Graduate Research Assistant - Final Report

Introduction

Context

Floods are one of the deadliest forms of natural disasters, and although the development of flood forecasts has been on the rise in recent years, there is a lack of ability to forecast flood subtypes, specifically flash floods. Flash floods have very distinct temporal and spatial characteristics, characteristics which generalised flood forecasts don't capture. Moreover, across West Africa devastating flash flood events occur frequently, often as a result of intense seasonal rains coupled with other factors such as poor urban planning, land degradation, and socio-economic systems that are not fit to effectively cope with these disasters. In addition, many populations across the region are extremely vulnerable to the impacts of flash floods. Therefore, it is important to create forecasting systems that are for flash floods specifically, and that have a user-focused approach, so that people can better prepare for these events.

Broader Project / Goals of the Position

This internship position was part of the NASA SERVIR - West Africa project. This project aims to promote the use of publicly available satellite imagery to help stakeholders and decision makers across WA make more informed decisions for 4 areas: agriculture and food security, water resources and hydro climatic disasters, weather and climate, and land cover and land use change and ecosystems. The main goal of the project this position is a part of is to develop a flash flood forecasting system based on satellite observations and short-term forecasts of precipitation for the West Africa region.

The key deliverable of this internship position was to test and validate the skill of the Ensemble Framework For Flash Flood Forecasting (EF5) hydrologic modeling tool over West Africa. EF5 is the hydrologic model used as part of the flash flood forecasting system being developed. Figure 1 shows the setup of EF5. The internship deliverable was broken down into 3 parts, as demonstrated in Figure 2.

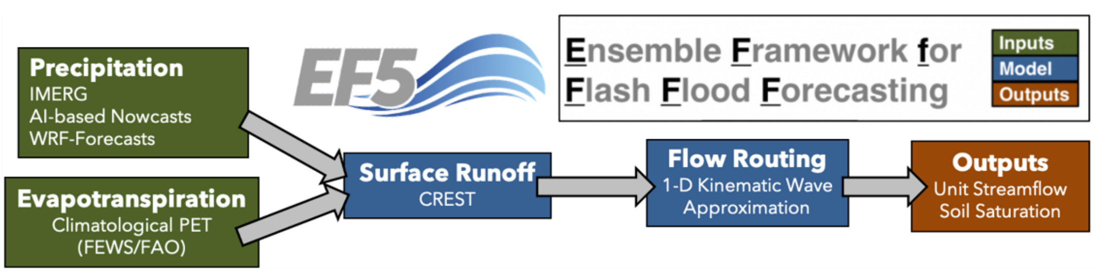

Figure 1 - A schematic showing the basic processes of EF5.

