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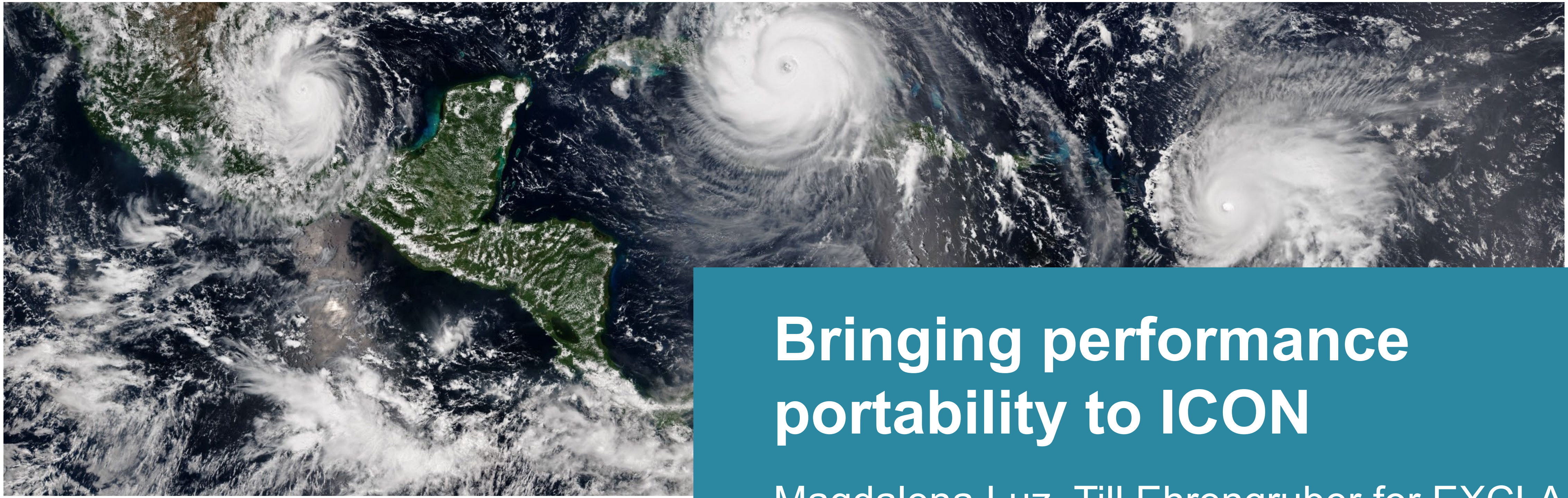

