



Marine Meteorological forecasts for Coastal Ocean Users - Perceptions, Usability and Uptake

Christo Rautenbach^{a, b, c} and Berill Blair^d

^a Coastal and Estuarine Processes, National Institute for Water and Atmospheric Research (NIWA), Hamilton, New Zealand

5 ^b Institute for Coastal and Marine Research, Nelson Mandela University, South Africa

^c Department of Oceanography and Marine Research Institute, University of Cape Town, South Africa

^d Environmental Policy Group, Wageningen University and Research, Wageningen, The Netherlands

Correspondence to: Christo Rautenbach (Christo.Rautenbach@NIWA.co.nz)

Abstract. The present study aims to address a proposed disconnect between science and the public. In this case, marine meteorological (metocean) information and the users of these data. Here, the focus is not only on the perceptions, usability and uptake of extreme event forecasts but rather focused on general, everyday situations. The research was conducted by means of a survey, designed around four research questions. Each question was then populated with propositions that were the guideline for the questionnaire. The research questions covered topics ranging from forecasting tool ergonomics, accuracy and consistency, usability, institutional reputation and uncertainties related to Climate Change (to name but a few). The survey was conducted in two southern hemisphere countries, South Africa and New Zealand. The online questionnaire was widely distributed to include both recreational and commercial users. Cultural Consensus Analysis (CCA) was used to investigate knowledge-based agreements within the total group of respondents as well as sectoral and community subgroups. The existence of subgroups within the communities (e.g. recreational and commercial) was also established. The general shared knowledge results are discussed together with user group demographic statistics. A comprehensive summary of all four research questions, with all the resulting propositions are also provide. The percentage of each subgroup's agreement with the knowledge-based score (CCA model derived) is also provided with the beforementioned. Finally, a conceptual diagram is proposed to highlight the important interplay between forecast product co-development and scientific accuracy/consistency.

Keywords: Forecasting, Perception, Science communication, Survey, Cultural Consensus Analysis, Co-production

25 1 Introduction

The accuracy of metocean predictions differ depending on the physical phenomena being forecasted. As an example, vertical ocean column structure parameters might be much more difficult to predict accurately than the prevailing ocean surface waves (in a very general sense as this statement is highly location dependent). The vertical water structure of both coastal and open oceans is driven by a larger number of environmental parameters which inevitably makes the physics, to be solved



30 by numerical techniques, more challenging (including the requirement for 3D numerical considerations). This contrasts with
2D wave forecasts, which predominantly depend on local winds, offshore swell conditions and local bathymetry. Prediction
techniques also play a large role in forecast accuracy, and have different computational demands associated with them. These
include considerations of forecast time period, spatial extent and dimensionality, temporal resolution and purpose. In the
present study the perception, usage and uptake of metocean forecast are assessed, predominantly focused on coastal and
35 ocean winds and waves.

Around the world, operational centres clearly articulate the importance for user-centric (or transdisciplinary) based Research
and Development (R&D) (e.g. Ebert et al., (2018)). Yet, limited anthropological studies have been conducted with user
perceptions of science-based forecasts as the main research goal (Doswell, 2003; Silver, 2015). Severe weather warning
40 perception and uptake have been studied in the past (e.g. Sherman-Morris, (2010)) but general (none-extreme) forecast
usability, preferences and accuracy perception have not been extensively investigated (also known as the social aspects of
weather or marine forecasting) (Silver, 2015). The few studies that did investigate the social aspects of weather forecasting
include Demuth, Lazo, & Morss, (2011), Katz & Lazo, (2011), Lazo, Morss, & Demuth, (2009) and Silver, (2015). These
studies are focused on North American countries (USA and Canada) and also illustrate how important weather forecasting is
45 for economic development (Lazo et al., 2009).

Weather salience and the connection with atmospheric weather forecasts are discussed in studies by e.g. Stewart, Lazo,
Morss, & Demuth, (2012) and Williams, Miller, Black, & Knox, (2017). The term ‘weather salience’ refers to the
psychological importance weather has for a particular individual (Stewart, 2009). Several other studies started investigating
50 how users’ technical understanding and competence influence their interpretation and perception of hydro-meteorological
products (Ramos et al., 2010). Ramos et al., (2010) also encouraged users’ technical training and direct engagement during
operational forecast and hazard (early warning) tool development. This is especially true for probabilistic forecasting. Ramos
et al., (2010) also highlighted the importance of exploring more effective ways of communicating forecasts.

55 User community perception is a crucial aspect of any marine-meteorological (metocean) information sharing or forecasting.
Here the word forecast is used broadly to describe current and future earth system dynamics prediction. Several studies have
established that active collaboration with users is needed to strengthen forecast service development, as a rich source of
specific user interest and routines and as a framework for translating user needs into tractable research questions (e.g.
Bremer et al., (2019); Lemos, Kirchhoff, & Ramprasad, (2012); Meadow et al., (2015); Vaughan & Dessai, (2014);
60 Vaughan, Dessai, & Hewitt, (2018); Wagner et al., (2020)). Codesign of services can help to provide the best information on
relevant scales for all users and increase the rates of uptake. If user uptake or the enhancement of knowledge do not
accompany the dissemination of forecast information, the forecast has limited relevance. Operational marine meteorological
centres typically serve a wide range of clients with varying needs. The effectiveness with which relevant information is



communicated to those clients can differ depending on the user's domain knowledge and the utilisation purpose. Specific
65 clients often require bespoke solutions not entirely transferable to other users.

1.1 Perception, preference and uptake of forecasts

Silver, (2015) investigated the perceptions, preferences, and usage of atmospheric forecasts information by the Canadian public. Environment Canada acknowledged the fact that their forecasts were reaching millions of citizens, but they were uncertain as to who or for what purpose these forecasts were being used. They thus investigated how their end users
70 obtained, interpreted, and used their forecasts (Silver, 2015). They made use of both semi-structured interviews ($n = 35$) and close-ended questionnaires ($n = 268$). One of the most interesting findings from Silver, (2015) was that forecasts were mainly used for pragmatic reasons. These would include checking the weather to decide what to wear for the day or for planning social activities, like going away for a weekend. The typical user did not pay attention to the ambient atmospheric conditions unless it was hard not to notice it (e.g. severe weather) (Silver, 2015). They also reported high levels of weather
75 salience with regards to local weather knowledge. Most of the public were however unable to differentiate between products, e.g. what makes them different. The latter directly relates to understanding the basics of model forecasting horizons as well as spatial resolutions. Silver, (2015) also reported that the Canadian public trusted the Environment Canada weather forecasts and actively gave preference to their products. Silver, (2015) highlighted numerous topics and questions that will be addressed and expanded upon in the present study, including the trust users have in various forecast products and why.
80 This question is also even more interesting in the light of our changing climate. With the continuing rise in Climate Change impacts and changing weather patterns, user understanding, and uptake of forecast products have never been more important (a sentiment echoed in the results of the present study). Here, we will focus on ocean and coastal users and include marine forecasts as the main predictand.

85 In the Northern hemisphere, Finnis, Shewmake, Neis, & Telford, (2019) presented a Canadian study where the marine forecasting needs of fishers were investigated and how the available marine forecasting products were used in their decision-making process. They followed a semi-structured interview process and found that there was a “subjective art” to the development/ dissemination and uptake of marine forecasts. Without a direct distinction between user groups, they found that forecasters (commercial/ specialist users) gave more attention to technical details, like model accuracy and consistency,
90 while the fishers (commercial/ recreational) focused more on usability. Kuonen, Conway, & Strub, (2019) also investigated the perception of risk associated with marine forecast products. Commercial fishermen were chosen as the main user group and their study highlighted how important user engagement is for successful marine forecast. Once again semi-structured interviews were used, and the study was based in the USA. These studies thus only had one user group as focus and did not consider a wider spectrum of typical ocean and coastal users. Other studies focused on forecast co-production in the northern
95 hemisphere includes: Bremer et al., (2019), Lemos et al., (2012), Lövbrand, (2011) and Meadow et al., (2015)



A distinction may also be made between commercial users and the general public, the latter typically being a public good concern. The distinction between these user groups might explain some of the results observed by (Silver, 2015). The suspicion is that commercial, or specialist users, will display a higher level of understanding when it comes to technical aspects of forecast usability perception. Marine information and forecast dissemination parameters include ocean winds, waves, temperature, current velocity, water level and water quality dynamics. Drift predictions, associated with search and rescue operations or oil spills, are examples of two services with major human and environmental consequences.

