Numerical Simulation of Local Intense Precipitation

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Plan

1. Extreme precipitation events in the USA
2. Modeling framework
3. Metrics used for model validation
4. Reconstruction of the intense Mesoscale Convective Systems (MCSs)
5. Reconstruction of the intense Tropical Cyclones (TCs)
6. Transposition of the intense TCs
7. Ongoing and future work

Classifications of extreme precipitation events in the USA

- Various classifications of extreme precipitation events in the literature

- In general, a distinction between tropical and non-tropical origin

- Classification proposed by Schumacher and Johnson (2005) and Stevenson and Schumacher (2014):

  ✓ Mesoscale Convective Systems: *convective systems with areal extents greater than 100 km and with durations between 3 and 24 h*

  ✓ Synoptic Systems: *events characterized by the strong large-scale ascent commonly associated with synoptic-scale features (e.g., extratropical cyclones) and/or events lasting longer than 24 h*

  ✓ Tropical Systems: hurricanes and events that are a direct result of a tropical cyclone or its remnants

Objective

Assess the suitability of a regional numerical weather model to

- Simulate local intense precipitation processes, such as MCSs and TCs
- Serve as a test bed for moisture maximization and storm transposition techniques, ultimately updating maximum precipitation estimates and quantifying uncertainty bounds

Selection of intense storms

- We selected 13 TCs and 14 MCSs which generated intense precipitation fields in the USA

  - Hurricane Floyd (1999)
  - Hurricane Isodore (2002)
  - Hurricane Frances (2004)
  - Hurricane Ivan (2004)
  - Hurricane Jeanne (2004)
  - Hurricane Ernesto (2006)
  - Tropical Storm Fay (2008)
  - Hurricane Gustav (2008)
  - Hurricane Irene (2011)
  - Tropical Storm Lee (2011)
  - Hurricane Isaac (2012)
  - Hurricane Sandy (2012)
  - Hurricane Matthew (2016)
  - June 22, 2002 MCS
  - August 22, 2002 MCS
  - September 15, 2004 MCS
  - June 25, 2005 MCS
  - August 17, 2005 MCS
  - September 25, 2005 MCS
  - July 18, 2007 MCS
  - August 19, 2007 MCS
  - June 5, 2008 MCS
  - August 8, 2009 MCS
  - July 23, 2010 MCS
  - September 23, 2010 MCS
  - July 28, 2011 MCS
  - June 22, 2013 MCS

- Intense precipitation events were identified using the website *http://schumacher.atmos.colostate.edu/precip_monitor/* from the Precipitation Systems Research Group in Colorado State University

- This website lists every event for which a given threshold (e.g. 100 year, 24 hour) was exceeded for at least one grid cell in the Stage IV precipitation analyses

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Modeling framework

• We used the Weather Research and Forecasting (WRF) model at 5-km resolution in order to reconstruct the intense precipitation fields

• Climate Forecast System Reanalysis (CFSR) was used for initial and boundary conditions. The provided spatial and temporal resolutions of CFSR are 0.5 x 0.5 degree and 6-hourly

• The WRF model was run in the offline mode: it was only subject to the influence of its initial and boundary conditions, and no observation was used to improve the simulations through nudging or other data assimilation techniques

Modeling framework

• The WRF model was configured to obtain satisfactory results for the simulation of each of the selected severe MCS and TC storm events with respect to the precipitation fields by trying different combinations of the parameterization schemes

- Microphysics
- Cumulus parameterization
- Planetary boundary layer
- Longwave radiation
- Shortwave radiation

• Validation of the WRF model in the offline mode is necessary for the purposes of the project

- Storm transposition (shifting)
- Downscaling of a climate projection from a GCM

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Validation of the results

The results of the WRF model were validated in two ways

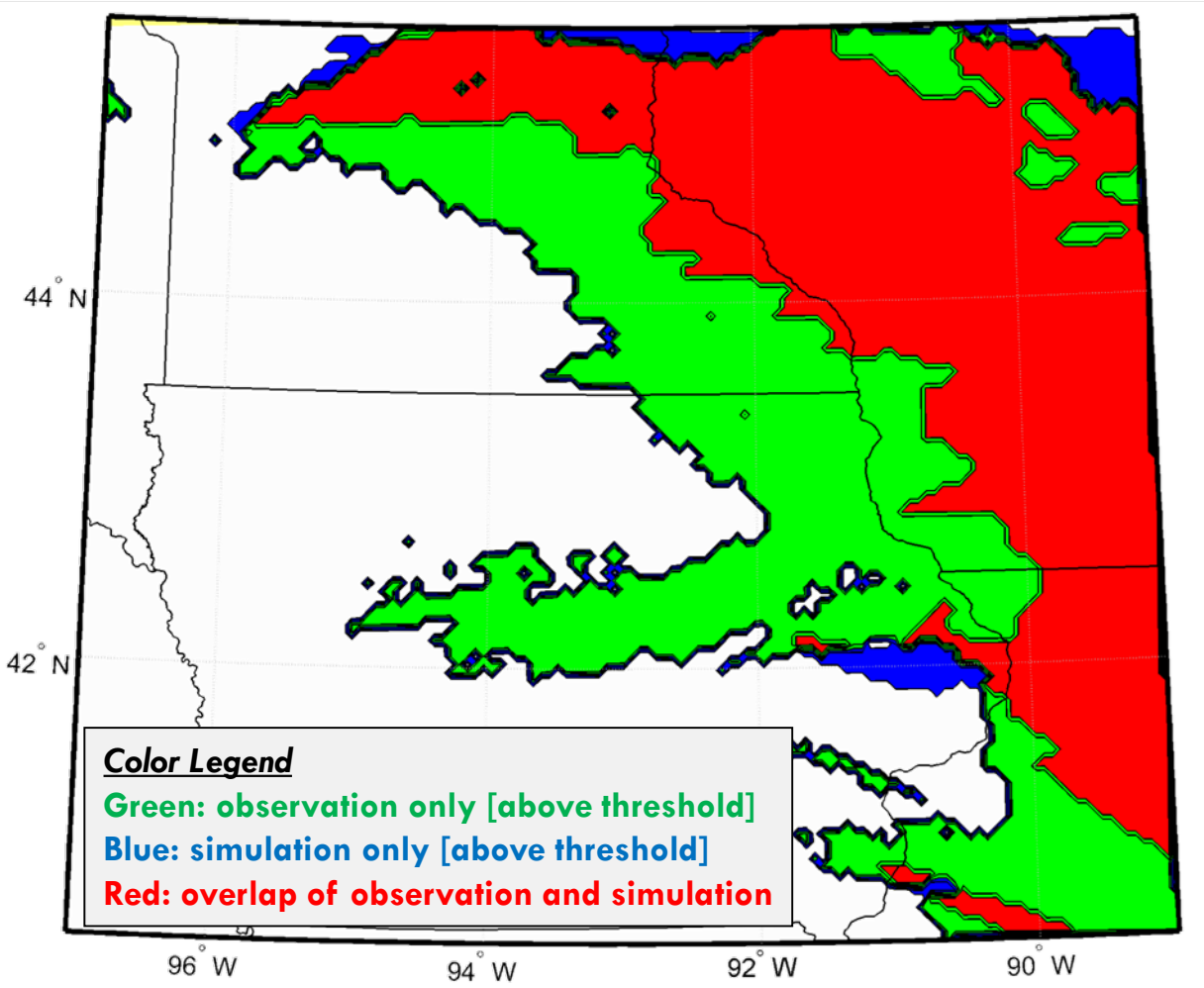
1. The observed and simulated precipitation fields were plotted in order to visually appreciate their similarities and differences, in terms of the fields' position, texture, and intensity

2. Three statistics were used to assess the model's performances
   A. Relative error: indicates if the model could adequately simulate the total precipitation depth over the period of interest

   B. Percentage of overlapping: indicates if the model could place the storm system in the appropriate location

   C. Precipitation field area ratio (PFAR): indicates if the model could properly simulate the size of the precipitation field

Percentage of Overlapping and Precipitation Field Area Ratio (PFAR)



Percentage of Overlapping

$$= \left(\frac{\text{red}}{\text{green} + \text{red}}\right) \times 100$$

$$= 54.8\%$$

PFAR

$$= \left(\frac{\text{blue} + \text{red}}{\text{green} + \text{red}}\right)$$

$$= 0.59$$

Best model performance when Percentage of Overlapping is close to 100% and PFAR is close to 1.

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Simulation domains for the Mesoscale Convective Systems

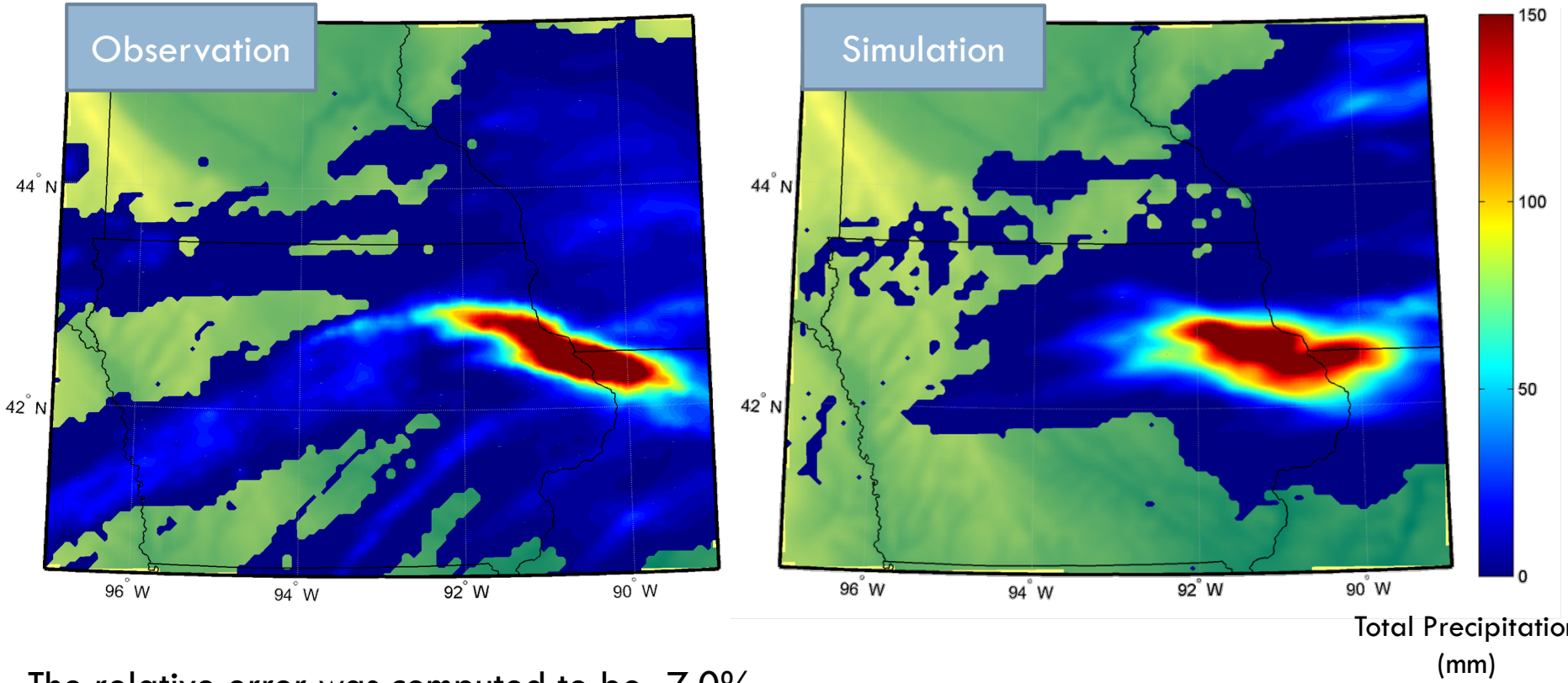
Two nested domains were set up for the WRF numerical simulation so that the inner domain covers an area where intense precipitation is frequently caused by Mesoscale Convective Systems

1. Domain 1 (purple) is the outer, parent domain. It has a resolution of 15 km (76 x 58)

2. Domain 2 (light blue) is the inner, nested domain. It has a resolution of 5 km (166 x 118)

July 28, 2011 Mesoscale Convective System

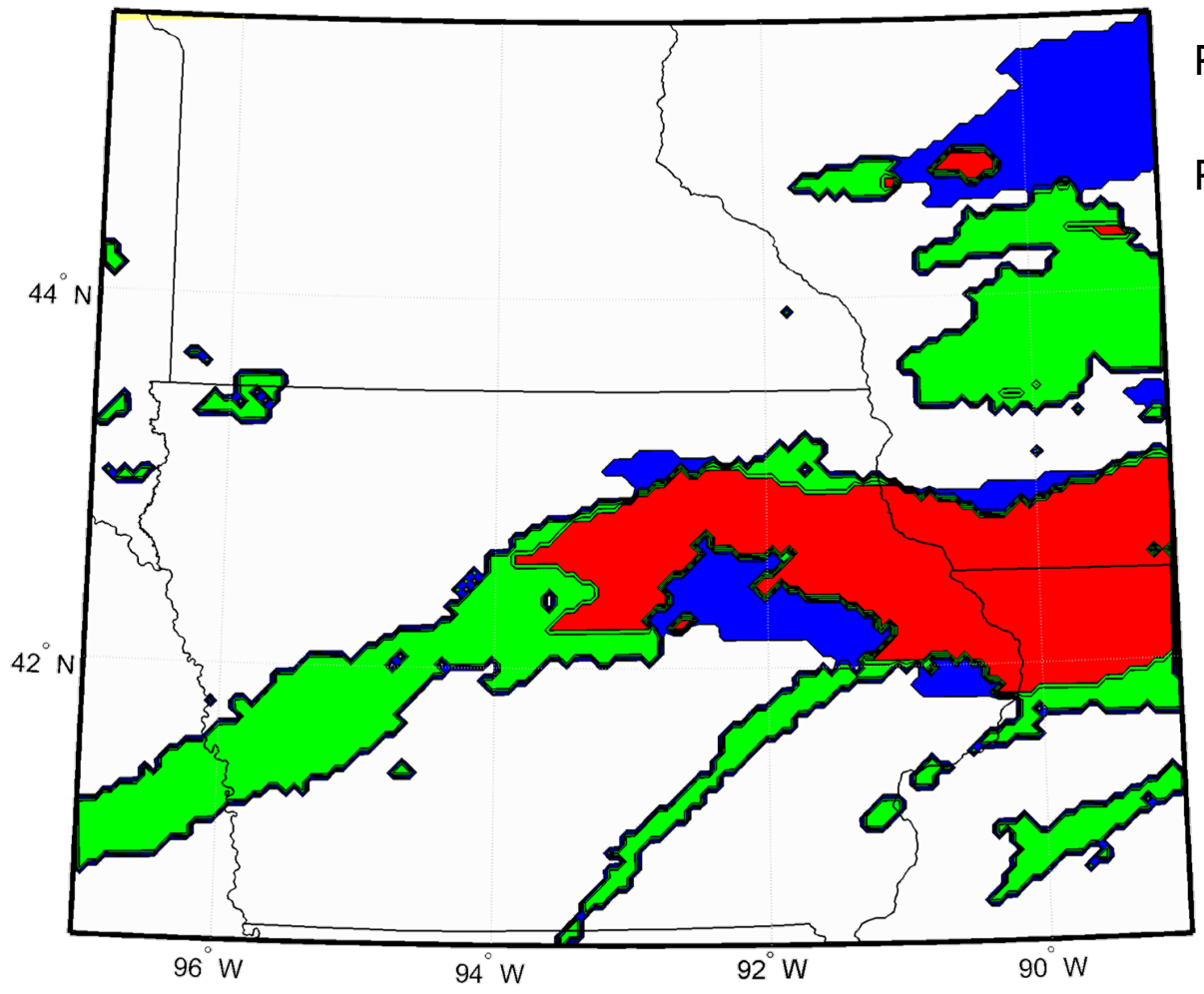
Total precipitation computed from
07/27/2011 at 15:00 to 07/28/2011 at 15:00



