U.S. Global Change Research Program

2 November 2017

To: Dr. Philip Mote (Chair) and the
NAS Committee to Review the Draft Climate Science Special Report

From: Michael Kuperberg (Executive Director, U.S. Global Change Research Program)
and the CSSR Writing Team

We want to thank the special committee convened by the National Academies of Sciences, Engineering, and Medicine for its thorough review of the Third-Order Draft of the Climate Science Special Report (CSSR). We value the consensus study report generated by the convened disciplinary experts – under tight deadlines (21 December 2016 – 13 March 2017) while juggling many other professional commitments, as all are recognized leaders in the many relevant disciplines that comprise climate science research and CSSR content. We appreciate both the statements the committee made about the report overall and the detailed analyses of where we could further clarify and/or improve the statements made in the Executive Summary and in the various chapters. The CSSR writing team took the comments very seriously and extensively revised the assessment prior to submitting a Fourth-Order Draft for a final interagency review by the Subcommittee on Global Change Research[1] (3-24 May 2017) and ultimately a Fifth-Order Draft for a final USGCRP-participating agency clearance process (21 July – 18 August 2017).

The Chapter Leads prepared short responses as to how they and their respective author teams dealt with the general comments from the NAS review. For the sake of brevity, disposition of the line-by-line comments provided as Appendix A of the NAS report has not been appended, but records remain on file at the USGCRP National Coordination Office. Since the full report underwent two additional rounds of review, edits have been made in the final draft that are not captured in the synopses that follow.

Executive Summary. An Executive Summary core writing team (CWT) extensively reorganized and rewrote the summary based on NAS input. To date, CWT meetings were held in-person at the Second and Third Lead Authors Meetings and remotely via nine teleconferences. The LAM3 session (21-22 March 2017 • Asheville, NC) focused on comments received from the NAS and public reviews. The Public Comment Period occurred in parallel (15 December 2016 – 3 February 2017). Edits reflected modifications to chapter Key Findings that "bubbled up" to the Executive Summary. The CWT also implemented guidance to generate a two-page summary of the Executive Summary to make CSSR content more accessible. In response to general guidance within Section II.3 of the NAS report, the writing team appreciated the fact that the NAS Committee felt the TOD summary was "…strong, well-written, and in most cases accurately represent[ed] the consensus and breadth of viewpoints." Subsequent revisions refined the product, including major changes to most of the figures. For example, Figure ES.1

[1] The SGCR falls under the rubric of the Committee on the Environment, Natural Resources, and Sustainability (CENRS), a component of the National Science and Technology Council (NSTC).

was redrawn to provide an easily distinguishable color for the areas where there was insufficient observational data. A new Figure ES.2 showed the human versus natural response to forcings from 1951-2010. The former Figure ES.2 depicting the scenarios used was expanded to include RCP2.6, 4.5, and 8.5. The figures for the extremes in temperature and precipitation were replaced. The nuisance flooding graphic was simplified and updated, and the Arctic figure provided a timeline of changes in sea ice areal extent from 1979 through 2016. The CWT also added material from Chapter 10 and more material from Chapter 2 as suggested by the NAS Committee. Finally, authors added a section on "What's New since the Third National Assessment (NCA3)."

Chapter 1. Extensive changes were made throughout Chapter 1 (Our Globally Changing Climate) in response to comments and suggestions from the NAS review. The NAS review recommended three major changes that were all adopted: (1) the topic of extreme event attribution, a major development over the last decade, should be discussed (paragraph added); (2) the long section on the hiatus in Box 1.1 of the CSSR TOD gave that event much more prominence than warranted (box since reduced); and (3) the chapter would be substantially easier to read with a renumbering that creates a series of top-level sections (reordered as requested). We also added additional quantitative language throughout the chapter as recommended, and provide additional chapter cross-referencing. There were questions raised about the choices of baseline periods, but the NAS reviewers had missed that those justifications were provided in the Front Matter; however, the team provided additional overall period trends as recommended anyway. The Key Findings were rewritten as suggested, and a number of other minor text changes were made to increase clarity throughout the chapter.

