The Process and Benefits of Developing Prototype Climate Services—Examples in China

Chris D. HEWITT1,2*, Nicola GOLDING1, Peiquan ZHANG3, Tyrone DUNBAR1, Philip E. BETT1, Joanne CAMP1, Timothy D. MITCHELL1, and Edward POPE1

1 Met Office, Exeter EX1 3PB, UK
2 University of Southern Queensland, Toowoomba QLD 4350, Australia
3 Beijing Climate Center/National Climate Center, China Meteorological Administration, Beijing 100081, China

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ABSTRACT

Changes in climate pose major challenges to society, and so decision-makers need actionable climate information to inform their planning and policies to make society more resilient to climatic changes. Climate services are being developed to provide such actionable climate information. The successful development and use of climate services benefits greatly from close engagement between developers, providers, and users of the services. The Climate Science for Service Partnership China (CSSP China) is a China–UK collaboration fostering closer engagement between climate scientists, providers of climate services, and users of climate services. We describe the process within CSSP China of co-developing climate services through trials with users to revise and improve a prototype. Examples are provided covering various scientific capabilities, user needs, and parts of China. The development process is yielding many benefits, such as increasing the engagement between providers and users, making users more aware of how climate information can be of use in their decision-making, giving the climate service providers a better understanding of the users’ requirements for climate information, and shaping future scientific research and development. In addition to the benefits, we also document some challenges that have emerged, along with ways of alleviating them. We have two key recommendations from our experiences: make the time and space for effective engagement between the users and developers of any climate service; bring the needs of the users in to the design and delivery of the climate service as early as possible and throughout the development cycle.

Key words: climate services, prototypes, user engagement

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1. Introduction

Changes in climatic conditions from month to month, year to year, and over the coming decades present major threats to society (UNFCCC, 2015). The risks of detrimental impacts that can arise from such changes vary from region to region due to varying vulnerability and exposure to climatic hazards, as well as regional variations in the climatic hazards themselves. A country with notably high vulnerability and exposure to variations in the climate is China, whose large population and growing economy frequently experience disasters arising from extremes of precipitation, temperature, and wind.

Decision-makers need to have access to actionable climate information to help inform their planning and policies on timescales from months to decades, to make society more resilient to risks arising from hazards such as those noted above. The global importance of this need has provoked a major undertaking over the past 10 years, resulting in the Global Framework for Climate Services (GFCS) to coordinate the development, provision, and uptake of climate services around the world (Hewitt et al., 2012, 2020). In addition, the science and information that the climate services use are constantly being developed and improved (Asrar et al., 2012; Vaughan et al., 2017; Su et al., 2018; Zeng et al., 2019).

In 2014, a Climate Science for Service Partnership China (CSSP China) was formed between the China...
Meteorological Administration (CMA), the Institute of Atmospheric Physics at the Chinese Academy of Sciences, and the UK Met Office with UK academic partners (Belcher et al., 2018). CSSP China is building close collaborations between scientists in China and the UK to develop underpinning scientific capability and knowledge, modeling systems, observational datasets, climate services, as well as building collaborations to improve engagement between climate service providers and their customers at the municipal, provincial, and regional scales. The science and services are being used to help better manage climate-related risks, in particular relating to agriculture, energy, urban environments, water resources, and air quality (Hewitt and Golding, 2018).

The operational provision of climate services within China is the responsibility of CMA and its partner agencies, and the activities undertaken in the CSSP China program directly support the development of CMA’s operational climate services but are not operational services themselves. A specific focus of the climate service development undertaken in CSSP China is to undertake trials of potential new climate services and to use prototype climate services to engage closely and effectively with potential users of the services, as introduced in Hewitt and Golding (2018). Some other programs have embarked on a process of developing prototypes, most notably the EUPORIAS project (European Provision of Regional Impacts Assessment on Seasonal and decadal timescales; Buontempo et al., 2018) and the Copernicus Climate Change Service Sectoral Information System (see for example Goodess et al., 2019). The work described below outlines the process as well as benefits of undertaking trials and co-developing prototypes that we have experienced in China and the findings are widely applicable to climate service development in other countries and situations.

