Scientific and technical motivations for the ICON development – An introduction to ICON

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Overview

- Scientific and technical background
- Model design and grids
- Application example
- Issues for HPC
  - Numerical methods
  - Code structure
  - Coupling
  - Output
  - Workflow
- Scaling test on Blizzard

Related presentations

- J. Biercamp
  A cloud resolving high resolution version of ICON
  – the HD(CP)^2 project

- T. Dubos
  An overview of the ICOMEX project

- W. Sawyer
  GPU implementations of the ICON non-hydrostatic solver

Scientific motivation

- DWD / NWP
  - Run regional refinement directly in global model, using seamless physics
  - Non-hydrostatic atm. dycore for global high resolution
  - Coupled system for seasonal forecasting
- MPI-M / climate research
  - Consistent discretizations of the continuity and transport eqns
  - Non-hydrostatic atm. dycore for regional or global high resolution
  - One modelling framework for a range of scales

Technical motivation

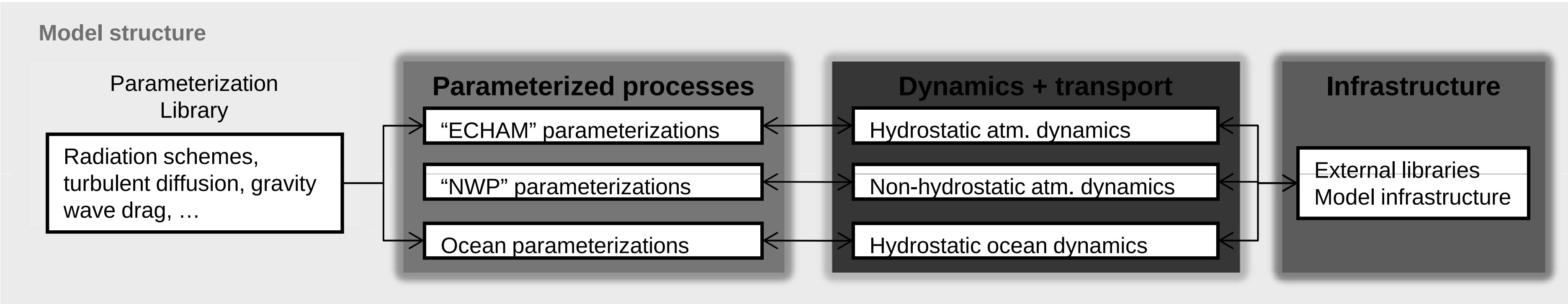
- Use single infrastructure for all model components
  - Atmosphere, land, ocean, ice
- Get model system (and workflow) that can exploit current and future architectures
  - Current: IBM Power6 @ DKRZ, NEC SX-9 @ DWD
  - Future: O(4+) cores
- Scalability of integration and IO
  - DWD / NWP: for very high resolution NWP
  - MPI-M / climate: High res. or high turnover ("CMIP5 millennium in a few days instead of 2 months")

Model design

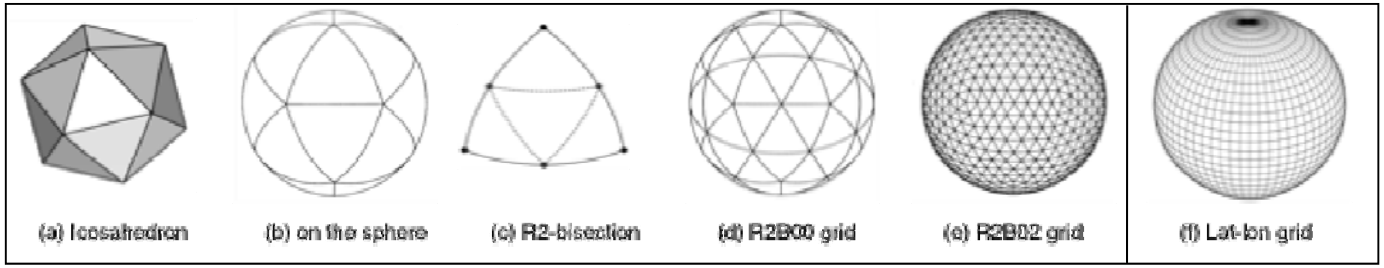
- Grid point model
  - icosahedral grids for uniform global resolution
  - C-grid discretization: scalars in cell centers + normal velocities at edge centers
  - Explicit, semi-implicit or Runge Kutta time stepping
- Unstructured grid
  - Recursive refinement of a single or of several regions
- Common model infrastructure
  - Grid generator → grid files as model input
  - MPI parallelization
  - Memory management
  - Control mechanism
  - Constants, orbit, …
  - I/O
  - Scripting
  - Test suite

