WWRP 2024 - 1

Report of the Tenth International Workshop on Tropical Cyclones

Bali, Indonesia, 5–9 December 2022

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

WORLD WEATHER RESEARCH PROGRAMME

Chair, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03
Email: Publications@wmo.int

OFFICIAL WORKSHOP PHOTOGRAPH

Participants attending the Tenth International Workshop on Tropical Cyclones (IWTC-10), Bali, Indonesia, 5–9 December 2022.

PREFACE

The Tenth International Workshop on Tropical Cyclones (IWTC-10) took place from 5-9 December 2022 in Bali, Republic of Indonesia. This workshop continued the goal of the original IWTC, held in 1985 in Bangkok, Kingdom of 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 World Meteorological Organization (WMO) efforts to encourage the advancement of TC forecasting and improve ways of communicating TC hazards to the general public.

Global efforts in TC forecasting 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 behavioural sciences, in ways that can lead to effective decision-making by stakeholders (e.g. government officials, emergency managers, media, general public). As such, the theme for IWTC-10 was "Improved tropical cyclone science and services for better decision-making". More about this theme, and how the workshop was structured around it, is discussed below.

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 and distributed to workshop participants before the workshop and it is now available online at: https://community.wmo.int/en/iwtc-10-reports.

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. While there were 140 in-person participants at the workshop, there were an additional 349 people who registered to participate remotely. Such a capability showed the potential of vastly increasing the number of people who can participate in IWTC, in particular from countries that may otherwise lack the resources to send personnel to the workshop. While nothing can beat in-person interaction, this ability for remote participation has the advantage of increasing participation globally.

For five days, an estimated 500 participants from fifty three Countries, both in-person and online, met to discuss research directions on TC hazards and impacts, search for opportunities to improve their forecasting, and chart out ways to improve 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. As recommended by IWTC-10, the reports included in the compendium in Chapter 4 have also been published in the Tropical Cyclone Research and Review journal.

Finally, we would like to thank the participants, the topic chairs and rapporteurs, the discussion group leaders and note-takers, the International Committee, the local organizing committee, the Indonesian Meteorological Service (BMKG), and the WMO staff for their collective effort which made this workshop a most fruitful event of learning and sharing.

Robert Rogers (United States of America) and Joseph Courtney (Australia), co-chairs IWTC-10.

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1 INTRODUCTION

1.1 Background

The International Workshop on Tropical Cyclones (IWTC) series started in November 1985 following the directive of the Ninth 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 (TCs) and to summarize the various TCs 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 had one or more important accomplishments.

Workshop	Dates	Location
IWTC-1	25 November–5 December 1985	Bangkok, Kingdom of Thailand
IWTC-2	27 November-8 December 1989	Manila, Republic of the Philippines
IWTC-3	22 November-1 December 1993	Huatulco, United Mexican States
IWTC-4	21–30 April 1998	Haikou, People's Republic of China
IWTC-5	3–12 December 2002	Cairns, Australia
IWTC-6	21–30 November 2006	San Jose, Republic of Costa Rica
IWTC-7	15–20 November 2010	La Réunion, France
IWTC-8	2–7 December 2014	Jeju, Republic of Korea
IWTC-9	3–7 December 2018	Honolulu, United States of America

IWTC-2 (Manila, Philippines, 1989) initiated the preparation of the Global Guide for Tropical Cyclone Forecasting, which was published just before IWTC-3 (Huatulco, Mexico 1993). A special session on global climate change and TCs was held during IWTC-3 under the chairmanship of J. Lighthill of the International Council for Science (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-4 (Haikou, China, 1998), revisions to the Global Guide for Tropical Cyclone Forecasting were proposed to include the latest knowledge on TCs and forecasting methods. A keynote session on the Present, Imminent and Future Satellite Observations for Tropical Cyclones was organized at IWTC-5 (Cairns, Australia, 2002), which was very well-received by TC forecasters.

IWTC-6 included a special session on the relationship between TCs and climate change, from which a Statement on Tropical Cyclones and Climate Change emerged. IWTC-7 saw the traditional two-week period of the workshop shortened to one week. Despite this shortened time, there were still many opportunities for focused, substantive interactions among workshop participants – a hallmark of all IWTCs. The following IWTC, IWTC-8, was held jointly with the third International Workshop on Landfall Processes (IWTCLP-3), 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 TC landfall. At this workshop more emphasis was placed 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 honouring Dr Gray was held at IWTC-9, highlighting many of his contributions to tropical meteorology, including fundamental discoveries regarding TC movement, structure and genesis, as well as his pioneering work on Atlantic basin seasonal hurricane prediction.

1.2 International Committee

The International Committee for IWTC-10 consisted of:

Mr Joseph Courtney	Australia, Co-Chair
Dr Robert Rogers	United States of America (the), Co-Chair
Dr Lixion Avila	United States of America (the)
Dr Michael Brennan	United States of America (the)
Ms Estelle de Coning	WMO
Dr Christopher Davis	United States of America (the)
Ms Anne-Claire Fontan	WMO
Mr Taoyong Peng	WMO
Dr Elizabeth Ritchie	Australia
Dr Kimberly Wood	United States of America (the)
Dr Zhuo Wang	United States of America (the)
Dr Munehiko Yamaguchi	WMO
Dr Hui Yu	China

IWTC-10 Recommendation Committee members:

Kim WOOD	Chair, research, United States of America (the)
Alan BRAMMER	Research/R2O, United States of America (the)
Suzana CAMARGO	Research, United States of America (the)
Joe COURTNEY	IWTC-10 co-chair, Australia
Anne-Claire FONTAN	WMO
Cyrille HONORE	WMO
Chris NOBLE	Operations, New Zealand
Rob ROGERS	IWTC-10 co-chair, United States of America (the)
Monica SHARMA	Operations, India
Hui YU	Research, China

1.3 Objectives of IWTC-10

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

- To report on current knowledge, forecasting and research trends on TCs 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

1.4 Workshop topics and organization

The theme for this Workshop was "Improved tropical cyclone science and services for better decision-making". Decisions are made at every point along the end-to-end warning cycle that need optimizing for ultimate appropriate community action during TC events. With that theme as the inspiration, the workshop keynote address was provided by Dr Brian Golding (United Kingdom of Great Britain and Northern Ireland), who edited a book entitled "Towards the 'Perfect' Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication" (Springer, 2022. https://doi.org/10.1007/978-3-030-98989-7). In this book Dr Golding discussed the concept of the Warning Value Chain, illustrated in Figure 1 below:

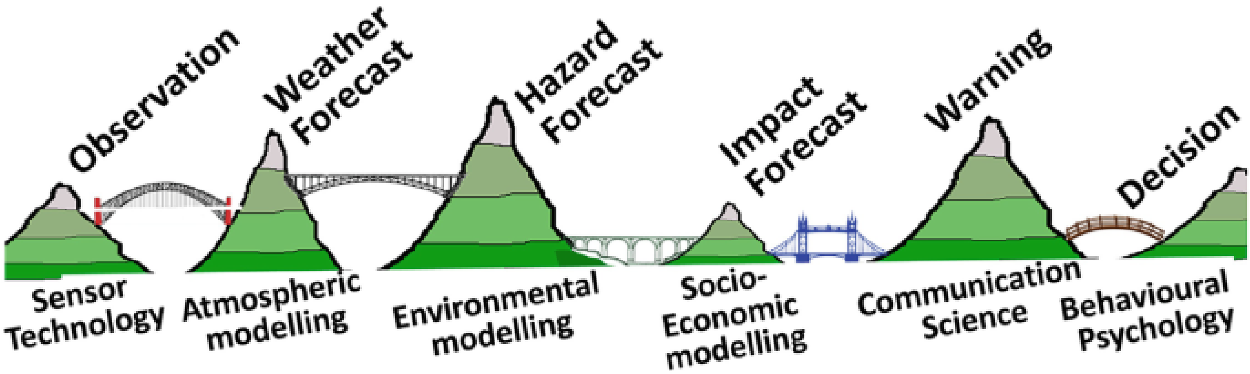

Figure 1. The "valleys of death" concept of a warnings value chain.

Source: © Crown Copyright 2020, Met Office, adapted from Golding (2022), "Towards the 'Perfect' Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication" (https://doi.org/10.1007/978-3-030-98989-7)

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 completely lost. While an oversimplification of the warning process, the concept is a useful one that highlights the very broad range of disciplines involved – and the need for those disciplines to communicate with each other effectively.

