ECRA Collaborative Programme
Sea Level Change and Coastal Impacts (CP SLC)

White Paper: Sea level related adaptation needs in Europe

Date: December 5th 2016

European Climate Research Alliance

The European Climate Research Alliance (ECRA) is an association of leading European research institutions in the field of climate research that has been launched in 2011. ECRA is a bottom-up initiative focusing on the objective to bring together, expand and optimize European expertise in climate research.

In four Collaborative Programmes, ECRA helps to facilitate the development of climate change research, combining the capacities of national research institutions and sharing existing national research capacities and infrastructures. The Collaborative Programmes organise regular Workshops related to relevant topics in climate research. These Workshops are platforms for climate scientists to share knowledge and to extract the most important research needs for the future. These ideas will be formulated in a „White paper“ and a „Strategy and Workplan“.

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EXECUTIVE SUMMARY

Even though sea level rise impacts have already been identified in the literature as a critical variable for the establishment and maintenance of biotic coastal communities, as a threat to biodiversity and as being responsible for the increasing magnitude and spatial extent of storm surge flood hazard, little has been discussed regarding the dimensions of the changes to come. Therefore, more research is needed concerning methods to assess the effects of climate change, establish sea level confidence thresholds, and to create and implement adaptation strategies to face the most drastic sea level rise impacts, particularly those associated with low-probability but high-impact changes.

The key questions for the European Climate Research Alliance (ECRA) Collaborative Programme on sea level and climate change (ECRA CP SLC) are as follows:

- How can coastal sea level projections be improved, at global, regional and local scales?
- How can coastal impact assessment, adaptation, and risk management be enhanced?
- How do we best achieve a common understanding of the science and risks amongst stakeholders, policy makers and scientists?

The first question involves long-term mean sea level change and changes in extremes, treatment of uncertainties and likelihood, and modelling capabilities in general. The second question is about adaptation needs and opportunities, and involves challenges due to fundamental geographical and physical differences between Europe's different ocean and coastal domains, different building practices and infrastructure, and the various governance policy practices in different countries. Is it possible to take a uniform approach in handling impact and adaptation assessments in Europe? The third question is perhaps the most pertinent challenge related to a proper and secure funding for collaborative research on sea level, impact, and risks ahead, which is one of the key activities of the ECRA CP SLC.

This white paper has been facilitated by ECRA and developed by the ECRA CP SLC during the ECRA/BCCR Workshop "Sea Level Change and Coastal Impacts - toward adaptation strategies" on June 21st and 22nd in Bergen, Norway. The white paper will be the base for the upcoming CP SLC strategy to further establish a research plan.

1. Introduction

Sea-level rise (SLR) poses a particularly ominous threat to human habitations and infrastructure in the coastal zone because 10% of the world's population (about 0.7 billion people) live in low-lying coastal regions within 10 m elevation of present day mean sea level. Climate projections from the International Panel on Climate Change (IPCC) are increasingly used in decision-making, and the most recent projections from the 5th Assessment Report (AR5) predict a global rise of 52–98 cm, and some extreme scenarios reach up to 2 m, by the end of this century under continued high emission scenarios, which would threaten the viability of many coastal cities and settlements.

Sea level extremes can result in coastal flooding and have a high impact including the potential of massive social, economic, and environmental consequences. Sea level extremes occur in concert with a climatic driven sea level rise and will thus reach higher in the future. Furthermore, there are potential changes in storminess or changes in tides. Therefore, both observations and models are essential to assess sea level variability at different space and time scales.

Regional studies combining knowledge of future regional sea level change, sea level extremes, and possible impacts are now starting to become feasible and form a necessary step for our research efforts. The need for global and regional adaptation to climate change is evident, but much more research is still required to refine our understanding of these important issues (expressed by the EU Flood directive, 2007/60/EC). The need for further research has been expressed repetitively after the Marine Strategy Framework from the European commission: 'the major challenge of its own implementation is to attain the necessary scientific knowledge of the elements that defines the state of the marine environment and a substantial need to develop additional scientific understanding to underpin the decision and to secure a successful revision'[1]. Moreover, despite all the progress in research in high-level policy-making, a great deal of work remains to be done. Indeed, the availability of regional-scale comprehensive vulnerability assessment studies, which are required by local stakeholders for designing adaptation strategies at the local level, is still limited.

2. Goals

Assessments of coastal impacts and adaptation to sea level changes are the ultimate goals for our contribution to society, where extreme events, regional sea level rise and appropriate adaptation measures on a local scale are in focus. A careful analysis of the interaction of different components contributing to local sea level changes and more accurate probability distributions for risk assessments are needed. This includes the mapping of scientist's expertise, assets and human activities for risk management, as well as shared experiences in applying suitable and cost-effective adaptation strategies.

The main goals are to encourage: (a) advances in the multidisciplinary observing system tailored to global, regional, and local sea level change; (b) the improvement of the reliability of model scenarios/predictions, accounting for the effect of both, regional sea level change

[1] See more at http://ec.europa.eu/environment/marine/good-environmental-status/index_en.htm

and extreme events, on the evolution of coastal areas; (c) the downscaling of sea level rise, i.e. from the global level to regional and local levels in order to classify patterns of evolution; and (d) the evaluation of the impacts of regional sea level on coastal communities and the effectiveness and efficiency of adaptation interventions.

