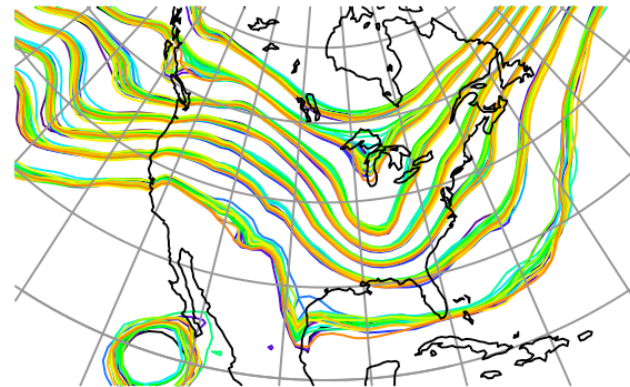


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Hydro-DART: Ensemble Streamflow Assimilation with WRF-Hydro and the Data Assimilation Research Testbed



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NCAR | National Center for
UCAR | Atmospheric Research

Technical Details: gharamti@ucar.edu



These are the researchers! I am the `pit crew`.



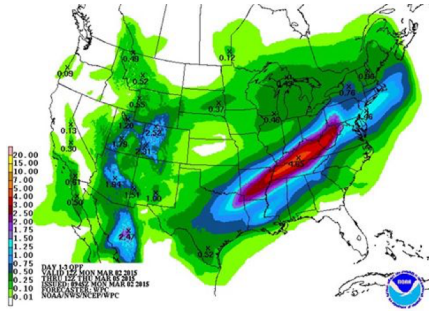
Outline

1. WRF-Hydro
2. A brief overview of ensemble assimilation
3. Hurricane Florence
4. DA results from an 80 member experiment
 - Model bias
 - Localization
 - Ensemble spread and Inflation
 - Gaussian Anamorphosis
5. Conclusion



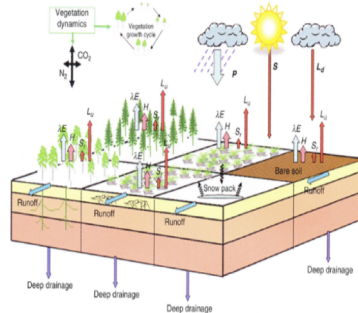
Weather Research & Forecasting Hydrologic Model

Weather Forcing Engine



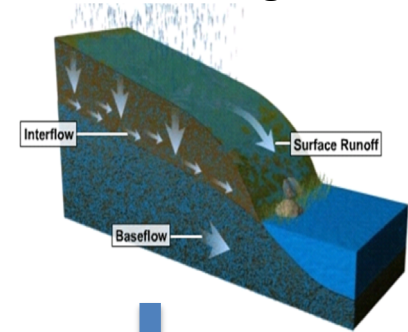
WRF-Hydro: https://www.ral.ucar.edu/projects/wrf_hydro

NoahMP Land Surface Model

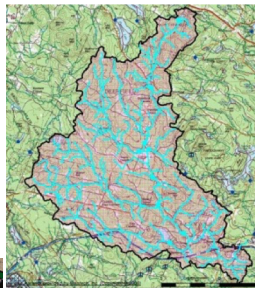


2-way coupling

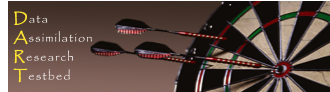
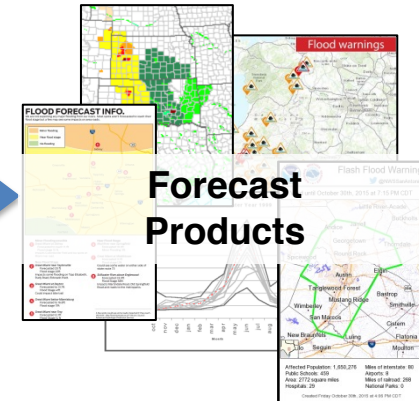
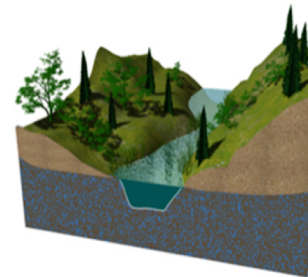
Terrain Routing Module



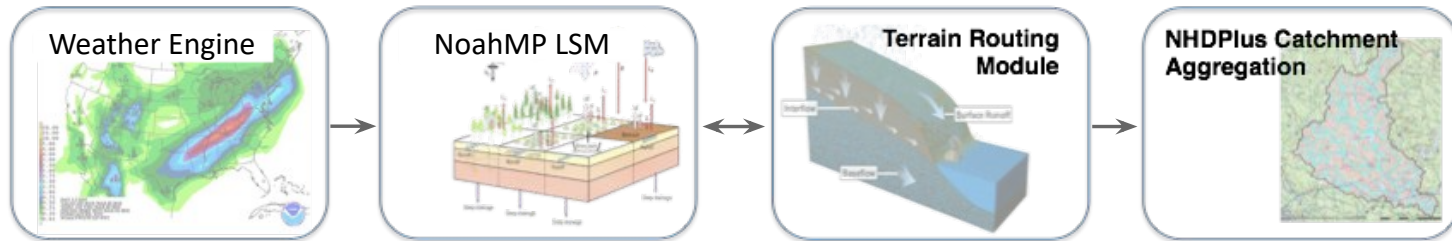
NHDPlus Catchment Aggregation



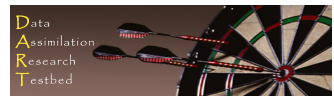
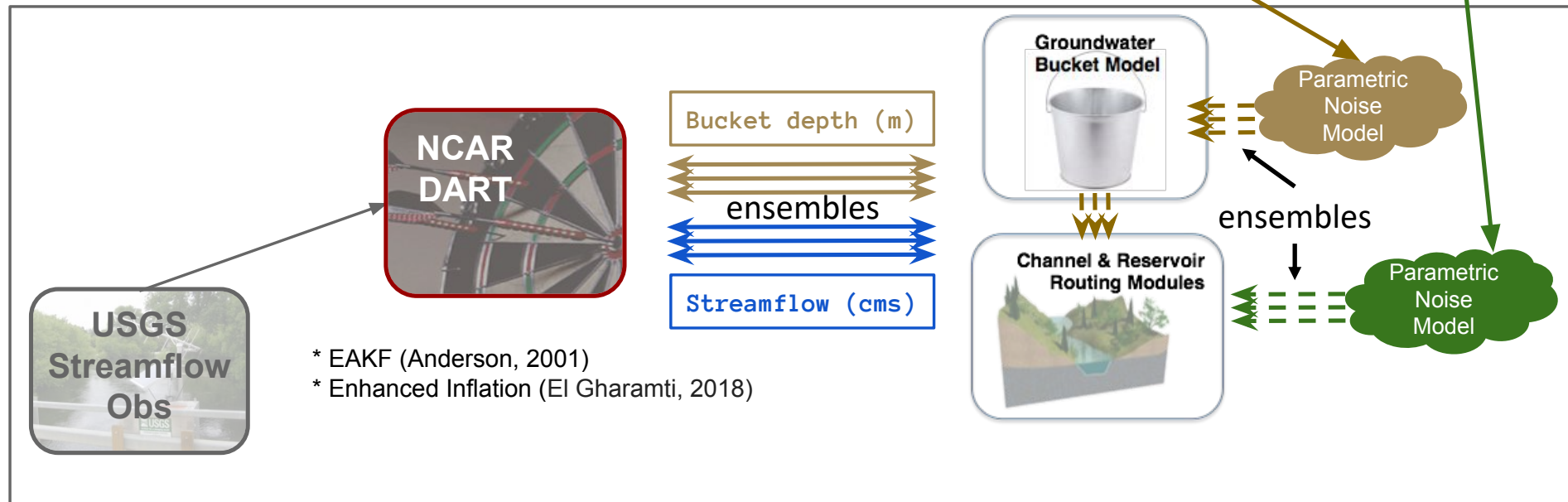
Channel & Reservoir Routing Module



WRF-Hydro & DART ... HydroDART



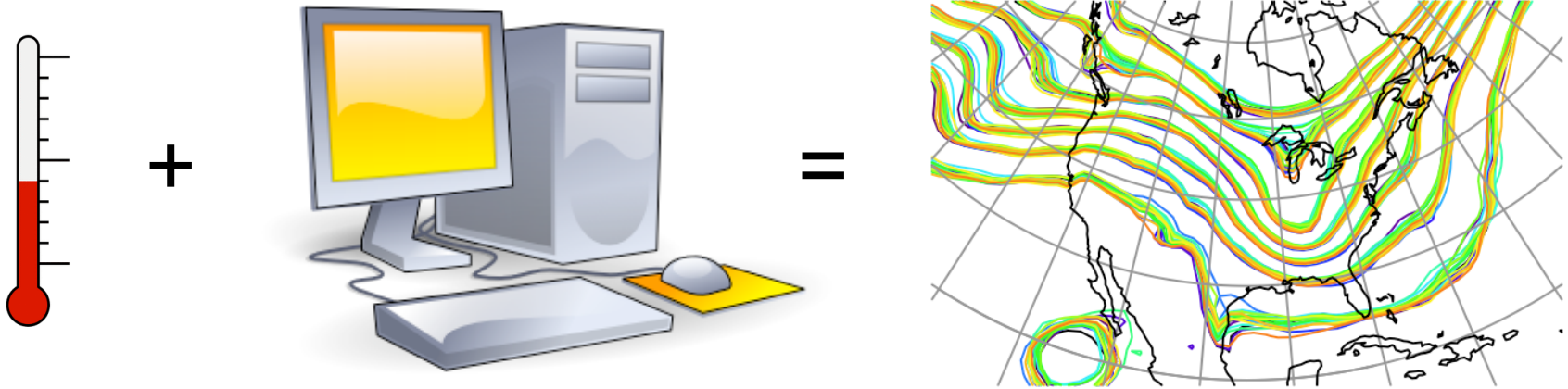
Channel-Bucket-Only Ensemble Data Assimilation



Python environment github.com/NCAR/wrf_hydro_py.git

What is Data Assimilation?

