CONFIDENTIAL

Weather Forecasting System Review

Final Interim Report

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[Updated on 7 May 2024 for consistency with final report and minor adjustments. However, any new material is included in the final report]

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Glossary

Abbreviation	Stands for
AI	Artificial Intelligence
BCR	Benefit Cost Ratio
CDEM	Civil Defence and Emergency Management
CIMS	Coordinated Incident Management System
CRI	Crown Research Institute
CV	Contingent Valuation
DOC	Department of Conservation
DPMC	Department of the Prime Minister and Cabinet
FENZ	Fire and Emergency New Zealand
FFC	Flood Forecasting Centre
FRST	Foundation for Research, Science and Technology
HIVE	Hazard, Impact, Vulnerability, and Exposure
ICAO	International Civil Aviation Organization
JMA	Japan Meteorological Agency
KPI	Key performance indicator
MBIE	Ministry of Business, Innovation and Employment
MetService	Meteorological Service of New Zealand
MFAT	Ministry of Foreign Affairs and Trade
MfE	Ministry for the Environment
MHEWS	Multi-hazard early warning system
ML	Machine learning
MoH	Ministry of Health
MoT	Ministry of Transport
MPI	Ministry for Primary Industries
NCMC	National Crisis Management Centre
NEMA	National Emergency Management Agency
NHP	Natural Hazards Partnership
NHS	National hydrological service
NIWA	National Institute of Water and Atmospheric Research
NMHS	National meteorological and hydrological service
NMS	National meteorological service
NPAT	Net profit after tax
NSC	National Security Committee
NWP	Numerical weather prediction
NZTA	Waka Kotahi New Zealand Transport Agency

ODESC	Officials Committee for Domestic and External Security Coordination
PWS	Public Weather Service
RIA	Regulatory Impact Analysis
SOE	State-Owned Enterprise
SSIF	Strategic Science Investment Fund
WMO	World Meteorological Organization
WTP	Willingness to pay

Acknowledgements

We would like to acknowledge the input from the Ministry of Business, Innovation and Employment (MBIE); the Treasury; the Meteorological Service of New Zealand (MetService) and the National Institute of Water and Atmospheric Research (NIWA) as well as external experts we consulted and the stakeholders who provided the time and thoughts during interviews or in completing our online survey. A full list of those we have engaged with is provided in Appendix A. These discussions have helped inform our thinking which has fed into this report. However, the views expressed in this report are those of the authors only and should not be taken as representing the views of any of the individuals met with during the process, nor any of the organisations they are associated with. We also appreciate comments received on an earlier draft of this report.

Executive summary

We have been engaged by the Ministry of Business, Innovation and Employment (MBIE) and the Treasury to review the weather forecasting system in New Zealand, focusing on the following objectives:

1. Identify and recommend the optimal arrangements and responsibilities in the weather forecasting system that will best position New Zealand to meet future weather-related challenges and impacts in the context of climate change.

2. Consider the structural configuration of MetService and NIWA, based on the optimal system arrangements identified in point 1 above.

3. Identify if changes in access to weather data should be made and what these should be.

As part of this process, we agreed to first consider the context in terms of current arrangements and future needs from the system, the issues to be considered in order to best meet New Zealand's future needs and the objectives for any proposed approach. This interim report reports on these, with further work planned between February and April 2024 to develop and assess different options in order to provide recommendations in relation to the above objectives.

The system performs as we might expect and delivers value but there is a case for change to meet future needs

Our key findings to date are that:

- public weather forecasting delivers **value to society**, and that value is likely **increasing**
- the **government has a role** in ensuring the provision of a "public good" weather forecast
- prior changes to institutional arrangements delivered efficiencies and the **system performs as should be expected** at present
- in order to meet future (increasing) needs, **there is a case for change** in institutional arrangements.

Given that case for change, we have developed a set of principles to inform the development and assessment of different options for the future system, to then inform the recommendations in our final report.

The value from the weather forecasting system is far-reaching and fits in a global context with opportunities ahead

Weather forecasting has social, cultural, and economic value. It is embedded in some industry processes (such as for airlines) and is present in many decisions from hanging out clothes to animal carry limits on farms.

Weather forecasting operates in a global context with global models, obligations to contribute data, common data standards and international obligations across a range of hazards. New Zealand provides important inputs to these global models. Further, developments in artificial intelligence and machine learning offer opportunities across the weather forecasting system.

There is a role for government in ensuring the provision of a "public good" weather forecast

The nature of weather forecasting means there is typically a role for government to ensure the provision of a 'public good' weather forecast, which might not otherwise be provided. Governments classically underfund public goods and "stretch" to pay for the optimal level of supply of services such as weather forecasting. However, both in New Zealand and internationally, research suggests that public weather forecasting delivers considerable net benefits to society – estimates vary but all agree it is a large multiple of cost.

Prior changes to institutional arrangements delivered efficiencies and the system performs as expected

Establishing MetService under a commercial model delivered efficiencies and allowed it to draw on additional revenues. For instance, we understand the cost of the Ministry of Transport contract decreased in real terms for up to 10 years following the move and MetService draws significant advertising and other revenues (advertising revenues being driven by the popularity of its website and mobile application and other sources of revenue from the private sector through the provision of services). These revenues in effect support more investments in its infrastructure and systems than would otherwise be the case.

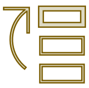
Survey respondents and those interviewed generally indicated a sense that the system was performing above average and as one might expect given the institutional arrangements. Looking across the system, we see more concentration in the provision of observations, basic infrastructure, data and modelling and greater competition in downstream applications. This is likely to (at least) partly reflect natural monopoly characteristics in those areas upstream within the system.

Weather forecasting will be of increasing importance in the face of climate change

Climate change is anticipated to result in more extreme weather in New Zealand, with increased risks and impacts of weather events. Many of the impacts are already evident. Among other things, the links between the weather forecasting system and emergency management will be of increased importance in the face of climate change.

Future system needs are expected to increase in light of this and provide a case for change

New Zealand's future system needs go beyond what existing arrangements are expected to deliver (with increasing risks and demands from the system in light of increasing prevalence and impacts of weather events as a result of climate change). Given this, there is a case for change to meet the needs of the future and make best use of capabilities and investment. These future needs are summarised below:

	Access to **global** observations, modelling and capabilities with an increased coverage of the South Pacific.
	Prioritised investment targeted at **New Zealand's highest value/needs.**

	Ability to **leverage computing** capabilities, artificial intelligence and machine learning and increasing data to better understand/**link** with: • risks **across hazards** (including with interactions and increasing extremes) • **impacts**, including understanding highly localised conditions and different uses/applications (safety and commercial) • research, operations, applications and consumer demands.
	Clear **communications and engagement** that are: • understood, insightful and trusted • accessible to relevant communities • clear on actions needed from different parties.
	Customer **choice**, input and engagement, and innovation in research provider, products/application, and advice that is supported by open data access.
	Changing role of the meteorologist, linking more with computer modelling and relevant environmental sciences.

Current institutional arrangements are associated with a number of potential barriers to the system meeting future needs

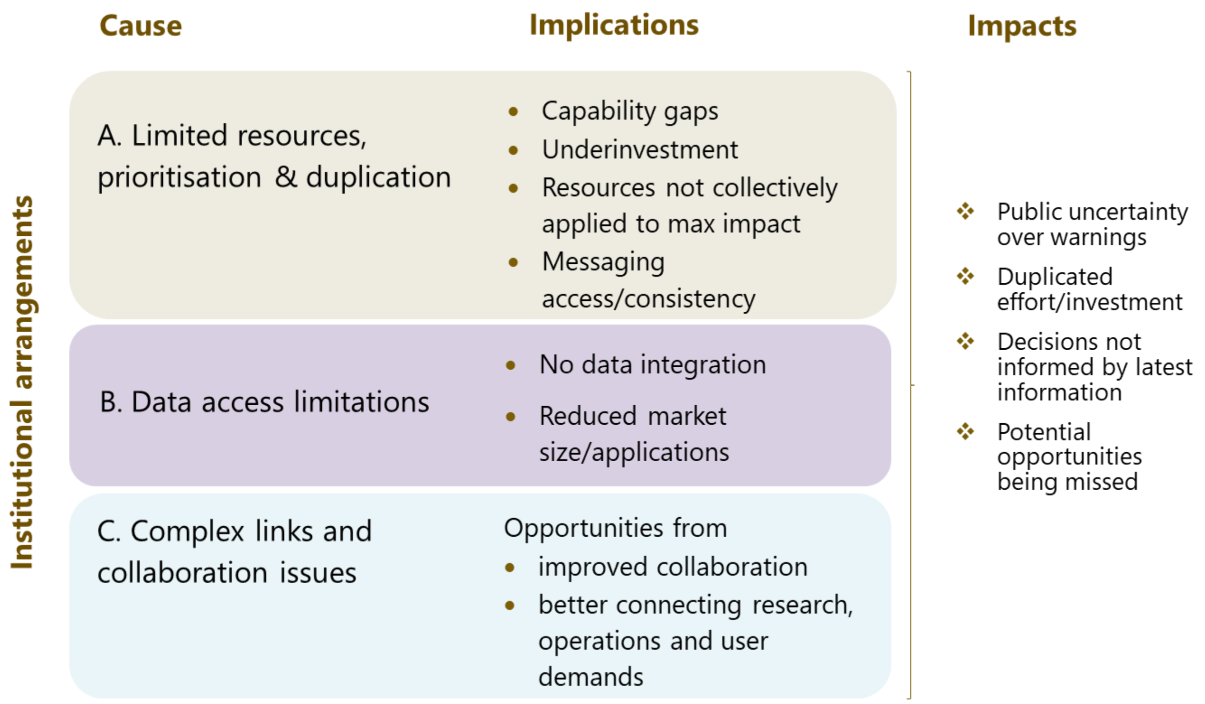
Our interviews, survey, workshops and research highlighted several potential barriers to meeting future demands. These potential barriers largely stem from the current institutional arrangements, which (among other things) lead to potential issues around the efficiency and prioritisation of what is delivered from government spending, integration of information produced from that spending, and availability of information to support decision-making relating to the impacts of weather. A summary of the root cause, themes that stem from this, the implications and impacts is illustrated below.

The figure illustrates that institutional arrangements are associated with:

A. **Limited resources and prioritisation as well as duplication** of effort, which leads to capability gaps, underinvestment, resources not collectively applied to most value for New Zealand, and issues around access to and consistency of public messaging.
B. **Data access limitations**, with a lack of integration between different data sources and barriers to accessing weather system data that reduce the potential size of the market and end applied use of data from the weather forecasting system.
C. **Complex links and collaboration issues**, where there are opportunities to improve collaboration and better connect research, operational requirements and end applications/user demands. This includes opportunities for research to better understand how people perceive and respond to information about hazardous weather and impacts

Collectively, this leads to impacts by way of:

- **Public uncertainty over weather warnings** (or watches), which ultimately causes risk to lives and properties as well as economic activities. These risks increase with rising frequency of extreme weather and increasing duplication in weather forecasting (including exposure and number of parties publicly commenting). The costs associated with extreme weather events appears to have been growing, with a market increase last year.
- **Duplicated efforts and investment**, which ultimately cost the Crown or customer and may lead to alternative activities not being undertaken. These risks increase with barriers/costs to accessing information and increasing duplication in weather forecasting (overlap in the scope of public providers). The former has been raised by stakeholders (and previously) and there is evidence of increasing overlap in scope of public providers. Overlaps appear present in both observation networks and associated costs as well as different services or areas of development/investment.
- **Decisions not being informed by the latest information**, which also causes risks to lives and properties as well as economic activities. These risks increase with barriers/costs to accessing information and issues of coordination/collaboration or role clarity, both of which have been raised as part of our analysis.
- **Potential opportunities that may be missed.** This risk also increases with barriers/costs to accessing information and issues of coordination/collaboration or role clarity, as well as any challenges in making the case for resourcing and making best use of resources available, each of which have been raised as part of our analysis.



Principles for optimising the system have been developed in this context to inform the assessment of options

In the context of the assessment of the current system and future needs, and in particular the potential barriers to meeting these needs, the following principles have been developed to consider the subsequent options that are identified to address these issues. We have also picked up issues relevant for pragmatic implementation if there were to be some change. The principles include:

Optimises use of **resources** to ensure **fit-for-purpose** core forecasting, informing & warning services, including associated infrastructure & capability (public weather and climate forecasting)

Improves **understanding/prediction of impacts, risks and necessary actions** and drives more **effective** planning and emergency management

Reinforces **trust** in the weather forecasting system and builds **social capital** across diverse needs

Builds strong **international links** and alliances supporting access to relevant global systems, data, infrastructure/models, and expertise

Enables **innovation** within system, including through ensuring ready **access** to public/publicly funded information

Is realistic, **practical** and minimises service disruption

Where:

- *Optimises use of resources* includes financial resources and different capabilities and encapsulates delivering net benefits to New Zealand and value from government investment by way of fit-for-purpose public forecasting services applying necessary inputs.
- *Improves understanding/prediction of impacts, risks and necessary actions* includes supporting collaboration across the weather forecasting systems, across hazards and with emergency management players to drive effective planning and emergency management (looking across the four Rs of emergency management – reduction, readiness, response and recovery – as well as similar thinking for other applications and sectors).
- *Reinforces trust in the weather forecasting system and builds social capital*[1] *across diverse needs* includes minimising the risk of confusion through unambiguous information from official sources and recognising the diverse needs of users and the importance of effective engagement. This is likely to involve clear roles and messaging around warnings and watches.
- *Builds strong international links and alliances supporting access to relevant global systems, data, infrastructure/models, and expertise* includes building on the existing relationships and forums for engagement and partnership.

[1] Social capital is defined in the likes of https://www.treasury.govt.nz/publications/speech/social-capital-and-living-standards-framework which states "Social capital refers to the social connections, attitudes and norms that contribute to societal wellbeing by promoting coordination and collaboration between people and groups in society".

- *Encourages innovation within the system* includes an openness to private competition and closeness to user demands. Importantly, it also involves working across the public and private parties and ensuring ready and easy access to public/publicly funded information (including channels to disseminate information) and ability to draw on and apply that information (such as appropriate formats and systems). However, this could be available for free or incorporate a charge to recover the cost of making this available (including both the marginal cost of provision and a contribution to appropriate overheads).
- *Being realistic and practical* also includes the management of any transition.

This report provides the context from which we will develop and assess potential options in order to present a recommended way forward in our final report and advice.

1. The Review seeks to address three key objectives

In September 2023, the Ministry of Business, Innovation and Employment (MBIE), together with the Treasury, engaged us to provide an independent review of New Zealand's weather forecasting system (the Review). The Review was termed Project Hau Nuku, meaning 'shifting winds', and has a steering group of members from the Ministry of Transport (MoT), MBIE and Treasury as well as terms of reference.[2] The terms of reference set out the following key objectives (with further detailed context and questions also set out):

1. Identify and recommend the optimal arrangements and responsibilities in the weather forecasting system that will best position New Zealand to meet future weather-related challenges and impacts in the context of climate change.
2. Consider the structural configuration of MetService and NIWA, based on the optimal system arrangements identified in point 1 above.
3. Identify if changes in access to weather data should be made and what these should be.

1.1 Project Hau Nuku builds on three reviews undertaken between 2001 and 2018

There have been three prior reviews of the weather forecasting system since the establishment of MetService and NIWA (in 2001, 2006, and 2018). The reviews were commissioned by the Minister of Finance, Minister for State Owned Enterprises, and Minister of Research, Science and Innovation as the shareholding Ministers of MetService and NIWA.[3]

The 2001 and 2006 reviews considered the possible risk to New Zealand's national weather and climate functions from maintaining the separation between NIWA and MetService.

The 2001 review identified long-term risks associated with existing arrangements and recommended an assessment group be established to consider options for the two organisations to work more closely together. The review led to shareholding Ministers setting expectations of greater collaboration between them.

The 2006 review found that MetService and NIWA were still not collaborating and recommended a merger of the two organisations, which ultimately led to a Memorandum of Understanding between them to improve collaboration.

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[2] See: https://www.mbie.govt.nz/science-and-technology/science-and-innovation/research-and-data/project-hau-nuku-weather-forecasting-system-review-terms-of-reference/

[3] Shareholding Ministers of MetService are the Minister of Finance and Minister of State-Owned Enterprises. Shareholding Ministers of NIWA are the Minister of Finance and the Minister of Research, Science and Innovation.

The 2018 review focused on access arrangements for weather data and whether those arrangements were limiting third parties who want to develop innovative, value-added weather insight products and services. The 2018 review suggested possible commercial gains from improved access to data but noted change would be needed to operating models if this were to be pursued, and would come with additional costs to the Crown.

More detail on the prior reviews can be found in Appendix B.

1.2 This interim report summarises the context, issues and objectives for the Review

We have broken the project up into five stages (as shown in Figure 1). The first three of these have been completed:

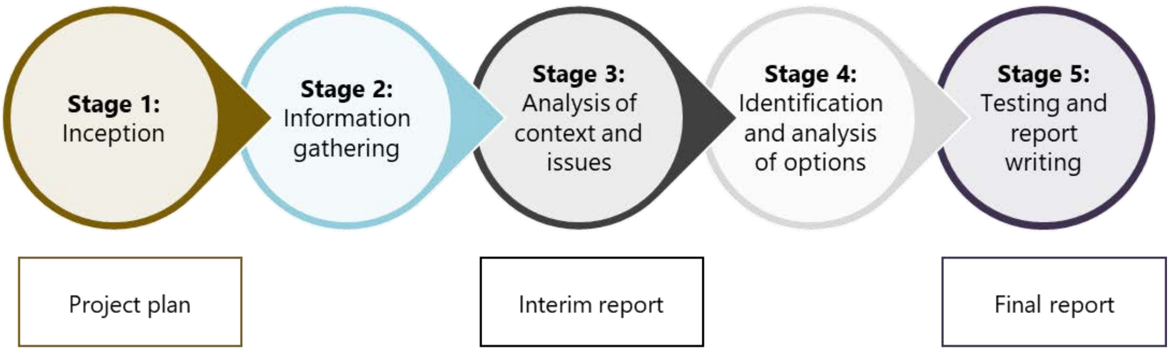
1. inception leading to a project plan and stakeholder list
2. information gathering through document review, research, and stakeholder meetings/interviews (as summarised in Appendix A)
3. analysis of context and issues (leading to this interim report).

We sought feedback on our draft interim report from our project partners, MBIE, Treasury, MetService, and NIWA before finalising it.

Having identified potential issues to be addressed and objectives for any options that are considered, the following stages of the project will involve:

4. identifying relevant options and analysing these
5. testing our findings and analysis, and presenting and reporting by way of our final report. This is expected to be completed by the end of April 2024.

Figure 1: Stages of the Review



1.3 Structuring the review around the Regulatory Impact Analysis (RIA) framework

We are using the established guidelines for Regulatory Impact Analysis (RIA) from Treasury as the framework for our analysis (New Zealand Treasury, 2017). The process for impact analysis is as follows:

- *Description of the status quo.* This focuses on the features of the market or relevant social arrangements, existing legislation and regulation, and any relevant decisions that have already been taken. Essentially, we are explaining the state of the world and what has got us to this point.
- *Defining the problem(s) and assessing magnitude*. Defining a problem relies on being able to explain the gap between the current situation and the outcome being sought. In this context, we are looking at the current state of the weather forecasting system and what is believed to be the future weather forecasting system New Zealand needs. This essentially describes the case for change (why do we want to act?) and relies on us being able to articulate the size of the problem(s), delineate the causes and symptoms of problem(s), and identify and diagnose the problem(s). These problems are typically market or regulatory failures that lead to suboptimal outcomes.
- *Defining the objectives.* Essentially, the objectives should describe what is being sought by taking action, and how any proposed intervention may have its effectiveness assessed.
- *Identifying and analysing the full range of options.* This involves coming up with potential interventions that address some or all of the objectives. Analysis of the options means assessing their relative effectiveness.
- *Considering consultation, implementation, monitoring, evaluation and review.* This involves, consulting on the above aspects, summarising options and recommendations, and considering how the recommended option would be implemented as well as plans for monitoring, evaluation and review.

Essentially, this process provides a tractable and readily usable framework for identification and analysis of issues and to be able to ask whether there is a role for Government to intervene, and if so, what that intervention might look like.

Table 1 lists examples of common market and regulatory failures, taken from the Treasury's best practice RIA guidelines (New Zealand Treasury, 2017).

Table 1: Examples of market and regulatory failures that can arise from voluntary transacting[4]

Failure	**Definition**
Imperfect competition	Where one or more party/parties can control a market for their own benefit at the expense of consumers or other firms.
Information problems	Where one party to a transaction does not have the information needed to act in its best interests. In extreme circumstances this can lead to significant costs to many parties and the market being under-developed because of a lack of trust.
Externalities (spillovers)	Where costs or benefits fall on people other than those who consume the good or service. This can lead to over- or under-provision of the good or service.

[4] Self- or co-regulatory arrangements can help to address some of these failures, but may also create further problems, such as the rise of unintended consequences (inducing behaviour or providing incentives that do not improve welfare), inefficient regulatory enforcement, moral hazard (e.g., incentives for an actor to partake in riskier behaviour because it does not bear the full costs of its actions), crowding out (reduction in private economic activity because of regulatory compliance), and rent seeking behaviour.

Public and mixed goods	Where a good or service is under-supplied because it cannot be charged for, under-consumed because consumers are being directly charged but their consumption is not incurring additional costs (i.e., it is non-rivalrous), or over-consumed because there is free access to the resource, but consumption still imposes costs.
Lack of clear property rights	Unclear, ill-defined, or poorly designed property rights can mean parties do not bear the consequences or receive the rewards that result from their actions.

1.4 The review used a range of sources to refine the findings

We summarise findings from engagements with a broad range of stakeholders across the weather forecasting system in the form of interviews, workshops, and an online survey. Stakeholders were asked to consider future trends applicable to the wider forecasting system, discuss the needs of the weather system in Aotearoa New Zealand, and identify barriers to those needs being met. We interviewed over 50 stakeholders, received 145 responses to our survey and held a workshop at the Meteorological Society of New Zealand annual conference 2023. We reviewed over 150 documents in the form of journal articles, reports, international guidelines, ministerial briefings, and content from stakeholders. The key inputs to our review are detailed in Appendix A.

1.5 The remainder of this report is set out in four further sections

The remainder of this interim report discusses the:

- role and importance of weather forecasting systems (section 2)
- current weather forecasting system arrangements in New Zealand (section 3)
- perceived performances and shortcomings of weather systems in New Zealand by stakeholders (section 4)
- principles for consideration of options for New Zealand's weather forecasting system and next steps (section 5).

Seven appendices then provide further detail on the:

- key inputs to our review
- past reviews of the weather and climate forecasting system
- structure of emergency management in New Zealand
- types of economic goods
- parties that operate across the weather forecasting system in New Zealand
- MetService and NIWA performance against Statements of Corporate Intent
- learnings from international experience.

2. The context of weather forecasting

Weather observing and forecasting have played a central role in people's decision making, both individually and as collectives, since ancient times (for example, to know where and what type of crops to plant) (Fiebrich, 2009). By observing and recording weather over time, these learnings could be applied to predict what might happen in the near future when similar phenomena occurred. This fundamental procedure has enabled the ability to predict the weather and subsequent improvements in weather prediction. Today, this continues to be a critical (and costly) part of weather forecasting that must be supported.

This section discusses the:

- role of weather forecasting, the type of economic good and role of government, and value derived from public weather forecasting
- increasing importance of the weather forecasting system in the face of climate change
- links between the weather forecasting system and emergency management.

2.1 Weather forecasting allows us to plan ahead and deal with uncertainty

Weather forecasting provides insights into the possible nature, location, timing, and intensity of future weather. Weather forecasting gives us information that in turn provides opportunity to allocate our effort and resources over time as efficiently as possible. This has significance for social, cultural, and economic development, particularly as the types of activities we engage in begin to change (e.g., globalised trade, how we organise ourselves as communities, etc.) and in the context of evolving weather patterns and climate change (National Research Council, 2003).

For example, in the electricity industry, weather forecasts feed directly into load (demand) forecasts on electricity networks. This helps system planners to understand how much energy is required to maintain a reliable and quality service (Hertzfeld et al., 2004).

Weather forecasting also provides us with an important tool for risk management and safety. Weather forecasts underpin the ability of emergency management systems to provide early warnings to the public and to take necessary steps to prepare for hazards, which include inducing public behavioural change to avoid and/or mitigate damage and negative consequences to lives, property, and livelihoods (Katz & Murphy, 1997; World Meteorological Organization, 2015d).

Weather forecasting is a powerful and important tool when we consider things like food security, transport and infrastructure (including the ongoing maintenance of lifeline utilities), public health, and in general, the avoidance of the negative economic impacts of unforeseen and/or extreme weather (Fiebrich, 2009).

Theoretically, the value of forecasting information can be measured by looking at the decisions one would make with and without access to the forecasting information, and calculating the difference between consequent outcomes.[5] Therefore, forecasting information is only deemed valuable if it influences the actions taken by a decision maker (Katz & Lazo, 2011).

More observations, observations of higher quality, faster and more-accurate numerical prediction models, and greatly improved computational methods have meant weather forecasting capabilities have significantly increased over time (Alley et al., 2019). Relatively speaking, we can now predict weather phenomena with greater confidence and further into the future. However, challenges remain in producing accurate forecasts (particularly as the climate changes) and in being able to deliver and use this information in the right ways to the right people.

2.1.1 The market is likely to underprovide weather forecasting products and services, so there is a role for government

In economics, a good is something that we as humans want and need and perceive to be beneficial to consume but is scarce in nature – effort is required to obtain the good. Goods are typically also transferable between people and can be traded on a market.

Goods are categorised in many ways, but most often through the following two dimensions:

1. **Excludability** refers to the ability to prevent people from consuming the good.
2. **Rivalrousness** refers to whether one person's consumption will prevent other people from consuming the good as well.

Table 2: Categorisation of goods based on if they are excludable and rivalrous

	Excludable	Non-excludable
Rival	Private good	Common good
Non-rival	Club good	Public good

Without some form of government provision, modern day weather forecasting products would likely mostly be club or private goods, with the potential for excludability.

- In cases such as news or weather reports behind a paywall (where information is developed once and somewhat generically), they are club goods. They are non-rival because the consumption of the good by one person does not stop another person from also consuming that weather forecast (and the costs of supplying that forecast to another person will be minimal, if not zero), and excludable because the provider of the weather forecast can feasibly prevent people from consuming it (i.e. paywall).
- In other cases, such as the contracting of the time and expertise of a meteorological consultant, weather forecasting products and services can be a private good. This is excludable because only those willing to pay for the contracting will be able to access the

[5] Under the economic decision theoretic framework, a decision maker would be looking to maximise 'utility'. It is implicitly assumed that decision makers will be looking to maximise their utility.

service and is rival because the consumption of the time of the meteorological consultant means that time cannot be consumed by anyone else.[6]

Why are most weather forecasting products not public goods?

Weather forecasting requires some way of observing weather phenomena and conditions, recording and storing observations, and then using the observations in some way (ranging in complexity) to predict the future atmospheric conditions.[7] Modern weather forecasting systems are incredibly complex and make use of expensive and expansive infrastructure to be as accurate as possible.

Assuming, at a minimum, a weather forecaster wants to be sustainable and able to provide weather forecasts well into the future, it would not be able to provide a weather forecast freely and openly (i.e., as a public good). The benefits of providing a public good weather forecast would accrue to society wholly (i.e., there are positive externalities). However, providing these benefits would not be compensated through a price mechanism. This is because if the weather forecast is non-excludable the public has no incentive to pay for access – it can simply free ride and enjoy the benefits.

Consequently, a provider would not provide the weather forecasts as a public good and would choose to make them excludable (i.e., a private or club good) to be appropriately compensated for the benefit it provides to consumers and the investment it has made in producing and delivering weather forecasts.

The role of government in ensuring provision of a 'public good' weather forecast

As a modern society and as part of the social contract, there is an expectation of public safety. That is, we expect the government to provide (or arrange for the provision of) certain services to keep citizens safe. Severe weather events can have significant social costs, including loss of lives, livelihoods, and property. Therefore, there is a need for some level of public provision of weather forecasting and warning services.

This is because not all members of the public have the ability or willingness to pay for weather forecasting and warning services, and therefore would be excluded from access to excludable weather forecasts. The level of forecasting and warning services that the private sector provides to the market will be lower than the socially optimal level of provision. Therefore, without some form of public provision, that group of society which does not have the ability or willingness to pay may be exposed to risk we as society deem unacceptable.

Public good weather forecasting is not unique to New Zealand. Countries all over the world operate national meteorological and hydrometeorological services (NMHS). To become a Member State of the World Meteorological Organization (WMO) one must operate and maintain a meteorological service,[8]

[6] We are aware that, pre-1980s, New Zealand's general public had the ability to freely access meteorological opinion through the New Zealand Meteorological Service via phone. This was non-excludable in that anyone had the ability to access the service, however it was rival, given the use of the meteorologist's time meant someone else could not use that same time, making it a common good.

[7] Spanning across this rudimentary description is also research, which plays a crucial role in better developing the forecasting process and in making predictions more efficient and accurate.

[8] As per Part 3 of the WMO Convention.

which means that, as of 2023, 187 Member States and six Territories globally each have their own meteorological service (World Meteorological Organization, 2023).

The specification or level of forecasts provided for 'public' purposes may vary from place to place, but arguably would reflect what is considered at least a minimum standard suitable for the purposes of public safety. However, the effectiveness of forecasts in ensuring public safety depend on each nation's investment, systems, and dissemination capabilities. As in the World Bank report, *The Power of Partnership: Public and Private Engagement in Hydromet Services* (Suwa et al., 2020), meteorological services can be separated into multiple different types. This is shown in Table 3.

Table 3: General typology of meteorological services, defined by economic characteristics

Type of services	Economic characteristics				
	Non-rival	Non-excludable	Economies of scale	Economies of scope	Natural monopoly
Basic systems					Most
Basic services					
Targeted services					
Industry-specific services					
Value-added services					

Source: adapted from Suwa et al. (2020)

From Suwa et al. (2020), basic systems exhibit the characteristics we have discussed in relation to public goods (non-rivalrousness and non-excludability). They also exhibit economies of scale (decreasing marginal costs as scale provided increases), economies of scope (decreasing marginal costs as scope of services broadens), and some characteristics of natural monopoly (most simply, where production from multiple suppliers is more costly than production by a single supplier).[9] All these characteristics suggest a possible role for government in ensuring provision of basic systems (and possibly some services, e.g., public safety) to address what would otherwise be a market failure.

Crucially, a role for government in ensuring provision of public good weather forecasting does not mean the government itself has to be the provider of a 'public' service. Suwa et al. (2020) state the private sector could produce some public services under supervision and contract by a regulator/government (i.e., a distinction between funding and providing), much like what happens in New Zealand. Here, the government itself does not provide weather forecasts and warnings to the public; it contracts for it under the Ministry of Transport (MoT) with MetService as a state-owned enterprise.

[9] Suwa et al. (2020) go on to say that often the upstream end of the hydrometeorological value chain (i.e. observation networks, etc.) is assumed to have natural monopoly characteristics, but this may not be as clear anymore due to the potential for significant technological change and development, particularly in the way we record, store, and use observations.

For things outside of basic systems or services (e.g., targeted services, industry-specific services, or value-added services which may be considered mostly non-public), Suwa et al. (2020) state there is less of a role for government in provision, and certainly opportunity for the private sector to compete and deliver innovation plus value-adding and consumer-responsive products and services. Suwa et al. (2020) stress that, like in the case for public services, non-public services are not necessarily provided exclusively by the private sector – but it is important the regulator/government ensures a free market and level playing field for all competitors. This is especially true if the public sector is producing non-public services alongside public services.

Investment in a public weather forecasting service should provide net benefits to society

Stating that there may be a role for government in ensuring the provision of public weather forecasting services implicitly assumes that it is an inherently good thing to do, in that it delivers net benefits to society. If public weather forecasting services did not provide net benefits to society, the government would not be concerned with ensuring there is some provision.

This is because an investment should not be undertaken by the government if it does not provide net benefits to society. Theoretically, there is almost always an alternative investment available that would provide net benefits and could be undertaken instead.[10] The government invests on behalf of the public as taxpayers, and therefore must focus on spending as efficiently as possible to keep the public satisfied.

For clarity, the choice of ensuring the provision of public weather forecasting services is distinct from the choice of how to ensure provision. In some cases (i.e., where there are net benefits from doing so) it may make sense for a nation to invest in its own capabilities to be able to provide public weather forecasting services. In other cases, particularly for smaller nations or areas, it may make sense to import public weather forecasting services from elsewhere.

2.1.2 Quantifying the value of public weather forecasting

While it is easy to talk theoretically about the need for net benefits to invest, quantifying the value of public weather forecasting in real, tangible terms is not a trivial task. There are many different benefits that can arise from public weather forecasting which accrue to multiple parties and are measured and expressed in multiple ways.[11] The difficulty is compounded by the blurriness between public and non-public weather forecasting products and services.

The following section does not aim to:

- exhaustively present the literature
- provide in-depth critique of any of the studies
- estimate the value of public weather forecasting in New Zealand.

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[10] Decision makers have scarce resources and numerous choices; they will thus want to ensure they are investing these scarce resources efficiently to get the most out of them.

[11] For example, benefit cost ratios show the benefits divided by the costs, to show for each dollar (or equivalent currency) invested, how much is returned. Net monetary benefit, on the other hand, is total discounted benefits minus total discounted costs. While these two measures use the same data, they are saying different things.

It is rather to provide a sense of the sort of exercise that might be undertaken to determine the value of a public weather forecasting service. It also aims to point toward some of the findings of studies to get a sense of the magnitude of benefits a public weather forecasting service provides to society.

Studies in multiple developed nations suggest public weather forecasting returns considerable net benefits to society

Korea

Park et al. (2016) conducted a contingent valuation (CV)[12] survey of 1,000 households to measure the economic value of the Korean National Meteorological Service (KNMS) to Korean households, by asking about the additional willingness to pay (WTP) over and above the observed price for its services (i.e., what households already pay for access to consistent service). The economic value of the national meteorological service was estimated as 2.01 USD per household per month (comprising of 1.26 USD current expenditure, and 0.75 USD mean additional WTP), scaling to 444.9 million USD a year in 2016 terms – implying the economic value of KNMS far outweighed the costs related to its upkeep and provision. Importantly, this only captures the value to households – there may be benefit arising from the NMS to other sectors as well.

Switzerland

Frei (2010) conducted a pilot study, aiming to value the economic and social benefits of Switzerland's national meteorological service (NMS) and the industry as a whole, extrapolating measures of economic benefit from a previous study also conducted in Switzerland. The author stresses that it is not possible to estimate one single figure representing the overall benefits of national weather services in a country, in part because of difficulty in separating public and non-public weather services and the benefits that are attached to each. Nonetheless, extrapolating figures from other literature allows the author to provide some indication of the order of magnitude of benefits provided by the entire weather forecasting industry, estimating the benefits to be in the hundreds of millions of Swiss francs (even when excluding aviation and climate), while the costs of providing the services was approximately 100 million Swiss francs (77.3 million for the NMS). In other words, it is expected that the benefits of provision far outweigh the costs.

United Kingdom (UK)

London Economics' review of the UK Met Office (2015) made use of existing analysis to extrapolate and estimate the value of the UK Met Office to UK society (both public and non-public weather services). Some of the value streams considered, and method of measurement, include:

- the value directly to the public (perception of value; WTP)
- flood and storm damage prevention (avoided cost)
- aviation industry benefits (market-based and avoided cost)

[12] Contingent valuation (CV) is a stated-preference survey method used to value non-market goods (i.e., things not traded on a market) by creating a hypothetical scenario/market. It asks respondents about their willingness to pay (WTP) for the good at varying levels to elicit the demand curve and ultimately the value ascribed to the good.

- other business sector benefits (market-based)
- winter transport (avoided cost)
- defence and security (avoided cost)
- international leadership benefits (market-based)
- health effects and lives saved (avoided cost)
- climate change information benefits (avoided cost).

In London Economics' analysis some of these value streams are quantified, and some are not (although potential magnitudes have been given). The base case of the UK Met Office as it stood at the time, relative to a 'do nothing' scenario, had a benefit cost ratio (BCR) of 14.1:1. Most of the quantifiable benefits arise from the contribution to business sectors, aviation, value directly to the public, and from climate change information.

A truly 'do nothing' scenario as a comparator may not make practical sense, as United Nations specialised agencies such as WMO and International Civil Aviation Organization (ICAO) require there to be some level of NMS to maintain Member State status and for aviation to happen, and some other provider may step into the role of the UK Met Office. Annex 1 of London Economics' analysis describes further how they dealt with this and specified the 'do nothing' case.

The UK Met Office conducted its own value for money review of its Public Weather Service (PWS, i.e., the public good weather forecasting services), also in 2015 (UK Met Office, 2023). The UK Met Office states that investment in PWS underpins all the UK's weather service capabilities; this includes PWS's investment in international infrastructure for data exchange, and access and maintenance of weather satellites. The UK Met Office estimated the quantifiable benefits of the PWS were approximately 1.5 billion GBP annually, with additional value in saving tens of lives a year from the direct impacts of weather. The key quantifiable benefits, in order of magnitude, were from direct value to the public, aviation, value-added activities in the economy, land transport, and flood and storm damage avoidance. The UK Met Office specified the overall costs of PWS for 2022/23 at 123.2 million GBP, meaning the benefits are considerably higher than the costs.

New Zealand

NZIER (2018) estimated the value of MetService's public weather forecasts and warnings (i.e., the products and services MetService provides under the MoT contract – not its contractual products and services to other users). They used a secondary research benefit transfer approach, taking estimates of benefits from other contexts (particularly London Economics' assessment of the Australian Bureau of Meteorology (Duke et al., 2016)), and applied this to a New Zealand setting (a function of both resource constraint and paucity of New Zealand evidence). Given a range for each of the benefits, NZIER estimated a benefit cost ratio between about 10:1 and 48:1, highlighting considerable benefits from the provision of public weather forecasting services over and above the costs of provision.

The authors again raise the problem with the counterfactual of a true 'do nothing' scenario – if there were no MoT contract, then there would likely be some other arrangements put in place for the provision of weather forecasts and warnings to meet WMO and ICAO requirements. Arguably, that counterfactual exists in some very poor developing countries with inadequate or no observations, and underfunded NMS, where services still come in from the global WMO infrastructure and from global models etc.

United States

A study by Lazo and Chestnut (2002) estimated the value to households of current weather forecasting services provided by the US National Weather Services by conducting a survey of WTP (varying the amount as the current cost to taxpayers). Household costs for weather services were about 25 USD annually, and the median value to households of the forecasting services was estimated at 109 USD annually, implying a conservative BCR of 4.4:1.

Reports by both NZIER (2018) and the WMO (2015a) point toward other examples of estimating the value of weather forecasting services (both public and non-public) across a range of settings.

What about continual improvement of weather forecasting services?

The evidence above suggests there is merit in having some form of national weather forecasting service because of its contribution to economic and social activity and the role it plays in public safety (e.g., avoiding unnecessary exposure of people and property to severe weather events).

However, there is also a question, once an NMS is established, as to whether continual incremental improvements offer net benefits to society. Numerous studies have looked at the value of improvement to services in one way or another (e.g., increased accuracy, extension of services, etc.). For example:

- Kull et al. (2021) estimate improvements in the coverage and exchange of surface-based observations to meet WMO Global Basic Observing Network specifications can deliver additional global socioeconomic financial benefits of over 5 billion USD annually (with further unquantified non-financial benefits such as lives saved and improvements to wellbeing). The proportion of these benefits that would accrue to New Zealand is not clear. However, improvements in global standards are bound to have some flow-on effects for New Zealand's meteorological system.
- In Lazo and Chestnut's (2002) aforementioned study, the average US household signalled a willingness to pay of about 16 USD annually to have weather forecast service quality improved to the maximum technically feasible level.
- A working paper by Molina and Rudik (2022) estimated the value of improved hurricane forecasting in the US. The authors found that improvements in forecasting since 2009 reduced total costs associated with hurricanes by 5 per cent (hundreds of millions). The aggregated benefits of the improvements far outweigh the cumulative budget for operating and improving the hurricane forecast system. Interestingly, the findings also suggest there are currently increasing returns to investment in hurricane prediction. The main benefits of the improvements arise from deaths avoided and damage to property and crops avoided.
- A working paper by Anand (2022) looked at the value of having longer lead times on forecasts in the context of winter driving in the US. The findings show that winter driving warnings with longer lead times reduce crashes, even when the warning is less accurate than what would be provided in a shorter lead time warning. The authors argue this is because when warning arrives earlier, people visit fewer places and snow plough crews intensify road maintenance operations.
- A working paper by Shrader et al. (2023) revealed preference estimates to determine the value of accurate weather forecasts in the context of mortality prevention from extreme

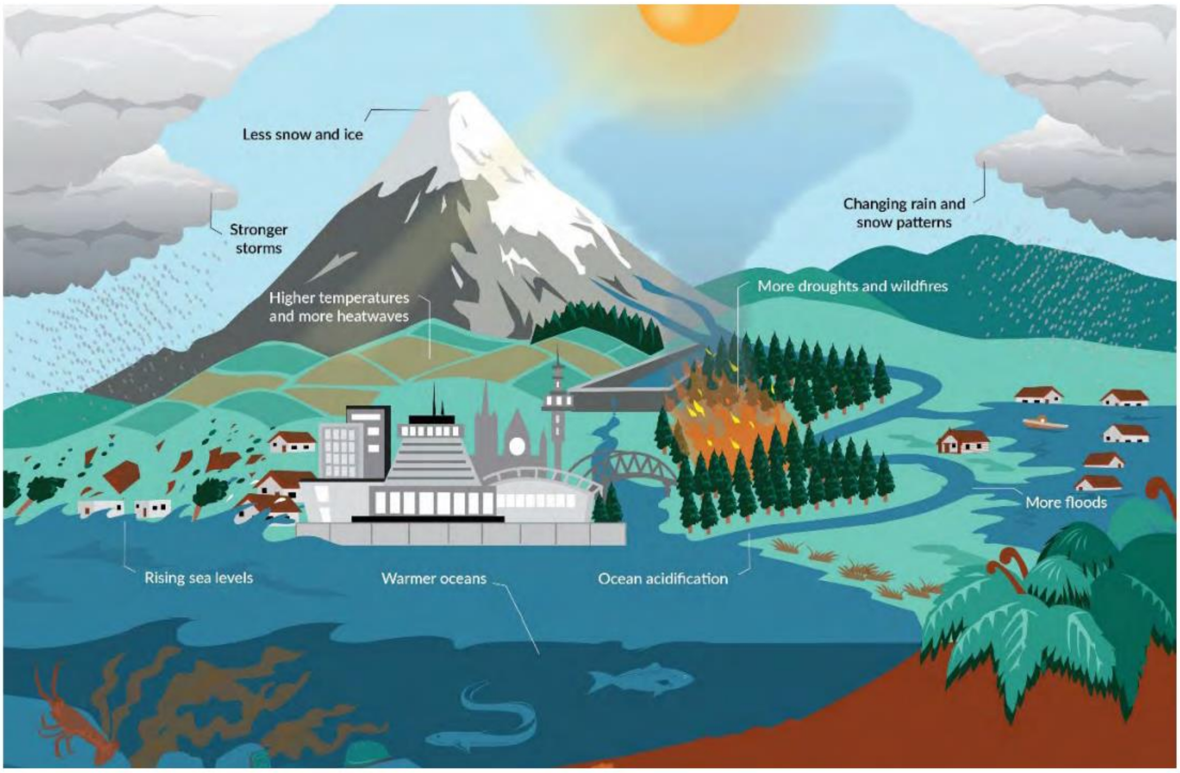
temperatures in the US. Results showed that erroneously mild forecasts increase mortality, but erroneously more extreme forecasts do not reduce mortality. The authors argue making forecasts 50 per cent more accurate (i.e., reducing standard errors by 50 per cent) would save an estimated 2,200 lives per year.

