

TROPICAL CYCLONE FORECASTING AND IMPACT ALERTING

Senior Management and Operation Course on Tropical Cyclone
Monitoring and Forecasting

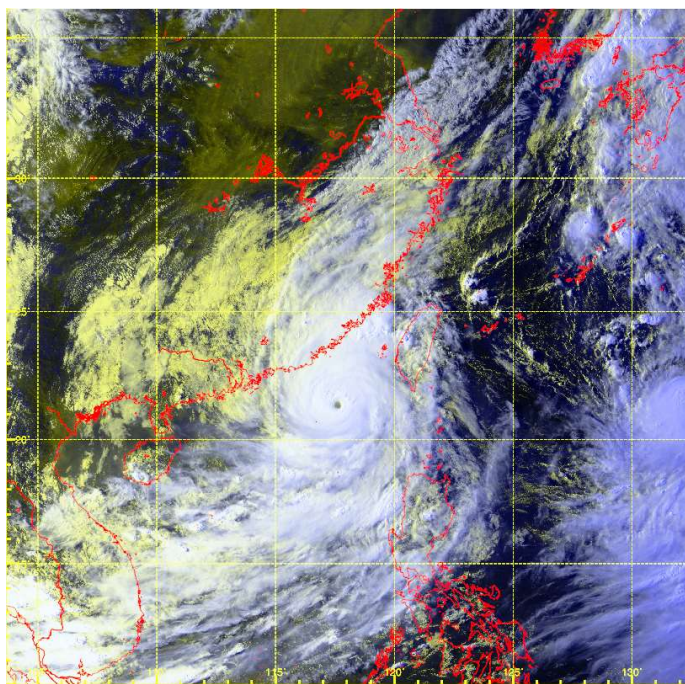
21 November 2023

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Scientific Officer

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FROM WEATHER OBSERVATIONS TO ACTION

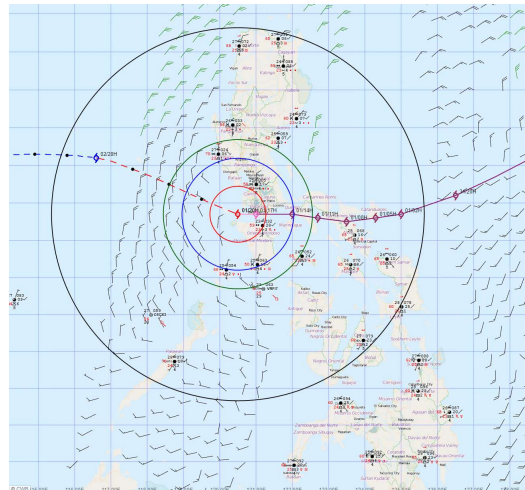


Super Typhoon Saola



Hong Kong Civil Aid Service

TROPICAL CYCLONE FORECASTING PROCESS



Analysis

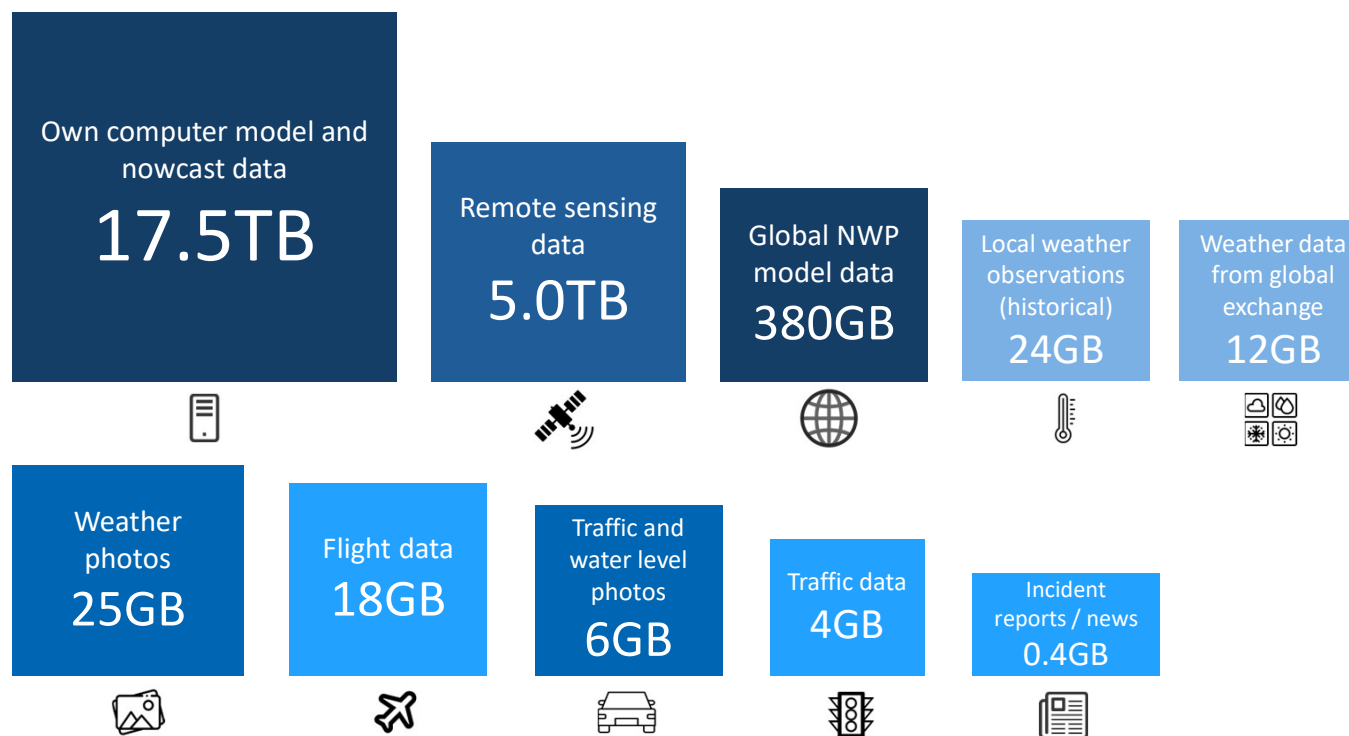


Track, intensity
and impact
forecast



Delivery of
warning
messages

THE WEATHER BIG DATA



TROPICAL CYCLONE FORECASTING AND IMPACT ALERTING

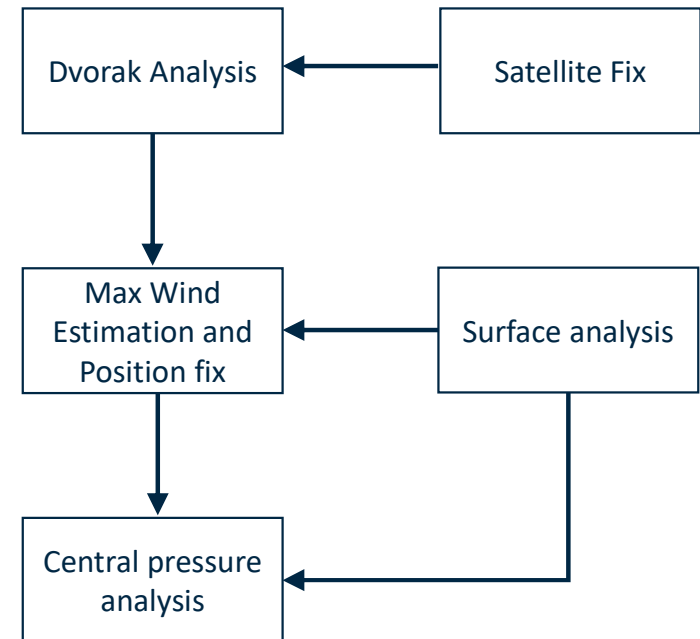
TOPICS

Tropical Cyclone Analysis	1
Tropical Cyclone Forecasting	2
Warning and Message Delivery	3
Systems and Tools for Forecasters	4
Impact Monitoring and Alerting	5

TROPICAL CYCLONE ANALYSIS

Operational TC analysis usually involves the following:

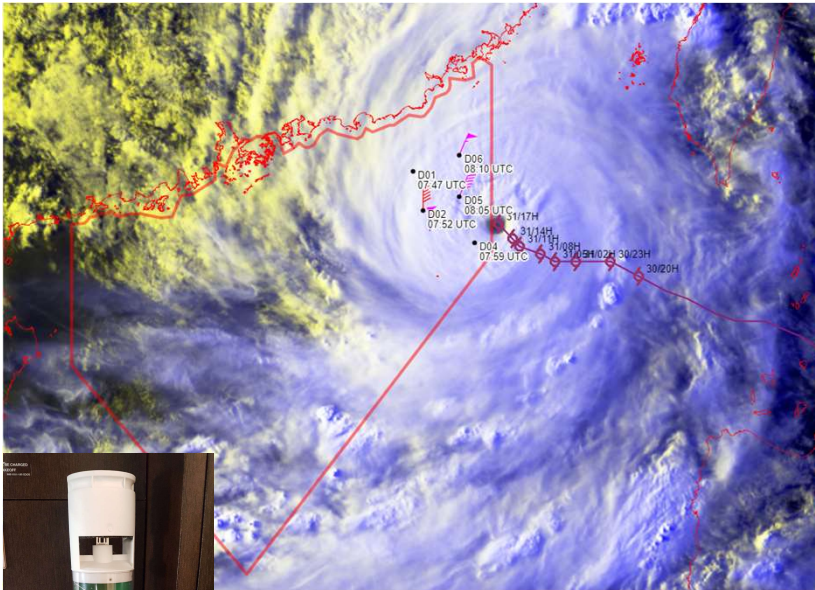
- Determine the centre location of the TC and deduce its movement
- Estimate the intensity of the system in terms of maximum winds
- Assess the size of the TC



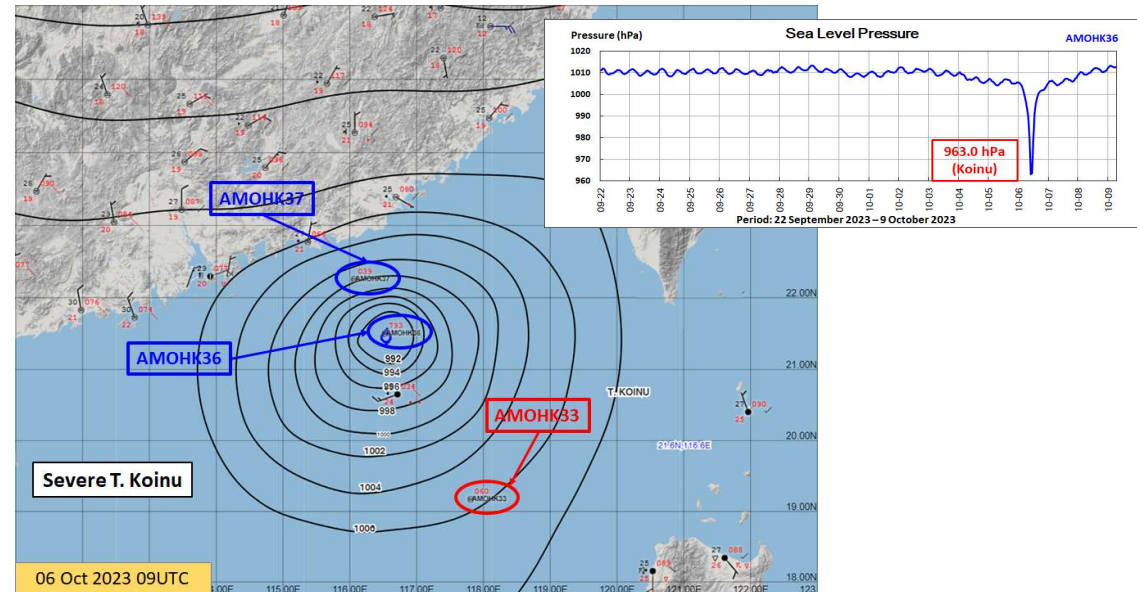
Typical TC analysis workflow

TROPICAL CYCLONE MONITORING

- Filling the gaps of observations over seas



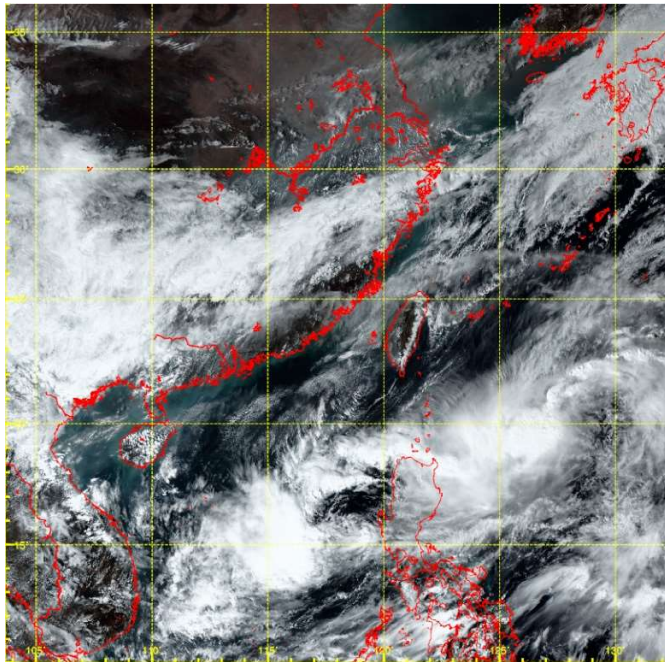
Dropsonde flights for TC Saola (31 Aug 2023)



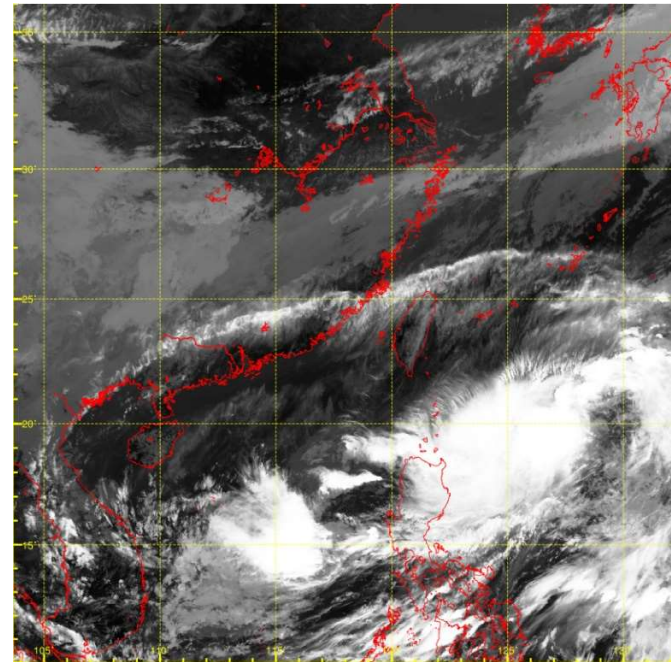
Drifting buoy observations during the passage of TC Koinu (Oct 2023)

USE OF SATELLITE IMAGERIES

- Low-level circulation centre is often more discernible on visible imageries



True Colour

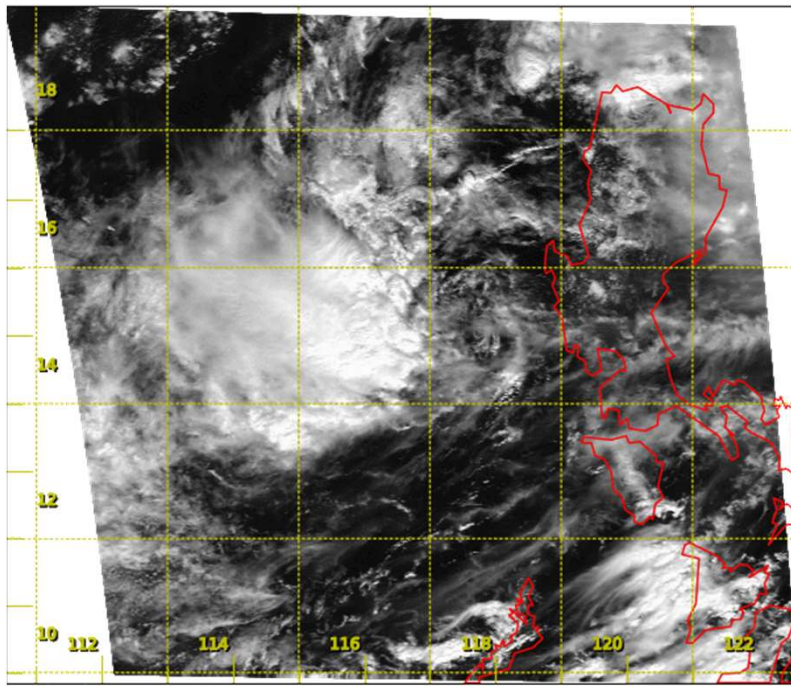


Infra-red

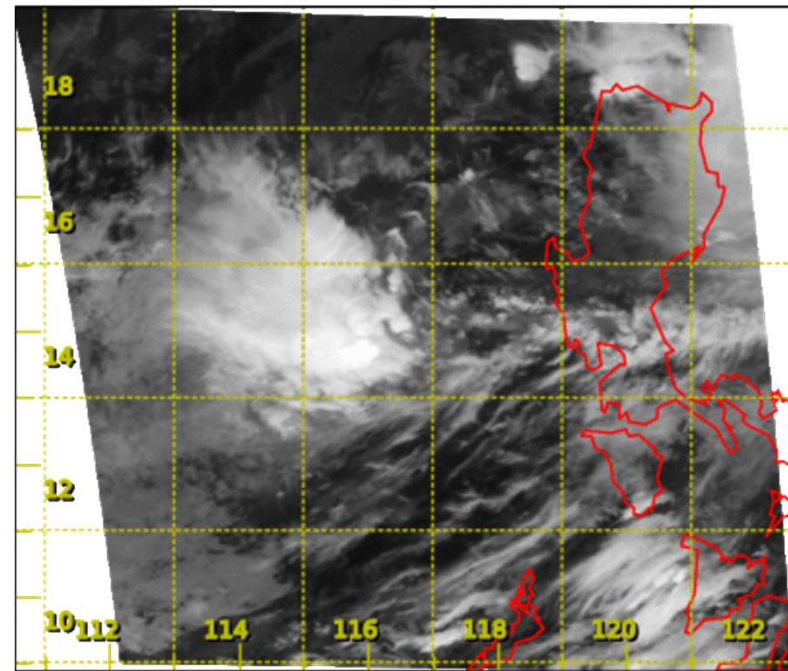
TC Goni 2 Nov 2020 0550 UTC

USE OF SATELLITE IMAGERIES

- Rapid scan animation may help identify the centre



Visible rapid scan



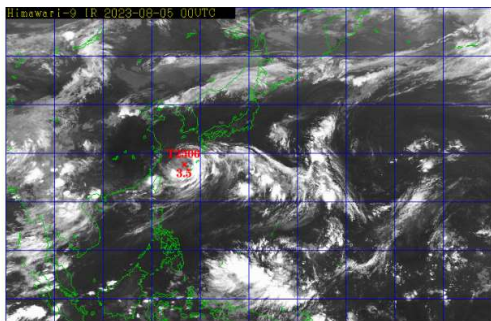
Infra-red rapid scan

MICROWAVE IMAGERIES

Numerical Typhoon Prediction Website

RSMC Tokyo - Typhoon Center

HOME	RSMC Advisories	Remote Sensing	Atmospheric Circulation	Ocean Condition	Numerical TC Prediction	Marine Forecast	Publication	Data
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About this site

The Numerical Typhoon Prediction (NTP) Web Site presents numerical predictions of tropical cyclone tracks performed by major NWP centers in the world, and other products useful for tropical cyclone analysis and forecast. This service is provided as part of the activities of the RSMC Tokyo - Typhoon Center for the ESCAP/WMO Typhoon Committee (TC) to facilitate better tropical cyclone forecasting and warning operations by its Members.

Communication platform

Click [here](#) to log-in to the communication platform between the RSMC Tokyo-Typhoon Center and Typhoon Committee members.

RSMC Tokyo Numerical Typhoon Prediction Website
<https://tynwp-web.kishou.go.jp/index.html>
 (Available for Typhoon Committee members)

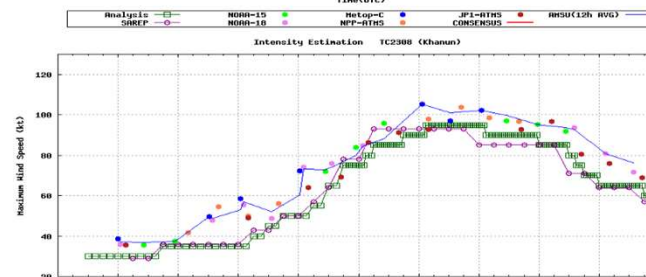
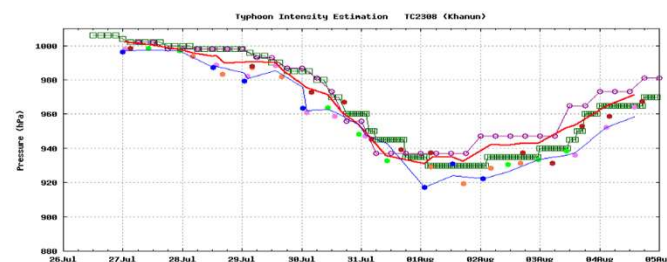
Remote sensing > Microwave:

Snapshot and Cross section images of tropical cyclones EDA020(T2306) Khanun

Num	Date	Time (UTC)	Operational (time interpolation)		Satellite	Imager	Sounder						Himawari	IR (B&W) (Color)	STW (K)	Cross section	
			Lat. (deg)	Lon. (deg)			37GHz H	37GHz V	89GHz H	89GHz V	PCT 37GHz	PCT 89GHz				E-W	N-S
164	04	AUG 22:33	27.8	126.7	NOAA-15	AMSU									4.617186	WE	NS
163	04	AUG 22:26	27.8	126.7	DMSP17	SSMIS	37GH	37GV	89GH	89GV	PCT37	PCT89	VIS	B&W Color			
162	04	AUG 20:26	27.8	126.5	DMSP18	SSMIS	37GH	37GV	89GH	89GV	PCT37	PCT89		B&W Color			
161	04	AUG 20:25	27.8	126.5	DMSP18	SSMIS	37GH	37GV	89GH	89GV	PCT37	PCT89		B&W Color			

Typhoon intensity estimation by Microwave image EDA020(T2306) Khanun

time-sequence diagram [amsu table](#) [atms table](#)



[Development of a product based on consensus between Dvorak and AMSU tropical cyclone central pressure estimates at JMA](#)

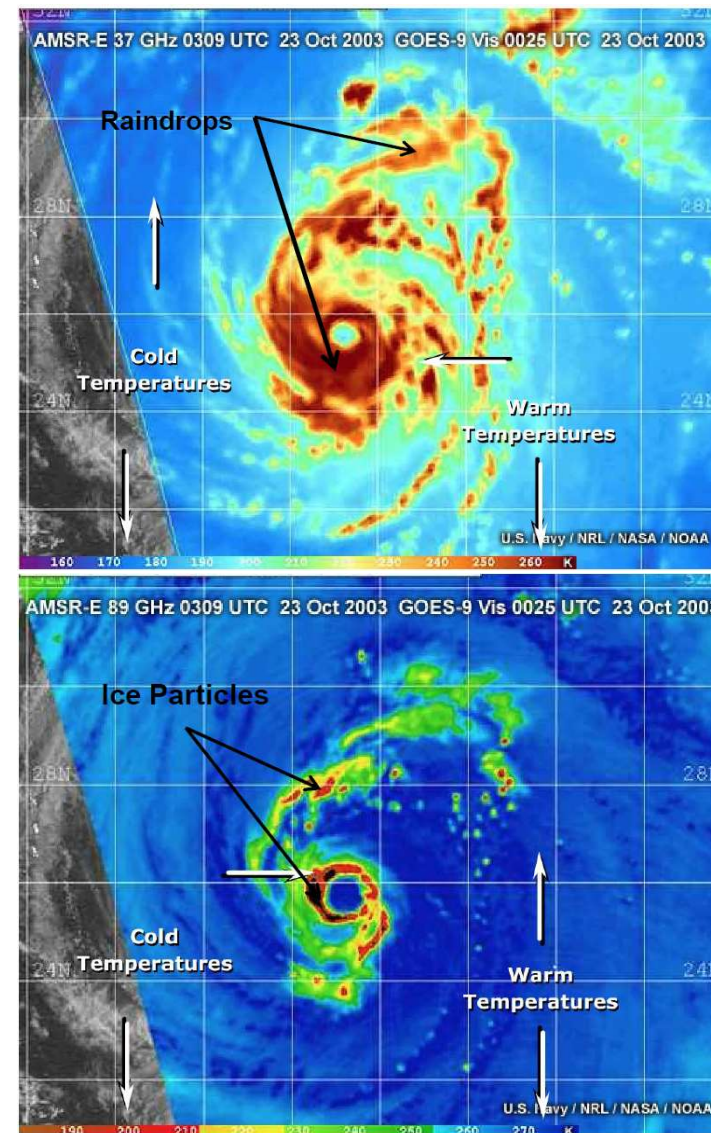
MICROWAVE IMAGERIES

- For lower frequencies, (~ 37 GHz):
 - water surfaces (e.g. ocean) have low emissivity (~ 0.4 - 0.5) and appear “cool” at microwave frequencies
 - land surfaces have a much greater emissivity (~ 0.9) and appear “warm”
 - **raindrops** have high emissivity and are “warmer” than they contrast against a “cooler” ocean background

Detects low-level cloud / raindrop distribution

- For higher frequencies (~ 85 GHz):
 - microwaves are scattered by **ice particles** in precipitating clouds, reducing the return energy and subsequently appear “cold”.

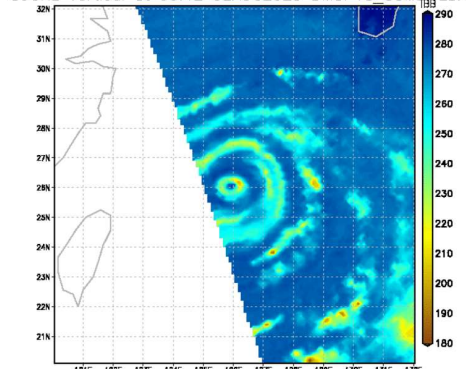
Detects deep convective cloud structures



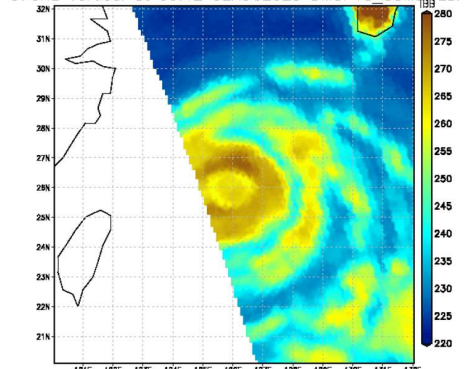
MICROWAVE IMAGERIES: TC KHANUN, AUG 2023

T Khanun (on 2 August 2023, 06Z)

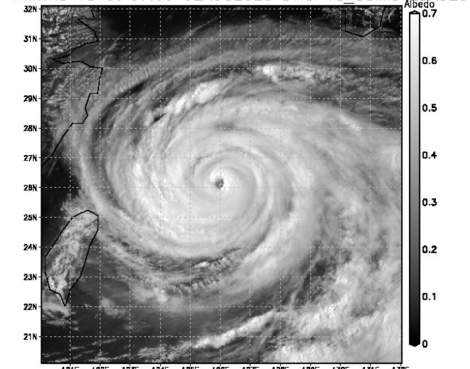
89GHz Vertical at 06:42 02AUG2023 DMSP18_SSMIS_EDA



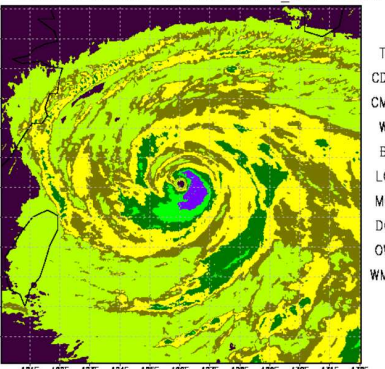
37GHz Vertical at 06:42 02AUG2023 DMSP18_SSMIS_EDA



HMWR8 VS at 07:00 02AUG2023 DMSP18_SSMIS_EDA020

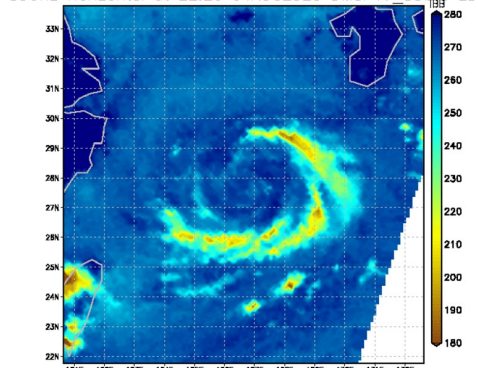


HMWR8 IR at 07:00 02AUG2023 DMSP18_SSMIS_EDA020

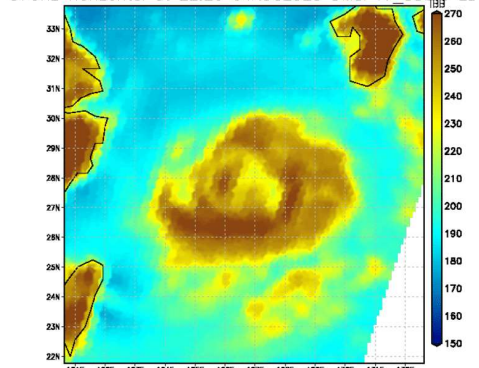


STS Khanun (on 4 August 2023, 22Z)

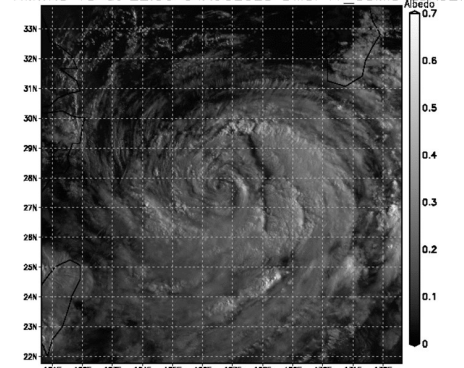
89GHz Horizontal at 22:26 04AUG2023 DMSP17_SSMIS_ED



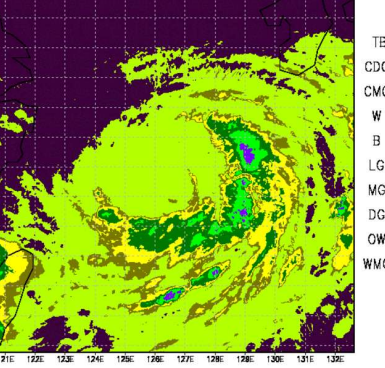
37GHz Horizontal at 22:26 04AUG2023 DMSP17_SSMIS_ED



HMWR8 VS at 22:30 04AUG2023 DMSP17_SSMIS_EDA020

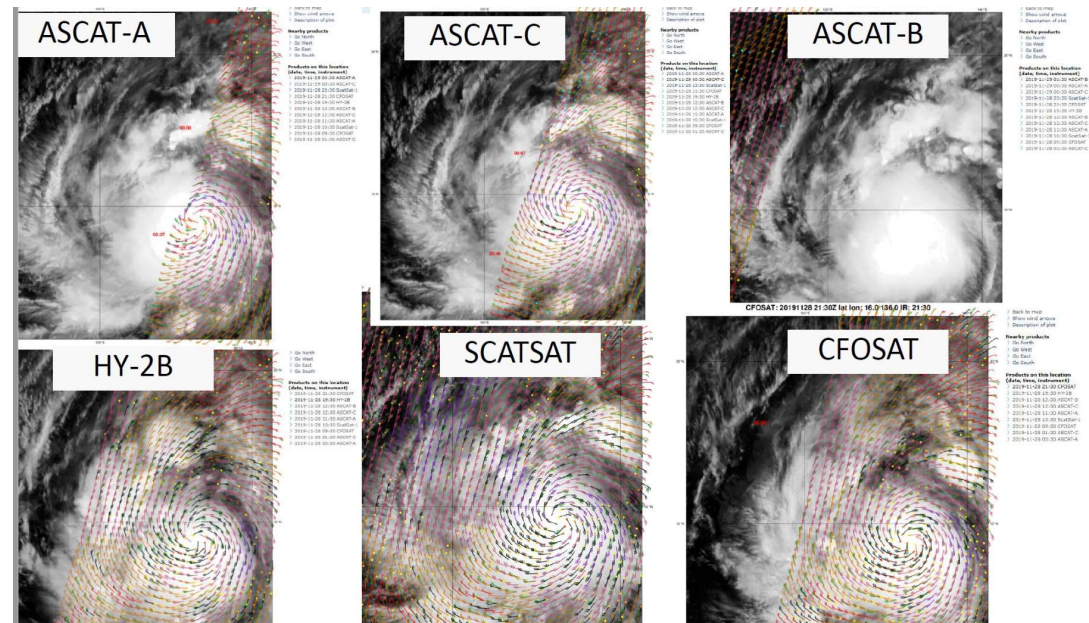
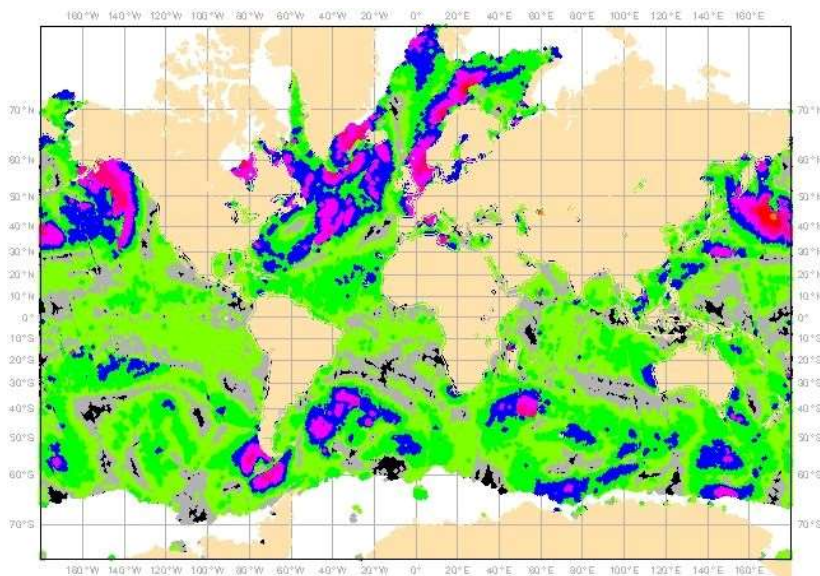


HMWR8 IR at 22:30 04AUG2023 DMSP17_SSMIS_EDA020



OTHER REMOTE SENSING PRODUCTS

- Scatterometer provides estimates of global *vector* wind field at resolution of 12.5 to 50 km



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

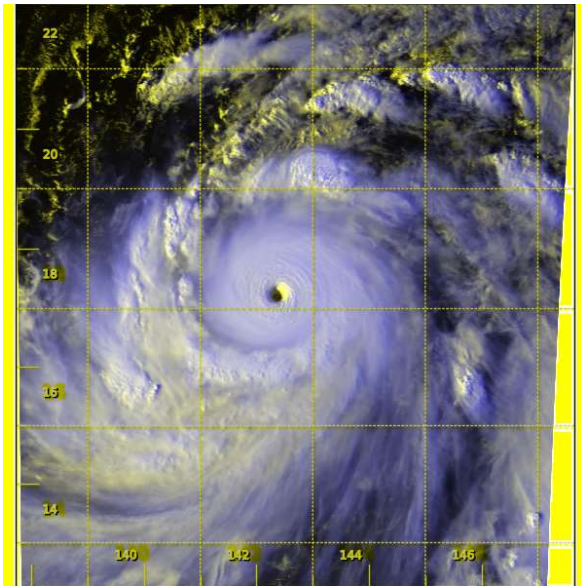
Scatterometer wind fields for TC Kammuri (2019)

