Third International Workshop on Satellite Analysis of Tropical Cyclones (IWSATC-3)

Online workshop

7–10 December 2021

Final report

Prepared by Joe Courtney and Derrick Herndon (Co-Chairs)

WEATHER CLIMATE WATER

World Meteorological Organization

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
Fax: +41 (0) 22 730 80 40
Email: publications@wmo.int

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Glossary

ADT	Advanced Dvorak Technique
AMSR2	Advanced Microwave Scanning Radiometer 2
ASCAT	Advanced Scatterometer
BOM	Australian Bureau of Meteorology
CSCAT	CFOSAT (Chinese-French Oceanography Satellite) Scatterometer or RFSCAT Rotating Fan Beam Scatterometer
CIMSS	Cooperative Institute for Meteorological Satellite Studies (USA)
CIRA	Cooperative Institute for Research in the Atmosphere (USA)
CMA	China Meteorological Administration
CPHC	Central Pacific Hurricane Centre
ERC	Eye Wall Replacement Cycle
FNMOC	Fleet Numerical Meteorology and Oceanography Center (USA)
FY	FengYun
GEMS	Geostationary Environment Monitoring Spectrometer
GeoIPS	Geo-located Information Processing System
HSCAT	Hai Yang scatterometer (referring to HY-2B and HY-2C)
IBTrACS	International Best Track Archive for Climate Stewardship
IFREMER	National Institute for Ocean Science (France)
IMD	Indian Meteorological Department
IWSATC	International Workshop on Satellite Analysis of Tropical Cyclones
IWTC	International Workshop on Tropical Cyclone
JMA	Japan Meteorological Agency
JTWC	Joint Typhoon Warning Center
KMA	Korea Meteorological Administration
KNMI	Royal Netherlands Meteorological Institute
MSG	Meteosat Second Generation
NHC	National Hurricane Center (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
NRCS	normalized radar cross section
NRL	Navy Research Laboratory (USA)
OSCAR	Observing Systems Capability Analysis and Review Tool
OSCAT	OceanSat Scatterometer
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
REMSS	Remote Sensing Systems
RMW	Radius of Maximum Wind
RSMC	Regional Specialized Meteorological Centers/Tropical Cyclone Warning Centers
SAR	Synthetic Aperture Radar
SATCON	Satellite Consensus (for TC Intensity)
SFMR	Stepped-Frequency Microwave Radiometer
SMAP	Soil Moisture Active Passive
SMOS	Soil Moisture and Ocean Salinity
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

All documents and presentations can be found on the workshop site at:
https://community.wmo.int/meetings/third-international-workshop-satellite-analysis-tropical-cyclones-iwsatc-3
Recordings available via WMO Vimeo at: https://vimeo.com/showcase/9113736

1. INTRODUCTION

Satellite data provide the majority of inputs for Tropical Cyclone (TC) analysis: position, intensity and structure, that underpins the entire value chain of the TC service. Hence a good analysis will provide a solid basis to ensure our communities are equipped with the best available information to make the appropriate decisions to safeguard life and property.

1.1 Background

1.1.1 This workshop is building upon the first two workshops in 2011 and 2016, both in Honolulu, and due acknowledgements to Chris Velden and Andrew Burton who were the key architects, and to WMO for their ongoing support.

The original impetus was to address a disconnect between the research and operations and also across the operational agencies. The focus of IWSATC-1 was to increase the accuracy and reliability of satellite analyses of TCs by sharing the latest knowledge and techniques developed by the TC research community with operational forecasters of the major warning centers, and at IWSATC-2 - to update operational analysis practices at the Regional Specialized Meteorological Centers/Tropical Cyclone Warning Centers (RSMCs/TCWCs) in the 5 years since IWSATC-I, and to explore greater use of emerging objective satellite-based aids.

A further impetus for this workshop was an outcome of the Ninth session on the International Workshop on Tropical Cyclone (IWTC-9, December 2018) which made this recommendation for WMO:
Encourage and support another IWSATC in the near future, expanding the role to better reach underdeveloped TC-prone countries to provide information on the satellite sensors, data availability, data accessibility, and platforms and to develop training for how to use the products/applications.

The growth of satellite information available operationally increases the requirement to enhance understanding the capability of sensors to deliver useful information and how to integrate the information for best practice analysis methods especially in challenging scenarios.

1.1.2 Recommendations from IWSATC-2

1. Noting the importance of satellite data for tropical cyclone disaster risk reduction, IWSATC-2 recommends that the WMO Space Program make every possible effort to ensure that the current observing system is maintained (e.g., microwave imagers/sounders) and new data streams are encouraged. For example, the developments in Microsats/CubeSats and the possible future commercialisation of some satellite data streams may impact future tropical cyclone monitoring capabilities.
2. Given the progress and achievements of the first two workshops, both the operational and research TC communities encourage the continued sponsorship by WMO for regular (2-4 years) IWSATC workshops (incorporating the International Best Track Archive for Climate Stewardship (IBTrACS)). This will facilitate the essential exchange of operational needs and research advances to meet them. It is further recommended that the next workshop include a “train-the-trainer” day to facilitate widespread adoption, optimal employment, and consistent application of new operational techniques.
3. Innovative satellite-based methods that are showing promise for TC analysis need to be integrated into the forecast process of each RSMC/TCWC for optimal employment. Therefore, the IWSATC-II recommends that WMO helps to identify resources for providing algorithm transition into operational center environments.

4. Noting the ongoing need for satellite validation datasets (reports during TC passage from local islands. buoys, ships, etc.), IWSATC-II recommends that WMO, through the Regional Associations, encourage RSMCs/TCWCs to share all available datasets with the TC research community.
5. Satellite observations of TCs are a primary contributor to global Best Tracks and reanalyses. Therefore, the IWSATC-II recommends that the satellite TC community continue to work closely with IBTrACS towards the goal of a global, unified Best Track record.
6. The IWSATC-II community re-emphasizes and strongly supports a recommendation from IWTC-VIII: “Recognizing the value and importance of the NRL Tropical Cyclone site [http://www.nrlmry.navy.mil/TC.html] for both real-time operational use and as a resource for researchers, the IWTC expresses concern that continuing development and availability of this resource may cease. Reflecting on the exceptional value that operational centers in particular place on this web site as a unique and effective means of providing global access to the full suite of microwave imagery, the IWTC community recommends that WMO send a letter of commendation to the development team at NRL-MRY in recognition of the significant contribution they make to global disaster risk reduction.” IWSATC-II also encourages WMO to request in this letter the continued support of this resource by NRL-MRY sponsors.
7. The IWSATC-II endorses the following recommendation from the IWTC-VIII. That satellite techniques be developed and calibrated for atypical TC structures, such as those

   that are problematic for the traditional Dvorak technique. Note: this encompasses the entire range of TC structures with specific focus on those atypical ones that have been problematic for forecasters in the past (e.g., subtropical and extra-tropically transitioning cyclones, monsoon gyres, as well as TCs making landfall).
8. The IWSATC-II recommends the development of a living document that provides details of the various satellite-based observations and techniques used in operational centers. The document should provide information about the observation or technique and any known strengths and weaknesses that would be useful to a forecaster in an operational setting. The document should be updated on an “as needed” basis by individuals identified as the responsible person for that particular observation or technique and should be made available on the WMO TCP web site and the Tropical Cyclone Forecaster Website hosted by Hong Kong Observatory.

1.1.3 Following the work of Chris Velden (Cooperative Institute for Meteorological Satellite Studies (CIMSS) and Andrew Burton (Australian Bureau of Meteorology (BOM)), WMO invited Derrick Herndon (CIMSS) and Joe Courtney (BOM) to chair this workshop with WMO's Secretariat co-ordinating support through Anne-Claire Fontan. COVID and travel restrictions necessitated the workshop to be conducted online.

1.2 Purpose and objectives

1.2.1 The purpose of IWSATC-3 was to increase the accuracy and reliability of satellite analysis of tropical cyclones through the sharing of the latest knowledge and technologies between the operational forecasters and the researchers in this area.

1.2.2 The specific objectives of IWSATC-3 were to:

1. Describe the latest operational procedures of TC satellite analysis from participating RSMCs/TCWCs;
2. Share recent and emerging developments in satellite sensors and associated analysis techniques for TC applications;
3. Enhance the understanding and application of TC satellite analysis techniques and recommend strategies for ongoing training and engagement as new technologies and applications emerge.

2. PROGRAM

A survey was sent to operational centres and to specific research and information providers to identify topics and associated presenters. This helped to guide the program content. There were 30 respondents, and the results are summarised in APPENDIX I. The online nature of the workshop and associated time constraints limited the range of topics. Therefore some requested topics could not be included.

The workshop was divided into four topics, each on one day.

- Day 1: Operational perspectives from TC warning centres.
- Day 2: Update on satellites and sensors - current status and emerging.
- Day 3: Update on objective Satellite TC analysis methods.
- Day 4: Best practice applications of satellite analysis techniques for operations using case studies.

Days 1 and 4 had an operational focus while days 2 and 3 had input from research and satellite information providers.

2.1 Accessibility and participation

2.1.1 Accessibility

Owing to travel restrictions, the workshop was held online via Zoom, hosted by WMO. All presentations were recorded and made available on the WMO sharepoint site and were later made permanently available on the WMO Vimeo page: https://vimeo.com/showcase/9113736

An analysis of time zones was conducted to ensure maximum reach for the majority of identified participants. Hence, the schedule was designed to reach as many participants as possible with a bias towards operations on days 1 and 4 and hence a start time of 02:00UTC, and an earlier start time at 00UTC on days 2 and 3 to have greater access to US-based presenters. It is acknowledged that this disadvantaged participants from Europe and Africa, but having recordings available was a way to include the global audience. The schedule was limited to 3.5 hours per day including a 10-minute break. In addition, the first three days included an optional extra session for informal open discussion for those willing to stay on which went for up to an hour.

2.1.2 Participants

Key researchers, information providers were invited to attend, while operational centres were invited to nominate participants. There was a total of 363 registrants from 50 countries, some of whom were only available on particular days. Approximate attendance numbers on each day varied from about 120 to 170.

2.1.3 Breakout rooms

To encourage participation each day included breakout room sessions, leaders were appointed to oversee discussions about key questions which varied according to the topic. On day 4, breakout sessions were designed around case studies. Key outcomes from each breakout room were shared with the wider group.

2.2 Day 1: Operational perspectives.

Invited operational centres presented for 10-15 minutes during the workshop, augmented by longer pre-recorded presentations that were made available on the WMO sharepoint ahead of the workshop for previewing. These recordings were later transferred to the Vimeo website. Presenters were provided with a template to address standard topics that included operational structure, satellites/sensors used, satellite-based techniques used, recent advances, issues and difficult case studies.
A summary of the operational recent advances and issues and challenges by each agency is presented in APPENDIX II.

Overall, when compared with previous IWSATC workshops, there was a noticeable degree of similarity across agencies in the use of satellite sensors and associated challenges. Subjective processes are still being used but there is now greater use of objective techniques. Difficult

cases highlighted the requirement for forecaster skilled intervention, which was also reflected in the requirement for ongoing training especially in integrating new sensors such as Synthetic Aperture Radar (SAR). Many agencies commented on the loss of sensors being a concern and demand for more. Other notable comments included the need to have reliable observations for validation studies and how best to share this information, and potentially build a database of cases that have “reliable ground truth”; and to assimilate data to high-resolution models being important for hazard prediction services - for example structure changes associated with Eyewall Replacement Cycles (ERCs).

