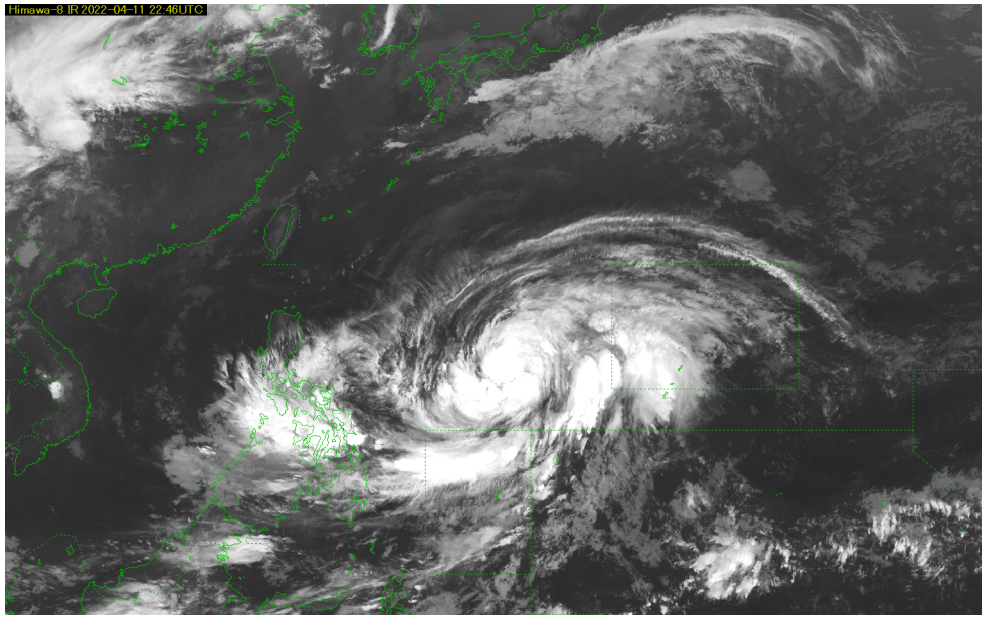
Operational TC forecasting at RSMC Tokyo – Typhoon Center



Ryo OYAMA

RSMC Tokyo-Typhoon Center

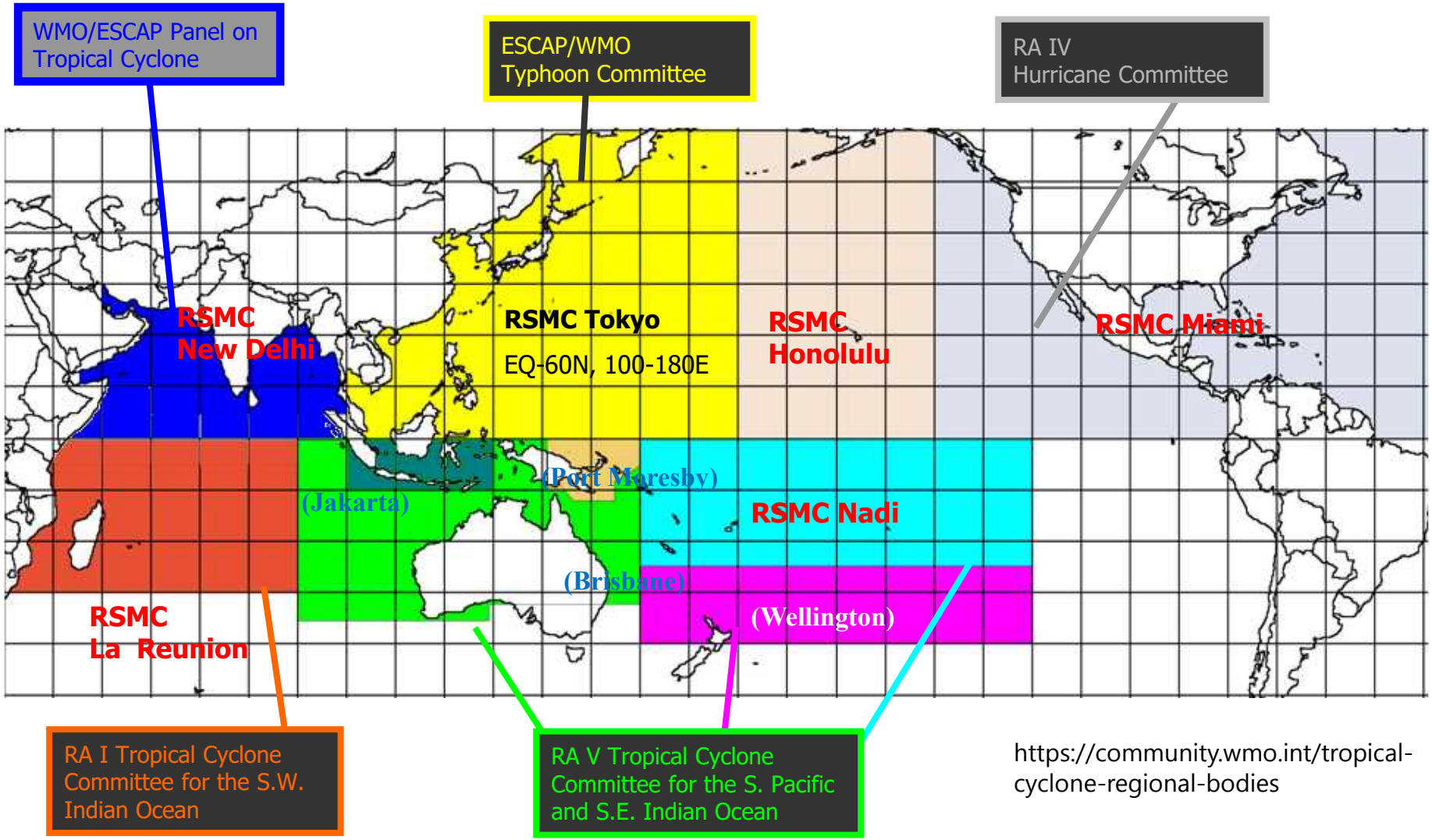
Japan Meteorological Agency (JMA)

Content

1. Introduction to RSMC Tokyo
2. Real-time tropical cyclone analysis & Tropical cyclone forecast at RSMC Tokyo

RSMC Tokyo – Typhoon Center (since 1989)

https://community.wmo.int/typhoon-committee



https://community.wmo.int/tropical-cyclone-regional-bodies

RSMC Tokyo -Typhoon Center at JMA is in charge of TC analysis and forecast for the western North Pacific ocean and South China Sea (EQ-60N and 100-180E).

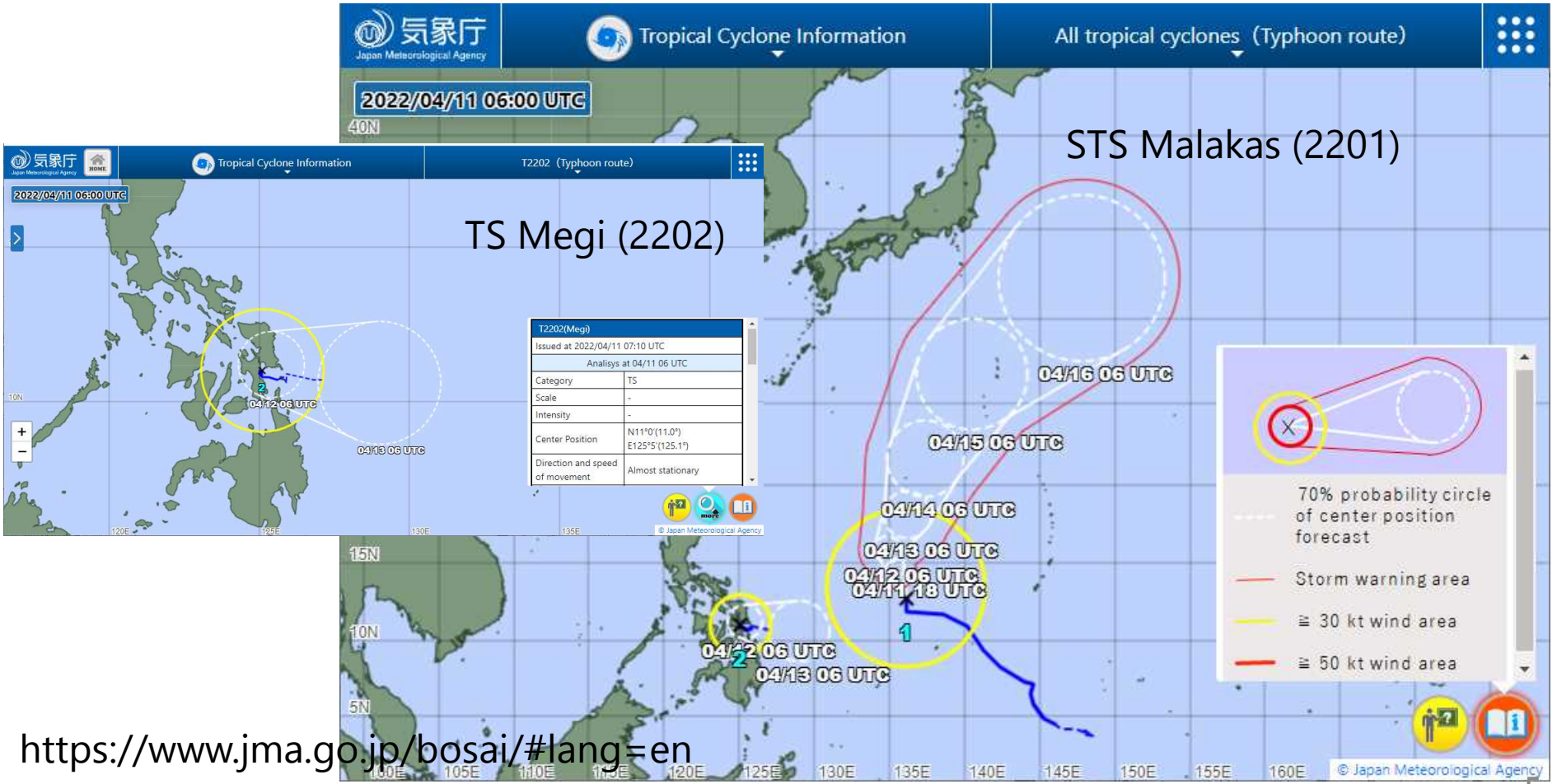
Met/Hydro-related Disasters in Japan

Diversity of Disasters in Japan

- Japan is exposed to the risk of various disasters, due to its geographical features.
- Even recently, there are still many disasters that cause serious damages.
- These are predicted to become more frequent and intense because of global warming.

Two TCs exist over the NW Pacific on 11 April 2022

Severe Tropical Storm Malakas (2201) approaches Japan.
Tropical Storm Megi (2202) is around the Philippines with heavy rainfalls.



https://www.jma.go.jp/bosai/#lang=en

Number of TCs in NW Pacific

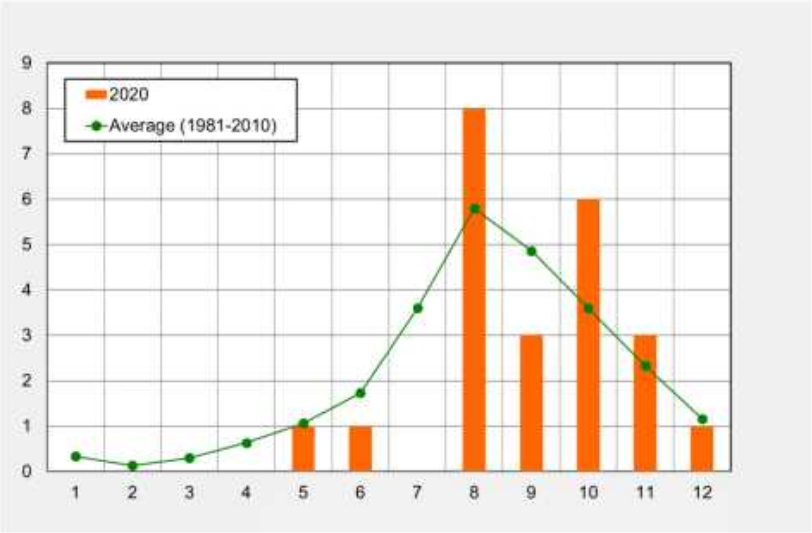


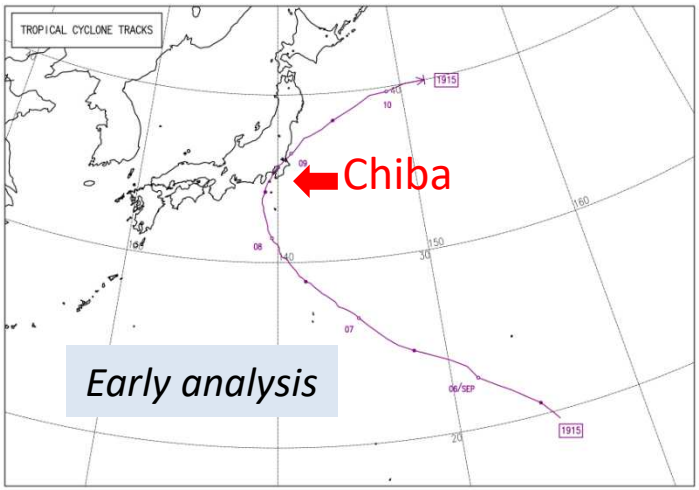
Figure 3.2 Monthly number of named TC formation for 2020 compared to the climatological normal