- Williams et al. (2022) conducted a cost benefit analysis of a heat health warning system (HHWS) in South Australia. The authors estimate a BCR of 2.0:1 – 3.3:1, with the main benefits being reductions in HHWS-attributable hospital admissions and ambulance callouts.
- The US Agency for International Development (2013) has some more sector-specific examples of the potential benefits of climate services (including weather forecasting).

2.2 Increasing importance in the face of climate change

Climate change is anticipated to result in more extreme and high-impact weather. The Ministry for the Environment (MfE) has identified that the projected changes and impacts of climate change on New Zealand include greater frequency of extreme weather events such as storms, heatwaves and heavy rainfall. There will be more frequent and more severe droughts and a greater risk of wildfires. MfE sets this out in the National Adaptation Plan and summarises it in the graphic below.

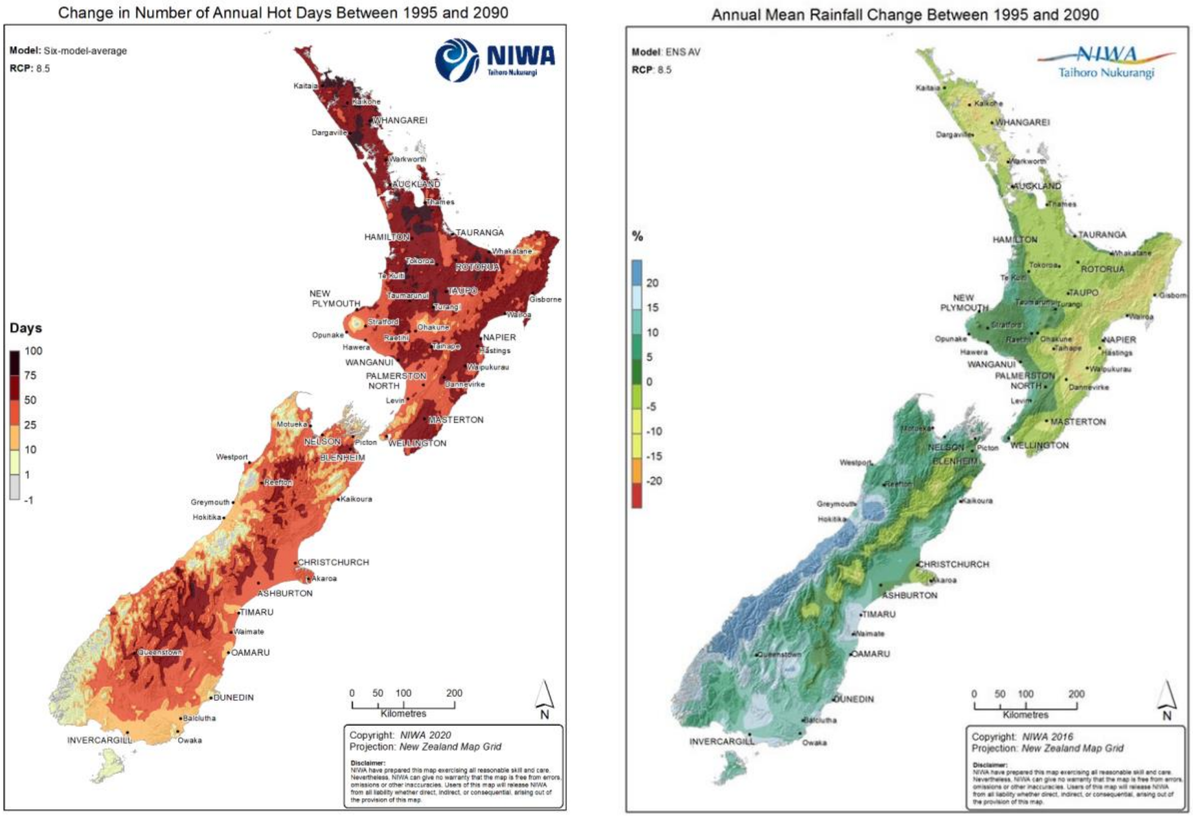
Figure 2: Projected changes and impacts of climate change.



Source: National Adaptation Plan 2022 (Ministry for the Environment, 2022, p. 22)

Similarly, NIWA notes New Zealand is expected to be warmer, wetter, and drier in future with changing frequency of extreme coastal flooding (Figure 3). What may be a once-in-a-century coastal flooding event in 2020 could be a once-a-year event in Wellington in 2040.

Figure 3 NIWA's projected changes in climate and environmental factors



Source: NIWA presentation, "Climate, Weather & Extremes: Impacts, Risk, Planning and Prioritisation" (NIWA, n.d.)

MfE highlights that these effects will vary depending on geography and that the impact and resilience (and ability to adapt) will differ greatly, with most harm falling on those most vulnerable (Ministry for the Environment, 2022, p. 32, 2023).

- Sites which are of significance to Māori in Taranaki, Auckland, the Coromandel, northern Hawke's Bay, Tasman, and parts of Canterbury and Otago are at risk of coastal erosion.
- The Māori economy is particularly vulnerable as 50 per cent of Aotearoa's fishing quota, 40 per cent of forestry, 30 per cent of lamb production, 30 per cent of sheep and beef production, 10 per cent of dairy production and 10 per cent of kiwifruit production is in Māori ownership.
- Around 750,000 people and 500,000 buildings, worth more than $145 billion, are near rivers and in coastal areas already exposed to damaging flooding.

Ability to respond will vary:

- Older people may be more reluctant to evacuate homes (due to income, accessibility and/or mobility issues) and may suffer loss of cultural and social networks.
- Language and integration barriers may add to vulnerabilities for ethnic minorities in disaster response.

- Low-income groups have less choice in the event of needing to relocate, and mobility-compromised and disabled people may have specific needs that could also limit options/pose additional costs.
- Variable effectiveness of weather-related messaging for different communities based on comprehension, interpretation, and trust in the channel of delivery, noting that trust in government can be affected in times of uncertainty or fear.

Effects will vary:

- Young people and children are more prone to psychological impacts from extreme events.
- Domestic and sexual violence can increase in times of disaster, impacting women disproportionately.
- Mental health of farming and rural communities can be affected by disruptions to livelihoods.
- Those with poorer health outcomes may physically suffer more from increased heat and disease (such as Māori, Pacific, children, and older people).

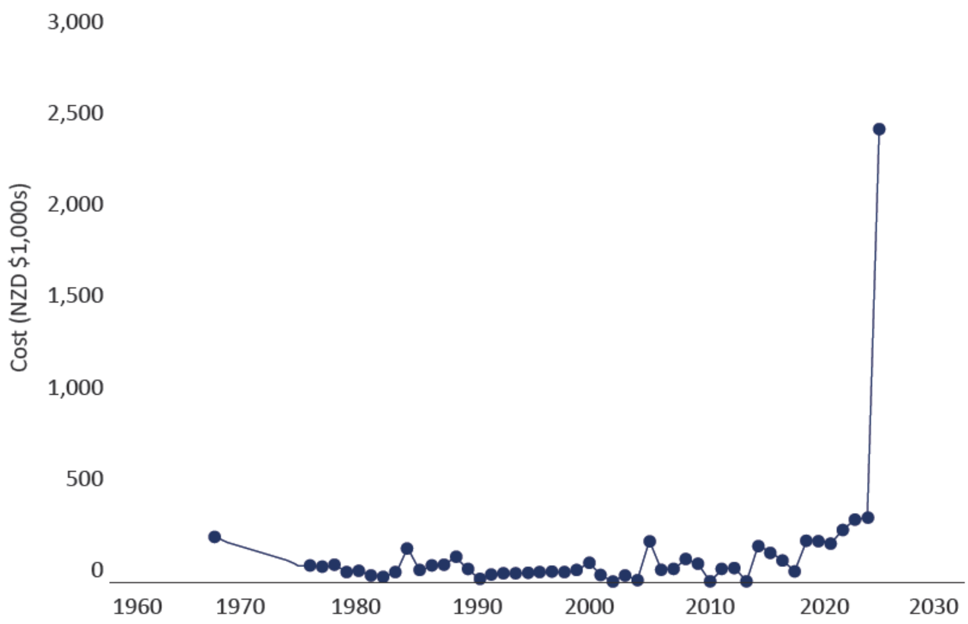
2.2.1 The impacts of climate change are already evident in New Zealand

The impacts of climate change are already evident in New Zealand. For example, from MfE's (2023) report:

- Annual average temperature increased by 1.26 (± 0.27) degrees Celsius between 1909 and 2022 (114 years), with eight of the 10 warmest years on record in the last decade.
- Agriculture and horticulture growing seasons are lengthening, and frost days are declining in most places.
- Annual rainfall during the last 60 years has changed in most places, with the south becoming wetter and the north and east becoming drier. Extreme high-rainfall events are also changing in most places.
- The frequency of medium-term (agricultural) drought is increasing in many places.
- Extreme weather events are becoming more frequent and intense. The frequency of extreme high temperature events has doubled due to human influence (Thomas et al., 2023).
- Treasury estimates the cost of repairing damage caused by Cyclone Gabrielle and the Auckland floods in 2023 to be between $9-14.5 billion (Ministry for the Environment, 2023), and the events caused 15 deaths (Radio New Zealand, 2023a, 2023b).

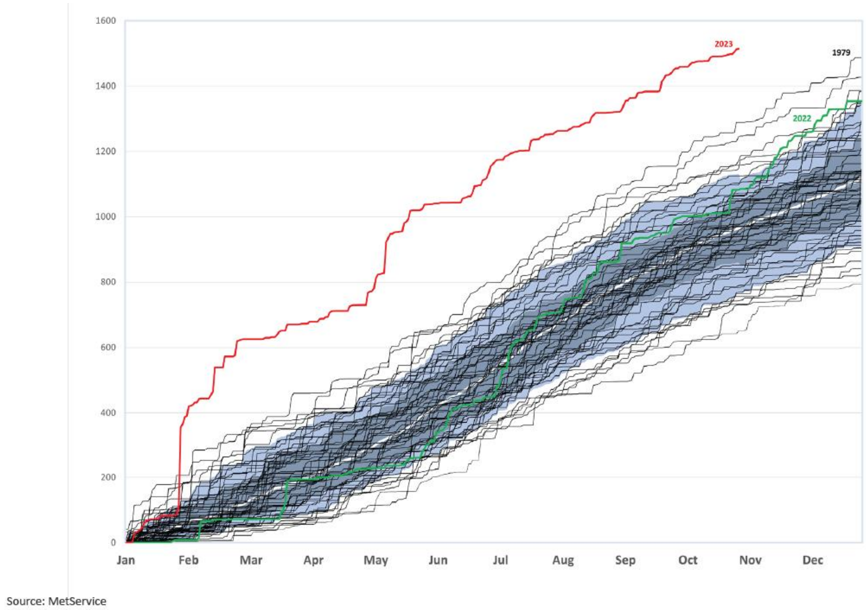
MetService highlights the huge spike in insurance costs associated with weather events in New Zealand in 2023 as well as the unprecedented rainfall in Auckland as shown in Figure 4 and Figure 5 below. We note that Lloyd's ranked New Zealand second out of the 43 countries it looked at in terms of expected losses from natural disasters with an annual expected loss of 0.7 per cent of GDP (calculated by multiplying the probability of natural disaster by the cost associated with natural disaster). It notes insurance penetration increased following the Christchurch earthquakes of 2011, which caused damage equivalent to 14 per cent of GDP but has decreased between 2012 and 2018 despite further seismic events and several significant floods (Lloyd's, 2018).

Figure 4: Insurance costs associated with weather events in New Zealand (c. 1970-2023)



Source: MetService's submission as part of this review, which is adapted from Insurance Council of New Zealand 'Strengthening Resilience to Shocks and Stresses' (MetService, 2023a).

Figure 5: Annual rainfall accumulation, Auckland Airport, 1963-2023



Source: MetService's submission as part of this review (MetService, 2023a)

NIWA also highlighted the recent international experience with fires and flooding, noting CarbonBrief 2022 found "71 per cent of 504 extreme weather events and trends found to be made more likely or more severe by human-caused climate change".

2.3 Weather forecasting and its critical role in emergency management

There is a role assumed by NMHSs around the world to provide public weather forecasting (that is, non-excludable and non-rival weather forecasting) – it is about giving the public free and open access to information that may allow them to appropriately adjust their behaviours in a timely manner to avoid the implications of severe weather.

At its core, public weather forecasting is about managing and avoiding risk to lives and property and thus is an essential part of emergency management locally, nationally, regionally, and internationally. As one of the international NMHSs we spoke with put it:

> "For us [overseas NMHS] it has been brought into focus around explicitly providing a public good service to deliver impact and good for public safety, industry competitiveness… We don't deliver against financial benchmarks but materially contribute to the safety and security and wellbeing of the nation… The primary directive is national capability that delivers public safety, national security, and industry competitiveness."

2.3.1 Multi-hazard early warning systems and impact-based forecasting

The UN Office for Disaster Risk Reduction (UNDRR, 2007) describes the purpose of a multi-hazard early warning system (MHEWS):

> "Multi-hazard early warning systems address several hazards and/or impacts of similar or different type in contexts where hazardous events may occur alone, simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects. A multi-hazard early warning system with the ability to warn of one or more hazards increases the efficiency and consistency of warnings through coordinated and compatible mechanisms and capacities, involving multiple disciplines for updated and accurate hazards identification and monitoring for multiple hazards."

NMHSs play an important role in multi-hazard warning systems, by providing information and data on meteorological and hydrological hazards and/or impacts, and in the context of New Zealand, severe weather warnings. New Zealand reports that it has a MHEWS in place (UNDRR, 2023).

Requirements for an effective multi-hazard early warning system

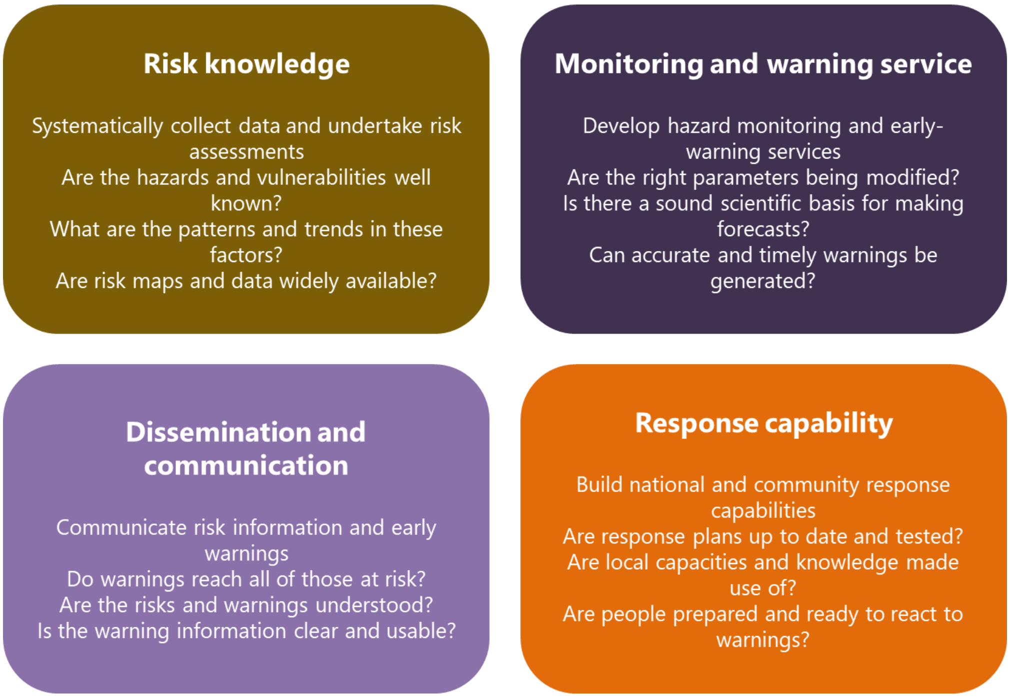
The World Bank report on effective early warning systems (Rogers & and Tsirkunov, 2013) gives some guidance on what one should look like. Rogers and Tsirkunov (2013) list three essential requirements for an effective early warning system:

- *Government leadership*. This leadership supports policies and preparedness, organising and coordinating disaster prevention and mitigation, and provides financial support for infrastructure and disaster relief.
- *Multi-agency coordination*. Through coordination, agencies develop warning platforms and mechanisms that ensure intersectoral emergency response and interaction is based on agreed levels of early warning signals.

- *Community participation*. Communities participate by contributing to research and insights, being prepared, holding drills, developing joint-preparedness teams, and raising awareness on self-rescue and mutual rescue (i.e., understanding of how to help themselves and others in an emergency).

Figure 6 below shows components of a people-centred early warning system.

Figure 6: Components of a people-centred early warning system



Source: adapted from Rogers & Tsirkunov (2013)

Rogers & Tsirkunov (2013) state some important points, like risk knowledge, should include the capture of all hazard, impact, vulnerability, and exposure (HIVE) data for a particular location (not just hazard information); warning services for different hazards should be coordinated where possible to gain the benefit of shared institutional, procedural, and communication networks; clear messages containing simple and useful information are critical and should be delivered through multiple channels, and regional, national, and community-level communication channels and authoritative voices must be established; communities should be well informed on the ways to act in an emergency through education programmes, and should also consider gender perspectives, cultural diversity, and disability.

Rogers and Tsirkunov (2013) also provide some lessons learned from the establishment of Shanghai's multi-hazard early warning system.

- NMHSs should evolve to focus on services that people need and want (i.e., user-oriented). This relies on an open and ongoing dialogue with public, communities, climate-sensitive sectors, and government agencies.
- Emphasis of the system should be on delivery of services. Weather and climate-related warning information should be delivered from a single platform (although could be through multiple channels).

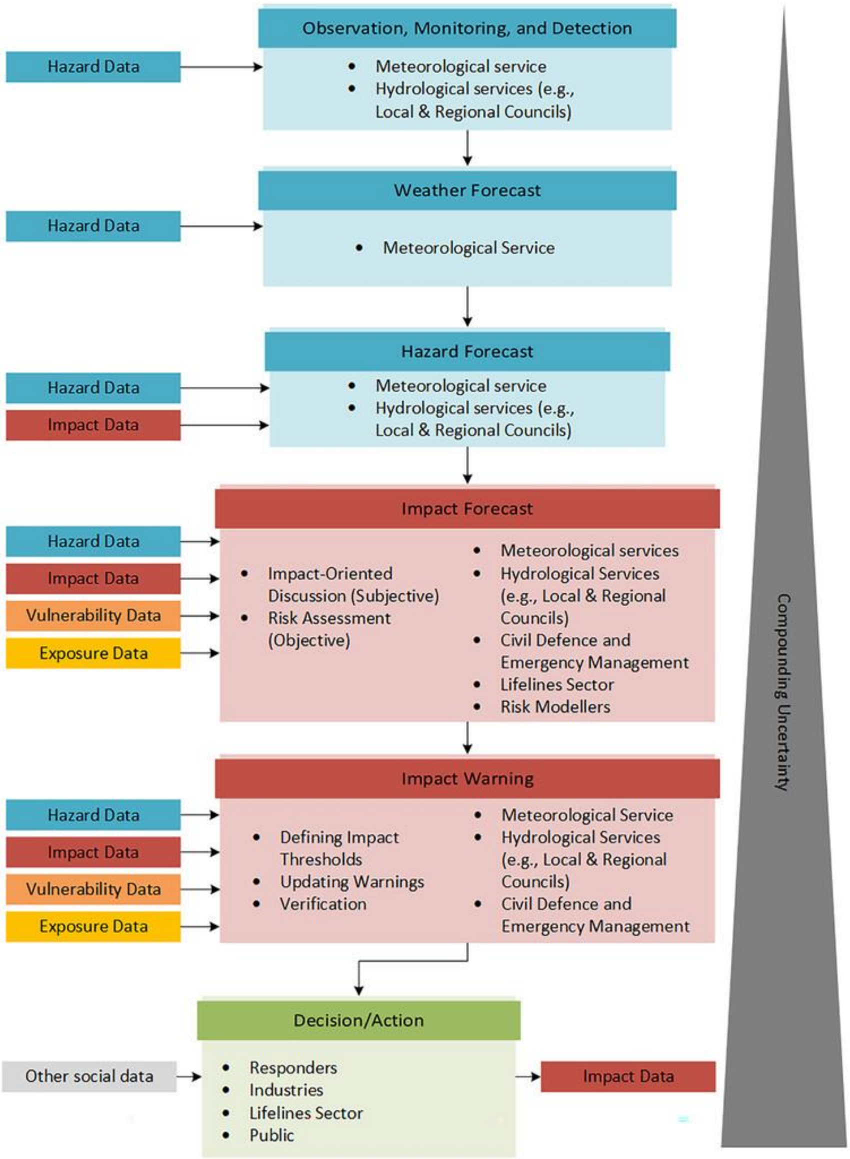
- Success requires strong government and political commitment to be able to establish the expectation other agencies must cooperate with the NMHS.
- Training should be expanded and offered to users of NMHS services (e.g., those who will have to make decisions based on warnings).
- Standards and best practice are essential to ensure consistency and continual improvement.

In its guidelines on multi-hazard early warning services (World Meteorological Organization, 2015b), the WMO recommends that NMHSs consider the potential benefits of providing impact-based warnings to the public and disaster reduction and civil protection agencies (i.e. those involved in emergency management). The key distinction made in the guidelines between general weather warnings and an impact-based warning is the inclusion and integration of other HIVE data. Impact-based warnings are not just about what the weather will be, but importantly, about what the weather will do and to whom.[13] Potter et al. (2018) found that impact-based warnings may be more effective than phenomenon-based warnings (i.e., about the weather itself being greater than some threshold) in influencing the recipient's perception of the hazardous event (e.g. sense of threat, concern, and understanding of potential impacts). Impact-based warnings are context specific, meaning they differ based on things like geography and the target audience for the warning.

A recent paper by Harrison et al. (2022) shows the impact forecast warning chain, the associated data inputs and outputs for each stage, along with the activities and actors responsible at different stages.

[13] One stakeholder raised the importance of the nuanced distinction between impact and impact-based forecasting and warnings. The former is about including impacts in a forecast and warning, whereas the latter – aligned with WMO guidelines – is about targeting the forecast and warning to an audience.

Figure 7: Impact forecast warning chain



Source: (Harrison et al., 2022)

What is HIVE data?

In the context of weather events, HIVE data includes (Harrison et al., 2021; World Meteorological Organization, 2015b):

- *Hazard*: observations and measurements about the weather, feeding into forecasts and, when severe, warnings.
- *Impact*: what the observations and measurements about the weather are likely to mean for things, activities, and people, and therefore what civil defence and emergency management (CDEM) organisations should plan for. A lot of this takes a historical view, based on the scale and magnitude of what similar weather events did to things, activities, and people in the past (e.g., a strong gale in this area meant cars tipped over).

- *Vulnerability*: the potential for people, livelihood, assets, etc., to be affected when exposed to a hazard. Usually includes information about infrastructure, buildings, land-use, census data, ecological data, and economic data.
- *Exposure*: highly specific and small-scale nature, usually at the individual, activity, or community level. Where people, livelihood, assets, etc., are in relation to the hazard and what could be affected.

Weather forecasting data forms just one part of the evidence base used by CDEM organisations in their decision making and response to emerging threats. Collectively, this data supports New Zealand CDEM organisations in their 'four Rs' integrated approach: reduction, readiness, response, and recovery.

Ideally, in the lead up to a weather event this data would be fed to CDEM organisations to allow them to know the likely nature of the weather event, what, who, and where the expected impacts of the event are likely to occur, and therefore the scale and magnitude of the event and how to plan for it and take appropriate and timely action. The different HIVE data would be in appropriate formats to allow for timely and relatively easy integration (e.g., the ability to mesh and overlay different GIS datasets), plus efficient reproducibility for when situations (and therefore data) change.[14]

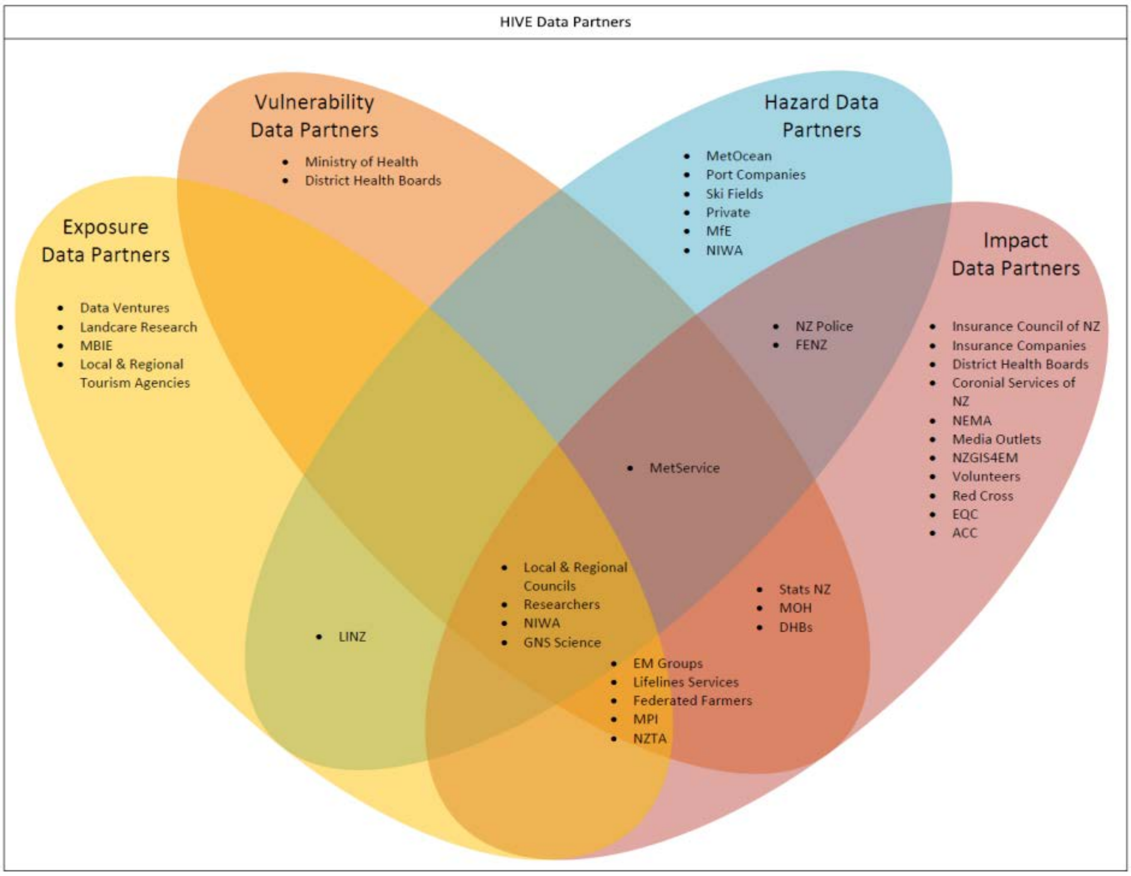
Where does other HIVE data sit, that weather forecasting is used alongside?

Figure 8 shows a multi-layered Venn diagram from Harrison (2022) that attempts to plot the homes of these different datasets in the context of severe weather impact forecasts and warnings.[15] This Venn diagram implies there is a complex web of communication channels and linkages to be able to make use of and integrate all the different sources of data for the purpose of CDEM.

[14] The WMO's multi-hazard early warning systems checklist (World Meteorological Organization, 2018) has more specific information on the ideal arrangements for such a system, such as the inclusion of central standardised repositories for storing all event/disaster and risk information.

[15] It should be reiterated this map is in the context of severe weather. The map would likely grow in size and complexity when viewing from the lens of a different hazard, or considering a wider range of hazards simultaneously (e.g., geohazards). We also note that NIWA provides vulnerability information through RiskScape for multiple weather-related hazards such as floods, storm surge, fire, and drought, so could be considered next to MetService in the diagram.

Figure 8: Hazard, Impact, Vulnerability, and Exposure (HIVE) data map for severe weather



Source: (Harrison, 2022)

3. New Zealand’s current weather forecasting institutions and the context in which they operate

This section provides a (brief) description of the recent history of New Zealand’s weather and climate forecasting system. It outlines the international meteorological framework that New Zealand operates in. It provides an overview of global weather forecasting models that predict weather for the entire planet and the AI-based weather models that are being developed at a rapid pace. This section then takes a closer look at the weather forecasting value chain in New Zealand and outlines in detail the organisational structures, current responsibilities, and weather forecasting systems of MetService and NIWA.

3.1 A recent history of weather and climate forecasting in New Zealand

In 1992, New Zealand’s weather and climate system was split across two Crown-owned organisations when NZMS, an agency inside of the Ministry of Transport, was disestablished. This followed a decision by New Zealand’s Cabinet in 1991 to restructure the scientific activities of the Department of Scientific and Industrial research, the Ministry of Agriculture and Fisheries, the New Zealand Meteorological Service (NZMS), and the Forest Research Institute into 10 Crown Research Institutes (CRIs) (Steiner et al., 1997). NIWA was established as the CRI for atmospheric and aquatic science.

It was initially suggested that weather forecasting would be a major component of NIWA but that due to its commercial nature, weather forecasting should be part of a subsidiary or joint-venture company. Due to competition from overseas suppliers for NZMS’s business, particularly in the aviation weather sector, Cabinet decided that only the climate and research functions should be transferred to NIWA and a separate state-owned enterprise, MetService be established to provide operational forecasting and compete in the market for weather forecasts (Steiner et al., 1997). When MetService was established, it was designated as New Zealand’s meteorological warning service via a contract with MoT. Under the contract MetService is also required to collect weather observation data and provide public good weather forecasting for New Zealand. The MoT contract is described further in section 3.6.

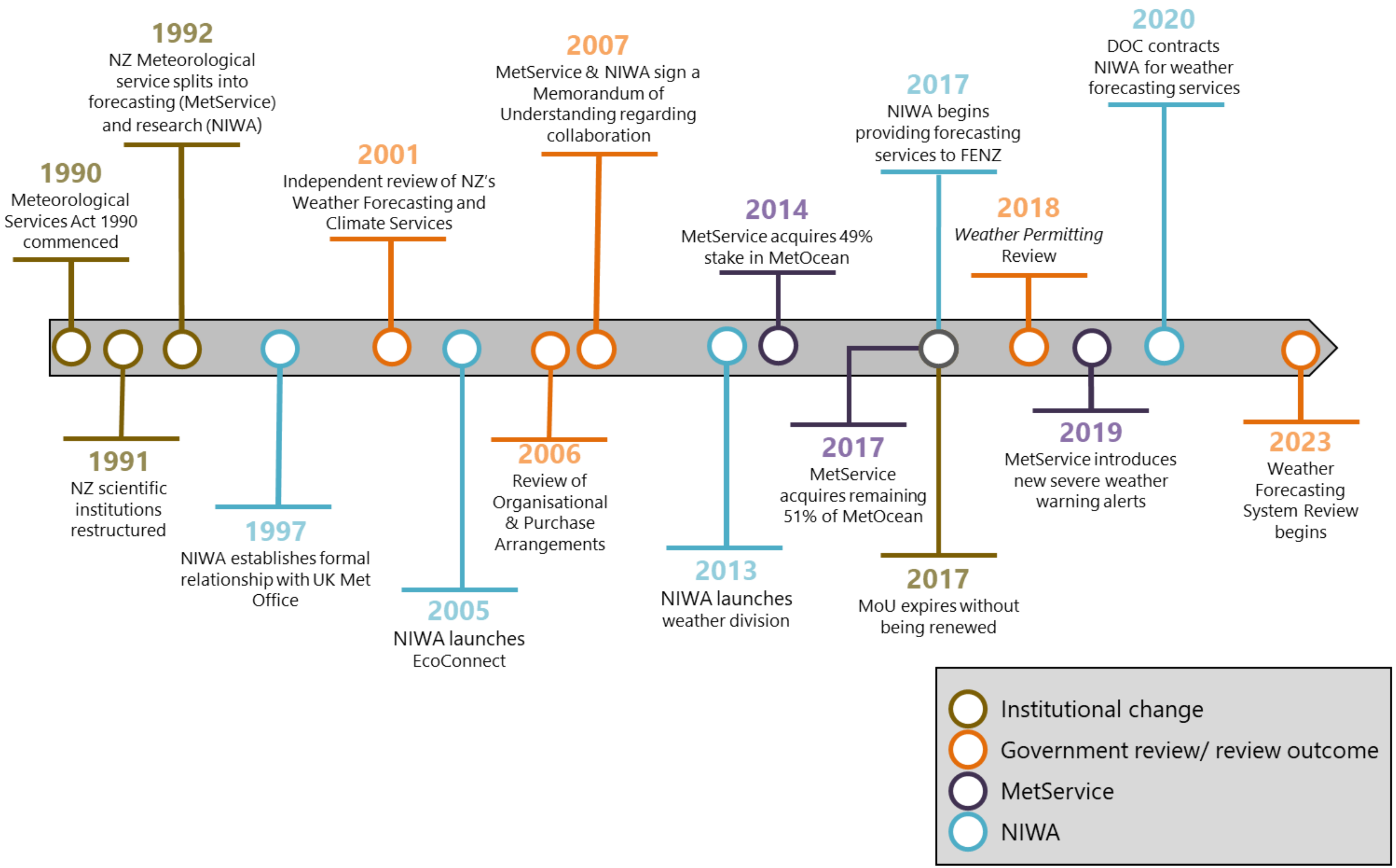
By most accounts, the split of NZMS’s functions between NIWA and MetService went relatively well, however some suggest that the relationship has deteriorated over the years. Indeed, there have been four separate reviews (including this review) of the two organisations over the last 23 years.

In 1997 NIWA established a formal relationship with the UK MetOffice. It subsequently invested in supercomputing capability, became the licensee for the use of the Unified Model for New Zealand and the Pacific region, and in the early 2000's started providing real-time environmental forecasting. Aspects of that service cometed directly with MetService in certain markets and played a part in Ministers requesting the 2006 review (see Appendix B) (Crown Company Monitoring Advisory Unit, 2004).

NIWA started its weather division in 2013 that coincided with the launch of a public-facing weather forecasting website and competes with MetService for weather forecasting contracts (notably, in 2017 NIWA won the contract to provide forecasting services to Fire and Emergency New Zealand (FENZ) and in 2020, NIWA won the contract to provide the Department of Conservation's weather forecasting services). In the same year, MetService acquired a partial stake in MetOcean, a company focused on oceanography (which it later went on to fully acquire in 2017). A timeline of some key events in New Zealand's weather forecasting system is shown in Figure 9, below.

While New Zealand now has two government organisations that provide weather forecasting services, MetService is recognised as the NMS for New Zealand by the WMO. MetService carries out all the traditional functions of an NMS relating to basic observations, weather forecasts and warnings, aviation services, etc. However, NIWA is recognised as the national hydrological service (NHS) by the WMO and carries out some of the traditional climate functions of an NMS.

Figure 9: Timeline of key events since the establishment of MetService and NIWA

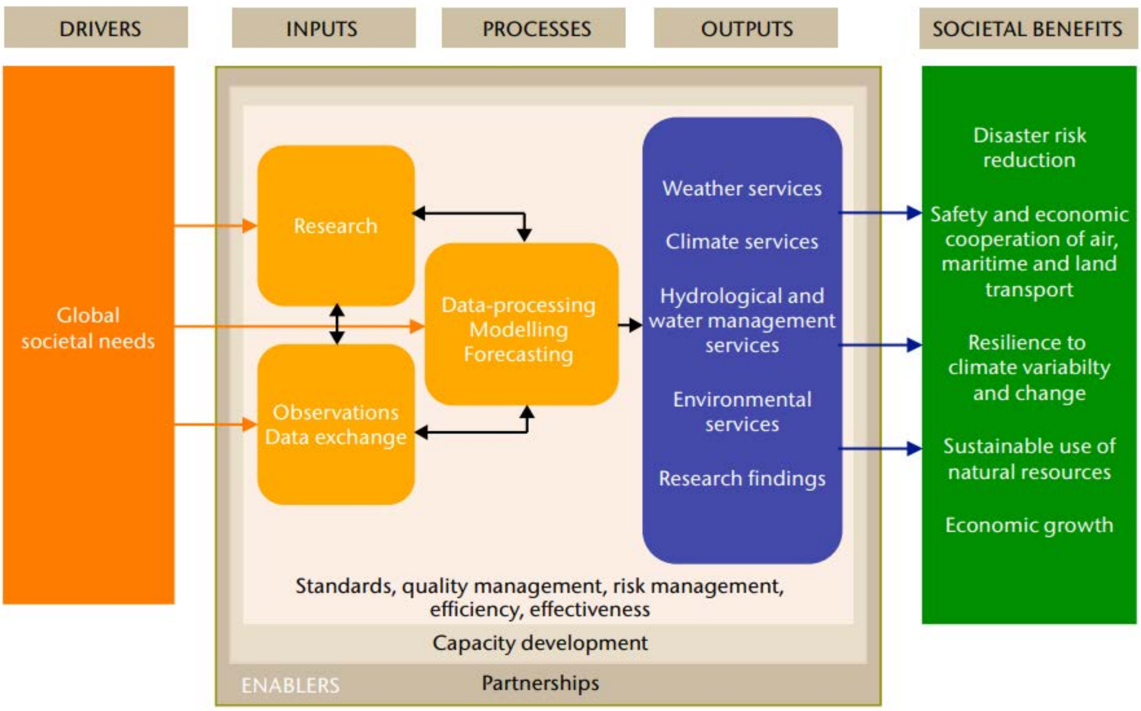


3.2 A framework of international standards and collaboration

New Zealand is a Member of the World Meteorological Organization (WMO). WMO is a specialised agency of the United Nations responsible for promoting international collaboration in meteorology, climatology, hydrology, and related environmental sciences. Weather has no boundaries so international collaboration is key to developing accurate weather and climate forecasts.

WMO facilitates free international data exchange and policy development between Members and maintains standards and technical regulations to optimise the production of weather, climate, and water-related services worldwide. Member States commit to fulfilling obligations that contribute to enhanced scientific understanding, improved forecasting capabilities, and mitigating the impacts of large-scale natural disasters (World Meteorological Organization, 2015e). WMO's strategic framework for delivering effective weather, climate, and hydrological services is shown in Figure 10 below.

Figure 10: The role of a national meteorological and hydrological service in responding to the global societal needs.



Source: (WMO, 2015)

New Zealand has been a Member of WMO since March 1950, and is one of 193 Member States and Territories. Each Member is represented by a Permanent Representative who is usually the head of the national meteorological and hydrological service (NMHS). The Permanent Representative represents both governmental and non-governmental organisations, which in New Zealand includes MetService, NIWA, academic institutions and the private sector.

It is not uncommon for the meteorological and hydrological functions of Member States to be divided between two entities. In such cases, the Member is typically represented by a Permanent

Representative, who is usually the director of the national meteorological service (NMS), and a Hydrological Advisor, who heads the national hydrological service (NHS) or is a senior official responsible for overseeing national hydrology operations. It is far less common for weather and climate to be divided between two entities, as is the case in New Zealand.

MetService is designated as New Zealand's NMS via a contract with the Ministry of Transport (MoT). Stephen Hunt, as CEO of MetService, is the Permanent Representative of New Zealand with WMO. Charles Pearson, National Manager – Environmental Information Operations at NIWA, is the Hydrological Advisor.

The MoT contract allows New Zealand to meet its obligations as a WMO Member by setting out the services that MetService must provide as the NMS. MetService must maintain a core observation network and contribute data from the observation network to the WMO's international information sharing system. Similarly, the Strategic Science Investment Funding that NIWA receives from MBIE enables New Zealand to provide hydrological data to the WMO's international sharing system.

For a small country, New Zealand contributes significantly to WMO. Beyond the core capabilities that MetService and NIWA provide, MetService also operates two regional specialised meteorological centres for marine and regional severe weather services in the South-West Pacific, a volcanic ash advisory centre (under the UN ICAO framework but aligned with WMO) and MetService and NIWA staff hold several roles in WMO subsidiary bodies (committees working groups and expert teams). MetService typically has 10 to 15 experts involved in WMO working groups. Expert roles MetService currently hold include:

- Co-Chair of the Panel on Polar and High Mountain Observations, Research and Services Executive Council committee
- Chair of the Regional Association V Tropical Cyclone Committee for the South Pacific and South-East Indian Ocean
- Chairperson of the Advisory Group on Severe Weather Forecasting.

NIWA currently has 20 experts involved in WMO working groups. Expert roles NIWA currently hold include:

- member of the Research Board
- National Hydrological Advisor
- member of the Hydrological Coordination Panel
- members of the Services Commission Standing Committees on Climate and Hydrological Services.

The WMO gives the international meteorological community a platform to collaborate and enables the sharing of global weather data. This approach has allowed for great improvements in the accuracy and coverage of weather forecasts. A good example of how WMO has enabled this are global weather models.

3.3 Global models simulate the atmosphere for the entire planet

Global weather models ingest real-time weather observation data from around the world to simulate the atmosphere, ocean, and land processes of the entire planet and are used to predict the weather up to 16 days out. The WMO's data exchange policy means that organisations can get global observational data that has been contributed by Member countries.

Most global models are numerical weather prediction (NWP) models that use mathematical calculations based on the laws of physics to predict the physical processes in the atmosphere, oceans and land. NWP models divide the planet into a grid of 3D cells and then apply the calculations to each point on the cell using information from the surrounding cell as inputs. The horizontal size of the cells in a model is known as the spatial resolution.

