The WCRP Lighthouse Activities

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The World Climate Research Programme (WCRP) has developed five new activities that aim to make critical near-term progress towards meeting WCRP's Vision, Mission, and four Scientific Objectives, as outlined in the WCRP Strategic Plan 2019–2028 (*https://www.wcrp-climate.org/about-wcrpx/overview/wcrp-strategic-plan-2019-2028*). The WCRP Lighthouse Activities (Fig. 1) are designed to be ambitious and transdisciplinary (integrating across WCRP and collaborating with partners) so that they can rapidly advance some of the new science and technologies, and institutional frameworks, that are needed to manage climate risk and meet society's urgent need for robust and actionable climate information more effectively.

To do this, the Lighthouse Activities will need to draw on WCRP's core scientific and technical capabilities, and strategic partnerships. Their scope encompasses building new knowledge of the Earth's climate system, its near-term predictability and longer-term trajectories, through to harnessing emerging technologies to better simulate the Earth system via a digital "twin", as well as exploring new approaches for managing climate risk that start with the decision context and user needs.

The science plans of the Lighthouse Activities were approved at the 42nd Session of the WCRP Joint Scientific Committee in July 2021. Here, we explain the objectives and plans of each of the Lighthouse Activities.

Explaining and Predicting Earth System Change

The formulation of robust policies for mitigation of, and adaptation to, climate change require a quantitative understanding of how and why specific changes are unfolding in the Earth system, and what might happen in the future. A quantitative explanation of observed changes–through robust process-based detection and attribution–is also fundamental to specifying confidence in climate assessments, predictions, and projections. However, this capability is very immature. The WCRP Lighthouse Activity on Explaining and Predicting Earth System Change will address this gap. Its overarching objective is to "design, and take major steps toward delivery of, an integrated capability for quantitative observation, explanation, early warning, and prediction of Earth System change on global and regional scales, with a focus on multi-annual to decadal timescales." Its goals are to:

- Assess and improve persistent errors in climate models and reanalyses of historical observations
- Build an integrated operational capability to attribute and predict multi-annual to decadal changes in the climate system and provide quantitative attribution statements to support World Meteorological Organization (WMO) forecasts and State of the Climate reports, a key component of which will be large ensemble single forcing simulations for the historical period
- Establish a methodology for assessing the adequacy of and recommending improvements to observational networks and modeling systems to capture early indicators and the full evolution of these changes in the climate system
- Provide quantitative assessments of current and future hazards, underpinned by robust process understanding
- Seek to maximize the value to users of the advances achieved, e.g., through the development of an international open-access multi-model archive of seasonal-to-decadal hindcasts and forecast data, and through case studies employing co-design of decision-relevant products

***Figure 1**. The five new Lighthouse Activities*

The Lighthouse Activity has three main themes:

1. Observing and modeling Earth system change
2. Integrated attribution, prediction, and projection (including early warning and the potential for abrupt change)
3. Assessment of current and future hazards

Initial activities of this Lighthouse Activity include a Workshop on Attribution of Multi-annual to Decadal Changes in the Climate System (*https://wcrp-epesc.sciencesconf.org/*) that takes place in September 2021 and the publication of several related papers. Longer-term deliverables include established methodologies for novel case study application, an international open-access multi-model archive of seasonal-to-decadal hindcasts and forecast data, improved capabilities for prediction of multi-annual to decadal changes in the climate system and their impacts on hazards, and quantitative assessments of the current risk of specific hazards and future risk under defined scenarios, supported by process-based understanding of the drivers of changing risk. These activities will build on the multi-annual forecasts that are now routinely issued on the WMO Lead Centre for Annual to Decadal Climate Prediction website and in the WMO Global Annual to Decadal Climate Update.

For more information, please see the draft Explaining and Predicting Earth System Change Science Plan (2021) (*https://www.wcrp-climate.org/epesc*).

My Climate Risk

The My Climate Risk Lighthouse Activity aims to develop and bring into the mainstream a "bottom-up" approach to regional climate risk, which starts with the requirements of decision-makers. The term "risk" in this context means the combination of hazard, vulnerability, and exposure that is particular to a given regional context. By developing a new framework for assessing and explaining regional climate risk using all the available sources of climate information (observations, reanalyses, model simulations, better understanding, etc.), climate information will be made meaningful at the local scale. Whilst any application of the framework will inevitably be specific and tailored to local concerns, the framework itself will be generic, hence flexible and applicable across a range of region types [large scale, urban, typical Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) region, etc.] and therefore provide much-needed support for the development of climate services. At the same time, the Lighthouse Activity will identify needs to be addressed by the WCRP Core Projects and other Lighthouse Activities (one example could be on the implications of model biases). My Climate Risk will primarily use a case-study approach, in the form of labs (communities of practice), where labs are understood to be dynamic, exploratory, transdisciplinary environments, and not physical infrastructure. Labs will be explored in partnership with a few regional hubs and will cover timescales that are meaningful to the decisions being considered.

