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Typologies of actionable climate information and its use

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ABSTRACT

Developing actionable climate information and integrating it into decision-making are two crucial elements for promoting effective societal responses to climate change. However, what constitutes actionable climate information, and how it is used, varies based on the actors, systems, and scales that are relevant to specific decisions. Yet, the terms ‘actionable climate information’ or ‘use of climate information’ are used abstractly. There is a lack of holistic understanding of the various types of information that can be deemed as usable by different users, and the different ways in which they may be used in decision-making. Typologies or generalizable categorizations can help both knowledge producers and users to better envision the entire landscape of climate information and its uses and can help to reduce the time and cost of actionable knowledge production. Through systematic coding and analysis of ∼ 4 years of co-production engagements between climate scientists and resource managers, this paper presents empirically derived typologies of actionable climate information and its use, and explores whether certain uses are better informed by specific types of climate information. These typologies provide a valuable starting point for climate information producers, users, and boundary spanners working on climate-informed resource management, to reduce some of the time-intensive elements of the process.

1. Introduction

Enhancing the actionability and eventual use of climate information in adaptation decision-making, has been a key topic for research and practice in the last few decades (Bremer and Meisch, 2017; Mach et al., 2020; Moss et al., 2019). However, adaptation to climate change involves a wide range of actors, scales, and decisions, and what constitutes actionable climate information or use of information, varies depending on the context (Carr et al., 2020; Reed et al., 2022b; Vincent et al., 2020b). Actionable climate information can encompass both climate data as well as knowledge based on climate data that users find useful (Bessembinder et al., 2019). This can range from time-series data for climate variables, to information on the range of potential climate futures, or guidance on using different types of climate models (Singh et al., 2018). Similarly, the use of climate information in decision-making can also be wide-ranging (Carr et al., 2020; Vaughan and Dessai, 2014) from running impact models, to informing planning or policy processes, or understanding which regions or communities will be most impacted by climate change. Yet, the terms ‘actionable climate information’ or ‘use of climate information’ are used abstractly and monolithically. This can lead to confusion in determining the types of information that are appropriate for specific uses, and in determining the scientific approaches and expertise needed to develop such information (Fischer et al., 2021; Parker and Lusk, 2019; Vaughan and Dessai, 2014). It also allows knowledge producers to make loose claims about actionability without truly considering users’ nuanced information needs (Porter and Dessai, 2017). Further, this vague notion of actionability has made it hard for both knowledge producers and users to recognize that, at its core, determining actionability is a collaborative task that needs the expertise of both groups (Jagannathan et al., 2021; Vincent et al., 2020a). It is almost impossible for either group by themselves, to a-priori envision all the types of information that can be actionable and the different ways in which they may be used (Arnott and Lemos, 2021; Bessembinder et al., 2019; Vincent et al., 2020a). Collaboratively developed typologies of actionable climate information and its use, that open the black-box of what actionability really entails, can hence be extremely valuable (Arnott and Lemos, 2021; Bessembinder et al., 2019; Vincent et al., 2020a).

A typology of actionable climate information describes the landscape of scientific information that is available and could be deemed

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actionable in different contexts (Bessembinder et al., 2019). On the other hand, a typology of use maps the different ways in which information is intended to be utilized in decision-making (VanderMolen et al., 2020). A common assumption in climate information needs assessments is that users are a-priori aware of, and able to articulate scientific details of the climate information they need. Yet, recent studies have found that typologies or frameworks are needed to enable users to verbalize the specific types of climate metrics, data, thresholds or analyses that are relevant to their decisions (Jagannathan et al., 2021; Vincent et al., 2020a). Similarly, articulation of the exact use of information has also been found to be a complex research endeavor which can be supported through the use of typologies (Arnott and Lemos, 2021). Overall, studies suggest that typologies can be valuable for both knowledge developers and potential users, to more quickly reach a greater level of detail on information needs and uses, by helping them to better envision the broader ecosystem of the various types of information and use that might be relevant (Bessembinder et al., 2019; Vincent et al., 2020a; Zhang, 2007). Since the expertise required to develop each type of climate information can vary significantly, understanding the nuances of the information needs (such as knowing whether users need high-resolution data or credibility assessments or examination of extreme event probabilities) also enables better mapping of the types of scientific expertise needed to deliver actionable information (Carr et al., 2020; Fischer et al., 2021).

Despite acknowledgement of their importance, comprehensive and empirically-derived typologies of actionable climate information and use have remained elusive, due to the data and methodological challenges associated with their development (Bessembinder et al., 2019; Meadow and Owen, 2021; Vincent et al., 2020a). Using the case study of a long-term co-production project, where a wide range of climate scientists collaborated with resource managers, this paper creates typologies of actionable climate information and its uses. Through systematic coding and analysis of ~ 4 years of iterative co-production engagements, this research identifies different categories of climate information that are deemed actionable by resource managers, and the different ways in which this information has been or is intended to be used by these managers. In addition, the paper also explores whether certain uses are better informed by specific types of climate information[1]. Through this research, we identified 3 main types of actionable climate information - Detailed data and results, Broad trends and patterns, and Data improvements and guidance, and 6 main ways in which managers use climate information - Understand, Motivate and Communicate, Inform, Plan, Fund, and Take Action. While we identified some patterns and relationships between types of information and use, overall, we found that more than one type of information was needed for a specific use or decision - and hence the relationship between type of information and type of use was extremely context-specific. While our typologies are not universally applicable, they can provide guidance for both knowledge producers and users working in certain climate-informed resource management contexts like ours.

2. Literature review

2.1. Typologies of actionable climate information

The most commonly used typologies of climate information focus primarily on time-scale, categorizing information into seasonal, annual, decadal or multi-decadal projections, or more broadly into short, medium or long-term climate information (Bruno Soares et al., 2018; Finnessey et al., 2016; Singh et al., 2018; Ziervogel et al., 2010). Some studies have differentiated between climate and impact information, where climate information is derived from climate models (temperature, precipitation, winds, etc.) and impact information is derived from impact models such as hydrology or flooding or crop models (change in streamflow, soil moisture or growing degree days) (Bessembinder et al., 2019; Jones et al., 2016; Singh et al., 2018). A select few studies have examined typologies within a narrow category of climate information; for example identifying types of actionable climate metrics or indicators (Grotjahn, 2021; Reed et al., 2022a; Vincent et al., 2020a; Vogel et al., 2020) or creating a typology of compounding extreme events (Zscheischler et al., 2020). The climate services literature offers a few more categorizations, although these often focus on characterizing broader climate services and are not specific to climate information per se. For example, Bessembinder et al. 2019 find that climate services are categorized based on sectors, themes, regions, purposes, time horizons or type of data/service provider. Several of these studies have also acknowledged that there is a dearth of comprehensive typologies describing all the different types of climate information that users may find to be actionable.

2.2. Typologies of use of actionable climate information

The most common typologies of use of actionable climate science have been derived from the broader literatures of research evaluation and policy sciences. One of the most cited typologies of knowledge use was introduced by Donald Pelz, which categorizes use as conceptual (science is used to improve understanding of a topic), instrumental (science is used to inform decision-making or actions directly), and symbolic (knowledge is used to justify or support existing decisions) (Pelz, 1978). This typology was further expanded by other scholars (Meagher and Lyall, 2013; Nutley et al., 2007), to include three more use categories. These include capacity-building (science is used to enhance expertise, skills, or capabilities), enduring connectivity (science leads to building of long-standing relationships among researchers and users of science), and attitudinal or cultural shifts (science is used to bring about changes in institutional cultures and individual attitudes). Another popularly used typology categorizes six types of knowledge use: Reception (science results were received), Cognition (science was understood), Reference (science was cited in reports that users developed), Effort (effort was made to adopt the science into decision-making), Influence (science actually influenced decision-making), Application/ Impact (science was applied and impacted outcomes) (Knott and Wildavsky, 1980). These three typologies have been frequently used by recent studies documenting the use of actionable climate science (Arnott and Lemos, 2021; Meadow and Owen, 2021; Owen, 2021; VanderMolen et al., 2020). While these have been useful in giving a broad-brush understanding of use of climate knowledge, many scholars have noted that empirically-derived typologies of how actionable climate science (specifically) is used in practice can be valuable but remain elusive (Arnott and Lemos, 2021; Wall et al., 2017).

