

Methane fluxes from Zambian tropical wetlands



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MOYA Project



ZWAMPS Project



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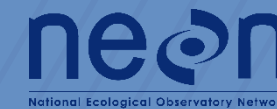


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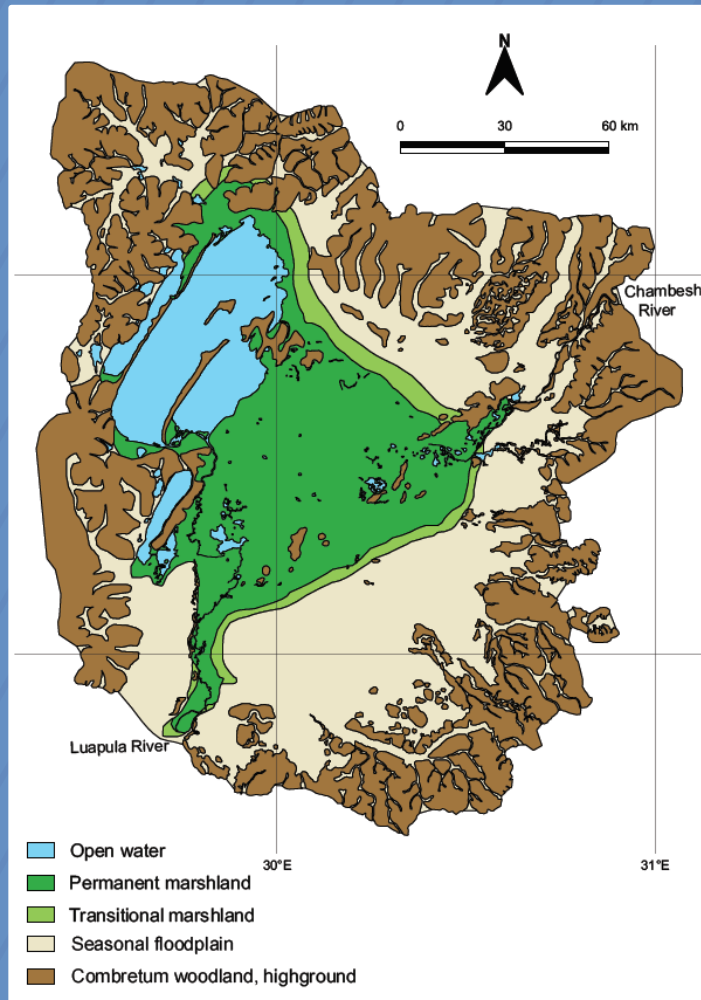
The MOYA/ZWAMPS campaign



- FAAM aircraft
 - In situ: CO_2 , CH_4 , N_2O , CO , O_3 , NO_x , VOCs, NMHCs, $\delta^{13}\text{C}_{\text{CH}_4}$
 - Meteorology: T, p, q, winds
 - Whole air samples: C_6 - C_{13} NMHC, O-VOCs, $\delta^{13}\text{C}_{\text{CH}_4}$
 - Remote sensing: FTIR, vertical profiles CH_4 , N_2O , NO_x , O_3 etc.
- Campaign
 - February 2019
 - Three flights; three wetlands

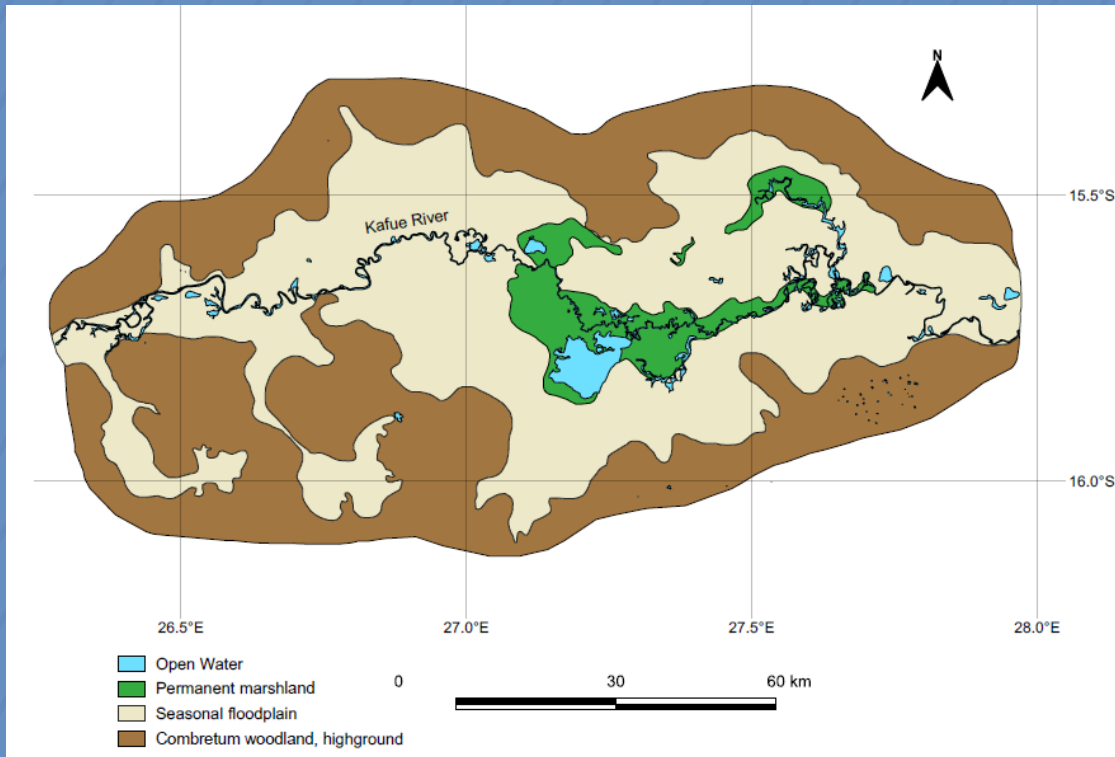
The wetlands: Bangweulu

“Where
the water
meets the
sky”