Chapter 2. The main issues identified for Chapter 2 (Physical Drivers of Climate Change) were (1) the need to have more emphasis on the interconnectedness of the Earth system to balance the chapter's strong focus on the atmosphere; (2) terminology/ definition issues; (3) the need for modest changes to several figures or figure captions, including updating with more recent data; (4) improved referencing in the Traceable Accounts; and (5) edits to the Key Findings. In response, authors added an introductory paragraph that includes reference to the interconnectedness of the Earth System. Land-use changes were referenced in Section 2.3 and detailed in a separate subsection. In Section 2.3.2 the authors thought it natural to discuss in detail the different anthropogenic forcings in order of importance, so descriptions of greenhouse gases and aerosols *do* precede land-use change, but an entire subsection on land-use change was added. More extensive discussion of both land and ocean changes occur later in the feedback section, since ocean changes are not directly driving forcing. The text was edited to significantly enhance the discussion of feedbacks within the Earth system to make clear the importance of these connections. We improved the definition of ERF (Effective Radiative Forcing) to be consistent with Myhre et al. (2013), and removed the use of previous aerosol terminology ("direct", "indirect", "semi-direct") from the Key Findings. We retained the usage in the main text to link previous and current usages. Figures 2.4 and 2.7 were updated to include data through 2015. Figure caption suggestions were adopted. Figure 2.2 was modified to address concerns that it appeared all changes occurred through temperature changes. Figure 2.7 was retained, and associated text improved. References were significantly enhanced in the Traceable Accounts. Suggested edits to Key Findings were made, with one exception: The team decided not to note specifically the "acceleration" in forcing from 1960 onward, but instead increased emphasis of this topic within the main text.

Chapter 3. The following substantial changes were made in Chapter 3 (Detection and Attribution of Climate Change). As recommended, a new Key Finding was added about rapid progress in event attribution science. The introduction was shortened and rewritten, and the conceptual framework of detection and attribution introduced at the beginning of Section 3.2, using global mean temperature as an example (new Figure 3.1). The denser material on methodologies in the original version of the introduction was expanded, as recommended, with additional references, and placed in an appendix on methodologies. Some recent methodological references were added, and the chapter team integrated two new figures. All specific suggested references from the NAS review were added. Further summarization of the NAS 2016 report on extremes was added, and that report referenced and paraphrased several places in the chapter. To address a number of points raised in the public review, two boxes were added to the appendix: one addressing Frequently Asked Questions about use of significance levels in attribution studies, and a second box illustrating the ingredients-based approach to event attribution using Hurricane Sandy as an example. More pointers to other chapters were added to highlight where attribution statements were made for particular phenomena. Note, however, that the overall report structure remained intact; that is, global mean temperature attribution, methodologies, and event attribution overview remained in Chapter 3, while attribution statements and discussions for most phenomena and cases were given in the individual chapters. The authors recognized that this differs from the IPCC approach, but this strategy was adopted during the Second Lead Authors Meeting and reaffirmed at LAM3.

Chapter 4. For Chapter 4 (Climate Models, Scenarios, and Projections), the NAS recommendations regarding enhancements to the evidence base were used as basis for significant revision of the structure and language of the Key Findings. Recommendations to expand the discussion of the evolution of climate modeling were incorporated both in the text and in the revised figure showing the history of climate models over the last century. Other figures were updated to include recommended content, including commitment scenarios and emissions of non-CO_2 greenhouse gases. The NAS Committee expressed concern regarding the overlap of the paleoclimate information and carbon budgets with Chapters 12 and 15. To address these concerns, the paleoclimate sea-level rise figure was moved to Chapter 12, and the section on carbon budgets removed, greatly shortened, checked for consistency with Chapter 15, and incorporated into the front matter of the chapter. The NAS Committee also expressed the desire to expand the discussion of regional climate modeling and empirical statistical downscaling. While limited by the overall size of the chapter, these sections were expanded in the specific areas mentioned, and many new references added to the citation list. Suggestions to remove or radically alter the discussion of scenarios were raised with the larger author team. Every effort was made to address the specific concerns and recommendations raised by the committee; however, the author team as a whole felt it essential to retain the discussion of both SSPs and global mean temperature targets, as the first are not well-understood by the scientific community but already in use in literature that will be cited in Volume II of the Fourth National Climate Assessment (NCA4), and the second serve as basis for new graphics used within CSSR as well as to NCA4.

