Simulating climate change impacts on the hydro-ecology of the Okavango River system, Southern Africa: Consideration of uncertainty

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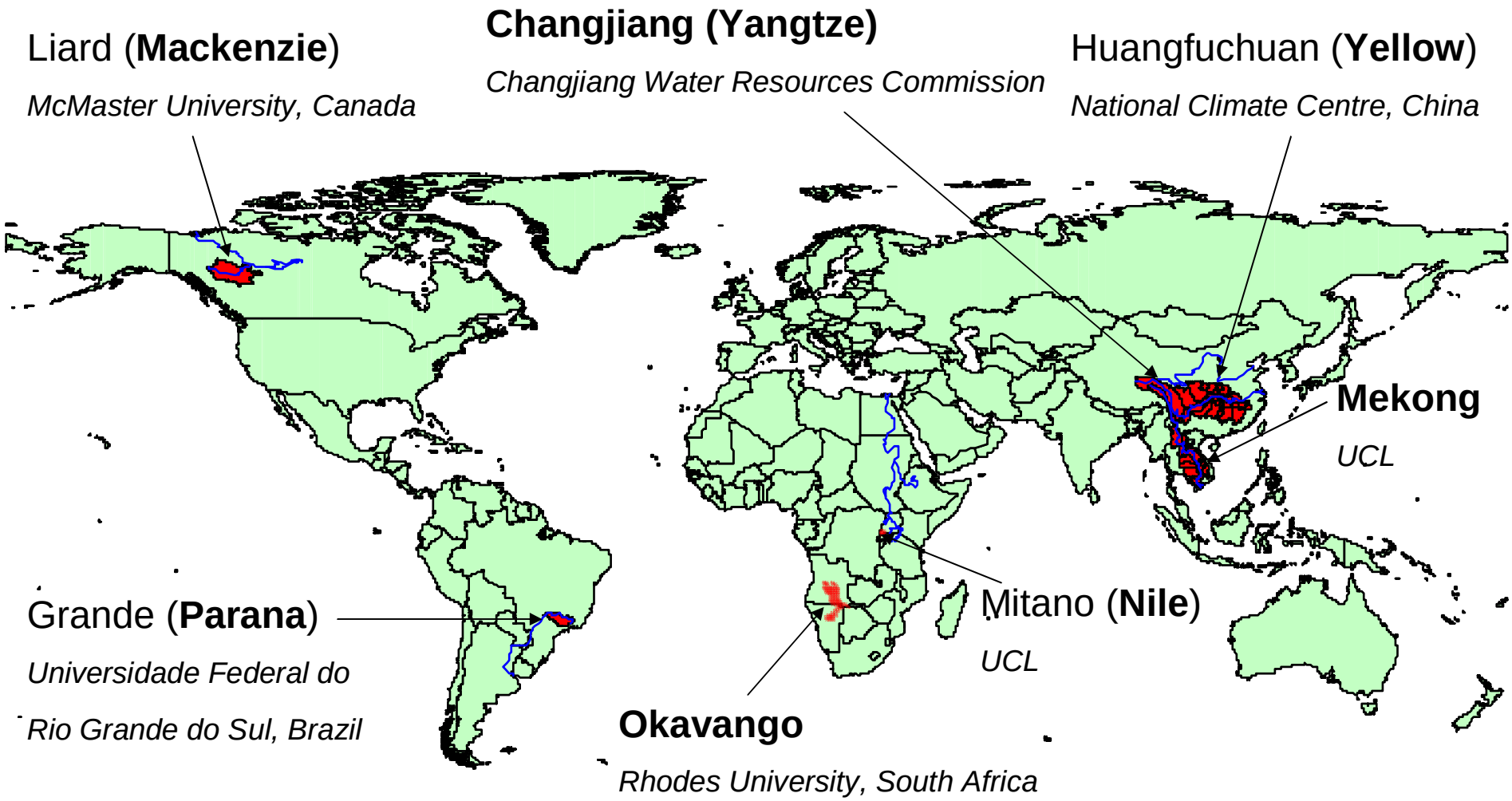
Water resources in developing countries: Planning and management in a climate change scenario, ICTP, 27th April-1st May 2009

QUEST-GSI catchment-scale studies

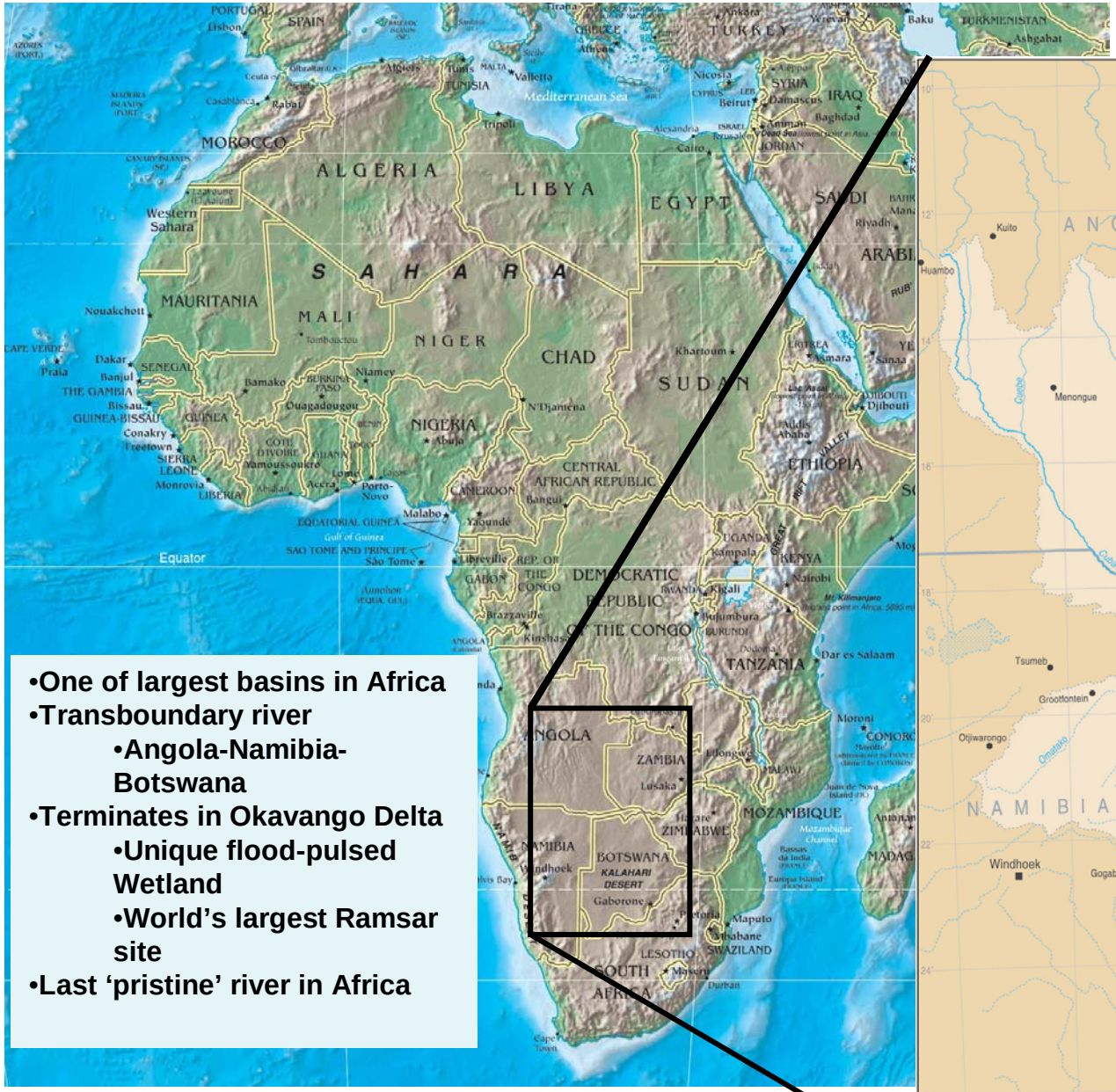
- basins represent a range of physical and human environments



Presentation overview

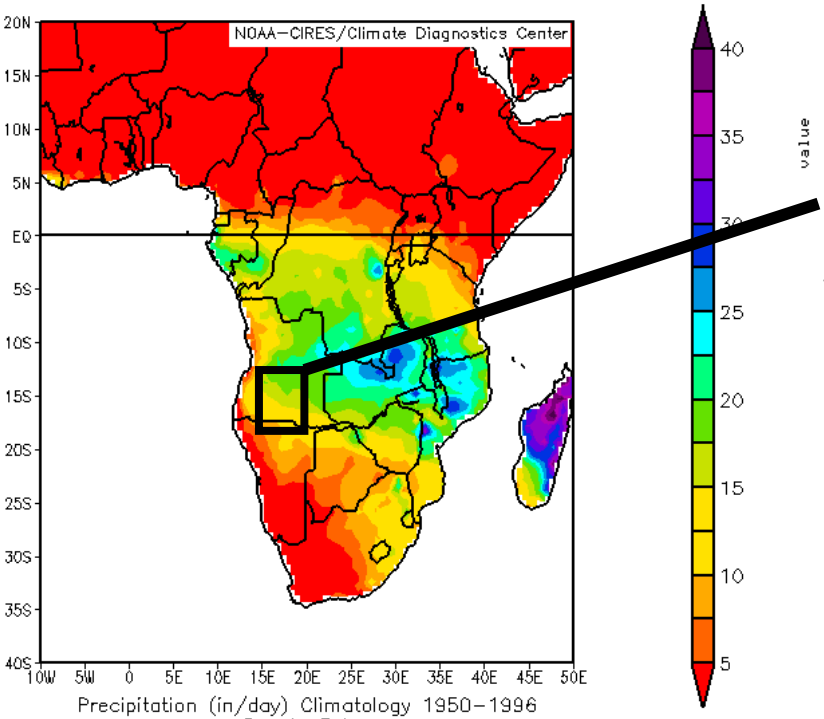
- The Okavango River system
  - Climate
  - Hydrology
  - Socio-economic and development context
- Hydrological and ecological modelling
- Simulating climate change impacts
- Conclusions

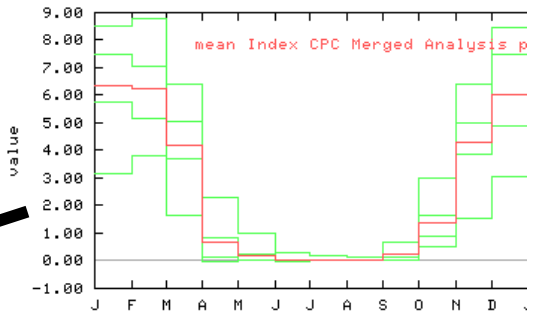
The Okavango River system



- **One of largest basins in Africa**
- **Transboundary river**
  - **Angola-Namibia-Botswana**
- **Terminates in Okavango Delta**
  - **Unique flood-pulsed Wetland**
  - **World's largest Ramsar site**
- **Last 'pristine' river in Africa**

Climatology

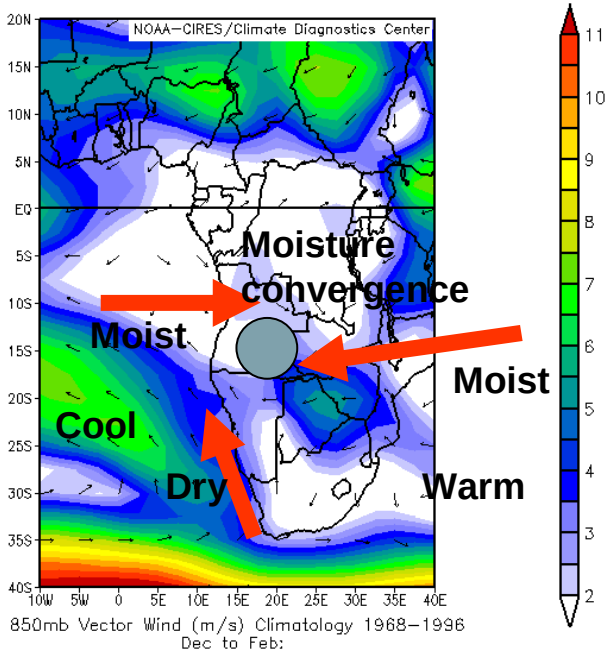




Summer wet season in southern African (SA) rainfall

Pronounced NE-SW moisture gradient in SA rainfall esp. over Okavango region

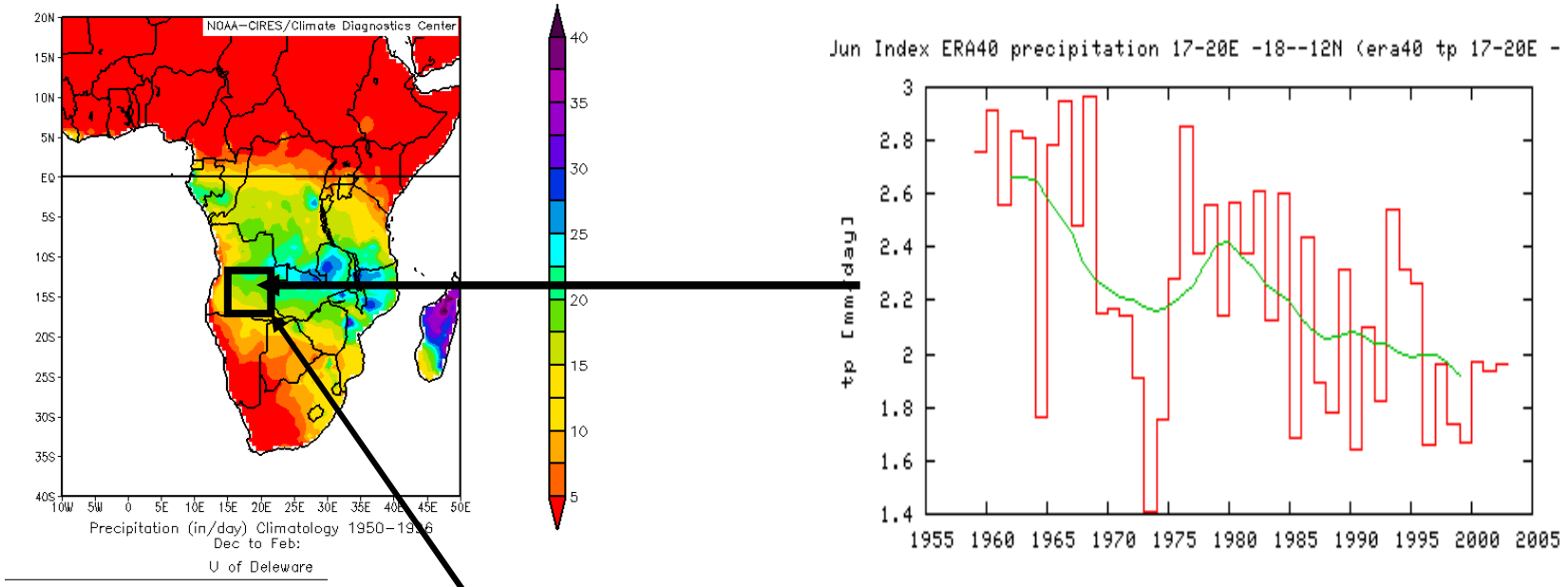
Basin region humid (max 1200mm/yr)
Delta region semi arid (~400 mm/yr)