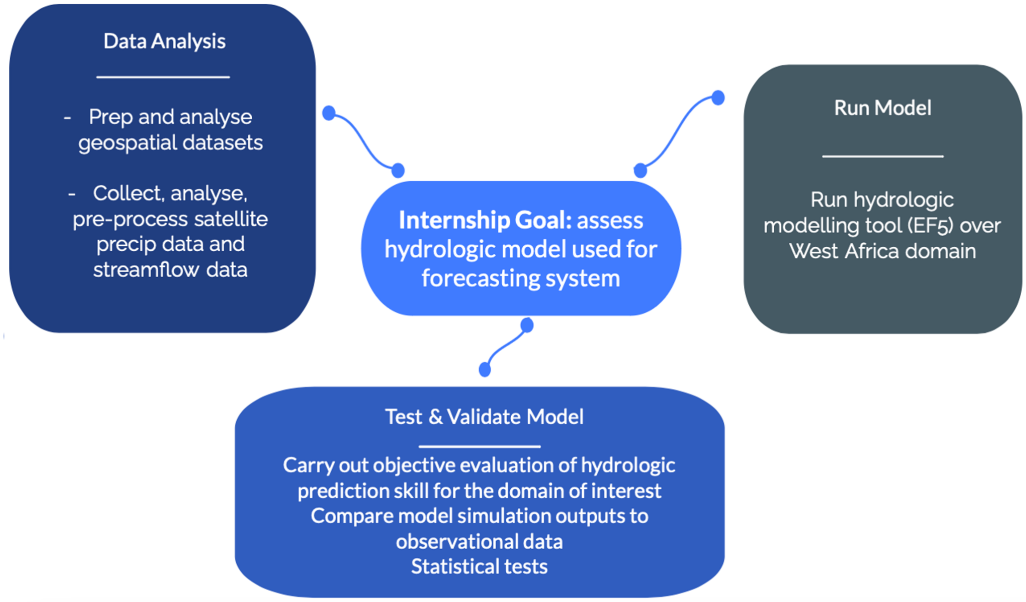

Figure 2 - A schematic outlining the key deliverables of the internship position.

The first step was to collect all the data that is needed to run the model. This included identifying flash flood events, preparing and analysing geospatial datasets, and collecting, analysing and pre-processing IMERG satellite data and streamflow data. The next stage was to run the hydrologic simulations with EF5 over the West Africa domain. The final step was to carry out an evaluation of the hydrologic prediction skill for the West Africa domain. This largely consisted of comparing model simulation outputs to observational data.

Data and Methods

Data

This work used the following datasets:

- IMERG satellite data. Early run, 30 minute, precipitation accumulation data was used, for the West Africa domain.
- Global Runoff Database Centre (GRDC) river discharge data. Daily data for all gauge stations in the West Africa region was extracted.

All data downloaded was for the West Africa domain, which is defined as xmin = -21.4, xmax = 30.4, ymin = -2.9, ymax = 33.1. The period of 2000-present was investigated, in order to match availability in both datasets. Figure 3 below shows the West Africa domain, and also demonstrates the locations of the GRDC gauge stations.

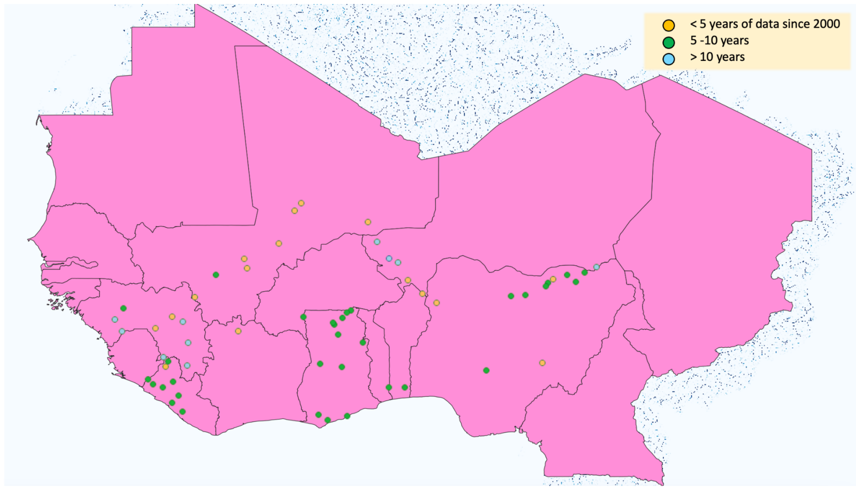

Figure 3 - A map showing the West Africa region. Dots represent GRDC gauge stations measuring river discharge, with colours indicating the number of years of available observational data.

Methods

The methodology was divided into four main tasks.

1) **Collecting reference data.** This involved downloaded GRDC river discharge data, and IMERG early run precipitation accumulation data. The details of this are discussed above. This task also involved compiling a list of flash flooding events across the West Africa domain. Three main sources were used: EMDAT, the Flash Flood Database, and Flood List reports. Once a list was compiled, events were selected based on available further evidence of the event, such as videos, images, or news reports. In the end, 5 flash flooding events were identified as focus points for further investigation.

