Climate Change Research Roadmap Annual Report FY16

October X, 2016

Contents

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Abbreviations and Acronyms

ACE	Air, Climate, and Energy research program (ORD)
EPA	U.S. Environmental Protection Agency
GHG	greenhouse gas
HHRA	Human Health Risk Assessment research program (ORD)
HSRP	Homeland Security Research Program (ORD)
OAR	Office of Air and Radiation (EPA)
ORD	Office of Research and Development (EPA)
OW	Office of Water (EPA)
PACT	Partner Alliance and Coordination Team
SHC	Sustainable and Healthy Communities research program (ORD)
SSWR	Safe and Sustainable Water Resources research program (ORD)
StRAP	Strategic Research Action Plan
USGCRP	U.S. Global Change Research Program

Executive Summary

The Climate Change Research Roadmap (Climate Roadmap) Annual Report is a snapshot of some of the key accomplishments, changes, and challenges that have occurred over the past year. Programmatically, 2016 has been a year of substantial effort to refine and implement the Strategic Research Action Plans (StRAPs) for the Office of Research and Development's (ORD) six National Research Programs and the four crosscutting research roadmaps, including the Climate Roadmap. The Climate Roadmap has undergone a major revision in response to comments from the Board of Scientific Counselors, with the goal of more effectively highlighting current issues in the context of future challenges. It also was revised to better describe the numerous and dynamic interactions among our U.S. Environmental Protection Agency (EPA) partners in Regional and Headquarters Offices, research colleagues in other Federal agencies, and our stakeholders across public and private sectors.

This Annual Report describes selected research accomplishments from across ORD's research programs, which cover a broad range of climate-related research topics of importance to EPA's ability to carry out its mission of protecting human health and the environment. These accomplishments include research on the impacts of climate change on human health; studies of the effects of climate change on watersheds, estuaries, and nearshore environments, with ultimate impacts on water quality and aquatic ecosystems; expanded understanding of the links between air quality and a changing climate; evaluation of current and possible future greenhouse gas emissions; and approaches to facilitate local decision-making on responses to climate change. The most notable of these accomplishments is the publication of *The Impacts of Climate Change on Human Health in the United States*, a product of the U.S. Global Change Research Program (USGCRP), the key findings of which relied on original ORD research.

The cross-EPA interactions associated with developing the revised StRAPs and roadmaps have highlighted the expanding opportunities for integration, interaction, and communication among the research programs, partners, and other agencies on climate change. New venues for interaction, including the topic-level Partner Alliance and Coordination Teams (PACTs) have been initiated to complement the existing cross-program PACT and other communication channels.

A significant indicator of the value of these interactions, including the roadmap revision efforts, is that the recent areas of research emphasis—the climate-health and climate-water quality assessments, wildland fires and integration of social sciences into that research, and emissions of methane—are all the product of substantial cross-program, cross-EPA, and cross-Agency interactions and coordination. The dedication of people from across ORD's research programs and EPA's Headquarters and Regional Offices in developing these research areas specifically, and the PACTs more broadly, reflects the commitment across EPA to work in concert to guide, develop, and apply ORD's climate-related research.

While the expanded interactions and communications have led to growing awareness and consideration of the impacts of climate change across ORD's programs and EPA's activities more broadly, they have also highlighted the growing need for information on, and understanding of, climate change and responses to its impacts. The consideration of climate change impacts as an additional stressor in non-

climate research areas has expanded the capability of ORD to meet the growing needs, but an increase in capacity has not occurred that would allow ORD to meet the growing demand for continuing needs for research in other areas.

I. Accomplishments

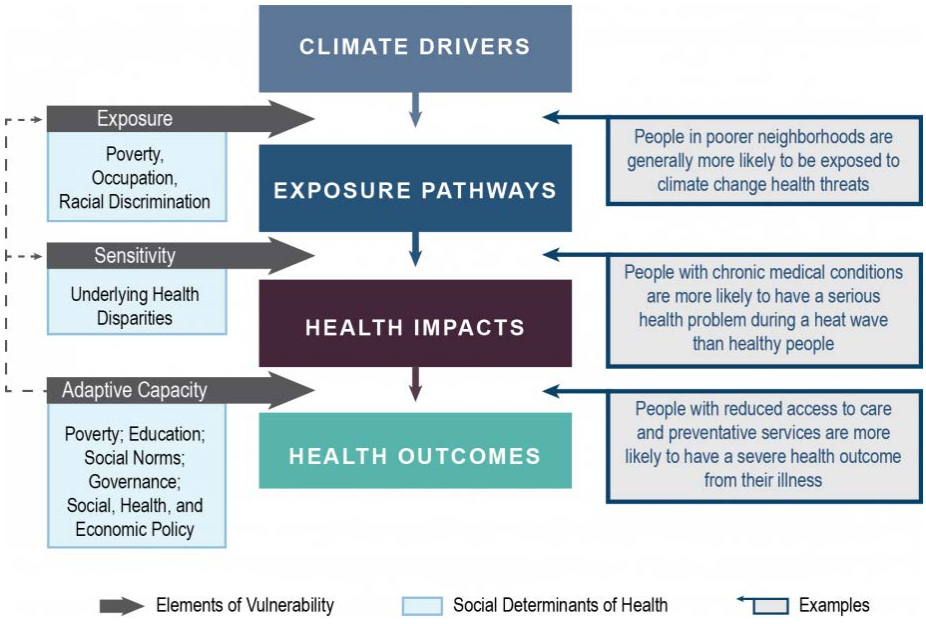
A. Impacts

The past year has been successful for climate research and integration across the U.S. Environmental Protection Agency (EPA) and its Office of Research and Development (ORD). The record of publications and presentation materials, growing collaboration across research programs, greater interactions with EPA partner offices, and development of research plans to meet future needs all point to the progress of the Climate Change research program in 2016. With the issue of climate change receiving greater national and EPA emphasis, the development of the 2016–2019 Strategic Research Action Plans (StRAPs), and the cross-Agency discussions on climate research needs and concerns, consideration of climate change is much more common across ORD's National Research Programs.[*] In addition, individual research activities are more integrated than they were immediately following the restructuring of ORD's research programs. Collaboration on climate change topics by researchers across programs, Laboratories, and Centers has increased. Initiation of the Partner Alliance and Coordination Teams (PACTs) has increased the opportunities for cross-Office and cross-Program coordination and communication, including substantially greater interactions with Regions. ORD is closely involved in key Agency activities related to emissions measurement, water quality, and benefits of climate policy actions. Researchers focused on climate change are playing key roles in efforts to integrate social sciences into studies on the risks of wildfires.

