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Progress of WMO Typhoon Landfall Forecast Demonstration Project (WMO-TLFDP)

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Executive summary

This report summarizes the progress of WMO Typhoon Landfall Forecast Demonstration Project (WMO-TLFDP). It will start with a short introduction of WMO-TLFDP, then the progress of training activity, Collection and archiving of data and forecast products, Dissemination of the forecast products will be introduced. Remaining of this report is primarily about forecast verification techniques and products, which are the main achievement of this project. We also propose some ideas for international coordination and conclude with some constructive suggestions.

1. Project introduction

The World Expo 2010 has been successfully held in Shanghai from May to October, 2010. Its related activities spread out around the Regions of Yangtze Delta and East China. To provide a better typhoon landfall forecast service for World Expo 2010, and to enhance the ability of forecasters and decision-makers to effectively use products of the most advanced typhoon forecasting techniques in the world, the "WMO Typhoon Landfall Forecast Demonstration Project (WMO-TLFDP)" was started in May 2010 as a component of the Shanghai Multi-Hazard Early Warning System (MHEWS) project.

The project completed its first phase in December 2012 and is now in its second phase (2013-2015). It is jointly supported and guided by World Weather Research Programme (WWRP), Tropical Cyclone Programme (TCP) and Public Weather Service Programme (PWS) of WMO. It works closely with the THORPEX North Western Pacific Tropical Cyclone Track Ensemble Forecast Research Project for Typhoon Committee Members.

Main tasks of the WMO-TLFDP include, a) to develop a system to collect, integrate and display real-time forecasting results for landfall typhoons, including their track, intensity, gale extent and rainstorm distributions, from various institutions; b) to develop and integrate techniques to evaluate accuracy of forecast for landfall location and time, gale distribution, and torrential rain; c) to make comprehensive analyses of the forecasts and evaluate their reliability; and d) to assess their social and economic impacts.

Through close international collaboration, the WMO-TLFDP aims to demonstrate and quantify the benefits of an end-to-end forecast system for landfalling typhoons using the latest advances in the science of tropical cyclone forecasting. The WMO-TLFDP, as a means of exchanging forecast experiences, a platform for the application of the latest typhoon forecast technology, and a bridge to connect forecast and public service, is expected to promote the implementation of the most advanced landfall typhoon forecast techniques in Typhoon Committee members which ultimately will be of benefit to other WMO Members as well.

2. Training activity

Two training workshops on tropical cyclone forecasting were held successfully in Shanghai, China in May 2010 and June 2012, respectively. Experts from a number of international institutions gave lectures covering global/regional models and their application in operational tropical cyclone forecast, basis and operational application of tropical cyclone ensemble forecast, experiences and new techniques/tools for tropical cyclone forecasting in different operational centers, forecast verification techniques and their application. More than 50 forecasters attended the workshops. STI/CMA hosted 4 visiting forecasters from DPRK, Thailand, and Viet Nam, respectively, as jointly funded by the Typhoon Committee and STI/CMA.

3. Collection and archiving of data and forecast products

A total of 13 typhoon forecast products providers (TFPPs) participate in the project by providing real-time forecast products through GTS, FTP, the intranet of CMA, or via TIGGE in collaboration with the NW Pacific Tropical Cyclone Ensemble Forecast RDP. The products include the deterministic track and intensity forecast, the ensemble track and intensity forecast, the deterministic wind radii forecast, wind probability forecast, 2-dimensional gridded wind and precipitation forecast, and 3-dimensional gridded model output. Observational data are collected through GTS and the intranet of CMA.

All the data and products of named tropical cyclones since May 2010 are archived by Shanghai Meteorological Service (SMS), which are available to research, training and capacity-building activities.

4. Dissemination of the forecast products

Products of the project are disseminated through the WMO-TLFDP website (http://tlfdp.typhoon.gov.cn) and the operational website of Shanghai Typhoon Warning Center, which is a component of Shanghai MHEWS. The forecasters can also have access to the project's products by using the interactive tool 'MICAPS TC Plug-in'. As a collaborative effort with the NW Pacific Tropical Cyclone Ensemble Forecast RDP, its website for browsing tropical cyclone ensemble forecasts (http://tparc.mri-jma.go.jp/cyclone) has been strongly recommended to the forecasters. End-user products are distributed by SMS's early-warning information dissemination platform, which is a key component of MHEWS.

5. Forecast verification techniques and products

Deterministic track forecast is verified in real time by calculating the distance error and the error in moving direction and speed. Deterministic intensity forecast is verified in real time by calculating the absolute error and relative error. The Model Evaluation Tools (MET) is adopted to perform real time verification of the precipitation forecast and other model outputs including temperature, wind, geo-potential height, and relatively humidity.

The operational status of tropical cyclone forecast verification is analyzed on the basis of an e-mail survey covering the Members of Typhoon Committee. It is concluded that significant efforts have been focused on the verification of tropical cyclone forecast guidance by operational forecast agencies in the region. However, only a few verification products are available for the probabilistic forecasts from the ensemble prediction system, and the verification of tropical cyclone precipitation and high wind forecasts are also lacking sufficient attention in the region.

Post-season verification and reliability analyses have been carried out on the track, intensity and precipitation forecast of tropical cyclones since 2010 till now. Forecasts of tropical cyclone tracks from operational forecast agencies and deterministic NWP models in 2012 and 2013 were evaluated and the results were reported to the 45th and 46th Session of Typhoon Committee, respectively. Part of the results has been published in TCRR (Chen et al., 2013, 2014).

Main results from the post-season verification for the track and intensity forecasts of 2014 are as follows.

5.1 Best track datasets

Currently, four agencies provide their own TC best track analyses for the WNP region: 1) Shanghai Typhoon Institute of China Meteorological Administration (STI/CMA, dataset can be found at http://tcdata.typhoon.gov.cn/en/index.html), 2) the Japan Meteorological Agency (JMA) Regional Specialized Meteorological Center (RSMC) in Tokyo (RSMC-Tokyo, dataset can be found at http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack.html), 3)Joint Typhoon Warning Center (JTWC, dataset can be found at http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/best_tracks/), 4)Hong Kong Observatory (HKO, dataset can be found at http://www.weather.gov.hk/publica/pubtc.htm). Table 1 provide the data period, characteristics and wind averaging time information of these four best track datasets. It should be noted that the TC position, intensity and structural information usually differ among agenciesdue to the lack of sufficient surface observations for TCs, as well as the different techniques used to estimate the position and intensity of a TC. Thus, differences in TC forecast performance may be obtained, depending on the best-track dataset used as a reference. In this report, we will choose RSMC-Tokyo, JTWC and STI/CMA best track dataset as references when verification work comes to the comparison of different results under using different reference datasets. And the remainder will use RSMC-Tokyo best track dataset as the typhoon center in RSMC-Tokyo is the regional center that carries out specialized activities in analysis and forecasting of WNP TCs within the framework of the World Weather Watch (WWW) Program of WMO.

5.2 TC track error

TC track error is defined as the great-circle difference between a TC's forecast center position and the best track position at the verification time. TC track errors typically are presented as mean errors for a large sample of TCs. Table. 4 provide track error which used RSMC-Tokyo, JTWC and STI/CMA best track data as the reference for each subjective methods, global models and regional models forecast guidance listed in Table. 2 One obvious characteristic demonstrated in Table.4 is the distinct difference in the variability of the TC track error with using different best track dataset. Fig. 1 demonstrate this divergence visually by bar plots and radar plots.