Global NWP models are computationally demanding and require a supercomputer, a sophisticated and expensive high-performance computer, to run. Significant computer power is required to gather and ingest observation data from around the world and use it to run simulations that require complex calculations for every cell in the model. Higher resolution or longer forecasts (e.g., forecasting out to seven days instead of 48 hours) increase the amount of computer power needed. It can take up to six hours to create and disseminate a global forecast (Golding, 2022). The costs associated with running and continually developing global models means that most global models have been developed by government or international organisations, rather than private companies. Although the spatial resolution of global models has increased over time,[16] the spatial resolution of global models currently tends to be in the low tens of kilometres due to limits in computational power.[17]

Some NMSs use outputs from the global models forecasts only, but it is more common for NMSs to take the global model data and use it as boundary conditions to initialise downscaled local area models that simulate the atmosphere at higher resolutions for smaller regions (e.g., a country). This allows the NMS to predict the weather at higher spatial and temporal resolutions. This is particularly important when fine-scale topography interacts with atmospheric conditions to change the behaviour of weather. New Zealand is a good example of where this is particularly true. For example, Figure 11 shows how Mount Taranaki is effectively flattened in the two global models compared to two local area models that represent Mount Taranaki closer to its true elevation. Running local area models also allows NMSs to input their own observation data to give a more accurate representation of real-world conditions. Consequently, global models do not predict local weather patterns as accurately as the local area models. It is important to note that the local area models are still dependent on the global models' boundary conditions. Thus, limitations or shortcomings in the global models' forecast can be passed down into the high-resolution models.

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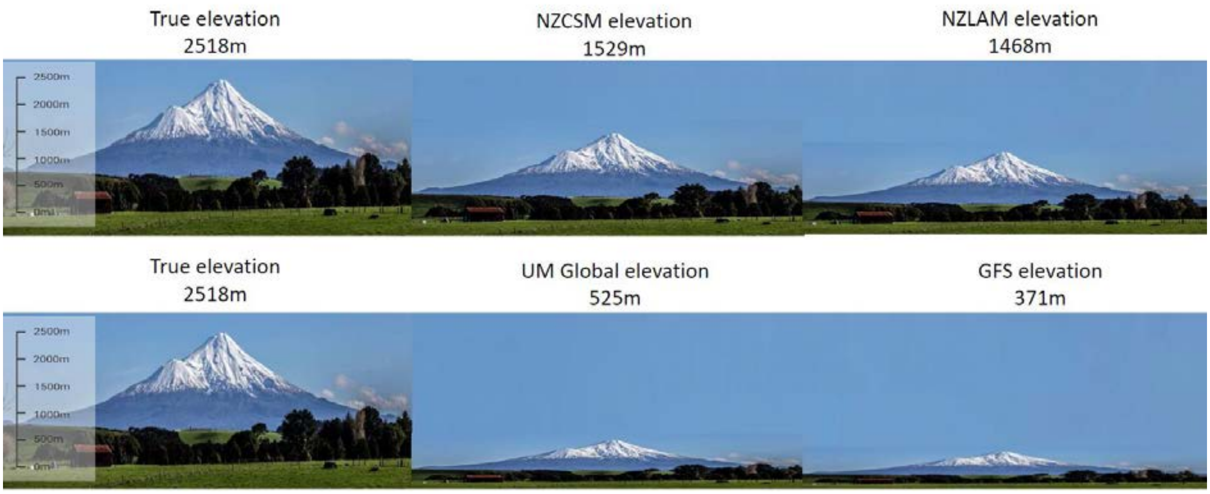
[16] For example the Unified Model has improved from a spatial resolution of 90-300km when it was first implemented in 1991 (UK Met Office, n.d.-a) to 10-20km in 2023 (UK Met Office, n.d.-b).

[17] The global models used in New Zealand have resolutions ranging from 10km to 30km.

Figure 11: Elevation of Mount Taranaki as it is represented in two NIWA local area models (NZCSM and NZLAM) and two global models (UK UM Global and US GFS).



Source: (NIWA, 2023b)

Many global models are available, however, MetService and NIWA use a combination of three of the leading global models to initialise local area models.

- European Centre for Medium-Range Weather Forecasts (ECMWF) Integrated Forecasting System (IFS)
- UK Met Office Unified Model
- United States National Center for Environmental Prediction Global Forecast System (GFS).

These models provide deterministic forecasts, as well as ensemble runs of many possible future outcomes. Deterministic forecasts are when a model only provides a single outcome. Because it is only one outcome, it does not account for the uncertainties in the model, the input data, and what can happen in the atmosphere. An ensemble model addresses the underlying uncertainties by running multiple simulations (in the range of 20 to 50) with slight differences to the input data and sometimes small changes to the included physics. An ensemble model produces a range of outcomes, which can be used to assess the confidence in the forecast (good, if all the ensemble members are similar; not so good if there is a lot of variation), as well as the probability that particular events will occur. Forecasters can then use this information to guide their own predictions, including to assess the likelihood of a range of different outcomes and the confidence of a forecast.

The organisations that run these models have teams dedicated to ongoing research to continuously improve their accuracy and efficiency. With recent advancements in Artificial Intelligence (AI) and Machine Learning (ML), some organisations have also started to explore the opportunities that AI/ML offer to global forecasting, especially in reducing computational needs.

For example, as a foundation member of the Unified Model Partnership, NIWA has made significant contributions to improvements in the global Unified Model over the past 15 years and runs ensemble models using the unified model, assessing them alongside ECMWF and other ensemble outputs for predicted extreme weather events.

3.4 Artificial intelligence and machine learning models are starting to catch up to NWP models

Advancements in the AI/ML space are moving rapidly, and private companies have entered the global forecasting space by developing global weather models that use AI-based forecasting instead of NWP. These models are data-driven – rather than using physics as in traditional NWP models, they use AI/ML techniques to learn from the decades of global weather model reanalysis data. AI/ML models still need to start from an initial global analysis provided by one of the traditional physics-based global model data assimilation and prediction systems, such as ECMWF's IFS (Bi et al., 2023). Nevertheless, they can then produce predictions using many orders of magnitude less computing resource and time, and they offer more of a spectrum of possibilities from wholly NWP models. Using models with differing degrees of reliance on AI enables forecasters to make trade-offs between accuracy, speed and cost.

AI/ML-based models still have limitations compared to traditional NWP models. However, it is expected that a mix of traditional and AI approaches will improve upon established scientific practices and methodologies rather than replace them.

Developments in this space are taking place extremely rapidly, and the involvement of large private technology companies is unprecedented. Training AI-based models requires large quantities of computer and data storage, requiring significant ongoing investment. There are several multi-national private companies bearing the cost and investing heavily internally in a race to develop AI-based forecasting systems. At this stage, these companies have been providing the systems free and open source (e.g., Google's GraphCast or NVIDIA's FourCastNet), undoubtedly with the hope that it will increase their use and lead to crowd-sourced improvements. It is possible that in time, the weather sector will be dominated by a few large companies who will move from open source to a commercial focus to leverage off the demand for weather forecasting. It is worth noting that ECMWF is also developing its own AI-based model – their Artificial Intelligence/Integrated Forecasting System, or AIFS. As of their latest update on 10 January 2024, this is running at a global resolution of 30 km and verification scores show significant improvement over their own physics-based IFS at that resolution (Lang, 2024).

In the New Zealand context, NIWA has been developing capability to produce mixed NWP and AI models in recent years. For example, NIWA is developing an AI-driven weather forecast model for New Zealand that is producing forecasts out to 21 days in a fraction of the time it would take an NWP model.

3.5 The weather value chain in New Zealand

When MetService and NIWA were established, the intention was that the two organisations collaborate so that NIWA's weather and climate research could feed into MetService to improve its forecasting, and MetService's forecasting experience could inform NIWA's research. Instead, the structure of the two organisations led to more competition than collaboration, particularly with NIWA developing commercial weather forecasting services and directly competing with MetService for weather forecasting contracts.

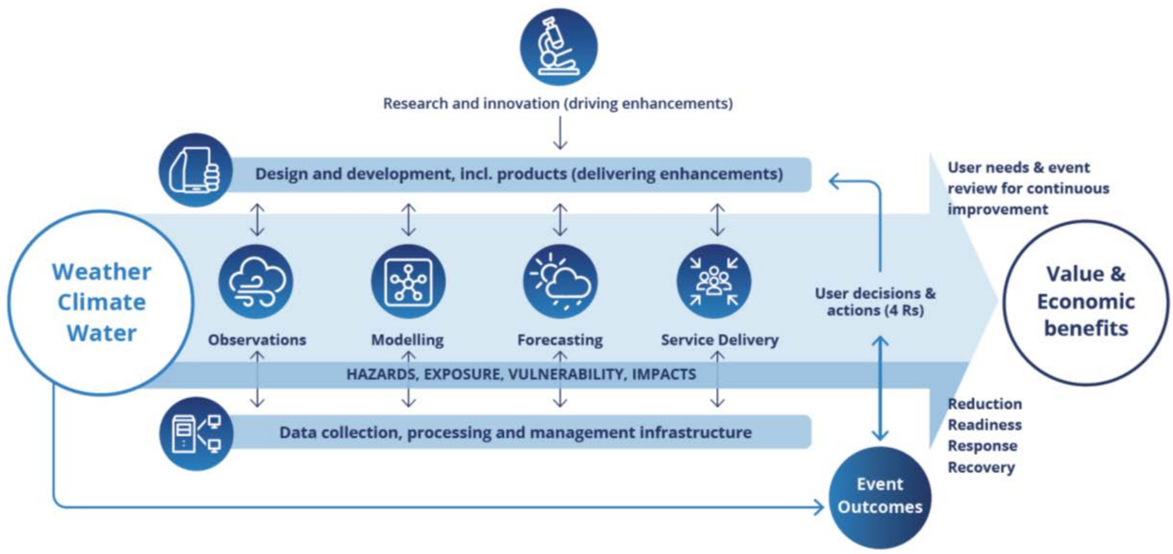
A high-level overview of how New Zealand's current forecasting value chain should operate is shown in Figure 12. The weather and climate are observed using infrastructure and instruments, and the data from these observations are processed and stored. The data is input into models to predict what will happen in the short to medium term (weather) to medium-term (seasons) through to long term (climate). The forecasts are used to inform decisions for short term (emergency management), medium term (drought preparation) through to long term (climate adaptation).

Weather and climate forecasting are used to produce products and applications, provide advice, and be communicated with public, government and private stakeholders. Underpinning all these processes is data infrastructure (transmission, storage, and processing) and research.

Each process should inform research that can be done to improve the accuracy and efficiency of the process. Research can then flow back into the operational process to improve weather and climate forecasts. This is known as the research-to-operations pathway.

As a result of the competition between MetService and NIWA there are links in the value chain where duplication of effort or a lack of collaboration leads to inefficiencies, a lack of collaborative input to research to improve the accuracy of weather predictions and warnings, and potentially reduced socioeconomic benefits. While both MetService and NIWA undertake research across the value chain, there is no dedicated research-to-operations pathway between the two organisations.

Figure 12: High-level overview of New Zealand's weather and climate forecasting value chain



Source: (MetService, 2023a)

There are other government agencies, academics, and local and international private companies involved across the value chain. Appendix E lists the parties that operate across different parts of the weather forecasting value chain and in which parts they operate. The infrastructure, data, and modelling links in the system in New Zealand are dominated by NIWA and MetService. The other parties tend to operate in forecasting and/or service delivery.

This review focuses specially on the optimal structural configuration with respect to MetService and NIWA. The following sections on MetService and NIWA look at the configuration of the two organisations and their current responsibilities and describe their weather forecasting systems.

3.6 MetService is structured as a State-Owned Enterprise

MetService was established on 1 July 1992 as a State-Owned Enterprise (SOE) under the State-Owned Enterprises Act 1986 and is a public company registered under the Companies Act 1993. MetService is wholly owned by the Crown. The shareholders are the Minister of Finance and the Minister for State-Owned Enterprises. As an SOE, MetService does not receive any direct government funding and must make revenue through contracts for service. Under the State-Owned Enterprises Act 1986, MetService is required to operate as a successful business and be:

- as profitable and efficient as comparable businesses that are not owned by the Crown
- a good employer
- an organisation that exhibits a sense of social responsibility by having regard to the interests of the community in which it operates and by endeavouring to accommodate or encourage these when able to do so.

MetService employs 281 people, of whom over 90 are WMO-qualified meteorologists. MetService headquarters are in Wellington, with offices spread around New Zealand and overseas.[18]

3.6.1 MetService is the authorised meteorological forecast and warning provider for New Zealand

MetService provides public good meteorological services to New Zealanders through its contract with the Ministry of Transport (MoT). It is the MoT contract that designates MetService, as the contract holder, as New Zealand's authorised meteorological warning service under the Meteorological Services Act 1990 and to fulfil the role of the Permanent Representative to WMO on behalf of New Zealand.

The services that MetService must provide are outlined in the MoT contract's schedule of services:

- marine weather forecasts and warnings
- severe weather warnings
- brief public and mountain forecasts
- tropical cyclone tracking, forecasts, and warnings
- Pacific Regional support services (support for weather observing and forecasting systems, maintain a regional telecommunication hub, back up for Nadi Tropical Cyclone Warning Centre)
- ancillary services (search and rescue support, emergency message relay, coastal wave warnings)

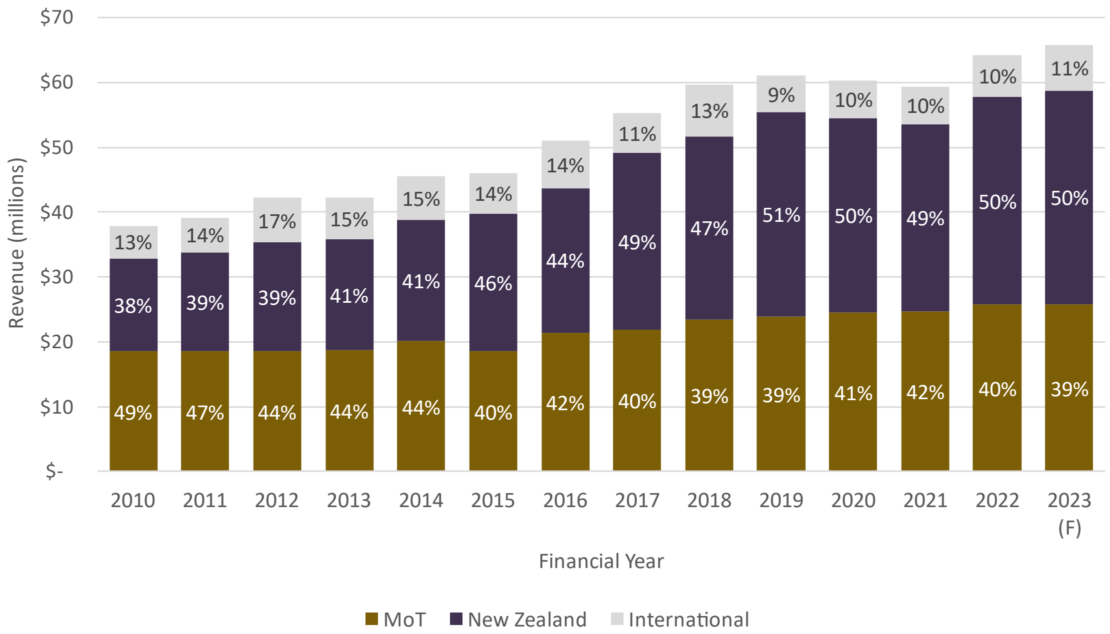
[18] MetService operates under the MetraWeather brand in Australia and the United Kingdom.

- additional support for emergencies and other unexpected events
- general aviation weather forecasts and observations
- make available some open access observational data
- maintain a meteorological observation network that complies with WMO technical regulations
- provide NIWA with agreed data services.

MetService fulfils its obligation to provide weather services and warnings to the public via its website, social media, radio, and its mobile application. Over two million devices have the app installed as of 31 January 2023, and there were 430,000 daily users across MetService's app and website up to 31 December 2022.

MetService anticipates that in 2023 the MoT contract will provide 39 per cent of MetService's total revenue. MetService's dependence on the MoT contract for revenue has decreased over the past 14 years from 49 per cent in 2010. MetService's remaining revenue comes from providing services to a range of government departments and public sector organisations, businesses, and local and international media organisations. While the MoT contract pays for the services listed above, unlike government departments, MetService must finance infrastructure and capital maintenance investment from its cashflow. Only depreciation and capital charges are funding through the contract. This does restrict the extent of investment MetService have the capacity to make.

Figure 13: MetService annual revenue split since 2010



Source: MetService

Figure 14: s 9(2)(b)(ii) [redacted]

s 9(2)(b)(ii) [redacted]

Source: MetService, Note: percentages do not add to 100% due to rounding.

s 9(2)(b)(ii) [redacted]

[redacted]

[redacted]

3.6.2 MetService financial analysis

MetService's financial performance has been analysed along two broad dimensions. The first dimension focuses on understanding key aspects of the firm's performance and financial structure over the past 10 years. Elements analysed include:

- revenue, expenses, and the evolution of the EBITDA margin

- net profit after tax (NPAT)
- dividends paid, and the payout ratio relative to net operating cashflows less maintenance capex (this ratio is targeted in the statement of corporate intent)
- capital expenditure over time
- the retention ratio, or what proportion of profits are reinvested into MetService
- the sources of financing for the entity, and their evolution over time.

Figure 15 displays MetService's revenue, operating expenses and EBITDA margin over the past 10 years. The EBITDA margin is a useful indicator of the profitability of a firm's core business before accounting for the impact of financing choices, tax rates faced, and the characteristics of the assets used to run the business. Prior to COVID-19, MetService's EBITDA margin hovered between 20 per cent and 24 per cent. This fell to 13.8 per cent in 2021, and 13.4 per cent in 2022. The EBITDA margin lifted slightly to 15 per cent in 2023.

Figure 15: MetService's revenue, operating expenses and EBITDA margin (2014 – 2023)

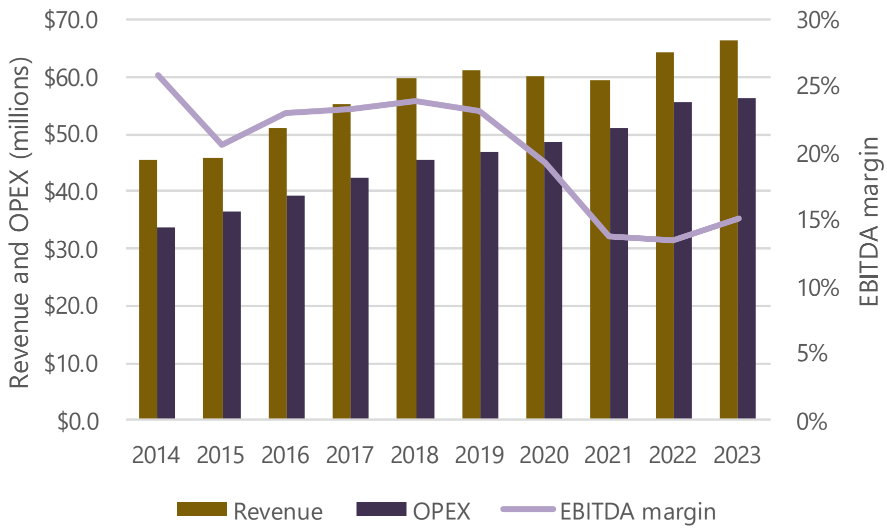


Figure 16 displays net profit after tax (NPAT) generated by MetService over the past 10 years. NPAT fell sharply between 2014 and 2015, as cost growth outstripped revenue growth before rising consistently over the 2015 – 2018 period. Discussions with MetService personnel have revealed that this decline in NPAT was driven by stalled negotiations with the Ministry of Transport contract. NPAT declined between 2018 – 2019 and continued this trend over the COVID-19 impacted 2020 – 2022 period, with the firm making losses of $596,000 and $124,000 in the 2021 and 2022 financial years respectively. In 2023 MetService returned to profitability, posting NPAT of $1.3 million. An analysis of MetService's annual reports reveals significant abnormal costs were incurred during this period associated with seismic challenges at its Kelburn facility. This resulted in accelerated depreciation for the building decreasing NPAT, associated costs with moving from a data centre in Kelburn to a cloud hybrid solution, and the move to Seabridge House. The impact of these events is illustrated by a discussion of normalised EBIT. Normalisation is the process of removing non-recurring expenses or revenue to paint a picture of the firm's ongoing operations. Normalisation of earnings before interest and taxation (EBIT) over the 2021 – 2022 period produces figures of $2.5 million and $2.2 million. This compares to the un-normalised values of -$0.2 million and $0.2 million respectively. A lower EBIT flows through to a lower NPAT.

Figure 16: MetService's net profit after tax (2014 – 2023)

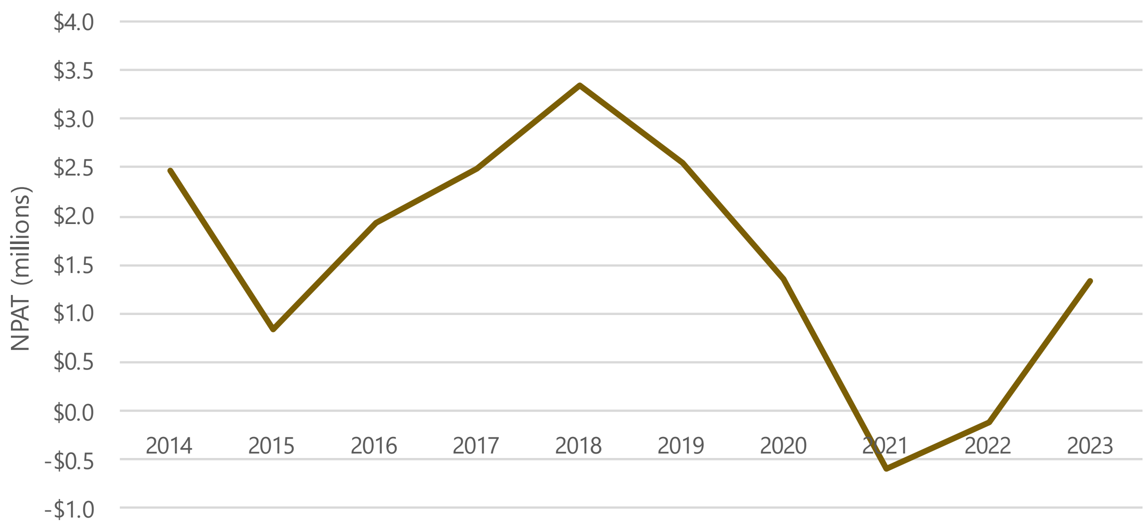


Figure 17 displays dividends paid by MetService to the Crown (LHS) and a dividend payout ratio aligned with MetService's statement of corporate intent (RHS). MetService's current statement of corporate intent (MetService, 2022) reaffirms its policy to pay out between 15 per cent and 40 per cent of net cash flow from operating activities, less maintenance CAPEX (NOCMEC). Over the past ten years, MetService has paid dividends four times. A $2.3 million dividend was paid in 2014, equal to 81 per cent of NOCMEC in that year. Smaller dividends have been paid out as a proportion of NPAT in 2017 – 2019, or a payout ratio of between 13 per cent to 15 per cent of NOCMEC. As displayed in Figure 16 above, 2014, 2017, 2018 and 2019 were the most profitable years for MetService. Over the 10-year period analysed, total NOCMEC was $85.5 million (estimated), and total dividends paid were $5.85 million or a payout ratio of 6.8 per cent. Excluding 2021 and 2022 on account of negative NPAT, the payout ratio rises to 8.4 per cent.

Figure 17: MetService's dividends and payout ratio (2014 – 2023)

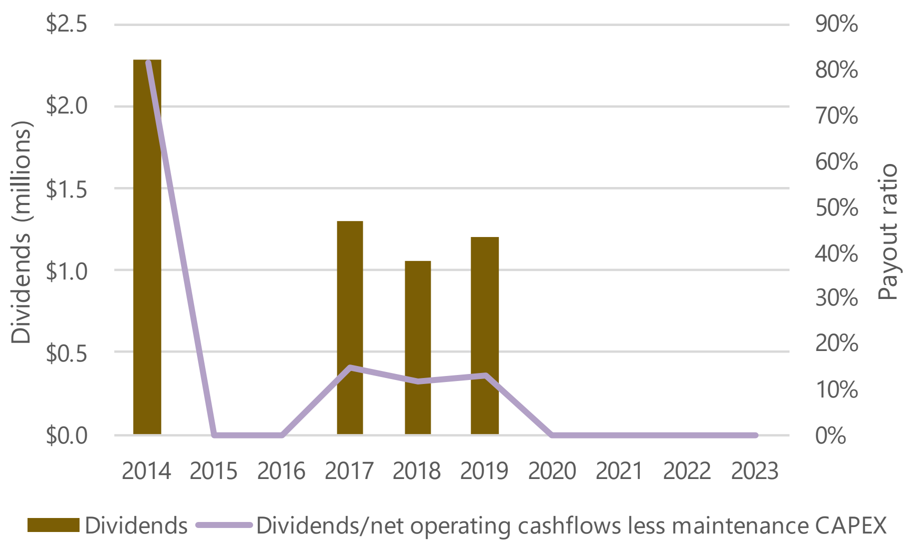


Figure 18 displays MetService's capital expenditure profile over time. Capital expenditure per annum has grown from $6.7 million in 2014 to $8.7 million in 2023, or a compound annual growth rate of 2.7 per cent.

Figure 18: MetService's capital expenditure (CAPEX, 2014 – 2023)

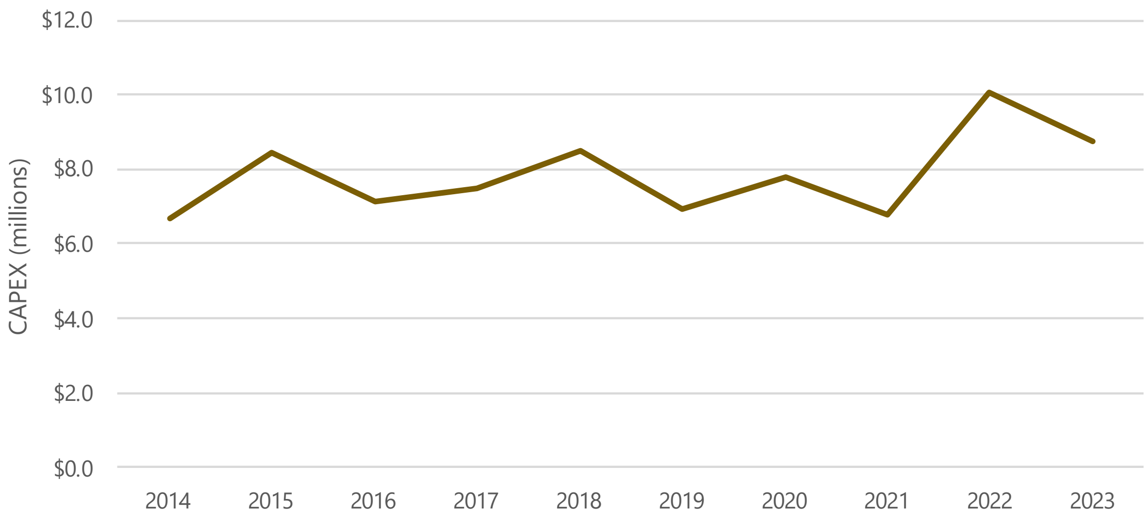


Figure 19 displays MetService's retention ratio. The retention ratio measures what percentage of net profit after tax is being retained by the firm after paying dividends to shareholders. Low retention ratios mean most profits are being paid out to shareholders, and high retention ratios mean the firm is retaining a high proportion of funds to either pay down debt or invest in capital projects. Over the 2014 – 2023 period, MetService had an average retention ratio of 72 per cent. Retention ratio values for 2021 and 2022 are not displayed as MetService had negative NPAT during these years.

Figure 19: MetService's retention ratio (2014 – 2023)

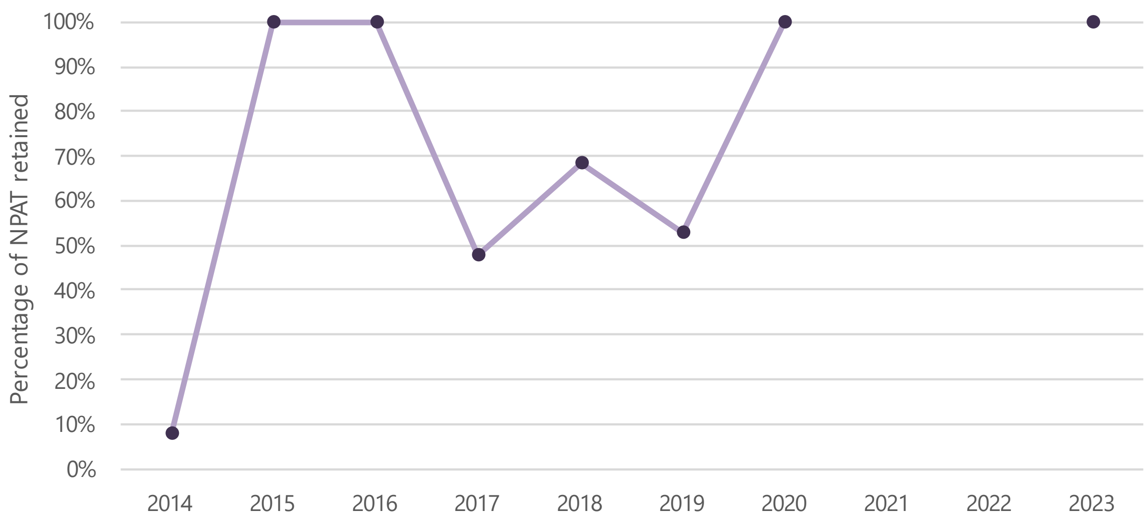
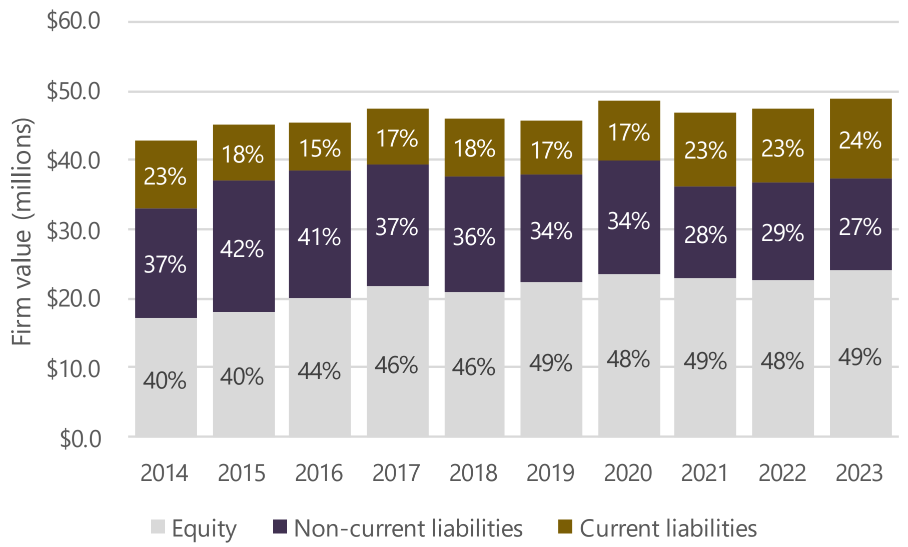


Figure 20 displays MetService's sources of funding in broad categories. The maturity of the firm's liability funding structure has shortened, with 37 per cent of assets funded by non-current liabilities in 2014, and 27 per cent in 2023. Equity funding as a proportion of total funding has increased over the analysis period from 40 per cent to 49 per cent of total assets.

Figure 20: MetService's sources of funding (2014 – 2023)



An assessment of MetService against its statements of corporate intent is included in Appendix F.

3.6.3 MetService's observation network expands beyond New Zealand's landmass, with access to observations from others

MetService's core weather observation network covers the landmass of New Zealand (Figure 21) and collects real time weather data. However, MetService uses a network of instruments and infrastructure to collect weather observations that extends their coverage to a large part of the South Pacific Ocean. MetService's observation network includes:

- approximately 100 core automatic weather stations (AWS)
- 10 weather radars
- three upper air weather balloon observation stations
- aircraft observation programme in cooperation with Air New Zealand
- 36 voluntary observing ships
- 42 drifting marine buoys
- 10 lightning detection sensors
- satellite receivers (via international agreements under WMO)
- webcams.

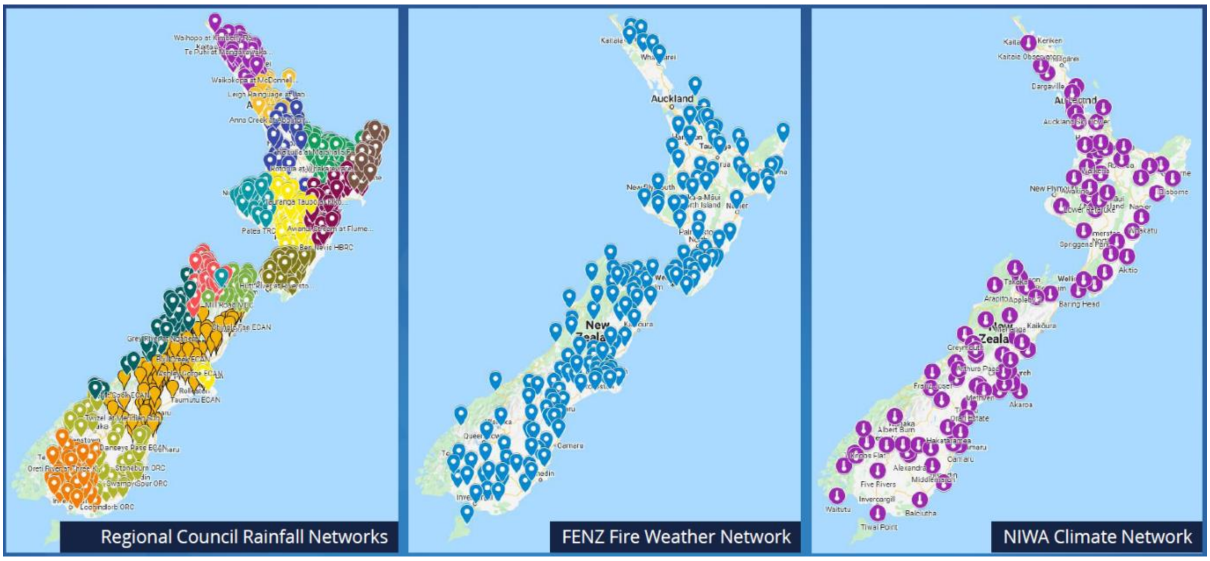
Figure 21: MetService's land-based weather observation network

Source: (MetService, 2020)

To bolster the core network, MetService has data sharing agreements with Regional, District, and City councils, FENZ, and NIWA to use data from their observation stations (Figure 22). The data sharing agreements allow MetService to draw on information from these networks for its forecasting, but it cannot make the data publicly available. MetService also has access to data contributed through WMO data sharing agreements.

MetService operates a network of 131 customer automatic weather stations to provide data for specific customer needs. For example, it operates 58 road weather stations for Waka Kotahi and 18 weather stations on the coast for the New Zealand Coastguard Federation. These stations do not all meet WMO standards and are used to meet specific customer needs.

Figure 22: Observations networks accessed by MetService via formalised data sharing agreements.



Source: (MetService, 2023b)

3.6.4 MetService uses several models to forecast weather in New Zealand

Modelling is an essential aspect of MetService's role in providing forecasts and weather warnings for New Zealand. MetService has access to data from three global weather prediction models and their associated ensemble prediction systems to inform their modelling: ECMWF IFS model, the UK Met Office Unified Model, and the United States National Centers for Environmental Prediction GFS model.

MetService uses data from the global models as starting parameters to run different scenarios/simulations of the atmosphere in the New Zealand and the South Pacific region using a downscaled local area model. MetService does this using the open-source Weather Research and Forecasting (WRF) model. Observation data that MetService collects or has access to is input into the WRF model to improve the accuracy of the predictions.

Running multiple scenarios based on different starting parameters gives a range of possibilities for what might happen. MetService forecasters then interpret the outputs from the local area model runs to determine the most likely scenario of what will happen in the real world.

The training and experience of the forecasters is critical to MetService's forecasting process. The forecasters use their knowledge of weather systems, the strengths, weaknesses and recent performance of the global and local models, coupled with current observations, to determine which model or blend of models to base the forecast on. They then need to use their understanding of New Zealand's atmosphere and complex topography to interpret what the outputs of the models will mean for local weather conditions.

3.6.5 MetService provides limited data to the public for free for personal use

MetService uploads limited data from its observation network to its website and app free for personal use. One-minute observations are provided in near real-time to view by location on their website, as is 30 days of summary data (e.g., high and low temperature, total rainfall, peak wind gust). MetService provides three-hourly data from its core observation sites (only the most recent data is available) and 12-hourly upper air data (temperature, humidity and winds).

Access to raw data from MetService's radar network, satellite imagery or for historic data requires a data agreement with MetService that comes with a cost in accordance with MetService's Data Access Policy and commercial services. Processed satellite and radar imagery are available for free on the MetService website and/or app.

3.7 NIWA is structured as a Crown Research Institute

NIWA was established as a Crown Research Institute (CRI) under the Crown Research Institutes Act 1992 and is subject to the Crown Entities Act 2004 and the Companies Act 1993. NIWA is wholly owned by the Crown. The Shareholders are the Minister of Research, Science and Innovation and the Minister of Finance.

Under the Crown Research Institutes Act 1992 NIWA must, in fulfilling its purpose, operate in a financially responsible manner so that it maintains its financial viability. It is financially viable if:

- regardless of whether it is required to pay dividends to the Crown, the activities of the CRI generate, on the basis of generally accepted accounting principles, an adequate rate of return on shareholders' funds
- the Crown Research Institute is operating as a successful going concern.

NIWA receives approximately 25 per cent of its revenue via funding from the Crown through the Strategic Science Investment Fund – Programmes (SSIF) Investment Contract (NIWA, 2022, p. 22). The Crown contracts NIWA via the SSIF to perform research activities that are agreed to annually with shareholding Ministers and set out in NIWA's Statement of Corporate Intent. As per section 5 of the Crown Research Institutes Act 1992, CRIs are expected to generate an adequate rate of return on shareholders' funds through fulfilling their purpose and to operate in a financially responsible manner to maintain financial viability long-term. This means NIWA also looks to earn revenue from other contracts for research and science (approximately 25 per cent of its revenue) or from turning that research and science into commercial products and services that it sells to government or the private sector (approximately 50 per cent of its revenue).

NIWA has developed capability to forecast the impacts of weather, including high intensity rainfall, a national river flood forecasting system, a drought index, wind forecasts (e.g., for Auckland Harbour bridge management), and information for wildfire management.

3.7.1 In the years, since it was established, NIWA's purpose has slowly extended into real-time weather forecasting

NIWA's purpose is set out in its Statement of Core Purpose:

> NIWA's purpose is to enhance the economic value and sustainable management of New Zealand's aquatic resources and environments, to provide understanding of climate and the atmosphere and increase resilience to weather and climate hazards to improve safety and wellbeing of New Zealanders (NIWA, 2023a).

NIWA's science can be categorised into four key domains – climate (and climate hazards), freshwater, coasts and oceans (including fisheries and aquaculture), and the focus on advanced technology and data science, as well as working with iwi partners, to create impact in those areas.

While the establishment documents for NIWA include weather, there is no mention of weather forecasting in NIWA's 1993 Statement of Corporate Intent (SCI). However, over the years, NIWA has shifted towards increasing its weather forecasting capabilities. In its 2003/4 SCI, NIWA indicated it would develop an operational forecasting service, and in 2008/09, it listed a desired outcome of:

> "New Zealand communities are more resilient to weather-driven, coastal, and marine geological hazards, now and in a changing climate".

It also lists the use of real-time technologies to forecast weather-related hazards as a strategic priority between 2008 and 2011. From 2011/12 onwards there was what appears to be a shift in NIWA's focus toward weather forecasting with:

> "increased resources being applied to developing real-time data and forecasting products that enable weather and water dependent sectors to make operational decisions that optimise returns from their assets."

3.7.2 NIWA developed weather forecasting services, drawing on its application of the Unified Model

In 1997, NIWA established a formal relationship with the UK Met Office, which gave NIWA access to the Unified Model, UK Met Office's weather and climate prediction model suite, and access to daily global meteorological model data. In 2005, NIWA launched EcoConnect, to produce environmental forecasting and climate information based on its Unified Model outputs. EcoConnect was developed as a delivery system to provide climate analysis, real-time observations, short-term weather, ocean, and river forecasts and their related impacts, and probabilistic weather outlooks from 15 days to three months ahead. NIWA relies on its membership of the Unified Model Partnership and its investment in supercomputing to produce its ground-up nationwide high-resolution NWP forecasts every six hours.

NIWA was a foundation member of the global Unified Model Partnership which gives NIWA continued access to the Unified Model (for New Zealand and the Pacific) and its development. As a member of this partnership, NIWA contributes a minimum of five FTEs of research and development in support of improving the model physics and operational efficiency. The Unified Model is fundamental to NIWA's weather, climate and impact forecasting capability. Over the past 15 years, NIWA has contributed to the improvements in elements of the Unified Model suite.

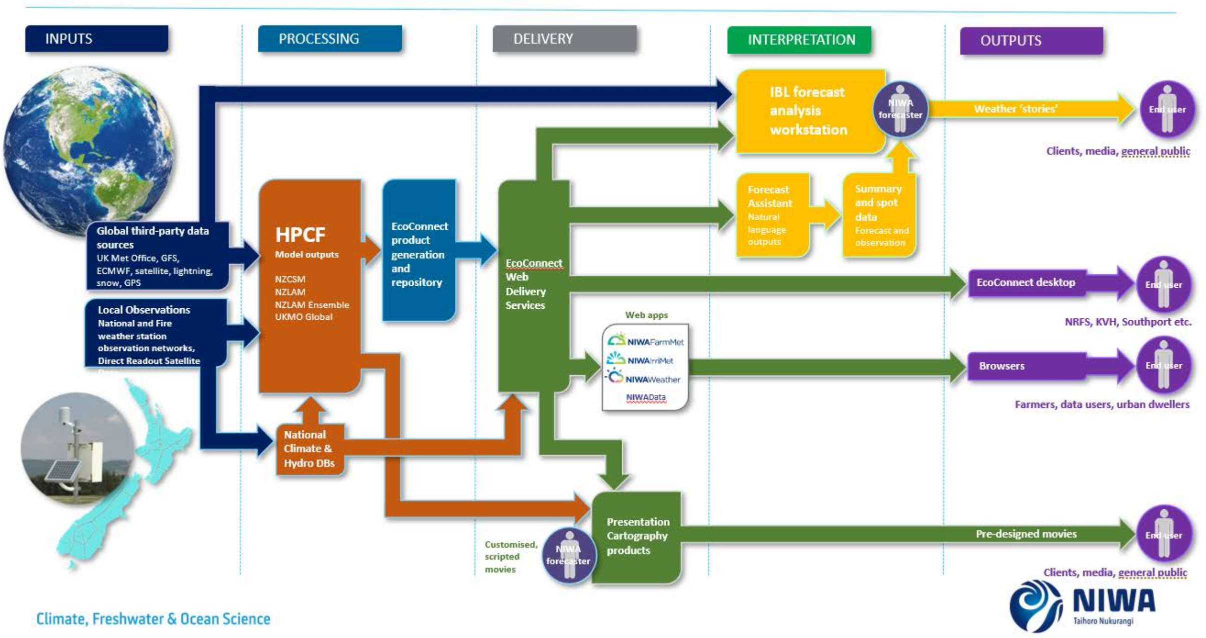
NIWA takes the data from the global Unified Model runs, as well as data from the GFS model and the ECMWF IFS model, and inputs the data as starting conditions into its local area models. NIWA also uses real time observation data from NIWA, regional councils, FENZ and other meteorological stations (360-400 stations) and several satellite data streams as inputs. These steps are very similar to the process MetService undertakes. However, NIWA's local area models run on its supercomputer and use the Unified Model suite of software to run high resolution local area forecast models over New Zealand and the South Pacific.