The most visible accomplishment of climate change research was the publication of *The Impacts of Climate Change on Human Health in the United States* by the U.S. Global Change Research Program (USGCRP) [1]. Key findings of this assessment relied on original research conducted by ORD, and the entire effort was aided by substantial ORD and EPA efforts from planning through development, review, and publication. Fifteen EPA experts were chapter leads or contributing authors, with additional EPA and ORD staff participating in the assessment's planning and review.

Seventeen research grants totaling more than $4.5 million annually were awarded over the past year across several research programs on topics ranging from life-cycle costs of water infrastructure alternatives, including impacts of extreme weather events, to effects of climate change on particulate matter. These grants are in addition to the $6-million annual funding to support three new Air, Climate, and Energy (ACE) Research Centers, which are multidisciplinary centers formed to investigate the effects of climate change, technology, and societal choices on local and regional air quality and health. The Centers are located at Carnegie-Mellon University, Harvard University, and Yale University. The grants will enable examination of how changes in emissions, climate, and other factors affect pollution mixtures, investigation of emerging energy transitions in the United States and factors contributing to air pollution and health outcomes, and evaluation of a range of technology and policy scenarios for addressing the Nation's air, climate, and energy challenges at national and regional scales.

[*] The six programs are: Air, Climate, and Energy (ACE); Chemical Safety for Sustainability (CSS); Human Health Risk Assessment (HHRA); Homeland Security (HSRP); Sustainable and Healthy Communities (SHC); and Safe and Sustainable Water Resources (SSWR).



Intersection of Social Determinants of Health and Vulnerability, from Chapter 9: Populations of Concern, in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* [1].

The year also marked the culmination of several years of research on the environmental impacts of expanded production and use of biofuels. Twelve journal articles were published on emissions and associated health impacts of biodiesel and ethanol-gasoline blends; a special issue of *Inhalation Toxicology* highlighted ORD's work on the potential toxicity of emissions from engines using biofuels [2]. These results have been of substantial interest to EPA's Office of Air and Radiation (OAR) as they evaluate the overall impacts and value of their biofuel policies. Additional research results are expected, and EPA is proceeding to develop the second triennial Report to Congress on the environmental impacts of biofuels in 2017. The pace of publication set in 2016, however, will slow considerably as research priorities change in the coming year in response to changing budgets. Efforts on biofuels have decreased, with the focus turning to assessing potential impacts of climate change and human health.

Finally, discussions with the Board of Scientific Counselors over the course of the year and their comments on the Climate Roadmap led to a substantial revision of the Roadmap. The process of developing and reviewing the revised draft and responding to input from across EPA provided an excellent means of communicating key ideas and perspectives on climate-related research directions.

Roadmap Recommendations Incorporated into Strategic Research Action Plans

The Climate Roadmap emphasized the importance of cooperation across Federal agencies, EPA Offices, and ORD research programs. This cooperation was critical to USGCRP's successful publication of the assessment of the health impacts of climate change. OAR was co-lead of the assessment development, and ORD was essential in conducting new research to evaluate the human health impacts of climate

change. The cross-EPA and interagency connections formed as the assessment was developed have been mutually beneficial: efforts within ORD to evaluate climate change impacts on human health have increased, focusing on areas that need additional research, and OAR is gaining useful information on the benefits of their efforts to reduce greenhouse gas (GHG) emissions.

Similarly, current work to assess the impacts of climate change on water quality began with discussions between ORD and EPA's Office of Water (OW) to identify critical topics that needed to be addressed. Following development of OW's National Water Plan, ORD and OW staff met to identify issues and questions about the impacts of climate change on water quality, which has fostered ongoing dialog on the key issues, including streamflow, water temperature, nutrients, sediment, pathogens and harmful algal blooms, sea level rise and saltwater intrusion, and aquatic communities. Experts on these topics were identified from both Offices to guide and, where appropriate, contribute to the development of the assessment. OW's participation has been critical in implementing the vision of the assessment, which is intended to discuss explicitly how scientific understanding can be incorporated into regulatory actions and policy decision at the State, Tribal, and local levels. Development of the assessment is continuing, with input from across multiple ORD research programs and OW Offices.

A method for surveillance of fugitive methane emissions was shown to perform well when tested against a limited data set of controlled methane releases [3].

An additional example of cross-EPA activity is the effort to improve our understanding of methane emissions. ORD and OAR are working together to ensure research activities are consistent with OAR's programmatic needs related to air quality and GHG emissions. Insights from ORD field studies are helping OAR interpret information on methane emissions information gathered from industry [3]. Expertise on nutrient-driven processes in temperate water bodies is leading to a greater understanding of methane emissions from reservoirs, which is being incorporated into Intergovernmental Panel on Climate Change discussions of global emissions [4]. Such efforts are allowing EPA to take a leadership role in interagency actions to improve inventories of methane emissions and approaches for reducing those emissions.

At the interagency level, ORD researchers are working with researchers from the Department of Energy on topics ranging from cookstoves to energy technology scenarios and with experts from the National Aeronautics and Space Administration with climate modeling data for use in developing downscaling techniques. ORD investigators are working with those from the Centers for Disease Control and Prevention, the National Institutes of Health, and the National Oceanic and Atmospheric Administration to build on the recent assessment of climate change on human health. Others are collaborating with National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, and State agencies to gain a better understanding of methane emissions. These research activities with interagency connections are but a few examples of the extent to which ORD's researchers interact with colleagues in other agencies; additional discussions and coordination occur through formal interagency working groups under USGCRP and other Federal coordinating bodies and through extensive personal communication networks.

Ongoing Activities across Research Programs

Dynamically downscaled fields may be more reliable than larger-scale fields for water resource applications (e.g., water storage within reservoirs) [6].

An emerging area of cross-program research is the effort to incorporate downscaled climate data into hydrology modeling work. Global and annual projections of climate parameters (e.g., temperature, precipitation) are computed at spatial and temporal scales too large for use in hydrology or air pollutant transport and chemistry models. These projection results are downscaled using several techniques to estimate meteorological parameters at scales over time and spatial resolutions that can be used to evaluate the impacts of climate change on water and air quality. Downscaling approaches developed within ACE to project changes in meteorological parameters under different scenarios of climate change [5,6] are being applied to hydrology modeling research in the Safe and Sustainable Water Resources (SSWR) research program to understand more fully how climate change might affect water quality.