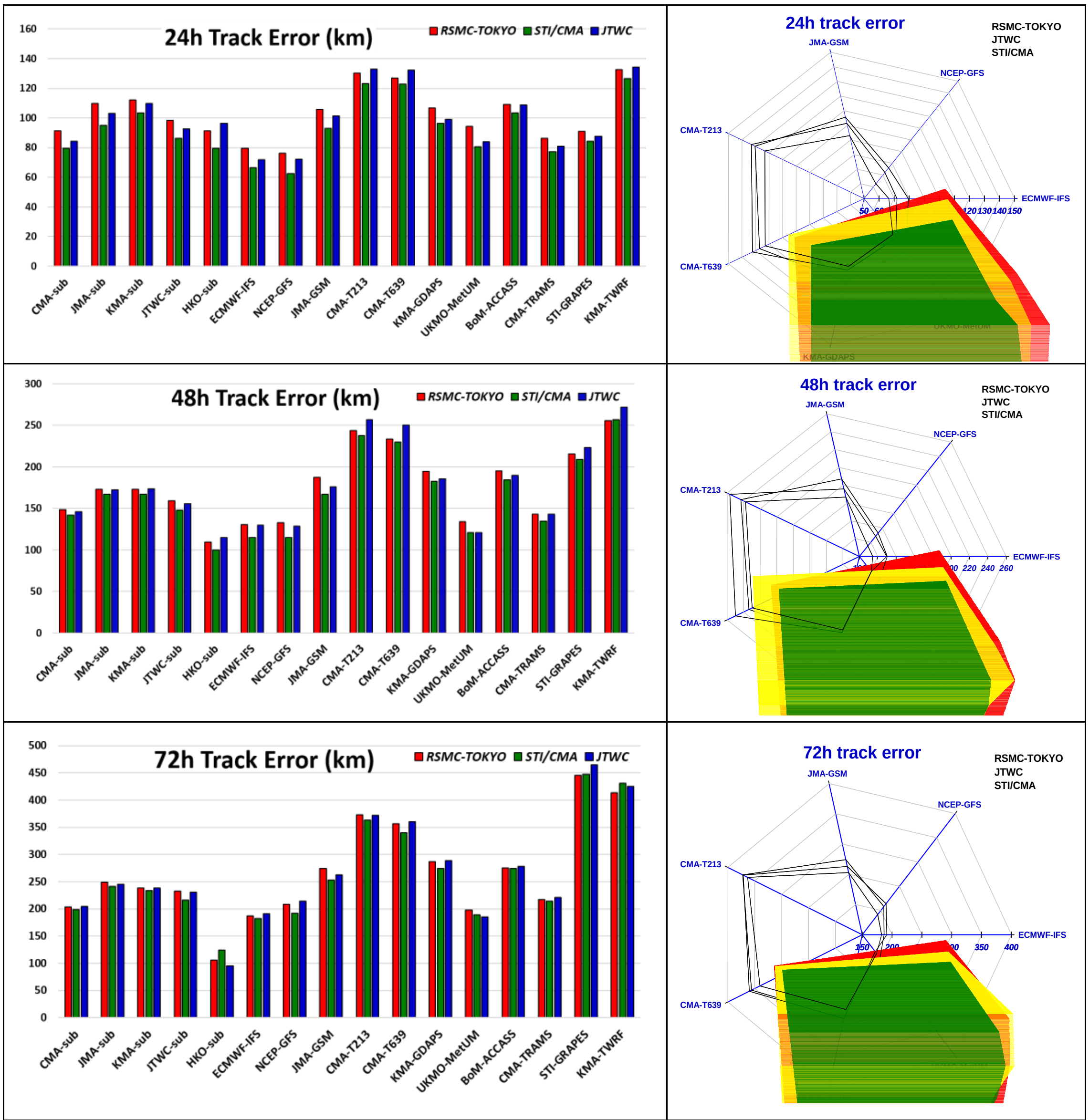
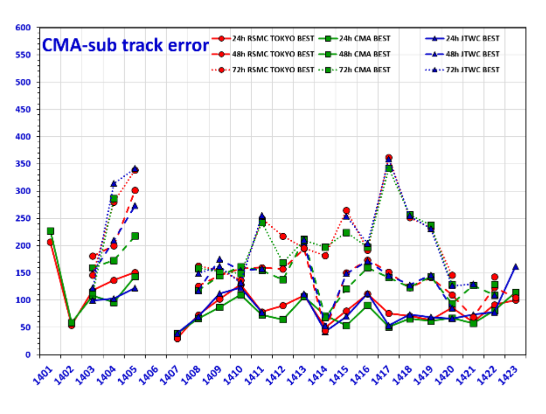
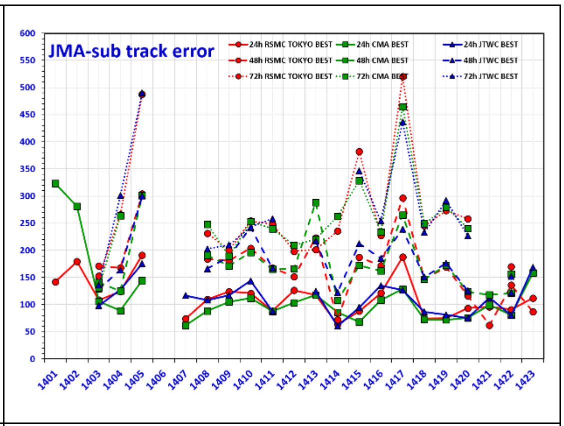


Fig.1 Bar plots (left) and radar plots (right) for track error at 24, 48 and 72h lead time levels. Different color represent using different best track dataset as a reference.

Fig.2 show the detail track error information by referring to RSMC-Tokyo, STI/CMA and JTWC best track dataset for each TC (from No.1401 to 1423). It is clear that the divergence is small for most TCs, especially for TC No. 1402, 1408, 1411, 1413 and 1418. A substantial amount of the TCs' track error there were also large differences. One thing should be noted that the impact of the small sample size must be taken into account in interpreting the results, like TC No.1405.





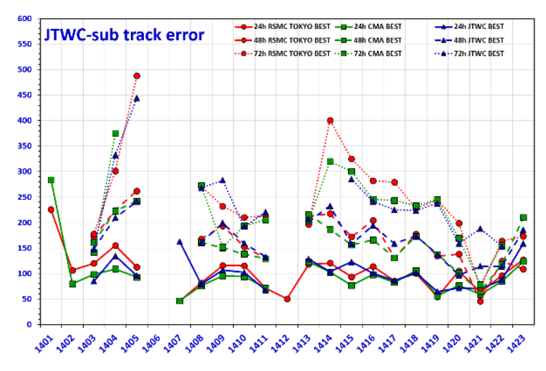
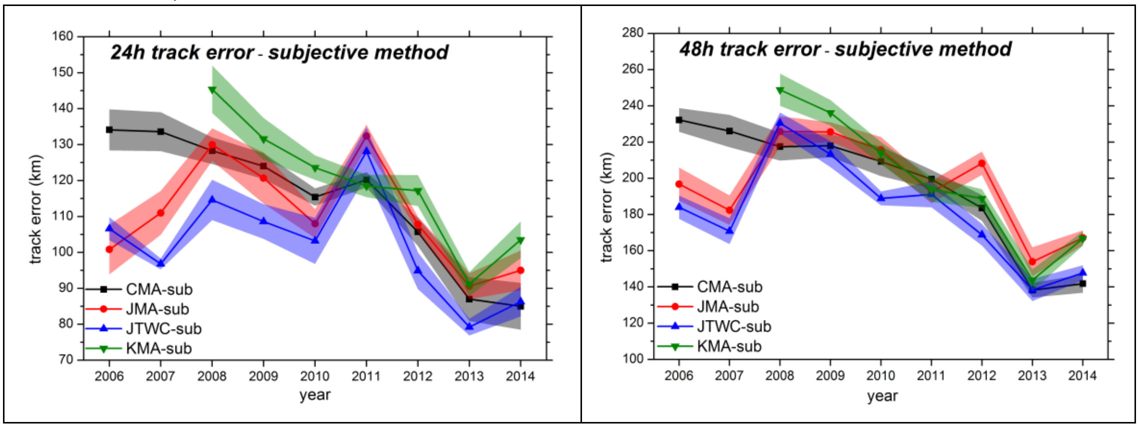


Fig.2 CMA (up-left), JMA (up-right) and JTWC (bottom-left) subjective methods' track error by referring to RSMC-Tokyo (red), STI/CMA (green) and JTWC (blue) best track dataset for TC No.1401 – 1423.

Considering the verification results may vary by referring different best track datasets, we re-calculated the mean errorsfrom 2006 to 2014 by referring RSMC-Tokyo, STI/CMA and JTWC best track datasets respectively. Fig.3 and Fig.4 show the trends of track error interval for subjective methods and global models at the lead time levels of 24, 48 and 72h. Encouragingly, Fig.3 and Fig.4 demonstrate that remarkable progress has been made in the past years. Track error at 72h almost reduced about 100km from 2008to 2014 for subjective method.