Chapter 5. Changes were made in Chapter 5 (Large-Scale Circulation and Climate Variability) in response to most NAS comments. The team provided needed context to caution against interpretation that U.S. temperature and precipitation variations, which occur concurrently with the Pacific Decadal Oscillation (PDO), are indeed an impact of the PDO. Authors also indicated that the PDO does not have a

preferred time scale. Authors revised and expanded the assessment of literature in relation to the Atlantic Multidecadal Oscillation / Atlantic Multidecadal Variability (AMO/AMV). Concerns regarding the Key Findings were addressed. Specifically, Key Finding 3 (KF3) was removed and KF1 rewritten to provide a statement regarding the observed change in the tropical belt and to clarify the likelihood/uncertainty language. KF2 was also revised. We comprehensively expanded the discussion of model fidelity in simulating natural modes of variability. The team also provided clearer statements regarding knowledge on how these modes are expected to change in the future and implications for U.S. climate change. Authors decided to keep Figure 5.1, and properly referenced it in the chapter, since it was added in response to reviewer comments on an earlier draft.

Chapter 6. Almost every recommendation from the NAS review was incorporated into the revised Chapter 6 (Temperature Changes in the United States). For Key Finding 1, the change in annual average temperature was expressed as a range, as in NCA3, and the confidence statement for the material reduced to "medium." Key Finding 2 was extensively revised to focus on cold waves, heat waves, and record-setting temperatures (and the Dust Bowl called out as the peak period for extreme heat). For near-term warming, Key Finding 3 was revised to state that the rate is approximately 2.5°F for all emissions scenarios and, for late-century warming, the range for each emissions scenario provided (the range being the difference between the average for the coolest three models and the average for the warmest three models). Within the chapter itself, the material on changes in extreme heat was streamlined to ensure consistency between text, figures, and tables; the metrics were described in more detail; and a new figure was added on changes in record high and low temperatures. All but a few minor graphical and statistical recommendations were implemented, and all line-specific changes made. Finally, the Traceable Accounts were all strengthened per the suggestions of the NAS Committee.

Chapter 7. The authors of Chapter 7 (Precipitation Change in the United States) respectfully disagreed with the main NAS comment that the confidence in observed changes in extreme precipitation events was overstated. Several CSSR authors have performed extensive research in the area of observed changes in extreme precipitation events in the United States and have written a number of journal articles documenting observed changes since the early 20th century. The Westra et al. (2013) paper the panel noted was already cited in the chapter, mainly as a global analysis (with some attention paid to North America). Differences highlight the tension between analyzing heavy precipitation events by station versus area-averaging. Precipitation data at the station level are notoriously noisy for reasons such as inhomogeneities and the spatially discontinuous nature of precipitation; thus, the team opted to use area-averaging to reduce the noise and bring out the signal. That said, the Westra paper has 9% of the stations with statistically significant trends, almost double the number expected by chance. Furthermore, the Westra paper includes stations with as little as 30 years of data, which likely is a reason for the lack of more stations with statistically significant trends. Lastly, the NCA3 statement on heavy precipitation had "high confidence" in the changes and, aside from the Westra paper, the authors concluded that there is no new evidence to lead to reduced confidence in Chapter 7 conclusions. The team accepted the other main comments regarding the Key Findings and other parts of the chapter, and made the appropriate changes – including more material on snow water equivalent, the addition of complementary tables to those in the temperature chapter (e.g., 6.1, 6.2, 6.4, and 6.5), and highlighting the time periods being analyzed in figures and graphs.

