

New Minds for New Science: The Forecast for Work in the Weather, Water, and Climate Enterprise

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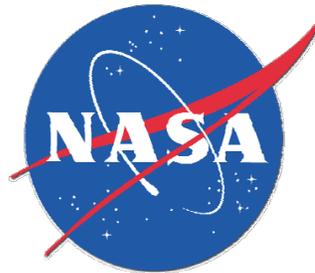
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About the AMS Policy Program

The AMS Policy Program has two primary goals. The first is ensuring that policy choices take full advantage of information and services relating to weather, water, and climate. The second is helping policy makers understand the ways that the broader society's welfare depends on information and services relating to weather, water, and climate. Meeting these two goals will help ensure that the scientific community receives the support and resources it needs to be able to make critical information and services available and, most importantly, will help the nation, and the world, avoid risks and realize opportunities related to the Earth system.

The Policy Program uses three primary approaches to help meet these goals:

- We develop capacity within the AMS community for effective and constructive engagement with the broader society.
- We inform policy makers directly of established scientific understanding and the latest policy-relevant research.
- We help expand the knowledge base needed for incorporating scientific understanding into the policy process through research and analysis.

Through these activities, we create new ways to reduce society's vulnerability to weather and climate events by sharing our resources and information with policy makers and the public.

Executive Summary

Work helps define our lives and the society we live in. The workforce is undergoing a period of rapid change due to a wide range of technological and societal shifts. These drivers of change will touch virtually every professional field and individual career throughout the world over the next 1–3 decades. This AMS Policy Program study examines workforce influences and needs for the weather, water and climate enterprise.

Four issues are central to advancing the weather, water, and climate workforce: 1) to understand the overarching social and technological factors that create opportunities and challenges for workforce development broadly; 2) to recognize the specific issues that relate to Earth system science, observation, and service (ESSOS) in particular; 3) to examine options within and beyond the enterprise for workforce advancement in weather, water, and climate (WWC) (including the role of AMS, K–12 education, professional development, and the policy process); and 4) to characterize remaining needs that, if addressed, could build workforce capacity.

Rapid technological advancement is affecting worker productivity and the skills employees need. We focus on four technological drivers: 1) artificial intelligence (AI), 2) new and nontraditional datasets, which contribute to Big Data techniques, 3) new forms of large-scale computing and collaborations across large distances, which are made possible by cloud computing, and 4) transformed access to information and new forms of communication, which are enabled by a new media landscape including mobile apps and social media.

Societal changes are altering the context in which businesses operate, the motivations of workers, and career opportunities for people throughout their lives. We emphasize four societal drivers: 1) growing recognition of the importance of diversity, equity, and inclusion (DEI) in scientific advancement and the application of science for societal benefit, 2) increasing demand for science to directly benefit the broader society, 3) the wide-ranging consequences of globalization, and 4) shifting roles and responsibilities among the public, private, academic, and NGO communities.

These technological and societal drivers are often interconnected and sometimes indistinguishable (i.e., technological changes drive societal change and vice versa). They also occur during a time of demographic changes in the US such as generational shifts and the increasing ethnic diversification of the American workforce.

The weather, water, and climate community is subject to these drivers and also has several distinct characteristics that influence workforce needs and opportunities. Most notably, public-private-academic-NGO partnerships are relatively advanced within the enterprise; the linkages among observations,

science, and service are particularly strong; WWC science is highly interdisciplinary; and enterprise work connects directly to people's daily lives and future prospects.

Here we identify eight opportunities and needs for workforce advancement. The weather, water, and climate enterprise should:

1. Build adaptiveness: to recognize and harness opportunities, and build resilience to face the challenges embedded in social change and technological advances, ranging from new media, to more flexible computing, and the internet of things.
2. Promote holistic approaches to Big Data and artificial intelligence (AI) that simultaneously consider issues of data quality, sharing, privacy, access, and bias.
3. Develop a diverse and inclusive culture; one that welcomes people from all backgrounds, empowers individual contributions, and encourages all to share their talents fully.
4. Enhance purpose-driven science that provides societal benefit. This will advance public wellbeing and create fulfilling career pathways for prospective members of the workforce.
5. Enable and promote phased retirement and succession planning.
6. Strengthen adaptive and evidence-based approaches to teaching and worker training.
7. Encourage development of high-value but nontraditional skills including collaboration and communication.
8. Facilitate collaboration across sectors, particularly in the education of students and workforce training.

Education will help determine the foundational skills and capabilities of the future workforce and how broadly distributed those capabilities are among the population. Policy choices will support or hinder workforce advancement by providing and directing resources; creating incentives to encourage (discourage) constructive (harmful) behaviors and practices; regulating behaviors; or encouraging challenging discussions associated with new technologies and societal developments.

As a result, progress in weather, water, and climate will depend on individual choices, community efforts, and societal decisions. Furthermore, efforts will be broadly distributed among the public, private, academic, and NGO communities. These must be considered both separately and together to promote maximum effectiveness.

AMS is engaged in a number of follow-on activities to understand workforce challenges and opportunities to help to meet future needs. For example, the newly formed AMS Department of Career Development strives to create resources to expand opportunity and support professional development across a wide range of traditional and nontraditional paths throughout one's career.

1. Introduction

For better and worse, work defines individuals and society to a large degree. The unemployment rate is used as one of the indicators of the health of our economy. Jobs are tightly linked to tax revenue and the movement of people. On a personal level, professions are often associated with economic success, mental and physical health outcomes, and social status.

