WCRP Climate Science Week

7-13 December 2019, San Francisco, USA

Key Messages for the WCRP Implementation Plan

The year 2020 marks the 40th anniversary of the World Climate Research Programme (WCRP. To celebrate this milestone and look to the future, the *WCRP Climate Science Week* was held as part of the American Geophysical Union (AGU) Fall Meeting in San Francisco, in December 2019.

The WCRP Climate Science Week included:

- A joint early-career researcher workshop (7 December 2019)
- The WCRP 40th Anniversary Symposium (8 December 2019)
- Four town halls, on each of the WCRP Strategic Objectives (9-12 December 2019)
- An AGU Union Session (13 December 2019)
- 40+ science sessions (9-13 December 2019)
- A WCRP exhibition booth (9-13 December 2019)

Full information on each event can be found on the WCRP website. An agency lunch was also held on Thursday 12 December.

Feedback on the implementation of the WCRP Strategic Plan

The four town halls, union session and agency lunch were all opportunities for the WCRP leadership to obtain feedback on the process of implementing the WCRP Strategic Plan. The key messages from each of the events are given below:

1. **Town Hall 1: Understanding the Climate System: Variability, Change, Dynamics, Reservoirs, and Flows (abstract)**

- Advancing our understanding of the Earth system is a slow process and this has to be accepted and defended.
- Closing the gap between process-oriented questions and climate (phenomenological) oriented questions is important.
- Pulling the community together for a large-scale field experiment to address a fundamental knowledge gap is something where WCRP could make a difference.

2. **Town Hall 2: Improved Prediction of Climate Systems on Timescales of Weeks to Decades (abstract)**

- Rapid progress in certain areas (S2S, decadal): predictability contribution from all sectors (earth components- including biogeochemistry and atmospheric composition, initialization/DA, ensemble generation, processing, etc.)
- Earth System models provide new opportunities to predict earth components besides the atmosphere (land, ocean, sea ice, biogeochemistry),
- Although developing adequate observational data for initialization and verification is a challenge that must be met in collaboration with the observation and reanalysis communities.
- Databases are at the core of intercomparison and progress (CMIP, S2S, CHFP)

- Hard issues: biases/systematic errors, precipitation etc. -> requires a concerted effort, e.g. Climate Process Teams
- Predictions systems, models: in support of services, attribution, observing system design, etc.
- Research priorities are somewhat scale dependent
- Because of finite resources, compromises must be made, eg. ensemble size vs resolution, and determining optimal choices will require drawing on community efforts and experience.
- Some regular surprises: e.g. S/N paradox needs to be cracked and is suggestive of key process(es) missing from models
- Multi-models: demonstrated benefit, although this could be explored more in depth (e.g. machine learning to determine optimal combinations)
- Common issues across time scales: WCRP could provide a framework for that
- Room for closer / organic collaboration between research and operations.

3. Town Hall 3: Evolution of the Long-Term Climate System: Responses, Feedback, Emergent Constraints, and Uncertainties (abstract)

Version 1

- Model accuracy is not improving fast enough and remains the key issue for forecasting on time scales from seasonal on up.
- Synergy/seamlessness between weather and climate forecasting is valuable—relates to models, but also objectives (protecting people). "Carbon weather," "ocean weather."
- Paleoclimate information is crucial for testing our understanding of very different climates, and more/better information would make it much more powerful.
- There is a need for coordination across communities (data, models, approaches)—CMIP is a useful paradigm / example within the modeling community, but we need to think beyond MIPs.
- We need to design and lobby for a better global observing system particularly of the atmosphere and land surface, coordinating the community to determine what would have greatest scientific value.
- Some uncertainties will not be resolved anytime soon, and we need to find ways to contextualize and communicate these to the public and to stakeholders.

Version 2

- Different research communities deal with data differently. There needs to be yet further coordination to facilitate comparing data from all types of observations and models.
- Early and mid-career scientists should be encouraged to do something other than MIPs.
- Systematic errors in climate modeling are not disappearing. There needs to be Big Science programs targeted at these, including relevant observational programs. The process understanding gained is very important.
- Developing nations need to be at the table in initiating, maintaining and producing Big Science programs.
- We are getting overwhelmed with data; there are computational constraints hindering analyses. Machine learning (big data, artificial intelligence) can help.
- We need a program to compute "carbon weather".
- Completing the global array of BGC-Argo floats is vital for measuring and understanding an array of important ocean-weather-climate processes.
- We don't need (and can't provide) a perfect forecast; we need to provide uncertainties in a smarter way.

- Understanding climate in regions requires knowing how to represent the scale interactions important for determining evolution of regional response to climate change.
- There has been a huge benefit from MIPs, but the community needs to determine how many MIPs can be supported.
- Paleo climate can tell us a lot about full-equilibrated conditions, but is complicated by incomplete data, poor assumptions, background state dependent changes.

4. Town Hall 4: Bridging Science and Society: Decision-Relevant Information About the Evolving Climate System (abstract)

- Climate services are the timely production, translation, transfer and use of actionable climate information and knowledge for the general society (Figure 1). The Town Hall was structured around these pillars.
- It is essential to start with a conversation around societal demand, and not with what the scientist thinks is needed (e.g. a "research question"). In order to co-design a climate service, involve the end-user at the very beginning of the process – and keep the user involved! This way the user also knows what is possible from a scientific perspective and the scientist understands user needs throughout. A two-way conversation is necessary along the entire climate service process.
- In order to guarantee long-term sustainability of climate knowledge, we need to educate the next generation, from high school kids and upwards, and have continued and dedicated funding. Translation is probably the most difficult step to achieve when bridging climate science and society – education is essential to achieve it.
- The information provided has to be fit for the users' purposes. There is no one overarching solution for all the user demands.
- Always provide information about uncertainties, for example via probabilistic information or error bars in deterministic forecasts. Produce probabilistic flexible forecasts, i.e., probabilistic forecasts for all thresholds of interest to the end user (as opposed to only the more traditional approach based on above-normal, normal and below-normal categories).
- Natural and human impacts are complex and specific to region and timescales. Hence, it is always necessary to provide context along with the climate information. For example, discuss historical and present behavior of a variable before talking about predictions.
- Users generally require information at multiple timescales: from hours to days to weeks, seasons, years, decades and long-term climate change scales. (IRI's Ready-Set-Go approach).
- Involve the private sector in the sustainability of climate services.

