Jerry Meehl's multi-decadal journey in IPCC

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In 1990 the Intergovernmental Panel on Climate Change, IPCC, published its First Assessment Report (FAR) that provided quantitative climate change projections as simulated by the first generation of coupled atmosphere-ocean climate models [*IPCC*, 1990]. In the years before, Jerry Meehl was already among a small group of climate scientists that carried out increasingly realistic climate simulations. Just in time for inclusion in FAR, Jerry, together with his long-time mentor and collaborator, the late Warren Washington, published a comprehensive paper on their simulations of the coupled response of the climate system to an increase of CO_2 in the atmosphere [*Washington and Meehl*, 1989]. They were among the only four of the nine centres that provided coupled ocean-atmosphere model simulations, and the only of these four that did not use flux adjustments in coupling the atmosphere and the ocean model components. Flux adjustments, or perturbation coupling, was a non-physical workaround that the majority of models of that generation had to resort to [*Kattenberg et al.*, 1996] and which generated many years of scepticism against coupled climate models.

Washington and Meehl's paper was a tour de force: they scrutinized their model output for every possible aspect in the atmosphere and the ocean, and critically discussed their findings, in great detail in no less than 38 display items, and evidenced the obvious shortcomings of their model. By today's standards their coupled model would be called "reduced complexity", with an R15 resolution in the atmosphere and 5° in a 4-layer ocean.

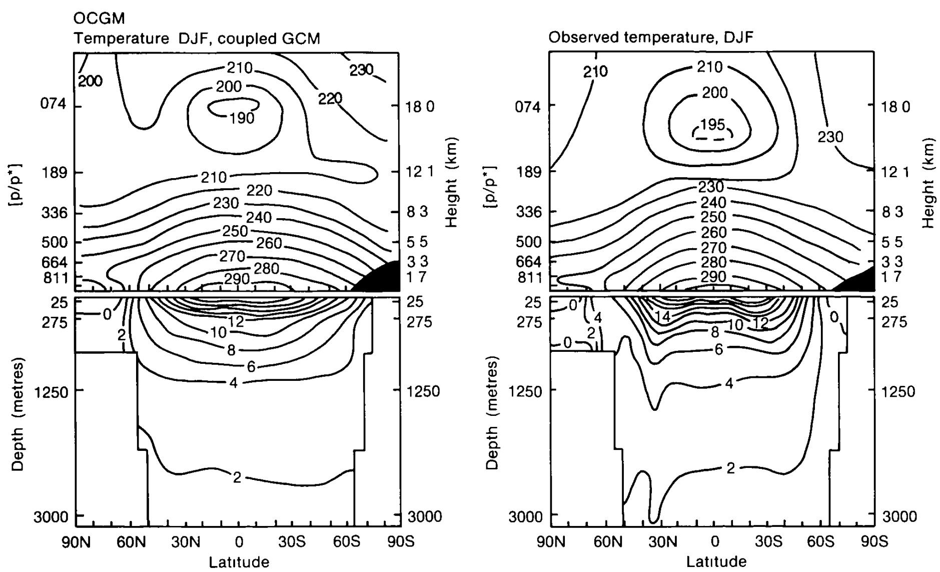

Figure 1: Zonal averages of winter temperatures in the atmosphere and ocean, as simulated by the NCAR model [*Washington and Meehl*, 1989], left, and observed, right. These results featured as Fig. 4.22 in the model evaluation chapter of the FAR [*Gates et al.*, 1996], the only coupled model result simultaneously showing ocean and atmosphere.

As Washington and Meehl stated in the introduction, their work was in the context of a previous, less detailed assessment of the effect of CO_2 on the Earth's climate [*National Research Council*, 1982]. These simulations, contributed to the FAR, were an impressive demonstration of the capability of coupled climate models to simulate fairly realistically the distribution of temperature in the atmosphere and ocean (Fig. 1).

However, the computational limitations of the 1980s allowed them to carry out just three 30-year runs: a control, an abrupt increase of CO_2, and a transient CO_2 increase of 1% per year. Welcome to the world of simple scenarios for GCMs in the early 1990s!

