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

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SPORT Short-term Prediction Research and Transition Center

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NATIONAL WEATHER SERVICE U.S. DEPARTMENT OF COMMERCE - NOAA

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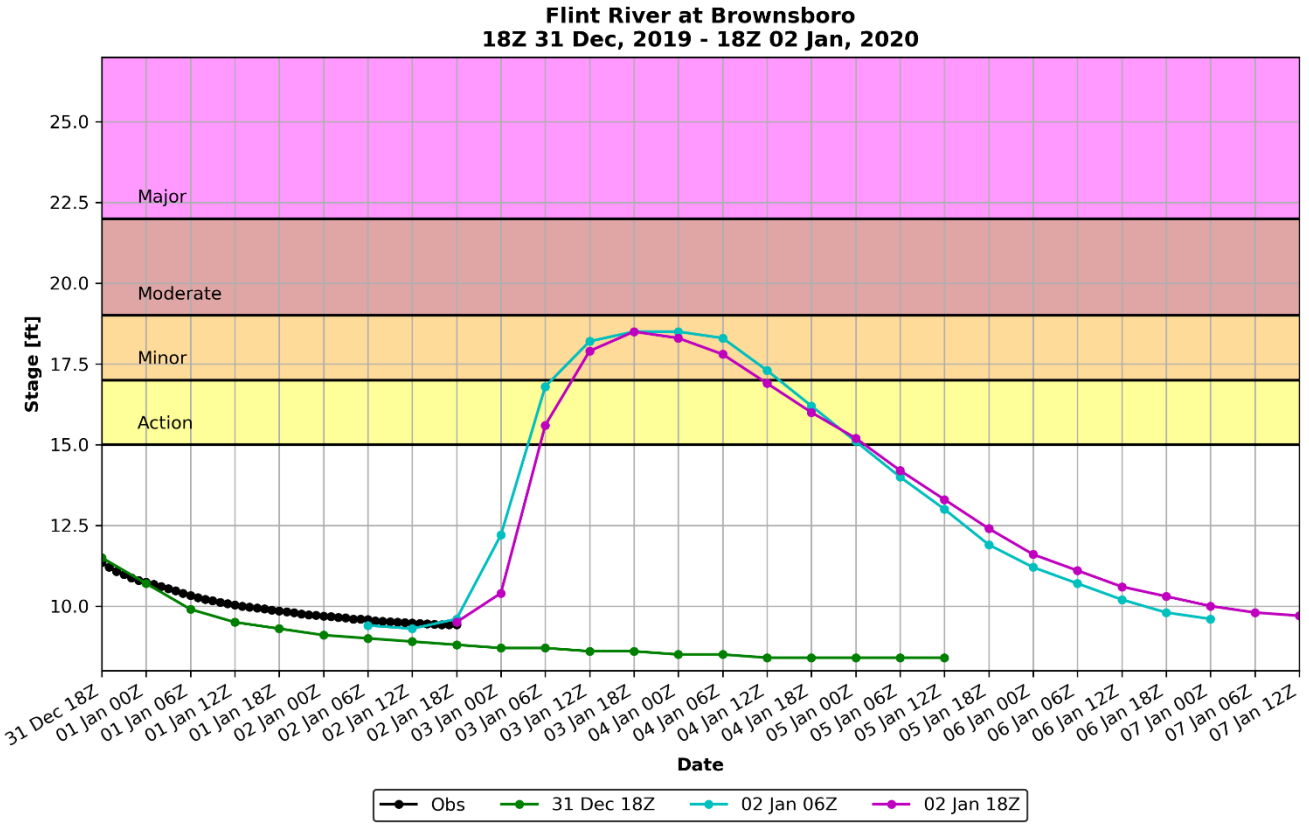
Background

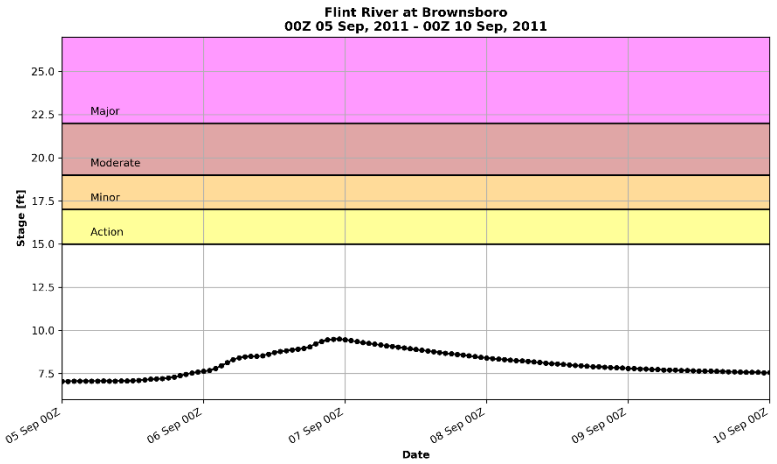
- During approaching flooding events, NWS offices rely on their River Forecast Center (RFC) to produce river gauge height predictions.
  - Typically, precipitation is only accounted for in the forecast out to 1 or 2 days.
  - Forecasts are only available for deemed “forecast points”
- Without rainfall forcing, forecasters have to rely on “rules of thumb”



