Integrated Climate Change Impact Assessment in the Lake Victoria Basin (LVB)

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Outline

- Needs, objective and framework
- Basin scale climate change (Nyando R. Basin)
- Regional changes in Extreme weather (LVB)
- Numerical weather prediction and downscaling of weather forecasts in the LVB
- Conclusions and recommendations
Background

• Extreme weather and climate events can lead to disasters (Field et al., 2012)

• Extreme weather events have increased in the past century (Easterling and Evans, 2000; Rahmstorf and Coumou, 2011; Coumou and Rahmstorf, 2012)

• A major concern with climate change is that future extreme events will increase (Easterling et al., 2000; Treut et al., 2007)

• Extreme rainfall and associated floods has been the leading disasters globally with more than six million lives lost between 1900-2012 (EMDAT, 2012)

• Integrated multi-dimensional impact assessment and extreme weather forecasting (for adaptation) approaches are few e.g. (Black et al., 2011; Jarvis et al., 2011; Arndt et al., 2010; Vuuren et al., 2009).
Why Lake Victoria Basin?

- LVB is trans-national, supports millions of livelihoods, source of Power for Uganda and Kenya
- Key source of R. Nile
- Population:
  - Most vulnerable to climate change
  - Increased poverty assoc. with climate change
- Loss of lives/incomes due to floods in Nyando, Yala, and other river basins
- Freak weather responsible for about 4000-5000 deaths each year over the Lake
- Its river basins synonymous with flooding
Vulnerability to climate change LVB..

• Climate change a significant factor contributing to poverty
• limited studies that address the complex interactions between the diverse factors and the coping mechanisms
• the majority of people in the LVB are vulnerable
• Prevalent conditions of extreme weather
• Unsustainable development
• prone to catastrophic diseases and do not have access to adequate healthcare

Lake Victoria Basin Commission, 2011
Prevailing weather-related issues

Key Needs:
Assess :-
- The existing weather observation network
- Data processing capabilities
- Timeliness of dissemination
- Weather products on the lake and its basin
- Identify existing inadequacies and
- Make suitable recommendations

LVBC commissioned feasibility study

(Semazzi et al., 2011)
OUTCOME: Enhancing Safety of Navigation and Efficient Exploitation of Natural Resources over Lake Victoria...

Semazzi et al., 2011

- Extreme weather: big challenge to transportation in the LVB
- More than 5,000 marine accident deaths / year
- Lack of reliable and useful weather forecasts
- Proposals
  - Marine and Atmospheric Special Observing Period (SOP) for LVB Project-
  - Plan for a Navigation Early Warning System (NEWS)
  - Plan for a Hotspots Atlas (CTOR2)
  - Plan for a Centre for Meteorological Services (CMS) for the Lake Victoria Basin (CTOR5).
What is needed?

• Climate change assessment – : **Scientific**
  – Need for an integrated approach
  – Multi-scale analysis \( \rightarrow \) e.g. link basin + regional scales
  – Multi-temporal approach
  – Multi-analytical approach (data, numerical, methods)

• Climate change adaptation – : **Operationalization**
  – Improved local scale resilience to a changing climate
  – Improved *forecasting* of “increasing” extreme weather
  – coordinated International efforts
  – **Real time solutions** e.g. realtime obs., realtime forecasts
What is the way forward?

- **Past/Present**
  - Ground-based Observations
  - Global Weather Forecasts
  - Reanalysis & Observations
  - 20th Century GCM
  - Current Floods
  - Flood modeling
  - Numerical modeling
  - Satellite Data Assimilation
  - Select GCMs

- **Future**
  - Flood Forecasting Adaptation
  - Understanding of Local Circulation Mechanisms
  - Extreme weather events
  - Regional and Synoptic Changes in Climate
  - Future Floods
  - Downscaled Climate Variables
  - Downscaling & Bias correction
  - Future projections
A. Multi-scale climate change assessment in the LVB

- To investigate projected changes in rainfall at river basin scale through downscaling of CMIP3 climate projections
- To investigate projected changes in flow regimes in Nyando river basin (within LVB)
- To investigate associated regional climatic changes and associated extreme weather event mechanisms
A.0. Basin scale climate change

NYANDO RIVER BASIN

Area: 3,500 sqr. Km
Elevation: 1000 – 3000 m Asl
Rainfall: 800 – 1600 mm/year
Population: ~ 1 Million
Soil: Loamy Sand
Landuse: Agriculture
Discharge: ~ 15 m³ s⁻¹

(Wang et al., 2009a, 2009b)

- Perennial flood basin
- > 750,000 persons
- High levels of poverty
- Agriculture-based economy
A.1. Methodology

