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Research Article

Development of maximum and minimum temperature guidance with Kalman filter for 63 cities in Vietnam up to 10 days ahead

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Abstract: Development of forecast guidance is one of the main activities of Output 3 of the JICA project to improve forecasting services of VNMHA. We applied the Kalman filter (KF) technique by using a calculation package which was provided in the JICA group training course in meteorology by the Japan Meteorological Agency (JMA) to Vietnam for the development of temperature guidance. Maximum and minimum temperature guidance was developed for 63 cities up to 3 days ahead using JMA Global Spectral Model (GSM) Grid Point Value (GPV) data and up to 10 days ahead using ECMWF Integrated Forecasting System (IFS) GPV data. Verification results show that Root Mean Square Errors (RMSEs) of GSM and IFS KF guidance are relatively large in the northern region in both maximum and minimum temperatures, but KF guidance greatly reduces RMSEs of direct model outputs in all regions throughout the year. RMSEs of IFS guidance become smaller than those of GSM guidance with increasing forecast time. Averaged RMSEs of KF guidance for 63 cities are smaller than those of city forecasts issued by forecasters in Nov–Dec 2019 and Jan–Feb 2020. These verification results suggest that accuracy of maximum and minimum temperature city forecasts will be improved by using KF guidance in daily forecasting.

Keywords: Temperature guidance; Kalman filter; Grid Point Value (GPV); City forecast.

1. Introduction

The JICA Project for Strengthening Capacity in Weather Forecasting and Flood Early warning System started in April 2018 [1]. The Project has four components: Output 1 (surface observation), Output 2 (radar products), Output 3 (weather forecasting) and Output 4 (local weather dissemination). This article describes development of maximum and minimum temperature guidance for 63 major cities in Vietnam as a main activity of Output 3 to improve forecasting services of VNMHA. A forecast working group (WG3) of 5 members from VNHMA and 2 members from the Japan Meteorological Business support Center (JMBSC) was organized to achieve the purpose of Output 3. In addition, a development team of 5 members from National Center for Hydro–Meteorological Forecasting (NCHMF) for operational use of forecast guidance was set up under the WG3.

JMBSC once implemented the technical cooperation project for enhancing capacity on weather observation, forecasting and warning in the Republic of the Philippines from 2014 to 2017 [2]. Maximum temperature (T_{max}) and minimum temperature (T_{min}) KF guidance was successfully introduced to forecasting services in the Philippines through the technical cooperation project. Based on the experience of JMBSC in the Philippines, we applied the Kalman filter technique used in the projects to Vietnam. In Vietnam, the KF technique has been applied to improve surface variable forecasts from the global model (GSM) and the High Resolution regional Model (HRM, developed by German Weather Service) for period 2000–2010 [3–4].

This paper will show the application of JMA's KF guidance scheme to improve temperature forecast guidance in Vietnam. The JMA's KF guidance scheme is based on the basis of earlier works [5–6], and started KF temperature guidance in 1996. Daily maximum temperature (T_{max}) and minimum temperature (T_{min}) KF guidance was developed for 63 cities in Vietnam up to 3–days ahead using JMA GSM GPV data and up to 10 days ahead using ECMWF IFS GPV data.

2. Materials and Methods

2.1. MOS and Kalman filter

NWP model products are fundamental materials for weather forecasting, but have systematic errors caused by difference between actual and NWP model topography and caused by approximation in physical process of NWP. The guidance produced from NWP and observation data with statistical interpretation is a useful prediction to reduce errors of NWP model output. Model Output Statistics (MOS) and Kalman filter (KF) are widely used for temperature guidance in many countries.

2.1.1. MOS

MOS is a popular guidance and is really simple and easy to use. MOS is used in US, Canada etc., and JMA used MOS until 1996 for temperature guidance. Its forecast equation is the Multiple Linear Regression (MLR) given below:

$$y = a_0 + a_1x_1 + a_2x_2 + \dots , \quad (1)$$

where y is the predictand (guidance); x_i the predictors and a_i the coefficients.

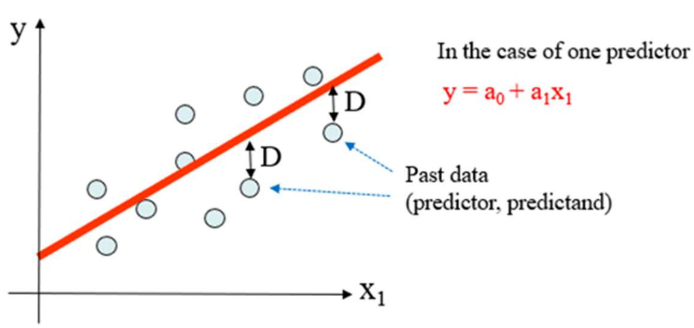


Figure 1. Image of simple Linear Regression (MOS).

Coefficients a_i are decided to minimize total errors by the least–squares method (Figure 1). Effective predictors x_i are objectively selected from potential predictors with stepwise method etc. MOS is easy to make and operate, but a large amount of data (about 2 years data) are necessary. In this JICA activity, as a preliminary survey, we calculated MLR guidance using every 2–month observation and NWP data of the latest 2–year period to evaluate performance of the MOS technique compared to the KF technique. As the result, KF guidance was better than MOS guidance in many cases. So, we decided to investigate the performance of KF guidance only in the following experiments.