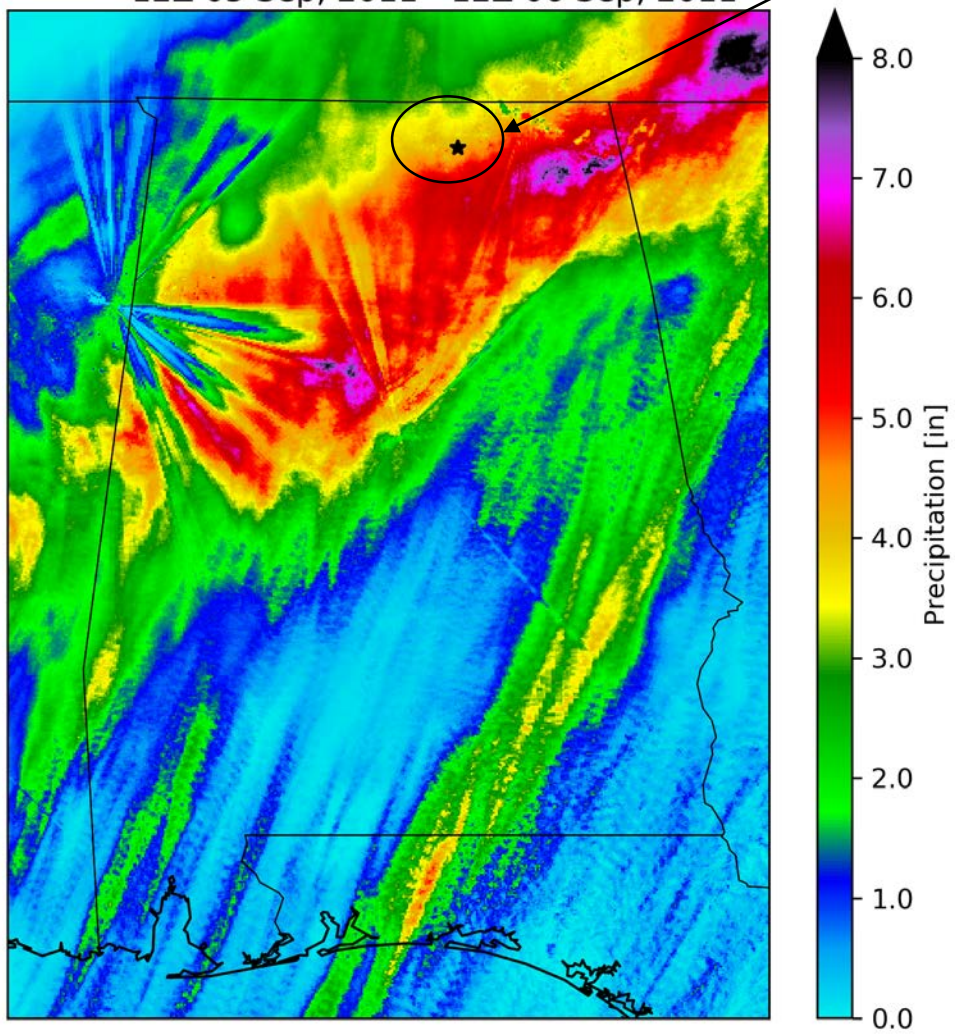
RFC forecasts for the Flint River in Northern Alabama.

Flood Forecasting

- Tropical Storm Lee case study
  - Heavy rainfall was forecasted over North Alabama.
  - Widespread river flooding was forecasted.
  - Very little flooding was observed.



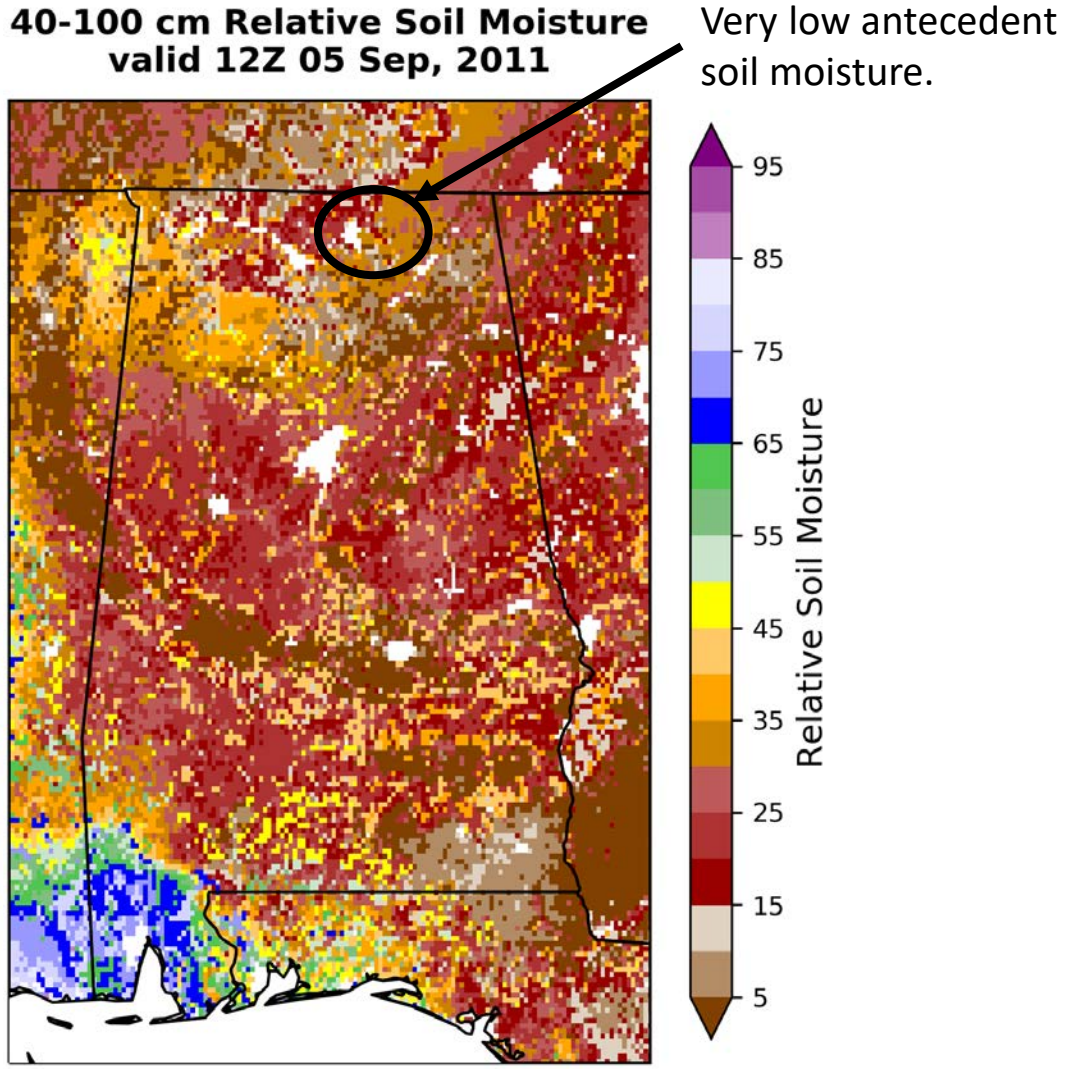
Minor rise in gauge height.



