Operational Use of the Typhoon Intensity Forecasting Scheme Based on SHIPS (TIFS) and Commencement of Five-day Tropical Cyclone Intensity Forecasts

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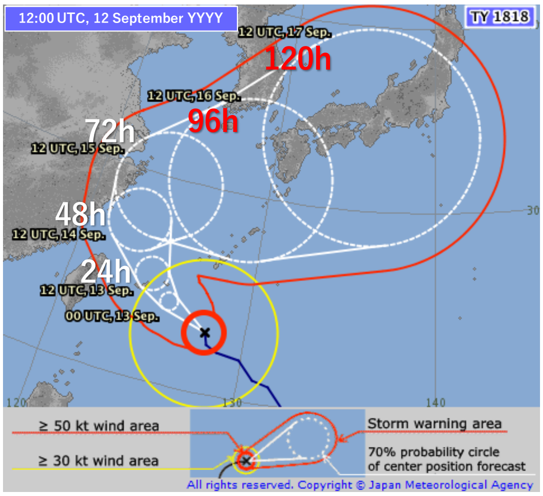
1. Introduction

1.1 Outline of five-day tropical cyclone intensity forecasts

The Japan Meteorological Agency (JMA) used to provide five-day track forecasts and three-day intensity forecasts for tropical cyclones (TCs) located over the western North Pacific and the South China Sea based on results from numerical weather prediction (NWP) models such as JMA's Global Spectral Model (GSM), Current Intensity (CI) numbers estimated from Dvorak analysis and other statistical data. In this context, there was previously a need to enhance the accuracy of intensity forecasts and extend the lead time up to five days in order to support disaster mitigation against TCs.

Recent advances in research on the TC intensification mechanism have led to NWP model improvement enabling tropical cyclone intensity forecasts with longer lead times based on up-to-date information. By way of example, guidance has been developed and put into operation in the United States for TC intensity forecasts with ever-increasing accuracy (DeMaria et al. 2014).

Against this background, JMA developed and implemented various forms of guidance along with research on their usage, extended the forecast time (FT) of NWP models, established related systems and operating procedures, and began providing five-day intensity forecasts (Fig. 1) in March 2019.



<Forecast for 12 UTC, 16 September>	
Intensity	Very strong
Center position of probability circle	N30° 55' (30.9°) E128° 40' (128.7°)
Direction and speed of movement	ENE 20 km/h (11 kt)
Central pressure	950 hPa
Maximum wind speed near center	45 m/s (85 kt)
Maximum wind gust speed	60 m/s (120 kt)
Radius of probability circle	480 km (260 NM)
Storm warning area	ALL 600 km (325 NM)
<Forecast for 12 UTC, 17 September>	
Intensity	-
Center position of probability circle	N34° 05' (34.1°) E135° 50' (135.8°)
Direction and speed of movement	ENE 30 km/h (17 kt)
Central pressure	980 hPa
Maximum wind speed near center	30 m/s (55 kt)
Maximum wind gust speed	40 m/s (80 kt)
Radius of probability circle	650 km (350 NM)
Storm warning area	ALL 800 km (425 NM)

Figure 1. A five-day TC intensity forecast

1.2 Development of intensity forecast guidance

In this work, JMA investigated various forms of guidance that demonstrated favorable outcomes in intensity forecasting. Based on the results, JMA introduced the Statistical Hurricane Intensity Prediction Scheme (SHIPS; DeMaria and Kaplan 1994, 1999; DeMaria et al. 2005) for guidance with intensity forecasts produced by the National Hurricane Center of the USA's National Oceanic and Atmospheric Administration (NOAA/NHC) via operational use on a trial basis. A major factor behind the scheme's introduction was its world-beating accuracy among forms of single guidance as of 2014 (e.g., Sampson and Knaff 2014) and its provision of information on the contribution of individual explanatory variables to intensity changes. SHIPS guidance supports hurricane intensity forecasting, in which TC intensity changes are predicted statistically based on TC analysis, environmental parameters around tropical cyclones calculated from NWP models, sea surface temperatures and observation data from meteorological satellites. The scheme is also recognized as a statistical-dynamical model for its use of input data dynamically estimated from NWP models and its forecasting of TC intensity using a statistically derived formula.

JMA's Meteorological Research Institute (JMA/MRI) developed SHIPS for the adjustment of JMA's operational system (Yamaguchi et al. 2018, 2019) in collaboration with Dr. DeMaria and other relevant parties in the United States, and JMA subsequently introduced the scheme with the name TIFS (**T**yphoon **I**ntensity **F**orecasting Scheme Based on **S**HIPS). The major difference between the original SHIPS and TIFS is that the former predicts only maximum wind speed in relation to TC intensity, while the latter also predicts central pressure. The newly developed TIFS intensity forecast guidance was incorporated into the operational system and subjected to testing and accuracy evaluation. In trial operation, the GSM forecast range was extended from 84 to 132 hours at the initial times of 00, 06 and 18 UTC to produce necessary data for five-day intensity forecast guidance (with the GSM at the initial time of 12 UTC providing 264-hour forecasts). Based on trial operation and verification results obtained since 2016, TIFS and its application were fine-tuned toward JMA's trial application of the scheme on an operational basis in 2017.

Figure 2 highlights JMA TC forecast accuracy. Steady improvements are seen both in official track forecasts and GSM track predictions in the long term, although year-to-year fluctuations are observed. The accuracy of intensity forecasts exhibited little notable improvement for a long period, but annual average of root mean square errors (RMSEs) were low in 2017 because there were fewer complex cases (such as those involving rapid intensification) than in 2016, and the use of TIFS also contributed to official forecasts. Accuracy in 2018 was lower than in 2017, partially because many TCs were difficult to forecast mainly due to rapid intensification and because there was room for improvement in operational procedures. Thus, annual mean errors/RMSEs are significantly affected by numbers of TCs that are difficult to forecast. Figure 3 shows the improvement ratio (%) of official TC central pressure forecasts to Statistical Hurricane Intensity Forecasts (SHIFOR; Jarvinen and Neumann 1979, Knaff et al. 2003), which can be used to highlight whether official intensity forecasts are actually improved by eliminating these effects. It can be seen that the improvement ratio is higher after 2016, when experimental use of TIFS was introduced. In this way, the accuracy of intensity forecasts has undoubtedly improved since the adoption of TIFS, but as above there is room for improvement. Further enhancement of TIFS itself as well as expanded application is expected.

Section 2 below gives an outline of TIFS, and Section 3 presents related statistical verification results and characteristics based on individual cases.