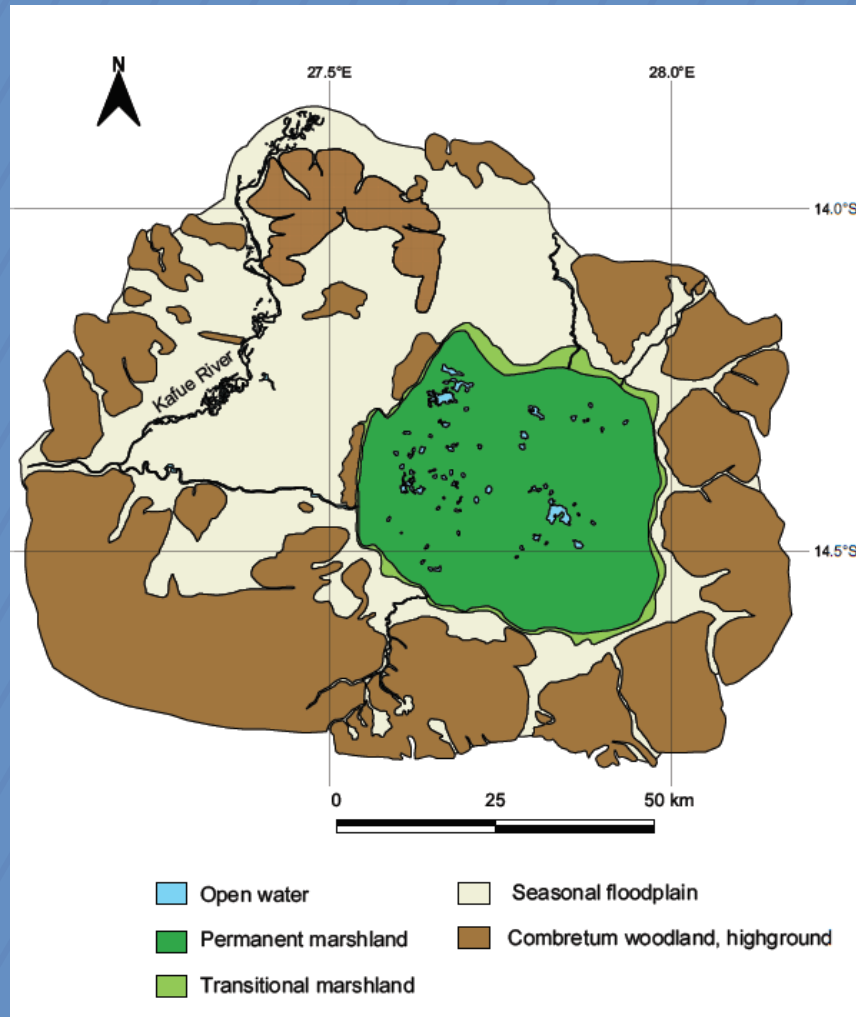
- Northern Zambia
- Upper Congo drainage basin
- Lake Bangweulu ~3,000 km²
- Total area ~11,000 km²
- Surveyed 1st February 2019

The wetlands: Kafue



- Southern Zambia
- Seasonally inundated around Kafue River
- Regulated by dams
- Area ~6,600 km²
- Surveyed 2nd February 2019

The wetlands: Lukanga



- Central Zambia
- Roughly circular, shallow depression
- Area ~2,600 km²
- Surveyed 3rd February 2019

Flux quantification methods

Mass balance box method

- Net flux through box
- High wind speeds:

$$E_{CH_4} = h \int_a^b (CH_4 - CH_4^+) u_{\perp} dx$$

- Low wind speeds:

$$F_{CH_4} = h \frac{dCH_4}{dt} - (CH_4^+ - CH_4) \left(\frac{dh}{dt} \right)$$

Pitt et al. 2019 (<https://doi.org/10.5194/acp-19-8931-2019>)
O'Shea et al. 2012 (<https://doi.org/10.5194/acp-14-13159-2014>)
Denmead et al. 1999 ([https://doi.org/10.1016/S0167-5117\(98\)80024-4](https://doi.org/10.1016/S0167-5117(98)80024-4))
Denmead et al. 1996 (<https://doi.org/10.1111/j.1365-2486.1996.tb00077.x>)

Airborne eddy covariance

- Vertical eddy-fluxes
- Detailed spatial attribution

$$COV_{a,b} = \frac{\delta j \delta t}{C_{\delta} N} \sum_{j=0}^J \sum_{n=0}^N \frac{w_x(a_j, b_n) w_y(a_j, b_n)^*}{a_j}$$

