

● PERSPECTIVES ●

Translational Science for Climate Services: Mapping and Understanding Users' Climate Service Needs in CSSP China

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ABSTRACT

The Climate Science for Service Partnership China (CSSP China) is a joint program between China and the United Kingdom to build the basis for climate services to support the weather and climate resilient economic development and welfare in China. Work Package 5 (WP5) provides the translational science on identification of: different users and providers, and their mandates; factors contributing to communication gaps and capacities between various users and providers; and mechanisms to work through such issues to develop and/or evolve a range of climate services. Key findings to emerge include that users from different sectors have varying capacities, requirements, and needs for information in their decision contexts, with a current strong preference for weather information. Separating climate and weather services when engaging users is often not constructive. Furthermore, there is a need to move to a service delivery model that is more user-driven and science informed; having sound climate science is not enough to develop services that are credible, salient, reliable, or timely for diverse user groups. Greater investment in building the capacity of the research community supporting and providing climate services to conduct translational sciences and develop regular user engagement processes is much needed. Such a move would help support the China Meteorological Administration's (CMA) ongoing efforts to improve climate services. It would also assist in potentially linking a broader group of "super" users who currently act as providers and purveyors of climate services because they find the existing offerings are not relevant to their needs or cannot access CMA's services.

Key words: climate services, credibility, usefulness, diverse decision contexts, information users, information providers

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1. Introduction

The Climate Science for Service Partnership China (CSSP China) is a joint program between China and the United Kingdom to build the basis for climate services to support weather and climate resilient economic development and welfare in China. The program is comprised of five work packages (WPs) designed to foster collaborations between UK and Chinese scientists, as well as strengthen China's capacities around weather and cli-

mate observation, forecasting, and projections. The fifth WP, under which this study is conducted, aims to support the evolution of climate services in China.

Climate services may be broadly defined as the provision and translation of weather and climate information into forms and formats that support the decision-making and operations of a broad array of users. The concept of providing weather and climate information to support decisions in different sectors is not new, going back to at least 1873 (Vaughan and Dessai, 2014). Services might

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be further divided into weather and climate information. Providers and some purveyors may distinguish between the two types of information according to the timescale of the product. Weather information encompasses nowcasts (current weather conditions) to sub-daily to weekly or multi-week forecasts. Climate information is sometimes defined as encompassing monthly and seasonal forecasts including up to multi-decadal projections, or examining of trends and shifts using long series of historical climate data. Only more recently has the provision of climate information been called “climate services,” and there has been considerable evolution in the conceptualization, breadth, and deployment of climate services.

Such evolution includes the emergence of program and initiatives in the 1970s and 1980s, such as the Famine Early Warning Systems Network (FEWS NET), which sought to incorporate climate information into disaster risk management, preparations and responses for humanitarian crises, agricultural planning, financial risk management, and fisheries and reservoir management (Changnon et al., 1980; Hecht, 1984; Pulwarty and Redmond, 1997; Dilley, 2000; Morss et al., 2005; Verdin et al., 2005). As climate change concerns entered the scientific and policy discourses, climate services in the early 2000s shifted to include providing climate information to support climate adaptation and mitigation planning (Goosen et al., 2014). The World Meteorological Organization (WMO) endorsed the Global Framework for Climate Services (GFCS; Hewitt et al., 2012; WMO, 2014) at the World Climate Conference-3 in 2009 with an original focus on climate services to support climate-related decision-making. Over the past decade, multiple initiatives, some linked with the GFCS and others not, have emerged, which continue the evolution of climate services to support disaster risk reduction, sustainable development, humanitarian preparation and response, sector-based planning, and climate mitigation and adaptation (Dessai and Soares, 2015; Street et al., 2019). This multi-faceted role for climate services aligns with the move toward greater coherence among these areas as reflected in the trilogy of international agreements: the Paris Agreement, the Sendai Framework, and the 2030 Agenda for Sustainable Development (GFCS, 2016; Street et al., 2019; Hewitt et al., 2020a).

Through expansion of service offers over the past few decades, climate service initiatives worldwide have documented common challenges in providing information to diverse sets of users with variable decision contexts and needs. Constraints around the uptake of climate services into decision-making on the part of users are often related to (McNie, 2007; Kirchhoff et al., 2013; Koldunov

et al., 2016): 1) difficulty in determining what information is available and credible; 2) knowing how to interpret and integrate it; 3) mismatches in the timeframes and format of the information compared with decision-making timeframes; the focus on near-term (or weather-related) concerns as dictated by decision operations, life-cycles, or mandates; and 4) the information often not having been translated into more meaningful application, such as the implications of climate variability and change (risks and responses) to decision or investment criteria, and economic or social benefits and losses for particular sector considerations and decision criteria.

Many decision makers across sectors and organizations recognize the relevancy of short-term weather forecasts, in particular those associated with extreme events. These services have demonstrated value and have been integrated into operations and associated decision-making and investments. The nature of these weather services (timeframe and demonstrated vulnerabilities and risk) has led to the development of services and decision-making processes that are more synchronized with diverse public and private sector decision priorities, contributing to the demand for these services (Perrels et al., 2013; Anderson et al., 2015).