The relative error was computed to be -7.0%

July 28, 2011 Mesoscale Convective System

For the 75th percentile (9.09 mm)



Percentage of Overlapping = 42.5%

PFAR = 0.66

Color Legend

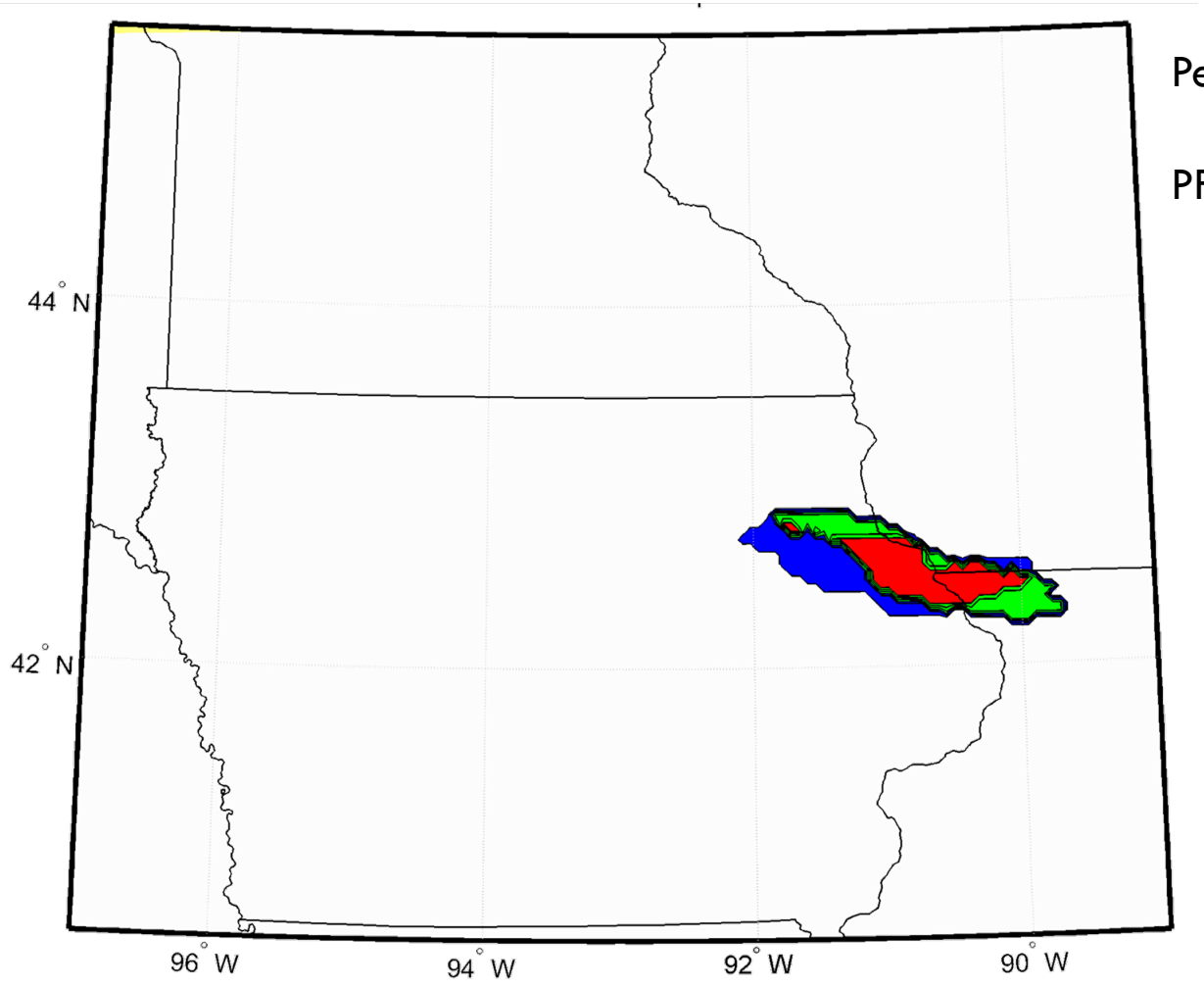
Green: observation only

Blue: simulation only

Red: overlap

July 28, 2011 Mesoscale Convective System

For the 99th percentile (132.63 mm)



Percentage of Overlapping = 61.7%

PFAR = 1.14

Color Legend

Green: observation only

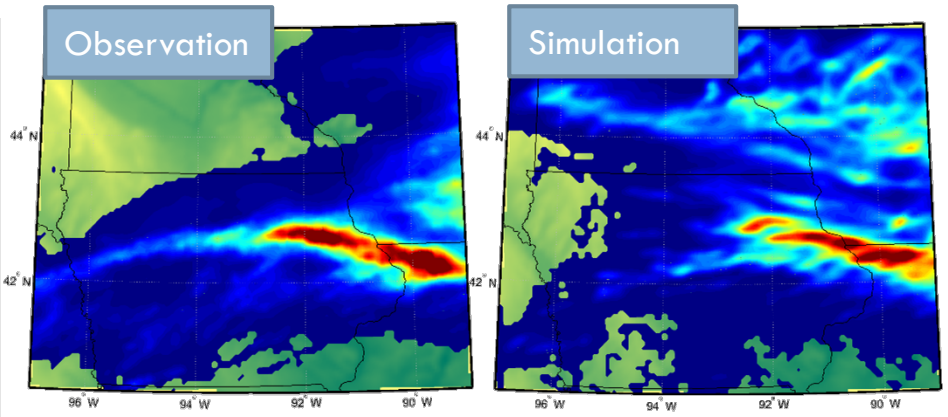
Blue: simulation only

Red: overlap

Overview of additional reconstructed Mesoscale Convective Systems

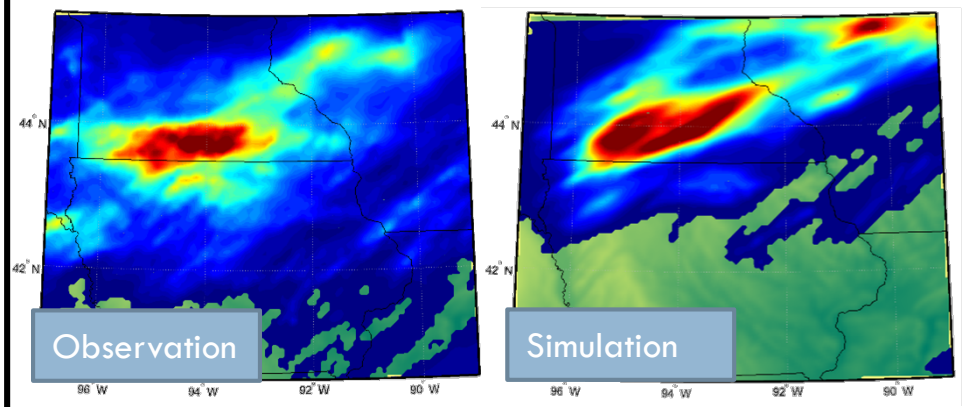
July 23, 2010 MCS

07/22/2010 at 18:00 to 07/23/2010 at 18:00



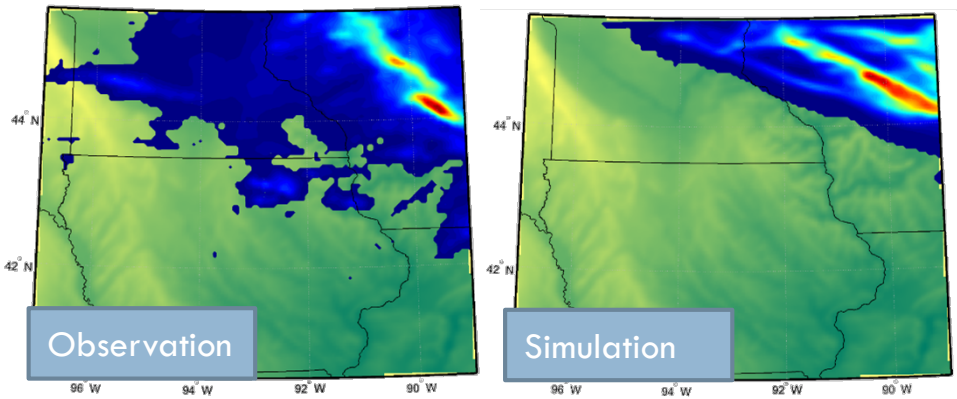
September 25, 2005 MCS

09/24/2005 at 21:00 to 09/25/2005 at 21:00



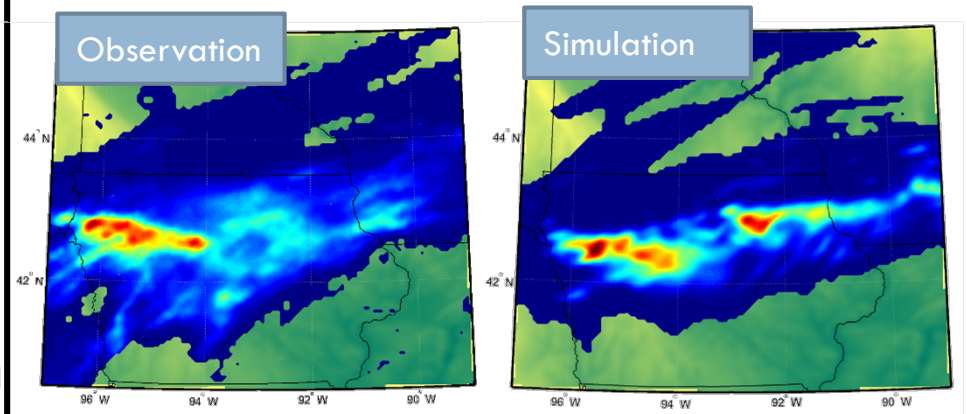
June 22, 2002 MCS

06/21/2002 at 19:00 to 06/22/2002 at 19:00



June 25, 2005 MCS

06/24/2005 at 18:00 to 06/25/2005 at 18:00



Reconstruction of intense Mesoscale Convective Systems

- Visually comparing the observation and simulation figures shows that the MCSs simulated by the WRF model are quite similar in shape, texture, and location to the MCSs shown on their corresponding observation figures

- The three statistics computed for each event also revealed that the WRF model simulated the total precipitation depth, the location of the storm, and the field size adequately well for all the MCSs

- The WRF model was capable of reproducing all the selected intense MCSs very well under the appropriate model parameterization schemes

