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Contents

1. Introduction

The World Climate Research Programme (WCRP) is undertaking a series of workshops in 2020 and 2021 to engage the community in guiding the implementation of the WCRP Strategic Plan 2019 – 2028 (WCRP JSC, 2019). The first of these on High-level Science Questions and Flagship Workshop, also known as the 'Hamburg' Workshop, took place in Hamburg on 24 – 26 February 2020. The resulting Hamburg Workshop Report was published online in April 2020.

Once the Hamburg Report was published, there was a call for the WCRP community to provide feedback on the report. The survey was opened on 20 April 2020 and closed on 11 May 2020, with 20 responses. The survey (Annex 1) asked for feedback on four of the five proposed WCRP Lighthouse Activities and also asked for general comments on the Hamburg Report.

The feedback received is provided in this supplement to the Hamburg Report. It must be kept in mind that 20 responses are a small sample and cannot be seen as representative of the entire WCRP Community. Nevertheless, the feedback will be valuable as the Lighthouse Activities are further developed. WCRP thanks everyone who took the time to comment on the Hamburg Report.

2. Proposed WCRP Lighthouse Activities

During the Hamburg Workshop, five Lighthouse Activities (high-visibility projects or experiments that are either led or co-led by WCRP and that will make progress toward reaching WCRP's Scientific Objectives in support of society) were proposed (Figure 1). Participants of the workshop developed short outlines of each of the Lighthouse Activities (except for the 'WCRP Academy,' as this is still being developed), which are outlined in the Hamburg Workshop Report.

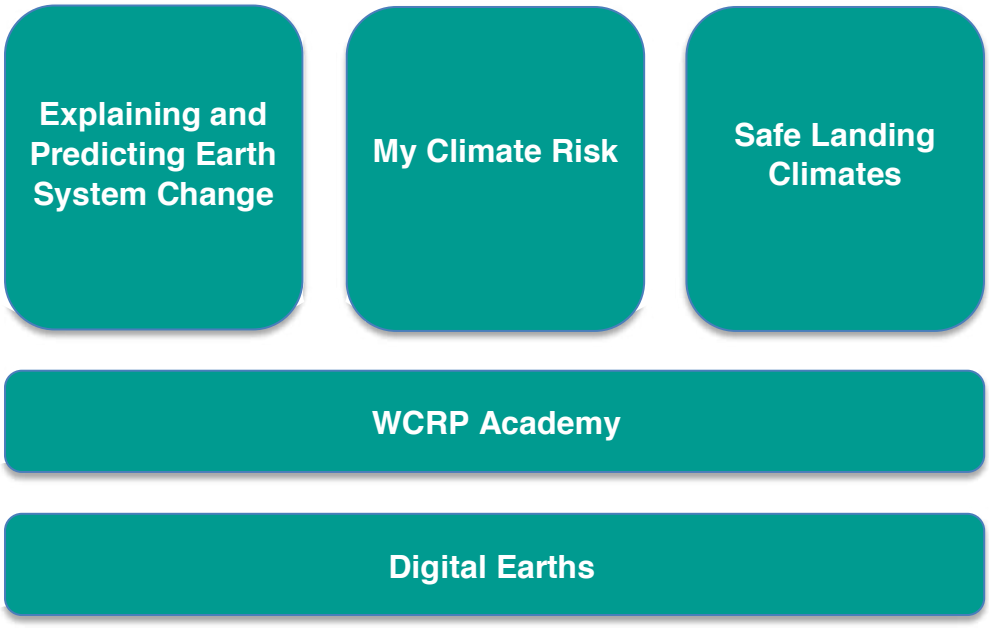

Figure 1: The five proposed WCRP Lighthouse Activities

3. Community Consultation

The comments below are arranged by theme, although there is some overlap with many of them. Only obvious typographical errors were corrected before publishing, but otherwise the comments are presented as they were submitted. Annex 2 provides a list of acronyms.

3.1. Explaining and Predicting Earth System Change

Comments on the proposed Explaining and Predicting Earth System Change Lighthouse Activity were:

General

- This Lighthouse Activity is well defined and articulated by providing a clear picture for major potential contribution that WCRP could play in the next decade.
- It is achievable, needed and it will help stakeholders and end users to better measure the changes in climate, and their impacts. It will provide a way to better integrate the Earth observing systems, modeling and predictions.
- The workshop outcomes represent a refreshing out-of-the-box thinking, and define future pathways for WCRP, not constrained by the existing status of WCRP activities.
- I would like to congratulate WCRP for putting this document together and for the relevance and urgency of the report.
- This activity addresses well-known knowledge gaps in our understanding of global changes. It aims to encompass and integrate observations and predictions, global and regional scales, process studies, and early warning.
- This activity represents the natural follow up of previous programs and will contribute to addressing the four WCRP Scientific Objectives.
- It might appear a summary of research activities that are currently underway with not much innovation in it.
- Despite past and present efforts by the scientific community, we haven't met yet the target represented by the integrated capability for quantitative observation, explanation, early warning, and prediction of Earth System Change. Therefore, this activity has to be pursued.

Scope

- This Lighthouse Activity could include sub-seasonal prediction. At the moment, it primarily focuses on multi-annual to decadal time scale. Why not sub-seasonal time scale? Without sub-seasonal prediction, WWRP may not be much interested in this Lighthouse Activity.
- Science for improving climate prediction capabilities should start at the subseasonal scale, while the production of "real-time" research-based predictions could start at the multi-annual scale. A protocol for submitting such predictions (a la CMIP) and their subsequent verification should be part of this.
- I'd say just "climate" instead of earth system change. The text also includes variability but then says, "with a focus on multi-annual to decadal timescales"; I'd say, "across timescales from sub seasonal to decadal", consistent with WGSIP, and consistent with Objects 1-3 as well. I see many S2S science, modelling and prediction activities mapping into this lighthouse activity.