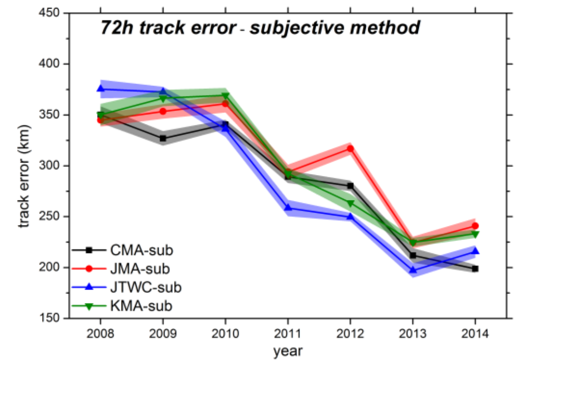
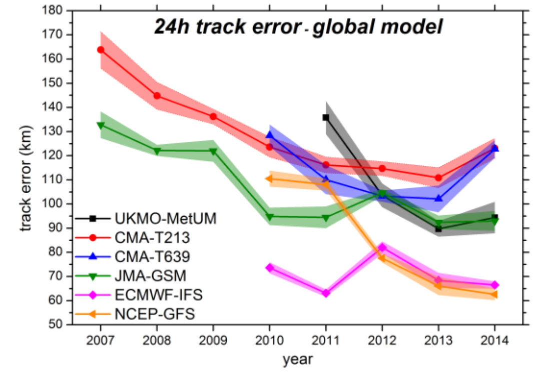
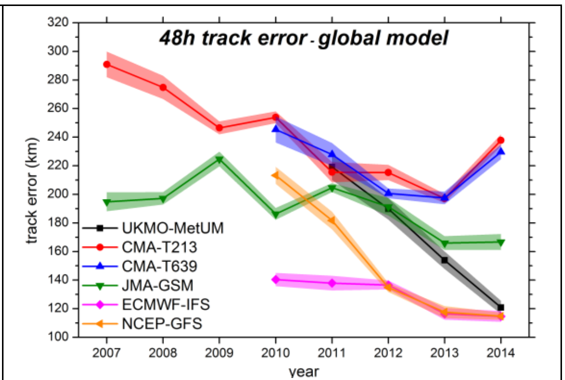


Fig.3 Trends of track error interval for subjective methods at the lead time of 24h (up-left), 48h (up-right) and 72h (bottom-left) from 2006 to 2014. Track error interval was calculated by using different track datasets, upper and lower boundary means max and min annual average error, solid line indicate mean error.





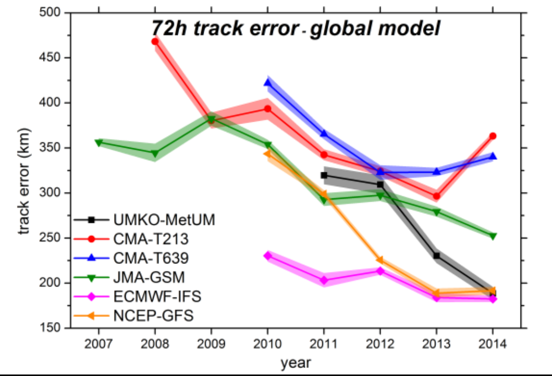


Fig.4 The same as Fig.3 but for global models.

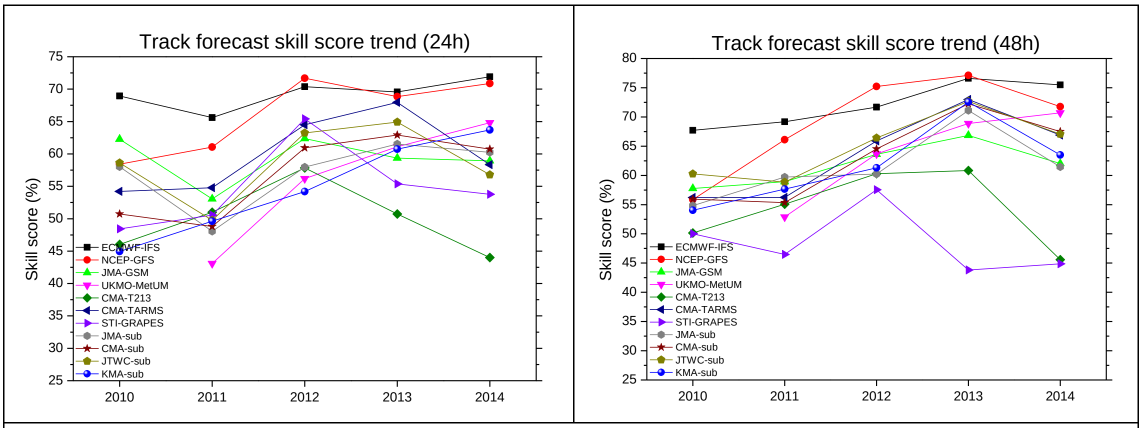
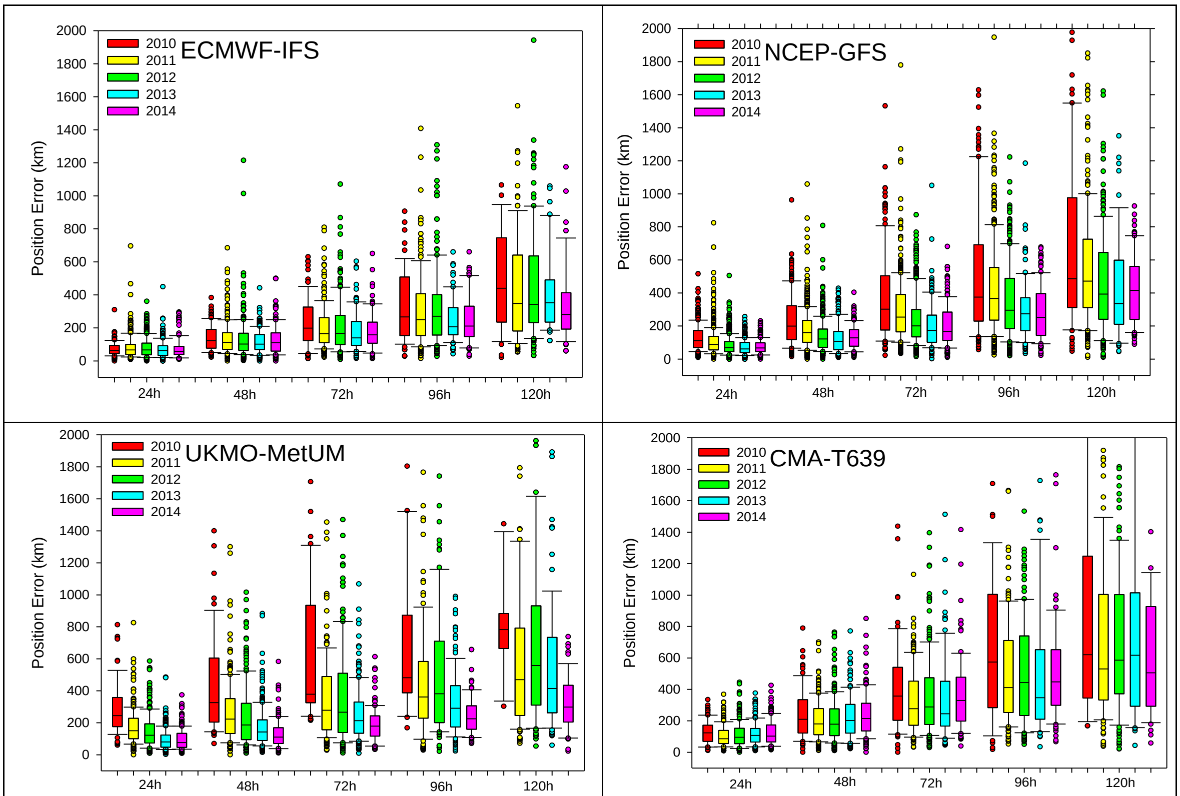
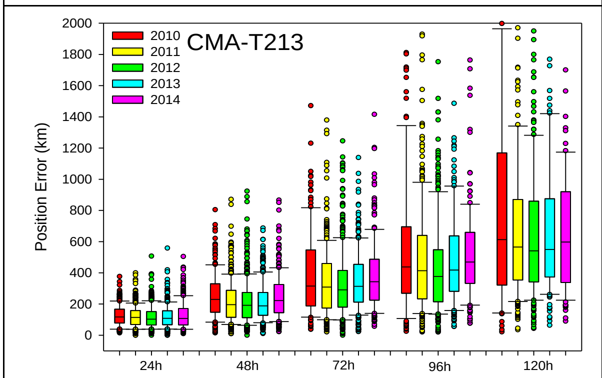


Fig.5 Track forecast skill score trend (referring to RSMC-Tokyo best track dataset) at 24h (left) and 48h (right) for subjective methods, global models and regional models.