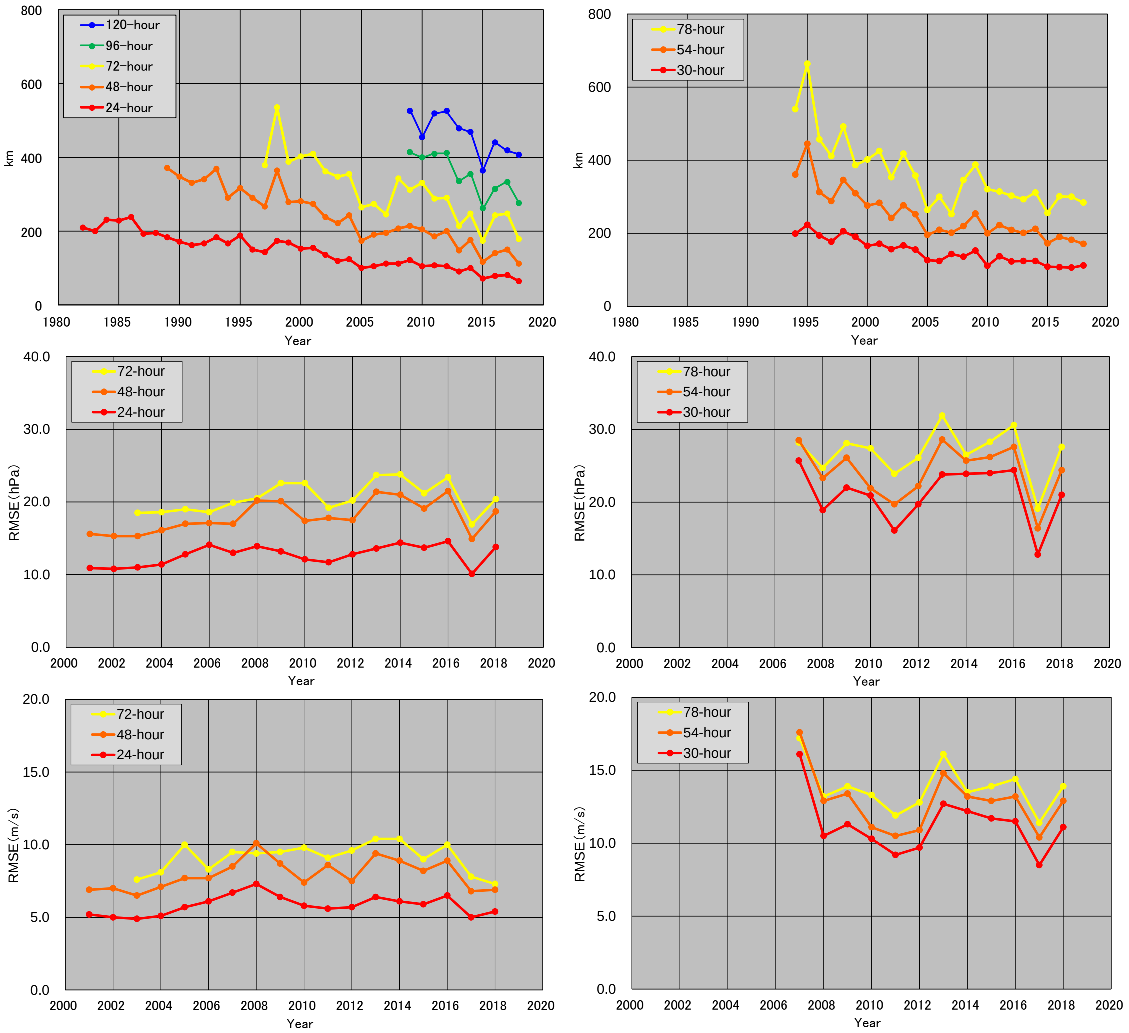


Figure 2. Annual mean error of TC track (center position) forecasts (top), annual mean RMSE of intensity forecasts for central pressure (middle) and maximum wind speed (bottom)
The figures on the left are errors for official forecasts, and those on the right are for GSM results.

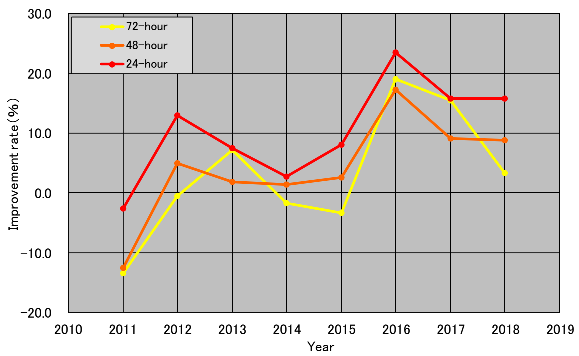


Figure 3. Improvement ratio (%) of official TC central pressure forecasts to SHIFOR

2. Outline of the Typhoon Intensity Forecasting Scheme Based on SHIPS (TIFS)

TIFS involves the use of a statistical method with multiple linear regression and expression of TC intensity change from the initial time to the target prediction time. As described in Section 1.2 in relation to SHIPS, the explanatory variable inputs for TIFS are TC analysis results, parameters for environments around TCs calculated from the GSM, parameters for oceanographic environments and observation data from the meteorological geostationary satellite of Himawari-8. The objective variables forming output data are central pressure and maximum wind speed, and are calculated every six hours with individual regression equations. As Figure 4 shows, the environmental parameters are averaged along a GSM-forecast TC track. The averages for an area within a certain distance of the estimated center position at each FT are set as representative values, and the average of representative values from the initial time to the target FT is the explanatory value at the target FT.

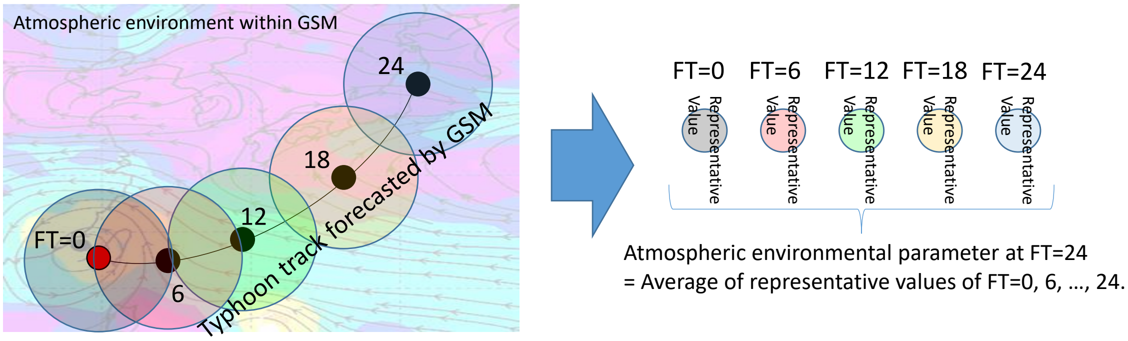


Figure 4. Retrieval of atmospheric environmental parameters at FT24 with TIFS

Original data are used in TIFS to calculate TC intensity, and the explanatory variables (referred to here as "environmental parameters") obtained from them are:

- Latest intensity analysis values and intensity change over the last 12 hours
- GSM analysis and prediction values (lower-level tangent wind speed, lower-level temperature advection, lower-level vorticity, lower-level temperature vertical gradient, mid-level moisture, upper-level divergence, upper-level temperature, vertical shear of horizontal wind, difference of θe (equivalent potential temperature) between surface and each level
- Sea surface temperature (SST) analysis values (maximum potential intensity)
- Analysis values of ocean heat content (OHC) or TC heat potential (TCHP) (Wada 2015)
- Himawari-8 observation data

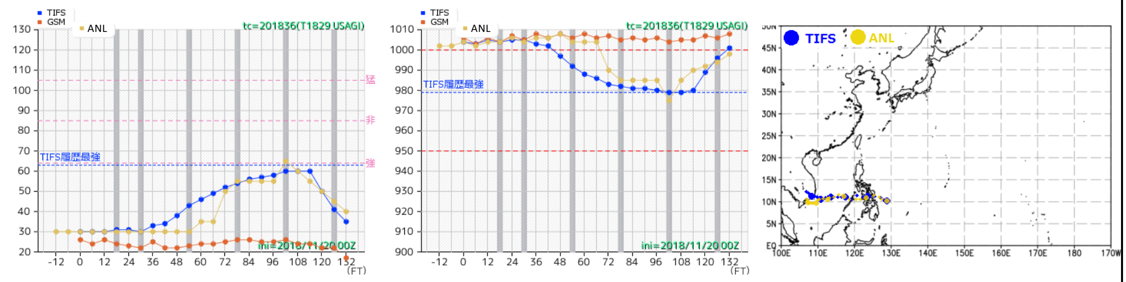
  (Ratio of area with infrared band 13 (10.4 μm) brightness temperatures lower than -30°C and standard deviation of brightness temperature)

Regression coefficients for TIFS were created with JMA best-track data on TCs for the period 2000 – 2012, Japanese 55-year reanalysis data (JRA-55, Kobayashi et al. 2015), centennial observation-based estimates of SST (COBE-SST, Ishii et al. 2005; as used in JRA-55 for boundary conditions), TCHP data created by JMA, and data on infrared brightness temperature from successive geostationary satellites. It should be noted that the coefficients were created with data from periods of TCs with maximum wind speeds of 34 kt or higher, while JMA best-track data also includes figures on TCs with maximum wind speeds lower than 34 kt and extratropical lows.

