Integrating Climate and Watershed Modeling to Improve Bridge Design

Iowa DOT Climate Change and Extreme Weather Vulnerability Assessment and Adaptation Project

August 21,2014

NHEC 2014
National Hydraulic Engineering Conference
Designing Sustainable Infrastructure in a Changing Environment

Project Partners

Lead: Iowa DOT (Dave Claman, Hydraulic Engineer)

Iowa State University (Christopher J. Anderson, Eugene S. Takle)

- Climate science and climate projection expertise
- Lead and contributing authors to IPCC AR4, NCA Agriculture

University of Iowa IIHR (Witold F. Krajewski, Ricardo Mantilla)

- Hydrology and hydraulics engineering and modeling
- Iowa Flood Center: ifis.iowafloodcenter.org

Project Objectives

Overarching Objective: Evaluate Vulnerability of Bridges on Primary Highway Systems in Iowa to Change in Streamflow from Projections of Greenhouse Gas Induced Climate Change

Sub-Objective 1: Quantify Variability in Streamflow Projection

- Type 1: Variability from Future Emissions Scenario
- Type 2: Variability from Representation of Rainfall in Climate Models
- Type 3: Variability from Interaction between Rainfall, Soil Moisture, and Basin Drainage

Sub-Objective 2: Evaluate Limitations of using Inherently Coarse Downscaled Climate Projection Data (1/8th degree grid at daily increment)

Project Data

Downscaled Climate Projection Data are obtained from an approach called the Asynchronous Regional Regression Model* (ARRM) that utilizes quantile regression.

- Data are available on $1/8^{th}$ degree grid with daily time step.
- Biases are well documented, and stationarity assumptions are tested.
- Continuous time series is available for 1960 – 2100.

Type 1: Variability from Future Emissions Scenarios

- Downscaled Data contains three plausible future emissions scenarios: Business as usual (A2), Modest reduction (A1B), Modest increase (A1FI)

Type 2: Variability from Representation of Rainfall in Climate Models

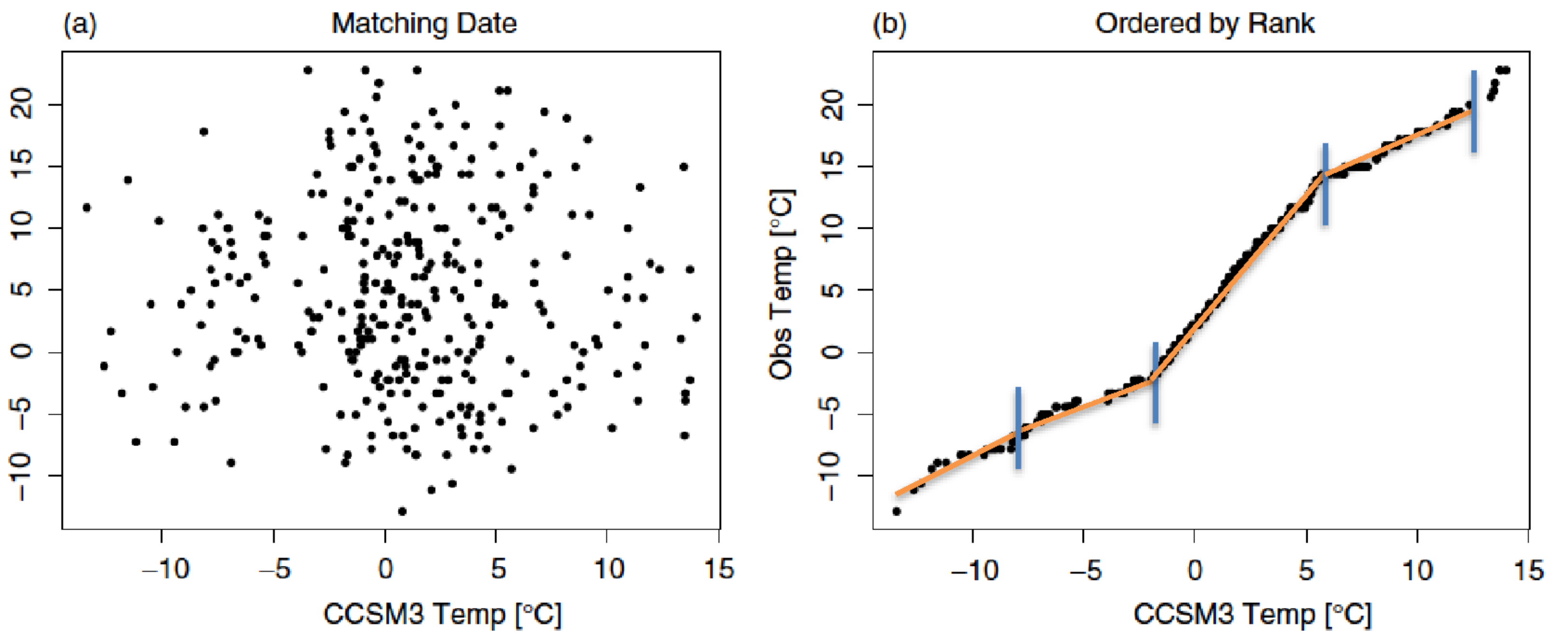
- Downscaled Data contains results from 9 Climate Models

Type 3: Variability from Interaction between Rainfall, Soil Moisture, and Basin Drainage

- Use ARRM rainfall data as input to mechanistic hydrological model based upon fluid dynamics equations.

* Stoner et al. (2013, International Journal of Climatology)

ARRM Downscaling Approach

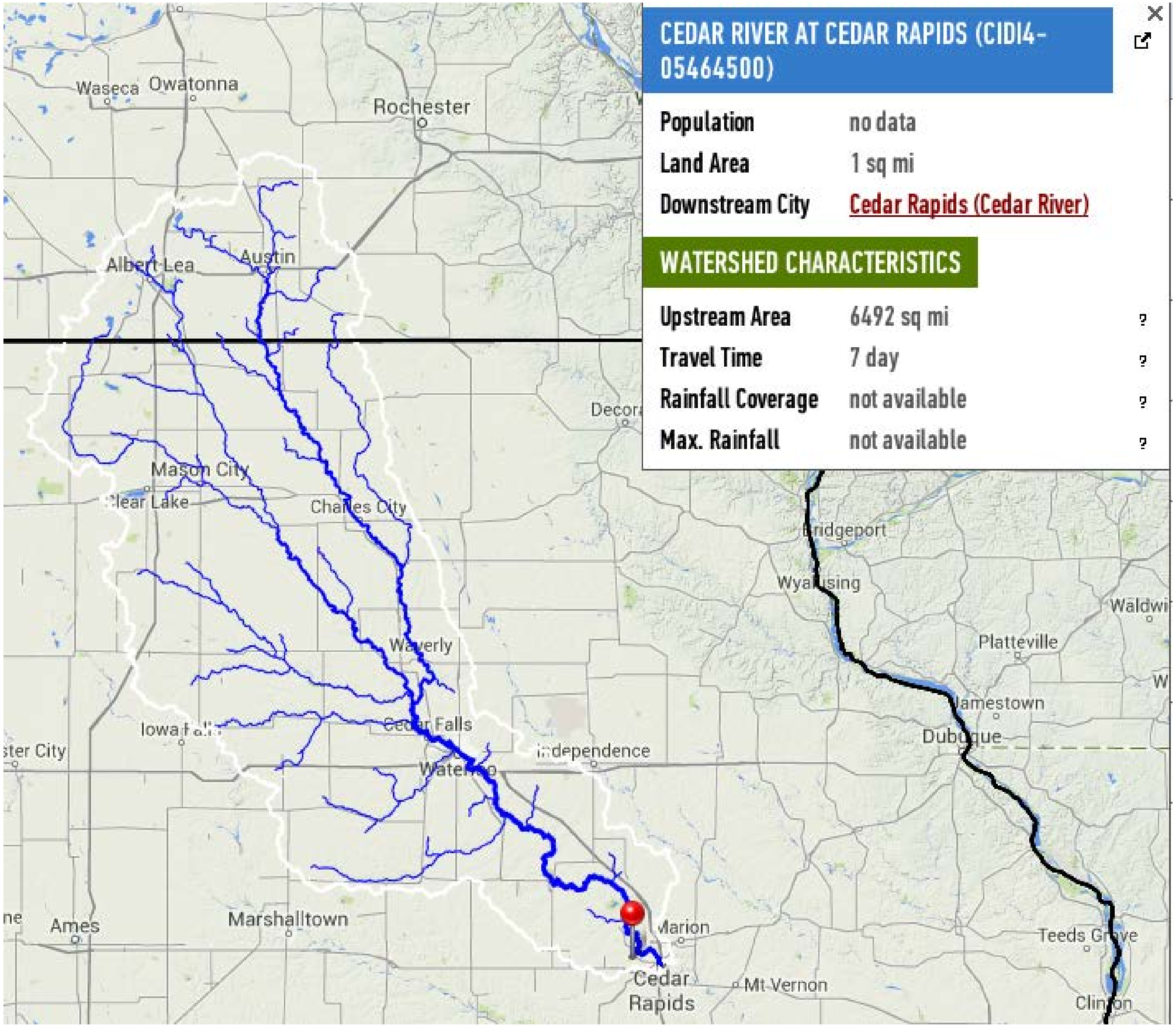


On Left, the scatter plot shows historical data and climate model data are not synced during 1960 – 1999 by the nature of climate simulation design. Thus, the data are uncorrelated.

On Right, the Q-Q plot shows rank of historical and climate model data are correlated.

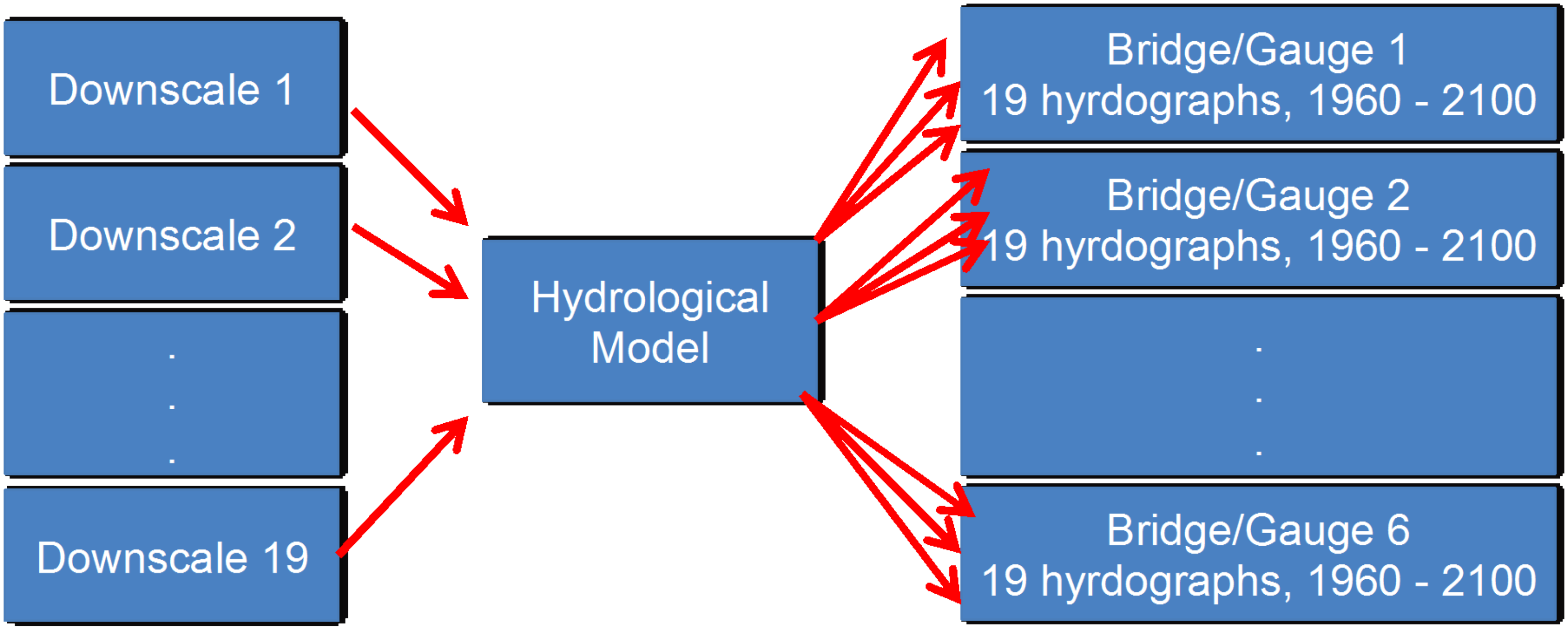
Use piecewise linear regression (orange lines) to predict observed rank given climate model rank.