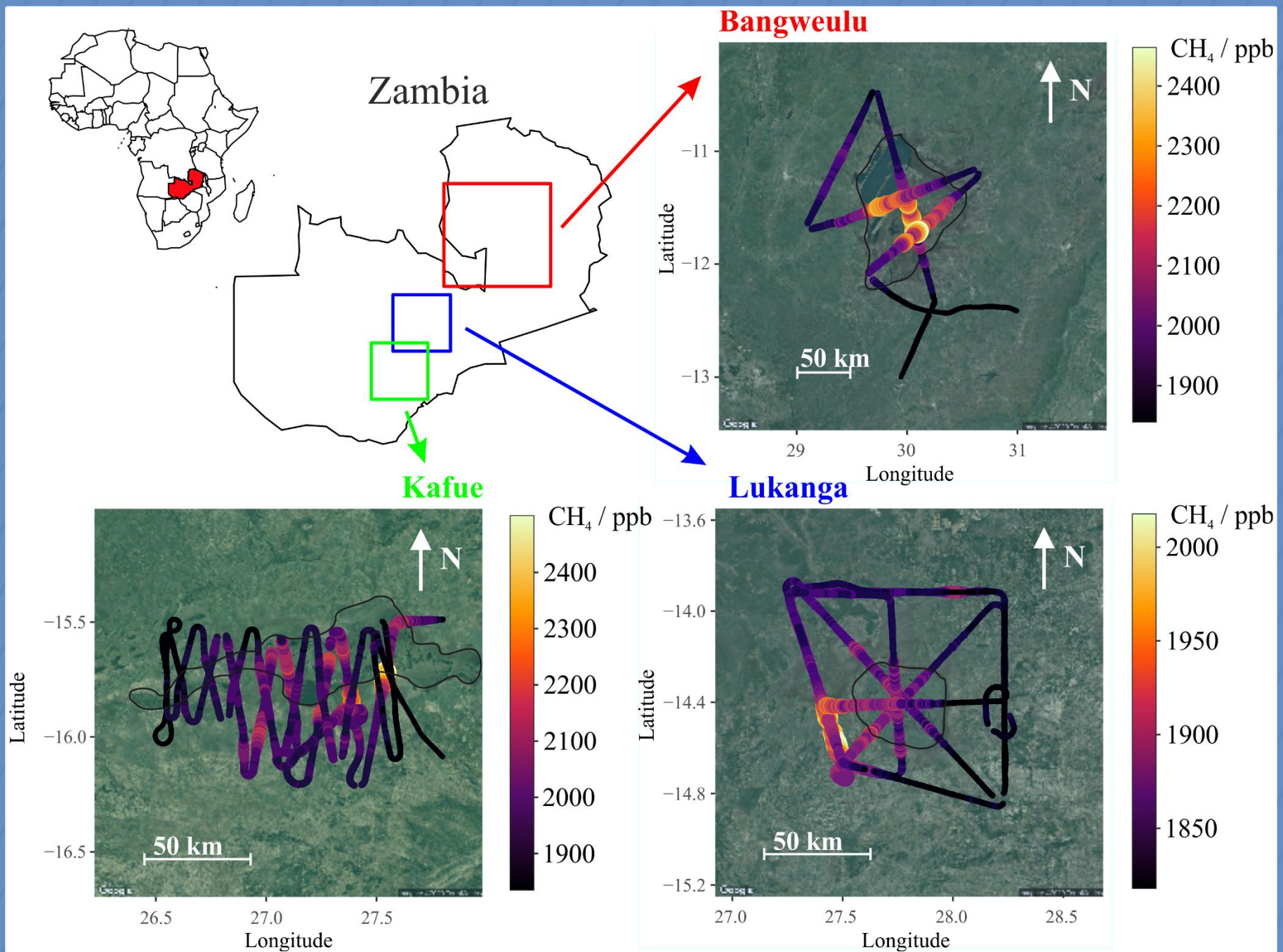
Vaughan et al. 2016 (<https://doi.org/10.1039/C5FD00170F>)
Metzger et al. 2017 (<https://doi.org/10.5194/gmd-10-3189-2017>)
Metzger et al. 2013 (<https://doi.org/10.5194/bg-10-2193-2013>)

NAME atmospheric inversion

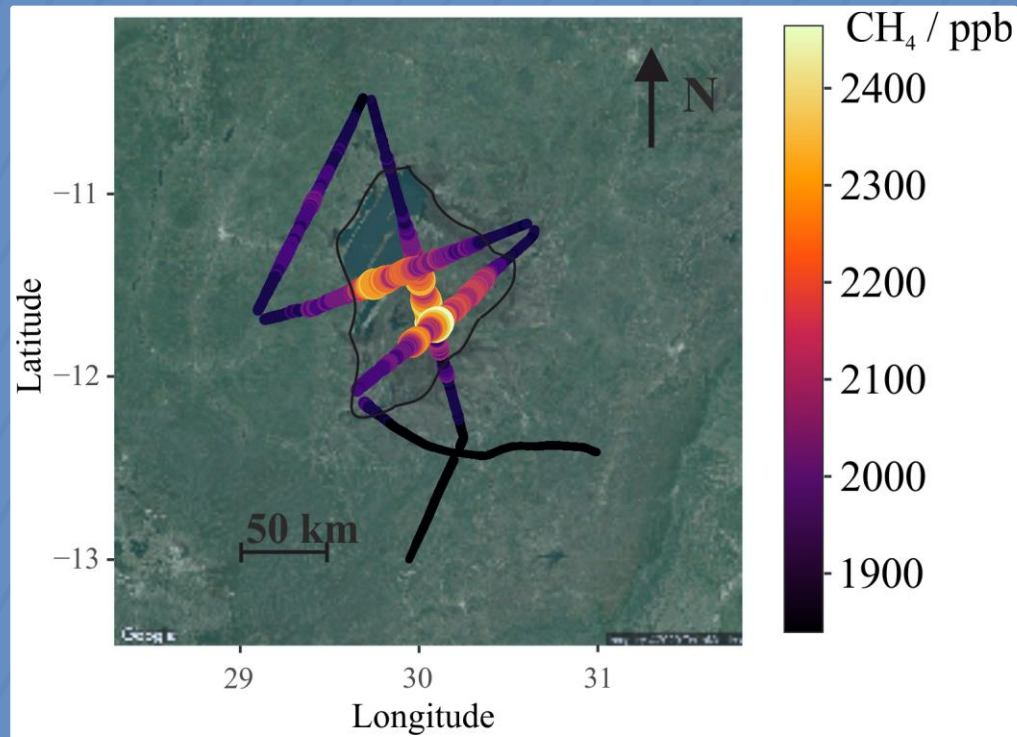
- Lagrangian particle dispersion model
(Numerical Atmospheric dispersion Modelling Environment)
- Hierarchical Bayesian inversion