- This is a very central lighthouse activity: to design an integrated capability for quantitative observation, explanation, prediction and early warning of Earth System Change on global and regional scales, with a focus on multi-annual to decadal timescales. However, I wonder whether "Earth System Change" instead climate change is not too broad. Future Earth in mentioned among the partners, but the overlap seems significant.
- A clearer explanation of how this plan complements (without duplicating) the earth system prediction efforts being undertaken by several national modeling centers is needed. What is the value added by WCRP to these individual earth systems understanding and prediction efforts? How will this plan build upon and synthesize those efforts?
- Earth system reanalyses: what variables will this include, in addition to the usual atmospheric and oceanic variables of existing reanalysis efforts?
- I like the emphasis on integrating observations and models, assimilation, process-based understanding, and connecting the physical climate system with the biogeochemistry and carbon cycles.
- I feel there is a strong "weather" imprint in it. Climate change is not only affecting weather and societal need as well as solutions to climate change do not lies only on weather or weather extremes. In particular, the ocean which covers 2/3 of the Earth strongly influences, mitigates weather and climate while it is undergoing to major changes that already affect society in many different ways. Yet the ocean (and the atmosphere over the ocean) observing system is not sustained. So, I would like to see across the lines more ocean emphasis in relation with these various aspects. Moreover, we need to consider not only the ocean as open-ocean system, but looking into coastal areas where changes affect society the most (hurricanes, storms, surges, sea-level rise, erosion, ocean heat-waves, ocean acidification and deoxygenation events ...)
- The descriptions are somewhat generic and missing out on practicalities that the stakeholders can identify themselves with, particularly with regard to lighthouse activities, such as ‘who does what’ and ‘who gets what’ within the WCRP ecosystem, including the current and future substructures.
- Monsoons constitute the most dominant climate phenomena affecting the lives of billions of people every year, in addition to concerns on the related implications of climate change. Understanding, modelling and predicting the monsoons on the relevant space-time scales remains a formidable challenge that needs a dedicated high-level attention from WCRP, in collaboration with partners such as WWRP. Improving monsoon representation in global climate models also has implications for skills in other areas. It is therefore suggested that a special focus be made on monsoon research in the lighthouse activities.
- The issues of importance for the southeast Asian region are, (i) documentation of past climate over past 3-5 centuries and finding out how the human locally adapted to that, (ii) what are the impacts of accelerated climate change on local weather (for example monsoon) and extreme events (for example dust storms, cyclones and associated storm surges, etc.) during next 50-100 years, (iii) impacts of sea level raise on the coastal population, (iv) impacts on fisheries due to deoxygenation and acidification of ocean waters. Hence, focused plans are to be made to address these issues.
- Need to improve extended range to seasonal forecasts, which have very high impacts on society, especially South Asia region. More research is required to improve the skill and development of suitable applications, especially on extended range to seasonal forecasts.
- More than 50% of the world population is impacted by monsoons, however the prediction skill of the present-day climate models is far below the potential predictability

limits. Predicting monsoon and its variability on various space and time scales are huge gap areas. (For example, on synoptic scales – we do have difficulty in predicting the monsoon lows and depression, on intraseasonal time scales – currently most models have difficulty in predicting on regional scales, on inter-annual scales – teleconnections with various events need to be better represented in the model). Improvement of monsoon forecast (not just Indian monsoon but encompassing Indian, East Asian, Australian and American monsoons) could be a lighthouse activity. Improving the understanding of monsoons on various scales could be a flagship activity.

- It may better specify to which specific areas the 'early warning' and 'tipping point' are referring to.
- I want to present some ideas to concrete the proposed plans. The Andes cordillera is the longest mountain chain on Earth. It runs through more than 7,000 km and 7 countries (Colombia, Venezuela, Ecuador, Peru, Bolivia, Chile and Argentina), from tropical South America to Patagonia, and housing all kinds of life zones, ecosystems, and an extraordinary diversity of climate and weather patterns. Nearly 80 million people live in the Andes. There is a tremendous urgency to understand, model and predict hydroclimate and weather patterns along and across the Andes. No consistent, coherent and systematic efforts have been developed in the region toward that end, and therefore we are proposing ANDEX as a prospective GEWEX Regional Hydroclimate Project (RHP) in the Andes. We have had three workshops in different places of South America and are preparing a White Book on the main hydroclimatological topics and their impacts in the Andes (see Annex 3). Also, we had sessions on ANDEX at the 2019 AGU Fall Meeting in San Francisco (link1, link2) and at the 2020 EGU General Assembly (link). The implementation plan of ANDEX is being developed as we speak and will be discussed in a meeting of the scientific steering committee in Cuzco, Peru on October 2020, and will be completely defined in October 2021.
- "Explaining and predicting ES changes" seems not sufficiently well defined to me, yet. In parts the description seems very broad ("Advance fundamental understanding of Earth System Change on global and regional scales"). However, one can also get the idea that it could be an activity clearly focused on attribution and prediction of interannual to decadal climate variability. It is unclear to me how broad or focused the lighthouse activities in general and this one in particular are envisaged. This may depend on the overall WCRP implementation plan. While "My Climate Risk" and "Digital Earths" seem to provide relatively clear ideas of how to approach the topics, this is less clearly visible for me in this case.
- This lighthouse activity has strong relevance for regional climate science and information. Examples of important scientific questions related to regional climate include the Monsoons, Third Pole Environment, among others. Explaining and Predicting Earth System Change provides a mechanism for linking global climate change to understand and quantify various aspects of regional changes: Extreme weather and climate events, Detection and attribution of regional climate change, Improving representation of monsoon precipitation / convection processes, Himalayan cryospheric changes, advancing subseasonal to seasonal predictions, quantify the role of natural forcing (e.g., volcanic aerosols, solar irradiance) and anthropogenic forcing (e.g., GHG, aerosol emissions, irrigation changes, land use and land cover changes) on the regional climate, environment and ecosystems, etc.).
- System for quantitative monitoring – as far as I understand this means working with existing groups/initiatives such as GEO on GEOSS and GCOS for instance and not developing new systems? In the early parts describing this it sounds like 'new systems' are to be developed but further down I gather it is developing and expanding existing systems an also that for instance the System for prediction and Projection of Earth

System Change - is a part if the digital Earth? Sounds like machine learning is an absolute must to build functioning such systems as they would need to be interactive/intelligent if the predictions are to take in the attribution results. The idea with these systems is very tempting and at the same time very 'large'! Would a smaller pilot project for, say, a hot-spot region be the start to investigate feasibility? ESMs needed both for global and regional – here the regional has some way to go and to be at all time scales more integration within WCRP would be needed. The description if this in the early text and then further down seem not to completely describe the same thing.

