Met Office Hadley Centre Climate Science Roadmap 2020-2030

25 May 2020

Introduction

- ✓ Motivation for this document
  - Following the new Met Office Corporate and People Strategies and the new Met Office Research & Innovation Strategy we set out the path for getting ourselves ready for a changing future with the ambition to be recognised as global leaders in Climate Science in a changing world 30 years after being set up as the Met Office Hadley Centre (MOHC)
- ✓ Aim
  - This Roadmap articulates our climate science priorities for the next 10 years
  - Focus is on how we can deliver on both the customer needs and the key science questions, playing to our strengths while shrinking in other areas where we increase our partnerships
  - This requires careful consideration of the changes in the demands for climate science, awareness of the next big things in science and technology and bridging of the gap between the core science and solutions (including science communication)
- ✓ Intended audience
  - Met Office staff, Science Review Group members, BEIS and DEFRA sponsors, and UK academic and international partners
  - This Roadmap will form the basis for future MOHC Climate Programmes for BEIS and DEFRA (note that the current contract which funds about 70% of the MOHC work ends in March 2021)
  - It will also inform related science plans for new projects under Newton, UK Research Infrastructure (UKRI), DFID and EU funds
- ✓ Relationship to Met Office strategies
  - This Roadmap is the Climate Science implementation plan for the new Met Office Research & Innovation Strategy 2020-2030
  - It aligns with the new Corporate Strategy and the related Corporate Strategic Actions on People, Partnerships, Data, etc.
  - It will interface with forthcoming roadmaps in Applied Science/Business Group, Weather Science and Foundation Science
- ✓ Future reviews
  - This Roadmap will be reviewed each year to ensure it remains fit for purpose
  - It will take account of the evolving climate science progress in the MOHC and the wider community, core climate science needs from the demonstration and operational climate services that the Met Office delivers, and views of stakeholders
  - At the midpoint of the ten-year period (FY2024/25) there will be a more extensive review and updating
  - The aim is to ensure that this Roadmap remains a living document, responsive to future developments

Content and timeline

- ✓ Priority activities
  - This Roadmap describes the 20 activities with highest priority for the coming decade
  - The priority activities relate to the two most important drivers for our research (policy or societal needs and fundamental climate science questions), to our areas of work (observational dataset development/monitoring and climate model development/predictions/projections), to cross cutting themes (such as IT tools/systems and data sciences), and to user-oriented output (policy advice, climate services development and climate science communication)
  - The priority activities are grouped according to the three pillars of the Research & Innovation Strategy 2020-2030 (Figure 1):
    Science for Services which refers to the way we develop and use scientific knowledge and services to inform risk-based decision making; and
    Pioneering Research which refers to the fundamental research we do to extend the frontiers of weather and climate knowledge;
    National Capability which refers to the underlying resources, systems, processes and expertise that enables the weather and climate community to meet UK and global strategic needs
- ✓ Priority outcomes
  - To measure progress and success for the 20 priority activities an associated set of 20 priority outcomes has been defined and review dates (Fiscal Years) for each of these outcomes are provided in the timeline of Figure 2
  - These are the first priority outcomes for each activity; additional priority outcomes will be defined as part of future reviews
- ✓ Partnerships
  - Building strong partnerships with our UK partners (in particular NERC) and international partners is essential to addressing the challenges we face in climate science and its applications
  - As highlighted towards the end of this document we rely on external partnering to be able to deliver the science in this Roadmap given the limited resources and increased complexity of observing and modelling the climate system
  - The section on Partnerships is a starting point for further discussions, e.g. how we align our plans with the new climate plans of NERC with the aim of maximizing synergies (see the NERC Delivery Plan 2019 and note that the current NERC multi-centre programmes including the Met Office/NERC project on Earth System Modelling will end in March 2021)
- ✓ Risks
  - This Roadmap concludes with a risk register and contingency plan with key decision points and necessary flexibility measures to remain agile and to enable acting quickly on changing future demands and surprises