Bringing performance portability to ICON

Magdalena Luz, Till Ehrengruber for EXCLAIM

18.09.2025 / 21st ECMWF workshop on high performance computing in meteorology

C2SM Center for Climate Systems Modeling

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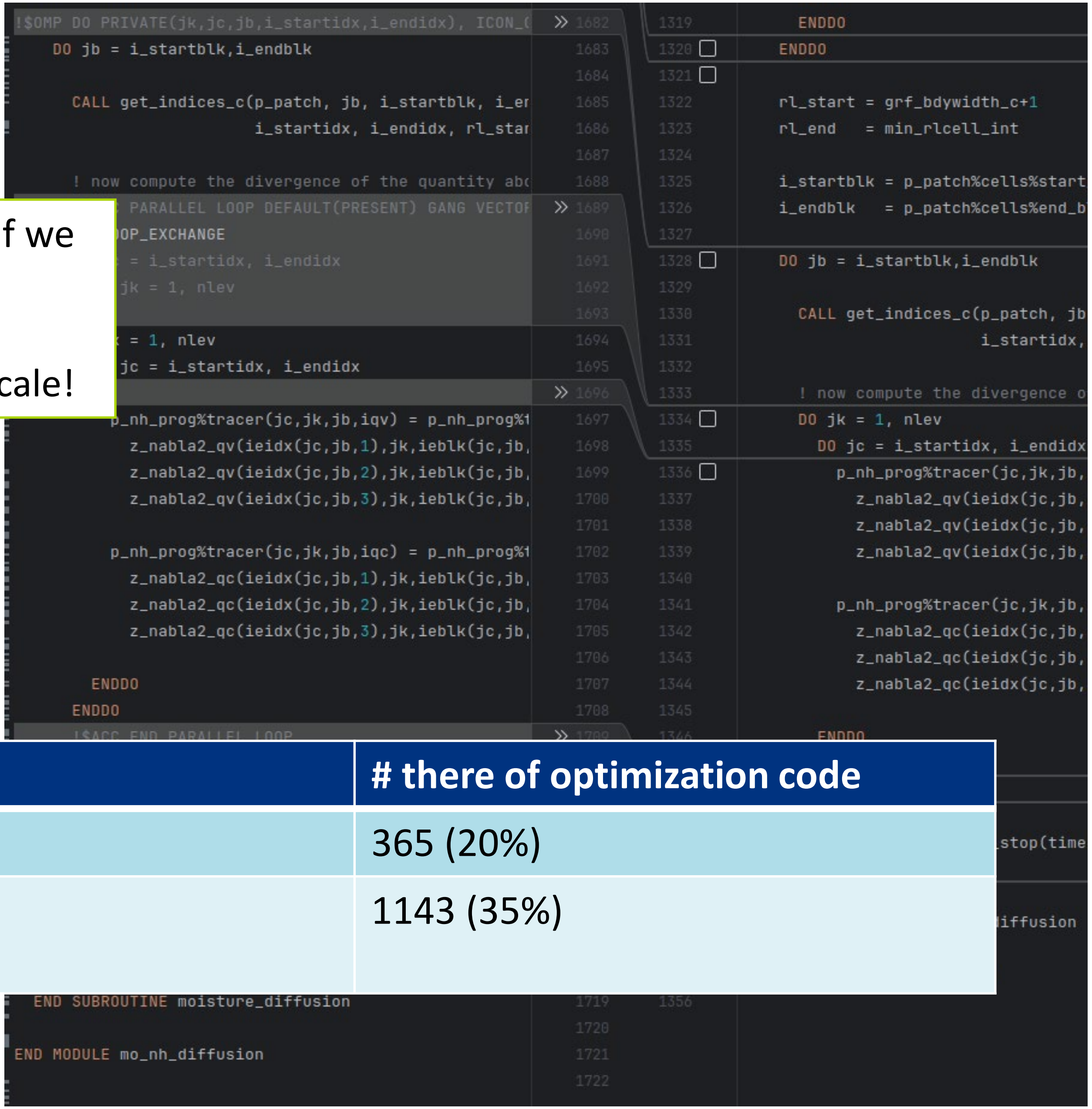
Classical ICON Code

What if you only had the physics in the source code? If we could hide away all the clutter.

New paradigm – and new statements... this does not scale!



Module	# lines	# there of optimization code
Diffusion	1720	365 (20%)
Dynamical Core (without advection)	3170	1143 (35%)

