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U.S. National climate assessment gaps and research needs: overview, the economy and the international context

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Abstract A number of knowledge gaps and research priorities emerged during the third US National Climate Assessment (NCA3). Several are also gaps in the latest IPCC WG2 report. These omissions reflect major gaps in the underlying research base from which these assessments draw. These include the challenge of estimating the costs and benefits of climate change impacts and responses to climate change and the need for research on climate impacts on important sectors such as manufacturing and services. Climate impacts also need to be assessed within an international context in an increasingly connected and globalized world. Climate change is being experienced not only through changes within a locality but also through the impacts of climate change in other regions connected through trade, prices, and commodity chains, migratory species, human mobility and networked communications. Also under-researched are the connections and tradeoffs between responses to climate change at or across different scales, especially between adaptation and mitigation or between climate responses and other environmental and social policies. This paper discusses some of these research priorities, illustrating their significance through analysis of economic and international connections and case studies of responses to climate change. It also critically reflects on the process of developing research needs as part of the assessment process.

1 Introduction

The third United States National Climate Assessment (NCA3) and the 5th and latest report of the Intergovernmental Panel on Climate Change (IPCC) Working Group 2 are important benchmarks in our understanding of the impacts of climate change and how we might respond. They synthesize hundreds of studies of how climate change is affecting the Earth, socioeconomic systems, and major regions. Yet, even after five IPCC reports and three US Global

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Change Research Program (USGCRP) climate assessments there are still major gaps in research such that the overall picture of how climate change is affecting us is incomplete or inaccurate and this may result in underestimates and inefficiencies in our response to climate change.

The research agenda chapter of the National Climate Assessment (Corell et al. 2014) together with the Sustained Assessment chapter (Hall et al. 2014) and the Sustained Assessment Report (Buizer et al 2013) identified a number of these research gaps and priorities based on input from other chapters, technical inputs to the NCA3 and the NCA advisory committee. These gaps and research needs are identified in the first section of this paper together with some guidelines for setting priorities for assessments.

These research gaps are then explored in greater depth including the need to study and assess the full range of climate impacts on the economy and the importance of analyzing local impacts in the international context of a globalized economy. Assessing a wider range of impacts on the economy is an important step in informing decision makers and the public about the climate impacts that may affect the sectors – services and manufacturing – that drive most regional and national economies in terms of GDP and employment. Understanding local impacts in an international context is critical if the research and policy community want to understand how climate change can affect local costs of energy, food, water and other goods. In an increasingly globalized world, with few trade barriers, many people and regions are dependent on imported goods or on goods whose prices are set by global markets. Whether it is the costs of computer components or oil or the price of winter fruit and vegetables, companies and consumers in the US and elsewhere are likely to be affected by climatic changes and extremes in other regions.

2 Research needs and the national climate assessment

Several methods were used to develop the research needs chapter of the NCA. Lead authors for each chapter in the assessment were asked to provide a summary of the research gaps and priorities identified in their chapters. The research needs chapter authors also consulted the final chapter drafts for any material relevant to research needs. They also used recent reports from the NRC and USGCRP as a background for the chapter, and presented the list of research needs and criteria for priorities to two meetings of the 60 member NCADAC (National Climate Assessment and Development Advisory Committee) for comment. As with other NCA chapters the chapter was extensively reviewed and revised in response to comments.

The research agenda chapter of the NCA identifies the importance of activities supporting assessment such as research to observe and understand the climate system, improve understanding of climate impacts, vulnerability and adaptation pathways, identify mitigation options and improve capacity and decision support (Table 1). As such, it directly responds to the legal mandate to not only assess and evaluate what is known, but also to discuss uncertainties (USGCRP 1990, Sec. 106). Of course, many of these priorities have been identified in other reports (e.g., NRC Committee on America's Climate Choices 2010) and most are included in the US Global Change Research Program's Strategic Plan (USGCRP 2012).

Within the goals and capabilities listed in Table 1 there are several research needs that emerged strongly in the preparation of the NCA3 and discussions about prospects for a sustained assessment beyond the report.