3. Topics

The following five research topics are currently the most important challenges named by ECRA CP SLC for improving sea level predictions and projections, impact and adaptation assessments, and communication with stakeholders, policy makers, and the public. Although the topics are grouped thematically below, the key for a successful implementation of collaborative research is to focus on interdisciplinary research, since meaningful results depend on their applicability across all disciplines and topics. Topic 5 addresses this overarching aspect of interaction between natural and social scientists and stakeholders.

Topic 1: Observations of mean sea level change and a better understanding of the contributing processes are important in order to improve the modelling of future regional sea level change.

- **Combined use of different types of Earth System data** is necessary in order to properly understand processes governing variability and long-term change, both on a global and on a regional scale. This include (but is not limited to) sources like altimetry, gravimetry, tide gauges, ocean temperature/salinity profiles, in situ ocean current measurements, and GNSS. Furthermore, the use and development of advanced statistical techniques to realise the combination of observations and provide reliable error estimates are needed.

- **Paleo sea-level records** help placing modern changes in context and can be used to constrain estimates of future sea level change. On a regional scale paleo records aid estimations of present and future vertical land motion. Paleo sea-level records can also help to place observed extreme events in a historical context.

- **Assimilation of high quality observational data** into operational models and development of decadal prediction systems is not only essential for prediction of decadal sea level changes (see Topic 2), but does also provide tools and results that can be used to study the underlying processes. Observations can also serve as validation of projections, if these would be to start within the observational period.

Topic 2: Modelling and projections of regional mean sea level need to be improved in order to provide useful local information for assessments of future impacts and adaptation. There are different aspects to this, and we address them in prioritized order below.

- **The largest and the most uncertain contributions** to relative regional sea level change need to be in research focus. For European coasts these are regional steric/dynamic changes, vertical land motion, and Antarctic ice-dynamics. The latter has very little regional difference over Europe, but is nevertheless the contribution that holds the largest potential amount of sea level rise, with poorly defined uncertainties in speed, magnitude and timing. The two former are the ones where progress in regional estimation and reduction of uncertainty can be expected faster, through concerted research efforts. For vertical land motion, better spatial coverage of observations, development of improved GIA models, and focus on other more local land motion processes are needed.

- **Ocean models should resolve the regional physics** governing continental shelf and coastal sea level change on a local scale. This may be achieved by either using higher resolution climate models or by nesting of finer resolved models. However, it is still uncertain which particular processes are most important, and whether they can be modelled correctly by exclusively improving the resolution of existing models, or to what extent new model systems have to be developed. In general, little is currently being done on regional scale with respect to ocean dynamics and expansion in the available projections.

- **Uncertainties and confidence in projections** need to be reduced and improved, respectively. In general there are three sources for uncertainties in climate projections: emissions scenario uncertainty, model uncertainty, and natural variability. For the sea level research community, it is purposeful to focus on the two latter. The model uncertainty may potentially be reduced if model performance is improved as mentioned above, but increased knowledge of any missing processes and the natural variability at play, will improve assignments of confidence to the projections. Higher confidence in projections will improve the usefulness of the ensemble spreads as basis for probability distributions, which is a prerequisite for risk assessments (see also about extreme sea levels below). This can be reached by further research on evaluating model performance, natural variability, and climate forcing.

- **Upper tail risks of regional sea level rise** are particularly important for adaptation of key infrastructure. The upper tails of the probability distributions represent low probability, high impact events. In order to acquire total sea level probability distributions that cover also these events, the combination of contributions to sea level and their probability distributions should be assessed. Several contributions could be assigned skewed distributions, according to their nature (e.g., ice-dynamics). The resulting probabilities of upper bounds can also be relevant for high impact assessments (which links to what is called *possibilistic* scenarios, see below).

- **Decadal prediction systems** will improve several aspects of our knowledge of the system and the way we model it. Directly, becoming able to predict slow changes in the mean sea level will facilitate better risk assessments of combined high water and extreme storm events (see Topic 3). But as important is the inevitable increase in our

fundamental understanding of all the above issues, such as regional physics, uncertainty, natural variability, processes involved, and model performance and confidence in the projections. Prediction systems may also aid the development of useful projections for planning horizons shorter than the centennial scale.

- **Particular regions of Europe** are the Baltic, Mediterranean, and Black seas, as well as the North Sea and the Arctic coastline. These seas are not properly resolved in the atmosphere-ocean general circulation models used for sea level projections. Some, in particular the enclosed seas, have special tidal regimes and sensitivity to weather and storms. Some of these also happen to have the most densely populated coastlines in Europe. These regions need special focussed research efforts, in most aspects treated in this document.

- **Reduction of emission scenario uncertainty** is a scientific topic from the socioeconomic side that feeds back to the natural science research on sea level projections. Currently the uncertainties of the modelled projections are larger than the emission scenario dependence, but there is a need for less ambiguous sea level projections, in order to take efficient adaptive measures.

Topic 3: Changes in extreme sea levels need to be assessed and projected on regional to local scales. This requires the promotion and development of consistent methodologies across Europe and between research groups and disciplines.

- **Storm surges and flood risks** need to be better known along our coasts, and ideally the same analysis methodologies should be used across Europe. There are efforts to provide consistent datasets for extreme value statistics and return levels, and these should be further supported. Methods for calculation of local values range from statistical analyses of tide gauge data and spatial interpolation methods to the use of storm surge modelling. Further research topics are the physics of sea level response to storms in our region, the likelihood for compound effects of maximum mean sea level, tides, and storm influence, as well as the combination of pluvial/fluvial flooding and storm surges.