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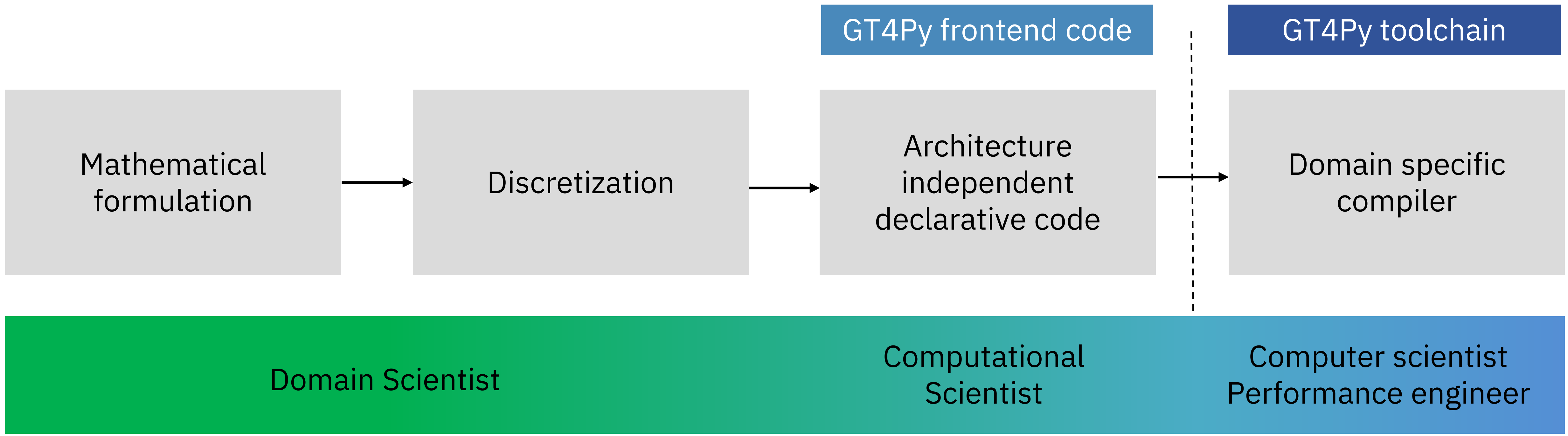
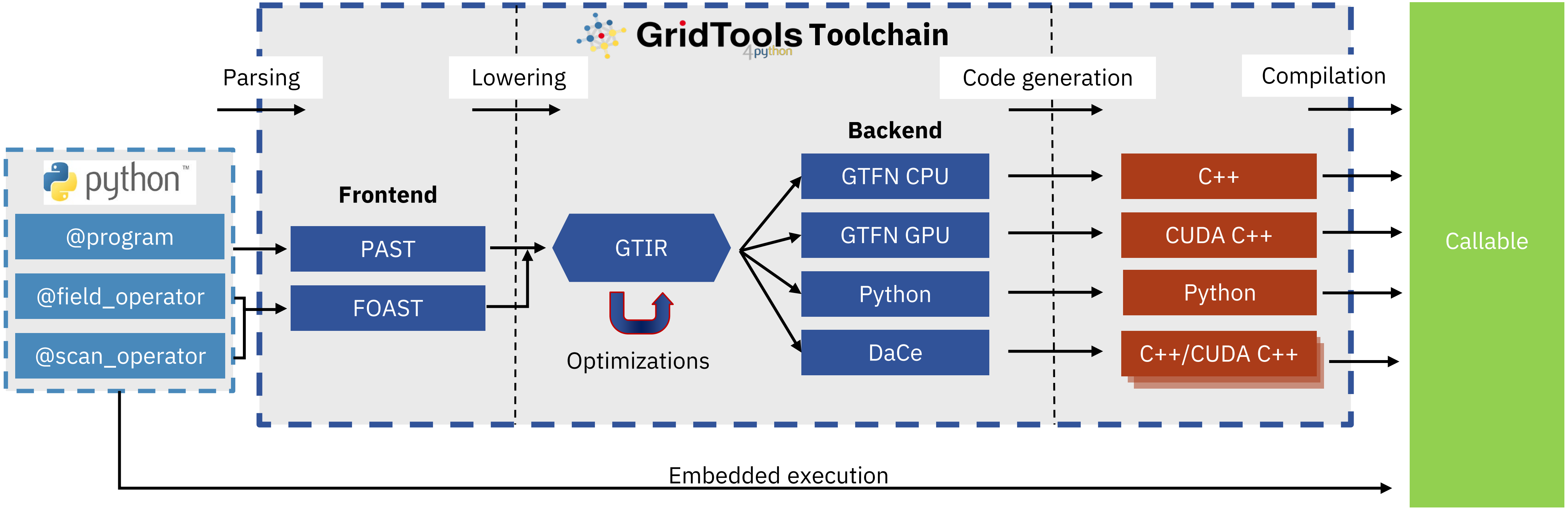
Bring performance portability to an existing model

DSL brings separation of concerns:



GT4Py Toolchain



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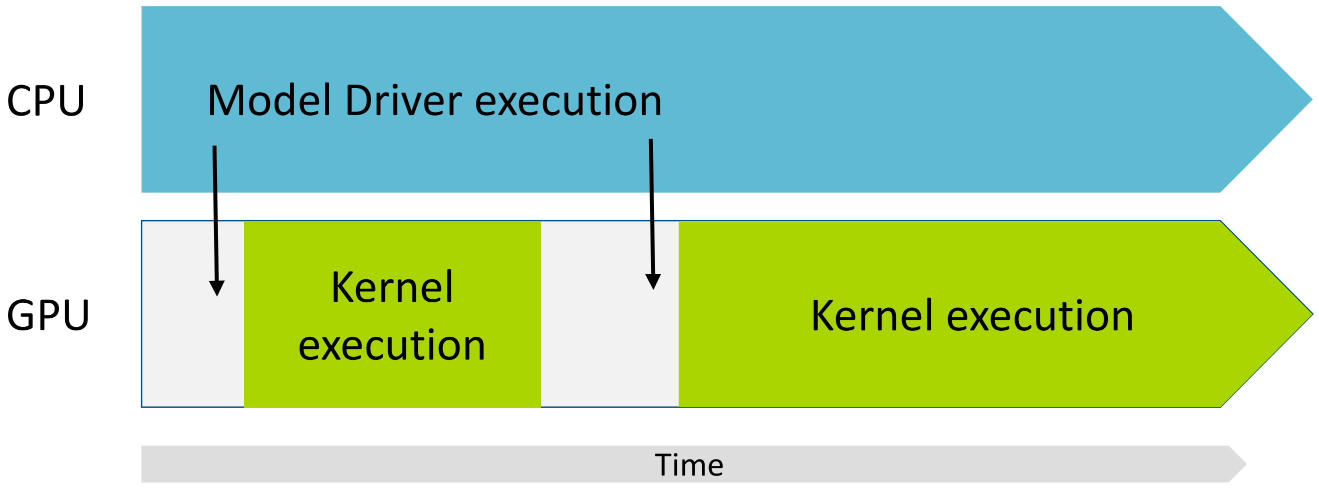
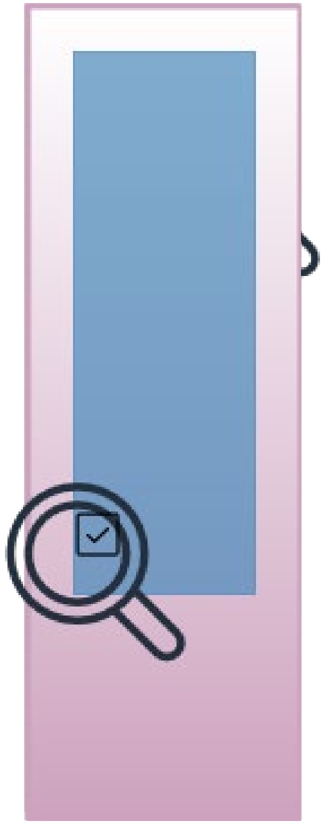
Asynchronous execution



- Driver continues execution while computations happen on the GPU (or other CPU threads in the future).
- With some care Python overhead is already low, asynchronous execution hides the rest.
- Exception: call overhead
  - Already small even with many field operators (< 5%)
  - Negligible with large field operators
    - Fewer calls -> less overhead
    - Goal: one field operator per timestep

"Inside-out" Approach



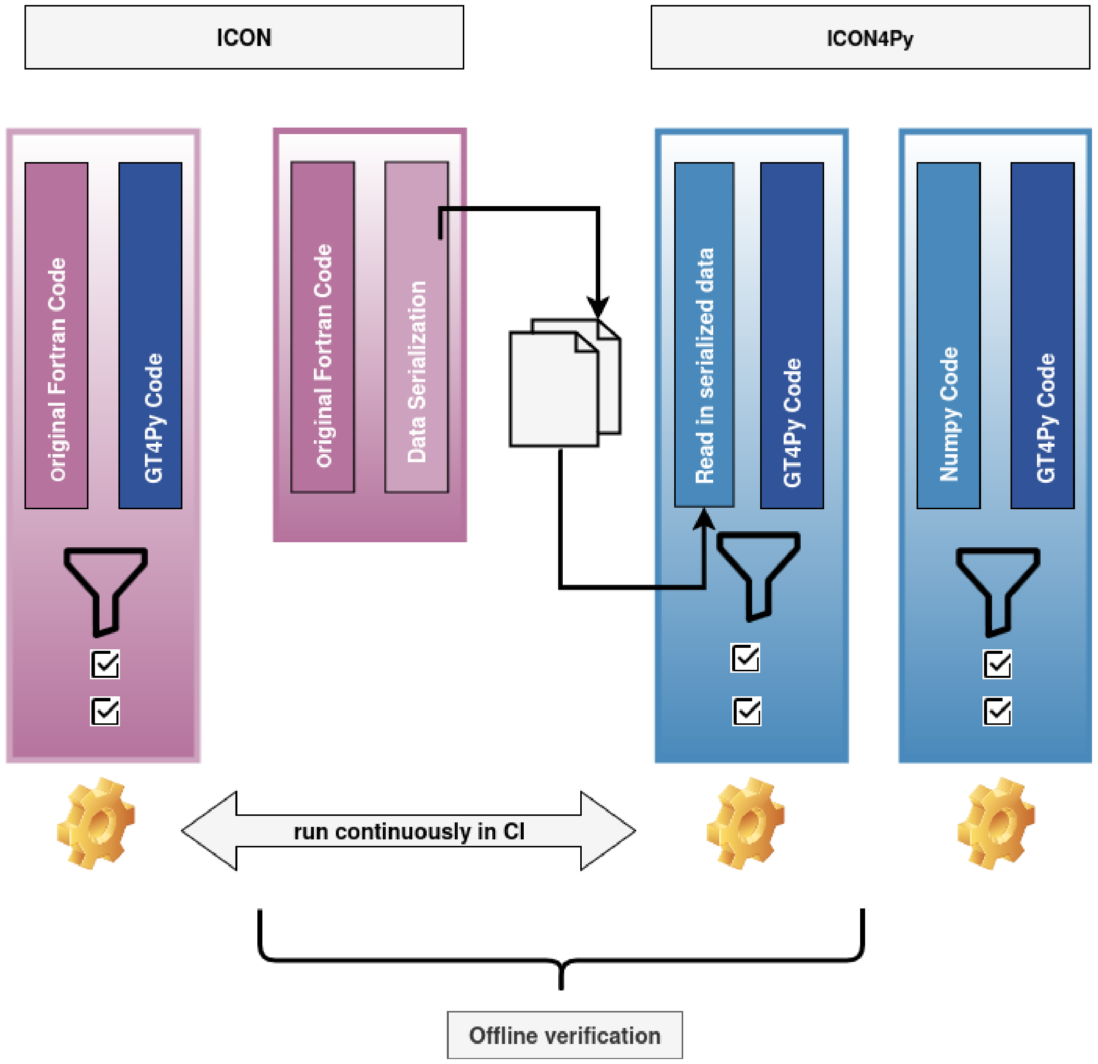
```python
class Diffusion:
    """Class that configures diffusion and does one diffusion step."""

    def __init__(
        self,
        grid: icon_grid.IconGrid,
        config: DiffusionConfig,
        params: DiffusionParams,
        vertical_grid: v_grid.VerticalGrid,
        metric_state: diffusion_states.DiffusionMetricState,
        interpolation_state: diffusion_states.DiffusionInterpolationState,
        geometrical_factors: grid_states.GeometryParams,
        backend: gtx_typing.Backend | None,
        exchange: decomposition.ExchangeRuntime | None = None,
    ):
    ...

    def run(self,
      diagnostic_state: diffusion_states.DiffusionDiagnosticState,
      prognostic_state: prognostics.PrognosticState,
       dtime: float,
    ):
    ...
```

```
ield[Dims[CellDim, K],float]]]:
```