2) **Configuring EF5.** This involved using QGIS to locate GRDC gauge stations on the 'correct' EF5 pixel. First, gauge stations were added to the QGIS file, and given coordinates based on GRDC information. Then, these gauge stations were overlaid with a raster file of the river channel network (flow accumulation grid) used by EF5. If the gauge stations were not located on an EF5 pixel with a river channel, then the coordinates of the station had to be revised. This is an important step as it enables EF5 to correctly pick up river discharge. This task also involved editing the EF5 configuration file. Gauge blocks had to be added to the configuration file, which matched with the revised coordinates of the GRDC gauge stations.

3) **Running EF5 simulations.** Two main runs of EF5 simulations were undertaken. Firstly, timeseries outputs were produced. This consisted of running EF5 for all gauge stations in the West AFrica domain, for the period of 2001 (not including a 6 month warmup period) to June 2023. Secondly, map outputs of maximum unit streamflow, QPE accumulation, and QPF accumulation were produced. These were run for specific flash flooding events (those identified in task 1), for the time period of 24 hours around the

given event. To accurately identify the 24 hours around the given events, the IMERG data was converted to animations, to easily identify when the precipitation for the flash flooding event occurred.

4) **Performing analyses of EF5 performance.** This task was two fold. Firstly, the map outputs produced for the specific flash flooding events were analysed. For this, the maps were added to the QGIS file and investigated based on how the EF5 outputs picked up the flash flood event, both in terms of location, spatial extent, and magnitude accuracies. Secondly, the timeseries outputs were analysed. Due to time constraints, only timeseries outputs for the gauge stations located in Ghana were assessed. In order to assess the performance of EF5 for these timeseries outputs, comparisons were made between simulations and observational data. The first step for this was to post-process the EF5 simulations. This changed the EF5 simulations from a temporal resolution of 30 minutes, and based on US time zones, to a temporal resolution of daily, based on Ghana time zones, so as to match with the observational data. From that, hydrograph plots were produced, to compare the simulated and observational timeseries. This then allowed for more specific assessments to be made.

Results

EF5 Spatial Assessment

5 flash flooding events were identified for further analysis, as mentioned above. These events were identified because they were recorded in at least two of the main sources used to compile all flash flood events in the West Africa domain, and because there was additional evidence available for the events, including videos and news reports. For these 5 events EF5 map outputs were produced and analysed. Figure 4 provides an overview of how the map plots can be interpreted.

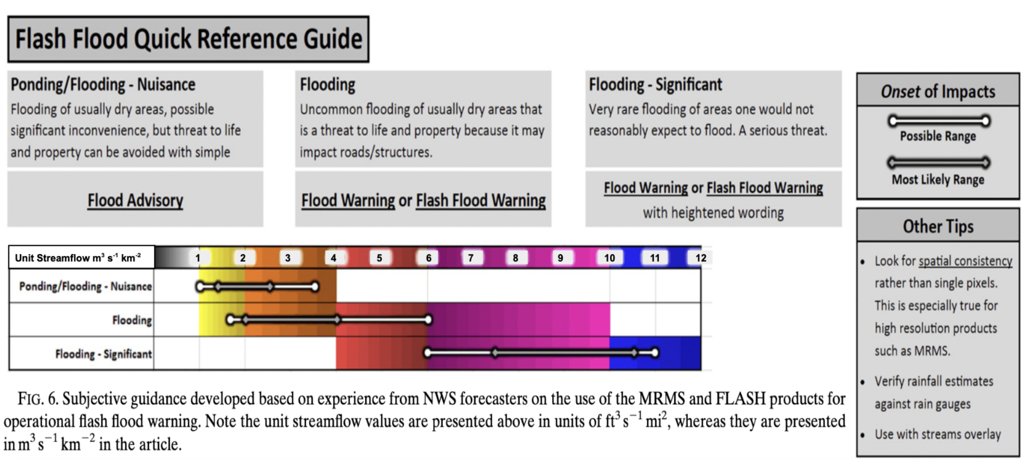

Figure 4 - A flash flood reference guide. This scale is used for issuing flash flood warnings in the US, and can be used to provide a general understanding of flash flood levels over the West Africa domain.