Table 1 Research goals and cross cutting capabilities for assessment

Research Goals	Foundational cross cutting research capabilities
Improve understanding of the climate system and its drivers	Integrate natural, social, engineering and other disciplinary approaches
Improve understanding of climate impacts and vulnerability	Ensure availability of observations, monitoring and infrastructure for critical data collection and analysis.
Increase understanding of adaptation pathways	Build capacity for climate assessment through training, education, and workforce development
Identify the mitigation options that reduce the risk of longer-term climate change	Enhance the development and use of scenarios
Improve decision support and integrated assessment	Promote international research and collaboration

Corell et al (2014) p 708

First, as our *understanding of the climate system* improves, assessments require that we focus on regional scale changes, possible thresholds and abrupt changes, and the interactions between anthropogenic climate change, natural variability and climate extremes. We also identified the need for development of indicators that can be used for regular reporting to policy makers and the public that are understandable and allow for attribution and anticipation of change.

Second, in terms of *understanding climate impacts and vulnerability*, the key research needs are to provide greater spatial and temporal detail in the monitoring and analysis of impacts, especially to expand beyond static snapshots of vulnerability to more dynamic analyses that reflect how climate interacts with other stresses on seasonal and inter-annual timescales to alter vulnerabilities and impacts. Other priority research needs include better understanding of the impacts of climate on particularly vulnerable groups and the interaction of multiple stresses and uncertainties. Perhaps the most important research gaps are the need for much better understanding of economic consequences of climate change, both in terms of costs, the regional and international context, and the impacts on the full range of economic sectors.

Third, there is a lack of research on *pathways to adaptation* including the identification, selection, implementation and evaluation of adaptation options. In order to identify best practices much better comparative research designs are needed that compare between different adaptation strategies and with no adaptation, and which identify the institutional and behavioral barriers to successful adaptation.

Fourth, the NCA research agenda chapter recognizes that managing climate risks, and reducing vulnerabilities, impacts and the need for adaptation, requires a priority focus on emissions reductions (*mitigation*) that reduce the risk of longer term climate change and provide synergies with adaptation at the local level. Reducing the greenhouse gas burden will reduce the severity and costs of impacts over the medium to long term. Many local decision makers are trying to manage mitigation and adaptation within single institutions and clusters of policies and need to understand the connections and trade offs between the two.

For successful *decision support* the research chapter of the NCA highlights the importance of better identifying decision-maker needs, especially under uncertainty, integrating information into risk management and developing costing and modeling tools that allow users to understand trade offs, benefits, and the implications for current action of long term scenarios.

In order to advance on these research needs, several cross-cutting capabilities are critical including support for *interdisciplinary research* that allows integration and for the infrastructure and people that provide *observations and data*. In addition the chapter identified activities that build *capacity* through education, training and workforce development that will provide the skills and people who can participate in decision-making and climate risk reduction activities. To the extent that climate risk reduction requires insight into the implications of different pathways and decisions into the future the chapter also recommended enhancing work on *scenarios*. And finally, the chapter emphasized the importance of *international cooperation* to facilitate the sharing of data collection, research responsibilities and infrastructure, to support international negotiations, and to understand the ways in which local scale impacts in the US are affected by climate changes elsewhere and global economic linkages (see below).

The NCA also includes a chapter on the design and core features of a sustained assessment – the ongoing process of understanding vulnerabilities and responses to climate variability and change that supports the adaptive management of climate risk in the United States. Several of the research needs mentioned above are especially important to a sustained assessment including capacity and network building, data collection, and the development of indicators and scenarios. A special report on sustained assessment (Buizer et al 2013) additionally recommends the development of better valuation methods, greater attention to the international context of US climate impacts, and more rigorous evaluation of assessment activities so as to support ongoing learning within the assessment community and supporting agencies.

The next section expands on several of these research gaps, illustrating their significance and some challenges in filling them in. This has required some new data analysis, theoretical framing, and synthesis of case studies that were not fully incorporated into the NCA and other recent assessments.

3 It's the economy….

The 2014 NCA report is one of many recent assessments that pay inadequate attention to key sectors of the economy, especially manufacturing and services. It includes chapters on climate impacts on natural resources such as water, forests, land and ecosystems, on urban, coastal, indigenous and rural communities, and on transport, energy and health. While these chapters include some discussion of climate impacts on infrastructure, food systems, or buildings they do not adequately address the broader effects on the economic sectors that drive national and regional productivity and employment. Emergent effects such as competition and trade offs for capital, labor and government funds and taxation are also overlooked, especially as funds are diverted to respond to climate change. This is partly due to the fact that that there is very little underlying research base to assess. For future assessments to improve on this gap, fundamental research on these sectors and connections is required. It is particularly important to look at the impact of changes in extremes.