Continuouesly test ... !!

Testing Strategies

- Simplistic Testing: validate against numpy implementation – very accessible but unreliable!
  - Simple stencils
  - Combined stencils
- Verify inside ICON – run Fortran and GT4Py code
  - only components, stencil integration has been removed
- Hybrid: serialize data from ICON, run verification inside ICON4Py
  - Combined stencils
  - Components



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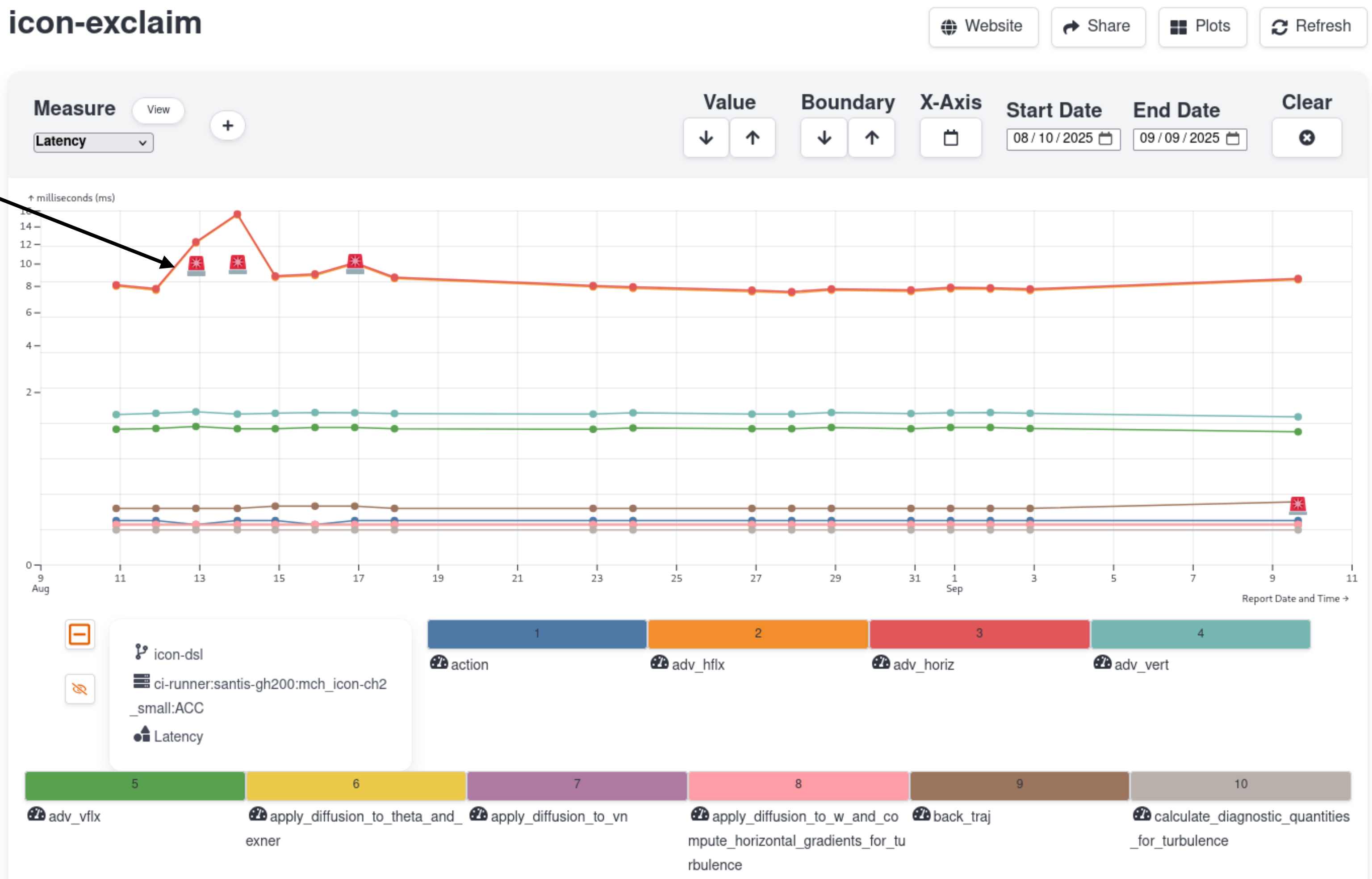
Continuous Benchmarking

Alert on performance degradation



https://bencher.dev/

Why choose such an approach?

Advantages

- Continuously **validate**
- Keep a version of the model running at all time
- Tackle complexity
- Build **trust** – in your own work, in the community

Disadvantages

- Restrictions in how to re-organize code internally and re-think the design
  - You must keep the functionality at the interface consistent
- Overhead – several integration modes along the way... to keep the model running

Blueline - Python dynamical core in FORTRAN

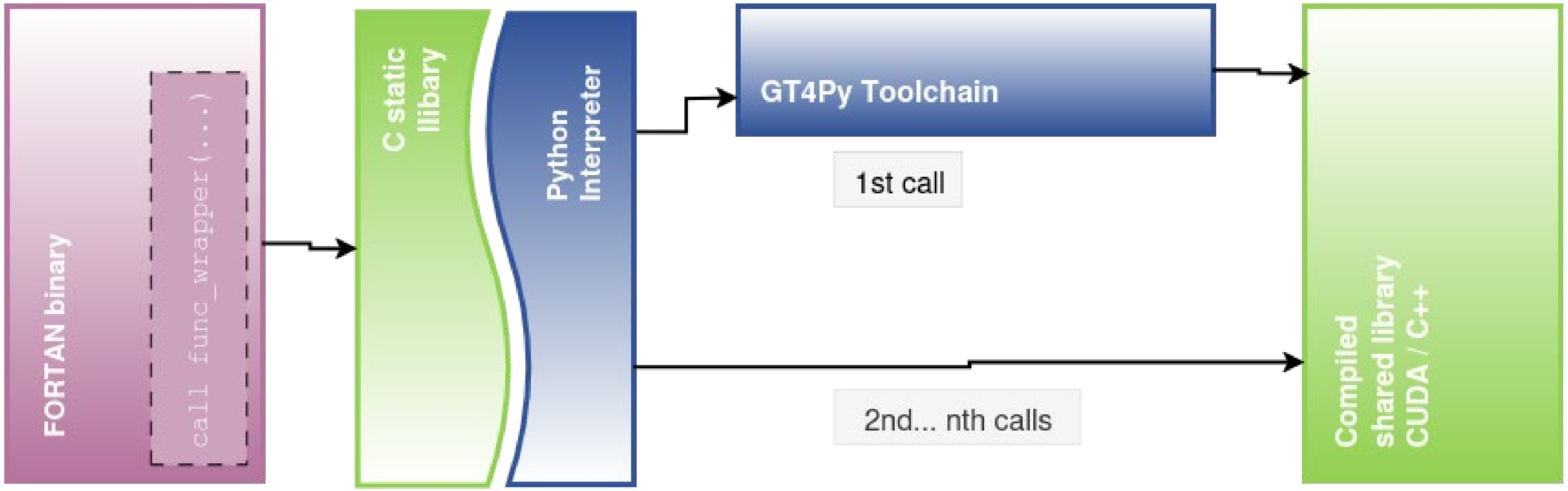
Run performance critical model components from the original FORTRAN code: `py2fgen` cli tool