Average number of TCs per year (1981-2010):
- Formation: 25.6
- Accession: 11.4
- Landing: 2.7

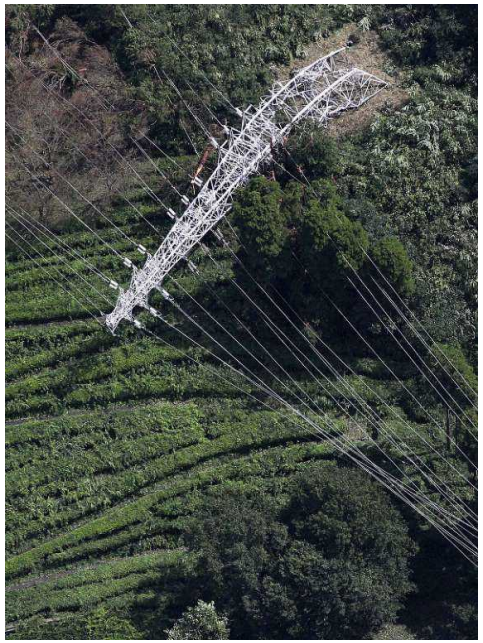
https://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/annualreport.html

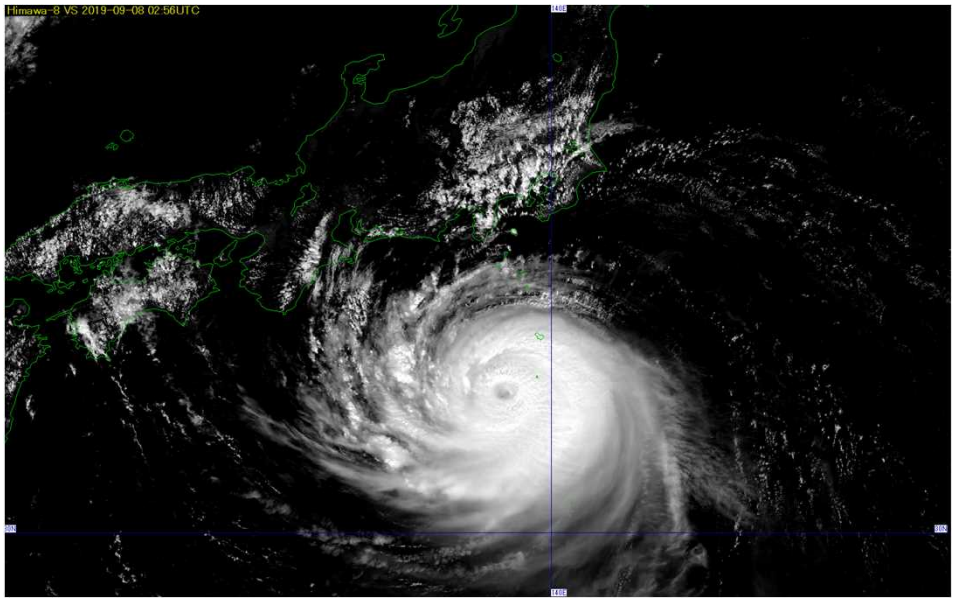
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2010			1				2	5	4	2			14
2011					2	3	4	3	7	1		1	21
2012			1		1	4	4	5	3	5	1	1	25
2013	1	1				4	3	6	8	6	2		31
2014	2	1		2		2	5	1	5	2	1	2	23
2015	1	1	2	1	2	2	3	4	5	4	1	1	27
2016							4	7	7	4	3	1	26
2017				1		1	8	6	3	3	3	2	27
2018	1	1	1			4	5	9	4	1	3		29
2019	1	1				1	4	5	6	4	6	1	29
2020					1	1		8	3	6	3	1	23
2021		1		1	1	2	3	4	4	4	1	1	22
2022				2									2

Typhoon Faxai (2019) : T1915



Typhoon Faxai (2019) formed near Minami-torishima island on 5 Sep 2019, and moved northwestward. Faxai made a landfall near Chiba city on 8 Sep. When making the landfall, Faxai was accompanied by strong winds (MSW= 80 kt) and low central pressure (MSLP= 960 hPa) causing serious damages to the infrastructures such as houses, power transmission towers, and so on.





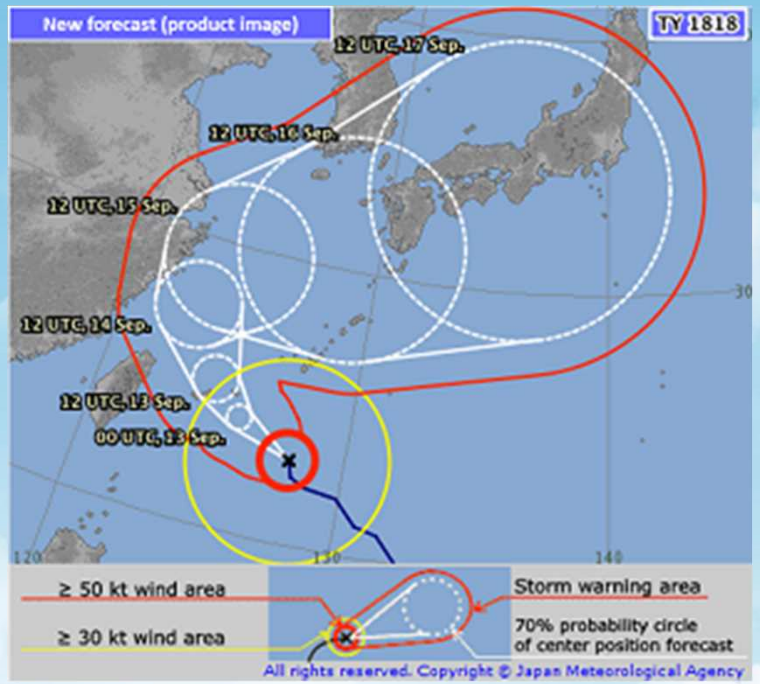
https://mainichi.jp/graphs/20190909/hpj/00m/040/002000g/21

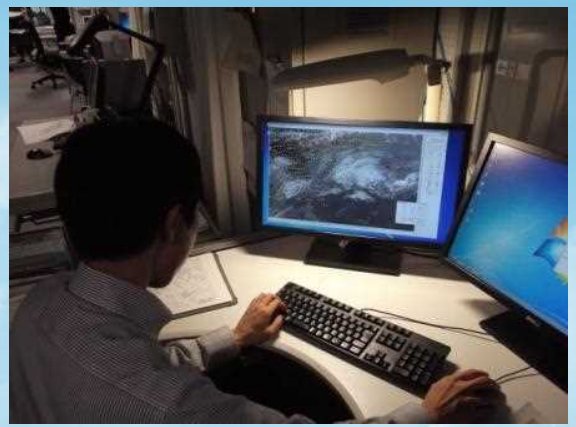
Classification of Tropical Cyclone

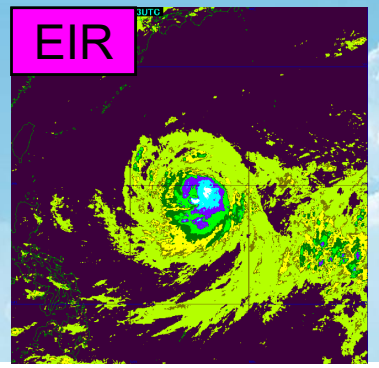
Region	Maximum Sustained Winds	34 – 47 kt	48 – 63 kt	64 kt –		
Western North Pacific	10 min	Tropical Storm (TS)	Severe Tropical Storm (STS)	Typhoon (TY)		
Eastern North Pacific Central North Pacific North Atlantic	1 min	Tropical Storm (TS)		Hurricane Cat.1 (64 – 82), Cat.2 (83 – 95), Cat.3 (96 – 113) , Cat.4 (114 – 135), Cat.5 (136 –)		
North Indian Ocean	3 min	Cyclonic Storm	Severe Cyclonic Storm	64 – 89 Very Severe Cyclonic Storm	90 – 119 Extremely Severe Cyclonic Storm	120 – Super Cyclonic Storm
Southwest Indian Ocean	10 min	Moderate Tropical Storm	Severe Tropical Storm (STS)	64 – 89 Tropical Cyclone	90 – 115 Intense Tropical Cyclone	116 – Very Intense Tropical Cyclone
South Pacific and Southeast Indian Ocean	10 min	Tropical Cyclone (gale)	Tropical Cyclone (storm)	Tropical Cyclone (hurricane)		

Tropical Cyclone Information

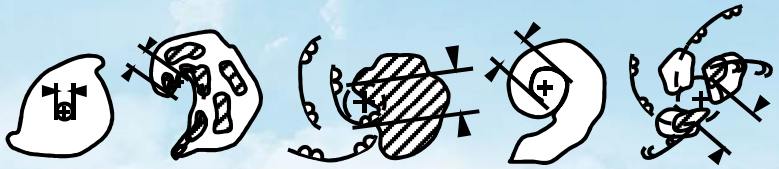
RSMC TC advisory for 5-day forecast (WTPQ50-55)	50/70 minutes after 00, 03, 06, 09, 12, 15, 18, 21 UTC
SAREP (IUCC10) in BUFR Format to issue TC real-time analysis	a half to 1 hour after 00, 03, 06, 09, 12, 15, 18, 21 UTC







Dvorak Analysis

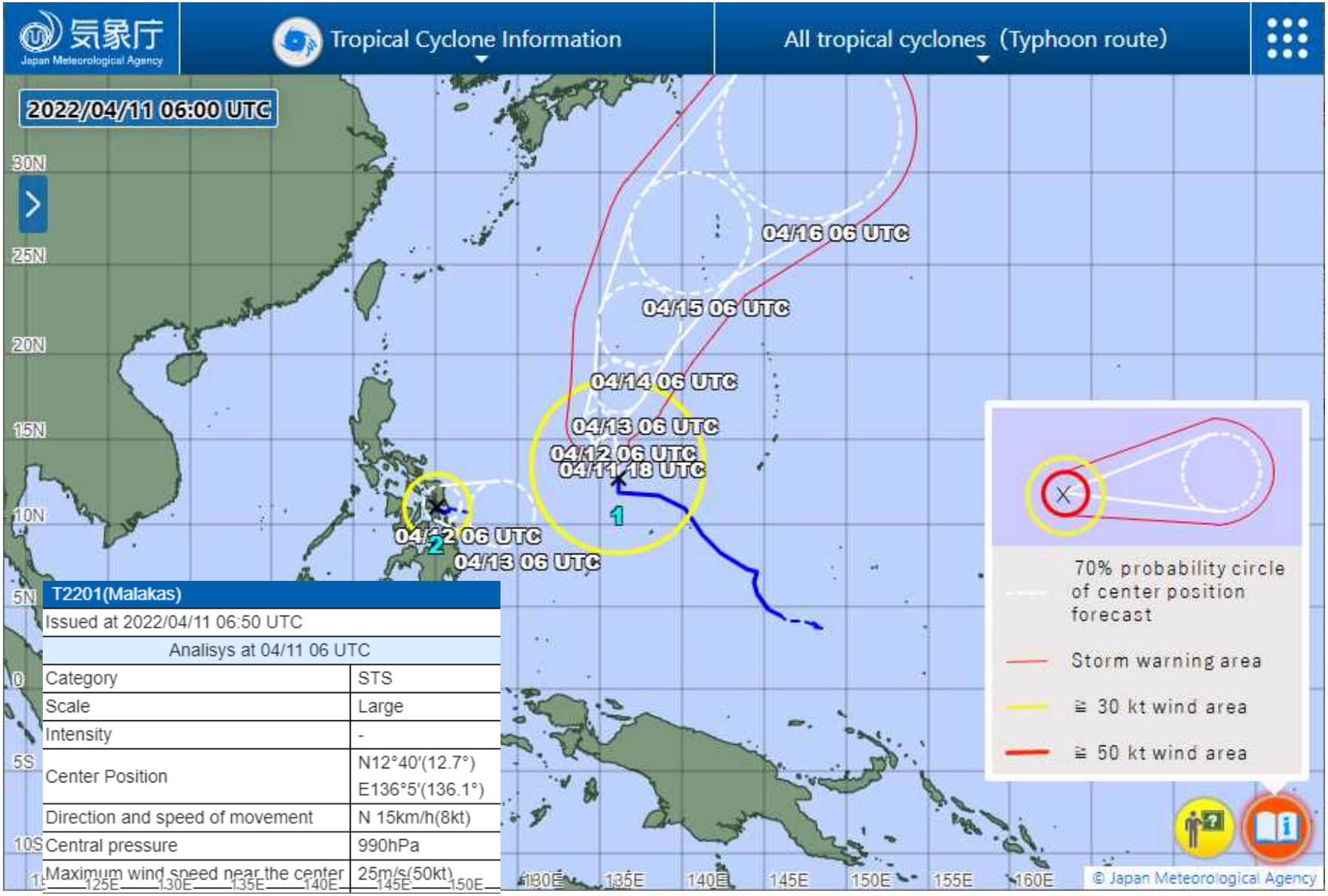


Other RSMC-Tokyo products

- TC predictions from JMA Global Spectral Model (GSM) and Global Ensemble Prediction System (GEPS)
  - ✓ Center position
  - ✓ Central pressure and maximum wind speed (deviation from initial time)