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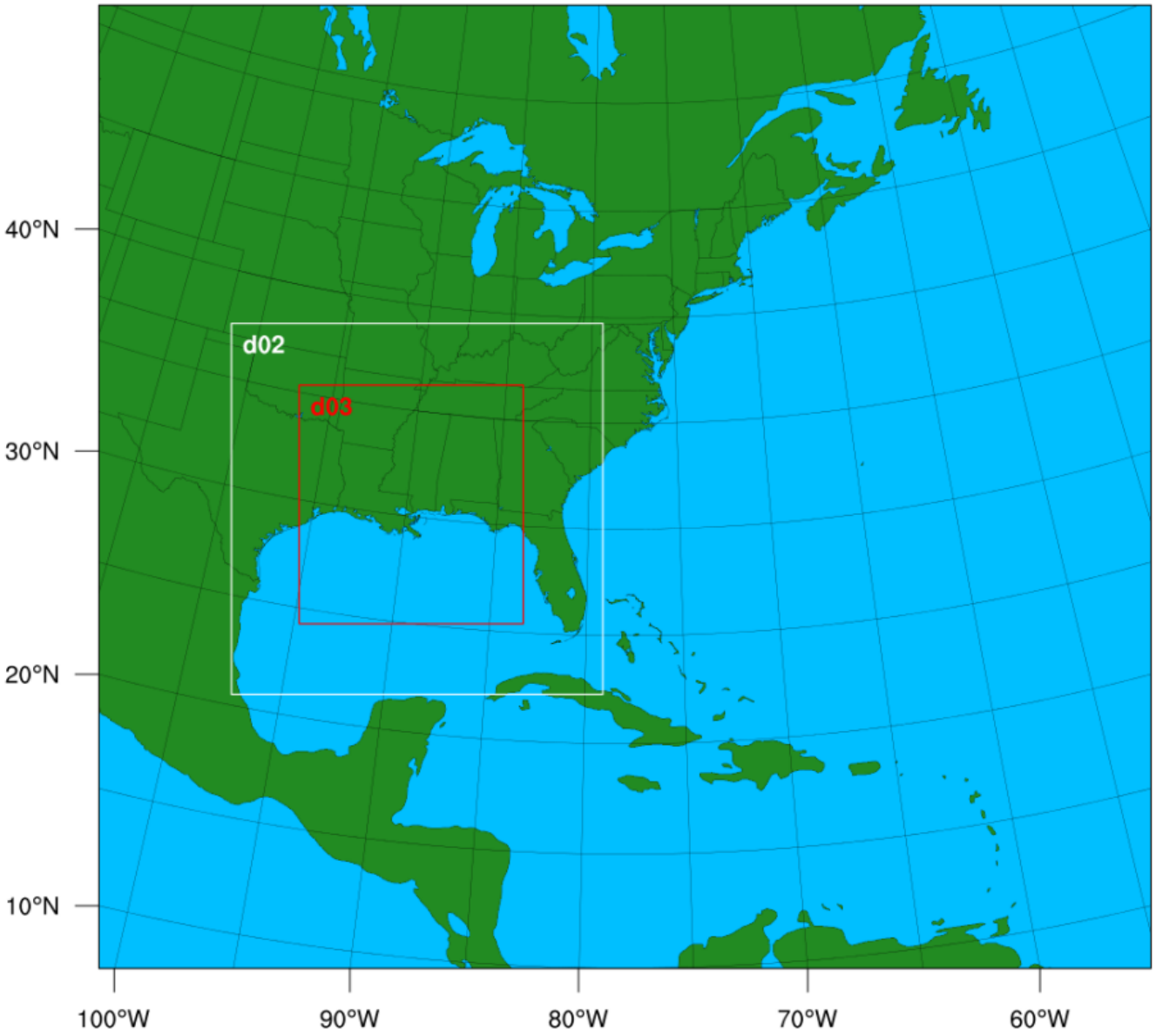
Simulation nested domains for Hurricane Isaac (2012)



- Domain 1 (same for all storms):

45 km resolution
120 x 110

- Domain 2:

15 km resolution
127 x 127

- Domain 3:

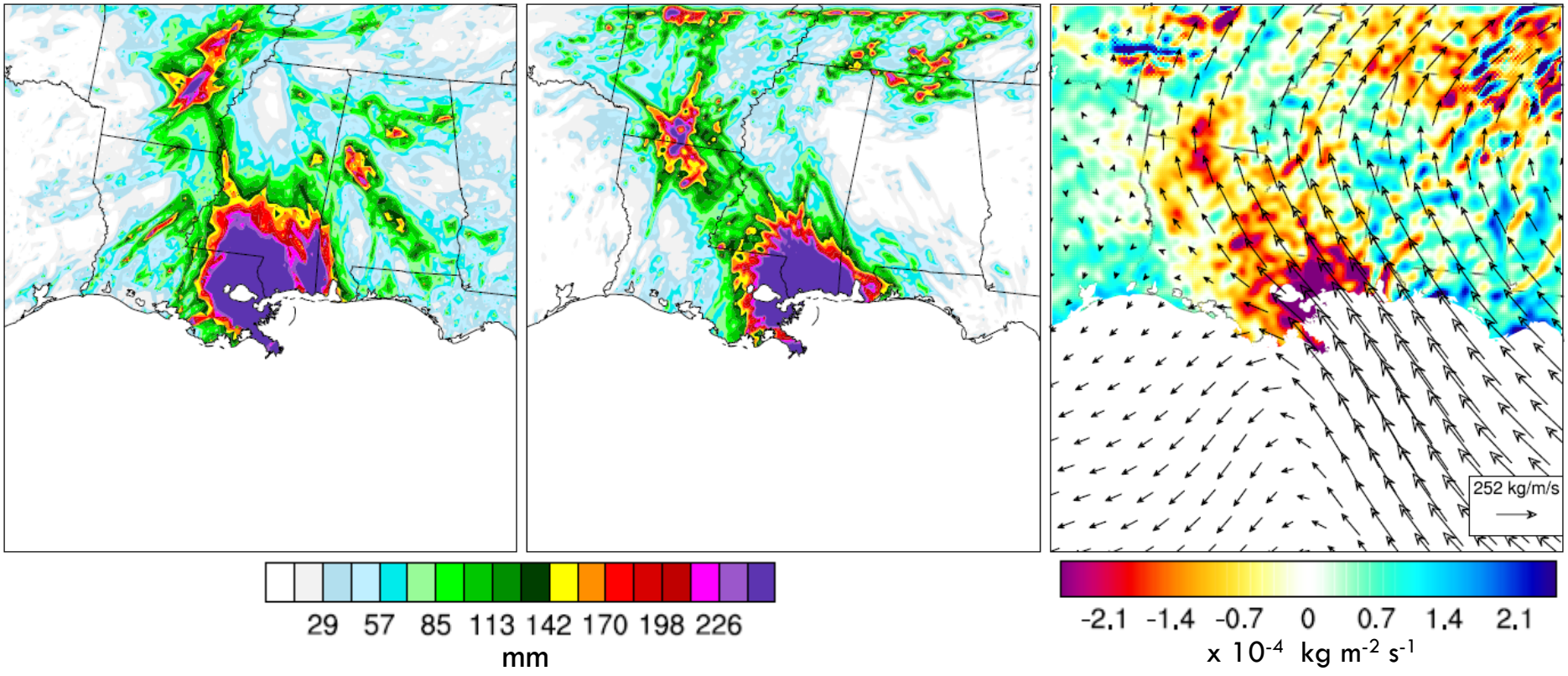
5 km resolution
229 x 244

Hurricane Isaac (2012)

Observed precipitation field

Simulated precipitation field

IVT and its divergence



	50th percentile		75th percentile		90th percentile		95th percentile		97.5th percentile		99th percentile	
Relative Error	% overlap	PFAR	% overlap	PFAR	% overlap	PFAR	% overlap	PFAR	% overlap	PFAR	% overlap	PFAR
-13%	56%	0.87	49%	0.94	53%	0.84	56%	0.72	40%	0.79	26%	1.27

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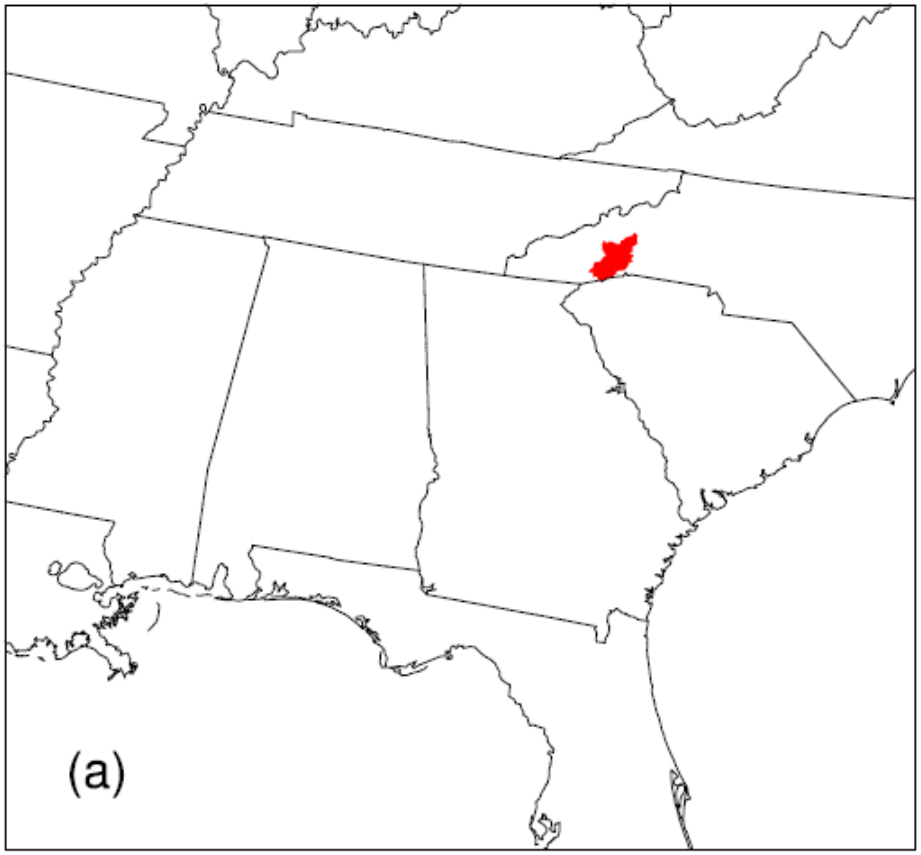
Storm transposition of Tropical Cyclones

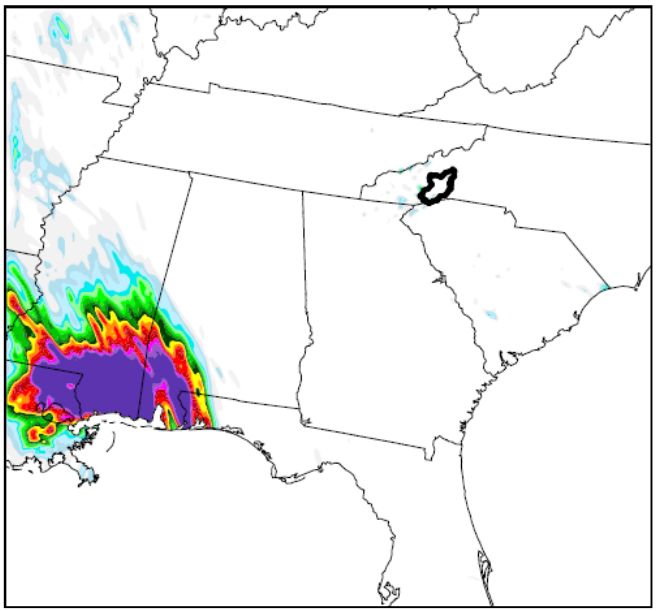
- We developed a new fully physically based method for the storm transposition (i.e. shifting) of TCs.

- The objective of this method is to find the amount of shift which maximizes the precipitation depth over a given target area.

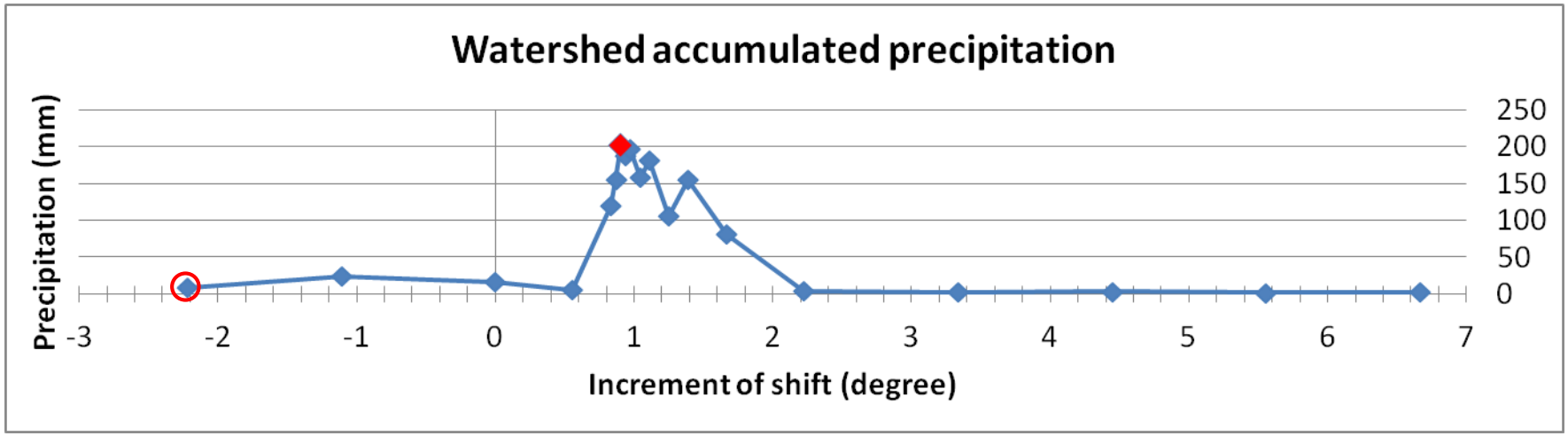
- It uses a regional atmospheric model (RAM) to numerically simulate a TC and its precipitation field. As a result, it has the fundamental advantage of conserving the mass, momentum, and energy in the system since the RAM numerically solves the equations governing the conservation of these quantities.

