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Sea Level Rise in Europe: A knowledge hub at the ocean–climate nexus

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1 Scope of the Knowledge Hub on Sea Level Rise and Knowledge Hub Assessment Report

The Knowledge Hub on Sea Level Rise (KH-SLR) is a joint effort by JPI Climate (http://www.jpi-climate.eu, last access: 28 July 2024) and JPI Oceans (http://www.jpi-oceans.eu, last access: 28 July 2024), focusing on regional to local sea level changes in Europe, as well as the need for science-based information of European policy-making and coastal planning communities. The establishment of the KH-SLR was endorsed by two consultation meetings with the European science and policy community at large in the summer of 2021. The KH-SLR governing structure was established in October 2021.

Even the lower-end projections for sea level rise are expected to impact the livelihoods of residents in the ever-growing coastal populations worldwide. Beyond the obvious threat of permanent inundation of low-lying areas, sea level rise induces numerous other coastal impacts. Key societal and ecological effects include coastal erosion; saltwater intrusion into surface water, groundwater, and agricultural soils; changes in coastal habitats and ecosystems; and damage to cultural heritage sites. It is crucial to continue monitoring current sea level rise and its drivers, develop localized SLR impact projections, and provide an evidence base to support coastal defence strategies.

The KH-SLR identifies scientific knowledge status and gaps and strives to engage coastal planners, managers, and European policymakers in providing up-to-date, accessible information at local and basin scales. Constructing this interface and responding to information needs requires active involvement from professionals in coastal management and policy development. A significant part of KH-SLR activities involves organizing scoping workshops and conferences, which facilitate discussions among scientists, coastal managers, practitioners, and policymakers. These events explore the scientific evidence of sea level rise, its impacts, adaptation planning, and the essential policy frameworks required for informed decision-making.

Actionable knowledge and user engagement (Mach et al., 2020) are the dual pillars of the KH-SLR mission, supporting the development and implementation of policies for the protection and sustainable use of coastal resources at local, national, and European levels. Since the establishment of the KH-SLR, the initial focus of KH-SLR activities has been the production of an assessment report, known as the KH-AR, which is presented in this volume.

The long-term objective of the joint JPI Climate and JPI Oceans KH-SLR could be to ensure a periodic update of the KH-ARs and the creation of a networking platform to facilitate the exchange, synthesis, integration, and generation of knowledge on regional and global historical and future sea level rise characteristics. This might involve creating a customized platform to present the outcomes of the assessment reports in a format that is accessible to various stakeholders. The platform would convey recent scientific and socio-economic developments in an aggregated manner, tailored to current themes and debates in policy and public discussions.

1.1 Goal of the assessment report

The goal of the KH-AR is to document the state of knowledge of sea level rise topics at the local, national, and European basin scales using an interdisciplinary and integrated approach; elucidate gaps in available information; and outline the present European landscape of policies, governance, and adaptation planning.

The KH-AR is designed to support policymakers in obtaining comprehensive information for informed decisions on protective and adaptive measures against sea level rise impacts. Compared to the IPCC assessment reports (e.g. IPCC, 2023), the KH-AR offers more detailed and region-specific analyses. A collaborative, interdisciplinary approach is adopted to facilitate knowledge and expertise transfer among European member states, fostering solutions for this global challenge and addressing its regional and local nuances.

This first KH-AR is prototyping a potential future program of periodically updated regional SLR assessments. An analysis of its uptake and feedback from stakeholders conducted by JPI Climate and JPI Oceans will determine the feasibility of the format, frequency, and governance of future releases.

1.2 Target audience

The intended audience for this report can be categorized into distinct levels.

1. *National and sub-national level*. This includes research, policy advice, and service organizations. These intermediate stakeholders are responsible for preparing information for policymakers in areas such as coastal planning, climate change adaptation, and infrastructure management, operating across various spatial scales (coastal management units).