1. Decorate function with `@py2fgen.export` and provide information on the function's

```
@py2fgen.export(
    param_descriptors={
        "scalar": py2fgen.ScalarParamDescriptor(py2fgen.FLOAT64),
        "array": py2fgen.ArrayParamDescriptor(
            rank=2, dtype=py2fgen.FLOAT64, memory_space=py2fgen.MAYBE_DEVICE, is_optional=False
        ),
    }
)
def foo(scalar: float, array: np.ndarray): ...
```

2. Run `py2fgen` cli tool - generates a Fortran interface and a (private) shared C library containing your python function

Blueline – Runtime view



- Uses Python [embedding feature of CFFI] under the hood
- Python interpreter is started only once and kept alive during runtime
- GT4Py tool chain triggered at first call

Greenline – Full Python model

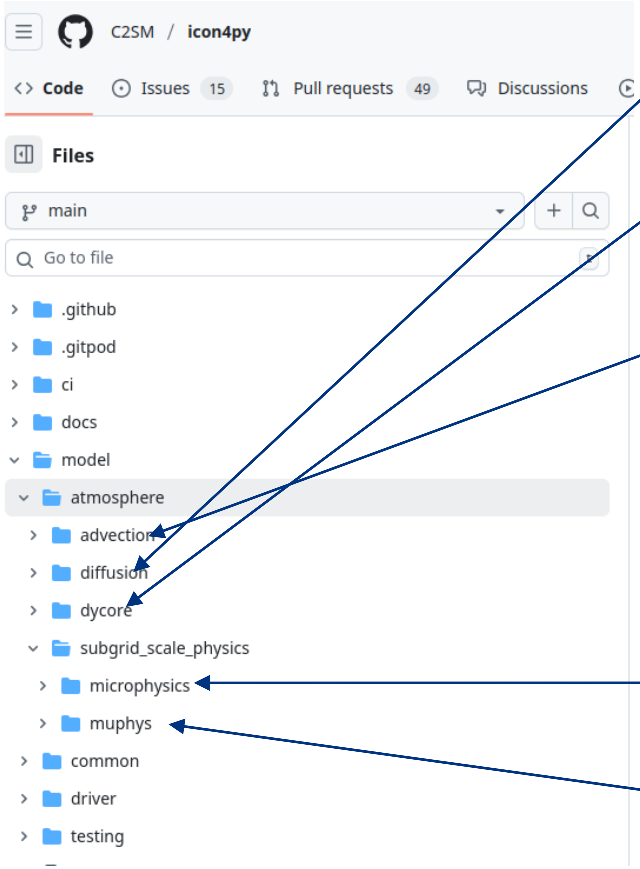
Re-implement the ICON model in Python.

- **Accessibility:** Python has a very rich ecosystem especially for scientific application – modeling code in Python allows to bridge the gap between model runs and analysis.

- **Interoperability:** Python is the language of the AI revolution, we need to make physical models interoperable with AI models. GT4Py is very close to be fully compatible with tools like JAX.

- **Productivity:** Performance portability taken one step further – develop & debug on your laptop, or in a jupyter notebook, run on HPC Cluster at scale

