# Performance analysis of long lead flood forecast information from GloFAS

### Introduction

RIMES is supporting national meteorological and hydrological agencies in Myanmar and Nepal to develop the flood forecasting systems for 3-days and 10-days lead time. The forecasting system is now developed and agencies in both countries are analyzing the performance before making the systems operational. Similar efforts are also on-going in Philippines, Sri Lanka and India.

As part of RIMES-ECMWF collaboration it was decided to support countries with 30-days lead time flood outlook by making enhanced use of GloFAS system. To integrate the GloFAS forecast in countries operational system it is important to test the model performance at important locations and further calibrate and validate the model as per the performance analysis. To begin the process RIMES requested ECMWF to share the GloFAS outputs for the hindcast period which was provided for selected locations in four river basins in South Asia. The model performance was tested for the period starting from April, 2008 untill December, 2014. The analysis for selected locations in Ayeyarwady river basin in Myanmar and Narayani river basin in Nepal is provided in this document.

### Methodology

The basin shape files and coordinates for the selected locations in Ayeyarwady and Narayani basins were used to extract the GloFAS data for hindcast period. The ensembles of 30 days flow outlook was provided in NetCDF format. The ensemble mean was extracted for all individual stations. Performance of ensemble mean was analyzed again the observations. The performance of forecast with lead time of 5-days, 10-days, 15-days, 20-days, 25-days and 30-days is presented in this document. Various statistical parameters including mean error (ME), root mean square error (RMSE), nash-sutcliffe efficiency (NSE), percentage bias (PBIAS) and coefficient of determination (R<sup>2</sup>) were considered. The hydrographs for the analysis period for different lead time of forecast and histograms representing the sampling of quantiles is also provided for better comparison of flow patterns.

The analysis for Ayeyarwady and Narayani river basins is provided in the subsequent sections.

#### I. Ayeyarwady River Basin, Myanmar

*Location*: lies between geographic coordinates  $17^{\circ}30$ 'N ~  $29^{\circ}45$ ' N latitude and from  $93^{\circ}10$ 'E ~  $98^{\circ}45$ ' E longitude

*Basin Characteristics*: 2170 km long draining the total basin area of 414,100 km<sup>2</sup>. The Ayeyarwady River has its source from the confluence of the Mali Kha and Mai Kha Rivers, both of which originate from the Eastern Himalayas and the Tibetan Plateau. The river is Myanmar's most important commercial water way. It is one of the world's top five rivers in terms of amount of suspended sediment loads, and this sedimentation provides for the rich rice growing areas in the delta.

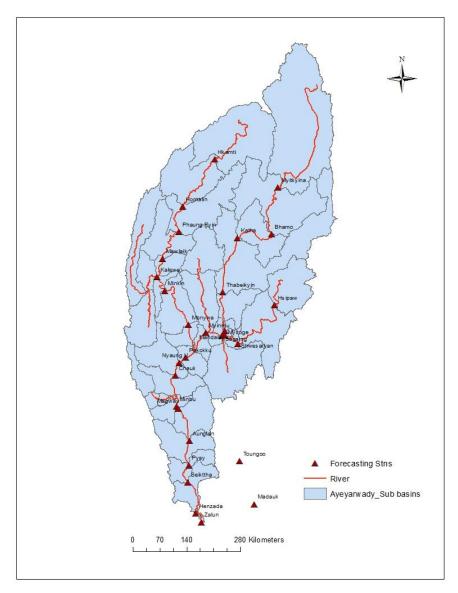


Figure 1 Ayeyarwady river basin and location of observation stations

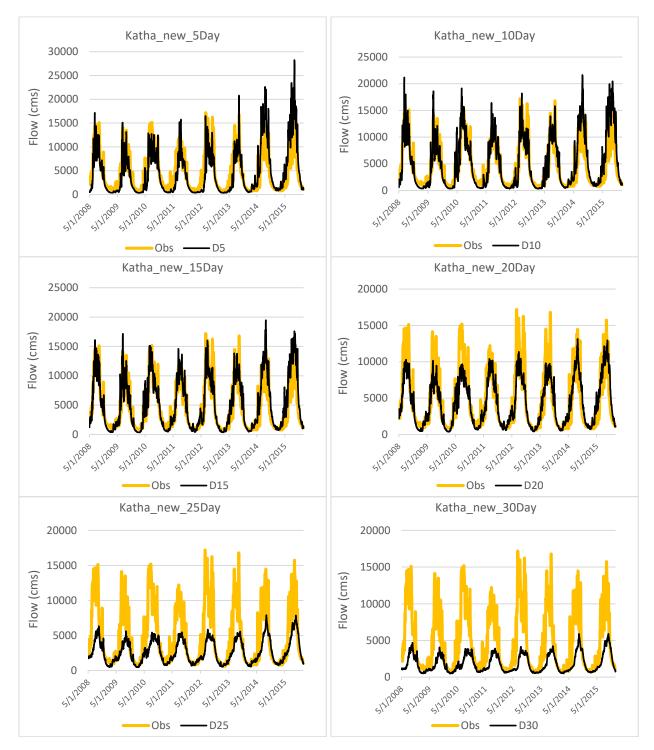
*Selected Location:* To well represent the performance in different sections of Ayeyarwady stations for performance analysis are selected from Upper Ayeyarwady (tributary from North east and upto the confluence), Chindwin river (tributary from North west) and Lower Ayeyarwady (after the confluence of upper Ayeyarwady and Chindwin). Bhamo and Katha were considered for Upper Ayeyarwady, Monywa was considered for Chindwin, Nyang Oo was considered in Lower Ayeyarwady just after the confluence and Zalun to represent the performance at basin outlet.

### Key Findings:

- Flow for the stations in upper Ayeyarwady (Katha) is good and model is able to capture the seasonal cycle as well as peaks upto 15-days.
- In Chindwin river (based on Monywa) model performance is good and able to capture the seasonality as well as peaks quite well upto 10-days. 15-day forecast performs well considering the error parameters but it is not able to capture the peaks. Beyond Day 15 model performance is not satisfactory. Although model is able to pick the seasonal cycle of flow in all forecasts.
- In lower Ayeyarwady i.e. after the confluence of Chindwin and Upper Ayeyarwady the model performance improves compared to stations at upstream. This is evident from the analysis of Nyang Oo and Zalun.
- At Nyang Oo model outlook is good upto 20-days. 5-day and 10-day forecasts capture the seasonality as well as timings of peak flows, although overestimate the magnitude of peaks. Model is able to predict high as well as low flows satisfactorily.
- At Zalun flow outlook upto 25-days is satisfactory.