The following sections provide a short summary of the science and services within CSSP China (Section 2), the approach used to trial and co-develop climate services (Section 3), real examples of prototypes being developed at different stages of maturity (Section 4), and conclusions and recommendations (Section 5).

2. Scientific capability for developing services

The research program that forms the core of CSSP China has four broad scientific themes, and an additional theme on climate services. The first theme is improving our understanding of climate and how it varies, based on monitoring of the climate, attribution of climate events, and climate reanalysis datasets. The second theme aims to improve climate predictions across the region through research into the dynamics of climate variability and change globally and regionally. The third theme is improving our understanding of modes of climate variability in the region, their teleconnections, and impacts on the water cycle and climate extremes in the region. The fourth theme is developing models and climate projection systems to underpin the modeling capability within climate prediction programs in China and the UK. The additional theme on climate services draws on the scientific capability from across the program to develop the services needed by decision-makers, and where needed develops the more applied and tailored science to support those services, as well as feeds back the needs of stakeholders to influence future scientific developments across the other four scientific themes.

Effective engagement between the users and providers is essential to successfully developing and delivering any climate service (Lemos et al., 2012; Golding et al., 2017a, b; Knudson and Guido, 2019). The engagement is needed to assess what the needs are from the users; to identify what capability exists or could be developed to meet those needs; and to explore what ongoing engagement can be established to ensure successful use and to elicit feedback for improvements to the service. In many cases, the engagement can also raise awareness and build capabilities with the users to enable them to better understand, interpret, and apply climate information. Such a user-centric approach has largely evolved out of recognition of the limitations and ineffectiveness of earlier one-way approaches where information and knowledge were simply generated and transferred from the knowledge producers to the recipients in a loading-dock approach (Cash et al., 2006).

The needs of the users are then brought into the design and delivery of the climate service, by using existing science and knowledge if possible; otherwise, consideration is given to generating new science and knowledge, noting that this is not always possible. Such feedback has influenced the scientific developments in some of the examples described in Section 4 below. The climate service providers are the key link between the scientists and the users, communicating the capabilities and the needs to the users and to the scientists respectively.

China has its own China Framework for Climate Services (CFCS; CMA, 2015), a national framework closely aligned to the GFCS, with key climate-sensitive socioeconomic sectors identified as priorities. The research, collaborations, and outputs from CSSP China are helping with the development and implementation of the CFCS, with a focus on agriculture, energy, urban envir-
environments, water resources, and air quality. Some targeted users within these sectors have been closely engaged with. Hewitt et al. (2017) note that what constitutes “effective engagement” will vary from case to case. Based on examples of good practice drawn from an international expert team under the World Meteorological Organization’s Commission for Climatology, three categories of engagement that transition from relatively passive to highly active are identified: website and web-based tools, interactive group-based activities, and focused relationships. For some climate services, one of these categories of engagement will be appropriate; others may use more than one. Other studies note the usefulness of co-design and co-delivery (see for example Vincent et al., 2017; Buontempo et al., 2018; Christel et al., 2018). The example prototypes described in Section 4 draw on all three of these engagement categories to differing degrees. We have been fortunate to have had sufficient resources available and the high levels of user commitment necessary to enable the more active engagement through focused relationships, thereby allowing us to truly co-design some climate services in some of these examples.

3. The process of prototype development and user trials

3.1 The selection process

The approach that has been adopted is as follows. Firstly, the selection of prototypes to develop and trial with users is based on the following criteria:

1. The prototype must align with one or more of the sectors identified as priorities within CSSP China, as listed above.
2. There must be an identified need for such a climate service, and ideally a committed user or stakeholder at the outset.
3. The scientific capability to underpin the prototype climate service must exist or be in development.

This selection process has been used to identify prototypes across the key sectors to take through to trials with users. These prototypes cover different sectors, users, capability, and regions, at very different stages of development.