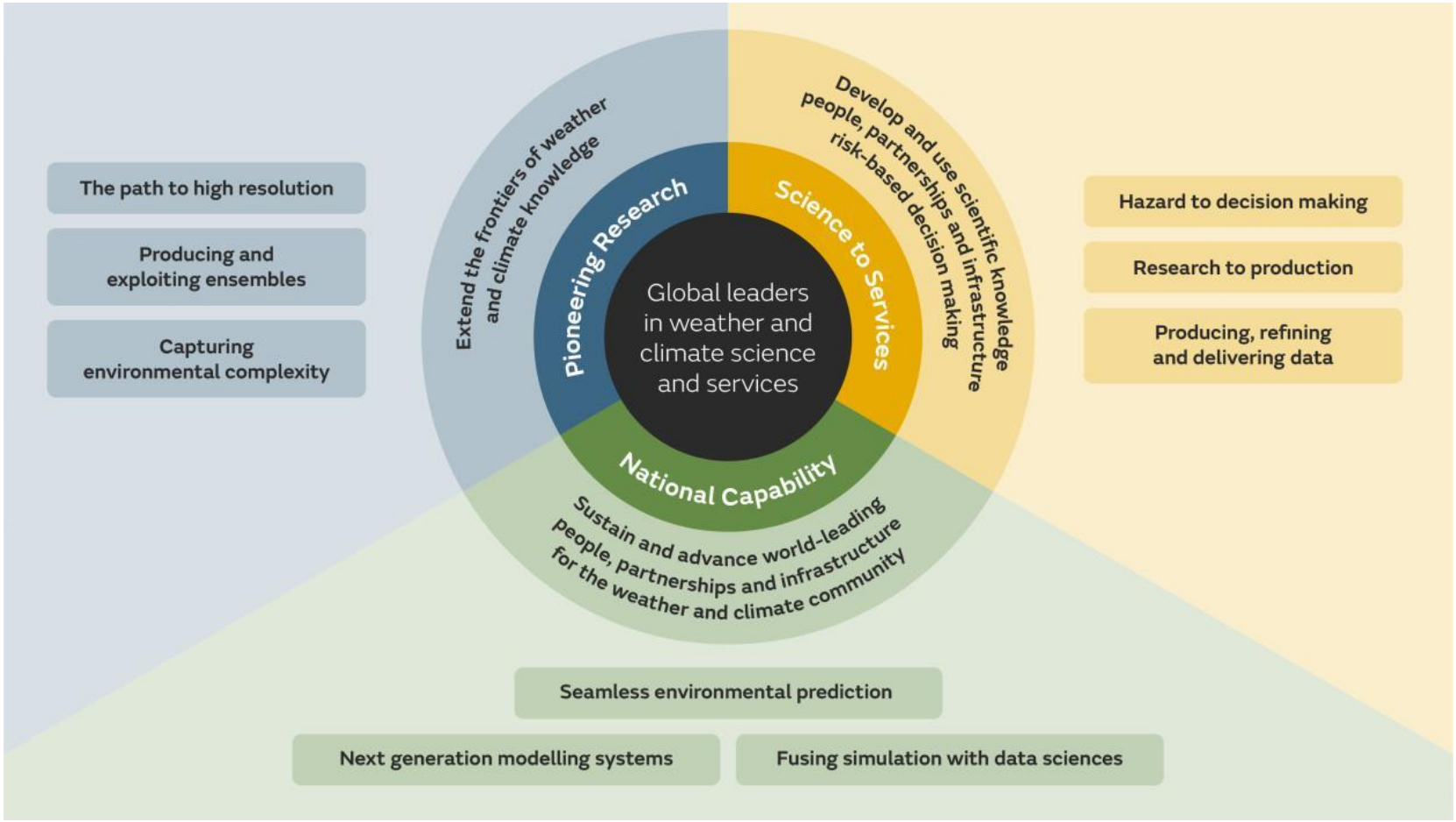

Figure 1: The 20 Roadmap activities are grouped according to the 3 pillars the Met Office Research & Innovation Strategy 2020-2030: Science for Services, Pioneering Research and National Capability.