However, cultivating demand for and proving the value of climate services is more difficult. Although many decision makers in various sectors (including nonprofits) and policy makers recognize that climate change will impact their organizations and activities, overall climate services still often play a minor role in decision-making (Kirchhoff et al., 2013; Brugger et al., 2016; Vincent et al., 2018). This is frequently due to mandates, decision-making processes, and priorities for dealing with perceived risks. Risks and responses are seldom assessed in a strategic manner. They are sporadically dealt with unless related to legal or regulatory requirements, driven by shareholder/stakeholder demands, by market considerations (commodities prices, labor conditions, and competition), or by specific business operations and investments. As such, long-term climate change is frequently perceived to be less relevant to many decisions. Other challenges are related to difficulties in integrating available information into policy and investment decision-making, often due to it being out of sync with planning and investment timeframes (Tall et al., 2018; Street et al., 2019). Further limiting the demand is the lack of a defined value or relevance (or perception thereof) for climate services in a manner that is meaningful to decision and policy makers (Street et al., 2015).

Despite the challenges in providing climate services, good practice experiences from the delivery of other

types of science (e.g., energy or hydrology assessments) to support decision-making provide pointers to needed evolutions in climate services. There are multiple modes of providing science to support decision-making (Kirchhoff et al., 2013), with three modes described as follows (Dilling and Lemos, 2011):

(1) Supply-driven and/or supply-driven, minimally user informed: Climate information providers determining what information is produced, and how it is formatted and disseminated (i.e., setting the information agenda) without necessarily understanding or engaging users.

(2) User-driven: Knowledge agendas and informational requests are set by decision makers who make the requests of climate information providers, but do not necessarily interact with or engage with the providers beyond making the request.

(3) Collaborative user-driven and science informed: Co-design, co-setting of information agendas and co-production of climate knowledge through iterative engagement and learning between users and providers. In this mode, services are driven to produce robust evidence in support of users' dynamic decision needs and can evolve as new knowledge, capacities, and policy priorities emerge and climate, socioeconomic, and environmental conditions change.

Climate services lie along this science to support decision-making design and delivery mode continuum. The last mode is becoming the preferred good practice mode for climate services (Street et al., 2015; Vogel et al., 2019). Within each service mode, weather and climate or a combination of the two might be delivered. Much depends on the degree of collaboration with various users, and with social scientists, in the design, delivery, and evaluation of the service.

Since 2014, WP5 of the CSSP China program has included the translational science—the identification and mapping of: different users and providers, and their mandates; factors contributing to communication gaps and capacities between various users and providers; and mechanisms to work through such issues to develop and/or evolve a range of climate services in China. In particular, our study has examined the perceptions, capacities, and needs of various users for climate versus weather information in the following seven sectors: water, agriculture, urban planning and building construction, urban heating and cooling, disaster risk reduction, transportation systems, and electricity generation and provisioning.

CSSP China separates weather services from climate services with climate services focused on monthly and longer timescales. While the program was designed in

this manner, the scientific separation is problematic as many of our interviewees did not distinguish between the two, as will be discussed later in this article. We therefore deliberately kept our framing of climate services for WP5 broader than that used within the wide CSSP China program in order to accurately record actual users' perceptions and understandings rather than restricting it to a supply-driven definition and framing.

2. Methodology

We identified a representative pool of potential users of climate information in the seven sectors mentioned previously through a qualitative organizational and policy review analysis, followed by stakeholder mapping. Users' perceptions, needs, and capacities to employ existing weather and climate products within their decision contexts, as well as providers' perceptions of users' climate information needs and provider constraints in developing and maintaining climate services, were then assessed by using semi-structured interviews, focus group discussions, and workshops with key types of information. Each is described in more detail as follows.

2.1 Policy and organizational analysis

In order to initially identify and refine a representative pool of users from each of the seven sectors, existing policies and laws related to the governance of that particular sector were examined. We also conducted a literature review of formal and gray literature of Chinese climate services studies and initiatives and drew from lessons and good practice examples from climate service initiatives in other countries.

The policy and literature review enabled a rapid organizational analysis of government ministries and agencies involved in the management of that sector, and their broad mandates for action (roles and decision-making responsibilities). Supporting organizations, such as research institutions, and their roles in providing or purveying particular types of scientific information to support decision-making were also identified.

2.2 Stakeholder mapping

The needs for and capacities to use and deliver climate information are shaped by the roles that people and organizations play in designing, producing, and delivering climate services. Frequently roles are broadly categorized as either a provider or a user; the actual roles may more effectively be described as provider, purveyor, or user and the chain of interaction between these stakeholders (Bessembinder, 2012; Street et al., 2015). Providers frequently are national meteorological agencies or

climate institutions maintaining observation infrastructure and developing and issuing forecasts to projections, among other information types. Purveyors are often described as those who translate, process, and transform weather and climate information for others; they may be providers themselves and/or be public (research institutions) or private sector (e.g., media companies) that modify information for specific purposes or to reach particular users. Users themselves can be quite diverse, ranging from researchers engaged in climate risks and resilience studies to policy makers or practitioners like engineering firms or water management institutions, all the way to the general public and media.

