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The Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) Advisory Board for CMIP6

Alex C. Ruane[1], Claas Teichmann[2], Nigell Arnell[3], Timothy R. Carter[4], Kristie L Ebi[5], Katja Frieler[6], Clare M. Goodess[7], Bruce Hewitson[8], Radley Horton[9], R. Sari Kovats[10], Heike K. Lotze[11], Linda O. Mearns[12], Antonio Navarra[13], Dennis S. Ojima[14], Keywan Riahi[15], Cynthia Rosenzweig[1], Matthias Themessl[16], and Katharine Vincent[17]

[1]NASA Goddard Institute for Space Studies, New York, USA
[2]Climate Service Center Germany (GERICS), Hamburg, Germany
[3]Department of Meteorology, University of Reading, UK
[4] Finnish Environment Institute (SYKE), Helsinki, Finland
[5]Department of Global Health, University of Washington, Seattle WA, USA
[6]Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany
[7]Climatic Research Unit, School of Environmental Sciences, University of East Anglia, UK
[8]Climate System Analysis Group, University of Cape Town, South Africa
[9]Center for Climate Systems Research, Columbia University
[10]Centre on Global Change and Health, London School of Hygiene & Tropical Medicine, UK
[11]Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada
[12]National Center for Atmospheric Research, Boulder, USA
[13]Centro EuroMediterraneo sui Cambiamenti Climatici and Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy
[14]Department of Ecosystem Science and Sustainability, Colorado State University, Fort Collins, USA
[15]International Institute for Applied Systems Analysis, Laxenburg, Austria
[16]Climate Change Centre Austria (CCCA), Vienna, Austria
[17]Kulima Integrated Development Solutions (Pty) Ltd and University of the Witwatersrand, Johannesburg, South Africa

Correspondence to: Alex Ruane (alexander.c.ruane@nasa.gov)

Abstract. The Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) Advisory Board was created to provide a strong bridge between climate change applications experts and climate modelers for the Sixth Phase of the Coupled Model Intercomparison Project (CMIP6). The climate change application community comprises researchers and other specialists who make use of climate information (alongside other socioeconomic and environmental information) to analyze vulnerability, impacts and adaptation of natural systems and society in relation to past, ongoing and projected future climate change. Much of this activity is directed toward the co-development of information needed by decision-makers for managing projected risks. The initialization of CMIP6 provided a unique opportunity to facilitate a two-way dialogue between CMIP6 climate modelers and VIACS experts who are looking to apply CMIP6 results for a wide array of research and climate services objectives. The VIACS Advisory Board convenes leaders of major impact sectors, international programs, and climate services in order to solicit community feedback that increases applications relevance of the CMIP6 Model Intercomparison Projects (MIPs). As an illustration of its potential, the VIACS community provided CMIP6 leadership with a list of prioritized climate model variables and MIP experiments thought to be of greatest importance to the climate model applications community. Climate modelers therefore received useful guidance as to the applicability and societal relevance of their simulation outputs. The VIACS Advisory Board also reflected on contributions to Obs4MIPs and user needs for the gridding and processing of model output. Furthermore, the wide application of climate model outputs by VIACS users provides an error check and ground-truthing of the climate model-based results.

1 Introduction

Charles David Keeling's observations of rising carbon dioxide concentrations at the Mauna Loa Observatory alerted the world to the formidable challenge of anthropogenic interference in the climate system more than 50 years ago (Keeling, 1960). In the years since there has been tremendous progress in our understanding of climate drivers, atmospheric circulation, interaction between climate system components, climate dynamics, human and natural system responses to climate change, and strategies that may safeguard these systems in a changing world (IPCC, 2013). The collective evidence base compiled by the climate science community culminated in action by the United Nations Framework Convention on Climate Change (UNFCC) to adopt the 2015 Paris Agreement to limit warming of the global climate and to increase the ability to adapt to adverse climate impacts (UNFCCC, 2015). The Paris Agreement reinforces the urgent need for climate applications based on cutting-edge science to support the implementation of emissions reductions and climate resilience around the world while not undermining social sell-being. It is therefore crucial that a platform is created to support an active dialogue between researchers and practitioners so that information exchange about climate change, sectoral system responses, and strategies to respond can be sustained.

Climate research is based on a foundation of observational data and understanding of the physical, chemical, and biological processes that govern the climate system. Climate models, bolstered by an exponential increase in computational resources, have emerged as an important tool for climate scientists seeking to fill gaps in knowledge of the climate system. In particular, climate models play an important role in simulating complex and interacting climate processes, testing climate hypotheses, illustrating the potential ramifications of emissions pathways, and acting as a laboratory of climate response. The Coupled Model Intercomparison Project (CMIP) emerged out of the earlier Atmospheric Model Intercomparison Project (AMIP – Gates et al., 1999), recognizing the rapid development from atmosphere-only general circulation models (GCMs) toward coupled ocean–atmosphere–cryosphere–land GCMs. The establishment of CMIP in 1995 was seen as an initiative to undertake systematic intercomparison and evaluation of climate models to spur model improvement and application of comparable outputs (Meehl et al. 2000).

The range of expertise required to develop climate models differs in many respects from the expertise underpinning studies of climate change vulnerability, impacts and adaptation (VIA). Although there are many overlapping areas of inquiry (e.g., vegetative response is of interest in climate models, for agricultural and forestry applications, and in ecosystem science), VIA experts commonly translate the physical quantities reported in climate output (e.g., temperature, precipitation, humidity) into societally-relevant quantities (e.g., crop and fisheries yield, available water and energy resources, disease prevalence, commodity market shifts, or species habitat loss). However, this translation process frequently demands much more than a deterministic representation of a climatic "cause" producing an "effect" on a given exposed system. System response under a changing climate is frequently mediated by parallel societal and environmental ("global") changes. It can also be influenced by factors that may be poorly understood and difficult to model, such as aspects of behavior and vulnerability, which require other expertise and methods to be deployed.

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Hence, the science of VIA analysis is both interdisciplinary and demands extensive knowledge of climate, other concurrent global changes (both biophysical and social), and the affected system itself.

VIA analysis is undertaken in varying contexts, ranging from publicly-funded academic research (e.g. developing new paradigms, methods, datasets or tools) to applications delivering products directly to specific clients with particular geographical areas or sectors of concern. The realm of climate services (CS, see below) is a subset of the latter category, in which experts combine sector-specific climate information and form knowledge products and tools for decision support across a number of public and private stakeholders. This "operationalizing" of climate science requires an understanding of decision-making needs, processes, timelines, incentives, priorities, level of risk-aversion, and tradeoffs that determine the tailored climate information products that would be most useful, for example. This understanding can, in turn, inform VIA methods, tools, and data products, particularly on inter-and transdisciplinary frontiers.

Figure 1 provides a simplified schematic of the interactions between the science of climate, the science of system behavior, and the operationalization of climate information. The Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) Advisory Board for CMIP is designed to facilitate communications between the climate modeling community and the various communities applying climate change information for scientific or operational purposes. By formalizing this process and involving leaders from each community, the VIACS Advisory Board aims to enhance the societal benefit of climate information.

2 Background

2.1 CMIP6

After its founding in 1995, the Coupled Model Intercomparison Project (CMIP) timed its phases to provide climate model projections of record for the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (AR). CMIP2, CMIP3, and CMIP5 formed the basis of global model simulations for the Third Assessment Report (TAR), Fourth Assessment Report (AR4), and Fifth Assessment Report (AR5; IPCC, 2015), respectively. CMIP is now in its sixth phase (CMIP6; Eyring et al., 2015), and continues in its role of systematically inter-comparing climate models and making outputs available to the applications communities in support of all three Working Groups of the Sixth IPCC Assessment Report (AR6).

CMIP6 is designed to answer three overarching science questions (Eyring et al., 2015): (1) How does the Earth System respond to forcing? (2) What are the origins and consequences of systematic model biases? and (3) How can we assess future climate changes given climate variability, predictability and uncertainties in scenarios? CMIP6 is organized around a historical climate simulation, a central set of simulations designed for Diagnostics, Evaluation, and Characterization of Climate (or “Klima” in German, giving an acronym DECK for these central simulations), and a number of Model Intercomparison Projects (MIPs) that explore specific aspects of climate, model performance, and/or diagnostics (Table 1). Diagnostic MIPs are unique in that they do not drive individual model experiments, but commit to specific aspects of analysis and contribute to evaluation and application. Together, these central experiments and MIPs address the World Climate Research Programme's Grand Science Challenges (covering Clouds, Circulation and Climate Sensitivity; Changes in Cryosphere; Climate Extremes; Regional Sea-level Rise; and Water Availability; Brasseur and Carlson, 2015; "Regional Climate Information" was originally included as a Grand Challenge but was discontinued in April, 2015, with work on regional climate designated as a Key Deliverable). CMIP6 provides participating modeling groups with an overarching structure, coordination, data framework, and hub to communicate results to the broader community, potentially including online visualizations and analyses.