In an initial attempt to distil marine forecast perceptions, a survey analysis was conducted in two southern hemisphere countries, namely New Zealand and South Africa. These two countries are characterised by vastly different social structures and ocean states, and thus different social dynamics. Other than sharing the Southern Ocean and austral seasons, these countries both have heterogeneous ocean and coastal user communities. From a metocean perspective, they also share similar climatologies and latitudes but on different continents with unique metocean dynamics. In our study we explore whether user perceptions of forecasting products are geographically localized or if the two user groups share similar understandings of current and future forecasting needs.

Limited studies have been performed linking southern hemisphere, metocean forecasting needs with available forecasting products. An example is presented by Vogel & O'Brien, (2006) where they focused on the uptake of seasonal atmospheric forecasts over southern Africa. Hewitt, (2020) also presented a high-level discussion on the challenges faced by the UK MetOffice in delivering climate services globally, including the southern hemisphere. The uptake of a metocean forecast depends on numerous factors beyond technical accuracy. Some are even related to the "look and feel" of the dissemination methods: e.g., are the forecasts being accessed via simple text messages, smart phone apps or via traditional publicly available media channels?

1.2 Aim

The present study aims to evaluate metocean forecast perception and thus the important factors that drive uptake, by engaging with members of the broader ocean community, with varying levels of ocean literacy and experience (e.g. recreational and commercial users). Confirming the knowledge viewpoints of these subgroups has not been investigated before and thus forms part of the present study. The present study also investigates the differences in the shared perceptions of geographically separate groups: South African and New Zealand users. This was achieved by means of a questionnaire. By understanding user perceptions, metocean forecasting agencies/ companies can focus on providing relevant information in a format that enables effective uptake. These covers both commercial and public services such as commercial fishermen, search and rescue agencies, paddle craft clubs and surfers. The dual, southern hemisphere country investigation also provides a unique and relevant perspective on global, metocean forecast user needs. This is achieved through investigating two countries with extensive coastlines and exceptionally diverse user communities.



2 Geography, operational settings and the cultural dimensions of ocean use

- 130 Most user perception related studies have been conducted in the northern hemisphere. Not only does the oceanography and atmospheric dynamics differ between hemispheres but so do the cultures established within this predominantly oceanic hemisphere. Both South Africa and New Zealand are in the southern hemisphere at similar latitudes. Both countries have a considerable coastline. South Africa used to be a crucial supply stop for ships traversing between the eastern and western trading routes (Worden, 2007) and currently has a coastline stretching approximately 3 000km. New Zealand, similarly, only
- 135 has Australia as close by neighbour and is considered as being two islands with an approximate coastline of 15 000km. Due to their geographical locations, these extreme coastlines exhibit a variety of coastal, shelf scale and open ocean dynamics (e.g. Barnes & Rautenbach, 2020; Chiswell, Bostock, Sutton, & Williams, 2015; Godoi, Bryan, Stephens, & Gorman, 2017; Rautenbach, Daniels, de Vos, & Barnes, 2020).
- 140 The seafaring heritage of New Zealand resulted in a nation that tends to be interested and involved in everyday metocean predictions. A large portion of the country is aware of the ocean and technically everyone is near the ocean. This is also depicted in the traditional art of New Zealand (Dunn, 2003; Keith, 2007; Ministry for Culture and Heritage, 2014). The culture and language are also weaved into ocean-based references and symbolism (Wolcott and Macaskill, n.d.). This general stance was also reflected in the results presented in the present study. South Africa on the other hand has a much less
- 145 direct relationship with the ocean. The European settlers were most directly linked with trading routes while the British came to colonise South Africa (Oliver and Oliver, 2017). South Africa is also part of the African continent, and thus the traditions and cultures were much more terrestrial focused (Compton, 2011); the Khoisan people being some of the few with a true and dependant relationship with the coastal oceans (Kim et al., 2014). Recently, South Africa made an active step towards focusing on the ecosystem services (blue economy) their vast coastline can offer through a project called Operation Phakisa.
- 150 Phakisa roughly translates to “hurry up” in Sesotho (Findlay, 2018).

The type of relationship users cultivate with the ocean, and the resulting information need that is generated, is not only driven by geographical contexts but also by sectoral differences that determine sociomaterial (linked human-technological) settings (Blair et al., 2020; Lamers et al., 2018). Forecast services are used in distinct ways in different sociomaterial

155 settings, and these differences impact the temporal and spatial scale at which information is needed for planning and for tactical decisions. Consequently, the socio-economic value that may be derived from salient forecasting services varies across a wide spectrum of geographic and sectoral contexts as well.

As more interdisciplinary research includes diverse stakeholders and their observations about the technical, natural and

160 human factors that drive the need for information, it is increasingly apparent that understanding user needs, often in cross-sectoral and cross-cultural settings, is a significant challenge. Traditional interview and questionnaire methods do not always



explain the variation in experiential knowledge that may exist across representatives of a wide range of sectors and decision environments. We used Cultural Consensus Analysis (CCA) (Romney et al., 1986) to document this variation and to look for patterns in user perceptions about the important factors that make forecast products trusted and used.

165 3 Methodology

The consensus model is a method that can reveal agreements among a group of people as a reflection of shared knowledge. This study contributes to knowledge about human dimensions such as cultural values, knowledge and behaviours that influence the direction of forecast products and services development. The consensus model can show shared understandings among users of forecasts, for example, to reveal the values and behaviours that impact the adoption of services and products.

170 We aimed to test the differences between the social norms, values and attitudes in the New Zealand and South African user groups (as well as recreational versus commercial users) toward what constitutes salient forecast service. There is a common perception that there does exist a difference between these user groups, but no formal investigation has yet been done to confirm these suspicions.

3.1 Questionnaire

175 In this study, recreational users include all participants who do not use metocean forecasts as part of their daily work or do not have a financial gain from the use of such platforms. Commercial users would then automatically be the other users, who not only use the platform commercially but also have responsibility linked with the understanding and accuracy of these forecasts. The questionnaire asked the participant to identify themselves within one of these definitions. The questionnaire had four main research questions:

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1. *Which factors impact marine forecast uptake by marine users?*
2. *What are the main requirements from users in the marine forecast environment?*
3. *What is the user perception of existing wave forecasting platforms? and*
4. *How important will accurate metocean forecasts be in the future?*

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The initial step was to formulate each research question based on experience in the metocean forecasting industry. Each question was then discussed in a workshop. The workshop members were from the meteorological service of New Zealand and the South African Weather Service (SAWS). Contributing scientists' competencies spanned atmospheric, hydrodynamic and wave forecasting and observations. Some scientists also had experience in science communication and client liaison and familiarity with the decision space (or operational context) of their respected user groups. The initial objective was to generate a list of propositions to work with, using constructs that frequently emerged in dealings with users in the past. The resulting propositions (constructs), per research question, were then collected and refined.

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The questionnaire was widely distributed. The questionnaire was advertised to both recreational and commercial users throughout both countries (New Zealand and South Africa). Coastal and ocean users emailing lists and platforms were used to spread the invitation as well as personal contacts.