- Prognostic Reasoning (WTPQ30-35 RJTD)
- Tropical Cyclone Best Track (AXPQ20)
- Tropical Cyclone Advisory for SIGMET (FKPQ30-35 RJTD)
- Other products on website only for committee members

JMA's typhoon information website



T2201(Malakas)	
Issued at 2022/04/11 06:50 UTC	
Analisys at 04/11 06 UTC	
Category	STS
Scale	Large
Intensity	-
Center Position	N12°40'(12.7°) E136°5'(136.1°)
Direction and speed of movement	N 15km/h(8kt)
Central pressure	990hPa
Maximum wind speed near the center	25m/s(50kt)

https://www.jma.go.jp/bosai/#lang=en

Operational TC analysis and forecast

Real-time TC analysis	Forecast
(i) Analysis of TC center and intensity by Dvorak Analysis including Early DA. (ii) Correction to TC center position and intensity estimated by Dvorak technique using the observations of polar orbiting satellites, in-situ observations, etc.	(i) Forecasts of TC center position at forecast times from 12 to 120 h using the forecasts of models by JMA, ECMWF, UKMO, and NCEP (ii) Forecasts of TC intensity at forecast times from 12 to 120 h using the TC intensity forecast guidance (TIFS).

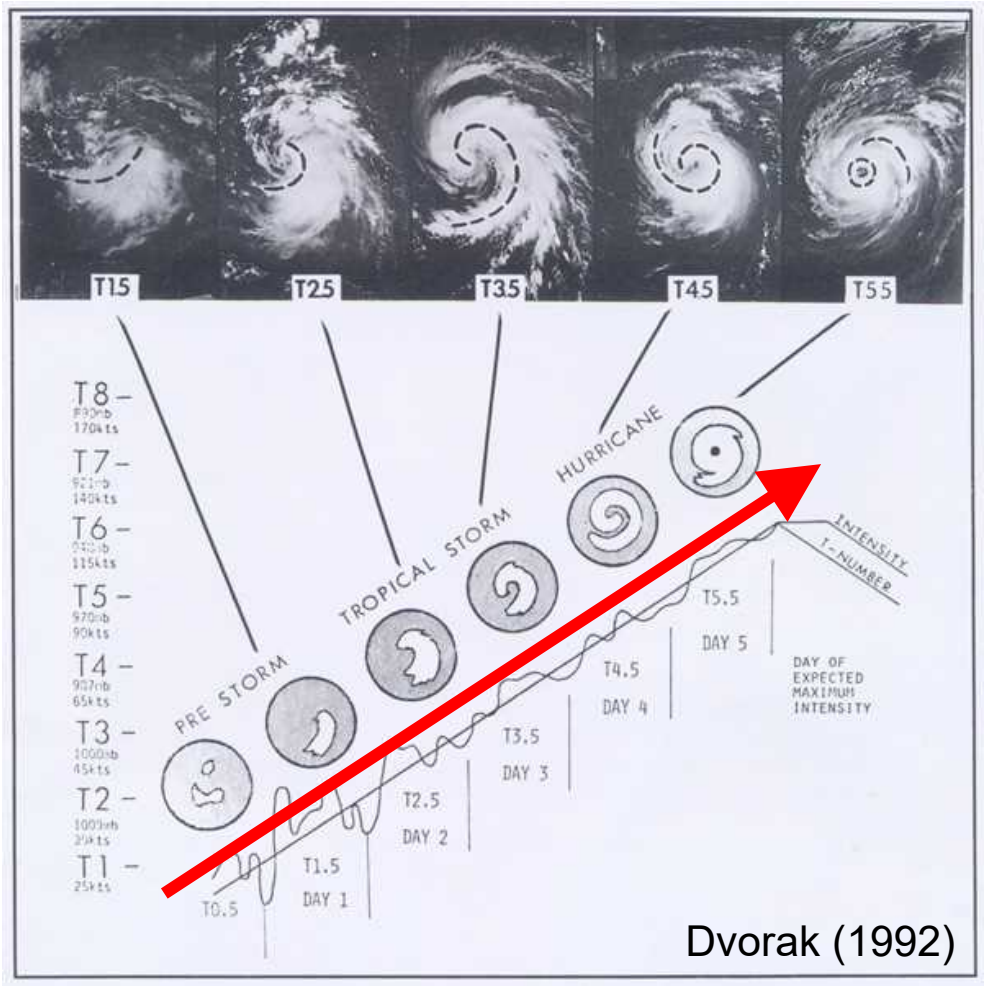
- RSMC Tokyo issues TC advisory when a TC with MSW greater than 34kt exists, or a tropical depression (TD) is expected to upgrade to a tropical storm (TS) intensity within 24 h.
- RSMC Tokyo operationally implements the real-time TC analysis (position and intensity) and forecasts (track, intensity and others) from FT24 to FT120.
- TC analysis and forecast are performed by two forecasters, respectively.
- RSMC Tokyo issues the TC analysis and forecasts by TC advisory (IUCC (SAREP), WTPQ3X, WTPQ5X etc.).

Real-time TC analysis

1. Estimations of TC center and intensity rely on Dvorak technique with reference to other observations

2. Wind radii (30kt, 50kt) are estimated using sea surface winds from the satellite microwave scatterometer and Himawari-8 AMVs, considering CDO size.

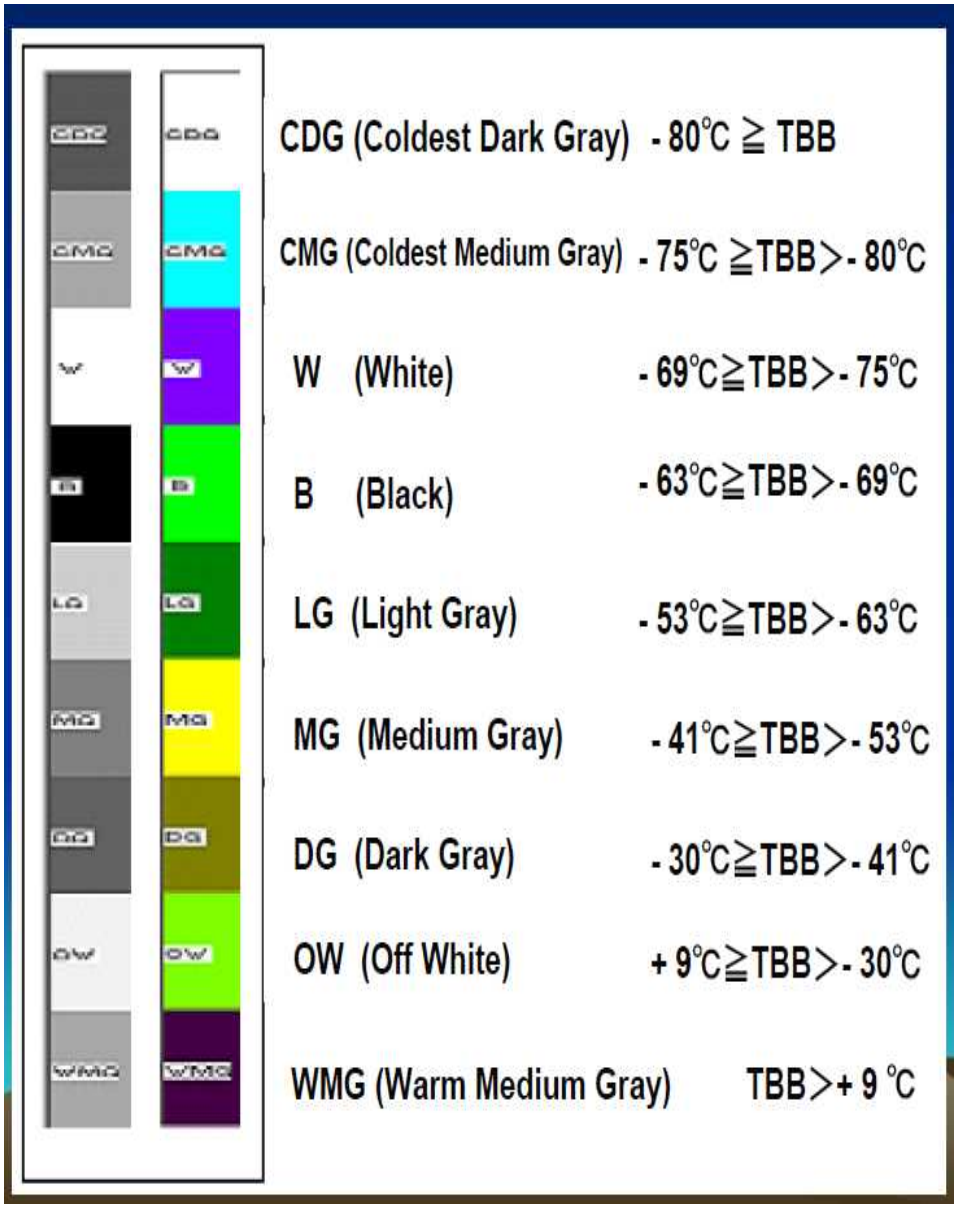
Dvorak Analysis



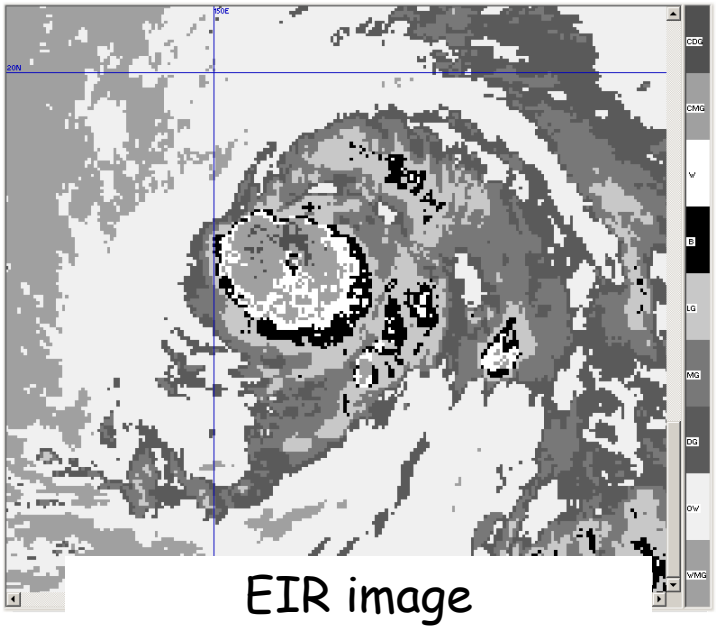
Dvorak (1992)

- Tropical Cyclones have their own characteristic cloud pattern for each life stage.
- Cloud pattern recognition using satellite imagery is a key to precisely estimate both of TC center and intensity.
- Original Dvorak analysis (Dvorak 1975 and 1984) gives Current Intensity (CI) numbers from 1.5 to 8.0.