The detailed analysis at Katha, Monywa, Nyang Oo and Zalun is provided here:





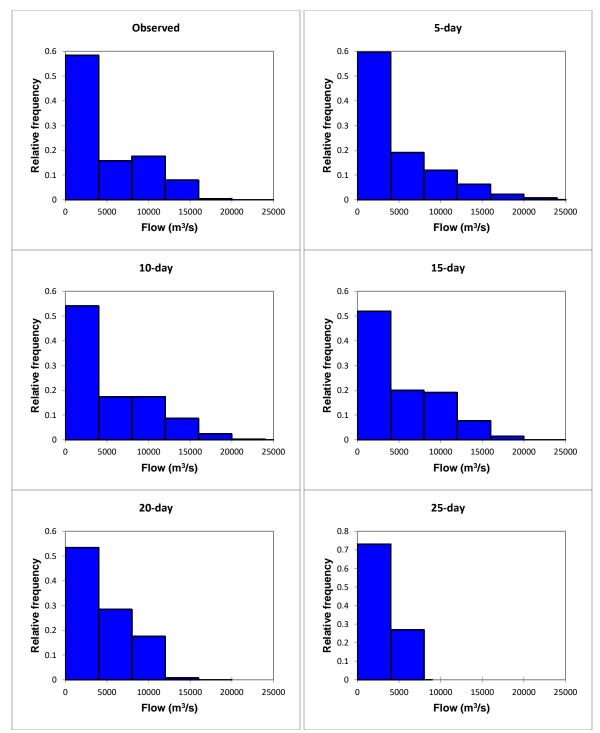
**Figure 2** Comparison between observed and GloFAS forecast discharge for 5-day, 10-day, 15-day, 20-day, 25-day and 30-day lead time at Katha.

The hydrographs in Figure 2 indicates the good performance of GloFAS for upto 15-day lead time forecasts. Although peaks are overestimated in most of the cases but model is able to pick the seasonal cycle and timing of peaks reasonably well. For 20-day onward forecast underestimates the peak flow. Also model is able to predicts the low flow, i.e. flow in dry season as shown in Figure 2 and also indicates in Table 1. Table 2 indicates that forecast efficiency in terms of NSE value is above 70% unto 20 days. Histograms in Figure 3 shows that 5-day, 10-day and 15-day forecasts are well able to capture the quantile distribution at Katha.

Katila, Ulit. III /S							
Statistic	Obs	5-day	10-day	15-day	20-day	25-day	30-day
Minimum	600.0	352.8	354.2	356.0	379.1	453.5	501.3
Maximum	17200.0	28248.9	21644.7	19474.4	13138.8	7900.4	5901.8
1st Quartile	3.0	1.0	1.0	1.0	1.0	1.0	1.0
Median	1300.0	759.8	970.8	1339.8	1452.4	1246.0	859.1
3rd Quartile	2650.0	2308.5	3287.2	3633.0	3587.5	2203.7	1348.0
Mean	8230.0	7211.6	8953.0	8635.4	7151.4	4124.2	2892.0
Standard							
deviation (n-1)	4823.1	4516.3	5153.1	5176.2	4362.2	2686.9	1873.7
Standard error of							
the mean	4259.8	4773.0	4878.2	4432.9	3200.1	1690.6	1229.3

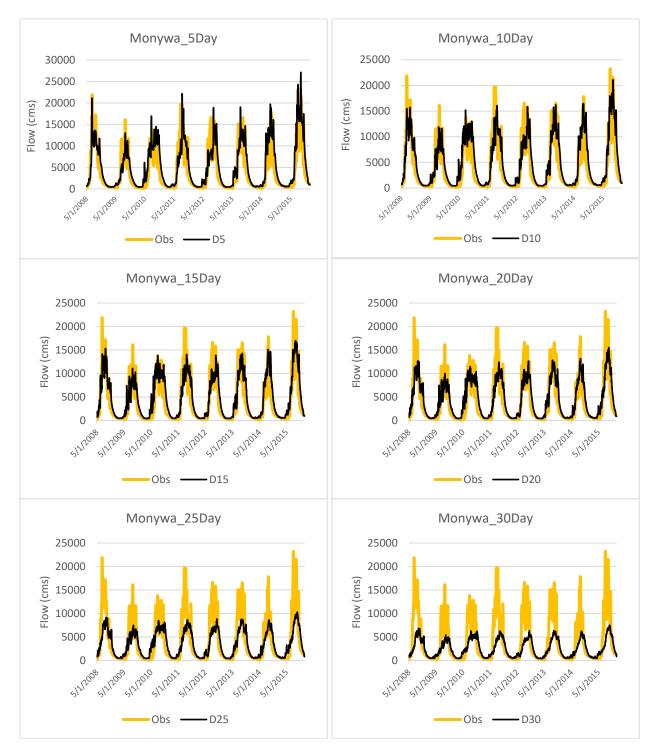
Table 1 Comparison of flow statistics of the observed and GloFAS forecasted flow series for Katha, Unit:  $m^{3}/s$ 

	MAE	ME	SS	PBIAS	NSE	<b>R</b> <sup>2</sup>
5-day	1742.21	-306.78	0.65	-6.36	0.72	0.852
10-day	1289.36	329.96	0.8	6.84	0.85	0.927
15-day	1186.71	353.05	0.83	7.32	0.85	0.925
20-day	1373.08	-460.93	0.77	-9.56	0.6	0.897
25-day	2349.09	-2136.28	0.2	-44.29	-4.08	0.767
30-day	2989.78	-2949.41	-0.19	-61.15	-13.27	0.648



**Figure 3** Histograms representing distribution of flow quantiles for observed and different lead time forecasts for Katha.

## 1.2 Monywa



**Figure 4** Comparison between observed and GloFAS forecast discharge for 5-day, 10-day, 15-day, 20-day, 25-day and 30-day lead time at Monywa.