The initial step will be to work with interested organizations from around the world on a series of workshops on local to regional climate risk to explore whether the topics raised and stakeholders involved would benefit from collaborating with the My Climate Risk Activity and would be good candidates for the overarching risk framework. The first of these workshops, Storying Climes of the Himalaya, Andes, and Arctic: Anthropogenic Water Bodies, Multispecies Vulnerability, and Sustainable Living (*https://www.icimod.org/event/storying-climes-of-the-himalaya-andes-and-arctic-anthropogenic-water-bodies-multispecies-vulnerability-and-sustainable-living/*), will take place online in October in collaboration with the Himalayan University Consortium. Further workshops and associated publications are being planned. My Climate Risk recently held a session (*https://sri2021.org/my-climate-risk/*) at the Sustainability Research and Innovation (SRI) Congress in June 2021 and has a special session planned at the American Geophysical Union (AGU) Fall Meeting in December 2021.

For more information, please see the draft My Climate Risk Science Plan (2021) (*https://www.wcrp-climate.org/my-climate-risk*).

Safe Landing Climates

The Safe Landing Climates Lighthouse Activity is an exploration of the routes to "safe landing" spaces for human and natural systems (Fig. 2). It will explore future pathways that avoid dangerous climate change while at the same time contributing to the United Nations Sustainable Development Goals (SDGs), including those of climate action, zero hunger, clean water and sanitation, good health and well-being, affordable and clean energy, and healthy ecosystems above and below water. The relevant time scale is multi-decadal to millennial.

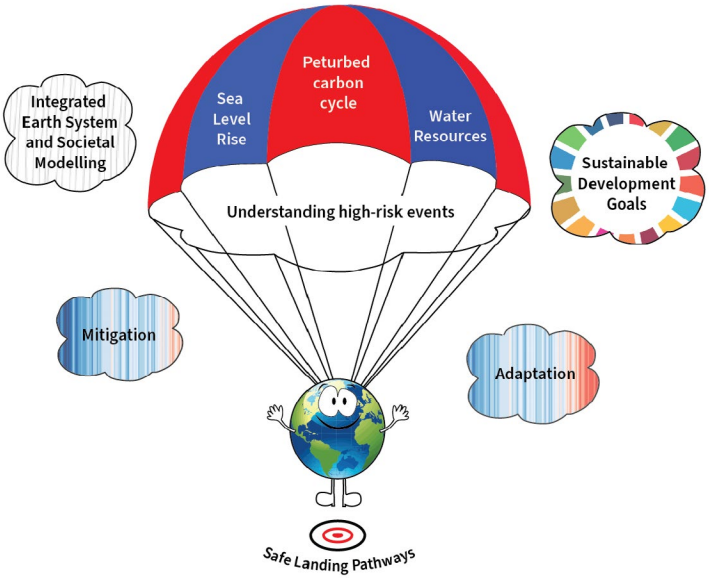

***Figure 2**. Schematic of the Safe Landing Climates Lighthouse Activity*

Safe Landing Climates has five scientific themes:

1. Safe landing pathways: what climate trajectories and destinations are safe and unsafe, and for whom? The objectives of this theme are to define safe landing climate pathways and landings, preserve habitability and food security, and identify adaptation limits. The theme aims to foster analytic, modeling, and model-data fusion tools that enable representing and estimating large-scale climate risks, including cross-system feedbacks (climate, biosphere, and society).
2. Understanding high risk events: what are the risks from low-probability, high-impact events? The objectives of this theme are to enhance our understanding of highly uncertain planetary risks (such as large carbon release, ice shelf and ice sheet collapse, high equilibrium climate sensitivity, regime shifts, multiplicative compound hazards, large-scale extreme events, fireball Earth, and biome collapse), facilitate the incorporation of uncertain risks into future projections, and identify adaptation limits and determine whether risks can be avoided (or caused) by climate mitigation or geoengineering efforts.
3. Perturbed carbon cycle: how will the carbon cycle change in the future? The objectives of this theme are to determine the climate implications of carbon dioxide removal (including bioenergy with carbon capture and storage)

while maintaining food and water supply, preserving biodiversity, and limiting ocean acidification. The theme will also assess the possible contribution to mitigation by methane, nitrous oxide, etc.; evaluate the risk of surprises or rapid changes in greenhouse gases due to land sources; determine the implications for allowable greenhouse gas emissions under the Paris Agreement; and build an understanding of the coupled carbon-energy-water cycle.

