Extreme rainfall events over southern Africa: influence of Atlantic SST on rainfall variability

Charles Williams¹
Dominic Kniveton²
Russell Layberry³

¹The Walker Institute, University of Reading, UK
²Department of Geography, University of Sussex, UK
³Environmental Change Institute, University of Oxford, UK
Background

• Well-established that climate change will significantly alter climatic variability, as well as mean climate

• Changes in climate variability = changes in extreme climate events e.g. increasing frequency of flooding, drought, etc – likely to be of far more significance for environmentally vulnerable regions e.g. southern Africa

• Especially problematic here because of
  1. Region of relatively low and highly variable rainfall
  2. High dependence on rainfed agriculture
  3. High social pressures e.g. population pressures, widespread disease, economic underdevelopment, HIV/AIDS crisis, civil war

• Relatively little work on links between South Atlantic SST, atmospheric circulation and rainfall extremes over southwestern Africa. However, composite analysis suggests that days with extreme rainfall are associated with regions of both cold and warm SST anomalies throughout the South Atlantic
3 steps:

1. Domain testing – to see whether using a different model domain size influences rainfall across southern Africa

2. Model comparison – to assess the ability of the model to reproduce southern African rainfall, by a comparison with satellite-derived rainfall estimates (the MIRA dataset)

3. Model experiments – to investigate the influence of South Atlantic SST on southern African rainfall by forcing the model with warm and cold SST anomalies
Domain sensitivity testing 1

- 3 x 9-yr integrations on HadRM3P, 1993-2001, forced with ERA-40

- Domain 2 (Dom2) = northern s. Africa (8.75°N – 18.75°S, 2.25°W – 54.25°E)
- Domain 3 (Dom3) = s. Africa (8.00°N – 45.50°S, 9.50°W – 59.00°E)

Note – 2 differences with Domain 3:
1. Integration was run on standalone machine ie. PRECIS, not HPCx ie. HadRM3P
Domain sensitivity testing 2
Domain sensitivity testing 3

Differences, Dom1 – Dom2

All months

Nov-Apr

DJF

JJA
Domain sensitivity testing 4

Differences, Dom1 – Dom3

All months

Nov-Apr
Rainfall variability = function of scale, so high spatial/temporal resolution data needed to identify extreme rainfall events – ie. as resolution increases, so too does ability to ‘see’ extremes.

Achieved by using new dataset of satellite-derived rainfall estimates, at high spatial/temporal resolution: the Microwave Infra-Red Algorithm (MIRA) dataset. 10 year’s worth of data, 1993-2002, covering Africa at 2-hourly resolution & at 0.1° lat/long.

Here, using southern African half of dataset (0° – 34°S, 10° – 50°E) at daily resolution.
Model comparison 2

- 10-year integration covering 1993-2001
- Model:
  - Global mode = HadAM3 (2.5° x 3.75°)
  - Regional mode = PRECIS (0.5° x 0.5°), run over southern African domain & driven at lateral boundaries by ERA-40

- Daily rainfall from model compared to MIRA, for full 1993-2001 period, monthly (January & July) and seasonal time periods – NDJFMA & DJF used as long & short wet season, respectively
- Rainfall was firstly compared over entire domain as daily spatial averages, secondly at pixel scale as temporal means, & thirdly number/spatial distribution of extreme pixels

- Extreme rainfall investigated at pixel scale, with definition adapted from that used by Samel et al. (1999)
- Definition used here: extreme pixel (on any given day) = any pixel where rainfall > 1.5% of climatological total for that pixel

Williams et al. (2007)
Model comparison 3

<table>
<thead>
<tr>
<th></th>
<th>MIRA</th>
<th>HadAM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.317</td>
<td>2.531</td>
</tr>
<tr>
<td>Mean error</td>
<td>-0.214</td>
<td></td>
</tr>
<tr>
<td>Mean error as %</td>
<td>-9.236</td>
<td></td>
</tr>
</tbody>
</table>

The graph shows a comparison of rainfall over days, with lines indicating MIRA and HadAM3 models. The table provides a comparison of mean, mean error, and mean error as a percentage of the MIRA mean.
Model comparison 4

- MIRA = 19,645 extreme pixels
- HadAM3 = 14,233 extreme pixels
Model experiments 1

Blue box: SST region used in HadAM3 (cold anomaly in central S. Atlantic)

Red box: SST region used in PRECIS (warm anomaly off Angola)

Experiments:
- Control
- -1°C
- -2.5°C
- -5°C

Experiments:
- -1°C, Control
- +1°C
- +2.5°C
- +5°C

Williams et al. (2008)
Model experiments 2

Had-1 minus Control

Had-2.5 minus Control

Had-5 minus Control
Model experiments 3

Had-1 minus Control

Had-2.5 minus Control

Had-5 minus Control
- Largest rainfall increases over central sA (arranged in TTT) during DJF, suggesting remote, indirect & lagged response of rainfall to anomaly
- Results suggest TTT shifted west relative to usual position, possibly due to Walker cells being shifted further west because of increased anticyclonic gyre over South Atlantic & stronger winds
Conclusions

1. Africa (especially southern Africa) is a region of low and highly variable rainfall, and is very vulnerable to rainfall-related disasters.

2. Work has suggested that rainfall extremes over southwestern Africa are associated with e.g. region of cold SST anomalies in central South Atlantic.

3. Sensitivity testing of model domain suggests southern African rainfall & variability is relatively insensitive to domain size.

4. HadAM3 appears to reproduce southern African rainfall, as shown by MIRA, with some accuracy. Also simulates most daily rainfall extremes highlighted by MIRA.

5. Model experiments suggest cold SST anomaly in central South Atlantic increases southern African rainfall, with largest increases arranged into a TTT but shifted further west (relative to usual location over southeastern Africa). May be associated with a westwards shift in the Walker-style circulation, where strengthened low-level anticyclonic gyre and associated winds draw circulation cells towards the west.
Current and future work

1. Further SST runs using HadRM3P – large domain (incorporating all of South Atlantic) to run with both warm and cold anomaly regions individually and simultaneously

2. Extend study of present-day rainfall variability to consider sensitivity of extreme rainfall to land surface processes:
   a) Individually (i.e. sensitivity of extreme rainfall to land surface changes)
   b) Coupled with SST (i.e. sensitivity of extreme rainfall to land-surface changes and SST variability)

3. Use scenarios of possible land surface changes under climate change to study impacts on future extreme rainfall