The hydrographs in Figure 4 indicates the good performance of GloFAS for 5-day and 10-day lead time forecasts. For 15-day and 20-day forecast also model have good skill to predict the seasonal variations and at certain instances also captures the pattern of peak events. Although the magnitude of peak flow is underestimated in 15-day and 20-day forecast. For 25-day and 30-day forecast GloFAS highly underestimate the flow. Also in all cases model over predicts the low flow, i.e. flow in dry season as shown in Figure 4 and also indicates in Table 3. Table 4 indicates that forecast efficiency in terms of NSE value is above 70% unto 15 days. Histograms in Figure 5 shows that 5-day and 10-day forecasts are well able to capture the quantile distribution as compared to observed flow at Monywa.

Statistic	Obs	5-day	10-day	15-day	20-day	25-day	30-day
Minimum	120.0	429.6	429.8	432.1	434.7	437.3	436.1
Maximum	23240.0	27123.2	21104.3	16959.1	15531.5	10298.1	7468.6
1st Quartile	464.0	787.4	788.4	794.1	838.0	868.6	827.2
Median	1388.0	2692.9	2711.4	2868.3	3095.5	2745.7	1962.3
3rd Quartile	7608.0	8768.8	8845.0	8567.0	7983.3	6040.0	4347.8
Mean	4197.5	5095.1	4925.5	4741.4	4460.3	3487.1	2571.3
Standard							
deviation (n-1)	4966.5	5134.6	4699.7	4338.5	3860.6	2705.0	1879.1
Standard error of							
the mean	93.8	97.0	88.8	82.0	72.9	51.1	35.5

**Table 3** Comparison of flow statistics of the observed and GloFAS forecasted flow series for Monywa, Unit:  $m^3/s$ 

**Table 4** Statistical criteria for examining the accuracy of forecast time series for Monywa

	MAE	ME	SS	PBIAS	NSE	$\mathbb{R}^2$
5-day	1783.4	897.7	0.73	21.39	0.75	0.89
10-day	1578.0	728.0	0.79	17.34	0.77	0.90
15-day	1606.0	543.9	0.78	12.96	0.71	0.89
20-day	1738.9	262.8	0.73	6.26	0.56	0.86
25-day	2085.8	-710.4	0.55	-16.92	-0.50	0.80
30-day	2486.1	-1626.2	0.29	-38.74	-3.94	0.72

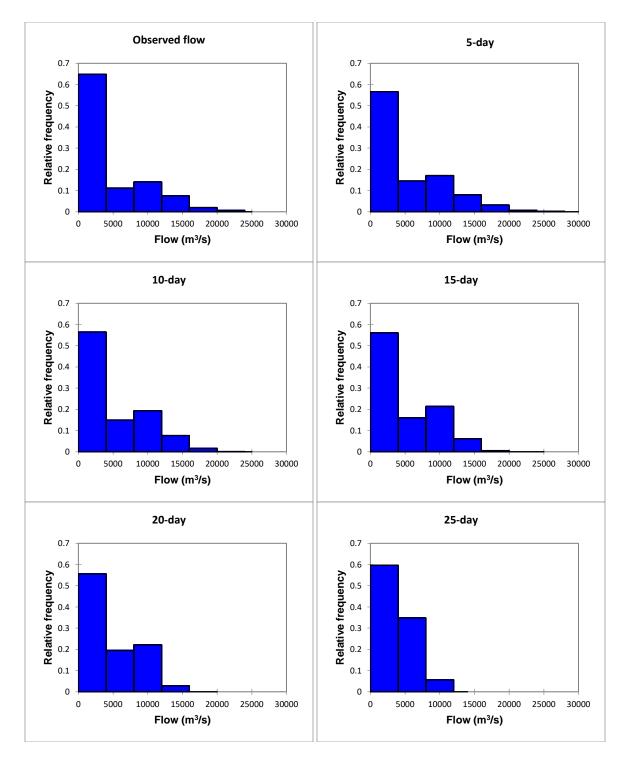
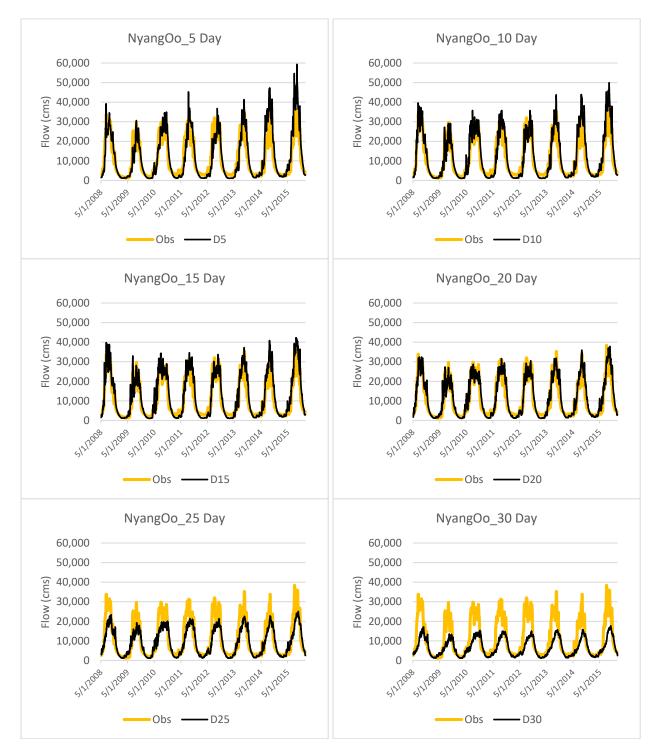


Figure 5 Histograms representing distribution of flow quantiles for observed and different lead time forecasts for Monywa.

## 1.3 Nyang Oo



**Figure 6** Comparison between observed and GloFAS forecast discharge for 5-day, 10-day, 15-day, 20-day, 25-day and 30-day lead time at Nyang Oo.

At Nyang Oo GloFAS overestimated the peaks for 5-day and 10-day forecast but it is able to pick the seasonal cycle and timing of peak events quite well (although magnitude is not captured well). 15-day and 20-day forecasts are able to capture the peak events as well as magnitude quite well. Although 20-day and 25-day forecasts are highly underestimated. Thus in this location model forecasts can be used upto 20 days for providing flood outlook. Frequency of flow quantiles in Figure 8 also justifies this findings. The model is well able to capture the low flows at this location.