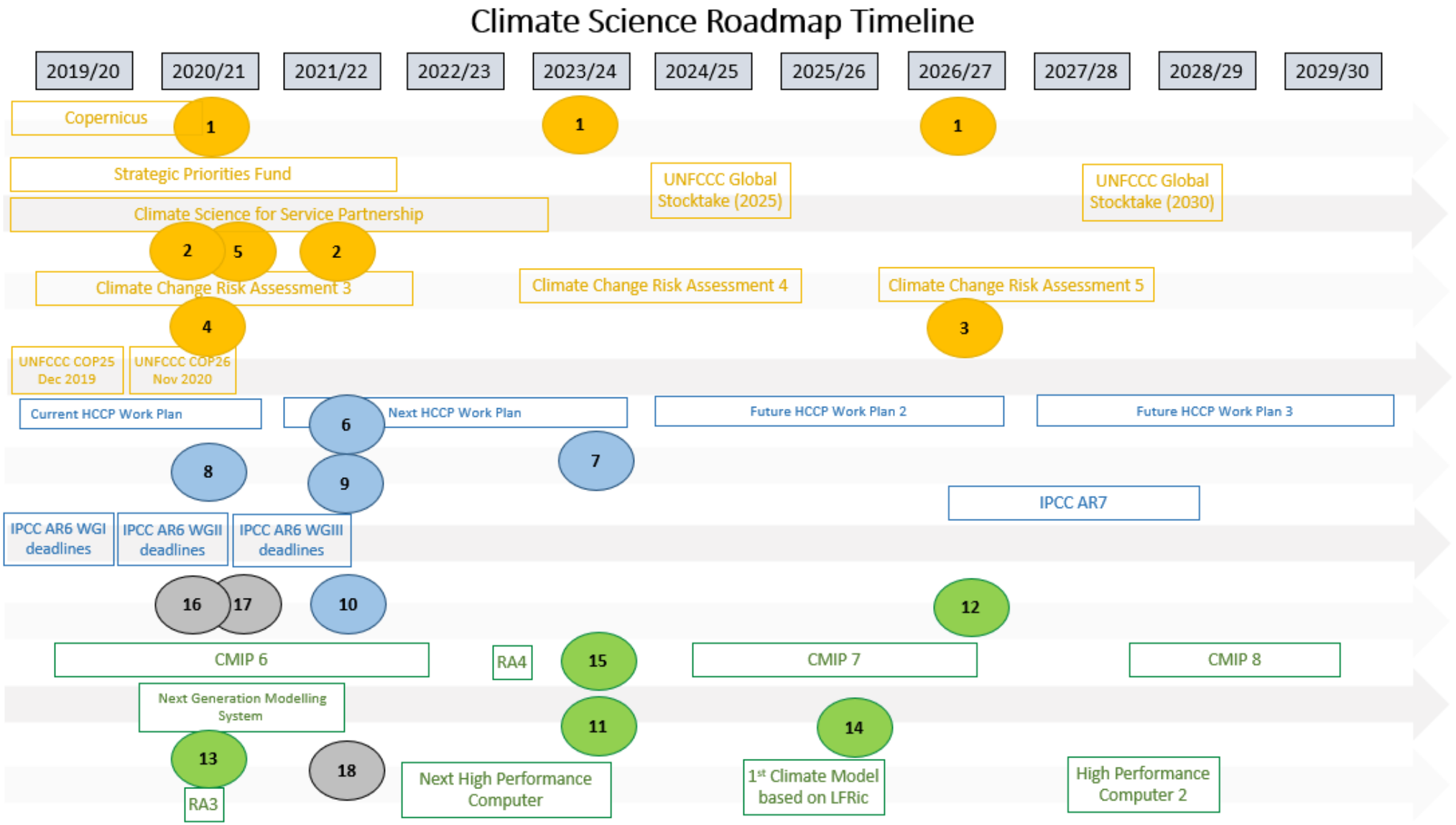

Figure 2: Timeline with 18 Roadmap priority outcomes against the background of important externally determined calendar items.

Science for Services

Priority activity 1) Work with government and stakeholders to jointly formulate policy and societal demands for future Climate Science

- Maintain a good understanding of the need for information and services on climate change mitigation and adaptation that protect the public, help businesses and advise Government
- Work internally with Government Services and continue the strong interaction with BEIS and DEFRA as part of the Hadley Centre Climate Programme (HCCP) governance structure
- Use the UKCP18 stakeholder groups experience to establish an HCCP user group that helps articulate so-called "Government questions" associated with the shift towards action in preparation for a net zero carbon emission economy by 2050 and for a climate resilient society and environment
- Work closely with the Committee on Climate Change (CCC) and pro-actively ensure that further updates and applications of UKCP and other MOHC climate science meet the needs of the ongoing Climate Change Risk Assessment process
- Work internally with Applied Science/Business Group to close the feedback loop of past experience in applied work informing future science (successful recent examples from UKCP18 include the two-degree target scenario and the 12 km downscaling product)
- Think beyond the current demands and anticipate the lag between future requirements and the time needed to develop the relevant science by maintaining our core underpinning science basis (the push-pull aspect of the policy-science link)

First priority outcome 1) Periodically updated set of "Government questions" as part of future HCCP programmes (FY20/21, FY23/24 and FY26/27):

- *refreshing the current set of questions around 1) Present weather and climate risks; 2) Future weather and climate risks under different emissions scenarios; 3) Mitigation strategies and the case for early action; 4) Impacts and opportunities of mitigation and adaptation*
- *addressing new questions around: 1) Profound changes in the role of climate change in society and in the strength of signals of climate change (global warming may have breached the Paris Agreement target of 1.5C and/or decarbonisation may be in full swing and hence it may be less necessary to do climate projections but may be more urgent to look at the implications of decarbonisation itself e.g. competition for land between bioenergy and food production); 2) Threats to national and global security, poverty eradication and economic prosperity; 3) Climate action in preparation for a net zero carbon emission economy by 2050 (including allowable carbon budgets to stay below particular temperature targets and impacts of climate pledges); 4) Solutions and their impacts (including nature-based solutions to reducing emissions and impacts on food*

security, pest emergence, etc.); 5) Impacts we will wish to avoid; 6) Adaptation and resilience (such as providing climate hazard information more aligned with different risks management approaches)

Priority activity 2) Coordinate the climate services (and delivery mechanisms) that match with both the needs and research priorities

- Build on earlier "Climate Service UK" ideas to establish a Met Office contribution to the UK and international delivery of climate services and clarify the Met Office role compared to delivery roles of private sector industry, including options for regulation and certification and the commercial interests of Business Group
- Work across research areas in Climate Science to identify potential climate services and provide support for producing demonstrators/pilots plus support the transition of suitable service areas through to high quality and relevant "operational" status where appropriate
- Embrace the principles of translating the science to develop seamless services relevant and fit for purpose for policy and decision making
- Adopt co-development with users as a principle of our climate service activities and incorporating learning as we go along, and provide support across the programmes on good practice
- Work internally with Government Services and Applied Science/Business Group to understand the whole "value chain" from hazard to impact and response, requiring stakeholder engagement and co-production across science domains
- Articulate the hand over to Applied Science/Business Group for translating hazard to risk (co-developed with sector specific vulnerability information) ensuring that the latest advances in Climate Science are taken on board
- Organize the feedback loop in which climate services inform future Climate Science priorities bringing service science requirements back into core underpinning science
- Work with internal stakeholders to outline the necessary steps towards a future Met Office "Public Weather and Climate Service (PWCS) to replace the current PWS
- Use the Corporate Strategic Action outcomes of Data Science, Data Platforms and Data Services to deliver services that allow business and industry to develop new exciting and interesting applications
- Expand climate services development to vulnerable countries, emerging economies and UK Overseas Territories together with Applied Science/Business Group (part of Newton Science for Services and DFiD Official Development Assistance projects)

First priority outcome 2) Framework for Climate Services, aligned with and supporting development and delivery across the Met Office (FY20/21) and the wider UK (FY21/22)