5. Union Session: Climate Research for the 21st Century: From Challenges and Opportunities to Implementation (abstract)

Guy Brasseur's posed questions:
- How sensitive is climate to GHG emissions and how does this link to Paris targets?
- How can we better manage the effects of climate variability and short-term changes?
- What will be the consequences of a warming larger than required by Paris agreement? (3,5,7 degrees C?)

The path forward:
1. WCRP must remain at intellectual forefront
2. Science research has to support society
3. We need knowledge that goes beyond physical climate
4. Open and citizen science

Observations

- Data must support fundamental understanding of the climate, forecasting and long-term projection
- Key areas identified for further cooperation:
  - Energy, water and carbon cycles
  - Observations for vulnerability, impacts and adaption
  - How do observational improvements impact modelling and understanding
- Collaborations between WCRP and other international projects are needed for a sustained global climate observing system

Understanding

- A new imperative is to include the role of the biosphere in the hydrosphere
- Are there tipping points in the climate system?
- We need to be tactical and strategic, joined up and connected.
- Future needs include capacity building, responding to new technology, education, new thinking, integrated modelling, recruiting students and building collaborations in engineering, big data, AI, social sciences, etc.

Modelling

- WCRP is uniquely positioned to provide the framework for international coordination of Earth system modeling:
  - process understanding
  - improving models
  - prediction: weather—subseasonal—seasonal—decadal—century
  - global to regional

Assessing

- Climate and Earth system models will play an increasingly important role
- We need to manage user expectations and recognize current limitations and realities
- We need to look at accuracy versus precision e.g. high accuracy vs low precision

Detlef and Helen

- We are moving towards impacts and solutions.
- Observing systems remain fundamentally important, alongside climate models
- People are at the core of WCRP and are central to achieving our goals.
- Partnerships and networks are key
- How do we provide rapid assessments and updates?
- We need to focus on questions that impact society, not just in the future but right now.

6. Agency Lunch: The aim of this event was to bring together key strategic funding partners and to seek initial advice, guidance and input to the development of a new WCRP Implementation Plan and funding.

- We need to ensure we have targeted outcomes in mind
- We need targeted observations and process understanding to address systematic errors
- We need to consider the value of the WCRP enterprise to stakeholders
- We need to focus on issues that require international cooperation
- We need to prioritize and not try and do everything
- We need to work closely with partners and focus on key issues.
- Open access is important

- We need to ensure we consider regional needs and how to build capacity
- It is important to co-fund, co-design and co-implement - but not all projects require this approach.
- We need to think about how we focus and brand WCRP and our activities

Appendix 1: Notes from the WCRP Town Hall 1

TH15G - World Climate Research Programme:
Understanding the Climate System: Variability, Change, Dynamics, Reservoirs, and Flows
Monday, 9 December 2019
18:15 - 19:45
Moscone West - 2002, L2

Abstract

The World Climate Research Programme (WCRP) invites you to discuss progress and new challenges in fundamental understanding of processes in the Earth system, including their temporal and spatial variations and changes under climate change. The discussion will focus on the physical, biological and chemical processes which drive the couplings between various components of the Earth system.

In this Town Hall, we will highlight the coupling processes which are less well understood or where our assumptions could have the strongest impact on our ability to observe and model the Earth system. Our scientific emphases are on 1) improving our understanding of the drivers, interactions, and feedbacks that lead to global and regional changes in oceanic and atmospheric circulations and 2) quantifying the reservoirs and flows of energy, water, carbon, and other climate-relevant compounds.

Our goal is to determine regions of the world where specific sets of processes and interactions are dominant and where joint efforts by the WCRP community as a whole could accelerate progress in better explaining past evolutions of the climate system and to anticipate future climate variations. This discussion should help us to also identify the scientific strategy, and observational and modeling efforts, needed to bring about new knowledge.

Conveners:
Pascale Bracconot (LSCE Laboratoire des Sciences du Climat et de l'Environnement)
J F Lamarque (NCAR)
Judith Perlwitz (NOAA)
Jan Polcher (CNRS/IPSL)

Presenters:
Helen Cleugh (Introduction)
CSIRO Climate Science Centre
Pascale Bracconot (Introduction, moderation)
LSCE Laboratoire des Sciences du Climat et de l'Environnement
Martyn P Clark (Panel)
University of Saskatchewan Coldwater Laboratory
Graeme L Stephens (Panel)
NASA Jet Propulsion Laboratory
Neil Richard Peter Harris (Panel)
Cranfield University
Wenju Cai (Unable to attend)
Centre for Southern Hemisphere Oceans Research (CSHOR), CSIRO Oceans and Atmosphere
Josef Aschbacher (Panel) (had to leave early, replaced by Jerome Benveniste)
European Space Agency (ESA-ESRIN)
Paul J Valdes (Panel)

University of Bristol

Notes

Introduction

Pascale and Jan introduced the Town Halls.

Helen gave an overview presentation including the WMO provisional 2019 State of the Climate and Global Carbon Budget 2019. She gave an example of the Australian continent warming due to climate change and climate variability, including bushfire emergencies, dust storms etc. These are the kind of risks that require WCRP science.

Panel Discussion

The panel was introduced and asked to give their thoughts on three overarching questions outlined below. After this the floor (and sli.do) were opened to questions.

1. What are the critical knowledge gaps in our understanding of the Earth System?

Josef, ESA: A good understanding of the *energy cycle* (e.g. ESA Explorer) and *energy balance*. The *water cycle* is another. *Ground water* is a challenging aspect of this as are *land surface processes*, especially for *urban regions*.

Graham, GEWEX: The critical knowledge gaps have been the same for many years. Big questions take a while to answer. *Water, energy and coupling to the rest of the system, in particular carbon*. The *role of aerosols in such couplings*. For example, *how do aerosols affect the hydrological cycle*.

Neil, SPARC: I would ask whether we can we do fundamental research on a shorter timescale? WCRP has not done much on the *composition of the atmosphere*. Perhaps WCRP and others need to put together a coherent programme focused on *key forcing agents*. *Changing OH over time* for example is still not well understood. *DMS… emissions and deposition*. We are getting better in understanding the connections and teleconnections. *How will these teleconnections change in the future*? How broadly should we discuss the climate system? *How is this linking into the human system*? It needs to be done with partners.

