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ScienceDirect

Tropical Cyclone Research and Review 12 (2023) 1–9

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The world meteorological organization Tenth International Workshop on tropical cyclones (IWTC-10): A summary

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Available online 4 May 2023

Abstract

The Tenth International Workshop on Tropical Cyclones (IWTC-10) occurred from 5 to 9 December 2022 in Bali, Indonesia. This workshop continued the goal of the original IWTC, held in 1985 in Bangkok, Thailand, to bring together forecasters and researchers from countries around the world that are impacted by tropical cyclones (TCs) to discuss the latest research and forecast advances and share best practices to improve TC forecasts globally. The workshops have continued as a regular feature of WMO efforts to encourage the advancement of TC forecasting and improve ways of communicating TC hazards to the general public.

Global TC forecasting efforts in the past 10–15 years have emphasized hazards and impacts of landfalling TCs beyond just track and intensity. Additionally, there has been a growing interest in improving the communication of these hazards and impacts, using concepts from social and behavioral sciences, in ways that can lead to effective decision-making from stakeholders (e.g., government officials, emergency managers, media, general public). As such, the theme for IWTC-10 was "Improved TC science and services for better decision-making." More about this theme, how the workshop was structured around it, and key outcomes from the workshop are discussed in this summary article.

Keywords: Tropical cyclone workshop; Forecasters and researchers; Warning value cycle

1. Overview of IWTC-10

The IWTC-10 has followed the well-established model of previous IWTCs. Topic chairs and rapporteurs, assisted by working groups of volunteers, summarized the advances in forecasting and research in the previous four years. Their work was collated to form the volume Workshop Topic Reports IWTC-10, published as a WMO Tropical Meteorological Research Programme Report Series and distributed to workshop participants before the workshop. It is now available online at: https://community.wmo.int/en/meetings/tenth-international-workshop-tropical-cyclones-iwtc-10.

Coming two years after the COVID-19 pandemic first appeared on the scene, there were many challenges in terms of planning for and executing this workshop. However, there were also many opportunities, most notably effectively exploiting technology for remote participation from presenters and attendees. Though there were 140 in-person participants at the workshop, an additional 349 people registered to participate remotely. Such a capability showed the potential of vastly increasing the number of researchers and forecasters who can participate in IWTC, in particular from countries that may otherwise lack the resources to send personnel to the workshop. While technology cannot perfectly replicate in-person interaction, this ability for remote participation has the advantage of

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Peer review under responsibility of Shanghai Typhoon Institute of China Meteorological Administration.

Production and Hosting by Elsevier on behalf of KeAi

https://doi.org/10.1016/j.tcrr.2023.04.001

increasing participation globally. Additionally, the freely available recordings and reports provide an ongoing resource for all.

For five days, an estimated 500 participants from 53 countries, both in-person and online, met to discuss research directions on TC hazards and impacts, search for opportunities to improve their forecasts, and enhance the communication of these forecasts for better decision-making. This report presents the result of their hard work. It contains a summary of the proceedings of the workshop and the recommendations for the next four years formulated by the participants.

The success of the workshop would not have been possible without the participants, the topic chairs and rapporteurs, the discussion group leaders and note-takers, the international committee, the local organizing committee (BMKG) and the WMO staff (Fig. 1). Their collective effort made this workshop a most fruitful event of learning and sharing.

2. History of IWTC

The International Workshop on Tropical Cyclones (IWTC) series started in November 1985 following the directive of the Ninth World Meteorological Congress in 1983 as one of the main activities of the WMO Commission on Atmospheric Science (CAS) Tropical Meteorology Research Programme (TMRP). Organized by a small group of meteorologists led by Dr. William Gray (USA), the objective of the Workshop was to review the current state of knowledge on tropical cyclones and to summarize the various tropical cyclone forecasting practices in different forecast offices around the world. The Workshop ended with a set of recommendations to WMO that included the publication of a "textbook," A Global View of Tropical Cyclones. Since then, an IWTC has been organized about every four years (listed below), each of which produced one or more important accomplishments (Table 1).

