2019 OCB Summer Workshop

Anthropogenic Perturbation of Nitrogen Cycling across the River-Coast-Ocean Continuum - A Global Modeling Perspective

Xiao Liu, Princeton University[1], NOAA GFDL[2]

Charles Stock[2], John Dunne[2], Minjin Lee[1,2], Elena Shevliakova[1,2], Sergey Malyshev[1]

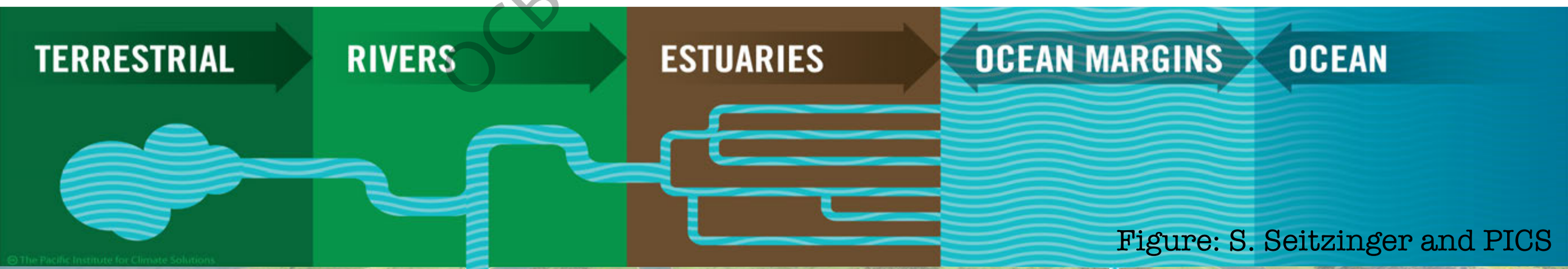


Figure: S. Seitzinger and PICS

Eutrophication Challenges Coastal Environment

Baltic Sea "dead zones"; sciencedaily.com

Dead fish from a Karenia brevis bloom; http://www.whoi.edu/redtide/

Decline of submerged plants; www.chesapeakebay.net

Figure: S. Seitzinger and PICS

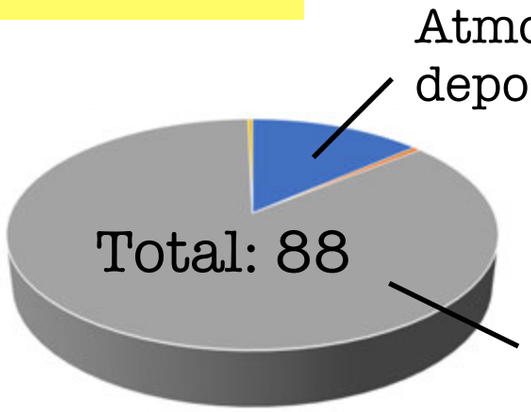
* How is river N cycled and transported across the land-ocean interface?

* How does increasing river N change our coastal ecosystems? How is the impact different from system to system?