Martin, Hydro: The *representation of the human component on the terrestrial water cycle* is not good in models at all. Some models still have weak theoretical underpinnings in hydrology. There is limited effort in simulating slowly evolving systems. We need more *model parametrizations and analysis*.

Paul, Past Climates: The *impact of aerosols on the climate system* needs a lot more effort. the idea of *abrupt climates (tipping points*) is an important aspect. There is a lot of evidence on this in the past. Temp, CO2 etc.

2. Which are the most effective tools to gain process or phenomenon understanding of the Earth system?

Graham: GEWEX has proposed to close the energy balance of the planet. *Model convergence needs to be improved*. We have systematic bias in models. These affect climate sensitivity. From an observational perspective, global observations are fundamental

and evolving but we need to ensure they cover the dynamical aspects better. WCRP used to focus around big programmes such as TOGA, WOCE etc. *perhaps we need to think of some new world field programmes*?

Paul: Observations are central. Ensuring connections between process-based models and GCMs doesn't happen as much as we might like. We need to think about coupling in much more detail. E.g. iceberg fluxes impacting iron flux into ocean.

3. How will our process and phenomenon understanding evolve in interaction with other disciplines?

Martin, hydro: Land models require input across communities. We have a lot of modelling silos…we *need to enable interoperability and sharing of codes etc. More community modelling*.

Discussion:

Q: Peter VdO: Is there any new message that we can convey?

Graham: Some of these challenges have been with us for decades. The challenge we have is to how to do this in a fresh way.
Neil: It is an urgency question. We already have data sets and model output that we are not fully utilizing.
Martin: I don't think they are all old questions e.g. *will the Arctic be a net source or sink of carbon*.

Q: Marta K: If politicians gave you a lot of money to help e.g. avoid disasters. What would you focus on?

Graeme: *Climate and weather extremes*. More computing, for example, would get us closer to reality. Observational strategies.
Paul: *Risk and uncertainty. High impact, low probability* events, for example. This requires a multidisciplinary approach.
Neil: Aerosols and how by controlling emissions we can make gains.

Q: Walt: Is the fact that e.g. we don't always predict hurricane systems because (a) we are too cautious, or (b) because we have imperfect understanding?

Martin: We need to focus the modelling community to answer these questions. Also getting back to the basics.
Paul: It is also about communication. We need to engage with users.

Q: Krishnan. There are biases in our models for monsoons. How do we translate new scientific understanding into models?

Graham: *Model biases are a big issue*. We should focus on particular issues and try to solve them.
Martin: Sometimes these biases are extremely difficult to solve! The power of the World Climate Research Programme. We *need a new WOCE or TOGA*.

Q: Slido: Are our observations accurate enough to address hypotheses?

Graham: It depends, but we need to focus on this e.g. satellite data products.

Q: Pascale. We don't see "where will we be in 10 years?" Are we getting too complex?

Neil: It is a complex problem, but we should be looking at *how to reduce uncertainty*.

Q, slido: Are there funding opportunities for these "slower" studies that might not be relevant to society in the short term?

Neil: A really good idea could make a difference.
Martin: We need to identify intermediate gains.

Q, SPARC: For Question 3 need to look at social sciences, the history of sciences...

Martin: I agree, we could for example look at how well scientific approaches have evolved over time.

Q, Detlef: We are talking to the community. We are not talking about 5-year scales, we need to look much longer. TOGA and WOCE came about in decades.

Neil: when TOGA started you could wait much longer, but now we have to look at shorter timescales.

Q, slido: Do we know enough to allow geoengineering to go ahead?

All said "no" except ESA (Jerome Benveniste) who answered that it's a step by step process.

Appendix 2: Notes from the WCRP Town Hall 2

TH25F - World Climate Research Programme:
Improved Prediction of Climate Systems on Timescales of Weeks to Decades
Tuesday, 10 December 2019
18:15 - 19:45
Moscone West - 2002, L2

Abstract

The World Climate Research Programme (WCRP) invites you to discuss the latest progress and new challenges in climate prediction on time scales of weeks to several decades. A specific focus will be on evolving risks of extremes within a changing climate. Climate variability will continue to challenge our preparedness and resilience to high impact weather and climate extremes, and skillful and reliable climate predictions offer significant opportunities to manage these risks. The development of next-generation operational systems to predict regional impacts at ever greater lead times will require fundamental research into sources of predictability including important scale interactions and nonlinearities along with their representation in models, and innovations in model-data fusion including coupled data assimilation. Merging predictions with longer-term projections is an important challenge toward seamless climate information.

In this Town Hall, we will discuss avenues for advancing climate prediction science and services. These include (i) determining limits of predictability and the relative roles of initial conditions and forcing, (ii) assessing the capacities of operational prediction systems to approach those limits, (iii) quantifying uncertainties, and (iv) effectively formulating and communicating forecast information. We will discuss the ability of prediction systems to represent key processes, and to predict risks of extreme events including unprecedented extremes and crossing of thresholds in vulnerable regions. Challenges spanning prediction across different Earth system components will be explored, as will implications of a non-stationary climate for the occurrence of “fast” extremes such as hurricanes, and “slow” extremes such as droughts.

Conveners:
Gabriele C Hegerl (University of Edinburgh)
William J Merryfield (Canadian Centre for Climate Modelling and Analysis)
Rym Msadek (CNRS/CERFACS)
Stephen G Yeager (NCAR, Oceanography)

Presenters:
William J Merryfield
Canadian Centre for Climate Modelling and Analysis
Rym Msadek
CNRS/CERFACS
Stephen G Yeager
NCAR, Oceanography
Cecilia M Bitz
University of Washington
Ben P Kirtman
University of Miami
Nicole S Lovenduski
University of Colorado
Andrew William Robertson

International Research Institute for Climate and Society, Columbia University
Doug M Smith
Met Office Hadley Centre

Notes

Bill Merryfield introduced the Town Hall in the context of the WCRP Climate Science Week and Goal 2 of the new WCRP Strategic Plan and its emphasis on extremes and prediction capabilities. He then also noted the role of WGSIP (including S2S and DCPP) in coordinating prediction research across the range of timescales and the Grand Challenge on Near-Term Climate Prediction.

