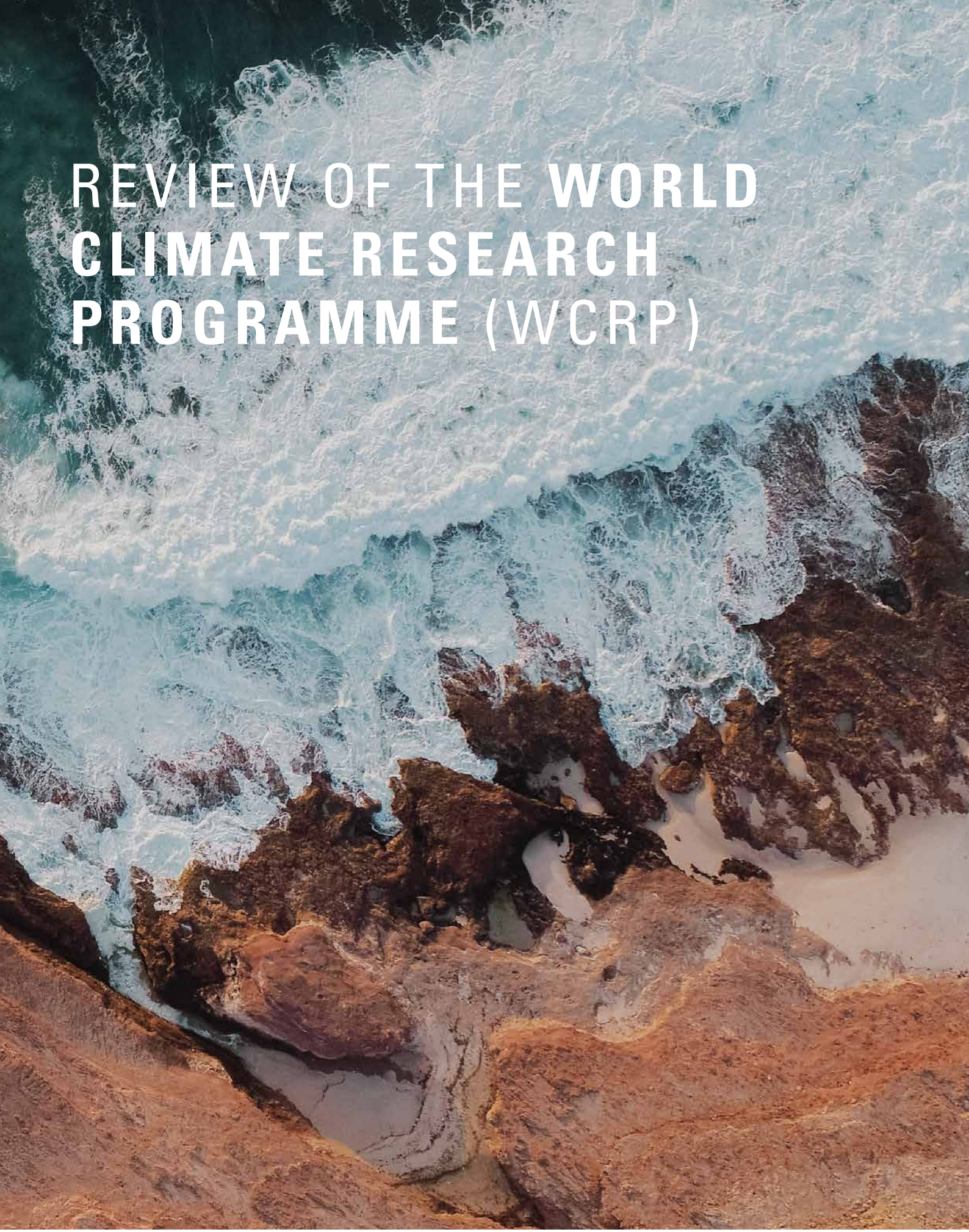
REVIEW OF THE **WORLD CLIMATE RESEARCH PROGRAMME** (WCRP)



WCRP World Climate Research Programme

International Science Council

WORLD METEOROLOGICAL ORGANIZATION

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

REVIEW OF THE **WORLD CLIMATE RESEARCH PROGRAMME** (WCRP)

Report from an ICSU-WMO-IOC Review Panel:
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ISC

The International Science Council (ISC) is a non-governmental organization with a unique global membership that brings together 40 international scientific Unions and Associations and over 140 national and regional scientific organisations including Academies and Research Councils. The ISC was created in 2018 as the result of a merger between the International Council for Science (ICSU, founded in 1931) and the International Social Science Council (ISSC, founded in 1952). The ISC brings together the natural and social sciences and is the largest global science organization of its type. The vision of the Council is to advance science as a global public good.

WMO

The World Meteorological Organization (WMO) is an intergovernmental organization with a membership of 191 Member States and Territories. It originated from the International Meteorological Organization (IMO), which was founded in 1873. Established by the ratification of the WMO Convention on 23 March 1950, WMO became the specialised agency of the United Nations for meteorology (weather and climate), operational hydrology and related geophysical sciences a year later.

IOC-UNESCO

The Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), established in 1960 as a body with functional autonomy within UNESCO, is the only competent organization for marine science within the UN system. The purpose of the Commission is to promote international cooperation and to coordinate programmes in research, services and capacity-building, in order to learn more about the nature and resources of the ocean and coastal areas and to apply that knowledge for the improvement of management, sustainable development, the protection of the marine environment, and the decision-making processes of its Member States.

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EXECUTIVE SUMMARY

The World Climate Research Programme (WCRP) was established in 1980 by three sponsors, the World Meteorological Organization (WMO), the International Council for Science (ICSU)*, and the Intergovernmental Oceanographic Commission (IOC) of UNESCO**, to facilitate the analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. Since then the WCRP has played a pivotal role in international climate science by initiating and coordinating major collaborative activities that could not have been delivered without the international cooperation which WCRP facilitates. Over the years there have been many notable examples, including WOCE, TOGA-COARE, GEWEX global datasets, and the CMIP archive that has underpinned successive IPCC reports.

WCRP does not fund research directly; it functions by engaging with, and gaining the commitment of, the international climate science community to its programme of work, and in turn ensuring that participants derive benefit from engaging in WCRP activities. Community engagement in WCRP continues to be broad and strong, and WCRP is recognized and valued for providing opportunities to work collaboratively to the greater benefit of the science.

WCRP is led by the Joint Scientific Committee (JSC), which formulates the overall scientific goals and concepts of the programme and organizes the required international coordination and research efforts that underpin it. In turn, the work of WCRP is supported by a Joint Planning Staff (JPS), hosted by WMO and led by the Director of WCRP whose role is to deliver the activities recommended by the JSC.

This review was instigated by the sponsors to ascertain the effectiveness of WCRP in delivering its mandate, how well it works in partnership with other organizations, and to advise on the future structure, governance and resourcing of the programme. A Panel (see page 71 for Review Panel membership) was appointed that reflects the scientific interests of the three sponsors, as well as covering the breadth of climate research, and its links to other organizations and to climate services. The review took place between February and October 2017, during which time the Panel met twice and took oral evidence from a broad range of participants, partners and stakeholders. It also took evidence from the sponsors, the JSC and the JPS on the governance, operational structure, management and resourcing of WCRP. In addition, it received comprehensive, written documents on the programme's activities.

After reviewing all the evidence, the Panel's judgement is that WCRP is at a critical point in its history, and that significant changes are required in its governance, structure and delivery for it to fulfil its mission in the context of 21st Century challenges. Moreover, the Panel is adamant that the core, underpinning climate science which WCRP delivers is needed more than ever, as society seeks solutions to climate change (Paris Agreement), to resilience to disasters (Sendai Agreement), and to sustainable development for the planet (UN Sustainable Development Goals). Without a strong foundation in climate science and prediction, none of these challenges can be addressed in a robust, cost-effective and durable way. However, the Panel is very clear that it is not the role of WCRP to deliver the end products and services, but that it should provide the bedrock knowledge, based on which these can be developed.

Since its inception, the key strength of WCRP has been its focus on cutting-edge physical climate science where international coordination enables scientific advances that would not happen otherwise. This must continue to be its focus, which means prioritizing what it does and recognizing where its unique role as a facilitator and integrator of climate research makes a difference. The Panel stressed that if WCRP does not continue to provide clear leadership, there is a danger of losing the engagement of the scientific community and its funders. WCRP is a strong brand and as such it needs to play an advocacy role, to interact strategically with big funders, and to focus on strategic positioning of WCRP in the climate arena. There is need for an important, recognized, international and collective voice for climate science, and WCRP should continue to meet this need.

The Panel was therefore very concerned to learn that WCRP does not currently operate in the context of an up-to-date overarching strategy; as a consequence, it is struggling to set priorities and to bring to an end less important activities. This must be rectified as soon as possible, with the findings of this review being fully addressed in the process. The current structure of WCRP has become increasingly unwieldy. It has evolved largely by accumulation

*On 4 July 2018, ICSU became the International Science Council (ISC), following the merger with the International Social Science Council. Given that the review took place in 2017, the previous name ICSU is used throughout this report. From 4 July 2018, the ISC is the co-sponsor of WCRP.

** IOC of UNESCO became a co-sponsor in 1993

of new working and advisory groups, and the initiation of the Grand Challenges. It continues to be built around its four Core Projects (GEWEX, CLIVAR, SPARC and CLIC), which have been in existence for a long time. Consequently, the structure and remit of the various elements of WCRP may not be valid in an era where more holistic Earth system and seamless weather-to-climate science approaches are needed, and where society requires science and services from the global to the local scale.

The Panel therefore recommends that WCRP seeks to simplify and re-purpose its core activities around a new structure that takes a holistic view of the climate system, and brings together the separate components of the climate system currently covered individually by the existing Core Projects. Recalling the principal aims of WCRP, which are to determine "to what extent climate can be predicted, and the extent of man's influence on climate", then these should be the fundamental cornerstones, here termed the 'capabilities', of the future WCRP. These capabilities need to be underpinned by a third capability in fundamental research on Earth system processes across timescales. These three 'Capability Themes' should replace the current Core Projects, and should act to frame WCRP's long-term research agenda.

Within and between the Capability Themes should be a small set of high-profile, but time-limited (5-10 years maximum), Cross-cutting Research Projects. Over time there should be an increasing emphasis on these projects as a means of attracting a new generation of scientists, for showcasing cutting-edge WCRP science, and for demonstrating the policy relevance of WCRP. The Research Projects should draw on the Capability Themes, and when appropriate, seek to co-design and implement the plan of work with other major programmes such as the World Weather Research Programme (WWRP) and Future Earth.

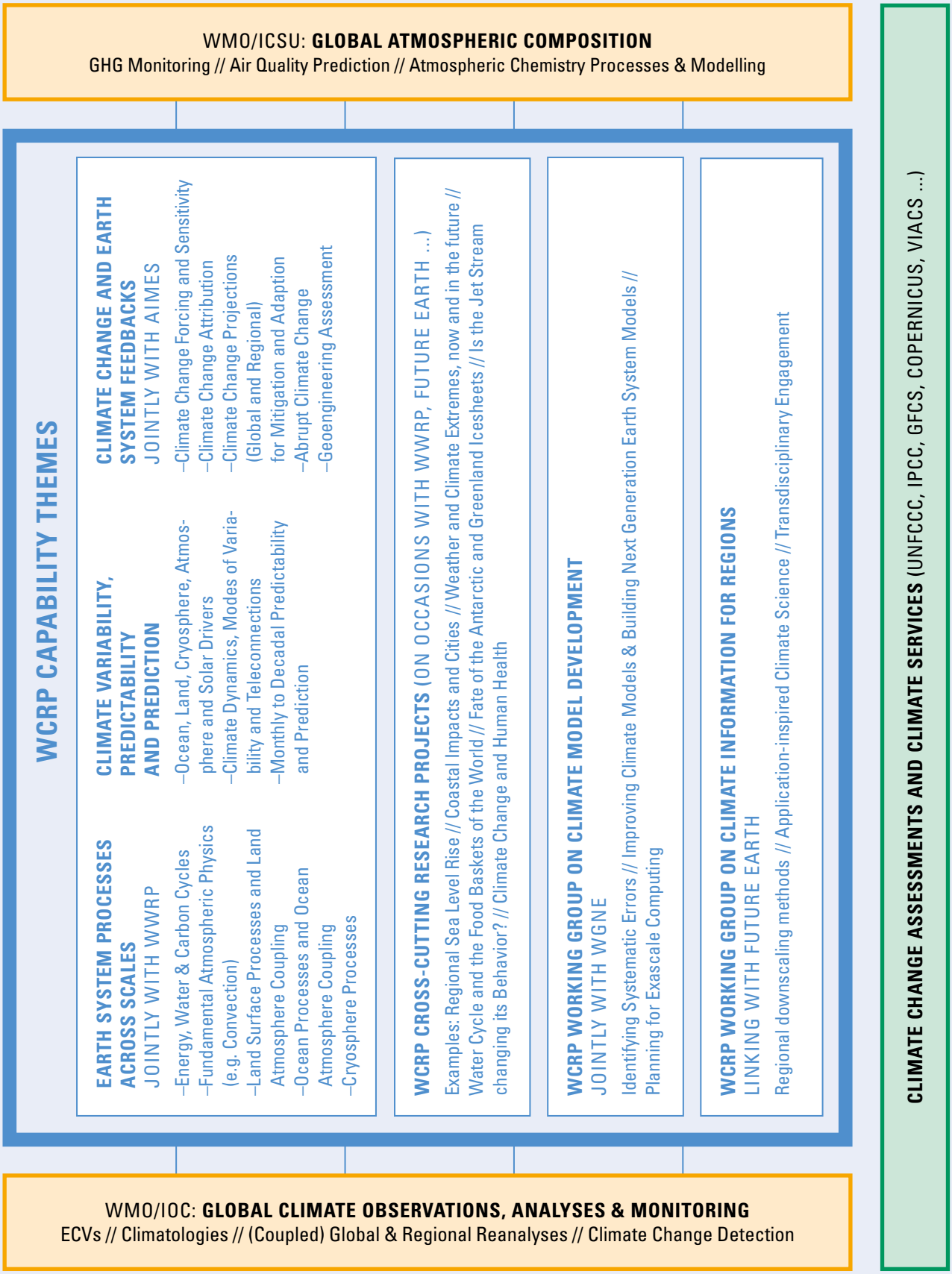
At the same time the Modelling Working Groups should be consolidated within the Capability Themes, to ensure that they are fully integrated with the science. This change recognizes that modelling is now the central plank for delivering science in WCRP, and that therefore the need for separate modelling working groups has passed, although their specific activities are still central to delivering WCRP's mission. However, the Panel is concerned that there is insufficient emphasis on model development, which continues to be hard work to prioritize and energize, yet is vitally important for WCRP and its partners. With the new agendas of seamlessness, of high-resolution Earth system modelling and the advent of exascale computing, with all that that implies in building a new generation of codes, a major push is required in climate model development. The Panel recommends that a new WCRP Working Group on Climate Model Development should be established, which would take the lead in the science for next-generation Earth system modelling and provide a forum for engaging with the vendors on the design of exascale machines.

The Panel also recommends that WCRP's approach to regional climate issues and the links through to applications require further and careful thought. Although WCRP should continue to focus on the fundamental, underpinning science that increasingly addresses regional and local climate on all timescales, it is essential that it formalizes and improves its links to applications and user needs, which involves more interdisciplinary approaches, including linking to the social sciences. These increasingly require information at the regional and even local level, and the panel commends WCRP for its thrust on providing 'Climate Information for Regions' and establishing an International Office to lead in delivering this. This activity should be formalized within a new Working Group that would act as a bridge between WCRP, GFCS and other climate service providers, by promoting applied and translational research and facilitating dialogues between underpinning climate science and customer-relevant services.

The Panel therefore proposes the following as a possible new structure for WCRP, for consideration by the sponsors, the JSC and the climate science community. This structure also seeks to place WCRP in the context of other, related activities on which WCRP will depend and also contribute. Based on the evidence that the Panel heard, the Panel proposes some restructuring of these activities for WMO and its partners to consider, with a view to providing greater coherence across the whole Earth, climate and weather system portfolio, and potentially leading to improved cooperation and more effective use of resources. WCRP is presented in the enclosed blue elements, and linkages with the surrounding boxes are implicit (see graph 1).

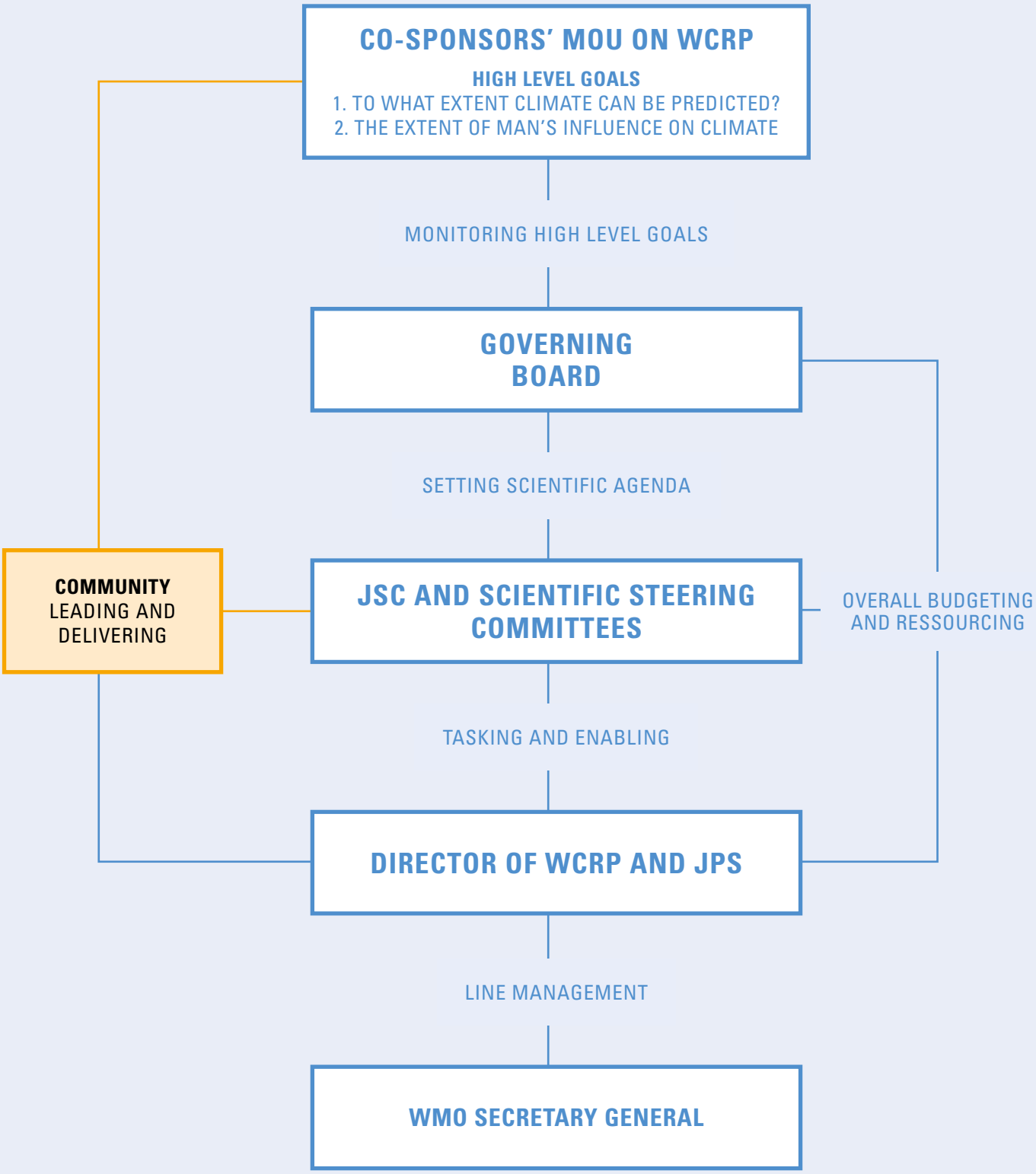
GRAPH 1

Strawman proposal for a new WCRP structure



GRAPH 2

Strawman proposal for a new Governance structure



Alongside the proposed re-structuring, the Panel also recommends stronger governance of WCRP, to address the weaknesses revealed during the review related to governance, management and resourcing, and the engagement of the co-sponsors and research funders in sustaining the programme (see graph 2). A formal, high-level Governing Board should be established by the sponsors, with the overall responsibility for WCRP residing with this Board and its Chairperson. The Board would oversee the implementation of the WCRP MoU and ensure the high-level goals of WCRP are delivered; it would facilitate the interaction with, and engagement of, the sponsors and other key stakeholders; and it would manage high-level risks and change, especially associated with funding. Its first activity should be the development of a new MoU to reflect new research agendas, the roles and responsibilities of the sponsors, the new governance structure, and the functioning of the JPS.

As outlined below, the overall scientific leadership of WCRP and its interactions with the community would continue to reside with the JSC. With the Governing Board in place, the JSC would be freed up to exercise its intended role, which is to provide science leadership, to set the science strategy and oversee its implementation, and to build a strong community of international scientists to work on grand challenge problems that require international coordination. The JSC tasks the JPS and its Director, whose responsibilities are to support WCRP's scientific activities, to facilitate international engagement and partnerships and manage the programme's resources. The sponsors should also consider whether the role of Director, and the JPS in general, should have more day-to-day discretionary executive power, enabling the JPS to be agile and responsive, but always in line with the guidance and direction of the JSC and in consultation with the JSC Chair and Officers as appropriate.