- **Combining extreme sea level estimates with mean sea level projections** in order to estimate future extreme levels is an emerging subject of research. Assuming the mean sea level change is what will change the extreme levels in the future, allowances can be calculated for how much the extreme statistics (i.e., return levels) has to be increased in order to preserve probability of flooding (Hunter, 2012). The methodology depends on the methods used for extreme-value statistics, as well as a direct assignment of probability to the ensemble spreads of the projected mean sea level changes (see above). In particular, the influence of the shape of probability distributions for sea level projections on the allowances, is unknown. Hence, there is large potential and urgency for research aimed at providing consistent allowances for the European coasts. It may also be worthwhile to investigate alternative methods to combine extremes with projected changes in mean sea level.

- **Changes in storms, wave climate, tidal regimes, and their interaction with changing mean sea levels** are subjects not widely incorporated in sea level change research efforts today, but of importance for potential future impacts. The methods described above do not take into account future changes in the storm surges themselves; there is currently little knowledge on this topic and some studies have revealed contradictory results for the same regions. For Europe long-term changes in 100- and 1,000-year return water levels by the end of the century are expected to be small on average (< 6 cm) even under high emission scenarios, with larger changes in certain areas such as the UK west coast and the eastern Baltic (Vousdoukas et al., 2016). These changes are small compared to the expected contribution of mean sea level rise, but superimposed will be the significant (and likely more important) variations on decadal to multi-decadal time scales (also compared to decadal mean sea level variability). Wave action has both the ability to inflict damage to structures, as well as to inundate regions by wave run-up, which will also be affected by mean sea level rise when surf zones move closer to shore and existing protection measures. With changed sea level in shallow regions such as continental shelves the tidal patterns may change, leading to changes in coastal tidal ranges in some regions. The assessments of climatic changes in wave climate and tidal patterns are hitherto limited. The temporal clustering of events is also a topic that is poorly understood but has important practical and financial implications.

Topic 4: Potential impacts of, and adaptation strategies to extreme sea levels and mean sea level change need to be assessed regionally using consistent methodologies across Europe and between research groups and disciplines. A specific focus is placed on extreme events. Although mean sea level change can be harmful by itself it is the extreme events that have the largest potential for damage, today and also in the future.

- **Socio-economic impacts of sea-level rise, extremes and adaptation measures** on human settlements and human activities need to be assessed and mapped out for our coastal regions. As highlighted in IPCC AR5, only few coastal impact assessments consider socio-economic impacts and adaptation and those that do generally focus on hard protection options, ignoring the wider range of adaptation options such as soft protection options, accommodation options and retreat options (Wong et al., 2014). Integrated models need to be developed to capture the interaction between potential impacts and diverse human adaptation strategies, as well as increasing pressures of population and economic development in coastal areas. The search for solutions is challenging and needs to take into account timescales, spatial variability, eco-morphology, water quality, socioeconomic impacts, and adaptation measures, as well as to consider how to set goals and measure improvements. Hence, there is a need for integral analysis of the problems and development of metrics that can be used by the several disciplines involved.

- **Adaptation governance and risk management** is needed for society in the face of the potential impacts. Research on socioeconomic risk management and risk governance is thus one of the ultimate research topics in our strategy. Coastal

adaptation needs to respond to multiple sea-level related risks (erosion, extreme event flooding, loss of land, loss of habitat, salinity intrusion, etc.), cuts across a variety of economic sectors (transport, tourism, fishery, agriculture, urban, etc.) and involves collective action amongst public and private actors at various levels of decision making and in the context of multiple policy goals. Adaptation cannot be readily ruled by a single list of guidelines. Adaptation challenges individuals, communities and governments to make good decisions that are suitable to local contexts. Moreover, given the heterogeneity of its concerns, there are likely to be many barriers to adaptation that range across scales, sectors and places. Therefore, research is needed to understand how societies currently deal with such complex coastal risks and management goals, which physical, technological, financial and institutional barriers arise and how they can be overcome, as well as how to improve decision making in the face of the deep uncertainties in the evolution of mean and extreme sea-levels risks as described in Topic 2 and 3.

The IPCC (2001) notes that adaptation can be planned – the result of a deliberate policy decision – or autonomous – not a conscious response to climate change but rather to accompanying changes in natural or human systems. Therefore, the simple implementation of an adaptation measure is not an endpoint; rather, adaptation is an ongoing process requiring the constant prioritisation of risks and opportunities, the implementation of risk-reduction measures, and reviews of their effectiveness. Hence, the performance of any adaptation measure (within the scope of an integrated coastal zone management framework) should be carefully monitored during its implementation to improve its maintenance and other future interventions (UNEP, 2010). Also, the development of a common indicator system for adaptation could be probably feasible.

Topic 5: Improved communication and collaboration between natural, social and economic scientists, stakeholders, policy makers, and the public, is a prerequisite for advancement of both research and decision-making on adaptation. It now seems widely acknowledged that adaptation to climate change requires more than facts; it matters a great deal how those facts are translated and made sense of in society and among decision-makers. For climate science this has been a difficult challenge. Climate change is typically defined in physical terms, often at the global scale, and using large time-horizons, which means that it is decoupled from the way people typically experience their surroundings (Hulme, 2008). Addressing coastal adaptation requires a trans-disciplinary approach that builds up a common understanding of the climatic changes and potential impacts, as well as a mutual understanding of the respective interests and needs of policy makers, researchers and practitioners.

Coastal impacts of climate change may in fact be one of the areas where such work transcending the traditional barriers in knowledge production can be achieved. Arguably, rising sea levels and challenges of coastal management are more directly experienced, and can be easier visualized and communicated, than many other climate change effects. For example, maps of how shifting coastlines may put land under water can illustrate these

changes on a human scale, which can in turn bring home the message that adaptive measures need to be taken.

