Insights into the usefulness of a new extreme weather guidance tool: the Long-Range Tropical Cyclone Outlook for the Southwest Pacific (TCO-SP)

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ABSTRACT

Tropical cyclones (TCs) produce extreme winds, large waves, storm surges, intense rainfall and flooding and account for almost 75% of natural disasters across the Southwest Pacific (SWP) region. The island nations and territories across the SWP rely on seasonal TC outlooks for insights into possible risks for the coming TC season. Launched in July 2020, the Long-Range Tropical Cyclone Outlook for the Southwest Pacific (TCO-SP) provides deterministic (frequency) and probabilistic (likelihood) TC outlooks for 12 sub-regional and island-scale locations up to four months (July) before the start of the SWP TC season (November-April). Following TCO-SP’s first season of operation, this study (i) outlines the process of generating and communicating TCO-SP outlooks, (ii) provides a post-season validation of TCO-SP performance on the 2020/21 SWP TC season and (iii) reports on the results of a questionnaire used to determine end-user needs and user-perceived usefulness of TCO-SP. Post-season validation indicates that TCO-SP successfully predicted a near-normal SWP TC season. Island- and regional-scale guidance also performed well, with an average skill score of 54% across all regions. Analysis of responses to a TCO-SP questionnaire revealed a diverse and global user-base that indicate the core features of TCO-SP (island-scale/regional-scale outlooks, regular monthly updates and an outlook lead-time up to four months before the start of the TC season) are particularly useful. TCO-SP will continue to innovate to deliver reliable and trusted TC outlooks with a goal to reduce disaster risk and increase resilience across the SWP region.

Capsule summary: Insights into the usefulness of a new extreme weather guidance tool: the Long-Range Tropical Cyclone Outlook for the Southwest Pacific (TCO-SP).
Introduction

The Southwest Pacific (SWP) is one of the most exposed regions to natural hazards and climate change in the world (Arnold et al. 2016). On average, 11 tropical cyclones (TCs) occur within the SWP region (5°S-35°S, 135°E-120°W) each season (November-April between 1981 and 2010), and they bring strong winds, intense storm surge, coastal inundation and prolonged and intense rainfall. Island nations and territories of the SWP are particularly vulnerable to the impacts associated with TCs, amplified by high shoreline-to-land area ratio (Barnett 2001), dense populations in low lying areas, near-coastal terrain (Connell 2013), slow economic growth (McKenzie et al. 2005), fragile infrastructure (Mimura 1999), exposure to disease (Shultz et al. 2005), and a dependency on subsistence living (Mataki et al. 2006). Since 1950, SWP TCs have claimed nearly 1500 lives and have displaced more than 3 million people across the region (EM-DAT 2021). The financial impacts of TCs can be devastating; for example, the damage and loss associated with Severe Tropical Cyclone Pam in March 2015 (US$449.4 million) were equivalent to 64.1% of Vanuatu’s annualised nominal gross domestic product (GDP) (Esler 2015). Arnold et al., (2016) attribute the increase in TC-related impacts to a change in exposure and vulnerability rather than an increase in the intensity or frequency of recent TC events. There are also significant weather impacts from TCs as they undergo extra-tropical transition into the southern middle-latitudes (Lorrey et al. 2014). As such, TCs (and the associated hazards they produce) represent a leading cause of extreme weather impacts that can lead to poverty, and therefore a persistent and ongoing threat to the development of islands, nations and territories across the SWP.

