AFRIVAL Project (African River Basins)
http://ees.kuleuven.be/project/afrival/
EGU General Assembly 2014, Vienna

Temporal variability and spatial dynamics of CO_2 and CH_4 concentrations and fluxes in the Zambezi River system

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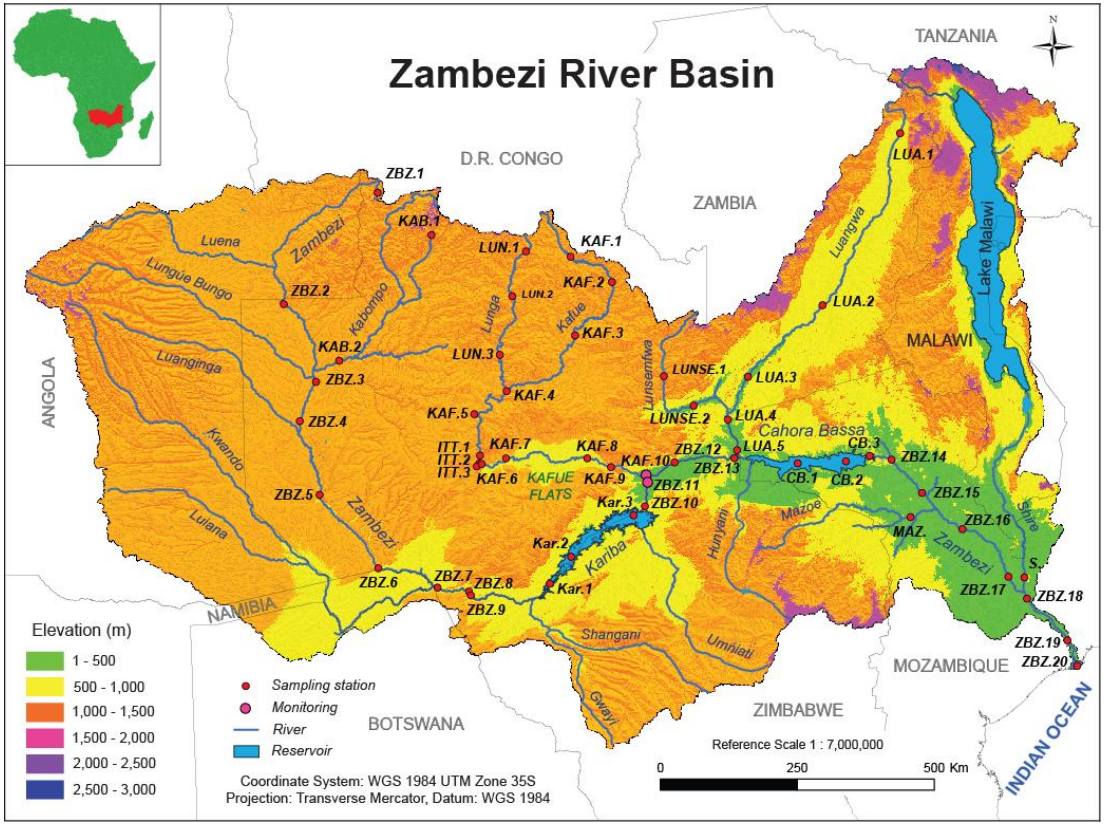
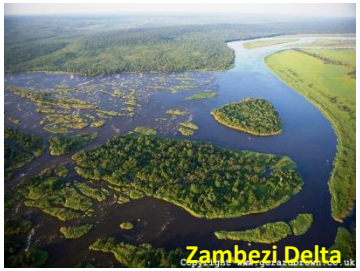
Introduction: Zambezi River Basin

The Zambezi River Basin – general characteristics

- 4th larges in Africa and the largest (from Africa) flowing in to the Indian Ocean
- Total length: over 3000 km; Drainage basin: ~ 1.4 Mio km^2 (shared by 8 countries)
- Main tributaries: Lungwebungu (115 m^3/s), Kabompo (270 m^3/s), Luangina (65 m^3/s), Kwando (53 m^3/s), Gwayi (85 m^3/s), Kafue (370 m^3/s), Luangwa (520 m^3/s), Shire (115 m^3/s)
- 2 main reservoirs: Kariba (5580 km^2; 180 km^3), and Cahora Bassa (2670 km^2; 52 km^3)

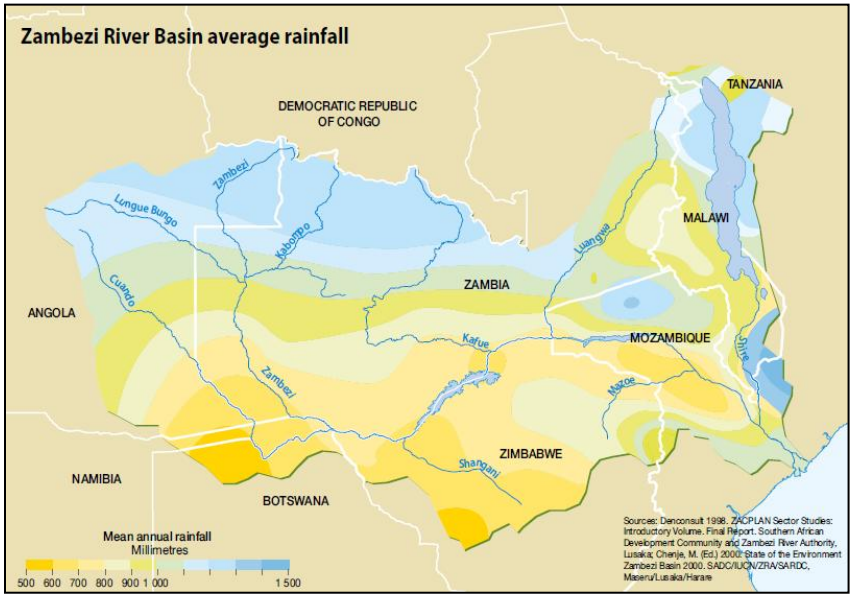


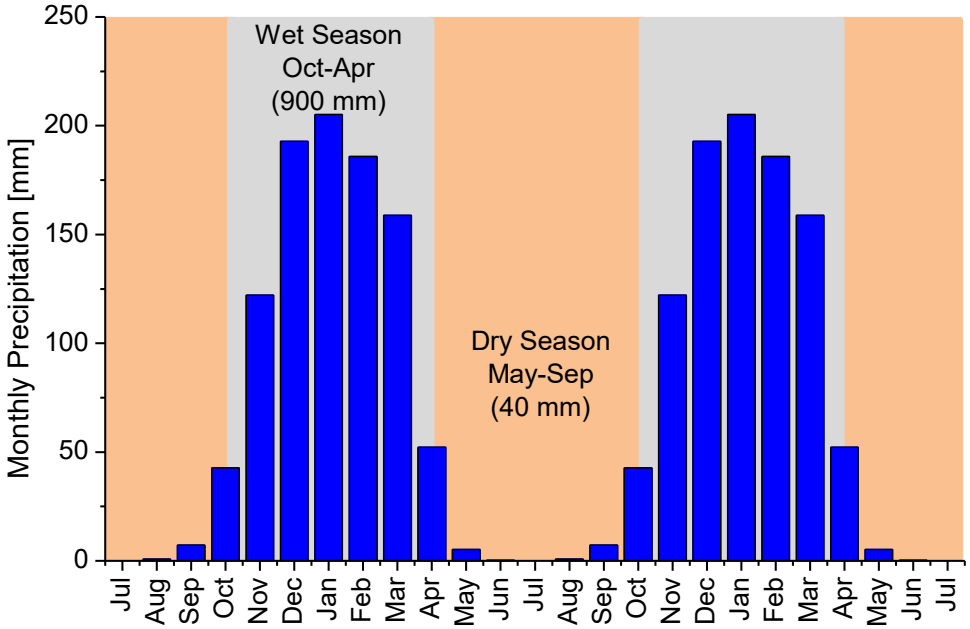


Introduction: Zambezi River Basin

The Zambezi River Basin – climate and rainfall

- Climate is classified as ***humid subtropical*** or ***tropical wet and dry***
- Temperature across basin ***varies with elevation*** and, ***and less with latitude***
- Mean monthly T: ***13°C*** for higher elevation in S to ***23°C*** in E (July); and ***23°C*** - ***31°C*** (Oct)
- Annual rainfall ***varies with latitude***: ***1400 mm*** in N to ***400/500 mm*** in S (mean average rainfall for entire basin: ***940 mm***)
- Two seasons:
  1. ***Wet season*** (Oct/Nov – Apr) corresponding to summer, with 95% of annual rainfall (***900 mm***)
  2. ***Dry season*** (May – Sep/Oct), corresponding to winter, with 5% of annual rainfall (***40 mm***). Dry season is further divided into cold dry: May-Aug and hot dry: Aug-Sep/Oct.

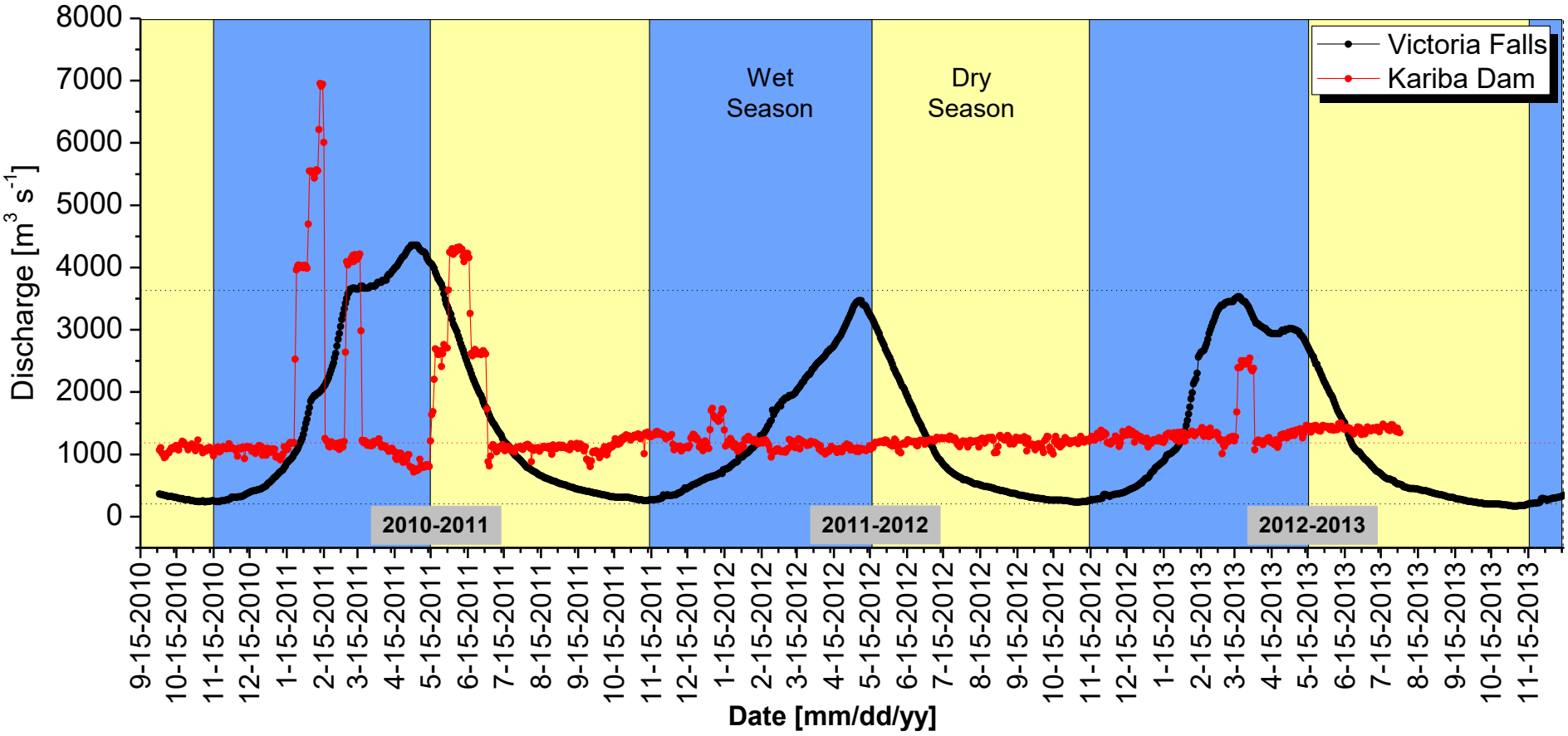




Introduction: Zambezi River Basin

The Zambezi River Basin – hydrological cycle

- Driven by seasonality in rainfall patterns, hydrological cycle of the basin has a bimodal distribution with a ***single main peak flood*** (max. Q: Apr/May) and min. flow in Oct/Nov
- Due to regional rainfall distribution, northern tributaries contribute much more water than southern ones
- Average annual discharge at Zambezi Delta: *3800-4130 m^3 s^{-1}*



