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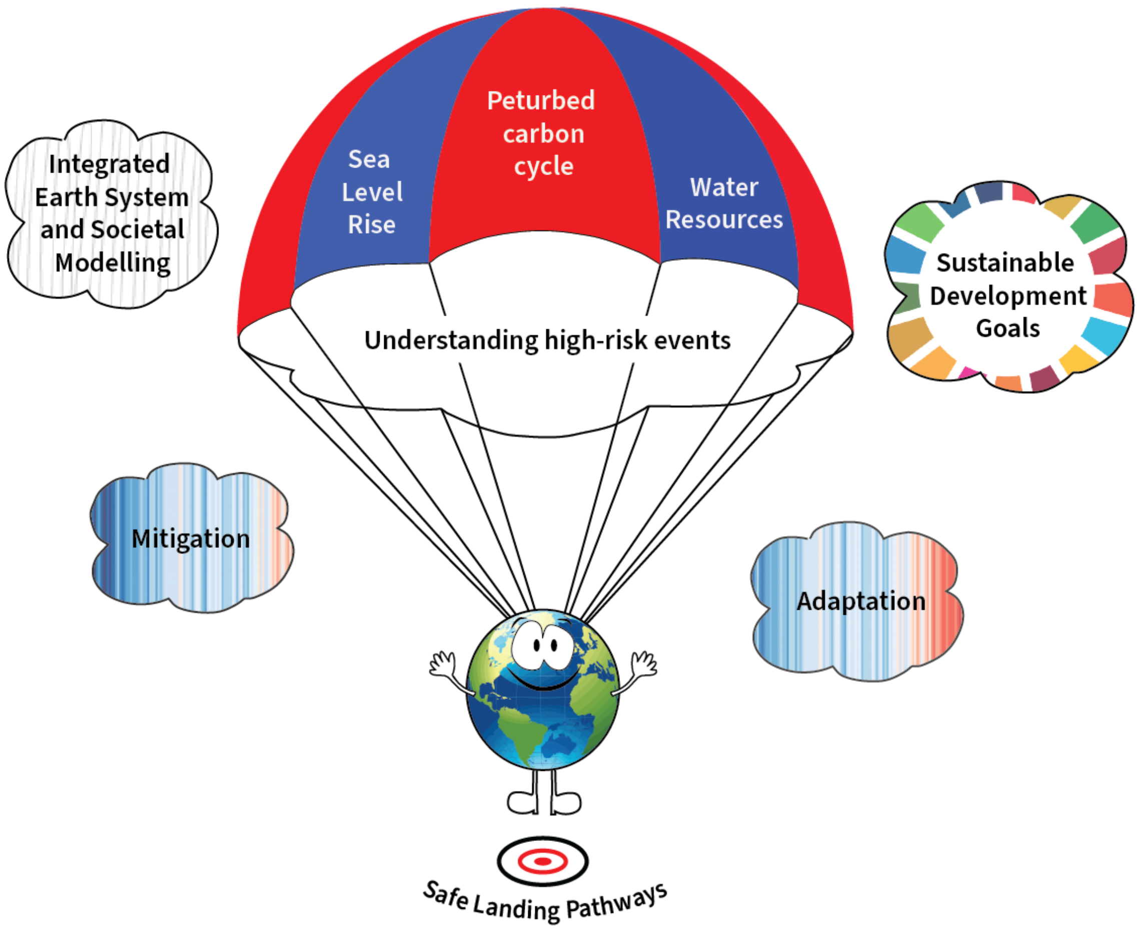
Safe Landing Climates



1. Introduction

This Lighthouse Activity (LHA) is an exploration of the routes to "safe landing" spaces for human and natural systems. 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.

