Response to V. Ramaswamy :

We are extremely grateful to Ram for providing us with such a nice and thorough review of our manuscript. All comments and suggestions (reproduced below in *italics*) were carefully considered, as indicated below.

*This is an exceedingly nice paper and, given the author list, no surprise at all. It has focused on the famous Charney report which is the forerunner of all other state-of-the-art climate assessments. This paper focuses on the prescient nature of the findings in that assessment whose fundamental tenets continue to apply. Indeed, the authors are performing a classic themselves by reminding the community about the nature of that report, and bringing to us a modern-day perspective on its continued application through into the future.*

We are honnored by these comments. Thank you.

*I have a few comments. Some of these are from the perch of a devil’s advocate, some from a nitpicking vantage point, some no doubt from a personal bias. I hope the comments serve to strengthen and sharpen the important messages in this paper, which are of vital need for advancing climate science and thus thoroughly aligned with WCRP’s objectives.*

***General***

1. *The sense of “simple” is used frequently and fairly strongly in the text. This represents a very important point. But, what is meant by “simple”, and should this be an all-defining characteristic? Simplicity and complexity are in the minds of the beholder/reader/doer. What is perhaps more important is the inferences distilled out of particular exercises and how sound a standing these enjoy scientifically.*

We agree that the main value of simple models is in their ability to distill scientific knowledge, as emphasized at different places in the text (e.g. in recommendations l. 588-589). Following your comment, we added at the beginning of the paper (l. 110-112) :

« The emphasis on the importance of physical understanding gained through theory and simple models, both for its own sake, to facilitate the distillation of scientific knowledge, and to help interpret and check the results of GCMs,... ».

1. *If we had not become aware of the non-CO2 forcing agents and their actions, and instead had concerned ourselves with only trying to model the CO2 effects for understanding the 20C climate change, we would have been stuck for explanations about the observed changes. While the manner of doing climate modeling and science was struck excellently in the Charney report, and particularly the concept of climate sensitivity was laid out starkly, there are now unanticipated entrants into the climate forcing and change issues. This is not intended as a criticism of the report, instead it is recognizing how powerful those findings are in the context of the present-day climate science. The Charney report’s dissection and groundbreaking rational thoughts on climate sensitivity are still an important guiding force in the thinking about the newer elements of climate physics.*

This is good point. We added l 238-240 : « ...no discussion of non-CO2 anthropogenic forcings (greenhouse gases other than CO2, aerosols, land-use changes). Nevertheless, the power of the climate sensitivity concept highlighted by the report is likely to have influenced the current thinking about the effect of non-CO2 forcing agents on climate. »

1. *A noteworthy absence in the literature referenced is the Manabe-Wetherald (MW) paper (JAS, 1967) paper. The investigations in that paper were actually intended as a precursor to the first GCM (MW, JAS 1975) work, but turned out to shape the understanding of climate processes in a profound way. Undoubtedly, there were other papers which added to the science, but that paper on one-dimensional radiative-convective modeling is a masterpiece in the context of this manuscript in at least two ways. One, the paper prepared the science platform for the understanding of: radiative-convective processes, water vapor feedback, link between radiative flux changes and surface temperature response, characteristics of important radiative perturbations and responses, and climate response to radiative perturbations. A significant feature was the ‘sensitivity’ studies which attempted to, and succeeded, in affording perspective into the solutions for a range of perturbations in radiative agents (CO2, ozone, water vapor, clouds, surface albedo, solar constant) with appropriate analyses. These results are all still relevant today, even quantitatively. The second aspect of this paper was that it was not just about modeling; it made remarkable and judicious use of observations of humidity available, which has proved pivotal in the understanding of the water vapor feedback process. (For accuracy, the earlier paper by Manabe and Strickler is also relevant since it was a precursor to the MW paper). I would suggest that more “sensitivity” studies with models, and the comprehensive yet discriminating use of relevant observations in the context of model studies, are sorely needed in today’s investigations of climate and climate change.*

You are right that the Manabe and Whetherald (1967) paper was a pionner on many issues addressed in the Charney report. The absence of citation of this paper (we cited Manabe and Whetherald 1975 but not 1967) is just an inexcusable omission. It is corrected (l. 186, 250).