As a result, understanding developments in the labor market is critical to individuals and society overall. One key to enhancing the experience and productivity of employers and employees is to anticipate changes in business models, technological trends, and societal developments. Consequently, there is great interest in predicting the future of individual professions or the labor market as a whole. The public attention to these forecasts has grown with an increasing uncertainty about the impacts of technological, societal, and political developments on the American workforce¹. At universities, researchers are working to improve our understanding of the impact of factors ranging from AI to an aging workforce. The future of our workforce has long been at the center of political discussions in Congress and presidential elections. The subject is the focus of a growing number of reports from academic institutions, Federal agencies, NGOs, and think tanks. It is beyond the scope of this report to summarize the existing literature in detail, but there are common threads which provide background and context:

- 1) The effects of data science and artificial intelligence on the workforce are highly uncertain but likely to be large. In particular, it is not clear which jobs will be replaced by automation and how fast, and which skills will be transferable to new professions².
- 2) Demand for jobs with very high and very low educational requirements is increasing, while the number of jobs that require a medium level of education is decreasing³.
- 3) The US economy will be affected by a number of demographic changes. Despite the tendency to work longer⁴, the widespread retirement of the “baby boomers”⁵ will result in millennials becoming the largest group in

¹ <https://tinyurl.com/y7bvjwel>

² <https://tinyurl.com/y62qktu8>

³ <https://economics.mit.edu/files/16724>

⁴ <https://tinyurl.com/tef28d5>

⁵ <https://www.census.gov/library/visualizations/2018/comm/historic-first.html>

the workforce⁶. By 2055, no ethnicity is expected to make up the majority of the workforce⁷.

- 4) Globalization makes it increasingly critical to understand workforce developments internationally⁸. Changes that occur anywhere can have effects everywhere.

Despite the large body of work on the future of the US workforce, there remains a great need to assess the changes specific to the workforce within the weather, water and, climate enterprise. As a professional society, helping to understand and navigate workforce challenges and opportunities is central to the mission of the American Meteorological Society. This AMS Policy Program Study is primarily based on a 1.5-day workshop that took place on April 28-29 2019 in Washington, DC. The event was attended by about 50 participants from the public, private, and academic sector as well as the NGO community. Additional input was provided through a number of interviews leading up to the workshop.

2. Technological Drivers

New Technologies are transforming almost every part of the Weather Enterprise

Meteorologists use cutting-edge technologies (e.g. satellites, high-performance computing) to collect data, conduct research, and disseminate forecasts. Now, a number of new technologies are again transforming almost every part of the value chain within the weather enterprise. Space technologies are becoming smaller and more affordable, opening the competition for new companies and new ideas. The development of small satellites (e.g., CubeSats) has the potential to greatly increase the number of observations from weather satellites. Similarly, the combination of new sensors and the Internet of Things have the potential to collect data with virtually any device. The development of autonomous vehicles exemplifies the new possibilities to collect data as well as the need to produce hyper-local predictions to enable new technologies. Here, we identify 4 areas where technological developments are transforming the work in weather, water, and climate science.

⁶ <https://www.pewresearch.org/fact-tank/2018/03/01/millennials-overtake-baby-boomers/>

⁷ <https://tinyurl.com/y4829d49>

⁸ <https://tinyurl.com/yy94ru6c>

A) Media Landscape

One area of rapid transformation is how forecasts are disseminated to customers and the public. The rise of social media and smartphones has coincided with a decline in subscriptions to newspapers and cable television. The result is a new media landscape requiring new strategies to provide every stakeholder with the information they need. The new platforms allow consumers to access weather information in most places and at all times. However, it can be difficult for the public to determine the quality of the information they receive. Additionally, the large number of products can also strain resources at media companies. Sustainable models to finance forecasting products across many platforms and to a variety of users are still being developed. At the same time, the demands on forecasts have steadily increased. Weather and climate predictions are increasingly local and often translated from physical variables to possible impacts and actions in response to the forecasted events.

The result is a new media landscape requiring new strategies to provide every stakeholder with the information they need.

In summary, there is a growing need for timely and local environmental information at the consumer's request and in a language that enables the public to make informed decisions. New hardware and software technologies are almost certain to play a key role in responding to this demand. It will be critical to identify the most effective use of broadcast (or multimedia) meteorologists to help the enterprise deliver on its promise to protect lives and property.

B) Cloud Computing

Traditionally, weather and climate forecasts have been produced using some of the most powerful high-performance computers in the world outside of defense applications. This technology requires substantial investments in performance upgrades every 5–10 years. Thus, it is mostly restricted to governments and allows for little flexibility and experimentation. The rapid onset of cloud computing over the last decade promises cheap and flexible access to large computational resources for a much larger group of stakeholders. For example, cloud computing plays an important role in NOAA's Earth Prediction Innovation Center (EPIC) initiative⁹. The agency anticipates that cloud computing will

⁹ <https://www.owaq.noaa.gov/Programs/EPIC>

provide developers with the resources they need when they need them. It should also facilitate access for academics and foreign researchers, whose ability to contribute is currently limited by security concerns that make it almost

impossible for foreign scientists to contribute to model development.

The rapid onset of cloud computing promises cheap and flexible access to large computational resources to a much larger group of stakeholders.