Gansan et al. 2014 (<https://doi.org/10.5194/acp-14-3855-2014>)
Jones et al. 2007 (https://doi.org/10.1007/978-0-387-68854-1_62)
Rigby et al. 2019 (<https://doi.org/10.1038/s41586-019-1193-4>)

Results



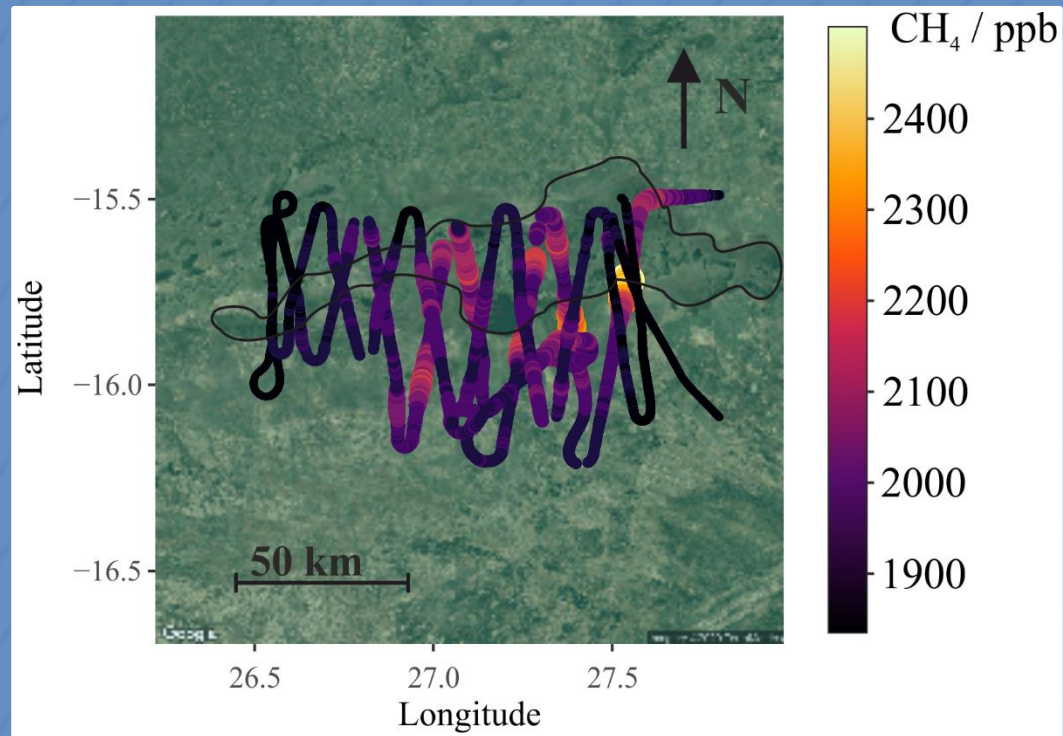
Bangweulu



- 600 ppb CH₄ enhancement over background
- Over vegetated area
- No (little) enhancement over lake
- Low wind speeds confused wind direction

Bangweulu	Per-unit-area flux / $\text{mg m}^{-2} \text{hr}^{-1}$	Bulk flux / kg s^{-1}
Mass balance	21.1 ± 6.1	46.9 ± 13.6
Eddy covariance	N/A	N/A
NAME inversion	9.0 ± 3.4	20.0 ± 7.6

