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This outline is an outcome of a workshop held in Hamburg in February 2020. For more details see the full report. The outline is provisional.

Explaining and Predicting Earth System Change

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Description of the activity
The formulation of robust policies for mitigation of, and adaptation to, climate change requires quantitative understanding of how and why specific changes are unfolding in the Earth system, and what might happen in the future. Quantitative explanation of observed changes – through robust process-based detection and attribution – is also fundamental to confidence specification in climate assessments, predictions and projections. However, the capacity to deliver these capabilities is very immature (evidenced, for example, in the recent debates around the "hiatus" in global warming of surface temperature). The proposed WCRP Lighthouse on Explaining and Predicting Earth System Change is intended to address this gap.

The 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.***

Form of activity
The core activity is a *research programme* to:

1. Design, improve and evaluate individual components of the capability and the integrated capability itself.
2. Advance fundamental understanding of Earth System Change on global and regional scales.

A headline output would be a major enhancement to, for example, the WMO State of the Climate Reports and the WMO Annual to Decadal Climate Updates (currently in pilot phase, with a focus mainly on predictions) as well as the Global Carbon Project and Future Earth activities such as the 10 Insights report. The enhanced annual reports would integrate predictions with the latest assessment and quantitative explanation of changes in the Earth system over recent years and decades, on global and regional scales. This initiative would achieve some of the purposes of the IPCC Assessment Reports (e.g. AR6 Chapters 2-4), but in a more nimble and timely (albeit less comprehensive) manner.

What will it deliver and/or achieve?
The design, and 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. This capability involves the following components:

1. A more complete and integrated capability for observing Earth system change (climate and composition) on global and regional scales. This component to be led by other partners but with WCRP contributions to the design. An "Earth Year", possibly culminating in an Earth Observation Decade, could provide a focal point for developing an enhanced observing system.
2. Earth system reanalyses and advances in the methods to deliver such reanalyses, supported by enhanced efforts in data rescue.
3. New capabilities for process-based explanation (detection and attribution) of Earth System changes on global and regional scales and multi-annual to decadal timescales, including quantified uncertainties. This component differs from "traditional" detection and attribution, which focuses on multi-decadal to centennial timescales, and also from "Event Attribution," which focuses on individual seasonal or shorter-timescale extreme events rather than system changes. A strong focus on understanding full causal chains at a process level is also essential.
4. Improved predictions of climate and Earth system change on multi-annual to decadal timescales, including new capabilities for early warning and improved confidence in predictions supported by quantitative understanding of recent changes. Regular outlooks for the next decade: these would initially focus on climate variables, but in time could expand to include, e.g., regional risks to food or water security. Longer-term outlooks could include early warning of potentially irreversible changes or tipping points in the Earth system.
5. Improved capabilities for quantitative assessment and prediction of the global energy, carbon and water budgets, supporting mitigation policies. (This component would build on and expand the work of, e.g., the Global Carbon Project).
6. Improved capabilities to quantify current and future weather and climate risks (building on, e.g., the Japanese d4PDF programme), informed by quantitative understanding of recent changes on global and regional scales, supporting adaptation policies.

Relation to the World Climate Research Program Strategy, including as appropriate any aspect that is new or novel.

This activity will contribute to addressing all four of the WCRP Scientific Objectives. It will provide a focused set of priorities and will ensure that advances in fundamental understanding of Earth System Change are targeted to meet the needs of decision-makers faced by climate related risks and opportunities.

Science requirement; including new science and how this draws upon the core research expertise of the WCRP community.

A research programme to address:

1. Enhancing capabilities for observing Earth System Change and for Earth system reanalysis, including advances in data assimilation for Earth System variables.
2. Process-based attribution of specific changes in the Earth System on global and regional scales (climate and composition) including development of attribution methodologies, e.g. using very large ensembles of high resolution historical and initialised simulations sampling internal variability, forcing uncertainties (e.g. emissions, land-use, volcanic eruptions) and process uncertainties affecting forcing and/or response.
3. Improving the fidelity with which climate models simulate internal variability, particularly on multi-annual to decadal timescales, and the response to natural and anthropogenic

forcings. Exploring the benefits of higher resolution, large ensembles and improved representation of Earth System Feedbacks.

4. Understanding regional changes in atmospheric circulation, including the "signal-to-noise" problem.
5. Quantification of current and future weather and climate risks, including improved capabilities for near-term outlooks/decadal predictions and early warning of Earth System Change, conditional on the latest observations.
6. Variability and predictability of: Earth's energy budget; carbon and biogeochemical cycles.

Partnerships needed to do this Activity; including if WCRP will be the lead or if it will be a jointly-lead Activity (and if so, who are the key Partners).

- WMO
- Global Climate Observing System (GCOS), Global Atmosphere Watch (GAW), European Space Agency (ESA), National Aeronautics and Space Administration (NASA), Copernicus, etc.
- The World Weather Research Programme (WWRP)
- Future Earth
- Climate services. Users of information especially quantification of risks for multiple sectors – e.g. transport, energy, agriculture, food and water, insurance etc.
- Other WCRP Lighthouse Activities, e.g. Digital Earths, Regional risks