2. *European level*. This encompasses experts from various operational, research, and policy services, including the European Environment Agency (EEA), Copernicus Services, the European Center for Medium Weather Forecast (ECMWF), the European Climate Research Alliance (ECRA), the European Marine Observation and Data Network (EMODnet), and the Joint Research Center and the European Commission. These experts contribute to the collection and dissemination of pan-European information and play a crucial role in shaping European policy frameworks.

2 Report's place in the assessment landscape

The existing assessment reports on sea level rise drivers and impacts span a wide range of focus areas, time windows, spatial scales, scenarios, and institutional settings.

In 2019, a Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) was released by the IPCC as part of the sixth assessment cycle (IPCC, 2019). By assessing the new scientific literature, the SROCC responds to government and observer organizations that require specific and updated information at a higher level of topical detail than the regular IPCC assessment reports. SROCC addresses the multidisciplinary and concurrent impacts of sea level rise (specifically in Chap. 8) while primarily focusing at large spatial scales exceeding those of the European coastal areas. The release of the IPCC AR6, in particular the Working Group 1 report (IPCC, 2021), has generated a comprehensive body of literature assessing the Shared Socioeconomic Pathways (SSPs; O'Neill et al., 2014), the Coupled Model Intercomparison Program Phase 6 CMIP6 (Eyring et al., 2016) projections, and the corresponding SLR scenarios. The KH-AR uses CMIP6 and SSP scenarios as a general reference.

The COordinated Regional climate Downscaling EXperiment (CORDEX) under the coordination of the World Climate Research Program (WCRP) has established common protocols for climate downscaling studies from projections of global climate models. For Europe, two main downscaling regions were considered: the EURO-CORDEX (Jacob et al., 2014) and Med-CORDEX (Somot et al., 2018) regions. At the moment of constructing the KH-AR the available downscaled data make use of older global climate simulations than CMIP6 (such as the projections assessed in the IPCC Fifth Assessment Report), although a first white paper on CMIP6-driven downscaling has been recently published (Sobolowski et al., 2023). However, CMIP6-based regional downscaling datasets are not yet widely available and have not been used extensively in this KH-AR.

Several international assessment reports dedicated to European sea basins have recently been produced. For the Baltic Sea Meier et al. (2022) provided an update of the second release of the Baltic Climate Change Assessment, addressing atmospheric, oceanic, cryospheric, and ecologic topics affecting the Baltic Sea region. A special journal issue dedicated to assessing physical, ecological, and socio-economic climate trends and sea level rise (SLR) in the Mediterranean Sea has been published (Somot et al., 2018).

A range of data platforms and portals to display analyses of observational data and CMIP experiments has recently become available. Data and projections on SLR and its impacts are primarily derived from the following portals:

1. the IPCC/NASA sea level projection tool (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool, last access: 28 July 2024) – a repository of all sea level rise products published in AR6 (Fox-Kemper et al., 2021);

2. the IPCC Interactive Atlas (https://interactive-atlas.ipcc.ch/, last access: 28 July 2024) published in AR6 (Gutiérrez et al., 2021);

3. the Copernicus Marine Service operated by Mercator Ocean International (https://data.marine.copernicus.eu/, last access: 28 July 2024);

4. the Copernicus Climate Change Service (C3S) operated by ECMWF (https://climate.copernicus.eu/, last access: 28 July 2024).

In addition, knowledge and experience on marine and coastal spatial planning are retrieved from the European Maritime Spatial Planning Platform (https://maritime-spatial-planning.ec.europa.eu/, last access: 28 July 2024). The EEA operates several online platforms assessing a range of climate indicators including sea level rise and building on an analysis of global and local observations and projections (https://www.eea.europa.eu/ims/global-and-european-sea-level-rise, last access: 28 July 2024). The EEA Climate Adapt portal (https://climate-adapt.eea.europa.eu/, last access: 28 July 2024) collects data, use cases, and adaptation support tools to support decision makers and practitioners with knowledge, information, and experience.

At the global and European scale, the Copernicus Marine Service publishes annually the Ocean State Report that is a reference report of the European Union where both observations and model-based sea level reconstructions and extreme events are published (von Schuckmann et al., 2023). The Copernicus Climate Change Service publishes sea level trend climate indicators, updating the information every year. It publishes annually the interactive European State of the Climate (ESOTC) report.