Furthermore, questions about the reliability of cloud computing systems at large scales and potential backup plans will have to be answered before operational forecasts models can be transferred from high performance computing centers to cloud computing. As a result, the transition to cloud computing will likely be a gradual one for public-sector employees.

The importance of cloud computing might be even larger in the private sector. A number of private-sector companies have elected to rely almost exclusively on cloud computing for their in-house modeling and postprocessing. The flexibility of cloud computing resources allows businesses to react nimbly to market forces and develop products for an increasingly diverse weather enterprise.

For most developers, the transition to cloud computing should be relatively smooth as their general skill set is likely applicable for many hardware solutions. Businesses and employees can benefit from the increased flexibility associated with cloud computing. Employees can access resources easily from almost any location and businesses can provide even more tailored products and on-demand computing.

C) Nontraditional Observations

Observations, which are of critical importance to the weather enterprise, are changing in profound ways. The relatively small number of traditional high-quality observations is now often supplemented by a large number of cheaper non-standardized measurements. For example, recent advances in space technology, have led to significantly lower prices to launch a given mass into space¹⁰. At the same time, the development of small satellites might produce useful data at even lower costs for some applications. In the future, the multi-

¹⁰ <https://www.futuretimeline.net/data-trends/6.htm>

billion dollar weather satellites launched by governments might be supplemented with many small satellites developed by private companies, universities, and others.

Closer to the surface, a number of private companies are exploring the value of many nontraditional datasets primarily to respond to the increasing demand for hyperlocal predictions on short timescales. The new datasets range from the attenuation of cell phone signals to highway cameras and consumer electronics. The combination of widespread access to broadband internet connections, the miniaturization of electronic devices, and the development of data science over the last decade have the potential to extract meteorological information from almost any device. Autonomous vehicles, usually equipped with a number of sensors, might lead to even more data while further increasing the need for extremely precise and local weather predictions.

The promise of new data and new markets has already sparked a number of activities and investments, especially in the private sector, but the use of non-traditional datasets also raises new questions. First, the new observations are usually not standardized by organizations such as the World Meteorological Organization. Thus, quality control will be particularly important and, eventually, a need for new standards might develop. Second, the majority of new datasets has been developed and used in the private sector. As companies need to protect their insights and advances to succeed in the marketplace, there is a lack of robust literature documenting these datasets and their impact on forecast quality. This in turn makes it harder to evaluate the value of datasets for potential buyers in the public and private sectors. Third, for decades the free exchange of observations has made weather information available to a wide range of governments, businesses, and individuals, who have used it to make advances in research, operations, and services. The ability of private companies to establish their own critical datasets might require adjustments to the way our community exchanges data nationally and internationally.

D) Artificial Intelligence

While computers have long been able to perform calculations which vastly exceed human abilities, they did so by solving equations, which were derived and understood by humans. Thus progress was made by humans finding new ways to deploy computers. Many experts believe that the rising importance of artificial intelligence (AI) is about to change this paradigm. AI is “a branch of computer

science dealing with the simulation of intelligent behavior in computers”¹¹. Most applications of AI use large datasets to come to conclusions beyond current human understanding. For example, traditional chess software is given the rules and strategies of the game and uses computing power to execute them at a high level. AI-based algorithms can be trained on past games (played by humans or computers) and infer their own strategies.

Given the amount of standardized and well-documented data in weather, water, and climate science, the potential applications of AI technology are vast. Current research ranges from the development of new parameterization of subgrid processes to the interpretation of completed ensemble simulations. At the

Most of the experts believe that the initial effects of AI will be largest for traditional weather forecasts

moment, it is difficult to foresee the precise impact of AI on the various components of the value chain in the weather enterprise. Most of the experts we consulted believe that the initial effects will be largest for traditional weather forecasts where models are already exceeding human capabilities for certain lead times.

However, the implementation of AI also raises new concerns and questions. By definition, the goal of these new algorithms is to gain insights beyond current human knowledge. Some scientists fear that weather forecasts will become a “black box”, trained on an increasing number of datasets without leading to an actual understanding of underlying processes. This approach might lead to improved forecast skill in the short term, but it could slow scientific progress and make it nearly impossible to identify the origin of model errors. Consequently, applying AI requires great care and deep understanding. The community would benefit from a workforce, that can weigh the pros and cons of AI applications and possibly tailor them to maximize public good.

Furthermore, the movement toward increased reproducibility in science might be complicated by AI — especially if the algorithms are not widely accessible or are trained on proprietary data. Experiments in other fields have shown that AI can perpetuate biases instead of eliminating them based on the training datasets. For example, facial recognition software is often most accurate in identifying white

¹¹ <https://www.merriam-webster.com/dictionary/artificial%20intelligence>

faces, because the training data contained fewer faces of people of color¹². Forecast errors are not uniform across regions or physical variables due to inhomogeneous observational density, scientific understanding, and operational capacity. It will be important to determine whether the next generation of software will increase or decrease such discrepancies.

This issue becomes particularly important as AI is not only used to advance science, but as an HR tool¹³. If computers replace human decision-making for hiring, firing and, career development, the consequences of AI can be life-altering. One can imagine software, which ranks male candidates for computer engineering jobs above equally qualified women, because the training data contained more men in these positions. Employees will need to understand the basis of the software-based or software-supported decisions. Publishing training data and demonstrating that the results are fair could be important first steps. This kind of transparency will be key to build public trust in decisions made by algorithms and to allow the enforcement of anti-discrimination laws and regulations. On the other hand, there is a need for broad society-wide conversations to determine the expectations for HR tools. Many employers are already using less sophisticated processes to automate at least some HR tasks. The development and deployment of more powerful decision support systems is a good opportunity to establish standards for the ethical use of such tools.