NIWA provides the weather forecasts to the public via its weather forecasting website and social media. The model outputs are used as inputs into NIWA's other downstream models, products and services for its customers, and its broader environmental research programmes and outputs.

NIWA's forecasting process is much more automated than MetService's and involves less manual interpretation of the model outputs by forecasters. While NIWA's meteorologists, hydrologists and climate scientists constantly review the forecast outputs, Figure 23 shows that NIWA's forecasters are primarily involved in the delivery of the forecasting products and interpreting the forecasts for customers, media, and the public.

NIWA delivers forecasting information via a range of technologies, including API, visualisation software, GIS software, and their website.

Figure 23: NIWA's weather and hazard forecasting operational system.



Source: (NIWA, 2023c)

3.7.3 NIWA does not separately record revenue and costs associated with weather forecasting

NIWA has stated meteorology, hydrology, oceanography and climate are core components of impact forecasting and environmental systems, and are incorporated into all NIWA's science domains/environments, meaning it is not possible extract revenue and associated costs specifically for weather forecasting from its other domains. In many cases weather forecasting is just one component of a programme or project and is indivisible from the other components. Therefore, NIWA does not record revenue and associated costs specifically for weather forecasting as distinct from other activities (though NIWA has subsequently provided estimates that are included in our final report).

NIWA estimates that combined weather/climate revenues were around $77-83 million (41-45 per cent of total revenue), based on 2022/23 financial results. About 50-55 per cent of NIWA's weather/climate revenue relates to research and is primarily from MBIE contestable funds and Strategic Science Investment Funds.

Key customers for NIWA's weather forecasting services include FENZ, the Department of Conservation, the Ministry for Primary Industries, several regional councils, port companies and other government entities such as SOEs (energy companies, KiwiRail).

s 9(2)(b)(ii) [redacted]

[redacted]

Figure 24: s 9(2)(b)(ii) [redacted]

s 9(2)(b)(ii) [redacted]

s 9(2)(b)(ii) [redacted]

3.7.4 NIWA financial analysis

NIWA’s financial performance has been analysed along two broad dimensions. The first dimension focuses on understanding key aspects of the firm’s performance and financial structure over the past 10 years. Elements analysed include:

- revenue, expenses, and the evolution of the EBITDA margin
- net profit after tax
- dividends paid, and the payout ratio relative to net operating cashflows less maintenance CAPEX (this ratio is targeted in the statement of corporate intent for MetService and included here for ease of comparability)
- capital expenditure over time
- the retention ratio, or what proportion of profits are reinvested into MetService
- the sources of financing for the entity, and their evolution over time.

The second dimension assesses NIWA’s performance against the KPI targets established in the statement of corporate intent.

Figure 25 displays NIWA’s revenue, operating expenses, and EBITDA margin over the 2014 – 2023 period. Revenue has grown from $124 million in 2014 to $186 million in 2023 or an annual average compound growth rate of 4.7 per cent, while operating expenses have grown from $104 million in 2014 to $159 million in 2023 or an annual average compound growth rate of 4.9 per cent. The EBITDA margin grew over the 2017 – 2021 period from 14.6 per cent to 24.3 per cent before falling back to 14.5 per cent by 2023.

Figure 25: NIWA's revenue, operating expenses and EBITDA margin (2014 – 2023)

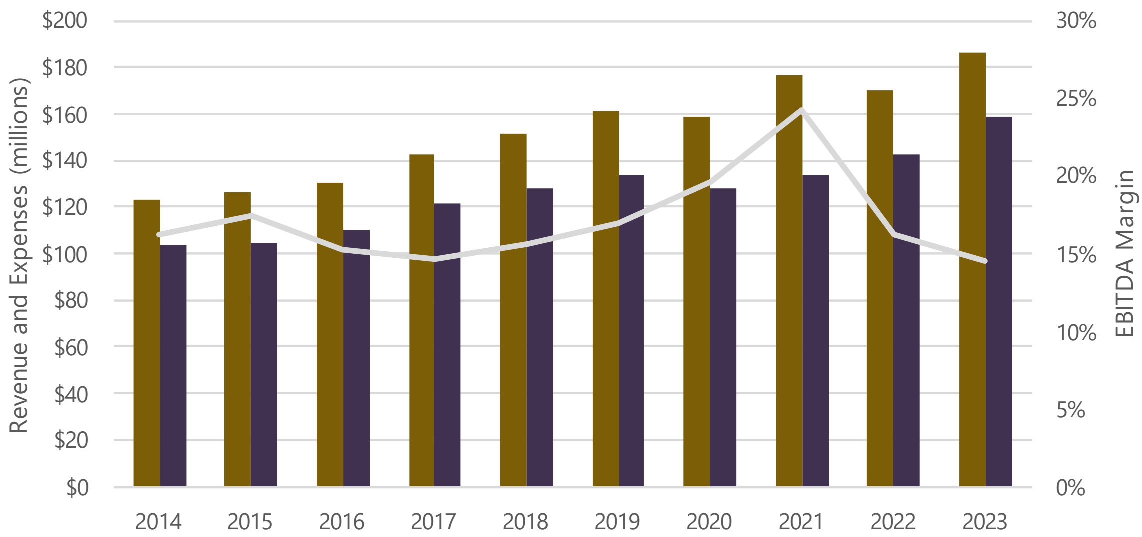


Figure 26 below displays NIWA's NPAT over the 2014 – 2023 period. NPAT trended generally upwards over the 2014 – 2020 period from $5.3 million to $7.4 million before spiking significantly in 2021 to $16.3 million. This large increase in NPAT is consistent with the increase in EBITDA margin above, as revenues grew by $18 million over the 2020 – 2021 period, while operating expenses only increased by $1.5 million. The biggest driver of this increased revenue is a year-on-year increase in the 'rendering of research services' of $15.3 million. NPAT fell to $6.5 million in 2022, before declining further to $5.9 million in 2023.

Figure 26: NIWA's net profit after tax (2014 – 2023)

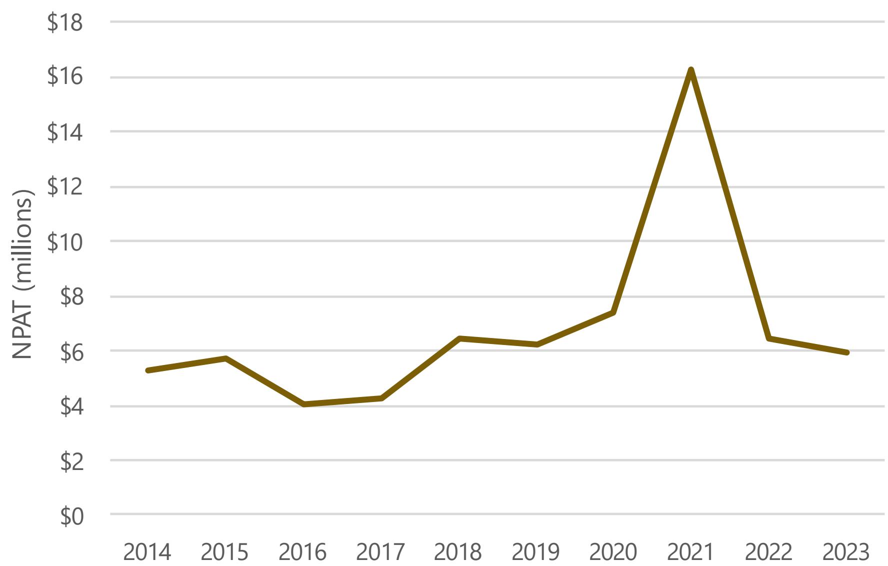


Figure 27 displays NIWA's dividends paid over the past 10 years. To enable comparability with MetService's history, dividends paid are compared to net cashflow from operating activities less maintenance CAPEX. NIWA paid dividends in both 2014 and 2015, of $2 and $4 million respectively, but not for the remainder of the analysis period.

Figure 27: NIWA's dividends and payout ratio (2014 – 2023)

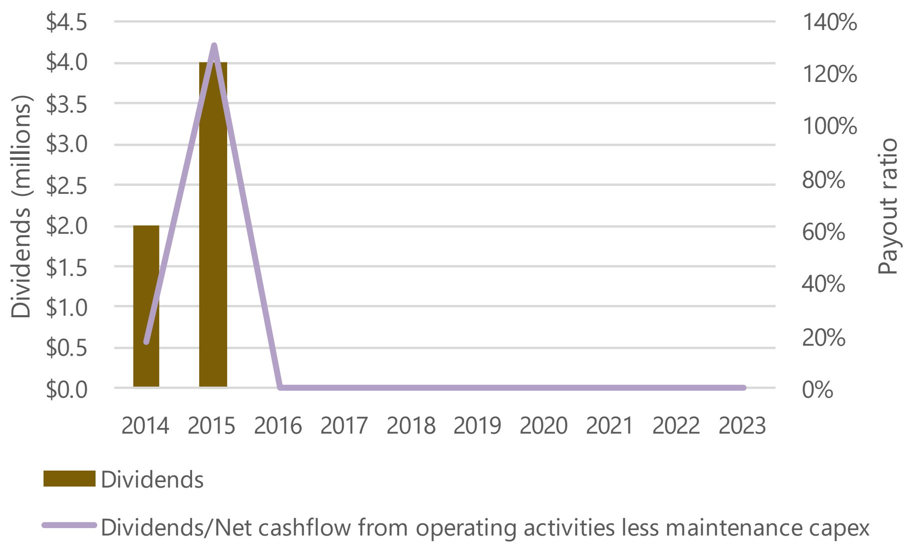


Figure 28 displays NIWA's capital expenditure spend over the 2014 – 2023 period. Annual capital expenditure rose from $10.9 million in 2014 to $45.3 million[20] in 2023, or a compound annual growth rate of 17.1 per cent. Other than a spike in 2018 – 2019, however, capital expenditure was fairly consistent over the 2014 – 2020 period. Growth over the 2020 – 2023 period was much faster at a compound annual growth rate of 45.0 per cent, or an increase in spend from $14.8 million in 2020, to $45.3 million in 2023.

[20] $57.8 million of capex spend is detailed in the cash flow statement in NIWA's annual reports, of which $12.5 million is prepayments for a new research vessel.

Figure 28: NIWA's capital expenditure (CAPEX, 2014 – 2023)

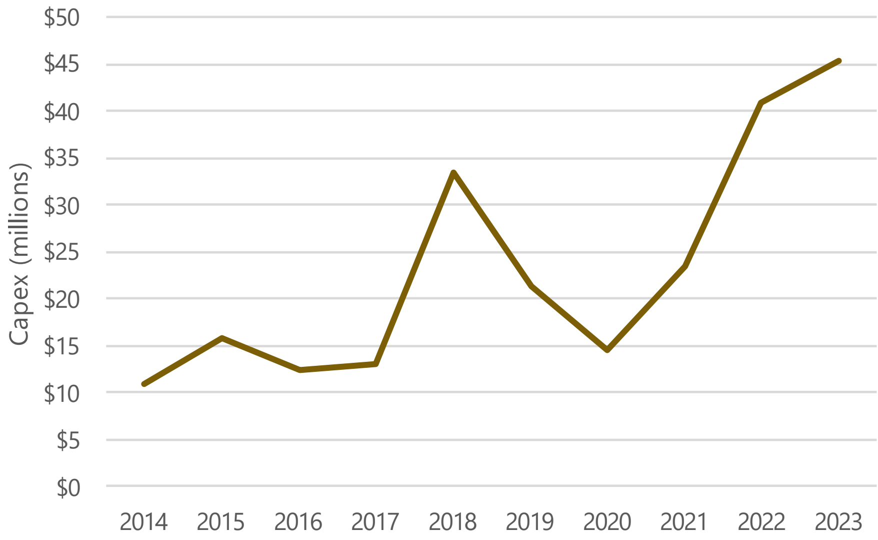


Figure 29 displays the retention ratio for NIWA over the 2014 – 2023 period. NIWA only paid dividends in 2014 and 2015 during the analysis period, translating to retention ratios of 62 per cent and 30 per cent respectively. The retention ratio for the remainder of the analysis period is 100 per cent.

Figure 29: NIWA's retention ratio (2014 – 2023)

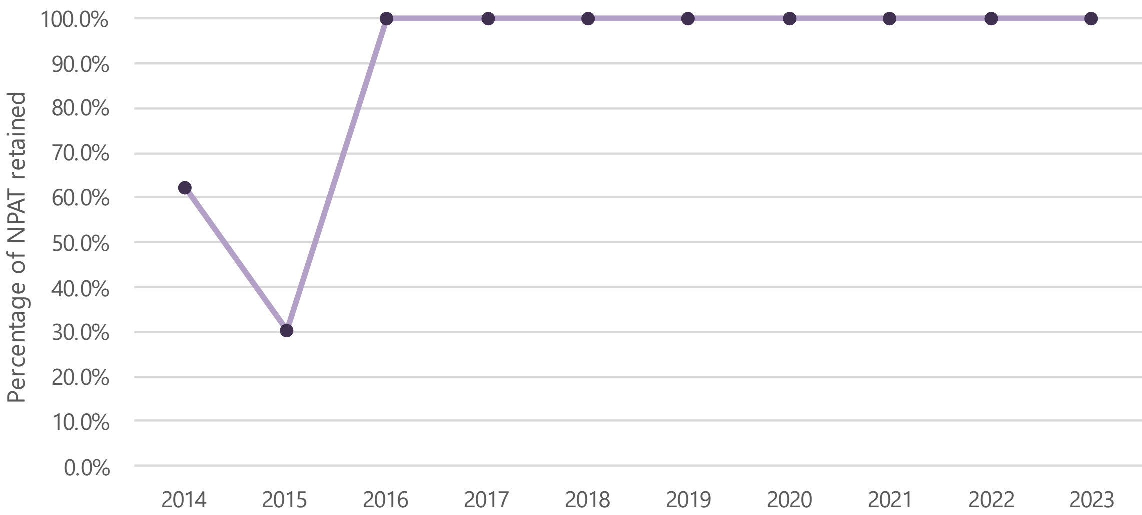
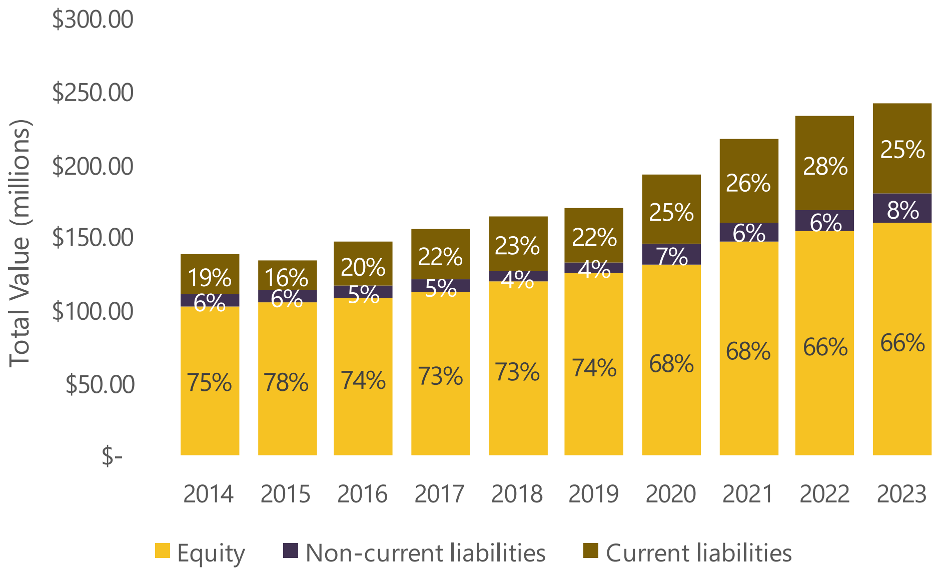


Figure 30 displays the evolution of NIWA's funding sources over time. NIWA's total asset value has increased from $138.3 million in 2014 to $242.8.4 million in 2023. Over this period, the reliance on current liabilities has increased, from 19 per cent of total assets in 2014, to 25 per cent of total assets in 2023. This has primarily come through a reduction in the share of total assets funded by equity, from 75 per cent to 66 per cent over the same period. While NIWA still has a debt-to-equity ratio greater than that of MetService, as illustrated in Figure 20, it is worth noting that the two entities are trending in opposite directions for this measure.

Figure 30: NIWA's sources of funding (2014 – 2023)



An assessment of NIWA against its statements of corporate intent is included in Appendix F.

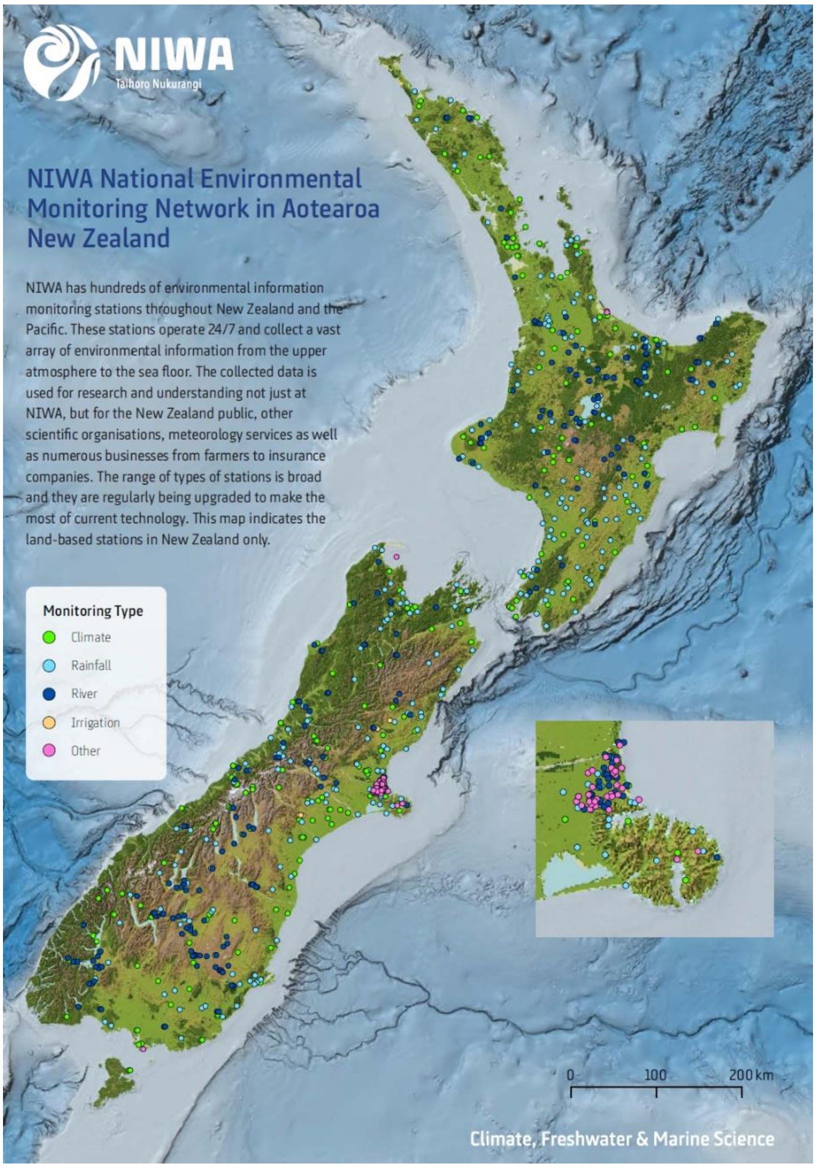
3.7.5 Resourcing for weather forecasting research in NIWA is considered alongside and against its other work domains

NIWA allocates its Strategic Science Investment Funding and CAPEX funding for forecasting research through its annual prioritisation process. All NIWA internal resourcing goes through this process. NIWA scientists submit business cases for funding, then the Science Management team prioritise the available funding by assessing the case against government and national priorities (e.g., strategies, shareholding Ministers' annual Letter of Expectations) and customer/stakeholder needs. The prioritisation is then approved by the Executive and Board and incorporated into NIWA's annual Statement of Corporate Intent.

3.7.6 NIWA maintains a network of observation stations that collect a range of climate and environmental data

Figure 31 shows NIWA’s environmental observation network in New Zealand.

Figure 31: NIWA's land observation network



Source: NIWA

3.7.7 NIWA manages the national climate database and makes most of its data freely available

In 1992, when the New Zealand Meteorological Service’s observation network was divided between MetService and NIWA, NIWA retained responsibility for New Zealand’s national climate database.

MetService data is still uploaded to the database via a data agreement with NIWA.[21] Part of the agreement is that there is a 24-hour embargo on NIWA using MetService's data and hourly data from MetService it is not freely available to the public.

NIWA reports that it makes 99.8 per cent of its weather, climate, and hydrological data freely available for public good purposes.[22] Charges and use restrictions are imposed for commercial use through a data access/license agreement. NIWA's weather and climate data is available to the public after a 24-hour embargo and hydrological data is available in real time. NIWA renegotiates the data agreement with MetService every five years.

3.8 Responsibilities and weather forecasting roles in the emergency management system

New Zealand's emergency management system is complex and has many moving parts. This is not necessarily unique to New Zealand – the impacts of an emergency can be widespread[23] and therefore a coordinated response to an emergency requires significant efforts in almost every area of society.

Appendix C provides more information on the structure of New Zealand's national emergency management system and how decision making happens.

NEMA and MfE are nationally responsible for the management of meteorological risks/hazards

The National Civil Defence Emergency Management Plan specifies the guiding principles and collates the roles and responsibilities of different agencies in New Zealand's national emergency management system, given to them through various legislation but foremostly the Civil Defence and Emergency Management Act 2002 (National Civil Defence Emergency Management Plan Order, 2015).

There are a range of agencies involved in CDEM and responsible for different risks/hazards at the national level. Relevant to weather, NEMA and the Ministry for the Environment (MfE) are the lead agencies responsible for geological and meteorological hazards at a national level (which includes coastal hazards, coastal erosion, storm surges, large swells, floods, severe wind, and snow).

NEMA functions as the steward and operator of New Zealand's CDEM system and has the responsibility of coordinating all hazards and risks across the system. NEMA provides national leadership in reducing risk, preparedness, and response and recovery from emergencies. NEMA typically has a lead or supporting role in response and recovery to events across the range of risks/hazards and is at the core of the CDEM system.

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[21] When the two organisations were established it was decided that MetService was required to make data collected for forecasting available to NIWA for climatological archiving for subsequent research (Steiner et al., 1997).
[22] The data is available via CliFlo, a web system that provides access to the national climate database.
[23] This is increasingly so as technology advances, sectors become more interdependent, new lines of communication and interaction appear, and, overall, already complex systems continue to grow in both size and complexity (Coskun & Ozceylan, 2011).

The Meteorological Services Contract with MoT designates a single authoritative voice for weather forecasting and warnings

It is in part through the MoT contract that there are flows of weather forecasting information into the national emergency management system and the designation of a single authoritative voice for weather forecasting and warnings. As discussed earlier, MetService is obliged to provide a range of services to a range of stakeholders, including (Minister of Transport & MetService, 2023):

- advice of local- and broad-scale severe weather, primarily to NEMA, CDEM Groups (as lead and support agencies), and regional councils, but also to be disseminated to other stakeholders such as New Zealand Police and Transpower
- wind and ice accretion warnings for coastal shipping, on the high seas, and local marine areas to Maritime New Zealand
- road snowfall warnings for New Zealand Transport Agency (Waka Kotahi NZTA)
- relay of Special Weather Bulletins issued by Fiji Meteorological Service, primarily to MFAT, but also for NEMA
- relay of messages concerning nuclear incidents, tsunamis, and other non-meteorological information as agreed by WMO
- advice of large waves in coastal areas and abnormally high sea water to regional councils.

National Civil Defence Emergency Management Plan specifies the roles of hydrological and meteorological agencies

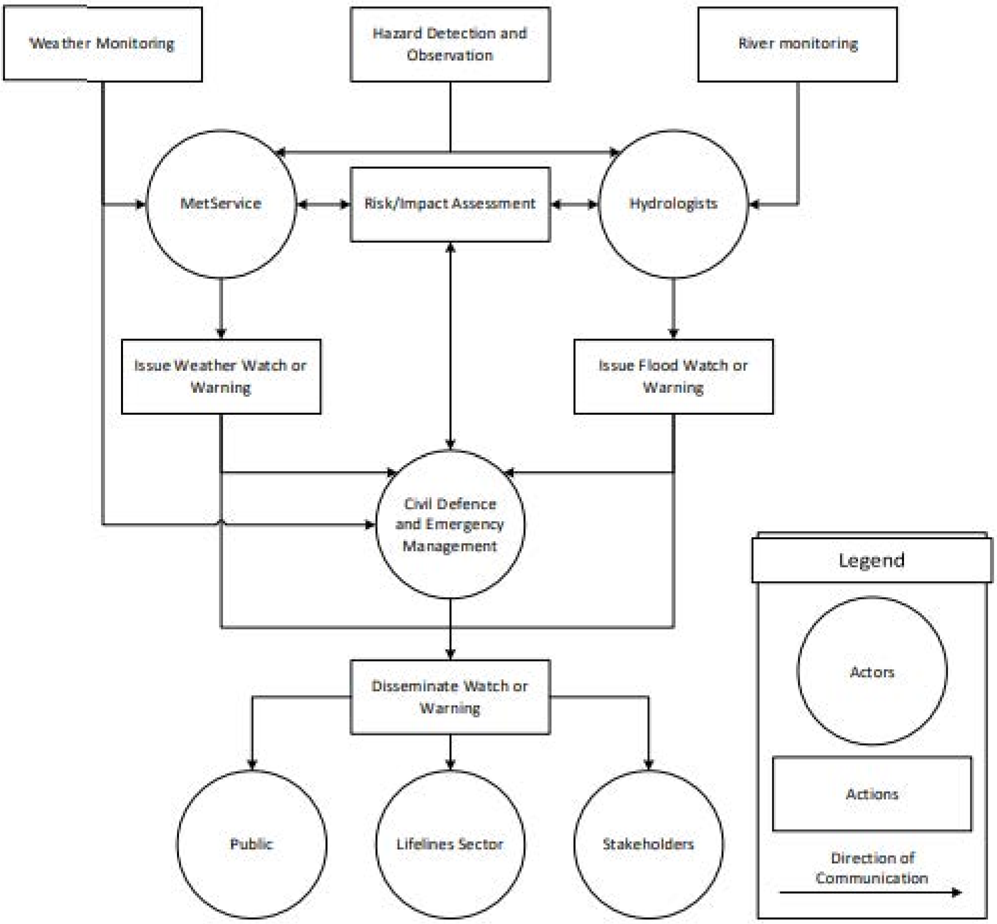
The National Civil Defence Emergency Management Plan further outlines some of the meteorological and hydrometeorological informational flows into the emergency management system. As per Section 85 of Part 3 of the Plan:

- MetService is responsible for maintaining a weather forecasting service and issues weather warnings to the public; contributing to the management of public information about weather hazards and associated emergencies; issuing, as necessary, volcanic ash advisories for the civil aviation industry; and providing scientific advice to the National Crisis Management Centre (NCMC), agencies, and CDEM groups as necessary. Section 119 of Part 8 specifies MetService's responsibility of monitoring, identification, and analysis of meteorological hazards and threats and the subsequent issuing of hazard information at all times.
- NIWA provides public information on climatic and seasonal risks (including drought), volumetric flows for river levels and flood prediction, marine geological, seafloor, and coastal hazards and processes; provides scientific advice to the NCMC, agencies, and CDEM Groups as needed; and provides representatives on the tsunami experts panel.
- Regional councils and some territorial authorities monitor rainfall, lake and river levels, and volumetric flows for flood prediction and management.

How weather forecasting officially interfaces with the CDEM system

Figure 32 shows a characterisation of the severe weather warning chain in New Zealand, based on Harrison's (2022) interviews with CDEM Groups and MetService. The CDEM circle includes NEMA as the system steward and coordinator across hazards and risks, as well as CDEM organisations (including CDEM Groups) at lower levels (e.g., community).

Figure 32: Severe weather warning chain in New Zealand



Source: (Harrison, 2022)

MetService and Regional Council hydrologists play roles in monitoring weather and rivers, respectively, and their associated hazards, then interpreting and applying a risk assessment before feeding this information and any subsequent warnings on to CDEM organisations and the public. NIWA is contracted by West Coast Regional Council to help it understand its flood hazard. NIWA also maintains a river monitoring network with regional councils (maintaining the network and data).

Under the MoT contract, MetService must provide public weather services which include advice of severe weather to NEMA and Regional Councils. Under the National CDEM Plan, MetService is responsible for maintaining a weather forecasting service and the issuance of weather warnings to the public. CDEM organisations are then responsible for coordinating and disseminating watches or warnings for the public, lifelines sector, and stakeholders.

A subtle interaction between weather forecasters and hydrologists

Our own interviews with CDEM organisations support Harrison's (2022) conceptualisation of the chain in Figure 32. MetService, NIWA and Regional Council hydrologists, and CDEM organisations each play a role in informing and collating the different sources of data they have access to and familiarity with (e.g., CDEM organisations knowing about local conditions and topography) to inform a risk/impact assessment, which then flows through to watches and warnings.

While the chain may stay relatively constant from event to event, the decision for MetService and hydrologists to issue a watch or warning can vary considerably given the context of the event and requires nuanced understanding of the impacts. This highlights the importance of the involvement of CDEM organisations early to ensure their local and tacit knowledge is paired with MetService or hydrologists' higher-level assessments.

Key questions CDEM organisations (as well as authorised providers) must consider when dealing with the weather forecasting information include:

- what information should go to the public?
- how will this information be shared with the public?
- what are the likely impacts, given the context and location of weather? What are the criteria used to determine these impacts?

Importantly, the chain described above is focused on official warnings in relation to CDEM legislation and the National Civil Defence Emergency Management Plan. This chain does not limit other organisations, such as NIWA, from providing watches and warnings, including those which are more personalised.

Other ways weather forecasting interfaces with the emergency management system

Section 119(2) of Part 8 of the National Civil Defence Emergency Management Plan specifies that relevant government agencies, CDEM groups, local authorities, and lifeline utilities are to maintain arrangements to receive and respond to hazard information. This suggests there will be other direct lines of official contact by which weather forecasting information is disseminated to and within the emergency management system from weather forecasting providers (including MetService and NIWA).

Other agencies and lifeline utilities may have commercial contracts with weather forecasting providers which provide non-legislative (but still formal) channels for weather forecasting and hazard information to flow through, in addition to the weather forecasting information and warnings provided from the authorised provider. These contracts may be to satisfy the requirements of the National Civil Defence Emergency Management Plan, or otherwise.

It is possible information shared through formal commercial channels, but outside of official public channels for weather forecasting and warnings, makes its way into national assessments and decision making and the information may conflict the official forecasting and warnings. Organisations are free to choose to contract with different providers for weather forecasting products and services to meet their needs, over and above what is provided publicly (i.e., what MetService is required to provide under the MoT Contract and National CDEM Plan). For example, we know FENZ has a contract with NIWA which could then inform the feedback it provides into the CDEM system, but also separately its own response activities.

Another interface of weather forecasting and emergency management is the NEMA weekly monitoring and alerting forum. NEMA set it up after Cyclone Gabrielle and it is essentially an all-of-government check-in. MetService attends as the authorised national provider of severe weather warnings and provides a weather forecast for the next week, plus disseminates a slide deck with further information. One stakeholder commented on the value of this forum in getting all agencies involved and up to speed with current weather events. NEMA also set up a pathway for direct links with NIWA around extreme weather events post Cyclone Gabrielle.

3.8.1 What weather forecasting information is provided to CDEM organisations, and how?

How and what weather forecasting information is provided to CDEM organisations is crucial. As described before, the information must be relevant and detailed enough and must be in such a format that it can be easily and readily interpreted and overlayed with other data and information to be able to inform CDEM organisations' responses to weather events.

The Coordinated Incident Management System (CIMS) framework for coordinated response

The Coordinated Incident Management System (CIMS) is a framework for the purpose of effectively coordinating incident and emergency management across responding agencies (New Zealand Government, 2019).

CIMS proposes common structures, functions, and terminology to be used by agencies in incident management. It informs the basis for how different agencies communicate with each other and work together while responding to an incident or emergency. Section 115 of the National Civil Defence Emergency Management Plan specifies that agencies involved in emergency response are expected to be trained and practised in its use.

Despite the CIMS framework, one CDEM organisation we spoke to said there is still different language and scales used across agencies involved in CDEM, which means there is a job of aligning and translation to understand the level of risk being communicated.

Current information provided to CDEM organisations is largely hazard-based

No doubt the information that MetService and NIWA must provide within their advisory services (i.e., the substance of the advisory/warning) varies considerably based on a range of factors, including the nature of the hazard itself, the amount of time between hazard identification and warning, the time the impacts of the hazard are expected to be realised, and location.

What we have heard from organisations involved in emergency management is that data and information shared by weather forecasting agencies is typically only focused on hazards, although recently there has been some improvement and movement toward basic impact forecasting. This includes examples such as MetService's colour coded warning system, which is issued when significant impact and disruption is expected.

> "Each council will get a report from MetService regularly. Largely the same with regional nuance. They try to sell outputs to everyone else. Very much not motivated by nuance of service but by trying to sell same product to as many people as they can."

> "Traditionally MetService has provided info in relation to nature of event (e.g. swell, rainfall, etc.). The job we have as a CDEM organisation, is to ask the so what? What is the

expected impact of this over a certain time frame? What does that mean for me, and should I be acting? Over recent years, MetService has got much better at that. Many of the warnings now have a lot of the language we have had from CDEM, for example, heavy rain likely to cause dangerous driving conditions, streams and rivers may rise, etc. Think that is good. Has been a really good journey – if that info isn't provided, we have to go back and ask them to help us understand what this means. Has to be a meeting of the minds of what they understand of the weather and what we know of the impacts. Back and forth required. Ability to answer question about so what? Is key. Getting better, but encourage it to continue."

This is generally aligned with the findings of Harrison et al. (2022), which state that currently impact forecasting tends to be impact-oriented discussion between different agencies, rather than model based or through the quantitative synthesis of data. These discussions often rely on tacit knowledge and the experience of people involved to recall previous events and to inform the thresholds at which a hazard is deemed threatening enough to warrant a warning. Like in Figure 32, there is a link from CDEM to risk/impact assessments – this tacit knowledge and experience of CDEM organisations helps to transform this from a purely risk/hazard assessment into one of impacts.

The WMO guidance on multi-hazard impact-based forecast and warning services (World Meteorological Organization 2015b) provides guidance for how impact-based forecasts and warning services could be done through developing impact models using vulnerability and exposure datasets as well as meteorological information.[24]

What about information and data through commercial channels?

Weather forecasting information provided through commercial arrangements will vary considerably based on the nature of the agreement and because arrangements would often be sought when bespoke products and services are required by the purchaser. CDEM organisations may have these commercial agreements for a range of reasons.

Depending on its nature, the information received through commercial arrangements could complement or go against what is received through official channels from MetService. Outside of severe weather events (or when there is enough advanced warning of a weather event), this potential for divergence of information across sources may be acceptable. In cases, plurality could even be useful. But when considering warnings and the activation of CDEM processes, it may cause confusion and issues.

CDEM organisations have varying willingness and ability to pay for commercial arrangements with the likes of MetService or NIWA to access data or get better information.[25] Decision makers seek the best possible information available to be able to make the best quality decisions, and this process often relies upon comparing multiple sources of data and models. For CDEM organisations which have the

[24] NIWA noted that the RiskScape tool takes this approach. RiskScape is a facility that provides customisable spatial data for multi-hazard risk analysis. It has been developed, and undergoes continuous improvement, by NIWA and GNS in partnership with EQC. It models impacts and risks, and assesses vulnerability through insights into asset fragility and exposure of assets to different hazards (e.g. multiple flooding events, or extreme wind gusts), and then calculates the likes of average annualised loss (a key impact measure in the insurance industry).

[25] For example, regional councils vary considerably in size and resource and therefore willingness and ability to pay for weather forecasting services.

primary functions of public safety, inability to access the best possible information to inform decisions can have particularly acute and significant consequences.

Some regional councils we spoke to said they cannot afford to access forecast data that they believe would help to prepare and take appropriate actions in emergency situations. A volunteer agency involved in CDEM response echoed this. Some organisations involved in CDEM – especially regional councils – have broad mandates and other responsibilities that compete for priority (i.e., the investment in weather information access cannot be justified).

In one regional council's experience, its inability to access some weather forecasting products and services because of not having a contract with a provider means its decision making is inhibited. The regional council may receive high-level information about severe weather from the commercial provider but is unable to look deeper into the modelling and information (i.e., there is no transparency because of no contracted access). This means the council is unable corroborate the information they have access to with the information they do not. The information they cannot access may therefore be inappropriately weighted in the decision-making process and lead to suboptimal outcomes.

Information provided to CDEM organisations during weather events is often static and difficult to integrate

The format and substance of information provided during weather events to CDEM organisations, as well as the ability to integrate it with other information, is incredibly important because it dictates the ability to use this in a timely and appropriate manner and therefore the quality of CDEM planning and response.

We have heard from many CDEM stakeholders the information they are provided is often static and comes in the form of a PowerPoint or PDF document. There is an obvious trade-off here – on one hand these sorts of formats are readily shareable and do not require significant investment in supporting infrastructure and/or capability (e.g., CDEM organisations requiring access to large databases, etc.). But provision of information and data in such formats makes it difficult to use the information in real time or overlay with other data such as exposure maps. The information and data provided is piecemeal, must be manually stitched together with other information and data, may be of a different format to what is required, and can become outdated quickly (particularly in fast moving emergencies and situations like the recent Cyclone Gabrielle).

3.9 Thinking of the role of Māori and mātauranga in weather forecasting and warning systems

Māori communities and organisations have particular perspectives, needs, and expectations regarding weather forecasting, warning systems, and the communication of information.

The use of mātauranga Māori in weather forecasting is re-emerging in Māori communities as they re-connect with traditional knowledge (mātauranga Māori). Māori communities and organisations may expect others involved in weather forecasting understand the potential uses and opportunities to engage with Māori while incorporating this knowledge. NIWA has been developing capability to engage with Māori over the past 18 years. Māori staff within Te Kūwaha (NIWA's National Centre for Māori Environment Research at NIWA) have researched these issues, toward delivering benefit for and with Māori partners. In the past, NIWA provided daily weather forecasts for Māori TV presented through a Māori lens in te reo which proved popular with Māori communities, however cuts in Māori TV funding brought this to an end.

Our project engagement with Māori thus far has been limited because of difficulty in connecting and finding the right people to talk to, at no fault of Māori stakeholders. This review comes at a time of great change and, in general, an overwhelming demand for time and input from Māori groups. The below summarises what we have learned from the literature, particularly in the context of emergency management. It must also be recognised that the literature is only one medium and store of knowledge, and the experience and perspective of Māori exists across many other media, particularly oration, which we have not accessed to the same extent. We endeavour to further capture the perspective of Māori.

Indigenous communities hold immense knowledge, arising from many years of experience and interaction with the physical and spiritual world around them. Indigenous knowledge and specifically mātauranga Māori and te ao Māori can play important roles in inputting knowledge into the national weather forecasting and warning system, as well as in designing and guiding how warnings are disseminated for different communities, including Māori, iwi and hapu at more localised levels.[26] Some of the ways Māori environmental knowledge can be applied to hazard management include sharing local knowledge of events and impacts, mapping that information to hazards, and to provide Māori involvement in planning (King et al., 2007).

For example, several Pacific meteorological services now use traditional seasonal calendars (relevant to biophysical environment and people's livelihoods) in their climate communication and education, including in forecasts and warnings (Chambers et al., 2021).

Māori environmental knowledge takes many forms and expressions because of different tribal histories, geographies, norms, and practices, but in all cases arises from an enduring and close relationship with te taiao (environment) (King et al., 2008). The knowledge and lessons learned are evidenced in traditional and modern practices of Māori and have been developed over many generations of experience, including in weather and climate forecasting. An important point raised by King et al. (2008) is there is considerable variability among iwi of the narratives that give meaning to the atmospheric elements and relationships to and between people themselves, but in all cases the intricacy of the connections include the notion that human actions can impact the climate, and all things in the environment (past, present, and future) have a distinct meaning and relevance. The power of indigenous knowledge is that it is not static – it is a living database that grows with experiences and as the climate changes, and there are various knowledges available with everyone's unique experiences (Lambert & Mark-Shadbolt, 2021; McDonald, 2022).

King et al. (2008) describe that, while knowledge systems and the way in which knowledge is created, stored, verified, and shared can be different, differences are not always in stark contrast. There is both

[26] Māori environmental knowledge must be used in a way that is authentic and appropriate. King et al. (2008) discuss Māori distrust and caution about Māori knowledge being taken and misused or used in the wrong context, in part due to the impacts of historic legislation banning traditional Māori practices.

tacit and codified[27] knowledge in both Māori and other knowledge systems and the authors argue the different knowledge systems can be blended.[28]

There is some literature on the role of Māori knowledge and mātauranga in relation to severe weather and what might be considered in science as natural hazards. We have found some examples which suggest these natural weather, climate, and earth phenomena are not seen as hazards by some Māori communities, but rather natural processes and events (Gabrielsen et al., 2018) where the role of humans is not to interfere, but to accommodate and care for the animate and inanimate things around (Lambert & Mark-Shadbolt, 2021).