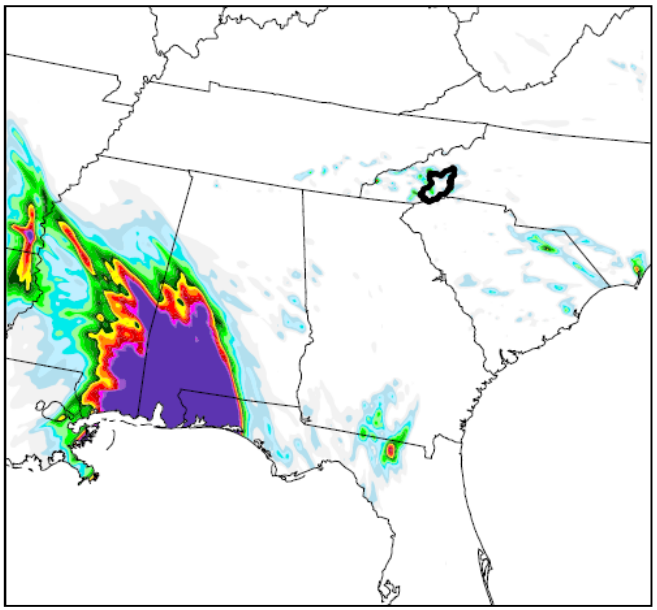
Target area



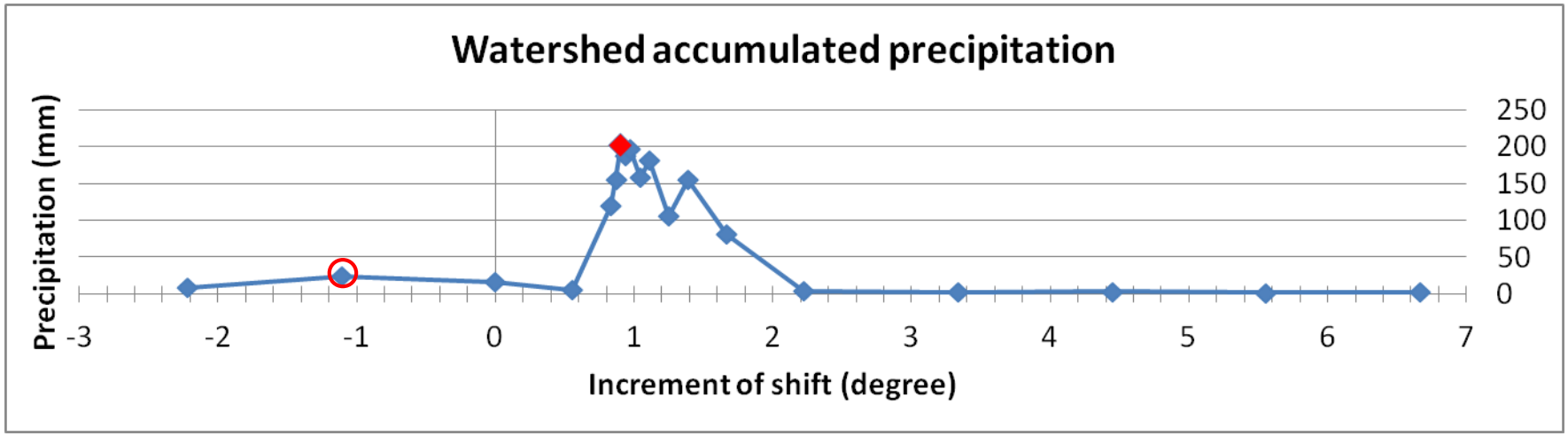


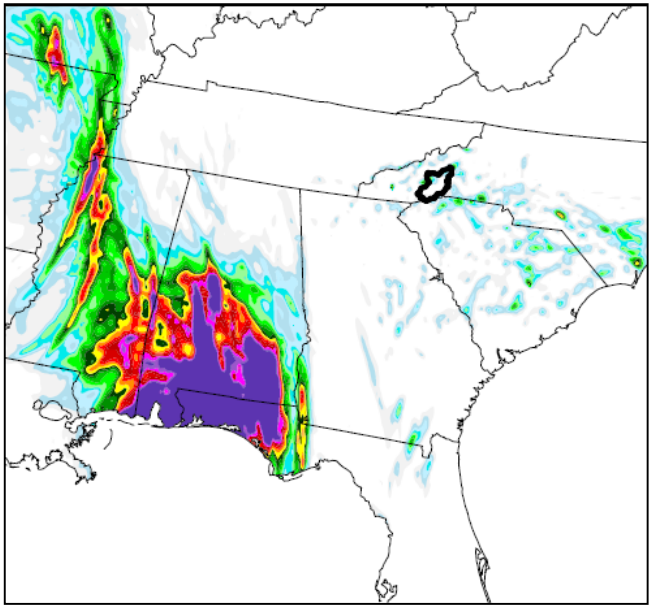
Precipitation	8 mm
WE Shift	-1.57 degrees
SN Shift	-1.57 degrees
Start Date	08/29 21h
End Date	09/01 21h



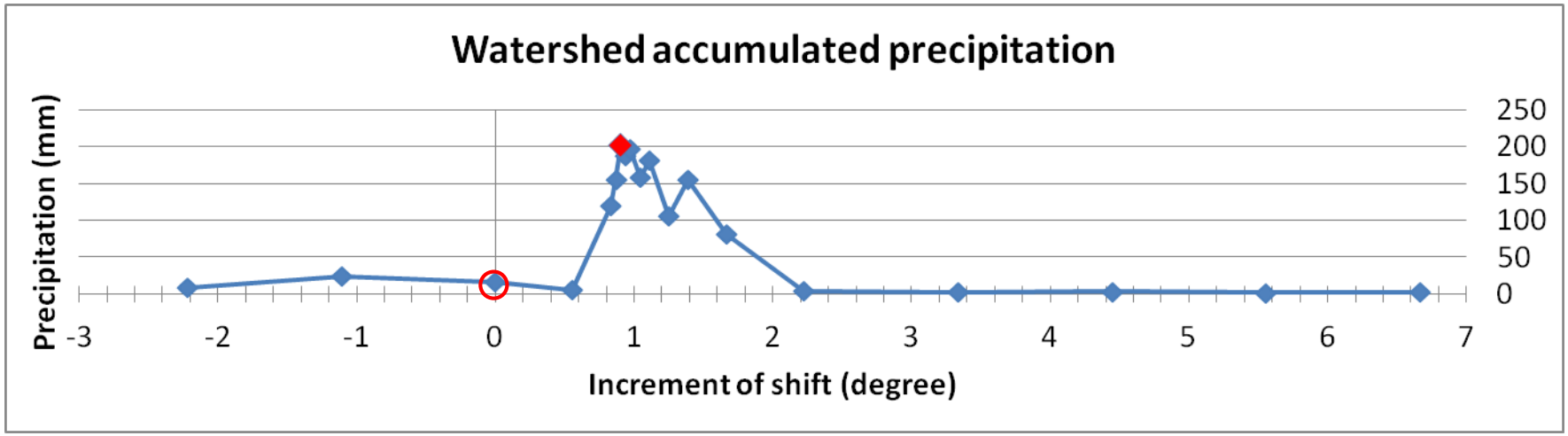


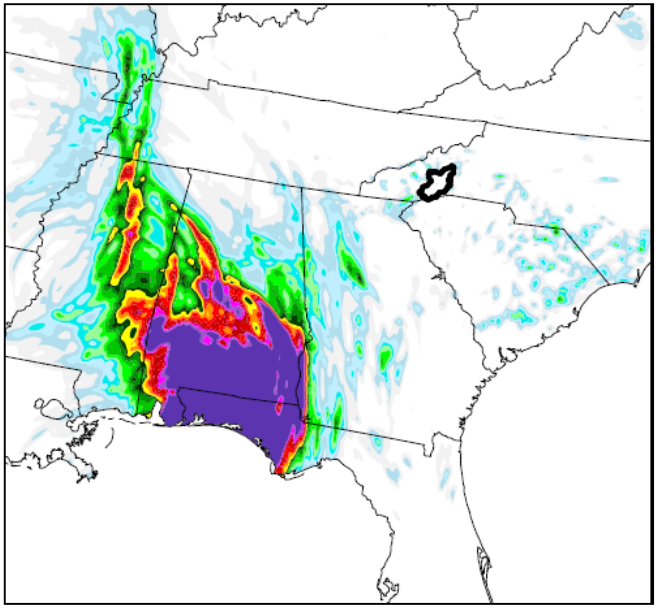
Precipitation	24 mm
WE Shift	-0.79 degrees
SN Shift	-0.79 degrees
Start Date	08/28 17h
End Date	08/31 17h



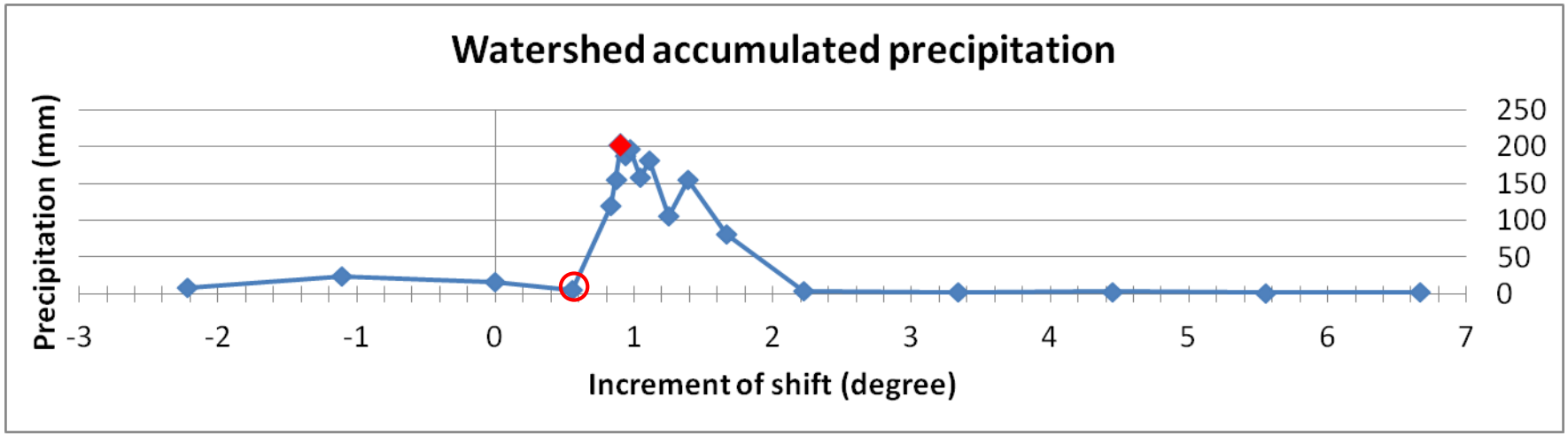


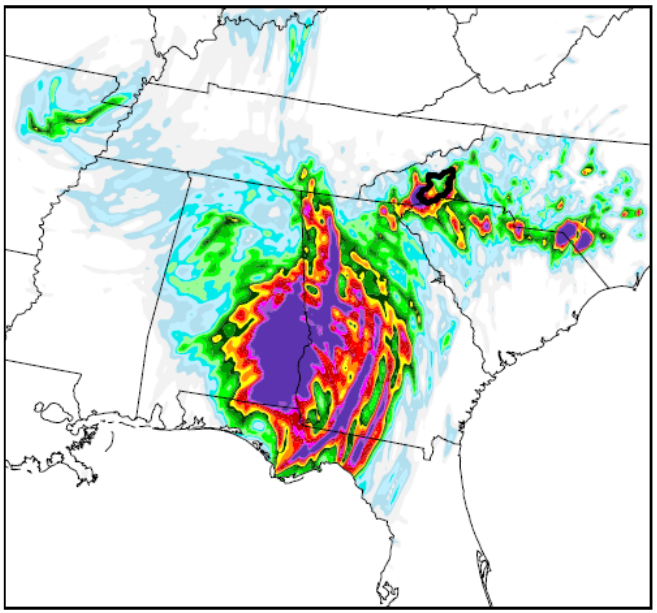
Precipitation	16 mm
WE Shift	0 degrees
SN Shift	0 degrees
Start Date	08/29 03h
End Date	09/01 03h



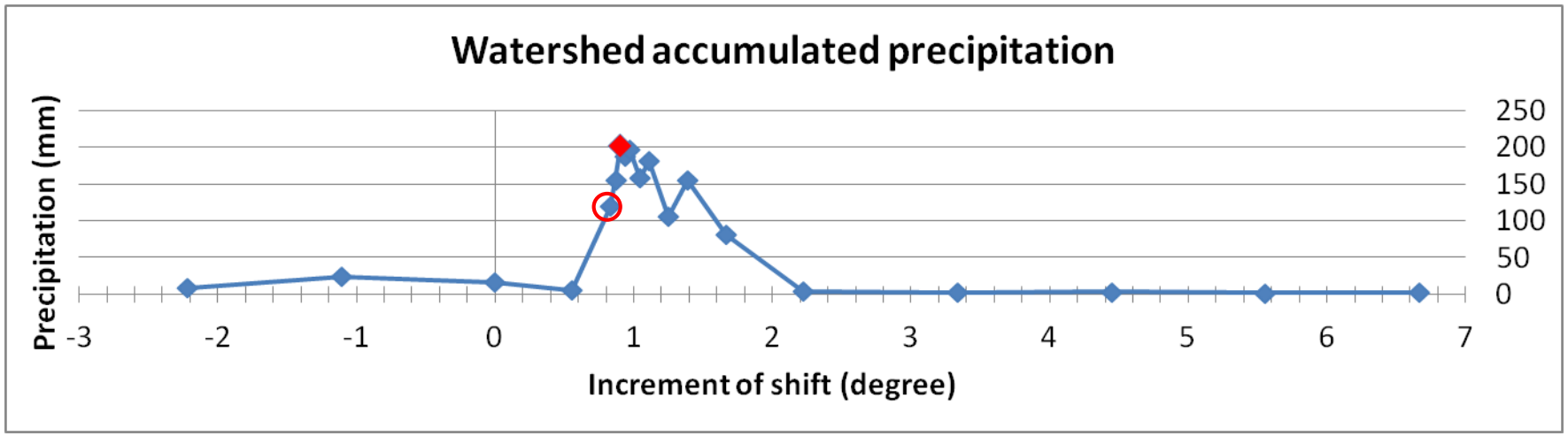


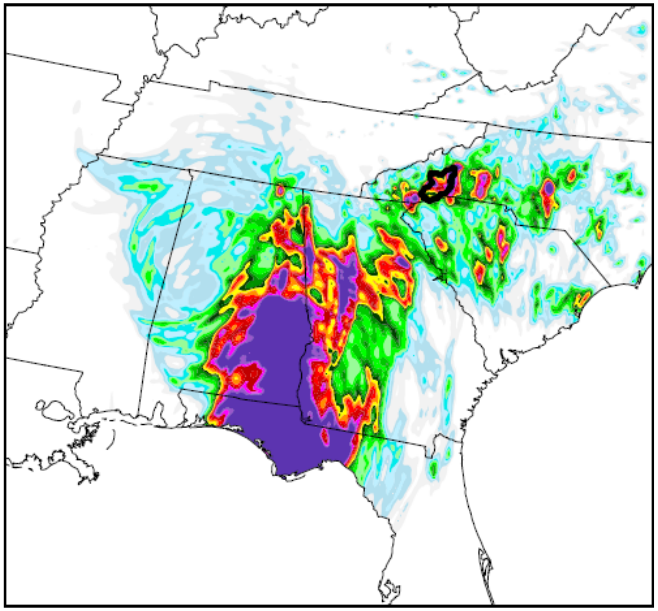
Precipitation	6 mm
WE Shift	0.39 degrees
SN Shift	0.39 degrees
Start Date	08/28 22h
End Date	08/31 22h



