OCEANUCA: OPERATIONAL OCEANOGRAPHIC AND ATMOSPHERIC SYSTEM TO IMPROVE COASTAL OBSERVATION AND FORECASTING IN ANDALUCIA. WRF MODEL IMPLEMENTATION.

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RESUMEN

El proyecto OceanUCA se enfoca en desarrollar una plataforma operativa destinada a optimizar las herramientas actuales creadas por la Universidad de Cádiz, integrando nuevos sistemas de observación y modelos numéricos de alta resolución, tanto atmosféricos como hidrodinámicos, configurados para alcanzar la máxima resolución a lo largo de la costa andaluza. Un elemento clave de esta plataforma es la implementación del modelo *Weather Research and Forecasting* (WRF) en modo operativo, lo que permitirá automatizar los procesos de preprocesamiento y ejecución rutinaria para generar pronósticos atmosféricos detallados.

Este proyecto busca mejorar los recursos computacionales existentes para satisfacer las necesidades sociales, impulsado por el aumento de la resolución espacio-temporal de los modelos. Esto permitirá respuestas efectivas a desafíos ambientales costeros específicos, como derrames de petróleo, olas de calor marinas y atmosféricas, y el seguimiento de eventos extremos. El sistema tiene como objetivo detectar los efectos del cambio climático, potenciar la protección ambiental, facilitar la conservación de los recursos naturales, desarrollar productos de alerta temprana y mejorar las previsiones a corto, medio y largo plazo. Además, la plataforma permitirá un uso óptimo de los servicios ecosistémicos costeros y apoyará la toma de decisiones por parte de instituciones y partes interesadas mediante el monitoreo de los procesos marinos y atmosféricos en la región.

Palabras clave: meteorología, modelos, observaciones, oceanografía, sistemas operacionales.

ABSTRACT
The OceanUCA project focuses on developing an operational platform to enhance the current tools created by the University of Cádiz, integrating new observational systems and high-resolution numerical models (both atmospheric and hydrodynamic) configured to achieve maximum resolution along the Andalusian coast. A key component of this platform is the implementation of the Weather Research and Forecasting (WRF) model in operational mode, which will automate preprocessing and routine execution processes to produce detailed atmospheric forecasts.
The project will improve existing computational resources to address societal needs, driven by the increasing spatiotemporal resolution of the models, allowing for effective responses to specific coastal environmental challenges such as oil spills, marine and atmospheric heat waves, and extreme event tracking. This system aims to detect climate change effects, enhance environmental protection, facilitate natural resource conservation, develop early-warning products, and improve short, medium, and long-term forecasts. The platform will enable optimal use of coastal ecosystem services and assist decision-making by institutions and stakeholders through the monitoring of marine and atmospheric processes in the area.

Key words: meteorology, models, observations, oceanography, operational system.

1. INTRODUCTION

The Andalusian coast presents a complex and vulnerable hydrodynamic and topographical environment characterized by the influence of the Gibraltar Strait, important estuaries, coastal marshes, and other particularities. In terms of population, Spain has a settlement pattern on coastal areas, with 56% of the population being in the coastal zone, of which 28% of the population reside in cities in the coastal zone (de Andrés et al., 2017). Specifically, in Andalucia, the coastal zone represents the area with the highest population growth rates and, consequently, this is where the highest population densities originate. However, these areas are also exposed to overexploitation, oil spills, pollution due to industrial activities, and extreme weather events that can have devastating effects, with associated impacts on social welfare and the economy.

In this context, tools devoted to provide near real-time advice allow the design of useful contingency and emergency plans, while the user-friendly format of these tools favors the day-to-day use by society in general.

Among the environmental processes of interest in the area of study are the transport of sediments, pollutants, and oil splits, enhanced by the elevated marine traffic in some areas; the extreme-temperatures events (heat waves); the formation of coastal winds (breezes) that can mitigate these extreme temperatures; the occurrence of intense wind events (especially close to the Strait of Gibraltar and when low-pressure systems approach to the area); etc. All these processes are impacted by the sea dynamics and the interaction between the surface (ocean and coastal land) and the atmosphere (Román-Cascón et al., 2021).

The growing international focus on the sustainability of marine environments (United Nations' Sustainable Development Goal 14) underscores the need for user-friendly systems capable of delivering comprehensive information to a wide range of users. For example, in the case of an oil spill, rapid and precise actions are required to minimize environmental and socioeconomic impacts. Accurate predictions of surface currents and pollutant dispersion are crucial for planning effective responses (Abascal et al., 2016; Azevedo et al., 2017; González et al., 2019). Such responses involve coordination between public and private sectors, as well as technical experts, all of whom require operational tools to interpret the available information effectively. Therefore, an operational system that integrates numerical models and high-resolution observational data from monitoring stations, developed by experts in the field, is essential for supporting these decisions.