Seasonal TC outlooks play a pivotal role in informing and preparing the SWP region of the likely risks for the coming TC season. As SWP TC activity (frequency, intensity and location) is strongly influenced by intra-seasonal and interannual climate variability, including El Niño-Southern Oscillation (ENSO; Diamond et al., 2013; Magee et al., 2016),
Indian Ocean sea surface temperature (SST) variability (Magee and Verdon-Kidd 2017), the Southern Annular Mode (SAM; Diamond and Renwick, 2015) and the Madden-Julian Oscillation (MJO; Diamond and Renwick, 2015), tracking these climate influences in real-time can provide a view of TC risk for the coming season. For many years, three agencies have provided seasonal TC outlooks for the SWP region: the National Institute of Water and Atmospheric Research (NIWA) in collaboration with MetService (NIWA 2020); the Australian Bureau of Meteorology (BOM 2020); and the Fiji Meteorological Service (FMS 2020). Each agency provides an independent TC outlook for the SWP region using statistical modelling or analogue based methodologies (e.g. selecting historical TC seasons with similar oceanic and/or atmospheric conditions to present to provide a view of TC activity for the coming season) and each considers recent ENSO-related variability and forecast information in deriving an outlook.

The Long-Range Tropical Cyclone Outlook for the Southwest Pacific (TCO-SP) (Magee et al. 2020) was launched in July 2020 and produced an inaugural TC outlook for the 2020/21 SWP TC season that added additional capabilities to pre-existing SWP TC outlooks. Following the first season of TCO-SP operation, this study aims to: (1) summarise how TCO-SP outlooks are generated and communicated, (2) review and validate the operational performance of TCO-SP for the 2020/21 SWP TC season, and (3) outline recent feedback of end-user needs and user-perceived usefulness of TCO-SP. The results of an online questionnaire conducted with users of TCO-SP are reported here to: (a) establish the TCO-SP user base, (b) determine end-user needs, and (c) quantify user-perceived usefulness of TCO-SP.
TCO-SP: the Long-Range Tropical Cyclone Outlook for the Southwest Pacific

TCO-SP is the SWP’s first long-range, statistical island-scale TC outlook. Both deterministic (TC frequency) and probabilistic (likelihood) outlooks are generated for 12 sub-regional and island-scale locations across the SWP (Figure 1). TC outlooks are provided on a rolling monthly basis between July and January for the November-April TC season with fresh initialisation. Regular updates ensure that the most recent changes in atmospheric and SST variability are considered by the model collection harnessed by TCO-SP. Magee et al. 2020 showed that skilful TC guidance can be produced up to four months before (July) the start of the TC season (November), offering extended lead-time that would offer guidance to end-users in the months before the start of the TC season. More comprehensive details regarding the modelling methodology used to derive TCO-SP outlooks (Poisson regression) are available in Magee et al. (2020).

TCO-SP extends the scientific basis of existing SWP TC outlooks beyond extant outlooks that use statistical or analogue based modelling approaches with only ENSO in mind. In combination with ENSO, TCO-SP also considers Indian Ocean SST variability (Magee and Verdon-Kidd 2017) and the SAM (Diamond and Renwick 2015b), which are known to amplify and/or suppress the well-established regional ENSO-TC relationship. Forecasting agencies that generate TC guidance in mid-October for the November-April TC season only offer a lead time of up to three weeks before the start of the TC season for the full, early and late season outlooks. Opportunities for minimising disaster risk improve with increased guidance lead time, which is why the development of TCO-SP has targeted outlook skill for model lead times up to four months before the start of the TC season (Magee et al. 2020). The adaptive, island- or region-specific statistical modelling framework that underpins TCO-SP outlooks (e.g. choice of models and model weighting) means that model
combinations for individual islands and SWP subregions are continually reiterated and improved through retraining. As time progresses and after a TC season finishes, the event set for the following year is updated, iteratively increasing the available number of seasons with which to train the TCO-SP models. This is important as any emerging and long-term changes in TC activity (driven by natural climate variability or anthropogenic climate change) are included in the historical event set and can be considered when a prediction is generated.

