Water Resource Sustainability Issues on Tropical Islands
3 Dec 2015 -Hawaii

Submarine groundwater discharge from tropical islands: Water quality and biogeochemical implications

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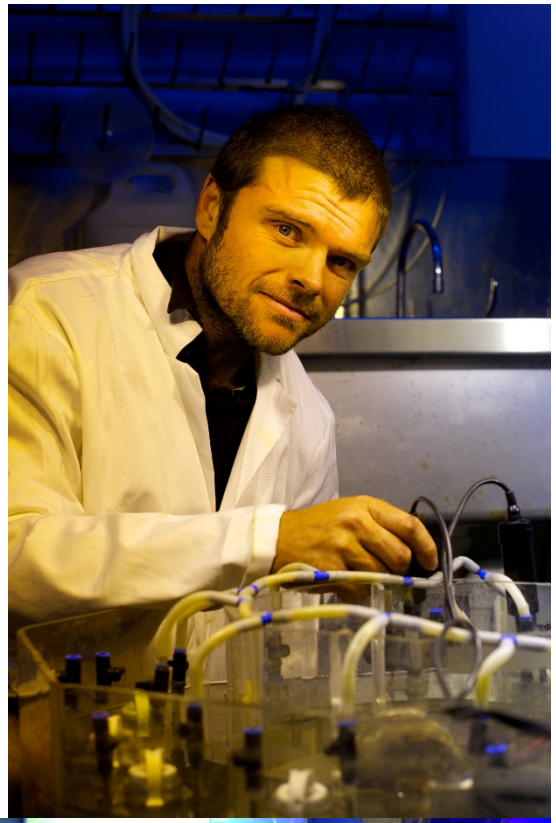
Acknowledgements

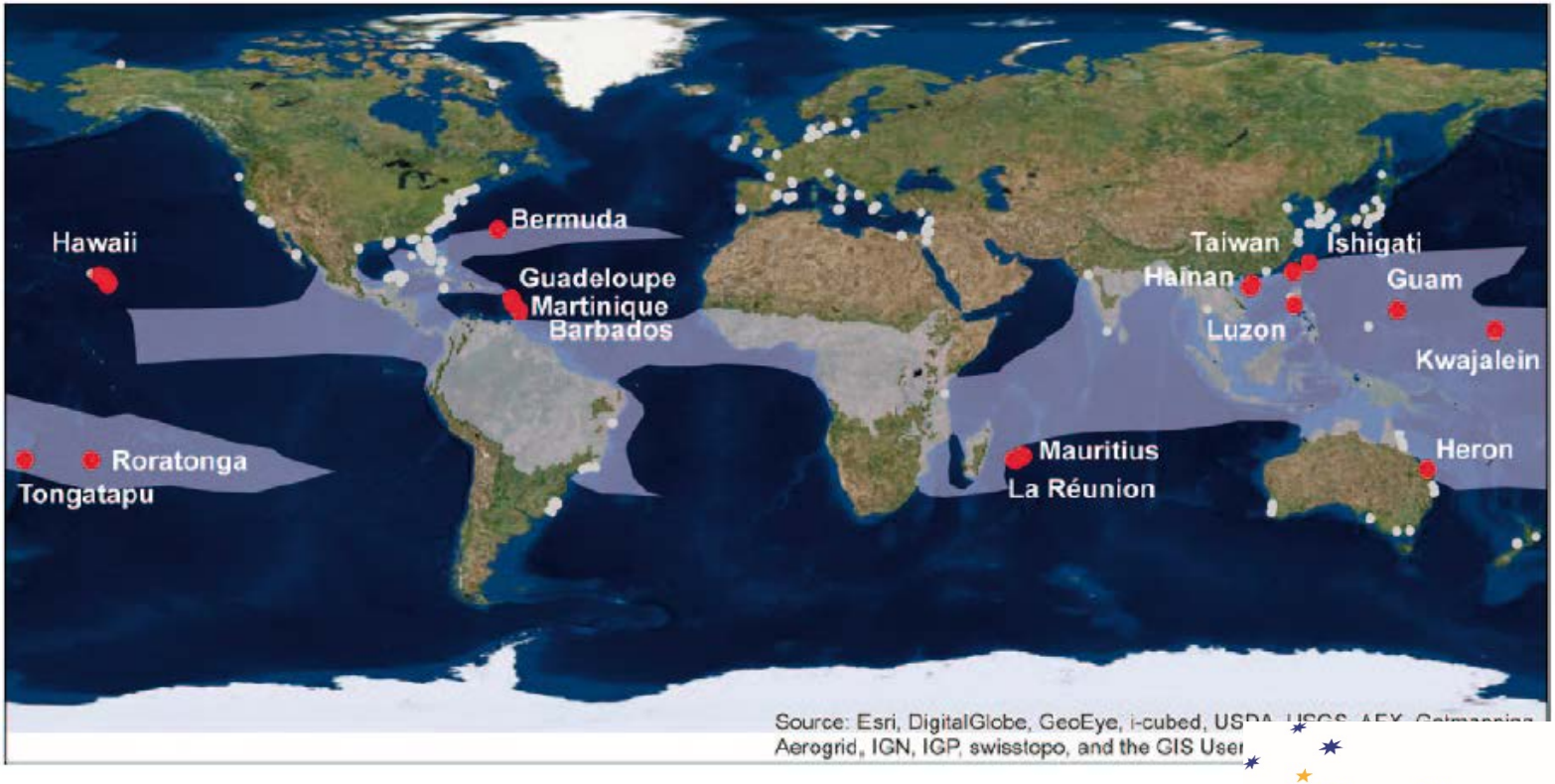
Funding from the Australian Research Council



Damien Maher, Douglas Tait, Dirk Erler, Thorsten Dittmar, Hans Brumsack, Melanie Beck, Mahmood Sadat-Noori, Perran Cook, Ling Li, Marnie Atkins, Jackie Gatland, Mitchell Call, Jamers Sippo, Ceyelena Holloway, Justin Gleeson, Uriah Makings, Ashly McMahon, Jason de Weys, et al.

Tropical islands as global SGD hotspots

Global SGD: ~2,400 km^3/y
Islands: ~915 km^3/y
Continents: ~1,485 km^3/y
(Zekster 2000)



Review by Moosdorf et al., 2014

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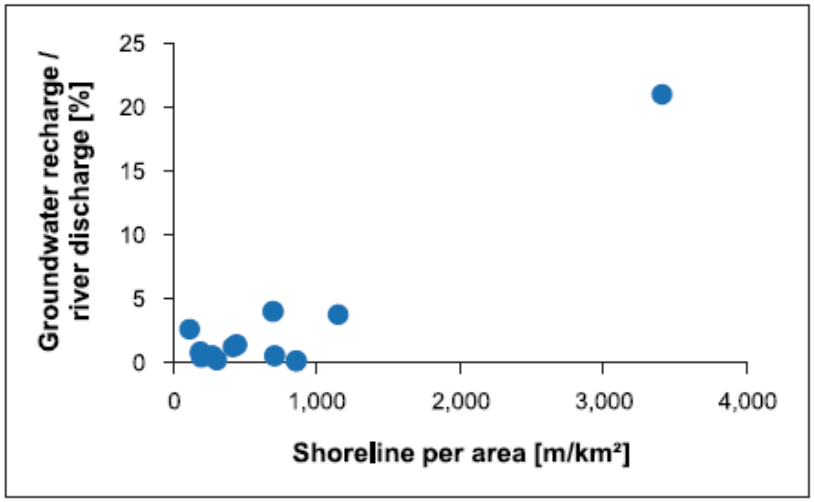
Tropical islands as global SGD hotspots



- **High shoreline/area ratio**
- High rainfall
- High relief
- Immature permeable soils

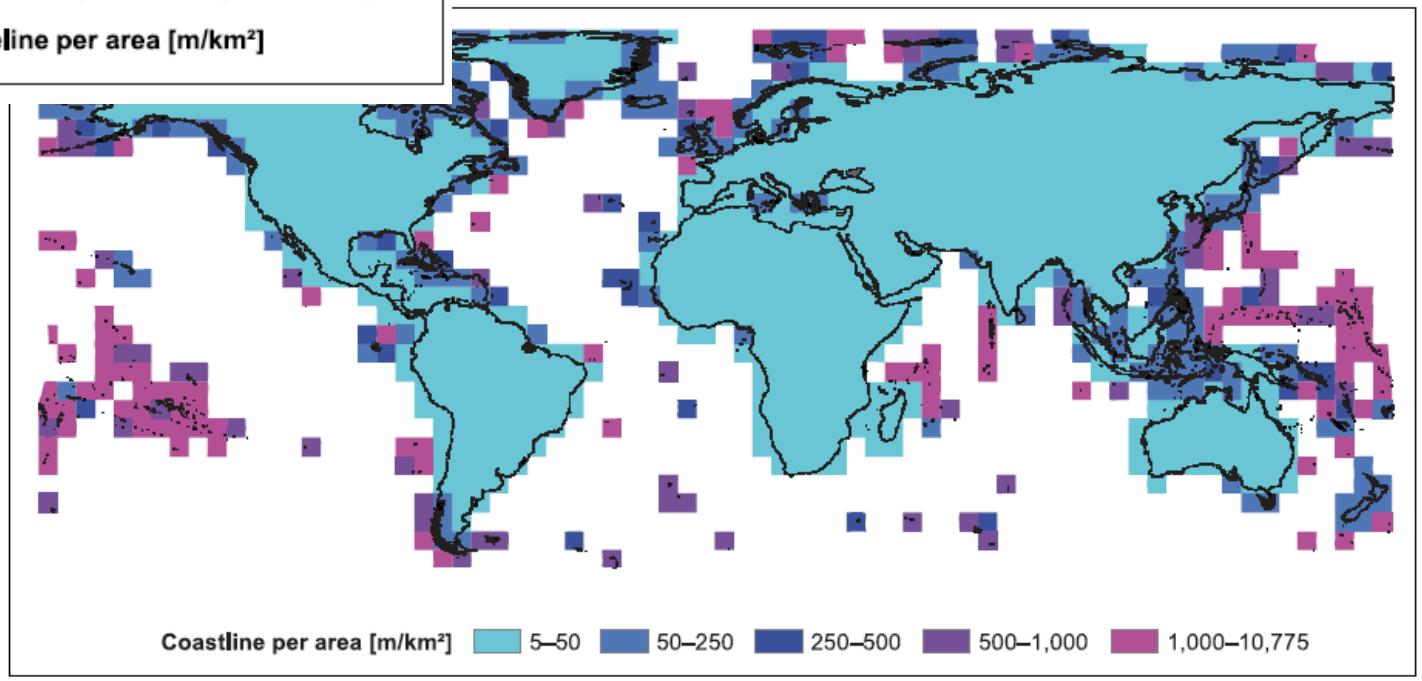


Fig. 4 Map of the ratio of coast length versus land area (in m shoreline per km² land area). Larger values indi
tial of SGD to the total land-ocean water fluxes

Review by Moosdorf et al., 2014

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Ocean acidification and eutrophication