Côte d'Ivoire flash flood June 2018

This event occurred on the evening of the 18th June 2018, in Abidjan and surrounding areas. Abidjan local media reports stated that around a week's worth of rain fell in 4 hours, and that Adiake, a town approximately 75 km east of Abidjan, recorded 113mm of rain in 24 hours. The disastrous event resulted in 18 reported fatalities and severe material damage.

Figure 5 shows that EF5 does well in simulating the flash flooding event. In terms of the magnitude, EF5 simulated maximum unit streamflow values of up to 4.5 at the centre of the event, indicating flooding to significant flooding, based on the above reference guide. Also, EF5 does well spatially, picking up the event in Abidjan, and also the event in Adiake which is mentioned in news reports. Also shown in Figure 5, the IMERG data picks up the rainfall of the event well, with cumulative precipitation values matching well with values mentioned in news reports.

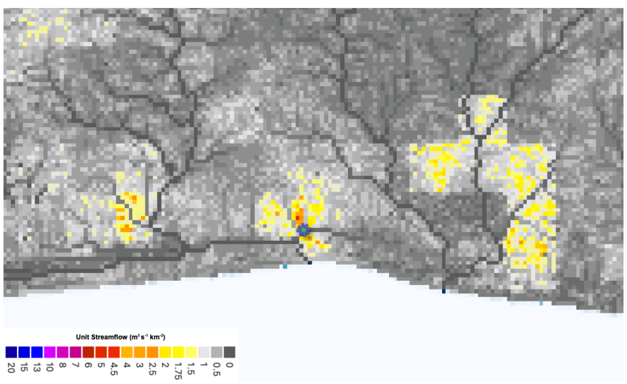
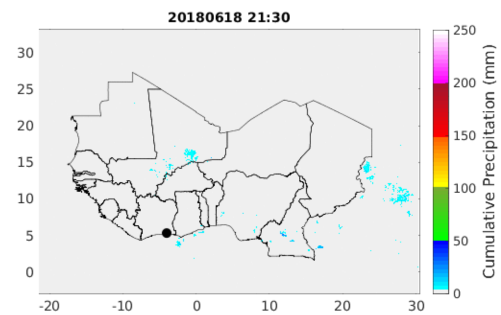

Figure 5 - EF5 maximum unit streamflow output for the event period (left). IMERG animation of cumulative precipitation for the event period (right).

Niger flash flood June 2020

This event occurred on the 18th June 2020, in Lagos. Reports noted that almost 90mm of rain fell in Lagos over the 24 hour period. The event caused 2 reported fatalities and displaced 20 families.

Figure 6 shows that EF5 performs averagely in simulating the flash flooding event. In terms of the magnitude, EF5 simulated maximum unit streamflow values peak at about 2.5 or 3, which would be interpreted as between nuisance flooding and flooding. Given the levels of flooding reported in news articles and further evidence, perhaps EF5 does not capture the full extent of the severity of the event. Spatially, EF5 again performs averagely, with largest maximum unit streamflow values occurring just south of where the event occurred, according to sources. The IMERG data picks up the location of the rainfall well, but cumulative precipitation values are slightly lower than news reports suggest.