Where are we? - Physics components



Dynamical core

Diffusion

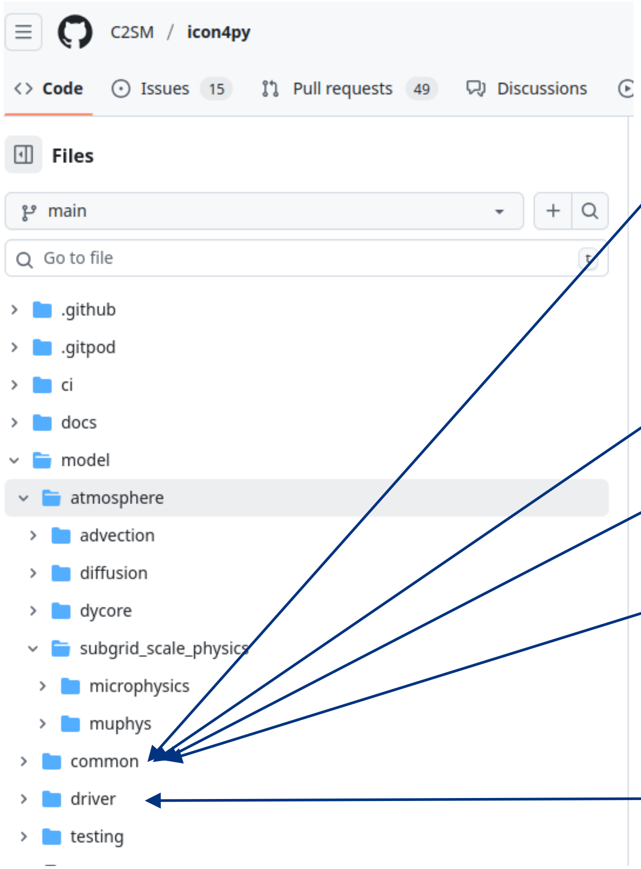
Tracer Advection

	vertical	horizontal
Scheme	Upwind 1st order PPM 3d order	Linear 2nd order
Limiter	Semi monotonic	Positive definite

ICON microphysics

Mu-phys scheme (MPI-M)

Where are we? - Model infrastructure



Grid Topology&Geometry
- Read topology
- Compute geometrical quantities

Basic common functionality
- Dimension definitions
- Allocation function
- Backend configuration

Precomputed static coefficients for horizontal and vertical interpolation

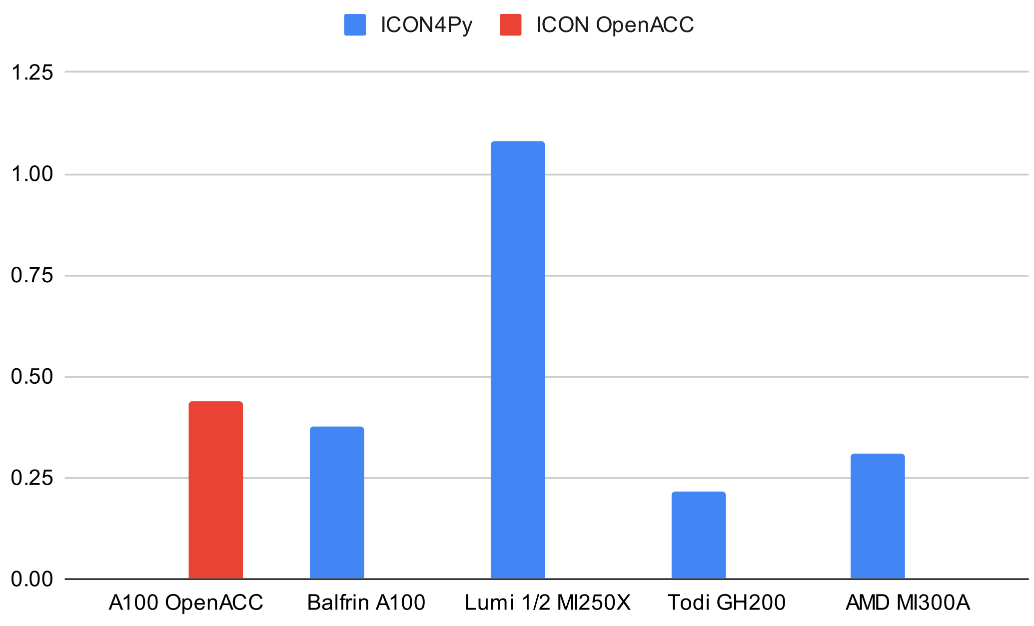
Decomposition
- Can do halo exchange on distributed grids.
- Distribution

Simple driver for atmospheric test cases
- Jablonoswki Williamson
- Gauss3d

Warm bubble

- Replace with more flexible, configurable driver (next)
- Enhance torus support

Greenline runs across systems



- Jablonowski Williamson test case on 20km resolution, single GPU runs
- Pure Python model ("EXCLAIM greenline")
- Python overhead from control flow is hidden by async scheduled kernels on GPU
- Took us ~1 day to get it run on AMD GPUs

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Thank you!

https://github.com/c2sm/icon4py
https://github.com/GridTools/gt4py

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