3.2 Data Analysis

The consensus model (Romney et al., 1986) estimates shared beliefs relying on three basic steps. First, it uses Principal Component Analysis (PCA) to test whether the responses are consistent with an underlying shared model for the topics covered in the survey. Eigenvalues are calculated to find a shared knowledge-domain, determined by the presence of a single factor that explains most of the variation in the responses, with a first to second eigenvalue ratio greater than, or equal to, 3.0. Secondly, the model provides a measure of individual knowledge for each respondent (a type of ‘competence’ in the specific shared mental model) by testing each respondent’s agreement with shared beliefs via a proportion match matrix that has been corrected for guessing. And finally, it aggregates individual answers to questions by weighting the final cultural model in favour of respondents with high competence. This set of responses produces the consensus-based result, an approximation of the collective knowledge of the group. The minimum sample size required for the consensus model depends on the level of agreement, the number of informants, and the validity of the aggregated responses (Weller, 2007). For example, at a low-level agreement of 50% (mean competence or knowledge score of .5) at .95 validity the minimum sample size is twenty-eight people per group. The same at 60% agreement is seventeen people. For data analysis we used the match coefficient method of the formal consensus model in the UCINET software package (Borgatti, S.P., Everett, M.G., and Freeman, 2002).

4 Results

4.1 Participant demographics

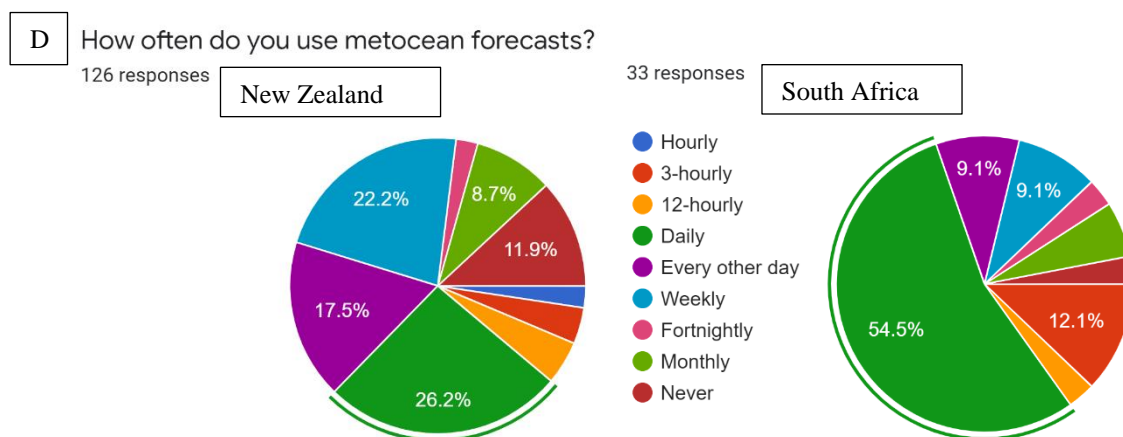
In total there were 157 respondents to the questionnaire. New Zealand received 126 completed responses and South Africa received 31. These numbers proved to be sufficient for the use of CCA because of the level of agreement (mean competence scores) and eigen value ratios obtained in the New Zealand and South African cohorts. It was possible to establish consensus models despite the different participation rates (refer to Section 4.2). A demographics related section was added as a part of the questionnaire. This enabled the present study to have insights into some crucial information that could explain trends observed in the CCA. These results are given in

Figure 1 and Appendix 1. The questions are listed from A to G together with the total responses.



In New Zealand the majority of respondents classified themselves as recreational users (~84%). South Africa had a similar result but with a much larger percentage of respondents being commercial users (~42%) versus the majority recreational users (~57%). These results are particularly interesting given the next set of questions (refer to Appendix 1, Questions B and C). In New Zealand, most of the respondents did in fact have both theoretical and practical ocean/ maritime related training (~70% and 68% respectively). Even more so in South Africa, with ~73% and 82% of respondents receiving theoretical and practical training respectively. Thus, it is not only individuals engaging with the ocean in a professional manner that received ocean related training at some point in their lives. This could also mean that even though people work in an ocean related industry (technically commercial users), their relationship with metocean forecasts are for recreational purposes. There thus might also exist a disconnect between metocean forecasts used professionally (possibly from other specialised, commercial providers and not the same tools used recreationally) versus freely available tools, platforms and products. These thoughts then lead to the next section of questions related to metocean forecasting platform usage and experience (refer to

Figure 1, Questions D and E).

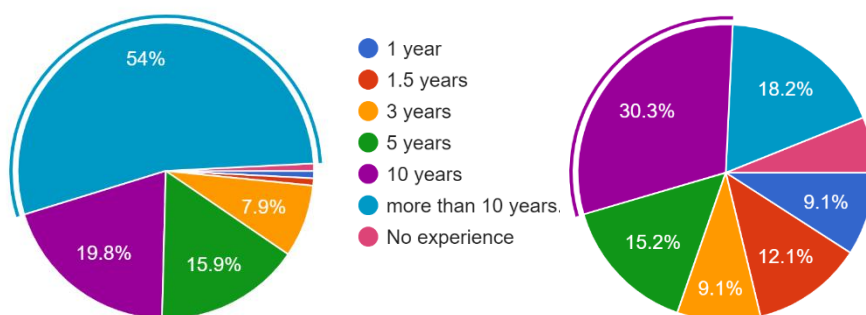




E How many years of experience do you have with ocean forecasting platforms?

126 responses

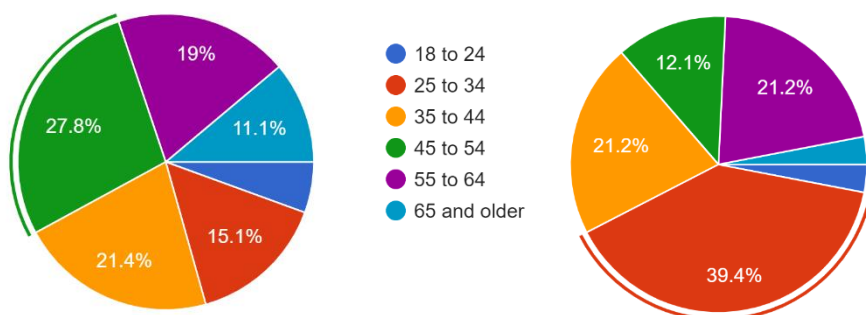
33 responses



F What is your current age bracket?

126 responses

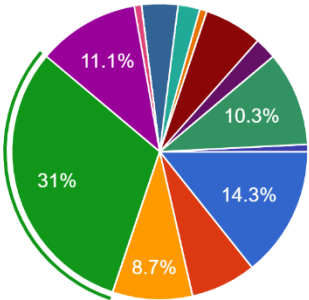
33 responses



G Which of the following do you consider to be your main ocean-based activity? Choose the most correct option and add another activity, if not list...ace provided after selecting the secondary activity.

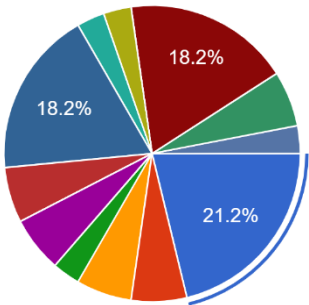
126 responses

New Zealand



33 responses

South Africa



- surfer
- beach goer
- paddle craft users
- fisher
- mariner
- coastal planner
- lifesaver
- offshore platform personnel
- coastal manager
- search and rescue
- shipping
- diver
- swimmer
- dredging
- harbour controle
- scientist
- engineer
- sailing
- windsurfing
- kitesurfing

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250 **Figure 1: Summary of demographic question related to the present study. Here Questions D to G is given with Questions A to C given in Appendix 1, together with their results.**

In New Zealand the most popular frequency of use ranged between daily, weekly and every other day (~ 26%, 22% and 18% respectively). In South Africa the vast majority of usage was daily (~55%), then 3-hourly (~12%) and every other day (~9%). From these results it seems that most people will only look at a forecast once a day, probably for planning purposes. This agrees with the finding of Silver, (2015), where they found that people might consult a forecasting service once during the planning of an outdoors activity. In the context of this study, it will be an ocean and coastal related activity. While South African users consult forecasts at a higher frequency, New Zealand users had much more experience compared to the South African respondents. ~54% of New Zealand respondents had over 10 years' experience using metocean forecasting platforms. ~ 20% had 10 years' experience (refer to

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Figure 1, Question E). In South Africa the majority of respondents had 10 years' experience (~30%) with ~18% more than 10 years' experience. In general, South Africa had more diversity in age with a larger contingent with less than 3-years' experience. These results correspond to the age of participants in

Figure 1, Question F. In New Zealand the majority of respondents were between 45 and 54 years old while in South Africa the majority were between 25 and 34 years old. Both countries have a significant contribution from the age brackets between 35-44 and 55-66 with New Zealand also having a significant number of participants older than 65.

