River Flood Prediction Using a Long Short-Term Memory Recurrent Neural Network

Andrew T. White[1], Kristopher D. White[2], Christopher R. Hain[3], Jonathan L. Case[4]

[1]University of Alabama in Huntsville/NASA MSFC SPoRT

[2]NWS/NASA MSFC SPoRT

[3]NASA MSFC SPoRT
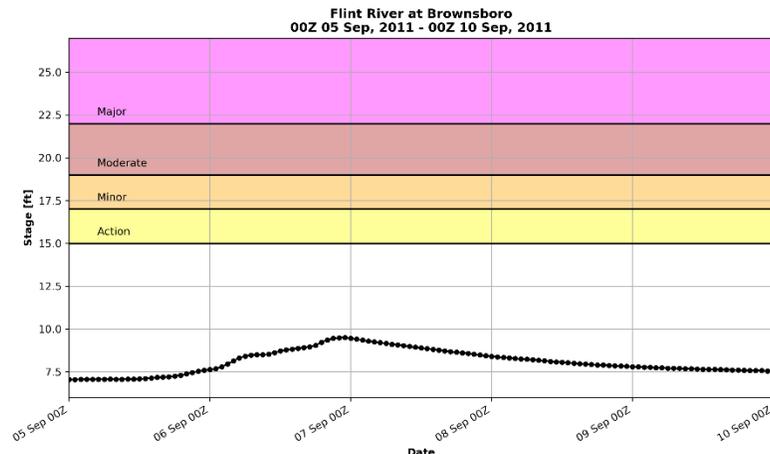
[4]ENSCO, Inc./NASA MSFC SPoRT

Background

➤ During approaching flooding events, NWS offices rely on their River Forecast Center (RFC) to produce river gauge height predictions.

  ➤ Typically, precipitation is only accounted for in the forecast out to 1 or 2 days.

  ➤ Forecasts are only available for deemed "forecast points"

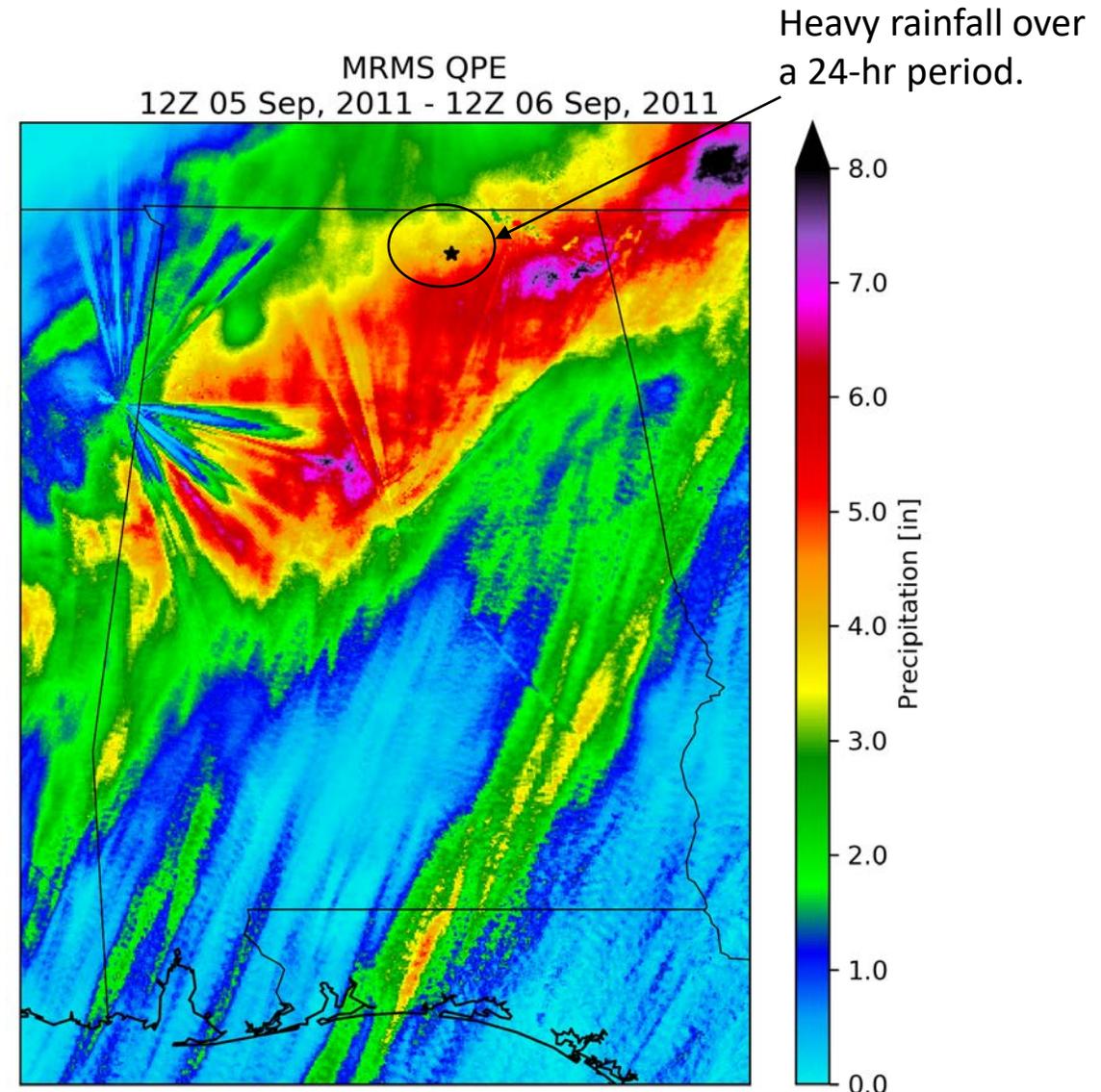➤ Without rainfall forcing, forecasters have to rely on "rules of thumb"
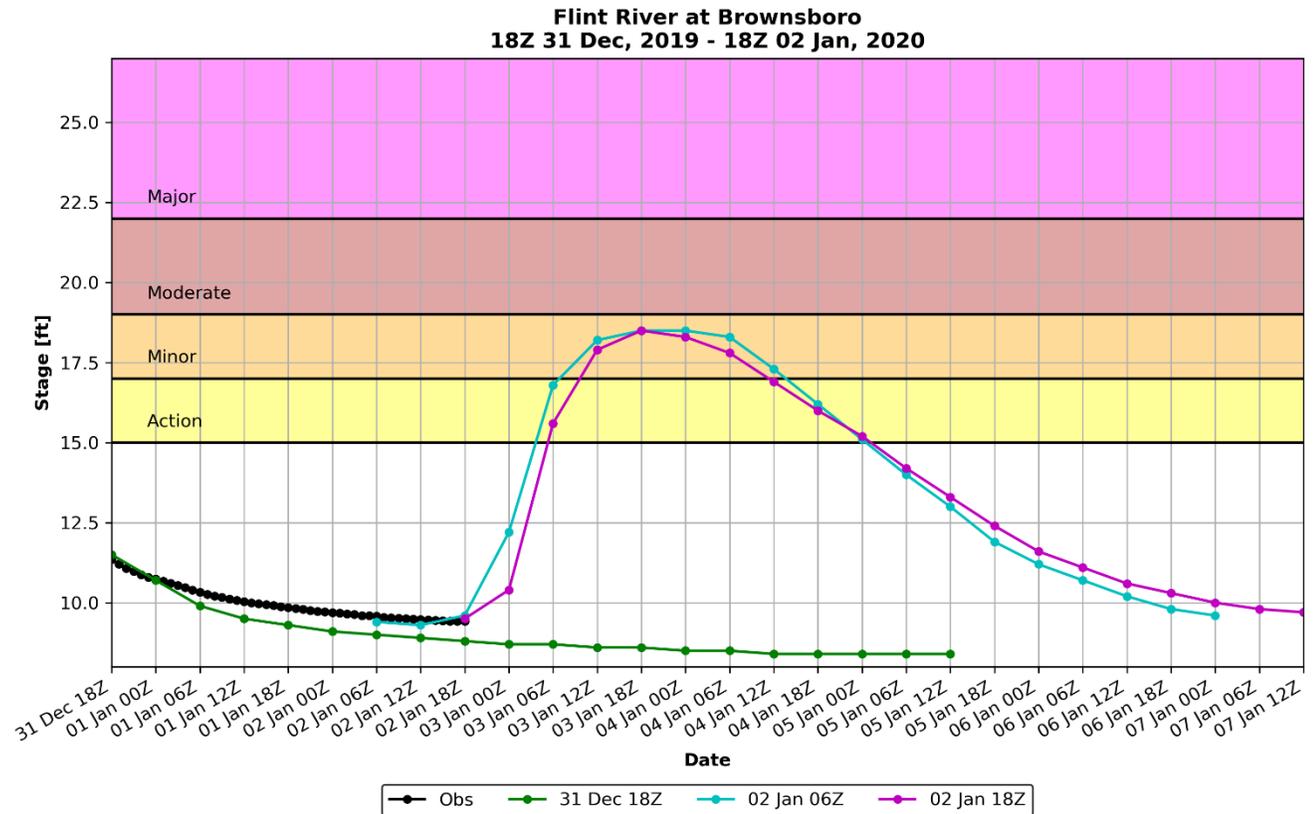
RFC forecasts for the Flint River in Northern Alabama.

