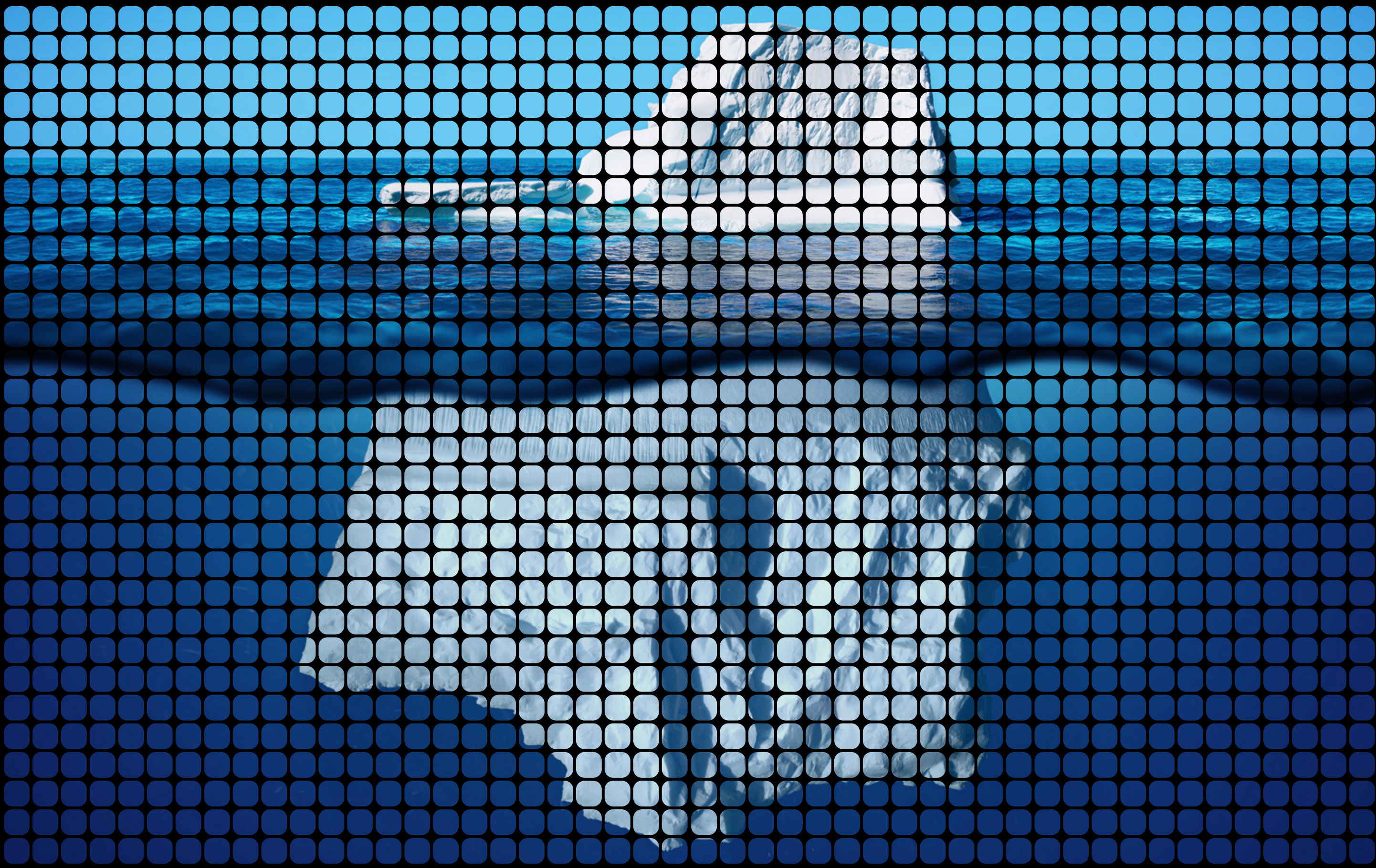

Digital Research Reports

The Landscape of Climate Research Funding

Analysis of climate research funding data highlights USA infrastructural dependency

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The USA government proposes policy and funding changes around environmental protection and climate research. As is often the case, it will be difficult to assess the impact until years after the policy has been enacted. However, funding data provide us with a more proximate bellwether than the traditional research analytics. In this report, we profile the balance of 'climate research' investment and note its impact on a diverse research portfolio that runs from ecology and atmospherics, to economics and public health. We explore the use of funding data as an analytical source, track the growth of 'climate change' as a topic and differentiate this from 'global warming'. We also disaggregate funding across fields of research and demonstrate a research shift from global climate to biological impact and adaptation and, now, towards response and mitigation.

The data highlight the ratio between a relatively small pool of research funds and its support of a much greater infrastructure for monitoring, regulation and response. The USA is identified as the largest single source of research grants, although European funds are growing rapidly. The USA provides key support and data worldwide, and may have been agile in shifting from background research into adaptation and mitigation. USA policy change could undermine many other efforts. The global research effort is shared because the climate is shared; so should be the responsibility to sustain these commitments.

"The global research effort is shared because the climate is shared; so should be the responsibility to sustain these commitments."

Introduction

Research funding has usually been described only at a very aggregate level. Analytics tools developed over the last 25 years for research policy use have rarely 'followed the money' but have instead been based on just one aspect of the research cycle and one type of data: research output in the form of journal articles and their citations. These data were a preferred source because of indexed, accessible, global data sources such as Clarivate Analytics Web of Science and Elsevier's Scopus. Publication analysis provided valuable but necessarily limited perspectives. Now, however, more comprehensive and diverse data, which give a fuller picture, are becoming available. They can provide not only new perspectives but complementary information about the other parts of the research environment and process.

The Dimensions database of competitive research grants is used in this report to explore trends in recent funding. Dimensions indexes more than $1 trillion across more than 1.5 million individual grants and awards, linked to principal investigators and to their institutions. Projects from many different national systems are assigned to a consistent set of categories, using the Australia-New Zealand system of Fields of Research (ANZSRC, 2008). Dimensions includes the grant abstract or summary text descriptor (translated to English) in most cases, so a free text search is supported. Grant values are normalised by conversion to US dollars.

In common with other research of policy interest, climate change is not a simple category. It covers a wide range of disciplines and is, as such, an excellent venue to explore new data sources. The funding of climate change research is of particular interest because it relates to policy with massive economic impact. For example,

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research from the University of Maryland shows that hotter summers in the USA Midwest could reduce corn and soya crop yields back to pre-1950s' levels (Liang, 2017). Given the World Meteorological Organization's latest report on record temperature and CO2 levels (WMO, 2017), the implications are obvious.

Changes in the focus or magnitude of research funding in one research-intensive economy can have direct and significant consequences for the wider global research landscape, particularly where cross-national dependencies exist in both research and outcome. Such a change has been forecast by the new Republican administration in the USA. The USA's National Oceanic and Atmospheric Administration (NOAA) supports data feeds and monitoring information from its satellites to many countries. However, within the $4.2 trillion USA budget for fiscal year 2017, the Office for Management and Budget proposes sharp reductions for NOAA in areas such as education, grants and research. Within this, the satellite data division could lose $513 million: 22% of current funds.

