CHAMFER
*a UK National Capability programme*

UK COASTAL HAZARDS, MULTI-HAZARD CONTROLS ON FLOODING AND EROSION
CHAMFER

*River modelling: the river meets the ocean*

*Task 1.3*

# The land-ocean interface in land surface models

CHAMFER Task 1.3

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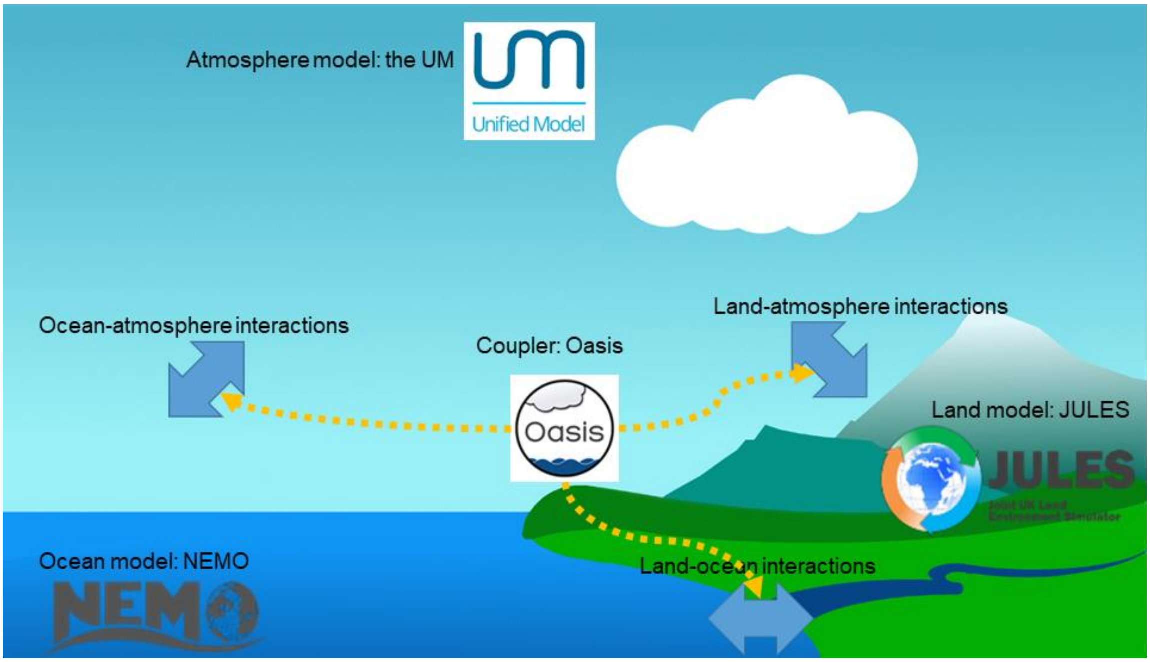


**Fig. 1:** The general approach followed by all global climate prediction models where the planetary biosphere is divided into what we can call three *top-level divisions*: atmosphere, land and ocean. At the UK Met Office, the coupling arrangements of the *UM* family of models reflect this: the family is composed of an atmosphere model (the UM), an ocean model (NEMO) and a land model (JULES), with exchange of information between these three main models synchronised by a coupler (OASIS). In the US, the Community Earth System Model (CESM) follows a similar approach with different component models (https://www2.cesm.ucar.edu/models/cesm1.0/).

Within each division there are also what we could call *second-level divisions* that are less globally standardised: dividing the ocean into shelf seas, deep ocean and sea ice (e.g. Lewis et al. (2018)) or dividing the land surface into surface soil, susurface soil and open water (e.g. Hallouin et al. (2022)). Exchange of information between second-level divisions may also be managed by a coupler.

## Introduction

Coastal hazards pose a very significant risk to people, property, and infrastructure in the UK (and worldwide). Over 1.8 million homes are at risk of coastal flooding and erosion in England alone and coastal flooding is recognized as one of the top two environmental hazards in terms of impact, with the potential for geographically widespread impact (UNEP-WCMC, 2011; NOC, 2022).