Nevertheless, the model yielded much physical insight and some important findings corroborating results from flux adjusted simulations: polar amplification of the atmospheric warming, penetration of heat into the ocean, a freshening of the polar ocean, a reduction of the overturning circulation in the Atlantic Ocean and the retreat of the Arctic sea ice. Shortcomings, such as a persistent climate drift in the simulations and the limited representation of regional phenomena due to the coarse grid resolution outlined the strategy for future development. A notable curiosity of their transient simulations over 30 years was a pronounced winter warming over the North American continent and a simultaneous strong cooling over the northern North Atlantic; the latter was interpreted as the effect of a weakening Atlantic meridional overturning circulation.

Jerry Meehl's multi-decadal engagement with IPCC jump-started with the FAR: He was a Contributing Author to three sections on validation, equilibrium change, and transient climate change. Along with the publications in the peer-reviewed literature, this consolidated the international position of the NCAR model in comprehensive climate modelling. Perhaps an anecdotal observation: three well-known modeling centers provided the only color plates of global maps of model simulations in the FAR. NCAR was not among them, and this may have spurred Jerry's ambition to engage even more substantially in the subsequent IPCC assessments.

The competition between the modeling centers was high, but there has always existed a strong spirit of scientific exchange which early on was put into an organisational framework. What started as an effort of a handful of scientists from a few institutions, guided by the Steering Group on Global Climate Modelling, of which Jerry Meehl was a member, has grown into a firmly established, worldwide operation, the Coupled Model Intercomparison Project (CMIP) [*Meehl et al.*, 2005; *Meehl et al.*, 2007a; *Taylor et al.*, 2012]. CMIP is a comprehensive and inclusive community-driven operation under the auspices of the World Climate Research Programme (WCRP) of WMO and other international institutions, to simulate, investigate and understand past, present and future climate change. Without the series of CMIPs since its inception in 1997 [*Meehl et al.*, 1997], IPCC could not *assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation* (quote from the Principles Governing IPCC Work).

Next, Jerry Meehl contributed to the IPCC Supplementary Report which appeared only 2 years after the first in support of the negotiations on the Framework Convention on Climate Change and in preparation of the Kyoto Protocol. A more responsible role followed in the IPCC's Second Assessment Report (SAR) where he was part of the lead author team of the chapter on climate model projections [*Kattenberg et al.*, 1996] and was contributor to three further chapters on processes, evaluation and detection and attribution.

Our paths then crossed in the preparation to the Third Assessment Report of the IPCC (TAR) for which we were both appointed Coordinating Lead Authors (CLAs) of a chapter. Jerry co-led the projection chapter which commonly garners most interest by the policymakers and the public [*Cubasch et al.*, 2001]. For the first time, multi-model ensembles could be presented, as the CMIP database comprising results from 31 comprehensive climate models and 3 climate models of reduced complexity became available. This innovation reduced inter-model differences and noise so that more robust global-scale projections could be made. Evidently, this came at the expense of the projection of extremes which were assessed in the form of a small but influential table listing eight types of extreme events and the assessed confidence of their observation in the 20th, and projection in the 21st century. This table was elevated to the Summary for Policymakers (SPM), and so the seed was laid for the next step in climate model analysis and assessment [*Meehl et al.*, 2000]. As CLAs in TAR, Jerry and I collaborated in the preparation of the Technical Summary and the SPM of Working Group I (WGI). Under the leadership of co-chair Sir John Houghton, we witnessed the power of concise formulations and compelling figures, as well as the strenuous path from negotiation to approval by consensus, the latter enabled by persistence and diplomacy.

The most contentious finding at the approval plenary of the TAR, held from 17 to 20 January 2001 in Shanghai, was the detection and attribution of global mean warming over the last 50 years. The key scientific insight came from very recent simulations by the UK's Hadley Centre, one of the institutions that already contributed to the FAR, but at that time only with an atmosphere coupled to a simple mixed layer ocean. Now using their coupled atmosphere-ocean model without flux corrections, they investigated factual and counterfactual worlds for the past 140 years. Only the simulations including all forcings (solar, volcanic and anthropogenic) matched the observed long-term increase in global mean temperature. This key element was presented in one figure in the TAR SPM and therefore required formal approval by the panel. A similar version of this figure was already included in the government and expert review draft of April 2000, but the underlying peer-reviewed publication appeared only one month before the IPCC plenary session. Hence, some delegates noted that such a short-notice addition to the top-level document would not be in line with the principles governing IPCC work, and they tried very hard to kill this key figure. After hours of strenuous negotiations, constant back and forth between the few insisting delegates and the lead authors, co-chair Sir John, after an emotional plea that "*this is the best science that can be offered to the panel*", finally gavelled down this figure and the associated statement *"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."* It is worth noting that this rectified, once and for all, the ugly and difficult situation emerging in 1995 after the approval of the famous statement "*The balance of evidence suggests a discernible human influence on global climate"* in the SAR, and which ignited the ire of the climate deniers [*Meehl*, 2023]. It is a remarkable show of scientific collegiality that all climate modelers participating as experts in the Shanghai plenary defended this result as a solid block, a key finding that based on simulations of just one of 31 climate models that were evaluated in TAR.