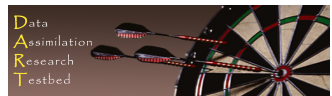
Observations combined with a Model forecast...



... to produce an analysis.

Overview article of the Data Assimilation Research Testbed (DART):

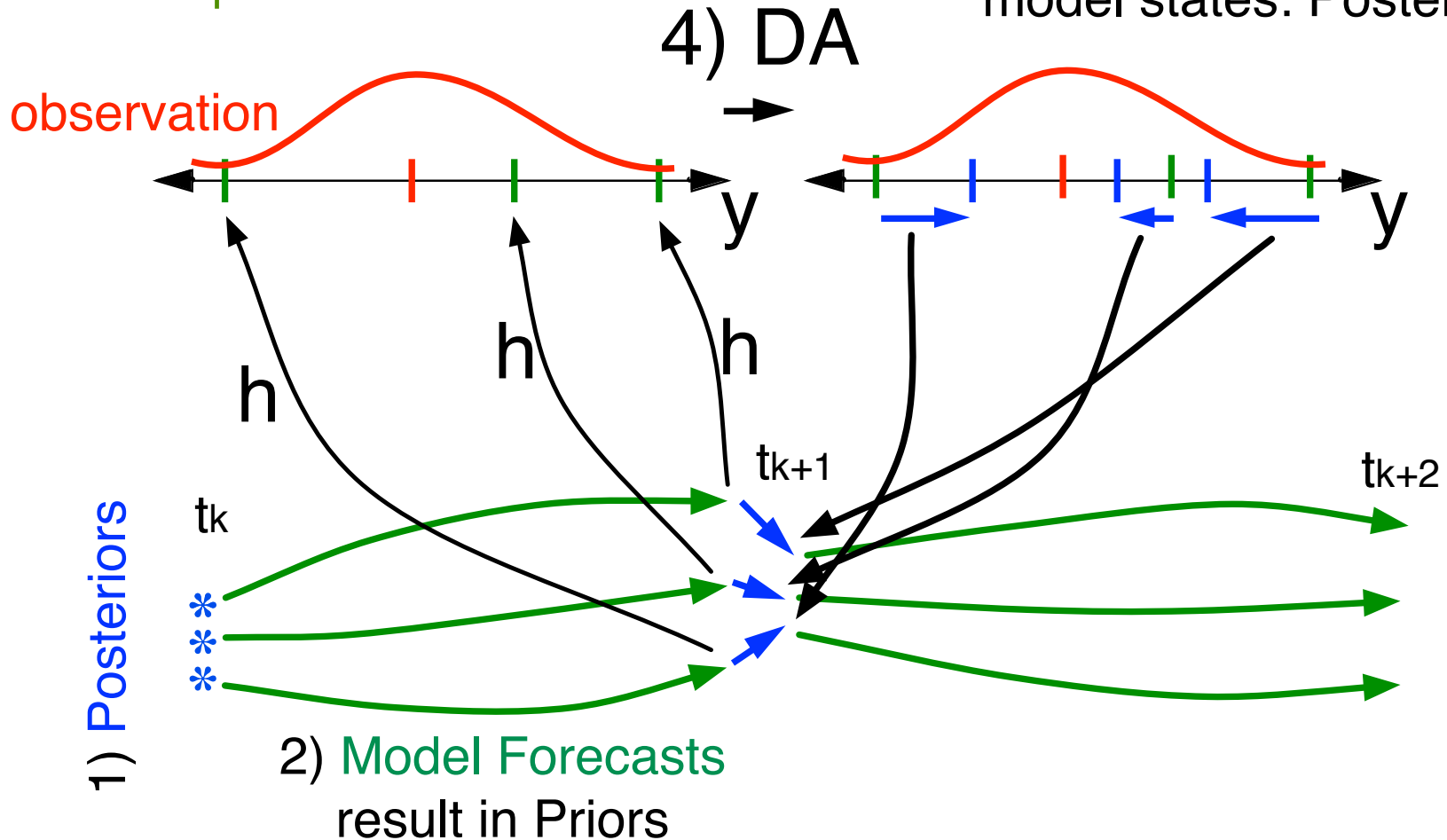
Anderson, Jeffrey, T. Hoar, K. Raeder, H. Liu, N. Collins, R. Torn, A. Arellano, 2009:
The Data Assimilation Research Testbed: A Community Facility.
Bull. Amer. Meteor. Soc., **90**, 1283–1296. [doi:10.1175/2009BAMS2618.1](https://doi.org/10.1175/2009BAMS2618.1)



Ensemble DA in DART

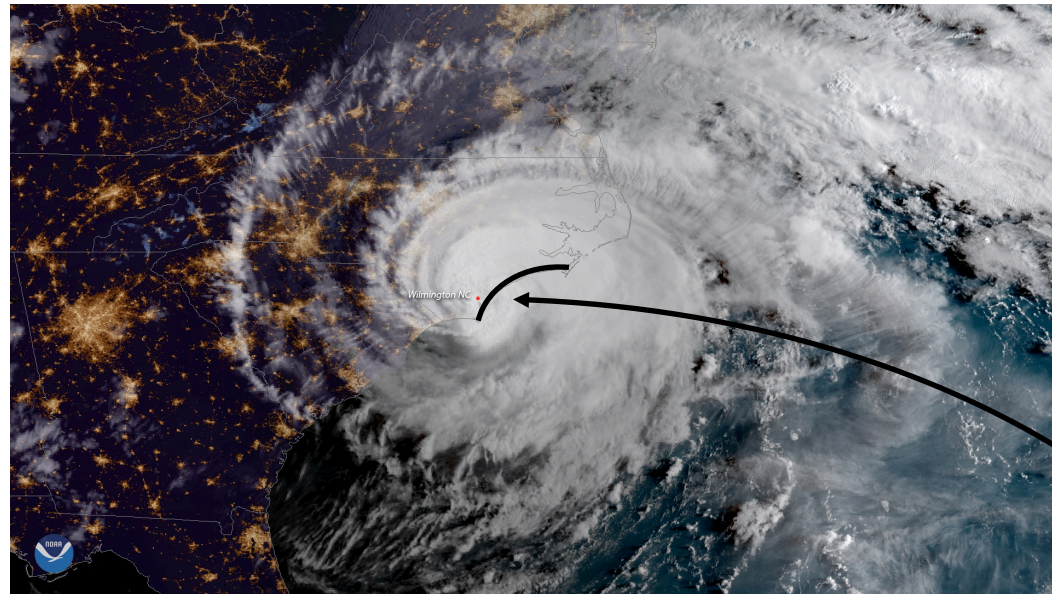
3) A forward operator (h) maps each model state to an expected observation