2.2 Applied Climate Communities

Observations and understanding of the effects of climate and weather on valued natural and human systems have raised concerns about potential adverse impacts of anthropogenic climate change, and about decisions that may be required for adapting systems to these impacts. Such concerns have motivated the development of practical approaches for analyzing impacts, making use of model projections of future climate along with scenarios describing concurrent changes in socioeconomic conditions affecting system exposure and vulnerability.

2.2.1 The Vulnerability, Impacts, and Adaptation (VIA) research community

In a review for the IPCC AR5, Burkett et al. (2013) document the emergence and rapid increase in climate impacts research, beginning with agricultural and biological research in the 1970s and then expanding into many areas of social science. To illustrate this evolution, they report that more than 100 papers were published on the topic of climate change "impacts" in 1991, with the topics of "adaptation" and societal "cost" only reaching that threshold in 2003. VIA publications still come disproportionately from European and North American institutions and focus largely on impacts in those regions, however VIA publications from other regions have become more numerous in recent years.

The evolution of VIA literature is also evident in successive assessments by IPCC Working Group II (IPCC, 1990, 1992, 1996, 1997, 2001, 2007, 2014). The assessments have been organized according to a format that has evolved with the development of the subject area, from largely impacts-orientated chapters in the first three full assessments (IPCC, 1990, 1996, 2001) toward a greater focus on adaptation and risk management across the working group in the latest two assessments (IPCC, 2007, 2014). All assessments have employed a sectoral and thematic treatment of VIA issues, with an additional regional approach introduced following the Second Assessment (IPCC, 1997). The majority of the literature was based on studies with a local-to regional-scale focus, though there are also studies examining global impact or using integrated assessment models. Very few studies use a systematic methodology across sectors with a global perspective (e.g., Arnell, 2016; Warszawski et al., 2014). One of the greatest challenges faced in Working Group (WG) II has been the need to aggregate and synthesize across multiple studies, sectors and regions, in order to identify key risks of climate change to be communicated to decision makers.

The researchers and practitioners conducting VIA studies are spread across many thousands of institutions, worldwide, with very few centers dedicated to VIA research. Until the establishment of PROVIA in 2010 (see below), there has been no single international program coordinating a research agenda to which most VIA researchers would naturally be aligned (equivalent to the World Climate Research Programme for climate researchers or the Integrated Assessment Modeling Consortium for mitigation researchers). The IPCC assessments have been among the few examples wherein hundreds of senior VIA researchers come together to review and interpret the latest published research findings within a coherent framework. In this connection, there have been calls in the past for consistency in approaches to VIA studies, to facilitate more effective comparison and integration of results between studies and regions. The need was raised in methodological guidelines for impact and adaptation assessment developed by the IPCC ahead of the first UN Conference of the Parties (IPCC, 1994b). Moreover, one of the original motivations for establishing the IPCC Task Group on Scenarios for Climate Impact Assessment (TGCIA) in 1997, the forerunner of TGICA (see section 4.1.1, below), was to help encourage the selection and application of a consistent set of climate and socioeconomic scenarios in climate change impact and adaptation studies (Parry, 2000). Ten years later, Rosenzweig and Wilbanks (2010) called for systematic intercomparison and evaluation across VIA methods and scales, as well as self-organization to increase communication within the community and with collaborators in the climate modeling and integrated assessment modeling communities. Nascent efforts to build cohesively organized research endeavors within various impact sectors and international programs provide a framework for VIA interaction with CMIP6 (as described in Section 4).

2.2.2 The Climate Services community

Climate services seek to enhance stakeholders' abilities to anticipate and build resilience to changing climate conditions through the co-design and co-production of tailored information for climate product development and user application. Such activities themselves are probably as old as climate research. However, it is only in recent years that the term "climate services" has been taken into widespread usage. There are several recent definitions of "climate services" emphasizing different aspects (Laurenco et al., 2016). The World Meteorological Organization's (WMO) Global Framework for Climate Services (GFCS; WMO, 2014) and the American Meteorological Society's (AMS) definitions focus on the aspect of the preparation and delivery of user-tailored climate data. The definition in the Climate Service Roadmap, a European Commission initiative to foster research and innovation for climate services, also includes "counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large" (European Commission, 2015).

A brief history of climate services is provided by Vaughan and Dessai (2014). They localize the foundation of climate services to the International Meteorological Organization (IMO; a precursor to the WMO) in the late 19th century. The World Climate Programme was created in the context of the first World Climate Conference (WCC) organized by the WMO, aiming to improve our understanding of the climate system and its impact on society. More recently the GFCS was created by the WMO in order to provide a worldwide mechanism for coordinated actions to enhance the quality, quantity and application of climate services (WMO, 2014). Growing interest in climate services recognizes the fact that, despite the rapid improvement and growth in the information base for understanding past climate events and future projections, much of this information is not informing climate risk management (McGregor, 2015; Eisenack et al., 2014). This also reflects the growing awareness that Climate Services have specific characteristics that may differentiate them from the established Meteorological Forecast Services; first and foremost the multidisciplinary nature of the information required and the probabilistic nature of most of the climate information.

3 The VIACS Advisory Board

3.1 Motivation

The need for strong communication between the climate modeling community and those who apply climate information has long been recognized, as there is a common need to:

- keep climate applications up to date on the latest model developments, outputs, and evaluations;
- track the ways in which climate model simulations inform the identification and prioritization of risk management and resilience-building strategies;
- provide feedback into priority areas for model improvements; and
- advise applications communities that do not have access to the technical skills and/or resources necessary to interpret CMIP model archives.

In the past these lines of communication have been formed in an *ad hoc* fashion that too often lacks stability or falls well short of its potential.

Figure 2a presents an illustration of the resulting lines of communications (gray lines) between climate modeling centers (black stars) and various VIACS communities (represented as colored shapes of various sizes and types). Although many lines of communication have been forged over the years, their utility has wide variation. These include formal relationships or memoranda of understanding at center levels, co-located climate modeling and VIACS groups, VIACS communities that have made strong efforts to reach out to many climate modeling centers (or vice versa), strong connections between individual modeling centers and individuals within a VIACS project, lines of communication developed for a particular project that are now fraying, and some groups that remain isolated with few lines of communication. Without a coherent mechanism for communication, soliciting the VIACS perspective for climate modeling or climate model center perspective on VIACS applications is an onerous and complex task involving many actors and organizations.

Figure 2b illustrates the potential for the VIACS Advisory Board for CMIP to play an *additional* role in communication between the climate modeling centers and VIACS communities. Utilizing CMIP's ability to organize and act as a communications hub for the modeling centers, the VIACS Advisory Board is similarly designed to survey the leaders of major VIA sector disciplines (e.g., agriculture, water resources, forestry, fisheries, terrestrial and marine ecosystems, infrastructure, urban, health, energy), regional integrated impacts studies, international agencies and committees, and projects (examples are described in Section 4 below). These leaders are often well-connected with the broader VIACS communities in their same field, allowing a manageable group of contacts to provide more

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coherent access to the broader VIACS communities. Depending on the request, information may be requested by discipline, project, or specific region, which allows solicitations to be efficiently targeted.

3.2 Endorsement, Mandate, and Formation of the VIACS Advisory Board

To form a more coherent and productive interaction between the climate modelers in CMIP6 and the VIACS communities, and to enhance the relevance of CMIP6 to society through all impact sectors, CMIP6 endorsed the creation of a VIACS Advisory Board for CMIP6. Launched in 2015 as a Diagnostic Model Intercomparison Project (MIP), the VIACS Advisory Board has not proposed new climate model experiments, but serves as an advisory body to encourage inputs from the VIACS community on experiment and output design for MIPs, guidelines for good practices in the use of CMIP6 outputs, and online metrics and visualizations intended for use by the VIACS community. The VIACS Advisory Board is designed to be a bridge between the VIACS community (generally those researchers whose work is assessed by IPCC Working Group II – *Impacts, Adaptation, and Vulnerability*) and the climate modeling community (generally those researchers whose work is assessed by IPCC Working Group I – *The Physical Science Basis*). Climate modeling groups that are interested in building stronger engagement with the climate change applications community, and likewise VIACS experts eager to spur climate model developments that would facilitate applications, are encouraged to interact with the VIACS Advisory Board through CMIP6.

Engagement with the CMIP modeling groups will help ensure that model output fits the climate service application needs, and also allows the modeling groups to provide synthesized input into the process by which climate information is distilled into climate applications messages. A close connection is also needed to CORDEX (also a CMIP6 Diagnostic MIP, see Section 4.1.4 below) in order to motivate downscaling methodologies with the potential to provide improved climate information on temporal and spatial scales required in research and for climate service applications. The VIACS Advisory Board will advise on the establishment of common evaluation concepts for global and regional climate data, best practices for the creation of individual climate service products, and online visualizations developed by CMIP to explore the sectoral implications of climate projections. Another goal of the Board is to help improve on the ways that climate services present information (e.g., vocabulary, uncertainties, information content, product consistency, the delivery and perception of messages). This can benefit from social science networks within the VIACS community.