Reefs will change to algal-dominated ecosystems

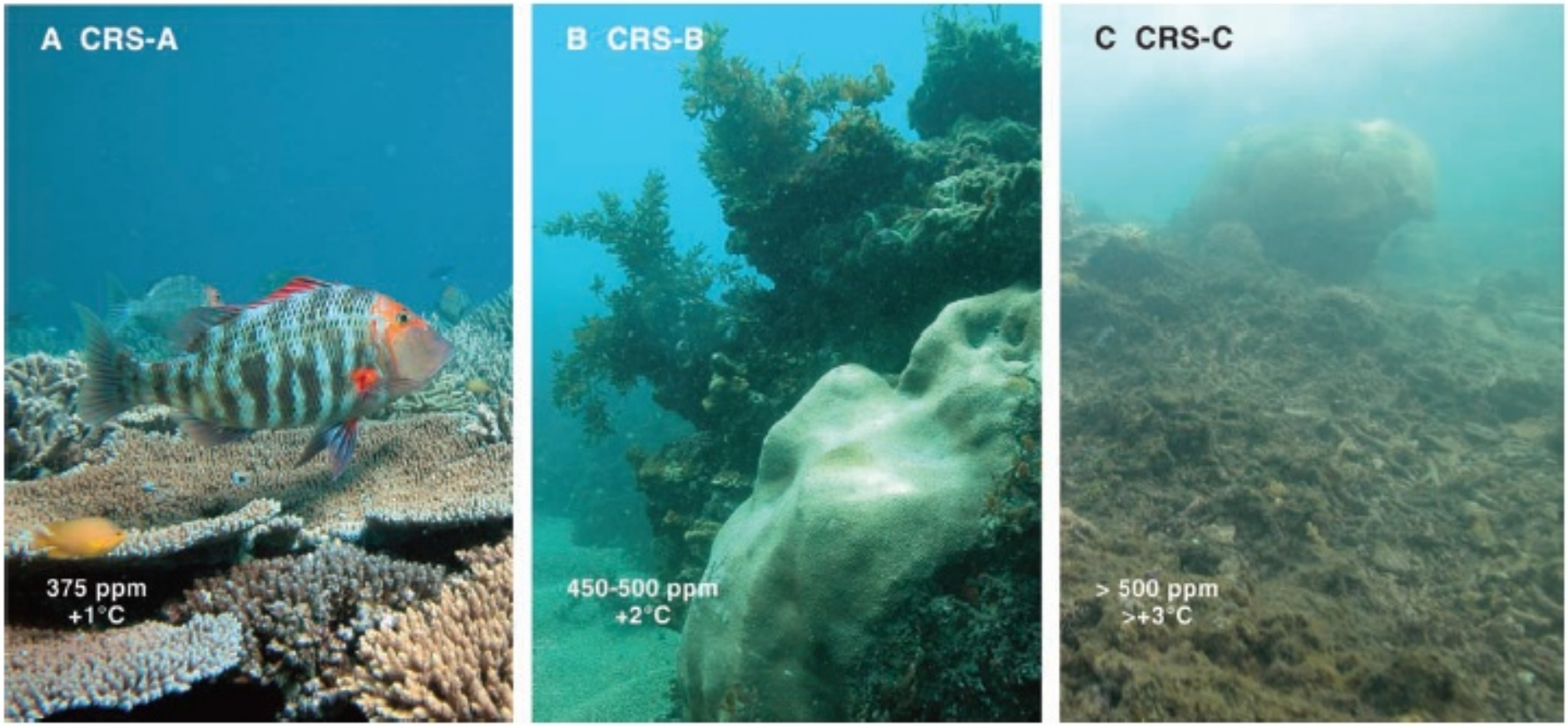

Fig. 5. Extant examples of reefs from the Great Barrier Reef that are used as analogs for the ecological structures we anticipate for Coral Reef Scenarios CRS-A, CRS-B, and CRS-C (see text). The $[CO_2]_{atm}$ and temperature increases shown are those for the scenarios and do not refer to the locations photographed. (**A**) Reef slope communities at Heron Island. (**B**) Mixed algal and coral communities associated with inshore reefs around St. Bees Island near Mackay. (**C**) Inshore reef slope around the Low Isles near Port Douglas. [Photos by O. Hoegh-Guldberg]

Hoegh Guldberg 2007

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Effects of nutrient enrichment on corals

	Dissolved inorg. nutr.	POM*	Light reduction	Sedimentation
Crustose coralline algae	↓			⬇
Bioeroders	↑	⬆		↓
Macroalgae	⬆	↑	⬇	↓
Heterotrophic filter feeders		⬆	⬆	↓
Coral diseases	↑			↑
Coral predators		⬆		

* including phytoplankton

Fig. 4. Synthesis of effects of the four main parameters of terrestrial runoff on the five main groups of organisms that affect coral cover. High abundances crustose coralline algae as settlement substrata promote coral populations, whereas high abundances of the other groups are assumed to negatively affect coral populations. Symbols as in Fig. 1.

Key issue: change from coral to algae-dominated ecosystem

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Does SGD drive water quality and the biogeochemistry of nearby coastal ecosystems?

1) Volcanic Island
(Cooks Islands)

2) Coral Cay
(Heron Island, Great Barrier Reef)

3) Delta Islands
(Gold Coast, Australia)

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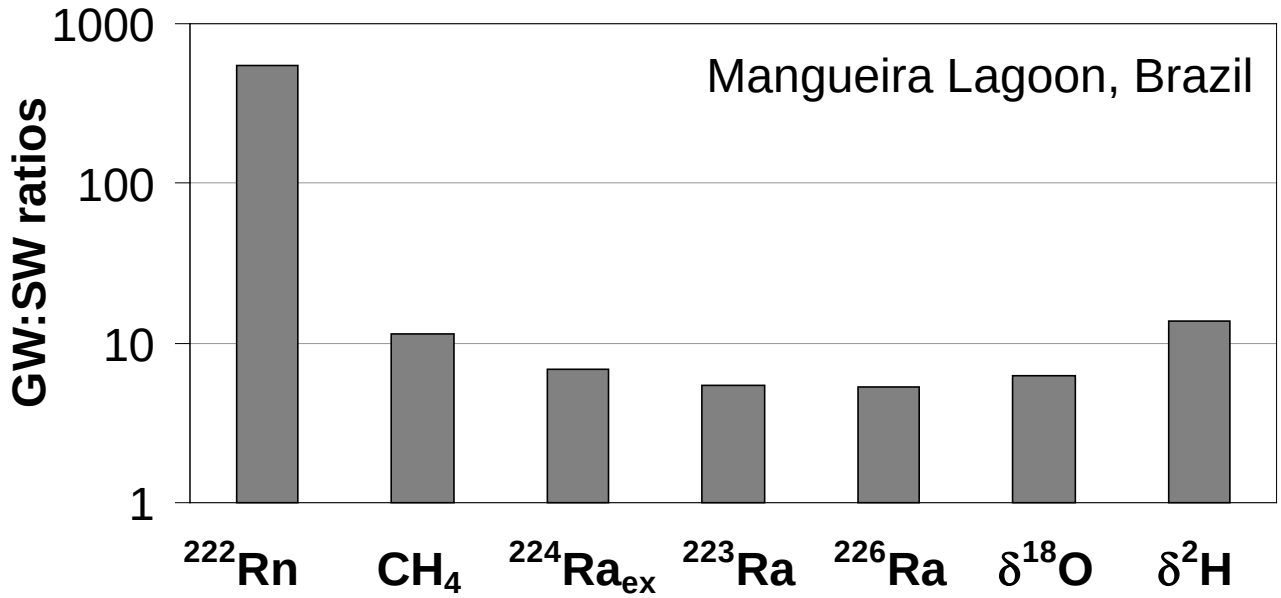
Natural groundwater tracers

- Particularly valuable in **heterogeneous, dynamic** systems
- Water column integrates the signal coming from multiple groundwater pathways
- Quick, precise, and cheap measurements are now possible



Santos et al. 2008. Journal of Hydrology 353, 275– 293

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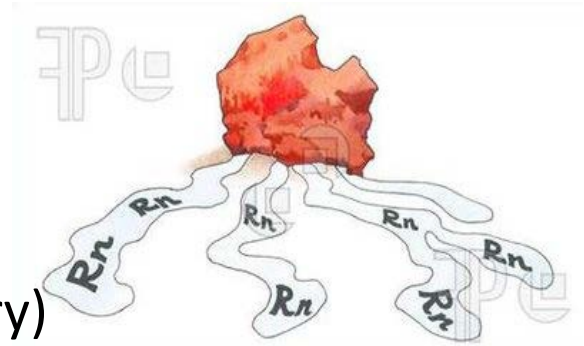
Radon as a groundwater tracer

- Very high in groundwater
- Low concentration in surface water
- Noble gas (no complicated chemistry)
- Radioactive, so dissipates quickly (short memory)
- Naturally-ocurring



- **Easy to measure!**

Before:
Large sample bottles

Now:
Automated measurements

Burnett et al., 2001

Continuous, portable ^{222}Rn measurements

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Experimental setup: Automated, high precision, in situ

Slide from Ashly MacMahon

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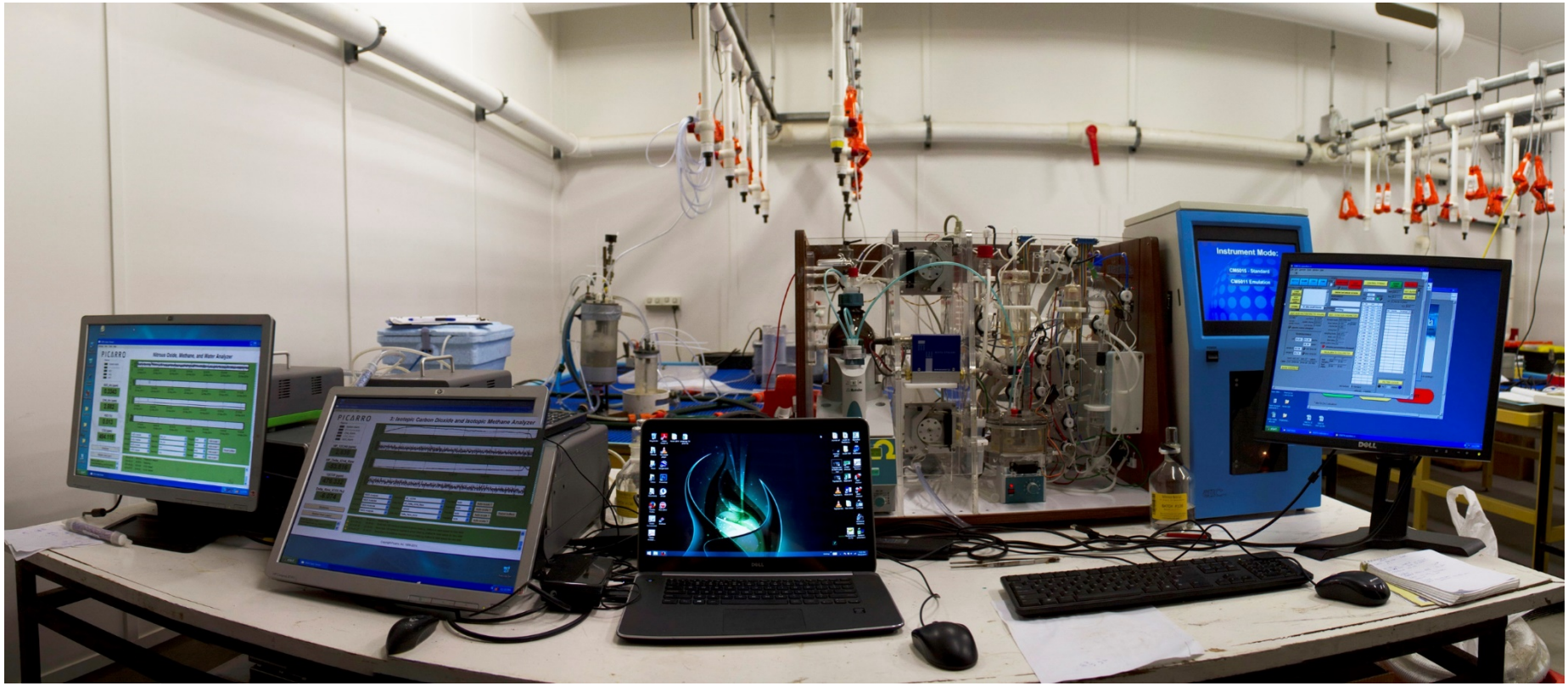
Combining radon, CO_2, CH4, and $\delta^{13}C$ measurements