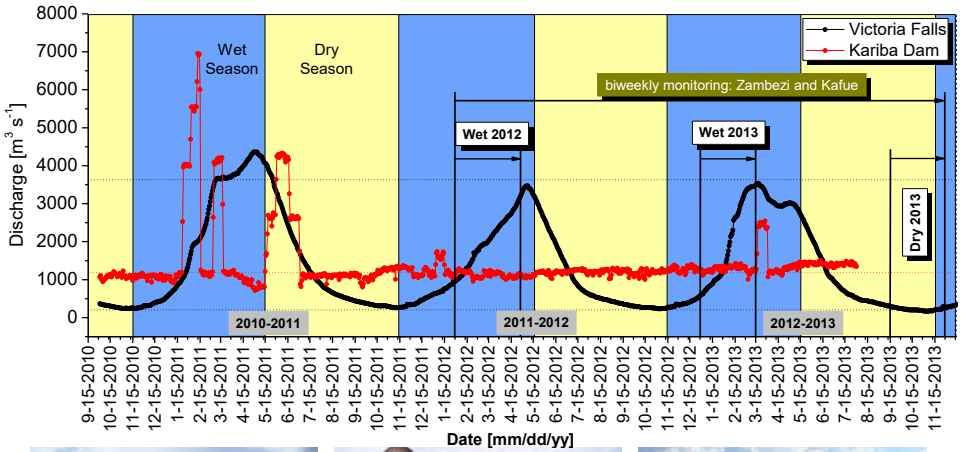
Sampling & Methods

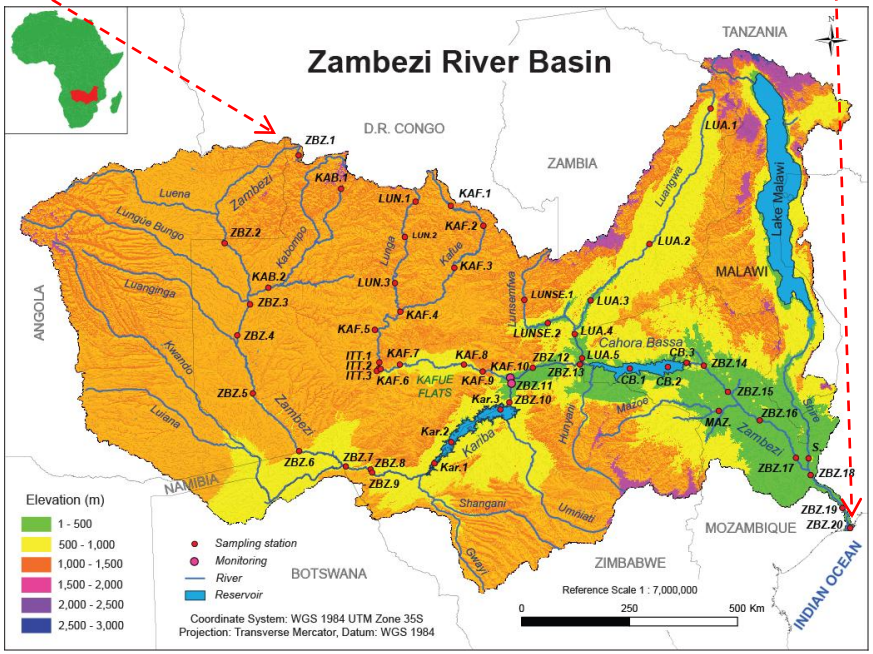
Sampling Strategy

- 3 sampling campaigns: ***Wet*** (Feb-Apr) 2012, ***Wet*** (Jan-Apr) 2013, ***Dry*** (Oct-Dec) 2013
- Over ***50 sampling sites***: 26 along Zambezi (Kariba & CB), and 30 on tributaries (ITT res.)
- ***2 monitoring stations*** (Feb 2012 – Dec 2013) :

ZBZ.11 ~ 5 km upstream the confluence with Kafue

KAF.10 ~ 6 km upstream the confluence with Zambezi

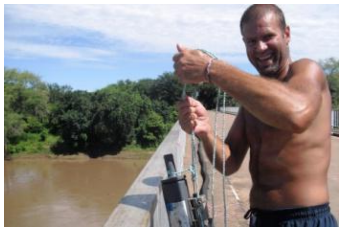




Sampling and Methods: Parameters

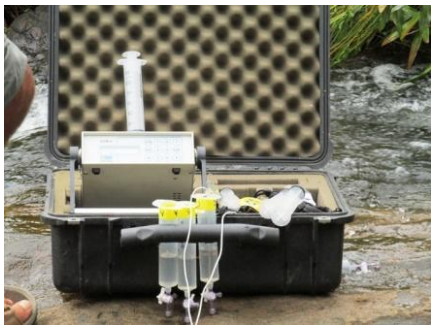
Measured parameters

- Physico-chemical: ***pH, O_2, T, conductivity, TA,*** nutrients, major elements
- Total Suspended Matter (TSM)
- Concentration and stable isotope (***$\delta^{13}C$*** and $\delta^{15}N$) composition of POC, DOC, ***DIC,*** PN and POP
- Aquatic metabolism: community respiration & primary production
- GHG (***CO_2, CH_4, N_2O***) concentrations and fluxes