The VIACS Advisory Board facilitates efforts to address all three key science questions of CMIP6. The VIACS community has an acute interest in the best possible information about (1) how the Earth System (in particular the impacted elements relevant to society) responds to forcing, (2) how model biases potentially influence decision-making in impacted sectors, and (3) how climate variability, predictability, and uncertainty may be handled in preparing climate change adaptation and mitigation strategies that benefit impacted sectors.

3.3 Structure

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The VIACS Advisory Board is led by Co-Chairs; one each from the VIA and the Climate Services communities. Board members serve two-year terms with rotating chairs to ensure new perspectives and a reasonable time commitment. Members of the VIACS Advisory Board have a mandate to coordinate with other experts within their region/sector/group to provide community-based guidance that can be integrated at the VIACS Advisory Board level and then presented to CMIP6. Board members survey their respective communities (not just their own inner circle) and provide comprehensive feedback for CMIP6 to consider in designing and prioritizing scenarios and metrics for analysis and benchmarking that would be relevant for VIACS applications. Board members also provide guidance from their experience developing metrics and visualizations that appeal to VIACS community researchers, stakeholders, and decision-makers. These include sector-specific indices (e.g., heat damage degree days for ecosystems, consecutive dry days for agriculture and water resources; temperature-humidity indices for health) and requirements for documentation and online guidance that will facilitate understanding of CMIP6 products by the lay public. The Board will also advise on the translation and dissemination of CMIP climate modelers' advice for best practices for the use of climate model outputs within the VIACS community.

3.4 Convening and Communications Plan

To fulfill its potential as a conduit for communication between the VIACS and climate modeling communities, the Board establishes regular communication between representatives of the CMIP6 MIPs and the VIACS community. High-level participation from both sides is required. Each consultation of the VIACS Advisory Board comprises five steps (summarized in Table 2). The VIACS Advisory Board is expected to convene approximately on a quarterly basis; however in the early stages of CMIP6 the Board's activities have been closer to a monthly schedule in response to urgent CMIP6 design questions.

The VIACS Advisory Board is also active in periods between teleconferences. Activities include outreach encouraging greater utilization of the VIACS Advisory Board as a unique resource for both climate modelers and VIACS communities, as well as the development of new network connections that will increase CMIP's reach into the climate applications community. Representatives of the VIACS Advisory Board also participate in major CMIP6 meetings to give voice to the VIACS perspective. Although the Board is tasked with providing feedback and ideas regarding the use of CMIP6 outputs for VIACS assessments, the assessments themselves are beyond the mandate of the VIACS Advisory Board itself but are likely to involve many of the Board members through their participation in independent studies.

4 Engaging the broader VIACS communities

The VIACS Advisory Board is a focused effort specifically mandated to link the VIACS and GCM communities for CMIP6. A portion of this mandate is shared by a range of other groups, and the VIACS Advisory Board seeks to complement these efforts by offering an additional level of coordination. This section highlights a non-exhaustive selection of the major groups within various VIACS communities with whom the VIACS Advisory Board engages in order to solicit feedback and inputs for the CMIP process.

4.1 International Programs

The VIACS Advisory Board builds on a legacy of research and applications networks and materials established by several high-profile expert groups and programs.

4.1.1 TGICA

Up to the time of the IPCC Second Assessment, while there was some coordination in the selection of scenarios describing alternative future developments of atmospheric greenhouse gas and aerosol emissions under the auspices of the IPCC (e.g. Leggett et al., 1992; IPCC 1994a), the consistent use of emissions scenarios as inputs to fully coupled AOGCMs run in transient (time-dependent) mode was still limited. Many GCMs were still being run for scenarios of doubling or quadrupling of CO_2; sensitivity-based simulation designs that were not suitable for many VIACS applications. Moreover, access to the outputs of climate model simulations had to be negotiated with the modeling centers themselves or through a few volunteer individuals and organizations who collected climate model information on behalf of a growing research community studying impacts (e.g. at the National Center for Atmospheric Research in the US and the Climatic Research Unit in the UK).

Ahead of the IPCC Third Assessment there was clear recognition of a need to engage and coordinate between different research communities whose work was based on the use of socioeconomic and greenhouse gas emissions scenarios. This resulted in the 1997 establishment of a Task Group on Scenarios for Climate Impact Assessment (TGCIA) to inventory impact studies and climate model runs, provide climate model outputs through a Data Distribution Centre (DDC; http://www.ipcc-data.org), and produce guidance materials to facilitate the use of scenarios. TGCIA and the DDC worked to facilitate cooperation and communication between the modeling and impacts communities, particularly with respect to the availability and accessibility of climate data. It was out of criteria suggested by TGCIA – for climate model simulations and the selection of standard variable datasets for downloading and storage – that the foundations for activities now coordinated by CMIP originated.

The IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) is the present-day counterpart of TGCIA. It comprises members drawn from nominations by national IPCC Focal Points, bringing together diverse expertise and experiences from a cross section of research communities representing all three IPCC Working Groups. TGICA's current mandate is to "facilitate wide availability of climate change related data and scenarios to enable research and sharing of information across the IPCC Working Groups". TGICA maintains the DDC as a means of accessing climate, socio-economic and environmental data, both from historical observations and from future projections (scenarios), in support of IPCC work and as used in the IPCC assessments. The DDC is designed primarily for climate change researchers, but is also relevant to educators, practitioners, governmental and non-governmental organisations, and the public. Importantly, the DDC hosts data relevant across Working Groups with a consistent quality control and appropriate supporting materials.

TGICA also contributes to building capacity, for example on the development and application of climate scenarios, other environmental and socioeconomic scenarios for climate change impact, and adaptation and vulnerability assessment (e.g. IPCC-TGICA 2007; Mearns et al., 2003; Nicholls et al., 2011; Wilby et al., 2004). In addition, TGICA facilitates expert meetings to contribute to regional capacity building. For example, an expert meeting on "Integrating analysis of regional climate change and response options" was held in 2007 to catalyse regional interdisciplinary research on climate change, impacts, adaptation, vulnerability and mitigation (Marengo et al., 2009).

4.1.2 PROVIA

The Global Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA; UNEP, 2013) represents an interface between the research community and decision-makers and other stakeholders to provide direction, coherence, and capacity-building at the international level for improved policy-relevant research on vulnerability, impacts and adaptation. PROVIA is recognized within the World Climate Programme as the body that helps to represent the perspectives of this highly diverse, transdisciplinary community, operating for researchers associated with IPCC Working Group II in a manner similar to the World Climate Research Program (WCRP) coordination of research associated with Working Group I. PROVIA's parent organizations are the UN Environment Program (UNEP), the World Meteorological Organization (WMO), and the UN Educational, Scientific, and Cultural Organization (UNESCO). PROVIA helps international communities share practical experiences and research findings by improving the availability and accessibility of knowledge to the people that need it most. Together with collaborative partners, knowledge networks, and the larger VIACS community, it is helping to identify and alert international organizations to research needs and gaps. In this way PROVIA helps the scientific community to mobilize and communicate the growing basis of information from VIACS research so that governments and other key stakeholders are able to consider this knowledge in their decision making processes.

The VIACS Advisory Board was endorsed by the Programme of Research on Climate Change Vulnerability, Impacts, and Adaptation (PROVIA; see Section 4.1.2 below), which will act as an anchor program to support the long-term balance and stability of the Advisory Board as well as to encourage participation of representatives from numerous regions, impacts sectors, and prominent international groups. PROVIA is focused on four objectives, each of which may be furthered by the VIACS Advisory Board: 1) Coordinating research on climate vulnerability, impacts, and adaptation; 2) Guiding investment in research; 3) Communicating high-quality scientific information to governments and international agencies with due urgency and specificity; and 4) building research capacity, especially in developing countries. The VIACS Advisory Board will enable a large number of researchers, stakeholders, decision-makers, and policy-makers to better integrate climate information into climate change risk assessments across a number of sectors, with results also feeding back into the design and implications of climate modeling experiments.

4.1.3 The WCRP Working Group on Regional Climate

The Working Group on Regional Climate (WGRC) was established by the WCRP in 2013 with a mandate to "coordinate regional climate research and science-based knowledge development for decision makers". This mandate

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to interact with both the physical climate science community (particularly within WCRP) and providers and users of climate information is reflected in the membership, terms of reference, and activities undertaken by the WGRC. For example, it has a specific role to oversee and promote CORDEX (see below) and in this context the emphasis has been on facilitating and guiding the tailoring and application of CORDEX outputs within regions (such as Latin America and the Caribbean, or Africa). Over the last three years, the WGRC has initiated and led discussion on the research challenge of "data distillation" – referring to the challenge presented by the conflicting information from global climate models (e,g,, CMIP GCM runs), regional climate models (e.g., CORDEX runs), empirical-statistical downscaled data (e.g., statistical models using CMIP outputs as predictors), and multiple competing observational datasets of historical change and variability. It has also promoted a subtle yet important shift in emphasis from "regional information" which puts the focus on data resolution for a location, to "information for regions" which recognizes that regions are related to climate processes at all scales. The latter approach brings a holistic perspective to the climate drivers for regional decision-scale needs, and hence also for the VIA and climate service communities. The two themes of data distillation and information for regions are brought together in the concept of Frontiers of Climate Information (FOCI) projects which are designed to help advance the transformation of the multiplicity of data products on climate change and variability into robust and scale-relevant information for decision needs.