1. *There is a sense missing about all the newer things that have come into the reckoning since the time of the Charney report. As pointed out in (2), if we are to extrapolate the strategies employed in that evaluation to today, it is not enough to merely involve CO2. Methane, the other long-lived greenhouse gases (LLGHGs), and ozone have to be considered now in an almost equal sense regarding present-day climate change (model calculations of the 20th Century response indicate that CO2 warming is only one-half of the warming due to changes in the long-lived species). True, by end of the 21st Century, it shall be mostly CO2, but we still have to undergo a few more decades of significant non-CO2 forcings (IPCC AR4). The manner of responses can be somewhat to a lot different than for CO2, especially spatially (horizontal and vertical dimensions). And, when it comes to the particulates, the science has different nuances which can even vary by species (global-mean will still be meaningful, but regional aspects of climate change may not be as distinctly related to global-mean as in the case of CO2). If a “Charney-like” report were to be constructed now, it is difficult to see how substantive non-CO2 considerations can be avoided. Of course, the objective to pursue process studies, with a hierarchy of modeling concepts, has to necessarily continue.*

Following your comment, we added (l. 125-129) : «  The importance of non-CO2 forcings such as methane or other long-lived greenhouse gases, ozone and aerosols, has been emphasized since the publication of the Charney Report, especially for interpreting the evolution of the 20th century climate. However, we expect the increase in CO2 concentration to dominate the acceleration... [...] Therefore anticipating the effects of CO2 on climate remains a key issue. ».

1. *Along with (4) come observations. Besides the ever-increasing length of the observed climate record which is a boon for testing/abandoning theories, the increase in the number of diverse climate variables observed today offers a wealth of insights into climate processes. These have surely advanced the science, and brought us further down the road than at the time of the report. In fact, this actually serves to showcase the intellectual depth and wisdom there was in that report in formulating its scientific conclusions concerning future climate change projections due to CO2 increases.*

We fully agree. This issue is mentionned in section 3.3 (l 227-230) :

« A number of issues that dominate many current discussions of climate sensitivity do not appear in the Charney report. [..] There is also little discussion of observational constraints on climate sensitivity -- such as the response to volcanic aerosol in the stratosphere, the response to the eleven year solar cycle, and the glacial-interglacial responses to orbital parameter variations (and many other paleoclimate observations), and most, obviously, the warming trends over the past century itself -- and the role of models in interpreting these observations, for example, by determining how a response to the Pinatubo volcano relates to responses to more slowly evolving greenhouse gas forcings. And the report reads very differently from recent assessments in that there is no discussion of detection and attribution, and consistently, no discussion of non-CO2 anthropogenic forcings (greenhouse gases other than CO2, aerosols, land-use changes). »

and in section 4.1 (l. 436-444) :

« However, coming as it did at the dawn of the satellite era, and in the early days of cloud-resolving modelling studies, it is interesting that the report did not emphasize the importance of these emerging technologies for our understanding of the susceptibility of the climate system to cloud changes... ».

1. *Substantial steps have to be taken to foster creative thinking, reward creativity from development of models to analyzing and understanding them and the simulations, and striving for novel insights that break new ground. Creativity has to continue to be a credo.*

It is an important point, indeed ! In our final recommendation, we added a few words about it l. 586 : « ...For this purpose, fostering creativity and developing new approaches or analysis methods that connect the behavior of complex models to concepts, theories or the behaviour of simpler model results should be strongly encouraged. *This process of distillation is central to the scientific process, and thus vital for our discipline*. »

1. *Not much is said in the paper about how the WCRP-sponsored intercomparisons and IPCC (WGI) framework compare with the manner in which the Charney report was compiled. It would be good to offer expert critique of these (e.g., CMIPs, and other WCRP-initiated exercises such as in GEWEX, SPARC), and make a recommendation on how existing exercises can be strengthened.*