TIFS is operated in accordance with the output time of GSM predictions, meaning that intensity prediction is conducted with initial times of 0, 6, 12 and 18 UTC. The scheme outputs both TC intensity change from the initial time and the contribution of environmental parameters for intensity forecasts. These data enable forecasters to understand the grounds for intensity forecasts, allowing issuance based on clear reasoning and forecast updates from quantitative evaluation of any differences between forecasts and observations. Figure 5 shows TIFS prediction results.

Typhoon Intensity Forecast scheme based on SHIPS

T1829 USAGI Initial time 2018/11/20/0UTC



Maximum wind speed (KT)
Peak 60KT 2018/11/24/06/UTC (FT=102)

Time	FT	ANL	GSM	TIFS
2018112000	0	30	26	30
2018112006	6	30	24	30
2018112012	12	30	26	30
2018112018	**18**	**30**	**24**	**31**

Central pressure (hPa)
Peak 979hPa 2018/11/24/06/UTC (FT=102)

Time	FT	ANL	GSM	TIFS
2018112000	0	1004	1006	1004
2018112006	6	1002	1003	1003
2018112012	12	1004	1006	1005
2018112018	**18**	**1004**	**1004**	**1004**

TIME	20th 00Z	20th 06Z	20th 12Z	20th 18Z	21st 00Z	21st 06Z	21st 12Z	21st 18Z	22nd 00Z	22nd 06Z	22nd 12Z	22nd 18Z	23rd 00Z	23rd 06Z	23rd 12Z	23rd 18Z	24th 00Z	24th 06Z	24th 12Z	24th 18Z	25th 00Z	25th 06Z	25th 12Z
FT	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132
Model Output																							
LAT	10.1	10.4	10.9	11.3	11.3	11.0	11.4	10.6	11.0	11.1	11.1	11.1	11.0	11.0	10.8	10.6	10.6	10.9	11.0	11.2	11.2	11.9	12.2
LON	128.8	128.1	127.1	125.6	123.7	122.3	120.8	119.0	117.5	116.6	115.5	114.5	113.6	112.8	112.0	111.4	110.9	110.4	109.8	109.2	108.3	107.5	106.9
SST	29.3	29.3	29.1	28.6	28.3	28.7	28.3	28.8	28.9	28.8	28.8	28.8	28.7	28.6	28.6	28.3	28.3	28.3	28.2	27.8	27.8	28.0	28.2
OHC	74	81	85	77	18	63	63	43	68	72	67	58	42	39	41	48	47	46	32	38	17	32	32
VWS_MAG	23	19	14	7	7	10	8	12	8	7	10	13	13	15	17	14	12	12	13	12	14	11	8
VWS_HDG	258	261	270	284	297	295	322	296	297	284	298	297	290	284	293	284	273	273	277	280	285	298	317
RH_MID	67	66	66	65	68	69	69	65	58	60	58	57	57	60	59	61	57	58	57	56	52	51	49
200DVRG	37	46	41	39	52	90	88	30	35	51	75	101	105	90	84	141	156	184	190	200	201	187	189
VMAX		24	26	24	23	22	25	22	22	23	24	24	25	26	26	25	25	26	24	24	22	22	17
MSLP		1003	1006	1004	1007	1005	1008	1006	1008	1006	1008	1006	1007	1005	1006	1005	1006	1004	1005	1005	1007	1006	1008
DISTANCE TOLAND	304	258	165	2	39	-32	94	14	170	245	327	411	487	402	324	274	225	161	97	31	-20	-131	-193
STEERING LV		721																					
TIFS Output																							
DELV		0	0	1	1	2	5	6	10	15	19	22	24	27	28	29	31	33	33	32	32	34	35
DELP		1	1	1	2	1	-2	-4	-8	-13	-17	-20	-22	-24	-24	-24	-25	-26	-26	-26	-25	-24	-25
VMAX	30	30	30	31	31	30	33	34	38	43	46	49	52	54	56	57	58	60	60	60	50	41	35
MSLP	1004	1003	1005	1004	1005	1005	1003	1002	997	992	988	986	983	982	981	981	980	979	979	980	989	996	1001
VMAX (NOLAND)		30	30	31	31	32	35	36	40	45	49	52	54	57	58	59	61	63	63	62	62	64	65
MSLP (NOLAND)		1005	1005	1005	1006	1005	1002	1000	996	991	987	984	982	980	980	980	979	978	978	978	979	980	979

Figure 5. TIFS prediction results

The upper figure shows TIFS and GSM intensity prediction values at each initial time for individual TCs with analysis data in line graphs as well as a map of tracks. The pink-colored and light blue-colored cells represent development and weakening from 12 hours before, respectively. The lower figure shows intensity prediction results and environmental parameters for each target FT. The pink-colored cells indicate values favorable for TC development while light blue-colored cells indicate those not favorable.

3. TIFS accuracy verification

3.1. Verification for TCs in 2017 and 2018

TIFS intensity prediction accuracy was checked for all 2017 and 2018 TCs using JMA best-track data based on the period from generation to just before dissipation (i.e., downgrade to tropical depression or extratropical low) for each TC. Verification was also conducted for GSM and SHIFOR (central pressure only) data. It should be noted that central pressure is analyzed every 2 hPa at 990 hPa or higher and every 5 hPa under 990 hPa, and that wind speed is analyzed every 5 kt in JMA best-track.

Figure 6 shows RMSEs and mean errors of intensity prediction results from FT = 6 to FT = 120 for central pressure and maximum wind speed. The RMSE of central pressure prediction for TIFS is around 7.5 hPa at FT = 6, then gradually increases to 20 hPa. SHIFOR shows a similar trend, but the RMSE is larger than that of TIFS except at FT = 6. The RMSE of the GSM is also larger than that of TIFS, showing values around 20 to 25 hPa for all FTs. In this way, TIFS is the best of the three in terms of central pressure prediction RMSE.

The mean error of central pressure prediction is almost zero for TIFS from FT = 6 to FT = 36, and the negative bias gradually increases to around -5 hPa at FT = 120; that is, TIFS exhibits no significant bias. Meanwhile, the GSM has a bias of around +10 hPa from FT = 6 to FT = 48, which larger than those of TIFS and SHIFOR, although it becomes smaller as FT increases and reaches almost zero at FT = 120. This is considered to be the cause of the large RMSE. In addition, it should be noted that the bias of SHIFOR is almost zero simply because SHIFOR central pressure prediction results vary randomly and not because of high skill, in consideration of the fact that the RMSE of SHIFOR is larger than that of TIFS.

The RMSE of TIFS maximum wind speed prediction is around 6 kt at FT = 6 and gradually increases to around 16 kt at FT = 120, while that of the GSM is around 19 to 22 kt for all FTs and much larger than that of TIFS. The mean error is almost zero with the maximum value of +1.6 kt for TIFS. That of the GSM is around -13 kt at FT = 6 and gradually becomes smaller, reaching -6.2 kt at FT = 120. Thus, there is a significant difference between TIFS and GSM figures.

These verification results indicate that intensity prediction accuracy is higher with TIFS than with SHIFOR and the GSM on average, which implies potential for more accurate forecast provision by leveraging TIFS central pressure and maximum wind speed predictions. Accordingly, further research was conducted on the characteristics of TIFS under various conditions. Sections 3.2 to 3.4 below feature case studies highlighting the weak points of TIFS, as clarifying such characteristics will lead to more appropriate forecasts.