4.1.4 CORDEX

The Co-ordinated Regional Downscaling Experiment (CORDEX; Giorgi et al., 2009) is a research project under the auspices of the WCRP with a vision to advance and coordinate the science and application of regional climate downscaling through global partnerships. CORDEX is principally focused on research using downscaling to better understand relevant regional/local climate phenomena as well as their variability and changes. In the process CORDEX seeks to improve regional climate downscaling models and techniques. Through regional teams CORDEX has been producing coordinated sets of regional downscaled projections for most regions of the world, and through the regional teams has fostered interaction with users of regional climate information. While there is high expectation that CORDEX will provide more skillful projections for regions, this is in part predicated on an assumption that higher resolution equates to better information, yet the added value of the downscaling is still a topic of active research. As such, output of CORDEX for the VIACS community should be viewed as a valuable additional source of information that is best incorporated alongside other data in the context of the WGRC's emphasis on "information for regions".

CORDEX has been successful in establishing regional research teams, and is currently in the process of establishing "Flagship Pilot Studies" (FPS) that will focus on targeted sub-continental regions to address key scientific questions and needs of the VIACS community. The main efforts are concentrated on the use of RCMs to dynamically downscale from the CMIP GCMs to resolutions between 25km and 50km. There is also an active stream of research on empirical-statistical downscaling (ESD) to both grid and point resolution. Currently CORDEX is developing ways to bring convergence between the RCM and ESD activities, in the context of the WGRC's distillation challenge.

4.2 Impacts Sector Communities

Research and applications communities have formed within a large number of impact sectors, offering an avenue of cohesive outreach for the VIACS Advisory Board. This section describes impact sectors' major focus, use of climate information, and community efforts for cohesive communication as an overview of the diverse VIACS communities and their unique needs for climate model outputs.

4.2.1 Agriculture and Food Security

Climate applications in the agricultural sector span sub-field-level support for management interventions to national and international level assessments of crop and livestock productivity, commodity prices, and food security. Climate information drives agricultural decisions on a continuum of time scales, with researchers and practitioners seeking to build systems that are sustainable and resilient to climate extremes, climate variability, and climate change. Climate model outputs (particularly temperature, precipitation, humidity, and CO_2 concentrations) have long been used to drive agricultural assessments using a number of process-based and statistical approaches (Rosenzweig, 1984, 2014; White et al., 2011; Lobell and Burke, 2010; Asseng et al., 2013; von Lampe et al., 2014; Challinor et al., 2015). In recent years several groups have emerged to focus community efforts on agricultural impacts, including the Agricultural Model Intercomparison and Improvement Project (AgMIP, now encompassing 30+ activities; Rosenzweig et al., 2015), and the Consultative Group on International Agricultural Research (CGIAR) Challenge Program on Climate Change, Agriculture, and Food Security (CCAFS; CGIAR, 2009). By connecting climate, crops, livestock, economics, and nutrition, the agricultural impacts community is engaged in many aspects of future scenario generation, integrated assessment, and decision support for a wide variety of actors (Rosenzweig et al., 2016). CMIP outputs are a crucial element of most agricultural impact studies, which use a variety of downscaling and bias-correction methodologies (White et al., 2011).

4.2.2 Fisheries and Marine Ecosystems

The ocean covers 70% of the Earth's surface, harbors rich diversity of species and ecosystems from the poles to the deep sea, provides 16% of animal protein consumed by humans globally, and supports the livelihoods for millions (Mora et al. 2011, FAO 2014). Thus, the identification of climate change effects on marine ecosystems and the services they provide for human well-being is becoming increasingly important for management, conservation and food security (Merino et al. 2012, Barange et al., 2014). Over the past decades, various fisheries and marine ecosystem models have been created and applied to develop scenario-driven projections of future fisheries production (Blanchard et al. 2012), marine ecosystem structure and functioning (Jennings and Collingridge 2015) and species compositions and distributions (Cheung et al. 2011). These individual models are often limited in scope (spatial, species, trophic group coverage), highly heterogeneous in terms of model structure, and dependent on the scientific or management question targeted. In addition, predicted outcomes are strongly dependent on which climate model is chosen to drive projections (Bopp et al. 2013), and so far there was limited choice among CMIP5 models due to missing data necessary to drive several marine ecosystem models (Tittensor et al. in review). Also, GCMs are often poorly resolved in coastal oceans where most fisheries production takes place (Barange et al. 2014). In 2013, the Fisheries and Marine Ecosystems Model Inter-comparison Project (FISH-MIP) was launched to systematically compare standardized

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climate scenarios across a broad range of both global and regional marine ecosystem models (Tittensor et al. in review). During its development phase, FISH-MIP identified a number of missing variables now requested from CMIP6 via communication through VIACS (see Section 5.1 below) that would allow for greatly improved model inter-comparison in the marine realm by including a wider range of GCMs and marine ecosystem models. FISH-MIP was also developed as part of the Inter-Sectoral Impact Model Inter-comparison Project (ISI-MIP, see Section 4.3.1) to compare standardized climate scenarios across sectors, such as changes in food production on land and in the sea, terrestrial and marine biodiversity, and land-derived nutrient run-off affecting coastal ecosystems. Recently, two other marine model inter-comparison projects have been developed; the ICES/PICES Strategic Initiative on Climate Change Effects of Marine Ecosystems (SICCME) and the Climate change and European aquatic RESources project (CERES). Both SICCME and CERES have a stronger focus on fisheries in selected regional ecosystems thus complementing the global focus of FISH-MIP. Together, these three initiatives – in conjunction with improved data availability from CMIP6 and communication via VIACS – will contribute to a better understanding of the impacts of climate change on fisheries production, marine biodiversity and ocean ecosystems.

4.2.3 Water Resources

Over the last couple of decades, there have been hundreds of studies into the impact of climate change on hydrological regimes and water resources (Jimenez Cisneros et al., 2014). The vast majority of these have been undertaken at the catchment or regional scale, using a wide range of hydrological models and socio-economic assumptions. The construction of climate scenarios is central to hydrological impact assessments, and a wide range of techniques has been used to create scenarios at the appropriate spatial and temporal scales ("downscaling"). These include the use of the delta method (applying projected changes to observed weather data), regional model output, bias-corrected regional or global model output, and stochastic weather generators. Whilst there have been attempts to inter-compare variants on a particular technique (e.g. different forms of bias correction), there have been no systematic assessments of the full range of potential methods at the catchment scale. Comparisons between different studies in different locations are made challenging by the use of different scenarios and downscaling techniques. There is greater coordination amongst the much smaller community of researchers assessing impacts on hydrological regimes and water resources across the global domain. This has most recently taken place through ISI-MIP (Schewe et al., 2014; see Section 4.3.1), which involves an intercomparison not only of model performance in simulating current hydrological regimes, but also of projected future changes.

4.2.4 Cities and Infrastructure

The world's population is more than 50 percent urban and growing (Hunt and Watkiss, 2011; Rosenzweig et al. 2011), with many of the largest concentrations in coastal regions. High population density and growth can enhance vulnerability and impacts. For example, in some cities rapid growth is concentrating more and more people in marginal areas, such as floodplains. Other vulnerabilities include the health impacts of the urban heat island effect and poor air quality (Hunt and Watkiss, 2011). In many cities of the world, baseline information is lacking on both historical climate hazards like storm surge and human populations, the latter in part due to rapid growth in those living uncounted in informal settlements (Revi, 2008). Key climate information needs include observations and projections of 1) sea level change and coastal flood frequency and intensity, and 2) integrated measures of heat stress that go beyond temperature to consider joint hazards associated with humidity, and 3) other key extreme event metrics such as precipitation, drought, and wind intensity-frequency-duration. Due to large variations in micro-climate within cities (due for example to the urban heat island), high-resolution observational networks and remotely-sensed products are needed. Downscaled projections such as outputs from regional climate models may be a valuable tool both 1) in regions where climate changes may be spatially heterogeneous (e.g. coastal regions) and 2) where there is a need for testing and evaluation of adaptation strategies at fine spatial scales (e.g. white-roofs or greening initiatives). As cities have emerged as hubs for climate solutions, more organizations have been building networks and making urban-focused contributions. These include the International Council for Local Environmental Initiatives (ICLEI), the Urban Climate Change Research Network (UCCRN), and the C40 Cities Climate Leadership Group.

Diverse infrastructure types are also concentrated in and around cities as they are hubs of population and industry. Climate applications related to infrastructure are often challenged to identify the appropriate spatial resolution and domain given urban infrastructure corridors/networks and the large spatial signature of water- and infrastructure sheds that cities rely upon. For the energy sector, the relevant spatial scale may approach the continental. Much infrastructure is long-lived, capital-intensive, and geographically-fixed. These characteristics have encouraged the use of extreme event return periods in the design and financing of infrastructure. Key climate science questions are focused on how return periods for rare extremes such as the 1-in-100 year inland and coastal flood may change as the century progresses. Other climate hazards include extreme high temperatures, which for example can buckle, strain, and damage electrical and transportation systems as well as lead to weight restrictions in the aviation sector. Minimum temperatures, include freeze-thaw cycles and related icing issues also have large impacts on infrastructure. Many of the infrastructure-driven climate needs are scientifically challenging due to their fine spatial scale and infrequency of occurrence, both of which amplify the signal of natural variability relative to climate change.