WCRP is at a critical point with regard to funding to support its activities. The current situation of a reducing funding base for the JPS is untenable, but yet the WCRP is one of the most highly regarded and widely recognized of the research efforts supported by the sponsors. Many of the projects that it delivers could not have been achieved without the international coordination and leadership that WCRP provides. The gearing of national investments that can be achieved from a small investment in WCRP is impressive and can be game-changing, and yet the community continues to struggle to find resources and funding from WCRP to support these activities.

The Panel therefore urges that the sponsors redouble their efforts to support the JPS financially at a higher level of enabling funding, so that it can operate more effectively, support the community in coming together to coordinate science, and continue to deliver the research outputs that society increasingly depends on.

In summary, the Panel commends WCRP for its long and vital contribution to international climate research, and intends that this review will help WCRP to plan its future and ensure that fundamental climate research continues to thrive and serve the needs of society as it tackles major 21st Century challenges.

The Panel makes the following recommendations and looks forward to significant progress in implementing these in time for the 40th anniversary of WCRP in 2020:

1 SCIENCE STRATEGY

A new ten-year WCRP science strategy and related five-year implementation plan must be developed as soon as possible in discussion with the sponsors and with wide consultation and community buy-in.

WCRP currently does not appear to operate within the context of an up-to-date, overarching and clearly focused strategy and this must be rectified as soon as possible. A consequence of the lack of a strong, and strongly implemented, strategy is that WCRP is struggling to set priorities and so to stop less important activities. If WCRP does not continue to provide clear leadership, there is a danger of losing the engagement of the scientific community and its funders, so a new strategy is badly needed.

In developing its strategy WCRP needs to reflect how climate science has evolved over recent decades, with the emergence of holistic Earth system modelling, of seamless weather and climate science, of the increasing skill and reliability of climate prediction, and the growing agenda for an increasing number of climate predictions and projections to guide resilience, adaptation and mitigation actions. The new strategy should respond directly to this review and encapsulate the following recommendations:

- It should identify the key societal needs for fundamental climate research to tackle 21st Century problems across climate resilience, adaptation and mitigation;
- It should focus on the scientific priorities where WCRP can make a unique contribution through its international, coordinated and integrative activities;
- It should reflect the recommendations regarding the structure of WCRP;
- It should show where recommendations regarding partnerships will add value to WCRP;
- Although the focus should be on providing the bedrock climate science, the strategy should demonstrate a clear pathway to applications, i.e. climate services;
- A short synthesis of the new WCRP strategy should be produced to enable the WCRP community to engage with potential new sponsors and funders and to act as advocates for fundamental climate research.

2 GOVERNANCE AND THE MOU

A formal high-level Governing Board for WCRP should be established to enable more effective engagement with the sponsors and enable them to fulfil their responsibilities for the programme. A new MoU should be put in place to reflect changes in governance, operations and structure.

The 2009 Review of the WCRP recommended (Recommendation 9) that:"WCRP's sponsors should meet regularly to review their mutual responsibilities for the Programme …". The issues that led to this recommendation remain in place today. The JSC and JPS are struggling to manage upwards and the sponsors are concerned with the responsiveness of the WCRP and its strategic alignment. The terms of the WCRP MoU are not being implemented effectively.

The core (and initial) membership of the Governing Board should include high-level representation from the sponsors, who would also recommend other members and elect an interim Chair. The Review Panel concluded that there is also a need for more explicit identification of key partners, and that a Governing Board would provide a means to recognize such partnerships. The JSC Chair and Vice-Chair should be ex-officio members.

The JPS should provide the secretariat for the Governing Board. Once fully constituted, the Chair should be an independent member. The membership should not exceed eight and, other than the sponsors, should be rotated on a biannual basis.

The terms of reference of the Governing Board should include:

- Overseeing the implementation of the terms of the WCRP MoU;
- Setting the overall aims and managing communication and interaction with, and engagement of, the sponsors and other key stakeholders;
- Approving the high-level science strategy and structure of WCRP;
- Managing high-level risk and change, especially associated with funding;
- Overseeing resource mobilization and garnering enabling support for administration.

The Governing Board would meet at least once per year, either through video-/tele-conference or in association with the JSC if that were convenient. The Board would be self-supporting. A first task of the Governing Board would be to update the MoU to include the changes to governance and any other relevant items needed to refresh it.

The advice of the JSC would be sought on all agenda items. The primacy of the JSC for scientific advice and setting scientific strategy and priorities would remain; the Governing Board would take overall responsibility for WCRP on behalf of the sponsors and in so doing it would provide oversight on matters such as resource mobilization, administrative support and engagement.

The Governing Board should consider appropriate metrics for assessing the performance of WCRP.

3 SCIENTIFIC LEADERSHIP

The JSC should be re-invigorated to focus on providing science leadership, setting the science strategy and overseeing its implementation, including establishing partnerships, and building a strong community of international scientists to work on grand challenge research problems that require international coordination.

The complexity of the WCRP structure, with its Core Projects, Working Groups and now Grand Challenges, means that the JSC meetings tend to be largely taken up by reviewing the activities rather than setting the strategy and overall direction. The JSC meetings need to be more focused on strategy and vision than has recently been the case. Overall the Panel concluded that morale in the JSC is not strong and that this is having a detrimental impact on WCRP as a whole.

With the Governing Board being responsible for managing the interface between the JSC, the sponsors and other external clients, the JSC would be freed up to exercise its intended role, which is to provide science leadership, to set the science strategy and oversee its implementation, and to build a strong community of international scientists to work on grand challenge problems that require international coordination.

→ The Panel recommends that the sponsors consider the constitution of the JSC and how members are nominated. The Panel supports the suggestions for an open call for nominations based on science excellence and leadership, and that the sponsors consider whether the JSC membership could be reduced from 18 to facilitate more effective decision-making.

4 OPERATIONS

Additional clarity should be provided in the terms of reference, structure and functions of the Joint Planning Staff and the Director of WCRP, to ensure that the JPS works effectively with the JSC to support its scientific activities, to facilitate international engagement and partnerships, and to manage WCRP's resources.

The JPS is a vital part of WCRP. Its role is to assist the JSC in implementing their decisions, and to facilitate the collaborative actions of the various elements of WCRP. The JPS is led by the Director of WCRP. His/her role is to lead the staff and be responsible for the scientific and technical tasks discharged by the JPS to the Chair of the JSC, acting on behalf of the sponsors.

→ As part of the recommended improvements in governance (Recommendation 2), the MoU should be revised to provide unambiguous guiddance for the roles of the WCRP Director and the JPS with respect to responsibility and accountability, to the guidance and direction of the JSC, and in terms of representation of the WCRP. The title of the role in itself can lead to confusion as to where decision-making and strategic direction is set within WCRP. The Panel believes the MoU is clear that those functions lie with the JSC (and in future also with the Governing Board).

→ The sponsors should consider whether the role of the Director of WCRP, and the JPS in general, should have more day-to-day discretionary executive administrative responsibility, enabling the JPS to be agile and responsive, but always in line with the guidance and direction of the JSC and in consultation with the JSC Chair and Officers as appropriate. The word "guide" should be avoided in the ToR of the JPS to avoid any confusion with the role of the JSC.

→ The name World Climate Research Programme should be used exclusively for the research enterprise defined in the MoU. In particular, the term should be avoided for administrative units unless the distinction is made clear (e.g. the Joint Planning Staff of WCRP).

→ Depending upon decisions with respect to governance and a Governing Board, the terms of reference should be updated to include support for the Governing Board and its role.

5 STRUCTURE

The JSC, in consultation with the newly created Governing Board, should work with the science community to establish a new structure for the WCRP research effort that best serves its new strategy and involves a simplified set of delivery mechanisms.

The existing structure is not the structure of tomorrow. However, in creating a new structure, it will be important not to destroy the legacy of what has been created – a community of engaged scientists; it will require a willingness from the community to change and for the community to be part of the change process.

The Panel anticipates that the JSC will work with the community and the newly created Governing Board to define a new structure that best serves its new strategy. The following aspects should be considered:

- That the new structure comprises a combination of a small set of top-level scientific problems with explicit societal relevance (which could be called Grand Challenges or cross-cutting Research Projects that are time-limited (e.g. 5 to 10 years) in their delivery), together with a small number of enduring Capability Themes that would nurture the long-term expertise needed to advise on, and contribute to these scientific problems being addressed effectively.

- The Capability Themes would replace the current Core Projects. The existing Core Projects have been in place for a long time and so may not be ideally structured to help deliver the scientific goals of today and the future, to be articulated in the new WCRP Strategy. These Capability Themes should aim to take a holistic Earth system approach, whilst recognizing that research on individual components of the Earth system remains essential.

- The modelling Working Groups should become part of the Capability Themes to reflect the importance of modelling as a tool for delivering WCRP science. The WCRP leadership should consider how best to reinvigorate climate model development in any revised structure.

- The Research Projects should directly address the goals of the new WCRP Strategy (and so they may not necessarily have a strong link to the existing Grand Challenges) and identify high-priority issues that require international partnership and coordination; they should yield "actionable information" for decision-makers.

- Regarding the existing structural elements, the Panel concluded that the case for continuing with WMAC and WDAC in any new structure was not strong. They potentially overlap with other relevant activities within WMO and elsewhere, such as WGNE and GCOS, and that in the future any such advisory councils should cover the breadth of WMO scientific activities. Consequently, the Panel recommends they not be a feature of the new structure.

- The Panel strongly recommends that the concepts of co-design and co-production be exploited as much as possible. This will involve the structural elements within WCRP strongly linking across to other proposed activities outside of WCRP, such as those within WWRP, GFCS, Future Earth, etc. This should be borne in mind as the new structure is being planned.

6 FINANCING

In light of the importance to society of the goals of WCRP and the precarious level of current financial support for the programme, the sponsors should redouble their efforts to support WCRP financially at a higher level of enabling funding so that it can operate more effectively.

WCRP is one of the most highly regarded and widely recognized of the research efforts supported by the sponsors. There are two distinct elements to the funding: that which supports the enabling activities of the WCRP executive ("enabling funding") and that which directly supports the research ("research funding"). This recommendation relates primarily to the enabling fund.

It should be more fully recognized than it is currently, that the different sponsors provide both financial and in-kind support and that the route for the financing is sometimes circuitous and therefore not always made fully visible or recognized. Elements that should help to improve the funding situation are as follows:

- The sponsors should agree to be clear about the financial and in-kind contributions that they make to WCRP. This needs to factor in, and be explicit about, the complex pathways for this funding to flow to WCRP. The WCRP Governing Board should examine the enabling funding annually and be pro-active in making the case for that funding within the sponsoring organizations, in accordance with their capacities.

- WCRP should, via its sponsors, encourage countries to make appropriate national contributions to the enabling funding, such as continuing to support International Project Offices and sponsoring Research Projects; a number of countries currently appear to be reducing rather than increasing their contributions.

- In future, there is a risk that research-funding could be increasingly diverted away from fundamental science. WCRP, through its Governing Board and the JSC, should play an advocacy role in mobilizing research funding for fundamental climate science. There is a need for a more strategic engagement with the research funding communities, and for someone who could talk at the higher level with the funders.

- Engagement with the Belmont Forum of research funders should be at a high level, ideally through a WCRP research funding representative. The Panel recommends that WCRP and its sponsors need to partner with others to influence Belmont Forum research funding. WCRP needs to be seen as a strong partner of Future Earth, and to be at the table. Only in this way can WCRP and its sponsors can continue to influence the research funding community about the need for fundamental science.

7 SCIENCE TO SERVICE

WCRP should take action to ensure its knowledge is brought to the service of society, especially in supporting the development of climate services.

While WCRP should continue to prioritize the advancement of fundamental science, it can and should seek opportunities to establish connections to relevant user communities through programme partnerships. In so doing, WCRP science can serve to inform quality services, and emerging practitioner needs can serve to inform further scientific inquiry.

- WCRP should pursue, in particular, partnering with Future Earth and its Knowledge-Action Networks. There are positive signs emerging of opportunities for productive research partnerships and these should be pro-actively developed by WCRP.

- WCRP should build pro-active bridges to the WMO's Global Framework for Climate Services and other science-to-service initiatives such as the Copernicus Climate Change Service and the Climate Services Partnership, by implementing a formal activity on Climate Information for Regions.

- A variety of other mechanisms for programme engagement should be explored. One option is through representation on the recommended Governing Board of WCRP. A second is to establish a (cross-cutting) working group that serves as liaison to the partner programmes.

- In engaging with climate services, WCRP should explore, and as appropriate pursue, opportunities this may offer for obtaining additional funding for its fundamental science.

8 PARTNERSHIP

WCRP should seek to develop strategic and strong partnerships with other WMO research programmes (specifically WWRP and GAW), with GCOS, and with Future Earth.

WCRP should be pro-active in establishing a process of full engagement with these partners via the practice of co-design of projects to exploit the synergies that seamlessness offers. A co-designed Roadmap for exploitation of such synergies would be an important first step to draw on a great research constituency. We recommend that:

- WCRP urgently explores the option of the co-design and co-production of projects that address key scientific challenges of common interest to WCRP, WWRP, GAW and Future Earth.

- Future Earth should be brought in as a high-level partner. The linkage between WCRP and Future Earth should be strengthened by a regular and formal set of meetings between the top-level management of the two initiatives to share experience and explore common interests, and also by jointly developing Knowledge-Action Networks, potentially involving other ICSU programmes. The strategy for collaboration, identification of areas of joint interest, and the creation of joint evaluation schemes for the collaboration, should be considered.

- WCRP should be open and dynamic for future opportunities to develop collaboration with new partners.

1 CONTEXT

The World Climate Research Programme (WCRP) was established in 1980 under the joint sponsorship of the International Council for Science (ICSU) and the World Meteorological Organization (WMO). In 1993, the Intergovernmental Oceanographic Commission (IOC) of UNESCO also became a sponsor. A joint agreement between the three sponsors was signed in 1993 that provides a definition of WCRP and the financial, governance and institutional arrangements for its international planning and co-ordination.

The mission of WCRP is to facilitate the analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. As stated in the original MoU, the WCRP aims to determine:

- to what extent climate can be predicted;
- the extent of Man's influence on climate.

These two principal aims remain valid and continue to underpin the work of WCRP.

The previous review of WCRP was conducted in late 2007-2008 with the review report published in early 2009; the review was undertaken simultaneously with a review of the International Geosphere-Biosphere Programme (IGBP) a research programme co-sponsored by ICSU and subsequently was absorbed within Future Earth. In 2016, the three sponsors of WCRP agreed to undertake another review of the programme in order to assess its achievements since 2009, including an assessment of the implementation of the recommendations that came out of the first review, and to provide directions for its strategic development in the future. In addition, the review would consider how to maxi-mize the future synergies between the strategic aims of WCRP and three sponsors, while ensuring scientific independence of WCRP.

1.1 CURRENT STRUCTURE AND GOVERNANCE OF WCRP

WCRP is led by the Joint Scientific Committee (JSC), comprised of 18 members appointed by the three sponsors. The JSC formulates the overall scientific goals and concepts of WCRP and organizes the required international coordination and research efforts that underpin the programme. The Chair of the JSC reports annually to the sponsors on the performance of the programme.

The work of the JSC and the rest of WCRP is supported by a Joint Planning Staff (JPS), which is hosted by the World Meteorological Organization (WMO) in Geneva, Switzerland but reports to WMO only on administrative and budget issues. The personnel of JPS are staff members of WMO, or are seconded by other sponsoring organizations.

The JPS is led by the Director of WCRP, who is selected by consensus agreement of the sponsors, who are cognizant of the recommendation made by the Officers of the JSC. The Director of WCRP is responsible to the Chairman of the JSC for the scientific and technical tasks discharged by the JPS, and to the WMO Secretary-General for financial and administrative matters. The Director of WCRP stepped down during the course of the Review and WMO has appointed an Acting Director as an interim measure.

WCRP works through a network of Core Projects, which focus on specific components of the climate system, and Working Groups which focus on specific applications of climate science, particularly involving numerical simulation. The Working Group on Numerical Experimentation (WGNE) is a shared activity with the WMO Commission for Atmospheric Science (CAS).

WCRP now also uses two supporting bodies to coordinate its work. These are the WCRP Modelling Advisory Council (WMAC), which promotes, coordinates and integrates modeling activities across WCRP; and the WCRP Data Advisory Council (WDAC), which acts as a single point of entry for all WCRP data, information and observation activities.

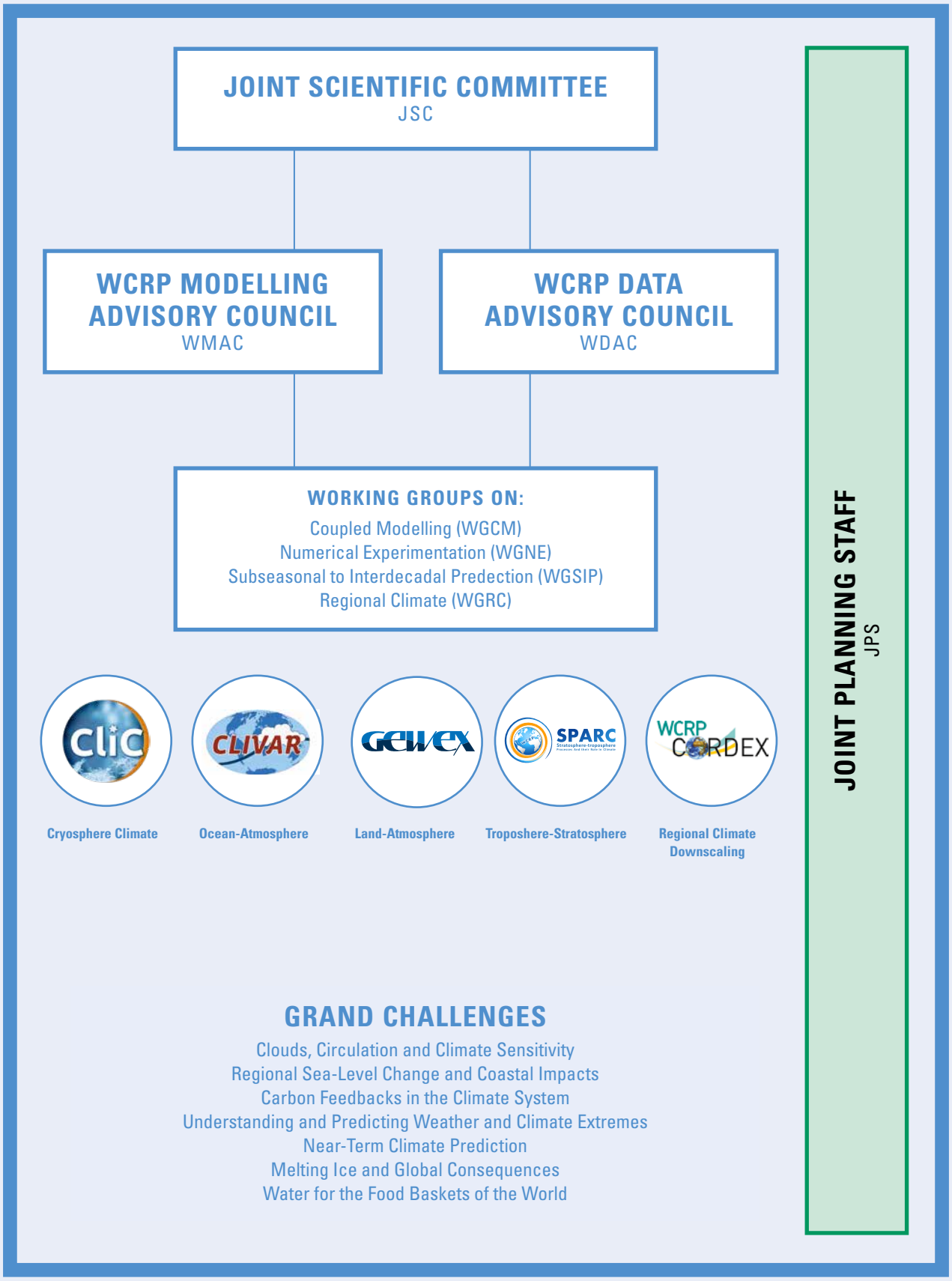
Most of these Core Projects and Working Groups have been in existence for many years and have a deep legacy of scientific achievement. They typically consist of a number of panels and working groups which focus on specific topics or specific regions; these have changed over time to reflect emerging scientific priorities or where the community perceives gaps in capability.

In the last decade, the Core Projects and Working Groups have been complemented by a number of Grand Challenges aimed at addressing specific topics that cut across the existing structure, so encouraging greater collaboration and cooperation between the Core Projects and Working Groups. The expectation is that these Grand Challenges will be time-limited.

The current organizational structure of WCRP is provided in graph 3. This also shows the recent

GRAPH 3

Current organizational structure of WCRP



addition of the regional climate downscaling project, CORDEX, in which the WCRP is a major player and which contributes regional climate change scenarios to the IPCC assessments.