2. Relevance to the World Climate Research Programme (WCRP)

Our aim is to contribute to international climate research that is relevant for societal well-being by focusing on what changes need to have been avoided to remain on a habitable planet that supports healthy populations and ecosystems. This activity will address the WCRP Strategic Plan element for long-term prediction of the climate system and do so probabilistically and in a risk framework. A novel aspect will be to more thoroughly illustrate alternative futures, ranging from crises that need to be prevented to avoiding dangerous changes, focusing not only on climate measures but on the SDGs. While this draws on projection work completed to date, it is a quite radical refocus away from best estimates with uncertainty ranges to a risk-based assessment of future climates (see Sutton, 2019). It has been informed by discussions during the centennial American Geophysical Union (AGU)Fall Meeting (see Alex Hall's AGU keynote talk) and the devastation wreaked, for example, by recent fire activity on several continents. By identifying and highlighting research needs to address the safe-landing aims, this LHA will contribute to fundamental understanding of the climate system, particularly the interactive Earth system – cryosphere, ocean, land surface and atmosphere – by focusing on how to avoid impacts beyond the capability to adapt, and better understand how the feedbacks between vegetation, carbon cycle, fire and extreme events will affect future habitability of the Earth.

The new scientific components of the Safe Landing Climates LHA are explored in the subsequent sections of this plan. Much of the required research draws on work that is ongoing, but that will take a more risk-based approach and aim to more fully incorporate the possibility of nonlinearities, "tipping points" and other global-scale risks. This includes those that can arise from linkages and feedbacks between Earth system components that transcend traditional disciplines, and that are not at present fully integrated in much of current projection work.

3. Scientific Themes

The Lighthouse Activity will focus on five main scientific themes, with the scope, knowledge gaps, and timeline elaborated for each theme individually, followed by an overall discussion of requirements, deliverables, and risks.

3.1 Safe Landing Pathways

Scope: This activity determines what climate trajectories and destinations are actually safe, and for whom? Which ones are unsafe and why? We will bring together interdisciplinary communities to determine pathways and "landings" that preserve habitability and food security, and identify societal adaptation limits and changes that must be avoided. This may involve finding a common footing for measuring and comparing impacts as seen from the SDG point of view. Addressing this goal requires a framework for defining and measuring safety, giving attention to how various communities are individually affected, and should consider interactions between SDGs, adaptation, and mitigation measures, including geoengineering.

Outcomes:

- Understanding and constraining individual risks, and assigning overall levels of risk to different potential future pathways
- Consideration of adaptation and resilience strategies across communities and ecosystems, and the impact of these and mitigation actions on SDGs, both regionally and globally.

This effort will draw on results from Themes 2-5. The construction of burning embers (e.g. Zommers et. al, 2020) in IPCC WGII and the underlying science ask similar questions. The lighthouse team is interacting with the teams from the Sixth Assessment Report (AR6), consulting on how to go beyond AR6 and on how to make a step change in our understanding of these risks associated with climate change rather than refining existing embers.

Timeline: in 2021, the activity aims at a broad consultation, followed by workshops (from 2022) on physical changes that exceed limits to adaptation and habitability on large scales, and metrics for informing judgements on safety.

3.2 Understanding High-Risk Events

Scope: We aim to identify risks from low-probability, high-impact possibilities with global-scale ramifications. What is known about their occurrence probabilities and consequences, and what significant scientific gaps exist? This theme will seek to identify any unexpected risks (cf. ozone hole resulting from heterogeneous chemistry), and to better incorporate known risks into projection ensembles. Risks that we will consider will include large natural carbon release, ice shelf/sheet collapse, regime shift of ocean/atmosphere circulation, extreme cloud feedbacks and climate sensitivity, multiplicative effect of compound hazards, biome (e.g., Amazon) collapse, "Fireball Earth," and large-scale extremes that challenge adaptation such as large-scale desertification, land and marine heat waves or storm sequences that exceed physiological limits or otherwise render large regions effectively uninhabitable.

We will identify adaptation limits for human, land and ocean ecosystems and resources, worst case (extreme/existential) scenarios, and global-scale tipping elements and points. We will also examine how (or if) tail risks could be avoided – or caused – by general or specific climate mitigation efforts, including negative emissions (Carbon Dioxide Removal (CDR)) or geoengineering / Solar Radiation Management (SRM). This activity will be informed by the results from Themes 3-5.

