Increasing parallelism in climate models via additional component concurrency

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• identify and quantify fundamental processes of Earth’s climate trajectory and variability during the last glacial cycle
• simulate with comprehensive Earth System Models (ESMs) from the peak of the last interglacial up to the present – 130k years
• assess possible future climate trajectories beyond this century

CHALLENGES

Physical System

Biogeochemistry

Synthesis and Analysis of Proxy Data

Optimization of Quality and Performance
Additional workload resulting from improved physical & biogeochemical processes like

- Feedbacks between continental ice sheets, sea level & large scale ocean circulation
- Dust sources, transport and deposition
- Variable land sea mask

Requirements (atmospheric component ECHAM only)

- LR (T63L47, 1.9°, 147km at 45°) desired
- CR (T31L47, 3.8°, 295km at 45°) tolerable for higher throughput
- 500-1000 SYPD needed to simulate 130k years in a reasonable amount of time

Approaches

- Novel numerical concepts (e.g. parallelization in time)
- Improved technical concepts (e.g. component concurrency)
ESiWACE: Centre of Excellence in Simulation of Weather and Climate in Europe

WP1 Governance & engagement
WP2 Scalability
Global high resolution model demonstrators
→ ICON, IFS, EC-Earth, NEMO
→ DYAMOND initiative
WP3 Usability
WP4 Exploitability
WP5 Management & dissemination

Meet us!
• ICT, 4-6 Dec 2018, Vienna
• EGU, 7-12 Apr 2019, Vienna
• PASC, 12-14 June 2019, Zurich
• ISC HPC, 16-20 June 2019, Frankfurt
DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains (DYAMOND)

- **Goal:** Intercomparison of global high-resolution models
- **Participation list:** ICON, NICAM, MPAS, FV3, SAM, NASA GEOS5, UM, ARPEGE-NH, IFS-H
- **Data management and support** through DKRZ/ESiWACE
- **More information:** [www.esiwace.eu/services/dyamond](http://www.esiwace.eu/services/dyamond)
Goal: 1 SYPD throughput
Extrapolation of ICON R2B9 DYAMOND to 1km:
17x too slow, assuming infinite number of (Broadwell) nodes
→ need for radical performance improvement at all levels
Issues at coarse resolution

- Scaling via domain decomposition reaches its limit
- New CPU based hardware will no longer give jump in performance
- Switching to GPU based systems require too much effort for legacy codes
- GPUs do not perform well on coarse grids

But still components exists that do scale!
Approach to Performance Improvement

- **ESiWACE:**
  - Single precision
  - OpenMP-based concurrency of radiation and wave model in IFS
  - DSL for performance portability (including GPUs)
  - HPC services to support wider community at performance tuning
  - evaluate concurrency on homogeneous & hybrid architectures (CPU,GPU), ICON: radiation as prototype, evaluate generalization [MPIM,DKRZ,MSWISS]

- **PalMod:**
  - single precision
  - flexible concurrent radiation using YAXT
  - Novel numerical methods
Component Concurrency

Based on:
- IFS: ECMWF investigated MPI based concurrent radiation (Mozdzynski, Morcrette)
- Coarse-grained component concurrency in ESM (Balaji et al.)
Concurrent radiation: time delay

**sequential:** \( \text{ATM}(t_0) \rightarrow \text{RAD} \rightarrow \text{ATM}(t_1) \ldots \text{ATM}(t_{NRAD}) \)

**asynchronous:** \( \text{ATM}(t_0) \rightarrow \text{ATM}(t_1) \ldots \rightarrow \text{ATM}(t_{NRAD}) \ldots \text{ATM}(t_{2 \times NRAD-1}) \)
YAXT communication library: overview

YAXT redistributes data between decompositions

Usability:
- No explicit message passing required
- User only supplies decompositions + data layout

Performance:
- Exploits MPI performance potential
- Applies collective communication optimization
YAXT: general aspects

- **Purpose:**
  - Reduce complexity of writing MPI applications
  - Exploit difficult to use performance potential of MPI:
    - Data layout description using MPI Derived Data Types (DDT)
    - Supports aggregation of communication

- **Concept:**
  - Data abstraction: global index definition
    - Decomposition = distribution of indices
  - Separation between decomposition and data layout
  - Each process only requires local knowledge
  - YAXT provides communication objects to change decompositions

- **Performance:**
  - Library on top of MPI, performance depends on quality of MPI [DDT] implementation
  - Cooperation with BULL/ATOS to improve derived datatypes in OpenMPI
Performance example: ECHAM Transposition gp->ffsl

T63L47 (synchronized measurement on prev. Pwr6 system)

- Original
- Optimized manually
- Using YAXT

Normalized Time

Cores

32 64 128 256 512 1024
YAXT: general aspects (cont.)

- Related tools (all in Fortran):
  - Unitrans (ScalES project), MCT, PILGRIM

- YAXT is maintained by DKRZ
  - Dev. Team: Thomas Jahns, Moritz Hanke, Jörg Behrens

- Access:
  - Documentation: [https://doc.redmine.dkrz.de/yaxt/html/](https://doc.redmine.dkrz.de/yaxt/html/)
Concurrent Radiation: communication aspects

**single-phase communication:**
- ATM tasks talk directly to RAD tasks
  - Communication costs at ATM depends on decompositions at both ends
  - Average communication costs for RAD and ATM
- Current test implementation:
  - Identical decompositions at ATM and RAD
  - Only single task to single task communication

**two-phase communication:**
1. ATM tasks talk to a similar intermediate decomposition at RAD
2. RAD performs an internal transposition to reach final decomposition
  - Minimal communication costs for ATM
  - Increased overhead for RAD
First Performance Results

Comparison of sequential and concurrent radiation scheme in ECHAM6 at coarse resolution (T31L47)

- Concurrent radiation scheme
- Sequential radiation scheme

![Graph comparing sequential and concurrent radiation schemes in ECHAM6 at coarse resolution (T31L47). The graph shows a significant increase in SYFP with concurrent radiation scheme, approximately 1.7 times compared to the sequential radiation scheme.](image)
First Comparison of Simulation Results

Surface temperature [C] sequential
- Radiation0(1970-1990)
  - min=-59.1498  mean=15.1217  max=33.4772

Surface temperature [C] asynchronous
- Radiation0(1970-1990)
  - min=-59.2852  mean=15.0742  max=33.2499

- Radiation0(1990-2010)
  - min=-58.5159  mean=15.4563  max=33.99

- Radiation0(1990-2010)
  - min=-58.8173  mean=15.4159  max=33.7608
First comparison of simulation results

2m temperature [K]

Total cloud cover (mean)

Mean sea level pressure [Pa]
Outlook

▪ Review and scientifically verify tolerable lag between ATM and RAD
▪ Further improve asynchronous scheme
  ▪ Evaluate (dynamic) load balancing for radiation tasks
  ▪ Align compute load in ATM and RAD to reduce waiting phases
▪ Technical optimization
  ▪ Communication aggregations
▪ Extent component concurrency to other processes, e.g. passive tracer
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More information about PalMod: www.palmod.de
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