Courtesy: Joe Courtney

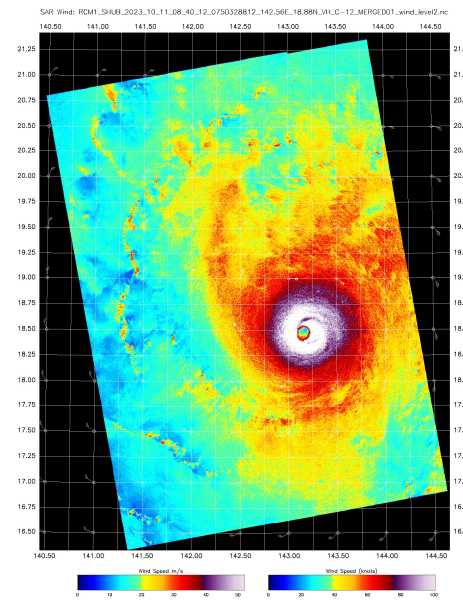
(Note: ASCAT-A; SCATSAT now decommissioned)

OTHER REMOTE SENSING PRODUCTS

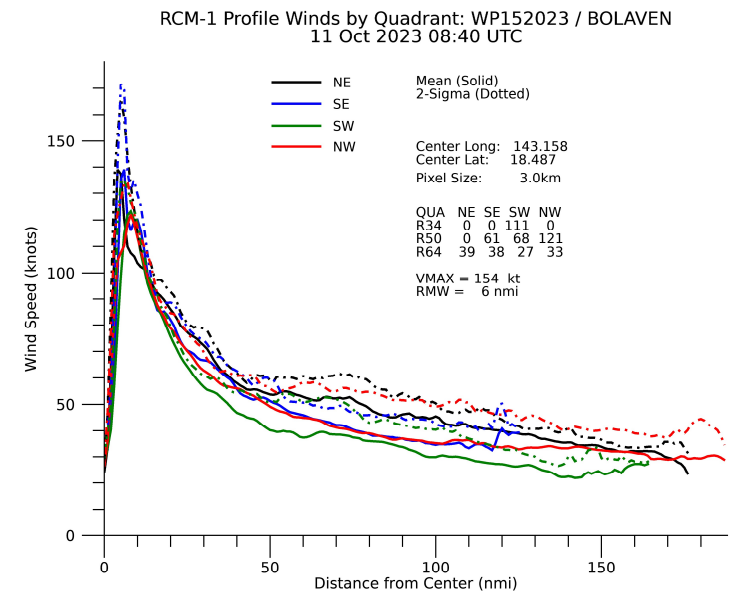
- Synthetic aperture radar provides high-resolution (0.1 – 3km) surface wind speed estimates and can capture the fine structure of the core of the TC



TC Bolaven (October 2023)



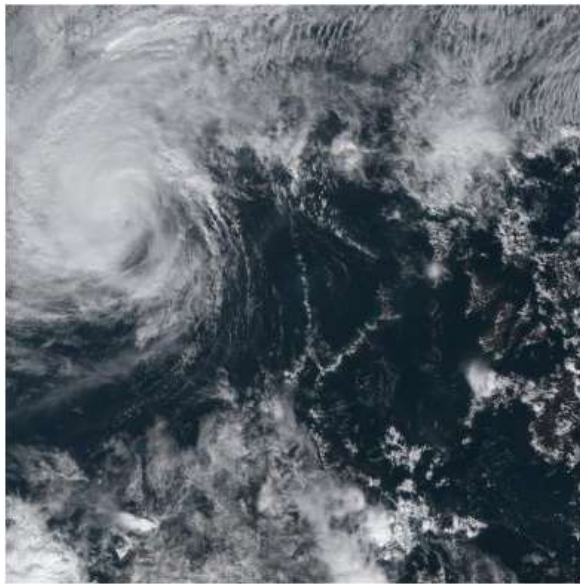
NOAA/NESDIS/STAR/2023/10/12/17:35:06 UTC
 BOLAVEN is an official mark of the Canadian Government
 Environment Canada / Environnement Canada



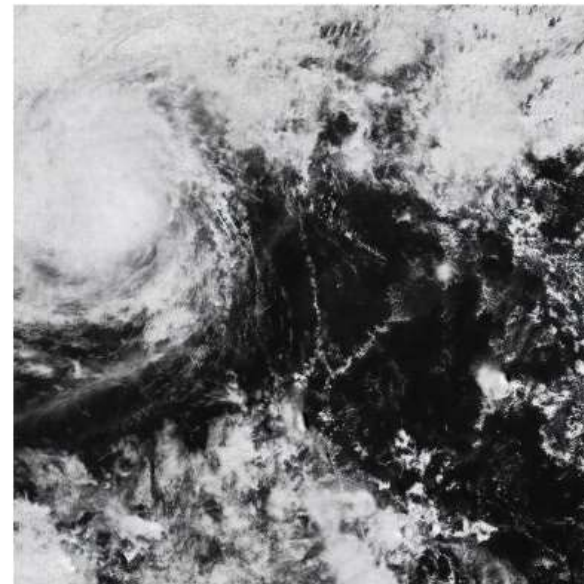
https://www.star.nesdis.noaa.gov/socd/mecb/sar/sarwinds_tropical.php

USE OF AI AND MACHINE LEARNING IN TC ANALYSIS

- “Virtual” visible satellite imageries during nighttime generated using conditional generative adversarial networks (CGAN), a deep learning technique



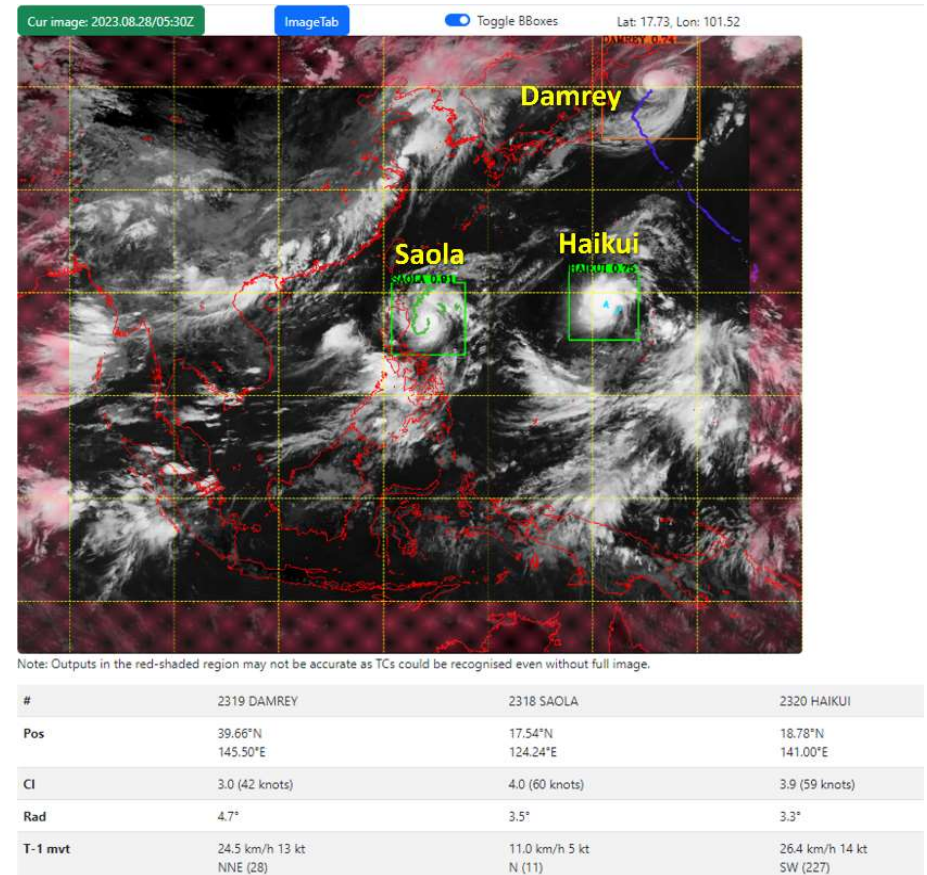
True colour imagery



Virtual visible imagery

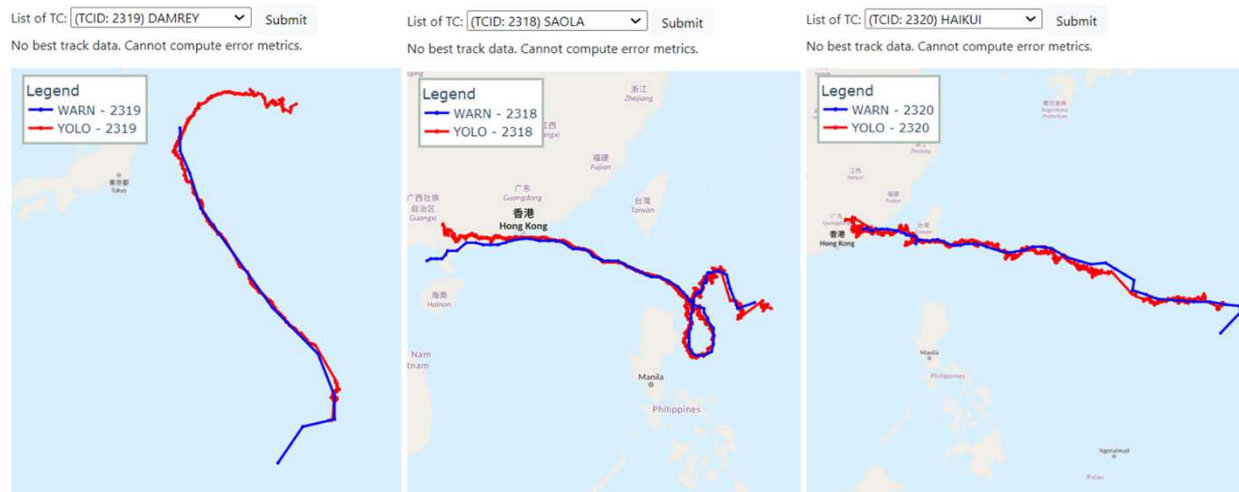
USE OF AI AND MACHINE LEARNING IN TC ANALYSIS

- Automatic TC analysis tool using AI techniques
 - Objective detection models for detecting TC location
 - Convolutional Neural Network (CNN) for current intensity (CI) estimation
 - Trained with satellite images and TC information from 2015 to 2021



USE OF AI AND MACHINE LEARNING IN TC ANALYSIS

- Verification for 15 TCs in the western North Pacific in 2022 showed a hit-rate of around 70% within 0.5 degrees absolute position error (APE) for all cases and a mean APE of 0.25 degrees for typhoon or stronger TCs. The trend in TC intensity change can be generally captured with a mean error in CI within 1.



Comparison of the automatically detected TC tracks (red line) for Saola (2318), Damrey (2319) and Haikui (2320) by AI-STORMVIS against HKO warning positions (blue)

TC INTENSITY CLASSIFICATION

Comparison of the Tropical Cyclone Classification							
Maximum Sustained Wind Speed near the centre of the tropical cyclone			western North Pacific				North Atlantic, central/eastern North Pacific
			Hong Kong, China (10-minute average)	China (2-minute average)	Japan (10-minute average)	United States (1-minute average)	United States (1-minute average)
kt	km/h	m/s	HKO	CMA	RSMC, Tokyo	JTWC	CPHC, NHC
< 34	< 63	< 17.1	Tropical Depression (TD)				
34 – 47	63 – 87	17.2 – 24.4	Tropical Storm (TS)			Tropical Storm	
48 – 63	88 – 117	24.5 – 32.6	Severe Tropical Storm (STS)				
64 – 80	118 – 149	32.7 – 41.4	Typhoon (T)		Typhoon 64 – 84 kts	Typhoon 64 – 129 kts	Hurricane categories 1: 64 – 82 kts
81 – 99	150 – 184	41.5 – 50.9	Severe Typhoon (ST)				Very Strong Typhoon 85 – 104 kts
≥ 100	≥ 185	≥ 51.0	Super Typhoon (SuperT)		Violent Typhoon ≥ 105 kts		3: 96 – 112 kts
							4: 113 – 136 kts
						Super Typhoon ≥ 130 kts	5: ≥ 137 kts

Note: the conversion between kt to km/h and kt to m/s may vary slightly subject to rounding practices and conversion factor decimal places.

	HKO	RSMC-Tokyo	JTWC	CMA
Record Period	1961 - 2013	1951 - 2013 ¹	1945 - 2013	1949 - 2013
Averaging period for MSW	10 min.	10 min.	1 min.	2 min.
Conversion factor to 10-min MSW	1	1	0.93 ³	0.96 ⁴

3,4 Harper et al. (2010) Guidelines for converting between various wind averaging periods in tropical cyclone conditions. Tropical Cyclone Programme Report WMO/TD-No.1555, WMO

TROPICAL CYCLONE FORECASTING AND IMPACT ALERTING

TOPICS

Tropical Cyclone Analysis

1

Tropical Cyclone Forecasting

2

Warning and Message Delivery

3

Systems and Tools for Forecasters

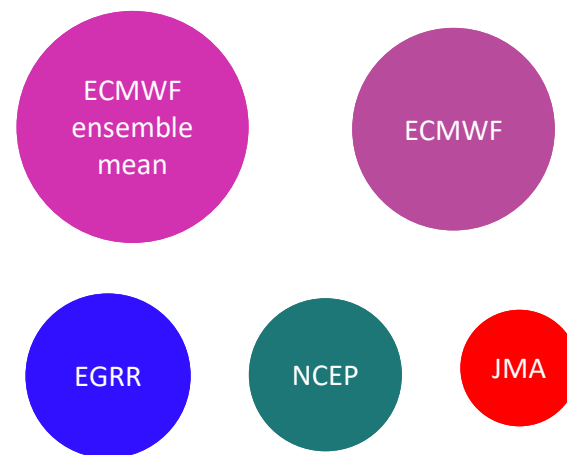
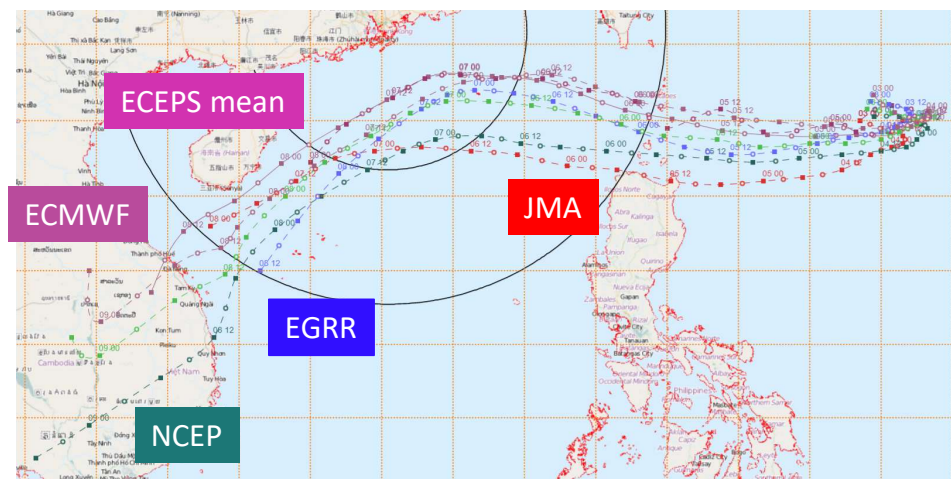
4

Impact Monitoring and Alerting

5

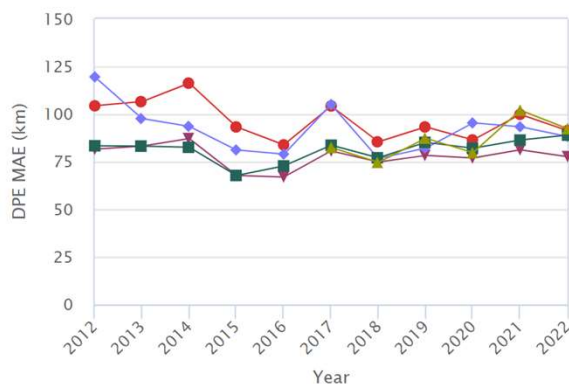
TRACK FORECASTING

- Multi-model ensemble track (or consensus) serves as the base reference at major warning centres in the formulation of subjective TC forecast track.
- A 5-member weighted ensemble has been used at HKO since 2018, with composition and weighting of models being reviewed each year based on their recent past performance.
- Subjective forecasts may deviate from the consensus in some situations, for example substantial divergence among models, persistent bias in position and/or speed.



DETERMINISTIC TRACK FORECAST PERFORMANCE

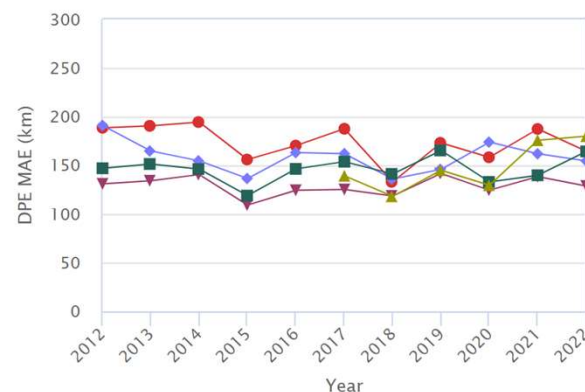
Historical comparison of DPE for T + 24



1. ECMWF
2. EGRR
3. NCEP
4. JMA
5. KMA

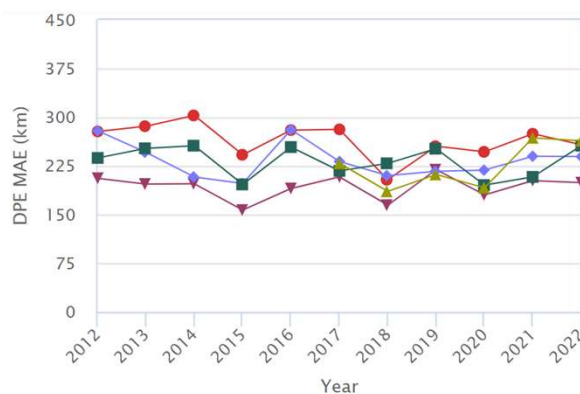
ECMWF JMA EGRR NCEP KMA

Historical comparison of DPE for T + 48



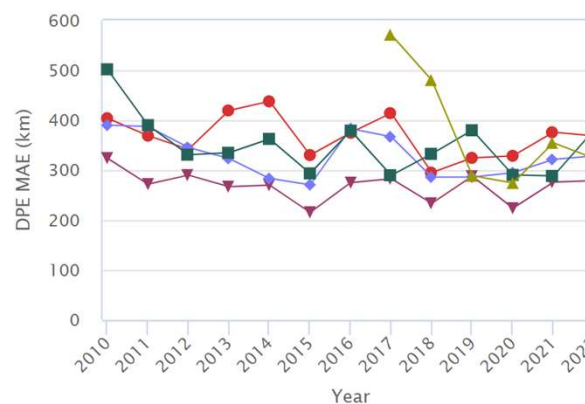
1. ECMWF
2. EGRR
3. NCEP
4. JMA
5. KMA

Historical comparison of DPE for T + 72



1. ECMWF
2. EGRR
3. NCEP
4. JMA
5. KMA

Historical comparison of DPE for T + 96

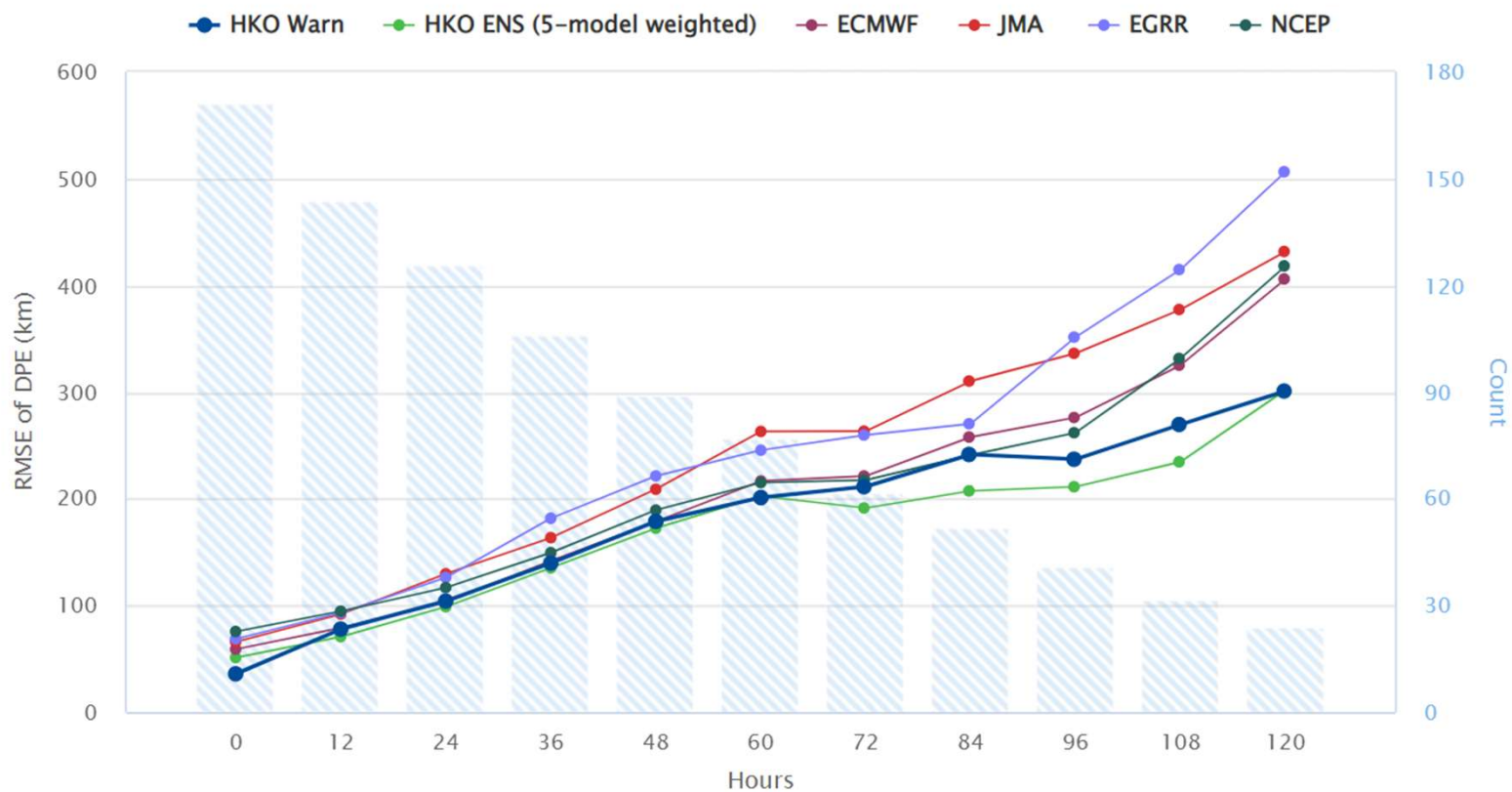


1. ECMWF
2. KMA
3. EGRR
4. JMA
5. NCEP

DETERMINISTIC TRACK FORECAST PERFORMANCE

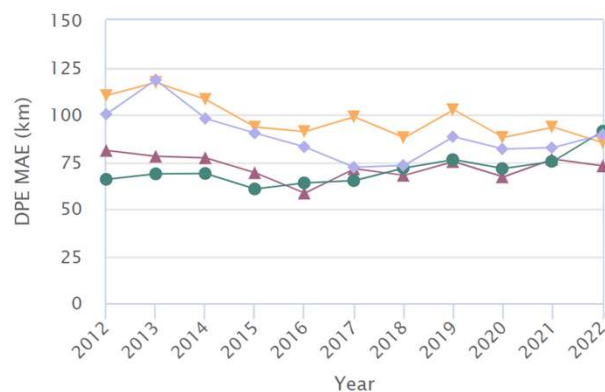
2022 TC Track Verification [CDS]

Best Track (Model +12 hours)



ENSEMBLE TRACK FORECAST PERFORMANCE

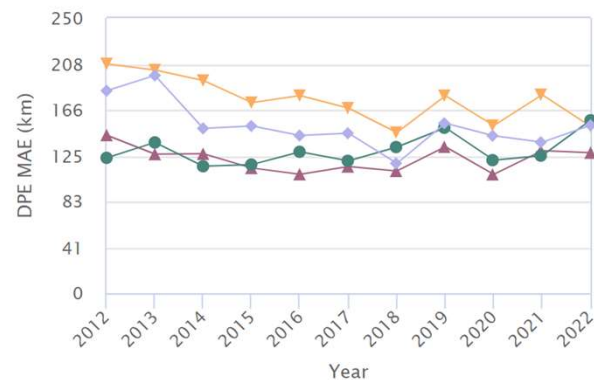
Historical comparison of DPE for T + 24



1. EC EPS
2. JMA EPS
3. EGRR EPS
4. NCEP EPS

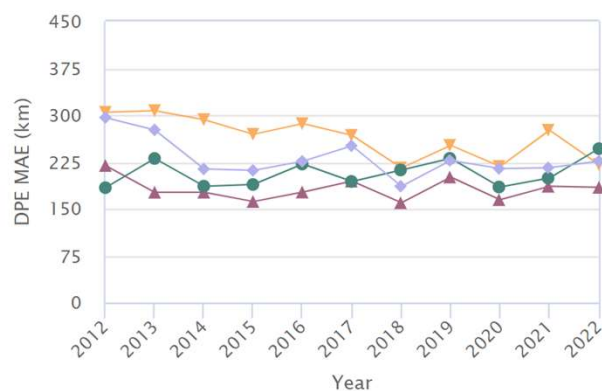
ECMWF EPS JMA GEPS EGRR EPS NCEP EPS

Historical comparison of DPE for T + 48



1. EC EPS
2. JMA EPS
3. EGRR EPS
4. NCEP EPS

Historical comparison of DPE for T + 72



1. EC EPS
2. JMA EPS
3. EGRR EPS
4. NCEP EPS

Historical comparison of DPE for T + 96

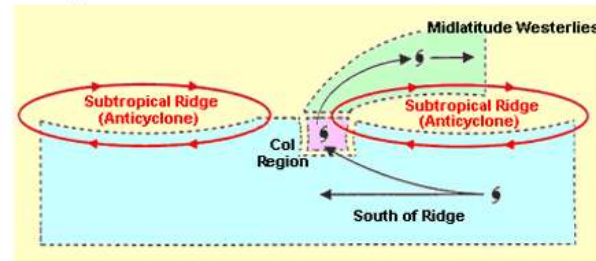


1. EC EPS
2. JMA EPS
3. EGRR EPS
4. NCEP EPS

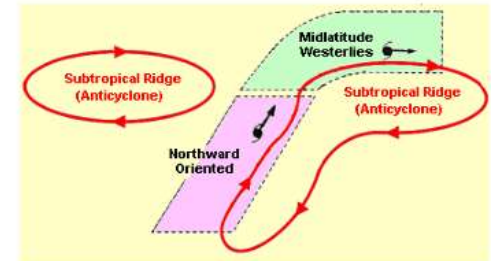
TIPS FOR TRACK FORECASTING

- Interpret models' forecasts on the characteristics of steering mechanisms at different vertical levels
- Diagnose / verify model performance in recent runs on reasons to take weighting in formulating forecast story
- (Near) real-time verification on direct, along-track, cross-track error
- Make use of EPS on alternative scenarios

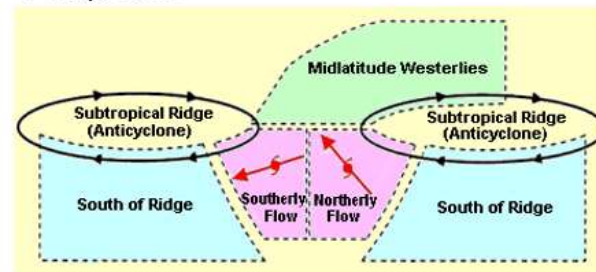
Ridge Pattern



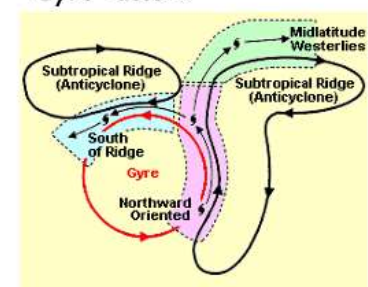
Northward Pattern



Multiple TCs

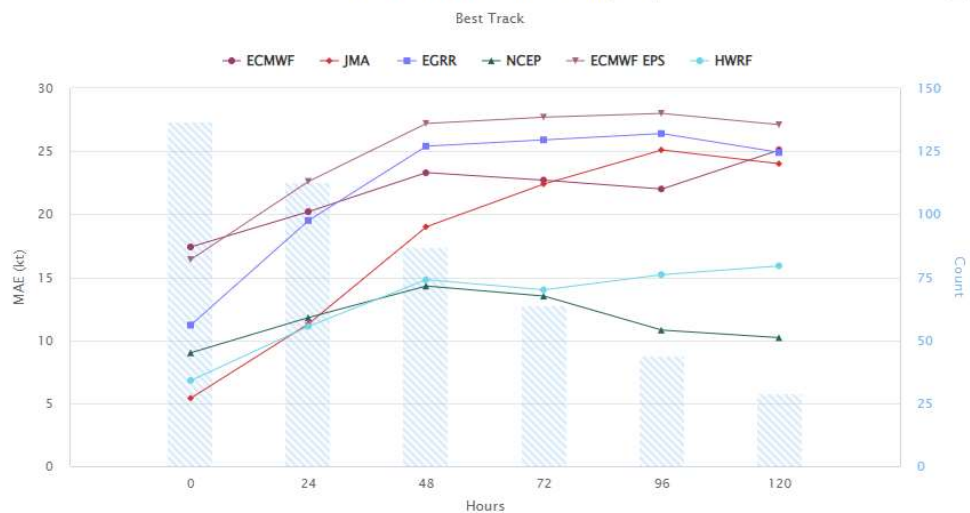


Gyre Pattern

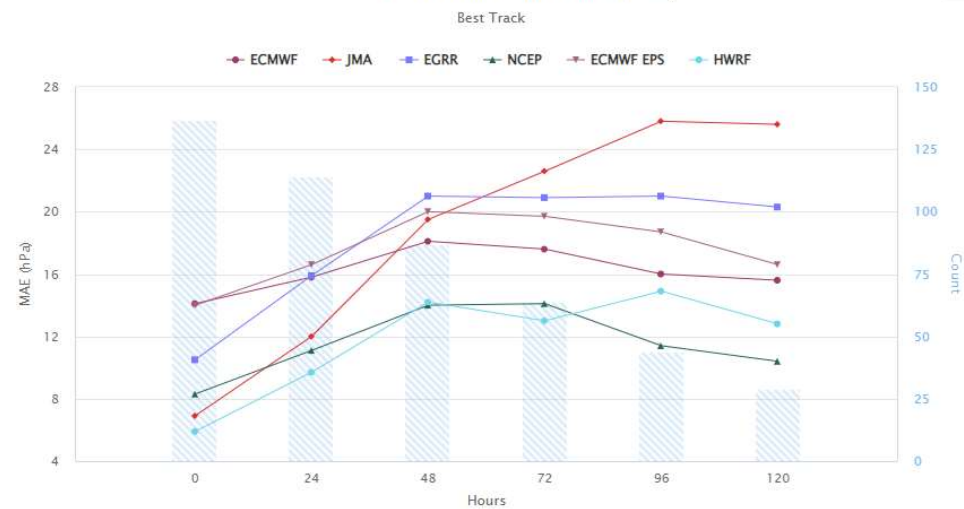


MODEL INTENSITY FORECAST PERFORMANCE

2022 Max. Wind Verification [CDS]

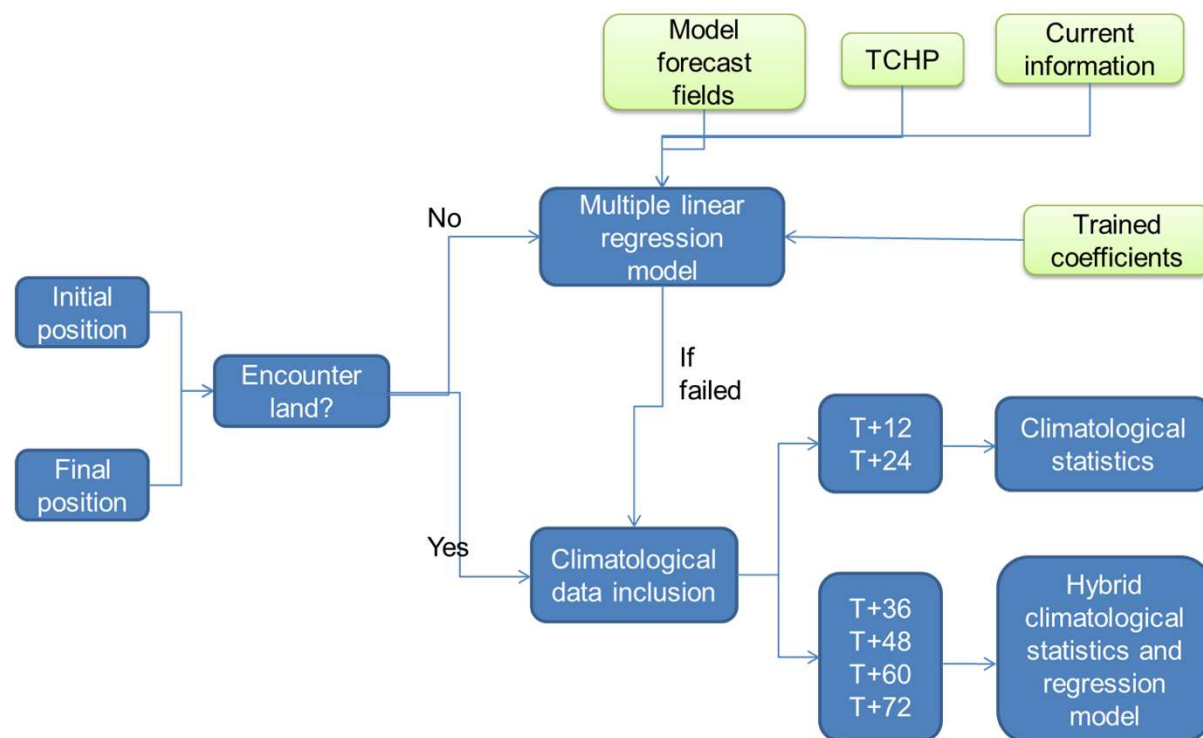


2022 Min. Pressure Verification [CDS]



INTENSITY FORECASTING: USE OF MODELS

- Dynamical models
 - Solving the governing equations for the atmosphere and ocean
 - Examples: ECMWF, JMA, NCEP, UKMO, HAFS ...
- Statistical-dynamical models
 - Usually based on climatology, persistence and statistical relationships to current and forecast environmental conditions
 - Examples: SHIPS used by NHC, TINT used by HKO



PREDICTOR POOL FOR TINT

	Predictors		
Position	Latitude (lat)		Longitude (lon)
Season	Day of year (jday)		
Cyclone history	Current intensity (intensity)	Previous 12 hour change in intensity (prevchange12)	Previous 12 hour zonal component of TC speed (Zonal_speed)
Atmospheric dynamics	200hPa divergence (200div)		850hPa relative vorticity (850vor)
Moisture	850-700hPa average RH (850-700RH)		500-300hPa average RH (500-300RH)
Wind shear	850-200hPa spacemean vertical wind shear (850-200vertshr)		
Ocean heat content	Tropical cyclone heat potential (TCHP)		

RAPID INTENSIFICATION

- Rapid Intensification (RI) is commonly defined by the 95th percentile of intensity change (e.g. Kaplan et al. 2010), e.g. RI over the Atlantic and ENP basins would be +30 kt / 24 hrs (1-min average)
- After converting to the WMO 10-min average, RI definition in the western North Pacific and the South China Sea adopted in the study will be :

Hours	WNP	Atlantic
12 hours	+ 15 kt	+ 20 kt
24 hours	+ 25 kt	+ 30 kt
36 hours	+ 40 kt	+ 45 kt
48 hours	+ 50 kt	+ 55 kt

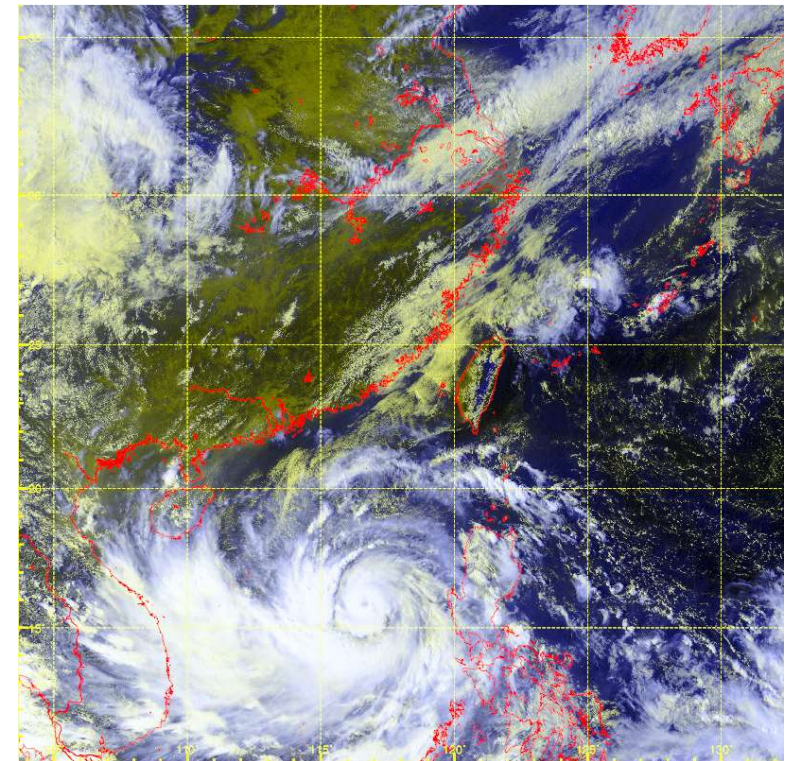
(Reference : J. Kaplan, M. DeMaria, and J. A. Knaff, 2010: A Revised Tropical Cyclone Rapid Intensification Index for the Atlantic and Eastern North Pacific Basins. *Wea. Forecasting*, **25**, 220-241.)