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Figure 1, Question G was related to the actual activities respondents engaged in. Participants were also given the opportunity to add activities that were potentially not listed in the questionnaire. The only two activities that stood out as not being listed, and thus recommended by a few respondents, were water-skiing and photography. In New Zealand most respondents use the ocean for fishing activities (31%) while in South Africa most respondents were surfers (~21%). The other significant New Zealand activities were surfing (~14%), mariners (~11%) and paddle craft users (~9%). The other prominent South African activities were Search and Rescue operations (~18%) and scientific studies (~18%). The questionnaire also asked how many years' experience each respondent had in ocean related activities (these are activities and not the use of forecasting platforms indicated in Figure 1, Question E). For the New Zealand users, 81% indicated more than 10-years' experience while South Africa revealed ~60% with more than 10 years' experience, ~18% with 10 years' experience and ~12% with 5-years' experience. For both countries very few respondents had less than 3-years' experience in ocean related activities.

As a final note on the geographical context, ~50% of New Zealand respondents were from the Auckland district, ~16% from the Waikato, ~11% from Wellington and ~10% from Northland. Fair representation was also received from the other districts (both on the North and South Island). In South Africa most respondents were from the Western Cape province. More specifically, ~49% from Table Bay and the Atlantic Seaboard, ~15% from Kommetjie- Cape Point and ~9% from Simons Town in False Bay (also the location of the South African Navy headquarters). Very few to no participation was received from the eastern provinces of South Africa.



4.2 CCA results

4.2.1 Degrees and patterns of consensus among respondent groups

295 We found that respondents in both countries and in both user-type groups displayed an overall similar answer pattern, and
 the data indicated broad agreement about the propositions presented in the survey. As indicated in Table 1, for all scopes of
 analysis the ratio between the first and second eigenvalues was above the 3 to 1 ratio, suggesting that there was a single-
 factor solution or a shared mental model regarding the main factors that impact user uptake of metocean forecasts. Analysis
 of the entire dataset consisting of all respondents and their responses to each proposition, resulted in an eigenvalue ratio of
 300 6.34 (subgroup model eigenvalue ratios ranged from 4.82-8.04). This finding suggests that respondents across all geographic
 and sectoral contexts share some of the basic understandings about what constitutes salient marine forecasts.

305 **Table 1: Cultural consensus analysis, group mean knowledge scores and eigenvalue ratios of the first to second factors for each study region and sector. Conclusion criteria regarding the consensus model are adapted from Caulkins & Hyatt, (1999). Here, SD refers to the Standard Deviation.**

Scope of analysis:	Eigen value ratio	Mean knowledge score (SD)	Mean knowledge score (SD): South Africa	Mean knowledge score (SD): New Zealand	Mean knowledge score (SD): Commercial users	Mean knowledge score (SD): Recreational users	Negative competence scores	Conclusions
Whole group consensus model (all respondents) N = 157	6.34	0.53 (0.17)	0.61* (0.12)	0.51 (0.18)	0.53 (0.19)	0.53 (0.17)	1	Coherent model: moderate agreement
South Africa consensus model N = 31	8.04	0.61 (0.12)	-	-	0.6 (0.12)	0.6 (0.13)	0	Coherent model: strong agreement
New Zealand consensus model N = 126	5.36	0.50 (0.18)	-	-	0.45 (0.20)	0.51 (0.17)	3	Non-coherent model: multicentric, contested
Commercial users' consensus model N = 34	4.82	0.52 (0.21)	0.62* (0.12)	0.44 (0.23)	-	-	1	Non-coherent model: weak agreement
Recreational	6.4	0.53	0.62*	0.52	-	-	1	Coherent model:



users' consensus model N = 123		(0.17)	(0.13)	(0.17)				moderate agreement
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*significant at $p < .05$

An average estimated knowledge score above 0.5 indicates moderate agreement about an underlying model of shared knowledge (Weller, 2007). The competence (or knowledge score) is the probability that an informant knows (not guesses) the answer to a question, and it is a value between 0 and 1. Analysis showed the average estimated knowledge score of the respondents to be 0.53 (SD = 0.17) in the whole-group consensus analysis (subgroup knowledge score averages ranged from 0.51-0.61 refer to Table 1). The eigenvalue ratio and average estimated knowledge scores at first glance indicated that despite regional differences in geophysical conditions and sectoral differences in sociometrical contexts, marine users generally agreed about important requirements for marine forecasts. But there was high variability in mean knowledge scores in some of the subgroups. We adopt the heuristic by (Caulkins and Hyatt, 1999) to help distinguish varying degrees of consensus, where multiple centers of agreement may exist and form so-called noncoherent models. Where multiple negative competence scores exist, and/or where one subgroup's mean competence is less than .5 (while the other is significantly higher) we identify the model as noncoherent regardless of the eigenvalue ratio.

The present study found some level of consensus in all the consensus analysis runs conducted. Respondents from different communities and sectors displayed slightly varying answer patterns (refer to Table 2) and levels of agreement. There were some negative knowledge scores, but in cases where scores are very close to zero and involve a single respondent, they can be assumed to be zero and don't impact the consensus results (Weller, 2007). Negative knowledge scores can occur when the method's function to correct for guessing pushes the lower limit of adjusted matches from 0 toward -1 (Romney et al., 1986). Negative scores signal that participants responded very differently from others; true negative knowledge scores can invalidate a dominant knowledge culture model. Noteworthy variations in Table 1 present the following patterns in the various consensus models:

- Whole group consensus model:* the 31 participants from South Africa (Mean = 0.61, SD = 0.12) compared to the 126 participants from New Zealand (Mean = 0.51, SD = 0.18) demonstrated significantly higher average knowledge score, $t(155) = 2.8$, $p = 0.0056$. There was no significant effect for sectoral affiliation. Out of 157 respondents, one had a negative knowledge score close to zero (-0.063). While these results suggest an overall shared knowledge domain regarding user needs, the significant variation in mean knowledge scores between the two countries means there are some issue areas that split perspectives between country-specific user contexts.



