A review of hurricane rainfall prediction guidance and probability distribution function formulations for flood mitigation

Pat Fitzpatrick

Mississippi State University (research professor)

- Rules of thumb
- Forecast guidance examples for Hurricane Florence
- Empirical and climatology applications for return-level studies
- Considerations for post-Harvey and post-Florence research
- Time period for general questions on hurricanes

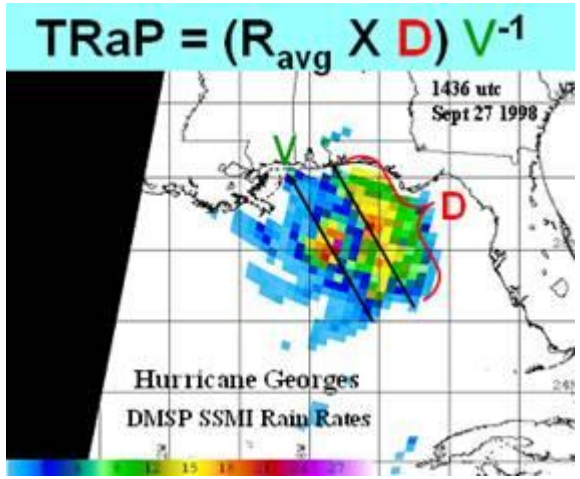
Rules of thumb

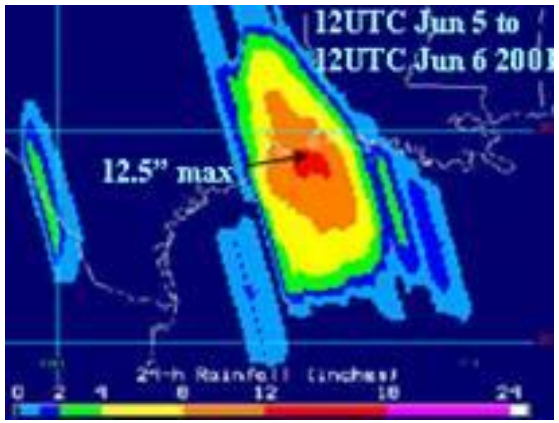
- Kraft equation (inches)

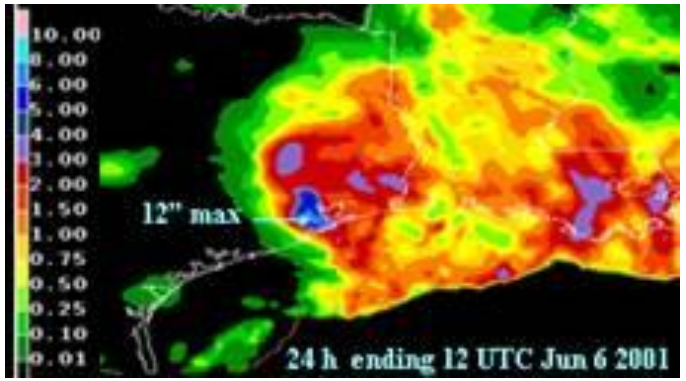
Maximum rainfall=100/speed (in knots)

- TRopical Rainfall Potential (TRaP)

Maximum rainfall=Avg measured rain rate X Length of rain shield/speed







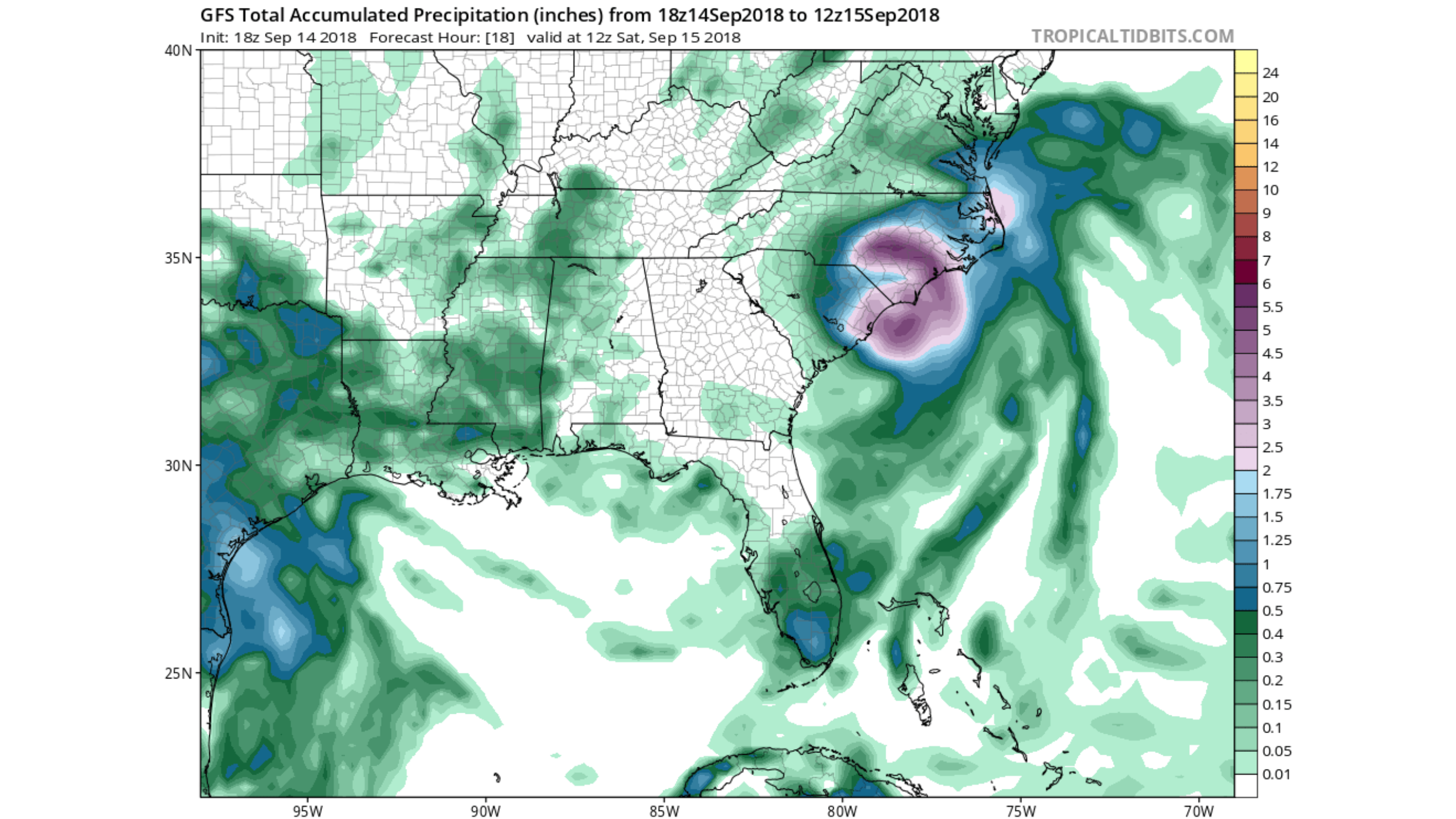
Forecast guidance examples for Hurricane Florence

Links, class notes, and video lectures available on JSU teaching website:

http://weatherclasses.com

Comparison global, regional, high-resolution models

18-h forecast rain total
Initialized Sept. 14, 18Z


GFS Total Accumulated Precipitation (inches) from 18z14Sep2018 to 12z15Sep2018
Init: 18z Sep 14 2018 Forecast Hour: [18] valid at 12z Sat, Sep 15 2018
TROPICALTIDBITS.COM
40N
35N
30N
25N
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90W
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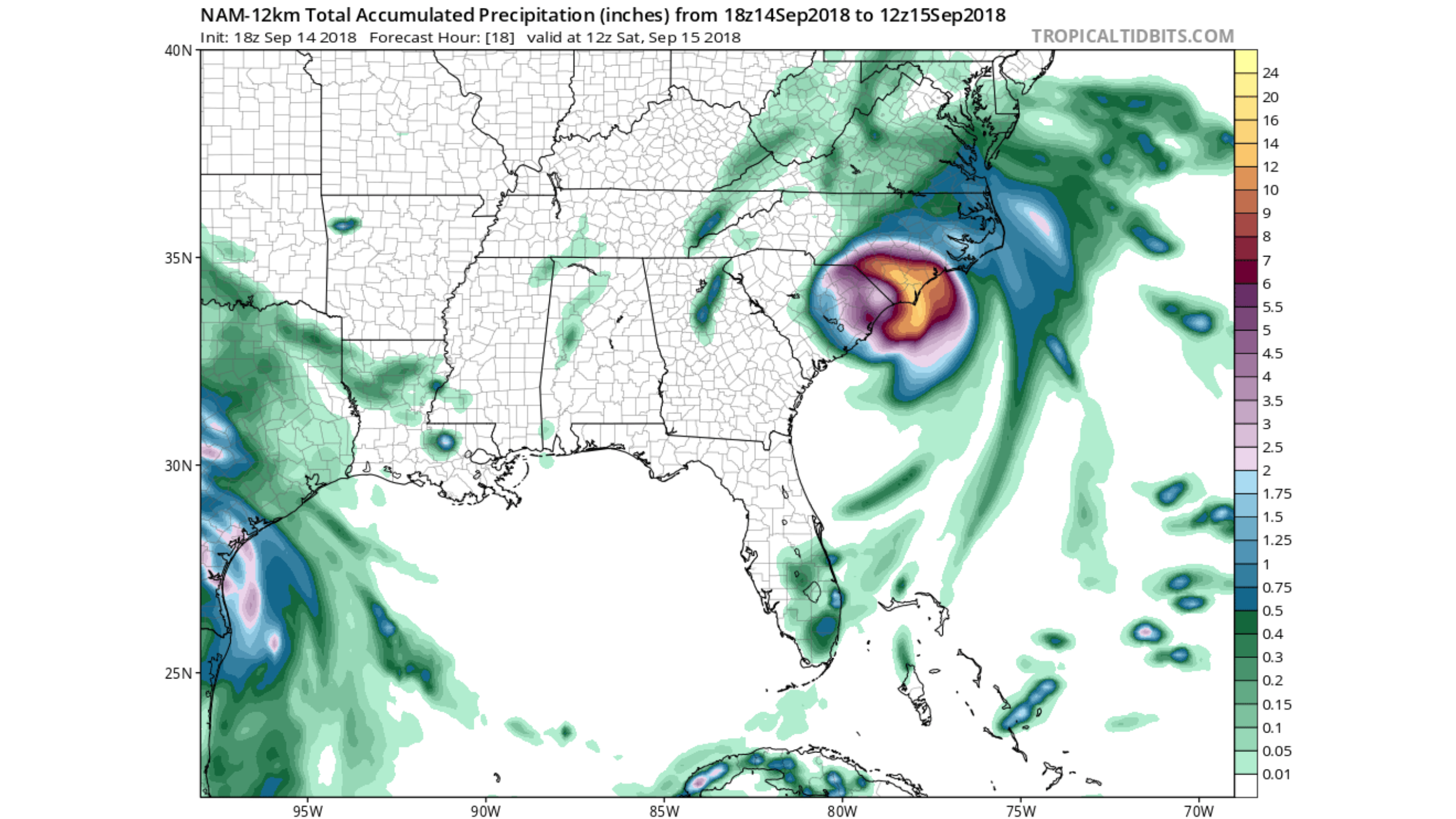
NAM-12km Total Accumulated Precipitation (inches) from 18z14Sep2018 to 12z15Sep2018
Init: 18z Sep 14 2018 Forecast Hour: [18] valid at 12z Sat, Sep 15 2018
TROPICALTIDBITS.COM
40N
35N
30N
25N
95W
90W
85W
80W
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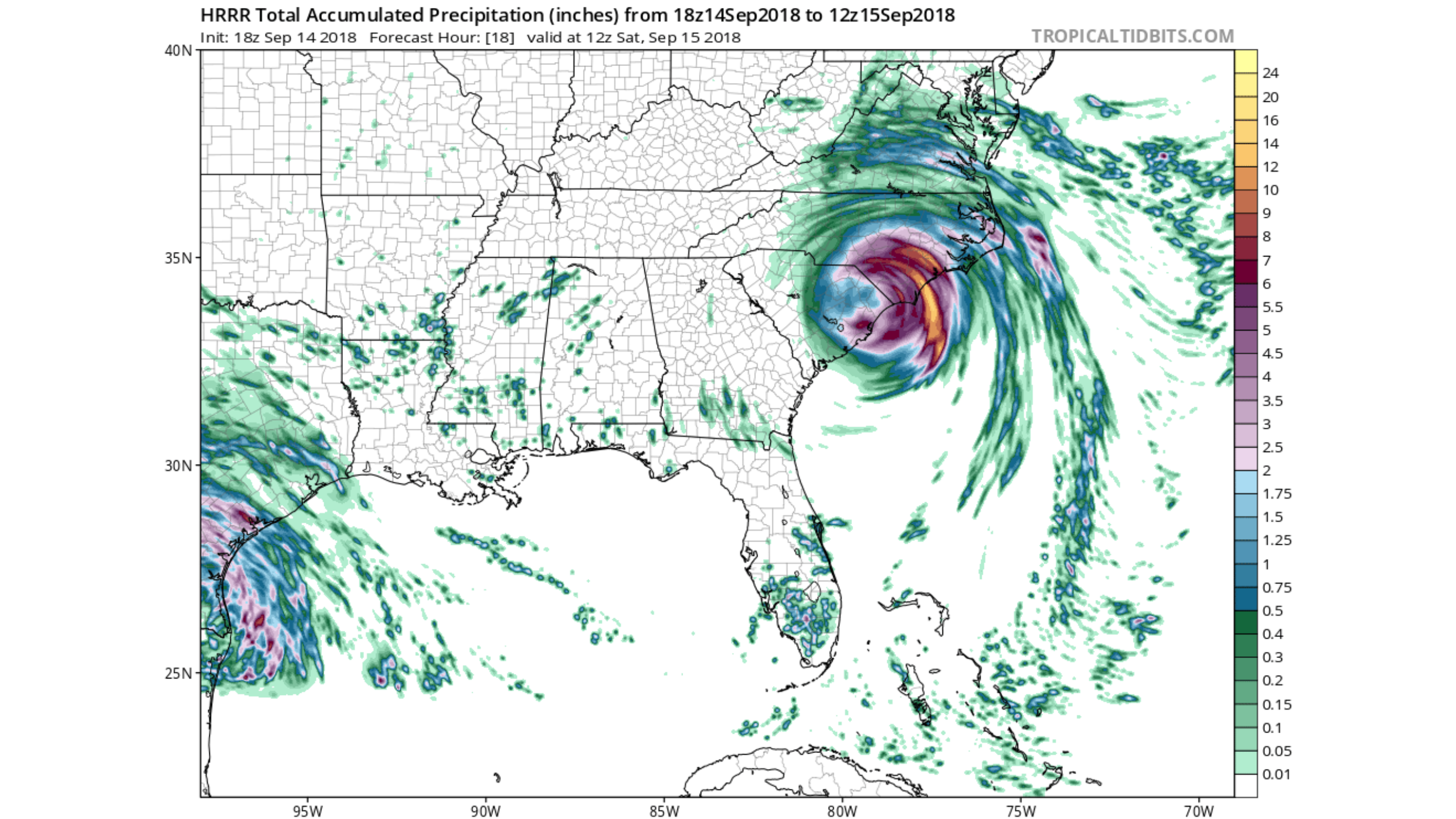
HRRR Total Accumulated Precipitation (inches) from 18z14Sep2018 to 12z15Sep2018
Init: 18z Sep 14 2018 Forecast Hour: [18] valid at 12z Sat, Sep 15 2018
TROPICALTIDBITS.COM
40N
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85W
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1.5
1.25
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0.75
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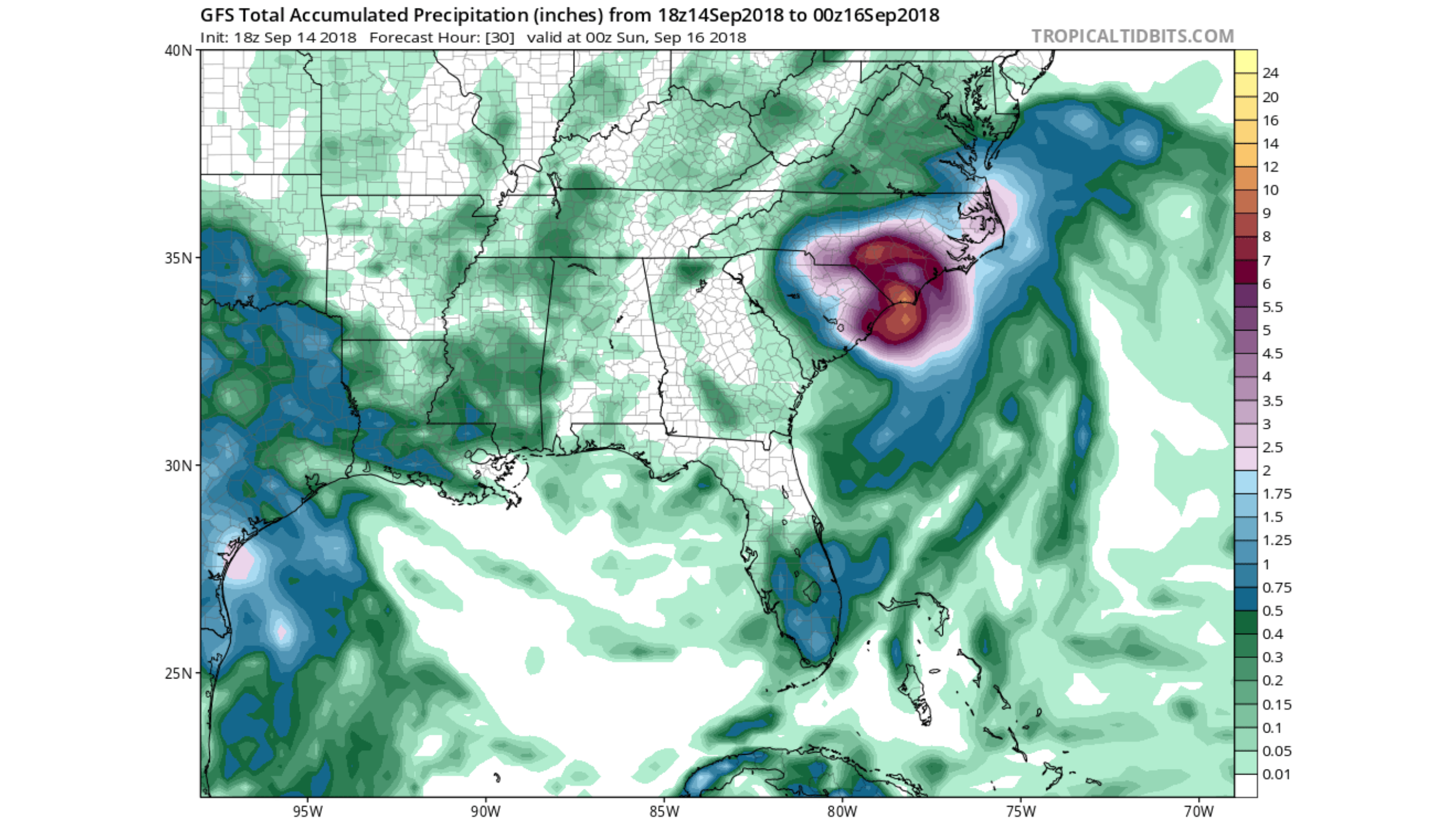
Comparison global, regional, high-resolution models