The four highlighted technological transformations are occurring simultaneously. Each alone (and all together) has great potential to alter workforce needs in weather, water, and climate science in wide-ranging and unpredictable ways. There are good reasons to believe that the current and incoming workforce can adjust to the switch from traditional high-performance computing to more cloud-based applications. First, the change will be gradual as governments are likely to rely on their own hardware for operational models in the foreseeable future. Second, the onset of cloud computing is unlikely to make the skillsets of many current employees obsolete. While additional training might be required, these new technologies are likely an extension of the existing ones instead of a paradigm shift.

¹² <https://time.com/5520558/artificial-intelligence-racial-gender-bias/>

¹³ <https://tinyurl.com/y6mz7f8p>

Similarly, the weather enterprise has adjusted to changes in media consumption since the beginning of operational weather forecasting. In fact, the recent movement toward impact-based weather predictions and the discussion about the best translation of climate assessments to local communities further emphasize the importance of communicating the work of our community to a variety of stakeholders. A new media landscape might require new business models, but the ability to use environmental intelligence to affect real-world outcomes is likely to remain a major form of employment in weather, water, and climate science.

The number of jobs in forecasting and the necessary skill set of future forecasters is hard to anticipate.

In contrast, the effects of AI and the new datasets it might be trained on are even harder to predict and potentially more disruptive to the workforce. As outlined above, AI might strongly affect the nature of weather and climate predictions. The new models might not only outperform the best human predictions, it is also unclear how human insight can be harnessed when algorithms are no longer based on the laws of physics. As a result, the number of jobs in forecasting and the necessary skill set of future forecasters is hard to anticipate. Meteorology curricula are already incorporating classes from math, physics, computer science, and other disciplines making it more difficult to train students in AI and Big Data. Organizations across all sectors will need to cooperate to identify obsolete skills as well as key skills to succeed in the labor market of the future. Additionally, employers need to weigh the pros and cons of teams of experts compared to a workforce with a broader skill set, but less experience in individual disciplines.

The use of AI to support HR decisions is not specific to the AMS community, but could potentially disrupt employer–employee relationships across industries. This change could be beneficial as it has the potential to remove human biases from decision-making, anticipate training needs beyond human predictive skills, and make employer priorities transparent. Conversely, a poorly implemented AI tool could introduce new biases or solidify existing ones, and make far-reaching decisions without human oversight. Balancing the need to protect proprietary software with the transparency necessary to ensure quality and fairness will be critical.

If all scientists feel safe, valued and welcome, independent of their identity, science will advance more rapidly.

3. Societal Drivers

Societal changes will also affect who works in weather, water, and climate science, what we work on, and how we connect with stakeholders. In this study, we identify four societal drivers, which affect the workforce now and into the future.

A) Diversity, Equity and Inclusion

The role of diversity, equity, and inclusion (DEI) in weather, water, and climate science is threefold. First, an emphasis on DEI can help minimize barriers to being part of the community for reasons of race, gender, sexual orientation, age, or field of expertise. Second, research has shown consistently that teams with diverse backgrounds outperform less diverse teams¹⁴. Increasing diversity is a shrewd business decision. If all scientists feel safe, valued, and welcome, independent of their identity, science will advance more rapidly. Third, diversity is particularly important in a field that attempts to reach every person almost every day. A workforce that looks like society at large is more likely to ensure that the benefits of science are equitably distributed.

A major issue in addressing diversity is a lack of reliable data. Race and gender distributions are generally better documented than other factors and we know more about students and the public workforce than about employees in the private and academic sectors. The American Geosciences Institute, the American Institute of Physics, the Bureau of Labor Statistics and federal agencies collect relevant data but drawing valid conclusions from the various datasets remains challenging. As the weather, water, and climate science community is relatively small, data are often aggregated with other fields making it difficult to identify trends unique to this field. Data specific to our community can lack the sample size necessary to calculate reliable statistics.

¹⁴ <https://www.sciencedirect.com/science/article/pii/S2212567114001786>

According to a NOAA Education Office analysis of Department of Education data, the number of women graduating in atmospheric sciences and meteorology is gradually increasing at the BS and PhD levels. At NOAA, women have been hired into entry-level positions at a rate of 50% of successful applicants or higher over the last few years. Nevertheless, the gender imbalance is still largest among meteorologists and progress is translating slowly to leadership positions. Taxing shift schedules and remote office locations remain two meteorology-specific hurdles to parents, which might be among the reasons for the lower retention and promotion rates of women.

Similar to other physical sciences, African Americans are underrepresented in meteorology, and the percentage of African Americans in meteorology has changed little over time. Hispanics are also underrepresented in meteorology but rates of participation are increasing slowly. There are a number of potential barriers limiting the participation of minorities in weather, water, and climate science. Potential students and employees may face selection bias when applying for university programs or job opportunities. Laws, regulations, and codes of conduct should protect minorities from conscious discrimination, but the effects of unconscious bias are well documented. Furthermore, the weather, water, and climate enterprise might need to increase its visibility in underrepresented communities and better communicate the value of working in these disciplines.