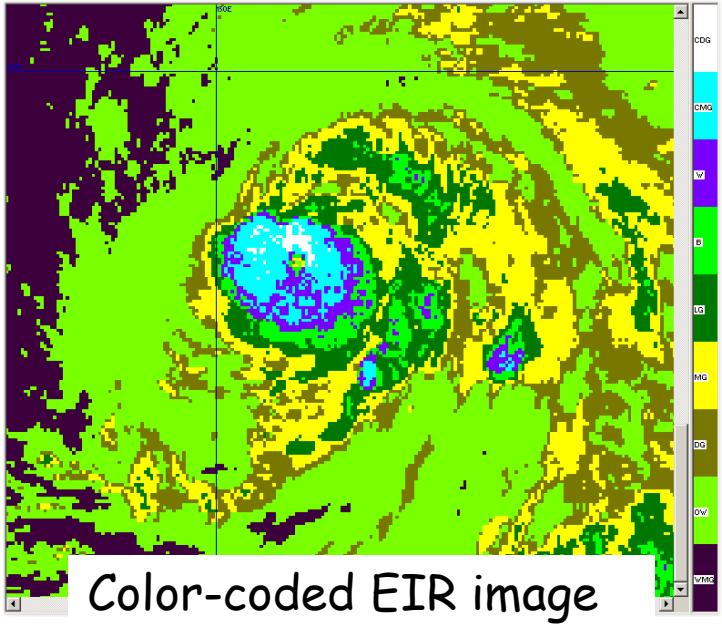
Enhanced IR (EIR) image



TBB: equivalent Black Body Temperature



EIR image

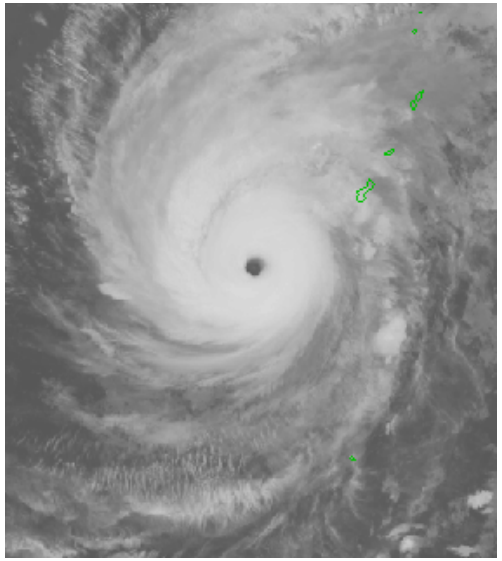


Color-coded EIR image

Dvorak technique - Eye pattern -

Step-1

Determination of cloud pattern using IR imagery



Hot spot exists around at the center of cloud system

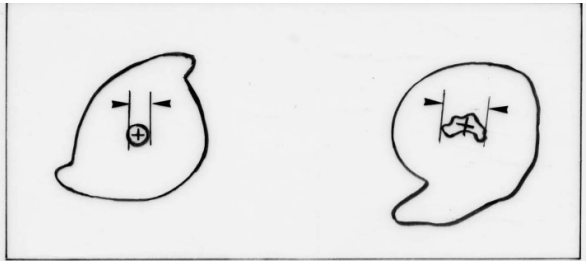
⇩

Eye pattern

Step-2

Determination of TC center

Eye pattern (except for banding eye pattern)

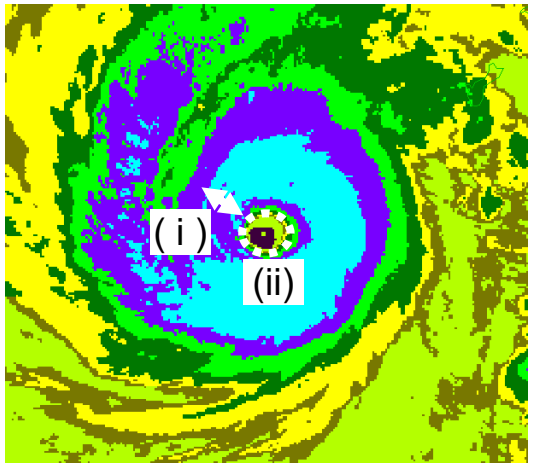


The cloud system center (CSC) is determined as the center of EYE using infrared image.

The accuracy of eye determination is obtained by measuring the maximum diameter of the eye.

Step-3

Determination of Digital T-number (DT number)



(i) E (eye)-number is estimated by measuring the thickness of eyewall.

(ii) Eadj (Eye adjustment) is computed based on the eye temperature and feature.

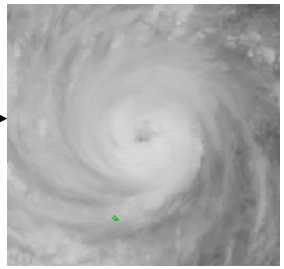
E-number + Eadj = DT number

Dvorak technique - Eye pattern -

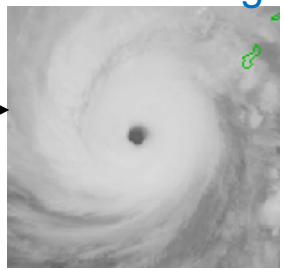
Step-4: MET-number

The difference in T number in the previous 24-h is estimated by comparing the present image with the image 24 h before.

24-h before



Present image

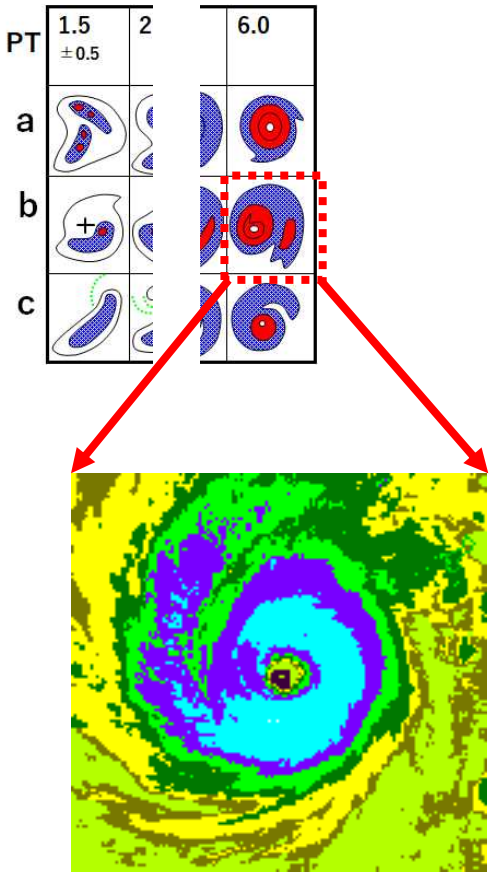


If a TC is judged to rapidly intensity during the previous 24 h,

MET-number (current) =
MET-number (24 h before) +1.5

Step-5: PT-number

PT-number is determined as the value between +/-0.5 from the MET-number.



Step-6: Final T-number

The final T-number is determined by selecting the most proper T-number among the three ones (DT, MET, PT).

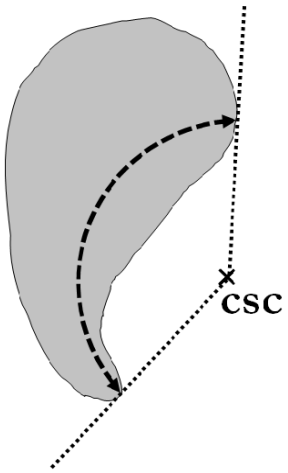
The CI number is determined from T-number considering the TC life stage.

Development phase：
CI-number = T-number
Decay phase：
CI-number = T-number-1.0
(until 12 h after the start of decay)

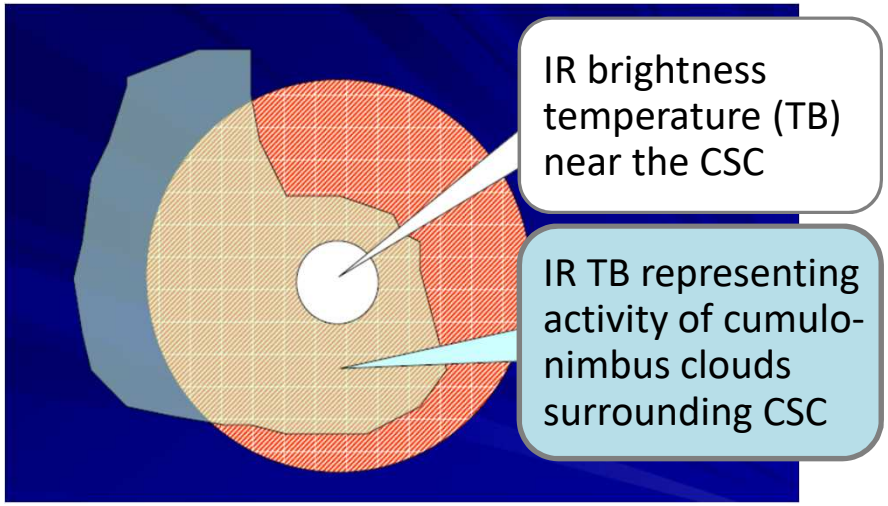
Objective estimation of DT-number by CLOUD

- ✓ Objective TC intensity estimation scheme, named “CLOUD”, enables to objectively compute DT number based on TC cloud pattern (Curved band, CDO, EYE, etc.) obtained from IR brightness temperature by Himawari-8.
- ✓ RSMC Tokyo started to use the objective DT number in 2014 for the real-time TC intensity analysis.

Curved Band pattern:
The DT number for Curved Band is estimated ba sed on the length of curved band consisting of C B clusters, which surrounds the TC center.



Eye/Embedded pattern:
The DT number for Eye/Embedded pattern is estimated based on the brightness temperature of the eye and CB cluster surrounding the TC center.



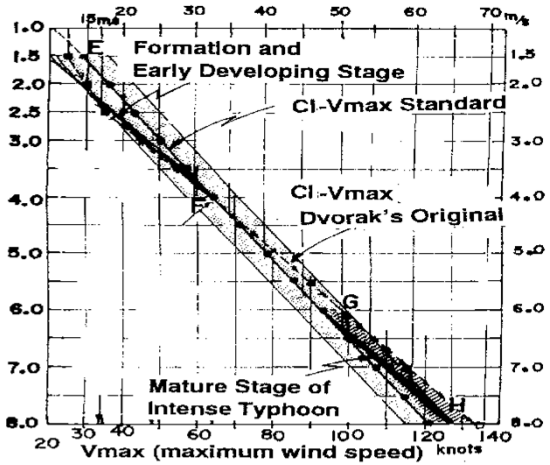
Kishimoto et al. (2014), RSMC Tokyo Technical Review
http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/techrev/text15.pdf

Estimation of TC intensity from CI-number

The forecaster obtains maximum sustained wind (MSW) and central pressure from the CI number.

CI-number = 1.5～8.0

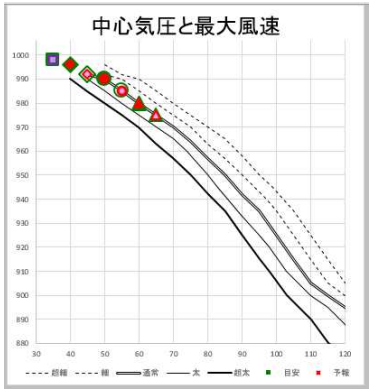
CI-number v.s. Vmax



MSW estimation

Relationship between MSW and Central pressure

FT		風速	type	中心気圧		type	暴風域	
		kt		hPa			nm	
0	□	35	通常	998	998	通常	0	0
12	◆	40	通常	996	996	通常	0	0
24	◇	45	通常	992	992	通常	0	0
48	●	50	通常	990	990	通常	0	0
72	○	55	通常	985	985	通常	30	30
96	▲	60	通常	980	980	通常	40	40
120	△	65	通常	975	975	通常	45	45

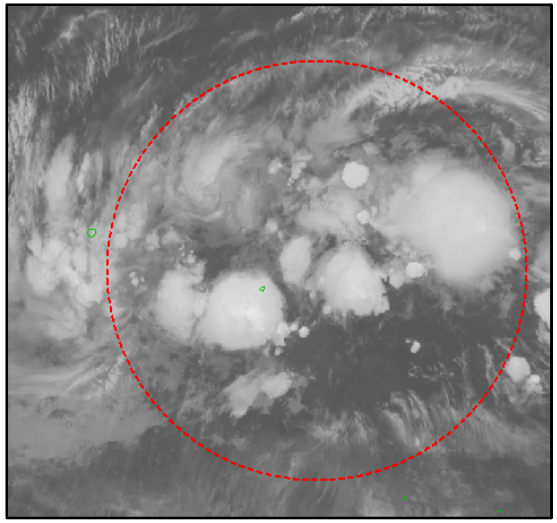


Central pressure estimation from MSW

Early stage Dvorak Analysis (EDA)

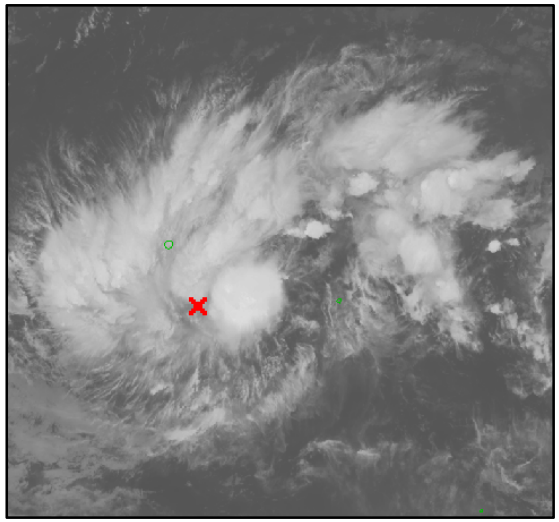
- Early stage Dvorak Analysis (EDA) is a subjective technique to estimate the intensity of tropical disturbance during the early developing stage.
- TC forecasters refer to CI number from EDA for judging whether it upgrades to TS intensity.