- *Includes a Met Office wide "product catalogue" for climate services*

- *Includes a Joint Weather and Climate Hazard Centre that enables better characterisation of the state/resilience of the system (e.g. is the hazard approaching a critical level for the system involved)*
- *Includes making the seasonal forecast production and the attribution service operational with migration of product generation to FSD*
- *Includes a process to identify new climate services and to take them towards operational deployment jointly with other parts of the Met Office*
- *Towards a future PWCS replacing existing PWS*

Priority activity 3) Develop the hazard component of a new "seamless risk service" which spans the historical/current (observations), near-term (seasonal/decadal) and longer-term (scenario planning) period

- Pull through science outputs into services using observed trends, hindcasts, attribution simulations, seasonal to decadal forecasts and climate change projections in a seamless way (underpinned by the unified model) drawing on the legacy of the EUCP and other projects (linking up to user needs and various risk management approaches)
- Focus on the following priority risks for the UK: inland flooding and coastal flooding and change, windstorms, high temperatures and human health, drought and shortages in water supply, natural capital, food production, pests, diseases and non-native species (source: CCRA2)
- Strengthen the links between event attribution and seasonal forecasting reliability and model evaluation
- Develop an updated climate projection system for a major update to UKCP18 (UKCPnext) in time for CCRA5, using tested Met Office and international modelling capability, and seeking to maximise credibility and consistency across UKCP components
- Integrate international multi-model decadal predictions and a global annual to decadal climate update through our role as WMO Lead Centre
- Implement a consistent statistical framework for uncertainty representation across time scales building on the legacy of SPF UKCR and EUCP
- Include understanding of robustness of methods, single and multi-hazard events, storylines (using weather regimes) and producing high-end scenarios for stress testing
- Consider framing this as a new "state of resilience of the nation service"

First priority outcome 3) UKCPnext unified risk estimation service for adaptation/resilience (26/27)

- *Run, analyse and document an updated set of UK climate projections to inform the 5th CCRA (following an update of UKCP18 (FY22/23) that exploits modelling currently available)*

- *Provision of risk across timescales; observations – attribution - predictions and projections using Event Attribution, UNSEEN, seasonal predictions, interannual predictions and projections-based estimates of hazards*
- *Capability to say more about the weather that has happened in the context of the past, near-term and future*
- *Includes the tails of the distribution to guide low probability / high impact risks*
- *Includes storyline-based framings (engaging with the community that is working on climate storylines/narratives)*
- *Wide consultation with UK community on exact needs and capability*

Priority activity 4) Develop a new "mitigation advice" service which informs climate policy

- Assess global Carbon budgets and emission pathways compatible with different levels of warming, including implications of delaying mitigation actions and consequences of an overshoot in temperature using the (lower resolution version of the) UKESM
- Further develop the annual CO_2 forecast to include a more process-based approach
- Assess global and regional/local climate impacts (and avoided impacts) of different emission pathways and consequences of mitigation policy for adaptation/resilience and SDGs (impacts and related opportunities, trade-offs and co-benefits e.g. on air quality, land use and food security, biodiversity and so-called "Natural Capital")
- Expand our efforts in this area, e.g. with research into geoengineering (and understanding the implications) and consider a wider set of drivers, such as changes in consumption patterns, trade and therefore food production and knock on effects on land use
- Include the tails of the distribution to allow mitigation pathways to take account of low probability / high impact outcomes
- Include storyline-based framings and adaptive mitigation pathways (engaging with the community that is working on climate storylines/narratives)

First priority outcome 4) Mitigation advice for COP26 (FY20/21)

- *Allowable Carbon budgets to likely stay below 1.5C and 2C supporting UK emission targets as part of Government's commitment to the Paris Agreement*
- *Regional carbon budgets*

Priority activity 5) Be seen as a trusted place for authoritative monitoring of important changes in the climate system

- Lead, where appropriate, national and international assessments such as the annual State of the Climate (UK, global and WMO) reports

- Report on global temperature rise, ocean changes, observed extremes and thresholds and records for the UK and Worldwide using traditional and new (impact-related) metrics based on our own datasets and those maintained by our partners
- Consider and integrate climate observations from different sources (in situ and remote sensing), model hindcasts (UNSEEN) and reanalyses into a climate system picture such as produced for the example of Summer 2018 and mainstream as part of the annual reporting cycle
- Point towards other sources of information available from partner organisations where appropriate
- Facilitate Carbon/GHG inventories and stocktake in support of UNFCCC climate action plans through monitoring tools and inverse modelling work
- Repackage information, if currently inaccessible, to make it more relevant to specific sectors other than global climate monitoring, in particular agriculture and natural capital
- Monitor global progress towards climate action using simple and easy to understand/communicate indicators based on an integrated view of quantities relevant to Nationally Determined Contributions under the Paris Agreement (this will bring together existing monitoring work and use a single metric to demonstrate progress towards action needed to mitigate climate change to within agreed limits)

First priority outcome 5) "State of the Climate dashboard" for the UK and for the Globe and Europe (FY20/21)

- *Includes where we are relative to Paris Agreement temperature targets and the UNFCCC Global Stocktake (every 5 years)*
- *Includes operational attribution results and forward looks to anticipate future changes*
- *Frequently updated using an online system*

Pioneering Research

Priority activity 6) Develop an integrated climate prediction system with traceable model hierarchy across scales and preferential configurations for each application