Example Target Bridge: Cedar River Basin at State Hwy 151

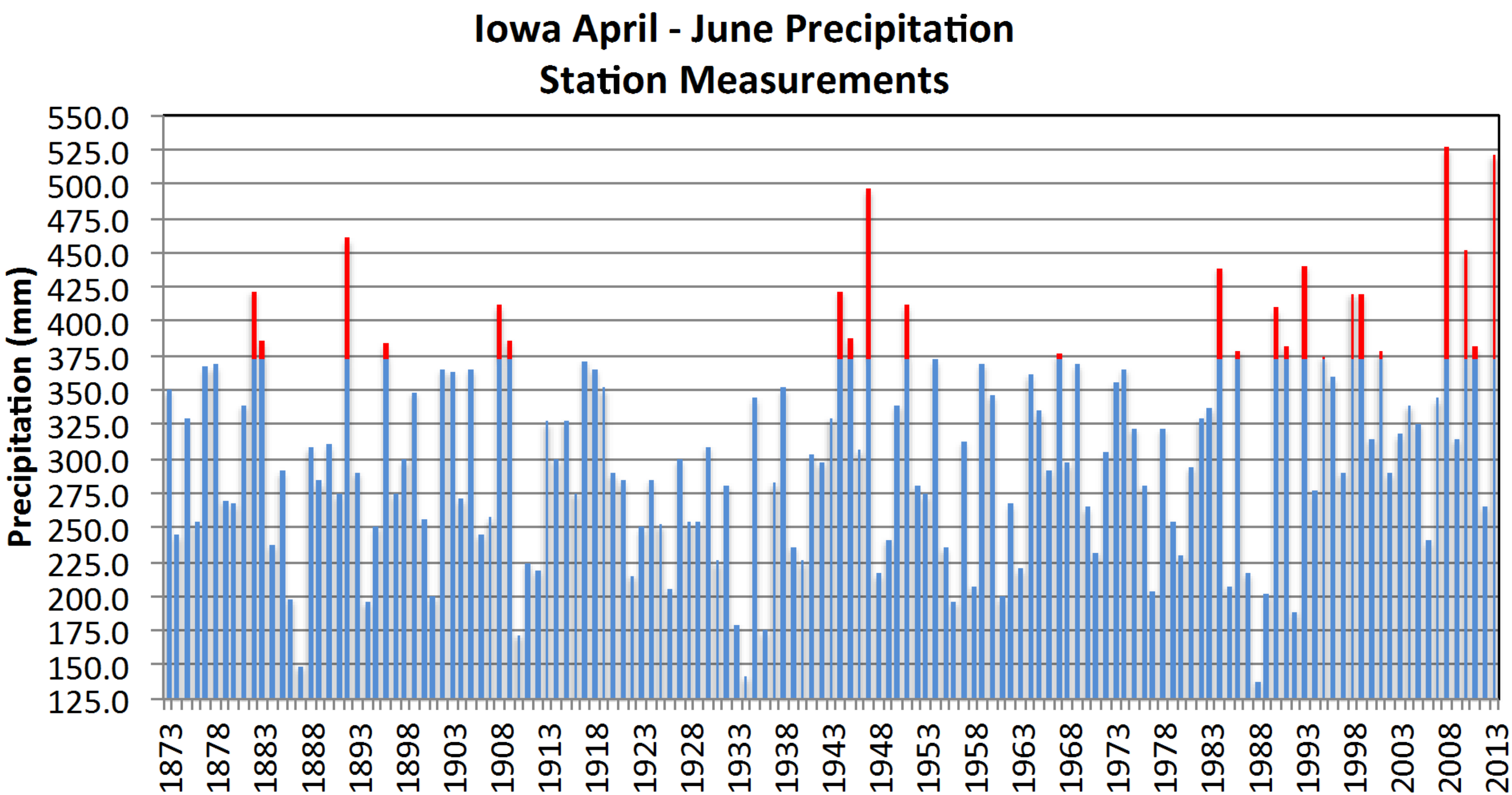


Iowa Flood Information System (IFIS), http://ifis.iowafloodcenter.org/ifis/main/

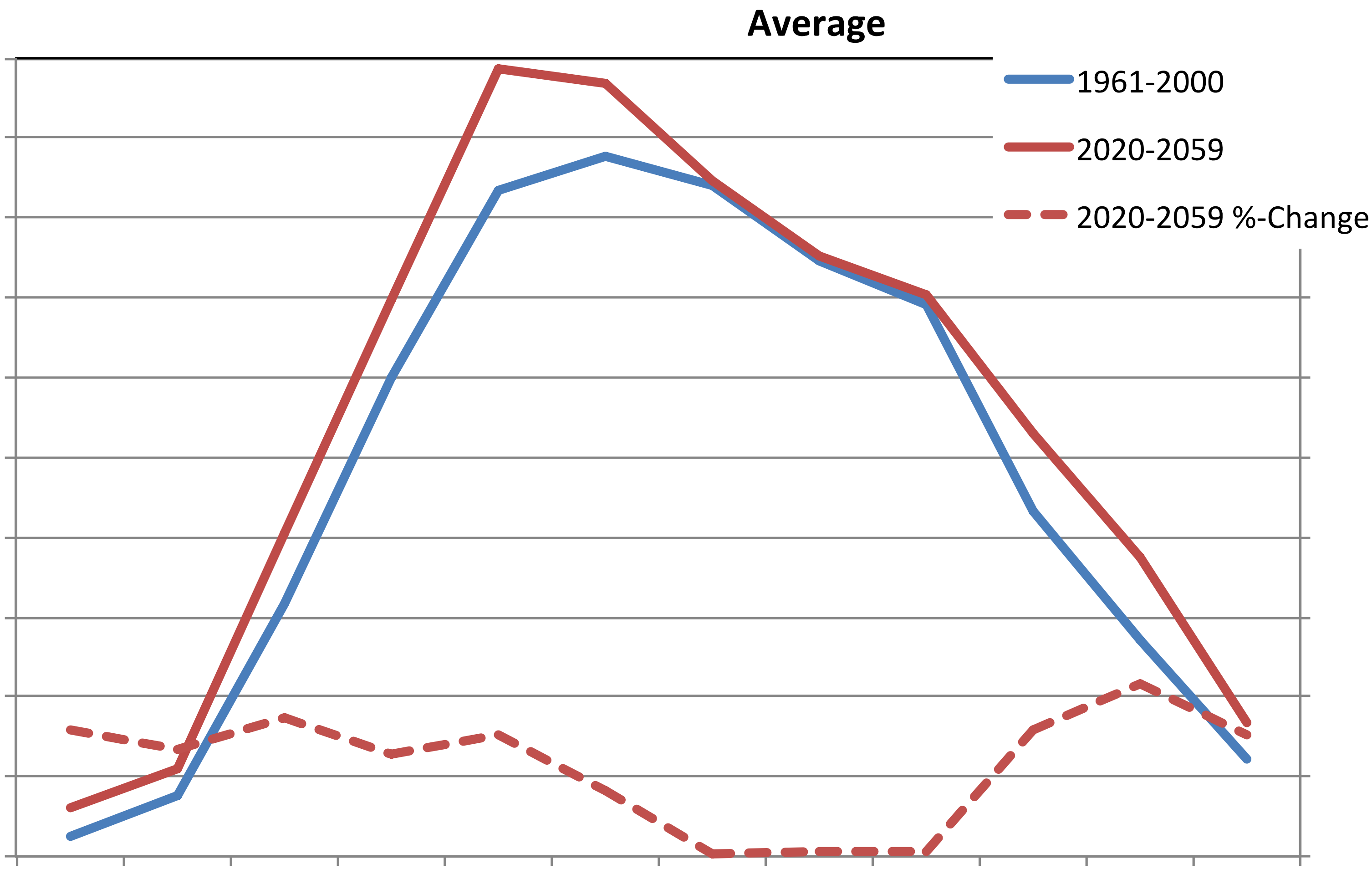
Ensemble Streamflow Simulation Design



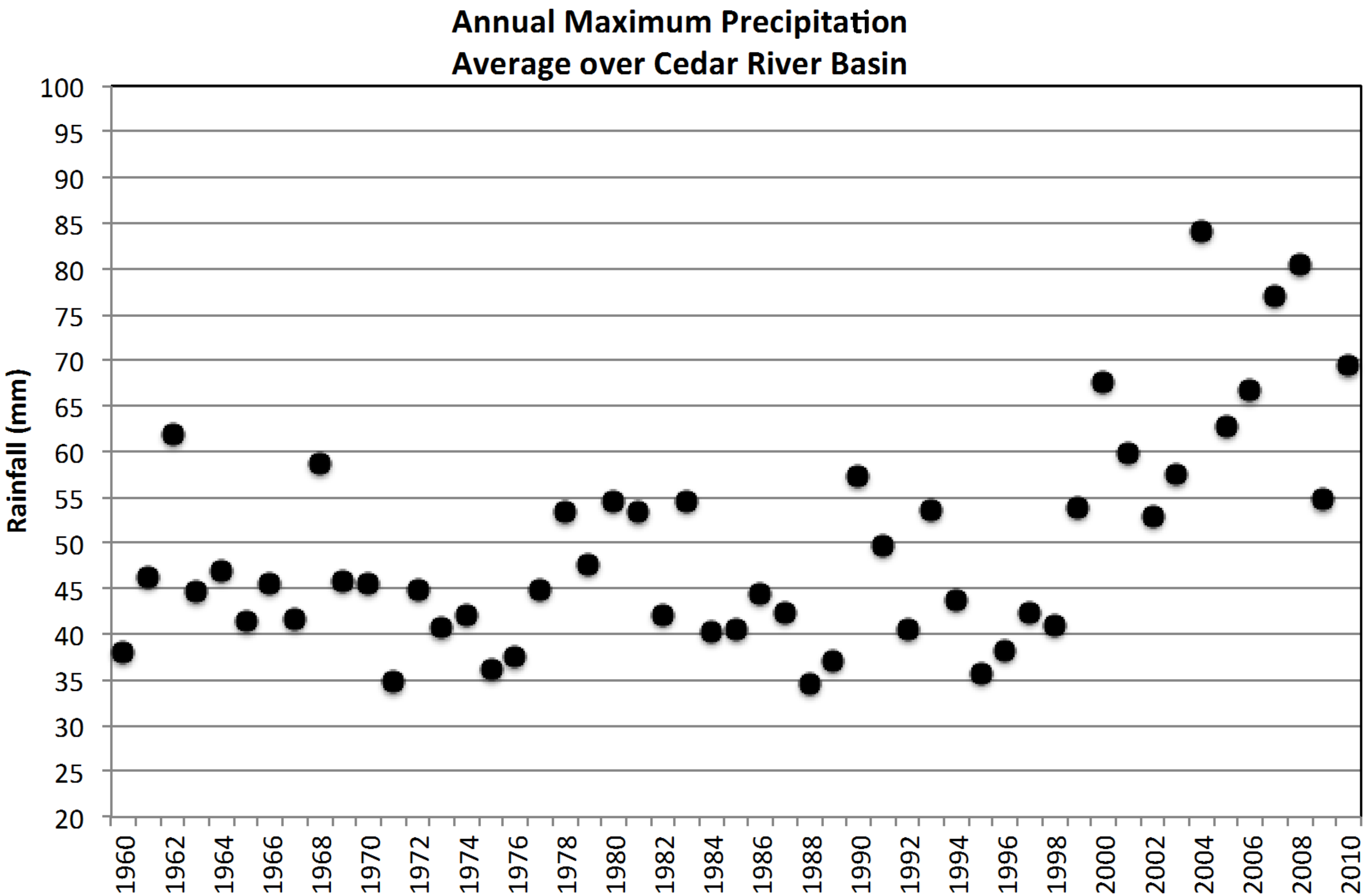
Historical Spring Rainfall Change



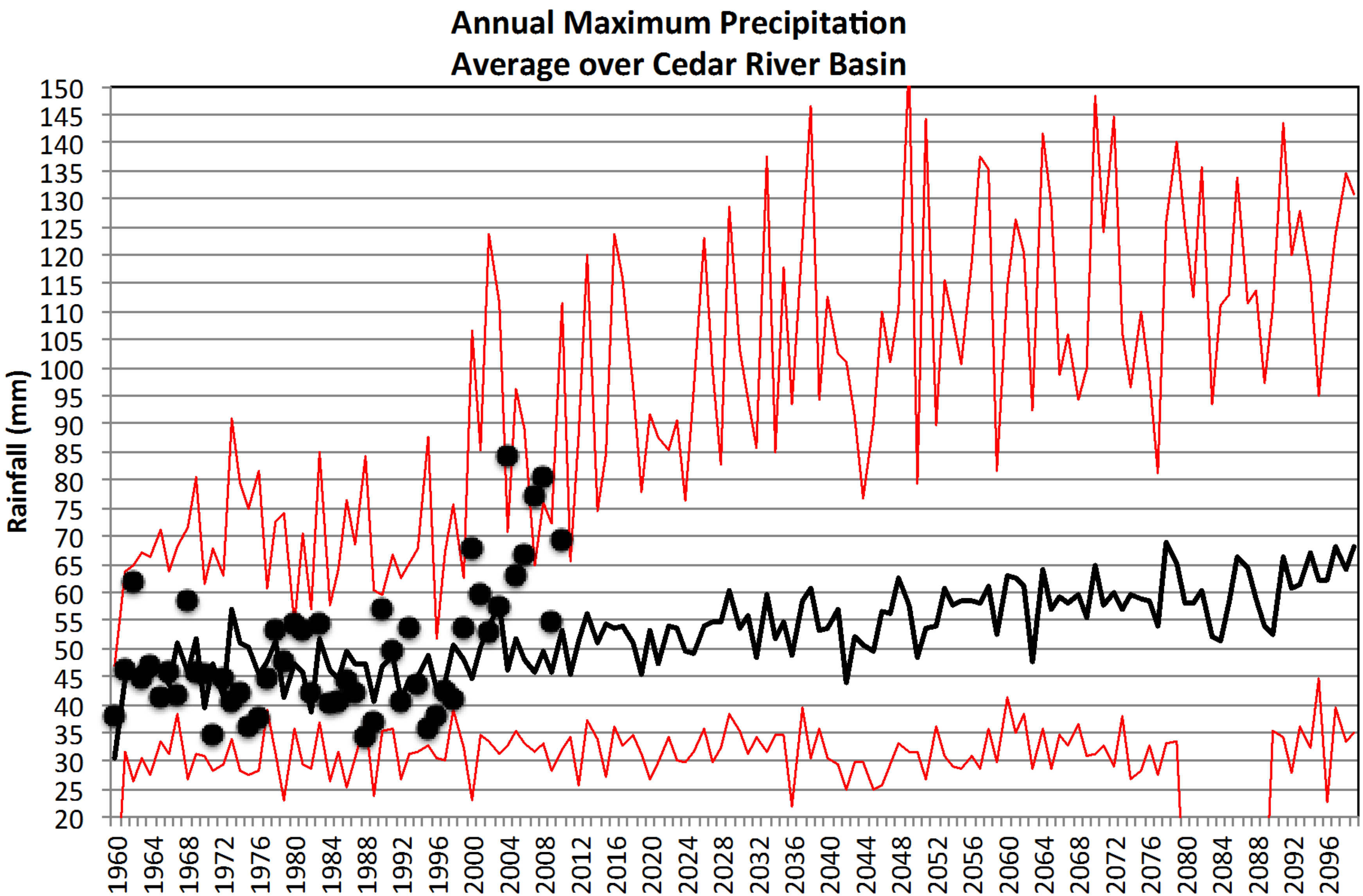
Projected Monthly Rainfall Change



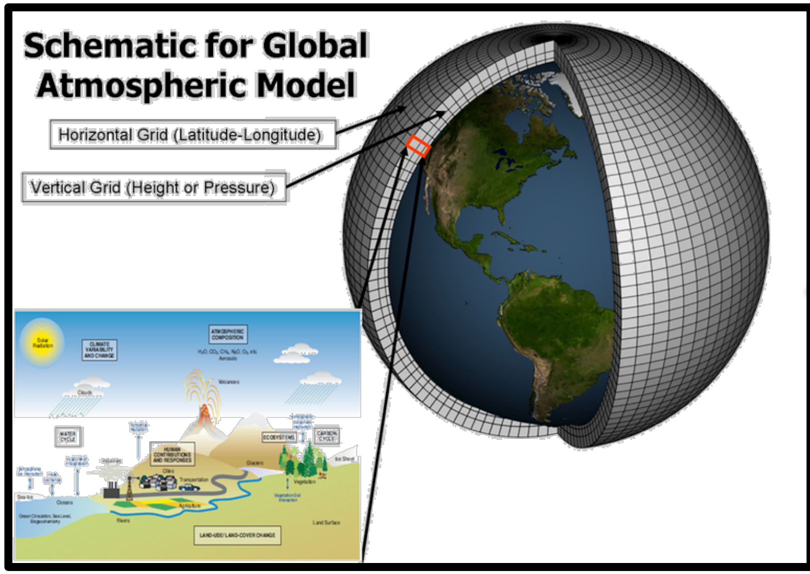
Historical Annual Maximum Precipitation Change



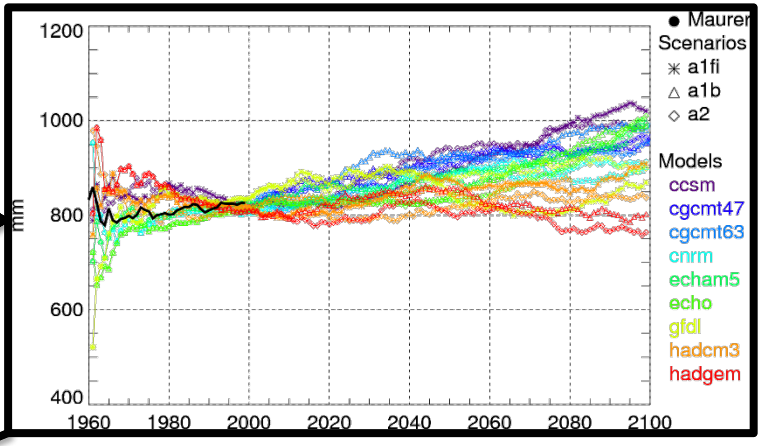
Projected Change
Annual Maximum Precipitation

