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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.

Digital Earths

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Description of the activity

Digital Earths is a digital and dynamic representation of the Earth system founded on an optimal blend of models and observations. Digital Earths will enable exploration of past, present and possible futures of the Earth system by adding a new dimension to climate information. Digital Earths will give open access to data, methodologies and software. Digital Earths will create innovation in science and technology in support of the WCRP Objectives and will lay the foundation for future needs of the activity.

Digital Earths will push the co-development of high-resolution Earth-system modeling and the exploitation of billions of observations with digital technologies from the convergence of novel high-performance computing, big data and Artificial Intelligence (AI) methodologies. Under WCRP, Digital Earths will be a key instrument to achieve the goals of the other Lighthouse Activities as they rely on much enhanced simulation and observational capability. There are large overlaps with similar opportunities under WWRP.

Form of activity

Digital Earths will be a joint activity with existing/novel, technology driven national and international projects supported by new institutions. While the external institutions will provide the main digital infrastructures, WCRP will implement selected versions for topics where significant progress is required (e.g. other Lighthouse Activities) and in regions where the supporting research and operations context is favorable.

What will it deliver and/or achieve?

The core of Digital Earths is to develop generic software-hardware solutions that allow simulation models and data assimilation to perform several orders of magnitude more efficiently. It will facilitate the extraction of Earth-system sector specific information from vast amounts of environmental data, both simulated and observed. The efficiency gains can be invested, for example, in upgrading simulations, ensembles and/or running more comprehensive scenarios.

While the digital infrastructure developments themselves will be carried out by institutions outside the direct control of the WCRP, there are specific activities that should be driven and supported by WCRP in support of the international research community:

- Lighthouse ‘Explaining and Predicting Earth System Change’:
 - Global and regional Earth-system reanalyses for climate monitoring at km-scale (observations and models)
 - Seasonal, multi-annual (potentially decadal) predictions at km-scale; ensemble based

- Support of counter-factual analyses through more (and more frequent) scenario assessments
- Advanced cause-effect diagnostics through transparent access to Earth-system information
- Lighthouse ‘My Climate Risk’:
 - Regional reanalyses for climate monitoring at sub-km scale; ensemble based
 - Earth-system component (e.g. hydrology, vegetation) impact assessment
 - Geophysical data - sector specific information - socio-economic risk assessment
- Selected configurations of Digital Earths can be implemented by region thus distributing the workload and empowering more communities. The specifications for such region-specific implementations depend on the regional primary interests and could develop and demonstrate solutions applicable elsewhere. WCRP can drive this selection.
- The set-up as an open access framework for data, methodologies and software supports the use of advanced technologies by less well-developed communities and countries. Digital Earths therefore directly contributes to the capacity building activities of WCRP.

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

Without Digital Earths, the urgent need to provide robust Earth-system simulations and data assimilation systems at the temporal and spatial scales relevant to decision makers, with large ensembles and for many scenarios in a near-continuous fashion cannot be fulfilled.

Digital Earths will contribute to all four WCRP Scientific Objectives. The availability of a comprehensive, high-resolution description of the Earth system will provide an unprecedented opportunity for a quantum leap in our understanding of its internal workings (Objective 1). The revolutionary prediction/projection capabilities of Digital Earths will support Objectives 2 and 3 through much advanced prediction systems based on high-resolution ensembles, the integration of climate and Earth-system components in a single modeling framework, and the enhanced synergy between observations and models. Objective 4 will be supported by the provision and co-production of its results with all relevant sectors of industry and society to enable a step-change in climate-related decision making across the globe.

Digital Earths will deliver a significant upgrade of critical infrastructure elements, namely seamless and unified simulation tools, optimal exploitation of observational information content and characterization of their uncertainties, open access to data, methodologies and software, and extreme-scale computing, big data handling and artificial intelligence methodologies.

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

Digital Earths will be based on climate – computational science co-developments. The new digital infrastructure developments (e.g. programming of heterogeneous processor architectures (memory layout, parallelization), task based parallelism, mixed precision, on-the-fly post-processing) influence the design of Earth-system models (e.g. dynamical cores, Earth-system physics, coupling, model uncertainty, minimization algorithms), their workflows and the way data will be made accessible and manageable. This offers yet unprecedented opportunities for Earth-system research and services.

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).

Given its scale, implementing Digital Earths will require the creation of new multi-national institutions. WCRP must play a critical role in promoting their establishment. Doing so requires engagement with the following partners:

- Main national funding agencies supporting digital infrastructure development (e.g. European Commission's EuroHPC (High Performance Computing (HPC)), Department of Energy, Japan's MEXT and RIKEN etc.); philanthropic support
- WWRP and GAW, national hydro-meteorological services, national climate centres
- Copernicus in Europe, Earth Cube in US, International Society on Digital Earth
- HPC and software industry
- Existing weather/climate-computational science efforts (e.g. US Energy Exascale Earth System Model (E3SM), European Centre for Medium-Range Weather Forecasts (ECMWF) Scalability Programme, Centre of Excellence in Simulation of Weather and Climate in Europe (ESiWACE), e-infrastructure of the European Network for Earth System Modeling (IS-ENES))
- Academia (model/data assimilation development, computational science)

Other relevant information

The need for creating one or more new, centralized 'Earth-system and computational science' facilities should be formally assessed because – with sufficient funding – it will accelerate progress and facilitate uptake and future support for the targeted digital infrastructures.

WCRP (WMO) is perfectly placed to carry out such an assessment and in doing so, promote the swift establishment of the facilities or generate the needed expertise and developments through other organizational forms.