- This justifiably remains a primary objective of the WCRP. It clearly focuses mainly on the climate system itself in terms of enhanced observations and modeling. It emphasizes delivery of information and importantly it also mentions the receiving side - the users as their needs have influence on the delivery. However, it does not emphasize enough the need for partnership with scientific organizations that provide the information for factors that study sources of forcing external to the climate system, such as changes in the cryosphere, and the possible future ability to predict volcanic eruptions and the properties of their aerosol emissions. Another missing factor, important in short and long-term prediction is the ability to represent in models coupling between human and the natural climate system, such as emissions and anthropogenic aerosols or human induced changes in land surface coverage.
- I like the near-term (multi-annual to decadal) focus of this activity because it allows for direct comparison with present-epoch observations and hence verification of how models represent observed climate/Earth system variability and changes, as well as processed-based diagnosis of model errors. This will also provide a synergistic impetus to develop reanalysis capabilities for Earth system variables i.e. carbon and biogeochemical cycles.
- I can't really get my head around the entire proposal so I will offer just one specific comment. I think it is ill advised to have the primary focus of the prediction theme on multi-annual and decadal. There is not a lot of evidence yet of any useful predictive skill beyond predicting the trend, despite some of the presentations. Multiyear and decadal are interesting to work on, but certainly not at the expense of subseasonal and seasonal. Maybe there is a perception by some that we are near limit of useful skill for subseasonal to seasonal, but it is like NWP: skill is going up incrementally and there is lots of scope for ongoing improvement.

Co-design and Partnerships

- While this is vital to advancing all four goals of the WCRP SP, it does seem incremental as presented in the report. I also wonder who will be engaged in and have access to the activity. This could end up with a strong focus on research agendas of the most economically and technologically advanced countries (i.e., the so-called "WIERD" nations - Western, Industrialized, Educated, Rich Democracies). There has to be effort in this that is linked to bringing in perspectives and expertise from across the entire world, with an equal footing for all participants.
- Partnerships needed: Since WCRP will not have resources to develop its own prediction code and run simulations, a necessary set of partnerships will be with all the national modelling centres producing earth system models and running simulations. What will the incentive be for these modeling centers to participate in this plan?
- Given that the climate landscape has many players, it is important to articulate the unique positioning of WCRP by highlighting aspects that the other players cannot deliver in a globally coordinated manner.

- Partners may also include GOOS (for ocean observation), and a broader BGC community in addition to Future Earth.

Communication, Collaboration and Integration

- This certainly represents where the short-term climate prediction is heading. Both observation and process understanding are important. But there is one thing missing, i.e., how to harness the advances that will be made within this "lighthouse" in other lighthouses?
- There is significant overlap between the five lighthouse activities identified, and it is not clear how these are taken up in a complementary manner and maintain consistency in the common elements. Cross-cutting aspects also need to be clearly brought out.

3.2. My Climate Risk

Comments on the proposed My Climate Risk Lighthouse Activity were:

General

- A much-needed step change in our approach to societal demand! I support it.
- This is the Lighthouse Activity that I feel is the most far-reaching of the set. It is providing a fresh look at how we integrate our climate research with the needs, interests and values of the diverse communities of the world. It does not mean that we give up some of the standard communication tools (e.g., pdfs, likelihood statements), but it recognizes that effective engagement by the WCRP with the rest of the world through all four of the SP goals must proceed in a framework that recognizes a broader purpose.
- Another very important lighthouse activity: to develop a new framework for assessing and explaining regional climate risk using all the available sources of climate information (observations, reanalyses, model simulations, etc.) in order to construct decision-relevant and scale-relevant information at the local scale. I think it is important to deliver climate information that is meaningful at the local scale and to shift the stakeholders' values to the starting point, not the end point. As the activity states, this requires transdisciplinary work, more than physical infrastructure. I wonder whether it suffices that "the climate scientists would start by listening". More social science competence might be required.
- There seems to be some confusion in labeling one of the lighthouse activities as "Your Climate Risk" or "My Climate Risk", with both the labels mentioned in the report at different places (this is now fixed).
- The paradigm shift to bring together regional actors all available resources of data and expertise to develop storylines and to distill explanation and solutions for Earth system changes is a big transformational change. More consideration may be needed on how to implement this in practice.
- I like the general idea of lighthouse activities, and also some of the proposed activities themselves: "My Climate Risk" and "Digital Earths" seem both sufficiently specific and exciting to create broad scientific interests in the climate science community.
- This activity proposes a new framework for assessing regional climate risk using all available sources of climate information. It proposes an integrated approach and a fundamental shift of paradigm, which in principle should outflank the "cascade of uncertainty" problem. This kind of approach is necessary to link regional and global

changes. This is somehow complementary to that described in activity No.1 (Explaining and Predicting Earth System Change).

- I have certainly forgotten that the title 'My Climate Risk' was decided. Or have the events of the last few weeks made me more sensitive to the relation between individuals and society? I guess we have all been thinking about the relation between individual interests and society's welfare during the confinement. There are obviously some parallels with climate change. Even if "my climate risk" is small or I have all the money needed to mitigate "my climate risk" we still need to act now and decisively for those living under more drastic climates. As we know, those most at risk are not those who created the problem. Our travel through the world and the social contacts we have had led to the elderly dying in the homes. We worry more about our individual achievement than their societal consequences.
- I think the expression "My climate risk" really gives the wrong impression. Especially when most of us have to stay at home to avoid that others in our society more at risk do not die from COVID-19.

Scope

- Should definitely not be focused solely on climate change (this should not be CORDEX), which is not necessarily the main concern related to climate information (cf. WMO GFCS). For instance, right now there is need from southern hemisphere countries for information on potential climate (winter) effects on COVID-19 but the only assessments available have a northern hemisphere focus and are therefore downplaying the potential summer effects. Most of the available studies have a strong climate data/science component, yet climate scientists are not contributing in a timely or organized manner in their assessment. Furthermore, this work should be done in coordination with health scientists.
- Like this a lot, but I think it should critically include *predicting* risk seamlessly across S2S and longer timescales, in the context of climate services, co-developed with stakeholder communities. The S2S real-time pilot activity to demonstrate potential value of S2S forecasts for mitigating climate risks could fit in well here. CORA could play a key role in developing integrated climate risk information that unifies objectives 2 & 3 to serve objective 4.
- Climate need not be seen only in terms of risks, and the opportunities it provides also need to be identified at the appropriate to space-time scales for the society to take advantage of them. Further, assessing climate risk also needs a good handle on the sectoral impact assessment, which may be beyond the scope of this activity, particularly at the space scales being considered. Can we simply say, “Climate for You”, implying science-based and actionable climate information for climate-sensitive decision making?
- Climate change dominates the narrative (with many references to IPCC), with only passing references to sub-seasonal to decadal prediction. Page 24 – “Sub-seasonal, seasonal and decadal prediction, their potential use to constrain climate projections and methods to reduce the impact of initial shock and drift” – not clear what this means. There is a sub-optimal operational use of the available skills in these domains, due to gaps in research to operations and operations to research linkages. Any improvement in this situation can yield immediate societal benefits, irrespective of the climate change context.
- More than 85 million people inhabit the Andes and will be impacted by climate and global environmental change. The mountainous areas of the Andes contain major cities and hundreds of medium and small sized towns that demand an ever-increasing supply

