Object-oriented evaluation of downscaled Midwest warm-season rainfall

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Motivation and Goals

Practitioner Problem: Bridge/Road Design, Flood Planning
Daily to multi-day rainfall is used for engineering standards and flood planning. What are credible* projections of daily rainfall?

Science Problem:
Daily rainfall from climate projections is relatively novel. Are flood-relevant rainfall days reproduced?

Goals:
Develop climate projection evaluation framework to identify daily rainfall events relevant to engineering design and flood planning.

*credible: Cash (2002), EOS (2013)
Waterway Traffic Jams: Rainfall timing and location create floods

• Rainfall at the north end of the Cedar River Basin requires ~ 7 days to reach its outlet.

Courtesy Iowa Flood Center http://www.iowafloodcenter.org/
Storms oriented along a river basin creates multi-day traffic jam scenario
Example Rainfall Swath in which all shaded points receive > 1” in 1 day (June 8, 2008)
Percentile and seasonal fraction for 0.5”

Apr- Sep Percentile for 0.5” day\(^{-1}\) ranges 85-90% in Midwest.

Fraction of Apr-Sep rainfall from 0.5” day\(^{-1}\) ranges 50-60%.
Applying Object Analysis to Downscaled Data

(a) Datasets (What is being evaluated)
Maurer 1/8th-degree forcing data for VIC retrospective simulations

(b) Object Definition (How the evaluation is conducted)
MODE software from METv3.0
All: 0.5” at two or more contiguous grid points
Large: 0.5” at 675 contiguous grid points (97,200 km²)

(c) Statistical Evaluation (What has happened)
Frequency, Seasonality, Correlation with Climate Indices, Trend, Contribution to Seasonal Rainfall, Correlation with Engineering Design Metrics, Spatial extent and orientation

(d) Meteorological Evaluation (How it has happened)
North American Regional Reanalysis (1979 – 2010) data at 00 and 12 UTC water budget components: wvconv, prw, evap, analysis_increment
Large 0.5” objects contribute 25-35% of Apr-Sep rainfall.

Large 0.5” objects contribute 50-60% of rainfall >0.5” day\(^{-1}\), equivalently 25-35% of Apr-Sep rainfall.
Large 0.5” objects and engineering standards: Annual Maximum Daily Precipitation

80-90% of annual maximum daily precipitation occurs within large object.
Large 0.5” objects and engineering standards: Annual Peak Streamflow

Drainage time, Two-day: South Skunk + Squaw Creek
Drainage time, Five-day: Raccoon River
Drainage time, Seven-day: Cedar River

<table>
<thead>
<tr>
<th></th>
<th>Correlation with Basin-Average Annual Maximum Daily Rainfall Cedar, Raccoon, South Skunk + Squaw</th>
<th>Correlation with Annual Peak Streamflow Cedar, Raccoon, South Skunk + Squaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed Daily Average</td>
<td>0.476 (0.462), 0.465 (0.248), 0.269 (0.208)</td>
<td>0.593 (0.638), 0.590 (0.612), 0.586 (0.530)</td>
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<tr>
<td>Apr-Sep (Apr-Jun)</td>
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<td>Accumulation</td>
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<td>Waterway Traffic Index</td>
<td>0.490 (0.480), 0.464 (0.271), 0.371 (0.114)</td>
<td>0.576 (0.633), 0.612 (0.608), 0.710 (0.588)</td>
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<tr>
<td>Waterway Traffic Index</td>
<td>0.584 (3), 0.439 (5), 0.551 (7)</td>
<td>0.602 (2), 0.539 (5), 0.674 (6)</td>
</tr>
<tr>
<td>Lag Maximum Correlation (Lag)</td>
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<tr>
<td>CDRA0.5 Frequency</td>
<td>0.603, 0.530, 0.510</td>
<td>0.552, 0.605, 0.628</td>
</tr>
<tr>
<td>CDRA 0.5 Frequency Lag with Maximum Correlation</td>
<td>0.603 (0), 0.530 (0), 0.510 (0)</td>
<td>0.552 (0), 0.629 (2), 0.628 (0)</td>
</tr>
</tbody>
</table>
Spatial Extent and Orientation: Point Frequency Maps (1960-1999)