IWTC-II (Manila, Philippines, 1989) initiated the preparation of the Global Guide for Tropical Cyclone Forecasting, which was published just before IWTC-III (Huatulco, Mexico, 1993). A special session on global climate change and tropical cyclones was held during IWTC-III under the chairmanship of James Lighthill of the International Council of Scientific Unions (ICSU), a summary of which was subsequently published in the Bulletin of the American Meteorological Society. In addition, a revision of the textbook A Global View of Tropical Cyclones was proposed and later published under the title Global Perspectives on Tropical Cyclones (WMO/TD No. 693). In IWTC-IV (Haikou, China, 1998), revisions to the Global Guide for Tropical Cyclone Forecasting were proposed to include the latest knowledge on tropical cyclones and forecasting methods. A keynote session on the Present, Imminent, and Future Satellite Observations for Tropical Cyclones was organized in IWTC-V (Cairns, Australia, 2002), which was well received by tropical cyclone forecasters. The Sixth IWTC (IWTC-VI) included a special session on the relationship between tropical cyclones and climate change, eventually resulting in a Statement on Tropical Cyclones and Climate Change. IWTC-VII saw the traditional two-week period of the workshop shortened to one week. Despite this shortened time, many opportunities were still provided for focused, substantive interactions among workshop participants – a hallmark of all IWTCs. The following IWTC, IWTC-VIII, was held jointly with the third International Workshop on Landfall Processes (IWTCLP-III), a sister workshop whose goal is to assess the state-of-the-art in research (including field programmes) and forecast advances, and then to determine what is required to improve forecasts and early warnings of tropical cyclone landfall. This workshop placed more emphasis on the effective communication of uncertainty in TC forecasts, recognizing the value of social and behavioural sciences that has become even more prevalent today. A special tribute session honoring Dr. Gray was held at IWTC-IX, highlighting many of his contributions to tropical meteorology, including fundamental discoveries regarding tropical cyclone movement, structure and genesis, as well as his pioneering work on Atlantic basin seasonal hurricane prediction.

Fig. 1. Official IWTC-10 photo.

Table 1
Dates and locations of all IWTC meetings prior to IWTC-10.

Workshop	Dates	Location
IWTC-I	25 November–5 December 1985	Bangkok, Thailand
IWTC-II	27 November–8 December 1989	Manila, Philippines
IWTC-III	22 November–1 December 1993	Huatulco, Mexico
IWTC-IV	21–30 April 1998	Haikou, China
IWTC-V	3–12 December 2002	Cairns, Australia
IWTC-VI	21–30 November 2006	San Jose, Costa Rica
IWTC-VII	15–20 November 2010	La Reunion, France
IWTC-VIII	2–7 December 2014	Jeju, Republic of Korea
IWTC-IX	3–7 December 2018	Honolulu, USA

3. Workshop objectives and international committee

The overarching objectives of IWTC-10 follow those of previous IWTC workshops:

- To report on current knowledge, forecasting and research trends on tropical cyclones from an integrated global perspective;
- To foster communication within and between the operational and research communities;
- To identify needs and opportunities in TC operations and research and offer recommendations for actions that will improve the global knowledge of and response to TCs.

The International Committee (IC), responsible for the planning and execution of IWTC-10, consisted of

- Mr. Joe Courtney – Australia, Co-Chair
- Dr. Robert Rogers – USA, Co-Chair
- Dr Lixion Avila – USA
- Dr. Michael Brennan – USA
- Ms. Estelle de Coning – WMO
- Dr. Christopher Davis – USA
- Ms. Anne-Claire Fontan – WMO
- Mr. Taoyong Peng – WMO
- Dr. Elizabeth Ritchie – Australia
- Dr. Kimberly Wood – USA
- Dr. Zhuo Wang – USA
- Dr. Munehiko Yamaguchi – WMO
- Dr. Hui Yu – China

4. Workshop theme, topics, and organization

The Theme for this Workshop was "Improved TC science and services for better decision-making." Decisions made at every point along the end-to-end warning cycle need optimising for ultimate appropriate community action during TC events. With that theme as the inspiration, the workshop keynote address was provided by Dr. Brian Golding (UK), who edited a book entitled "Towards the 'Perfect' Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication." In this book, Dr. Golding discussed the concept of the Warning Value Chain (Fig. 2).