Bill presented a list of nine Key Research Questions to stimulate contributions from the audience.

Andy Robertson

- Presented S2S, objectives, forecast skill from weeks to season, rapid progress on MJO skill, challenges in seasonal prediction of precipitation (e.g. no progress on the IRI ones over the last decades)
- Phase II: science (predictability from land, ocean, stratosphere, aerosols MJO and teleconnections, ensembles), users and service (verification, R-O, pilots), database at the core
- Broad cooperation with many WCRP groups
- MJO teleconnections are still a challenge
- Highlight: real-time pilots building on real-time release of forecast to get people 's interest
- Andy provided his view on where S2S could fit in the conceptual framework
- Challenges: skill on precipitation, systematic errors (e.g Western Boundary Currents), ensemble generation, …
- Opportunities: seamless across communities and users, lots of science DA, ensembles, aerosols, stratosphere, coupled initialization

Anca: highlighted the benefit of multi-models
Andy: there is some indication that a 3-member ensemble outperforms single models

Detlef: What is the role of S2S in services? (cf goal 4 of SP)
Andy: the role of the pilot is to move in that direction.

Doug Smith

- The good news is that there is more skill than we thought
- The bad news is that there are still major problems in models (huge uncertainty if models are taken at face value)
- The ensemble mean is highly correlated with observations, and should explain 69% of observed variability
- The magnitude of the ensemble mean is inconsistent with correlation
- Forecasts have a high amount of variability but proportion of …?
- We need a very large ensemble to extract the signal
- RPC> in many regions
- Especially in precipitation and pressure

The worry is that probability and errors based on skill measurements will give inaccurate estimates. This can be improved by stochastic physics BUT could exacerbate the problem
Event attribution will give inaccurate estimates of the probability of extremes.

Skillful climate forecasts are now possible for NAO on S2D timescales.
Resolving this paradox could reduce ensemble size.

Decadal predictions: benefit from initialization but dominated by overall trend.

Initialized predictions capture some of the variability but.. ?

There is significant skill using large ensembles.
Initializations can improve the response to forcing.

Arun: NAO forecast, 7-8 years smoothing, 3 deg of freedom
Doug: Bootstrapping to prove statistical signal

Bill: Major model improvements
Doug: Eddy feedback but cannot afford to run it at high resolution

Masahide: The signal/noise problem should be a strong be a focus in WCRP
Doug: The signal/noise paradox has different expression/location depending on time scale (tropics vs extra tropics, NAO, etc.)

Pavel: That there is little benefit from initialization is bad news. Do you have any recommendations?

Doug: There is clear improvement from initializing (eg IPCC AR5 slide), but uninitialized runs have surprisingly a lot of skill (the surprise!). The bad news is more optimistic as long as we apply right treatment.

Cecilia Bitz

- Sea ice: source of predictability, lots of research
- Extent, Cover, thickness (highly predictable)
- Sea-ice: different than other quantities (it is present OR not)
- How to present results (eg extent) -> social experiment, lots of excitement, ultimately has motivated people to improve forecasts
- Lot of sea-ice models are not initialized

Ben

What I am worried about lately:

- Resolution vs complexity vs ensemble size vs diversity: community effort can address these
- Model bias: very slow progress
- Data driven science: machine learning, potential disruptor, could take advantage of this new technology
- OSE and OSSEs: optimize observing systems, how can we decide where and what to observe (but we do not trust our models)
- Credibility problem: example of ocean current shown

Nikki

- There is some potential in prediction of biogeochemistry on interannual scales
- Variables: phytoplankton, ocean acidity, air-sea and terrestrial carbon fluxes: all bring predictability for various reasons
- Opportunities: fisheries CO2 emissions, science, observing network design
- Verification: lack of observations
- Predictability: physical vs bio-geochemical
- Modeling center: convince them to add bio-geochemistry tracers

Discussion:

Q: Martin: Why such a focus on decadal prediction? Isn't the entire envelope important as well?
Doug: Hindcasts can also help to manage risk (capturing the envelope)

Q: What key processes are needed to improve prediction?
Nikki: Eddies in ocean models
Andy: Land-atmosphere coupling and how to initialize land
Doug: S/N rational, need to get that right
Ben/Cecilia: Long standing biases, need to correct them (but usually we only correct them after the fact)

Q: What observations are needed?
Andy: Soil moisture/snow cover for S2S

Q: Bias - Machine learning to correct biases, how risky could this be?
Andy: It is ok to try but we need to benchmark and check added value.
Ben: We need to use 1st principles.

Pavel: NWP and extend, climate models for weather runs, bring strengths of both together, where is the meeting point?
Ben: this approach exists already.

Detlef: Not just about S/N, bias etc. If we put more effort into modelling, where?

Ben: We also need to understand
NOAA Climate process teams: bring observations, models, etc. together
Identify the problem and put resources there.
WCRP to play that role.

Andy: CMIP and S2S archive: maybe look at both to identify some solutions.

Martin: The role prediction can play in attribution.

Cecilia: We need modeling to test hypotheses.

Doug: lots of work on this.

Gokhan: Biases in models, poses an issue for the attribution approach and credibility
CPT: there was an idea to have broader international level CPT groups

Helen: Attribution is related to carbon and the global stocktake. What is WCRP's role?

Niki: ESM models

Lars: Sea ice can be predicted from Atlantic inflow, e.g for fisheries.
It's important also to identify what is important not to do (e.g. simple models sometime work very well if we understand processes well).

Cecilia: It depends on the question.

Jerry:
Surprises: bio-geochemistry was more predictable.
More relevance on near term problems: this has implications for CPU resources.
The complexity question has overwhelmed the resolution question (aerosols, etc.)
There are three communities facing some common issues: could define some common work, where WCRP can provide a framework.

Nikki: The amount of simulation data, we will need to worry about.

Andy: Regional CORA could bring to bear info from different time scales.
Cecilia: It is hard for research groups to produce operational forecasts: we need to integrate research.

Doug: Skill from external forcing on decadal forecasts.