Figure 2: Colleagues in attendance of the First Lead Author meeting of Chapter 10: Global Climate Projections of the IPCC's Fourth Assessment Report, held in Trieste from 26 to 29 September 2004. Front row (from left to right): Patricio Aceituno, Gerald Meehl, Thomas Stocker, Sarah Raper, and Zhong-Ci Zhao. Back Row:, Akio Kitoh, James Murphy, Ian Watterson, William Collins, Amadou Gaye, Pierre Friedlingstein, Jonathan Gregory, and Akira Noda. Andrew Weaver could not attend.

As usual at the completion of an IPCC assessment cycle, the leadership of the next cycle is elected. It consists of the Co-Chairs and the bureaus of the three working groups. WGI assessed the scientific basis and was led by Susan Solomon (USA) and Qin Dahe (China) for the Fourth Assessment Report (AR4).

Susan had many years of experience in scientific assessments, both in the ozone assessment and the IPCC and therefore had clear ideas regarding the potential coordinators of the various chapters of AR4. The model projection chapter should reflect both the emerging hierarchy of climate models and the use of these models for both paleoclimate applications and climate projections. This is why in May 2004, Jerry and I were invited by the WGI Bureau to coordinate Chapter 10: Global Climate Projections. By experience, we were aware of the burden and the responsibility this entailed; and we were both looking forward to an intense collaboration over the next four years. In contrast to TAR, where the CLAs could hand-pick several of their Lead Authors, in AR4 the decision was entirely taken by the bureau. So here we were, with a great group of highly motivated leaders in climate modelling across the globe (Figs. 2 and 3) – and a list of seven bullet points, approved in the scoping process of IPCC, that needed to be comprehensively covered within 50 printed pages! Well, eventually the page count stopped just short of 100 [*Meehl et al.*, 2007b].

Figure 3: Final composition of the lead author team of Chapter 10 at the third meeting in Christchurch from 13 to 15 December 2005. From left to right: Ian Watterson, William Collins, Reto Knutti, Jonathan Gregory, Andrew Weaver, Gerald Meehl, Sarah Raper, Thomas Stocker, Akira Noda, Pierre Friedlingstein, Zhong-Ci Zhao, James Murphy, and Akio Kitoh.

As CLAs we also participated in the author teams of the Technical Summary and the SPM. It turned out that the combination of Jerry, who had already more than 20 years of climate modelling experience and was deeply involved in the CMIP efforts, and me as "junior partner" with a paleoclimate background developing and using climate models of reduced complexity, was perfect. We were able to deliver, together with a strong lead author team, 78 contributing authors and two review editors, a substantive chapter that contributed three of the seven figures to the SPM. The approval plenary, held in Paris from 29 January to 1 February 2004, required our full attention. On several occasions, new text had to be crafted, because negotiations were stuck, and the authors would hand proposals of altered text or adjusted figures to the co-chairs. But we were also called to give short informal science talks to the delegates during breaks or before the start of the morning sessions. These were to inform the delegates and explain difficult or contentious issues from a purely scientific point of view. I had the task to present the concept and assessment findings of equilibrium climate sensitivity, with Jerry following who explained the projections proposed in the SPM (Fig. 4). We were quite nervous since our performance determined whether the negotiations of these findings would generate many, or only few, questions and interventions in the formal session. As it turned out, although no time for direct questions was available immediately after the informal presentations, the approval of this material turned out to be quite smooth. The entire plenary and our role as CLAs were described by Jerry in a detailed essay [*Meehl*, 2007].