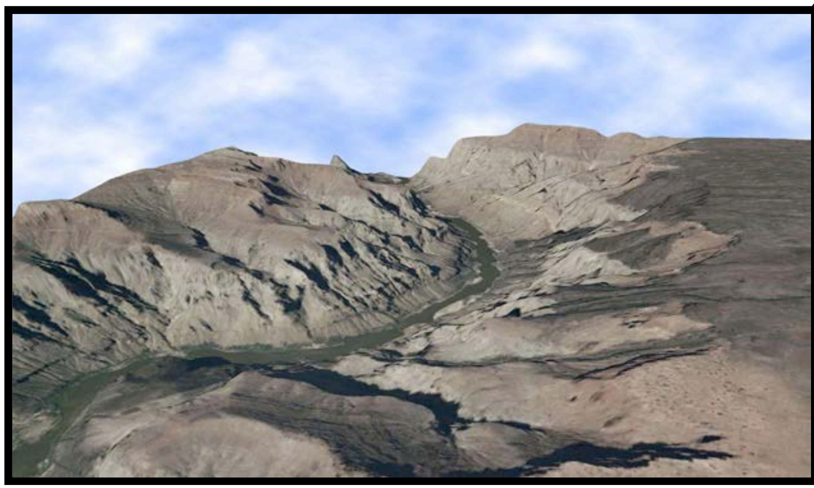


Using GCM rainfall projections to assess changes in flood frequencies

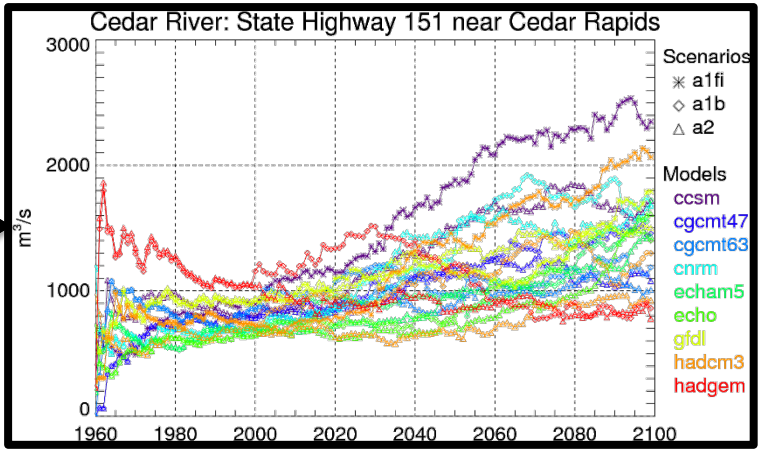


Rainfall



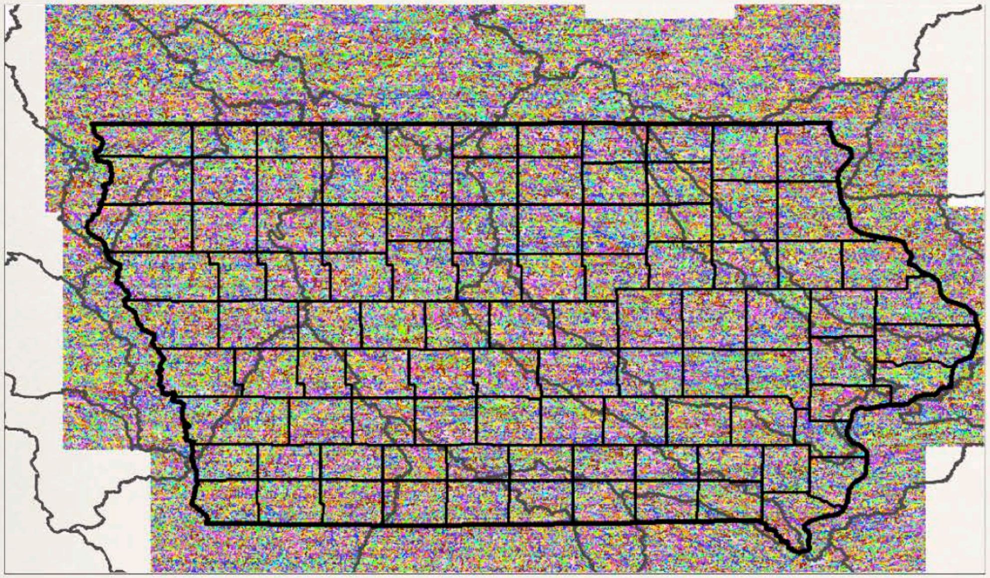


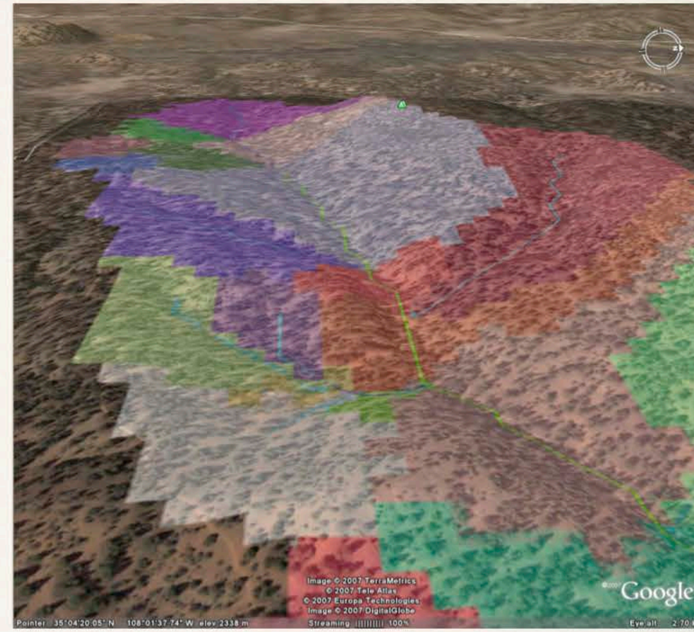
Annual Peak Flows



Hydrological model discretization

hillslope area: ~0.05km^2



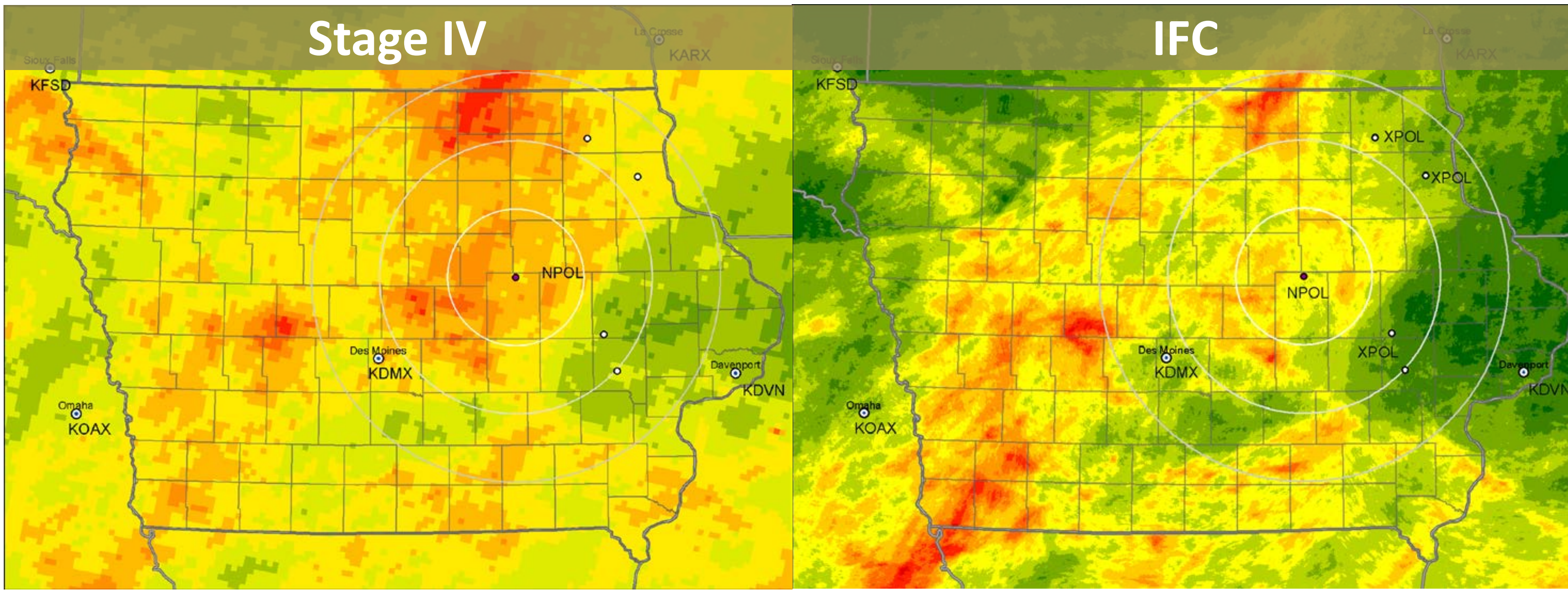


The model provides hydrographs everywhere in the drainage network

Iowa Flood Center

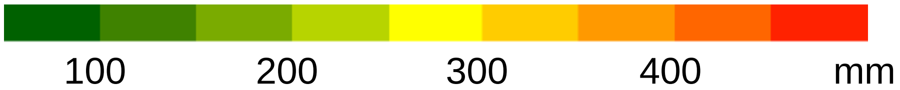
Model Forcing (Radar-derived)

Rainfall Totals (May 1st – June 15th, 2013)

