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ERF: Energy Research and Forecasting

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Software

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Summary

The Energy Research and Forecasting (ERF) code is a new model that simulates the mesoscale and microscale dynamics of the atmosphere using the latest high-performance computing architectures. It employs hierarchical parallelism using an MPI+X model, where X may be OpenMP on multicore CPU-only systems, or CUDA, HIP, or SYCL on GPU-accelerated systems. ERF is built on AMReX (Zhang et al., 2019, 2021), a block-structured adaptive mesh refinement (AMR) software framework that provides the underlying performance-portable software infrastructure for block-structured mesh operations. The "energy" aspect of ERF indicates that the software has been developed with renewable energy applications in mind. In addition to being a numerical weather prediction model, ERF is designed to provide a flexible computational framework for the exploration and investigation of different physics parameterizations and numerical strategies, and to characterize the flow field that impacts the ability of wind turbines to extract wind energy. The ERF development is part of a broader effort led by the US Department of Energy's Wind Energy Technologies Office.

ERF Features

Hydrodynamics Models

ERF solves the fully compressible Navier-Stokes equations for dry or moist air and includes a planetary boundary layer (PBL) parameterization as well as subfilter flux parameterizations for large-eddy simulations (LES). The PBL parameterization is based on the work of Mellor and Yamada (Mellor & Yamada, 1982) and Nakanishi and Niino (Nakanishi & Niino, 2009), the so-called MYNN model for mesoscale simulations. LES parameterizations are Smagorinsky-type (Lilly, 1967; Nakanishi & Niino, 1963) and Deardorff (Deardorff, 1980).

Microphysics Options

Microphysics options in ERF include a warm, non-precipitating model that evolves cloud water and cloud vapor and a single-moment model (Khairoutdinov & Randall, 2003) that evolves precipitating and nonprecipitating tracers, such as water vapor, rain, ice, snow, and graupel. These prognostic variables can track particle evolution through all the important mechanisms of ice and water growth, including vapor deposition, aggregation, autoconversion, and condensation.

Time and Space Discretization and Terrain

The time discretization in ERF utilizes a third-order Runge-Kutta scheme with substepping of perturbational quantities at the acoustic time scale (Klemp et al., 2007). (A non-substepping method is also available as a run-time option.) The spatial discretization in ERF uses the classic Arakawa C-grid with scalar quantities at cell centers and normal velocities at cell faces. For simulations over complex topography, a terrain-following, height-based vertical coordinate is employed. The model includes capability for application of some common map projections (e.g., Lambert Conformal, Mercator). The advection terms may be calculated using second- through sixth-order accurate spatial discretizations, including both centered difference and upwind schemes. Third- and fifth-order weighted essentially non-oscillatory (WENO) advection schemes are also available for the cell-centered scalars. ERF supports both static and dynamic (adaptive) mesh refinement, with subcycling in time at finer levels of refinement.

Physical Forcings and Boundary Conditions

Physical forcings include Coriolis and geostrophic forcing as well as Rayleigh damping in the upper regions of the domain. Lateral boundary conditions can be specified as periodic, inflow/outflow, or time-varying values read in from external files in netcdf format generated by the WRF Preprocessing System (WPS) (Skamarock et al., 2021). The surface boundary condition may be specified either as a simple wall or by using Monin-Obukhov similarity theory (MOST) (Monin & Obukhov, 1954; van der Laan et al., 2017) to model the surface layer. The initial data can be read from WPS-generated files, reconstructed from 1-d input sounding data, or specified by the user.

Statement of need

Most widely used atmospheric modeling codes today do not have the ability to use GPU acceleration, which limits their ability to efficiently utilize current and next-generation high performance computing architectures. ERF provides an atmospheric modeling capability that runs on the latest high-performance computing architectures, from laptops to supercomputers, whether CPU-only or GPU-accelerated. In addition, ERF is based on AMReX, a modern, well-supported AMR library, which provides a performance portable interface that shields ERF from most of the detailed changes needed to adapt to new systems. The active and large developer community contributing to AMReX helps ensure that ERF will continue to run efficiently as architectures and operating systems evolve.

To support renewable energy research and development, ERF provides an essential resource characterization and forensic capability for terrestrial and offshore applications. For wind energy, ERF includes a standard suite of physical process parameterizations that supports simulation across weather (meso) and turbulence-resolving (micro) scales, allowing for efficient downscaling of flow field information that specifies realistic inflow, surface, and background conditions for wind farm simulation. Realistic conditions can include extreme wind-shear events (e.g., low-level jets), thunderstorms, or tropical cyclones (e.g., hurricanes). This modeling capability also captures the impacts of clouds and precipitation, and is similarly applicable to solar farms and hybrid energy systems.

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