The notes of Day 1 breakout rooms are available in APPENDIX III

Table 1. Day 1 schedule.

Time (UTC)	Description	Presenter
0200-0215	Introductions, overview & protocols	Co-chairs: Joe Courtney and Derrick Herndon
0215-0500	Operational Perspectives from TC warning centres (10-15mins) INCLUDES 10min break	• JMA (Yasushi Mochizuki) recording (17min) • KMA (Jun Park) recording (13min) • PAGASA (Philippines, Robb Gile) recording (30min) • CMA (Chunyi Xiang) recording (24min) • BoM (Craig Earl-Spurr) recording (22min) • Fiji (Stephen Meke) recording (8min) • NHC/CPHC (Jack Beven) recording (36min) • IMD (Chinmay Khadke) recording • MeteoFrance (Sebastien Langlade) recording (27min) • JTWC (Brittany Bermea); extended recording (Brian Howell, 31min)
0500-0525	Breakout rooms and discussion	Questions 1. From the range of presentations from operational centres, what approaches, methods or initiatives struck you as being potentially useful, either for your agency or more broadly? 2. How can research and satellite information providers better support operational forecasters?
0525-0530	Close	Derrick Herndon and Joe Courtney

2.3 Day 2: Update on satellites and sensors - status and emerging.

As noted previously a number of new satellite missions have launched or will soon launch since IWSATC-2. The schedule for the second day of the workshop focused on these new missions/sensors and the capability to monitor TC position, intensity and structure. Because of the prolific number of Cubesat/smallsat missions some time was dedicated to this emerging data source.

Scatterometers continue to provide an excellent data source especially for TC structure information including radius of critical wind radii. Attendees pointed to the desire to maintain the rich constellation of scatterometers. Presentations summarized the current state of the constellation including ASCAT, OSCAT-2/3, HSCAT-B/C/D, CSCAT (CFOSAT) and WindRad on FY-3E. Further information on satellite sensors available via the WMO website: https://space.oscar.wmo.int/spacecapabilities

One challenge in the extreme wind environment of the TC inner core is validation. While buoys provide a direct measurement of these winds these observations are rare. Comparisons to aircraft data including dropsondes and SFMR (Stepped-Frequency Microwave Radiometer) provide additional ground truth. Increasingly well-calibrated Synthetic Aperture Radar (SAR)

data which also provides a 2D wind field has been compared to scatterometer wind retrievals with the goal to extend the maximum sustained wind limits that can be derived. One area of concern is access to all available data with low latency.

SAR data became a focus of the workshop as this data has become more accessible thanks to efforts from NESDIS and IFREMER. Previous use of SAR focused on TC position location however recent efforts to use the NRCS (normalized radar cross section) data to extract the 2D wind field in the TC, including maximum winds, Radius of Maximum Wind (RMW) and wind radii show significant skill. One question addressed is what averaging period the SAR data represents. Presenters acknowledge this is ongoing research to best determine the spatial averaging distance that best represents wind averaging times used by operational centers (1-minute, 10-minute, etc.). The ability of SAR to represent the concentric eyewall structures of TCs, which has a significant impact on the TC intensity forecast, was also noted. A problem with SAR data is that TC overpasses must be planned in advance and is currently on a request basis. It is suggested that WMO continues to support endeavours to prioritize acquisition of this critical data.

SMAP/AMSR2 wind retrievals are a somewhat newer tool for TC analysis. The latest efforts to validate this data and understand under-sampling characteristics was shown. Access to this data has improved with REMSS providing both imagery and intensity estimate fixes for maximum winds and critical wind radii. Operational centers are increasingly using this data source in analysis.

One recommendation that emerged is a desire for greater summary information from a central website on the status of current and planned satellite missions and sensor information. The OSCAR WMO website is a repository of such information and is encouraged to provide updated information on sensor health and future missions such as a quick view of what is available and which sensors have failed or are degrading. It was noted that access to FY-3 and FY-4 data is limited compared to say Himawari, Meteosat Second Generation (MSG) and GOES-16/17 data. Geostationary microwave sounder missions planned for the future could be potentially powerful in all-weather monitoring of TCs.

Recent Cubesat launches including GEMS and TROPICS show the ability of smaller and cheaper satellite platforms to provide quality TC analysis data. Presentations included a summary of the current TROPICS Pathfinder Cubesat mission that is in evaluation mode presently. TROPICS provides microwave moisture and temperature sounder data that can be used for TC all-weather position and intensity estimates. Attendees note that additional training on Cubesat capabilities is desirable. In addition, this training should be provided prior to satellite launch so that the data can be used as close to post-launch as possible. This is especially important given the potentially shorter lifespan of these satellites.

The notes of Day 2 breakout rooms are available in APPENDIX IV

Table 2. Day 2 schedule.

Time (UTC)	Description	Presenter
0000-0015	Introductions, overview & protocols	Co-chairs: Joe Courtney and Derrick Herndon
0010-0025	ASCAT and extreme wind measurements in TCs	Ad Stoffelen (KNMI)
0025-0045	Use of SAR for TC analysis	Alexis Amouche (IFREMER) and Chris Jackson (NOAA)
0045-0105	SMAP and AMSR2 for measuring TC intensity and structure	Thomas Meissner and Lucrezia Ricciardulli (REMSS)
0105-0125	Near future satellite missions	Jeff Hawkins (NRL-retired)

	relevant to TC analysis	
0125-0145	An update on the TROPICS CubeSat mission	Derrick Herndon (CIMSS)
0145-0155	Break	
0155-0225	Session Q/A	Panel
0225-0300	Breakout rooms	Breakout room leaders
0300-0330	Plenary discussion and close	Derrick Herndon and Joe Courtney

2.4 Day 3: Update on objective Satellite TC analysis methods.

The third day talks focused on updates to satellite algorithms and TC display systems provided by research organizations and operational centers. Many of the algorithms to estimate TC intensity and structure have undergone updates since IWSATC-2 and the results of these changes were presented. This includes changes to the product suites and web page displays from CIRA and CIMSS. An increasing focus on satellite-based analysis is on estimating the 2D wind field in addition to intensity and wind radii. A number of Artificial Intelligence (AI)-based techniques that use microwave, geostationary or both are emerging. The Deep MicroNet (DMN) technique that uses 89 GHz imagery at CIMSS is nearly operational. An AI version of the ADT has also been added to the CIMSS product suite. More training is needed on Artificial Intelligence/Deep Learning (AI/DL) methods so that operational forecasters can gain trust in using the estimates.

New display systems and upgrades to existing systems were shown by KMA and JMA. Additional tools that leverage the latest geostationary and polar orbiter satellite data have been added to these displays. These include both objective algorithms to estimate storm position/intensity and improved displays for subjective assessment of storm structure. An open-source display and analysis system called GeoIPS is being developed by the NRL team as a tool to augment and possibly replace the NRL TC web page. The python-based system could be locally installed and produce satellite imagery displays and analysis information in the future.

The notes of Day 3 breakout rooms are available in APPENDIX V

Table 3. Day 3 schedule.

Time (UTC)	**Description**	**Presenter**
0000-0015	Welcome, review and introduction.	Co-chairs: Joe Courtney and Derrick Herndon
0015-0035	Some Objective Satellite Algorithms for Estimating TC Wind Structure and Intensity	John Knaff (CIRA/NESDIS)
0035-0055	Deep Learning approaches to TC intensity and structure	Tony Wimmers (CIMSS)
0055-0115	An update on CIMSS TC products and the GeoIPS analysis and display system	Derrick Herndon (CIMSS)
0115-0135	KMA TC analysis system GK2A	Jun Park (KMA)
0135-0155	Objective TC Analysis at JMA	Ryo Oyama (JMA)
0155-0210	Break	

0210-0230	Session Q/A	Panel
0230-0300	Breakout rooms	Breakout room leaders
0300-0330	Plenary discussion and close	Derrick Herndon and Joe Courtney

2.5 Day 4: Best practice applications of satellite analysis techniques for operations using case studies.

This was designed to offer a more hands-on interactive opportunity to explore the application of satellite information and techniques across three different and difficult cases: Typhoon Chanthu in the Northwest Pacific, Tropical Cyclone Habana in the southwest Indian Ocean and Hurricane Teddy in the north Atlantic. Participants were grouped into breakout rooms to work through the analysis and then discuss in the wider group the key issues and features. Inputs included subjective Dvorak estimates, scatterometry, microwave, Advanced Dvorak Technique (ADT) and SATCON, radiometers from Soil Moisture and Ocean Salinity (SMOS), Soil Moisture Active Passive (SMAP) and Advanced Microwave Scanning Radiometer (AMSR2) and SAR - noting not all were available for each analysis.

Typhoon Chanthu case was in two parts, the first at 12UTC 7 September was presented as a demonstration in the early stages but undergoing rapid intensification. The most likely intensity was 75 kn (10 min) which was consistent with the subjective Dvorak and higher than objective techniques. The second case, the following day at 12UTC 8 September, highlighted SAR having a much higher wind estimate than other inputs which was considered more accurate given the very small nature of the system (Radius of Maximum Wind - RMW=3km). At these RMW, other methods will underestimate the intensity. All the breakout rooms made similar conclusion.

TC Habana case on 12UTC 10 March 2021 was a strong system with a well-defined eye undergoing an Eye Wall Replacement Cycle (ERC) that attracted much discussion. The ADT was quite high (CI=7.0) but breakout rooms all had a lower intensity albeit varying from 110 to 125 kn (10 min) reflecting differences in how to factor in weakening during ERC. A second case, 12 hours later at 00UTC 11 March was discussed in the broader group further exploring the use of SAR.

Hurricane Teddy was undergoing transition towards extra-tropical structure. The two cases - 00 and 12UTC on 22 September - also attracted much discussion, although many participants were not familiar for this type of scenario. For the second case, the SMAP was noticeably higher than SAR and above expectations for the scenario. There was greater uncertainty with this scenario, some trusting SAR, while others most concluded a mid-point estimate was a safe way. All noted re-intensification was occurring through baroclinic processes. There was agreement that Dvorak estimates (subjective and ADT) were erroneously too low.

Table 4. Day 4 schedule.

Time (UTC)	Description	Presenter
0200-0215	Introductions, overview & protocols	Co-chairs: Joe Courtney and Derrick Herndon
0210-0305	Case Study: Typhoon Chanthu Includes breakout session	Joe Courtney (BoM)
0305-0400	Case Study: TC Habana Includes breakout session	Sebastien Langlade (RSMC La Réunion, Météo-France)
0400-0410	Break	

0410-0505	Case Study: Hurricane Teddy Includes breakout session	Derrick Herndon (CIMSS)
0505-0530	Plenary for summary, evaluation, review, recommendations	Derrick Herndon, Joe Courtney
0525-0530	Workshop close	Derrick Herndon, Joe Courtney and Anne-Claire Fontan

3. OUTCOMES

The IWTC-3 report and recommendations will be submitted to the WMO Advisory Group on Tropical Cyclones for further actions.