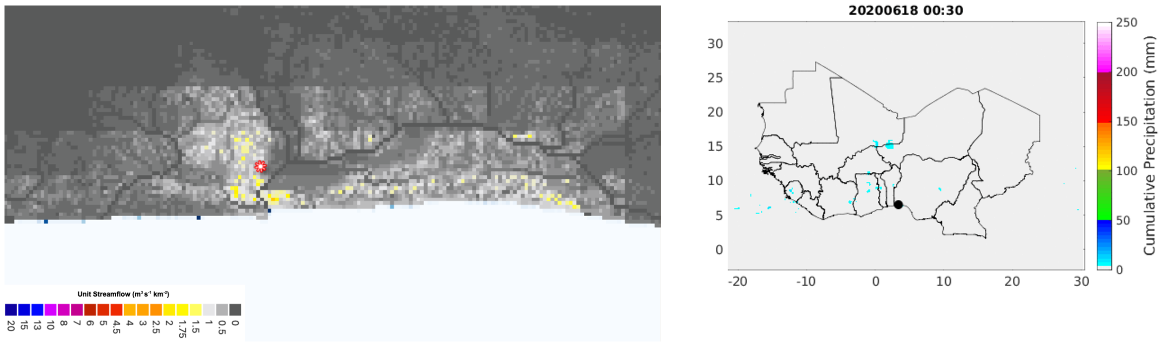

Figure 6 - EF5 maximum unit streamflow output for the event period (left). IMERG animation of cumulative precipitation for the event period (right).

Côte d'Ivoire flash flood June 2020

This event occurred from the 24th-25th June 2020, in the Cocody suburb of Abidjan. According to news reports, 240mm of rain fell in a few hours in Cocody, and 146.4mm fell over the 24 hours period in Abobo. There were 5 reported fatalities, 36 people evacuated, and damage to roads and houses.

Figure 7 shows that EF5 does not do well in simulating this flash flooding event. The maximum unit streamflow values range from 0-1 across the region, which indicates no flash flooding occurred. Similarly, EF5 does not pick up the rainfall that occurred in the region, and therefore it is probable that this lack of rainfall detection was the reason why the EF5 simulations show no occurrence of a flash flood.

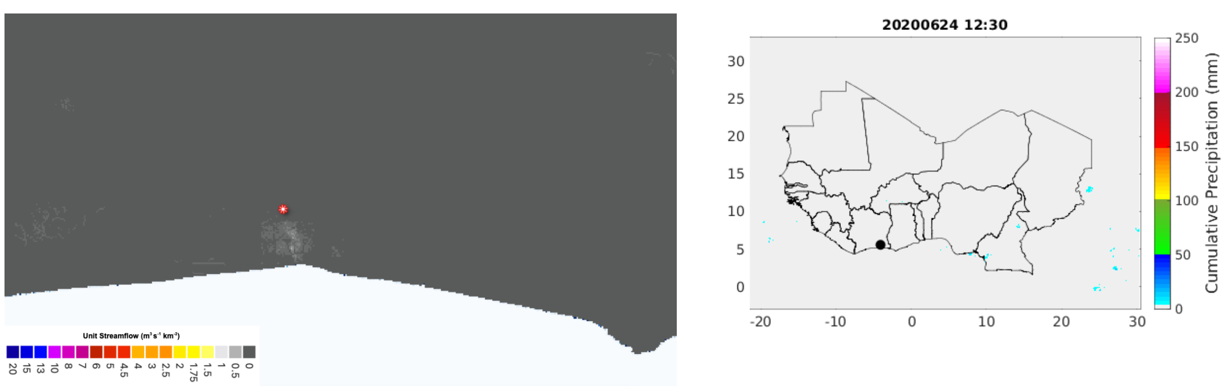

Figure 7 - EF5 maximum unit streamflow output for the event period (left). IMERG animation of cumulative precipitation for the event period (right).

Ghana flash flood October 2020

This event occurred on the 10th October 2020 in areas of Accra and neighbouring Kasoa, in the Central Region. Reports stated over 78 mm of rain in 24 hours was recorded at the Kotoka International Airport. There were no reported fatalities or displacement from this event, but there were reports of vehicles being abandoned or swept away.

Figure 8 shows that EF5 performs averagely in simulating this event. Simulated maximum unit streamflow shows values of up to 2 at the centre of the event, indicating nuisance flooding. Spatially, EF5 does a good job of accurately picking up the location of the event. The IMERG data picks up low values of rainfall for the event period, which again is likely the reason for the poor EF5 performance.