**DIAS** → **Select GCMs (CMIP3)** → **Statistical Downscaling** → **GCM Acronym**

<table>
<thead>
<tr>
<th>GCM</th>
<th>Acronym</th>
</tr>
</thead>
<tbody>
<tr>
<td>ingv_echam4</td>
<td>ingv</td>
</tr>
<tr>
<td>mpi_echam5</td>
<td>mpi</td>
</tr>
<tr>
<td>mri_cgcm2_3_2a</td>
<td>mri</td>
</tr>
</tbody>
</table>

**Model Selection**

GCM Vs. Reanalysis

Statistics:
- Minimum RMSE
- High spatial correlation with obs.
- Good seasonality
- Minimum bias

**Downscaling**

Statistical
- No-rain days: frequency
- Normal Rain: Gamma CDF
- Extreme: Extreme distribution functions

**Hydrological Modeling**

**PAST**
20cm GCM
1981-2000

**FUTURE**
A1B, Forcing
2045-2065

**DISCHARGE**
Change = Future - Past

**Extreme Floods**
Return periods

Input: Framework for adaptation
A.2. Projected changes in rainfall (basin scale)
A.3. Extreme rainfall events
A.4. Projected changes in flow regimes

- Increasing trend: all GCM
- OND: largest projected increase
- Higher uncertainty due to inherent model bias in October: models disagree

**Simulated Discharge 1988 - 1990**

<table>
<thead>
<tr>
<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nash = 0.70</td>
<td>Nash = 0.30</td>
</tr>
<tr>
<td>Bias = 3.8%</td>
<td>Bias = 5%</td>
</tr>
</tbody>
</table>

**a)** Mean discharge (1981-2000): GCMs

**b)** Mean discharge (2045-2065): GCMs
A.5. Flood extremes under climate change

- Models project increase in extremes
- Ingv projects the largest increase
- MPI projects a moderate increase
A.6. GCM Uncertainty

- Consistency in increased rains and floods
- Both seasons MAM and OND likely to flood
- Uncertainty between models highest in OND and MAR-APR
A.7. Regional climate change

GCM : CMIP3 (past, future)

Select GCMs

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<tr>
<td>ingv_echam4</td>
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</tr>
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</table>

PAST
20cm GCM
1981-2000

FUTURE
A1B
2045 – 2065

Compute change (Future-past)

Changes in precipitation, circulation

Changes in Extremes, ENSO, IOD

Climate change

2/14/2013
A.8. Regional changes in rainfall

- Both seasons projected to experience enhanced rainfall
- More pronounced in OND season
A.9. Extreme weather indices

- **EXTREMES**: Over 50% increase in rainfall events > 40mm, more pronounced over E. of LVB
- **INTENSITY**: Intensity likely to increase by about 2-15%
A.10. Summary

• To investigate projected changes in rainfall and flow regimes at river basin scale through downscaling
  – Models project an increase in rainfall in the basin
  – General trend of increasing rainfall extremes
  – Higher probability of floods in Nyando basin most likely under the SRES A1B scenario

• To investigate projected regional climatic changes using CMIP3 GCMs
  – Increase in rainfall over the LVB, consistent with IPCC AR4
  – NE regions projected to experience more extreme rainfall
  – There’s need to investigate characteristics of the extreme events
B. Improving weather forecasting in the LVB. An adaptation option?

- To dynamically downscale global weather forecasts and improve extreme rainfall event prediction in the LVB through satellite data assimilation (AMSR-E)
- To investigate applicability of downscaled forecasts as forcing for hydrological flood simulation
B.0. Improved weather prediction as a climate change adaptation strategy!

- Improved observation system e.g. radar can lead to better prediction of storm systems → **better timely flash flood forecasts**
- Improved forecasts can be better integrated into river flood forecasts for real-time solutions
- Improvement of the weather forecasts for use in flood mitigation would **offset some of the deleterious effects** of such intensification due to global warming
- Seasonal forecasts can be used for **dam optimization** during dry / very wet years
- Reliable seasonal forecasts can be used in **farming decision making processes**

2/14/2013
B.1. Methodology

TRMM rainfall > ¼ domain → Select Extreme Weather Event → Mesoscale System (IR)

AMSR-E available?