The production of warnings can be considered a value chain (or cycle, emphasizing the two-way flow of information) whose aim is to provide the information that enables the best decisions to be taken, both by individuals and by those with responsibility to protect others. In a perfect warning cycle, the warning received by the end user would contain precise and accurate information that perfectly met their need, contributed by each of the many players in the cycle. In real warning cycles, however, information, and hence value, are always lost as well as gained at each link in the cycle in what has come to be known as "valleys of death." Successful communication of information from one contributor of expertise to the next is represented by spanning the valleys with bridges. Without a bridge, there is no communication, and the expertise of a particular contributor is lost. While an oversimplification of the warning process, the concept is a useful one that highlights the broad range of disciplines involved – and the need for those disciplines to effectively communicate with each other.

After Dr. Golding's keynote address, there was a special focus session on Communicating Hazards targeting one of the "mountains" and associated "bridges" shown in Fig. 2 above. This session included presentations from forecast agencies and social scientists in six different countries (USA, Philippines, India, Cayman Islands, Turks and Caicos Islands, Fiji, and Mozambique) to highlight the challenges in communicating TC hazards particular to their countries and the solutions developed to overcome them.

Six other topics were then presented and discussed during the subsequent days:

- Topic 1: Remote Sensing
- Topic 2: Tropical Cyclone Intensity Change
- Topic 3: Tropical Cyclone Structure Change
- Topic 4: Tropical Cyclone Track and Genesis
- Topic 5: Forecasting Tropical Cyclone Hazards and Impacts
- Topic 6: Tropical Cyclone Variability Beyond the Synoptic Scale

For each topic, a rapporteur of a sub-topic first gave their summary of the state of knowledge of that topic and the roadblocks for further advancement. The floor was then open for discussion. After all the rapporteurs made their presentations, the topic chair then made a summary of the topic followed by general discussion. The participants were then divided into eight groups, each consisting of a mix of researchers and forecasters. Each group's assigned leader was charged to facilitate discussion of recommendations related to the given topic based on the material presented as well as the plenary session discussions, and a second group member was charged with taking notes to share with the Recommendations Committee. To enhance dialogue among the participants, they were assigned to a different group each day.

In addition to the topics mentioned above, special focus sessions were held on Impact-based forecasting by the Indonesian Meteorological Service (BMKG), summaries of WMO-endorsed projects and field campaigns in China (Typhoon

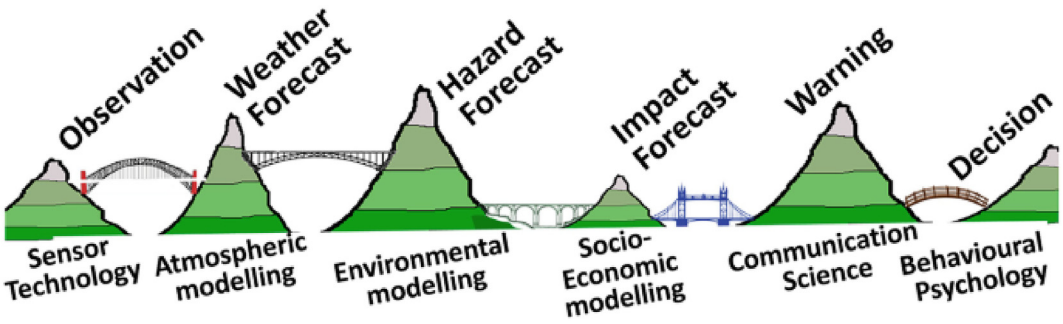

Fig. 2. The "valleys of death" concept of a warnings value chain. (© Crown Copyright, 2020, Met Office, adapted from Golding, 2022, "Towards the 'Perfect' Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication").

Landfall Forecast Demonstration Project, Experiment on Typhoon Intensity Change in Coastal Area, Understanding and Predicting Rainfall in Landfalling Tropical Cyclones), an update on outcomes from the WMO-supported Tropical Cyclone Probabilistic Forecast Products, and a demonstration on the TC genesis forecast process from the Bureau of Meteorology in Australia. The full schedule of talks is shown in Appendix 1.

5. Recommendations

A Recommendations Committee was formed to develop and finalize the list of recommendations coming from the workshop. In a departure from past workshops, this committee was created in advance. Innovations in the breakout sessions that led to recommendations took advantage of COVID-related technological advances, including community bulletin boards on which people could contribute ideas and suggestions to be examined by all participants, both in-person and remote. The Committee synthesized the recommendations from all discussion groups and presented them at a plenary session on the final day of the workshop, with some follow-up discussion post-workshop. The final set of recommendations, with the reasoning for each recommendation (another innovation of this workshop) is listed below.