An alternative approach to examining the average errors is to consider the distributions of errors. In Fig.6, box plots are used to summarize the annual distributions of errors in forecasts from 2010 to 2014 for each global model. One characteristic demonstrated in Fig.6 is the increase in the variability of the errors with increasing lead time. Another obvious characteristic is the stepped decreases in the values of each quantile were made at every lead time level form 2010 to 2014, especially for ECMWF-IFS, NCEP-GFS and UKMO-MetUM models.





Box plots show specific quantiles and other statistics used to represent a distribution. The bar in the middle of the plot represents the median, the lower and upper ends of the boxes represent the 0.25th and 0.75th quantile values. The bars below and above the box represent the non-outlier extreme values, and the specific circles represent the outliers.

Fig.6 Box plots for representing the distributions of track errors for TC forecast from 2010 to 2014 (referring to RSMC-Tokyo best track dataset).

A new approach called the Track Forecast Integral Deviation (TFID) integrates the track error over an entire forecast period (Yu et al., 2013). TFID is based on the mathematical consideration that a good forecast has small distance to the observed track not only at zero-order but also at higher-orders. Fig.7 show the annual distribution of TFID for ECMWF-IFS, NCEP-GFS, UKMO-MetUM, CMA-T213 and CMA-T639 from 2010 to 2014.

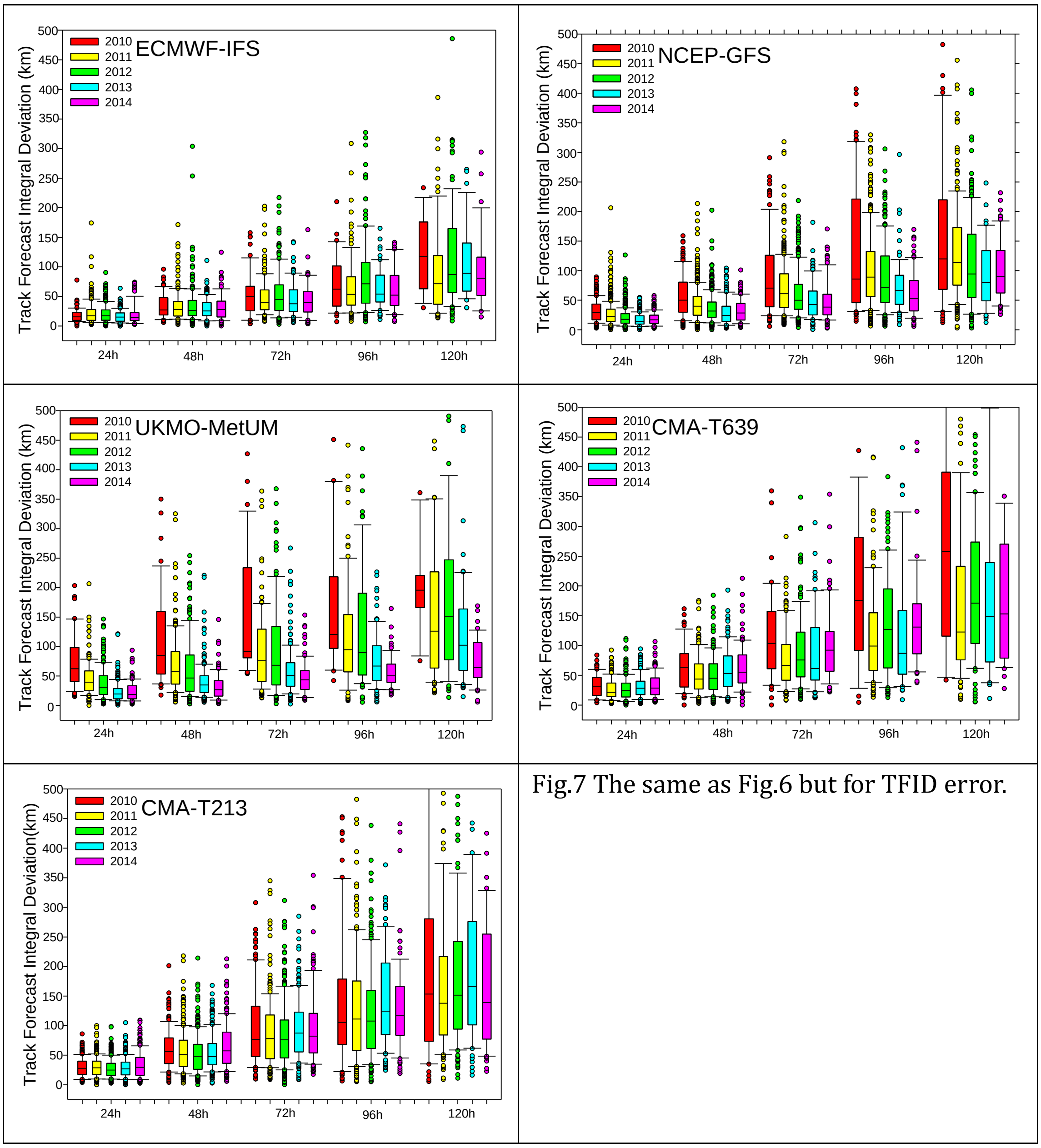


Fig.7 The same as Fig.6 but for TFID error.

Fig.8 is the polar scatter plots which depicting the combined direction and magnitude errors around the actual storm location for each method at different lead time levels in 2014. In general, Fig.8 show that the forecast locations of most methods (not only for objective but also for subjective methods) focused in a zone which extended from northeast to southwest. However, the chief disadvantage of Fig.8 is that it can't show the systematic bias clearly.

If we calculate the average position of the forecast location at each lead time levels, the systematic bias of track forecast of each method will be showed clearly. Fig.9 display this kind of systematic bias. In Fig.9, numbers with different colors denote annual average locations which relative to actual storm locations. Plots like those in Fig.9 provide information that is useful for pre-estimate the bias of a certain method.