Agriculture contributes just over 1 % to US Gross Domestic Product (GDP), whereas industry and manufacturing constitutes 20.5 % and services are 78 % (Table 1). Industry includes mining, construction, utilities, transport, and the manufacturing of durable goods (e.g., machinery, electronics, motor vehicles), food and beverages, textiles and paper, and chemicals. Each of these contributes more to GDP than the whole agricultural sector. The service sector includes tourism, information, arts and media, finance and insurance, real estate,

retail, law and professions, waste management, education, health care and government. Finance and real estate, professional services, and government contributed the most to USGDP in 2012 (see Table 2).

In terms of employment, the agriculture, forestry, and fishing sector is only 1.6 % of jobs, whereas services are 79.5 % and industry and manufacturing are 13 % of employment (US Bureau of Labor Statistics 2015 www.bls.gov). Most Americans work in manufacturing (8 %), retail (10 %), professional services (12 %), education and healthcare (14 %), arts, hospitality and tourism (10 %) and government (15 %).

While some sectors of manufacturing and services are discussed in assessments and in the research literature others are almost completely overlooked and under researched, especially given their significance to the economy and employment. Tourism, transport and insurance have received the most attention; textiles, auto and electronics, retail, and IT are rarely even mentioned. Although there are hundreds of studies on climate impacts on agriculture hardly any of these track the impacts through commodity chains and the food system to assess the effects on the enormous food wholesale and retail sector.

This lack of attention to important economic and employment sectors is a research gap in terms of full accounting of climate impacts and a national and regional response to climate change, and also has serious implications for public and policy awareness of climate risks and opportunities. If research overlooks the sectors where most people work, and which drive our

Table 2 Economic sectors and the US Economy in 2012

Economic Sectors	Value added as % of GDP_1	Employment (thousands of jobs)	Percent $employment_2$
AGRICULTURE, FORESTRY, FISHING AND HUNTING	1.2	2122	1.6
INDUSTRY	20.5		13.00
Mining, oil and gas	2.6	800	0.60
Utilities	1.7	554	0.41
Construction	3.6	5640	3.9
Manufacturing Durable Goods	6	11918	8.2
SERVICES	78.3		79.5
Services Wholesale trade	5.9	5672	3.9
Services: Retail trade	5.7	14875	10.2
Services: Transportation and warehousing	2.9	4414	3.0
Services: Information	4.8	2677	1.8
Services: Finance, insurance, real estate, rental, and leasing	19.5	7786	5.4
Professional and business services	11.9	17930	12.3
Educational services, health care, and social assistance	8.2	20319	14.0
Arts, entertainment, recreation, accommodation, and food services	3.71	13745	9.5
Government services	13.5	2113	15

Data Source: 1. US Bureau of Economic Analysis 2015 http://bea.gov/industry/ (Accessed April 2014), 2. Bureau of Labor Statistics 2015 www.bls.gov (Accessed July 2015)

economy, then it is not surprising that many key decision makers and the public are inattentive to assessments and the risks of climate change.

Even at the regional level, agriculture and forestry are not very important to state economies. No state obtains more than 15 % of their GDP from agriculture and forestry, and only the Dakotas, Iowa, Kansas, Montana, Idaho, and Nebraska have agriculture and forestry as more than 5 % of state GDP (US Bureau of Economic Analysis 2014 http://bea.gov/iTable/index_regional.cfm).

Why have industry and services been overlooked in climate impact research and assessments? Although the IPCC did include a chapter 'Key Economic Sectors and Services' in the latest report (Arendt and Tol 2014) it focused on climate impacts on energy and water demand and supply and on transport, tourism and insurance. Only a brief section and a few references commented on the impacts on mining, manufacturing, real estate, finance, and health services. Indirect impacts on the economy were assessed through general equilibrium models with very little discussion of supply chains. The report states "For most economic sectors, the impact of climate change will be small relative to the impacts of other drivers (p 662) and "Economic activities such as agriculture, forestry, fisheries, and mining are exposed to the weather and thus vulnerable to climate change. Other economic activities, such as manufacturing and services, largely take place in controlled environments and are not really exposed to climate change" (p. 688). However the impacts on manufacturing and services from Hurricane Sandy, of cooling or pollution control costs during heat waves, and on supply chains from the Bangkok floods suggest that these sectors suffer considerable exposure to climate change (see references below). The IPCC chapter does admit, "Not all key economic sectors and services have been subject to detailed research" (p 663) and proposes more research is needed on manufacturing and services.