Stereotypes and biases hinder progress among disciplines as well. Too often, we emphasize the differences between members of our communities and prolong stereotypes. For example, computer scientists might be labeled as “coders” and not respected as scientists. Similarly, social science is often juxtaposed with “hard science” instead of the critical link between scientific information and societal outcomes. AMS and its members should continue to lead the movement toward a welcoming culture to everyone with an interest in weather, water, and climate science. The result will be improved science with maximized benefit to society.

B) Science with a purpose

Career choices are influenced by a variety of factors ranging from personal interests to financial considerations and work–life balance. Recently, there seems to be a renewed focus on the translation of scientific progress to societal outcomes. This development affects the workforce in two ways.

Young employees express their desire to make a positive impact on society.

1) Today, employers in the public and private sectors report that young employees express their desire to make a positive impact on society. Employees who feel that they are making a difference are more motivated, learn faster, and have higher retention rates. Recognizing the renewed demand for a purpose beyond financial incentives might help companies to compete for highly talented people in a tight labor market. It will be necessary for employers to demonstrate how their work benefits society and how individuals will be able to contribute. However, companies may need to balance their support of social causes with their pursuit of profits, if they do not perfectly align.

2) Society increasingly demands the effective translation of scientific progress into societal benefits. Doing so more effectively might require adjustments to the design of scientific projects in the public, private, and academic sectors of the weather, water, and climate enterprise. Employers may emphasize oral and written communication skills more than they used to. Employees could also be asked to engage in the co-creation of knowledge with local communities and citizen scientists or to increase their outreach efforts. In the past, societal impact has too often been an afterthought at the end of projects instead of a cornerstone during the planning phase. New projects should respect and incorporate local communities to ensure science truly addresses their needs. In particular, communities of color or low socioeconomic status have sometimes felt like the object of science instead of contributors to (and beneficiaries of) it. As outlined above, working toward equitable access to science might also help efforts to improve diversity and inclusion.

Redesigning scientific projects with an emphasis on societal impacts may also require realigning incentive structures over time. For example, decisions on tenure in academia are still mostly based on publications records and successful grant proposals. A more holistic approach could allow for a smaller number of publications, if a candidate invested a lot of time in citizen-science projects, outreach, or delivered on other forms of societal benefits. Similar adjustments could be made to the process of approving academic grant proposals. Incentives for the private sector might be implemented in the language of contracts given out by public agencies. Lessons can be learned from a number of place-based science organizations, which already exist. The NOAA RISA and Sea Grant

programs, the USGS Climate Science Centers, and the USDA Regional Climate Hubs are examples of organizations that frame science with the needs of particular communities and stakeholders.

If done right, actions to improve the translation of scientific advances into societal benefits might also help to attract the next generation of talent and vice versa.

C) International Relationships

While this study is primarily focused on the American workforce and domestic developments, international factors have the potential to affect the US labor market and the business models of companies operating in the US. We identify three current policy debates with the potential to impact work across boundaries in our community.

First, many policy makers across the political spectrum agree that legal immigration into the US needs to be reformed¹⁵. Any changes to the current system could change (in either direction) the number of students and employees who are allowed to enter the country and are available to join the weather, water, and climate enterprise.

Second, policy makers have become increasingly concerned with the protection of American-held intellectual property within and outside of the country. While it is important to protect American innovation, some are worried about the possible negative consequences for individuals from certain countries and the academic sector more broadly¹⁶.

Maintaining the free exchange of data will be important to all parts of the enterprise in the US and abroad.

Third, trade tensions between the US and other markets have the potential to affect the weather, water, and climate enterprise. So far, tariffs have not centered on the products and services of our community, although disputes in the

¹⁵ <https://www.brookings.edu/blog/fixgov/2019/02/11/can-immigration-reform-happen-a-look-back/>

¹⁶ <https://www.wbur.org/edify/2019/09/18/aicum-colleges-international-students-letter-visa-delays>

communication and semiconductor industries could have spillover effects to high performance computing or remote sensing. Critically, services and the transfer of data have not been impacted, allowing observations and forecasts to be shared across borders. Maintaining the free exchange of data will be important to all parts of the weather, water, and climate enterprise in the US and abroad.

D) Evolving responsibilities across sectors

Some new technologies have enabled the private sector to take on tasks which were traditionally only associated with governments. For example, today, the private sector is disseminating warnings issued by the National Weather Service and satellites are being launched on rockets built by private companies. As capabilities evolve so will the roles of the sectors and the institutions within them. Collaboration across sectors has been a strength of the weather, water, and climate community in recent decades. AMS will continue to provide a venue for the sectors to convene and improve cooperation.

The emergence of nontraditional datasets affects the balance between the public, private, and academic sectors. If future satellites are more likely to be operated by private companies or producers of consumer electronics and collect invaluable environmental datasets, it could be an impetus for a further shift in the roles of the public and private sectors. Governments and companies would have to adjust to the fact that less data might be publicly available and new methods to exchange data within the enterprise might become necessary.

In summary, all members of the community can provide services for the public good. The ideal balance between the sectors will change as technologies, capabilities, and public demand develop over time. Educating the workforce about the importance of cross-sector collaborations and fostering of meaningful conversations might lead to smoother transitions and avoid harmful disruptions for employers, employees, and end users.

4. Federal Workforce

Technological and societal drivers affect the entire workforce, but the unique circumstances of the different sectors lead to varying impacts across the enterprise. Public investments are often instrumental in developing new technologies or helping them break into legacy sectors of the economy. In these

cases the government's public service mission enables research investments and the absorption of risk that the private sector could not tolerate. On the other hand, public investments in existing technologies can be less nimble than in the private sector where market signals can quickly attract capital. As a result, federal agencies need to invest in people with a sufficient understanding of developing technologies to steer public investments.