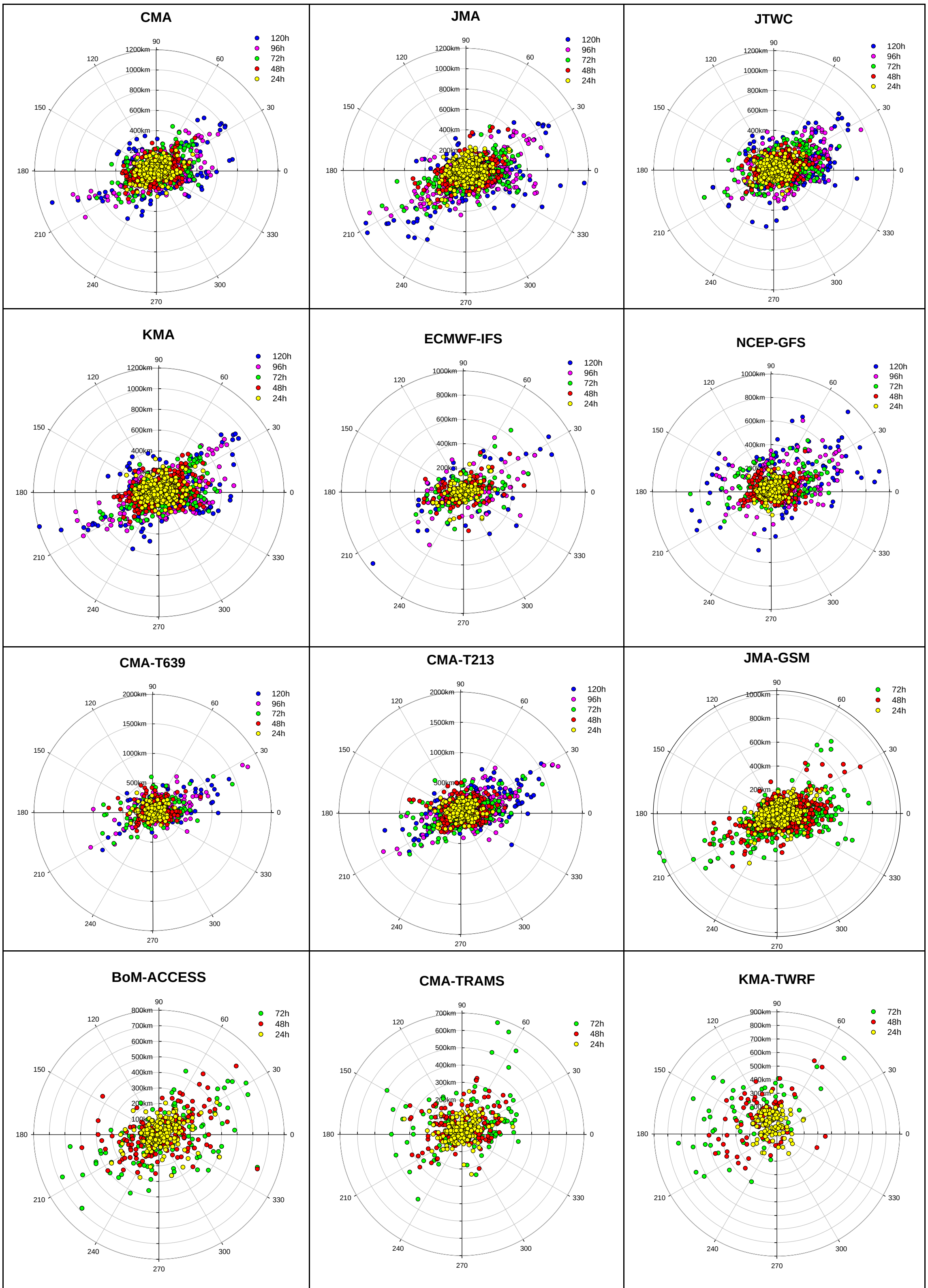
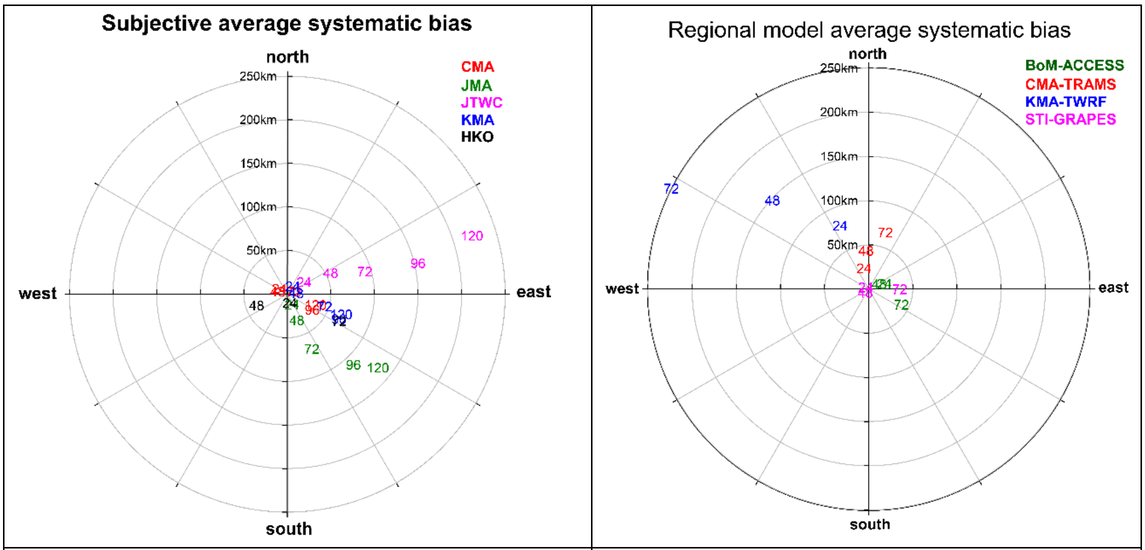


Fig.8 Polar scatter plots depicting the combined direction and magnitude errors (referring to RSMC-Tokyo best track dataset) around the actual storm location for each method at different lead time levels in 2014.



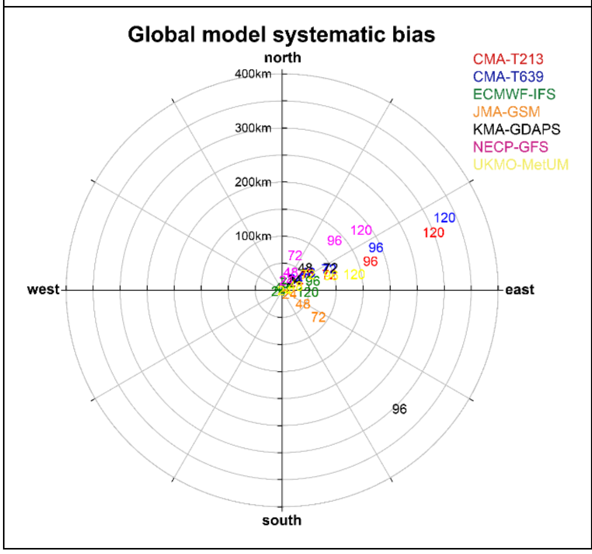
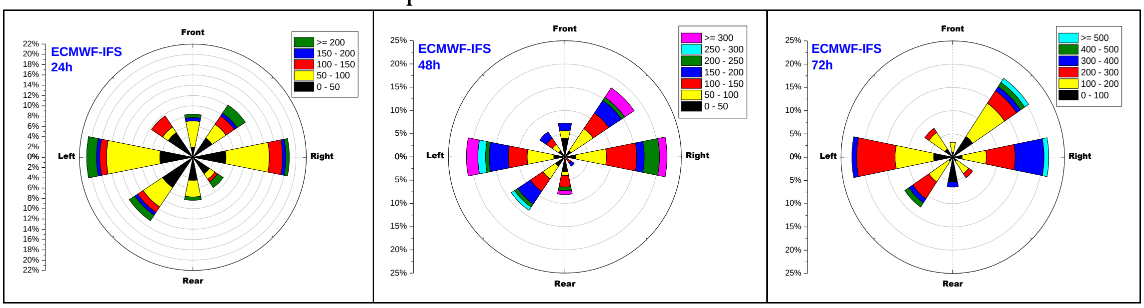


Fig.9 Polar scatter plots depicting the **average** combined direction and magnitude errors (referring to RSMC-Tokyo best track dataset) around the actual storm location for each method at different lead time levels in 2014.

Another useful tool to evaluating the systematic bias is named "Track Error Rose (TER)" (Chen et al, 2014), TER use the same conception of "wind-rose" diagram as reference, as in Fig.10. In this example, each color bar represents different magnitude of track error, and the length of alignment of color bars represents the proportion of each azimuth angles. There are eight allied color bars in the whole circle, each of them represent 45°. TER diagram may reveal the track error distribution (both the error magnitude and percentage) at each divided azimuth angles zone.

Fig.7, Fig.8, Fig.9 and Fig.10 can be used to gain a better understanding of certain method's systematic bias, and are highly recommended as diagnostic tools for forecasters and forecast developers.



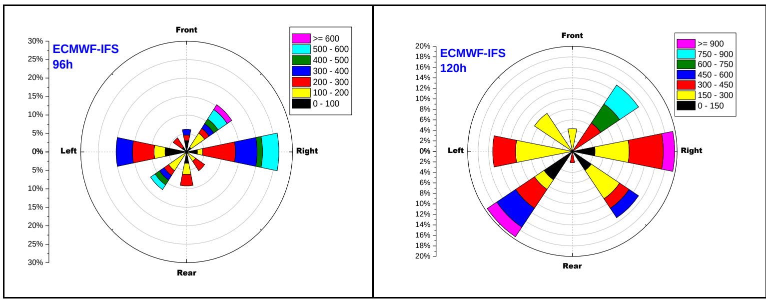


Fig.10 Examples of track error-rose diagram to represent the direction and magnitude distributions of track errors (referring to RSMC-Tokyo best track dataset).

5.3 Intensity error

TC intensity forecasts (i.e., maximum wind speed and minimum pressure) are typically evaluated as continuous parameters, using standard verification measures such as the Mean Absolute Error (MAE) or Mean Error (ME). MAE provides an indication of the average magnitude of the error, whereas ME measures the bias in the forecasts. Fig.11 show the MAE of maximum wind speed forecasts for each methods at 24 and 48h lead time levels in 2014. It is the same as track error that we used RSMC-Tokyo, STI/CMA and JTWC best track as reference, respectively. One thing should be remember that the wind speed of both forecast and best track were converted to 2-min average according to the WMO documentation[1].