In reality, a person’s or organization’s role can change depending on the specifics of the task at hand, and interactions behave more like a dynamic web rather than a chain (Street et al., 2015). Nonetheless, mapping types of stakeholders within a particular climate service context and their different roles and decision mandates can be a useful means by which to understand subsets of targeted users’ information requirements and to produce climate information more inline with these. Some examples of types of users are in Table 1; we interviewed some researchers, practitioners, policy makers, and media.

Potential representative stakeholders in the seven sectors were first mapped by the administrative level of operation and roles and then categorized by typology along the provider to user landscape. Stakeholders were additionally identified through studying investigator networks and referrals made as possible interviewees through snowballing.

2.3 Stakeholder consultations

Semi-structured interviews were used to qualitatively

ascertain stakeholder capacities and use of weather and climate information in decisions and operations, as well as level and strength of communication between the user and information providers. User and provider workshops were held separately to allow each group to frankly offer their perspectives about climate services, how such information is/could be used in operations and planning, and/or how such services are currently developed and deployed to different target audiences. Given our networks, it was easiest to arrange workshops and interviews at the municipal- (Tianjin), provincial- (Gansu), and prefecture-level (Linyi City).

Supplementary informal interviews related to climate risk and adaptation planning at the provincial-level were conducted with representatives of four provincial Development and Reform Commissions (DRCs) from Guizhou, Jiangxi, Inner Mongolia, and Ningxia, and research institutions (national- and provincial-level) involved in the Adapting to Climate Change in China Phase II (ACCCII) project funded by the Swiss Agency for Development and Cooperation in collaboration with the China National Development and Reform Commission (NDRC). These informal consultations provided additional perspectives on climate adaptation planning contexts and challenges, including the accessibility and limitations of supporting science, and the capacities of providers to deliver policy-relevant information to decision makers in the context of adaptation planning.

3. Chinese climate services landscape

The landscape of weather and climate services providers, purveyors, and users in China is complex and fre-

Table 1. A climate services user typology continuum (adapted from Bessembinder, 2012)

User	Description
Researchers	Researchers working on landuse and urban planning, climate impacts, adaptation and mitigation studies and assessments. Discipline and purpose of research determine climate information needs and shape capacities to use. May also be purveyors.
Practitioners	Engineers, planners, investment portfolio managers. Located within local government, industry, and business, including financial services providers. These represent a diverse and evolving group of users that can use publicly available information, but also are interested in bespoke climate services.
Consultancy companies	Private companies that conduct climate and/or disaster risk analysis, repackaging climate information (e.g., seasonal forecasting to decadal prediction and climate projections), and/or support other decision makers, researchers, or the public. May also be purveyors.
Policy and decision makers; non-governmental organizations (NGOs)	Tend to require more climate and societal/environmental impacts information from direct climate information like seasonal forecasts. Often rely on researchers, practitioners, and consultancies to translate climate information to their particular decision contexts, rather than working directly with meteorological services. Particular decisions makers—such as for directing urban heating or transportation—are more interested in weather than climate information.
Education	Teachers and those developing educational material and curriculum about climate and climate change. Do not need detailed climate information.
General public	Potentially interested in seasonal or longer forecasts or predictions depending on sector of employment (e.g., farmers, but with highly diverse requirements and often low capacities to interpret). Information must be simple and related to their concern. Most of the general public are more concerned with daily to weekly weather.
Media	Requires graphics and information soundbites for news and documentaries.

quently blurred within sectors due to divisions of decision-making responsibility and mandates for different ministries, institutions, administrations, and bureaus as historically set by the State Council. The State Council is comprised of ministers from 21 line ministries, 3 commissions, the People's Bank of China, and the National Audit Office (State Council, 2020)—each of which supervises a single sector, though there is overlap between mandates within a sector. The meteorological services, and now the evolving climate services, within China strongly reflect the sectoral nature of Chinese administrative bodies and their historical decision mandates within the Group.

3.1 Providers and purveyors

The premier government organization charged with providing weather and climate information products is the China Meteorological Administration (CMA). At the national level, CMA is organized into a number of internal bodies and institutions. CMA provides weather and climate services within China at five administrative levels—national, regional, provincial, prefectural, and county—through the National Meteorological Center (NMC), the National Climate Center (NCC), the Public Meteorological Service Center (PMSC), 31 provincial meteorological service centers, 14 meteorological bureaus of municipalities and regions, 317 prefectural (or city-level) meteorological offices, and some 2440 county meteorological bureaus—see Fig. 1 (China Meteorological News Press, 2012; CMA, 2016). Weather and climate services provided by CMA may be further categorized by function as observation and information networks, data storage and management; forecasts, predictions, and projections; and dissemination of weather and

climate information products as services.