Statistic	Obs	5-day	10-day	15-day	20-day	25-day	30-day
Minimum	1100.0	1108.7	1109.0	1111.3	1122.3	1129.0	1148.5
Maximum	38350.0	59329.2	49859.7	42294.9	37835.1	25046.7	17689.5
1st Quartile	3240.0	2247.6	2246.8	2387.6	2683.3	2845.1	2610.2
Median	5662.0	6690.4	7029.9	8130.5	8571.2	7673.7	5399.5
3rd Quartile	20556.0	21517.7	22852.5	22928.7	21184.4	15726.1	10935.5
Mean	11257.5	12334.5	12585.3	12647.8	12013.9	9334.0	6747.2
Standard deviation (n-1)	9740.8	12106.4	11799.6	11229.3	9944.4	6769.5	4518.2
Standard error of the mean	184.1	228.7	223.0	212.2	187.9	127.9	85.4

Table 5 Comparison of flow statistics of the observed and GloFAS forecasted flow series for Nyang Oo, Unit:  $m^3/s$ 

Table 6 Statistical criteria for examining the accuracy of forecast time series for Nyang Oo

	MAE	ME	SS	PBIAS	NSE	$\mathbb{R}^2$
5Day	3659.28	1076.99	0.69	9.57	0.8	0.905
10Day	3094.97	1327.77	0.79	11.79	0.86	0.941
15Day	2755.03	1390.31	0.84	12.35	0.88	0.952
20Day	2474.23	756.36	0.88	6.72	0.88	0.944
25Day	3546.86	-1923.5	0.72	-17.09	0.42	0.894
30Day	5226.34	-4510.28	0.31	-40.06	-2.21	0.797

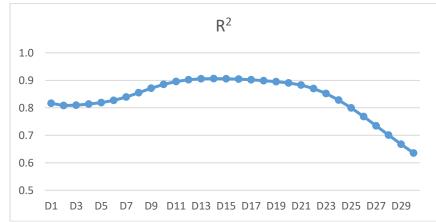


Figure 7 Day wise variation of Coefficient of determination  $(R^2)$  for 30 days forecast for Nyang Oo.

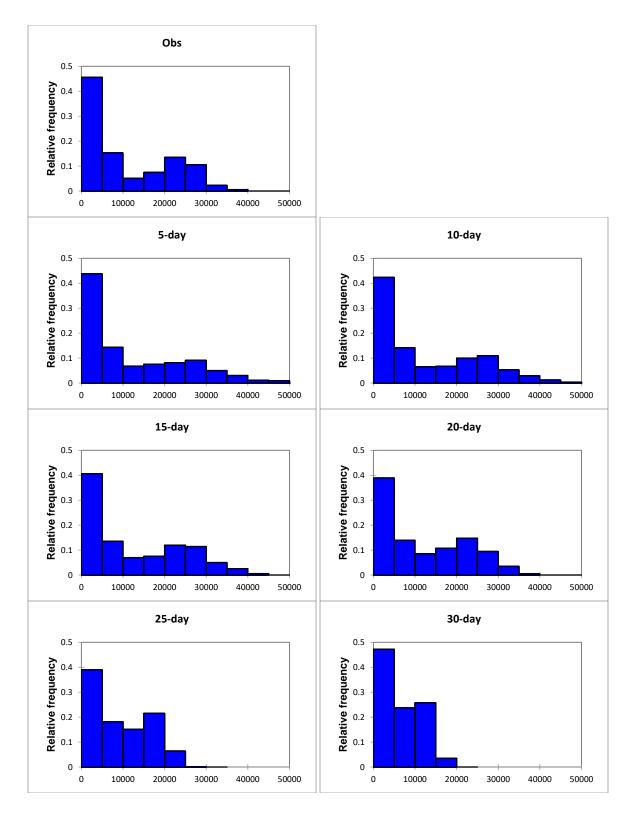
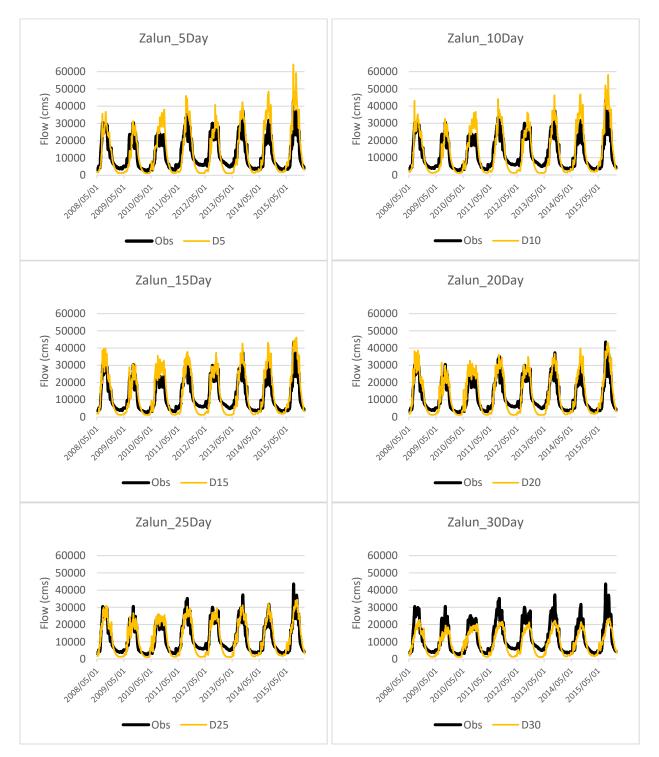


Figure 8 Histograms representing distribution of flow quantiles for observed and different lead time forecasts for Nyang Oo. Unit:  $m^{3}/s$ 





**Figure 9** Comparison between observed and GloFAS forecast discharge for 5-day, 10-day, 15-day, 20-day, 25-day and 30-day lead time at Zalun.

At Zalun the model performance is almost similar as for Nyang Oo. The peaks were overestimated for 5-day and 10-day forecast but it is able to pick the seasonal cycle and peak events quite well (although magnitude is not captured well). 15-day and 20-day forecasts are able to capture the peak events as well as magnitude quite well. At Zalun even 25-day forecast shows some promising results to provide the flood outlook. Although GloFAS is underestimating the low flows at Zalun. The distribution of flow quantiles in Figure 11 also indicate that GloFAS predict higher frequency at lower quantiles as compared to observed flow.