Does the active convection within a radius of 300 NM continue for 6 hours ?



YES

Cloud System Center (CSC) can be determined by analyzing the curvature of CB clusters' arrangement and the movement of stratus.



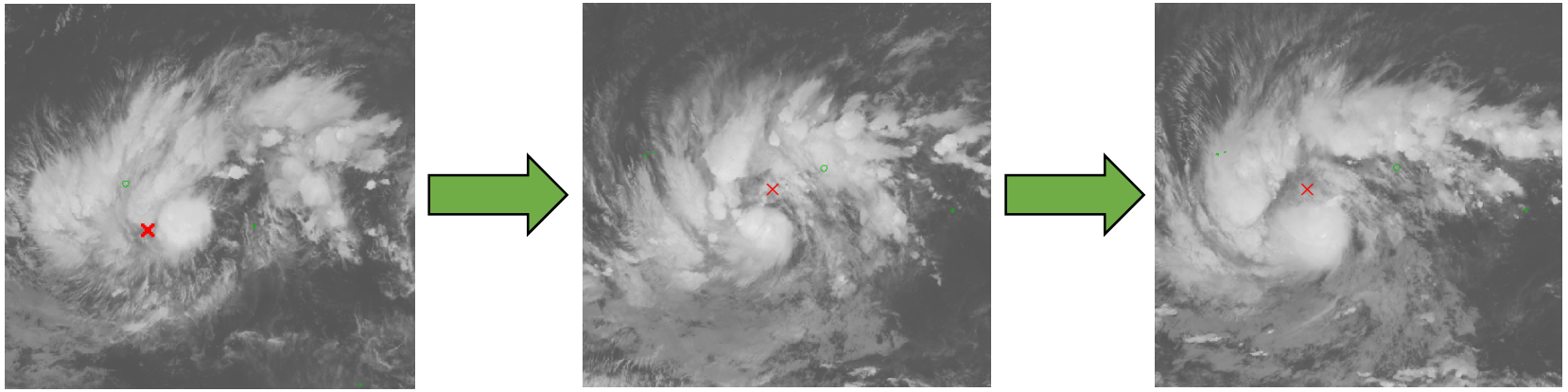
YES

EDA starts with T-number of 0.0.

Kishimoto 2008, https://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/techrev/text10-1.pdf

EDA is conducted every 6 hours (at 00, 06, 12, and 18 UTC)

1. If the cloud system develops in the previous 6 h, the present T-number is computed as the previous T-number plus 0.5.
2. If the cloud system does not change in the previous 6 h, the present T-number is equal to the previous T-number.
3. If the cloud system decays in the previous 6 h, the present T-number is computed as the previous T-number minus 0.5.



T-number = 0.0 *T-number = 1.0* *T-number = 2.0*

When T-number reaches 2.0, the forecasters consider if the cloud system should be upgraded to the category of Tropical Storm (TS; 34 kt < MSW).

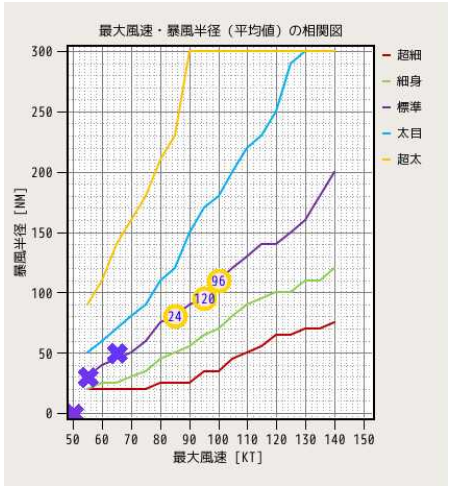
50-kt wind radius

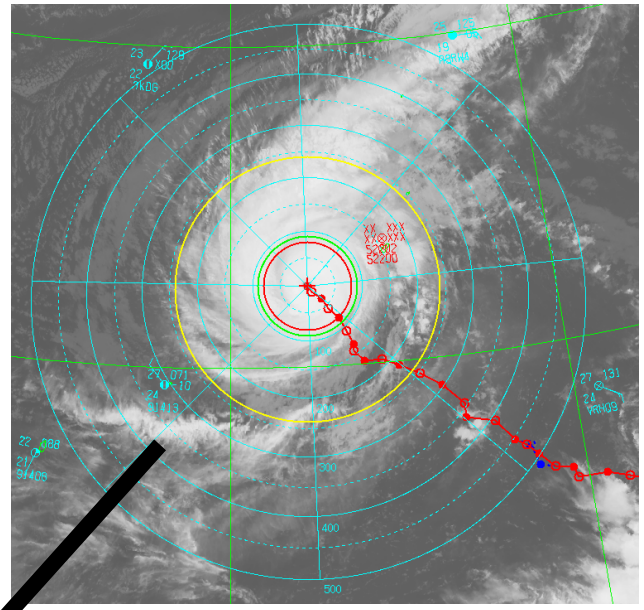
The forecaster estimates 50-kt wind radius based on the table between Maximum Sustained Wind (MSW) and 50-kt wind radius, and the size of central dense overcast (CDO).

The relationship between MSW and 50-kt wind radius

Measurement of dense cloud area such as Central Dense Overcast

FT	風速	type	中心気圧		type	暴風域	
	kt		hPa			nm	
0	35	通常	998	998	通常	0	0
12	40	通常	996	996	通常	0	0
24	45	通常	992	992	通常	0	0
48	50	通常	990	990	通常	0	0
72	55	通常	985	985	通常	30	30
96	60	通常	980	980	通常	40	40
120	65	通常	975	975	通常	45	45



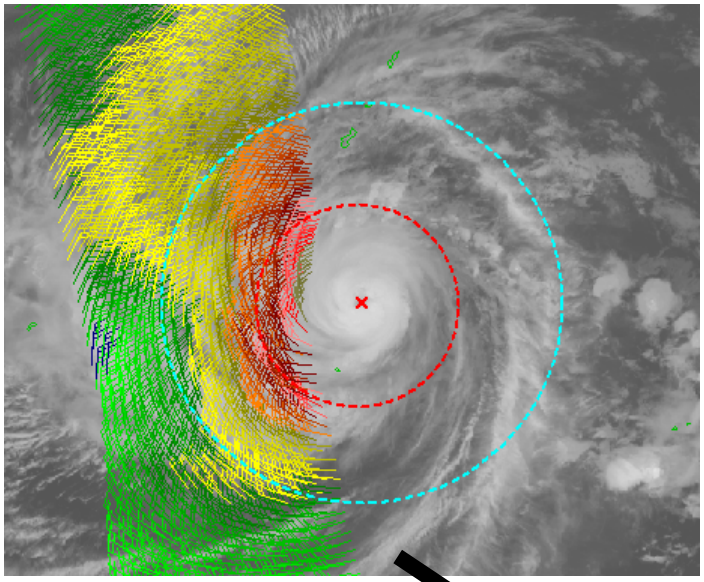


Estimation of TC 50-kt wind radius

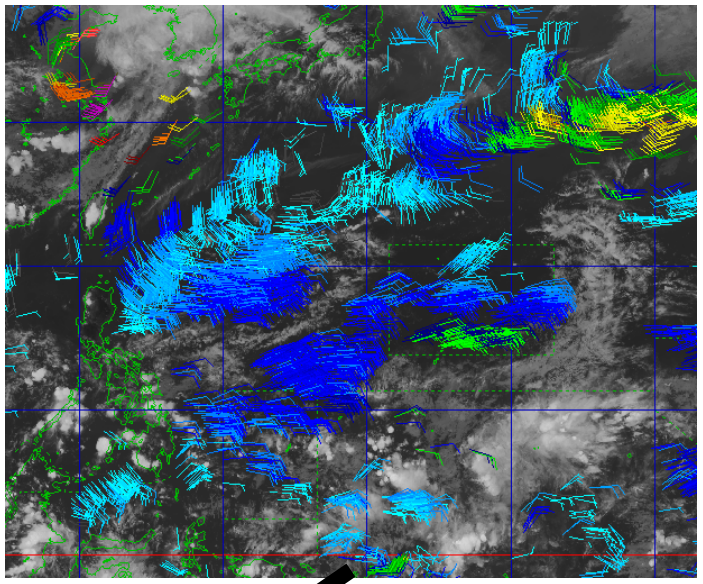
Estimation of 30-kt wind radius

The forecaster estimates 30-kt wind radius using sea surface winds derived from the microwave scatterometer observations and Sea surface winds based on Himawari-8 AMVs (ASWinds).

Sea surface winds from microwave scatterometer observations (MetOp, etc.)



Sea surface winds estimated from Himawari-8 AMVs (ASWind)



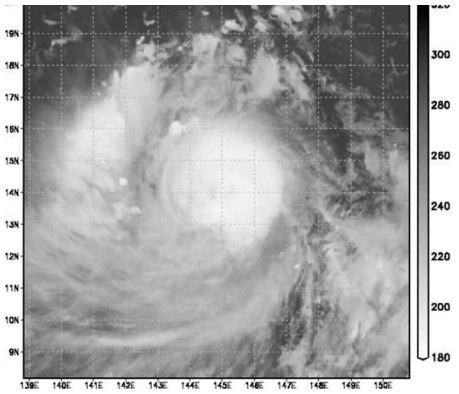
Estimation of 30-kt wind radius

Correction to TC center estimation using in-situ and satellite MW observations

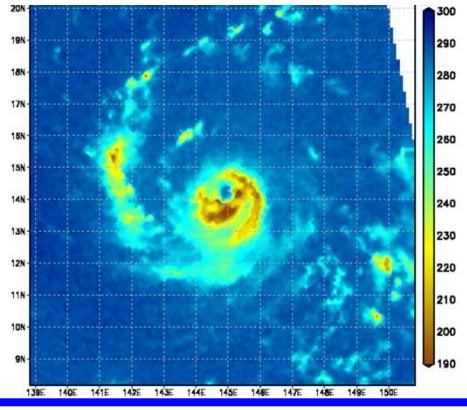
The first guess of TC center is given by Dvorak technique. Then, it is modified subjectively by using in-situ observations which are obtained from meteorological reports.

Example

Himawari-8 TB (IR, Band13: 10.4 μm)



SSMIS PCT (89 GHz)



Meteorological reports:
SYNOP, SHIP, RADOB

Plotting the observational data on the satellite image

Correction to TC center obtained by Dvorak technique

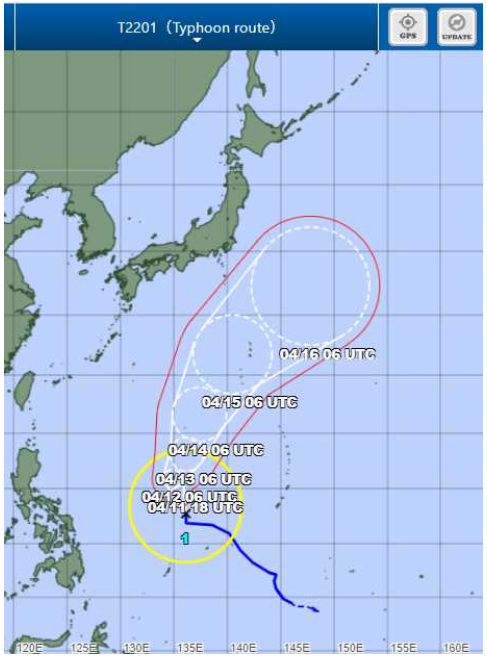
Tropical cyclone forecast

- RSMC Tokyo issues 5-day forecasts for tropical cyclone (TC) track, intensity and other elements for TCs in the responsibility region.
- Targets are (1) Named TC (maximum wind speed ≥ 34 kt) and (2) TD (maximum wind speed < 34 kt) expected to reach Tropical Storm intensity (MSW ≥ 34 kt) within 24 hours.
- TC advisory for 5-day forecast is issued at 00, 06, 12, and 18 UTC.