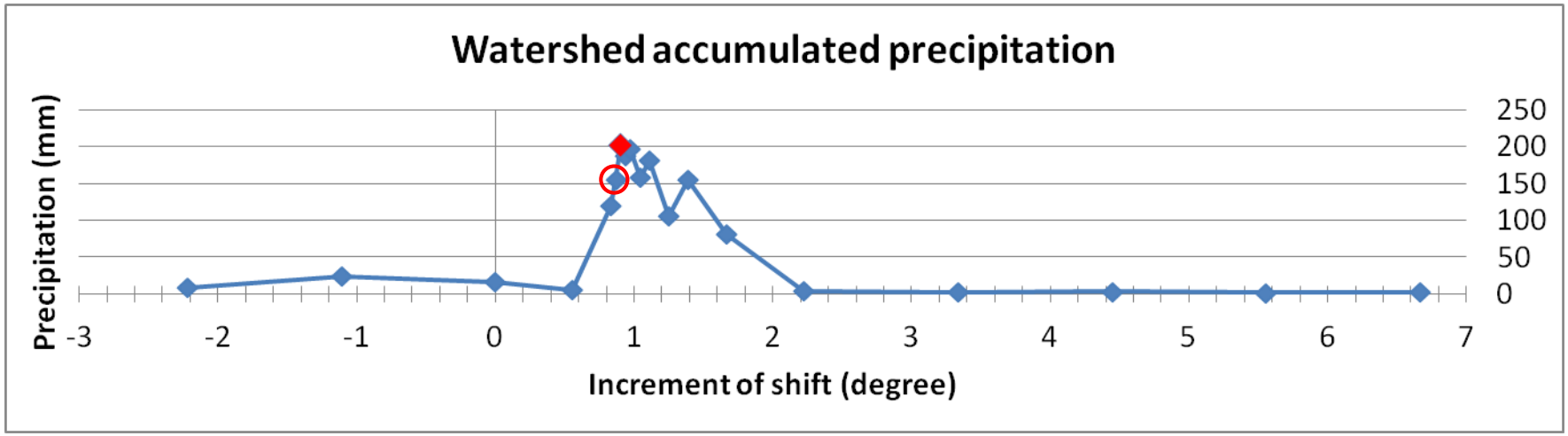


Precipitation	119 mm
WE Shift	0.59 degrees
SN Shift	0.59 degrees
Start Date	08/29 11h
End Date	09/01 11h

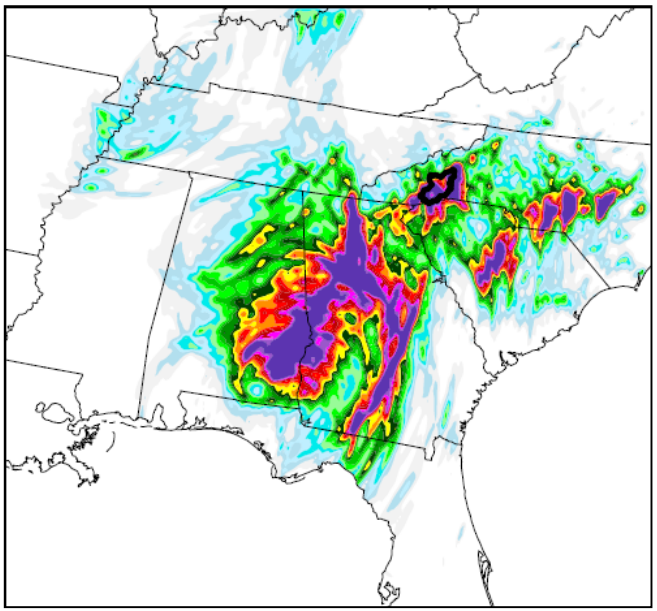




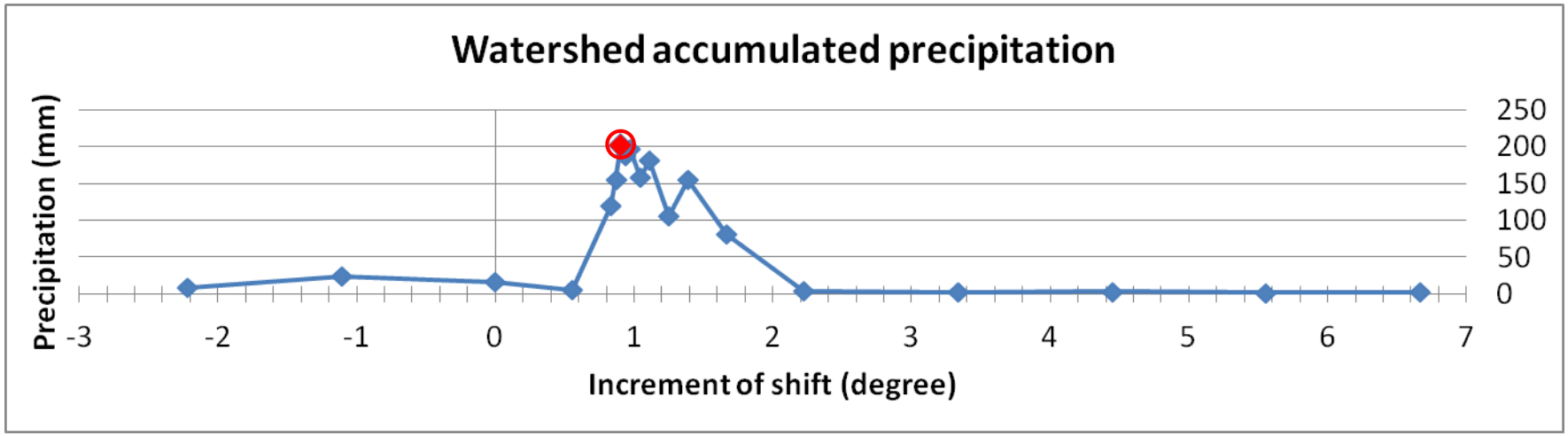
Precipitation	155 mm
WE Shift	0.61 degrees
SN Shift	0.61 degrees
Start Date	08/28 16h
End Date	08/31 16h

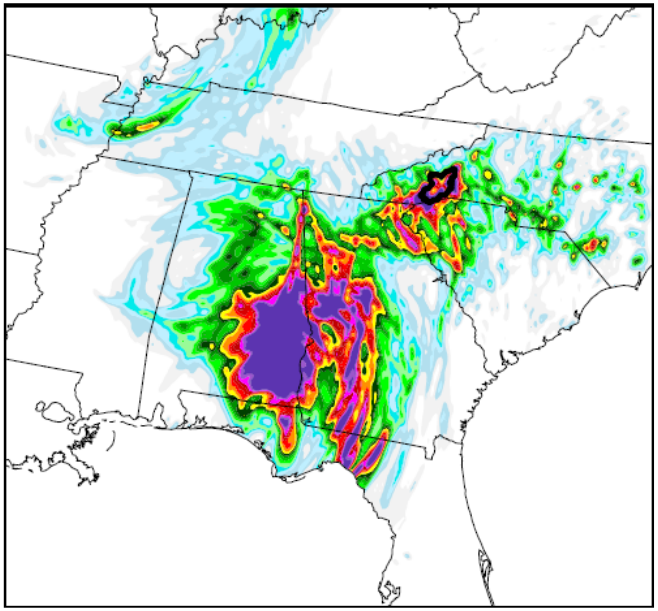


"Maximum"

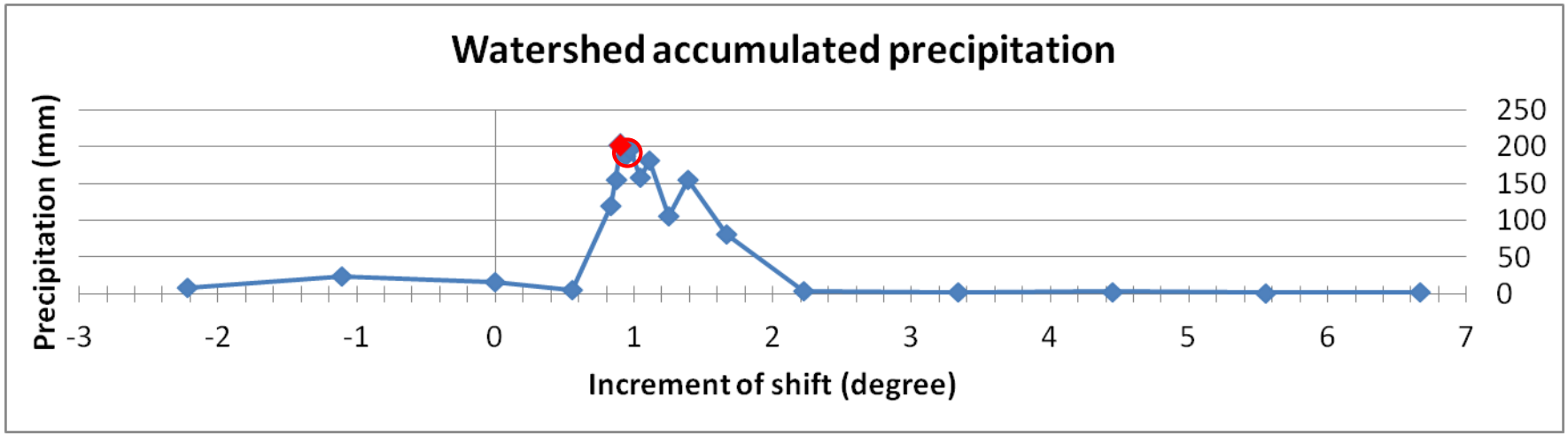


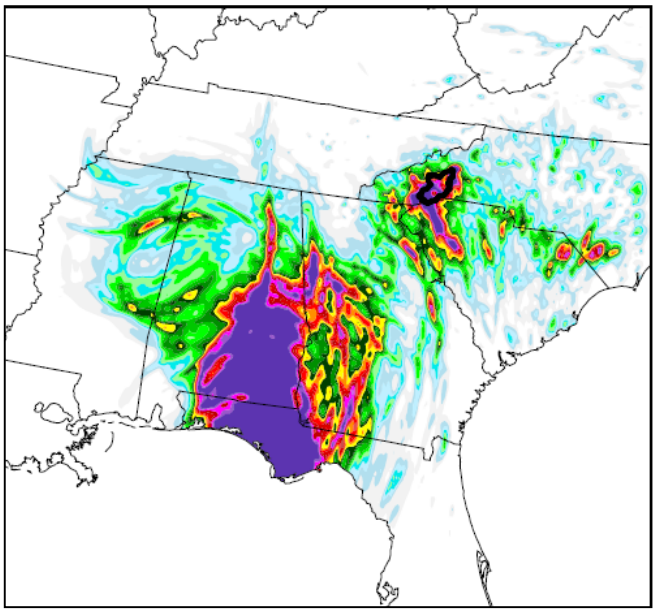
Precipitation	202 mm
WE Shift	0.64 degrees
SN Shift	0.64 degrees
Start Date	08/29 12h
End Date	09/01 12h



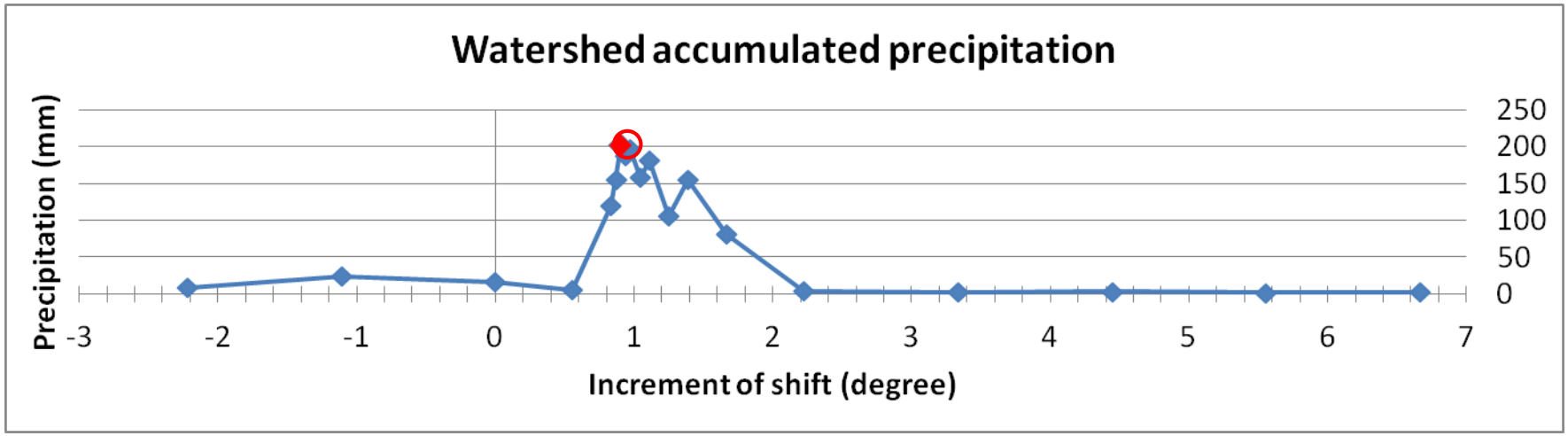


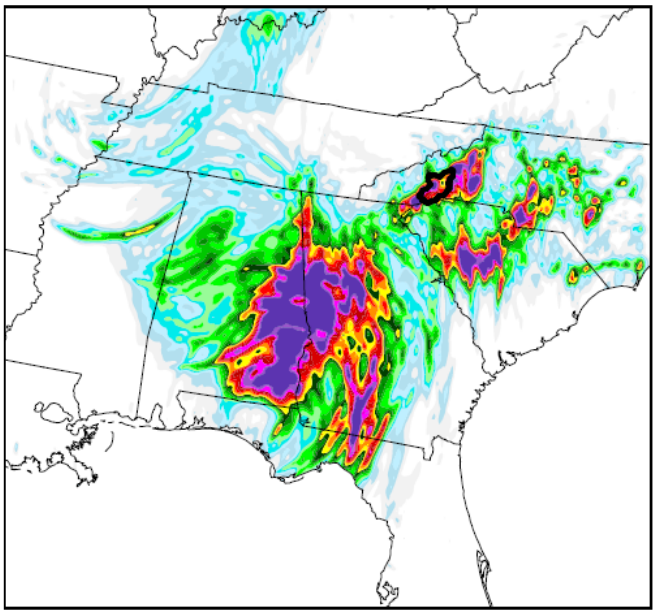
Precipitation	188 mm
WE Shift	0.66 degrees
SN Shift	0.66 degrees
Start Date	08/29 12h
End Date	09/01 12h