Flood Forecasting

➢ Tropical Storm Lee case study

  ➢ Heavy rainfall was forecasted over North Alabama.

  ➢ Widespread river flooding was forecasted.

  ➢ Very little flooding was observed.

Heavy rainfall over a 24-hr period.

MRMS QPE
12Z 05 Sep, 2011 - 12Z 06 Sep, 2011

Precipitation [in]

Flint River at Brownsboro
00Z 05 Sep, 2011 - 00Z 10 Sep, 2011

Stage [ft]

Major
Moderate
Minor
Action

Date

Minor rise in gauge height.

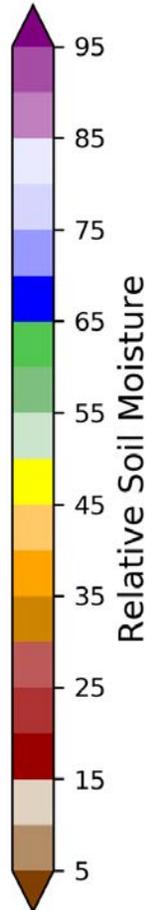# Importance of Soil Moisture

➢Rainfall alone is not enough to infer flood potential.

➢Soil moisture conditions control rainfall infiltration rates.

➢Incorporation of SPoRT-LIS into flood forecasting.

➢Analyze pre-storm soil moisture conditions.