In section 3.6 (l 337), we now compare the number of models considered in the Charney report with that involved in recent inter-comparisons (CMIP5). Moreover, in our 1st recommentation of section 4.4, we emphasize : «  ...*In striving to connect our climate projections to our understanding* (what we call the Platonosphere in Fig. 4)*, the promotion and inclusion of highly idealized or simplified experiments in model intercomparison projects must play a vital role. »*

***Specific***

*Introduction*

*l. 50: The description starts out with Arrhenius’ seminal work. With regards to water vapor and atmospheric infrared absorption, Fourier (who argued about the presence of the atmosphere, ~1820s) and Tyndall (who discovered that some gases block infrared radiation, ~1860) deserve credit prior to the Swedish chemist’s discoveries.*

Joseph Fourier's work is now cited in the first sentence of the introduction (l 50-51).

*Section 2*

*l. 95-101: The ‘simpler” treatments from that time would include one-dimensional radiative-convective models, the concept of an atmosphere tending to conserve relative humidity, the careful differentiation between radiative and radiative-convective equilibrium, sensitivities to the different radiative perturbations known at that time and pretty solidly grounded by studies of that time, reliance on diagnostic use of measurements to arrive at the water vapor feedback quantification and its role. All this physics was shown strikingly in the MW work. Undoubtedly, there are other significant works, but the MW paper represented pioneering science.*

Manabe and Wetherald (1967) is now cited l 186 and l 250.

*l. 108-118.: “simple” models. One essence, no matter the degree of complexity of the model, was to figure out innovatively how to set up, perform and analyze key sensitivity tests that demonstrated the significance of the science.*

This notion is conveyed l 111-112 («  the importance of physical understanding gained through theory and simple models, both for its own sake, to facilitate the distillation of scientific knowledge, and to help interpret and check the results of GCMs »), and in section 4.4 (l 579-589).

*l. 122-123: too casual; anthropogenic forcing over the next few decades may still comprise a lot of the short-lived forcings (include methane as well); it would be more accurate to point out CO2’s dominance clearly so in the latter half of the century.*

See our response to general comment #4.

*Section 3.2*

*MW laid the foundation for a generalized concept of radiative perturbations through their experiments. From my imperfect recollections, later, Dickinson and Cicerone (1982?), and then Cess (??) distilled the earlier works to lay the foundation for the ‘forcing, feedbacks, climate sensitivity’ idea, which is now a cornerstone for thinking about the global-mean problem (at least, for the LLGHGs). MW’s neat demolition of surface forcing as a measure of surface temperature response, and showing the value of TOA forcing for understanding of the response, was an important milestone.*

We agree. Manabe and Wetherald (1967) is now cited l 186 and l 250.

*l. 187-197: The validity of the Charney report forcing numbers came through the International Comparison of Radiation Codes for Climate Models (ICRCCM) project, whose first set of works (JGR, 1991; e.g., Ellingson et al) confirmed the necessary radiation fundamentals. The Collins et al. work has further solidified those notions.*

Thanks for the information. Collins et al. (2006) is cited l 200.

*l. 198-206: Radiative forcing evolution now involves several other LLGHGs and, of course, aerosols. The non-CO2 LLGHGs have grown in importance relative to CO2, with only about half the RF (present minus preindustrial) of LLGHG coming from CO2. While the physics of the climate system response to the other LLGHGs also has a similarity to the surface response due to CO2, there are differences in the midtroposphere and stratosphere.*

Non-CO2 effects are now mentionned l. 125-128 and l. 238-240.

*Section 3.4*

*l. 238-251: Much is owed to the MW paper but, just as importantly, things have changed very little because of the robustness of the Clausius-Clapeyron equation and its application.*

OK*.*

*l. 261-277: Series of confirmatory papers demonstrating the solidity of the Charney Report assessment of water vapor feedback has involved the use of satellite observations e.g., column water vapor over oceans and their linkage with temperature, and upper troposphere moistening following the understanding of relative humidity (e.g., Soden et al., Science, 2005).*

We agree. We now mention the role of observations in confirming some of the assessments of the Charney report : l 260-261: « ...while our best estimate of the magnitude of these important feedbacks has changed little since the Charney Report, considerable effort and progress has been made in establishing the robustness of the physical reasoning that underpinned their assessment, and in assessing it using observations (e.g. Soden et al. 2005).