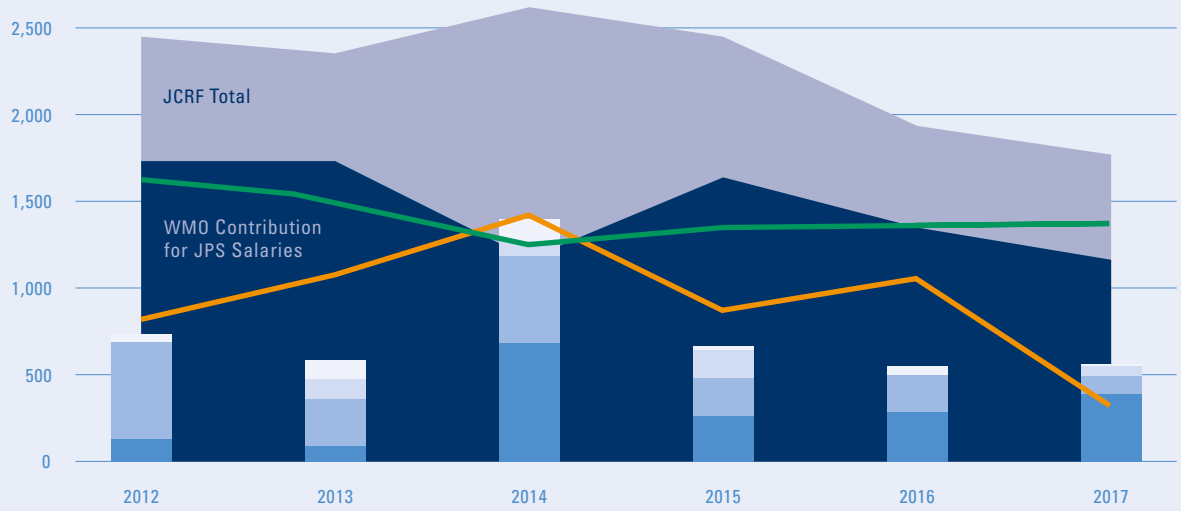
1.2 CURRENT FUNDING ARRANGEMENTS

Since the Programme's inception, WCRP activities have been supported through funding from its three sponsors. Under the terms of the MoU funding is provided as follows:

- A special account, to be known as the Joint Climate Research Fund (JCRF), will be established by the Secretary-General of WMO, and contributions to the JCRF will normally be made in equal amounts by WMO, IOC and ICSU. The JCRF is used to fund the JPS salaries of staff at WMO and, through its operations funds, coordination and meetings of the Core Projects and Working Groups.
- Budget estimates for the activities of the JSC and JPS in the biennium to follow are prepared by the JSC with the support of the JPS, and submitted for approval to the executive bodies of WMO, IOC and ICSU.
- Should there be any divergence between the level of biennial appropriations approved by the respective executive bodies, then the lowest approved level shall prevail.
- However, if one of these bodies is prepared to fund at a greater level without matching funds from the other organizations, the total level of appropriations may exceed that jointly agreed upon.
- Additional contributions or grants to the JCRF from sources other than WMO, IOC or ICSU may be accepted by the Secretary-General of WMO provided that the purposes of such contributions or grants are to support activities consistent with the aims and interests of the sponsoring organizations.

GRAPH 4

Annual operation of the Joint Climate Research Fund (JCRF) from 2012 to 2017



EXPENSES
- JPS Salaries
- WCRP Coordination

CONTRIBUTIONS
- Other Contributions
- IOC Contributions
- NATIONAL Contributions / ICSU
- WMO Contribution for WCRP coordination

Annual operation of the Joint Climate Research Funds (JCRF) from 2012 to 2017. The area chart shows the variation of annual income to JCRF; the "JCRF total" (dark grey area) is the summation of the WMO contribution for JPS salaries (dark blue area) and the general contributions for WCRP coordination (stocked columns), for each year. The stocked columns show the contributions to JCRF from the various entities. The line graphs show the expenses for JPS salaries and expenses for the WCRP activities (e.g. meetings of all Core Projects, Working Groups and other WCRP groups), respectively. The values for 2017 are indicative, reflecting the projected/estimated expenses and income.

In the early years, each sponsor contributed equally to the JCRF but over time the contributions from WMO increased, a trend which ICSU and IOC were unable to match. More recently ICSU and IOC contributions have declined as their operating models have changed, and pressures on their budgets from other sources have increased. The graph 4 shows the evolution of the JCRF over the last five years. The WMO contribution to JCRF is currently running at over 80 % of the total. In addition, national research funders have provided resources to support the Project Offices of the Core Projects, although those too have come under pressure in recent years. To sustain the JPS both WMO and IOC were able to contribute additional funds for the latter half of 2017.

1.3 REVIEW PROCESS AND EVIDENCE COLLECTION APPROACH

The Terms of Reference (ToR) for this Review are:

→ Provide strategic directions for future development of the Programme.

→ Review scientific achievements and impacts of WCRP since 2009 and the future plans, with specific attention to:

- **a** setting international scientific agenda on climate prediction and climate change,
- **b** providing opportunities for innovative research, including inter/trans-disciplinary research of high quality,
- **c** generating high-quality scientific outputs,
- **d** involving the scientific communities from all parts of the world, including developing countries, as well as attracting a younger generation of scientists,
- **e** generating scientific knowledge for climate services,
- **f** providing scientific input for major international policy processes and assessment activities (e.g. the Paris Agreement of UNFCCC, Agenda 2030, IPCC assessments).

→ Review appropriateness and effectiveness of the governance, operational structure, management and resourcing of WCRP. Specific attention should be given to:

- **a** providing recommendations on changes to be made in the existing agreement signed by three co-sponsors in 1993,
- **b** reviewing the roles and contributions of three co-sponsors,
- **c** assessing the adequacy of the competence, size and terms of reference of the Joint Scientific Committee,
- **d** assessing roles, effectiveness and complementarity of WCRP operational structures (groups, committees, etc.),
- **e** assessing the adequacy of Joint Planning Staff structure, its human and financial capacities, and modes of work, and
- **f** evaluating the adequacy and effectiveness of WCRP fundraising efforts.

→ Assess the implementation of the recommendations that came out of the 2009 WCRP Review.

→ Assess WCRP linkages and relationships within the climate science community (including with members and other programmes run by the co-sponsors, e.g. Future Earth, SCOR, SCAR), and also with non-academic stakeholders.

→ Assess the appropriateness and effectiveness of WCRP communication efforts for visibility of the Programme and its co-sponsors, as well as their positioning in the overall climate arena (including policy fora, e.g. the Paris Agreement).

→ Assess how the aims and strategy of WCRP complements and supports the strategies and priorities of three co-sponsors, and make recommendations on how synergies can be enhanced.

The WCRP review took place between February and October 2017. The review process consisted of two physical meetings and several teleconferences between members of the Review Panel.

The first teleconference took place on 13 February 2017, during which the WCRP sponsors presented to the Review Panel the objectives of the Review, its work plan, timeline and background information about WCRP. During this call, the Review Panel also began identifying key stakeholders to be interviewed during the review process.

The Panel held its first meeting in Paris on 3-5 April 2017 in conjunction with the WCRP JSC meeting, and this provided an opportunity to collect input from the JSC members. During the meeting, the Panel reviewed the ToR, analysed the findings and recommendations of the previous WCRP review, discussed the self-assessment report provided by the Director of WCRP, and key documents submitted by the WCRP secretariat and WCRP sponsors (for a full list of documents provided to the Review Panel see Annex 1; these are all available at bit.ly/2BBcKZa).

Furthermore, the Panel received oral input from the Director of WCRP, the Chair, the Vice-Chair and ordinary members of JSC, senior representatives of the Intergovernmental Panel on Climate Change (IPCC), the World Meteorological Organization (WMO), the International Council for Science (ICSU), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the Commission for Atmospheric Sciences (CAS), the World Weather Research Programme (WWRP) and the Global Atmosphere Watch Programme (GAW).

The Review Panel also held discussions with the senior representatives of WCRP core projects (GEWEX, CLIC and SPARC) and the Grand Challenge on Understanding and Predicting Weather and Climate Extremes. Through a teleconference, the Panel also held a discussion with a co-chair of the Belmont Forum, representing the research funding community (see Annex 2 for the list of people who contributed to the review process). During the meeting, the panel identified key issues for follow-up, agreed on the list of people to be interviewed during the site visit and additional information required for that visit.

The site visit took place on 31 May – 2 June 2017 in Geneva, Switzerland, during which the Panel interviewed the leadership of WMO, ICSU and IOC of UNESCO. It also met the representatives of the WMO Climate and Water Department, and Climate Prediction and Adaptation Branch, GAW, WWRP, and Atmospheric Research and Environment Branch, and the Global Climate Observing System (GCOS).

The Review Panel also held discussions (via teleconference) with the representatives of: the WCRP JSC, the WCRP core project CLIVAR, the Future Earth Global Paris Hub, the UNFCCC Secretariat/SBSTA, NOAA Geophysical Fluid Dynamics Laboratory, the US National Center for Atmospheric Research, and the UK Met Office. It also met the WCRP Joint Planning Staff (JPS). The Chair of the Panel also attended the meeting of the WCRP Modelling Advisory Council and the modelling Working Groups in Exeter, UK in October 2017.

On the final day of the site visit, the Review Panel analysed the inputs from multiple sources and drafted the report's recommendations. Members finalized the draft report through electronic communication and teleconferences.

The review findings and recommendations are based on the evidence collected and analysed through:

- Study of documentation, including the 2009 WCRP Review, agreement between sponsors, the WCRP Strategic Framework 2005-2015, the WCRP Implementation Plan 2010-2015, summaries of the JSC meetings, annual budgets, WCRP structure and reporting lines, website content (see Annex 1/bit.ly/2BBcKZa);
- A self-assessment report written by the Director of WCRP on the performance of the programme and future plans;
- Written input on WCRP achievements prepared by the Chair of JSC;
- Written self-assessment reports prepared by the Advisory Councils, Working Groups, Core Projects, and Grand Challenges;
- Interviews with key stakeholders during the meeting in Paris and the site visit in Geneva (see Annex 2). The stakeholders were selected based on their knowledge of, and interactions with, WCRP; and their expertise in the climate change domain.

2 WHAT THE REVIEW PANEL LEARNED

The ToRs provided the framework for the Review, but in gathering its evidence and forming its recommendations the Panel also emphasized the importance of the following elements during the review process:

- The need to recognize the seamless nature of climate-weather science. The Panel agreed to seek to understand how WCRP is addressing this and furthermore how it interacts with the weather community (including WWRP).
- Climate science is the bedrock of the Earth system science; therefore, there is a need to ensure that the Earth system science aligns with the priorities of climate science and vice versa. Therefore, the panel agreed that interactions with Future Earth should be examined.
- There is a need to make sure that there is a strong fusion of models and observations, and that their strategies and priorities are aligned. Therefore, the panel agreed that relationships between WCRP, GCOS and the Commission for Climatology should be explored.
- The relationship between WCRP and the climate service community should be defined. There is a risk of diluting fundamental science by trying to be relevant to the user. Nevertheless, the panel recognized that connections with the service community are important for identifying priorities for climate research and for establishing relevance and impact.
- There is a risk that, in the future, funding could be increasingly diverted from fundamental science. WCRP should play an advocacy role in mobilizing funding for fundamental climate science. There is a need for a more strategic engagement with the funding communities.

2.1 OUTCOME OF THE 2009 REVIEW OF WCRP

The 2009 Review recognized a number of important achievements of the WCRP; however, it concluded that WCRP lacked the focus, planning and funding to meet the challenges of global climate change. It made the following recommendations:

1. immediately focus its 2005 WCRP Strategic Framework to better capture the WCRP role in providing the science that underpins research on climate predictability, adaptation, and mitigation, thus strengthening the links with key end-user groups.
2. rapidly implement its focused Strategic Framework, paying special attention to societal needs while maintaining its science-driven approach.
3. introduce clear priorities into WCRP as a whole, collaborating with other Global Environmental Change programmes to take into account urgent science required for IPCC and other societal demands.
4. lead the initiative on Earth system modelling, in collaboration with IGBP and other Programmes, utilizing the full richness of relevant disciplines, and explicitly addressing scientific problems that lie at the interfaces with these disciplines.
5. consolidate and strengthen its focus as a user and promoter of observations as well as its support of the components of the Global Climate Observing System.
6. set specific strategy and goals for building its scientific capacity in diversity of age and gender and for participation of developing country scientists in planning and research.
7. build its resource capacity by enhancing support for coordination and advocacy for research and infrastructure needs. This will necessitate expanding its funding sources outside traditional targets and working through IGFA.

8 expand its strategic outreach activities to target greater visibility and better uptake and utilization of WCRP outputs by the climate research community, the policy world and private sector, and more broadly to the general public.

9 WCRP's sponsors should meet regularly to review their mutual responsibilities for the Programme in light of society's increasing need for climate understanding, mitigation, and adaptation.

10 WCRP, in partnership with other global environmental change programmes, should develop a framework for future joint research operation, with the initial focus on the elements identified in this Review. A sponsor-convened 12-month study is proposed to initiate and plan the process.

Recommendations 1 and 2 were directed at development and implementation of a WCRP Strategic Framework. WCRP established a strategy for the period 2005-2015 and added to this guidance through the development of the Grand Challenges for the subsequent period as approved by the JSC. WCRP has been following this guidance but recognizes that this strategy needs to be upgraded and formalized now. This lack of an up-to-date Strategic Plan means priorities are not clear (**Recommendation 3**). This recommendation also encouraged collaboration with other global environmental change programmes i.e Future Earth) and although WCRP decided not to become part of Future Earth, it has formed partnerships in some areas but overall the collaboration has stalled while Future Earth is still being established.

Recommendation 4 concerned leadership for Earth system modelling and this continues to be a WCRP strength, especially in the Working Group on Coupled Modelling (WGCM) and the Coupled Model Intercomparison Project (CMIP), which underpins the IPCC Assessment Reports. Earth system models started to appear in the IPCC 5th Assessment Report and are likely to dominate the 6th Assessment Report in 2022, ahead of the first Global stocktake in 2023.

Recommendation 5 focused on WCRP as a user and promoter of observations. The WCRP Data Advisory Council responds directly to this recommendation, but in doing so WCRP may have inadvertently weakened the links to GCOS.

WCRP has responded well to **Recommendation 6** which related to diversity in age, gender and development status in the WCRP Community. The YESS (Young Earth System Scientists) initiative is an excellent initiative which should continue.

Recommendation 7 focused on resource mobilization and the results have been mixed. Some early progress was made in garnering support for the JPS, but the Review Panel finds the JPS support base now worse than in 2009. WCRP responded, but seemingly lacks the strategy and the financial wherewithal to achieve a major change.

Clearly outreach is now being made a priority (**Recommendation 8**) and the WCRP was prominent in the IPCC 5th Assessment Report. However, engagement with the sponsors and key partners seems mostly ad hoc and lacking real purpose.

Recommendation 9 stated "WCRP's sponsors should meet regularly to review their mutual responsibilities for the Programme"; there is no evidence that this recommendation has been implemented.

Recommendation 10 addressed the big picture – Global Environmental Change research in general. Arguably, Future Earth has responded directly to this challenge, but by deciding to remain separate from Future Earth, the WCRP has lost the ability to lead or co-lead.

2.2 EFFECTIVENESS OF THE CURRENT STRUCTURE

In undertaking its review the Panel emphasized the importance of recognizing that WCRP is not a funding agency, and therefore cannot dictate what work is done by the participating scientists. WCRP only functions effectively if it can engage with, and gain the commitment of, the international climate science community to its programme of work, and in turn ensure that participants derive bene-

fit from engaging in WCRP activities. The Panel was very reassured to learn that community engagement continues to be broad and strong and that the WCRP provides opportunities to work collaboratively to the greater benefit of the science.

When gathering evidence the Panel was keen to identify activities and achievements that could not have been delivered without the international cooperation facilitated by WCRP. Over the years there have been many notable examples, including WOCE, TOGA-COARE, GEWEX global datasets, and the CMIP archive that underpins the IPCC reports.

2.2.1 CORE PROJECTS

Although the focus of the review is to make recommendations for the future structure and governance of the WCRP, the Panel considered it important that the current performance of the major elements of the programme were reviewed to provide the right context.

The Panel received written and oral evidence from the Co-Chairs of the four Core Projects - GEWEX, CLIVAR, SPARC and CLIC. The Panel was impressed by the long history of high performance of the Core Projects. They continue to be strong, to exercise aspiration, to have cohesive communities and to be effective in forward planning. Each Core Project has a big community resource; for example SPARC has about 3000 scientists involved in its activities, and the other projects have similar levels of engagement. One of their unique qualities is that the Core Projects can mobilize community involvement quite quickly.

The Core Projects also provided evidence of continued delivery of valuable products and services to the community as well as facilitating important scientific advances. These include new observational datasets, model intercomparisons, field experiments and a range of fora for discussing emerging science issues. They also recognize the importance of involving scientists from developing countries, and the need to foster the next generation of researchers. The Panel was pleased to hear about the excellent work of the Young Earth System Scientists (YESS) community that WCRP supports.

The Core Projects have been in existence for a long time and derive from the WCRP MoU, where the initial research priorities of WCRP were embodied in the (then) three major internationally-coordinated core projects. That being the case, the present Core Projects might be considered as the embodiment of the current research priorities of WCRP. However, the Panel was unclear as to whether the Core Projects recognize and respond to the changing research agenda required by societal needs for climate science. They appear to be more content instead to continue to follow their traditional agendas. The Panel felt that engagement with the stakeholders, be they the sponsors, national research funders or climate service providers, could be stronger.

The Panel also noted that, although the individual strategies of the Core Projects reflected the current state of the science in their particular areas and that community engagement is strong, they are not well coordinated between each other and there is evidence of potential duplication and 'mission creep', which is undesirable. This seems to have arisen because of the lack of a strong overarching WCRP strategy in which the functions and priorities at the level of the Core Projects should be properly articulated.

In terms of issues related to specific Core projects, the Panel noted the following:

- CLIVAR evolved out of WOCE and TOGA. Because of the dominant role of the oceans on climate variability it has been seen as the focal point for the ocean science within WCRP. With the removal of the WGSIP from its portfolio, its current strategy is almost entirely focused on the oceans. However, it is clear that to deliver the WCRP aim of understanding the extent to which climate can be predicted, WCRP should increasingly consider other drivers of natural variability and predictability. These include the role of the stratosphere, land surface feedbacks and the cryosphere.

- SPARC was established in 1992 to consolidate knowledge on the role of the middle-atmosphere in climate and develop understanding of the processes involved. This would complement the work already being done in research programmes on stratospheric ozone depletion. More recently its focus on stratosphere-troposphere interactions has led to some major advances in coupled chemistry-climate science

and in atmospheric dynamics. As noted later there are overlaps with other activities related to atmospheric composition and climate-chemistry interactions, such as GAW, that SPARC could be joined with. Likewise, the Panel was concerned to hear that SPARC is planning to take the lead on climate/atmospheric dynamics, something that might be expected to fall within the remit of CLIVAR, although it understands that SPARC is seen as the atmospheric component of WCRP. Overall, the Panel was not convinced that the distinctiveness of SPARC is still there, and that as part of a more seamless approach it might be more logical for stratospheric processes, atmospheric dynamics and the influence of the stratosphere on the troposphere to be integrated within other elements of WCRP and with WWRP.

→ The importance of polar regions in the climate system is undeniable and the panel is very aware of the excellent work done by CLIC over the years, which has enabled significant advances in observing, modelling and understanding the Arctic and Antarctic. Its contribution to the science behind sea-level rise and climate change has also been noteworthy. However, science is moving on and it is increasingly evident that the polar regions are not isolated from the global atmosphere and oceans and that a more holistic approach might be needed, going forward. For instance, the Panel noted that CLIC has an activity on the northern and southern oceans which might more naturally fit within CLIVAR. Similarly, the emphasis on prediction, such as the YOPP, and the WWRP Project on Polar Prediction emphasizes the importance of considering a more holistic and seamless approach.

→ In recent years, GEWEX has been considered the focal point for understanding land surface processes and their role in the climate system. But many of the issues that GEWEX now seeks to address are global in reach and cover all elements of the climate system, so GEWEX can no longer be constrained to problems related to the land regions. Likewise, GEWEX is now pioneering improved understanding and representation of key atmospheric processes such as cumulus convection. Many of the issues that it seeks to address are the same as those that concern the weather science community. The Panel was pleased to know that GEWEX is already working well with WWRP, for example through the use of cloud system resolving models to study convection problems in its panel on Atmospheric System Studies (GASS). The Panel was convinced that the fundamental process science that WCRP promotes is essential, that it should consider all aspects of the coupled Earth system, and should be increasingly done in partnership with WWRP.

So, the Panel concluded that the concept of each Core Project focusing on a specific component of the climate system may not be fit-for-purpose going forward. Because of the longevity of the Core Projects, their structure and remit may reflect where climate research was 20+ years ago, and therefore they may not represent the WCRP priorities of today. In an era in which more holistic and seamless science is needed and where societal needs require science and services from the global to the local scale, a more flexible arrangement might be needed.