5) observation increments and regression create new model states: Posteriors

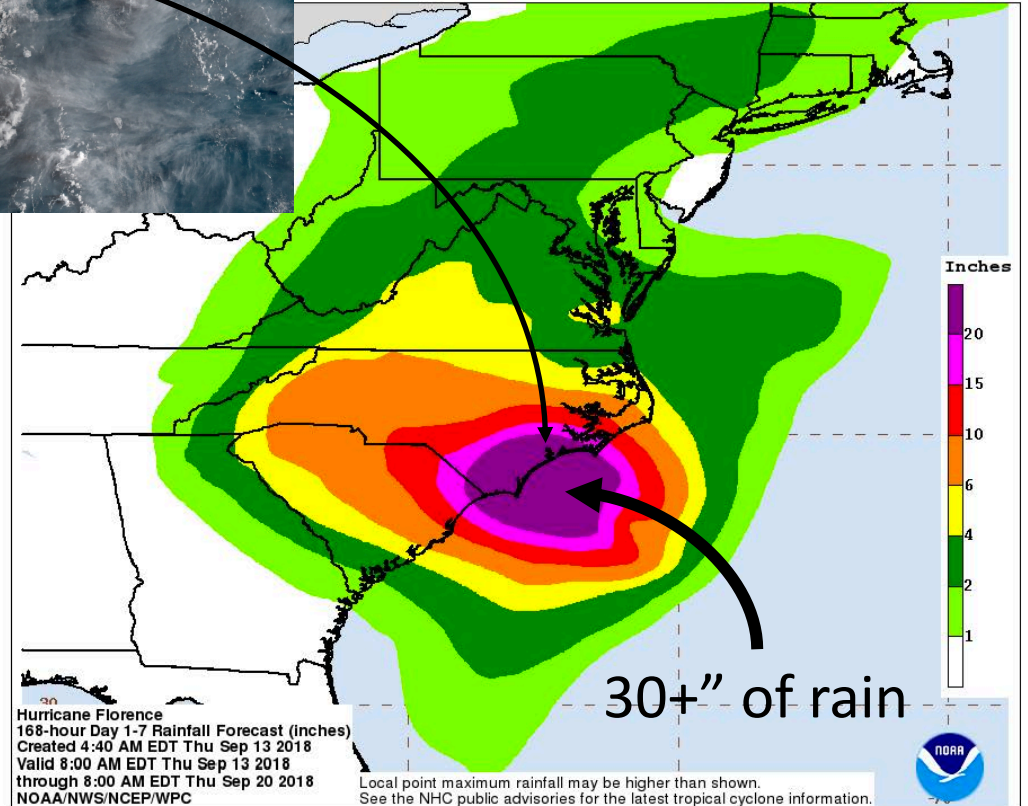


Hurricane Florence (2018)

Hurricane Florence made landfall near Wrightsville Beach, North Carolina at **7:15 a.m. ET September 14**. The GOES East satellite captured this geocolor image at 7:45 a.m. ET



Winds up to 150 mph (240 km/hr)
Damage: \$24.23 billion
NOAA/NWS/NCEP/WPC



'scale' of Florence Domain

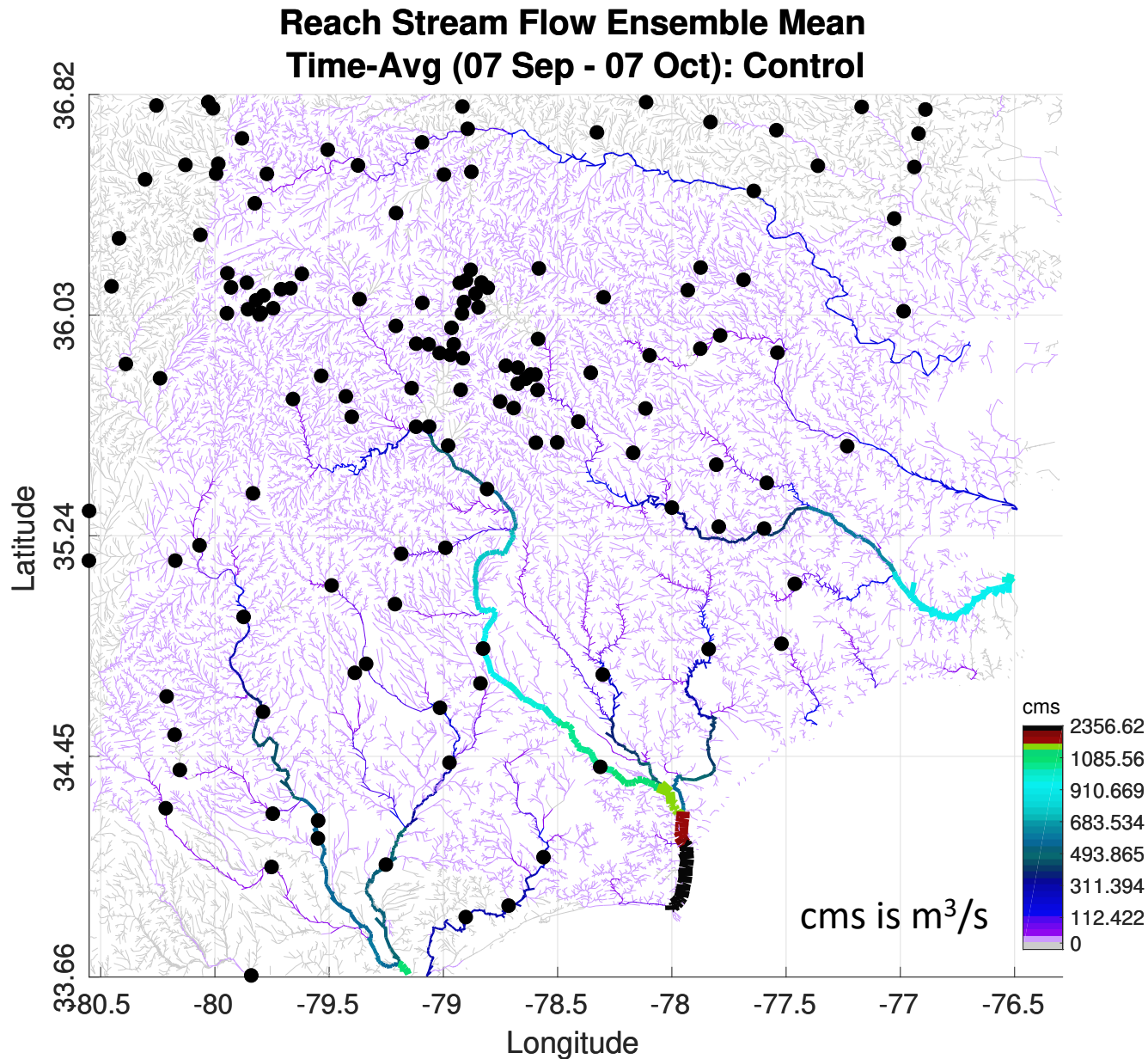


Control: No Assimilation

Monthly mean of the model. The streamflow is driven by the precipitation.

More than 100 gauges, reporting every 15 mins.

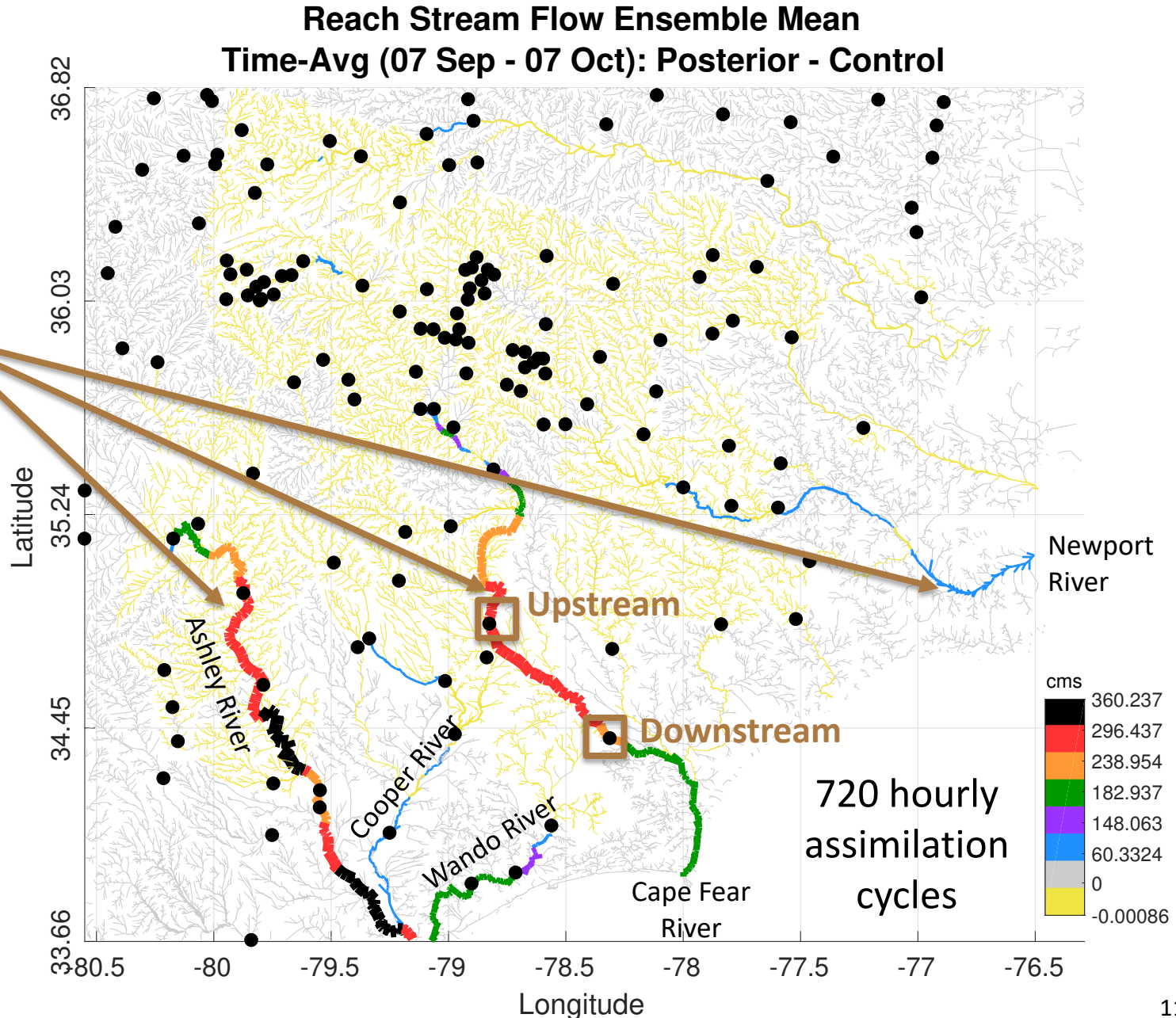
Now, what happens when streamflow gauge data is incorporated through DA?