After Dr Golding's keynote address, there was a special focus session on Communicating Hazards, targeting one of the "mountains" and associated "bridges" in Figure 1 above. This session included presentations from forecast agencies and social scientists in six different countries and territories (the United States of America, the Republic of the Philippines, the

Republic of India, Cayman Islands and Turks and Caicos Islands, the Republic of Fiji, and the Republic of Mozambique) highlighting the challenges in communicating TC hazards particular to their situations and the solutions developed to overcome them.

Six other topics were then presented and discussed during the subsequent days (two per day):

Topic 1: Remote sensing for tropical cyclone analysis

Topic 2: Tropical cyclone intensity change

Topic 3: Tropical cyclone structure change and mid-latitude interactions

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 subtopic 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, with a mix of researchers and forecasters in each group. A group leader was assigned to each group and charged to lead the members of the group to make recommendations on the topic based on the material presented as well as the discussions during the plenary sessions. These recommendations were then passed to 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, there were special focus sessions on impact-based forecasting by the Indonesian Meteorological Service (BMKG), summaries of WMO-endorsed projects and field campaigns in The People's Republic of China (Typhoon 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 (TC-PFP) and a demonstration on the TC genesis forecast process from the Bureau of Meteorology in Australia.

A Recommendations Committee was formed, consisting of Kim Wood (United States of America, Chair), Alan Brammer (United States of America), Suzana Camargo (United States of America), Joe Courtney (Australia), Chris Noble (New Zealand), Robert Rogers (United States of America), Monica Sharma (Republic of India), and Hui Yu (People's Republic of China) and supported by the WMO secretariat. In a departure from past workshops, this committee was created in advance of the workshop. Innovations in the breakout sessions that led to recommendations took advantage of COVID-related technological advances, including community bulletin boards to which people could contribute ideas and suggestions to be examined by all participants, both in-person and remotely. 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 is listed in the following section.

2 RECOMMENDATIONS

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

Research	=	research community
Operations	=	operational forecaster community as well as operational modelling centres
WMO	=	WMO
Integrated research + operations	=	needs partnerships between researchers and operational forecasters
All	=	targets research, operations and 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 subsurface, 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 artificial intelligence (AI)/machine learning (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 saildrones) 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:

(a) Datasets based on long-term data (e.g. scatterometer, reanalysis data) made available to the research and operational community;

(b) 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 data set 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 multimodel 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 modelling centres to encode vortex parameter files in a standardized format (e.g. BUFR, CXML) and exchange them in a timely and consistent manner, such as the Global Telecommunication System (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 Basic Documents No. 2: Manual on the WMO Integrated Processing and Prediction System Annex IV to the WMO Technical Regulations (*WMO-No. 485)*. 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 life cycle (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 that 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 Advisory Group on Tropical Cyclones (AG-TC). [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, analyse, diagnose and predict cyclone wind structure across all operational centres to identify advantages and shortcomings in these methods. Develop operational tools to overcome those gaps by incorporating new observational data, derived products (e.g. Atmospheric Motion Vectors (AMVs)) and numerical weather prediction (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 analyse and predict TC precipitation (both direct and remotely-forced) across all operational centres 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 secondary eyewall formation (SEF)/eyewall replacement cycle (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 SEF and 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 World Weather Research Programme (WWRP) Working Group on Tropical Meteorology Research (WGTMR) with advice from 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. extra-tropical cyclone (ETC), severe tropical cyclone (STC), TC, Mediterranean hurricane (Medicanes)) and transition pathways among these types (extratropical transitions (ET), tropical transitions (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 reanalysis 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 WGTMR with advice from the AG-TC.

15. Continue to investigate the physical mechanisms behind global TC frequency using both observations and modelling 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 multidecadal datasets related to TCs and better quantify uncertainty in these datasets. [Integrated research + operations]

Reasoning: Our assessment of TC behaviour 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, then that uncertainty can be incorporated into analyses using these datasets.

17. Encourage the development of skilful 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 behaviour 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 centres 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 multimodel 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 timescales (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 Figure 1)*. 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 behaviour 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 Figure 1). By sharing past experiences and learned best practices, all stand to benefit.

3 EVALUATION

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

A total of 92 responded to the online survey, 53 from in-person attendees and 39 from online attendees of which Zoom (17), YouTube (5) or a mixture of Zoom and YouTube (17). A total of 47 identified as some type of forecaster; either as 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 an impression having a count of 37, while others were more evenly spread – with "climate change" (24), "Remote sensing: current and emerging sensors" (23) and "Forecasting hazards/impacts: rainfall" (21) attracting the next highest totals.

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
- The venue or online experience

The results are shown in the table below.

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**

In terms of satisfaction with the workshop overall, 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 "neither satisfied nor dissatisfied" or "somewhat dissatisfied".

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 the 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
- Good to have both operational and research rapporteurs

What could be improved upon

Some of the feedback suggesting improvements included:

- Improve the experience for those on Zoom: chat and Q&A privileges, for example: simplify by having everyone on mute but ensuring that everyone has the same access to chat and ability to unmute; have one online breakout room to allow participation from the 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 one rapporteur. Be clear about expectations and suggested ways of working for working groups.
- Rapporteurs present summaries not recommendations and topic leads only present recommendations. Then discuss recommendations in breakout sessions.
- Breakout sessions: less emphasis on recommendations and more on engagement between participants with common interest.
- Determine the venue earlier and make the selection with greater transparency (perhaps by nomination via regional committees with clear guidelines for how the selection is decided). Delayed selection of the venue created difficulties in travel planning and timely report completion.

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 to 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.

4 COMPENDIUM OF REPORTS[1]

4.1 Remote sensing

Monitoring the position, intensity and structure of a TC is often a key point for subsequent decisions in the warning chain. Our capabilities of analysing TCs and its interaction with the upper ocean, have improved over the last four years thanks to: increasing possibilities to better observe extreme winds from space, increasing spatial and temporal resolution from geostationary satellites, development of AI based methods to derive TC fixes and the invaluable contribution of in situ data from aircraft recon and/or emerging new unmanned systems.

4.1.1 Remote sensing and tropical cyclone analysis: current and emerging satellite sensors

This report describes recent advances in the capability of new satellite sensors for observing the fine structure of TCs and wind field and temporal evolution. Firstly, we focus on polar orbiting sensors, such as C-band SARs, L-band and combined C/X-band radiometers, scatterometers and microwave imagers/sounders; then we address progress made with the new generation of geostationary and small satellites. Lastly, we describe how the newest sensors are used in operations and data assimilation for TC forecasting and research.

4.1.2 Objective satellite methods including AI algorithms

Here we explore the latest four years of using satellite data to objectively analyse TCs and make recommendations for improved analysis. First, we discuss new methods of direct retrieval from SAR and geostationary imagers. Next, we survey some of the most prominent new techniques in AI and discuss their major capabilities (especially accuracy in nonlinear TC behaviour, characterization of model uncertainty and creation of synthetic satellite imagery) and hazards (especially lack of transparency and limited amount of training data). We also identify concerns with biases and unlabelled uncertainties in the best-track records as being a first-order limitation for further progress in objective methods. The section concludes with recommendations to improve future objective methods, especially in the area of more accurate and reliable training data sets.

4.1.3 Advancements in aircraft and in situ observations of tropical cyclones

Observations of TCs from aircraft and in situ platforms provide critical and unique information for analysing and forecasting TC intensity, structure and their associated hazards. This report discusses the data collected around the world on TCs over the past four years since IWTC-9, improvements to observing techniques, new instruments designed to achieve sustained and targeted atmospheric and oceanic observations and select research results related to these observations.

In the Atlantic and Eastern and Central Pacific basins, changes to operational aircraft reconnaissance are discussed along with several of the research field campaigns that have taken place recently. The changes in the use and impact of these aircraft observations in NWP models is also provided along with updates on some of the experimental aircraft instrumentation. Highlights from two field campaigns in the Western Pacific basin are also discussed. Examples of in situ data collected within recent major hurricanes such as Ian, also demonstrate that new, emerging technologies and observation strategies reviewed in this report, definitely have the potential to further improve ocean-atmosphere coupled intensity forecasts.

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[1] For detailed content, check reports available on https://community.wmo.int/en/iwtc-10-reports

4.2 Tropical cyclone intensity change

This topic addresses recent advances in understanding TC intensity change, from both research and operational points of view. Some of the research advances include improved understanding of surface and boundary layer processes, TC internal structure and microphysical processes and radiation interactions with TCs. Additionally, new findings about the importance of the salinity-stratification of the ocean, vertical wind shear and rapid intensification, the Saharan Air Layer (SAL) plus other aerosol influences are catalogued. For operations, significant improvements in dynamical models have helped many TC forecast centres achieve record low intensity forecasts during the past four years.