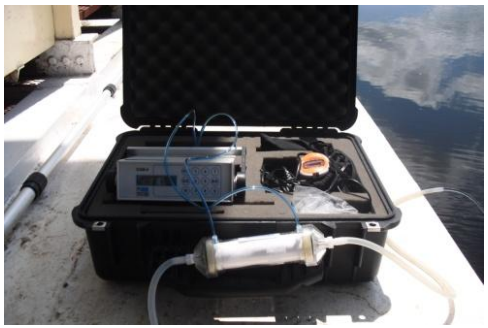


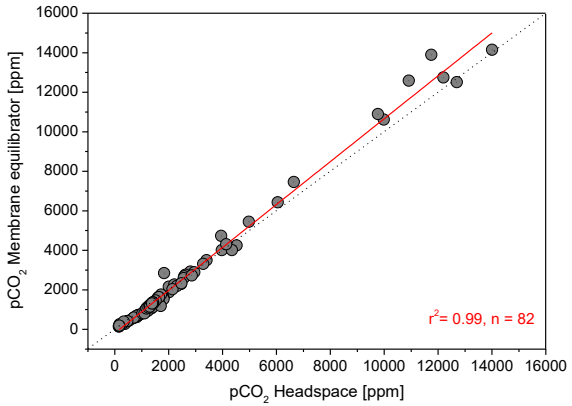
In-situ pCO_2 measurements

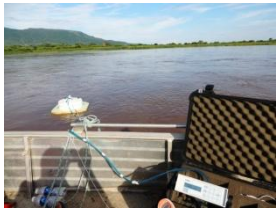
Headspace Technique

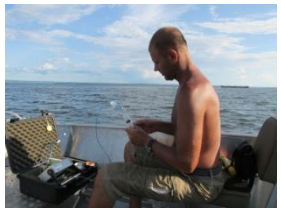


Membrane Equilibrator



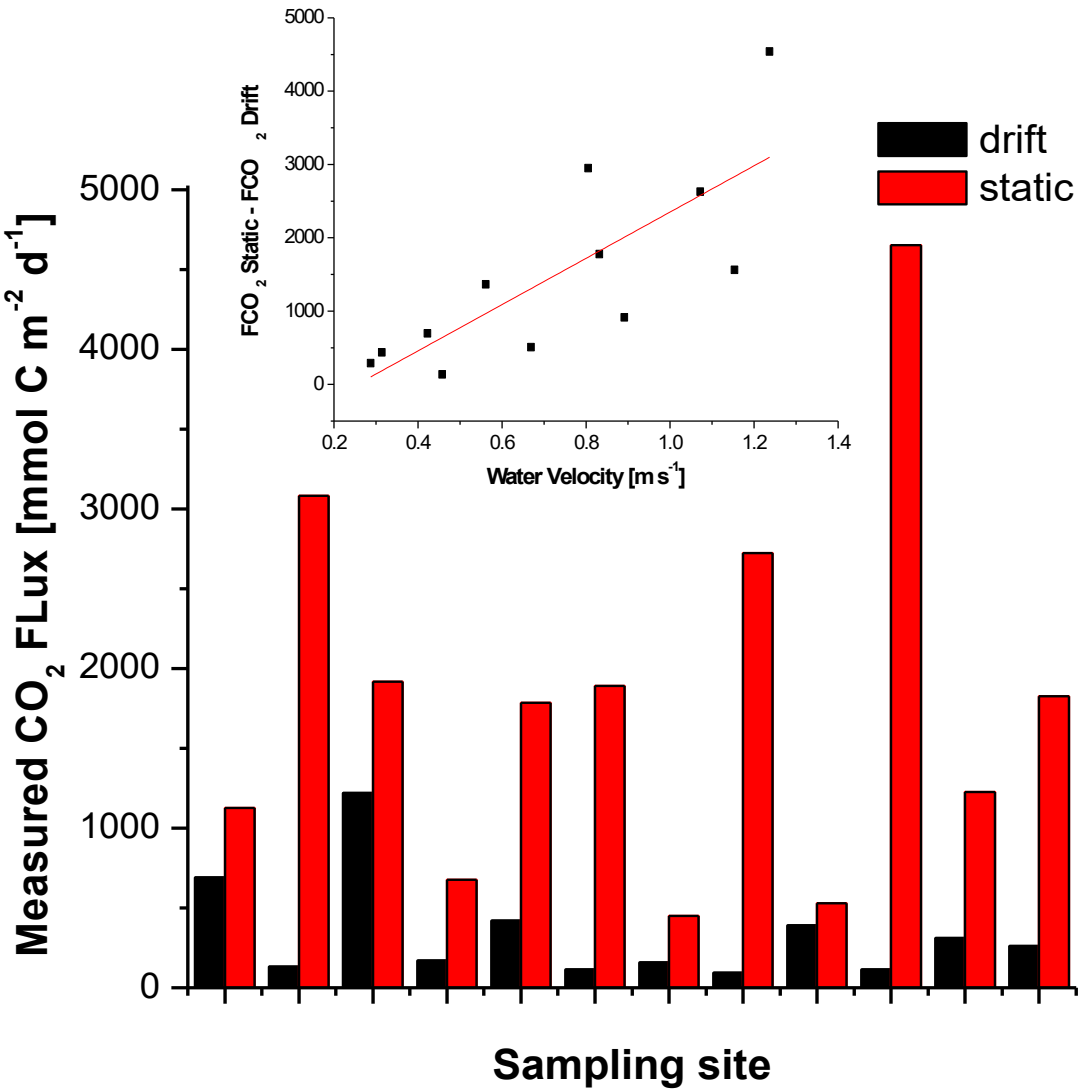






Sampling and Methods: Parameters

Flux measurements: Floating chamber

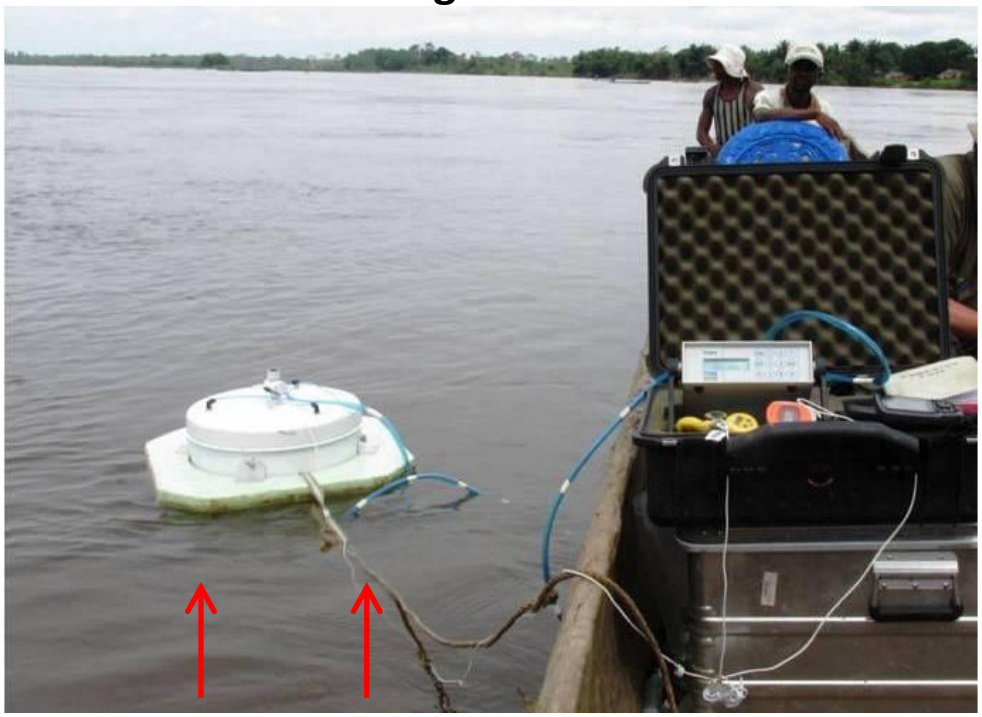


Drift mode

Static mode

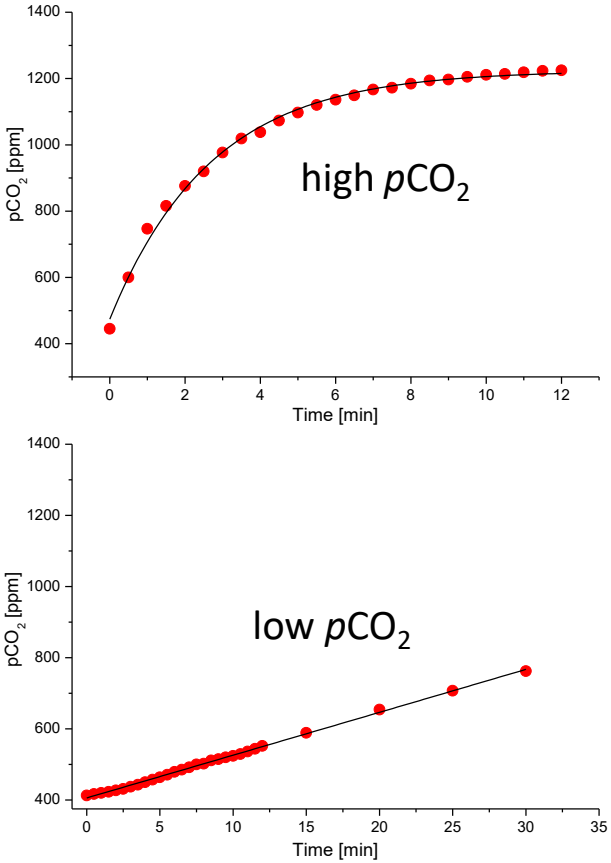
Sampling and Methods: Parameters

Floating chamber



FCO_2 Total FCH_4

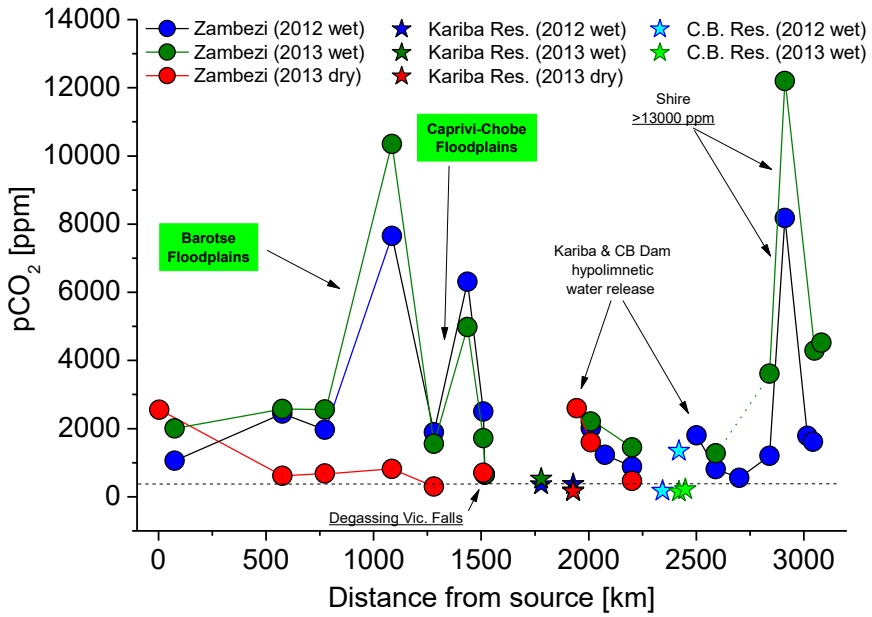
Increase in gas conc. over time

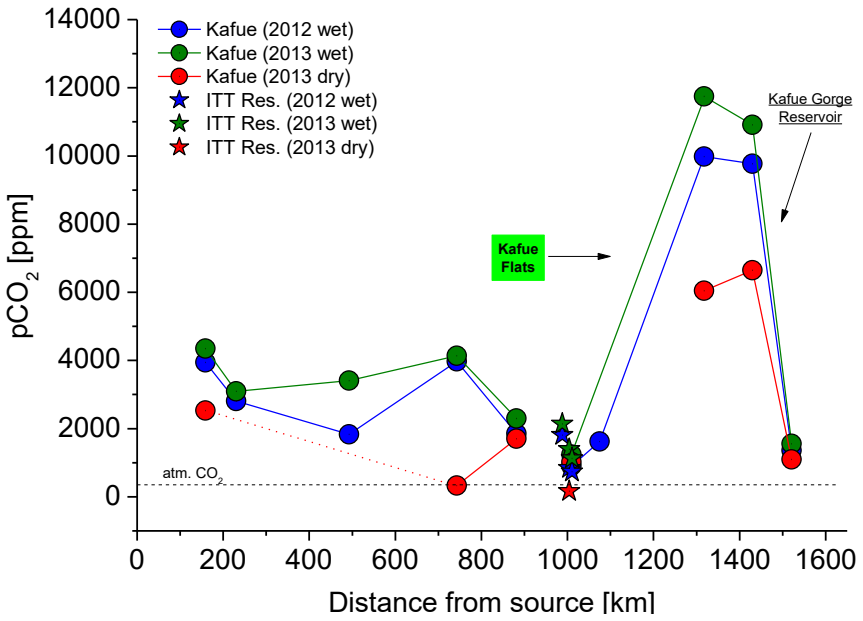


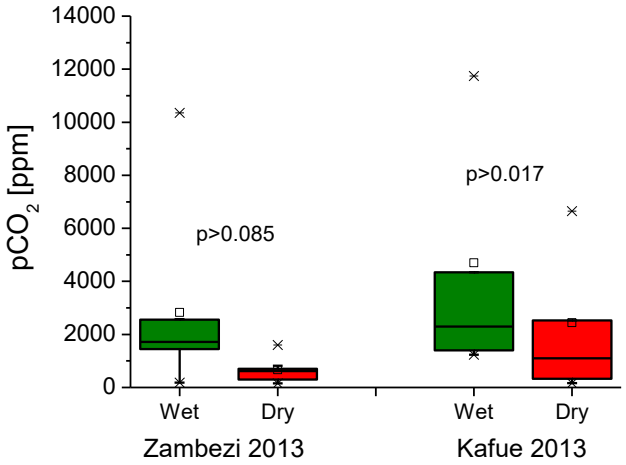
$F_{CO2} = k \Delta CO_2$ ➡ $k = F_{CO2} / \Delta CO_2$

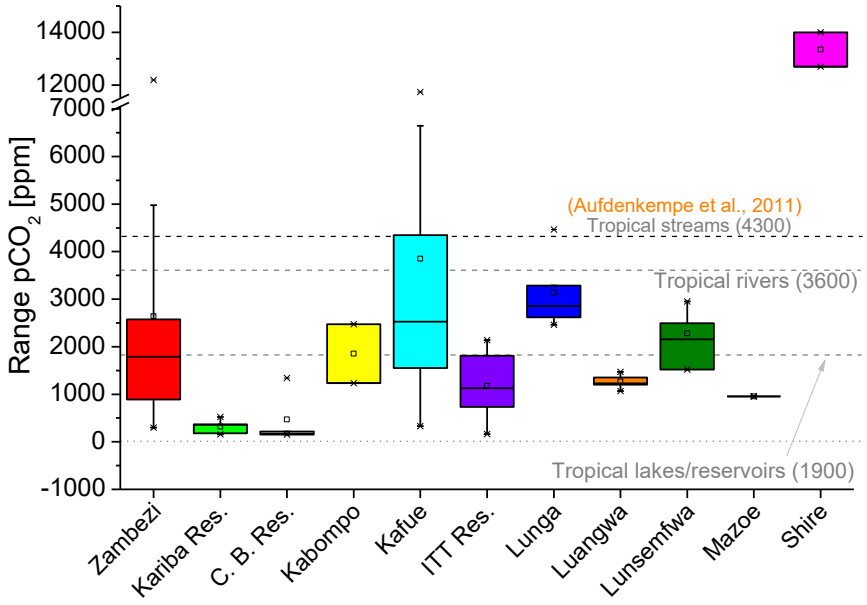
Diffusive $F_{CH4} = k \Delta CH_4$ ➡ Total F_{CH4} = diffusive F_{CH4} + Ebullitive F_{CH4}

Results: CO_2 – spatio-temporal dynamics

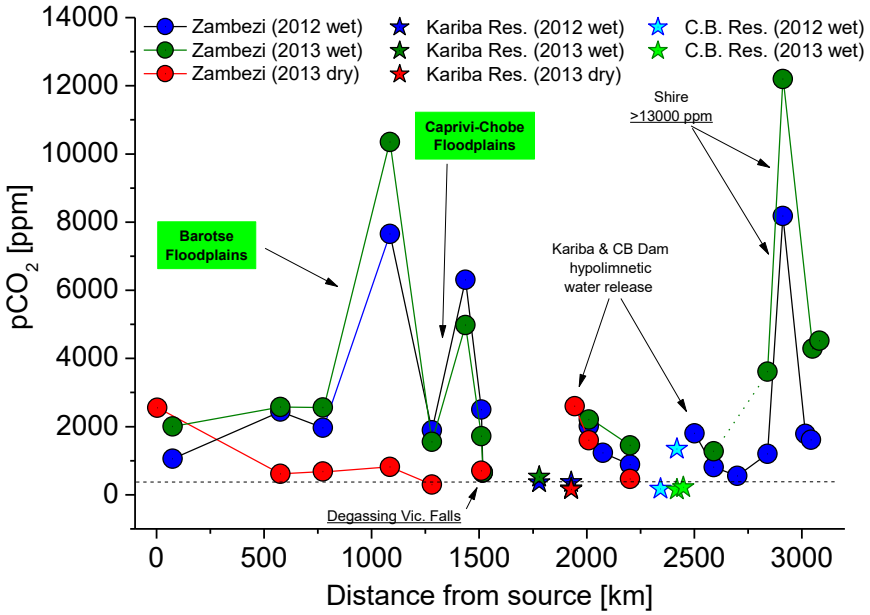


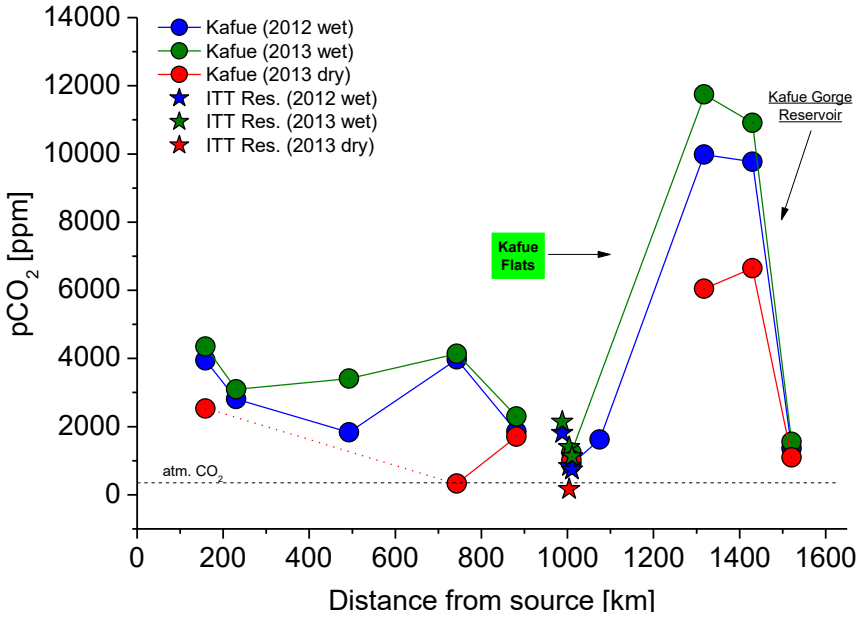


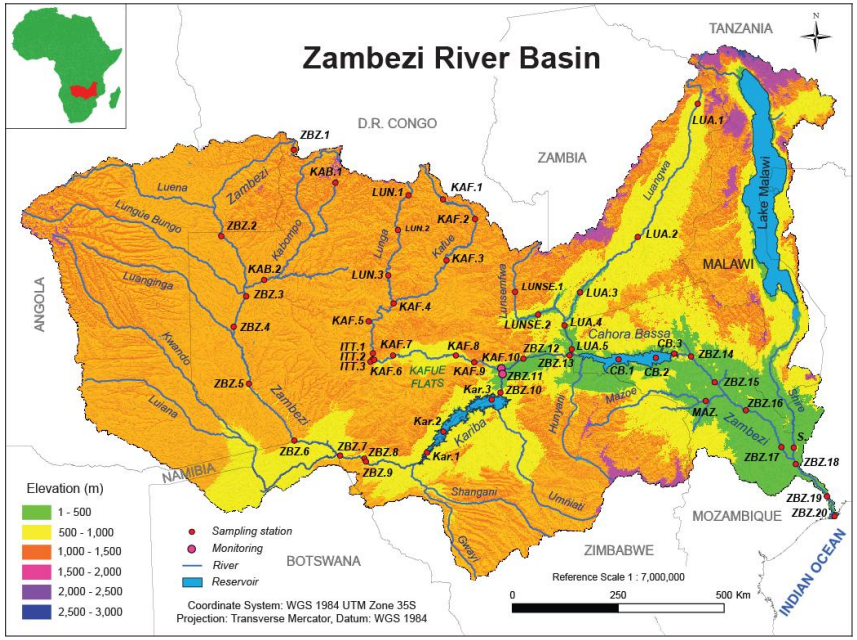




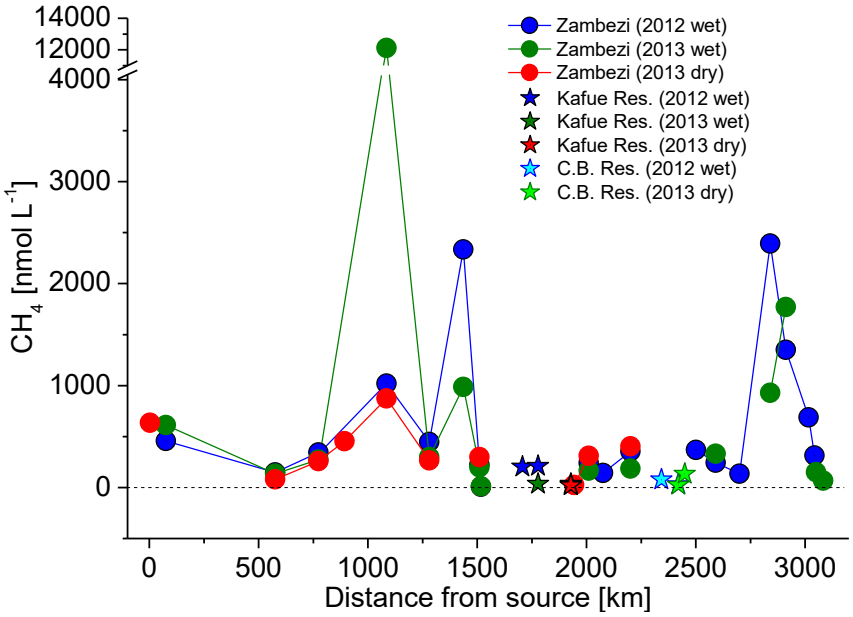
Results: CO_2 – spatio-temporal dynamics