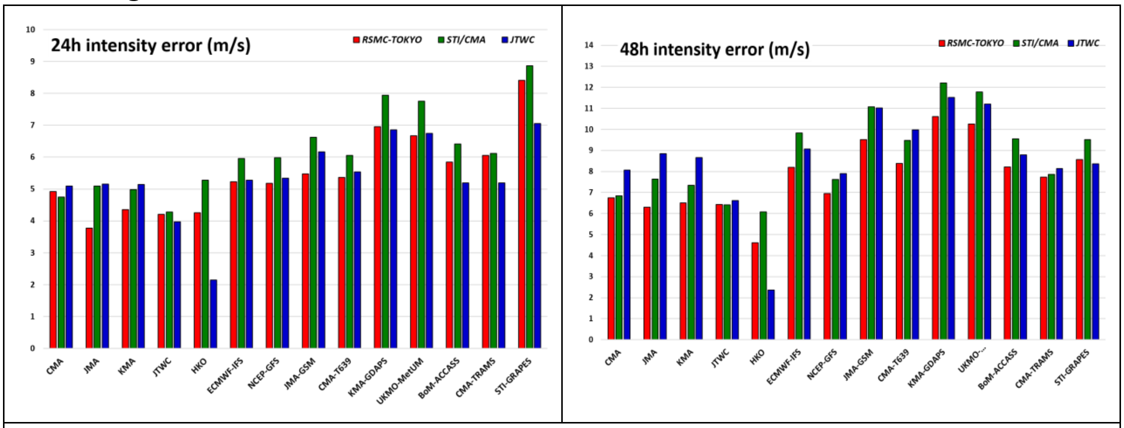


Fig.11 Bar plots for intensity error at 24 and 48h lead time levels. Different color represent using different best track dataset as a reference.

Fig.12 show the intensity error interval of subjective methods from 2006 to 2014 referring to RSMC-Tokyo, STI/CMA and JTWC, respectively. One obvious characteristic demonstrated in Fig.12 is the progress of intensity forecast performance was infinitesimal during last eight years. This characteristic is also revealed by time series plot of intensity skill score (Fig.13). Another characteristic indicated by Fig.4 is the sharp division on intensity between the different best track datasets.

[1]WMO, Guidelines for converting between various wind averaging periods in tropical cyclone conditions.

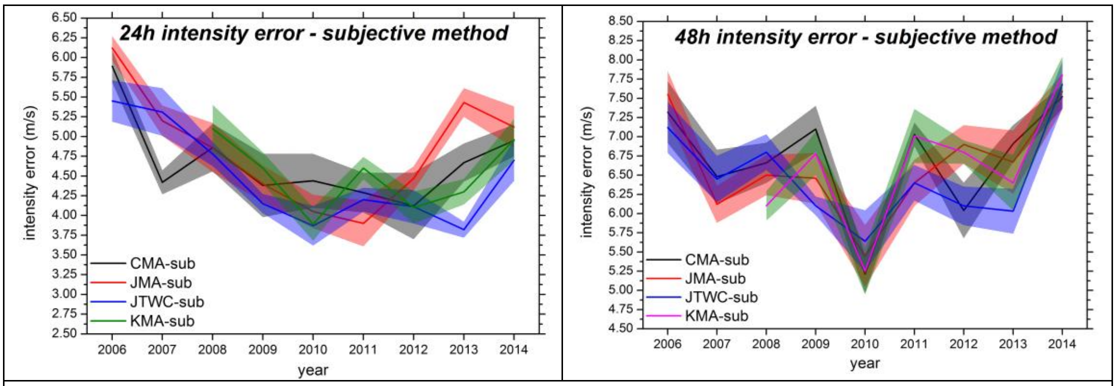


Fig.12 The same as Fig.3 but for global models' intensity error.

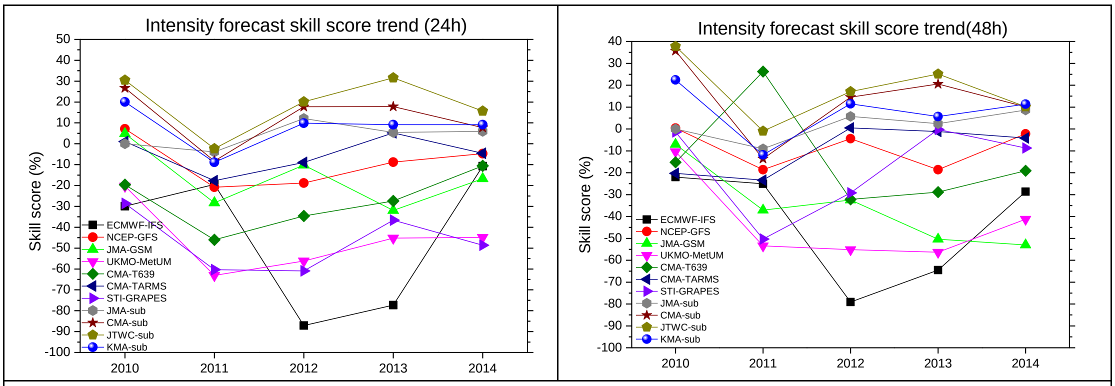


Fig.13 The same as Fig.6 but for intensity error (referring to RSMC-Tokyo best track dataset).

Some new TC intensity verification mentality have been on trial for the past year in STI. Plots like those in Fig.14 is called Taylor diagram (Taylor, 2001). Taylor diagram is introduced in the verification of TC intensity forecast to analyze the internal relationship between the standardized deviation, correlation coefficient together with center different root-mean-square. The best prediction always with highest correlation coefficient compared to "OBS", and with standardized deviation and center different root-mean-square closed to "1". According to Fig.13 the RMS error of both minimum surface pressure and maximum wind speed were smallest at 0h for JMA. This make sense that the result was take RSMC-Tokyo beat track dataset as reference.

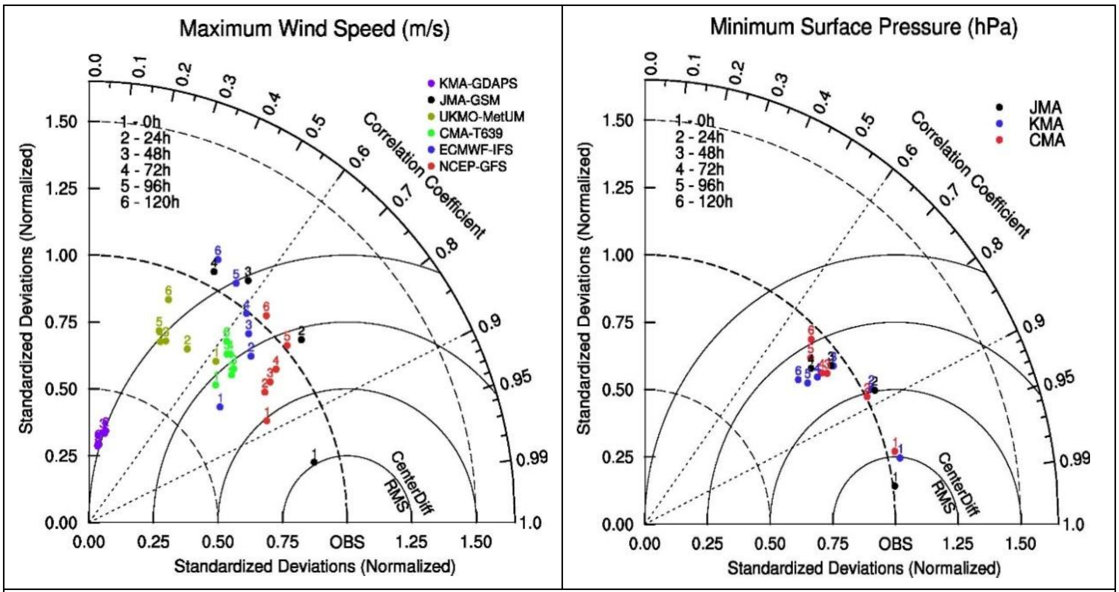
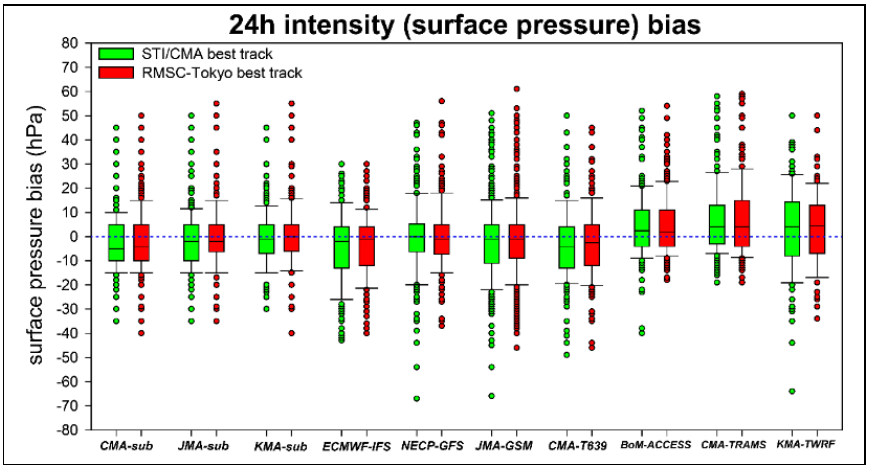


Fig.14 Taylor-diagram to evaluate TC intensity forecast(referring to RSMC-Tokyo best track dataset).