Nevertheless, there is scope for better work to link what we know about sea level rise, the risks and uncertainties of these assessments, and the measures that need to be taken by society. This involves several aspects:

- **Appropriate terms to communicate** sea level change and impacts across the science–society–policy interface should be revised. This ranges from the simple choice of parameters (e.g., ensemble mean vs. percentiles or scales at which results are presented) to more fundamental methodological concepts (e.g., using probability or considering any possible scenarios; upper limits instead of probabilities). Also, a more shared understanding is needed on general issues relating to adaptation (e.g., what are useful time horizons for planning and adaptation?). Natural scientists can work with social scientists and others to develop parameters and concepts that can be understood and their information acted upon in society.

- **Co-design of projects** from the start is necessary in order to achieve trans-disciplinary communication and co-production of knowledge that can be practically relevant for decision-making. There is at least a rhetorical emphasis on the importance of these types of projects now, even though it remains to be seen whether the multiple barriers to the funding of co-designed projects can be overcome. The critical success factor for these projects is likely that they are problem-oriented and that the problems are defined together by different knowledge communities.

- **Collaboration with other initiatives** focussing on communication between natural and socioeconomic research in climate (e.g., Future Earth) should be increased in order for the sea level and impact research community to succeed in making a common effort. There is also scope for better cooperation between neighbouring countries, regions and communities which are experiencing the same challenges, to learn from experience, optimize procedures, and share data and results.

- **Community engagement and education** is particularly important because there is still significant reluctance in many communities to accept adaptation. This is likely due to lack of knowledge and adaptive capacity, but also to unclear science communication around risk and uncertainties. In the context of the post-financial crisis austerity, many European communities are in precarious economic situations where it seems reasonable to focus on shorter-term challenges of employment and basic services. This has reduced economic, institutional and political capacity to deal with adaptation. In turn, this challenges scientists to engage with communities in adaptation, and to help construct adaptive practices as part of broader social change.

Appendix

I. Supporting Institutions in ECRA CP Sea Level Change and Coastal Impacts

ECRA members

Bjerknes Centre for Climate Research (BCCR)

The Bjerknes Centre for Climate Research (BCCR) is a collaboration on climate research, between the University of Bergen, Uni Research, the Institute of Marine Research, and NERSC (see below for relevant partner institution description). BCCR covers most topics related to climate science, and is a key provider of first-rate knowledge on climate change to policy makers, industry, and the general public. The overall aim of the Bjerknes Centre is to understand and quantify the climate system for the benefit of society.

Danish Meteorological Institute (DMI)

The Danish Meteorological Institute (DMI) provides meteorological, oceanographic and climate related services and research to the community of Denmark and Greenland, including surrounding waters and airspace. DMI holds the national responsibility for storm surge warning, and we have a long tradition of sea level observations and storm surge forecast development in close collaboration with stakeholders and international colleagues. DMI has significant experience as provider of operational oceanographic products for the Baltic Sea as a key partner for EU in the Copernicus Marine Environmental Service and is active in the research and application of coastal altimetry, especially for storm surge purposes. DMI also has extensive experience in climate research: we have developed and maintained state-of-the-art global and regional models for the climate system of atmosphere, ocean, sea ice and recently also Greenland ice sheet. We also act as knowledge centre for climate in Denmark and provide in-depth information and advice on climate and climate change to governmental institutions and the general public.

Delft University of Technology, TU Delft Climate Institute (TU Delft)

TU Delft's mission is to make a significant contribution towards a sustainable society for the twenty-first century by conducting ground breaking scientific and technological research, which is acknowledged as world-class, by training scientists and engineers with a genuine commitment to society and by helping to translate knowledge into technological innovations and activity with both economic and social value. The TU Delft Climate Institute brings together the available climate-related expertise: research activities include, but are not limited to, the creation of sensors, the development of geophysical models and the study of strategies to cope with climate change.

GEOMAR - Helmholtz Centre for Ocean Research Kiel

This centre is one of the world's leading institutes in the field of Oceanography and Marine sciences. The institute investigates the chemical, physical, biological and geological processes of the seafloor, oceans and ocean margins and their interactions with the atmosphere. It consists of four research divisions including: Ocean Circulation and Climate Dynamics, Marine Biogeochemistry, Marine Ecology and Dynamics of the Ocean's Floor. With this broad spectrum GEOMAR is unique in Germany. Additionally, the centre has successfully bridged the gap between basic and applied

science in a number of research areas. The GEOMAR is a foundation under public law jointly funded by the federal (90 %) and state (10 %) government. GEOMAR has a scientific staff of 950 and a yearly budget of around 72 Mio Euro.

Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research, Geesthacht, Germany (HZG)

HZG is one of 18 members of the Helmholtz Association of German Research Centres. HZG comprises 3 research institutes, among them the Institute for Coastal Research (IfK) focusing on environmental research in marine, coastal and polar systems. Since the year 2000, researchers at HZG have coordinated some 35, and have participated in more than 110 EU projects co-financed by the European Commission through FP5, FP6 and FP7 priority programs. HZG has a long tradition in analyzing past and future long-term changes in coastal and shelf sea climate and also in analyzing sea level variability, including extreme events (storm surges). For this purpose, HZG maintains a variety of state-of-the-art numerical models such as regional atmosphere, tide-surge, or wind wave models and participates in international modelling groups such as the Climate Limited Area Modelling Group (CLM) or the WISE (Waves in Shallow Water Environment) group. The core area of research is the North Sea and the Baltic Sea.

Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)

The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) consists of nine research centres and five laboratories across Italy, and its headquarters in Rome. Its research and innovation activities are focused on seven sectors, mainly Energy Efficiency, Renewable Energy Sources and Nuclear Energy, and furthermore Climate and Environment, Safety and Health, New Technologies, and Electrical System Research. It has total staff of over 2,700. ENEA's activities within the Climate and Environment sector focus on Environmental Characterization, Prevention and Recovery; Environmental Technologies; Energy and Environmental Modeling; Marine Environment and Sustainable Development; and Expeditions in Antarctica and Research in Polar Areas.

Nansen Environmental and Remote Sensing Center (NERSC)

The Nansen Center is an independent research foundation founded in 1986 and affiliated with the University of Bergen, Norway. NERSC conducts basic and applied environmental and climate research with interdisciplinary scientific expertise in satellite remote sensing, modelling , and data assimilation. Research foci are in Earth sciences, particularly covering topics such as physical and biological oceanography, meteorology, sea ice/cryosphere studies, hydrology and climate studies, including remote sensing in all these themes.

Swedish Meteorological and Hydrological Institute (SMHI)

SMHI is carrying out research at the frontier of regional climate modelling and is actively participating in global climate modelling efforts (as a leading partner in the EC-Earth consortium). Model development and process understanding as well as climate projections and decadal prediction are integral components of the modelling strategy. In that set-up, the Arctic is a key research area for SMHI.

Technical University of Denmark (DTU)

The Technical University of Denmark (DTU) conducts research and teaching in the areas of engineering and natural sciences, with a focus on sustainability. DTU is furthermore involved in

industrial collaboration and public sector consultancy. DTU's main campus is in Lyngby, with several other departments and research centres located across Denmark. It offers over 30 Bachelor and 50 MSc programmes and 19 PhD schools. A total of 10,311 students were enrolled in 2014, with a staff of 5,813. Its expenses were DKK 4.8 billion (ca. €644 million) in 2014. Of DTU's 60 institutes, centres and research groups several engage in climate change and sustainability issues across disciplines and institutes. The Department of Management Engineering runs a research group on Climate Change and Sustainable Development. It conducts technical and economic research into climate change impacts, mitigation and adaptation. E.g., DTU Space conducts research into climate change, sea level rise and extremes, and the institute has a particular regional focus on North European and Arctic conditions.

The Royal Netherlands Meteorological Institute, Weather and Climate modelling group (KNMI)

The KNMI carries out a wide variety of climate and weather related research, from fundamental to applied. Research topics include weather forecast improvements, satellite observations of the Earth and atmospheric composition, regional and global climate modelling and providing climate services. Part of the global climate modelling is focused at the Arctic region. Using the global Earth System Model EC-Earth, research includes Arctic climate feedbacks, seasonal to longer-term predictability and the effect of Arctic changes on the mid-latitudes (specifically Western Europe).

Uni Research Climate

The focus of Uni Research Climate is how the climate is changing, the consequences, and how we mitigate or adapt to climate change, with emphasis on climate analyzes and calculations on how the climate system is changing both locally and globally - and how basic physical and chemical systems interact. Uni Research Climate activities for example include development of climate projections for users in the public and private sector and assessments of the feasibility of subsurface CO2 storage as a suitable technology to mitigate climate change. The research is important for the society's ability to plan and for other research communities to analyze the consequences of observed and future climate changes.

University of Bergen (UiB)

The University of Bergen is a young, modern university with about 14,500 students, and 3,200 staff. In addition to research and education in the traditional university disciplines, the academic profile of the University of Bergen has two major foci: marine research and co-operation with developing countries. The University of Bergen performs a full range of Arctic projects from detailed turbulence field campaigns in the boundary layers, to studies of the North Atlantic regional climate variability.

Non - ECRA members

Centre for Marine and Environmental Research (CIMA)

The Centre for Marine and Environmental Research (CIMA) is, by nature, a multi-disciplinary unit that explores the connections between environments, processes and human populations using scientific methods coupled with state-of-the-art modelling techniques. Apart from research, CIMA places a strong emphasis on training and education, as well as providing consultation services, digital applications and scientific information to the scientific and public domains. CIMA activity is focused on three general aims: (1) scientific research; (2) training at Masters and PhD level; and (3) production of digital applications and provision of expert services. CIMA possesses 1300 m2 of

laboratory space at the University of the Algarve's Gambelas and Penha Campus, with facilities for toxicology, proteomics, geochemistry, sedimentology, minerology, microbiology, biotechnology, molecular ecology, oceanography, palynology and information technology.

Global Climate Forum (GCF)

The Global Climate Forum initiates and performs high-class research on climate change in close interaction with stakeholders. It provides a pluralistic communication platform in the emerging global field of governments, local authorities, businesses, and social movements. This field is made up of linkages that lie beyond traditional ones between academic institutions and the nation states hosting them. It requires a capability to learn from each other in situations where consensus is impossible, perhaps not even desirable. As a key requisite for addressing the climate challenge in this spirit, GCF contributes to a theory of global socio-ecological systems, including the world economy that will enhance the capability to manage climate risks. Within GCF, the department of Adaptation and Social Learning provides support to adaptation policy making and practice around the world through its research on coastal risk assessment, adaptation decision-making and governance.