of environmental services and socio-economic resources. The extreme geography and climate set the stage for hydro-meteorological hazards that include flooding, landslides and debris flows that have taken thousands of lives in recent decades. Extreme climate and weather events, combined with a degraded environment will likely affect the wellbeing of communities within the Andes in terms of failure to provide enough natural resources, such as fresh drinking water. Poverty in the Andean region, the disappearance of native and ancestral cultures, human encroachment, large-scale deforestation, erosion and land degradation, accelerated loss of biodiversity and soils, large-scale pollution of water sources owing to mining activities, oil industry activities, agriculture, cattle dwellers and coca growers make it all the more urgent that basic studies and applied research be conducted in this region. At the same time the natural biodiversity and the breadth of current and potential environmental services provided by these ecosystems may provide solutions for sustainable development of this vast region. Therefore, a thorough assessment and understanding of the Andes system is necessary, including the interactions between natural ecosystems and social systems.

- Risk assessments due to Monsoon precipitation extremes, floods and droughts, surface and ground water availability, regional sea level rise, Himalayan cryospheric and glacier changes, fresh water availability, Impacts on agriculture, regional terrestrial and marine ecosystems.
- The notion of “labs” is a bit vague maybe… Also, there might be a risk to somehow limit the research to a kind of collection of case studies and storylines… Probably the part related to the “understanding” should be emphasized more in the description…
- Why not, therefore, aim even higher to develop realizable, automated methodologies for producing climate risk information on demand in response to queries from individual stakeholders? The same information sources could be mined, and quantitative outputs such as risks or event probabilities and associated uncertainties could additionally be communicated as narratives or storylines. Achieving this would doubtless require leveraging artificial intelligence and other developments in computing and would almost certainly exceed WCRP’s direct capabilities. However, it is not very different from the Digital Earth activity in that respect, and indeed there might be some significant synergies between those two efforts.
- An additional comment is that sub-seasonal, seasonal and decadal predictions are mentioned only as a basis for constraining climate projections and establishing methods to reduce the impact of initial shock and drift. However, they also provide information about climate risks on those time scales that is very much in demand, besides being an essential element of Strategic Plan Objective 2. Ideally, an automated system such as described above (comment above this one) would return information seamlessly for whatever time scale is relevant to the user (whereas the information that is “in the box” would not have to be seamless as per comments by Christian Jakob). Overall, I think both “top down” and “bottom up” assessment capabilities should be developed.

Co-design and Partnerships

- I am not sure why in the partners list WMO is just listed in General, and not per department or programme. Since subseasonal to seasonal scales are mentioned here, the WCRP/WWRP programme S2S should be mentioned in the partners list? This risk-based approach brings the regional/local climate at the centre of the arena and this will lead to positive implications in terms of involvement of a larger interdisciplinary research community and direct impacts on society's needs.
- This is more like a repackage of "regional activity", my experience is, this may not lead us very far. We need to be prepared that, for this kind of work to succeed, we need not

only engage outside WCRP, we need to work as partners with our user communities, in a very interactive process. I have been leading an effort in Canada to develop climate change information to be adopted in Canada's national building code. What I have learned is that, either climate scientist or engineer alone, cannot produce something that is sound in climate science and that is also useful and usable by the engineers. Even if we can understand what the user needs are by talking to them, and even if we produce proper information, there is still no guarantee the information will be used and interpreted properly. But if the users cannot interpret information properly, the information can be misused which means that we cannot realize our ultimate objective, understanding "climate risk".

- I like the way this activity focuses on leveraging existing modeling and prediction efforts, with local interest groups through the "labs". Key to development of these labs will be groups which include stakeholders, social scientists and participants from diverse regions. Unfortunately, the Hamburg workshop included no participants from the developing world. This must be remedied in the next stage, so that the climate risk labs are more widely relevant.
- Relevant for achieving the WCRP Strategic goal 4 but should be more user driven. Needs to include a strong bottom-up mechanism to channel the needs and should be responsive, even if in the short-term, to those needs.
- The current WCRP JSC Task Team on Regional Activities could help shape this further.
- The cascading of climate information in the global-regional-national-local stream (both ways) is not adequately addressed, which also needs substantial research effort to optimize the inputs coming from multiple sources with a range of skills and biases. In fact, it is important for the lighthouse activity “My Climate Risk” to be explicitly tied to the climate services domain through partnerships. In particular, WCRP has a key role in supporting the establishment of a robust Climate Services Information System, one of the foundational pillars of the Global Framework for Climate Services (GFCS), which is surprisingly not referred to anywhere in the document.
- Here initiatives such as the webinar Climate data and climate services for the finance sector 24 April are good examples where the climate risks and how to tackle them are discussed in a way that appeals to funders and policy makers/stakeholders. If we are to give the worst-case scenarios – what are then the time spans/return times for this – needs to be discussed with policy/finance (including insurance companies). If only short simulations are possible for very high-res then maybe low-res simulations can give guidance towards what time slices very high-res would be necessary. Sharing of best practices including how to interact with necessary ‘partners’/users would be very useful. Maybe there is something to be learned from experiences in for instance the process if making Marine Spatial Plans.
- This activity focuses on developing new methodologies for producing regional climate risk assessments that synthesize multiple data streams (i.e. observations, reanalyses, model outputs, etc.) and provide decision- and scale-relevant information. This would be a very good thing, as would the focus on stakeholders’ values as a starting point for each assessment. However, such an end product is still human-based, and appears to require each stakeholder to connect to one or more climate experts who are willing to invest time and effort to develop a risk assessment. Even if the assessment process applies methodologies that become standard and routine, it seems very unlikely that the capacity on the climate expert side will ever match the demand for such information from all sectors in all regions.

