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Report on the *Clouds, Circulation and Climate Sensitivity* Grand Challenge

The activities of this GC aim at promoting and focusing research on four science questions which are critical for the understanding and prediction of climate change (Bony, Stevens et al., *Nature Geoscience*, 2015). For this purpose, this GC promotes a few strategic initiatives which have the potential to significantly accelerate progress and to get the best of the complementarity between modelling, observation, process studies and paleo-climate studies.

1. Highlights for JSC

This GC promotes three main strategies:

- A strategy to narrow bounds on Climate Sensitivity: the concept of Equilibrium Climate Sensitivity (ECS) constitutes a central measure of climate change, but for more than 40 years, its precise quantification has remained elusive (current model estimates still range from 1.5K to 4.5K). A particular problem in quantifying plausible bounds for ECS has been to account for all of the diverse lines of relevant scientific evidence. Following the Ringberg workshop organized by this GC in 2015, a strategy has been proposed for narrowing bounds on Earth's climate sensitivity (Stevens et al., Earth's Future, 2016): developing and refuting physical storylines (or hypotheses) for values outside any proposed range has the potential to better constrain these bounds and to help articulate the science needed to narrow the range further. The application of this strategy forms the basis of a community assessment on Climate Sensitivity that is being coordinated by this GC, and is being led by S. Sherwood and M. Webb. The plan is to publish this assessment by early 2018, thereby supporting the 6th Assessment Report of the IPCC.

- A field study to test mechanisms that control the low-cloud feedback in climate models: as emphasized by the IPCC AR5, the main source of uncertainty in model estimates of climate sensitivity remains the cloud feedback associated with shallow-cumulus clouds. Physical mechanisms for this feedback have been proposed based on model studies, but they have not been tested so far owing to the lack of appropriate observations. To fill this gap, we are organizing a field study named EUREC^{4}A (Elucidating the role of clouds-circulation coupling in climate) on Jan-Feb 2020 in the lower North-Atlantic trades near Barbados. The campaign is supported by an ERC grant to Bony and substantial funding by the Max Planck Society. It will be based on very comprehensive measurements from two aircraft equipped with the most advanced remote sensing instrumentation, a number of Research Vessels and the Barbados Cloud Observatory. Beyond the question of cloud feedbacks, the campaign aims at assessing and improving the representation of clouds and convective processes in process, weather and climate models, and retrievals of clouds and winds from two flagship space missions (EarthCARE and ADM-Aeolus). More information on EUREC^{4}A is available from the project website www.eurec4a.eu (in construction) or in: Bony, Stevens et al., Surveys in Geophysics, submitted.

- A modelling strategy to accelerate understanding of the role of clouds in climate: clouds can affect climate in many ways. To decipher cloud-climate interactions more easily and formulate hypotheses that may then be tested using observations, the GC has promoted the use of a model hierarchy. This is done by organizing workshops (e.g. the 2016 Model Hierarchy

workshop organized in Princeton by this GC and WGCM) emphasizing this strategy and by coordinating model inter-comparison projects based on this approach. Four such projects are presently being promoted: TRAC-MIP (*Tropical rain belts with an Annual cycle and Continent MIP*) that aims at understanding the position, the strength and the variability of ITCZ and monsoons), Easy-Aerosols, that aims at pointing out robust impacts of aerosols on the large-scale circulation and regional precipitation patterns, and of course CFMIP (the *Cloud Feedback Model Intercomparison Project*) that aims at addressing the four questions of this GC through a hierarchy of models and experiments. Contributions by the GC to CFMIP is complemented by contributions to the design of RFMIP (the *Radiative Forcing Model Intercomparison Project*). Finally, a fifth project named RCE-MIP will soon be advertised, that will aim at running Radiative-Convective Equilibrium simulations both with General Circulation Models and Cloud-Resolving Models to study the physics and impact on climate of convective organization.

2. Early success and/or planned activities in 2017/2018

Early success:

- Presentation of the four science questions around which this GC is articulated (Bony et al., Nature Geosci., 2015). This article has been influential and is heavily cited (69 citations per Thompson-Reuters, 110 per Google Scholar).
- Stevens and Bony both served on the CMIP panel and contributed to the organization of CMIP6 so as to emphasize this and all GCs.
- Presentation of the TRAC-MIP initiative and early results (Voigt et al., JAMES, 2016)
- Proposition of a strategy for narrowing the uncertainty in Climate Sensitivity (Stevens et al., Earth' s Future, 2016) based on the GC workshop on Earth's Climate Sensitivities.
- Proposition of a new modelling approach to study the impact of aerosols on climate (Voigt et al., JAMES, 2017; Stevens et al., GMD, 2016) and contributions to RFMIP (Pincus et al., GMD, 2017)
- Workshop on storm tracks (Shaw et al., Nature Geosci., 2016)
- Presentation of the next phase of CFMIP (Webb et al, GMD, 2016) in support of this GC
- Organization (jointly with WGCM) of the 2016 Model Hierarchy Workshop in Princeton
- A GC workshop organized in 2016 at ISSI (International Space Science Institute) on "Shallow clouds, water vapour, circulation and climate sensitivity" had led to an edited book (expected publication in 2018) on the topic of the workshop. This activity has also contributed to the NASA decadal survey.
- As a follow-on to the workshop an ISSI International Science Team (composed of 12 experts from modelling, satellite and airborne remote sensing, analysis) has been proposed and selected by ISSI for two years of support for questions related to this GC and to the EUREC^{4}A campaign. The science team brings together experts from the modelling and observational community to focus on the "mesoscale organization of shallow convection". A first meeting of the science team took place Feb 27-Mar 3 2017.
- Funding has started to be secured for the organization of the EUREC^{4}A field study (European Research Council and Max-Planck Society)