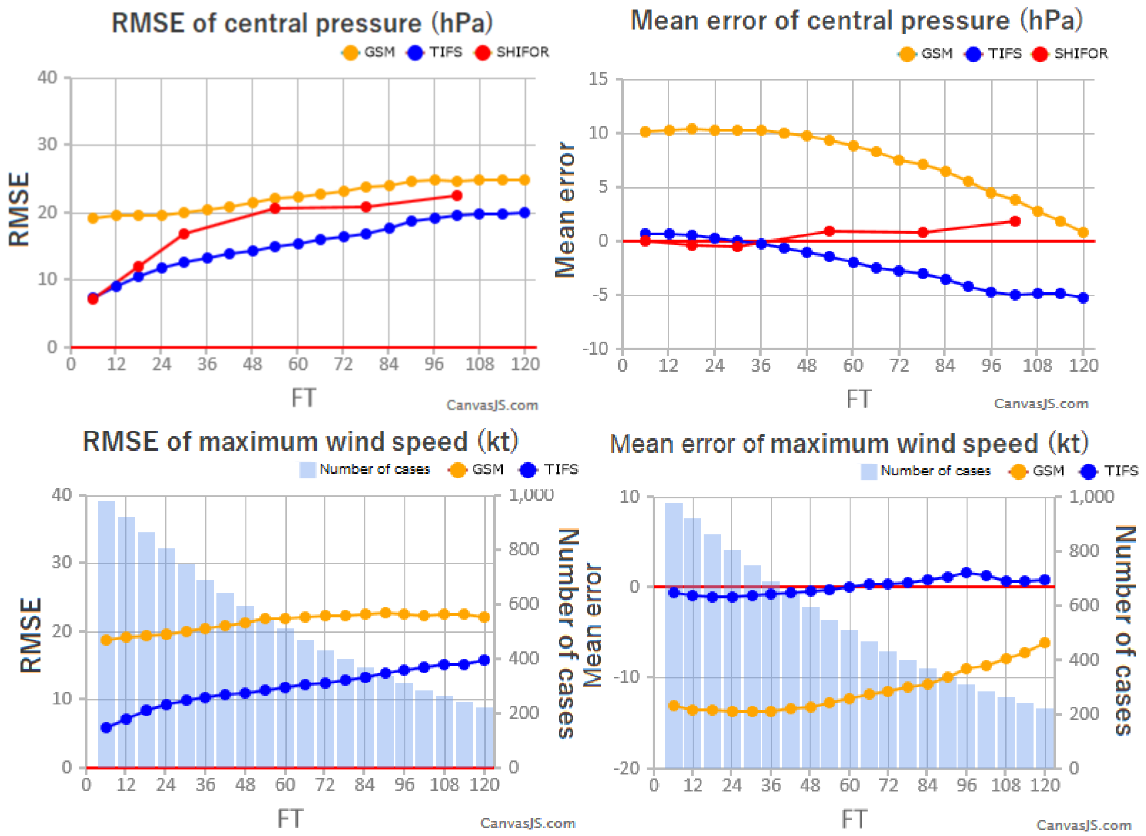


Figure 6. RMSE (left) and mean error (right) of intensity forecast results for all TCs in 2017 and 2018 (top: central pressure (hPa); bottom: maximum wind speed (kt))
Yellow, blue and red lines indicate GSM, TIFS and SHIFOR prediction values, respectively.
The axes on the right indicate numbers of cases.

3.2 TY Jelawat (1803)

Jelawat formed as a tropical depression (TD) around the Caroline Islands at 18 UTC on 24 March 2018 and moved west-northwestward. It was upgraded to tropical storm (TS) intensity over the same waters 12 hours later and turned gradually northward. Decelerating in the same direction, it was rapidly upgraded to typhoon (TY) intensity around the sea east of the Philippines at 00 UTC on 29 March. After turning sharply east-northeastward, it reached its peak intensity with maximum sustained winds of 105 kt and a central pressure of 915 hPa southeast of Okinotorishima Island at 06 UTC on 30 March. Jelawat was rapidly downgraded to TS intensity around the sea west of the Northern Mariana Islands at 18 UTC on 31 March. It weakened to TD intensity over the same waters at 00 UTC on 1 April and dissipated there 12 hours later (Figure 7).

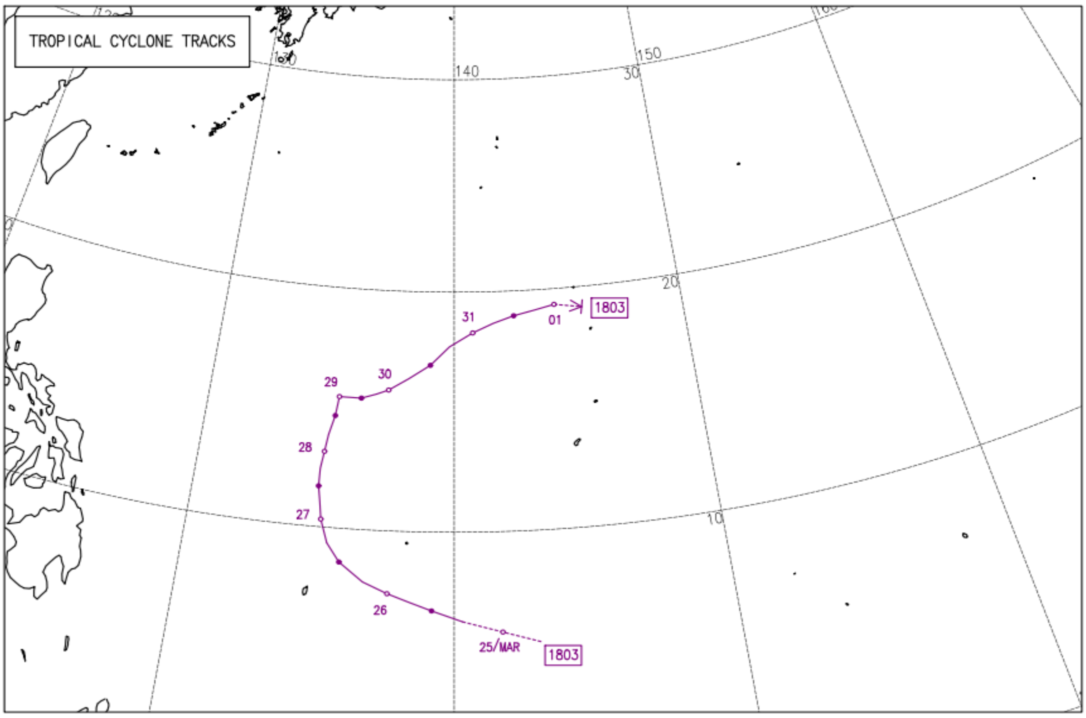
Figure 8 (a) and (b) show TIFS and GSM intensity prediction results with initial times at 00 UTC on 25 March before TS status was reached. GSM central pressure prediction was favorable and similar to JMA's best-track analysis results up to FT = 90, but did not foresee the subsequent rapid intensification, and the error reached + 43 hPa at FT = 120. The maximum wind speed prediction underestimated actual winds for all FTs, and the error reached -43 kt at FT = 120. Meanwhile, TIFS over-intensified values during the development stage, but the intensification decelerated and related errors were only +2 hPa and -5 kt at FT = 120.

As described in Section 2, TIFS regression coefficients were created with data from periods of TCs with maximum wind speeds of 34 kt or higher, meaning that data from TD status periods were not used. This is considered to have caused over-intensification during the development stage, and this tendency was also recognized with TCs other than Jelawat. This should be considered in relation to TIFS application.

Figure 8 (c) and (d) show TIFS and GSM intensity prediction results with initial times at 06 UTC on 27 March immediately before rapid intensification was observed. The trends of intensity changes in both are similar except for maximum wind between FT = 96 and 108, but the TIFS prediction results are around 15 hPa and 10 kt closer than those of the GSM to JMA's best-track analysis results at around FT = 72. The TIFS results were almost the same as JMA's best-track analysis results up to FT = 48, indicating that TIFS predicted short-term rapid intensification (such as a 25-hPa drop within 24 hours) well. However, TIFS did not predict the subsequent further rapid intensification well, forecasting much weaker intensity with errors reaching +39 hPa and -32 kt at FT = 72. This tendency was also seen in comparison of results with the initial time at 00 UTC on 29 March immediately before further rapid intensification (Figure 8 (e) and (f)).