As we conducted this literature review, we also noted an apparent disconnect between the literature documenting the types of actionable climate information, and the literature on types of use of actionable knowledge. While the former is more prevalent in the climate science, modeling, and climate services fields, the other is found in the science and technology studies and research impact domains. Further, most empirical studies examining different types of use of actionable knowledge rarely report on the types of science that led to a specific use, and vice versa. Presumably, the type of information has a big role in determining how the scientific information can potentially be used, therefore this disconnect represents a surprising but important gap in current research on the use of actionable science for decision-making.

[1] In this paper we use the term climate information to refer to past or future projections of climate at multi-annual or multi-decadal scales, and that are derived from climate models. We do not focus on monthly or seasonal forecasts. We also do not include other types of equally valuable information such as impacts of climate on social or economic or health systems, or climate observations.

2.3. Methodological challenges for developing typologies

The lack of nuanced typologies is, in part, due to the methodological and data-availability related challenges in examining the actionability and eventual use of scientific information (Arnott and Lemos, 2021; Lemos et al., 2018; Meadow and Owen, 2021). Mapping the landscape of climate information and its use requires both scientists' and potential users' knowledge and expertise (Jagannathan et al., 2021). Co-production processes that bring together scientists with decision-makers to collaboratively develop knowledge have been effective in identifying both the needs of users and the capabilities of producers (Bremer et al., 2019; Jagannathan et al., 2020a; Vincent et al., 2020a), and hence can be used to develop such typologies. But co-production projects are inherently time and resource intensive (Kolstad et al., 2019; Lemos et al., 2018), and creation of generalizable guidance (like typologies) from these projects requires additional time and resources. For example, creation of typologies would require collection of rich qualitative data on the contexts in which information may be deemed actionable, and tracing the different ways in which such information moves into use; and such data is often not recorded in many co-production projects (Meadow and Owen, 2021; Turnhout et al., 2020; Vincent et al., 2020a). In addition, there exists a time-lag from when scientific information moves into use, and within this time memories may fade, making it challenging to reconstruct details of which particular information type was useful and how it was actually used (Meadow and Owen, 2021; VanderMolen et al., 2020). Approaches that follow actionable knowledge generation projects throughout their lifetime (and beyond), collecting longitudinal qualitative data on the types of actionable information and their potential use can help overcome some of these methodological challenges, yet such longitudinal data is not available (or collected) (Arnott et al., 2020a; Mach et al., 2020; Porter and Dessai, 2017). Overall fewer studies aim to, and are funded to, focus on broader reflective 'meta' questions that probe more generalizable answers on actionable information production and its eventual use. (Bamzai-Dodson et al., 2021; Carr et al., 2020; Jagannathan et al., 2020a; Lemos et al., 2018).

3. Methods

3.1. About HyperFACETS

We developed the typologies of actionable information and its use from ~ 4 years of scientist-stakeholder engagements conducted as part of the US Department of Energy funded co-production project - "HyperFACETS" (formerly known as Hyperion). HyperFACETS is a basic sciences project that aims to improve understanding of decision-relevant climate processes and enable credible climate modeling for management relevant outcomes. The project identifies the types of climate information that is actionable for resource managers, evaluates how well regional models or datasets predict this information, identifies model or data biases and improvements, and develops improved data, projections and approaches that are useful for decision-makers. The project is designed based on principles of co-production where scientists and managers work collaboratively and iteratively throughout all the stages, starting from identifying research gaps and questions of relevance, to developing results and outputs.

3.2. Project participants

HyperFACETS brings together ~ 30 climate scientists from ten research institutions with ~ 30 resource managers from nineteen management agencies across different regions of the US: Sacramento/San Joaquin, Southern California, Upper Colorado, Utah, Susquehanna Basin, Delaware Basin, and South Florida. The scientists include atmospheric and earth systems scientists, climate, and hydrology modelers, as well as social scientists. They have a wide-range of expertise relevant to development of actionable climate information, such as in examining climatic drivers and processes (like atmospheric rivers, snow, coastal storms), extreme event analyses (such as droughts, wildfires, flooding), multi-sector interactions (energy-water-land interactions), and new methodological approaches (like machine learning and metric development). The project's practitioners include water, energy, and land managers, although most of them are from the water sector. The managers have varied functions including planning and managing (water and energy) demand and supply, emergency management (including flood control, drought, and wildfire management), infrastructure design, etc. These managers have high levels of technical expertise and were selected purposefully because of their interest in using climate information for decisions, and their ability to dedicate time for the co-production engagements. Most of them had a western science background, a good level of familiarity with climate information, and had applications for climate models, projections, and datasets. The project team also consisted of four boundary spanners (including three of the co-authors of this paper) who designed, facilitated, and mediated the co-production engagements. Overall, the diversity in scientists and managers, and the broad scope of the project led to many types of actionable information and their use being discussed and developed. A core set of 15 scientists and 12 practitioners have been with the project since its start in late 2016, and other participants were added through the course of the project, as new interests or needs for expertise arose.

3.3. Co-production engagements

The project involves iterative discussions (both formal and informal) between scientists and managers. Engagement mechanisms include workshops, focus group discussions surrounding a scientific topic/s, team meetings, surveys, soliciting feedback via shared google documents or emails, and other informal conversations between project team members. For this paper, we systematically analyzed 16 focus group and workshop discussions (Fig. 1). Although not included in our systematic review, we also draw from numerous surveys, informal discussions, meetings, and written feedback (including managers' feedback on preliminary and final versions of the typologies themselves).

Each focus group discussion was 1.5 to 2.5 h in duration with anywhere from 8 to 40 participants, and the agenda differed based on the research topic and stage of the project (Fig. 1). Some discussions were directly on actionable information and its use, while others were indirect (such as conversations on decision-contexts and scientific approaches). Both types of discussions yielded valuable insights into the types of information that was useful and how it may (or is) being used. Several of the uses of climate information that we identified early in the project were anticipatory, while discussions at later stages were on how exactly the project's results had been used. Even when actual use was discussed, practitioners mentioned decisions or uses as currently underway but not yet fully occurred. This long-term nature of the uses and the decision-making process involving climate information, made it very hard to clearly point out or distinguish between anticipatory and actual use (or stages in between the two), so we chose to include both in our analyses.

3.4. Document coding and creation of typologies

Sixteen focus group and workshop discussion transcripts were systematically coded using the qualitative data analysis software MaxQDA through a two-staged approach. The first round of coding was to develop a list of categories or types of information and use. This was conducted using an inductive approach based on which emergent thematic categories were identified. The preliminary typology was presented to the project team for feedback and refinement. Once the typology was finalized, a detailed codebook was developed with definitions, examples, and explanations. A second round of coding was then conducted, where all the documents were re-coded systematically based on the detailed codebook. The documents were coded by one author and a

Fig. 1. Timeline showing the different co-production engagements that were undertaken from 2016 – 2020 along with their key objectives. Transcripts from select engagements were coded systematically to develop typologies.