Chapter 8. In Chapter 8 (Droughts, Floods, and Wildfires), a number of changes were made based on the NAS review. All of the Key Findings were revised for clarification. In particular, for Key Finding 4, the team agreed that a stronger statement was required. The discussion on floods and drought in the text were also extensively revised. After discussion amongst the full CSSR team, it was decided to move most of the wildfire discussion to Chapter 8 and an additional Key Finding was added. The team also added more material on snowpack. Regarding the California drought, the NAS Committee wrote that "existing studies do not use a sufficiently consistent formulation to lay out a clear case for attribution and this should be stated," while the team had in place "A principal attribution question regarding the precipitation deficit concerns the causes of this SST anomaly. Observational records are not long enough and the anomaly was unusual enough that similarly long-lived structures have not been often seen before. Hence, attribution statements, such as that about an anthropogenic increase in the frequency of geopotential height anomalies similar to 2012–2014 (e.g., Swain et al. 2014), are without associated detection (Ch. 3: Detection and Attribution)." And concluded with "Attribution of the California drought and heat wave remains an interesting and controversial research topic." The team felt that the NAS concern was sufficiently addressed in the chapter as it stood, but included the suggested additional citations. The NAS comments on Key Finding 3 were useful but somewhat at odds with the authors' assessment of the literature on future soil moisture. Indeed, observed increases in seasonal precipitation, as documented in Figure 8.7, lead to reduction in some agricultural drought measures. However, there is no evidence that these increases are anthropogenically forced. In fact, projections indicate little change in average summer precipitation throughout the CONUS region. Furthermore, at the end of the century under RCP8.5, CONUS summer temperature would increase to an extent that has not been experienced before in human existence. Hence, models project extensive surface soil moisture drying, not only in the CONUS, but across the planet, even in regions of projected increased precipitation. Projections of both future seasonal precipitation and soil moisture is made "without attribution" – a concept introduced in Chapter 3, specifically to describe this case. The authors agreed that the original likelihood and confidence statements were too strong because of the lack of attribution; however, the lack of an emergent anthropogenic signal does not invalidate the projection.

Chapter 9. Review comments were fully addressed in Chapter 9 (Extreme Storms). Most of the comments were of a fairly minor nature, only requiring some modifications and small additions to the text. The confidence stated in the Key Finding related to tornado activity was reduced from "high" to "medium" and the text and Traceable Account for that section modified accordingly. The figure describing tropical cyclone projections was replaced and a discussion of statistical significance added. Additional cross-chapter references were introduced.

Chapter 10. The authors of Chapter 10 (Changes in Land Cover and Terrestrial Biogeochemistry) improved and supplemented text as recommended – particularly with regard to supporting evidence for Key Findings, and ensuring better consistency between the text and derived findings. Overarching comments prompted some reorganization to clarify changes in land use/land cover and biogeochemistry forcings and feedbacks to the climate system. Two new sections were inserted after the introduction to address these topics. There were comments regarding overemphasis of albedo as a forcing and the growing season length. While the original text had included discussions regarding surface roughness and latent and sensible heat exchange, the team ensured that discussion of these additional physical attributes