Appendix 3: Notes from the WCRP Town Hall 3

TH33E - World Climate Research Programme: Evolution of the Long-Term Climate System: Responses, Feedback, Emergent Constraints, and Uncertainties
Wednesday, 11 December 2019
12:30 - 13:30
Moscone West - 3005, L3

Abstract

The World Climate Research Programme (WCRP) invites you to discuss the latest progress and new challenges in simulation capabilities in order to assess the response of the climate system to natural and anthropogenic forcings, feedback mechanisms and emergent constraints across Earth System components on multidecadal time scales from global to regional scales.

In this Town Hall, we will discuss the requirements of future climate projections, including the limits of prediction and associated uncertainties at different spatial scales and time windows. We will discuss non-linear processes and internal variability, and system sensitivities to imposed forcing, such as fossil-fuel emissions, land use change, volcanic eruptions, solar variability, and geo-engineering, which can inform climate change projections and scenarios. We will also discuss developing ideas on emergent constraints and how to reduce uncertainty in model projections and climate sensitivity. Important issues also include interactions among climate, the land, ocean, ice and carbon reservoirs; and the local and regional expressions of global change, as addressed for example by downscaling approaches.

Conveners:
Wenju Cai (Centre for Southern Hemisphere Oceans Research (CSHOR), CSIRO Oceans and Atmosphere)
William J Gutowski (Iowa State University)
Carolyn A. Reynolds (US Naval Research Laboratory)
Steven C Sherwood (University of New South Wales)

Presenters:
Eelco Johan Rohling
Australian National University
Reto Knutti
ETH Swiss Federal Institute of Technology Zurich
L. Ruby Leung
Pacific Northwest National Laboratory
Joellen L Russell
University of Arizona

Notes

Eelco Rohling: Climate feedbacks over geological timescales

- Multiple feedbacks:
  - Fast feedbacks typically included in equilibrium climate sensitivity (over 100-200y timescales, needed for surface ocean warming.
  - Geological record shows total response to all
  - “Correction” needed from total response to ECS.
- Alternative approach to classical approach (Martinez-Boti et al., 2015 Nature).

- Opportunities:
  - Paleo data only real-word data for significantly warmer climate
  - Model-data integration can address key uncertainties in past and future warm states
  - Real-world illustration of state dependence can be sought
  - Can look at cold vs warm state dependence of climate sensitivity
- Challenges
  - Representative global mean temps
  - Feedback efficacies
  - Land-ice: temp relationship changes through time
  - Non-CO2 greenhouse gas concentrations
  - Vegetation albedo
  - Aerosol feedbacks
  - Cloud feedbacks
- Conclusions
  - Paleo climate can tell us a lot about full-equilibrated conditions, but is complicated by incomplete data, poor assumptions, background state dependent changes.

Reto Knutti:

- Global climate models are cornerstones for IPCC
- WCRP crucial coordination point (e.g., CMIP)
- MIPS map well onto grand challenges
- If all you have is the next version of your GCM, then projections will look the same (uncertainties not decreasing).
- Models are getting better, but range remains (10% improvement with each model generation).
- Patterns of biases persist (e.g., precipitation biases).
- Climate model genealogy (family tree) show interconnectedness of models.
- Wide range of projected changes persist (all equally realistic?)
- Arguments for high-res, large ensembles, risk assessments
- Conclusions:
  - Huge benefit from MIPS
  - Models improving but projection spread remains
  - Ensembles of opportunity can be difficult to interpret
  - Storylines and risk perspectives, complementary high-resolution models?
  - Earth system models? Complexity and types of models for different MIPS
  - Number of MIPS that can be supported?
  - Timeline of MIPS and IPCC
  - Data availability and processing?
  - Funding and continuity

Ruby Leung:

- Downscaling regime (large-scale changes impact regional response, but also need regional forcing changes), but regional response doesn't have big impact on large scale.
- E.g., orographic-enhanced AR precipitation and snowpack / run-off impacts.
- Scale interaction regime: fine scale processes and large-scale changes impact regional response (difficult to predict).
- Mesoscale convective systems with top-heavy heating profile, can generate impacts on large-scale impacts that in turn impact storms.
- Gaps and opportunities
  - Regional response
    - Global and regional storm resolving modeling

        - Unstructured meshes
        - Observations to support
    - Scale interaction region, need to represent interactions important for determining evolution of regional response
    - Need to address uncertainties (e.g. though ensembles).

Joellen Russell:

- Carbon and biogeochemical cycles
- Global warming is ocean warming
- Emphasizes "seamlessness" between weather and climate models (e.g., FV3)
- Southern Ocean
    - Accounts for 67-98% of excess heat that is transferred from atmosphere into ocean each year.
    - Up to half of annual oceanic uptake of anthropogenic carbon
    - Window to deep ocean, only place with direct upwelling.
    - Problems with wind stress simulations
    - SOCCOM floats around drake passage
    - Biogeochemical ARGO lots of data
    - Want to reduce uncertainties in ocean sinks
- Next steps
    - Finish build out of global array of BGC-Argo floats
    - Get Zephyr up to calculate "carbon weather"
    - Show top 10 economies their monthly carbon "bill".

Discussion:

Q: Augment regional dynamical climate modeling with statistical regional climate modeling
RL: Could be very useful for uncertainty
Hendrick Tollman happy to see seamlessness highlighted

Q: Where are coordination opportunities?
ER: Assimilation of info has to be done through models, bring in DA and look
RK: what can we say from paleo record, satellite record. Issue is that different communities deal with data differently. Need coordination in data. Also brings up computing constraints.

Q: Really hard to interpret more complete models
RL: Regional response, community should come together with putting data sets together for different regions. Need coordinated effort to make it easier to compare model output. Encourage early and mid-career scientists to do something different (other than MIPS).
JR: Not organized enough for our own decadal survey. Computational resources needed.

Slido questions:

Q: How can WCRP help reduce uncertainties or learn to live with uncertainties?
RK: What can we do with info that we have? Don't need a perfect forecast, how can we provide uncertainties in a smarter way.
RL: Uncertainty should be put in context of state holders
JR: Not thinking big enough
Hendrick Tollman: From weather side, Big Data and AI helpful under computational constraints.
ER: Lots of ML being applied to paleo data suites (let ML find lagged relationships) in paleo climate

Wayne Higgins: From NOAA perspective. Need Big Science (e.g., seasonal forecasts not getting better for precip). Why? Systematic errors. Targeted observations to help, and process understanding. Need process understanding and less engineering. Process understanding really important.