ORD is conducting research across ACE, SSWR, and the Sustainable and Healthy Communities (SHC) research program related to the impacts of climate change on coastal ecosystems. Studies of coastal acidification, increasing water temperatures, and sea level rise [7] are underway, including several efforts focused on specific issues of concern to Regional Offices. For example, research through the Regional Applied Research Effort program is addressing ecological health of shellfish in New England (Region 1) and climate adaptation in the San Juan Bay estuary and enhancement of ribbed mussel populations in mid-Atlantic salt marshes (both Region 2).

Additional efforts to support adaptation at the community level are illustrated by efforts to develop resilience indicators, with research from ACE, SHC, and the Homeland Security Research Program (HSRP), including a demonstration of indicators for the Washington, DC urban area [8]. Efforts through the Regional Applied Research Effort program are incorporating climate change into resiliency planning in Regions 2 and 6.

Research is ongoing to understand the influences of climate change and health and environmental effects of wildland fires, which are expected to increase in frequency and magnitude as the climate changes. Researchers in ACE are studying wildland fire emissions and evaluating health impacts of exposure to wildfire smoke. Experts in Regional and EPA Headquarters offices are evaluating methods to account adequately for the effects of fires on air quality compliance decisions [9]. The work in ACE is complemented by efforts in SSWR to increase our understanding of how water quality might be affected directly by fires and indirectly by runoff from fire-damaged landscapes. These efforts are of interest to HSRP, the Human Health Risk Assessment (HHRA) research program, and SHC, given the implications of fires for emergency response, health, and debris generation and solid waste management.

The recognition that the carbon and nitrogen cycles are interconnected, and both depend on climate conditions, is the impetus behind research in ACE and SSWR to understand how climate change can affect nutrient-related water quality issues and nitrogen deposition onto vegetation and land [10,11].

Climate-driven impacts on deposition are of interest to HHRA as they develop assessments of the ecosystem effects of nitrogen.

Research in SSWR to evaluate approaches and benefits of green infrastructure and stormwater management is closely linked to efforts within ACE to understand the impacts of climate change on water infrastructure [12]. SSWR, ACE, and SHC also are working in concert to examine the connections between nutrient management and climate change, including effects on the carbon cycle and emissions of GHGs. These three programs also contribute research to refine our knowledge of the links between water and energy, including changes in water demand as energy production technologies are changed to decrease GHG emissions, impacts of biofuel production on water demand and water quality, and reduction of GHG emissions from water treatment systems [13,14].

A new version of the Integrated Climate and Land Use Scenarios tool was completed for public review in 2016 [15]. The update incorporates numerous improvements to the underlying models representing changes in migration, transportation, and sectoral growth, and is consistent with the global Shared Socioeconomic Pathways scenarios and Representative Concentration Pathways.

Additional research efforts in ORD are less explicitly crosscutting, but nonetheless influenced by the development and discussion of the strategic issues addressed in the Roadmap. Research on harmful algal blooms in SSWR includes evaluating the effects of increasing water temperature. Development of life-cycle assessment methods and studies of adaptive governance [16] in SHC are relevant to climate mitigation and adaptation research and are informed by other climate-related research results across ORD. ACE research to understand how extreme heat might affect responses to air pollutant exposures [17,18] has implications for community response and resilience, a focus of the SHC research program.

Increases in ozone because of climate change result in an increase in mortality burden. Mortality attributed to ozone exceeding 40 ppb increases by 7.7% (1.6–14.2%) [17].

Research within ACE to evaluate the performance of cookstoves and the potential health impacts of their emissions is continuing. Several performance test reports on individual stove designs [19] have been developed based on a testing protocol developed with substantial ORD input and guidance.

Outreach to Partners and Stakeholders

Within EPA, several efforts have been initiated to improve outreach to and coordination with our partner Offices. PACTs bring together representatives from across EPA to enable exchange of perspectives on research needs and directions, discussion of research results, and identification of opportunities for collaboration and integration. The initial PACT meetings related to climate topics were held in summer 2016 with participants from Regional and Headquarters Offices and ORD National Research Programs, Laboratories, and Centers. The meetings are scheduled to continue on a monthly or quarterly basis. The members of the climate-related PACTs are listed in Appendix B.

In addition to the PACTs focused on climate-related research activities, a cross-EPA advisory group[†] has been initiated by ORD to facilitate monthly EPA program-level discussions on climate research issues. This group will provide perspectives on USGCRP's development of interagency climate change research priorities (submitted to the Office of Management and Budget to guide Federal research directions) and discuss intra-Agency strategic research directions for ORD's climate-related research across the National Research Programs.

Data from ORD's internal Scientific and Technical Information Clearance System are used as a means to ensure that our partners are informed about the full range of climate-related research activities underway within ORD. Monthly summaries of climate-related papers, reports, presentations, posters, and other research products prepared for release outside EPA are provided to the partners to ensure they are aware of ORD's work products and external presentations. Since the second half of 2014, partners have received notification of more than 600 research products and have requested additional information for about 100 of them. Not only do these data provide information on the range of climate-related research across ORD, they also can provide insights into cross-Program interactions by analyzing author networks.

Interagency Coordination

ORD has led the efforts to ensure EPA's research needs are communicated to the broader community of Federal climate research and to link that community's results with users in EPA. ORD staff were part of the team that developed the triennial update to the USGCRP Strategic Plan that guides the Federal climate research portfolio and led the cross-EPA review of that update. ORD staff have been closely involved in the development of the fourth quadrennial National Climate Assessment, including membership on the Steering Committee. ORD also has worked with other interagency bodies, including the Subcommittee on Disaster Reduction and the Air Quality Research Subcommittee (both under the National Science and Technology Council's Committee on Environment, Natural Resources, and Sustainability) to communicate interagency research needs and directions related to climate-driven changes in extreme weather impacts and wildfires. ORD also participates on an interagency group to coordinate Federal measurement and monitoring of methane emissions. This effort, which involves close interaction with OAR, has facilitated our participation in an interagency effort to evaluate the response to the Aliso Canyon methane leak in California.

ORD has provided input to interagency guidance on climate-related activities, including for the development of the Interagency Environmental Justice Workgroup's Climate Impacts Subcommittee and presentation of several climate-focused research efforts in ORD for possible international collaboration at a White House science summit on the Arctic held in September 2016.