PREDICTORS FOR RAPID INTENSIFICATION

- Incorporate atmospheric, oceanic factors and TC characteristics
- Performance optimized
- Correlation between predictors minimized

Category	Predictors (Total: 6 predictors)
Ocean	Tropical Cyclone Heat Potential (TCHP) nearest to the TC
Atmosphere (from ECMWF ERA-Interim reanalysis)	200hPa divergence averaged over 9° radius 300-500hPa RH averaged from 2° to 7° radius 200-850hPa Space Mean Vertical Wind Shear (VWS) averaged over 5° radius
TC characteristics	Persistence (previous 12-hour intensity change) Current Intensity (Actual analysis)

EXAMPLE: TROPICAL CYCLONE NORU (SEP 2022)



EXAMPLE: TROPICAL CYCLONE NORU (SEP 2022)

TINT Rapid Intensification Module (TINT-RI)

2022 ▾ Noru(HKID2227) ▾ 2022092212Z ▾ Oceanic Predictor: TCHP ▾

TINT-RI Forecast for Noru at 2022092212Z (TCHP)

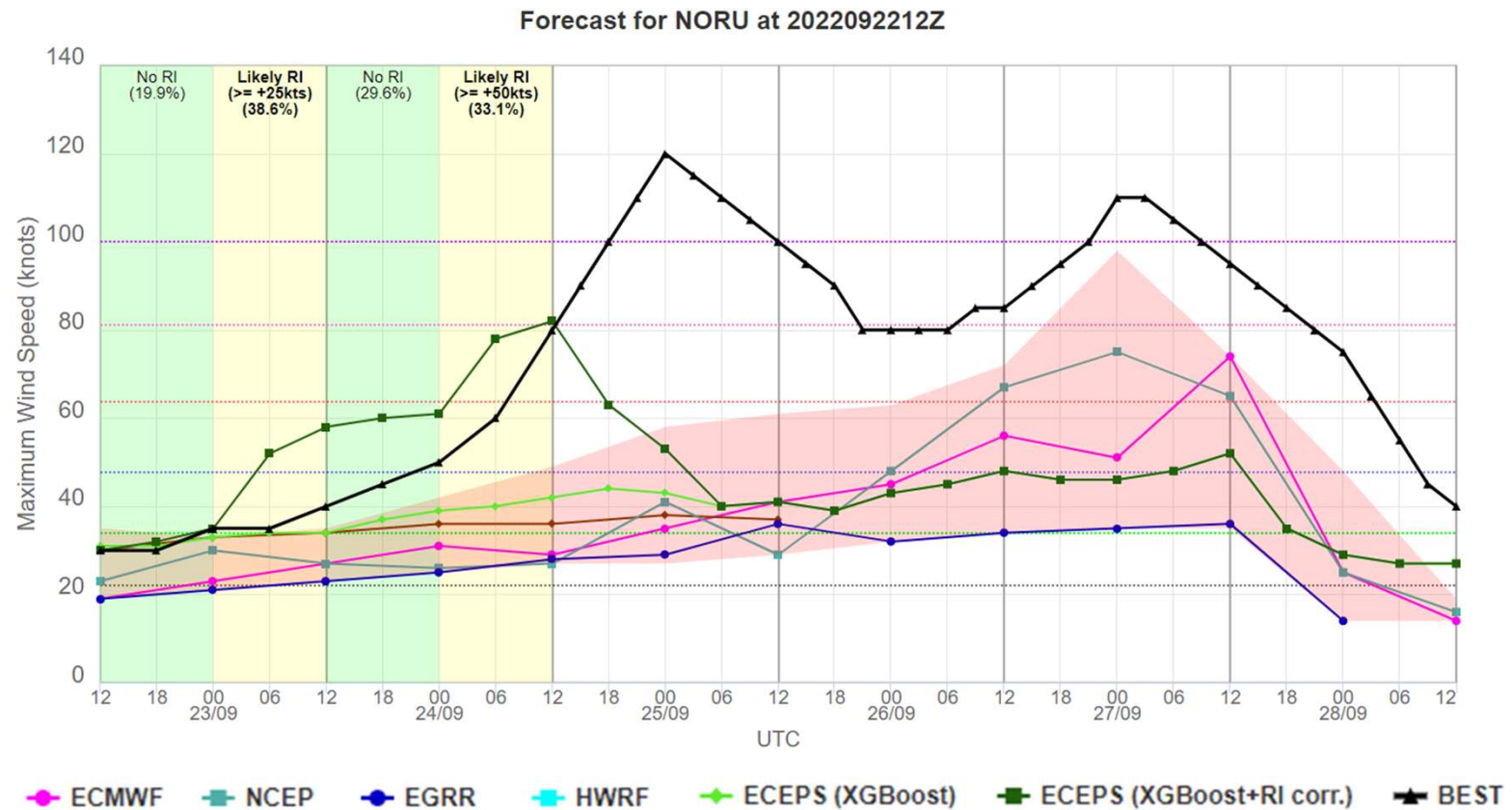
Warning: This is an early guidance based on spare persistence/current intensity data. This guidance maybe less reliable.

	T+12 2300Z	T+24 2312Z	T+36 2400Z	T+48 2412Z
RI Forecast	No	Likely	No	Likely
Intensity gain from T+0 (T+0: 30 knots)	---	>=25knots	---	>=50knots
TINT intensity gain rule	Passed	Passed	Passed	NA
Change of VWS rule	Passed	Passed	Passed	Passed
RI Probability	19.9%	38.6%	29.6%	33.1%
Actual RI Occurrence based on Best track (Intensity gain)	N	N	N	Y(50knots)

Predictors (Click to show box plot!)	Min.	Median	Max.	Current Value
Persistence	-5	10	35	4.185
200hPa divergence(10^{-6})	-3.15	5.54	16.24	3.78
500-300hPa avg. RH	29.0	66.7	83.6	63.8
850-200hPa VWS	14.5	5.2	0.2	3.8
TCHP	0	93.78	156.69	104.372
Current Intensity	25	55	115	30

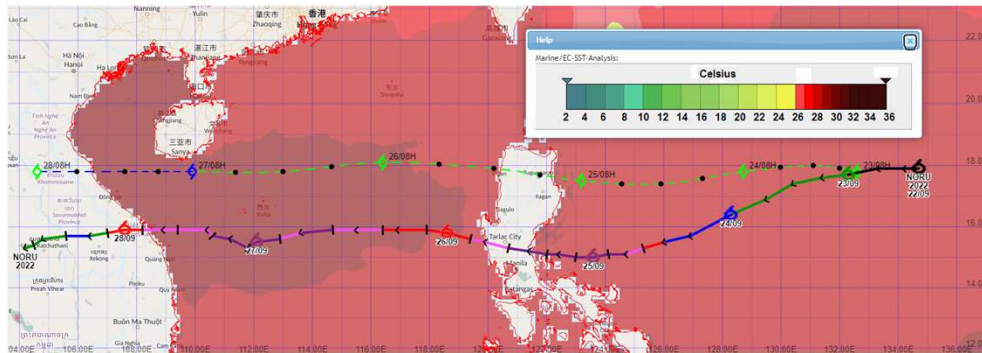
[Raw Data](#)

EXAMPLE: TROPICAL CYCLONE NORU (SEP 2022)

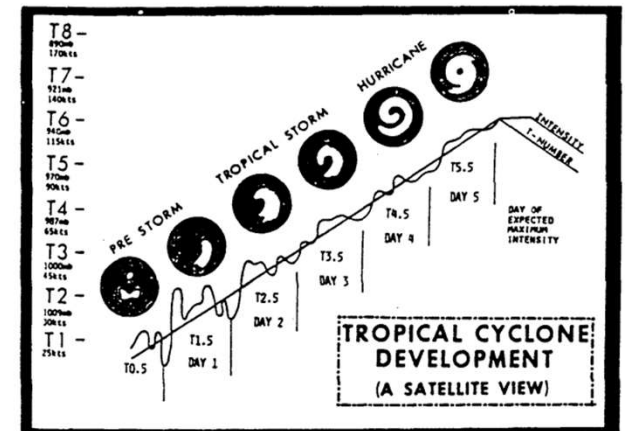
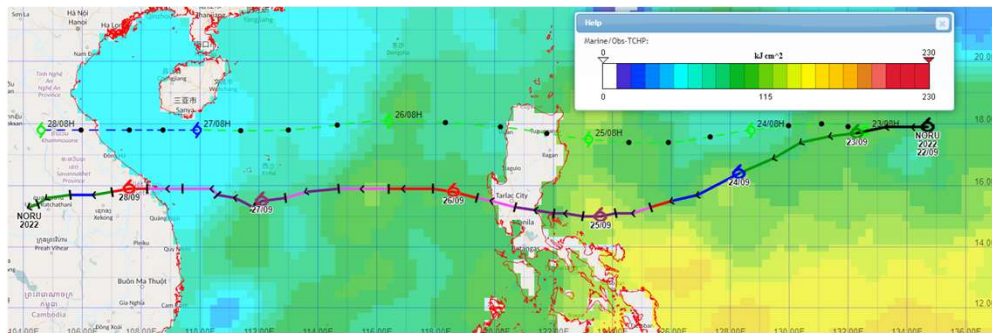


EXAMPLE: TROPICAL CYCLONE NORU (SEP 2022)

SST was generally $>26.5^{\circ}\text{C}$ in September



TCHP was generally $> 80 \text{ kJcm}^2$



- Atmospheric conditions were favourable further development of TC
- According to the life cycle of TC, 4-5 days of sea track is already enough for the system to develop into a mature state (e.g. typhoon or above).

EMERGING: AI MODELS IN WEATHER FORECASTING

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Article | [Open access](#) | Published: 05 July 2023

Accurate medium-range global weather forecasting with 3D neural networks

Kaifeng Bi, Lingxi Xie, Hengheng Zhang, Xin Chen, Xiaotao Gu & Qi Tian 

Nature **619**, 533–538 (2023) | [Cite this article](#)

138k Accesses | 23 Citations | 1608 Altmetric | [Metrics](#)

 An [Author Correction](#) to this article was published on 14 September 2023

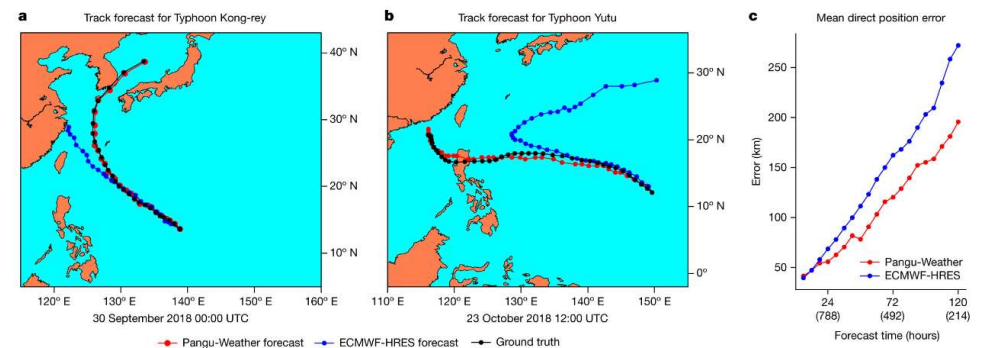
 This article has been [updated](#)

Abstract

Weather forecasting is important for science and society. At present, the most accurate forecast system is the numerical weather prediction (NWP) method, which represents atmospheric states as discretized grids and numerically solves partial differential equations that describe the transition between those states¹. However, this procedure is computationally expensive. Recently, artificial-intelligence-based methods² have shown potential in accelerating weather forecasting by orders of magnitude, but the forecast accuracy is still significantly lower than that of NWP methods. Here we introduce an artificial-intelligence-based method for accurate, medium-range global weather forecasting. We show that three-dimensional deep networks equipped with Earth-specific priors are effective at dealing with complex patterns in weather data, and that a hierarchical temporal aggregation strategy reduces accumulation errors in medium-range forecasting. Trained on 39 years of global data, our program, Pangu-Weather, obtains stronger deterministic forecast results on reanalysis data in all tested variables when compared with the world's best NWP system, the operational integrated forecasting system of the European Centre for Medium-Range Weather Forecasts (ECMWF)³. Our method also works well with extreme weather forecasts and ensemble forecasts. When initialized with reanalysis data, the accuracy of tracking tropical cyclones is also higher than that of ECMWF-HRES.

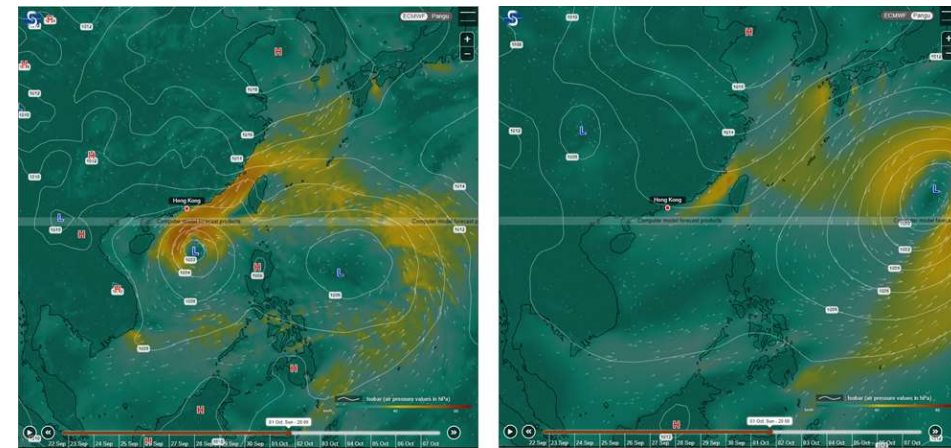
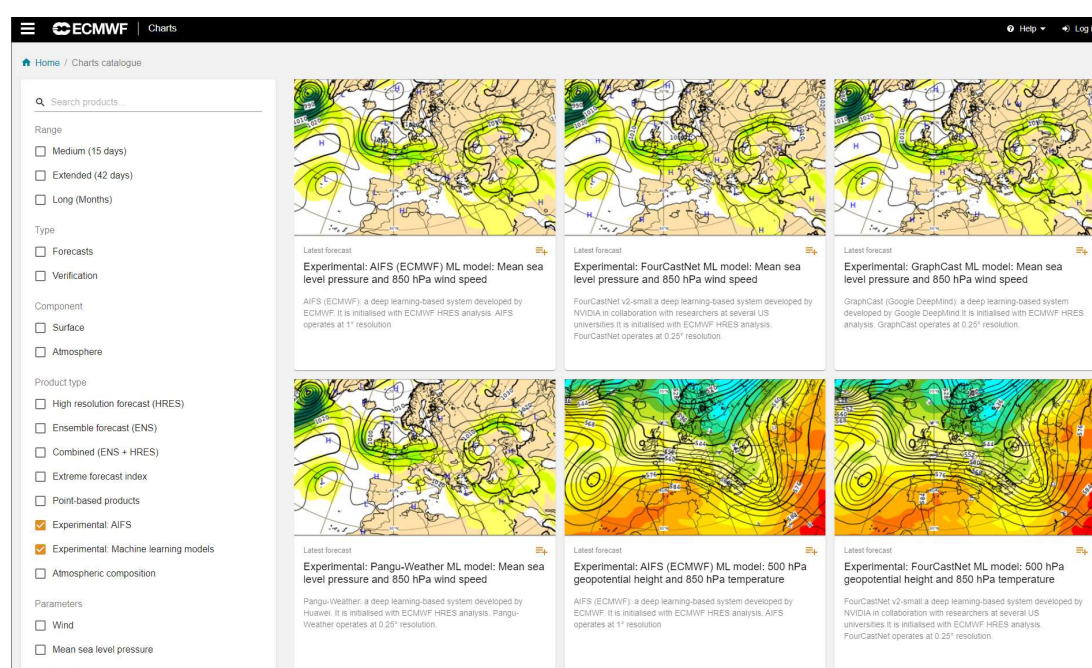
Fig. 4: Pangu-Weather is more accurate at early-stage cyclone tracking than ECMWF-HRES.

From: [Accurate medium-range global weather forecasting with 3D neural networks](#)



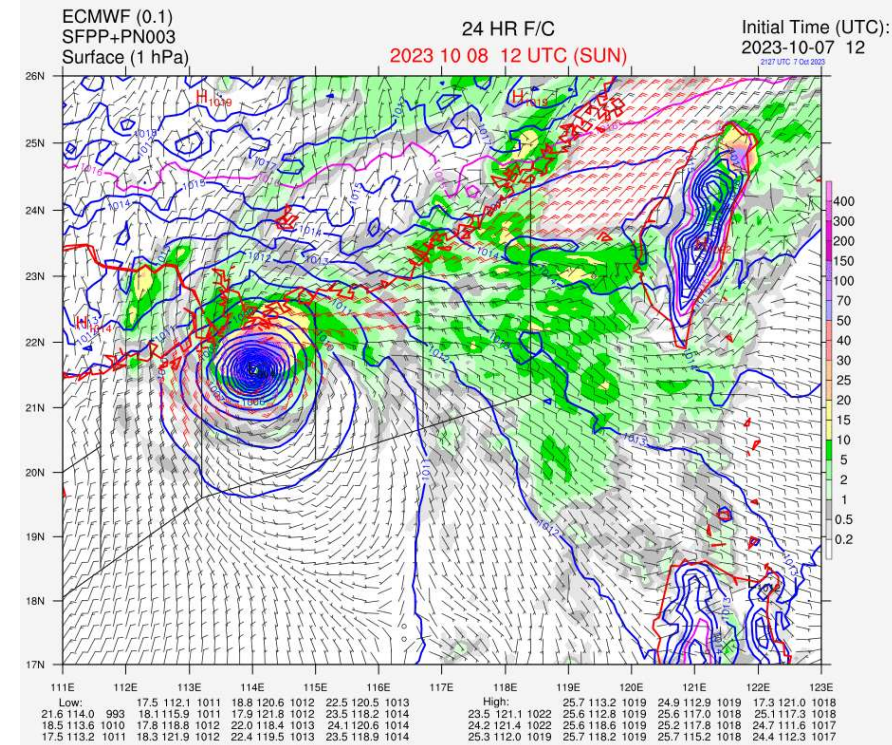
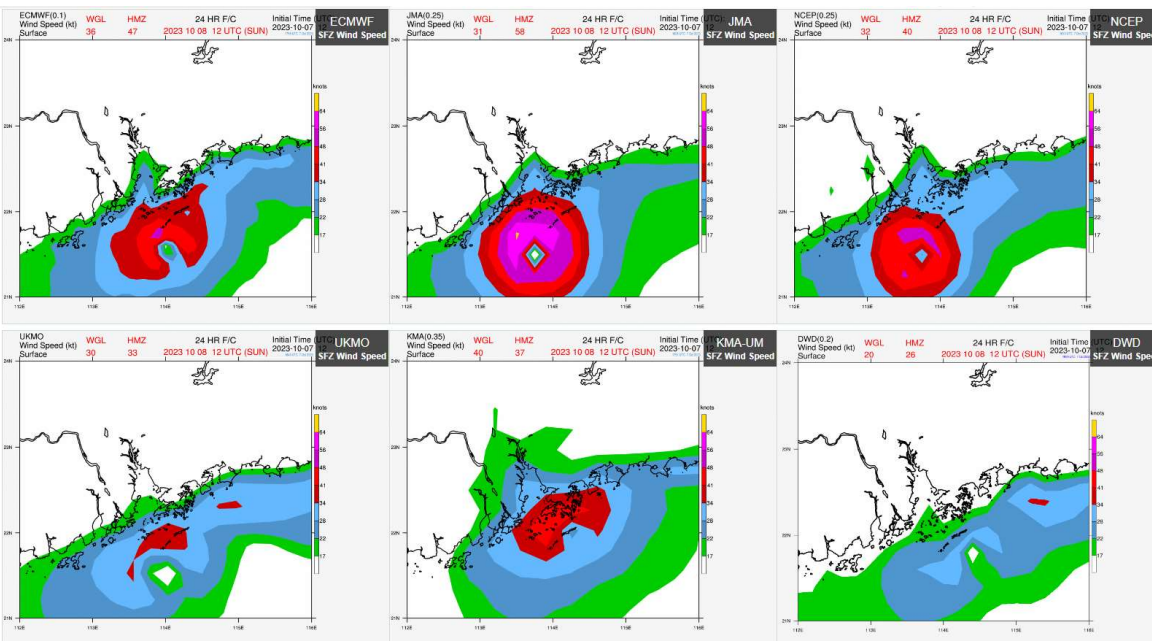
a, b, Tracking results for two strong tropical cyclones in 2018, that is, Typhoon Kong-rey (2018–25) and Yutu (2018–26). The initial time point is shown below each panel. The time gap between neighbouring dots is 6 h. Pangu-Weather forecasts the correct path of Yutu (that is, it goes to the Philippines) at 12:00 UTC on 23 October 2018, whereas ECMWF-HRES obtains the same conclusion 2 days later, before which it predicts that Yutu will make a big turn to the northeast. **c,** A comparison between Pangu-Weather and ECMWF-HRES in terms of mean direct position error over 88 cyclones in 2018. Each number in brackets in the x-axis indicates the number of samples used to calculate the average. For example, ‘(788)’ means that there are in total 788 initial points from which the typhoon lasts for at least 24 hours, and the 788 direct position errors of Pangu-Weather and ECMWF-HRES were averaged into the final results. Panels **a** and **b** were plotted using the Matplotlib Basemap toolkit.

EMERGING: AI MODELS IN WEATHER FORECASTING



Forecast for 1 October 2023 on mean sea level pressure (indicated by isobars) and wind speed (indicated by coloured layer) by the European Centre for Medium Range Weather Forecasts (ECMWF) model (left) and “Pangu model” (right) made on 22 September 2023. The former forecasted that a tropical cyclone would affect the northern part of the South China Sea, while the latter did not indicate development of low pressure systems in that region.

FORECASTING IMPACTS: HIGH WINDS

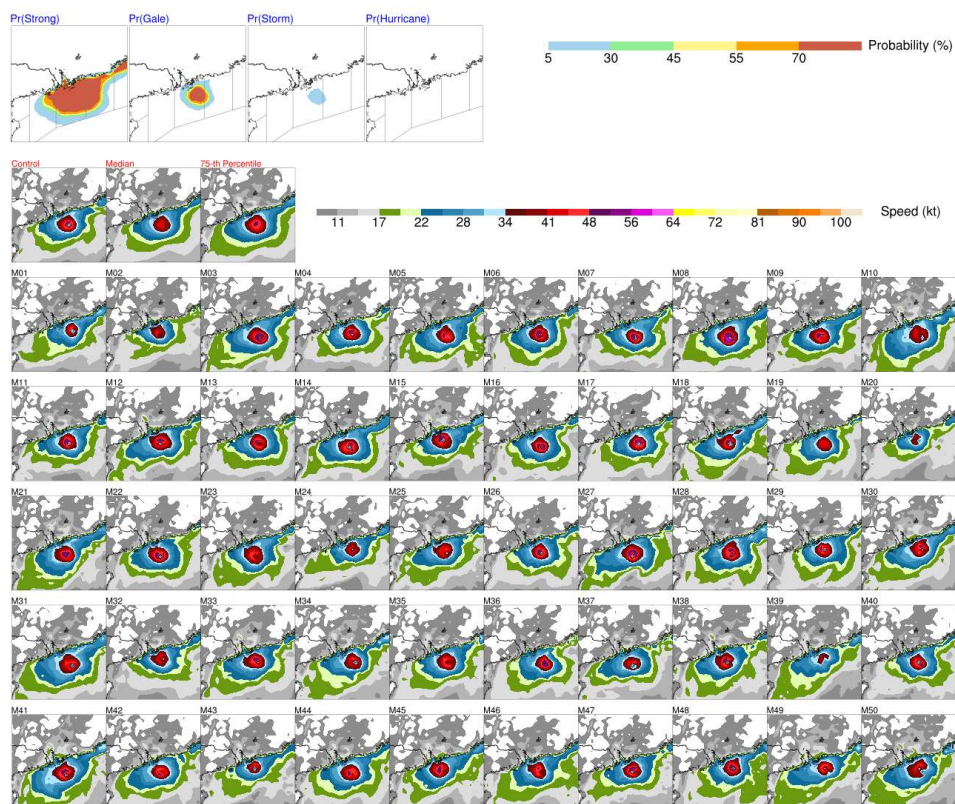


FORECASTING IMPACTS: HIGH WINDS

ECMWF EPS
Wind speed at 10m

2023-10-08 00:00 UTC (Sun)

T+12 h forecast from
2023-10-07 12:00 UTC



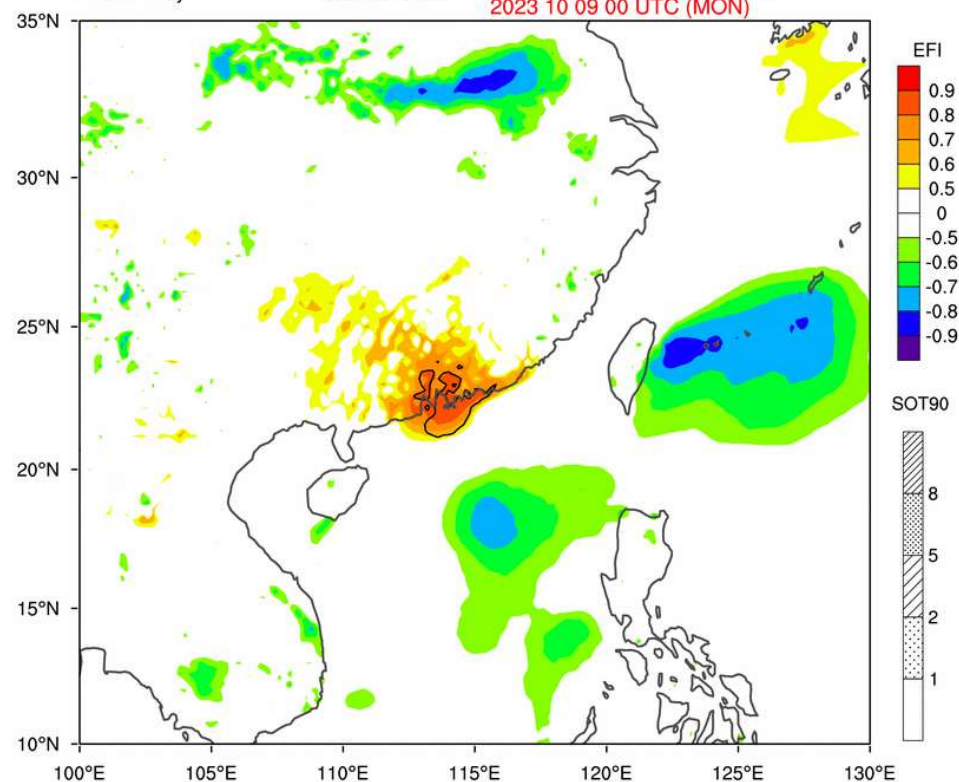
ECMWF
EFI+SOT90: 10m Wind Spd
Period: 1-day

EFI 0.86
SOT90 0.34

12 - 36 HR F/C (DAY 1)

2023 10 08 00 UTC (SUN) to
2023 10 09 00 UTC (MON)

Initial Time (UTC):
2023-10-07 12



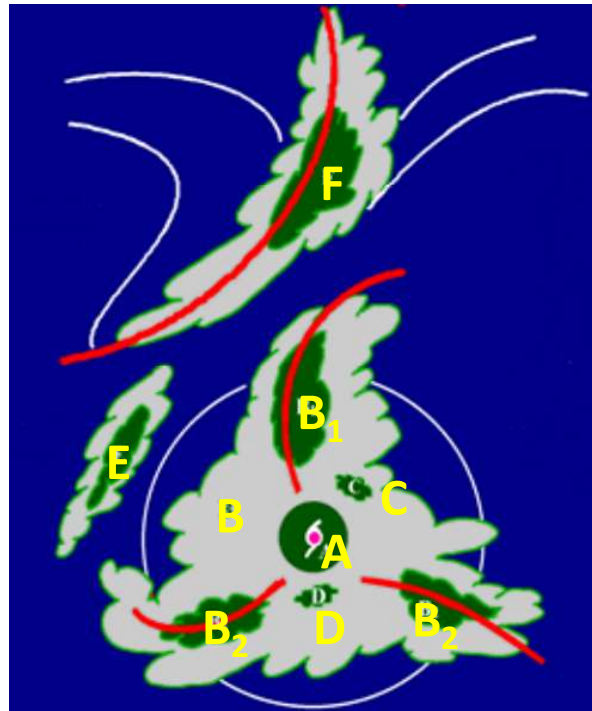
FORECASTING IMPACTS: RAINFALL

- Challenge: NWP models capture rainfall associated with tropical cyclones less well compared to winds

F – “**Remote precipitation**” due to (a) interaction with westerly trough, or (b) associated with topographic convergence / development away from TC circulation

E – “Peripheral rain” associated with **squall lines** ahead of approaching TC that may conducive to tornadogenesis

D – “**Unstable rain**” associated with warm and moist air on low levels underneath of upper-level cold air



A – **Inner Core** Rainfall

B – **Spiral rain band** (envelop rain)

B₁ – Inverted trough

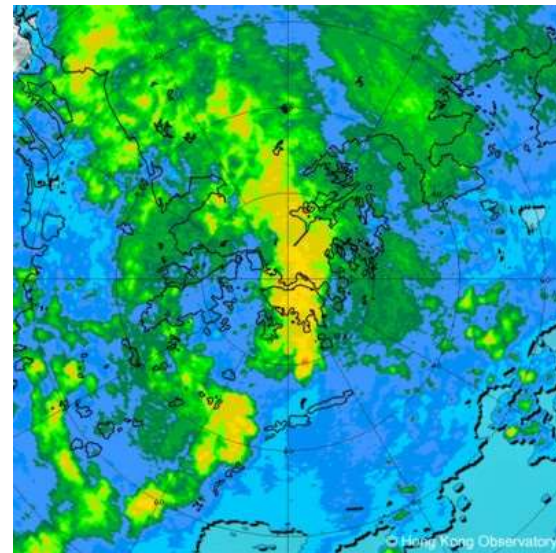
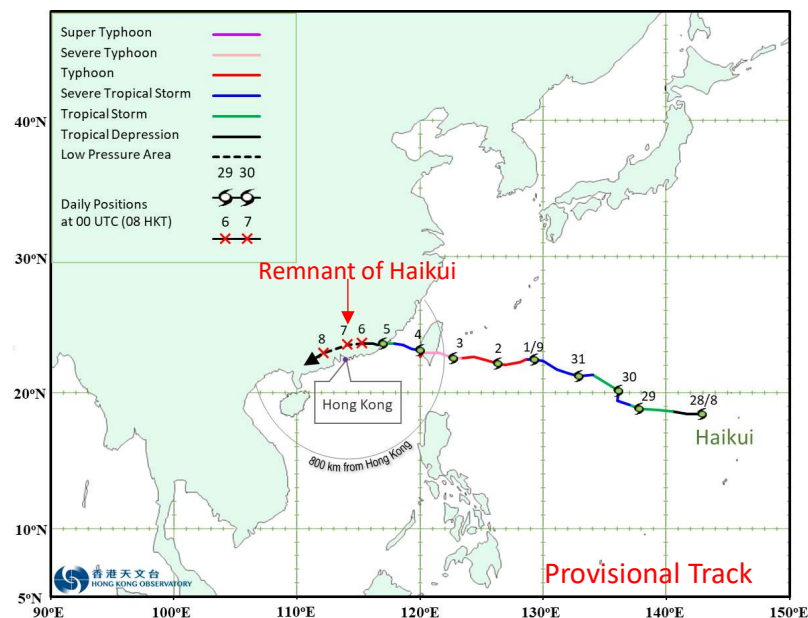
B₂ – Shear line

C – **Mesoscale to microscale** (tornadic) systems in NE quadrant

Classification of rainfall associated with landfalling tropical cyclones

RECORD-BREAKING RAINSTORM: REMNANTS OF TC HAIKUI

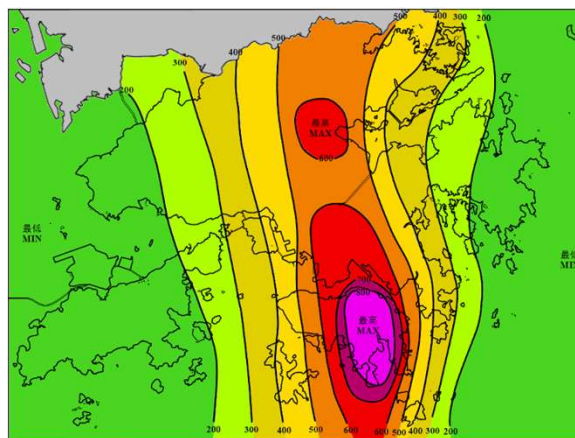
- Tropical cyclone Haikui (2311) made landfall over eastern Guangdong and weakened into an area of low pressure over inland on 5 September.
- Under the influence of a trough of low pressure associated with the remnant of Haikui over the coast of Guangdong, the weather of Hong Kong started to deteriorate with heavy rain and squally thunderstorms on the night of 7 September. The incessant downpour continued to affect the territory till the next day.



