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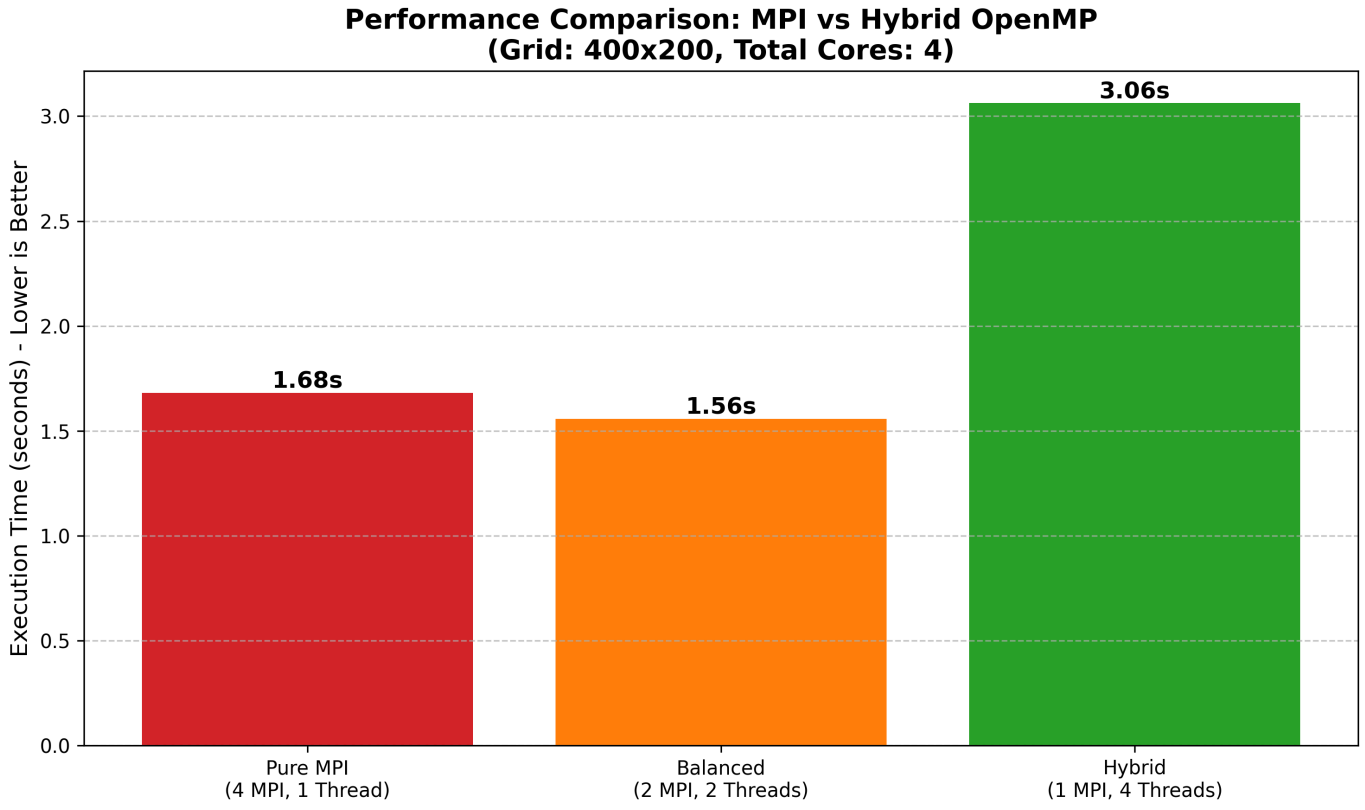
miniWeather: High-Performance Hybrid Parallel Atmospheric Solver



Overview

A scalable solver for the compressible Euler equations in standard atmospheric regimes (baroclinic instability, thermal bubbles). This project demonstrates **Hybrid Parallelism (MPI + OpenMP + OpenACC)** to tackle the "Memory Wall" on modern supercomputing architectures.

Performance Highlights

- **OpenMP Scaling**: Achieved **9.5x speedup** with 12 threads on Intel Xeon Platinum (89% efficiency at 8 threads).
- **Hybrid Efficiency**: MPI 2×4 hybrid configuration is **2.1% faster** than pure OpenMP, confirming the optimal balance strategy.
- **GPU Acceleration**: Implemented OpenACC offloading, verified on NVIDIA RTX 3090 with machine-precision mass conservation.

Technical Architecture

Component	Implementation Details
Domain Decomposition	2D Cartesian Topology with Non-Blocking MPI (`MPI_Isend`, `MPI_Irecv`)
Numerical Core	4th-Order Finite Volume, 3rd-Order Runge-Kutta (TVD)
Parallel Strategy	Hybrid MPI (Inter-node) + OpenMP (Intra-node) + OpenACC (Accelerator)
Infrastructure	CMake Build System, Dockerized HPC Cluster