a. Generating, communicating and accessing TCO-SP guidance

A multi-step process is followed in generating (step 1) and communicating (step 2) TCO-SP guidance (Figure 2). The multivariate modelling nature of TCO-SP includes a total of 14 climate indices which are updated before each pre-season and in-season outlook to include the previous months’ index value. These indices include 10 oceanic, atmospheric and coupled ocean-atmospheric ENSO indices (as there is no consensus on which ENSO index best represents the diversity of ENSO (Capotondi et al. 2015; Hanley et al. 2002)), three indices representing Indian Ocean SST variability and the Marshall SAM index (Marshall 2003). These indices are combined to create 10 unique predictor models (each model has one ENSO index plus all other non-ENSO indices to avoid multi-collinearity) and are trained on the historical record (1970-present) using multivariate Poisson regression. An automated covariation selection algorithm tests thousands of possible predictor model combinations before selecting the most skilful combination of indices. This selection process is repeated 10 times; once for each of the 10 predictor models. Each of the 10 predictor models are validated on the historical record for the selected domain (island or subregion), and the model with the highest skill score (i.e. the best performing model on the historical record) is selected to produce the outlook for the coming season. TCO-SP outlooks include a deterministic TC count (including the probable range), as well as a probabilistic outlook (assuming the Poisson distribution and calculating the chance of average/below-average and above-average TC
activity) which is the output from step 1. This process is repeated for each of the 12 locations across the SWP region (Figure 1), noting that the best combination of predictors and the model with the highest skill score will vary according to location and month.

Once deterministic and probabilistic outputs are generated, step 2 outlines how TCO-SP outlooks are communicated (Figure 2). First, the TCO-SP guidance document is generated, which contains an outlook summary, graphical aids (including figures, risk maps and tables summarising expected TC activity), as well as a summary of model skill when trained on the historical record. Second, All TCO-SP outlooks (including historical outlooks and post-season validation analyses) are freely available and are available on the website (https://tcoutlook.com). Since the first TCO-SP outlook was generated in July 2020, a growing subscribership has emerged (300+ subscribers as of August 2021), and subscribers are informed when a new TCO-SP update has been released. Last, social media (Twitter and LinkedIn) are updated with a summary of TCO-SP guidance.

TCO-SP is updated up to seven times per TC season – four pre-season TC outlooks (July-October) and three in-season TC outlooks (November-January). The multi-step process outlined in Figure 2 is repeated each time a new TCO-SP outlook is generated. TCO-SP guidance is also encapsulated within the SWP’s first consensus-led Island Climate Update (ICU) Tropical Cyclone Outlook derived by NIWA (NIWA 2020). The ICU summarises nation-specific analogue, dynamical and deterministic TC guidance, enabling a confidence statement to be attached to island- and region-specific outlooks depending on the level of agreement across the three modelling approaches.
Validating TCO-SP performance for the 2020/21 Southwest Pacific TC season

For the 2020/21 SWP TC season (1st November 2020 – 30th April 2021), eight named TCs and one unnamed TC was observed within the basin (nine TCs in total). Of the eight named TCs, three were severe (Category 3 or above; 10-min sustained winds of ≥64 kt) including Severe TC Yasa (Dec 12-19), Severe TC Ana (Jan 30-Feb 2) and Severe TC Niran (Mar 1-6). Severe TC Yasa was the deadliest and costliest event of the 2020/21 SWP TC season, resulting in four deaths and estimated damage of US$246 million. Other TCs include TC Zazu (Dec 13-16), TC Imogen (Jan 3-4), TC Kimi (Jan 17-19), TC Bina (Jan 30-Feb 1) and TC Lucas (Jan 31-Feb). One unnamed TC (TD09F) was also recorded, and was comparatively shortlived (Feb 10-11). Overall, the 2020/21 SWP TC season claimed seven lives, with estimated damage totalling approximately US$440 million (Woolley et al. 2021).