A seasonal rainfall forecast service was the first prototype to be identified by using the above criteria; this was developed in 2015 primarily for the operators of the large hydropower dams on the Yangtze River. Since then, additional prototypes have been identified to draw on a wider range of the scientific capability from within CSSP China, different sectors and regions of China, and different temporal and spatial scales. These prototypes have not all been successful. For example, while the seasonal rainfall forecast service prototype was being developed, it was realized that a similar prototype could be developed using much of the same underpinning scientific and technical capability, but for a seasonal forecast of wind (Lockwood et al., 2019). Such a prototype was intended for use by the huge renewable wind sector in China, but a committed user or stakeholder has not yet been forthcoming. While this prototype met Criteria (1) and (3), it only partially met Criterion (2), and so has not yet reached the stage of a user trial, even though an initial prototype is ready.

The development of three prototypes are described in more detail in Section 4 as examples; the Yangtze River seasonal rainfall forecast, a food security climate change risk assessment, and seasonal tropical cyclone (TC) landfall risk forecasts for East China. Other prototypes identified in the project will be considered for trials with users at a later stage when appropriate.

3.2 Cycle of prototype development

Once the topic for the prototype has been identified, a cycle of prototyping through user trials begins by undertaking the following five stages (Fig. 1) in order, although iterations between different stages should take place when appropriate:

1. Explore: Understand user needs.
2. Exploit: Develop a prototype to meet the user needs utilizing current capability.
3. Expose: Provide and explain information through user engagement.
4. Examine: Provide the service by assessing its usefulness and its shortcomings.
5. Expand: Feedback requirements into underpinning
science and prototype improvements.

The climate service providers are the key link between the scientists and the users throughout all of these stages, ensuring that everyone is aware of the capabilities and needs and ensuring that everyone is able to play their respective roles in each stage. For example, ensuring that the users are engaged properly to articulate their needs in Stage 1, to understand the capability in Stage 3, and to evaluate the service in Stage 4. Similarly, ensure that the scientists are engaged properly, for example, to develop and evolve the capability that underpins the prototypes in Stages 2 and 5.

3.2.1 Stage 1—explore

In order for a prototype to have been selected, some understanding of user requirements will already exist (selection criteria number 2). Nonetheless, a better understanding of the detailed decision-making processes and the climate information needs of a specific user, or user group, is likely to be needed, or at the very least, a better understanding of the detailed role of climate information in the users’ decision-making processes. As other stages in the cycle of prototyping are undertaken, it will often be appropriate to revise and improve our understanding of the users’ needs; and as the cycle evolves, so might the users’ needs. Assessing the needs of the users can be a very time-consuming and challenging activity; but the better the understanding, the more likely will be the development and delivery of a useful climate service. Therefore, time spent in this first stage has been seen as essential in CSSP China and has been a focus since the start of the program.

3.2.2 Stage 2—exploit

In the first iteration through the cycle, a very early prototype is developed, perhaps as a bespoke product or a case study, to start to attempt to meet the user’s needs. This initial version of the prototype will be developed using current scientific capability and knowledge, based on the understanding from Stage 1 of what could be useful for the user. There are often challenges in trying to draw on existing capability and knowledge to produce something that will be seen as engaging and potentially of value to the user, perhaps because the capability is a long way from being of use, or because the requirements are insufficiently realized at this stage. However, having an early prototype has proven to be an effective way of initiating and building engagement between the climate service providers and users. As other stages in the cycle of prototyping are undertaken, Stage 2 is frequently revisited to revise and improve the prototype.

3.2.3 Stage 3—expose

The prototype is then used in trials with the user to deliver information through appropriate engagement, preferably with some interactive elements to ensure greater engagement, and to build trust and buy-in for the service. A similar approach has been adopted during the development of the GFCS, whereby donors invested in early priority projects to create partnerships and build trust with users (WMO Secretariat, 2014). Key challenges are to ensure that there is sufficient time to properly and effectively engage; to assess whether the service requirements are being met; and to communicate the science and its limitations at an appropriate level. The appropriate user must be engaged: they must be either a decision-maker or in a position to influence decision-makers; they must have appropriate technical understanding; and they must have sufficient time available to engage.