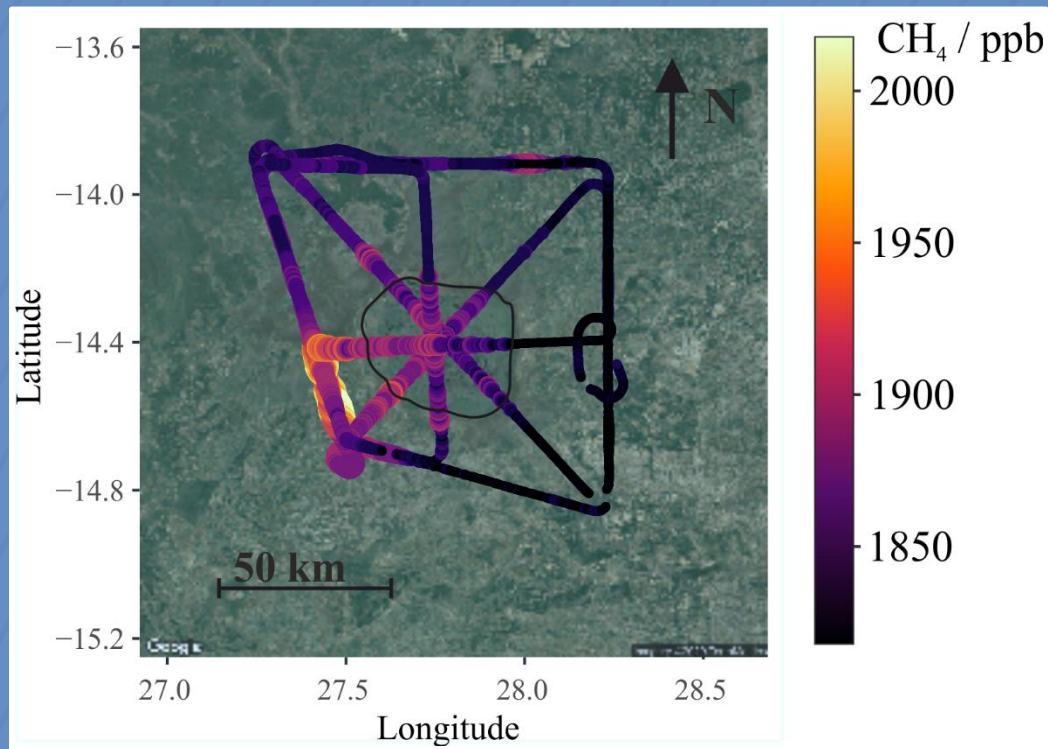
Kafue



- Up to 500 ppb CH₄ enhancement over background
- Dispersed enhancement
 - Not suitable for mass balance

Kafue	Per-unit-area flux / $\text{mg m}^{-2} \text{ hr}^{-1}$	Bulk flux / kg s^{-1}
Mass balance	N/A	N/A
Eddy covariance	23.0 ± 31.6	42.2 ± 58.0
NAME inversion	5.0 ± 0.7	10.5 ± 1.8

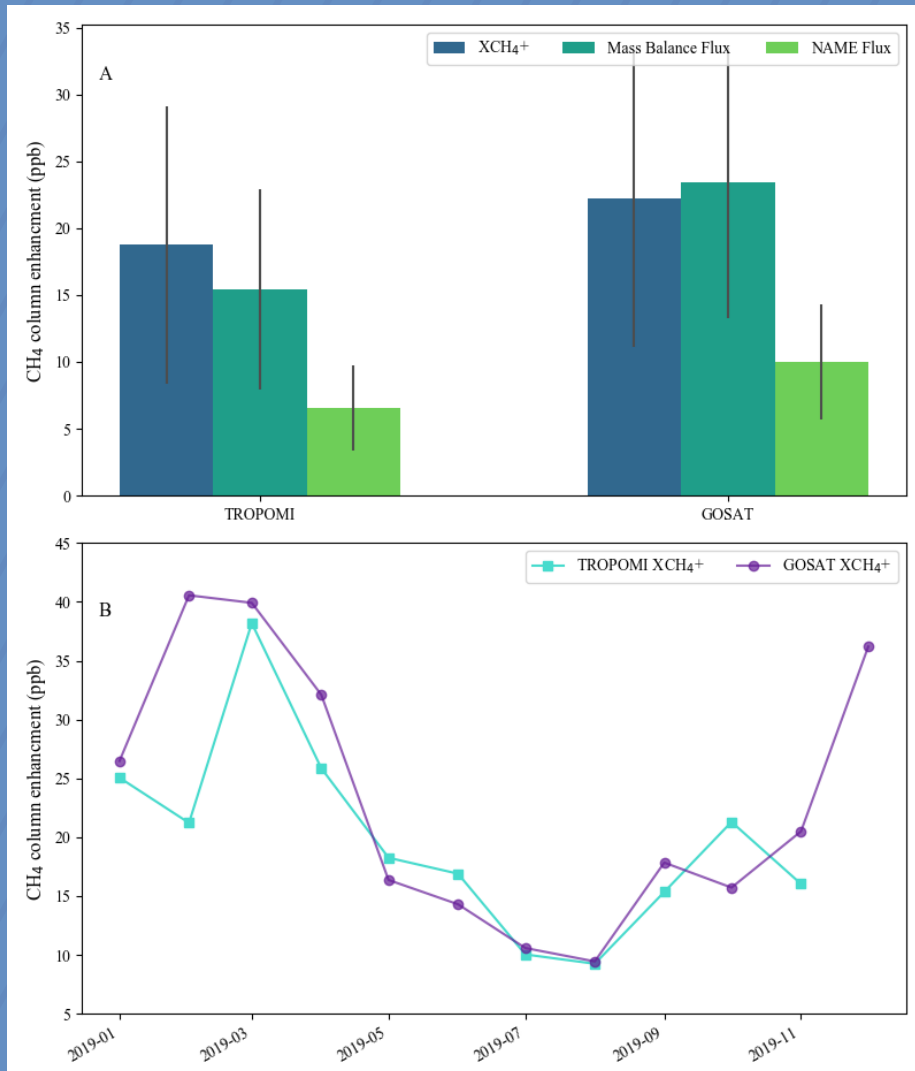
Lukanga



- 200 ppb CH₄ enhancement over background downwind
- Strong north-easterly wind blew emissions to southwest

Lukanga	Per-unit-area flux / $\text{mg m}^{-2} \text{hr}^{-1}$	Bulk flux / kg s^{-1}
Mass balance	15.5 ± 2.7	11.2 ± 2.0
Eddy covariance	27.9 ± 14.3	20.2 ± 10.3
NAME inversion	14.6 ± 2.5	10.5 ± 1.8

What do satellites see?