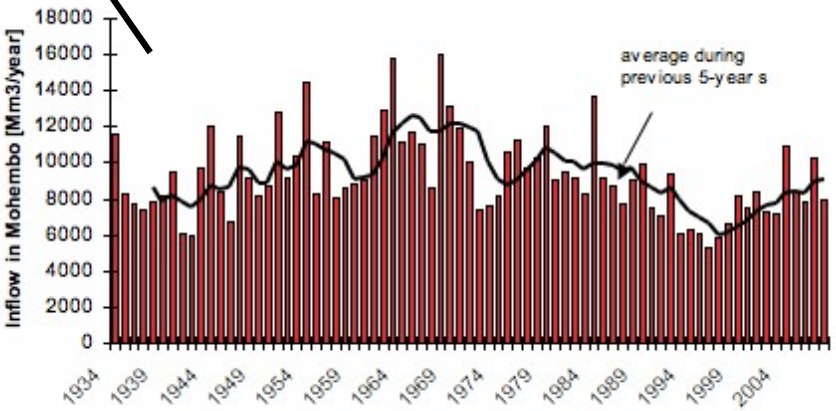


Climatology

Okavango basin region has highly variable climate

- Interannual to multi-decadal



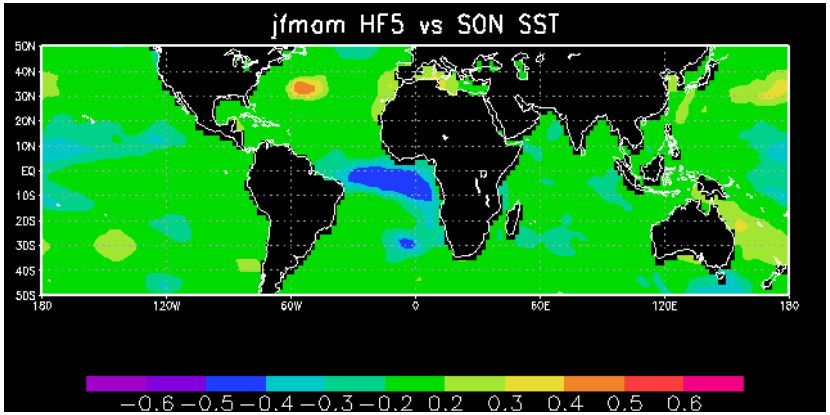


Similar variability in discharge into Okavango delta

What drives climate variability in this region?

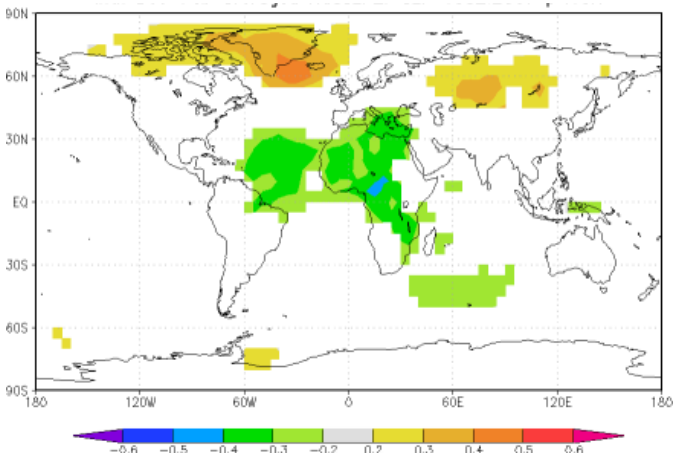
- Problematic to study: Data gap since 1970
- Use the Okavango discharge record
- Filter to retain high frequency (interannual) and low frequency (multi-annual) components

Correlation of HF Q with SST



Variability in Equatorial Atlantic SST (Atlantic Nino) may be primary driver of interannual variability

Correlation of LF Q vs SLP



Driven by decadal NAO and/or associated SSTs?

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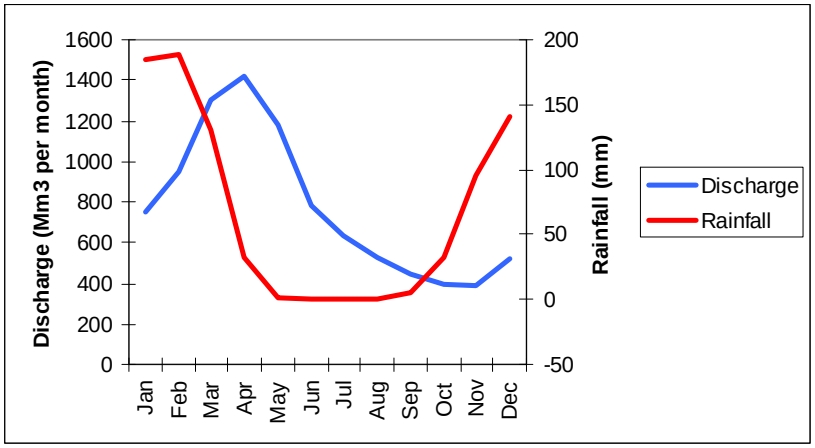
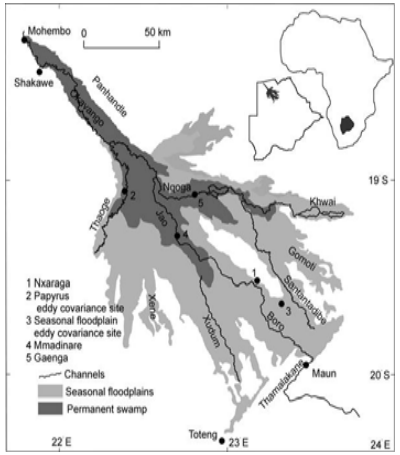
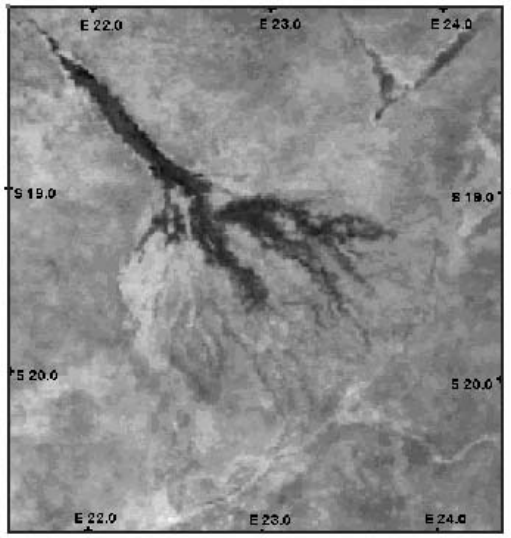
Hydrology of the Okavango Delta: flood pulse

Flooding in the Delta is a product of interaction of
- inflow from upstream catchment (peak April)
- local rainfall (peak Jan)
- antecedent wetness

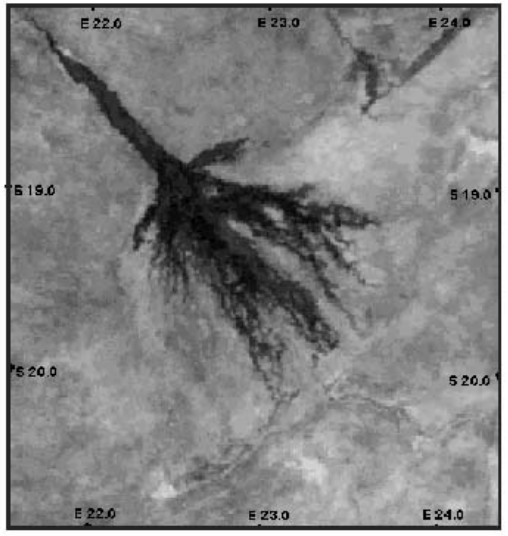




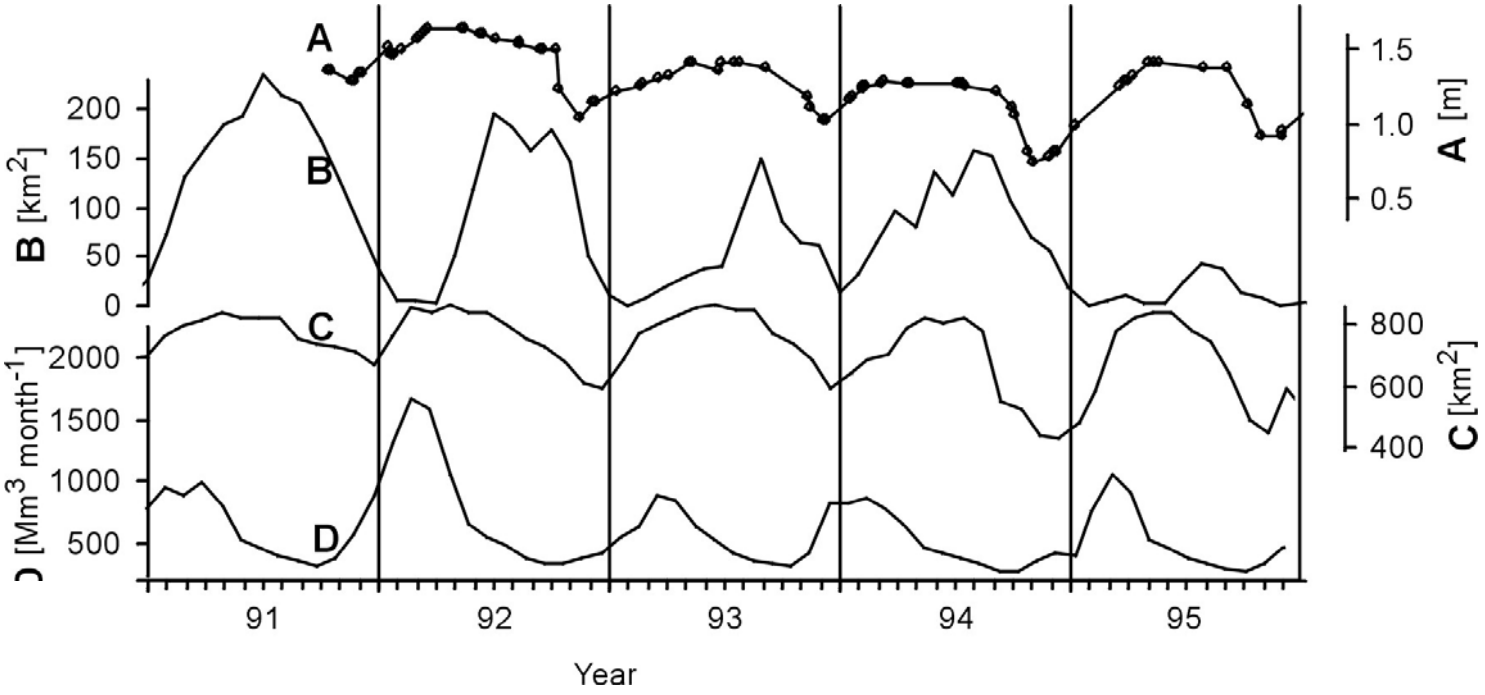
Minimum in February

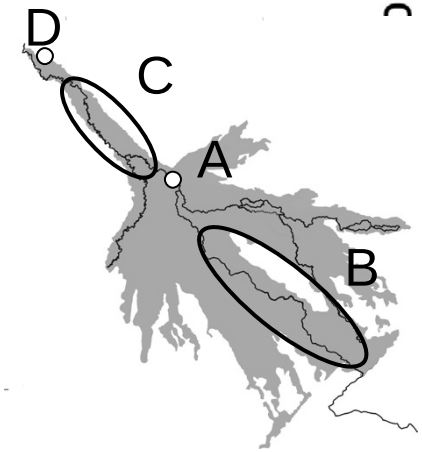


Peak in September



Nature of flood wave





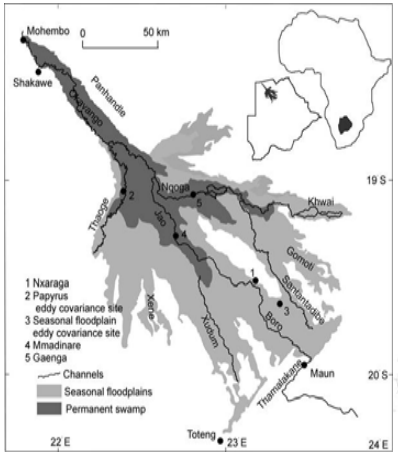
Hydroperiod

Hydroperiod - description of varying water levels at a site

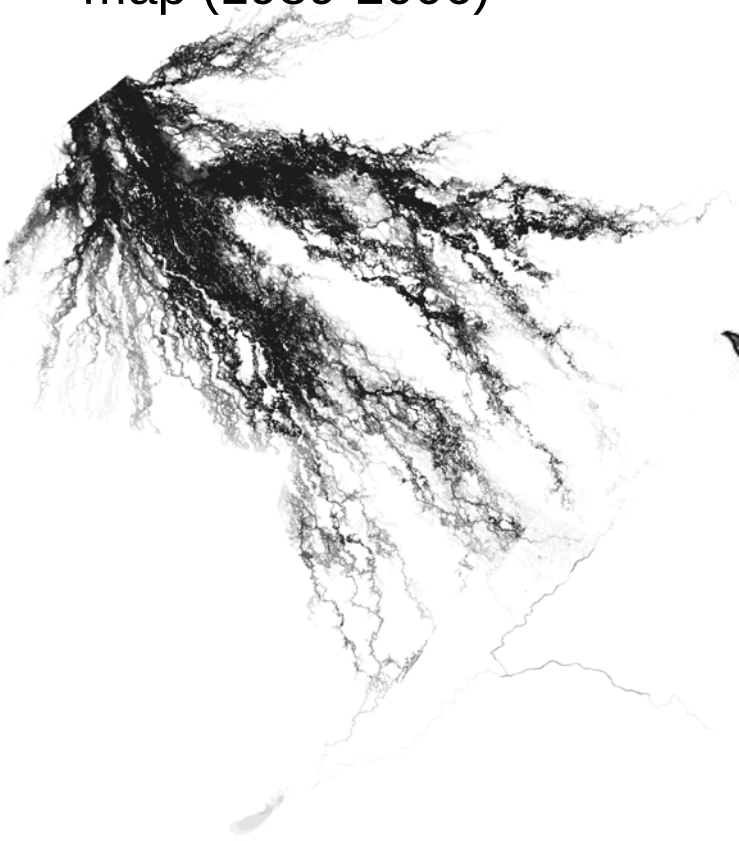
- Duration of inundation
- Depth of inundation
- Amplitude of water level fluctuations
- Frequency of inundation