In addition, there are organizations within the public and private sectors in China whose primary climate service roles is that of a purveyor (see Table 2 and the case studies comprising Section 4). For example, in China some private sector companies, particularly in the energy sector, use each other's forecasts rather than those issued through their respective prefectural meteorological service center. Other private sector climate service companies, for example, Sprixin Co., Ltd. or Tianyuan New Energy, provide wind or solar radiation forecasting services for wind or solar power enterprises.

The public also turns to mobile phone apps and websites of private sector purveyors (CMA, 2015). These companies have developed mobile phone apps to push weather forecasts and early warning messages. The purveyors do not generate forecasts on their own—they source them through the CMA meteorological service centers and translate and reformat the forecasts for public consumption. The mobile apps MoWeather (Moji FengYun Software Tech Developing Co., Ltd.) and Caiyun Weather are particularly popular; MoWeather is currently the preferred public source of weather forecasts in many urban areas (ibid).

3.2 Users and climate services

Water, agriculture, urban planning, and urban heating sectors, as well as climate information provision, within China are administered by a number of different government ministries and agencies operating at different divisions. Provinces, autonomous regions (e.g., Inner Mongolia Autonomous Region), special administrative regions, and the four municipalities (Beijing, Chongqing, Tianjin, and Shanghai) are just beneath the central gov-

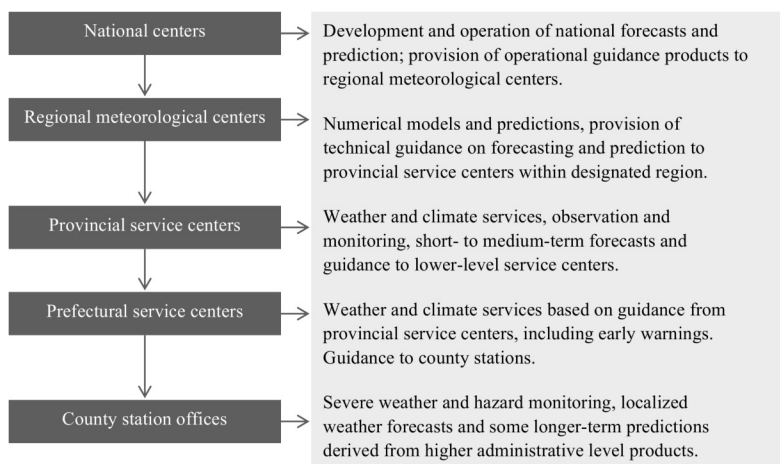


Fig. 1. Overview of the services provided by the CMA centers at various administrative levels. Derived from CMA (2012, 2016) and Zheng et al. (2016).

Table 2. The weather and climate user, purveyor, and provider landscape in China

User	CMA (provider)	Provider and purveyor	
		Government ministries and sub-agencies (not CMA—provider and purveyor) Examples include: Ministry of Water Resources (MWR), Ministry of Agriculture and Rural Affairs (MARA)	Private sector purveyor: MoWeather, Caiyun Weather, Energy companies, Utilities
Government: National ministries	Weather forecasts and seasonal predictions	Weather forecast and prediction for in-house use	
Provincial	Early warning	Early warning (in-house)	
Prefecture	Meteorological hazard risk	Sector-specific hazard risk	
City	Climate change projections	Climate change projections (in-house)	
County	Climate change assessments		
Businesses and public with sector-specific interests (e.g., farmers, cargo shippers)	Sector-specific sub-daily to seasonal forecasts and climate predictions Climate change projections	Weather forecast and prediction (in-house) Early warning Sector-specific hazard risk	Sector-specific weather forecast and prediction for specific users Early warning dissemination
General public	Weather forecasts Early warning and hazard warning (co-issued with other ministries/agencies)	Early flood or drought risk warning, hazard warning (co-issued with CMA)	Dissemination, but not necessarily production: Weather forecasts Early warning

ernment in terms of authority. The national-level ministries—central government agencies with particular functions and mandates, such as the Ministry of Water Resources (MWR)—are at the same administrative level as the provinces and coordinate directly with them and provincial departments on monitoring and reporting. Provinces and autonomous regions are further divided into smaller administrative units: prefecture or district and then county-level units. The types of weather or climate information that they can use or need to support their decision mandates are based on their understanding of vulnerabilities, risks, and implications for their sphere; the courses of action open to them for acting upon their mandates (policy constraints); and the resource constraints of the organization.

4. Mismatches and overlaps in user decision criteria and provider “climate” services

The weather and climate services provided by CMA do not currently serve all users’ needs, nor are all users looking to CMA to provide required weather or climate information for their decision contexts. More sophisticated users, such as some national ministries, large-scale water operators, and private companies, have developed their own weather or climate services in-house to support their operations and decision-making. Some private sector companies are generating their own products and commercializing them in the public realm, and the public turns to a wide array of products that may conflict with official ones released by CMA. This section presents a summary of research findings for three of the seven sectors: agriculture, water, and urban planning and construc-

tion (Opitz-Stapleton et al., 2016, 2017a, b). It provides an overview of primary stakeholders—from public users to researchers, to purveyors and providers—and a summary of their roles; the differences in how some of the stakeholders are accessing and using weather and climate information in their planning and operations; and gaps and challenges in developing user-driven science-informed climate services for that sector. Our findings for the other sectors investigated are detailed in the final technical reports, which are available upon request.