From our search, here are some key findings:

- *The likes of wānanga, karakia, tikanga, laments, family history, and narrative are important channels for information sharing*. This is true for the sharing of Māori environmental knowledge, both within Māori communities and in bi-cultural systems (Gabrielsen et al., 2018; King et al., 2008). Other important avenues may be those which are culturally relevant. In a study of tsunami risk in Poverty Bay, Repia and Jo (2021) found most research participants placed strong emphasis on waiting for formal warnings before evacuating, mostly from Ngāti Porou radio station, Te Tairāwhiti CDEM Group, or 'the siren'. We heard from one interviewee that they used Ngāti Porou radio to feed weather forecasting and warning information to local communities.
- *The substance of a message is incredibly important*. Iwi and hapu may have established ways of describing and naming local phenomena, as well as environmental indicators to forecast weather (King et al., 2008; McDonald, 2022; NIWA, 2017). Messaging will vary dependent on context and local area, but these descriptions, names, and indicators may play an important part in communication of hazard and risk to local communities. Some of these indicators for weather are changing over time and becoming less reliable because of changes in climate, but consensus-based approaches may be used and indicators considered collectively. The study by King et al. (2008) highlighted the need for iwi-based research on the efficacy of local environmental indicators and ways to adapt them in the face of climate change. The study by Gabrielson et al. (2018) states the gap between science-based hazard management and mātauranga Māori adaptation strategies, in the context of Ruapehu volcanic warnings and plannings, could be bridged by determining mātauranga Māori-based cultural descriptors or indicators traditionally used to monitor volcanic hazards and plan for risk.
- *Where possible, messages should be localised*. Local narratives provide an effective way of understanding natural hazards specific to the community, land, and place (Repia & Jo, 2021). Repia and Jo (2021) found national messaging did not resonate with the community because it was not specific to the context of the area and iwi. When presented with CDEM campaigns and television messaging, participants of the research wanted to

[27] See discussion from (Kimble, 2012; Olomolaiye & Egbu, 2005; Polanyi, 1958) for more discussion on tacit versus explicit knowledge.
[28] Again, with caution.

know more about the tsunami's potential effects on their own region and what they needed to do to prepare.

- *Embodiment of te ao Māori principles*.[29] This includes Māori involvement in decisions (rangatiratanga) as well as in planning and response to events (for example, iwi-initiated monitoring of culturally significant sites with the support of other agencies) (Auliagisni et al., 2022; Gabrielsen et al., 2018).

3.10 Assessments of system performance, gaps, and the need for change

This section summarises our findings from our engagements with a broad range of stakeholders across the weather system in the form of interviews, workshops, and an online survey. Stakeholders were asked to consider future trends applicable to the wider forecasting system, discuss the needs of the weather system in Aotearoa New Zealand, and identify barriers to those needs being met. We triangulate findings from our stakeholder engagement with relevant literature, including work from the WMO (World Meteorological Organization, 2015c) and previous reviews of New Zealand's forecasting and climate services.

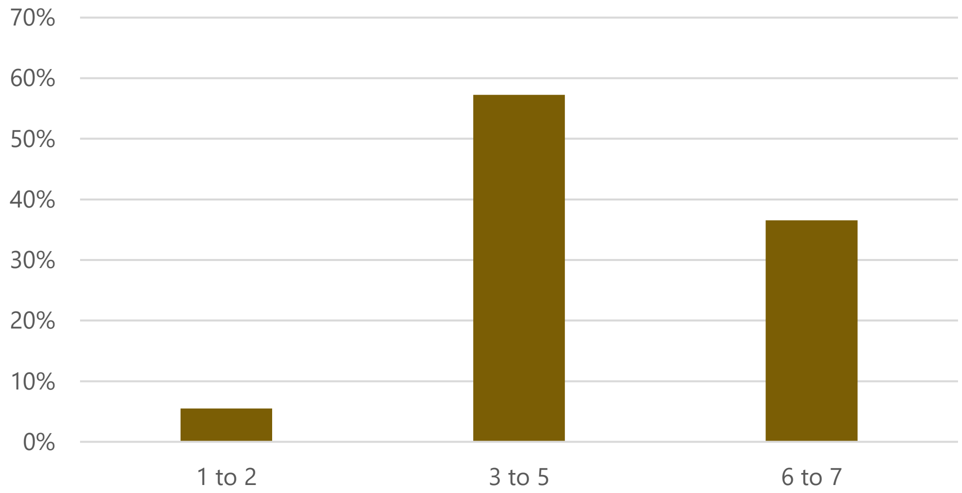
3.10.1 An above average experience for users' current purposes

Weather system stakeholders, across the board, report an above average experience interpreting and applying weather forecast information in Aotearoa New Zealand. Stakeholders also highlighted positive experiences with forecasters and forecasting teams, placing a high value on those interactions.

Survey respondents were asked to rate their experience in obtaining, interpreting, and applying weather forecasts in Aotearoa New Zealand on a scale of 1 (very poor) to 7 (excellent). Across the entire sample of respondents. Around 57 per cent of respondents provided a rating in the 3-5 range, 37 per cent of respondents provided a score of 6-7, while 6 per cent provided a rating of 1 to 2.

[29] Including Whakawhanaungatanga (establishing relationships), Manaakitanga (respect, generosity, care for those around), and Kaitiakitanga (guardianship of te taiao)

Figure 33: Distribution of respondent experience of the weather system



Source: Sapere analysis

There were no significant differences in how respondents rated the system. The highest average rating, per respondent affiliation, came from agriculture and local government (6). The lowest average rating (3) came from respondents primarily affiliated with central government.

Respondents who provided high ratings cited their experience and expertise as a factor

Alongside their rating of their experience obtaining, interpreting, and applying weather forecast information, respondents were asked to provide a reason for their rating. Respondents who rated their experience highly (6-7), often cited their prior experience and expertise as important factors in navigating and utilising forecasting information. These respondents also noted that the information they tend to look for is readily available and easy to access.

For those who provided a mid-level rating (3-5), respondents noted that information was available, but often in siloes, vague, uncertain, limited, and not always available at speed. These respondents also noted that data is often not freely available and that there are too many sources of data, making it difficult to determine which outputs are accurate.

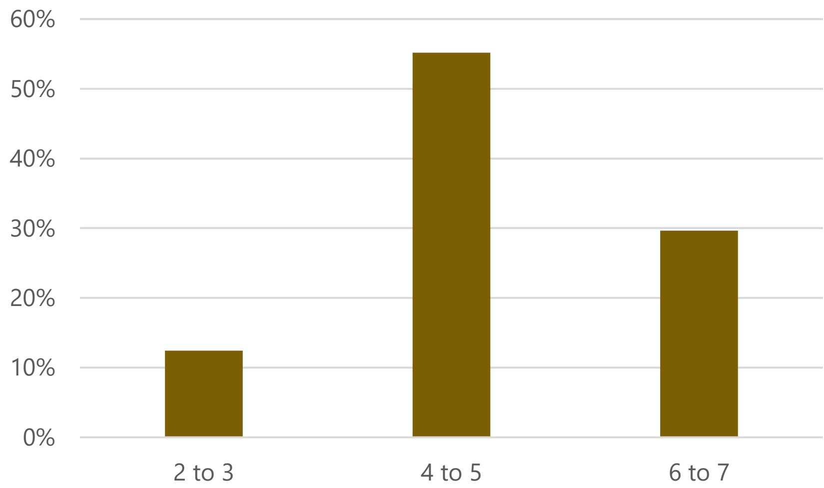
Respondents who provided the lowest ratings (1-2) cited the lack of access to radar data in certain formats, source disparity, and a lack of open-access data as reasons for their ranking.[30]

[30] Survey responses may be biased upward because of the targeted nature of the survey (i.e., going to a pre-identified group of stakeholders who use or have interests in weather forecasting, in either a professional or advanced personal capacity). The respondents would have some form of professional or advanced personal interests in weather forecasting and therefore would likely possess the knowledge and skills to be able to use the weather forecasting information and services and interpret them in appropriate ways. The same may not be said for the general public and its ability to interpret and use the weather forecasting products and services.

Weather system stakeholders rate the quality of weather forecasting services above average

Survey respondents were asked to rate the quality, including the accuracy, timeliness, responsiveness, and coverage, of weather forecasting in New Zealand. Ratings ranged from 1 (very poor) to 7 (excellent). Around 12 per cent of respondents rated 2-3, while 55 per cent rated 4-5, and 30 per cent rated 6-7. No respondents provided a score of 1, and 3 respondents did not provide a rating.

Figure 34: Distribution of quality rating of weather system



Source: Sapere analysis

Again, there were no significant differences in the average ratings between respondents, as per their primary affiliations. Aviation, energy, maritime, emergency services, hobbyists, MetService and NIWA, and transport provided the highest average ratings (5). Central and local government, as well as private weather providers provided the lowest average rating (4).

Respondents who provided high ratings cited world-class weather predictions, public access, and intuitive apps

In their open-ended responses, participants who provided high ratings (6-7), cited world-class weather predictions, running models concurrently, intuitive apps, and good access to the public. These respondents noted that while accessibility to forecasting information is good, it could be improved for rural and isolated communities. Other respondents cited the accuracy of forecasts as the reason for their high ratings, as well as the consistency, reliability, and effective monitoring of forecasts. However, these respondents (who largely rated a 6) noted that a lack of a unified infrastructure and overlapping effort constrained the forecasting system and prevented it from receiving the highest possible rating.

Respondents providing a rating within the overall average (4-5), indicated that forecasts are accurate, but only for those with a commercial subscription, and not for the public. Others noted how 2023 extreme weather events had highlighted deficiencies in extreme weather forecasting. Respondents providing a rating of 4 also highlighted forecasting inaccuracies, particularly in the longer term. The disconnect between actors in the system was also cited as an issue by these respondents.

Respondents who provided lower ratings (2-3) indicated that forecasting is too frequently inaccurate, particularly for people living on non-mainland locales. Again, the disconnect between organisations in the forecasting system was stated as reflecting a suboptimal configuration, which underserves the public. Large gaps in the observation network were also identified as a reason for providing a low ranking.

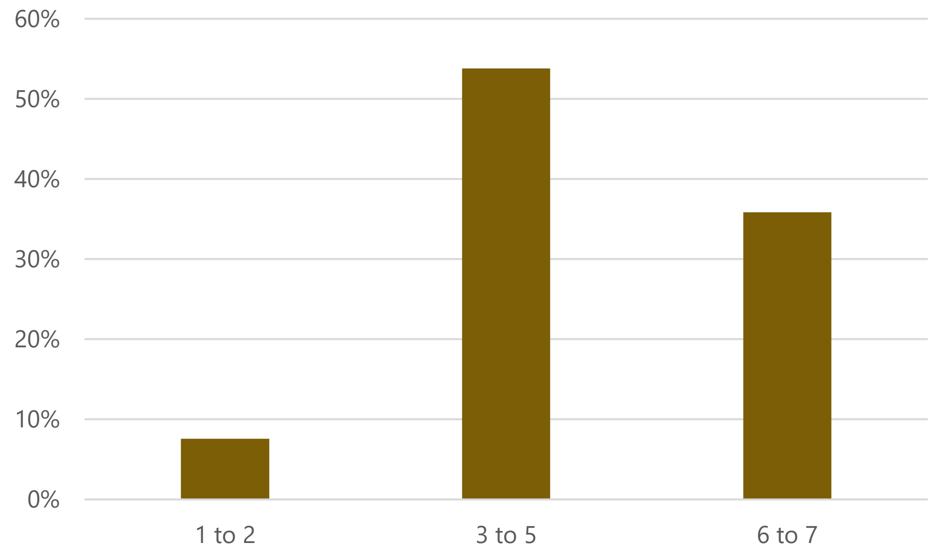
3.10.2 A perception of need for considerable change to meet future needs

Despite recording an above average rating of the weather system, survey respondents were of the view that considerable change to the weather system is needed to meet future needs

Respondents were asked what level of change is required within the weather forecasting system and/or institutions to meet future needs. Respondents were asked to rate from 1 (no change) to 7 (complete change).

Around 8 per cent of respondents rated 1-2 (indicating no or low change), 54 per cent rated 3-5 (indicating considerable change), while 36 per cent rated 6-7 (indicating significant and complete change).

Figure 35: Need for change distribution



Source: Sapere analysis

Local government respondents provided the highest rating (7), while those in transport and agriculture provided the lowest rating (3). Importantly, no respondent group were of the view that no change was required.

Determining what New Zealand wants and needs from a weather system is required to determine the optimum system configuration

Insights from weather system representatives in other international settings (UK, Australia, and Canada) indicated that there is no one right answer for the ideal configuration of a weather system. The needs, wants, and aspirations of the country must be understood, before determining how the weather system should be organised. This is important when considering both public and non-public weather forecasting and warning products and services and particularly the role that government has in enabling provision. One representative noted that it is best to start the process by asking:

- "What does success look like for New Zealand?"
- "What can and should the country expect from the weather system?"

By asking the question of needs, success, and aspirations, weather systems in other countries have been able to bring their roles and targets into focus. One participant explained, in the context of public weather forecasting:

> "We know what the government expects of the service. For us it has been brought into focus around explicitly providing a public good service to deliver impact, public good, and industry competitiveness."

The representative noted that the clarity and focus on what is wanted from a public weather forecasting provider informs the purpose, and outcomes, of their agency's actions, stating:

> "We have no need to deliver against financial benchmarks, and can focus on materially contributing to the safety, security, and wellbeing of the nation."

Identifying the role, purpose, and objectives tends to mean that the NMS conducts fewer activities. However, it may also mean that there is a greater contribution from more focused activities and an opportunity for the private sector to compete and value-add targeted and bespoke products and services. As one representative explained:

> "We do less things than 20 years ago, but we demonstrably have more impact for the nation. If others can do it better, our job is to get out of the way. Either we do it, we don't do it, or we partner with people that do…It all starts with deep understanding of where we will make the most impact."

With a comprehensive understanding of what success looks like, and what is expected, the weather system can then be organised and configured in a way that facilitates meeting those expectations.

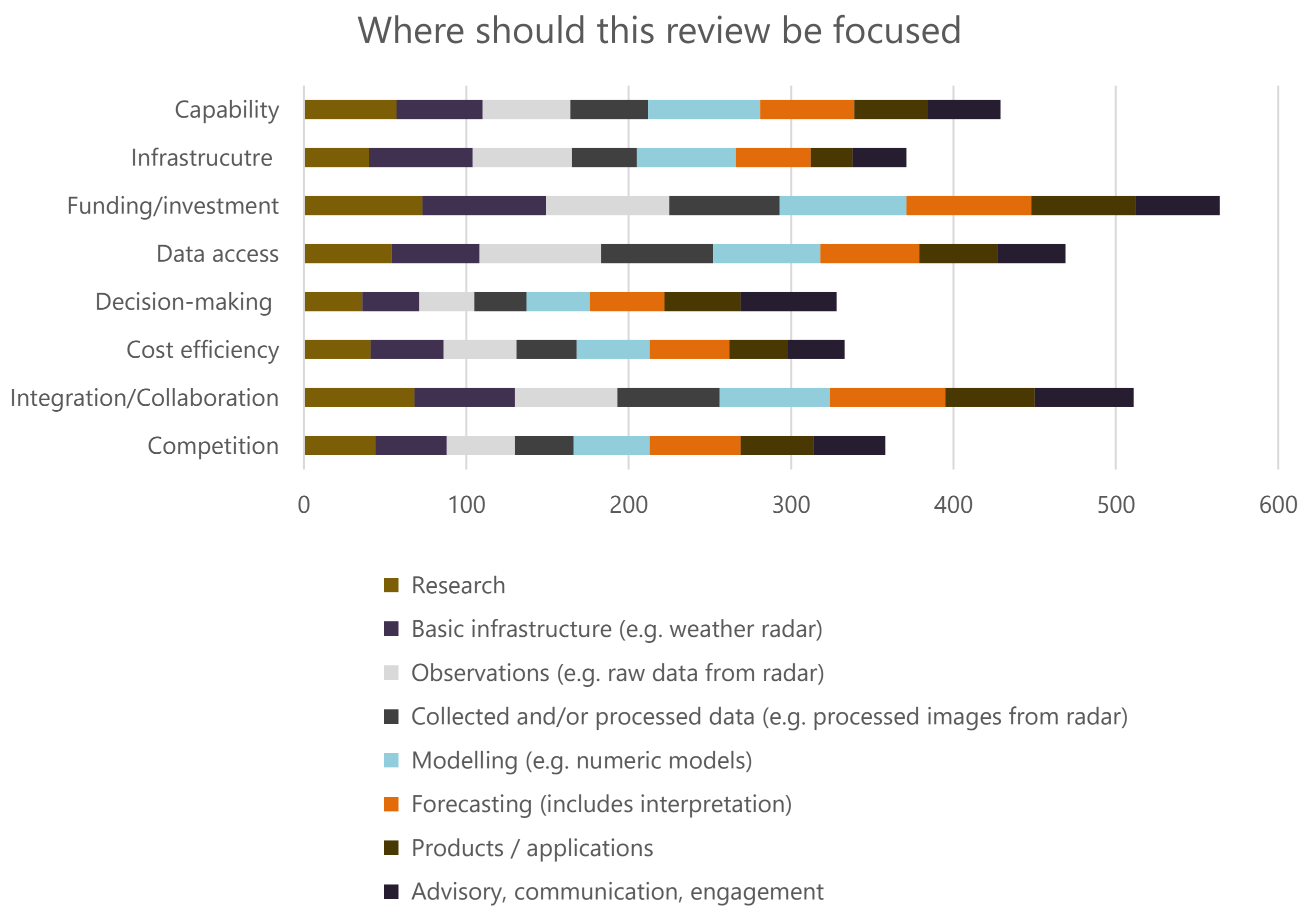
It was noted, however, that while determining success and aspirations is an important first-step to determining configurations, it is also important to recognise that the landscape of success and aspirations is dynamic. Rapidly changing expectations are generally enforced by the pace of technological change. Understanding aspirations, therefore, is not a static exercise, and must be regularly revisited.

International participants also advised that it is important to understand the "price tag" associated with the aspirations and expectations of New Zealanders. As such, costing aspirations and expectations is also part of the exercise. This is to facilitate planning and adjusting activities to budgets that may not sufficiently facilitate aspirations and expectations.

Weather system stakeholders identified funding and investment as the main area of focus for this review

Survey respondents were asked to consider the focus of this review across eight domains, including competition, integration/collaboration, cost efficiency, decision-making, data access, funding/investment, infrastructure, and capability. Within those domains, respondents were presented with eight focus areas including research, basic infrastructure, observations, collected/processed data, modelling, forecasting, products/applications, and advisory, communications, and engagement.

Figure 36: Focus of the review



Source: Sapere analysis

Although funding and investment prevails slightly as the area where respondents feel the review should be focused, closely followed by integration and collaboration, all other areas have attracted significant levels of response. Altogether, this indicates that respondents feel that all facets of the weather system need to be considered in the review.

3.10.3 Gaps in forecasting capability and data accessibility

Forecasting capability and data accessibility were the main gaps identified in the weather system by survey respondents.

89 per cent of survey respondents identified several gaps in the weather system – most of these gaps could either be considered in terms of forecasting capability or data access issues. On forecasting capability, respondents highlighted:

- space forecasting
- nowcasting of severe weather

- ensemble forecasting
- flood and storm surge forecasting
- landslide forecasting
- improved long-range forecasting.

Other gaps related to gaps in data, or data accessibility limitations. Data gaps and access limitations included a lack of public access to data, ineffective communication and messaging, insufficient data granularity, oceanographic information, and river flow forecasting data. Stakeholder interviews highlighted the importance of two-way sharing of information to understand the local impacts of different weather.

It appears that some survey responders are not aware of the extent to which ensemble forecasting is well established within NIWA for New Zealand, or that flood and storm surge forecasting models have already been developed by NIWA for New Zealand, although not included as part of the public national forecasting service.

As noted earlier in this report, NIWA state that 99.8 percent of weather data held in the National Climate Database (which includes all NIWA and MetService weather station data) which is typically downloaded by over 40,000 users each year is freely available. The survey responses might suggest that there is an expectation that the outputs of models derived from the data (e.g., river flow forecasts, oceanographic information) should also be freely available.

4. Current issues, future needs and potential barriers

Here, we discuss current issues with the weather system, the future needs of New Zealand from the weather system, and potential barriers to those needs being met. Our discussion is informed by a combination of stakeholder interviews, a review of relevant literature, and the survey we issued to a large sample of weather system stakeholders. Our discussion addresses the issues of institutional arrangements, credible messaging, technology and innovation, data access, open-science, collaboration, competition, and establishing a single, unified voice in communicating hazards and extreme weather events.

4.1 The institutional arrangements appear to be the root cause for most issues identified

The institutional arrangements of New Zealand's weather forecasting system, as well as its participants, appear to be the root cause for most issues identified throughout the review thus far, which are presented in the following sections. When we say institutional arrangements, we mean the commercial form and structure of organisations, as well as contracting arrangements and funding.

This may be unsurprising because the institutional arrangements provide the fundamental basis for how organisations can operate within a system and society more broadly. Institutions shape and provide the incentives and directives for how we, and organisations, choose to conduct ourselves.

In other words, our behaviours and actions are shaped by the incentives we face, which are provided by the institutions of the systems we operate within. Therefore, to be able to influence behaviours and actions requires reflecting upon and changing the institutional arrangements, to adjust the incentives.

A range of technical and non-technical changes are required to meet New Zealand's needs in the next 5 to 20 years

Our survey respondents were asked to consider what changes will be required to address gaps in the New Zealand weather system over the next 5 to 20 years. A range of changes were identified. Interestingly, the same kinds of changes were identified by respondents, regardless of their earlier response regarding the degree of change required. Only those that rated the degree of change required as 1, did not identify changes that will be required to the weather system. Those respondents expressed confidence in the present system's ability to meet future needs.

Respondents who indicated a high level of change required (6-7), indicated that over the next 5 to 20 years, more accurate modelling, ensemble forecasting, nowcasting, open-access data, improved co-operation between MetService and NIWA, integration of other sciences, improved accessibility, localised forecasting, a greater emphasis on historical data, and the centralisation of data are needed to meet New Zealand's needs.

All other respondents (2-5) broadly conformed with the changes required over the next 5 to 20 years, but also cited open access to data and models, the need for a single authoritative voice, reduced competition, machine learning, impact forecasting, forecasting for commercial outcomes, and improved regional forecasting.

However, there are barriers, mainly financial, to meeting New Zealand's future forecasting needs

Survey respondents were asked to identify barriers to the weather system being able to meet New Zealand's future needs. Several issues were identified relating to the configuration of this system, namely the presence of two competing organisations. Respondents identified overlap in work, a lack of collaboration, the lack of a single authoritative voice, territorialism, confusions regarding the roles of each organisation, and general disconnect between agents in the system.

Respondents commonly expressed the view that there is insufficient financial support to meet future needs, and that the financing system is too rigid. Some respondents also noted that there is a lack of funding certainty to adequately plan for the changes that may be required.

Respondents also cited a lack of political will and interest from the public to enact the policy changes required for the weather system to meet the needs of New Zealand in the future.

An absence of voice or authority on space weather, which is becoming an increasing issue

Although not central to the review, multiple stakeholders raised the issue of space weather (i.e., activity on the surface of the sun, such as solar flares), the lack of clarity around responsibility or strategic planning for response to events, and New Zealand's lack of space weather capability.

Space weather releases energetic particles which interact with Earth's magnetic field. These particles cause magnetic disturbances and interfere with things like satellites and the electricity transmission grid, causing mis-operation and/or equipment damage.[31] The impacts of space weather are likely to become more pronounced over time, for example, as we become more dependent on radio communication technologies for day-to-day life. A 2016 study commissioned by the European Space Agency (2016) estimated the costs of space weather events to the European economy, finding that over 15 years space weather events could have costs of up to 13 billion EUR (presented in 2016 terms) due to interruption of satellite operations, aviation and transport/logistics, resource exploitation, and power grid operation.

Right now, there is no designated authority for space weather in New Zealand and no national monitoring activity. Organisations such as the National Oceanic and Atmospheric Administration (NOAA) in the United States provide monitoring and warnings of space weather events globally, but like everything else, the impacts felt locally in New Zealand will be more nuanced and likely context-specific based on our ground (electrical conductivity), how things like our electricity system are configured and operated (i.e., infrastructure that will be affected by space weather), and both the social and economic frameworks we operate within (i.e., influencing our activities and decisions).

[31] For example, see (Fang et al., 2022) for discussion on the space weather environment when SpaceX lost 38 of its 49 Starlink satellites deployed in February 2022.

A New Zealand market for space weather forecasting products and services may develop over time as its impacts become more pronounced.[32] There may also be a role for government, like with weather forecasting, in providing some form of public space weather forecasts and warnings in the interests of public safety and national security.

Access to data, particularly historical, is important but missing, which requires enabling platforms and infrastructure

A plethora of data are used in weather forecasting and things like numerical models are computationally intensive. Often this data is kept for many years and helps with activities like hindcasting[33] and model calibration but is not easily accessible, even for particular research purposes. This is closely tied to the issue of commercialisation for both MetService and NIWA. The enabling platforms and infrastructure required to make historical data easily accessible for anyone to use may require investment which may not see a financial return. Additionally, historical data is a relatively easy avenue for commercialisation given the data is already there (the marginal cost of providing access may be quite low) and access is easily excludable.

Other stakeholders raised the importance of some form of shared and open access database to record the impacts of past weather events. This would help with understanding likely future impacts of similar weather events and reduce the reliance on accessing siloed tacit knowledge to be able to make appropriate decisions in a severe weather event. Of note was a suggestion from one CDEM stakeholder for a collaborative impacts database, managed by those involved in forecasting and warning, CDEM organisations, and communities, where each can input information about impacts (including things like stories, photos, list of damage, as well as weather conditions, etc.) to allow for the identification of trends and patterns over time and to use this information for future preparation and response.

However, making data open access comes with a cost that is not covered under current institutional arrangements. In October 2017, after receiving the 'Weather Permitting' review (MBIE, 2017), MBIE requested information from NIWA and MetService on costs related to the organisations' meteorological station networks and associated data collection, revenue from the data, and the potential loss of revenue if New Zealand made more data freely available and removed restrictive licencing around its use.

At the time, NIWA estimated that costs for their weather observation network totalled $6.8 million per annum for collection, quality-control, and storage of the data. NIWA estimated that to make data freely available would cost an additional $1-3 million per annum for quality-control. NIWA received $3.1 million from the government to carry out these activities. NIWA also received approximately $4 million per annum for providing real-time quality assured observational data to its clients. It expected revenue to grow to $6-$8 million per annum by 2020. It therefore anticipated that revenue loss from

[32] Right now, there may not be incentives to invest in the development of a service because the customer base is not there (i.e., the effects of space weather are not felt acutely enough yet).

[33] Hindcasting refers to the use of modelling and historical data to try and recreate weather patterns or events that happened at specific points in time. Hindcasting forms an important part of earth scientific research because it allows us to better understand how certain weather patterns arise and therefore how we can better forecast them in the future.

making the data publicly available would be $3-$6 million. NIWA estimated that an extra $4.7-5.2 million would be needed from the government to fund the network.

MetService estimated that the costs to collect, quality assure and make publicly available its observational data totalled around $7.2 million per annum. It estimated that a one-off cost of $1.25 million would also be incurred. MetService estimated that publishing all surface observation and radar data would result in loss of revenue greater than $12 million annually.

Several stakeholders mentioned the Moana Project[34] as an example of what successful open-access historical data sharing could look like, and the types of research and innovations it could contribute to. The Moana Project is funded through an $11 million MBIE Endeavour Fund grant and includes a 28-year hydrodynamic hindcast of ocean data in and around New Zealand. The funding for this project was time-bound and will end in 2024, and we understand that after that time the Moana Project data (which may also be useful for weather hindcasting) will no longer be free to access from the information sources as the funding did not cover ongoing service or data costs.

Resilience of observations and a need for more ground-truthing and other sources of observations

Several stakeholders raised the issue (and potential for future issues) of overreliance on automatic, remote, and digital observation infrastructure. Ground-truthing (i.e., confirming what remote sensors are indicating by having someone also observing the weather or automated in-situ measurements to compare against remote ones – e.g., rain gauges to compare with weather radar, or surface measurement to compare with satellite) and manual observations may continue to play an important role in the meteorological observation network, particularly in severe weather events when automatic weather stations are unavailable (damaged, offline, etc.). The recent example weather event in Auckland was referenced, where there were questions and hesitation over whether the readings being received from automatic stations were valid and should be acted on.

One stakeholder believed there could be benefits in shorter-term investment in other observational infrastructure like a small satellite that could capture weather conditions as well as other earth information. This satellite could be used to update base maps for the purpose of emergency management and response. Current practice is flying planes and helicopters post-disaster to inform base map updates, which is slow and costly. During Cyclone Gabrielle, optical satellites were not usable because of storm cover and therefore decision makers and CDEM organisations had to hire helicopters to do aerial mapping and take photos shortly after the event.

4.2 Establishing consistent and accessible messaging

According to the WMO (2022), it is important that the NMS is seen as a competent and authoritative provider.

> "Each NMS has an implicit, or ideally an explicit, mandate from its government to act as the agency providing "official" or "authoritative" information for a defined set of

[34] https://www.moanaproject.org/

> hazardous weather, climate and water conditions/phenomena, therefore supporting the government's responsibility for the protection of life and property."

Consistent with "official" or" authoritative" information, stakeholders highlighted the importance of providing consistent and credible weather messaging. Internationally, both NIWA and MetService were recognised by participants as highly capable and well-run organisations. However, there was some confusion and criticism levelled against the New Zealand system for having two state funded forecasters operating in the same domain, as one participant noted:

> "It's bonkers having two state funded weather forecasts in any nation and even more in a small country like NZ."

Reasons for confusion and criticism included the overlap in work being conducted, economic inefficiencies, and potential confusion for the end user.

Unified official voice and hazard communication

Interviewees and survey respondents stated that the importance of a singular, recognisable authoritative voice during extreme weather events may well warrant a unified communication platform, particularly for hazard-related information. Some suggested that a unified approach advocates for a national-level platform, consolidating communications instead of having disparate organisations trying to separately communicate information. Effectively, this means that the work to develop warnings and information could happen in many different places, but the actual communication and dissemination of the warnings and information would come from one source.

Drawing from experience communicating heat warnings in the UK, we understand there was a deliberate effort to avoid having two state bodies (UK Met Office and UK Environment Agency) providing separate information on the topic with differing datasets. In the interest of clear communication and therefore public safety, the UKMO handled the responsibility of communicating warnings to the public (the UK Met Office and UK Environment Agency work with Natural Resources Wales to provide a combined Flood Forecasting Centre).

A good example of integrating different information and delivery through a consistent channel is FENZ's wildfire information being on the MetService website and application. This sort of delivery through a consistent channel that users are familiar with may help with control of divergent messaging and in making the appropriate information easily recognisable, particularly for the public.[35]

National-level notification system for hazards

Some stakeholders argued that to effectively disseminate warnings related to hazards, like severe weather events and earthquakes, there needs to be implementation of a national-level notification system directly reaching individuals, for example, through their phones. Public trust in these notifications is crucial to ensure prompt and appropriate responses, such as evacuations where appropriate.

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[35] In this example, however, the wildfire risk is dependent on NIWA's high resolution weather and impact forecasts. There could still be divergence between the wildfire risk measure and MetService's own weather forecasts due to underlying differences in data and modelling between MetService and NIWA.

Enhanced applications and communication channels

Interviewed stakeholders and survey respondents suggested improvements in applications, free from advertisements and capable of delivering push notifications, present opportunities for integration by entities such as the National Emergency Management Agency (NEMA). Integrating functionalities across these platforms may enhance communication efficiency during hazard events. Many stakeholders indicated that applications free from advertisements were desirable, to improve the apps accessibility. MetService now removes ads from their applications during an extreme weather event, maintaining the ads during times of normal weather for revenue generation.

Inclusive and credible messaging

Effective messaging extends beyond technicalities. It must resonate across diverse cultures and languages. Ensuring accessibility and credibility in both data and forecasts is pivotal to building and maintaining public trust. Stakeholders explicitly mentioned the importance of ensuring that messaging reaches, and is trusted by, Māori communities. One noted that during COVID-19, Māori organisations were empowered to ensure key messaging was delivered to Māori communities and that a similar system may be valuable in the context of conveying weather information. The WMO White Paper #1 (World Meteorological Organization, 2021) suggests there are opportunities for adopting "supplementary information based on indigenous and traditional knowledge". As such, involving Māori in the data collection process, using indigenous knowledge, could be an opportunity for ensuring inclusive messaging in Aotearoa New Zealand.

A lack of consistent messaging has potentially damaging effects during extreme weather events

Working independently on related issues can lead to a lack of coordination in addressing complex problems that require a multi-agency, integrated approach. Additional issues may arise when the two agencies are providing conflicting warnings. The evacuation of parts of the Wellington south coast (June 2021) is a salient example of this.

4.3 Technology, innovation, and the consumption of forecasting

Stakeholders noted changing consumption and distribution patterns in weather forecasting. The themes that were noted to us were:

Diverse information sources

According to key stakeholders, consumers are presented with a range of information sources. From traditional meteorological agencies to a proliferation of digital platforms and independent weather experts, the range of choices reflects a growing appetite for varied data streams. However, this abundance also introduces challenges, as navigating through multiple sources can be overwhelming. For some, being able to access diverse information sources is important and desirable. Several civil defence and emergency management (CDEM) stakeholders said they would like more information about uncertainty when receiving weather forecasts so that they could take appropriate precautions for severe weather events. An example of this may be through ensemble forecasts, where multiple forecast model runs are included in a single output to show the range of potential future states. As one stakeholder put it, CDEM organisations are the ones responsible for emergency response and therefore even in the most severe and extreme of events, CDEM organisations must be prepared. Understanding uncertainty around forecasts would help CDEM organisations to be able to consider the full scope of what is possible and/or probable and therefore plan for those situations.

Translating forecasts into impactful insights

Stakeholders were broadly of the view that there is a rising need to translate weather forecasts into tangible and relevant impacts. Consumers increasingly seek forecasts that elucidate the potential risks associated with weather events. Understanding the likelihood of droughts, floods, or other weather-related challenges and their potential impacts is crucial for businesses, policymakers, and individuals to make informed decisions. This necessitates a shift in forecasting paradigms, from solely providing predictions to offering comprehensive insights that outline the potential consequences and implications for various sectors and regions. Consistent with this view, the World Meteorological Organization White Paper #1 (World Meteorological Organization, 2021), suggests that there is a growing need to provide expanded knowledge to provide informative output to the user:

> "Future weather and climate observational data should be interoperable with socioeconomic, biophysical and other data, especially at the local and urban levels, to expand knowledge generation and to provide informative forecasting results to end users."

The WMO strategic plan 2016-2019 (World Meteorological Organization, 2015c) also points to the needs for impactful insights, noting that understanding and integrating the needs of end user communities into forecasting and warning systems is essential to end-user decision-making, preventing loss of life and property, contributing to economic growth, and supporting environmental stewardship.

Demand for centralised forecasting products

The 2001 review of New Zealand's forecasting and climate services expected that changing consumer behaviour would shift demand for more sophisticated products; this was also discussed as part of our Meteorological Society of New Zealand workshops. In accordance with that expectation, stakeholders advised, in response to the expanding information landscape and the need for impactful insights, there is a growing call for a centralised platform — a one-stop-shop — for weather forecasting products and services. Such a hub would streamline access to diverse forecasts, specialised insights, and tailored services. By consolidating these resources into a singular, easily navigable platform, consumers could efficiently access the breadth of available information without encountering the complexities associated with multiple sources. Relevant to the point above on diverse information sources, this may also prove a valuable concept for CDEM applications to ensure appropriate and timely response to severe weather events.

AI's mainstream integration

Stakeholders advised artificial intelligence (AI) and machine learning (ML) have shed their status as emerging technologies and are becoming increasingly central in weather forecasting, but also noted that numerical prediction models remain superior at present. This mainstream integration signifies a significant shift in the tools and techniques employed within the field. The World Meteorological Organization White Paper #2 also addresses the issue of AI and ML, suggesting ML solutions might be integrated into weather and climate service workflows to avoid heavy data processing and to allow for interactive use. Stakeholders of the services would be supported to interactively use information, data, and products together with weather and climate information provided by the NMS. One participant advised, however, that while AI represents exciting new opportunities, care should be taken that the noise of AI does not crowd out other relevant technological advancements. A consensus among stakeholders was that AI and machine learning are likely to redefine the skillset essential for meteorologists. Skillsets will require realignment with new forecasting methodologies resulting from AI and machine learning.

Quality data and continuous investment

Sector stakeholders agreed that the adage "garbage in, garbage out" rings particularly true in the context of AI-powered forecasting. The effectiveness of these advanced technologies relies heavily on the quality of input data. Therefore, sustaining and improving the quality of baseline data necessitates ongoing investment in observation networks.

Potential of citizen science

According to some stakeholders, a potential avenue for enhancing AI capabilities is citizen science. Leveraging the collective power of public contributions is an opportunity for enhancing the quality and diversity of data inputs, like in the previously mentioned example of a collaborative impacts database. AI could be used to help filter, sort, and analyse the contributions of communities and agencies to the database to provide impact insights to inform future CDEM activities (both pre-emptive and responses).

Emerging, new weather models

International players such as Google and NVIDIA are at the forefront of advancing AI weather modelling, utilising their technological strengths to develop stronger models and issue specialised alerts and warnings. According to some participants, the models produced by Google and NVIDIA have the potential to become comparatively stronger than those used by NIWA and MetService. Having said that, over the past three years NIWA has been employing its weather, climate, data science and supercomputing expertise to develop AI weather models for short-, medium-, and long-term prediction.

An international participant, as well as some domestic stakeholders, noted a key risk of overreliance on international players for weather forecasting and warning services is their commercial incentive, which may not be in the interests of national resilience or security:

> "If designate [provision of services] to Google rather than your [own] meteorological service they could turn around in six months and say it's not profitable and you are stuck without a warning system."

Integration of radar data

Stakeholders noted the integration of radar into models and nowcasting represents an interesting model for New Zealand to follow, for more accurate and responsive weather forecasts.

4.4 Rise of integrated data platforms

Shift towards continuous forecasting

Stakeholders explained integrated data platforms signal a shift from discrete forecasting to a more continuous system, focusing on observations and extending into the realm of impacts. Globally, meteorological services are increasingly engaged in assessing these impacts, broadening their scope beyond conventional forecasting practices. In a similar vein, the WMO strategic plan (2015c) highlights the importance of improved data-processing, modelling, and forecasting, noting producing "better weather, climate, water and related environmental information, predictions and warnings to support, in particular, reduced disaster risk and climate impact and adaptation strategies."

Balancing scale and context

"Thinking big but not too big" resonates in New Zealand, with its small population and limited domestic resources was a sentiment expressed by some stakeholders. Maximising the utility of available information across diverse domains — such as flood management, hydrology, and understanding the landscape influenced by rainfall — requires an integrated approach to optimise outcomes, which is reflected in the Japanese weather system, as described later in this report.

Interconnectedness of climate, ocean, and earth models

Some stakeholders emphasised the importance of climate and ocean models in numerical weather prediction (NWP) and earth systems, highlighting the intricate relationships and overlapping boundaries between these domains. The synergies between these models contribute significantly to the refinement and accuracy of forecasting methodologies and understanding of impacts.

4.5 Embracing open science and data accessibility

Stakeholders noted the practice of sharing forecasting data and open access data models is common in other parts of the world, such the US. They see this as a global norm.

Benefits of open-source data

Interviewed stakeholders and survey respondents identified opportunities with open-source data, noting open-source data stands out for its potential to significantly enhance productivity while offering substantial value for investment. This accessibility contributes to the value and tailored services, helping to create a package of weather-related applications. Interestingly, this sentiment was also expressed in the 2017 review of open access to weather data in New Zealand (MBIE, 2017), where it was argued that making observation data available in an open access way would encourage competition in the market for weather services by allowing more organisations to participate. This could, however, impact the level of service and costs for users including government contracts and revenues for MetService and NIWA.

Balancing open access and authoritative information

Stakeholders also noted, however, that while open access to data would provide benefits, there is a need for a balanced approach when it comes to the dissemination of authoritative information. Being able to access information openly and freely would no doubt mean information could be accessed and disseminated through more channels, but this should not detract from responsibilities within the sector, and maintaining a single authoritative voice is crucial for warnings. In more nuanced applications, such as predicting localised weather phenomena, the need for open access to diverse sources of information was highlighted as important.

4.6 Costs and opportunities associated with collaboration

Some stakeholders suggested partnering with international and online platforms, conglomerates, and global research initiatives presents an avenue for capitalising on overseas advancements and collective problem-solving. Collaborative efforts enable leveraging developments in meteorological research beyond national boundaries. Some stakeholders also noted that the imperative for collaboration is greater for New Zealand when compared to other developed nations given our relative resource limitations.

The sentiment of collaboration is reflected in the WMO's idealised vision of NMS. It states:

> "The NMS participates in national and international collaborative ventures that will improve its services to end users and other governmental agencies. The NMS thoroughly understands its users and their demands and how they use/want to use data from the NMS. The NMS allows itself to be challenged by its users and stakeholders. The funding of the NMS has a competitive element, for the purpose of securing quality and impact of research and development activities."

Most respondents agree that the weather system would be improved by integration and collaboration in the supply chain

Survey respondents were asked if "there might be improved services and/or efficiencies from integration/collaboration at this stage in the supply chain". Across the different domains of the weather system, respondents generally agreed with the statement.

Table 4: Agreement with the view that supply chain integration and collaboration support improvements and efficiencies

There might be improved services and/or efficiencies from integration/collaboration at this stage within the supply chain	No. in agreement	% Agreed
Research	85	58%
Basic infrastructure (e.g., weather radar)	77	52%
Observations (e.g., raw data from radar)	88	60%
Collected and/or processed data (e.g., processed images from radar)	84	57%
Modelling (e.g., numeric models)	90	61%
Forecasting (includes interpretation)	85	58%
Products/applications	73	50%
Advisory, communications, engagement	71	48%

Source: Sapere analysis

The only domain to not garner agreement from more than 50 per cent of respondents was advisory, communications, and engagement, where 48 per cent of respondents agreed with the statement. The domain where the most agreement was given by respondents was modelling (61 per cent), mirroring sentiments from other stakeholders regarding the need to share data and modelling capabilities more widely.

Institutional arrangements of MetService and NIWA have led to competition over collaboration

Instead of working together, the current structures of MetService and NIWA have led to competition between the two organisations. The two prior reviews that highlighted the risks of continued separation of MetService and NIWA did not lead to any significant changes that reduced the risk situation. Stakeholders have commented that they consider it a success if they get MetService and NIWA in a room to work together on a project. Competition between the organisations has led to several unintended consequences.

MetService and NIWA do not collaborate on operational forecasts and warnings

Several stakeholders stated that MetService and NIWA very rarely collaborate and do not commonly share any information other than atmospheric observation data. We understand that MetService receives NIWA's forecast model outputs four times a day for viewing in their forecast room and for non-commercial use. The information flow is one-way only and its effectiveness is unclear.

Competition between the organisations means that New Zealand has no effective two-way dedicated research-to-operations pathway between its climate, freshwater and oceans research focused CRI and its operational national meteorological service responsible for issuing severe weather warnings.

Competition has also led to duplicated effort and government resources (observation networks, products being offered, payment for multiple models) and fragmented service delivery (confusion around authoritative voice during extreme events, flood forecasting).

There are good relationships at scientist level, but incentives at executive level relationships prevent collaboration

Stakeholders consistently raised that there are good relationships between scientists and researchers from MetService and NIWA and they want to work together on projects. However, it was sometimes suggested that at the executive/management level relationships were so commercially focused that collaboration could not happen.