In Okavango Delta driven by:
- External factors:
    - inflow
    - local rainfall
- Internal factors
    - Channel-floodplain interactions
    - topogaphy
    - geomorphological processes

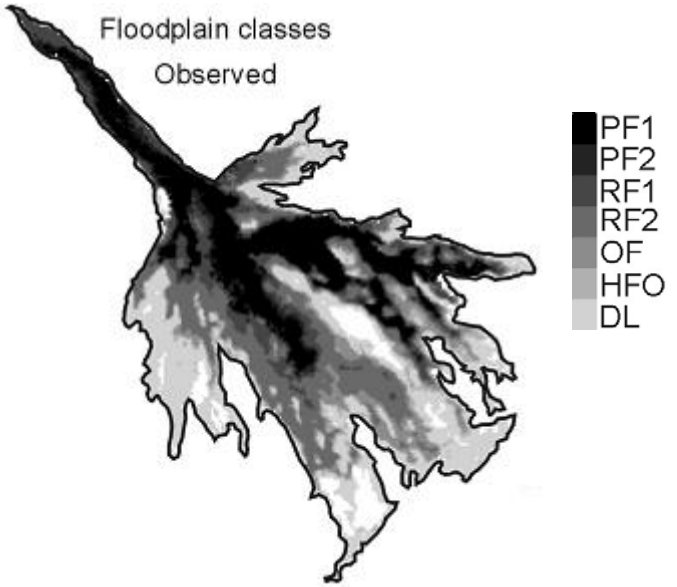
Inundation frequency from TM satellite imagery



Inundation frequency (hydroperiod) map (1989-2006)



Flood classification

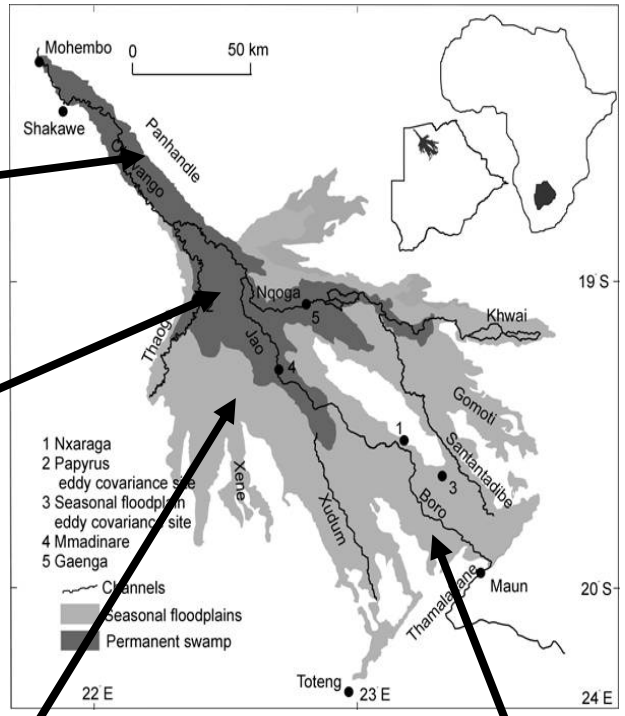


Delta environments

Panhandle

Permanent swamps

Seasonal swamps



Occasionally Flooded

Hydroperiod determines ecological status (Ecotopes)

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Water resource development and adaptation issues

Subsistence Agriculture

National Food Security

Conservation

Hydroelectricity

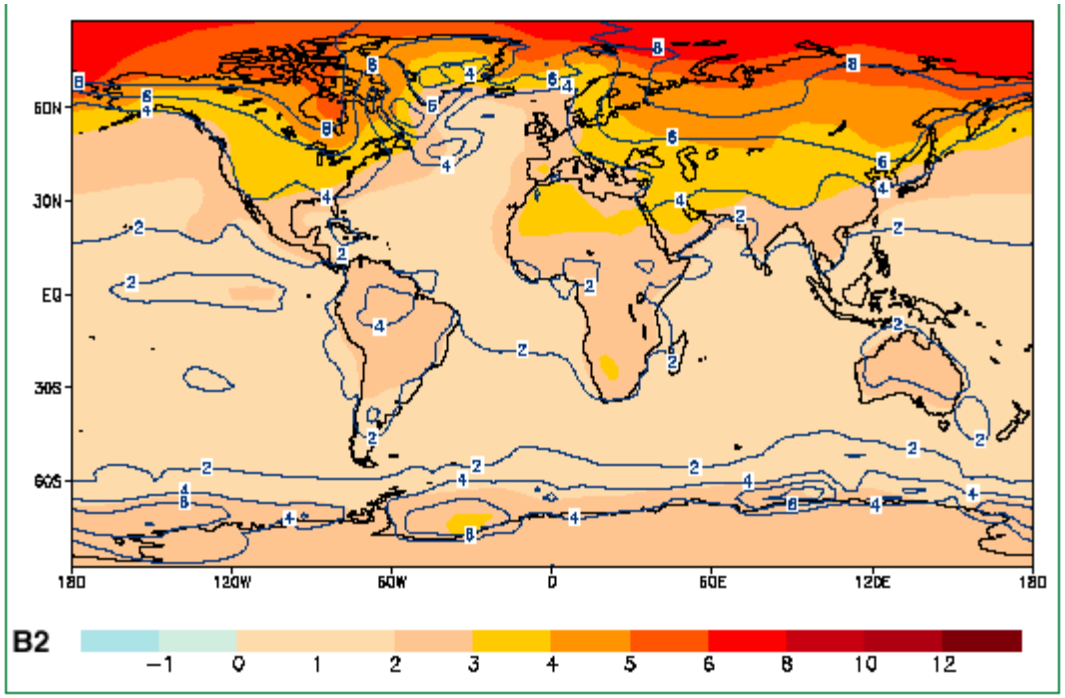
Urban & Industrial Growth

Rural Development

Post-Conflict Reconstruction

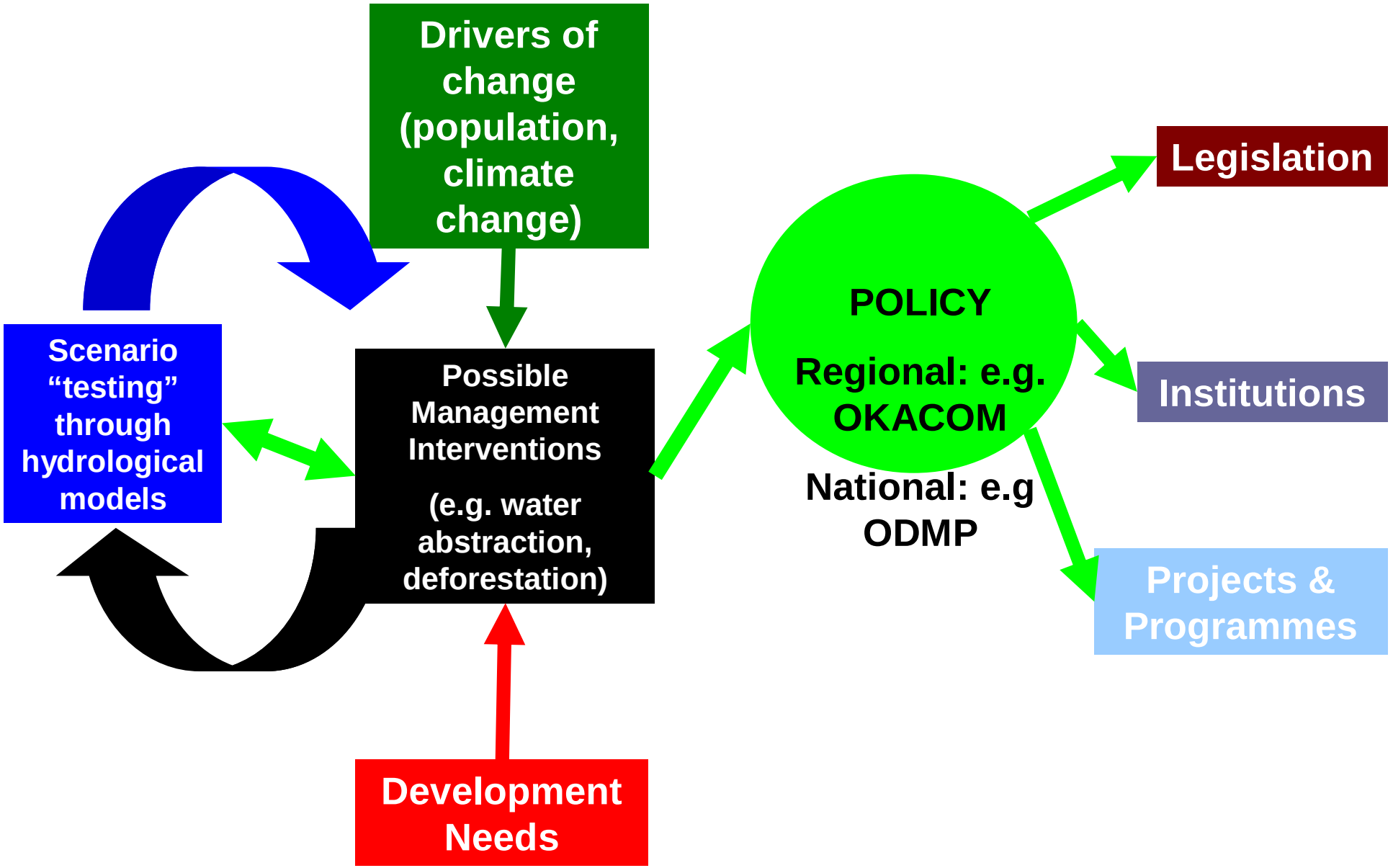
Eco-Tourism Development

Water resource development and adaptation issues



Tri-nation committee OKACOM has responsibility for developing Integrated Water Resources Management plan

Scenario modelling can inform management Policy Process



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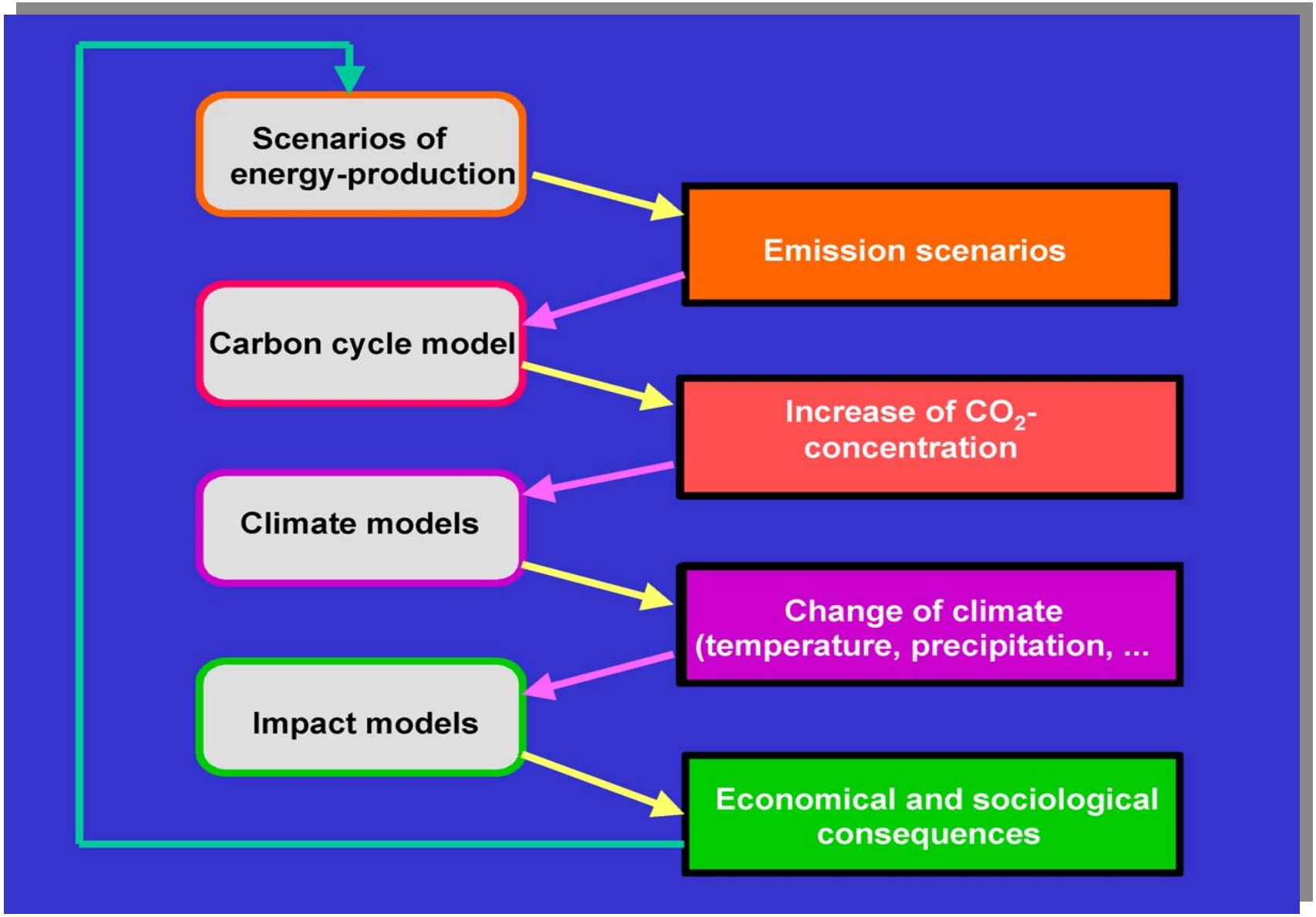
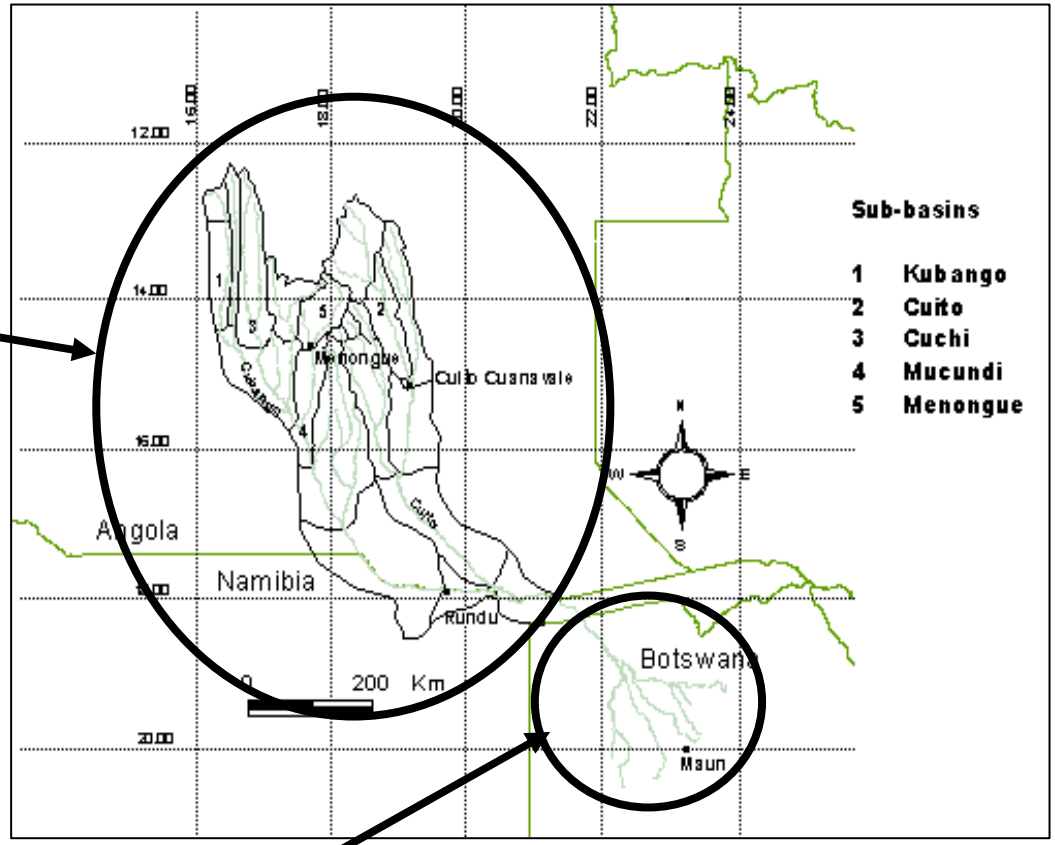
The information chain leading to a climate projection