The budgets of federal agencies related to the weather, water, and climate community have been relatively flat over the last decade. As a result, job growth in the private sector has generally been greater compared to the public sector. Currently, these agencies do not expect increased job growth over the next few years. Federal agencies tend to have high retention rates, which leads to a workforce with strong institutional knowledge. The reasons for the low turnover are likely a combination of the satisfaction from advancing the public good, high job security, and a benefit system incentivizing long government careers. However, as the technologies and capabilities evolve so will the necessary skill set for public employees. Creative management strategies and on-the-job training will be required to balance the low workforce turnover with short-term needs and long-term investments.

Attracting and retaining new talent for federal agencies will be a major challenge in the upcoming decades.

One opportunity to align the collective skill set of the federal workforce with new trends in society and technology is filling positions of retiring employees. The history of many agencies has resulted in a large number of federal servants who will qualify for retirement over the next few years. Filling the resulting vacancies strategically and in anticipation of future needs will be critical for NASA, NOAA, and other agencies. However, the outgoing workforce will also leave with invaluable institutional knowledge. Programs to allow senior personnel to reduce hours and move into a mentoring role promise a smoother transition as the next generation of leaders emerges.

Attracting and retaining new talent for federal agencies will be a major challenge in the upcoming decades. Many of the new technologies have applications far beyond the weather enterprise leading to a large number of well-paid jobs in the private sector. Given the federal pay scale, outbidding tech giants for talent in AI

or cloud computing appears unrealistic. One option is for agencies to compete for employees based on the importance of public service. As described above, showcasing the value of work for society and for specific communities might be one way to appeal to the next generation. There is also a sense that employees outside the government change jobs more often than ever. It is likely that new hires will expect more flexibility to develop their careers as public servants. Extended details, facilitated transitions between agencies, and the support to take care of a newborn or return to university are just some of the possibilities to create more varied career paths without the need to leave the government. These efforts could also help to attract and retain a more diverse workforce.

A unique issue in the public sector is the relationship of civil servants and private contractors. The two groups often work side by side with similar qualifications and responsibilities, but could be compensated very differently and enjoy different benefits and rights. For example, careers of federal employees are generally less affected by economic downturns, while contractors may have more flexibility in planning their careers. This contrast has the potential to affect workforce morale and further complicates the rules of public–private engagement. Navigating these circumstances will likely be an ongoing leadership challenge at federal agencies.

It is worth mentioning that this study only explored opportunities and challenges for the workforce at the federal level. While much of this chapter might still apply at the state and local level, one can expect local differences to affect at least some of the statements.

5. Private–Sector Workforce

The private sector ranges from large, decades-old companies to small consulting businesses, and from instrument development to forecast dissemination. Thus, the employers and employees face very different challenges and opportunities depending on the type of company they represent. Additionally, we find that new companies are joining the weather enterprise and that members of our community find jobs at employers who are not traditionally known to hire weather, water, and climate scientists. Many of the new companies are associated with the technological developments described above. Small satellites and new nontraditional datasets have led to entrepreneurial activity. Additionally, there

appears to be an increased need to tailor environmental information to the local and often specific needs of customers and stakeholders. The resulting companies often blend technical expertise with consulting functions. We also see increased employment in the energy, finance, and logistics sectors. As these employees are often outnumbered by experts in other fields, little is known about this relatively new type of employment. Anecdotally, it is more difficult for these scientists to remain active members of our community because their employers are less likely to attend conferences, subscribe to publications, or engage with academic programs in our field. AMS and its members will need to proactively reach out to support them and prepare the next generation for jobs in these growing fields. In general, the job growth in the private sector is expected to be larger than in the public sector.

Large established companies face some of the same challenges as federal agencies. They often expect a significant number of retirements in the near future, compete with the largest tech companies for talent, and strive for a more diverse workforce. The tight labor market has forced some of them to groom the next generation of employees from high-school age on. Many of the large companies specializing in weather, water, and climate have begun to offer new career paths which are better aligned with the demands of new employees. These programs may include fast promotions for highly qualified hires, the ability to switch jobs within the company, and work experiences abroad.

We also see increased employment in the energy, finance and logistics sectors.

Early and significant investments in new technologies such as cloud computing and AI are common among these firms. Today, these technologies impact not only the science and products of large corporations, but they are transforming the workflow. For example, AI tools can be used to predict the skills a company needs, which employees need to acquire new skills to remain valuable to the company, or assist in hiring decisions. An important issue going forward will be how the benefits of AI are distributed among employers, employees, and the public. As outlined above, the challenge will be to navigate the opportunities of new insights and challenges of concerns over privacy, bias, and opaque decision-making processes.

In contrast, a large number of smaller companies in the AMS community face somewhat different challenges. Many of these firms cannot afford the high levels of investments in new technologies and the professional development of their employees. The deployment of cloud computing has revolutionized the access to flexible high-performance computing for these firms. Cloud-based systems allow companies to hire across many locations and provide more flexibility to employees. The large amount of freely available data in the US and collaborations with partners are keys to the success of many smaller businesses. In many cases, targeting niche markets with highly specialized products gives smaller businesses an advantage over their larger competitors. Employees in smaller companies often need a more entrepreneurial skill set. AMS programs, such as short courses, certifications, and networking events, can be particularly powerful for businesses, which lack the resources and size to invest in such programs individually. Small companies can often offer unique experiences to new employees including possibilities to take on greater responsibility as early career-scientists. On the other hand, these companies may lack the resources for extensive training programs or conferences.