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.



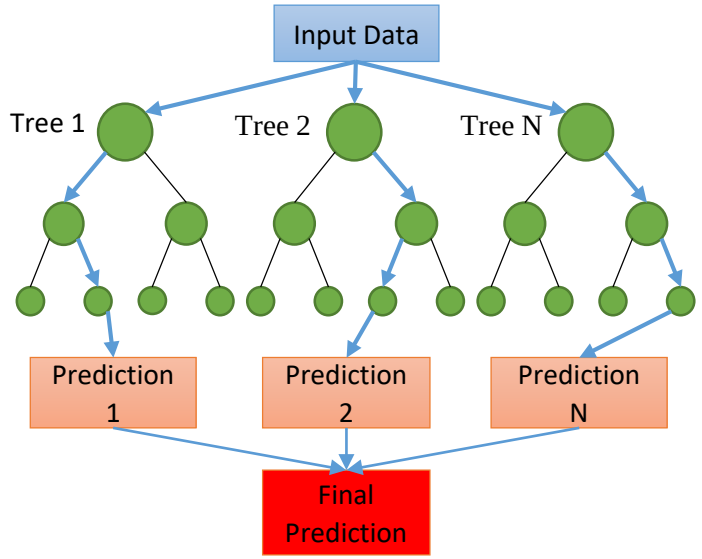
Forecasting Challenges Remain

- 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?

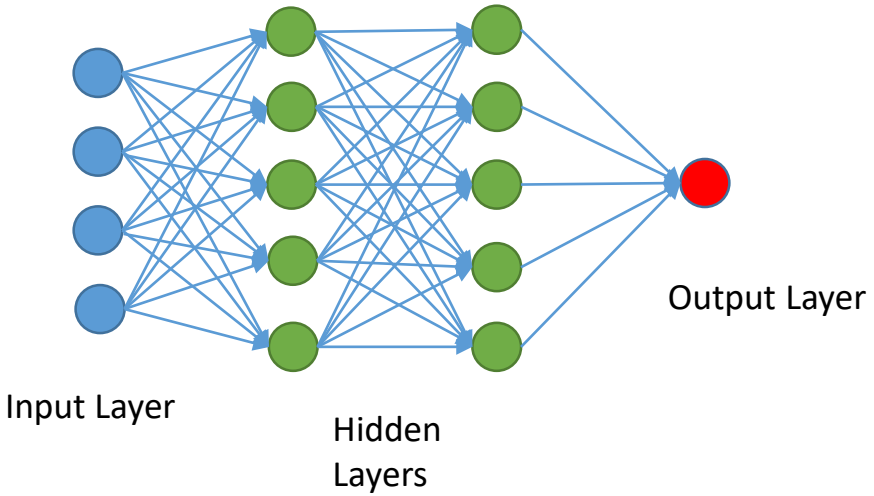
Machine Learning

- 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

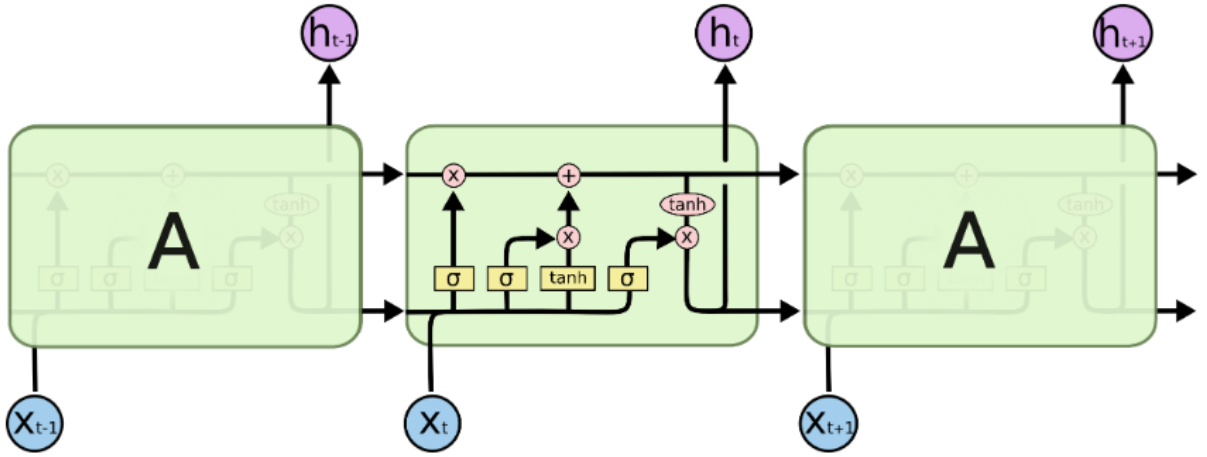


- Neural Network



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.