of the land system received equal weight. Growing season is an emergent property of the climate system that integrates temperature and precipitation; as such, the team assessed advances and current understanding of the often conflicting aspects of changes in growing season length on land cover and subsequent interactions with the climate system. The NAS Committee also provided several comments on tree mortality and ecosystem structure that belong in the impacts volume of NCA4; nonetheless, more detail was added to the chapter to reflect how changes in land cover and subsequent biogeochemistry contribute to climate feedbacks. Concerns regarding the Key Findings were addressed. Specifically, Key Finding 1 was clarified to reflect land cover forcings to the climate system such as albedo, latent/sensible heat, soil moisture, carbon fluxes, and snow radiative forcings from changes in land cover. Inconsistencies between reference periods 1850 versus 1750 between Figures 10.2 and figures in Chapter 2 were addressed as radiative forcing data for constituent land cover/land cover change/aerosols, CO_2, CH_4, and N_2O do not extend as far back as the more aggregated categories discussed in Chapter 2. Clarity for Key Finding 2 was provided to not mislead the reader into an impact assessment but, rather, keep within the scope of the CSSR. Key Finding 2 was re-framed to address land cover and climate feedbacks. The team addressed the 'correlation is not causation' trap identified for Key Finding 3, and the text for the urban-climate forcings and feedbacks presented in Key Finding 4: Urban systems and climate coverage was updated significantly.

Chapter 11. The primary recommendations provided for Chapter 11 (Arctic Changes and their Effects on Alaska and the Rest of the United States) included improving clarity, adding additional reference to strengthen evidence, consistency with other chapters, and slight reorganization. First, all inconsistencies with other chapters were addressed. Sections that overlap with other chapters (e.g., Greenland, wildfire, permafrost, and sea level) were trimmed and proper cross-referencing inserted. Second, all Traceable Accounts were strengthened by including additional citations to support the Key Findings. For Key Finding 1, references providing observational support were added. For Key Finding 3, additional references to modeling studies were provided and several sentences added about the sensitivity of future sea ice to future emission levels. For Key Finding 4, the team elevated the likelihood statement to say that a human contribution is *virtually certain* and added that "Human activities have *likely* contributed to more than 50% of September sea ice decline since 1979." Though the NAS Committee recommended removal of Key Finding 5, authors decided to retain it to bring attention to a potential high impact outcome. A significant number of comments were made about the permafrost discussion, specifically identifying the need to strengthen the associated key finding and reorganize the section. Authors added the recommended text to the key finding and the permafrost section was reorganized by separating it from the snow cover discussion and combining it with the permafrost-carbon feedback section. Lastly, the comments indicated that authors misrepresented the results of Schädel et al. (2016). This unintended issue was addressed by changing the text to directly state the paper's main results that more carbon is released as CO_2 than as CH_4 from thawing permafrost. Lastly, the recommended references provided throughout the comments were included.

Chapter 12. As recommended for Chapter 12 (Sea Level Rise), the dates/time intervals used to describe sea level rise (SLR) change were made more consistent (e.g., 1900 to 2000 and 1993 to present). An expanded discussion of the mid-Pliocene warm period was added, and the former Figure 4.3 (showing paleo temperature, sea level, and CO_2 levels) moved to Chapter 12. Because the mid-Pliocene warm

period likely had CO_2 concentrations comparable to current levels, this element was retained in the graphic. The range of rates of future SLR associated with six new interagency scenarios was discussed for the 2100-2150 period. The chapter emphasized that North America faces greater risk from ice loss in Antarctica than from ice loss in Greenland. Further, the loss of marine-based ice (e.g., in West Antarctica) was cast as a long-term commitment, due to the slow thermal response (cooling of the ocean). Additional discussion providing alternative views of Antarctica's potential contribution to future SLR was included for completeness. Discussion regarding the anthropogenic influences on SLR was expanded, and a figure showing the counterfactual (no 20th century warming) projections inserted. The spatial pattern of recent and ongoing thermosteric (e.g., within Western Pacific) and ocean dynamical (e.g., recently along East Coast) SLR were further discussed in terms of impacts from such variability. Authors highlighted that the large land ice contribution to SLR (relative to thermosteric) since 2005 represents a departure from the relative contributions earlier in the 20th century. More discussion was included about land-water storage effects on sea level, while highlighting that the term's contribution is modest in all estimates.