A ‘cascade’ of uncertainty

Modelling the Okavango river system

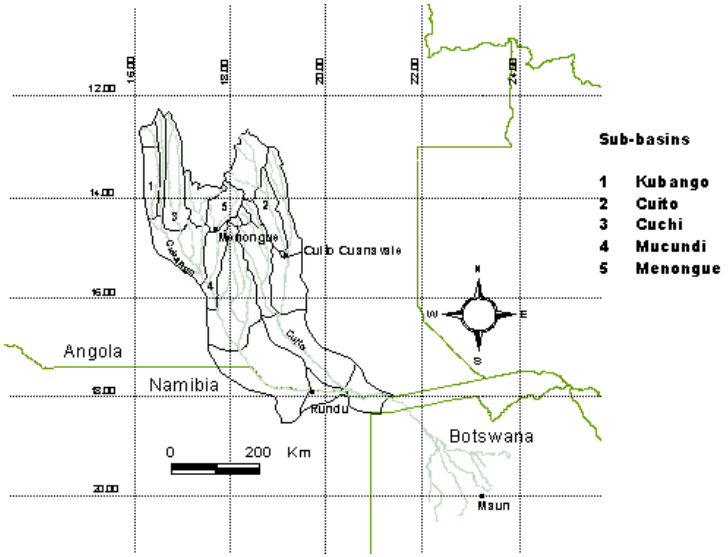
Distributed Pitman model of river basin



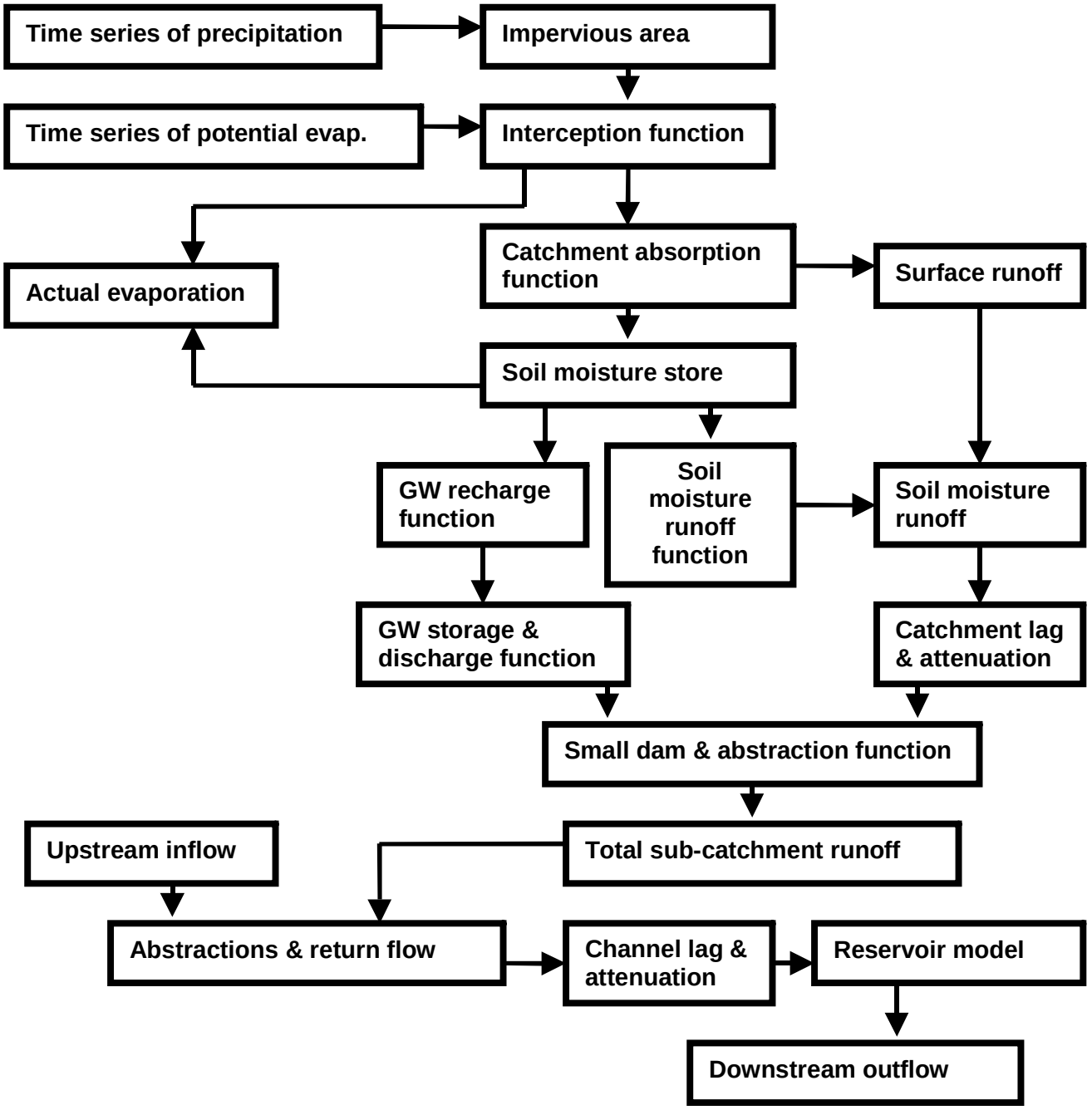
Okavango Delta: Semi-distributed water balance 'reservoir' model

Modelling the Okavango river basin

- Modified Pitman rainfall/runoff model utilised (STATSIM) developed at Rhodes University, RSA
  - Water balance with groundwater and channel routing functions.
  - Semi-distributed (24 sub basins)
  - Data requirements
    - catchment average monthly rainfall
    - catchment average monthly potential evaporation (derived from Hargreaves equation)

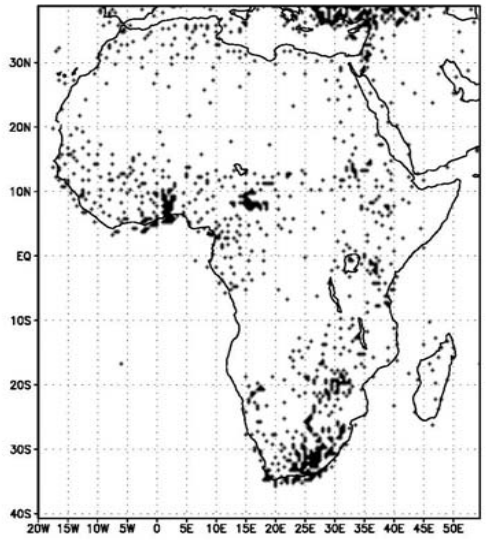


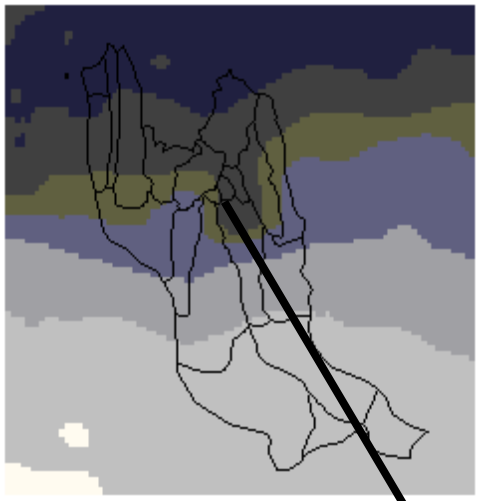
Hughes et al., 2006, Journal of Hydrology, Vol 331

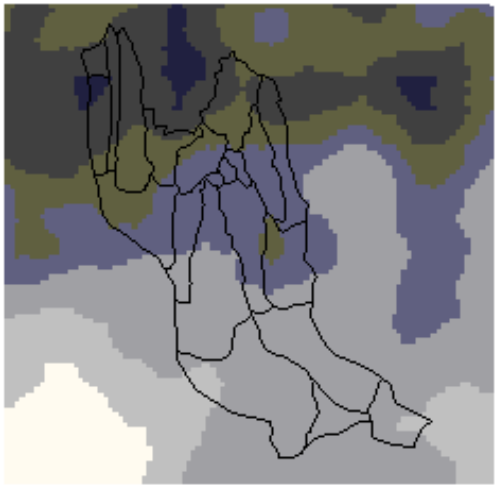

Time series of precipitation
Impervious area
Time series of potential evap.
Interception function
Actual evaporation
Catchment absorption function
Surface runoff
Soil moisture store
GW recharge function
Soil moisture runoff function
Soil moisture runoff
GW storage & discharge function
Catchment lag & attenuation
Small dam & abstraction function
Upstream inflow
Total sub-catchment runoff
Abstractions & return flow
Channel lag & attenuation
Reservoir model
Downstream outflow