Similarly, the USA's Environmental Protection Agency (EPA) is reported to be facing a 31% cut in its $8.1 billion budget, as well as a 20% reduction of its workforce, while the ARPA-E advanced energy research programme would disappear entirely (Reardon et al., 2017). The specifics of the budget were reviewed by Michael Greshko in National Geographic (10 March 2017). Greshko notes that, after adjusting for inflation, EPA in 2016 spent roughly what it did in 1987 whilst the proposed cuts would fund the U.S. Department of Defense ($583 billion budget) for just over 30 hours.

"The USA's Environmental Protection Agency (EPA) is reported to be facing a 31% cut in its $8.1 billion budget."

Data on the awards of competitive grant funding can give us a timely insight into the tangible consequences of policy change. However, it is important to beware that, like the beautiful iceberg pictured on the report cover, a large part of funding behind any area is difficult to find and can be hidden. This is both a strength – because a modest research budget can underpin much greater areas of monitoring and regulation - and a weakness – because assessing funding spend can be extremely challenging. Not all the key grants in an area come from competitive funding – much comes from block funds to organisations like the Max Planck institutes and agencies like the EPA or NOAA, while further money comes from industry. But the funding trends for competitive funding give a firm idea of current policy patterns and this information can throw light on trends that emerge and shape future research space. The analysis in this report will therefore also be a benchmark to track the impact of reductions in the USA contribution.

Understanding Funding Data and its Analysis

Over 50 years of scientometric study – the study of measuring and analysing science, technology and innovation – has created an excellent understanding of how publication and citation data should be managed and what makes for good indicators. Funding data has no such historical development so, in this report, we shall introduce some of these issues for discussion.

When research analysts look at publications, they usually look at journal articles and their citations, and they use a commercial database. This is a rather partial view, because it misses most conference proceedings and almost all books and their chapters, which are primary output routes for some disciplines. Journal data also completely misses the 'grey literature' of reports to government and other agencies where research delivers tangible impact.

When we look at research funding we recognise parallel challenges. The Dimensions' database takes us to competitively-won, individual project grants that detail the specificity of research activity by location, date and topic. This has never been available in the past. Agency budgets listed funds for large research institutes but not the detail of how that was used. National reports to the OECD, global in scope and audited to a common standard, are also opaque in the detail. Funding analysis will have to shift between these 'lenses' for a rounded view, filling in detail where possible.

"Like the beautiful iceberg pictured on the report cover, a large part of funding behind any area is difficult to find and can be hidden."

Defining a Topic Boundary

Definition of topics for research analysis can be a challenge. The task is tractable for very specific areas if we accept some granularity and trust some assumptions. We can define what we mean by, for example, freshwater ecology because we can agree a journal set that captures the significant global literature in that area. We can then use that to build a keyword set that identifies the associated research.

'Climate change' presents us with a more common dilemma. If asked 'what do you mean by climate change', a physicist, an ecologist and an economist will start from different points. Their descriptions may overlap but their emphases will differ as we shift from the measurement of systems change, through the effects of change on wildlife, to societal impacts and their mitigation. To compound the problem, research changes with time so the dataset that captured 'climate change research' in 2005 (or even in 2015 in a fast-moving area) might not map neatly to 2016 definitions.

The text in grants and in papers may also describe research topics differently. The question here is one of audience: a paper written to sit neatly in a particular journal will have a well-understood subject focus; a grant written to meet a particular funding call might be presented as interdisciplinary, multinational and/or innovative in the "right" way to obtain the grant. But, critically, the grant captures the whole project, whereas the paper is always a specific perspective.

Defining Research

What do we mean by 'research' and how do we try and capture the activity? Our focus could span basic, blue-skies research through to research development, applications and policy.

Analysts generally assume that research publications represent underlying activity in a rather uniform way. In fact, publications are a proxy for research, not a real measure, and different kinds of publication indicate different things. Researchers know that some output is very fundamental and some is from applied work done to solve specific problems. Title and abstract may therefore be very partial descriptors because publications targeted at other academics differ in style and content from those targeted at research users.

By comparison, the fuller descriptions associated with a project grant give a rounded picture of what researchers are actually doing. Even so, there is a very real problem about recognising where a research theme shifts between the stages of exploratory work, development and full-blooded application.

From the Dimensions' database, we can look at the detailed picture derived from competitive, peer-reviewed research grants, which are probably balanced towards basic research. We could then seek to extend the analysis into the more opaque picture we have of national agencies and research laboratories, which tend to be mission-led, core-funded and balanced towards applied research.

Analysis

"The research 'iceberg', has a visible research budget and a hidden but massive range of beneficial development and impact."

Our pragmatic definition of 'climate change' research is: any grant indexed in the Dimensions database that includes this as a term in the title, keywords or abstract.

More than 27,000 projects in the Dimensions' database refer to 'climate change'. They cover a total of $14.6 billion of research funding between 2003 and 2016, with a recent average of about $1.5 billion per year. Compare this with the US EPA budget of (currently) $8 billion per year and note that other countries have similar bodies. This balance of funding – between original research and its impact when it is used - is a reminder of how a modest global research budget can underpin the infrastructure of monitoring, regulatory, policy and advisory agencies with great reach and power. This is the research 'iceberg', with a visible research budget and a hidden but massive range of beneficial development and impact.

The 'climate change' project count makes up less than 1% of the total stock of indexed projects each year at the start of the period. It has been an area of growing interest: by 2009 it included about 1.75% of the project count in each year. Even that may seem a modest slice of global research activity given weekly newspaper headlines around the topic, but it does not include the D part of the R&D work of the other agencies.

Climate change is a scientific, and accurate, description of uneven and uncertain shifts in global systems. Google Trends shows that the term 'global warming' was a far more frequent search term over the last decade, so how does that appear in the Dimensions' database? Using a general search, as for 'climate change' and over the same period, there are 4,600 discoverable project grants that have 'global warming' in the title or abstract. That makes for around one-sixth of the 'climate change' total.

