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High Resolution Atmospheric Hindcast

A Joint Industry Project Proposal by Weather Water Sand Srl

Introduction

The availability of reliable global meteo-marine data is crucial for efficient planning, development and operation of offshore wind farms. Despite recent advances in climate observation systems there is still a lack of continuous high-resolution data at various heights above ground surface and sufficiently extended in time and space, making it difficult to accurately predict wind conditions and design energy infrastructures. The challenge is further increased when considering the uncertainty in the evolution of future climate. Validated atmospheric numerical simulations of weather conditions over a sufficiently large temporal period, and on a high spatial resolution, to produce realistic and reliable statistical information is necessary to achieve the best outcome for wind energy project planning and operation.

The present project proposes the development of a high-resolution hindcast of meteo-marine conditions for the past 40 years (1982-2022) over a selected Area of Interest (AOI). The project is expected to produce a state-of-the-art 3D grid of meteorological parameters with high spatial (2.5 km) and temporal (1 hr) resolution that can be used for the engineering design and planning of operation conditions for wind energy projects. The work program has been designed for an AOI of approximately 10 million km^2, with an initial proposal over the Yellow Sea region where there are several planned wind projects. The work program can be adapted to specific requirements of project sponsors, including a different AOI, different spatial/temporal resolutions and specific meteo-oceanographic parameters.

Project Team & Resources

Weather Water Sand (WWS) is a new start-up company formed in 2021 as a spin-off of the Department of Civil, Environmental and Chemical Engineering (DICCA) of the University of Genova. WWS scientists provide advanced technical services with an emphasis on innovative approaches to environmental flow modelling. Prof. Andrea Mazzino has extensive experience in atmospheric modelling, forecasting and hindcast at multiple spatial and temporal resolutions and will be the project leader. WWS will partner with other scientists from the DICCA at the University of Genova to execute this project.

We will utilize High-Performance Computing available through commercial platforms, most likely Amazon Web Services (AWS) which can provide virtually unlimited, scalable computing power and storage. We have previously worked with this platform to conduct similar hindcast[1] and forecast[2] projects in other areas.

Project Description

This project represents the state of the art in numerical simulation of meteo-marine conditions of the past (hindcast). The atmospheric simulations (Figure 1) will use the Weather Research and Forecasting (WRF) model, version 4.3.3, a numerical weather prediction model designed for both research and operational applications.