In addition, the Panel heard that each Core Project has its own family of panels and working groups that focus on specific regional or scientific aspects that the community considers important. Over the years, these have tended to grow organically, but without additional funding to support their activities; overall the complexity of the structures has increased, potentially to a level where the Core Projects may not be sustainable in the future. There is evidence that the Core Projects go through a regular review of their activities, close those that are completed, and set new priorities. In that regard, the community has shown that it can organize itself around issues where collaboration, co-design and dialogue are beneficial, and they recognize that having the association with the WCRP Core Project brand is helpful. However, the Panel is concerned that this organic growth is putting additional pressures on the WCRP budget and on the JPS. Better ways of supporting self-organizing and self-funding activities under the WCRP Core Project banner may need to be found.

The Panel also received evidence on the potential benefits of 'cutting the cake' differently, either from a scientific perspective and/or in terms of capability. If the Core Projects were to change significantly, there are concerns that the engagement of the science community, which currently identifies itself with the existing Core Projects, might be affected. Some funding agencies also understand the brand name and there is a risk that research funding, for which the Core Projects provide gearing, may be compromised. Branding is important, as is how the scientific community identifies itself with particular Core Projects, so re-structuring will need to be acted upon carefully. Nevertheless, views were expressed that the community might be more flexible and adjust to different organizational structures if they are involved in the re-design of WCRP.

2.2.2 WORKING GROUPS

The Working Groups encompass the internationally coordinated modelling activities of the WCRP. Historically the joint CAS/WCRP WGNE was the vehicle for communicating and collaborating on atmospheric model development and intercomparison (e.g. AMIP). It continues to provide a very valuable forum where model developers across weather and climate can work together. Its contribution to identifying and understanding atmospheric model systematic errors remains vital. It engages a very broad community and is an excellent example of the importance of working seamlessly across all space and timescales.

As coupled climate modelling came to the fore in the 1990s, the Working Group on Coupled Modelling (WGCM) was formed within CLIVAR to provide a focus for ocean-atmosphere model development, akin to the focus on atmospheric modelling provided by the WGNE. The first Coupled Model Intercomparison Project (CMIP) was initiated in 1995 and has since become the formal vehicle for coordinating the delivery of climate change simulations and projections, including for the IPCC assessments. Through its coordinating and data dissemination activities it has had a massive impact on climate change science, and has enabled a huge community of scientists to engage with the IPCC process. There is no doubt that CMIP has been one of the great success stories for WCRP and, whilst there are aspects that need improving such as the linkage to the weather community's knowledge about data assimilation, atmospheric physical processes and global model systematic errors, this needs to continue.

However, the Panel also heard evidence that the priority given to CMIP and the focus on climate change in support of the IPCC within the WCGM, have meant that other areas of WCRP science that involve coupled modelling (e.g. seasonal to interannual prediction) and especially coupled model development may not have fared as well.

Over the years other modelling Working Groups were formed within the Core Projects, such as the Working Group on Ocean Model Development (WGOMD) within CLIVAR, where they could draw on the latest underpinning science and observational datasets within the host Core Project. However, in recent years the Working Group on Subseasonal to Interdecadal Prediction (WGSIP) was transitioned from a CLIVAR activity to a cross-cutting WCRP Working Group, in order to give it more prominence and to enable it to work more closely with the WGCM and WGNE. The Panel heard evidence that this move has not been entirely successful and that CLIVAR has been weakened as a result.

The Working Group on Regional Climate (WGRC) is relatively new and was formed as part of the WCRP response to the formation of the Global Framework for Climate Services (GFCS), which emerged following the World Climate Conference 3 (WCC-3) that called for the development of climate services. The mission of WGRC is to prioritize and coordinate regional climate research within WCRP and serve as the conduit for two-way information exchange between WCRP and the various institutions and coordinating bodies that provide climate services, including the GFCS. Its focus is on the application and translation of WCRP outputs in terms of user-relevant products and services.

The panel heard evidence that WGRC has struggled to gain traction and that there is confusion around its relationship with CORDEX, the Coordinated Regional Climate Downscaling Experiment. Formally CORDEX should be part of WGRC, but it now has its own Project Office and works independently. At the WMAC meeting held in October 2017 it was agreed that CORDEX should become part of WGCM, further undermining the function of the WGRC.

Although the aims of CORDEX embrace a broad portfolio of research on regional refinement techniques, it has focused primarily on the production

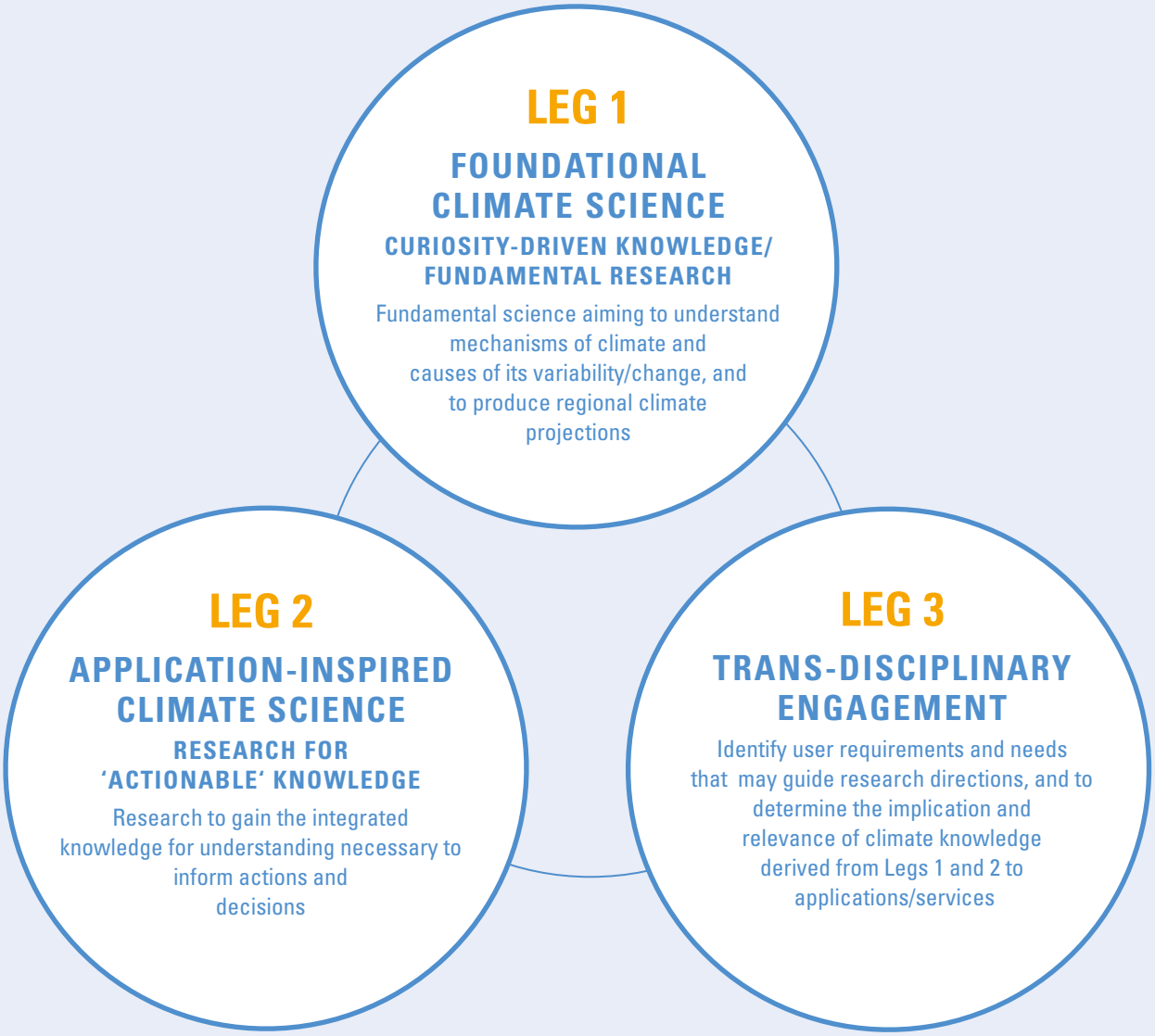
and evaluation of downscaled climate change scenarnarios for 14 regions of the world, which will form part of WCRP's contribution to IPCC. It engages strongly with those regions, providing training workshops and engaging local scientists and stakeholders. It is clear from feedback received by the Panel that CORDEX plays an important role in networking and capacity-building in developing countries, and this is much valued.

However, the Panel notes that the CORDEX regional downscaled scenarios still have relatively coarse resolution for understanding climate change impacts and are subject to some of the same limitations as the global models. This approach differs from regional modelling activities in other parts of WCRP (e.g. GEWEX) and within the weather community, where the focus is on cloud-systems, kilometre-scale modelling with notable advances in predicting local information such as extreme rainfall and winds.

It is clear to the Panel that regional climate research within WCRP has lacked clear direction and that a more strategic view across the portfolio of activities is needed. Where should regional climate research sit - should it be a core scientific goal of WCRP or should it form part of WCRP's engagement with end users? At its most recent meeting in March 2017, the JSC endorsed recommendations regarding the three aspects ('legs') of WCRP's regional activities. These comprise the three legs as follows: (see graph 5)

GRAPH 5

Climate information for regions



The aim of this new approach is to enhance the scientific basis for understanding regional climate and its changes; identify, quantify and deliver high quality, reliable and accessible regional climate information that takes account of user needs.

The Panel noted that GFCS already undertakes statistical downscaling over land, and has a strong need for regional climate information on all timescales, not just related to climate change. In moving to this new structure, the Panel notes that the relationship between WGRC, CORDEX and GFCS must be clarified. The Panel understands that WGRC will be focused on leading Leg 2 and will implement the Frontiers of Climate Information (FOCI) Project that has a city/regional focus, approved by the JSC in 2015. In this role, WGRC would facilitate and support relevant scientific efforts across the WCRP as well as initiate activities within the WGRC terms of reference. This may include developing guidance and catalysing linkages with external partners for climate services, especially GFCS and the Climate Services Partnership. The Panel is pleased to learn that WCRP has been successful in attracting international support to establish a coordinator for its regional activities.

2.2.3 GRAND CHALLENGES

In the wake of the Review of 2009, WCRP introduced Grand Challenges to enable it to provide emphasis and focus on topics that the community regards as requiring urgent attention and that needed a holistic, integrated approach. They identifed high-priority issues that require international partnership (often with partners outside WCRP) and coordination, and that should yield "actionable information" for decision makers. Following ideas and topics solicited at the WCRP Open Science Conference in 2011, which attracted more than 1900 participants, the WCRP JSC announced a list of six Grand Challenge areas. Since then the JSC has approved the current 7 Grand Challenges which very much reflect these initial topics:

- Melting Ice and Global Consequences
- Clouds, Circulation and Climate Sensitivity
- Carbon Feedbacks in the Climate System
- Weather and Climate Extremes
- Water for the Food Baskets of the World
- Regional Sea-Level Change and Coastal Impacts
- Near-term Climate Prediction

The Grand Challenges are intended to be activities that cross boundaries and that have immediate relevance, but require acceleration. They should have a defined lifespan, show progress and then close. It is clear though that they could not occur independent from the WCRP Core Projects, but rather they should work across the Core Projects and often extend into research communities beyond WCRP. The legacy of the Grand Challenges should be held within the Core Projects and help to steer the long-term WCRP strategy.

The Panel heard divergent views about the Grand Challenges. Based on the evidence that the Panel received, it is clear that some are performing well, for example Clouds, Circulation and Climate Sensitivity where there is strong and energetic leadership, but that others are struggling to have an impact. While the Grand Challenges address pertinent questions, there is not always enough integration with the Core Projects, which should provide their foundations, and in some cases the context for their development. Although the intention was that the Grand Challenges should cut across the Core Projects, the reality is that some live within a single Core Project. The Panel also heard that there is not consistent support for the Grand Challenges from the scientists working within the Core Projects; some see the Grand Challenges as a distraction that dilutes the work being done in the Core Projects which they regard as more fundamental research priorities. The Panel was pleased to learn that the Grand Challenges are attracting greater engagement from younger researchers, who find the topics relevant and exciting.

The Panel also heard that when the Grand Challenges were established, not much thought was given to their governance. The Panel noted that if the Grand Challenges were intended to be an organizing mechanism for WCRP, there should be a clear definition as to what constitutes a Grand Challenge; however the Panel heard different definitions.

In the Panel's view, the Grand Challenges should stimulate transformative and frontier science that pushes the boundaries.

The decision-making process for selecting priorities among Grand Challenges is not clear and this is of concern because they add another level of complexity within WCRP and place additional pressures on resources. The Panel noted that it was not clear how resources are being mapped to the Core Projects and to the Grand Challenges and were not convinced that the Grand Challenges lead to efficiencies. In addition, seed funding for the Grand Challenges is becoming more and more difficult. The Panel noted that the Grand Challenges are intended to be time-limited, and heard that the JSC is currently considering how to review progress, to potentially focus on those that are performing well, and to decide on sunset dates. There is a suggestion that the proposed conference in 2020 to celebrate WCRP's 40th anniversary would provide the opportunity for the Grand Challenges to present their conclusions. On the other hand, some of the Grand Challenges were scheduling implementation in 2018 and 2019, and so will clearly not be concluding until well after 2020.

2.2.4 ADVISORY COUNCILS

Recognizing that modelling and data activities are conducted in various forms across all the Core Projects and Working Groups, the JSC decided in 2011 that it needed to strengthen the coordination and synergies between the various efforts and to find a more effective way for issues to be brought to the attention of the JSC. Consequently, it established two Advisory Councils, the WCRP Modelling Advisory Council (WMAC) and the WCRP Data Advisory Council (WDAC).

The WCRP Modelling Advisory Council (WMAC) coordinates high-level aspects of modelling across WCRP, ensuring cooperation with the main WCRP modelling partners such as within WWRP, and acts as a single-entry point for all WCRP modelling activities. Likewise, the WDAC acts as a focal point for all WCRP data, information, and observation activities with its sister programmes, and coordinates their high-level aspects across WCRP, ensuring cooperation with main partners such as GCOS and other observing system programmes.

The Panel received written reports from the Advisory Councils that provided reassurance of their efficacy, particularly with regard to the WDAC links to the observational community. At its October 2017 meeting, the WMAC highlighted the dearth of model development activities within the WCRP portfolio, but yet a plethora of modelling activities. In a recent survey of modelling projects, WMAC identified 67 distinct modelling projects of which only a small fraction was concerned with model development. WMAC concluded that despite many efforts over the years, model development still has not achieved the central status in WCRP that it deserves and lacks proper leadership. This is in large part due to the fact that modelling is now the fundamental technology through which WCRP delivers advances in climate research. The modelling Working Groups effectively coordinate the delivery of science using models, rather than performing science for model development.

A significant achievement of WCRP has been the coordination of major multi-model ensembles for monthy to decadal prediction (WGSIP) and climate-change projection (CMIP). These sets of hindcasts, predictions and projections are an invaluable resource for international science, but the software tools for archiving, accessing and analysing these large datasets are not well-coordinated across WCRP, although the Earth System Grid Federation (ESGF) is gradually becoming the system of choice internationally. The Panel noted that the responsibility for managing multi-model ensemble data does not seem to fall within the remit of WDAC.

Other evidence that the Panel received suggested that the community is not particularly aware of the Councils and that it has mixed views about their relevance and usefulness. Concerns were also expressed about the lack of data assimilation activities in the WCRP and whether the Councils should be doing more in this area. Initialized climate prediction is an important part of WCRP and coupled data assimilation is challenging and may need a focused research effort. The Panel also noted the importance of reanalysis in underpinning a large body of climate research and model evaluation.

Overall, the Councils appear to be light-touch bodies which do not require great resources, but nevertheless are seen as useful for information exchange and for carrying out a small set of overarching initiatives. The introduction of the model development and data prizes is a positive development.

2.3 ROLE AND EFFECTIVENESS OF THE JSC

As already noted the role of the JSC is to formulate the overall scientific goals and concepts of WCRP and to organize the required international coordination and research efforts that underpin the programme. The Panel was concerned to learn in their evidence-gathering that the JSC appears to be no longer performing this role adequately, and the Panel sought to understand the reasons.

The Panel heard that the JSC members, who are nominated by national agencies, are on the whole a very positive and dedicated group of individuals, although some members rarely attend or do not contribute much to the meetings. Concern was expressed that the process of selection might be too politicized, with a view that WCRP might prefer to allow the community to select individuals through an open call for nominations based on scientific excellence and leadership. There was also a suggestion that the membership of 18, allocated across the three sponsors, is too large for effective decision-making.

The complexity of the WCRP structure with its Core Projects, Working Groups and now Grand Challenges means that the JSC meetings tend to be largely taken up by reviewing activities rather than setting the strategy and overall direction. The Panel learned that the Core Projects increasingly set the strategy in their respective areas and that the JSC collectively has little impact in ensuring these strategies are coherent across WCRP's overarching goals. Indeed, at the last JSC meeting there were so many in attendance (~70) that parallel sessions were used to report on the Core Projects, a situation which is far from ideal. The Panel concluded that in many respects the JSC does not have a clear role in terms of coordination and guidance of the Core Projects.

Concern was also expressed by some of those giving evidence to the Panel that the planning for the JSC meetings was not ideal. Whilst the JSC meetings do provide opportunities for learning about, and connecting with, other projects, they are not strategic and visionary; the listen-consider-decide aspects are poorly executed. The meetings need to be prepared a long time in advance but often members are requested to contribute at short notice. The Panel was also surprised to learn that JSC members feel that they do not have any authority in setting the agenda of the meetings; often members make suggestions but they are not acted upon.

The Panel was also concerned to hear from JSC members that they do not believe WCRP is functioning well because the lines of communication between the JSC, JPS and the core components of the programme are not effective. Some JSC members feel that their expertise is not appreciated and they hear that they do not engage properly; this has led to members feeling reluctant to contribute their voluntary time if their contributions are not acted upon or ignored. Overall the Panel concluded that morale in the JSC is not high and that this is having a detrimental impact on WCRP as a whole.

2.4 ROLE AND EFFECTIVENESS OF THE JPS

The Review Panel was asked to assess the adequacy of Joint Planning Staff structure, its human and financial capacities, and modes of work; it was not asked to assess the performance of the Director nor that of the JPS staff. These findings should be seen in that context. Financial capacities are covered in the Finance sub-section.

The JPS is a vital part of WCRP. As described earlier, the role of the JPS is to assist the JSC in implementing its decisions, and to facilitate the collaborative actions of the various elements of WCRP. The JPS is led by the Director of WCRP. His/her role is to lead the staff and be responsible for the scientific and technical tasks discharged by the JPS, to the Chair of the JSC, acting on behalf of the sponsors. The Director can also play an important role in communicating between the sponsors and other programmes that relate to the WCRP (e.g. WWRP, Future Earth).

The Panel learned that there have been tensions recently around the Director's role, the degree of autonomy he/she has to make decisions, and his/her accountability to the sponsors for managing and setting the budget. There has been disagreement between the JSC and the former Director of WCRP about the discussion of budget issues, with the former Director indicating that the budget was his privilege and not a topic for the JSC. The Panel notes that this in conflict with the terms the MoU, which states that the budget shall be prepared by the JSC.

The Panel was concerned that the specification of the role of Director was not sufficiently clear. As a result, the JSC feels that the JPS often ignores or gives little weight to the JSC decisions. The JPS is viewed as not very responsive, and often JSC recommendations are not taken on board. Furthermore, the JSC is often not aware of what the JPS is doing; for example the JSC was not aware of WCRP interactions with Future Earth on cities, but only learned about them once they had occured.

The Panel received some very helpful evidence from JPS members and was impressed by their commitment, breadth and depth of scientific and technical understanding. However, it was clear to the Panel that they are very stretched, overworked and in some instances stressed by the increasing demands placed upon them at a time when budgets are falling. This has been compounded by tensions and ambiguities around the Director's role noted above.

The Panel concluded there were some issues with the modes of working of the JPS, ultimately arising from different interpretations of the terms 'guide' and 'assist' in Annex C of the MoU, and in the duty statement for Director of WCRP.

Overall the Panel felt that the effectiveness of the JPS was currently compromised because of issues related to leadership, to the strategic direction of the WCRP, and its interactions with the JSC, all of which need attention. Furthermore, the expansion into Grand Challenges and the addition of WGRC and CORDEX, have added to the complexity of what needs to be planned and supported, while resources have not increased.

2.5 RELATIONSHIP WITH THE SPONSORS

As noted earlier, WCRP is a body of its three sponsors: WMO, IOC and ICSU. The JSC reports to all sponsors, and they are responsible for agreeing the WCRP budget. However, the Panel learned that the level of engagement of the sponsors differs. Some do not always attend the JSC meetings, and the panel was concerned to hear that sponsor directors rarely meet and discuss the strategic development of WCRP in the context of their requirements. The Panel was not surprised to learn therefore that despite having three sponsors, WCRP acts on its own, and the current leadership and management generally do not take into account the priorities of the sponsors.

Funding for WCRP is shared between the sponsors on the basis of their ability to contribute. As already noted, funding has been declining over the years, with only WMO maintaining its funding to WCRP of around 1.5 million CHF per year, covering staff positions. So, WCRP is facing an uncertain future in terms of resourcing, which has not been helped by the fact that the sponsors have varying funding mechanisms (ICSU receives its financial support mainly through membership contributions; the IOC is mainly funded by UNESCO; WMO receives its funding from governments) and budgeting processes. The perception that WCRP asks for resources without providing its priorities is also a concern; it is not clear how WCRP priorities are being set and how decisions about budget allocations are being made. The Panel heard evidence that better communication of the benefits and relevance of WCRP to global societal challenges might help to secure more support from the co-sponsors.