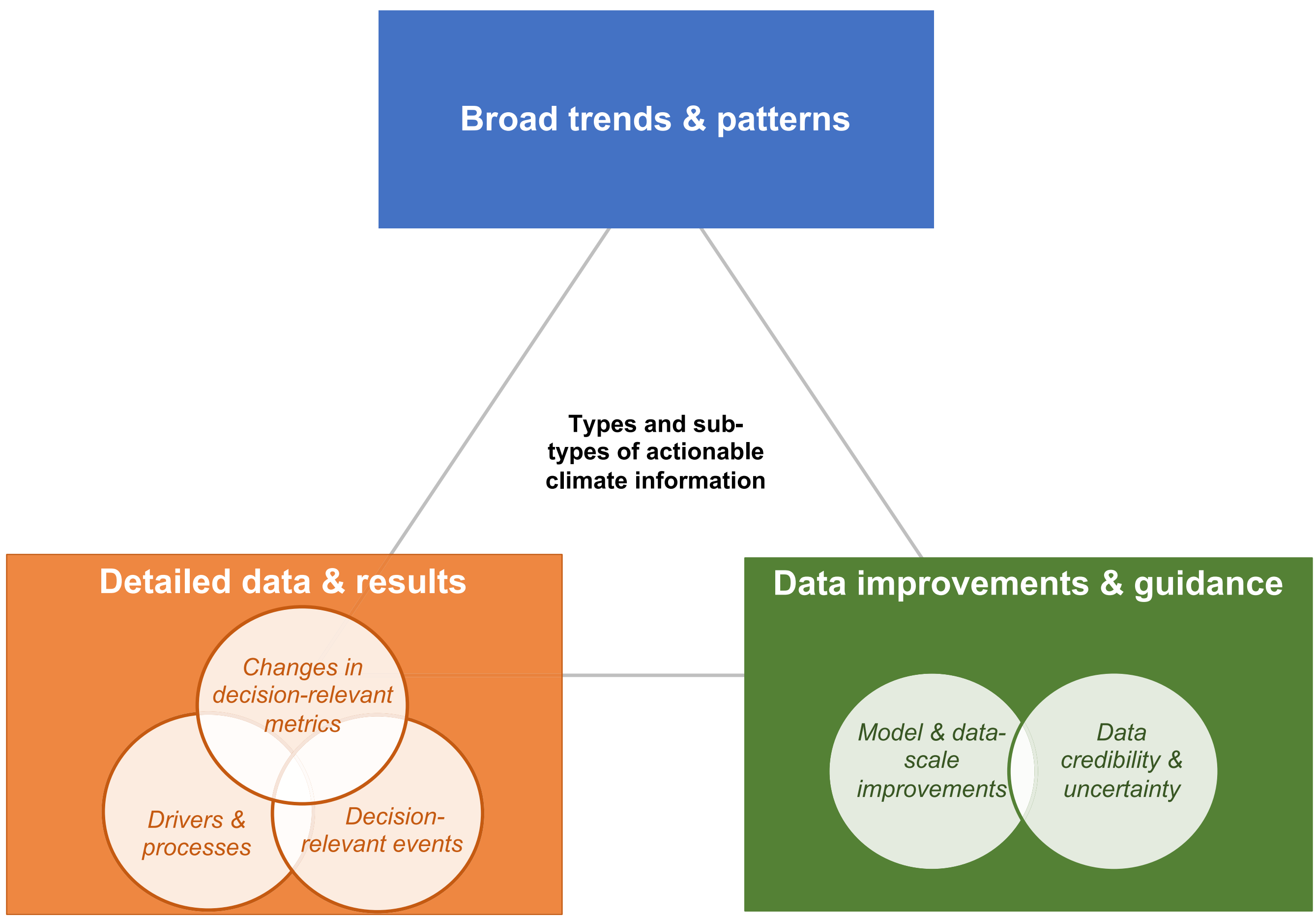

Fig. 2. Illustration of the 3 main types and corresponding sub-types of actionable climate information. From left to right, the first type is Detailed data and results which includes three sub-types: Atmospheric **drivers and processes** (e.g., tropical storms, El Nino patterns or hurricanes), **decision-relevant events** (e.g., flood or drought events), and broader climatological **changes in decision-relevant metrics** (e.g., future changes in average or extreme precipitation metrics). The three sub-types overlap in many ways, for e.g., drivers such as tropical storms can lead to decision-relevant events such as floods. Both storms and floods can influence long-term climatological changes in related decision-relevant metrics such as extreme precipitation. The second type of information refers to synthesized knowledge or insights about **broader trends and patterns** in regional hydro-climatology (e.g., whether a region is expected to be wetter or drier in the future). The third type of information in the far right, refers to data improvements and guidance which includes 2 related sub-types: **Data credibility and uncertainty** (e.g., information on model skill in capturing storms) as well as **model and data-scale improvements** (e.g., need for improved precipitation data at relevant temporal and spatial scales). These two sub-types also have overlaps, e.g., model improvements can impact data credibility. The three main types of information also influence each other in multiple ways (e.g., detailed data and results can help to examine broad trends and patterns, data improvements can impact the quality of detailed data and results, etc.).

rigorous quality assurance protocol was followed through cross-checks by two other authors. We also conducted basic counts of the data to identify the frequency of occurrence of different types and sub-types of actionable information and its use. In addition, we conducted an "intersection analysis" to identify which types of information were commonly associated with which types of use. More details of the codebook, quality assurance protocol, and intersection analysis are in the Supplementary Material.

4. Results

4.1. Typologies of actionable climate information

From our co-production engagements we identified 3 main types and 6 corresponding sub-types of actionable climate information (Fig. 2). Table 1 provides detailed definitions and examples of the types and sub-types of information. The first and most prominent type of actionable information was "**Detailed data and results''** where managers sought specific data or results on projections of certain climatic processes, decision-relevant events, or metrics. This was the most discussed type of actionable information (63% of actionable information codes, Fig. 3). This category has 3 sub-types:

- *Changes in decision-relevant metrics:* Several management decisions often require projections of long-term climatological changes for a specific climatic metric. Such changes represent the combined impact of multiple processes and events on statistical properties of climate variables. For example, managers requested time-series data such as of average streamflow to input into reservoir models or high-flow metrics for examining water supply and quality. We identified several types of decision-relevant metrics that are further explained in Table1.
- *Decision-relevant events:* Managers also sought information on frequency, intensity, duration, or distribution of different types of extreme events including record-breaking events or compounding events. For example, as one manager stated: *"We want to know how many more drought events we are going to have and how much water we would need to store."* Talking about the need for information on worst case scenario events, one manager stated that *"There was a June 2006 flood event that was a record flood, so the discharge that's used to define regulatory floodplains or assess levees may need to change. No one is looking ahead to say whether climate signs suggest we can expect these record events to continue to look this way in the future."*
- *Drivers and processes:* Managers wanted to understand how key regional processes such as atmospheric rivers, tropical storms, or El Niño cycles might change, or how antecedent conditions might be impacted by climate change. As one of our managers explained, *"How sea breeze patterns may change, especially during this wet and rainy season, is very important to us as they could affect the water we get."* On antecedent conditions, another manager stated: *"We have an event that comes in and essentially primes the base for the second one to be pretty disastrous because you have antecedent soil moisture and higher flow levels."*

The second type of actionable information was **"Broad trends and patterns"** where, rather than specific type of data or results, managers wanted insights on how climate change might broadly impact regional hydro-climatological processes. Examining these broader trends or patterns needed a synthesis of multiple studies, or lines of evidence, or expert judgements on key topical areas (4% of codes, Fig. 3). As one manager in Florida stated: *"Broadly we would like to know if the future wet season in our region is going to be drier or wetter than the past"*. Or as another manager asked, "*We want to know in 50 years, how much will the temperature go up by, do we think one and a half or two degrees is a good number for our region.*" Although this type of information only occurred in 4% of codes, such broader insights were considered extremely valuable by practitioners. However, since the primary scope of the initial phase of the project (the period for which systematic coding was conducted) was on data and modeling, this type of information was not discussed as often, despite its potential value. Due to the small number of codes, we also were not able to further sub-categorize this type. Based on practitioner feedback on the importance of this category, subsequent phases of the project (that are currently ongoing) are focusing more on broader trends and synthesized knowledge.

The final type of actionable information was **"Data improvements and guidance",** where managers had access to some data, but sought improvements in data scale and quality, or wanted guidance on how to appropriately use the information in decision-contexts (33% of codes, Fig. 3). Managers reiterated that information pertaining to data skill, quality and its appropriate use were key prerequisites for them to be able to effectively use any of the climate data or results. The two sub-types under this category are:

- *Model and data-scale improvements:* In several instances, managers felt that the data available to them needed improvements or refinements both in terms of their accuracy in representing key regional processes, as well as in terms of scale to match specific decisions. For example, one of the managers in Colorado pointed out the need for spatial resolution improvements: *"Projections for the upper portions and lower portions of watershed are completely different, so having them in one band does not give us any information, we need finer spatial resolutions of data."* In terms of model improvements, one manager stated: *"We need the right improvements in models so that they are able to resolve for sea breeze"*.
- *Data credibility and uncertainty:* This sub-type refers to information on data skill and uncertainties in capturing regional processes, including guidance on appropriate model selection and data use. As one of our managers stated: *"Information on how well models perform is incredibly valuable if you want to ask folks to make a paradigm shift towards implementing some of the new science. That's proof needed to build confidence in the information."* In terms of model selection, one manager stated: *"We need science on which models to use, what are better products for different applications, what is the best approach for model or data selection for decision-making?"*

4.2. Typologies of use of climate information

In terms of use of the actionable climate information, 6 main types and 14 sub-types emerged from the analysis (Fig. 4). The six main categories broadly follow the adaptation decision-making cycle, and hence there was some overlap or fluidity between the different types of use. Table 2 provides detailed definitions and examples of the types of use. The first type of use of climate information was to **"Understand"** where managers used the science to improve conceptual understanding on climate related topics and regional issues without having an explicit intention to use the knowledge for any instrumental purpose (20% of total codes for types of use, Fig. 5). This category has 3 sub-types:

- *Understand conditions that cause management issues:* This sub-type included using information to understand potential system risks in the future or to monitor parameters that might trigger a management relevant event. One manager stated that *"We need to know how bad the wet and dry season peaks are going to be, because they can break or stress our systems"*. On the need to monitor key parameters, another manager stated that *"Timing of peak snow melt is a potential indicator we monitor for flooding risk"*.
- *Understand regional atmospheric or hydrologic processes:* Here, managers wanted a general understanding of how regional or seasonal hydroclimate would change (regardless of whether it causes any risks to their system). For example, as one manager stated: *"For the rainy season average, we simply want to see if there's any shift. How is the mean being shifted due to the changing climate compared to the past 50 years?"*

Table 1
Detailed definitions, descriptions and examples of the types, sub-types and further categorization of actionable climate information.

