UP 5: Modelling and Prediction Across Scales

Seamless prediction and boundary-layer physics; the session then broadens to cross-cutting modelling, multiscale methods, data assimilation, computational techniques, and optimization of fuel combustion.

Time: Tuesday 14:00–15:30 Location: MER/0002

Invited Talk UP 5.1 Tue 14:00 MER/0002

A path to seamless modelling of the convective atmospheric boundary layer — •Mirjana Sakradzija — Ludwig Maximilian University of Munich, Germany

Numerical weather prediction (NWP) has reached operational grid spacings of less than 1 km at several leading weather centres. The possibility of using the same model configuration across various applications and spatial scales, ranging from local large-eddy-resolving cases to global NWP and climate simulations, is now a reality. I will explore one such possibility by using an operational NWP model at sub-km resolutions and examining its ability to represent relevant processes in the atmospheric boundary layer (ABL) compared with standard large-eddy simulations, and micro- and sub-mesoscale meteorological observations. Next, I will discuss the current state of development of a unified parameterization of ABL turbulence, convection, and clouds, and the prospects for a smooth transition from parameterized to resolved scales. The importance of land-atmosphere coupling emerges at all spatio-temporal scales as the key forcing factor for the ABL and one of the largest sources of uncertainty in both modelling and observations.

UP 5.2 Tue 14:30 MER/0002

Projected variability of solar resources in the Eastern Mediterranean and Middle East — •Nikolaos Papadimitriou[1,2], Kostas Douvis[2], Stergios Misios[2], Antonis Gkikas[2], Andreas Kazantzidis[1], Christos Zerefos[3,4,5], and Ilias Fountoulakis[2] — [1]Department of Physics, University of Patras, Patras, Greece — [2]Research Centre for Atmospheric Physics and Climatology, Academy of Athens, Athens, Greece — [3]Biomedical Research Foundation, Academy of Athens, Athens, Greece — [4]Navarino Environmental Observatory (N.E.O.), Messinia, Greece — [5]Mariolopoulos-Kanaginis Foundation for the Environmental Sciences, Athens, Greece

Climate change is expected to alter key atmospheric parameters influencing downwelling solar irradiance, including cloudiness and aerosol concentration. The Eastern Mediterranean and Middle East region, identified as a climate hotspot and known for its high levels of solar exposure, constitutes a particularly relevant case study for assessing future variability of solar energy potential. We use data from three global climate models that participated in the 6th phase of the Climate Model Intercomparison Project (CMIP-6): CNRM-CM6-1-HR, INM-CM5-0, and MPI-ESM1-2-HR. Projections were evaluated under three different Shared Socioeconomic Pathways (SSPs 245, 370, 585). In this study, we analyzed trends in surface downwelling solar irradiance and associated climatic drivers and estimate the photovoltaic (PV) power potential by performing simulations with the climate data interface of the GSEE model.

UP 5.3 Tue 14:45 MER/0002

An optimization-based approach to track the Asian summer monsoon anticyclone across daily and interannual variability — •Oleh Kachula, Bärbel Vogel, Gebhard Günther, and Rolf Müller — Forschungszentrum Jülich, 52428 Jülich, Germany

The Asian summer monsoon anticyclone (ASMA) is an upper troposphere-lower stratosphere (UTLS) meteorological circulation system that develops over Asia during summer months in the Northern Hemisphere. It strongly influences regional weather, particularly monsoon rainfall, and shapes the climate of densely populated regions such as India and Southeast Asia. The ASMA also plays a major role in transporting near-surface anthropogenic pollutants to the UTLS, with important implications for air quality and stratospheric chemistry. Improving our understanding of this complex system is essential for enhancing weather prediction capabilities and for better assessing climate and environmental impacts.

We present a novel method based on the absolute vortex moments that defines the ASMA boundary by solving an optimization problem. Here, we address the ASMA's climatology (1980-2023), interannual variability, the variability of the start and end dates and the duration of the anticyclone peak phase calculated with help of the defined novel method by using the ERA5 reanalysis provided by ECMWF. Our findings show that the ASMA area decreases at 370, 390 and 410 K over the period 1980-2023 in contrast to previous studies. Further, we provide evidence of possible bimodality of the ASMA.

UP 5.4 Tue 15:00 MER/0002

Differentiable Operators for Ocean Simulation and Inverse Problems — •Pauleo R. Nimtz[1,2], Vadim Zinchenko[1], Kubilay T. Demir[1], Anthony Frion[1], and David S. Greenberg[1] — [1]Helmholtz-Zentrum Hereon, Geesthacht, Germany — [2]Universität Potsdam, Potsdam, Germany

Gradient-based optimization is a powerful tool for fitting mechanistic simulations to observation data and is crucial for modern machine learning frameworks. However, in established numerical models of ocean hydrodynamics (e.g. NEMO, ICON-O, SCHISM) and biogeochemistry (e.g. ECOSMO, HAMMOC), the required gradients with respect to model input are typically not available. To address this, we implemented a family of differentiable operators in PyTorch, focusing on the transport and interaction of tracers in fluid dynamical simulations. We provide key operations such as advection, turbulent mixing and biogeochemical processes, with native GPU support and efficient vectorized code. Gradients are computed automatically with memory-efficient custom backpropagation routines for implicit time integration. These operators enable auto-differentiable simulations, with applications including model tuning, data assimilation, physics-informed neural networks, and hybrid physical and data-driven models. We demonstrate their utility by performing data assimilation to identify initial conditions in simulations of inert tracer transport and spatially extended models of light- and nutrient-dependent aquatic ecosystems. These tools provide an essential step towards building and tuning differentiable ocean models, and fitting them to observation data.

UP 5.5 Tue 15:15 MER/0002

Approximating the universal thermal climate index using sparse regression with orthogonal polynomials — •Sabin Roman[1], Gregor Skok[2], Ljupco Todorovski[2,1], and Saso Dzeroski[1] — [1]Department of Knowledge Technologies, Jozef Stefan Institute — [2]Faculty of Mathematics and Physics, University of Ljubljana

The Universal Thermal Climate Index (UTCI) is widely used to quantify outdoor thermal comfort, but its standard sixth-degree polynomial approximation can yield substantial numerical errors, especially under extreme conditions. We present a new approximation method that preserves computational efficiency while offering markedly improved accuracy and stability. The method employs sparse regression with Legendre polynomial bases, whose orthogonality ensures well-conditioned models and a hierarchical coefficient structure. Adjusting sparsity constraints yields families of models that span a clear Pareto front between accuracy and complexity. Compared with the standard UTCI approximation, the proposed models substantially reduce mean, absolute, and root-mean-square errors and significantly limit large deviations. Training on only 20% of the data while testing on the remaining 80% demonstrates strong generalization, further supported by bootstrap analysis. The resulting representation acts as a Fourier-like expansion in an orthogonal basis, providing an efficient and highly accurate approximation of the UTCI.