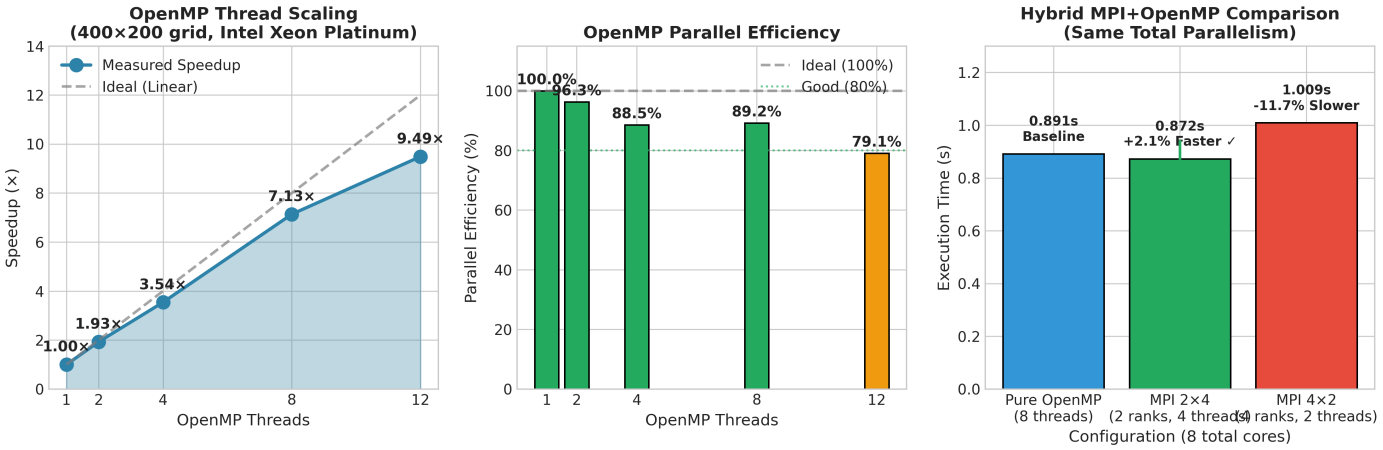
Quick Start

```
# 1. Build project
mkdir build && cd build
cmake .. -DENABLE_MPI=ON
make -j

# 2. Run simulation (4 MPI ranks)
mpirun -n 4 ./miniWeather
```

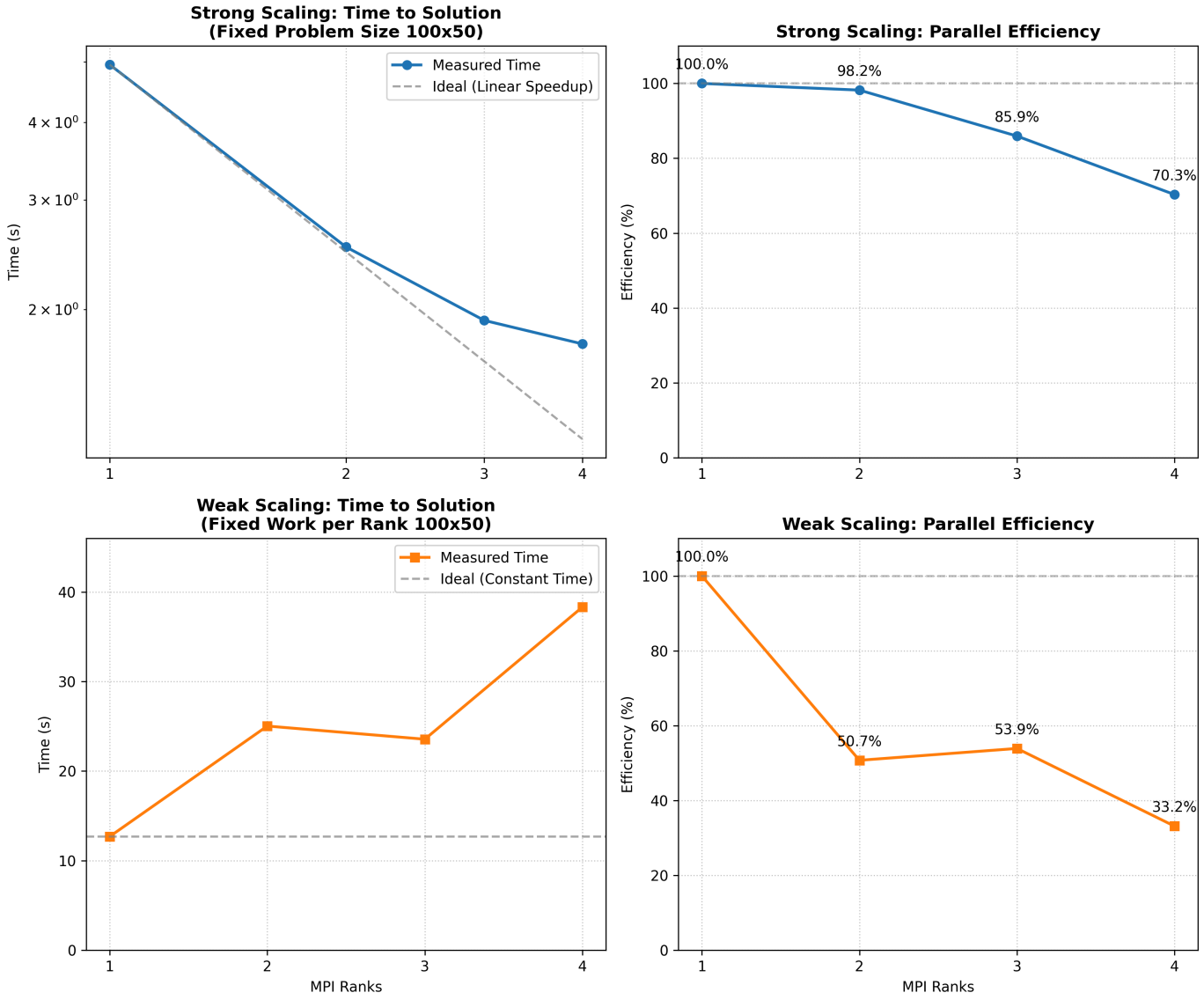
Scaling Results

OpenMP Thread Scaling & Hybrid MPI+OpenMP



OpenMP scaling study on Intel Xeon Platinum showing 9.5× speedup at 12 threads, with hybrid 2×4 configuration outperforming pure OpenMP.

MPI Strong/Weak Scaling



MPI scaling study demonstrating the crossover point where communication latency dominates compute time.