4.1 Agriculture

The agricultural weather and climate services review consisted of consultations with a sample of users ranging from members of the interested public (e.g., farmers in Inner Mongolia, Ningxia, and Yunnan) to agricultural researchers supporting the Ministry of Agriculture and Rural Affairs (MARA; Opitz-Stapleton et al., 2017a).

Weather and climate services to support the Chinese agricultural sector are shared between CMA and MARA, and their subordinate internal departments and institutions (interviews; Chen, 2009). CMA has the remit to provide agrometeorological services to the MARA. The MARA then acts as a purveyor translating, transforming, and communicating the information in the form of technical guidance and recommended responses to provincial and lower-administrative level governments and agricultural units and networks (as the “end users”) (MARA, 2017).

The national CMA also releases some types of agrometeorological data directly to its regional-, provincial-, and prefectural-level service centers, which also translate and transform (e.g., downscale, run more localized

weather forecasts, etc.) the information to be more relevant to “local” conditions and agricultural needs along administrative chains of command. The prefectural- and city-level meteorological service centers’ agrometeorological desks also provide bespoke services for paying users, such as agricultural facilities, villages, and prefecture-level farm bureaus that further translate and transmit the information to family farms, livestock breeding operations, and large-scale farming companies. Some prefecture desks provide information via briefs, reports, and consultation services to government decision makers and county-level meteorological bureaus; and to farmers and urban agricultural enthusiasts via SMS, cell phone apps, a website, TV displays at parks or community centers, and dedicated weather personnel that go to public spaces to issue warnings, forecasts, and education to the general public or farmers organizations.

Public user interviewees (farmers and livestock herders) did not always have a high degree of trust in using CMA’s agrometeorological services due to perceptions of seasonal forecast accuracy and the timeliness of the forecasts. Cost of purchasing subscriptions to the mobile phone meteorological SMS issued by the provincial service centers (relative to farmer incomes) and actual accessibility (including signal strength) in rural settings closely followed as chief challenges mentioned in interviews (Opitz-Stapleton, 2014; Hang et al., 2015; Zheng et al., 2016).

Some purveyors and providers noted that the capacity of lower administrative-level departments and farmers to correctly interpret and act upon the transmitted information was sometimes limited, contributing to maladaptive actions and over-adaptation, occasionally leading to greater losses during particular cropping seasons. For example, a purveyor described how some farmers in Northeast China are planting wheat varieties more suited to southern China when seasonal summer forecasts indicate warmer temperatures, and incurring crop and financial losses because the southern varieties are still not suitable for the northern climate. Farmers’ perceptions of forecast accuracy and trust in it, combined with low capacity to correctly interpret said forecasts, at times, are contributing to maladaptive actions.

Climate services to support researchers conducting studies on long-term agricultural impacts due to joint considerations of climate change projections and socioeconomic preferences also face some challenges. This research includes medium (multi-year) to long-term (multi-decadal) agricultural studies related to climate variability and change (MARA, 2017). We interviewed researchers at Institute of Environment and Sustainable Develop-

ment in Agriculture (IESDA), a research institute of the Chinese Academy of Agricultural Sciences, which primarily focuses on understanding the impacts of climate variability and change, in conjunction with shifts in agricultural technology on agricultural yields. Their research is used by the Ministry of Science and Technology (MoST), MARA, and the NDRC to inform agricultural policy development and prioritization.

The challenges associated with climate services supporting agricultural–climate change impact research relate to the availability of data of sufficient quality and usable format (gridded versus station data), as well as the capacity of the research community to use and translate that available to their models and the costs associated with seeking more tailored climate products than that currently available. Thus, there remains some scope for improvement in the provision of historical climate data and climate change projections to agricultural researchers, who themselves act as purveyors of climate agricultural impacts information to policy makers.

4.2 *Water sector*

The Chinese water sector is comprised of many actors at different administrative levels, with mandates and roles for particular water services—e.g., sewage, wastewater treatment, raw water provisioning, and irrigation and drinking water—often split rather than carried out by a single entity. We consulted with a sample of water resource managers, planners, and researchers from the Yellow River Conservancy Commission, the Yellow River Basin Water Resources Protection Bureau, Gansu Province, and Linyi City Reservoir (Opitz-Stapleton et al., 2016).

There are nine national-level ministries involved in water administration and policy within China. The MWR is charged with many aspects of water resource policy formulation and coordination, although some of its mandates overlap with those of other ministries and legislation resulting in some lack of clarity as to which mandates belong to which ministries (Feng et al., 2006; Silveira, 2014). MWR is divided into a number of departments and seven River Commissions, and bears principal responsibility for coordinating activity in transboundary (inter-provincial and multi-national) surface water resources. Provinces have departments analogous to the national-level ministries, with various aspects of water decision-making and management split among departments.

