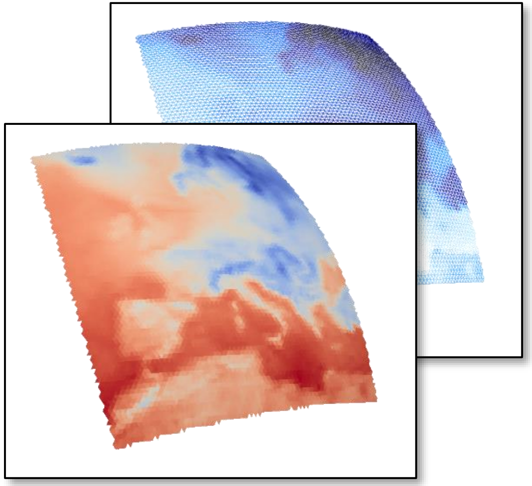
- not part of the open source release; developed as an add-on
- based on a Fortran 2003 library “libicontools.a”
  that is also used by the fieldextra COSMO software

- ICONREMAP utility: horizontal remapping,
  widely used to pre-process initial and boundary data.
- consider the Climate Data Operators (CDOs) as a
  powerful alternative!
  … see later slide …



ICONSUB utility (DWD ICON Tools)

- **SUB**grid extraction:
  cut subregions out of given data set.
- GRIB2 and NetCDF support;
  writes full topology of sub-grid.



Subregion specification

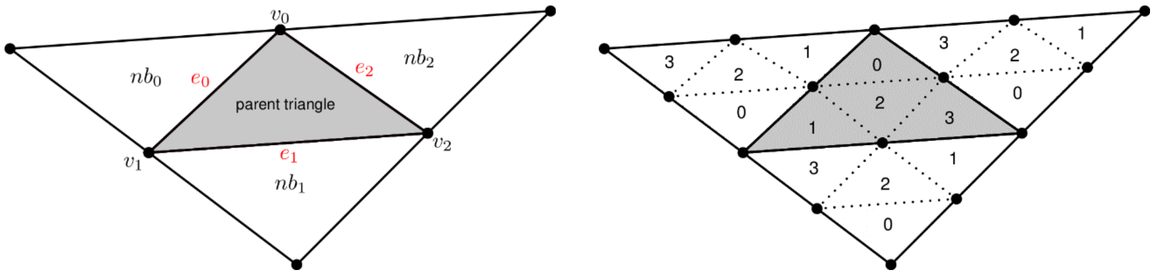
- south-west/north-east corner & rotation pole
- or: boundary strip (driving ICON-LAM)

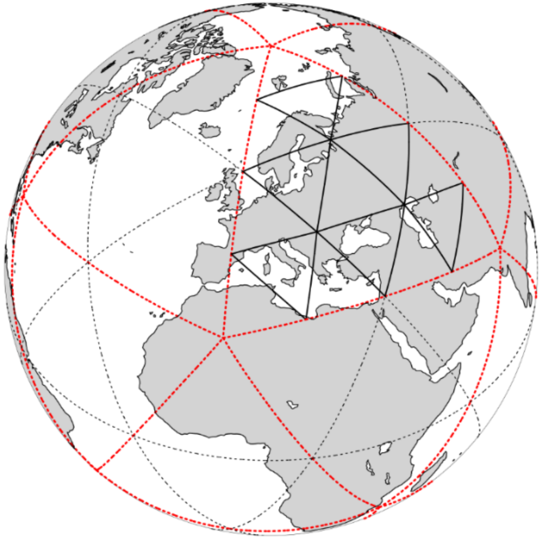
ICONSUB runs behind the scenes on DWD's HPC to provide datasets to NHMSs.

ICONGRIDGEN utility (DWD ICON Tools)

Simple grid generator: creates/refines ICON input grids

- generation of grid topology and child-to-parent relations
- generation process without storage of global grids





ICONGRIDGEN is primarily used as an online tool (web service).

Climate data operators (CDO)

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CDOs are a collection of tools for NetCDF and GRIB data.

- based on CDI, developed and maintained at MPI-M
- source code and documentation available from
  https://code.mpimet.mpg.de/projects/cdo

Example: Dataset Information

```
> cdo sinfov test.nc

File format: netCDF2
 -1 : Institut Source   Ttype    Levels Num  Gridsize Num Dtype : Parameter name
  1 : ECMWF    unknown  instant      90   1     11324   1  F32  : T
  2 : ECMWF    unknown  instant       1   3     11324   1  F32  : PMSL
Grid coordinates :
…
```

Operator description can be obtained with `cdo -h [operator]`

Remapping with the CDOs

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The CDO are also capable of remapping data to regular grids and triangular grids.

- recipes for ICON: https://github.com/deutscherwetterdienst/regrid

```
module load cdo
cdo -f nc2 remapcon,$LOCALGRID:2 \
     -selname,$FIELDS \
     -setgrid,$INPUTGRID:2 $DATAFILE output.nc
```

1st order conservative interpolation

Caveat: GRIB2 metadata sometimes mangled by CDO.

However, compared to, e.g., the DWD ICON Tools:
CDOs are freely available, well-maintained, feature-rich.