At the same time that sponsors' funding has been falling, fund-raising by WCRP itself from national research organizations has also been on the decline. The Panel heard evidence that this may be a consequence of the increased complexity of the programme following the introduction of the Grand Challenges. It is not obvious how a research funder (e.g. NSF) might support a Grand Challenge, whereas it may well see the value of supporting a specific activity of a Core Project to produce tangible products, such as datasets that are of global value, a good example being NASA's ongoing support of GEWEX. It is important therefore that WCRP, through its Core Projects and Grand Challenges, continues to promote the relevance of its activities and seeks to get them funded by research agencies.

The Panel also heard that research funders are no longer around the table, in part because they feel there is no strong link in decision-making between the JSC and the Core Projects, as noted earlier. In the past, for example, NSF frequently attended the JSC to learn about the latest developments in international science but they are no longer involved in strategic discussions. Recently the funding agencies have tended to focus more on Future Earth, but nevertheless they remain interested in WCRP. It is an important strategic advisory body for them;

it provides a key input to help determine national research funding priorities; and it helps them deliver international gearing from their national investments in science.

The Panel explored with each of the sponsors what it regarded the role of a sponsor to be and what sponsorship should constitute. Is it all about funding or are there important, but less tangible, contributions such as engagement with international programmes and research funders, and exposure to a broader range of multi-disciplinary science?

IOC is the authoritative body for the ocean sciences and oversees operational ocean-observing systems. It is recognized as such within the UN system, and if IOC were no longer a sponsor of WCRP there would be a risk of duplication in ocean science. IOC stated that it derives important benefits from WCRP; in turn, ocean science and ocean-observing systems are crucial to WCRP for delivering its goals.

ICSU stated that although it does not provide direct funding to the Joint Climate Research Fund, it provides support in-kind and facilitates national contributions. It also works to ensure scientific independence and to make sure the scientific community can express its views. ICSU also works to ensure that its co-sponsored programmes can contribute to international policy processes. ICSU has several channels to access those processes, and endeavours to engage its programmes in them. However, ICSU noted that it places greater emphasis now on integrated science and on science that delivers socially-relevant solutions, and the Panel therefore felt it important to understand ICSU's future relationship with WCRP.

The Panel heard on several occasions that the community is keen to keep the relationship with ICSU because it ensures the engagement of the academic community; otherwise there was a concern that WCRP might be dominated by the national meteorological services. However, the Panel was reassured that this should not be a concern, since other WMO programmes, such as WWRP, have a large proportion of academics involved in their activities. Instead, being hosted at WMO provides good opportunities for WCRP to connect with governments and service providers (e.g. through GFCS), and to reap the benefits of synergistic opportunities across WMO departments, especially with WWRP and GAW.

Although, ICSU and IOC do not provide as much direct funding to the JCRF as the WMO, their sponsorship provides scientific breadth and depth to the programme, as well as access to communities other than those that are normally involved in purely WMO activities. Funding agencies and intergovernmental organizations consider WCRP to be an independent, authoritative and respected voice, and therefore feel comfortable in looking to it for advice.

Overall, the panel heard convincing evidence that, although having a single sponsor might be easier since there is a clear line of accountability, the current structure of several sponsors has significant advantages. It brings together the inter-governmental and academic perspectives, it provides a more formal engagement with academia, and it ensures that one organization does not dominate the agenda of the programme. There is no doubt that having multiple sponsors provides access to different fora, networks and communities, although it was not clear to the panel that the current WCRP leadership has exploited this as fully as it might.

2.6 RELATIONSHIP WITH OTHER RESEARCH PROGRAMMES

Since WCRP was created almost 40 years ago, climate science has evolved substantially and now engages many different disciplines beyond meteorology to oceanography, chemistry and biology. Climate models no longer consider just the physical climate system but increasingly include Earth system processes such as the carbon cycle. At the same time, the need for climate information on all space- and time-scales has led to the recognition that weather science is fundamentally important to climate science and that seamlessness across weather forecasting and climate prediction is increasingly important.

With this context in mind, the Panel was keen to explore the relationship between WCRP and other programmes, particularly those of WMO and ICSU, to identify potential gaps, duplications and opportunities for greater collaboration.

2.6.1 WMO PROGRAMMES

WMO is in the process of restructuring and consolidating its research programmes in order to optimize the synergies and to promote science as an important part of its remit. It asked the Review Panel to consider the relationship between WCRP and other parts of WMO, specifically the World Weather

Research Programme (WWRP), the Global Atmospheric Watch (GAW), which monitors and addresses scientific questions around atmospheric composition, the Global Climate Observing System (GCOS) and the WMO Commission for Climatology (CCL).

Currently WWRP and GAW sit within the Commission for Atmospheric Science (CAS), and the panel heard from the CAS President that cultural differences may exist between CAS and WCRP that act to inhibit greater cooperation. CAS is producing science-for-service and addresses science issues through the whole value chain; on the other hand, WCRP is more curiosity-driven, so the approaches are different. To foster closer integration, the CAS President suggested that there is a need to identify short- and longer-term steps to break down these cultural differences. The Panel found the culture issue puzzling and felt that it may be more an issue of territory. With the need now for more seamless science and services, these barriers should be removed, and respect and trust instilled between the various players.

WWRP

The Panel heard that interactions between WWRP and WCRP are improving, although strategic co-design of projects is still missing. WCRP scientists are involved to a greater or lesser extent in the three major WWRP projects on High Impact Weather, Polar Prediction and Sub-seasonal to Seasonal Prediction, although their approaches are different and opportunities for integration and seamlessness are still being missed. Links are also developing between GEWEX and WWRP where there are common interests in atmospheric processes such as organized convection and the use of convective scale models. However, the Panel learned that these links have been serendipitous rather than programmatic and strategic.

In addition, WGNE plays an important role in bringing the weather and climate communities together around modelling issues such as systematic errors. The Panel was pleased to hear that since 2014 there has been a joint WCRP/WWRP International Prize for Model Development.

Overall, the Panel was reassured that there is increasing cooperation between WWRP and WCRP and heard that there were more opportunities for co-design of activities. Nevertheless, there is still some considerable way to go before a truly seamless approach to weather and climate research can be implemented. It will be important that WCRP works with WWRP when it is developing its new strategy, just as WWRP worked with GAW in developing and implementing its strategy.

The Panel heard evidence that greater alignment might be possible if WCRP were a more integrated part of a consolidated WMO research department, where the WCRP and WWRP Directors and their staff could work together more effectively. However, the co-sponsorship of WCRP would need to be recognized as a distinctive characteristic that needs to be appropriately managed by WMO.

GAW

Within WMO, GAW works on maintaining and applying global, long-term observations of atmospheric chemical composition and selected physical characteristics of the atmosphere. In its last implementation plan, it proactively embraces the idea of science informing applications and downstream products. More recently GAW has implemented a project to monitor greenhouse gas (GHG) emissions, which will be critical for assessing the effectiveness of the Paris Agreement as part of the UNFCCC Global Stocktake.

In WCRP, research on atmospheric composition has traditionally been covered within SPARC, with the initial focus on stratospheric ozone depletion. However, climate–chemistry interactions are now much more pervasive and SPARC also considers tropospheric chemistry issues. Similarly, GEWEX is engaged in cloud–aerosol interactions. Air quality is also emerging as a major issue in future climate change. So, the Panel was keen to understand how WCRP manages atmospheric composition and air quality and its links with the wider community.

The Panel heard that GAW interacts with WCRP in a number of areas and that joint discussions at the JSC were very positive, although there is still a need to communicate more effectively and engage earlier in the development stages of projects with potential joint interests. For example, the links between GAW's integrated GHG information system and GEWEX's work on GHG fluxes could be better, and GAW would be keen to connect with the Grand Challenge on the carbon cycle.

In terms of atmospheric chemistry, the landscape is very complicated, with GAW, SPARC and Future Earth's International Global Atmospheric Chemistry (IGAC) Project all working in this area. The Panel

heard evidence that there needs to be better integration of these activities, especially around atmospheric pollution and air quality, in which WMO could potentially act to bring these communities together. It also heard that GAW, SPARC and IGAC tend to share the same communities of scientists and that more intelligent interactions and co-design of activities across these organizations would be beneficial and potentially lead to efficiencies. For example, the joint IGAC/SPARC Chemistry–Climate Model Initiative (CCMI) was established recently to coordinate future (and to some extent existing) chemistry–climate model evaluation and associated modeling activities.

Overall the Panel was concerned about the multiplicity of activities in atmospheric composition and felt that there is a need for a more strategic approach across timescales and across observing, monitoring and modelling atmospheric composition and air quality, building on what GAW has already achieved, and bringing in SPARC and IGAC. The Panel heard that GAW is perceived as a monitoring programme and that SPARC is where all the exciting science happens; clearly the reality is different and there would be much to be gained if WCRP could forge a stronger relationship with GAW. In particular, greater cohesion could lead to improved pull-through of science in to services related to atmospheric composition and air quality through, for example, the Copernicus Atmosphere Monitoring Service (CAMS) with which GAW engages.

GCOS

Observations and monitoring of the climate system remain an essential input to what WCRP does. They contribute to climate-change detection and attribution, to initialization of seasonal to decadal prediction systems and they underpin climate model evaluation. GCOS was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. It is co-sponsored by WMO, IOC, UNEP and ICSU and works through its joint panels and the WDAC. WDAC acts to facilitate the best exploitation of observations in (re)analysis and prediction efforts within WCRP. GCOS works with partners to ensure the sustained provision of reliable physical, chemical and biological observations and data records for the total climate system – across the atmospheric, oceanic and terrestrial domains, including hydrological and carbon cycles, and the cryosphere.

The Panel was reassured to hear that GCOS has strong relationships with WCRP through a number of joint panels, although GCOS admitted to finding the WCRP structure complex and difficult to understand where it can be best supported. This is important because climate research must help to define observational networks. Previously there was the WCRP/GCOS panel on observation and assimilation (WOAP), where research and observations met and where strategic priorities between these communities were discussed. This has since been replaced by the WDAC which is more of an overarching body and does not design joint activities. The panel heard that in this regard WDAC is weaker than the former WOAP and may be the reason that data assimilation is less visible in the WCRP.

CCL

The Panel also explored the relationship between GCOS, WCRP and the WMO Commission for Climatology (CCL). The CCL oversees international technical activities within WMO under the World Climate Programme (WCP) and the Global Framework for Climate Services (GFCS) to obtain and apply climate information and knowledge in support of sustainable socio-economic development and environmental protection. As such it is at the operational end of WMO's climate activities. The Panel heard evidence from GCOS that there are strong connections with CCL, although there is a sense that they are running on separate tracks. Nevertheless, GCOS is working with CCL on helping to define climate indicators that national governments can use to monitor progress with respect to the Paris Agreement as part of the Global Stocktake.

However, it was less clear to the Panel how WCRP relates to the CCL in areas of mutual interest, such as climate-change detection, attribution and indices. The joint CCL/WCRP/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) exists to provides international coordination and collaboration on climate-change detection, but the Panel understands that the CCL has decided to fold this into a new team on operational climate monitoring, although there is still a clear need for research related to the detection and attribution of extremes.

Throughout the review the Panel has been concerned about the visibility and coordination of climate-change (as opposed to climate-variability) research within WCRP. As currently constituted, WGCM is the focus for climate change through its CMIP activities, and with other elements scattered through the Core Projects and Grand Challenges, such as sea-level rise. The issue of the closure of the ETCDDI highlights that for research in some areas, such as climate-change detection and attribution of extremes, there is no visible home for these activities. It could be argued that, whilst the coordination of climate-change modelling activities is well catered for in the WCRP, the same is not true for other activities and that this needs to be addressed.

2.6.2 FUTURE EARTH

Future Earth is a 10-year initiative co-sponsored by ICSU to advance Global Sustainability Science, build capacity in this rapidly expanding area of research, and provide an international research agenda to guide natural and social scientists working around the world. Future Earth is built on many decades of international research on global environmental change carried out by DIVERSITAS, the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP). In the past, as Earth system modelling developed and became an integral part of CMIP and a focus of the IPCC WG1 assessments, WCRP worked closely with IGBP to ensure that research on bio-geochemical cycles and feedbacks was strongly rooted in the physical climate system, even though there were tensions between the two programmes.

With the formation of Future Earth, it might have therefore seemed logical that WCRP would also be incorporated within it to ensure that the interdisciplinary science that Future Earth promotes is founded on the bedrock of physical climate science. However, that ignores the increasingly strong links with the weather science community and other elements of WMO, which the climate science community also value greatly. There was also the concern that WCRP could get lost in the very broad agenda of Future Earth and that its fundamental science might be diluted by the push to applications.

The Panel was briefed by the senior leadership of ICSU and Future Earth who expressed regret that WCRP had not joined, that an opportunity to bring communities together had been wasted, and that as a result there are inefficiencies, potential duplications and competition for resources that are hindrances to progress. For instance, the Future Earth Knowledge Action Network on Oceans cannot really be meaningful without CLIVAR, and although CLIVAR is engaged, establishing a collaboration has created additional transactional costs and time on institutional issues.

There is no logical scientific argument for separating the physical climate system from full Earth system science; indeed, the Panel's view is that it is impossible to assess carbon cycle feedbacks, for example, without understanding what the water cycle is doing. So, there is a real cause for concern that the links between WCRP and Future Earth are not as strong as they should be, and indeed need to be. The Panel heard evidence that this has led to fragmentation of the Earth system modelling community at a time when issues around climate change increasingly demand a joined-up approach. The Panel was told that there is a huge deficit in this area, even though WGCM interacts with Future Earth's programme on Analysis, Integration and Modeling of the Earth System (AIMES).

The WCRP leadership also noted that although there are connections with Future Earth, these have not been straightforward because Future Earth is still in its early stages. Once Future Earth is better established, closer connections should be sought. However, it is clear that those connections should be nurtured in advance of new initiatives that potentially involve both communities; WCRP has come to the table rather late in Future Earth's projects on the oceans, cities and disasters.

Future Earth engages with the Belmont Forum, which promotes a trans-disciplinary approach to research and aims to make basic science related to Global Environment Change available to stakeholders and decision-makers. Currently, the Belmont Forum is comprised of 26 funding agencies on six continents, and through its Collaborative Research Actions, has funded 48 projects.

The Panel heard, however, that the purpose of the Belmont Forum is not to fund fundamental research, which remains the responsibility of the national funding agencies. Nevertheless, the Belmont Forum has funded initiatives that relate strongly

to WCRP science, such as Climate Predictability and Inter-Regional Linkages, and the Panel was concerned that WCRP seems not to be exploiting these opportunities. Since the Belmont Forum may not be the ideal route to major WCRP funding, a similar forum on fundamental climate science might be, if it could be established.

Overall, the evidence received by the Panel suggests that the relationship between WCRP and Future Earth (and thereby the Belmont Forum or similar) needs to be much stronger and that benefits would accrue on both sides in terms of acceleration of the science, improved pull-through of science of benefit to stakeholders, and greater awareness and promotion of the importance of fundamental climate research in the Earth system sciences.

2.7 CONTRIBUTING TO MAJOR INTERNATIONAL POLICY PROCESSES AND ASSESSMENT ACTIVITIES, SUCH AS THE IPCC AND UNFCCC

As already noted, WCRP is an integral part of the IPCC assessments, through the Coupled Model Intercomparison Project (CMIP) of WGCM, which supplies the climate change scenarios that IPCC uses as the basis for its Reports. But WCRP's contribution is far more than just the provision of the main global scenarios; it contributes to understanding the confidence in the projections; it coordinates work between those producing model data and those analysing the simulations; and it interprets the results in terms of climate impacts such as extreme weather, drought and sea-level rise. More recently WCRP has coordinated a growing component on near-term prediction, and supported the generation of regional climate-change scenarios through CORDEX that will contribute to IPCC Working Group II.

The Panel heard from the co-Chair of IPCC Working Group 1 that only WCRP has the capability to support the international coordination of basic climate research, and that through its facilitation role new knowledge is emerging. WCRP is also recognized for its coordination across different communities, and for bringing high-level scientists from developing countries into the IPCC process; this is very important and should be acknowledged.

The support for WCRP from the IPCC is very strong, and there is no doubt that WCRP's continuing contribution will be vital for the future work of the IPCC.

However, the IPCC is not a funding body and the continuing engagement of WCRP, and the scientific community it represents, relies on funding continuing to flow to these activities. The awareness of stakeholders and users of WCRP and IPCC outputs is important for promoting what WCRP does and ensuring its future viability. So, the Panel was keen to explore the links with the UNFCCC and how it views its relationship with WCRP.

The Panel heard evidence from the SBSTA (Subsidiary Body for Scientific and Technological Advice) of the UNFCCC. The SBSTA was established at the first Conference of the Parties (COP) to the UNFCCC in August 1995 to provide the COP and, as appropriate, its other subsidiary bodies with timely information and advice on scientific and technological matters relating to the Convention on Climate Change.

As part of COPS, UNFCCC/SBSTA organizes a research dialogue day where the latest science can be presented to the policy makers; WCRP together with Future Earth, GCOS and WMO are part of that day. The UNFCCC/SBSTA has attended the JSC meetings to talk about its priorities. It is also encouraging its members to address future challenges that climate science may face. For instance, CMIP6 will have high-resolution outputs, but the WCRP community will face a problem of storing a lot of data, and UNFCCC is trying to encourage governments to support data centres.

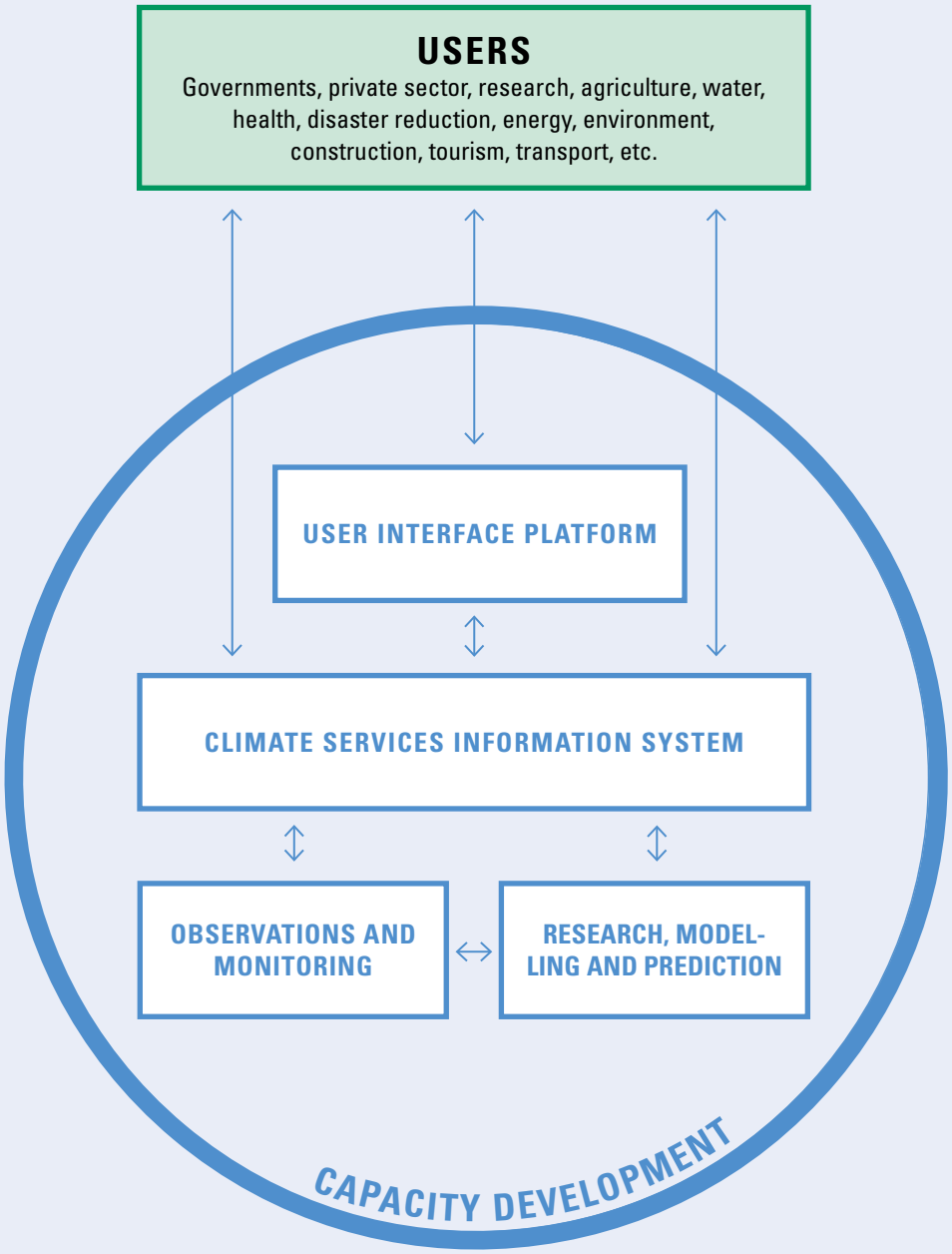
The Review Panel was reassured to hear about the strong interactions between WCRP and UNFCCC, and the dependence of the latter on WCRP science. It queried whether UNFCCC should be a formal sponsor of WCRP, but learned that the UNFCCC is not in the right position to do so; it is not an implementing agency, it is a secretariat of the Convention, so it cannot act as a sponsor.