Model design

- Dynamical cores for different purposes
  - Non-hydrostatic atmosphere (for triangles and hexagons)
  - Hydrostatic atmosphere
  - Hydrostatic ocean
- Parameterizations packages
  - Currently: by heritage
  - Later: distinguish packages by scale, as needed, and use same package for NWP and climate research, if done at same scale.



Grid construction



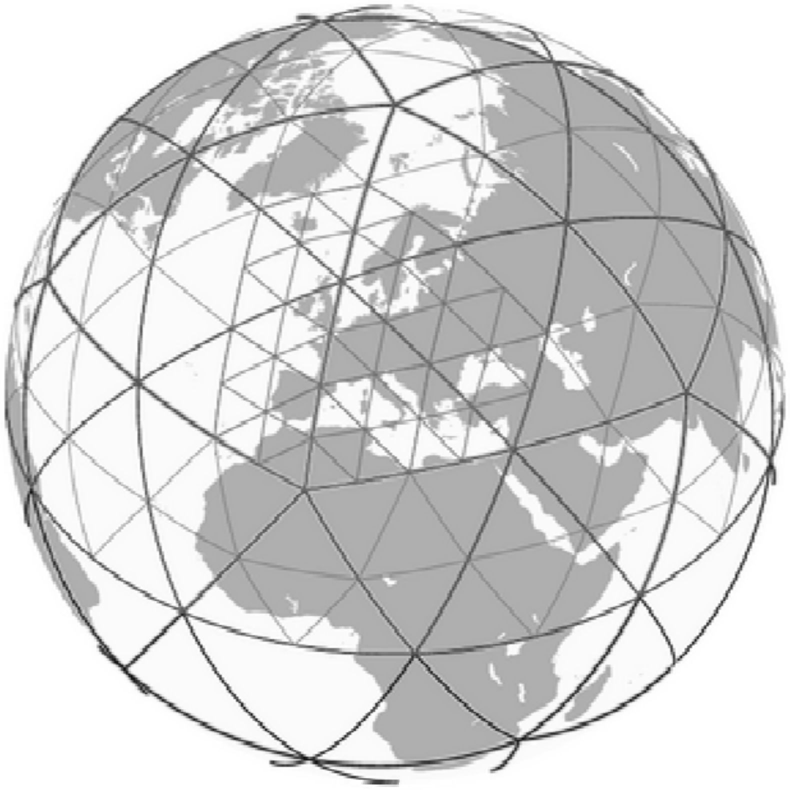
(a) → (b) Project the icosahedron into the sphere

(c) and (d) Root refinement: Partition each edge into m sections of equal length and connect these points with great circle arcs parallel to the edges → “Rm”