- Well... not very much owing to cloud cover! we're in the tropics remember
- Used TROPOMI and GOSAT
- GEOS-Chem (global chemical transport model) to remove influences of other CH₄ sources (anthropogenic, fire, etc.) from observations
- Observations match mass balance flux (or even greater)

Lunt et al. 2019 (<https://doi.org/10.5194/acp-19-14721-2019>)

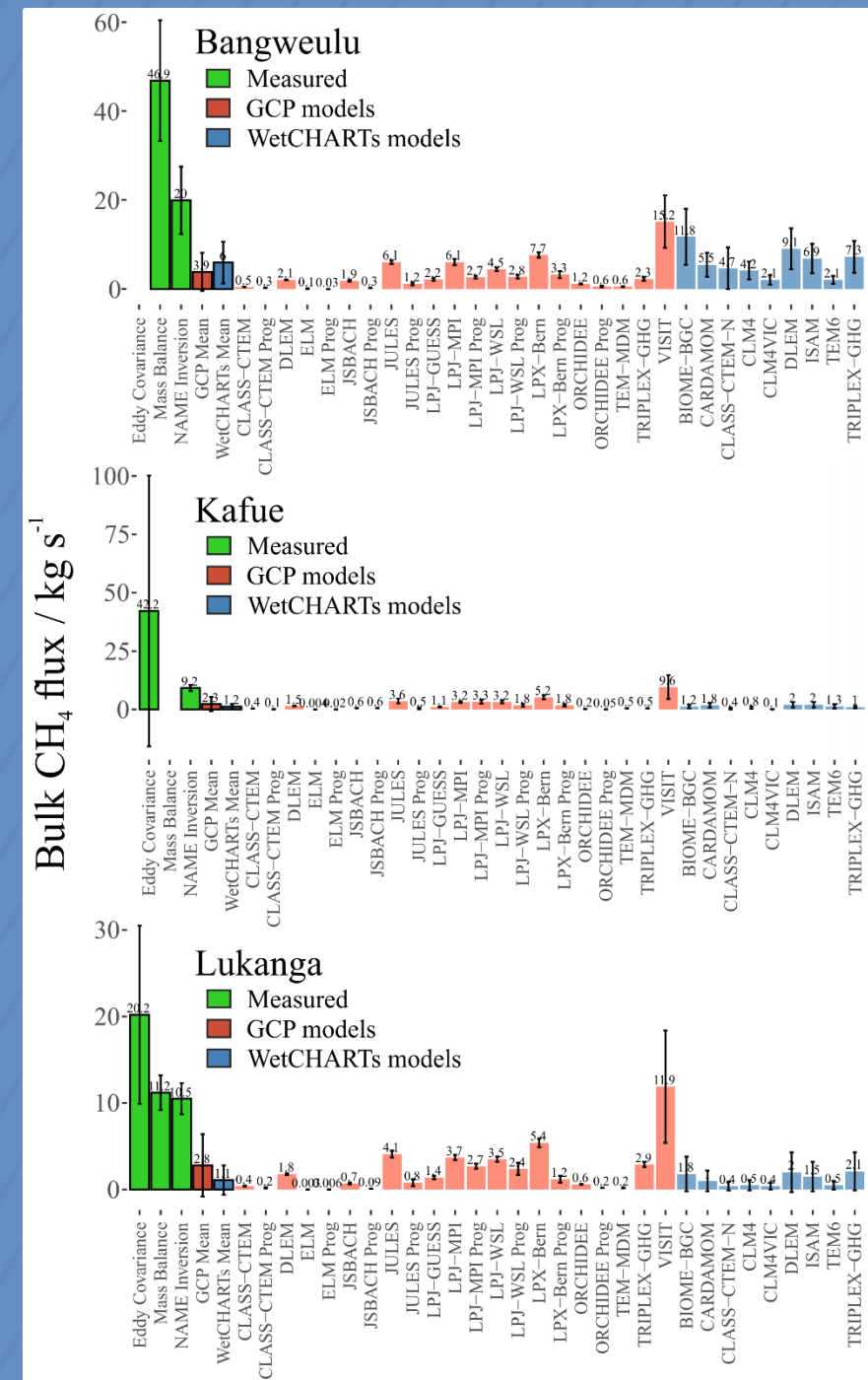
Lorente et al. 2021 (<https://doi.org/10.5194/amt-14-665-2021>)

Lunt et al. 2021 (<https://doi.org/10.1088/1748-9326/abd8fa>)

Butz et al. 2021 (<https://doi.org/10.1029/2011GL047888>)

What do models say?

- Used GCP and WetCHARTs suites of wetland process models
- All (pretty much) ^{except VISIT maybe?} underestimate emissions relative to measurements

