Exploring the DestinE Continuous Extremes DT: Insights from Extreme Weather Events

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1. Introduction

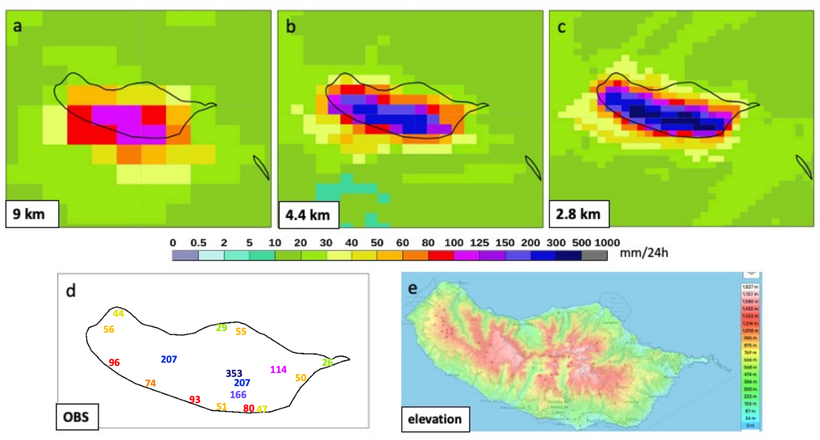
Different extreme **weather events** from **2016-2023** have been analysed for **the Continuous Extremes Digital Twin (DT)** simulations. These simulations are evaluated in terms of the physical realism of the representation of extreme events at km-scale with the ECMWF Integrated Forecasting System (IFS) cycle 48r1. We compare km-scale simulations (**4.4 km** and **2.8 km** resolution) with **observations** (e.g., SYNOP, radar, satellite derived products), the operational analysis of ECMWF (at 9km) and research simulations with IFS (**25 km**).

Different types of extreme events were selected, including **tropical cyclones**, **medicanes**, polar lows, tornadoes, extratropical cyclogenesis, **mid-latitude windstorms**, **extreme precipitation,** flooding events, squall lines, fog events, severe convective events and extreme temperature. Although most of them occur in **Europe**, some are spread around the entire **world**.

This evaluation **informs** on the **model developments** required to further improve the representation of extreme events in the Continuous Extremes DT simulations at the targeted km-scale resolutions (4.4 km and potentially higher resolutions).

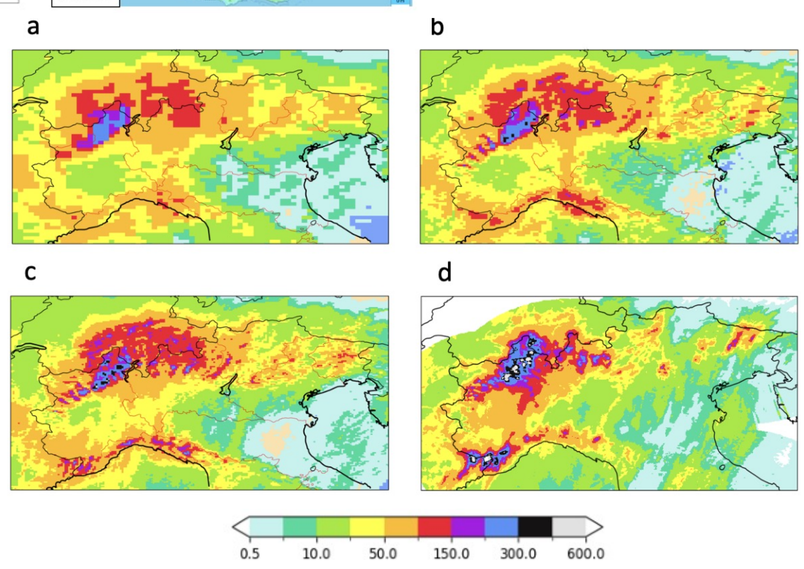
2. Extreme precipitation

- Extreme precipitation forecast benefits significantly from the increment in horizontal resolution up to 4.4 km and 2.8, particularly in areas with **complex orography**.
- In **small but orographically complex islands,** higher resolution captures better convective triggers and blocking orographic patterns, resulting in more defined coastal lines and improved precipitation accumulations and intensities.
- Extreme precipitation forecast over flat terrain does not improve much when increasing the resolution. **Further diagnostics** are essential to explore potential enhancements in other aspects (parametrizations, data assimilation...) of the forecast model.



Small islands with complex orography: Madeira

Precipitation accumulated (mm) over 24h on 7th June 2023 at (a) 9 km, (b) 4.4 km and (c) 2.8 km resolution, (d) SYNOP observations and (e) real elevation map of Madeira Island. All forecasts were initialized on 5th June 2023 00 UTC and valid at T+48h.