4.2.5 Human health and well-being

Weather and climate are among the drivers of a wide range of climate-sensitive health outcomes, including their incidence, geographic range, and seasonality (Smith et al. 2014). Climate information in the health sector has been used primarily for risk management, particularly for developing early warning and response systems. Weather and climate variables of interest depend on the health outcome, from relatively simple measures of daily temperature and precipitation for adverse health impacts from heatwaves and flooding, respectively, to more complex variables spanning seasonal to annual cycles, such as combinations of minimum and maximum weekly to monthly temperature with seasonal maximum and minimum precipitation to determine thresholds for outbreaks of malaria and other infectious diseases (e.g. Drake and Beier, 2014; Tonnang et al., 2010). There are few health outcomes for which there are multi-model projections of risk based on comparable assumptions, time slices, and scenarios (Caminade et al. 2014). Modeling the health risks of climate change is challenging because, in addition to weather and climate variables, multiple, interacting factors determine the overall health burden by affecting vulnerability, such as urbanization trends that affect urban heat islands, access to safe water, and other critical services; and by affecting the ability of communities and nations to prepare for and manage adverse health outcomes (Ebi and Rocklov, 2014). However, there are limited fine-scaled projections of these factors and their interactions. Different socioeconomic development pathways will lead to different levels of underlying vulnerability that will affect future health burdens (Ebi, 2013). Constructing scenarios with different combinations of emission and development pathways is needed to span the range of possible futures. Because many of the drivers of health outcomes arise in other sectors, efforts are needed to link health models with models of how climate variability and change could affect, for example, food- and water-security, energy production, land use, and ecosystem services.

4.2.6 Terrestrial Ecosystems

Climate impacts on ecosystems cover a range of biological and landscape features and management challenges ranging from biodiversity conservation, habitat changes, disturbance patterns, and ecosystem processes and services (such as carbon, nitrogen, and other biogeochemical fluxes and freshwater resources). A number of recent studies present evidence of climate change impacts on ecosystem aspects, and together they indicate increasing vulnerability across numerous taxa and ecosystems which are being affected.

Given this diversity of impacts on various ecosystem services, it is inherently important to develop climate services in collaboration with the community managing these ecosystem services at scales that their decision making and management units exist. In recent efforts, in the US various agencies, including the Department of Interior (US DOI), US Department of Agriculture (USDA), and National Ocean and Atmospheric Administration (NOAA), have a set of collaborative efforts ongoing between the research community and the management community and structured around regional centers enabling more focused dialogue for delivery of climate services. What has emerged from these interactions has been a more nuanced dialogue between the practitioners in the field and climate change applications researchers (e.g., McNeeley et al., 2016). This has enhanced understanding of constraints embedded in current climate projections and the temporal and spatial scale of ecosystem management decisions across various ecosystem services.

Ecosystem vulnerability studies and guidance to the management entities are challenged to provide climate information which are consistent across multiple scales in time and spatial extent. The climate information of seasonal characteristics and sensitivities related to variability of extreme events under differing climate realizations are useful to ecosystem level impact analyses. Efforts to develop these products with the user community is an ongoing process which the VIACS Advisory Board can further enable.

4.2.7 Other impacts sectors

Additional impact sectors are not strongly represented by current members of the VIACS Advisory Board despite considerable research and applications activity. These include the forestry and energy (e.g., wind and solar power generation) sectors. The VIACS Advisory Board is eager to develop strong points of contact within these sectors to enhance communication with CMIP6 and other VIACS communities, and will look to bring in leaders from these sectors in the next Board term.

4.3 Integrative Communities

Communities that integrate physical and multi-sectoral research provide another resource that the Advisory Board utilizes to solicit VIACS expertise.

4.3.1 ISI-MIP

Climate change will simultaneously impact different sectors. Projection of aggregated effects and an accounting for interactions, trade-offs, or co-benefits requires cross-sectorally consistent simulations (i.e., climate impacts projections that are forced by the same climate input data and based on the same story lines). The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP; Warszawski et al., 2014) is designed to support the generation of these consistent projections through a common cross-sectoral protocol that could be integrated into the simulation protocols of sectoral initiatives such as the ones listed above. Analogously to CMIP, the simulation data are provided to all kinds of users in an open repository and the project is organized in different modelling rounds that will be dedicated to individual focus topics that will be selected by the impacts modelling communities and the users of the simulations (Rosenzweig et al., in review).

4.3.2 The Integrated Assessment Modeling Consortium

The Integrated Assessment Modeling Consortium (IAMC; http://www.iamconsortium.org) was created in 2007 in response to an IPCC call for a research organization to lead the integrated assessment modeling community in the development of new scenarios that could be employed by climate modelers for a new generation of climate change and related VIA projections. Its core missions include fostering the development of integrated assessment models (IAMs), peer interaction and vetting of research associated with IAMs, and the conduct of research employing IAMs, including model diagnosis, intercomparison, and coordinated studies. Most importantly, the IAMC promotes, facilitates and helps to coordinate interactions between IAM community and research communities studying climate change including climate modelers, VIA researchers, and technology and engineering communities. The IAMC has been active together with the International Committee On New Integrated Climate change assessment Scenarios (ICONICS) in establishing the overall conceptual framework and architecture for representative concentration pathways (RCPs) and shared socioeconomic pathways (SSPS) (O'Neill et al, 2014; van Vuuren et al., 2014; Kriegler et al., 2014) and organized the development of the quantitative projections of the SSPs (Riahi et al., 2016), which will serve as inputs into CMIP6 climate and VIA assessments.

4.4 Climate Services Community

Many international, national and regional organizations exist to bring forward the development of climate services. The Roadmap for Climate Services of the European Commission (2015) defined 4 models of climate service providers, which are extended here to recognize coordinated funding activities: (1) Governmental cooperation/framework; (2)

Extension of meteorological services; (3) Public climate services; (4) University/groups of universities; (5) Private business development; and (6) Incorporation in business consultancy.

Various regional initiatives exist on climate services. The European Roadmap for Climate Services has a market-based approach, aiming to grow the demand for climate services, build a market framework (including standards) and also to enhance the availability and relevance of climate information (European Commission, 2015). The Copernicus Climate Change Service (http://climate.copernicus.eu/) was also awarded in 2016 and tenders are currently under way to prepare the components including seasonal forecasts, climate data at global and regional levels, and economic and societal information for various impacts sectors. In the developing world the focus is more on improving availability of data to produce climate services products, reflecting recognised gaps (e.g., African Climate Policy Centre, 2013). In Africa, for example, the Climate for Development in Africa programme (under WMO Global Climate Observing System) and UNDP-led Programme on Climate Information for Resilient Development in Africa are playing a role in particular on the supply side of climate services. At the same time, there is increasing interest on the nature of demands for climate services.

At the first International Conference on Climate Services (ICCS) in 2011, participants agreed to form an open and informal coalition, the Climate Services Partnership (CSP), to improve the provision and development of climate services worldwide. The CSP has subsequently developed a paper on the ethics of climate services (CSP, 2015) and a review of on economic valuation of climate services (USAID, 2013). It continues its dialogues through annual ICCS (Vaughan, 2011; CSP, 2012; Lustig et al., 2014; Vaughan et al., 2015).

As a result of a decision made at the 2009 third World Climate Conference, in 2014 a Global Framework for Climate Services (GFCS; WMO, 2014) was established that is overseen by an Intergovernmental Board on Climate Services (IBCS). GFCS is supported by the CSP and operationally implemented by WMO with the aim of "providing climate information in a way that assists decision-making by individuals and organizations". GFCS has identified five priority sectors – agriculture and food security, disaster risk reduction, energy, health, and water – and is supporting projects in these areas around the world with a focus on developing services through engagement with users. A goal for the VIACS Advisory Board is to establish a formal relationship with the GFCS in order to better communicate between the climate services and climate modelling communities.

5 VIACS Activities

Since its launch in 2015, the VIACS Advisory Board has engaged the CMIP community on several issues summarized here in order to illustrate the types of interactions and information that this new conduit of communication enables.