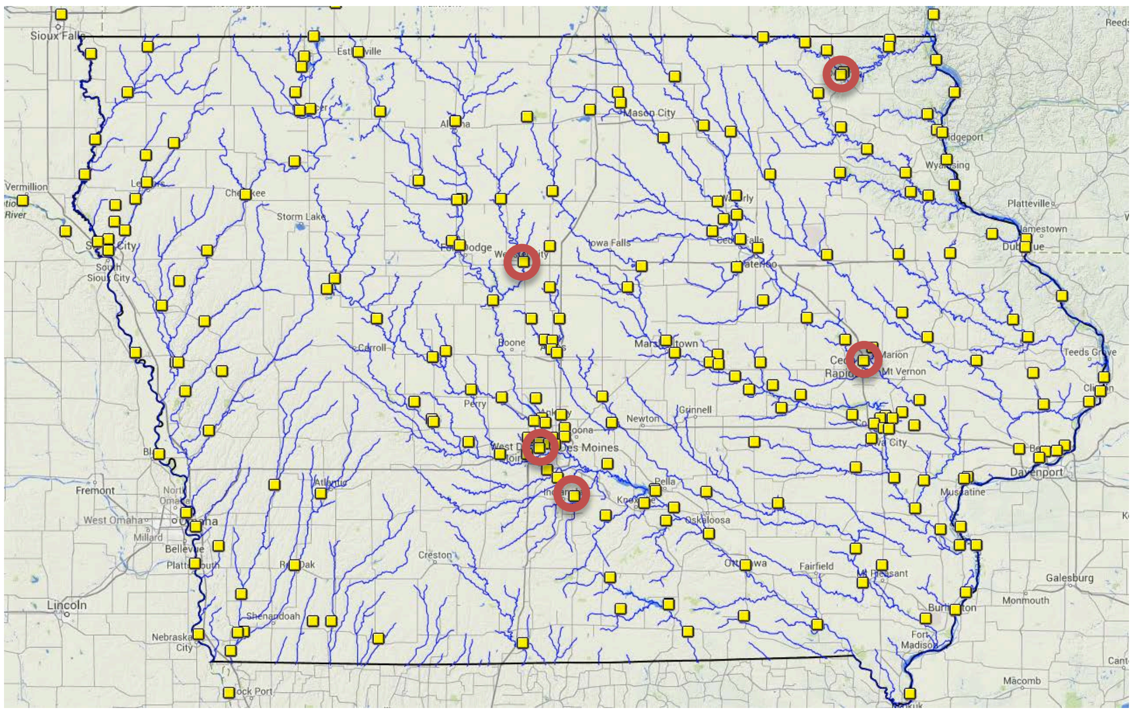


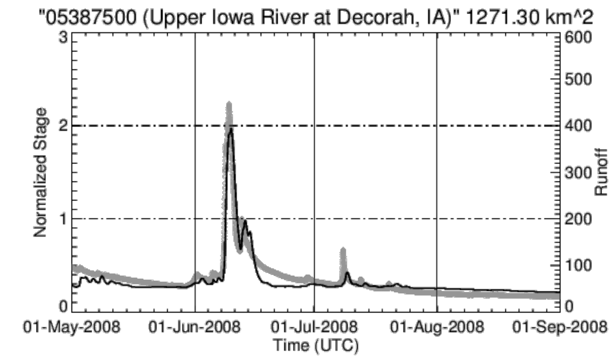
ΔT = 1 h, Δx = 4 km

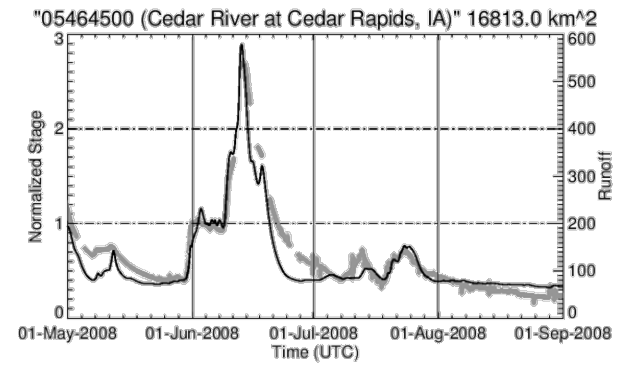
ΔT = 5 min, Δx = 500 m

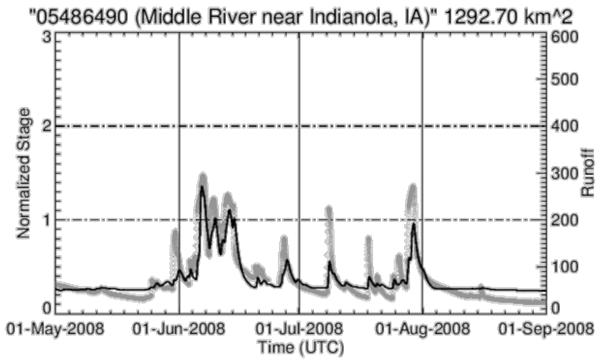


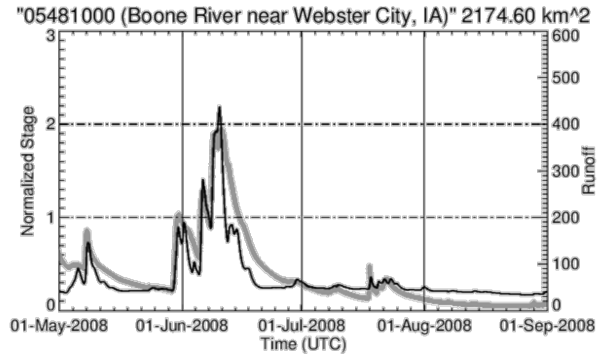
Model Performance for 2008 Floods

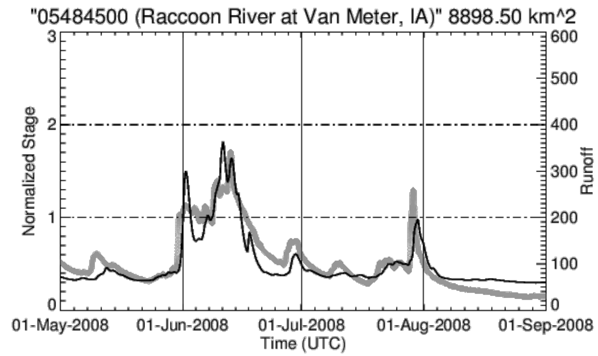






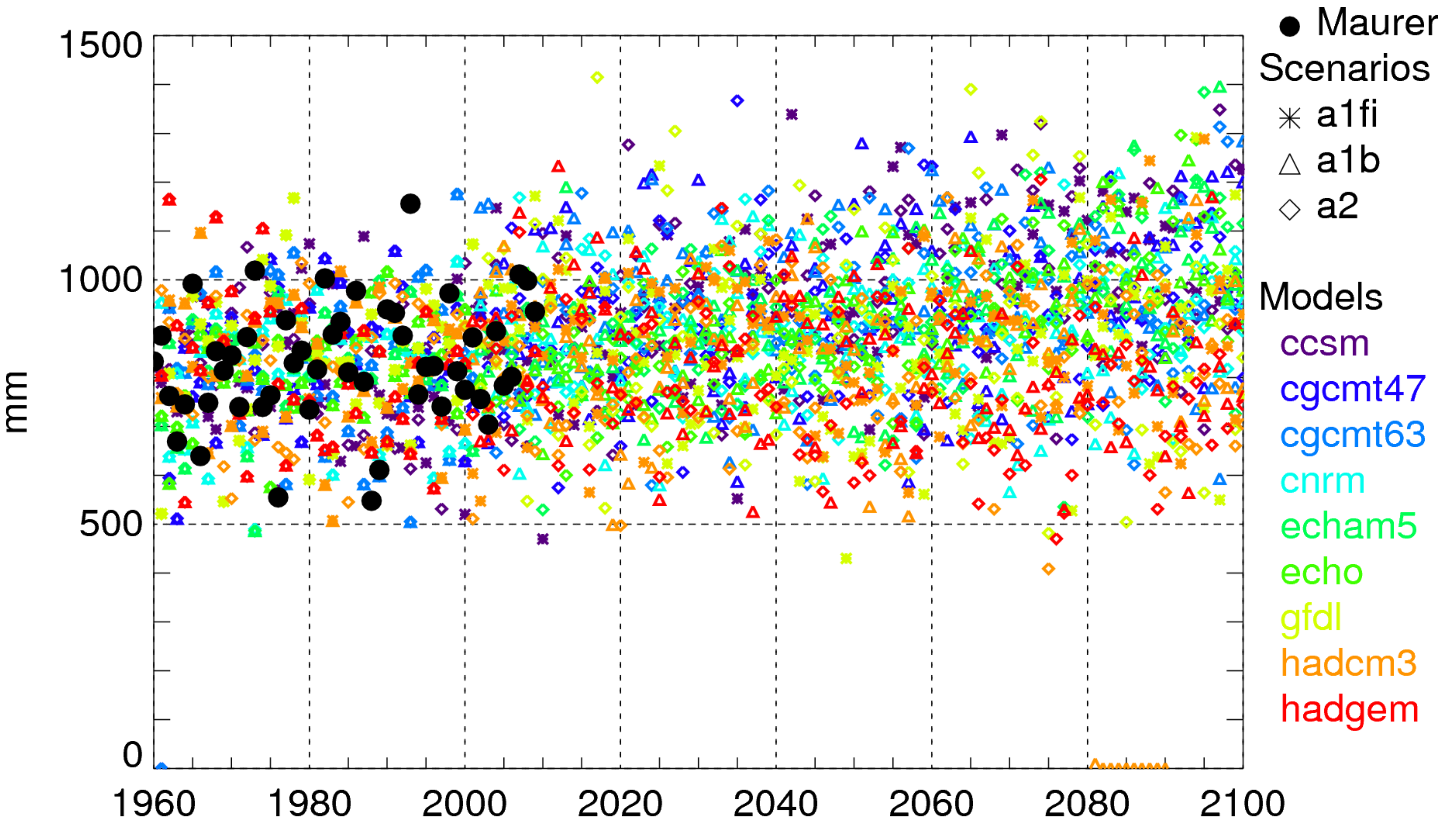






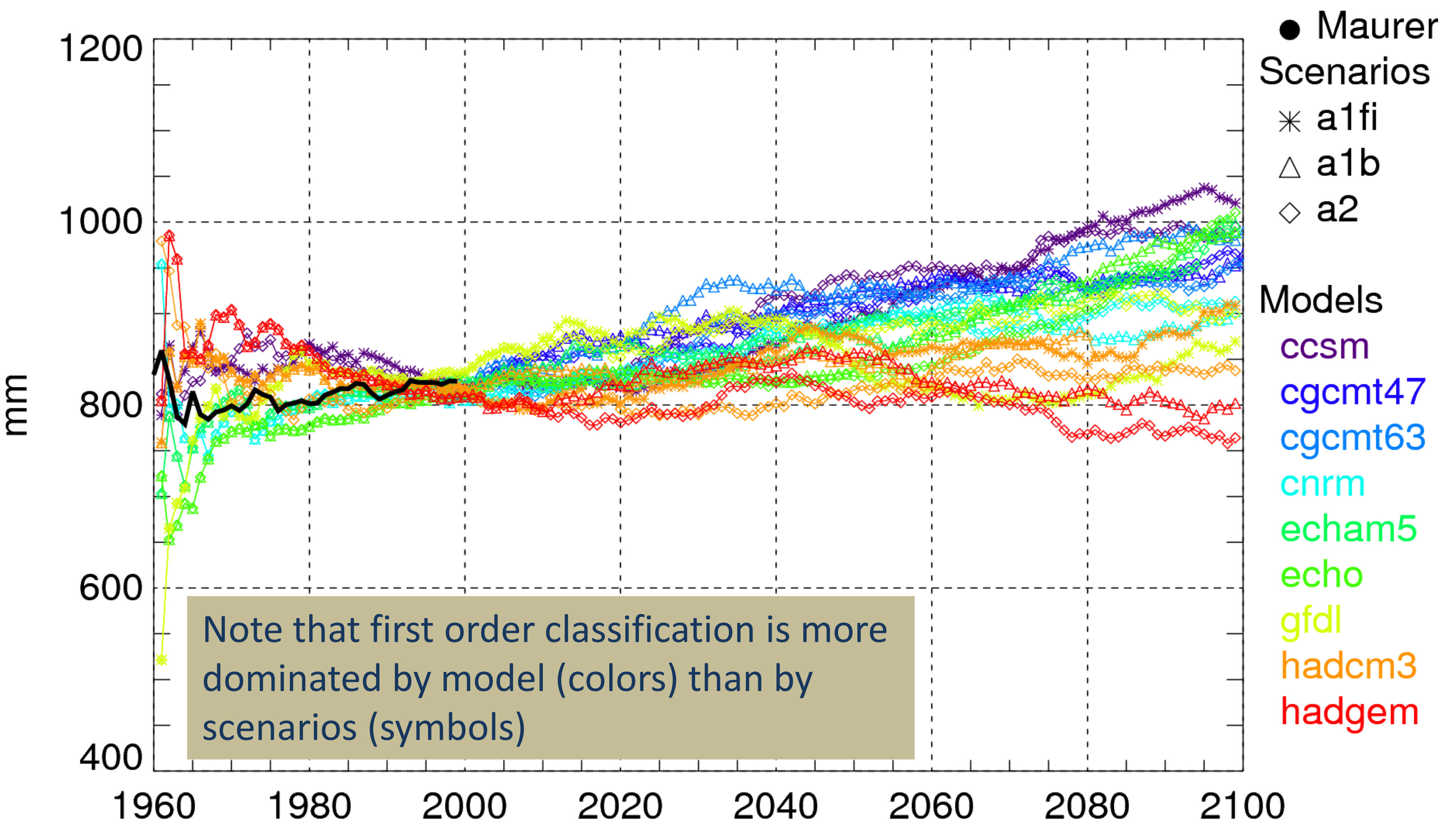
19 Projections (model/scenario)