30-h forecast rain total
Initialized Sept. 14, 18Z


GFS Total Accumulated Precipitation (inches) from 18z14Sep2018 to 00z16Sep2018
Init: 18z Sep 14 2018 Forecast Hour: [30] valid at 00z Sun, Sep 16 2018
TROPICALTIDBITS.COM
40N
35N
30N
25N
95W
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85W
80W
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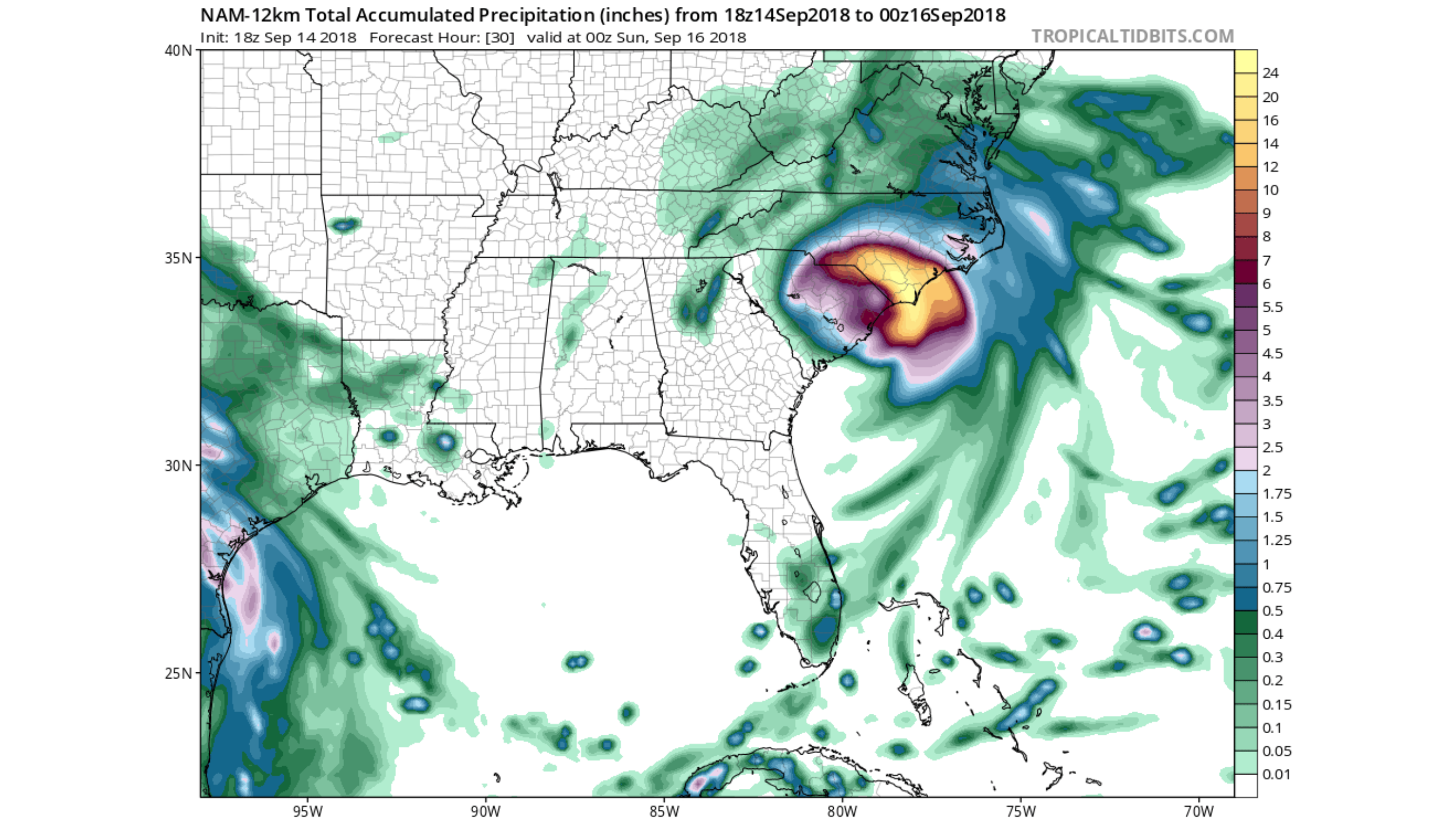
NAM-12km Total Accumulated Precipitation (inches) from 18z14Sep2018 to 00z16Sep2018
Init: 18z Sep 14 2018 Forecast Hour: [30] valid at 00z Sun, Sep 16 2018
TROPICALTIDBITS.COM
40N
35N
30N
25N
95W
90W
85W
80W
75W
70W
24
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2
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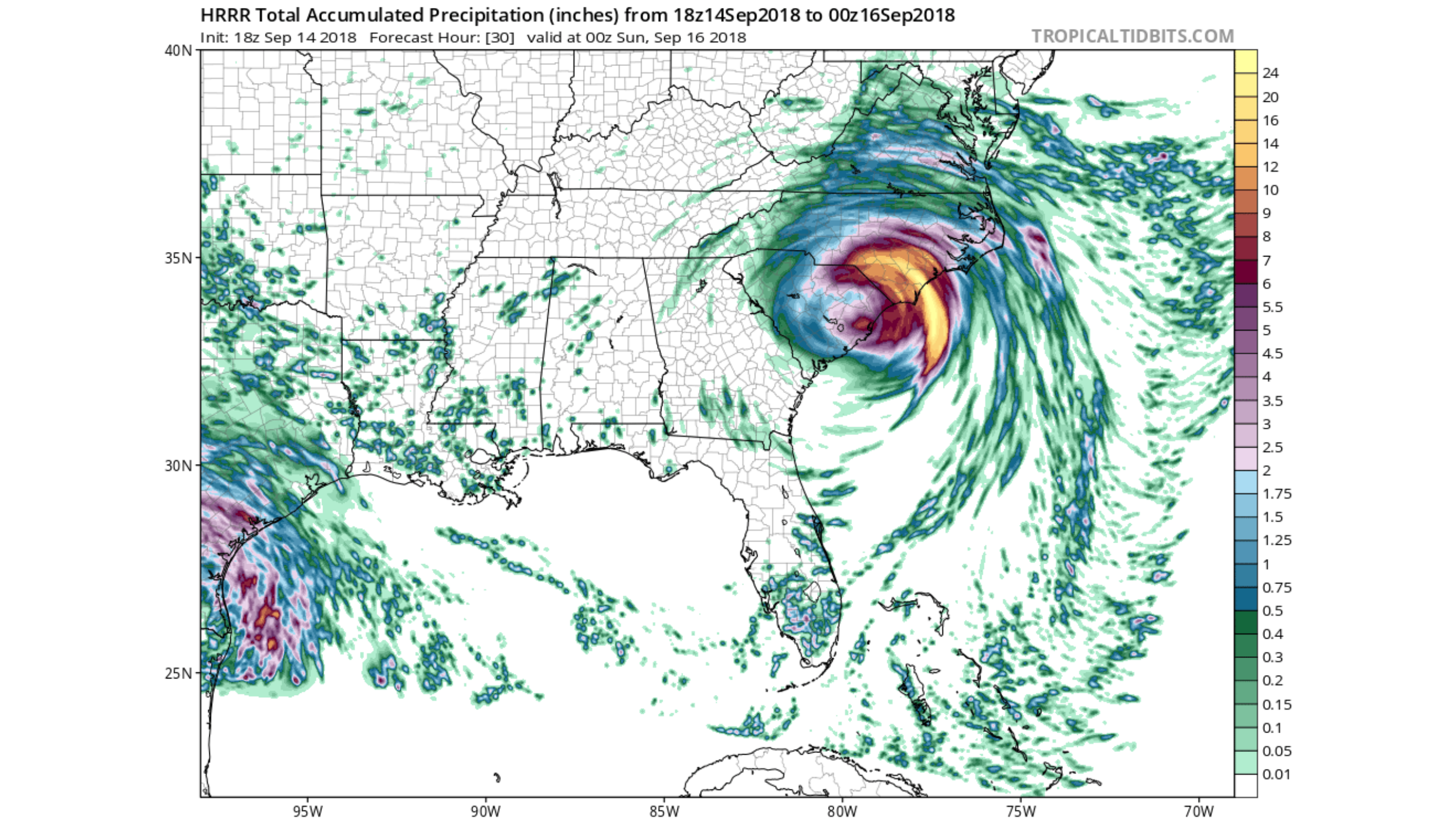
HRRR Total Accumulated Precipitation (inches) from 18z14Sep2018 to 00z16Sep2018
Init: 18z Sep 14 2018 Forecast Hour: [30] valid at 00z Sun, Sep 16 2018
TROPICALTIDBITS.COM
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0.4
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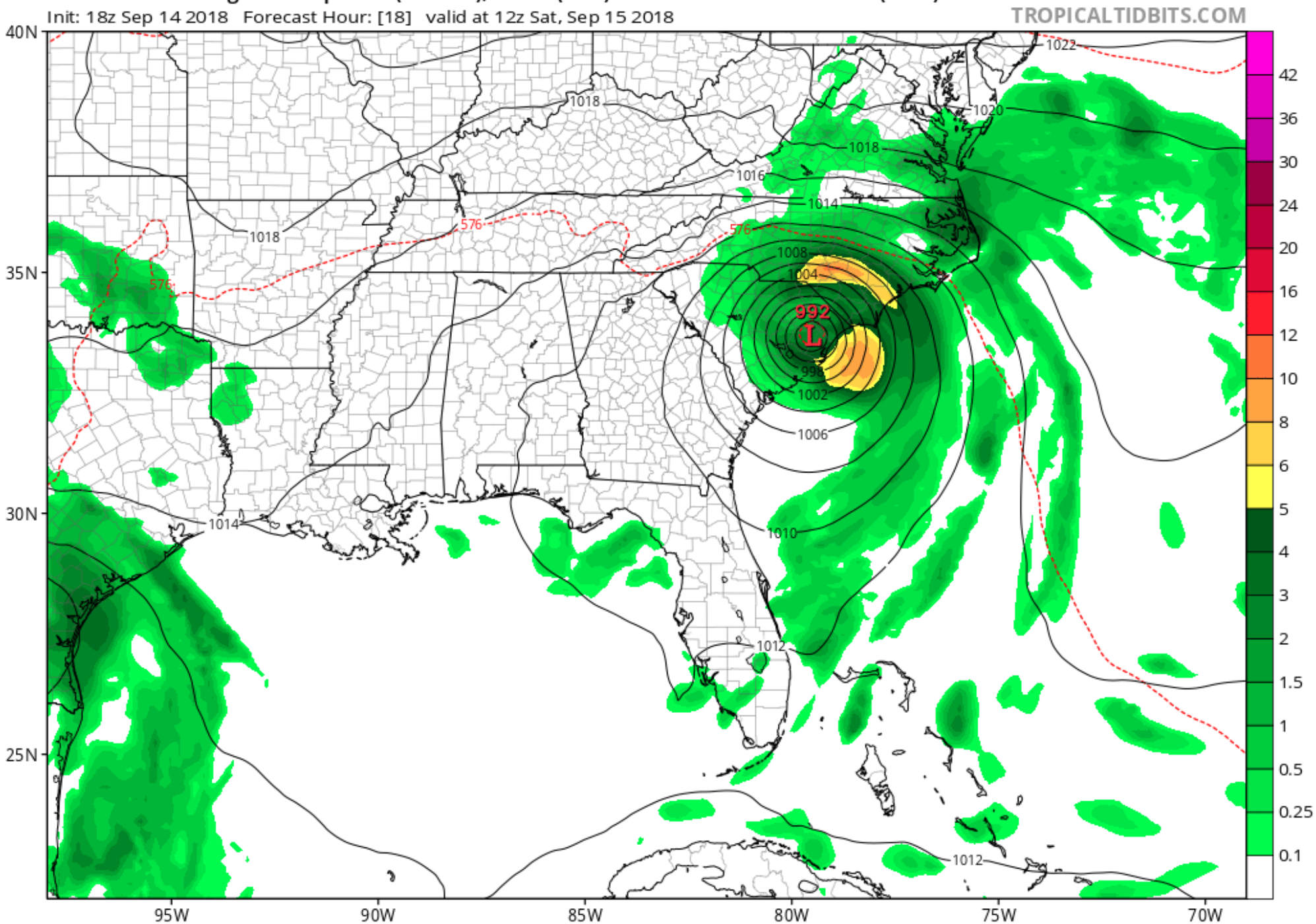
0.01

Comparison global, regional, high-resolution models and hurricane model

18-h forecast rain rate or radar reflectivity (derived from rain rate)
Initialized Sept. 14, 18Z


GFS 6-hour Averaged Precip Rate (mm/hr), MSLP (hPa) & 1000-500mb Thickness (dam)
Init: 18z Sep 14 2018 Forecast Hour: [18] valid at 12z Sat, Sep 15 2018
TROPICALTIDBITS.COM
40N
35N
30N
25N
95W
90W
85W
80W
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992
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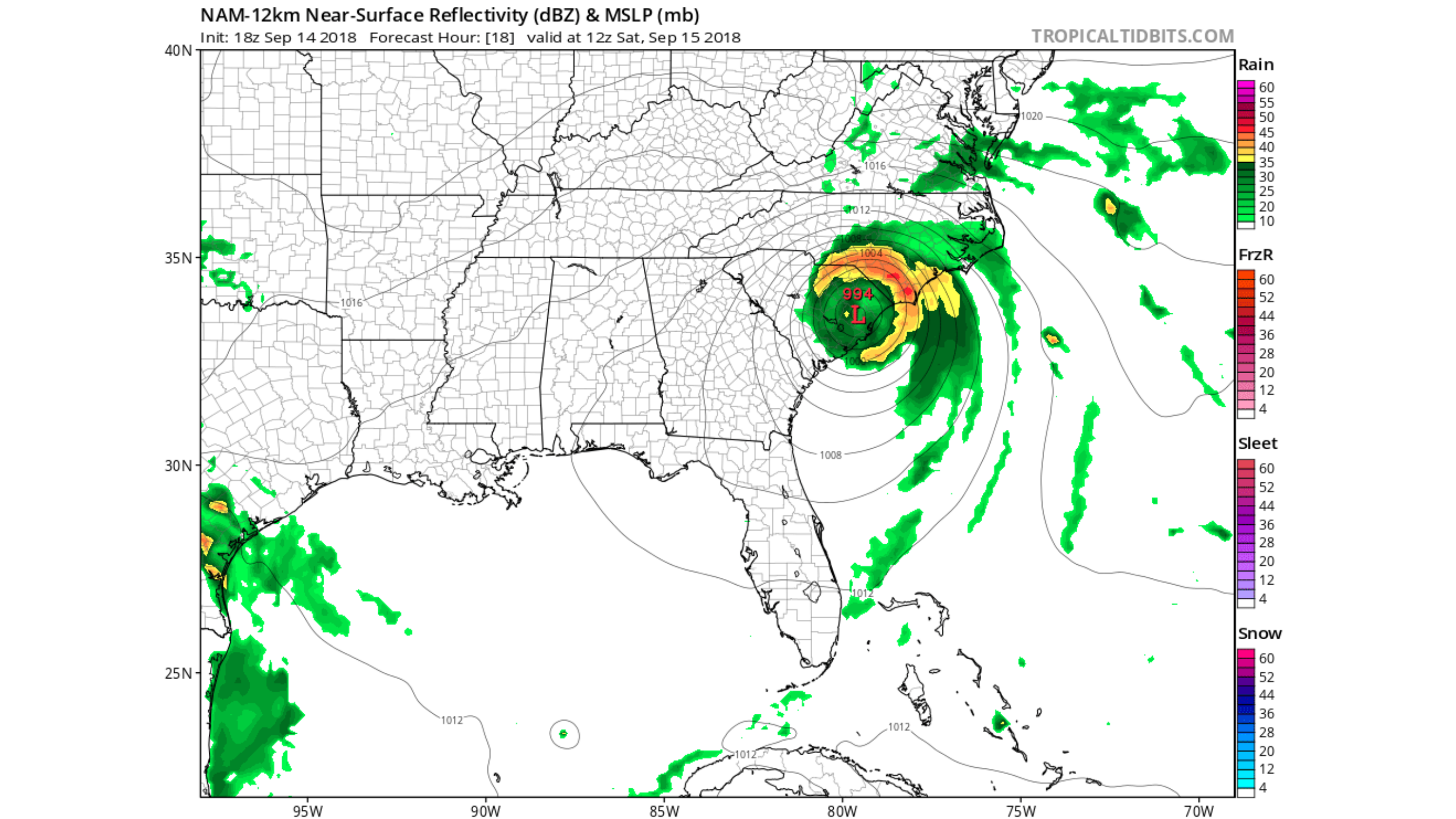
NAM-12km Near-Surface Reflectivity (dBZ) & MSLP (mb)
Init: 18z Sep 14 2018 Forecast Hour: [18] valid at 12z Sat, Sep 15 2018
TROPICALTIDBITS.COM
40N
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30N
25N
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90W
85W
80W
75W
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1016
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1008
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Rain
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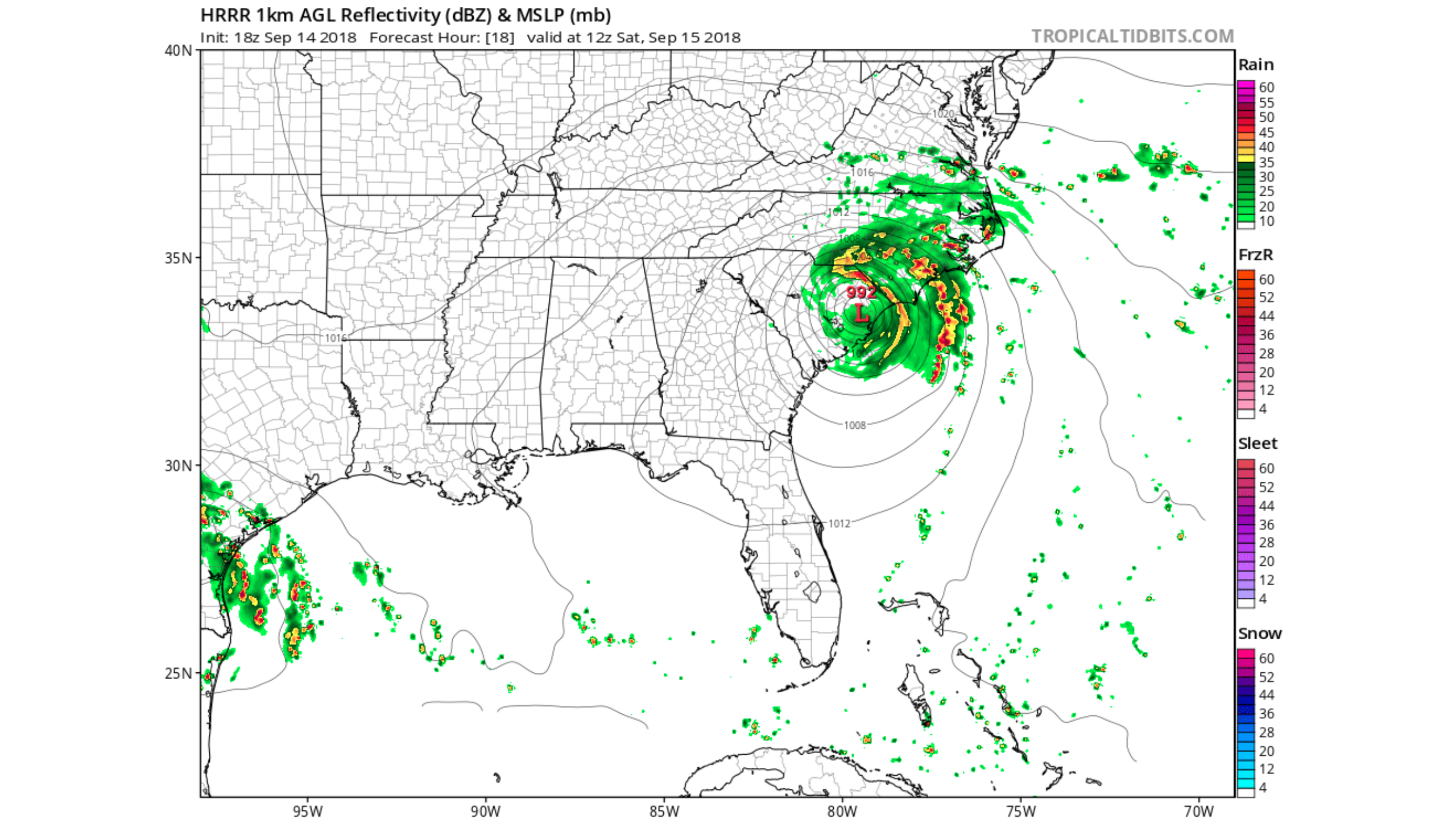
HRRR 1km AGL Reflectivity (dBZ) & MSLP (mb)
Init: 18z Sep 14 2018 Forecast Hour: [18] valid at 12z Sat, Sep 15 2018
TROPICALTIDBITS.COM
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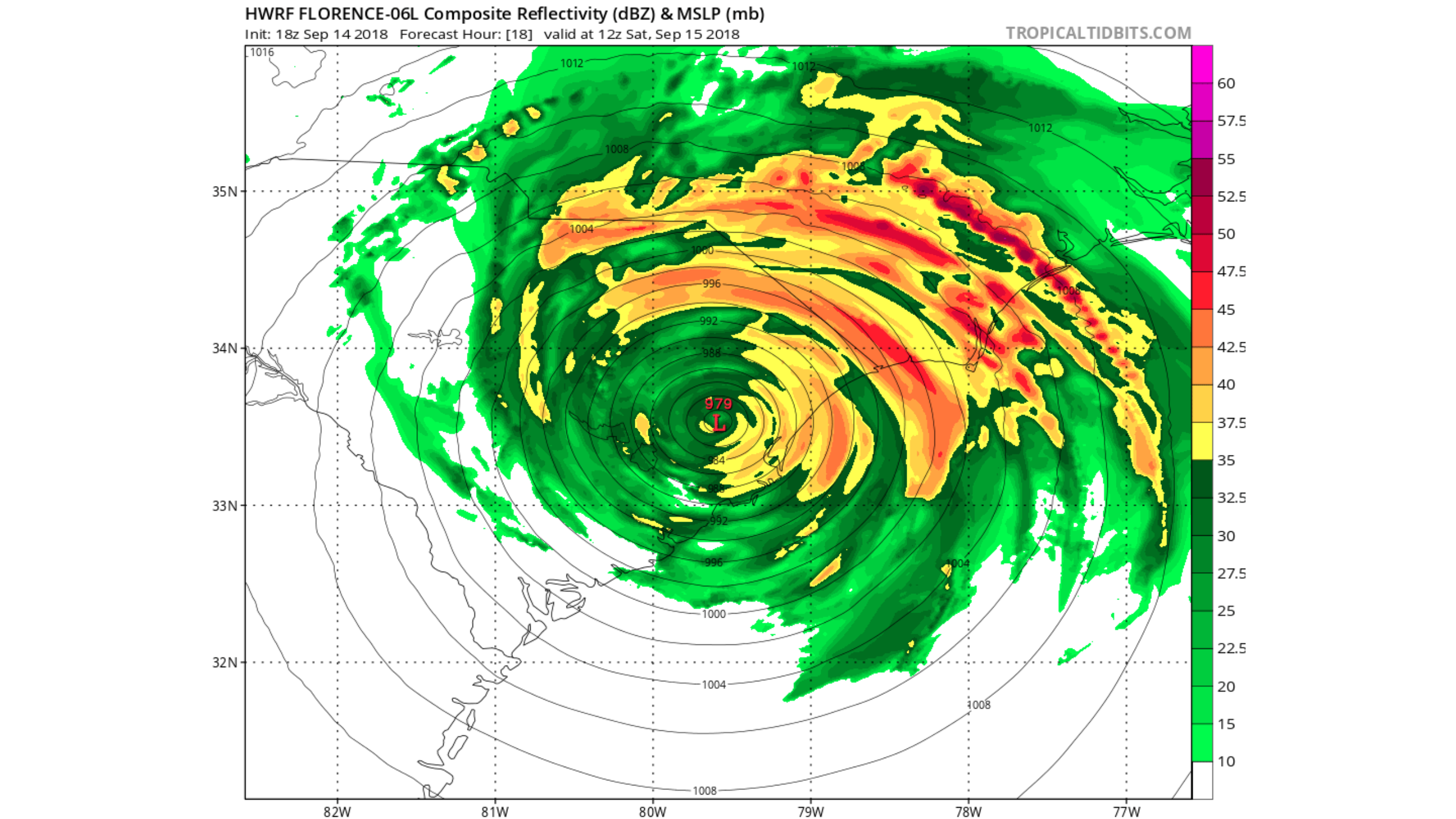
HWRF FLORENCE-06L Composite Reflectivity (dBZ) & MSLP (mb)
Init: 18z Sep 14 2018 Forecast Hour: [18] valid at 12z Sat, Sep 15 2018
TROPICALTIDBITS.COM
979
L
35N
34N
33N
32N
82W
81W
80W
79W
78W
77W
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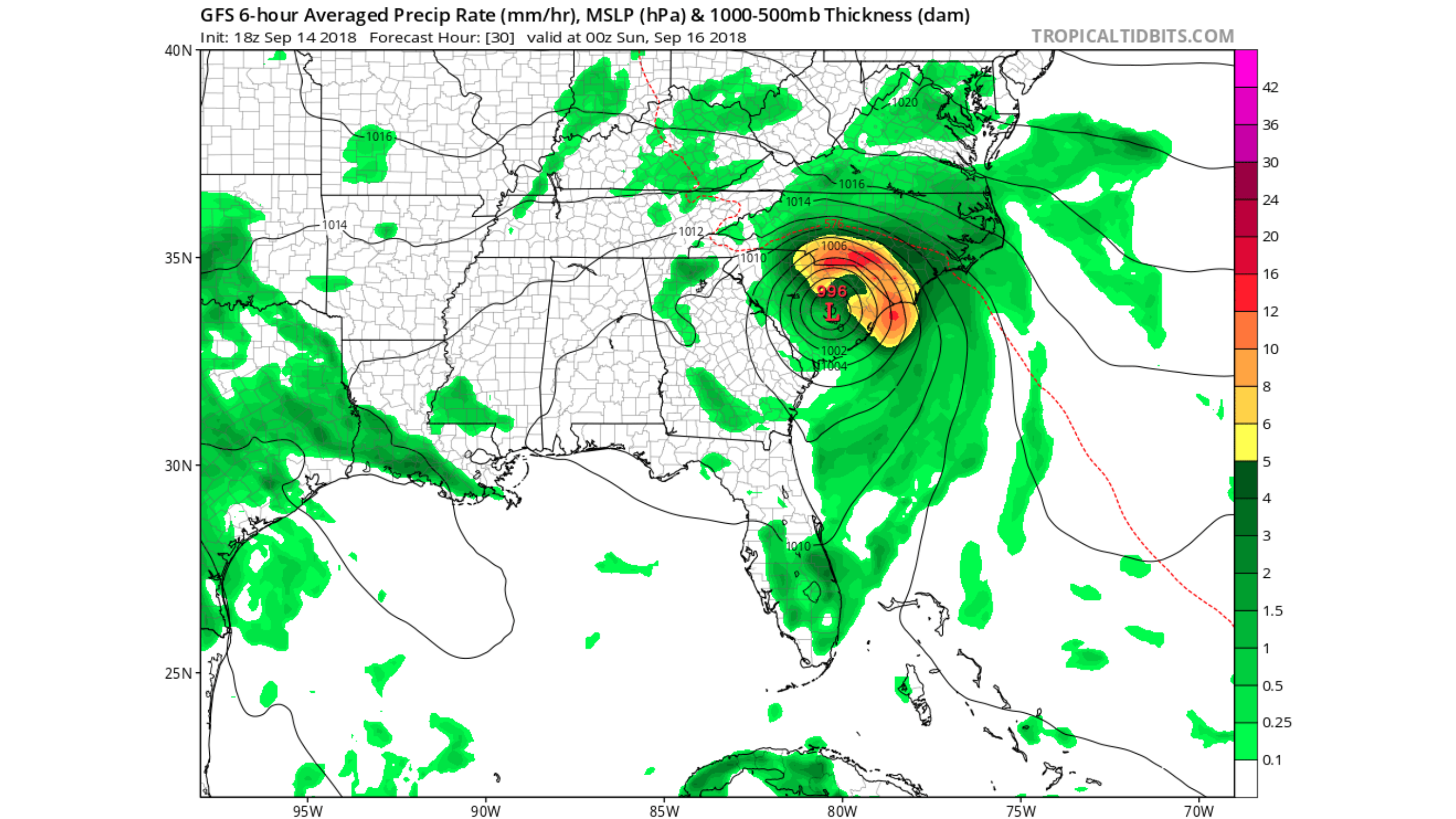
Comparison global, regional, high-resolution models and hurricane model