Data Assimilation Impact

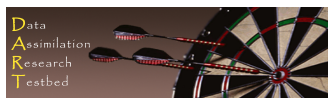
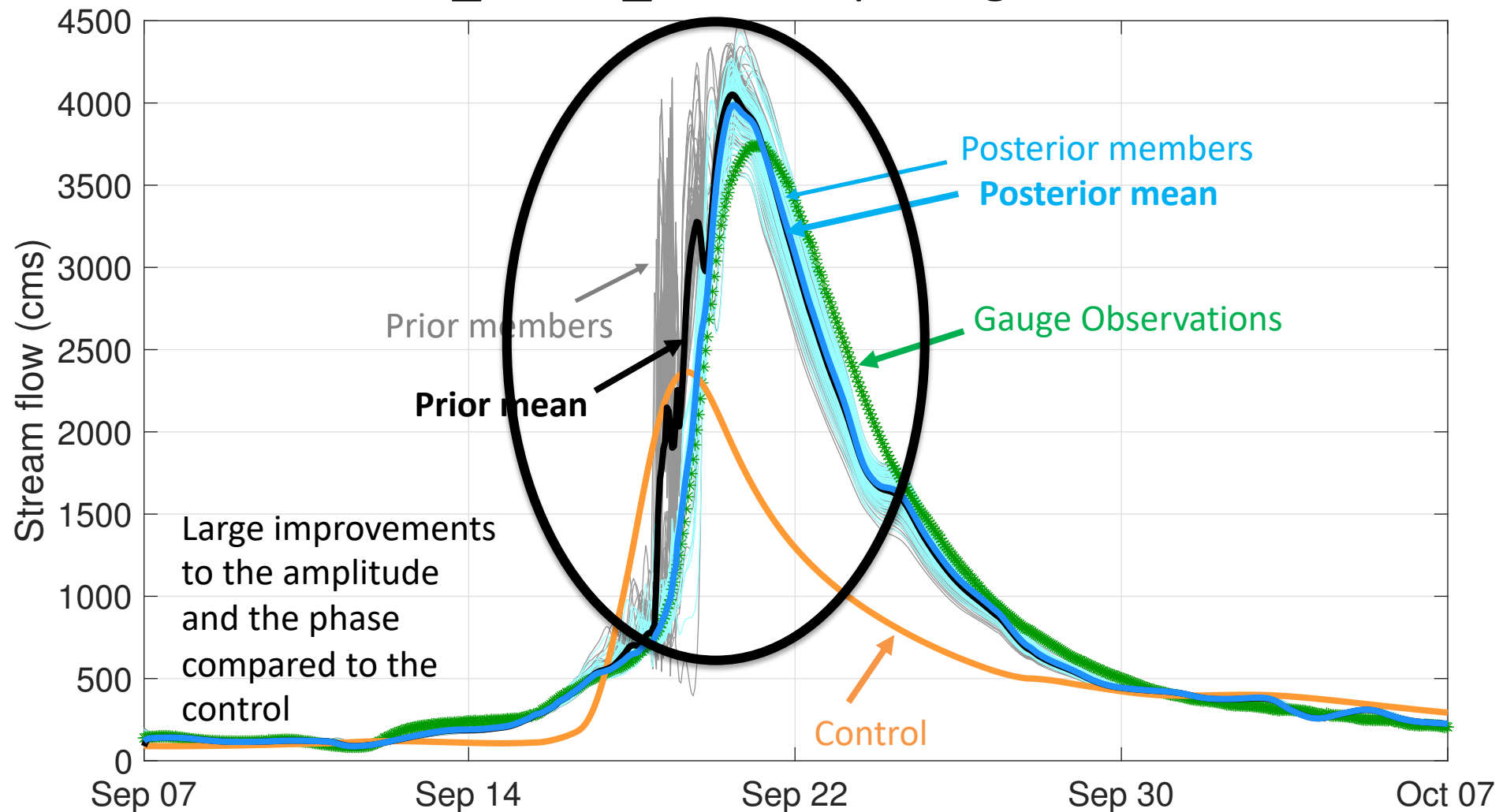
Assimilation happens every hour

Correction along major reaches. DA is adding water to the stream channels.



Upstream Gauge

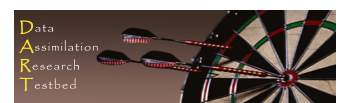
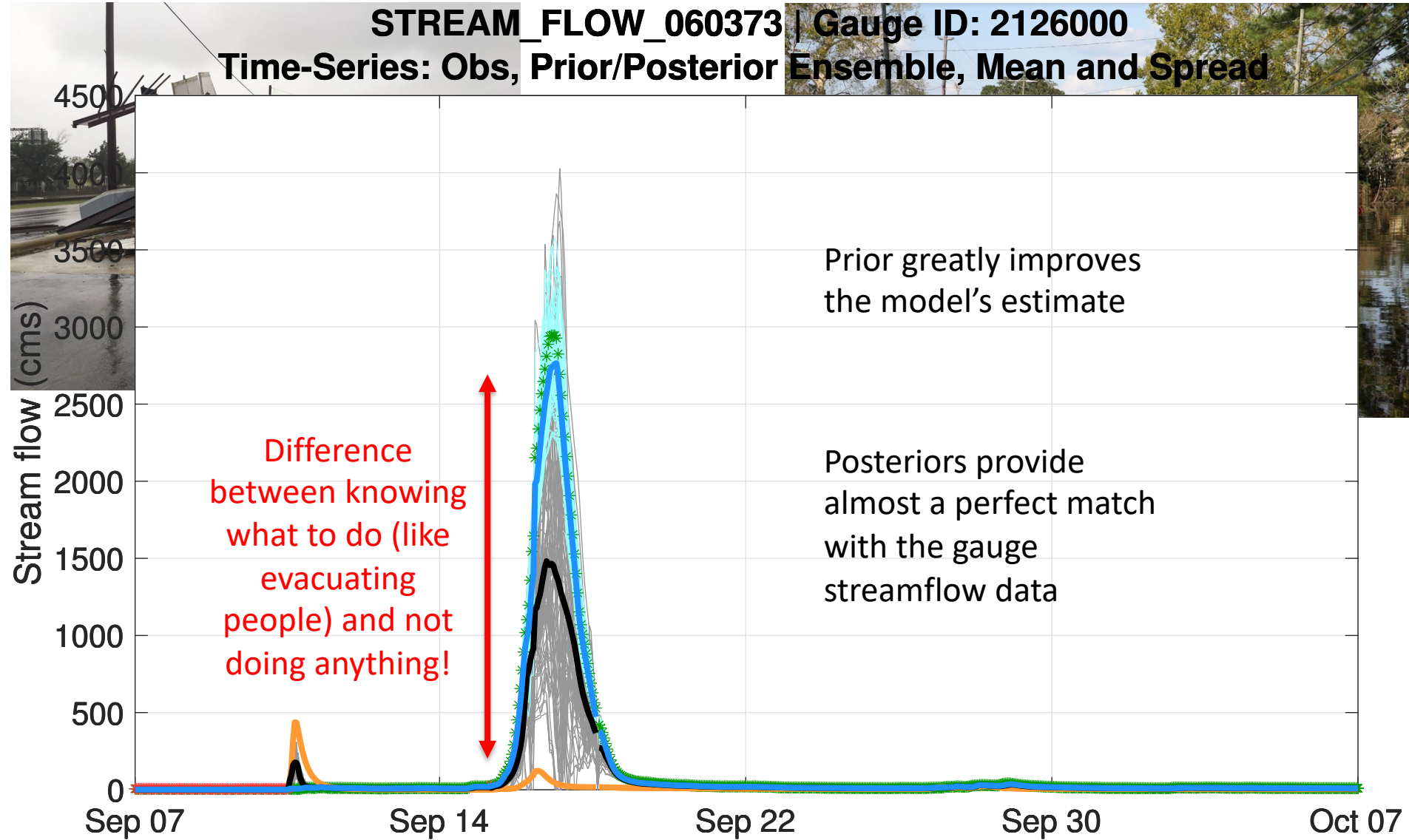
STREAM_FLOW_066453 | Gauge ID: 2131000