This case highlighted the difficulty of using TIFS to predict significant rapid intensification in which central pressure values exceeding 30 hPa significantly fall within 24 hours. This is partially attributed to explanatory variables of TIFS at a certain target FT being calculated by averaging representative values along a forecasted TC track from the initial time to the target FT, meaning that rapid changes around a TC cannot be fully reflected. In addition, TIFS is essentially a statistical model representing average TC development/weakening, and therefore tends to predict slightly larger/smaller intensity changes than actual conditions for TCs accompanied by intensity changes smaller/larger than average.

Figure 8 (g) and (h) show TIFS and GSM intensity prediction results with an initial time at 12 UTC on 30 March, at which weakening commenced. Jelawat rapidly weakened according to JMA's best-track analysis results, but TIFS did not predict such an immediate intensity change; rather, the prediction results showed much higher intensity at FT = 30 immediately before downgrade to TD status, with errors of -35 hPa and +35 kt. This is consistent with the above consideration regarding the tendency of TIFS, which was also recognized for other TCs, indicating a trend of underestimation for rapid intensity changes in the stages of development and weakening.



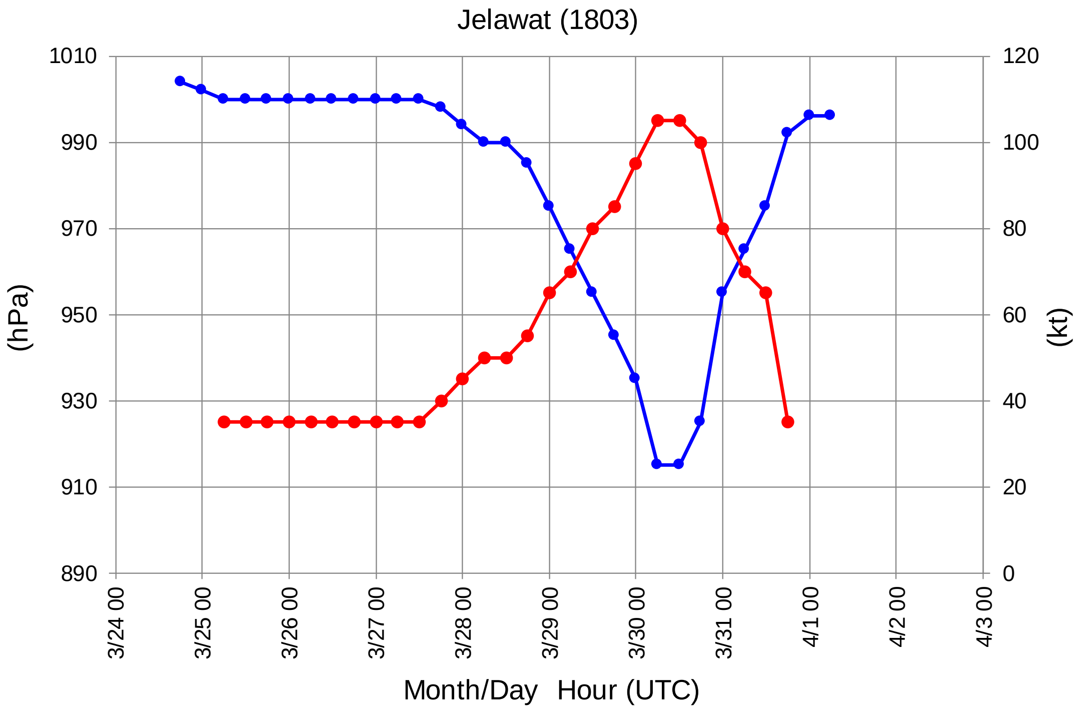


Figure 7. Track (top) and intensity changes (bottom) of TY Jelawat (1803)

The purple line in the top figure shows the track of TY Jelawat with boxed TC numbers. Circles along the track indicate the center position at 00 UTC on each day, and dots indicate the center position at 12 UTC. The arrow indicates the dissipation point. The track line is solid for TS status or higher and dotted for tropical depression or extratropical low status. The blue line in the bottom figure represents central pressure (hPa), and the red line shows maximum wind speed (kt).

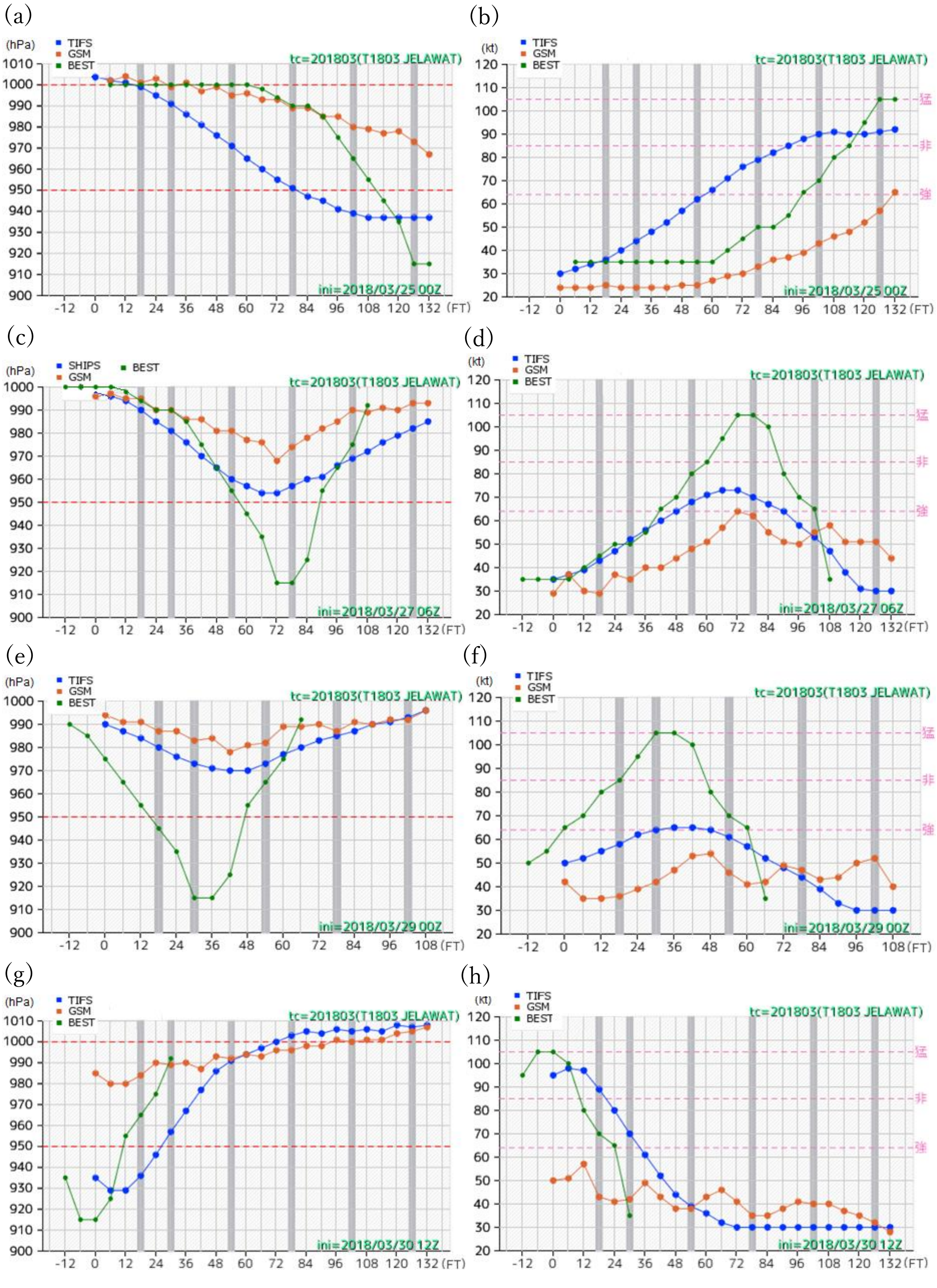


Figure 8. TIFS and GSM intensity forecast results of for TY Jelawat (1803)