- Develop and maintain a 10-year forward look on modelling capability (taking into account the changes in model architecture and HPC and the time and cost constraints)
- Agree on the ideal combination for ensembles/resolution/realism for each application (larger ensembles for seasonal forecasts and risk assessment; higher resolution for urban questions and larger process realism for supporting Paris Agreement mitigation goals)
- Limit the proliferation of too many model configurations and base decisions on the necessary compromises on specific research evidence where possible
- Agree on an appropriate balance between bottom up ('improving scientific fidelity') and top down ('fitness for purpose') drivers of model development
- Include relevant environmental complexity in our seamless simulations in order to understand the impacts of climate change and inform mitigation policy on impacts of land use changes, tipping points and carbon budgets
- Work with partners to improve the sub model components
- Consider how best to design hybrid multi-scale versions of the model (e.g. running ESM components at lower resolution and/or reduced process realism and physics at higher resolution) or using machine learning components to make running cheap
- Define a strategy and rationale for the CPM resolution in our RCM work (e.g. towards urban scales), and how this interacts with the high-resolution global modelling framework
- Define the potential and science/user priorities for regional integrated environmental modelling system(s) on seasonal to centennial timescales (UKEP and possible equivalents for other regions). Support developments and partnerships as appropriate.
- Ensure that diagnostics relevant to seasonal, decadal and centennial predictions and projections feed into the Met Office model development process to benefit climate applications

First priority outcome 6) Prediction system with preferential climate model configurations (FY21/22)

- *Desirable suite of different global and regional climate model configurations with different resolution, ensemble size and realism to address the diverse set of questions (see Table 1)*
- *Includes regional modelling and new urban scale focus*

Application		Previous	Current	Next generation
Seasonal forecasting	resolution (a,o): ensemble size: process realism:	60km, 25km 42 HadGEM3 pre-GC2	60km, 25km 42 GC2	… 100 GC5
Decadal forecasting	resolution (a,o): ensemble size: process realism:	130km, 100km 10 HadGEM3 pre-GC2	60km, 25km 10 GC3.1	… 20 GC5
CMIP (physical climate)	resolution (a,o): ensemble size: process realism:	130km, 100km 4-5 HadGEM2 AO	60km, 25km 1-4 GC3.1	… 15 GC5
CMIP (ESM)	resolution (a,o): ensemble size: process realism:	130km, 100km 5 HadGEM2-ES	130km, 100km 4-16 UKESM1	60km, 25km … UKESM2
Exploring frontiers of resolution (PRIMAVERA)	resolution (a,o): ensemble size: process realism:	60km, 25km 1 HadGEM3 pre-GC2	25km, 10km 1 GC3.1	10km, 10km … GC5
UKCP global	resolution (a,o): ensemble size: process realism:	250km, 100km 12 HadCM3	60km, 25km 20 GC3.05	… … …
UKCP regional	resolution (a): ensemble size: process realism:	25km 12 HadCM3	12km 12 GC3.05	… … …
UKCP local	resolution (a): ensemble size: process realism:	N/A	2.2km 12 GC3.05	… … …
(Event) Attribution	resolution (a): ensemble size: process realism:	… … …	… … …	… … …

Table 1: Preliminary version of previous, current and next generation global, regional and local climate model configurations with different resolution, ensemble size and process realism for selected applications

Priority activity 7) Contribute to model evaluation from the climate perspective

- Further develop model evaluation from a climate perspective including coupled as well as component evaluation, global climate system properties, diagnostic schemes for extremes, and user relevant metrics (e.g. to assess whether model improvement helps with impacts projections through reducing the need for bias correction)
- Exploit the fact that the Met Office model is seamless to learn from shorter, fully coupled and much longer (e.g. historical period) runs and from more extreme runs to check for unforeseen surprises in performance
- Implement diagnostics and metrics developed in projects with partners and add into central assessment package
- Improve model development/evaluation cycle to address climate issues as early as possible in the process
- Clearly articulate needs for observations to enable model evaluation and work with developers of observational information to effectively pull it through

First priority outcome 7) ESMValTool used for all routine model evaluation in time for CMIP7 (FY23/24)

- *transition from auto-assess to ESM-VAL tool and include climate variability (teleconnections and modes), initialised prediction information and climate change tests (climate sensitivity and feedbacks, 20th century simulation, transient climate evolution)*

Priority activity 8) Determine and understand the climate system response to external forcings and the limits to predictive skill

- Contribute to WCRP science and identify processes whose poor or missing representation in our models limit the reliability of climate prediction and projection
- Improve understanding of these processes and their implications, and target model development at them (e.g. the double ITCZ problem, Southern Ocean SST bias, ice sheets, signal to noise paradox)
- Understand the sources of predictability from seasonal to centennial timescales
- Understand the cause of regional prediction and projection uncertainty for the UK and other focus regions (e.g. the processes that produce extreme events and drive their future changes, teleconnections and how they change, limits of predictability of regional climate across timescales, importance of internal variability in the coming decades)
- Understand the relationship between climate change and ecosystems, in particular processes related to biophysical feedbacks and impacts e.g. soil moisture, river flows, vegetation productivity, ocean change
- Exploit our unique seamless modelling position to approach this topic

First priority outcome 8) Climate sensitivity perspective paper (FY20/21)

- *Includes high ECS and transient response and the changing role of models in Climate Science*