5.1. Committee members

Kim WOOD (**chair**, research, USA); Alan BRAMMER (research/R2O, USA); Suzana CAMARGO (research, USA); Joe COURTNEY (IWTC-10 co-chair, Australia); Anne-Claire FONTAN (WMO); Chris NOBLE (operations, New Zealand); Rob ROGERS (IWTC-10 co-chair, USA); Monica SHARMA (operations, India); Hui YU (research, China) and supported by the WMO secretariat through Cyrille HONORE.

The target audiences are listed in [*brackets*] at the end of each recommendation:

- *Research* = the research community
- *Operations* = the operational forecaster community as well as operational modeling centers
- *WMO* = the World Meteorological Organization
- *Integrated research + operations* = needs partnerships between researchers and operational forecasters
- *All* = targets Research, Operations, and the WMO

1. Explore the development and deployment of low-cost technologies (e.g., balloons, gliders, uncrewed systems, animal-borne sensors) for collecting *in situ* measurements of sub-surface, air-sea interface, lower boundary layer, and three-dimensional measurements of kinematic and thermodynamic fields in the TC inner core and environment. When possible, make these observations available in real time. [Research]

   Reasoning: Such platforms have the potential to provide "ground truth" data across the globe, one of the benefits of which will be to support AI/ML model development along with validation of satellite remote sensing techniques. Such efforts should lower the barriers to acceptance of AI by forecasters. These platforms can provide valuable data to regions which are unable to leverage the value of aircraft reconnaissance.

2. Encourage continued collection and sharing, in real time when possible, of quality-controlled and documented *in situ* observations (e.g., aircraft reconnaissance, emerging technologies such as uncrewed balloon systems and sail-drones) with the research and operational communities. [*Integrated research + operations*]

   Reasoning: in situ observations are a known need, and those with the resources to obtain them are encouraged to share those observations with the broader community to support research, forecaster training, etc. We acknowledge that data sharing is ongoing at the regional level, and this recommendation encourages broadening knowledge of the available datasets, partnerships, and potential challenges associated with these efforts.

3. Encourage continued investment in the planning, launch, and support of low-earth orbit satellite missions to sustain and improve spatial and temporal coverage of observations that capture TC size, structure, and intensity (e.g., microwave imagery, scatterometers, synthetic aperture radar) including low-cost missions such as CubeSats. [*WMO*]

Reasoning: Infrequent observations from the currently operational satellite constellations do not adequately meet forecaster needs. Many IWTC-10 attendees commented on the usefulness of and/or otherwise expressed interest in synthetic aperture radar (SAR) observations with some concern expressed over loss of SAR from Sentinel. Consider collaborating with The Coordination Group for Meteorological Satellites (CGMS) with a near-term step to convey this recommendation to CGMS at the upcoming meeting in May 2023.

4. Develop high-quality wind structure datasets to advance understanding of processes that affect TC structure in an operationally-relevant framework:
   - Datasets based on long-term data (e.g., scatterometer, reanalysis data) made available to the research and operational community
   - Global high-quality best track parameters for wind radii (e.g. RMW, R34) to facilitate operationally-relevant research and technique development

   [*Integrated research + operations*]

   Reasoning: To improve our understanding of TC structural evolution, a robust dataset of quality-controlled size parameters is required.

5. Continue to advance research and operational use of post-processing tools (statistical guidance, model consensus, AI/ML techniques, and multi-model ensemble uncertainty) for intensity change forecasts with a focus on rapid intensity change and cases identified as operationally-challenging forecasts. [*Integrated research + operations*]

   Reasoning: The research community has vast experience with an array of tools that can be targeted on difficult forecast scenarios in collaboration with forecasters to ensure resulting products are operationally useful and applicable.

6. Encourage modeling centers to encode vortex parameter files in a standardized format (e.g., BUFR, CXML) and exchange them in a timely and consistent manner, such as GTS. [*WMO*]

   Reasoning: Standardized formats both simplify the workflow of operational forecasters and support research efforts using the same data. Timely and consistent availability ensures forecasters have what they need when they need it. We note that there have been ongoing efforts toward making vortex parameter files mandatory/core data under the Manual of Global Data-processing and Forecasting System (GDPFS). Consider investigating an improved format.