Annual Precipitation over the Iowa Domain (API)



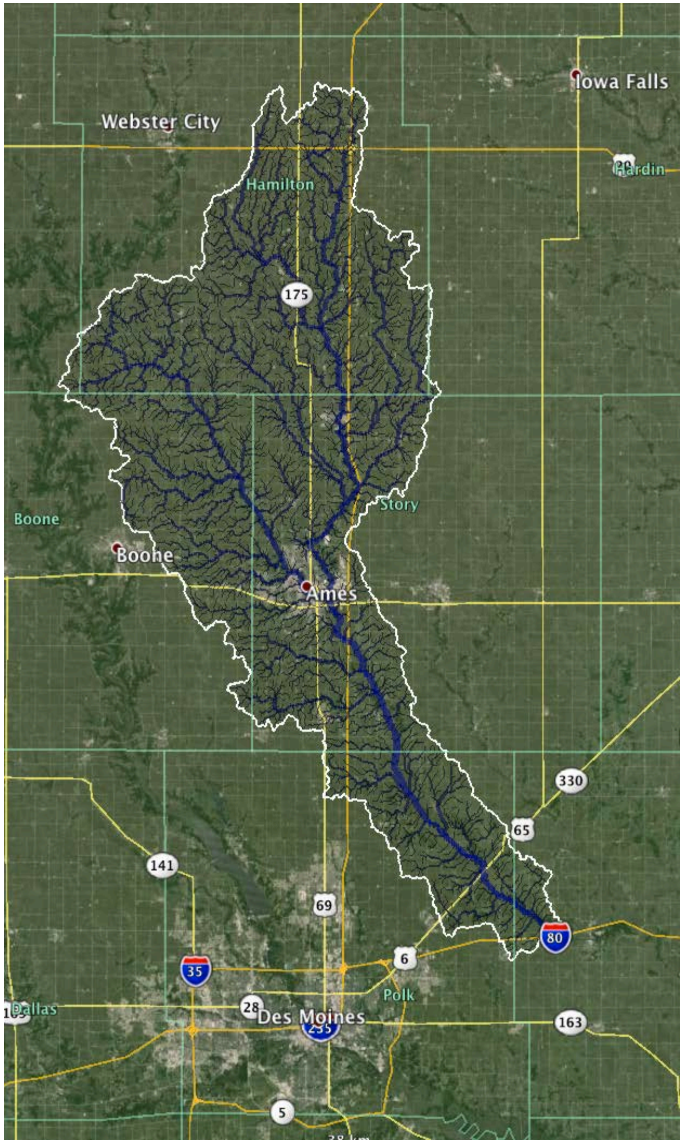
Rainfall Analysis

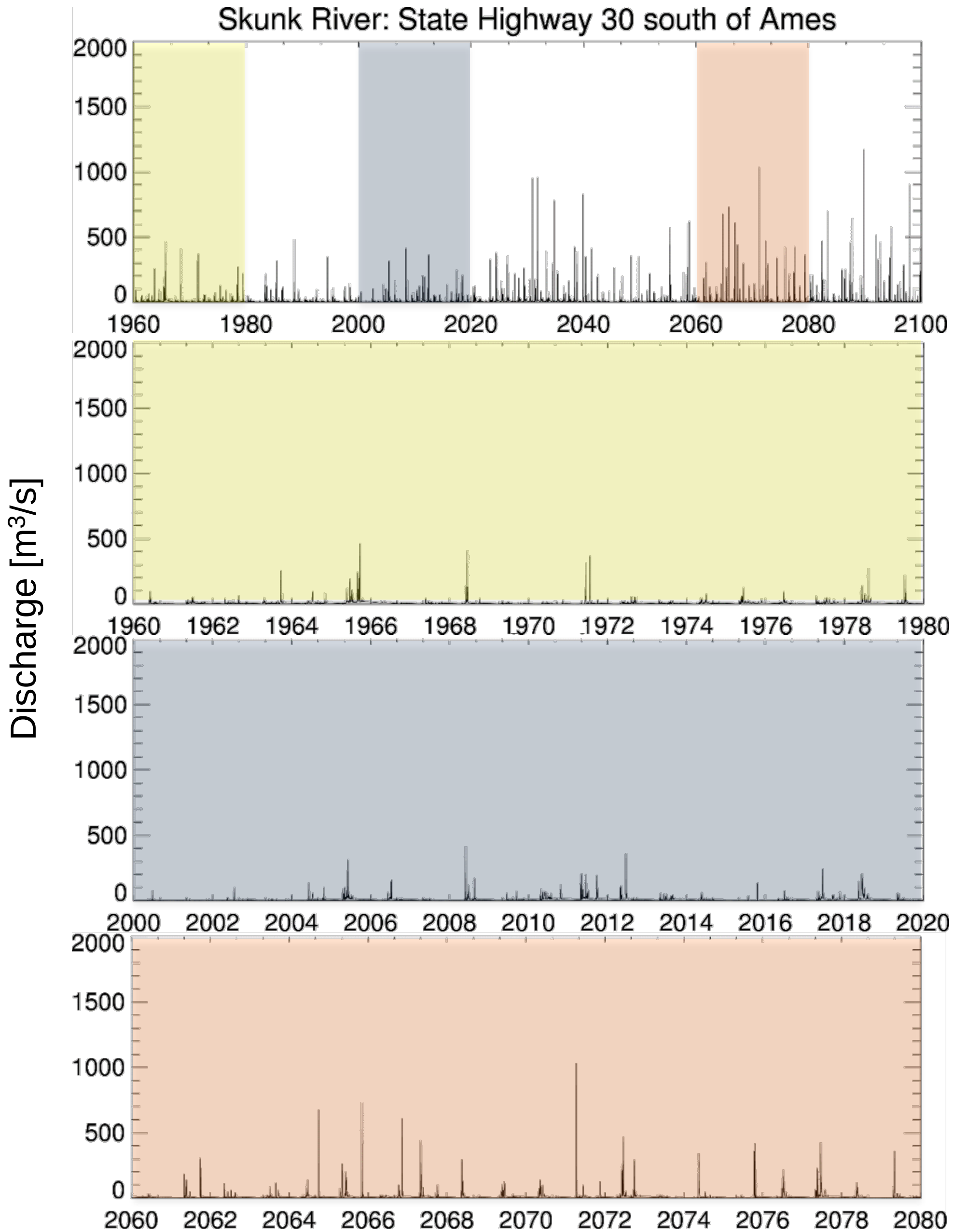
40-year moving average API ($MAPI_{40}$)



Note that first order classification is more dominated by model (colors) than by scenarios (symbols)

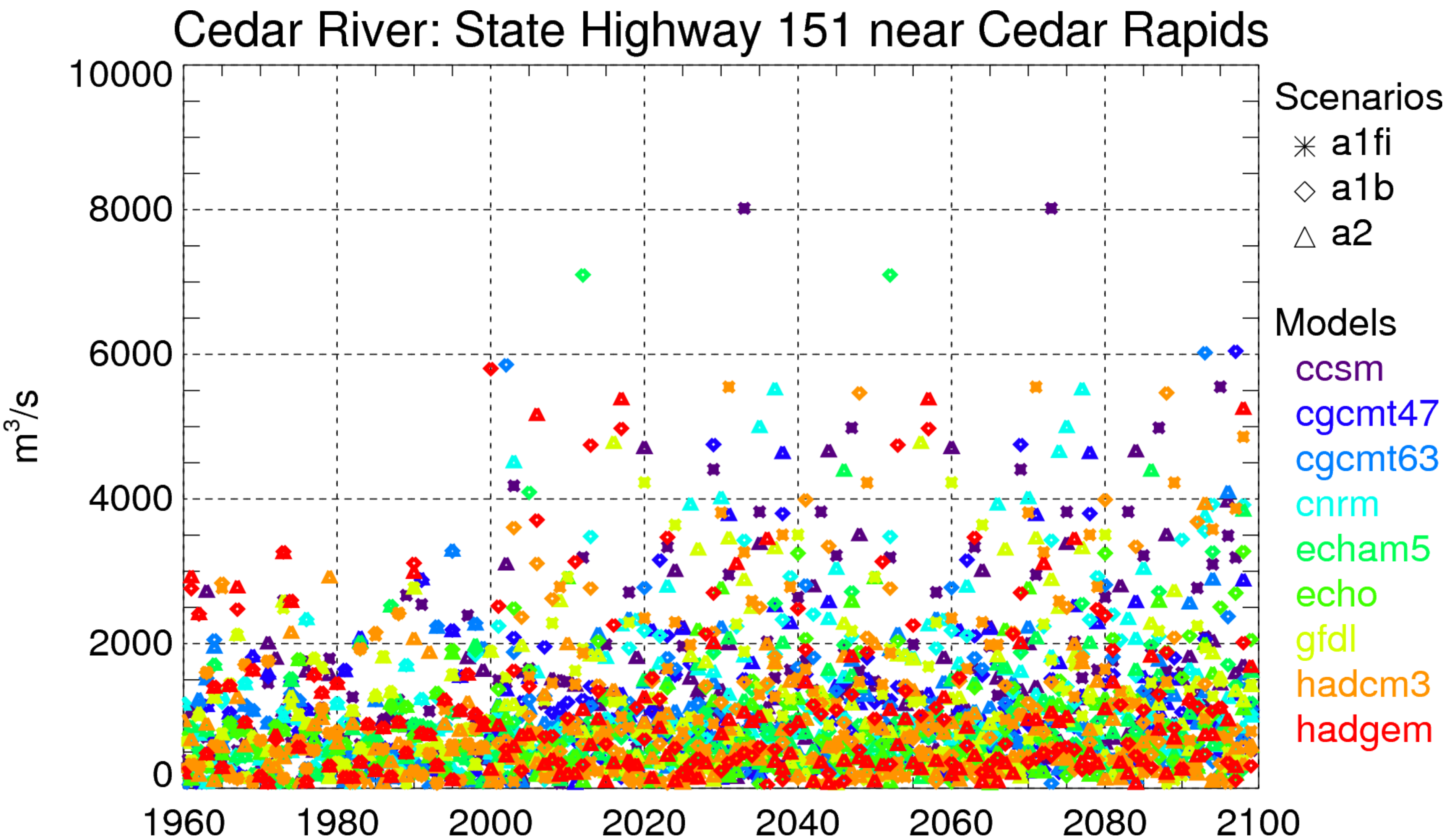
140-year simulation: hadcm3, a1fi



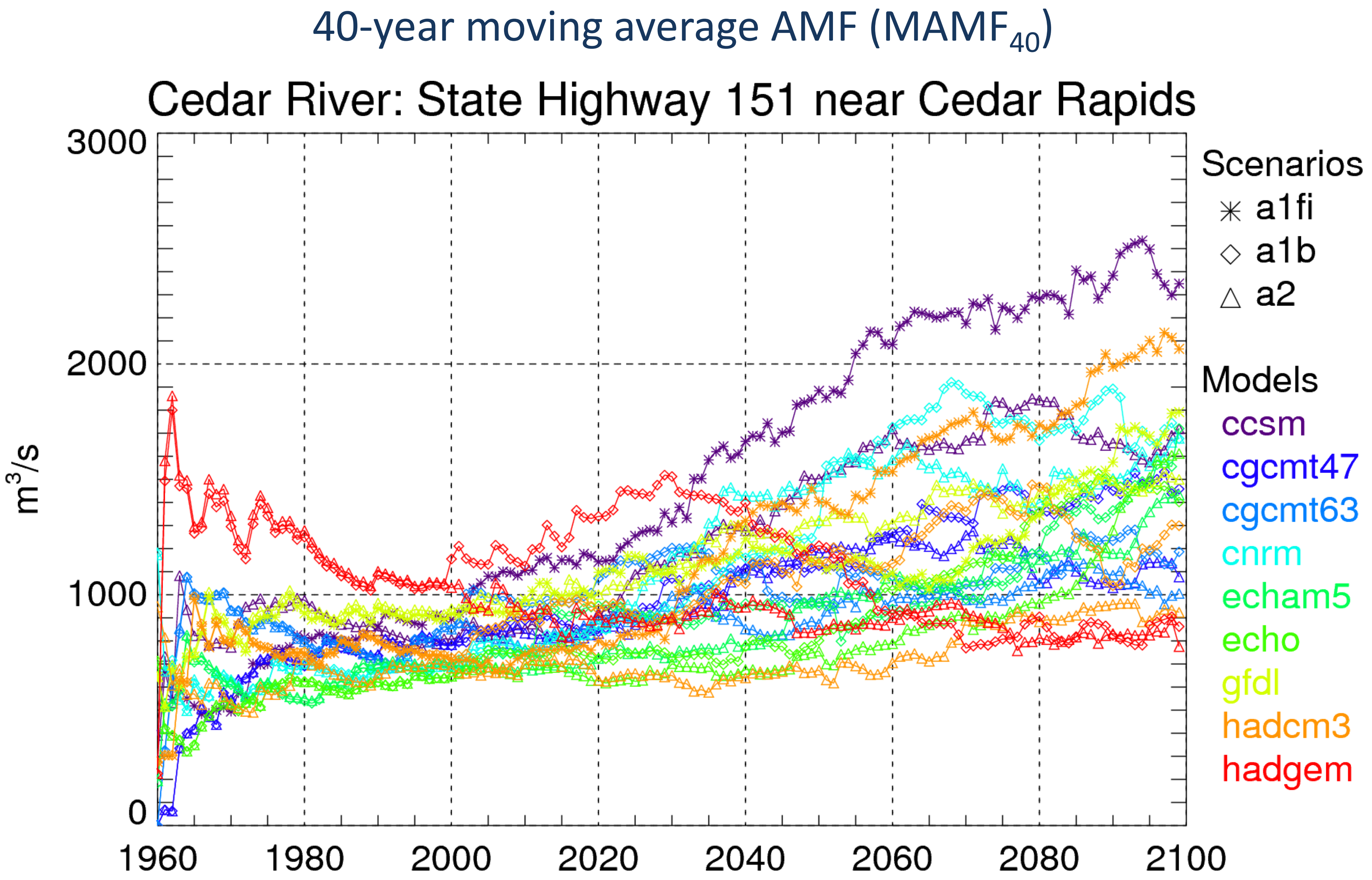


140-year continuous simulation

Annual Maximum Flow (AMF)