5.1 Prioritization of CMIP experiments and outputs

On request from the CMIP6 leadership, the VIACS Advisory Board tasked its members to solicit feedback from their respective communities as to the variables and experiments of highest priority for their planned applications of CMIP6 model output. This feedback benefits the CMIP modeling groups in that they can determine the potential for variables or experiments to be used by different applications groups. In response, the VIACS Advisory Board constructed a single spreadsheet with the set of more than 900 CMIP5 variables and the list of 188 proposed CMIP6 MIP experiments and requested that VIACS experts prioritize sets of variables and the experiments they are interested in exploring via a template. This spreadsheet was distributed through the Board members to many VIACS communities along with a document detailing the request for input in the CMIP6 planning process. It is clear that the large number of variables and experiments was daunting to some VIACS experts, so the VIACS Advisory Board received a mixture of spreadsheet and more generally-written feedback. Key messages emerged in the VIACS community response:

Key Message 1: Core variables were already in CMIP5, but different VIACS communities need different sets of variables and additional skill metrics and validation of GCM outputs against observations would be helpful.
Many of the VIACS groups felt that the key variables for impacts assessment were already present in CMIP5 and wished to see them continued in CMIP6. Chief among these were temperature, rainfall, radiation, and humidity variables at daily and monthly time scales, which were requested by nearly all communities. Beyond these core variables there is a tremendous diversity in variables requested across impacts sectors, although the majority of these variables were already in the CMIP5 variable list. It was not practical to merge these variable lists into a single priority list, as variables that are of high priority for one impacts sector may not be needed by another. Groups also indicated that modeling groups should consider variable sets in addition to isolated variables, as some applications need a complete set of variables to proceed (e.g., mitigation studies need a set of variables related to land use and carbon content but are challenged to proceed if some are missing; statistical methods may only be possible if a set of variables are available). Many of the groups requested that the climate modeling community enhance analysis of these variables' biases (e.g., biases in projected regional changes of humidity or solar radiation) and develop guidance for VIACS applications that must deal with these biases.

Key Message 2: Additional variables are requested.
The agricultural, fisheries, and climate services communities requested additional variables, as detailed in Table 3. These include entirely new variables, altered temporal resolution for existing variables, and capture of sub-grid-scale information that is otherwise lost in aggregation. To better understand extreme events and their impact on agriculture, energy, urban areas, health, and climate services in many sectors, statistics of high-frequency events could be provided at a monthly scale. Examples include the average precipitation rate on days where precipitation occurred paired with number of precipitation days, the maximum 2-hourly precipitation total in a given month, or wind gusts at various altitudes (for wind power applications).

Key Message 3: Several groups indicated that high-resolution variables may be best produced through downscaling rather than directly from global climate models, but that it would also be helpful to have the GCM outputs as a basis for comparison.

Several groups detailed the variables needed to run their impacts models, but also indicated that they expect to draw their inputs from statistical scenarios or from CORDEX (or other regional climate model) results (often with additional bias correction) rather than from the global models themselves. This is particularly true for temperature and precipitation extremes as well as water and energy balance variables related to hydrology, agriculture, energy, and coastal processes. In a similar manner, climate service providers (in particular) noted that the monthly outputs provided by CMIP in previous IPCC Assessment Report phases were not as desirable; daily (or sub-daily) time scale is of greatest interest. This opinion is not universally held, but it may be worth provision of more variables at daily resolution, with overall archive size depending on the level of interest and utility within the VIACS community.

Key Message 4: The experiments of greatest interest are the Historical Simulation, the DECK experiments, the RCPs within ScenarioMIP, and the hindcasts and forecasts of the Decadal Climate Prediction Project.

Members of the VIACS Advisory Board also expressed an interest in providing perspective to MIPs with societal implications, for example including the development of RCPs (van Vuuren et al., 2011) and SSPs (O'Neill et al., 2014; Riahi et al., 2016) with ScenarioMIP, the use of ecosystem and agricultural models in conjunction with LUMIP, the health impacts of pollution policies in AerChemMIP, or the role of water resource management in LandMIP. In many cases the MIPs contain experiments that explore specific physical relationships within the climate system, and only a subset is directly relevant to societal applications. VIACS researchers and practitioners often expressed interest in this small subset of experiments (or even one single experiment) from a given MIP's experiment group, which will help modeling groups determine an efficient provision of the requested outputs while avoiding comprehensive variable lists where there is little interest in a large portion of the data. Only the Radiative Forcing MIP did not have any experiments specifically requested for sectoral application in the VIACS solicitation.

5.2 Obs4MIPs

CMIP6 leadership requested input from the VIACS community about observational datasets utilized by various VIACS sectors that could be used as additional sources of validation for climate model output as part of Observations for Model Intercomparisons (Obs4MIPs). The WCRP's Data Advisory Council (WDAC) Observations for Model Evaluation Task Team curates these Obs4MIPs datasets to improve model evaluation and process understanding.

The VIACS Advisory Board found that, in general, there were few recommendations for new data sets to include in Obs4MIPs. One concrete example was to better compare climate output with observations related to snow for a variety of applications including water resources. There are a number of satellite-based data products such as those from the Globsnow project (providing northern hemisphere daily snow extent and snow water equivalent; Metsämäki et al., 2015) that have not yet intensively been compared to climate model output. It would be useful to look at crop season and yield databases (e.g. Ramankutty et al., 2008; Monfreda et al., 2008; Ray et al., 2015) in order to better align seasonal variation in productivity, greenness, and soil moisture over agricultural lands against climate models' vegetation/land-surface model outputs (which often represent crops as generic grasses that lack the observed sequences of crop and fallow periods).

The VIACS Advisory Board also discussed the potential creation of an equivalent to Obs4MIPs for the VIACS communities, facilitating validation and process understanding for sector models. For example, this could include recently-created datasets for agriculture such as time series of yield (Ray et al., 2015), fluorescence (Joiner et al., 2014), and above-ground biomass (Tucker et al., 2005). European climate services also indicated an interest in more closely aligning efforts to compare with the Copernicus operational satellite services being developed by the European Commission. Many VIACS communities have opportunities to coordinate efforts on climate-related datasets even if they are not directly comparable to climate model outputs. This new "Obs4VIACS" could potentially be an element of Obs4MIPs or could be organized as a parallel effort.

5.3 Gridding of GCM outputs

The VIACS Advisory Board also solicited feedback on a CMIP6 data request seeking input on the extent of harmonization that was needed for model output grids. At issue was the contrast between raw climate model output (which may come on irregular and/or unique grids) and the need for a regular and harmonized grid for applications purposes.

Feedback indicated that the VIACS communities are interested in GCM outputs eventually reaching a common grid for model intercomparison and multi-model applications, and that regular grids are most useful for these purposes. This is particularly true because VIACS communities often utilize multiple climate output variables and observational data sets. It is therefore desirable to have a smaller number of necessary conversions, and useful to have common methods for multiple variables. Many groups have developed techniques to re-grid and/or interpolate to common grids (often ~0.5x0.5 degrees), but several groups indicated that it would be preferable to have CMIP or other climate experts perform this re-gridding so that it could be quality-controlled and consistent across applications. Some common gridding and scenario generation has been done within ISI-MIP in the past (Warszawski et al. 2014), but a central and community-driven effort would be welcome.

Although there was interest in the common grids, VIACS Advisory Board members also indicated an interest in the raw model outputs as these are needed to understand the physical basis and relationships among variables contained in the outputs. Only providing harmonized and re-gridded outputs would limit the opportunity to test out the benefits of different methods for re-gridding that may be advantageous for different applications. The VIACS Advisory Board therefore requested that model outputs be provided in their native format and that CMIP initiate a re-gridding effort oriented toward producing a common and regular grid to facilitate applications.

5.4 Visualizations, Documentation, and Guidance

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Future activities of the Board will also support the creation of products that facilitate the use and uptake of climate model outputs for societal applications. VIACS guidance will support the development of online metrics and visualizations for the VIACS community of researchers, practitioners, stakeholders, and decision-makers. These include metrics and derived variables made through a combination of climate outputs or sector-specific thresholds (e.g., frost-free days for agriculture, over-winter minimum temperatures for health and ecosystems, days of airplane weight restriction due to temperatures), potentially in collaboration with the Expert Team on Climate Change Detection and Indices (Sillmann et al., 2013a, 2013b). Although the production of guidance documents is beyond the purview of its mandate, the VIACS Advisory Board will help determine requirements for documentation and online guidance that will facilitate the use of CMIP6 products by the lay public. The Board will also encourage capacity building as well as further evaluation and transfer of good practices in CMIP output application within the VIACS community.

6 Summary and Benefits

The VIACS Advisory Board was created as an element of CMIP6 to facilitate communications between the climate modeling community and the scientific and operational communities that apply climate model output for societal benefit. Launched in 2015, the VIACS Advisory Board developed a framework to interact with the CMIP6 leadership, convene experts of the VIACS impact sectors and programs, and solicit wider input from the broader communities they represent. Initial activities demonstrate the utility of this approach in the identification and prioritization of CMIP6 output variables and MIP experiments for VIACS applications, and Board inputs are also expected as visualization and communication products are created to further disseminate CMIP6 outputs to the applications community.

The VIACS Advisory Board will be most successful if it is utilized by both the climate modeling and climate applications communities. A continuing challenge will be the identification of contact points and networks that allow for broad and inclusive interaction, as well as maintaining willingness within the communities to respond to requests in a timely manner. The Board is designed to benefit a number of communities that engage in CMIP6 and applications efforts, and aims to synthesize contributions beyond the sum of its individual interactions.