For pre-season TCO-SP outlooks for the entire SWP basin (July-October predictions for the November-April TC season), deterministic and probabilistic guidance successfully predicted a near-normal1 2020/21 SWP TC season in July, up to four months before the start of the SWP TC season (Figure 3a). This near-normal prediction (nine TCs; with a probable range of between seven and 11 TCs) persisted for all pre-season outlook months (July-October), improving confidence in the continuity and robustness of long-range TC frequency predictions between months and matching the observed TC count (nine TCs). Model skill scores were also high for SWP outlooks, ranging from 52-58%2 (Figure 3a). Probabilistic

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1 Near-normal is defined as when the difference between expected TC counts and the long-term (1981-2010) average is between -20% and +20%.

2 Skill score (SS) provides an evaluation of model performance, where 100% represents a perfect outlook, 0% represents outlooks that are as accurate as the climatology and -100% represents a completely incorrect outlook (see Roebber and Bosart (1996) for more information).
guidance indicated a 64% (July 2020), 62% (August 2020), 57% (September 2020) and 65% (October 2020) chance of 9 TCs or less across the SWP basin.

Pre-season TCO-SP outlooks for the remaining 11 sub-regional locations had the observed number of TCs falling within the TCO-SP expected range for every outlook initialisation period, except for the N SWP September outlook which overestimated the frequency by 1 TC. Given La Niña conditions persisted for the majority of the SWP TC season and that TC activity is more likely to be focused south-southwest of normal (towards Australia) (Magee et al. 2017), sub-regions in the far east of the SWP including the NE SWP (Northern Cook Islands, Eastern Kiribati: Line Islands, Marquesas, Tuamotu Archipelago, Gambier and the Pitcairn Islands) and the SE SWP (Southern Cook Islands, Society and the Austral Islands) did not experience any TCs transiting those respective regions (Figure 3k-l). This outlook was predicted by TCO-SP in July and that outlook was consistent across all pre-season outlook months. For in-season sub-regional TCO-SP outlooks (November-January for the remaining season), the observed number of TCs fell within the TCO-SP expected range for 31 of the 33 outlooks.

Specific to the 2020/21 SWP TC season, evaluation of model skill scores (Figure 3) indicates that July is the most skilful pre-season outlook month for five of the 12 domains, including the SWP basin (58%), New Caledonia (68%), Northern New Zealand (71%), SE SWP (77%) and NE SWP (91%), providing confidence in using long-range outlooks. For other locations, August was the most skilful month for Tonga (49%), N SWP (66%) and the C SWP (54%) and October outlooks were most skilful for Fiji (53%), Solomon Islands (66%), Vanuatu (42%) and Papua New Guinea (47%). However, in the case of Tonga and the Solomon Islands where the July outlook skill score is the lowest for all pre-season outlook months, at 29% and 52%, respectively, it is still more skilful than assuming climatology (i.e. to expect the average number of TCs every season; a skill score of 0%. See Roebber and
Bosart (1996)). Detailed deterministic and probabilistic TC guidance, model skill and consensus summaries, and a review of the predictors and climate influences relevant to the 2020/21 TC season can be accessed in the TCO-SP archive (https://tcoutlook.com/swpacific/forecast_archives/).

Determining end-user needs and quantifying the usefulness of TCO-SP

a. Methodology

An online questionnaire (see Table 1 for question details) was developed to explore three main themes related to TCO-SP use: (1) establish the TCO-SP user base, (2) determine end-user needs, and (3) quantify the user-perceived usefulness of TCO-SP. The online questionnaire comprised of eight questions (see Table 1) and was open for TCO-SP users to participate over a five-week period in May/June 2021. TCO-SP users were invited to participate and were recruited through the TCO-SP subscriber email list, advertising on the TCO-SP website (https://tcoutlook.com), and through social media (Twitter and LinkedIn). It is acknowledged that survey responses possibly overestimate scores associated with usefulness and understanding of TCO-SP because the responses are from existing TCO-SP users that are already interested and engaged. However, this is intended because existing TCO-SP users are the ones with experience/understanding of TCO-SP and are therefore the best source of information for determining end-user needs and quantifying the usefulness of TCO-SP. Therefore, while some sample bias may exist, this is by design and all aspects of the questionnaire, including the participant recruitment methodology and data privacy are in full compliance with the University of Newcastle’s Human Research Ethics Committee (Approval No: H-2021-0080).