In addition to improved output from global models, new forecaster techniques and improved rapid intensification techniques have also led to high skill intensity forecasts. Significant challenges remain, however, with intensity forecasting, especially in cases of rapid intensification, where the probability of detection is only slowly rising and with significant false alarms. A combination of dynamical model upgrades (for resolution, data assimilation and physics packages in both regional and global models), new regional hurricane models and TC observations is thought to be contributing to the continuation of the positive trends seen during the last four years in intensity prediction.

4.2.1 Intensity change: internal processes

In the last four years, significant progress has been made in a variety of topic areas related to internal TC intensity change processes. These topic areas include surface and boundary layer processes, TC internal structure and microphysical processes and radiation interactions with TCs. Recent studies better frame the uncertainty in the surface drag and enthalpy coefficients at high wind speeds. These parameters greatly impact TC intensity, and it is therefore important that more direct measurements of these boundary layer parameters are made. Particularly significant scientific strides have been made in TC planetary boundary layers. These advancements have been achieved through improved coupled models, large-eddy simulations, theoretical advancements and detailed observations. It is now clear that the research field needs to better represent the eddy viscosity throughout the depth of the boundary layer. Furthermore, detailed study of coherent structures in TC boundary layers will likely be a propitious direction for the research community. Meanwhile, in-depth observational field campaigns and assiduous data analysis have made significant headway into verifying theory and modelling studies of intensification processes related to TC vortex alignment, efficient latent heating distributions and overall 3D structure. Finally, significant effort has been made to better understand the intricate roles radiative processes play in TC evolution and intensity change. Overall, there have been well-earned gains in the understanding of intensity change processes intrinsic to the TC system, but the journey is not complete. This report section highlights some of the most relevant and important research areas that are still shedding new light into internal factors governing TC intensity change.

4.2.2 Intensity change: external influences

Over the past four years, numerous research advances on the influences of external factors on TC intensity change have sprung up. This report encapsulates these new results. It has been discovered that ocean salinity-stratification plays a non-negligible part in TC intensity change. Vortex misalignment induced by vertical wind shear controls the onset of significant TC intensification, but complete alignment is not a requirement for TC rapid intensification. Blocking due to upper-level outflow from TCs can reduce the magnitude of vertical wind shear, making for TC intensification. Enhanced TC-trough interactions are found to be vital for rapid intensification in some TC cases because of strengthened warm air advection, but upper-level troughs are found to limit TC intensification in other cases due to dry midlevel air intrusions and increased shear. Aerosol effects on TCs can be divided into direct effects involving aerosol-radiation interactions and indirect effects involving aerosol-cloud interactions. The absorption of radiation by the aerosols can change the temperature profile and affect outer rainbands through changes in stability and microphysics. Sea spray and sea salt aerosols are more important in the inner region, where the aerosols increase precipitation and latent heating, promoting more intensification. For landfalling TCs, the intensity decay is initially more sensitive to surface roughness than soil moisture and the subsequent decay is mainly due to the rapid reduction in surface moisture fluxes. In addition, physics-based models have been proposed to predict the time-dependent weakening response of post-landfall TCs. These new insights further sharpen our understanding of the mechanisms by which external factors influence TC intensity changes.

4.2.3 Intensity change: operational perspectives

The accuracy of TC intensity forecasts issued by operational forecast centres depends on three aspects:

(1) Real time observations from various observational means, including high-resolution flight reconnaissance;

(2) NWP TC dynamic model forecast guidance;

(3) Techniques and methods used by forecasters.

This report reviews the progress made in the past four years (2018–2022) in all three aspects. The dynamic model forecast guidance continues to be the main factor leading to the improvements of the operational TC intensity forecasts. This report focuses on recent advances and developments of major operational TC models and their intensity forecast performance, including the Hurricane Weather and Research Forecasting model (HWRF), the Hurricane Weather and Research Forecasting model (HMON), the Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC) and Global and Regional Assimilation and Prediction System for typhoons (GRAPES-TY). Some of the increased skill of TC intensity forecasts by global dynamical models is due to their increased horizontal and vertical resolution, as well as improved data assimilation. This report also discusses the progress made in global systems, including the National Oceanic and Atmospheric Administration's (NOAA) Global Forecast System (GFS), the Met Office Global Model (MOGM) and the European Centre for Medium-Range Weather Forecasts (ECMWF) Integrated Forecasting System (IFS). The tools and techniques, along with recent challenging cases identified by operational forecast centres are also presented and discussed.

4.3 Structure change and midlatitude interactions

Since IWTC-9, research and forecasting of TC structure and structure change have proceeded along several key paths because of both the improved capability of models to simulate small scale structures and the existence of satellite platforms that can now observe fine-scale inner core features at much higher spatial and temporal resolutions. There has been a lot of focus on: investigating key structure associated with rapid intensification; SEF and ERC; the impact of asymmetries in the boundary layer; the continued analysis of new aircraft and satellite observations and methods that increase the ability to utilize in situ observations and new technologies. Structure change is closely tied to storm intensity, which can vary from a variety of internal and external sources. In this topic, key findings from the years following IWTC-9 are summarized with respect to physical processes, the stage of the TC life cycle, the air-sea interface and the atmospheric boundary layer.

4.3.1 Tropical cyclone structure change processes: inner core

We provide a review for the latest research on the structure change processes in the TC inner core. The inner core structure is influenced by processes involving convection, vortex structure and environmental condition, which are also important for the intensity and size of TCs. The processes have been investigated by analysing observation data, conducting numerical simulations and developing theoretical models. Previous studies have examined the effects of vertical wind shear during the rapid intensification, structural changes during landfall, differences from dry TC and the effects of the environment on inner core structure. Also, effects of stationary band complex, stratiform precipitation, vertical wind shear and processes in the boundary layer on SEF and ERC have been intensively investigated.

A questionnaire that has been conducted by group members revealed that operational agencies focus on the analysis of the radius of maximum wind and inner core structure. Observations, such as those provided by satellites are often used subjectively for operational analyses. Climatological changes in the inner core structure have been investigated despite the expensive computational costs and hence further studies are expected to be conducted in the future.

4.3.2 Tropical cyclone structure change processes: outer circulation

This report summarizes recent updates to TC outer size and structure forecasting and research. A more complete understanding of TC outer wind and precipitation is key to anticipating storm intensification and the scale and magnitude of landfalling hazards. We first discuss the relevance of TC outer size and structure, improvements in our understanding of its life cycle and inter-basin variability and the processes that impact outer size changes. We next focus on current forecasting practices and differences among warning centres including recent advances in operational forecasting and new data for the storm outer wind field. Finally, we summarize recent research on projected TC outer size and structure changes by the late twenty-first century.

4.3.3 Tropical cyclone structure: phase transitions

This report reviews the latest research findings and operational practices relevant to cyclone phase transitions (extratropical, subtropical and tropical) and cyclone types with particular emphasis on subtropical cyclones. The CPS method is widely used in both historical investigations and real-time assessment; however, CPS parameter values depend on the data source (e.g. operational forecast models, reanalysis fields) and the resolution of those fields. Consequently, universal thresholds do not currently exist to confirm when a cyclone transitions from one type to another, such as from subtropical to tropical or tropical to extratropical. In addition, the use of CPS as well as additional criteria to define phase transitions and cyclone type varies between operational meteorological centres. It is recommended that future efforts on these topics investigate the potential for a more universal classification methodology to consistently identify cyclone type and cyclone phase transitions. Such work would require a comprehensive assessment of cyclones in all basins where tropical and subtropical cyclones occur, including the South Atlantic Ocean and the Mediterranean Sea.

4.4 Tropical cyclone track and genesis

In this section, efforts to improve the science and services related to TC track and genesis in the years since IWTC-9 are reviewed. Tropical cyclogenesis is a complex multiscale process that poses significant challenges for prediction. In the last four years there have been a range of observational, theoretical and numerical modelling studies on the influence of large-scale environmental factors, the multiscale nature, balanced and unbalanced dynamics and the dynamical and thermodynamical aspects of genesis. Tropical cyclogenesis forecast services have also advanced, with operational centres providing genesis forecasts at longer lead times and for systems that are not yet observable as a coherent circulation. Improvements in the reliability of operational probabilistic genesis forecasts over the last four years are also noteworthy.