Outcomes:

- Sufficient understanding of the physical processes underlying tipping points and high-impact events to reliably quantify risks
- Earth System models that can credibly incorporate tail risks, compound extremes, uncertain shocks and tipping elements including those arising from feedbacks between multiple components of the Earth system
- Strategies to accurately and transparently incorporate low probability/high impact possibilities into projections, risk analysis and adaptation planning.

We anticipate collaboration with the Analysis, Integration and Modeling of the Earth System (AIMES) project and others for expertise on scenarios and planning.

Timeline: In mid-to-late 2021, we plan on conducting a webinar series on key tail risks and tipping points. This will be followed by a workshop on Earth system and emulator approaches to quantify tail risks and risk of catastrophic extremes and runaway feedbacks (in 2022), and a possible joint workshop with AIMES on developing global risk frameworks (date TBD).

3.3 Perturbed Carbon Cycle

Scope: We will explore the acceptability and climate implications of carbon dioxide removal (CDR) systems (including bioenergy with carbon capture and storage (BECCS)) while maintaining food and water supply, preserving biodiversity, and limiting ocean acidification. A further goal is to assess the risk of surprises or a rapid change in Greenhouse Gases (GHGs), including large or rapid carbon release (e.g., from permafrost melt, large scale fires, or the Southern Ocean), the reversibility of the anthropogenic perturbation, and climate and carbon cycle feedbacks in the context of negative emissions. We will also explore metrics for controlling short- vs. long-lived forcing in the context of negative emissions, and implications for allowable GHG emissions in the context of the Paris Agreement. We will build an understanding of the coupled carbon-energy-water cycle, impact on food, water supply, and biodiversity.

Outcomes:

- Improved observation and modelling of terrestrial biogeochemistry (in particular permafrost) and possible future sources of GHGs, as well as the ocean carbon cycle, especially in the Southern Oceans.
- Improved integration of ocean and land biogeochemistry models within Earth System Models to better constrain the future evolution of natural GHGs sources and sinks in a world with negative emissions
- Improved understanding of the risk of land/ocean CO_2 release when atmospheric CO_2 decreases
- Assessment of CDR strategies (efficacy, side effects, etc.).

Timeline: We plan a workshop (in 2022) on land-based mitigation and Earth system response, including impact assessment.

3.4 Water resources

Scope: We will address uncertainties in the long-term redistribution of water in land-based natural systems or reservoirs, their resilience and vulnerabilities, and impacts of changes to these systems. Key systems include glaciers (crucial for water supply in mountain regions) and tropical rainforests (which play an important role in the local water cycle and deliver other important ecosystem services). We consider impacts on these systems from climate change and also from direct human impacts (e.g., deforestation, agriculture, aerosol darkening of glaciers), seek to determine thresholds of tolerance beyond which substantial change or collapse occurs, and better characterize the possible consequences for society and ecosystems if this were to occur. We aim to integrate research across physical/climate and social sciences and local and indigenous knowledge to assess and communicate the value of these systems and assess the implications of different mitigation and adaptation scenarios including SRM/geoengineering. This will also be used to prioritize science needs, among which are water recycling and transport, atmospheric chemistry in the canopy area, and feedback mechanisms between these water systems and regional and global climate.

Outcomes:

- Address gaps in understanding and modeling of coupling between the land biosphere, cryosphere, and atmosphere, including via chemical processes and aerosols
- Address gaps in knowledge of forest and glacier dynamics and resilience
- Connect physical sciences with human systems (e.g., water management, adaptation) in order to ensure water resource changes and responses are reflected in safe landing pathways.

This Theme will draw on and extend the International Geosphere-Biosphere Programme (IGBP) Large Scale Biosphere-Atmosphere Experiment (LBA-ECO), and work with Future Earth, Global Energy and Water Exchanges (GEWEX) (including ANDEX), Past Global Change (PAGES), and Climate and Cryosphere (CLiC).

Timeline: We will conduct a webinar series on key aspects of forest-climate self-regulating roles (2021-2022), followed by a workshop on the possible consequences of large-scale deforestation/afforestation for local and global water cycles (2023), in tandem with Future Earth. A subsequent workshop could be focused on the role of tropical forest-induced rainfall on global atmospheric-oceanic circulation changes and their implications for the global water cycle (2024).