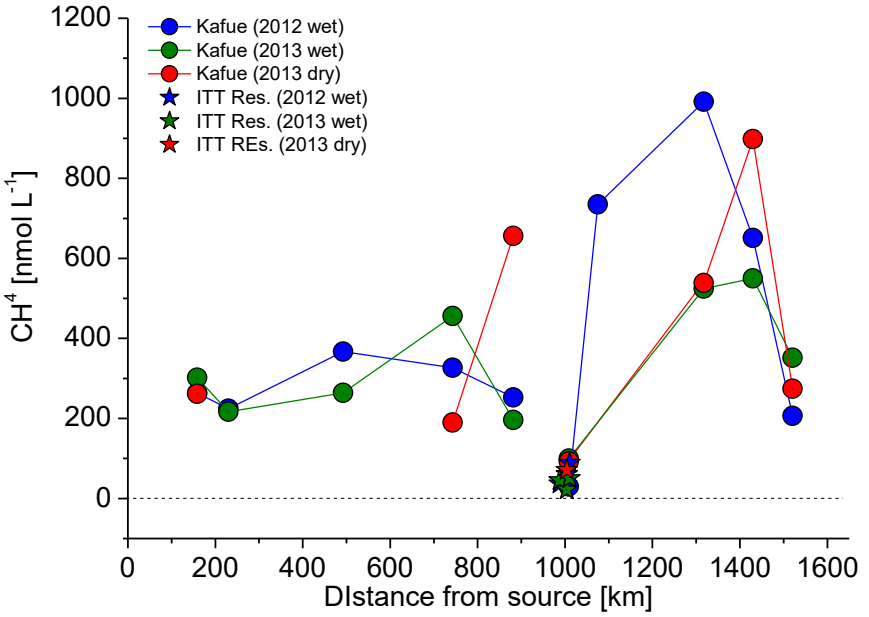


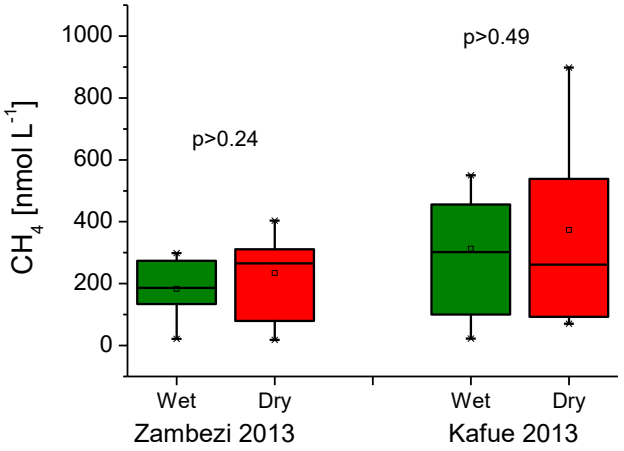


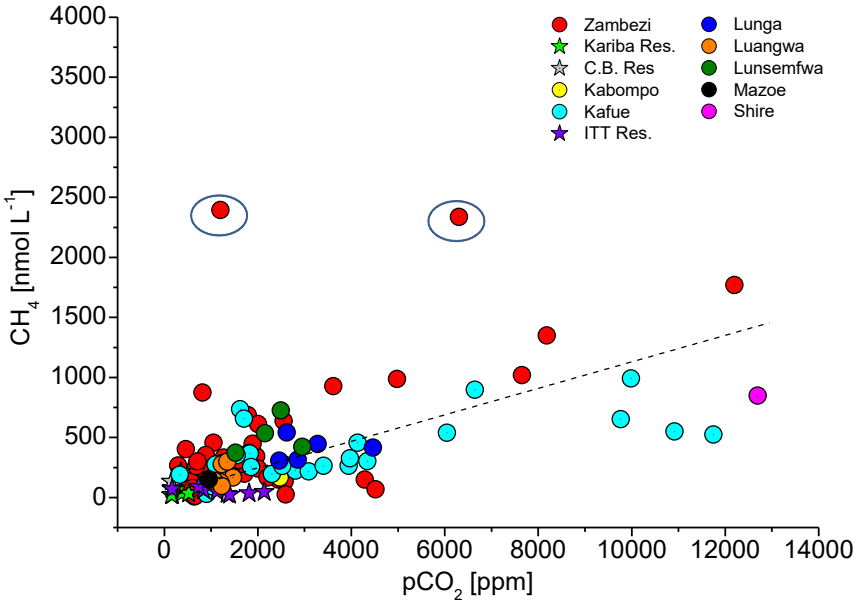


Results: CH_4 – spatio-temporal dynamics

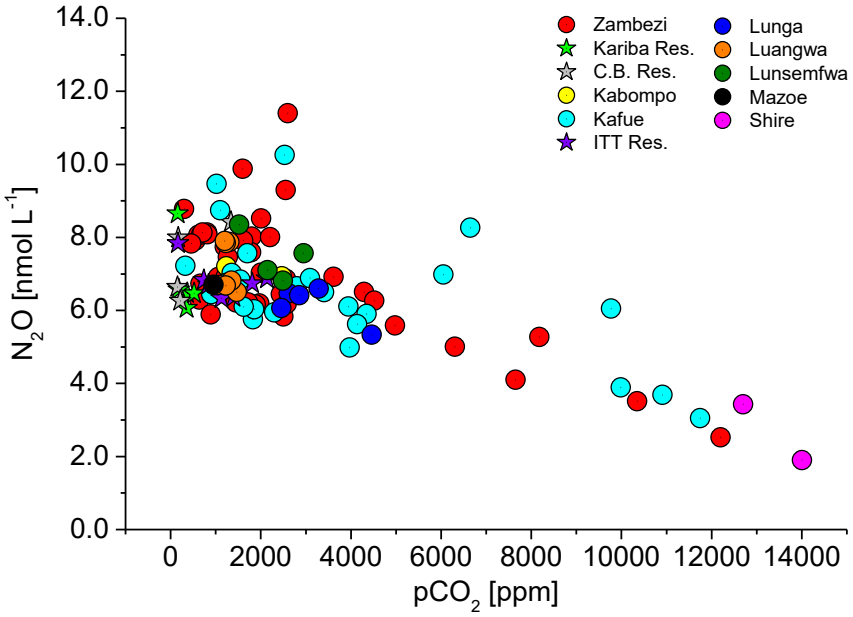


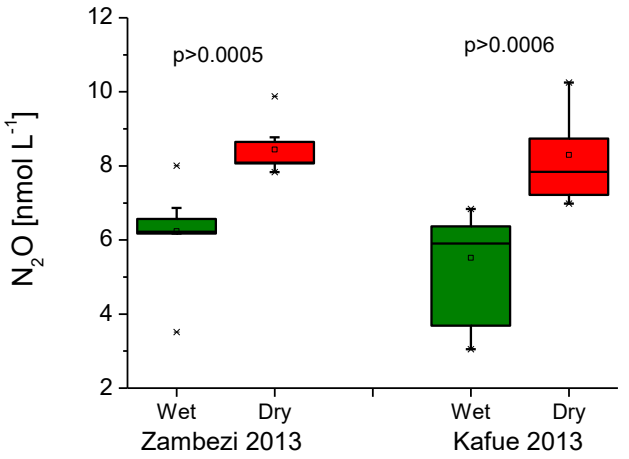


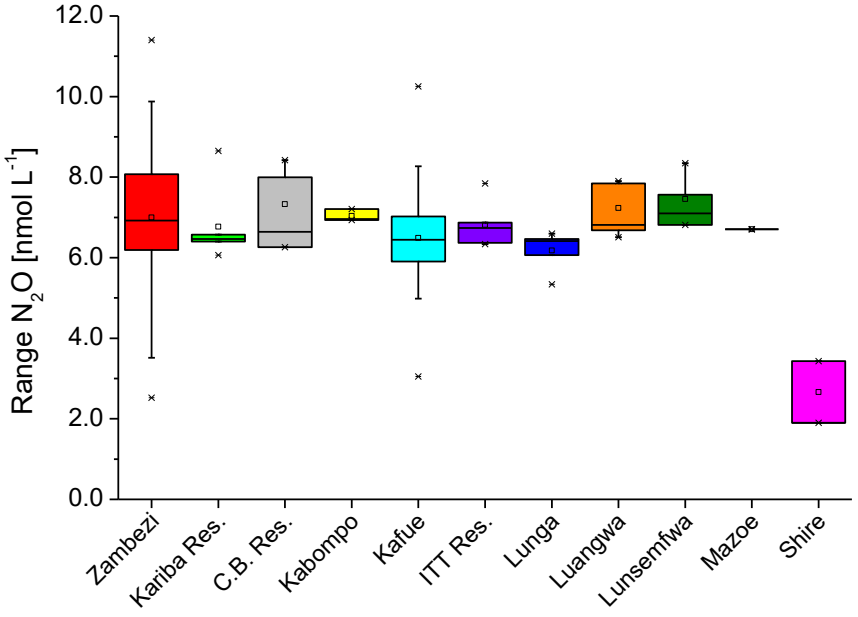




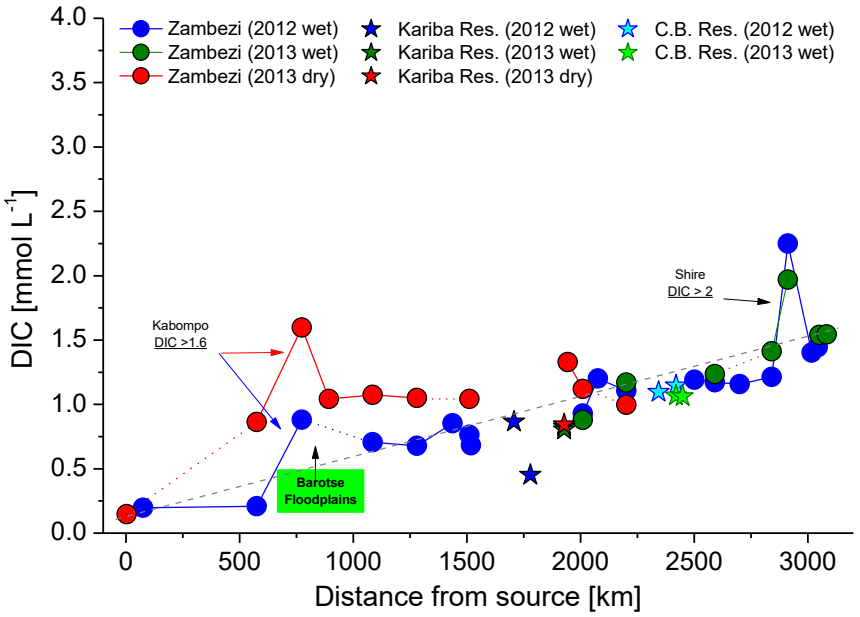
Results: N_2O – spatio-temporal dynamics