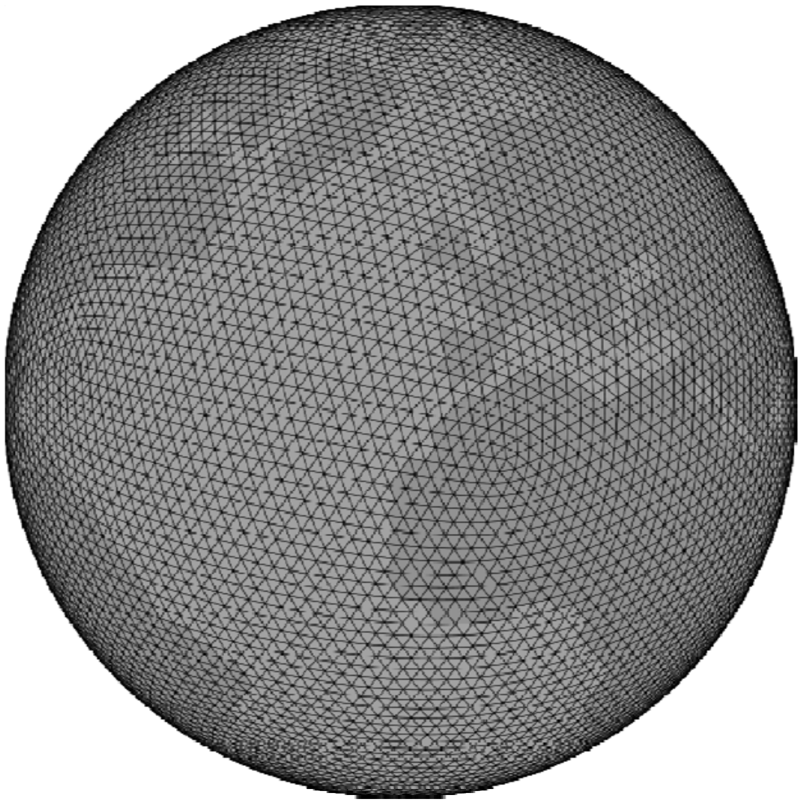
(e) Further global refinements: Make bisection of edges and connect by great circle arcs, repeat n times → “Bn”

Regional refinement: As for global, but limited to a region

Grid examples



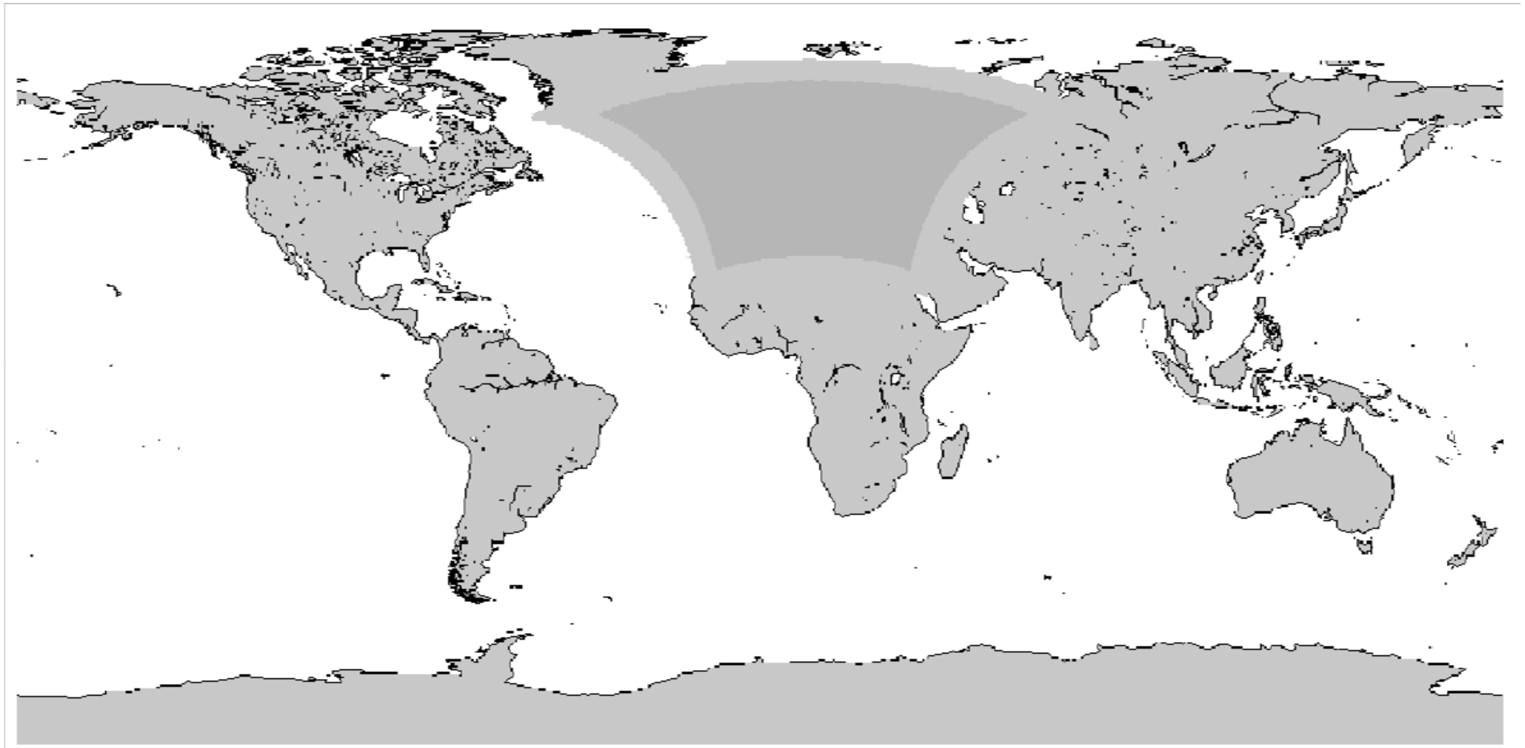
- Light blue: spherical icosahedron (R1B0)
- Dark blue: global R2B0
- Green: Northern hemisphere R2B1
- Red: Europe R2B2