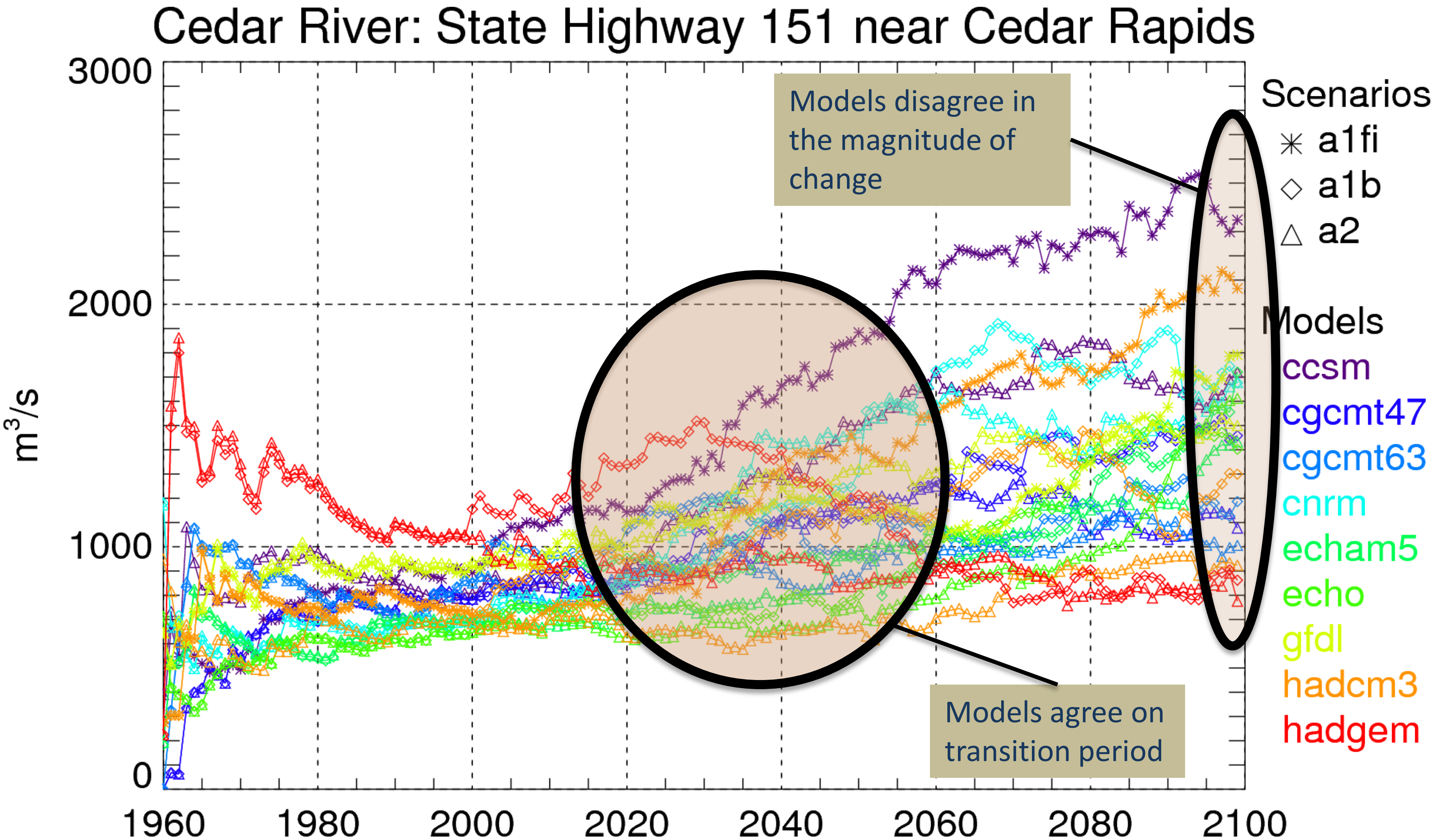


140-year continuous simulation



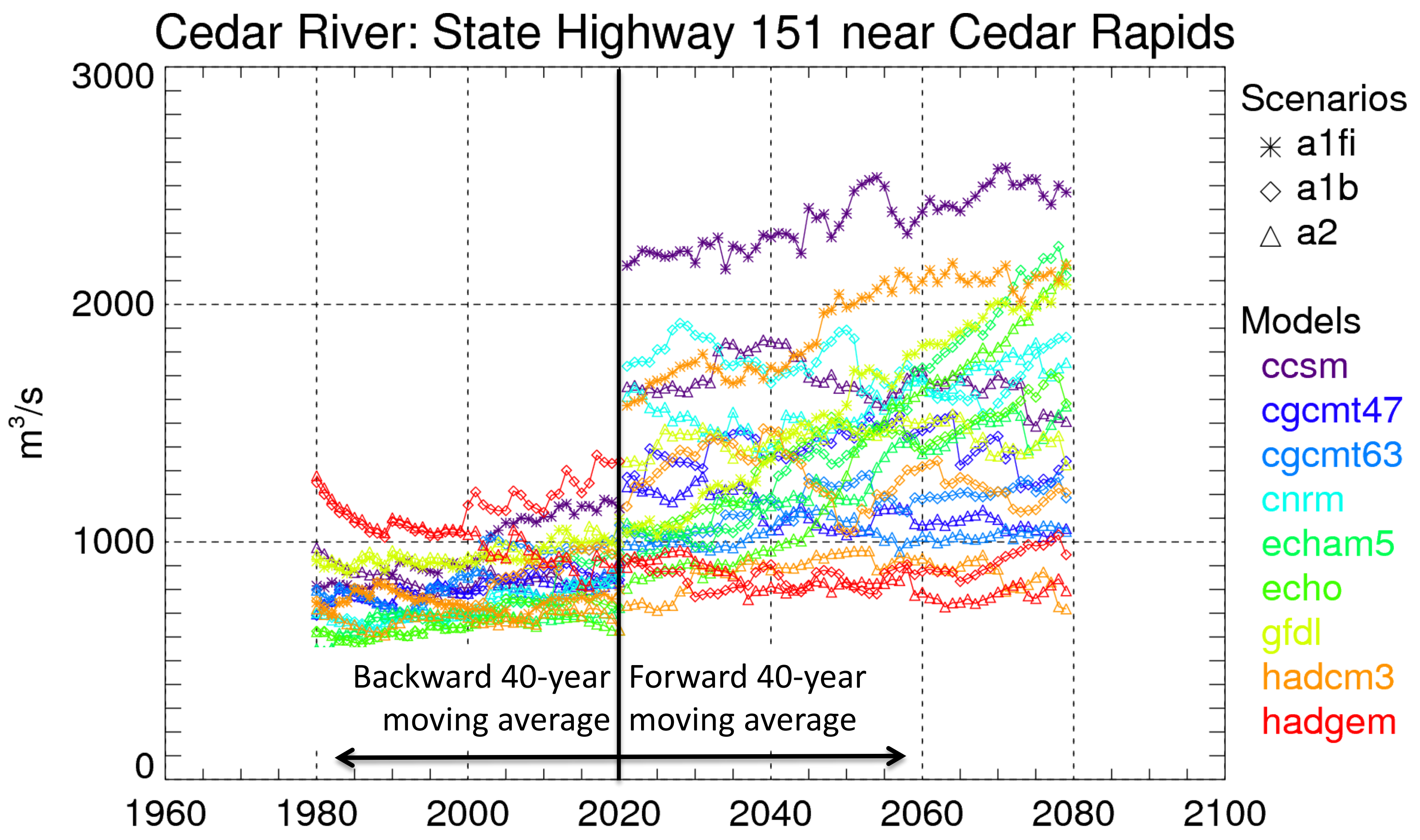
140-year continuous simulation

40-year moving average AMF ($MAMF_{40}$)