Visualization tools

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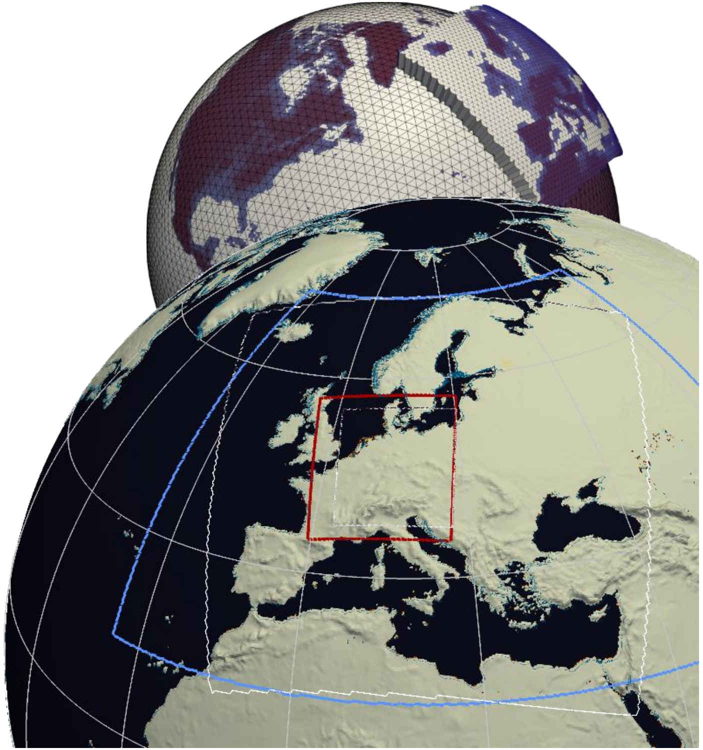
The ICON Tutorial book (Chapter 10) presents quick start examples for

- NCAR Command Language (NCL)
- R (statistical computing environment)
- "Generic Mapping Tools" (GMT)
- the Python programming language …



[Visualization with ParaView, another open viz package]

Plotting with Python

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Introductory example using **matplotlib**, a plotting library for the Python programming language.

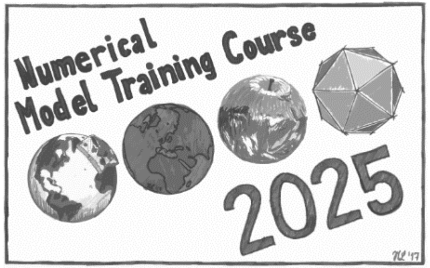
The **cartopy** package extends the Matplotlib functionality and offers map projection definitions.

```
fig = plt.figure(figsize=(9, 9))

ax  = plt.axes(projection=cartopy.crs.PlateCarree())
ax.add_feature(cartopy.feature.BORDERS,edgecolor='gray`)
ax.tricontourf(cx, cy, src_data,
               transform=cartopy.crs.PlateCarree())
```

draw filled contours on unstructured grid

Wrap-Up



Wrap-Up

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ICON

Introduction → Configure & Building → Source code overview → Namelist setup → Model output → Parallel execution → Data structures in ICON → Data processing & visualization

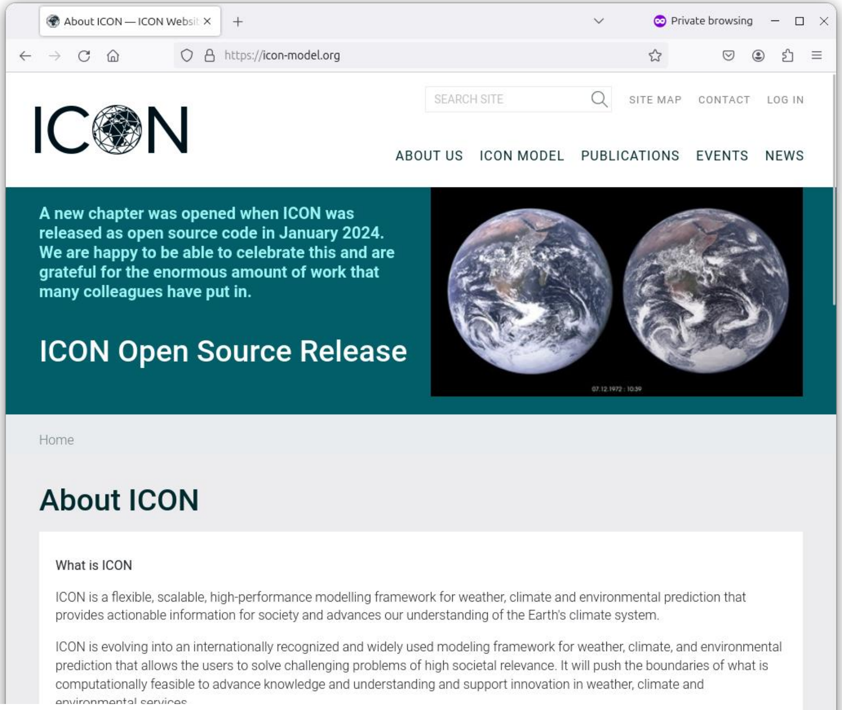
ICON Open Source Release

Since January 31, 2024, the source code of the ICON model has been released to the public under **the BSD-3C Open Source License**.
https://www.icon-model.org/

Moreover:

Special ICON-COSMO support license
for national weather services
icon-support@cosmo-model.org

ICON development takes place in Git repositories (restricted access).



https://icon-model.org – 2024-05-28

Questions?

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