3.5 Sea Level Rise

Scope: We aim to quantify an “acceptable” rate of sea level rise and its irreversibility from multiple decades to millennia. We will estimate the impact of storm surges and cyclones on coastal communities and assess the potential for adaptation. The aim will be to improve projections by facilitating better coordination between global climate, cryosphere, and coastal modeling. This requires a regional/local perspective and interaction with coastal planners, because anthropogenically induced sea-level hazards are already affecting coastal habitats and threatening livelihoods in some regions. Depending on the local setting, safe landing in terms of sea level means that the rate of sea-level rise must be limited, slowed, or reversed to allow adaptation measures to keep pace and be effective.

Outcomes:

- More accurate understanding and prediction of poorly understood processes including ice sheet melting (Pacific) and future ice loss in Antarctica and Greenland, storm surges, and other global and regional sea-level drivers (including land subsidence)
- A fuller range of ice sheet models of different levels of complexity and resolution with evaluation to better constrain uncertainties
- New research on frameworks of coastal planning, adaptation, coastal protection, and the limits of adaptation
- Interaction of modelling efforts across spatial scales from global to coastal

This topic will draw on the Grand Challenge on Regional Sea-Level Change and Coastal Impacts.

Timeline: We will identify and coordinate with workshops organized by partners (e.g., My Climate Risk). We will also take advantage of planned workshops, e.g. PALSEA: Improving understanding of ice-sheet and solid-Earth processes driving paleo sea-level change, Palisades NY (13-15 September 2021) and the Grand Challenges on Regional Sea-Level Change and Coastal Impacts Sea Level 2022 Conference, Singapore (11-15 July 2022).

4. Partnerships

Safe Landing Climates will interact with the WCRP Core Projects and other LHAs while paying particular attention to problems not comprehensively addressed by an existing activity. We will also partner with organizations outside of WCRP to connect with disciplines beyond the core research expertise of WCRP.

Table 1 lists identifies our partnerships. The lighthouse team is in the process of interacting with these partners and involving them in further developing our research plan.

Table 1: Proposed Safe Landing Climates Partnerships

Theme	Other LHAs	WCRP	other
1: Safe Landing Pathways	Digital Earths	Working Group on Coupled Modelling (WGCM), Regional Information for Society (RIfS) Core Project, Climate and Ocean Variability, Predictability and Change (CLIVAR), Stratosphere-troposphere Processes And their Role in Climate (SPARC), GEWEX.	Intergovernmental Panel on Climate Change (IPCC) WGII and WGIII (burning embers), AIMES, Surface Ocean Lower Atmosphere (SOLAS), Earth Commission
2. Understanding High-Risk Events	Prediction and attribution, My Climate Risk	Earth System Modelling and Observations (ESMO), WGCM (projections), GEWEX, CLIVAR, SPARC, Grand Challenge (GC) on Weather and Climate Extemes (+ follow-up), GC on Regional Sea-level Change and Coastal Impacts (+ follow-up)	AIMES and Integrated Assessment Models (IAMs)/Earth System Models (ESMs). Past Global Changes (PAGES), Future Earth (Global Land Programme (GLP), Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS), Earth Commission), Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), Risk KAN

3. Perturbed Carbon Cycle	My Climate Risk	ESMO, GC on Carbon Feedbacks in the Climate System, GEWEX, CLIVAR, SPARC and CLiC	Future Earth GLP, iLEAPS, AIMES), Global Carbon Project (GCP), IAMs, PAGES, The Carbon Dioxide Removal Model Intercomparison Project (CDRMIP), ISIMIP and the impact community (food, water, biodiversity)
4. Water Resources	My Climate Risk, Explaining and Predicting Earth System Change, Digital Earths, Academy	WCRP Climate Research Forums, GEWEX, CLIVAR, CLiC	ISIMIP, International Centre for Integrated Mountain Development (ICIMOD), Future Earth SOLAS, iLEAPS
5. Sea Level Rise	My Climate Risk, Digital Earths	GC on Regional Sea-level Change and Coastal Impacts (+ follow-up), ESMO, CLIVAR, CLIC	AIMES, Future Earth, PAGES including PALeo constraints on SEA level rise (PALSEA) WG, Scientific Commitee on Antarctic Research (SCAR) INStabilities & Thresholds in ANTarctica (INSTANT), ISMIP

The science needed for this Lighthouse Activity sits quite strongly within the WCRP remit. The present exception is long-term carbon cycle feedbacks, but it is hoped that we can also draw on a Core Project for that topic within WCRP.