40-100 cm Relative Soil Moisture valid 12Z 05 Sep, 2011
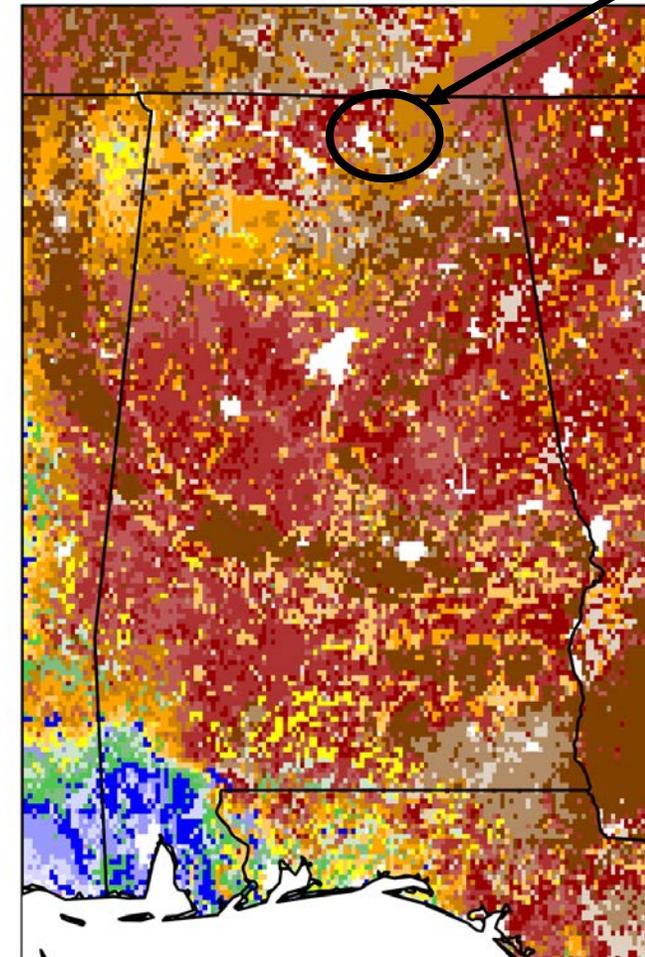
Very low antecedent soil moisture.

Relative Soil Moisture

95
85
75
65
55
45
35
25
15
5

Forecasting Challenges Remain

➢ While incorporation of soil moisture in flood forecasting has been beneficial, uncertainties remain.

  ➢ Which soil layer is most important?

    ➢ 0 – 10 cm, 10 – 40 cm, 40 – 100 cm, 100 – 200 cm, 0 – 200 cm

  ➢ Are there a critical values at which flooding becomes more likely?

  ➢ How fast does soil moisture change?

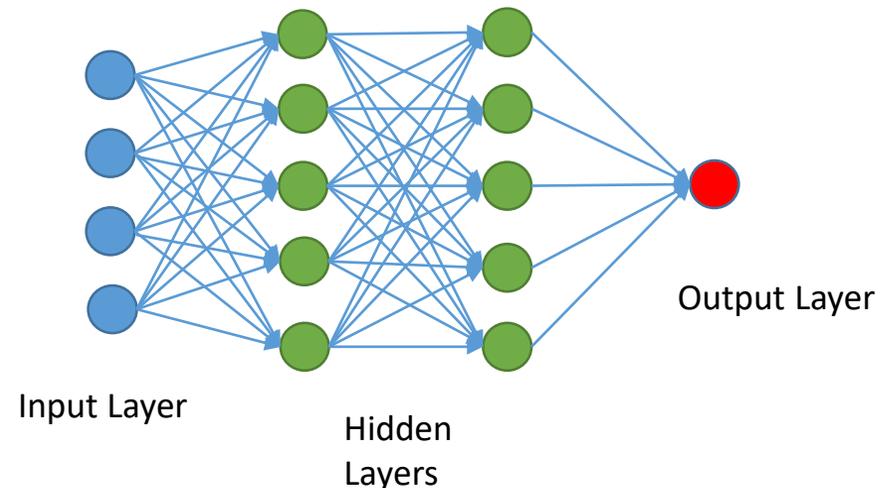   ➢ What type of soil is located in the basin of interest?

Machine Learning

➢Machine learning consists of finding statistical relationships to go from an input(s) to an output.

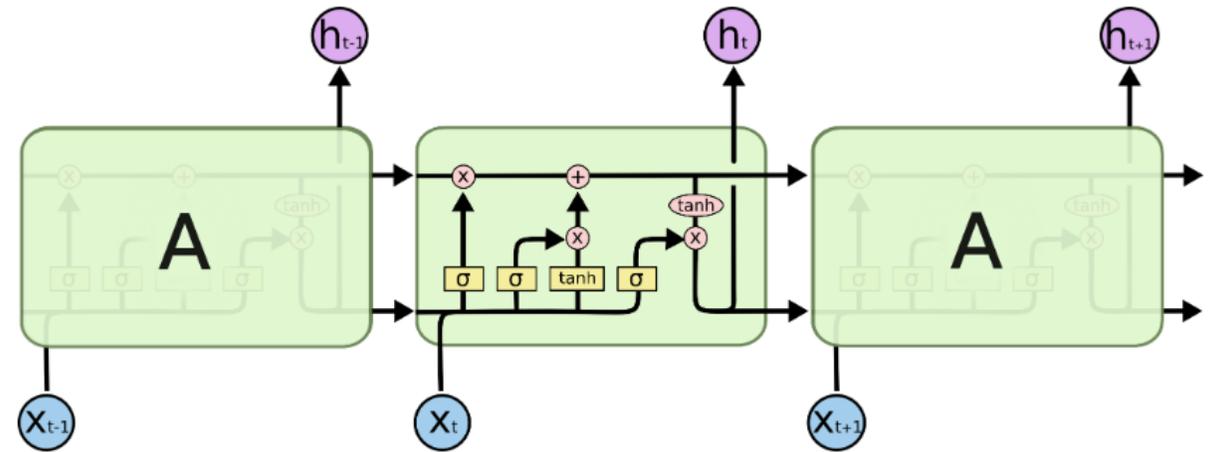➢The developed relationships are learned from the data.