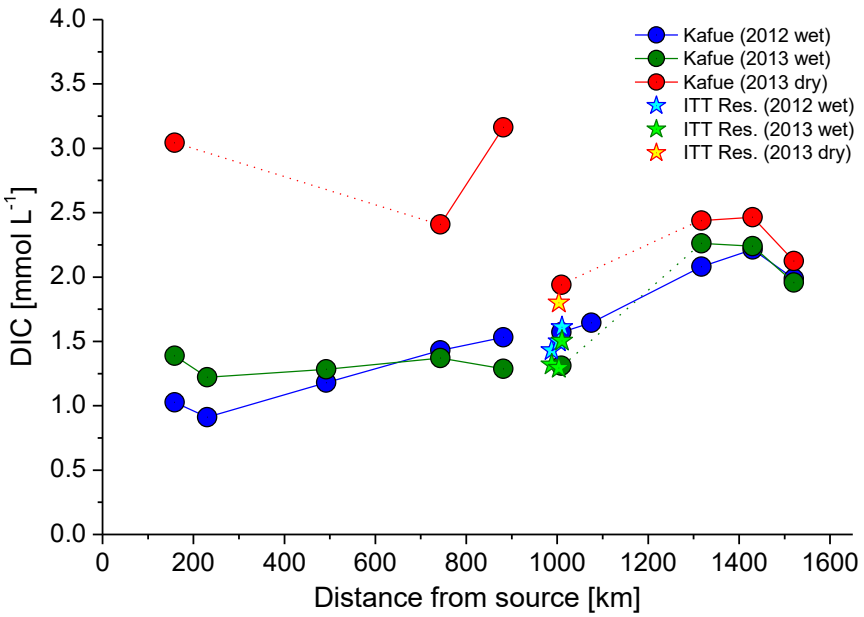


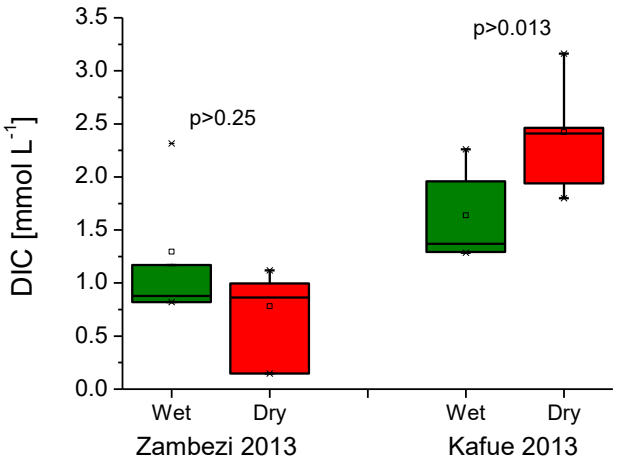


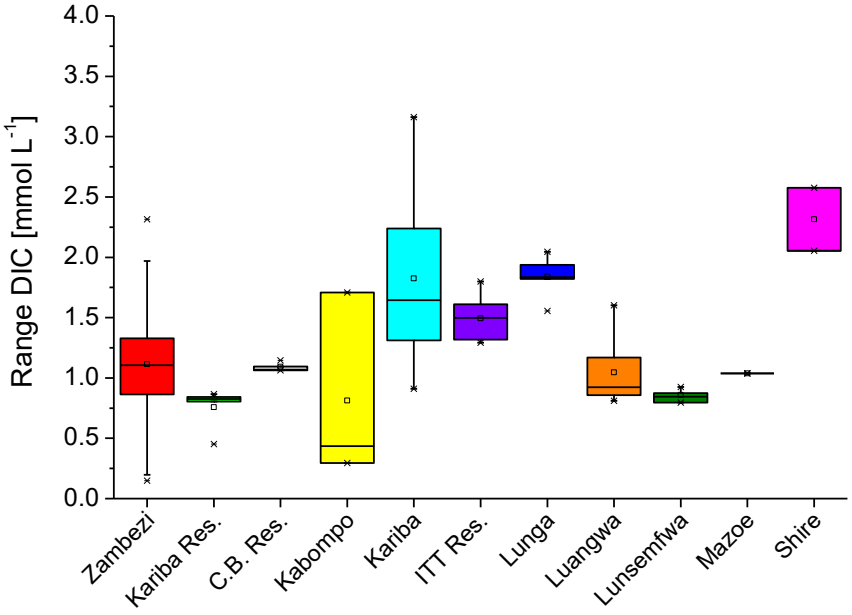


Results: DIC - spatio-temporal variability

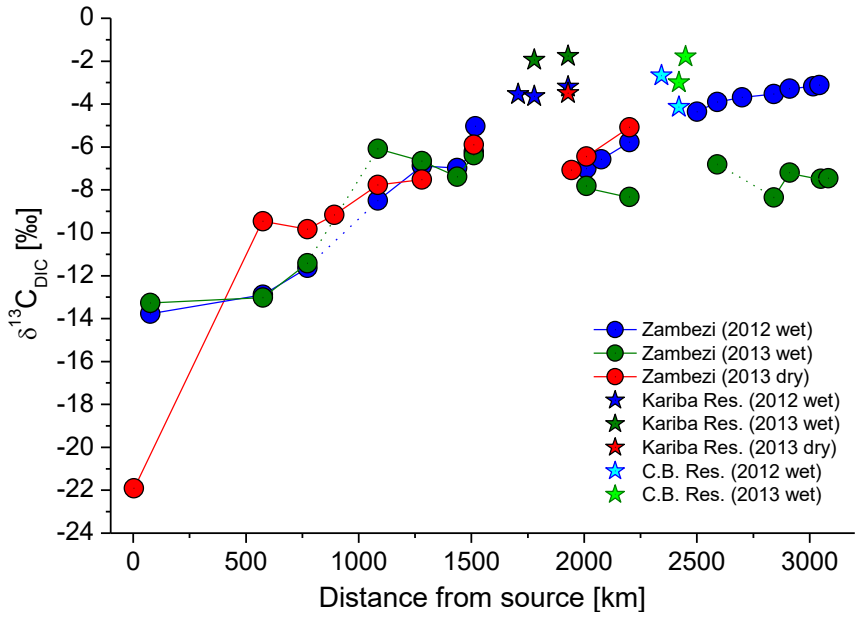


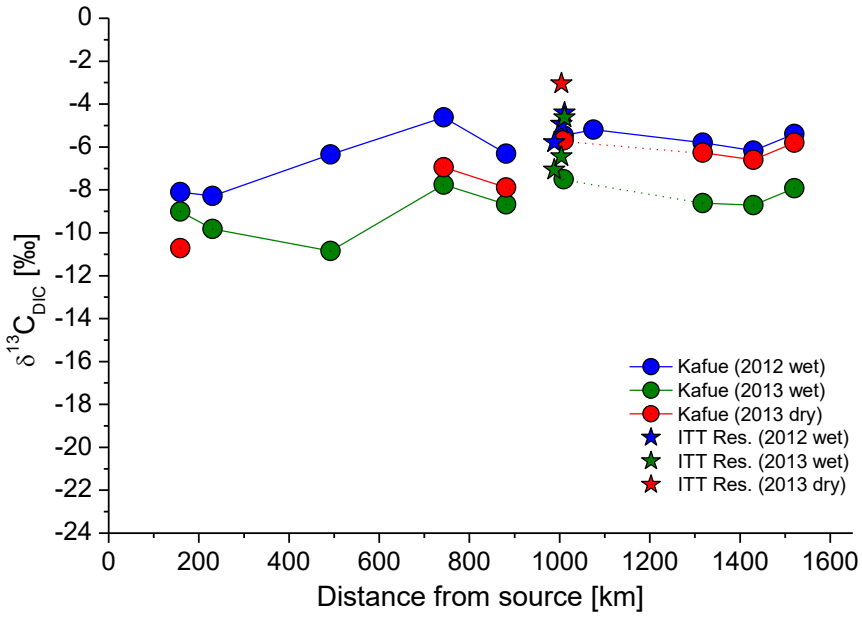


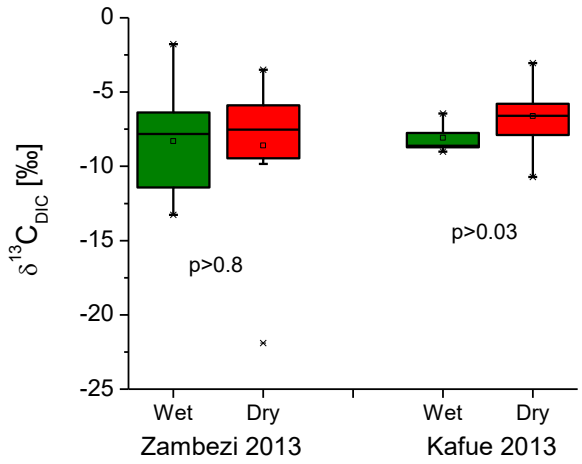


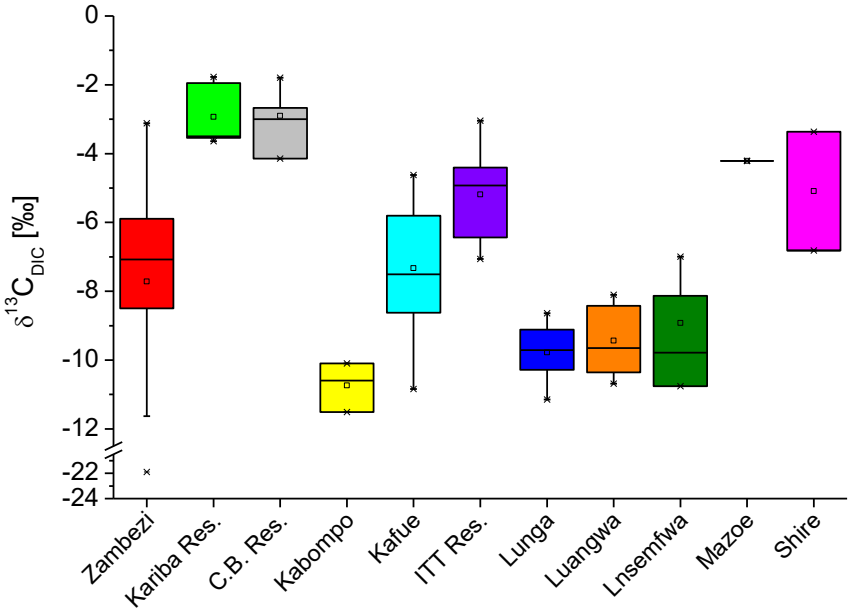


Results: $\delta^{13}C_{DIC}$ - spatio-temporal variability

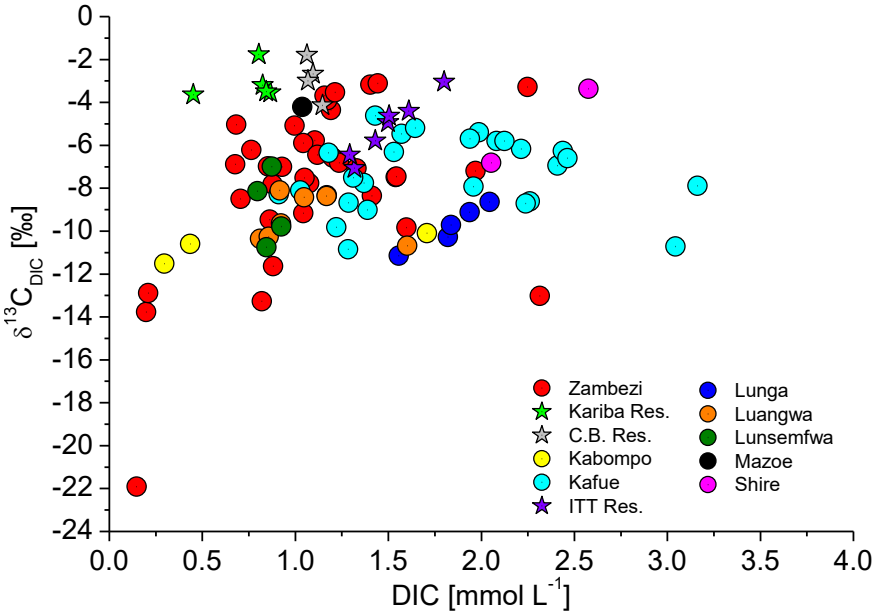


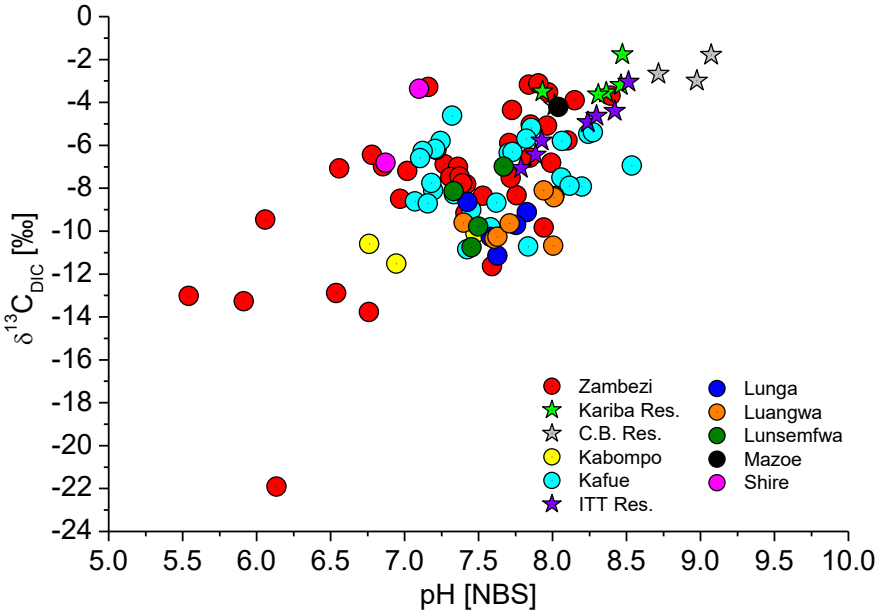






Results: DIC & $\delta^{13}C_{DIC}$

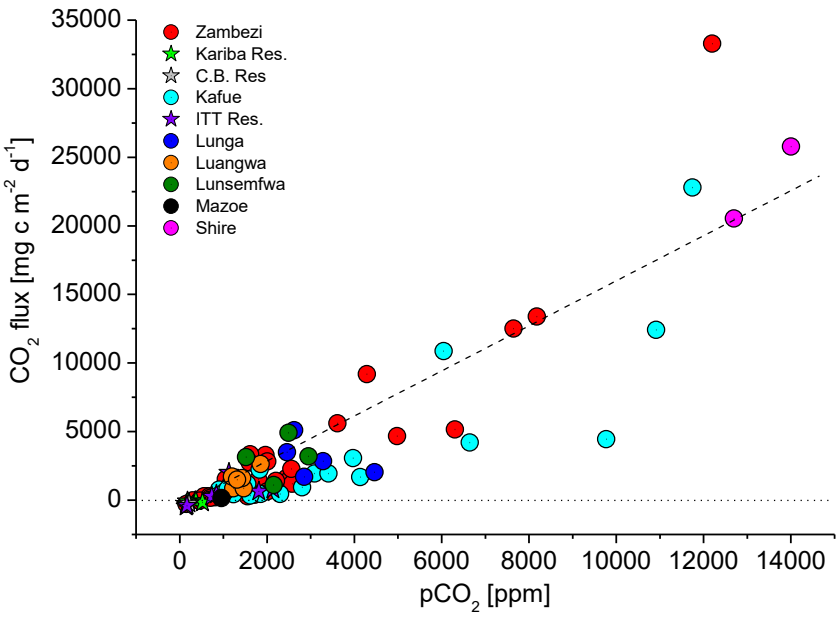


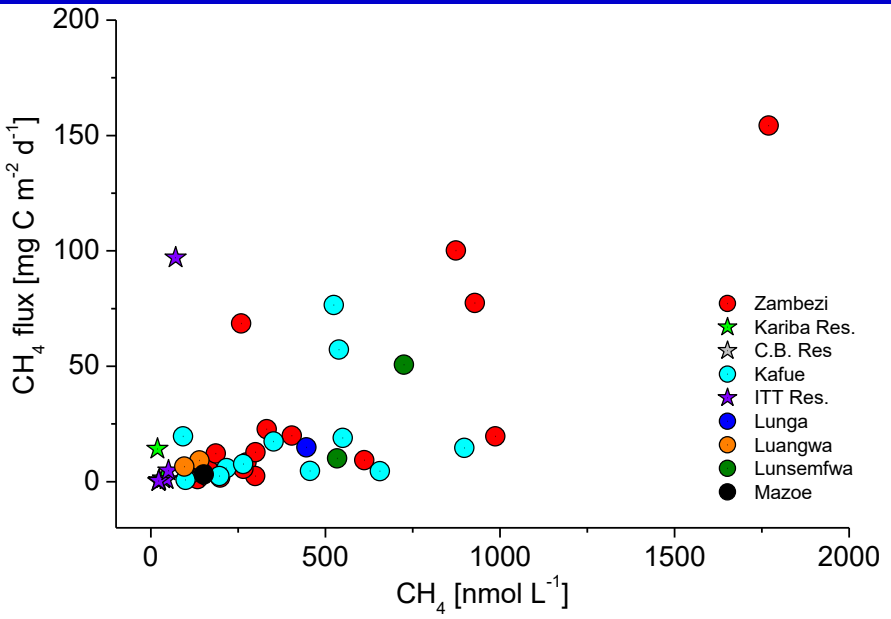


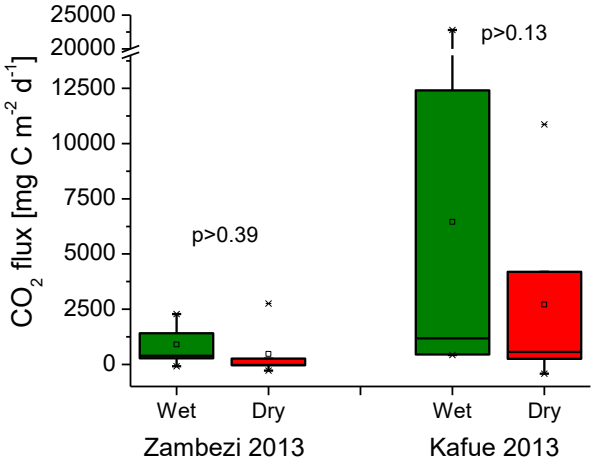
River	DIC [mmol L^{-1}]	$\delta^{13}C_{DIC}$ [‰]
Zambezi	1.11	-7.72
Kafue	1.83	-7.33
Kariba Res.	*0.76*	*-2.93*
C.B. Res.	*1.09*	*-2.90*
ITT Res.	*1.49*	*-5.19*
Kabompo	0.81	-10.74
Lunga	1.84	-9.78
Luangwa	1.05	-9.43
Lunsemfwa	0.86	-8.92
Mazoe	1.04	-4.21
Shire	2.32	-5.09