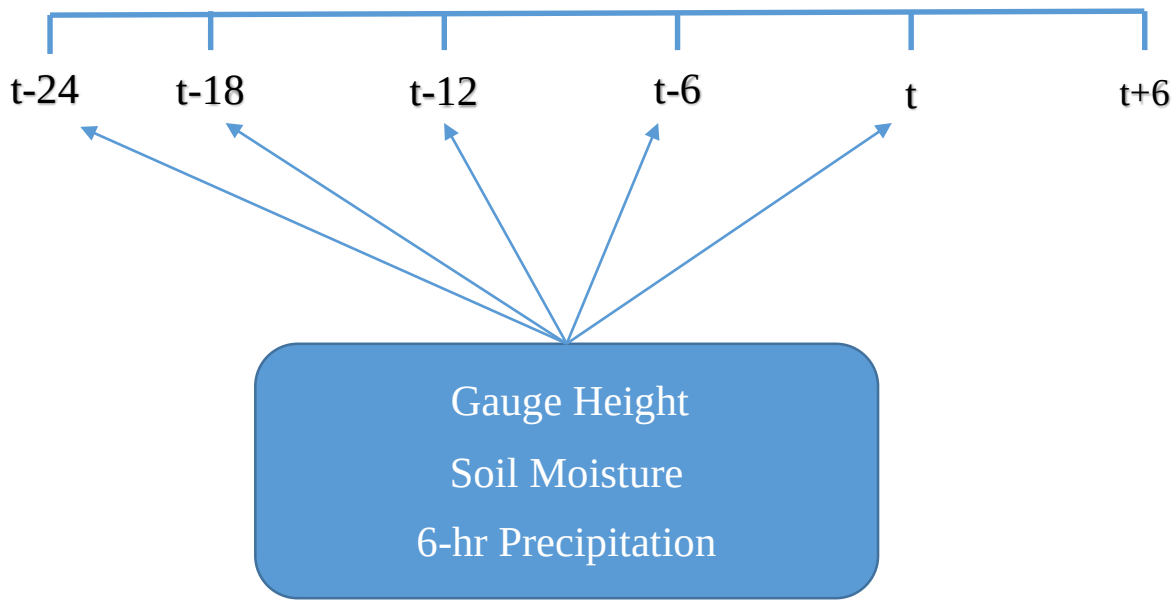


Example LSTM Diagram

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)

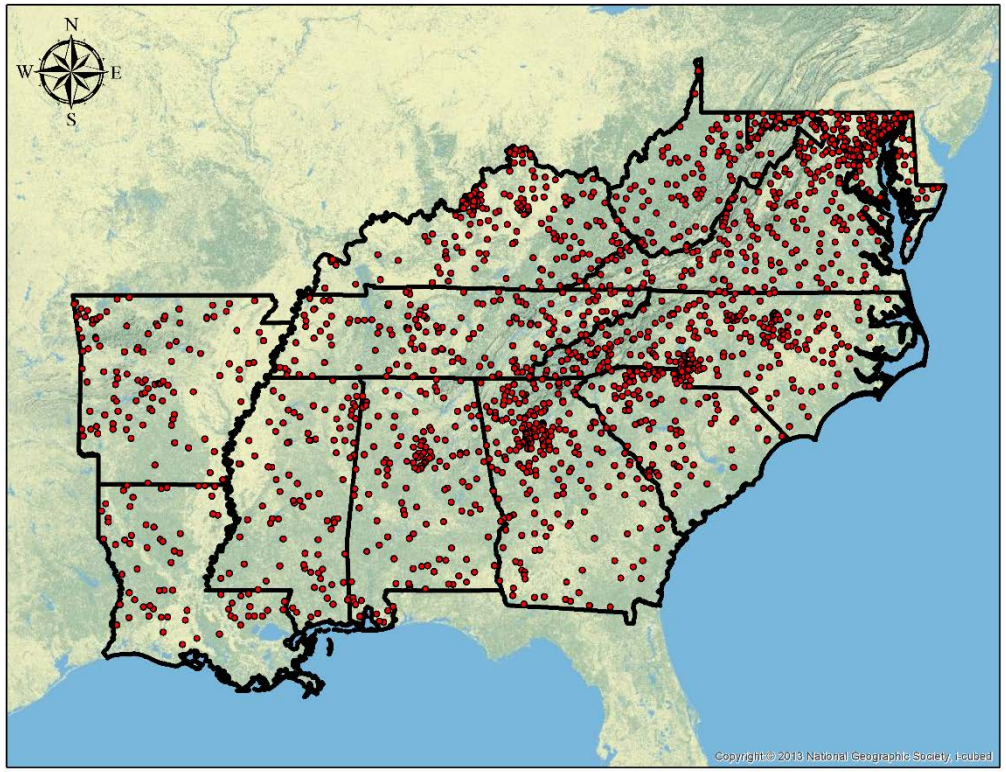


Project Area

- 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.