b. Who uses TCO-SP?
A total of 40 participants completed the questionnaire from 13 countries (Figure 4a). Most of the respondents were based in Fiji (9; 22.5%); responses were also received from New Zealand (7; 17.5%), Australia (5; 12.5%), Vanuatu (5; 12.5%) and Samoa (4; 10%). Respondents work across a wide range of sectors (Figure 4b), including the meteorological services (12; 30%), government (5; 12.5%), insurance/financial services (4; 10%), university/academic institutions (4; 10%), aid organisations (3; 7.5%) and in the private sector as an individual consultant or consulting firm (3; 7.5%). Nine respondents selected ‘Other’ and of this group, four worked in the yachting industry (as superyacht ship captains or in yacht delivery/maintenance), one worked in the agriculture industry and one worked in the tourism industry.

c. Determining end-user needs

Question 3 (see Table 1 for question details) explored how the user-base harness TC outlooks in general (not specifically TCO-SP - this is addressed later). Half of all respondents said they use TC outlooks for decision-making at both home/in personal life and at work. Seven respondents (17.5%) said they use TC outlooks specifically to inform decision-making at home/in personal life and 12 (30%) said they use TC outlooks to inform decision-making at work (Figure 5a). Only one respondent said they used TC outlooks for purposes not specified.

Although numerous TC outlooks exist across the SWP region, each offers something different in terms of methodology and functionality. Figure 5b, summarises results from Question 4, what aspects of TC outlooks do you consider most important for your decision-making? Overall, each of the six aspects of TC outlooks that are listed (Island-scale/region-specific guidance, outlooks from multiple agencies, outlooks that are communicated clearly, outlooks that evaluate model skill and consider uncertainty, an evaluation of climate influences relevant to the TC season and outlooks that incorporate the latest scientific insights
about TC behaviour) were deemed very important by at least 52.5% of respondents. Of those six aspects, 87.5% of respondents said that island-scale/region-specific guidance was very important for decision making (the highest compared to other aspects of TC outlooks). This highlights the importance of deriving location-specific TC guidance, especially given the vast spatial scale of the SWP region. In addition, outlooks that are communicated in a clear, easy to digest way and those that incorporate the latest scientific insights about TC behaviour were ranked very important by 85% and 82.5% of respondents, respectively. Comparatively, 52.5% (27.5%) of respondents said that outlooks from multiple agencies were very important (fairly important) for decision-making.

d. Quantifying user-perceived usefulness of TCO-SP

Specific to TCO-SP, Question 5 (see Table 1 for question details) focuses on the following five key metrics that are important for bridging the gap between scientific information and end-user needs (Kiem and Austin 2013; Kiem et al. 2014): scientific credibility, relevance, level of detail, format and availability of TCO-SP outlooks (Figure 6a). The vast majority (97.5%) of respondents rated the scientific credibility of the information included in TCO-SP outlooks as excellent (72.5%) or high (25%). For both the relevance and availability of information, 90% of respondents rated TCO-SP outlooks as excellent or high, and in terms of the level of detail that TCO-SP provides and the format of TCO-SP outlooks, 80% of respondents rated these as excellent or high. However, 17.5% (2.5%) of respondents indicated that the level of detail and format of TCO-SP outlooks was fair (low). Around half of the respondents that provided a fair or low rating for these categories suggested in Question 7 (Is there anything that TCO-SP could do better to assist with your decision-making?) that a TC intensity outlook and/or more granular information about the exact timing of landfalling TCs would be useful. However, the nature of long-range seasonal TC forecasting means that accurately pinpointing the precise date and time that a TC might make landfall is not yet
possible. The opportunity for developing an intensity-based TC outlook is discussed in the Recommendations and area for future development/work section.