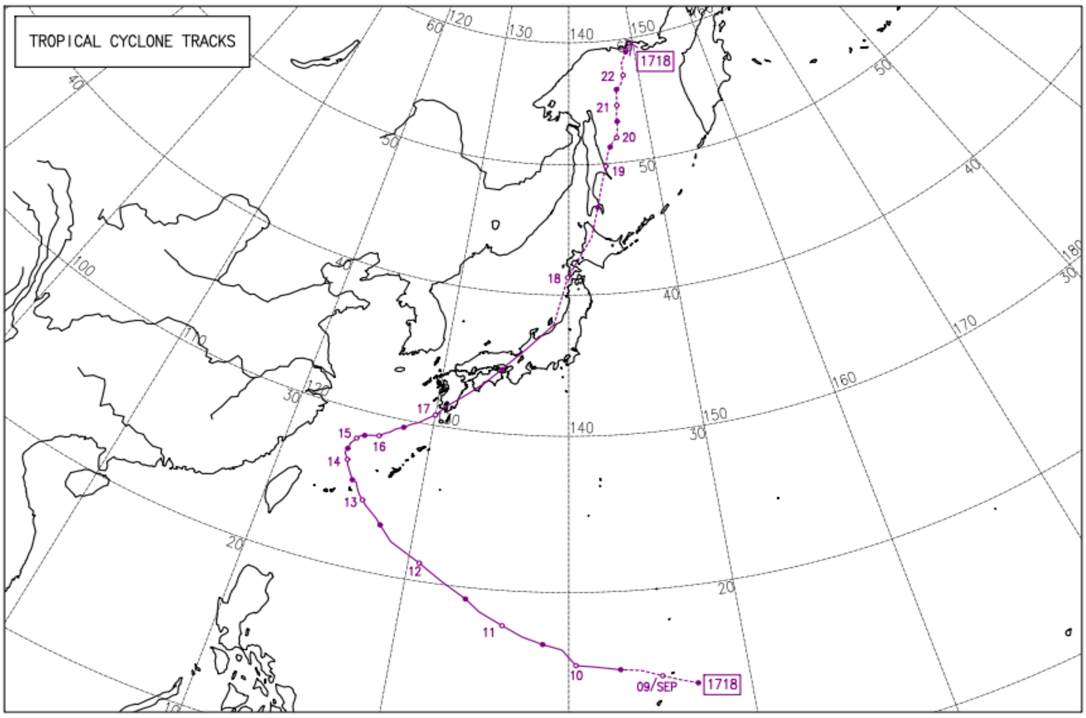
(a), (c), (e) and (g) show central pressure (hPa), and (b), (d), (f) and (h) show maximum wind speed (kt). Initial times are (a) (b): 00 UTC on 25 March 2018; (c) (d): 06 UTC on 27 March 2018; (e) (f): 00 UTC on 29 March 2018; and (g) (h): 12 UTC on 30 March 2018. The green lines indicate JMA best-track data analysis values, and the orange and blue lines show GSM and TIFS prediction values, respectively.

3.3 TY Talim (1718)

Talim formed as a TD over the sea northeast of Guam Island at 12 UTC on 8 September 2017. Moving west-northwestward, it was upgraded to TS intensity northwest of Guam Island at 12 UTC the next day. Keeping its west-northwestward track, it was upgraded to TY intensity east of the Philippines at 18 UTC on 11 September. It reached its peak intensity with maximum sustained winds of 95 kt and a central pressure of 935 hPa north of Ishigakijima Island at 00 UTC on 14 September. Maintaining TY intensity for a while and then gradually weakening, it moved over the Sea of Japan and transformed into an extratropical low around Sado Island at 18 UTC on 17 September before accelerating north-northeastward and dissipating over the Sea of Okhotsk at 00 UTC on 23 September (Figure 9).

Figure 10 (a) and (b) show TIFS and GSM intensity prediction results with initial times at 12 UTC on 9 September. TIFS predicted monotonic intensification up to around FT = 102, exhibiting a close fit with JMA's best-track analysis results until FT = 72. After this point, Talim did not intensify as predicted by TIFS in actual conditions; rather, its intensity was maintained for a while and then started to increase rapidly at FT = 90. Figure 11 shows Himawari-8 water vapor imagery (Band 10; wavelength: 7.3 μm) with GSM analysis values of relative humidity (%) calculated for 500 hPa at 12 UTC on 12 September. Band 10 exhibits peak sensitivity at around 450 – 550 hPa, and is suited for capture of the amount of mid-level water vapor. The figure shows a distinct dry area in the upper level (expressed as a dark area in water vapor imagery) in front of Talim's direction of movement. Based on relative humidity distribution at 500 hPa, this area generally corresponds to a region with humidity of 50% or lower at 500 hPa. Accordingly, intensification is considered to have halted between FT = 72 and FT = 90 because convective activity was suppressed due to dry air ahead of it. In other cases too, TIFS falsely predicted intensification where dry areas were present around a TC. TIFS is therefore considered to have a tendency to underrepresent the negative impact of dry areas in front of the TC direction of movement in mid to upper levels.

Figure 10 (c) shows TIFS and GSM intensity prediction results with an initial time of 18 UTC on 16 September. JMA's best-track analysis results show a gradual increase in central pressure, and Talim was downgraded to an extratropical low at FT = 24. TIFS intensity prediction was initially favorable, but central pressure upon downgrading (i.e., at FT = 24) was high with a relatively large error of +14 hPa. Re-intensification was also represented appropriately from FT = 24 to 30 but soon weakened, while in reality intensity was maintained for longer, and the error therefore reached around +15 to 20 hPa. This is because, as described in Section 2, TIFS regression coefficients are created with data from the period of TC presence. Accordingly, it should be noted that TIFS is not suitable for intensity prediction in cases such as that of Talim, where a TC is expected to transform into an extratropical low and re-intensify.