Slide from Ashly MacMahon

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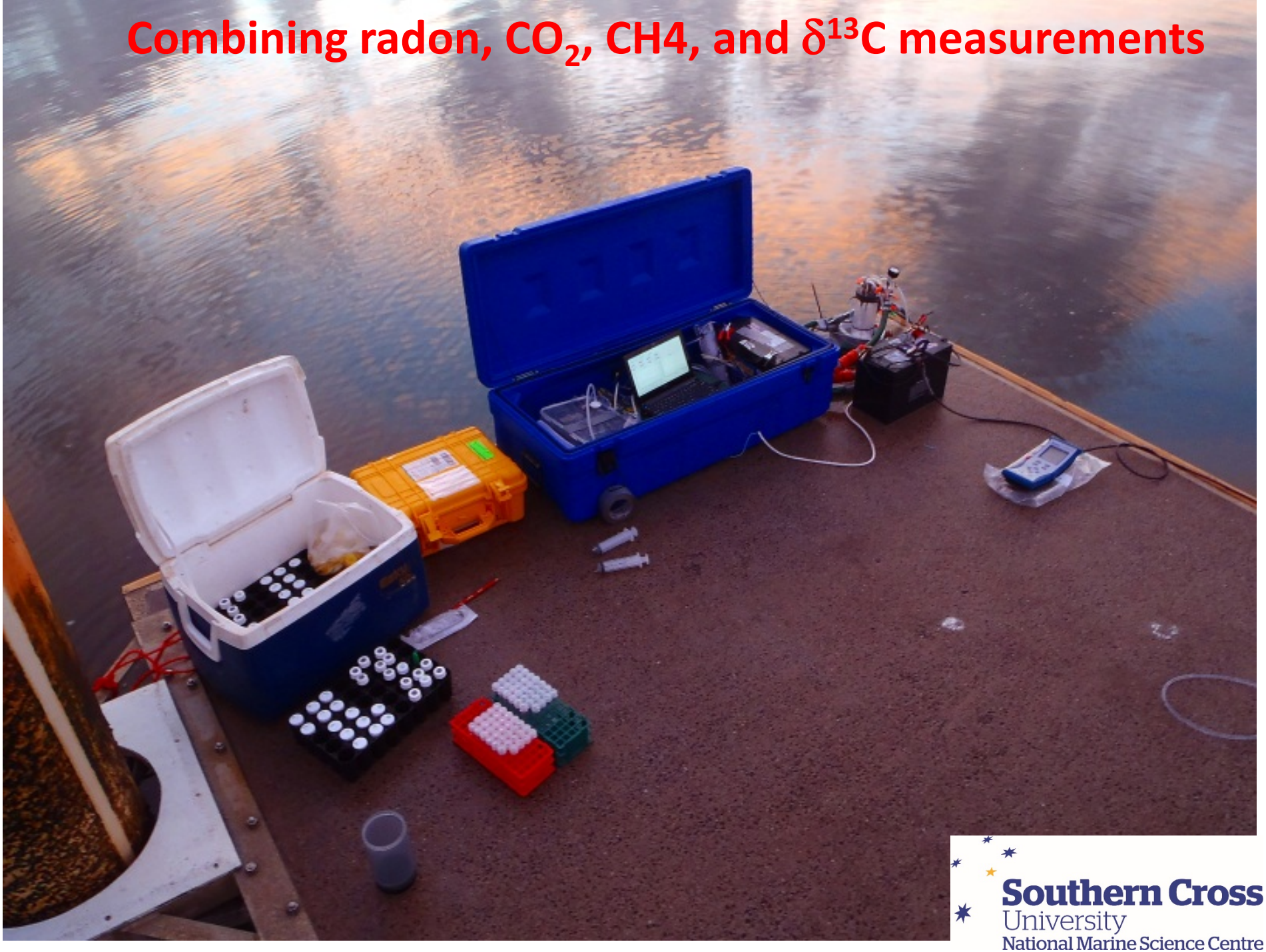

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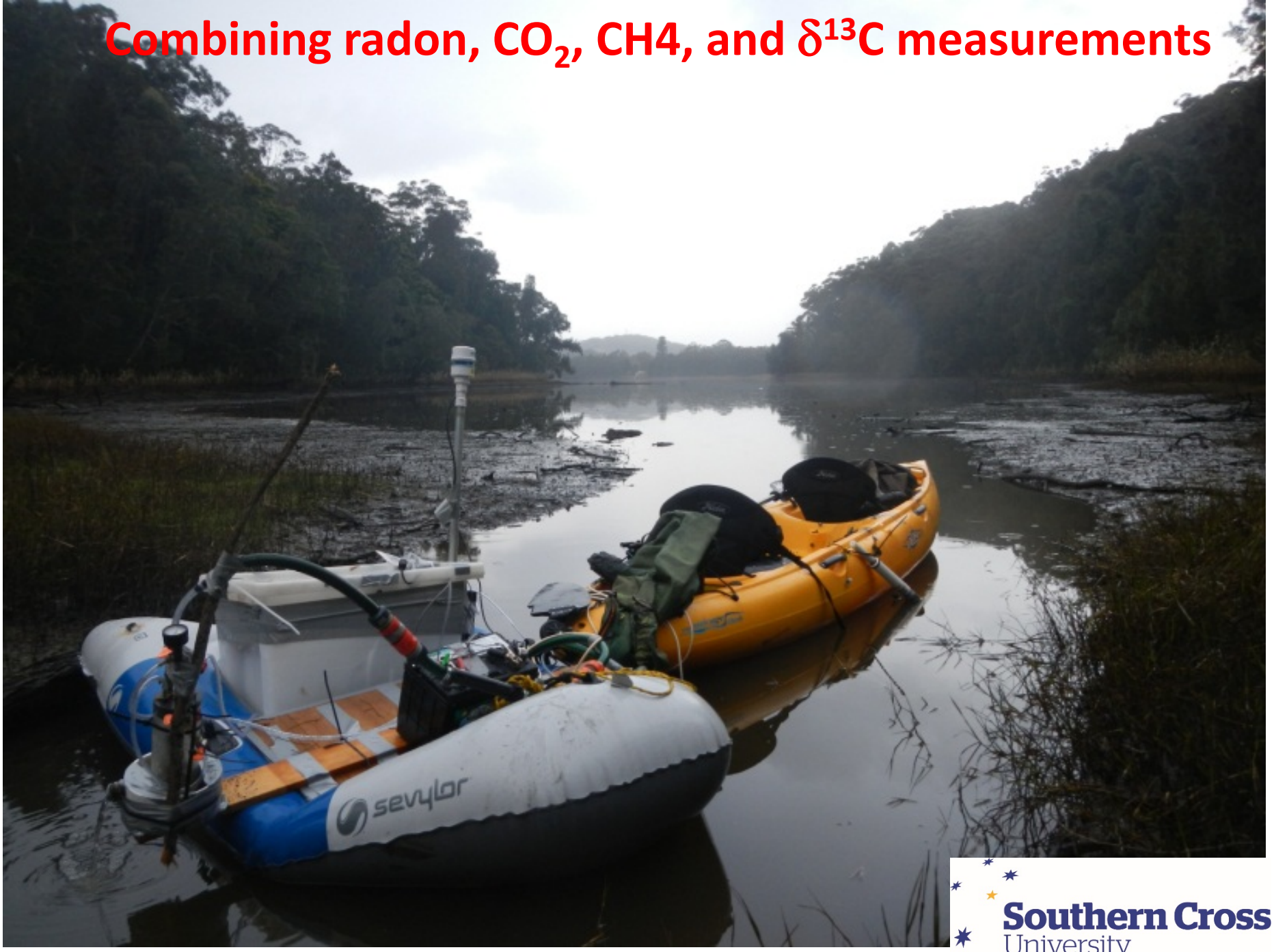

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Combining radon, CO_2, CH4, and $\delta^{13}C$ measurements

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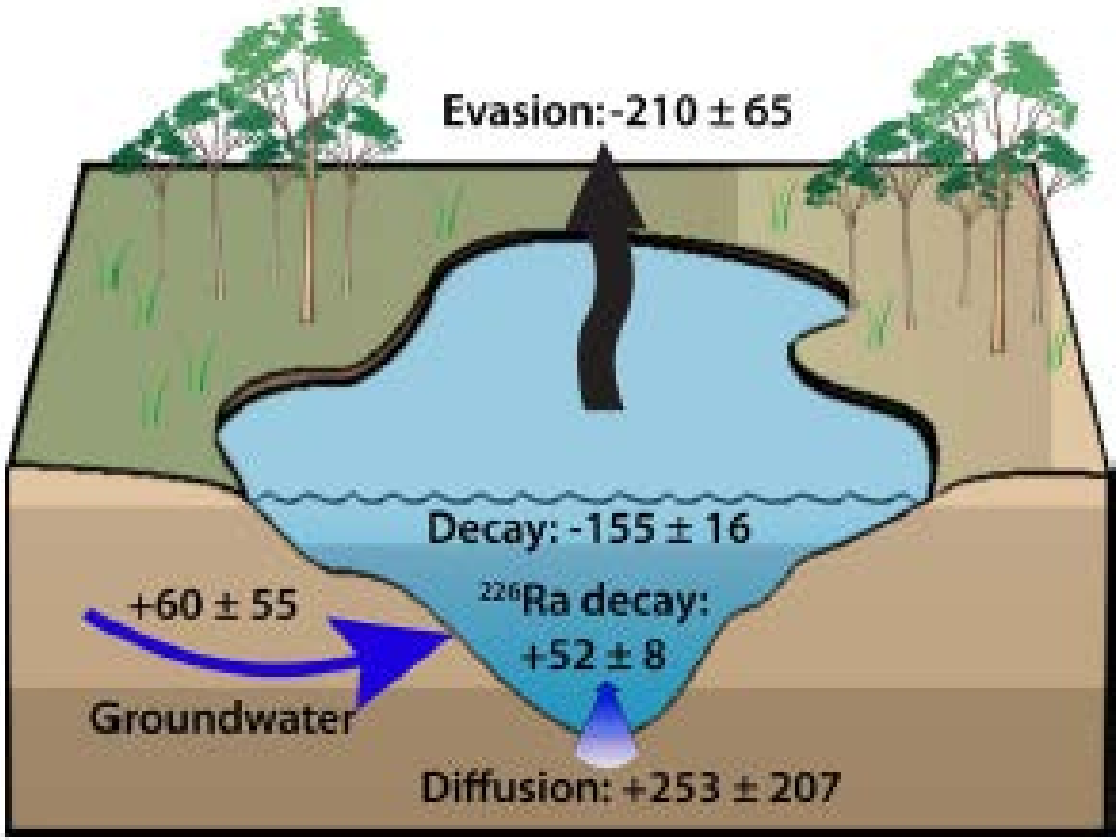
Apply mass balance models to solve for groundwater + porewater inputs