3.1 Recommendations

IWSATC-3 supports the following to:

1. Further develop SAR acquisitions, processing and operational availability through the Copernicus program; and also through RADAR-STAR and STAR.
2. Further efforts for calibration and validation studies using high quality 'ground truth'.
3. Further develop GeoIPS and a hosting site (CIMSS?) and for new satellite data to be incorporated into GeoIPS, such as CMA FY/HY satellite data output. Ways to add CMA data to be explored.
4. Develop more training opportunities including all new sensor data and techniques to be accompanied by an accessible training resource.
5. Advance Smallsat/Cubesat data to become available and useful for operations.
6. Conduct future IWSATCs, possibly more frequent but shorter online updates.
7. WMO continues to maintain and enhance the OSCAR website that includes a summary of current satellite platforms and planned near future launches and updated to include sensor health information.

3.2 Workshop Evaluation

A survey was made available to participants at the end of the workshop. A total of 99 responded. The results are included in APPENDIX VI. Feedback was overwhelmingly positive including the use of online Zoom platform and range of content. The vast majority (>95%) had their expectations met or exceeded on each of the four days.
There was a large range of answers to what people liked most. Many noted the practical exercises, opportunities to contribute to the breakout sessions and the updates on sensors and techniques. Having the mix of research and operational participants was appreciated.

For suggested improvements, many expressed the preference for face-to-face meetings in the future but there was general acknowledgement of the benefits of having at least an online component to reach a wider audience. Many indicated a request for more frequent gatherings, possibly of shorter length. Those having English as a second language were sometimes challenged as were those not familiar with the sensors and techniques and requested more training opportunities. Some noted the disadvantages posed by the times chosen. It was requested to have greater participation in breakout rooms as often only a few people contributed, which in part is related to language barriers.

3.3 Future activities

3.3.1 The Tenth International Workshop on Tropical Cyclones (IWTC-10)

The tenth International Workshop on Tropical Cyclones (IWTC-10) will be held in December 2022. The topic on remote sensing led by Derrick Herndon (CIMSS) and Sebastien Langlade (Meteo-France, RSMC La Reunion) will have a significant satellite component and will build upon the work of IWSATC.

3.3.2 Future workshops

The success of IWSATC-3 indicates the demand for continuing the workshop in the future. While these workshops are nominally held every four years, there was also interest in more frequent but shorter online updates especially as new sensors and techniques become available. The use of existing technologies such as the virtual laboratory (VLAB) could enable this with links made available from the WMO forecaster website. Feedback indicated the need for more basic training activities which could be included as part of future workshops.

4. TRAINING RESOURCES AND FURTHER INFORMATION

4.1 Training resources

TC Forecaster website: links to WMO training workshops:
http://severeweather.wmo.int/TCFW/

VLAB: Monthly 1h seminars on various topics:
http://www.virtuallab.bom.gov.au/archive/regional-focus-group-recordings/

BoM Learn: online modules on topics (free but have to register to site)

- Microwave for TC analysis: https://learn.bom.gov.au/course/view.php?id=727

  Passkey: microwave

- Scat/radiometers for TC analysis: https://learn.bom.gov.au/course/view.php?id=701

  Passkey: scatterometer

AMS Hurricane conference: https://www.ametsoc.org/index.cfm/ams/meetings-events/ams-meetings/34th-conference-on-hurricanes-and-tropical-meteorology/
EUMETSAT Oscar information on satellites
https://space.oscar.wmo.int/spaceagencies/view/eumetsat

COMET:

Remote Sensing of Ocean Wind Speed and Direction: An Introduction to Scatterometry

Using Scatterometer Wind and Altimeter Wave Estimates in Marine Forecasting

European scat measurements, processing, and product considerations via KNMI: Ocean and Sea Ice SAF Wind Processing Centre in the form of technical reports, papers and user manuals.

CIRA:
https://rammb.cira.colostate.edu/training/visit/links_and_tutorials/tropical/resources.html

4.2 Useful operational links

CIMSS: http://tropic.ssec.wisc.edu/

CIRA: http://rammb-data.cira.colostate.edu/tc_realtime/

NRL: https://www.nrlmry.navy.mil/TC.html

FNMOC: https://www.fnmoc.navy.mil/tcweb/cgi-bin/tc_home.cgi

KNMI: https://scatterometer.knmi.nl/tile_prod/

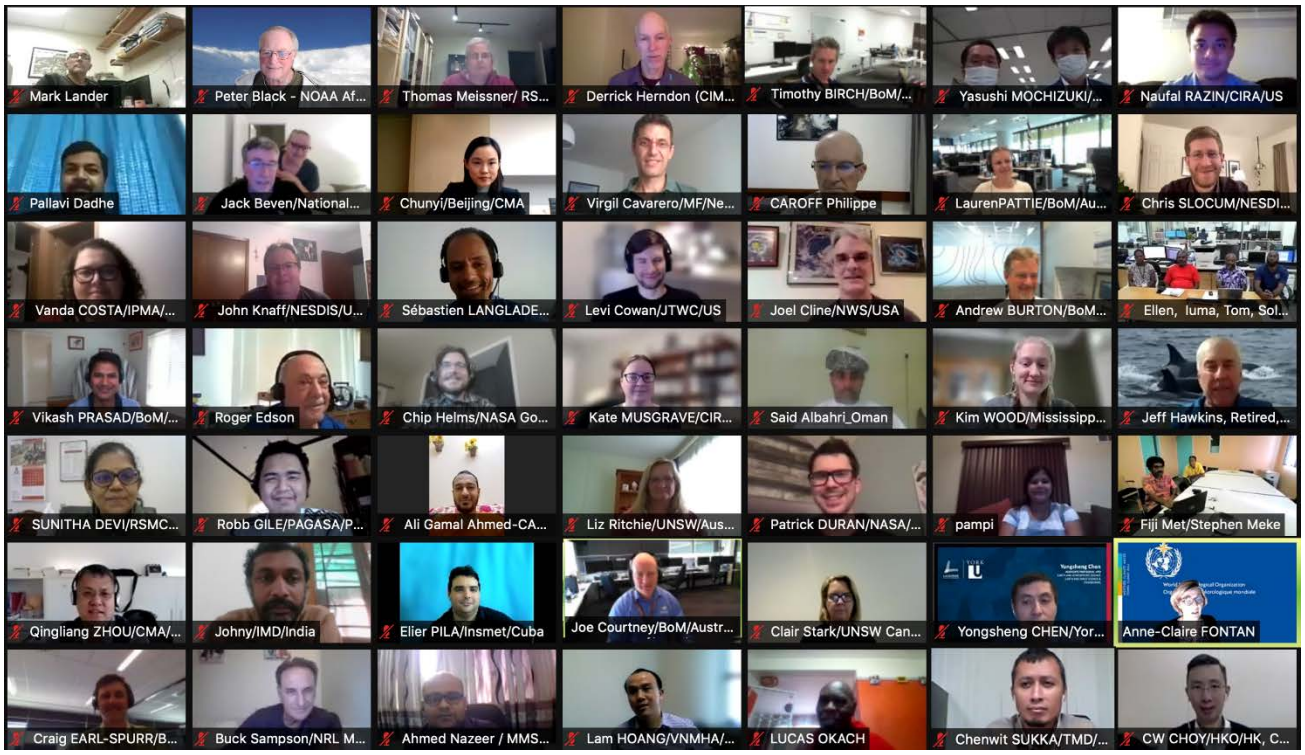
REMSS: http://www.remss.com/storm-watch/

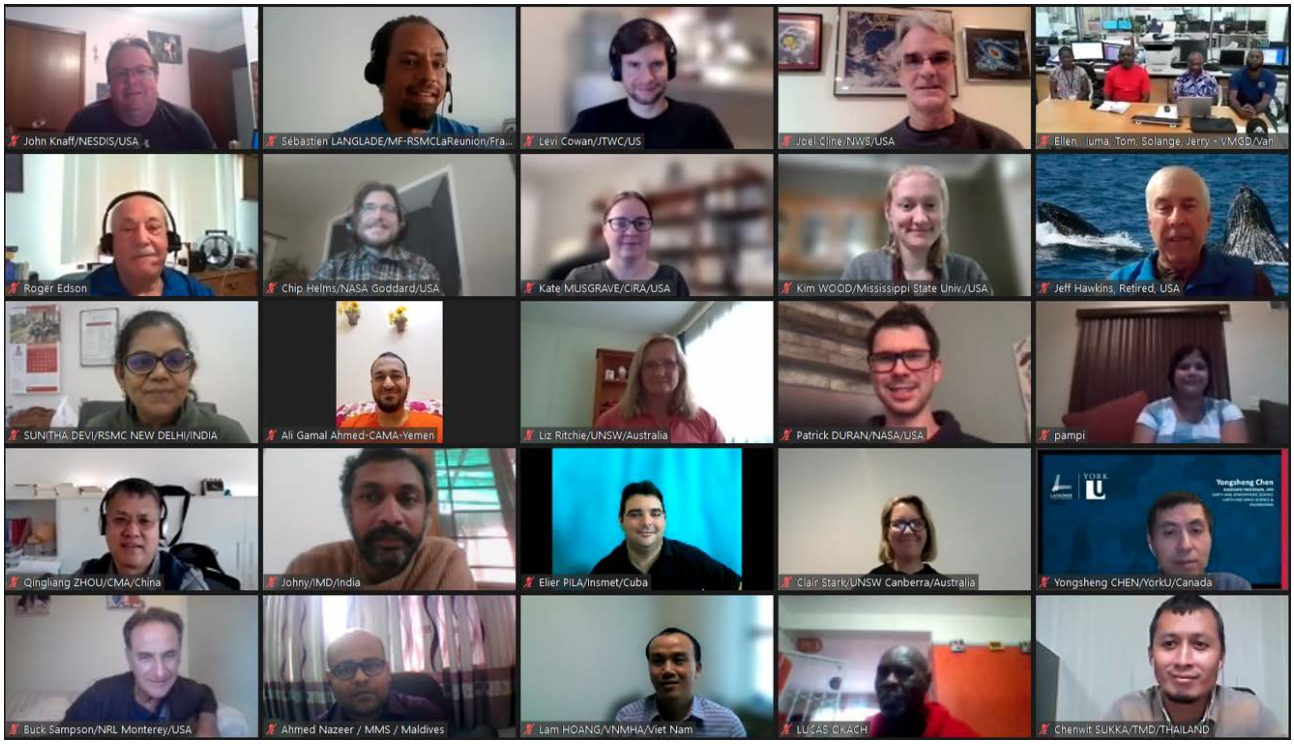
JTWC policy: https://www.metoc.navy.mil/jtwc/jtwc.html

NOAA (STAR) scatwinds: https://manati.star.nesdis.noaa.gov/datasets/ASCATData.php

NOAA SAR:
https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/tropical/index.html

***C**aptures of some online participants.*





LIST OF APPENDICES

APPENDIX I: Pre-workshop survey results

A survey was sent to operational centres and to identified research and information providers helped define the program. There were 30 respondents.