This operational system will provide an intuitive and accessible environment that offers both atmospheric and hydrodynamic information and data to institutions, research groups, and the general public. The results will be managed through an open, interactive software tool based on a GIS environment accessible via the web. In addition to developing the operational tool, the project aims to identify and involve users to understand their needs and co-design the platform, thereby ensuring a functional final product that is tailored to their specific requirements.

A key component of this operational system (OceanUCA) is the implementation of the WRF model in operational mode. This includes automating the preprocessing and routine execution processes of the WRF model to produce detailed atmospheric forecasts for the Andalusian region, providing critical insight into atmospheric and oceanographic interactions. The outputs from these simulations will feed into coupled hydrodynamical models and be made available to governmental institutions, emergency services, researchers, and other users. Through this system, the project aims to enhance the region's capacity to respond effectively to atmospheric and environmental events.

2. PROJECT DEVELOPMENT PLANNING

The main objective of this project is the adaptation and consolidation of an operational oceanographic and atmospheric system on the Andalusian coast (with the capacity for being extrapolated to other domains). This will allow us to respond to emergencies such as oil spills, castaways, or atmospheric and oceanographic physical events monitoring in a user-friendly format, providing open data to institutions, research institutions, and society, in general.

The planned system consists of a combination of services based on numerical model output and observational data, including 9 oceanographical models at high resolution (UCA 2D, 2.5D, 3D PdE IBI/MERCATOR, Nivmar, WAM, IH WWIII, SWAM, Ualg SOMA) and the atmospheric Weather Research and Forecasting (WRF) model (Fig. 1), whose operational and research use continues growing nowadays. The latter model incorporates different physical options (parameterizations) that are in continuous improvement by the scientific community. All the data from these models will need to be adapted and homogenized to the current output protocols for the interaction with the online application that will be developed.

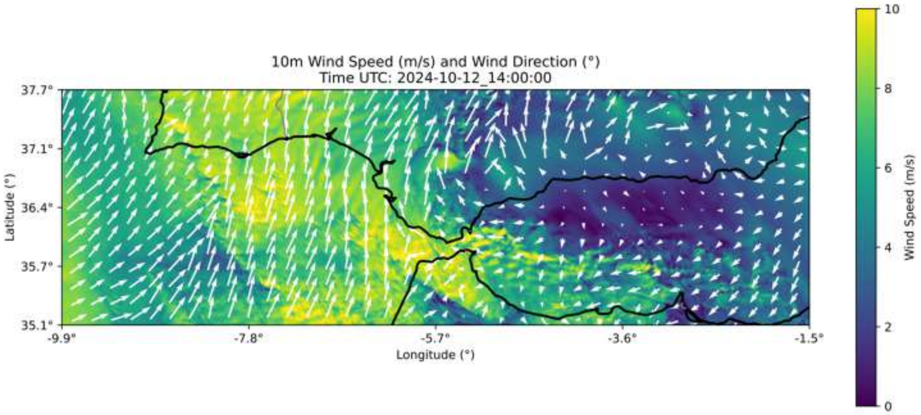

Fig. 1. Example of an atmospheric numerical output from the atmospheric Weather Research and Forecasting (WRF) model. In this case, the wind speed (colored contours, in m/s) and the wind direction (arrows, º from North) are represented for the 12 of October 2024 at 14 UTC in the region of the Andalusian coast. Model simulations like this one will be included in the new platform, with updated and improved visualization tools to analyse the past, present and future conditions on the Andalusian coast. Additionally, numerical output from the atmospheric models (variables such as wind speed or wind direction) could be used as input for the hydrodynamical models.

Besides the models, the system will incorporate observational data from different sources: oceanographic buoys, satellite imagery, video-monitoring of beaches and dunes, meteorological weather stations (e.g., Fig. 2), surface fluxes instruments, high-frequency (HF) coastal radars, and all the data from the oceanographic and atmospheric field campaigns developed by different research groups. All these data and information will be incorporated into an interactive updated and state-of-the-art GIS tool. The combined use of models and observations will also allow the continuous model evaluation, interesting from the operational point of view but also, to provide feedback to the modeling community in charge of the model development and improvement.
The last step will be the implementation of the commented data into the different layers OceanUCA web environment (Fig. 3), adapted to the new computational needs, with greater calculation and data storage capacity.

Fig. 2. Example of coastal observations that will be included in the new OceanUCA platform. In this case, the picture shows a remote automatic weather station installed in Chipiona, providing real-time data on wind speed, wind direction, temperature, humidity, pressure, and downward short-wave radiation data. Besides, this station has a 3D sonic anemometer at its top to calculate turbulence and surface heat flux data directly from high-frequency measurements (10 Hz) through the Eddy-covariance technique. These types of observations will be also included in the system.