2.1.2. Kalman filter

The Kalman filter is used for the same purpose as MOS to reduce systematic errors of NWP output. MOS's forecast equation uses fixed coefficients calculated with past NWP and observation data, while the KF forecast equation uses coefficients updated successively depending on deference between guidance and observation. The KF forecast equation is given below:

$$f(x)^{(t)} = a_0^{(t)} + a_1^{(t)}x_1 + a_2^{(t)}x_2 + \dots , \quad (2)$$

where *f(x)* is predictand (guidance), x_i the predictors, a_i the coefficients, and *t* means the time. Forecast equations of MOS and KF are similar, but the particular difference is that the coefficients of KF are updated successively to reduce the error:

$$\text{error} = \text{observation } (y^{(t)}) - \text{guidance } (f(x)^{(t)}) \quad (3)$$

The coefficients are updated to reduce the error:

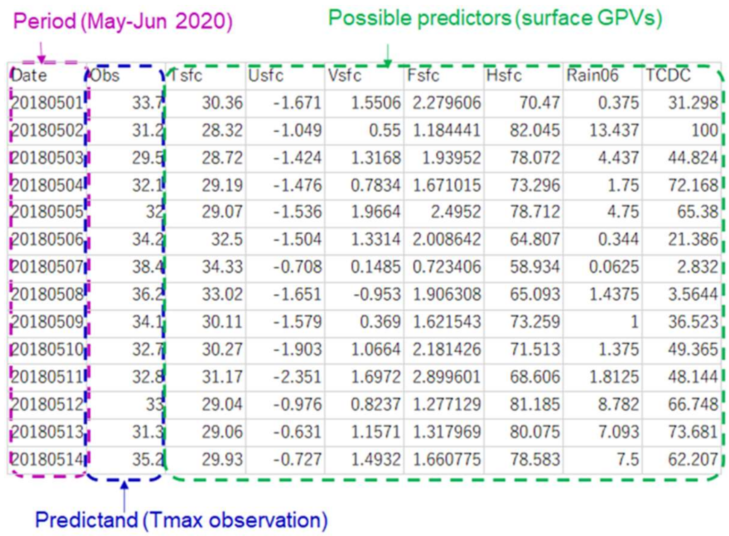
$$a_i^{(t+1)} = a_i^{(t)} + K_i^{(t)} * \text{error} \quad (4)$$

where $K_i^{(t)}$ is called "Kalman gain" which is estimated based on Bayes' theorem. This study used the calculation package developed by JMA to calculate the Kalman gain ($K_i^{(t)}$) and update coefficients ($a_i^{(t)}$) of the KF equation. In the calculation, constant measurement error variance (4: about RMSE*RMSE of guidance) and constant covariance matrix of process noise (diagonal components: 0.01 for constant, 0.0001 for each predictor component, others: 0) are used. JMA's KF guidance is described in Outline of the Operational Numerical Weather Prediction at JMA [7]. At first, one predictor of model surface temperature (2 m temperature) was chosen to develop KF guidance for maximum and minimum temperatures.

2.2. NWP GPV and T_{max}/T_{min} observation data set

For executing successive KF updating cycle, the latest NWP GPV data and T_{max}/T_{min} observation data are necessary. As a first step of the guidance development, we decided to use JMA High–Resolution GSM Data Service for NMSs and started downloading GSM surface GPV data of 00 UTC initial (https://www.wis–jma.go.jp/cms/gsm/download.html). They are 0.25x0.25–degree grid point data of 3–hourly up to 84 hours, and available at around 11 a.m. in local time in Vietnam.

As for observation data, National Center for Hydro–Meteorological Forecasting (NCHMF) prepares Excel data set of 186 stations (186smMMyYY.xls) every day including T_{max}, T_{min}, precipitation and wind observations. These NWP GPV and observation data are used for KF updating cycle. A sample of GSM GPV and observation data set for Hanoi Day1 in May–Jun 2018 is shown in Figure 2.



Date	Obs	Tsfc	Usfc	Vsfc	Fsfc	Hsfc	Rain06	TCDC
20180501	33.7	30.36	-1.671	1.5506	2.279606	70.47	0.375	31.298
20180502	31.2	28.32	-1.049	0.55	1.184441	82.045	13.437	100
20180503	29.5	28.72	-1.424	1.3168	1.93952	78.072	4.437	44.824
20180504	32.1	29.19	-1.476	0.7834	1.671015	73.296	1.75	72.168
20180505	32	29.07	-1.536	1.9664	2.4952	78.712	4.75	65.38
20180506	34.2	32.5	-1.504	1.3314	2.008642	64.807	0.344	21.386
20180507	38.4	34.33	-0.708	0.1485	0.723406	58.934	0.0625	2.832
20180508	36.2	33.02	-1.651	-0.953	1.906308	65.093	1.4375	3.5644
20180509	34.1	30.11	-1.579	0.369	1.621543	73.259	1	36.523
20180510	32.7	30.27	-1.903	1.0664	2.181426	71.513	1.375	49.365
20180511	32.8	31.17	-2.351	1.6972	2.899601	68.606	1.8125	48.144
20180512	33	29.04	-0.976	0.8237	1.277129	81.185	8.782	66.748
20180513	31.3	29.06	-0.631	1.1571	1.317969	80.075	7.093	73.681
20180514	35.2	29.93	-0.727	1.4932	1.660775	78.583	7.5	62.207

Figure 2. GSM GPV and T_{max} observation data set for Hanoi Day1 T_{max} May–Jun 2018. Surface GPVs (Tsfc: temperature, Usfc: wind u–component, Vsfc wind v–component, Fsfc: wind speed, Hsfc: humidity, Rain06: 6–hour rainfall, TCDC: total cloud amount).

Two–monthly Obs–GPV data set like Figure 2 was prepared for 63 cities, for Day1, Day2 and Day3 from Jan–Feb to Nov–Dec in 2018. Statistical interpretation was made with past 2–month Obs–GPV data set and we applied the obtained forecast equation to the next 2–month period with KF cycle (Figure 3). In this process, only surface model temperature (Tsfc) was used as a predictor for easy understanding of the interpretation and verification results.

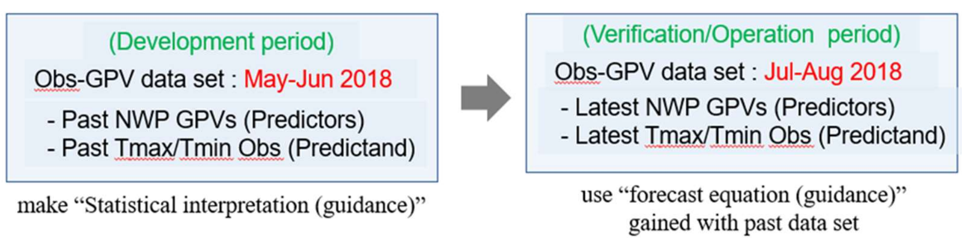


Figure 3. Calculation procedure with past–2month and the next 2–month Obs–GPV data set.