Perkins et al., 2015

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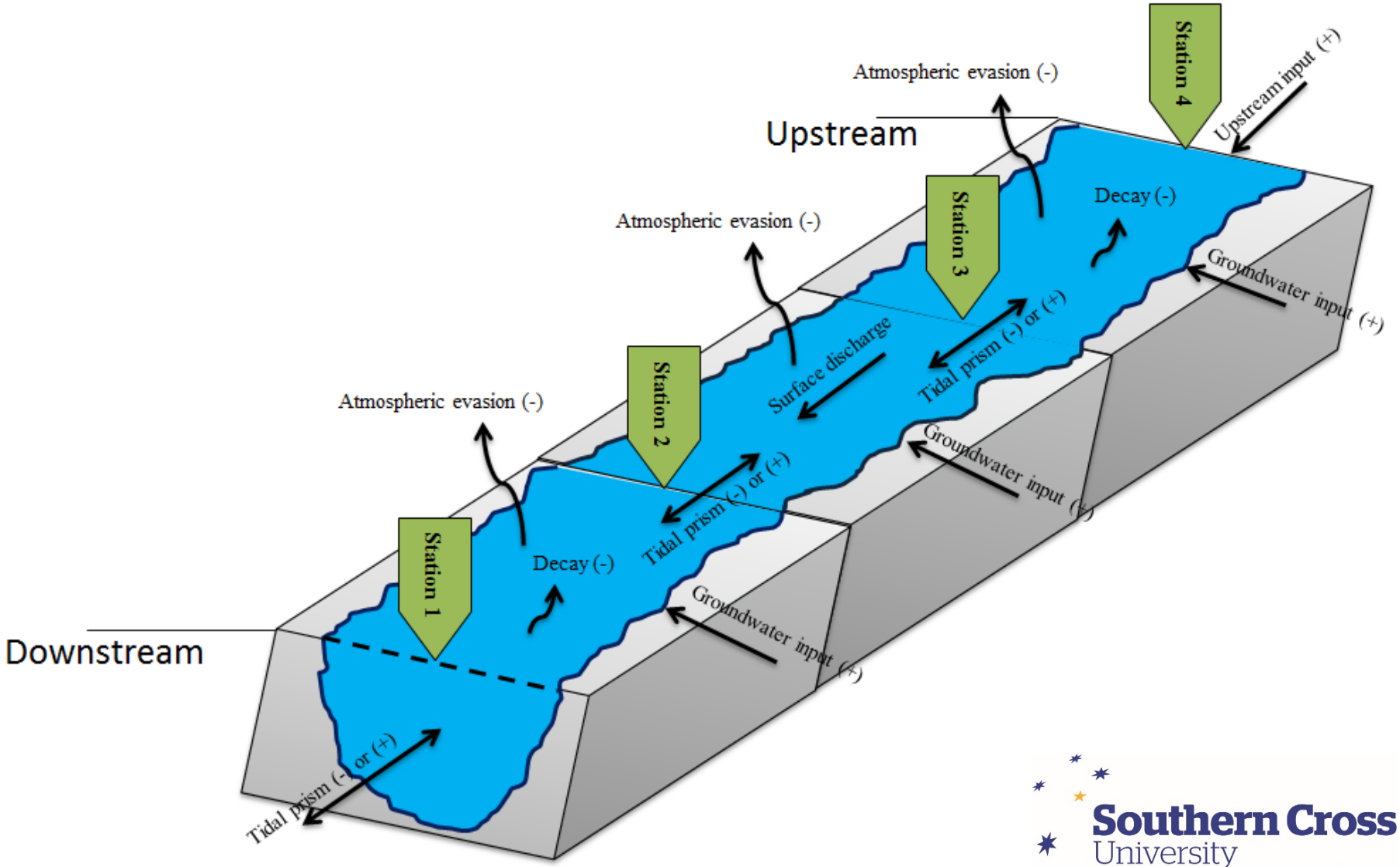
Apply mass balance models to solve for groundwater + porewater inputs



Sadat-Noori et al., 2015

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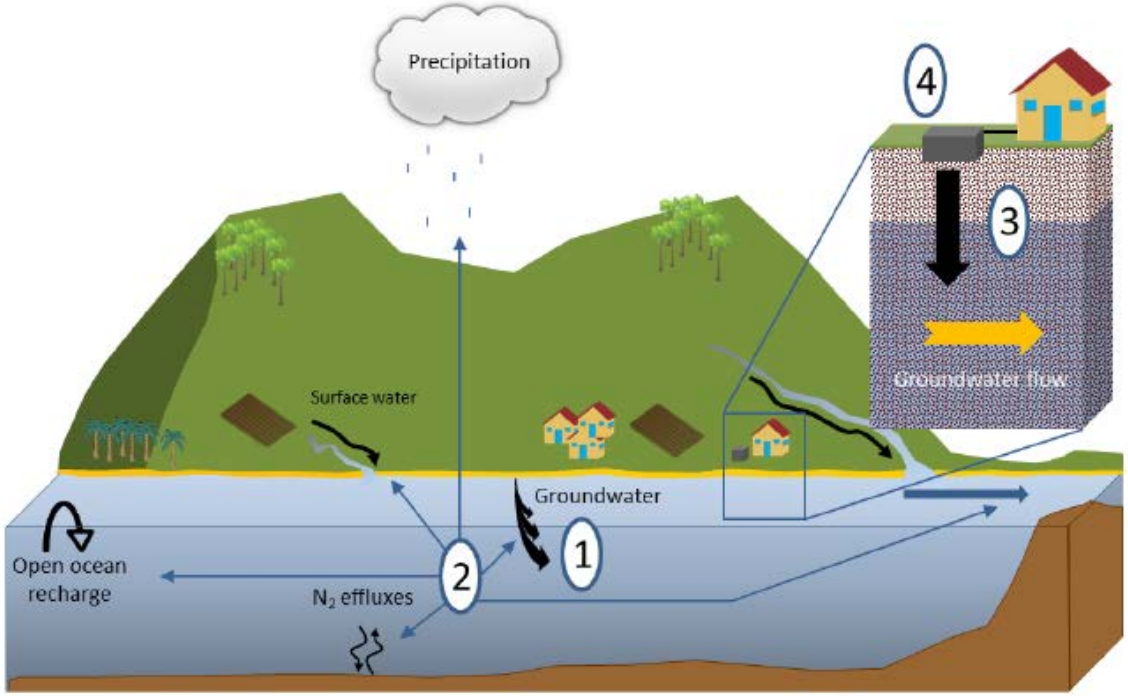
Coral reef lagoon (Raratonga, Cook Islands)



Tait et al., (2014)

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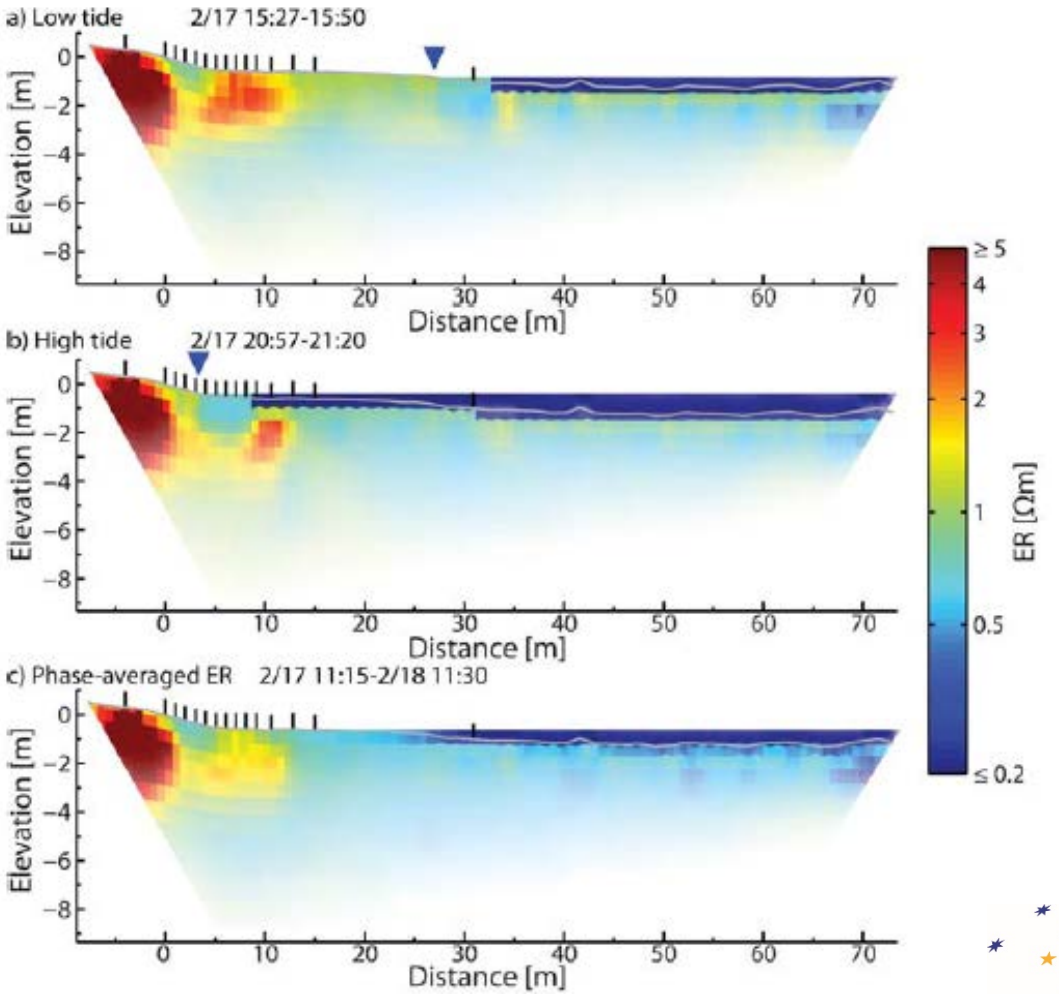
Coral reef lagoon (Raratonga, Cook Islands)

Resistivity time series across the beach



Befus et al., (2013)

