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Unlocking Renewable Energy Insights with Plume: Extensions for Wind Energy and Beyond

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Destination Earth (DestinE) is the European Union's flagship initiative to develop Digital Twin (DT) models of the Earth system. It leverages cutting-edge advances in numerical prediction, digital technologies, high-performance computing, and AI to enhance our understanding of climate change and evolving weather extremes. One of its key objectives is to support the European Commission's Green Deal by enabling the large-scale integration of renewable energy into Europe's energy system. This ambition is pursued through several energy-related use cases, such as the ongoing Onshore & Offshore Wind Energy Information project, or closed Energy Systems for making a resilient power system.

European Centre for Medium-Range Weather Forecasts (ECMWF) has developed Plume, co-funded by the European Commission under the DestinE initiative. Plume is a plugin mechanism for Earth system models that extends their processing capabilities through modular add-on functionalities. Plume dynamically loads plugins at runtime and provides read access to in-memory model fields via a well-defined interface (based on the Atlas library (Deconinck, et al., 2017)), enabling application-specific processing alongside the main model without costly I/O operations. This framework has been applied in the EU Horizon project DTWO, which develops a Digital Twin for wind energy applications. In collaboration with DTWO partners, ECMWF created two Plume plugins, introduced at the 2025 European Meteorological Society Annual Meeting, for wind farm modelling and extreme weather event detection, tested in Extremes DT-like experiments.

This presentation focuses on recent extensions to the Plume framework that enhance these plugins' usability and relevance for the wind energy value chain, while enabling broader development of renewable-energy applications through improved configurability. Wind energy applications require high-frequency, high-resolution data at turbine hub heights (50-200m). The Extremes DT, running the Integrated Forecasting System (IFS), computes wind fields on model levels, from which hub-height winds can be interpolated. However, certain heights, e.g., 100m, are only computed at output steps, limiting availability for plugins during model integration, and the typical output heights do not fully capture the required range. To address these limitations, Plume now includes its own data generation capability. Beyond interfacing with original model fields, Plume can manage derived fields and variables, feeding plugins with relevant data while centralising processing costs and methods, e.g., hub-height wind interpolation. This feature is implemented using an observer pattern, propagating updates from source model data to Plume-

managed fields and triggering strategy-based recalculations. The design prioritises extensibility and avoids redundancy in plugin code by concentrating derived data generation within Plume. For the wind farm modelling plugin, this enhancement enables direct retrieval of wind data at configured hub heights, supporting more accurate resource assessments while keeping the implementation application-focused. By consolidating these capabilities within Plume, the framework fosters greater collaboration on iterative improvements and plugin development, engaging a broader community of stakeholders in shaping its evolution.