Priority activity 9) Understand the potential for and consequences of high impact, low probability (HILP) outcomes tipping points in the climate system

- Increase emphasis on evaluating and managing the risks associated with low probability, high impact tails of distributions (HILP/H++) and understand the physical nature of these plausible extremes
- Review ongoing science on HILP events and tipping points and decide where we best contribute to the WCRP evidence base using our advanced seamless modelling system
- Assess potential impacts of passing tipping points and develop methods to integrate understanding from this area with the advice to policy from mainstream projections
- Understand how plausible a collapse of the AMOC and Antarctic ice sheet is, if tipping points are coupled and what are the impacts of passing tipping points
- Build capability to address new questions on system thresholds for example for polar and Amazon regions
- Determine what tools are required including GCMs but also simpler models, observations and emulators
- Investigate actionable early warning systems for abrupt changes

First priority outcome 9) AMOC tipping points perspective paper (FY21/22)

- *Includes simulation of relevant physics in our climate model*

Priority activity 10) Develop (event) attribution and near-term prediction science

- Develop (event) attribution and underpinning understanding (also of the impacts) needed to make authoritative statements about emerging severe weather events
- Develop seasonal and decadal prediction capability by increased understanding of the sources and mechanisms of year to year and multiyear climate variability and improved prediction systems
- Focus on the different forcings and natural variability across seasonal to decadal through to centennial timescales
- Provide coherent (event) attribution and near-term prediction advice from different sources of information for Global, North Atlantic / UK region (and other focus regions)

First priority outcome 10) Proof of concept of operational event attribution system (FY21/22)

- *Part of Copernicus C3S consortium deliverable*
- *Includes communication aspects*

National Capability

Priority activity 11) Develop improved observed data sets of GCOS ECVs and UK observed data sets

- Maintain and develop existing global and UK 'Had' family of datasets, include historical data rescued in ACRE and other digitization projects and describe uncertainties using ensembles and other techniques
- Choose GCOS ECVs (including extremes of ECVs) which we develop ourselves, those for which we work with partners and those which we advocate others to develop
- Implement process for enabling development of experimental data sets of new variables which can be fast tracked to enable test uses
- Explore needs for developing new impact relevant data sets (and proxies) for hail, lightning, wind storms, fire weather, etc.
- Focus on data sets of extremes for the UK (both climate extremes and high impact weather events) and UK-responsibility observations back to 1800 and stimulate and coordinate rescue of historical data to improve such data sets
- Develop new UK climate reference normals for WMOs new normal period 1991-2020 (includes question of non-stationary normal)
- Work internally with Observations to explore the climate potential of new sensing technologies, autonomous measurement techniques (internet of things) and citizen science
- Contribute to ECWMF and NOAA 20CR reanalysis efforts and consider restarting Met Office global and regional reanalysis activities that are complementary

First priority outcome 11) Updated global temperature analysis extended back to the 18th century from GloSAT (FY23/24)

- *Example of aspiration for GCOS ECVs*

Priority activity 12) Design, produce and deliver climate change simulations for CMIP and UKCP and seasonal/decadal predictions for WMO

- Engage in scoping of CMIP7 and CMIP8, in collaboration with NERC, to influence the overall scope
- Develop contributions (including experimental design) and document these in the scientific literature
- Prioritize to which future MIPs we will contribute
- Avoid using cutting-edge versions of our model which have not been sufficiently evaluated for CMIP
- Commit to a long-term UKESM national capability which requires UKESM development as part of a collaborative effort
- Develop and deliver regular seasonal and decadal climate predictions as part of our WMO Lead Centre activities

- Define contributions to regional modelling in PRECIS and CORDEX (working with Applied Science)

First priority outcome 12) CMIP7 contribution (FY26/27)

- *Includes contribution to scoping CMIP7 based on lessons learned from CMIP6*

Priority activity 13) Exploit data sciences tools in Climate Science

- Support the Corporate Strategic Action and capitalize on data sciences opportunities and complement the current simulation approaches with cutting-edge machine learning and other data science techniques
- Leverage data sciences techniques for a breadth of climate applications including data curation, error characterization of observations, model development, post processing and hazard to impacts work
- Develop the necessary cloud technology, machine learning, block chain knowledge and scaling capability
- Develop machine learning approaches, with an increasing role for emulators and surrogate model components engineered by ML, and integrate these into the modelling systems at an appropriate point in the development cycle
- Build in some flexibility in the HCCP to take advantage of new data sciences approaches and allow for relatively quick pivot resource to be delivered in response to anything that starts to show early promise

First priority outcome 13) Corporate Strategic Action 8 "Exploit data sciences for the benefit of our customers" (FY20/21)

- *Programme of targeted outreach (communication material to inform on the ongoing data sciences work and the progress of this action targeted to a wider community and to inspire our own scientists and engineers on how data sciences can be used in the Met Office research and production enterprise)*
- *Initial underpinning capability to enable data sciences (software solutions/systems/tools and access to cloud computation)*
- *Training scheme for all staff at all levels of competence and an active community of practice that supports communication of learning to a wider audience*
- *Pilot projects selected from a wider pool of concrete examples of projects using data sciences including one end to end application across different directorates (with key learning points captured and incorporated into our development plans for future projects)*
- *Guide for how to turn pilot project experience into operational business as usual including desired partnerships with 2-3 UK institutes for operational implementation*