There is no effective two-way dedicated research-to-operations pathway between NIWA and MetService, impacting the level of research and value from it

Stakeholders have raised opportunities with MetService to improve the quality of forecasts but often MetService does not have the capacity or funding to do this research. MetService does undertake some research, but it is limited and they do not appear to influence NIWA's research priorities, nor do they receive any of the forecasting research that is done by NIWA (though they do receive forecast model outputs four times a day).

There was evidence that researchers from MetService and NIWA influence each other's work and collaboration was more common at the scientist level. MetService and NIWA staff often present their research at the Meteorological Society of NZ annual conferences, and read and publish in the same journals. Results from research undertaken by both agencies are often discussed and assessed in a collaborative way. NIWA and MetService researchers work together in government-funded projects, although several government stakeholders noted there was often friction between the two organisations when this occurred.

NIWA has the mandate to conduct research and ensure it is applied for the benefit of New Zealand, and it was originally intended that weather and forecasting related research could be operationalised by MetService. This has not been fully realised. When the organisations were established, there was a formal contractual obligation for MetService to pay for NIWA to provide research services, however as Steiner et al., (1997) put it:

> "the level of services both ways declined as each company sought to be more in control of its own resources, except where there is an ongoing need for expertise, facilities and information which it would be pointless to duplicate."

NIWA's research is funded each year through an internal competitive bidding process. NIWA's Chief Scientists prioritise funding based on Government national priorities and customer needs (including their willingness to pay), scientific innovation, and national and international research trends. This means that funding for weather forecasting research, unless it is project-specific funding e.g. Endeavour grant, must compete against NIWA's other business activities. Stakeholders have raised that weather research often loses out to other priorities in this process, although NIWA state that weather and climate related research utilises a large part of its research funds.

Three of the international meteorological services that were interviewed have dedicated research-to-operations teams or functions. This drives improvements in their forecasting abilities to ensure they are keeping up with technological improvements and best practice.

Fragmentation of networks, data, and forecasts create uncertainty and generate high transaction costs

The issue of disparate but also sometimes overlapping infrastructure (observation, data, etc.) has been raised by many stakeholders in and outside the context of CDEM.

For example, regional councils, MetService, and NIWA individually have developed their own observation networks. The observation data from these networks is typically not linked and therefore less comprehensive than what a fully joined set would look like. This means forecasting and modelling could potentially have great uncertainty and may not be able to be conducted at the desired resolutions for where there is little data (i.e., where there is no accessible network).

The fragmentation of these networks (i.e., not having a comprehensive national network) also means there is heterogeneity in the service users get from region to region, particularly if you cannot access weather forecasting information outside of MetService's public weather forecasts.

> "Heterogeneity in service from region to region and user group to user group... See it in all regions for different groups. It means you have differences in best practice too. Sometimes, the best warning you get is hopefully you see the MetService app has a warning for you."

These individual and separate infrastructures (that come with commercial restrictions and usage rights) mean a comprehensive national picture of weather is not as readily available as it could be. This has implications for agencies like NEMA and the ability to make strategic, national decisions (such as resource prioritisation), as well as conduct broad-scale analysis, for example, of severity or frequency of rainfall. Some regional council staff said MetService already take some of the rainfall data from regional councils and therefore may be best placed to begin this, but do not display the data at a national level. Again, this is likely a consequence of the commercial incentives MetService has (i.e., limited investment in ventures that are not expected to generate returns) as well as any restrictions MetService may face on use of data that is being shared with it (e.g., commercial contracts, through MOU).

A further issue is that because these are individual and separate infrastructures, owned and operated by different parties, each party has the potential and discretion to have their own operational procedures and way of doing things – particularly when it comes to how data is recorded, stored, and used (e.g., choice of software). There is a lack of standardisation of processes across different parties in weather forecasting which means data is not easily integrated.

The consequence of all the above is high transaction costs for parties that need to access and use a wide range of sources of data (such as CDEM organisations), because there is a job of reconciling, checking, manipulating, and merging data to be able to get it in the right format for use. The impacts of these transaction costs are likely felt most acutely in CDEM and in severe weather events because high transaction costs limit the ability for CDEM organisations to plan and effectively respond.

It is clear the format which information and data are currently provided to CDEM organisations is linked to the investment incentives the organisations face, particularly for MetService as an SOE. Despite the likely (considerable) public benefits from investing in infrastructure to make this data more accessible and easier to integrate, there would not necessarily be the commercial business case for the likes of MetService or NIWA unless these services could be monetised (and if not for this purpose, somewhere else). The costs and data infrastructure requirements are likely prohibitive, and without some form of funding, could impact the sustainability of the organisations tasked with weather forecasting and warning services. Consequently, it is reasonable to expect the weather forecasting agencies under their current structures and arrangements to provide data in the ways they currently do.

There could still be the business case at an all-of-government level and when considering the wider science and research ecosystem of New Zealand. Although, there could be coordination challenges. This raises a question of the appropriateness of contracting arrangements for weather services, particularly across government from both NIWA and MetService and whether these arrangements best serve the wants and needs of wider New Zealand. Having an array of contracts for similar and sometimes duplicate services across government may not represent good value for money, and may also contribute to the transaction costs described above (e.g., an all-of-government approach is hindered if different agencies have different data access rights).

Observation networks have been developed in isolation to serve different purposes, however there are significant domains of overlap

System fragmentation is evident across MetService and NIWA observation networks. The AWS network of MetService traces back to the earlier NZ Meteorological Service's Synoptic Station Network, comprised of 95 sites. Weather observers reported observations every three hours, totalling eight times a day. While the primary focus was on real-time data, the information from these stations also held significance for climate-related services. NIWA's network, consisting of 120 AWSs, has its roots in the former NZ Meteorological Service's Climate Network, encompassing 300 sites. In this network, observers compiled a daily summary of the previous 24 hours' weather at 9 am each day, typically submitted by post at the month's end.

Despite their distinct origins, both networks continue to uphold their foundational purpose — maintaining the country's climatological record and providing real-time weather observations for forecasting. Over time, both organisations have expanded their networks to fulfil these roles and cater to specific customer groups.

Both networks have been developed to serve each organisation’s need (at least since the two entities were set up); however, there are still significant domains of overlap (highlighted in gold), as shown in Table 5.

Table 5: MetService and NIWA observation networks

NIWA Network	MetService Network
120 Climate weather stations	100 Core Automatic Weather Stations (AWS)
749 Hydrometric Stations	131 Customer AWS locations
237 Manual Rain Gauges (voluntary observers)	10 Weather Radars
56 Automated Rain Gauges	4 Upper Air Observatories
25 Manual Climate Stations (voluntary observers)	1 Lightning Detection Network
Research-based observation programmes	Aircraft Observing Programme
13 Regional Field Maintenance Offices	1 National Field Maintenance Centre
1 Calibration Lab (Christchurch)	1 Calibration Lab (Paraparaumu)
Marine Observation Programme	Marine Observation Programme

Increasing overlap may fragment capabilities where there is sub-optimal collaboration

Beyond observation networks, NIWA has invested in developing commercial weather capabilities and the NIWA Weather website and pursued a voice in traditional and social media, leading to competition in public weather forecasting. Similarly, MetService has added Oceanography to its skillset and service offering through its purchase of MetOcean, while this is also an area of expertise for NIWA. With issues raised around potential barriers to collaboration, this may risk such skillsets not being used to their maximum potential and may not support the continual development of these areas of expertise to the extent that may be possible.

We also heard of several instances of potentially overlapping investment or products. For instance, both MetService and NIWA have explored opportunities for improved flood modelling/management across councils. While we can see the potential benefit (as noted above) from greater consistency and integration in this area, the fact that two publicly owned entities have separately investigated this (and in fact we understand there have been prior efforts from other parties as well) illustrates an example of duplicated efforts.

Adopting a consumer focus can assist with narrowing the scope of activities and making a greater impact

Some international participants explained that some NMS overseas have been guilty of neglecting consumer wants and expectations. They explained "most [NMS] are science houses that push things out…but are poor at understanding needs and…knowing who consumers are."

A shift away from operating as science houses, utilising a technology-push approach to products and services, towards a demand-pull model requires an understanding of what research is important for a consumer. This in itself is an exercise in market research, receiving feedback from consumers and channelling it into research operations. One international representative explained the circular model they have adopted:

> "We have a dedicated team [in our organisational structure] called research to operations and another called ops to research. So circular – what research is important for customer – needs to be feedback from customers."

The discussions with international participants echo what was said by Rogers and Tsirkunov (2013), in that successful NMHSs should evolve to focus on services that people need and want and actually delivering them, relying on open and ongoing dialogue with end-users. We were also advised, however, that shifting to a demand-pull model may engender some institutionalised resistance.

It is worth noting that both MetService and NIWA are incredibly consumer-focused

MetService has invested in the exploration of novel observing methods, social science research into how people/communities engage with warnings, and market research into user needs. MetService have stated they are on a journey to drive genuine, constructive behavioural response across society to hazardous weather and climate events.

The CRI model under which NIWA operates was developed specifically to ensure that the research undertaken is of benefit to New Zealand. Consequently, the 'circular model' was adopted by NIWA soon after its establishment resulting in circa 50 per cent of its revenue being derived from applied science services, i.e., science that customers want and are prepared to pay for. However, from a climate and weather forecasting perspective, this is done in isolation from MetService.

Private sector partnerships can ensure expectations are met, while maintaining a narrow scope

We heard from two international representatives that they maintain good relationships with industry to acquire data, conduct various forms of analysis, and add value. These relationships enable the NMS to move away from the model of doing everything in-house, while also meeting consumer expectations.

4.7 Enhancing models and systems for trans-Pacific utility

Value of data in remote Pacific areas

Stakeholders advised that the remote and isolated nature of certain areas in the South-West Pacific gives the data collected there significant value, not only locally but also on a global scale. Some stakeholders suggested that collaborative efforts aimed at leveraging and utilising this data could yield substantial benefits. There are good examples of both MetService and NIWA providing weather forecasting for areas of the Pacific separately but less so in collaboration.

Collaboration for public good

Stakeholders also advised that collaborating with Pacific nations is crucial for advancing meteorological capabilities for the greater public good. They noted that the resourcing and vulnerability of Pacific meteorological services, coupled with their exposure to extreme weather events, underscores the importance of shared efforts to fortify forecasting capabilities in the region.

Economic benefits of improved forecasting

Importantly, stakeholders also advised that enhancing forecasting models and systems in the Pacific region is not just about providing aid; it holds significant economic value. Improved forecasting has the potential to yield economic benefits that surpass traditional aid, emphasising the importance of collaborative initiatives aimed at fortifying meteorological capabilities in the region.

New Zealand positionality and the importance of geopolitics

International NMS representatives argued that New Zealand has a demonstrated history of successful engagement in the Pacific region, and in general internationally, and is therefore well placed to support the development of weather forecasting systems in the Pacific. It was suggested that there is also a geo-political imperative to a "five-eyes presence" in the region's weather systems. It is noted that NIWA and MetService have worked together on many occasions in the Pacific Region in a rare example of their combined capability being brought to bear often to benefit communities.

4.8 Scientific capability to meet future forecasting needs is essential

Strengthening research, education, and funding for scientific capability to meet future forecasting needs

The WMO Strategic Plan 2016-2019 (2015c) highlights the importance of the availability of *"well-trained, motivated and competent personnel to gather, process, archive and facilitate the rapid exchange of data and products."* The Plan also emphasises the importance of *"enhanced capabilities of Members to produce better weather, climate, water and related environmental information, predictions and warnings to support, in particular, reduced disaster risk and climate impact and adaptation strategies."* In meeting those imperatives, stakeholders explained it is essential that the research, education, and funding landscapes for meteorology in New Zealand are improved.

Strengthening national education in the scientific capability to meet future forecasting needs

Stakeholders argued that strengthening the national education system in the scientific capability to meet future forecasting needs is essential. Acknowledging financial constraints in competing globally, providing clarity on specialised roles and identifying crucial areas requiring expertise (such as effectively communicating weather to diverse audiences) was considered imperative to encourage long-term commitment in climate and weather forecasting education and attract students to the discipline.

Fostering diverse expertise and collaboration

Stakeholders advised meteorology demands a cohort of experts capable of collaborating across various domains. Creating international linkages in meteorological and hydrological research and education, and other required disciplines for effective forecasting, amplifies collective learning and expertise. International participants provided several rationales for international collaboration between NMSs including defence, competitiveness, and technology.

They argued global defence strategies highlight the importance of understanding oceans and atmospheric dynamics. As defence capabilities pivot toward higher technological reliance, comprehensive intelligence encompassing atmospheric, land surface, and oceanic insights becomes increasingly important. Effective deployments are contingent upon this intelligence, highlighting the value in collaboration.

They also argued that to maintain competitiveness on the global stage, independent efforts are often insufficient. Collaboration demands contribution rather than relying on others' resources. New Zealand is well-positioned to offer valuable contributions, albeit with technological disparities compared to larger international players like the EU or China. This can foster an environment of mutual respect and preventing unintentional overlaps.

Rising demand for data scientists and intermediate roles

Workshop stakeholders suggested there is an increasing need for data scientists and intermediate roles bridging domain expertise with machine learning, models, and coding.

Investment in advanced modelling and research

Investing in advanced modelling techniques and making the best use of available resources may address contemporary needs in meteorological research, according to some stakeholders.

AI, climate change, and funding

Some stakeholders argued in favour of dedicated funding for research into AI and modelling, particularly in the context of climate change, as important for advancing meteorological capabilities.

Government funding and long-term commitment

Some argued encouraging innovation in a commercial setting, while also recognising that forecasting is a public good, points towards sustained government funding and a requirement for a long-term commitment to sufficient resourcing, and a shift away from the ‘user pays’ model. Appropriate public funding was also identified, in the 2001 review of New Zealand’s forecasting and climate services, as being required to encourage scientific advances and innovation in climate forecasting.

Access to high-performance computing

Several stakeholders argued in favour of access to high-performance computing infrastructure as it improves the capacity for advanced meteorological research and modelling. Consistent with this view, previous white papers (World Meteorological Organization, 2022; World Meteorological Organization, 2021) and previous New Zealand weather system reviews have asserted that access to high-performance computing is essential for the future advancement of weather and climate forecasting. Whether that access could be through international/private sector partnerships or required investment from a publicly-owned entity operating in the system was identified as an open question.

4.9 Establishing a unified and reliable national framework

The WMO (World Meteorological Organization, 2022) vision for an idealised NMS in 2030+ includes some centralisation of some services, stating:

> "The NMS continues to play a central role in provision of weather, climate, and water services for its country. It has the mission of supporting national needs, including the protection of life and property of citizens in the context of high-impact meteorological events. The NMS will be the main representative of national interests regarding international weather, climate, and water communities and will be a facilitator of enhanced cooperation, collaboration, and coordination globally, regionally, and locally."

Stakeholders described how centralisation of some aspects of the New Zealand system could be beneficial:

Centralised data management

A number of stakeholders suggested New Zealand requires a single, centralised system for storing and cataloguing weather data. Currently, regional data exists in different places, making it incomplete. Bundling our impressive capacity in New Zealand together, it was suggested, would be beneficial.

Consistent and reliable long-term funding

Participants explained that ensuring continuous and dependable funding is crucial for maintaining our weather infrastructure. It's essential for sustainability and effective operation. Others advised that long-term funding certainty is essential for planning and adapting to future needs.

Unified infrastructure

Some participants were of the view that instead of various councils and national entities owning separate observation stations, a more efficient approach would be to establish a single service with standardised systems. This unified approach could streamline operations and ensure consistency.

Several CDEM stakeholders expressed a desire to have a range of different earth science (and other HIVE) data collated and in appropriate formats so that it is more easily and readily usable. For example, one stakeholder said they currently get separate warnings for wind and storm surges. Another said they would like the data to be shared using common geographic information systems (GIS) formats so that it can be easily linked to other data. In general, stakeholders thought hydrology should be incorporated with meteorology to be able to make the most of what each provide individually.

Some participants were of the view that competition among government providers might not be the best configuration, as the monetisation of weather data does not align with broader social goals. It was suggested combining resources could lead to cost savings and better service delivery.

4.10 Weather system stakeholders assess the system as being closed off to competition

To assess the competitiveness of the weather system, survey respondents were asked various questions about the present state of the system and the ability of suppliers to enter the system. Findings indicate that there may not be sufficient choice of suppliers and the system, and the ability of new suppliers to enter the market is limited.

Respondents were largely of the view that existing suppliers are not responsive to their needs

Respondents were asked to agree or disagree with the statement that suppliers in the weather system are responsive to the needs of customers. Respondents, across the board, reported strong disagreement with this statement.

Table 6: Suppliers' responsiveness to customer needs

Suppliers are responsive to customer needs	No. in agreement	% Agreed
Research	35	24%
Basic infrastructure (e.g., weather radar)	30	20%
Observations (e.g., raw data from radar)	28	19%
Collected and/or processed data (e.g., processed images from radar)	30	20%
Modelling (e.g., numeric models)	29	20%
Forecasting (includes interpretation)	45	30%
Products/applications	40	27%
Advisory, communications, engagement	46	31%

Source: Sapere analysis

Advisory, communications, and engagement is identified as the area where suppliers are most responsive to customer needs (31 per cent agreed), closely followed by forecasting (including interpretation 30 per cent). Concurrently, modelling and observations were the areas identified by respondents where suppliers are least responsive to customer needs, scoring 20 per cent and 19 per cent, respectively.

Respondents feel that there is limited choice available in the market

Survey respondents were asked if they agreed or disagreed with the statements “there is sufficient choice in the market”. The vast majority of respondents disagreed with this statement.

Table 7: Sufficiency of choice of suppliers in the market

There is sufficient choice in the market	No. in agreement	% Agreed
Research	32	22%
Basic infrastructure (e.g., weather radar)	34	23%
Observations (e.g., raw data from radar)	31	21%
Collected and/or processed data (e.g., processed images from radar)	30	20%
Modelling (e.g., numeric models)	34	23%
Forecasting (includes interpretation)	47	32%
Products/applications	38	26%
Advisory, communications, engagement	44	30%

Source: Sapere analysis

The extent of agreement with the statement, while low across the board, is variable per domain of the weather system.

Respondents felt that it was difficult for existing weather system suppliers to expand

Survey respondents were asked if they agreed with the statement "existing suppliers can expand". Agreement with the statement was limited to around one third of respondents across the different domains of the weather system.

Table 8: Suppliers' ability to expand

Existing suppliers can expand	No. in agreement	% Agreed
Research	54	37%
Basic infrastructure (e.g., weather radar)	51	35%
Observations (e.g., raw data from radar)	53	36%
Collected and/or processed data (e.g., processed images from radar)	47	32%
Modelling (e.g., numeric models)	55	37%
Forecasting (includes interpretation)	52	35%
Products/applications	55	37%
Advisory, communications, engagement	55	37%

Source: Sapere analysis

This suggests the ability of existing suppliers to increase the level of competition across the weather system may be prohibited.

Respondents, largely, did not agree that new suppliers can enter the weather system

Survey respondents were asked if they agreed with the statement "new suppliers can enter and compete". The vast majority of respondents across the system expressed disagreement with this statement. The domain of products and applications received the greatest level of agreement (32 per cent of respondents).

Table 9: Suppliers' ability to enter and compete in the system

New suppliers can enter and compete	No. in agreement	% Agreed
Research	33	22%
Basic infrastructure (e.g., weather radar)	20	14%
Observations (e.g., raw data from radar)	21	14%
Collected and/or processed data (e.g., processed images from radar)	23	16%
Modelling (e.g., numeric models)	35	24%
Forecasting (includes interpretation)	42	29%
Products/applications	47	32%
Advisory, communications, engagement	36	25%

Source: Sapere analysis

Products and applications are the domains of the weather system where respondents agreed the most that new suppliers can enter and compete. Concurrently, respondents indicated that basic infrastructure is the most difficult domain for new suppliers to enter and compete in.

4.11 Insufficient investment and cost recognition in weather infrastructure

The WMO (World Meteorological Organization, 2022) and previous reviews of New Zealand's forecasting and climate services have argued in favour of sufficient and sustainable funding for NMS, arguing that adequate funding is essential for encouraging advancements in climate forecasting. Stakeholders agreed with this view, highlighting several issues with the present state of the funding landscape:

Inadequate funding scaling

Stakeholders felt that current funding levels are not keeping pace with new technology and opportunities impacting the system's ability to modernise. Investment in modern data platforms was considered crucial as reliance on paper records remains, necessitating digitisation efforts.

Limitations of competing for government funding through budget processes

Stakeholders articulated a concern about securing public funding for weather infrastructure, and that this might hinder efforts to secure funding for essential advancements.

Efforts to secure funding distracting and potentially undermining strategic and long-term focus

Concern was also expressed regarding the significant time and effort spent in securing funding, diverting attention from core objectives. Improved funding models, it was suggested, could enable a more strategic and long-term approach rather than being constrained by yearly financial cycles.

Competition and cost recognition

There was also concern expressed that the availability of free online weather observations opens up competition, and by extension threatens revenues and ability to invest. It was suggested that emphasising the fixed and essential nature of weather infrastructure costs could highlight the value and necessity of ongoing investment in this area.

Separation of commercial and national interests

Some stakeholders argued that recognition is needed that weather forecasting systems should not be driven solely by commercial arrangements. The argument was made that the state's responsibility in funding vital infrastructure, such as radar networks, should be distinct from commercial endeavours.

4.12 Challenges in establishing a single authoritative weather forecasting voice

An important distinction to make is between weather forecasting and weather warning functions and services. Variety and competition in weather forecasting services more generally are not inherently bad things. When there is not a severe weather event, having the choice of a variety of models, forecasts, and services is likely important and valuable for users who can pick and choose what best suits their needs.

The views on plurality and competition tend to change when considering weather warnings for severe weather events and the potential for these events to have impacts on public safety. Authorities charged with keeping the public safe will want to be able to provide clear guidance that holds weight to encourage the appropriate behaviour change to avoid and/or minimise the impacts of the severe weather event. To do this, a provider of warnings must be seen as an authoritative voice (National Emergency Management Agency, 2013).

The WMO has a very clear position – it states the most important service provided by an NMHS is as the single authoritative voice on weather warnings within its country (Lazo et al., 2015; World Meteorological Organization, 2017). In Europe, most NMHSs are obliged to issue official and authoritative weather warnings on behalf of the government (Weyrich, 2020). Similarly, in New Zealand, MetService is the authorised provider of severe weather warnings under the MoT contract.

Although establishing a single authoritative voice was noted as generally desirable, stakeholders noted that there are several obstructions prohibiting its establishment, including:

Diverse sources of information

Stakeholders argued that the proliferation of non-official forecast sources, particularly on social media, can lead to public confusion and potential misinformation. The abundance of sources makes it challenging for the public to discern reliable information. According to these stakeholders, this confusion is compounded by the overlapping activities of two government-funded entities.

A separate voice offering warning-like messaging may not cause material issues if its messaging is broadly consistent with the official authoritative warning from MetService in both substance and timing (i.e., when the warning is issued). However, when the substance or timing of other warning-like messaging is not consistent with the official authoritative warning, and/or uses emotive and extreme language that can be perceived by the public as a warning, this could erode the power of an authoritative warning and create 'warning fatigue'[36] (Potter et al., 2021) as well as general confusion amongst public. This effect may be compounded if people are unable to recognise the authority of the provider of the information (e.g., inability to distinguish between NIWA and MetService as different agencies because both are funded by the government).

Multiple stakeholders raised concerns about NIWA's involvement in the weather forecasting space, primarily because it is also government funded and people may not easily recognise the difference between MetService and NIWA. To some, they may see both as representing the perspective of the New Zealand Government, rather than MetService or NIWA individually. One stakeholder mentioned it is further confusing because NIWA's messaging can be warning-like, even if not an authoritative and official warning.

Decentralised communication

While MetService issues warnings to councils, the responsibility for communications and decisions rests with individuals. The absence of a centralised notification system similar to the NWS in the US was considered by some stakeholders to hamper the effectiveness of red warnings or emergency alerts.

Superseding by international players

International weather entities sometimes overshadow local systems, according to stakeholders, contributing to fragmented information sources. The competitive landscape to reach consumers exacerbates communication challenges.

Discrepancies in forecast and warning information

Variances in forecast and warning information from MetService and NIWA contribute to public uncertainty and a lack of uniformity in weather reporting.

In part, different messaging may arise because of different perspectives and the knowledge and data available at the time. This also includes the use of different models and assumptions to arrive at outcomes – nuance that the audience of the weather forecasts and warnings may not recognise.

[36] Warning fatigue is also referred to as the 'cry-wolf' effect, where over-warning (i.e., warning more than necessary or appropriate) leads to people becoming apathetic, tired, or cynical of warnings and less likely to consider them as genuine or valid, and make the desired behaviour changes when there is an event that warrants action (in the context of bushfires, see Mackie, 2014).

Some CDEM stakeholders gave examples of situations of divergent information, where the CDEM stakeholders had the tacit and local knowledge to know that the conditions did not warrant a warning, despite other parties warning or using warning-like language.

One stakeholder mentioned that they believe, anecdotally, the relationship between MetService and NIWA specifically has shown signs of improvement over time and that rather than disseminating separate information, NIWA is sharing this information to MetService directly and they may feed into its official authoritative warning. Similarly, some regional councils gave the example of working with NIWA in the flood forecasting space to focus its efforts toward providing hydrological services and advice to regions that may not have the capability or resources to do it themselves, rather than for regions that do have capability and where there could be conflicting messaging.

Lack of a single authoritative voice can lead to bad outcomes

Some literature suggests competition for warning authority can delay or prevent good decision making in a severe weather event and that a key source of uncertainty for those having to interpret warnings is around recognition of authority to be providing the warning (Mileti & Sorensen, 1990). In Switzerland, it was found that inconsistency in warning messaging negatively impacted the evaluation of warning quality (Weyrich et al., 2019). Official warning messages promote the formation of accurate perceptions (of the riskiness of the event, likely impacts, etc.) only if the messages are consistent with other publicly announced advisements. In other words, inconsistency in messaging impacts the decisions made by the public and its engagement in risk-minimising behaviour during a weather event.

> "When rubber hits road is where things get confusing for citizens. Who is the voice we should be listening to? Mandate to do certain things… every time we review large scale floods, that is where most confusion resides in our communities as a whole… every time the issue is communication."

Globally, competing warning services exist on a spectrum. At one end private providers are increasingly looking to integrate authoritative warnings in their own weather forecasting services for consistency and to make their services and products more user-oriented (Kaltenberger et al., 2020), while at the other end some provide conflicting messaging and alerting. In the middle, there is variation in the extent to which the authoritative warnings are reproduced.

There is also an important distinction between target audiences – warnings provided to other CDEM organisations will likely be different than provided to the public. One CDEM stakeholder said having multiple different voices feeding different information into the CDEM system greatly increases the transaction costs of this information sharing and requires burdensome back and forth between organisations to establish and corroborate the best sources of information before being able to make decisions. This is a particular issue in emergencies because of their fast-moving nature and the desire to be able to take action as quickly as possible to avoid and/or mitigate damage and losses.

> "Shouldn't have [to have our] communications teams trying to unpick warnings [from different agencies]."

One CDEM stakeholder provided an anecdote of an emerging severe weather threat where they received different information from NIWA and MetService, where MetService was the authorised warning provider. The stakeholder's partner agency wanted to evacuate people based on the nonauthoritative warning from NIWA. Although there were no reported serious consequences, it highlights how divergent messaging can impact warning user's actions (and inaction).

Other CDEM stakeholders reported similar experiences, where there was conflicting information presented by different parties resulting in confusion and delays in decision making.

Any NMHS needs to be prepared and able to deal with challenges and divergent messaging

Scolobig et al. (2022) argue only in an ideal world would the warnings all tell the same story, and realistically the authorised provider of warning services needs to be able to monitor and issue corrective statements to counteract false information before it spreads. In light of competition in the warnings space, authorised providers should use dissemination channels and branding that are easily recognisable and associated with the trusted voice to help speed up recognition by the user and to remove the noise around the official message (Scolobig et al., 2022).

Clarity required around responsibilities and lines of accountability in emergency situations

It is crucial to know where responsibilities lie across CDEM organisations so that in an event, the appropriate and necessary actions are taken in a timely manner. This is consistent for both system and operational level organisations and includes the likes of NIWA and MetService, who feed critical information into the system. Some stakeholders suggested roles need to be made more explicit in the MoT contract for public weather forecasting and warnings, with clear links back to legislative responsibilities. Although this presents as a boundary issue to the review, we believe it is still important to note.

Isolated and separate activities mean the substance of messages can be piecemeal, and result in people not accessing all the information they need to make the best decisions possible

A key gap relates to the fragmentation of information and siloing of data and modelling (and the expertise and knowledge that sits behind it). For example, flooding and landslides often happen concurrently and therefore being able to integrate the data and modelling for both flooding and landslides would help to provide a richer picture of hazards, impacts, vulnerabilities, and exposures to allow CDEM organisations to take appropriate actions. Stakeholders implied that this integration was not currently happening in the hydrometeorological forecasting space, since the modelling for flooding sits within regional councils and/or NIWA and landslide modelling sits within GNS. The consequence of these missing links is that appropriate emergency management decisions cannot be made.[37]

[37] It is important to note GNS and NIWA work together regularly, for example, on RiskScape, in partnership with EQC. RiskScape is one tool that seeks to address this problem.

5. Principles for consideration and next steps

We have developed the below principles for developing and assessing options. These principles have been developed considering the examples of market and regulatory failures in Table 1 as well as the future needs and potential barriers to meeting these discussed in the prior section. We have included a principle relating to being practical and pragmatic to implement, conscious of minimising any impact on services.

Figure 37: Principles for developing and assessing options

- **Optimises** use of **resources** to ensure **fit-for-purpose** core forecasting, informing & warning services, including associated infrastructure & capability (public weather and climate forecasting)
- Improves **understanding/prediction of impacts, risks and necessary actions** and drives more **effective** planning and emergency management
- Reinforces **trust** in the weather forecasting system and builds **social capital** across diverse needs
- Builds strong **international links** and alliances supporting access to relevant global systems, data, infrastructure/models, and expertise
- Enables **innovation** within system, including through ensuring ready **access** to public/publicly funded information
- Is realistic, **practical** and minimises service disruption

Where:

- *Optimises use of resources* includes financial resources and different capabilities and encapsulates delivering net benefits to New Zealand and value from government investment by way of fit-for-purpose public forecasting services applying necessary inputs.
- *Improves understanding/prediction of impacts, risks and necessary actions* includes supporting collaboration across the weather forecasting systems, across hazards and with emergency management players to drive effective planning and emergency management (looking across the four Rs of emergency management – reduction, readiness, response and recovery – as well as similar thinking for other applications and sectors).
- *Reinforces trust in the weather forecasting system and builds social capital*[38] *across diverse needs* includes minimising the risk of confusion through unambiguous information from official sources and recognising the diverse needs of users and the importance of effective engagement. This is likely to involve clear roles and messaging around warnings and watches.

[38] Social capital is defined in the likes of https://www.treasury.govt.nz/publications/speech/social-capital-and-living-standards-framework which states "Social capital refers to the social connections, attitudes and norms that contribute to societal wellbeing by promoting coordination and collaboration between people and groups in society".

- B*uilds strong international links and alliances supporting access to relevant global systems, data, infrastructure/models, and expertise* includes building on the existing relationships and forums for engagement and partnership.
- *Encourages innovation within the system* includes an openness to private competition and closeness to user demands. Importantly, it also involves working across the public and private parties and ensuring ready and easy access to public/publicly funded information (including channels to disseminate information) and ability to draw on and apply that information (such as appropriate formats and systems). However, this could be available for free or incorporate a charge to recover the cost of making this available (including both the marginal cost of provision and a contribution to appropriate overheads).
- *Being realistic and practical* also includes the management of any transition.

In addition to using these principles, Appendix G presents some of what we can learn from international experience.

5.1 Next steps

The next steps from here are:

- Develop a long-list and then short-list of potential options.
- Analyse the options, including assessment of the short-listed options against the above principles and cost-benefit analysis of any recommended option against the status quo.
- Draft overall review thinking discussed with the steering group in March.
- Draft report shared with MBIE and Treasury at the end of March for feedback.
- Report finalised in April.

References

Alley, R. B., Emanuel, K. A., & Zhang, F. (2019). Advances in weather prediction. *Science*, *363*(6425), 342–344. https://doi.org/10.1126/science.aav7274

Anand, V. (2022). *Does Getting Forecasts Earlier Matter? Evidence from Winter Advisories and Vehicle Crashes* (SSRN Scholarly Paper 4206910). https://doi.org/10.2139/ssrn.4206910

Auliagisni, W., Wilkinson, S., & Elkharboutly, M. (2022). Learning from Floods—How a Community Develops Future Resilience. *Water*, *14*(20), Article 20. https://doi.org/10.3390/w14203238

Bi, K., Xie, L., Zhang, H., Chen, X., Gu, X., & Tian, Q. (2023). Accurate medium-range global weather forecasting with 3D neural networks. *Nature*, *619*(7970), Article 7970. https://doi.org/10.1038/s41586-023-06185-3

Cabinet Office. (2008). *The Pitt Review—Learning Lessons from the 2007 floods*. Cabinet Office. https://webarchive.nationalarchives.gov.uk/ukgwa/20100702215619/http://archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html

Chambers, L. E., Plotz, R. D., Lui, S., Aiono, F., Tofaeono, T., Hiriasia, D., Tahani, L., Fa'anunu, 'Ofa, Finaulahi, S., & Willy, A. (2021). Seasonal Calendars Enhance Climate Communication in the Pacific. *Weather, Climate, and Society*, *13*(1), 159–172. https://doi.org/10.1175/WCAS-D-20-0035.1

Coskun, E., & Ozceylan, D. (2011). *Complexity in Emergency Management and Disaster Response Information Systems (EMDRIS)*. International ISCRAM Conference, Lisbon, Portugal. https://idl.iscram.org/files/coskun/2011/415_Coskun+Ozceylan2011.pdf

Crown Company Monitoring Advisory Unit. (2004). *Meteorlogical Service of New Zealand Ltd (MetService) and the National Institute of Water and Atmospheric Reserach Ltd (NIWA): Briefing for meeting 24 Novmeber 2004*.

Crown Company Monitoring Advisory Unit, Treasury, & Ministry of Research, Science and Technology. (2006). *Final Report on Organisational and Purchase Arrangements Supporting New Zealand's Weather, Climate, and Environmental Forecasting Functions*.

Department of the Prime Minister and Cabinet. (2022, December 15). *New Zealand's Nationally Significant Risks*. Department of Prime Minister and Cabinet. https://www.dpmc.govt.nz/our-programmes/national-security/national-risk-approach/new-zealands-nationally-significant-risks

Duke, D. C., Godel, M., Koch, L., Suter, J., & Ladher, R. (2016). *A study of the economic impact of the services provided by the Bureau of Meteorlogy*. London Economics. https://reg.bom.gov.au/inside/London_Economics_Study_of_the_Bureau_of_Meteorology_2016_Final.pdf

European Space Agency. (2016). *A cost-benefit analysis of the SSA programme*. https://esamultimedia.esa.int/docs/business_with_esa/Space_Weather_Cost_Benefit_Analysis_ESA_2016.pdf

Fang, T.-W., Kubaryk, A., Goldstein, D., Li, Z., Fuller-Rowell, T., Millward, G., Singer, H. J., Steenburgh, R., Westerman, S., & Babcock, E. (2022). Space Weather Environment During the SpaceX Starlink Satellite Loss in February 2022. *Space Weather*, *20*(11), e2022SW003193. https://doi.org/10.1029/2022SW003193

Fiebrich, C. A. (2009). History of surface weather observations in the United States. *Earth-Science Reviews*, *93*(3–4), 77–84. https://doi.org/10.1016/j.earscirev.2009.01.001

Flood Forecasting Centre. (2022, November 1). *Flood Guidance Statement user guide*. GOV.UK. https://www.gov.uk/government/publications/flood-guidance-statement-fgs-user-guide/flood-guidance-statement-user-guide

Francis. (2015). *Météo-France GRIB files finally for free – Navigation Mac*. https://www.navigation-mac.fr/les-fichiers-grib-de-meteo-france-enfin-libres/?lang=en

Frei, T. (2010). Economic and social benefits of meteorology and climatology in Switzerland. *Meteorological Applications*, *17*(1), 39–44. https://doi.org/10.1002/met.156

Gabrielsen, H., Procter, J., Rainforth, H., Black, T., Harmsworth, G., & Pardo, N. (2018). Reflections from an Indigenous Community on Volcanic Event Management, Communications and Resilience. In C. J. Fearnley, D. K. Bird, K. Haynes, W. J. McGuire, & G. Jolly (Eds.), *Observing the Volcano World: Volcano Crisis Communication* (pp. 463–479). Springer International Publishing. https://doi.org/10.1007/11157_2016_44

Golding, B. (Ed.). (2022). *Towards the "Perfect" Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication*. Springer International Publishing. https://doi.org/10.1007/978-3-030-98989-7

Harrison, S. E. (2022). *Exploring the data needs and sources for severe weather impact forecasts and warnings: A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Emergency Management at Massey University, Wellington, New Zealand* [Massey University]. http://hdl.handle.net/10179/16939

Harrison, S. E., Potter, S. H., Prasanna, R., Doyle, E. E. H., & Johnston, D. (2021). 'Where oh where is the data?': Identifying data sources for hydrometeorological impact forecasts and warnings in Aotearoa New Zealand. *International Journal of Disaster Risk Reduction*, *66*, 102619. https://doi.org/10.1016/j.ijdrr.2021.102619

Harrison, S. E., Potter, S. H., Prasanna, R., Doyle, E. E. H., & Johnston, D. (2022). Identifying the Impact-Related Data Uses and Gaps for Hydrometeorological Impact Forecasts and Warnings. *Weather, Climate, and Society*, *14*(1), 155–176. https://doi.org/10.1175/WCAS-D-21-0093.1

Hatori, M., Toya, T., Tonouchi, M., Yokoyama, H., Mikami, M., Jyoumura, T., & Makihara, Y. (2016). *Modernization of Meteorological Services in Japan and Lessons for Developing Countries*. World Bank Global Facility for Disaster Reduction & Recovery.

Hertzfeld, H. R., Williamson, R. A., & Sen, A. (2004). Weather satellites and the economic value of forecasts: Evidence from the electric power industry. *Acta Astronautica*, *55*(3), 791–802. https://doi.org/10.1016/j.actaastro.2004.05.015

Kaltenberger, R., Schaffhauser, A., & Staudinger, M. (2020). "What the weather will do" – results of a survey on impact-oriented and impact-based warnings in European NMHSs. *Advances in Science and Research*, *17*, 29–38. https://doi.org/10.5194/asr-17-29-2020

Katz, R. W., & Lazo, J. K. (2011). Economic Value of Weather and Climate Forecasts. In M. P. Clements & D. F. Hendry (Eds.), *The Oxford Handbook of Economic Forecasting* (p. 0). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195398649.013.0021

Katz, R. W., & Murphy, A. H. (1997). *Economic Value of Weather and Climate Forecasts*. Cambridge University Press.

Kimble, C. (2012). *Knowledge management, codification and tacit knowledge*. https://informationr.net/ir/18-2/paper577.html

King, D. N. T., Goff, J., & Skipper, A. (2007). Māori environmental knowledge and natural hazards in Aotearoa-New Zealand. *Journal of the Royal Society of New Zealand*, *37*(2), 59–73. https://doi.org/10.1080/03014220709510536

King, D. N. T., Skipper, A., & Tawhai, W. B. (2008). Māori environmental knowledge of local weather and climate change in Aotearoa – New Zealand. *Climatic Change*, *90*(4), 385–409. https://doi.org/10.1007/s10584-007-9372-y

Kull, D., Riishojgaard, L. P., Eyre, J., & Varley, R. A. (2021). *The Value of Surface-based Meteorological Observation Data*. World Bank. https://doi.org/10.1596/35178

Lambert, S., & Mark-Shadbolt, M. (2021). Indigenous Knowledges of forest and biodiversity management: How the watchfulness of Māori complements and contributes to disaster risk reduction. *AlterNative: An International Journal of Indigenous Peoples*, *17*(3), 368–377. https://doi.org/10.1177/11771801211038760

Lang, S. (2024, January 16). *First update to the AIFS* [Text]. ECMWF. https://www.ecmwf.int/en/about/media-centre/aifs-blog/2024/first-update-aifs

Lazo, J., Bushek, N., Laidlaw, E., Raucher, R., Teisberg, T., Wagner, C., & Weiher, R. (2015, November 12). Economic Valuation and Application of Services. *World Meteorological Organization*. https://public-old.wmo.int/en/bulletin/economic-valuation-and-application-services

Lazo, J., & Chestnut, L. (2002). *Economic Value of Current and Improved Weather Forecasts in the U.S. Household Sector*. US Department of Commerce. https://www.researchgate.net/profile/Jeffrey-Lazo/publication/268415603_Economic_Value_of_Current_and_Improved_Weather_Forecasts_in_the_US_Household_Sector/links/570ebb3d08aee328dd6548c7/Economic-Value-of-Current-and-Improved-Weather-Forecasts-in-the-US-Household-Sector.pdf

Legifrance. (n.d.). *Légifrance—National law in force—Circulars and instructions—Circular n°6264/SG of April 27, 2021 relating to public policy on data, algorithms and source codes*. Retrieved December 15, 2023, from https://www.legifrance.gouv.fr/download/pdf/circ?id=45162

Lloyd's. (2018). *A world at risk: Closing the insurance gap*. https://assets.lloyds.com/assets/pdf-lloyds-underinsurance-report-final/1/pdf-lloyds-underinsurance-report-final.pdf

London Economics. (2015). *Met Office—General Review*. London Economics. https://londoneconomics.co.uk/wp-content/uploads/2016/03/MET-Office-General-Review-Final-Published.pdf

Mackie, B. (2014). *Warning fatigue: Insights from the Australian Bushfire Context*. http://hdl.handle.net/10092/9029

MBIE. (2017). *Weather Permitting: Review of open access to weather data in New Zealand*.

McDonald, R. A. (2022). *He moana pukepuke e ekengia e te waka: Navigating a changing climate: A waka voyaging perspective* [Thesis, The University of Waikato]. https://researchcommons.waikato.ac.nz/handle/10289/15749

Météo France. (2022). *The objectives and performance contract*. https://meteofrance.fr/etablissement/strategie/le-contrat-dobjectifs-et-de-performance

Météo France. (2023). *As of January 1, 2024, all Météo-France public data will have the possibility of access without any cost and will be reusable free of charge | Meteo France*. https://meteofrance.fr/actualite/presse/au-1er-janvier-2024-donnees-publiques-en-acces-libre

MetService. (2020). *MetService Briefing to Incoming Ministers*. MetService. https://www.beehive.govt.nz/sites/default/files/2020-12/State%20Owned%20Enterprises%20-%20MetService.pdf

MetService. (2022). *MetService Statement of Corporate Intent 2022/23—2024/25*. https://about.metservice.com/assets/Company-documents/MetService-Statement-of-Corporate-Intent-June-2022-Final.pdf

MetService. (2023a). *Forecasting Success: Maximising capability for a changing climate*.