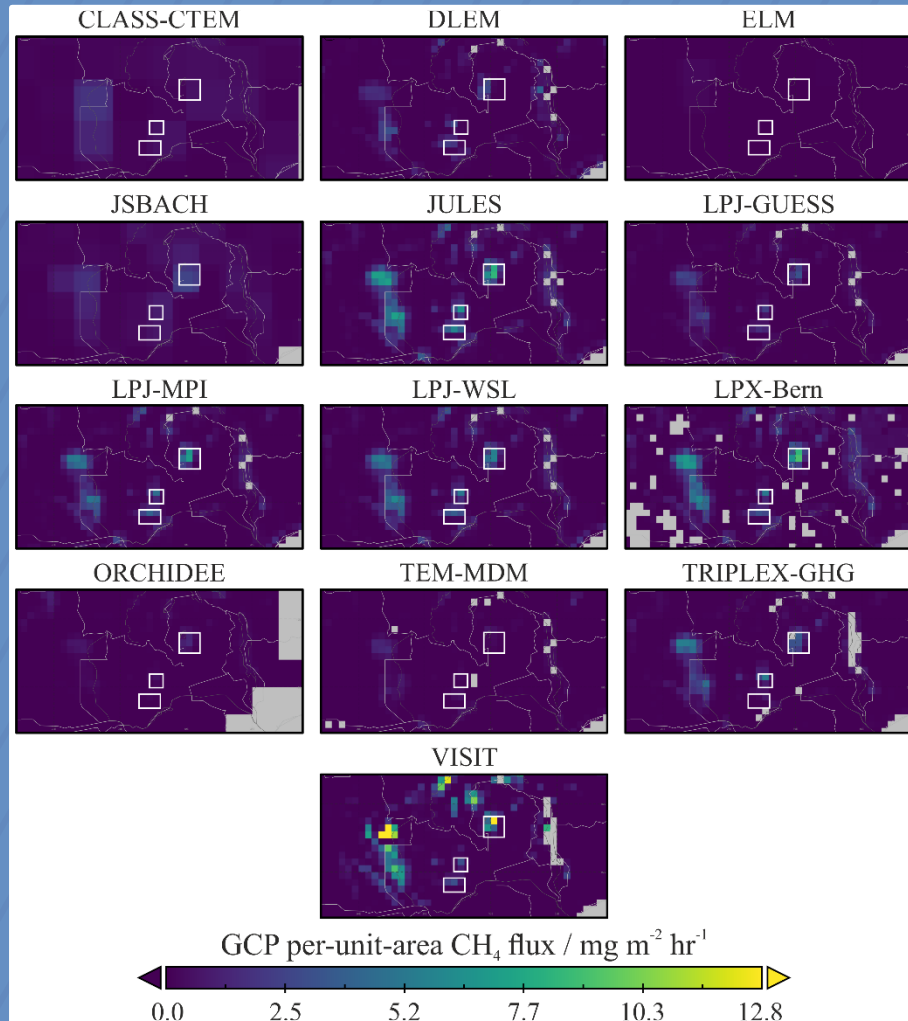


Saunois et al. 2020 (<https://doi.org/10.5194/essd-12-1561-2020>)

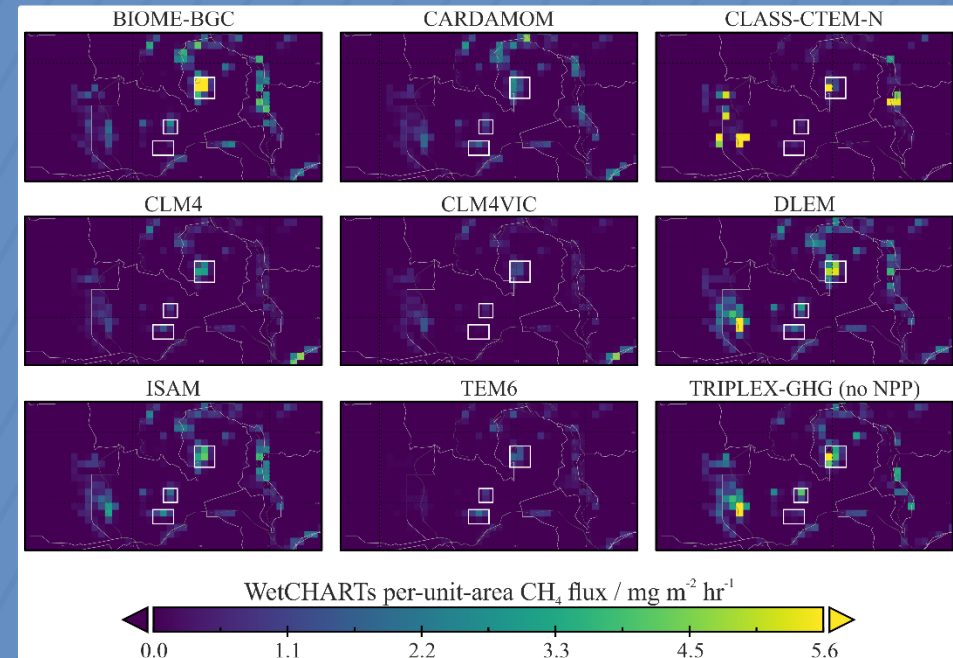
Bloom et al. 2017 (<https://doi.org/10.5194/gmd-10-2141-2017>)

Melton et al. 2013 (<https://doi.org/10.5194/bg-10-753-2013>)

What do models say?



- Some differences between where models simulate greatest emissions
 - Open water or not?



Summary

- First aircraft measurements of methane over central African wetlands
- Three independent flux quantification techniques all show greater fluxes than model simulations
- Satellite observations match measured fluxes
- Most methane coming from vegetated marshland not open water

veg acts as conduit?

There is potentially a lot of methane coming from African tropical wetlands!