2.8 ROLE OF WCRP IN CLIMATE SERVICES AND LINKS TO GFCS

In 2009, the World Climate Conference-3 unanimously decided to establish a Global Framework for Climate Services (GFCS), a UN-led initiative spearheaded by WMO to guide the development and application of science-based climate information and services in support of decision-making in climate-sensitive sectors. A Task Team was set up by the WMO Executive Council in 2011 to develop the draft implementation plan and suggest the governance structure of the GFCS.

The GFCS structure is shown in graph 6, in which Research, Modelling and Prediction features as one of the five pillars of the GFCS. The Panel was keen to understand the degree to which WCRP represents this pillar and how the translation of fundamental climate science, predictions and projections into user-relevant information at the regional and local levels is achieved.

GRAPH 6
The GFCS structure



During the review the Panel heard from a number of respondents who have different understandings of what climate services mean, which suggests that there is still a need for the GFCS to communicate more effectively. It was clear though that WCRP under stands that it needs to be driven by societal needs, but it does not know how to create that value chain, from fundamental science to user-relevant products and services, and how far down that value chain WCRP should go.

The Panel was concerned that the fundamental climate science that WCRP delivers could be diluted if it tries to take on too much translational research and to be too driven by user needs. Fundamental climate research needs to be protected.

When building the interface between WCRP and climate services, there could be an assumption that it is a zero-sum game, but it is not. Currently, funding for climate-service-related research comes for the climate research community, and research outputs "pushed" into services, though there are good arguments that the process could be the other way around. Getting the right balance between "research pushing and user pulling" is critical. The role of WCRP in providing credibility and quality assurance for climate-service applications, such as objective measures of model performance, could become increasingly important.

Based on the evidence, the Panel concluded that in order for WCRP to work more effectively as a research arm of GFCS, it is important to have a formal structure that would connect WCRP with climate services. For instance, to improve the "push–pull" balance, WCRP representation in GFCS governance/structure could be improved; likewise, WCRP could consider including users in its governance structure. The Panel was pleased to hear that there was a strong participation from the WCRP community in the last GFCS meeting. Furthermore, although WCRP is not yet appointed as the leading entity on the "Research, Modeling and Prediction" pillar, this issue has been raised as part of GFCS's own review and progress on this matter could empower the WCRP Working Group on Regional Climate (WGRC), for example, as the formal WCRP entity to make this linkage effective.

The Panel learnt that GFCS designs its services on the basis of country needs where users want regional and local information. The aim of the WGRC is to provide climate information based on user needs, but as already noted, the Panel has concluded that WCRP's approach to regional climate science needs to be clarified, and recognizes that the establishment of the International Office for WGRC is good first step. In so doing this would help to determine where WCRP sits within the value chain from science to services and how it might engage more effectively with the GFCS.

If WCRP is to engage more strongly in GFCS and become its research arm, then this can only happen if there are new resources and if new communities are brought in. The Panel heard from GFCS that there is the potential for it to invest of the order of 10% of the budget it wins from organizations, such as the World Bank, on research for climate services. Bearing in mind that projects related to the development of climate risk and early warning systems are currently attracting multi-million dollar investments, it is possible for them to be designed in a such a way that research is also included, thereby providing an additional funding line for WCRP. However, these projects do have limitations because they are outcome-oriented and the research has to be targeted at the applied/translational end. Nevertheless, this could be a mechanism that would stimulate and pull-through service-related research.

Overall the Panel concluded that the role of WCRP in climate services needs clarifying and that the relationship between the WRCP and GFCS needs much more thought.

3 CONSIDERATIONS FOR THE FUTURE WCRP

3.1 CONTEXT

After reviewing all the evidence, the Panel's judgement is that WCRP is at a critical point in its history, and that significant changes are required in its governance, structure and delivery for it to fulfill its mission in the context of 21st Century challenges.

The Panel's view is that the core, underpinning climate science which WCRP delivers is needed more than ever, as society seeks solutions to climate change (Paris Agreement), to resilience to disasters (Sendai Agreement), and to sustainable development for the planet (UN Sustainable Development Goals). Without a strong foundation in climate science and prediction none of these challenges can be addressed in a robust, cost-effective and durable way.

The Panel is very clear that it is not the role of WCRP to deliver the end products and services, but it should provide the bedrock knowledge, based on which these can be developed. WCRP needs to articulate and demonstrate its core values more effectively, along with the societal relevance of its work; to this end the WCRP should place a stronger focus on these global initiatives. It should work with its sponsors to say to different communities that they need bedrock climate science and that WCRP is there to work with them to ensure that they have access to it.

The Panel considered the role of the sponsors and what sponsorship means in the context of WCRP. There is no doubt that, in principle, each sponsor brings a different perspective to what the WCRP does and enables it to engage with different communities. So, the Panel's view was that the existing sponsors should continue, although there should be greater clarity on what sponsorship means and the supporting actions it requires – is it just about financial support to the JCRF or is it about wider inputs and benefits?

Furthermore, the sponsors need to be clear that, under the terms of the MoU, WCRP is not designed to be a directed programme with specific priorities set by the sponsors. The Panel's view is that this status should continue. WCRP succeeds because it attracts an international community of scientists who are supported through the investment of billions of dollars by national research funders, but yet are happy to gear their activities around a set of objectives and priorities that they define in agreement with WCRP. Nevertheless, the sponsors should work with WCRP to ensure that its overall high-level aims and objectives respond to the overarching strategies of its sponsoring organizations.

Since its inception, the key strength of WCRP has been its focus on cutting-edge physical climate science where international coordination enables scientific advances that would not happen otherwise. This must continue to be its focus, and that means prioritizing what it does and recognizing where its unique role as a facilitator and integrator of climate research makes a difference. It should set some clear priorities and how it will deliver them.

The Panel stressed that if WCRP does not continue to provide clear leadership, there is a danger of losing the engagement of the scientific community and its funders. It was therefore very concerned to learn that WCRP currently does not operate in the context of an up-to-date overarching strategy; as a consequence, WCRP is struggling to set priorities and to stop less important activities. This must be rectified as soon as possible, with the findings of this review being fully addressed in the process.

In developing its strategy, WCRP needs to reflect how climate science has evolved over recent decades with the emergence of holistic Earth system modelling, of seamless weather and climate science, and of the increasing skill and reliability of climate prediction. It will need to respond to the growing agenda for an increasing number of climate predictions and projections to guide resilience, adaptation and mitigation actions, reflected in the needs of IPCC, UNFCCC, GCFS and other users of climate research. It needs to shape its new strategy and its structure, activities and partnerships around this growing agenda.

After a lot of consideration and despite the strong performance of the existing Core Projects and Working Groups, the panel feels strongly that the existing structure is not the structure of tomorrow. At the same time, the Panel recognises the importance of not destroying the legacy of what has been created – a community of engaged scientists; it will require a willingness from the community to change and for the community to be part of the change process.

In its deliberations, the Panel focused on several areas where they wished to make recommendations to the sponsors on the future governance, structure and delivery of WCRP.

3.2 GOVERNANCE AND THE MOU

A theme that ran throughout the review has been the apparent lack of, or at least weaknesses in, the overall governance of WCRP. Key elements of the MoU are being partially or wholly ignored. The Panel concluded that the relative roles of the JSC and the JPS have become unclear, that the sponsors are not sufficiently engaged, and that there is a lack of clarity around responsibilities and accountabilities (within the WCRP high-level structure and with sponsors). Furthermore, WCRP needs to operate using an overarching strategy that drives its activities and sets its structure. The Panel concluded that high-level governance needs to be reinvigorated and repur-posed.

The 2009 Review of WCRP recommended (**Recommendation 9**) that "WCRP's sponsors should meet regularly to review their mutual responsibilities for the Programme …". The issues that led to this recommendation remain in place today. The JSC and JPS are struggling to manage upwards, and conversely the sponsors are concerned with the responsiveness of WCRP and its strategic alignment with their aims. The sponsors do need to understand under what conditions the programme is operating, and yet they do not meet to discuss its development; the terms of the WCRP MoU are not being implemented effectively.

The Review Panel concluded that a formal high-level governance structure should be put in place by the WCRP sponsors to enable more effective engagement and to exercise their responsibilities for the programme. The Panel recommends the creation of a WCRP Governing Board to:

- Oversee the implementation of the terms of the WCRP MoU and ensure that the overall goals of WCRP are delivered;
- Manage communication and interaction with, and engagement of, the sponsors and other key stakeholders.
- Approve the WCRP high-level science strategy developed by the JSC, and ensure that the JSC sets research priorities that are in harmony with the overall aims and interests of the sponsors;
- Manage high-level risk and change, especially associated with funding;
- Oversee resource mobilization and garnering enabling support for administration.

The primacy of the JSC for scientific advice and setting scientific strategy and priorities would remain; the Governing Board would provide a mechanism to ensure the supplementary strategy for funding, resource mobilization, administrative support and engagement, as well as direct involvement of the sponsors. The Director of WCRP would report to the Governing Board on the JPS, its budgeting and resourcing. A strawman structure for the future governance of WCRP is suggested below for consideration by the sponsors (see graph 2 on next page).

The core (and initial) membership of the Governing Board would be nominated by the sponsors who would elect an interim Chair. The JSC Chair and Vice-Chair would be ex-officio members. The JPS would provide support. Additional independent members (i.e. not affiliated to or directly associated with the sponsors, and drawn from the science and/or user communities) would be selected by the sponsors to ensure appropriate levels of expertise across the terms of reference. Once fully constituted, the Chair should be an independent member. The Panel's view is that the membership should not exceed eight and should be rotated on a biennial basis.

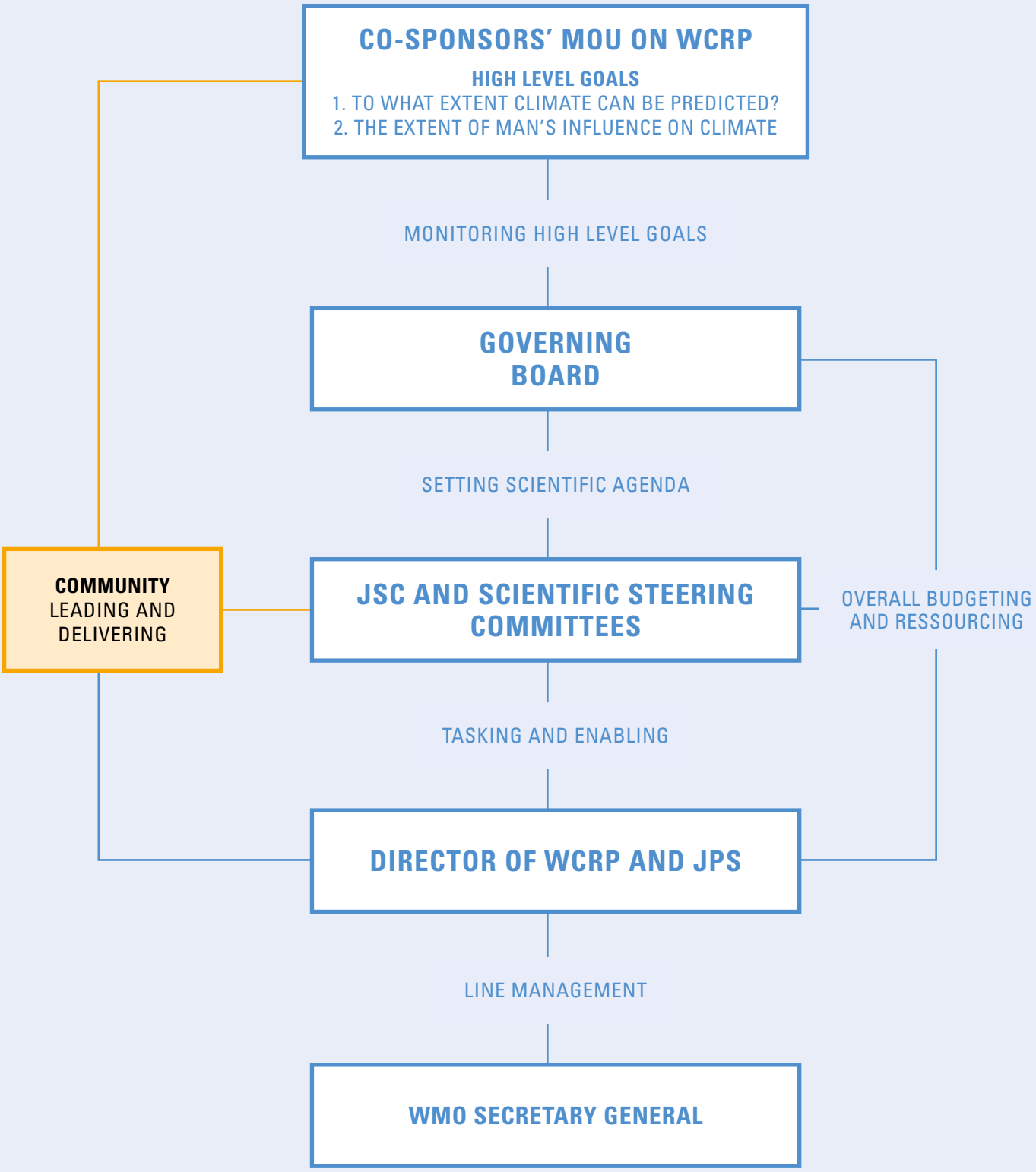
The Governing Board would meet at least once per year, either on its own or in association with the JSC, if that is convenient. The advice of the JSC would be sought on all agenda items.

In considering the governance of WCRP, the Panel noted that the existing MoU was set in place over 20 years ago, and no longer reflects the contributions of the three sponsors and the importance of fundamental climate science in the latest international agendas. The Panel concluded that a new MoU should be prepared to reflect the new research agenda requirements, the arrangements between the sponsors and the role of the proposed Governing Board. The first task of the Board would be to develop the new MoU.

The new MoU should define what sponsorship means, noting the need to understand what different values different sponsors bring to the table.

GRAPH 2

Strawman proposal for a new Governance structure



Although the functions of the various parts of WCRP in the original MoU are still valid, the role of the Governing Board would need to be defined. The new MoU should also clarify the role of the Director of the JPS. He/she should be encouraged to act on WCRP's behalf to promote the WCRP, to engage with the co-sponsors, to seek additional funding and form new partnerships; but the Director must be accountable to the JSC and the Board at all times.

The Panel also recommends that the co-sponsors consider the constitution of the JSC and how members are nominated. The current process whereby individuals are nominated by national agencies with quotas for each sponsor, does not necessarily attract the best scientific leaders. The Panel supports the suggestions for an open call for nominations based on science excellence and leadership, and that the JSC membership should be reduced from 18 to facilitate more effective decision-making.

The opinion of the Panel is that with this new governance structure in place there will be much greater clarity on roles and responsibilities, and more engagement of the sponsors in the future direction and overall health of WCRP. With the Governing Board being responsible for managing the interface between the JSC, the sponsors and other external clients, the JSC will be freed up to exercise its intended role, which is to provide science leadership, to set the science strategy and oversee its implementation, and to build a strong community of international scientists to work on Grand Challenge problems that require international coordination.

3.3 FUTURE STRUCTURE

WCRP is built around its four Core Projects, which have been in existence for a long time; consequently, their structure and remit may not be valid in an era in which more holistic Earth system and seamless weather-to-climate science approaches are needed, and where society requires science and services from the global to the local scale.

One of the key questions for the current review is whether the existing Core Projects are the right ones. Do they make sense scientifically and do they reflect properly the societal needs for climate science in the 21st Century? The Panel concluded, based on the evidence summarized earlier, that the answer must be an emphatic 'No'.

The Panel was urged to provide guidance on how WCRP might be structured going forward. The structure should flow from the strategy, so the first requirement is that the strategy be developed. A process should then be undertaken to develop a new structure that best supports the strategy. In the absence of an overarching strategy, the Panel nevertheless offers the following suggestions for consideration.

Recalling the principal aims of WCRP, which are to determine "to what extent climate can be predicted, and the extent of man's influence on climate", then these should be the two core pillars of WCRP. These pillars should take a holistic view of the climate system, and bring together the separate components of the climate system that are currently covered by the Core Projects.

These two core pillars need to be underpinned by a third pillar on fundamental research on Earth system processes across timescales - for example, from the fast scales of organized convection to the slow scales of dynamic vegetation and melting ice-sheets. At the core of this activity is the recognition that understanding processes at fine scales, through observations, field experiments and simulation, is essential for developing paramerizations at the larger scale, and for ensuring that climate and Earth system models are delivering reliable and robust simulations.

Numerical weather prediction increasingly involves Earth system processes, including ocean–atmosphere coupling, but continues to be hampered by long-standing fundamental problems, such as representing atmospheric-organized convection and land–atmosphere fluxes. These are typically the same physical processes and problems that have hampered climate simulation and advancing climate prediction. The Panel heard evidence from GEWEX of the importance of understanding multi-scale processes and how working with the weather community is vital for the future. The Panel therefore recommends that WCRP and WWRP consider whether it might be more effective to establish a joint Capabil ity Theme on Earth System Processes, to deliver the benefits of seamless science across scales.

With those drivers in mind, the Panel proposes that WCRP should be structured around these three pillars. It suggests that they might be termed 'Capability Themes' to reflect their enduring nature, rather than the term 'Core Project' which implies a

time-limited activity. These Themes would facilitate community activities around long-term fundamental research, akin to the role currently played by the Core Projects but taking a more holistic Earth system approach. They would replace the existing Core Projects, but just as now, continue to provide the underpinning science for more topical and time-limited activities, currently captured within the Grand Challenges.

Each Capability Theme would have a Theme Leader and a Scientific Steering Committee that would set their own research priorities and activities, to deliver the WCRP overarching strategy, and facilitate communication across the Themes, similar to the way the Core Projects currently function. Each would have its own Secretariat to facilitate meetings and activities. The role of the JSC should be to ensure that the Capability Themes work well together, and that their specific activities are harmonious with the overarching WCRP Strategy.

Two of the proposed Capability Themes relate to two of the existing Core Projects, with the addition of a new core activity on Climate Change and Earth System Feedbacks, something the Panel regards as very important and badly needed to promote and coordinate WCRP's contribution to climate change. The Panel anticipates that the activities within the existing Core Projects would map across to the relevant Capability Themes, guided by the new WCRP Strategy.

In the process of evolving to the new structure, the Panel strongly recommends that WCRP should aim to simplify the existing panels and working groups within the current Core Projects, and seek to prioritize its research to those areas where international collaboration facilitated by WCRP really makes a difference. The Panel is keen that the community continues to self-organize itself, working together around problems, but not necessarily seeking WCRP resources.

This proposal differs from earlier suggestions, following the 2009 review, to structure WCRP around the component parts of the climate system (atmosphere (SPARC), land (GEWEX), ocean (CLIVAR) and cryosphere (CLIC)), but the panel feels strongly that such a change would not facilitate the more joined-up holistic Earth system approach that it considers necessary to address 21st Century problems. However, this does not mean that research on specific components of the climate system, such as the oceans, cryosphere and the stratosphere, which are prominent in the existing structure and currently covered within CLIVAR, CLIC and SPARC, cannot continue; indeed the panel strongly recommends that such research does continue, and this is reflected in the topics within each Capability Theme. The Panel fully recognizes the risk that those communities may feel disenfranchised, but wishes to reassure them that this is absolutely not the intention; instead the Panel hopes that any affected communities will find the proposed move to a more holistic approach, which place their research in the wider context, both stimulating and rewarding.

The Panel also recommends that the Modelling Working Groups should be consolidated, whereever possible, within the Capability Themes, to ensure that they are fully integrated with the science. This change recognizes that modelling is now the central plank for delivering science in WCRP, and that therefore the need for separate modelling working groups has passed, although their specific activities are still central to delivering WCRP's mission.

WGSIP, CORDEX and the CMIP component of WGCM should be embedded within their relevant Capability Themes, where they would contribute grand ensembles of simulations, hindcasts and predictions for use by the research community and wider stakeholders, as well as promoting specific model intercomparisons to aid understanding of feedbacks and sensitivities within the climate and Earth system.

CMIP and CORDEX would become essential parts of the Capability Theme on Climate Change and Earth System Feedbacks, and WGSIP would provide a similar contribution to the Capability Theme on Climate Variability, Predictability and Prediction.

Within and between the Capability Themes should be a small set of high-profile, but time-limited (5-10 years maximum) Cross-cutting Research Projects. Over time there should be an increasing emphasis on these projects as a means of attracting a new generation of scientists, for show-casing cutting-edge WCRP science, and for demonstrating the policy relevance of WCRP. The Research Projects should draw on the Capability Themes, and when appropriate, seek to co-design and implement the plan of work with other major programmes, such as WWRP and Future Earth. The Panel recommends that ideally each Research Project should be led by independent and preferably younger, mid-career sci-

entists to increase the talent at WCRP's disposal. It is suggested that each Research Project has a lead Capability Theme, which takes responsibility for reporting upwards to the JSC.