Communication, Collaboration and Integration

- Page 20 – WMO is also issuing a Global Seasonal Climate Update (GSCU) in pre-operational mode, which can be another product that the lighthouse activity “Explaining and Predicting Earth System Change” can consider collaborating on.
- It might also be necessary to consider how to communicate/interpret the climate risks to different stakeholders/users in an understandable language, as well as to tailor the information of risks with different needs (and perhaps also tolerance) of users.
- This important lighthouse activity, which has local and direct human relevance should also explicitly include attention to compounded risk. Also, should link to other scientific disciplines such as ground hydrology.

3.3. Safe Landing Climates

Comments on the proposed Safe Landing Climates Lighthouse Activity were:

General

- Exploring the routes to climate safe-landing spaces for humans and natural systems is a very novel, fascinating and multi-disciplinary concept.
- This is a “vision of possible safe futures” activity aiming to explore possible present-to-future pathways leading to sustainable development goals. In this activity, the connection between socio-economic (social) sciences and the Earth system is supposed to be tight and mutually beneficial.
- The exploration of different safe paths for the future evolution of our planet compliant with sustainable development goals has to be carried out (sooner or later) and WCRP represents the right framework for initiating and supporting it.
- Very interesting, completely necessary and enormous task! None if the bullets on the list at page 27 can really wait – are there thoughts on how this will be organized?

Scope

- My understanding that the 'Safe Landing Climate' is trying to provide guidance for human development with considering long-term global response to climate change. However, the current way of description for this activity is not very clear, as it emphasizes more on the interaction with Lighthouse Activity #1, 2 and 4 (which is essential), but less on the linkage with the mitigation and adaptation strategy.
- Not clear to me if this includes adaptation strategies? I think it would and be connected with "My Climate Risk" through that.
- Thought the report has addressed all issues to be dealt with. However, the issues that need to be dealt with in the immediate time frame need to be identified and stated clearly. For example, as stated on page 5, the attempt should be to identify the biases in the climate models that needs to be reduced and target them immediately. In our opinion, rather than hunting for the biases globally, they should be examined regionally with rigour.
- While establishing the scientific basis for adaptation and mitigation, the actions towards creating a climate resilient society should be region specific because the adaptability and capability for mitigation will vary from region to region.
- The impact of climate change on the monsoons need to be understood better. While the extreme events will increase in the coming years but the extent and regions which are most vulnerable to it needs to be studied and identified. Also, we know that propensity

of heat waves is likely to increase in climate change scenarios. This is a major issue for South Asia and its prediction at smaller scales with longer leads would be very helpful for disaster management.

- Deleterious positive feedbacks between poverty, land degradation, deforestation and climate change in the Andean region make more urgent to understand and predict the on-going and future impacts of climate variability, climate change and human induced changes that hamper the reaching of the SDG in the Andean countries. These problems are now aggravated by the strong impacts of the on-going COVID-19 pandemics in the Andean countries. We also need to adjust the existing adaptation plans for climate change and provide the scientific knowledge to inform the decision-making process in the Andean countries. This requires developing new science and expertise of the scientific community in the Andes and elsewhere, including natural and social sciences.
- I have the impression that this activity is designed to cover time scales longer than decadal. If all time scales mentioned in the WCRP strategic plan should be covered by lighthouse activities then I'm wondering where the time scales shorter than interannual are covered.

Co-design and Partnerships

- It is not clear how WCRP could attract social scientists.
- If handled in conjunction with "My Climate Risk", the connection with the SDGs provides an important focus and forward-looking view of opportunities for achieving SDGs in a world where climate is non-stationary and there is not a new equilibrium climate, at least for the rest of 21C. This puts changing climate in a positive view in that opportunities are expressed in the face of the challenges of climate change, rather than simply providing dire messages.
- This is another activity which will require a strong input from social scientists and stakeholders with a need to involve participants from a wide geographical distribution, including South America, Africa and Asia.
- Direct connection with the Sustainable Development Goals: to explore the routes to climate-safe landing 'spaces' for human and natural systems, exploring present-to-future "pathways" for achievement of SDGs, such as climate action, zero hunger, good health and well-being, clean water, life below water and life on land, on multi-decadal/centennial to millennial time scales. While WCRP would be leading this activity, it would need partnership with Future Earth, the Integrated Assessment Modeling Consortium, the Belmont Forum, the UN Sustainable Development Goals programme and others. I think this lighthouse activity would offer a broad range of past and present WCRP work to make great contributions.
- Very interesting and novel activity. Requires strong outside partnerships and also consideration of human-natural system coupling.

Communication, Collaboration and Integration

- There is a significant connection between this lighthouse activity and the earth system prediction activity which is not touched on in the description: it is the earth system prediction activity which will allow the safe landing climates to be simulated.
- There is a lack of linkage to "My Climate Risk."
- Very important activity to link with and guide future socio-economical pathways. It should also develop concrete links/actions with Lighthouse activity "My Climate Risk".
- "Safe landing climates" seem to have quite some overlap with "My climate risk". If one wants to have two such activities, they would need to be clearly distinguishable.

- The collaboration across different disciplines for the realization of comprehensive Earth Systems at different complexity including natural environment and human socio-economic systems will provide (at least) a better integration between climate and socio-economic development sciences.
- There is the risk that the various communities and the state of the art of the respective research are not yet ready for such an integrated approach and that the activity will spread too thin across tiny creeks with not sufficient interaction.
- The aspect that this activity “will promote the development of new methodologies to include risks assessments of impacts on human and natural systems, of climate instabilities, extremes, and irreversible transitions at global and regional scales in the long term” could be seen to overlap substantially with the Climate Risk activity, although it is apparently intended to be broader.

3.4. Digital Earths

Comments on the proposed Digital Earths Lighthouse Activity were:

General Comments

- Great way to connect WCRP with the rapidly growing data science world, both for transdisciplinary needs ("My Climate Risk”) as well as promoting cross-fertilization between climate data-driven (empirical) modelers, with the larger computer science/Bayesian statistics communities. Promoting accessibility through cloud computing to empower young researchers from developing countries is especially vital.
- Very good initiative. While the Digital Earth can be a global effort it should have wide ranging capabilities for regional modelling, analysis and for risk assessment.
- This is an encouraging activity, as it emphasizes on the synergy of existing effort, including of new technologies (e.g. AI), as well as being inclusive to be an open access framework. The sustainability of this activity needs to draw more attention through carefully analysis of resources and capacity needed in particular by developing countries.
- I like the general idea of lighthouse activities, and also some of the proposed activities themselves: "My climate risk” and “Digital Earths” seem both sufficiently specific and exciting to create broad scientific interests in the climate science community.
- Valuable documentation of the evolution of the Earth System from the past, into the present and the future, for humankind.