➢Random Forest
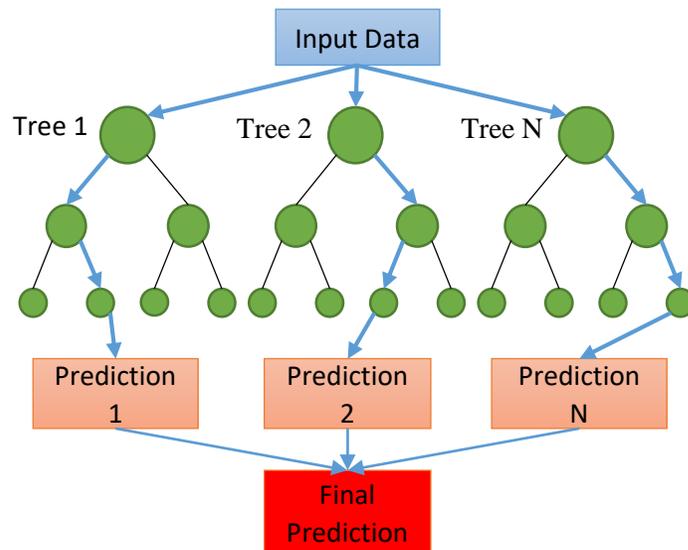
➢Neural Network

Long short-term memory (LSTM) model

➢Type of Recurrent Neural Network (RNN)

   ➢Composed of several, connected networks which are time-dependent.

   ➢Variation of on the traditional RNN designed to use time dependent data more effectively.


Example LSTM Diagram

LSTM Model Input

➢ The LSTM model was trained using available data over the Jan. 2010 – Dec. 2018.

➢ Input time-lagged features:

  ➢ SPoRT LIS Relative Soil Moisture (0 – 10 cm, 10 – 40 cm, 40 – 100 cm, 100 – 200 cm, 0 – 200 cm)

  ➢ Gauge Height

 ➢ MRMS 6hr QPE for training (any QPF can be used for forecasting)
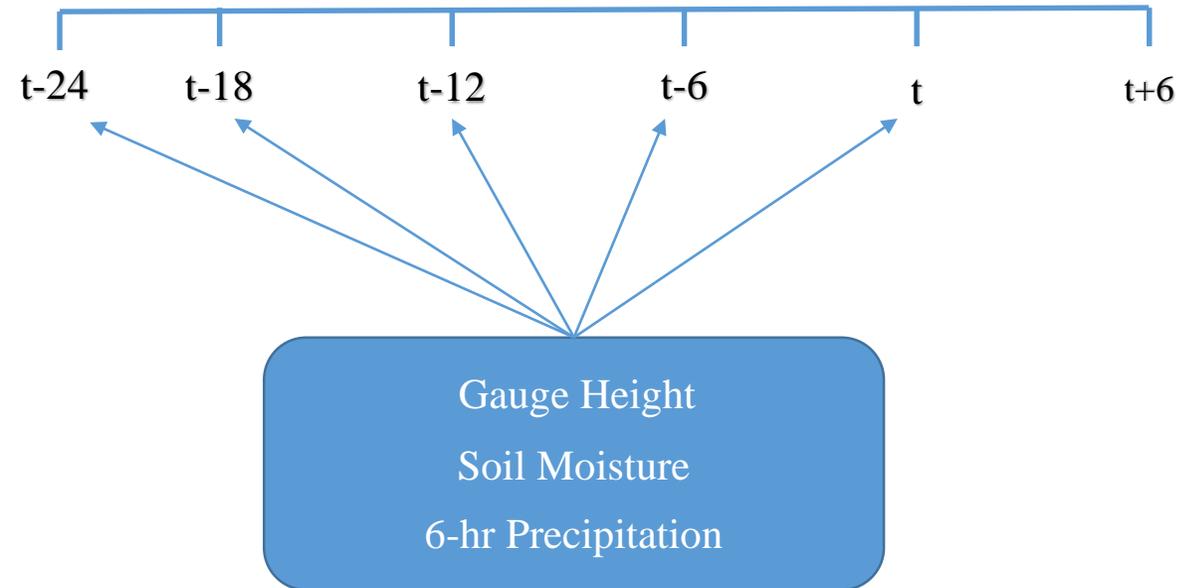
Project Area

➢ The Geospatial Attributes of Gages for Evaluating Streamflow, version II, (GAGES-II) produced by USGS was used to get gauge and basin delineation shapefiles.

➢ 1,796 basins within the southeast U.S. were chosen for initial testing.