Although track forecast errors have continued to decrease at most lead times, there is some evidence that we may be approaching theoretical limits in predictability at shorter lead times. Issues associated with unusual tracks and track forecasts with large errors, are attracting limited research and continue to be a challenge for warning agencies. Warning agencies continue to explore probabilistic forecast processes and products for track prediction, to better support decision-making under uncertainty. A range of approaches is being used to better characterize track uncertainty, including attempts to develop a calibrated grid of location probability.

4.4.1 Genesis: controlling factors and physical mechanisms

In this review, advances in the understanding of the controlling factors and physical mechanisms of tropical cyclogenesis (TCG) are summarized from literature published in the last five years (2018–2022). Observational, theoretical and numerical modelling studies published in recent years have advanced our knowledge of the influence of large-scale environmental factors on TCG. In addition to this, the multiscale nature, balanced and unbalanced dynamics and the dynamical and thermodynamical aspects of TCG have been diligently addressed: multiple studies reported the applicability of unified theories and physical mechanisms of TCG in different ocean basins and progress has been made to understand the role of climate change on global and regional TCG. However, there are still significant gaps which need to be addressed to obtain a better understanding of prediction of TCG.

4.4.2 Genesis: forecast processes

TC genesis prediction is a major scientific challenge to the TC operation and research community. This report surveys the current status of TC genesis forecasts by a number of major operational centres covering the key ocean basins across both hemispheres. Since IWTC-9, we have seen an emergence of probabilistic TC genesis forecast products by operational centres, typically supported by the statistical processing of a combination of ensemble prediction and satellite analysis, covering time periods of couple of days to weeks ahead. The prevalence of multi-centre grand ensemble approach highlights the uncertainties involved and the forecast challenges in quantitative genesis prediction. While operational practice might differ across agencies, verification efforts generally report a steady or slightly improving skill level in terms of reliability, which likely result from the continual improvement in global NWP capability.

4.4.3 Unusual tracks: statistical and controlling factors

The progress of research and forecast techniques for TC unusual tracks in recent years is reviewed. A major research focus has been understanding which processes contribute to the evolution of the TC and steering flow over time, especially the reasons for sharp changes in TC motion over a short period of time. When TCs are located in the vicinity of monsoon gyres, TC track forecast become more difficult to forecast due to the complex interaction between the TCs and the gyres. Moreover, the convection and latent heat can also feed back into the synoptic-scale features and in turn modify the steering flow.

In this report, two cases with unusual tracks are examined, along with an assessment of numerical model forecasts. Advances in numerical modelling and in particular the development of ensemble forecasting systems have proved beneficial in the prediction of such TCs. There are still great challenges in operational track forecasts and warnings, such as: the initial TC track forecast, which may be based on a poor pre-genesis analysis, TC track forecasts during interaction between two or more TCs and track predictions after landfall. Recently, AI methods such as ML or deep learning have been widely applied in the field of TC forecasting. For TC track forecasting, a more effective method of centre location is obtained by combining data from a number of sources and fully exploring the potential of AI, which provides further possibilities for improving TC prediction.

4.4.4 Track forecast: operational capability and new techniques (in combination with Tropical Cyclone-Probabilistic Forecast products Stage 1)

The rate of improvement in the accuracy of official forecast tracks (OFTs) appears to be slowing down, at least for shorter lead times, where we may be approaching theoretical limits. Operational agencies continue to use consensus methods to produce OFT with most continuing to rely on an unweighted consensus of four to nine NWP models. There remains limited use of weighted consensus techniques, which is likely a result of the skills and additional maintenance needed to support this approach. Improvements in the accuracy of ensemble mean tracks is leading to increased use of ensemble means in consensus tracks.

Operational agencies are increasingly producing situation-dependent depictions of track uncertainty, rather than relying on a static depiction of track forecast certainty based on accuracy statistics from the preceding five years. This trend has been facilitated by the greater availability of ensemble NWP guidance, particularly vortex parameter files and improved spread in ensembles. Despite improving spread-skill relationships, most ensemble NWP systems remain under spread. Hence many operational centres are looking to leverage "super-ensembles" (ensembles of ensembles) to ensure that the full spread of location probability is captured. This is an important area of service development for multi-hazard impact-based warnings as it supports better decision-making by emergency managers and the community in the face of uncertainty.

4.5 Forecasting tropical cyclone hazards and impacts

TCs are multi-hazard events causing damage to life and property due to a number of primary hazards including heavy rain and flooding, strong winds, tornadoes and storm surge as well as secondary hazards including landslides, landslips etc. Despite recent advances with respect to observations, modelling, forecasting and early warning communication and dissemination which have resulted in significant reduction in loss of lives due to TCs, there are gap areas such as insufficient observational networks, non-availability of high-resolution model guidance for all areas, inadequate representation of TC forecast uncertainty into impact-based forecasts and warnings, lack of exposure and vulnerability data for appropriate hazard, risk and vulnerability and last mile connectivity. All these need to be addressed to mitigate the disasters associated with TCs. The latest developments with respect to research and operational aspects of TC hazard monitoring and forecasting during 2018–2022 are discussed in this report.

4.5.1 Forecasting tropical cyclone rainfall and flooding hazards and impacts

The advances in forecasting TC rainfall and its impacts in the last four years are reviewed in this report. Major physical processes that can modulate TC rainfall distribution, including topography, storm motion, vertical wind shear and intensity, along with the fundamental physics of rain bands and clouds as simulated by numerical models, diurnal variation of rainfall and various synoptic and mesoscale features controlling the rainfall distribution are briefly discussed. Improvements to the dynamic core and physical processes in global models are providing usable forecasts nearly up to seven days. Some tools that have been developed to predict TC rainfall are discussed. Recently, operational forecasting centres are tending towards the use of multimodel ensemble systems for rainfall forecasting that demonstrate superior performance over individual models, ensemble members or even single model ensembles. Major impacts include pluvial and fluvial floods and landslides; the techniques developed by various forecasting centres to assist in predicting and communicating the impacts associated with these events are also presented in this report along with recommendations for further developments.

4.5.2 Forecasting tropical cyclone wind hazards and impacts

The winds associated with TCs vary significantly over both spatial and temporal scales resulting in a hazard which is complex to describe and quantify through the course of such an event. To assist hazard modelling, user understanding and decision-making, wind hazard forecasts have been developed and are becoming an increasingly more common product offered by operational centres. The various solutions provide complimentary information to a system-centric forecast, focusing on the strength and timing of a number of wind hazards at locations of interest. An additional benefit is a clearer presentation of how uncertainties in the forecast may impact the evolution of the wind field. Impact-based forecasts that incorporate hazard, vulnerability and exposure data are intended to further contextualize information for users. Efforts to develop impact-based TC wind hazard forecasts are generally still in their infancy. Their development and operationalization presents a number of challenges that many forecast centres are still considering how to deal with. In this report, various approaches taken to produce wind hazard forecasts, gap areas and recommendations for further improvements are discussed.

4.5.3 Forecasting tropical cyclone coastal and marine hazards and impacts

The understanding and communication of coastal hazards associated with TCs has improved significantly in the last few years. This report highlights the progress various regions have made with respect to numerical modelling techniques and the dissemination of coastal hazard warnings and products. More specifically, regions have started to confront the uncertainty that cannot be removed from TC analyses and forecasts and further communicate those hazards within the context of risk [probabilistic] based information. Progress also includes impact-based forecasts such as communicating coastal inundation information relative to total water level instead of storm surge specifically (i.e. anomaly from astronomical tide and waves). Lastly, updates to model grid configuration, model resolution and coupled dynamical systems continue to resolve the costal hazards more effectively. Those approaches have likely helped reduce loss of life relative to historical standards. However, regions agree that the dissemination of coastal hazard information still need be improved as populations continue to grow along the coast and expose more people.

4.5.4 Forecasting tropical cyclone tornadoes and impacts

This report synthesizes global TC tornado research and operation practices to date. Tornadoes are one of the secondary (and lesser researched) hazards contributing to the devastation TCs leave in their wake. While gale force winds and storm surge produce the majority of damage and fatalities globally, TC tornadoes also pose a fatal threat, complicating evacuation plans and protective actions as the storm moves inland. Climatological studies characterize TC-spawned tornadoes as weak and short-lived, primarily originating from miniature supercells in the outer rainbands. These tornadic features make forecasting and radar detection particularly challenging. Additionally, TC tornadoes can pose a threat to communities 12 hours prior to and beyond 48 hours after a TC makes landfall.