Human Impact on Land N Fluxes and Inventory

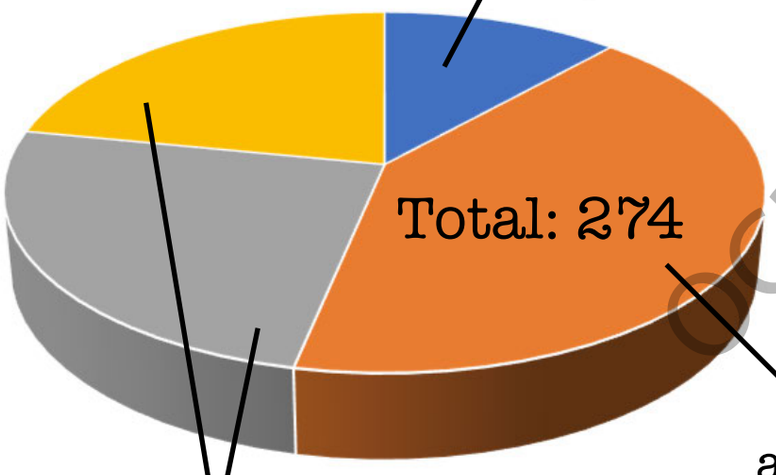
Land N source

1831-1860



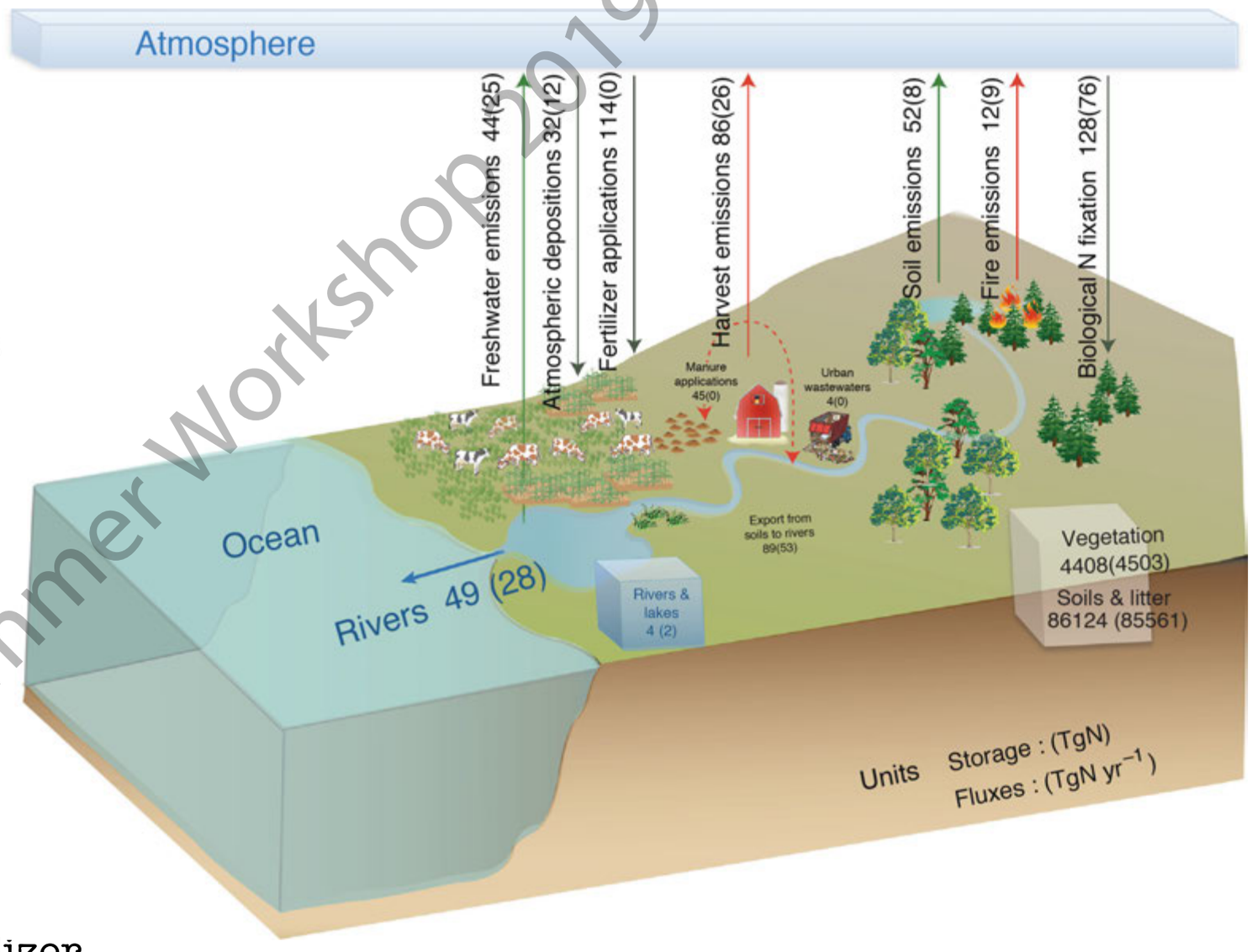
N_2 fixation by land plants (natural; 76)

1991-2005



N_2 fixation by land plants (natural and agricultural; 128)

NOAA GFDL's LM3-TAN model



Modified from Lee et al. 2019 Nat. Comm. Fig. 1

In agreement with:
Galloway et al., 1995, 2004, 2008
Cleveland et al. 2013
Herridge et al., 2008