Potential benefit to the climate modeling community. The VIACS Advisory Board has already provided advice on important climate variables to be requested from climate modelers, including downscaled information, for use in VIACS analyses. The Board aims to improve the relevance of climate model outputs to society through the development of more creative, robust, and efficient applications of climate model outputs. The Board also facilitates dissemination of important scientific findings and model-specific caveats that need to be recognized in the design and communication of climate impact assessments.

Potential benefit to the Vulnerability, Impacts, and Adaptation (VIA) community. The VIACS Advisory Board seeks to enhance substantially the level of communication between CMIP and the VIACS community, with mutual benefits.

In particular, the Board communicates and disseminates information to the VIACS community regarding access to, and understanding of, key climate model and related scenario outputs for VIACS research and wider societal applications. The Board also helps improve linkages across the IPCC Working Groups.

Potential benefit to the Integrated Assessment Modelling (IAM) community. Beyond their role in exploring mitigation, IAMs also represent climate change impacts and adaptation, albeit in simplified form. The IAM community relies on results and insights from VIACS studies to test and calibrate their models. Moreover, IAMs can provide valuable information to VIACS applications that also require scenarios of socioeconomic and/or land use change concurrently with climate projections. The VIACS Advisory Board has the potential to advise on important socioeconomic variables to be requested from global IAMs that are consistent with climate projections generated in the CMIP6 process, most notably through interactions with SceanrioMIP (O'Neill et al., this issue).

Potential benefit to policymakers. The VIACS Advisory Board has the potential to help CMIP6 incorporate the experience of VIACS community interactions with policy-makers around the world, with plans for online metrics tailored toward policymakers and a greater translation of climate model output toward societally-relevant outcomes that are central to policymaker interests.

Data Availability: As a diagnostic and advisory contributor to CMIP6, the VIACS Advisory Board does not generate new data or model output. Documentation of community engagement and feedback is provided to CMIP6 leaders, and is available upon request. The VIACS Advisory Board is also developing a website to house information about the Board and documentation of communications activities, which will be linked to the main CMIP webpage (http://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6).

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Table 1. Summary of the CMIP6 DECK and CMIP6-Endorsed Model Intercomparison Projects (MIPs). More detail about CMIP6 organization is provided by Eyring et al. (2015), and each of these MIPs is described in more detail in a separate contribution to this Special Issue.

Short Name	***Long name***	***VIACS community expressing interest in at least one experiment*** [a]
Central Set		
Historical	CMIP6 Historical Simulation	All
DECK	Diagnostics, Evaluation, and Characterization of Klima	All
MIPs (each contains a set of experiments)		
AerChemMIP	Aerosols and Chemistry Model Intercomparison Project	Agriculture, Terrestrial Ecosystems, Health
C^{4}MIP	Coupled Climate Carbon Cycle Model Intercomparison Project	Ag, Fisheries, Marine Ecosystems
CFMIP	Cloud Feedback Model Intercomparison Project	Fisheries, Marine Ecosystems
DAMIP	Detection and Attribution Model Intercomparison Project	Agriculture, Fisheries, Marine Ecosystems, Climate Services
DCPP	Decadal Climate Prediction Project	All
FAFMIP	Flux-Anomaly-Forced Model Intercomparison Project	Fisheries, Marine Ecosystems
GeoMIP	Geoengineering Model Intercomparison Project	Agriculture, Fisheries, Marine Ecosystems
GMMIP	Global Monsoons Model Intercomparison Project	Fisheries, Marine Ecosystems, Terrestrial Ecosystems
HighResMIP	High Resolution Model Intercomparison Project	Fisheries, Marine Ecosystems
ISMIP6	Ice Sheet Model Intercomparison Project for CMIP6	Fisheries, Marine Ecosystems
LS3MIP	Land Surface, Snow and Soil Moisture	Terrestrial Ecosystems
LUMIP	Land-Use Model Intercomparison Project	Agriculture, Terrestrial Ecosystems, Climate Services
OMIP	Ocean Model Intercomparison Project	Fisheries, Marine Ecosystems
PMIP	Palaeoclimate Modelling Intercomparison Project	Fisheries, Marine Ecosystems
RFMIP	Radiative Forcing Model Intercomparison Project	None
ScenarioMIP	Scenario Model Intercomparison Project	All
VolMIP	Volcanic Forcings Model Intercomparison Project	Agriculture
Diagnostic MIPs (no experiments, but specific analyses planned)		
CORDEX	Coordinated Regional Climate Downscaling Experiment	N/A
DynVar	Dynamics and Variability of the Stratosphere-Troposphere System	N/A
SIMIP	Sea-Ice Model Intercomparison Project	N/A
VIACS AB	Vulnerability, Impacts, Adaptation and Climate Services Advisory Board for CMIP6	N/A

[a] Not all VIACS communities weighed in on initial variable and experiment request; dialogue ongoing.

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Table 2. Five steps followed for each VIACS Advisory Board consultation in order to focus on CMIP/VIACS communications. If the VIACS community requests information from the CMIP community, a similar process would is conducted in the opposite direction.

Step	***Description***
1	VIACS Advisory Board Co-Chairs reach out to CMIP6 representatives to solicit input, requests, or questions to propose to the VIACS Advisory Board (via email or teleconference).
2	VIACS Advisory Board Co-Chairs prepare summary documents or worksheets that provide a coherent template for the solicitation of input across the VIACS communities.
3	The VIACS Advisory Board holds a teleconference to discuss the CMIP6 questions, request solicitation of information using the provided templates, and raise issues from the VIACS communities.
4	Board members survey their respective networks of colleagues and provide collated responses back to the Co-Chairs.
5	Co-Chairs submit a summary of the CMIP6/VIACS community interactions, solicitation results, and action items identified by the Board to all Board Members and the CMIP6 leadership (to be shared with MIP leaders as needed).

Table 3: Additional variables requested through the VIACS Advisory Board process. Note that the solicitation allowed each respondent to nominate variables of interest, but additional work is needed to iterate and gauge interest on these variables across all of the VIACS communities.

Time Resolution	Name (plus description as needed)	Units	Additional Notes
	New variables requested by Agricultural sector		
Monthly	surface concentration of Ozone	kg m-3	Also for use ecosystem and health sectors
Daily, monthly	cropland tile maximum temperatures	K	Tile contains information from agricultural fraction of land in a given GCM grid box.
Daily, monthly	cropland tile minimum temperatures	K	
Daily, monthly	cropland tile precipitation	K	
Daily, monthly	cropland tile minimum relative humidity	K	
Daily, monthly	cropland tile wind speed	K	
monthly	number of precipitation days where accumulation was above 1 kg m-2	#	These two variables combine to describe the intensity of rainfall when it does occur
Monthly	average precipitation accumulation on days where accumulation was above 1 kg m-2	kg m-2	
	New variables requested by Fisheries and Marine Ecosystems sectors		
Monthly	Photosynthetic active radiation (PAR, 400-700nm)	W m-2	
Monthly	Euphotic depth 1 = depth at which there is 1% of surface PAR	M	
Monthly	Euphotic depth 2 = depth at which the PAR is 0.1 W/m2	M	
Monthly	3-D (depth-resolved) ocean temperature	K	
Monthly	3-D (depth-resolved) salinity	Psu	
Monthly	3-D (depth-resolved) current velocity u	m s-1	
Monthly	3-D (depth-resolved) current velocity v	m s-1	
Monthly	3-D (depth-resolved) dissolved oxygen concentration	mmol m-3	
Monthly	3-D (depth-resolved) pH	pH	
Monthly	3D (depth-resolved) primary productivity	mol C m-3 s-1	
Monthly	3D (depth-resolved) phytoplankton carbon concentration	mol m-3	
Monthly	3D (depth-resolved) small phytoplankton carbon concentration	mol m-3	
Monthly	3D (depth-resolved) large phytoplankton carbon concentration	mol m-3	
Monthly	3D (depth-resolved) zooplankton carbon concentration	mol m-3	
Monthly	3D (depth-resolved) small (micro-)zooplankton carbon concentration	mol m-3	
Monthly	3D (depth-resolved) large (meso-)zooplankton carbon concentration	mol m-3	
Monthly	3D (depth-resolved) small particulate carbon concentration	mol m-3	
Monthly	3D (depth-resolved) large particulate carbon concentration	mol m-3	
model-specific	size ranges or Min-Max of phyto and zooplankton groups (would need to know the range of sizes for the biogeochem model variables; e.g. ESM2M has small and large groups)	mass ranges	
	New variables requested by Climate Services		