This balance reflects the distinction between popular focus and research typology. Data supplied by the Policy Institute at King's College London, from a topic search in Web of ScienceTM, reveal a similar balance in research publications. Through 2003-2016, there were about 133,000 journal publications that referred to climate change and 23,500 that referred to global warming, a ratio (1 to 0.18) that is much the same as the grants' data (1 to 0.17). The

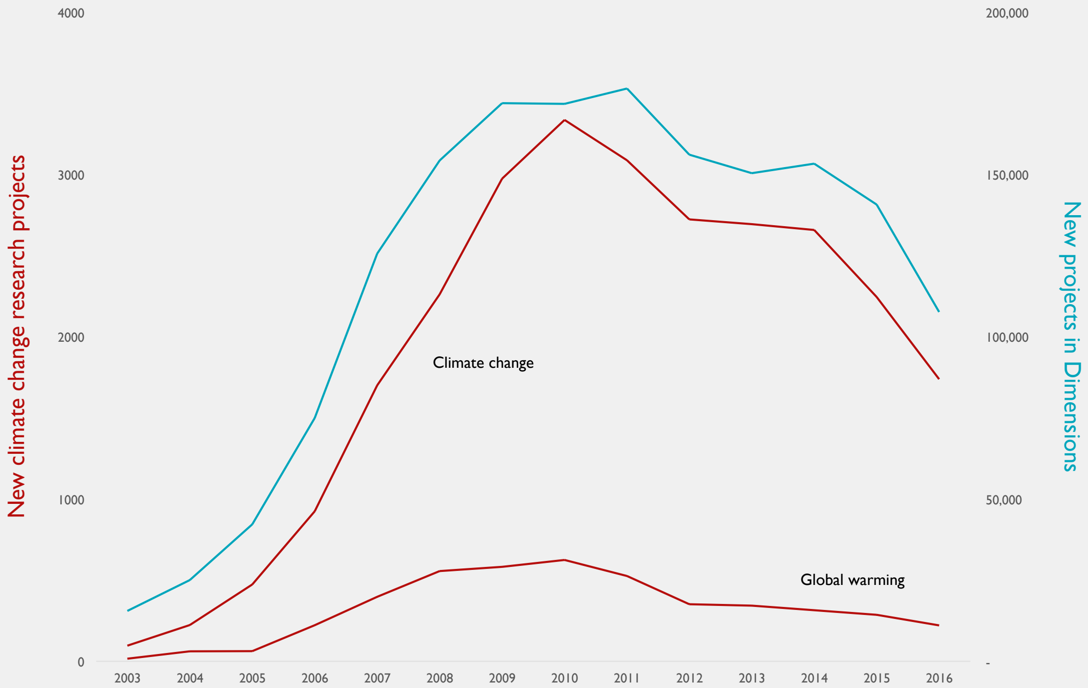


Figure 1. Projects indexed in the Dimensions database with 2003-2016 start dates. The number of projects specific to 'climate change' and 'global warming' (left axis) are compared with the total volume indexed (right axis), which changes by year. When counts are normalised relative to overall volume, 'climate change' grows to around 1.7% of the projects starting each year.

overlap between the searches is also similar for each of the two data sources: 93% of the 'climate change' publications are not found among the 'global warming' publications, and 94% of 'climate change' grants are similarly unique. This suggests that researchers have a strong sense of appropriate terminology and apply it consistently in labelling and summarising both grant applications and articles.

Initial exploration of the funding information throws up some data management issues. For example, the overall time-based profile for project counts in Figure 1 reflects, first, the relatively recent foundation of the Dimensions system and, second, the variable latency with which funders make their data accessible. Analysis will need to account for the changing data availability between years.

First, the annual project count rises through to 2009. We might expect this for 'climate change' because the research field grew through the decade as more governments focussed their policy concern. But a steeply rising overall project count cannot have been globally true, so analysis needs to index any specific topic as a percentage of the database total.

Second, after 2011 there is a falling profile both for the overall count and the topics for which we have searched. The drop in 2016 is particularly steep. This is because some funding agencies release their audited data long after the funding is allocated. This accounts for up to one-third of the likely global total funding in the most recent year, and progressively smaller amounts going back year by year. Fortunately, major funders such as the US National Science Foundation (10,000 projects per year), the UK's Research Councils' group (5,000 projects), the European Commission's Framework Programme (5,000 projects), and the Australian Research Council (2,000 projects) are all prompt in releasing information.

We need to 'normalise' annual project counts as analysts have always done for citations. If we index 'climate change' as a percentage of the total indexed projects we find it rises from 0.6% of project count in 2003 through 1.2% in 2006 to 1.75% from 2009 through to 2016. So, 'climate change' has indeed become more frequent as a part of overall data. It is now an established rather than expanding part of the global portfolio. The fall in the indexed project count in the last year or so does not affect our interpretation.

'Global warming' is a small part of the climate change project total, and in fact declines in relative frequency in the most recent years, down from about 0.3% to 0.2% of total Dimensions projects. This probably reflects a shift in both terminology and in the research agenda rather than a shift in significance. Later in the report we will look at the ways in which the funding data capture the dynamics of climate change research.

The Spread of Projects by Conventional Category

What does 'climate change' include? We can revert to a variety of conventional categories to get a feel for the material included in the topic we selected for analysis. This provides a sense-check (are these the categories we would expect?) and gives us an idea of the balance (what are the frequent categories?). Where we have topics to compare, as we have with 'climate change' and 'global warming', we can also see if and how they differ in that balance across categories.

Global warming		ANZSRC Field of Research	Climate change	
4,562	%		%	27,128
409	9.0	0602 Ecology	8.7	2,350
179	3.9	0502 Environmental Science & Management	**8.1**	**2,193**
290	6.4	0406 Physical Geog & Environmental Geoscience	7.5	2,037
258	5.7	0405 Oceanography	5.1	1,382
205	4.5	0403 Geology	4.8	1,306
169	3.7	0401 Atmospheric Sciences	4.5	1,219
139	3.0	0604 Genetics	2.9	795
113	2.5	0607 Plant Biology	2.3	636
51	1.1	0501 Ecological Applications	**2.2**	**593**
91	2.0	0503 Soil Sciences	1.9	520
131	**2.9**	0402 Geochemistry	1.6	446
42	0.9	1402 Applied Economics	1.3	358
26	0.6	0603 Evolutionary Biology	**1.3**	**356**
76	1.7	0907 Environmental Engineering	1.2	338
36	0.8	1117 Public Health and Health Services	1.0	280
20	0.4	0806 Information Systems	**1.0**	**264**
171	**3.7**	0306 Physical Chemistry (incl. Structural)	0.9	249
136	**3.0**	0915 Interdisciplinary Engineering	0.8	210

Table 1. The spread across frequent Fields of Research of research projects in Dimensions that are captured by topic searches for 'climate change' and for 'global warming'. The 4-digit codes refer to the ANZSRC classification system. Fields are ranked by frequency among 'climate change' data and relatively frequent categories are highlighted in Red.

The frequent Fields of Research for these topics will probably accord with most researchers' expectations. The list is led by ecology, oceanography, atmospheric and earth sciences. Areas more closely associated with application (engineering) and response (economics, public health) are less frequently found but they appear slightly more frequently in the 'climate change' pool.

How has the relative frequency changed over time and are there any evident trends on the balance of research fields? The focus in Dimensions is on competitively-won research grants, so it is likely that the data will reflect basic research more than application. As the impact of research becomes apparent, so governmental funding will shift from research funding agencies to mission-led organisations that take on the political, societal and economic outcomes. That will happen at different times across research fields.