Institute for Marine and Atmospheric Research Utrecht (IMAU)

The IMAU is part of Utrecht University and was founded in 1966. It is based in the Faculty of Science, department of Physics and Astronomy, with a significant contribution from the Faculty of Geosciences. There are about 15 staff members to run the undergraduate and graduate teaching programmes and to carry out research projects. The institute employs around 50 PhD's and Postdocs. IMAU consists of 3 chairs: Meteorology, Physical Oceanography and Atmospheric Physics and Chemistry. Research is built on 5 themes: Ice and Climate, Atmospheric Dynamics, Oceans and Climate, Coastal and Shelf Sea Dynamics and Atmospheric Physics and Chemistry. The mission of the Institute is to contribute to the basic science of the oceans, atmosphere and cryosphere. This knowledge is used in studies on climate change and the possible implications for mankind. Sea level research at IMAU is housed in the Ice and Climate group and therefore focuses on the cryospheric contributions to sea-level change (palaeo, present and future).

National Oceanography Centre (NOC)

The National Oceanography Centre (NOC) undertakes integrated ocean research and technology development from the coast to the deep ocean. It provides long-term marine science capability including: major facilities; sustained ocean observing, mapping and survey; data management, and scientific advice. The NOC is owned by the NERC comprising the UK's leading institution for sea level science, coastal and deep ocean research and technology development. The centre works in close partnership with institutions across the UK marine science community and with national capability delivery partners

Norwegian Mapping Authority (Geodetic Institute and Hydrographic Service)

The Geodetic Institute is responsible for national geodetic information on which all positioning, measuring, mapping and Earth observation is based. The institute operates a nationwide positioning service using satellite-based GNSS data as well as operating the geodetic observatory at Ny-Ålesund, Svalbard. The institute measures and maintains the national reference frame and plays a key role in work on global reference frames and monitoring our changing planet.

The Hydrographic Service is responsible for preparing and updating nautical charts, and covers all marine and coastal waters in Norway and around Svalbard, as well as polar waters. As well as cartographical work, the Hydrographic Service is also responsible for maintaining the Norwegian

Tide Gauge network and for providing information about tides, water level, storm surges and vertical datums. The Hydrographic Service is required to facilitate safe and effective navigation in Norwegian coastal and marine areas. It undertakes this task by gathering, administering, processing and publishing official maritime information to a range of user groups. Data from the Hydrographic Service is used in coastal zone planning and the sustainable management of the marine ecosystem in Norway.

University of Central Florida (UCF), Excellence Cluster on Sustainable Coastal Systems

The broad-based research and development cluster integrates science and social needs to address coastal issues and train students in conservation and resource management. It also transforms thinking beyond disciplinary limits and investigates new challenges for the coming century, such as understanding complex local, national and international problems related to anthropogenic and natural changes in coastal systems. The threats and challenges Florida faces are the same that coastal communities around the world face. The solutions, methodologies and technologies developed at UCF will have immediate application to other geographic locations, with the potential to be state-wide and national models for how coastal states should address future environmental and economic challenges and growth opportunities.

University of Siegen, Dept. of Hydraulic and Coastal Engineering, Research Institute for Water and Environment (fwu)

The Research Institute for Water and Environment (fwu) was founded in 1994 as collaboration between the Dept. of Water Resources Management and Climate Impact Research, Dept. of Sewage and Waster Technologies, and the Dept. of Hydraulic and Coastal Engineering. Since several years interdisciplinary solutions for coastal water engineering issues have been the core competence of the Dept. of Hydraulic and Coastal Engineering. This comprises the understanding current and future sea level changes, the application of univariate and multivariate statistics of extreme sea levels, wind waves, and river runoff, the assessment of compound events, the development of statistical and numerical models of extreme sea levels, and modelling coastal and inland flood risk.

University of Southampton

The University of Southampton is an internationally renowned Russell Group university and 81st in the QS World University rankings. The University coastal remit covers three faculties, including (i) Engineering and the Environment, (ii) Geography and Ocean and (iii) Ocean and Earth Science. Research topics including sediment processes, surveys, tides, long-term oceanic records and measurements, oceanic processes, remote sensing, sea-level rise, geomorphology, energy, maritime transport, flood risk, impacts of climate change, ports, engineering, governance and management. We specialise in deltas, small islands, rivers, cliffed environments. Our work focuses on pure science, and also the wider implications to society, cross cutting different topics (e.g. with social science, law) in the coastal field. Wider national and international networks within the University, including the Southampton Marine and Maritime Institute (SMMI; joint with Lloyds Register) and the Tyndall Centre for Climate Change Rese.

II. Expertise in ECRA CP „Sea Level Change and Coastal Impacts“

Institution	Country	Expertise (Topics, regional focus)	Facilities and relevant projects	Point of contact
ECRA Members				
Danish Meteorological Institute (DMI)	DENMARK	Topics: - Sea level observations (tide gauges, altimetry), - Regional and global ocean modelling, - Statistical analysis. Regional focus: - North Sea – Baltic Sea and Arctic Sea/Greenland.	Facilities: - 3D-regional ocean model for operational sea level forecasts and climate scale studies, - Own supercomputer Projects: - ABC4CDE (Copernicus Climate Change Service on Assuring Best practices for Climate model Data Evaluation), - Baltic Sea Checkpoint (EMODNET project including reconstruction of last century sea level), - Copernicus Baltic Monitoring and Forecasting Centre leaders and operational model providers, - eSACP (NordFORSK project on Statistical Analysis of Climate Projections), - eSurge (recently finished ESA project on earth observations for storm surge	Torben Schmith (ts@dmi.dk) Kristine S. Madsen (kma@dmi.dk)