MetService. (2023b, October 25). *Hau Nuku Weather Forecasting Review: MetService's Observing Programmes*.

Mileti, D. S., & Sorensen, J. H. (1990). *Communication of emergency public warnings: A social science perspective and state-of-the-art assessment* (ORNL-6609). Oak Ridge National Lab. (ORNL), Oak Ridge, TN (United States). https://doi.org/10.2172/6137387

Minister of Transport, & MetService. (2023). *Amendement Agreement relating to the procurement of meteorological and related services*. Ministry of Transport.

Ministry for the Environment. (2022). *Aotearoa New Zealand's first national adaptation plan*. https://environment.govt.nz/assets/publications/climate-change/MFE-AoG-20664-GF-National-Adaptation-Plan-2022-WEB.pdf

Ministry for the Environment. (2023, October 11). *New report highlights pressures on Aotearoa New Zealand's climate*. Ministry for the Environment. https://environment.govt.nz/news/new-report-highlights-pressures-on-aotearoa-new-zealands-climate/

Ministry of Justice (Japan). (1952, June 2). *Japan Meteorological Service Act English Translation*. https://www.japaneselawtranslation.go.jp/en/laws/view/1968/en#je_ch3

Molina, R., & Rudik, I. (2022). *The Social Value of Predicting Hurricanes* (SSRN Scholarly Paper 4266614). https://doi.org/10.2139/ssrn.4266614

National Civil Defence Emergency Management Plan Order (2015). https://www.legislation.govt.nz/regulation/public/2015/0140/latest/whole.html#whole

National Emergency Management Agency. (2013). *Public Information Management*. National Emergency Management Agency. https://www.civildefence.govt.nz/cdem-sector/guidelines/public-information-management

National Emergency Management Agency. (2015). *Guide to the National CDEM Plan 2015: Management of emergencies*. National Emergency Management Agency. https://www.civildefence.govt.nz/assets/Uploads/documents/publications/guide-to-the-national-cdem-plan/Guide-to-the-National-CDEM-Plan-2015-Section-03.pdf

National Research Council. (2003). *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations*. The National Academies Press. https://doi.org/10.17226/10658

New Zealand Government. (2019). *Coordinated Incident Management System (CIMS): Third edition*. New Zealand Government. https://www.civildefence.govt.nz/assets/Uploads/documents/cims/CIMS-3rd-edition-FINAL-Aug-2019.pdf

New Zealand Treasury. (2017). *Guidance Note: Best Practice Impact Analysis*. New Zealand Treasury. https://www.treasury.govt.nz/sites/default/files/2018-03/ia-bestprac-guidance-note.pdf

NIWA. (n.d.). *Climate, weather & extremes: Impacts, risk, planning & prioritisation*.

NIWA. (2017). *Traditional Māori Weather and Climate Forecasting*. https://niwa.co.nz/sites/niwa.co.nz/files/Traditional-Maori-Weather-and-Climate-Forecasting-poster.pdf

NIWA. (2022). *Science for a resilient future: NIWA annual report 2022* (p. 36). https://niwa.co.nz/sites/niwa.co.nz/files/FINAL_NIWA_AR%202021_22.pdf

NIWA. (2023a). *NIWA Statement of Corporate Intent 2023/24*.

NIWA. (2023b, November 10). *Current Forecasting Capabilities: Weather, Climate, Atmosphere, Hazards, Water, Oceans*.

NIWA. (2023c, November 10). *NIWA Forecasting System*.

NZIER. (2018). *The value of MetService's public weather forecasts and weather warnings*. NZIER. https://www.nzier.org.nz/hubfs/Public%20Publications/Client%20reports/the_value_of_metservice_final_report_february_2018.pdf

Olomolaiye, A., & Egbu, C. (2005, November 1). *Tacit vs. Explicit knowledge—The current approaches to knowledge management*. https://www.semanticscholar.org/paper/Tacit-vs.-explicit-knowledge-the-current-approaches-Olomolaiye-Egbu/f44058c34ff507e59e65c3262beb9d5c0d501a79

Park, S.-Y., Lim, S.-Y., & Yoo, S.-H. (2016). The Economic Value of the National Meteorological Service in the Korean Household Sector: A Contingent Valuation Study. *Sustainability*, *8*(9), Article 9. https://doi.org/10.3390/su8090834

Polanyi, M. (1958). *Personal Knowledge: Towards a Post-Critical Philosophy* (M. J. Nye, Ed.). University of Chicago Press.

Polis. (2023, October 30). *Forecasting success: Maximising capability for a changing climate*.

Potter, S., Harrison, S., & Kreft, P. (2021). The Benefits and Challenges of Implementing Impact-Based Severe Weather Warning Systems: Perspectives of Weather, Flood, and Emergency Management Personnel. *Weather, Climate, and Society*, *13*(2), 303–314. https://doi.org/10.1175/WCAS-D-20-0110.1

Potter, S., Kreft, P., Milojev, P., Noble, C., Montz, B., Dhellemmes, A., Woods, R., & Gauden-Ing, S. (2018). The influence of impact-based severe weather warnings on risk perceptions and intended protective actions. *International Journal of Disaster Risk Reduction*, *30*, 34–43. https://doi.org/10.1016/j.ijdrr.2018.03.031

Radio New Zealand. (2023a, January 31). *Auckland flood victims: The four people killed in extreme and unprecedented weather event*. RNZ. https://www.rnz.co.nz/news/national/483404/auckland-flood-victims-the-four-people-killed-in-extreme-and-unprecedented-weather-event

Radio New Zealand. (2023b, February 20). *Cyclone Gabrielle: Who are the 11 victims?* RNZ. https://www.rnz.co.nz/news/national/484536/cyclone-gabrielle-who-are-the-11-victims

Repia, H., & Jo, B. (2021). Designing tsunami risk communication with communities: A site-specific case study from Tūranganui-a-Kiwa, Aotearoa New Zealand. *Australasian Journal of Disaster & Trauma Studies*, *25*(1). https://web.s.ebscohost.com/abstract?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=11744707&AN=151477220&h=1P2NdZoEjXil4xzTXhVg4gaMsfnpf2acwzkeyCcU%2fy05SoN1Ep3RGg0%2b6AF3LjxU98MLN%2fnrSQ2r4LBrxhozkg%3d%3d&crl=c&resultNs=AdminWebAuth&resultLocal=ErrCrlNotAuth&crlhashurl=login.aspx%3fdirect%3dtrue%26profile%3dehost%26scope%3dsite%26authtype%3dcrawler%26jrnl%3d11744707%26AN%3d151477220

Rogers, D. P., Tsirkunov, V., Thorpe, A., Bogdanova, A.-M., Suwa, M., Kootval, H., Hodgson, S., & Staudinger, M. (2021). *The Level Playing Field: Business of Weather, Water, and Climate Services*. http://hdl.handle.net/10986/35670

Rogers, D. P., & Tsirkunov, V. V. (2013). *Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-0026-9

Scolobig, A., Potter, S., Kox, T., Kaltenberger, R., Weyrich, P., Chasco, J., Golding, B., Hilderbrand, D., Fleischhut, N., Uprety, D., & Rana, B. (2022). Connecting Warning with Decision and Action: A Partnership of Communicators and Users. In B. Golding (Ed.), *Towards the "Perfect" Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication* (pp. 47–85). Springer International Publishing. https://doi.org/10.1007/978-3-030-98989-7_3

Shrader, J. G., Bakkensen, L., & Lemoine, D. (2023). *Fatal Errors: The Mortality Value of Accurate Weather Forecasts* (Working Paper 31361). National Bureau of Economic Research. https://doi.org/10.3386/w31361

Steiner, J. T., Martin, J. R., Gordon, N. D., & Grant, M. A. (1997). Commercialisation in the provision of meteorological services in New Zealand. *Meteorological Applications*, *4*(3), 247–257. https://doi.org/10.1017/S1350482797000480

Stephens, E., & Cloke, H. (2014). Improving flood forecasts for better flood preparedness in the UK (and beyond). *The Geographical Journal*, *180*(4), 310–316. https://doi.org/10.1111/geoj.12103

Suwa, M., Bogdanova, A., Siercke, G., & Kull, D. (2020). *The Power of Partnership: Public and Private Engagement in Hydromet Services*. World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/910251601530521791/The-Power-of-Partnership-Public-and-Private-Engagement-in-Hydromet-Services

Thomas, A., McDonald, A., Renwick, J., Tradowsky, J. S., Bodeker, G. E., & Rosier, S. (2023). Increasing temperature extremes in New Zealand and their connection to synoptic circulation features. *International Journal of Climatology*, *43*(3), 1251–1272. https://doi.org/10.1002/joc.7908

UK Met Office. (n.d.-a). *History of numerical weather prediction*. History of Numerical Weather Prediction. Retrieved January 17, 2024, from https://www.metoffice.gov.uk/weather/learn-about/how-forecasts-are-made/computer-models/history-of-numerical-weather-prediction

UK Met Office. (n.d.-b). *Numerical weather prediction models*. Met Office. Retrieved January 17, 2024, from https://www.metoffice.gov.uk/research/approach/modelling-systems/unified-model/weather-forecasting

UK Met Office. (2023). *How valuable is the Met Office?* UK Met Office. https://www.metoffice.gov.uk/about-us/what/pws/value

UNDRR. (2007, August 30). *Early warning system*. United Nations Office for Disaster Risk Reduction. http://www.undrr.org/terminology/early-warning-system

UNDRR. (2023). *Global status of multi-hazard early warning systems 2023*. UN Office of Disaster Risk Reduction. https://www.undrr.org/reports/global-status-MHEWS-2023

USAID. (2013). *The Value of Climate Services Across Economic and Public Sectors: A review of relevant literature*. United States Agency for International Development. https://pdf.usaid.gov/pdf_docs/PA00KJXW.pdf

Weyrich, P. (2020). *To act or not to act: Warning communication and decision-making in response to weather-related hazards* [Doctoral Thesis, ETH Zurich]. https://doi.org/10.3929/ethz-b-000404058

Weyrich, P., Scolobig, A., & Patt, A. (2019). Dealing with inconsistent weather warnings: Effects on warning quality and intended actions. *Meteorological Applications*, *26*(4), 569–583. https://doi.org/10.1002/met.1785

Williams, S., Nitschke, M., Wondmagegn, B. Y., Tong, M., Xiang, J., Hansen, A., Nairn, J., Karnon, J., & Bi, P. (2022). Evaluating cost benefits from a heat health warning system in Adelaide, South Australia. *Australian and New Zealand Journal of Public Health*, *46*(2), 149–154. https://doi.org/10.1111/1753-6405.13194

World Meteorological Organization. (2015a). *Valuing Weather and Climate: Economic assessment of meteorological and hydrological services*. World Meteorological Organization. https://documents1.worldbank.org/curated/en/711881495514241685/pdf/Valuing-weather-and-climate-economic-assessment-of-meteorological-and-hydrological-services.pdf

World Meteorological Organization. (2015b). *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services*. World Meteorological Organization. https://library.wmo.int/records/item/54669-wmo-guidelines-on-multi-hazard-impact-based-forecast-and-warning-services

World Meteorological Organization. (2015c). *WMO Strategic Plan 2016-2019* (WMO-No. 1161; p. 20). https://library.wmo.int/viewer/54863/download?file=wmo_1161_en.pdf&type=pdf&navigator=1

World Meteorological Organization. (2015d, November 12). *Public Weather Services for Disaster Risk Reduction*. World Meteorological Organization. https://public-old.wmo.int/en/bulletin/public-weather-services-disaster-risk-reduction

World Meteorological Organization. (2015e, November 27). *About us*. https://public-old.wmo.int/en/about-us

World Meteorological Organization. (2017). *Guidelines on the Role, Operation and Management of National Meteorological and Hydrological Services* (WMO-No. 1195). World Meteorological Organization. https://library.wmo.int/records/item/55823-guidelines-on-the-role-operation-and-management-of-national-meteorological-and-hydrological-services

World Meteorological Organization. (2018). *Multi-hazard Early Warning Systems: A Checklist*. World Meteorological Organization. https://library.wmo.int/records/item/55893-multi-hazard-early-warning-systems-a-checklist#.W_PbsKlRdR4

World Meteorological Organization. (2021). *WMO Open Consultative Platform White Paper #1—Future Weather and climate forecasting*. World Meteorological Organization.

World Meteorological Organization. (2022). *Future of National Meteorological or Hydrometeorological Services: Evolving roles and responsibilities*. https://library.wmo.int/records/item/57995-wmo-open-consultative-platform-white-paper-2?offset=44

World Meteorological Organization. (2023, January 20). *WMO Members*. World Meteorological Organization. https://wmo.int/about-wmo/wmo-members

Appendix A Key inputs to our review

We discuss the documents received to inform our review, as well as the interviews held and external expertise we tested key aspects with.

Documents received

To inform our analysis, in addition to publicly available information, we requested and reviewed documents from:

- MBIE and the Treasury in relation to prior reviews and their monitoring of MetService and NIWA.
- MetService and NIWA relating to (among other things):
  - Revenue, spending and personnel
  - Strategy and future trends
  - Organisational structure
  - Observation networks
  - Data and information systems
  - Key relationships
- Additional material was provided by the above organisations or others we met where identified as potentially relevant to the review. A summary of key documents reviewed is below.

Source	Documents	Notes
MBIE	10	Briefings to shareholding Ministers, 2001 review, 2006 review, MoU between NIWA and MetService.
MetService	64	Governance and legislation, briefings and board inductions, strategies, MoT contract, quarterly reports.
NIWA	22	Documents from initial presentation and high-level responses to questions.
Project partners	16	Documents to help inform the weather landscape, identify future demands, international standards, benchmarks, etc.
Other	100+	White papers, journal articles, and annual reports

Interviews held

Our team held interviews with the following as input to the review. We consulted MBIE, the Treasury, MetService and NIWA on appropriate stakeholders to meet with and to identify relevant contacts. To date we have met with the following:

- The Project Steering Group
- Treasury
- MBIE (various parts)
- MetService (various parts)
- NIWA (various parts)
- Chief Science Advisors Forum
- Ministry of Transport
- Ministry for Primary Industries
- Ministry of Foreign Affairs and Trade (2 parts)
- Department of Internal Affairs
- Royal New Zealand Airforce
- New Zealand Defence Force
- Fire And Emergency New Zealand
- Department of Conservation
- Civil Aviation Authority
- Maritime New Zealand
- National Emergency Management Authority
- Te Whatu Ora
- GNS (various parts)
- ESR
- Mountain Safety Council
- Surf Life Saving New Zealand
- Milford Road Alliance
- Met Office (UK)
- WMO
- Australian Bureau of Meteorology
- Meteorological Service of Canada
- National Oceanic and Atmospheric Administration
- Northland Regional Council
- Wellington Region Emergency Management Office
- Horizons Regional Council
- Bay of Plenty Regional Council
- Tasman District Council
- Hawke's Bay Regional Council
- Auckland Council
- Oceanum Ltd
- Auckland University of Technology
- Bodeker Scientific
- Weather Watch
- Blue Skies
- TVNZ
- Air New Zealand
- Meridian Energy
- Climate Prescience

- Sanford
- Victoria University of Wellington
- University of Canterbury
- University of Otago
- Waka Kotahi and Auckland Transport
- Moana New Zealand
- Project Moana personnel
- Members of the science community
- A retired meteorologist.

In addition to these interviews, we held a workshop during the Meteorological Society's annual conference as part of the review.

Survey

A survey was issued to identified stakeholders, including members of the Meteorological Society, and Met Service and NIWA to circulate with relevant staff. Stakeholders were also able to share the survey with others, in a form of snowball sampling.

The survey consisted of 22 qualitative and quantitative questions. Questions were asked to:

- determine respondents' associations with the weather system
- determine respondent perceptions of the functioning of the weather system
- identify gaps in the weather system
- identify future needs for New Zealand's weather system
- identify barriers to meeting future needs
- understand how respondents perceive the competitive and cooperative landscape of the weather system.

145 responses to the survey were received from respondents from a range of backgrounds and experience. Survey responses were treated anonymously.

External expertise

In order to test and work through aspects of the review, we are consulting the following external experts at key stages of the review:

- David Smol
- Neil Gordon
- Richard Jefferies
- Russell McMurray
- Kyle Clem.

Appendix B Past reviews of the weather and climate forecasting system

2001 independent review of New Zealand's Weather Forecasting and Climate Services

Purpose

To identify if there is any material risk in the long-term to the future capability of New Zealand's weather forecasting and climate service (including forecasting related hazards) by maintaining the present separation between NIWA and MetService. If such material risk exists, what is the quantified extent of that risk?

Findings

- Although it made sense in 1992 to divide responsibility for weather forecasting and climate service delivery (including forecasting related hazards), scientific and technological advances had blurred the lines between them.
- MetService and NIWA regard each other as competitors rather than effective collaborators and opportunities for collaboration were already being lost.
- The long-term risk to future capabilities by not collaborating were medium to high with potentially moderate or significant impact on operational capability, scientific capacity, and societal, economic, and business competencies if the risk materialised. For example, the review found that New Zealand's scientific capacity in weather forecasting and climate services was compromised by the separation. Examples they gave was low levels of resourcing available for some research projects and a lack of strong operational and cultural linkages between operational and research elements. The review correctly predicted the growing importance of multi-disciplinary linkages (e.g., meteorology and flooding) and noted that MetService and NIWA would not realise their potential under the current separation.
- The net economic benefit of the at-risk revenue was estimated to range between zero and about $30 million.

Recommendations

The review recommended that a strategic assessment group be established to analyse the policy, feasibility, and practical implications of three options for reducing the risk of ongoing separation of MetService and NIWA. The options put forward were:

- No change
- Status quo, complemented by shareholding Ministers setting out expectations regarding the management of the relationship between NIWA and MetService

- Maintain existing operations in their present forms but re-define the specifications of the current Ministry of Transport (MoT) and Foundation for Research, Science and Technology (FRST) contract regimes.

Outcome

Following the review, shareholding Ministers set out their expectations in letters to the Chairs of the organisations to encourage closer working between them:

- NIWA to become the preferred supplier of R&D for MetService
- MetService to become a preferred commercialisation partner of NIWA's research work
- Two common directors be maintained on the Board of each company.

The 2006 review recommended MetService and NIWA merge and resulted in an MOU

Purpose

The 2006 review was commissioned because shareholding Ministers again had concerns of the possible risk to New Zealand's national weather forecasting and climate system. Shareholding Ministers' preferences following the 2001 review had not been meaningfully progressed other than to maintain two common directors on the Board of each company. Concerns were initially raised because one of the joint directors wrote to Ministers about the potential commercial risk posed to MetService from NIWA working with the UK Met Office to develop an operational forecasting service.

The purpose of this review was to determine what changes to the organisational and purchasing arrangements of the national weather and climate functions would be most likely to result in the minimisation of the risk to New Zealand's weather and climate functions and deliver the greatest benefit to New Zealand (Crown Company Monitoring Advisory Unit et al., 2006).

Findings

The 2006 review found that the capability risk identified in 2001 remained and had two major elements:

- Current arrangements lack integration and are unlikely to enable New Zealand to obtain maximum benefit from its weather, environmental and climate-related capabilities.
- Increasing levels of duplication in infrastructure and human capital are likely to develop as MetService and NIWA pursue their separate strategic directions.

The 2006 review stated that environmental forecasting (including hazard forecasting) would play an increasingly significant role in the future development of national capability. The review also noted the SOE and CRI framework made it inevitable that Met Service and NIWA would become either collaborators or competitors.

Recommendations

The review considered there to be a strong national benefit argument to support the development of a nationally coordinated weather, climate, and environmental function. Four options were put forward, with the recommended option being that MetService and NIWA merge. This was considered the most likely option to address the two components of capability risk and deliver a national strategy.

Outcome

Shareholding Ministers concluded that the risks associated with structural change were too high and decided to continue with the current arrangements and identify areas of mutual interest where MetService and NIWA can engage constructively and positively.

Shareholding Ministers asked the Chairs to increase the level of strategic integration between the research and operational components of the national weather, environment, and climate forecasting functions.

NIWA and MetService subsequently signed a Memorandum of Understanding in 2007 on the scope and process for ongoing collaboration between the two organisations and agreed on a set of National Benefit Objectives.

The 2018 review suggested possible gains from improved access to data but change would be needed to operating models

Purpose

The 2018 *Open Access to Weather Data* review[39] investigated if there is a level of government held weather data (in addition to weather data already accessible to the public) which should be opened for public access to better stimulate innovation and economic growth. The review was limited in scope to raw observational data.

Findings

This review found that, when compared internationally, New Zealand's model is positioned at the most commercial and restrictive end in terms of cost and limitations on data use. This is largely due to the SOE and CRI models that MetService and NIWA operate under, respectively. For example, MetService made a limited amount of data open access but it is difficult to interpret and use. The

[39] The 'Weather permitting' review report was written in 2017, however the review was not concluded until 2018.

review found that the data access arrangements may be limiting innovation and economic opportunities in value-added products and services using weather data.

The review determined that making raw observational data more accessible would likely increase gains for commercial users and encourage competition in the market for weather services by allowing others to participate.

Making more data freely available was considered inconsistent with MetService's mandate as an SOE and it was suggested that legislative change would be needed to alter MetService's funding model. The review stated that NIWA could make its data freely available under the existing model, however, the shortfall in revenue would need to be funded by the government.

Recommendations

The 2018 review did not make recommendations.

Outcomes

Data access arrangements for NIWA's and MetService's data have remained restrictive and both organisations continue to charge users for access under restrictive licensing agreements. It is worth noting that when the review was done France was used as a comparable country and the review found that, at the time, France was also at the commercial end of the data availability spectrum (see Figure 38) (MBIE, 2017). However, as noted in the case study below, France has since developed an open data policy and is making data freely available via accessible APIs with non-restrictive limitations on data use.

Figure 38: Table from the 2017 review 'Weather Permitting' on data availability across countries.

		Open data policy	Accessible API	Real-time data available	Non-restrictive licensing	Free or minimal cost
Countries	USA	✓	✓	✓	✓	✓
	Norway	✓	✓	✓	✓	✓
	Australia	✓	✗	✓	✓	✗
	UK	✓	✓	✓	✓	✓
	France	✗	✗	✓	✗	✗
	New Zealand	✓	✗	✓	✗	✗

Source: (MBIE, 2017)

Appendix C Emergency Management in New Zealand

The Officials Committee for Domestic and External Security Coordination (ODESC) boards, the Hazard Risk Board, and the Security and Intelligence Board oversee and govern New Zealand's management of national risks (Department of the Prime Minister and Cabinet, 2022). DPMC maintains a National Risk Register to support a proactive and coordinated approach to identification and management of significant risks to New Zealand (Department of the Prime Minister and Cabinet, 2022).

The management of emergencies deemed nationally significant is organised through the ODESC system. The ODESC system is in place for any emergency requiring national management, coordination, or support. It is used by central government in the oversight and governance of national security issues, including during events where the consequences are of national significance and therefore an all-of-government approach to prioritise and act in response is warranted. It serves a coordinating function to advise Ministers, bring together analysis from different perspectives and areas to help develop options for response, and ultimately assists the decision making of the government.

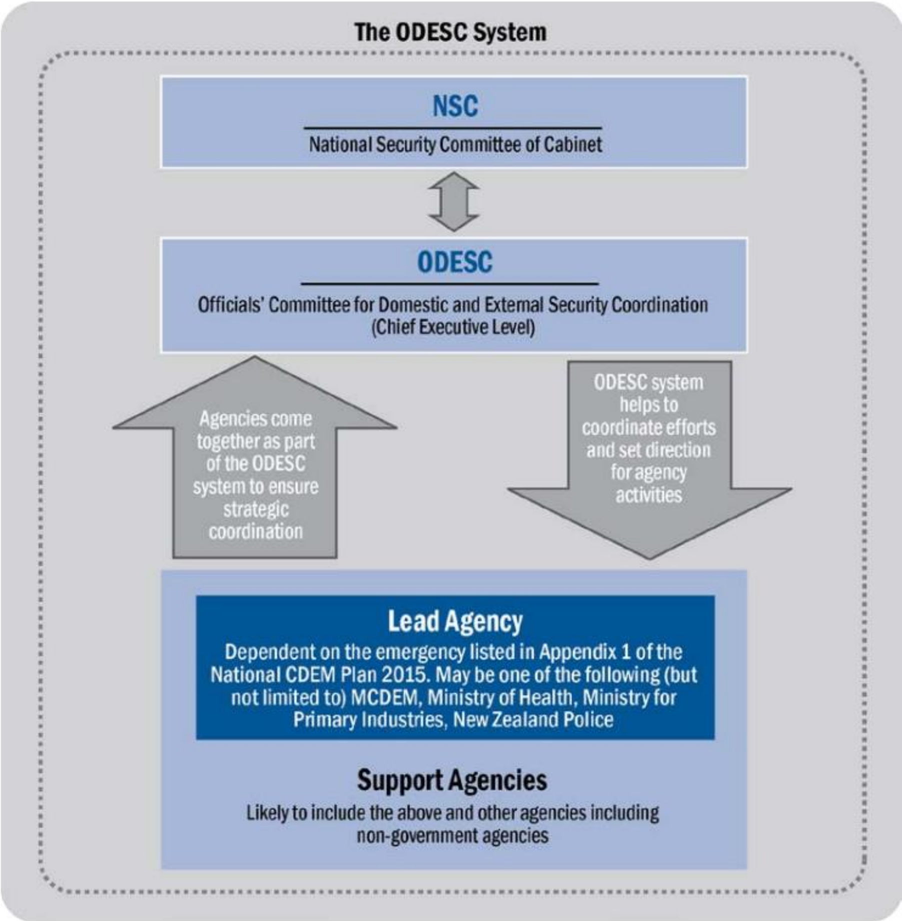
Within the ODESC system there are three levels:

- **National Security Committee (NSC)** of Cabinet, which is the key decision-making body of the executive government for coordinating and directing national responses. It is chaired by the Prime Minister and has powers to act when there is a need for urgent action, or when security considerations require it to do so.
- The **ODESC** Board, which is a committee of Chief Executives of government departments. The ODESC Board is chaired by the Chief Executive of DPMC. ODESC is the strategic mechanism for coordination of all-of-government response to emergency events and helps inform Ministerial responses. It is unclear, but this may also be where the Hazard Risk Board and Security Intelligence Board sit.
- Watch groups and working groups of senior officials as required.

Figure 39 shows the ODESC system visually and describes the flows of information between the NSC, ODESC, and Lead and Support Agencies (which each have responsibilities for different types of risks – more on this below).[40]

[40] MCDEM (the Ministry of Civil Defence and Emergency Management) has been superseded by NEMA.

Figure 39: New Zealand Government crisis management arrangements



Source: (National Emergency Management Agency, 2015)

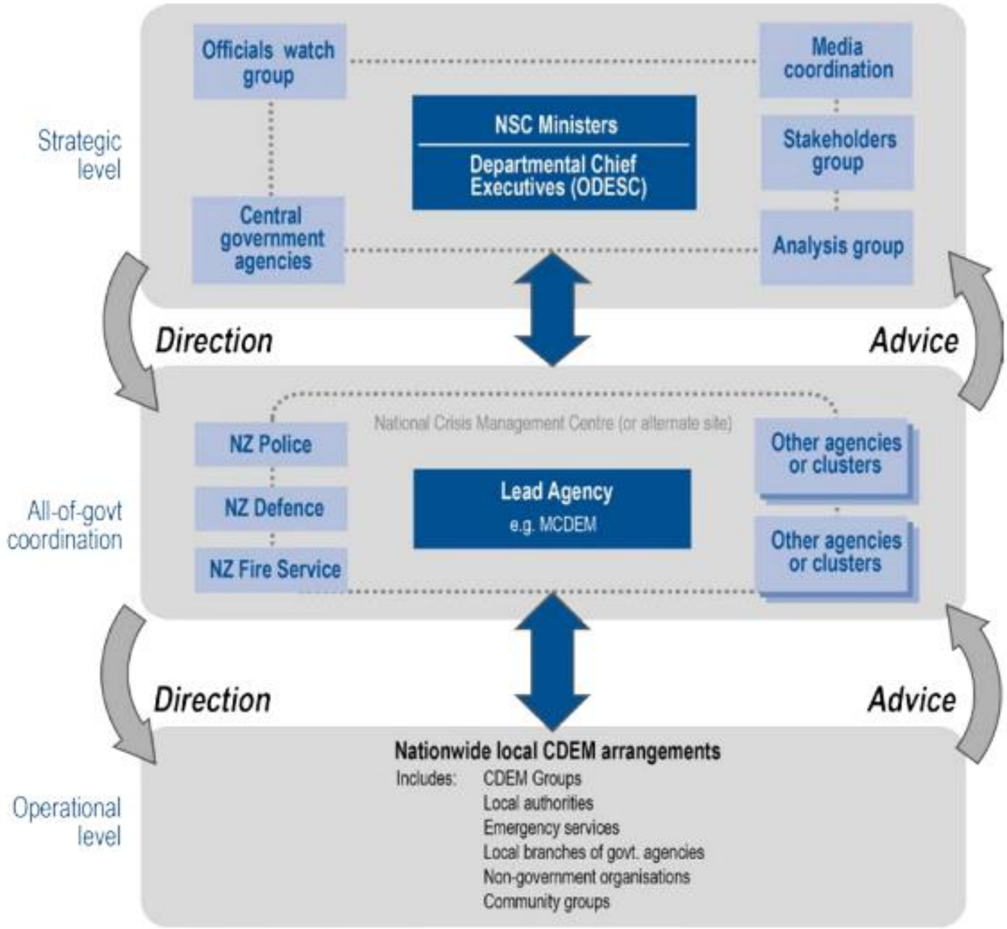
Lead Agencies form the link between the national strategic level and local operational level

Various pieces of legislation designate Lead Agencies, which have a primary mandate for managing the response to emergencies, monitoring and assessing emergencies as they progress, coordinating the dissemination of public information, and reporting to ODESC and providing policy advice to inform the national and strategic decisions that must be made in response to an emergency. The Lead Agencies are at the core of response and their roles include the communication of information both upward nationally (and strategically) and downward more locally (and operationally).

Support Agencies are expected to coordinate and work with Lead Agencies to provide an integrated response and can be called upon to provide a liaison to the National Crisis Management Centre (NCMC) within NEMA, plus manage its own response to the emergency. Sometimes Support Agencies are asked to be represented at the ODESC system level and to report directly to ODESC.

Figure 40 shows the national crisis management model in an emergency, using the example of MCDEM (superseded by NEMA) as a Lead Agency. For NEMA specifically, if another agency is designated as the Lead Agency, NEMA may support that Lead Agency by coordinating a civil defence emergency management response and other recovery activities.

Figure 40: National crisis management model in an emergency



Source: (National Emergency Management Agency, 2015)

There is a feedback loop, in that advice is given at the operational level from a range of agencies (including CDEM Groups, local authorities, emergency services, community groups, etc.) to Lead Agencies, who then use this advice to coordinate an all-of-government response. Advice is then given from Lead Agencies to ODESC and NSC who make strategic level decisions. These decisions result in direction (i.e. instructions and guidance) which flows back down to the Lead Agencies and informs the all-of-government response. This direction then flows further to the operational level from Lead Agencies to inform how other agencies act.

Table 10 shows a summary of New Zealand's national risks/hazards and the agencies responsible for them (i.e. Lead Agencies) in emergency management.

Table 10: Summary of New Zealand's national risks/hazards and the agencies responsible for them in emergency management

Risk/hazard	**Lead agency at national level**	**Lead agency at local/regional level (where specified)**
Geological (earthquakes, volcanic hazards, landslides, tsunamis)	National Emergency Management Agency (NEMA)	CDEM Group

Risk/hazard	Lead agency at national level	Lead agency at local/regional level (where specified)
Meteorological (coastal hazards, coastal erosion, storm surges, large swells, floods, severe winds, snow)	NEMA; Ministry for the Environment (MfE)	CDEM Group
Critical infrastructure failure	Department of Internal Affairs (water); Ministry of Business, Innovation, and Employment (MBIE) (energy); MoT (transport); MBIE (information and communications technology)	CDEM Group
Drought (affecting rural sector)	Ministry for Primary Industries (MPI)	MPI
Animal and plant pests and diseases (biosecurity)	MPI	MPI
Food safety	MPI	MPI
Infectious/communicable human diseases	Ministry of Health (MoH)	Te Whatu Ora
Wildfire	Fire and Emergency New Zealand (FENZ)	FENZ; Department of Conservation (DOC); New Zealand Defence Force (NZDF)
Fire and explosions	FENZ	FENZ
Hazardous substance emergency	FENZ	FENZ
Major transport incident	MoT; New Zealand Police	New Zealand Police
Major oil spill	Maritime New Zealand	Regional Council
Radiation incident	MoH	FENZ
Space weather	TBD	-
Biodiversity loss	DOC	-
Ecosystem disruption (soil)	MfE	-
Resource depletion (marine fisheries)	MPI	-
Vector-borne diseases	MoH	-
Global navigation satellite system (GNSS) disruption	TBD	-
Commodity/energy price shocks	MBIE	-

Risk/hazard	Lead agency at national level	Lead agency at local/regional level (where specified)
Major trade disruptions	Ministry of Foreign Affairs and Trade (MFAT); MPI	-
Financial crisis	New Zealand Treasury	-

Source: Combination, where possible, of (Department of the Prime Minister and Cabinet, 2022; National Civil Defence Emergency Management Plan Order, 2015; National Emergency Management Agency, 2015).
Note: malicious threats have been excluded from this table, although there may still be some interface between these and weather forecasting (e.g. bioterrorism).

Appendix D Types of economic goods

As discussed, one of the main ways of categorising economic goods is through excludability and rivalrousness. Below are brief explanations and examples of the different types:

- Private goods are both excludable and rival. They must be purchased before they can be consumed, which means those who do not or cannot pay are excluded from consuming. The consumption by one person means that good is no longer available for consumption by another person. For example, a consultation service from a meteorologist to a customer is a private good because one must purchase it before they can consume it, and that specific consultation service time cannot be consumed by anyone else.
- Common goods are non-excludable but rival. It is not possible to exclude someone from consuming common goods, but the consumption by one person means another person cannot consume that same good. For example, fish stocks are traditionally studied as a common good. It is not practical nor possible to exclude someone from fishing, but the consumption by one person (i.e. catching of fish) depletes the stocks and means another person cannot consume that fish.[41] In weather forecasting, an example might be where the public is able to freely call someone in the national meteorological service and ask them for weather information. Anyone can do this (non-excludable), but it takes up the time of the meteorologist and means others cannot use that same time (rival).
- Club goods are excludable but non-rival. This means that people can be prevented from consuming them, but consumption by one person does not preclude another from consuming the same good.[42] For example, weather information behind a paywall, or a subscription-based service, are club goods – they are excludable by the paywall or whether someone has a subscription, but one person's consumption does not limit another person's consumption. As long as they both have the rights to access (through payment), they will be able to consume the same product. In general, the marginal cost of providing club goods (i.e., the cost to provide to another person) is zero or close to zero.
- Public goods are both non-excludable and non-rival. It is not possible to exclude people from consuming the good and the consumption of the good by one person does not preclude consumption by another person. National defence is a common example of a public good – it would not be possible to exclude individual citizens of New Zealand from 'consuming' national defence (or benefiting from it), nor does one citizen's consumption preclude another citizen from being able to consume. Public goods are typically paid for using taxes. In weather forecasting, both publicly available forecasts and weather warnings and watches are public goods.

[41] This is where the idea of the 'tragedy of the commons' arises: when there are no well-defined property rights and/or enforcement mechanisms and therefore non-excludability and rivalrousness lead to negative outcomes, like in the example of fishing, overharvesting and depleting fish stocks below sustainable levels.

[42] There are some functional limits to non-rivalrousness, like how many people you can fit in a space. Obviously at the margin if there are too many people in a space, one person's consumption may prevent the next person from consuming.

Appendix E Illustrative list of parties that operate at different points of New Zealand's weather forecasting system

Organisation	Research	Infrastructure/ Observations	Data	Modelling	Forecasting	Products / applications	Advisory, communication, engagement
NIWA	✓	✓	✓	✓	✓	✓	✓
MetService	✓	✓	✓	✓	✓	✓	✓
FENZ		✓	✓				✓
Regional Councils[43]		✓	✓	✓	✓		✓
Blue Skies					✓	✓	✓
MetVUW						✓	
Weatherwatch					✓	✓	✓
International 3rd party providers[44]				✓	✓	✓	✓
NGOs	✓						
Universities	✓						✓
Mountain Safety Council					✓	✓	✓
Weather Radar NZ	✓	✓	✓		✓	✓	✓
RiskScape						✓	
Safe Swim						✓	
NEMA							✓
DOC							✓
Media organisations							✓
International NMHSs[45]		✓	✓	✓		✓	
Other private NZ companies[46]		✓	✓			✓	

[43] Hydrological modelling and forecasting
[44] For example, AccuWeather , Yr, Windy, Meteologix. Apple, Google, NVIDIA, etc.
[45] ECMWF, NOAA, UK Met Office
[46] For example, Transpower and NZTA both have their own private observation networks and there are many private companies that offer weather products or applications for New Zealand.

Appendix F Assessment of MetService and NIWA against their statement of corporate intents

MetService Performance

This section assesses MetService's performance against the key performance indicator (KPI) targets established in the statement of corporate intent. KPIs are monitored across the following categories:

- shareholder returns
- profitability
- leverage/solvency
- bank covenants
- growth/investment.

KPIs are set at the start of each financial year and therefore reflect expectations about the year ahead. Unexpected events can therefore make meeting KPIs challenging. In this context, the COVID-19 pandemic heavily impacts KPI performance in the 2020 financial year. As discussed earlier, the stalling of the MoT contract in 2015 also plays a part in poor achievement against KPIs in this year.

Table 11 displays MetService's performance against KPIs set to measure shareholder returns. While in most years 60–100 per cent of shareholder return KPIs were met, on average in any given year MetService met 54 per cent of its shareholder return targets. This is driven in part by a failure to pay dividends in most years, and only meeting the dividend payout target in one year. Additionally, the average is dragged down by the failure to meet any KPI targets in both 2015 and 2020.

Table 11: MetService's performance against shareholder returns KPIs (2014 - 2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Actual performance										
Total shareholder return	4.3%	0.0%	8.4%	4.3%	5.6%	8.1%	-10.8%	0.2%	-1.9%	0.0%
Dividend yield	4.3%	0.0%	0.0%	2.2%	1.7%	1.9%	0.0%	0.0%	0.0%	0.0%
Dividend payout	39.7%	0.0%	0.0%	10.6%	9.2%	10.2%	0.0%	0.0%	0.0%	0.0%
ROE	15.1%	5.2%	9.5%	11.7%	15.6%	11.8%	5.9%	-2.6%	-0.5%	5.7%
Return on Funds Employed	15.4%	6.5%	10.0%	11.9%	13.2%	13.3%	6.7%	-0.7%	0.6%	6.2%
Target in Statement of Corporate Intent										
Total shareholder return	4.3%	0.9%	0.8%	2.0%	1.8%	2.0%	2.2%	0.0%	0.0%	0.0%
Dividend yield	4.3%	0.9%	0.8%	2.0%	1.8%	2.0%	2.2%	0.0%	0.0%	0.0%
Dividend payout	40.1%	10.3%	9.5%	19.0%	11.2%	12.6%	11.5%	0.0%	0.0%	0.0%
ROE	16.9%	16.1%	10.3%	11.6%	12.5%	13.8%	13.2%	-14.7%	-4.5%	1.5%
Return on Funds Employed	15.4%	14.3%	9.8%	11.6%	12.0%	12.9%	13.4%	0.3%	0.3%	3.1%
Target met or exceeded										
Total shareholder return	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes
Dividend yield	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes

Dividend payout	No	No	No	No	No	No	No	Yes	Yes	Yes
ROE	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes
Return on funds Employed	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Proportion of targets met or exceeded	60%	0%	40%	80%	60%	40%	0%	80%	80%	100%

Table 12 displays MetService's performance against KPIs designed to measure profitability. On average, in any given year, 54 per cent of KPI targets were met or exceeded. In both 2015 and 2020 no profitability KPI targets were met. The least often met KPI target is the asset turnover target.

Table 12: MetService's performance against profitability KPIs (2014 - 2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Actual performance										
NPAT	$2.6	$0.9	$1.9	$2.4	$3.4	$2.6	$1.4	-$0.6	-$0.1	$1.3
Normal Trading EBIT	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$2.5	$2.2	$2.1
EBIT	$5.1	$2.3	$3.6	$4.4	$4.9	$4.8	$2.4	-$0.2	$0.2	$2.1
EBITDA	$11.8	$9.5	$11.8	$12.9	$14.3	$14.2	$11.7	$8.2	$8.6	$10.0
Asset Turnover	1.1	1.1	1.2	1.2	1.3	1.4	1.3	1.3	1.4	1.4
Operating Margin (EBITDA)/(EBITDAF)	25.8%	20.7%	23.1%	23.4%	23.9%	23.2%	19.3%	13.8%	13.4%	15.1%
Operating Margin (Normal Trading)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	3.5%	3.2%
Operating Margin (EBIT)	11.1%	4.9%	7.1%	8.0%	8.1%	7.9%	4.0%	-0.4%	0.3%	3.2%
Target in Statement of Corporate Intent										
NPAT	$2.9	$3.1	$1.9	$2.4	$2.9	$2.9	$3.1	-$3.2	-$1.0	$0.3
Normal Trading EBIT	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.1	$0.1	$1.0
EBIT	$5.0	$5.1	$3.5	$4.3	$4.7	$4.7	$4.8	-$2.9	-$0.4	$1.0
EBITDA	$11.7	$12.3	$11.4	$13.3	$14.4	$15.2	$14.3	$8.5	$8.3	$9.1
Asset Turnover	1.2	1.1	1.2	1.3	1.3	1.4	1.4	1.2	1.2	1.4
Operating Margin (EBITDA)/(EBITDAF)	24.4%	25.3%	22.3%	23.5%	23.9%	25.0%	21.9%	15.0%	13.6%	14.2%
Operating Margin (Normal Trading)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	1.6%
Operating Margin (EBIT)	10.5%	10.3%	6.9%	7.5%	7.8%	7.7%	7.3%	-5.1%	-0.7%	1.6%
Target met or exceeded										
NPAT	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes
Normal Trading EBIT								Yes	Yes	Yes
EBIT	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
EBITDA	Yes	No	Yes	No	No	No	No	No	Yes	Yes
Asset Turnover	No	No	No	No	No	No	No	Yes	Yes	No
Operating Margin (EBITDA)/(EBITDAF)	Yes	No	Yes	No	Yes	No	No	No	No	Yes
Operating Margin (Normal Trading)								Yes	Yes	Yes
Operating Margin (EBIT)	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Proportion of targets met or exceeded	67%	0%	67%	50%	67%	33%	0%	75%	88%	88%

Table 13 displays MetService's performance against leverage and solvency KPIs. On average, 75 per cent of KPI targets were met or exceeded. The net gearing ratio was the most consistently met, with actual gearing meeting or exceeding[47] KPI targets in every year bar 2015. Notably, in both 2015 and 2019, only 25 per cent of leverage and solvency KPI targets were met.