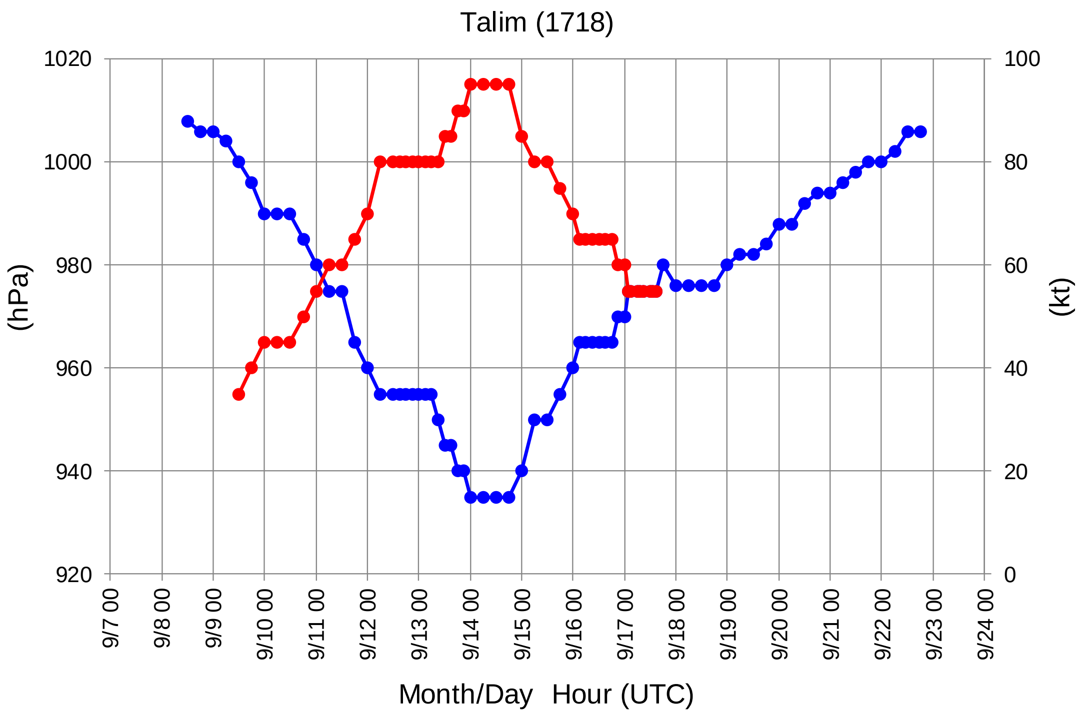


Figure 9. Track (top) and intensity changes (bottom) of TY Talim (1718)

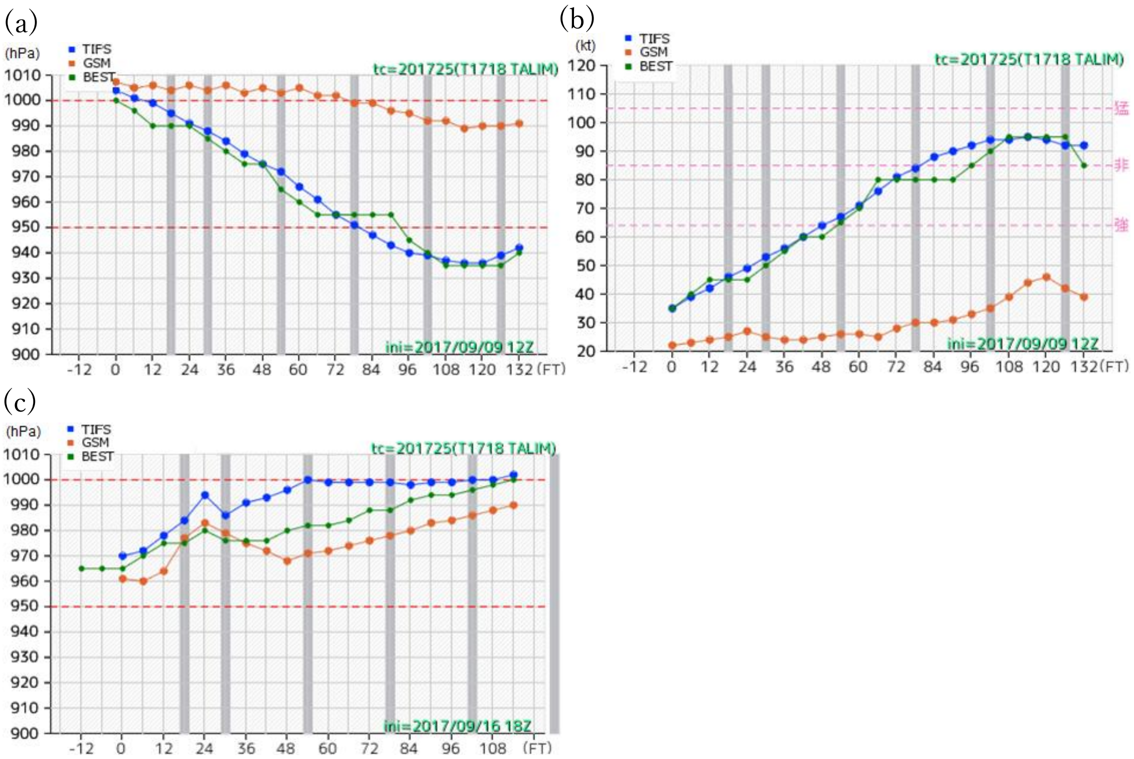


Figure 10. TIFS and GSM intensity forecast results for TY Talim (1718)

(a) and (c) are for central pressure (hPa), and (b) is for maximum wind speed (kt). The initial times are (a), (b) 12 UTC on 9 September 2017 and (c) 18 UTC on 16 September 2017.

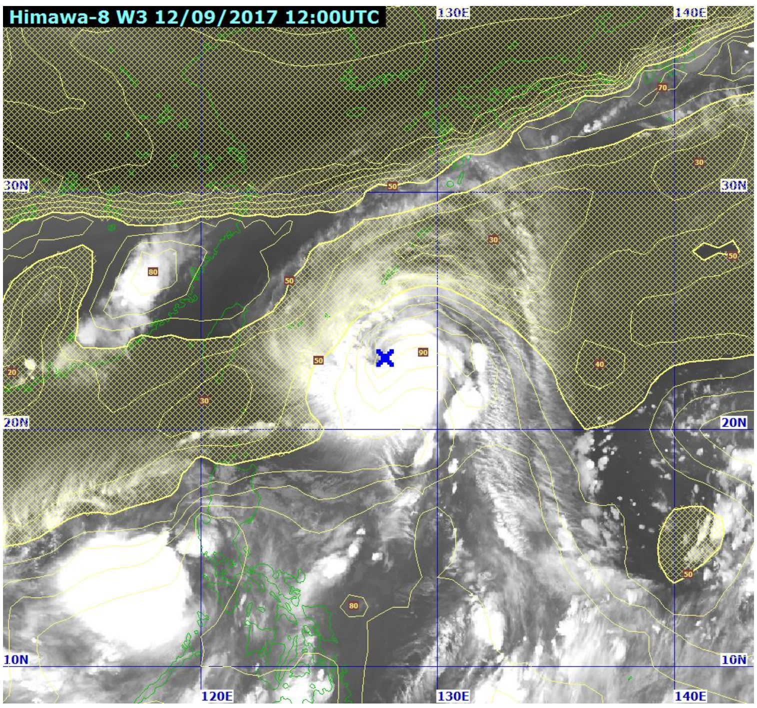


Figure 11. TY Talim (1718) captured in Himawari-8 water vapor imagery (Band 10) with GSM analysis values of relative humidity (%) calculated at 500 hPa (yellow isolines) at 12 UTC on 12 September 2017.

Areas with humidity of 50% or lower are hatched. The blue X indicates Talim's center.

3.4 TY Mangkhut (1822)

Mangkhut formed as a TD around the Marshall Islands at 12 UTC on 6 September 2018 and moved westward. It was upgraded to TS intensity over the same waters at 12 UTC on 7 September. Keeping its westward track, it was upgraded to TY intensity around the sea east of the Mariana Islands at 00 UTC on 9 September. It reached its peak intensity with maximum sustained winds of 110 kt and a central pressure of 905 hPa around the sea west of the Mariana Islands at 12 UTC on 11 September before gradually turning west-northwestward. Having maintained TY intensity for more than three days, it rapidly weakened to TD intensity over southern China at 06 UTC on 17 September and dissipated there 18 hours later (Figure 12).

Figure 13 (a) and (b) show TIFS and GSM intensity prediction results with an initial time of 12 UTC on 8 September. TIFS predicted the intensification very well up to FT = 48, but did not predict the later rapid intensification with errors of +37 hPa and -20 kt at FT = 72. GSM intensity prediction results were similar but lower by around +10 hPa and -10 kt (see Section 3.2 for information regarding the difficulty of predicting rapid intensity changes). It should be noted here that the rapid intensification was appropriately predicted in JMA’s official forecasts with an error of only +5 hPa (and no error in maximum wind speed) with reference to JMA’s best-track analysis results at FT = 78 (issued as a 72-hour forecast). To cover the shortcomings of TIFS, JMA monitors TIFS prediction results as well as rapid intensification (RI) index values (Yamaguchi et al. 2019; Chapter 4). In this case, high index values were observed. JMA forecasted rapid intensification exceeding the results of TIFS prediction in consideration of this index and with reference to predictions of other models.