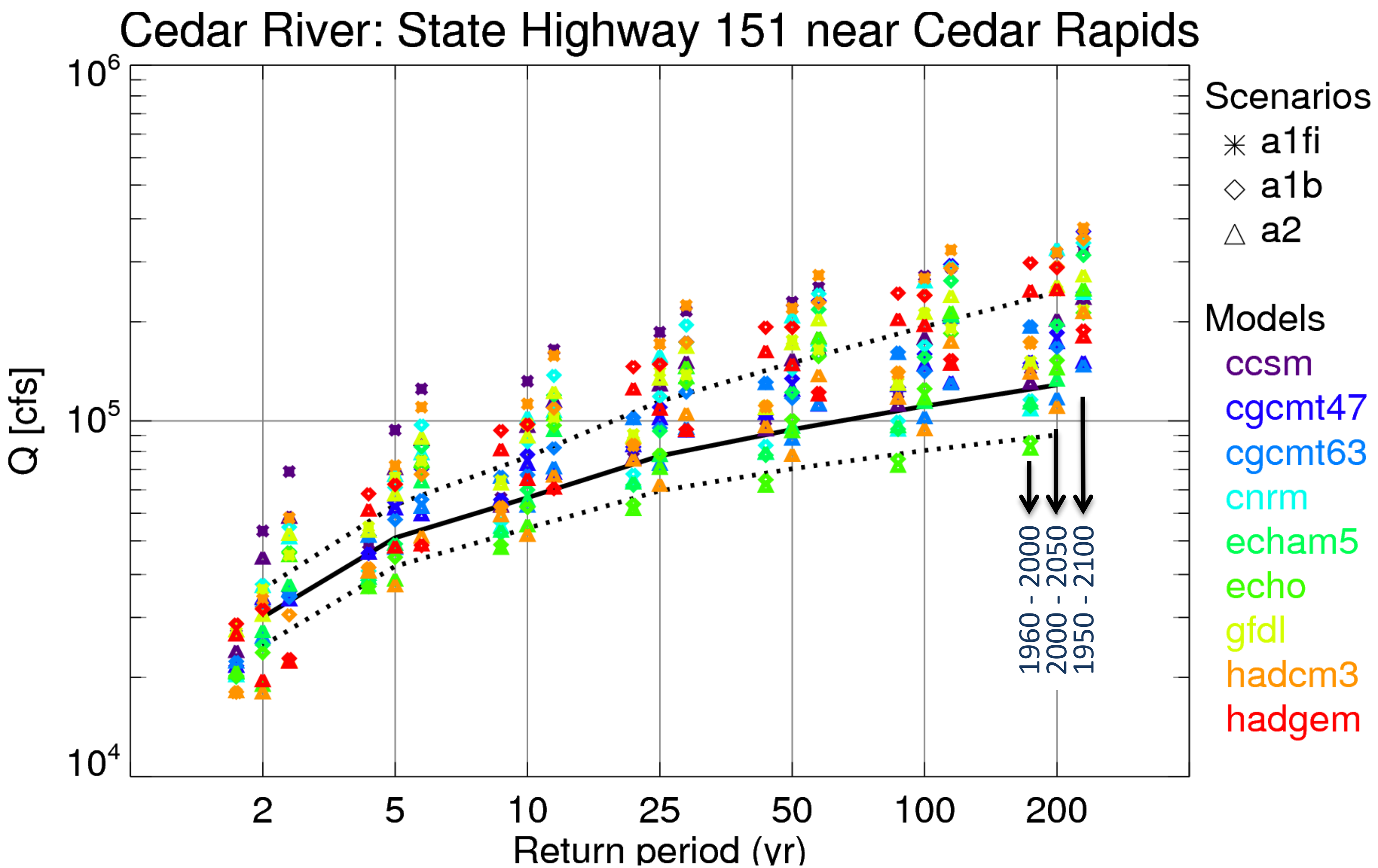
Floods Analysis

A sharp transition in flood regime



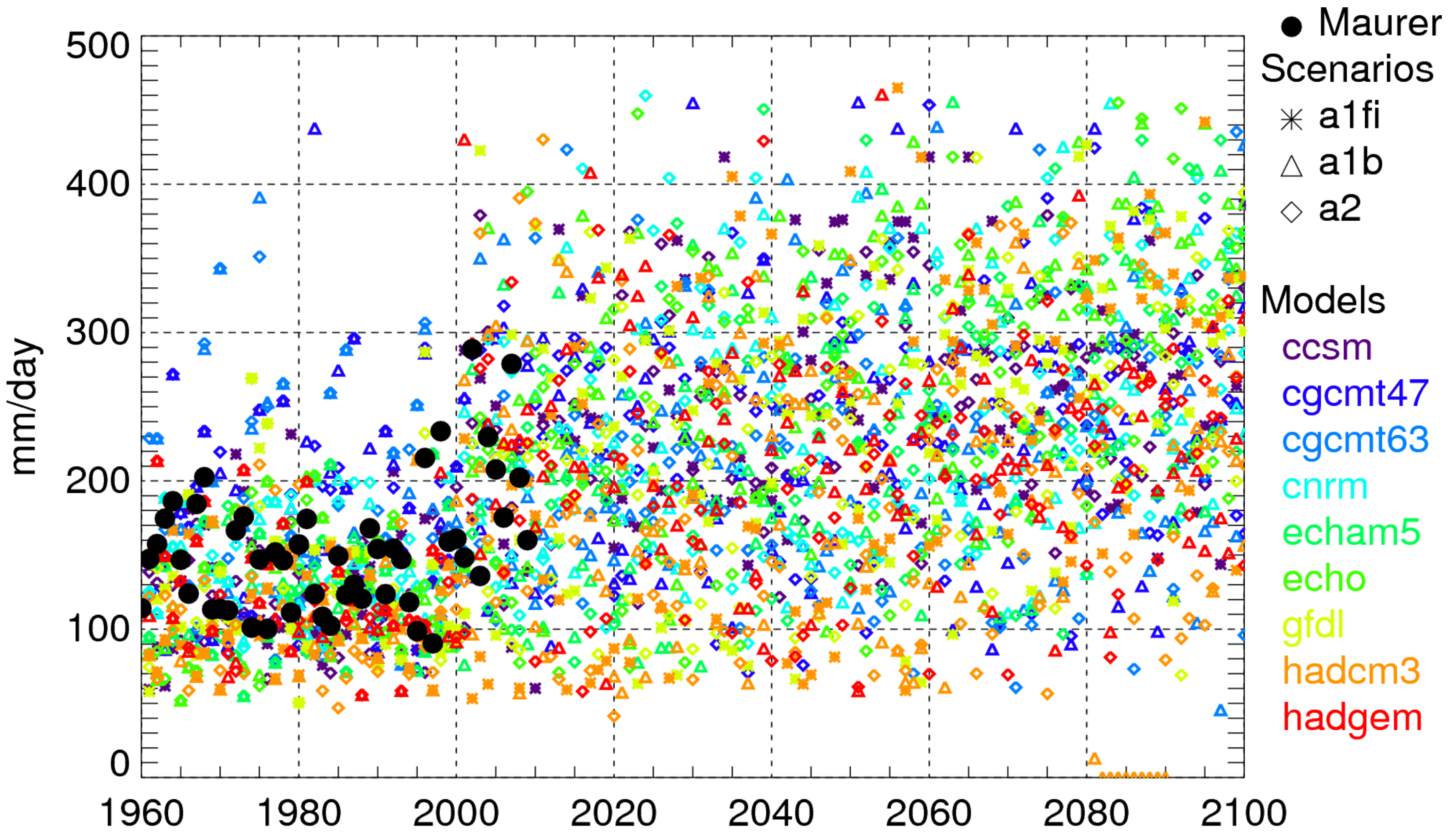
Floods Analysis

Changes in flood quantiles



Rainfall Analysis

Maximum Daily Precipitation over the Iowa Domain (MPI)



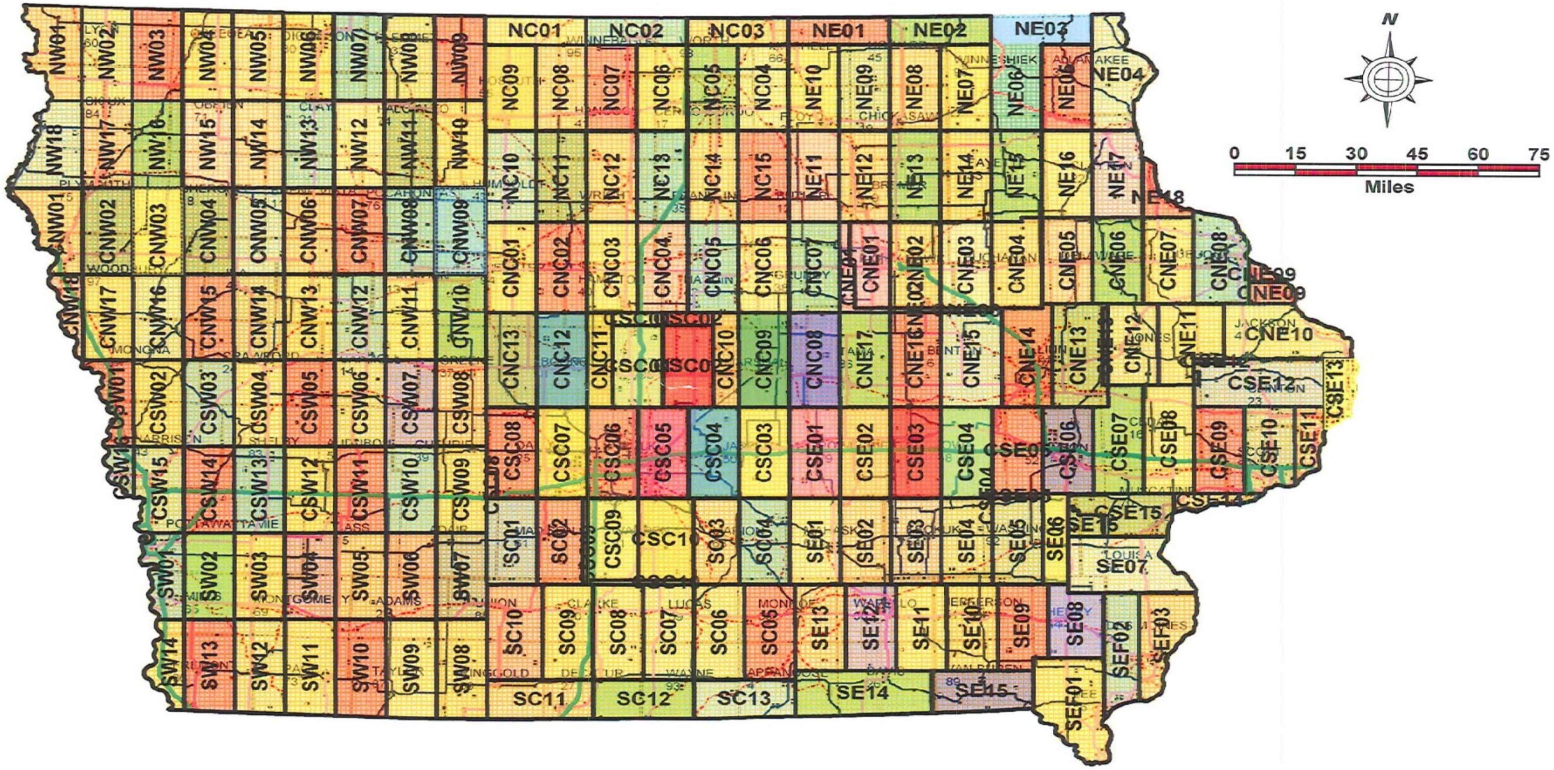
Conclusions From Flood Analysis

- Models disagree on magnitude of change
- Worse case scenario predicted is a doubling of Mean Annual Flood
- **Models agree on sharp transition in flood regimes** (artifact of datasets – Y2K Bug - or actual transition of a nonlinear system?)
- Magnitude of change in flood quantiles is similar to changes in the mean annual flood
- Initial analysis points to changes in extreme rainfall to explain changes in flood statistics

Iowa's Statewide LiDAR

- LiDAR – Light Detection and Ranging
  - Creates a ground surface
- Cooperative Effort Between Iowa DNR, Iowa DOT & Iowa Dept. of Agriculture
- USGS contract for statewide acquisition
  - Sanborn Map Company
  - LiDAR Accuracy
    - +/- 8" vertical
  - Cost = 8.5 Cents per Acre or $3.1 Million
  - Total Cost = $5.8 Million (inc. high resolution photography, processing, web access, etc

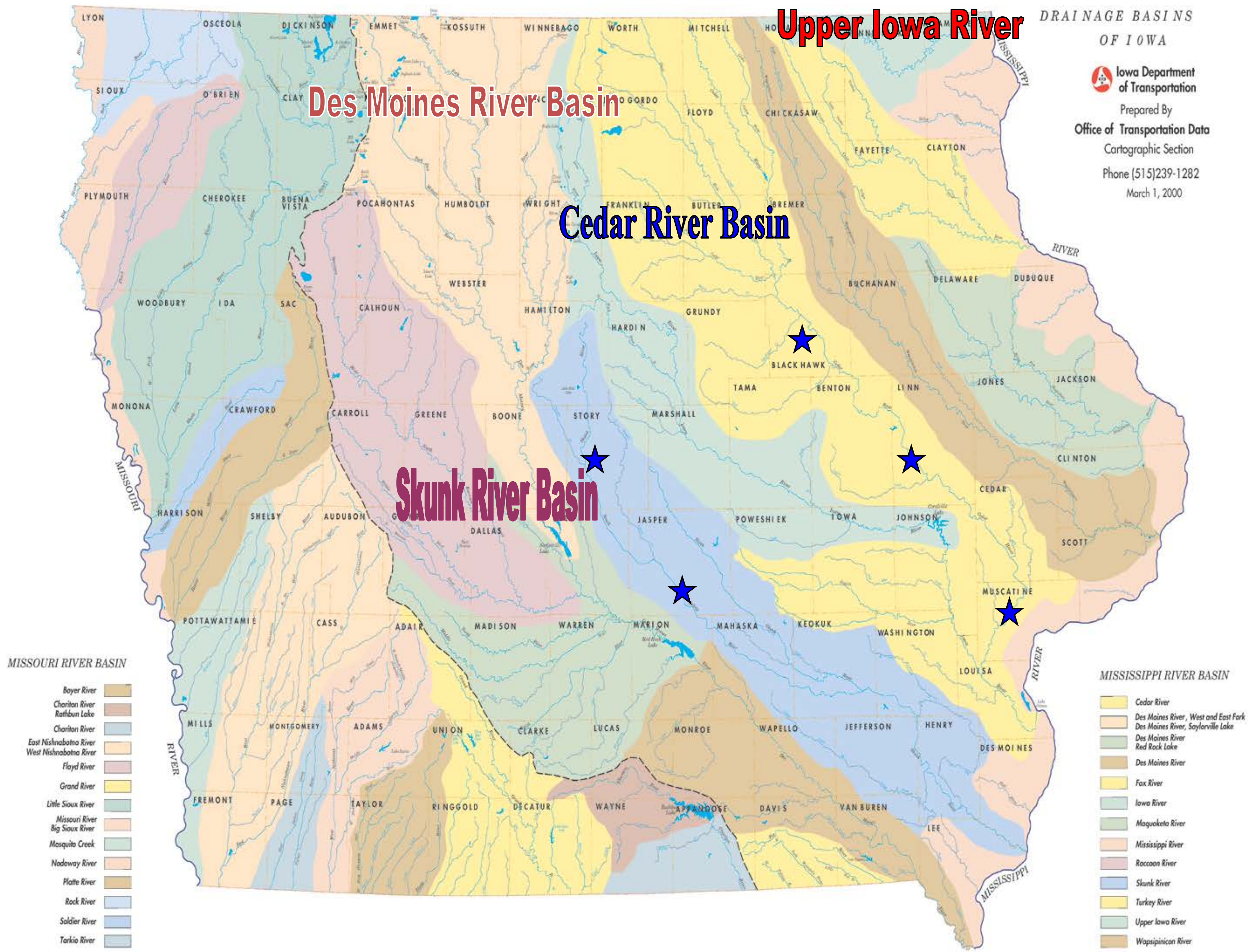
LiDAR Data Received
October 14, 2010



Data set is now complete.
New Tiles (LAS and XYZi formats):
CNC01, CNC02, CNC04, CNC05, CNC06, CNE10, CNE14, CNE02, CNE09, CNW02, CNW06, CNW07, CNW08, CSE11, CSE07, CSW14, NE18, NW10, NW11, NW12, NW07, SEF01 and SEF03