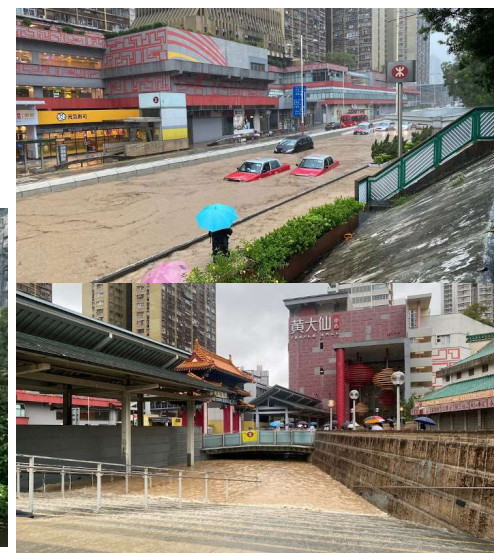
Radar imagery at 23:36 on 7 September 2023 when torrential rain was affecting Hong Kong

RECORD-BREAKING RAINSTORM: REMNANTS OF TC HAIKUI

- During the torrential rain, the Hong Kong Observatory Headquarters registered a **record-breaking hourly rainfall of 158.1 millimetres** from 11 p.m. to midnight on 7 September, the highest since records began in 1884.
- More than 400 millimetres of rainfall were recorded over many parts of the territory and **rainfall even exceeded 800 millimetres** over the Eastern District and Southern District of Hong Kong Island on 7 – 8 September.
- Flash floods and landslides affected many parts of the territory, causing widespread traffic disruption and damage to infrastructures.
- According to preliminary reports, there were over 200 reports of landslides and 60 reports of flooding. Power and water supply were temporarily interrupted in some places. At least two people were killed and more than 140 were injured during the rainstorm.

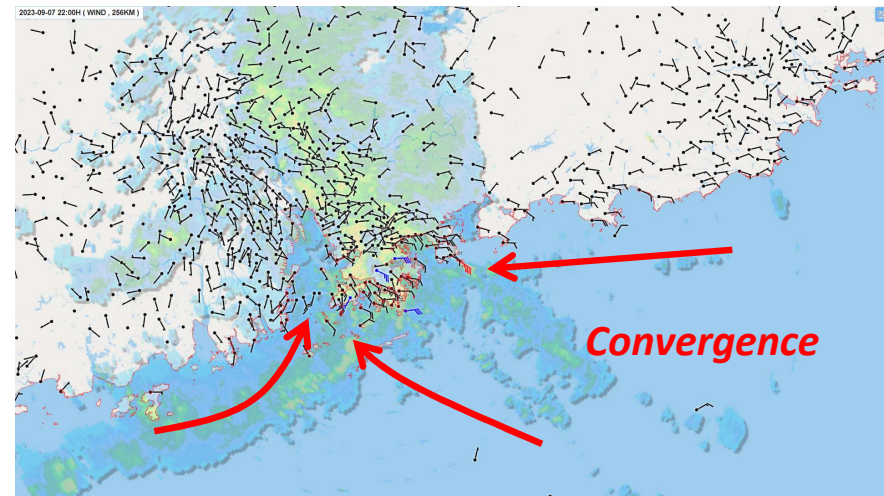
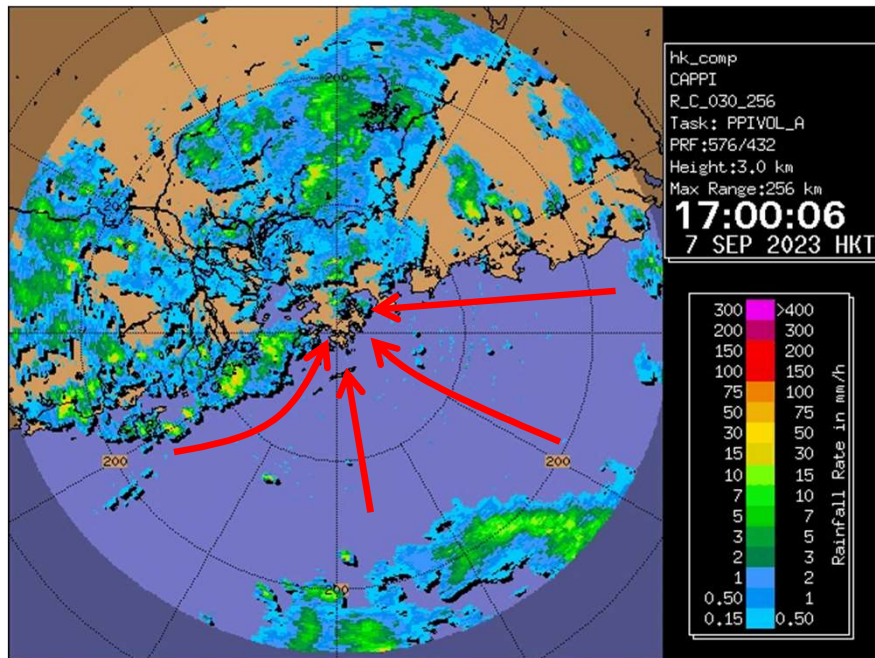


24-hour rainfall distribution map (16:00 on 7 September 2023 to 16:00 on 8 September 2023)

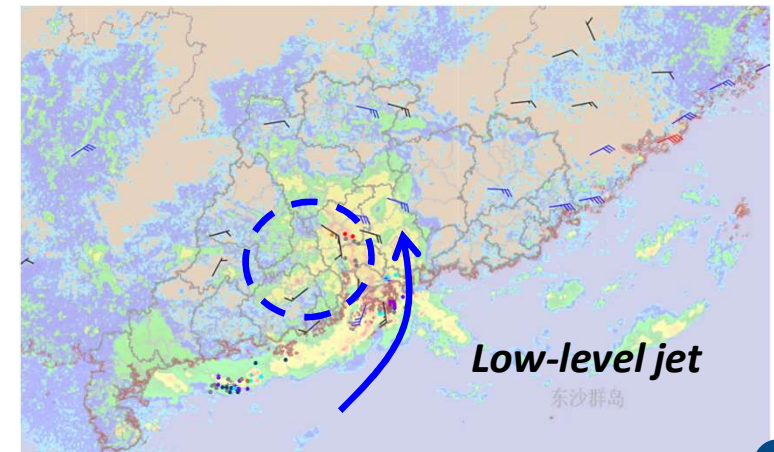


(Courtesy: CRHK News)

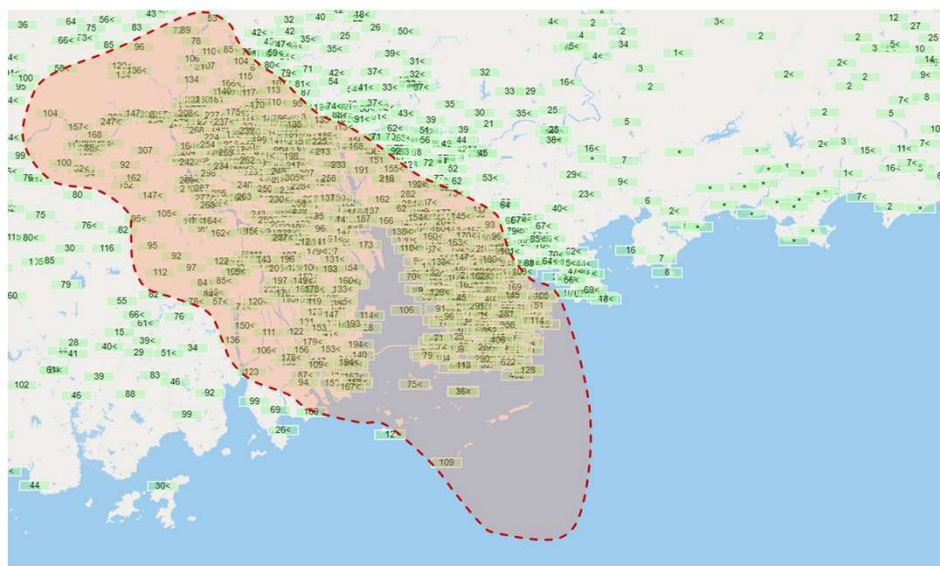
RECORD-BREAKING RAINSTORM: REMNANTS OF TC HAIKUI



850-hPa wind field
(wind profiler)

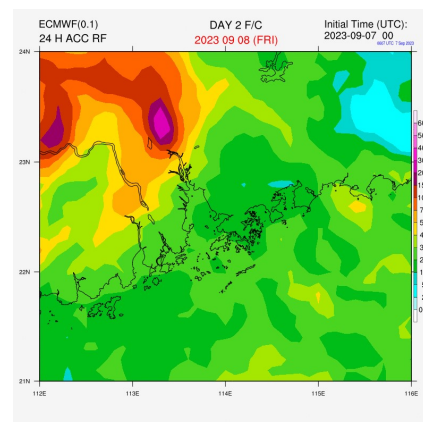


RECORD-BREAKING RAINSTORM: REMNANTS OF TC HAIKUI

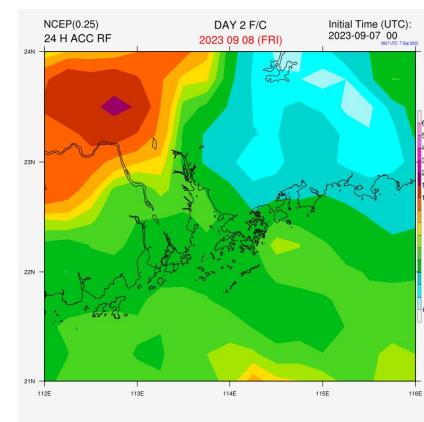


Accumulated rainfall for 8 Sep 2023
(areas with rainfall over 100 mm highlighted in **red**)

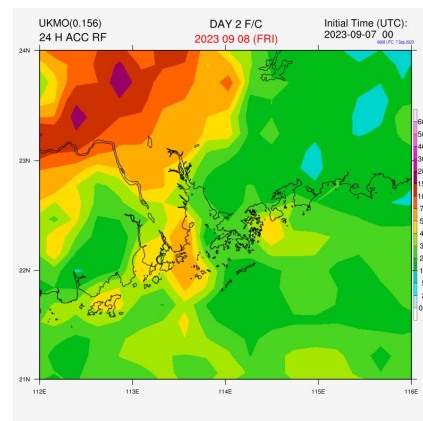
Average rainfall over Hong Kong: 336.6 mm



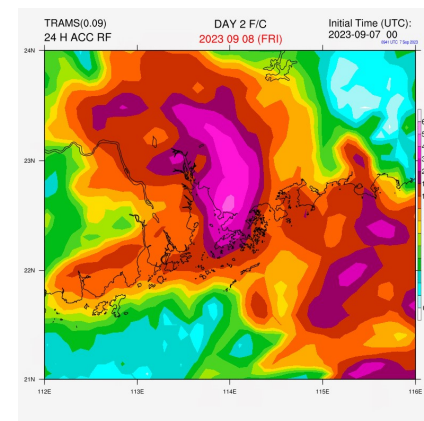
ECMWF



NCEP



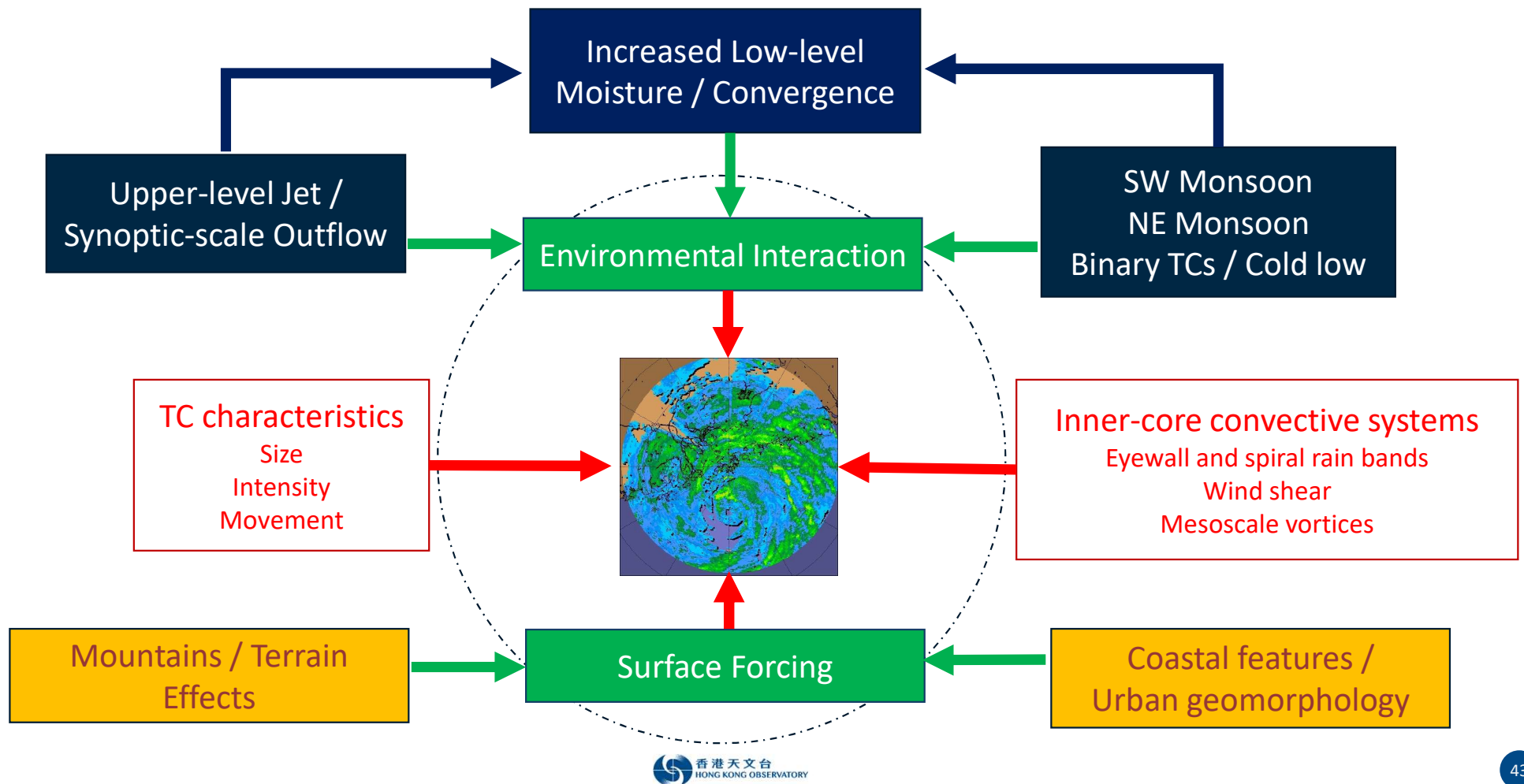
UKMO



TRAMS: Tropical Region Atmospheric
Model System for South China Sea

Model forecast rainfall (mm) for 8 Sep 2023 (based on 00Z run of 7 Sep)

FACTORS AFFECTING TC RAINFALL



TROPICAL CYCLONE FORECASTING AND IMPACT ALERTING

TOPICS

Tropical Cyclone Analysis

1

Track and Intensity Forecasting

2

Warning and Message Delivery

3

Systems and Tools for Forecasters

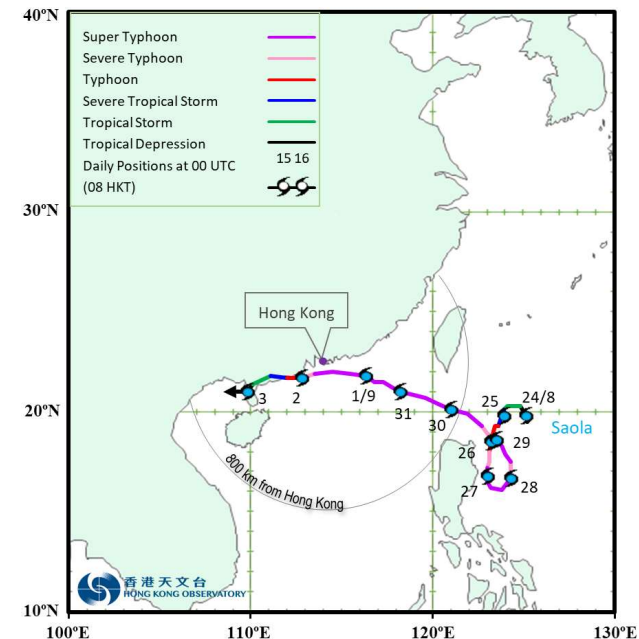
4

Impact Monitoring and Alerting

5

SUPER TYPHOON SAOLA

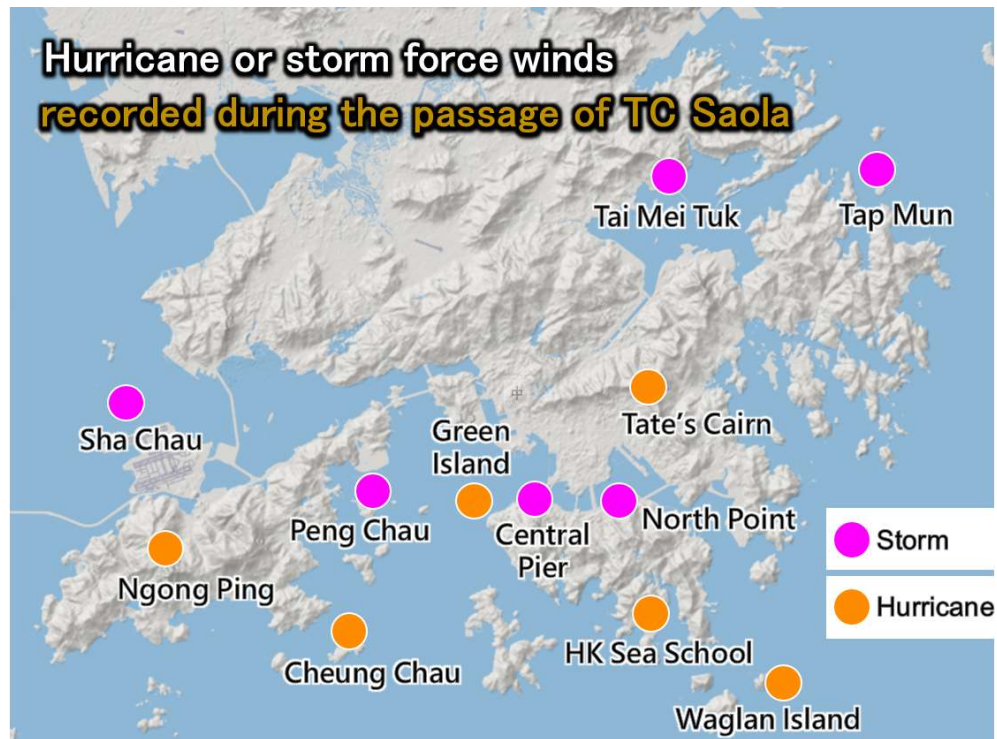
- Super Typhoon Saola (2309) moved generally westwards across the coastal waters of Guangdong on 1 September and skirted past **within 40 kilometres** to the south-southeast of Hong Kong that night. It continued to move across the coast of western Guangdong and weakened from a super typhoon into a tropical depression progressively the next day.
- During the passage of Saola, destructive high winds, storm surge and squally heavy rain associated with Saola affected Hong Kong on 1 and 2 September 2023.



Provisional Track

SUPER TYPHOON SAOLA

- The storm to hurricane force winds of Saola impacted many places in Hong Kong on 1 – 2 September. The maximum 60-minute mean wind speeds recorded at Waglan Island and Cheung Chau were 154 km/h and 116 km/h respectively.



SUPER TYPHOON SAOLA

- According to preliminary reports, there were over 3,000 reports of fallen trees, 21 reports of flooding and 2 reports of landslides in Hong Kong.
- There were also about 40 reports of damaged scaffolding, signboards and windows.
- Power supply was temporarily interrupted in some places.
- 460 flights were cancelled at the Hong Kong International Airport.
- While more than 80 people were injured, there was no fatality in Hong Kong during the passage of Saola.
- The storm surge induced by Saola also resulted in flooding in some low-lying coastal areas of Hong Kong, including Sha Tin, Tai Po, and Tai O. The water level at Sai Kung rose to about 4.5 mCD at midnight on 1 September.
- Saola brought squally heavy showers to Hong Kong on 1 – 2 September. **More than 150 millimetres of rainfall** were recorded over most parts of the territory.

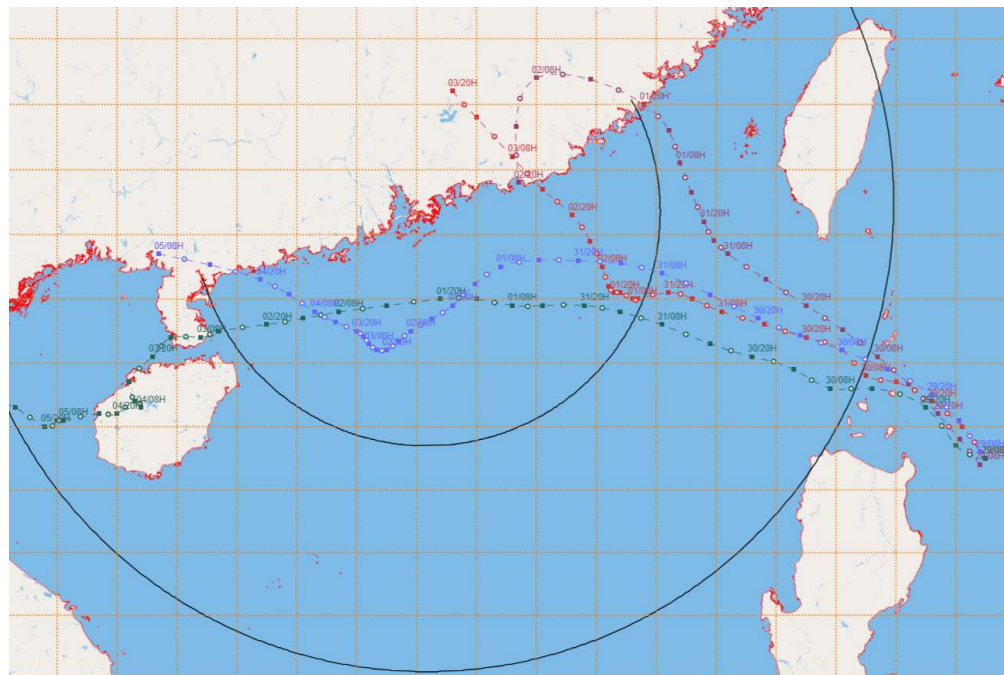


*The approach of Saola resulted in fallen trees in many parts of the territory
(Courtesy of Dr. T. C. Lee and Dr. Martin Williams (bottom left))*



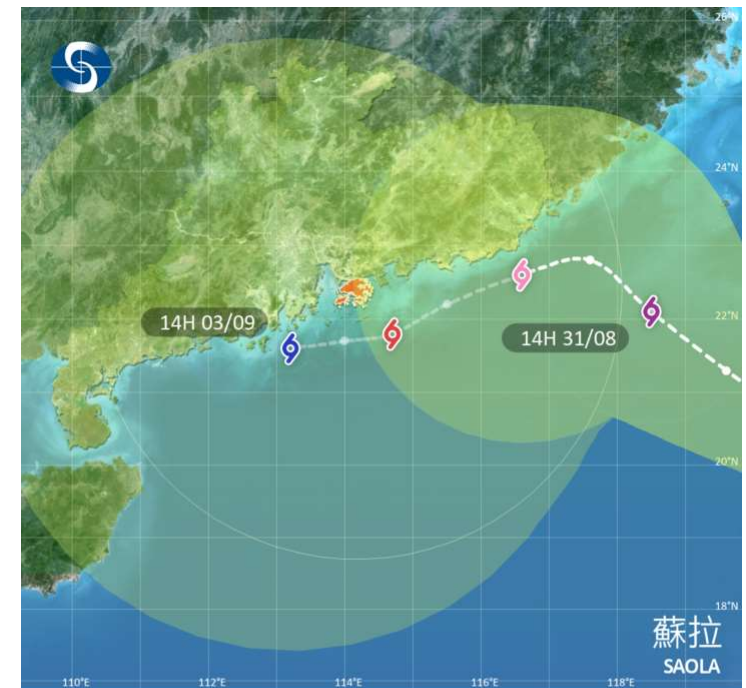
*Flooding of Shing Mun River due to storm surge induced by Saola
(Courtesy of Poon Chi Ming)*

SUPER TYPHOON SAOLA: FORECAST UNCERTAINTIES



Computer model forecast track (00Z run for 29 Aug)

UKMO
JMA
ECMWF
NCEP



- 熱帶低氣壓
Tropical Depression
- 熱帶風暴
Tropical Storm
- 強烈熱帶風暴
Severe Tropical Storm
- 颱風
Typhoon
- 強颱風
Severe Typhoon
- 超強颱風
Super Typhoon
- 低壓區 / 溫帶氣旋
Low Pressure Area / Extratropical Low

HKO TC forecast track (06Z for 29 Aug)

TRADITIONAL WEATHER BULLETINS

9-Day Weather Forecast

General Situation:

Tropical Cyclone Saola will move across the Luzon Strait in the next couple of days, and move towards the vicinity of the coast of eastern Guangdong to southern Fujian. Meanwhile, Tropical Cyclone Haikui located to the east of Saola will move in the general direction of the vicinity of the Ryukyu Islands in the next couple of days. **It may interact with Saola and the subsequent movement of Saola has a rather high uncertainty. Saola may move westwards along the coastal waters of Guangdong or weaken overland in southeastern China.** Under the influence of the outer subsiding air of Saola, it will be very hot over Guangdong in the next couple of days. Showers associated with Saola is expected to affect the northern part of the South China Sea and the coast of Guangdong in the latter part of this week and early next week. It will be windier and there will be swells over the region.

Date/Month 30/8 (Wednesday)

Wind: North to northeast force 3 to 4.

Weather: Sunny periods and isolated showers. Very hot during the day.

Temp Range: 26 - 33 C

R.H. Range: 60 - 90 Per Cent

Probability of Significant Rain forecast: Low

Date/Month 31/8 (Thursday)

Wind: North force 4 to 5, occasionally force 6 on high ground.

Weather: Sunny periods. Very hot and dry during the day.

Temp Range: 27 - 34 C

R.H. Range: 55 - 85 Per Cent

Probability of Significant Rain forecast: Low

Date/Month 1/9 (Friday)

Wind: North to northwest force 4 to 5, occasionally force 6 offshore and on high ground.

Weather: Sunny periods and a few showers. Very hot during the day. Isolated thunderstorms later. There will be swells.

Temp Range: 27 - 33 C

R.H. Range: 65 - 90 Per Cent

Probability of Significant Rain forecast: Medium Low

Date/Month 2/9 (Saturday)

Wind: North to northeast force 4 to 5, occasionally force 6 offshore and on high ground.

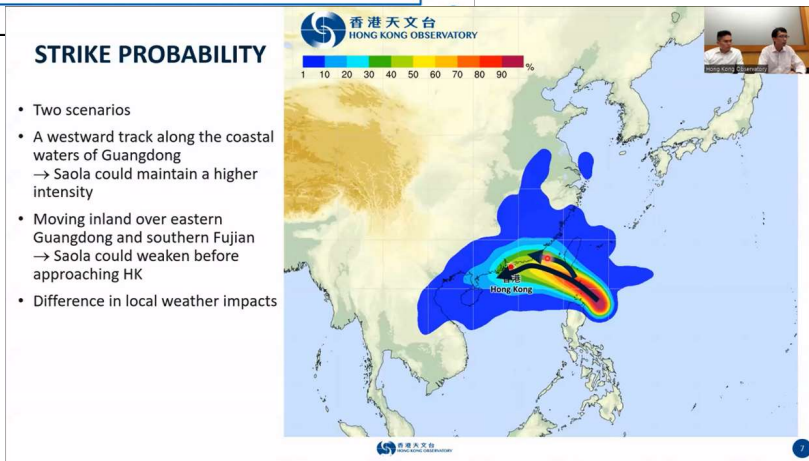
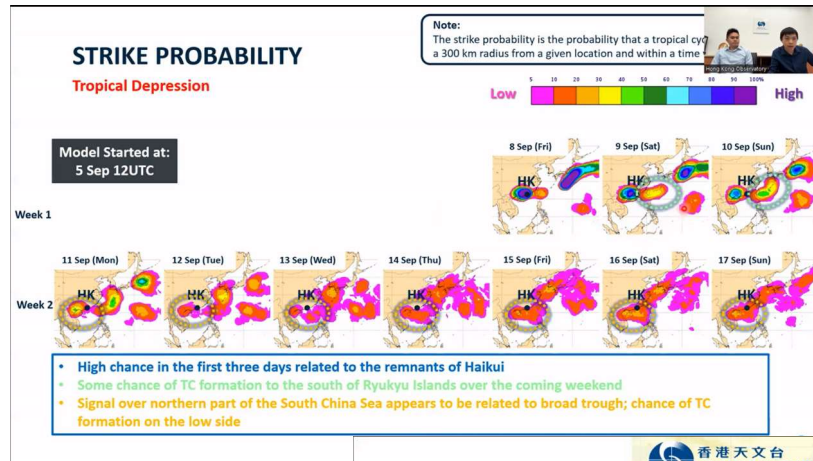
Weather: Mainly cloudy with occasional showers and thunderstorms. There will be swells.

Temp Range: 28 - 32 C

R.H. Range: 70 - 95 Per Cent

Probability of Significant Rain forecast: Medium High

TROPICAL CYCLONE OUTLOOK BRIEFING



- HKO conducts **biweekly online briefings** on potential tropical cyclone activities to invited government bureau / departments and special users, aiming at raising their awareness and assist the relevant parties to have early preparation and better manpower allocation.
- An ad-hoc briefing was conducted three days prior to the approach of Super Typhoon Saola to provide users the latest information of the TC, explanation of forecast uncertainties at that time as well as the potential impacts to the local weather under different track scenarios, including high winds, heavy rain and storm surge, so that they could carry out preparation work before tropical cyclone warning signals for the public were issued.

“WEATHER NOTE”

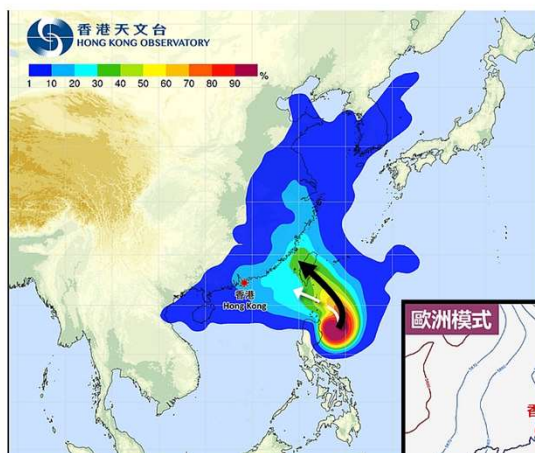
拖拖拉拉的蘇拉

星期日, 2023年8月27日

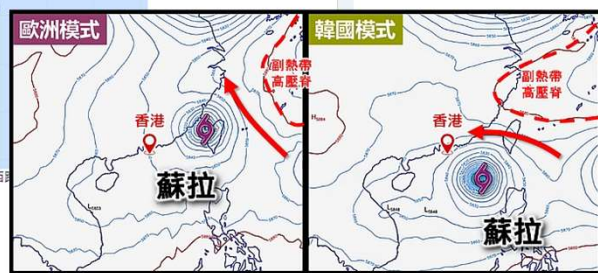
- 熱帶氣旋蘇拉會在未來兩三日北抬並移向台灣一帶。
- 隨後蘇拉較大機會登陸福建或廣東東部沿岸，但其路徑存在變數。
- 一股微弱的東北季候風會在星期二抵達華南，該區驟雨增多。
- 本週中至後期華南較大機會受東北季候風及蘇拉的外圍下沉氣流共同影響，天氣酷熱，較為乾燥，日夜溫差較大。

在過去數日，由於缺乏主導的環境氣流，熱帶氣旋蘇拉一直在呂宋以東海域徘徊，顯得有點「拖拖拉拉」。而該區海水較暖，大氣垂直風切變偏低，令蘇拉逐步增強為超強颱風。

主流電腦模式均預測未來一兩日有一道西風槽東移並向南擴展，除了會為南方帶來一股微弱的東北季候風外，亦有助帶動蘇拉逐漸北抬。同時，配合太平洋高壓脊向西伸展，環境氣流會加強並引導蘇拉向西北方向移動，加速移向台灣一帶（圖一）。



圖一：蘇拉的路徑概率預測圖。蘇拉移向台灣一帶的概率較高（黑色箭頭），但仍然有一定可能採取偏西



- Article published on HKO website serves as special notice and early warning to the public about the possibility of potential tropical cyclone and the associated local weather changes ahead.
- Apart from standard weather bulletins, “Weather Note” uses less formal approach to attract attention from media and the public.

SPECIAL WEATHER TIPS

- Short, concise message disseminated via HKO website, media and push message on HKO mobile app

According to the present forecast track, Tropical Cyclone Saola will enter within 800 kilometres of Hong Kong in the next couple of days, and will move towards the coastal area of eastern Guangdong to southern Fujian.

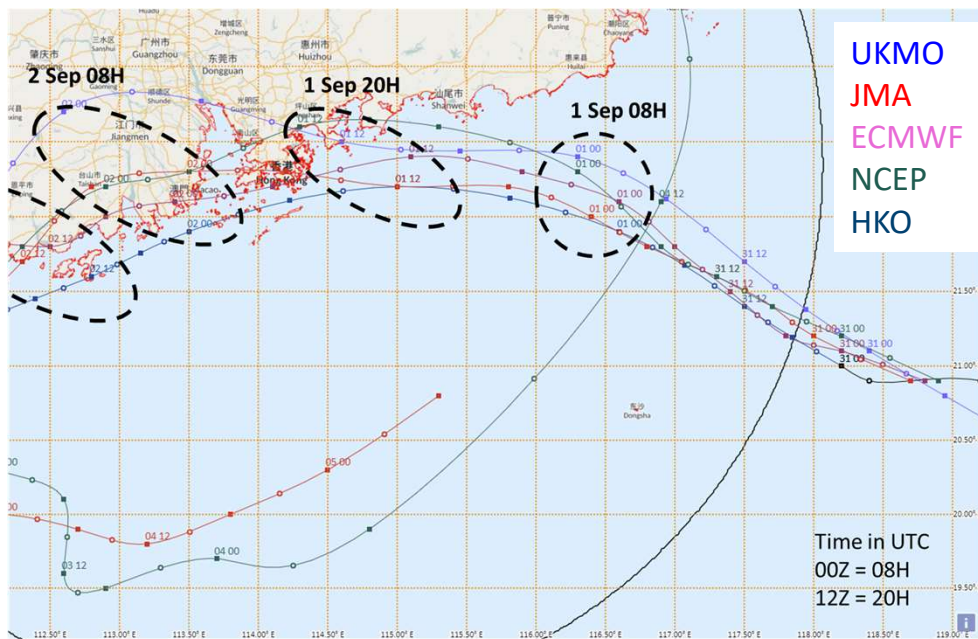
As Saola may interact with Tropical Cyclone Haikui located to the east of Saola, the subsequent movement of Saola has rather high uncertainty. It may move westwards along the coastal waters of Guangdong or weaken over the inland areas of southeastern China. The Observatory will consider issuing the Tropical Cyclone Warning Signal in the next couple of days. Members of the public please take note of the latest weather forecast.

Dispatched by Hong Kong Observatory at 12:00 HKT on 29.08.2023

Heavy rain continues to affect the northeastern part of the New Territories. Meanwhile, rainbands in the waters south of Hong Kong are moving north and approaching the territory. There might be heavy rainstorm over the territory shortly. Members of the public should stay on high alert.

Dispatched by Hong Kong Observatory at 20:26 HKT on 15.09.2023

GETTING READY FOR SUPER TYPHOON SAOLA



Joint press conference by various government departments

CONVEYING KEY INFORMATION

- Focus on weather impacts
- Make reference to historical extreme cases
- Explain possible scenarios
- Highlight precautionary measures

Tropical Cyclone Warning Bulletin

Here is the latest Tropical Cyclone Warning Bulletin issued by the Hong Kong Observatory.