[†] Group members include Rona Birnbaum, Pat Dolwick, Lisa Bacanska, and Allison Crimmins of OAR; Karen Metchis and Jeff Peterson of OW; Marc Thomas of OLEM; Ken Mitchell (lead Region representative); Joe Williams and Anne Rea (SSWR); Emily Snyder (HSRP); Andrew Geller (SHC); John Crowden (CSS); Annie Jarabek (HHRA); Anne Grambsch and Chris Weaver (NCEA); Sherri Hunt, Vito Ilacqua, and Darrell Winner (NCER); Gayle Hagler (NERL); Lisa Baxter and Peter Beedlow (NHEERL); and Carlos Nuñez (NRMRL).

Emerging Issues and Advisory Committee Recommendations

ORD has made considerable progress in responding to recommendations from advisory committees and identifying emerging issues related to its climate-related research. Increased emphasis has been placed on research related to climate change and health, because of both increased awareness of the issue across ORD and as an outgrowth of the successful cross-EPA and interagency collaborations on the USGCRP Climate-Health Assessment. We are also taking steps to expand opportunities to integrate social sciences into climate research, from expanding connections to research on community resilience and decision-making to discussions of approaches to increase emphasis on valuation and damage functions as a means to better quantify the benefits of avoided climate impacts.

ORD also led an effort to raise awareness of recent studies suggesting sea level rise could occur substantially more rapidly than previously estimated, by identifying this issue for discussion by an internal, cross-EPA strategic horizon-scanning effort. The information was presented by the horizon-scanning group in a briefing to the EPA Deputy Administrator as one of several issues worthy of further evaluation and increased awareness across the Agency. A subgroup of the Cross-EPA Climate Adaptation Working Group, led by EPA's Office of Policy, is being formed to incorporate updated sea level rise projections into Regional and Headquarters Office adaptation plans over the coming year.

Antarctica has the potential to contribute more than a meter of sea-level rise by 2100, if emissions continue unabated [23].

B. Current list of products and peer-reviewed publications

Between July 2015 and June 2016,[‡] more than 360 climate-related research products were submitted for internal review, including journal articles, book chapters, EPA reports, presentations, posters, and abstracts. During the same period, 62 articles by ORD authors and co-authors related to climate change were published in peer-reviewed journals, with 52 more submitted for internal review before journal submission. Over the same period a year earlier, 39 articles were published. The published articles are listed by topic area in Appendix A.

C. Encouraging Innovation

We participated in ORD's efforts to develop open-source challenges that seek innovative solutions from the public to difficult problems or approaches to provide information to the public, using a competition format to identify the best solutions. An open-source challenge related to climate change was developed soliciting ways to present community-level comparisons of local temperature, precipitation, and GHG concentration information to long-term averages and extremes. The information would be made available at community gathering places such as parks or community centers, with the goal of informing the public about how their current weather compares to past—and possibly projected—climate conditions, and how their local GHG concentrations compare to average ambient levels. The

[‡] This period was chosen to reflect the most recent full year of publication data available to meet the Annual Report development and review schedule.

challenge also seeks to incorporate citizen science opportunities to report local observations of seasonal plants and animals, which would provide input into databases such as those maintained by the National Phenology Network. Although this challenge was not selected among those to be presented seeking public solutions, it has been chosen as an option for inclusion in the broader ORD efforts on sensors.

D. Challenges & Opportunities

Cross-Roadmap Interactions

Several opportunities have arisen to coordinate climate-related research activities across ORD roadmaps. Information from the Climate Research Roadmap was incorporated into the discussions of the Climate Impacts Subcommittee of the Federal Interagency Working Group on Environmental Justice. The goals of the Subcommittee include ensuring vulnerable populations are considered in all agency activities regarding climate adaptation and providing relevant tools, systems, and policies to communities and businesses needed to mitigate impacts on natural resources and human health due to climate change. Both goals involve research coordinated under the Environmental Justice and Climate Research Roadmaps.

Research to evaluate the impacts of climate change on the nitrogen cycle connects the Climate Roadmap and the Nitrogen and Co-Pollutant Roadmap. Several research products were developed that address the interactions between the nitrogen and carbon cycles, including impacts of and on climate change, and research to gain insight into the potential change in nitrogen emissions as a consequence of changing energy technologies [20,21]. Additional research conducted under the SHC research program incorporated the impacts of climate change into a multimedia modeling approach to evaluate effects of nitrogen deposition and runoff on ecosystem services [22].

Interest in and research on the health impacts associated with a changing climate have grown in recent years, as demonstrated by the development of the USGCRP climate-health assessment. This assessment included discussions of vulnerable populations, including children. Children's environmental health issues are further addressed in the Climate Roadmap through the Science to Achieve Results grants awarded to investigate links between climate change and indoor air quality.

Changes in the Broader Scientific and Policy Landscapes and Impact on Research Directions

Recent studies indicating the potential for a significant increase in the rate of sea level rise resulted in discussions with OW, OAR, and the Office of Policy on approaches for considering potentially higher sea levels [23,24] in Agency adaptation plans, should further evaluation of the science so warrant. This topic was incorporated into internal EPA horizon-scanning efforts, as noted above.

Over the past year, EPA's efforts to take action on climate change have maintained their general direction and do not indicate a need to change overall research directions significantly. Agency emphasis on implementing its climate change policies have increased substantially, especially in the Regions, along with providing the information needed for informing and advancing implementation. For example, ORD has provided key support in addressing the need for improved understanding of methane

emissions sources, including work to develop and evaluate remote sensing methods for methane sources. ORD is continuing to work with OAR and the Regions to identify opportunities for further research on methane emissions and to develop coordinated perspectives on research needs that other agencies can address.

The increased Administration emphasis on climate change has led to a growing demand for information on the impacts of, and responses to, climate change from across EPA internal partners and external stakeholders. Because much of this information is developed by climate researchers in other agencies and institutions, the demand is coupled with a need for guidance on how to evaluate and appropriately apply the information in the context of EPA activities. This increased demand requires no change in the overall research direction, but it does affect our ability to address the portfolio of priority research needs. The growing demand includes research that addresses topics beyond those historically conducted in ORD research programs, such as in the social sciences.

II. The Year Ahead

Over the coming year, emphasis on several research areas, including wildland fire and social sciences, is expected to increase. A recent internal workshop was held to discuss programmatic and research activities across EPA related to these topics, and additional workshops are scheduled to take place in Region 8 to identify approaches for integrating social sciences into wildland fire research. The workshops are designed to build connections across EPA to enhance collaboration on wildfires by drawing on the expertise and perspectives from across Offices and programs. The workshops are also expected to help evaluate how integration of social sciences can be put into practice and whether that integration has measurable impacts on outcomes of importance to EPA.