Both the IPCC and NCA overlook literature in business and economic geography that would provide important insights into supply chain vulnerabilities and climate impacts on key sectors (e.g., Jarmin and Miranda 2009; Leichenko and Thomas 2012; Linnenluecke at al 2011; Peck 2006; Webb et al 2000). The coastal and urban chapters of both the IPCC (Field et al. 2014 Chapter 8) and NCA (Melillo et al. 2014 Chapters 11 and 25) assessments do discuss the impacts of climate change on ports, infrastructure and energy dependent industries but the manufacturing and service sectors are given little attention beyond cities and coasts. The technical inputs to the NCA on infrastructure and urban systems and on energy supply and use provide useful overviews of what is known about impacts on energy exploration, generation and costs and on urban infrastructure, especially transportation (Wilbanks and Fernandez 2012; Wilbanks 2012). Although mention is made of supply chain links and of impacts on energy manufacturing there is little detail on key sectors such as retail, finance, or goods manufacturing except by inference from discussion of energy, water or infrastructure.

The transport and coastal chapters of the NCA do raise concerns about how climate impacts on US infrastructure may affect trade through, for example, sea level rise impacts on ports and canals or flooding of road and rail routes.

Many journals (e.g., Disasters, Natural Hazards) have articles that discuss the impacts of extreme climate and weather events on business (e.g., Marshall and Schrank 2014; Schrank et al 2013; Xiao and Nilawar 2013). Research after Hurricane Sandy is providing important insights into which sectors suffer and benefit from climate extremes in the U.S. (Leichenko et al 2014; Mantell et al 2013; Rosenzwieg and Solecki 2014; US Department of Commerce 2013). These studies show that the impacts of Hurricane Sandy were severe in the short term – with almost a billion dollars in lost tourism revenues, another billion in property damage, more than 50,000 jobs lost and declines in productivity in the utilities, chemicals, food and electronic industries – but there were some benefits for the construction sector during longer term recovery and many sectors rebounded within a year.

Floods, winds and service disruption affected more than 10,000 manufacturing facilities and in New Jersey almost 20,000 small businesses were damaged (US Department of Commerce 2013).

One reason for the lack of attention to manufacturing and services is that the government departments with responsibility for the service and manufacturing sectors are less likely to have staff with expertise relevant to environment and climate change and do not play a major role in the USGCRP.

Future assessments should take account of a broader scope of literature, especially in business and on natural disasters. There is clearly a need to encourage more research on climate impacts on manufacturing and services including case studies, detailed modeling and following secondary impact (Dell et al 2013). Disaggregating sectoral impacts provides insights into distributional effects whereby some sectors lose and others benefit from climate extremes and change – such as when a construction boom, fueled by government relief and insurance payments, rebalanced regional economic productivity following Hurricane Sandy.

4 Climate impacts in a globalized economy

Understanding how contemporary economies function is also critical to understanding how communities are affected by climate change far beyond their local region, and reveals how studies that do not pay attention to global links can misjudge local climate impacts. The NCA and many other regional climate impact studies generally do not take account of the global context for local climate impacts. For example, in most regions of the US the supply of food, energy and other goods is imported from other regions and countries, so that only looking at how climate affects local agricultural, energy and economic production provides only a partial window on how climate change and variability affect US communities. Most major companies operate within global supply and value chains, where for example, the automobile industry and major food retailers can be affected by climate events far across the world (Jira and Toffel 2013).