What level of interest is there in the following topic?
Rank 1-5: 1: Not interested to 5: Extremely interested.
Operational analysis in organisation by RSMC/TCWCs: 4.45 average
Update on objective Satellite TC analysis methods: 4.84 average
Update on microwave and scatterometry sensors: 4.77 average
Best practice use of satellite web portals: 4.39 average
Training exercises in applying objective techniques for operations: 4.45 average
Emerging and future satellite technologies for TC analysis: 4.90 average

Are there other topics not listed above?
Emerging and future operational needs that may leverage satellite information
Comparison of Manual and SATAID D'vorak Analysis
Objective methods that provide quick answers to operations (e.g., consensus methods)
Rainfall satellite estimates of tropical cyclones
The reliability of the Dropsonde wind speed reference scale
All topics are listed
Tools for training, collaboration and combined documentation of TCWC and other organizations' current satellite analysis tools / methods (websites/platforms – e.g., WMO Tropical Cyclone Forecaster Website)
Tools and methods for analyzing "satellite signatures" associated with large-scale environmental patterns that impact TC formation, intensity and motion (MJO, mid-latitude features, etc.) (recognizing how/when these features are interacting with or will interact with developing/existing tropical cyclones)
Agency satellite analysis procedures for atypical cases (very small TCs, monsoon depressions, gyres, subtropical/hybrid cyclones)
Best practices for estimating tropical cyclone intensity and wind distribution over land when observations are sparse or unavailable and subjective Dvorak and other techniques are less reliable (include: available techniques, verification studies, use of surface observations (winds, SLP values) to estimate intensity and accuracy of Harper's (2008) 'Off-Sea(0.90)', 'Off-Land(0.87)', and 'In-Land(0.84)' conversions)
Best practices regarding application of the Dvorak technique after TC has re-emerged over water…how to jump-start Dvorak estimates based on other data, break constraints
Understanding and improving availability / timeliness of RSMC / TCWC intensity estimates via RSMC / TCWC websites, email, GTS, etc.
Discussion of intensity estimates from new sensors (SAR, SMAP, SMOS, AMSR2, cubesats, etc.) and potential value for satellite consensus methods.
Discussion of potential for a multi-national field campaign to validate new high-windspeed estimates for TCs in basins outside ATL/EPAC.
Recommend exploring/discussing importance of maintaining and expanding the satellite constellation for TC analysis and highlighting the current and prospective role of cubesats (TROPICS, CYGNSS, etc.)
Recommend following up on this recommendation from the IWTC-II:
"The IWSATC-II recommends the development of a living document that provides details of the various satellite-based observations and techniques used in operational centers. The document should provide information about the observation or technique and any known strengths and weaknesses that would be useful to a forecaster in an operational setting. The document should be updated on an "as needed" basis by individuals identified as the responsible person for that particular observation or technique and should be made available on the WMO TCP web site and the Tropical Cyclone Forecaster Website hosted by Hong Kong Observatory."

What are the most significant issues facing your organisation with regards to satellite information for tropical cyclones (describe up to three)?
Near-real time availability

Timely access and processing of information
Ability to develop and share algorithms with partners
Resources to develop better products
1. improvement of the accuracy of center location, intensity using Advanced Dvorak Technique
2. when the satellite images are hard to follow the lower level cloud"
"High resolution Himawari satellite images can be downloaded only at a frequency of every 30 minutes due to bandwidth limitations.
High resolution Goes satellite images are currently unavailable due to hardware limitations that do not pair up with their latest satellite."
Availability of near real-time microwave imagery.
1. Maintaining currency of knowledge and skills as new instruments and platforms become operational. Includes understanding the strengths and weaknesses of each instrument and technique.
2. Sourcing operational satellite information during operations - NRL TC page has been a great resource for aggregating TC satellite information in a one-stop easy-to-use web portal. Increasingly we are having to go to multiple web pages to check availability and view satellite information"
(i) Further effective use of geostationary satellite rapid scans which are taken at intervals shorter than 5 min for tropical cyclone monitoring/analysis
(ii) Further effective use of multi-bands (e.g., multi-water-vapor bands) of geostationary satellite for tropical cyclone monitoring/analysis, for example, via data assimilation with numerical model.
(iii) Typhoon intensity estimation based on satellite imagery by using deep learning.

Identification of T numbers, 10 minute radial wind gusts and associated central pressure.
- Not able to receive polar orbiting image/product directly on the Workstation
- Interpretation of scatterometry data
- Dealing with different channel/characteristics of Micro-wave sensors"
1. Lack of high-resolution (spatial and temporal) satellite based ocean surface vector wind data. Current scatterometers cannot sample the peak winds and RMW in stronger TCs and data coverage is too sparse in space and time to be useful for all operational forecast cycles.
2. Decreasing number of high-resolution microwave imagers for TC analysis.
3. Gaps that still exist in fully utilizing satellite sounder information for TC analysis for forecaster and NWP applications. "
1. Getting methods into the numerous operational workstations so forecasters can better use information
2. Funding for satellite application development
3. Gatekeeping (allowing some folks to test new technologies and denying others) by some of the operational centers. "
Confidence on the satellite intensity estimates of tropical cyclone
Limited quantitative information on TC size, especially hurricane force wind radii.
Antiquated technique for subtropical cyclone intensity classification (Hebert-Poteat)"
1. Developing new techniques for satellite analysis of TCs from the new satellite instruments, most notably the ABI/AHI-type imagers.
2. Ensuring the continuity and expansion of 36/89 Ghz microwave imagery for TCs.
3. Expanding the number of ocean-surface-wind measuring satellites and adding them to NHC operations."
Wind calibration
Temporal frequency of wind acquisitions
Spatial resolution of images"
None-routine outage of satellite resulting in inaccurate positioning of system
None at this stage, Himawari Cast provides satellite imageries from the west and the GOES W supports the operation from the east.
However, we'd like to do more practice on Dvorak Analysis for estimating intensity"
Quantitative Rain Forecast in land areas (flat terrain, pre-mountain and mountain areas)
Short range Wind Estimation (forecast) before landfall.
Tropical Cyclone genesis."
1) Ways to better incorporate new satellite technology and products into tropical cyclone analysis and forecasting (e.g., new bands, multispectral imagery/RGBs, GLM)

2) Transitioning new satellite products and tools into an operational environment"
We are reliant on microwave scans that sometimes don't cover the area of interest
Recognizing and adjusting to rapid intensity changes (especially rapid intensification) – when to break subjective Dvorak constraints, which datasets to “favor” in the best track analysis, etc.
Analyzing intensity and wind radii for atypical cyclones such very small TCs, monsoon depressions, subtropical/hybrid systems, transitioning (e.g., to extratropical) systems
Reconciling discrepancies among individual wind speed estimates from different sensors at different times; especially, weighing very large differences among objective estimates, subjective Dvorak estimates, and newer satellite methods like SAR, SMAP, SMOS
Additional issues identified by forecasters/satellite analysts, included since this is a combination of many people's thoughts:
Difficulties determining, interpreting and applying statistical performance metrics (mean errors, biases) for multiple new passive microwave and SAR wind intensity estimates
Determining the applicability of various wind speed estimates in different scenarios (dependencies on storm structure, intensity, proximity to land, etc.)
Missed and partial passes over storms
Determining best track intensity and/or wind radii when various satellite data sources and methods indicate widely different intensities and/or wind radii
Accurately assessing TC intensity over land
Receiving data in near-real time for best track analysis and numerical model bogus/vitals preparation
Limited access to data from certain sensors and countries; agencies not utilizing TP bulletin format/GTS for dissemination of TC fixes
Comprehensive documentation of emerging capabilities and how forecasters can effectively leverage them
Lack of ground truth verification data or in situ data (e.g. air recon data) to validate techniques or remote sensing data/technologies.
How best to distribute our synthetic aperture radar based tropical cyclone products into the community
How do we best connect with possible users

Any other comments?
Too bad it is virtual...Hawaii is always a nice visit especially in December! :-)
Get together the practical exercise between the agencies for the same tropical cyclone case.
Looking forward to this workshop.
Good luck! I love this workshop.
I would like to see more pull from operations in this meeting. I think the field is nearing a point where there is enough data and advanced techniques that we can really start to address user needs, but a list of priorities and most difficult/time consuming aspects of their jobs is needed.
Difference between day-time and night-time satellite measures
Satellite measures of tropical cyclone size
Observations of tropical cyclone remnants
Eyewall replacement cycles in tropical cyclones
Tropical cyclones and topography interactions seen by satellite
Why not in person in November 2021? The pandemic will be over by then.
Great you are doing this. Thanks for including us.
Thank you for the opportunity to participate

APPENDIX II: Operational recent advances and issues and challenges

1. Recent Advances (by agency in alphabetical order)

BOM, Australia
- Greater use of AMSR2, SMAP/SMOS, SAR for winds
- Himawari in Rapid Scan mode, would like more surface wind analysis
- Other: Greater integration of NWP with analysis and synthetic cloud for forecast

CMA, China
- Developments of Geostationary Satellite:
- FY-4B was launched on 3rd June, anchored at 123.5° E, which includes Multiple-bands Scan-imaging Radiometer, Atmospheric Interference Sounder, Lightning Imager (2021)
- Developments of Polar Orbit Satellite:
- FY-3D was launched on 15th November 2017 with 10 remote sensors (2017)
- FY-3E was launched on 5th July 2021 with MERSI-LL, MWTS-III, MWHS-II, WindRAD, HIRAS-II, etc, which was the first mooring-nightfall orbit satellite (2021)
- Operational use of Geostationary Satellite:
- TC monitoring and analysis based on FY-4A satellite data and DAV technique (2017).
- Intelligent estimation of typhoon intensity based on FY-4 satellite image data (2017)
- Intelligent recognition of typhoon vortex based on depth image target detection (2019)
- Discrimination of TC Rapid intensification trend based on FY-4 satellite (Experimental)
- Operational use of Polar Orbit Satellite:
- Objective algorithm of Typhoon intensity based on FY-3 Polar orbit Meteorological satellite (2019)
- Inversion of typhoon wind structure based on FY-3D satellite microwave thermometer data (Experimental)

IMD, India
- RAPID: Real-time Analysis of Products and Information Dissemination
- Rapidscan for INSAT-3DR
- EUMETSATCAST hosted at IMD
- ADT V8.2.1 at IMD

JMA, Japan
Operational
- In July 2017, JMA started to use Himawari-8 AMV-based Sea Surface Winds (ASWind) for sea surface winds in the vicinity of TCs (Nonaka et al. 2019).
- Use of RGB images created from Himawari-8 multiple WV band images for monitoring wet/dry area in the mid-upper troposphere.

Experimental
- Use of upper-level AMVs from Himawari-8 for monitoring TC cloud-top outflows, including synoptic scale flow (e.g., outflow jet).
- Use of Himawari-8 Near-IR (1.6μm) images for determining the rotation center of low-level clouds.