Provision of weather and climate information within the water sector remains fragmented. The MWR and CMA both operate separate weather stations—MWR’s

are along rivers and major reservoirs—and data sharing is not consistent. The national-level CMA has historically had a fairly limited role in providing weather and climate services to support water allocation planning and operations. CMA's climate services to and with MWR are centered around meteorological-related hazards through seasonal predictions and weather forecasts. CMA signed a memorandum of understanding with MWR to improve coordination and communication in 2012, enhancing efforts on sharing evolving weather and climate information products to support flood and drought early warnings (China Meteorological News Press, 2014). In 2015, CMA and MWR jointly issued a notice signaling intent to improve coordination and communication, and facilitate information sharing (China Meteorological News Press, 2015).

Given the historic lack of coordination, many of the MWR's departments and institutions (e.g., the River Basin Commissions or RBCs) developed their own in-house climate services—from observation, research, and information systems to application-specific weather and climate information products for use in other internal divisions. The RBCs and some provincial water departments/bureaus produce their own daily, monthly, and seasonal temperature and precipitation forecasts to assist in allocation and flood risk planning (interviews; Yellow Basin Project Team, 2010; Cenacchi et al., 2011). Other institutes (e.g., the Research Center for Climate Change under the MWR) develop climate projections for use in water balance models to estimate the potential impacts of climate change on water supply throughout the country (interviews; Wang et al., 2016).

Provincial- and prefectural-level hydrological agencies or water bureaus may not be as savvy users of climate information in their respective decision contexts, though capacities to access and use information vary from province to province. An interviewee at the Gansu Hydrological Agency indicated that the agency does not employ water balance, rainfall–runoff, or other types of hydrological models. It also does not incorporate weather or climate information of any type into planning or decision-making—this in spite of it being the organization in charge of managing the province's reservoirs, irrigated areas, and rivers. Other provinces' water bureaus may have higher capacities and desires for climate information; informal interviews with some water sector operators from Ningxia and Inner Mongolia under ACCII indicated higher capacities to interpret information and incorporate in water planning and management and had greater demand for information.

Operators of the Linyi Tangcun Reservoir Hydrological

Station were concerned more with weather data (daily and sub-daily) as their mandate is around flood control, than they were with climate information; their decision timeframes did not go beyond sub-daily to a few weeks (interviews). Furthermore, provider capacities to understand users' requirements and decision contexts, and give salient information, may also be limited at lower administrative levels. A prior study by two of us (Han and Ye) found that a mismatch exists between the local meteorological office and the reservoir managers in defining the precipitation thresholds that could trigger flooding in Linyi (Han et al., 2011).

Much more engagement, awareness, and capacity building efforts are required to target a spectrum of users at the provincial- and prefectural-level. While generalities should not be made, it is safe to say that few of the smaller organizations at lower administrative levels have the capacities and sophistication of RBCs or other MWR departments. Interest in building capacity and incorporating weather and climate information is also varied.

4.3 *Urban planning*

The spectrums of users to providers in urban planning that we consulted demonstrate similarly diverse capacities and needs to access and use available weather and climate information (user spectrum) and/or understand and meet those needs (provider spectrum) as those in water and agriculture (Opitz-Stapleton et al., 2017a). Decision-making users range from the NDRC to the Ministry of Housing and Urban–Rural Development (MoHURD) at the national administrative level to city government departments and divisions. In some cities, such as Tianjin or Qingdao where our consultations were concentrated, city divisions work in conjunction with city university research institutions around urban planning—including green space design, building density and orientation, and transportation networks.

Interviewees indicated that their weather and climate information needs varied widely, depending upon the decision context and planning life cycle (e.g., 50+ years for major infrastructure). Increasing public interest and subsequent policy mandates regarding air pollution and haze elevated concerns of long-term spatial planning around building orientation, urban green space, and building spacing in facilitating urban ventilation, particularly as temperatures increase. Few cities considered the potential impacts of climate change, including non-stationarity in local climate regimes that were used in urban planning and building design, prior to 2012. However, with the introduction of China's National Adaptation Strategy in 2013, as well as urban climate risk pilot programs like

Sponge Cities introduced by MoHURD, university-based researchers in some of the cities now see value on the need to include longer-term (multi-decadal) climate change information in their planning models, though capacity building efforts to support them to do so are needed. Given lower awareness of the potential impacts of climate change, city department planners and construction companies interviewed remain more focused upon historical climate observations and sub-daily (i.e., weather) to annual forecasts related to wind, temperature, and precipitation predictions and projections for urban spatial planning.