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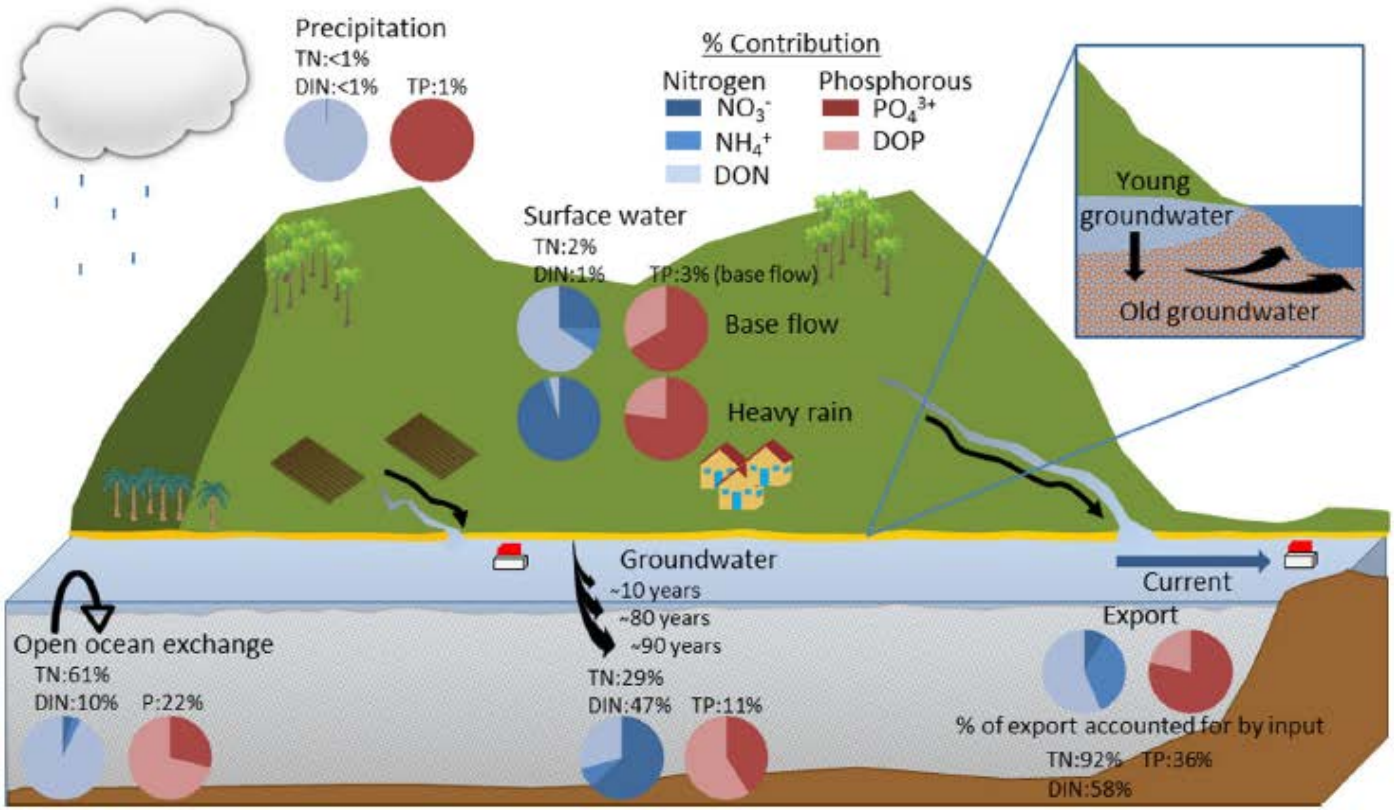
Coral reef lagoon (Raratonga, Cook Islands)



- **~50 years old groundwater account for ~ 29-47% of nitrogen inputs**

Tait et al., (2014)

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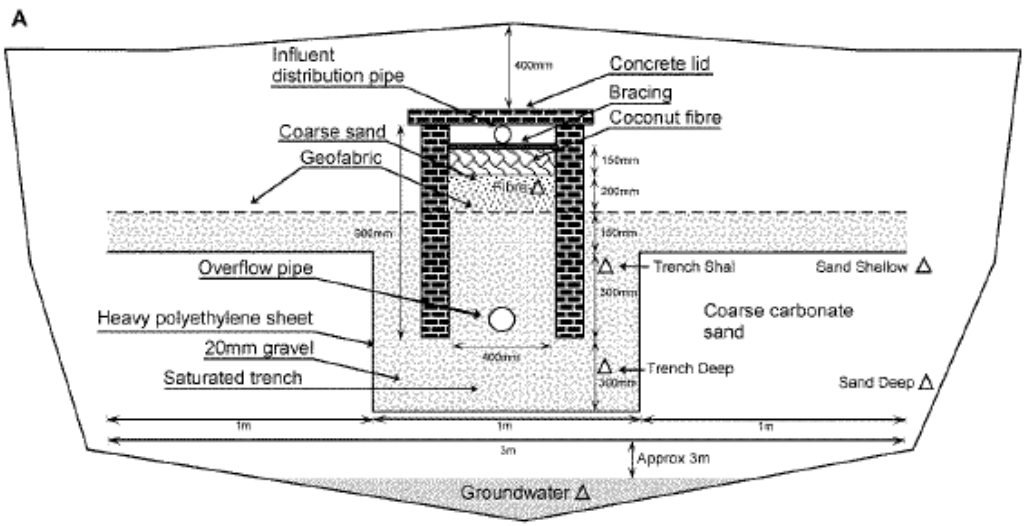
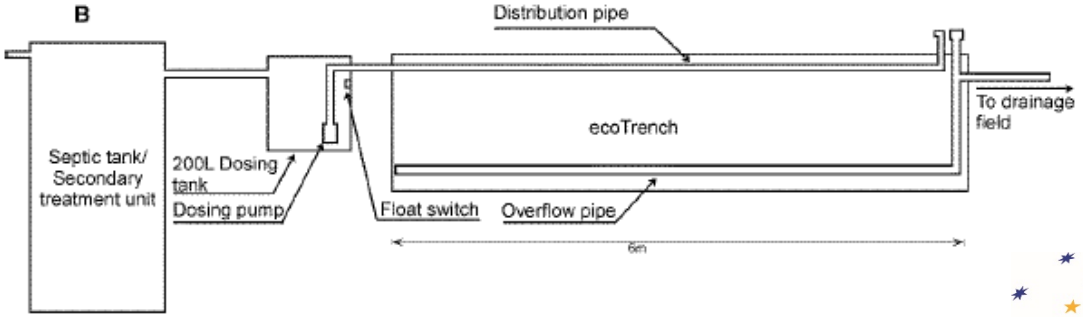
Coral reef lagoon (Raratonga, Cook Islands)

The Ecotrench – simple and cheap decentralized system





Tait et al., (2014)

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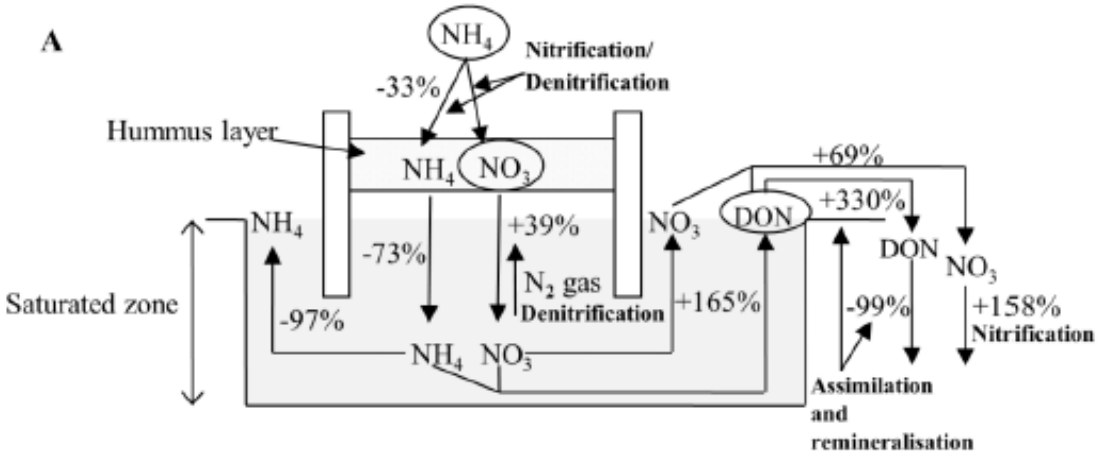
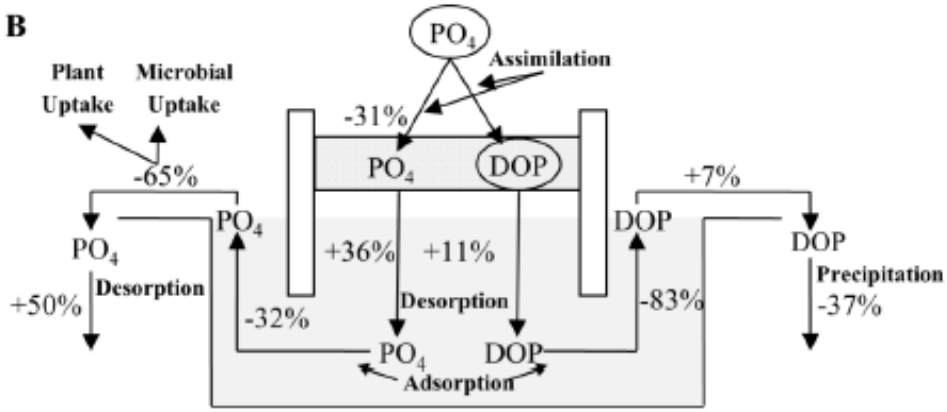
Coral reef lagoon (Raratonga, Cook Islands)

The Ecotrench – simple and cheap decentralized system



- ~40% Total Nitrogen removal
- Conversion of ammonium to nitrate



- ~46% Total Phosphorus Removal

Tait et al., (2014)

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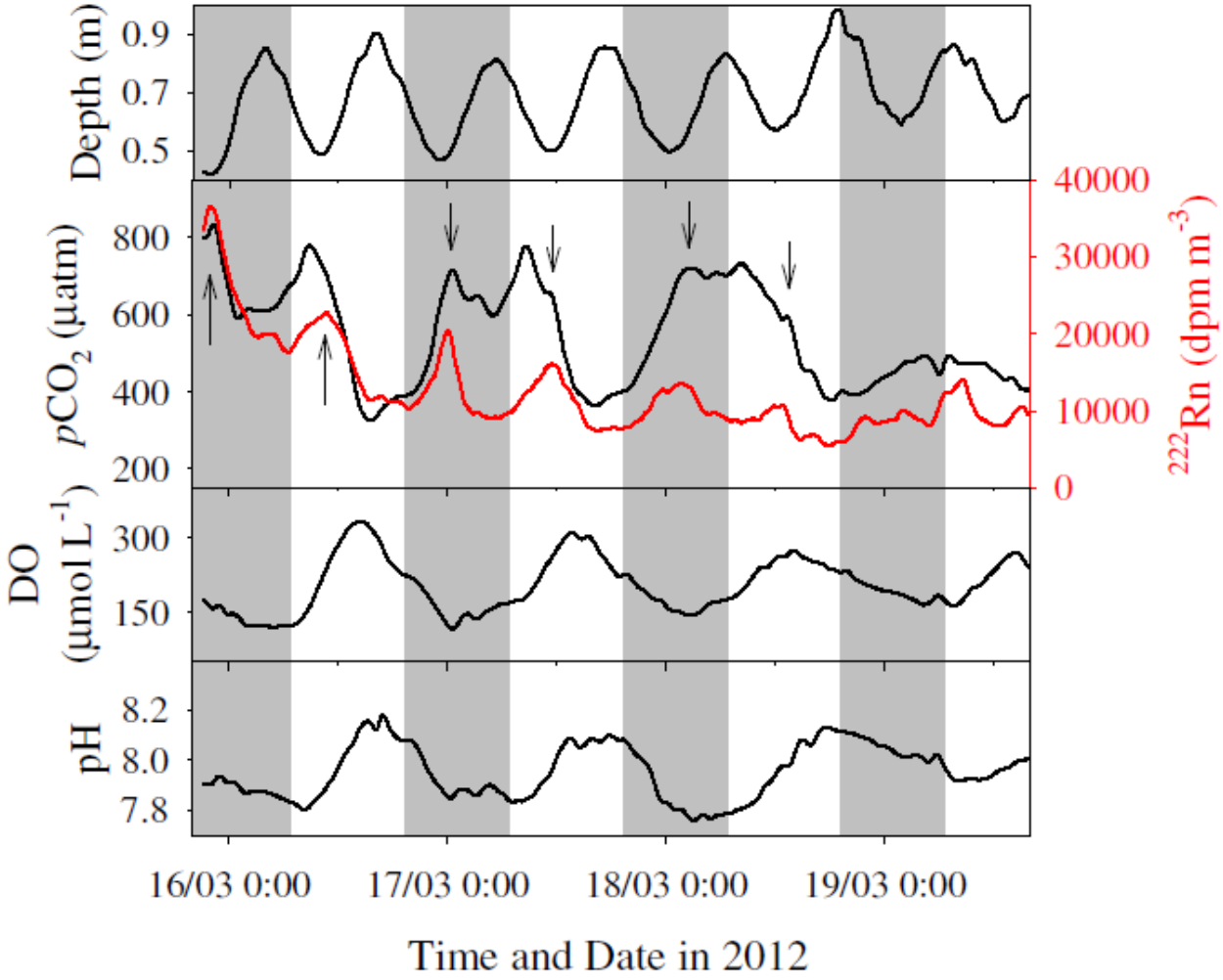
Coral reef lagoon (Raratonga, Cook Islands)