30-h forecast rain rate or radar reflectivity (derived from rain rate)
Initialized Sept. 14, 18Z


GFS 6-hour Averaged Precip Rate (mm/hr), MSLP (hPa) & 1000-500mb Thickness (dam)
Init: 18z Sep 14 2018 Forecast Hour: [30] valid at 00z Sun, Sep 16 2018
TROPICALTIDBITS.COM
40N
35N
30N
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85W
80W
75W
70W
1016
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1012
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1020
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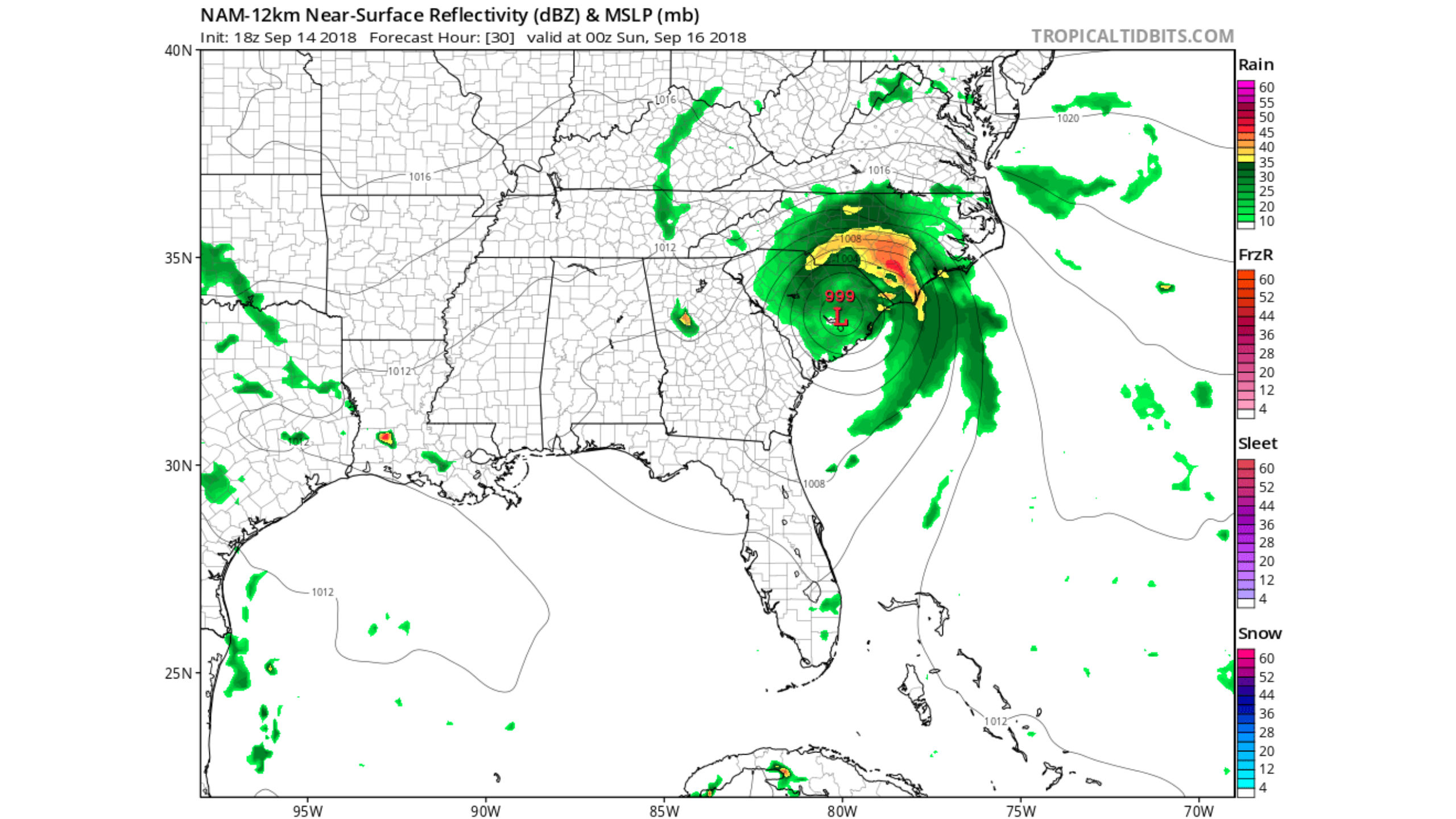
NAM-12km Near-Surface Reflectivity (dBZ) & MSLP (mb)
Init: 18z Sep 14 2018 Forecast Hour: [30] valid at 00z Sun, Sep 16 2018
TROPICALTIDBITS.COM
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90W
85W
80W
75W
70W
1016
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1008
1004
999
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Rain
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FrzR
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Sleet
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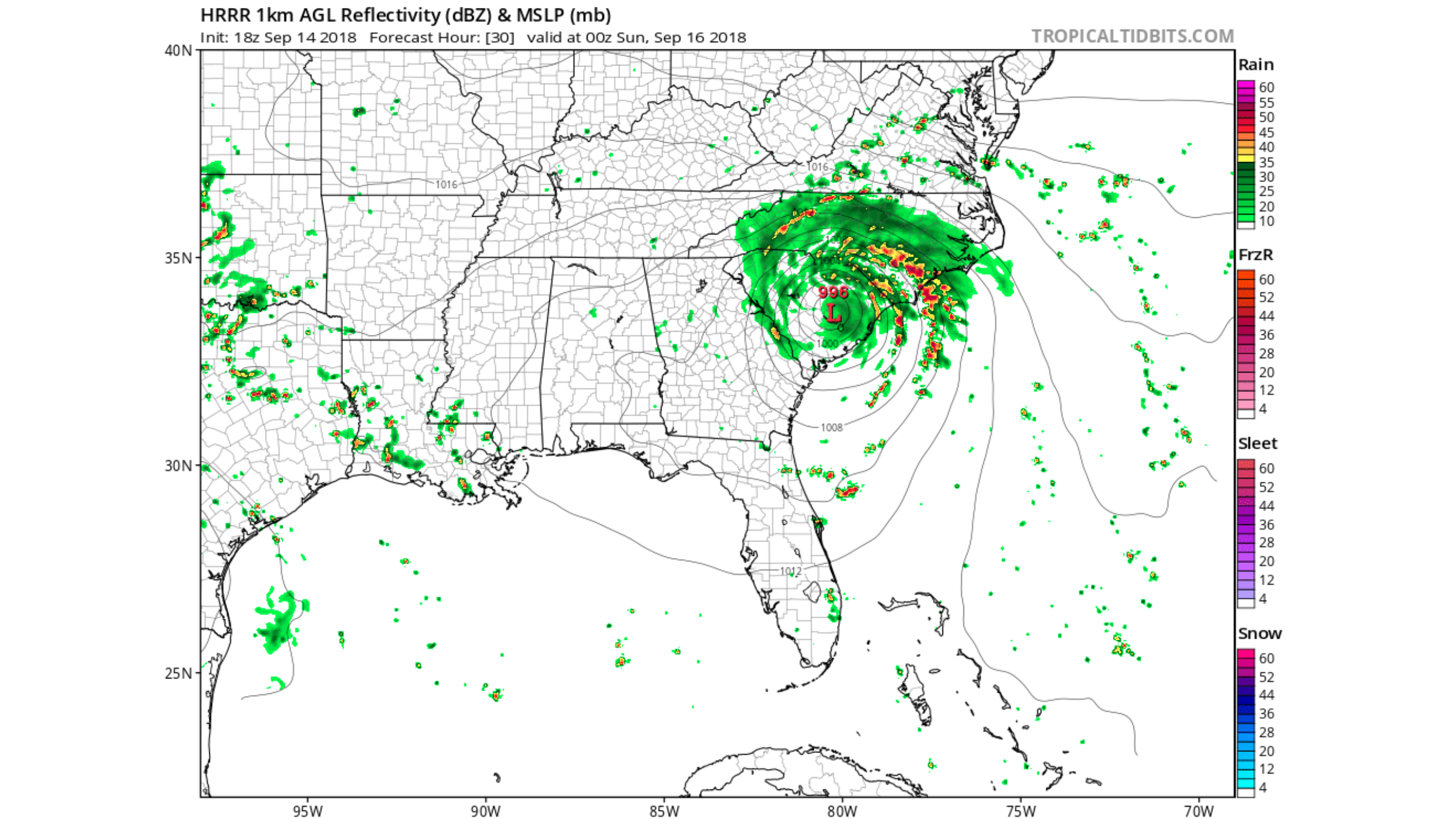
HRRR 1km AGL Reflectivity (dBZ) & MSLP (mb)
Init: 18z Sep 14 2018 Forecast Hour: [30] valid at 00z Sun, Sep 16 2018
TROPICALTIDBITS.COM
40N
35N
30N
25N
95W
90W
85W
80W
75W
70W
1016
1016
1004
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1008
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Rain
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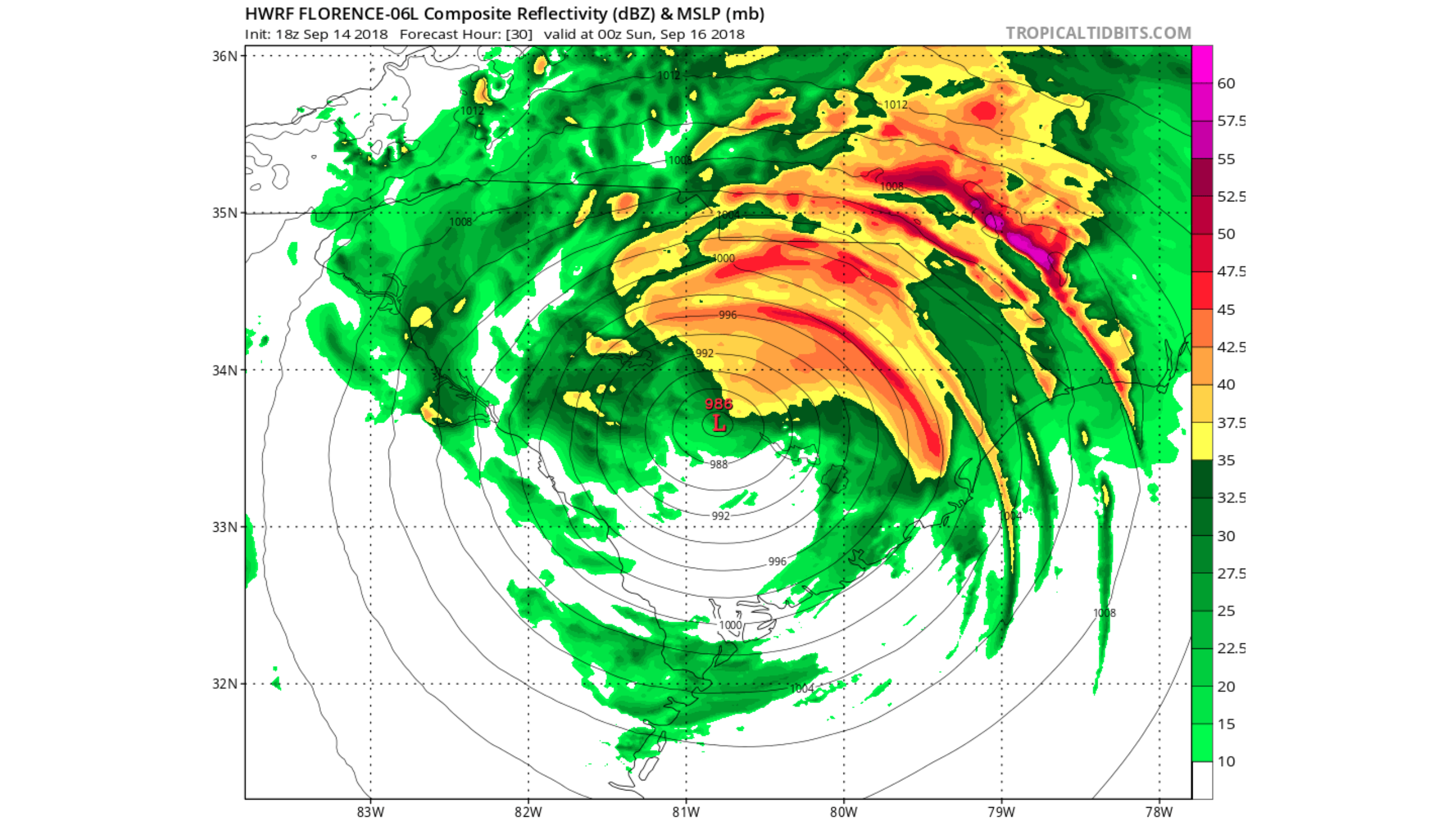
HWRF FLORENCE-06L Composite Reflectivity (dBZ) & MSLP (mb)
Init: 18z Sep 14 2018 Forecast Hour: [30] valid at 00z Sun, Sep 16 2018
TROPICALTIDBITS.COM
36N
35N
34N
33N
32N
83W
82W
81W
80W
79W
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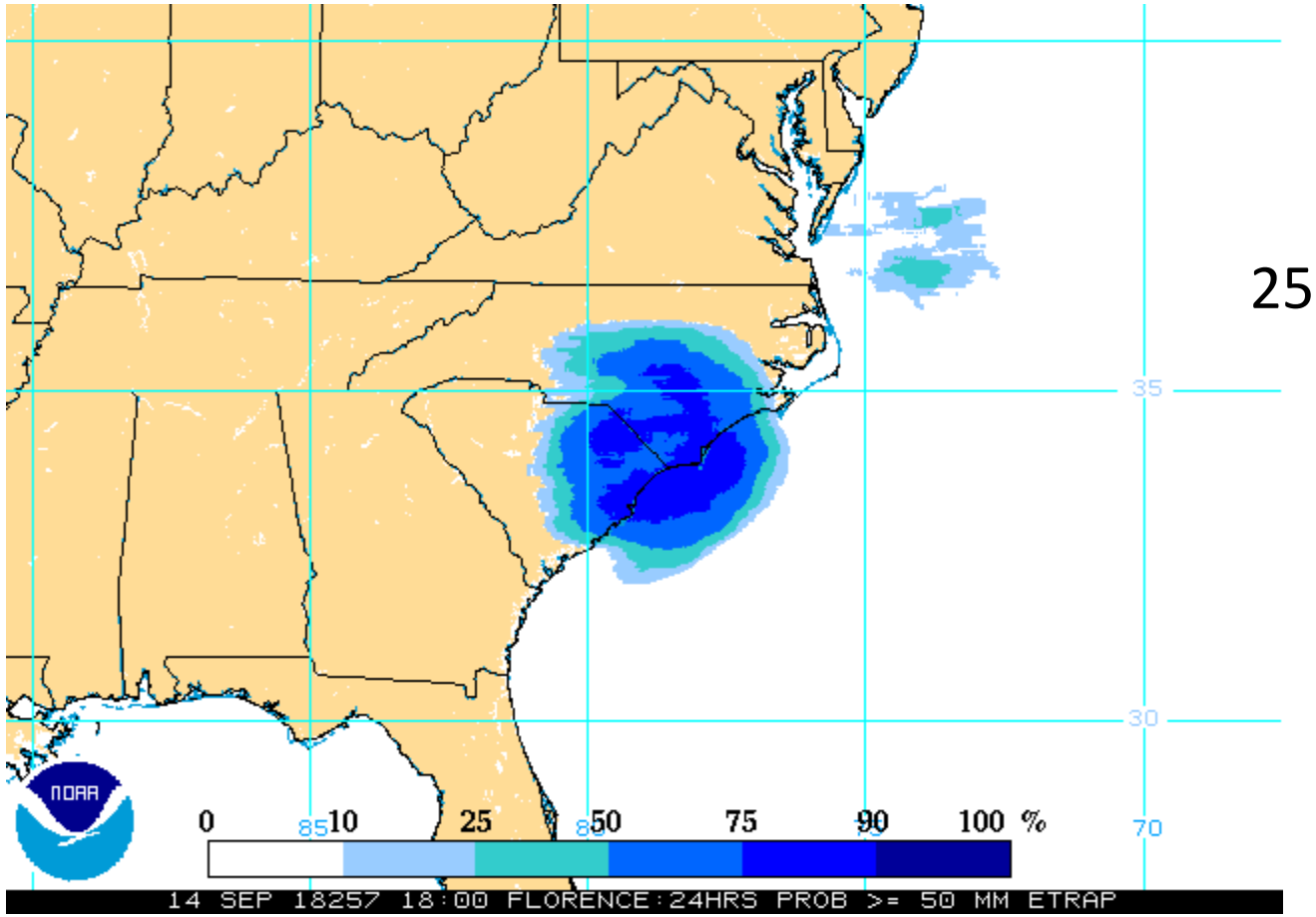
10

Ensemble Tropical Rainfall Potential (eTRaP)