Types and sub-types of Actionable Climate Information			Description	Examples
1. Detailed data and results			Specific data or results on projections of certain climatic processes, decision-relevant events or metrics.	
1.a.	**Changes in decision-relevant metrics**		Projections of long-term changes for a specific climate metric that informs a management decision. These metrics describe statistical properties of climate variables.	
	i.	Average/cumulative	Metrics that represent average or cumulative parameters.	Average instantaneous flow, Cumulative Apr-July runoffs
	ii.	Peak/Ebb	Metrics that represent peaks or ebbs.	Maximum temperature, Annual maxima or minima flows
	iii.	Variability	Metrics that represent variability such as standard deviation or variance.	Standard deviation in monthly snowmelt
	iv.	Threshold	Metrics that involve a threshold number.	Days above 100 deg F, Flow > x amount
	v.	Annual or seasonal cycle metrics	Metrics that represent a seasonal or annual cycle of a phenomenon.	Annual cycle of streamflow, Start date, length & duration of rainy season
	vi.	Distributions of a metric	Probability distributions for a metric.	Distributions of possible temperatures or rainfall volumes
	vii.	Tails of distributions	Metrics that represent the tails of distribution of a parameter.	10th or 95th percentile flows
	vii.	Other	Any other metric not included in the above.	Palmer Drought Severity Index (PDSI), Standard Precipitation Index (SPI), Other water shortage indicators
1.b.	**Decision-relevant events**		Information about a climatic event that is relevant in a decision-making or regional context. Event can be described as an occurrence that has a specific temporal duration and timing.	
	i.	Characteristics of extreme events	Frequency of occurrence of an extreme event, its intensity, seasonality, etc.	Probability of occurrence of multi-year drought, Intensity of 1-in-10-year flood
	ii.	Distribution curves for extreme events	Distribution curves for extreme events with different thresholds.	Intensity Duration Frequency (IDF) curves for storms of different frequencies, Volume Duration Frequency curves for flows of different volumes
	iii.	Record events	Occurrence of worst-case scenarios or record events.	Likelihood of black swan events, Likelihood of the 1960 s Northeast US drought occurring again
	iv.	Sequences of events or compounding events	Series of conditions or events that are relevant for management or operations.	Consecutive dry months, Specific sequences of concern like wet-dry-wet, dry-dry-wet
	v.	Other	Other events not included above.	Frequency of 3-day rainfall events
1.c.	**Drivers and processes**		Atmospheric, hydrologic, or other climatic conditions or processes that lead to (or can predict) a specific climatic phenomenon or impact. This information is one-step “upstream” of specific events or phenomena of management relevance.	
	i.	Key atmospheric or circulation processes	Processes or hydroclimatic conditions that drive regional phenomena or impacts	Atmospheric river intensities, Hurricane patterns
	ii.	Antecedent conditions	Precursors to, or conditions preceding a key event or phenomenon	Soil moisture conditions before precipitation events
	iii.	Other	Any other information pertaining to drivers or processes, not included in the above	
2. Broad trends and patterns			Broad insights on how climate change impacts regional processes and assumptions. Such insights need synthesis or review of multiple studies or lines of evidence, or expert judgements on key topical areas.	Whether a region will get wetter or drier in the next 50 years, General trends on groundwater levels in the region
3. Data improvements & guidance			Improved data in terms of scale and quality, and better interpretations or guidance on how to appropriately use climate information in decision-contexts.	
3.a.	**Model and data-scale improvements**		Improved or refined projections for specific regional or local use, or improvements in models or representation of key processes.	
	i.	Spatial scale	Spatial scale improvements.	Downscaled local or regional data, High-resolution data
	ii.	Temporal scale	Temporal scale improvements.	Need for daily or hourly data
	iii.	Model/Process improvements	Model improvements through better process representation.	Improving representation of sea breeze in models
	iv.	Other	Other improvements not included above.	Better representation of rainfall
3.b.	**Data credibility & uncertainty**		Information pertaining to the credibility or skill of different datasets for informing decisions, better understanding of uncertainty or variability in projections, best practices for selecting appropriate models for decision-making.	
	i.	Model performance and skill	Understanding and evaluating the skill of models (model credibility) in representing regional processes and metrics.	Model skill for regional processes, What spatial and temporal scales are reliable for use in applications

(*continued on next page*)

Table 1 (*continued*)

Types and sub-types of Actionable Climate Information		Description	Examples
ii.	Model selection and appropriate use of ensembles	Scientific guidance or best practices on how to select and use multi-model ensembles for a decision-context.	How many and which models to select for decision-making, How to use a range of GCM results in applications
iii.	Approaches to account for variability in projections	Information on how variability in results (outside of variability due to model selection) should be accounted for, in planning.	Understanding range of emission scenario possibilities for planning, How to account for internal variability or intra-model variability
iv.	Other	Other guidance not included above.	

- *Understand the state of science:* Sometimes managers used information to improve their understanding of the latest advances in climate modeling and on best practices for using climate information for decision-making. As one manager stated, *"This helps us understand the capabilities and limitations of the science and models"*, or as another suggested "*Overall, what is the state of science for water management decisions? This is something I want to know"*.

The next category of use is to **"Motivate & Communicate"** (5% of codes, Fig. 5), where managers use climate knowledge to make the case for climate action. Relatedly, they also used information to better discuss or communicate about climate issues (such as model credibility, climate trends, or specific impacts) with peers, board members and community members.

- *Buy-in/support for adaptation:* Here information is used primarily to garner support for climate action. As one manager pointed out, *"The person who is making decisions (on adaptation) is our board of directors and for convincing them we need science that's digestible. If you are running a model, we need clear takeaways from climate modeling to share with the management"*.
- *Communicate reliability /uncertainty in climate information:* Several managers also used scientific knowledge to better communicate details of climate information. As one manager explained: *"How definitively can we say that we are likely to get more extremes in the future? Is that a robust result or not? When we see stakeholders in legal row meetings, we need information based on which we can talk about this"*. As another detailed: *"Uncertainty characterization communication is the most challenging thing in our career now. You have to be honest and translate the range {of projections} we are seeing."*

The third type of use was to **"Inform"** (9% of codes, Fig. 5) where climate data or results are used to inform practitioner models or research activities.