Research, both basic and operational, has increased globally over the last few years in efforts to move from a climatological to ingredients-based approach to detect and forecast TC tornadoes. While the United States of America has led the charge, given the increased exposure to tornadoes year round, other nations such as the People’s Republic of China, Japan and Australia have increased their efforts to record and detect TC tornadoes. Despite this advancement, more work needs to be done globally to understand the TC environment conducive to tornadic activity. Recommendations for future forecasting and research for TC tornadoes include:

(1) A need for a comprehensive global tornado database to improve research and forecasting effort;

(2) Use of innovative technology to detect tornadoes;

(3) The conducting of field campaigns to thoroughly sample TC tornado environments, particularly along coastlines.

4.6 Beyond synoptic timescales

Subseasonal TC prediction has continued to advance over the past four years, with a focus that still includes the Madden-Julian oscillation/boreal summer intraseasonal oscillation. The latter has been shown to significantly impact TC activity in all global TC basins. Additional research has focused on extratropical wave breaking, which has been shown to significantly impact TC activity via modulations in vertical wind shear and mid-level moisture. Multimodel ensemble datasets of subseasonal to seasonal predictability have highlighted current predictability differences for various models and TC basins.

Seasonal TC forecasting has continued to advance over the past few years, with efforts focused on prediction of TC activity in El Niño-Southern Oscillation (ENSO) neutral years, additional utilization of ML/AI models and expansion of seasonal TC forecasts to decadal timescales.

The relationship between TCs and climate change has been studied extensively over the past few years. The formerly well-accepted paradigm of fewer named storms with climate change has been challenged recently, leading to more uncertainty in future projections. TC seeds have been proposed as a mechanism to better understand how named storm frequency may change in the future. Confidence has grown that climate change will likely lead to stronger hurricanes in the future. Additional research has focused on potential deceleration in TC translation speed and medicanes.

4.6.1 Sub-seasonal tropical cyclone prediction

In this report we discuss progress in TC subseasonal variability understanding and forecasting in recent years. There has been a large effort in the scientific community towards understanding the sources of predictability at subseasonal timescales beyond the well-known modulation of TC activity by the Madden-Julian oscillation. In particular, the strong modulation of TC activity over the western North Pacific by the boreal summer intraseasonal oscillation has been documented. A lot of progress has also been realized since IWTC-9 on better understanding the role of tropical-extratropical interactions to improve subseasonal forecasts. In particular, several recent publications have shown that extratropical wave breaking may have a role in the genesis and development of TCs. Analyses of multimodel ensemble data sets, such as the Subseasonal to Seasonal (S2S) and Subseasonal Experiment (SubX) have shown that the skill of S2S models in predicting the genesis of TCs varies strongly between models and regions. There has been an increase over the past four years in the number of modelling centres issuing subseasonal TC forecasts using various techniques (statistical, statistical-dynamical and dynamical). More extensive verification studies have been published over the last four years, but often only for the North Atlantic and eastern North Pacific.

4.6.2 Seasonal tropical cyclone forecasting

This section reports recent research and development in seasonal TC forecasting. In addition to regular activity reports from each research and operational group, this subsection features new research topics on seasonal TC predictability in ENSO neutral conditions, forecasting techniques of seasonal TC activity including ML/ AI and annual-to-decadal TC predictions. For the TC science and services to move forward for better decision-making, this subsection also summarizes collaborative international activities on multimodel ensembles and model intercomparisons. The community’s recommendations are also given for further enhancing our capability and usability of seasonal TC forecasting.

4.6.3 Tropical cyclones and climate change

A substantial number of studies have been published since the IWTC-9 in 2018, improving our understanding of the effect of climate change on TCs and associated hazards and risks. They reinforced the robustness of increases in TC intensity and associated TC hazards and risks due to anthropogenic climate change. New modelling and observational studies suggested the potential influence of anthropogenic climate forcings, including greenhouse gases and aerosols, on global and regional TC activity at the decadal and century timescale. However, there is still substantial uncertainty owing to model uncertainty in simulating historical TC decadal variability in the Atlantic and owing to limitations of observed TC records. The projected future change in the global number of TCs has become more uncertain since IWTC-9 due to projected increases in TC frequency by a few climate models. A new paradigm, TC seeds, has been proposed and there is currently a debate on whether seeds can help explain the physical mechanism behind the projected changes in global TC frequency. New studies also highlighted the importance of large-scale environmental fields on TC activity, such as snow cover and air-sea interactions. Future projections on TC translation speed and medicanes are new additional focus topics in our report. Recommendations and future research relevant to the remaining scientific questions and assisting policymakers are proposed.

APPENDIX 1. IWTC-10 PROGRAMME, 5-9 DECEMBER 2022

Day	**Time UTC**	**Time LST**	**Topic**
Sunday	0900–1000	1700–1800	Optional pre-workshop orientation, esp. for presenters
Monday	0000–0100	0800–0900	Registration
	0100–0130	0900–0930	Welcome and introduction: BMKG/WMO/Co-chairs
	0130–0200	0930–1000	**Tropical cyclone warning value cycle** (Brian Golding, the United Kingdom of Great Britain and Northern Ireland)
	0200–0315	1000–1115	**Special focus session on communicating hazards: country presentations** United States of America (the) (Gina Eosco) Philippines (the) (Robb Gile) India (Monica Sharma) Cayman Islands/ (Shamal Clarke) Turks and Caicos Islands (Holly Hamilton) Fiji (Stephen Meke) Mozambique (Guelso Mauro Manjate)
	0315–0345	1115–1145	Break (group photo)
	0345–0445	1145–1245	Communication breakout session
	0445–0600	1245–1400	Lunch
	0600–0730	1400–1530	**Topic 1: Remote sensing for tropical cyclone analysis (Sebastien Langlade)** 1.1 Current and emerging satellite sensors (Lucrezia Ricciardulli) 1.2 Objective satellite methods (Quoc-Phi Duong) 1.3 Developments and science using in situ platforms (Heather Holbach) Summary (Sebastien Langlade)
	0730–0800	1530–1600	Break
	0800–0930	1600–1730	Topic 1 breakout session
	1100–1400	1900–2200	Workshop dinner, Patra Hotel

Tuesday	0030–0100	0830–0900	Review of IWTC-9 recommendations (Rob Rogers)
	0100–0230	0900–1030	**Topic 2: Tropical cyclone intensity change** 2.1 Internal influences (Chris Rozoff) 2.2 External influences (Benjamin Jaimes de la Cruz) 2.3 Operational Perspectives (Eric Blake) Summary (Eric Blake)
	0230–0300	1030–1100	Break
	0300–0430	1100–1230	Topic 2 breakout session
	0430–0545	1230–1345	Lunch
	0545–0715	1345–1515	**Topic 3: Tropical cyclone structure change** 3.1 Structure change processes: Inner core (Kosuke Ito) 3.2 Structure change processes: Outer circulation (Chris Noble) 3.3 Phase transitions (Kimberley Wood) Summary (Liz Ritchie)
	0715–0745	1515–1545	Break
	0745–0915	1545–1715	Topic 3 breakout session
	0915–1000	1715–1800	Social/open space
Wednesday	0030–0100	0830–0900	**Forecast demonstration: 7-day cyclogenesis in the Australian region** (Craig Earl-Spurr and Rabi Rivett)
	0100–0230	0900–1030	**Topic 4: Tropical cyclone track and genesis** 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 technique (Adam Conroy) Summary (Andrew Burton)
	0230–0245	1030–1045	**Tropical cyclone-probabilistic forecast products update** (Helen Titley)
	0245–0315	1045–1115	Break
	0315–0445	1045–1245	Topic 4 breakout
	0445–0530	1245–1330	Lunch
	0530–1130	1330–1930	Options: excursion to Bali forecast office and Uluwatu Beach performance

Thursday	0030–0100	0830–0900	**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)
	0100–0230	0900–1030	**Topic 5: Forecasting tropical cyclone hazards/impacts** 5.1 Rainfall (Alex Lamers) 5.2 Wind (Craig Earl-Spurr) 5.3 Coastal inundation/storm surge (Nadao Kohno) 5.4 Wind-tornadoes (Dereka Carroll-Smith) Summary (Monica Sharma)
	0230–0300	1030–1100	Break
	0300–0430	1100–1230	Topic 5 breakout
	0430–0545	1230–1345	Lunch
	0545–0715	1345–1515	**Topic 6: Tropical cyclone variability beyond synoptic scale** 6.1 Sub-seasonal TC prediction (Frederic Vitart) 6.2 Seasonal TC forecasting (Yuhei Takaya) 6.3 Climate Change (Suzana Camargo) Topic 6 Summary (Phil Klotzbach)
	0715–0745	1515–1545	Break
	0745–0915	1545–1715	Topic 6 breakout
Friday	0030–0145	0830–1000	**Special focus topics** Tropical Cyclone Research and Review (TCRR) (Dongliang Wang) Typhoon Landfall Forecast Demonstration Project (TLFDP) (Hui Yu) Experiment on Typhoon Intensity Change in Coastal Area (EXOTICCA) (Jie Tang) Understanding and Prediction of Rainfall Associated with Landfalling Tropical Cyclones (UPDRAFT) (Kun Zhao)
	0145–0230	0945–1030	Recommendation summary
	0230–0300	1030–1100	Break
	0300–0430	1100–1230	Recommendation summary continued
	0430–0500	1230–1300	Closing Ceremonies