In addition, research focused on links between climate change and health impacts is expected to expand in the coming year. Potential efforts include evaluating combined exposure to heat and environmental stressors such as ozone or particulate matter and continuing work to evaluate health impacts of extreme weather events [25,26]. Some of the initial work in the ACE Research Centers under the Science to Achieve Results program is expected to emphasize climate and health.

Additional progress is anticipated on providing guidance in the selection and application of climate projection data appropriate for use for particular parameters, such as projected precipitation, in specific locations. Several efforts are underway within ORD and other agencies to provide information regarding how to select from the wide range of climate model projection data and scenarios when evaluating the impacts of climate change in a given location and how to interpret the variability in the projections in the context of adaptation planning or regulatory requirements.

Sea level rise also is expected to be a topic of concern over the coming year given recent studies that estimate sea levels to rise more rapidly than recent assessments suggest. Should recent studies warrant adjustment in sea level rise projections, adaptation plans will need to be reviewed to determine whether the risks should be reevaluated.

Discussions of impact quantification are expected to continue, with a focus on improving the damage functions associated with various levels of climate change. This work will be increasingly important for informing estimates of avoided impacts, or benefits, of GHG mitigation options.

Given the 2018 publication date for the fourth National Climate Assessment quadrennial report, ORD will assist by writing and reviewing assessment chapters, particularly those focused on health, air quality, and water quality.

Programmatically, the coming year is expected to yield considerable insight into using the PACTs as a means of interaction between ORD and our partners. As the participants gain experience with this approach to broad-based and ongoing interaction on the various research topics, the participants from across ORD and the Agency are anticipated to gain a deeper understanding of the ongoing research and its needs.

Initial discussions are underway to determine whether additional cross-ORD/partner interaction on climate research issues is needed, possibly through a face-to-face meeting or workshop. Such an effort involves substantial investment in time and finances; discussions will continue as venues for interaction, such as the PACTs, evolve.

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17. Wilson, A., B.J. Reich, C.G. Nolte, T.L. Spero, B. Hubbell, and A.G. Rappold (2016). "Climate change impacts on projections of excess mortality at 2030 using spatially varying ozone-temperature risk surfaces." *Journal of Exposure Science and Environmental Epidemiology*, doi: 10.1038/jes.2016.14.

18. Hampel, R., S. Breitner, W. Kraus, E. Hauser, S. Shah, C. Ward-Caviness, R. Devlin, D. Diaz-Sanchez, L. Neas, W. Cascio, A. Peters, and A. Schneider. "Short-term effects of air temperature on plasma metabolite concentrations in a cohort of cardiac catheterization patients." *Environmental Research* (submitted).

19. Jetter, J., and S. Ebersviller (2016). Test Report – InStove 60-Liter Institutional Stove with Wood Fuel – Air Pollutant Emissions and Fuel Efficiency, U.S. EPA, National Risk Management Research Laboratory, March 2016.

20. Loughlin, D., K. Kaufman , B. Keaveny, and A. Macpherson, "Regional and sectoral marginal abatement cost curves for NOx incorporating controls, renewable electricity, energy efficiency and fuel switching," presented at the 14th Annual Community Modeling and Analysis System Conference, Chapel Hill, NC, October 5–7.

21. T.L. Greaver, C.M. Clark, J.E. Compton, D. Vallano, A.F. Talhelm, C.P. Weaver, L.E. Band, J.S. Baron, E.A. Davidson, C.L. Tague, E. Felker-Quinn, J.A. Lynch, J.D. Herrick, L. Liu, C.L. Goodale, K.J. Novak, and R.A. Haeuber. "Ecological responses to nitrogen are altered by climate change," *Nature Climate Change* **6**(9): 836-843.

22. Cooter, E., L. Ran, and J. Bash (2016). "Response of a one-biosphere nutrient modeling system to regional land use and management change," presented at the International Society for Ecological Modelling Global Conference, Baltimore, MD, May 8–12.

23. DeConto, R.M, and D. Pollard (2016). "Contribution of Antarctica to past and future sea-level rise," *Nature* **531**: 591–597, doi:10.1038/nature17145.

24. Hansen, J., M. Sato, P. Hearty, et al. (2016). "Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous," *Atmospheric Chemistry and Physics* **16**: 3761–3812.

25. Crooks, J.L., W.E. Cascio, M.S. Percy, J. Reyes, L.M. Neas and E.D. Hilborn (2016). "The association between dust storms and daily non-accidental mortality in the United States, 1993–2005." *Environmental Health Perspectives*, doi 10.1289/EHP216.

26. Jagai, J.S., Q. Li, S. Wang, K.P. Messier , T.G. Wade, and E.D. Hilborn (2015). "Extreme precipitation and emergency room visits for gastrointestinal illness in areas with and without combined sewer systems: An analysis of Massachusetts data, 2003–2007." *Environmental Health Perspectives* **123**(9).

Appendix A. Climate-Related Journal Publications by Topic, July 1, 2015-June 30, 2016

Appendix A. Climate-Related Journal Publications by Topic, July 1, 2015 – June 30, 2016
Adaptation
Hughes, S. (2015). "A meta-analysis of urban climate change adaptation planning in the U.S." Urban Climate 14, Part 1: 17–29.
Air Quality Modeling
Bowden, J.H., K.D. Talgo, T.L. Spero, and C.G. Nolte (2016). "Assessing the added value of dynamical downscaling using the standardized precipitation index." *Advances in Meteorology* 2016: 14.
Gan, C.M., J. Pleim, R. Mathur, C. Hogrefe, C.N. Long, J. Xing, D. Wong, R. Gilliam, and C. Wei (2015). "Assessment of long-term WRF–CMAQ simulations for understanding direct aerosol effects on radiation 'brightening' in the United States." *Atmos. Chem. Phys.* 15(21): 12193–12209.
Hogrefe, C., G. Pouliot, J. Xing, J. Flemming, S. Roselle, R. Mathur, and S. Galmarini (2016). Global and Regional Modeling of Long-Range Transport and Intercontinental Source-Receptor Linkages. *Air Pollution Modeling and its Application XXIV*. G.D. Steyn and N. Chaumerliac. Cham, Springer International Publishing**:** 245–250.
Seltzer, K.M., C.G. Nolte, T.L. Spero, K.W. Appel, and J. Xing (2016). "Evaluation of near surface ozone and particulate matter in air quality simulations driven by dynamically downscaled historical meteorological fields." *Atmospheric Environment* **138**: 42–54.
Spero, T.L., C.G. Nolte, J.H. Bowden, M.S. Mallard, and J.A. Herwehe (2016). "The impact of incongruous lake temperatures on regional climate extremes downscaled from the CMIP5 Archive using the WRF Model." *Journal of Climate* **29**(2): 839–853.
Xing, J., R. Mathur, J. Pleim, C. Hogrefe, C.-M. Gan, D.C. Wong, C. Wei, and J. Wang (2015). "Air pollution and climate response to aerosol direct radiative effects: A modeling study of decadal trends across the northern hemisphere." *Journal of Geophysical Research: Atmospheres* **120**(23): 12,221-212,236.
Xing, J., J. Wang, R. Mathur, J. Pleim, S. Wang, C. Hogrefe, C.-M. Gan, D.C. Wong, and J. Hao (2016). "Unexpected benefits of reducing aerosol cooling effects." *Environmental Science & Technology.*
Aquatic Ecosystems
Carey, J.C., K.B. Raposa, C. Wigand, and R.S. Warren (2015). "Contrasting decadal-scale changes in elevation and vegetation in two Long Island Sound salt marshes." *Estuaries and Coasts*: 1–11.
Druschke, C.G., L.A. Meyerson, and K.C. Hychka (2016). "From restoration to adaptation: the changing discourse of invasive species management in coastal New England under global environmental change." *Biological Invasions*: 1–9.