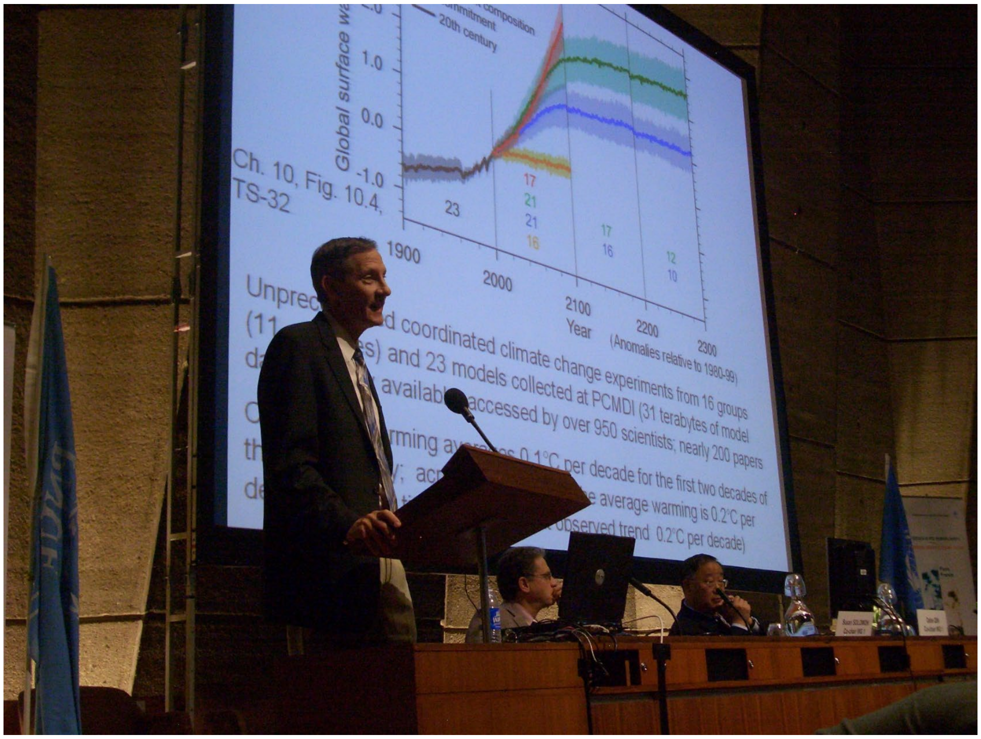

Figure 4: Jerry presenting the climate model projections at the informal science talk of the approval plenary of WGI in the morning of 31 January 2007, with me and co-chair Qin Dahe onlooking.

The meeting in Paris ended after a long night session on February 2, 0:40 am; the press conference was scheduled for 10:00 am with not much time to recuperate. Susan Solomon presented the key findings from the approved SPM and, evidently, Jerry and I were very proud when we could see Figure SPM.6, that we produced during the negotiations, prominently projected before the media (Fig. 5). The multi-model simulations from CMIP3 allowed us, for the first time, to estimate likelihoods of the near-term and the end-of-century warmings (panels in the left column of the Figure). This was indisputably a great milestone for the climate modeling community who initiated the CMIP effort 10 years before.

Soon after AR4, Jerry and colleagues of the climate modelling community teamed up to address the next big topic: decadal climate prediction [*Hurrell et al.*, 2009; *Meehl et al.*, 2009]. This also influenced the scoping process of the WGI contribution to the Fifth Assessment Report (AR5). From AR4 it was clear that two broad emerging topics needed deeper consideration: sea level rise and decadal prediction. During the preparation phase of the content of the WGI contribution to AR5, IPCC, the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP) jointly convened the workshop *New Science Directions and Activities Relevant to the IPCC AR5* that was held in Honolulu from 3 to 6 March 2009. Over 150 leading climate scientists from around the world gathered at the International Pacific Research Center of the University of Hawaii to discuss the latest developments in climate change science. Also, this was the historical occasion at which all former WGI co-chairs, who hosted Technical Support Units, were present at the meeting and shared with me their experiences and offered valuable advice (Fig. 6).