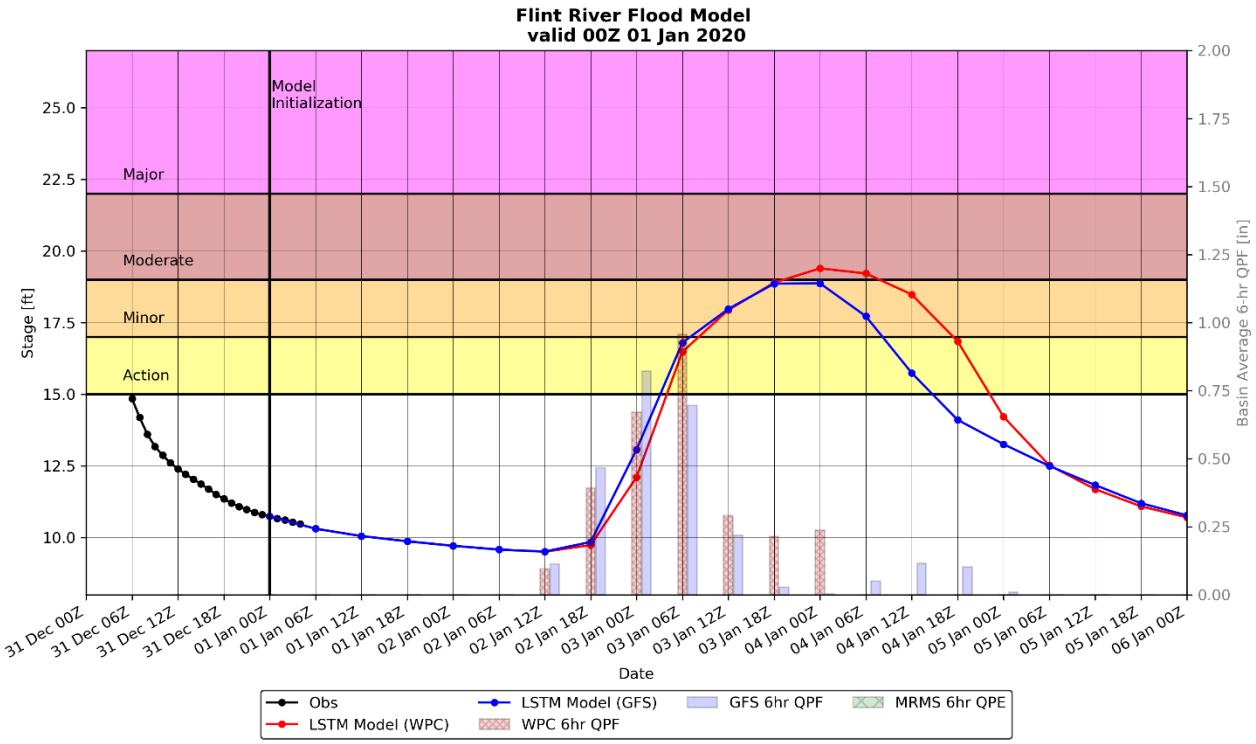
- Defined basin boundaries are used to take areal averages of rainfall and soil moisture.