For this part of the analysis we focus just on the data in the 'climate change' topic. As part of the total Dimensions database, the 'climate change' projects that reference ecology and environmental science make up only 8% of all Dimensions indexed projects for those Fields of Research, whereas 'climate change' includes 15% of oceanography research projects and 25% of atmospheric science projects.

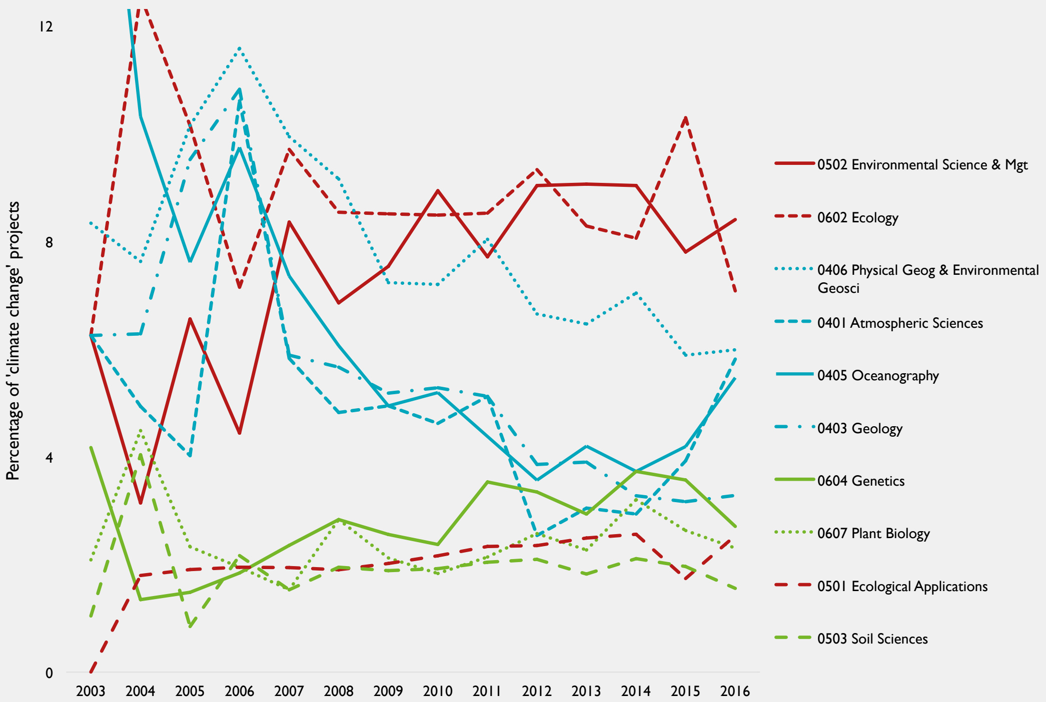
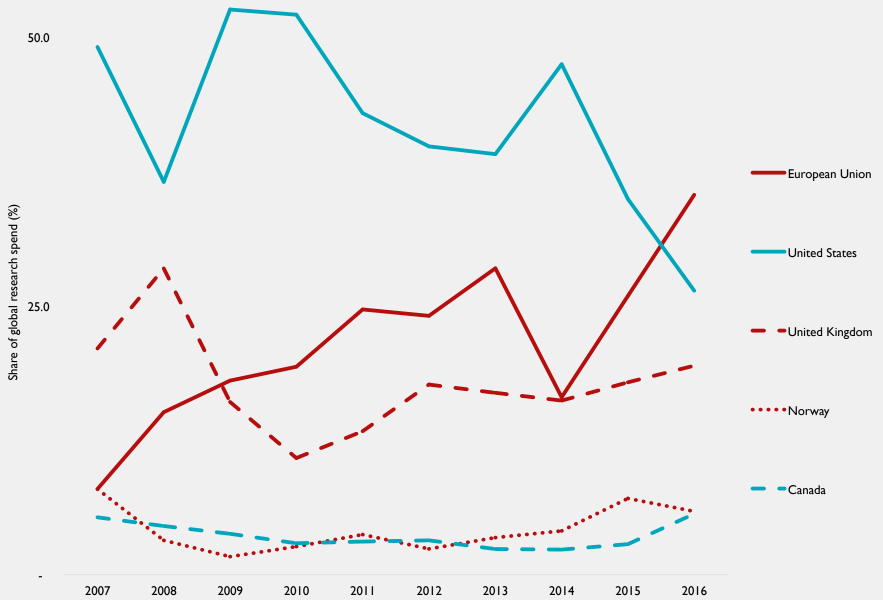


Figure 2. Trends in the relative frequency of specific fields of research within the topic search for projects on 'climate change' indexed in the Dimensions' database. Over the data period, funding for global atmosphere, ocean and earth systems declines while environmental and ecological funding is sustained. Funding is rising for areas that research the impacts of climate change.

As the data volume of research projects indexed in Dimensions has expanded, so the erratic profiles due to smaller counts in the early years (up to 2007) settle into better defined profiles that suggest some emerging trends over the last decade.

For example, atmospheric science, oceanography, and both physical geography and geology decline relative to the overall abundance of projects in the topic. Since the 'climate change' pool remains around 1.7% of the total data in recent years, this indicates that there are fewer recent grants that reference these fields. By contrast, ecology grants are sustained and environmental science and management is increasing in frequency as are ecological applications. So, the data suggest an underlying shift – perhaps from research descriptive of the global system towards research on effects on ecosystems.

The nature of research may also be changing. Some research areas might be supported by fewer but more multidisciplinary - and more highly resourced – projects to address the complexity of 'climate change' challenges. In fact, analysis of average grant size over the period shows limited evidence for any such trend, except in projects associated with applied economics. As noted in the Introduction, individual projects can be associated with more than one discipline so these may be projects where the economics of climate impact, and its mitigation, are a critical aspect of physical and biological analysis.



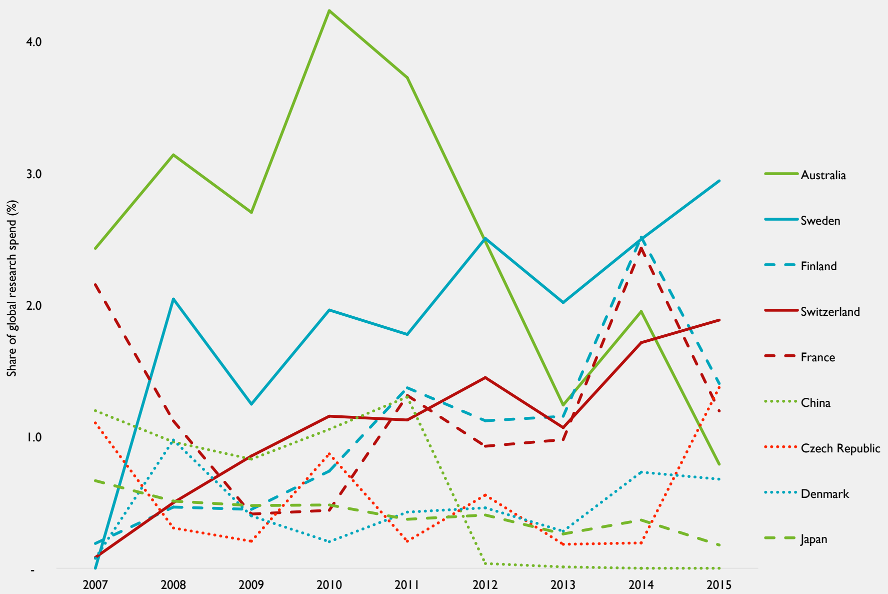


Figure 3. National spend on research grants for 'climate change' by project start year as a share of the value of global total research grants. A. Larger research budgets. B. Medium research budgets.