- *Input data into hydrology or other impact modeling efforts:* Here, detailed climate data was used by practitioners in their in-house hydrology or planning models, or for other data-driven research like model skill evaluations, or risk assessments, etc. Many managers had specific requests for data; *"I need time-series data of streamflow into reservoirs for input into the reservoir models that I work with."*
- *Broadly inform models or other practitioner-led research:* Instead of integrating detailed time-series of data into the models, managers sometimes wanted to use broader climate change trends and results (such as x% change in temperature or precipitation in a region) to inform their own research and modeling. Some examples that came up were: "*Your results on snowmelt would be really helpful for validating our water management model, not necessarily by integrating data but by informing whether we are representing snow-related processes reasonably*", and *"From our exploratory modeling we find that the summer rainfall will be less by x%, and we will see earlier dry seasons. So we want to know from your modeling whether this is a robust result."*

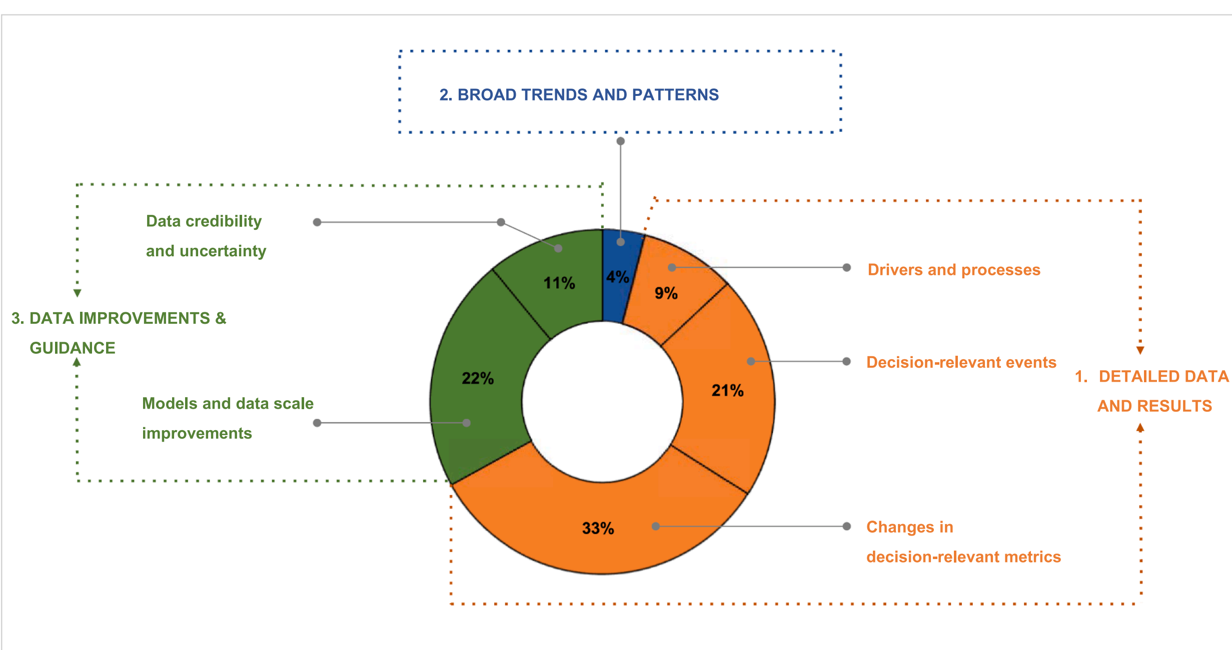

Fig. 3. Frequency of occurrence showing how often the different types and sub-types of actionable information were discussed in the co-production engagements. These percentages are calculated out of a total of 1192 actionable information codes.

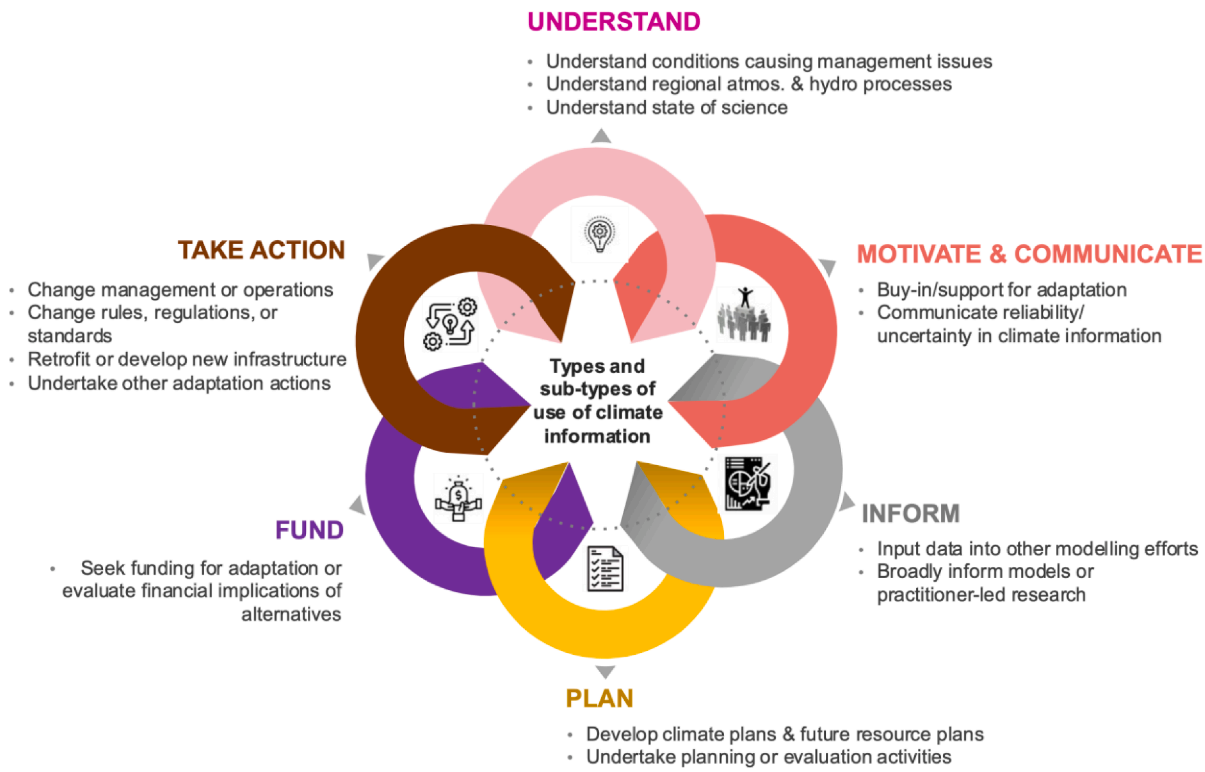

Fig. 4. Illustration of the 6 main types and corresponding sub-types of uses of climate information: Understand, Motivate & Communicate, Inform, Plan, Fund, and Take Action.

The next use was to **"Plan"** where the information was used to develop planning documents, or to undertake broader planning activities (discussed in 15% of the codes, Fig. 5). This has two sub-types:

- *Develop climate change plans or other resource planning documents:* Under this sub-type, climate information is used to develop climate-related planning documents such as future climate condition maps, vulnerability assessments, climate action plans, etc. Information is also used in other resource planning documents such as resource availability plans, infrastructure design plans, etc. One specific example that came up multiple times was using extreme precipitation data for developing future flood conditions; *"Results on IDF set of metrics and evaluation capability are important because we're developing new flood elevation maps based on future conditions."*
- *Undertake planning or evaluation activities:* Sometimes managers used climate information more broadly to undertake planning or evaluation as activities without necessarily developing a report or a plan document. For example, several managers stated that they would use climate information during future water supply or disaster response planning meetings. *"Studies are showing that we will have 10 to 20% less water in the streams by mid-century. We use information on low-flow for both long-range and reactionary planning, especially when we meet with irrigators and ranchers."*

The fifth type of use was **"Fund"** where climate information was used to seek funding for adaptation or to evaluate financial implications of different adaptation options (5% of the codes, Fig. 5). As one of our managers discussed, *"These probabilities of extreme precipitation help us decide on flood protection infrastructure investments",* and as another example: *"Rainfall intensities are valuable because there can be financial consequences of sizing decisions. Costs for a bigger culvert can be quite high, so appropriate sizing based on intensities is very important."* There were no sub-types for this use.

The final type of use of climate information was to **"Take Action"** where the science is directly used to implement adaptive actions, such as, to change management and operations, or rules and policies. This was, by far, the most discussed type of use of climate information which occurred in 46% of the codes on types of use (Fig. 5).

- *Change management or operations:* Here, science is used to undertake changes in management or operations. For instance, while talking about the use of drought scenarios, one manager stated that *"Information on persistent drought and low-flow conditions can help us in storage management - how much storage we have, how much can we serve? And what is a trigger point for emergency actions?"* Another manager said, *"The specific action based on precipitation is to decide when and how much we're going to bring in a supply source to meet a certain level of reliability for our system."*
- *Change rules or regulations or standards*: Climate information can also be used to make decisions on changing reservoir operating rules, water permits/allocations, infrastructure design standards, water flow/quality standards, etc. One manager stated that, *"IDF curves help us define modern design standards, for updating the infrastructure design standards based on climate projections"*. Another manger stated that *"Change in seasonal patterns or in overall magnitude of flows across the years in the future could help us in changing the paradigm of how we issue allocations."*
- *Retrofit existing infrastructure or undertake new infrastructure projects*: Science can also be used to undertake improvements of existing infrastructure or develop new infrastructure. For example, one manager suggested that *"Precipitation projections can be used for determining where and when to implement infrastructure projects to increase flood protection"* and another manager stated that, *"We need precipitation and flood projections which robustly consider climate change to conduct major infrastructure changes, including improvements to degrading levees and filling canals."*
- *Undertake restoration, conservation, or other adaptation activities:* Here, science is used to support the implementation of restoration,

Table 2
Detailed definitions, descriptions and examples of the types, and sub-types of use of actionable climate information.