Large objects have a SW to NE orientation with 0.6 point frequency covering ~50% of Iowa and 0.4 point frequency covering the entire state.
Large objects can be
(1) more extensive outside of NE and IA
(2) less spatially coherent outside of NE and IA
Water vapor convergence is 
(1) persistent with nocturnal maximum for large objects in Iowa, 
(2) transient, perhaps embedded within a fast-moving synoptic system, for large objects in North Dakota, and 
(3) short-lived with afternoon maximum for large objects in Colorado.
Precipitable Water Change is

(1) persistent for large objects in Iowa,

(2) widespread and locally persistent for large objects in North Dakota, and

(3) short-lived with afternoon maximum for large objects in Colorado.
Applying Object Analysis to Downscaled Data

(a) Datasets (What is being evaluated)
NARCCAP: Dynamical Downscaling, nominal 50-km grid
Asynchronous Regional Regression (ARRM): Statistical Downscaling (percentile regression), 1/8<sup>th</sup> degree grid using Maurer as target

(b) Object Definition
MODE software from METv3.0
All: 0.5” at two or more contiguous grid points
Large: 0.5” at 675 contiguous grid points (97,200 km<sup>2</sup>)

(c) Statistical Evaluation
Point Frequency Maps, Change in Frequency
ARRM: 1960 – 1999 (training period), 2020-2059, 2060-2099

(d) Meteorological Conditions
Not easy to do!
All Objects

Maurer (1960 – 1999)

ECHAM5

ECHO

HADCM3

IOWA STATE UNIVERSITY
Climate Science Program
All Objects

Maurer (1960 – 1999)

WRFG NCEP-Driven

CRCM NCEP-Driven

MM5I NCEP-Driven
Historical Period Object Analysis

(a) ARRM
Pass-through of GCM spatial structure.
Objects can be grouped into two categories: very little or a lot of spatial variability.
Size of all objects is more like observed large objects.

(c) NARCCAP
Different RCMs produce similar spatial structure.
Size and orientation of all objects is more like observed large objects.

(d) Meteorological Conditions
Not easy to do!
Future Period Object Analysis


CCSM A1fi: 2020 - 2059

CCSM A1fi: 2060 - 2099
Future Period Object Analysis

CGCM3_T47 A2: 1960 - 1999

CGCM3_T47 A2: 2020 - 2059

CGCM3_T47 A2: 2060 - 2099
Future Period Object Analysis

WRFG NCEP: 1981-2004

WRFG CCSM A2: 1971-1999

WRFG CCSM A2: 2041 - 2069
Future Period Object Analysis

MM5I NCEP: 1981-2004

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Future Period Object Analysis

CRCM NCEP: 1981-2004

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Percent Change of Large Object Frequency
ARRM, 1960-1999 and 2020-2059

CCSM A1FI

CGCM3_T47 A1B

CCSM A2

CGCM3_T47 A2
Percent Change of Large Object Frequency
ARRM, 1960-1999 and 2020-2059

CCSM A1FI

CGCM3 T47 A1B

HADCM3 A2

EHCAM5 A1B
Percent Change of Large Object Frequency
NARCCAP, 1971-1999 and 2041-2069

CRCM CCSM A2

WRFG CCSM A2

CCSM A2

MM5I CCSM A2
Summary

- I have used object-oriented analysis (MODE) to evaluate rare, high-amount 1-day rainfall events in historical and downscaled data.

- The object-oriented analysis in the Midwest enables us to:
  - *relate directly rainfall and flood engineering design statistics*
  - identify relevant meteorological conditions and their spatial and temporal variation
  - evaluate spatial and temporal variability of flood-relevant rainfall within the training period of downscaled data sets
  - evaluate changes of flood-relevant rainfall in climate projections

- Preliminary findings are:
  - ARRM and NARCCAP 0.5” objects have spatial size similar to observed large 0.5” objects
  - ARRM passes-through GCM spatial pattern of 0.5” objects while NARCCAP adjusts the spatial pattern
  - Neither downscaling method predicts a change in spatial pattern of 0.5” objects
  - Most downscaled projections predict an increase in frequency ~10%.