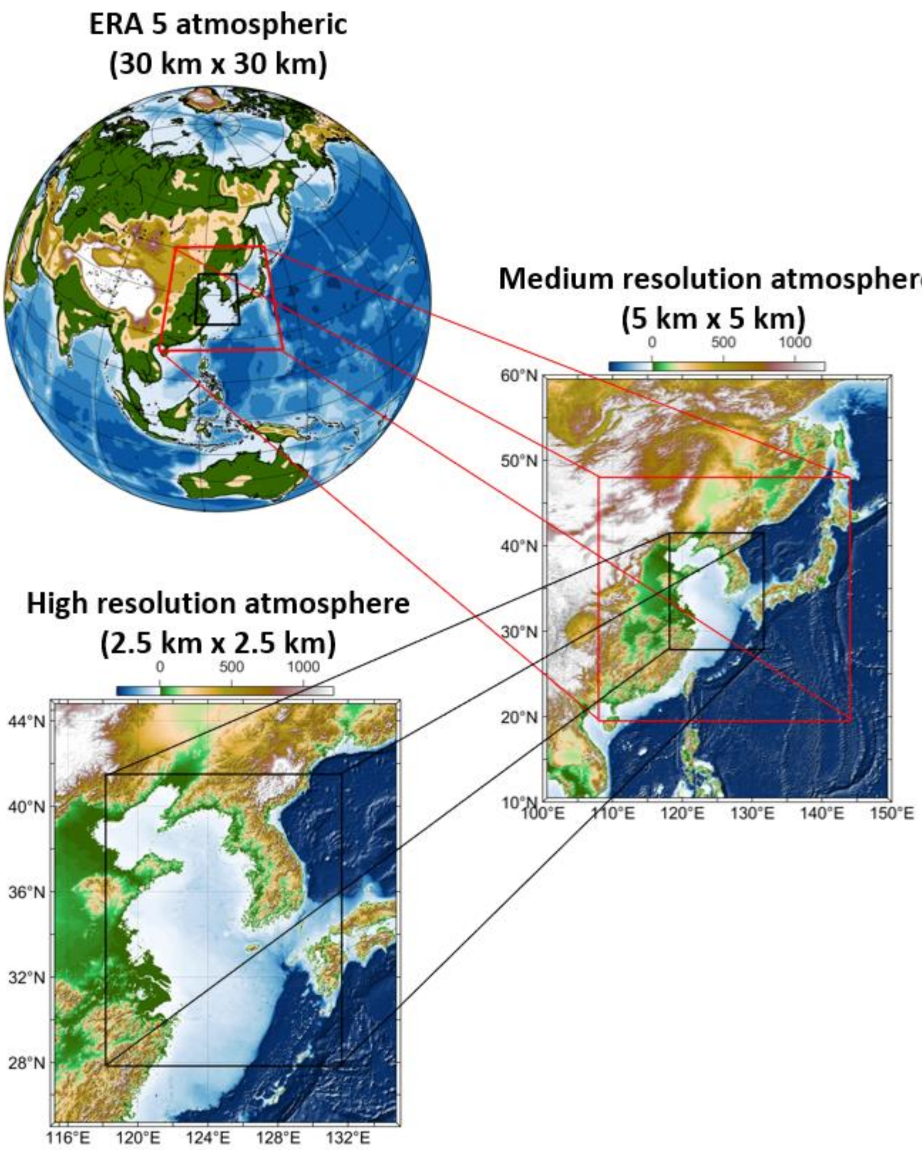

Figure 1. Modelling setup for high-resolution atmospheric hindcast model.

[1] Mentaschi, L., Besio, G., Cassola, F. and Mazzino, A., 2013, Developing and validating a forecast/hindcast system for the Mediterranean Sea. *Journal of Coastal Research*, 65: 1551-1556.
Ferrari, F., Besio, G., Cassola, F. and Mazzino, A., 2020, Optimized wind and wave energy resource assessment and offshore exploitability in the Mediterranean Sea. *Energy*, 190: 116447.

[2] Real-time forecasting project link: www.weatherwatersand.com/what-we-do/weather-forecasting/

Using large-scale atmospheric input from the ERA5 model (ca. 31 km resolution), WRF allows to simulate weather conditions, up to a remarkably high resolution, reaching 2.5 km resolution for atmospheric simulations using a nested-resolution downscaling technique. The high resolution allows the representation of different physical phenomena acting at different spatial and temporal scales that play a fundamental role in the evolution both of the atmosphere and of the sea. As an example, the interaction between synoptic circulation and thermally induced small-scale motion originates from temperature gradient between the Padana Valley and the Ligurian Sea (see Figure 2).