More information can be obtained by examining the distributions of intensity bias rather than focusing only on MAE.Fig.15 are box plots to represent the distributions of intensity errors for each method by referring RSMC-Tokyo and STI/CMA best track datasets. It is clearly show that the intensity predictions of CMA-sub, JMA-sub, ECMWF-IFS, and CMA-T639 commonly stronger than the observations. On the contrary, three regional models' predictions (BoM-ACCESS, CMA-TRAMS, and KMA-TWRF) are always weaker than the observations.



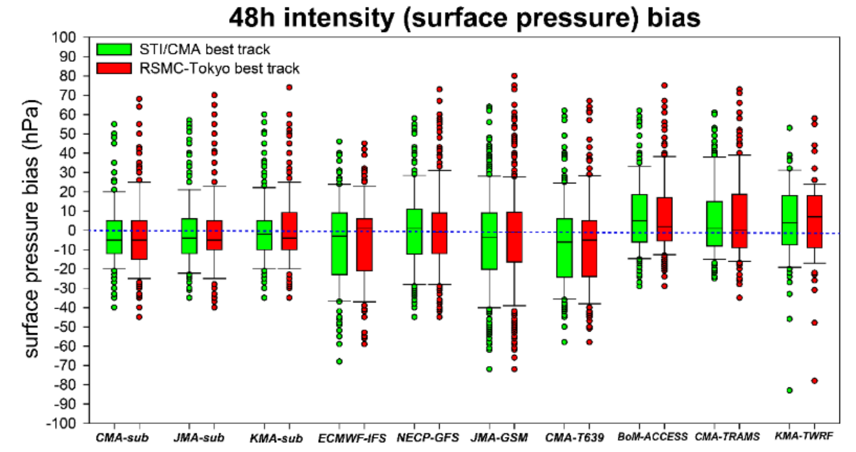


Fig.15 Box plots to represent the distributions of intensity errors for each method by referring RSMC-Tokyo (red) and STI/CMA (green) best track datasets in 2014.

The ensemble forecasts of TC intensity from the TIGGE ensemble prediction systems as listed in Table.3 have been evaluated using history ranking analyses, Brier Score (BS), and Ranked Probability Score (RPS) since 2013. According to the history ranking analyses (Fig. 16), it is obvious that all the ensemble systems have the problem of having too weak initial tropical cyclones. A simple initial correction can improve the situation notably. By initial correction, all the forecast intensity is modified with the difference between the observed initial intensity and the initial intensity of the model.

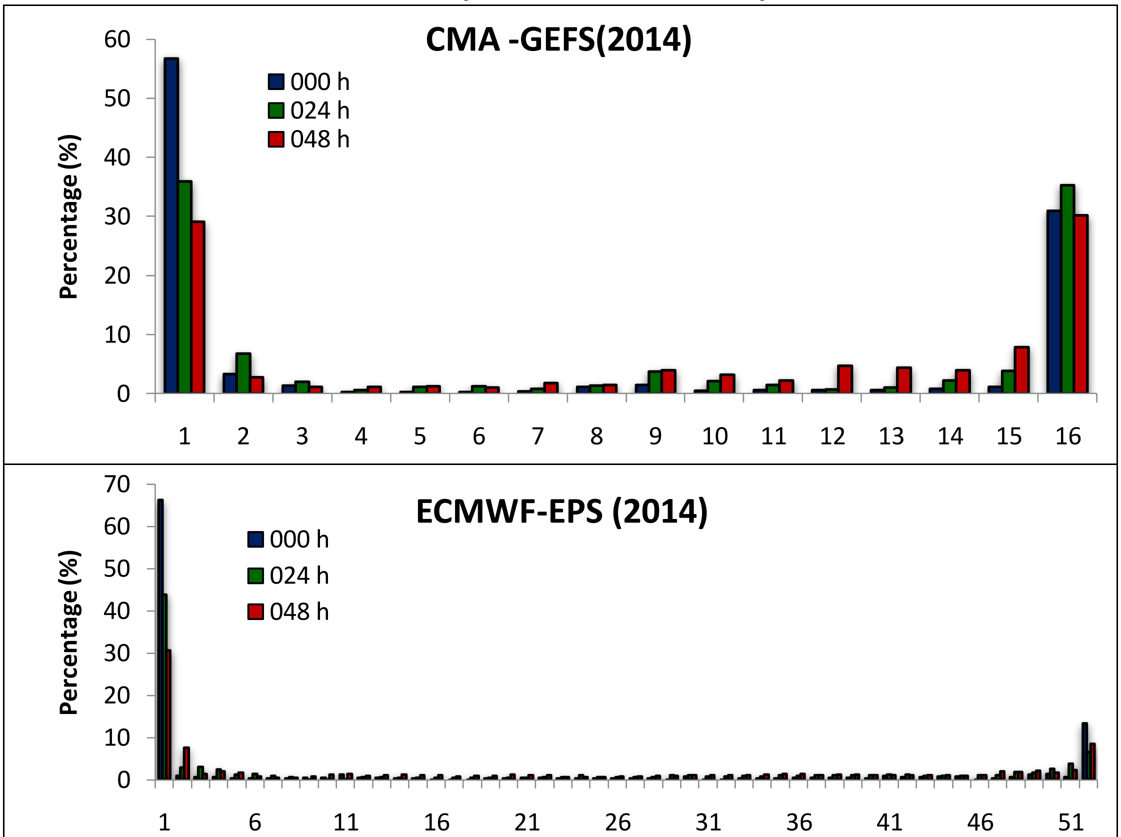


Fig.16 History ranking analyses for CMA-GEFS and ECMWF-EPS. Abscissa is the number of ensemble members. Ordinate is the percentage.

As indicated by the BS (Fig. 17), the ensemble system of UKMO-EPS outperforms other systems significantly. The positive contribution of initial correction degrades quickly from 6h to 30h for seven of the eight systems. The effect of initial correction is in-significant or even negative for some systems after 30 h. The ranked probability scores tell us similar information.

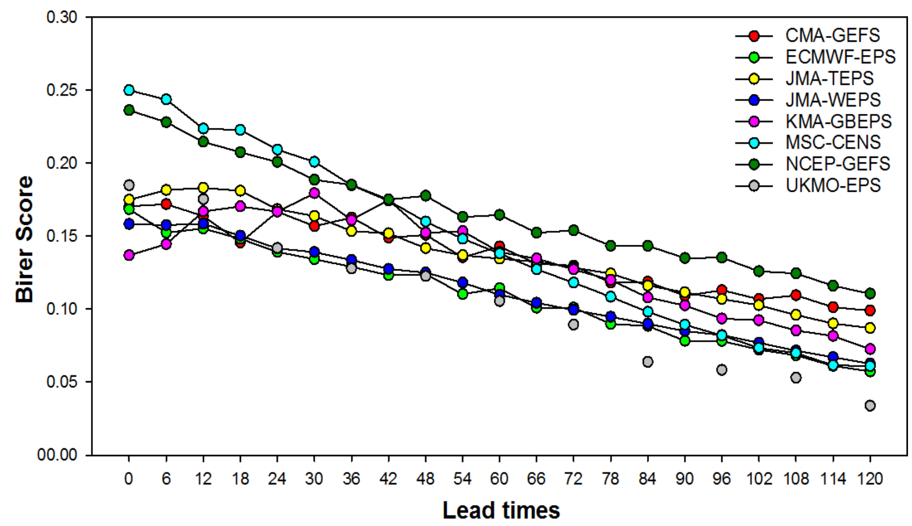


Fig.17 Brier Score for EPS intensity forecast in 2014.

6. Future works of the project

Verification of tropical cyclone track and intensity is important for improving the NWP and statistical guidance, and further underpinning the subjective method. This report firstly has briefly introduced the progress of WMO-TLFDP, meanwhile showed some verification examples and new trials for forecasts of TC track and intensity. We will continue to promote this project and plan to concentrate on developing and improving methodologies for verifying forecast of TC genesis, warnings for landfill timing and location, cone of uncertainty and strike probability.

Some suggestions will be offered here for coordination of TC verification to encourage consistent and facilitate forecast method inter-comparisons.