Types and Sub-Types of Use of Climate Information		Definition	Examples
1	**Understand**	Science is used to improve conceptual understanding on climate related topics and regional hydroclimatic issues without the explicit intention to use the knowledge for any instrumental purposes.	
a	Understand conditions that cause management issues	Science is used to understand changes that may cause the system or infrastructure to be at risk or to be stressed; or for monitoring key parameters or conditions that might trigger a management relevant event.	Flood or drought watch and monitoring, Understand potential events that could cause dam failure
b	Understand regional atmospheric or hydrologic processes	Information is used to better understand how regional processes have been changing in the past and will change in the future (regardless of whether or not it causes any risks to their system).	Understand future basin hydrology, Water season changes
c	Understand state of science	Science is used to understand latest research advances and approaches in climate modeling, and best practices on using climate information for decision-making	Understand new models and cutting-edge approaches, Understand model reliability for decisions
2	**Motivate and Communicate**	Science is used to garner support for climate action, and to better discuss and communicate climate issues with peers, board members or other communities.	
a	Buy-in/support for planning or adaptation	Science is used to garner support for adaptation planning.	Change in future storms used to gather support for adaptation actions
b	Communicate reliability /uncertainty in climate information	Learnings are used to better communicate reliability (and associated uncertainties) in models and information for guiding decisions.	Communicate robustness of modeling results, Science used to build confidence in climate models
3	**Inform**	Climate data or results are used in modeling activities or research that practitioners undertake.	
b	Input data into hydrology or planning or other modeling efforts	Climate data is used as input data for hydrology or planning models, or for other data-driven research like model skill evaluations that practitioner agencies undertake.	Data for storm surge models, Input data for water supply planning models, Data for model skill evaluations
a	Broadly inform models or other practitioner-led research	Scientific insights or results are more broadly used to inform models or to compare with practitioners' in-house research or modeling efforts.	Cross-check robustness of practitioner agency results or data and identify potential biases
4	**Plan**	Science is used to develop future planning reports and documents or is used to undertake broader planning activities (without necessarily developing specific planning documents).	
a	Develop climate change plans or other resource planning documents	Develop climate plans or reports such as vulnerability assessments, future resource availability plans, future infrastructure design plans, best management practices, etc.	Develop resiliency plans, Demand or supply or shortage forecasts, Future flood or drought maps, Climate change reports
b	Undertake planning or evaluation activities	Undertaking planning as an activity without necessarily developing a report or a plan document.	Assessment of water supply restrictions, Land-use planning, Conducting risk evaluations
5	**Fund**	Science is used to seek funding for adaptation or other projects, or to evaluate financial implications of adaptation options to see where funding needs to be allocated.	Prioritizing adaptation investments, Comparing cost of adaptation actions
6	**Take Action**	Science is used to undertake adaptive action directly, such as changing management or rules, or undertaking new infrastructure or restoration projects, etc.	
a	Change management or operations	Science is used to undertake changes in management or operations.	Undertake flood control measures, change use-refill cycles, Allocate back-up supplies, Change sediment or nutrient management or water resource rotations
b	Change rules or regulations or standards	Science is used to change resource or infrastructure related rules or regulations or standards.	Changing reservoir rule curves, Drought operating rules, Water, allocation limits, Modify design criteria or standard engineering practices
c	Retrofit existing infrastructure or undertake new infrastructure projects	Science is used to build new infrastructure or change/improve existing infrastructure design and undertake retrofits.	Building new storage facilities, seawalls or dykes, Undertake repairs/retrofits of current buildings or roads
d	Undertake restoration, conservation, or other adaptation activities	Science is used to support the implementation of restoration or conservation projects or other land-use change or adaptation actions.	When and where to locate water conservation measures, How to implement ecosystem restoration projects or land use actions

conservation, or other adaptation actions. As one manager pointed out; *"Information on snowpack and streamflow is useful because we are having conversations about what to do for 10, 20, 50 years in the future in terms of increasing conservation efforts"*. Another manager stated, "*We need information on whether precipitation projections will be higher or lower, wetter or drier, as we try to restore the Everglades by creating storage areas for water quality.*"

4.3. Relationships between types of information and types of use

Results from the intersection analysis also helped to identify some

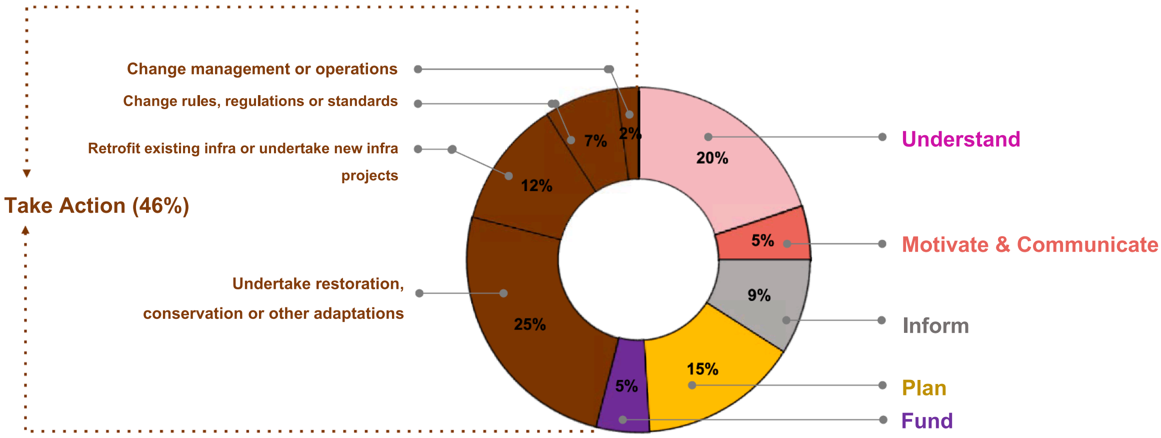

Fig. 5. Frequency of occurrence showing how often the different types of use of actionable information were discussed in the engagements. These percentages are calculated out of a total of 905 codes on use of actionable information. We also present the frequency of occurrence of sub-types of the largest use category of "Take Action".