- Land sea mask at R2B4 (~140 km)
- Ocean cells have 2 wet edges
- Additional manipulation required for straits, passages etc.

Prototype grid setup at DWD

- Global R2B7 (~20 km)
- 2 fold refinement over Europe (~5 km)



Application example

Coupled aqua planet experiment

- The coupled aqua planet is a simplified setup concerning the boundary conditions for the atmosphere and the ocean, which nevertheless allows to assess the full model with respect to the general circulation and the parameterized processes in the atmosphere and ocean.

- Debug the components and their coupling!

Configuration

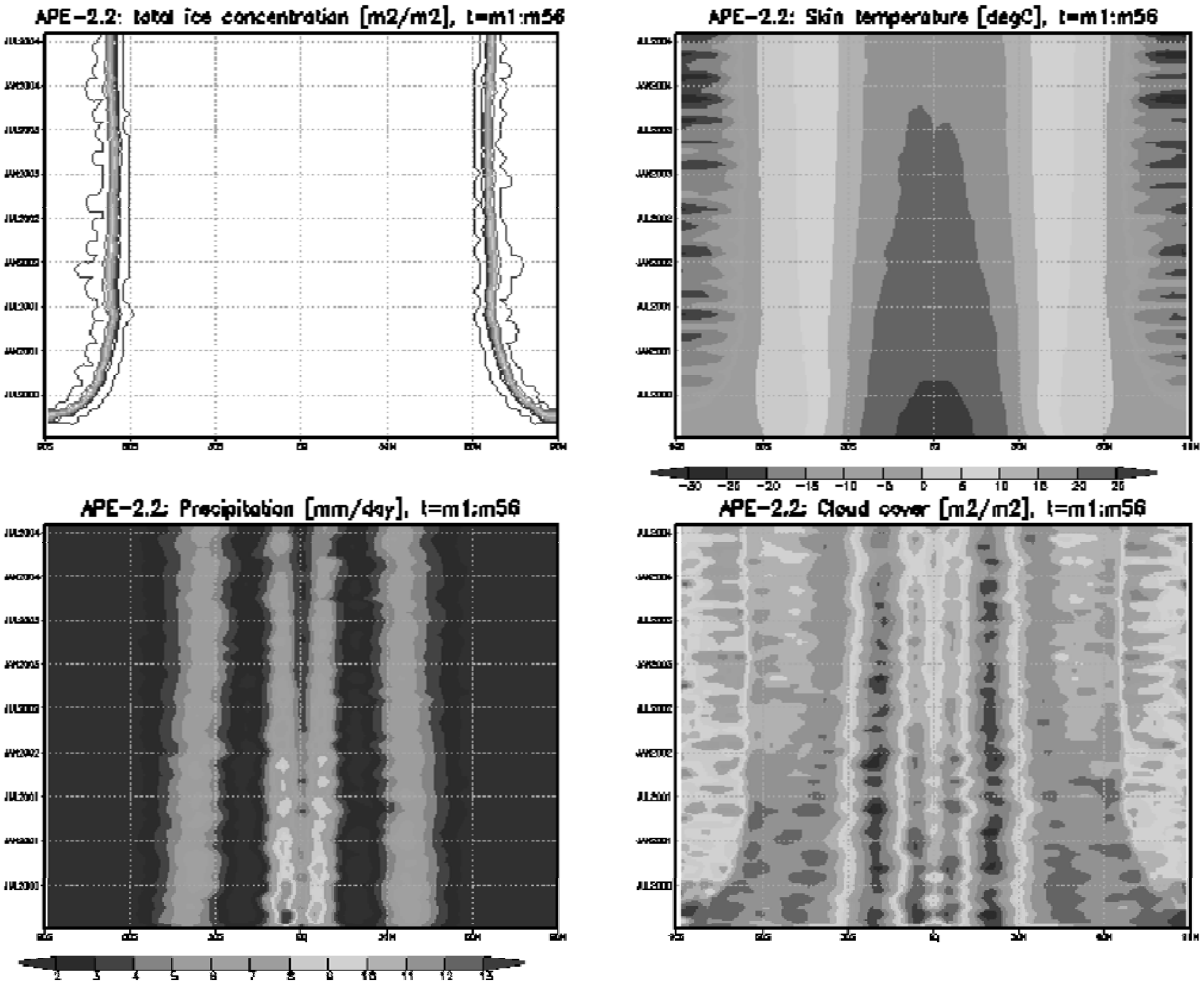
- Atmosphere
  - Hydrostatic dynamics + ECHAM6 physics
  - R2B4, 47 levels up to 0.01 hPa, p_{top} = 0 hPa
- Ocean
  - R2B4, 15 levels down to 5250 m, z_{bot}=5500 m
  - Vertical mixing of MPIOM, cart. hor. mixing (no GM)
- Coupling
  - Every ocean time step = 30 minutes
- Boundary conditions:
  - 1361 W/m^2
  - Circular orbit, perpetual equinox, diurnal cycle
  - Well mixed GHG of 1990s, APE ozone, no aerosol