Not sure about person asking question: Best practices about communicating results.
JR: don't hesitate to talk to the public about the good and bad, also understanding local concerns. Need to train and encourage involvement from diverse communities.

From S. Africa: Where is developing nation science? Big science can entrain developing nation scientists.
Chuck from Electric Power: Ocean observations and analysis, need more than 10 years to capture important ocean variability. Need 30 year or 50 years of ocean observations.
ER: 10 years better than nothing, if you ask for more, politicians may say no. Start project than stop lobbying for longer programs.
Detlef Stammer: 40th Anniversary, strategic plan will be updated.

Appendix 4: Notes from the WCRP Town Hall 4

TH45E - World Climate Research Programme: Bridging Science and Society: Decision-Relevant Information About the Evolving Climate System
Thursday, 12 December 2019
18:15 - 19:45
Moscone West - 2002, L2

Abstract

The World Climate Research Programme (WCRP), together with partners, invites you to review progress and discuss emerging challenges in climate-society interactions and in generating decision-relevant climate information and knowledge in support of policy and services. Climate science is generating a wealth of data from observations all over the globe and model output that requires distillation into information, knowledge and practical advice. The transfer of uncertainties along the generation process, including socio-economic elements, is very complex but a necessary condition to make informed decisions and manage risk about our Earth system.

In this Town Hall, we will discuss some innovative approaches providing avenues to sort through this vast amount of information, reconcile and explain outcomes, and extract useful knowledge. We will explore pathways to produce climate services, accurate scientific assessments and public communication strategies, all of which require collaborative efforts with civil society, governments and private industry. We will also discuss how the scientific community can take a more active role in the climate transition, for instance by developing tools and know-how for virtual conferences.
The session will focus on existing examples of good practice within advice for policy, use of updated climate data in education, and general outreach from ongoing research projects to citizens using social media.

Conveners:
Lisa Alexander
University of New South Wales
Angel Munoz
International Research Institute for Climate and Society, Columbia University
Sonia I Seneviratne
ETH Zurich
Lars Henrik Smedsrud
Geophysical Institute, University of Bergen and Bjerknes Centre for Climate Research

Presenters:
Claudia Tebaldi
Joint Global Change Research Institute
Julie Johnson
Tres Sabores
Teresa Sprague
Woodard & Curran
Morven Muilwijk
Geophysical Institute, University of Bergen and Bjerknes Centre for Climate Research

Notes

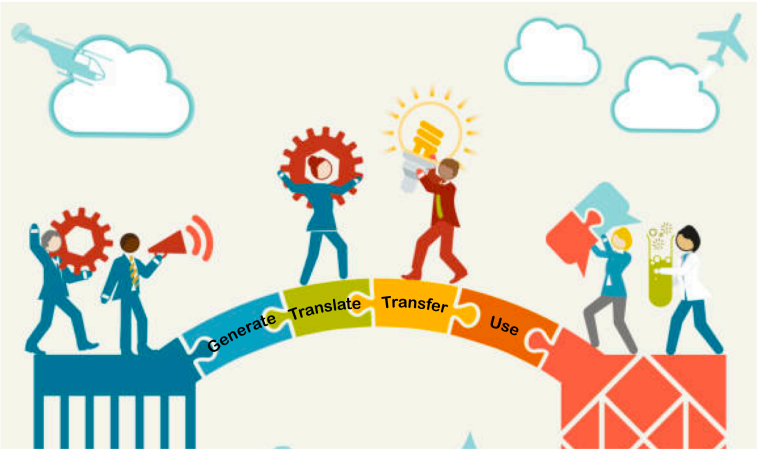

Figure 1. Bridging climate and society with climate services.

The following are notes taken by Mike Sparrow

Introduction by Ángel. Started with poll "what words come to mind when you think about how to bridge science and society"…outcomes included "communication" "listening " "equity" "citizen science " "transparency" "outreach" "respect" "simplify" "listening" etc.

Speakers:

1. Julie:
Wine growing conditions: warm and dry (before 1980). Broad range of wine grapes etc. After 1980 warm and wet. Several impacts such as the need to spray more to keep pests at bay, fire events etc. Imperative to engage with climate scientists.

2. Claudia:
Hazards are sector and region specific. We need to translate trends and changes in extremes into metrics relevant to impacts on human and natural systems, e.g. heat extremes for human health, energy production and agriculture.
Aiding real world decisions is difficult: local scales, multiple connected drivers, precision requirements vs. accuracy, reliability, robustness and uncertainty characterization; predictability limits – need for scenario approaches.
Many areas of research are motivated and/or stimulated by users' needs

- Model evaluation and development over new metrics/quantities and phenomena (extremes, small scales, etc.);
- Bias Correction;
- Ensemble construction and interpretation;
- Model weighting;
- Probabilistic projections;
- Detection and Attribution/ Event Attribution;
- Scenario construction, storyline approaches;
- Data collection, curation, standardization, sharing; reproducibility.

3. Teresa:
From data to decisions (and back): Questions and framing for successful translation.

“Important questions and framing” – problem framing, how to connect, agreement on purpose and expectations.

4. Morven:
How can we as scientists contribute to educating the next generation?

Discussion:

Q: Pavel: There is a gap between WCRP and expectations from users? What is a sensible bridge between what folk need and what WCRP can provide?

Julie: We need scheme for sharing and accessing data.
Teresa: Climate change analysis and assessments. Examples of how to use a climate change analysis for a local plan.

Q: Slido: How to engage scientists who think outreach is not their business?

Morven: Not everyone is interested in doing outreach. More important to support those who want to. More emphasis and incentives.

Q: Jose: In the four Strategic Objectives of WCRP this is the most difficult to achieve. Not all need to do outreach, but all should care.

Teresa: The importance of engaging with users!

Q: Slido: What should research funding agencies and research institutions do to encourage scientists to engage more regularly in outreach?

Q: Jens: How can the nice examples from these talks be elevated to consideration by WCRP?

Morven: Need support and funds to do these things.

Julie: Users also need to be prepared to engage and make themselves available.

Comment: If one of our goals is to get information from scientists to users we need “business intelligence” …systems that pull out key metrics etc.

Q: Detlef: Do you actually need WCRP? Strategic Objective 4 is broader than outreach. What are your expectations from WCRP?

Julie: Standard tools are required.