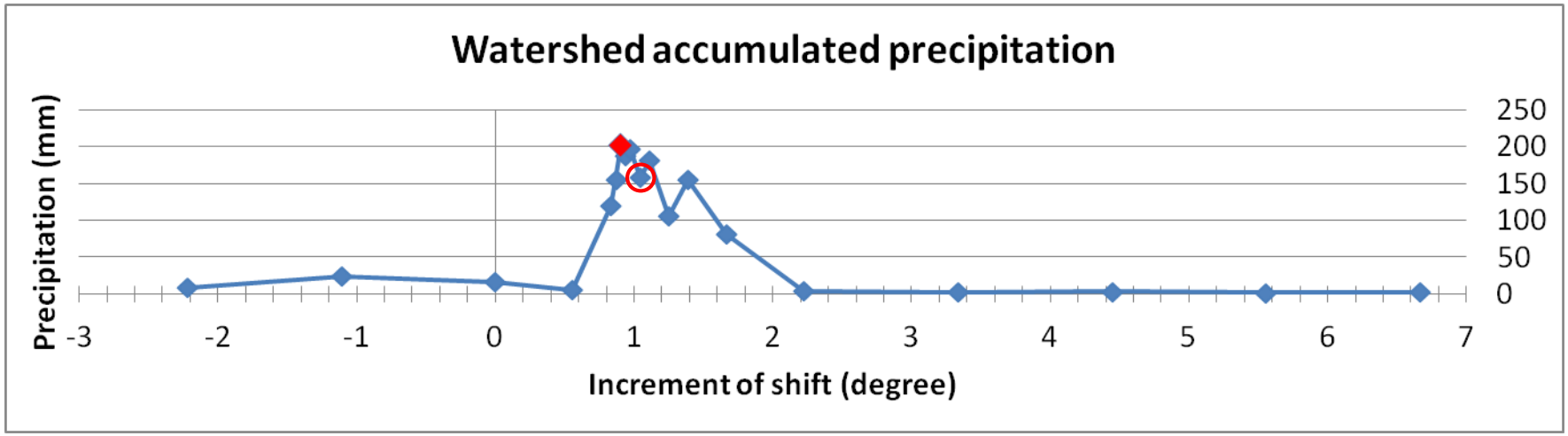


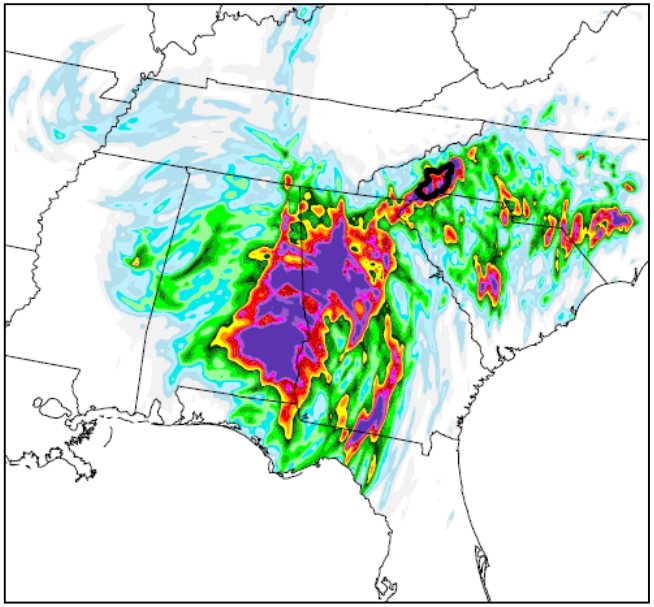
Precipitation	197 mm
WE Shift	0.69 degrees
SN Shift	0.69 degrees
Start Date	08/28 17h
End Date	08/31 17h



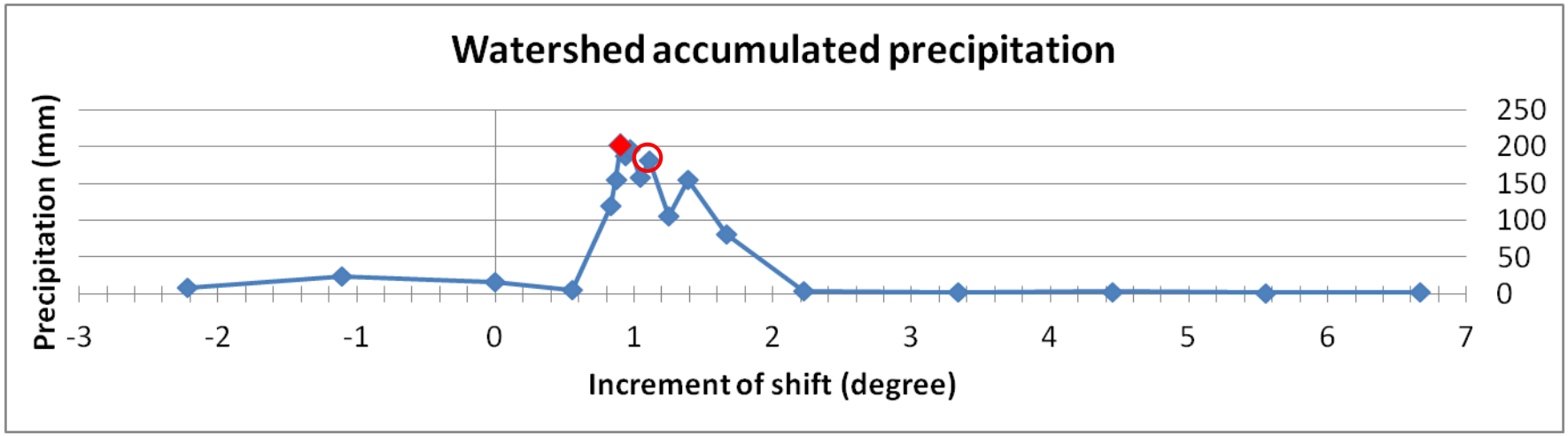


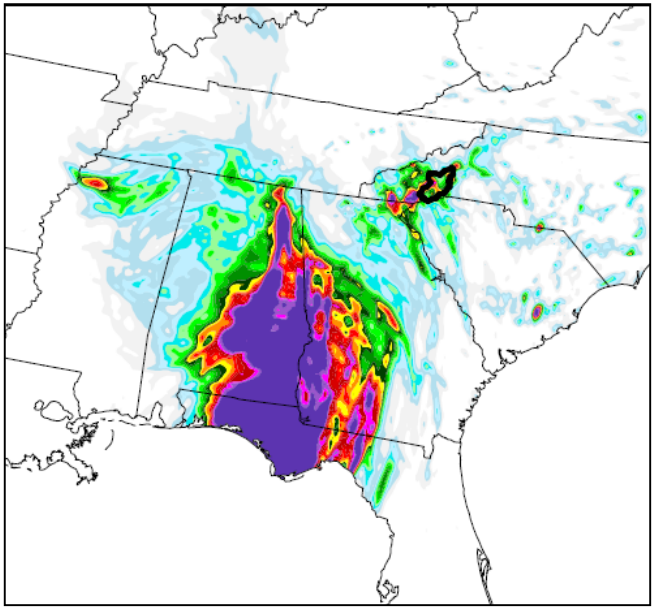
Precipitation	158 mm
WE Shift	0.74 degrees
SN Shift	0.74 degrees
Start Date	08/29 12h
End Date	09/01 12h



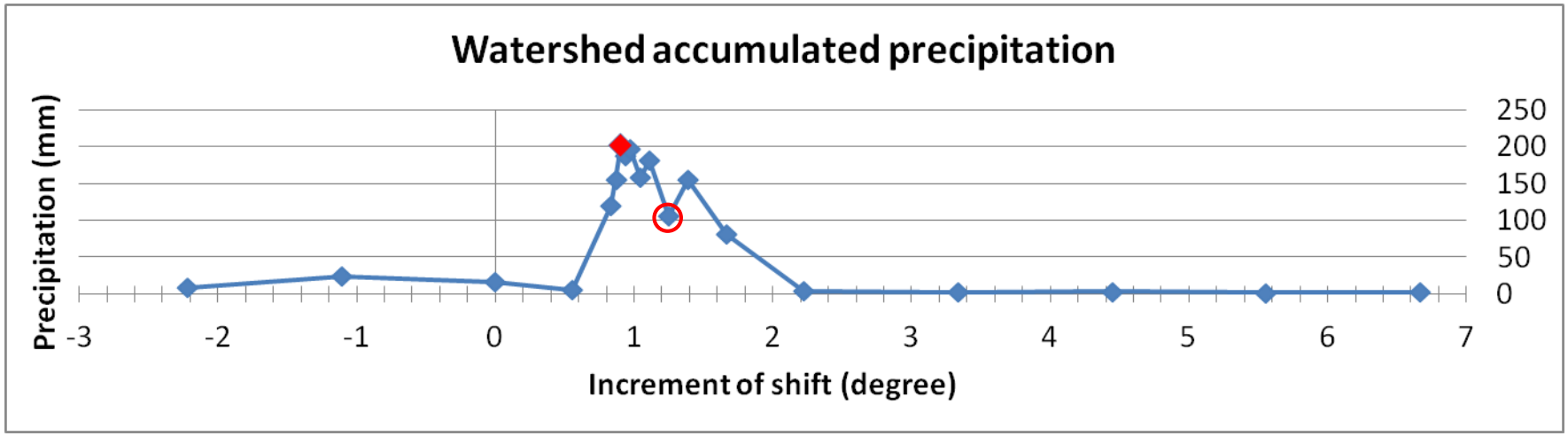


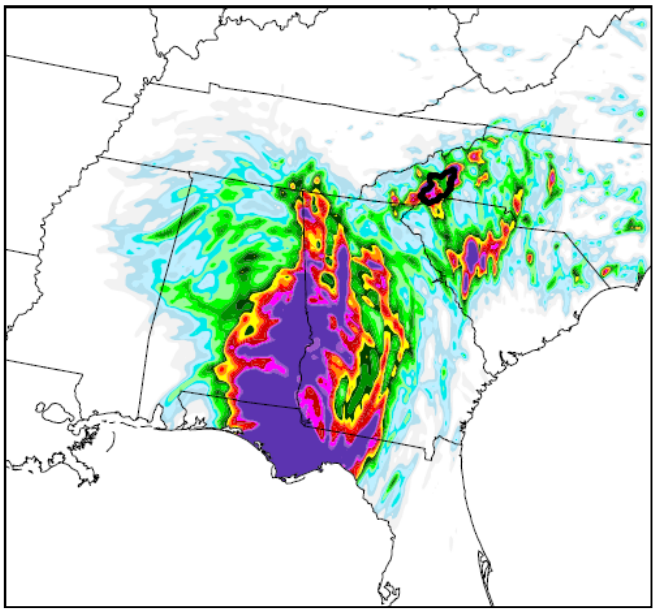
Precipitation	181 mm
WE Shift	0.79 degrees
SN Shift	0.79 degrees
Start Date	08/29 08h
End Date	09/01 08h



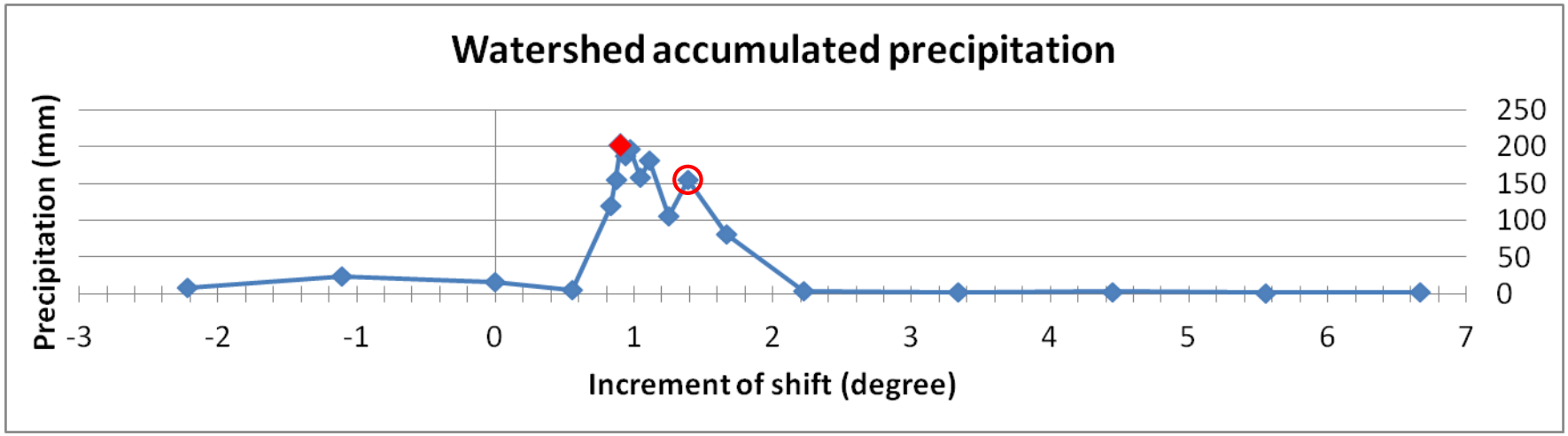


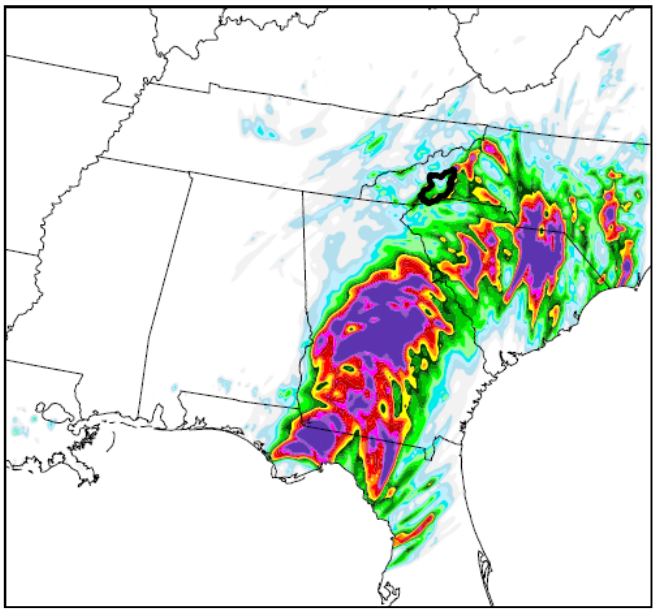
Precipitation	106 mm
WE Shift	0.88 degrees
SN Shift	0.88 degrees
Start Date	08/28 16h
End Date	08/31 16h