The Strong Wind Signal, No. 3 is in force.

This means that winds with mean speeds of 41 to 62 kilometres per hour are expected.

At 5 p.m., Super Typhoon Saola was estimated to be about 370 kilometres east-southeast of Hong Kong (near 21.4 degrees north 117.6 degrees east) and is forecast to move west-northwest at about 10 kilometres per hour towards the coast of eastern Guangdong.

According to the present forecast, Saola will be rather close to Hong Kong later tomorrow (1 September) and will pose a threat to Hong Kong. The Observatory will issue the Gale or Storm Signal No. 8 between 2 a.m. and 5 a.m. tomorrow. Local weather is expected to deteriorate significantly, with heavy squally showers and violent winds, during the day tomorrow.

Under the influence of storm surge, the water level in Hong Kong is expected to rise appreciably towards midnight tomorrow until noon on Saturday (2 September). There may be serious flooding in low-lying coastal areas. Impact of storm surge depends on the intensity and location of Saola when it skirts the territory. **If Saola skirts south of the territory as suggested by present forecast track, the maximum water level induced by the storm surge may be similar to that when Mangkhut hits Hong Kong in 2018. However, if Saola makes landfall to the east of Hong Kong and skirts to the north of our territory, its impact will be relatively small.**

Members of the public are advised to stay away from the shoreline and not to engage in water sports.

COMMUNICATION WITH DIFFERENT SECTORS



Hourly central briefing for the public

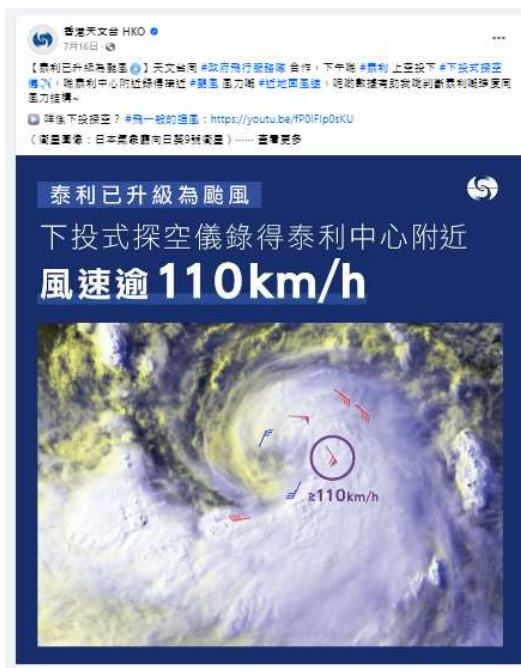


Briefing at Emergency Monitoring and Support Centre

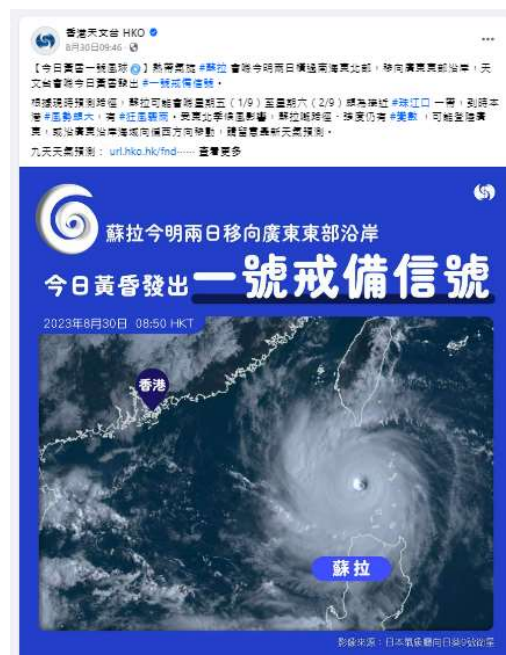


*Aeronautical Meteorological
Adviser at Integrated Airport
Centre, Hong Kong International
Airport*

OTHER ONGOING EFFORTS



Facebook posts to raise public's awareness of the approach of tropical cyclones



Educational videos "Cool Met Stuff"

TROPICAL CYCLONE FORECASTING AND IMPACT ALERTING

TOPICS

Tropical Cyclone Analysis

1

Track and Intensity Forecasting

2

Warning and Message Delivery

3

Systems and Tools for Forecasters

4

Impact Monitoring and Alerting

5

HOW TO MAKE BEST USE OF WEATHER DATA?

- The amount of data available to weather forecasters is increasing
 - Both observation and model data are growing
 - Increase in types, time resolution, spatial resolution ...
 - More high-resolution NWP model data are becoming “open”
- The time for forecasters to assimilate the data and make decisions is limited
- Systems and tools to help forecasters assess such data are important – this requires investment in IT resources

Model upgrade increases skill and unifies medium-range resolutions

27 June 2023

Share



An upgrade of ECMWF's Integrated Forecasting System (IFS) to Cycle 48r1 implemented on 27 June has substantially improved the skill of the Centre's weather predictions and has increased the resolution of medium-range [ensemble forecasts](#).

The horizontal resolution of medium-range ensemble forecasts (ENS) has increased from 18 to 9 km, which is the same resolution as the current high-resolution forecast (HRES). In the future, HRES and the unperturbed control forecast of the ensemble will be merged.

In addition, configuration changes for the extended-range ensemble forecast result in substantial improvements in forecast skill and utility for users.

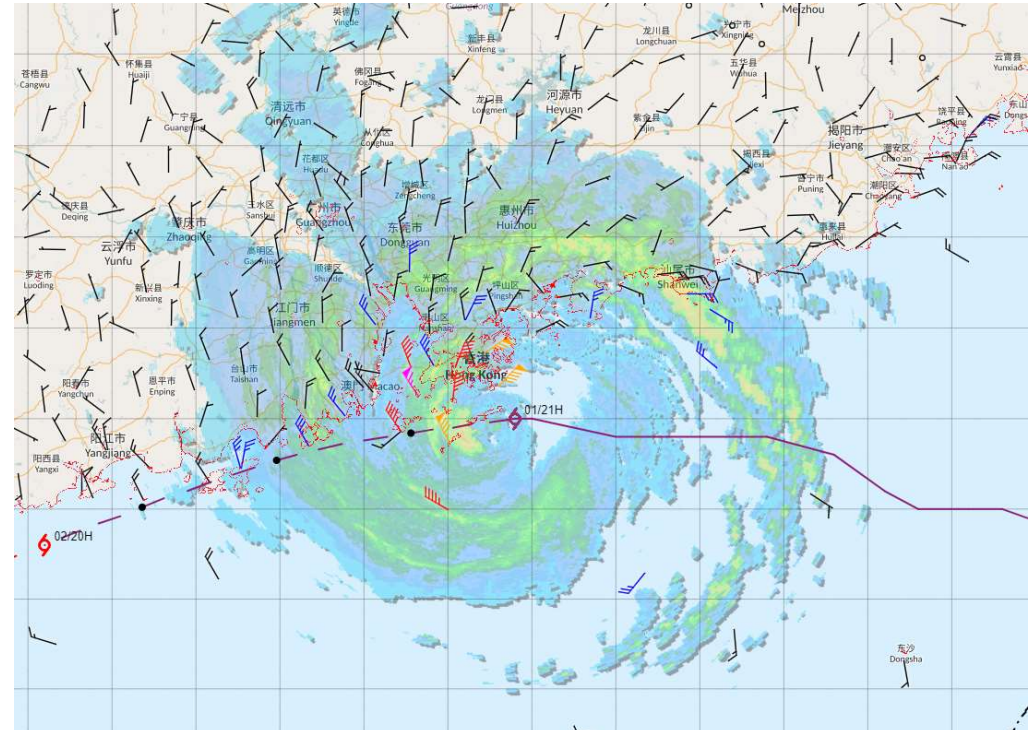
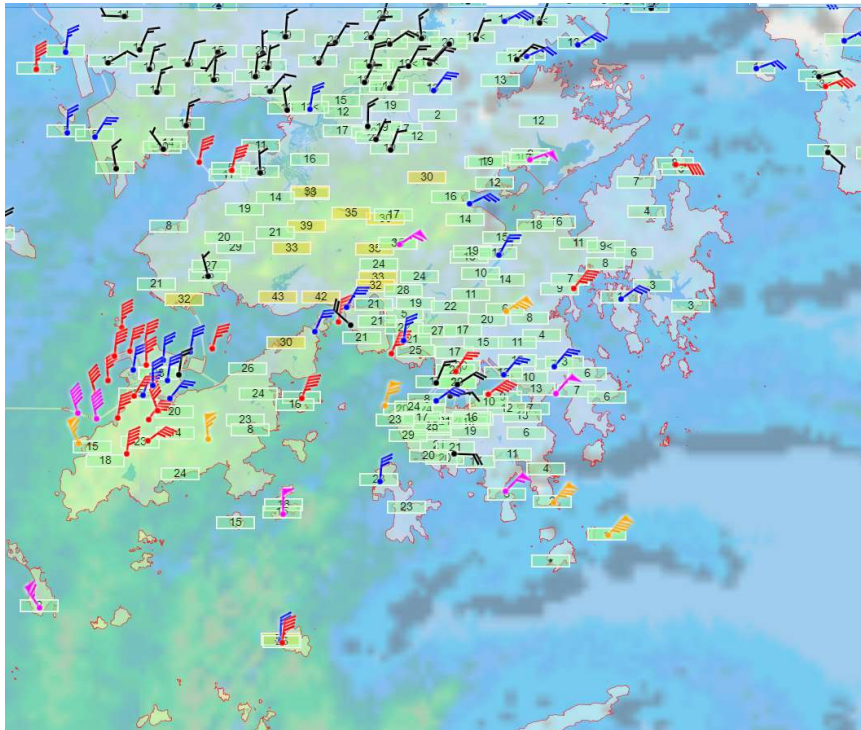
There have been many other changes in the forecast model and in [data assimilation](#), leading to much-improved skill scores. The largest forecast skill improvements are associated with the ensemble forecasts because of the ENS resolution upgrade. For example, most ENS scores of surface variables are improved by 2% to 6%.

Changes in the forecast model

An example of the impact of the horizontal resolution increase is the case of severe tropical cyclone Ilsa, which made landfall over Western Australia in April 2023.

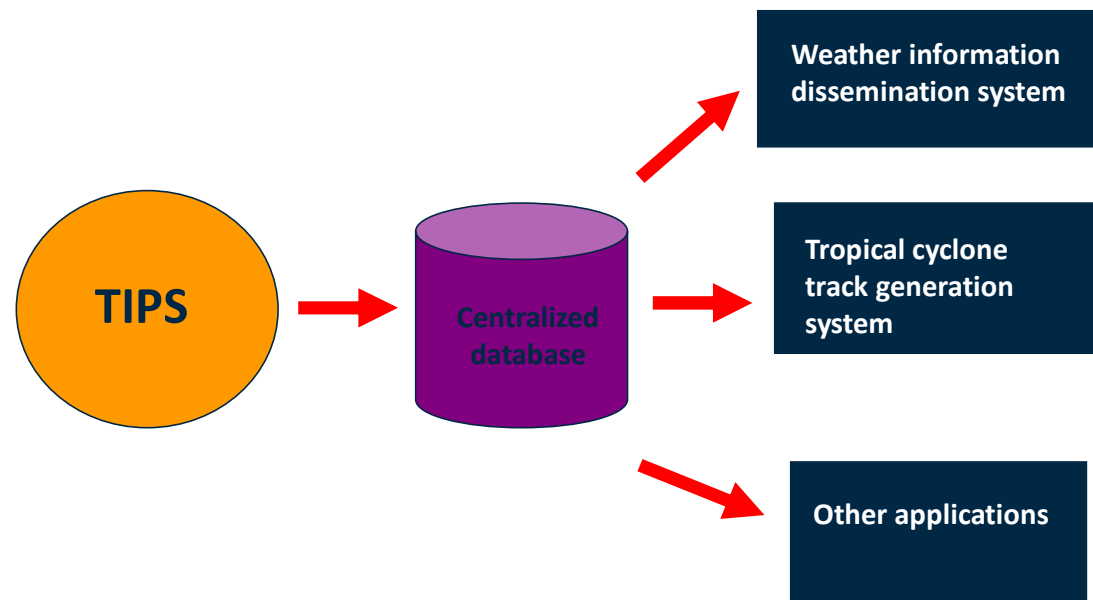
<https://www.ecmwf.int/en/about/media-centre/news/2023/model-upgrade-increases-skill-and-unifies-medium-range-resolutions>

INTEGRATED OBSERVATION DISPLAY PLATFORM

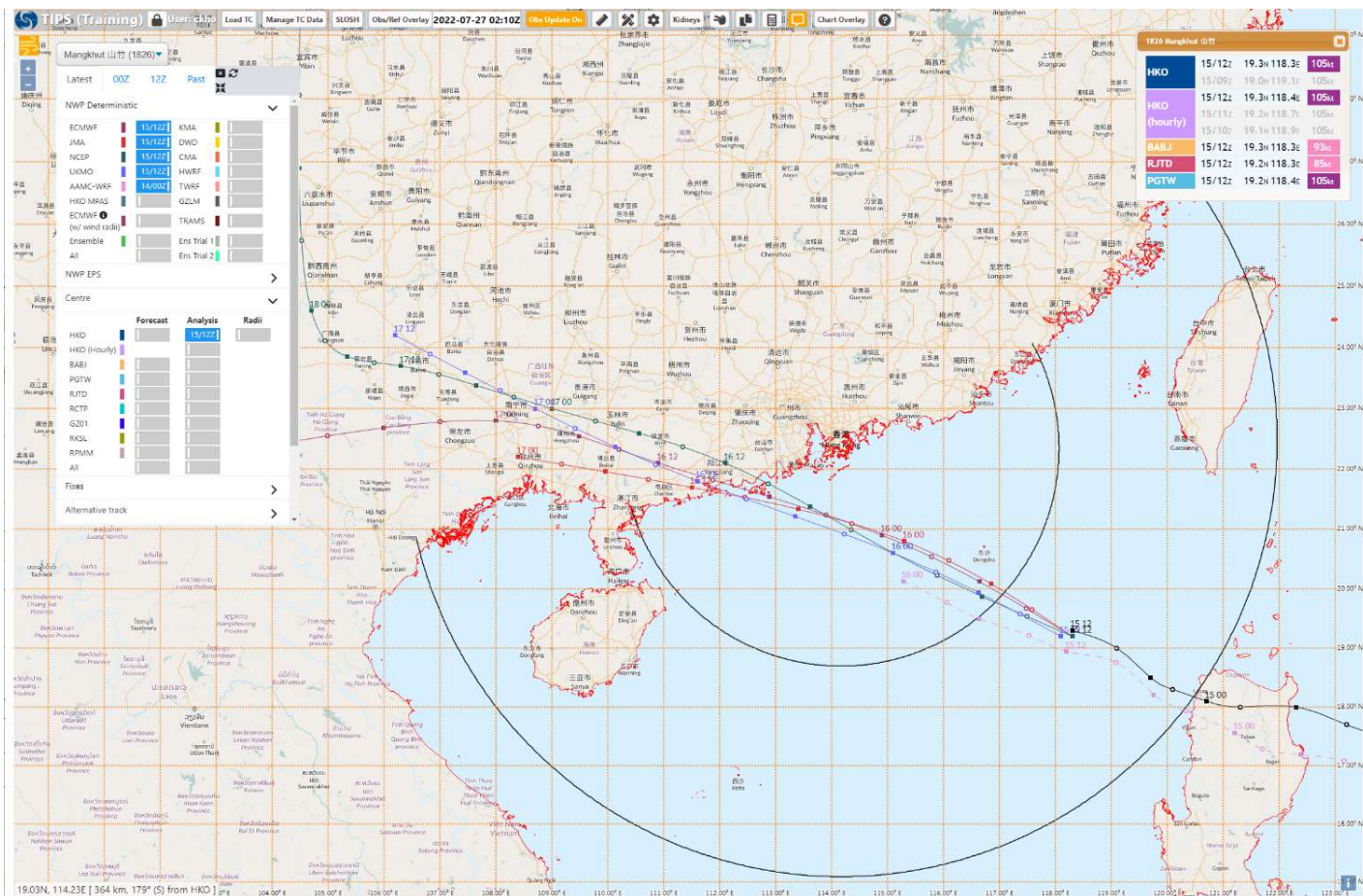


INTEGRATED TC FORECASTING SYSTEM FOR FORECASTERS

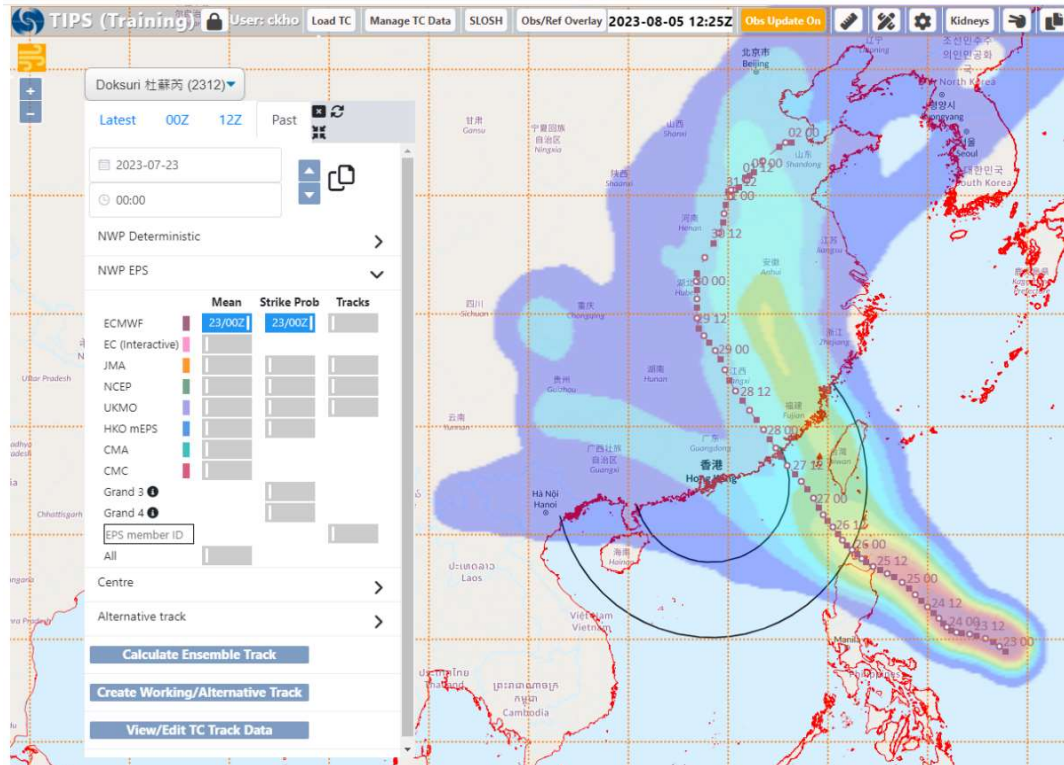
- Tropical Cyclone Information Processing System (TIPS)
 - A web-based system on GIS platform
 - Integrate all TC related information and data
 - Assimilate TC track data for computation of an ensemble track for operational forecasting
 - Compute key parameters for evaluating local impact to facilitate warning decisions
 - Generate and dispatch forecast and warning products to the local public and other weather centres



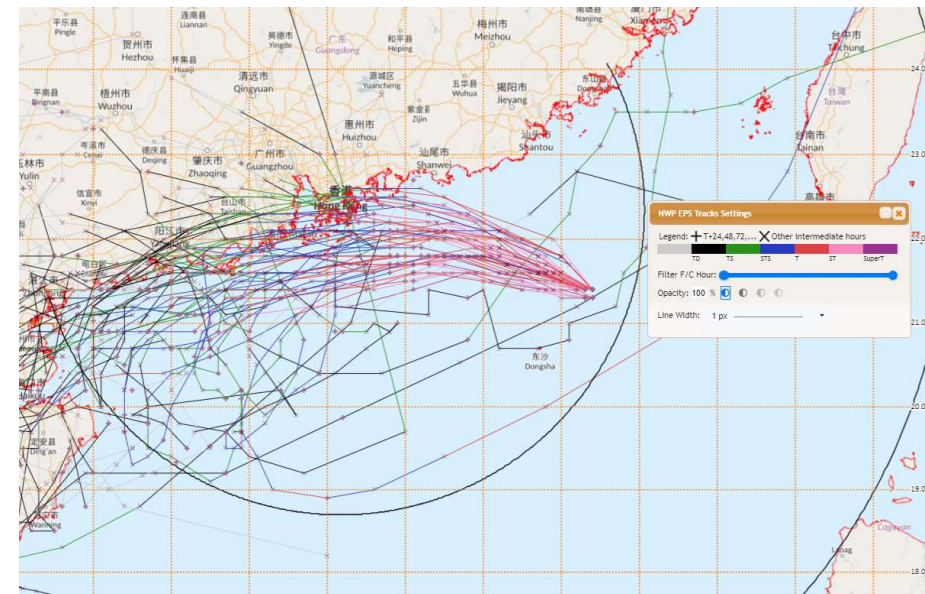
TROPICAL CYCLONE INFORMATION PROCESSING SYSTEM



TROPICAL CYCLONE INFORMATION PROCESSING SYSTEM

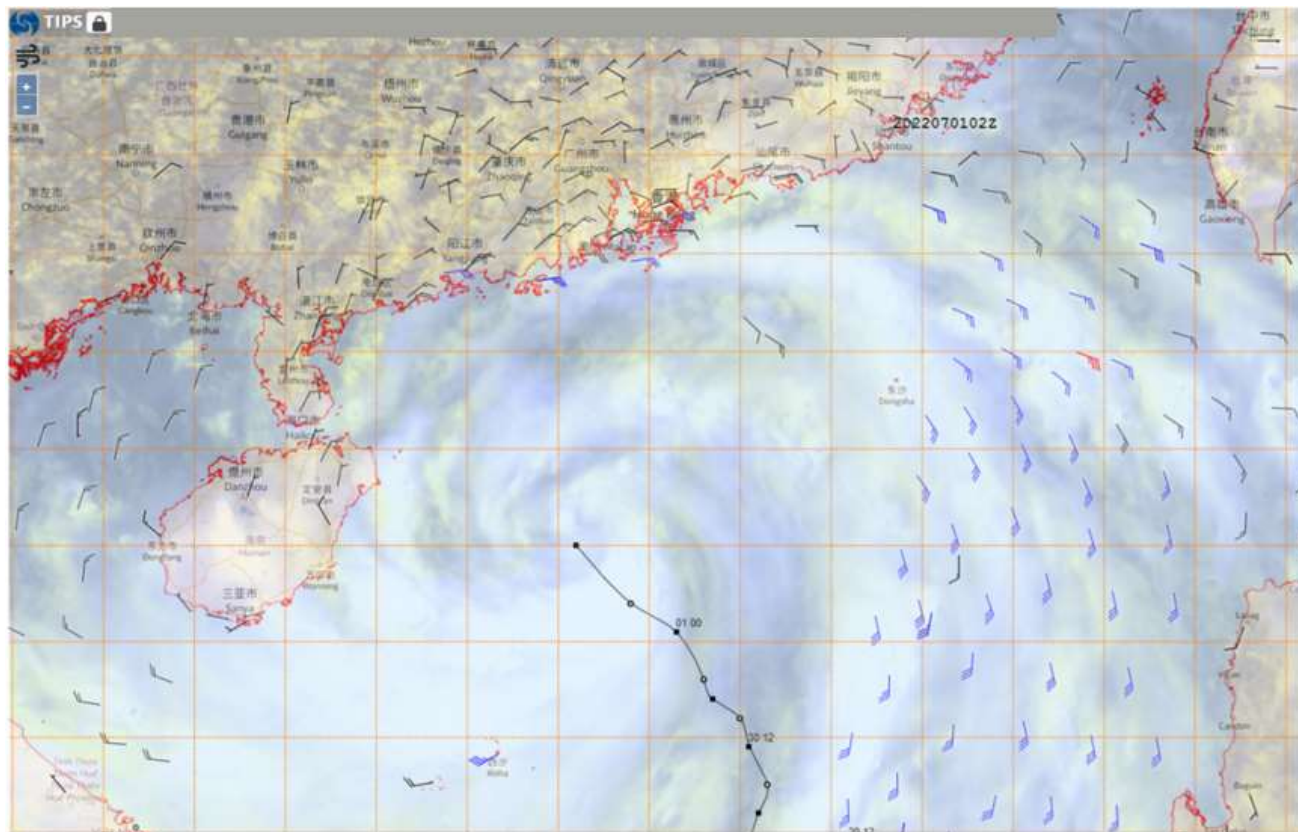


EPS mean track and strike probability



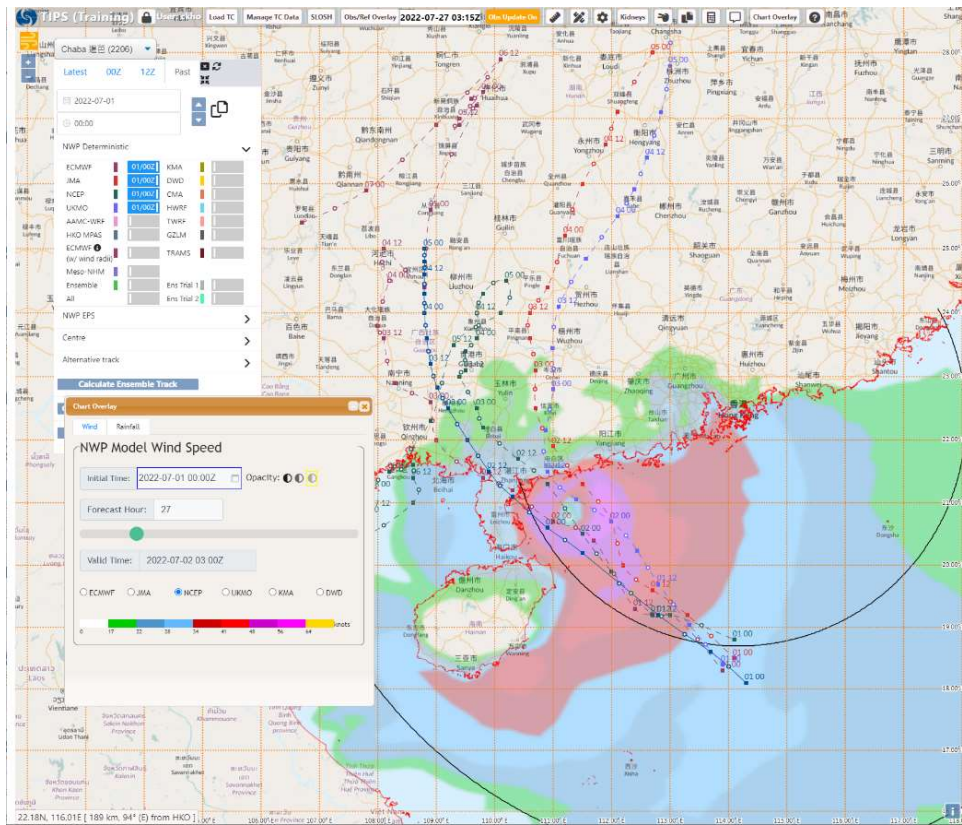
Individual EPS member tracks

TROPICAL CYCLONE INFORMATION PROCESSING SYSTEM

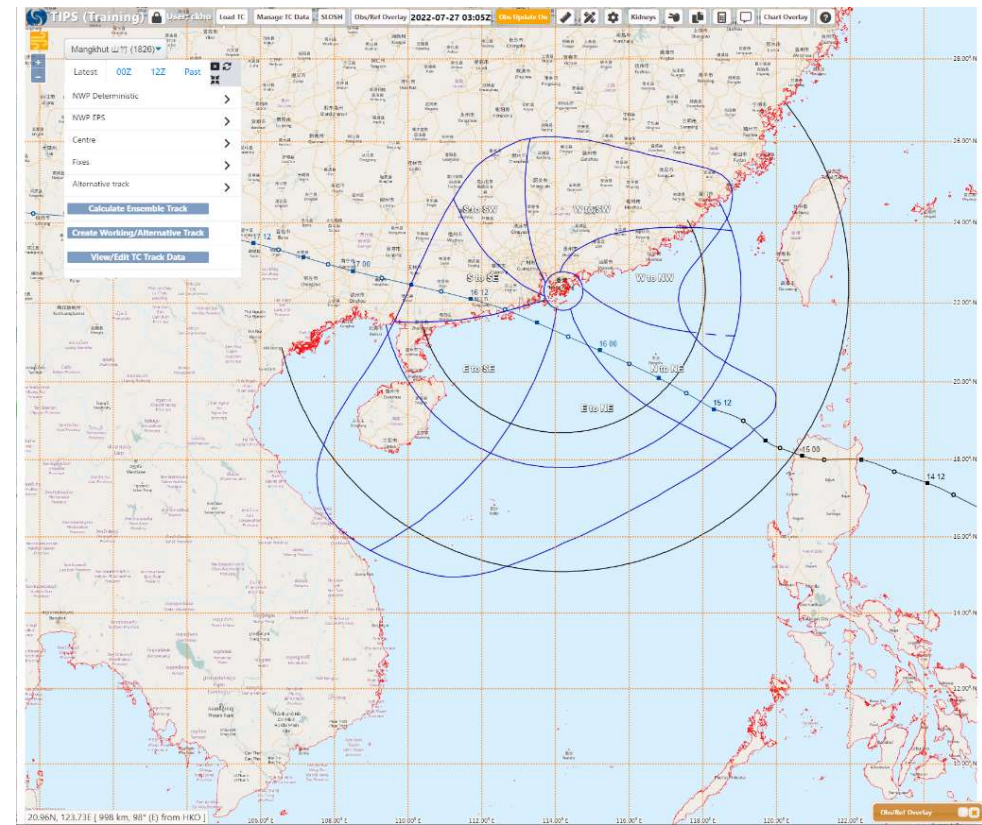


Overlay of various weather observations

TROPICAL CYCLONE INFORMATION PROCESSING SYSTEM

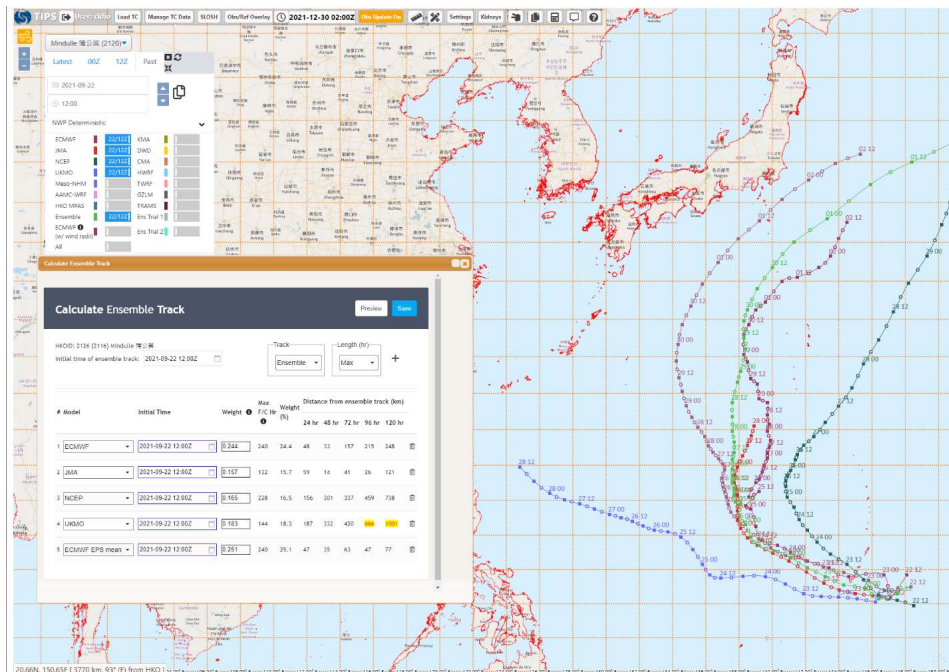


Overlay of NWP wind speed charts

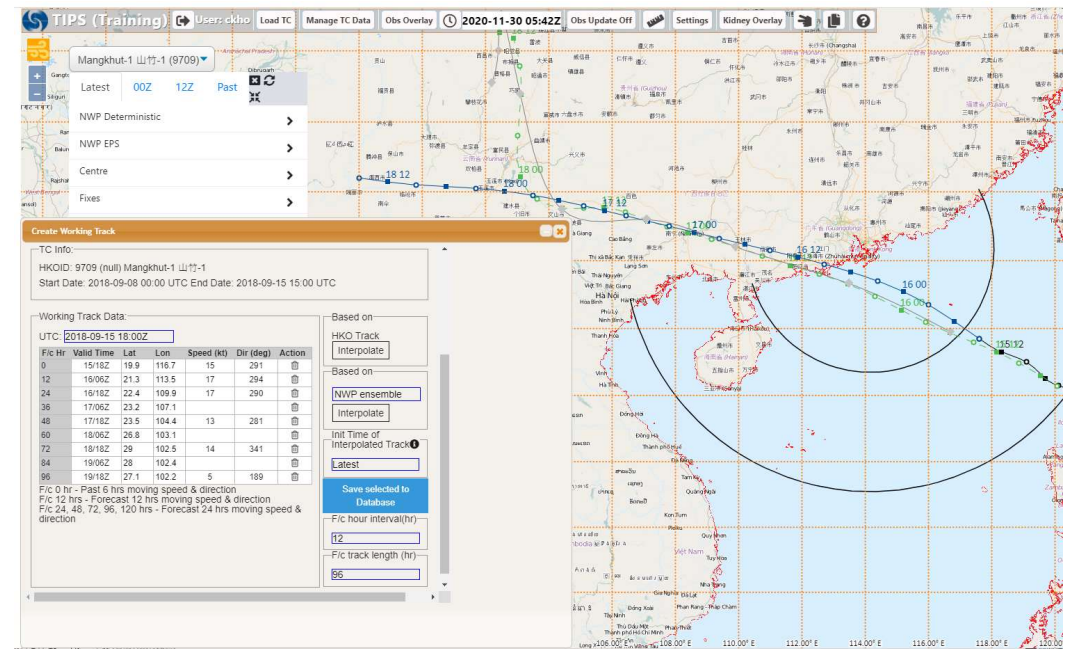


Overlay of statistical-based forecasting tools (e.g. wind direction)