JTWC, USA
- Maximizing use of microwave/scat/radiometers for sat operations
- Use of future SAR and future small--satellite sensing: satellite sensing:
  - Have potential to greatly reduce temporal sensing gaps; however
  - Planned U.S. sensors are less capable passive design; not all-weather / high wind capable
  - High-wind capable sensors & algorithms (SAR / SMAP) great for wind speed, but lack direction vectors
  - Many CubeSat programs (except TROPICS) generally limited to coarser resolution sounding channels

KMA, Korea
- GEO-KOMPSAT-2A(GK2A) launched on 4th December 2018 and operational service starts 00UTC on 25 July 2019

- GK2A data in netCDF format are distributed via land line service and satellite broadcasting service
- Level 1B data are released to NMHSs (similar to Himawari Cloud) via FTP in real time and via NMSC website(http://nmsc.kma.go.kr/enhome/html/main/main.do)
- GK2A request-based Rapid Scan Observation available for Asian Pacific region (RA II and V)
- The official request of target area observations every 2minutes with flexibility location to support monitoring the natural disaster are available http://datasvc.nmsc.kma.go.kr/datasvc/html/special/specialReqMain.do
- Provide significant improvements in the real-time monitoring

La Reunion, France
- Dvorak constraints at 18h and 24h modified according to Sangster & Landsea, 2020
- Integrate guidelines from Kossin & Sitkowski during ERC
- Greater use of SMAP/SMOS/SAR (Best-Track & operations)
- Consolidating intensity analysis procedure: from Subj. Dvorak to micro-wave/objective guidance/winds data integration to derive Vmax (10 min)
- Consolidating estimation of Radius of Maximum Winds

NHC/CPHC, USA
- GOES-R/16 launched in November 2016 and was used for ATLC/EPAC hurricane seasons starting in 2017.
- GOES-S/17 launched in March 2018 and was used for the EPAC/CPAC hurricane seasons starting later that year.
- GOES-T currently scheduled for launch March 1, 2021.
- GOES-R series satellites currently employ 10-min full disk scans, 5-min focused area scans, and 1-min to 30-sec mesoscale sector scans.
- Data from the 16-channel Advanced Baseline Imager (ABI) is combined into multispectral RGB imagery to highlight upper-level airmass features, African dust, convective features, and more.
- A very useful multispectral product is Gallina Cherkova's ProxVis imagery, which provides almost visible-quality imagery at night.
- Lightning frequency data also available from the Geostationary Lightning Mapper (GLM).
- New data from SMAP, SMOS, SAR, and H2YB scatterometers becoming available, but forecasters need better familiarity with the data.

PAGASA, Philippines
- Continuing capacity enhancement through technical trainings hosted by various Typhoon Committee centers.
- RSMC Tokyo and other operational/R&D centers (i.e. CIMSS) have integrated more satellite-derived products and aids for open use by national centers in the region.
- Routine usage of satellite-based objective aids for position, intensity, and structure analysis (mostly of which comes from CIMSS) due to improved accessibility.
- Initial use of other scatterometer data (HSCAT, RFSCAT) in operations to supplement ASCAT-B/C overpasses –more relevant especially with the MetOp-A end of mission.
- Hoping to integrate SAR usage even more

2. Issues and challenges

BOM
- Manual analyses required for position, structure&intensity
- Time during operations to consult all the inputs for quick decisions - e.g., HY-2B only from KNMI site.
- Scat (lack of) coverage – ScatSat loss - e.g. 2 days no data
- Less microwave availability and reliance on NRL/FNMOC
- Resolving conflicting information
- Need for more sophisticated shear diagnostics
- Consistent diagnostics from analysis to NWP - e.g., shear
- Keeping up to date with technique changes (training load)

- Intensity definition – e.g. SAR?
- Large datasets are an issue for local archiving

CMA
- Balance between microwave satellite image and Geostationary
- Balance between new techniques and traditional ones
- Restriction from old version of Dvorak analysis
- Location of week/strong VWS/ night TC
- Selection of multiple data sources

FIJI
- Internet ISP speeds in Fiji slow to download 10 minute satellite data for 16 channels
- Low Resolution Satellite image (Himawari Cast) used as Backup to High Resolution
- Accessing and visualizing Rapid Scan (Satellite images)

IMD
- Data sparse region
- most countries have limited observations in terms of surface/coastal/ upper air and RADARs
- 20 Buoys deployed by India
- Ship observations are decreasing over the years
- Hence there is need to augment Satellite based observational support
- Even though there has been substantial improvement in centre and intensity estimation of TCs over NIO, there is an average error of about 55km in centre fixing and T no 0.5-1.0 in intensity estimation, hence there is still scope to improve further.
- NIO being dominantly witnessed by sheared systems especially during monsoon season, existing Dvorak technique has limitations.

Specific needs –
- Need for more scatterometers
- Development of technique to derive surface winds from multisat observations and data for validation
- Need for more microwave imagery and data availability
- Need for ASCAT and microwave imagery over GIS platforms
- McIDAS compatibility similar to METEOSAT-8 for other geostationary satellites like HIMAWARI, KOMPSAT
- Proposal to have a dedicated server link for RSMCs/members - containing ASCAT and Microwave datasets in near realtime similar to those currently available at McIDAS-V
- Access to Latest ADT Version

JMA
- Less frequency of sea surface wind observations by satellite microwave scatterometers. Now, MetOp-B and -C and SCATSAT-2 are available in the JMA's operational TC monitoring. How about the future observations ?
- Shortage of sea surface wind observations with wind speed greater than 50kt (the limit of scatterometor winds).
- Manual analyses required for determining TC position, structure (wind/pressure profile), and intensity.
- High-dependency of TC intensity estimation on manual Dvorak analysis.
- Keeping up to date with technique changes (training load).
- Large datasets are an issue for local archiving.

JTWC
- The growing list of satellite sensors recently lost or operating beyond end of life is increasing tropical cyclone coverage gaps pending acquisition/launch of replacements
- Limited sensor swath widths further increase the gaps between successful collections

KMA
- Lack of Scatterometer (EOL)
  - ScatSat-1/OSCAT: January 29, 2021

- MetOp-A/ASCAT: November 15, 2021
- Outranges
- High genesis latitude of TC
  - approaching to Korea within 3 days
- Rapidly strengthen/weaken TCs
  - break the Dvorak constrains

NHC/CPHC

- GOES-17 ABI has a major cooling issue, and several channels become unusable at certain times of the year. Due to this, GOES-S is scheduled to replace GOES-17 as soon as it becomes operational.
- Better intensity estimates
  - Current non-microwave satellite intensity estimation techniques for TCs use only VIS/IR Window channels – 1970's technology!
  - This meeting should recommend that new intensity estimation techniques be developed from the more advanced data types.
  - While specific algorithms are outside the scope of this meeting, these techniques could be derivatives of the ADT or DAVT, built on neural networks, or something completely new.. Feel free to think outside the box!
- The Stepped Frequency Microwave Radiometer, the aircraft instrument for estimating ocean surface winds, has shown an apparent high bias in winds of above 115 kt/59 m s-1.
- This has created larger than normal uncertainties for the best track intensities of strong hurricanes, and in the use of those best tracks in calibrating satellite intensity estimates.
- 37 GHz microwave channels can be used for a unique depiction of the low-level clouds/ convective structure of tropical cyclones, and this has proven useful in aiding forecasts of rapid intensification
- The number of 37 GHz instruments in orbit are decreasing, and there are few with high resolution data. Only one satellite with a high-resolution 37 GHz channel is currently scheduled for launch.
- TROPICS cubesats do not have an adequate substitute for this channel.
- This meeting should recommend the development and launch of a suite of LEO satellites with high spatial resolution 37 GHz data and high temporal resolution.
- Nadir gap under the ASCAT satellites remains problematic. Staggering of METOP-A orbit helped with the problem, but that satellite is now de-orbited.
- Chinese H2YB scatterometer data may help fill in gaps, but more experience with this data is needed.
- CYGNSS ocean surface wind data was not delivered to forecasters in real time.
- This meeting should recommend better temporal ocean surface wind coverage by increasing the number of satellites and number of orbits in the ocean surface winds constellation.
- Use of GLM data is very qualitative, and there is an ongoing need to better understand lightning in tropical cyclones.
-

PAGASA

- Manual analysis still performed extensively to finalize position, intensity, and wind structure

estimates (Yes! Hand-analyzed maps)

- Considerable data latency in some satellite data
- Resolving conflicting information
- Dwindling scatterometer data sources
- Bridging operational procedures of subjective Dvorak technique (Dvorak 1984), EDA (Kishimoto 2008), and Hebert and Poteat (1975) subtropical cyclone technique
- Establish a standard for defining monsoon depression in an operational setting.
- Issue with CCC - in relation to JMA Dvorak procedure vs those in Dvorak (1984),
- Intensity definition used in satellite products

La Reunion

- Time is lacking during operations to consult/analyse the increasing number of data and

inputs from various sources for quick decisions
- Overlap of Analysis & Forecast process during operations
- Resolving conflicting information
- Scat (lack of) coverage – ScatSat/Ascat-A loss
- Less microwave availability and reliance on NRL/FNMOC
- Intensity definition – eg SAR?
- Wind averaging when dealing with remote sensing wind data

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APPENDIX III: Day 1 Breakout Room notes

Question 1. From the range of presentations from operational centres, what approaches, methods or initiatives struck you as being potentially useful, either for your agency or more broadly?

JMA -> the use of upper levels AMVs to monitor TC outflow -> insight on TC primary – secondary presentation. Good to share within the other operational centers

Importance of blending information for TC intensity estimates
-> We need low latency product to be used in operations and data sharing enhancement

Demand for scatterometers – though more utility from current products may be easier
Better coordination on best practice for incorporating new technologies and products into operations

SAR
Multi-spectral imagery in novel ways, particularly proxy-Vis during night time useful for Dvorak overnight
Integrated viewers to being different data sources together.

Dvorak Technique; RGB values assigning and better training on RGB imagery
Challenge Weaker storms over BOB It is difficult to forecast long-range intensity/track forecast 5 days earlier.
JMA ASWinds look promising for gale radii
JMA/China/Inida presentations showed a lot of data of various sorts and techniques that may not have been shared across the world

AMV based Sea surface winds (AS winds) for locating the Swirls or multiple low level circulation centres & upper level AMVs for monitoring the TC related cloud-top outflow – JMA (also being utilised by a few more operational centres).

Use of RGB imageries to identify wet & dry regions in the mid & upper levels for providing guidance to the forecasters in intensification / weakening trends.

Deep Learning & application of Artificial Intelligence in Typhoon intensity estimation vortex-based depth image target detection.

New methods applied to obtain the wind structure both in horizontal & vertical.
Use of multi-spectral Proxy visible imagery & also super posing Lightning imagery to locate areas of maximum convection.

ProxyVIS imagery and differential WV imagery. New DVK constraints for 18 and 24 h.

Use of lightning data. Use of RGB and ProxyVis. Rapid intensification.

The discussion of methods for improved use of Radarsat-2 and Sentinel-1 SAR imagery for improved estimation of hires wind fields including dual use of microwave imagery to flag regions of high precip that the SAR dual pol system still cannot properly resolve.

The JMA's Surface winds estimates from himawari-8. More details of how these are estimated and where those data can be gotten.

Don't have our own Sat so advances in Goes Sat that we use will be great.
Everyone wants more Scat images.

During Week Cyclone, Models fails to predict (transition between intensified TC into weakening and vice versa) within less than 12 hours. But models are capable to predict the intensified TC very well.

Access to CMA's FY3 and 4 polar orbiter data

Question 2. How can research and satellite information providers better support operational forecasters?