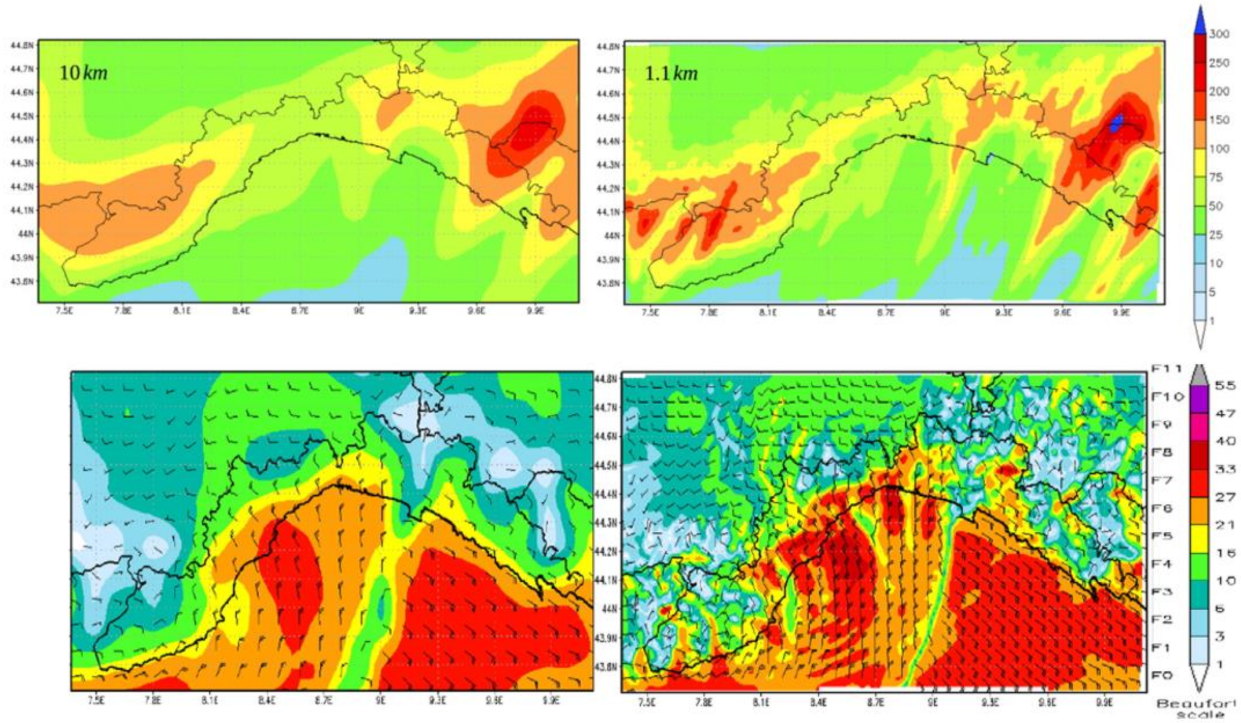

Figure 2. The key role played by spatial resolution in resolving extreme events: only the highest resolution simulations (right panels) capture the observed cumulated precipitations and the spatial structure of the wind field associated to flow convergence. This example is from the area of the Gulf of Genova, Italy. For details see [3]

This high-resolution represents the state of the art for a hindcast dataset. This kind of resolution is fundamental to facilitate accurate predictions of severe events. A specific example is provided by the simulations of extreme precipitations in the presence of interactions between (large scale) synoptic motions and locally (small scale) induced circulations. The three panels of Figure 3 show one of such extreme events which occurred in Liguria (Italy) on 9 October 2014. The key role of high-resolution simulations clearly emerges: only the right panel reproduces the observed cumulated precipitation pattern (upper panel) while the lower resolution simulation (left panel) tends to underestimate the precipitation.

[3] Cassola, F.; Ferrari, F.; Mazzino, A., 2015. Numerical simulations of Mediterranean heavy precipitation events with the WRF model: A verification exercise using different approaches. *Atmospheric Research*, 164–165, 3–18.
Ferrari, F., Cassola, F., Tuju, P.E., Stocchino, A., Brotto, P. and Mazzino, A., 2020. Impact of Model Resolution and Initial/Boundary Conditions in Forecasting Flood-Causing Precipitations. *Atmosphere*, 11(6): 592-611.