ARPS Downscaling + No assimilation → GFS (FNL) Forecasts

CALDAS Downscaling + Assimilation

Validation: TRMM

POD, FAR, TSS
Maps, scatter plots

WEB-DHM

Flood

Assimilation
CALDAS (Rasmy, et al, 2012)
ATM: ARPS model
23 GHZ: Water vapor
89 GHZ: Cloud water
Cost function: SCUEA

2/14/2013
Coupled Atmosphere and Land Data Assimilation System (CALDAS)

System:
- GCM
- NCEP
- ARPS
- Atmospheric Model
- Land Surface Model
- SiB2

Fluxes & Land State:
- Assimilated Soil moisture
- Modeled Land State
- Atmospheric State
- Forcing & Land State
- Atmosphere & Land State
- Atmospheric State (Moisture & Temp.)
- Atmospheric State

Assimilation Scheme:
- SCE
- EnKF

Time Integration Grid Integration:
- COUPLER

Observation:
- 6.9 & 10.6 GHz
- 23 & 89 GHz
- Observation
- Cloud Microphysics Scheme
- Lin’s Ice
- Observation Operator
- Soil RTM
- Atm. RTM

Forcing (radiation & rainfall) → cloud assimilations

SCE – Shuffled Complex Evolution

(Rasmy., et al, 2012)
B.2. Domain and model set up

- **ARPS mesoscale Model**
  - Nested run 30 → 10 → 5km
  - SiB2 Land surface scheme
  - Kain and Fritsch cumulus parameterization outer grids only
  - NCEP FNL → Boundary + initial conditions

- **Assimilation / Prediction**
  - AMSR-E @ 23: 10
  - Prediction run: 00hrs + (12hrs)

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**KEY EXPERIMENTS**

**Date:** 2004.04.04 – AMSR-E available, reasonably extreme event present

**ARPS** : First experiment *without assimilation* (just downscaling)

**CALDAS** : Second experiment *with assimilation* (AMSR-E) + sensitivity experiments

**Validation** : TRMM, 3hourly, + Globally merged IR (cloud top)
### Experiments

<table>
<thead>
<tr>
<th>TRMM (Obs.)</th>
<th>No assimilation</th>
<th>Assimilation (qv,qc,qs,qi)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>After 1 hour</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRMM Rainfall (mm/hr) [002] 0007054PR2004</td>
<td></td>
<td></td>
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<tr>
<td></td>
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<tr>
<td><strong>After 3 hours</strong></td>
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<tr>
<td>TRMM Rainfall (mm/hr) [032] 032054PR2004</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TRMM (Obs.)**
- No assimilation → poor simulation of the event
- Simulates the event → wrong place
- Persistent overestimation NW ~ (32E, 0N)

**Assimilation (qv,qc,qs,qi)**
- Assimilation improves forecast
- Spatial pattern similar to observed (TRMM)
- Quantitatively: still a way to go
B.4. Assessment of accuracy

The black line on b) and d) shows the assimilation time (23:10 UTC 4\textsuperscript{th} April, 2004)
B.5. CALDAS-based flood forecast

- Simulated discharge far and above historical floods
- Too much rainfall from CALDAS
  - There’s a need to improve the forecast quantitatively = classical NWP problem
  - Need to consider ensemble forecasting
B.6. Summary

• To dynamically downscale global weather forecasts and improve extreme rainfall event prediction in the LVB through data assimilation
  – Assimilation of AMSR-E improves QPF forecast
  – QPF reasonable for early warning, but still far from operational use

• To Investigate applicability of downscaled forecasts as forcing for hydrological flood simulation
  – Reasonable performance, but with overestimation
  – Needed: quantitative improvement in weather forecasts
Discussion

- Multi-scale climate change reveals a projected increase in extreme weather
- Likely increase in floods at basin scale
- NWP with assimilation produces a reasonable precipitation forecast
- Qualitatively:- promising, quantitatively:- need more work
- Improved weather forecasting useful for adaptation to climate change
Challenges

• **Data**
  – Availability, short-term and access restrictions
  – Quality and temporal resolutions (only daily)
  – Sparse and missing values
  – Storage limitation (Satellite, Climate projections)

• **Technical**
  – Limited computing power and skill
  – Limited manpower
  – Independent initiatives

• **Organizational**
  – Funding
  – Coordination
Proposals (1)

**Space Agencies (NASA, JAXA, NASRDA, ESA...)**
- Develop integrated datasets for the LVB
- Ease of access to satellite products

**Numerical Weather prediction centers (JMA, ECMWF, NOAA...)**
- Provide short and mid-term weather forecasts in real-time
- Provide long term reanalysis with finer resolution

**Climate centers (JMA, ECMWF, NCEP...)**
- Provide climate projections with all variables → dynamic downscaling
- Numerical modelling support
Proposals (2)

Research community (CORDEX, ICPAC, Universities...)

• Coordinated research efforts e.g. support for dynamic downscaling of climate projections
• Multi-scale integrated studies

ODA donors (JICA, UN, GEO, Governments...)

• Provide support for capacity-building e.g. training courses
• Provide support for long term monitoring systems
• Provide support for acquisition and installation of Real-time systems (prototypes)
Thank you.