Downstream Gauge

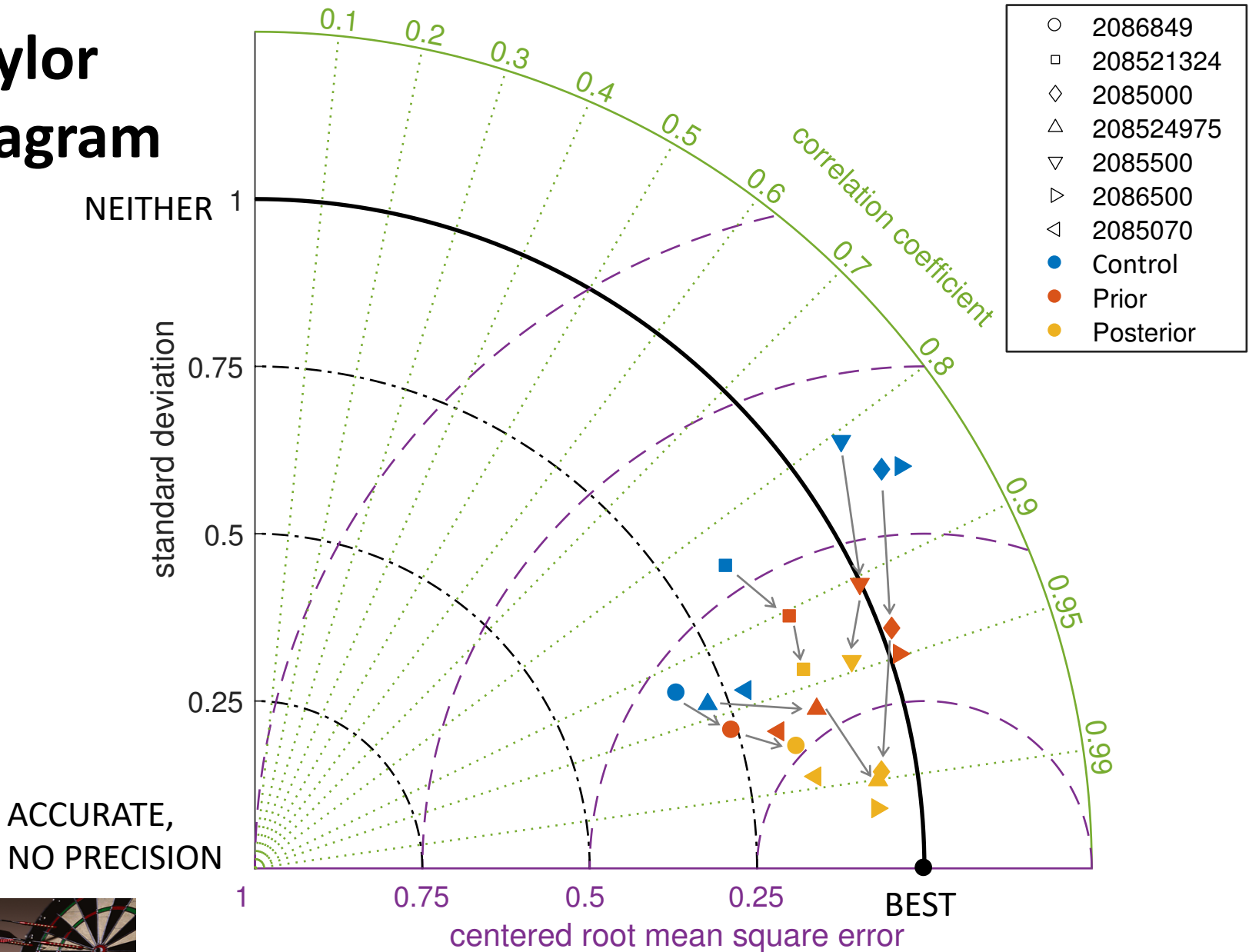
STREAM_FLOW_060373 | Gauge ID: 2126000

Time-Series: Obs, Prior/Posterior Ensemble, Mean and Spread



Improvements: control->prior->posterior

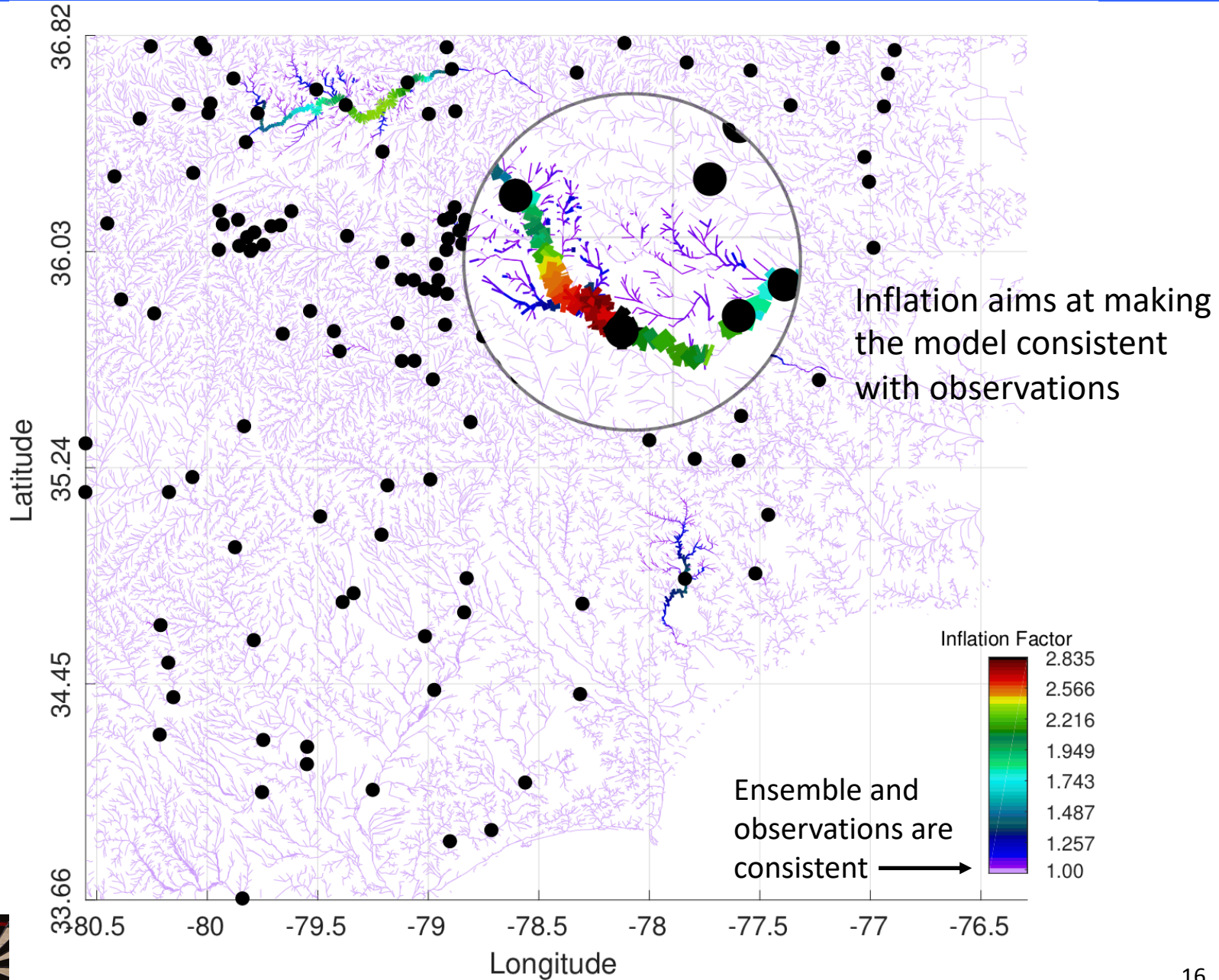
Taylor Diagram



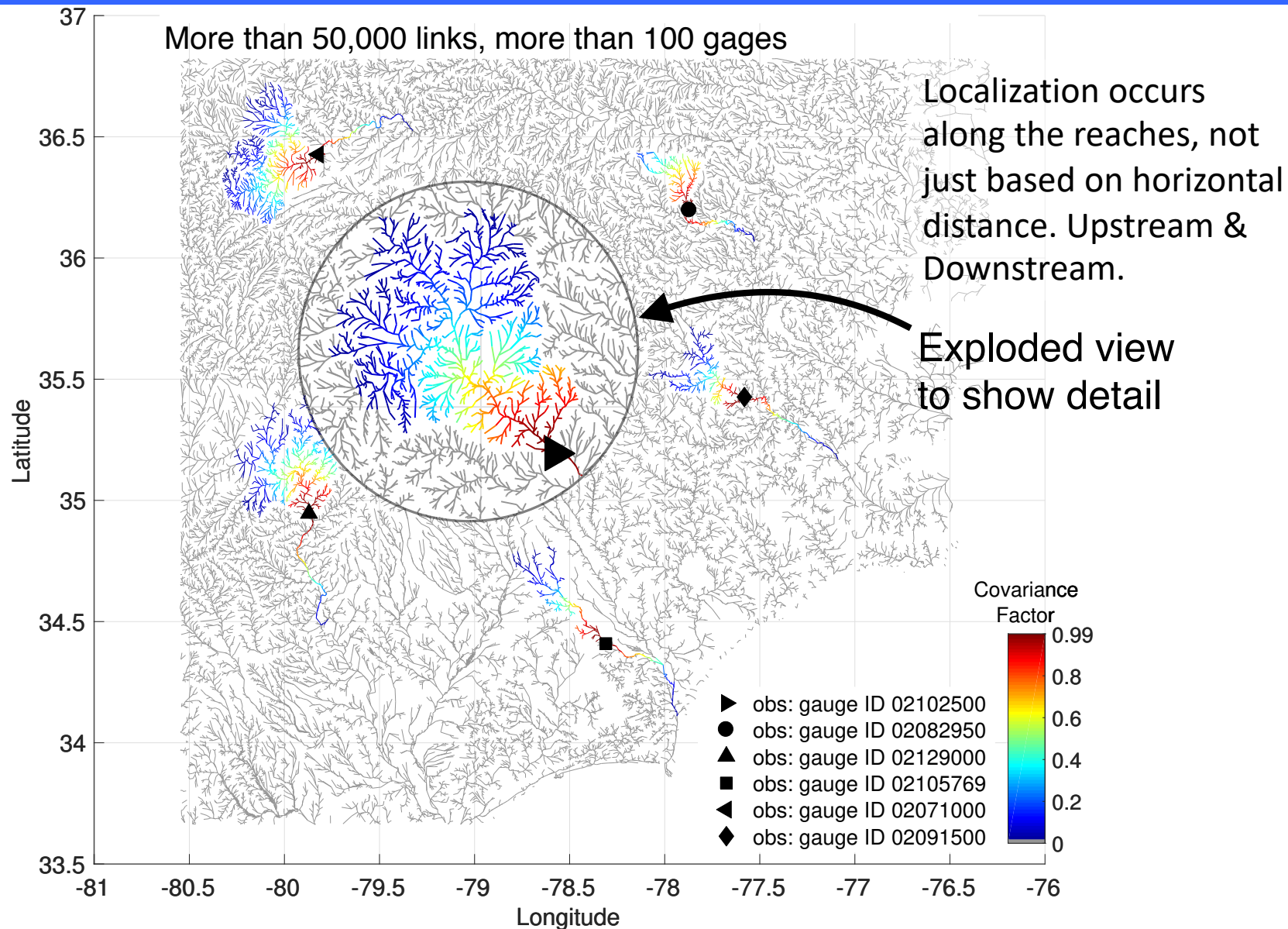
Significant Technical Enhancements

- 1. Inflation:** As a way to increase ensemble uncertainty, adaptive both in space and time
- 2. Pattern-based (Along-the-stream) localization:** To minimize sampling errors
- 3. Gaussian Anamorphosis:** Variable transform to accommodate positive definite variables (with non-Gaussian distributions)

Adaptive Inflation



Florence Domain: localization



100 km localization distance is used



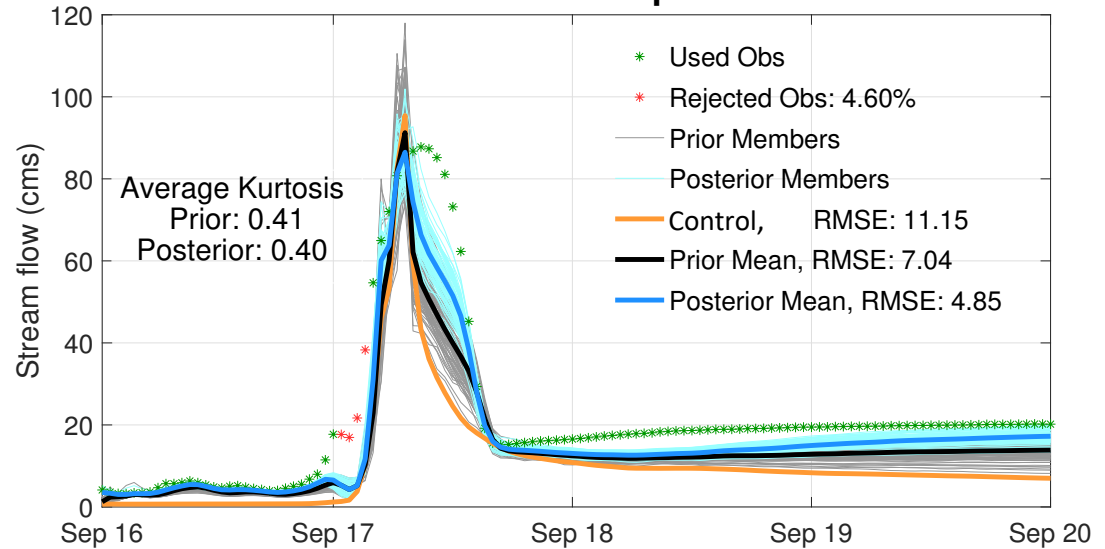