7. Continue research toward improved understanding of the conditions, precursors, and processes leading to TC intensity change throughout the entire TC lifecycle (pre-formation through to decay), taking into account its multiscale nature ranging from the convective to the synoptic scale. Special focus should be given to rapid intensification and near-coast formation, including onset, duration, and potential intensification rate. [*Research*]

   Reasoning: TC intensity change is a non-trivial forecast concern with impacts throughout the value cycle, particularly for preparations made ahead of a TC impacting a coastline.

8. Encourage operations to promote the difficult cases database to the research community, explore improvements to the database based on research needs, and update the database on a regular basis. [*Operations*]

   Reasoning: A database does exist (https://severeweather.wmo.int/TCFW/) but is not well-known, and forecasters do not know whether its current form is one that supports research efforts using its entries. To expand its reach across the TC community, consider sharing updates via an outlet such as blog posts or WMO news outlets once each year after post-season analysis is completed and new cases are added.

9. Recommend further research into explainable and validated AI/ML techniques with the cooperation of the operational community to address components in the TC analysis and forecast process. [*Integrated research + operations*]

   Reasoning: AI/ML recommendations were made throughout IWTC-10 topics, highlighting both interest in and importance of these tools. Breakout session feedback frequently mentioned the need for the output from these methods to be trustworthy and explainable to increase the chance such methods would be used within the forecast process.

10. Exploit online communication technologies (e.g., Zoom) and leverage in-person meetings to facilitate training sessions and workshops on the expanding range of emerging challenges in TC analysis and forecasting as identified by the AG-TC (Advisory Group on Tropical Cyclones). [*WMO + operations*]

    Reasoning: Smaller-scale, targeted workshops motivated by the success of the Third International Workshop on Satellite Analysis of Tropical Cyclones in 2021 (IWSATC-3) would reduce online fatigue when held virtually while potentially building a repertoire of training material to help forecasters remain up to date with new techniques and exploit new data sources. In-person meetings such as IWTC should be capitalized upon to facilitate in-person training sessions and workshops.

11. Develop a list of current methods to define, analyze, diagnose, and predict cyclone wind structure across all operational centers to identify advantages and

shortcomings in these methods. Develop operational tools to overcome those gaps by incorporating new observational data, derived products (e.g., AMVs), and NWP. [*All*]

Reasoning: Assessment of current operational practices is needed to determine where to target research efforts in creating and/or refining tools relevant to the operational forecast process. We recognize that all hazards are important, but this recommendation and the next one reflect priorities raised at IWTC-10.

12. Develop a list of current methods to analyze and predict tropical cyclone precipitation (both direct and remotely-forced) across all operational centers to identify advantages and shortcomings across these methods. Develop operational tools to overcome those gaps by incorporating new observational data, derived products, and NWP. [*All*]

    Reasoning: Assessment of current operational practices is needed to determine where to target research efforts in creating and/or refining tools relevant to the operational forecast process. We recognize that all hazards are important, but this recommendation and the previous one reflect priorities raised at IWTC-10.

13. Develop a consistent definition for SEF/ERC onset and cessation, including confidence levels, to develop a database of SEF/ERC events that would enable evaluation of its effects on TC structure and intensity change. [*Research*]

    Reasoning: a database would enable further research on the impacts of secondary eyewall formation (SEF) and eyewall replacement cycle (ERC) events, but such a database requires a definition to be created. This need presents an opportunity for a specialist group of researchers and forecasters to be formed by the WWRP Working Group on Tropical Meteorology Research (WGTMR) with advice from the Advisory Group on Tropical Cyclones (AG-TC) to address this recommendation.

14. Pursue the development of a holistic approach to consistent basin-specific definitions of multiple cyclone types (e.g., ETC, STC, TC, medicanes), and transition pathways among these types (ET, TT, etc.), that builds on the cyclone phase space. Develop and share diagnostic techniques. [*Research*]

    Reasoning: work has demonstrated the variability of cyclone types across basins, thus a global definition may not be feasible but basin-specific definitions might be. Cyclone phase space (CPS) is already a widely-used tool that could be augmented by datasets such as satellite observations and requires additional evaluation with newly-available high-resolution datasets such as ERA5 and improved global forecast model output. Though this recommendation is directed at the research community, partnerships with forecasters remain key. This recommendation presents an opportunity for a specialist group of researchers and forecasters to be formed by the WWRP Working Group on Tropical Meteorology Research (WGTMR) with advice from the Advisory Group on Tropical Cyclones (AG-TC).