Examples shown for 6-hr forecast

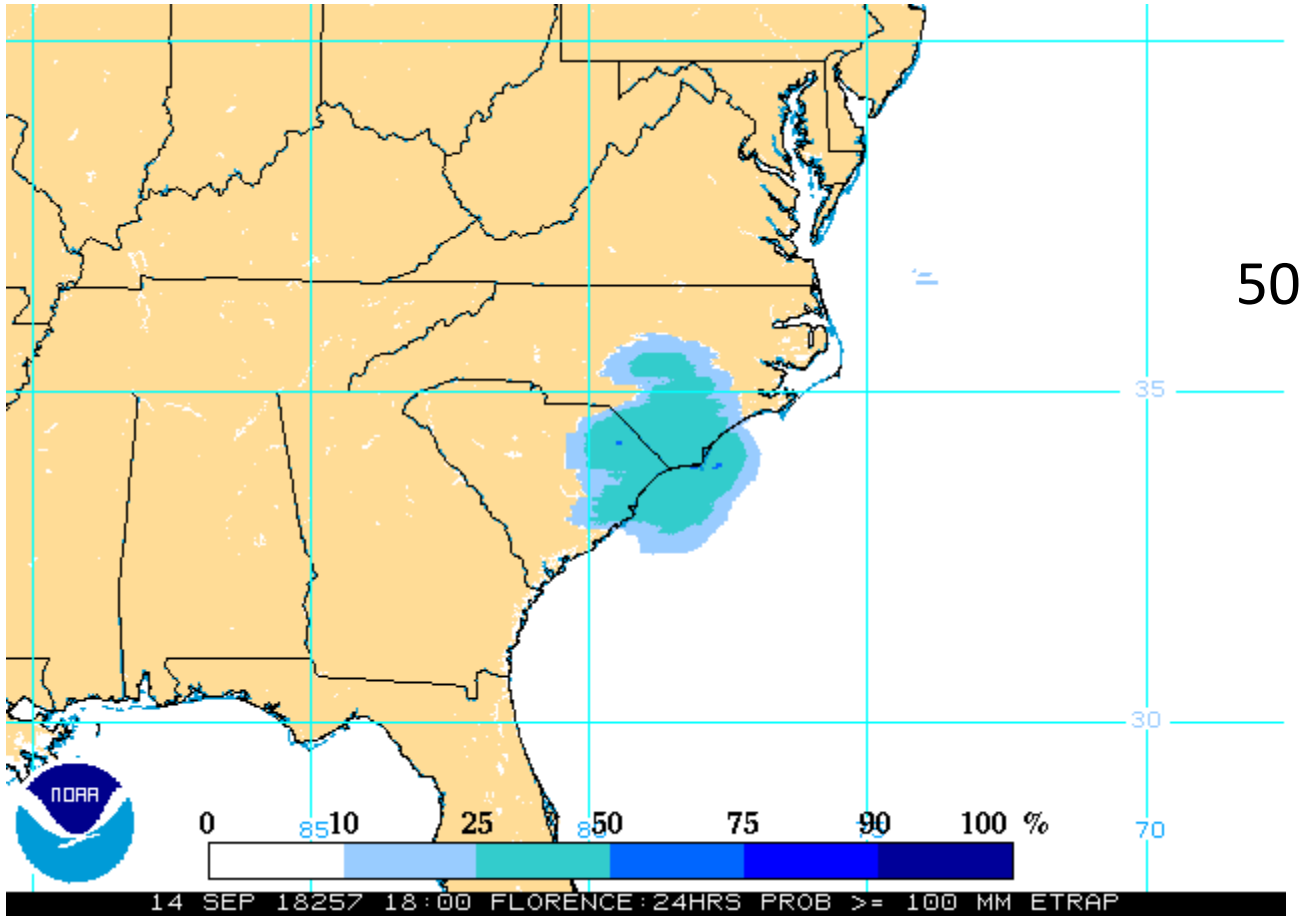
Initialized Sept. 14, 18Z

Probability of Precipitation (POP)>25 mm



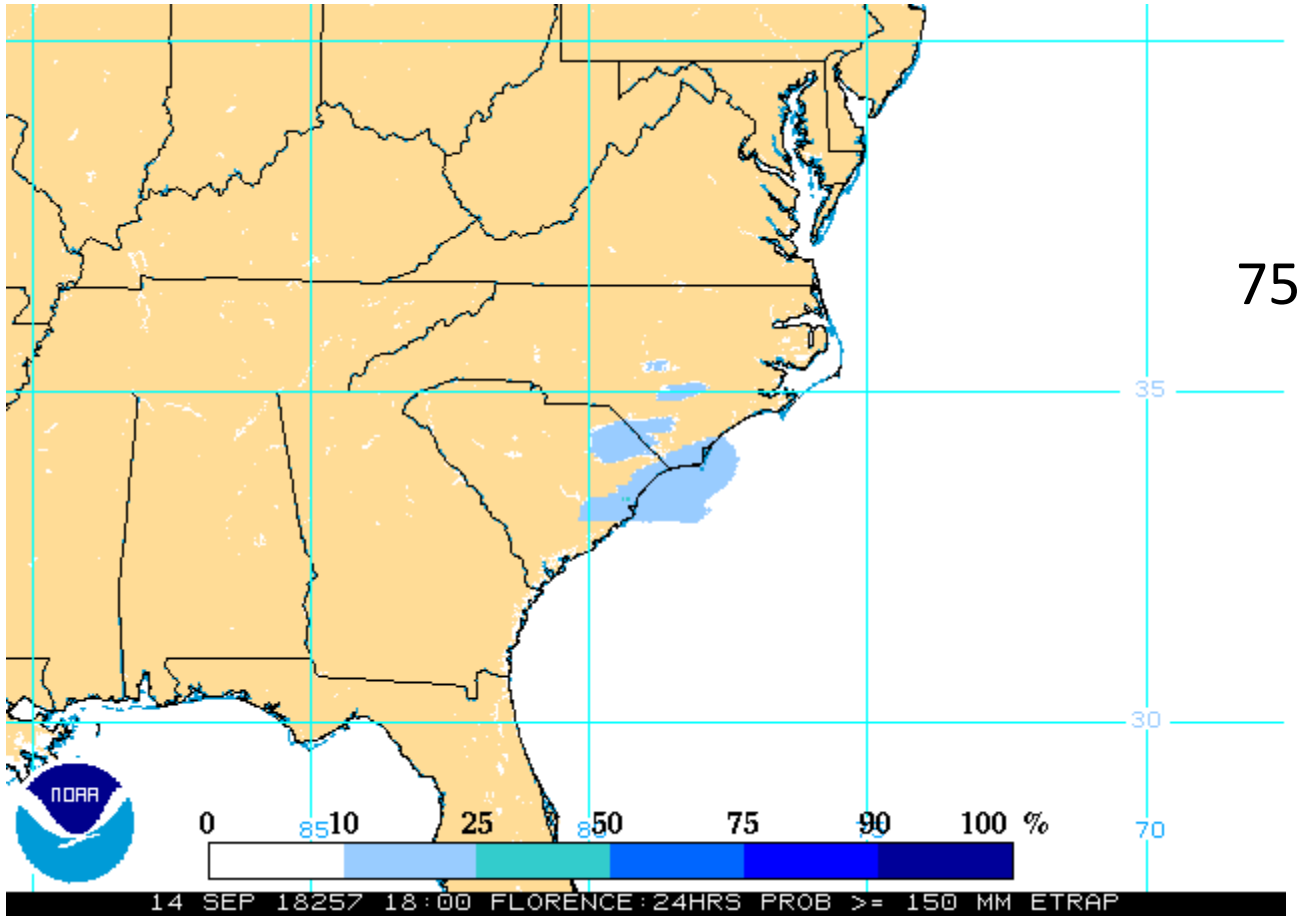
25 mm ≈ 1 inch

Probability of Precipitation (POP)>50 mm



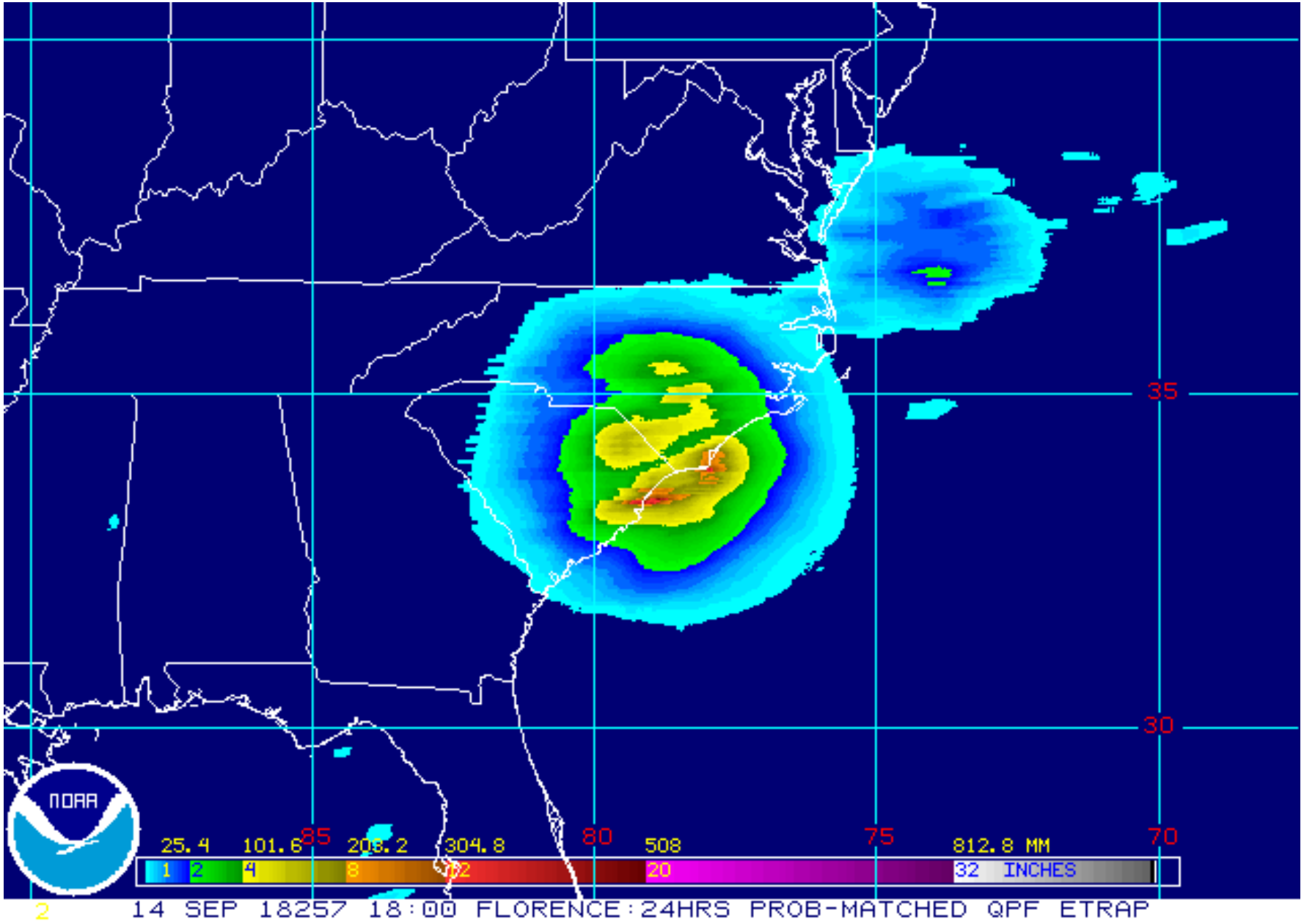
50 mm ≈ 2 inches

Probability of Precipitation (POP)>75 mm



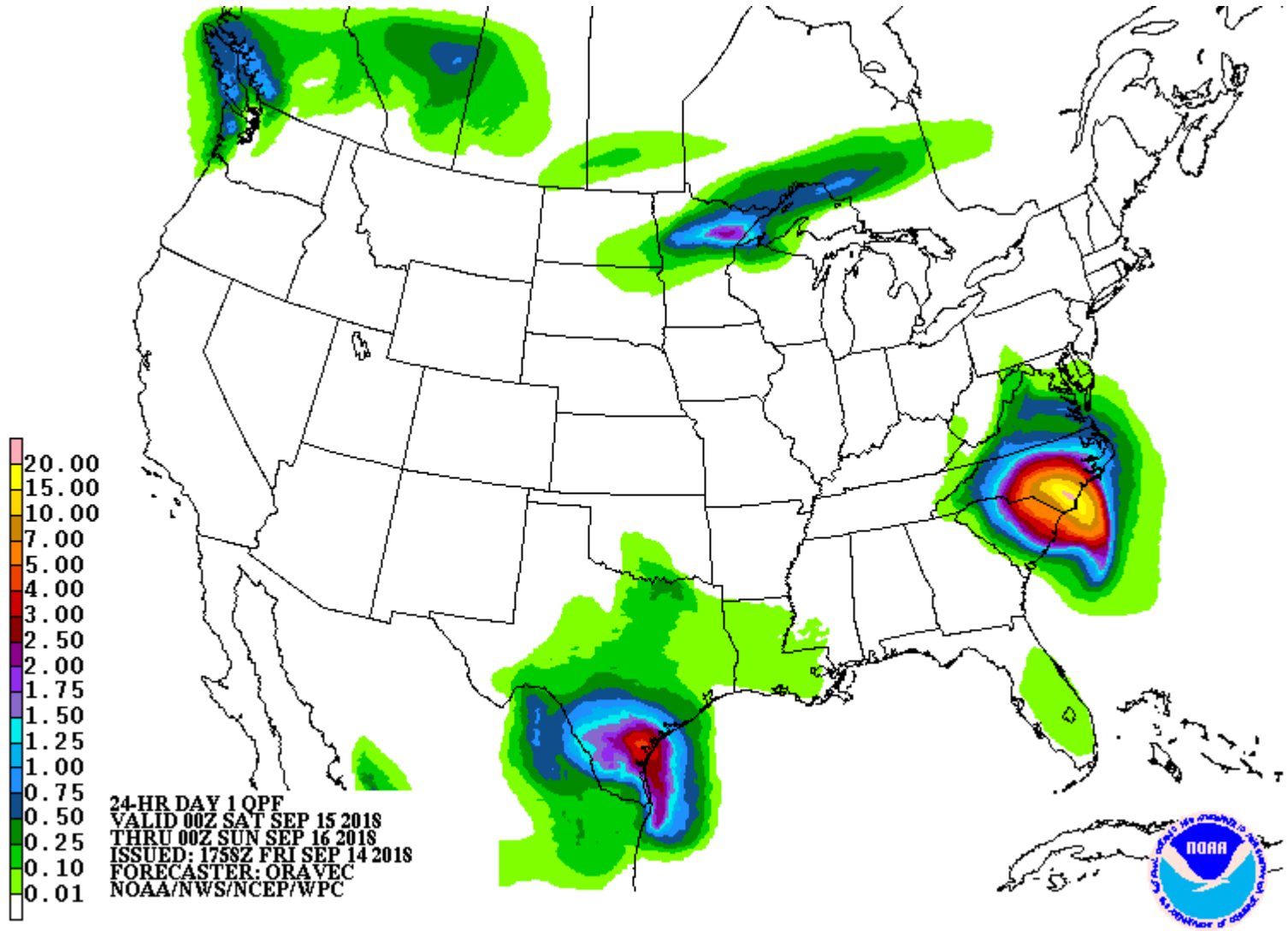
75 mm ≈ 3 inches

ETRAP 6-hr rain totals



NOAA’s Weather Prediction Center (WPC) generalized graphics

Initialized Sept. 14, 18Z


20.00
15.00
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7.00
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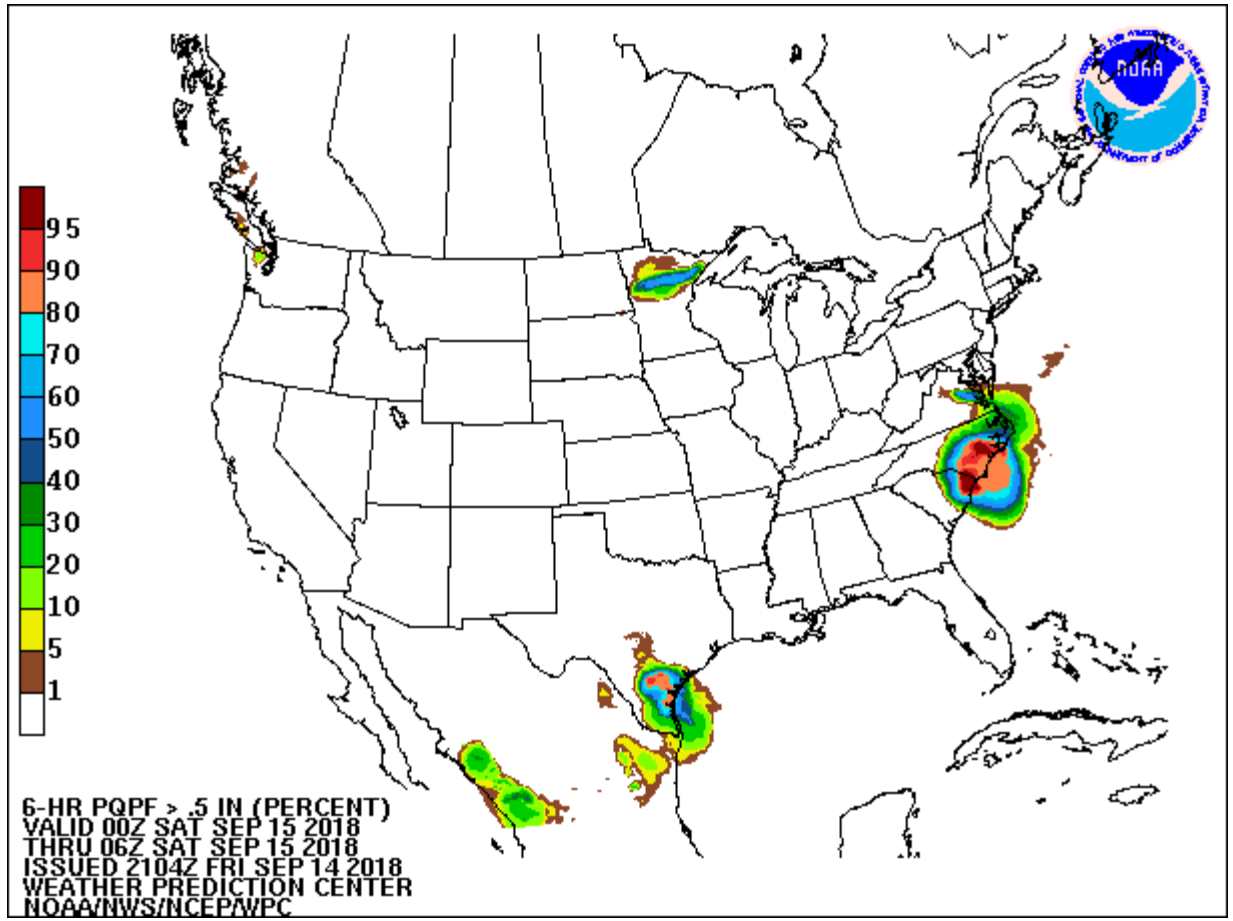
4.00
3.00
2.50
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.10
0.01
24-HR DAY 1 QPF
VALID 00Z SAT SEP 15 2018
THRU 00Z SUN SEP 16 2018
ISSUED: 1758Z FRI SEP 14 2018
FORECASTER: ORAVEC
NOAA/NWS/NCEP/WPC
NOAA


95
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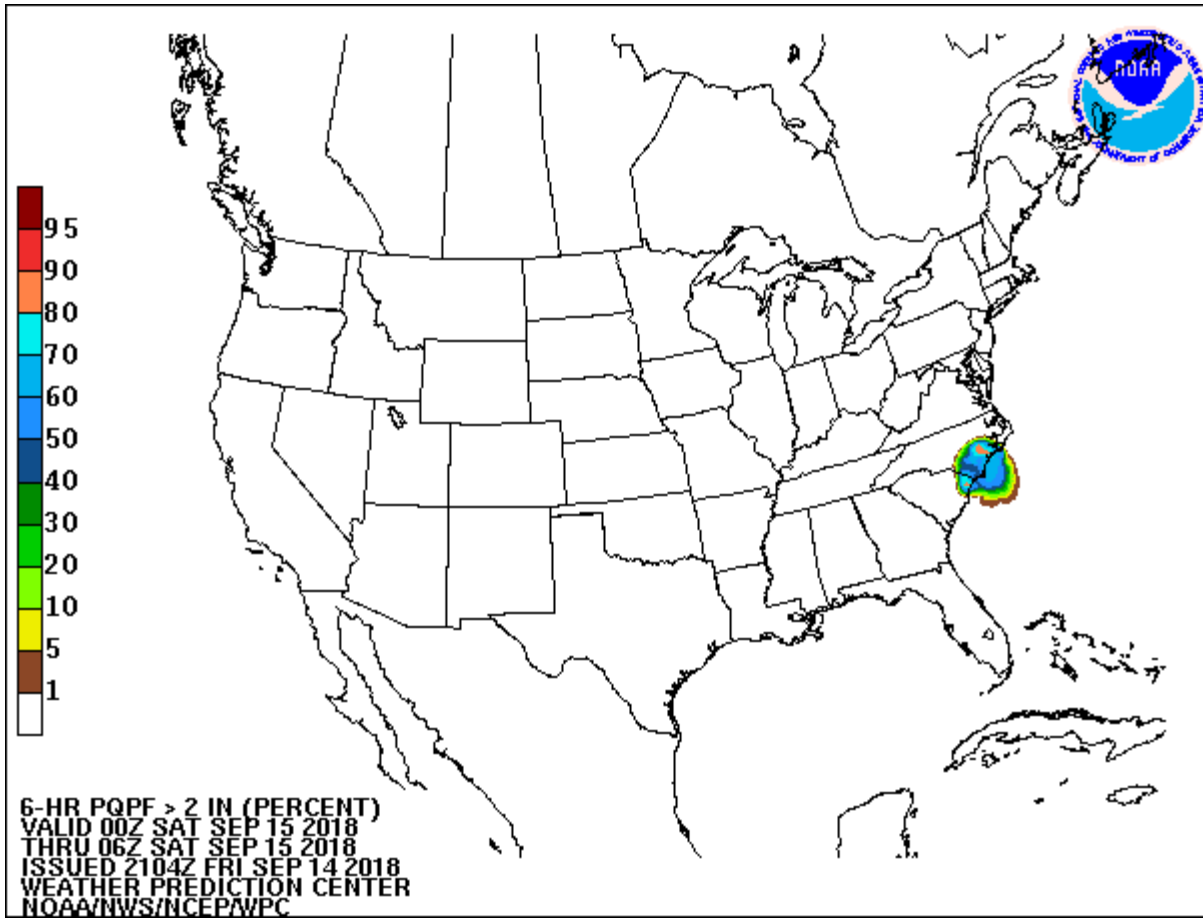
1
6-HR PQPF > .5 IN (PERCENT)
VALID 00Z SAT SEP 15 2018
THRU 06Z SAT SEP 15 2018
ISSUED 2104Z FRI SEP 14 2018
WEATHER PREDICTION CENTER
NOAA/NWS/NCEP/WPC


95
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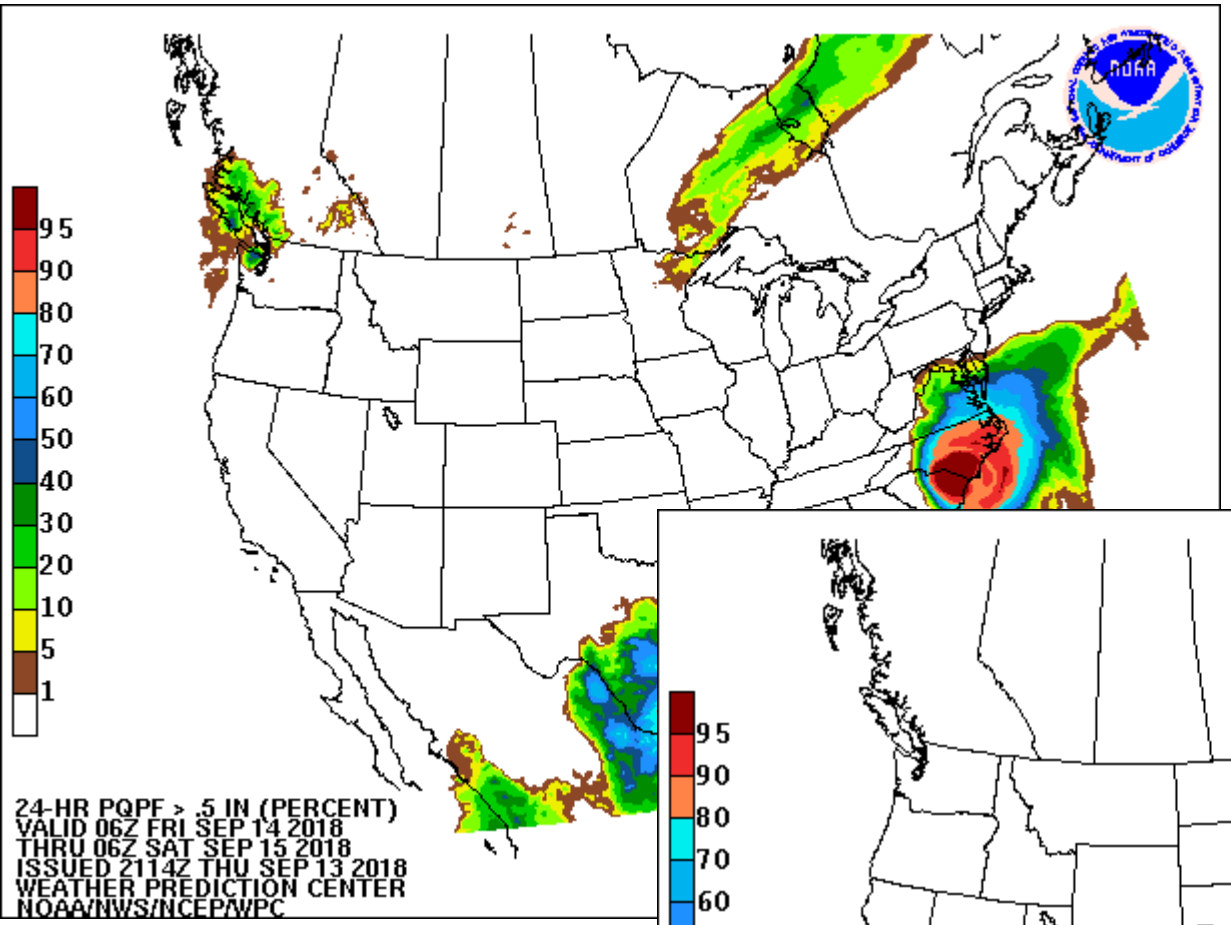
6-HR PQPF > 2 IN (PERCENT)
VALID 00Z SAT SEP 15 2018
THRU 06Z SAT SEP 15 2018
ISSUED 2104Z FRI SEP 14 2018
WEATHER PREDICTION CENTER
NOAA/NWS/NCEP/WPC