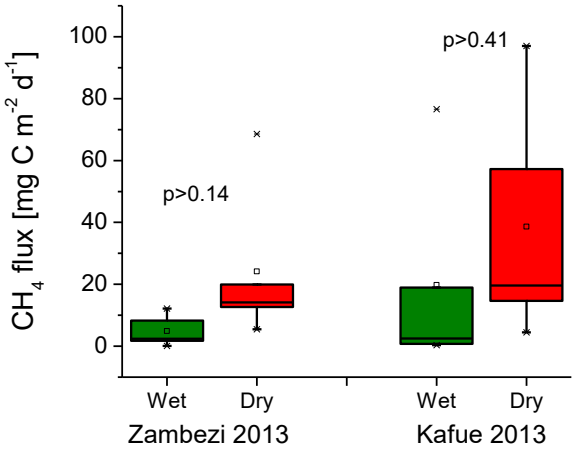
- ***Zambezi and Kafue rivers*** have ***$\delta^{13}C_{DIC}$*** -7
- ***$\delta^{13}C_{DIC}$ enrichment*** => carbonate weathering /dissolution and/or downstream degassing of groundwater
- **Reservoirs *$\delta^{13}C_{DIC}$*** - outgassing & photosyntesis
- ***Kabompo, Lunga, Luangwa*, Lunsemfwa** => increased contribution of soil CO_2 with C4 vegetation (~ -9‰) or weathering

Results: Fluxes to atmosphere - CO_2 and CH_4



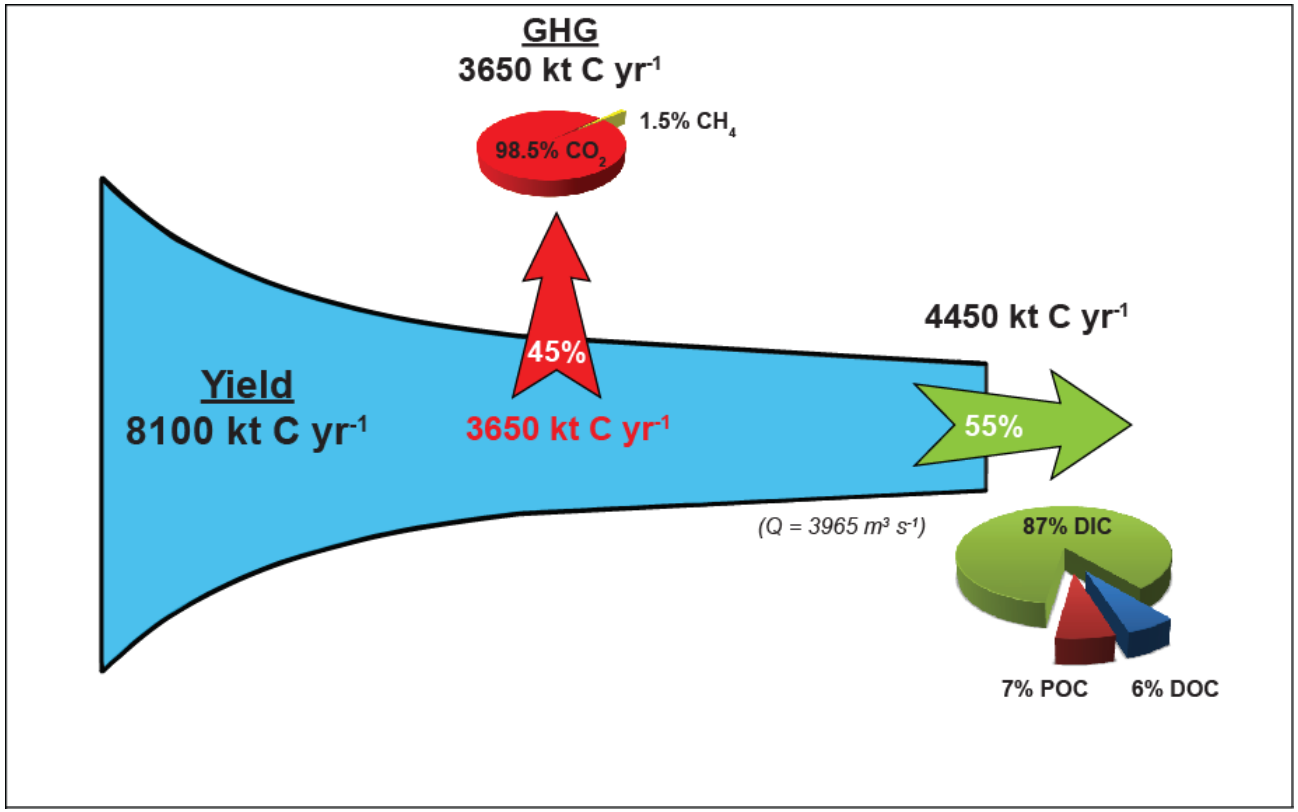






Results: Mass Balance

Carbon Budget Zambezi River



	Area	*CO_2 flux*	*CH_4 flux*	*CO_2*	*CH_4*
	[km²]	[mg C m⁻² d⁻¹]		[kt C yr⁻¹]	
Zambezi	1879	4291	45.0	3870	40.7
Kariba Res.	5580	-191	4.8	-389	9.7
C.B. Res.	2670	-356	1.4	-347	1.4
Kafue	287	2962	20.0	310	2.1
ITT Res.	364	1102	18.1	146	2.4
KG	7.4	956	17.4	3	0.05
Total	**10787**	**677**	**27**	**3594**	**56**

Conclusions

- pH, SpC, TA, DIC and d13CDIC - display a longitudinal pattern (increase towards the ocean) with overall low interannual variability

- Seasonality (higher DIC conc. and more enriched d13CDIC) more pronounced in the headwaters (upstream of reservoirs)

- All rivers are oversaturated in CO_2, CH_4 in respect to atmospheric concentrations

- CO_2 and CH_4 spatial dynamics – driven by the presence/absence of floodplains/wetlands; Lower conc. during dry seasons – due to loss of connectivity with wetlands

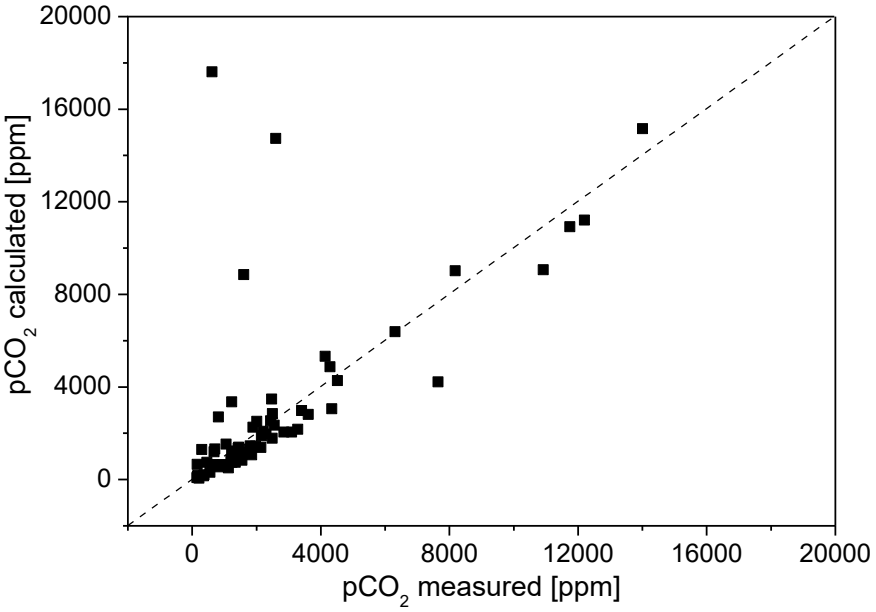
- Reservoirs are sinks of CO_2 and source of CH_4

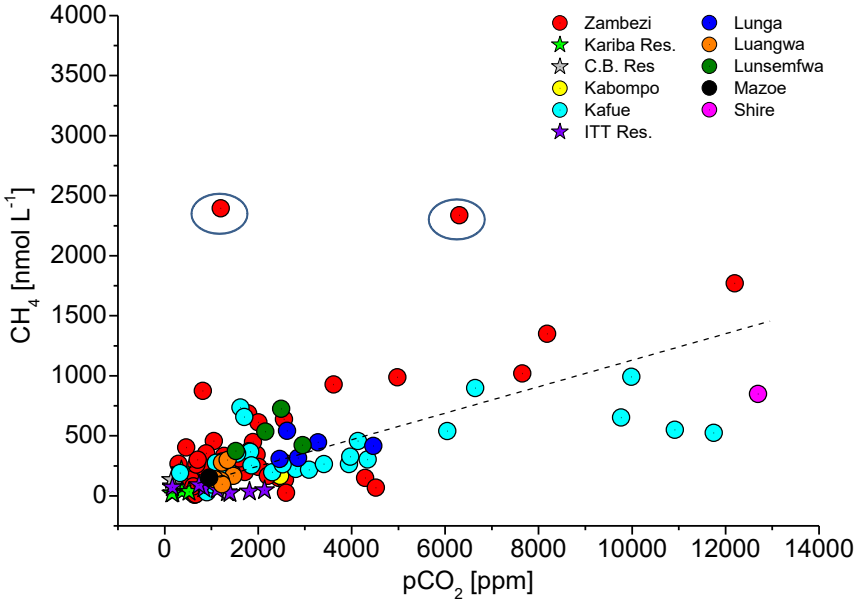
- N_2O – high seasonality (higher conc. during dry season)

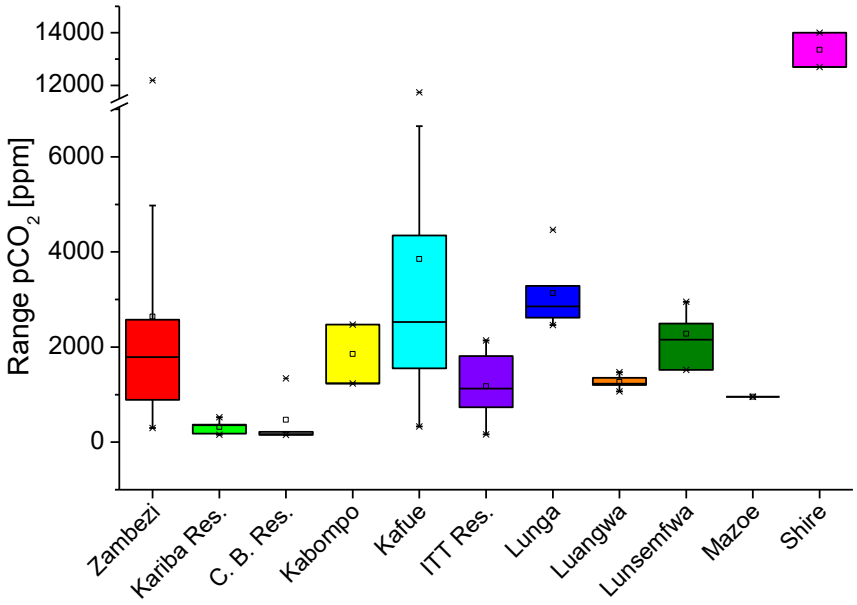
- Fluxes are slightly lower than literature values for tropical systems

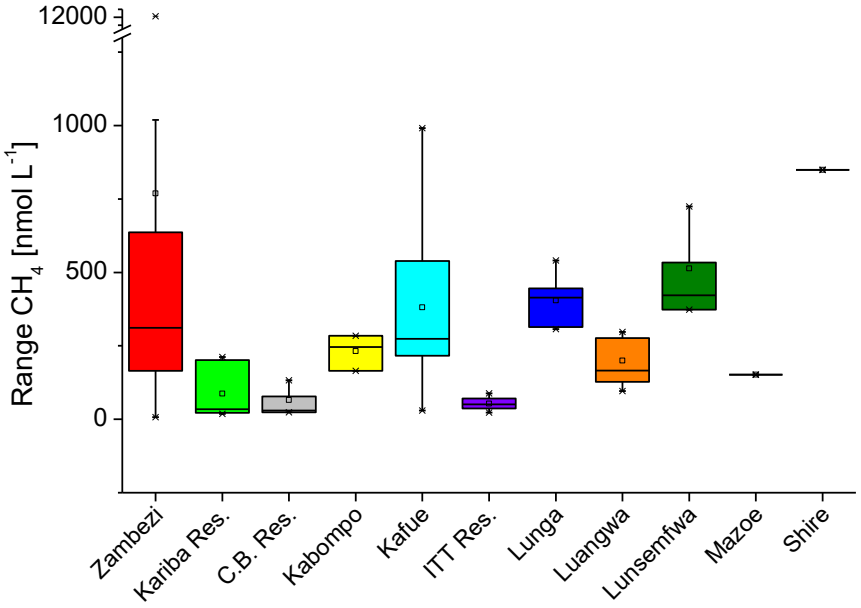
Thank you for your attention!