Claudia: Need to improve “attitudes” to be more committed to interdisciplinarity, social sciences, collaborations beyond physical climate system.

Angel gave a short final talk: Climate Services - need services across timescale i.e. seamless approach. Interaction with social sciences. Main outcomes were listed in a final word cloud…. "hope," "co-design, " "co-production," "inclusion" etc.

Appendix 5: Notes from the WCRP Union Session

U52A - World Climate Research Programme: Climate Research for the 21st Century: From Challenges and Opportunities to Implementation
Friday, 13 December 2019
10:20 - 12:20
Moscone South - 303-304, L3

Since its inception 40 years ago, the World Climate Research Programme (WCRP) has played a unique role in facilitating the analysis and prediction of the Earth system variability and change with its mission to determine to what extent climate can be predicted and the extent of human influence on climate. Climate science has evolved substantially since then, through advances in fundamental science and innovation in observations and simulations. Everything from satellites to supercomputers have revolutionized our understanding and prediction of the climate with ever-increasing skill. Climate science now engages many different disciplines towards an integrated Earth system approach.

During the session past successes and open question of the WCRP will be summarized, and new WCRP science direction will be presented together with first thoughts on how to structure WCRP in support of future science challenges. The audience will also be engaged in a dialogue about the future WCPR structure.

Conveners:
Detlef Stammer
University of Hamburg
Pavel Kabat
World Meteorological Organization
Chairs
Rixen Michel
World Meteorological Organization
Detlef Stammer
University of Hamburg

Abstracts:
10:20 Introductory Remarks
10:22 Summary of past successes and lessons learned (Invited) Guy P Brasseur, National Center for Atmospheric Research, Boulder, United States
10:47 The world climate research for the next decade: strategy, opportunities and challenges (Invited)Detlef Stammer, University of Hamburg, Hamburg, Germany
Helen Cleugh, CSIRO Climate Science Centre, Canberra, Australia
11:37 The world climate research for the next decade: community engagement and implementation in partnerships (Invited)Pavel Kabat, World Meteorological Organization, Geneva, Switzerland
11:42 Panel Discussion (Invited)
12:18 Concluding Remarks

Notes

Guy Brasseur
- WCRP lays out the foundation for many agreements such as Paris agreement.
- However, emissions of greenhouse gases continue to increase.

- The role of science knowledge in political process; science questions regarding long term evolution of climate system remain open as do a number of science questions in the short term.
- What are the questions that remain to be addressed and what is the role of WCRP?
  - How sensitive is climate to GHG emissions and how does this link to Paris targets?
  - How can we better manage the effects of climate variability and short-term changes?
  - What will be the consequences of a warming larger than required by Paris agreement? (3,5,7 degrees C?)
- Science must be liberated from addressing topics that are already understood…predictability of climate variability across scales, physical processes that determine sensitivity. Role of interactions and feedbacks, tipping points, regional and extreme manifestations of climate change
- Climate change is a global problem, but the solutions required integrate information and the regional and local scales…
- The path forward: 1. WCRP must remain at intellectual forefront 2. Science research has to support society 3. Need knowledge that goes beyond physical climate 4. Open and citizen science…

WCRP: Partnerships – Observations

- Partnerships for observations include IHP, PAGES, GCOS, CEOS, GOOS, GAW etc.
- GCOS: WCRP and GCOS have the joint panels AOPC, OOPC, TOPC
- Data must support understanding of climate, must support forecasting and long-term projection.
- Energy, water and carbon cycle, observations for variability, impacts and adaptation:
  - WCRP and WG on Climate
  - WCRP and GOOS
  - WCRP and PAGES
  - Future WCRP partnerships-observations. Requires coordinated communications of observation needs to space agencies and in situ networks and taking into account ECVs.

iLEAPS

- The role of the biosphere in the climate system. Includes SOLAS, AIMES, IGAC, PAGES, GCP, etc.
- New imperative to include the role of the biosphere in the hydrosphere
- Are there tipping points in the climate system?
- Need to be tactical and strategic, joined up and connected (some examples e.g. GEWEX working with iLEAPS)
- Future needs: Capacity building, respond to new technology, education, integrated modelling, recruit students and build collaborations in engineering, big data, AI, social sciences, etc.

Modelling (Jerry Meehl)

- Process understanding, improving models, prediction, global to regional….
- Process Understanding: CMIP and MIPs
- Improving models: WGNE
- Prediction with partners such as WWRP -weather-subseasonal-seasonal-decade-century
- Global to regional: e.g. CORDEX

Pavel Kabat

- Climate and Earth system models will play an increasingly important role
- Users expectations vs current limitations/realities
- Accuracy versus precision e.g. high accuracy vs low precision….
- Three key parameterizations can be eliminated from climate models by going down to 1 km (deep convection etc.). So if 1 km so important, why are we not doing it? Needs human and computational resources.

Belmont Forum (Erica Key)

- USGCRP
- Belmont: 17 collaborative research actions

Detlef Stammer and Helen Cleugh

- The purpose of the week: celebrating 40 years, thanking the community, entrain next generation, discuss future plans.
- Summary of WCRP SP
- Transition from our current WCRP to new WCRP requires: a transparent bottom up approach, identifying high level science goals and key actions to reach them; identifying elements of a new WCRP to put the SP into action: structures, milestones, deliverables, resources, measures of success, risk assessment.
- Draft Goal statement. WCRP delivers societally relevant knowledge and info to inform mitigation adaptation and risk management. Strategic Objectives 1, 2 and 3 feed into 4 and this needs to be a two-way process.
- Conceptual framework.
- High level science questions are essential
- Synthesis from town halls: Model accuracy, climate sensitivity, impacts and consequences of geoengineering, evolving carbon cycle, atmos. Carbon assessments, regional to local scale climate information (see Helen's slides)
- Moving to impacts and solutions How will climate change affect weather in different regions of the world, ecosystems and food, air quality etc. What would a 4,5,7 degree world look like? Pathways from now to 2100; what are questions, experiments etc., that can only be done by WORLD climate research programme?
- Climate Science Capability-Infrastructure: Observing systems remain fundamentally important, climate models etc. High performance computing and data, CMIP going forward.
- People partnerships and networks: People are at the core of WCRP. We cannot achieve our goals without partnerships
- Bridging climate science and society.
- Regular syntheses assessments and gap analyses - rapid assessments and updates.
- Bottom up community process. Evolution not revolution, a smooth transition.