APPENDIX 2. LIST OF TOPICS AND WORKING GROUP MEMBERS

Topic 1: Remote sensing for tropical cyclone analysis		
Leads	**Organization**	**Country**
Derrick Herndon	CIMSS (UWisconsin)	United States of America (the)
Sebastien Langlade	La Reunion RSMC	France
1.1 Current and emerging satellite sensors		
Brian Howell (Rapporteur)	JTWC	United States of America (the)
Lucrezia Ricciardulli (Rapporteur)	REMSS	United States of America (the)
Jeff Hawkins		United States of America (the)
Ryo Oyama	JMA	Japan
Joe Courtney	BoM	Australia
Alexis Mouche	IFREMER	France
Chunyi Xiang	CMA	China
Masahiro Kazumori	JMA	Japan
Tony McNally	ECMWF	United Kingdom of Great Britain and Northern Ireland (the)
Julian Heming	UK Met Office	United Kingdom of Great Britain and Northern Ireland (the)
Willian Blackwell	MIT	United States of America (the)
Nicolas Reul	IFREMER	France
Jun Park	KMA	Republic of Korea (the)
Hyeong-Seog Kim	KMA	Republic of Korea (the)
Chris Jackson	NOAA	United States of America (the)
Chris Fogarty	Environment Canada	Canada
Ad Stoffelen	KNMI	Netherlands (Kingdom of the)
Chinmay Khadke	IMD	India
Michael Brennan	NHC	United States of America (the)
Maria Ana Glaiza Escullar	PAGASA	Philippines (the)
Thomas Meissner	RSS	United States of America (the)

1.2 Objective satellite methods (including AI algorithms)		
Tony Wimmers (Rapporteur)	CIMSS (UWisconsin)	United States of America (the)
Quoc-Phi Duong (Rapporteur)	LACy	France
Derrick Herndon	CIMSS (UWisconsin)	United States of America (the))
Zhe-Min Tan	Nanjing University	China
Jing-Yi Zhuo	Nanjing University	China
Qifeng Qian	CMA	China
John Knaff	NOAA/NESDIS	United States of America (the)
Ibrahim AlAbdulsalam	Center of Excellence for Satellite Applications	Oman
Takeshi Horinouchi	Hokkaido University	Japan
Ryota Miyata	University of the Ryukyu	Japan
Arthur Avenas	IFREMER	France
1.3 Developments and science using in situ platforms		
Heather Holbach (Rapporteur)	FSU/NOAA	United States of America (the)
Olivier Bousquet (Rapporteur)	LACy	France
Jun Zhang	UMiami/NOAA	United States of America (the)
Paul Chang	NOAA	United States of America (the)
Zorana Jelenak	UCAR/NOAA	United States of America (the)
Jason Sippel	NOAA	United States of America (the)
Kazuhisa Tsuboki	Nagoya Univ. and Yokohama National Univ.	Japan
Sarah Ditchek	UM/NOAA	United States of America (the)
Kosuke Ito	University of the Ryukyus	Japan
Hiroyuki Yamada	University of the Ryukyus	Japan
Jonathan Zawislak	UMiami/NOAA	United States of America (the)
Jim Doyle	NRL	United States of America (the)
Lisa Bucci	NHC	United States of America (the)

Jie Tang	Shanghai Typhoon Institute	China
Hui Yu	Shanghai Typhoon Institute	China
Xiaotu Lei	Shanghai Typhoon Institute	China
Ming-Jen Yang	Pacific Science Association	Pacific Science Association
Jean Philippe Duvel	CNRS/LMD	France
Jack Elston	Black Swift Tech	United States of America (the)
Gustavo Goni	NOAA /AOML	United States of America (the)
Lynn Shay	UMiami	United States of America (the)
Rick Lumpkin	NOAA/AOML	United States of America (the)
Elizabeth Sanabia	USNA	United States of America (the)
Andrey Sushko	Windborne Systems	United States of America (the)
Clive McMahon	SIMS	Australia
Chrostopher Reason	UCapeTown	South Africa
Joe Cione	NOAA/AOML	United States of America (the)
Topic 2: Tropical cyclone intensity change		
Liguang Wu	Fudan University	China
Eric Blake	NHC	United States of America (the)
2.1 Internal influences		
Christopher Rozoff (Rapporteur)	NCAR	United States of America (the)
Xiaomin Chen (Rapporteur)	HRD	United States of America (the)
Michael Bell	CSU	United States of America (the)
Kristen Corbosiero	University at Albany / State University of New York	United States of America (the)
Jian-Feng Gu	Reading University	United Kingdom of Great Britain and Northern Ireland (the)
Eric Hendricks	NCAR	United States of America (the)
Falko Judt	NCAR	United States of America (the)
John Kaplan	AOML/HRD	United States of America (the)
John Knaff	NESDIS	United States of America (the)

Kate Musgrave	CIRA/CSU	United States of America (the)
Robert Rogers	HRD	United States of America (the)
Daniel Stern	NRL	United States of America (the)
DanDan Tao	University of Bergen	Norway
Yuqing Wang	UHawaii	United States of America (the)
2.2 External influences		
Qingqing Li (Rapporteur)	NUIST	China
Joshua Wadler (Rapporteur)	Embry-Riddle Aeronautical University	United States of America (the)
Johna Rudzin	Mississippi State University	United States of America (the)
Benjamin Jaimes	UMiami	United States of America (the)
Michael Fischer	HRD	United States of America (the)
Guanghua Chen	Institute of Atmospheric Physics of the Chinese Academy of Sciences	China
Brian Tang	University at Albany, State University of New York	United States of America (the)
Nannan Qin	Fudan University	China
Jie Chen	GFDL	United States of America (the)
2.3 Operational perspectives		
Zhan Zhang (Rapporteur)	NOAA/NCEP/EMC	United States of America (the)
Weiguo Wang (Rapporteur)	EMC	United States of America (the)
James Doyle	NRL	United States of America (the)
John Cangialosi	NHC	United States of America (the)
Jon Moskaitis	NRL	United States of America (the)
Julian Heming	UK Met Office	United Kingdom of Great Britain and Northern Ireland (the)
Levi Cowan	JTWC	United States of America (the)
Michael Brennan	NHC	United States of America (the)
William Komaromi	NRL	United States of America (the)

Suhong Ma	CMA	China
Ananda Kumar	IMD	India
Peter Clegg	BoM	Australia
Takuya Hosomi	JMA	Japan
John Knaff	NESDIS	United States of America (the)
John Kaplan	AOML/HRD	United States of America (the)
Monica Sharma	IMD	India
Thomas Birchard	CPHC	United States of America (the)
Masaaki Ikegami	JMA	Japan
Mrutyunjay Mohapatra	IMD	India
Topic 3: Tropical cyclone structure change and mid-latitude interactions		
Leads	**Organization**	**Location**
Elizabeth Ritchie	Monash University	Australia
Matthew Kucas	JTWC	United States of America (the)
3.1 Structure change processes: Inner core		
Yoshiaki Miyamoto (Rapporteur)	Keio University	Japan
Chun-Chieh Wu (Rapporteur)	Typhoon Dynamics Research Center	Pacific Science Association
Kosuke Ito (Rapporteur)	University of Ryukyus	Japan
Margie Kieper		United States of America (the)
Tsz-Kin Lai	Imperial College of London	United Kingdom of Great Britain and Northern Ireland (the)
Nannan Qin	Fudan Univ.	China
Derrick Herndon	CIMSS (UWisconsin)	United States of America (the)
Lauren Pattie	BoM	Australia
Dandan Tao	University of Bergen	Norway
Jun Zhang	HRD	United States of America (the)
James Hlywiak	NRL	United States of America (the)
Yi-Hsuan Huang	Pacific Science Association	Pacific Science Association
Udai Shimada	JMA-MRI	Japan