3. Result

3.1. Preliminary investigation

WG3 agreed to set a goal to improve T_{max} and T_{min} city forecasts which NCHMF started issuing in 2018, and decided to develop guidance to improve accuracy of T_{max} and T_{min} forecasts for 63 cities up to 3 days ahead as a first step. After the baseline survey in July 2018, collection of necessary observation data and GSM GPV data, and preliminary investigation on the development of T_{max} and T_{min} guidance were conducted. In the investigation, MOS and KF temperature guidance was developed for 13 stations of major cities with T_{max} and T_{min} observation and GSM GPV data from January 2017 to April 2018. Through the comparison of RMSEs of GSM surface temperature GPVs and KF guidance, we confirmed that KF guidance greatly reduced RMSEs of GSM model surface temperature throughout the year (Figures 4a, 4b).

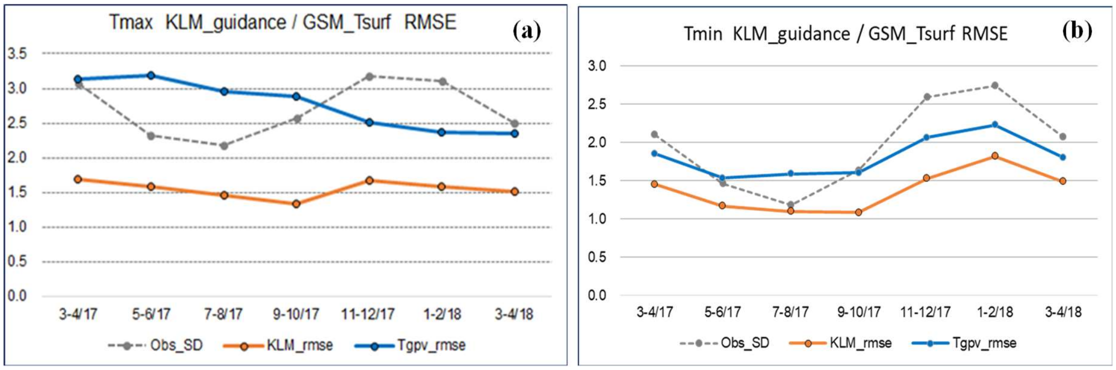


Figure 4. (a) Average RMSEs of Tmax_Day1 KF guidance for 13 cities every 2–month period from Mar 2017 to Apr 2018. Standard Deviation of T_{max} and T_{min} observations (Obs–SD) is shown to see the seasonal change of variability of temperature fluctuation, RMSE of KF guidance (KLM_rmse) and RMSE of GSM surface temperature (Tgpv_rmse); (b) Average RMSEs of Tmin KF guidance; others are the same as (a).

3.2. T_{max} and T_{min} KF guidance with GSM up to 3 days ahead

Using the prepared Obs–GPV data set, T_{max} and T_{min} KF guidance for 63 cities up to 3 days ahead was developed with JMA GSM GPV data of 00 UTC initial. This study followed the method used in the JICA Group training course in meteorology implemented by JMA for the development of the KF guidance.

In order to understand the performance of developed KF guidance, we carried out accuracy verification of T_{max} and T_{min} city forecasts for 63 cities issued by forecasters and KF guidance with JMA GSM GPV data. Figure 5 shows averaged RMSEs of persistence forecasts, city forecasts and KF guidance for T_{max} and T_{min} in Nov–Dec 2018. RMSEs of KF guidance were smaller than those of persistence forecasts and city forecasts, and we confirmed that accuracy of city forecasts would be improved by introducing KF guidance.

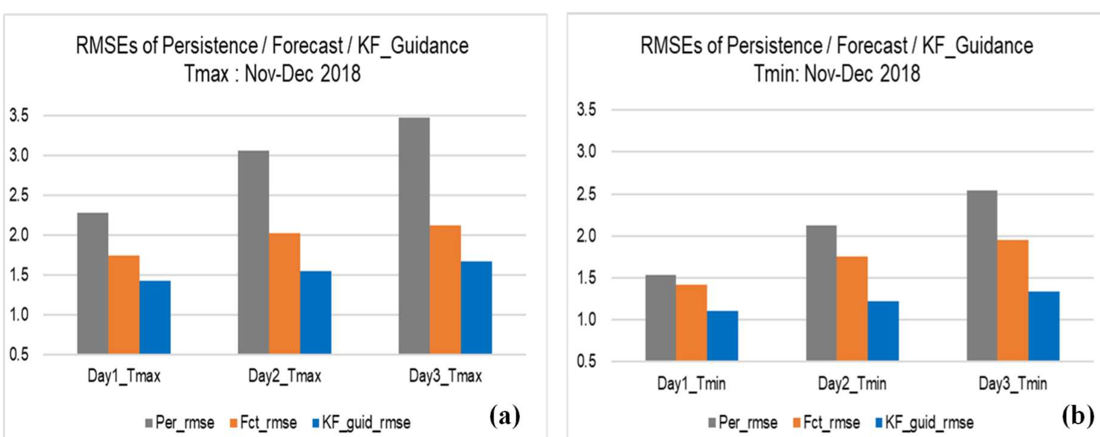


Figure 5. Averaged RMSEs of persistence forecast, city forecast and KF guidance for 63 cities: (a) T_{max} and (b) T_{min} in Nov–Dec 2018. Persistence forecast assumes conditions of the day are unchanged up to 3days ahead.

In 2019, we undertook development of T_{max} and T_{min} guidance for 63 cities up to 3 days ahead for operational use to improve accuracy of T_{max} and T_{min} city forecasts. First, a R–script for preparing necessary dataset for daily calculation of KF guidance with JMA GSM GPV data of 00 UTC initial and SYNOP observation data of 63 stations in the cities was developed in July 2019.

3.3. T_{max} and T_{min} KF guidance with IFS up to 10 days ahead

3.3.1. Development of T_{max} and T_{min} KF guidance with IFS GPV data

In addition to the development of KF guidance with JMA GSM GPV data, this study developed T_{max} and T_{min} KF guidance with ECMWF IFS GPV data in response to the request by NCHMF. Figure 6 shows RMSEs of IFS–KF guidance and GSM–KF guidance for T_{max} at every city forecast points in May and June 2019. RMSEs of IFS–KF guidance are slightly smaller than GSM–KF guidance in the northern region, where daily change of the maximum temperature is rather large in May and June. RMSEs of them for minimum temperature are almost the same.