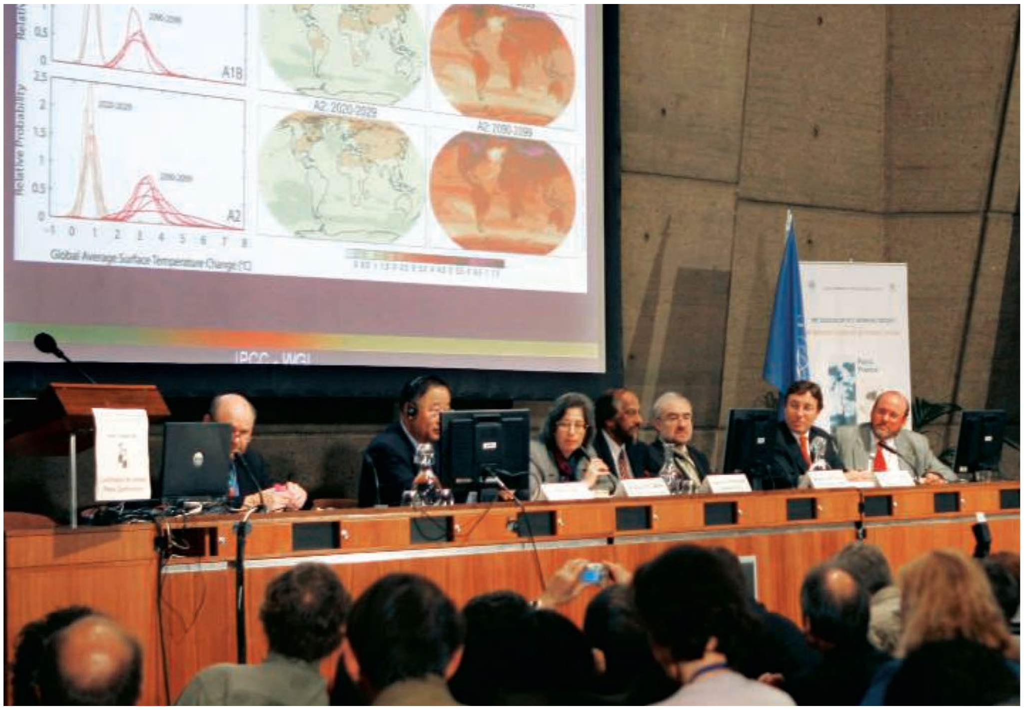

Figure 5: Presentation of climate model projections by co-chair Susan Solomon at the media conference in Paris on 2 February 2007. From the left: Martin Manning (Head WGI Technical Support Unit), Qin Dahe and Susan Solomon (Co-Chairs WGI), Rajendra Pachauri (IPCC Chair), Michel Jarraud (Secretary General WMO), Achim Steiner (Secretary General UNEP), unknown.

Figure 6: Jerry Meehl (chair of the scientific steering committee) with the three WGI co-chairs Susan Solomon (AR4), Sir John Houghton (FAR, SAR, and TAR), and me (AR5) at the IPCC-WCRP-IGBP Workshop held in Honolulu in March 2009.

Among the findings that were discussed by the scientists at this meeting were interaction of biogeochemical cycles, new feedback processes involving climate system spheres, the fate of the large polar ice sheets and the role of ocean warming in promoting ice shelf melt and hence impact projections of sea level rise. Ron Stouffer, Karl Taylor and Jerry presented the plans of CMIP5 near- and long-term simulations. The former addressed the issue of predictability on a climate time horizon that was most policy relevant.

The final stage of Jerry's multi-decadal contribution to IPCC WGI was his lead authorship in Chapter 11 *Near-term Climate Change: Projections and Predictability* where he and his colleagues distilled the robust findings from the CMIP5 simulations for the near-term period 2016 to 2035. Jerry found himself as an IPCC veteran among the 259 lead authors and review editors (Fig. 7). This was a totally different situation from FAR where just 34 authors lead the 11 chapters. Nevertheless, Jerry was as motivated and engaged in AR5 as in each of the earlier assessments. Thanks to his seniority, and our journey since TAR, he was a valuable and very helpful resource of advice and support in the seven years I and Qin Dahe led WGI.

The power of scientific expertise in WGI was just mind boggling. To keep the overview and a personal approach to guiding the author team, a booklet was created in which each lead author was featured, with Jerry Meehl as no exception (Fig. 8). This document served the Co-Chairs as an invaluable aide memoir.

Figure 7: Official group photo of the first lead author meeting, held in Kunming, China, from 8 to 11 November 2010.