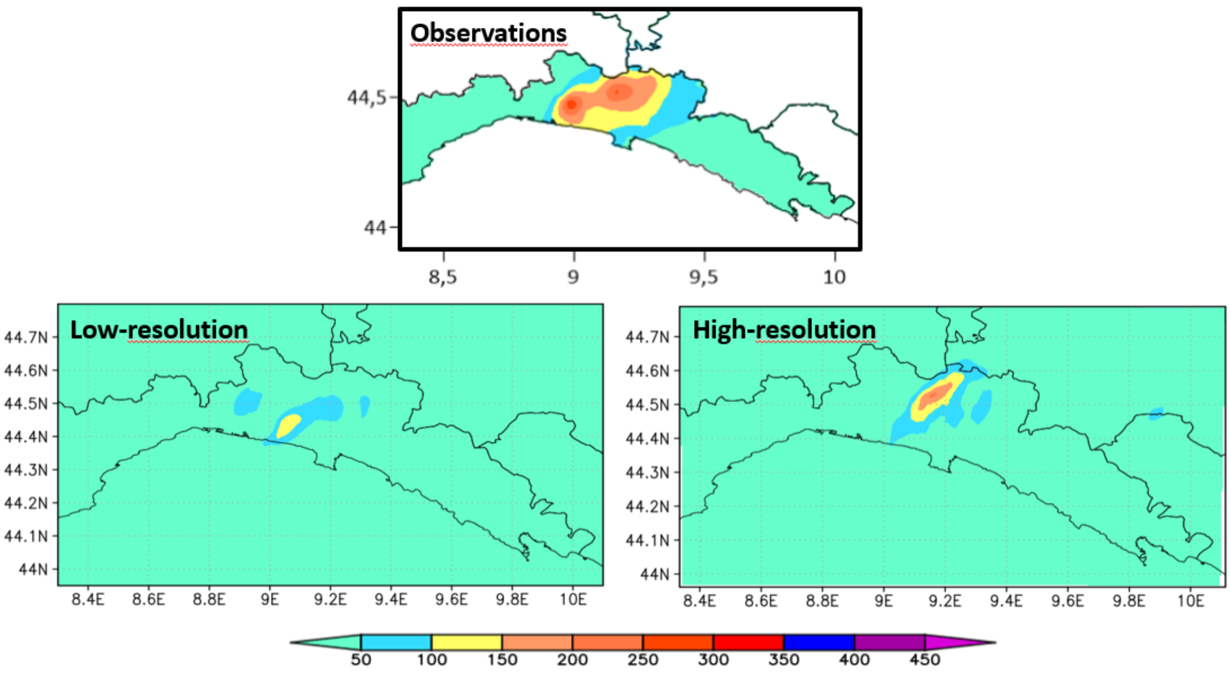

Figure 3. Cumulated precipitation for the extreme event occurred in Liguria on 9 October 2014. The upper panel shows the cumulated precipitation measured from the Ligurian rain gauge network. The two lower panels refer to the results from the meteorological model WRF, with the right panel reporting the results from high-resolution simulation to be compared with the lower resolution simulation on the left. Source [4]

We anticipate that the high-resolution downscaling approach is particularly relevant to the characterization of extreme weather events, such as tropical cyclones which are common in the proposed AOI. While these extreme weather events may not have a significant impact on energy production due to their sporadic nature, they are important for the appropriate design of wind mills/towers and for wind farm operation planning. These high-resolution requirements come at an extremely expensive computational cost. High Performance Computing through cloud services is really the only viable option to deliver the amount of computational power required.

We aim to reconstruct past atmospheric conditions in the last 40 years over the entire computational domain (outer+inner AOI), plus a set of additional simulations necessary to identify the best computational setting and validate the model with direct field observations provided by available in-situ measurements from SYNOP stations and /or buoys having at least one year of past measurements.

The proposed high-resolution AOI covers the Yellow Sea (including Korea and Bohai bays) and a portion of the Sea of Japan where numerous wind energy projects are currently in the planning, construction and operating phases (Figure 4). We will rely on the scalability and agility of the cloud allowing near unlimited compute power to be applied while allowing agility in terms of the size and number of nodes to be chosen based on the simulation being constructed. This is a critical success factor in the proposed reconstruction of the past atmospheric conditions over

[4] Ferrari, F., Cassola, F., Tuju, P.E. and Mazzino, A., 2021. RANS and LES face to face for forecasting extreme precipitation events in the Liguria region (northwestern Italy). *Atmospheric Research, 259: 105654.*

the proposed AOI. We will dynamically downscale ERA5 reanalysis (native resolution of about 31 km) to a 5 km resolution grid covering the outer-AOI, and a 2.5 km resolution in the inner-AOI. The end product will have a full 40 year hindcast with 5 km resolution in the outer AOI and 2.5 km resolution in the inner AOI. Vertically the results will include 40 layers with higher resolution near ground level.