Scope

- I do not see here any discussion on observations. To improve predictions observations are key. How and what observing we need to feed the "Digital Earth"? The "Digital Earth" is not just linked to weather and atmosphere predictions but should encompass also the other subsystems.
- The activity "Digital Earths" intends to set up a digital and dynamic representation of the Earth system founded on an optimal blend of models and observations, enabling exploration of past, present and possible futures of the Earth system by giving access to data, methodologies and software. I found this a bit hard to read: what does "by adding a new dimension to climate information" mean? I guess mainly pushing the "co-development of high-resolution Earth-system modeling and the exploitation of billions of observations with digital technologies from the convergence of novel high-performance computing, big data and Artificial Intelligence (AI) methodologies.

- High resolution spatiotemporal weather and climate modelling and prediction along the Andes demand very high computational resources that are non-existent in the region. Also, monitoring activities demand costly systems, technologies and capabilities that need to be deployed by the Andean countries, but international collaboration will be crucial to improve the observational network.
- The Earth sciences scientific community needs to develop the capability of developing and integrating high-resolution Earth System modeling, billion-size observations, and novel methodologies as Artificial Intelligence. This is a necessary step towards the Twin (at least sibling) Earth.
- Much (probably most) of the value in sub-seasonal to decadal predictions is realized through periodically produced large ensembles of predictions from multiple models, and there would inevitably be a tradeoff should models having massively increased resolution be applied for those purposes. That said, such application may point toward the solution of longstanding issues in prediction models including persistent biases and the signal-to-noise issue. In addition, greatly increased resolution relative to current standards will one day become the norm, and so offers a means for anticipating the challenges and opportunities inherent in tomorrow's high-resolution predictions.

Co-design and Partnerships

- It seems to me like this activity is primarily aimed at software and hardware required to make the other activities function. However, this means, since WCRP doesn't have its own models or computing resources, that will lean heavily on external and national partners. What is the exact role that WCRP will undertake - an interface to combine, integrate, and share the products of the partners? Or is this mainly an effort of encouraging national efforts to follow this goal?
- I have the same concern that I have for "Explaining and Predicting Earth System Change": Who makes the decisions on developing and implementing Digital Earths? How will perspectives, interests and values across the world be engaged? Who will have access, not only to the output, but to the shaping of these tools that demand substantial technological resources and expertise?
- Is this an ECMWF and US activity? How can we not make this as an elite club? How can the entire climate research community benefit to this?
- Having high resolution 'showpiece' simulations as part of the implementation plan sounds like a good idea. However, WCRP should ensure that participation is open to all who might be able to undertake such an activity. The Hamburg report lists particular modelling groups and funding organisations as examples and care needs to be taken not to exclude others. It is also important that the more routine CMIP-type models are not seen as inferior to this effort. They will continue to provide multi-model ensemble information on climate risk.
- The lighthouse activity 'Digital Earth' currently as described reads like a formal research proposal for 3 modelling centres aligned to HPC funding. WCRP should be promoting the science activity here and not prescribing how the work should be fulfilled. This needs to be something that all modelling centres active in the WCRP family can engage with. Additionally, the ideas of developing new pathways e.g. for developing countries to access results from these limited numbers of models seems to ignore the many strong existing pathways, both within modelling centres and notably of course through WCRP e.g. CMIP on ESGF.

Communication, Collaboration and Integration

- It is not directly clear how the interface to "Explaining and Predicting Earth System Change" will be defined.
- Seems interesting and could certainly bring earth system science/modeling forward if possible to find a way to manage it and agree on for instance: where would the centers be located, what would be prioritized and who would prioritize, how and who to finance the centers and how to make sure it's not just the Rich World deciding and doing? Nordic example of sharing computers and model development in weather prediction works nicely although an advantage there is that the cultural differences are not so large. Who would be 'counter parts' to WCRP in the social/economic sciences if we are to bring in human activity - potential funding?

3.5. Overarching Comments

General Comments

- Despite my comments, which are negative at times, I do like the overall motivation for Lighthouse Activities as organizing efforts that are WCRP beacons guiding the world in a changing climate. I also very much like the concept of a Climate University and Open Lab. The advances in online education, the variety of tools that can be brought to bear on climate research and dissemination of information provide a tremendous opportunity for engaging with the whole world and growing the reach of the WCRP in productive ways.
- While I agree these are good ideas, they also sound a bit familiar, something like mega grand challenges. Integration and interaction among the "lighthouses" are important and are missing.
- I didn't see a comment box for the WCRP academy, so I'm including my comments here: This could play a very important role of collecting open source educational material regarding the earth system, providing knowledge transfer and capacity building, being a first place for stake-holders from around the world to go to learn climate information.
- I would like that WCRP claims very openly that we also need to improve the Earth Observing System by rationalizing observations that for the moment are sustained only for the atmosphere. There is a big risk that observations (and essentially in situ observations) will decline in the future for many different reasons and this will prove dramatic for any kind of prediction/forecast.
- The need to improve the Earth Observing extending sustained observations and capabilities also to the other key subsystems of the Earth is as key as developing new modelling and analyses capabilities.
- The discussion by the Hamburg workshop participants touched on interesting points: (1) Guy Brasseur made a "point about bringing back fascination, in the same way that centers like CERN are driven by fascination." I would argue that young scientists working on climate feel the fascination very well. (2) Neil Harris framed WCRP's priorities as "nurturing and encouraging scientists interested in fundamental climate science for its own sake on one side, but also an urgent societal need for information on how to mitigate and adapt to climate change on the other." I would fully agree and think these two important points are fully compatible. (3) Bjorn Stevens wrote: "If people think climate change is important then why is there no international infrastructure that

supports it. Why does our claim to success (CMIP/CORDEX) lie in rummaging like vagrants through the debris of output from outdated modeling tools developed on infrastructures inherited from — here speaking as an early career scientist — our grandparents". Good point, but unlike Bjorn I would not think better infrastructure can solve the problem. Climate scientists are warning for long that we are on a dangerous, life-threatening course. I cannot believe that better infrastructure would change this. Rather, we have a psychological/sociological problem. And this has to do with better selling our results. I do not have a solution, but I think we should discuss this point. I miss this discussion in the present report.