3 Knowledge Hub on Sea Level Rise's operational processes

The knowledge hub process has applied approaches for user consultation to build bridges between research and key stakeholders. These include JPI Climate and JPI Oceans country representatives as well as the European coastal management and research communities at large.

The consultation activities resulted in setting up a governance structure for the KH-SLR management under the auspices of both joint programming initiatives, the implementation of an ad hoc consultation with five European basin-scale communities via workshops, and the organization of a science-policy conference enabling topical discussions between policymakers from different European regions. Those combined efforts finally led to the compilation of the present assessment report. In the following we will describe these collaborative activities and their outcomes.

3.1 The KH-SLR governing structure

To establish the KH-SLR governance structure in 2021, members of the JPI Climate and JPI Oceans governing boards appointed national contact points (NCPs) forming a KH-SLR governing council (GC). Nine countries contribute to this structure: Belgium, France, Germany, Ireland, Italy, Norway, Spain, Sweden, and The Netherlands.

The GC appointed a management committee (MC) which is directed by two co-chairs with the support of the secretariats of the two JPIs. The MC is composed of experts in various disciplines regarding SLR drivers and impacts. Several task groups (TGs) were established:

- TG-1 – co-design and user engagement, responsible for the survey, scoping workshops, and a dedicated KH-SLR conference (delivered in 2022; see Sect. 3.2);
- TG-2 – topical science experts on adaptation policies and governance;
- TG-3 – topical experts on physical science addressing SLR and its impacts;
- TG-4 – outreach and communication.

Membership of these TGs was formed by experts from all countries that actively support the KH-SLR, supplemented by experts from non-supporting countries for larger representativity and sharing of workload. The TG experts were primarily involved in the discussion and writing of the KH-AR as well as the preparation of the scoping workshops and the conference. Every TG is directed by two co-chairs, and the collection of co-chairs forms the MC that oversees the scientific development and process management supporting the KH-AR. The overall governance structure is visualized in Box 1.

3.2 The user consultation process

For the various ocean basins in Europe, scoping workshops were organized to make an inventory of the requested knowledge on SLR and its impacts, the governance arrangements, and adaptation strategies. During these workshops, interaction between scientists and policy practitioners took place, leading to comparative discussions on challenges and options for regional SLR management. All workshops followed a similar format, and each workshop was held online and spread over two consecutive days. The European ocean basins considered are the Arctic, the Baltic Sea, the North Sea, the eastern Atlantic, the Mediterranean, and the Black Sea.

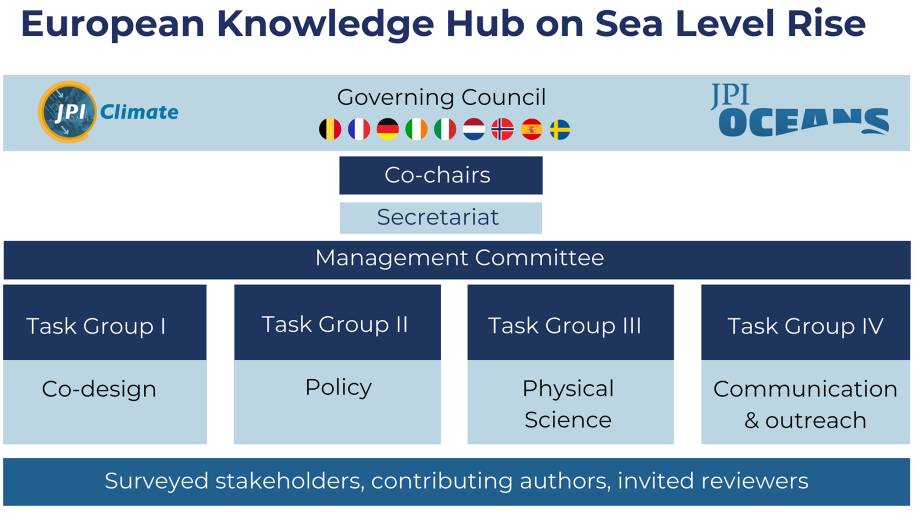
The final step of the user consultation was achieved by a European SLR conference held in Venice on 17–18 October 2022. Aims and outcomes of the conference are outlined in Box 2.