Yohei Yamada	JAMSTEC	Japan
Sachie Kanada	Nagoya University	Japan
Anthony Didlake	PSU	United States of America (the)
3.2 Structure change processes: Outer circulation		
Chris Noble (Rapporteur)	MetService NZ	New Zealand
Ben Schenkel (Rapporteur)	UOklahoma	United States of America (the)
Kate Musgrave	CIRA	United States of America (the)
Kelvin Chan	Sun Yat-sen University	China
Daniel Chavas	Purdue University	United States of America (the)
Stephen Barlow	JTWC	United States of America (the)
Amit Singh	FMS	Fiji
3.3. Phase transitions		
Wataru Yanase (Rapporteur)	JMA	Japan
Kimberly Wood (Rapprteur)	Mississippi State University	United States of America (the)
Jack Beven	NHC	United States of America (the)
Suzana Camargo	IRI, Columbia University	United States of America (the)
Chris Fogarty	CHC	Canada
Junya Fukuda	JMA	Japan
Naoko Kitabatake	Meteorological College	Japan
Ron McTaggart-Cowan	Environment and Climate Change Canada	Canada
Michelle Simões Reboita	Federal University of Itajubá	Brazil
Jacopo Riboldi	Uppsala University	Sweden
Joe Courtney	BoM	Australia
Matthew Kucas	JTWC	United States of America (the)

Topic 4. Tropical cyclone track and genesis (incorporating outcomes of tropical cyclone-probabilistic forecast products (TC-PFP) stage 1)		
Leads	**Organization**	**Location**
Hui Yu	STI	China
Andrew Burton	BoM	Australia
4.1 Genesis: controlling factors and physical mechanisms		
VPM Rajasree (Rapporteur)	IMD	India
Gerard Kilroy	Uni. Munich	Germany
Kelly M. Núñez Ocasio	NCAR	United States of America (the)
George R. Alvey III	NOAA	United States of America (the)
Xi Cao	Chinese Academy of Sciences	China
Minhee Chang	Korea Institute of Science and Technology	Republic of Korea (the)
Hsu-Feng Teng	NCAR	United States of America (the)
C Chelsea Nam	CSU	United States of America (the)
Hironori Fudeyasu	Yokohama National University	Japan
Hamish Ramsay	CSIRO	Australia
4.2 Genesis: forecast processes		
KK Hon (Rappoteur)	Hong Kong Observatory	Hong Kong, China
Xinyan Lu	CMA	China
Akira Shimokobe	JMA (RSMC Tokyo)	Japan
Seonghee Won	KMA	Republic of Korea (the)
Robb Gile	PAGASA	Philippines (the)
Hoang Lam	VNMHA	Viet Nam
Ralf Toumi	Imperial College, London	United Kingdom of Great Britain and Northern Ireland (the)
Mrutyunjay Mohapatra	IMD	India
Monica Sharma	IMD (RSMC New Delhi)	India
Robert Ballard	NOAA (RSMC Honolulu)	United States of America (the)
Eric Blake	NHC	United States of America (the)

Charles (Chip) Helms	NASA	United States of America (the)
Daniel Halperin	Embry-Riddle Aeronautical University	United States of America (the)
Steph Bond	BoM	Australia
4.3 Unusual tracks: statistics and controlling factors		
Ying Li (Rapporteur)	Chinese Academy of Meteorological Sciences (CAMS, China)	China
Ryan D. Torn	State University of New York	United States of America (the)
Julian Heming	UK Met Office	United Kingdom of Great Britain and Northern Ireland (the)
Yinglong Xu	CMA	China
4.4 Track forecast: operational capability and new techniques		
Adam Conroy (Rapporteur)	BoM	Australia
Abhijit Sarkar	NCMRWF	India
Paromita Chakraborty	NCMRWF	India
Alan Brammer	CSU	United States of America (the)
Matthew Ford	MetService NZ	New Zealand
Guomin Chen	STI	China
Levi Cowan	JTWC	United States of America (the)
Helen Titley	UK Met Office	United Kingdom of Great Britain and Northern Ireland (the)
Rabi Rivett	BoM	Australia
Topic 5: Forecasting tropical cyclone hazards and impacts		
Leads	**Organization**	**Country**
Robbie Berg	NOAA	United States of America (the)
Monica Sharma	IMD	India
5.1 Rainfall		
Sunitha Devi (Rapporteur)	IMD	India
Alex Lamers (Rapporteur)	NOAA/WPC	United States of America (the)

Jose Manuel Galvez	NOAA/WPC	United States of America (the)
Zifeng Yu	STI	China
Tarik Kriat	RSMC La Reunion	France
Sareti Cardos	CONAGUA SMN	Mexico
David Grant	BoM	Australia
Lorenzo Moron	PAGASA	Philippines (the)
5.2 Wind		
Andrea Schumacher (Rapporteur)	NOAA/CIRA	United States of America (the)
Craig Earl-Spurr (Rapporteur)	BoM	Australia
Craig Arthur	Geoscience Australia	Australia
Jeff Kepert	BoM	Australia
Iosefo Cauravouvinaka	FMS	Fiji
Mark DeMaria	CIRA/CSU	United States of America (the)
T. Arulalan	IMD	India
Monica Sharma	IMD	India
Seonghee Won	KMA	Republic of Korea (the)
Philippe Caroff	RSMC La Reunion	France
5.3 Coastal inundation/storm surge		
Cody Fritz (Rapporteur)	NOAA/NHC	United States of America (the)
Nadao Kohno (Rapporteur)	JMA	Japan
PLN Murty	IMD	India
Diana Greenslade	BoM	Australia
Devon Telford	ECC	Canada
Cristina Uson	PAGASA	Philippines (the)
Sakeasi Rabitu	FMS	Fiji
5.4 Tornadoes		
Dereka Carroll-Smith (Rapporteur)	NIST-PREP	United States of America (the)

Ben Green (Rapporteur)	NOAA/GSL/EPAD	United States of America (the)
Roger Edwards	NOAA/SPC	United States of America (the)
Eugene (Bill) McCaul	U Alabama-Huntsville	United States of America (the)
Lanqiang Bai	Sun Yat-Sen University	China
A.J. Litta	Weathernews	Japan
Lauren Pattie	BoM	Australia
Xianxiang Huang	Foshan Tornado Research Center	China
Scott Overpeck	NOAA	United States of America (the)
Topic 6. Tropical cyclone variability beyond the synoptic scale		
Topic Leads	**Organization**	**Country**
Marie-Dominique Leroux	Météo-France	France
Phil Klotzbach	CSU	United States of America (the)
6.1 Sub-seasonal tropical cyclone prediction		
Carl Schreck (Rapporteur)	NC State/NOAA	United States of America (the)
Frederic Vitart (Rapporteur)	ECMWF	United Kingdom of Great Britain and Northern Ireland (the)
Chia-Ying Lee	Columbia University	United States of America (the)
Russell Elsberry	NPS	United States of America (the)
Suzana Camargo	Columbia University	United States of America (the)
Paul Gregory	BoM	Australia
Yuhei Takaya	JMA	Japan
Zhuo Wang	U Illinois	United States of America (the)
Michael Ventrice	DRW Holdings	United States of America (the)
Justyn Jackson	US Air Force	United States of America (the)
Phil Klotzbach	CSU	United States of America (the)
Jon Gottschalk	NOAA	United States of America (the)
Joanne Camp	BoM	United Kingdom of Great Britain and Northern Ireland (the)
Masuo Nakano	JAMSTEC	Japan

Matthew Janiga	NRL	United States of America (the)
James Darlow	JTWC	United States of America (the)
Kasuo Takamura	JMA	United States of America (the)
Kurt Hansen	NRL	United States of America (the)
Lindsey Long	NOAA	United States of America (the)
Matthew Kucas	JTWC	United States of America (the)
6.2 Seasonal tropical cyclone forecasting		
Louis Philippe Caron (Rapporteur)	Barcelona Supercomputing Center/Ouranos	Canada
Yuhei Takaya (Rapporteur)	JMA	Japan
Eric Blake	NHC	United States of America (the)
Jo Camp	BoM	United Kingdom of Great Britain and Northern Ireland (the)
Johnny Chan	City University of Hong Kong	Hong Kong, China
Namyoung Kang	Kyungpook National University	Republic of Korea (the)
Seonghee Won	National Typhoon Center/KMA	Republic of Korea (the)
Yuriy Kuleshov	BoM	Australia
Hiro Murakami	GFDL/NOAA	United States of America (the)
Frederic Vitart	ECMWF	United Kingdom of Great Britain and Northern Ireland (the)
Ruifen Zhan	Fudan University	China
Adam Lea	University College-London	United Kingdom of Great Britain and Northern Ireland (the)
Julia Lockwood	UK Met Office	United Kingdom of Great Britain and Northern Ireland (the)
Yohan Ruprich-Robert	Barcelona Supercomputing Centre	Spain
Francois Bonnardot	Météo-France	France
Jhordanne Jones	Purdue University	United States of America (The)
Tom Philp	Maximum Information	United Kingdom of Great Britain and Northern Ireland (the)