- 335 • *South African consensus model:* There were no negative knowledge scores, and both commercial and recreational user subgroups attained similar mean scores (~ 0.6 .) This subgroup's consensus model shows high levels of agreement among respondents; and the agreement bridges across commercial and recreational users.
- 340 • *New Zealand consensus model:* three respondents had negative knowledge scores. Two of these were close to zero (-0.053 and -0.003) and the third ~ 0.1 . The overall mean consensus score was moderate at 0.5 , and the difference between commercial versus recreational user average scores was not statistically significant. However, the commercial group's 0.4 average indicates low levels of agreement in this subgroup with a potential consensus model. It is difficult to definitively infer the existence of a clearly defined cultural pattern in this case: some of the assumptions of a cultural model are met (eigen value ratio > 3.0) but three negative knowledge scores -even if two are very close to zero- speak to a contested consensus domain, though large parts of the mental models may overlap between subgroups.
- 345 • *Commercial users' consensus model:* the mean group knowledge score was moderate at 0.52 , with one respondent attaining a negative knowledge score near the ~ 0.1 level. The 14 respondents from South Africa (Mean = 0.62 , SD = 0.12) compared to the 20 respondents from New Zealand (Mean = 0.44 , SD = 0.23) demonstrated significantly higher average knowledge score, $t(32) = 2.572$, $p = 0.015$. Seven of the twenty participants from the New Zealand subgroup had a knowledge score below 0.4 (including the respondent with the negative score), and a moderate but notable variability (SD ± 0.23) in individual knowledge scores. Despite the sufficient eigen value ratio, the significant variation in mean group scores between commercial users from the two nations and low knowledge scores in one subgroup suggest a noncoherent consensus model in this sector that does not span well across the geographic divide.
- 350 • *Recreational users' consensus model:* the 17 respondents from South Africa (Mean = 0.62 , SD = 0.13) compared to the 106 respondents from New Zealand (Mean = 0.52 , SD = 0.17) demonstrated significantly higher average knowledge score, $t(121) = 2.193$, $p = 0.03$. Despite these variations the New Zealand cohort's mean score shows moderate agreement with the consensus model, and there was only one, near-zero negative knowledge score (-0.009). In this sector, there is a moderate level of agreement in the consensus model between users in the two countries.

360 The presence of agreement among the group as a whole (and within each subgroup) was checked, visually, with multidimensional scaling (MDS) (refer to Figure 2 for whole group agreement and Figure 3 for all subgroups) which confirmed overlapping agreement among subgroups with some scattering of low knowledge score participants. These visualizations depict the proportion of similarities between respondents as indicated in the agreement matrix and represented as a pattern of proximities in a multidimensional space. The blue oval gives an approximate grouping of all respondents who had a knowledge score of 0.6 or higher. The stress value is the distortion that occurs when data are transposed over multiple dimensions. These values are reported in the figure captions and in all cases meet criteria set by Sturrock and Rocha (2000).



The whole-group consensus model (refer to Figure 2) indicates that most South African respondents (red squares) cluster closer and centrally located together with New Zealand respondents (blue squares) who have high individual knowledge scores. This group at the centre of the plot had the highest levels of agreement with other respondents and therefore the highest knowledge scores. Respondents who are more peripheral and scattered outside the blue zone had lower knowledge scores: the farther away their location, the lower their score. These individuals frequently answered propositions differently than the consensus model. Peripheral individuals located on opposite sides of the plot had high levels of disagreement not only with the consensus model but also with each other. South African respondents who are outside of the blue zone are still located relatively close to the centre, compared with the outliers farthest away who belong in the New Zealand subgroup. New Zealand commercial users are disproportionally represented on the outside of the blue oval (13 of 20 individuals) in Figure 2, aligning with findings based on patterns of agreement (Table 1) in the various subgroups.

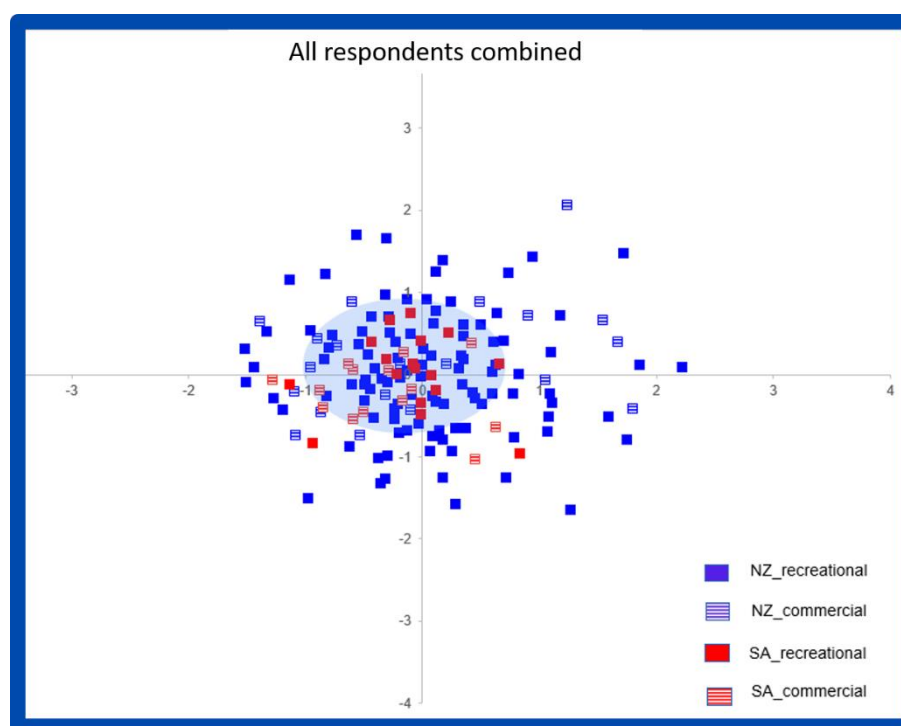


Figure 2: Nonmetric, multidimensional scaling of agreement in the whole-group analysis (stress = 0.264). Blue oval at centre is an approximate grouping of respondents whose knowledge score was 0.6 or greater.

Country/sector-specific and community-specific analyses revealed that commercial users from New Zealand have unique patterns of agreement, independent of whether the analysis includes fellow New Zealand users such as in the New Zealand consensus model with mixed sectors (Figure 3 (A)), or South African users in the commercial users model with mixed



geographies (Figure 3 (D)). The visualizations indicate that commercial users from New Zealand scatter outside the blue oval in disproportional numbers. Commercial and recreational users from South Africa demonstrated equally high levels of knowledge in their shared consensus model (Figure 3 (B)). When the South African commercial and recreational user groups were analysed in sector-specific contexts with their New Zealand counterparts (commercial and recreational users consensus models), both groups demonstrated significantly higher shared knowledge scores than New Zealand participants (see also Figure 3 (C)). This means that South African respondents have a more homogenous shared mental model among themselves and they share high levels of agreement with New Zealand users who attained high knowledge scores.