Gaussian Anamorphosis Capability

Observation rejection is improved with GA.

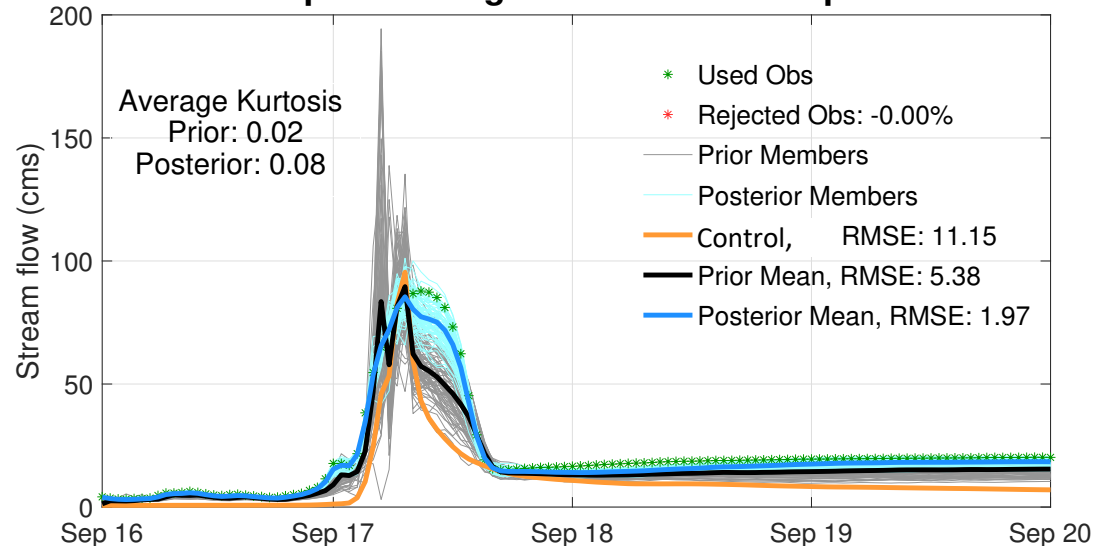
Better fit to the observations on Sep. 17th.

Higher order moments are almost completely eliminated using GA.

Standard DA update



DA update using Gaussian Anamorphosis



Conclusion

We use DART to perform streamflow and flood prediction with WRF-Hydro (NWM) during Hurricane Florence.

DART greatly improved the streamflow estimates

Novel enhancements to the DA algorithm were required:

- Using pattern-based localization
- Spatially and temporally varying inflation
- Gaussian anamorphosis

Next Steps: Update soil moisture, groundwater and ice; force the coupled system with an ensemble of atmospheric forcing, ...