TROPICAL CYCLONE INFORMATION PROCESSING SYSTEM

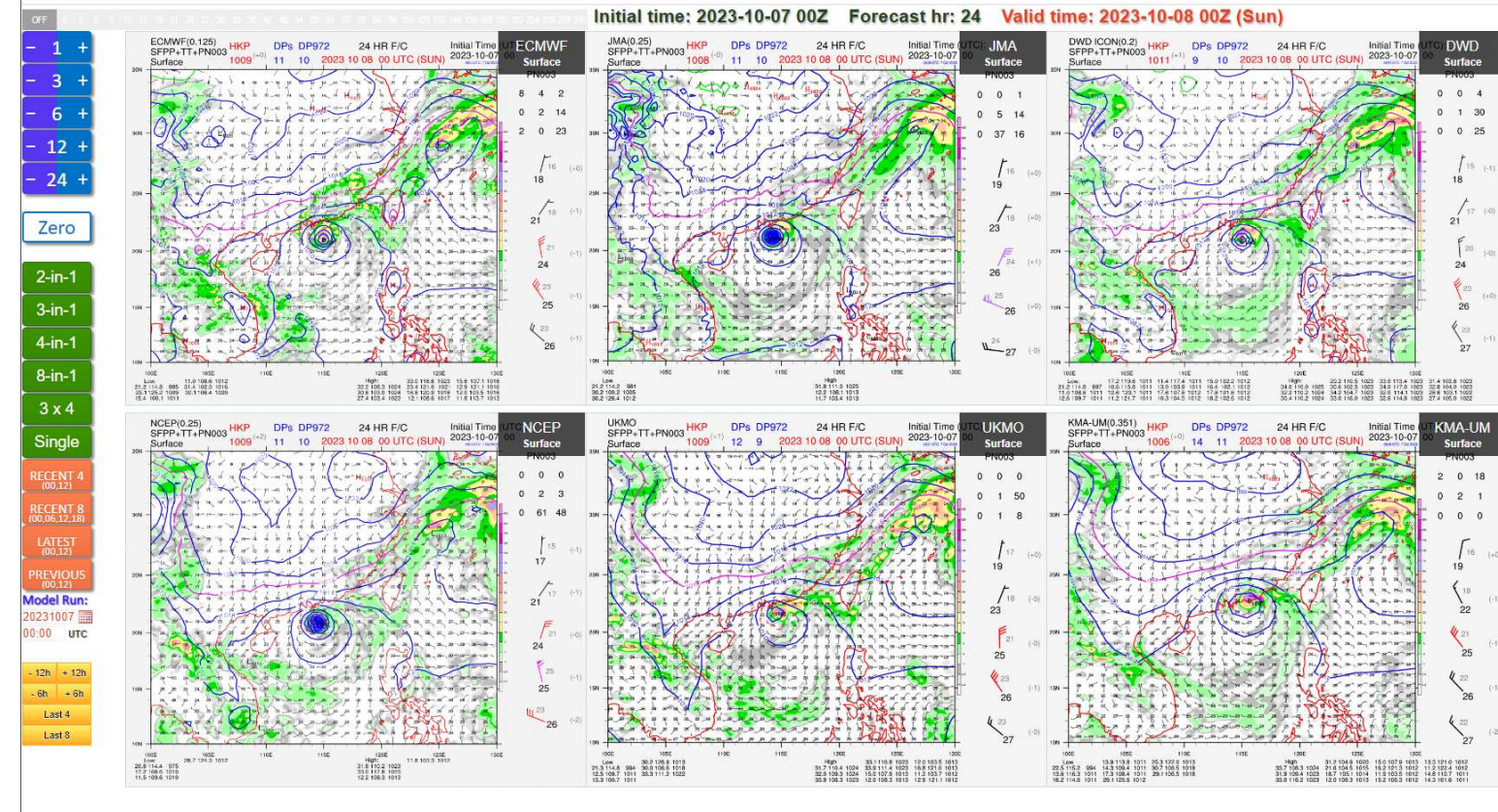


Calculation of model ensemble tracks



Preparation of TC warning tracks

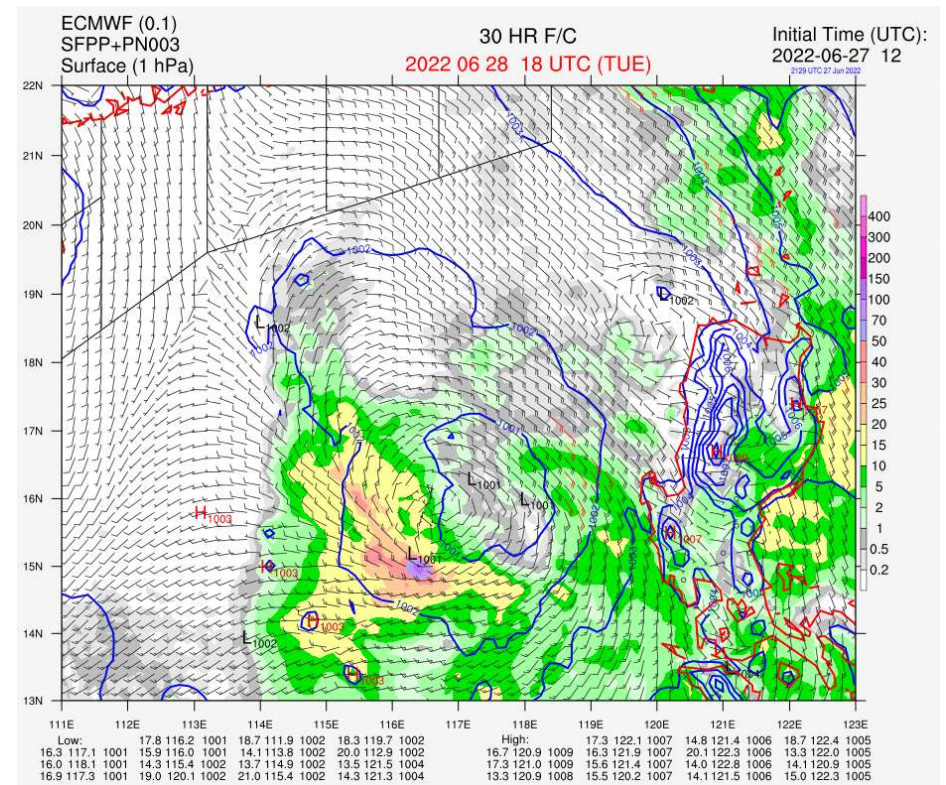
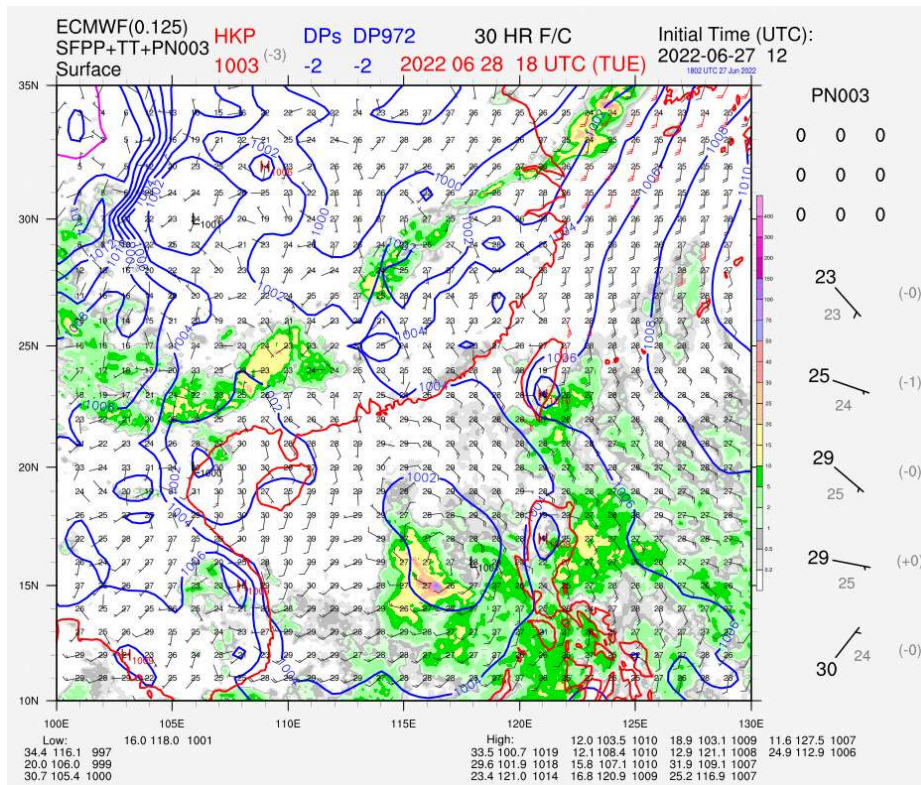
NWP VIEWER



- Helps forecasters view prognostic charts efficiently
- Compare different models, different initial time
- View different charts (e.g. different vertical levels) all at once

	Global A	Global B	Mesoscale	ML models	Misc	Extended	EPS sets	
Syncl	EC-Zoom	IM-Zoom	NC-Zoom	UK-Zoom	KMA-1IM(Z)	KMA-KIM(Z)	OW-Zoom	CMA-Zoom
300 ~	200 Div=U	200 Div=U	200 Div=U	200 Div=U	200 Div=U	200 Div=U		200 Div=U
300 ~	200 Z (A4)	200 Z (A4)	200 Z (A4)	200 Z (A4)				200 Z (A4)
300 ~	300 Div=U	300 Div=U	300 Div=U	300 Div=U				300 Div=U
300 ~	300 Z (A4)	300 Z (A4)	300 Z (A4)	300 Z (A4)				300 Z (A4)
300 ~	500 RH=U	500 RH=U	500 RH=U	500 RH=U	500 RH=U	500 RH=U	500 RH=U	500 RH=U
500 ~	500 Z (A4)	500 Z (A4)	500 Z (A4)	500 Z (A4)	500 Z (A4)	500 Z (A4)		500 Z (A4)
700 ~	700 RH=U	700 RH=U	700 RH=U	700 RH=U	700 RH=U	700 RH=U	700 RH=U	700 RH=U
800 ~	700 Yr=U	700 Yr=U	700 Yr=U	700 Yr=U	700 Yr=U	700 Yr=U	700 Yr=U	700 Yr=U
850 ~	850 RH=U	850 RH=U	850 RH=U	850 RH=U	850 RH=U	850 RH=U	850 RH=U	850 RH=U
850 ~	850 Yr=U	850 Yr=U	850 Yr=U	850 Yr=U	850 Yr=U	850 Yr=U	850 Yr=U	850 Yr=U
925 ~	925 RH=U	925 RH=U	925 RH=U	925 RH=U	925 RH=U	925 RH=U	925 RH=U	925 RH=U
SF 60 ~	SF RH=U	SF RH=U	SF RH=U	SF RH=U	SF RH=U	SF RH=U	SF RH=U	SF RH=U
SF 60 ~	SF2 RH=U	SF2 RH=U	SF2 RH=U	SF2 RH=U	SF2 RH=U	SF2 RH=U	SF2 RH=U	SF2 RH=U
SF2 10 ~	SF2 (2h) RH=U	SF2 (2h) RH=U	SF2 (2h) RH=U					
SF PC4 ~	SF PC24	SF PC24	SF PC24	SF PC24	SF PC24	SF PC24	SF PC24	SF PC24
SF TC4 ~	SF TC24	SF TC24	SF TC24	SF TC24	SF TC24	SF TC24	SF TC24	SF TC24
SF W4 ~	SF Wind Speed	SF Wind Speed	SF Wind Speed	SF Wind Speed	SF Wind Speed	SF Wind Speed	SF Wind Speed	SF Wind Speed
SF2 W4 ~	SF2 Wind Speed	SF2 Wind Speed	SF2 Wind Speed	SF2 Wind Speed	SF2 Wind Speed	SF2 Wind Speed	SF2 Wind Speed	SF2 Wind Speed
SF2 W4 ~	SF2 (6h) W4	SF2 (6h) W4	SF2 (6h) W4	SF2 (6h) W4				
SF2 W4 ~	SF ACC 6F							
SF2 V05=U								

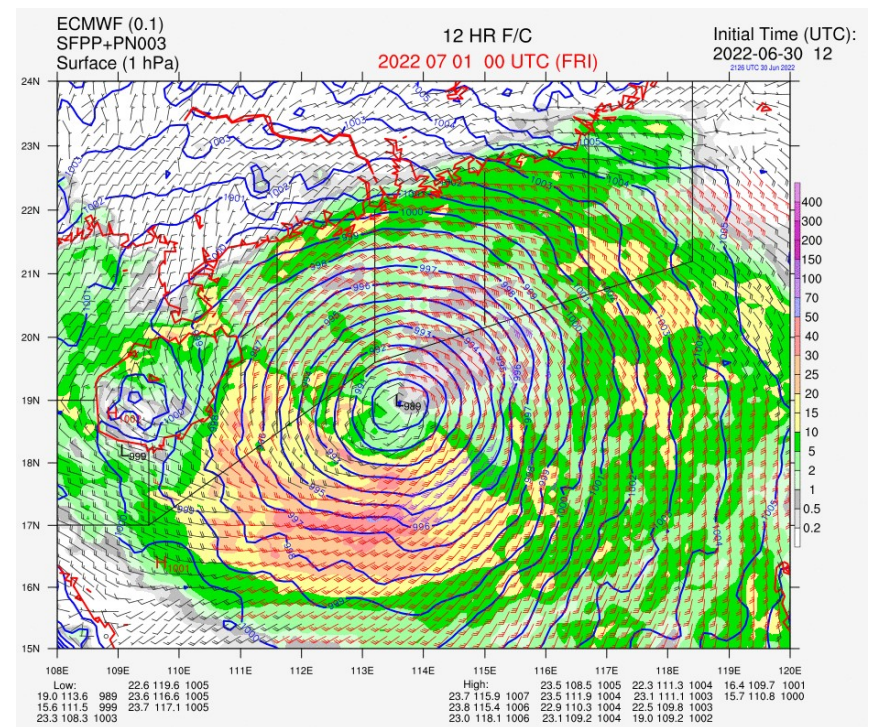
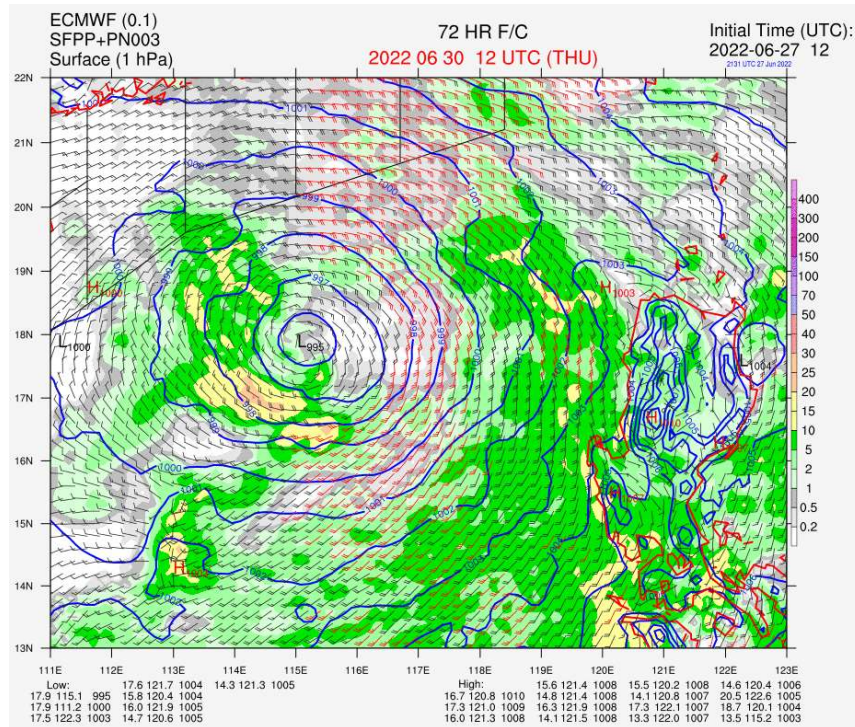
ZOOM-IN PROGNOSTIC CHARTS



High-resolution NWP outputs for short lead time may be helpful in appreciating the structure of TCs. (Note the limitations of NWP models though)

- TC in formative stages, e.g. presence of multiple low-level circulation centres

ZOOM-IN PROGNOSTIC CHARTS

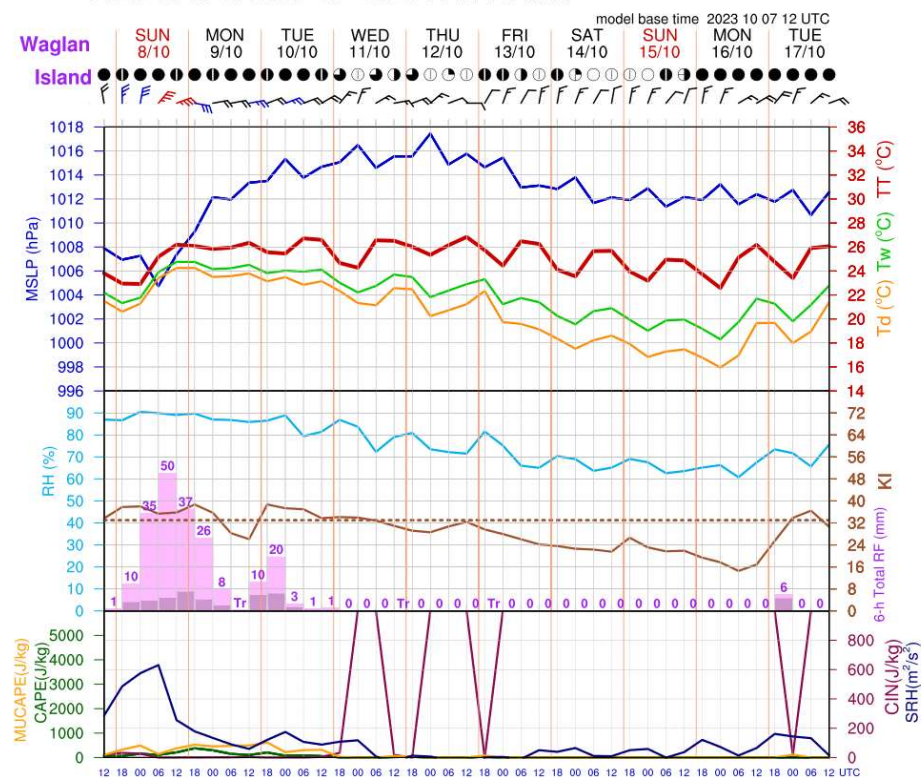


High-resolution NWP outputs for short lead time may be helpful in appreciating the structure of TCs. (Note the limitations of NWP models though)

- Wind distribution
- TC at dissipating stage

NWP TIME SERIES CHARTS

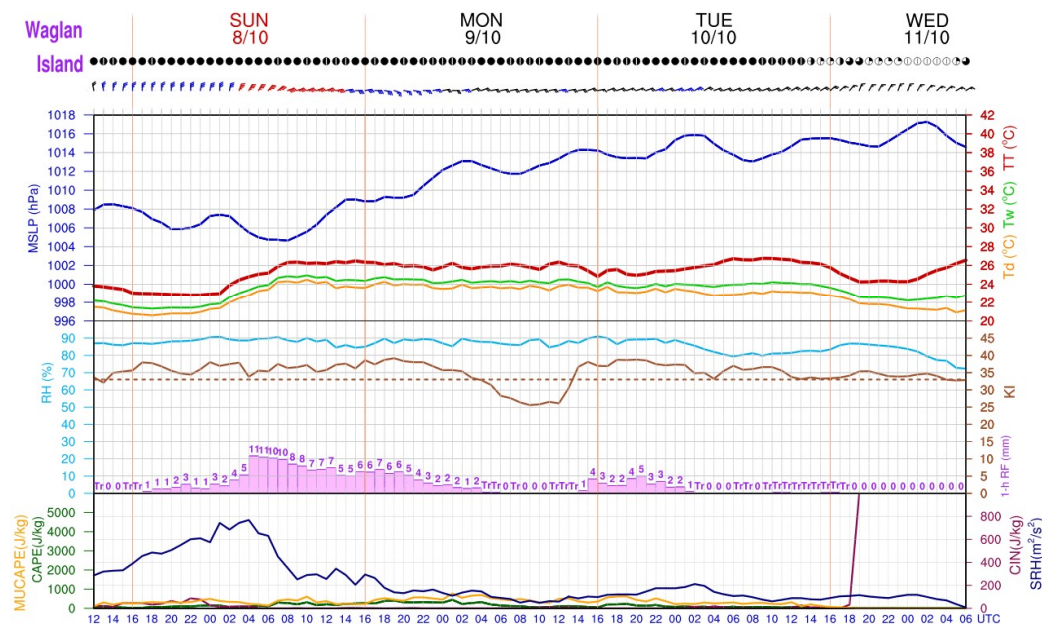
ECMWF ECMWF Forecast Time Series at Waglan Island, Grid (22.20N, 114.30E)
2023 10 07 20 HKT to 2023 10 17 20 HKT



ECMWF

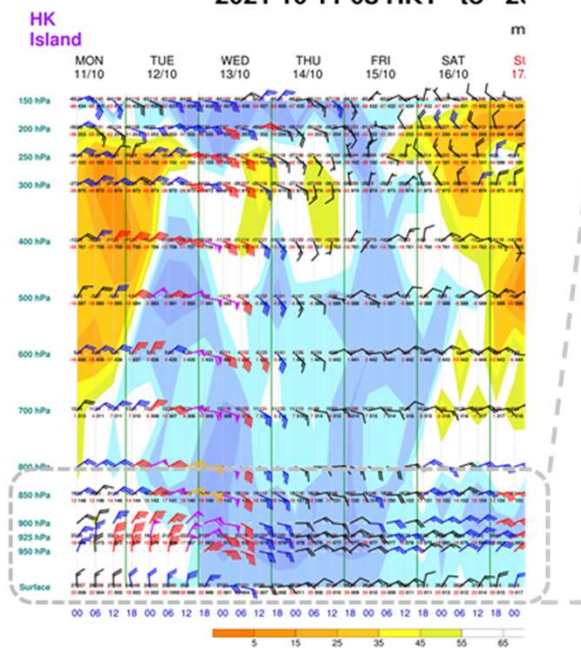
ECMWF Forecast Time Series at Waglan Island, Grid (22.20N, 114.30E)
2023 10 07 20 HKT to 2023 10 11 14 HKT

model base time 2023 10 07 12 UTC



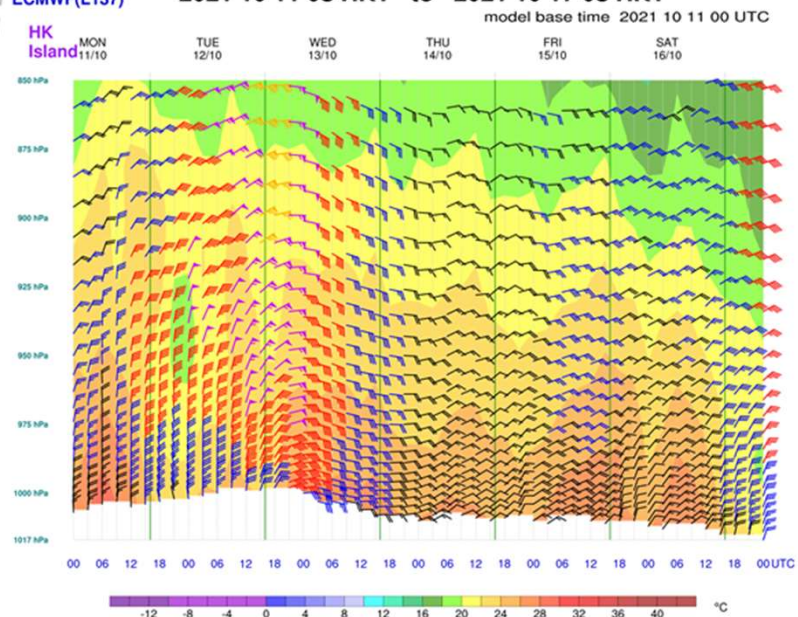
NWP TIME CROSS CHARTS

ECMWF(0.125) Forecast Time Cross at HK Isl
2021 10 11 08 HKT to 2021 10 17 08 HKT

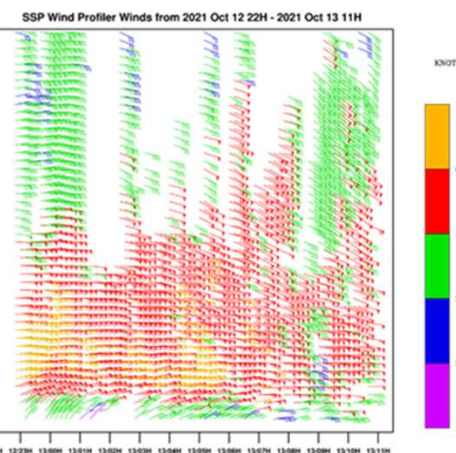


Standard pressure-level time cross with RH contours

ECMWF(L137) Forecast Time Cross at HK Island, Grid (22.25N, 114.25E)
2021 10 11 08 HKT to 2021 10 17 08 HKT



137-level time cross (low-level zoom-in with TT contours)



Wind profiler obs

RAINFALL FORECAST SUMMARY TABLE

Quantitative Precipitation Forecast (QPF) Summary Table

☒View selected model run

☐Compare selected with previous model runs

Select model run (UTC):

12

6

20231007

12

6

12

6

<<

Daily R/F map

>>

Model:

☒ECMWF☒NCEP☒JMA☒UKMO☐KMA-KIM☐KMA-UM☐DWD☐CMA-GFS☒AAMC-WRF☐TRAMS☒ECEPS☒HKO MEPS☐GRAPES REPS

[Go to Multi-model Average / Maximum](#)

Type:

☐Closest to HKO☐Min☒Avg☐Max☐EPS Supp Info

Model	Grid / Type	Forecast Date											
		8/10 (Sun)	9/10 (Mon)	10/10 (Tue)	11/10 (Wed)	12/10 (Thu)	13/10 (Fri)	14/10 (Sat)	15/10 (Sun)	16/10 (Mon)	17/10 (Tue)	18/10 (Wed)	19/10 (Thu)
ECMWF	Average	96.3	64.8	28.5	0.5	< 0.1	< 0.1	< 0.1	0.0	< 0.1	1.2		
ECMWF	Maximum	128.9	110.0	43.7	2.1	< 0.1	0.2	< 0.1	0.0	< 0.1	7.5		
NCEP	Average	101.5	13.3	0.5	0.6	0.5	1.1	0.3	0.0	< 0.1	0.2	0.0	< 0.1
NCEP	Maximum	175.8	19.4	0.6	0.9	0.6	1.6	0.7	0.0	< 0.1	0.5	0.0	< 0.1
JMA	Average	57.4	80.9	46.9	0.1	< 0.1	0.0	0.0	0.1	0.0	0.0	0.0	
JMA	Maximum	111.0	106.3	75.3	0.3	0.3	0.0	0.0	0.5	0.0	0.0	0.0	
UKMO	Average	117.5	122.9	6.1	< 0.1	0.0	< 0.1						
UKMO	Maximum	235.1	192.5	9.0	0.1	0.0	0.3						
KMA-UM	Average	138.5	106.6	15.5	< 0.1	< 0.1	< 0.1	0.0	< 0.1	< 0.1	< 0.1	< 0.1	0.0
KMA-UM	Maximum	256.8	204.3	26.6	< 0.1	< 0.1	< 0.1	0.0	0.3	0.3	< 0.1	< 0.1	0.0
AAMC-WRF	Average	23.4	22.8	3.1									
AAMC-WRF	Maximum	78.9	65.3	10.8									
ECEPS	50%-tile	84.4	46.0	20.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ECEPS	75%-tile	129.7	67.4	37.2	0.5	0.1	0.0	0.0	0.2	0.1	2.4	5.6	3.0
ECEPS	PoP (Yes/No)	100%	100%	96%	42%	36%	39%	42%	48%	49%	47%		
ECEPS	PoP (Moderate)	99%	98%	72%	4%	0%	0%	3%	4%	7%	14%	21%	19%
ECEPS	PoP (Heavy)	98%	95%	63%	2%	0%	0%	2%	2%	6%	10%	18%	15%
ECEPS	EFICAL-HK	410.2	238.5	62.8	0.9	0.1	0.2	0.1					
ECEPS	EFICAL-Max	425.3	444.1	85.2	0.9	0.1	0.2	0.5					
HKO MEPS	50%-tile	5.5	15.6	8.6	0.0								
HKO MEPS	75%-tile	21.5	68.8	44.8	0.6								
HKO MEPS	PoP (Yes/No)	98%	100%	99%	49%								
HKO MEPS	PoP (Moderate)	38%	58%	47%	1%								
HKO MEPS	PoP (Heavy)	30%	51%	41%	0%								

Quantitative Precipitation Forecast (QPF) Summary Table

View selected model run Compare selected with previous model runs Select model run (UTC): 12 6 20231007 12 6 12 6 12 6

Model: ☒ ECMWF ☒ KMA ☒ JMA ☒ UKMO ☒ NCEP ☐ AAMC-WRF ☒ ECEPS ☒ HKO MEPS ☒ GRAPES REPS ☐ TRAMS Type: ☐ Closest to HKO ☐ Min ☒ Avg ☐ Max ☐ EPS Supp Info

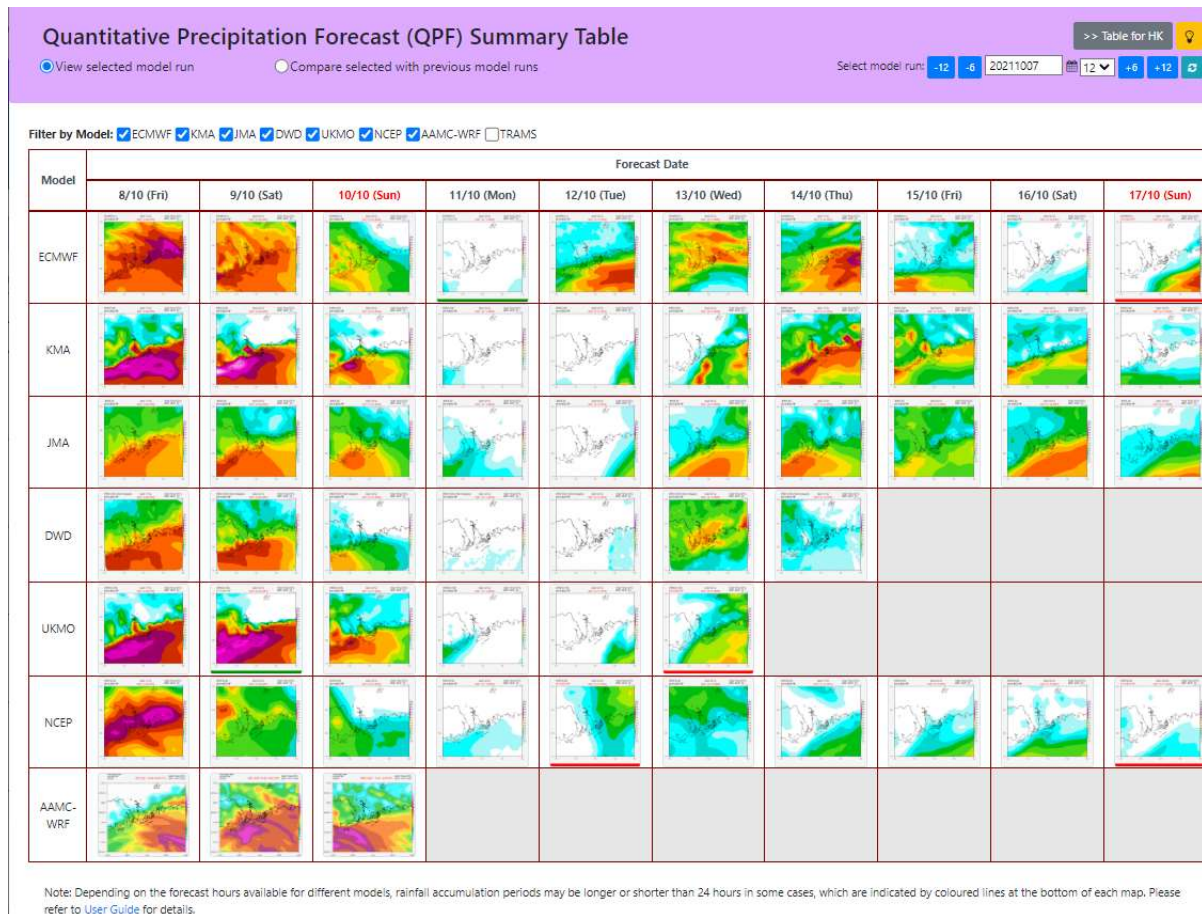
08 (Fri) 09 (Sat) 10 (Sun) 11 (Mon) 12 (Tue) 13 (Wed) 14 (Thu) 15 (Fri) 16 (Sat) 17 (Sun)

Forecast Date : 08 Oct 2021 (Fri)

Model	Grid / Type	Base Time															
		07/12 Z	07/06 Z	07/00 Z	06/18 Z	06/12 Z	06/06 Z	06/00 Z	05/18 Z	05/12 Z	05/06 Z	05/00 Z	04/18 Z				
ECMWF	Average	152.7	187.2	174.8	93.7	73.0	48.4	37.5	46.1	20.1	4.4	9.8	8.9				
ECMWF	Maximum	199.8	271.2	231.1	112.8	95.2	71.5	64.2	72.5	29.6	13.3	17.4	16.7				
KMA	Average	125.8		81.1	114.2		125.2		106.3		111.6						
KMA	Maximum	229.4		182.2	273.3		287.9		193.6		189.7						
JMA	Average	72.0	48.4	44.2	40.9	47.4	49.1	53.8	36.1	35.4	18.0	2.1	5.1				
JMA	Maximum	94.9	67.6	68.0	73.4	70.3	74.8	83.1	52.3	59.8	25.4	5.3	11.6				
DWD	Average	71.8		70.4		38.3		74.6		57.9		79.8					
DWD	Maximum	95.7		88.7		127.3		112.0		128.1							
UKMO	Average	79.8		60.4	73.8		76.6		79.5		64.9						
UKMO	Maximum	156.4		126.0	144.3		157.5		157.6		138.3						
NCEP	Average	182.9	196.8	150.8	206.5	26.7	5.3	4.6	4.9	5.5	37.6	66.8	2.2				
NCEP	Maximum	240.4	248.4	177.7	234.0	47.1	8.3	7.9	10.9	8.9	63.1	97.8	5.6				
ECEPS	50%-tile	127.1		111.7		81.5		35.7		45.4		32.2					
ECEPS	75%-tile	147.4		133.2		101.5		59.3		78.5		72.7					
ECEPS	PoP (Yes/No)	100%						98%		98%		95%					
ECEPS	PoP (Moderate)	100%		100%		100%		89%		84%		73%					
ECEPS	PoP (Heavy)	100%		100%		99%		81%		80%		66%					
HKO MEPS	50%-tile	57.8	33.8		9.2	10.3	80.6	56.6	63.1	39.1	41.8	19.9	24.6				
HKO MEPS	75%-tile	71.4	47.9		31.3	41.2	109.4	127.9	103.1	66.8	104.6	54.6	58.7				
HKO MEPS	PoP (Yes/No)	100%	100%		93%	99%	100%	100%	100%	100%	99%	91%	99%				
HKO MEPS	PoP (Moderate)	87%	84%		48%	63%	100%	97%	99%	86%	84%	64%	70%				
HKO MEPS	PoP (Heavy)	83%	77%		41%	52%	100%	92%	97%	79%	77%	57%	61%				
GRAPES REPS	50%-tile	116.1		108.6		80.2		43.3		42.1		97.3					
GRAPES REPS	75%-tile	151.1		138.7		121.7		75.5		76.6		126.0					
GRAPES REPS	PoP (Yes/No)	100%		100%		100%		97%		92%		100%					
GRAPES REPS	PoP (Moderate)	100%		100%		98%		73%		73%		92%					
GRAPES REPS	PoP (Heavy)	100%		100%		97%		86%		68%		91%					

Note: Depending on the forecast hours available for different models, rainfall accumulation periods may be longer or shorter than 24 hours in some cases (indicated in *italics*). Please refer to [User Guide](#) for details.