5-day forecast	
Configuration	• The center and radius of forecasted TC • Moving speed and direction • Central pressure • Maximum sustained wind (MSW) • Maximum gust wind • 50-kt wind radius
Time for issuing Advisory	120-h (5-day) forecast: 00, 06, 12, 18 UTC 24-h (1-day) forecast: 03, 09, 15, 21 UTC

JMA HP

https://www.jma.go.jp/bosai/#lang=en



Contents:

- Center position
- Moving speed and direction
- Central pressure
- Maximum sustained wind
- Maximum gust wind
- 70% probability circle of center position forecast
- Storm warming area (50kt <)

T2201(Malakas)	
Issued at 2022/04/11 06:50 UTC	
Forecast at 04/14 06 UTC	
Category	TY
Intensity	Strong
Center of probability circle	N21°35'(21.6°) E137°25'(137.4°)
Direction and speed of movement	NNE 15km/h(9kt)
Central pressure	960hPa
Maximum wind speed near the center	40m/s(75kt)
Maximum wind gust speed	55m/s(105kt)
Radius of probability circle	260km(140NM)
Storm warning area	WIDE410km(220NM)

3-day forecast

T2201(Malakas)	
Issued at 2022/04/11 06:50 UTC	
Forecast at 04/15 06 UTC	
Category	TY
Intensity	Strong
Center of probability circle	N26°40'(26.7°) E140°30'(140.5°)
Direction and speed of movement	NNE 30km/h(15kt)
Central pressure	970hPa
Maximum wind speed near the center	35m/s(65kt)
Maximum wind gust speed	50m/s(95kt)
Radius of probability circle	370km(200NM)
Storm warning area	WIDE500km(270NM)

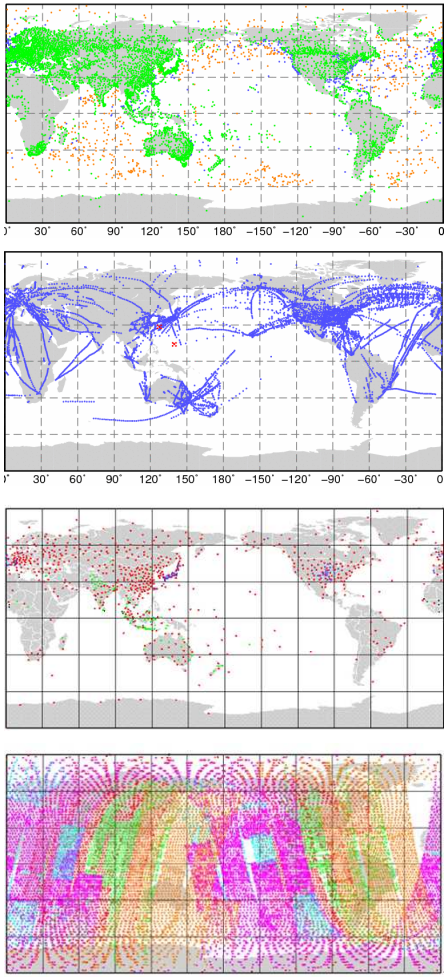
4-day forecast

T2201(Malakas)	
Issued at 2022/04/11 06:50 UTC	
Forecast at 04/16 06 UTC	
Category	STS
Intensity	-
Center of probability circle	N32°10'(32.2°) E147°50'(147.8°)
Direction and speed of movement	NE 40km/h(21kt)
Central pressure	980hPa
Maximum wind speed near the center	30m/s(55kt)
Maximum wind gust speed	40m/s(80kt)
Radius of probability circle	520km(280NM)
Storm warning area	WIDE600km(330NM)

5-day forecast

NWP models provide basis for TC forecast

Observation data

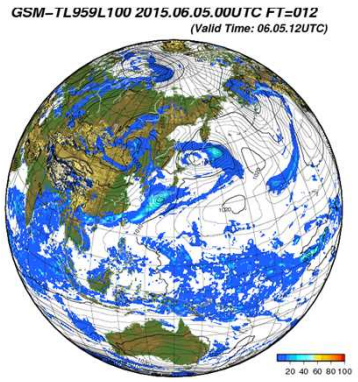


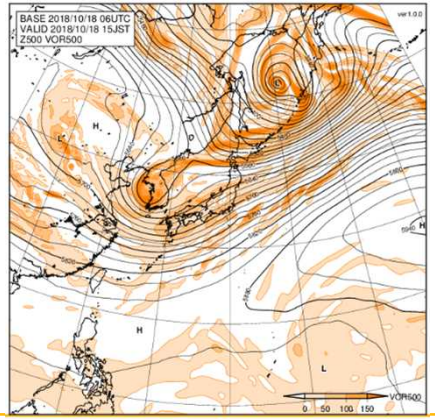
assimilation

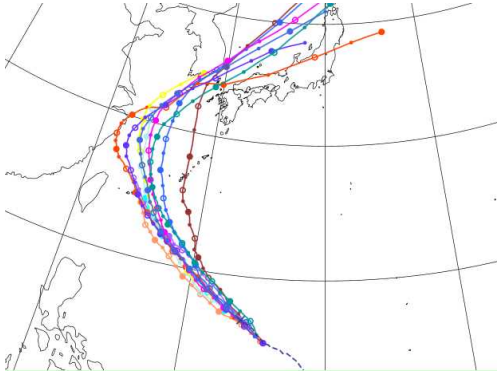
Numerical Prediction

Super Computer
(10th-generation since 1959)

NWP products







TC Track Forecast Error Trend

Annual mean position errors in 24-, 48-, 72-, 96- and 120-hour operational track forecasts

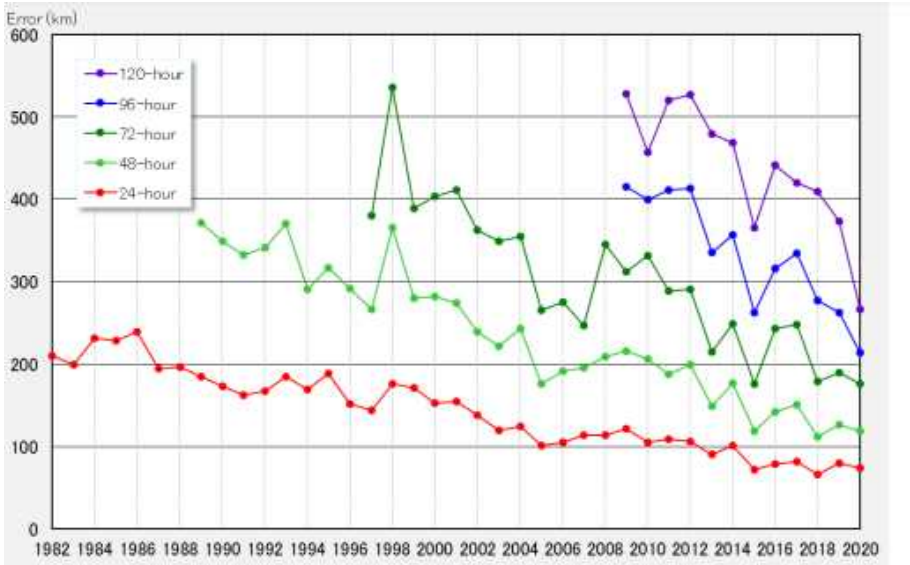


Figure 4.1 Annual mean position errors in 24-, 48-, 72-, 96- and 120-hour operational track forecasts

Annual mean improvement ratios in 24-, 48-, 72-, 96- and 120-hour operational track forecasts (against CLIPER)

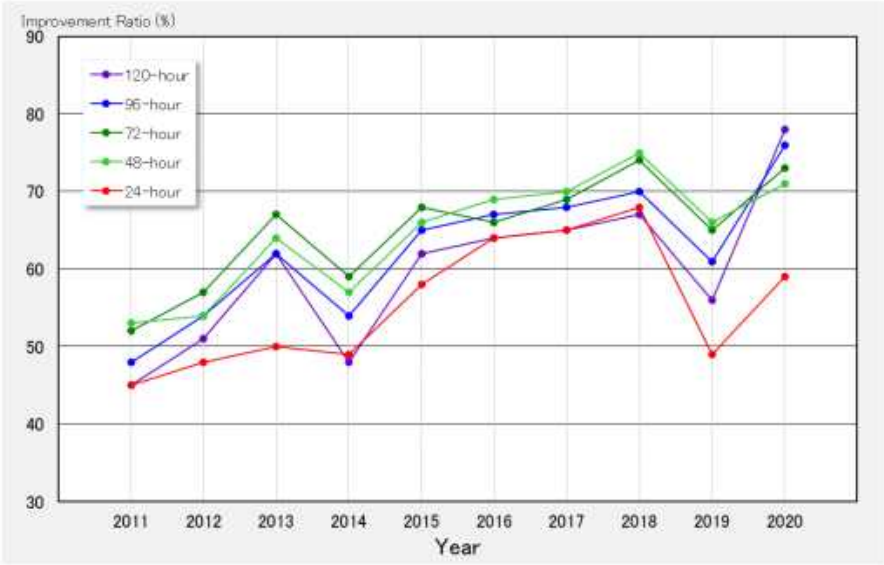
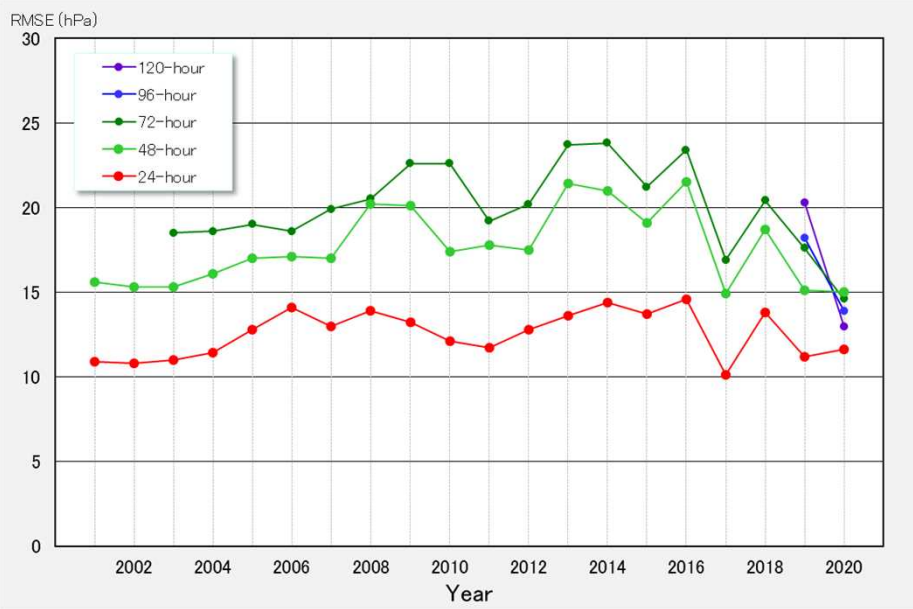


Figure 4.2 Annual mean improvement ratios in 24-, 48-, 72-, 96- and 120-hour operational track forecasts

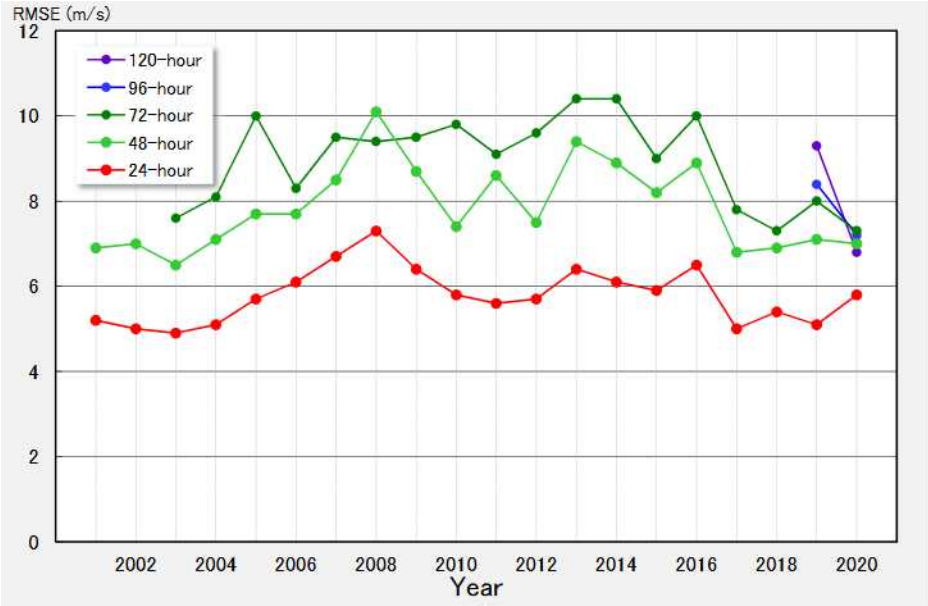
https://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/annualreport.html