 Table 7 Comparison of flow statistics of the observed and GloFAS forecasted flow series for Zalun, Unit: m<sup>3</sup>/s

Statistic	Obs	5-day	10-day	15-day	20-day	25-day	30-day
Minimum	2588.0	1129.0	1129.3	1129.4	1129.4	1130.2	1137.4
Maximum	43600.0	64226.7	58162.4	46188.7	43083.5	34453.5	23675.7
1st Quartile	4880.0	2240.4	2286.8	2307.5	2339.7	2377.2	2579.2
Median	7690.0	6989.2	7021.6	7344.4	8273.3	8606.1	7944.6
3rd Quartile	19800.0	23947.4	23957.5	24435.3	23928.1	21128.0	15959.3
Mean	11980.6	13260.8	13101.2	13246.2	13013.1	11775.7	9368.1
Standard							
deviation (n-1)	8794.5	13137.4	12739.1	12346.9	11570.1	9714.0	6845.9
Standard error							
of the mean	166.2	248.2	240.7	233.3	218.6	183.5	129.4

**Table 8** Statistical criteria for examining the accuracy of forecast time series for Zalun

	MAE	ME	SS	PBIAS	NSE	<b>R</b> <sup>2</sup>
5Day	4780.3	1280.2	0.5	10.7	0.76	0.83
10Day	4547.9	1120.6	0.5	9.4	0.78	0.84
15Day	4158.8	1265.6	0.6	10.6	0.82	0.88
20Day	3681.2	1032.5	0.7	8.6	0.84	0.88
25Day	2980.2	-204.9	0.8	-1.7	0.85	0.86
30Day	3869.7	-2612.5	0.7	-21.8	0.44	0.76

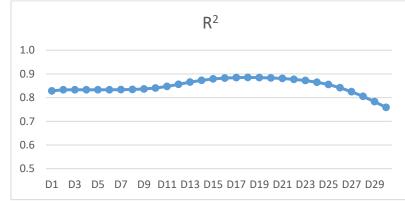


Figure 10 Day wise variation of Coefficient of determination  $(R^2)$  for 30 days forecast for Zalun.

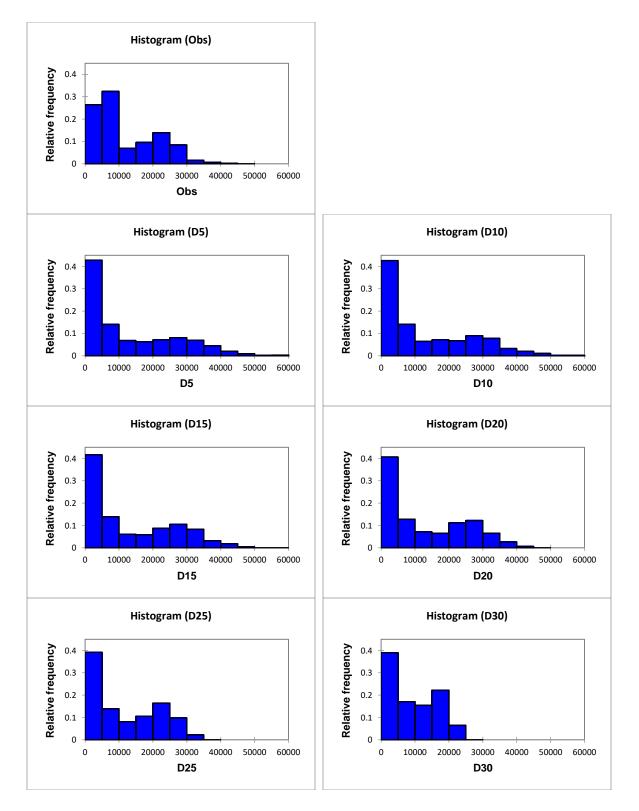


Figure 11 Histograms representing distribution of flow quantiles for observed and different lead time forecasts for Zalun.

### II. Narayani Basin, Nepal

*Location*: lies between geographic coordinates 27.36° to 29.33°N latitude and from 82.88° to 85.70°E longitude

*Basin characteristics*: Narayani River is 360 km draining the total basin area of 32000 km<sup>2</sup> in the Western Development Region of Nepal (Figure 12). The Narayani river system has five major tributaries, the Kali Gandaki, Seti Gandaki, Marsyandi, Budhi Gandaki and Trisuli. The Trisuli and Budhi Gandaki originated in the Tibet Autonomous Region of China, while the other three originated within Nepal. The Kali Gandaki is the main river in this drainage system. After the confluence of its five tributaries, the Narayani flows through Devghat and meets the Ganges in India. The Narayani Basin is one of major development hubs of Nepal, contributing about 50 per cent of the total hydropower production of the country. Agriculture is the major activity in Terai part of the basin. Various major floods have occurred in the basin in last 2 decades.

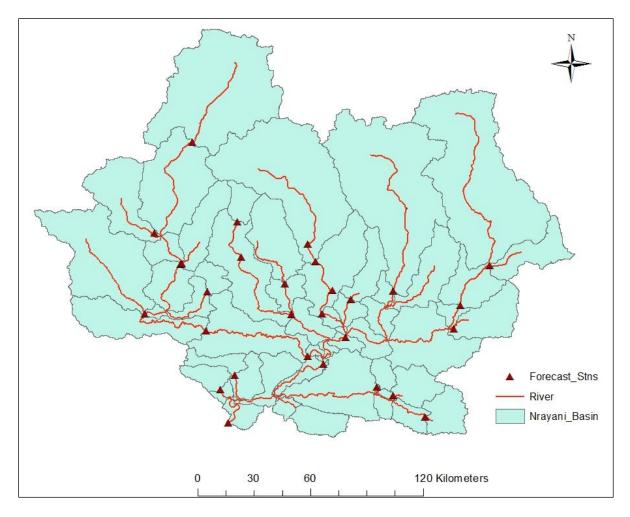
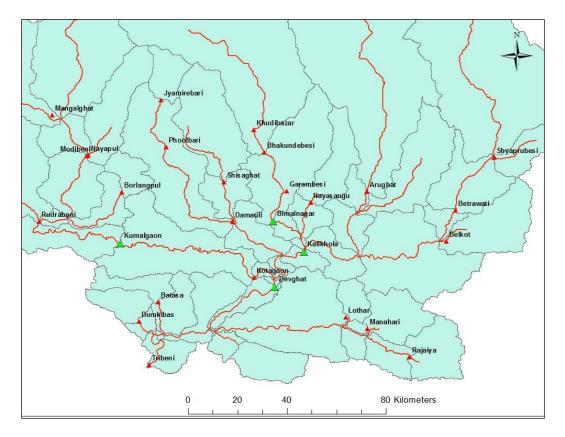


Figure 12 Narayani river basin in Nepal

*Selected Location:* Narayani basin located in Himalayas has very complex topography. To well represent the performance in different sections the analysis of GloFAS performance was performed at four locations in Narayani. The selected stations are represented by green triangles in Figure 13. The stations were selected to represent the flow drained by western part of the Narayani at Kumalgaon, central part of the basin at Bimalnagar and eastern part of the basin at Kalikhola and one to consider the basin outlet, Devghat.