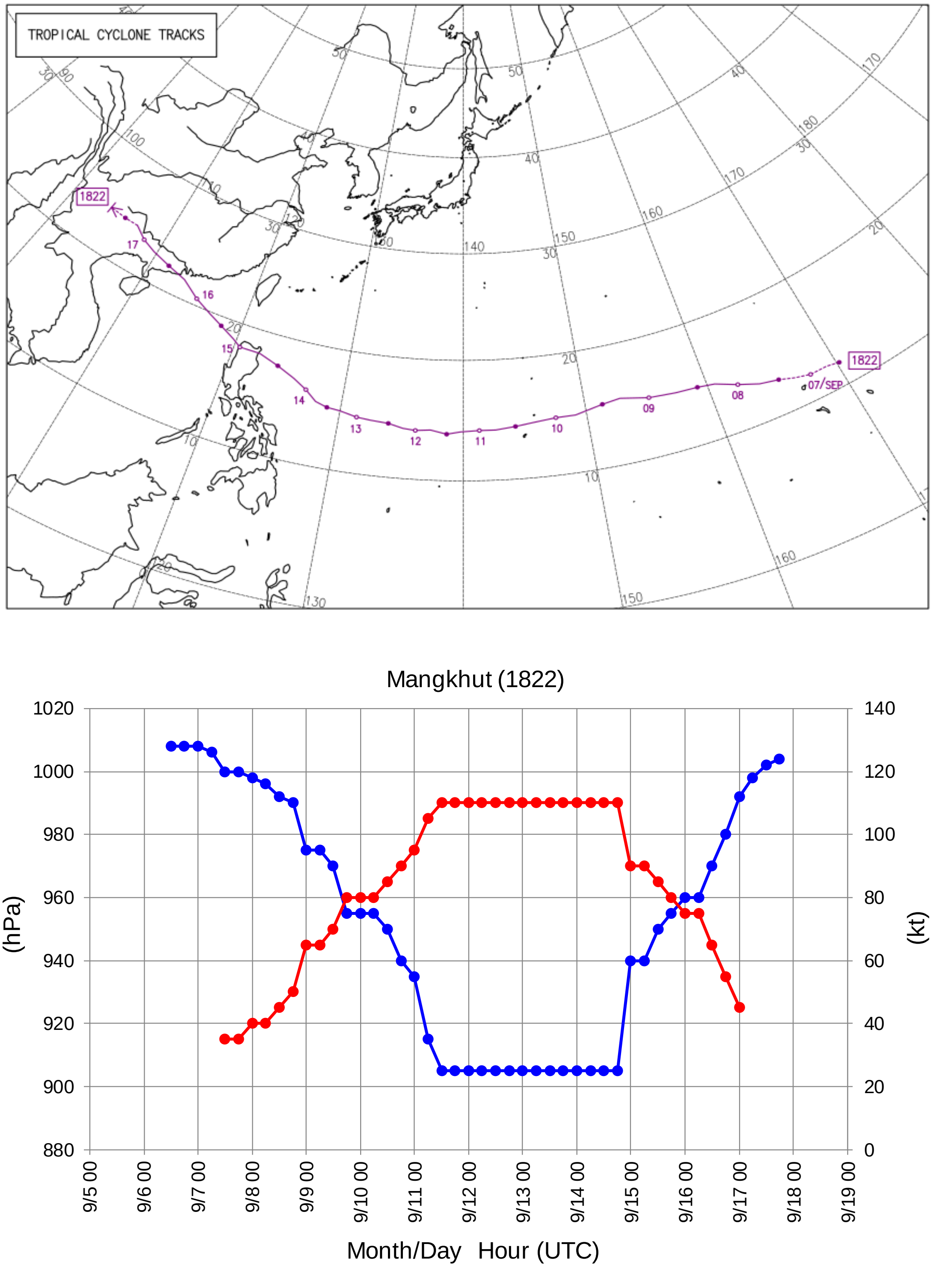


Figure 12. Track (top) and intensity changes (bottom) of TY Mangkhut (1822)

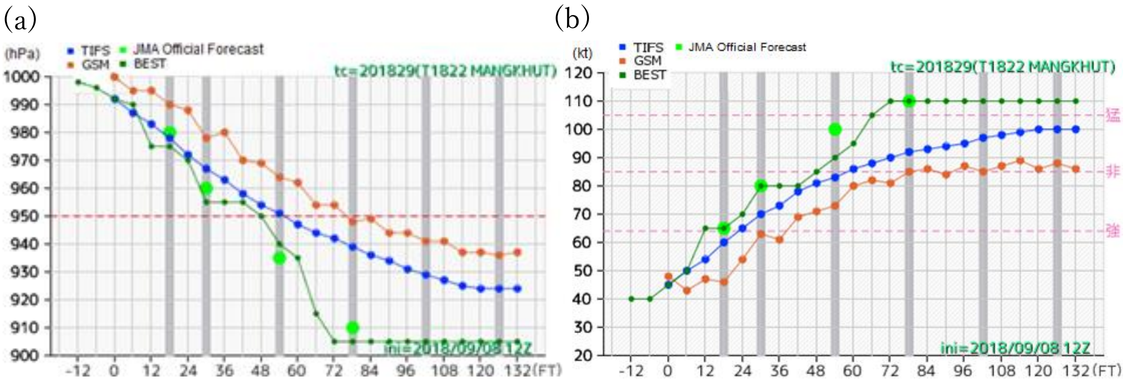


Figure 13. TIFS and GSM intensity forecast results for TY Mangkhut (1822)

(a) shows central pressure (hPa) and (b) shows maximum wind speed (kt) for an initial time of 12 UTC on 8 September 2018. Light-green dots indicate official JMA forecasts. The initial times of TIFS and GSM predictions available for official forecasts are six hours ahead.

4. Summary

JMA began using TIFS on a trial basis in 2016. Monitoring of its general behavior and characteristics under various conditions showed that resulting TC intensity forecasts were generally more accurate than those made with the GSM and SHIFOR. However, the scheme is associated with a tendency to overestimate TC intensity in the genesis stage, response is slow with extremely rapid intensification/weakening, and it is not suited to handling of re-intensification after TC transformation to extratropical low status. JMA will maintain its application of TIFS for basic TC intensity forecast data, and will continue working on verification and research toward better utilization for improved forecasting. JMA/MRI experts are currently working toward further enhancement using data on TC rainfall and structural characteristics (Shimada et al. 2018) and developing a method involving multiple TIFS models and an artificial intelligence (AI) algorithm (Shimada 2018) for improved TIFS prediction accuracy. By way of example, TIFS is currently applied to GSM TC track forecasting, so it will be effective to improve the system to enable to apply TIFS using environmental parameters (consistent with official track forecasts) as explanatory variables when differences arise between GSM and official forecast tracks. In addition, as TIFS values are significantly influenced by TC intensity changes from the initial time, greater flexibility will be preferred by enabling selection of the most suitable prediction results based on the latest TC intensity analysis values, among several predictions for various possible TC intensity that are prepared in advance.

JMA will continue its efforts to enhance the accuracy of TC intensity forecasts using TIFS as a relatively new application.

Acknowledgement

JMA is deeply grateful to Dr. Mark DeMaria (NOAA/NHC), the original developer of SHIPS, Dr. Kate Musgrave (Colorado State University (CSU)), Mr. Charles Sampson (Naval Research Laboratory), Dr. John Kaplan (NOAA/Atlantic Oceanographic and Meteorological Laboratory), and Dr. John Knaff (CSU), and all other relevant experts for their great support in operating Typhoon Intensity Forecast Scheme Based on SHIPS, or TIFS, at JMA.

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