95
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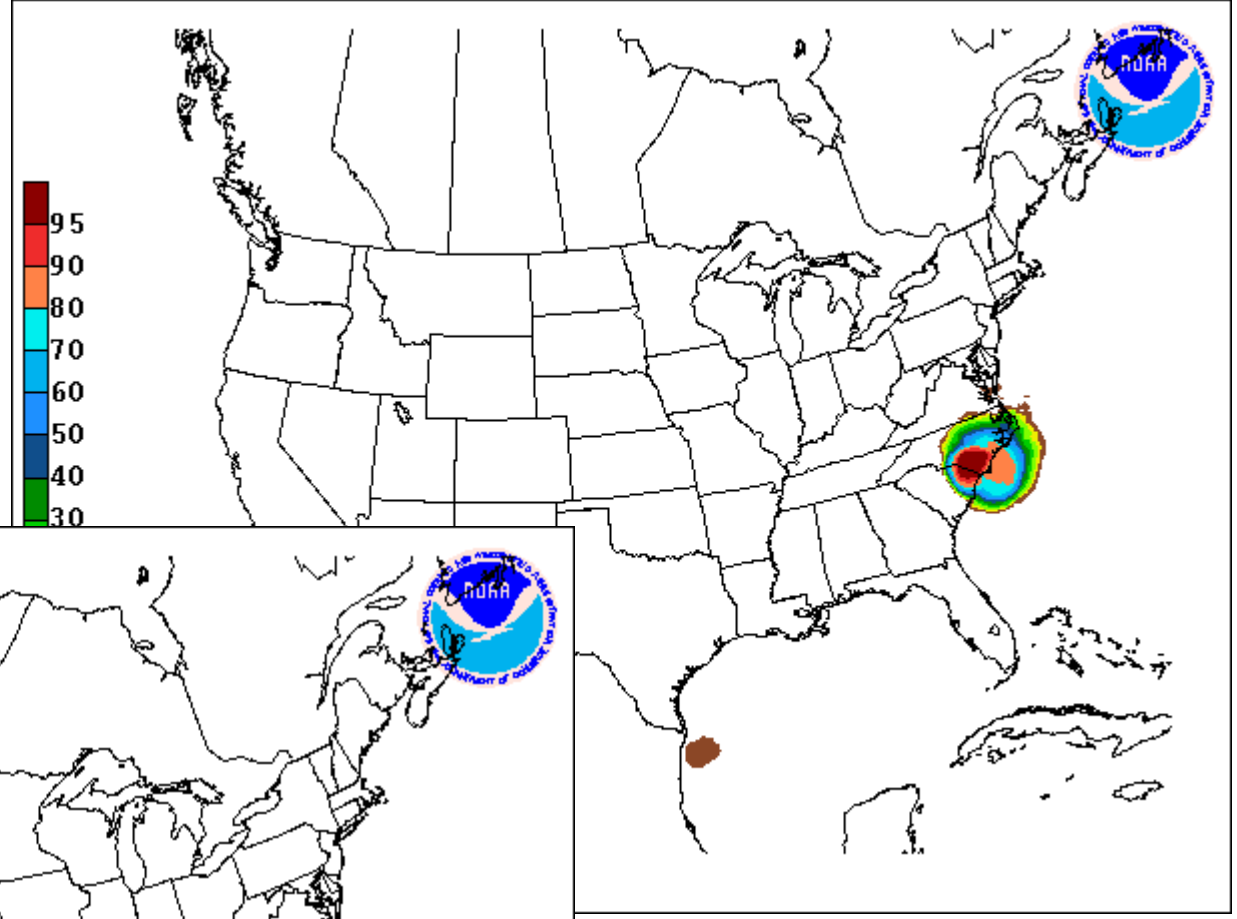
24-HR PQPF > .5 IN (PERCENT)
VALID 06Z FRI SEP 14 2018
THRU 06Z SAT SEP 15 2018
ISSUED 2114Z THU SEP 13 2018
WEATHER PREDICTION CENTER
NOAA/NWS/NCEP/WPC


95
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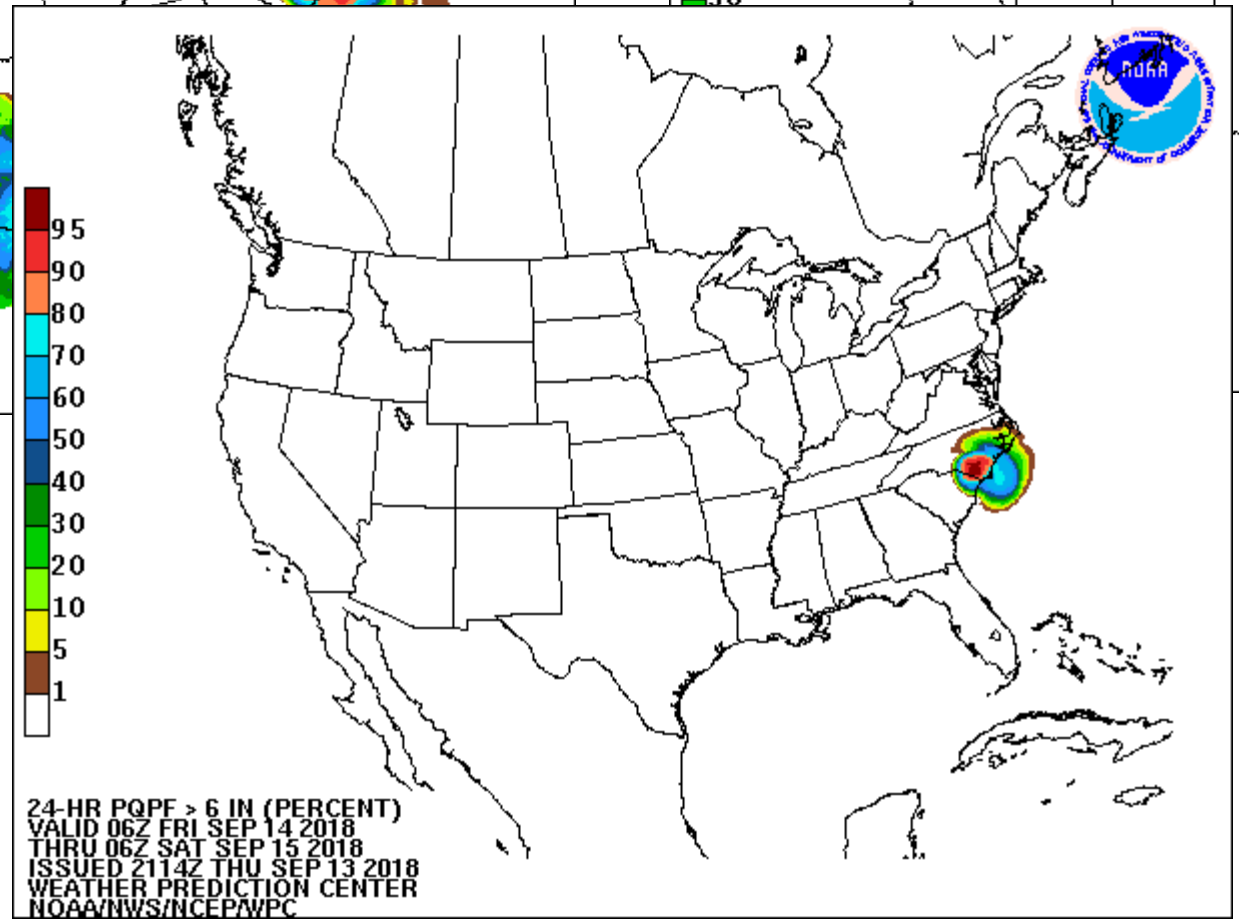
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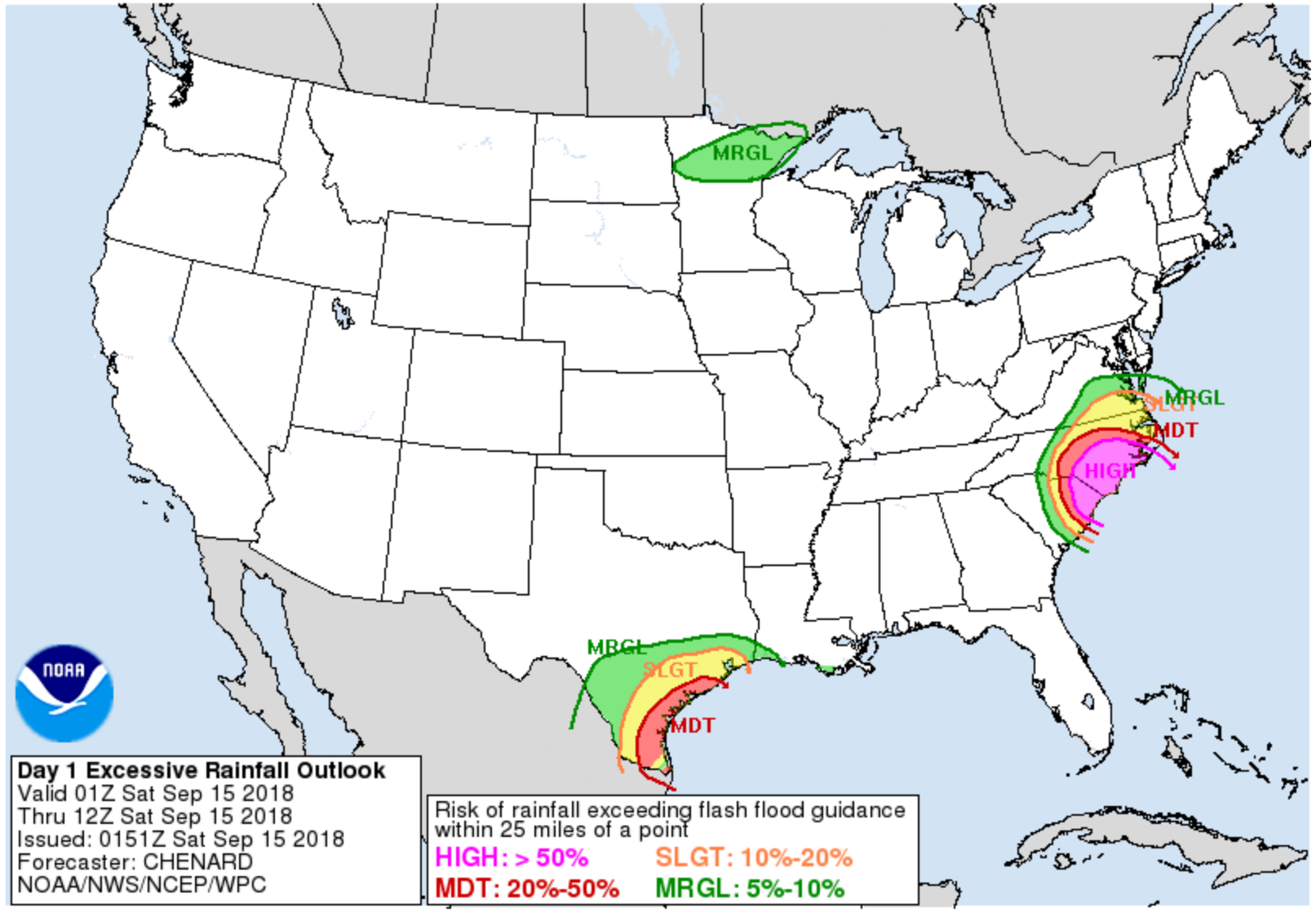
24-HR PQPF > 6 IN (PERCENT)
VALID 06Z FRI SEP 14 2018
THRU 06Z SAT SEP 15 2018
ISSUED 2114Z THU SEP 13 2018
WEATHER PREDICTION CENTER
NOAA/NWS/NCEP/WPC


MRGL
MRGL
SLGT
MDT
HIGH
MRGL
SLGT
MDT
Day 1 Excessive Rainfall Outlook
Valid 01Z Sat Sep 15 2018
Thru 12Z Sat Sep 15 2018
Issued: 0151Z Sat Sep 15 2018
Forecaster: CHENARD
NOAA/NWS/NCEP/WPC
Risk of rainfall exceeding flash flood guidance within 25 miles of a point
HIGH: > 50%
SLGT: 10%-20%
MDT: 20%-50%
MRGL: 5%-10%

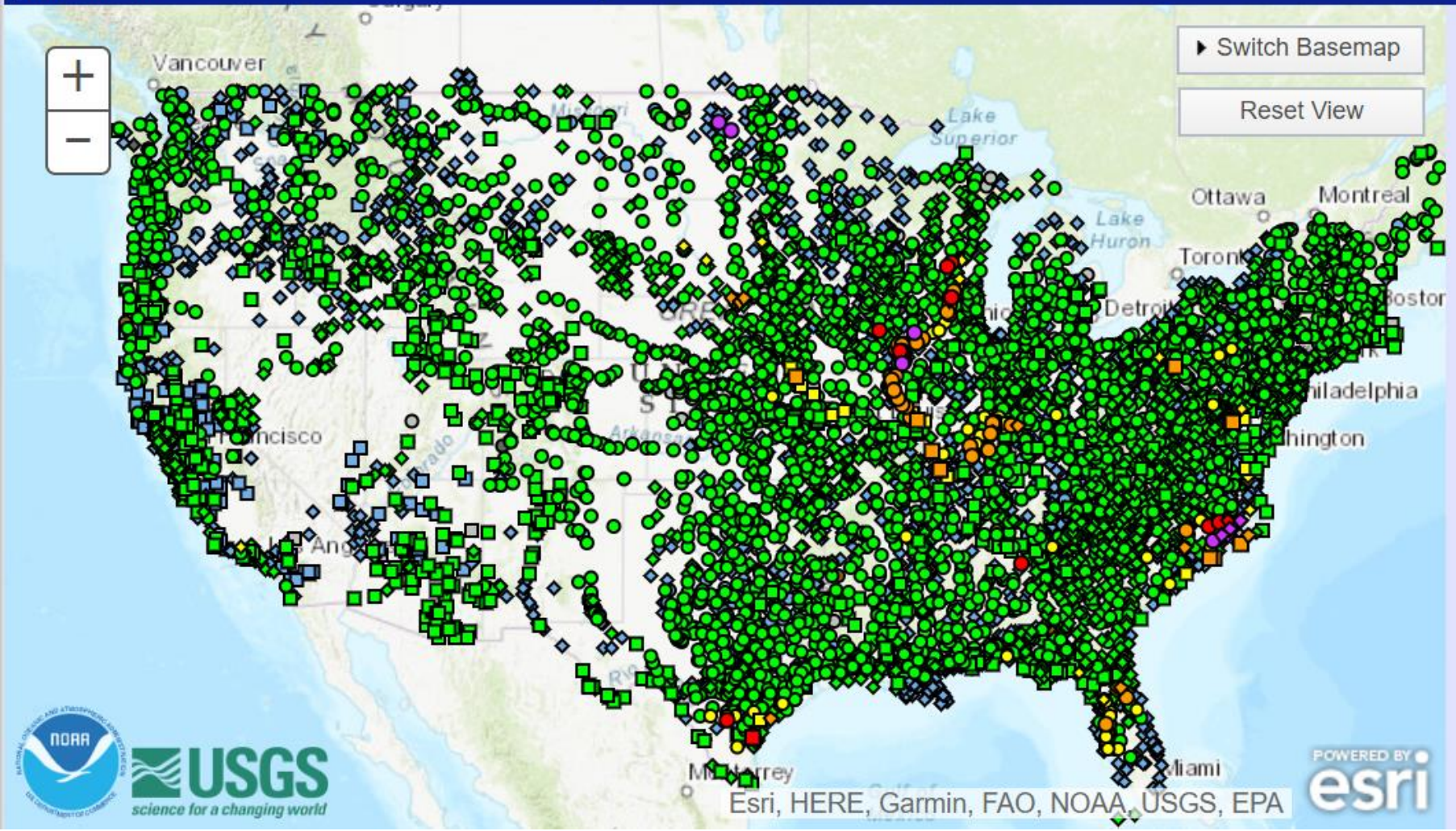
Hydrology tools

https://water.weather.gov/ahps/

Auto Refresh: OFF

Print this map | Permalink | BOOKMARK

All Locations



Click on the map or select one of the data views below:

- United States
- NWS Weather Forecast Offices
- NWS River Forecast Centers
- Water Resources Regions

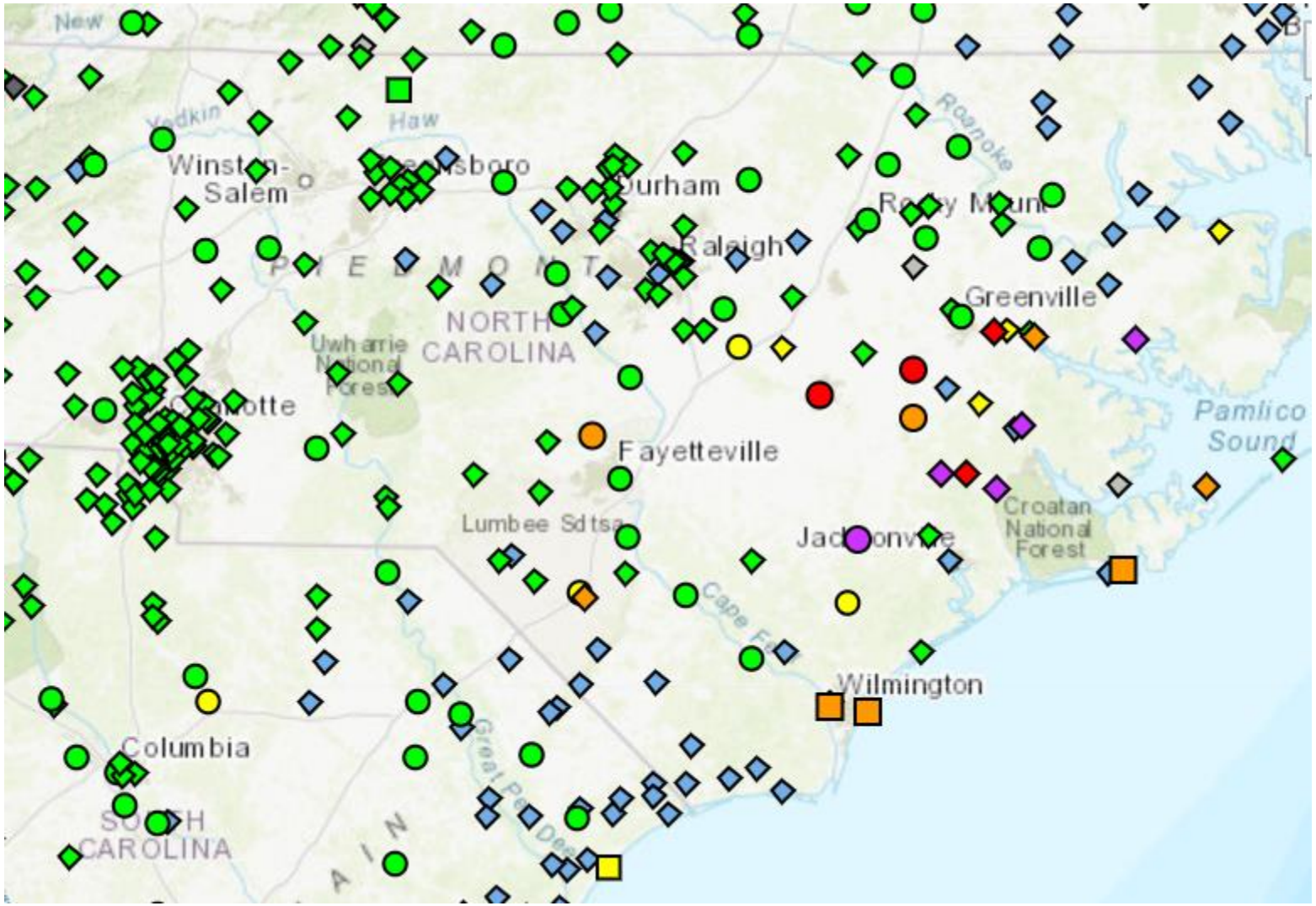
○ Probability and forecasts available
◇ Observations only available
□ Forecasts available

8900 total gauges

Show all locations in flood (79)

- 9 Gauges: Major Flooding
- 17 Gauges: Moderate Flooding
- 53 Gauges: Minor Flooding
- 84 Gauges: Near Flood Stage
- 5669 Gauges: No Flooding
- 2686 Flood Category Not Defined
- 19 At or Below Low Water Threshold
- 284 Gauges: Observations Are Not Current
- 79 Gauges: Out of Service

Show all locations

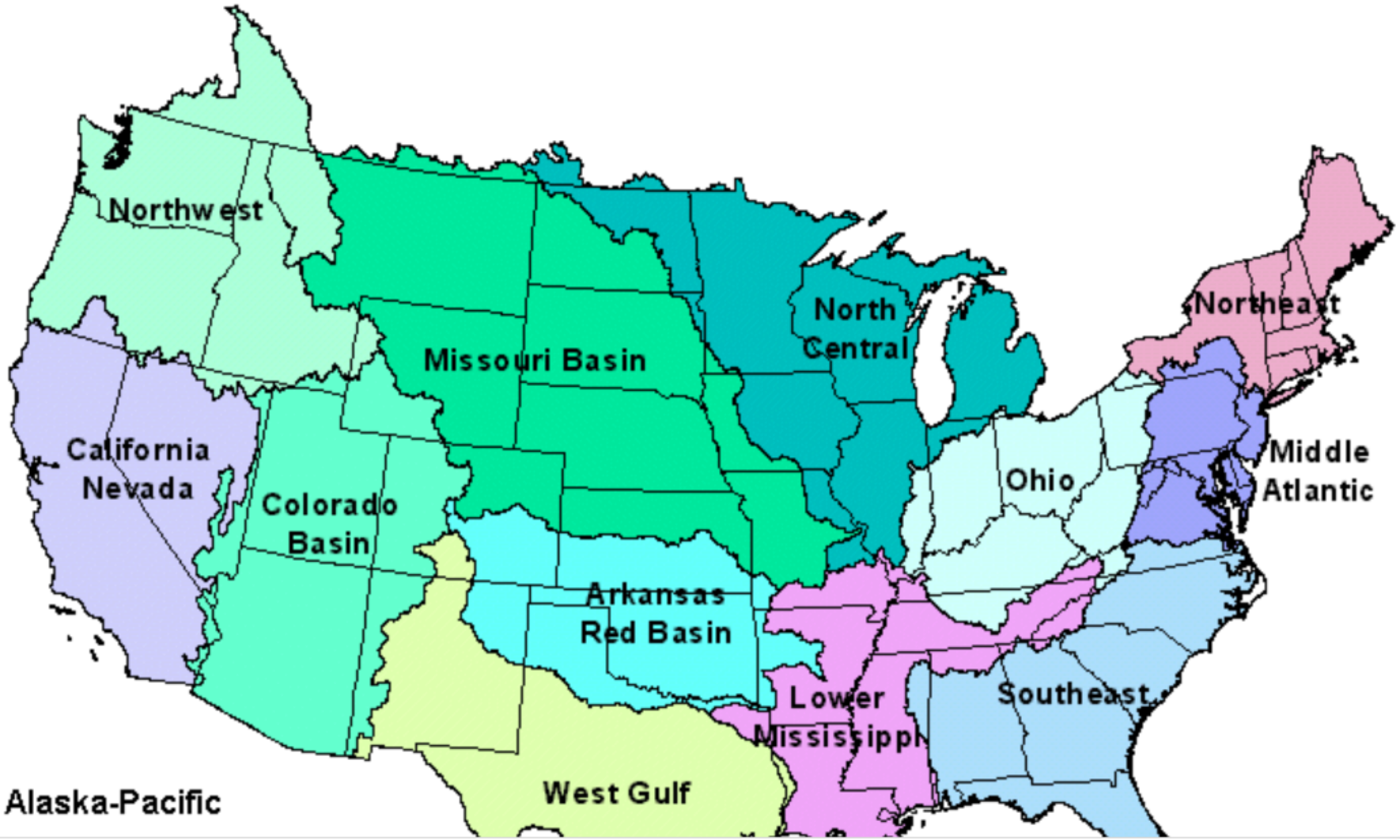

Winston-
Salem
Durham
Raleigh
PIEDMONT
NORTH
CAROLINA
Greenville
Uwharrie
National
Forest
Fayetteville
Pamlico
Sound
Lumbee Sdtsa
Croatan
National
Forest
Wilmington
Columbia
SOUTH
CAROLINA