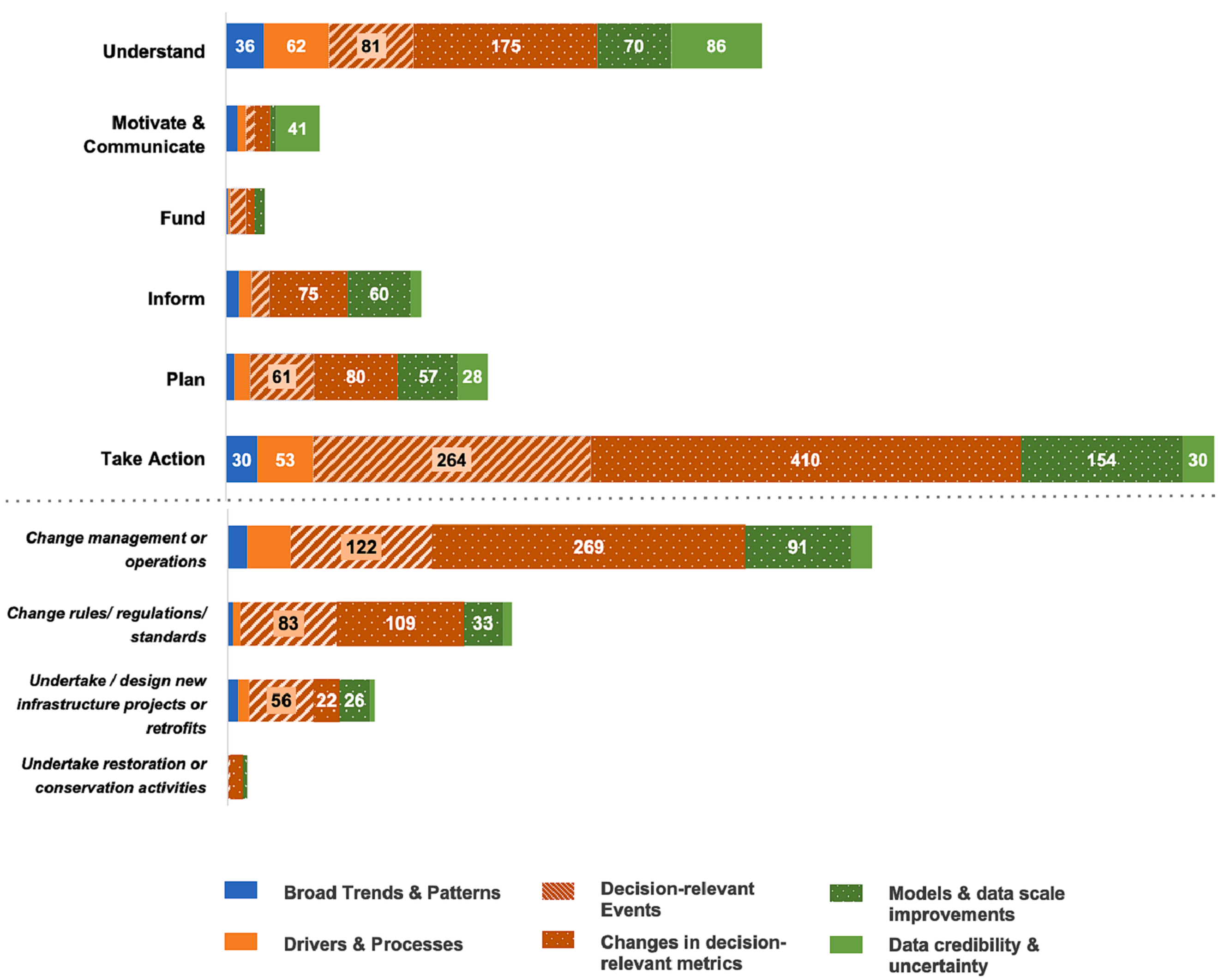

Fig. 6. Results from the intersection analysis showing the relative proportion of different types of information that were most frequently associated with each type of use. Numbers in the bar graph represent the number of times that the specific type of information was discussed with the use-case, for example, decision-relevant events were discussed 81 times as useful for the 'Understand' use while data credibility was discussed 86 times.

patterns or relationships that describe whether certain types of use are better informed by certain types of climate information (Fig. 6). As can be seen from the first bar of Fig. 6, for improving conceptual understanding about climate change (i.e., the 'Understand' use), managers found all different types of information useful; ranging from specific data on decision-relevant metrics, to information on data credibility as well as knowledge about drivers and processes. On the other hand, to effectively communicate about climate related issues ('Communicate' use), having information about model credibility and uncertainty was of paramount importance. For example, one of the managers stated that while responding to public comments or discussing climate issues at stakeholder engagement meetings, they need to have information on reliability of the climate models and data they are presenting - *"I think the bottom line is if you just choose models at random, then it could be considered arbitrary and capricious. If there is a study that's been done showing that you're selecting models based on skill and performance, then that certainly seems to meet the standards [to respond to public comments]"*.

For the Fund and Plan uses, extreme events, data on specific decision-relevant metrics, and data at the right temporal and spatial scales came up as the most frequently discussed information types. This was because motivation for adaptation funding and planning is often based on probability and impact of extreme events. For example, on drought planning, one manager stated that: *"We tend to look at a bunch of drought events, we look at events in the 30 s, at '76, '77 and '89 to '92. We look at all of those periods as we are planning for droughts."*.

When it came to information needed for input into models or research ('Inform' use), managers discussed the need for data on decision-relevant metrics, and for model and data quality improvements because the models they use need data for very specific climatic variables or metrics at specific spatial and temporal scales. *"We can run our system operational model using bias-corrected or statistically downscaled precipitation data as input and examine the reliability of our system [under climate conditions]."*.

Under the 'Take Action' use, for changing management/operations, information on long-term changes in decision-relevant metrics was most frequently discussed, while for infrastructure projects, it was information on extreme events. This was because many management or operational decisions were often made based on changes in specific hydroclimatic phenomena or metrics, while infrastructure decisions were often made based on extreme events. For example: one of the managers discussed the need for data on changes in the peak streamflow metric for water quality management *"We need to have daily maxima [flow] for each year, or* max *of daily average value over the years or over some months, for water quality [management] purposes."* On the need for extreme event information for infrastructure projects, one manager stated that *"For already built infrastructure, frequency of extreme events of a given intensity threshold are important because you need to know potential for the system to break. For new infrastructure, the highest future intensity of a given frequency interval [of extreme event] is important to make sure it is built for that range."* For changing rules/standards - both data on specific metrics and information on extreme events were discussed as being important.

We also did a preliminary review to see whether there was any clustering of 'users' (i.e., whether there were differences in how specific groups of users - distinguished by geography or specific management role - were framing use), but did not find any clear patterns or clusters. Overall, while we saw some important patterns and relationships in how often a type of information was discussed as important for a specific use, we found that in practice, more than one type of information was needed for a specific use or decision - and this could be extremely context-specific.

5. Discussion

Despite the increasing popularity of co-production and other stakeholder-engaged scientific approaches, persistent gaps remain between the demand and supply of actionable climate information (Fischer et al., 2021; Kolstad et al., 2019), and also between the production and eventual use of such actionable knowledge (Arnott and Lemos, 2021; Baker et al., 2020; Howarth et al., 2022). While existing efforts to co-produce climate knowledge have seen some success (Chambers et al., 2021; Jagannathan et al., 2020a; Karcher et al., 2021), the increasing demand and urgency for integrating climate information into decisions, is outweighing the pace at which such information is being provided and being used (Fischer et al., 2021; Vincent et al., 2020b). One of the main reasons for this persistent gap is that effective approaches for developing actionable knowledge (such as co-production) remain time and resource intensive (Briley et al., 2015; Kolstad et al., 2019; Lemos et al., 2018). Several critical elements of actionable knowledge co-production including - organizing the process, eliciting specific user needs, translating between different groups, finding common interests, and ensuring outputs are decision-relevant - are much more complex and intensive that is often presumed (Jagannathan et al., 2021; Kolstad et al., 2019; Parker and Lusk, 2019; Vincent et al., 2020a). Guidance on these key elements can help to reduce the time and cost of actionable knowledge co-production (Arnott and Lemos, 2021; Bamzai-Dodson et al., 2021; Lu et al., 2022). Our empirically grounded typologies, derived from a systematic review of ∼ 4 years of co-production engagements, provides a valuable starting point to others working in similar geographies and management contexts as ours (i.e., who are engaging with technically proficient practitioners familiar with climate models and datasets), to reduce some of the time and costs involved in mapping information needs and uses.

To our knowledge, our typology of actionable climate information is one of the few attempts to map the landscape of climate information beyond just classifications of timescale or sectoral services. We found that stakeholders' needs for science were broader than just tailored climate data, which is the most recognized type of actionable climate information (Bessembinder et al., 2019). Indeed, data on long-term changes for climate metrics came up frequently in our engagements, but managers insisted that for effecting long-term and institutional changes they needed more than just data. They wanted to know how key physical processes and events were changing, and wanted scientists to analyze data credibility, improve modeling processes, and provide broader guidance on how to work with uncertain climate data. Information such as model credibility or changes in physical processes are not often thought of as actionable since they focus on the processes or credibility evaluations rather than the decision-relevant data per se. However our findings corroborate other work surrounding the "Practitioners' Dilemma" that suggests actionable information is not always about tailored projections or numbers but includes information on how to assess data credibility, how to pick between datasets, and overall how to use climate information wisely (Barsugli et al., 2013; Briley et al., 2020; Moss et al., 2019; Reed et al., 2022a). One reason for this interest in a broader suite of actionable information could be because the resource managers in our project are technically advanced and highly knowledgeable about climate change. Despite this potential bias in our sample, our overall experience is that actionable information is far broader than the literature suggests.