Investigate the range of 'difficult' cases to assess performance of objective aids
More detailed verification studies using collated ground truth – joint issue with access to obs networks.
IMD: Observations are essential, more microwave passes
HKO: More products towards the windfield structure

KMA: Need to design sophisticated techniques (Deep learning, IA …) to deal, in real-time, with the increasing numbers of data and to provide quick reliable informations to TC forecasters.
SAR - calibration to 1 min and 10 min means.
Agree on a "ground truth" for intensity in product. Possibly build a database of cases that have "reliable ground truth."
Need for replacements and additional for microwave imagers in the 37 GHz and 85-91 GHz as well as scatterometers. TC analysts prefer higher resolution data from imagers, modellers and data assimilation prefers sounders which end up being lower resolution

Research on breaking Dvorak constraints.
Need more scatterometers, MW radiometers, HY-2 to WMO RSMCs

Better training on SAR data – strengths and weaknesses. More emphasis on pre-hurricane stages. (Use NRCS for center location.)

Accurate surface winds derived from satellites.

Role of SAR and SCAT data in TC existence determination.

Great to have events like this to get researchers and forecasters together – the more interaction the better
Better knowledge amongst forecasters of who to provide feedback too on respective products

Limitation of Scatterometers winds (beyond 50 knots) to be resolved with advanced technology.
Constraints of Dvorak technique (rapid intensity changes as well as in highly sheared system).
In providing the knowledge how in better utilization of SAR.
Guidance on how to resolve conflicting information from various sources.
CAL-VAL exercises with in-situ observations mainly for various Oceanic parameters like SST, OHC etc.

Maybe we can use real-time satellite observatory during cyclone and feed into Data Assimilation and do run model forecast for next 6 or 12 hours at regional scale (instead of Global to save time) for every 3 hourly cycles instead of 6 hourly cycles. It may improve the forecast during rapid intensifications of TC.

Make data available with lower latency and publish strengths and weaknesses and bias relative to other objective aids/ techniques. Put more high-resolution MW sensors into operations.

Research and climatic information may provide climatic information to forecaster, it can also identify gaps that may be usefull in parametization processes

Daily discussions on TC situation being considered for forecast.

Develop methods for resolving contradictory information from different sensors and old/new techniques.

I think there should be a more coordinated repository of data or a formal agreement that NRLMRY should provide those images. Support for such a repository with common formats for downloads on many systems is desirable.

Some research as to why systems slow down around topography of Jamaica/Caribbean.
Rapid intensification.
DAV technique developed further. Better obs network would assist.

Lack temporal coverage of Microwave data is impacting all the centres. More research on tropical depressions, not just Typhoons. More data from Chinese polar orbiting satellites would be useful (or knowledge on where to access). More research on applying Dvorak to Microwave imagery.

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APPENDIX IV: Day 2 Breakout Room notes

Question 1. What tools are needed in order to reconcile differences in TC intensity estimates from newer sensors/retrieval techniques such as SAR, SMAP, AMSR2 and other sensors? (Is access to the data and estimates an inhibiting factor?)

Present what time-averaging period the wind most closely represents from each sensor/processing method.
Compare with external data that are trusted in that situation. E.g. intensity estimates from Dvorak in cases where you trust them. Establish correlation and relative bias between different data sets. Is SFMR the best reference data?

latency and frequency is the biggest issue. 1 hour latency for very sensitive products could be great.
Like SATCON plots some (but not all) the inputs for intensity estimates, there is a need to have 1 way to overview ALL inputs for intensity / structure estimates.
My suggestion is that more training should be given to forecasters including how to use those data, the evaluation of each sensor in different basins and every seasons.

Easy access to data and products in familiar formats would help compare the estimates.
More ground truth information could assist, like Doppler radar.
Interpreting and visualizing the data is important.

Compare with external data that are trusted. E.g. intensity estimates from Dvorak in cases where you trust them.
Analyse correlation between different data sets. Important: Can the new data set see RI or deintensification.
When comparing sensors of different spatial resolution, they need to be resampled to the coarsest resolution.
Analyse difference as function of external parameters (rain, wave height, …).
Acquiring data at low latency is crucial.

Compile and share a document containing what each sensor is measuring, how it should be compared (time and spatial averaging), uncertainty associated to the measurement; and recommended “ground truths” to be compared to.
This is a monumental task for one single group. The task can be split among groups if the same ground truth and methodology is well defined.
A suggestion for intercomparisons/reconciling different measurements is to convert them to something like Dvorak Current Intensity (CI number), thus avoiding the 1-min versus 10-min definition/scaling issues.

Quality information for existing techniques to compare and reconcile differences as well as how to resolve issues with interpreting partial overpasses
Better training from satellite/retrieval technique providers to know how to use the information in operations
World wide database with best observed cases for each basin
“Ground truth” in the form of a dedicated field program focused on validating satellite sensors as opposed to the typical effort to study a specific TC attribute (dynamics, thermodynamics, outflow, etc.)

It was also noted that the forecast centers lack how to interpret new TC satellite data products, thus specific guidance is needed to highlight the strengths and weaknesses of each one. This could be done via examples or case studies.
Yes, access is an inhibiting factor. Also need data decoders for various instrument data (e.g., SAR, SMAP, SMOS, AMSR).
See where sensor is measuring in TC (averaging technique or other?)
How conversions of winds are being done
Accepted uncertainty in wind estimates provided by the different tools

Accessibility - data is accessed through Internet and depends on speed.

Data overload is an issue for an operational environment
Visibility - ability to display data on one platform would be helpful
Latency - inconsistent passes and old data is an issue
Confidence - it is difficult to use data without ground truthing. Maybe some sort of data analysis with the images would be good or sensor scores (statistical scores).
Education - a comparison chart of the sensors and their sensitivities.
Are drop-sondes used for the sensors only in the Atlantic?
Need more data in the early stages of TC
SMAP hasn't been used operationally
SAR passes, Multiform and ASCAT are used operationally
French Polynesia downloads microwave data and display using a microwave viewer

Question 2. Of the upcoming satellite missions in the near future what sensors are of the most interest to the operational communities?
CIMR Copernicus Imaging Microwave Radiometer - the combination of imaging and sounding with high wind retrieval and ability to retrieve in rain.
Microwave sensors on SmallSats/CubeSats (eg TROPICS) depending on capabilities - expect good coverage but may have limited capability in high winds and rain? (Though TROPICS sounds promising.)

Microwave imagery on geostationnary
dire need of anything relevant for TC intensity/structure estimates !!

TROPICS. Earlier objective estimate of intensity.
Greater temporal coverage.
Geo-stationary microwave.
Rapid-scan of geostationary satellite in the Caribbean, sooner than current.

Microwave sensors: scatterometers (2nd generation Scat), SAR, radiometers (AMSR3, CIMR).
Geostationary satellites.
Joint Polar Satellite System.
Ice Cube.

SCATSAT-1 satellite carries a Ku-band Scanning Scatterometer radar instrument operating at 13.515 GHz. The payload instrument is a vital tool globally used to study wind patterns above the ocean, air-sea interactions, ocean circulation and for Weather Forecasting, Cyclone Detection and Tracking
The Suomi National Polar-Orbiting Partnership satellite (SNPP) launched in October, 2011, is part of the Joint Polar Satellite System (JPSS), the next generation polar-orbiting operational environmental satellite system dedicated for forecasting tropical cyclones. SUOMI NPP VIIRS satellite sensor is the latest sensor technology for hurricane analysis
Ice Cube is a nano satellite that uses a new, miniature, high-frequency microwave radiometer (HARP) to measure cloud ice. The data on cloud ice can be used in weather forecasting and storm tracking.
(Input by Raja Acharya,IMD,India)

Anything that helps with positioning (e.g., microwave data)
More 37 (for low level structure) & 89 GH; 118 & 200 GHZ are going to be interesting
Many C-Band Cross-pol Scatterometers

Continuation of existing capabilities for microwave and scatterometers and expanding SAR
AI/ML techniques to improve wind retrievals and exploit multispectral information
GEO microwave capabilities

Scatterometers and better temporal coverage was the most frequent request since they help in the formation and early tropical storm phases that are key to starting the forecasters on the right path. Everyone loves SAR data sets, but they typically are best for stronger systems and then we have other sensors (sounders, Dvorak, ADT, SMAP) that come into play.

proxyvis use of IR on Geostationary
Cross polarisation measurements that identify stronger winds
CMA series of satelite output
Tropics data from 2022

SAR, Scatterometers, MW radiometers, VIS/IR (geostationary)

Question 3. Given the short lifespan of cubesats/smallsats (a few years) and the training time needed to educate the community on their capabilities, how best can data providers get this data to the operational community while the platforms are still providing data?
Simulated datasets for training would help.
Can calval time be reduced?

Start the training before the data will be provided
Regional reception connection to enhance global broadcasting

Good educational information before launch. Including what products are possible. Standardisation of data communication, data formats and products. Or methods to convert from new format to old format to help adoption of new formats.

Validation takes about 3 months after launch, if nothing goes wrong. Prompt and flexible distribution to users for additional testing after Cal/Val would be critical. Real-time distribution should be part of funding in new missions. One-stop place for data distribution would be ideal
Set up a channel/document for users to provide feedback to data processing centers/providers on the assessment of early distributed data.
Maybe non-governmental ground station could speed up the distribution: flexibility in the ground stations.

Develop a set of community guidelines for data format/structure and visualization for smallsats/cubesats so that it can be interpreted/digested into operations. Avoid scattering the information across a myriad of websites.
Provide limitations and issues of all novel data while still in calibration/validation
Involve the operational community in the calibration/validation process

SmallSats/CubeSats currently being flown and in the near future are DEMOs and thus are built as inexpensively as possible. Thus, there is no effort to prolong the CubeSats life with more expensive redundacies that are mandatory with legacy sensors designed to last 7 years minimum. Most CubeSat sensors are what we call “single string” electronics.. If one part fails, the whole thing stops working. Other parts are NOT bought with cutting edge state-of-the-art performance since it’s a DEMO, but once proven, can be upgraded to something much closer to legacy numbers. Data downlink is currently expensive, thus most R&D efforts do NOT have near real-time data (NRT) readouts. However, most can downlink the data in NRT as part of quasi-operational time frames to get forecaster feedback after the cal/val team has certified the sensor and algorithms. This is what will be done for TROPICS with a designed NRL time period. Depending on the feedback, the team can then go to NASA/NOAA and request additional funds to regain NRT status.

Most SmallSats/CubeSats will be flown as part of a constellation that might range in number from just a few to maybe dozens. Operational CubeSats would include some redundant electronics that prolong their lifespan and potentially thrusters to maintain altitude longer. These actions can mitigate the relatively short lives experienced with R&D versions that are simply created to prove a specific capability is doable.

Given the short lifespan of cubesats/smallsats (a few years) and the training time needed to educate the community on their capabilities, how best can data providers get this data to the operational community while the platforms are still providing data?

Usually takes on order of year just to calibrate sensors, so new processes likely needed to

improve timeliness. Phenomenal potential.

By utilizing the working groups; seminars;

Try to base algorithm training on prior sensors of the same or similar type.

Online workshop
Recorded video
Examples and resources from different scenarios

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APPENDIX V: Day 3 Breakout Room notes

Question 1. Satellite-based algorithms increasingly have the ability to depict not only TC intensity but the complete 2D wind field. What impacts on the forecast process do you anticipate from these products? For example how would the knowledge of structure changes such as ERCs and significant wind asymmetries impact the forecast? On what time scales do such structure changes become important or are transient changes on shorter time scales of less interest operationally?