Cyronak et al., 2014. GBC

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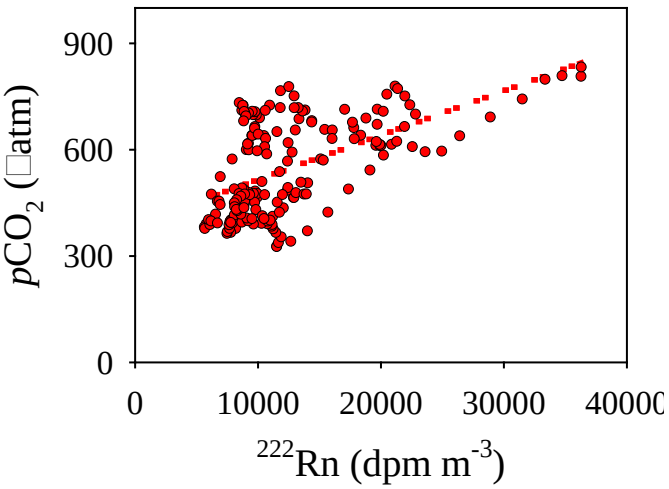
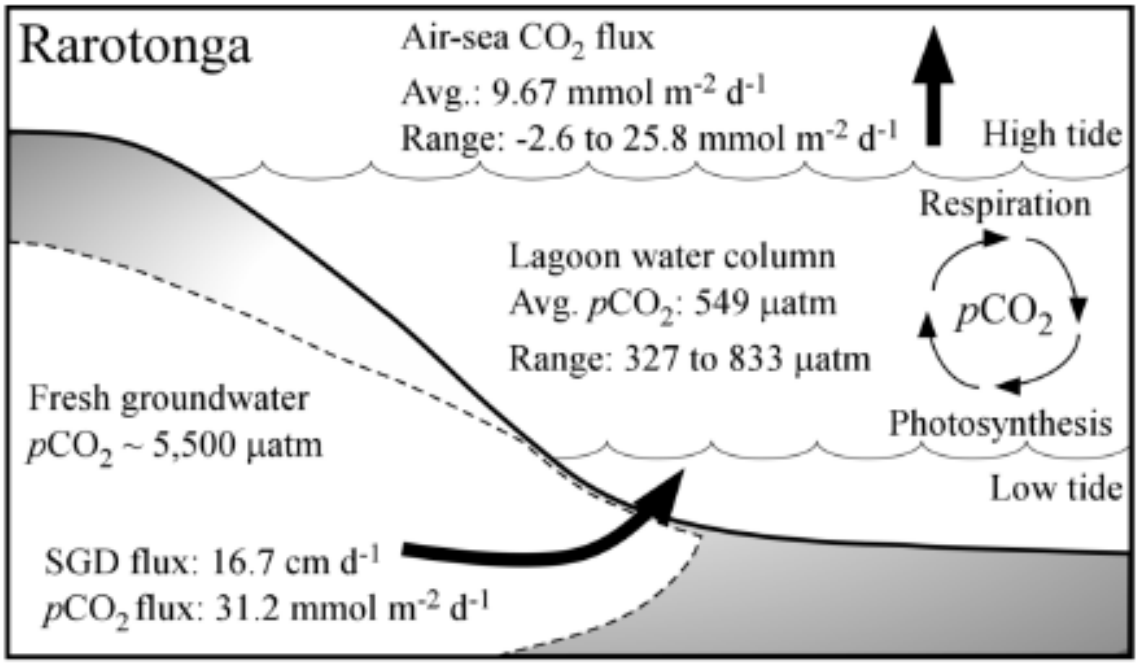
Coral reef lagoon (Raratonga, Cook Islands)





- **Groundwater derived free CO_2 exceeds evasion to the atmosphere, and coral uptake**
- **Localized groundwater inputs = ocean acidification?**

Cyronak et al., 2014. GBC

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Coral reef lagoon (Heron Island, Great Barrier Reef)

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Coral reef lagoon (Heron Island, Great Barrier Reef)

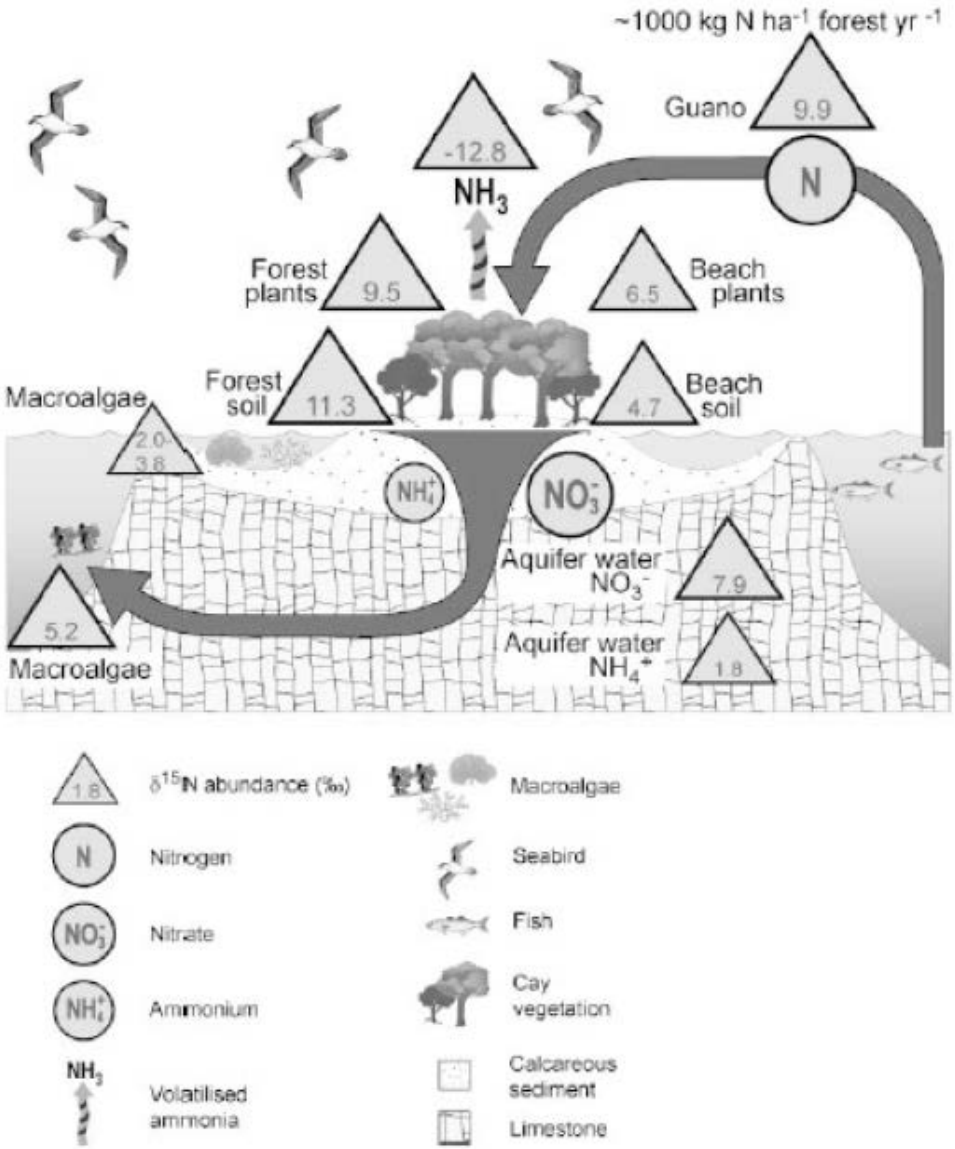

Fig. 7. Conceptual model of suggested Heron Island N relations based on $\delta^{15}N$ values and N analyses. Seabirds

Schimidt et al., 2004

-Qualitative conceptual model based on stable isotopes

-N deposition rates of 1000 kg N ha^{-1} y^{-1} (10-fold larger than sugar cane farming!)