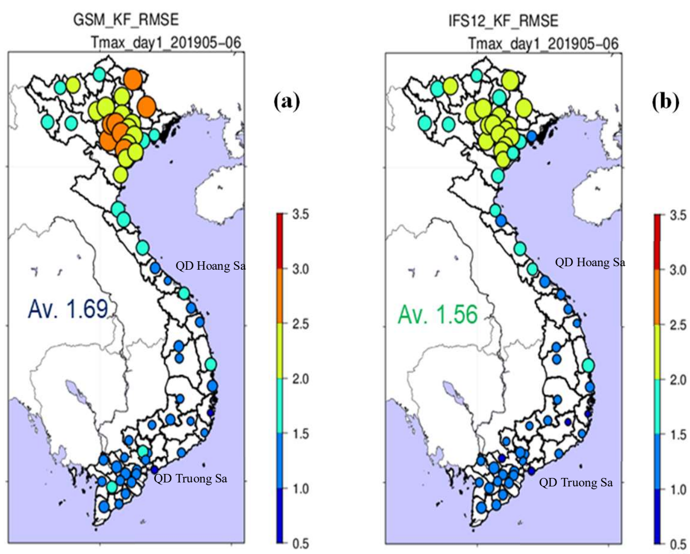


Figure 6. Distribution of RMSEs: (a) GSM–KF guidance; (b) IFS–KF guidance in May–June 2019 for T_{max}, Day1 (tomorrow).

3.3.2. Trial operation of KF guidance, monitoring and improvement

We set a PC for guidance development at the forecasting room of NCHMF for auto download of JMA GSM GPV data, auto copy of SYNOP Excel data and collecting IFS GPV data through the internal network. Then we started trial operation of GSM–KF guidance and IFS–KF guidance for 63 cities up to 3 days ahead.

KF guidance needs the daily update process of observation data to update coefficients of KF equation according to errors between KF guidance outputs and observations. As observation data missing was found sometimes during the trial operation, we checked daily observation update process and improved the process.

3.3.3. Development of T_{max} and T_{min} guidance with IFS up to 10 days ahead

VNMHA issues T_{max} and T_{min} city forecasts up to 10 days ahead, and we need to develop KF T_{max} and T_{min} guidance up to 10 days ahead. As previous verification results showed RMSEs of IFS KF guidance were smaller than GSM KF guidance with increasing forecast time, we developed IFS–KF T_{max} and T_{min} guidance up to 10 days ahead with 00 UTC and 12 UTC initials and started its trial operation.

IFS GPV data of 12 UTC initial are available at around 3 to 4 am in local time of Vietnam, and IFS GPV data of 00 UTC initial are available at around 3 pm and GSM GPV data of 00 UTC initial are available at around 11 am. Considering these data availability, IFS KF guidance with 12 UTC initial (IFS12) up to 10 days ahead is prepared at around 10:30 am, GSM KF guidance with 00 UTC initial (GSM00) up to 3 days ahead at around 11:30 am and IFS KF guidance with 00 UTC initial (IFS00) up to 10 days ahead at around 3:30 pm Examples of IFS KF Guidance up to 10 days ahead and monitoring sheets of GSM KF guidance for every station are shown in Table 1 and Figure 7, respectively.

Table 1. Example of IFS–KF T_{max} and T_{min} guidance up to 10 days ahead (IFS12UTC on 30th Nov 2019 initial).

Station	**IFS Day0**	**Day1 min**	**Day1 max**	**Day2 min**	**Day2 max**	**Day3 min**	**Day3 max**	**Day4 min**	**Day4 max**
LaiChau	20191201	14.3	17.4	10.9	18.2	10.6	19.8	10.1	19.2
DienBien	20191201	16.4	25.3	13.4	25.8	13.9	26.0	11.6	26.0
SonLa	20191201	12.2	19.5	9.2	20.9	9.3	21.0	8.3	21.6
HoaBinh	20191201	14.1	21.2	11.9	22.2	12.8	21.6	11.4	21.7
LaoCai	20191201	15.4	19.3	14.3	20.0	14.5	22.7	15.8	24.8
YenBai	20191201	16.2	17.7	14.6	18.6	13.6	20.4	15.7	21.3
HaGiang	20191201	16.0	20.7	14.5	22.5	12.8	23.8	12.4	24.3
TuyenQua	20191201	15.7	20.2	15.3	22.3	12.2	22.8	13.5	22.6

Day5 min	**Day5 max**	**Day6 min**	**Day6 max**	**Day7 min**	**Day7 max**	**Day8 min**	**Day8 max**	**Day9 min**	**Day9 max**
7.2	19.3	7.0	21.0	6.9	21.0	8.5	21.5	7.4	20.9
10.2	25.5	9.1	26.6	9.0	24.8	8.4	26.9	9.3	28.5
6.6	22.0	5.5	23.7	6.0	24.4	6.8	24.3	8.3	25.6
10.4	21.7	12.0	23.7	10.4	24.4	10.5	22.5	10.0	23.6
13.3	24.6	10.5	25.7	10.5	25.2	12.5	25.0	12.5	25.6
14.7	21.3	12.3	23.5	12.3	23.6	10.4	22.6	11.9	23.2
9.6	24.7	7.8	24.9	7.9	25.8	8.3	25.4	8.3	25.5
12.7	22.9	10.7	25.0	10.9	24.1	10.2	24.1	10.1	23.8

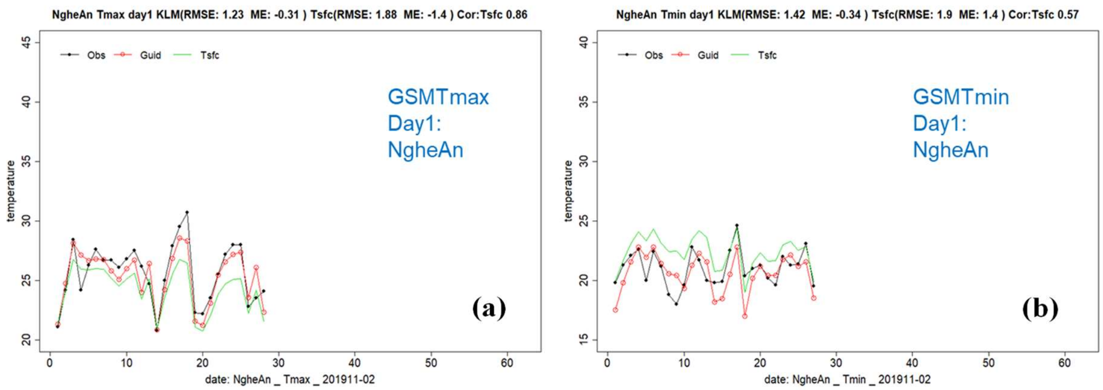


Figure 7. Example of Monitoring sheets of GSM–KF: (a) T_{max} and (b) T_{min} guidance for NgheAn (Black: Observation, Green: GPV Tsfc, Red: GSM–KF guidance).