A) Worried about changes in how best track intensity/radii are developed. Likely overall increase in intensity estimates with more detection, even accounting for shorter time scales.
B) Little experience with SMAP, SMOS, SAR. Would be great to have SAR products designed for different wind speed averaging periods, and where the area average is based on the wind speed (if possible). For example, larger area average for 150 kt wind than for 30 kt wind.

It will have a big impact, but only once forecasters trust it. Have not yet seen reliable structure information outside scatterometry. Need improved forecast skill for ERCs before we could confidently modify intensity (too much variance in timing and magnitude of change), though important structure changes (growth in size, effect on impact) we can be more confident of. Transient changes of <6 hours are less important. When they do occur close to landfall most response decisions have already been made.

Satellite-based algorithms increasingly have the ability to depict not only TC intensity but the complete 2D wind field. What impacts on the forecast process do you anticipate from these products?

Inputs from Cuba: improve the warning of affected areas regarding winds hazards and storm surge. It will be a very good tool to show to the public and government the actual size of the storm. In case of very weak system, as we had the last two years in Atlantic, will manifest the difference between TC of similar intensity and very different wind field distribution. The knowledge of the “real” wind field helps to get, and idea of the actual extension of the effects, especially in the range of 6 to 12 hours prior to impact direct to land, a moment where the effects will happen outside the trajectories or uncertainty cone, that in some cases make the people feel “safe”, because the centre will not cross near them.

Inputs from NESDIS (John): give opportunity to more holistic vision of danger areas (more or less concentrated around the centre), easily understandable by the general public

Inputs from La Reunion: increasing use of IKE index to monitor TC activities (in addition to ACE)

Inputs from BoM: onset of gales; duration; wave&storm tide; ingestion to models for structure is so important

Inputs from PAGASA: improve our own operational estimates of radii of strong, gale, storm, typhoon force winds + better timing for onset of gales + better estimation of asymmetry esp. during TC events coinciding summer or winter monsoon surges --> better land warnings for public users, sea warnings for marine users, and specialized warnings for civil aviation.

For example, how would the knowledge of structure changes such as ERCs and significant wind asymmetries impact the forecast?

Knowledge of these information will be beneficially esp. in the critical 18-24 hours before landfall when there is a need to escalate higher levels of wind warnings if ERC is anticipated before landfall or if significant asymmetric expansion of wind radii is expected.

Inputs from Malaysia: better understand what’s behind the tools.

Communication of complex radii can be difficult, can lead to simplification.
Increased accuracy in intensity and wind field would be very useful for impact forecasting.

Knowledge of ERC's leads to short term intensity forecast, but unsure how long it would affect intensity. More guidance on duration would be very useful.

The key is improving the confidence in the analysis.
For some forecast situations, the important thing is that it captures the 12-24 hr changes well, especially close to landfall.

Easier to tell if system is transitioning to subtropical or extratropical, which can aid other analysis types such as Dvorak classification
Wind field asymmetries could help correct intensity biases for fast-moving storms or environments with strong gradients
Relevant timescales depend on the phenomenon and how long it will take to impact the forecast, e.g., ERC vs. Interaction with frontal boundaries or wrapping of max wind bands around low-level center

Situational awareness for the product and context for how to use a product in a specific scenario
Transient changes on short time scales are not captured in the best track so not as important.

Need these products to help fill in the gap between scat passes and other such data.
Need to know what products are actually used in the analysis and how old they are.
Consistency of the analysis is important.
Need a confidence factor for the analyses and the various factors that can affect the quality of the analyses.

All the details may introduce some uncertainty to the forecast. The data increase without an increase in forecaster time may make things more hurried and need for automation. Forecaster looking at the outputs and comparing to forecast – if these techniques do not give you what you expect then question and ask what are we missing? But if it does fit what you expect then it increases the forecaster confidence. Always like more data so these techniques are helpful. Time latency for those satellite techniques is important to operational forecasts. The 2D winds are important to modelling efforts.
TS Maria was 35 knots but mesovortex feature caused 65 knots over Guam AFB but it was a TS – but could aid short fused warnings to move people to safety. But cannot see from satellite imagery (in most cases). Detailed information aids the explanation for IDSS delivery to land based emergency managers.

Question 2. Deep learning approaches to TC analysis can have a "black box" stigma attached to them. What is needed to move beyond this and how can these approaches be blended with legacy techniques?
A) Evaluation of “black box” techniques is key to use. “If it works, we will use it.” Subjective Dvorak still the mainstay. Like to compare against all objective methods.
Tony Wimmers showed that you can look under the hood to a limited extent and get some insights into what information the AI is leveraging. But this ability seems quite limited. A combination of proven superior skill, the ability to have some understanding of what information the algorithm is using and the use of legacy techniques to improve conceptual understanding may help us move beyond the black box stigma.
Early education of users on how the technique works will help give greater confidence.
Comment that even DVK can be used in a black box manner
In operations the comparison with established methods will help to establish confidence but it is likely to take at least a season, and some best tracking experience, before people feel comfortable using them.

Deep learning approaches for forecasting Tropical Cyclones help to overcome insufficient representations of the air–sea energy exchange under very high wind speed conditions which hinders simulating the intensity of TCs more effectively and thus supersedes black box stigma. (Machine Learning in Tropical Cyclone Forecast Modelling: A Review by Chen et al Atmosphere 2020, 11(7), 676; https://doi.org/10.3390/atmos11070676) (Input by Raja Acharya, IMD)

Deep learning approaches to TC analysis can have a "black box" stigma attached to them. What is needed to move beyond this and how can these approaches be blended with legacy techniques?

Should be aware of each parameter and how it affects the answer. Additional information (graphics, metrics) provided with the answer so forecasters can better understand what is going. Bring some light to the black box.

Compare results of deep learning with well understood legacy methods... build confidence. Forecasters need to understand what they are using.

Educate analysts and forecasters about deep learning as a general topic.
Information about inputs and importance of each one.
Takes time for people to become familiar with the outputs.
Documentation and presentation of the products is important.
Training programs to rotate to agencies to update them in new methods.
Extra: Lightning as an input?

In-person engagement is very important for trustworthiness.
It helps to know the nuts and bolts – the more we can be told about the working of the model the better. If we can't get a quantitative description of the workings, then perhaps a subjective description of the behaviour of the model would be helpful, though it's hard to know ahead of time.

Graphical representations of neural network layers may be helpful to understand the deep learning model decision process
Methods like Tony Wimmers showed using SHAP values to illustrate which pixels or parameters were most important to the model are very compelling and would help inform forecasters determine whether the prediction is reasonable. It may even teach humans something. (Like AlphaGo teaching Go)
Is it possible to have a simplified version of deep learning models running in parallel to the full versions that can attempt to elucidate which inputs were most important?
Conducting case studies for those with reliable ground truth, but the output of deep learning approaches is significantly different from that of legacy techniques and one is much closer to the reliable ground truth, so that we can know more the strengths and weaknesses of deep learning approaches and look for room for improvement.
Domain knowledge integration into deep learning.

Subjective Dvorak should/can be the baseline/reference to access new techniques. If the new technique works, it gets used.
Both legacy and new techniques are not that different. Training for new products and techniques, experience with techniques in operations, and comparison to other mentions.
Time will be an issue so other information (error bounds or explainable AI techniques may not be useful). Could be valuable in training and post-season analysis.

Other comments
SAR might need to have a graduated averaging so that it is closer to the appropriate averaging period and other averaging periods should be provided

Need training on how the black box works and diagnostics on how the deep learning AI came to the decisions it did.

Black box if works well – then people question it less and forecasters will use it. Even if you know when it works well versus when NOT to use it, then it helps the forecasts. Error bars or know when to apply these black boxes. Training is key to learn some of the mystery behind the black box.
If use the "black box" for the forecast and it goes badly – is there enough information to understand and answer why the forecast did not perform well.

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APPENDIX VI: Summary of post-workshop evaluation

Following the completion of the workshop, participants were requested to complete an evaluation (in MSForms) of 10 questions. The summary results are presented here.
The first five questions asked whether expectations were met for each of the four days and on the workshop online format.

Question	Below Expectation	Met Expectation	Exceeded expectation	Total
Day 1	2	68	29	99
Day 2	0	59	40	99
Day 3	1	51	47	99
Day 4	2	54	43	99
Workshop format	6	56	37	99

Q6 Was the design of the workshop appropriate - did you feel your voice was heard?
Yes 94; No 2; Other 2.
It was great for sharing information. It was hard for interaction and engagement.
We need more preliminary knowledge about the topic. Most of cases we failed to cop up with the presenters.

Q7. Was the information accessible? - was it given too much in details - was it not enough?
Definitely accesible.
Super
the information was accessible
Information was more than enough
Hard to fly around the screen, like I'm doing now!
this is ok
It was accessible and very informative
Despite the apparent information saturation due to the limited time per day and the platform being used, the information was delivered well and remained accessible.
yes, and content was appropriate
It is long, but I was surprised at how much I enjoyed it.
It was accessible and had adequate details.
Information was accessible.
The information was easily accessible on Day 1, and it was getting a little harder to digest yet interesting to dig more into from Day2 to Day4
The right amount for a meeting of this frequency
I though the level of detail was perfec**t**
It left me with a reasonable amount to follow up on after the meeting.
I was able to follow the information, it was a good level detail. Plenty of questions but given volume of content further detail during the workshop would be too much
Yes, it was enough for operational forecaster
Yes, enough
it is very accessible but for junior like me need more details and more explanation about the short form in slide
The information was crisp and easily accessible
Very informative!
Just right. A bit more on ERC might be helpful before case studies.
Good enough
Yes, the info were available in advance and also sufficient.
Yes, enough
Yes. It was good enough
Few lectures were too detailed and few could not be detailed due to constraints of time
It was enough
The more, the better
It was good. All information was well prepared. It would be better if the products links was

shown.
Very clear and useful information.
Good balance
Yes. I would like to suggest that Tutorial sessions can be included in the future sessions of this workshop.
Yes, it is given detail information for each designed topics. Hope it will be continued in the next workshop.
Excellent
As a general rule, yes. But some presentations were harder to digest than others
The information is accessible
Yes. There was no issue.
Accessible
It was OK.
enough
Information was too much in details
Participants have easy access to information. It is very detailed and sufficient to study.
The trainees received enough information. Very accessible and detailed.
Need more explanation and basic of the topic. As I am new for this this topic.
Information was accessible but not enough documentation of techniques and tools.
I think there was a correct balance
given enough in details
The case studies could be less of them with more information for each. It was great but felt hurried.
An appropriate amount of detail was given
Accessible
Sufficient information was made readily available.
The information presented was sufficient to convey the concepts that this workshop was set up for.
The information was accessible and given in a proper amount of detail.
It was suitable
The information was accessible
Enough info. Class was not as interactive as hoped for
IT IS FINE
Information provided were well suited for the training.
Was given in details
NOT too detailed, seemed to straddle the academic/operational schools of thought pretty well.
Accessible, more details expected
was accessible, I hope there will be more workshop of this nature
The information was accessible. It was given properly.
It was accessible and enough.
The assumption was made that everyone was on the same level. More explanation of technical terms was needed.
Enough
It was helpful that longer presentations were available for greater detail.