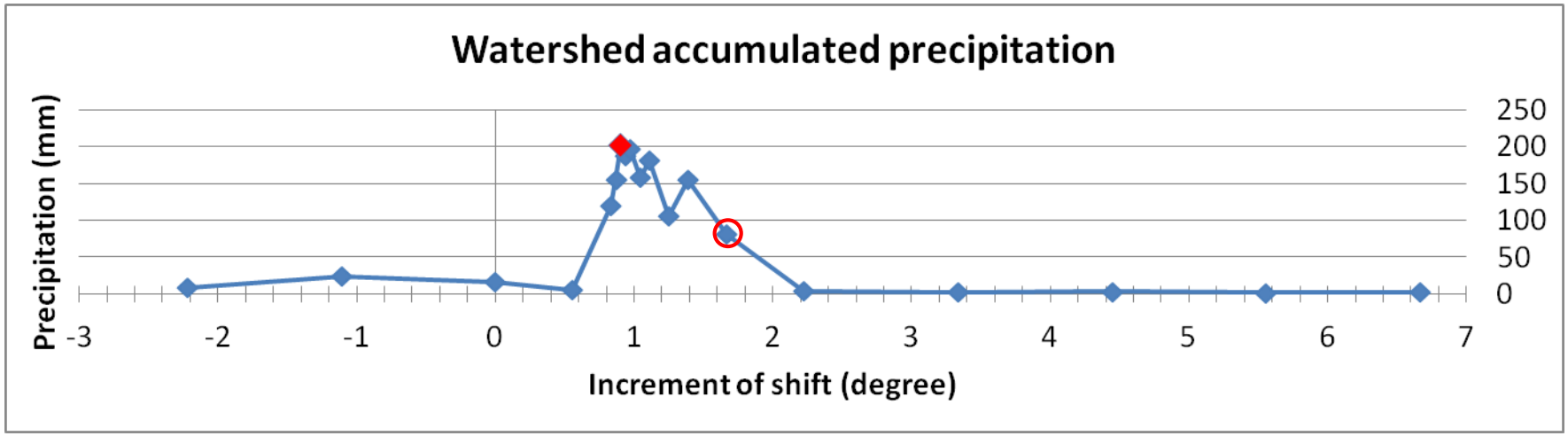


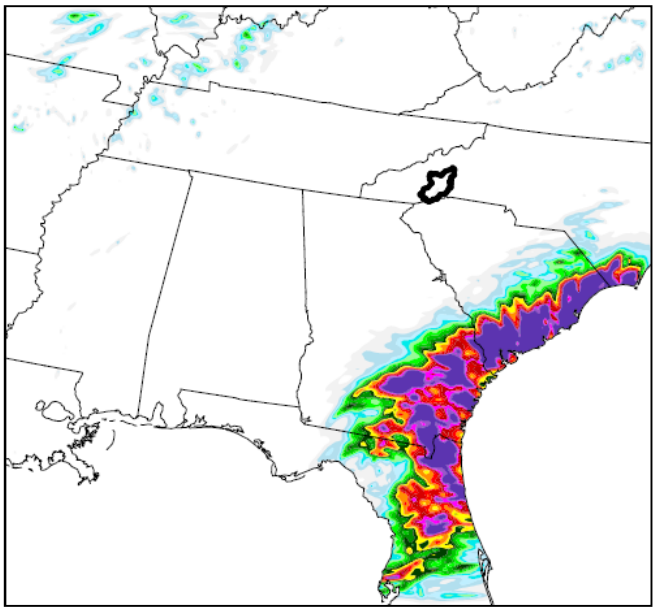
Precipitation	155 mm
WE Shift	0.98 degrees
SN Shift	0.98 degrees
Start Date	08/28 17h
End Date	08/31 17h



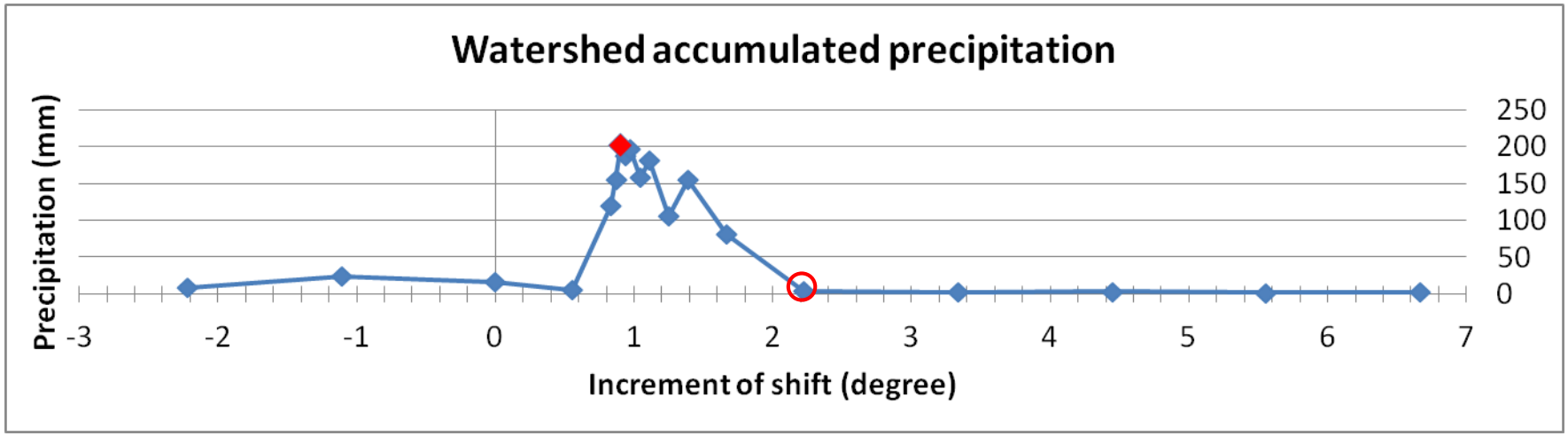


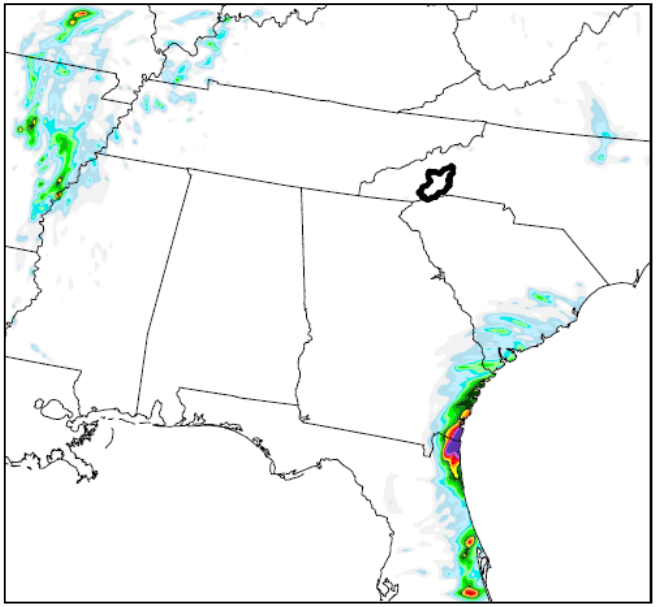
Precipitation	80 mm
WE Shift	1.18 degrees
SN Shift	1.18 degrees
Start Date	08/29 02h
End Date	09/01 02h



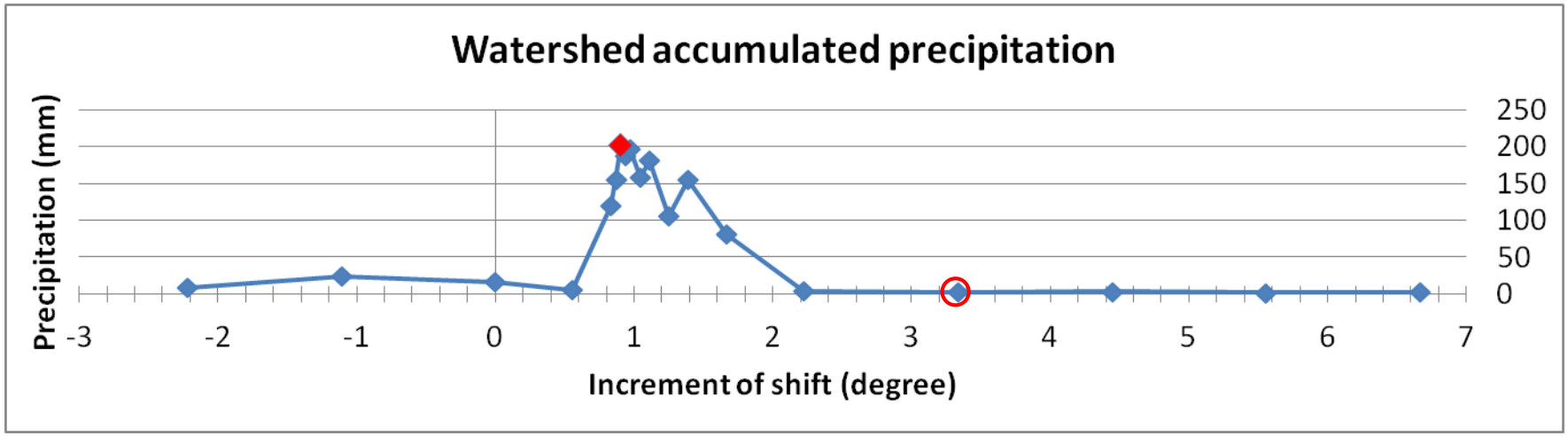


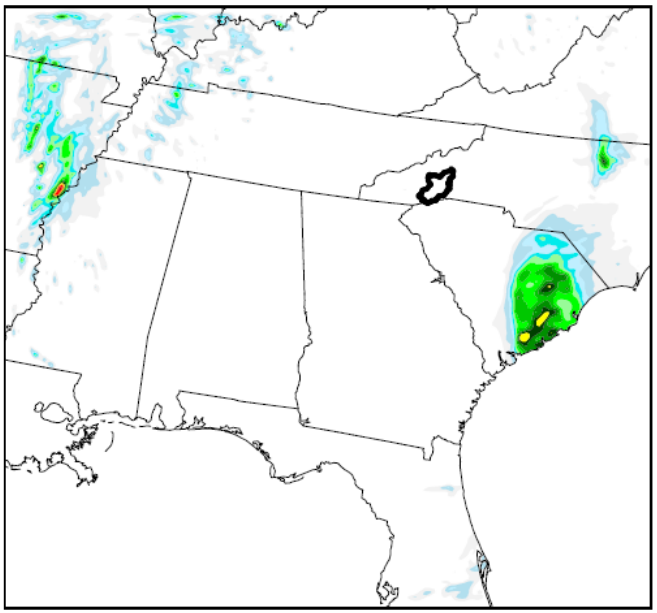
Precipitation	4 mm
WE Shift	1.57 degrees
SN Shift	1.57 degrees
Start Date	08/26 23h
End Date	08/29 23h



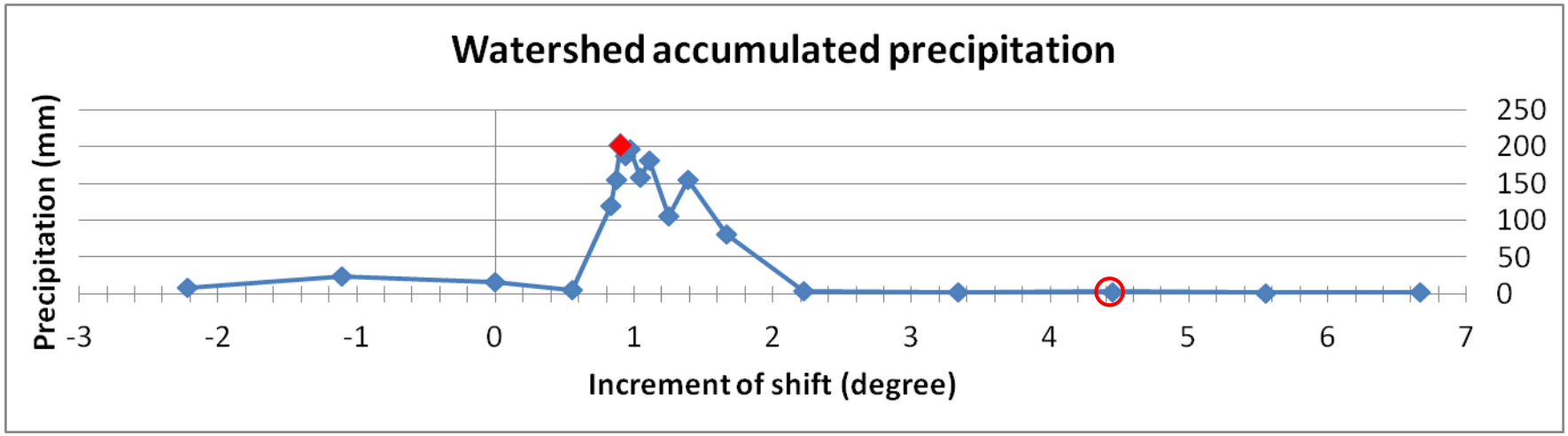


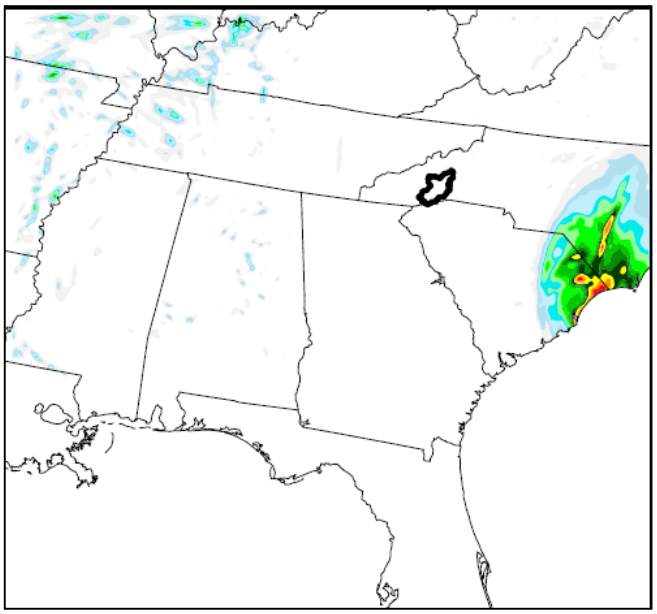
Precipitation	2 mm
WE Shift	2.36 degrees
SN Shift	2.36 degrees
Start Date	08/25 10h
End Date	08/28 10h