The topic of near-term climate projections required a careful discussion of the difference between prediction and projections, and generally, predictability. An obvious dilemma arose: the classical approach to projecting climate change was to communicate using multi-model means. However, on the decadal time scale, natural variability is often still dominating the slowly growing forced changes. Therefore, individual simulations, and their time characteristics must be assessed. For example, periods of unusually rapid warming for several years, or alternatively "warming pauses" can be considered only in single simulations. As the evolution of an observed quantity is only just one of an infinite number of realizations, the same applies to model simulations. It turned out that as the AR5 authors pondered about the topic of near-term predictability, nature confronted us with an unexpected realisation: an apparently slower global mean warming from 1998 to 2012. This was readily picked up and inflated by the climate deniers, arguing that because the climate scientists did not predict this phenomenon and could not explain it quantitatively, the entire IPCC assessment must be considered as flawed.

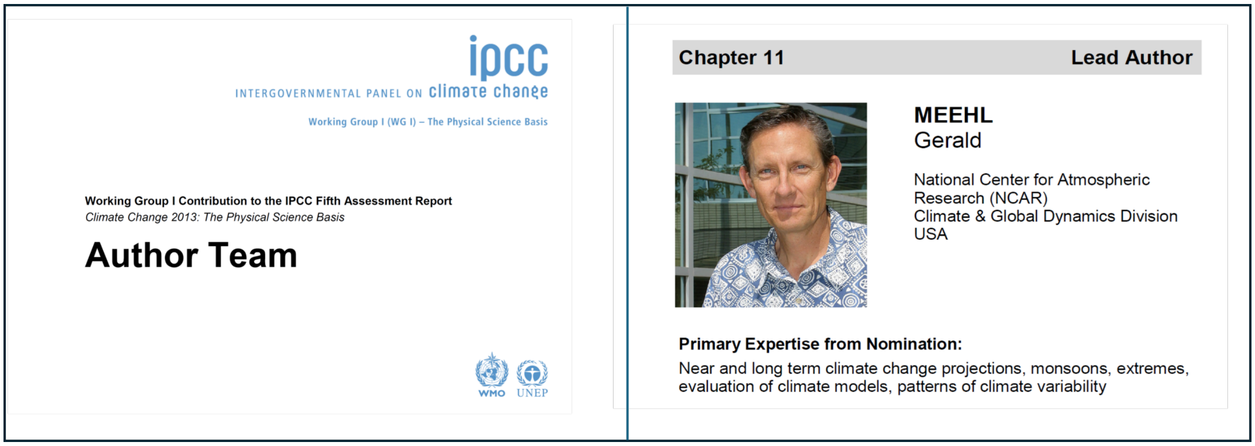

Figure 8: One of 259 entries in the Co-Chair's Author Brochure, produced by the Technical Support Unit of WGI, listing all authors and review editors of WGI in AR5.

This prompted a heated debate at the WGI approval plenary in Stockholm from 23 to 26 September 2013. Some countries requested that the warming pause must be addressed in several new bullets in the SPM, while others argued to the contrary, dismissing it as an irrelevant episode in the multi-decadal observed warming of the climate system that was unequivocal. In this difficult situation a pragmatic solution was called for. After consultation with the observation chapters, we proposed adding a new footnote 5 to the SPM which gave the mean values and 5-95% uncertainty intervals of 15-year trends of global mean temperature starting in 1995, 1996, and 1997. It was obvious that such trends could vary by a factor of almost 3, depending on the starting year. The evident message was that 15-year trends are clearly insufficient for a robust statement about global warming. Clearly, Chapter 11 was the key chapter to assess and clarify such internal variability of the climate system that would confound, and sometimes mask, the long-term trends. In addition to his work in Chapter 11, Jerry Meehl was also contributing author four additional chapters in AR5.

In 2015, the sixth assessment cycle of the IPCC started, this time without an official role of Jerry Meehl. This allowed him to return to his original activity of scientific investigation, discovery and understanding, free of the burden of comprehensive assessment of the peer-reviewed literature. However, the indirect contribution to IPCC, i.e., the production of new science and original results, is equally important as it will prepare the foundation of the next assessment. And here, the 92 publications that Jerry authored or co-authored since 2013 have made and will make a lasting impact on AR6 and future climate change assessments.

Continuing simulations with improved and better resolved climate models, increased availability of computing time, and emerging assistance by Machine Learning will certainly increase understanding and narrow uncertainties regarding projections of regional climate changes, changes in weather systems, and risks and impacts of extreme events, sea level projections, clarify climate tipping points and biogeochemical changes affecting terrestrial and marine life, and eventually ecosystem services.

Bern, 4. November 2024

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