3.4. Verification results of IFS KF and GSM KF guidance

3.4.1. Verification results of IFS KF guidance up to 10 days ahead

Figure 8 shows verification results of IFS12, IFS00 up to 10 days ahead in Nov–Dec 2019 and in Jan–Feb 2020. RMSEs of IFS Tsfc of 00 UTC initial, IFS00_KF and IFS12_KF increase gradually from Day1 to Day9. Both IFS00_KF and IFS12_KF RMSEs are significantly smaller than RMSEs of direct model output (Tsfc), and RMSEs of IFS00 KF guidance are slightly smaller than those of IFS12 KF guidance.

IFS00 KF guidance, however, is a bit late for issuing the city forecast from Day1 to Day 10 because forecasters have to issue city forecasts by 4 pm at the latest. So, IFS12 KF guidance are to be used mainly to issue city forecasts and IFS00 KF guidance are to be used as a reference for checking. RMSEs of IFS12 KF guidance are slightly larger than IFS00 KF guidance, and IFS12 KF guidance will work for issuing T_{max} and T_{min} city forecasts.

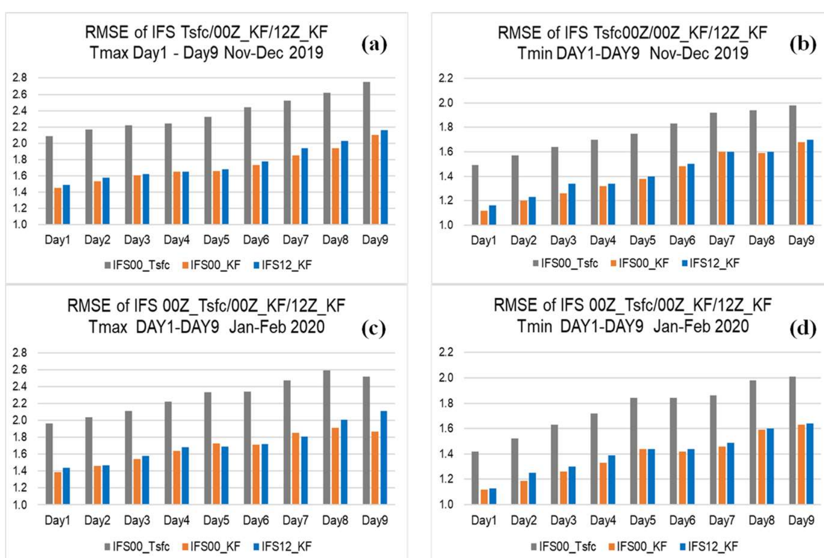


Figure 8. Averaged RMSEs of IFS surface temperature (Tsfc) of 00 UTC initial, IFS00 KF guidance and IFS12 KF guidance for Day1 to Day9: **(a)** T_{max}, Nov–Dec; **(b)** T_{min}, Nov–Dec; **(c)** T_{max}, Jan–Feb 2020, **(d)** T_{min}, Jan–Feb 2020.

3.4.2. Verification results of GSM and IFS KF guidance for Day1, Day2 and Day3

Figure 9 shows verification results of city forecasts issued by forecasters, GSM00 KF guidance, IFS00 KF guidance and IFS12 KF guidance for Day1, Day2 and Day3 in Nov–Dec 2019 and in Jan–Feb 2020. Verification results are summarized as follows:

· RMSE of IFS00 for T_{max} Day 1 is the smallest among these forecasts in Nov–Dec 2019. RMSEs of these forecasts increase gradually from Day1 to Day3: 1.45 (IFS00 Day1) to 1.61 (IFS00 Day3), 1.49 (IFS12 Day1) to 1.62 (IFS12 Day3), 1.52 (GSM00 Day1) to 1.76 (GSM00 Day3).

· Features of RMSEs for T_{max} in Nov–Dec 2019 are similar to those of T_{min} in Nov–Dec 2019, and those of T_{max} and T_{min} in Jan–Feb 2020. RMSEs of IFS12 KF guidance are smaller than those of GSM00 KF guidance and slightly larger than those of IFS00 KF guidance.

· RMSEs of KF guidance are smaller than those of city forecasts of T_{max} and T_{min} for Day1, Day2 and Day3 in Nov–Dec 2019 and Jan–Feb 2020.

The results show that IFS00 KF guidance could be used to improve accuracy of T_{max} and T_{min} city forecasts. However, as previously mentioned, IFS00 KF guidance is available at around 3:00 to 3:30pm, and it is a bit late to use operationally. So IFS12 KF guidance and GSM00 KF guidance are to be used mainly for daily forecasting.