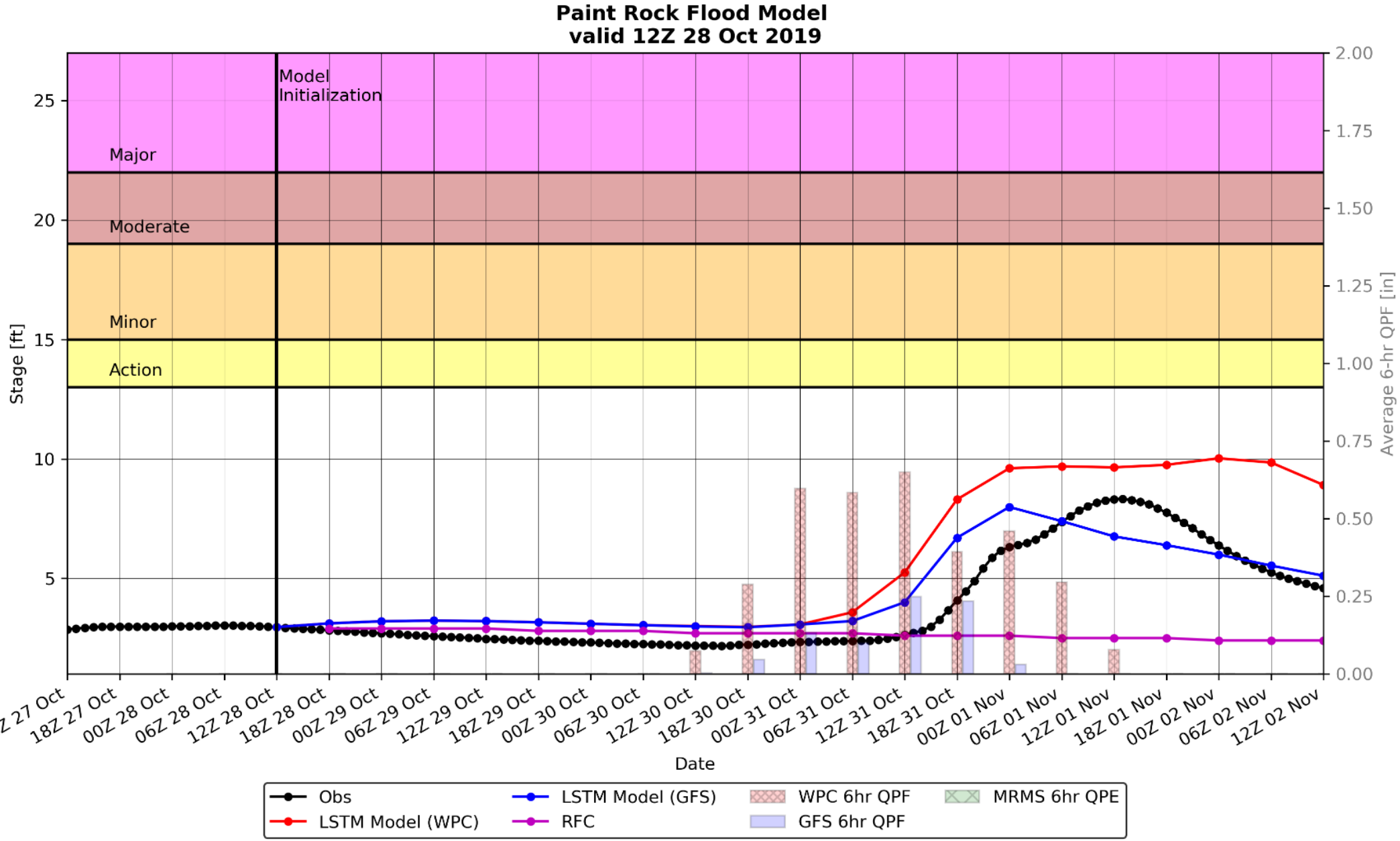


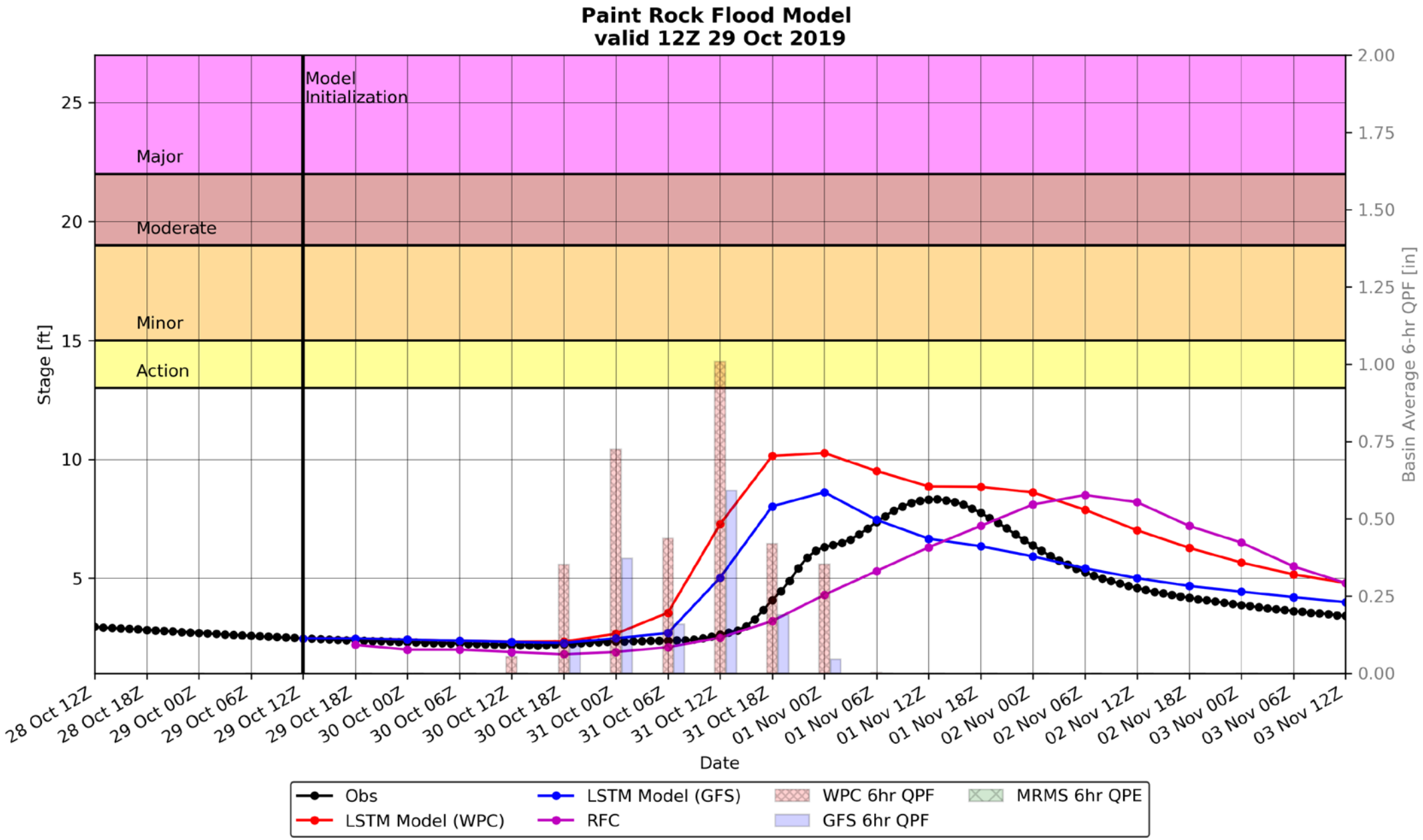
Southeast U.S. Domain