15. Continue to investigate the physical mechanisms behind global TC frequency using both observations and modeling studies to clarify the expected changes of TC frequency in the future. [*Research*]

    Reasoning: Such efforts would support the assessment of current trends in TC activity and the mechanisms affecting those trends as we have yet to physically explain the trend toward decreasing TC numbers as well as future projections of decreasing TC numbers. For example, clearly-defined TC seeds would support advances in this topic via the development of TC seed datasets.

16. Continue to develop and maintain climate-quality multi-decadal datasets related to TCs and better quantify uncertainty in these datasets. [*Integrated research + operations*]

    Reasoning: Our assessment of TC behavior and variability under current and future climates will be more representative when reliant upon longer-term TC data. If the uncertainty of the data is known, that uncertainty can be incorporated into analyses using these datasets.

17. Encourage the development of skillful seasonal and sub-seasonal forecasts across all ocean basins that would meet stakeholders' needs through dynamical and statistical methods as well as intercomparison and evaluation of the forecasts. [*Integrated research + operations*]

    Reasoning: Variability between TC behavior and influences on TC activity across basins requires seasonal forecasting efforts to be targeted to basins and to the needs of those working in those basins. In this recommendation, the term "stakeholders" includes a broad range of users from individual members of the public to emergency managers and operational centers and a corresponding variety of specific products, including sub-basin metrics. Consider the feasibility of WMO coordination of seasonal TC forecasts to support TC community awareness of such forecasting efforts.

18. Expand verification studies of TC prediction from individual models towards multi-model ensembles and expand verification metrics to include precipitation, intensity, life-cycle interactions, and impacts that would be closer to stakeholders' interests, providing consistent metrics and comprehensive measures of skill that are adequate for different time scales (sub-seasonal, seasonal, decadal, and beyond). [*Research*]

Reasoning: Preparation ahead of TC impacts often requires long lead times, and efforts prompted or continued in response to this recommendation would support decision-making both ahead of and during a TC season in line with the value cycle (see Fig. 1, https://doi.org/10.3389/fcomm.2022.949949). Existing metrics are biased toward track verification, thus this recommendation highlights needs beyond track.

19. Encourage the engagement of social scientists with forecasters to enhance communication under a range of TC impact scenarios to support the decision-making process down to the local level. Forecasters should share outcomes and lessons learned with the global operational TC community. [*Integrated research + operations*]

Reasoning: Effective communication of potential TC impacts requires expertise in crafting messages and understanding human behavior and response. Given the range of resources available across the community, the sharing of outcomes and lessons learned would broaden access to tools for successful support of decision making.

20. Ensure the WMO Cataloguing of Hazardous Events database includes TC-specific hazards, with associated TC metadata. [*WMO*]

Reasoning: Many breakout session comments voiced a desire for more data regarding past TC-related impacts, and this existing WMO effort could facilitate the development of such a database. The motivation for updating this database is to support the development of analytic tools which contribute to risk assessment based on past observed TC-related hazards.

21. Improve disaster risk knowledge of TC hazards and their impacts from the extended range to nowcast scale, including research, education, outreach, and community engagement, and enhance warning communication and dissemination strategies for effective response. [*All*]

Reasoning: Research, education, and outreach ahead of potential TC impacts are an essential component of supporting effective preparation for and response to those impacts. It is also important to interact with an affected community after a TC causes impacts and after an area was expected to be impacted but ultimately was not (e.g., a "near miss"). These efforts will demonstrate to those communities that their experiences and feedback are valued and ensure future products are created with their needs in mind. This recommendation strongly overlaps with ongoing WMO capacity-building efforts and programs.

22. Strengthen multi-institutional mechanisms involving operations and research communities and disaster management agencies for impact-based forecasts and warnings to effectively mitigate TC impacts. Share best practices to enable effective collaborations. [*All*]

Reasoning: Cooperation between agencies is essential to effective communication and hazard response in line with the value cycle (see Fig. 1, https://doi.org/10.3389/fcomm.2022.949949). By sharing past experiences and learned best practices, all stand to benefit.

6. Workshop evaluation

An online survey was presented to participants on the last day of the workshop combined with a post-workshop review by the organisers to evaluate the workshop. The feedback demonstrated that IWTC-10 was a highly successful workshop. The in-person experience was superior to being online; however, the ability to extend access to online participants provided access to a much larger audience, and recordings being available online will continue to be a great resource into the future. The lessons learned can be factored into future workshops.