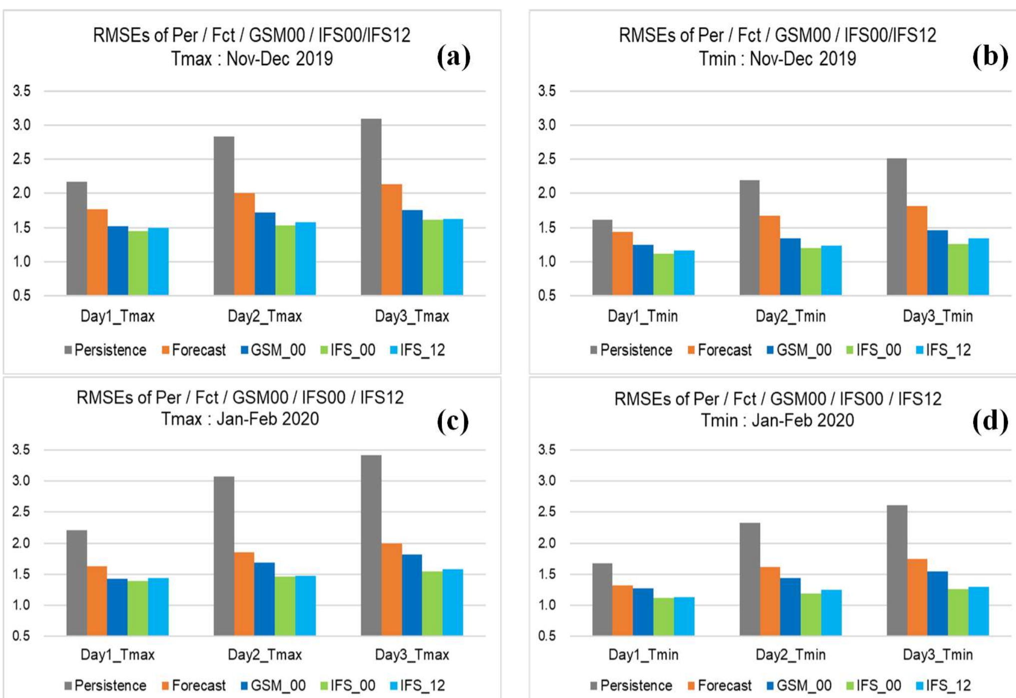


Figure 9. Averaged RMSEs of Persistence forecasts, City forecasts issued by forecasters, GSM00 KF guidance, IFS00 KF guidance and IFS12 KF guidance for Day1, Day2 and Day3 in Nov–Dec 2019 and in Jan–Feb 2020: **(a)** T_{max}, Nov–Dec 2019; **(b)** T_{min}, Nov–Dec 2019; **(c)** T_{max}, Jan–Feb 2020; **(d)** T_{min}, Jan–Feb 2020.

3.4.3. Verification results of GSM and IFS KF guidance at each station

RMSEs of previous verification results are averaged RMSEs of 63 stations for 2–month periods. Error features are likely different depending on the station and the season.

At first, we checked variability amplitude of observed T_{max} and T_{min} temperatures at each station. Figure 10 shows Standard Deviation (SD) of T_{max} and T_{min} observations at each station in Nov–Dec 2019 and Jan–Feb 2020. From these distribution charts of SDs, we get the following features:

· SDs are relatively large in the north region and they are small in the central and southern regions in Vietnam. Looking at those four distribution charts, SDs of T_{max} in Jan–Feb 2020 in the northern region are larger than others and over 4 degrees in many stations.

· Daily change of T_{max} and T_{min} are large in the northern region around Hanoi, particularly in the winter season.

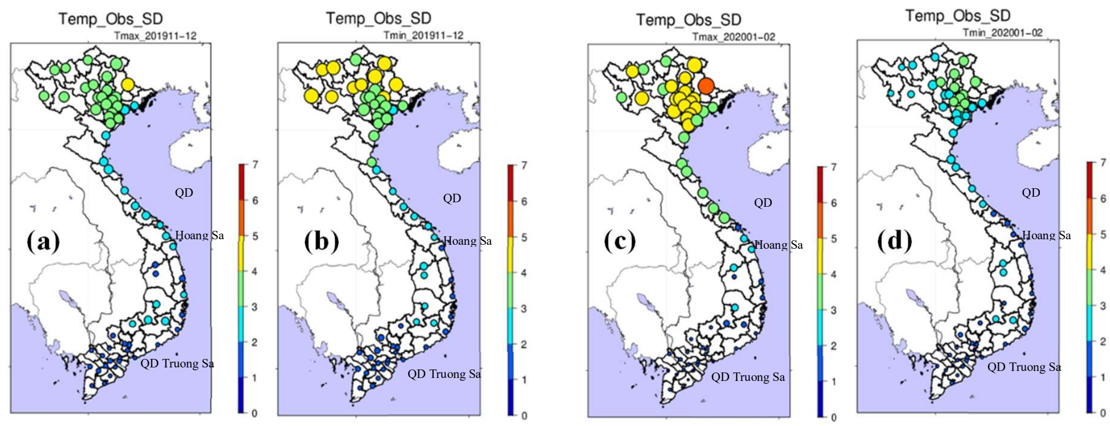


Figure 10. Standard Deviation (SD) of T_{max} and T_{min} observations at each station: **(a)** T_{max}, Nov–Dec 2019; **(b)** T_{min}, Nov–Dec 2019; **(c)** T_{max}, Jan–Feb 2020; **(d)** T_{min}, Jan–Feb 2020.

Figure 11 shows RMSEs of Tmin city forecasts, GSM00 KF guidance and IFS12 KF guidance for Day 1 at each station in Nov–Dec 2019. RMSEs are relatively large in the northern region compared to in the central and southern regions, because daily temperature changes are large and forecasts for cities in the northern region are relatively difficult. RMSEs of GSM00 KF guidance and IFS12 KF guidance are smaller than city forecasts in many stations around Hanoi in particular.