➢ Defined basin boundaries are used to take areal averages of rainfall and soil moisture.
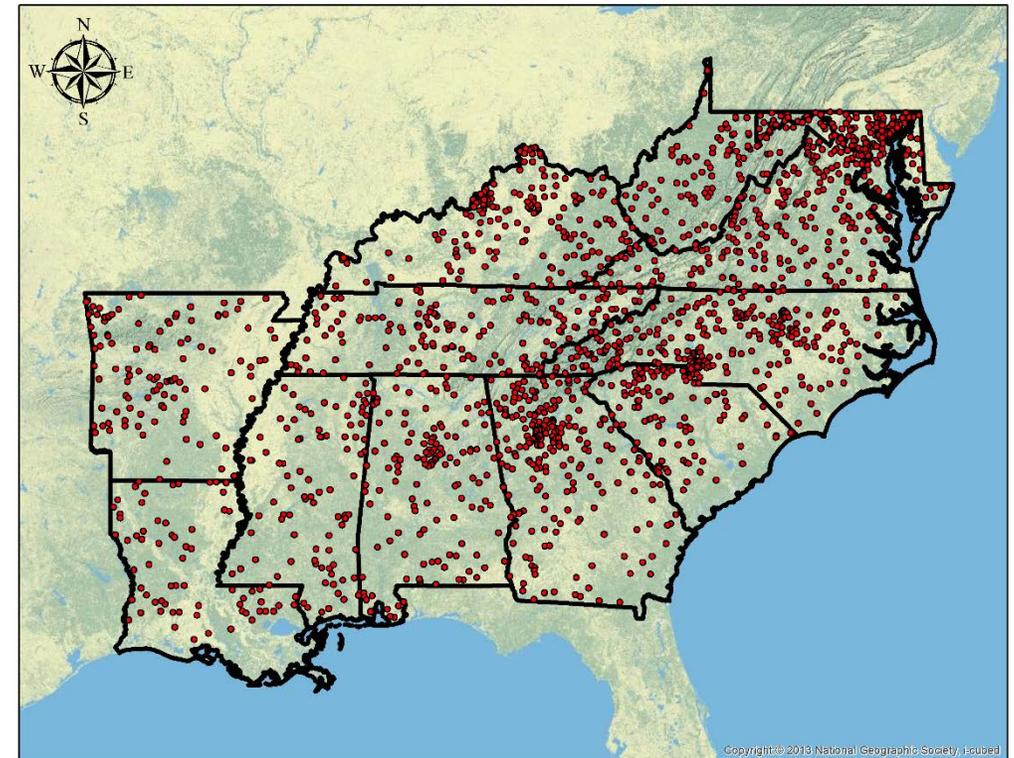

Southeast U.S. Domain

Operational Forecasts

➢ 5 day forecast of gauge height are being produced 4 times a day (0, 6, 12, 18 UTC).

➢ Gauge height is predicted every 6 six hours within the 5 day period.

➢ Multiple models are run with different QPF (GFS, WPC) forcing.

➢ Basin average precipitation is overlaid to allow forecasters to observe the model response to different forcing.
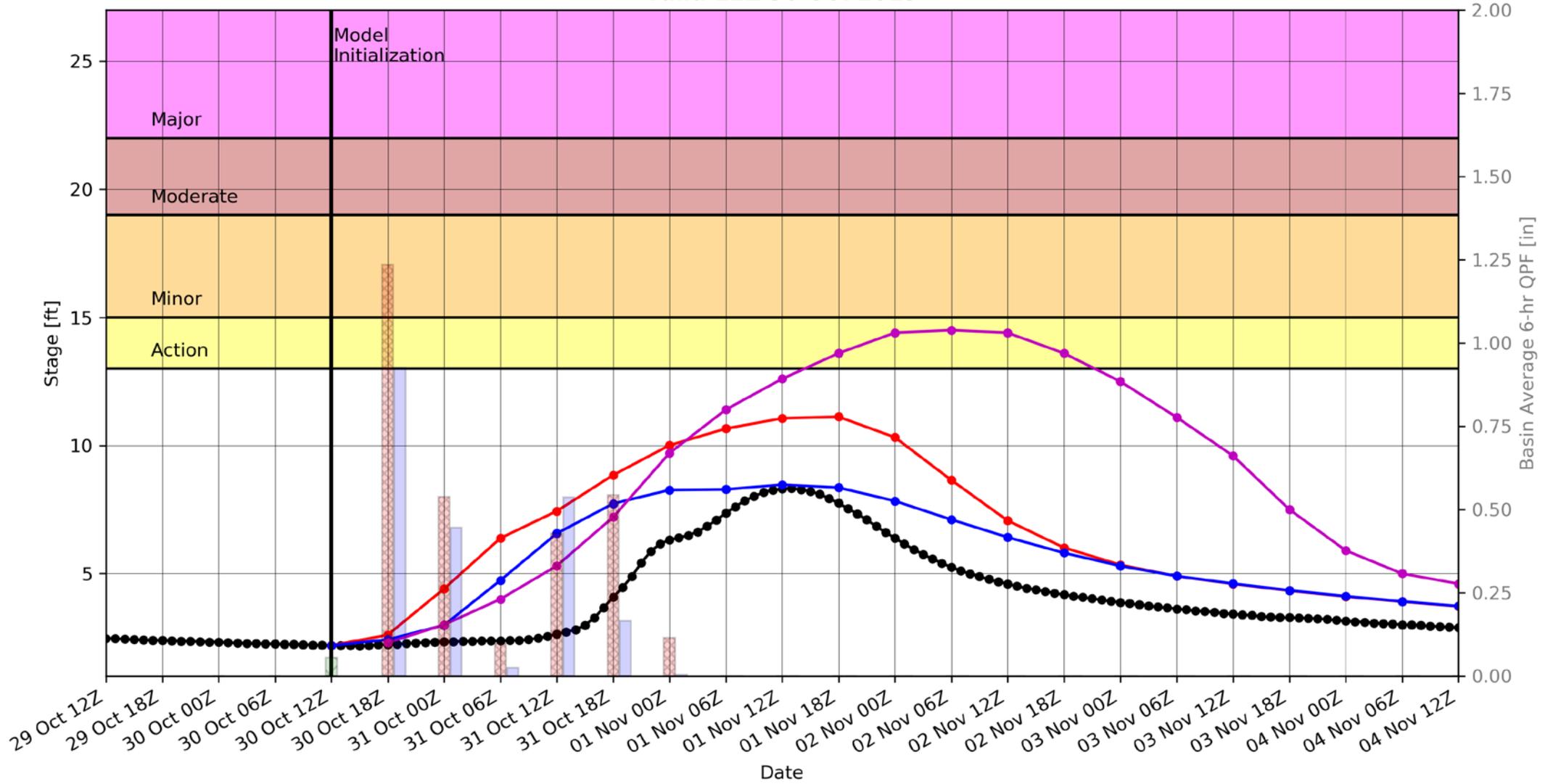