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Not specified	Sunshine Duration	s	Defined using threshold value to determine intense sunshine
Not specified	Potential Evaporation	mm	ideally separately by land use (as calculated)
Not specified	Evapotranspiration	mm	
Not specified	CO_2 Concentration in near-surface layer	kg m-3	Agriculture and ecosystems
Not specified	Wind Speed	m s-1	Stored at model level not pressure level Renewable energy (wind)
Not specified	Wind Direction	Degrees	
Not specified	100m Wind Speed and Gusts	m s-1	Also 80m and 120m for energy resources and infrastructure
Not specified	10m Wind Gusts	m s-1	
	Wave Height Max	m	
also 3- or 6-hourly	Geopotential Height	m	On more pressure levels 300, 500, 850, 925, 1000hPa
3- or 6- hourly	Boundary Layer Height	m	
3- or 6- hourly	Vertical Velocity	Pa s-1	At more frequent output times
3- or 6- hourly	Convective Precipitation	kg m-2 s-1	solid and liquid separated
3- or 6- hourly	Total Soil Moisture Content	kg m-2	Possibly more layers
3- or 6- hourly	Soil Temperature	K	At more frequent output times
3- or 6- hourly	Relative Vorticity	s-1	
3- or 6- hourly	Relative Humidity	%	
3-hourly	Mean Sea Level Pressure	hPa	At more frequent output times
3- or 6- hourly	Large Scale Precipitation	kg m-2 s-1	
3- or 6- hourly	Eastward Wind	m s-1	On more pressure levels
3- or 6- hourly	Northward Wind	m s-1	300, 500, 850, 925, 1000hPa
3- or 6- hourly	Specific Humidity	1	300, 500, 850, 925, 1000hPa
3- or 6- hourly	Snow Depth	m	At more frequent output times
3- or 6- hourly	Snow Density	kg m-3	Comment from Swedish Meteorological and Hydrological Institute: "everything related to snow is desired"
3- or 6- hourly	Snow water equivalent	kg m-2	
1-hourly	Precipitation	kg m-2 s-1	High frequency precipitation data
3-hourly	Precipitable water in the atmospheric column	kg m-2 s-1	
Monthly	Maximum accumulated precipitation over 1 hour	kg m-2	Similarly, maximum accumulated precipitation over 1-, 2-, 6-, 12-, and 24-hour periods
Monthly	Maximum ocean wave energy	Not provided	
Monthly	Total atmospheric heat content	Not provided	
Monthly	Total oceanic heat content	Not provided	
Monthly	Total land heat content	Not provided	
Monthly	Total glacier heat content	Not provided	

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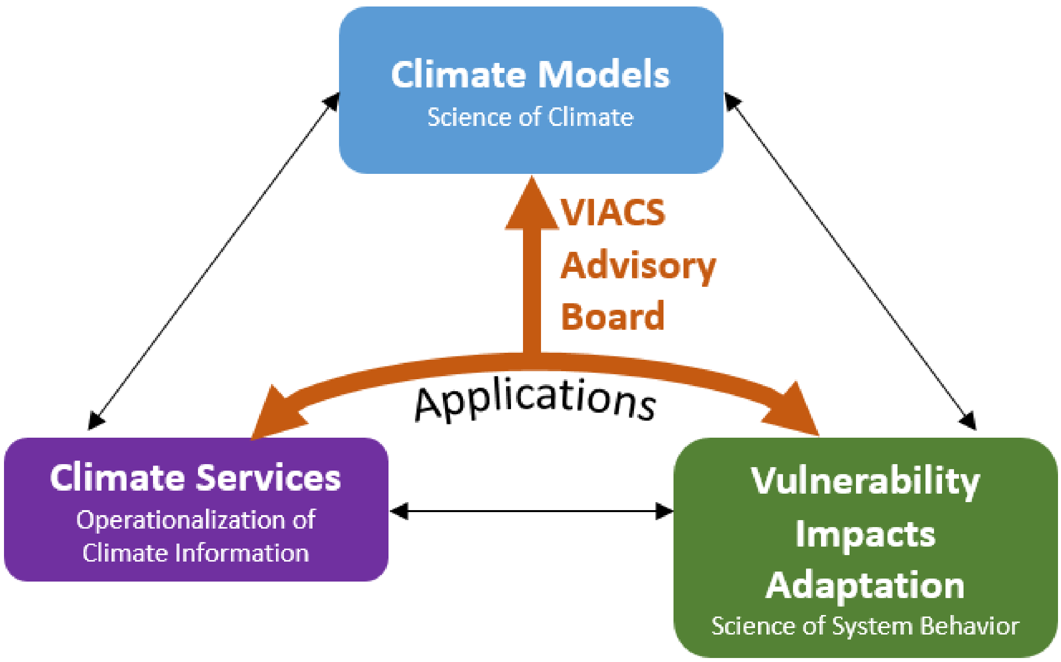

Figure 1: The VIACS Advisory Board provides a new mechanism to help integrate the Vulnerability, Impacts, and Adaptation communities with the Climate Services community, allowing for more comprehensive communication between the climate modeling community and those who apply climate model outputs. Black lines represent previous lines of communication, with the VIACS Advisory Board now helping to connect applications communities and provide a conduit for communications with the climate modeling community.

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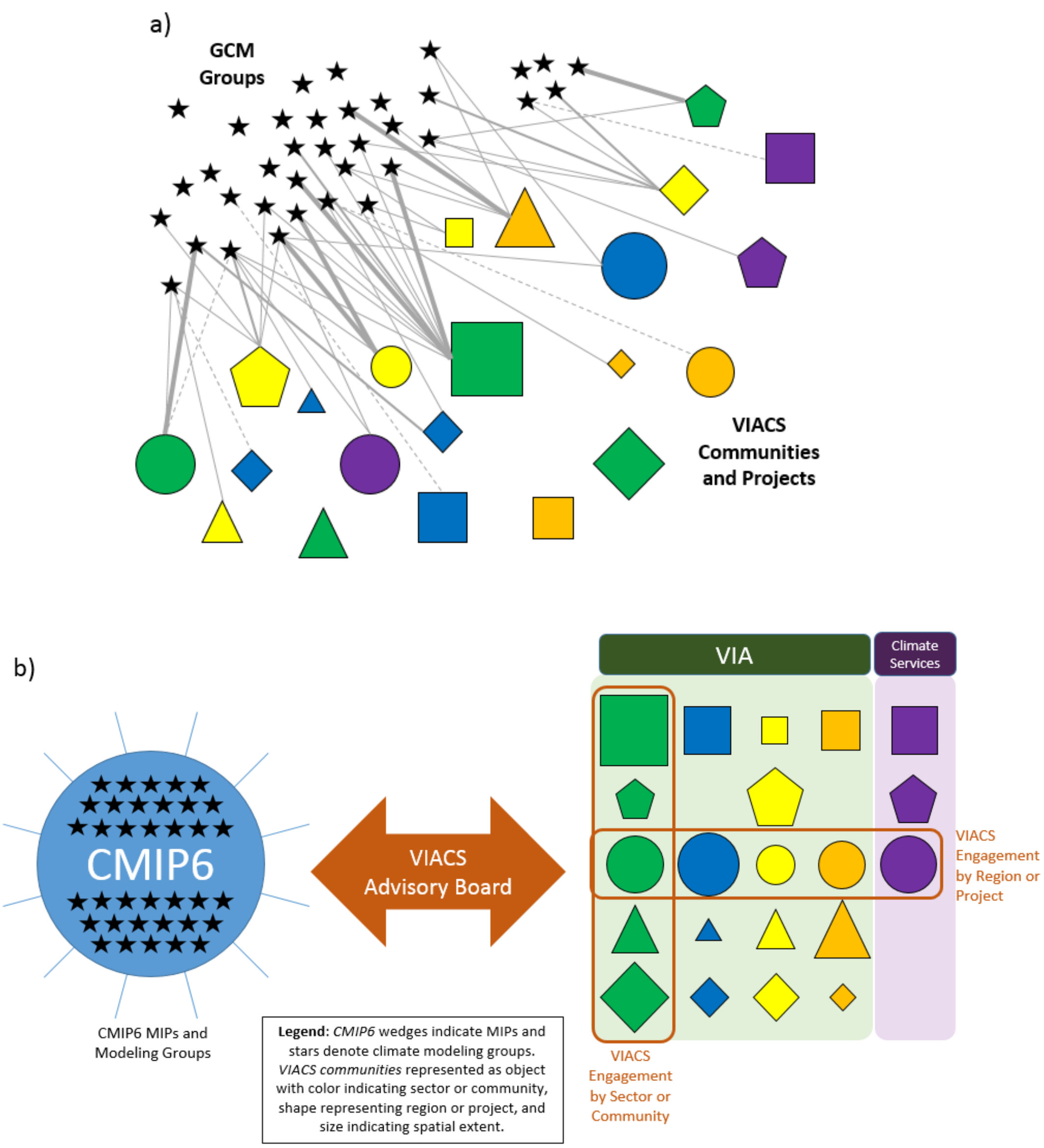

Figure 2: Schematic illustrating the development of the VIACS Advisory Board as an organized process of communication between the climate modeling community and the climate application communities. a) Absent organized communication, each climate modeling center and each climate applications entity had to connect and maintain communications, resulting in a mixture of strong, convoluted, or absent lines of communication. b) As the climate modeling community has organized interactions through CMIP6 (and its MIPs; Eyring et al., 2015), the applications communities of VIA research and the emerging climate services community can utilize the VIACS Advisory Board to provide coherent interaction with CMIP6 leadership and modeling groups. Note that lines of communication are not equivalent to modes of data access, which would include various data distribution centers and clearinghouses.