Data over the catchment region is poor

Interpolated gauge data 1960-72 Satellite estimate 1990-01

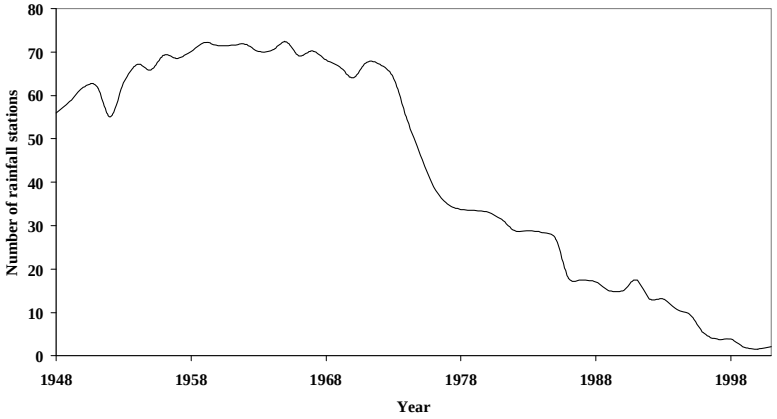




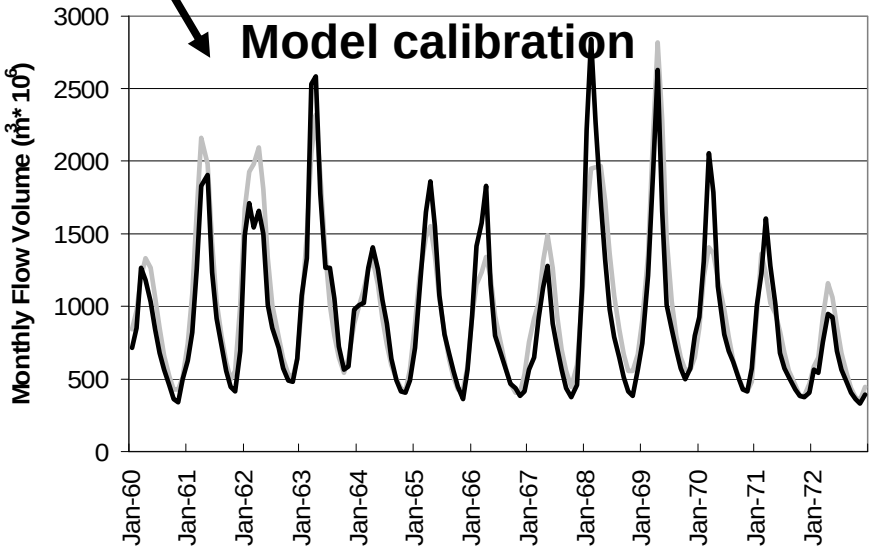


Simulated Observed

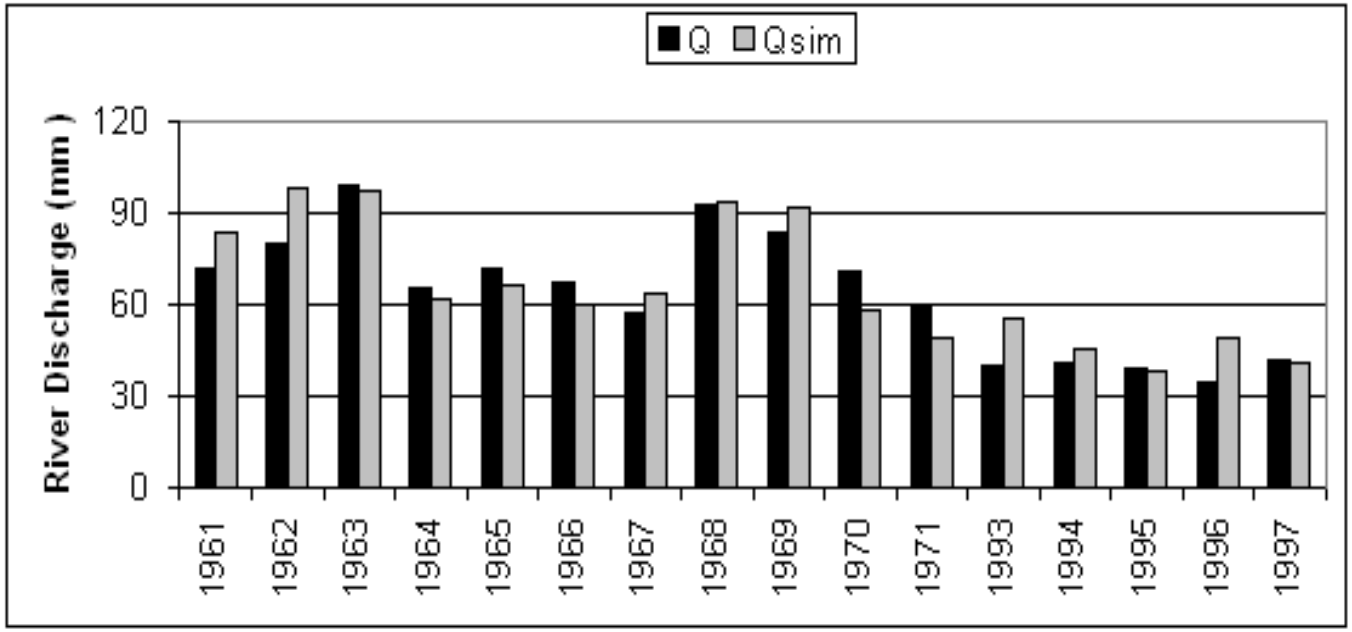
Number of gauges has declined



Model calibration



Data over the catchment region is poor



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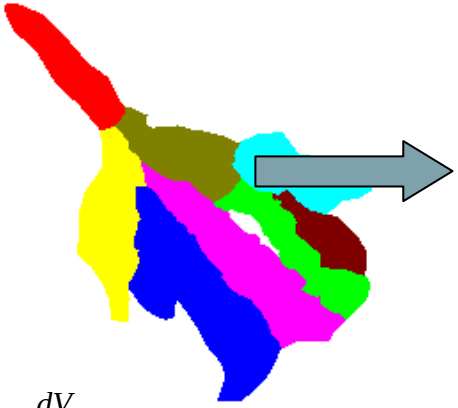
Hydrological model of the Okavango delta

- Okavango delta is highly complex and dynamic mosaic of surface conditions
- Very difficult to model with distributed grid based model.
- Developed simple water balance ‘reservoir’ model
  - Network of interlinked reservoirs
- ‘Semi-distributed’
  - Water balance calculated for each of 8 major distributaries (‘reservoirs’) within the delta

Wolski et al., 2006, Journal of Hydrology, Vol 331

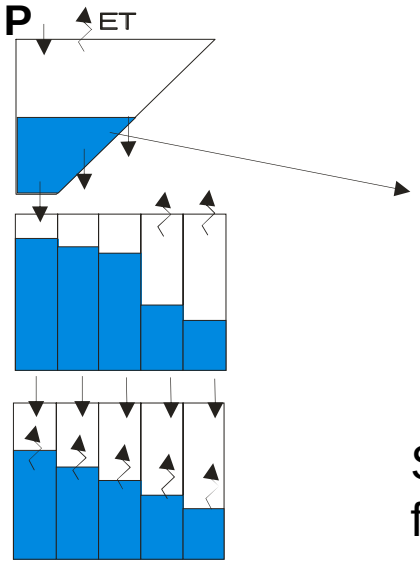


$$\frac{dV}{dt} = I + P - E - Q - Q_{\inf}$$

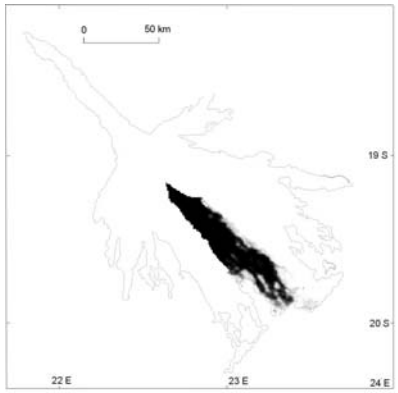
Surface water

Floodplain groundwater

Island groundwater

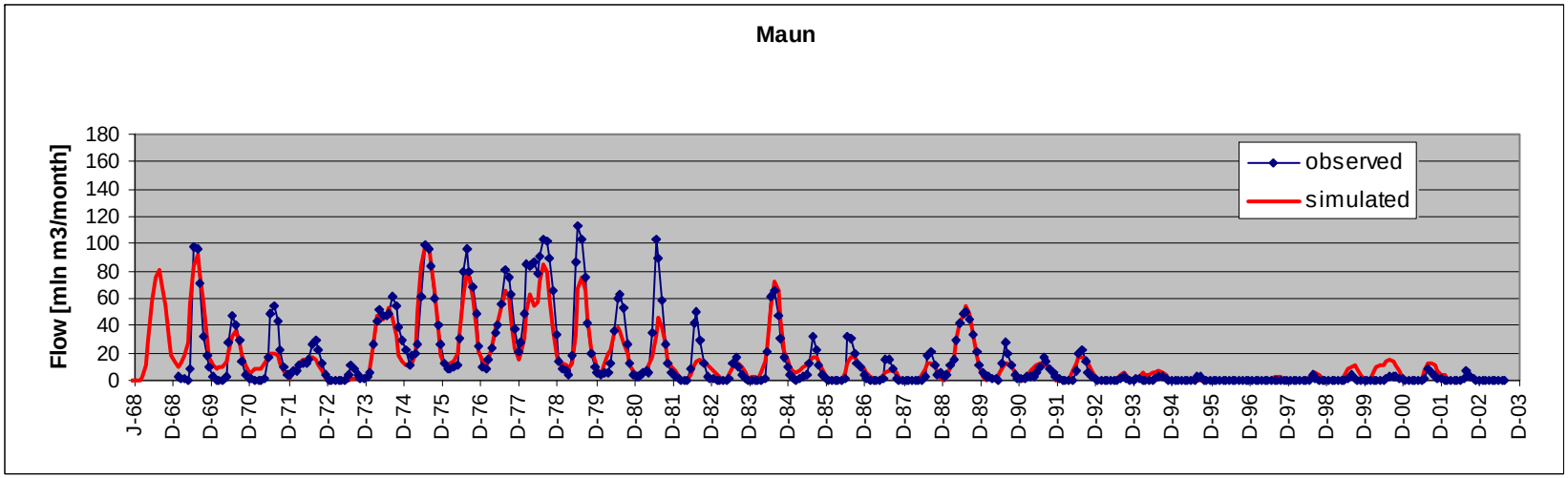


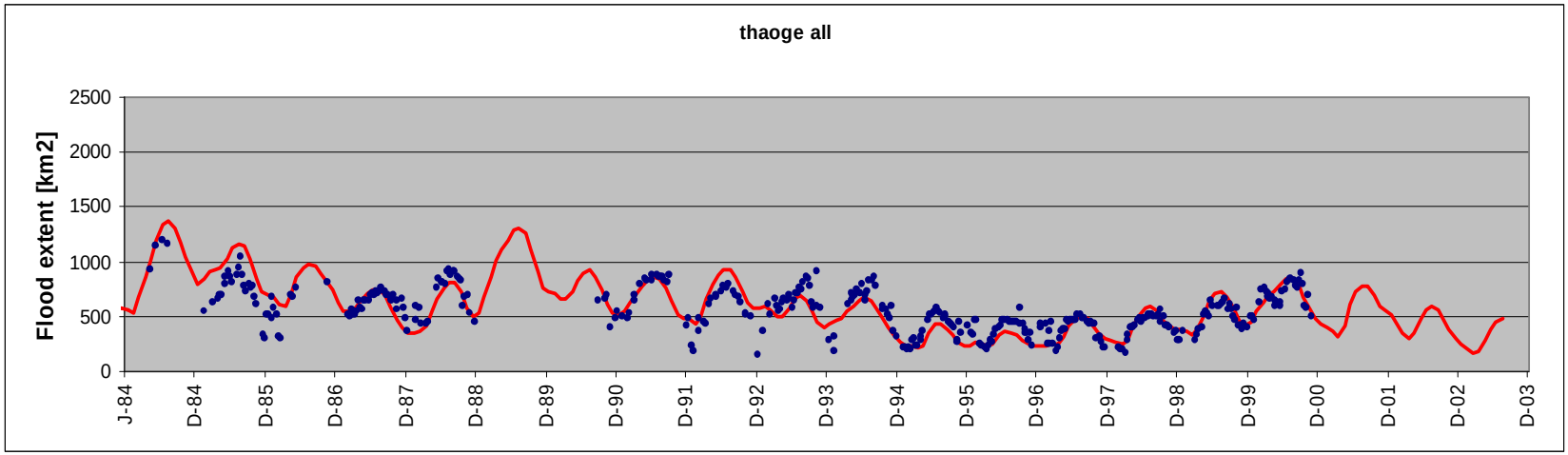
Flood extend (km2)



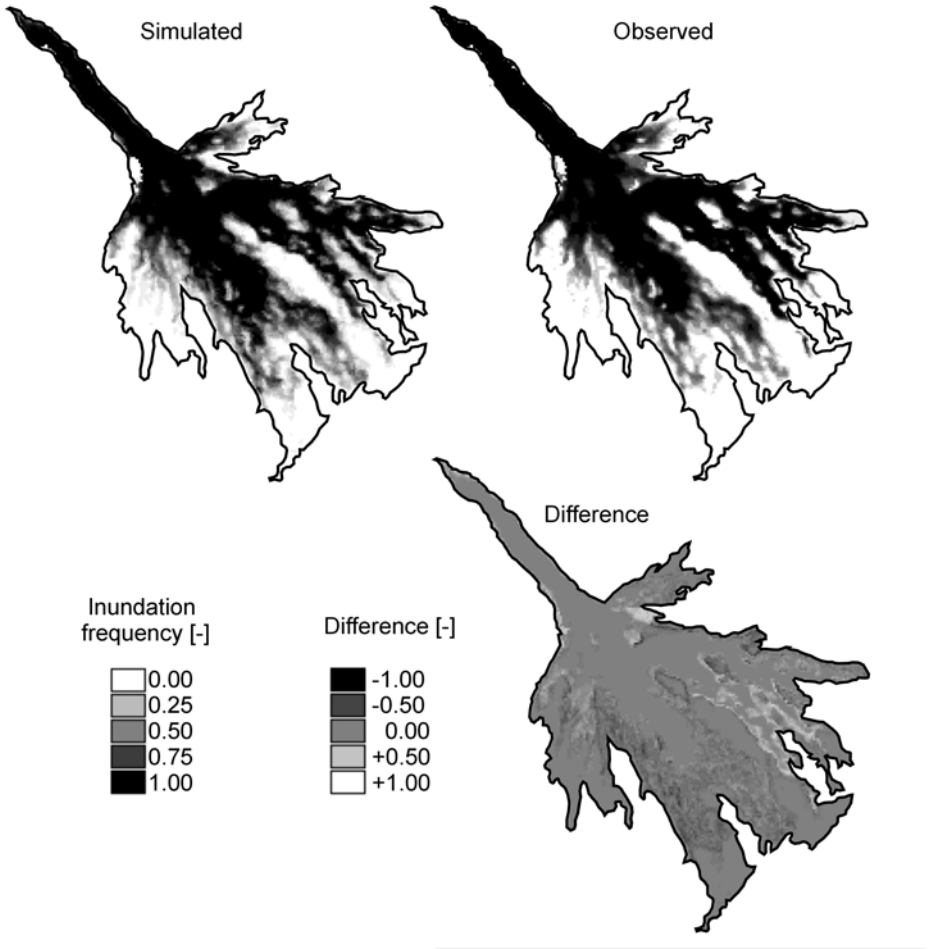
Spatially distributed from historical satellite data

Model validation





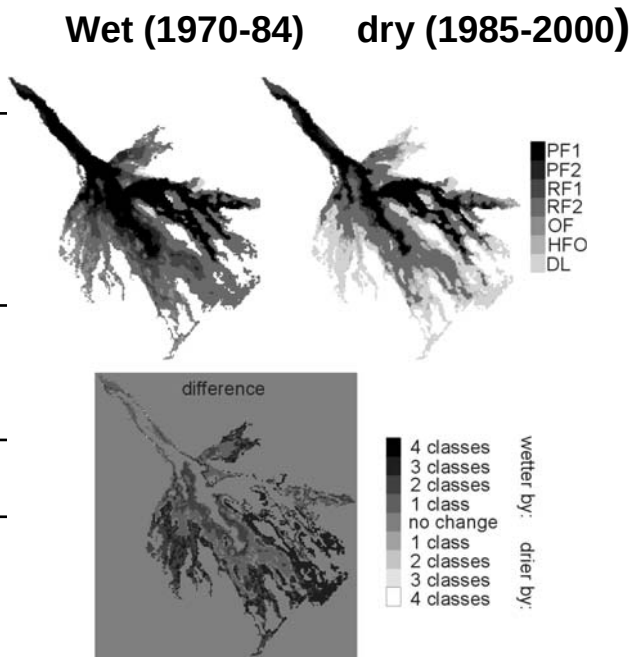
Delta model validation



Good simulation of hydroperiod

Hydroperiod classification

Floodplain class	Sub-class	class code	flood frequency	flood duration (months/year)
Permanent floodplain	proper	PF1	1	12
	fringe	PF2	1	8-12
Regularly flooded seasonal floodplain		RF1	1	4 - 8
		RF2	0.5-1	
Occasionally flooded seasonal		OF	0.1-0.5	1-4
High floods only		HFO	<0.1	<2
Dryland		DL	0	0