"Pirates of the Zambezi"

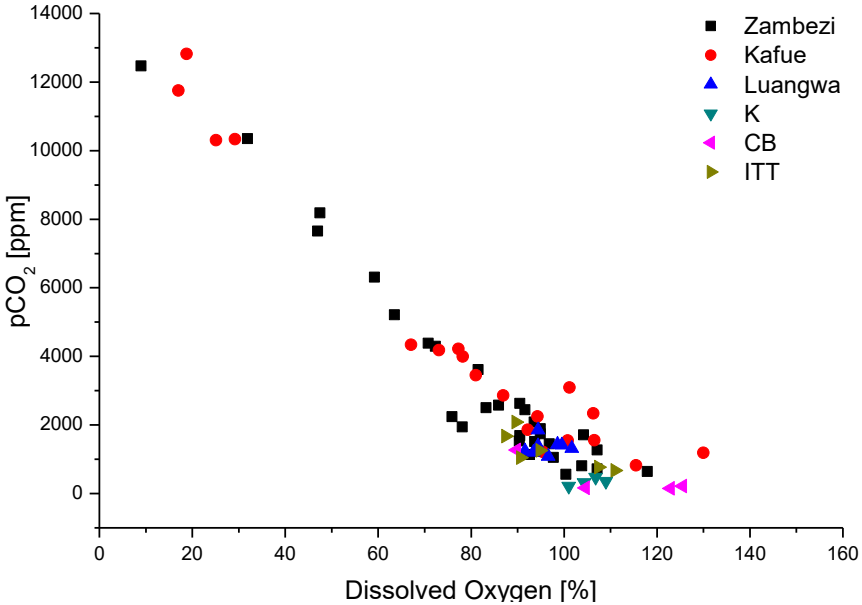

pCO2 calculated [ppm]
pCO2 measured [ppm]
0
4000
8000
12000
16000
20000

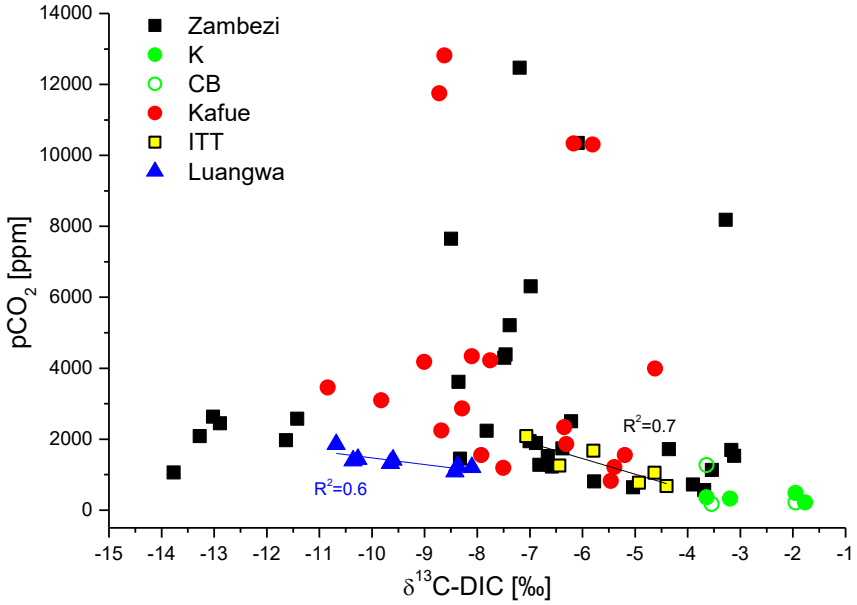

CH4 [nmol L-1]
pCO2 [ppm]
Zambezi
Kariba Res.
C.B. Res
Kabompo
Kafue
ITT Res.
Lunga
Luangwa
Lunsemfwa
Mazoe
Shire

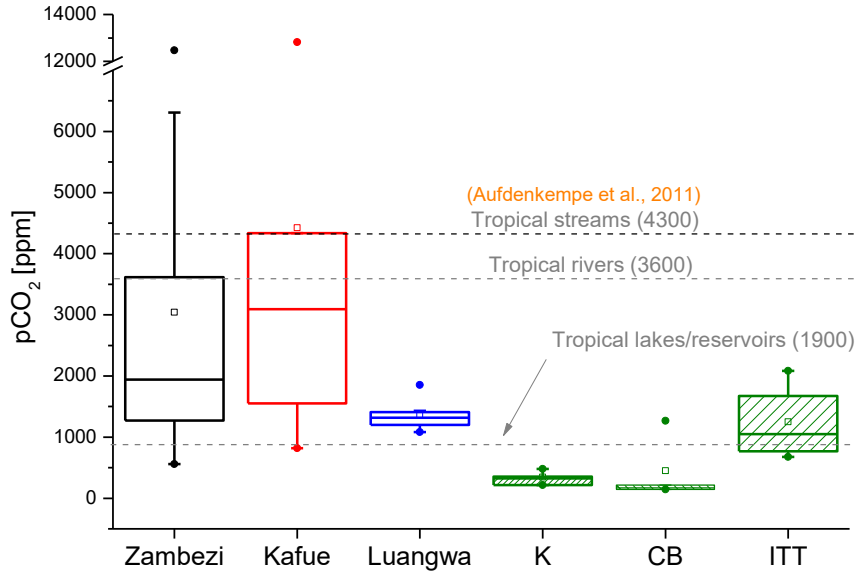

Range pCO2 [ppm]
Zambezi
Kariba Res.
C. B. Res.
Kabompo
Kafue
ITT Res.
Lunga
Luangwa
Lunsemfwa
Mazoe
Shire


Range CH4 [nmol L-1]
Zambezi
Kariba Res.
C.B. Res.
Kabompo
Kafue
ITT Res.
Lunga
Luangwa
Lunsemfwa
Mazoe
Shire