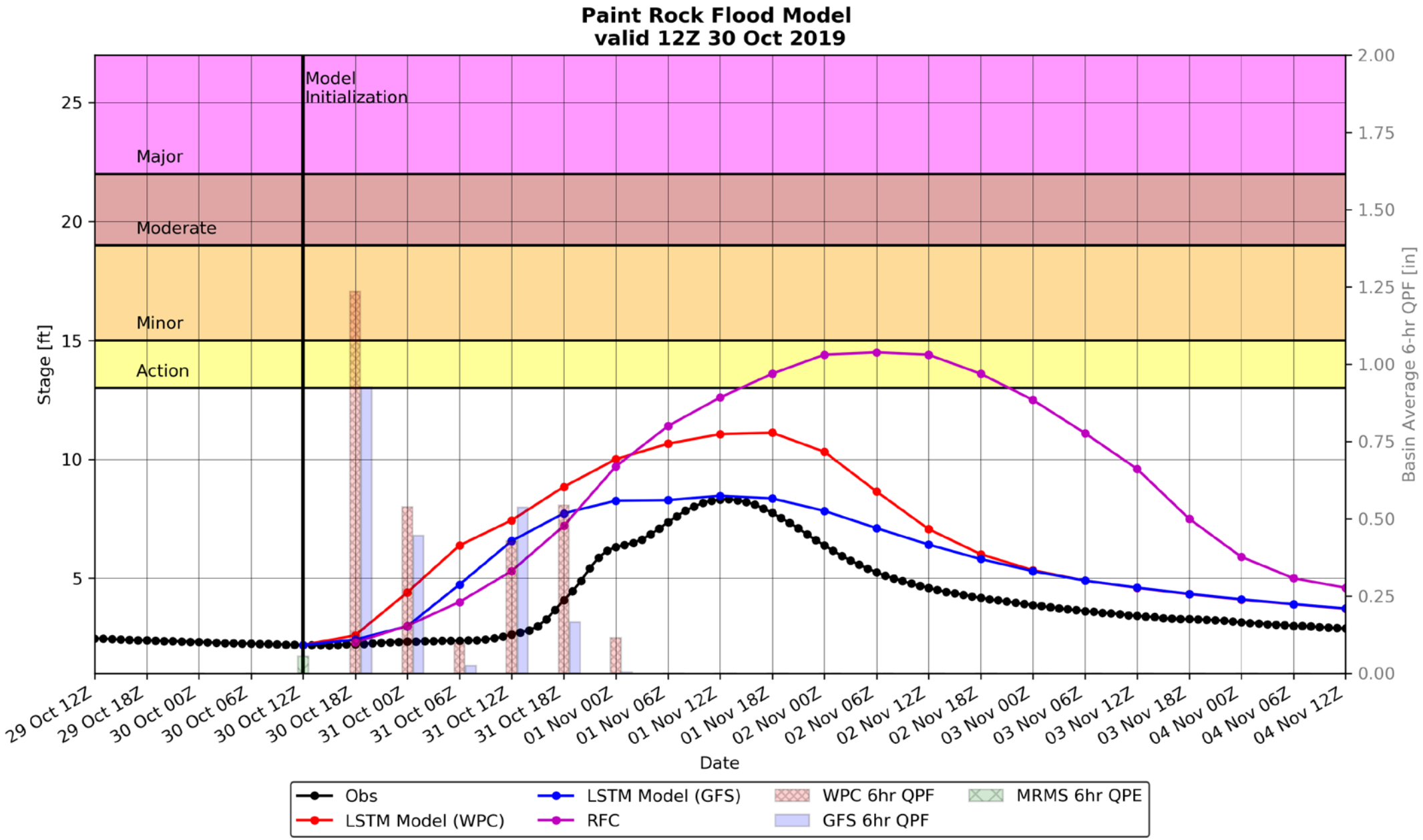
Operational Forecasts

- 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.