Flint River Flood Model
valid 00Z 01 Jan 2020
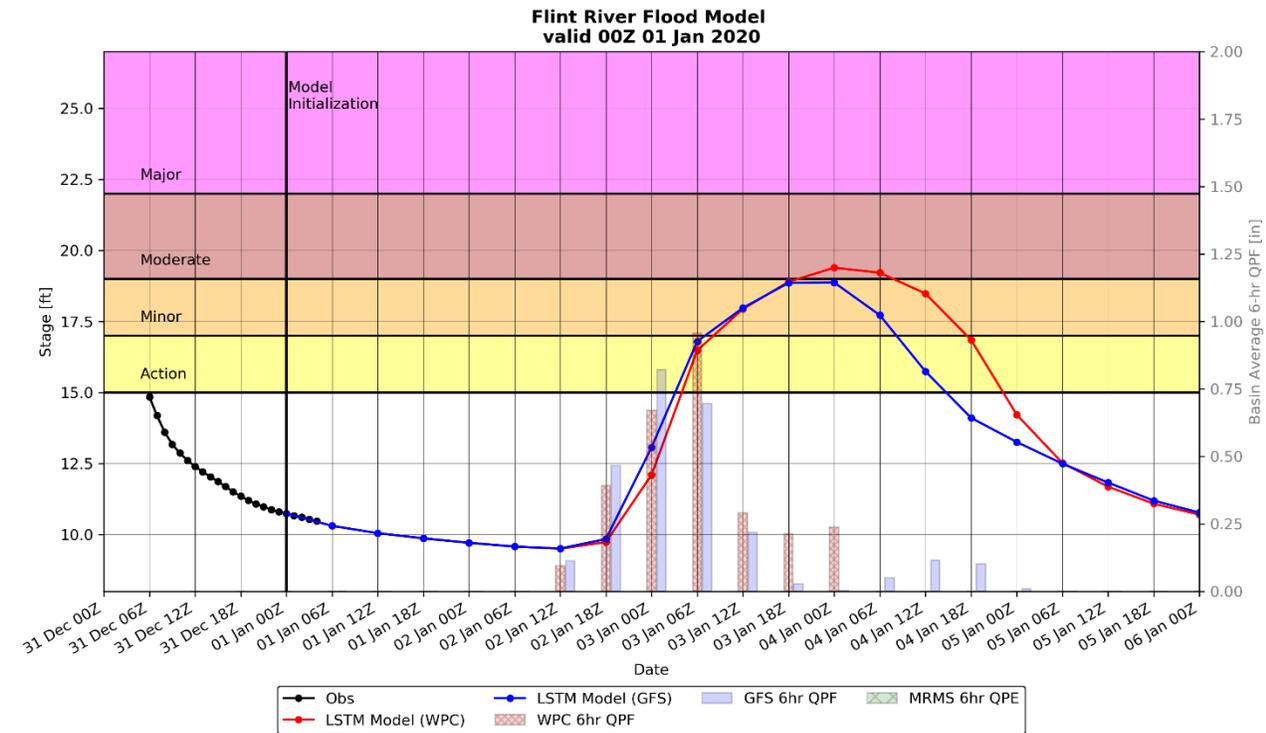
Paint Rock Flood Model
valid 12Z 28 Oct 2019
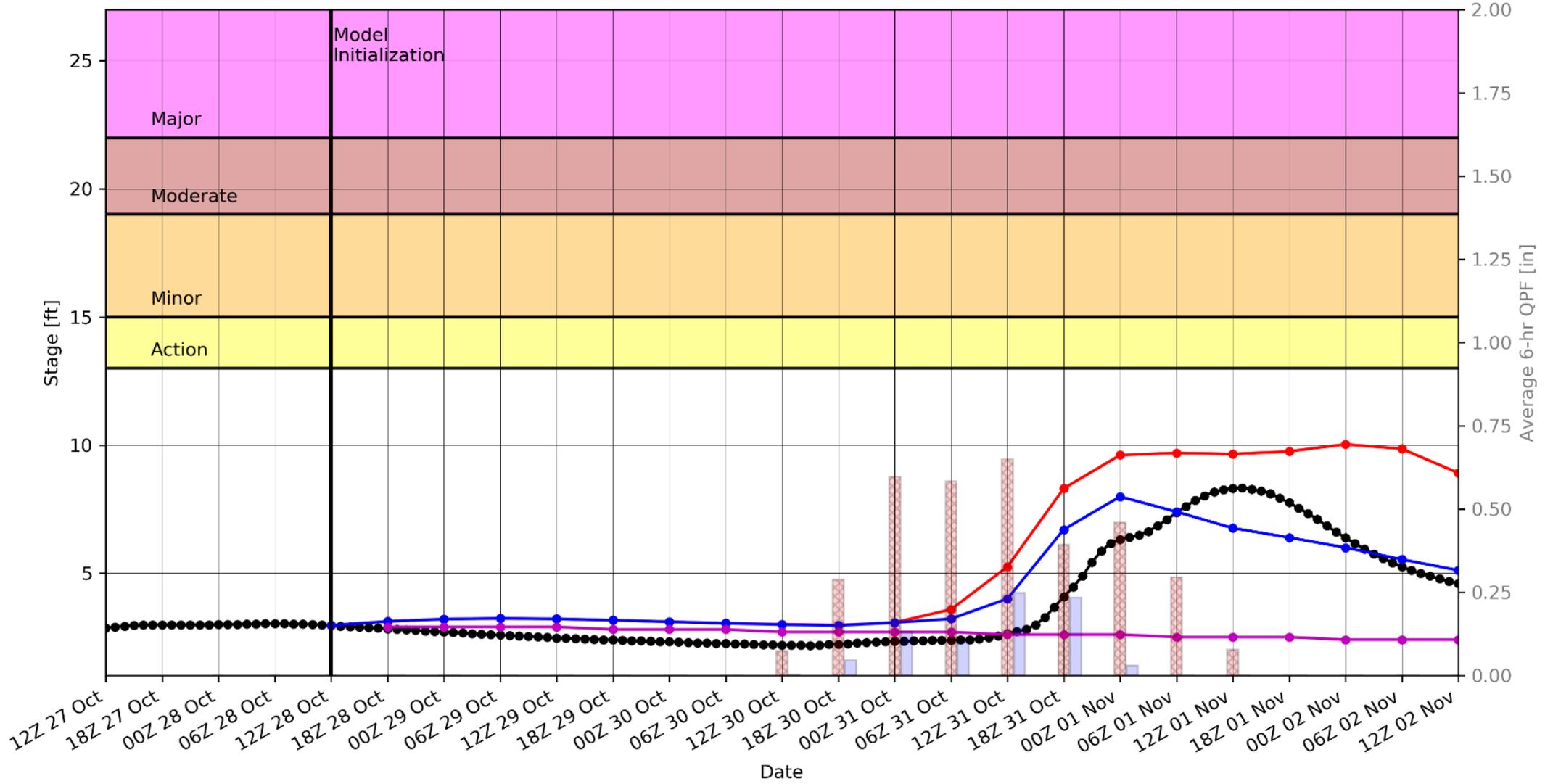
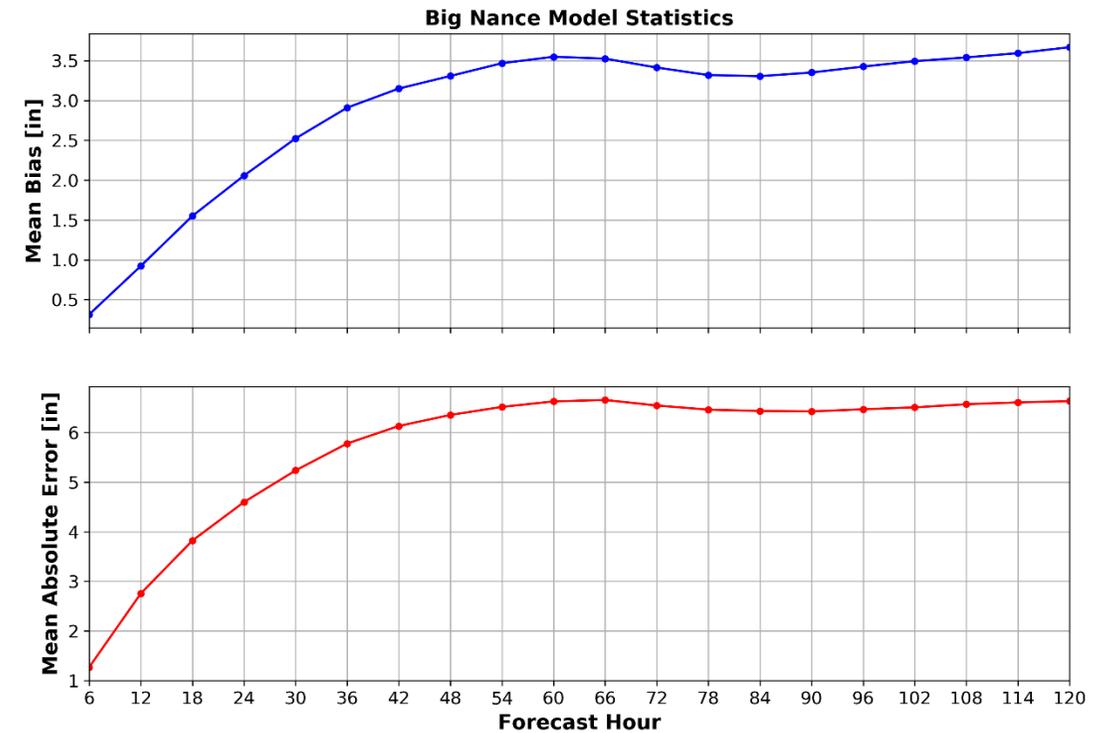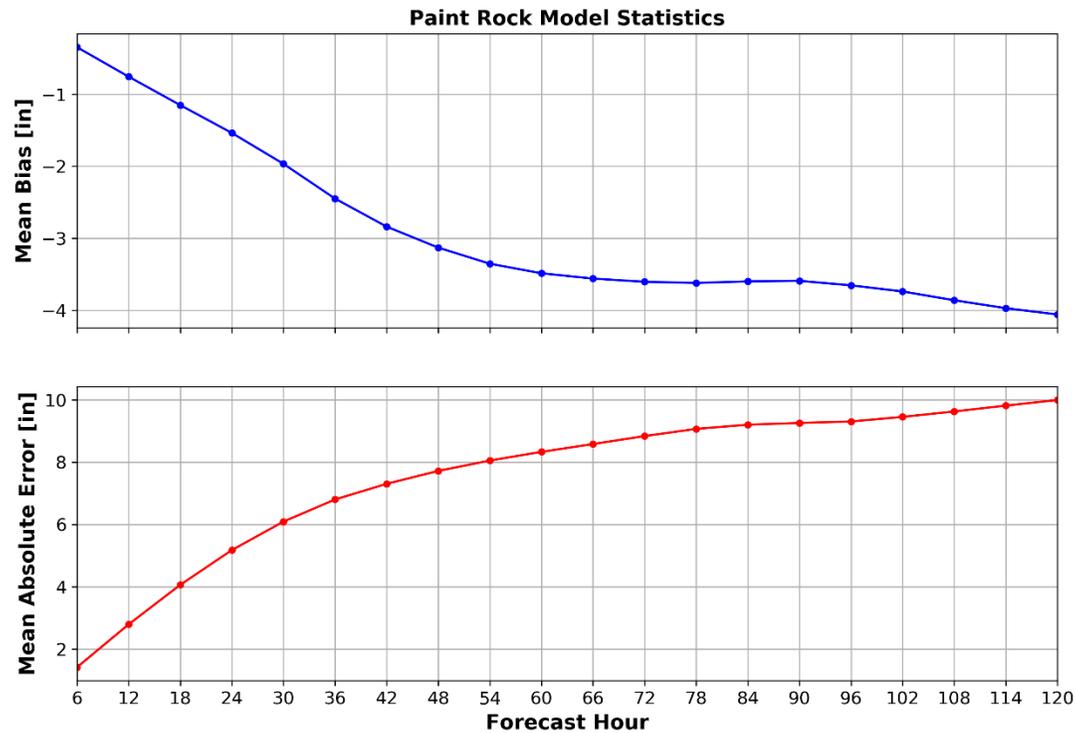Paint Rock Flood Model
valid 12Z 29 Oct 2019
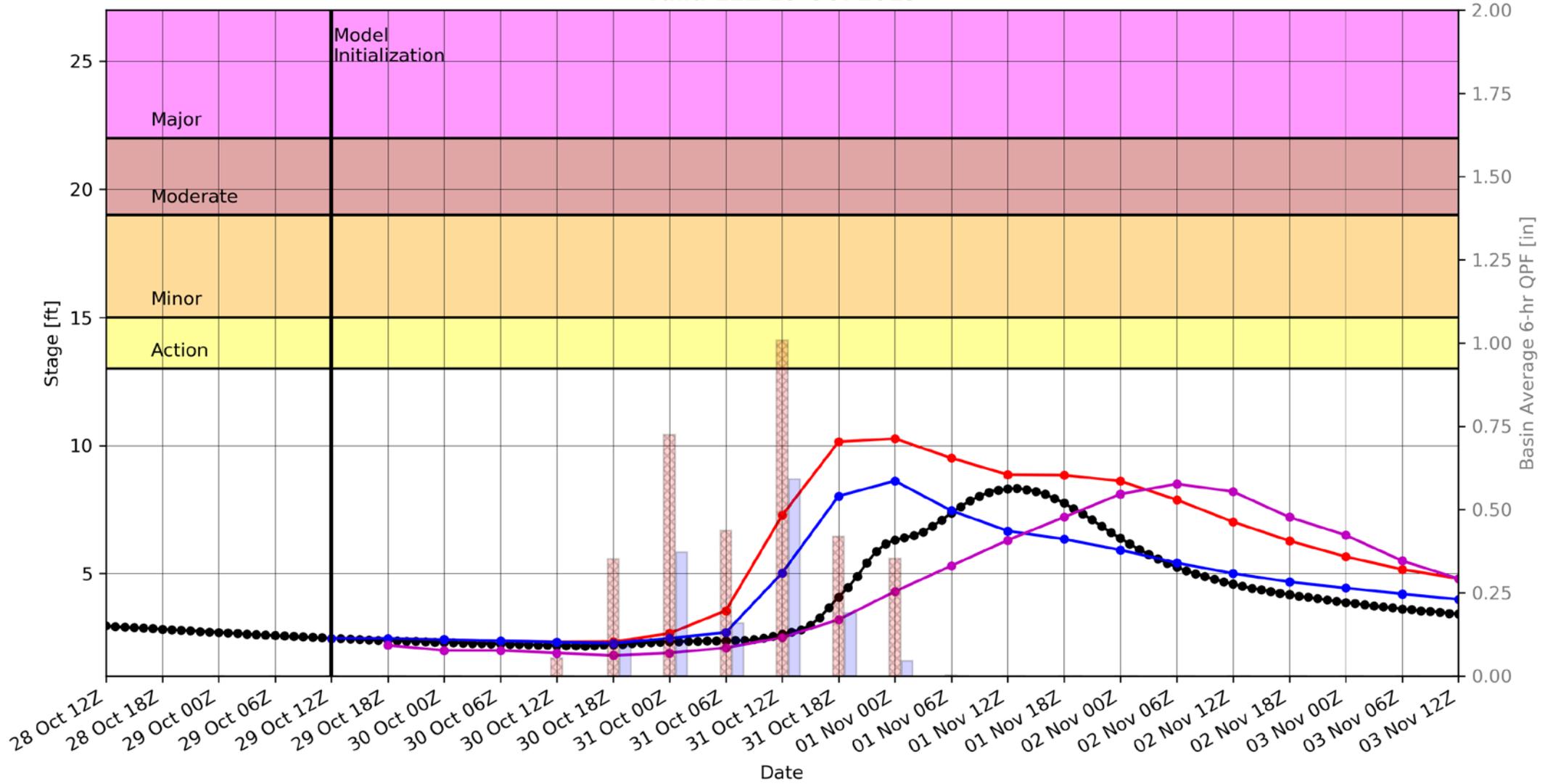
Paint Rock Flood Model
valid 12Z 30 Oct 2019

Validation

➤ Preliminary validation was done over the January 2019 – May 2019 time period.

  ➤ Mean bias and mean absolute error were calculated based on this time period.

Summary

➢ The LSTM approach presented here can be applied to any gauged river basin.

    ➢ This allows NWS WFOs to have forecasts for basins that are not provided by their River Forecast Center (RFC).

➢ The developed model provides long-term forecasts that account for rainfall throughout.

➢ While the model has shown to have low error, it is only as good as the input QPF.

    ➢ Forecasters must account for QPF uncertainties when looking at the output.

Thank you!

andrew.t.white@nasa.gov