For more information:

CAM *GCOM* *CAM-Chem* *FESOM* *ROMS*
GITM *CABLE* *WRF-Hydro* *WACCM* *WRF*

CLM

Data
Assimilation
Research
Testbed



POP

AM2

BGRID

SQG

<https://dart.ucar.edu>

COAMPS

NOAH

NCOMMAS

dart@ucar.edu

PE2LYR

MITgcm_ocean

WRF-Chem

COAMPS_nest

NAAPS

TIEGCM

MPAS_ATM

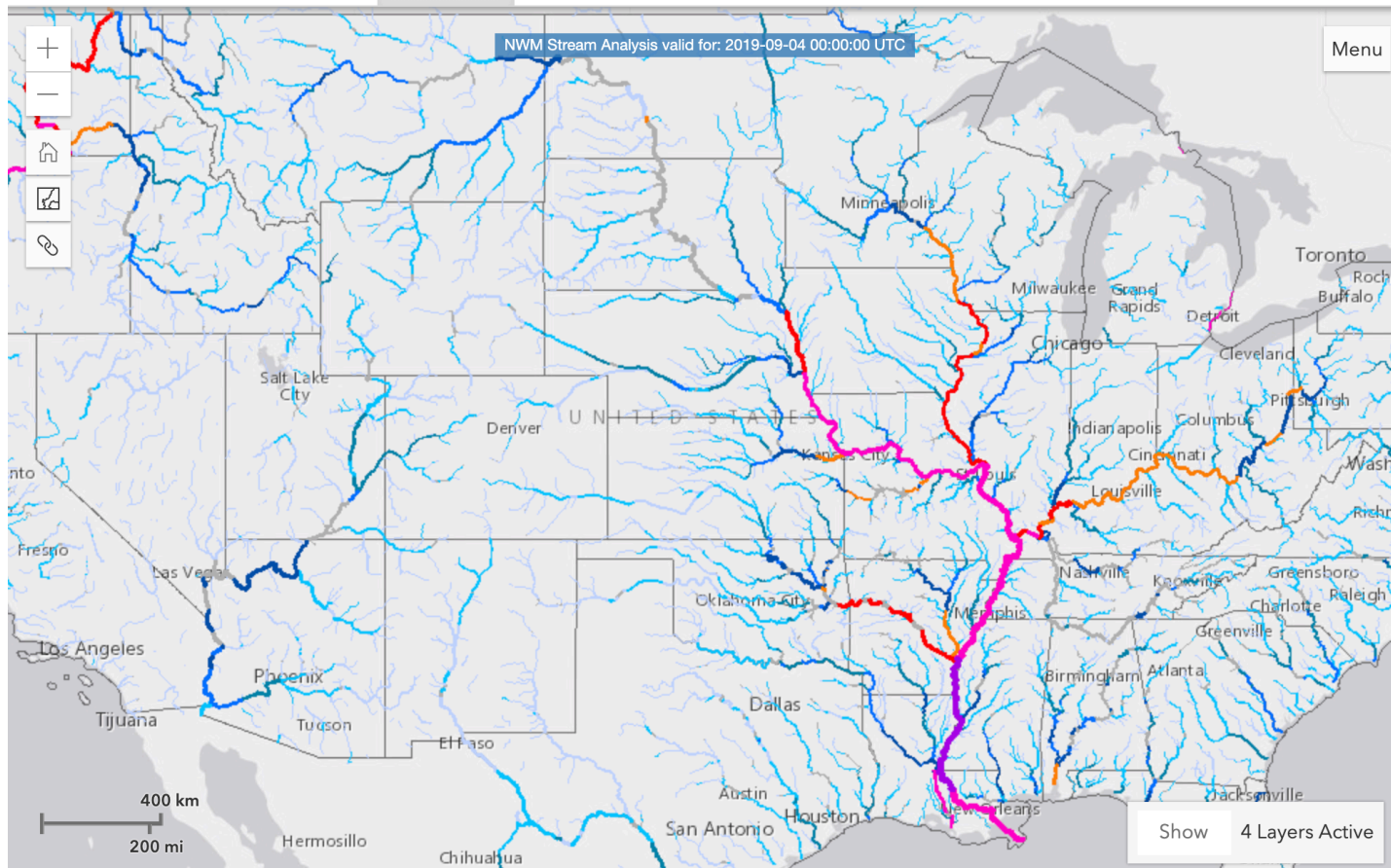
WACCM-X

MPAS_OCN

PBL_1d

NOAH-MP

NATIONAL WATER MODEL (NWM)



Legends

NWM Stream Analysis: Streamflow

Very Large Streams

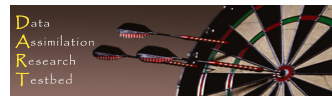
Line Color (ft³/sec)

- > 1.25M
- 500K - 1.25M
- 100K - 500K
- 50K - 100K
- 25K - 50K
- 10K - 25K
- 5K - 10K
- 2.5K - 5K
- 250 - 2.5K
- 0 - 250
- No Data

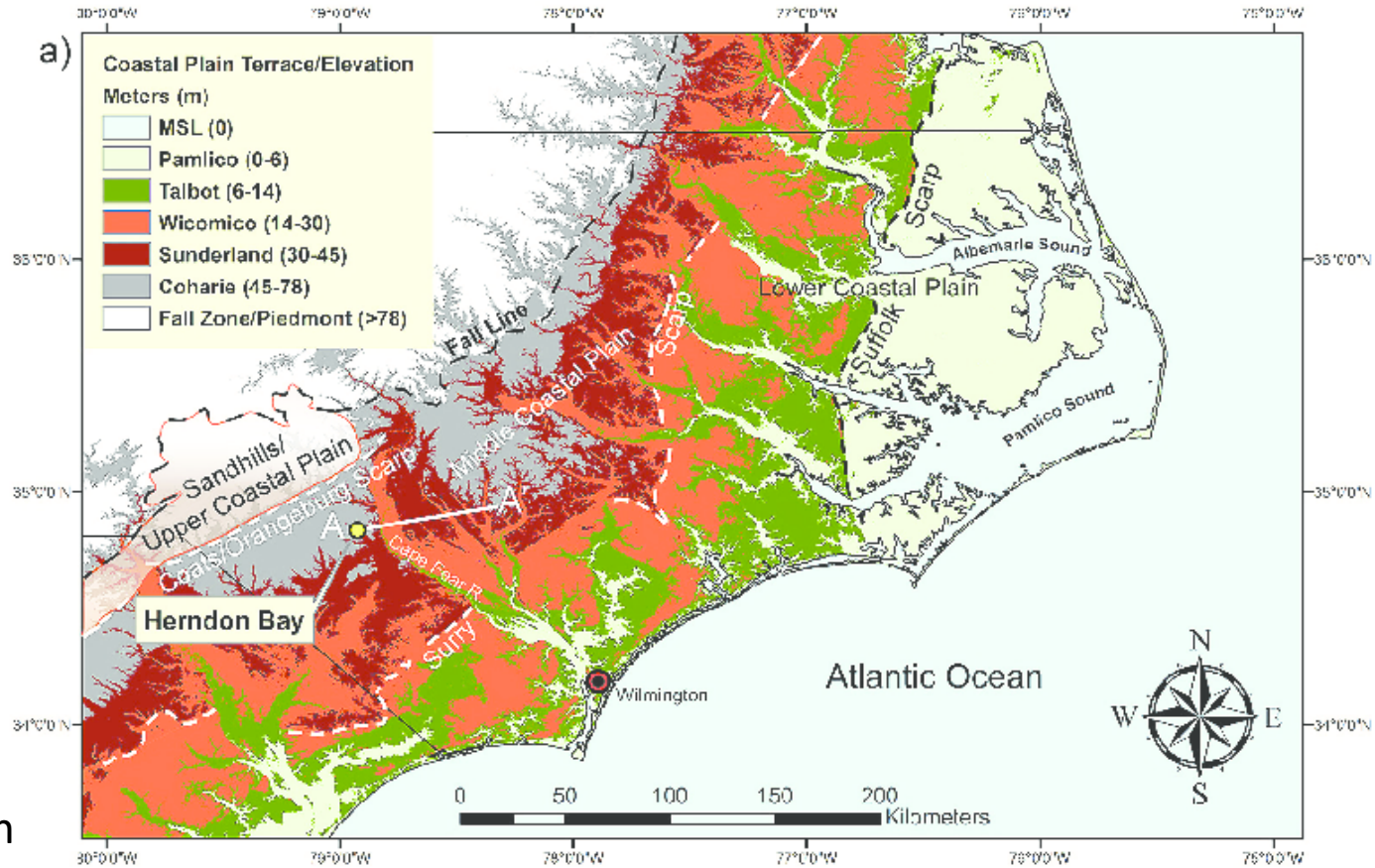
Line Thickness: (Stream Order)