– Length: 5 years

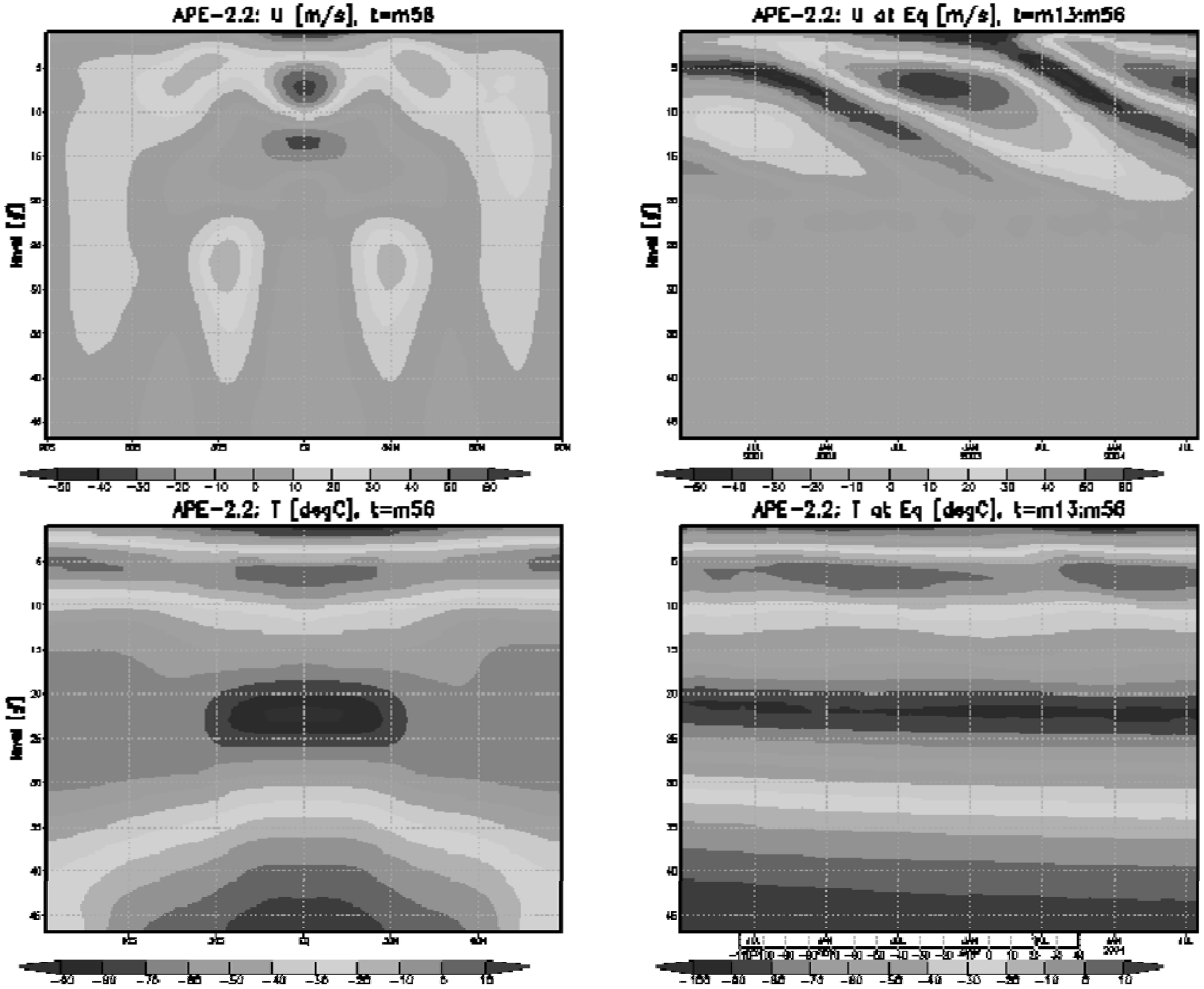
Coupling

- Series of experiments form simple to full coupling
  - Temperature relaxation only
    constant salinity, no ice
  - …
  - Heat flux + wind stress
    salinity as tracer, ice thermodynamics
  - Fresh water flux, heat flux + wind stress
    dynamically active salinity, ice thermodynamics
  - …
  - Fresh water flux, heat flux + wind stress
    salinity, ice thermodynamics + dynamics

Surface


APE-2.2: total ice concentration [m2/m2], t=m1:m56
APE-2.2: Skin temperature [degC], t=m1:m56
APE-2.2: Precipitation [mm/day], t=m1:m56