The Spread of Projects by Country

The geographical spread of funding for 'climate change' can be seen from both a funder perspective and by looking across the landscape of organizations that receive research grants. Money stays within national boundaries for most research funding agencies. This is not universally true, however, and the funding data picks up such flows. The most important cross-national funding is that supported by pan-European organisations: of the European Commission Framework Programmes; and the European Research Council.

A very large part of 'climate change' research grant funding seems to come from a relatively small group of countries: major G7 research funders and Scandinavia. The USA has been by far the largest contributor, but the expansion of climate research in the European Framework Programme now puts Europe in the global lead. The UK, Canada, Australia and Norway, Sweden and Finland also make substantial national contributions.

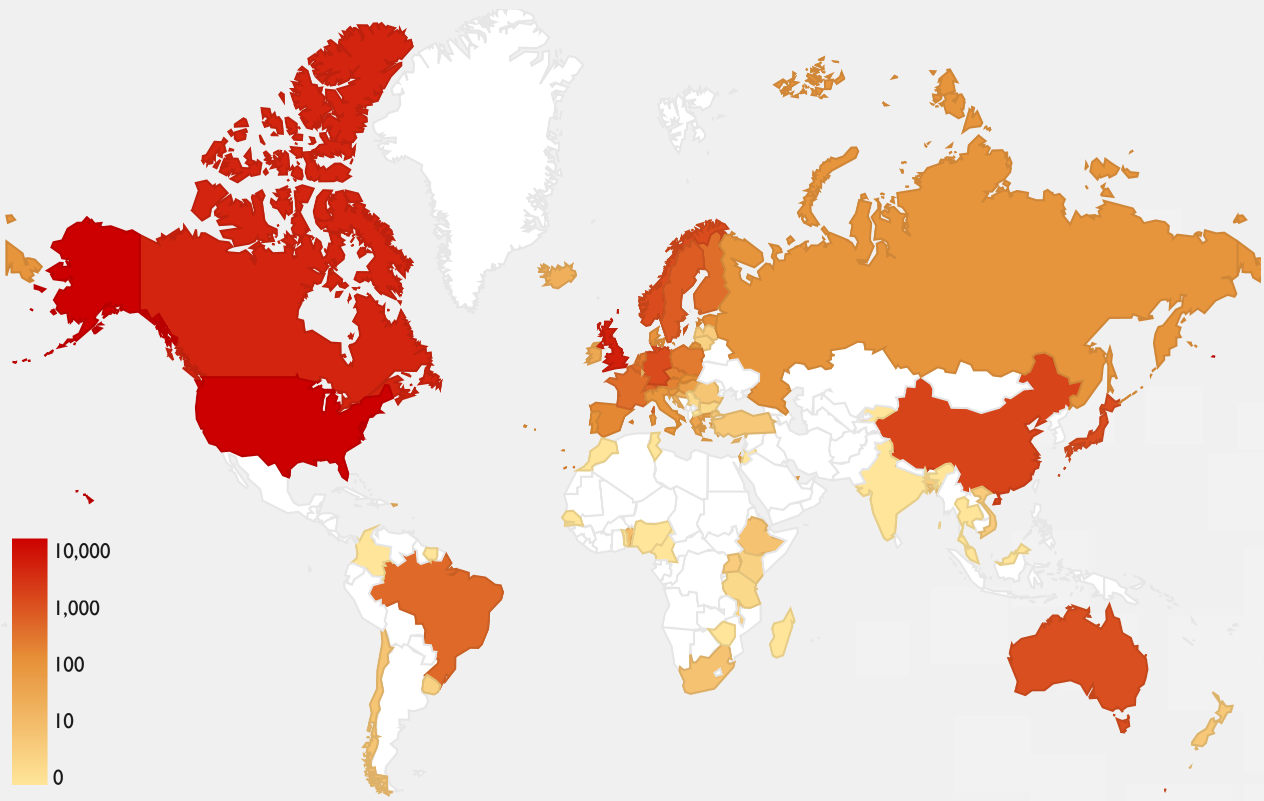
Research analysts will be surprised by the comparatively low level of funding for France in Figure 3B and the complete absence of Germany from Figure 3. These countries would usually be prominent in any conventional research analysis, and China would also be expected to play a major role. The explanation comes from economic and policy factors that any research funding analysis will need to take into account.

- Dimensions is a database of research grants, usually won through competitive peer review. It does not cover all forms of research funding and it does not include central block grants to mission-led institutes.
- France (with the CNRS) and Germany (with the Max Planck and other systems) have very strong institutes and relatively few competitive research grants. Other national systems like theirs will be similarly difficult to analyse.
- Dimensions' data show award values. Currency, research costs and salary levels all vary between countries and over time. Ideally, the data would be adjusted for Purchasing Power Parity, but OECD indices work at a national economic level atypical for research costs.

A count of projects shows that China is in fact increasing its investment in 'climate change' research. However, the unit cost of Chinese research grants is relatively low so it seems likely that 'full costs' typical of the USA and UK are not fully captured. Additionally, Chinese data are only available up to 2011 so analysis of recent years is in deficit.

To illustrate the distribution of 'climate change' research across countries, we made use of the count of awards rather than their value, because of the differing national cost bases for research. We also used project counts by awarded country rather than donor country: first, because the EU funds many projects but does not actually carry out the research; and second because we wanted to capture international collaborations.

Figure 4. The distribution of grants awarded to countries for research on 'climate change'. More intense colour indicates a greater relative number of grants to the country.



The map (Figure 4) confirms the summary values plotted in Figure 3, but because we have used awarded projects we can see a better distribution across Europe and we can see the links into Africa and Asia. The USA has over 10,000 individual projects indexed on Dimensions, and four other countries have more than 1,000 (UK – 4,220; Canada – 3,587; China – 1,290; Germany – 1,016). Norway, Japan, Sweden and Switzerland each have over 500 projects.

This basket of activity would, of course, provide further material for study. An obvious next step would be to explore the differences between countries in the balance of FoRs within the 'climate change' topic. How specialist are countries in their research and how is this trending?