- I think for each activity, the resources needed as well as the indicators to evaluate the success of the activity should be considered as well.
- The Implementation priorities currently read as if WCRP is intending to engage in activities beyond its mandate; e.g. to 'develop new institutional approaches' and to 'evaluate mitigation strategies' which imply WCRP will be working in areas of policy, economics, social science etc. I understand this is not was is meant, so words need to be carefully used here.
- Within the science themes identified for the ANDEX RHP, the following specific research questions have been identified: 1) What are the dynamical feedbacks between the Andes and the processes involved in the hydrologic cycle over the Andes (water vapor, precipitation, evapotranspiration, sublimation, soil moisture, infiltration, groundwater, and river flows) at a wide range of spatial and temporal scales, for average and extreme conditions? Among those processes the following were highlighted: water vapor sources and pathways, precipitation recycling, low-level jets and atmospheric and aerial rivers, the Bolivian High anticyclone, the Madden-Julian Oscillation (MJO), tropical easterly waves, and El Niño Southern Oscillation (ENSO). Among the most important extreme events the following were identified: intense storms, mesoscale convective systems, floods, droughts, cold spells, hail storms, lightning, fires, Zonda winds, and landslides. 2) What are the physical dynamics of processes involved in the surface energy budget over the Andes across a wide range of spatial and temporal scales? 3) How does the dynamical coupling between 1 and 2 operate across the Andean altitudinal, latitudinal, and longitudinal gradients and from glaciers to deserts? 4) What is the influence of the cryosphere on the surface hydrologic cycle of the Andes, and what is the influence of the atmospheric hydrologic cycle on the Andean cryosphere? 5) What are the current and future human impacts from water diversion and pollution, deforestation, land use and land cover, and climate change on processes and variables involved in water and energy budgets over the Andes? 6) How should these impacts be dealt with from a water (and other life support systems) management perspective? 7) How will the current and future water and energy budgets along the Andes affect ecosystem services, water supply, hydropower generation, food production and food security, natural hazards, and human health? 8) What is the effect of the Andes on pollution in urban valleys and what are the risks for human health?
- Comment on implementation priorities: I do not understand well the specific purpose of implementation priorities formulated in such a way. One could also write "foster scientific advances, future technologies, and institutional approaches required to reach the scientific objectives formulated in the strategic plan". I find it rather confusing that instead there are four new bullet points which are related but not necessarily equal to objectives mentioned elsewhere.
- Lighthouse activities to implement the WCRP strategy are all rather 'enormous' and some of them are broken down to more constrained and measurable' activities but some seem still a bit too large to put into action so-to-say.

Co-design and Partnerships

- I was wondering how these lighthouse activities are linked to the recently developed goals of the Research Board. Although these activities are very good, to me it is crucial to link this to the overall goals of Science & Innovation (WMO and RB).
- Although partners are listed, I also wondered how this will be implemented, by whom. The reason I ask is that all the listed partners also have other objectives in their own jobs, also goals from other WMO objectives (for example people in GAW/WWRP also have their own Implementation Plans, S2S project has its 5 year plan and then the RB has new ideas/concept notes etc.) and these people work on a voluntary basis for WMO - yet they get tasks/projects from all directions... which might lead to overload... "
- Overall, I would like to see the WCRP make a much greater effort to be inclusive in developing these plans. The Hamburg workshop was scheduled at very short notice, which severely limited attendance. I note especially that while the WCRP JSC and WCRP activities representatives were fairly gender balanced, the 9 additional experts (who must have been invited) were all men working in North America or Europe. No-one representing Africa or South America was present, and there was only one participant from Asia. WCRP is a world-wide organization and important decisions need to be made by a group representing world interests, not just the interests of North America and Europe. More time needs to be given to participants to schedule such a meeting in between other commitments and make travel plans. Urgency is not an excuse to shut people out.
- The document states that a task of the Hamburg Workshop was to identify "pan-WCRP Lighthouse Activities" that need to be pursued to make critical near-term progress towards meeting WCRP's Vision, Mission and Objectives, outlined in the WCRP Strategic Plan. I would not call the four Lighthouse Activities described here "pan-WCRP", rather they reach far beyond the outer limits of WCRP, e.g. into Future Earth. While this might be a good approach to "thinking big", we would need to clearly define how to set up this collaboration (this will not be a piece of cake).
- The WCRP Academy is an excellent concept to enhance climate research capacities, particularly on regional and national scales. It is important to work closely with the existing structures and processes such as WMO Regional Climate Centres, WMO Regional Training Centres, National Meteorological and Hydrological Services (NMHSs), etc., as a global network but ensuring that individual regional and national needs are adequately addressed. "One size fits all" will not work in this context. It may also be useful to look at the WMO Global Campus concept (link) to draw on possible synergies. "Climate Services Toolkit", another major initiative of WMO in support of the GFCS, can be a good framework to build on, in this context.
- In all countries, NMHSs are the primary providers of authentic climate information. NMHSs also support a substantial amount of WCRP work in many countries. It is therefore important that the research needs of NMHSs to constantly improve their operational climate products are adequately addressed and efforts made to improve the visibility of WCRP to ensure continued climate research investments at the national level. NMHSs find no mention at all in this report.
- Overall, an emphasis on worthy traditional WCRP goals that do need continuous attention but with time-relevant emphasis, which reflects also the growth in WCRP's understanding its role of in the present and near-term future. The novel approach to the traditional activities and the newly conceived ones requires building strong partnerships to science organizations outside WCRP. This is well emphasized and a really important goal.

- There is a need to facilitate joint planning for advancing the spectrum of prediction activities (sub-seasonal to decadal) within the framework of the SP and IP.

Communication, Collaboration and Integration

- They seem very inter-related and overlapping, and of course shouldn't become silos!
- Relation of lighthouse activities to other elements of the WCRP structure: I think the question how broad or narrow lighthouse activities can or should be will depend crucially on the broader implementation plan. Are they supposed to replace “Grand Challenges” and “Core Projects”? Then they will need to be sufficiently broad. Are they supposed to co-exist with one or the other element of the former WCRP structure? Then it would be useful to clarify relations and roles of elements.

4. Summary of Themes

The following themes emerged from the feedback in Section 3.