As already noted, WCRP's approach to regional climate issues and the link through to applications requires careful thought. WCRP is already considering the structure of its regional activities and the role of the Working Group on Regional Climate (WGRC) within those. It could act as a bridge between WCRP and GFCS, by promoting applied and translational research and facilitating dialogues between underpinning climate science and customer-relevant services.

As already noted, model development continues to be hard work to prioritize and energize, but yet it is vitally important for WCRP and its partners if they are to deliver the climate science advances that society requires. With the new agendas of seamlessness, and of high-resolution Earth system modelling and the advent of exascale computing, with all that that implies in building a new generation of codes, a major push is required in climate model development. In this context, the panel noted that most of the activities of the existing modelling Working Groups revolves around using models to deliver science rather than science for model development.

In light of this, the Panel recommends that a new WCRP Working Group on Climate Model Development should be established. This would consolidate the climate model development activities currently in WGCM, those in the Ocean Model Development Panel (OMDP currently in CLIVAR) and any that are scattered through the Core Projects. The new Working Group would take the lead in the science for next-generation Earth system modelling and provide a forum for engaging with the vendors on the design of exascale machines. It would be anticipated that this new Working Group would work closely with the Capability Theme on Understanding Earth System Processes in the development of new parametrizations, and potentially be a joint activity with WGNE, which focuses primarily on atmospheric modelling. Alternatively, WMO could consider whether WGNE should be repurposed and empowered to become the focus for all model development (coupled and uncoupled, atmosphere, ocean and Earth system) across WCRP and WWRP.

With the consolidation of the modelling Working Groups within the Capability Themes, and the recognition that modelling is now the fundamental tool for delivering science, the need for the WCRP Modelling Advisory Council is removed and it could be disbanded. Furthermore, the restructuring of WMO science activities, currently ongoing, may decide that a top-level Advisory Panel is required to represent all modelling and prediction needs across weather and climate.

With regard to WDAC, the Panel suggests that this may also be disbanded; instead, the Panel recommends that WMO, with the IOC, considers how GOOS, GCOS and CCL can work more effectively together and with WCRP, to coordinate the observational needs for climate science, including the delivery of reanalyses. This would also provide a home for routine climate monitoring and climate change detection.

This still leaves a gap on how best to handle Big Data from multi-model ensembles of hindcasts, predictions and projections; the Panel recommends that WCRP works with WWRP and other parts of WMO to consider how best to provide international leadership in data system development, potentially through a WMO-wide Advisory Panel on Research Data.

In considering the new structure for WCRP, the Panel strongly urges WMO and ICSU to reflect on its activities in atmospheric composition and Earth system modelling, with a view to strengthening co-design and co-working. There is no doubt that when Future Earth was created, the opportunity to forge stronger links between WCRP, IGBP and IGAC was missed. Although the Panel heard criticism of WCRP for not joining Future Earth, it understands why that would not have been a good outcome, because of the increasingly important links with weather research and with climate services.

With regard to atmospheric composition, the Panel heard some compelling evidence for joining together the activities of GAW, IGAC and SPARC. Coupled chemistry modelling is a critical part of WCRP's climate-change activities, and air quality at the regional and local levels, and on both weather and climate timescales, will have major societal impacts. The Panel suggests that WMO and ICSU consider whether a jointly sponsored research programme in global atmospheric composition, taking in GAW, IGAC and SPARC, might serve the scientific and user communities more effectively.

Over the last decade, climate system models have evolved to Earth system models, which include a

range of bio-geochemical cycles that formally fell within the remit of IGBP. It is now the case that CMIP6, which will underpin the IPCC 6th Assessment Report, will be dominated by Earth system models. At the same time, it is increasingly appreciated that Earth system feedbacks, which are so important for climate-change science, cannot be understood and modelled without detailed understanding of the physical climate system, especially the water cycle.

The Panel was concerned therefore that there is a potential disconnect between WCRP's activities and Future Earth's AIMES project on Analysis, Integration and Modeling of the Earth system. It is evident that there is significant overlap in the scientific community that each programme draws on, and the Panel recommends that the proposed WCRP Capability Theme on Climate Change and Earth System Feedbacks seeks to work even more closely with AIMES, or even to consolidate the two activities.

Although WCRP should continue to focus on the fundamental, underpinning science, it is essential that it formalizes and improves its links to applications and user needs that involves more interdisciplinary approaches, including linking to the social sciences. These needs increasingly require information at the regional and even local level, and the panel commends WCRP for its thrust on providing climate information for regions and establishing an International Office to lead in delivering this. The Panel therefore recommends the formation of a new Working Group on Climate Information for Regions, which will essentially capture the activities of Legs 2 and 3 in WCRP's latest regional plan. The Panel envisages that Leg 1 will be delivered through the Capability Themes and Research Projects as part of the growing agenda in regional and local underpinning climate science.

Taking all these points into consideration the Panel proposes the following strawman structure for consideration by the sponsors, the JSC and the wider WCRP community. It is important to stress that this is only a proposal and is offered in the spirit of helping discussion and finding a way forward. In the Panel's view, it addresses the on-going core aims of WCRP; the new global agendas on climate change, disaster risk and sustainability; the need for stronger links with the weather community and with Future Earth; and the imperative of reducing the complexity of WCRP's existing structures.

This structure seeks to place WCRP in the context of other, related activities on which WCRP will depend and also contribute. Based on the evidence that it heard, the Panel also proposes some restructuring of these activities for WMO and its partners to consider, with a view that these could provide greater coherence across the whole Earth, climate and weather system portfolio, and potentially lead to improved co-operation and more effective use of resources (see graph 1).

WCRP is presented in the enclosed blue elements, and linkages with the surrounding boxes are implicit. The three fundamental pillars of WCRP are represented by the Capability Themes. The topics within each pillar indicate the areas of science that might fall within each Theme and are intended to show how the existing Core Projects might map across; they are not indicative of specific activities.

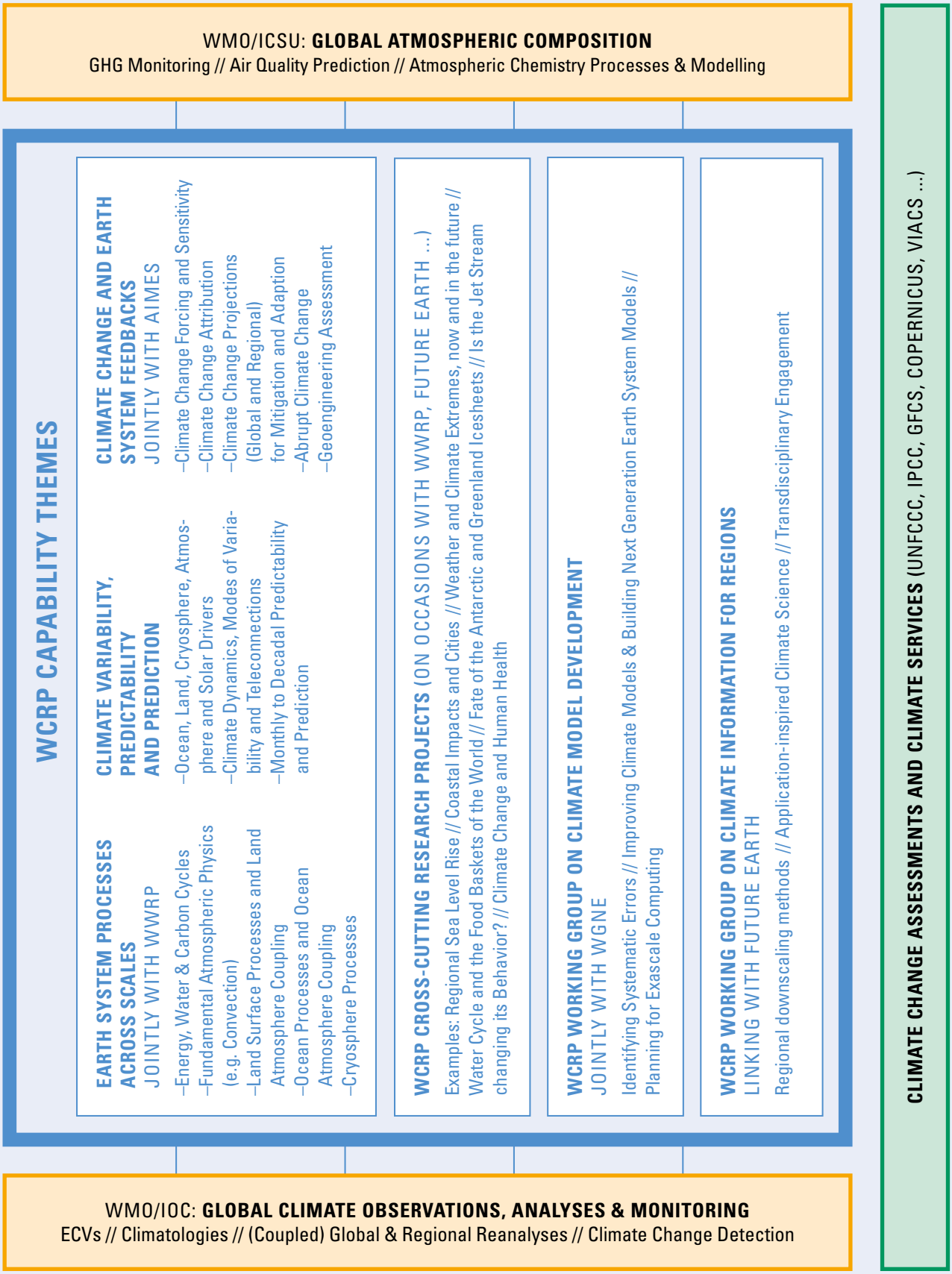
The Capability Themes should evolve from the existing Core Projects and Working Groups, by combining different elements in such a way that the community remains engaged and empowered. The development of the Capability Themes will provide an opportunity for WCRP to refocus, simplify and rationalize its activities within the existing Core Projects, something that is urgently required. The Panel heard on a number occasions that there are too many working groups and panels within the existing structures, which is why there is confusion and duplication, as well as wasted resources.

The Panel recognizes that the Capability Themes overlap and that, for example, climate variability cannot be viewed separately from climate change. However, an organizing structure is essential and will serve to highlight what WCRP does to the external community. It will be very important, nevertheless, that the Capability Themes work together as much as possible and where appropriate, design joint activities.

The Cross-cutting Research Projects should evolve from the existing Grand Challenges and become more prominent in WCRP over time, representing its flagship activities. The topics in the figure are not concrete suggestions, but indicative of the sorts of cross-cutting questions that WCRP should seek to answer. The Research Projects should be time-limited (5-10 years) and work across the Capability Themes. The Theme Leaders should work together to

GRAPH 1

Strawman proposal for a new WCRP structure



co-design the Research Projects in consultation with the JSC and within the context of the new strategy developed with the climate science community. In order to deliver the maximum impact, the Research Projects should, where appropriate, engage with other communities and stakeholders.

One of the benefits of creating a new structure is that WCRP can now take a fresh look at how it wants to deliver its new strategy and what activities are needed. The evolution from Core Projects and Modelling Working Groups to the proposed new and streamlined structure (or similar depending on the deliberations of the WCRP community) should be guided by the new WCRP strategy, with the goal of establishing clear plans for evolving to the new structure before the 40th anniversary of WCRP in 2020. Recognizing that there is a certain timescale related to contractual arrangements with International Project Offices, the Panel nevertheless would like to see the re-structured WCRP fully in place by no later than 2022.

The Panel acknowledges that restructuring will require resources to help the transition and re-mapping of activities. WCRP will need additional support from its sponsors to achieve this, although in the longer term the Panel foresees a more sustainable and viable future for WCRP.

3.4 PARTNERSHIPS

3.4.1 SEAMLESS SCIENCE AND WORKING WITH WWRP

As global weather and climate modelling and prediction develop, it is becoming clearer, and widely accepted, that there is convergence in the characteristics of the models and prediction techniques used for both weather and climate. The modelling approach involves fully coupled atmosphere–ocean land surface models, and the data assimilation and ensemble approach, developed within weather prediction, is becoming commonplace in climate, particularly on short to medium climate timescales. This convergence is encapsulated in the phrase "seamless prediction" or even "seamlessness".

Another perspective is that the weather science and prediction community (as represented within the various WWRP programmes) have a long experience of the analysis and prediction of weather events and the physical processes that need to be included to make predictions as accurate as possible. This means that bringing together the expertise and experience of the weather prediction community and that of the climate modelling community offers great benefits for WCRP. The advent of the seamless convergence of weather and climate models means that the time is now right to exploit these opportunities.

The WCRP Review Panel feels that this synergy between WWRP and WCRP is not being fully capitalized upon by WCRP at the moment – it represents something of a missed opportunity. There are examples of parallel initiatives, for example in high-impact weather/extremes and sub-seasonal to seasonal prediction, where these would have benefited from greater alignment through a rigorous co-design phase in which WWRP and WCRP worked together to ensure the initiatives (or single integrated initiative) realized and maximized the synergies.

In conclusion, the Panel recommends that WCRP be pro-active in establishing a process of full engagement with WWRP via the practice of co-design of projects to exploit the synergies that seamlessness offers. A co-designed Roadmap for exploitation of such synergies would be an important first step. During the course of drawing in evidence for this Review, the view was expressed that there are cultural differences in the way WCRP and WWRP operate, in part due to the operational nature of weather forecasting; breaking down these differences would be highly beneficial to both sides.

3.4.2 EARTH SYSTEM SCIENCE AND WORKING WITH FUTURE EARTH

Since the establishment of Future Earth and the decision by WCRP to remain independent but to forge collaborations with it, the climate science agenda has evolved to a position where more holistic, Earth system approaches are increasingly needed. The Panel recommends that the sponsors consider clarifying their respective roles and co-benefits of working with Future Earth and how best to value and streamline core physical climate science within transdisciplinary efforts. In particular, the Panel makes some specific suggestions around streamlining research on atmospheric composition and Earth system modelling which reflect their dependence on physical climate science.

3.4.3 ROLE OF WCRP IN 'SCIENCE TO SERVICES'

As already stated, the Panel feels strongly that WCRP should not be diluted by moving away from underpinning, fundamental climate science into the translational, applied science required for climate services. However, WCRP does need to be cognizant of what the users and stakeholders require from climate science, and should therefore maintain an active dialogue with them, directly and through its sponsors. This would deliver multiple benefits; not only would WCRP be able to articulate the value of its core science for addressing societal needs, but it would also give users access to the latest scientific developments so that they can shape their services accordingly.

The Panel noted that there still seems to be confusion around what the term 'climate services' means, and recommends that WCRP and GFCS work more closely together to close that gap and to communicate the complementary roles of WCRP and GFCS to their communities. GFCS already contributes to JSC meetings and that should continue; the Panel also recommends that a senior representative from GFCS serve on the proposed Governing Board. Likewise, the GFCS should ensure that WCRP is represented on its top-level board; it should also aim to involve WCRP in discussions with potential users, stakeholders and funders where appropriate (e.g. European Commission, Copernicus, World Bank).

Society's needs for climate information are frequently at the regional and local levels. With that in mind the Panel welcomes WCRP's refocusing of the Working Group on Regional Climate (WGRC), with a view to its playing a strong, linking role with climate service providers on behalf of WCRP. Noting the significant funding opportunities available to GFCS, the Panel expresses the hope that research funding to support the activities of the WGRC and its community will flow from those opportunities. Whatever structure is agreed on, the Panel urges WMO to break down the silos of climate science versus climate services, to help WCRP avoid being seen as an 'ivory tower'.

The Panel was less clear on what opportunities are available with Future Earth to bring science through to services. It understands that Future Earth is still in its development phase and beginning to build links with business and other stakeholders. The Panel urges ICSU, as a sponsor, and particularly through Future Earth, to have WCRP in mind when it enters into dialogue with potential stakeholders; it should promote what the WCRP can offer, although the Panel noted that Future Earth, WCRP and another ICSU-sponsored programme, Integrated Research on Disaster Risk (IRDR), have already initiated a joint action to develop a new Knowledge-Action Network (KAN) on Emergent Risk and Extreme Events. The Panel also notes that the recent merger of ICSU with ISSC is a positive move and opens up new opportunities for linking to and understanding user needs. The Panel recommends that the sponsors review the relationship of WCRP with their user communities on a regular basis and especially through the proposed Governing Board.

3.5 OPERATIONAL DELIVERY

3.5.1 FUNDING

WCRP is at a critical point with regard to funding to support its activities. The current situation of a reducing funding base for the JPS is untenable, but yet WCRP is one of the most highly regarded and widely recognized of the various research efforts supported by the sponsors. Many of the projects that it delivers could not have been achieved without the international coordination and leadership that WCRP provides.

Furthermore, the gearing of national investments that can be achieved from a small investment in WCRP is impressive and can be game-changing. CMIP is an excellent example of such a project, without which the IPCC assessments would have struggled. A conservative estimate of the national investments in CMIP6 places their value in excess of US$ 3 billion, based on scientists' time to develop and run the models and to design the experiments, and the supercomputing costs to deliver the simulations. The investment by the sponsors in facilitating CMIP and enabling the scientists to meet to discuss plans and progress is tiny in comparison, and yet the community continues to struggle to find resources and funding from WCRP to support these activities.

The Panel therefore urges the sponsors redouble their efforts to support the JPS financially at a higher level of enabling funding, so that it can operate more effectively, support the community in coming together to coordinate science, and con-

tinue to deliver the research outputs that society increasingly depends on.

Whilst the Panel recognizes that the different sponsors provide both financial and in-kind support and that the route for the financing is sometimes circuitous, there must be greater clarity and forward planning. The proposed Governing Board is intended to facilitate this, but can only do so if WCRP and its JSC and JPS adhere to a proper budgeting process and enable the sponsors to make strong cases for funding within their respective organizations. The Panel recommends that the three heads of the sponsoring organizations should meet to discuss the future of WCRP and how it can be sustained.

The Panel agreed, nevertheless, that WCRP cannot rely solely on its sponsors to support the breadth of its activities. In the past, there has been much stronger involvement of national funding agencies, who saw real benefits in engaging with WCRP science. They were interested in WCRP because it was an important delivery body for them; it was how national products got to the rest of the world, and it was how they could maximize the international gearing for their investments in national science. The Panel hopes that national WCRP committees will once again be formed within national academies to provide national focal points.

The Panel also recommends that WCRP be proactive in seeking national contributions to support its cross-cutting Research Projects, similar to the approach used by WWRP in support of its Projects. National funding agencies are no longer round the table, and the Panel urges the sponsors to work with WCRP, and especially the JSC, to re-engage with research funders and encourage countries to make appropriate national contributions to the JCRF and other supporting mechanisms such as sponsorship of the cross-cutting Research Projects. However, the Panel recognizes that all of this can only be done once WCRP has a strategy that sets its future priorities and articulates its value to society.

It is worth remembering that WCRP only exists because of the scientific community that engages with it. At a time when research budgets are under threat and there is a risk that funding could be increasingly diverted away from fundamental science towards impact-driven science, the Panel is keen to see WCRP play an advocacy role, with its sponsors, in mobilizing research funding for fundamental climate science. The Panel recommends that engagement with the Belmont Forum of research funders should be at a high-level, and that WCRP needs to partner with others to influence Belmont Forum research funding; it should be seen as a partner of Future Earth, and to be at the table. Only in that way can it continue to influence the research funding community of the need for fundamental science.

WCRP should also consider promoting an alliance of funders interested in supporting fundamental climate science and next-generation climate modelling and computing, akin to the Belmont Forum, by demonstrating that without the coordinating role of WCRP, international collaborative research such as national level commitments to CMIP would not happen.

3.5.2 JOINT PLANNING STAFF

Overall, the Panel felt that the effectiveness of the JPS was currently compromised because of issues related to leadership and the strategic direction of WCRP, both of which need attention. The Panel recommends that additional clarity be provided in the terms of reference, structure and functions of the Joint Planning Staff and the Director of WCRP. The Panel also noted the benefits of greater integration of WCRP within the WMO Research Department, so that the JPS interacts on a daily basis with those involved in delivering weather and atmospheric composition research. There is no doubt that this would deliver more joined-up planning and delivery, and engender seamless thinking.

The sponsors should also consider whether the role of Director, and the JPS in general, should have more day-to-day discretionary executive power, enabling the JPS to be agile and responsive, but always in line with the guidance and direction of the JSC and in consultation WITH the JSC Chair and Officers as appropriate.

3.5.3 MEASURES OF SUCCESS

Although WCRP is a facilitating and coordinating body it should nevertheless have aims and objectives, and the degree to which those have been achieved should be monitored. In the past, this has been difficult but the Panel recommends that as WCRP develops its new strategy, it should consider how it measures its success in delivering the strategy.

In developing its metrics, WCRP should consider how WWRP measures its success, and some commonalities in approach might be desirable. It should also work with its sponsors to understand how they view success. Is it the degree to which WCRP mobilizes researchers to address its key issues? Is it in delivering socio-economic value from climate research? Is it the leverage of research funding through setting research agendas that appeal to funders? Is it through ensuring that fundamental climate research remains visible and important?

4 SUMMARY AND RECOMMENDATIONS

WCRP is at a critical point in its history, and significant changes are required in its governance, structure and delivery for it to fulfil its mission in the context of 21st Century challenges.