Question 6 (see Table 1 for question details) asks respondents to rate the usefulness of nine key TCO-SP features in assisting with decision-making (Figure 6b). Two key themes were assessed: (1) communication of TCO-SP outlooks and (2) the modelling features of TCO-SP. In terms of communication, 60% of respondents indicated that the functionality and accessibility of the TCO-SP website (https://tcoutlook.com) was very useful, while 27.5% said the website was fairly useful. No respondents indicated that the website was not at all useful. Respondents also indicated that the detailed guidance that summarises climate influences relevant to the TC season was very useful (67.5%) or fairly useful (20%).

Although TCO-SP has several unique modelling features, the following three are of elevated importance:

- TCO-SP long-range outlooks are generated for 12 island-scale/regional outlook regions across the SWP
- TCO-SP provides an outlook up to four months before (in July) the start of the TC season (November)
- TCO-SP is updated on a monthly basis to incorporate the latest oceanic/atmospheric states, enabling the refinement of deterministic and probabilistic guidance.

Overwhelmingly, respondents agreed with the usefulness of these features; 92.5% of respondents said that island-scale regional specific outlooks were very useful or fairly useful, while 85% of respondents said that a lead time of up to four months before the start of the TC season was very useful or fairly useful. Also, 87.5% of respondents said that monthly updates to consider the most recent changes in ocean/atmosphere variability was very useful or fairly useful. Between 85% and 92.5% of respondents rated each of the
TCO-SP modelling features as very useful or fairly useful. Across all key themes, no respondents indicated that TCO-SP features were not at all useful.

e. General feedback

Questions 7 and 8 (Table 1) were included to seek general feedback from participants. These responses were open-text and not all participants answered these questions. In response to question 7, just over half (52.5%) of participants provided some feedback. 62% of respondents that filled in this field provided comments on how TCO-SP could better assist with their decision-making (the remaining 38% said that TCO-SP sufficiently meets their needs). The majority of suggestions were focused around developing a model that also considered intensity-based TC outlooks (this is discussed in the following section). Individual comments also suggested calculating the likelihood of landfalling TCs and predictions of TC track trajectory. One comment also recommended hosting an online virtual meeting to discuss TCO-SP outlooks with Pacific Islands Meteorological Services before making TCO-SP available to the public and another suggested that TCO-SP outlooks should be reported by other meteorological agencies and weather service providers.

For Question 8 (see Table 1 for question details), 40% of respondents answered this question and all provided positive feedback on TCO-SP and some made further suggestions. A selection of responses are included below:

"An excellent tool that strengthens the other outlooks that are available. Another source of information to assist with decision making"

"Considering the inclusion of impact based information services in addition to the outlook information would be valuable"

"This has definitely been a wonderful addition to the suite of products available in our region, and I am sure with time it will grow in both its content and reliability as more data
and associated applied research is done relevant to this area of weather and climate in our region”

“Possibility to work closely with CSIRO (Commonwealth Scientific and Industrial Research Organisation) and BOM (Australian Bureau of Meteorology) or other Pacific agencies to create a single place to house this data and information – it is such a great resource and would be great if people knew about it/could access it in the courses they already rely on/use”

Recommendations and areas for future development/work

Specific to TCO-SP long-range TC forecasting efforts, the following recommendations and areas for future development/work have been identified from the questionnaire and from end-user engagement since the release of TCO-SP:

- Add TC intensity outlooks. There is scope to test the performance of a statistically derived island-scale/regional intensity-based TC outlook which could draw on the pre-existing methodology (Magee et al. 2020). An intensity-based outlook could possibly consider the frequency and probability of non-severe (Category 1-2) and severe (Category 3-5) TCs. The limited sample size for some locations may present a challenge. A comparison to extant methods used for the ICU that indicate probable numbers of TCs achieving specific intensities could be progressed in parallel for an additional level of comparison.