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Aquatic Ecosystems
Hanson, A., R. Johnson, C. Wigand, A. Oczkowski, E. Davey, and E. Markham (2016). "Responses of *Spartina alterniflora* to multiple stressors: changing precipitation patterns, accelerated sea level rise, and nutrient enrichment." *Estuaries and Coasts*: 1–10.
Oczkowski, A., C.W. Hunt, K. Miller, C. Oviatt, S. Nixon, and L. Smith (2016). "Comparing measures of estuarine ecosystem production in a temperate New England estuary." *Estuaries and Coasts*: 1–18.
Paranjpye, R.N., W.B. Nilsson, M. Liermann, E.D. Hilborn, B.J. George, Q. Li, B.D. Bill, V.L. Trainer, M.S. Strom, and P.A. Sandifer (2015). "Environmental influences on the seasonal distribution of *Vibrio parahaemolyticus* in the Pacific Northwest of the USA." *FEMS Microbiology Ecology* **91**(12).
Shafer, D.J., T.M. Swannack, C. Saltus, J.E. Kaldy, and A. Davis (2015). "Development and validation of a habitat suitability model for the non-indigenous seagrass *Zostera japonica* in North America." *Management of Biological Invasions* **7**.
Watson, E.B., K. Szura, C. Wigand, K.B. Raposa, K. Blount, and M. Cencer (2016). "Sea level rise, drought and the decline of *Spartina patens* in New England marshes." *Biological Conservation* **196**: 173–181.
Biochar
Ducey, T.F., J.M. Novak, and M.G. Johnson (2015). "Effects of biochar blends on microbial community composition in two coastal plain soils." *Agriculture* **5**(4): 1060–1075.
Novak, J.M., J.A. Ippolito, R.D. Lentz, K.A. Spokas, C.H. Bolster, K. Sistani, K.M. Trippe, C.L. Phillips, and M.G. Johnson (2016). "Soil health, crop productivity, microbial transport, and mine spoil response to biochars." *BioEnergy Research* **9**(2): 454–464.
Phillips, C.L., K.M. Trippe, G. Whittaker, S.M. Griffith, M.G. Johnson, and G.M. Banowetz (2016). "Gasified grass and wood biochars facilitate plant establishment in acid mine soils." *Journal of Environmental Quality* **45**(3): 1013–1020.
Biofuels
George, I.J., M.D. Hays, J.S. Herrington, W. Preston, R. Snow, J. Faircloth, B.J. George, T. Long, and R.W. Baldauf (2015). "Effects of cold temperature and ethanol content on VOC emissions from light-duty gasoline vehicles." *Environmental Science & Technology* **49**(21): 13067–13074.
Tu, Q., M. Lu, Y.J. Yang and D. Scott (2016). "Water consumption estimates of the biodiesel process in the US." *Clean Technologies and Environmental Policy* **18**(2): 507–516.

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Biofuels/Health
Bass, V.L., M.C. Schladweiler, A. Nyska, R.F. Thomas, D.B. Miller, T. Krantz, C. King, M. Ian Gilmour, A.D. Ledbetter, J.E. Richards, and U.P. Kodavanti (2015). "Comparative cardiopulmonary toxicity of exhausts from soy-based biofuels and diesel in healthy and hypertensive rats." *Inhalation Toxicology* **27**(11): 545–556.
Farraj, A.K., N. Haykal-Coates, D.W. Winsett, M.I. Gilmour, C. King, Q.T. Krantz, J. Richards, and M.S. Hazari (2015). "Comparative electrocardiographic, autonomic and systemic inflammatory responses to soy biodiesel and petroleum diesel emissions in rats." *Inhalation Toxicology* **27**(11): 564–575.
Hazari, M.S., N. Haykal-Coates, D.W. Winsett, C. King, Q.T. Krantz, M.I. Gilmour, and A.K. Farraj (2015). "The effects of B0, B20, and B100 soy biodiesel exhaust on aconitine-induced cardiac arrhythmia in spontaneously hypertensive rats." *Inhalation Toxicology* **27**(11): 557–563.
Herr, D.W., D.L. Freeborn, L. Degn, S.A. Martin, J. Ortenzio, L. Pantlin, C.W. Hamm, and W.K. Boyes (2016). "Neurophysiological assessment of auditory, peripheral nerve, somatosensory, and visual system function after developmental exposure to gasoline, E15, and E85 vapors." *Neurotoxicology and Teratology* **54**: 78–88.
Madden, M.C. (2015). "Comparative toxicity and mutagenicity of soy-biodiesel and petroleum-diesel emissions: overview of studies from the U.S. EPA, Research Triangle Park, NC." *Inhalation Toxicology* **27**(11): 511–514.
Mutlu, E., D.G. Nash, C. King, T.Q. Krantz, W.T. Preston, I.M. Kooter, M. Higuchi, D. DeMarini, W.P. Linak, and M.I. Gilmour (2015). "Generation and characterization of diesel engine combustion emissions from petroleum diesel and soybean biodiesel fuels and application for inhalation exposure studies." *Inhalation Toxicology* **27**(11): 515–532.
Mutlu, E., S.H. Warren, S.M. Ebersviller, I.M. Kooter, J.E. Schmid, J.A. Dye, W.P. Linak, M.I. Gilmour, J.J. Jetter, M. Higuchi, and D. DeMarini (2016). "Mutagenicity and pollutant emission factors of solid-fuel cookstoves: Comparison to other combustion sources." *Environmental Health Perspectives*.
Mutlu, E., S.H. Warren, P.P. Matthews, C. King, L. Walsh, A.D. Kligerman, J.E. Schmid, D. Janek, I.M. Kooter, W.P. Linak, M.I. Gilmour, and D.M. DeMarini (2015). "Health effects of soy-biodiesel emissions: mutagenicity-emission factors." *Inhalation Toxicology* **27**(11): 585–596.
Mutlu, E., S.H. Warren, P.P. Matthews, J.E. Schmid, I.M. Kooter, W.P. Linak, M. Ian Gilmour, and D.M. DeMarini (2015). "Health effects of soy-biodiesel emissions: bioassay-directed fractionation for mutagenicity." *Inhalation Toxicology* **27**(11): 597–612.
Ross, J.A., G.B. Nelson, E. Mutlu, S.H. Warren, M.I. Gilmour, and D.M. DeMarini (2015). "DNA adducts induced by in vitro activation of extracts of diesel and biodiesel exhaust particles." *Inhalation Toxicology* **27**(11): 576–584.