A total of 92 people responded to the online survey, 53 from in-person attendees and 39 who attended online either by Zoom (17), YouTube (5), or a mixture of Zoom and YouTube (17). A total of 47 identified as some form of forecaster: forecaster/manager (1), forecaster/researcher (2) or forecaster/modeller (1), researcher/forecaster (4), modeller/forecaster/researcher (1), researcher/forecaster/technique developer (1), technique developer/forecaster (1), manager/forecaster (2).

Respondents were asked which topic had the highest impact for them and were allowed three choices. Of the most impactful topics, the special session "Communicating hazards and impacts" made the strongest impression (37), while other impactful topics were more evenly spread among climate change (24), remote sensing: current and emerging sensors (23), and Forecasting hazards/impacts: Rainfall (21).

Participants were asked to rate their satisfaction with the following:

- Overall satisfaction with the workshop;
- The opportunities to engage with others through breakout sessions and informal opportunities in the workshop; and
- The venue or online experience.

The results are shown in Table 2 below. In terms of overall satisfaction with the workshop, 98% of participants gave a rating of very satisfied or somewhat satisfied, and 83% of in-person attendees were very satisfied. A total of 81% of respondents (75 of 92) indicated very or somewhat satisfied in having opportunities to engage with others. This increased to 96% (51/53) for those attending in person.

In-person attendees were happy with the venue, 74% indicating they were very satisfied. A total of 56% of online attendees were very satisfied, although 27% were either neither satisfied nor dissatisfied, or somewhat dissatisfied.

Table 2
Results from survey on workshop satisfaction.

Satisfaction	Overall workshop		Opportunity to engage		Venue	Online experience
	All (%)	In person (%)	All (%)	In person (%)		
Very Satisfied	**70 (76)**	**44 (83)**	**60 (65)**	**43 (81)**	**39 (74)**	**19 (56)**
Somewhat satisfied	**20 (22)**	**8 (15)**	**15 (16)**	**8 (15)**	**13 (24)**	**6(18)**
Neither satisfied nor dissatisfied	**1 (1)**	**0**	**9 (10)**	**0**	**1 (2)**	**5 (15)**
Somewhat dissatisfied	**0**	**0**	**5 (5)**	**0**	**0**	**4 (12)**
Very dissatisfied	**1 (1)**	**1 (2)**	**3 (3)**	**2 (4)**	**0**	**0**

6.1. What worked well

Some of the feedback considered as working well included:

- Breakout sessions and ability to meet with other participants in general;
- Venue was excellent as was assistance provided by local organizing committee;
- Having a break in the middle worked well and excursions were well received;
- Despite the difficulties in sourcing social science expertise and participation, the special focus session on communicating hazards and impacts worked out well;
- In-person attendance offered the best experience and having the online option allowed greater access to those not able to travel;
- YouTube live was excellent for accessibility and archiving and also superior to zoom in quality; and
- Good to have both operational and research rapporteurs.

6.2. What could be improved upon

Some of the feedback suggesting improvements included:

- Improved experienced for those on Zoom: chat and Q&A privileges. Suggested to simplify to have everyone on mute but everyone to have same access to chat and ability to go off mute. Have one online breakout room to allow participation for online audience;
- Ensure there is sufficient time for discussion rather than being dominated by presentations. Timings, especially on the first day, were tight and delays meant Q&A and breakout sessions were often truncated;
- Have at least one experienced Topic Lead and Rapporteur each. Be clear about expectations and suggested ways of working for working groups;
- Rapporteurs present summary not recommendations and topic leads only present recommendations. Then to discuss recommendations in breakout session;
- Breakout sessions: Less emphasis on recommendations and more on engagement between participants with common interest; and
- Determine the venue earlier and selection made with greater transparency (perhaps by nomination via regional committees with clear guidelines for determination). Delayed selection presented difficulties in travel planning and report completion in time.

6.3. Net Promotor Score

Participants were asked "How likely is it that you would recommend this workshop to a colleague or friend? (1: Not at all likely, 10: Extremely likely)" for the purposes of calculating the Net Promotor Score (NPS). NPS counts the number of promotors (scores of 9–10) subtracts the number of detractors (scores of 0–6), divided by the total number and expressed as a percentage. For the 92 participants, 75 rated 9 or 10 while only three rated between 1 and 6 resulting in an NPS of 78%, which is very good.