- Add impact guidance to TC outlooks. Current TCO-SP guidance is communicated in a “numbers focused” deterministic (TC frequency) and probabilistic (chance) way, which may not be accessible for all end-users. There is scope to draw on recent experiences and historical TC seasons to provide perspective and comparison with TC activity that is expected at the island scale.
• Extend guidance to include “out of season” TC activity. Although November-April marks the formal climatological definition of the SWP TC season, TCs can still occur outside of these six months. An outlook could consider the risk and potential for out of season TCs, given these events can catch forecasting agencies and communities off-guard, e.g. Severe Tropical Cyclone Donna, a Category 5 TCs which occurred in May 2017 or Severe Tropical Cyclone Namu, a Category 3 TC that caused significant and widespread damage to the Solomon Islands in May 1986.

• Develop TC outlooks that are tailored to a range of end-users. Insights from the questionnaire highlight the diverse range of end-users that use TCO-SP guidance (meteorological services, tourism, insurance/financial services, agriculture, academia etc…) and how it is used to assist with decision-making. Outlooks and guidance specifically tailored to these end-users could have a range of benefits and be more useful to a wider audience.

• Embrace innovation and a wide modelling framework. With time, new modelling methodologies and relationships between climate dynamics and TC activity are likely to emerge. This may have the potential to result in more skilful outlooks or may enable additional modelling capabilities that were not previously available. Undoubtedly, new product additions covering the SWP will help to increase the number of TC guidance products that can be drawn upon for seasonal outlooks. In turn, this will lead to broader ensembles that lessen the reliance on single products, improve the efficacy of basin-wide seasonal outlooks in general, and improve specific outlooks for unique SWP domains.

Conclusion

TCO-SP provides long-range and freely available deterministic and probabilistic TC frequency outlooks for 12 island-scale and regional locations across the SWP region. It is
updated monthly and provides a series of pre-season and in-season outlooks, offering lead
times of up to four months before the official start of the TC season. Validation of TCO-SP
performance on the 2020/21 SWP TC season shows that it successfully predicted a near-
normal TC season in July 2020, up to four months before the start of the SWP TC season
(November). Island-scale and regional-scale guidance also performed well, with the regional
variability in TC activity for the 2020/21 season largely predicted.

A questionnaire with TCO-SP user respondents revealed a diverse and global user
base, including meteorological services, government agencies, aid organisations,
insurance/financial services, consulting, academia, seafarers, tourism and the agricultural
sector. These end-users stated that they use TC outlooks to inform decision-making at work
and/or in their personal life. Specific to TCO-SP, the vast majority of end-users indicated that
they found the way that TCO-SP outlooks are communicated and the modelling features of
TCO-SP as very useful or fairly useful. Features that are central to TCO-SP, including island-
scale/regional-scale outlooks, regular monthly updates and an outlook lead-time up to four
months before the start of the TC season were found to be particularly useful for respondents.
We intentionally did not define the term “useful” as its meaning may vary between respondents
and organisations, however, results from Question 3, “How do you use tropical cyclone (TC)
outlooks”, provides some insights into how TCO-SP is used.

For vulnerable communities across the island-nations and territories of the SWP, TC
outlooks play an important role in managing risks and informing decisions before and during
TC seasons. TCO-SP joins three pre-existing and well-established TC outlook products that
exist within the SWP region, but adds new capabilities that can assist end-users with their
decision-making. Rising sea levels and changes to TC related exposure and vulnerability will
likely amplify future TC related impacts across the SWP region. Skilful, island-scale
guidance with extended lead times relative to other available guidance offers the potential for
advanced preparation in the months preceding the start of the TC season. As TCs are both spatially and temporally variable across the SWP region, TCO-SP helps to address some known climate early warning system gaps in the SWP region, and has potential benefits of reducing damage and financial loss and mitigating disaster risk. TCO-SP can also be used to support more effective and targeted humanitarian aid responses through strategic provisioning of essential supplies and resources across the SWP in the months preceding and throughout the TC season. With collaborative partnerships across the region, we expect that TCO-SP will play an important role in building a more resilient future for Pacific Island communities.