TC Intensity Forecast Error Trend

Annual mean RMSE of
official central pressure forecast



Annual mean RMSE of
official maximum wind speed forecast

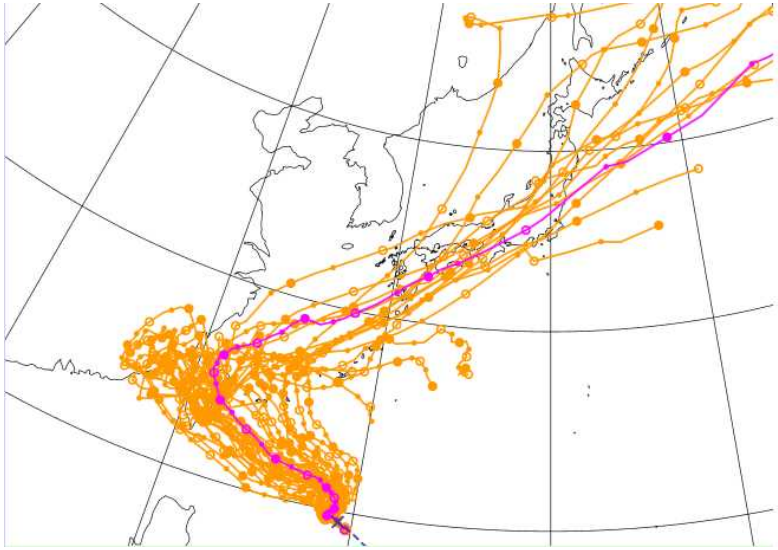


https://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/annualreport.html

TC Track Forecast

- Track forecasts by the ensemble prediction system provide a good measure of the uncertainty and level of confidence.
- The forecast track averaged over multiple NWP results (consensus) generally has a better performance than individual forecasts.

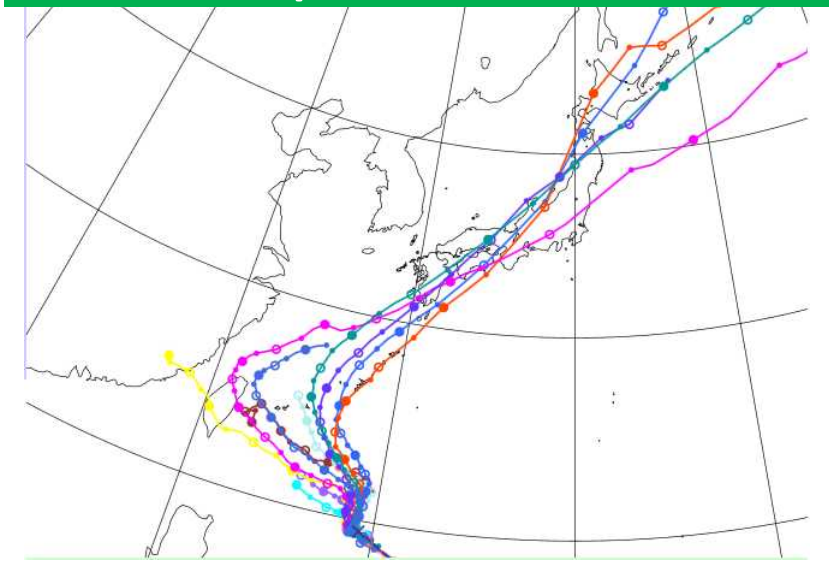
Ensemble forecast
by JMA Global Spectral model (GSM)



Track forecasts for T1824(TRAMI) from JMA ensemble forecast. Initial at 12UTC on Sep. 24, 2018.

Consensus

Deterministic forecasts from multiple NWP centers

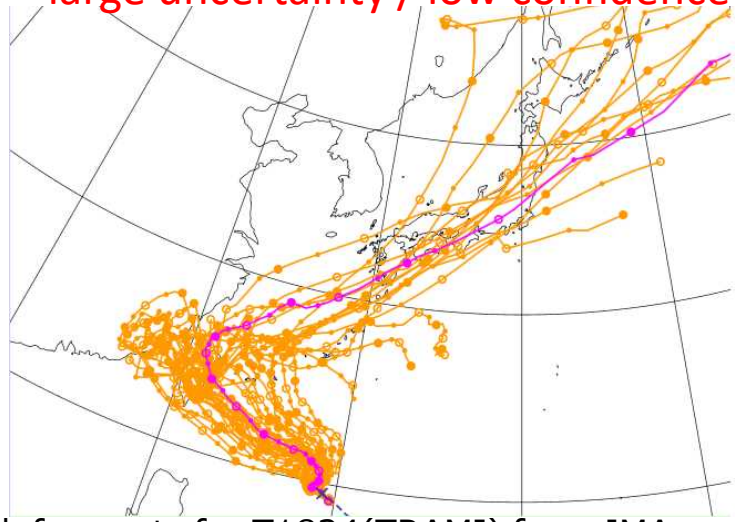


Track forecasts for T1824(TRAMI) from numerical weather forecast centers of Japan, China, Korea, the US, Canada, Germany, Britain and Europe. Initial at 12UTC on Sep. 24, 2018.

GSM Ensemble track forecast

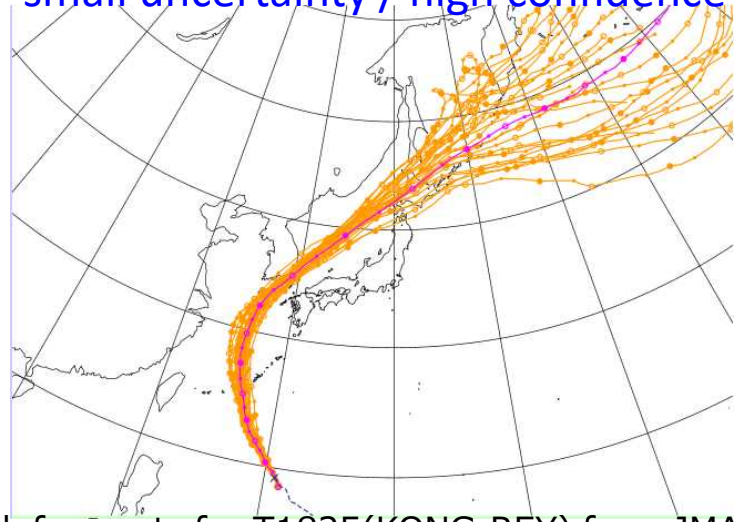
- Forecasters need to know the degree of uncertainty and level of confidence.
- Track forecasts by the ensemble prediction system provides a good measure.

large uncertainty / low confidence



Track forecasts for T1824(TRAMI) from JMA ensemble forecast. Initial at 12UTC on Sep. 24, 2018.

small uncertainty / high confidence



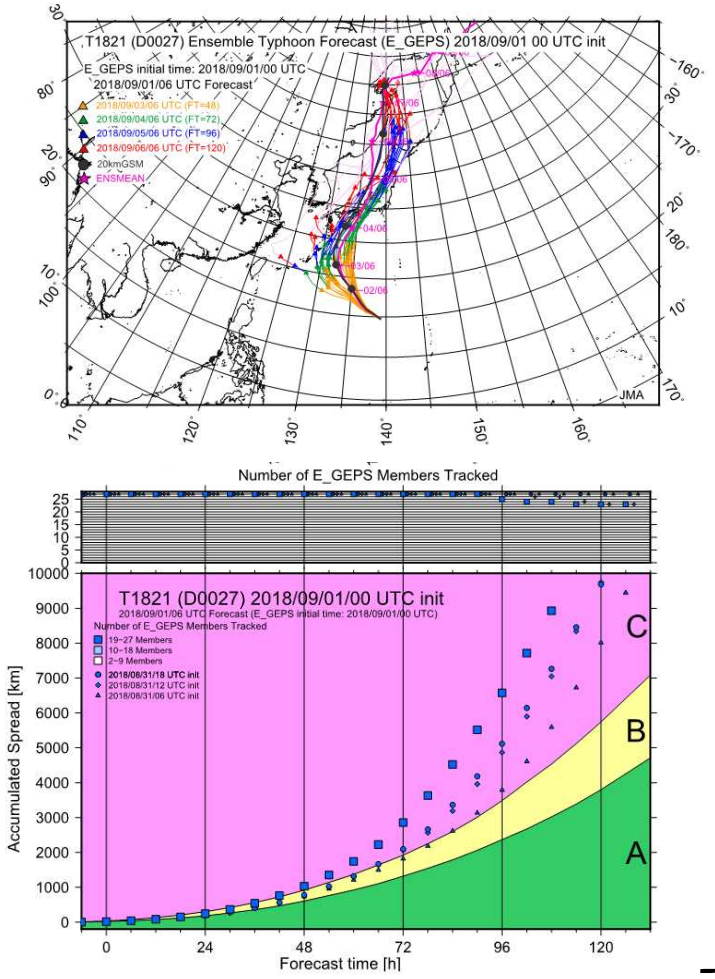
Track forecasts for T1825(KONG-REY) from JMA ensemble forecast. Initial at 12UTC on Oct. 2, 2018.

JMA models for TC Forecast

	Models	Forecast Range
Global Model	T_L959 L128 *about 20 km in horizontal*	up to 132h (00,06,18UTC) up to 264h (12 UTC)
Global EPS	T_Q479 L128, 51 members *about 27km in horizontal*	up to 132h (06, 18UTC) up to 264h (00, 12UTC)

70% probability circle of TC center position forecast

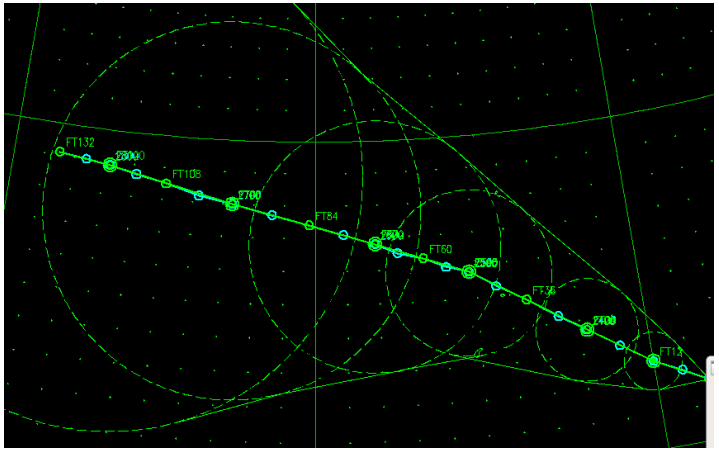
Spreads of the ensemble TC track forecasts by JMA, ECMWF, UKMO, and NCEP



70% probability circles for TC center forecast errors (A, A', B, B' and C) for forecast times from 3 h to 120 h

The radius of 70% probability circle

FT (h)	Forecast error (km)				
	A	A'	B	B'	C
3	10		15		20
6	15		20		25
9	15		25		35
12	20		30		40
15	20		35		50
18	25		40		55
21	25		45		65
24	30	40	50	60	70
48	60	75	90	100	120
72	100	120	140	160	180
96	140	170	200	230	260
120	200	240	280	325	350



Fukuda and Yamaguchi (2019), Tokyo Technical Review

TC intensity forecast by Typhoon Intensity Forecast Scheme (TIFS)

- A guidance that predicts typhoon intensity on dynamical and statistical basis using multiple linear regression.

  $y = a_0 + a_1x_1 + \cdots a_Nx_N$

  y: prediction, x_i : explanatory factors, a_i : coefficients
- TIFS predicts central pressures or maximum wind speeds up to 132 hours ahead at interval of 6 hours.
- Explanatory factors include :

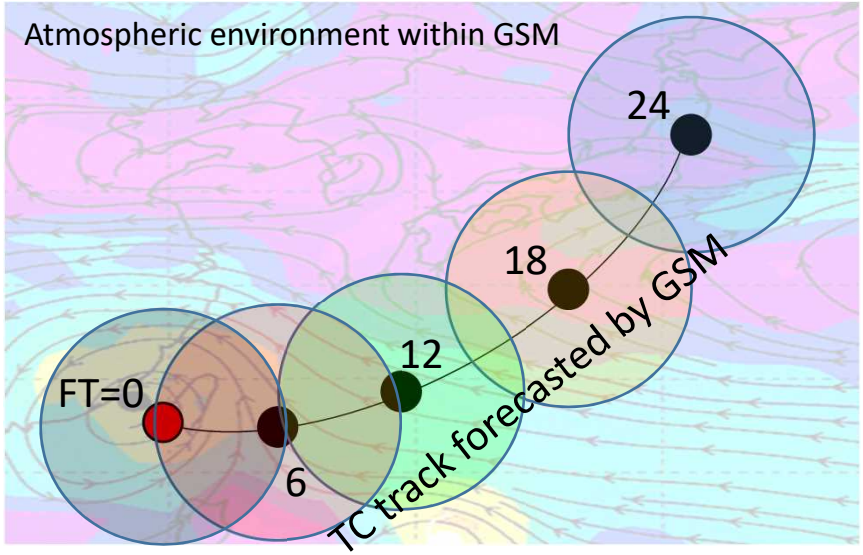
  initial typhoon intensity
  maximum potential intensity
  SSTs and ocean heat content
  cloud top temperatures
  vertical wind shear, divergence, water vapor, vorticity, temperature
- Atmospheric factors are derived from the GSM forecasts
- TIFS is an adaptation from “SHIPS”, which was originally developed by Dr. Mark DeMaria, NOAA/NHC, for hurricane predictions in the Atlantic.