Nicolas Bruneau	Reask	United Kingdom of Great Britain and Northern Ireland (the)
Paul Gregory	BoM	Australia
Akio Nishimura	RSMC Tokyo, JMA	Japan
Ralf Toumi	Imperial College	United Kingdom of Great Britain and Northern Ireland (the)
Dushmanta R Pattanaik	IMD	India
6.3 Tropical cyclones and climate change		
Suzana Camargo (Rapporteur)	LDEO/Columbia University	United States of America (the)
Hiro Murakami (Rapporteur)	GFDL/NOAA	United States of America (The)
Nadia Bloemendaal	Vrijie University Amsterdam	Netherlands (Kingdom of the)
Savin Chand	Federation University	Australia
Medha S. Deshpande	Indian Institute of Tropical Meteorology	India
Christian Dominguez Sarmiento	National Autonomous University of Mexico	Mexico
Juan Jesús Gonzálex-Alemán	Spanish National Weather Service (AEMet)	Spain
Thomas R. Knutson	GFDL/NOAA	United States of America (the)
I-I Lin	Pacific Science Association	Pacific Science Association
IL-Ju Moon	Jeju National University	Republic of Korea (the)
Christina M. Patricola	Iowa State University	United States of America (the)
Kevin Reed	Stony Brook University	United States of America (the)
Malcolm Roberts	UK Met Office	United Kingdom of Great Britain and Northern Ireland (the)
Enrico Scoccimarro	Euro-Mediterranean Center on Climate Change	Italy
Chi Yung (Francis) Tam	The Chinese University of Hong Kong	Hong Kong, China
Elizabeth Wallace	Rice University	United States of America (the)
Liguang Wu	Fudan University	China
Yohei Yamada	Japan Agency for Marine-Earth Science and Technology	Japan

Wei Zhang	Utah State University	United States of America (the)
Haikun Zhao	Nanjing University of Information Science and Technology	China

APPENDIX 3. LIST OF IN-PERSON ATTENDEES

Name	Country
Andrew Burton	Australia
Joe Courtney	Australia
Paul Gregory	Australia
Craig Earl-Spurr	Australia
Greg Holland	Australia
Gary Foley	Australia
Clive McMahon	Australia
John McBride	Australia
Rabi Rivett	Australia
Elizabeth Ritchie-Tyo	Australia
Gregory Thompson	Bahamas (the)
Md Shaheenul Islam	Bangladesh
Andrew Daniel	Barbados
Andrea Sealy	British Caribbean Territories
Angela Guy	Belize
Michelle Reboita	Brazil
Lonh Nrak	Cambodia
Devon Telford	Canada
Yihong Duan	China
Yu Hui	China
Jie Tang	China
Liguang Wu	China
Wanzhi Xu	China
Zhe Xu	China
Chunyi Xiang	China
Zhou Xingyang	China
Xiaoyong Zhuge	China

Nathalí Figueredo	Cuba
Jose Rubiera Maria	Cuba
Marshandy Luciano	Curacao
Albert Martis	Curacao
Wagner Rivera	Dominican Republic (the)
Lorena Rosaura Soriano de Cruz	El Salvador
Stephen Meke	Fiji
Arthur Avenas	France
Sebastien Langlade	France
Marie-Dominique Leroux	France
Alexis Mouche	France
Quoc-Phi Duong	France
Roger Smith	Germany
Kai-Kwong Hon	Hong Kong, China
Yuk-sing Lui	Hong Kong, China
Francis Tam	Hong Kong, China
Ajit Tyagi	India
Ananda Kumar Das	India
Med ha S. Deshpande	India
Chinmay R Khadke	India
Monica Sharma	India
Fachri Radjab	Indonesia
Bagus Rachmat Rievan	Indonesia
Idhan Abubakar	Indonesia
Kharisma Aprilia	Indonesia
I Gusti Ayu Putu Putri Astiduari	Indonesia
Dr Endarwin	Indonesia
Anni Arumsari Fitriany	Indonesia
Rahma Hayati	Indonesia

Margaretha Harianja	Indonesia
Yosafat Donni Haryanto	Indonesia
Kiki Kiki	Indonesia
Gede Dedi Krisnawan	Indonesia
Yuli Kartiningsih	Indonesia
I Kadek Nova Arta Kusuma	Indonesia
I Gede Agus Mahendra	Indonesia
Nurhidayat	Indonesia
Hasalika Nurjannah	Indonesia
Putu Agus Dedy Permana	Indonesia
Ida Pramuwardhani	Indonesia
Agie Wandala Putra	Indonesia
Yessie Widya Synthiarani Putri	Indonesia
Robbi Aziis Ramadhan	Indonesia
Purwanti Lelly Sabrina	Indonesia
Miming Saefudin	Indonesia
Ana Oktavia Setiowati	Indonesia
Fatimah Mega Sugihartati	Indonesia
Kadek Setiya Wati	Indonesia
Agus Yarcana	Indonesia
Rezky Yunita	Indonesia
Imbuh Yuwono	Indonesia
Enrico Scoccimarro	Italy
Laurence Brown	Jamaica
Junya Fukuda	Japan
Takeshi Horinouchi	Japan
Takuya Hosomi	Japan
Kosuke Ito	Japan
Nadao Kohno	Japan

Masuo Nakano	Japan
Akio Nishimura	Japan
Ryo Oyama	Japan
Yuhei Takaya	Japan
Wataru Yanase	Japan
Min Ju Choi	Republic of Korea (the)
Eu Soo Hoi	Republic of Korea (the)
Dong Jin Kim	Republic of Korea (the)
Seong Su Kim	Republic of Korea (the)
Kyungho Lee	Republic of Korea (the)
Bounteum Sysouphanthavong	Lao People's Democratic Republic (the)
Zo Andrianina Patrick Herintiana Rakotomavo	Madagascar
Fadila Jasmin Fakaruddin	Malaysia
Ram Dhurmea	Mauritius
Alejandra Girón	Mexico
Rafael Trejo Vázquez	Mexico
Guelso Mauro Manjate	Mozambique
Han Swe	Myanmar
Chris Noble	New Zealand
Ibrahim Al Abdulsalam	Oman
Mahmood Al-Khayari	Oman
Yuei-An Liou	Pacific Science Association
Sarfaraz	Pakistan
Robb Gile	Philippines (the)
Tarek Nourrice	Seychelles
Kgolofelo Mahlangu	South Africa
Juan Jesús Gonzalez Aleman	Spain
P.M. Jayakody	Sri Lanka
Omary Ramadhani	United Republic of Tanzania (the)

Somprat Srithagon	Thailand
Ozorio Obet Rud Anunu	Timor-Leste
Laitia Fifita	Tonga
Paula Wellington	Trinidad and Tobago
Xiangbo Feng	United Kingdom of Great Britain and Northern Ireland (the)
Julian Heming	United Kingdom of Great Britain and Northern Ireland (the)
Helen Titley	United Kingdom of Great Britain and Northern Ireland (the)
Eric Blake	United States of America (the)
Alan Brammer	United States of America (the)
Chris Brenchley	United States of America (the)
Suzana Camargo	United States of America (the)
Benjamin Jaimes de la Cruz	United States of America (the)
Michael Fiorino	United States of America (the)
Philip Klotzbach	United States of America (the)
Hiroyuki Murakami	United States of America (the)
Lucrezia Ricciardulli	United States of America (the)
Rob Rogers	United States of America (the)
Kim Wood	United States of America (the)
Jerry Timothy	Vanuatu
Hoang Phuc Lam	Viet Nam
Anne-Claire Fontan	WMO Secretariat
Cyrille Honore	WMO Secretariat
Taoyong Peng	WMO Secretariat
Munehiko Yamaguchi	WMO Secretariat

For more information, please contact:

World Meteorological Organization

Research Department

World Weather Research Programme

7 bis, avenue de la Paix – P.O. Box 2300 – CH 1211 Geneva 2 – Switzerland

Tel.: +41 (0) 22 730 81 11 – Fax: +41 (0) 22 730 81 81

Email: cpa@wmo.int

Website: http://www.wmo.int/pages/prog/arep/wwrp/new/wwrp_new_en.html

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