APE-2.2: Cloud cover [m2/m2], t=m1:m56

Atmospheric T and U



Issues to be addressed

Memory

- How to organize memory and loop structure in an optimal way for different architectures?
  - Vector CPUs
  - CPUs
  - CPUs with many cores
  - GPUs → ICOMEX
- How to write a single code that works equally well for different architectures?
  - Domain specific language → ICOMEX

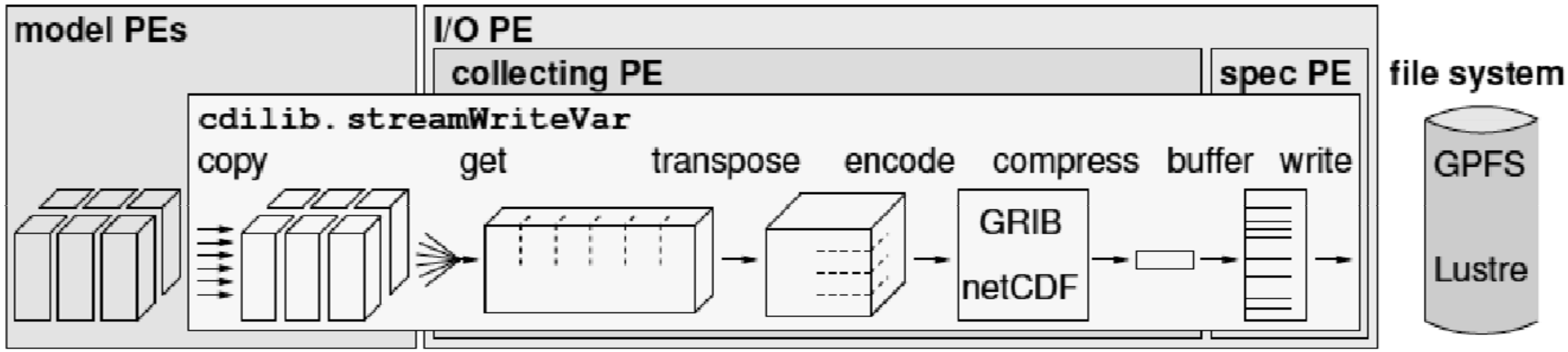
Coupler

- ICON has unstructured grids
- Possibly large number of cells → requires:
  - a priory knowledge of grid indices, or
  - a scaling search algorithm
- Must work with domain decomposition