3.2.4 Stage 4—examine

A formal evaluation of the trial is conducted by the developers of the prototype and the users. Evaluation is carried out during and after the trial, both through direct opportunities to discuss what works and what needs to be improved, as well as through indirect means such as questionnaires and surveys. The benefits of this stage are clear: without such an evaluation, it is hard to determine how to improve the prototype and to assess what value it has or what value it could have. There are challenges in determining what does and does not work, often arising through the lack of additional time from the users to provide the information, or through language or cultural issues that affect the understanding or supply of criticism.

3.2.5 Stage 5—expand

The final stage of the cycle is to provide feedback about further requirements and improvements to evolve the underpinning scientific capability and the design of the product or service. Without such feedback, the prototype is unlikely to evolve into something more useful for the user. The main challenge at this stage is to translate the feedback from users into something that is meaningful and useful for the scientists who are developing the prototype, while being both scientifically possible and appropriate.

3.2.6 Post development cycle

The approach and learning are captured in a short document for each prototype, typically no more than two pages of text, which summarizes the rationale for the prototype, the scientific requirements to underpin the prototype, and the requirements from the user. As noted above, CMA is the operational climate service provider in China and the findings and outcomes arising from the trials and prototype development are for CMA to consider in their operational climate services and more
broadly in the development of the CFCS.

This approach to developing prototypes through trials is intended to draw together the science and knowledge from within CSSP China and to demonstrate the use of that science in user-driven services. In turn, this is intended to foster closer engagement between climate scientists, providers of climate services, and users of climate services. An additional benefit of this approach is to better understand the process and barriers in developing and delivering climate services. Such understanding is potentially applicable in other countries and contexts.

4. Examples of developing prototypes in China

4.1 Seasonal TC landfall risk forecasts for East China

TCs are a significant hazard to many sectors in China, including those identified as priorities in CSSP China. The forecasting of TCs on seasonal timescales now has sufficient skill to be potentially useful in some decisions, and applications for this emerging capability are being considered. A workshop was held with typhoon scientists, intermediaries, and user representatives in Shanghai in October 2018 to assess the likely needs of users for forecasts of TCs on timescales of seasons and longer. Key areas of interest were identified; in particular, the forecast capability for East China was of interest to the Ministry of Water Resources of China, who has responsibility for flood management.

Seasonal forecasts of landfalling TCs in East China were selected as being the most promising to develop into a prototype and introduce in user trials. Such a prototype meets the three criteria described in Section 3.1, although there was not a committed user or stakeholder at the outset. While there are fewer landfalling TCs experienced in the east of China than in the south, the impacts on the eastern coastline can be devastating due to the high concentrations of population, agriculture, and assets and infrastructure, particularly around the Yangtze River delta (e.g., Typhoon Lekima in 2019; Camp et al., 2020). An initial assessment of user interest and user needs has been conducted (Stage 1 in Fig. 1), although more needs to be done in due course to better understand users’ decision-making processes and to engage users.

An initial prototype has been developed (Stage 2), providing probabilistic information about likely numbers of landfalling TCs in summer in East China (Fig. 2; Camp et al., 2020). The number of landfalling TCs in East China is strongly linked to the strength of the western Pacific subtropical high (WPSH), a climate phenomenon in which the Met Office Global Seasonal forecast system (GloSea5) has significant predictive skill (Camp et al., 2019). The intention is for this product to sit alongside forecasts from the Beijing Climate Center and the Shanghai Typhoon Institute.