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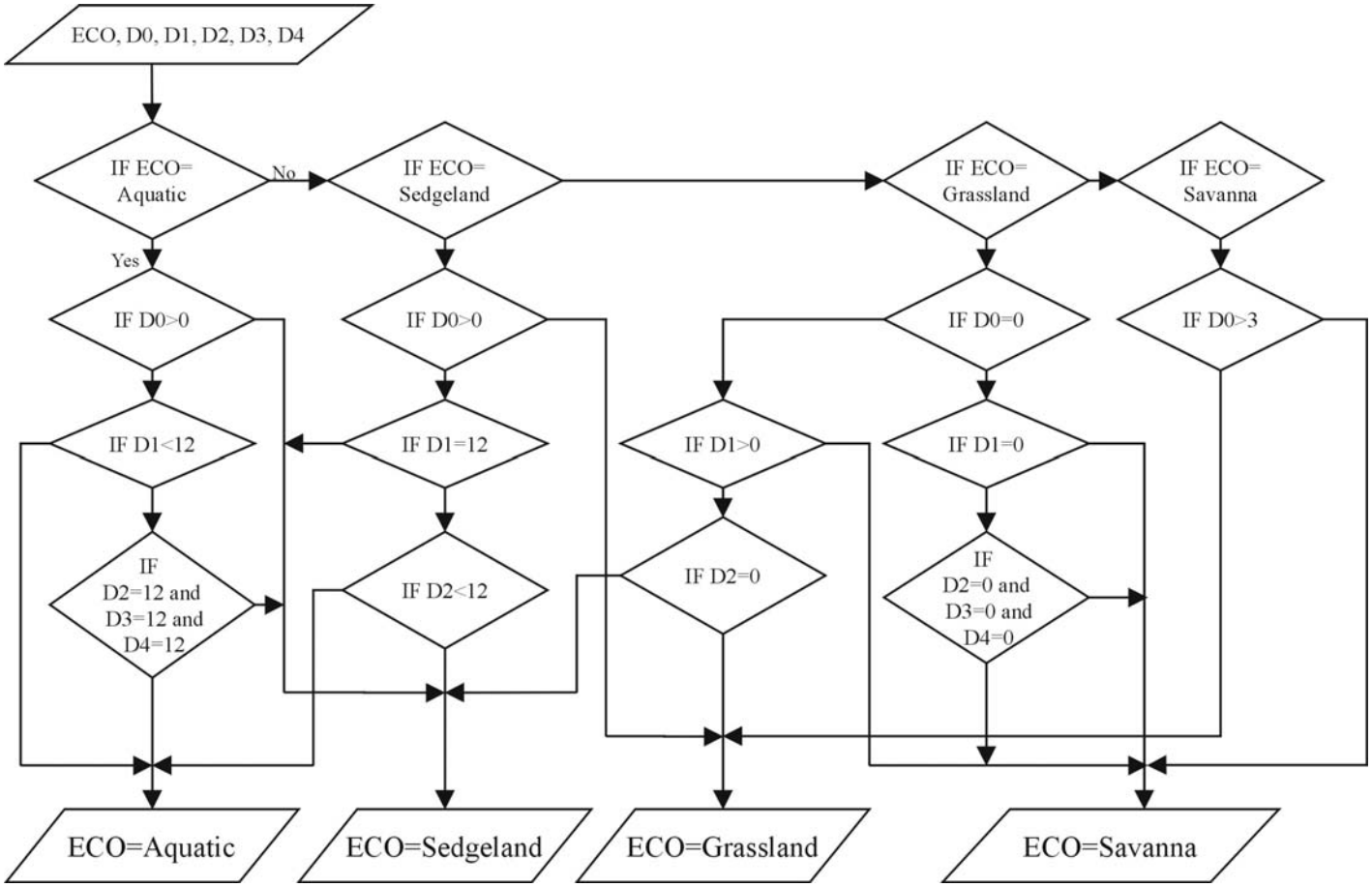
Ecotopes - vegetation communities

Dynamic ecotope model



Expert system. Current ecotope depends on:

- **ecotope in previous year**
- **inundation duration in previous 5 years**

Wolski & Murray-Hudson, Water SA, 34, 605-610

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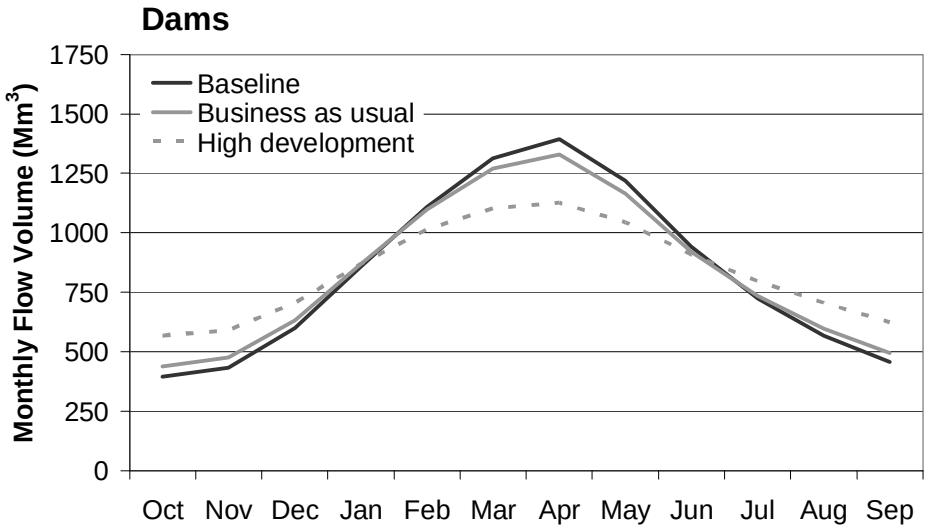
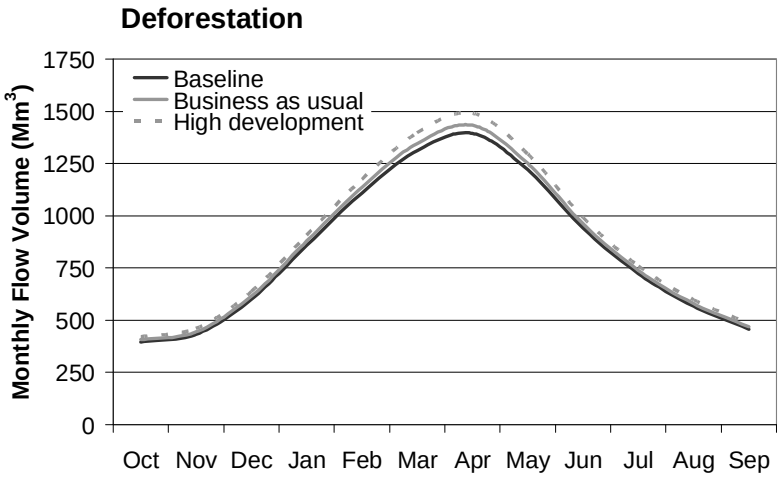
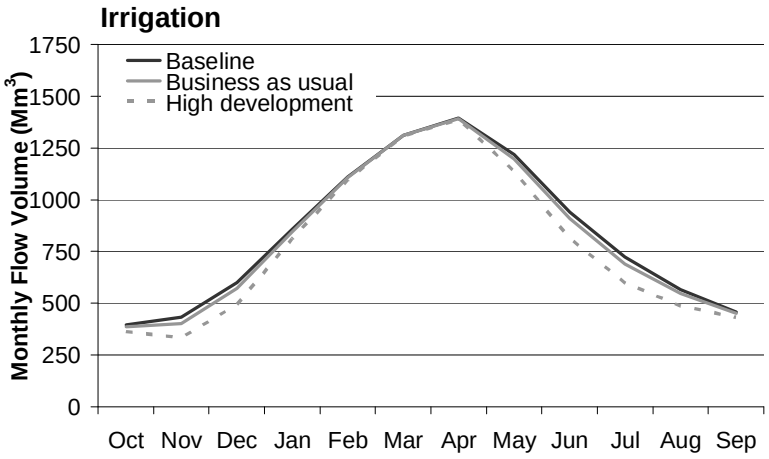
Development scenarios

- 3 contrasting scenarios of future water use derived.
  - Quantifying losses due to domestic use, livestock, water abstractions for irrigation and urban supply, dams
- Low development:
  - low population growth, small scale irrigation and no additional abstractions
- Medium development:
  - medium population growth, small and large scale scale irrigation, riparian deforestation, two dams and no additional abstractions
- High development:
  - As medium but with all proposed dams and pipeloine to Windhoek, Mamibia.

Results: Simulated mean future Okavango river discharge under devlopment scenarios







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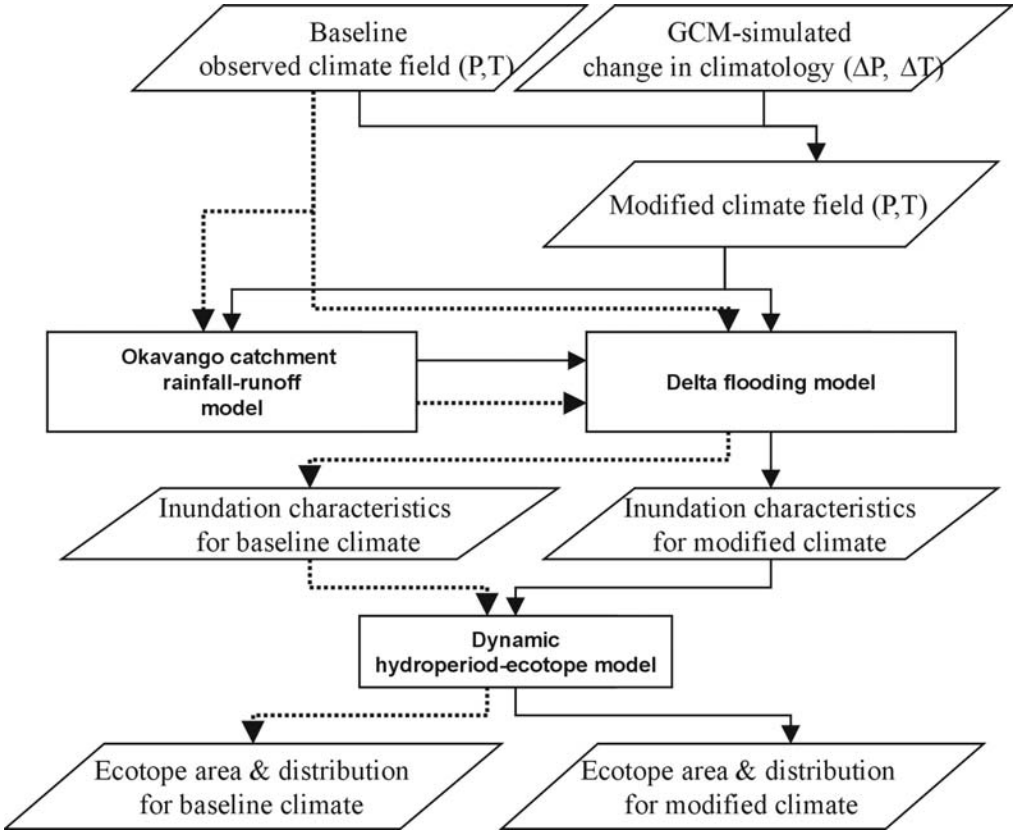
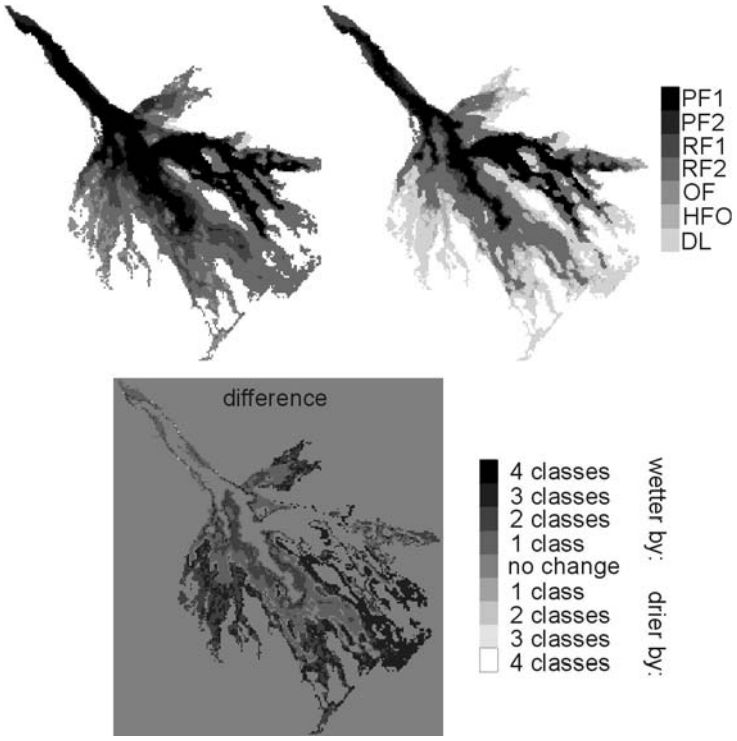
Methods

General framework of analysis of climate change impact:



Simulated changes in Okavango delta flood class distribution

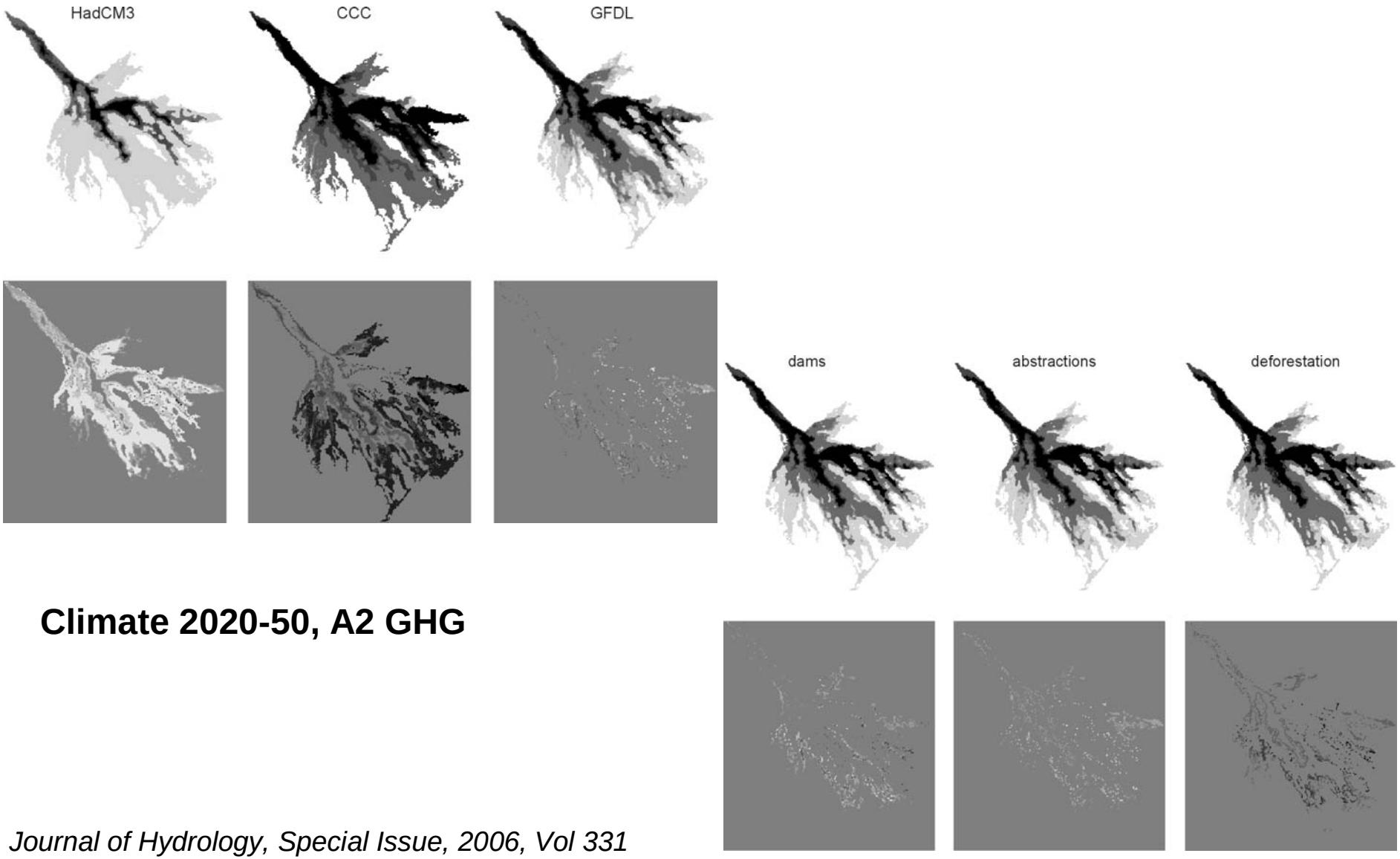
Wet (1970-84) **dry (1985-2000)**



Changes relative to ‘dry’ baseline conditions

Journal of Hydrology, Special Issue, 2006, Vol 331

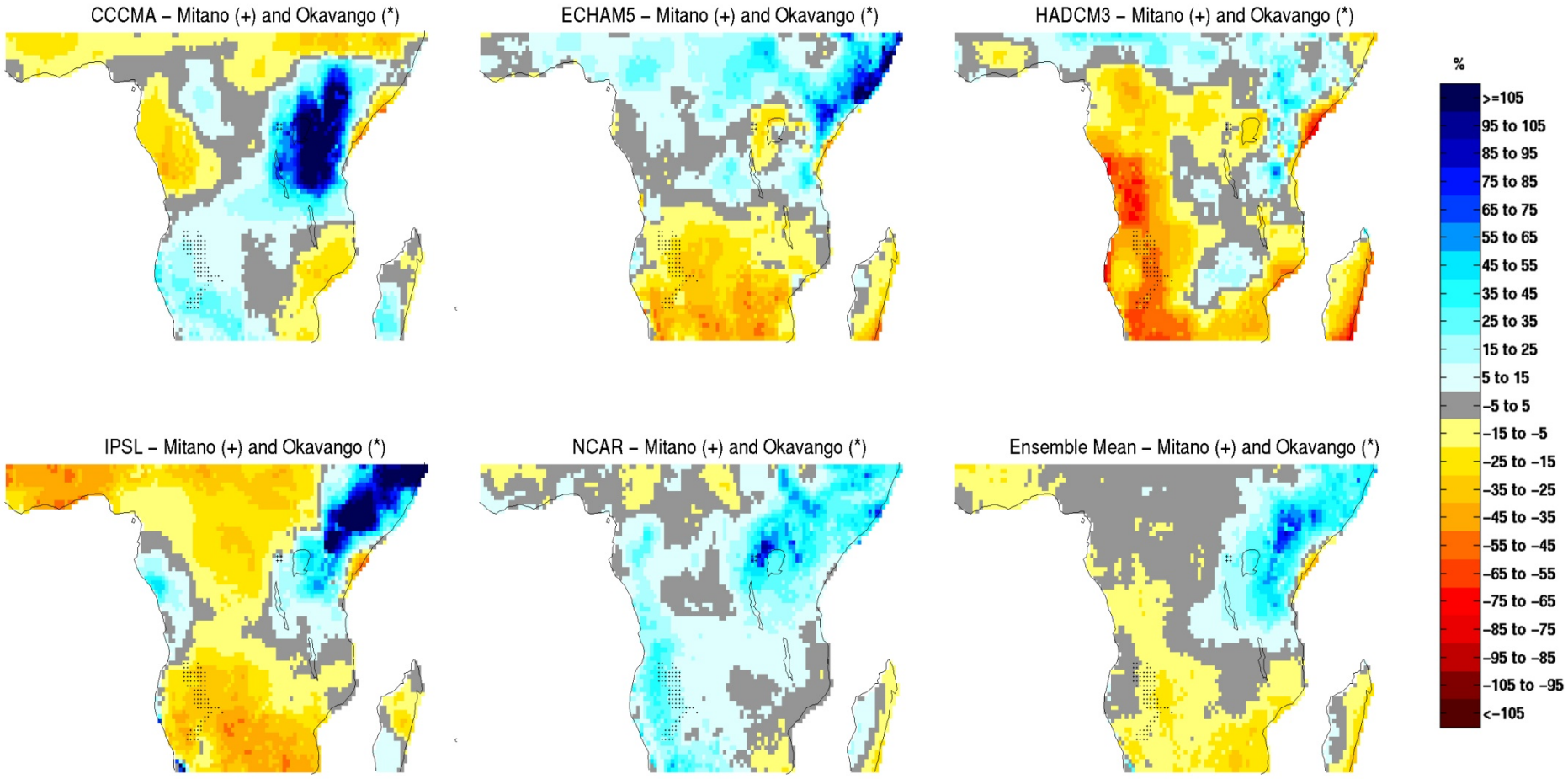
Simulated changes in Okavango delta flood class distribution



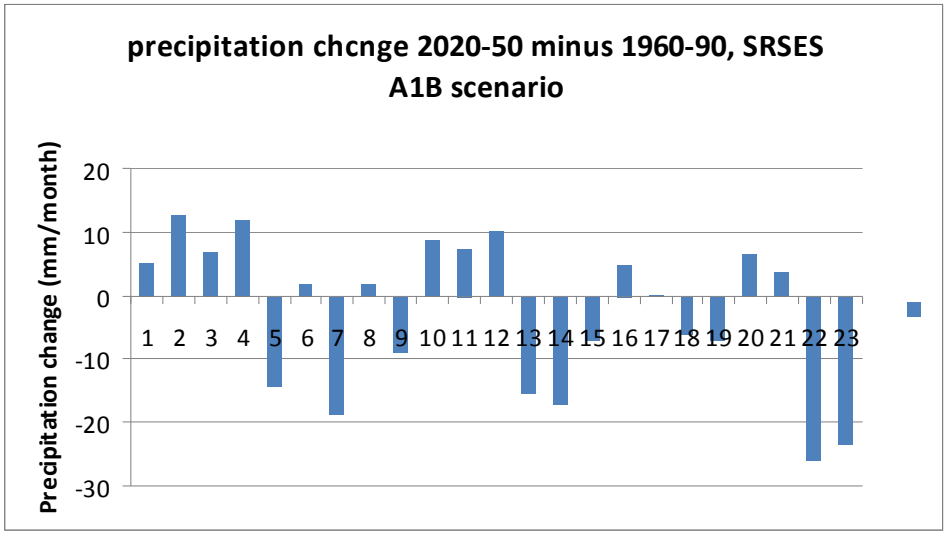
Climate 2020-50, A2 GHG

Journal of Hydrology, Special Issue, 2006, Vol 331

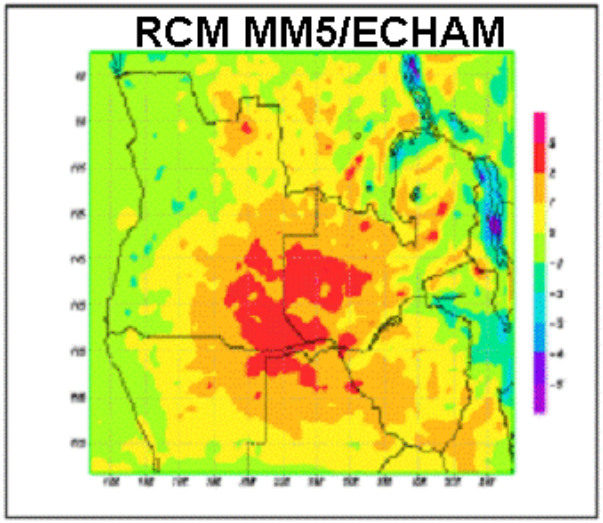
Climate change uncertainties



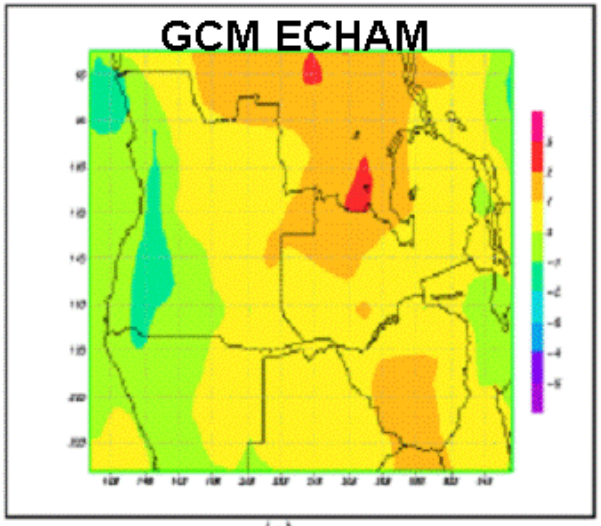
Climate change uncertainties



Downscaling climate change signal



(a)



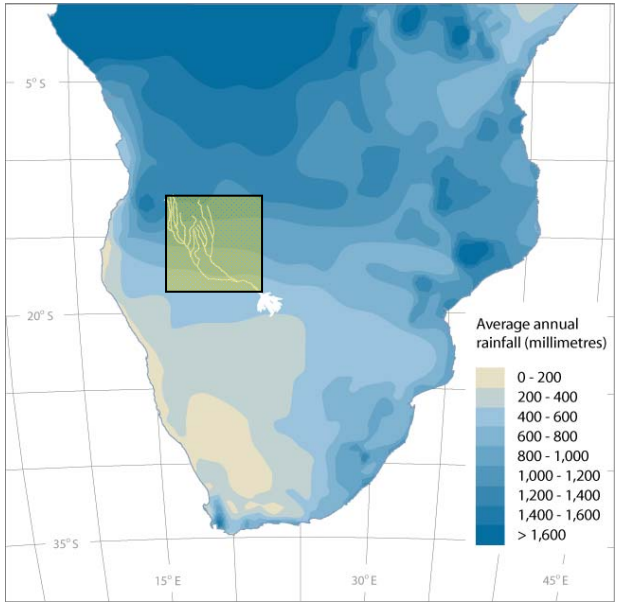
(c)

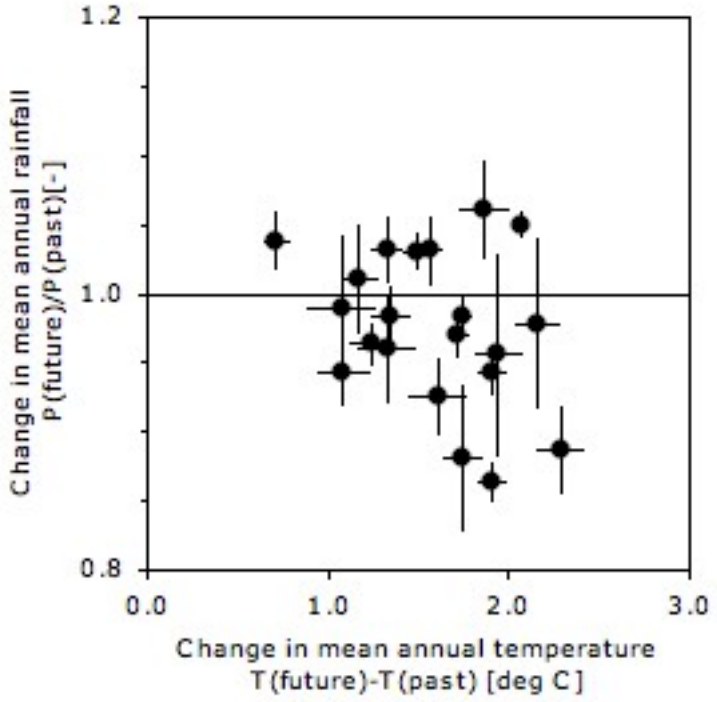
Presentation overview

- The Okavango River system
- Hydrological and ecological modelling
- Simulating climate change impacts
  - Probabilistic climate change estimates
- Conclusions