Priority activity 14) Prepare for future supercomputer architectures

- Contribute appropriately to the re-engineering of the Met Office simulation approach in the science-wide Next Generation Modelling Systems (NGMS) programme, replacing the Unified Model with LFRic, to better exploit Exascale computing architectures (implementing separation of concerns, co-design and data science principles)
- Develop the infrastructure to make running, testing and evaluating the model easier (also for our partners)
- Change data workflows with more "in-machine" or "online" analysis, more parallel "post-processing" and capability to visualize and evaluate data on the fly during model runs (e.g. calculating ensemble statistics as an ensemble runs because storage not increasing in line with HPC and tools may not keep scaling with data volumes)
- Define pathways for uptake of this re-engineering work in Climate Science

First priority outcome 14) LFRic-based climate model ready for CMIP8 (FY25/26)

- *Jointly with Weather/Foundation Science*
- *Ongoing engagement to ensure Climate Science requirements are considered at all stages in LFRic development*

Priority activity 15) Form the technical core of a National Climate Science Capability

- Provide the IT tools, expert guidance, and support required to undertake the key technical elements of other activities in this Roadmap
- Provide (fixed) releases of our climate models to help the academic community get familiar and make this an effective tool
- Work with NCAS CMS to enable them to provide effective support to the UK academic community
- Make best use of the Met Office data services platforms together with other external cloud hubs for which sophisticated services have been developed (ESGF for CMIP, CEDA for UKCP18, Copernicus climate data store, DIAS etc)
- Enable running of common/shared impact models/metrics/analyses on common datasets across institutes
- Follow the 8 Met Office Data Strategy principles and implement FAIR principles of data management
- Engage with the development of, and comply with open data policy regulations and with journal/partner/sponsor requirements
- Guide development of observational data set production systems through system maturity matrices (e.g. as developed by the CORE-CLIMAX EU-project)
- Ensure systems for production of observational data are robust, supported and enable routine development
- Develop fit-for-purpose archive for climate observations that links metadata, change history, source with data
- Support interoperability and standardize the internal process for climate data management, use fewer repositories for our observational and model data and maintain overview lists of all model experiments and data available for each experiment

- Use standardized IT implementations for different projects (e.g. CMIP solution also for regional models and UKCP) and include IT sanity checks in all projects gate keeping new developments
- Encourage open science and communication (e.g. using Jupyter Notebook) to make tutorials and demonstrators and provision of user guides

First priority outcome 15) First official version of a National Climate Capability platform (FY23/24)

- *Data handling system able to cope with significantly larger volumes of data and improved end-to-end processing environment*
- *First version includes pointers to observational data, climate models and bench mark simulations (in addition to available CMIP runs and seasonal and decadal predictions)*
- *Consistent guidelines for use of all data sets making them more easily discoverable, documented and accessible, without imposing disproportionate overheads on scientists and scientific software engineers*

Cross cutting activities

Priority activity 16) Make Climate Science communication a mainstream activity

- Become more innovative and pro-active in Climate Science communication
- Engage scientists in communication activities and develop their skills working with communication experts
- Provide opportunities for more scientists and scientific software engineers to go and present new scientific insights and technological developments directly to the Government sponsors
- Value and recognise the importance of this work and overcome barriers (time, recognition, dissent views, training and support) that prevent staff from engaging in science communication activities
- Develop sound approaches routed in communication theory to understand our audiences, maximise the impact of the communication and monitor its effectiveness
- Work with People Committee to establish career paths in Climate Science communication either full time or part time
- Lead the debates on new climate model results (e.g. the high ECS in CMIP6 models) in the international scientific arena, for Government stakeholders and in the media and provide an authoritative community voice
- Act as hub for trusted information for UK government and public with a direct link to the peer reviewed underpinning science which provides reassurance that climate advice is built on science of the highest quality
- Organize quality assurance or assessment of our communication outputs (e.g. standards for data visualisation, producing graphics of datasets, giving talks, interviews and how to measure how effective they are etc.)
- Broaden the remit of the KI team (who take the climate research and translate it into the evidence needed by the sponsoring Government Departments to underpin policy) to cover translation/Q&A/briefings for all our sponsors using the Met Office website and social media and to act as a conduit providing support, direction and links to scientists to do the communicating
- Prepare at an earlier stage for upcoming significant weather events through fact sheets, infographics, webpages etc
- Develop innovative ways to visualise and communicate climate data, in a way more likely to resonate with a public audience (e.g. the climate dashboard, infographics, video explainers, storylines around aspects of everyday life)
- Work internally with the Operations (OPS) Centre (e.g. to appoint staff members to work with OPS at the time of a significant weather event and enabling meteorologists to add a climate component to their daily weather messages)

First priority outcome 16) Calendar of pro-active and event-based science communication activities for COP26 (FY20/21)

- *Includes events that note the 30th anniversary of the Hadley Centre in 2020*
- *Addresses stakeholders and public audience*

Priority activity 17) Empower staff by training and development opportunities and personal accountability