			monitoring and modelling), - VARSKO (national storm surge inundation project).	
Delft University of Technology, TU Delft Climate Institute (TU Delft)	THE NETHERLANDS	Topics: - Sea level observations and budgets, - Vertical land motion observations, - Numerical modelling of solid earth deformation and sea level fingerprints.		Riccardo Riva (R.E.M.Riva@tudelft.nl)
GEOMAR - Helmholtz Centre for Ocean Research Kiel, Germany	GERMANY	Topics: - Ocean circulation and climate Dynamics, - Internal climate variability, - Uncertainty in climate projections, - Ocean and atmosphere modelling. Regional focus: - Tropical Regions.	Projects: - BMBF RACE (No. 03F0651B), - EU FP7 NACLIM (grant agreement no. 308299), - European Union's PREFACE (FP7/2007-2013, no. 603521), - SPACES/SACCUS (No. 03G0837A), - RACE II Project of BMBF (Grant Agreement No. 03F0729C).	Mohammad Hadi Bordbar (mbordbar@geomar.de)
Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research, Germany (HZG)	GERMANY	Topics: - Sea level observations, - Numerical modelling and statistical analysis of coastal sea level variability with a focus on extremes, - Local and regional research on the needs and questions of	Facilities: - In-house numerical modelling of mean and extreme sea level and wave dynamics for the past decades and potential future developments (regionally limited), - Baltic Earth working group on sea level dynamics,	Katja Woth (katja.woth@hzg.de) Insa Meinke (climate services) (Insa.Meinke@hzg.de)

		stakeholder/decision maker, implementation of regional climate change assessment reports (e.g., BACC, NOSCA), climate service for Northern Germany. Regional focus: - Coasts of North Sea, - Baltic and South East Asia.	- Northern German climate office. EU Projects: a) with focus on wave and storm surge climate: WASA, STOWASUS, HIPOCAS, PRUDENCE, THESEUS (finished) b) with focus on storm surge extremes and on adaptation and climate service strategies: RISES-AM, ECLISE, EUCLEIA	
Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	ITALY	Topics: - Mediterranean thermohaline circulation (MTHC), - Ocean General Circulation Models, - Internal Tides, - Waves, - Paleoclimatology (sea level variations), - Ocean, atmosphere, and climate modelling (both at regional and global scales). Regional focus: - Mediterranean, - Tyrrhenian Sea, Strait of Gibraltar, - Turkish Strait System (Boshorus-Marmara Sea-Dardanelles).	EU Projects: - CLIM-RUN (concluded), - CRESCENDO, - SPECS, - IMPACT2C, - COPERNICUS. Other: - Projects on its hydrological cycle (HyMeX), - Regional climate modelling (Med-CORDEX) and on providing climate services at local scales.	Gianmaria Sannino, *co-chair of CP Sea Level and coastal impacts* (gianmaria.sannino@enea.it) Giovanna Pisacane (giovanna.pisacane@enea.it) Fabrizio Antonioli (fabrizio.antonioli@enea.it)
Nansen	NORWAY	Topics:	Facilities	Jan Even Øie Nilsen, *Co-chair of CP*

Environmental and Remote Sensing Center (NERSC)/Bjerknes Centre for Climate Research (BCCR)		- Climate modelling, - Ocean and coastal remote sensing, - Regional sea level change - Thermohaline circulation in the Nordic Seas, - High-resolution forecasting regional systems, data assimilation. <u>Regional focus:</u> - Mainly on northern Europe and polar regions, with activity also in Gulf of Mexico, - South China Sea, - Indian Ocean, and Agulhas Region.	- Norwegian Earth System Model (NorESM), - Norwegian Climate Prediction Model (NorCPM) and TOPAZ; also includes MICOM and HYCOM systems. <u>EU Projects:</u> - ESA CCI Sea level <u>Other Projects:</u> - iNcREASE, - NoRthern European and Arctic Sea lEvel, - SEALEV (Sea Level Change and Ice Sheet Dynamics), - NORMAP (Norwegian Satellite Earth Observation Database for Marine and Polar Research).	*Sea Level and coastal impacts* (even@nersc.no) Francois Counillon (francois.counillon@nersc.no) Johnny A. Johannessen (johnny.johannessen@nersc.no) Léon Chafik (UiBergen, BCCR) (leonchafik@gmail.com)
Norwegian Mapping Authority, Geodetic Institute	NORWAY	<u>Topics:</u> - Post glacial rebound, - Sea level, - Geodetic data. <u>Regional focus:</u> - Norway.	<u>Facilities:</u> - Geodetic observatory Svalbard, - Permanent GNSS network.	Matthew J.R. Simpson (matthew.simpson@kartverket.no)
Norwegian Mapping Authority, Hydrographic	NORWAY	<u>Topics:</u> - Tides, - Extreme sea levels.	<u>Facilities:</u> - Norwegian tide gauge network.	Oda R. Ravndal (oda.ravndal@kartverket.no) Hilde S. Borck