4. Water resources: how will major reservoirs of water change in the future? The objective of this theme is to identify the long-term redistribution of water in land-based natural systems or reservoirs, including glaciers and tropical rainforests, due to climate change and direct human activity (e.g., deforestation, agriculture). This theme will identify thresholds of tolerance and risk of collapse, and integrate physical climate, social and economic sciences, and local and indigenous knowledge. It will also assess the implications of mitigation and adaptation scenarios, including solar radiation management and geoengineering or climate intervention.
5. Sea level: how will the habitability of our coasts change in the future? The objectives of this theme are to quantify "acceptable" sea level rise and its irreversibility, estimate the impact of storm surges and hurricanes on low elevation land, communities, and ecosystems, and assess the potential for adaptation. The theme will facilitate the interaction of modeling efforts across spatial scales from global to coastal, and will foster the interaction and co-production between sea-level experts and coastal planners worldwide.

The Safe Landing Climates Lighthouse Activity is planning a discussion series (*https://www.wcrp-climate.org/slc-events-opportunities/slc-tipping-points-discussion*) and workshops in 2021 and 2022, including a science session at the AGU Fall Meeting in December 2021.

For more information, please see the draft Safe Landing Climate Science Plan (2021) (*https://www.wcrp-climate.org/safe-landing-climates*).

Digital Earths

The Digital Earths Lighthouse Activity will carry out research activities that support the establishment of integrated interactive digital information systems that provide information on the past, present, and future of our planet. In this case, "integrated" means that the system combines all elements required to describe the coupled Earth system as well as models of human systems so that the impacts of a changing Earth on such systems can be estimated. Digital Earths systems may exist at both global and regional scales and there may be interim systems that act as stepping stones towards full Digital Earths systems.

The initial objectives of Digital Earths are to:

- Establish a global research network with expertise in ultra-high-resolution (kilometer-scale or finer) of the global Earth system and its individual components

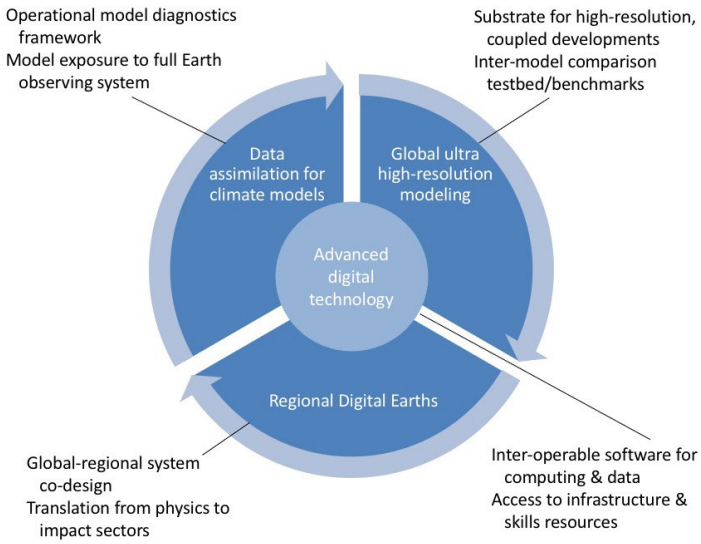

***Figure 3**. The four themes of the Digital Earths Lighthouse Activity*

- Establish an active research community in data assimilation for climate that builds on the existing numerical weather prediction (NWP) and reanalysis efforts and significantly expands them to fulfill the needs of Digital Earths applications
- Support the establishment of both global and regional Digital Earths demonstration projects across the globe and provide a collaborative network for their development
- Enable the above by optimally exploiting extreme-scale computing and data handling resources through interoperable software infrastructures

Digital Earths is founded on an ideal blend of models and observations. The activity will push the co-development of ultra-high-resolution Earth system modeling and the exploitation of billions of observations with digital technologies from the convergence of novel high-performance computing (HPC), big data, and Artificial Intelligence (AI) methodologies. The Lighthouse Activity will provide open access to data, methodologies, and software. The work of Digital Earths will be developed through national and international consortia, such as the Destination Earth consortium in Europe. The role of the Digital Earths activities within WCRP is to support such initiatives by providing fundamental science and technology developments.

The four major areas of activity (Fig. 3) in which WCRP must play a leading role are:

1. Global coupled ultra-high-resolution modeling
2. Data assimilation for climate
3. Regional digital Earths systems
4. Advanced digital technology

Although the fourth area of activity on advanced digital technology is not an area of core expertise in WCRP, the successful im-

plementation of Digital Earths science depends on strong connections to existing expertise in this space. The aim is that in ten years from now, Digital Earths systems developed with the support of WCRP science will be delivering open-access actionable climate information for the globe in a fully-shared framework.