- 10
- 9
- 8

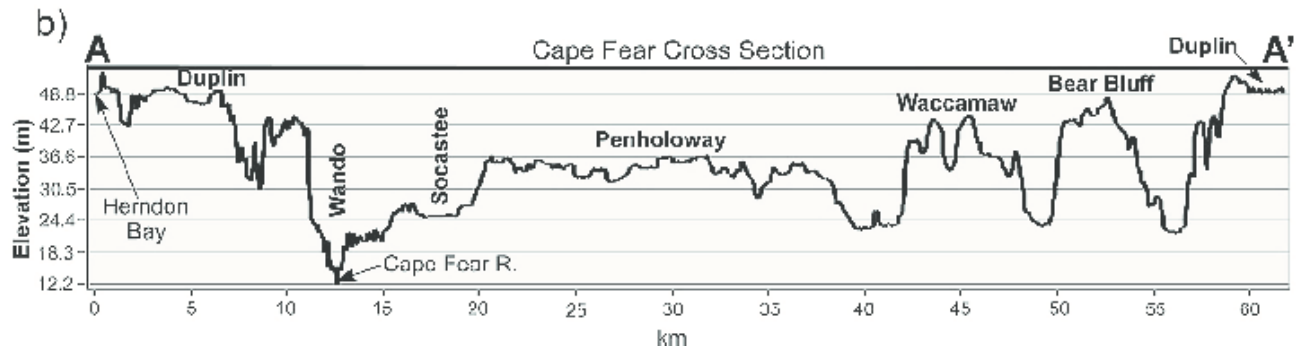
<https://water.noaa.gov/about/nwm>



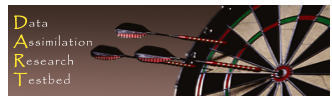
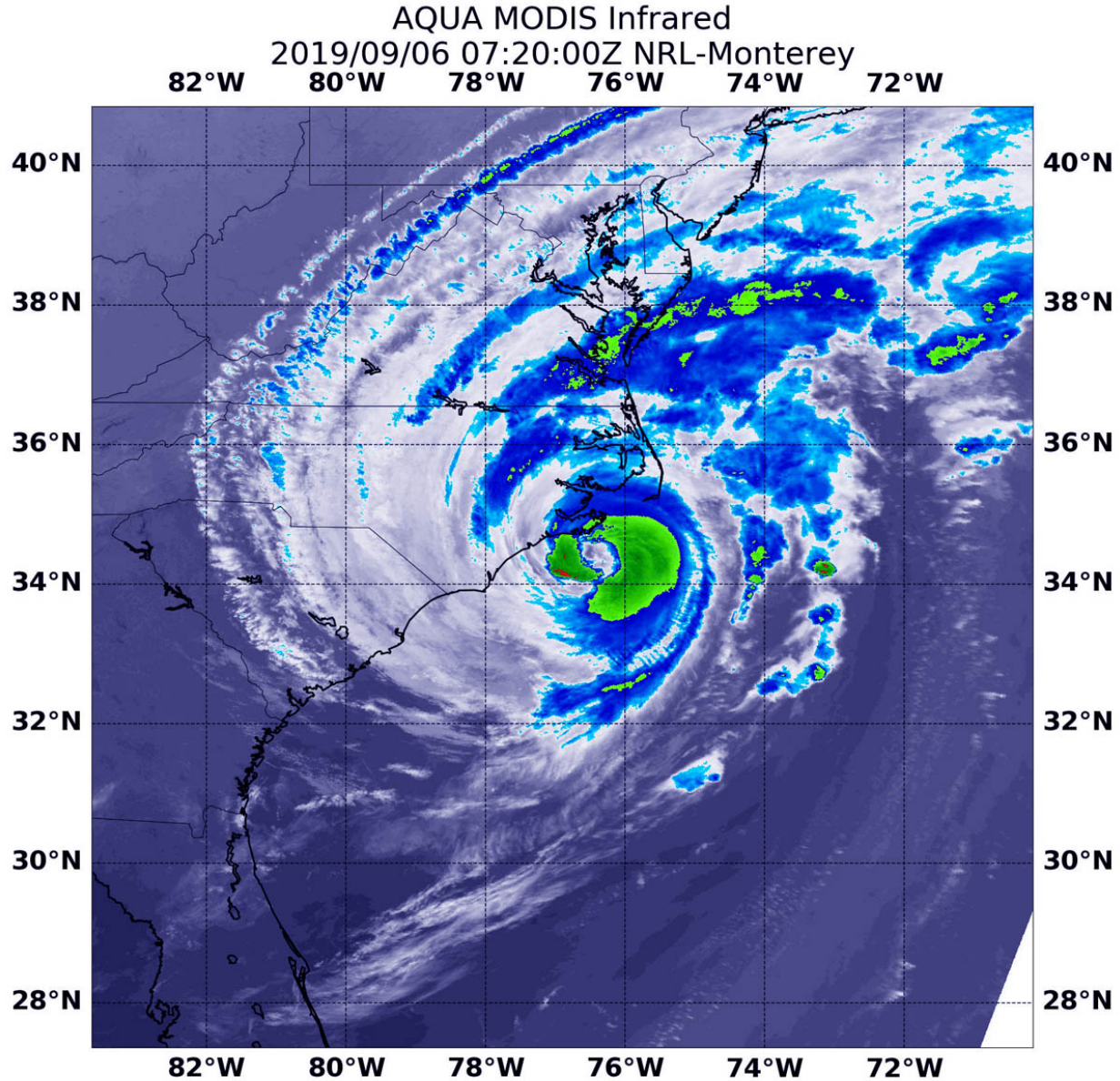
Topography of North Carolina



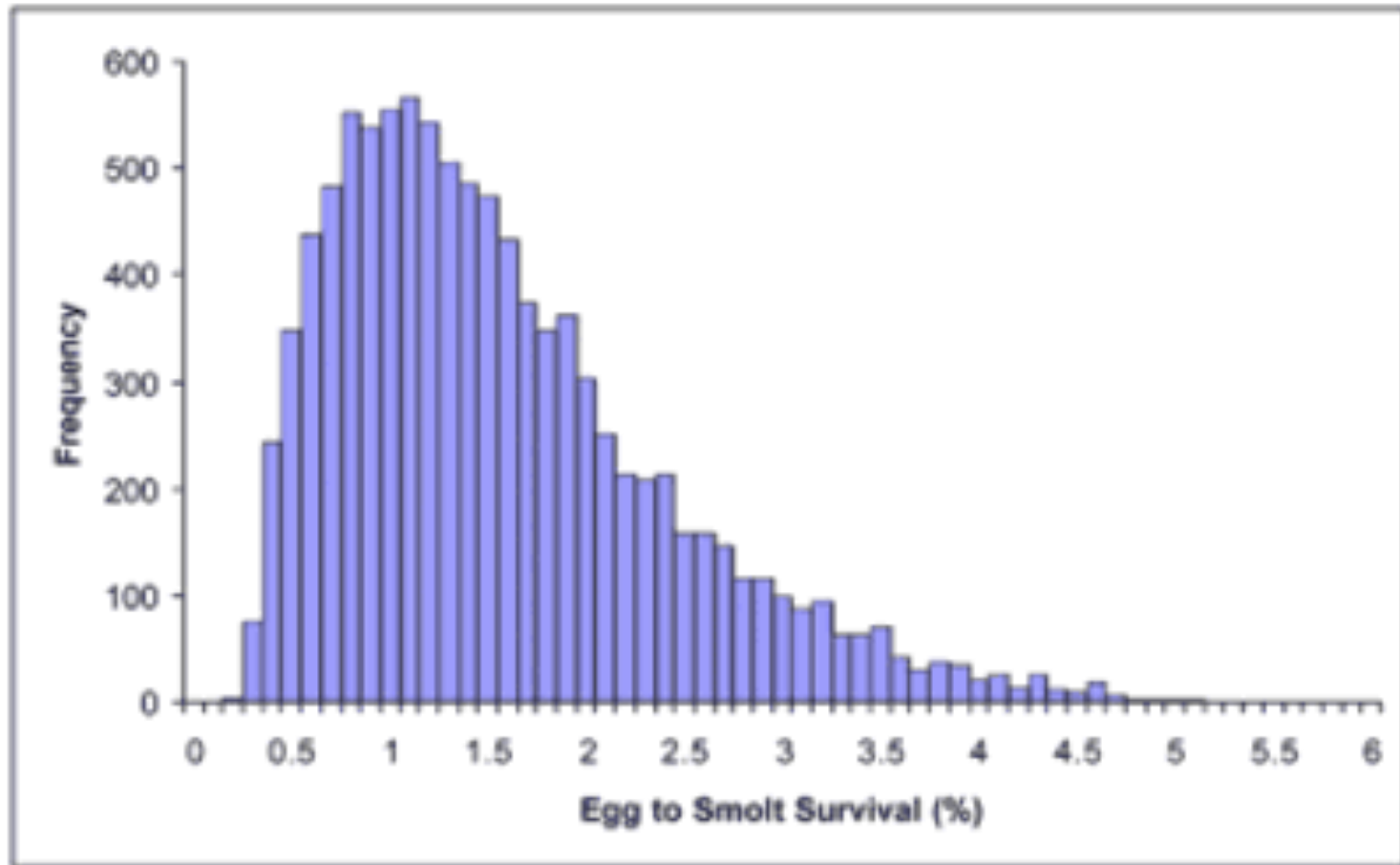
Moore, et al. *Southeastern Geology* 51(4):145- 171,
March 2016



Dorian (aside)



Gaussian -> NonGaussian positive



From: Penn State Stats 400 level online course.