Planned activities in 2017/2018:

- Climate Sensitivity assessment (2018) – workshop to be held in 2017 or early 2018
- CFMIP meeting (Tokyo, Sept 2017), focusing on the different questions of our GC

- Design and launch of RCE-MIP to answer the question: "What role does convective aggregation play in climate?" (CFMIP meeting, Tokyo, Sept 2017).
- Workshop on the Future of Cumulus Parameterization (Jul 2017, Delft, NL)
- Modelling workshop on the "Challenges associated with the prediction of weather and climate in the trades", to be held in Barbados on early 2018 with the NWP, GCM, CRM, LES groups involved in the EUREC4A campaign.
- TRAC-MIP summer school (ICTP, Trieste, Jul 2018) contributing to the question: "What controls the position, strength and variability of the tropical rain belts?"
- 4th ICESM conference (Aug-Sep 2017, Hamburg DE), including a session on this GC.
- Second meeting of the ISSI International Science Team on shallow clouds (Bern, Nov 2017)
- Follow-up workshops on Storm Tracks and Convective Aggregation (tentative)

3. Partners for GC

- EUREC^{4}A is funded by the ERC through an Advanced Grant (to S. Bony) and by the Max Planck Society (through a proposal by B. Stevens). In addition support is provided by ERC funding for CloudBrake, a contributing project to EUREC^{4}A, as well as the German Science Foundation and the Caribbean Institute for Meteorology and Hydrology.

- The International Space Science Institute (ISSI) has supported the GC by providing funding for a workshop and an International Science Team.

- WGCM (host of this GC, co-organizer of Model Hierarchy Workshops) and CMIP.

- SPARC (through the organization of workshop on TRAC-MIP, storm tracks, etc).

- PAGES (through PMIP): contribution of the paleo community to the Climate Sensitivity assessment and to TRAC-MIP (on-going)

- GEWEX (discussions with the Data and Assessments Panel)

- Possible connections to WGNE (through the workshop on cumulus parameterization and the participation of the NWP community to the modelling component of the EUREC^{4}A field study, and RCE-MIP).

- Possible connections to CLIVAR (e.g. through the contribution to the EUREC^{4}A field study, that will focus, as one of its complementary objectives, on the role of ocean mesoscale eddies on air-sea interactions).

4.Overall GC timeline (include any milestones)

- **2012-2015**: definition phase: Ringberg workshops to define strategies and priorities, writing of perspective papers, contribution to strategic meetings – e.g. Climate Symposium on Earth observation.

- **2016-2020**: mature phase: development of TRAC-MIP, RCE-MIP, Easy Aerosols, RFMIP, CFMIP activities & elaboration of a GC assessment on Climate Sensitivity (to be published in 2018) & organization of the EUREC^{4}A field study (to be held in 2020) and of its associated components on modelling (process, climate, NWP), remote

sensing (incl. CalVal of space missions on clouds and circulation), water isotopes (observations and modelling), oceanography (characterization of ocean mesoscale eddies) & workshop on the future of convective parameterization.

- **2021-2022**: summary and conclusion phase with a culminating international conference (what have we learned from this GC?)

5. Issues and challenges:

- Do GEWEX, WGNE and CLIVAR see opportunities to link some of their activities to those of this GC? In particular, are they interested in contributing to the preparation, the organization and/or the scientific exploitation of the EUREC^{4}A field study? Several modelling groups have already expressed interest in using EUREC^{4}A to test the representation of momentum transport, cumulus clouds and convective organization in regimes of shallow convection using a hierarchy of models, from LES through NWP to GCMs; plans to support several (3-5) Research Vessel in the EUREC^{4}A campaign offers opportunities for oceanographic studies, and a substantial CalVal component is also foreseen. The nucleation of EUREC^{4}A within this GC opens the door for EUREC^{4}A to be transformed into a high-profile contribution of the WCRP to international climate science if there is buy-in from the WCRP core projects or other working groups (e.g., WGNE)

- Members of the Grand Challenge have provided substantial input to GCOS over the course of two annual meetings, in associated workshops and conferences, and by reviewing the 2016 GCOS Implementation Plan, but the communication has not been as effective as we wish in drawing GCOSs (and the climate observing community more broadly) attention to important shortcomings in the developing climate observing strategy.

- Can WCRP become more proactive in helping support some of the activities mentioned above?

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