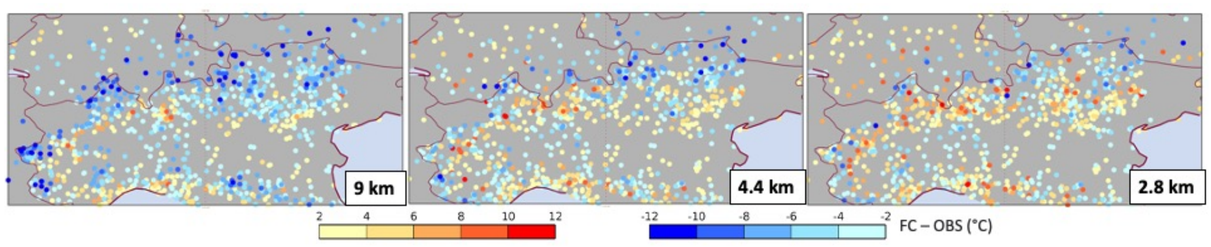


Large mountain ranges: Alps

Precipitation accumulated over 24h (in mm) during the Storm Alex in IFS forecasts at (a) 9 km, (b) 4.4 km and (c) 2.8 km resolution and (d) ARPAE regridded gauges dataset. All forecasts are initialized on 1st October 2020 00UTC and valid at T+60h.

3. 2 m temperature extremes

- High-resolution forecasts are better at resolving small-scale processes and reducing 2 m temperature forecast errors in **stable and cold conditions** (i.e. better at resolving low-level inversions) over Scandinavia or complex orographic areas at night.
- We will evaluate other case studies related to **heatwaves** and local effects to determine whether forecasts of extreme warm events can be improved with higher resolution.



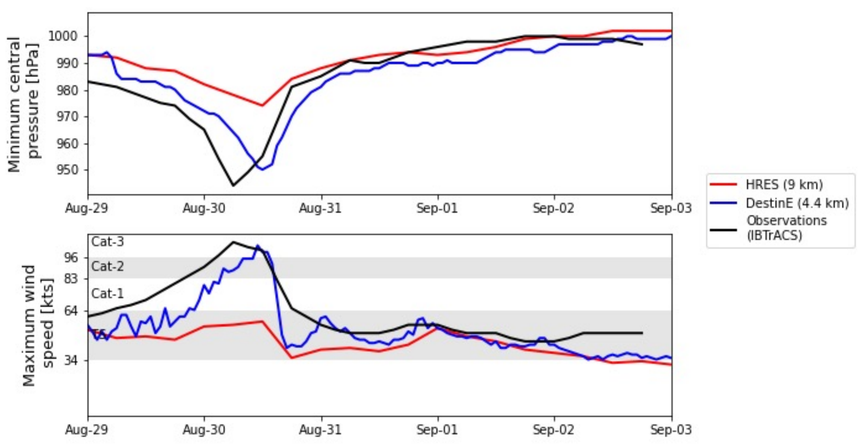
2m temperature errors (forecast-observations) on 12th February 2023 at (left) 9 km, (middle) 4.4 km and (right) 2.8 km resolution, compared to SYNOP/HDOBS observations. All forecasts were initialized on 11th February 2023 00 UTC and valid at T+24h.

4. Tropical cyclones and medicanes

- **Tropical cyclone** and **medicane** forecasts benefit from the increased resolution in many ways: **TC intensity errors are reduced** the most from 9 km to 4.4 km, while even higher resolution better resolves TC **structure and physical processes** in the eyewall relevant to rapid intensity changes.
- The ability of enhanced representation of temperature gradients in the TC core is key to predicting the correct storm nature and hence the basis for modelling phase transitions (e.g., extratropical transition).