1. Suggest to establish a SOP for evaluating regional typhoon forecast routinely, fit it into SSOP-II.
2. Continue to promote verification practices and methodologies.
    a) To encourage and facilitate sharing of relevant observational data for verification TC forecasts among Typhoon Committee Members.
    b) To establish the relevant international standardization to reduce the divisions of best track datasets.
    c) Sharing of the verification techniques, products, and tools should be further encouraged across the TC members to promote the operational capability in a general sense.
    d) To continue the data collection and evaluation efforts on available objective TC forecast guidance, including NWP, EPS, statistical and consensus products and report the results annually.

e) To further develop the project's website through including more real-time fo recast and verification products, such as TC genesis forecast products.

3. To work closely with the on-going "The Experiment on Typhoon Intensity Change in Coastal Area (EXOTICA)". Suggest to fit WMO-TLFDP into EXOTICA and extend WMO-TLFDP until 2018.

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Table list

Table 1. Descriptions of Western North Pacific best-track datasets. (Adapted from Lee et al. 2012)

Agency	Period	Characteristics	Wind
RSMC Tokyo	1951 to present	Includes extratropical cyclone stage, longitude, latitude, MCP and TS markers since 1951; MSW and typical severe wind radii since 1977 (without TD cases).	10 min
CMA	1949 to present	Includes sub-centers, some double eyewall cases/coastal severe wind of landfalling TCs (until 2004); includes TD cases; extratropical cyclone stage; longitude, latitude, MSW and MCP since 1949.	2 min
HKO	1961 to present	Includes TD cases; longitude, latitude, MSW and MCP since 1961 (extratropical cyclone stages are not marked).	10 min
JTWC	1945 to present	Includes TD cases; extratropical cyclone stage since 2000; longitude, latitude, and MSW since 1945; MCP and TC size parameters since 2001.	1 min

Table 2. Details of deterministic forecast guidance

Category	**Abbreviation**	**Full name or short description**	**Source**
Subjective method (5)	CMA-sub	China Meteorological Administration	CMA
	JMA-sub	Japan Meteorological Agency	JMA
	JTWC-sub	Joint Typhoon Warning Center	JTWC
	KMA-sub	Korea Meteorological Administration	KMA
	HKO-sub	Hong Kong Observatory	HKO
Global NWP model (7)	CMA-T213	Global spectral TC model of CMA at a resolution of T213	CMA
	CMA-T639	Global spectral model of CMA at a resolution of T639L60	CMA
	ECMWF-IFS	Integrated Forecasting System of ECMWF	ECMWF
	KMA-GDAPS	Global Data Assimilation and Prediction System of KMA	KMA
	JMA-GSM	Global Spectral Model of JMA	JMA
	NCEP-GFS	Global Forecast System of NCEP	NCEP
	UKMO-MetUM	Unified Model system of UKMO	UKMO
Regional NWP model (4)	BoM-ACCESS	Tropical cyclone model in the Australian Community Climate and Earth-System Simulator Numerical Weather Prediction systems	BOM
	STI-GRAPES	Regional TC-forecasting model based on the Global/Regional	STI/CMA
	CMA-TRAMS	Tropical model based on GRAPES	ITMM/CMA

KMA-TWRF	Regional TC-forecasting model based on WRF with GFDL typebogussing	NTC/KMA

Table 3. Details of ensemble forecast guidance

Model name	**CMA-GEFS**	**ECMWF-EPS**	**JMA-TEPS**	**JMA-WEPS**	**KMA-GBEPS**	**MSC-CENS**	**NCEP-GEFS**	**UKMO-EPS**
Resolution	T213L31	TL639 (0-10d)	TL319L60	TL319L60	T213L40	0.9°	T126L28	
Data resolution	0.5625°	\	0.5625°	0.5625°	0.5625°	1°	1°	
Members	15	51	11	51	24	21	21	24
Perturbation method	BGM	Singular Vector	SVD	SVD	Bred Vector	Ensemble Kalman	Ensemble Transfor	
Forecast time	00:00 12:00	00:00 12:00	00:00 12:00	12:00	00:00 12:00	00:00 12:00	00:00 06:00 12:00 18:00	00:00 12:00
Interval (h)	6	12	6	6	6	6	6	12
Forecast hour(h)	120	120	132	216	120	240	240	

Table 4. Average track error for each method by referring different best track datasets in 2014 (Unit: km)

Lead times	24h			48h			72h			96h			120h		
Method / Best track	RSMC-Tokyo	STI/CMA	JTWC	RSMC-Tokyo	STI/CMA	JTWC	RSMC-Tokyo	STI/CMA	JTWC	RSMC-Tokyo	STI/CMA	JTWC	RSMC-Tokyo	STI/CMA	JTWC
CMA-sub	91.2	79.5	84.3	148.5	141.8	146.3	203.1	198.8	204.2	271.2	261.1	273.6	357.3	345.3	384.9
JMA-sub	109.7	95	103.2	172.9	167.1	172.3	248.7	240.9	244.6	353.7	344.2	333.1	467.8	460.1	395.4
KMA-sub	112.1	103.5	109.9	173.2	166.7	173.3	237.8	233.3	238.7	316.4	315.8	310.4	403.6	396.9	362
JTWC-sub	98.4	86.3	92.5	159.3	147.8	155.4	232.3	215.7	231	302.9	298.5	309.8	411	404.2	414.9
HKO-sub	91.4	79.6	96.5	109.4	99.8	115.1	105.5	124	94.9	\	\	\	\	\	\
ECMWF-IFS	79.4	66.5	71.9	130.4	114.6	129.8	186.6	182.5	191.3	250.9	255.6	273.7	350.1	368.3	375
NCEP-GFS	76.2	62.6	72.2	132.7	114.8	128.4	208.1	191.6	214	287.1	262.4	300.3	429.6	390.1	447.8
JMA-GSM	105.6	93	101.4	187.1	166.7	175.8	274.2	252.8	262.9	\	\	\	\	\	\
CMA-T213	130.3	123.1	133	243.4	237.8	256.7	372.4	363.2	371.4	487.9	470.6	479	627	598	620.4
CMA-T639	127	122.8	132.2	233.6	229.7	249.9	356	340.2	360.1	474.6	451.4	475.1	603.4	563.7	592.4
KMA-GDAPS	106.6	96.4	99	194.6	182.4	185.5	286.7	273.8	288.7	542	577.4	540.7	899.6	922.6	920.3
UKMO-MetUM	94.4	80.7	83.8	134.1	120.9	121.1	197.7	188.7	185	259.8	251.9	262.6	335.4	340.5	352.5
BoM-ACCASS	109.2	103.4	108.9	195.1	184.5	189.5	275.4	273.9	278.1	\	\	\	\	\	\
CMA-TRAMS	86.2	77.3	80.8	143.3	134.8	143.1	216.9	214.2	221.2	\	\	\	\	\	\
STI-GRAPES	90.9	84.3	87.6	215.3	208.8	223.4	445.7	447.4	465.2	\	\	\	\	\	\
KMA-TWRF	132.5	126.6	134.3	255.8	256.5	271.8	413.5	431.3	424.9	628.4	658.2	645.7	812.7	801.4	812.6

Table 5. Average absolute intensity error for each method by referring different best track datasets in 2014 (Unit: m/s)

	24h			48h		
	RSMC-Tok	**STI/CMA**	**JTWC**	**RSMC-Tok**	**STI/CMA**	**JTWC**
CMA-sub	4.92	4.75	5.08	6.74	6.84	8.06
JMA-sub	3.77	5.09	5.15	6.3	7.64	8.84
KMA-sub	4.36	4.98	5.13	6.5	7.35	8.65
JTWC-sub	4.2	4.28	3.97	6.43	6.42	6.62
HKO-sub	4.26	5.28	2.14	4.62	6.08	2.36
ECMWF-IFS	5.23	5.95	5.27	8.2	9.84	9.07
NCEP-GFS	5.18	5.98	5.33	6.96	7.62	7.90
JMA-GSM	5.47	6.62	6.16	9.51	11.08	11.01
CMA-T639	5.36	6.05	5.53	8.38	9.48	9.98
KMA-GDAPS	6.96	7.94	6.85	10.62	12.21	11.52
UKMO-MetUM	6.67	7.75	6.74	10.25	11.79	11.20
BoM-ACCASS	5.85	6.41	5.19	8.21	9.55	8.79
CMA-TRAMS	6.05	6.12	5.19	7.73	7.86	8.14
STI-GRAPES	8.41	8.86	7.04	8.57	9.51	8.37