# Figure 13 Selected stations for GloFAS performance analysis in Narayani river basin, Nepal

Key Findings:

- The analysis at four stations indicated that GloFAS is underestimating the flow in Narayani basin.
- The skill is quite reasonable upto 15 days at Kumalgaon and Bimalnagar.
- At Kalikhola GloFAS is able to capture the seasonal cycle but not able to pick the peaks. It either overestimates or underestimates the peak flows.
- Model is able to capture the flow pattern at Devghat but significantly underestimate the peaks.
- In general for Narayani the model is not able to capture the peaks. Model performance drops drastically from Day 15 onwards.

The performance assessment of GloFAS at Kumalgaon, Bimalnagar, Kalikhola and Devghat is provided here:

## 2.1 Kumalgaon



**Figure 14** Comparison between observed and GloFAS forecast discharge for 5-day, 10-day, 15-day, and 20-day lead time at Kumalgaon.

Flow hydrographs of Kumalgaon in Figure 14 shows that GloFAS underestimates the peaks in all forecast series. Seasonality of flow is captured by forecast to a certain extent until 15-day. Since 20-day forecast model is not able to capture the flow in Narayani. The statistics for Kumalgaon in Table 9 also reveals that forecast is not able to capture the characteristics of observed flow. Histograms in Figure 15 also shows the mismatch in flow quantiles especially at the higher end.

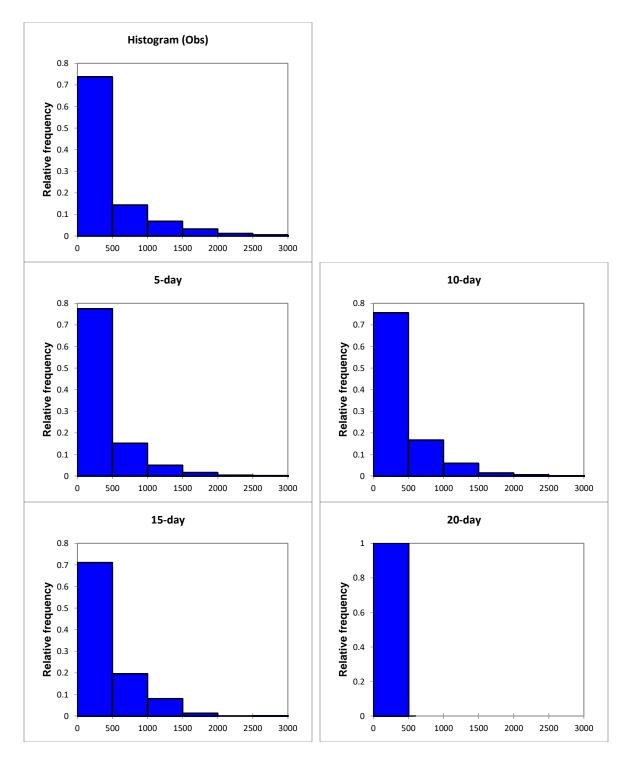
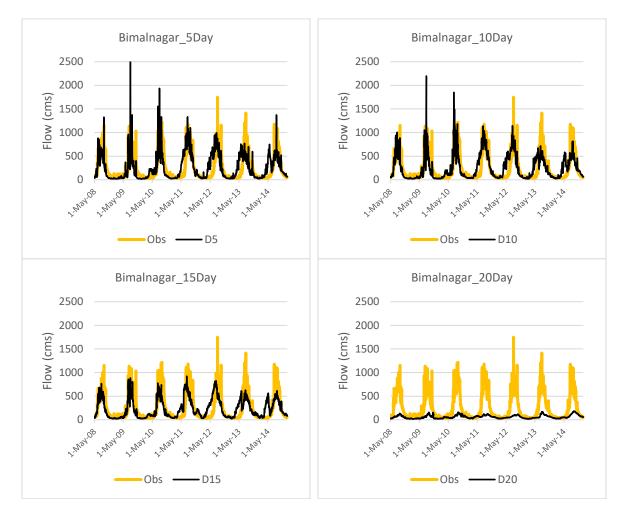


Figure 15 Histograms representing distribution of flow quantiles for observed and different lead time forecasts for Kumalgaon. Unit:  $m^3/s$ 

Statistic	Obs	5-day	10-day	15-day	20-day	25-day	30-day
Minimum	48.3	34.1	39.4	39.6	39.0	30.3	27.3
Maximum	5120.0	3679.9	3482.0	2639.4	390.5	267.9	201.3
1st Quartile	77.0	58.9	65.3	76.3	59.5	42.6	35.1
Median	128.5	126.4	143.7	219.7	107.6	52.7	40.4
3rd Quartile	534.0	424.8	488.0	633.0	189.7	92.7	63.8
Mean	396.9	319.8	332.6	387.2	132.1	73.4	54.4
Standard							
deviation (n-1)	527.1	421.8	406.0	394.0	81.0	43.9	29.2
Standard error							
of the mean	10.8	8.7	8.3	8.1	1.7	0.9	0.6

Table 9 Comparison of flow statistics of the observed and GloFAS forecasted flow series for Kumalgaon, Unit:  $m^3\!/\!s$ 

#### 2.2 Bimalnagar



**Figure 16** Comparison between observed and GloFAS forecast discharge for 5-day, 10-day, 15-day and 20-day lead time at Bimalnagar.

At Bimalnagar 5-day and 10-day forecast is able to capture the seasonality in flow but highly mismatch the peak flow values. Flow is overestimated in certain years and underestimated in other years. 15-day onwards flow forecast is highly underestimated.