The best example of supply disruption is probably that of the 2011 floods in Thailand that damaged an important manufacturing center around Bangkok (Benfield 2012; Courbage and Stahel 2012). As business adopts 'just in time' supply of key parts or depends on raw materials and manufactured goods in climate vulnerable agglomerations of facilities the risk of climate disruption can increase (Smith 2013). When serious flooding inundated industrial estates around Bangkok the estimated loss of manufacturing production cost over $40 billion US with impact on more than 14,500 companies and critical supply chains for automobiles and computers (Abe and Ye 2013; Amado et al 2013). Nissan and Toyota both had to suspend production worldwide because of problems in obtaining parts from Thailand. Only ¼ of the loss was insured (Courbage and Stahel 2012) and global prices of hard disks doubled because almost half of the world's hard disks were produced in Thailand. The vulnerability of these global supply chains was increased by geographical conditions in Thailand including construction on flood plains, deforestation upstream, and problems in water governance (Haraguchi and Lall 2013).

The humanitarian NGO Oxfam has identified supply chain vulnerability as a key component of corporate responsibility in which business needs to understand and manage the impacts of climate on the small-scale producers they depend on (Thorpe and Fennell 2012). They use case studies of coffee company Starbucks and retailers Marks and Spencers and the Body Shop to show how the supply chains of these companies are vulnerable to climate change impacts on coffee, cotton and sesame oil, and the strategies that can reduce the vulnerability of source regions and producers.

There are lots of examples of the dependence of other U.S. regions on imports and global supply chains. For example, Table 3 shows key categories of imports into the US. Of total 2012 imports of $1.8 trillion dollars, almost 1/3 of the value was machines (e.g., computers), 14 % transport (e.g., cars), 25 % chemicals, minerals and metals, and about 6 % each for textiles and food. Economic vulnerability to climate shocks and change beyond the US depends on the sources of imports. In 2012 44 % of US imports were from Asia (mostly China, Japan and South Korea), 23 % from Canada and Mexico and 23 % from Europe (Table 4).

Climate impacts are also mediated by prices that are established over very large regions in a world dominated by free trade. The price of grains, oil, minerals and other goods are set within global commodity markets that can be driven by events and speculation anywhere within a global system. The spike in food prices that occurred in 2008-09 (Fig. 1) was driven by a combination of increased demand for biofuels worldwide and for meat and dairy in Asia, increased prices for energy and inputs, and climate caused declines in production of basic grains in regions as far apart as Australia and Eastern Europe (Ingram et al. 2010; Von Braun and Tadesse 2012). Speculation exacerbated volatility and the price increases prompted many farmers to put more land and inputs into production in subsequent years (Clapp and Helleiner 2012; Clapp 2014).

As an example, a freeze that damages citrus production in Latin America can benefit producers in Florida who can sell at higher prices; sour cherry production in the US Midwest interacts through markets with production in Poland. The globally connected food system is a powerful example of how even when climate has some negative effects on local agriculture, farmers can still benefit if things are worse elsewhere and they can obtain higher prices. Those studies that focus only on yields, or which do not take account of traded goods and global price signals are providing inaccurate insights into climate impacts in a globalized world. Several recent projects are starting to look further at the need for multiregional climate assessments as they relate to international markets (Barsugli et al. 2013; Winkler et al 2010; Liu et al 2013)

5 Identifying research needs through assessment

The NCA chapter on research needs was based on a review of research gaps noted in various topical and regional chapters and through specific requests to chapter authors. In my own view

Table 3 U.S. imports of key commodities

Sector	Percent of import value
Machines and instruments	34.10 %
Vehicles	14.05 %
Chemicals and Pharmaceuticals	9.30 %
Oil	5.26 %
Other Minerals	3.47 %
Metals	8.94 %
Textiles and footwear	7.13 %
Plastic and Rubber	3.75 %
Food	2.93 %
Other (paper, wood, glass, animal and veg products, art, weapons)	11.07 %

Source: MIT Atlas of Economic Complexity http://atlas.media.mit.edu/)

Table 4 Origins of US Imports

Name	Percent
China	22.11 %
Mexico	13.61 %
Canada	9.83 %
Japan	7.79 %
Germany	5.98 %
South Korea	3.49 %
United Kingdom	2.91 %
France	2.03 %
Italy	1.98 %
India	1.88 %
Brazil	1.52 %
Ireland	1.50 %
Switzerland	1.30 %
Rest of world	24.07 %

Source: MIT Atlas of Economic Complexity http://atlas.media.mit.edu/)

this did not produce the most effective or useful list of research needs because some chapters and chapter authors did not actually identify research gaps and there was overreliance on the previous experience of the Research Needs chapter authors. Such exercises also run the risk of generating laundry lists of every research gap and individual priority, because selecting the most important research needs is very challenging. Partly because of this we also relied on National Research Council (NRC) and US Global Change Research Program reports such as America's Climate Choices and the USGCRP Strategic Plan, which devoted more time and resources than the NCA to research needs identification.

