

HPC aspects for physics-based ocean models

Personal views of the presenter to start a discussion

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Why do we even care about physics-based models?

- Physics-based models are not dead; they just smells funny
 - Frank Zappy paraphrase quote: Jazz is not dead; it just smells funny,
- Ocean reanalysis systems like GLORYS (MOi), ORASX (ECMWF) etc. are used as input to ML training
 - Data assimilation systems combines models and observations
- Hybrid modelling via e.g. spectral nudging as done at ECCC for the atmosphere shows a lot of potential
- Physical based models enable some science (like looking at sensitivity to mixing parameters) which is hard to do with AI/ML models
- The jury is still out on the best way to make the best ocean data available to users

The HPC world is changing in a different way than earlier:

- GPUs are very fast and energy efficient but also very expensive in today's market
 - Single NVIDIA 2U GPU NVIDIA Grace Hopper node is ~ 50000 to 100000 USD
- The AI/ML revolution not just in our field has increased the demands for GPUs and memory
 - We might need the AI bubble to burst before we can buy computers with GPUs for physical models
- Memory prices have almost tripled from August 2025 to December 2025
 - https://en.wikipedia.org/wiki/2024%E2%80%93present_global_memory_supply_shortage
- The next ECMWF HPC to be installed in 2027 is going to be less than a factor of 2 more powerful than the current one
 - The AI/ML activities are going to scoop up all the GPUs
 - I don't think this is just an ECMWF problem

Programming physics-based models

- Traditionally we have used Fortran as the programming language of choice
 - The Message Passing Interface library (MPI) is used to allow us to use many computer nodes connected via an interconnect/network
 - Distributed memory parallelization, all data need to be communicated explicitly
 - Within a node we can add an additional level of parallelism using OpenMP (or similar)
 - Shared memory parallelization, no communication needed, but care needs to be taken to avoid race conditions
 - If the nodes have a GPU attached, then we can offload part of the computations by moving data from CPU memory to GPU memory and instruct the GPU what to do and move data back to the CPU memory
 - OpenACC and/or OpenMP directives can be used for this
 - In early stages of the GPU revolution this had to be done by the developer, but some recent systems like NVIDIA Grace Hopper GH200 can do this in hardware via unified memory
- A complicated and error-prone development model in which the model developer needs to understand the hardware to make the best use of it
 - Porting to new hardware can be a pain as has been seen when porting our models to GPUs (which we can't now not afford)

Are there better ways?

- Fortran is not quite dead, but it does smell very funny and the number of developers is shrinking
- Separation of concerns:
 - Domain scientists should ideally focus on developing parameterizations, time stepping schemes etc and not HPC hardware
- Domain specific languages (DSL's) and alternative languages:
 - A specialized programming or specification language tailored to a specific problem domain
 - Example from our field:
 - LFRic/PsyClone: new MetOffice atmospheric model
 - Can also transform NEMO F90 source code
 - gt4py: Python library for generating high-performance implementations of stencil kernels for weather and climate modeling from a domain-specific language (DSL)
 - oceananigans.jl: Fast and friendly ocean-flavored Julia software for simulating incompressible fluid dynamics in Cartesian and spherical shell domains on CPUs and GPUs.
- The porting to new hardware is done within the DSL's by computer experts and not domain scientists

So why haven't we transitioned to something more modern already?

- We have spent getting to where we are in terms of physical modelling capabilities
 - Evolution (improve existing modelling systems) versus revolution (new modelling systems)
- With the emerging AI coding agents then we should be able get it done without investing a lot of human time doing so
 - So maybe we don't need to do the boring stuff
- Shameless promotion of an ECMWF event:
 - Workshop on software strategies for sustainable physical modelling at ECMWF
 - ECMWF | Reading | 23-27 November 2026
 - <https://events.ecmwf.int/event/529/>