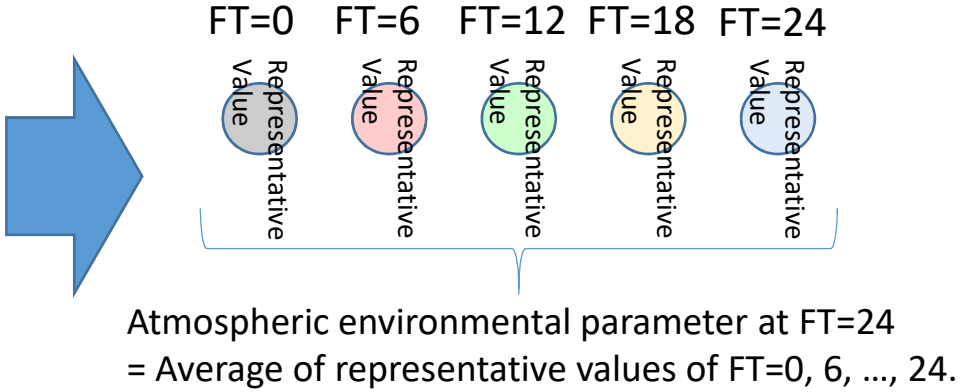
Essential explanatory factors for TIFS

Variable name	Description
PERSISTENCE	Change in max sustained wind during the last 12 hours
SHEAR	Vertical wind shear between 200 and 850hPa levels
POTENTIAL	Difference between the latest TC intensity and its maximum potential intensity
TANGENTIAL	Tangential wind speed around the TC at 850hPa level
MAXWIND	The latest max sustained wind
TEMP200, TEMP250	Temperature at 200 and 250hPa
MID_RH	Relative humidity in the mid-troposphere
VOR850	Vorticity at 850hPa
DIV200	Divergent at 200hPa
MOTION	Zonal component of translation speed of the TC
OHC	Ocean heat content
IR	Portion of cloud area with infrared irradiance below -30^{o}C

Computation of explanatory factors

Atmospheric explanatory variables are determined by area-averaging GPVs from GSM over the vicinity of the predicted positions of the TC center.

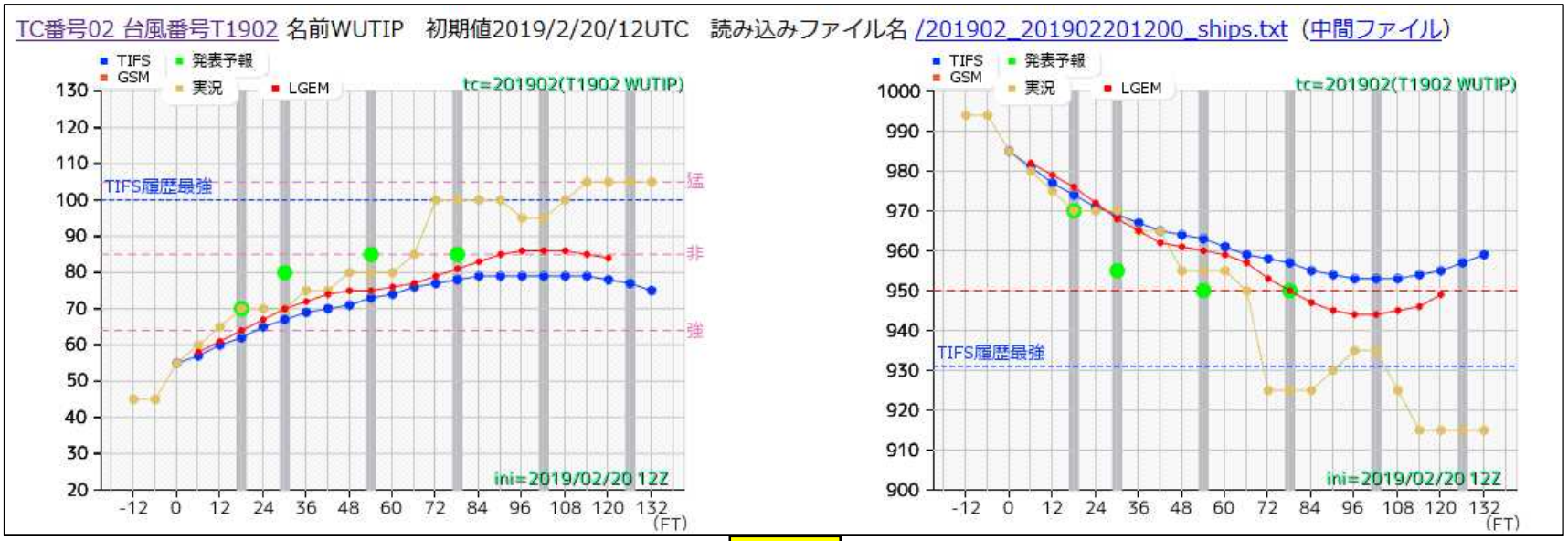




TC intensity forecast by TIFS

TIFS forecasts Maximum sustained winds (MSWs) and central pressures 12, 24, 48, 72, 96, 120 h after the initial time TIFS (Ono et al., 2019)

https://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/techrev/text21-2.pdf



TC forecasters obtain the forecasts of MSW and central pressure at 12, 24, 48, 72, 96, and 120 h after the initial time.

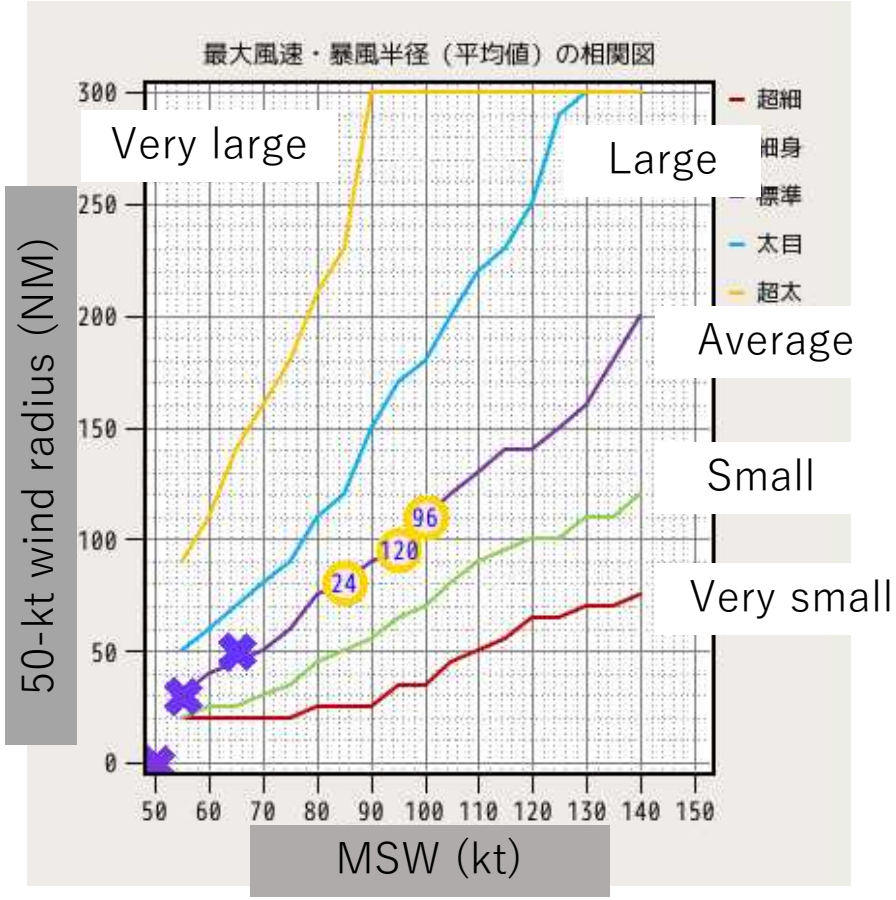
Supplemental information:

- The look-up table relating MSW to central pressure
- TC intensity forecasts by other NWP model, e.g., HWRF

Forecast of 50-kt wind radius

The forecaster predicts 50-kt wind radius based on MSW forecast and TC size.

Statistical relationships between MSW and 50-kt wind radius for different TC sizes



MSW forecast & TC size

estimation

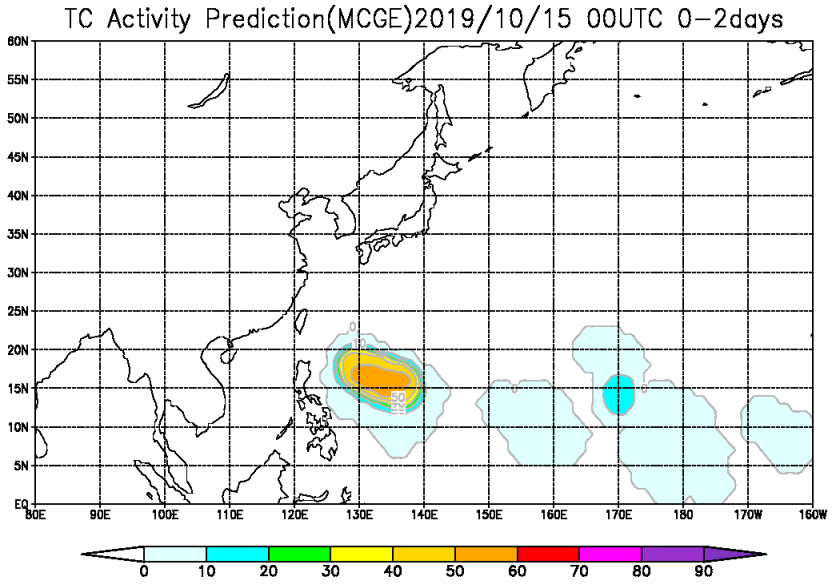
50-kt wind radius

TC activity prediction for TC genesis

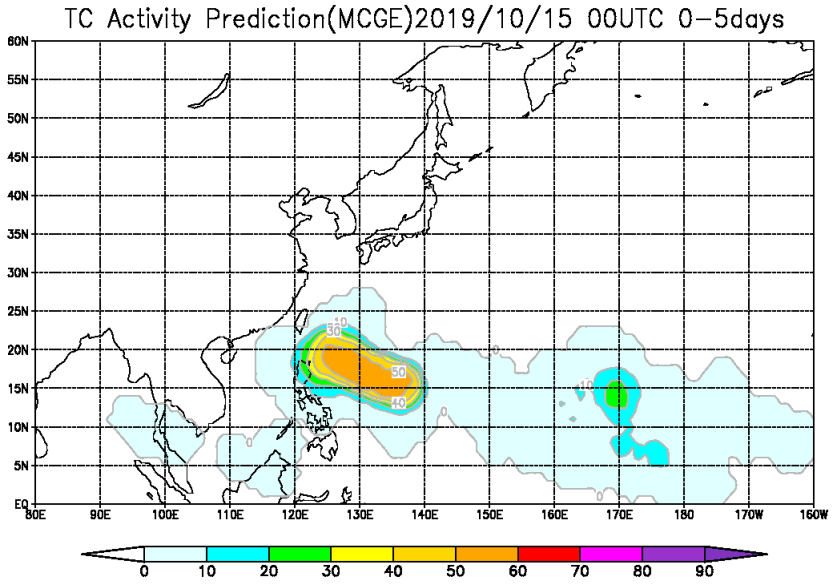
For Typhoon Committee members, Tropical Cyclone Activity Prediction (TCAP) is calculated as a percentage of ensemble members of the four EPSs in which TC-like vortices exist between 25° N and 0° at the start of forecast periods.

http://journals.ametsoc.org/doi/pdf/10.1175/WAF-D-14-00136.1

0 - 2 days



0 - 5 days



Multi- NWP center grand ensemble
(JMA, ECMWF, UKMO, NCEP)

End