The impact of new technologies is already affecting jobs at the intersection of meteorology and media. The large number of cable channels and the onset of streaming services, smartphones, and new online platforms (e.g., YouTube) has led to smaller audiences for individual TV channels over the last few years. As a result, there is more pressure on the advertising-based business model of TV news broadcasts as well as on their meteorologists.

Social media has had a profound impact on broadcast meteorologists as well. They are now able and expected to connect with their audiences across many different forms of media and outside of shift schedules. The implications for broadcast meteorologists are twofold: 1) they have additional tools at their disposal to reach people anywhere and at all times; 2) they are expected to produce more content without a commensurate increase in pay. Additionally, web and app developers have produced an enormous number of internet-based weather applications. While the AMS certifies broadcast meteorologists, no similar mechanism currently exists to ensure the quality of online products, leaving customers with the difficult task of determining the quality of these newer products. Experts uniformly explained that one key to connect with people and affect their behavior is the ability to talk about weather, water, and climate in stories instead of meteorological jargon. This illustrates a

growing need for meteorologists to better understand social science and its implication for effective oral and written communication.

6. Education

One important reason to identify future workforce needs is to ensure that current education and training programs prepare students and employees as well as possible for the jobs that will be available to them. Educators and employers emphasize the importance of adopting new teaching methods based on advances in pedagogy over the last 10–20 years, particularly at the undergraduate level¹⁷. In many cases these new teaching methods replace the classic lecture format with group and project-based classes and make creative use of technology. While curricula vary from school to school, it is essential that all students graduate with sufficient skills in core sciences (physics, chemistry, etc.), math, problem solving, and critical thinking. Additionally, students need to be exposed to current programming languages and computational architectures.

At the graduate level, the lack of nontechnical skills such as communication, project management, teamwork, and business acumen is a major concern of employers in the geosciences¹⁸. There is an opportunity for graduate programs to tailor training modules to improve the students' preparation for careers in the private sector. New hires often need a significant amount of time to make substantial contributions if they choose to leave academia. While it is difficult to imagine an AMS certification of graduate programs, it might be possible to agree on some general guidelines to communicate key competencies for Masters and PhD students.

There are significant barriers to implementing new teaching methods at universities. First, education research on weather, water, and climate science is underdeveloped compared to other STEM fields. Rigorous research to find the most effective ways to teach technical and nontechnical skills (ideally at the same time) is a necessary first step to convince educators to change. Second, implementing new curricula and teaching methods, and the use of technology in the classroom, requires resources. Developing new courses is time intensive, new forms of teaching often limit class sizes, and investing in technology can be

¹⁷ <http://www.jsg.utexas.edu/events/future-of-geoscience-undergraduate-education/>

¹⁸ <https://tinyurl.com/vzaajvy>

expensive. Teachers will need support from universities and funding agencies to enable the adoption of state-of-the-art pedagogy. Additionally, it is important that incentives are created to maximize the uptake of education guidelines that prepare the next generation of students for the jobs of the future.

Given the speed of technological development cycles, it is unrealistic to teach students everything they need to know before they begin their careers. Instead, preparing students for lifelong learning and development can make them more resilient to the inevitable changes during their careers. On the flip side, employers may need to adjust their expectations to hire perfectly trained individuals, but be prepared to invest in the training of their employees as technology advances. There is great potential for collaborations across sectors to support the education of students of all ages and early career scientists. There are large discrepancies among employers' abilities to offer training to their employees. While some training units might give companies competitive advantages, making them proprietary, partnerships to develop widely available courses on more general topics could benefit the entire community.

Deeper relationships between employers and the academic sector could be beneficial as well. Private employees can connect classroom material to business skills and help students learn about possible future employment opportunities. These interactions help students and employers to expand their networks and can lead to internships or advantages in recruiting. Private companies can also provide case studies to universities to allow students to work on the kind of problems they might face after graduation.

Education can play an important role in attracting diverse talent to weather, water and climate science.

Lastly, education can play an important role in attracting diverse talent to weather, water, and climate science. Ideally, students are exposed to engaging material on Earth sciences early and often during their K–12 education, and also informally. Piquing interest at an early age and broadly throughout the population might help to attract students, particularly among those who are less likely to learn about our science outside of the classroom. Partnerships with universities (e.g., Historically Black Colleges and Universities) are another

Society, not nature, controls the impact of societal and technological drivers on the workforce

opportunity to reach students where they are instead of hoping to attract them later in their careers.

7. Conclusions

Rapid technological changes and powerful societal drivers have the potential to disrupt the workforce in our community and beyond. It is important to realize that society, not nature, controls the impact of these changes. How fast automation will replace human labor is determined by societal choices. A broad conversation is required to develop the rules we want AI to abide by. Human capital is arguably our greatest resource and using it to the benefit of the individual and the community will be an ongoing challenge.

The weather, water, and climate community is subject to these drivers and also has several distinct characteristics that influence workforce needs and opportunities. Most notably, public–private–academic–NGO partnerships are relatively advanced within the enterprise; the linkages among observations, science, and service are particularly strong; weather, water, and climate science is highly interdisciplinary; and enterprise work connects directly to people’s daily lives and future prospects.