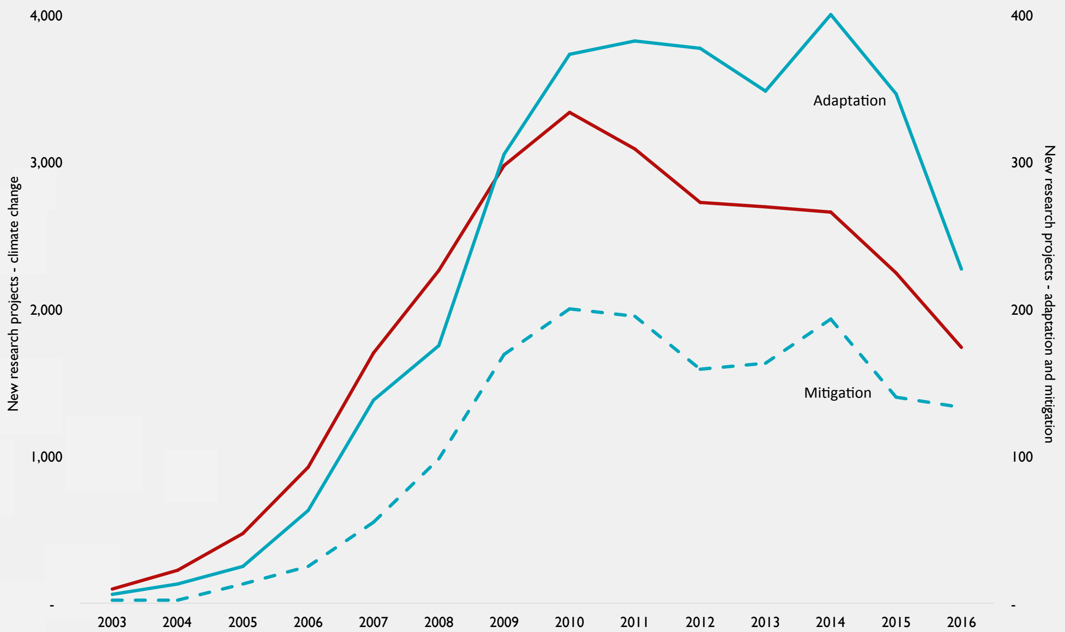
Dynamics of the Research Focus

The changing balance of discipline categories in Figure 2 implies a shift from 'climate change' research on global systems and towards ecological impacts and, perhaps, responses. How can the text content of the research grants' database be used to evaluate such indications?

Two emerging areas that support the responses to 'climate change' are adaptation and mitigation. If research focus is turning to these areas then we should be able to pick up the signal of their growing significance by changing the search criteria to a Boolean expression such as ["climate change" AND mitigation].

These searches reveal that both adaptation and mitigation have indeed increased in relative frequency within the growing portfolio of 'climate change' research. There are 3,201 research grants that reference 'adaptation' and they now make up about 15% of the 'climate change' annual total, having doubled as a proportion over a decade. 'Mitigation' remains less common with 1,569 research grants, but it too has risen as a share of 'climate change'.

Figure 5. Projects indexed in Dimensions with 2003-2016 start dates. The number of projects for 'climate change' generally (left axis) are compared with the more specific strands including adaptation and mitigation (right axis). When counts are normalised relative to overall volume, these strands take an increasing share of the climate change topic.



Fields of Research (ANZSRC system)	Climate change CC)	CC and adaptation	CC and mitigation
TOTAL	27,409	3,201 (11.7%)	1,569 (5.7%)
0602 Ecology	2,374	270	70
0502 Environmental Science & M'g't	2,219	340	194
0406 Physical Geog & Environ'l Geosci	2,060	149	69
0405 Oceanography	1,392	80	41
0403 Geology	1,315	42	33
0401 Atmospheric Sciences	1,227	112	65
0604 Genetics	801	240	13
0607 Plant Biology	643	95	24
0501 Ecological Applications	604	68	40
0503 Soil Sciences	527	36	66
0402 Geochemistry	447	3	8
1402 Applied Economics	366	76	78
0603 Evolutionary Biology	358	115	7
0907 Environmental Engineering	343	16	27
0705 Forestry Sciences	306	26	32
1117 Public Health & Health Services	287	63	43
0806 Information Systems	268	32	15
0703 Crop and Pasture Production	261	44	13
0306 Physical Chemistry	249	0	7
0605 Microbiology	230	25	10
0909 Geomatic Engineering	222	6	6
1605 Policy and Administration	217	67	46
1608 Sociology	215	43	23
0915 Interdisciplinary Engineering	210	3	12
0801 Artificial Intelligence & Image Proc'g	195	23	12
1604 Human Geography	182	84	25
0905 Civil Engineering	146	24	32
0606 Physiology	45	17	0
0701 Agriculture, Land & Farm M'g't	27	3	9

Table 2. Count by frequent Field of Research of 'climate change' projects indexed in Dimensions (2003-2016) and the numbers found by specific searches that also reference 'adaptation' and 'mitigation'. Cells highlighted in green are counts above average as a share of total 'climate change' and those in red are shares below average. Totals also indicate the average (across a rising trajectory) of the percentage shares over the period

Grant sizes differ between these areas: average research grant for ["climate change" AND mitigation] was 20-50% greater than that of 'climate change' generally in eight of the last ten years. Further analysis is needed to reveal what components of these, presumably interdisciplinary and complex, projects account for the premium value that funding agencies put on this work. Nonetheless, project descriptions and budget information evidently provide enhanced information compared to publication counts that could lead to intriguing new lines of enquiry.

Beneath the overview given by the search terms is a changing diversity of research activity captured in the text analysis and the assignment of Fields of Research (FoRs) that Dimensions uniformly applies to project grants from national systems with very different typologies. We noted a shift from systems research towards application areas (Figure 2). In Figure 5, we see that adaptation and mitigation – areas where applications will be important - are a growing part of the 'climate change' portfolio. How does this play out in the detailed FoRs?

Table 2 summarises changes and differences, visualised in Figure 6. The drop noted in projects around global systems (atmosphere, oceans and geoscience) is balanced by the growing adaptation and mitigation strands: relative share of these FoRs is much lower in these areas than in the parent topic.