Increasing River N Loading to Coastal Oceans

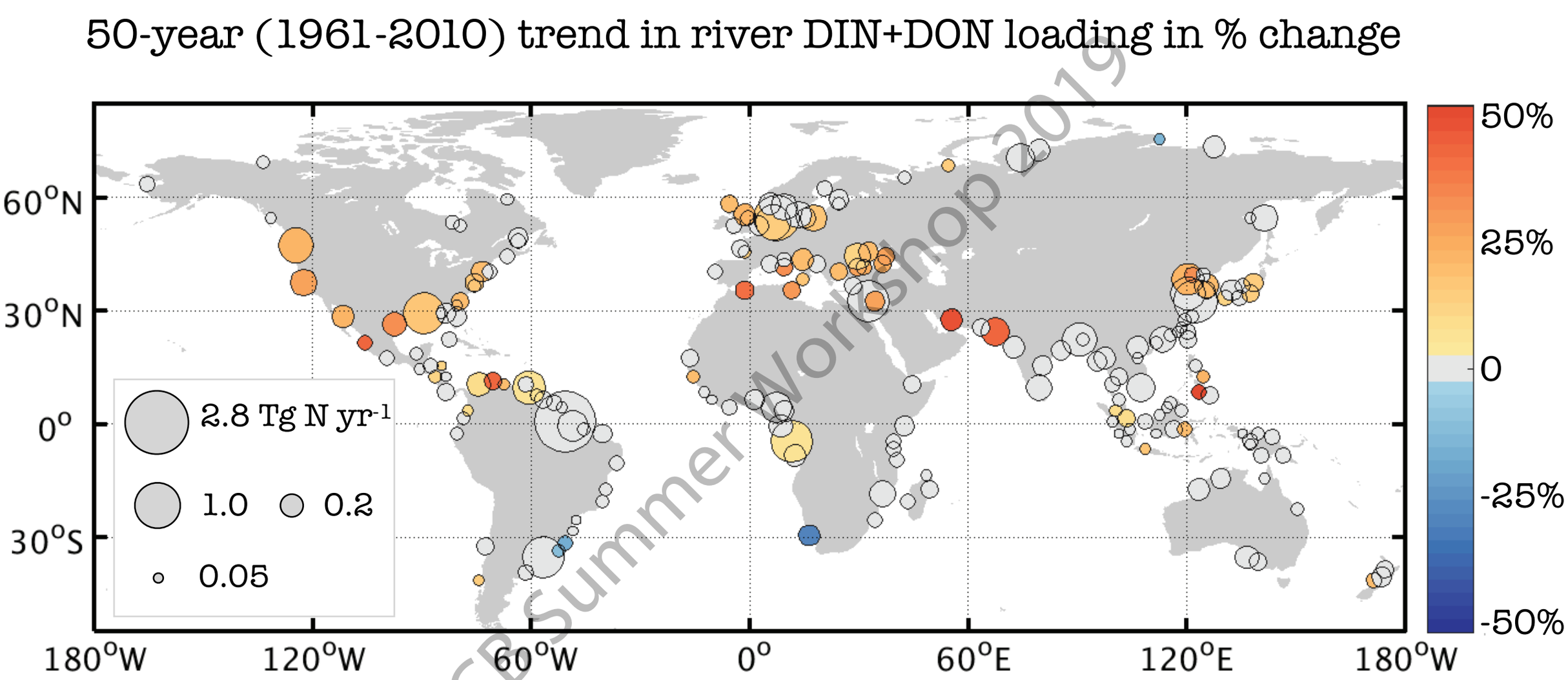
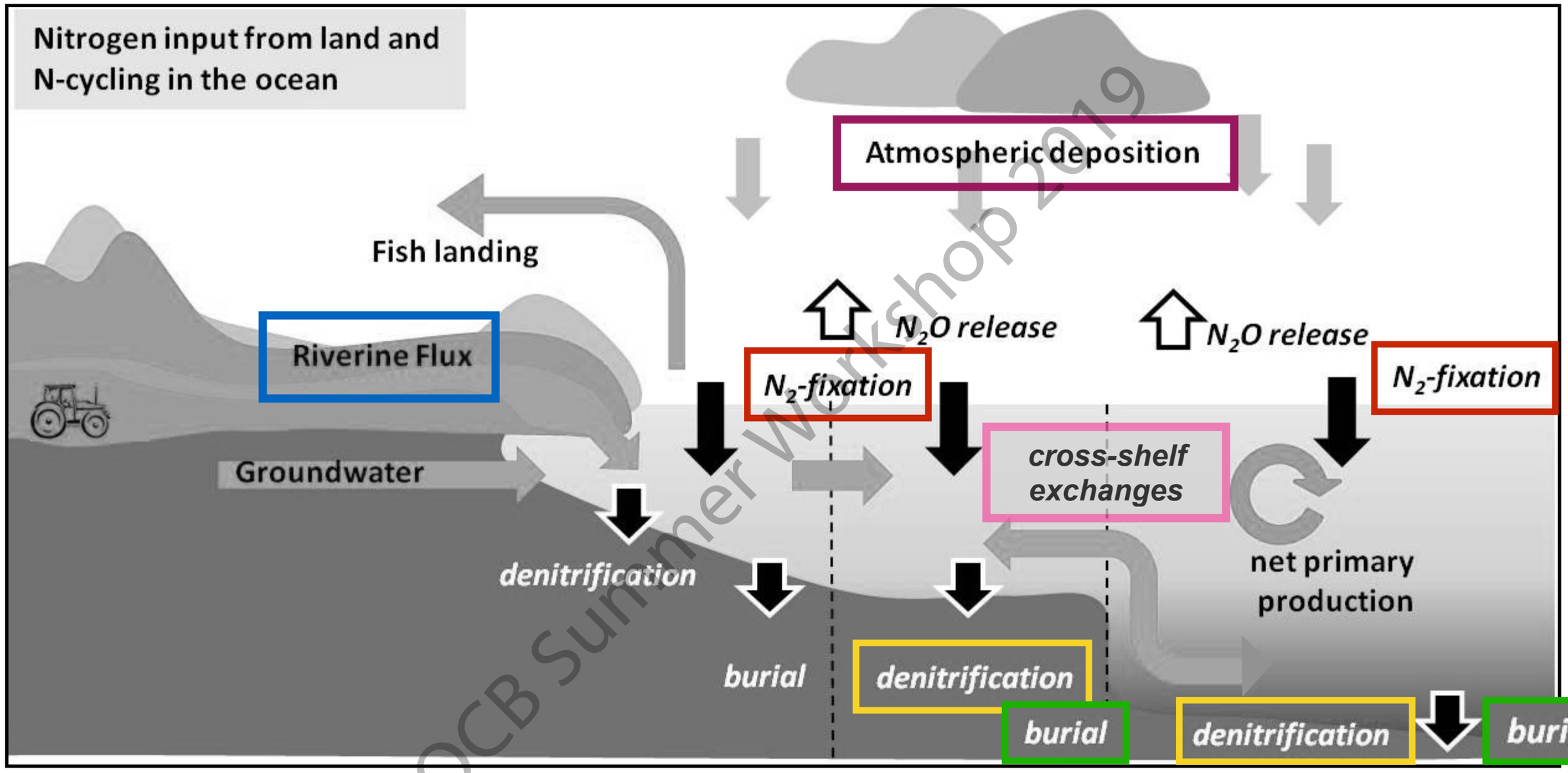