5. Requirements

Requirements include logistical support from WCRP for planning and conducting activities, such as support for lighthouse meetings, topic webinars and workshops (online and in-person).

6. Budget

2021: For this year we do not anticipate significant costs other than administration support for our own meetings and planned networking and webinar activities.

2022-2023: Presently the activity includes four workshops, one by each theme except for Theme 5 which can draw on existing workshops. We anticipate ca. 50 people per workshop. The total cost of providing accommodation and food for these would be over the WCRP budget, so we will seek to identify options including piggy-backing onto major meetings, external funding, or lower-cost/subsidized venues where e.g., the host institution can provide accommodation.

7. Deliverables and outcomes

Safe Landing Climates will have been successful if we have identified and quantified the most substantial risks associated with climate change, climate pathways and mitigation actions, and limits to adaptability. This would include increased research on tipping elements, thresholds and compound events in the fully coupled Earth-human system. Second, the activity will have been successful if the climate change community has moved beyond plotting "plumes" of predicted future climate to recognizing multiple possible futures and multidimensional risks to society and the SDGs that need to be considered or avoided, and which are increasingly being considered in impact and cost analysis. We do not expect to resolve these problems but we do aim to highlight their importance and empower worldwide research to address them.

8. Communication and capacity exchange

Safe Landing Climates has links to many of the organizations listed in Table 1 through its steering committee and, where not, has established links through conversations. We anticipate the proposed AGU Fall Meeting session on Safe Landing Climates (December 2021) will be an important milestone in our planning phase, and an opportunity to inform the research community and discuss how to co-design this activity. The next milestone after this is the WCRP Open Science Conference 2023, where we will report our updated work to the community. We also aim to write a white paper for a high-level journal (e.g., a perspective piece) in 2021 to communicate the plans of our lighthouse activity.

9. Risks

We see an important potential risk being the overcommitment of the steering committee and follow-on members. This can be handled by the WCRP leadership providing reasonable timelines, and by ensuring regular but not overly rigid reporting frameworks. The work proposed is very novel and arguably important, and needs to develop at pace, but also with enough time to enable thoughtful input. Hence enough time needs to be allowed for the lighthouses to scope their collaborations well. A second and related risk is duplication of or conflict with other efforts, especially outside WCRP, which may have ostensibly similar goals (but different points of view). We are attempting to mitigate this risk by early engagement with Future Earth and other organizations.

10. Supplementary information

The present steering committee is not very well balanced geographically, nor by career stage. We aim to entrain enthusiastic early career researchers after more clearly scoping the activity, for example by drawing on contacts through the existing Core Projects or the Young Earth System Scientists (YESS), the Association of Polar Early Career Scientists (APECS) or other similar networks.

11. Steering Committee

The present steering team is listed below. Our aim has been to clearly identify research topics by the time of the 42nd Session of the Joint Scientific Committee, and then to develop these over 2021 entraining team members with more geographic and career-stage diversity. The plan to transition towards this aim is presently being discussed by the team.

Present team:
Steven Sherwood, UNSW Sydney, Australia
Gabi Hegerl, Geosciences, Univ. Edinburgh, UK
Pascale Braconnot, IPSL, Paris, France
Pierre Friedlingstein, Exeter Univ., UK
Heiko Goelzer, NORCE, Norway
Neil Harris, Cranfield Univ., UK
Beth Holland, Univ. South Pacific, Fiji
Hyungyun Kim, Univ. Tokyo, Japan
Paulo Nobre, INPE, Brasil
Bette Otto-Bliesner, NCAR, USA
Kevin Reed, Stony Brook Univ., USA
Jim Renwick, Victoria Univ. of Wellington, New Zealand

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