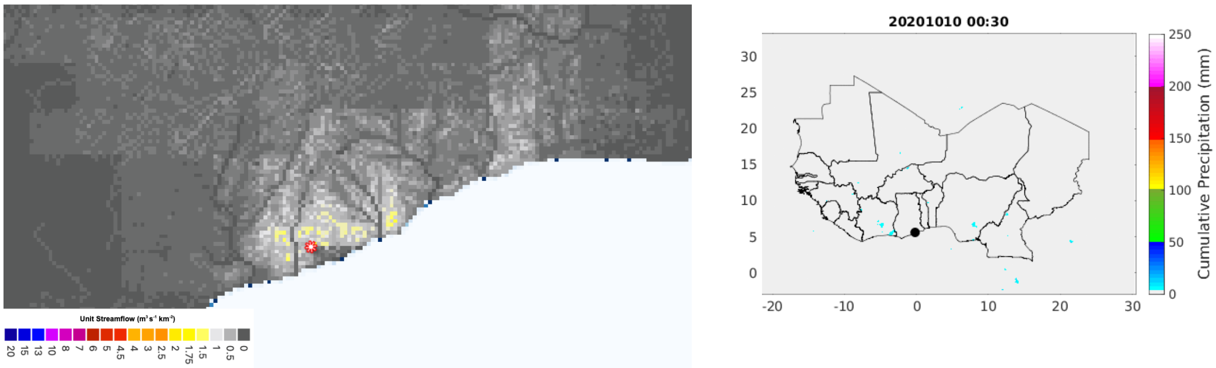

Figure 8 - EF5 maximum unit streamflow output for the event period (left). IMERG animation of cumulative precipitation for the event period (right).

Ghana flash flood March 2023

This event occurred on the 7th March 2023 in Accra. There is limited local news reporting of the event, but the Ghana Meteorological Agency stated that "Southeastern Ghana has been engulfed by a rain-bearing cloud. This is producing rain of varying intensity within the Volta region". The event resulted in 3 reported fatalities, blackouts in part of the city, and severe traffic disruption.

Figure 9 shows that EF5 does well in simulating the flash flooding event. In terms of the magnitude, EF5 simulated maximum unit streamflow values of up to 4 at the centre of the event, indicating flooding to significant flooding. Also, EF5 does well spatially, with highest values being seen at the location of the event. The IMERG data also picks up the rainfall of the event well, with cumulative precipitation values reaching over 100 mm.

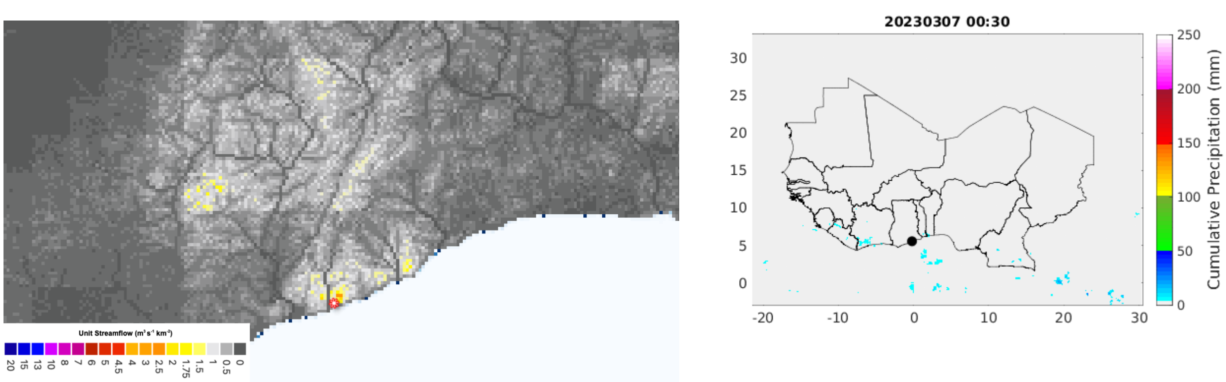

Figure 9 - EF5 maximum unit streamflow output for the event period (left). IMERG animation of cumulative precipitation for the event period (right).