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Black Carbon
Holder, A.L., G.S. W. Hagler, J. Aurell, M.D. Hays, and B.K. Gullett (2016). "Particulate matter and black carbon optical properties and emission factors from prescribed fires in the southeastern United States." *Journal of Geophysical Research: Atmospheres* **121**(7): 3465–3483.
Decision and Governance
Eason, T., A.S. Garmestani, C.A. Stow, C. Rojo, M. Alvarez-Cobelas, and H. Cabezas (2016). "Managing for resilience: an information theory-based approach to assessing ecosystems." *Journal of Applied Ecology* **53**(3): 656–665.
Energy Systems/Technology Assessment
Aitken, M.L., D.H. Loughlin, R.S. Dodder, and W.H. Yelverton (2016). "Economic and environmental evaluation of coal-and-biomass-to-liquids-and-electricity plants equipped with carbon capture and storage." *Clean Technologies and Environmental Policy* **18**(2): 573–581.
Gamas, J., R. Dodder, D. Loughlin, and C. Gage (2015). "Role of future scenarios in understanding deep uncertainty in long-term air quality management." *Journal of the Air & Waste Management Association* **65**(11): 1327–1340.
Lenox, C., and P.O. Kaplan "Role of natural gas in meeting an electric sector emissions reduction strategy and effects on greenhouse gas emissions." *Energy Economics*.
Forests/Ecosystems
Lee, E.H., P.A. Beedlow, R.S. Waschmann, D.T. Tingey, C. Wickham, S. Cline, M. Bollman, and C. Carlile (2016). "Douglas-fir displays a range of growth responses to temperature, water, and Swiss needle cast in western Oregon, USA." *Agricultural and Forest Meteorology* **221**: 176–188.
Phelan, J., S. Belyazid, P. Jones, J. Cajka, J. Buckley, and C. Clark (2016). "Assessing the effects of climate change and air pollution on soil properties and plant diversity in sugar maple–beech–yellow birch hardwood forests in the Northeastern United States: Model simulations from 1900 to 2100." *Water, Air, & Soil Pollution* **227**(3): 1–30.
Voelker, S.L., J.R. Brooks, F.C. Meinzer, R. Anderson, M.K.F. Bader, G. Battipaglia, K.M. Becklin, D. Beerling, D. Bert, J.L. Betancourt, T.E. Dawson, J.-C. Domec, R.P. Guyette, C. Körner, S.W. Leavitt, S. Linder, J.D. Marshall, M. Mildner, J. Ogée, I. Panyushkina, H.J. Plumpton, K.S. Pregitzer, M. Saurer, A.R. Smith, R.T.W. Siegwolf, M.C. Stambaugh, A.F. Talhelm, J.C. Tardif, P.K. Van de Water, J.K. Ward, and L. Wingate (2016). "A dynamic leaf gas-exchange strategy is conserved in woody plants under changing ambient CO_2: evidence from carbon isotope discrimination in paleo and CO_2 enrichment studies." *Global Change Biology* **22**(2): 889–902.
Wickham, J., C.A. Barnes, M.S. Nash, and T.G. Wade (2015). "Combining NLCD and MODIS to create a land cover-albedo database for the continental United States." *Remote Sensing of Environment* **170**: 143–152.

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GHG Emissions
Beaulieu, J.J., C.T. Nietch, and J.L. Young (2015). "Controls on nitrous oxide production and consumption in reservoirs of the Ohio River Basin." *Journal of Geophysical Research: Biogeosciences* **120**(10): 1995–2010.
Global Warming Potential
Betowski, D., C. Bevington, and T.C. Allison (2016). "Estimation of radiative efficiency of chemicals with potentially significant global warming potential." *Environmental Science & Technology* **50**(2): 790-797.
Health
Crooks, J.L., W.E. Cascio, M.S. Percy, J. Reyes, L.M. Neas, and E.D. Hilborn (2016). "The association between dust storms and daily non-accidental mortality in the United States, 1993–2005." *Environmental Health Perspectives*.
Lin, C.J., T.J. Wade, E.A. Sams, A.P. Dufour, A.D. Chapman, and E.D. Hilborn (2016). "A Prospective study of marine phytoplankton and reported illness among recreational beachgoers in Puerto Rico, 2009." *Environmental Health Perspectives* **124**(4): 477–483.
Jagai, J.S., Q. Li, S. Wang, K.P. Messier, T.G. Wade, and E.D. Hilborn (2015). "Extreme precipitation and emergency room visits for gastrointestinal illness in areas with and without combined sewer systems: An analysis of Massachusetts data, 2003–2007." *Environmental Health Perspectives* **123**(9).
Wilson, A., B.J. Reich, C.G. Nolte, T.L. Spero, B. Hubbell, and A.G. Rappold (2016). "Climate change impacts on projections of excess mortality at 2030 using spatially varying ozone-temperature risk surfaces." *Journal of Exposure Science and Environmental Epidemiology*.
Methane/Oil & Gas
Albertson, J.D., T. Harvey, G. Foderaro, P. Zhu, X. Zhou, S. Ferrari, M.S. Amin, M. Modrak, H. Brantley, and E.D. Thoma (2016). "A mobile sensing approach for regional surveillance of fugitive methane emissions in oil and gas production." *Environmental Science & Technology* **50**(5): 2487–2497.
Eisele, A.P., S. Mukerjee, L.A. Smith, E.D. Thoma, D.A. Whitaker, K.D. Oliver, T. Wu, M. Colon, L. Alston, T.A. Cousett, M.C. Miller, D.M. Smith, and C. Stallings (2016). "Volatile organic compounds at two oil and natural gas production well pads in Colorado and Texas using passive samplers." *Journal of the Air & Waste Management Association* **66**(4): 412–419.
Humayun, M., R. Divan, L. Stan, D. Rosenmann, D. Gosztola, L. Gundel, P.A. Solomon, and I. Paprotny (2016). "Ubiquitous low-cost functionalized multi-walled carbon nanotube sensors for distributed methane leak detection." *IEEE Sensors Journal* **PP**(99): 1–1.