The prototype is delivered to CMA for them to disseminate to their users (Stage 3). The first prototype was delivered in May 2019 and monthly thereafter. A meeting with some users took place in June 2019 to gain some early feedback and evaluation of the service (Stage 4), and discussions between scientists and climate service providers in China and the UK are now underway. Further development of the underpinning science, the seasonal forecast capability for TCs, and the evolution of the prototype are being driven by the feedback received (Stage 5). In particular, the prototype would be most useful to CMA if it were supplied at a longer lead time, to fit into the schedule for their own seasonal forecast. Consequently, the skill of GloSea5 was evaluated and significant skill was found for 1 March (Camp et al., 2020). As a result, the 2020 prototype will be issued on 1 March rather than on 1 May, as it was in 2019. Improvements are also being made to the statistical model of the relationship between the number of landfalling TCs and the strength of the WPSH, as well as selection of the area of East China for which the forecast is issued, which is being narrowed both in response to user demand and to improve forecast skill. Finally, the translation and presentation of forecast information are being revisited to develop a revised prototype to test with users and iterate through the cycle of development again throughout 2020. This will allow us to better assess user needs, revise and deliver the prototype, and continue to co-develop it through feedback and development, as well as to initiate relationships with users that we can look to work more closely with over the next few typhoon seasons to tailor and improve the prototype service.

Two key challenges have already been identified that need to be tackled. One is communication around uncertainty, as it is not clear how much trust that users have in the current forecast (Zeng et al., 2019). While there is good skill in the forecast, we do not want to mislead or oversell this to users. The other is the significant gap between the user requirement and the scientific capability. The seasonal forecast is for the number of landfalling TCs, while users often want information about intensity, wind, and rainfall. It is important to not push the science beyond its appropriate use, but to reassure users of the potential benefit of the currently available information. In return, scientific capability, keeping in mind user requirements, could be routinely evaluated as scientific
understanding and model development progress.

### 4.2 Climate change risk assessment for food security

Work is underway to progress from theoretical research to produce policy-relevant information that describes the risk to agriculture in the northeast farming region of China arising from natural climate variability and climate change. This region is important for Chinese and global food security, meaning that more complete understanding of the climate risk in this region is imperative.

The prototype climate service—the provision of policy-relevant information—considers climatic risk in both the

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**Fig. 2.** An example of the prototype seasonal tropical cyclone (TC) landfall risk forecast for East Asia.
present day and the future under climate change, with a focus on maize production. The prototype meets the three criteria described in Section 3.1 above (although again lacking a committed end user) and the prototype has gone through the first two stages in the cycle described in Section 3.2.

Engagement with a range of stakeholders in China, including national and regional climate service providers, as well as the Chinese Academy of Agricultural Sciences and groups that they engage with, has highlighted a requirement to assess the risk to agriculture from climate change (Stage 1). This engagement has taken place through face-to-face meetings; for example, a meeting was held at the Liaoning Regional Climate Center in 2016 (Fig. 3) involving the national climate service center, the regional climate service center, and Shanghai climate center, which discussed methods for assessing climate risks to food security. These early discussions also led to an ongoing collaboration between the UK and Chinese scientists exploring methods for assessing climate change impacts in the northeast farming region of China (Xu et al., 2019; Tian et al., 2020). Scientific understanding of current climate and projections of future climate for key variables such as temperature and rainfall are being used to assess the current and future risks to key regions and crops. Current and future risks of shocks to the production of major crops in China have been assessed through a novel approach developed under Stage 2 of the prototyping cycle, and the risk of coincident shocks in other regions of the world producing maize has been analyzed (Kent et al., 2017, 2019). In many regions in China, the modeled likelihood of adverse conditions for crop production is higher than previously thought, suggesting that previous adaptation and resilience planning may need to be updated.

The next stage (Stage 3) is to engage with key stakeholders with the aim of providing this evidence to better inform decision-makers with their long-term planning in agricultural investments at the provincial, regional, and national scale. This information is intended to help long-term planners in China to build a resilient food system under a changing climate. Stages 4 (evaluation) and 5 (feedback requirements to improve the prototype) will be essential to co-develop the policy-relevant material and communicate it. A key priority will be to translate results into language and formats appropriate for users.