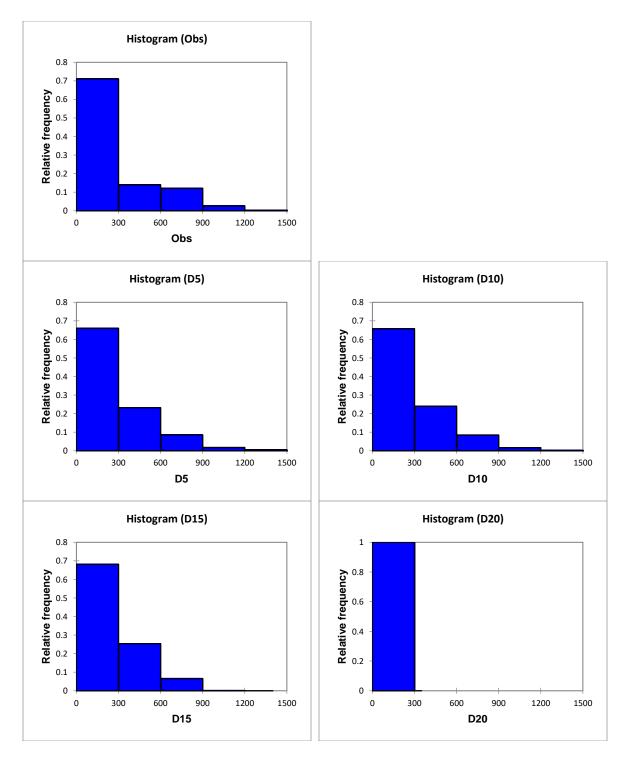
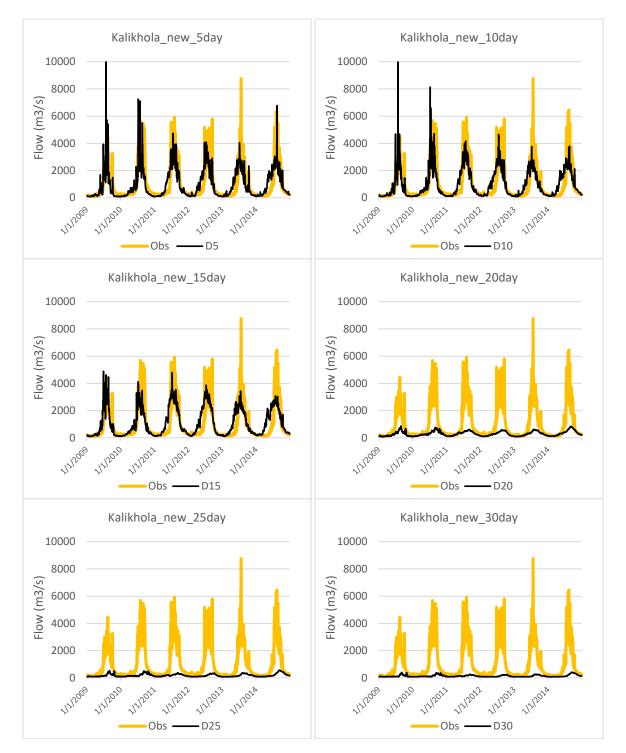


Figure 17 Histograms representing distribution of flow quantiles for observed and different lead time forecasts for Bimalnagar.

Statistic	Obs	5-day	10-day	15-day	20-day	25-day	30-day
Minimum	32.9	18.5	19.5	21.5	18.5	15.7	14.0
Maximum	1749.0	2505.6	2196.8	921.8	183.0	124.4	91.9
1st Quartile	54.1	42.8	50.4	65.3	32.9	20.3	17.0
Median	102.0	137.7	139.5	152.6	52.6	29.3	21.3
3rd Quartile	395.5	425.7	419.3	379.6	82.3	50.3	35.8
Mean	249.1	251.9	251.3	232.2	62.0	38.7	28.9
Standard							
deviation (n-1)	274.0	265.4	250.8	200.4	35.4	23.3	16.2
Standard error							
of the mean	5.6	5.4	5.1	4.1	0.7	0.5	0.3

Table 10 Comparison of flow statistics of the observed and GloFAS forecasted flow series for Bimalnagar, Unit:  $m^3/s$ 

### 2.3 Kalikhola



**Figure 18** Comparison between observed and GloFAS forecast discharge for 5-day, 10-day, 15-day, 20-day, 25-day and 30-day lead time at Kalikhola.

Statistic	Obs	5-day	10-day	15-day	20-day	25-day	30-day
Minimum	96.0	84.1	90.8	102.0	88.7	77.6	70.2
Maximum	8762.0	13660.3	11499.9	4885.6	870.5	552.4	407.0
1st Quartile	227.0	166.3	188.7	238.0	142.1	97.2	82.5
Median	372.0	460.0	540.4	618.0	259.4	135.4	100.7
3rd Quartile	1288.0	1582.3	1642.1	1932.5	415.6	230.3	163.2
Mean	1006.0	970.6	1002.1	1088.6	301.2	176.9	133.0
Standard							
deviation (n-1)	1239.0	1109.7	1060.5	1013.2	175.4	104.2	71.7
Standard error							
of the mean	26.5	23.7	22.7	21.6	3.7	2.2	1.5

Table 11 Comparison of flow statistics of the observed and GloFAS forecasted flow series for Kalikhola, Unit:  $m^{3}/s$ 

**Table 12** Statistical criteria for examining the accuracy of forecast time series for Kalikhola

	MAE	ME	SS	PBIAS	NSE	$\mathbb{R}^2$
5Day	478.64	-35.49	0.56	-3.53	0.45	0.761
10Day	473.3	-3.94	0.58	-0.39	0.43	0.767
15Day	489.33	82.58	0.58	8.21	0.37	0.765
20Day	710.37	-704.82	-0.13	-70.06	-55.6	0.739
25Day	829.09	-829.09	-0.36	-82.41	-191.76	0.545
30Day	873.08	-873.08	-0.45	-86.78	-432.26	0.433