*NO mention of aerosol-induced changes in clouds in this section??*

We did not focus on aerosol-induced changes in clouds in this section because the uncertainty in climate sensitivity does not primarily depend on cloud-aerosol interactions (the same range of climate sensitivity estimates is obtained in experiments with and without cloud-aerosols interactions). However, we added a sentence ; 272-273 :

«  Admittedly little progress has been made in narrowing the uncertainty the Charney Report ascribed to the net effects of these climate feedbacks. Discussions about the potential role of cloud-aerosols interactions in these feedbacks have even complicated the issue. But this does not imply that progress in our understanding and estimation of climate feedbacks is out of reach...etc »

*Section 4.1:*

*l. 372-373: assertive, more substantive argument would help.*

We slightly changed the formulation of the sentence.

*l. 388-390: In fact, there could be counterintuitive features which go against what a simple surface warming might lead one to believe e.g., stratospheric ozone influences, aerosol-induced influences.*

Agreed.

*l. 397-400: Importance of spatially inhomogeneous distribution of the short-lived forcing agents.*

Agreed.

*l. 416: The infamous double ITCZ in some models seems to be sensitive to spatial resolution.*

Agreed

*Section 4.2*

*l. 444: a comment could be added here about the fact that reduction of uncertainties does not necessarily follow even though there may be a better grasp of the problem.*

We convey this idea l. 273-274 : « Admittedly little progress has been made in narrowing the uncertainty the Charney Report ascribed to the net effects of these climate feedbacks. [...] But this does not imply that progress in our understanding and estimation of climate feedbacks is out of reach [...] ».

*l. 455-456: need to do even more smart diagnostic analysis (via brainware+hardware) in order to get to greater scientific understanding,*

Agreed

*l. 461: radiative transfer and chemistry within clouds affecting cloud properties.*

*Agreed*

*l. 464-465: This is the key statement. Neither simplicity nor complexity of the models need be damned, but there need to be clever sensitivity studies that power the science forward. Only then can there be praises!*

*Agreed.*

*l. 477-479: Rather pessimistic. Could be true, but you are not giving the chance to observations, understanding of models, and the diagnostic exploration together leading to sensible pushing of the envelope.*

We changed « will » in « may » to make it sound less pessimistic...

*l. 480-495: Too little attention to the forcing aspects and its temporal evolution in the 21st C.*

*Agreed*

*Recommendations*

*l. 530-541: The “complexity” necessarily involves quantifying the physics of the interactions across the different components of the systems, and on different timescales.*

*Agreed.*

*l. 542-550: There is a scope beyond just clouds and moist processes. It also has to reckon with the manner in which the “forcing” itself is characterized spatially and temporally. Also, ice albedo feedbacks interacting with the other feedbacks? Atmosphere-ocean interactions?*

Agreed. We now state : « Promote research devoted to better understanding interactions between cloud and moist processes, the general circulation and radiative forcings. » (l 561).

*l. 552-560: Missing the nuances associated with short-lived climate forcing agents.*

We agree that many other aspects would need to be improved in climate models...

*l. 562-571: Routine comparisons with reliable observations should be strengthened and sustained, along with model intercomparisons focused towards inter-model differences and causes, and the model biases with respect to observations. How to communicate the understanding along with the uncertainties will continue to be important, even more so in the future.*

We now state our last recommendation as : « Prioritize community efforts and experimental methodologies that help identify which processes are robust vs which lead to the greatest uncertainty in projections and use this information to communicate with society, to guide future research and to identify needs for specific observations. »

*Conclusions*

*l. 583: “…climate system works and changes”.*

We leave the sentence as is to avoid repetition.

*l. 585: lots of fundamental physics (and chemistry) still to be done, including rigor for that which is inadequately understood at present.*

Agreed.