Weather and climate services to support cities are provided by the prefecture/city-level service centers, and directly or indirectly by CMA and the provincial-level services. The data and services provided, and client relationships vary significantly across China as each prefecture/city service center has considerable leeway in how they design, implement, and operate services; there is not standardization across the centers. In Tianjin where the Service Center has built strong relationships through consistent engagement with clients, products are developed based on user requests (interviews). The Tianjin Service Center provides seasonal forecasts, climate predictions, and some climate projections on a project-specific basis for different clients. Yet, not all cities' service centers have strong relationships with potential users, and the usability, salience, and timeliness of products offered via online databases or other transmission modes vary. Users indicated that their climate service challenges, beyond payment for services, were related to understanding what was available and their capacity to identify and use the products. Users with strong relationships with their respective service centers reported greater understanding of available products and felt more comfortable in requesting for new products and assistance in interpreting them.

A particular concern raised by providers and some of the urban planning researchers was that a number of the products and services provided have not yet incorporated the implications of different climate change scenarios (e.g., snow loading or potential changes in storm intensity, duration, and frequency). Users indicated that mandate and resource constraints also limit their ability to use climate information, with limited funding and political will for allocating resources to begin mainstreaming considerations of climate change risk into urban planning. For example, while Tianjin government is beginning to consider sea level rise scenarios and new storm intensity–duration–frequency curves, it is very expensive to retrofit the storm water drainage network. Population increases, loss of impervious surface, and development of

water-removing pumping and infiltration sites are also overwhelming the system. Yet, funds currently only exist to repair the system according to historical standards, not according to non-stationarity, climate change, and shifting urban conditions. Thus, while demand for climate projection information might grow, urban planners and decision makers are not yet able to adequately act upon such information, potentially limiting its effectiveness in urban climate resilience planning. Climate services to support urban climate adaptation need to engage more with a variety of urban planning researchers and decision makers to understand their constraints and requirements for long-term planning.

5. A process roadmap for user-driven and science-informed services

Climate services are still relatively new and highly specialized. The difficulty in integrating climate services into existing decision and investment contexts arises as the current focus on climate services is still primarily supply-driven. Many climate science products and services are looking for a market—rather than co-produced and science informed. As within business or engineering communities, climate services face low success rates in bringing new products or services to market. Rarely is it the supply of appropriate services or technology that is the limiting factor for widespread uptake, but rather (Shekar, 2007; Brooks, 2013; MARCO, 2017): 1) a mismatch between available services and the unexpressed/unknown needs of users; 2) institutional, administrative, and structural barriers to building a sustainable business model for services; and 3) uncertain value in the service that may cause some potential users to hesitate paying for services and/or seeking alternative sources of information. Marketing strategies from business product development and science policy initiatives point to good practice elements for overcoming some challenges in climate services:

(1) Co-design and co-production of information and services to work toward appropriate use and support information uptake in decisions and operations (Dilling and Lemos, 2011; Steynor et al., 2016). Additionally, contributions from social scientists are needed to provide the political economy, risk governance, and decision-making processes analysis to inform the production and translation of information, and facilitate engagement with a broad range of users.

(2) Consistent engagement and communication between providers and targeted users, particularly to assist with the first element and to enhance relationships and

improve credibility (van Pelt and Ludwig, 2014; Street et al., 2015).

(3) Monitoring and evaluation of the systems to enhance the credibility, salience, usefulness, and sustainability of weather and climate information (McNie, 2013; Vaughan and Dessai, 2014).

We developed a process-based roadmap (Fig. 2) in this study that moves the intended service from a supply-driven modality to a user-driven and science-informed modality (Opitz-Stapleton et al., 2017b). This roadmap encompasses a hybridization of the stages and good practice concepts set out in New Product Development, New Service Development, and Stage-Gate processes—well known processes developed by businesses for developing and bringing products and services to market, as well as the UK Climate Impact Programme’s Risk, Uncertainty and Decision-Making guidance (Willows and Connell, 2003; Shekar, 2007; Cooper, 2008; Bhuiyan, 2011).

Importantly, this roadmap also incorporates key considerations at each stage based on good practice guidelines for user-driven and science-informed services (of any kind) and observations from CSSP China. These considerations are not inclusive of all those, of which providers or savvy users should be aware, but instead are meant to spark further thinking about what is required for the co-design and co-evaluation of climate services. The roadmap stages themselves are grouped according to degree of stakeholder engagement, with the first two

stages—initial service capability concept and monitoring capability system for tracking service development progress—largely concerned with building the business model and case for the proposed service, which are reliant on focused engagement within the provider organization and/or with service partners.

The remaining stages—service evaluation and screening, developing a working prototype, beta-testing, co-evaluation, full service development and implementation, and monitoring and co-evaluate (continuous learning and improvement)—focus on specific service development and as such require significant user engagement, and are specific to the climate service development, deployment, and continued improvement.