1. Direct coupling embedded in model (Redler @ MPI-M)
   - Couples components by MPI communicator
   - Works for ICON grids
   - Each component has its own decomposition and time step
2. External coupler library (Hanke @ DKRZ and Redler @ MPI-M)
   - “OASIS” for unstructured grid, with scaling search

Output

- Writing data to disk must scale
- Scales sub-project: Asynchronous parallel IO
  - Cooperation of MPI-M and DKRZ
  - Based on Climate Data Interface (CDI)
  - Split PEs in model and IO Pes
  - Write global files



Workflow

- Architecture specific model configuration
  - Relate experiment requests to system specific resources resolution, turnover rate, “CPUs and memory”
  - Compiling
  - Process – “CPU” binding
- Monitoring
- Integrated diagnostics (“online post-processing”)
- Parallelized post-processing
- Visualization
- Test suite for model development

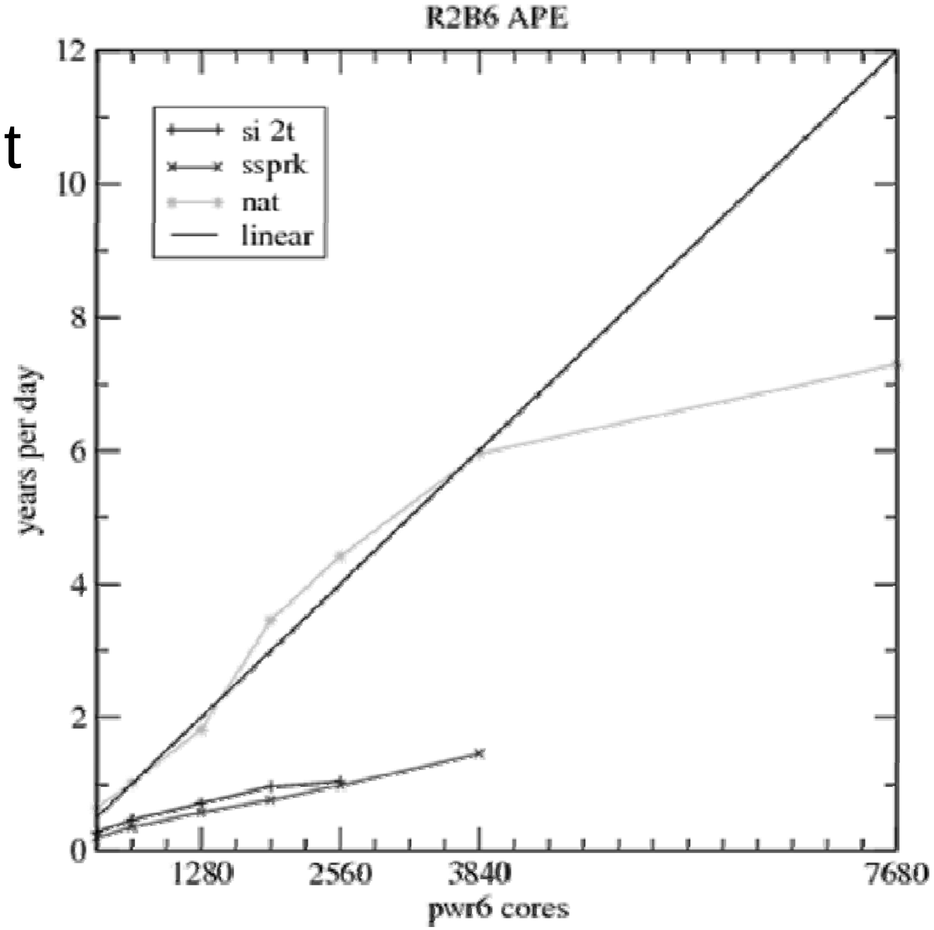
Scaling tests on Blizzard @ DKRZ

- Blizzard:
  - IBM Power6, 264 nodes * 32 cores/node = 8448 cores
  - MPI + OpenMP parallelization
  - Use10 to 240 nodes
- Experiment:
  - Aqua planet experiment (Neale and Hoskins, 2000)
- Model:
  - Horizontal grid: R2B6, 35 km, resolution for scalars
  - No output, except timer information
  - 3 configurations
    - Non-hydrostatic core, “NWP” physics, 78 levels
    - Hydrostatic core + SI time integration, ECHAM physics, 95 levels
    - Hydrostatic core + RK time integration, ECHAM physics, 95 levels