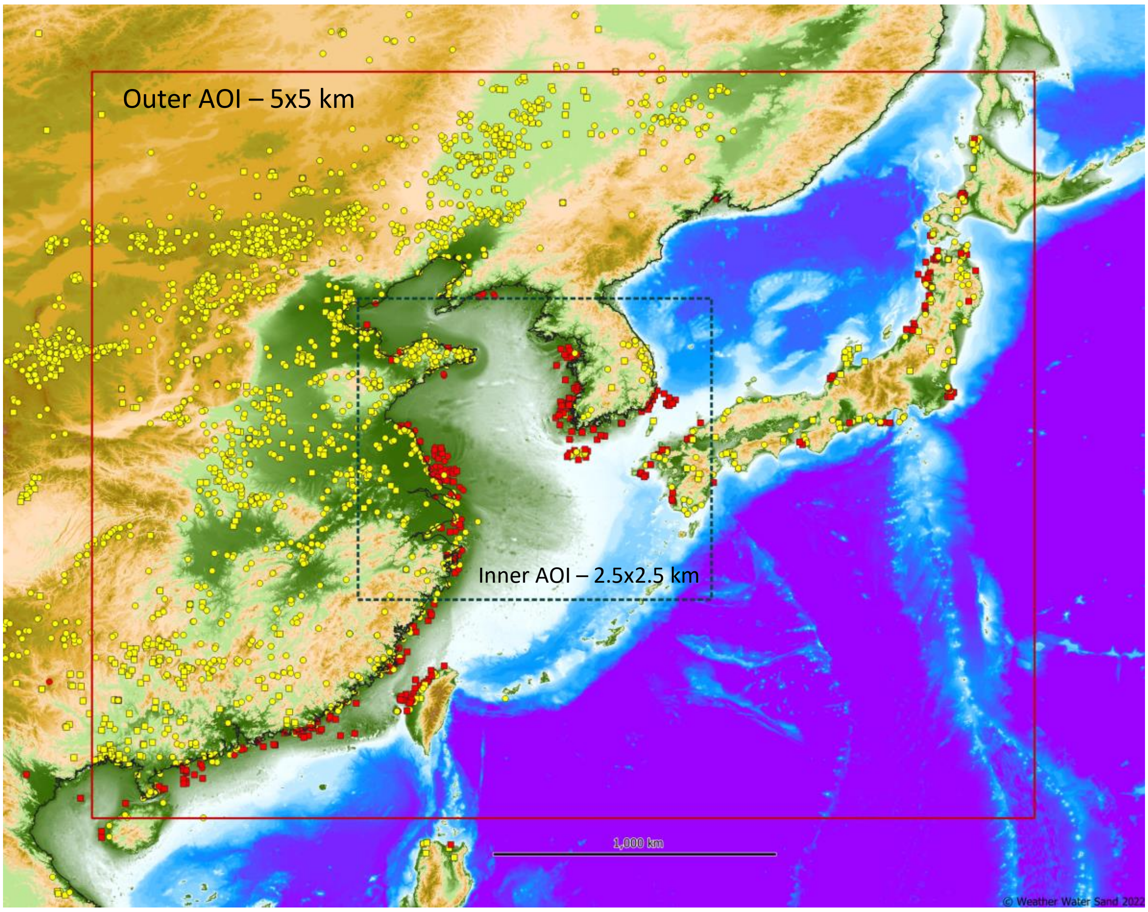

Figure 4. Proposed Area of Interest. A nested hindcast will be produced for a 40 year period (1982-2022) with a 5 km resolution in the outer AOI (red box) and 2.5 km resolution in the inner AOI (dashed black outline). The precise location of the AOIs can be adjusted at the project kick-off in accordance with sponsor's interests. The map illustrates the topography and bathymetry of the area (from GEBCO) and the locations of onshore (yellow) and offshore (red) wind energy projects. Circles represent projects currently in operation, and squares represent projects in planning or in construction (source: Global Wind Power Tracker, Global Energy Monitor, May 24, 2022).

Project Timeline

The project is planned for a duration of 6 months. An additional 6-months period is included comprising storage of the results in the cloud after the completion of the project. We anticipate the earliest start date by November 1, 2022, with project completion by end April, 2023. A set of Tasks and Milestones are planned as follows:

<u>High-Resolution Atmospheric Hindcast</u>

Task 0: Project startup and management

- ◊ Milestone 1: kick-off meeting

Task 1: ERA-5 atmospheric model download and preparation

Task 2: Compilation and setup of hindcast model (WRF)
Task 3: Validation of high-resolution hindcast WRF model (~3-year simulation period)

- ◊ Milestone 2: review meeting

Task 4: Simulation of 40-year high-resolution hindcast (1982-2022) of atmospheric climate
Task 5: Data QC and preparation