The core, underpinning climate science which WCRP delivers is needed more than ever before, as society seeks solutions to climate change (Paris Agreement), to resilience to disasters (Sendai Agreement), and to sustainable development for the planet (UN Sustainable Development Goals). Without a strong foundation in climate science and prediction none of these challenges can be addressed in a robust, cost-effective and durable way.

Since its inception, the key strength of WCRP has been its focus on cutting-edge physical climate science where international coordination enables scientific advances that would not happen otherwise. This must continue to be its focus, and that means prioritizing what it does and recognizing where its unique role as a facilitator and integrator of climate research makes a difference.

WCRP is a strong brand and as such it needs to play an advocacy role, to interact strategically with big funders, and to focus on strategic positioning of WCRP in the climate arena. There is a need to have an important, recognized, international and collective voice for climate science, and WCRP should continue to play this role.

1 SCIENCE STRATEGY

A new ten-year WCRP science strategy and related five-year implementation plan must be developed as soon as possible in discussion with the sponsors and with wide consultation and community buy-in.

WCRP currently does not appear to operate within the context of an up-to-date, overarching and clearly focused strategy and this must be rectified as soon as possible. A consequence of the lack of a strong, and strongly implemented, strategy is that WCRP is struggling to set priorities and to stop less important activities. If WCRP does not continue to provide clear leadership, there is a danger of losing the engagement of the scientific community and its funders, so a new strategy is badly needed.

In developing its strategy WCRP needs to reflect how climate science has evolved over recent decades, with the emergence of holistic Earth system modelling, of seamless weather and climate science, of the increasing skill and reliability of climate prediction, and the growing agenda for an increasing number of climate predictions and projections to guide resilience, adaptation and mitigation actions.

The new strategy should respond directly to this review and encapsulate the following recommendations:

- It should identify the key societal needs for fundamental climate research to tackle 21st Century problems across climate resilience, adaptation and mitigation;
- It should focus on the scientific priorities where WCRP can make a unique contribution through its international, coordinated and integrative activities;
- It should reflect the recommendations regarding the structure of WCRP;
- It should show where recommendations regarding partnerships will add value to WCRP;
- Although the focus should be on providing the bedrock climate science, the strategy should demonstrate a clear pathway to applications, i.e. climate services;
- A short synthesis of the new WCRP strategy should be produced to enable the WCRP community to engage with potential new sponsors and funders and to act as advocates for fundamental climate research.

2 GOVERNANCE AND THE MOU

A formal high-level Governing Board for WCRP should be established to enable more effective engagement with the sponsors and enable them to fulfil their responsibilities for the programme. A new MoU should be put in place to reflect changes in governance, operations and structure.

The 2009 Review of the WCRP recommended (**Recommendation 9**) that "WCRP's sponsors should meet regularly to review their mutual responsibilities for the Programme …". The issues that led to this recommendation remain in place today. The JSC and JPS are struggling to manage upwards and the

sponsors are concerned with the responsiveness of the WCRP and its strategic alignment. The terms of the WCRP MoU are not being implemented effectively.

The core (and initial) membership of the Governing Board should include high-level representation from the sponsors, who would also recommend other members and elect an interim Chair. The Review Panel concluded that there is also a need for more explicit identification of key partners, and that a Governing Board provides a means to recognize such partnerships. The JSC Chair and Vice-Chair should be ex-officio members.

The JPS should provide the secretariat for the Governing Board. Once fully constituted, the Chair should be an independent member. The membership should not exceed eight and, other than the sponsors, should be rotated on a biannual basis. The Terms of Reference of the Governing Board should include:

- Overseeing the implementation of the terms of the WCRP MoU;
- Setting the overall aims and managing communication and interaction with and engagement of the sponsors and other key stakeholders;
- Approving the high-level science strategy and structure of the WCRP;
- Managing high-level risk and change, especially associated with funding;
- Overseeing resource mobilization and garnering enabling support for administration.

The Governing Board would meet at least once per year, either through video-/tele-conference or in association with the JSC if that were convenient. The Board would be self-supporting. A first task of the Governing Board would be to update the MoU to include the changes to governance and any other relevant items needed to refresh it.

The advice of the JSC would be sought on all agenda items. The primacy of the JSC for scientific advice and setting scientific strategy and priorities would remain; the Governing Board would take overall responsibility for the WCRP on behalf of the sponsors and in so doing would provide oversight on matters such as resource mobilization, administrative support and engagement.

The Governing Board should consider appropriate metrics for assessing the performance of WCRP.

3 SCIENTIFIC LEADERSHIP

The JSC should be re-invigorated to focus on providing science leadership, setting the science strategy and overseeing its implementation, including establishing partnerships, and building a strong community of international scientists to work on grand challenge research problems that require international coordination.

The complexity of the WCRP structure with its Core Projects, Working Groups and now Grand Challenges means that the JSC meetings tend to be largely taken up by reviewing the activities rather than setting the strategy and overall direction. The JSC meetings need to be more focused on strategy and vision than has recently been the case. Overall, the Panel concluded that morale in the JSC is not strong and that this is having a detrimental impact on the WCRP as a whole.

With the Governing Board being responsible for managing the interface between the JSC, the sponsors and other external clients, the JSC will be freed up to exercise its intended role, which is to provide science leadership, to set the science strategy and oversee its implementation, and to build a strong community of international scientists to work on grand challenge problems that require international coordination.

- The Panel recommends that the sponsors consider the constitution of the JSC and how members are nominated. The Panel supports the suggestions for an open call for nominations based on science excellence and leadership, and that the sponsors consider whether the JSC membership could be reduced from 18 to facilitate more effective decision-making.

4 OPERATIONS

Additional clarity should be provided in the terms of reference, structure and functions of the Joint Planning Staff and the Director of WCRP, to ensure that the JPS works effectively with the JSC to support its scientific activities, to facilitate international engagement and partnerships, and to manage WCRP's resources.

The JPS is a vital part of WCRP. Its role is to assist the JSC in implementing its decisions, and to facilitate the collaborative actions of the various elements of WCRP. The JPS is led by the Director of WCRP. His/her role is to lead the staff and be responsible for the scientific and technical tasks discharged by the JPS to the Chair of the JSC, acting on behalf of the sponsors.

→ As part of the recommended improvements in governance (**Recommendation 2**), the MoU should be revised to provide unambiguous guidance for the roles of the WCRP Director and the JPS with respect to responsibility and accountability, to the guidance and direction of the JSC, and in terms of representation of the WCRP. The title of the role in itself can lead to confusion as to where decision-making and strategic direction is set within WCRP. The Review Panel believes the MoU is clear that those functions lie with the JSC (and in future also with the Governing Board).

→ The sponsors should consider whether the role of the Director of WCRP, and the JPS in general, should have more day-to-day discretionary executive administrative responsibility, enabling the JPS to be agile and responsive, but always in line with the guidance and direction of the JSC and in consultation with the JSC Chair and Officers as appropriate. The word "guide" should be avoided in the ToR of the JPS to avoid any confusion with the role of the JSC.

→ The name World Climate Research Programme should be used exclusively for the research enterprise defined in the MoU. In particular, the term should be avoided for administrative units unless the distinction is made clear (e.g. the Joint Planning Staff of the WCRP).

→ Depending upon decisions with respect to governance and a Governing Board, the terms of reference should be updated to include support for the Governing Board and its role.

5 STRUCTURE

The JSC, in consultation with the newly created Governing Board, should work with the science community to establish a new structure for the WCRP research effort that best serves its new strategy and involves a simplified set of delivery mechanisms.

The existing structure is not the structure of tomorrow. However, in creating a new structure, it will be important not to destroy the legacy of what has been created – a community of engaged scientists; it will require a willingness from the community to change and for the community to be part of the change process.

The Review Panel anticipates that the JSC will work with the community and the newly created Governing Board to define a new structure that best serves its new strategy. The following aspects should be considered:

→ That the new structure comprises a combination of a small set of top-level scientific problems with explicit societal relevance (which could be called Grand Challenges or cross-cutting Research Projects that are time-limited (e.g. 5 to 10 years) in their delivery), together with a small number of enduring Capability Themes that would nurture the long-term expertise needed to advise on and contribute to these scientific problems being addressed effectively.

→ The Capability Themes would replace the current Core Projects. The existing Core Projects have been in place for a long time and so may not be ideally structured to help deliver the scientific goals of today and the future, to be articulated in the new WCRP Strategy. These Capability Themes should aim to take a holistic Earth system approach, whilst recognizing that research on individual components of the Earth system remains essential.

- The modelling Working Groups should become part of the Capability Themes to reflect the importance of modelling as a tool for delivering WCRP science. The WCRP leadership should consider how best to reinvigorate climate model development in any revised structure.

- The Research Projects should directly address the goals of the new WCRP Strategy (and so they may not necessarily have a strong link to the existing Grand Challenges) and identify high-priority issues that require international partnership and coordination; they should yield "actionable information" for decision-makers.

- Regarding the existing structural elements, the Panel concluded that the case for continuing with WMAC and WDAC in any new structure was not strong. They potentially overlap with other relevant activities within WMO and elsewhere, such as WGNE and GCOS, and that in the future any such advisory councils should cover the breadth of WMO scientific activities. Consequently, the panel recommends they not be a feature of the new structure.

- The Review Panel strongly recommends that the concepts of co-design and co-production be exploited as much as possible. This will involve the structural elements within WCRP strongly linking across to other proposed activities outside of WCRP, such as those within WWRP, GFCS, Future Earth, etc. This should be borne in mind as the new structure is being planned.

6 FINANCING

In light of the importance to society of the goals of WCRP and the precarious level of current financial support for the programme, the sponsors should re-double their efforts to support WCRP financially at a higher level of enabling funding so that it can operate more effectively.

WCRP is one of the most highly regarded and widely recognized of the research efforts supported by the sponsors. There are two distinct elements to the funding: that which supports the enabling activities of the WCRP executive ("enabling funding") and that which directly supports the research ("research funding"). This recommendation relates primarily to the enabling fund.

It should be more fully recognized than it is currently that the different sponsors provide both financial and in-kind support and that the route for the financing is sometimes circuitous and therefore not always made fully visible or recognized. Elements that should help to improve the funding situation are as follows:

- The co-sponsors should agree to be clear about the financial and in-kind contributions that they make to WCRP. This needs to factor in, and be explicit, about the complex pathways for this funding to flow to WCRP. The WCRP Governing Board should examine the enabling funding annually and be pro-active in making the case for that funding within the sponsoring organizations, in accordance with their capacities.

- WCRP should, via its sponsors, encourage countries to make appropriate national contributions to the enabling funding, such as continuing to support International Project Offices and sponsoring Research Projects; a number of countries currently appear to be reducing rather than increasing their contributions.

- In future, there is a risk that research-funding could be increasingly diverted away from fundamental science. WCRP, through its Governing Board and the JSC, should play an advocacy role in mobilizing research funding for fundamental climate science. There is a need for a more strategic engagement with the research funding communities, and for someone who could talk at the higher level with the funders.

- Engagement with the Belmont Forum of research funders should be at a high-level, ideally through a WCRP research funding representative. The Panel recommends that WCRP and its sponsors need to partner with others

to influence Belmont Forum research funding. WCRP needs to be seen as a strong partner of Future Earth, and to be at the table. Only in this way can WCRP and its sponsors continue to influence the research funding community about the need for fundamental science.

7 SCIENCE TO SERVICE

WCRP should take action to ensure its knowledge is brought to the service of society, especially in supporting the development of climate services.

While WCRP should continue to prioritize the advancement of fundamental science, it can and should seek opportunities to establish connections to relevant user communities through programme partnerships. In so doing, WCRP science can serve to inform quality services, and emerging practitioner needs can serve to inform further scientific inquiry.

→ WCRP should pursue, in particular, partnering with Future Earth and its Knowledge-Action Networks. There are positive signs emerging of opportunities for productive research partnerships and these should be pro-actively developed by WCRP.

→ WCRP should build pro-active bridges to the WMO's Global Framework for Climate Services and other science-to-service initiatives, such as the Copernicus Climate Change Service and the Climate Services Partnership, by implementing a formal activity on Climate Information for Regions.

→ A variety of other mechanisms for programme engagement should be explored. One option is through representation on the recommended Governing Board of WCRP. A second is to establish a (cross-cutting) working group that serves as liaison to the partner programmes.

→ In engaging with climate services, WCRP should explore, and as appropriate, pursue opportunities this may offer for obtaining additional funding for its fundamental science.

8 PARTNERSHIP

WCRP should seek to develop strategic and strong partnerships with other WMO research programmes (specifically WWRP and GAW), with GCOS, and with Future Earth.

WCRP should be pro-active in establishing a process of full engagement with these partners via the practice of co-design of projects to exploit the synergies that seamlessness offers. A co-designed Roadmap for exploitation of such synergies would be an important first step to draw on a great research constituency. We recommend that:

→ WCRP urgently explores the option of the co-design and co-production of projects that address key scientific challenges of common interest to WCRP, WWRP, GAW and Future Earth.

→ Future Earth should be brought in as a high-level partner. The linkage between WCRP and Future Earth should be strengthened by a regular and formal set of meetings between the top-level management of the two initiatives to share experience and explore common interests, and also by jointly developing Knowledge-Action Networks, potentially involving other ICSU programmes. The strategy for collaboration, identification of areas of joint interest, and the creation of joint evaluation schemes for the collaboration, should be considered.

→ WCRP should be open and dynamic for future opportunities to develop collaboration with new partners.

ACRONYMS AND ABBREVIATIONS

AIMES	Analysis, Integration and Modeling of the Earth System
AMIP	Atmospheric model development and intercomparison
CAMS	Copernicus Atmosphere Monitoring Service
CAS	Commission for Atmospheric Science
CCI	Commission for Climatology
CCMI	Chemistry-Climate Model Initiative
CMIP	Coupled Model Intercomparison Project
COP	Conference of the Parties
ESGF	Earth System Grid Federation
ETCCDI	Expert Team on Climate Change Detection and Indices
GAW	Global Atmosphere Watch Programme
GCOS	Global Climate Observing System
GFCS	Global Framework for Climate Services
ICSU	International Council for Science
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IGFA	International Group of Funding Agencies for Global Change Research
IHDP	International Human Dimensions Programme on Global Environmental Change
IOC	Intergovernmental Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change
JCRF	Joint Climate Research Fund
JPS	Joint Planning Staff
JSC	Joint Scientific Committee
MoU	Memorandum of Understanding
NSF	National Science Foundation of USA
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCAR	Scientific Committee on Antarctic Research
SCOR	Scientific Committee on Oceanic Research
ToR	Terms of Reference
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WCC-3	World Climate Conference 3
WCRP	World Climate Research Programme
WDAC	WCRP Data Advisory Council
WGCM	Working Group on Coupled Modelling
WGNE	Working Group on Numerical Experimentation
WGOMD	Working Group on Ocean Model Development
WGRC	Working Group on Regional Climate
WGSIP	Working Group on Subseasonal to Interdecadal Prediction
WMAC	WCRP Modelling Advisory Council
WMO	World Meteorological Organization
WOAP	WCRP/GCOS panel on observation and assimilation
WOCE	World Ocean Circulation Experiment
WWRP	World Weather Research Programme
YESS	Young Earth System Scientists

ANNEX 1
LIST OF DOCUMENTS

All documents are available at www.bit.ly/2BBcKZa

Review Panel membership
Terms of Reference for review
Link to WCRP website: www.wcrp-climate.org/
Agreement between WMO, ICSU and IOC of UNESCO, 1993
WCRP review 2009
WCRP Achievements 2009
WCRP Accomplishments 2013
WCRP Strategic Framework 2005-2015
WCRP Implementation Plan 2010-2015
WCRP annual budgets 2012-2016
Scoping a framework for WCRP regional activities, 2016
WCRP structure, reporting lines, staff profile
A self-assessment report, written by the Director of WCRP on the performance of the programme and future plans
Written input on the WCRP achievements prepared by the Chair of JSC
Roadmap for a 2019-2029 WCRP Strategic Plan, prepared by the WCRP Officers
Areas for possible cooperation between WCRP/ WWRP/GAW – Perspectives from the JSC Chair
Directions for WCRP, a presentation by the JSC Chair
A brief history of the WCRP Grand Challenges
A list containing web links to main outcomes of WCRP
Written self-assessment reports submitted by:
- –Advisory Councils: WDAC and WMAC
- –Working Groups: WGCM, WGNE, WGSIP, WGRC
- –Core Projects: CLIVAR, CORDEX, SPARC, GEWEX, and
- –Grand Challenges: NTCP, Carbon feedbacks in the climate system; Clouds, Circulation and Climate Sensitivity; Water for the Food Baskets of the World

Draft CliC implementation plan
Presentations on possible interactions between WCRP, WWRP, GAW and CAS
The list of JSC members and their ToR
JSC Session summaries 2014-2016
Draft minutes of the 38th of the JSC meeting, 2017
Minutes of the "Lessons Learnt for Climate Change Research" meeting in September 2014 to evaluate AR5 and revisit the WCRP Grand Challenges
Brasseur, G., and D. Carlson (2015), Future directions for the World Climate Research Programme
Written input from Vladimir Ryabinin, IOC of UNESCO
Strategies of WMO, ICSU, IOC of UNESCO
IPCC vision paper
WWRP organogram with all projects and reporting lines
WWRP resource mobilization booklet
Future Earth Governing Council
Introduction to the Belmont Forum
GCOS review MoU 2015
GFCS and WCRP, written input prepared by Jens Sunde, chair of the Intergovernmental Board on Climate Services
WCRP Communication Strategy 2017-2020

ANNEX 2
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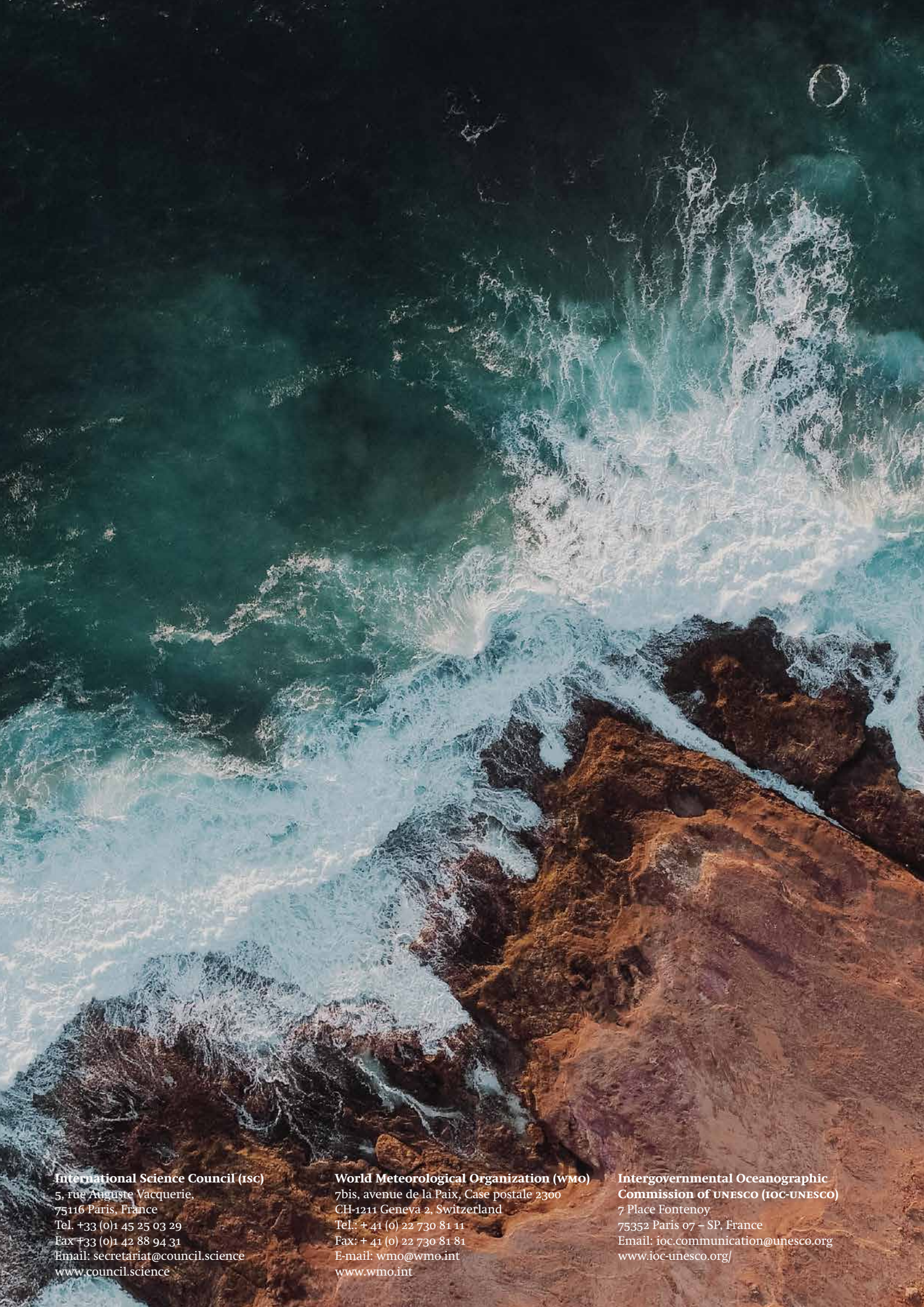

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