-Tidally-driven groundwater flows potentially important

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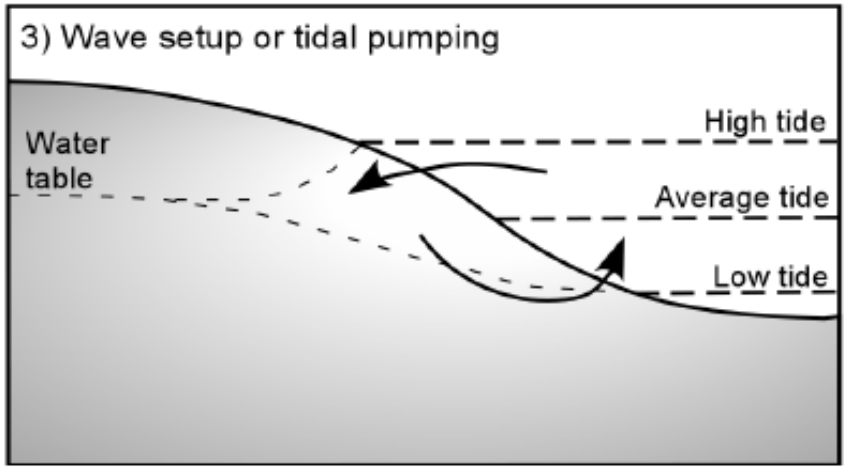
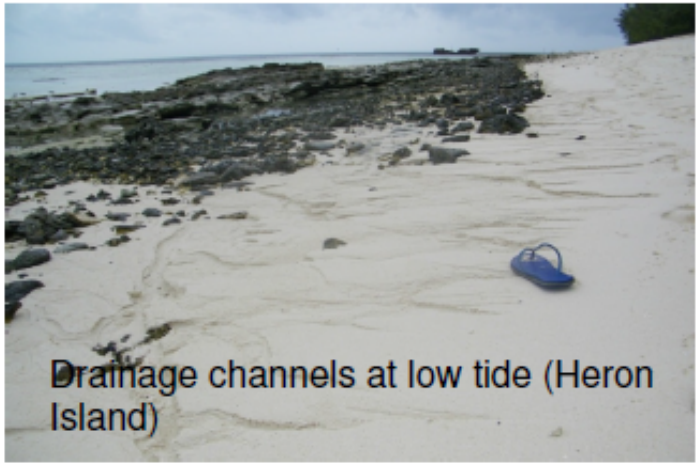
Coral reef lagoon (Heron Island. Great Barrier Reef)

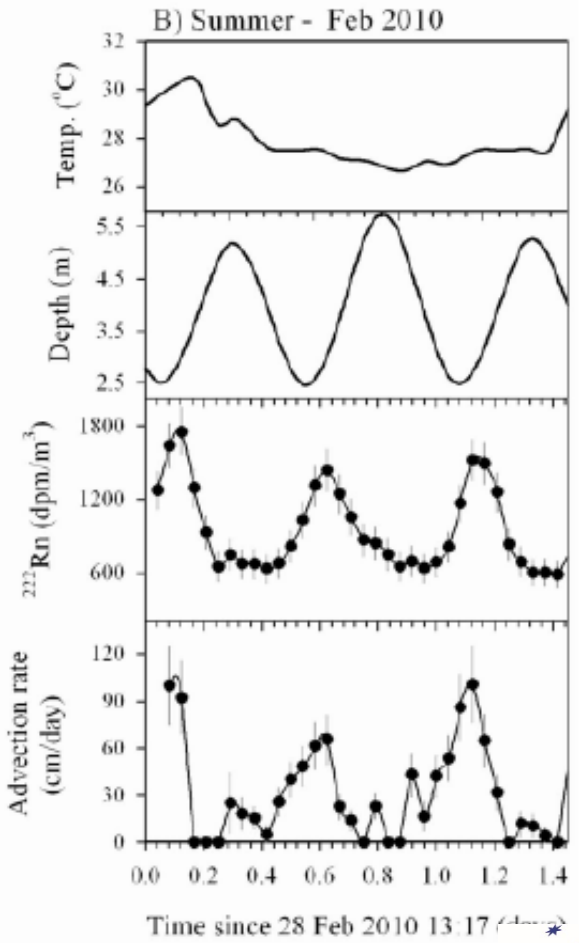
Tidal pumping





Beach "breathing":

inhale *seawater at high tide;*
exhale *groundwater at low tide*



Santos et al., (2010)

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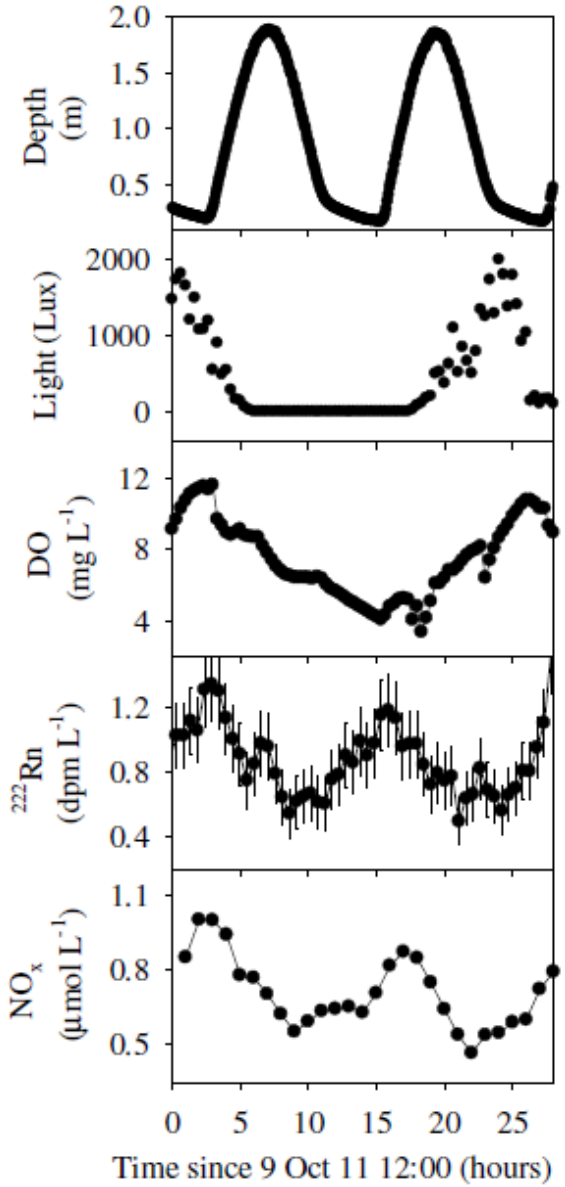
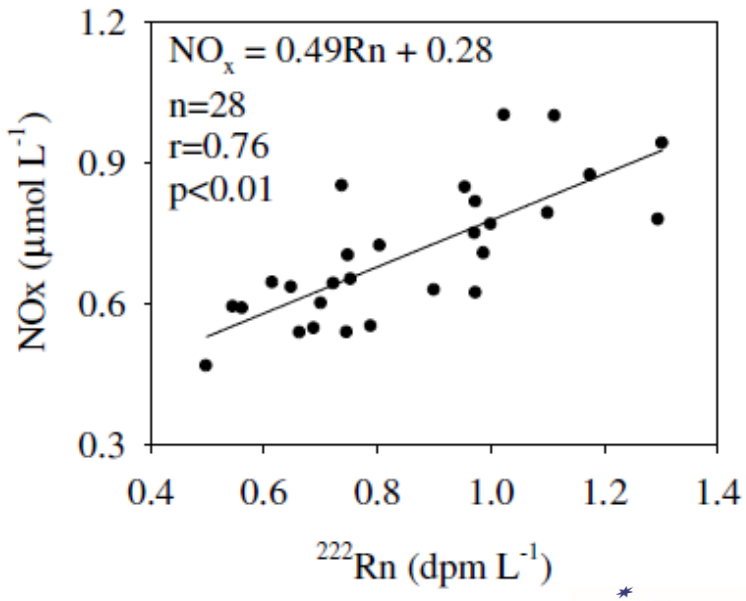
Reef lagoon water time series



- Diel (DO) versus tidal (Rn) pattern

-No major lags

- Clear correlation between radon and nitrate



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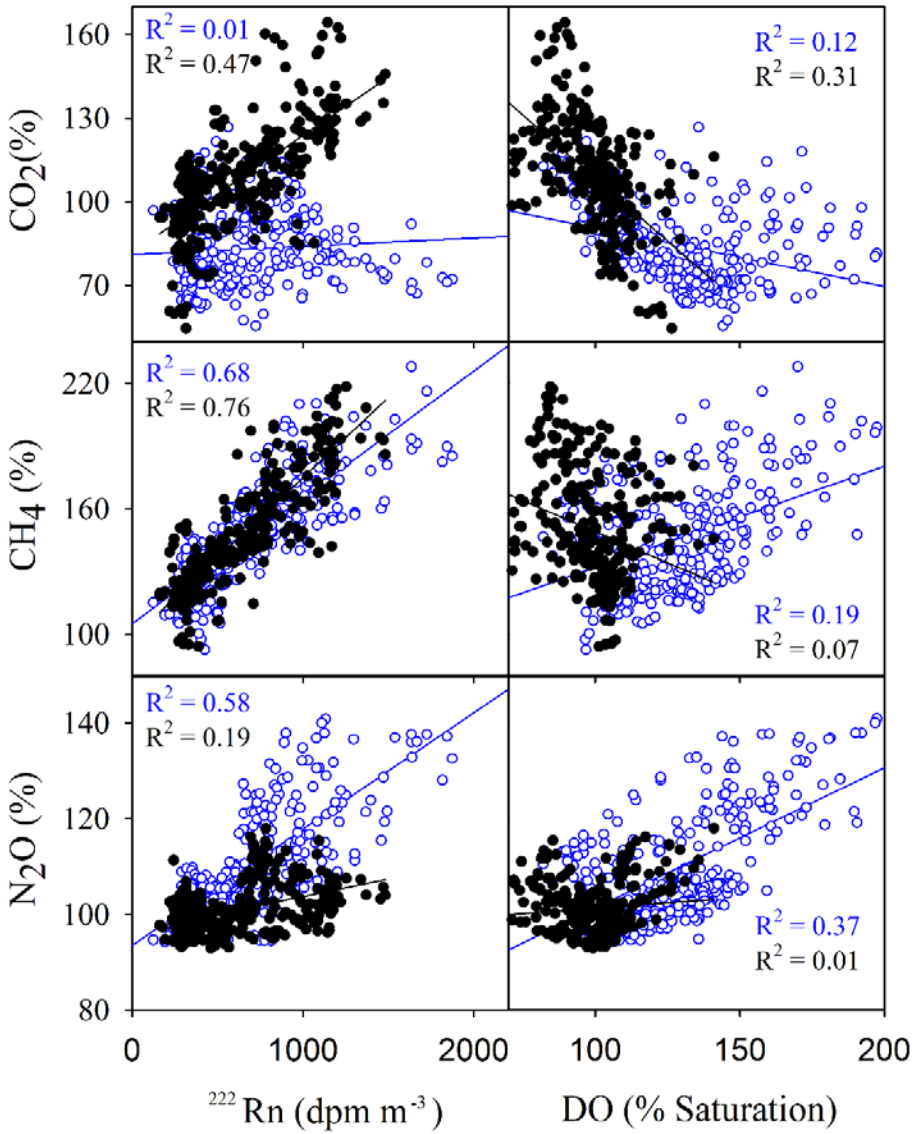
Coral reef lagoon (Heron Island, Great Barrier Reef)



Groundwater observations:

CO_2 = 1060% saturation

CH_4 = 2680% saturation

N_2O = 1205% saturation

O'Reilly et al., 2015. GRL

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Modified deltas and coastal wetlands (Gold Coast)