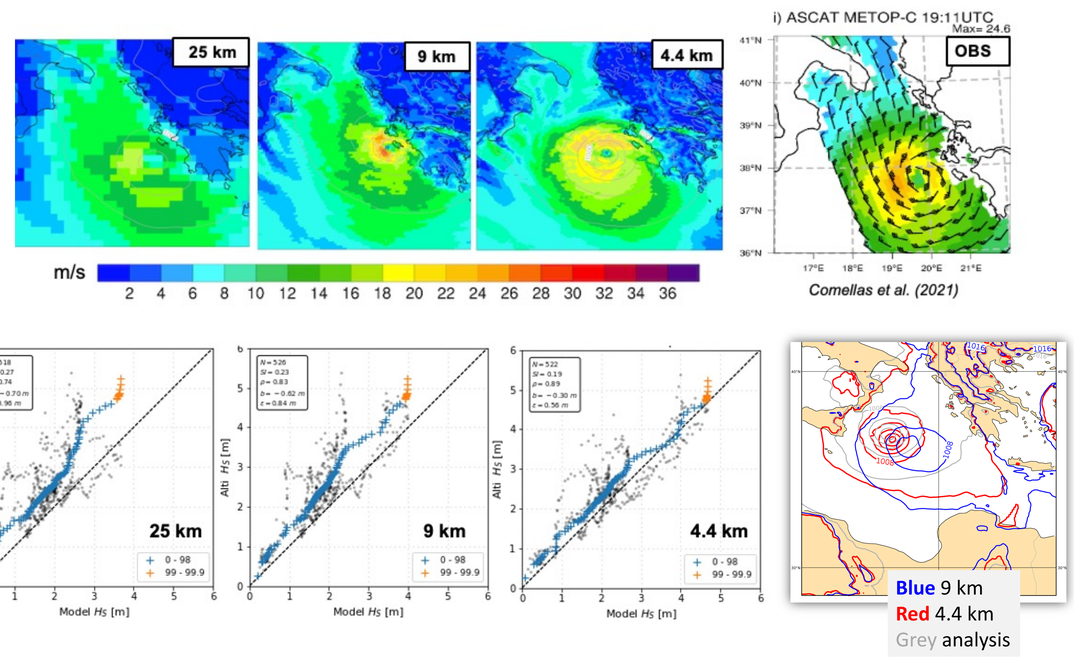
Tropical cyclone Idalia

Minimum central pressure and maximum sustained wind speed for Hurricane Idalia, for HRES, DestinE, and observations (IBTrACS). Base time 29 August 2023 00 UTC.



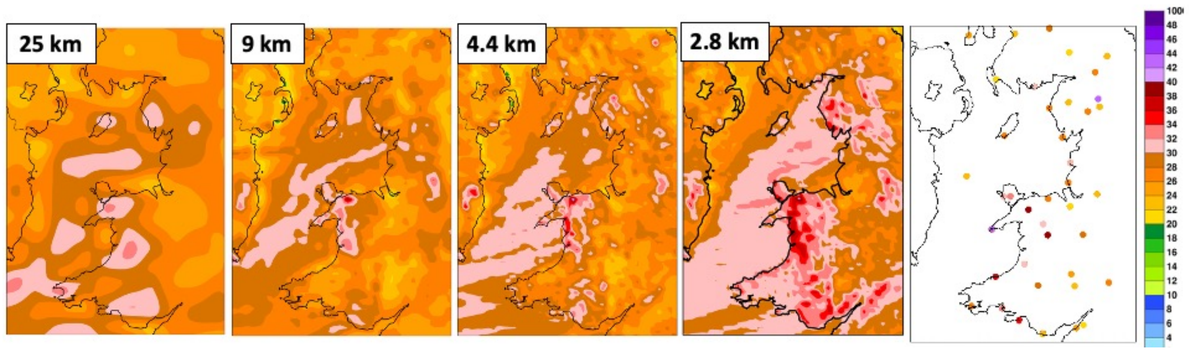
Medicane Ianos

Surface wind speed during landfall of medicane Ianos (16 Sept 2020 at 18UTC) at T+66h (top). Linear regression and QQ plots of waves model forecast vs altimeter observations, valid at T+84h (bottom). On the bottom right, MSLP in the ECMWF operational analysis (grey), the 9 km (blue) and 4.4 km DestinE runs (red) simulations with IFS cycle 48r1. Forecast initialised on 15 Sept 2020 at 00 UTC and valid at T+48h.



5. Windstorms and extreme wind gusts

- The 4.4 km did not seem to be sufficient to improve the realism of **wind gusts** compared with the 9 km resolution, although there is increased structure in regions of complex orography. However, we observe a noticeable **improvement** in **2.8 km** resolution.
- Wind gusts over land are more difficult to simulate due to roughness features and the propagation of convective showers.



Storm Ciara

10 m max wind gusts forecasts (m/s) in 24h during storm “Ciara” in the cycle 48r1 model cycle at with 25 km, 9 km, 4.4 km and 2.8 km horizontal resolution and the corresponding SYNOP observations for the valid time period (bottom). The forecast is initialised on 1 October 2020 00 UTC and valid at T+60h.

Mediterranean Derecho

10 m max wind gusts forecasts (m/s) in 24 h during the Derecho in the Mediterranean in the cycle 48r1 at with 25 , 9, 4.4 and 2.8 km horizontal resolution and the corresponding SYNOP observations. The forecast is initialised on 17 Aug 2022 00 UTC and valid at T+48h.
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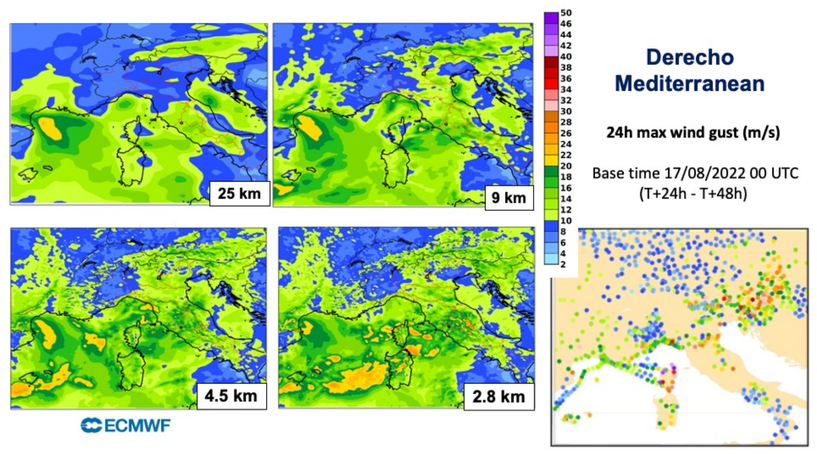

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