- In line with the Met Office People Strategy, ensure that our 3 Strategic People Actions (Transforming our leadership capability for the future; Enhancing equality, diversity and inclusion; Enabling and developing our people) are delivered over the next 10 years (working with the Science Learning and Development Group and Human Resources /Partners and Organisational Development)
- Support the delivery of current and future skills requirements including nurturing scientific, IT and communication excellence, with a focus on high impact publications, quality assurance, excellence in model and dataset development and software
- Develop an atmosphere of transparency and trust and work increasingly in an open science and open data context
- Support the People Committee's work on Professions and Roles and the Chief Scientist's work on improving the Government Science and Engineering Profession's Skills Framework with the aim that career paths for all staff will be clearer and career development options will be improved (also for scientific software engineers and communication experts)
- Out-reach to future possible talent through our support of training, apprenticeships, summer schools and hackathons
- Find hybrid solutions to fixed and flexible desking to provide optimal conditions for science and services development
- Limit the sectors in which we are active to avoid spreading ourselves thin and only embark on new projects if these fit into this Roadmap and come with the required additional headcount
- Maintain a vibrant distinguished visitors programme
- Organize change management around this Roadmap
- Develop ways of working with our increasingly diverse funding base, that allow delivery of the science in this Roadmap
- Streamline project management and reporting to help ease the administration load on science staff and maintain agility to take up new things (e.g. making optimal use of the new so-called "deliverable tracker" across all projects)
- Develop guidance for productive and efficient use of different internal communication channels (MetNet, Glisser, trac/wiki, SharePoint, Office365, the external MOHC website)

First priority outcome 17) Definition of changed skill set required to deliver on this Roadmap (FY20/21)

- *Includes career paths for IT/data science and KI work*

Priority activity 18) Consider environmental impact and ethical aspects of our work

- Reduce the impact of our work on the environment
- Consider ways to limit travel to reduce carbon footprint, while maintaining a strong profile in the international science community
- Note the role of values (such as integrity and transparency) and ethical practices (such the need to engage with a community of practice in co-exploration of knowledge) in particular for our international projects
- Build on our long-term expertise in international projects and draw on social science expertise and skills from outside the Met Office to quality assure the ethical aspects of our work and exploit diversity
- Consider different modes of constructing and communicating climate information in cross-cultural contexts and the heterogeneity of developing nations

First priority outcome 18) Best practices for environmentally friendly and ethical ways of working (FY21/22)

- *Travel options and alternatives agreed with partners and the international community to enable remote participation/a new way of doing our business*
- *Active contributions to Met Office Corporate environment policies*
- *Addressing cultural differences part of international science projects (in particular Newton Science for Services projects with first implementation in WCSSP South-Africa)*

Partnerships

Priority activity 19) Establish the required partnerships

- Partner with MOAP universities, NERC institutes, UM partners and the international science community according the table below
- Develop more detailed future partnerships working internally with Science Partnerships

Science for Services
Work with the UK (and where appropriate, beyond) research community (and in particular the solutions part of NERC's science programmes) to develop and deliver policy advice and climate services, and on the need for a 'start-to-finish' process of co-design and co-produce with stakeholders
Partner with the Integrated Assessment Modelling community, e.g. by including human decision (and economic) theory
Work with UK partners with expertise in fields outside of MOHC expertise and/or who are applying MOHC science to risk assessments, to ensure appropriate application of climate science and to help inform future research directions and experimental design of projections

Pioneering Science
Benefit from climate model development experience and expertise in other centres and partner with UM and JWCRP (NERC and Met Office) partners and link up JWCRP modelling programmes for model components (JLMP, JMMP, UKCA) and coupling (UKESM, UKEP) and priority science challenges
Maintain a strong and sufficiently influential role in a small number of strategic international consortia to provide certain key elements of our modelling systems (currently NEMO, NEMOVAR, WaveWatch3, exploring ESMValTool)
Partner with model development teams in Weather/Foundation Science and with the JULES/UKESM community and internationally with the OBS4MIP and wider WCRP community

National Capability
Develop climate code jointly with NERC and other partners under the auspices of the JWCRP as supercomputing and data handling demand joining up with academia
Partner with NERC centres and STFC
Work with UK partners in a more organized way to form competitive advantage in climate research internationally
Work with NERC and academia to facilitate access to observational data sets, UM-based climate model configurations, community models (UKESM, JULES, NEMO), supercomputing hardware and data services

Continue structured partnerships in observational data set development (such as HadCRUT with UEA-CRU) and for the optimal use of observational data sets from elsewhere (such as global precipitation datasets) also for model evaluation
Work with NCEO and others to explore the climate potential of remote sensing observations (satellite, radar) for climate quality ECV data sets
Explore and adopt as appropriate novel non-gridded, non-stationary spatio-temporal representations of observations and their extremes partnering with academia on novel methodologies
Partner with the international event attribution community (e.g. World Weather Attribution) playing to our strength in integrated model-based assessments and communication
Partner with Alan Turing Institute and carefully selected UK universities, industry and international partners (UM partners and others)

Cross cutting
Develop mechanisms to obtain NERC/UKRI/academic contribution to Met Office climate science communication to be able to meet the wide range of needs
Work with others in communication and social sciences space and determine the optimal climate science communication role for the Met Office in the wider UK landscape and support existing communication pathways
Partner with strategically relevant CDTs to bring in talented, trained staff and provide PhD/MSc supervision opportunities for staff

Risk register and contingency plan

Priority activity 20) Determine the risks

- Identify key decision points and necessary flexibility measures to remain agile and to enable acting quickly on changing future demands and surprises as in the table below

[placeholder for future table with risk items for each pillar]

Science for Services

Pioneering Science

National Capability

Cross cutting