https://water.weather.gov/ahps/rfc/rfc.php

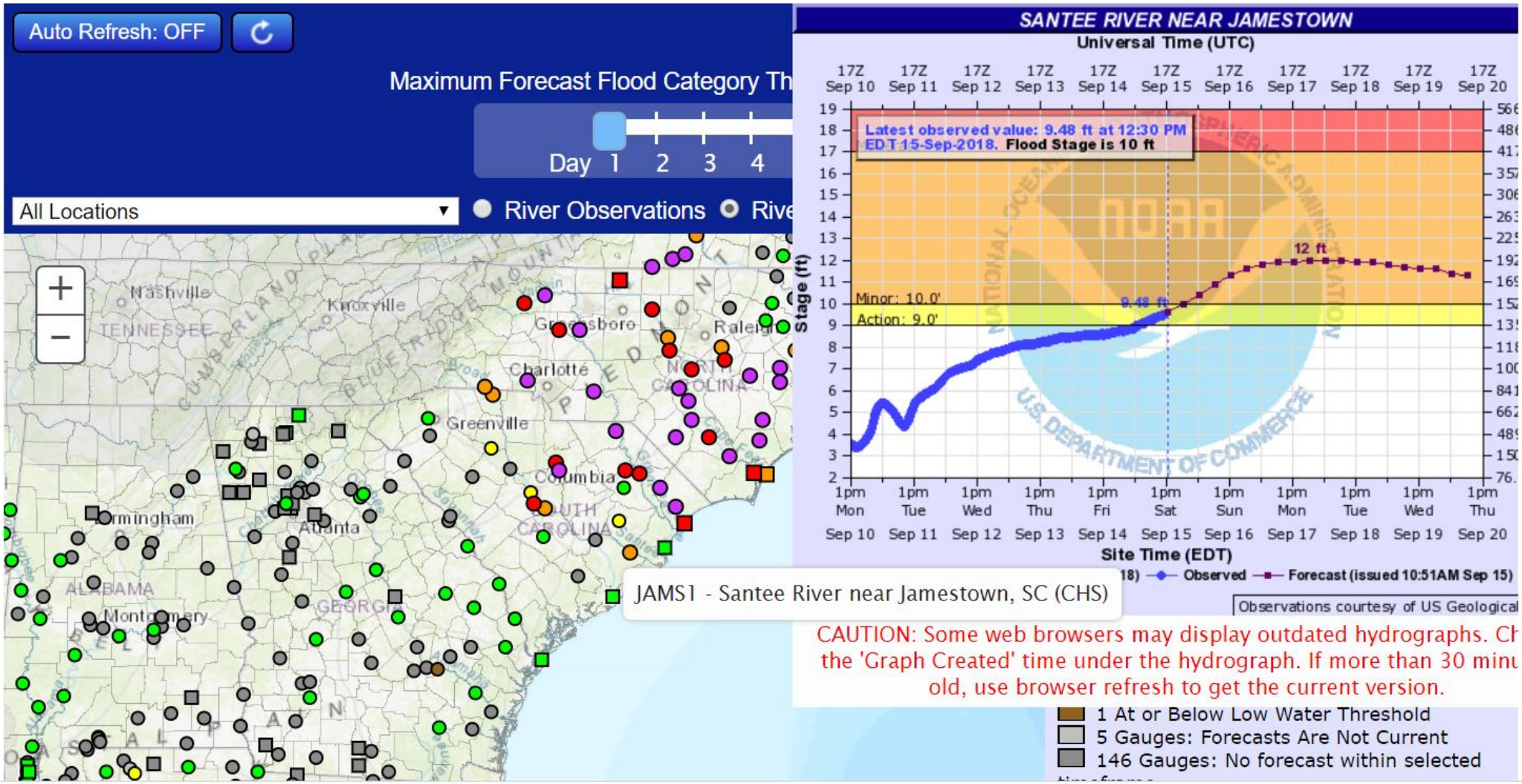
Home News Organization Search for:

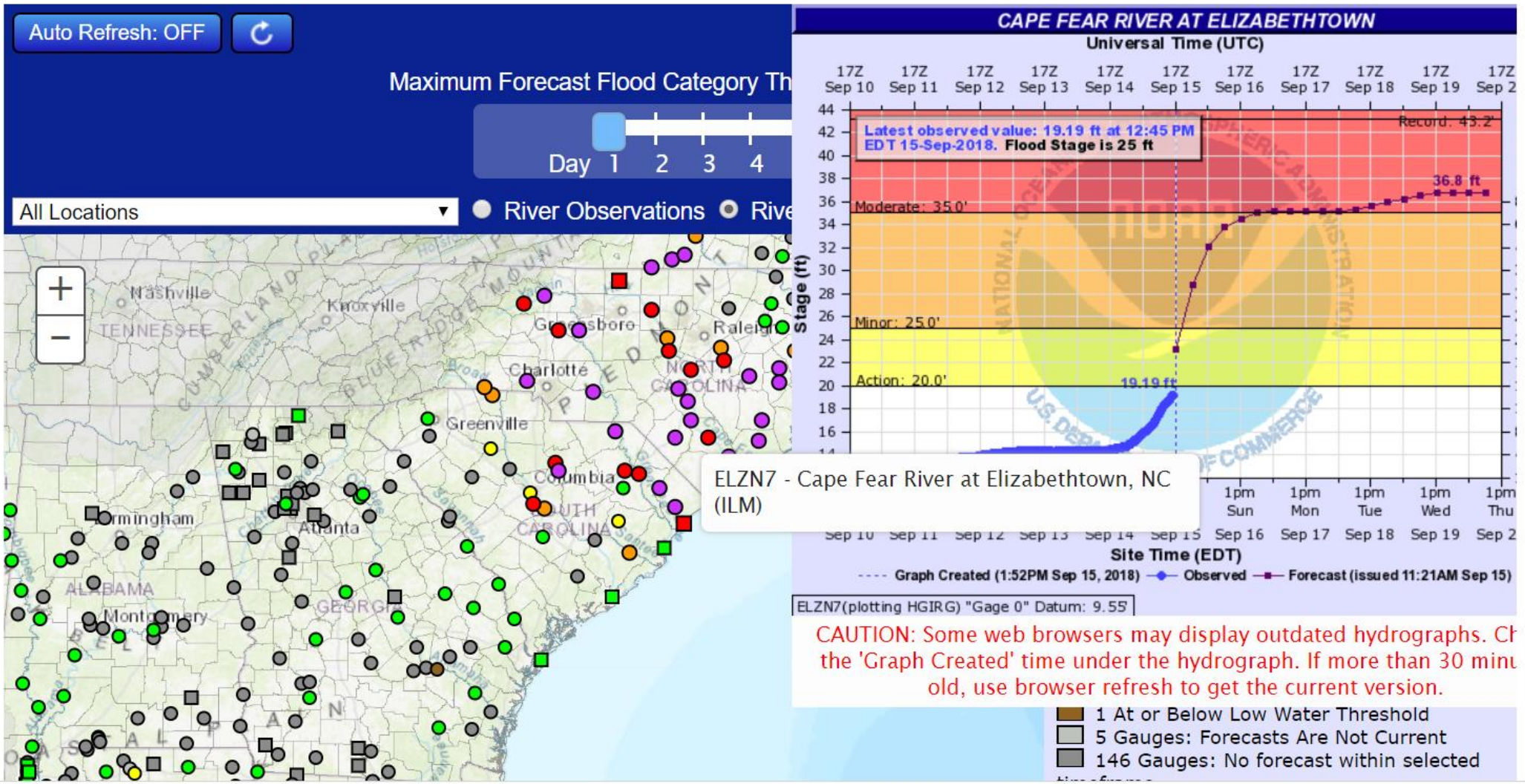
National Observations

River Forecast Centers

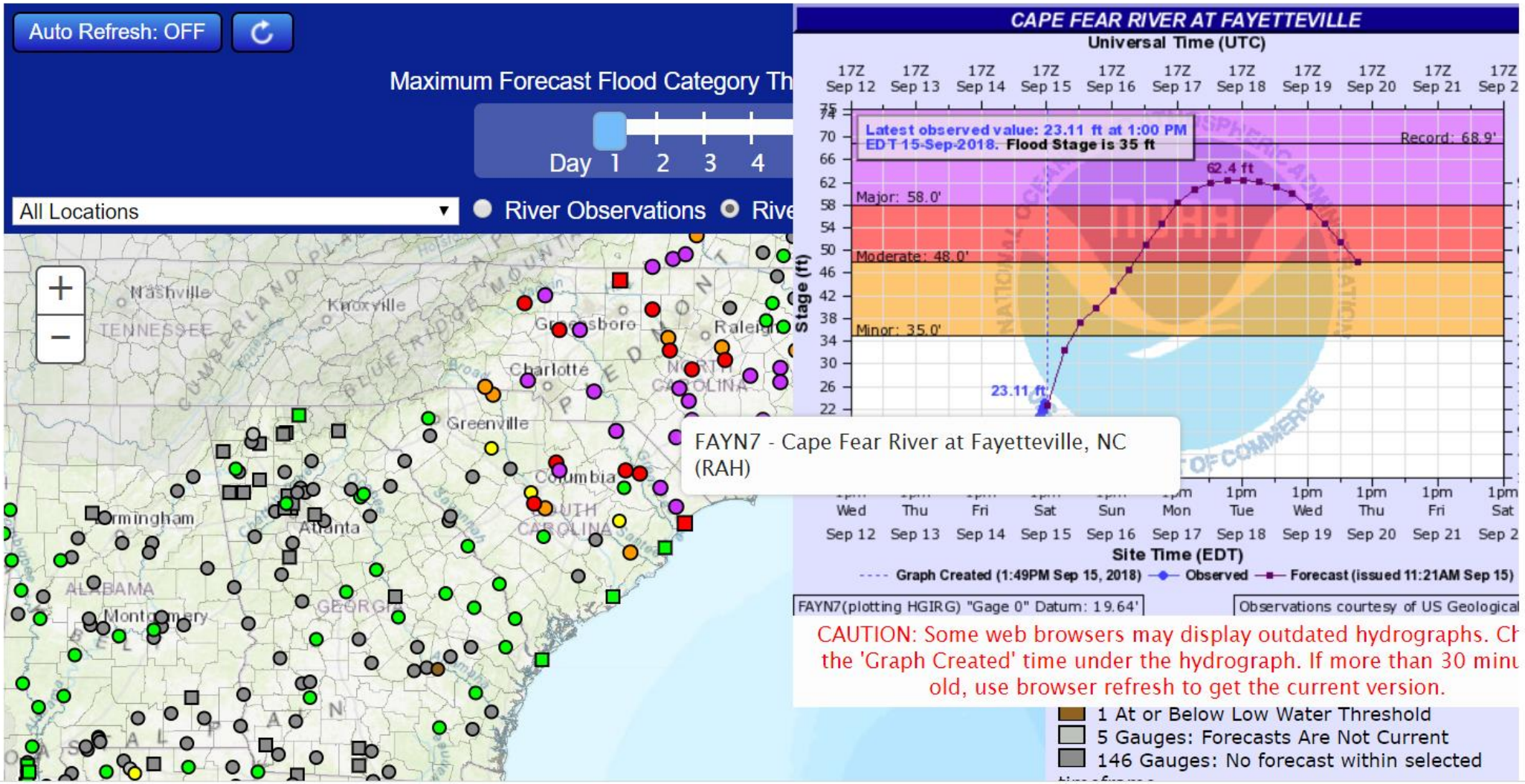


Use the map below to view forecast locations experiencing flooding and link to detailed forecast information.




Auto Refresh: OFF
Maximum Forecast Flood Category Th
Day 1 2 3 4
All Locations
River Observations
Nashville
Knoxville
Greensboro
Raleigh
Charlotte
Greenville
Columbia
Atlanta
Montgomery
TENNESSEE
ALABAMA
GEORGIA
SOUTH CAROLINA
NORTH CAROLINA
CAPE FEAR RIVER AT ELIZABETHTOWN
Universal Time (UTC)
Latest observed value: 19.19 ft at 12:45 PM EDT 15-Sep-2018. Flood Stage is 25 ft
Record: 43.2'
36.8 ft
Moderate: 35.0'
Minor: 25.0'
Action: 20.0'
19.19 ft
Stage (ft)
Site Time (EDT)
Graph Created (1:52PM Sep 15, 2018)
Observed
Forecast (issued 11:21AM Sep 15)
ELZN7(plotting HGIRG) "Gage 0" Datum: 9.55'
ELZN7 - Cape Fear River at Elizabethtown, NC (ILM)
CAUTION: Some web browsers may display outdated hydrographs. Ch
the 'Graph Created' time under the hydrograph. If more than 30 minu
old, use browser refresh to get the current version.
1 At or Below Low Water Threshold
5 Gauges: Forecasts Are Not Current
146 Gauges: No forecast within selected

Use the map below to view forecast locations experiencing flooding and link to detailed forecast information.



NOAA’s Water Model

Not secure | water.noaa.gov/tools/nwm-image-viewer

National Water Model Experimental Image Viewer

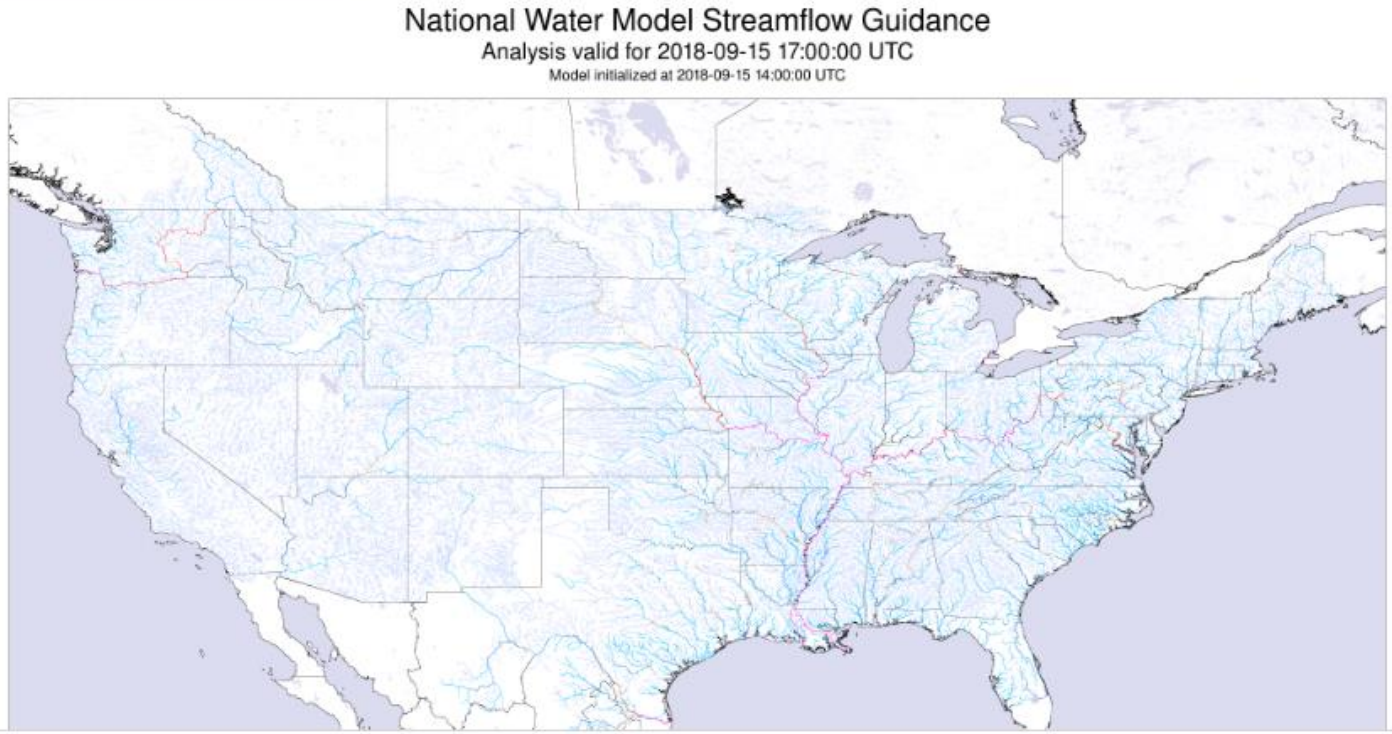
The viewer below has been made available to view the pre-generated imagery depicting output from the National Water Model. For dir
imagery shown in the viewer, visit the following location: https://www.nohrsc.noaa.gov/pub/staff/keicher/WRFH_ppd/web/static_images

Dataset:

Streamflow

Forecast Type:

Analysis



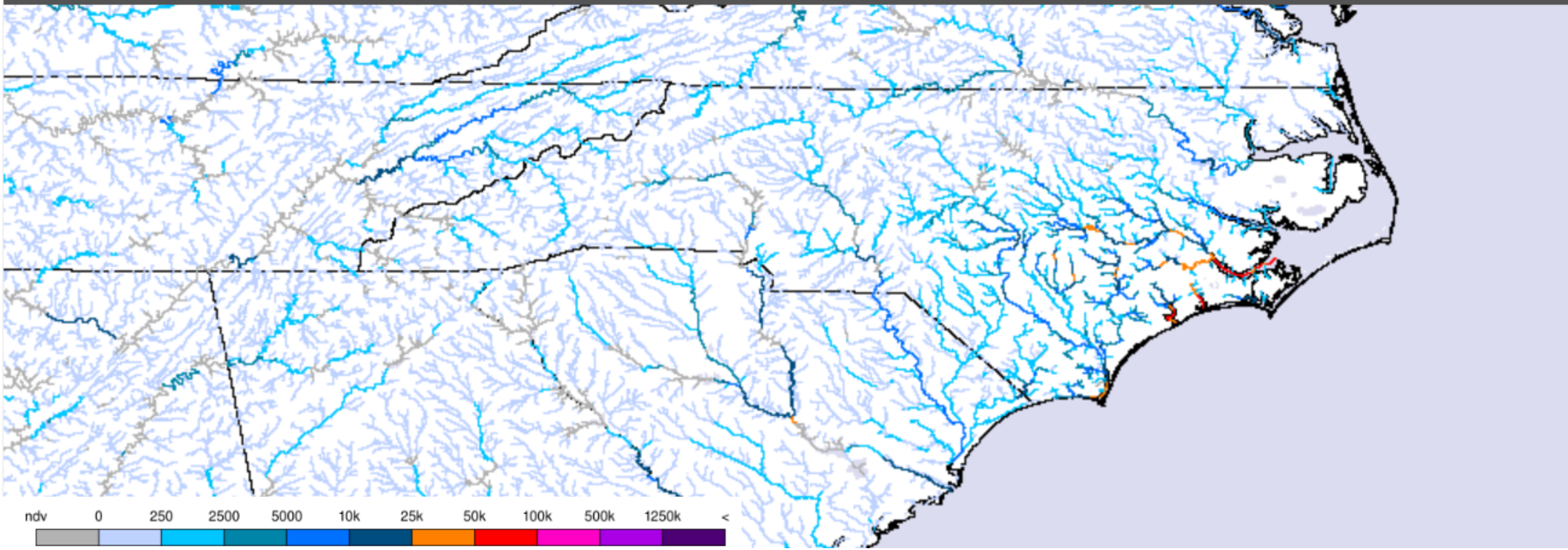
Dataset:

Streamflow

Forecast Type:

Analysis

2018-09-15 17:00:00 UTC



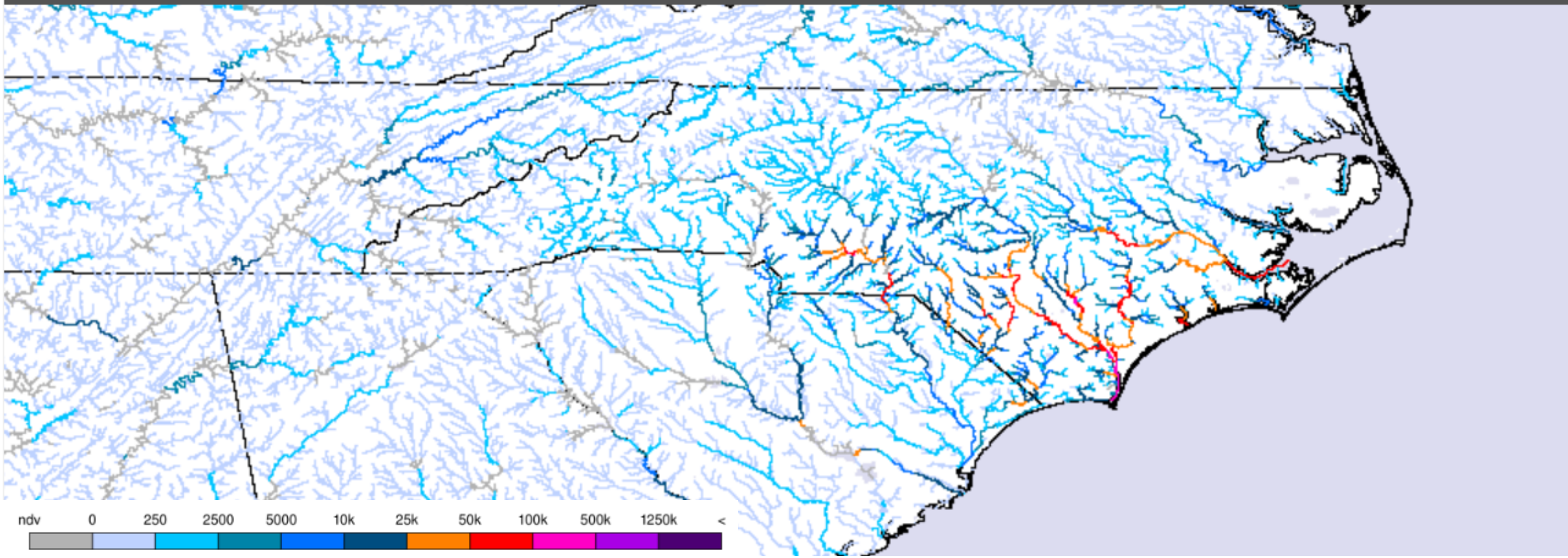
Dataset:

Streamflow

Forecast Type:

Short Range

2018-09-16 10:00:00 UTC



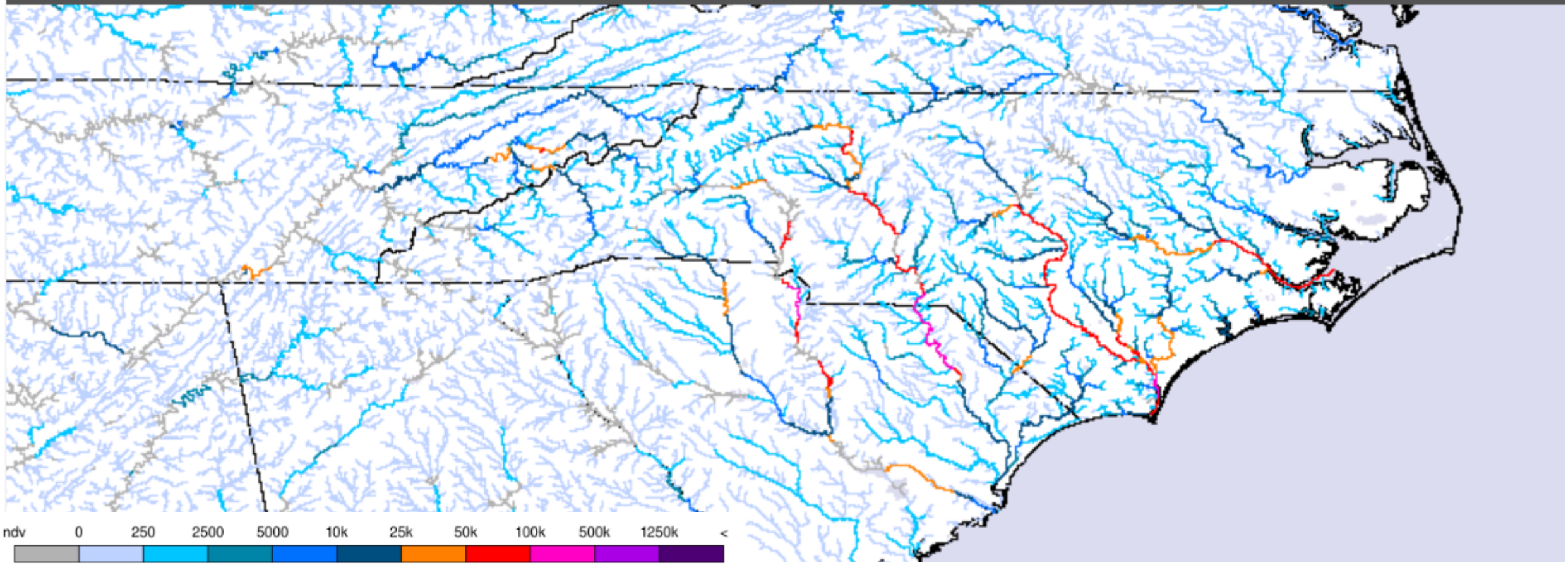
Dataset:

Streamflow

Forecast Type:

Medium Range

2018-09-17 12:00:00 UTC



USGS Flood Page

https://water.usgs.gov/floods/

Regional and Local Flood Alerts

PROJECT ALERT NOTICE (GA NC SC) HURRICANE FLORENCE
Sat, 15 Sep 2018 13:00:16 EDT
Hurricane Florence makes landfall on NC coast.