4.3 Seasonal rainfall forecast prototype for hydropower and flood management

The first, and most advanced, CSSP China prototype climate service is the probabilistic seasonal forecast of rainfall in summer for the basin of the Yangtze River. The scientific capability underpinning this prototype, the user requirement, and the prototype itself have all been documented extensively (Li et al., 2016; Golding et al., 2017a, b; Bett et al., 2018, 2020; Golding et al., 2019). In summary, discussions with stakeholders in the hydropower industry have highlighted needs for improved seasonal rainfall forecasts, particularly for the flood season in summer. These will be used for the power production

![Fig. 3. Mapping the climate risk to food security in China—co-developing services and knowledge sharing between UK and Chinese scientists at a workshop hosted by the Liaoning Regional Climate Center in 2016.](image-url)
forecasts demanded by the hydropower companies’ customers and for adjusting flood management plans. Aligned to this, Li et al. (2016) showed that the GloSea5 seasonal forecasting system exhibits significant skill for predicting rainfall in summer for the basin of the Yangtze River. These factors meant that the prototype met the three criteria described in Section 3.1 above; and so the prototype then went through the stages in the cycle described in Section 3.2.

A range of stakeholders have been successfully engaged, including national, regional, and provincial climate service providers in China; energy companies; and operators of dams along the Yangtze River. The engagement has been through face-to-face meetings (e.g., the meeting shown in Fig. 4) followed up by email discussions and a survey. A prototype product showing probabilistic seasonal forecasts of rainfall for the summer flood season was developed in 2016 ahead of what was expected to be a very wet season following the 2015/2016 winter strong El Niño event. This product was used in a successful trial with the stakeholders in 2016, eliciting discussions and planning in the Yangtze River basin. The performance of the seasonal forecast was evaluated (Bett et al., 2018) and the usefulness of the prototype was assessed through targeted engagement with decision-makers from the hydroelectric power facilities along the Yangtze River, and a wider number of decision-makers through a survey assessing their needs (Golding et al., 2019).

The first trial in 2016 identified several areas of improvement, such as: can the forecast be provided for smaller regions; might sub-seasonal forecasts be possible; can the forecast release timings be better aligned with the decision-making schedule; and can the forecast be presented in a more useful way? Some progress was made toward these requirements for the second trial in 2017, in particular improving the presentation of the information. Subsequent evaluation with the stakeholders, through meetings, emails, a survey, and a visit to the UK Met Office by several of the end users, highlighted similar areas of improvement. Additional scientific research was then conducted to investigate whether scientifically robust forecasts for smaller regions and sub-seasonal forecasts could be provided. The conclusion was that forecasts could be provided for two separate regions in addition to the entire river basin—one above and one below the Three Gorges Dam, using dynamical monsoon indices as predictors (Liu et al., 2018). These improvements have been incorporated into the next version (i.e., the current version) of the prototype for use in subsequent trials and evaluation.

This prototype has been through all five stages of the prototype cycle, including acting on feedback from stage 5, with iterations between some of the stages, and at least one further complete pass through all five stages. The process has involved additional scientific research, an update of the science that underpins the prototype, and an update of the product itself, all through close interaction.

Fig. 4. Presenting and discussing the seasonal rainfall forecast prototype for hydropower and flood management with climate service providers and hydropower and flood management stakeholders in the Yangtze River basin in Wuhan in May 2016.
with a range of stakeholders. The process has highlighted numerous challenges, but overall has been a successful example of co-production thanks to the engagement of key stakeholders including scientists, product developers, climate service providers, and end users in the form of decision-makers.

Two main challenges are worth highlighting here. Firstly, it can be difficult to assess how the end users employ the service in their decision-making, and therefore to identify which potential improvements to the service are key. Secondly, climate service providers are only prepared to provide a service based on scientifically robust and credible information, but feedback often identifies major shortcomings in the usefulness and value of such information. It can be a major undertaking then to develop the science further, and to provide something of greater use and value. Some of the requirements may be unserviceable (scientifically speaking), and some may take years of research and development; keeping the users interested and engaged on such long timescales is challenging.