Change in mean annual values

- SRES B1 scenario, 2021-2050 compared to 1961-1990

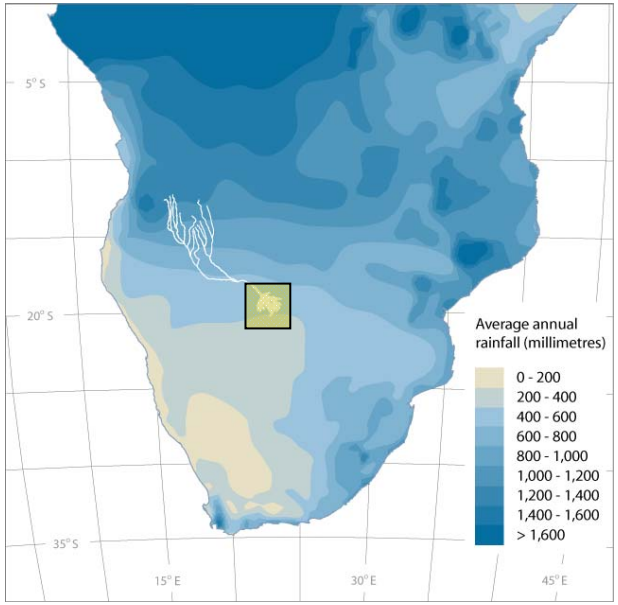


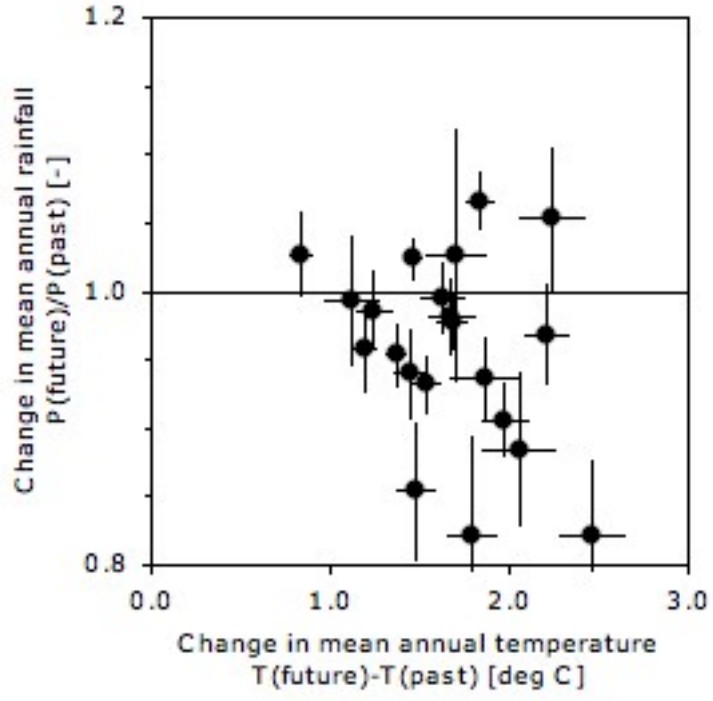


Bars denote +/- one standard error

Change in mean annual values

- SRES B1 scenario, 2021-2050 compared to 1961-1990





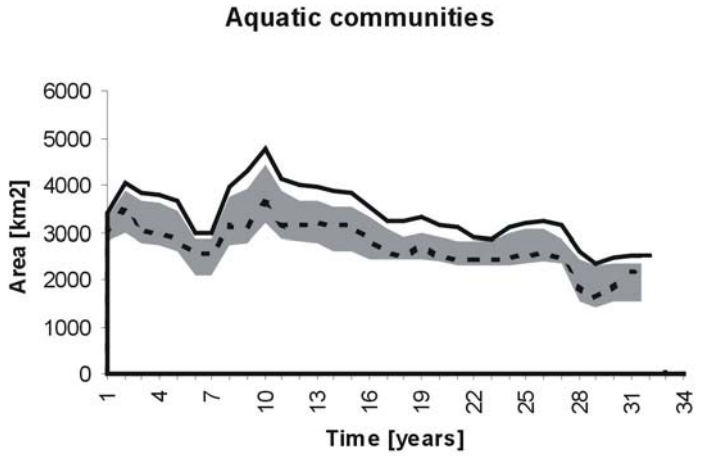
Bars denote +/- one standard error

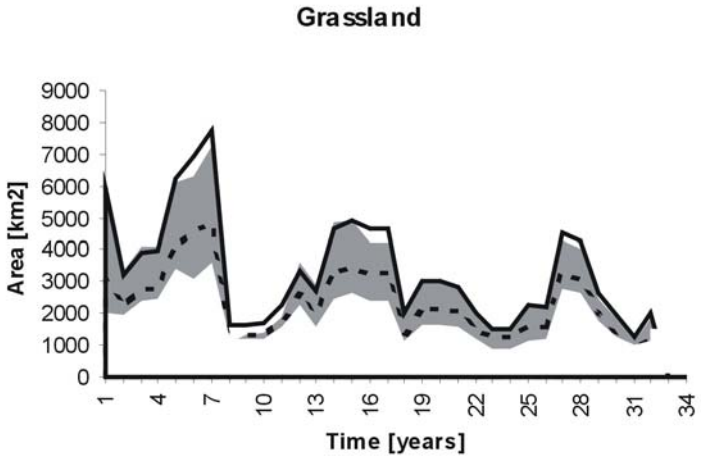
Deriving probability distributions from the multi-model ensemble

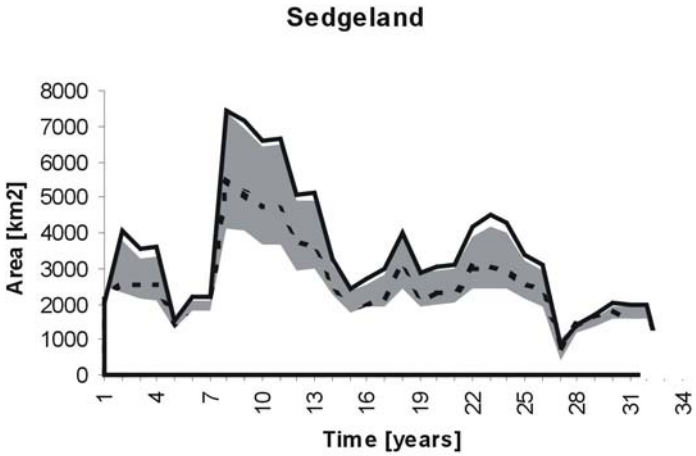
- Use Bayesian approach of Tebaldi et al. (2005)
  - Extension of Reliability Ensemble Averaging approach of Giorgi and Mearns (2002) in which GCMs weighted according to by
    - Model bias (error vs. historical obs)
    - Convergence (how close their projected climate is to that of ensemble mean)
- In Bayesian method prior distributions representing climate change uncertainty and likelihoods (from model bias and convergence criteria) are combined to give posterior distributions of climate change (using Markov Chain Monte-Carlo with Gibbs sampler)

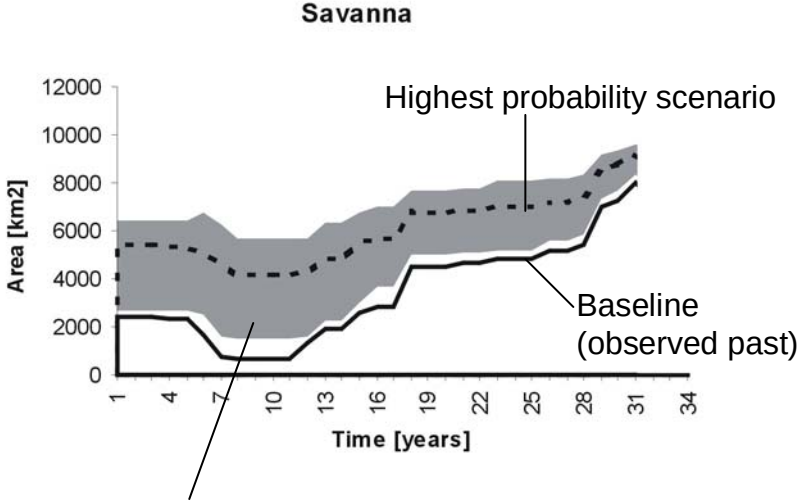
Ecotopes - vegetation communities

Results – simulated distribution of ecotopes



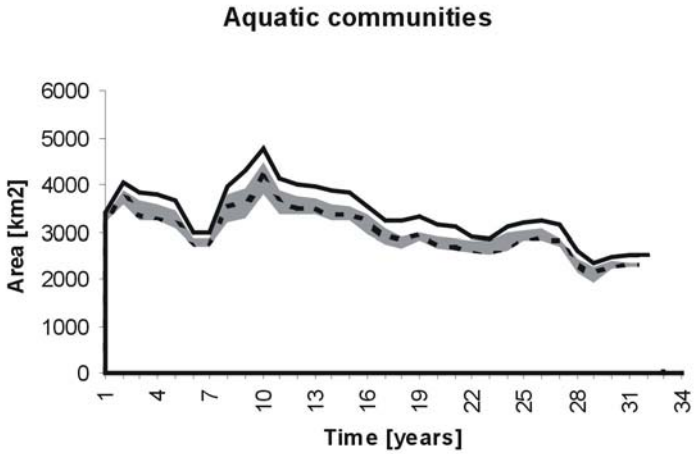


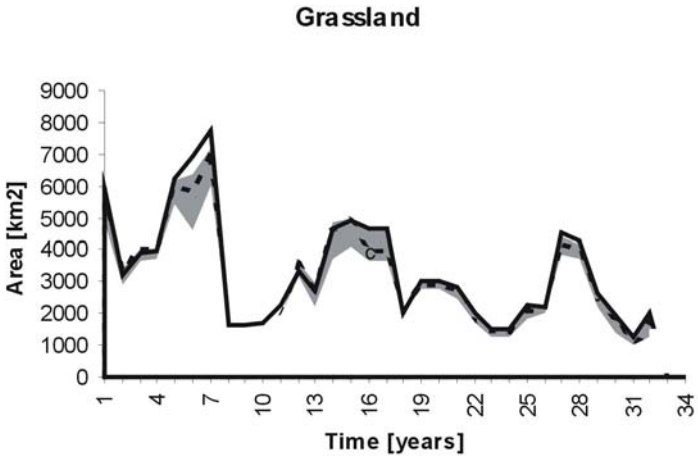


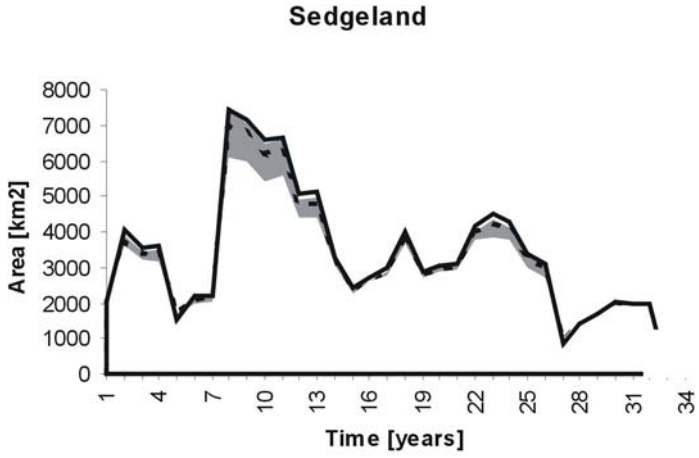


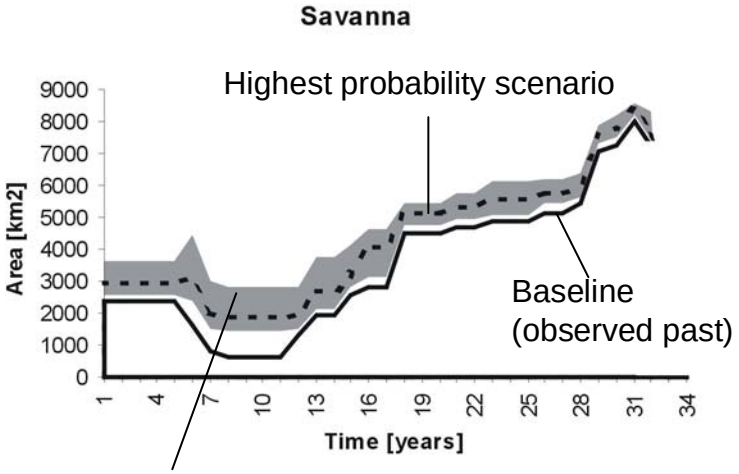
from Wolski (in prep)

Results - effects of increase in evapotranspiration in the Delta only



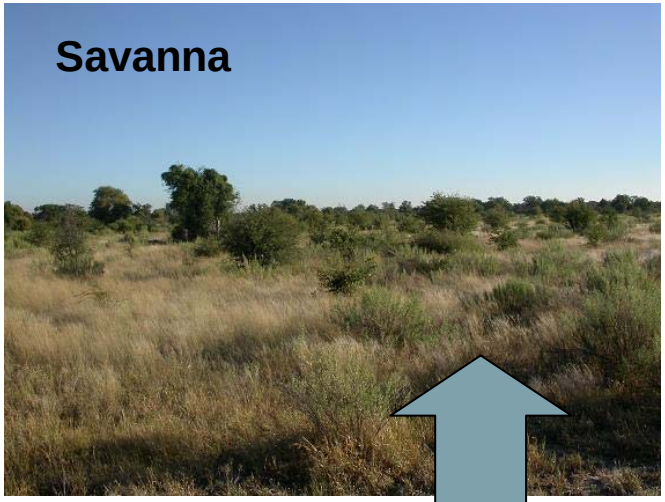






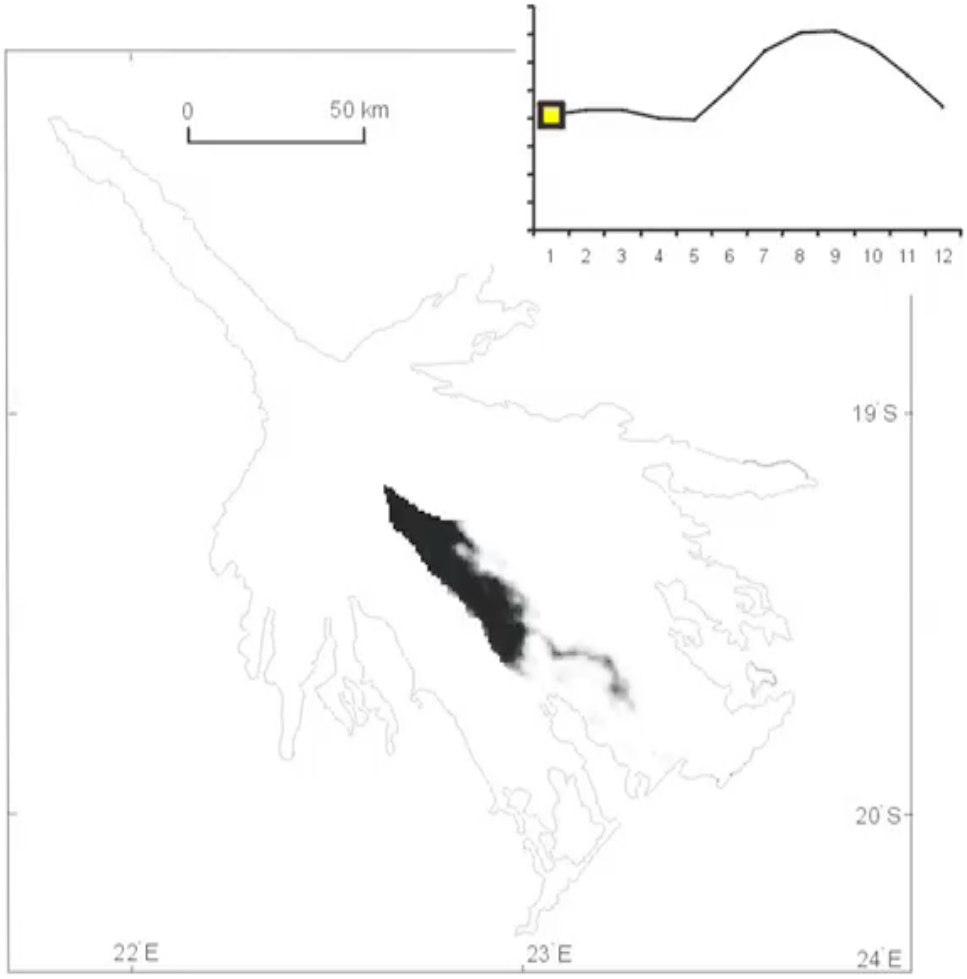
from Wolski (in prep)

Result: Transition to drier ecology



Summary and conclusions

- Okavango river is of major socio-economic and ecological importance in Africa
  - River catchment and delta provide vital ecosystem services
- Complex climate with pronounced variability
- Potential climate change impacts assessed using suite of hydrological and ecological models
- Results indicate that climate change impacts are potentially very large
  - Greater than variability in 20th century
  - (greater than development scenarios)
- Uncertainty in projected impacts very large and sign uncertain
  - Problematic for policy makers
- Probabilistic estimates of future climate
  - Indicate likely drying in hydrology in the Delta
- Criteria for GCM weighting is a contentious issue



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