The UK Coastal Hazards: Multi-hazard controls on Flooding and Erosion project (CHAMFER) was formulated to improve our capacity to understand and address these environmental hazards in the UK (NOC, 2022). Event-scale coastal flooding and erosion mainly occur in response to synoptic scale meteorological events. These meteorological events can result in a series of individual hazard components to coastal environments, such as storm surges, extreme waves, extreme rainfall, and extreme river flows (hence these are 'multi-hazards' as defined by UNDRR https://www.undrr.org/terminology/hazard). From a modelling point of view, these coastal hazards are caused by multiple elements of the climate system (Fig. 1).

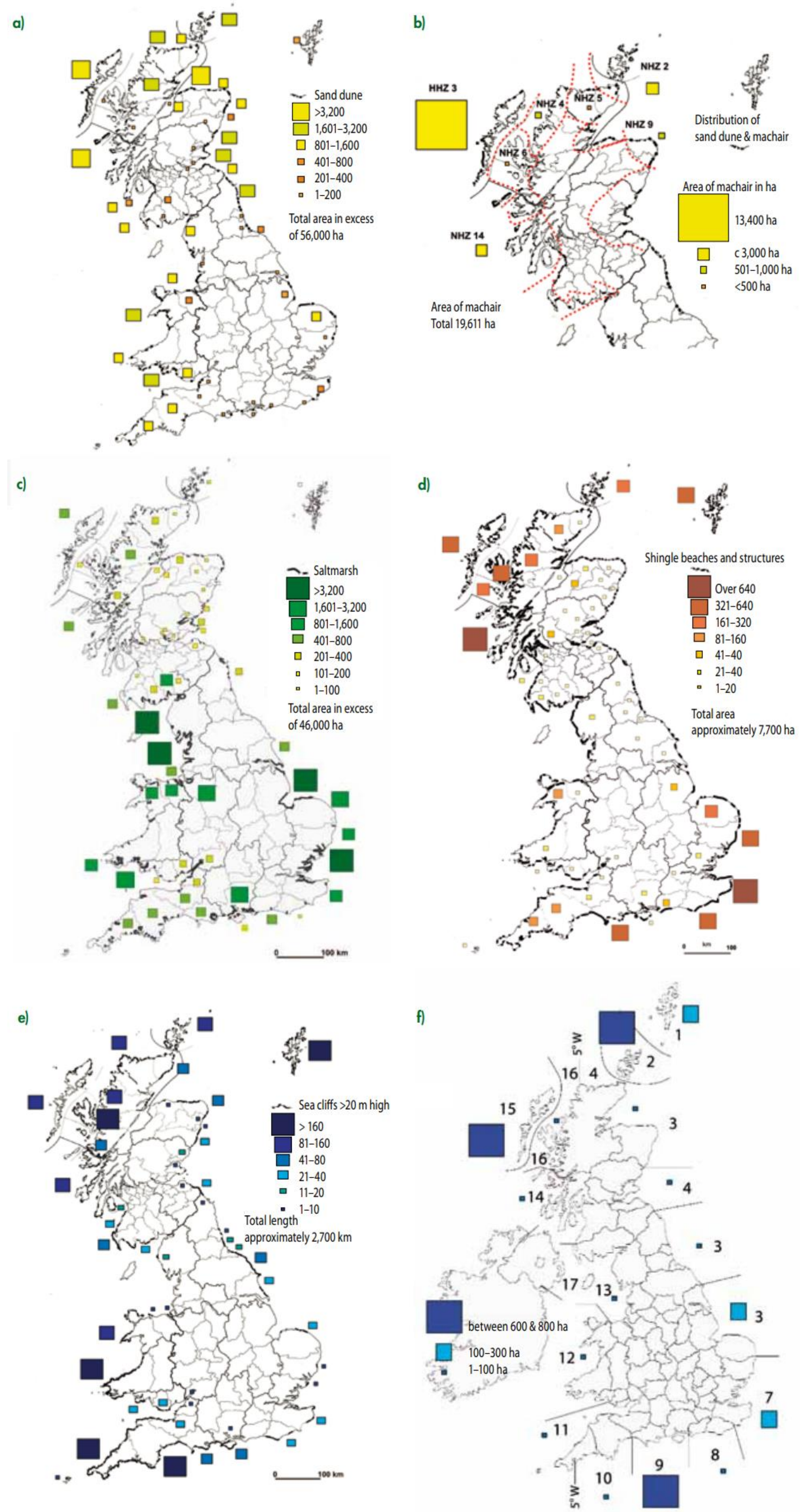


**Fig. 2:** Reproduction of Fig. 11.2 from UNEP-WCMC (2011): Distributions and approximate extent of six Coastal Margin habitats in Great Britain, by county: a) Sand Dunes, b) Machair in Scotland, c) Saltmarsh, d) Shingle, e) Sea Cliffs (>20 m high), f) Coastal Lagoons.