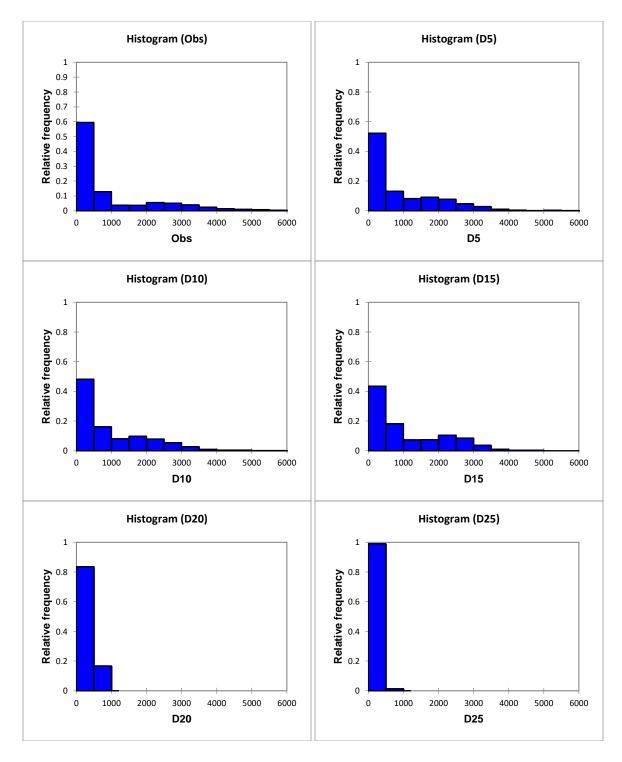
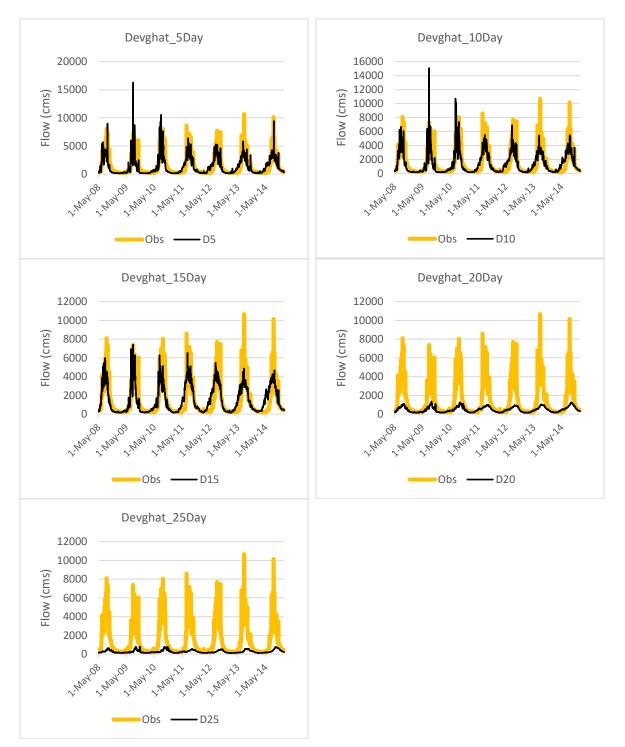


Figure 19 Histograms representing distribution of flow quantiles for observed and different lead time forecasts for Kalikhola.

## 2.4 Devghat (Basin Outlet)



**Figure 20** Comparison between observed and GloFAS forecast discharge for 5-day, 10-day, 15-day, 20-day, 25-day and 30-day lead time at Devghat.

Statistic	Obs	5-day	10-day	15-day	20-day	25-day	30-day
Minimum	168.0	129.8	136.8	155.7	138.6	118.5	102.3
Maximum	10674.0	16324.6	15093.3	7387.9	1360.4	800.2	595.6
1st Quartile	287.3	230.7	262.9	320.2	220.7	151.5	124.5
Median	552.0	594.5	710.4	851.5	413.5	207.5	150.2
3rd Quartile	2155.3	2002.3	2145.2	2633.5	693.2	350.2	246.3
Mean	1457.6	1314.0	1376.6	1501.4	485.2	269.7	198.8
Standard							
deviation (n-1)	1706.4	1523.0	1486.1	1426.9	283.7	153.6	104.6
Standard error							
of the mean	34.6	30.9	30.1	28.9	5.7	3.1	2.1

Table 13 Comparison of flow statistics of the observed and GloFAS forecasted flow series for Devghat, Unit:  $m^3/s$ 

**Table 14** Statistical criteria for examining the accuracy of forecast time series for Devghat

	MAE	ME	SS	PBIAS	NSE	$\mathbf{R}^2$
5Day	614.3	-143.5	0.7	-9.9	0.6	0.677
10Day	597.1	-80.9	0.7	-5.6	0.6	0.683
15Day	628.8	43.9	0.7	3.0	0.5	0.649
20Day	1001.8	-972.4	-0.1	-66.7	-38.4	0.634
25Day	1188.0	-1187.9	-0.4	-81.5	-170.3	0.343
30Day	1258.7	-1258.7	-0.5	-86.4	-395.8	0.206

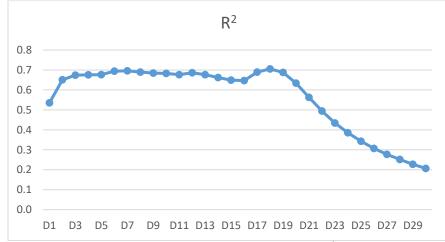


Figure 21 Day wise variation of Coefficient of determination  $(R^2)$  for 30 days forecast for Devghat

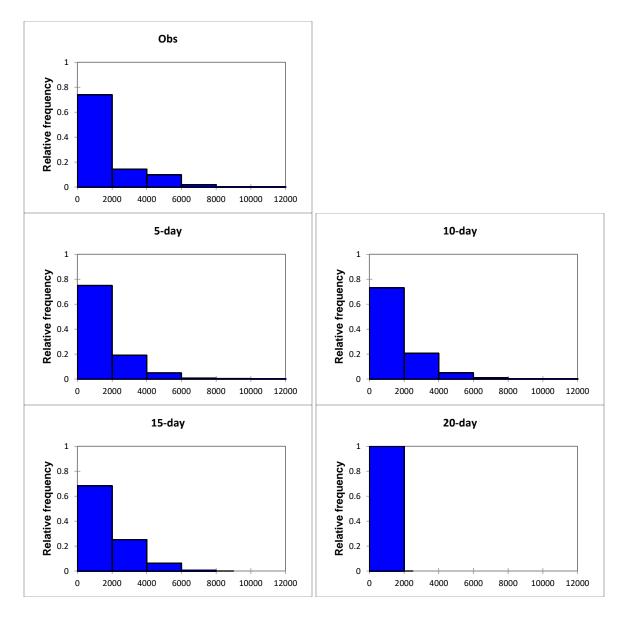


Figure 22 Histograms representing distribution of flow quantiles for observed and different lead time forecasts for Devghat.