Why is it important to have a research gaps chapter in assessments? How might such a chapter be developed more rigorously in sustained or future assessments?

Drawing on my own experience I can suggest several barriers and challenges in the development of research needs reports and chapters. There are also several research articles that address the assessment process – mostly the IPCC – that are helpful in considering barriers to assessments and their role in defining research needs (Anderegg et al 2010; Berkout 2010; Griggs 2014; Grundmann 2012; Hulme 2010; Janko et al 2014; Jasanoff 2010; Jones 2013: Lahsen 2013; Lemos and Morehouse 2005; Shapiro et al 2010; Stocker 2013; Tol 2011; Viner and Howarth 2014; NRC 2007)

First, almost all assessments and National Academy reports are primarily based on volunteer efforts or time taken from other responsibilities. Authors and members of committees are drawn from the scientific community and key stakeholders who almost always have full-time jobs in universities, government, the private sector, or nongovernmental organizations. While every effort is made to include the top experts in relevant fields, some key individuals may be too busy to participate. Although most individuals are not paid, the costs of bringing people together and of even a modest support staff can limit participation, especially if international expertise is required. There may also be a tendency to rely on the usual experts because of their seniority and reliability, rather than early career scholars with new ideas and more diverse perspectives. To be sure, many early career scholars will choose to devote their time to original scholarly work in order to advance their careers and younger researchers from developing

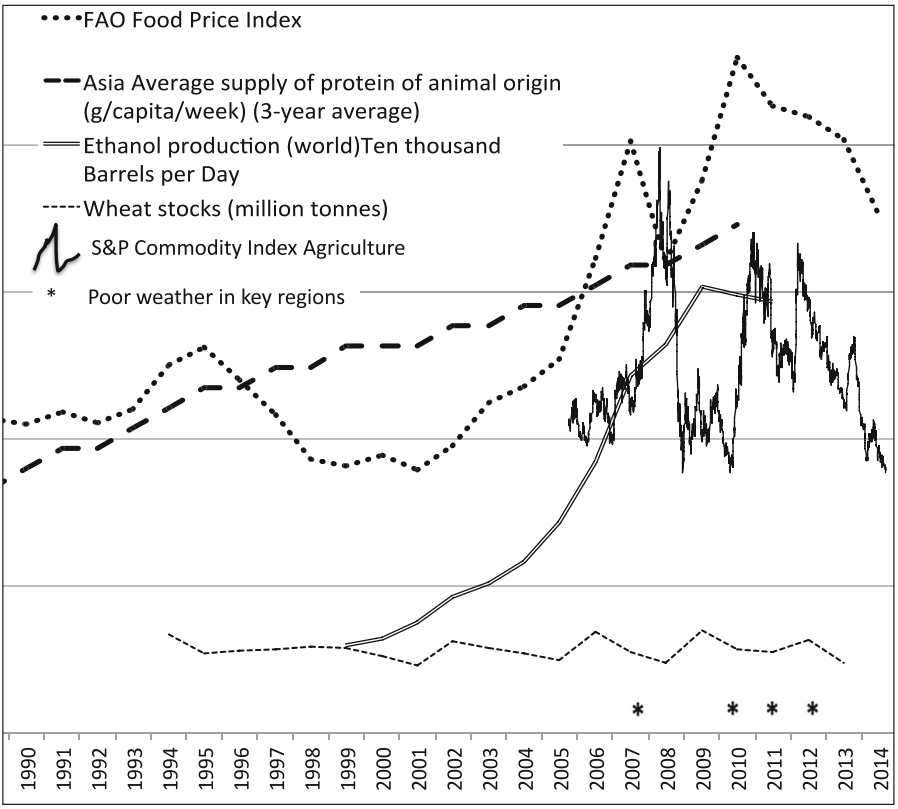

Fig. 1 The nature and selected causes of the 2007-08 food crisis. Food price index showing steep increases in 2007-08 and 2011 driven by **a**) increasing per capita consumption of meat in Asia (data from faostat.org) **b**) lower food reserves in 2008 (Data from USDA FAS) **c**) steep increase in biofuels, especially from maize (data from US Energy Information Agency) **d**) speculation in agricultural commodities as indicated by Dow Jones agricultural index with increases in 2007-08 and from 2011-2013 (data from Dow Jones S&P GCSI) **d**) bad weather in key regions. Factors not shown include increases in energy and input costs and protectionist policies