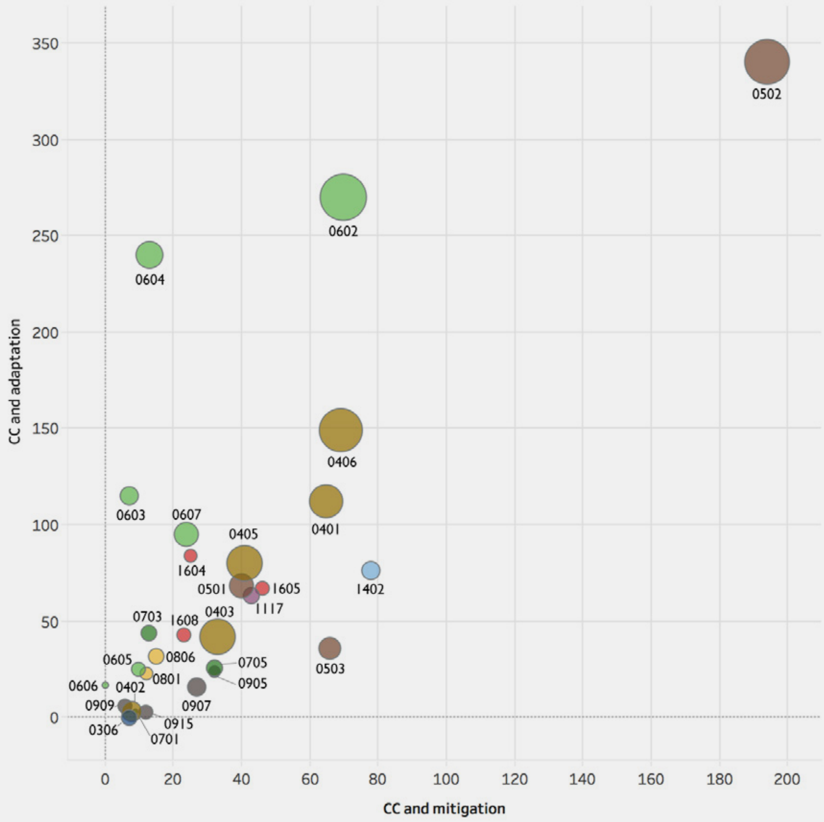


Figure 6. The distribution of 'climate change' grants by topic of research, positioned according to mitigation strand (grant count, horizontal axis) and adaptation strand (grant count, vertical axis). The size of the bubble is determined by the total count of 'climate change' grants for that FoR.

There is a general correlation in Figure 6 but the FoRs that are relatively more frequent in one or other strand are the 'outliers' off the main trend line. In the 'adaptation' strand, FoRs like genetics, plant biology, crops and evolution are on the rise as the response of bio-systems comes under scrutiny. In the 'mitigation' strand, it is soil and forestry sciences, and some areas of engineering while other areas fall back. For both strands, applied economics, public health, policy, and sociology have increased substantially relative to the broad parent dataset. This supports the idea that climate change research funding is shifting away from core description towards political and societal issues.

Obviously, a time-related analysis would pick up even more detail of the dynamics of these FoRs. Nonetheless, even a general view gives a valuable picture of a shift in funding focus with research maturity, a recognition of implications and the emerging relevance of policy and economic response. The data also tie up the relatively higher average grant size noted earlier for economics and later for 'mitigation'.

The FoR codes that start 04XX codes are earth sciences and indicate a main diagonal trend line where mitigation has about half the number of grants for adaptation: these include 0401 atmospheric sciences, 0403 geology, 0405 oceanography and 0406 environmental geosciences. The codes starting 05XX refer to environmental sciences and tend to be relatively more frequent below the main diagonal in the 'mitigation' area: they include 0502 environmental management and 0503 soil sciences. Applied economics (1402) is also in this area. The codes starting 06XX refer to biological sciences and are more frequent in the upper 'adaptation' area: they include 0602 animal and 0607 plant biology and ecology.

At country level, over the period 2011-2015, the USA awarded around 43% of grant funds adaptation and over 44% of funds for mitigation while European funds accounted 29% of adaptation and 36% of mitigation. This means that USA cuts could fall harder on global research in adaptation, whereas European funds are relatively strongly invested in mitigation. However, since European funds overall are now somewhat greater than the USA (Figure 3), but are below the US for these two strands, Europe may be slower in shifting out of background science and into these 'response' areas.

Climate Change and Arctic Research

Research funding for 'climate change' is not spread evenly across the globe, because some systems and some peoples are much more vulnerable to its impact than others. It is clear to any observer that a region highly vulnerable to 'climate change' is the Arctic, a region we define for this report with reference to geographical and indigenous peoples' names and any research for which the object of study is located within the area of the Arctic Council (see 'Arctic' Endnote). Studies show that Arctic habitats and communities face climate change at twice the rate of the rest of the world.

'Climate change' research funding and Arctic Research funding have a significant intersection and Arctic Research is as diverse as the climate portfolio. There is $14.6Bn of research funding in 'climate change' between 2003 and 2016. Over the same period, about $6.8Bn has been directed to Arctic research. The intersection of these two research areas covers about $1.5Bn of research funding: Arctic research that is related to 'climate change'. This means the total budget spent of 'climate change' that meet the criteria for Arctic research is about 10% of all 'climate change' research.

The data in Figure 7 show that about 20% of all Arctic research is in 'climate change'. There has been a slightly rising trend over the period, with an anomalous peak in 2009 due to the construction of the Alaska Region Research Vessel. The data also show the net contributions to Arctic Research made by organisations within the University of the Arctic (UArctic) and by other research producers that are not members of UArctic.

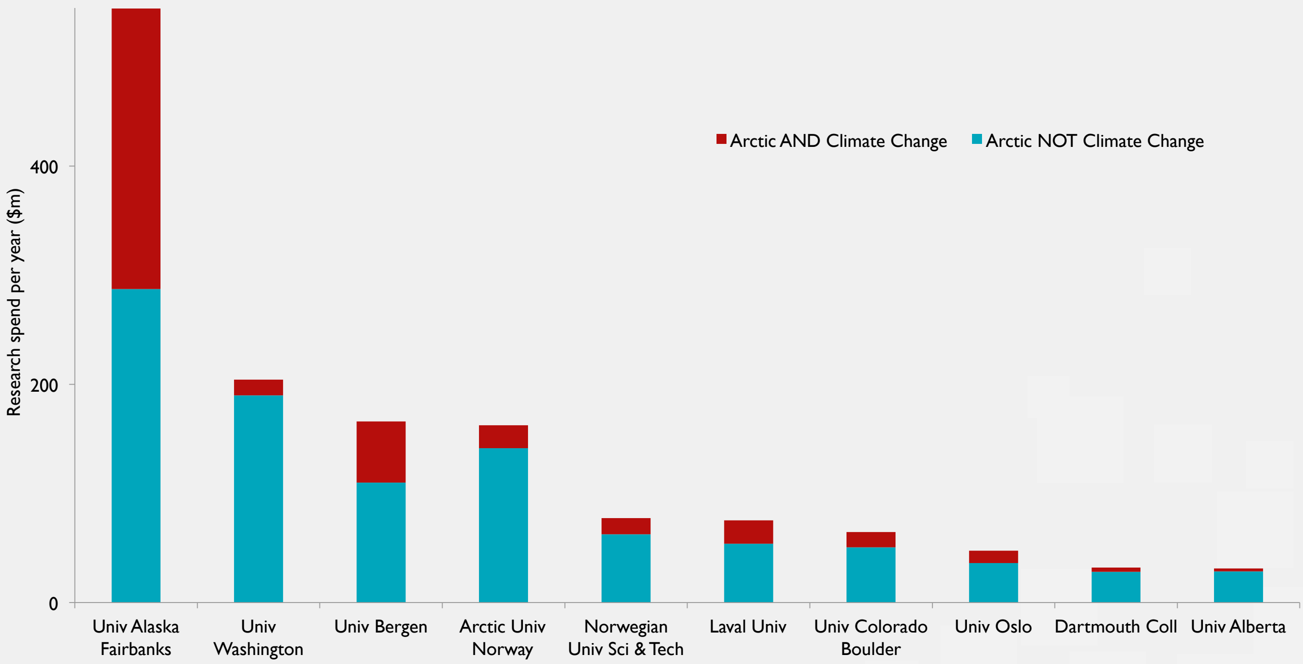


Figure 7. Annual research expenditure on 'climate change' research in the Arctic region by organisations that are members of the University of the Arctic and by other organisations. The right-hand scale shows this regional spend as a percentage of overall global 'climate change' research.