RAINFALL FORECAST SUMMARY TABLE



WIND FORECAST SUMMARY TABLE

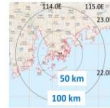
NWP Wind Forecast Summary

Model run: 20231007 12

-6 +6 -12 +12 -24 +24 Latest

Max wind speed for grid point :
(deterministic)

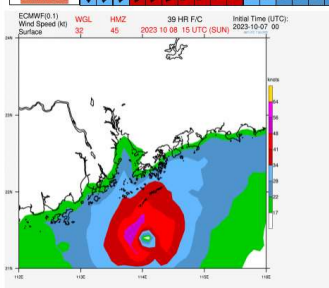
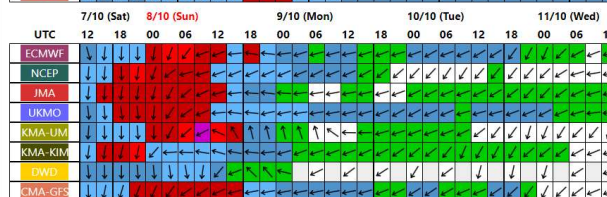
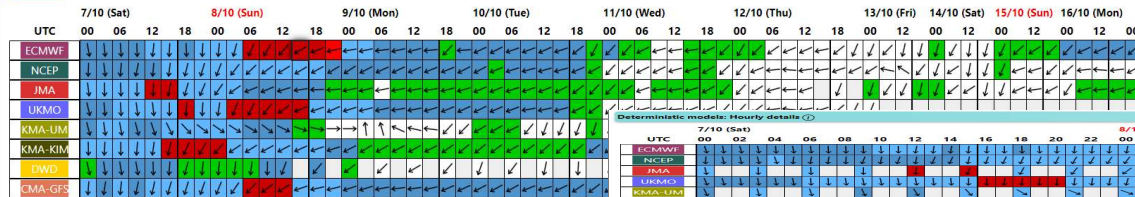
● in the vicinity of HK
○ within 50 km of HKO



Wind direction :
(deterministic)
Grid point : SE SW

Deterministic models: 10-day summary

UTC/HKT



Deterministic models: Hourly details



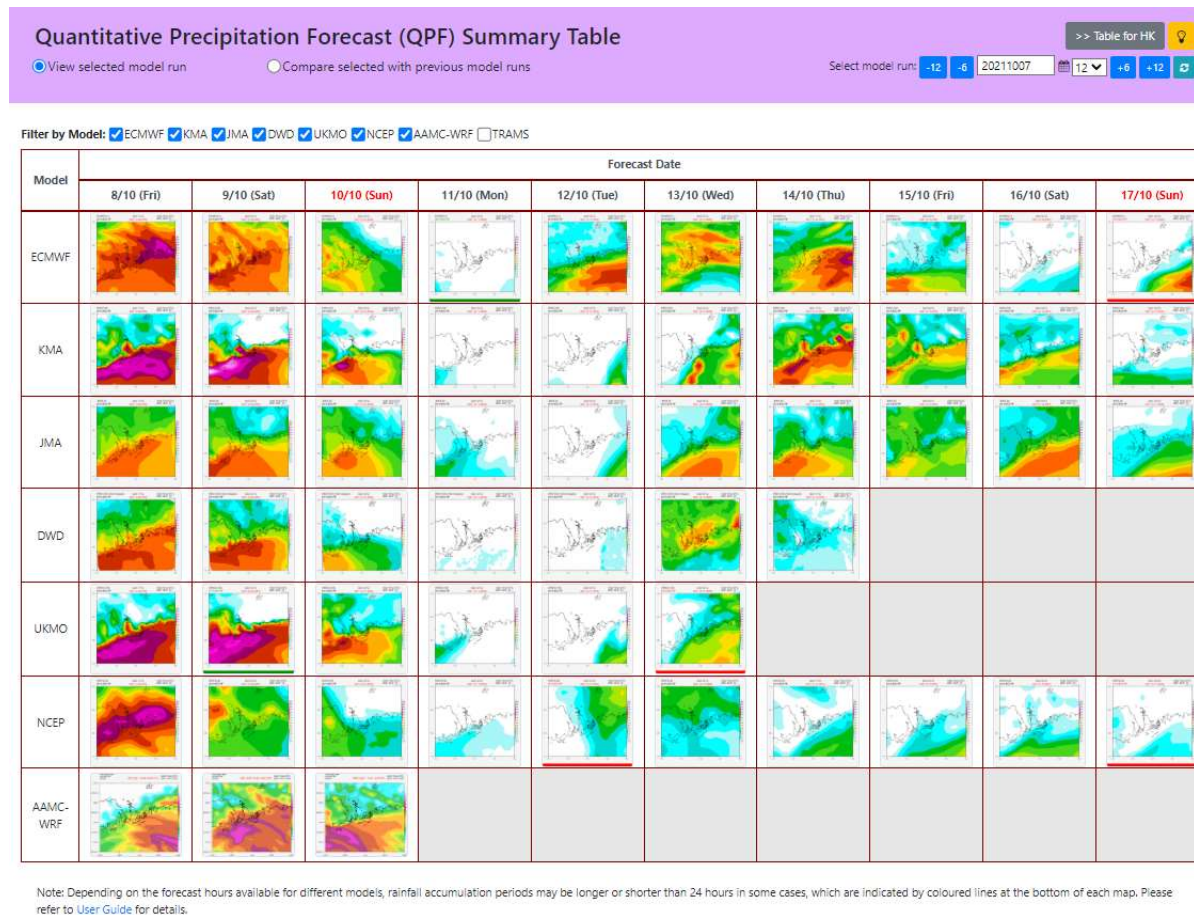
Force <5 5 6 7 8 9 10 11 12

Deterministic models: Hourly details

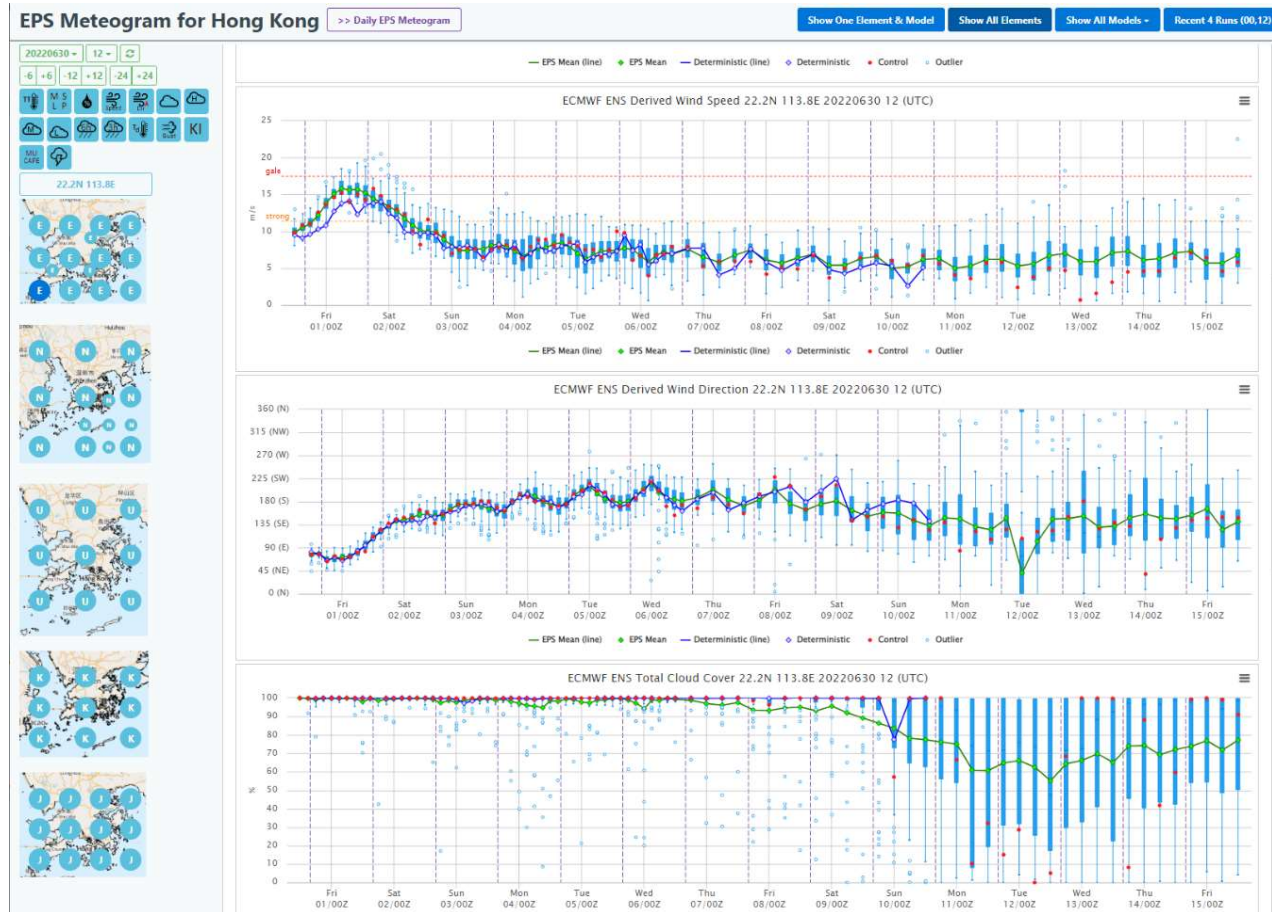


Force <5 5 6 7 8 9 10 11 12

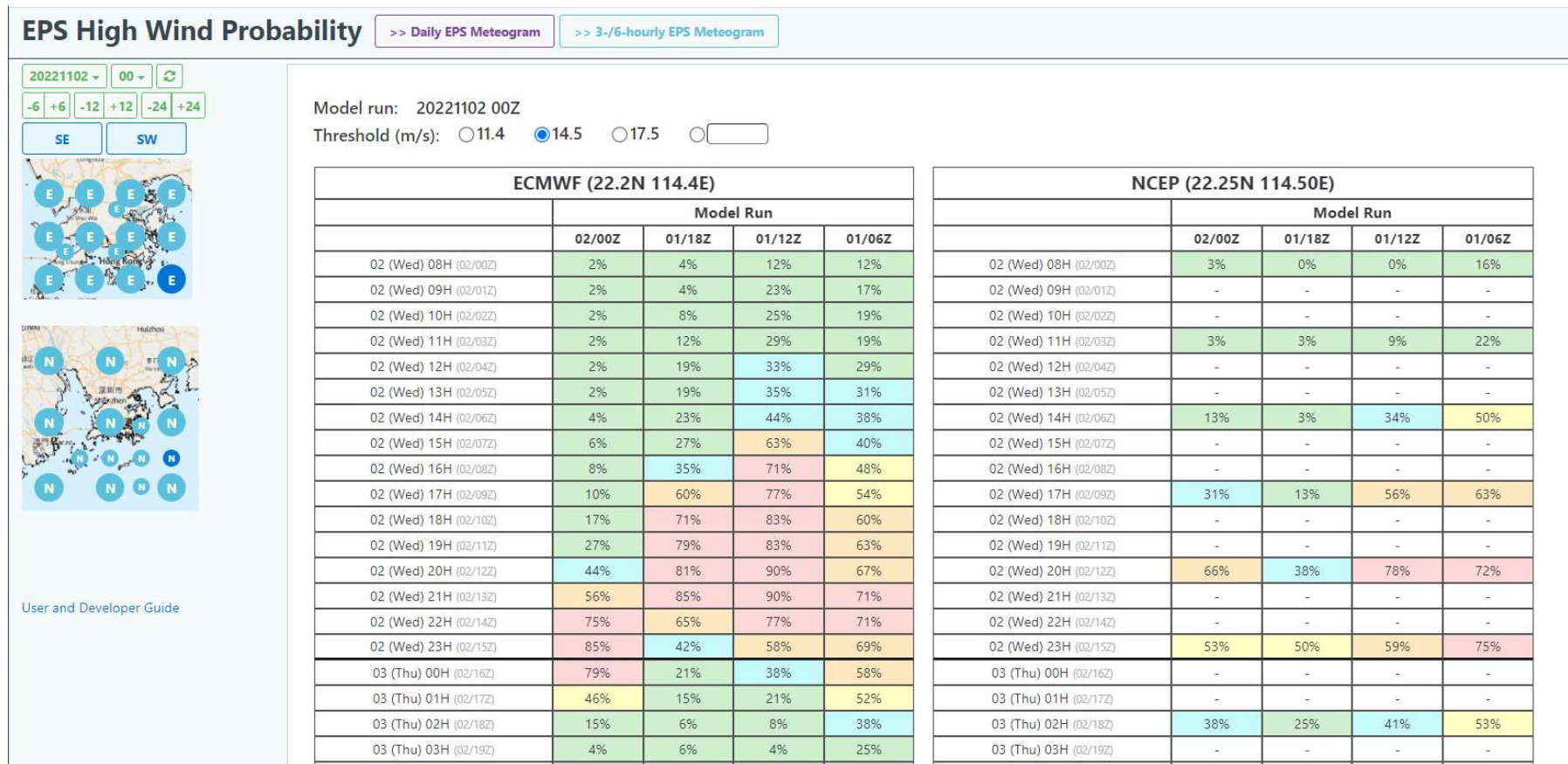
RAINFALL FORECAST SUMMARY TABLE



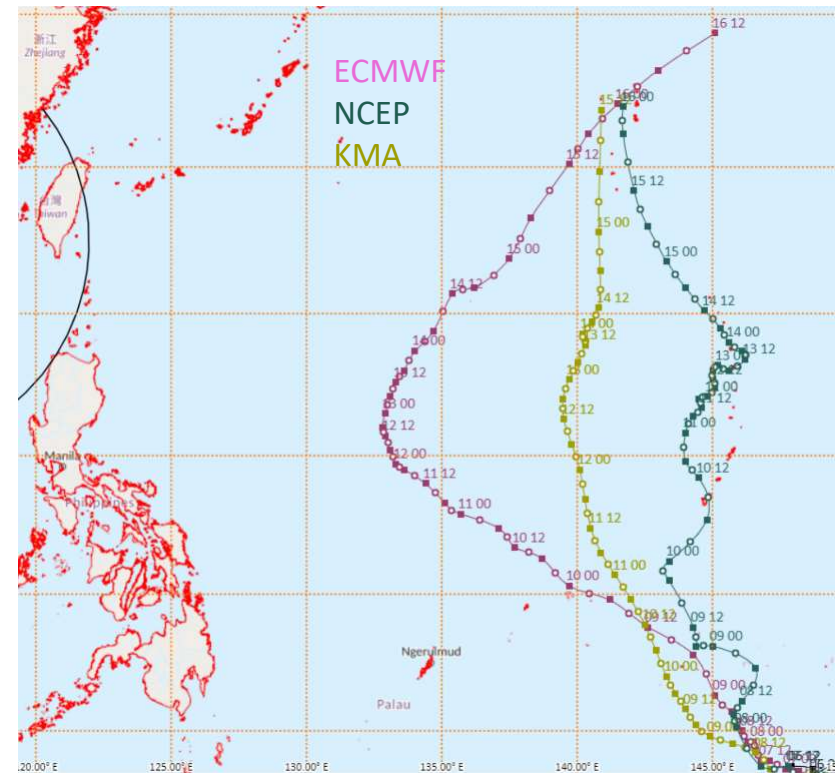
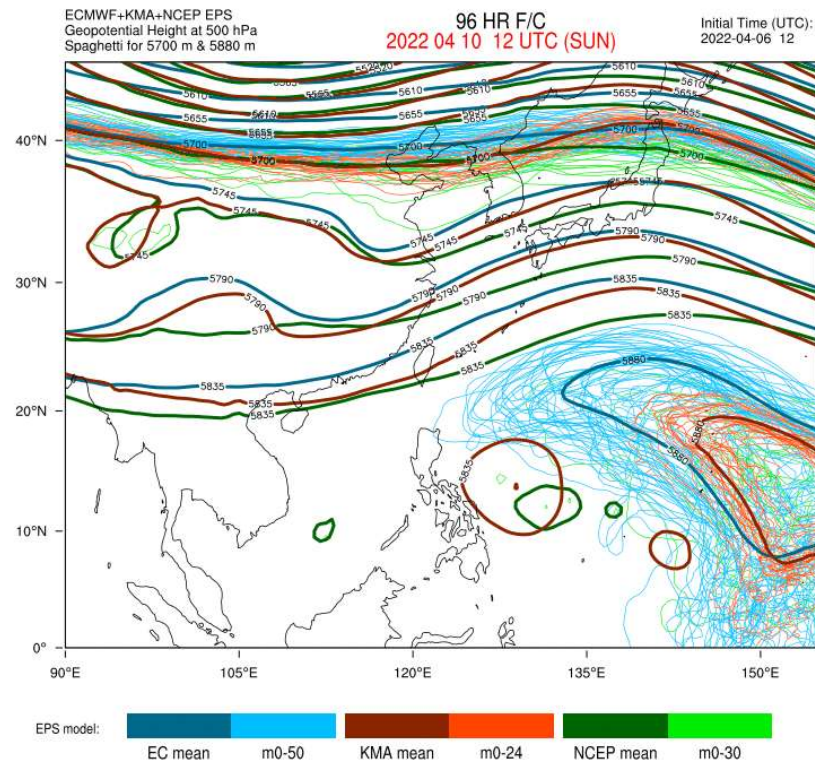
EPS METEOGRAM



EPS HIGH WIND PROBABILITY

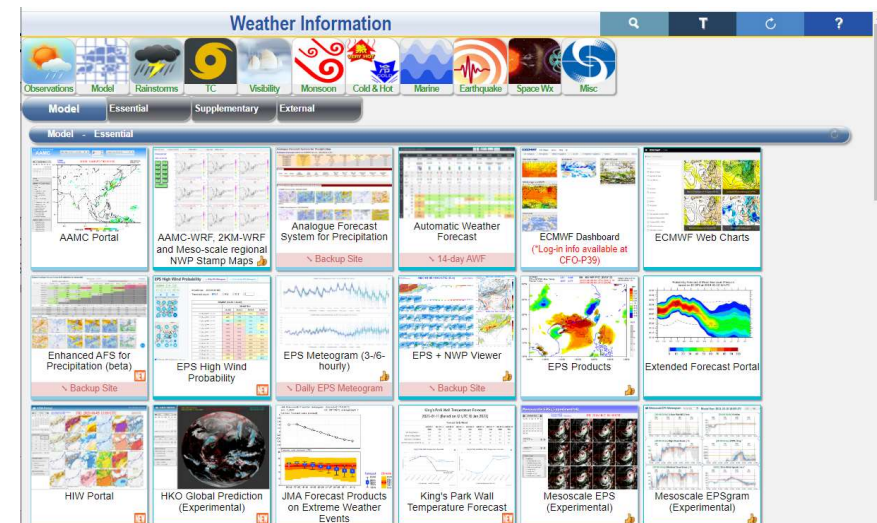


COMBINED EPS MAPS: 500 HPA GEOPOTENTIAL HEIGHT



DEVELOPING SYSTEMS AND TOOLS FOR FORECASTERS

- Web-based systems with open source libraries
- Make best use of high-resolution products
- Allow easy comparison between different
 - NWP models
 - model initial time
 - parameters
- Highlight important information (e.g. extreme values)
- Try to use consistent colour scheme across different products (e.g. wind speed, rainfall values, TC category, or even NWP models)



TROPICAL CYCLONE FORECASTING AND IMPACT ALERTING

TOPICS

Tropical Cyclone Analysis

1

Track and Intensity Forecasting

2

Warning and Message Delivery

3

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4

Impact Monitoring and Alerting

5

ASSESSMENT OF TROPICAL CYCLONE IMPACTS

- Traditionally, assessment of impacts of TCs rely on media reports and post-event surveys
- Collection, processing and analysis of TC impact Big Data are beneficial in a number of ways:
 - Improves **real-time** situational awareness of weather forecasters
 - Provides greater **detail** of impacts, e.g. location, time and severity
 - Useful for **research** and **public education**
 - Supports development of **impact-based forecasting**



表 4.10 二零一七年熱帶氣旋在香港所造成的損失
TABLE 4.10 DAMAGE CAUSED BY TROPICAL CYCLONES IN HONG KONG IN 2017

熱帶氣旋名稱 Name of tropical cyclone	月份 Month	物質損失 Damage in physical terms						金錢損失 (百萬港元) Damage in monetary terms (million HK\$)				
		農業 Agriculture	公用建設 (處) Public works facilities (site)	公用事業 (處) Public utilities (site)	物業單位 (間) Property (unit)	山泥傾瀉及斜坡倒塌 (宗) Landslip and collapse of slope (case)	受到破壞的船隻數目 (艘) Ships lost or damaged (number)	農業 Agriculture	公用建設 Public works facilities	公用事業 Public utilities	私人物業 Private property	共 Total
強烈熱帶風暴苗柏 Severe Tropical Storm Merbok	6	農地 Farmland: 5130 公頃 hectares 農作物 Crops: 2547 噸 tons	道路 Road: 2 小徑 Footpath: 3 公園 Cemetery: 2	鐵路 Railway: 1 安全護欄 Road barrier: 1	2	9	2	39.78000		0.00101		39.78101
熱帶風暴洛克 Tropical Storm Nika	7					2	2					
超級颱風天鴿 Super Typhoon Hato	8	農地 Farmland: 5841 公頃 hectares 農作物 Crops: 1274 噸 tons 塘魚 Pond fish: 583 噸 tons	道路 Road: 1 避風亭 Rain Shelter: 2 欄杆 Railing: 25	電信設施 Telecommunication facilities: 1 变电站 Substation: 1	66	1	36	67.08000		0.11700	1.09949	68.29649
強烈熱帶風暴帕卡 Severe Tropical Storm Pakhar	8		工地 Construction site: 1		3	3	15			1.78846		1.78846
強烈熱帶風暴瑪娃 Severe Tropical Storm Mawar	8						8			0.00640		0.00640
強烈風暴卡努 Severe Typhoon Khanun	10					1	3					

備註：資料由各有關政府部門及公共事業機構提供，同時也參考了本地報章上的調查報導。

N.B.: Based on information supplied by relevant government departments and public utility companies. Damage reports in the local press were also examined and collated.

WEATHER-RELATED IMPACT REPORTS

Weather-related hazard reports extracted from GNMIS Date: 20190731 Reload D-1 D+1

Time series on/off Note: Please use Chrome or Firefox for best results.

Keywords: Alert Find in page Reports containing Special Note to Roadside Alert have

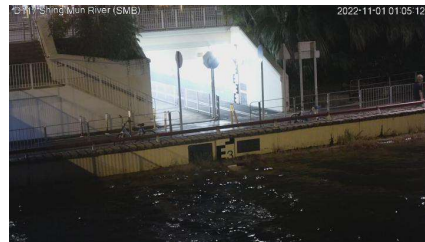
17: Department: Fire Services Department - Incident
Serial No.: INC2019073101061

FSD INC: Emergency Incidents received by FSD from
18:00:00 to 18:29:59 on JULY 31, 2019

"Date" "Time" "Type of Incident" "Address"
"2019/07/31" "18:03:49" "No. 1 Alarm" "10 MUK NING STREET, KOWLOON BAY AREA."
"2019/07/31" "18:06:07" "Special Service (Tree Cutting)" "HANG TAI ROAD, NA ON SHAN AREA."
"2019/07/31" "18:10:55" "No. 1 Alarm Automatic Fire Alarm" "SHEUNG MUN HOUSE UPPER NGAU TAU KOK ESTATE, KWUN TONG AREA."
"2019/07/31" "18:13:05" "Traffic Accident (With Reported Injury)" "NEAR 2 KWUN TSING ROAD, TAI LAM CHUNG AREA."
"2019/07/31" "18:21:26" "Person Being Shut In Lift" "TUNG SING HOUSE LEI TUNG ESTATE, AP LEI CHAU AREA."

Potential hazard to life and property may exist at scene of incident.

Incident reports from emergency services



Photos from weather camera, water-level monitoring cameras and traffic snapshots

Keyword extraction + Geocoding

交通消息

可重溫過去12個月的交通消息

請選擇日期 2018 11 11 去

2018-11-11

1. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 18:25)

2. 中環有線式進行，近新區議會對面，發現有車輛在路邊停車，(HKT 18:15)

3. 大馬路或馬路土庫，由12:11(星期四)至14:00:05:00，所有長途巴士的車輛禁止在轉入車公廟路旁，(HKT 18:08)

4. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 17:55)

5. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 17:51)

6. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 17:30)

7. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 17:15)

8. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 16:55)

9. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 16:40)

10. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 16:37)

11. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 16:17)

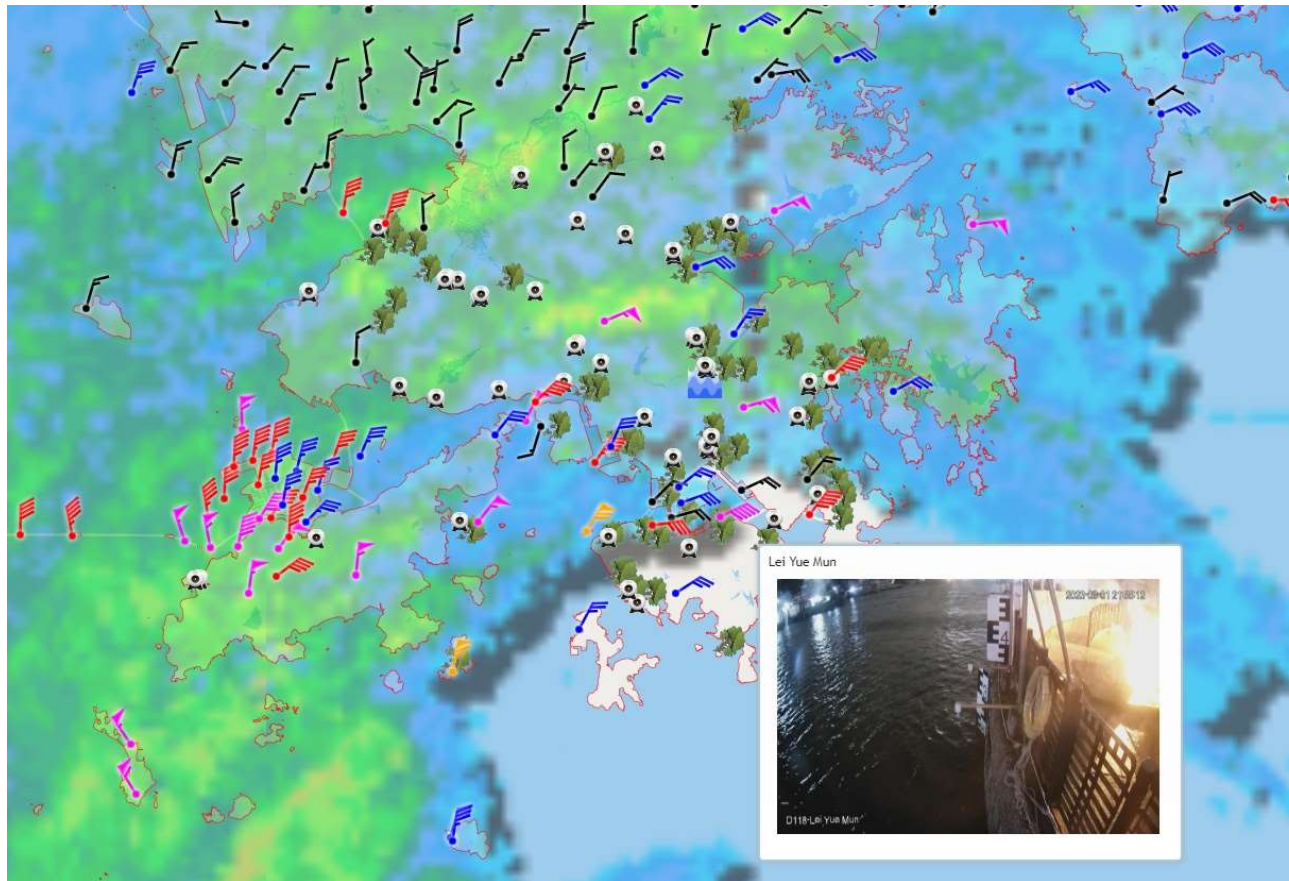
12. 新區議會往新區議會方向，近新區議會對面，發現有車輛在路邊停車，(HKT 16:15)

Traffic news from the media

Deep-learning network for analyzing the news

GIS Display for forecasters' reference

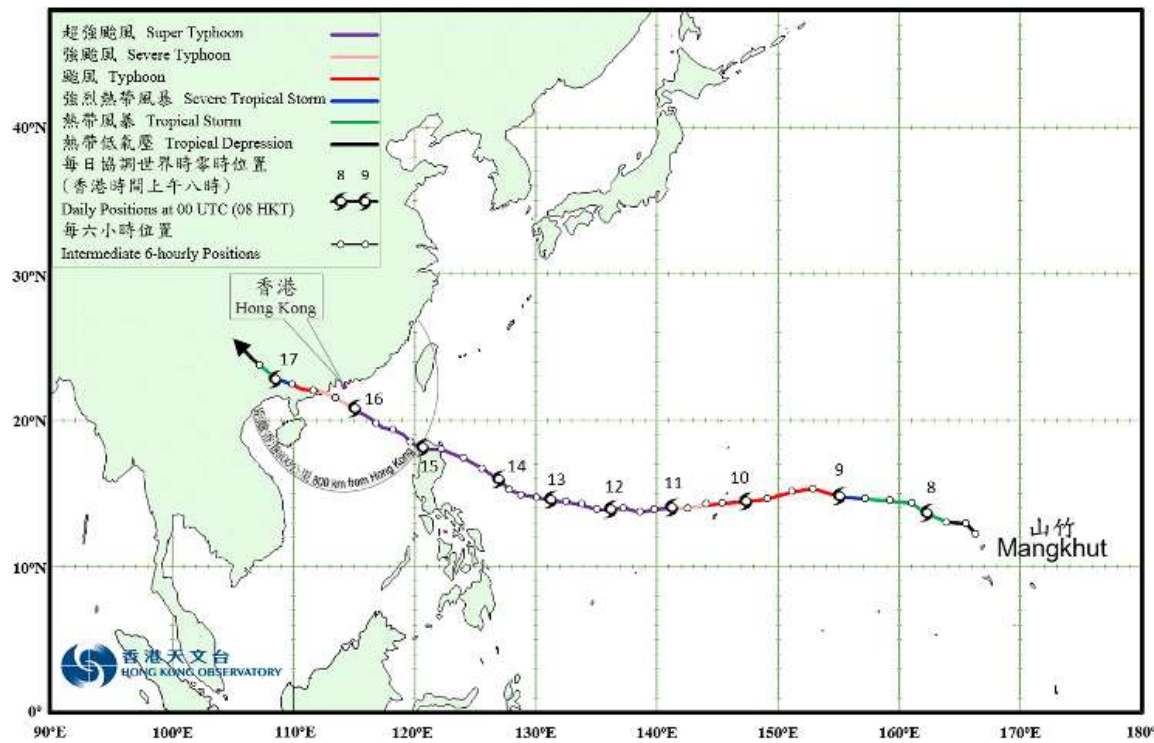
INTEGRATED WEATHER AND IMPACT DISPLAY



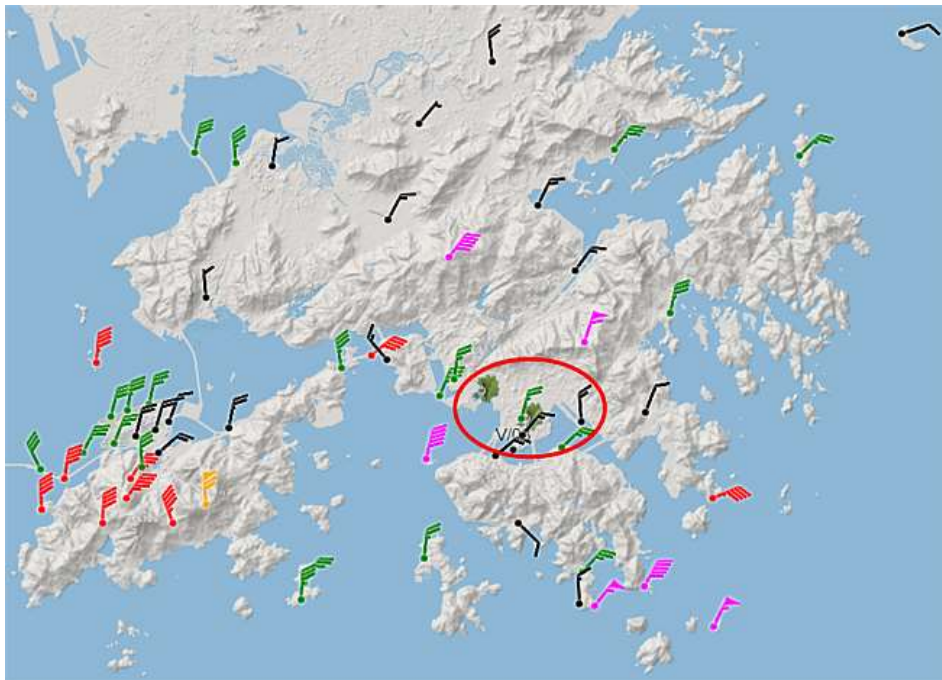
Super Typhoon Saola
(22:00 HKT, 1 Sep 2023)

- Wind observations
- Radar imagery
- Incident reports (fallen trees, flooding)
- Water-level monitoring cameras
- Other available overlay: traffic speed

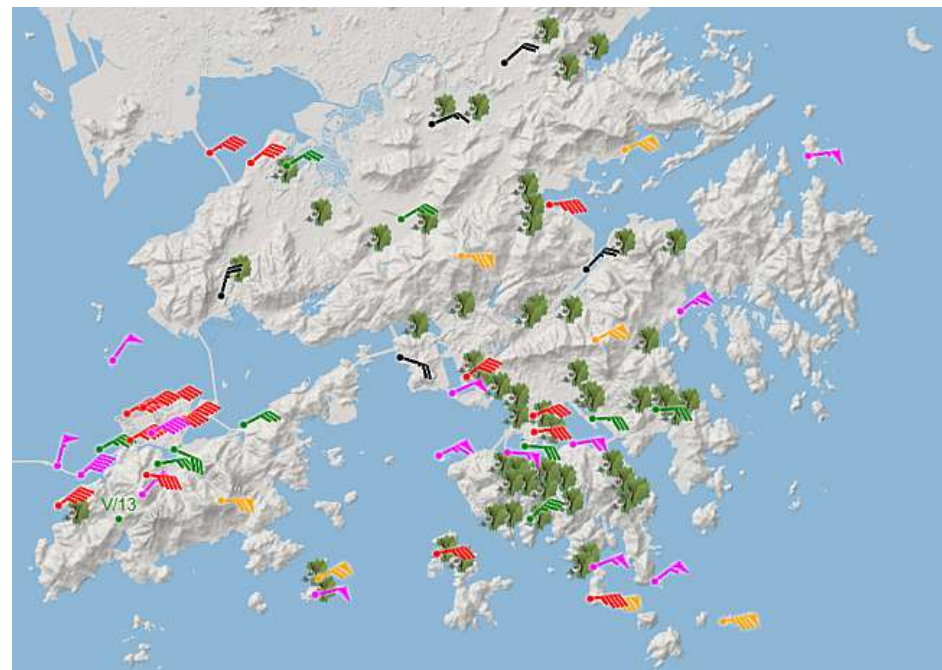
IMPACT ANALYSIS: TC MANGKHUT (SEP 2018)



IMPACT ANALYSIS: TC MANGKHUT AND FALLEN TREES



Wind obs + Fallen tree reports at 0800HKT



Wind obs + Fallen tree reports at 1200HKT

16 Sep 2018

- More fallen trees were found when local winds turned easterlies, which were less sheltered from terrain