## The coastal zone

The meeting point of the land and the ocean (the land-ocean interface, Fig. 1) is a critically important area not only for humans (globally, 44% of all people live within 5 km of the sea), but also for ecosystems and wildlife, with many species being dependent on the unique intersection of marine and terrestrial environments. Understanding the forcing and effects of global change on coastal systems is critically important: it is here that human population pressures are globally highest and development pressures the most intense.

The six Coastal Margin habitats identified in the UK (Fig. 2) make up only 0.6% of the UK's land area, but are far more important to society: Rocky shores on exposed coasts provide important habitats for sessile species (e.g. mussels, barnacles, starfish) and wave-sheltered areas host saltmarshes and seagrasses and are very important for bird populations. Additionally, coastal wetlands in particular have been identified as very important for climate change mitigation and adaptation (UNEP & CIFOR, 2014).

The majority of coastal exchange occurs at estuaries, where water and nutrients flow from the land to the ocean (river outflow) and extreme events bring saline water from the ocean to the land (tidal and storm surges). Therefore, estuaries are a natural focus of CHAMFER and form the basis of our fieldwork plan (NOC, 2022). Estuaries are also the primary coastal exchange points in the context of land-ocean fluxes (Fig. 1) and are therefore also the starting point for the coupled modelling aspects of the project (see below).

UKCEH in particular has long had a focus on the Land-Sea Interface (e.g. see Garbutt et al. (2019)), most recently reemphasised in a new Land-Sea-People initiative (Emmett et al., 2022). The UKMO and NOC have an equally long interest on Coastal waters, including through the current Joint Marine Modelling Programme (*JMMP*). These initiatives reflect wider priorities at national level within the UK (e.g. the Flood and Coastal Erosion Risk Management Strategy Roadmap to 2026) and at other international institutions around the world (e.g. UNEP's Regional Seas Programme and the IGBP's Land-Ocean Interaction in the Coastal Zone (*LOICZ*) Core Project).

## Coupled models

In the context of this report, a *coupled model* is a process-based model where relevant data is regularly exchanged between the top-level divisions of the simulation, i.e. land, ocean and atmosphere (Fig. 1). Coupled models are becoming increasingly important in understanding the evolution of our planet and have the potential to provide solutions to many questions posed by climate change. These large, complex, multi-model systems are the result of decades of work through international collaborations, bringing together research from many fields by combining climate, ocean and land processes to build large scale representations of the Earth system (Jones, 2020; Fisher and Koven, 2020).

Before the 2000s, climate models and LSMs were always separate models, but since then there has been a broad global effort to integrate simulated systems more closely and produce fully-coupled models of the whole global environment (Marthews et al., 2022). This has led to programmes and projects such as the Coupled Model Intercomparison Project (e.g. CMIP6) designed to better understand past, present and future climate change. Large-scale research programmes have been very successful in improving our predictive ability in the context of climate change. However, they have also helped to identify areas where the individual ESMs and component submodels require improvement, not only individually, but in their integration through coupling frameworks (Fig. 1) (Fisher and Koven, 2020; Lewis et al., 2019; Lewis et al., 2018).

## Evidence gaps and need for greater capacity

The challenge of CHAMFER is to understand the impacts of short-term, high-impact extreme events within the coastal zone and on this kind of event we do not yet have adequate data, either in terms of impacts and occurrence, or in terms of causes and initiation mechanisms (NOC, 2022). In addition to a sampling plan designed to collect comprehensive data on the occurrence and impacts of the multi-hazards, we also need a much greater national capacity to be able to model and predict these events. In terms of standard coupled model paradigms, this requires a strong emphasis on understanding land-ocean interactions (Fig. 1).

Historically, ocean-atmosphere and land-atmosphere interactions have benefited from far greater research effort because of the global emphasis on greenhouse gas emissions (from land and ocean) and budget calculations to estimate their flux into the atmosphere. Relatively less work has focused on the ocean-land interface, despite this interface being of course critical for CHAMFER because of its role controlling river outflow to the ocean as well as episodic inundation on the land surface as a result of storm surges and coastal flooding.