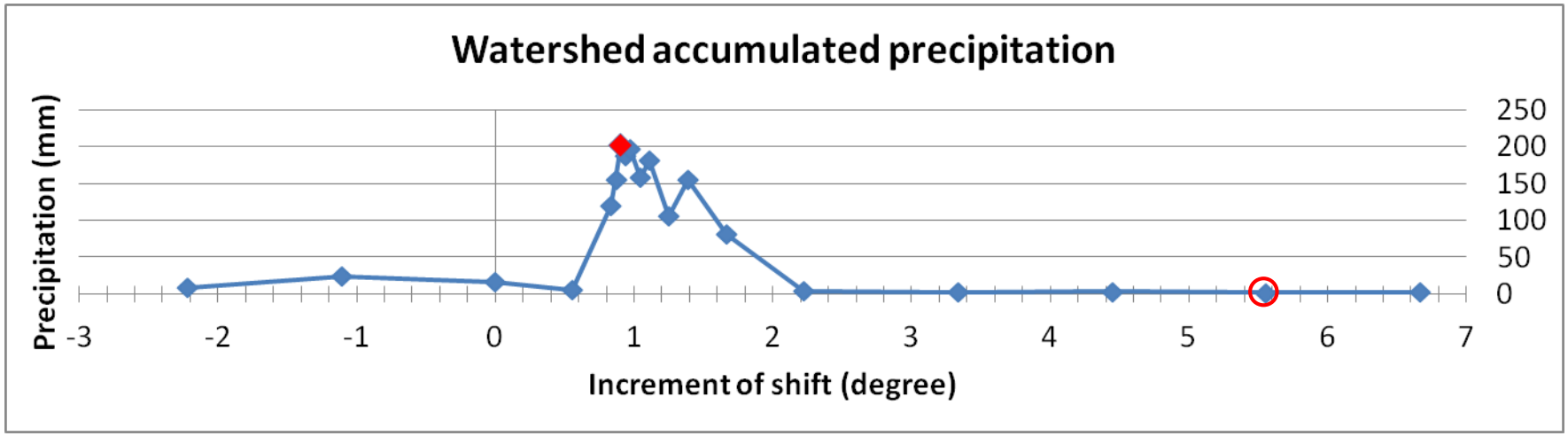


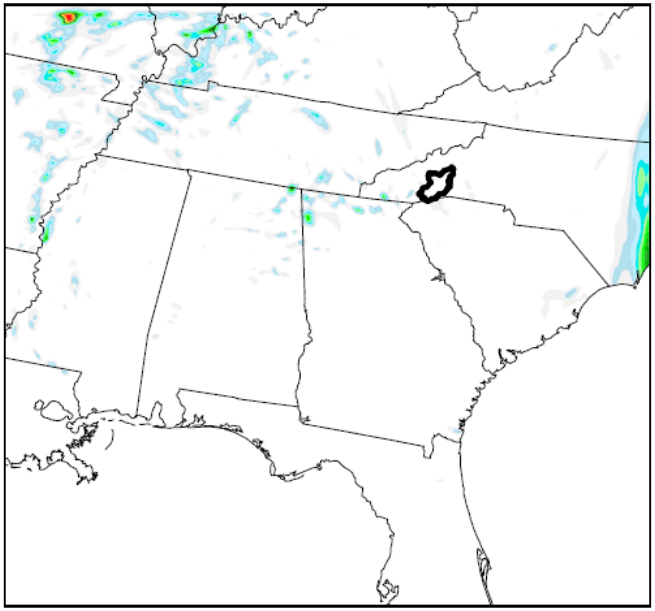
Precipitation	3 mm
WE Shift	3.15 degrees
SN Shift	3.14 degrees
Start Date	08/25 06h
End Date	08/28 6h



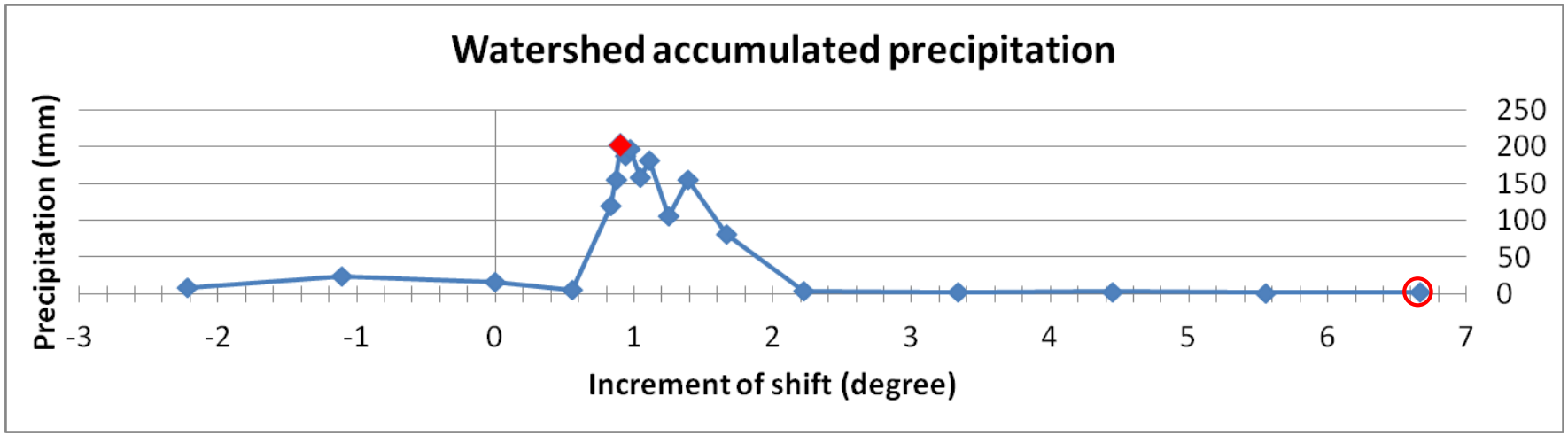


Precipitation	2 mm
WE Shift	3.93 degrees
SN Shift	3.92 degrees
Start Date	08/25 22h
End Date	08/28 22h





Precipitation	2 mm
WE Shift	4.72 degrees
SN Shift	4.71 degrees
Start Date	08/25 22h
End Date	08/28 22h

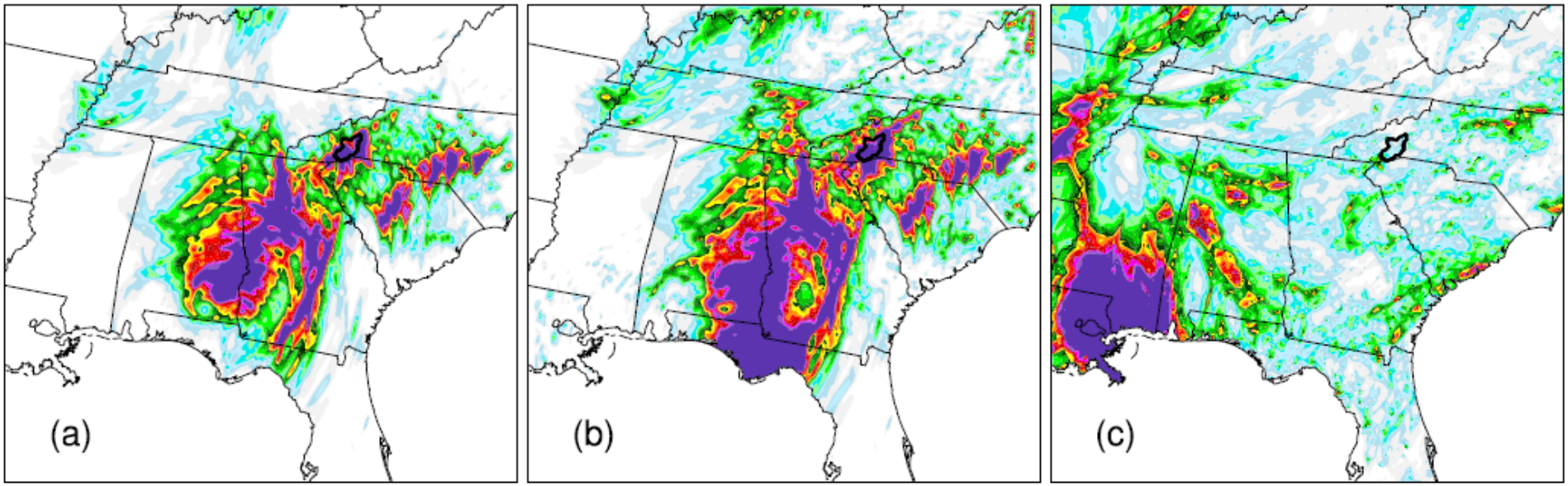


Transposition of Hurricane Isaac (2012)

Maximized 3-day accumulated precipitation field

Maximized 7-day accumulated precipitation field

Observed 7-day accumulated precipitation field

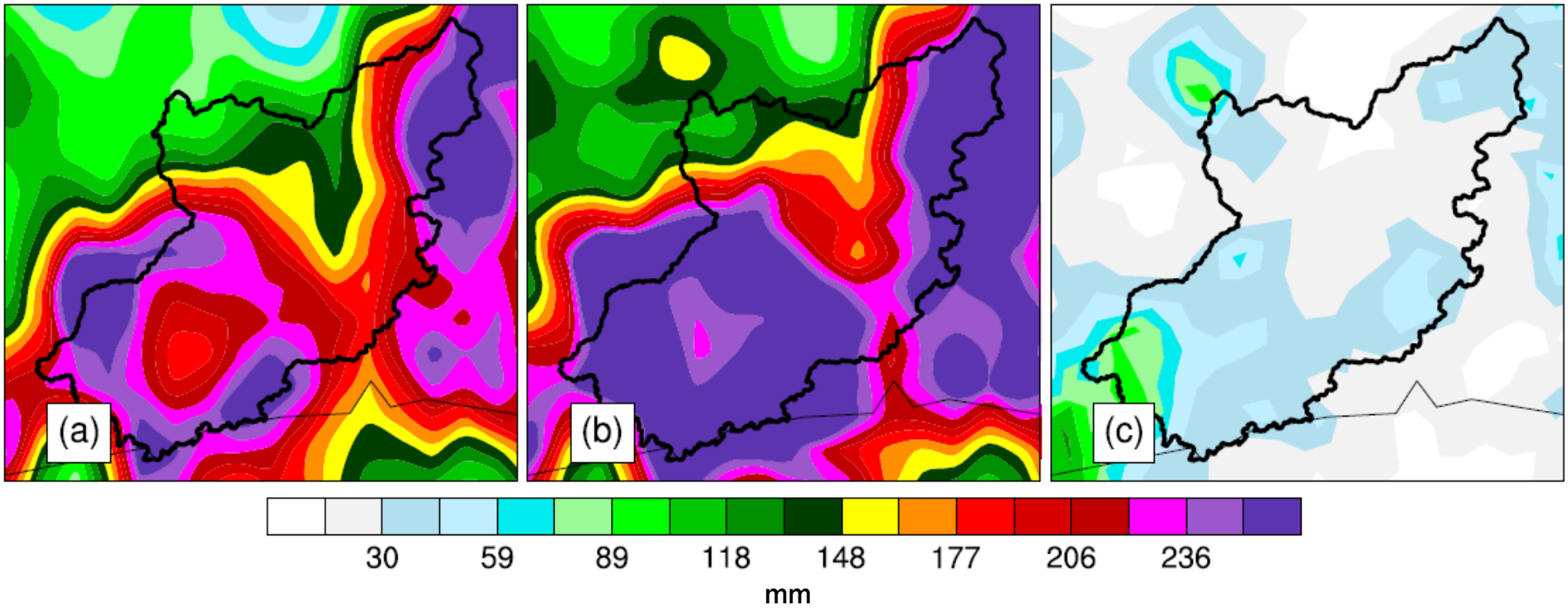


Zoom over target area

Maximized 3-day accumulated precipitation field

Maximized 7-day accumulated precipitation field

Observed 7-day accumulated precipitation field



Plan

1. Extreme precipitation events in the USA
2. Modeling framework
3. Metrics used for model validation
4. Reconstruction of the intense Mesoscale Convective Systems (MCSs)
5. Reconstruction of the intense Tropical Cyclones (TCs)
6. Transposition of the intense TCs
7. Ongoing and future work

Ongoing and future work

- Perform the storm transposition exercise for one MCS

- Determine the most intense future storm for each region (for the two storm types) using the Community Climate System Model version 4 (CCSM4) climate projection, and perform transposition of these 2 storms

Numerical Simulation of Local Intense Precipitation

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