- Engagement with the developing nations and bringing them along, both in terms of developing the science in the Lighthouse Activities but also in terms of these communities as research partners and users of the science, knowledge and information, is very important.
- Earth System Change: do we include weather and climate or just climate? There are differing views on where the emphasis could/should be. Also, there is a strong plea to include the sub-seasonal to seasonal timeframe; and not focus on multi-annual to decadal at the cost of sub-seasonal to seasonal
- Role of observations: this is critically important and perhaps not sufficiently emphasized
- Links **between** the Lighthouse Activities are not sufficiently well articulated
- Some Lighthouse Activities are seen as forward-looking and ambitious; others may be still too incremental. There is a risk that they might just repeat the Grand Challenges. There is some concern that they are too large to be managed by WCRP.
- There needs to be thought about links to other parts of WMO; and more broadly how will these Lighthouse Activities connect to global modelling centres who are likely to be needed to do the actual modelling work?
- We need to rethink the Lighthouse Activities titles, particularly “My Climate Risk."
- We need to clearly state what WCRP will do and what will be done with partners.
- We need to clearly outline the resources required and success criteria.

The next step will be to develop detailed proposals for each Lighthouse Activity, taking into consideration this and any subsequent feedback.

Annex 1 - Survey Questions

WCRP High-level Science Questions and Flagship Workshop Report

Thank you for taking the time to provide comments on the outcomes of this workshop. The deadline for comments is 11 May 2020. https://www.wcrp-climate.org/wcrp-hamburg/hamburg-report

1. Section 1

Contact details
Please fill in your contact details.

1. First name:

2. Last name:

3. Email address:

4. Position, Organization:

2. Section 2

We welcome your comments...

Please provide comments on the four Lighthouse Activities proposed by participants of the Hamburg Workshop (excluding the 'WCRP Academy', which has yet to be developed):

5. Explaining and Predicting Earth System Change

6. My Climate Risk

7. Safe Landing Climates

8. Digital Earths

3. Section 3

Any further comments?

9. Please provide any further comments (including any suggestions for other potential Lighthouse Activities that would advance WCRP's Mission):

Annex 2 - Acronyms

AGU	American Geophysical Union
AI	Artificial Intelligence
BGC	BioGeoChemistry
CMIP	Coupled Model Intercomparison Project (WCRP)
CORA	Coordination Office for Regional Activities (WCRP)
CORDEX	Coordinated Regional Climate Downscaling Experiment (WCRP)
COVID-19	Coronavirus Disease 2019
ECMWF	European Centre for Medium-Range Weather Forecasts
EGU	European Geosciences Union
ENSO	El Niño-Southern Oscillation
ESGF	Earth System Grid Federation
ESM	Earth System Model
GAW	Global Atmosphere Watch (WMO)
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems (GEO)
GEWEX	Global Energy and Water Exchanges (WCRP)
GFCS	Global Framework for Climate Services (WMO)
GHG	Greenhouse Gas
GOOS	Global Ocean Observing System
GSCU	Global Seasonal Climate Update
HPC	High Performance Computing
IOC	Intergovernmental Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change
ISC	International Science Council
JSC	Joint Scientific Committee
MJO	Madden–Julian Oscillation
NMHS	National Meteorological and Hydrological Services (WMO)
NWP	Numerical Weather Prediction
RB	Research Board (WMO)
RHP	Regional Hydroclimate Project (GEWEX)
S2S	Subseasonal-to-seasonal (S2S) Prediction Project (WCRP)
SDG	Sustainable Development Goal
SP	Strategic Plan (WCRP)
UN	United Nations
US	United States (of America)
WCRP	World Climate Research Programme (WMO-IOC-ISC)
WGSIP	Working Group on Subseasonal to Interdecadal Prediction (WCRP)
WMO	World Meteorological Organization
WWRP	World Weather Research Programme (WMO)

Annex 3 - ANDEX White Book Chapters

The following chapters of the ANDEX White Book have been published as peer-reviewed papers in a special issue of Frontiers in Earth Sciences entitled "Connecting Mountain Hydroclimate Through the American Cordilleras":

1. High Impact Weather Events in the Andes, German Poveda, Jhan Carlo Espinoza, Manuel D. Zuluaga, Silvina A Solman and Rene Garreaud. Accepted on 29 April 2020; Front. Earth Sci. doi: 10.3389/feart.2020.00162
2. Climatological and Hydrological Observations for the South American Andes: In situ Stations, Satellite, and Reanalysis Data Sets. Thomas Condom, Rodney Martínez, José Daniel Pabón, Felipe Costa, Luis Pineda, Juan Jose Nieto, Freddy López, and Marcos Villacis. Published on 09 April 2020; Front. Earth Sci. doi: 10.3389/feart.2020.00092
3. A review of the current state and recent changes of the Andean cryosphere. Mariano Masiokas, Antoine Rabatel, Andres Rivera, Lucas Ruiz, Pierre Pitte, Jorge Luis Ceballos, Gonzalo Barcaza, Alvaro Soruco, and Francisca Bown. Accepted on 20 March 2020; Front. Earth Sci. doi: 10.3389/feart.2020.00099
4. Hydroclimate of the Andes Part I: Main Climatic Features, Jhan Carlo Espinoza, René Garreaud, Germán Poveda, Paola A. Arias, Jorge Molina-Carpio, Mariano Masiokas, Maximiliano Viale, and Lucia Scaff. Published on 20 March 2020; Front. Earth Sci. doi: 10.3389/feart.2020.00064
5. Observed and Projected Hydroclimate Changes in the Andes, José Daniel Pabón-Caicedo, Paola A. Arias, Andrea F. Carril, Jhan Carlo Espinoza, Lluís Fita Borrel, Katerina Goubanova, Waldo Lavado-Casimiro, Mariano Masiokas, Silvina Solman, and Ricardo Villalba, Published on 17 March 2020; Front. Earth Sci. doi: 10.3389/feart.2020.00061
6. Hydroclimate of the Andes. Part II: Hydroclimate variability and sub-continental patterns, Paola A. Arias, Rene Garreaud, German Poveda, Jhan C. Espinoza, Jorge Molina-Carpio, Mariano Masiokas, Maximiliano Viale, Lucia Scaff (Under review).

The
World Climate Research Programme (WCRP)
facilitates analysis and prediction of Earth system change for use in a range of practical applications of direct relevance, benefit and value to society.