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Methane/Oil & Gas
Humayun, M.T., R. Divan, Y. Liu, L. Gundel, P.A. Solomon, and I. Paprotny (2016). "Novel chemoresistive CH_4 sensor with 10 ppm sensitivity based on multiwalled carbon nanotubes functionalized with SnO_2 nanocrystals." *Journal of Vacuum Science & Technology A* **34**(1): 01A131.
Humayun, M.T., R. Divan, L. Stan, A. Gupta, D. Rosenmann, L. Gundel, P.A. Solomon, and I. Paprotny (2015). "ZnO functionalization of multiwalled carbon nanotubes for methane sensing at single parts per million concentration levels." *Journal of Vacuum Science & Technology B* **33**(6): 06FF01.
Nitrogen
Watersheds/Hydrology
Leibowitz, S.G., R.L. Comeleo, P.J. Wigington, M.H. Weber, E.A. Sproles, and K.A. Sawicz (2016). "Hydrologic landscape characterization for the Pacific Northwest, USA." *JAWRA Journal of the American Water Resources Association* **52**(2): 473–493.
McManus, M.G., G.J. Pond, L. Reynolds, and M.B. Griffith (2016). "Multivariate condition assessment of watersheds with linked micromaps." *JAWRA Journal of the American Water Resources Association* **52**(2): 494–507.
Ranatunga, T., S.T.Y. Tong, and Y.J. Yang (2016). "An approach to measure parameter sensitivity in watershed hydrologic modeling." *Hydrological Sciences Journal*: doi:10.1080/02626667.2016.1174335.
Sproles, E.A., S.G. Leibowitz, J.T. Reager, P.J. Wigington Jr., J.S. Famiglietti, and S.D. Patil (2015). "GRACE storage-runoff hystereses reveal the dynamics of regional watersheds." *Hydrol. Earth Syst. Sci.* **19**(7): 3253–3272.
Water Infrastructure
Kaushal, S., W. McDowell, W. Wollheim, T. Johnson, P. Mayer, K. Belt, and M. Pennino (2015). "Urban evolution: the role of water." *Water* **7**(8): 4063.
Xue, X., T. Hawkins, M. Schoen, J. Garland, and N. Ashbolt (2016). "Comparing the life cycle energy consumption, global warming and eutrophication potentials of several water and waste service options." *Water* **8**(4): 154.
Water Quality
Imen, S., N.-B. Chang, and Y.J. Yang (2015). "Developing the remote sensing-based early warning system for monitoring TSS concentrations in Lake Mead." *Journal of Environmental Management* **160**: 73–89.

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Wildland Fire
Baker, K.R., M.C. Woody, G.S. Tonnesen, W. Hutzell, H.O.T. Pye, M.R. Beaver, G. Pouliot, and T. Pierce (2016). "Contribution of regional-scale fire events to ozone and PM2.5 air quality estimated by photochemical modeling approaches." *Atmospheric Environment*.
Black, R.R., J. Aurell, A. Holder, I.J. George, B.K. Gullett, M.D. Hays, C.D. Geron, and D. Tabor (2016). "Characterization of gas and particle emissions from laboratory burns of peat." *Atmospheric Environment* **132**: 49–57.
George, I.J., R.R. Black, C.D. Geron, J. Aurell, M.D. Hays, W.T. Preston, and B.K. Gullett (2016). "Volatile and semivolatile organic compounds in laboratory peat fire emissions." *Atmospheric Environment* **132**: 163–170.
Tinling, M.A., J.J. West, W.E. Cascio, V. Kilaru, and A.G. Rappold (2016). "Repeating cardiopulmonary health effects in rural North Carolina population during a second large peat wildfire." *Environmental Health* **15**(1): 1–12.
Other
Campbell, D.E. (2016). "Emergy baseline for the Earth: A historical review of the science and a new calculation." *Ecological Modelling*.

Appendix B. Members of Climate-Related Partner Alliance and Coordination Teams

Members: Climate Impacts, Vulnerabilities, and Assessments (CIVA) PACT		
ORD		
Lisa Baxter, NHEERL	Chris Nolte, NERL	Chris Weaver, NCEA
Peter Beedlow, NHEERL	Jeff Yang, NRMRL	*ACE Facilitators*
Britta Bierwagen, NCEA	Rick Greene, SSWR	*Andy Miller*
Anne Grambsch, NCEA	Marc Russell, SHC	*Beth Hassett-Sipple*
Regional Offices		
Mike Cox, Region 10	Megan Goold, Region 3	Regina Poeske, Region 3
Laura Farris, Region 8	Alyssa Hall, Region 1	
Virginia Galinsky, Region 5	Esther Nelson, Region 2	
Headquarters Offices		
Lisa Bacanskas, OAR	Karen Metchis, OW	Marc Thomas, OLEM
Pat Dolwick, OAR	Mike Moltzen, OAR	
Bryan Hubbell, OAR	John Shoaff, OAR	

Members: Sustainable Energy and Mitigation (SEM) PACT		
ORD		
Rebecca Dodder, NRMRL	Carlos Nunez, NRMRL	*ACE Facilitators*
Sherri Hunt, NCER	Tiffany Yelverton, NRMRL	*Andy Miller*
Ozge Kaplan, NRMRL		*Laurel Schultz*
Regional Offices		
Bob Drake, Region 10	Kelly Fortin, Region 4	Patrick Miller, Region 8
Headquarters Offices		
Roger Fernandez, OAR	Bruce Moore, OAR	Rob Sobocinski, OAR
Alex MacPherson, OAR	John Shoaff, OAR	Phil Zahreddine, OW
Mike Moltzen, OAR		