Q8. What did you like the most about this workshop?
Learning about the machine learning approaches and GeoIPS.
LOTS of work by Joe and Derrick...plus their co-helpers
The Dvorak used in comparison with satellite analysis. I need to do some more reading on it for mroe clarity.
Always love the case studies, and group Dvorak analysis exercises
yes
The operational exercises of Day 4.
"It was PAGASA's first time to participate in the IWSATC-3. Having the opportunity to present during Day 1 was an honor and privilege.
The workshop allowed us to connect to the developers of all the tools that we've been using operationally for so long. We really appreciate all the learnings! "
I loved the new stuff from JMA, SAR. I also loved interacting with my colleagues. I also enjoyed the case studies!

Accessibility, practical conversations
Sensors
Updates on techniques / products along with case studies on last day.
Interaction with many people you would never meet otherwise
Case studies on Day 4.
The exercise! I've learned a lot from this!
"Full range of topics covered - operational perspectives, sensors, research advancements and practical exercises
Availability of presentations and recordings online is VERY helpful too
As a product developer it was great to hear from the actual forecasters to understand their needs and problem. (I know I came away with a long to do list).
I actually really liked day 4 - to learn more about how the forecasters think and do their job.
A minor problem with Day 4 breakout sessions - was there was not very much participation by many of the people in the room (the non-native English speakers). No one spoke up or even entered comments in the chat. Dont know if it was a technical problem.. or a language problem. And I was actually kicked off and never put in a room for the third breakout session (Zoom problem?).
The interactive format.
Opportunity to discuss ideas with a variety of people outside of my organisation. Get a better idea of how other agencies perform equivalent roles to what I do. Hear from people with more experience and knowledge than myself about how to use tools best and where they see the challenges.
1) Well delivered presentation by all presenters and leaders of breakout room.
2) Timing wise"
Using new techniques using Satellite
Chat discussion with old friends
everything
Organization and breakout sessions
yes
The case study discussion
Sharing the thoughts, new technologies, and experiences.
The information on latest development by the research community. Bringing both operational and research communities together.
It has presentations from different op**e**rational centers around the globe. Helped me to understand how other centers carry out their forecast.
Discussion during the brea**k**out session and case studies on day 4
Everything was good. It was well structured. Great to see it was done online and via zoom. Hope future ones can be done similarly via zoom to increase accessibility.
The interaction Sessions held on day-1 and also the share point folder containing recorded pre-recorded presentations.
Thanks for organising this workshop. Every institute shared their operational usage of Satellite and methodology, idea for the Tropical Cyclone.
I feel the exercise was the good part of the workshop.
COMPREHENSIVE
Good material and breakroom problems and discussion
The meeting was organized very efficiently. There were excellent experts, rich practice and sufficient communication time.
Many new satellite products. The methods were introduced in detail.
Share with specialist from all around the world, and know about how they work in the different RMSC. Great comunication between lecturers/presenters and the participants.
Bringing together researchers and forecasters. The ability for so many people to attend.
I like the breaking sessions most as it was really innovative. It is suggested that inputs submitted by the participants in the break sessions files of Day-1,2 & 3 may be incorporated in the final report along with the name of the participant who provided the input.
Fruitful presentations . Well organization.
Zoom enabled a much wider reach, all future ones should at least have a streaming option.
All the knowledge imparted, the new technologies for the future, deep learning making its way into TC analysis and forecasts, all the experience shared from the RSMC/TCWC. All in all, I can honestly say I loved this workshop very much.

The part that I like the most is how they showed the analysis methods and then shouted how the are used in the real world with examples.
Sharing the operation and research among operational centers and institutes is informative.
Breakout sessions through the meeting were so exciting, and giving participants the precious opportunity for discussion.
Exercise ADT SATCON DAY4
Presentations on new tools and techniques.
Best practice applications of satellite analysis techniques for operations using case studies.
Many countries sharing the information
satellite analysis techniques
Best practice applications of satellite analysis techniques for operations using case studies
The topic was interesting. But I personally need more preliminary exercise and knowledge about the topic.
The case studies in day-4.
learn about everything that is being done in relation to satellite information and the new products and tools available soon
AI TC intensity analysis and forecasts.
products for TC nowcasting and prediction
Day 3 - was fantastic where we went through the many satellite sensors to perform the task. I was unable to attend on Day 2 but suspect that would have been my favorite. Really enjoyed this event and thought it was one of the better meetings I have ever attended.
The virtual format meant that I was able to attend during what has been a very busy time of the year for me. If this were not virtual I would likely not have attended. On the other hand, the virtual format makes the time zone issue problematic with it being a very late night for those on the east-coast US and a very early morning for those around the Indian Ocean.
Good sharing of methods and knowledge from various warning center
Both the lectures and breakout rooms, as well as the inclusion of Meteorological organizations from around the world.
Hearing from the many different viewpoints on how the various TCWC's and RSMC's utilize satellite data and the emerging tech that's coming down the pipe.
The number of people across the tropical cyclone community who attended.
Interaction between forecasters and researchers.
I got many experience and knew many case studies. It was great.
The topic and lecture were very useful for me, the lecturer was very ardour.
Time
DAY1 AND DAY4
good interactions
Discussion and Q&A
Every presentation was good
The e-mail reminders 6/7 hours in advance and then 1/2 hour in advance just to ensure the time was correct, since all times were given in UTC and the start time changed between days.
Collaborating with international peers. Being able to participate since it was held online.
The "survey" of available tools and resources nature of the schedule.
Use of remote sensing for operational TC monitoring
I liked the most about the CB cloud observation based on the satellite image
I like the new technology and mesurements such as SAR, and want to know more detail about how to access and use SAR data.
The scientists who taught the modules.
It was so informative.
The exposure to what was going on in different countries
Very good
The availability of the archive of presentations for later use.

Q9. What suggestions do you have to improve this workshop?
Maybe every two years
Really miss face-to-face, but this meeting was OK!
Encourauge more feedback from the operational attendees, especially in the breakout rooms
Facilitate the establishment of a post-workshop communications platform to enable collaborative exchange between developers, researchers, and operational forecasters.

Maybe more spread out. 1-day for 3 h every 3 months... select focused topics
Better copy of zoom? We did have some technical issues. Still, we all survived and learned something.
A participation letter will be highly appreciated. Moreover it may be continued in virtual mode in coming years.
Online mode did allow greater participation however time zone difference was challenging. A physical workshop would definitely help along with yearly/bi-yearly workshops or expert talks with cases.
Make it more often. Also, Maybe make in-between workshops occasional 2-3- hour sessions just for 1 day
Everything's good
More frequent meetings, maybe shorter in duration, would be a good thing, particularly since satellites, datasets and practices are changing so rapidly right now.
During the breakout sessions I often found that very few people were actually contributing to the discussion. I'm not sure how to encourage those who weren't actively involved to do so, but I feel that hearing from more people is hugely beneficial.
It could have been better if there was no COVID-19 that we can all get together in a place and interact face-to-face
If the situation become better, I hope face-to-face meeting with online participants.
need more details and more explanation about the short form in slide for junior meteorologist
Similar workshops to other aspects of satellite based weather forecast
Even after COVID-19, hybrid meeting(both in-person and online)! possibly more often.
Face-to-face meeting might be more interactive.
IF THE PRESENTERS COULD GIVE MAX INFO WITHIN THE STIPULATED TIME
The in-person meetings will be more effective due to time differences.
It is suggested that we make full use of the new intensity evaluation criteria and methods found in geostationary meteorological satellites by pooling our wisdom
In the case of virtual workshop, the use of a platform more accesible from Cuba, because the US embargo we can't not access directly and it reduce the internet speed and sometimes it's not accesible.
"I think it works well and there is ongoing need for it. I hope WMO can continue to support it.
I was disappointed that operations prevented me attending the last day
This was an excellent workshop.
In addition I would like to suggest the following for your kind consideration.
a. The workshop proceedings, recommendations and final report may be placed in the WMO workshop website. It is requested to kindly include list of participants of the workshop in the final report.
b. The future sessions of this workshop may kindly be conducted in virtual mode or least in hybrid mode so as to enable interested persons to participate for greater exchange of knowledge.
c. Tutorial sessions can be included in the future sessions of this workshop.
d. In future sessions of IWSATC workshop, it is suggested that Working groups may be constituted from within interested participants on cyclone track and intensity forecasting, sensors, satellite observation, ocean observation, analysis techniques for preparing best practices report and other reports as deemed necessary.
e. Last but not the least a letter of participation may be issued on request as this is a high value workshop and participation in this workshop from knowledge and career perspective and can be mentioned in annual reports.
A. Hope the final report of IWTCSA-3 can list out all the linkage and demos to introduce the relevent sensor and scattermetors, like SAR. AMRS-2.
B. For better usage and evaluation of those retrieved 2-D winds, raw data should be given rather than images.
C. Group dicussion could be expand by adding some other topics and urgent demonds."
Hybrid format, in person and streaming.
Possibly every 2 years, stream and shorter, then next one both formats and longer every 4 years.
None. I would keep this format to reach a larger audience. Maybe a hybrid format would work too.
Just a better timing .

I understand that it can not be helped to hold the meeting online due to the COVID-19.
I hope that the meeting will be sometimes hold as face-to-face meeting in the future.
Interpretation in the WMO official languages, if not ask the presenter to speek clearly and slowly
Virtual meeting is not ideal in many aspects but one issue is linked to the difference in time zones. It would have been good to try to have more balance between the different time zones (it was perfect for people from WesPac region and Western U.S., much less for others...),i.e. having one session at a different and more convenient time for India and Africa region (+Europe)...
Make the time good for everyone
Each participant has different English language skills. The training organizer should send information or content to the participants in advance.
Because the trainees have different English skills. The training organizer should send information or content to the trainees in advance.
Need more basic-oriented presentation. In addition, need presenters who are explaining the topic more rigorously with patience.
Quarterly or half-yearly discussion on update on data/tools/application or typical cyclone cases for new kind of understanding.
that is done on another platform or in person
good enough.
It seems that a lot of countries other than those that speak English as a first language were reluctant to participate during the break-out groups except for La ReUnion. Not sure why but their participation would have made the experience richer.
instructors should emphasise more on satellite analysis techniques
Less time on the general overviews of the various centers, as most people who are in attendance already know in general what the other centers do. There was a lot of repeat that ate up time. Instead, more time should be devoted to what's "new", what's coming in the future, and discussion on new techniques, including more time for Q&A and interactive discussions.
Need a face-to-face component once the pandemic is over. There wasn't a lot of time for the more in-depth discussions that can occur at breaks and other social settings associated with face-to-face meetings.
It was perfect.
Add more practical exercise
More interactive platform
so far so good
It will be great to have pre and post-training to analyse scenario that was and may occur.
It was good
Improve break out room discussions. It was good to have discussions at the end of the workshops.
I DID NOT see Day 1, disregard answer. As for the workshop, no suggestions: but there is too much stuff out there and no comprehensive gouge on the various strengths/weakness/sources and techniques for using all the tools....a "Satellite-based analysis Tools for Dummies," if I may. As an operator, I have to dig around too much through too many disparate web-pages and papers. Thanks though, this was a really well-done workshop.
Few initial lectures should be intended for beginners who just ventured in this field
I would appreciate it if the next workshops were to take place during the period when everyone is awake and not at night, especially in Africa.
Some topic of the breakout sessions could be more specific.
Maybe make it regional.
Do it face to face .
The breakout rooms sessions needed a bit more planning
Nothing special.

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