Legend

Iowa_Tiles

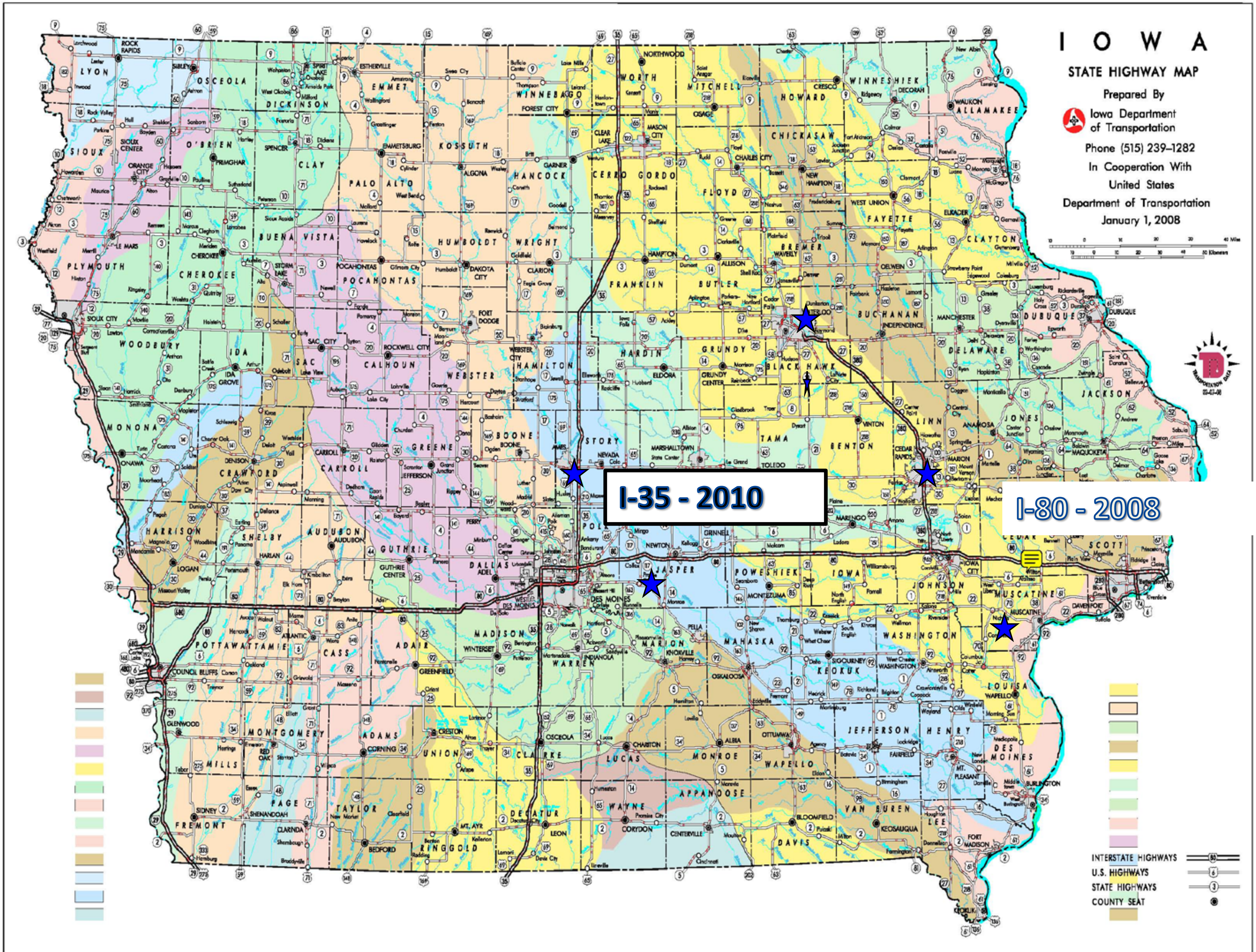


Upper Iowa River
DRAINAGE BASINS OF IOWA
Iowa Department of Transportation
Prepared By
Office of Transportation Data
Cartographic Section
Phone (515)239-1282
March 1, 2000
Des Moines River Basin
Cedar River Basin
Skunk River Basin
MISSOURI RIVER BASIN
Boyer River
Chariton River Rathbun Lake
Chariton River
East Nishnabotna River West Nishnabotna River
Floyd River
Grand River
Little Sioux River
Missouri River Big Sioux River
Mosquito Creek
Nodaway River
Platte River
Rock River
Soldier River
Tarkio River
MISSISSIPPI RIVER BASIN
Cedar River
Des Moines River, West and East Fork Des Moines River, Saylorville Lake
Des Moines River Red Rock Lake
Des Moines River
Fox River
Iowa River
Maquoketa River
Mississippi River
Raccoon River
Skunk River
Turkey River
Upper Iowa River
Wapsipinicon River
LYON
OSCEOLA
DICKINSON
EMMET
KOSSUTH
WINNEBAGO
WORTH
MITCHELL
SIOUX
O'BRIEN
CLAY
FLOYD
CHICKASAW
FAYETTE
CLAYTON
PLYMOUTH
CHEROKEE
BUENA VISTA
POCAHONTAS
HUMBOLDT
WRIGHT
FRANKLIN
BUTLER
BREMER
WEBSTER
BUCHANAN
DELAWARE
DUBUQUE
WOODBURY
IDA
SAC
CALHOUN
HAMILTON
GRUNDY
HARDIN
BLACK HAWK
MONONA
CRAWFORD
CARROLL
GREENE
BOONE
STORY
MARSHALL
TAMA
BENTON
LINN
JONES
JACKSON
CLINTON
CEDAR
HARRISON
SHELBY
AUDUBON
DALLAS
JASPER
POWESHIEK
IOWA
JOHNSON
SCOTT
MUSCATINE
POTTAWATTAMIE
CASS
ADAIR
MADISON
WARREN
MARION
MAHASKA
KEOKUK
WASHINGTON
LOUISA
MILLS
MONTGOMERY
ADAMS
UNION
CLARKE
LUCAS
MONROE
WAPELLO
JEFFERSON
HENRY
DES MOINES
FREMONT
PAGE
TAYLOR
RINGGOLD
DECATUR
WAYNE
APPANOOSE
DAVIS
VAN BUREN
LEE
MISSOURI RIVER
MISSISSIPPI RIVER

Flood Frequencies

- South Skunk River - Over 500 Yr. Flood in 2010
  - Previous Peak = 26,000 cfs
  - 2010 Flood = 36,000 cfs (38% increase)
  - Gage has 63 years of record

- Cedar River – 1.4 x 500 yr at Cedar Rapids
  - Gage has 110 years of record
  - Previous Peak – 86,000 cfs
  - 2008 Flood – 150,000 cfs

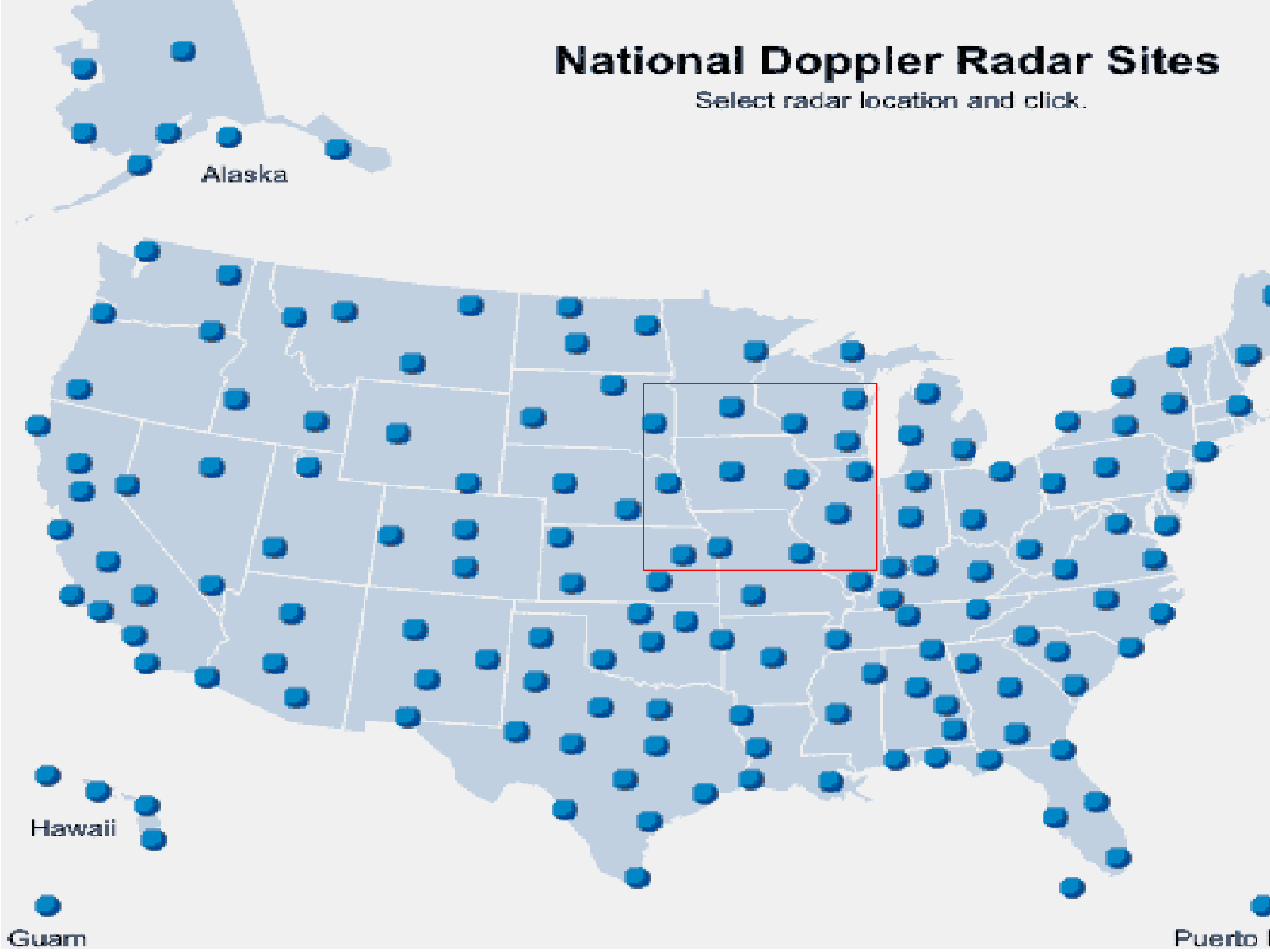


I-35 - 2010
I-80 - 2008
IOWA
STATE HIGHWAY MAP
Prepared By
Iowa Department of Transportation
Phone (515) 239-1282
In Cooperation With
United States
Department of Transportation
January 1, 2008
INTERSTATE HIGHWAYS
U.S. HIGHWAYS
STATE HIGHWAYS
COUNTY SEAT

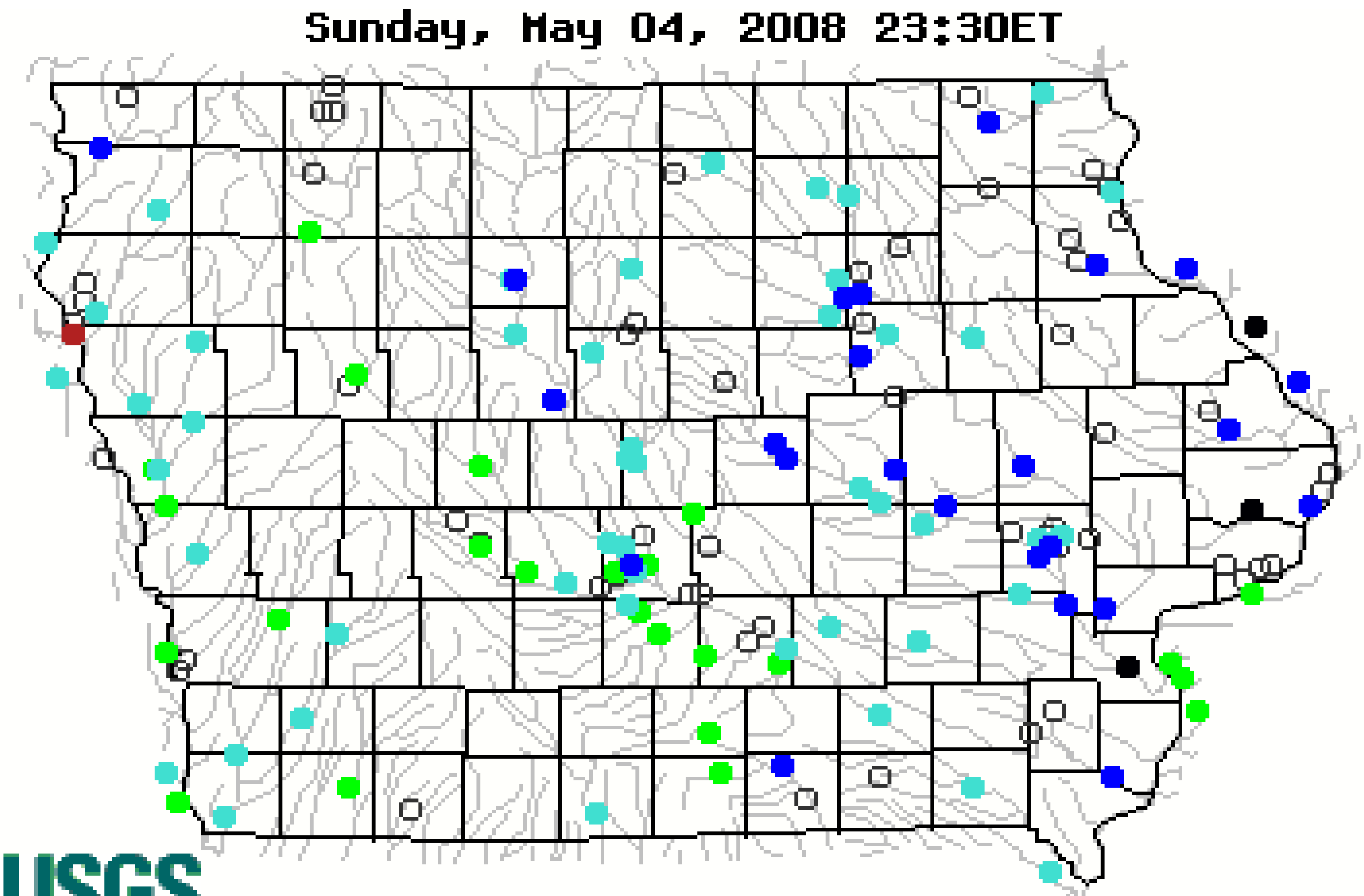
Infrastructure Database

- Develop/Correlate Rating Curve at Vulnerable Highway Sites
- Capture Low Road and Low Beam Elevations
- Utilize BridgeWatch to Proactively Protect Traveling Public from Roadway Overtopping

BridgeWatch


National Doppler Radar Sites
Select radar location and click.
Alaska
Hawaii
Guam
Puerto

Iowa has 148 USGS Stream Gauge Sites



USGS

THOUGHTS and NEXT STEPS

- The Range of Future Streamflow is Significant.
  - However, we need to acknowledge uncertainty for Climate and Hydrologic Modeling

- Should results be grouped by model rather than scenario?
  - Small sample, but streamflow (and rainfall) change appears to be Model specific rather than Scenario specific.

- Further analysis of rainfall metrics and peak streamflow
  - 3-day and 5-day consecutive dry and wet periods (frequency and amount for wet periods)

QUESTIONS?

Chris Anderson, ISU

Ricardo Mantilla, U of I

Dave Claman, Iowa DOT