Many Experts¹⁹²⁰ agree that the rate of change in technology and society is likely to increase. The path to a more advanced and resilient workforce will not be uniform among the organizations of the weather, water and climate community, but here we identify eight common building blocks that are likely to play key roles:

1. Build adaptiveness to recognize and harness opportunities, and build resilience to the challenges embedded in social change and technological advances, ranging from new media, to more flexible computing, and the Internet of Things.
2. Promote holistic approaches to Big Data and AI that simultaneously consider issues of data quality, sharing, privacy, access, and bias.

¹⁹ <https://www.visualcapitalist.com/rising-speed-technological-adoption/>

²⁰ <https://ourworldindata.org/technological-progress>

3. Develop a diverse and inclusive culture; one that welcomes people from all backgrounds, empowers individual contributions, and encourages all to share their talents fully.
4. Enhance purpose-driven science that provides societal benefit. This will advance public wellbeing and create fulfilling career pathways for prospective members of the workforce.
5. Enable and promote phased retirement and succession planning.
6. Strengthen adaptive and evidence-based approaches to teaching and worker training.
7. Encourage development of high-value but nontraditional skills including collaboration and communication.
8. Facilitate collaboration across sectors, particularly in the education of students and workforce training.

Education will help determine the foundational skills and capabilities of the future workforce and how broadly distributed those capabilities are among the population. Policy choices will support or hinder workforce advancement by providing resources; creating incentives to encourage (discourage) constructive (harmful) behaviors and practices; enacting regulations to mandate or proscribe behavior; invest in research or education and engage; or promote diplomatically challenging discussions associated with new technologies and societal developments.

As a result, progress in weather, water, and climate will depend on individual choices, community efforts, and societal decisions. Furthermore, efforts will be broadly distributed among the public, private, academic, and NGO communities. These must be considered both separately and together to promote maximum effectiveness.

8. Looking forward – Next Steps

Preparing individual and organizational members for changes in the workplace is at the core of the work of a professional society. AMS is engaged in a number of follow-on activities to understand workforce challenges and opportunities to help meet future needs. In July 2019, AMS co-sponsored the “Mind the Gap” workshop in Boulder, CO, which brought together students, private-sector employers, and academics to discuss possible mismatches between industry needs and college-level education. The AMS Policy Program will conduct

additional workforce-based studies to further improve understanding of enterprise needs to meet current and future workforce challenges as effectively as possible. Earlier this year, AMS established a new department on workforce development recognizing the increased need for members of our community to continuously add to their skillset. It strives to create resources (ranging from short courses at the annual meeting to webinars, podcasts, and online career fairs) to expand opportunity and support professional development across a wide range of traditional and non-traditional paths throughout one's career. Efforts to improve education research, DEI, and training in nontechnical skills are in the planning stages.

Appendix: Workshop Agenda

WHEN: April 29th – April 30th, 2019

WHERE: AAAS Building, 1200 New York Avenue NW, Washington, DC 20009

Monday April 29, 2019

- 8:30 AM Registration and light breakfast
- 9:00 AM **Welcome**
Paul Higgins, Director, AMS Policy Program
- 9:10 AM **Overview**
Andy Miller, Policy Fellow, AMS Policy Program
- 9:30 AM **K1: The Future of the Workforce in Earth Sciences**
Jack Kaye, NASA
- 10:00 AM **Discussion**
- 10:15 AM **S1: Technological Drivers of Workforce Developments**
Dulcy O'Rourke, Lockheed Martin
Gary Geernaert, Department of Energy
David Barnes, IBM
- 11:00 AM **Discussion**
- 11:20 AM **Break**
- 11:35 AM **S2: Societal Drivers of Workforce Developments**
Neil Barker, UCAR
Tracy Hansen, NOAA
Raj Pandya, American Geophysical Union
- 12:20 PM **Discussion**
- 12:40 PM **Networking lunch**
- 1:40 PM **K2: Building and sustaining the workforce of the future for the National Weather Service**
Peyton Robertson, National Weather Service
- 2:10 PM **Discussion**
- 2:30 PM Break

- 3:00 PM **S3: Drivers of Workforce Change in Weather, Water and Climate**
Erica Grow, NBC
Morgan Yarker, Yarker Consulting
Trish Mikita, AccuWeather
David Margolin, Rutgers University
- 4:00 PM **Discussion**
- 4:30 PM End of Day 1

Tuesday April 30, 2019

- 8:30 AM Light breakfast and networking
- 9:15 AM **Review of yesterday**
Bill Hooke, Associate Executive Director, AMS Policy Program
- 9:30 AM **S4: Knowledge, Abilities and Skills for the future**
David Evans, National Science Teacher Association
Manda Adams, National Science Foundation
Emily Miller, Association of American Universities
- 10:15 AM **Discussion**
- 10:30 AM **K3: Knowledge, Abilities and Skills for the future**
Jenni Evans, Penn State University
- 11:00 AM **Discussion**
- 11:15 AM Break
- 11:30 AM **S5: Knowledge, Abilities and Skills for the future**
Madhulika Guhathakurta, NASA
Mona Behl, Sea Grant Georgia
- 12:00 AM **Discussion**
- 12:15 PM **Synthesis and conclusion**
Andy Miller, Policy Fellow, AMS Policy Program
- 12:30 PM Workshop concludes