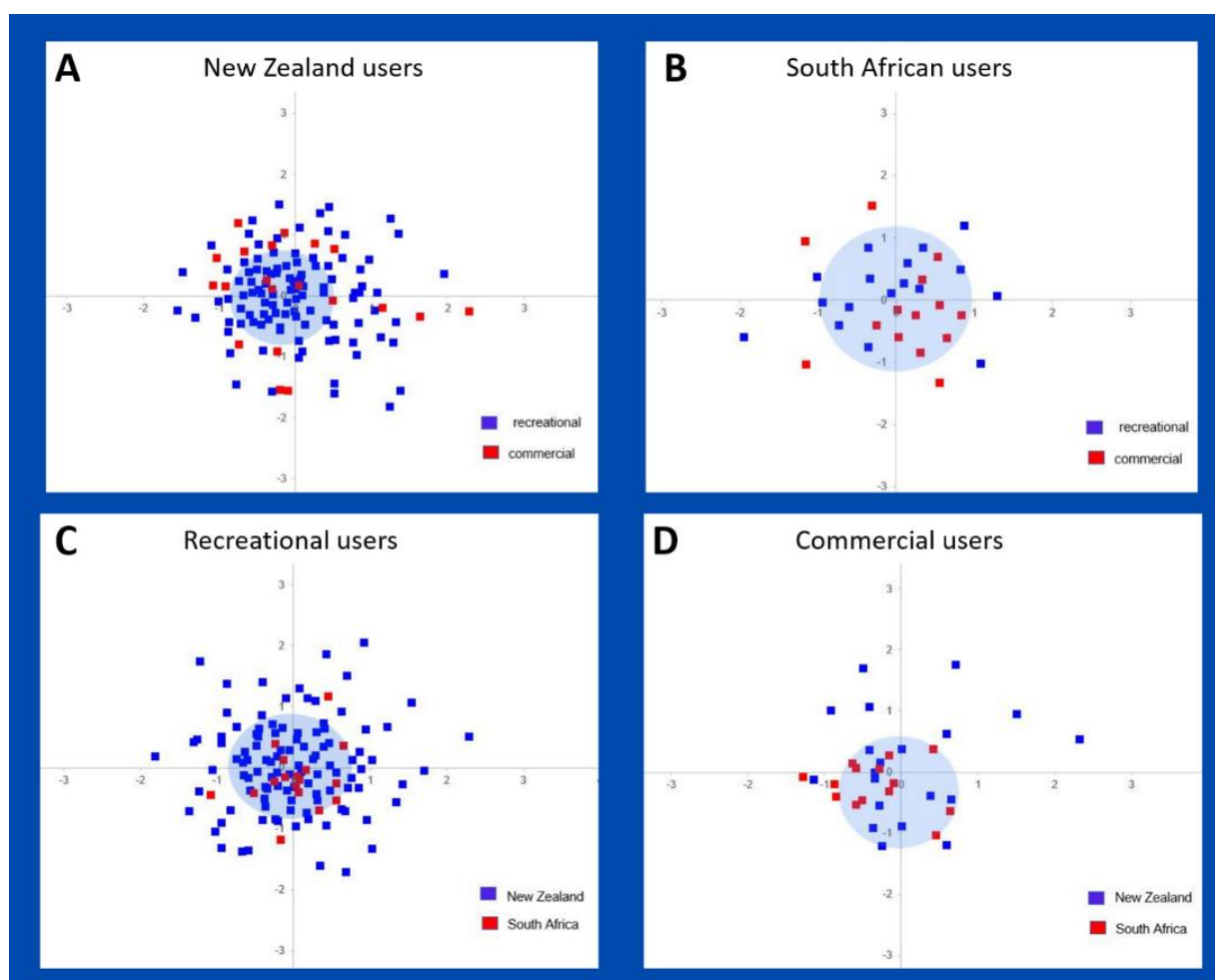


Figure 3: Nonmetric, multidimensional scaling of agreement in the subgroups. Blue oval at centre is an approximate grouping of respondents whose individual knowledge score was 0.6 or greater. Panel A: New Zealand ocean users (stress = 0.263); Panel B: South African ocean users (stress = 0.237); Panel C: recreational ocean users (stress = 0.258); Panel D: commercial ocean users (stress = 0.207).



4.2.2 The consensus model: factors that impact user uptake of metocean services

In Table 2 the level of consensus measured by the frequency of culturally correct answers (CCA) for all propositions are given. These are the direct questions and resulting propositions that were distributed in the survey and form the base of the present study. The whole-group CCA is based on the analysis of the entire dataset consisting of all respondents. This consensus model is indicated as true/ agreement with a green icon or false/disagreement with a red icon. Values are percent of responses matching the whole-group CCA. Where a subgroup's own consensus-model deviates from the whole-group CCA, the added icon indicates the correct answer in the sub-group.

Table 2: Level of consensus measured by the frequency of culturally correct answers (CCA) for all propositions. The whole-group CCA is based on the analysis of the entire dataset consisting of all respondents; this consensus model is shown as true/agreement (green icon) or false/disagreement (red icon) with the propositions. Values are percent of responses matching the whole-group CCA. Where a subgroup's own consensus-model deviates from the whole-group CCA, the added icon shows the correct answer in the sub-group.

Topic areas	Research questions and propositions	Whole-group CCA	NZ subgroup	SA subgroup	Recreational users subgroup	Commercial users subgroup
	Which factors impact marine forecast uptake by marine users?					
Ease of use	The visual experience offered by a forecast	✓	84	90	85	88
Easily cross-referenced geographical parameters	Easy access to location of interest	✓	64	55	63	59
Number of clicks	Number of clicks to relevant information (less is better)	✓	81	84	80	85
Easily cross-referenced physical parameters	Easy access to variable of interest	✓	77	84	77	82
Institutional reputation	Whether provider is an established entity or a “newcomer”*	✗	56	✓	55	✓
Terminology	Use of jargon Intimidating**	✓	56	84	59	71



	or scientific terminology makes a forecasting site:	Untrustworthy	✗	90	90	90	91
Marketing	Word of mouth and recommendation by peers		✓	90	97	92	88
Accuracy	Inaccurate forecasts (loss of trust in provider)		✓	74	71	74	71
Consistency	The consistency of inaccuracies (forecast can still be useful if consistent)***		✓	66	74	67	68
Community engagement	Interactive features (ability to submit photos, info is better)		✓	48	61	49	56
Simple metrics	Simplified concepts, graphs and plots and easy-to-understand, quick uptake scaling of metocean conditions		✓	70	74	72	65
Intuition / experience	User's own intuition as a part of the safety calculus/decision making when predicting conditions		✓	73	84	77	68
	What are important requirements from users in the marine forecast environment?						
Speedy answers	The length of time taken between navigating to a forecast service and arriving at the desired data		✓	86	100	87	94
Bespoke forecast	Customizable preferences to facilitate faster access to desired information		✓	93	94	92	97
Forecasting horizon	A forecasting period between 3 and 7 days		✓	92	97	93	91
Training	Training in the science behind and use of marine forecasts		✓	56	65	55	65



	What is the user perception of existing wave forecasting platforms?						
	Public platforms (e.g. Windy, Windguru, Magicseaweed and Buoy Weather):	have a high reputation among marine users		85	94	87	85
		are reliable for most locations in the nearshore		65	61	71	
		are most useful further away from the coastline		61	48	64	
		have a likeable visual appeal		87	94	87	94
	How important will accurate metocean forecasts be in the future?						
Reliability	Reliable metocean forecasts will be even more important			82	94	85	79
Consequences	The consequences of mispredictions will be more severe			73	65	72	68
Climate change	Climate change is making the ocean more difficult to predict			48	68	51	53
Institutional reputation	The scientific reputation of forecast providers will become more important			75	81	76	79
Scientific support	Science based forecasts will be more important in the future.			87	90	87	88
Training	Climate change will make an understanding of the science behind ocean forecasts more important			75	100	78	88

415

*Respondents suggested that while familiarity and established trust in a provider can encourage uptake of services, users are open to newcomers and view some of their products as very trustworthy.

**The New Zealand and recreational users' subgroups indicated that users are generally able to figure out the meaning of technical terminologies.

420

*** Respondents noted that while in such cases the forecast can still be useful, the inaccuracies decrease usefulness.



The first research question explored which factors impact marine forecast uptake by marine users. These factors range from aesthetics to practical considerations, like the number of clicks required to get to the required information. All users and regions rate the ease of use as being very important. This includes easy navigation and ergonomics of the tool or site. The opinion of others is also important to all users. So, if a site is being promoted through a community via word of mouth, uptake and usage of the forecasting site or tool will increase. It is also interesting to note that if a forecast is inaccurate, there were a significant proportion of the user communities that would not necessarily stop using the forecast, as long as the inaccuracies are consistent. The South African and commercial users' subgroups agreed that services from established entities are trusted more than those offered by newcomers, while all subgroups agreed that intuition (in combination with forecast products) helps to keep operations safe.

When considering the requirements from users, speedy answers were strongly agreed upon, so much so that 100% of South African respondents, regardless of sectoral affiliation, agreed. All users agreed on a preferred forecast horizon (3-7 days) and that training on the use of products is needed. The conviction about training was not as strong as the other propositions, with the sentiment strongest expressed by all South African users and the commercial user's subgroup. Well-known metocean forecasting platforms are trusted and enjoyed by all user groups, but perceptions about the location of highest accuracy varied. The fourth and final research question is related to Climate Change and the uncertainties associated with it. All groups and subgroups agreed that reliability of metocean forecast will be more important in the future and the role of training in forecast use will be even more significant for safe operations. Consensus was weak however, around an overall agreement, that climate change impacts will make the ocean more difficult to predict. It should be mentioned that the participants were also question regarding their trust or perception of their own national weather services. In South Africa it is the South African Weather Service (SAWS) and in New Zealand the MetService. Both institutes were evaluated very highly but were not included in the whole-group consensus analysis of the present study as these were country-specific institutions. They each were found to be trustworthy, reputable, high quality, reliable nearshore, with likeable visual appeal.