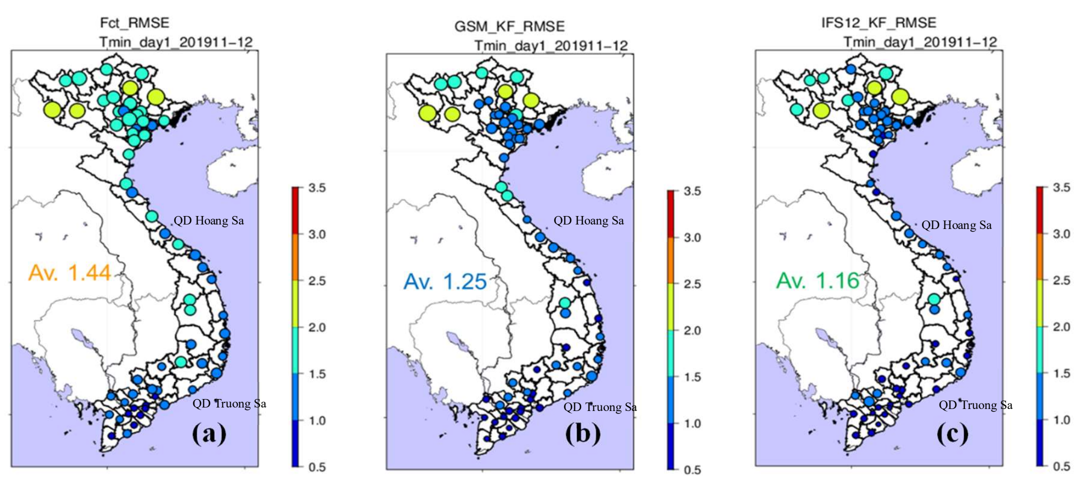


Figure 11. (a) RMSEs of city forecasts; (b) GSM00 KF guidance; (c) IFS12 KF guidance; for T_{min} Day 1 at each station in Nov–Dec 2019.

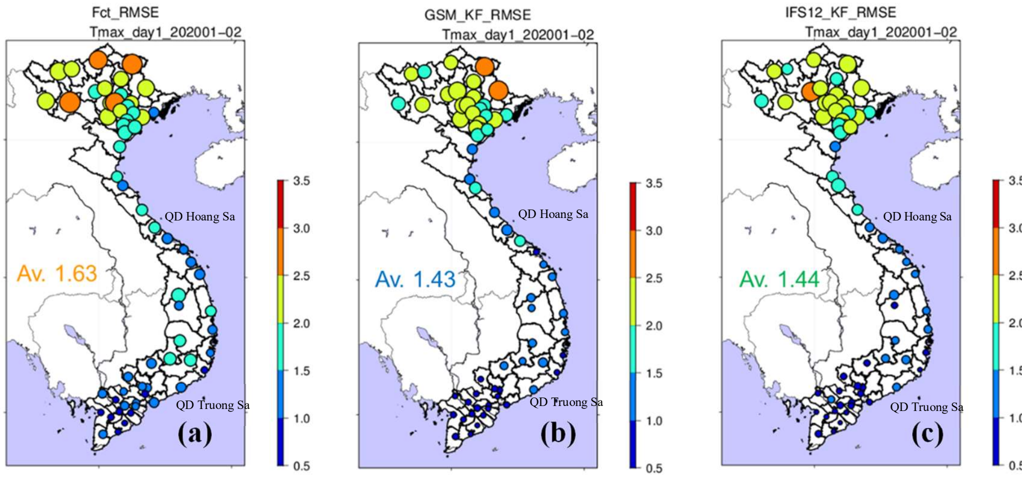


Figure 12. (a) RMSEs of city forecasts; (b) GSM00 KF guidance; (c) IFS12 KF guidance for T_{max} Day1 at each station in Jan–Feb 2020.

Figure 12 shows RMSEs of T_{max} city forecasts, GSM00 KF guidance and IFS12 KF guidance for Day1 at each station in Jan–Feb 2020. Features of RMSE distribution are similar to T_{min} RMSE distribution in Nov–Dec 2019. RMSEs are larger in the northern region than those of in the central and southern regions. RMSEs of KF guidance are smaller than city forecasts in many stations.

3.4.4. Consideration of predictors

Trial operation and verification of T_{max} and T_{min} KF guidance were made with one predictor; Tsfc (model surface temperature) of JMA GSM and ECMWF IFS surface GPV data. Some consideration to predictors was made by adding one or two predictors to Tsfc for further improvement of the KF guidance. Figure 13 shows RMSEs of GSM KF guidance of possible combination of predictors: "Tsfc", "Tsfc+Hsfc(humidity)", "Tsfc+U(wind_U–component)", "Tsfc+V(wind_V–component)", "Tsfc+TCDC(total cloud amount)", "Tsfc+Rain (rainfall)", "Tsfc+Hsfc+U" and "Tsfc+Hsfc+TCDC". Considerable reduction of RMSE was not found among these combinations of predictors, but small improvement was found in the combination of "Tsfc+Hsfc" for both T_{max} and T_{min} throughout the period from Nov 2019 to Feb 2020. We expected some improvement by adding wind component to Tsfc, but no substantial improvements were obtained.

By checking RMSEs of "Tsfc+Hsfc" at each station, 0.15 degrees to 0.3 degrees reduction of RMSE was found at several stations in the northern area including Hanoi and Haiphong. Figure 14 shows daily monitoring sheets of "Tsfc" KF guidance and "Tsfc+Hsfc" KF guidance of Hanoi and Haiphong for T_{max}–Day1 in Jan–Feb 2020. "Tsfc+Hsfc" predictors reduced RMSE of "Tsfc" predictor by 0.21 degrees in Hanoi and by 0.38 degrees in Haiphong. Errors of "Tsfc+Hsfc" predictors KF guidance are obviously smaller than "Tsfc" predictor KF guidance in a few days of H1 and H2 periods. We may have some improvement in the northern area, where daily changes of T_{max} and T_{min} are large and temperature forecasts are most difficult in the country, by using "Tsfc+Hsfc" predictors.