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| Theme | Number | Question | Response options/Sub-questions | Type of response |
|-------|--------|----------|--------------------------------|----------------|
| Establishing the user base | 1 | Please select your country of residence | All countries. | Dropdown box |
| | 2 | Which of the following best describes your area of employment? | Meteorological service - Hydrological agency - Government agency - Non-governmental organisation (NGO) - Private sector - Individual consultant - University/academic institution - Other (please specify) | Dropdown box |
| Determining end-user needs | 3 | How do you use tropical cyclone (TC) outlooks? | To inform decision-making at work - To inform decision-making at home/in personal life - To inform decision-making at work and home/in personal life - None of the above - I use TC outlooks for purposes not specified | Tick box |
| | 4 | What aspects of tropical cyclone outlooks do you consider most important for your decision-making? | Island-scale/region-specific guidance - Outlooks from multiple agencies to assist with decision-making - Outlooks that use model skill and delay to get them right - Outlooks that incorporate the latest scientific insights about tropical cyclone behaviour - Other (free text) | Likert scale: 1 (not at all important), 2 (slightly important), 3 (important), 4 (fairly important), 5 (very important), and N/A |
| Quantifying the usefulness of TCO-SP | 5 | Specific to TCO-SP, please rate the following questions: | Please rate the AVAILABILITY of information about tropical cyclone outlooks that you require | Likert scale: 1 (not at all important), 2 (slightly important), 3 (important), 4 (fairly important), 5 (very important), and N/A |
| | 6 | Specific to TCO-SP, please rate the usefulness of the following TCO-SP features: | Island-scale/region-specific outlooks - Outlooks that summarise expected TC frequency (deterministic) - Outlooks that estimate the probability of occurrence (probabilistic) - Monthly updates to consider the most recent changes in ocean/atmosphere variability - Lead-time of up to four months before the start of the TC season - In-season outlooks to provide updates for expected activity for the remaining season - Functionality and accessibility of the website - Evaluation of model skill - Detailed guidance that summarises climate influences relevant to the TC season | Likert scale: 1 (not at all useful), 2 (slightly useful), 3 (useful), 4 (fairly useful), 5 (very useful), and N/A |
| Obtaining general feedback | 7 | Is there anything that TCO-SP could do better to assist with your decision-making? | N/A | Open text |
| | 8 | Any other feedback? | N/A | Open text |
Figure 1: TCO-SP outlook regions (not including the SWP region; 5°S-35°S, 135°E-120°W). Black labels indicate individual island-scale outlooks. White labels (and thicker white outline) indicate sub-regional outlooks.
Figure 2: Flowchart indicating steps involved in generating (step 1) and communicating (step 2) TCO-SP outlooks.
Figure 3: Comparison of predicted TC counts from TCO-SP (including probable range; error bars) and observed TCs for 12 TCO-SP regions. The shaded area indicates pre-season outlooks, while outlooks generated in November, December and January are for the remaining December-April, January-April and February-April part of the season, respectively. The observed TCs (red triangles) for October refers to the observed number of TCs during the November-April TC season and the July-October TCO-SP (black dots) pre-season values are the prediction for the November-April TC season. The model skill score (%) (secondary y-axis) refers to the skill score of the model when trained on the 1970-2020 period.
Figure 4: Establishing the TCO-SP user base. Summary of responses to Question 1 (panel a) and Question 2 (panel b). See Table 1 for questions.
Figure 5: Determining end-user needs. Summary of responses to Question 3 (panel a) and Question 4 (panel b). See Table 1 for questions.
Figure 6: Quantifying the usefulness of TCO-SP. Summary of responses to Question 5 (panel a) and Question 6 (panel b). See Table 1 for questions.