Panel Discussion

Q: Given the relationship of WCRP to global stocktake, how can one accelerate the kinds of analysis that are useful in the timescale of the global stocktake?

Detlef: We are WCRP. There is stocktake and also a lot of research required as well as observations. Energy budget for example.

Q: How can the interaction between WCRP, Future Earth, DRR work best?

Erica: With Belmont forum funds are focused on DRR as well as others. Will have Congress next year in Brisbane.

Helen: WCRP are hoping to do some co-design of activities in Brisbane.

A lot of collaborations are already happening

Q: Identification and evaluation of tipping points? How do we approve the knowledge? For example, deforestation, Greenland melting.

Guy: The concept of tipping points came up a few years ago. Traditional models have not been focusing on this issue. WCRP needs to be involved. Needs to take into account e.g. the biosphere and a number of processes such as the development of fires.

Helen: Those are the sort of questions we should be looking at. The kind of weather that bushfires create so you get a larger spread. Do these fires become a net source of CO2 in the longer term?

Jerry: The problem is that you can't model what you don't understand. We need process studies, but also observations! WCRP has a strong role.

Eleanor: Not only tipping points in the Earth System, but a tipping point in humanities understanding.

Q: Town Halls were very much into applications but not much about the need to build knowledge.

Guy: We won't be able to respond to a problem unless we have a strong body of knowledge. We need to have a number of projects that would respond to a number of issues. How are we going to develop this knowledge? Assessments, conferences? It can only work with strong support from national funding agencies.

Q: What are the specific plans to demonstrate how fundamental science will help achieve the SDG framework?

Erica: There is a lot of fundamental science that is disciplinary, interdisciplinary etc. It's those critical intersections and pathways that are fundamental.

Q: Do we want to study 3,5,7 degree C climate? Do we waste resources if we focus on too many pathways?

Jerry: One of successes of WCRP is connecting communities.

Appendix 1: Notes from the WCRP Agency Lunch

Guests

Jack Kaye	NASA
Wayne Higgins	DOC/NOAA
Kathy Hibbard	NASA
Erica Key	Belmont Forum
William Veatch	CIV USARMY CEMVN (US)
Ariane Pinson	CIV USARMY CEMVN (US)
Gyami Shrestha	GlobalChange.gov
Jennifer Carroll	NSF
Susanna Ehlers	Inter-American Institute for Global Change Research (IAI)
Guido Lüniger	DFG, Germany

WCRP

Pavel	Kabat
Mike	Sparrow
Mich	Rixen
Narelle	van der Wel
Detlef	Stammer
Helen	Cleugh
Jens	H. Christensen
Martin	Visbeck
Beatriz	Balino
Wiebke	Schubotz
Bill	Gutowski
Tercio	Ambrizzi
Hans	Volkert
Pascale	Braconnot

Implementation Priorities:

- We need to ensure we have a targeted outcome in mind e.g. *an increase in confidence in precipitation predictions* (i.e. predictions are not getting better. Why? Need targeted observations and process understanding to address systematic errors)
- It was suggested that we look at USGRCP framework priorities (focused on e.g. climate sensitivity, carbon cycle, etc.)
- We need to consider what is the value of the WCRP enterprise to stakeholders (agencies are key WCRP stakeholders)

- We need to focus on issues that require international cooperation
- How do we measure if we are successful? It was suggested that we look at our return on investment, though not easy to do. 5- to 10-year targeted outcomes are helpful, where an outcome could be an increase in confidence or skill. We have moved away from metrics to evaluation frameworks - this is more inclusive of transdisciplinary research.
- USGCRPs approach is to produce white papers, have workshops and then flesh out the white papers and move on to implementation. There are a suite of inter-agency working groups, including the Social Science Coordination Task Force.
- WCRP shouldn't try to do everything but work closely with partners and focus on key issues. WCRP shouldn't only focus on reducing uncertainty (sometimes increased understanding actually increases uncertainty. New things have to be put into models)
- The importance of growing the scientific community in an inclusive way was emphasized.
- Do we need a new global experiment, such as to tackle the model bias problem?
- Quality reference data sets are important but need to be accessible to all.
- In a mature programme like WCRP regional issues becoming more important. What are the regional needs? How important is it to a national community to be part of the international community?
- We all run global models, but we all have the same systematic errors. We need to focus on near term, S2S, timeframe.
- It is important to begin with the idea of the end in mind. Our needs are different depending on users. Often a plausible range is more important than probabilistic ranges (Grand Challenge on Regional Sea Level and Coastal Impacts as a good example of practice).
- In the Belmont Forum several themes e.g., migration have a strong climate theme. It is important to co-fund, co-design and co-implement (though other opinions said not everything has to be co-designed etc.)
- How do we (WCRP) make what we do valuable to individuals, including vulnerable communities? How do they access this information (especially in countries without fast internet)?
- NOAA is moving from programmatic to topic focus using assessments, such as for extreme heat, coastal inundation etc. It is important to work out what stakeholders need. Could WCRP use assessments to guide its process?
- Countries can use WCRP as a way to leverage funding for projects on many levels. They start with societal question and then to the science questions. They need to reach out to other partners, as we cannot do everything.
- We need to pick a couple of things that WCRP can do really well, e.g. the precipitation challenge.
- We should see the new WCRP as an opportunity to do some big science to improve our understanding of what is predictable. We need workshops to cover the "what".
- Not everything is about the end user. Don't get pushed into delivering something that is not useful.
- Having targeted science questions in mind is important. The planning horizon gets later the more people involved.
- Nowadays individual countries can do these big experiments e.g. China. VAMOS, for example, gave a huge boost to science. There is a big increase in population in Africa but the least capacity. Perhaps WCRP needs to have a conversation with African countries to build up capacity etc.

Comments on a new WCRP Structure:

- For the Core Projects and some of WCRP's other activities perhaps we need to think not about restructuring but a rebranding and refocusing
- Form follows function. We need to work out priorities and then see what we need. But need to think about communities and not then disrupt them too much.

NSF Proposal:

- Need to ensure we include USGCRP, NSF etc. priorities
- Pavel will produce a 1 pager per agency and ask for feedback to ensure usefulness.