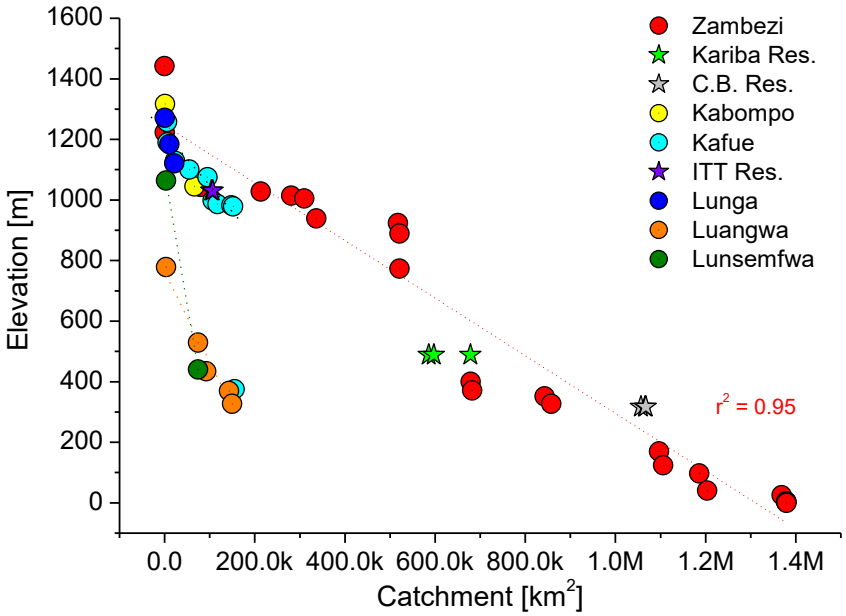
Results: CO_2 dynamics

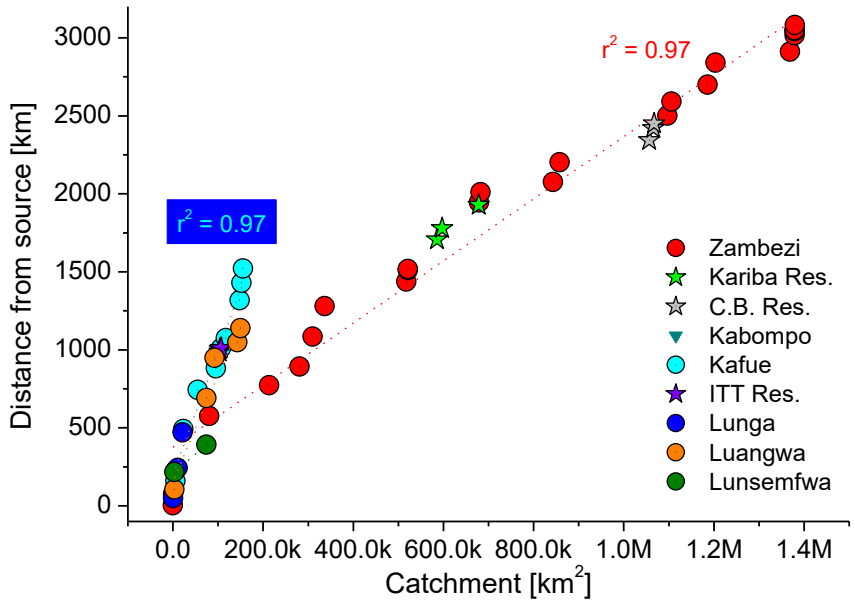


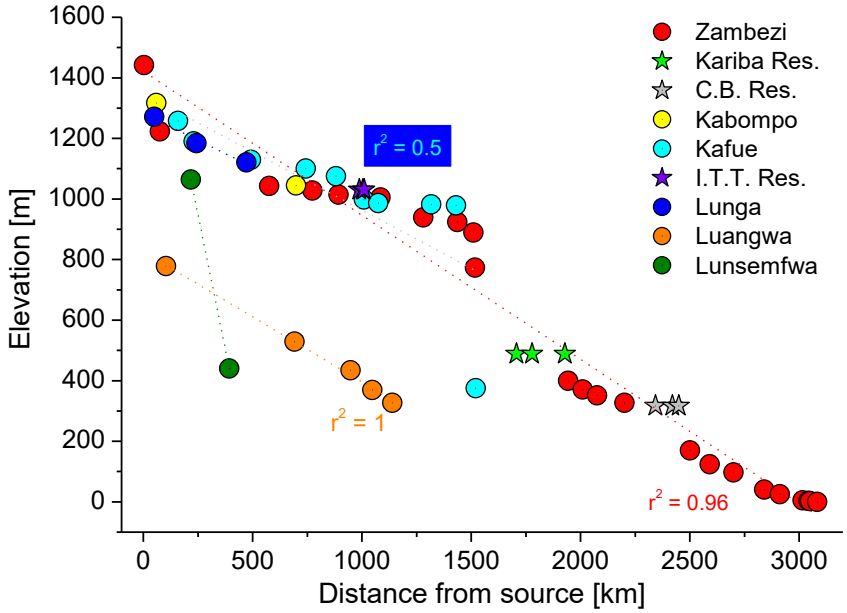




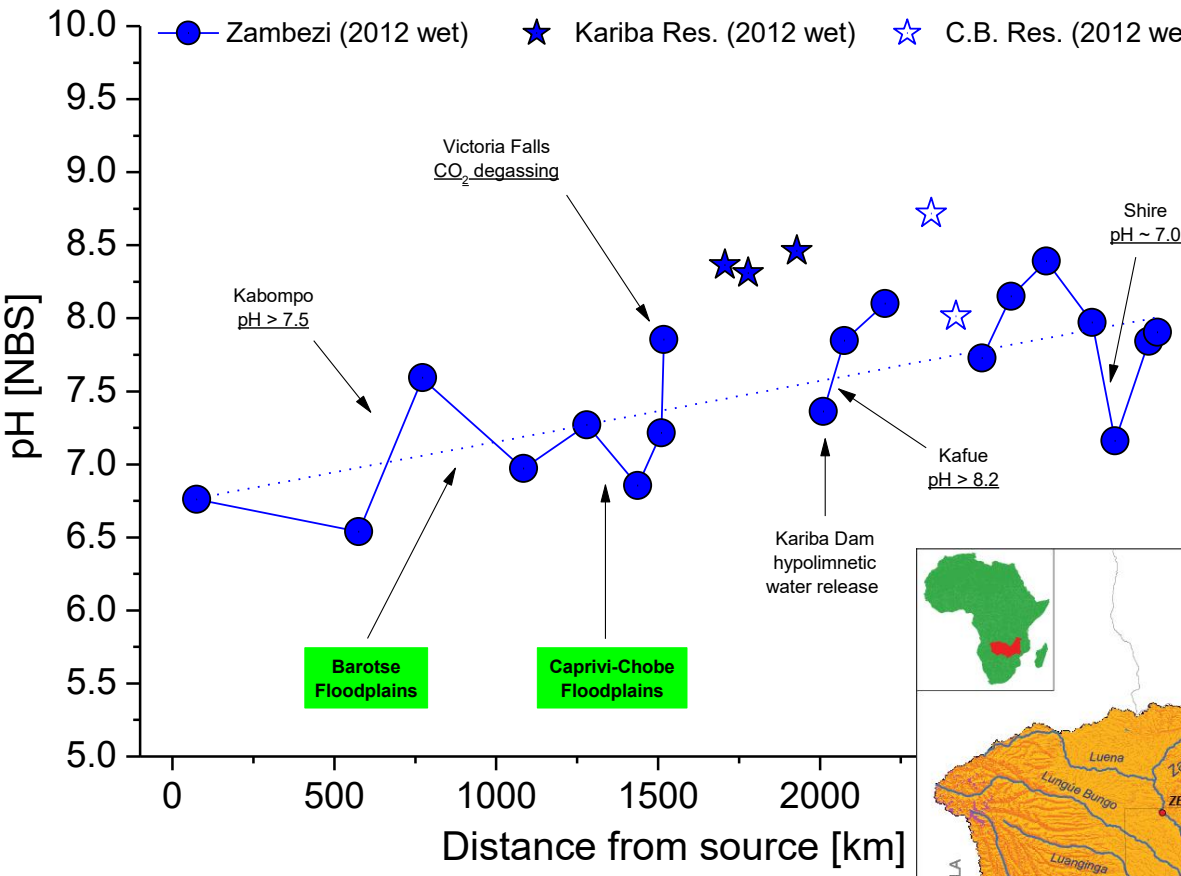
Results: Landscape Characteristics

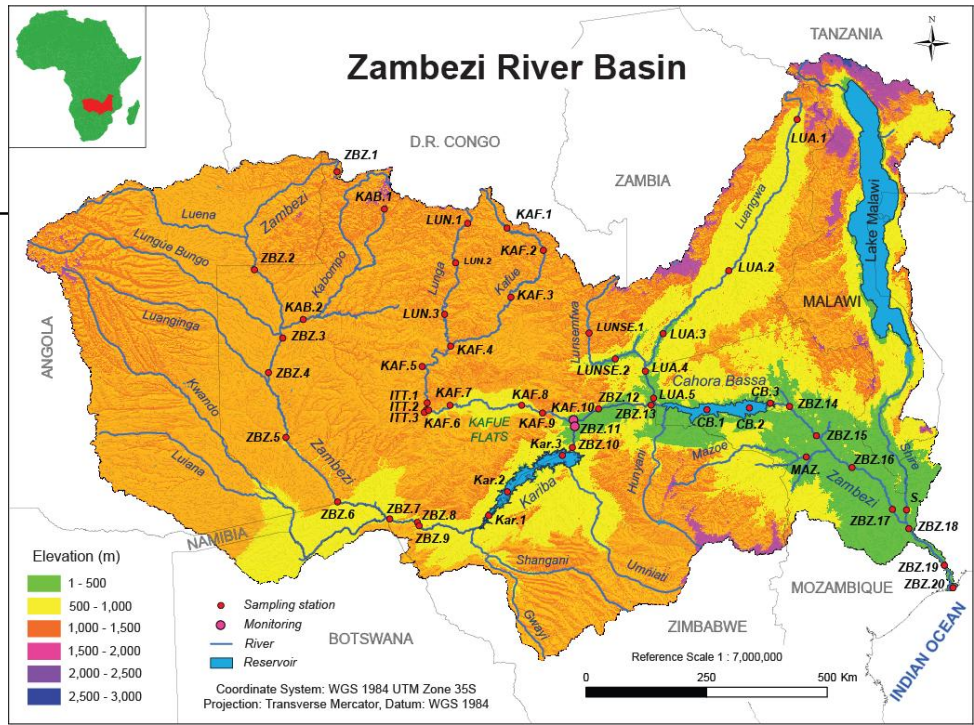






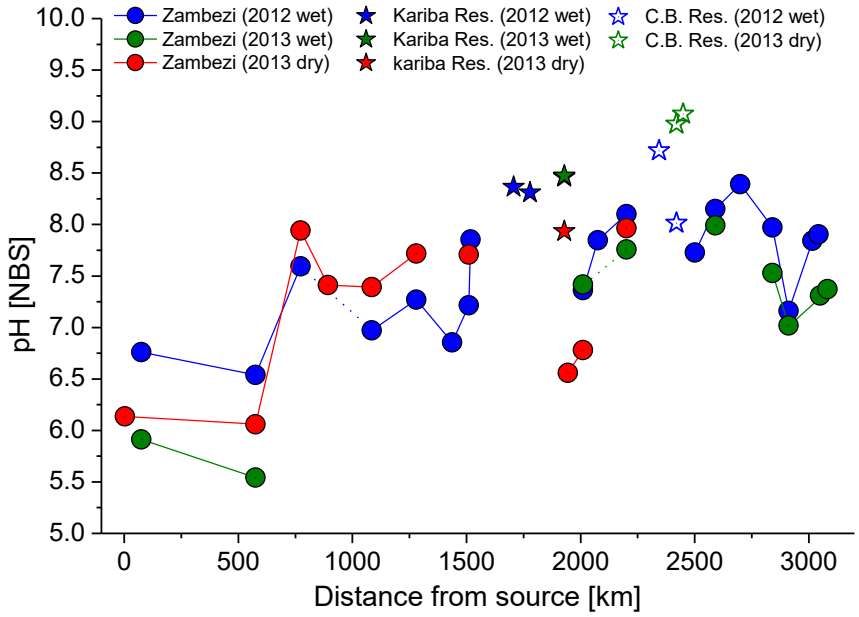
Results: pH

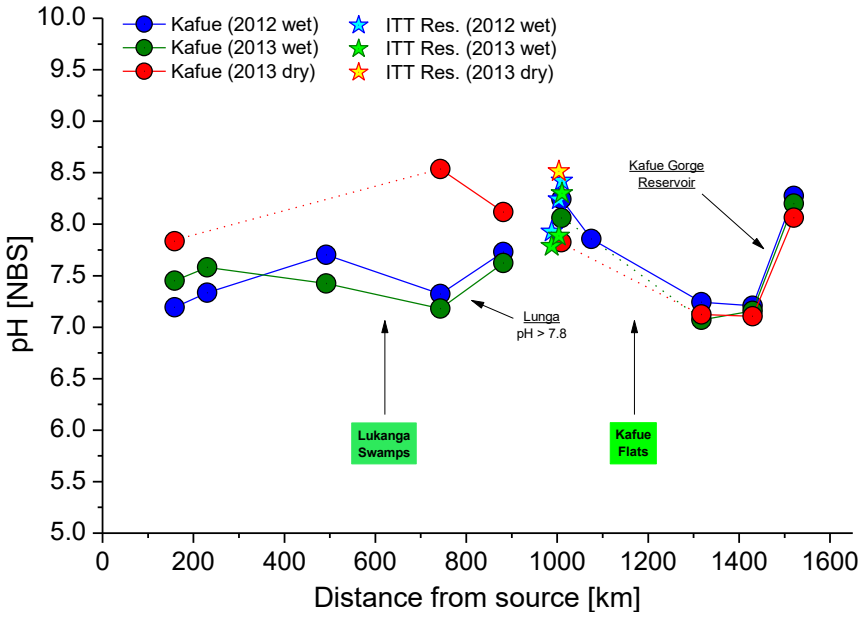


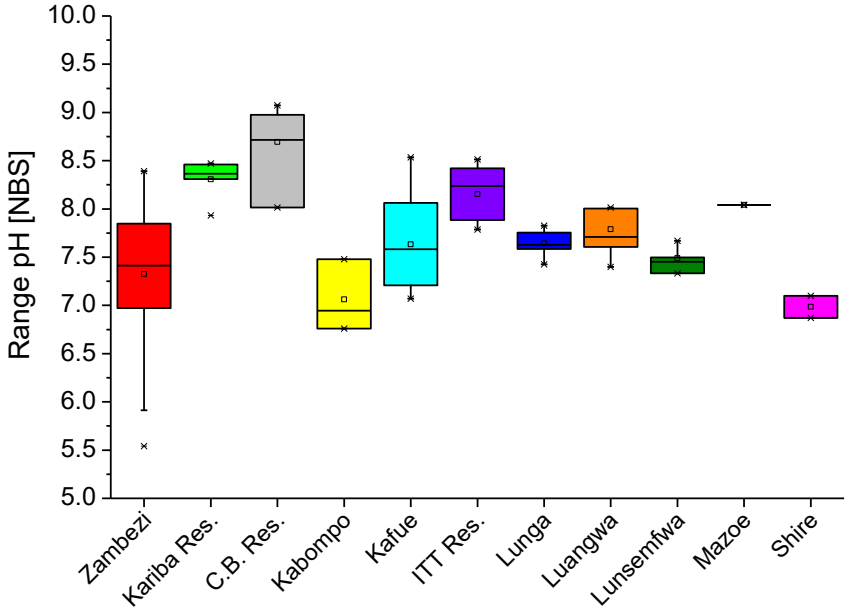


pH - Spatial variability along the Zambezi River during wet season 2012

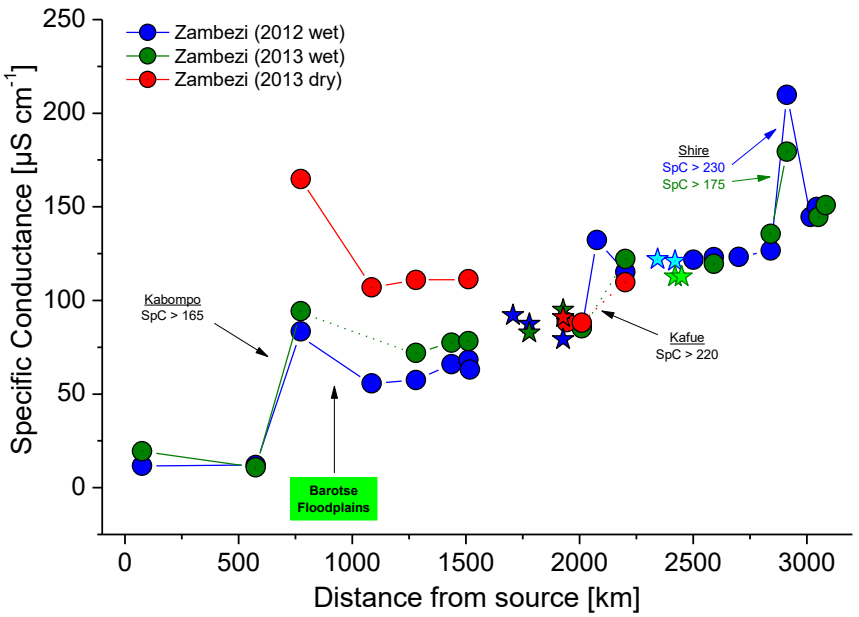
Results: pH - spatio-temporal variability

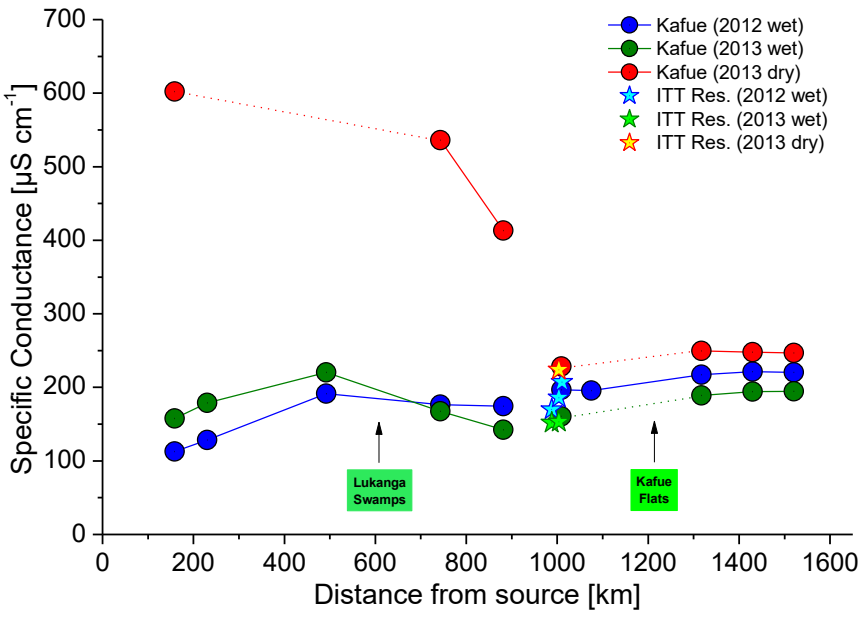


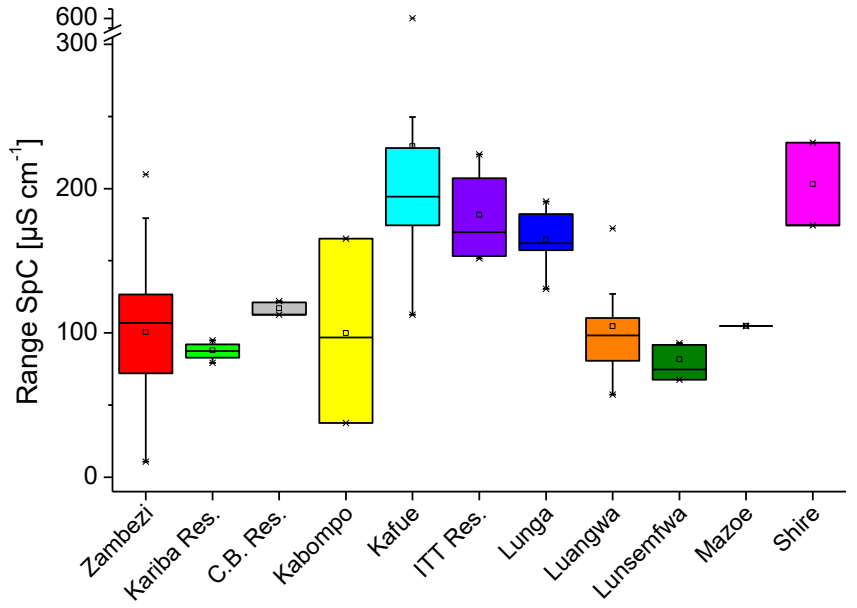


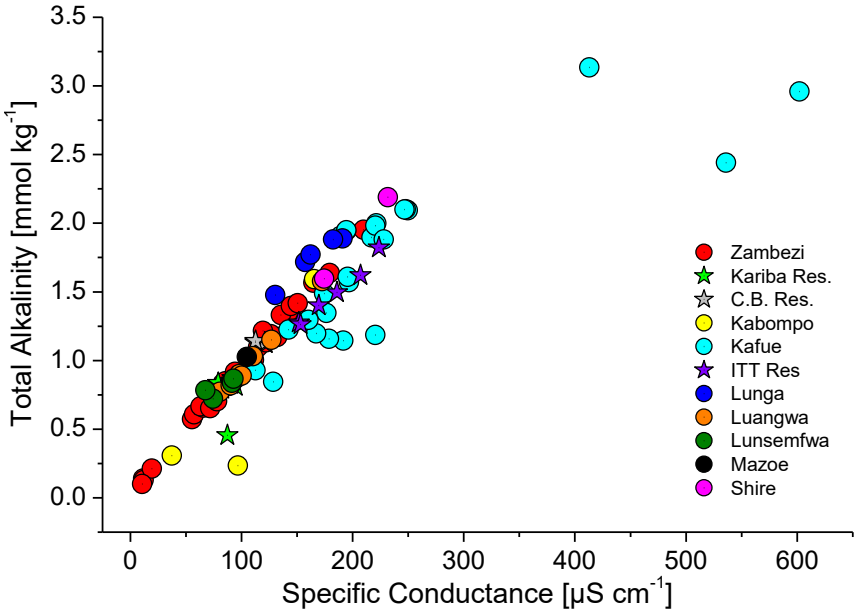


Results: Conductivity & Total Alkalinity









Introduction: Zambezi River Basin

The Zambezi River Basin – Land Use & Land Cover

- ***75%*** of area – ***forest and bush***; ***13% - croplan***d (rain-fed agriculture); and ***8 % grassland***
- 4 major biomes (Chenje, 2000)
  - **Zambezian** (95% of basin): ***woodlands, grasslands, swamps and lakes***
  - **Congolian** : moist and warmer climate with ***tropical forest and miombo woodlands***
  - **Montane** (1800-2000 m a.s.l.): cooler, wetter: ***evergreen forest and grasslands***
  - **Costal**: no marked dry season, little temperature fluctuations, mostly ***dry forest and grasslands***

Population in the basin

•***31.7 millions in 1998***, (1/3 of total population of the 8 basin countries), out of which over 85% leaves in Malawi, Zambia and Zimbabwe

•Ten years later (2008) the population reached over ***40 million***, and it is predicted to achieve ***51.2 million by 2025*** (SADC/SARDC et al., 2012)