This roadmap and the associated good practice guidelines (Opitz-Stapleton et al., 2017b) offer a framework to assist providers in developing user-informed, science-driven climate services. The roadmap and guidelines will need to evolve as practices, users’ needs and decision contexts, and the science behind them change. The roadmap and guidelines are not comprehensive or intended to be prescriptive; they are a reflection of good practices in service development as seen at this time. Social, economic, environmental, and political conditions (national and international), as well as business environments and the science, are constantly shifting. It is our contention, however, that the framework and the learning that is embedded in the processes and guidelines—re-

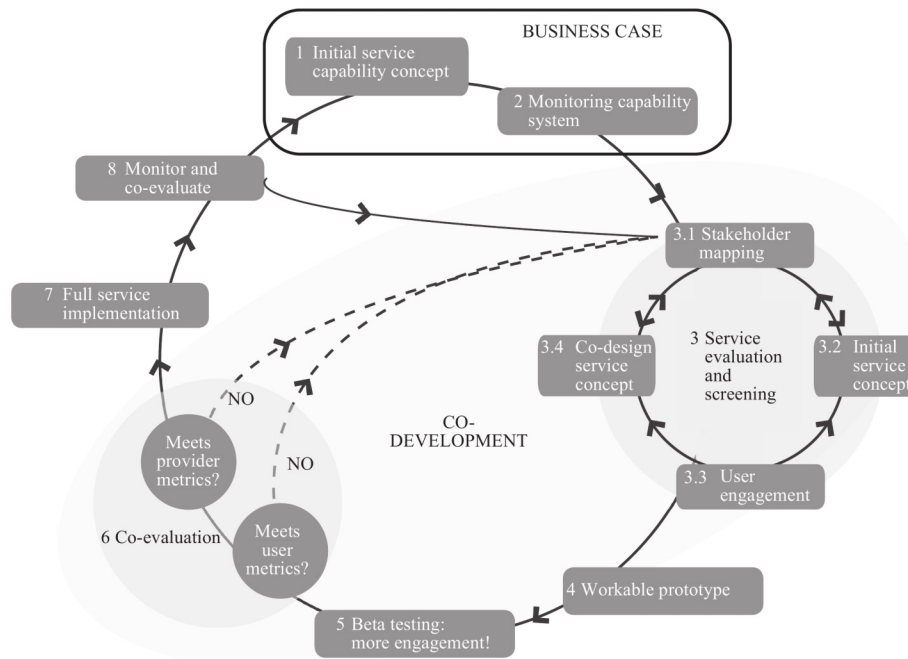


Fig. 2. A climate service roadmap depicting a process-based framework to facilitate the development, implementation to market, monitoring and evaluation, and evolution of climate services. It can be used to inform the translation of emerging climate science to support more user-driven and science-informed climate services.

commendations for developing a monitoring and evaluation system and a plan to deliver it—provide opportunities to continually improve the services provided as limitations are addressed. Testing and evaluation of the roadmap and good practice guidelines in other countries could also lead to their further development, and enhancement of their credibility in assisting climate services.

6. Summary and moving forward with climate services in China

This study found that the diversity of purveyors and users is high in China and that CMA is facing similar challenges to other national meteorological agencies in developing and furthering China's climate services. At the onset of the study, the supply-driven mode of climate services dominated. Some CMA interviewees noted how difficult it was to convince their managers of the need for consistent engagement with clients, and for training or collaboration with social scientists to build their own capacities for understanding users' diverse decision contexts and information needs.

At program outset, the interviews revealed that only researchers regularly use climate information from CMA in their decision contexts. Other entities under ministries such as MARA and MWR have in-house climate services and may also act as purveyors to other departments within the organization; this is largely based on historical mandates. Such in-house providers and purveyors are slowly seeking additional services and collaborations from CMA. The appetites, capacities, and abilities of many government decision makers involved in spatial, socioeconomic, and other sectoral planning to demand and use climate information remain limited. Policy makers' focus is predominantly on weather information, but needs will shift as the central government is beginning to prioritize climate change mitigation and adaptation planning across multiple sectors (Nadin et al., 2016).

Other translational science projects have been conducted under WP5 of CSSP China since the finish of this study, and those projects are building on and benefiting from this study's findings. One project investigated the treatment, communication, use, and interpretation of uncertainty in climate services in China, through strong engagement with decision makers in a range of sectors, and close collaboration with providers of climate services in China (Taylor et al., 2021). The project developed, as an example of translational science, guidance for the appropriate treatment and communication of uncertainty in the Chinese cultural context, and materials to support de-

cision makers in their understanding and interpretation of uncertainty in climate information.

Another project (underway at the time of writing) is focusing on challenges related to the use of multiple models in climate prediction and projection, and the communication of results to users. This project is developing methodologies and will provide guidance to aid climate service providers and users in dealing with information derived from multiple climate models. It will identify challenges from both a provider- and user-centric view of having access to information derived from multiple climate models both for climate predictions on seasonal timescales and climate projections on multi-decadal timescales.

In addition to these translational science projects, work in CSSP China is actively developing prototype climate services and trialling them with users (Hewitt et al., 2020b). CSSP China offers pilot mechanisms and a process-based roadmap to assist CMA in conducting the social and translational science to evaluate purveyor and user needs and capacities, and to test engagement strategies, in order to design and deliver collaborative user-driven and science-informed services and foster a sustainable market for these.

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