Chapter 13. As per the NAS Committee recommendation, Chapter 13 (Ocean Acidification and Other Ocean Changes) better described ocean heat content and ocean circulation, linking this chapter to broader climate system changes. The chapter as a whole was rewritten to simplify the material for those with and without knowledge of oceanography. More specifically, effort was made to clarify the discussion of ocean acidification and the terms used within that section. Review of the literature post-2013 was used to develop the ocean circulation/AMOC paragraphs and to better represent a complete view of the evidence. In addition, a more thorough analysis of upwelling with additional citations was included. Other chapters' information was incorporated into the ocean chapter to improve consistency and linkages across the report. The Key Findings were restructured and justification for confidence levels strengthened. Key Finding 1 was split into multiple findings, and more evidence was included to underpin the findings for AMOC, upwelling, ocean heat content, and deoxygenation. Ocean circulation and ocean heat content were moved into separate sections. Instead of one Key Finding for all projected changes to the ocean, projected changes were incorporated into the associated current findings. Finally, new graphics were added that reflect regional changes to sea surface temperatures and ocean heat content.

Chapter 14. Comments and suggestions from the NAS review for Chapter 14 (Perspectives on Climate Change Mitigation) were incorporated into the revised draft. The authors agreed with the NAS comment that the chapter needed to make clear "what could be the chapter's central point: a consequence of the essentially permanent nature of warming from CO_2 is that stabilization of CO_2 at any given concentration can only be achieved if CO_2 emissions fall to zero or become negative." In combination with material already in the chapter (including a figure demonstrating this concept), the team added text to explicitly and prominently address this overarching comment, both within the Key Findings and in the underlying chapter. The authors understood the reasoning for the NAS comment to frame the "mitigation challenge as one of risk," including both the "risk of impacts at any level of warming" and the "probability that a given emissions trajectory holds warming below a given goal." The authors addressed this comment with minor changes to text. To more fully discuss risks associated with any future warming levels would go beyond the scope of CSSR and encroach on content better suited for the second volume of NCA4 on impacts. The authors agreed with the NAS comment (and similar public comments) that not enough attention was paid to non-CO_2 species. To that end, the team added text to both the chapter and the Key

Findings, supported by new references, to better address the differential climate effects of CO_2 versus other key non-CO_2 species, and the implications of these differences for mitigation pathways. This included use of a 790 (rather than a 1,000) cumulative carbon budget that is compatible (with two-thirds likelihood) with the objective of limiting warming to below 2°C. The 790 GtC estimate, according to IPCC AR5, takes into account the non-CO_2 forcing, whereas the 1,000 GtC estimate considers CO_2 forcing only. Finally, the Key Finding about solar geoengineering was re-crafted, taking into account specific language offered in the NAS review.

Chapter 15. For Chapter 15 (Potential Surprises: Compound Extremes and Tipping Elements), the team restructured the introduction to lead with a focus on the Earth system as a complex dynamic system with both positive and negative feedbacks. The new approach explained why positive feedbacks are more relevant than negative feedbacks to the topic of potential surprises. The new introduction also more directly discussed known unknowns vs. unknown unknowns, and highlighted lessons from paleoclimate. Although some of the NAS comments suggested venturing into a more thorough discussion of risk management, this topic was deemed more appropriate for the second volume of NCA4. A number of other changes were made throughout the text, including the Key Findings, for further clarification.

General Comment. In response to the general comment made by the NAS Committee to "provide sufficient detail for values and plots to be reproducible," the CSSR work plan included this requirement from the start. Metadata have been collected for all figures in the report following the ISO 19115 standard which includes the necessary information to achieve reproducibility. For NCA3, a subset of the metadata was accessible to readers of the online version of the report. The metadata viewer for that report extracted information from the Global Change Information System (GCIS). The dedicated CSSR web site will make the <u>full</u> metadata collection available to users via (1) expanded GCIS data fields, (2) transfer software so that all ISO 19115 metadata fields are stored within GCIS itself; and (3) a new metadata viewer.