Total methane	Bangweulu	Kafue	Lukanga
Annual methane flux / Tg yr ⁻¹	0.5 – 3.0	0.2 – 1.3	0.2 – 0.7

Extra relevant literature

Nisbet et al. 2016 (<https://doi.org/10.1002/2016GB005406>)

Nisbet et al. 2013 (<https://doi.org/10.1029/2018GB006009>)

Schaefer et al. 2016 (<https://doi.org/10.1126/science.aad2705>)

Ganesan et al. 2019 (<https://doi.org/10.1029/2018GB006065>)

Parker et al. 2018 (<https://doi.org/10.1016/j.rse.2018.02.011>)

Pangala et al. 2017 (<https://doi.org/10.1038/nature24639>)

Barba et al. 2018 (<https://doi.org/10.1111/nph.15582>)

Pandey et al. 2021 (<https://doi.org/10.5194/bg-18-557-2021>)

Methane fluxes from Zambian tropical wetlands

Jacob Shaw and MOYA Team

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MOYA Flight Campaign

- Zambia in February 2019
- UK FAAM research aircraft
- Three flights
- Three wetlands; Bangweulu, Kafue, Lukanga



Flux quantification ×3

Mass
balance

Eddy
covariance

NAME
inversion

BANGWEULU

“Where the water meets
the sky.”

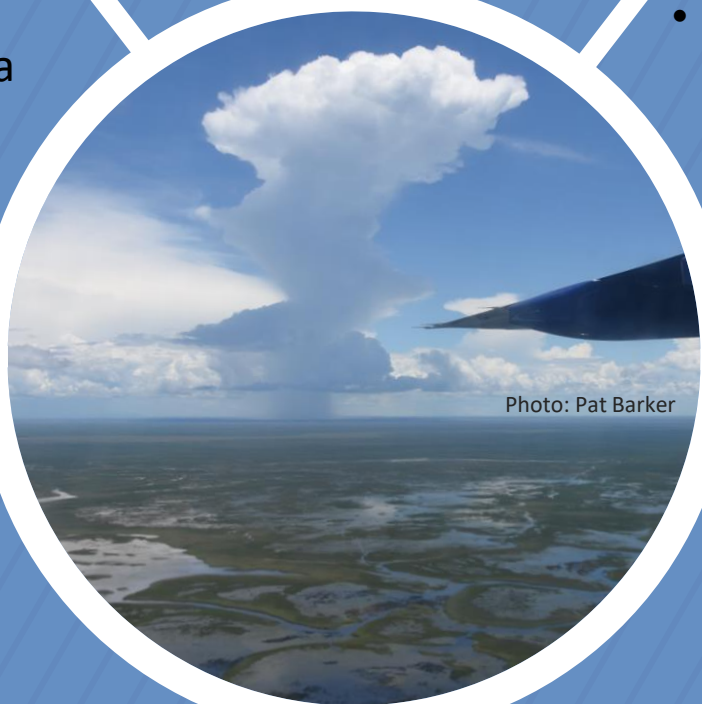
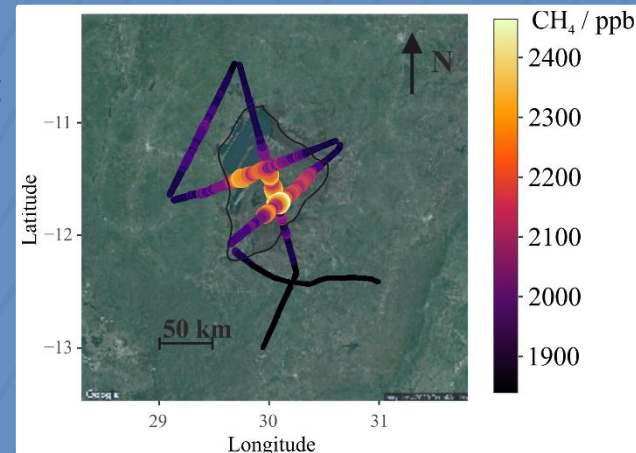


Photo: Pat Barker

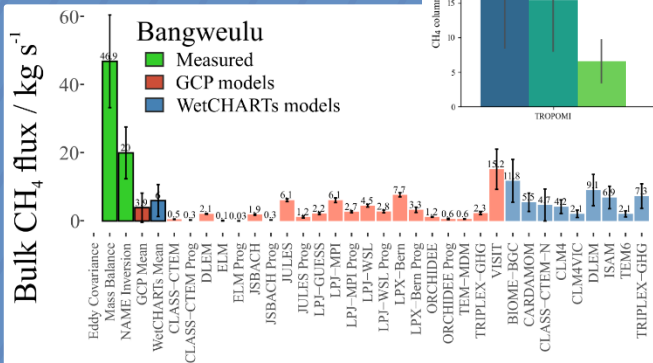
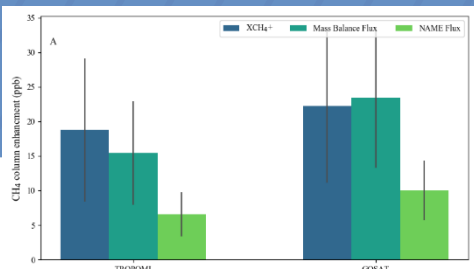
Methane measurements

- 600 ppb enhancement
- ~11,000 km²
- Mass balance
46.9 ± 13.6
- NAME inversion
20.0 ± 7.6
- kg s⁻¹



Models & satellites

- Satellites agree
- TROPOMI/GOSAT



- All models underestimate fluxes
- Global Carbon Project/WetCHARTs

Context:

UK annual flux = ~2 Tg CH₄ yr⁻¹

Conclusions

- Bangweulu annual flux is **>1 Tg CH₄ yr⁻¹**
 - Methane mostly from vegetated marshland (not open water)
- All aircraft-derived fluxes greater than process model fluxes
- More work needed on African wetlands

For more information visit my uploaded slides:

- Flux methods
- Kafue
- Lukanga