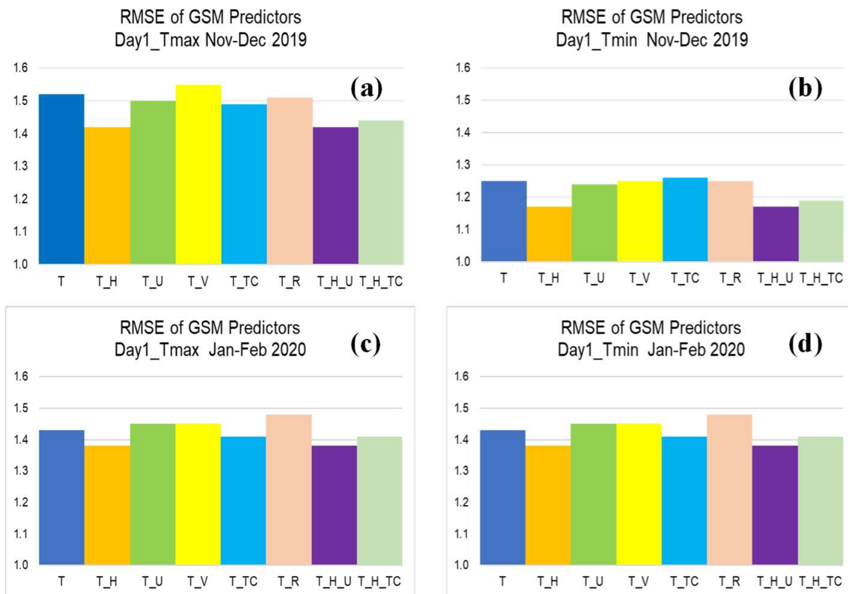


Figure 13. RMSEs of GSM00 KF guidance of City forecasts, GSM00 KF guidance of each combination of possible predictors: "Tsfc(T)", "Tsfc+Hsfc(T_H)", "Tsfc+U(T_U)", "Tsfc+V(T_V)", "Tsfc+TCDC(T_TC)", "Tsfc+Rain(T_R)", "Tsfc+Hsfc+U" and "Tsfc+Hsfc+TCDC" for Day1; (a) T_{max} Nov–Dec 2019; (b) T_{min} Nov–Dec 2019; (c) T_{max} Jan–Feb 2020; (d) T_{min} Jan–Feb 2020.

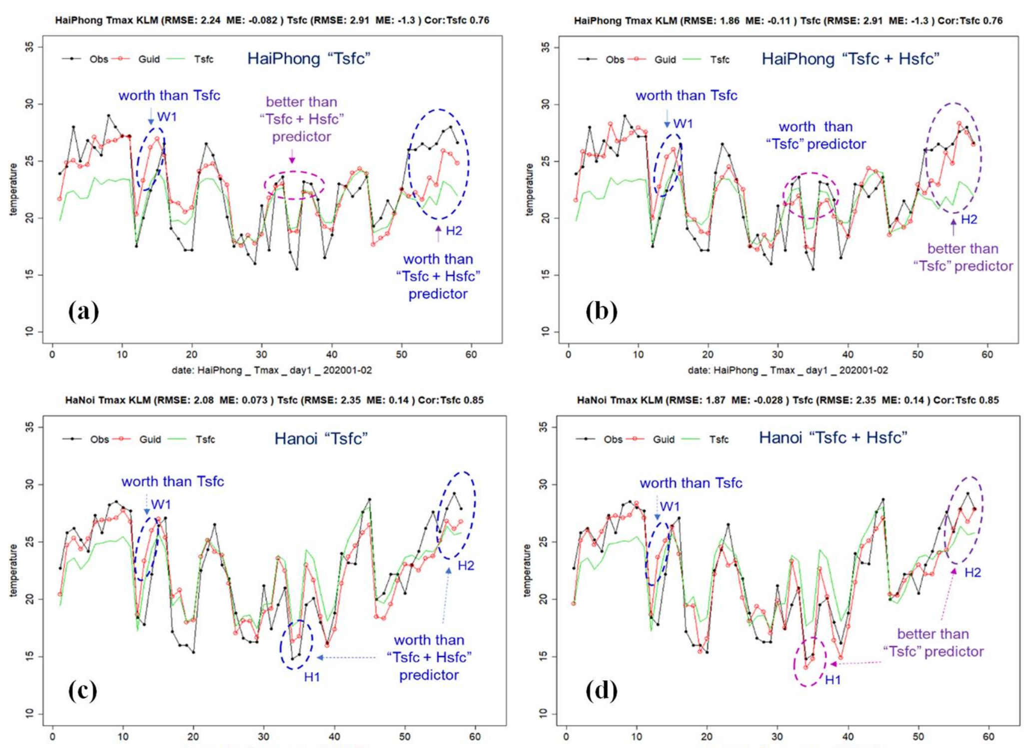


Figure 14. (a) monitoring sheets of "Tsfc" GSM00 KF guidance of Hanoi for T_{max}–Day1in Jan–Feb 2020; (b) "Tsfc+Hsfc" guidance of Hanoi; (c) "Tsfc" guidance of Haiphong; (d) "Tsfc+Hsfc" guidance of Haiphong.

We must note that the Kalman filter can catch up with a gradual weather change (seasonal weather change) but cannot catch up with the rapid weather change. A KF forecast may yield a large error when the weather changes suddenly, because the KF successive cycle is a "catch up with the previous relationship" system. For example, in Figure 14, T_{max} observations were higher than Tsfc at the beginning, then T_{max} observations became nearly equal to Tsfc (W1 period). As KF guidance caught up the relationship at the beginning, KF guidance were worth than Tsfc in the W1 period.

4. Conclusion and discussion

Maximum and minimum temperature guidance was developed with Kalman filter for 63 cities up to 3 days ahead using JMA GSM GPV data and up to 10 days ahead using ECMWF IFS GPV data as an activity of the JICA Project for Strengthening Capacity in Weather Forecasting and Flood Early warning System. Verification results show that RMSEs of GSM and IFS KF guidance are relatively large in the northern region, but KF guidance substantially reduces RMSEs of direct model outputs in all regions throughout the year. RMSEs of IFS guidance become smaller than those of GSM guidance with increasing forecast time. Averaged RMSEs of KF guidance for 63 cities are smaller than those of city forecasts issued by forecasters in Nov–Dec 2019 and Jan–Feb 2020. These verification results suggest that we will be able to improve accuracy of T_{max} and T_{min} city forecasts by using T_{max} and T_{min} KF guidance operationally in daily weather forecasting. We will continue to conduct verification and case studies for rapid weather change events in the next activities for operational use of KF guidance in daily weather forecasting.

Next our target is to develop rain guidance such as possibility of precipitation (PoP), mean precipitation amount or maximum precipitation amount. In preparation for development of rain guidance, we started collecting necessary observation data for rain guidance. As prediction accuracy of precipitation amount by NWP models is not so reliable compared to temperature predictions, we will start to grasp prediction accuracy and features in 3–regions; North–east region (PhuLien regional forecasting center), North–Central region (Vinh regional forecasting center) and Central–delta region (Hanoi central forecasting center). According to a first preliminary investigation, it seems rather difficult to prepare reliable rain guidance, but we will tackle to this challenging but important issue in the next activities.

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