5. Discussion

The results presented in Section 4 elucidated numerous interesting behaviours within regional (or sector) groups as well as community groups. Part of the aims of the present study was to explore the existence of a common or global typology for salient forecast services that spans geographic and sectoral contexts, to the extent it is possible. In doing so, we also aimed to establish subgroup-level perceptions that are unique to specific contexts among metocean forecast users. Using two southern hemisphere countries as test cases, some shared fundamental factors in salient forecasts, and context-specific distinctions were thus confirmed. Numerous studies acknowledge varying user needs and opinions but the delineation between recreational and commercial users has not been suggested or illustrated before. Understanding user needs are very well understood in other commercial industries, but in the everyday metocean forecasts the connection between research,



products and user needs are not well established. Even more so in the southern hemisphere, in every-day (none-extreme),
455 forecasting domains. Drawing the results together into a clear discussion requires the consideration of all the results,
including the demographic description provided in Section 4.1. The discussion will follow the results presented in Table 2
and draw on all the other results to elucidate user perceptions, usability and uptake.

Another interesting outcome was the user relationship with the organisation or institution providing the forecast. In the past,
460 users knew of state-owned research institutes with well-established reputations. This instilled trust from the users without
much question. When new and unknown companies brought new products (especially science related) to the market, users
were sceptical (Li et al., 2008). Through the development of technology, the public has grown accustomed to providers that
they have never hear of before. Apps, websites and online shopping has changed the way society sees the world and
inevitably their trust relationship with tools, products and services. This is reflected in the survey results, where the total
465 CCA knowledge model disagreed that if an institution is established or not matters much. The South African and commercial
users' subgroups did however agree with this statement, aligning with findings from an investigation of the trust in
Environment Canada's forecasting products (Silver, 2015). Therefore, evidence suggests that commercial users do still
require institutional reputation, probably because there will be consequences for them based on the reliability of the forecast.
Scientific integrity will continue to be an important factor in users' trust in products and services, and therefore, in their
470 uptake. All user subgroups confirmed that their own intuition plays an important role in predicting conditions and safe
operations. The demographics presented in Section 4.1 supports this, as a significant number of users had a lot of experience
with coastal and ocean activities and with metocean forecasting platforms. Consistently inaccurate forecasts were also
mainly perceived as being useful. This also testifies of more experienced users as they will be able to recognise recurring
inaccuracies and knowingly compensate for these. For example, if a significant wave height forecast for a particular region is
475 always underpredicted, the users (through experience) can compensate for it. If the inaccuracy is erratic, this becomes
impossible. The recreational surfing community is a good example of a community that applies local knowledge daily to
compensate for model and forecast inaccuracies. This community tends to be expert metocean forecast users and have learnt
how to interpret particular synoptic scale events and forecast to sufficient accuracies of metocean conditions in the
nearshore. Their interpolation also exceeds most resolutions of even coast model forecast and (mostly) unknowingly
480 compensate for various coastal processes (like friction, refraction, shoaling etc.). The same reasoning applies to most
commercial users (including Search and Rescue operators).

The importance of a bespoke forecast was highlighted by very high levels of agreement (>90%) among respondents. This
aspect of forecast delivery is still underexplored by numerous metocean forecast providers and thus requires investigation
485 and further development. A three to seven day forecast horizon seemed to be preferable for most users. Much like the
farming community, there still exists the need for longer term and seasonal scale forecasts as well. These are predominantly
used for planning purposes by aquaculture farmers, coastal hazard assessments and governance authorities (Alexander et al.,



2020). But for most users, who also use metocean forecasts daily (refer to Section 4.1.) short-term forecasts are most useful, probably due to pragmatic activity planning purposes (Silver (2015)).

490 Well-known metocean forecasting platforms were well-reviewed on reputation and visual appeal. These platforms do not necessarily conduct independent research on model calibration, validation or improvements in the underlying physics. They generally repackage freely available forecast products in an easy to understand and ergonomic fashion. The features of most of these sites are user-centrally designed and thus enjoy high esteem from all users (as confirmed by the present study as well). Most of these repackaged, freely available products are not accurate or reliable in the nearshore. This is due to model
 495 resolution and the presence of land. Both atmospheric and oceanographic parameters do not take nearshore topography or bathymetry into account and can thus not solve the relevant physical with high enough detail. The degree to which these models are inaccurate will vary depending on the coastal location (Daniels et al. (2020)). The commercial users' subgroup CCA model was the only cohort that disagreed with the proposition that these models/ platforms are reliable in the nearshore. This is an indication that commercial users are more aware of the underlying assumptions of these models. This is
 500 also reflected in the South African cohort, as their commercial representation was larger (refer to Section 4.1). These models are in fact more useful and accurate further away from land and again the general knowledge base disagreed with this. Only the commercial users agreed with this, theoretically, correct statement.

This perception or sentiment indicates that all users have a concept of the unknow related to Climate Change and the future,
 505 in general. Interestingly, when it comes to the uncertainties of the future, all users and subgroups agree that scientific reputation is important. This indicates that users understand that scientific rigour is needed to analyse and accurately account for possible change. This is supported by the topical area postulations regarding institutional reputation, scientific support and training. 100% of South African users, across both communities, agree that training will be required in the future to help users understand the science behind ocean forecasts.

510 Although everyday use of the coastal ocean in South Africa is evident (de Vos and Rautenbach, 2019) the vast majority of the public is not as closely linked with the ocean as Kiwis (New Zealanders) are (refer to Section 2). This cultural difference was also observed in the present study where a greater contingency of the survey participants in South Africa were commercial users. These also include members of the public who have a more direct technical relationship with the ocean.
 515 Even though the New Zealand population is approximately 10 times smaller than South Africa the present study survey obtained approximately four times more interest in New Zealand; illustrating the influential role of the ocean among New Zealanders. The distinct consensus patterns obtained in this study present an image of South African users who are quite homogenous in their understanding of salient forecast products and user needs. The New Zealand recreation cohort, though a remarkably heterogenous sector that includes a diversity of ocean uses, still exhibited a moderate-level agreement with the
 520 consensus model (both in the country- and sector-specific models). It is noteworthy that New Zealand commercial users had

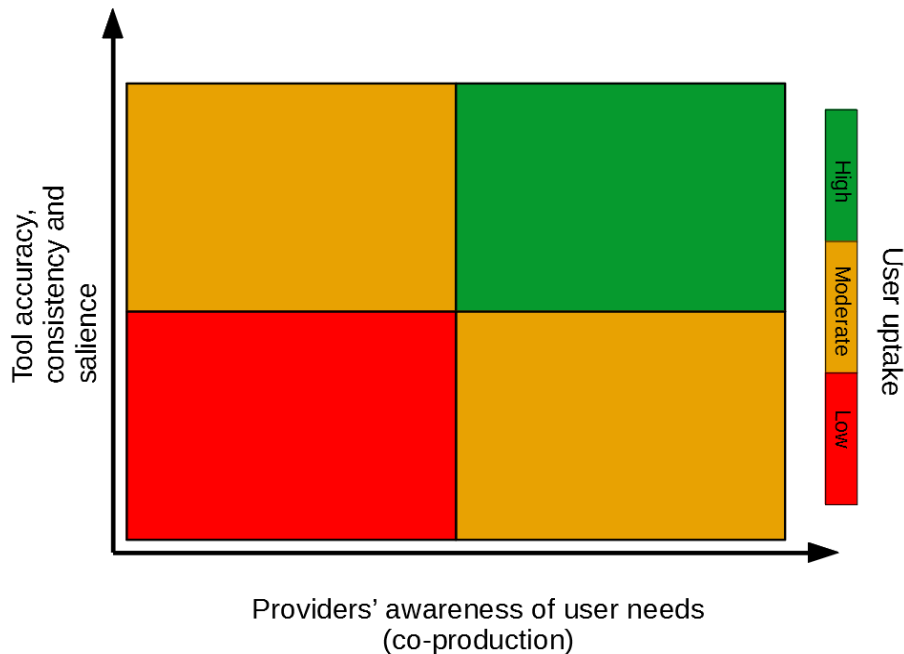


weak levels of agreement in all consensus models. This could be due to the larger range of participants (and thus ocean activities), representing a wider variety of commercial users (refer to Figure 1, Question G).