The Digital Earths Lighthouse Activity plans several workshops and at least one white paper in 2021 and 2022. It also intends to establish a kilometer-scale modeling coordination group and a WCRP-wide Task Force to identify opportunities for the application of Digital Earths outputs and to propose demonstration projects of their potential utility.

For more information, please see the draft Digital Earths Science Plan (2021) (*https://www.wcrp-climate.org/digital-earths*).

WCRP Academy

The WCRP Academy's mission is to equip current and future climate scientists with the knowledge, skills, and attributes required to tackle the world's most pressing and challenging climate research questions. The Academy's activities will promote and advance lifelong learning opportunities and global equity in climate science training. It will measure its success by the scope and diversity of the global climate research community that engages with the Academy as well as its ability to improve global access to high-quality climate science training and professional development without prohibitive costs to the trainee.

The WCRP Academy's objective is to determine the requirements for climate research education and build enabling mechanisms. One mechanism is an online marketplace for climate science training, which connects training providers and climate scientists who are seeking training (Figure 4). This will be both inward facing, which aims to consolidate and support WCRP training activities, and outward facing, which will bring together an even broader range of training opportunities. The Academy will also identify training gaps and advocate for those needs to be met.

To build the Academy marketplace, the science team will work with WCRP core activities, including the other Lighthouse Activities, and established climate education providers, including universities. There will be an annual training stocktake survey to ensure that the Academy continues to meet the needs of the climate science community by asking what education and training in climate science is available now, what and where the gaps are, and what support the Academy can provide for online climate science and related training opportunities. The first WCRP Academy Training Stocktake Survey (*https://www.wcrp-climate.org/academy-survey*) will be open until 26 November 2021.

The Academy has a special session planned as part of the AGU Fall Meeting 2021 and is planning a workshop as part of the International Conference on Southern Hemisphere Meteorology and Oceanography (ICSHMO) Conference in February 2022.

For more information, please see the draft WCRP Academy Science Plan (2021) (*https://www.wcrp-climate.org/academy*).

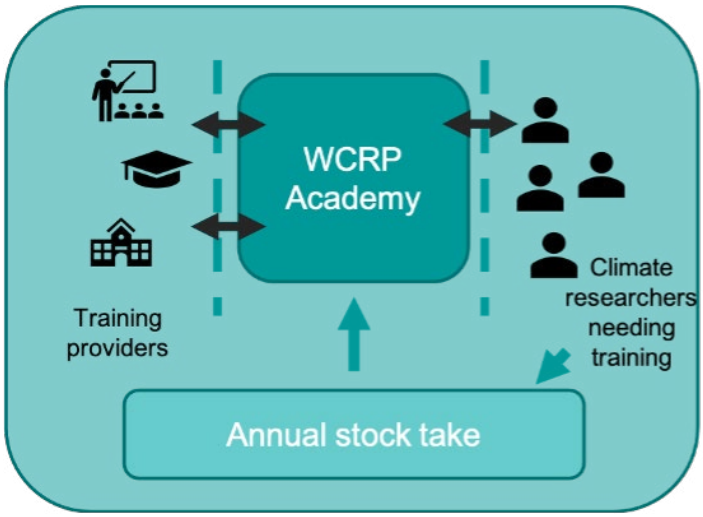

***Figure 4**. Schematic of the WCRP Academy Marketplace*

Next Steps

The Lighthouse Activities will now start to implement their science plans, which are still evolving. Initial activities are being planned, but at the same time, the science teams will continue to connect with partners to ensure that ongoing planning is part of a larger international effort. The implementation of the Lighthouse Activities will start with the science teams convening discussions and workshops to identify specific actions that will work towards their objectives and to build communities.

There will be many opportunities to become involved in the Lighthouse Activities and to participate in events being planned. As well as the opportunities already mentioned in this article, the science teams of the Lighthouse Activities will evolve in the next year, with an emphasis on creating groups that have the expertise needed, that are geographically and gender diverse, and that include all career stages. While each Lighthouse will have two co-chairs and a core team responsible for the scientific direction of the Activity, each will necessarily have a slightly different structure, tailored to respond to the specific mission and objectives. How the Lighthouse Activities organize themselves will be somewhat flexible and may change as these ambitious projects find the best path forward. The success of these Activities will mean that in a decade from now, we will have made some giant strides in our understanding of climate science and of the risks and opportunities of a changing climate. At the same time, we will work from the research side to ensure that all decision makers, from the heads of governments to the village farmer, have the climate information they need, when they need it, in a form that they can easily access, use, and understand.

Acknowledgement

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