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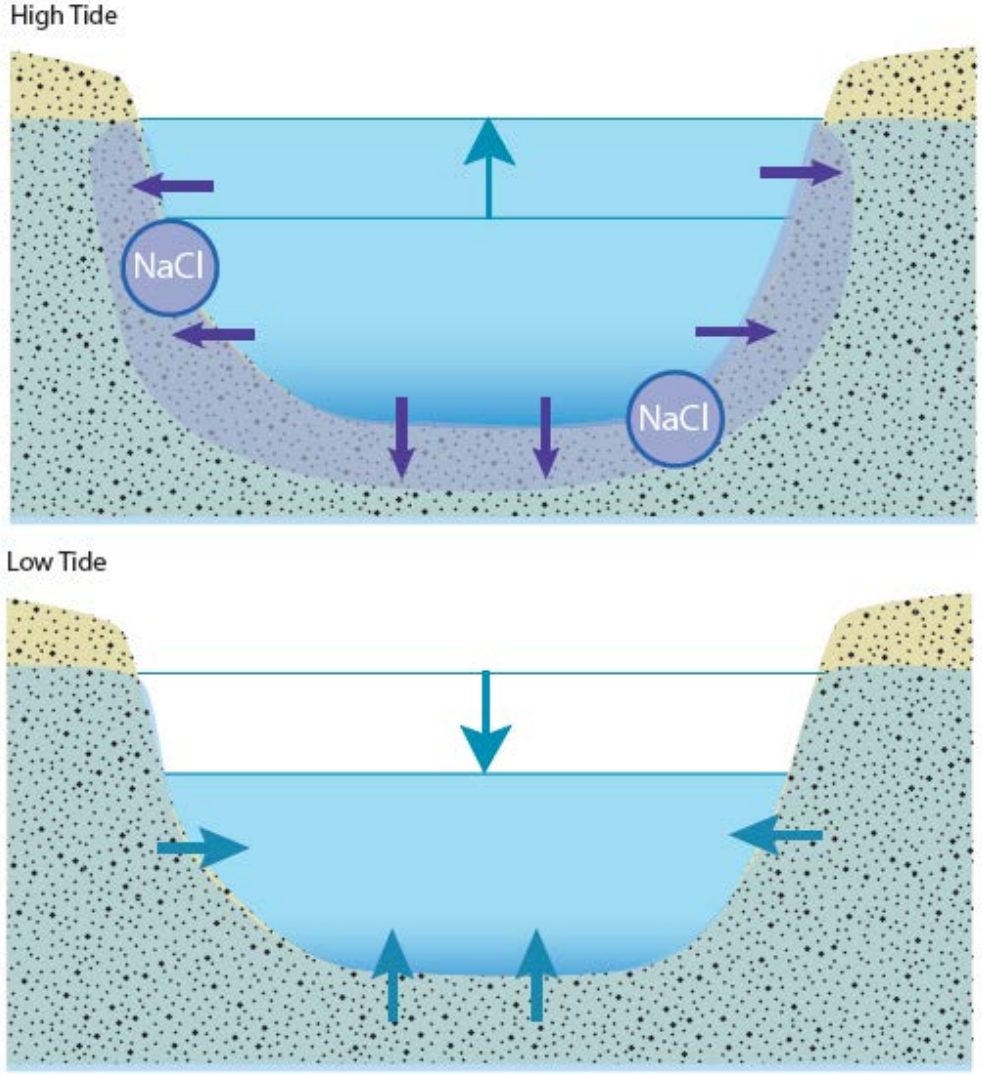
Modified deltas and coastal wetlands (Gold Coast)



From wetland C sinks to sources of atmospheric CO_2?

P.A. Macklin et al. / Marine Chemistry 167 (2014) 82–92

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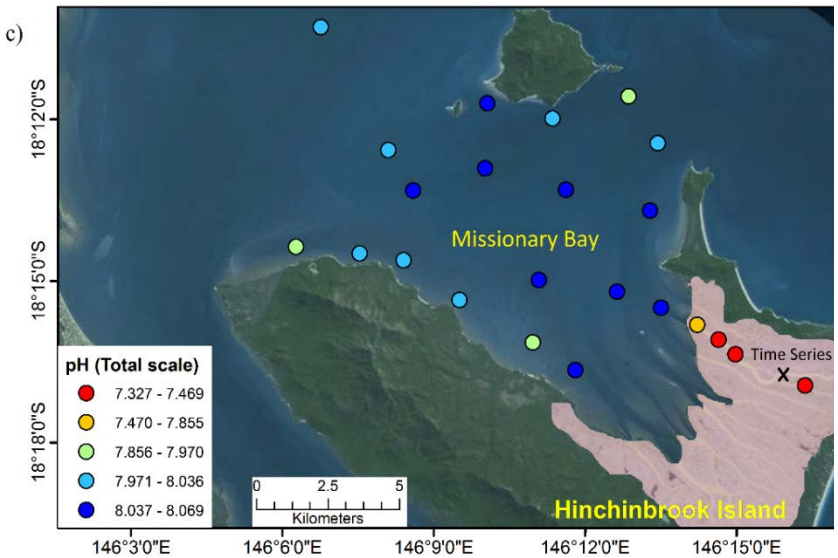
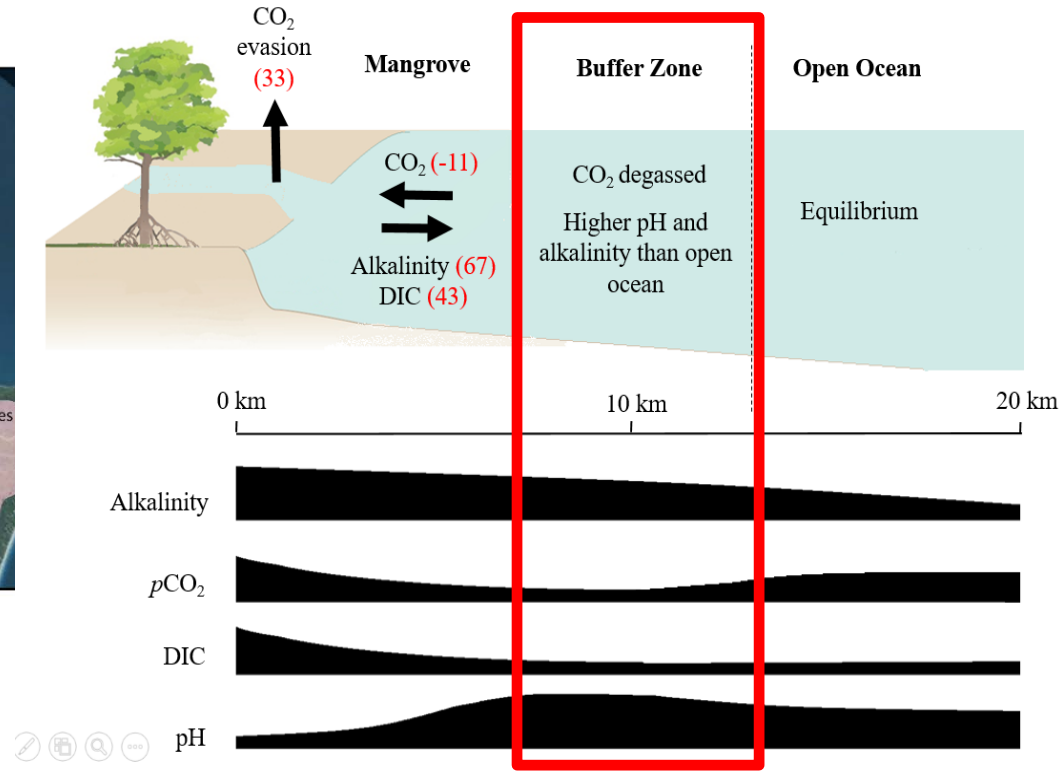
Natural wetlands prior to drainage

Groundwater-derived alkalinity release buffers coastal acidification





James Sippo in submission

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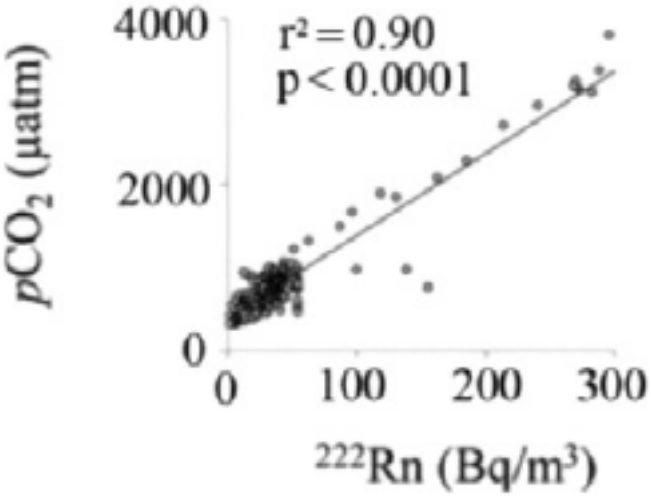
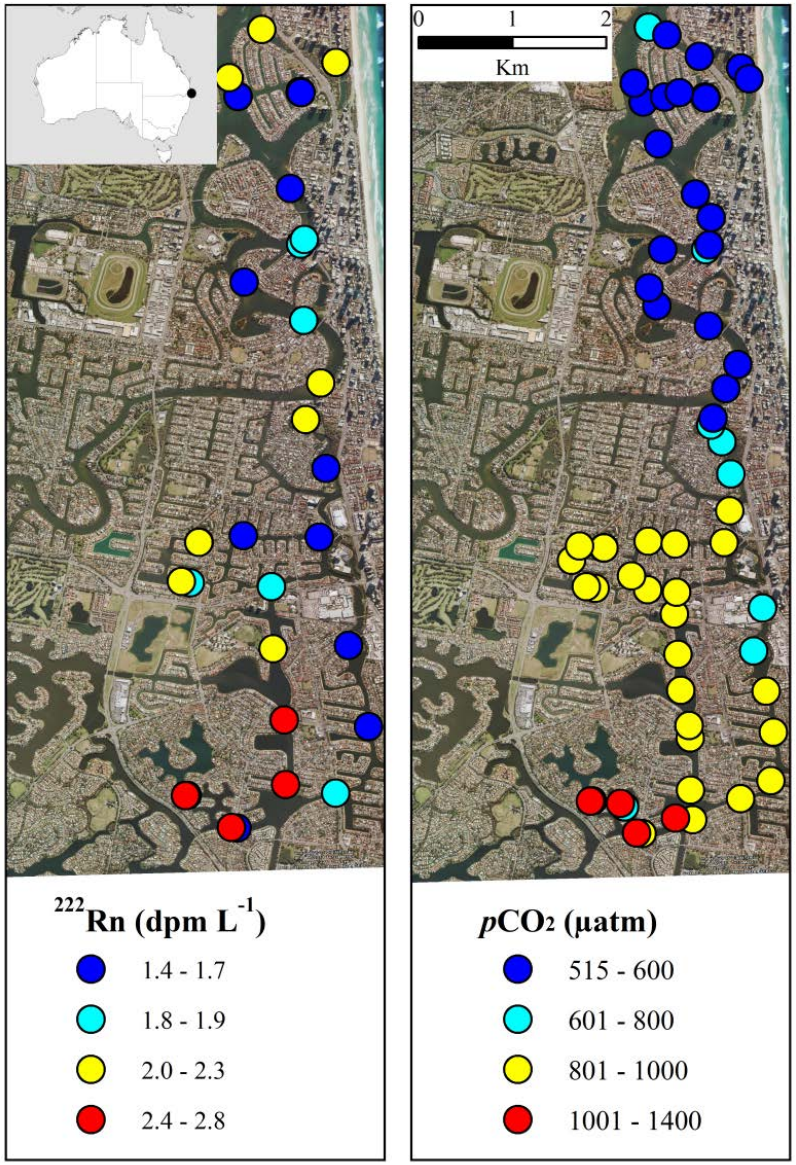
Gold Coast Canal Estate

-Canals act as a window to the coastal aquifer

-Canals account for >50% of CO_2 evasion from waterways





P.A. Macklin et al. / Marine Chemistry 167 (2014) 82–92

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Summary and conclusions

1) Islands are often SGD hotspots.

2) SGD is major driver of surface water nutrient and carbon budgets near islands.

3) Automated observations allow for links between SGD and water quality to be established.

4) Draining may convert wetlands from carbon sinks to carbon sources due to enhanced SGD.

5) SGD should be considered when assessing coral reef health.

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