525 These new perspectives from two southern hemisphere countries, with different cultures, still demonstrated numerous coherent opinions and perceptions. The valuable insights presented here are useful for both local and global forecast agencies who must cater for a global market and public good.

5.1 A general conceptual user decision quality framework

530 In order to summarise the lessons learnt from engagement with the user of metocean information, the following conceptual matrix is used. Here, it is asserted that users' decision quality is a function of the service provider's awareness of user needs and the accuracy, consistency and salience (how forecast is packaged and communicated) of a product. This framework holds true for varying contexts of local and sectoral knowledge and general ocean literacy. In Figure 4 this conceptual framework is depicted schematically.



535 **Figure 4: A conceptual matrix illustrating user uptake as a function of co-production and tool accuracy and consistency. This framework illustrates the co-dependence between science communication and bespoke, user centric, forecasting tools and products.**



540 This conceptual model demonstrates the need for product and service coproduction with users. While we established several important factors in forecasts salience that can be classified under a global (cross-geographic, cross-sectoral) typology, other user needs were context-specific and/or were generated by varying degrees of ocean literacy. Service providers benefit from coproduction as it can help to ensure that products are useful, usable and used (Vaughan et al., 2018). And according to our respondents, considering rapid biophysical shifts that are anticipated due to climate change, there is an increased need for science-based forecast, and for greater understanding of (and training in) forecasts and the science behind forecast services. This means that users to benefit from collaboration with service providers through mutual learning, and the development of more bespoke products. Investment in coproduction can increase user trust in providers by increasing for users the transparency and comprehensibility of forecast skill and relevant metrics. Our conceptual model can be applied to various locales, industries or interest groups, in deciding where the focus in new product development should be. For example, it might be that whilst a product performs relatively well (high quantified skill level), local knowledge is lacking, and this is the reason for poor decision making. As such, resources might be better spent addressing the local or sectoral knowledge gap and ensuring that the product is used correctly, with appropriate regard for its limitations (Alexander et al., 2020).

6. Conclusion

We used a consensus model approach to document and explore a potential typology of the factors that make forecasts salient for users, in two southern hemisphere nations. In addition to these geographic settings, we also explored the consensus around current and anticipated future user requirements in their sector-specific contexts. Cultural consensus analysis allowed us to systematically explore regularities and variation in perceptions. We found varying degrees of consensus among the whole group versus different subgroups of users. South African respondents were homogenous in their agreement independent of sectoral affiliation. New Zealand's recreational users were in moderate agreement amongst themselves and with South African user groups, but commercial users were divided. For all user groups, ease of use, customizable features, consistency and accuracy were some of the important factors in service uptake, however established reputation of the provider was important specifically in the commercial users and South African respondent cohorts. Respondents emphasized a number of priorities for science-based forecasts in the future in light of anticipated Climate Change impacts. Based on our findings we proposed a decision-quality framework schematic that 1) builds on the global dimensions of established user requirements and 2) emphasizes the role of co-production in generating context-specific knowledge. We aim to bring prominence to the need to move to demand-driven models of service development by reworking the user-provider relationship. Going forward, future work could extend the consensus method toward evaluating the risks and uncertainties that are of most priority to different user groups, and which services are most relevant and/or lacking to reducing those uncertainties. Coproduction may help to operationalize such practical evaluations of risks, and of the evaluative criteria needed for a comparison across multiple settings and contexts for better service provision. While coproduction may not always be the desired approach - especially when the problem uncertainty and/or service demand are low and supply-driven



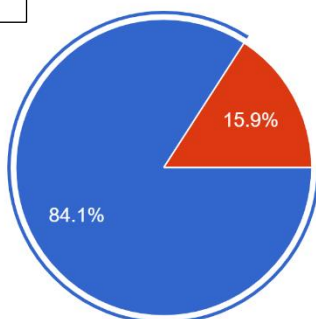
solutions suffice. But when many users are impacted, and uncertainties are high, user collaboration helps to ensure product salience, the eventual uptake of services, as well it adds value to the forecast value chain by supporting and promoting safe marine activities.

575 Appendix 1

A Would you say you are primarily a recreational or commercial user of the coast or ocean?

126 responses

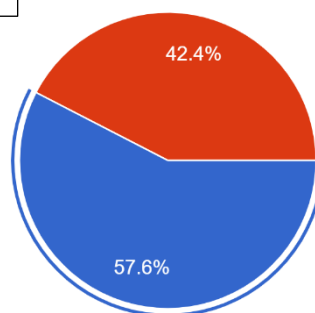
New Zealand



33 responses

South Africa

● Recreational
 ● Commercial

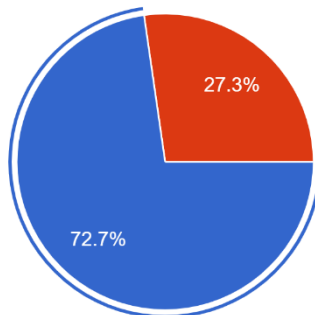
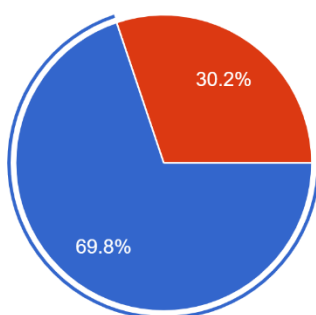


B Have you had any theoretical ocean/maritime related training?

126 responses

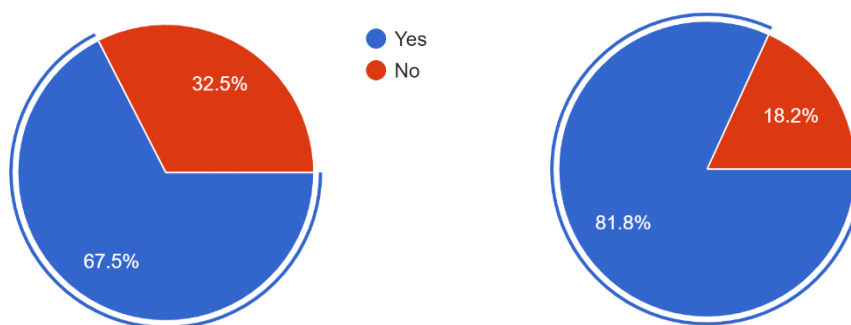
33 responses

● Yes
 ● No





C Have you had any practical ocean/maritime related training?
 126 responses 33 responses



Author contribution

580 Dr. Rautenbach conceptualized the original idea. Dr. Blair helped in evolving the original idea into the resulting study and co-developed the aims and goals of the study. Dr. Rautenbach took the lead in data curation. This entailed distributing the survey, collecting the responses and summarising them into an initial digital format. Dr Blair took the lead in the formal analysis, doing the CCA analysis and producing the quantified results. Dr. Rautenbach secured the funding for the study. The investigations of the study were done by both Dr. Rautenbach and Dr. Blair through numerous online discussions. The methodology was jointly developed but with Dr. Blair taking the lead with the CCA analysis. Dr. Rautenbach took the lead in project administration and providing sector specific insights. Both authors contributed to data visualisations. Both authors wrote the manuscript. Dr. Rautenbach wrote the original draft with significant contributions from Dr. Blair during the reviewing process.

Competing interests

590 There is no conflict of interests.

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