Service		Regional focus: - Norway		(Hilde.Sande.Borck@kartverket.no)
Swedish Meteorological and Hydrological Institute (SMHI)	SWEDEN	Topics: - Climate modelling, - Ocean modelling, - Regional mean sea level changes, - Changes in extreme sea levels. Regional focus: - Baltic Sea, - North Sea.	Facilities: - Swedish tide gauge network, - Regional coupled atmosphere-ocean model (RCA4-NEMO), - Regional 3d ocean model (NEMO-NORDIC). Projects: - Hazard Support (funded by Swedish Contingencies Agency), - Flooding risks in present and future climate (funded by Länsförsäkringar, insurance company research fund), - Governmental Commission to produce national guidance for producing dimensional sea level at the Swedish coast.	Helén Andersson (Helen.Andersson@smhi.se) Anette Jönsson (anette.jonsson@smhi.se)
Technical University of Denmark (DTU)	DENMARK	Topics: - Climate change and sustainable development, - Extremes, - Coastal hazards, - Impacts and risks, - Climate (ocean/land/ atmosphere) monitoring e.g., from satellite altimetry, - Geodesy and isostasy. Regional focus:	Projects: - ICE-ARC (EU FP7), - LOTUS (Preparing Land and Ocean Take Up from Sentinel-3), - Cryosat 4 Plus (ESA).	Per Knudsen (pk@space.dtu.dk) Carlo Sass Sørensen (carlos@space.dtu.dk)

		- Northern Europe, - The Arctic.		
The Royal Netherlands Meteorological Institute, Weather and Climate modelling group (KNMI)	THE NETHERLANDS	Topics: - Global climate modelling with EC-EARTH, - Regional ocean modelling with ROMS, - Sea level projection using individual contributions. Regional focus: - European coast, and in particular the Dutch coast.		Dewi Le Bars (dewi.le.bars@knmi.nl)
University of Bergen (UiB)	NORWAY	Topics: - Human geography, - Governance, - Cities, - Social change, - Societal transformation. Regional Focus: - Northern Europe/Norway.	Projects: - European cities as actors in climate and energy transformations (Bergen Research Foundation), - GOVLAND: Legal governance in land use planning (Research Council of Norway).	Håvard Haarstad (Havard.Haarstad@uib.no)
Non - ECRA Members				
Centre for Marine and Environmental Research	PORTUGAL	Topics: - Coastal processes, - Coastal management, - Risk assessment,	Facilities: - 2D numerical model for hydro and morphology, - Simulating the impacts of sea-level	Rita Carrasco (azarcos@ualg.pt)

(CIMA)		- Numerical modelling.	rise in a coastal lagoon, at different timescales.	
Global Climate Forum (GCF)	Germany	Topics: - Governance of human-environment interactions, - Coastal risk and adaptation assessment, - Adaptation decision making, - Economics of coastal adaptation, - Financing of adaptation. Regional focus: None	Facilities: - DIVA Modeling framework (Dynamic and Interactive Vulnerability Assessment) for assessing coastal impacts and adaptation. EU Projects: - Coastal adaptation: RISES-AM, GREEN-WIN, - Green economy and financial risks: SIMPOL, SYMPHONY, CoeGSS Other Projects: - Sea-level rise and society (DFG)	Jochen Hinkel (hinkel@globalclimateforum.org)
Institute for Marine and Atmospheric Research Utrecht (IMAU)	THE NETHERLANDS	Topics: - Regional ice sheet modelling (RACMO), - Firn modelling , - Automatic Weather Stations deployment on glaciers, - Ice core analysis, - Cryospheric contributions to sea-level change (global and regional). Regional focus: - Greenland, - Norway,	EU Projects: - EPICA, - ice2sea Other projects: - Organization for Scientific Research (NWO), - Division Earth and Life Sciences (ALW) (e.g. the ALW Open Program and the Netherlands Polar Program.	Aimée Slangen (aimee.slangen@gmail.com) Roderik van de Wal (r.w.s.vandewal@uu.nl)

		- Spitsbergen.		
National Oceanography Centre (NOC)	UK	Topics: - Sea level science, - Sea level observations (South Atlantic tide gauge network), - Data analysis and tidal analysis for the UK tide gauges, - Regional and global ocean modelling, - Global sea level reconstructions - Global and regional sea level projections, - Extreme sea levels. Regional focus: - Global sea level and global coastal sea level, - European coast, UK.	Facilities: - Permanent Service for Mean Sea Level (PSMSL), - British Oceanographic Data Centre, - NEMO global and regional models. Projects: - EU project RISES-AM, - NERC project Sea level projections, with warming of 1.5 degree.	Svetlana Jevrejeva (sveta@noc.ac.uk)
University of Siegen, Dept. of Hydraulic and Coastal Engineering, Research Institute for Water and Environment (fwu)	GERMANY	Topics: - Global and regional sea level change, - Sea level variability, - Detection and attribution, - Storm surges, - Storminess, - Hydrodynamical models, - Extreme value statistics regionalization, - Multivariate statistics and compound events,	Facilities: - Regional hydrodynamic-numerical water level and wave models, - Numerical simulation of dam breaks, - Statistical-empirical models, - Univariate and multivariate extreme value statistics software.	Sönke Dangendorf (soenke.dangendorf@uni-siegen.de)

		- Storm surge forecasts, - Flood risk modelling.		
University of Central Florida (UCF)	US	<u>Topics:</u> - Changes in sea level, storm surges, ocean waves, precipitation, and river discharges, - (coastal-) engineering design concepts, - Extreme value analysis - Climate adaptation and resilience, - Integrated coastal vulnerability and risk assessment, - Stochastic and numerical modelling of tides, storm surges, waves, and river flows, - Multi hazards, - Coastal processes and hydrodynamics.	<u>Facilities:</u> - New excellence cluster initiative including one cluster (with numerous faculty members) on Sustainable Coastal Systems.	Thomas Wahl (thomaswahl@mail.usf.edu)

Contact:

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