5. Concluding remarks

The Climate Science for Service Partnership China (CSSP China) is fostering closer collaboration between scientists in China and the UK to develop climate science and climate services. Perhaps more importantly, CSSP China is also fostering closer engagement between climate scientists, climate service providers, and users of climate services. The development of prototype climate services and user trials described above is proving instrumental in enabling this closer engagement. Three examples have been described above, covering a range of scientific capability, different user needs, and different parts of China. The process of developing the prototypes is uncovering useful lessons, both good and bad, that we feel are useful to others, in terms of benefits and challenges, as follows, with some specific suggestions for actions that can be taken to improve the development of climate services.

In terms of benefits, the process of undertaking user trials is building collaboration between the providers of climate services and scientists in China and in the UK, and helping the providers and users of climate services engage more closely and more effectively. Such engagement is making users more aware of how climate information can be of use in their decision-making, building trust in climate services, and developing the users’ capacity and capability to better understand, interpret, and apply climate information when making decisions. In turn, the climate service providers are gaining much better understanding of the users’ requirements for climate information and their decision-making processes. Some of this learning is context specific, but some commonalities have emerged, which are transferable across sectors and beyond China, such as generic issues around dealing with risk, dealing with uncertainty, understanding governance and who the key stakeholders are in the decision-making process, and the appropriateness of different methods for user engagement. The cycle of prototyping involving the users in co-developing is helping make the climate services more useful and of higher value to the decision-makers. In addition, the feedback received is helping shape future scientific research and development.

An additional benefit of this whole approach has been to better understand challenges associated with developing and delivering climate services, most of which are relevant in other countries and contexts. Several key challenges have emerged, along with some ways of alleviating them. Being able to provide something that will be seen as engaging and potentially of value to the user is a major challenge, perhaps because the capability is a long way from being of use, or because the requirements are insufficiently realized, or because of misunderstanding of the capability, or due to the technical language that non-scientific audiences find difficult to understand. However, having an early prototype has proven to be an effective way of initiating and building engagement between the climate service providers and users.

The time required to properly and effectively engage the users of the prototype with the developers, as well as challenges in communicating the science and its limitations, should not be underestimated and may prove problematic in some cases. In addition, it can be difficult to find the right users to engage with (either in terms of which organizations, or which people within an organization), and it can take several meetings with the same people to successfully proceed through the user trial in terms of understanding requirements, explaining capability, and evaluating the prototype. In the case of international collaboration, such as within CSSP China, differences in language and culture need to be factored in as potential issues. A common barrier encountered in CSSP China has been that most users only want and see a need for weather services, and finding users who either have a need, or can see a need, for climate information is more difficult. We have found that providing examples, such as case studies, on the potential use of longer-term climate information alleviates this, sometimes through examples of similar information used by the same sector elsewhere in the world. Finally, translating the feedback
into specific guidance to inform future science and service developments in terms of understandable, realistic, and achievable guidance is also often problematic. Having scientists and service developers involved in the user trials and prototype development has proven effective in our examples, but this is not always possible, particularly if the relevant groups are not joined up.

We have outlined the process and the benefits of undertaking trials and co-developing prototypes. The approach is proving effective in making climate information more accessible, useful, and understandable to decision-makers, such as in the case of the seasonal rainfall forecast prototype for hydropower management. The approach is also directing the development of underpinning scientific capability and helping deliver socio-economic benefits to Chinese citizens, government, and industry. A common ambition found in this study, and common to other published studies, is to deliver scientifically credible and robust climate information in which scientists have sufficient confidence, which is of use and value to the users, who often require increased resolution (spatial and temporal), detail and skill or certainty.

As noted above, the operational provision of climate services in China is the responsibility of CMA and its partner agencies, and the prototypes being developed within CSSP China are then for operational climate service providers in China to either learn from or incorporate in their services. In addition, the experiences that we have documented, along with the benefits and challenges, should be applicable in other countries and other situations.

We would like to conclude with two recommendations: make the time and the space for effective engagement between the users and the developers of any climate service; and building on this, the needs of the users should be brought in to the design and delivery of the climate service as early as possible and throughout the development cycle.

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