PROJECT ALERT NOTICE (VA WV) USGS VA-WV WSC DEPLOYING SENSORS IN ADVANCE OF HURRICANE FLORENCE
Tue, 11 Sep 2018 12:47:13 EDT
USGS staff is deploying water level and meteorological sensors in advance of Hurricane Florence.

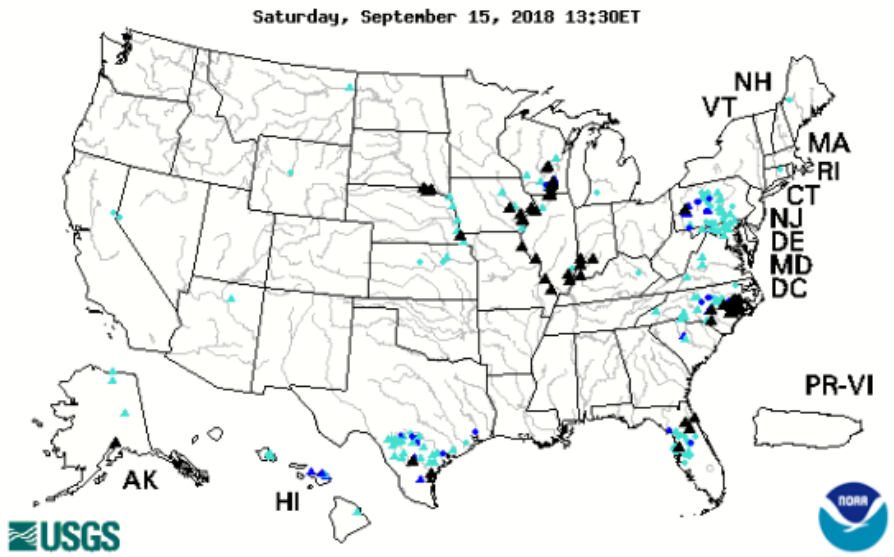
PROJECT ALERT NOTICE (MD) USGS PREPARES FOR DATA COLLECTION IN RESPONSE TO HURRICANE FLORENCE (MD-DE-DC WSC)
Tue, 11 Sep 2018 12:04:26 EDT
Field crews deploy monitoring assets ahead of potential impacts from Hurricane Florence.

PROJECT ALERT NOTICE (MD) HIGH RIVER FLOWS AND FLOODING IN WESTERN MARYLAND
Mon, 10 Sep 2018 14:08:33 EDT
Radar-estimated rainfall totals ranging

USGS Flood Information

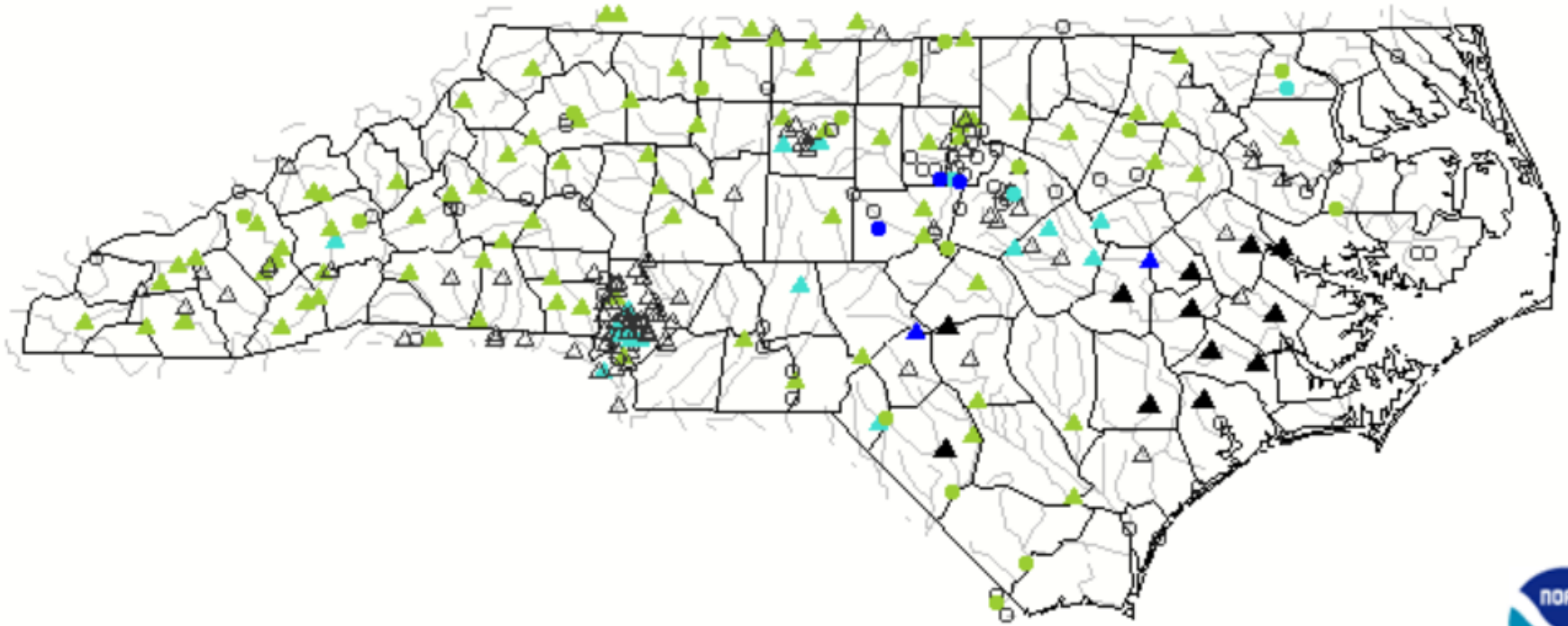
CURRENT FLOODING | HISTORICAL FLOODING | FLOOD

This section contains information about active and recent events tracked by the USGS National Floods Specialist. Streamflow data is v agencies to forecast flood magnitude and timing, operate flood control systems, and manage emergency response. In addition, USGS and dissemination of geospatial imagery and map products used for flood response and evaluation.



Today's Flood Conditions (USGS WaterWatch)

- River Above Flood Stage
- 99th Percentile
- 95-98 Percentile



USGS

NOAA

Search USGS streamgage

Choose a data retrieval option and select a location on the map

○ **List of all stations** ◉ **Single station** ○ **Nearest stations** ○ **Peak flow**

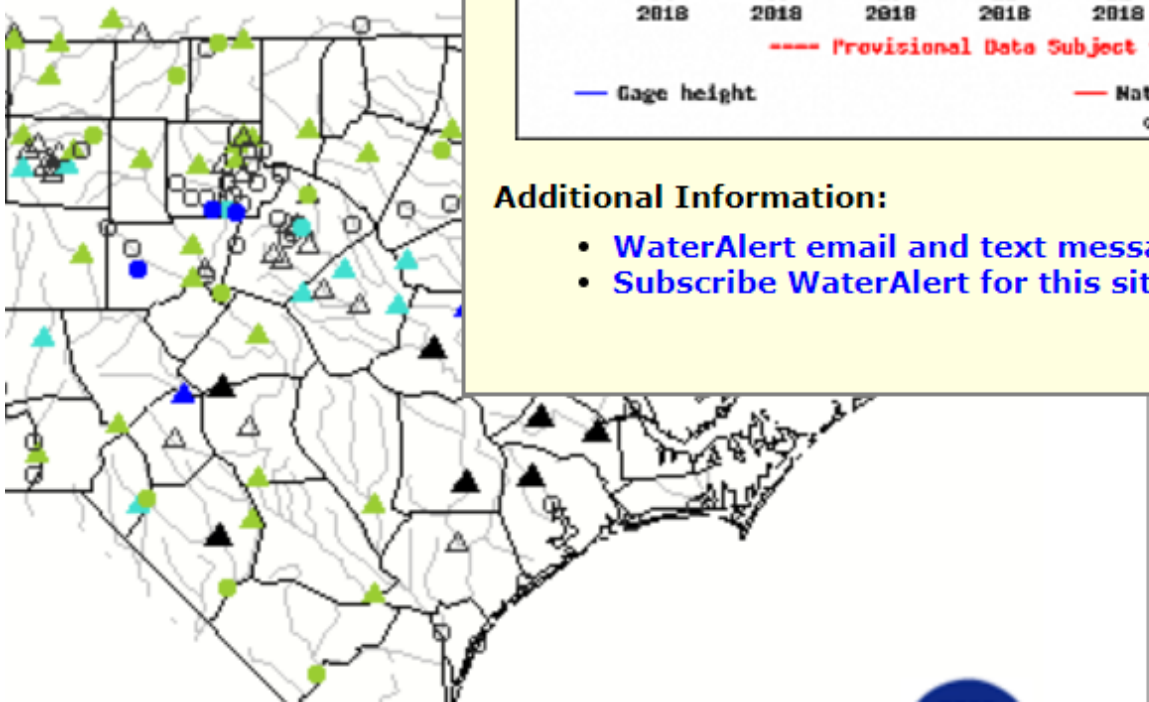
Explanation - Percentile classes				
<95	95-98	>= 99	River above flood stage	Not ranked
△ Streamgage with flood stage ○ Streamgage without flood stage				

ble | Web Map

w condition (No

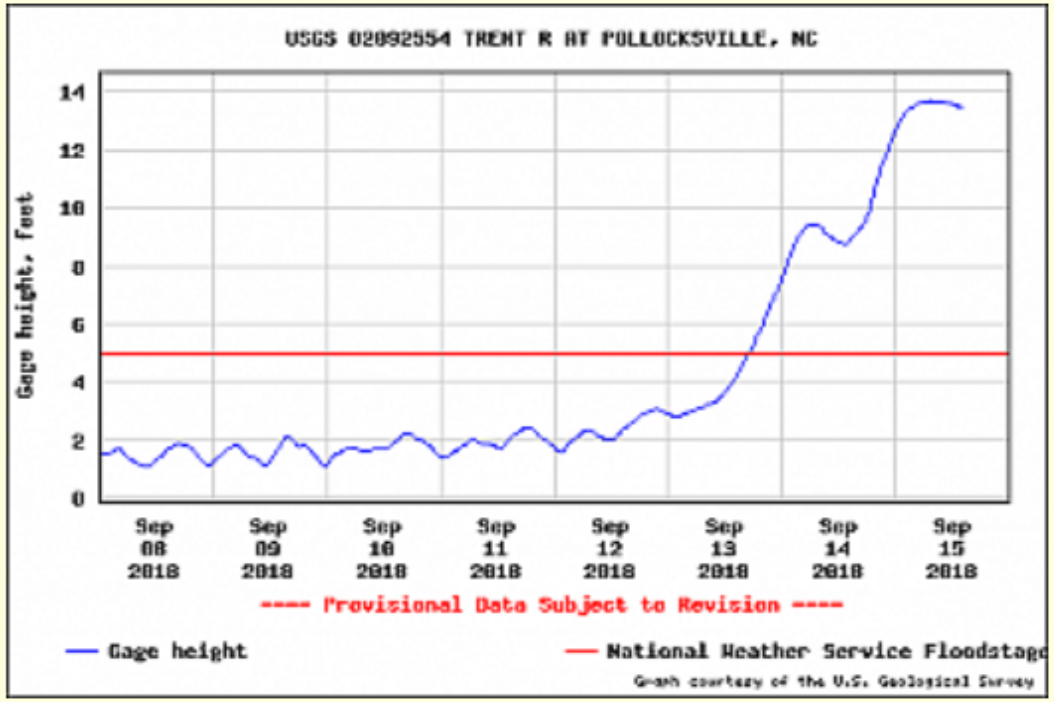
Water-Resources Regio

ber 15, 2018 13:30ET



WaterWatch: Water Resources Conditions

Summary | Hydrograph | Peak | Forecast | Rating



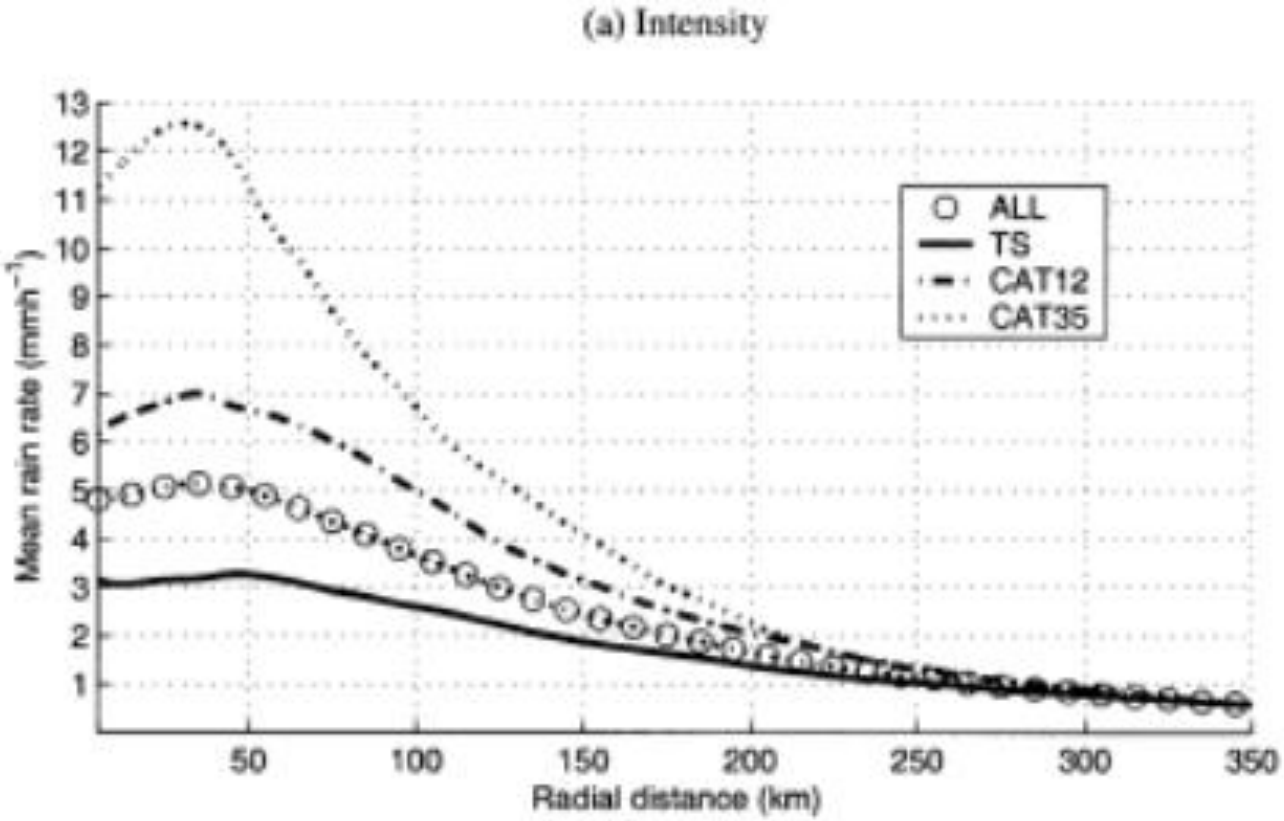
Additional Information:

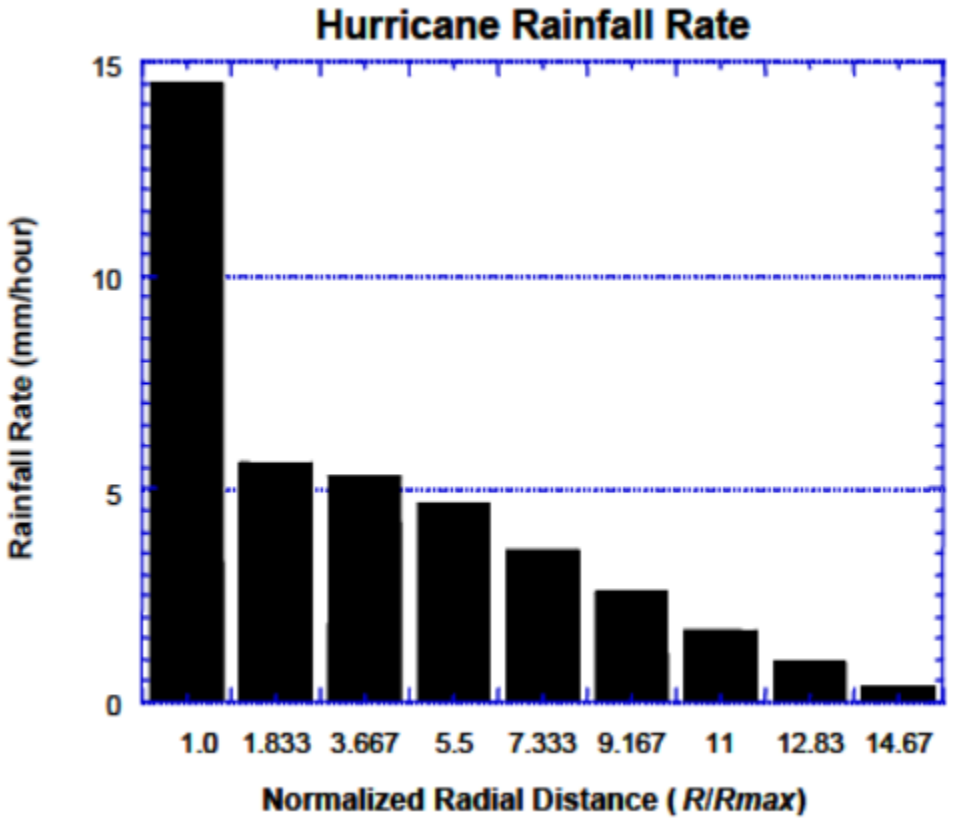
- WaterAlert email and text message alerts
- Subscribe WaterAlert for this site

Empirical and climatology applications for return-level studies

Rainfall CLImatology and PERsistence (R-CLIPER)

$$RR = -5.5 + 110(R_{max}/R) - 390(R_{max}/R)^2 + 550(R_{max}/R)^3 - 250(R_{max}/R)^4 \quad (2.19)$$





Variants used for baseline skill metrics (models should perform better!) and FEMA's Mitigation division (HAZUS software)

Satellite-derived rainfall rate pdfs

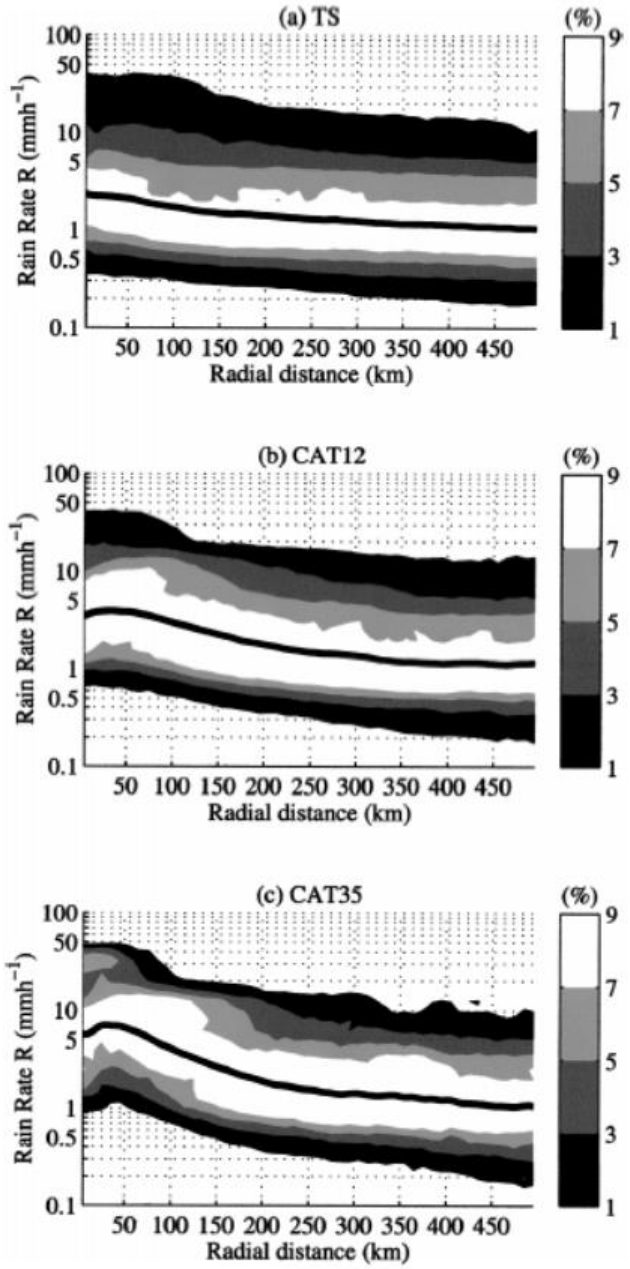
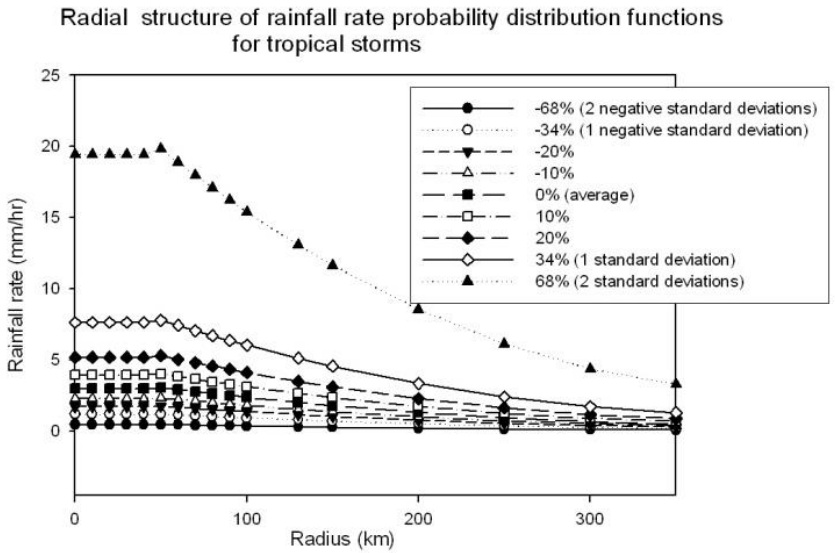
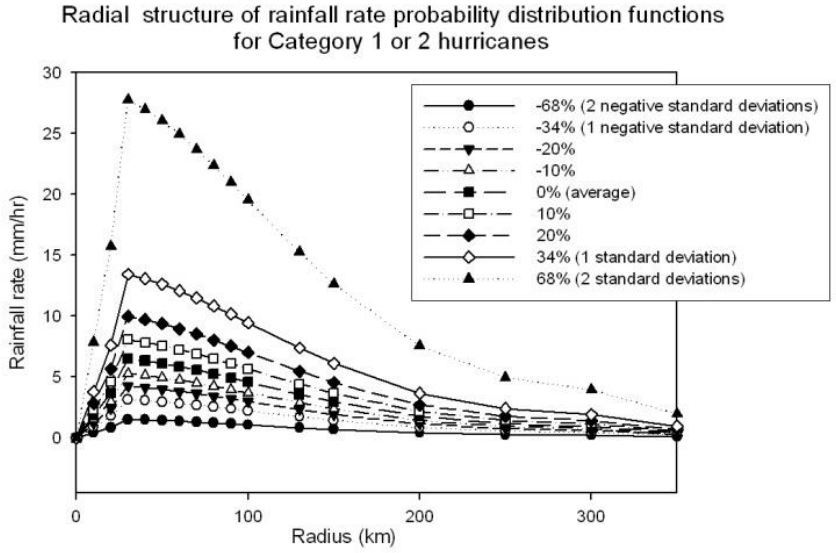


