EGU26-11190, updated on 08 Jun 2026
https://doi.org/10.5194/egusphere-egu26-11190
EGU General Assembly 2026

Century-long global kilometre-scale climate simulations with the eddy-rich IFS–FESOM coupled model

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We present novel century-long global climate simulations at kilometre-scale resolution performed with the coupled IFS–FESOM climate model, featuring a ~9 km atmospheric component and an ocean with a minimum grid spacing of ~5 km. Following the HighResMIP protocol, the experimental design comprises a 50-year high-resolution coupled spin-up, a 65-year historical simulation (1950–2014), a future scenario simulation (SSP2-4.5, 2015–2050), and a 100-year control simulation using fixed 1950 radiative forcing. This framework enables the explicit representation of ocean mesoscale eddies within a long-term global climate context.

Compared to CMIP6-class models, the simulations exhibit an overall improved mean climate state and a reduction of long-standing systematic biases, with the exception of remaining deficiencies in the polar regions. Global performance metrics indicate reduced errors in near-surface temperature, winds, and cloud properties. The eddy-rich ocean configuration realistically captures boundary-current variability and mesoscale dynamics, leading to improved sea-surface salinity distributions and a strengthened Atlantic Meridional Overturning Circulation, with a peak transport of approximately 20 Sv. Internal climate variability is well represented, including a realistic El Niño–Southern Oscillation characterized by a quasi-periodicity of ~4–5 years and physically consistent teleconnection patterns.

Despite persistent sea-ice and high-latitude biases, the coupled system remains stable over centennial time scales with minimal long-term drift. These results demonstrate the feasibility and scientific value of global coupled climate simulations operating in the ocean eddy-rich regime at sub-10 km resolution. The IFS–FESOM kilometre-scale configuration thus represents a significant step forward in the development of next-generation Earth system models that robustly bridge global climate dynamics and regional-scale processes over multi-decadal to centennial periods.