Overall, these events suggest that EF5 performs fairly well at simulating individual flash flooding events, but relies heavily on IMERG data inputs. When IMERG does not pick up the precipitation, EF5 will not pick up the flash flooding event.

EF5 Skill Assessment in Ghana

To assess the skill of EF5 in Ghana, hydrographs were produced, comparing EF5 timeseries discharge simulations to GRDC observational discharge values. Due to the time constraints of this position, only GRDC gauge stations in Ghana were investigated, however in the future this assessment should be performed for all gauge stations across the West Africa domain.

This section will not show all hydrograph plots produced, but instead will show 4 examples.

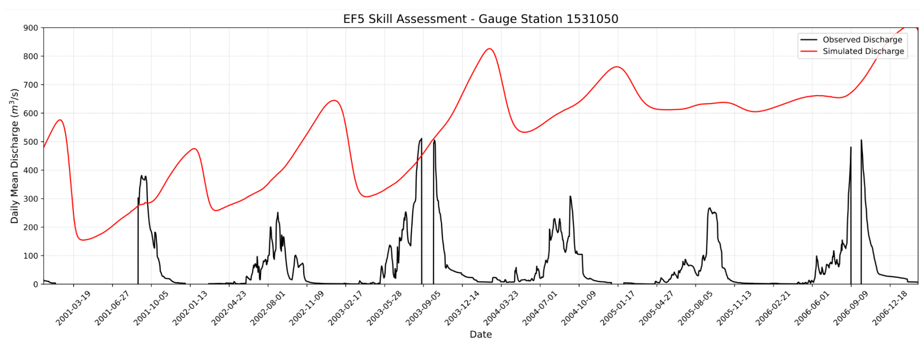

Figure 10 - Hydrograph plot comparing EF5 simulations to observed data at the Gauge Station 1531050.

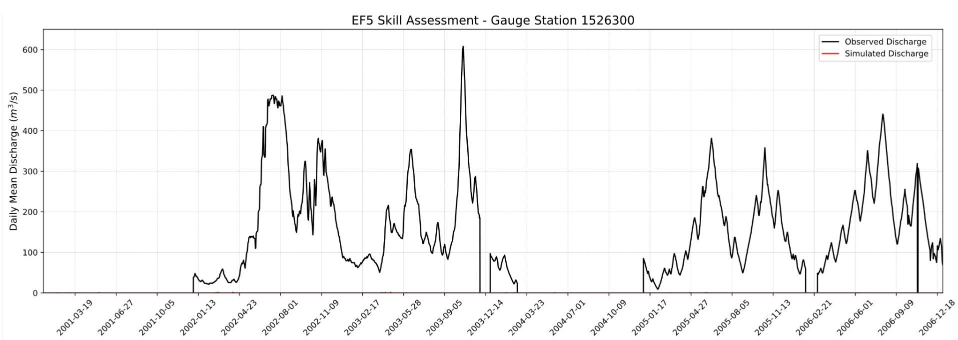

Figure 11 - Hydrograph plot comparing EF5 simulations to observed data at the Gauge Station 1526300.