3.3 The review process

The AR papers were initially structured by the coordinating authors (being the co-chairs of the task groups) and co-authors (members of the task groups). A first review was carried out by members of the KH-SLR governing council and

management committee. Based on the feedback from this internal review, revisions were made to produce a second-order draft, which was submitted as a series of chapter papers to the scientific journal *State of the Planet*. An open discussion stage was initiated, during which all five papers were posted as preprints for public commenting by invited referees, authors, and the scientific community following the review procedures of the journal. This ensured comprehensive evaluation and transparency, and after a number of review iterations it resulted in five accepted manuscripts. The "Summary for Policymakers" (SPM) was drafted as a stand-alone document and was subjected to a similar review process.

Box 1: KH-SLR governance structure



Box 2: The Venice Sea Level Rise Conference

A KH-SLR pan-European conference took place on 17–18 October 2022 at the Scuola Grande San Giovanni Evangelista of Venice, Italy. The conference convened researchers, stakeholders, and policy professionals to evaluate existing and needed scientific knowledge regarding regional–local sea level change in Europe. Discussions also focused on policy development and implementation, incorporating the latest geographical and contextual details. The outcome of the conference was the scope and rough outline of the first assessment report. Through a diverse set of keynotes, panels, and other sessions, the conference has put the needs and involvement of policy-making and coastal planning at the centre of exchanges on regional to local sea level changes in Europe. The conference endorsed the following recommendations:

1. The KH-SLR Assessment Report (KH-AR) is a valuable repository of actionable science in climate change adaptation and mitigation.

2. The KH-AR provides regional specificity, assessing projections and drivers of SLR impacts, utilizing common benchmarks, datasets, and analysis tools.

3. Beyond rising waters, the KH-AR explores compound floods, flood-erosion patterns, and shoreline changes, proposing solutions such as nature-based approaches and addressing groundwater salinization.

4. The KH-AR goes beyond physics, encompassing marine spatial planning options, methodologies for finalizing and assessing risk, and considerations of risk perception and learning scenarios.

4 Structure of the assessment report

The KH-AR is composed of five scientific peer-reviewed papers published in the Journal *State of the Planet*, each addressing major conceptual milestones of the KH-SLR mission. It is concluded with a stand-alone "Summary for Policymakers" compiled from the paper's findings.

The first paper (Jiménez et al., 2024) reports the results of the external stakeholder consultation, consisting of basin workshops organized during 2022, the European Sea Level Rise Conference, and a web survey. During this consultation actionable knowledge needs were collected, which shaped the contents of the KH-AR.

The second and third papers offer an overview of research results from observational and modelling data sets for Europe, synthesizing SLR (Melet et al., 2024) and its impacts (van de Wal et al., 2024) in the European regional seas.

The fourth paper presents an inventory of adaptation principles and activities undertaken in Europe (Galluccio et al., 2024), while the fifth paper discusses governance aspects connected to adaptation plans (Bisaro et al., 2024). A summary for policymakers concludes the assessment report (van den Hurk et al., 2024).

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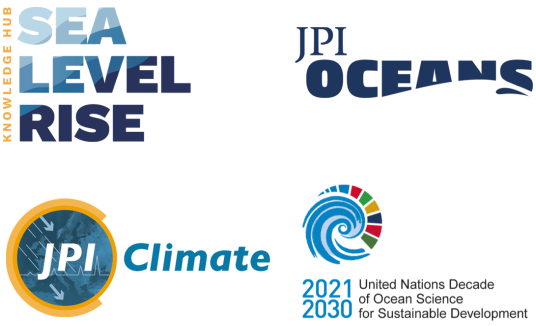

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