Table 13: MetService's performance against leverage and solvency KPIs (2014 - 2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Actual performance										
Net Gearing Ratio	0.5	0.5	0.4	0.3	0.3	0.2	0.1	0.1	0.2	0.2
Interest Cover	12.1	9.8	12.3	21.2	22.0	24.3	22.8	15.1	19.5	17.2
Solvency	0.7	0.9	1.4	1.5	1.4	1.8	1.8	1.4	1.2	1.1
Debt Coverage Ratio	3.4	7.5	4.7	3.5	3.1	2.9	5.4	0.0	50.8	5.0
Target in Statement of Corporate Intent										
Net Gearing Ratio	0.5	0.4	0.5	0.4	0.4	0.3	0.2	0.3	0.4	0.2
Interest Cover	11.4	12.2	11.4	14.0	20.6	25.1	27.6	0.1	13.9	16.5
Solvency	0.8	0.9	1.0	1.1	1.2	2.8	1.4	0.0	1.1	1.0
Debt Coverage Ratio	3.2	3.2	4.8	3.6	3.5	3.1	2.5	-	-	10.5
Target met or exceeded										
Net Gearing Ratio	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Interest Cover	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Solvency	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Debt Coverage Ratio	Yes	Yes	No	No	No	No	Yes			No
Proportion of targets met or exceeded	75%	25%	75%	75%	75%	25%	75%	100%	100%	88%

Table 14 displays MetService's performance against growth and investment KPIs. On average, 44 per cent of KPI targets were met or exceeded. In three years no growth or investment targets were met: 2014, 2015 and 2020. Each individual KPI was met at a similar frequency, with EBITDA growth and capital renewal KPIs met four times, and NPAT growth and revenue growth KPIs met five times over the past 10 years.

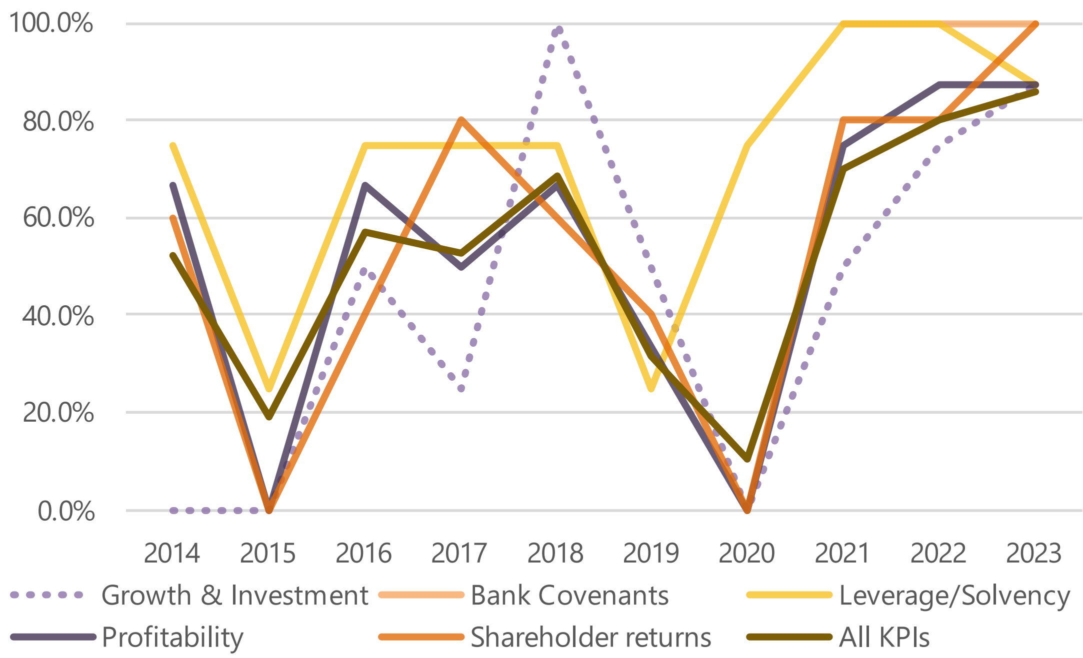
[47] In this case exceeding the ratio occurs when the firm's net gearing is less than the KPI target. This is because a high net gearing ratio occurs when a company has a large amount of debt relative to equity on its balance sheet.

Table 14: MetService's performance against growth and investment KPIs

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Actual performance										
Revenue Growth	7.9%	0.9%	10.8%	8.5%	7.8%	2.4%	-1.3%	-1.4%	8.0%	3.5%
EBITDA Growth	12.8%	-19.3%	23.6%	10.0%	10.4%	-0.7%	-17.6%	-29.5%	4.7%	16.3%
NPAT Growth	-5.6%	-64.5%	90.9%	26.1%	37.3%	-23.7%	-46.7%	-143.8%	-79.2%	1170.2%
Capital Renewal**	1.0	1.2	0.9	1.1	0.9	0.8	0.9	0.8	1.3	1.3
Target in Statement of Corporate Intent										
Revenue Growth	12.5%	7.2%	12.7%	11.2%	6.6%	2.4%	8.3%	-6.5%	3.0%	2.1%
EBITDA Growth	15.6%	6.3%	20.5%	13.1%	10.3%	9.3%	3.5%	-28.7%	-24.7%	5.6%
NPAT Growth	17.1%	1.5%	80.1%	33.3%	35.3%	6.2%	13.8%	-377.5%	-100.1%	161.2%
Capital Renewal**	1.5	1.3	1.2	0.6	0.9	0.6	1.2	1.2	2.4	1.2
Target met or exceeded										
Revenue Growth	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes
EBITDA Growth	No	No	Yes	No	Yes	No	No	No	Yes	Yes
NPAT Growth	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
Capital Renewal**	No	No	No	Yes	Yes	Yes	No	No	No	Yes
Proportion of targets met or exceeded	0%	0%	50%	25%	100%	50%	0%	50%	75%	100%

Overall performance against KPI targets is displayed in Figure 41. This graphs the proportion of the time that KPIs were met or exceeded across each category, and across MetService as a whole.

Figure 41: MetService KPI performance



NIWA Performance

The second dimension assesses NIWA's performance against the key performance indicator (KPI) targets established in the statement of corporate intent. KPIs are monitored across the following categories:

- profitability
- liquidity
- capital structure and absolute firm size
- other.

Table 15 displays NIWA's performance against KPIs set to measure profitability. In most years 83–100 per cent of profitability KPIs were met, with an average across years of 82 per cent of KPIs met. Notably, however, low achievement against KPI targets occurred in both 2022 and 2023. Only the adjusted return on equity and return on average equity KPIs were met in 2022, and only the revenue growth KPI met in 2023.

Table 15: NIWA's performance against profitability KPIs (2014 - 2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Actual performance										
Operating margin	16.20%	17.40%	15.20%	14.60%	15.60%	17.00%	19.70%	24.30%	16.30%	14.50%
Profit per FTE					$37,000		$47,000	$64,000	$40,000	$39,000
Adjusted return on equity	6.70%	7.00%	4.70%	4.80%	6.90%	6.20%	6.90%	13.90%	5.00%	4.40%
Revenue growth					6.20%		-1.50%	11.30%	-3.80%	9.30%
Return on assets	5.20%	5.60%	3.60%	3.40%	5.10%	4.80%	5.40%	10.90%	3.90%	3.10%
Return on average equity	5.20%	5.50%	3.70%	3.80%	5.50%	5.10%	5.70%	11.60%	4.30%	3.80%
Target in Statement of Corporate Intent										
Operating margin	16.10%	15.70%	15.10%	12.00%	15.80%	16.70%	18.00%	19.60%	18.10%	17.80%
Profit per FTE					$36,000		$43,000	$46,000	$45,000	$46,000
Adjusted return on equity	6.20%	6.00%	4.50%	0.40%	6.20%	6.20%	4.80%	6.00%	5.00%	4.90%
Revenue growth					5.90%		1.80%	0.20%	1.30%	7.40%
Return on assets	5.00%	4.70%	3.60%	0.20%	4.20%	4.70%	4.40%	4.90%	4.60%	5.00%
Return on average equity	4.80%	4.60%	3.50%	0.30%	5.00%	5.00%	3.90%	5.00%	4.20%	4.20%
Target met or exceeded										
Operating margin	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No
Profit per FTE	Yes				Yes		Yes	Yes	No	No
Adjusted return on equity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Revenue growth					Yes		No	Yes	No	Yes
Return on assets	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Return on average equity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Proportion of targets met or exceeded	100%	100%	100%	100%	83%	100%	83%	100%	33%	17%

Table 16 displays NIWA's performance against KPIs designed to measure liquidity. On average, across years 73 per cent of KPI targets were met or exceeded. In practice, this means that in most years all targets were met, and in four years, one or two targets were missed, with all targets missed in 2023.

Table 16: NIWA's performance against liquidity KPIs (2014 - 2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Actual performance										
Current ratio	1.40	1.50	1.60	1.70	1.30	1.40	1.50	1.60	1.30	0.90
Quick ratio	1.90	2.10	2.20	2.80	1.90	2.20	2.90	3.10	2.40	1.20
Interest coverage								56.50	17.90	13.16
Target in Statement of Corporate Intent										
Current ratio	1.30	1.20	1.50	1.40	1.40	1.70	1.30	1.90	1.20	1.00
Quick ratio	1.80	1.50	1.90	2.00	2.00	2.10	1.92	3.60	2.1	1.60
Interest coverage								15.50	15.80	22.90
Target met or exceeded										
Current ratio	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	No
Quick ratio	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Interest coverage								Yes	Yes	No
Proportion of targets met or exceeded	100%	100%	100%	100%	50%	50%	100%	33%	100%	0%

Table 17 displays NIWA's performance against capital structure and absolute firm size KPIs. On average, across years 71 per cent of KPI targets were met or exceeded. The average total assets ratio was the most consistently met, with KPI targets met in every year.

Table 17: NIWA’s performance against capital structure and absolute firm size KPIs (2014 - 2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Actual performance										
Average total assets	$137,003	$136,754	$141,150	$151,542	$160,388	$167,855	$182,279	$205,741	$225,998	$238,458
Average shareholders' funds	$102,022	$104,505	$107,370	$111,454	$116,826	$123,169	$128,984	$139,841	$151,225	$157,417
Capital expenditure		$15,652								
Capital renewal					214%		69%	122%	227%	245%
Proprietorship (%) (average shareholders' funds/total assets)	74%	76%	73%	71%	71%	72%	67%	64%	65%	65%
Revenue and other gains	$123,790	$126,259	$130,373	$142,618	$151,416	$161,292	$158,860	$176,887	$170,233	$186,036
Operating expenses, depreciation, and amortisation	$116,421	$118,649	$125,352	$137,539	$143,232	$153,208	$149,070	$154,397	$161,331	$178,562
Profit before income tax	$7,324	$8,005	$5,492	$5,950	$9,074	$8,708	$9,982	$22,594	$8,958	$7,764
Profit for the year	$5,278	$5,755	$4,011	$4,250	$6,472	$6,247	$7,370	$16,263	$6,470	$5,938
Target in Statement of Corporate Intent										
Average total assets	$134,030	$136,657	$139,696	$146,170	$159,393	$163,820	$178,910	$191,266	$205,102	$226,396
Average shareholders' funds	$100,280	$101,942	$106,347	$108,660	$116,218	$122,760	$129,200	$136,047	$143,604	$158,389
Capital expenditure		$12,541								
Capital renewal					210%		129%	122%	251%	261%
Proprietorship (%) (average shareholders' funds/total assets)	75%	75%	76%	75%	73%	75%	70%	72%	69%	68%
Revenue and other gains	$124,042	$126,604	$137,038	$133,130	$148,670	$161,293	$165,326	$159,820	$171,255	$177,630
Operating expenses, depreciation, and amortisation	$117,295	$120,192	$131,987	$132,898	$141,945	$153,548	$157,405	$150,525	$161,728	$166,198
Profit before income tax	$6,706	$6,540	$5,202	$506	$8,072	$8,552	$7,994	$9,487	$9,305	$11,600
Profit for the year	$4,827	$4,706	$3,744	$362	$5,809	$6,157	$5,070	$6,830	$6,030	$6,648
Target met or exceeded										
Average total assets	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Average shareholders' funds	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Capital expenditure		Yes								
Capital renewal					Yes		No	No	No	No
Proprietorship (%) (average shareholders' funds/total assets)	No	Yes	No	No	No	No	No	No	No	No
Revenue and other gains	No	No	No	Yes	Yes	No	No	Yes	No	Yes
Operating expenses, depreciation, and amortisation	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	No
Profit before income tax	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Profit for the year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Proportion of targets met or exceeded	71%	88%	71%	71%	75%	71%	50%	63%	50%	25%

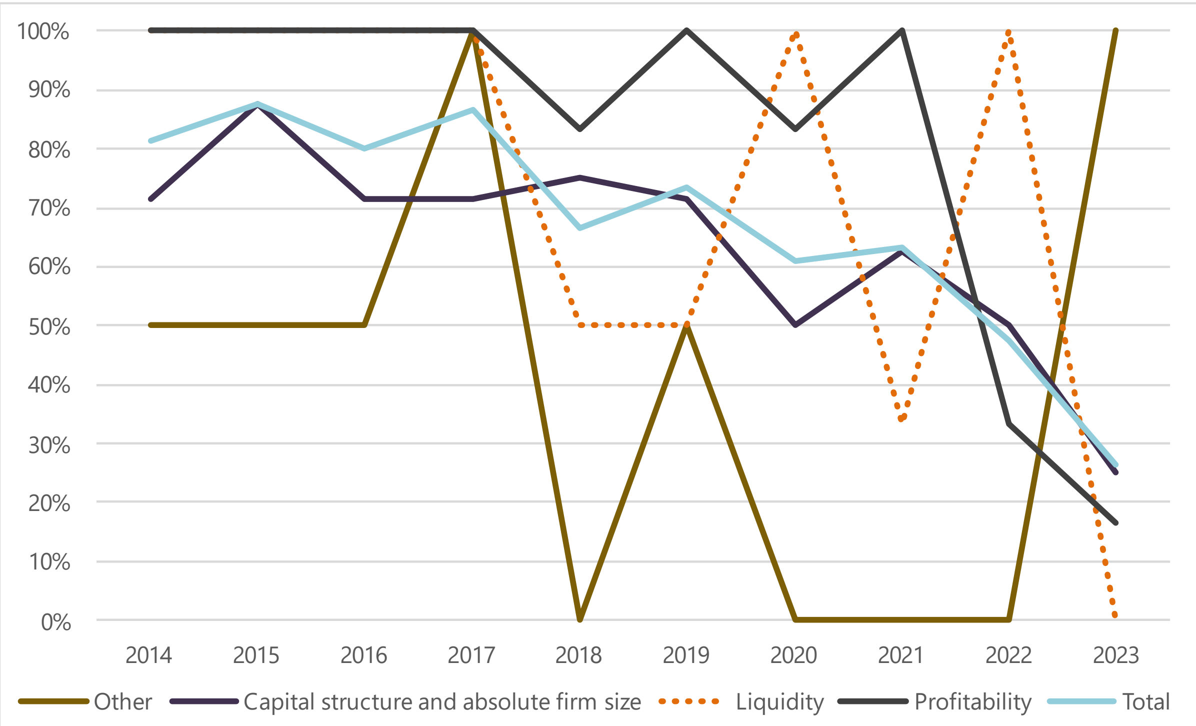
Table 18 displays NIWA's performance against 'other' KPIs. On average, across years 40 per cent of KPI targets were met or exceeded. In four years no 'other' KPIs were met: 2018, 2020, 2021 and 2022. The forecasting risk KPI was met more often than the profit volatility KPI.

Table 18: NIWA's performance against other KPIs

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Actual performance										
Profit volatility	14.00%	10.10%	6.40%	6.10%	7.20%	12.70%	18.90%	29.50%	24.30%	21.70%
Forecasting risk	-0.20%	-0.30%	1.00%	1.10%	1.20%	1.00%	1.40%	2.90%	2.20%	2.10%
Target in Statement of Corporate Intent										
Profit volatility	12.20%	6.50%	4.10%	10.10%	6.90%	6.20%	15.30%	18.70%	12.80%	24.20%
Forecasting risk	2.30%	2.00%	2.20%	1.10%	1.10%	1.50%	1.20%	1.90%	2.10%	2.90%
Target met or exceeded										
Profit volatility	No	No	No	Yes	No	No	No	No	No	Yes
Forecasting risk	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes
Proportion of targets met or exceeded	50%	50%	50%	100%	0%	50%	0%	0%	0%	100%

Overall performance against KPI targets is displayed in Figure 42: NIWA KPI performance. This graphs the proportion of the time that KPIs were met or exceeded across each category, and across NIWA as a whole. While the proportion of KPIs met in each category varies on a year-to-year basis, the overall trend across the analysed time period is poorer achievement of KPI targets. Note that this isn't to say the firm is performing poorly in general, as KPI targets are adjusted on a year-by-year basis to reflect expectations about trading conditions, but simply that the tendency to meet these targets has declined in total. Additionally, this high-level approach treats meeting each KPI as equally important. In practice, this is unlikely to be the case. Meeting KPIs for profitability and liquidity, for example, is likely to be more important than meeting targets for profit volatility or absolute revenue.

Figure 42: NIWA KPI performance



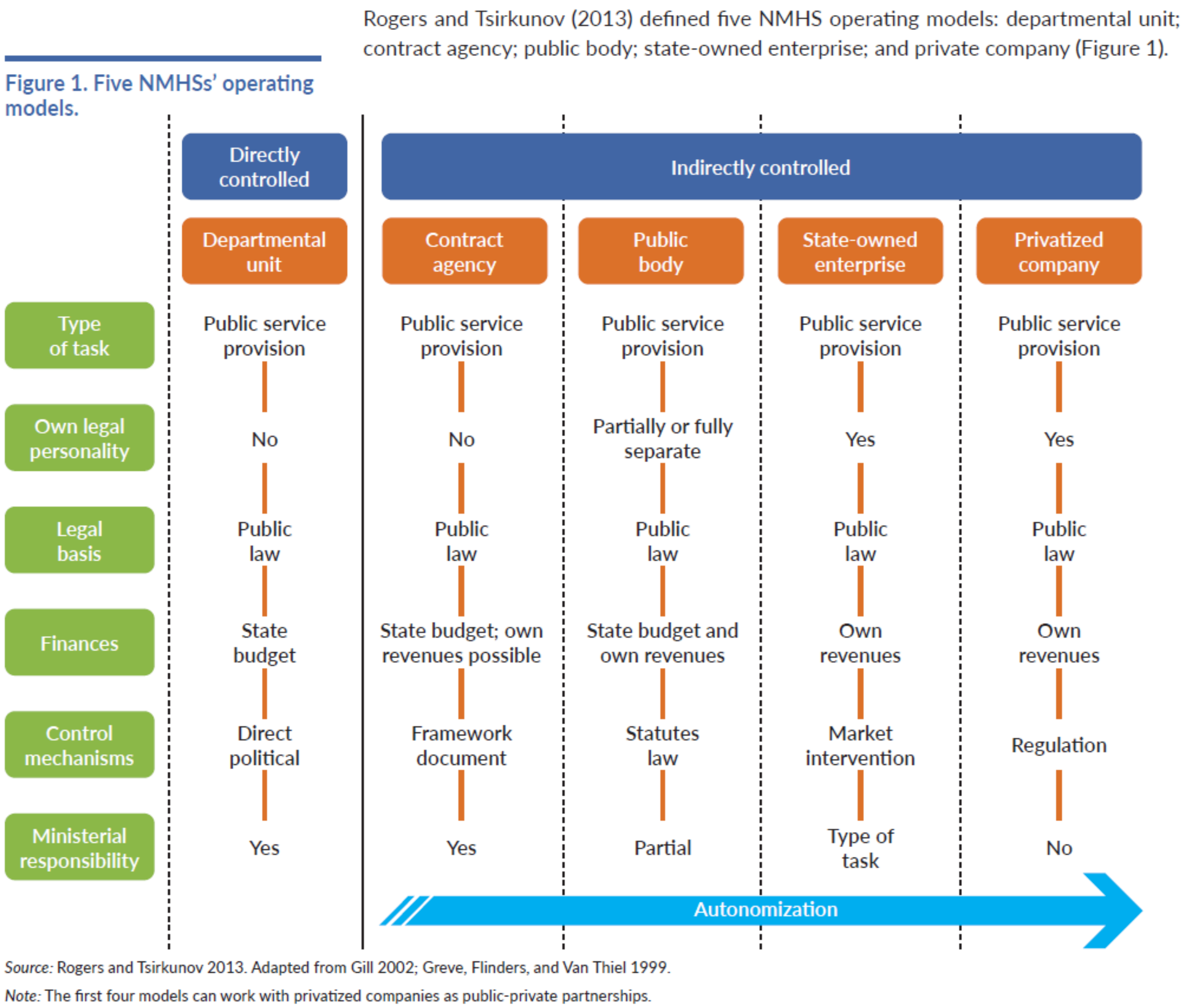
Appendix G What we can learn from international experience

The Level Playing Field (Rogers et al., 2021) notes:

> "The Power of Partnership: Public and Private Engagement in Hydromet Services report (World Bank 2019) recommended minimizing the role of public entities in the provision of nonpublic services when the private sector is able to provide them or, if that is not possible, ensuring a level playing field for all participants."

And further provides the following overview of different operating models:

Figure 43: Overview of different operating models



The paper identifies some of the trade-offs across the models and notes:

- **Approximately 40 countries used a departmental unit model**, financed by the state budget to deliver non-commercial services to the public or support other government bodies, at the time of the analysis of these arrangements by Rogers and Tsirkunov (2013). These include the United States, though it was noted that of those using this model, many have or were transitioning to alternative models (e.g. Kenya, Tanzania, and Uganda).

- **Contract agencies** with parent departments **include the Federal Office of Meteorology and Climatology** (MeteoSwiss), which is part of the Swiss Federal Department of Home Affairs as well as the Danish Patent Office and the Netherlands Service for Immigration and Naturalization.
- **Public bodies** operating at arm's length from the central government where there is a degree of commercial services have been used in France[48], the Netherlands, Scandinavia, and the UK (Rogers & Tsirkunov, 2013). It is suggested this has prompted other governments, particularly in Africa, to consider the application of public bodies.
- **MetService is the only example of an SOE** which is financed by its own revenues but sometimes subsidised by government.
- An example of **privatisation** occurred in the Netherlands where the Royal Netherlands Meteorological Institute (KNMI) privatised its commercial interests into the Holland Weather Services and KNMI reverted a government entity closer to the departmental model (Rogers & Tsirkunov, 2013).

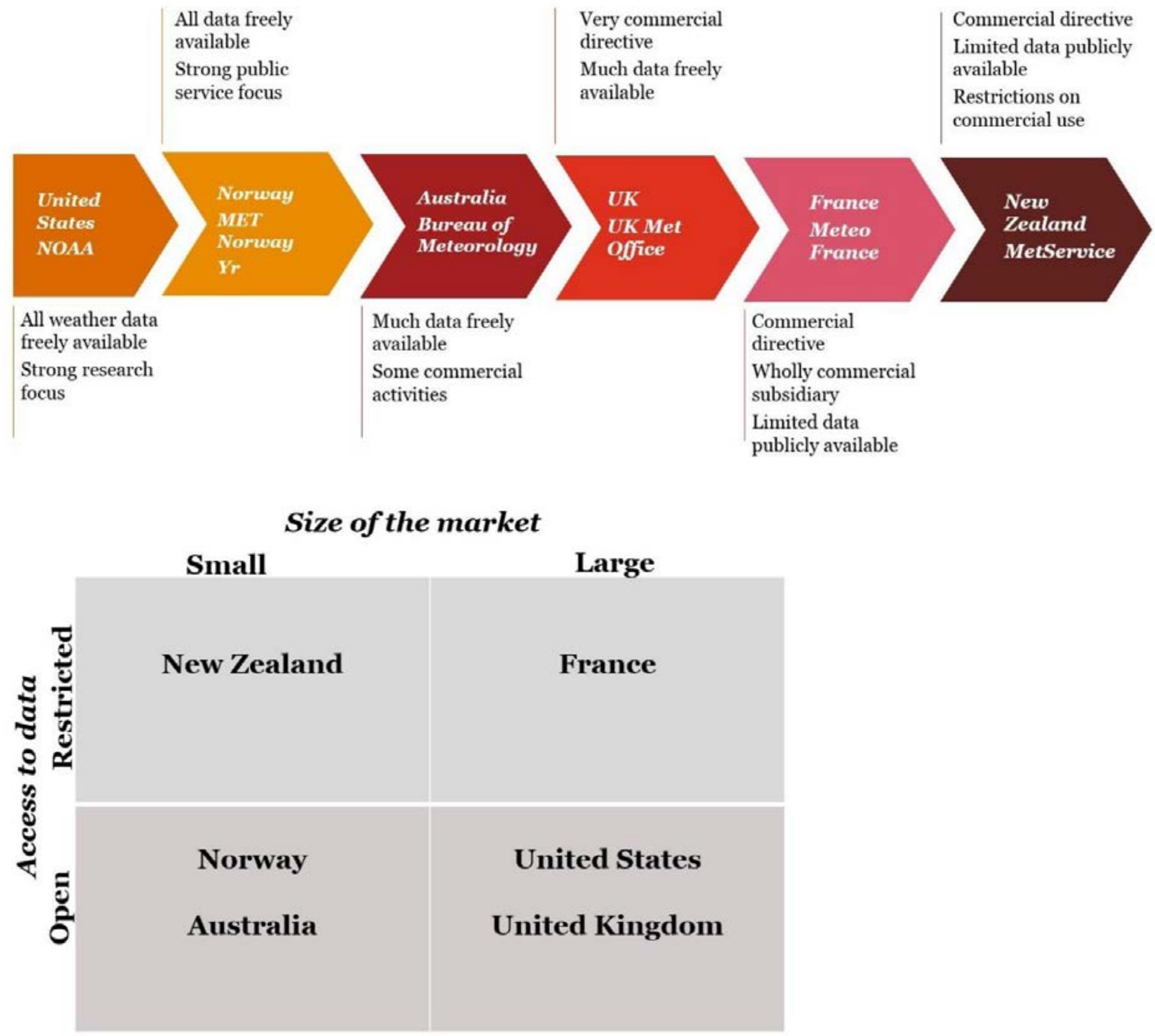
The Level Playing Field also notes that:

> "The variety of operating models for NMHSs is matched by an equally varied ownership within government including ministries of environment, transport, business, science, agriculture, defence, communication, and education. Still others report directly to a state council or equivalent body."

- We note that the 2017 review "Weather Permitting" found that New Zealand's model was the most commercial and least open access to data at the time relative to the models it considered (summarised below):

[48] As of 1 January 2024 France has made all data freely available with minimal restrictions on its use.

Figure 44: Overview of models considered in Weather Permitting



		Institutional arrangement	Closest New Zealand comparison	Data charges
Countries	*USA*	Federal agency within the Department of Commerce	Government department	Free[41]
	Norway	Public institute under the Ministry of Education and Research	Crown agent	Free[42]
	Australia	Government bureau	Government department / Crown agent	Cost-recovery[43]
	UK	Trading fund within the Department for Business, Energy and Industrial Strategy	Crown entity company	Free up to a limit, then charged on cost-recovery[44]
	France	Public Administrative Institution (EPA)	Crown entity company	Profit[45]

Countries		Open data policy	Accessible API	Real-time data available	Non-restrictive licensing	Free or minimal cost
	USA	✓	✓	✓	✓	✓
	Norway	✓	✓	✓	✓	✓
	Australia	✓	✗	✓	✓	✗
	UK	✓	✓	✓	✓	✓
	France	✗	✗	✓	✗	✗
	New Zealand	✓	✗	✓	✗	✗

Source: Weather Permitting (MBIE, 2017)

Further, more recent work commissioned by MetService provides the following overview of selected international comparators:

Figure 45: Overview of international comparators

Country	Delivery of climatological, meteorological and hydrological functions	Internal organisational structure between forecasting and research functions	Funding structure / contractual mechanism ($NZD)	Access to data
Australian Bureau of Meteorology	All three functions vertically integrated into a "non-corporate entity" operating as an **executive agency** within the Department of Agriculture, Fisheries and Forestry	**Community Services Group** responsible for forecasting. **Science and Innovation Group** responsible for conducting climate and weather research	70% direct **government** budget appropriation ($270m). 30% **own-source income** from commercial/research contracts ($75m)	**Paid access** to data charged on a cost-recovery basis. Third parties can purchase licensed data for commercial use
Ireland National Meteorological Service	All three functions vertically integrated into a **"line of division" entity** of the Department of Housing, Planning and Local Government	Four divisions including **"Infrastructure", "Services"** and **"Research"**. Services division further separated into general forecasting, flood forecasting and aviation subdivisions	Infrastructure directly funded through annual **budgetary appropriation** ($96m). Research funding mixed between **government grants** and **third-party commercial** sources	**Open access** to 2,000 data sets. Third parties free to adapt data commercially under Creative Commons Attribution 4.0 licence
Royal Netherlands Meteorological Institute	All three functions vertically integrated as an **"expert agency"** within the Ministry of Infrastructure and Water Management	Forecasting falls within the **Weather Service department**. Climate observations fall within the **Climate and Seismology department**. Departments undertake subject matter specific R&D	Two-thirds of annual funding ($72m) derived from **government** to fund upkeep of infrastructure. One-third ($37m) from **service contracts** with government/corporate clients	**Open access** to data published on KDP data platform. All data free to use for commercial purposes by downstream players with attribution
Swedish Meteorological and Hydrological Institute	All three functions vertically integrated operating as an **"specialist expert authority"** within the Ministry of Climate and Enterprise	**Community Preparedness Services department** responsible for forecasts and observations. **R&D department** responsible for all applied research	**Tripartite funding** model from annual government budgetary grants, commissions from other agencies and business activities on commercial terms	**Open access** to all data via in-house digital platform
Norwegian Meteorological Institute	Vertically integrated climate research and meteorological operations as an **agency** that is part of the Ministry of Climate and Environment	Dedicated **Forecasting department**, **Observation and Climate department**, and **Research and Development department**	Infrastructure is **government funded** via budget appropriations ($56m). Research funded from mixture of **government/EU grants** and **commercial** sources	**Open access** to official data sources for commercial use via 'Yr' meteorological data platform and online API, eKlima
United Kingdom Met Office	All three functions vertically integrated into a government **Trading Fund Agency** owned by the Department for Science, Innovation and Technology	Weather forecasting split from research through the **Public Weather Service Customer Group** responsible for overseeing the **Public Weather Service** via a customer supplier agreement	80% of revenue from **public sector service contracts**. Other research revenue derived from government/international **grants** and **private entities**	Weather data licensed under UK **Open Government Licence**
Meteorological Service of Canada	All three functions vertically integrated as a **division** of the Environment and Climate Change Canada federal department (ECC)	MSC sits as one of 12 divisions within the ECC	Direct **government funding** of infrastructure via a $255 million budget appropriation	**Open access** to majority of datasets via GitHub for commercial purposes

Source: "Forecasting success: Maximising capability for a changing climate" presentation (Polis, 2023)

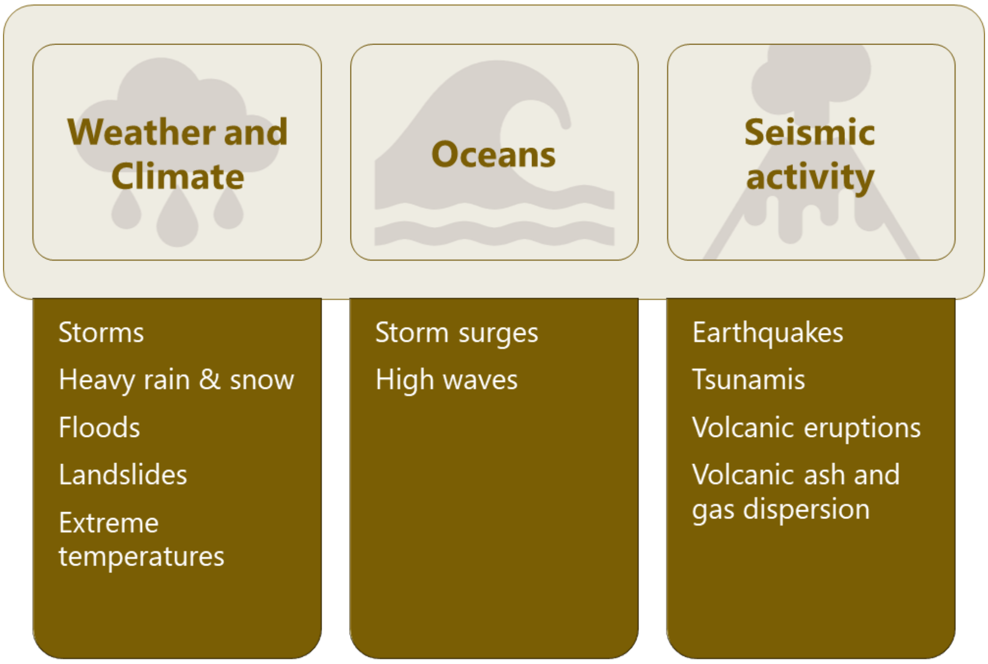
Below we provide relevant insights from three international case studies which may be most relevant in the context of issues discussed in this report. These relate to arrangements in Japan, the UK and France.

Japan’s integrated hazard approach

Japan is similar to New Zealand in that it is an island country on the Pacific Rim that is at risk of natural hazards related to weather, ocean, and seismic activity. Where the countries differ is that Japan has a single organisation with the authority to issue warnings related to these hazards, compared to New Zealand, which has several.

When it was established in 1956, the Japan Meteorological Agency (JMA) was only responsible for issuing warnings related to weather and flooding. However, recognising the necessity of a single authoritative voice for warnings of severe natural hazards, its mandate was expanded to include warnings for earthquakes, tsunamis, and volcanic eruptions (Figure 46).

Figure 46: List of natural hazards and phenomena for which JMA is the responsible authority for issuing warnings



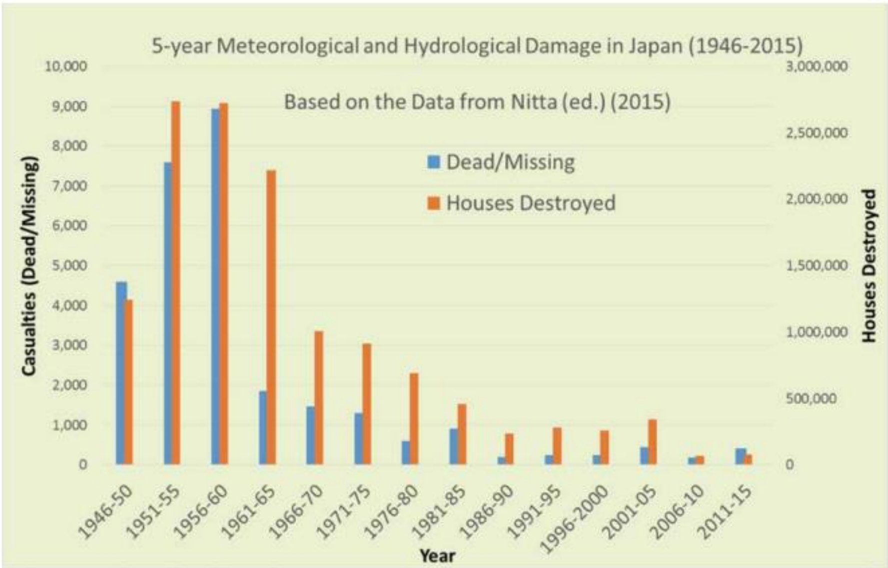
The importance of meteorological services and early warning services is recognised in Article 13 of Japan’s Meteorological Service Act (Ministry of Justice Japan 1952):

> “(1) The Japan Meteorological Agency shall, pursuant to the provisions of Cabinet Order, give suitable forecasts and warnings for general use concerning meteorological phenomena, terrestrial phenomena (in the case of earthquakes, limited to earthquake ground motions; hereinafter, the same shall apply in this Chapter except in Article 16), tsunamis, storm surges, high waves, and floods.
>
> (2) In addition to the forecasts and warnings set forth in the preceding paragraph, the Japan Meteorological Agency may, pursuant to the provisions of Cabinet Order, give suitable forecasts and warnings for general use concerning any hydrological phenomena other than tsunamis, storm surges, high waves, and floods.
>
> (3) The Japan Meteorological Agency shall, when giving the forecasts and warnings set forth in the preceding two paragraphs, not only independently take measures to

publicize the forecast matters and warning matters but also endeavour to make them publicly known by seeking cooperation from the mass media."

To enhance its capability to provide hazard warnings, JMA has focused on continually improving its early warning and disaster management systems through investment in technology and community engagement to raise public awareness (Hatori et al., 2016). This focus, along with developments in infrastructure, are believed to have significantly reduced the impacts of meteorological and hydrological hazards in Japan over the past 60 years (Figure 47). Advances in monitoring and forecasting technology have greatly improved JMA's ability to identify risks of hazards early, and a comprehensive warning system allows its warnings to have maximum reach.

Figure 47: Damage from meteorological and hydrological events in Japan between 1946 and 2015



Source: (Hatori et al., 2016)

JMA uses multiple communications channels to disseminate warnings. Warnings are sent to national and local government agencies, to the public, and to socio-economic sectors. To reach the public, JMA disseminates warnings on its website, social media, and to telecommunications providers and media outlets. JMA also uses a national instant warning system which transmits emergency information to the public via satellite. JMA's early earthquake warning system transmits directly to mobile devices too.

Japan has a seamless early warning service with a comprehensive multi-hazard approach – monitoring, forecasting and warning for most severe natural hazards are done by one government authority, in collaboration with relevant authorities. It has developed a multi-hazard risk-based warning service for weather and climate services. There is a multi-hazard approach for cyclones, earthquakes and volcanic activity. Coordinated information to government authorities and the public is considered crucial.

UK integrated met and hydro – flood warning system

In the United Kingdom, the Met Office is responsible for issuing weather warnings and the Environment Agency is responsible for issuing flood alerts and warnings. The two agencies developed a partnership, following a failure to predict disastrous flooding in 2007. The floods caused the deaths of 13 people and widespread socio-economic losses. An independent review of the floods put forward 92 recommendations to overhaul the UK's flood risk management practice. The sixth recommendation was "the Environment Agency and the Met Office should work together, through a joint centre, to improve their technical capability to forecast, model and warn against all sources of flooding" (Cabinet Office, 2008).

In 2009, the Met Office, the Environment Agency, and Natural Resources Wales[49] combined their expertise to establish the Flood Forecasting Centre (FFC). The FFC's purpose is to provide 24/7 flood forecasting and guidance service to support the UK government and CDEM organisations. The FFC is housed in the UK Met Office operations centre in England.

Responsibility for warnings remains with the partner agencies. However, the Met Office and the Environment Agency/Natural Resources Wales work with the FFC hydrometeorologists to agree on warnings by discussing forecasts and the likelihood that conditions will cause flooding impacts.

The FFC provides short-term (up to five days) and medium- to long-term (six to 30 days) flood risk assessments at a national and local scale for coastal, river, surface water, and groundwater flooding. The forecasts and risk assessments are communicated at least once a day to government departments, CDEM organisations (e.g., the emergency services, local authorities, and National Hydrological Service) and organisations that are involved in flood response (e.g., transport and utility companies). Public flood risk forecasts are also available (Flood Forecasting Centre, 2022).

The FFC initially based their flood risk forecasts on rainfall amounts but this has shifted to a detailed risk matrix approach that combines the likelihood of flooding with potential impacts to make it easier for users to understand. The risk matrix was developed by the Natural Hazards Partnership (NHP), a partnership of 19 government agencies and research centres in the UK (including FCC partners). The NHP uses the interdisciplinary expertise and knowledge of its partners to develop a common and consistent approach to modelling and forecasting natural hazard impacts.

Figure 48: UK Flood Forecasting Centre's flood risk matrix for flooding

Likelihood \ Impact	Minimal	Minor	Significant	Severe
High	Very low risk	Low risk	Medium risk	High risk
Medium	Very low risk	Low risk	Medium risk	Medium risk
Low	Very low risk	Very low risk	Low risk	Medium risk
Very Low	Very low risk	Very low risk	Low risk	Low risk

Source: (Flood Forecasting Centre, 2022)

The FFC has supported the Met Office and the Environment Agency/Natural Resources Wales to work together to develop improved flood forecasting capability and better understand the risks of flooding in England and Wales. Via the NHP they have developed a risk matrix that considers the likelihood of floods and the potential severity of the impacts of those floods. This provides a comprehensive view of flood risk that is easily understandable by its users. From the earliest signs of a possible flood risk, government and CDEM organisations can be organised and prepared for the potential impacts (Stephens & Cloke, 2014).

Météo-France's open access to data

Météo-France is France's national meteorological and climatological service. It provides services for the needs of public authorities, aeronautics, businesses and the general public. Météo-France's 2022-2026 objectives state that it must support France in the face of meteorological risks, climate change, and in major environmental challenges. To do so, it will provide precise, reliable, and high quality information to enable informed decisions (Météo France, 2022).

Météo-France is funded approximately €300 million from state grants, aeronautical royalties, and the sales of commercial services (Météo France, 2022). With this funding, it generates between €1.1 billion and €2.6 billion in socio-economic benefits (Météo France, 2022).

Since 2012, Météo-France has had a proactive policy of opening public data. The policy led to the public data portal being developed that allows access to over 30 datasets. The portal enables access to 15 terabytes of data, with 1.5 terabytes of data downloaded daily (Météo France, 2022).

The French Prime Minister's circular no. 6264/SG on 27 April 2021 called for data policy to be a strategic priority of the State. The circular outlined a renewed ambition for the openness and circulation of data (Legifrance, n.d.).

In accordance with this circular, Météo-France established Objective 14 in its 2022-2026 objectives: "serving growth and innovation through access to the establishment's public data likely to create value, in particular through the continuation of their online posting and the development of APIs". Under this objective, it made all its public data freely available on 1 January 2024. The aim is to support the greatest number of uses and innovations. It is expected that this release will lead to a sharp increase in the volume of data accessed. The public data includes:

- observation data from ground stations and precipitation radars
- forecast data of up to four days ahead
- climatological data from the past several decades
- future climate forecast data including climate projections until the end of the century (Météo France, 2023).

[49] The Environment Agency and Natural Resources Wales are responsible for coastal, surface water, and groundwater flooding in England and Wales respectively.

By making this data publicly accessible, Météo-France will now no longer receive income from royalties from the use of this data. Extrapolating commercial revenue figures from 2014, we estimate commercial revenue in 2022 to be around €26 million. Of this figure, €1.6 million is attributed to royalties (Francis, 2015). It is not clear how Météo-France intends to fund this lost revenue.

Anecdotally, we have heard that opening the access to data has led to increased use of Météo-France's weather data for research.

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