countries may face even greater financial barriers. Training in assessments and synthesis is rarely part of graduate or early career experience.

While the NCA took considerable effort to include a diverse set of scholars, my personal observation and discussions with authors suggest that some chapters and discussions were dominated by seasoned experts. Especially when it comes to research needs, younger scholars may be reading a broader range of literature.

A second consideration is the need to rely on the peer-reviewed literature – a problem mostly for the IPCC since the NCA did include publically available non-peer reviewed reports under the Data Quality Act requirements. Some assessments have been cautioned not to use reports or other publications that are not peer-reviewed even when they include information that might fill research gaps. This can be a particular problem in evaluating the impacts climate on the business community or at the local level where important case studies occur in non-peer reviewed reports or the media. Thus, information to fill the research gap is there that cannot be used. For assessments that need regional results, the constraint maybe the difficulty of

publishing yet one more regional case study in a peer reviewed research literature that prizes originality. One solution is to encourage the publication of papers that review and evaluate non-peer reviewed literature in ways that represent peer review.

A third observation is the tension that sometimes emerges between identifying new research priorities and the process of funding research through government agencies. Agencies and their representatives who help write research agenda chapters may feel constrained by the politics of research funding, the time it takes to develop new funding programs and get them approved, the need to support expensive and essential long-term observations, and a reluctance to end client relationships with productive and powerful groups of scientists or institutions.

As just one example, many research agenda reports and assessments argue for more social science research but it is difficult to shift money from the natural to social sciences when most agencies employ mostly natural scientists, are more comfortable with natural science research, or fear political skepticism of social sciences (Agrawal et al 2012; Carey et al 2014; Castree et al 2014: Hackmann et a 2014; Grundmann 2012; Lahsen 2013; Stern et al 2013; Weaver et al 2014; Whitmarsh et al 2011). Calls for more social science involvement have been made many times over the years (USNRC 1992). And although NRC committees are independent, their findings can be constrained by the task they were given by the NRC or study funders.

Fourth, authors may also be reluctant to identify a large number of research gaps in case this undermines messages about what we do know. Studies suggest that when scientists to discuss uncertainties and the limits of knowledge this can reduce public and decision-maker confidence in assessments and recommendations.

Finally, climate assessments, for the most part, have approached their task beginning with the climate science and connecting through resource impacts to the rest of society. The alternative would be to begin with what matters to society, the economy, or stakeholders and then work back to understand if and how these issues are sensitive or vulnerable to climate change (Lemos et al 2012, 2014). This might result in different authors, research agendas and assessment chapters.

6 Conclusion

This paper summarizes some of the research gaps and needs that emerged from the US National Climate Assessment and takes the opportunity to reflect on the process and limitations of identifying research needs during assessment. Two research gaps are explored in greater detail – the impacts of climate change on key economic sectors and the importance of assessing impacts within a global economy. The importance of these two topics are demonstrated by discussing relevant literature that was not sufficiently included in the NCA or recent IPCC reports, and by a new analysis of economic data that demonstrates the importance of the services and manufacturing sectors and of the role of commodity chains and trade in connecting climate change and extremes elsewhere to impacts within US regions. Unless we do more research on climate impacts on manufacturing and services – which constitute most of the productivity and employment in the US and many other countries – assessments will not include the sectors where most people work or where most business and government generates growth. And unless we take account of the increasingly global connections that influence local food, energy and other commodity prices we will be unable to provide useful and accurate assessments of how climate variability and extremes affect regions, states and communities. Filling these gaps should be a high priority within sustained and future assessments if we want decision makers and the public to understand the full scope of climate change effects and if we wish to develop comprehensive responses.

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