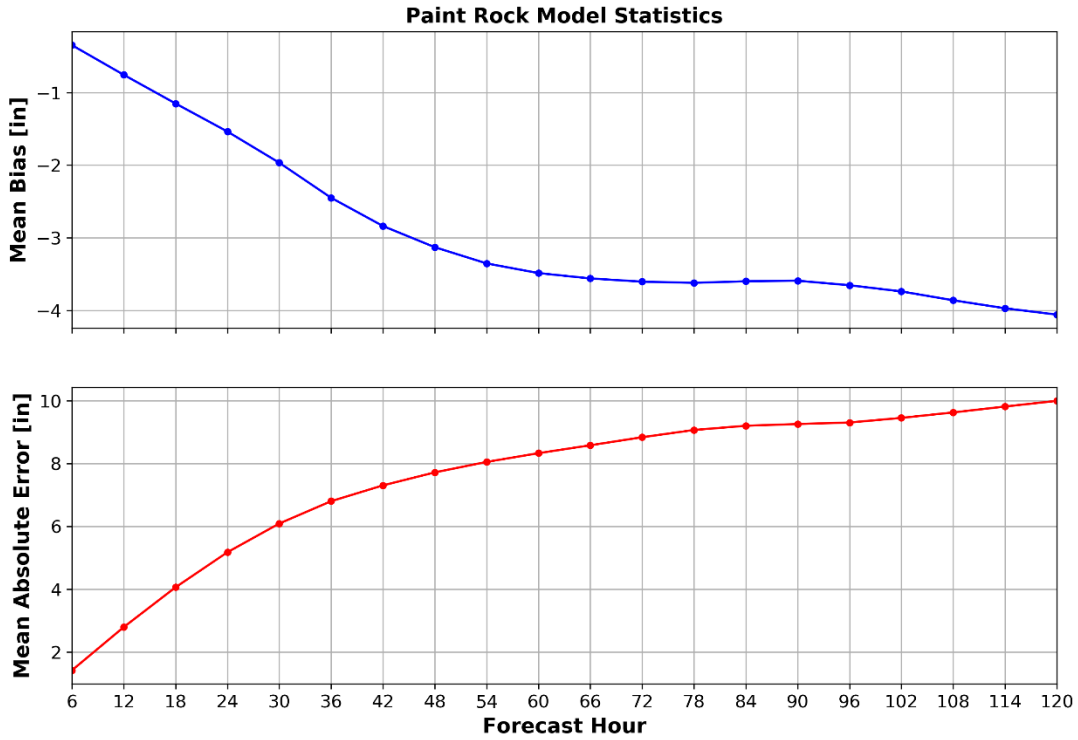

Paint Rock Flood Model
valid 12Z 28 Oct 2019
Model
Initialization
Major
Moderate
Minor
Action
Stage [ft]
Average 6-hr QPF [in]
25
20
15
10
5
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
12Z 27 Oct
18Z 27 Oct
00Z 28 Oct
06Z 28 Oct
12Z 28 Oct
18Z 28 Oct
00Z 29 Oct
06Z 29 Oct
12Z 29 Oct
18Z 29 Oct
00Z 30 Oct
06Z 30 Oct
12Z 30 Oct
18Z 30 Oct
00Z 31 Oct
06Z 31 Oct
12Z 31 Oct
18Z 31 Oct
00Z 01 Nov
06Z 01 Nov
12Z 01 Nov
18Z 01 Nov
00Z 02 Nov
06Z 02 Nov
12Z 02 Nov
Date
Obs
LSTM Model (WPC)
LSTM Model (GFS)
RFC
WPC 6hr QPF
GFS 6hr QPF
MRMS 6hr QPE

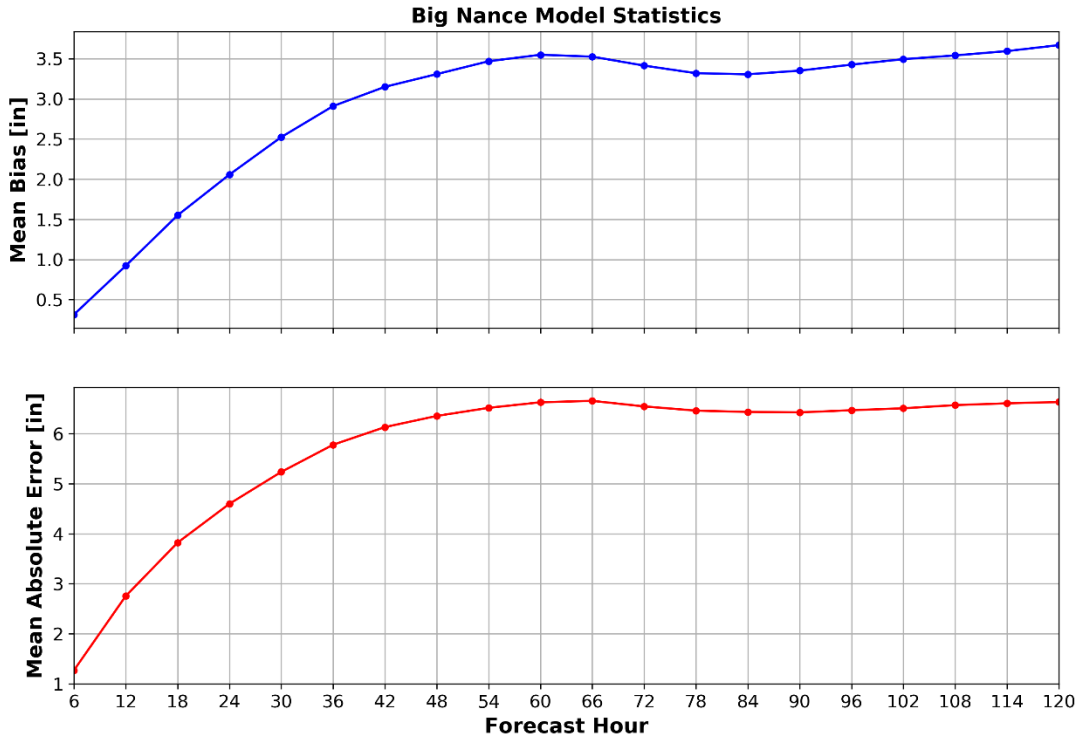

Paint Rock Flood Model
valid 12Z 29 Oct 2019
Model
Initialization
Major
Moderate
Minor
Action
Stage [ft]
Basin Average 6-hr QPF [in]
Date
28 Oct 12Z
28 Oct 18Z
29 Oct 00Z
29 Oct 06Z
29 Oct 12Z
29 Oct 18Z
30 Oct 00Z
30 Oct 06Z
30 Oct 12Z
30 Oct 18Z
31 Oct 00Z
31 Oct 06Z
31 Oct 12Z
31 Oct 18Z
01 Nov 00Z
01 Nov 06Z
01 Nov 12Z
01 Nov 18Z
02 Nov 00Z
02 Nov 06Z
02 Nov 12Z
02 Nov 18Z
03 Nov 00Z
03 Nov 06Z
03 Nov 12Z
Obs
LSTM Model (WPC)
LSTM Model (GFS)
RFC
WPC 6hr QPF
GFS 6hr QPF
MRMS 6hr QPE


Paint Rock Flood Model
valid 12Z 30 Oct 2019
Model
Initialization
Major
Moderate
Minor
Action
Stage [ft]
Basin Average 6-hr QPF [in]
Date
29 Oct 12Z
29 Oct 18Z
30 Oct 00Z
30 Oct 06Z
30 Oct 12Z
30 Oct 18Z
31 Oct 00Z
31 Oct 06Z
31 Oct 12Z
31 Oct 18Z
01 Nov 00Z
01 Nov 06Z
01 Nov 12Z
01 Nov 18Z
02 Nov 00Z
02 Nov 06Z
02 Nov 12Z
02 Nov 18Z
03 Nov 00Z
03 Nov 06Z
03 Nov 12Z
03 Nov 18Z
04 Nov 00Z
04 Nov 06Z
04 Nov 12Z
Obs
LSTM Model (WPC)
LSTM Model (GFS)
RFC
WPC 6hr QPF
GFS 6hr QPF
MRMS 6hr QPE

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!

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