- ◊ Milestone 3: review meeting & data delivery

Task 6: Data storage (6 months)

Task	month 1	2	3	4	5	6	6-12
T0: Project Management	◆						
T1: ERA5 model retrieval and preparation							
T2: Hindcast Model compilation, setup							
T3: Model validation (3-yr simulation)			◆				
T4: 40-yr high-res hindcast simulation							
T5: Data QC, reporting, preparation, delivery						◆	
T6: Data Storage (50 Tb - 6 mo., EFS+S3 10 Tb, 6 mo., +NAS)							

Project Cost

Project management costs (T0) include project startup, monitoring and interaction with sponsors and will be the main responsibility of the project lead. Costs associated with tasks T1 and T2 represent technical labor by a junior and a senior member of our staff. Costs associated with T3 and T4 represent the cost of utilization of HPC cloud computing services and associated technical labor costs. Our estimate for a nested resolution hindcast as shown in Figure 4 is approximately 3 hours of computing per 1 day of hindcast (assuming a c.5x24large instance with AWS). This represents approximately 47'120 hours or 1'963 days of computing for the full hindcast (40 years) using one HPC instance. We plan to achieve the full hindcast computation in 3 months using 20 to 24 HPC instances in parallel. Task 5 represent technical labor costs for data QC, preparation, and delivery to sponsors. At the end of the computation, we estimate that 50 Tb of data will be generated. During computation we will use two 10 Tb cloud allocations (one S3 and one EFS) to store intermediate results, and as results accumulate, we will secure full cloud storage up to 50 Tb, where the data will remain available to sponsors for 6 months after hindcast completion.

Interested sponsors should contact WWS (email: info@weatherwatersand.com) for details and participation costs.

Risks and mitigation

The project team has previous experience running high-resolution hindcasts of this scale and we are confident that the results can be delivered within the timeline proposed. The project team has had previous experience with working with ERA-5 model results (Task 1) and with compiling the WRF model in various HPC platforms (Task 2). The computing time is approximately linear with the number of HPC instances, and the cost depends on the hours of computing, the type of HPC instance used and the priority. Thus, if necessary, we are able to accelerate the project, particularly regarding the WRF simulations, through the scalability of cloud computing resources. We propose to use c.5x24large instances with AWS in spot mode, i.e., with relatively low priority which reduces the cost significantly. Our time estimates contain a 10% buffer which would allow for times when our processes are killed by the service provider in case of external high computational demand. Project monitoring will determine whether we need to use additional HPC instances to meet the project timeline.

Deliverables

Hindcast dataset 1982-2022 (40 years) for the selected AOI with:

- Spatial resolution:
  - ✓ 5 km x 5 km over the outer-AOI
  - ✓ 2.5 km x 2.5 km over the inner-AOI
- Temporal resolution: 1 hour
- Vertical: 40 layers (full atmosphere with higher resolution near ground/sea level)

Output parameters for the hindcast will include an extensive set of atmospheric model parameters, including among others, wind speed and direction at various vertical levels, temperature, atmospheric pressure, precipitation, solar radiation, etc.

WWS will process the dataset and deliver timeseries at specific sites as requested by sponsors. The full hindcast dataset (inner and outer AOI) also will be made available to sponsors for download from cloud storage for a period of 6 months. After that period the data will be transferred to local storage at our facilities and available to sponsors upon request.

Sponsor benefits

We anticipate the project costs to be equally shared among multiple sponsors. We will start the project as soon as we have reached a sufficient funding level from one or more sponsors. If additional sponsors subscribe after the project has begun, they would be admitted and the cost per sponsor will be reduced accordingly. Once the results are delivered to sponsors (end of month 6) the dataset will remain exclusive to sponsors for a period of 6 months. At the end of this period, WWS will be free to commercialize the results of the project to other parties.

The sponsors will receive a report containing a description of the methodology, data QC, validation and initial results analysis. Detailed data analysis of the hindcast is excluded but can be executed as a separate project by WWS upon request by sponsors.

Potential future phases of study

Phase 2 – Hindcast of waves.
Phase 3 – High resolution calibrated atmospheric forecasting for selected sites.

Interested parties should contact us via email at info@weatherwatersand.com