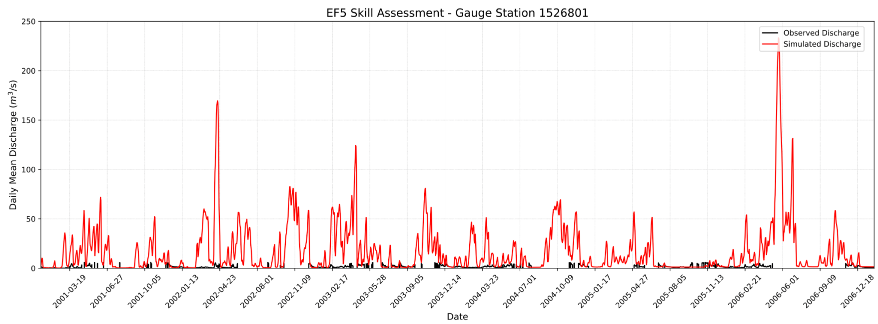

Figure 12 - Hydrograph plot comparing EF5 simulations to observed data at the Gauge Station 1526801.

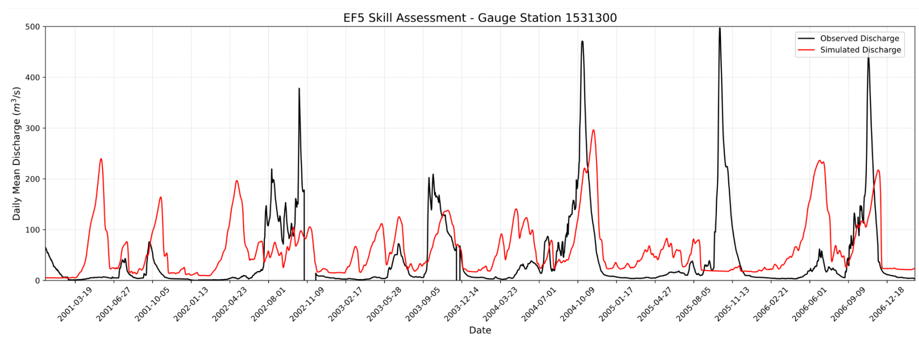

Figure 13 - Hydrograph plot comparing EF5 simulations to observed data at the Gauge Station 1531300.

These 4 hydrograph plots show varying skills of EF5 simulations. This can occur for a number of reasons. For Figure 10, it is likely the case that there is a problem with the parameters of EF5. For Figure 11, discharge is not picked up by EF5 at all. This is likely because the location of the gauge station on the EF5 grid is not on a river channel pixel. For Figure 12, there is very high simulated discharge compared to observed. The River Volta is heavily managed (especially the large Akosombo Dam), and so for any stations downstream of the dam, such as this gauge station, the discharge will be affected. This information is not inputted into EF5, and so the model does not take into account the impacts of the dam on discharge. For Figure 13, the simulated and observed discharge often match up fairly well. However, often the simulations show increases in discharge, when the observations do not. It could be the case that the groundwater reservoirs are bigger than EF5's estimates, and so spikes in rainfall do not cause as big an increase in discharge as EF5 simulates. Also, EF5 does not pick up the magnitudes of the biggest spikes in observational data. This could be a result of IMERG data not picking up the spike events.

For more hydrograph plots, and further details of assessments of the skill of EF5 in Ghana, see the slide deck 'EF5 Skill Ghana'.

Conclusions

Overall, EF5 has a mixed performance in terms of its skill. For map outputs of maximum unit streamflow, EF5 often does well in simulating the magnitude and spatial characteristics of the event. However, this is only the case when IMERG data accurately picks up precipitation levels. When IMERG data fails to pick up rainfall, EF5 outputs have a very poor skill. In terms of hydrograph results from timeseries outputs, EF5 shows varying skill. It is often the case that the EF5 simulated discharge does not match well with the observed discharge, and potential reasons for this include the presence of structures such as dams, incorrect gauge station locations for the EF5 pixels, and problems with the parameters of EF5.

Due to time constraints, this skill assessment of EF5 that was performed was limited. In the future, EF5 timeseries skill assessments should be performed for all gauge stations in West Africa, not just Ghana. This task would first involve post-processing the EF5 timeseries outputs, and then plotting hydrographs for all gauge stations. Also, statistical tests should be performed to compute the skills of EF5 quantitatively.