Turn over in years/day

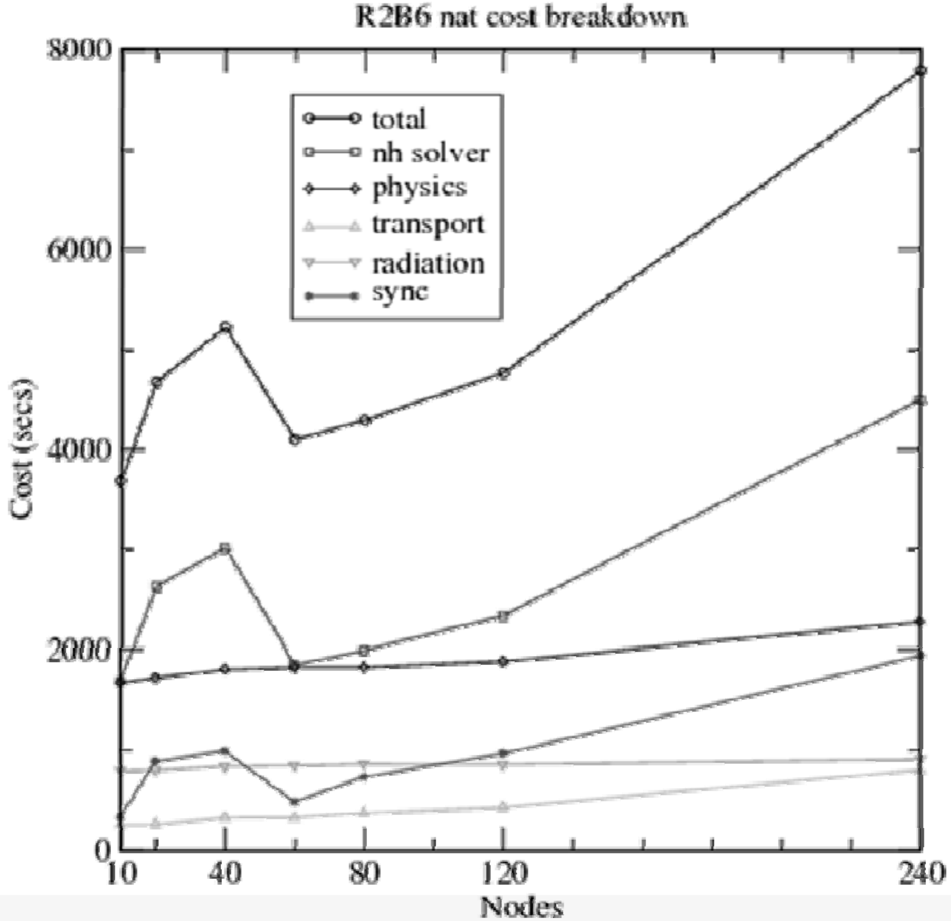
- Green:
  non-hydrost. + explicit
- Red:
  Hydrostatic + RK
- Blue:
  Hydrostatic + SI

o 240 nodes:
  42 cells per domain



Normalized costs for non-hydr. model

(Costs on n nodes run) / (Costs on 10 nodes run)



Summary

- The ICON project is motivated by goals, which cannot be reached with the operational models at DWD (GME, COSMO) and MPI-M (ECHAM6, MPIOM)
- Develop atmosphere, land and ocean models in the same infrastructure
- Flexibility of code for high numerical efficiency on NEC SX-9 and IBM Power6, or other architectures requires additional means (DSL)
- Work for strong scaling needs improved domain decomposition and shared memory parallelism
- Other ongoing efforts:
  - Coupler for unstructured grids with scaling search algorithm
  - Asynchronous and parallel output (CDI-pio)

END