The majority of 'Member Organisations' of the University of the Arctic (UArctic) are Universities. These organisations are generally in the Northern Hemisphere and have a particular interest in Arctic Research, or in the outcomes of such research for the economy and well-being of their communities. The ten member organisations with the greatest concentration of funding for Arctic research are shown in Figure 8.

For most institutions, the spread of 'climate change' arctic research and non 'climate change' arctic research is fairly similar with around 20% of activity being climate orientated. The University of Alaska Fairbanks is the major funded organisation is this analysis, and is also the recipient of a $148m grant from the National Science Foundation (Directorate for Geosciences) to fund the Arctic Research Vessel. This is an important example of one nation's infrastructure supporting a collaborative, regional research effort. The University of Bergen is an institution with more than 20% Arctic research focussed on 'climate change'. It has been particularly successful in receiving six EC grants totalling $17.5m and a grant worth $14.1M from the ERC during the last ten years in 'climate change' within arctic research.

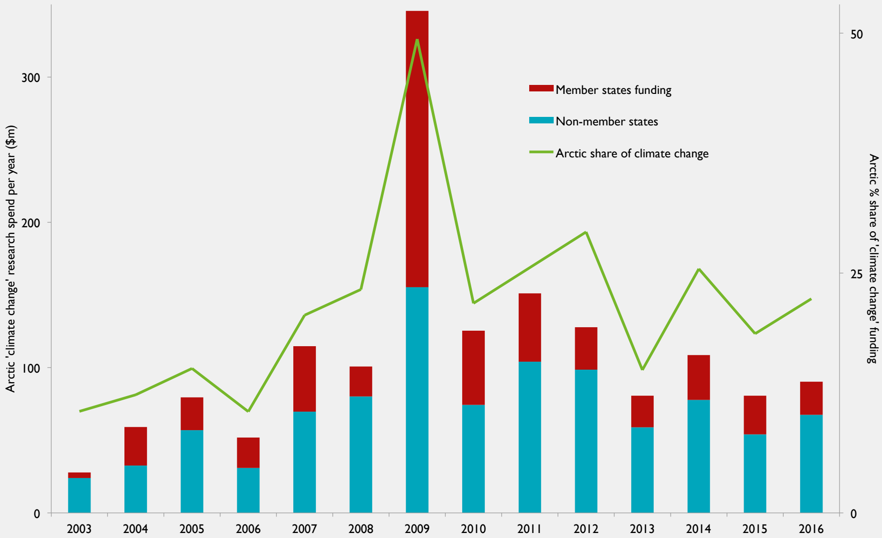


Figure 8. Annual funding for Arctic research from ten major research producers

Other Organisations and Their Budgets

The data on competitive research grant funding is just one part of the overall budgetary picture. We noted that the investment in underpinning original research was actually small compared to the infrastructure of monitoring and regulatory applications that were supported. In the same way, bio-medical research is a small part of the overall costs of most national health services. In both environment and health areas, there is essential feedback between the two parts of the system. The data that arise in monitoring and in service delivery form the basis and direction for further research, analysis, modelling and understanding.

To extend a fuller funding analysis we would go into the budgets of these other bodies. In the same way, a publication analysis would extend from the research world seen in journal articles to the development and application picked up in the 'grey literature' of government and agency reports that show how research is used in policy and applied in practice. It is not impossible to do this, but it is not feasible here. If sufficiently nuanced, it could be the subject of a completely separate report.

Conclusions

The message from our analysis of climate change funding is clear: not only does the USA support major environmental agencies with pervasive monitoring and regulatory roles but the grants' analysis shows it is also is one of the biggest funders of fundamental research. It provides key support and data to other organisations worldwide and it may have been more agile in shifting from background research into adaptation and mitigation. At a detailed level, NSF support for research infrastructure in Alaska helps underpin a global regional Arctic Research network. USA policy change could undermine the efforts of many others unless other governments step in to remind the USA of its mutual service obligations. The global research effort is shared because the climate is shared; so should be the responsibility to sustain these commitments.

"USA policy change could undermine the efforts of many others unless other governments step in to remind the USA of its mutual service obligations."

The research system is complex. This analysis has highlighted the relative size and shape of the budgets that support original research and the budgets that address the implications and impact of that research. Agencies that use climate change research draw on a wide environmental research portfolio in their missions. We see the same relationship between original research and its wider impact in climate research as in the well-studied area of biomedical research and health services (e.g. Hanney *et al*., 2015).

Climate change research funding grew as a share of indexed research projects since 2003 and is now around 1.7% of total research grants and about $1.5 billion annually. The portfolio has shifted away from global systems research towards impacts and responses, and from physical sciences to research that includes social sciences. This is seen in the relative expansion of the adaptation and mitigation threads, which themselves draw on distinctive research portfolios. UArctic organisations are major contributors to 'climate change' research but they, too, have a portfolio of research in related priorities.

"Climate change has shifted from global systems research towards impacts and responses."

The USA is the biggest national funder, but the EU matches that through joint programmes and collective national research, especially in the UK and Scandinavia. What happens if the USA reduces support for climate change research and analysis? The Paris accord, agreed by almost 200 governments in 2016, formally entered into force last November. Ban Ki-Moon, speaking with France's Francois Hollande, commented in Paris in March 2017 that, "what was once unthinkable has become unstoppable." But Hollande cautioned, "The United States, the largest economic power in the world, the second largest greenhouse gas emitter, must respect the commitments it has undertaken": agreement was "irreversible".

The critical cuts may be not to research but to the agencies that implement the research. If EPA is no longer able to monitor and to pass data streams to researchers and agencies elsewhere then problems may become severe before they are properly tracked. It is essential that other governments make clear to the US the service obligations that exist and that must be supported.

There are also lessons for research analytics. Publication data have been available globally for fifty years in well curated form. Methodology now needs to be agreed for funding data as well. Familiar challenges like normalization by year, variations in national practices, and subject differences will need further unpacking. There is continuity between funding and publication data, however, and a satisfactory complementarity between input and output perspectives will improve good research management.

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