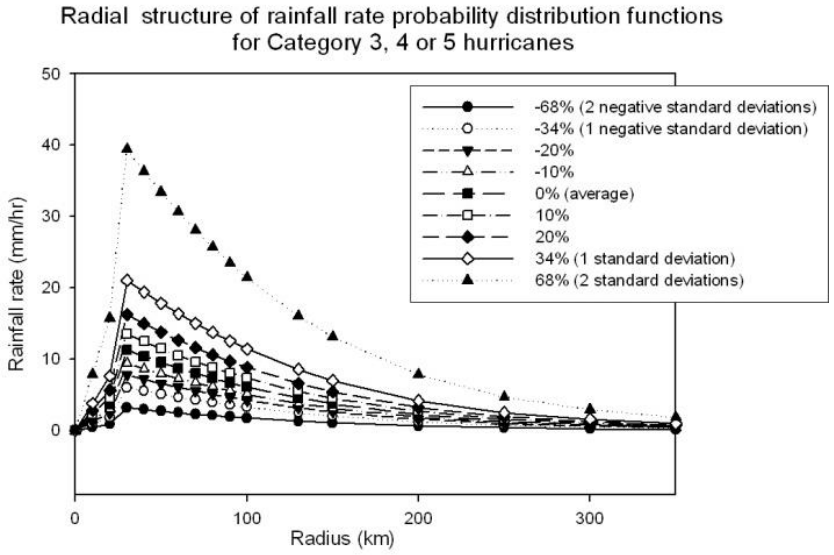
FIG. 14. Radial distribution of rainfall PDFs for (a) TS, (b) CAT12, and (c) CAT35 storms. The color scale and black lines are as described in Fig. 13

Reference: Lonfat, M., F. D. Marks, and S. S. Chen, 2004: Precipitation distribution in tropical cyclones using the Tropical Rainfall Measuring Mission(TRMM) microwave imager: A global perspective. Monthly Weather Review, 132, 1645-1660.

R-CLIPER for TS, Min Hurr, and Major Hurr, with avg, ± 10%, ± 20%, ± 34%, ± 68%,



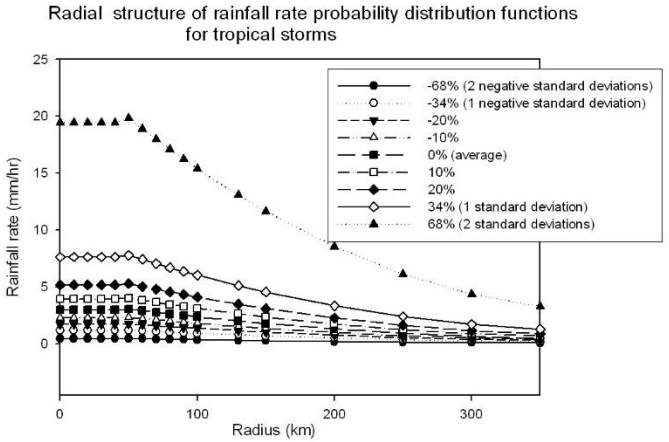


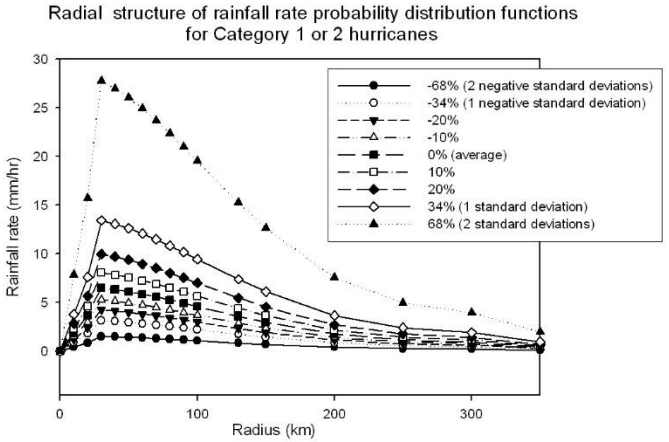


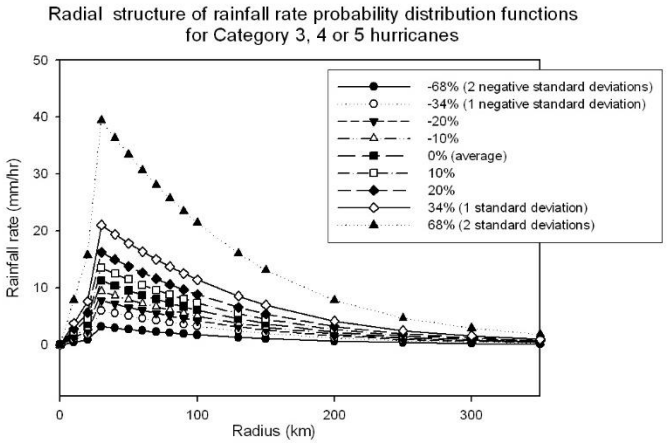
From Fitzpatrick and Lau (2011) Based on Lonfat et al. (2007)

Reference

Geoghegan, K. M., P. J. Fitzpatrick, R. L. Kolar, and K. M. Dresback, 2018: Evaluation of a synthetic rainfall model, P-CLIPER, for use in coastal flood modeling. Natural Hazards, 92, 699-726.







P-Cliper PDF equations (-90% ≤ f ≤ 90%)

For tropical storms

$$R_{TS}(r,f) = A_{TS}\, exp(B_{TS}\, f) \quad ; \qquad r \le 50$$

$$R_{TS}(r,f) = (2.05957684\times 10^{-5} r^2 - 1.672969851\times 10^{-2} r + 3.838964806) exp(B_{TS}\, f) \quad ; \qquad r > 50$$

$$A_{TS}=2.995207,\ B_{TS}=0.027499$$

For Category 1 and 2 hurricanes

$$R_{C12}(r,f) = A_{C12}\, exp(B_{C12}\, f)\frac{r}{30} \quad ; \qquad r \le 30$$

$$R_{C12}(r,f) = (-2.474340293\times 10^{-9} r^4 + 1.935560971\times 10^{-6} r^3 - 4.444507808\times 10^{-4} r^2 + 6.840501651\times 10^{-3} r + 6.656484399) exp(B_{C12}\, f) \quad ; \qquad r > 30$$

$$A_{C12}=5.539108,\ B_{C12}=0.0213$$

For Category 3, 4 and 5 hurricanes

$$R_{C35}(r,f) = A_{C35}\, exp(B_{C35}\, f)\frac{r}{30} \quad ; \qquad r \le 30$$

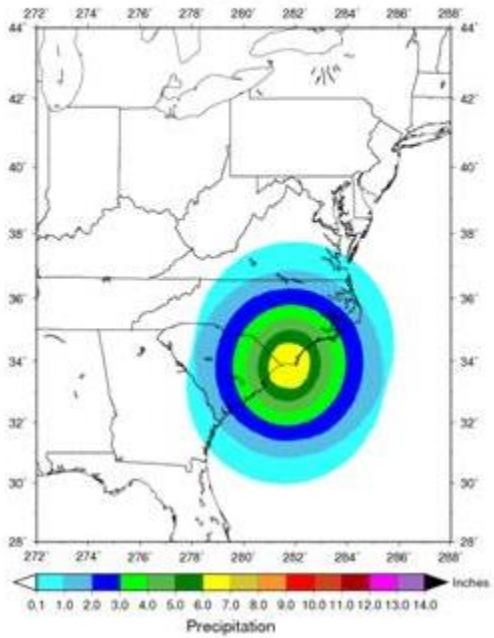
$$R_{C35}(r,f) = (-2.984284245\times 10^{-7} r^3 + 3.033414728\times 10^{-4} r^2 - 1.088545019\times 10^{-1} r + 14.25059433) exp(B_{C35}\, f) \quad ; \qquad r > 30$$

$$A_{C35}=10.94344,\ B_{C35}=0.018433$$

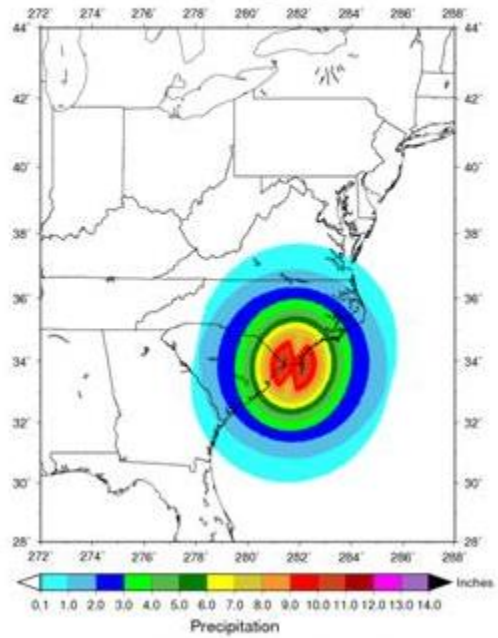
24-h accumulated rainfall (inches) for different intensities and speeds

One standard deviation above normal

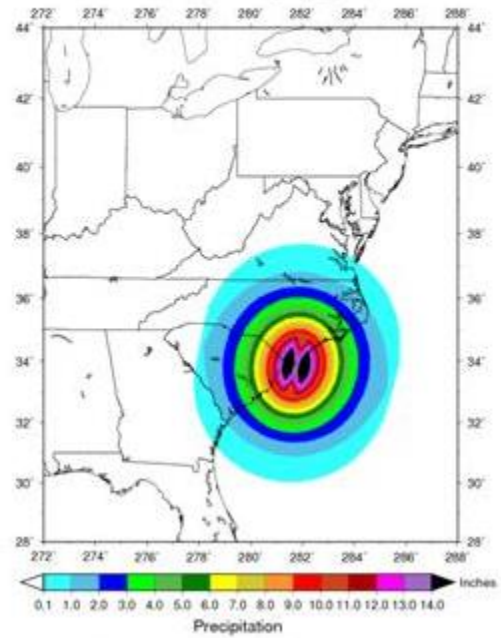
accumulatedRain_TS_5mph_f34 24 hours



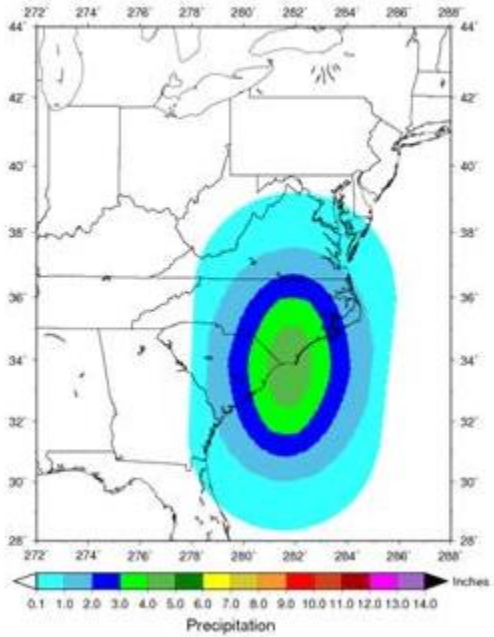
accumulatedRain_CAT12_5mph_f34 24 hours



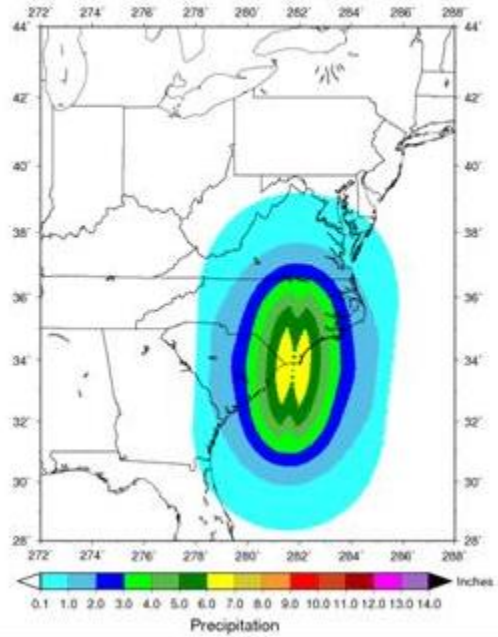
accumulatedRain_CAT345_5mph_f34 24 hours



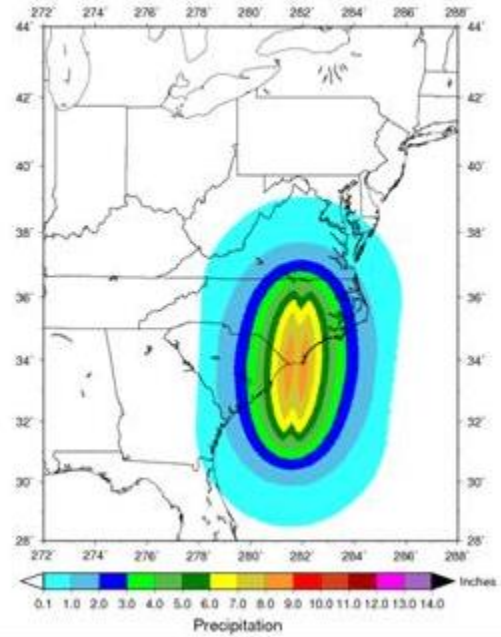
accumulatedRain_TS_15mph_f34 24 hours



accumulatedRain_CAT12_15mph_f34 24 hours



accumulatedRain_CAT345_15mph_f34 24 hours



Asymmetry and width should be added through wind shear, topography, dry air intrusion, 2D wind structure, and size

A version of R-CLIPER, known as R-PHRaM, considers only shear and topography. No known CLIPER model's for other parameters.

$$R_{\mathrm{PHRaM}} = R_{\mathrm{R\text{-}CLIPER}} + R_{\mathrm{shear\ mod}} + R_{\mathrm{topography}}$$

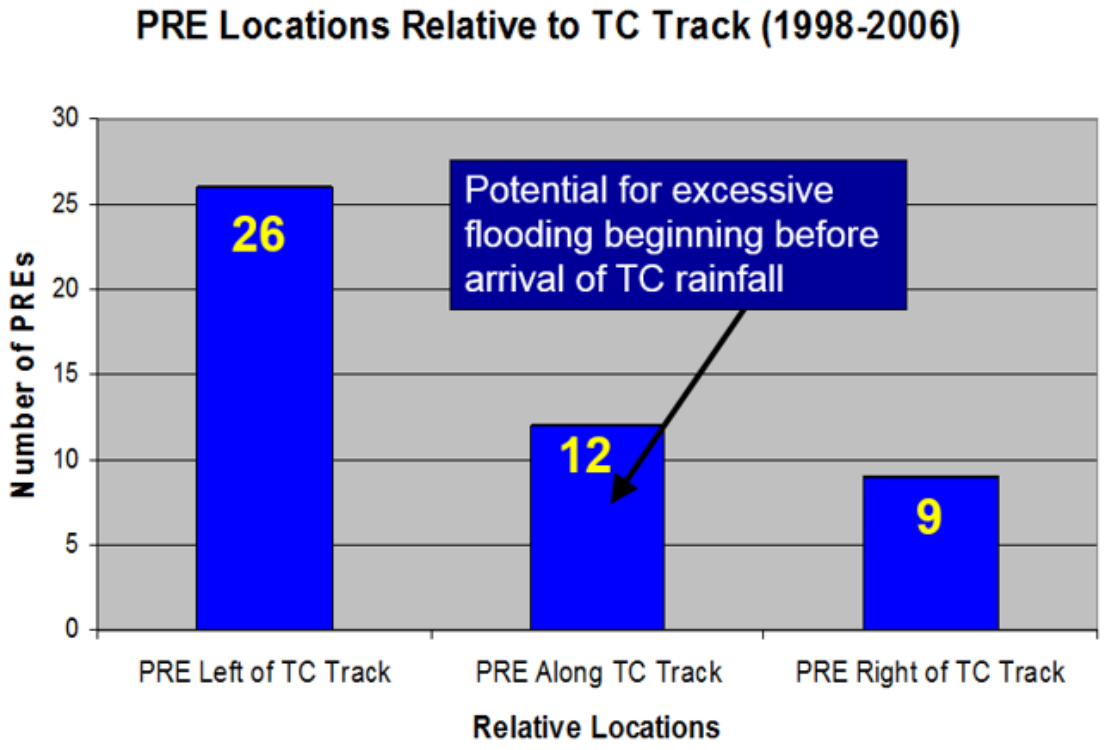
More complicated terms could also incorporate frontal and trough interactions, as well as extratropical transitions

Also not considered in mitigation formulations are Predeccor Rainfall Events (PRE).

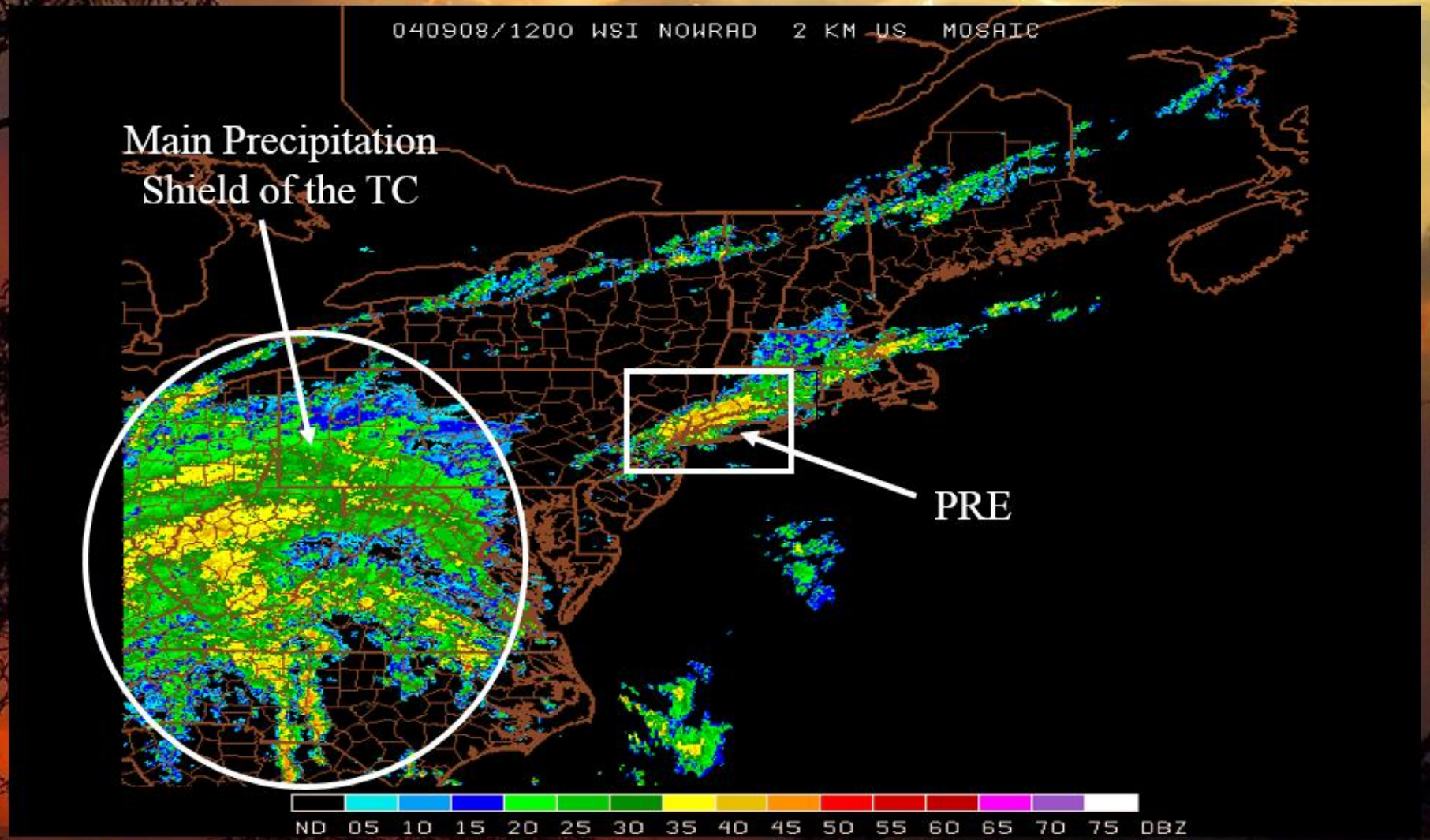
A PRE is a coherent area of heavy rainfall poleward of a tropical cyclone, which is distinct from its main precipitation shield, but still indirectly related to the storm.

Potential for excessive flooding before cyclone's arrival

River flooding could also coincide with surge event (most studies assume river rise lags surge event)



PRE Example – Frances (2004)



Results of the Frances PRE

York Times

NEW YORK, THURSDAY, SEPTEMBER 9, 2004

Seth Wenig for The New York Times

A stretch of Ninth Street in Brooklyn yesterday, between Smith Street and Second Avenue. Bystanders said the area was prone to flooding even in times of light rain. Some said it was waist high at its worst yesterday.

Downpour Overwhelms Transit in Morning Rush

Considerations for post-Harvey and post-Florence research

General questions and discussion