Our typology of use of actionable climate information is a bottom-up categorization of how exactly climate information can or has been used by a varied set of resource managers. This typology, expectedly, has several similarities to the broader research impact typologies that we describe in our literature review. Our "understand" category is similar to Pelz's conceptual use while "take action" is similar to instrumental use of science (Pelz, 1978). Similarly, Knott and Wildavsky's categorization of reception and cognition are similar to our "understand" category, reference and effort have similarities with "communicate" and "plan", while adoption and implementation are similar to "take action" (Knott and Wildavsky, 1980). We also find that our typology follows Moser and Ekstrom's widely cited adaptation decision-making cycle – starting from understanding the problem, to planning and assessing adaptation options, and finally implementing and managing adaptation actions (Moser and Ekstrom, 2010). The added value of our typology comes from the nuanced sub-types that we empirically derived to identify uses that are specific to climate information. While the generic typologies of knowledge use are helpful to characterize broader research outcomes and impact, our typology specifically examines the use of climate information to elucidate in detail, how complex climate science gets used by institutions and in different decisions. For example, our "understand" sub-categories highlight that managers are not just looking to improve their understanding of potential risks to their systems, but also more broadly understand the hydroclimate of their region, the state of climate science and advances in modeling. Similarly, we identified that when managers state that they *"use the science for infrastructure design",* it could mean either changing the infrastructure design standards or retrofitting existing infrastructure for future climate conditions - both of which are distinct uses which might need different types of information. Interestingly, although the "take action" category was most discussed in our engagements, in many informal conversations, managers stated that their biggest gain from the project was that it improved their understanding on different topical areas, and on climate modeling in general (i.e., the "Understand" use category). This finding is similar to other studies on use and impacts of climate knowledge, where participants suggest that the conceptual gains and relationship-building during the co-production process are often the most valued (Chambers et al., 2021; Djenontin and Meadow, 2018; Owen, 2021).

Our typologies of information and use have three main applications for users and producers working in similar contexts as ours: (a) they enable more efficient (in terms of time and cost) and more detailed climate information needs assessments; (b) they help to identify the specific scientific expertise needed to generate actionable information; and (c) they enable tailoring of information to very particular uses. Eliciting the different types of climate-related uses or decisions, as well as determining the specific types of climate information that are needed for these decisions, are both non-trivial research activities that require diverse and iterative engagement strategies (Bamzai-Dodson et al., 2021; Jagannathan et al., 2020b; Meadow and Owen, 2021). Therefore, clean-slate conversations that directly ask users to articulate their scientific information needs or potential uses are often insufficient and only scratch the surface of identifying information needs and uses (Arnott and Lemos, 2021; Skelton et al., 2019; Vincent et al., 2020a). The types and sub-types of use of actionable information that we identified, allow for tailoring of climate information to the specific needs of the user by showcasing how different stages of the decision-making process might entail different information needs even when the overall climate issue remains the same (Dewulf et al., 2020; Moser and Ekstrom, 2010). For example, information needed to communicate the importance of future droughts to board members might differ from the data needed to run a drought model or the information needed to set drought standards, and the typologies can help highlight these critical differences.

While we also present numbers on how often different types of information or uses were discussed in our conversations, these numbers should be interpreted with caution. As is the nature of co-production engagements, there was often not enough time to thoroughly discuss every type of information or use. Our intersection analysis also has similar limitations. While the presence of an intersection strongly suggests an association between the type of information and use, the absence of one can either mean absence of association, or simply that we did not have enough time to discuss every type of association. Overall, we found resource managers made many climate-related decisions, and each decision is not a discrete event but a dynamic and long-drawn process (Arnott and Lemos, 2021; Owen, 2021) requiring different types of information at different times. The long-drawn and complex decision-making process also made it methodologically difficult to disentangle anticipated, ongoing, and actual use of the climate information, and robustly pin-point 'when' the use of information actually occurred. For instance, practitioners would mention that they are using the project's results to *"start to inform reservoir operations"* or that they are *"planning to take some of the data"* to their drought management teams. Our practitioners often reminded us that use of information is not one linear event. There are several, iterative steps between when information is imbibed for a use/decision and when the information use fully materializes, which, in the examples above would be either changing future reservoir operations or informing drought management. What is actionable information and how it is used, hence, is not a stationary concept, and is expected to evolve over time as more information is available and gets used in a step-by-step long-term decision-making process.

Upon reflection of our methodological process, we think that a few unique features of the HyperFACETS project enabled the creation of these typologies. First, the project brought together and developed a variety of scientific knowledge that was useful to a diverse group of resource managers. This gave our project the breadth and richness of engagements needed to develop nuanced typologies. Second, the project's long timeframe (the project is currently ongoing in its 7th year) allowed for in-depth iterative conversations on the various types of useful information and allowed time for managers to digest the complex information and think about how such results may be used in decisions. Third, was the focus on (and funding for) meticulous recording and transcription of longitudinal data for each co-production engagement that allowed for a systematic review. And finally, the lead-authors of this paper were also the boundary spanners who facilitated the engagements and hence were able to reflect on their first-hand conversations with the participants which provided invaluable context while analyzing the messy and complicated multi-person discussion transcripts. Overall, our experience echoes other actionable knowledge scholars who have called for more such in-depth and reflective longitudinal studies to help scale-up actionable knowledge effectively (Arnott et al., 2020b; Driscoll et al., 2012; Lemos et al., 2018; Mach et al., 2020; Meadow and Owen, 2021; Turnhout et al., 2020).

Finally, although our typologies were derived through several years of engagement with a somewhat diverse group of scientists and managers, these typologies are neither exhaustive nor meant to be universally prescriptive. The fundamental scope of this use-inspired basic science project greatly influenced the methods and outcomes of the project. We were only able to engage with technically-proficient, western science trained practitioners who were not only familiar with climate models and projections, but also had the ability to utilize these in their decision-making. Hence our typologies may not be applicable in many other contexts, such as where users are not as familiar with climate models and datasets, or in other geographical and cultural contexts where priorities may be vastly different. Co-production engagements with other types of users and knowledge-holders (such as politicians, local communities, Indigenous peoples), are crucial to expand upon this typology, or to perhaps create new typologies that are tailored for these groups. Further, our work is also limited to a narrower scope of actionable climate projections, and we did not discuss the several other types of actionable climate information e.g., climate impact information, climate projections-based decision-support tools, climate stories or narratives, local knowledge-based climate observations, etc. Therefore, while our typologies are a good starting point to map the landscape of climate information and use for a specific set of technically-proficient practitioners, more work is needed to understand whether and how these typologies may need to be refined or expanded, to cater to a broader set of stakeholders. Testing these typologies with broader stakeholder groups can help shed light on its generalizability for different uses or user groups, and more importantly identify where the typology might not be sufficient. It can also help to identify potential patterns or clustering of users, i.e., whether there are differences or similarities in how different user groups frame actionability or use.

6. Conclusions

As the window of opportunity to shift towards climate resilient development pathways narrows, there is an increased urgency to accelerate adaptation actions across the world. Integrating climate information into decision-making is an integral aspect for promoting effective societal and policy responses to climate change. However, co-producing actionable knowledge for societal use remains a resource intensive and slow process. Frameworks and typologies based on learnings from existing projects (such as frameworks for developing co-produced research plans, frameworks for identifying effective engagement approaches, or typologies of climate information, its uses, its users, or evaluation metrics) can provide guidance to ongoing and future efforts in the development and use of actionable knowledge. While there can be no one-size fits all, our typologies provide a valuable starting point for climate information producers, users, and boundary spanners working on climate-informed resource management contexts like ours, to reduce some of the time-intensive elements of the actionable knowledge process. We welcome other scholars and practitioners to test, expand, refine, or critique these typologies, or generate new typologies for different contexts, as we seek to accelerate efforts towards climate action across the world.

Author contributions

KJ led and coordinated the development of the manuscript. AJ is the overall lead for the stakeholder engagement task for the HyperFACETS project and led the recruitment of resource managers. PU is the main Principal Investigator for the HyperFACETS project. AJ and KJ led the design and facilitation of the co-production engagements that form the basis of this manuscript. SB and PU supported the facilitation of these engagements. KJ, AJ, and SB led the conceptual development, data analysis and writing for this manuscript. KJ and SB undertook the qualitative coding with support from AJ. PU contributed to conceptual development and writing, and provided detailed feedback on the preliminary and final typologies. The HyperFACETS project team (members' names are mentioned in the acknowledgements) were an integral part of the co-production engagements and provided feedback on the draft typologies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data used in the manuscript is available in the manuscript figures, tables and supplementary material.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2023.102732.

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