Acknowledgments

The authors' participation in IWTC-10 was supported by NOAA Base Funds and MSU Department of Geosciences.

Appendix 1
IWTC-10 Program, 5–9 December 2022 (breaks, meals, etc. omitted)

Day	Topic
Monday	Welcome and introduction: BMKG/WMO/Co-chairs Keynote address: TC Warning Value Cycle: Brian Golding Special Focus Session on Communicating Hazards: Country presentations: US: Gina Eosco Philippines: Robb Gile India: Monica Sharma Cayman Is: Shamal Clarke/Turks and Caicos Is: Holly Hamilton Fiji: Stephen Meke Mozambique: Guelso Mauro Manjate Communication breakout session Topic 1 Remote Sensing: Sebastien Langlade and Derrick Herndon 1.1 Current and emerging satellite sensors: Lucrezia Ricciardulli and Brian Howell 1.2 Objective satellite methods: Quoc-Phi Duong and Tony Wimmers 1.3 Developments and science using in-situ platforms: Heather Holbach and Olivier Bousquet Topic 1 Summary Topic 1 breakout session

(*continued on next page*)

Appendix 1 (*continued*)

Day	Topic
Tuesday	Review of IWTC-9 recommendations: Robert Rogers
	Topic 2 TC Intensity change: Eric Blake and Liguang Wu
	2.1 Internal Influences: Chris Rozoff and Xiaomin Chen
	2.2 External Influences: Qingqing Li and Josh Wadler
	2.3 Operational Perspectives: Zhan Zhang and Weiguo Wang
	Topic 2 Summary
	Topic 2 breakout session
	Topic 3 TC Structure change: Liz Ritchie and Matt Kucas
	3.1 Structure change processes: Inner Core: Yoshiaki Miyamoto, Chun-Chieh Wu, and Kosuke Ito
	3.2 Structure change processes: Outer Circulation: Chris Noble and Ben Schenkel
	3.3 Phase Transitions: Kimberly Wood and Wataru Yanase
	Topic 3 Summary
	Topic 3 breakout session
Wednesday	Forecast Demonstration - 7-day cyclogenesis in the Australian region:
	Craig Earl-Spurr and Rabi Rivett
	Topic 4 TC Track and Genesis: Andrew Burton and Hui Yu
	4.1 Genesis: controlling factors and physical mechanisms: Rajasree VPM
	4.2 Genesis Forecast Processes: KK Hon
	4.3 Unusual Tracks: statistics and controlling factors: Ying Li
	4.4 Track Forecast: operational capability and new techniques: Adam Conroy
	Topic 4 Summary
	TC-Probabilistic Forecast Products (TC-PFP) update: Helen Titley
	Topic 4 breakout

Appendix 1 (*continued*)

Day	Topic
Thursday	Special Focus Topics - BMKG:
	Impact based forecast: Agie Wandala
	Low latitude TC Forecast (TC Seroja case study): Kiki
	Post Event Survey of Seroja: Idhan Abu Bakar
	Topic 5 Forecasting Hazards/impacts: Robbie Berg and Monica Sharma
	5.1 Rainfall: Alex Lamers and Sunitha Devi
	5.2 Wind: Craig Earl-Spurr and Andrea Schumacher
	5.3 Coastal inundation/Storm Surge: Nadao Kohno and Cody Fritz
	5.4 Wind-Tornadoes: Dereka Carroll-Smith and Ben Green
	Topic 5 Summary
	Topic 5 breakout
	Topic 6 TC variability beyond synoptic scale: Phil Klotzbach and Marie-Dominique Leroux
	6.1 Sub-seasonal prediction: Frederic Vitart and Carl Schreck
	6.2 Seasonal forecasting: Yuhei Takaya and Louis Philippe Caron
	6.3 Climate Change: Suzana Camargo and Hiro Murakam
	Topic 6 Summary
	Topic 6 breakout
Friday	Special Focus Topics:
	Tropical Cyclone Research Review: Dongliang Wang;
	Typhoon Landfall Forecast Demonstration Project (TLFDP): Hui Yu
	Experiment on Typhoon Intensity Change in the Coastal Areas (EXOTICCA): Jie Tang
	Understanding and Predicting Rainfall in Landfalling Typhoons (UPDRAFT): Kun Zhao
	Recommendation summary: Kim Wood