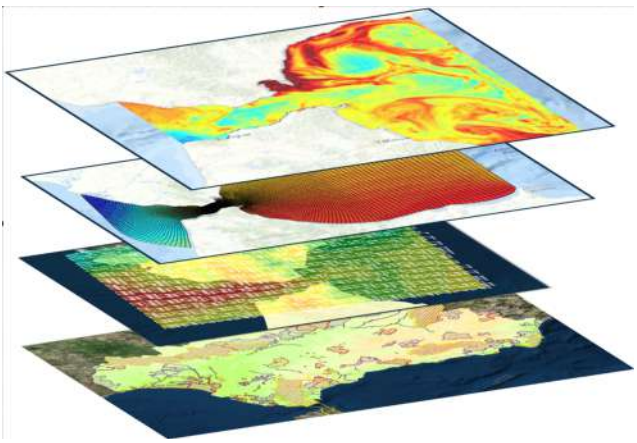

Fig. 3. Schematic representation of the idea of OceanUCA, incorporating different layers through Geographic Information System (GIS) tools that will be gathered in the website of the application that will be developed.

The last part of the project will be devoted to identifying final users, groups, and institutions (at the national and international level) through communication activities that include collaboration protocols and information sharing with third parties, as well as with other observatories. This will also include the direct transfer to society through outreach activities, including specialists and other interested users, due to the wide nature of the offered data.

3. WRF MODEL IMPLEMENTATION

One of the main objectives of the project is to implement the WRF model in operational mode, allowing to produce detailed forecasts for the area and to feed some of the hydrodynamical models.

To achieve this objective, both the preprocessing and routine execution processes of the WRF model will be automated. The model will be configured with a domain that covers the Andalusian region with a resolution of 3 km, including the adjacent seas. Additionally, a higher resolution domain (1 km) will be defined for the specific area covering the entire Andalusian coast (Fig. 1), allowing for a more detailed analysis of this critical zone. The most appropriate technical and physical configurations will be carefully studied and validated by the research team (Mulero et al., 2022; Román-Cascón et al., 2021).

This automated approach will generate numerical outputs that can be integrated into coupled models as well as directly into the operational system. These outputs will provide operational variables that will be made available to researchers, gubernamental institutions, emergency agencies, and external users. Additionally, the system will facilitate the storage of less common variables, which, due to their large size, will be housed on dedicated servers associated with the project and made accessible upon request.

The implementation of this system aims to improve the operational capacity to respond to atmospheric events.

4. SUMMARY AND CONCLUSIONS

The OceanUCA project aims to gather numerical model output and observational data in an updated, unified platform to provide current, past, and future information about the oceanographic and atmospheric state of the environment on the coast of Andalucia.

This system will allow for the observation and monitoring of oceanic and atmospheric coastal processes, as well as their forecasting and nowcasting. By providing an intuitive and accessible environment, OceanUCA will deliver both atmospheric and hydrodynamic information to institutions, research groups, and the general public. The results will be managed through an open, interactive tool based on a GIS environment, accessible via the web, allowing a wide range of users to engage with and utilize the data effectively.

Beyond the technical development, the project is committed to actively involving users to understand their needs, enabling a co-design process that ensures the final platform is functional and tailored to specific user requirements. The ultimate aim is to establish a system that supports the development of early warning systems, natural resource surveillance, environmental protection, long-term climate change detection, and provides critical information for the decision-making of institutions that rely on this data.

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REFERENCES
Abascal A. J., Castanedo S., Núñez P., Mellor A., Clements A., Pérez B., Cárdenas M., Chiri H., Medina R., (2016). A high-resolution operational forecast system for oil spill response in Belfast Lough. Mar. Pollut. Bull. 114, 302-314. doi: 10.1016/j.marpolbul.2016.09.042.
Azevedo A., Fortunato A. B., Epifânio B., Den Boer S., Oliveira E. R., Alves F. L., De Jesus G., Gomes J. L., Oliveira A., (2017). An oil risk management system based on high-resolution hazard and vulnerability calculations. Ocean Coast. Manage. 136, 1-18. doi: 10.1016/j.ocecoaman.2016.11.014.
de Andrés, M., Barragán, J. M., & Sanabria, J. G. (2017). Relationships between coastal urbanization and ecosystems in Spain. Cities, 68, 8-17.
González, C. J., Reyes, E., Álvarez, Ó., Izquierdo, A., Bruno, M., & Mañanes, R., (2019). Surface currents and transport processes in the Strait of Gibraltar: Implications for modeling and management of pollutant spills. Ocean & Coastal Management, 179, 104869.
Mulero-Martinez, R., Román-Cascón, C., Mañanes, R., Izquierdo, A., Bruno, M., & Gómez-Enri, J. (2022). The Use of Sentinel-3 Altimetry Data to Assess Wind Speed from the Weather Research and Forecasting (WRF) Model: Application over the Gulf of Cadiz. *Remote Sensing*, *14*(16), 4036.

Román-Cascón, C., Lothon, M., Lohou, F., Hartogensis, O., Vila-Guerau de Arellano, J., Pino, D., Yagüe, C. & Pardyjak, E. R. (2021). Surface representation impacts on turbulent heat fluxes in the Weather Research and Forecasting (WRF) model (v. 4.1. 3). *Geoscientific Model Development*, *14*(6), 3939-3967.