The coastal zone is an extremely challenging ecotone to represent reliably in global model frameworks primarily because of its position between two of the major divisions of the biosphere (Fig. 1). However, the model development issues are actively being addressed by our collaborators at the UKMO and elsewhere (e.g. through the UK Environmental Prediction project (Lewis et al., 2019; Lewis et al., 2018) and its successor, the Regional Environmental Prediction project (Cooper et al., 2022)). We believe that the time is ripe to bring together these model development efforts and produce a new version of these component models that can simulate and ultimately predict reliably fluxes across the land-ocean interface and, thereafter, apply these new tools to the prediction of coastal multi-hazards.

## Approach of the CHAMFER project

CHAMFER will develop new and essential knowledge and understanding by bringing together teams from the NOC, UKCEH and BGS to characterise how multi-hazards at the coast control coastal flooding and erosion, to determine how these multi-hazards will respond to climate change and coastal management, and to provide advice to stakeholders on coastal management and adaptation options (NOC, 2022). This will be enabled by the development of a new system of analysis and prediction that combines the regional-scale hydrodynamics (sea and rivers) of the coastal zone and its drivers, with local controls from biogenic and abiogenic coastal habitats. Actively drawing on decades of model development in global coupled modelling across the UK (including many years of contributions from the UKMO, UKCEH and NOC), we will be able to develop a robust and reliable prediction tool that may be applied to make predictions about hazards in the coastal zones of the UK.

## Conclusion

A reliable representation of the coastal zone based on a global land surface model (LSM) has arguably never yet been achieved. In the UK we have a unique combination of world-class data availability in many coastal areas, and also state-of-the-art modelling capacity that will allow us to address this directly through the CHAMFER project.

By modifying and improving an existing modelling framework and validating its predictions across a selection of case study coastal areas across the UK, we intend to achieve a step-improvement in our national capacity in coastal zone prediction. Improved predictions for river outflow and seawater intrusion on UK coasts - especially at estuaries - will directly improve our ability to predict the dynamics of specific habitats (e.g. seagrass beds) and to offer much more robust recommendations and advice to stakeholders reliant on the health of UK coastal environments. In a wider context, this will contribute to a huge step forward in the UK's capability to respond to the challenges of committed climate change, and its critical impacts especially in the densely-populated coastal zone.

Nomenclature

- **BGS**: British Geological Survey https://www.bgs.ac.uk/ .
- **ESM**: Earth system models (ESMs) are models that simulate the coupled interactions between the atmosphere, ocean, ice and land surface. Several ESMs are under development around the world and are usually built up in a modular fashion from pre-existing models that simulate individual components.
- **CHAMFER**: A NOC-led project focusing on UK Coastal HAzards, Multi-hazard controls on Flooding and ERosion https://noc.ac.uk/projects/chamfer .
- **CMIP6**: The WCRP's Coupled Model Intercomparison Project Phase 6 https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6 is a worldwide modelling effort initiated in 2016 that is fostering improvements in climate models, LSMs and ESMs (IPCC, 2021; WCRP, 2022).
- **GEWEX and WCRP**: The Global Energy and Water Cycle Exchanges Project (GEWEX) is the core project in the World Climate Research Programme (WCRP) concerned with studying the dynamics and thermodynamics of the atmosphere and interactions with the Earth's surface.
- **JLMP**: The JULES land modelling programme http://jules.jchmr.org/sites/default/files/JLMP_Intro_0.pdf .
- **JULES**: The Joint UK Land Surface Environment Simulator https://jules.jchmr.org/ .
- **LSM**: Land surface models (LSMs) are the part of Climate Models or ESMs that simulate processes happening at the Earth's surface. LSMs include standalone models as well as the component models of Climate and ESMs that are concerned with the dynamics of the land surface.
- **NEMO**: Nucleus for European Modelling of the Ocean https://www.nemo-ocean.eu/ .
- **NOC**: UK National Oceanography Centre https://noc.ac.uk/ .
- **OASIS**: Ocean Atmosphere Sea Ice Soil (Coupler software) https://oasis.cerfacs.fr/en/ .
- **UKCEH**: UK Centre for Ecology & Hydrology https://www.ceh.ac.uk/.
- **UM**: The Unified Model is a numerical model of the atmosphere used at the UKMO for both weather and climate applications https://www.metoffice.gov.uk/research/approach/modelling-systems/unified-model . Outside the UKMO and internationally, it is used across the UM Partnership of collaborating institutions.

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