USE OF AI IN IMPACT MONITORING

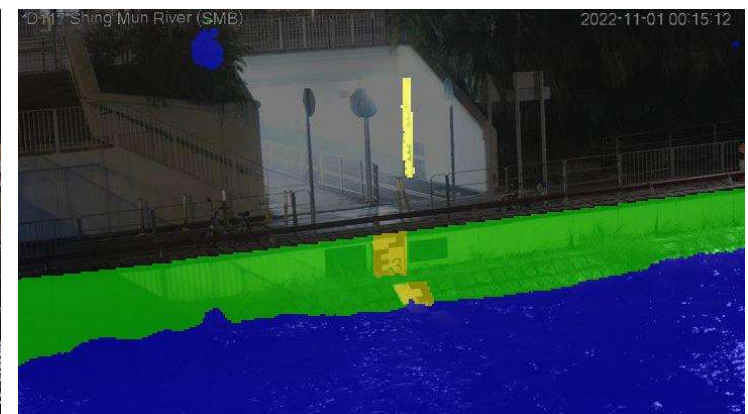
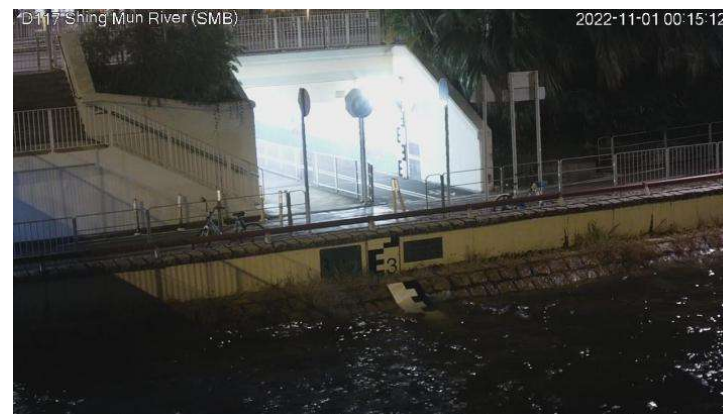
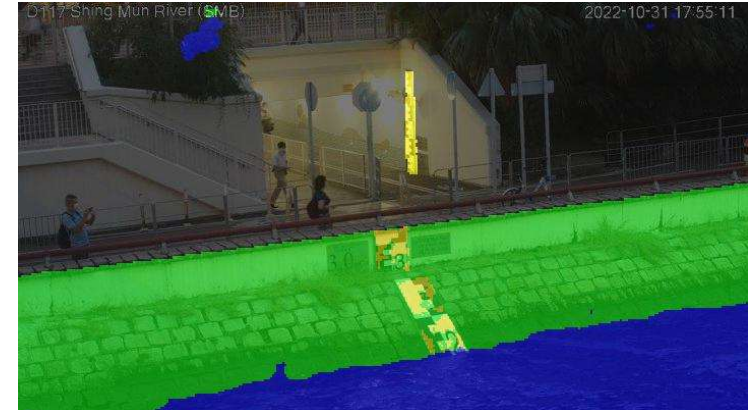
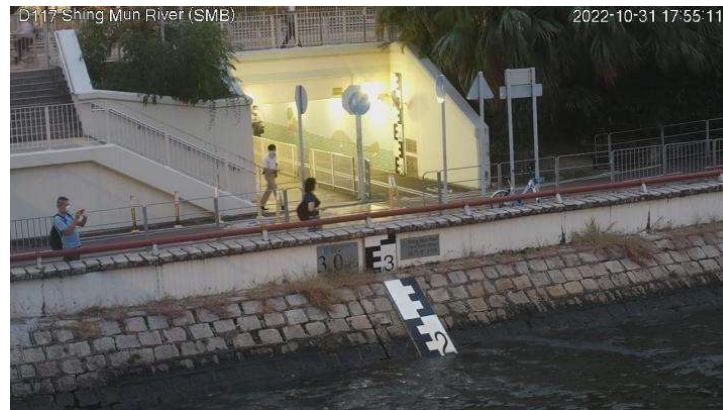
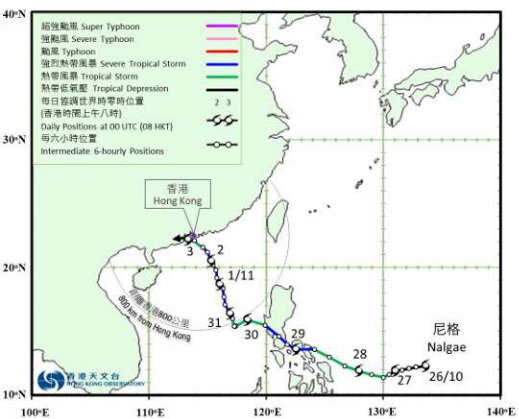
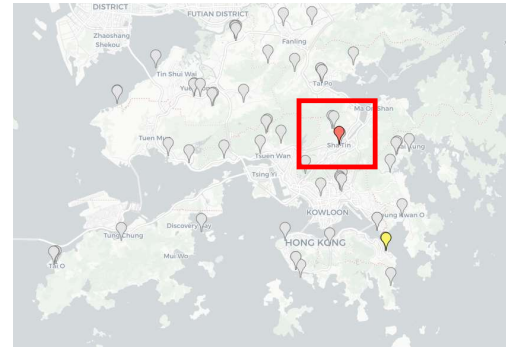


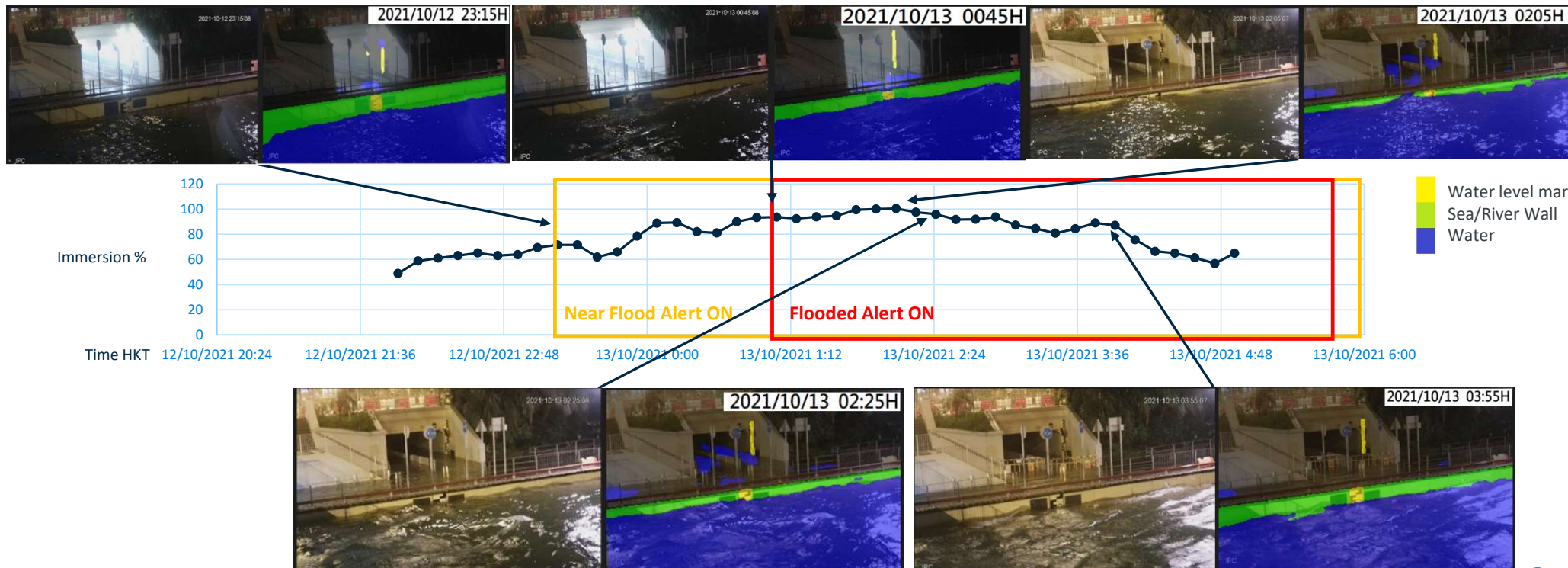
Photo analysed by AI system, water surface in blue

FLOODING ANALYTICS



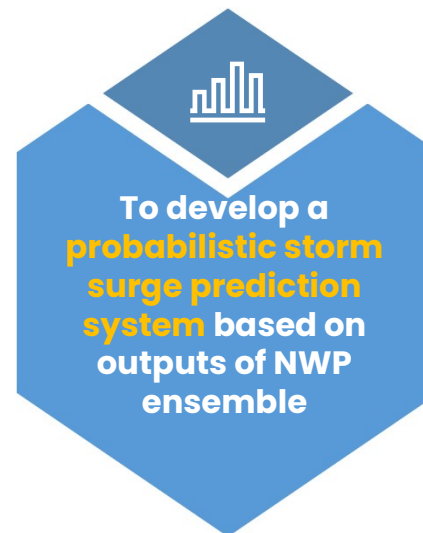
Marine

Based on the real-time photos from DSD, the water level near 城門河 is/are rising and flooding is expected to occur or is occurring in the area(s). Please assess the weather conditions/tide level and take actions required.



RISK-BASED IMPACT FORECASTING: STORM SURGE

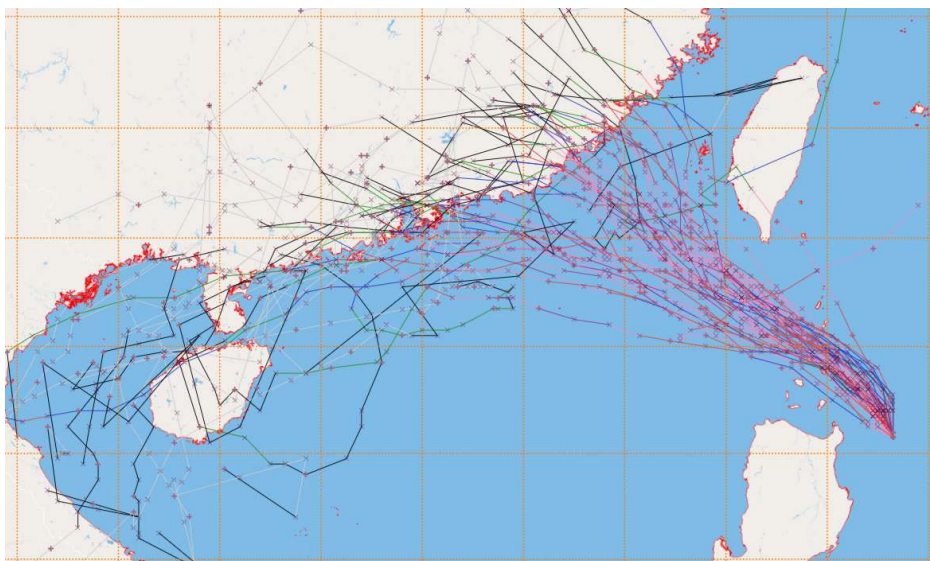
TRIAL UNDER A WMO PILOT PROJECT



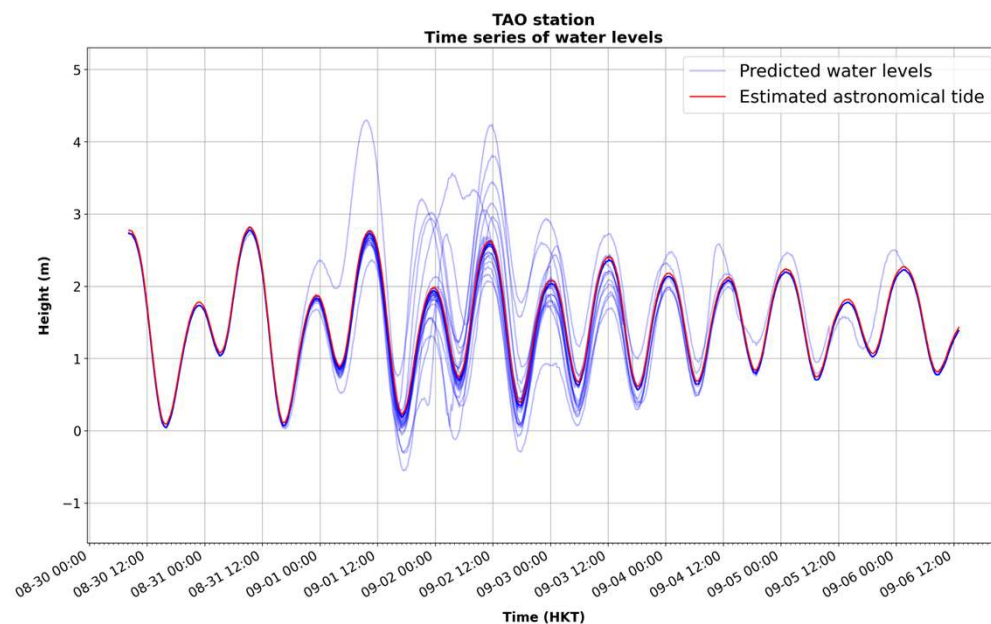
RISK-BASED IMPACT FORECASTING: STORM SURGE

PROBABILISTIC STORM SURGE PREDICTIONS

- Based on HKO's operational storm surge prediction model "SLOSH"
- Probabilistic storm surge predictions at different locations are generated by running SLOSH using 51 different track scenarios (forecast positions + *post-processed* intensity forecasts) based on ECMWF EPS



Example: ECMWF EPS Ensemble Tracks for TC Saola (00Z run 29 Aug 2023)



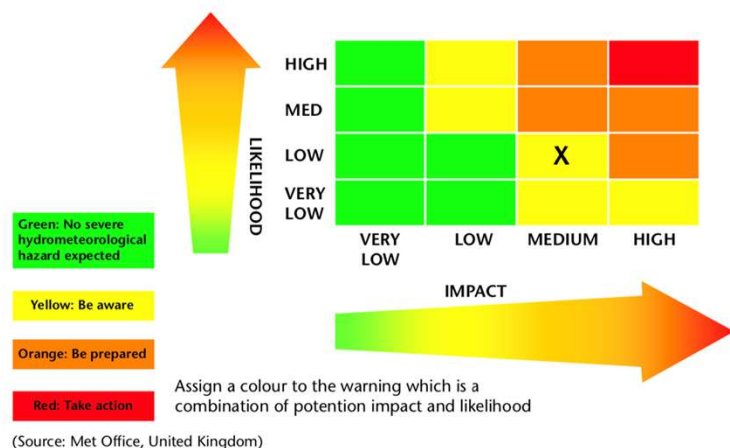
Corresponding predicted water levels at Tai O

RISK-BASED IMPACT FORECASTING: STORM SURGE

RISK MATRIX

- Probability (likelihood) and tidal level (impact) thresholds are **site-oriented**.

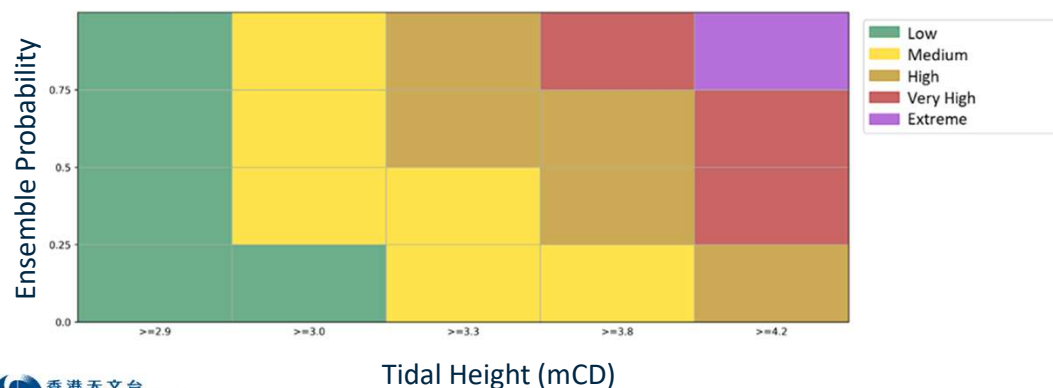
$$|Risk\ of\ impact\ (x,\ t)| \equiv |hazard\ (x,\ t)| \cup |vulnerability\ (x,\ t)| \cup |exposure\ (x,\ t)|$$



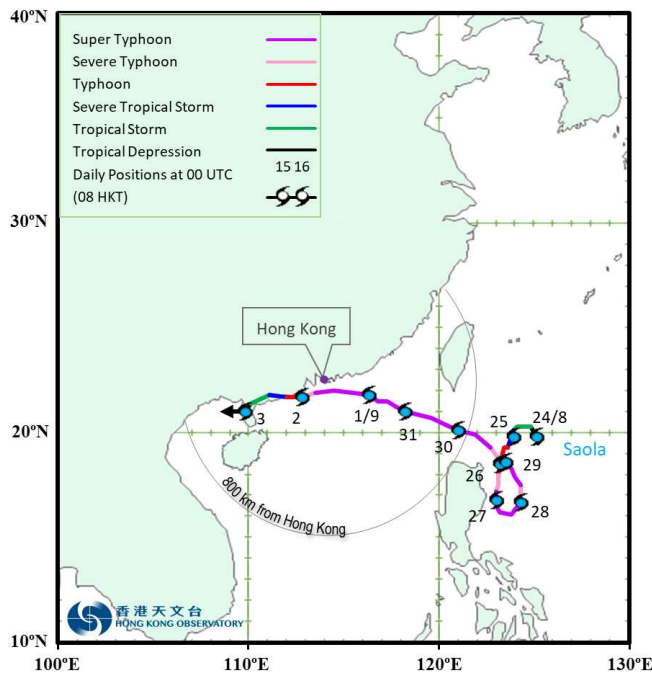
Sea Level Height (mCD)	Impacts
≥ 3.0	Minor flooding occurs in low-lying area
≥ 3.3	Sea water can overflow riverbanks
≥ 3.8	Most extreme storm surge events in the past (Mangkhut, Hato & Hagupit)
≥ 4.2	Extreme circumstances in climate change



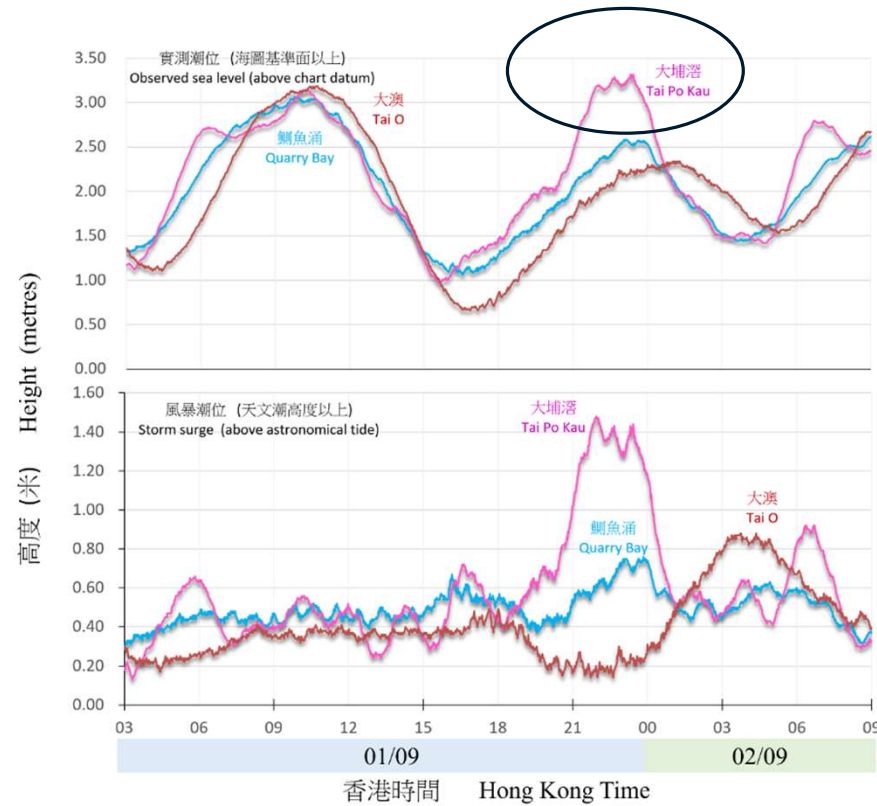
Risk Matrix for Tai O



EXAMPLE: SUPER TYPHOON SAOLA



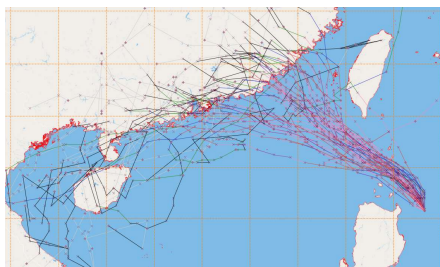
Provisional track



Flooding of Shing Mun River due to storm surge induced by Saola
(Courtesy of Poon Chi Ming)

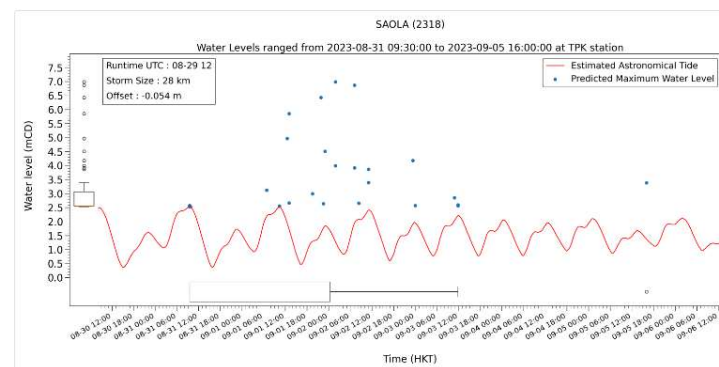
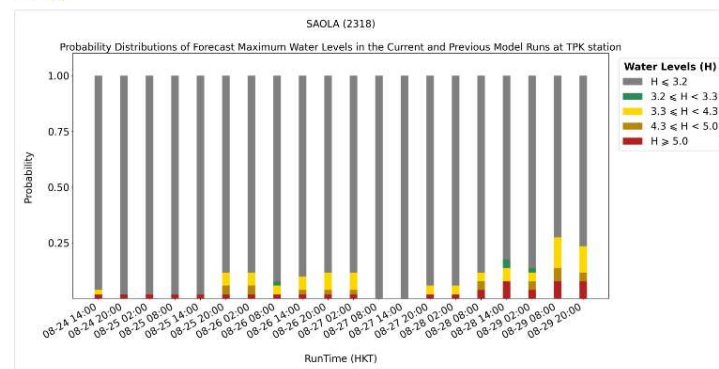
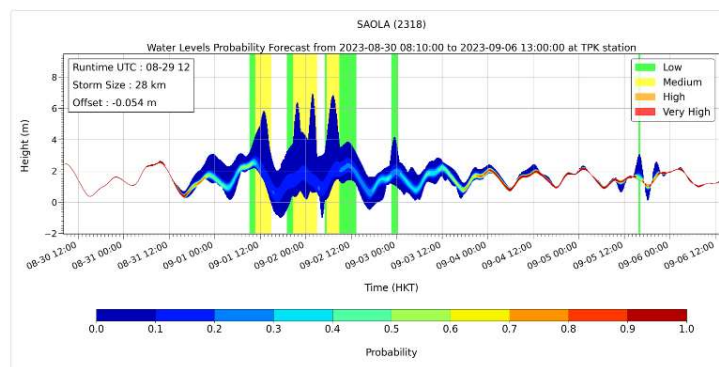
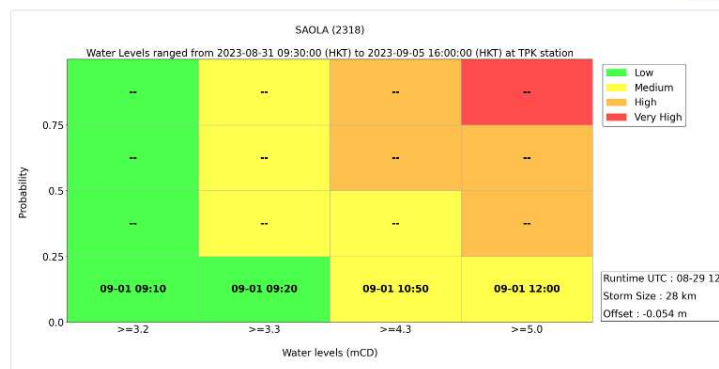
SUPER TYPHOON SAOLA: RISK-BASED PRODUCTS

3 days before
closest approach



ECMWF EPS Ensemble
Tracks for TC Saola (00Z run
29 Aug 2023)

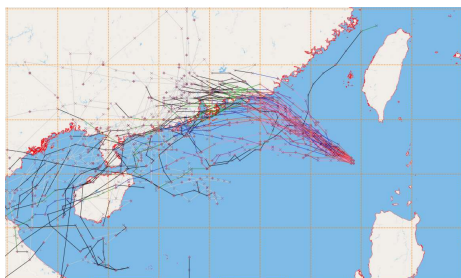
Tai Po Kau (TPK)



- Indication of low-probability, high-impact water level

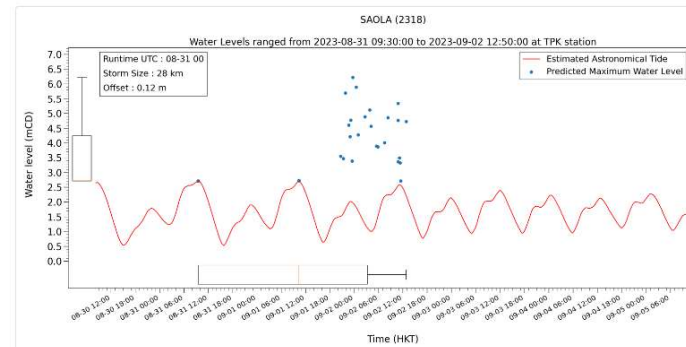
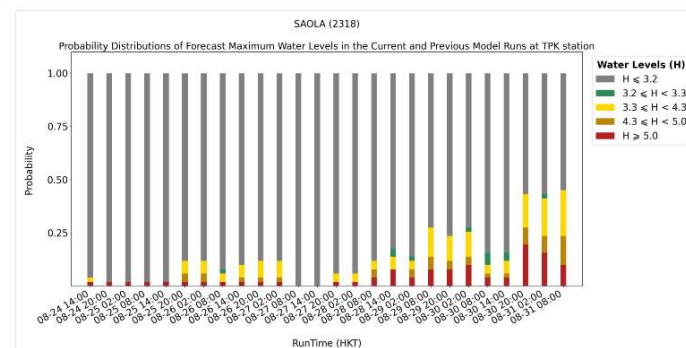
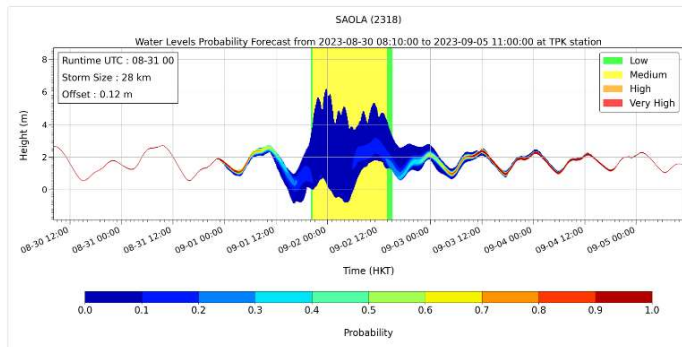
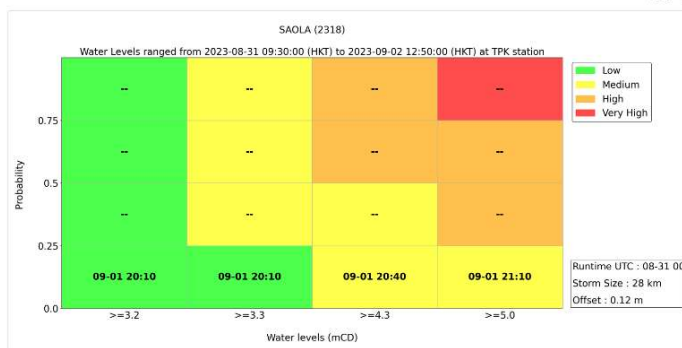
SUPER TYPHOON SAOLA: RISK-BASED PRODUCTS

1.5 days before
closest approach



ECMWF EPS Ensemble
Tracks for TC Saola (12Z run
30 Aug 2023)

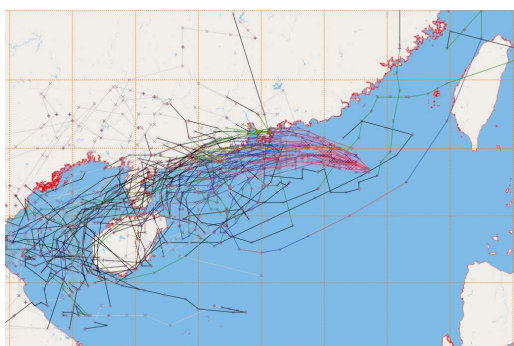
Tai Po Kau (TPK)



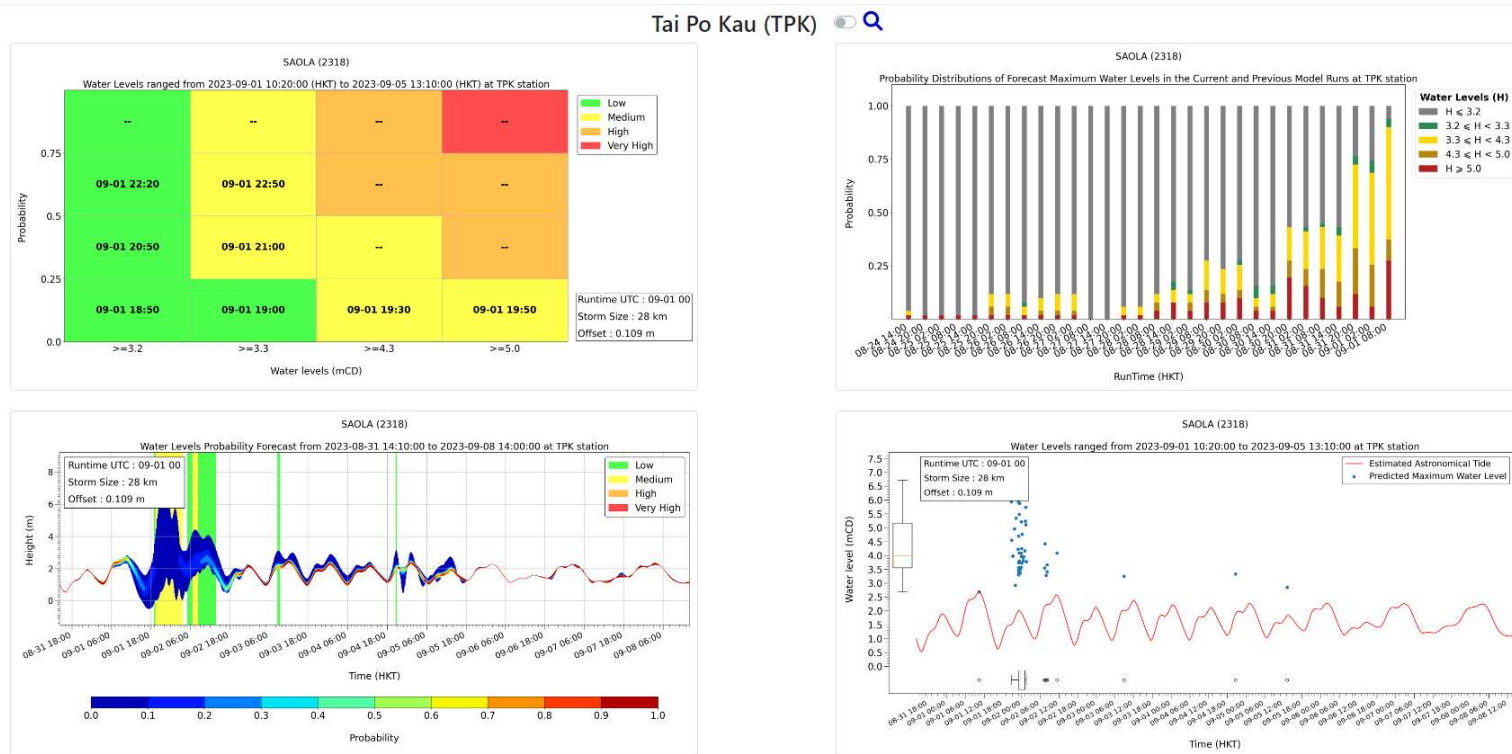
- Probability of high water level increased slightly with reduction in track uncertainties
- Increased risk but time window for medium risk became more precise

SUPER TYPHOON SAOLA: RISK-BASED PRODUCTS

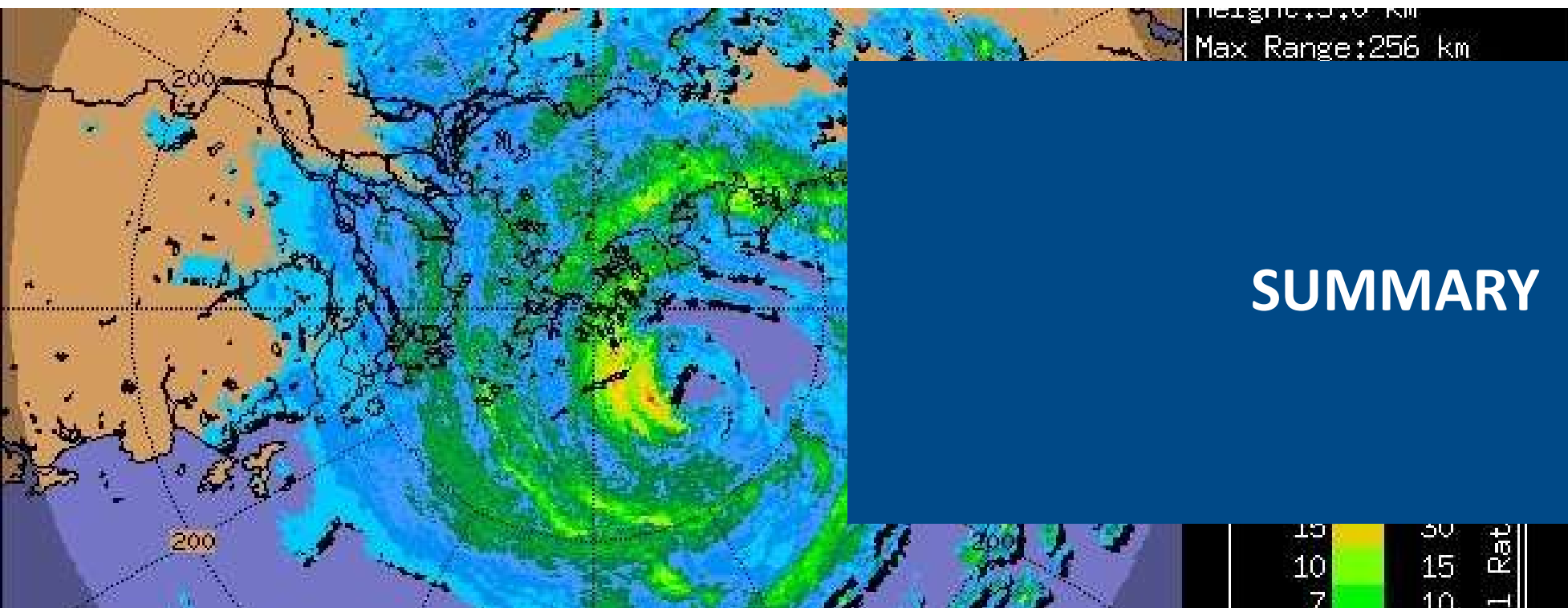
*0.5 day before
closest approach*



ECMWF EPS Ensemble
Tracks for TC Saola (12Z run
31 Aug 2023)



- High chance of water level exceeding 3.3 m at Tai Po Kau, but overall risk remained medium; further refinement in time window with medium risk



TROPICAL CYCLONE FORECASTING AND IMPACT ALERTING

SUMMARY

Analysis and Forecasting

- Sparse observations over seas remain a challenge in TC analysis, but more remote sensing data are becoming available – know their advantages and limitations.
- NWP models are becoming more skillful in TC track forecasting. Diagnosis of steering pattern and model performance is important.
- Intensity forecasting is still challenging – beware of rapid intensification under favourable conditions.
- AI-based models may play a significant role in TC forecasting in the near future.

Message Delivery

- While text-based weather bulletins are still important, alternative ways to convey tropical cyclone forecast information making use of mobile app, social media, or online conferencing can be considered.

TROPICAL CYCLONE FORECASTING AND IMPACT ALERTING

SUMMARY

Systems and Tools for Forecasters

- With more observations and NWP outputs becoming openly available, the amount of data supporting forecasters is steadily growing.
- Effective systems and tools integrating different observation and model forecast data will help forecasters assimilate the information efficiently, supporting them in formulating forecast and warnings.

Impact Monitoring and Alerting

- Collection of weather impact information improves real-time situational awareness of weather forecasters.
- AI techniques are useful in processing and analyzing weather impact data.
- With good understanding of impacts in collaboration with stakeholders, risk-based forecasts incorporating likelihood and impacts will be useful in informing actions to be taken.



香港天文台
HONG KONG OBSERVATORY