Fig. generated from LM3-TAN output, Lee et al., 2019

Complex Processes Shaping Coastal N Cycle



GFDL's MOM-COBALT (33-tracer Carbon, Ocean Biogeochemistry and Lower Trophics model, Stock et al. 2014)

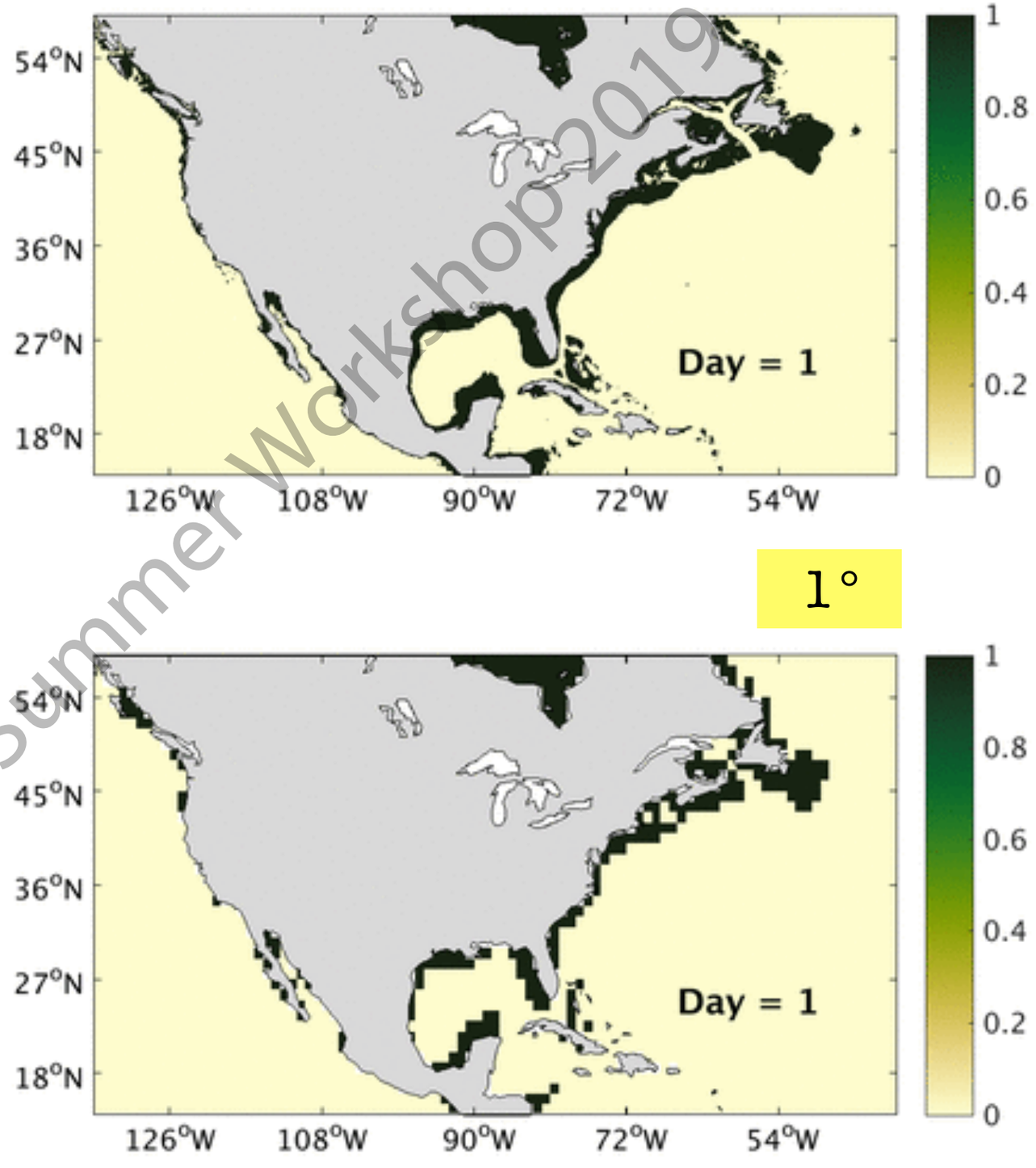
Representing Coast-Ocean Exchanges

* GFDL's global ocean-ice model MOM6

* 1°, 1/2°, 1/4°, 1/8°

dye release experiment

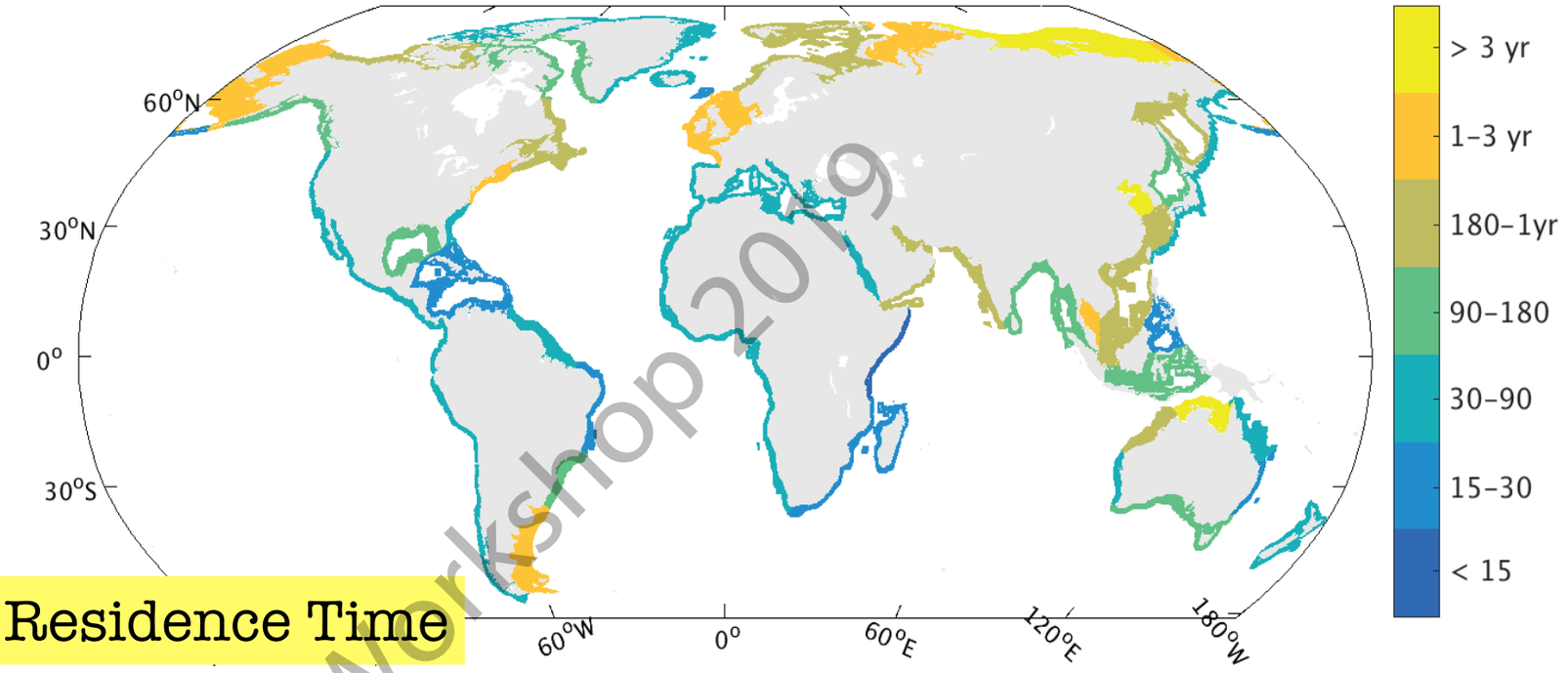
1/8°



1°

Representing Coast-Ocean Exchanges

* GFDL's global ocean-ice model MOM6
* 1°, 1/2°, 1/4°, 1/8°
* Coastal age tracer for residence time estimates



Coastal Residence Time

(#) LME	Coastal Residence Time: Observations	1°	1/2°	1/4°	1/8°	Study Site	Reference and *Methods
(1) East Bering Sea	~ 1.6 years	0.68	0.73	0.86	**1.2**	≤ 200 m isopleth	[b]Li et al., 2017
(2) Gulf of Alaska	≤ 12 months	**0.9**	**2.4**	**2.6**	**3.4**	~ 50 km from shore	[a]Weingartner et al., 2005
(3[#]) California Current	≤ 18 days	**17**	**14**	**12**	**7.5**	≤ 20 km from shore	[b]Cobert and Hammond, 2007
(6) SE US Shelf	~ 6 weeks	4.3	3.2	**6.0**	**7.0**	≤ 100 km from shore	[b]Moore, 2007
(16[#]) East Brazil Shelf	7-14 days	[^]n/a	3.8	**11**	**10**	≤ 20 km from shore	[b]Moore and de Oliveira, 2008
(22) North Sea	~ 1 year	**0.91**	1.4	1.6	1.7	≤ 200 m isopleth	[a]Huthnance et al., 1997
(47) East China Sea	~ 12 months	**11**	5.7	6.8	6.8	50-500 m isopleth	[a]Ren et al., 2006
(48) Yellow Sea	5-6 years	12	3.7	**4.1**	**4.3**	≤ 200 m isopleth	[b]Kim et al., 2005
(57) Laptev Sea	3-6 years	**4.4**	**3.8**	**5.0**	**4.6**	< 50 m isopleth	[a]Eicken et al., 2005

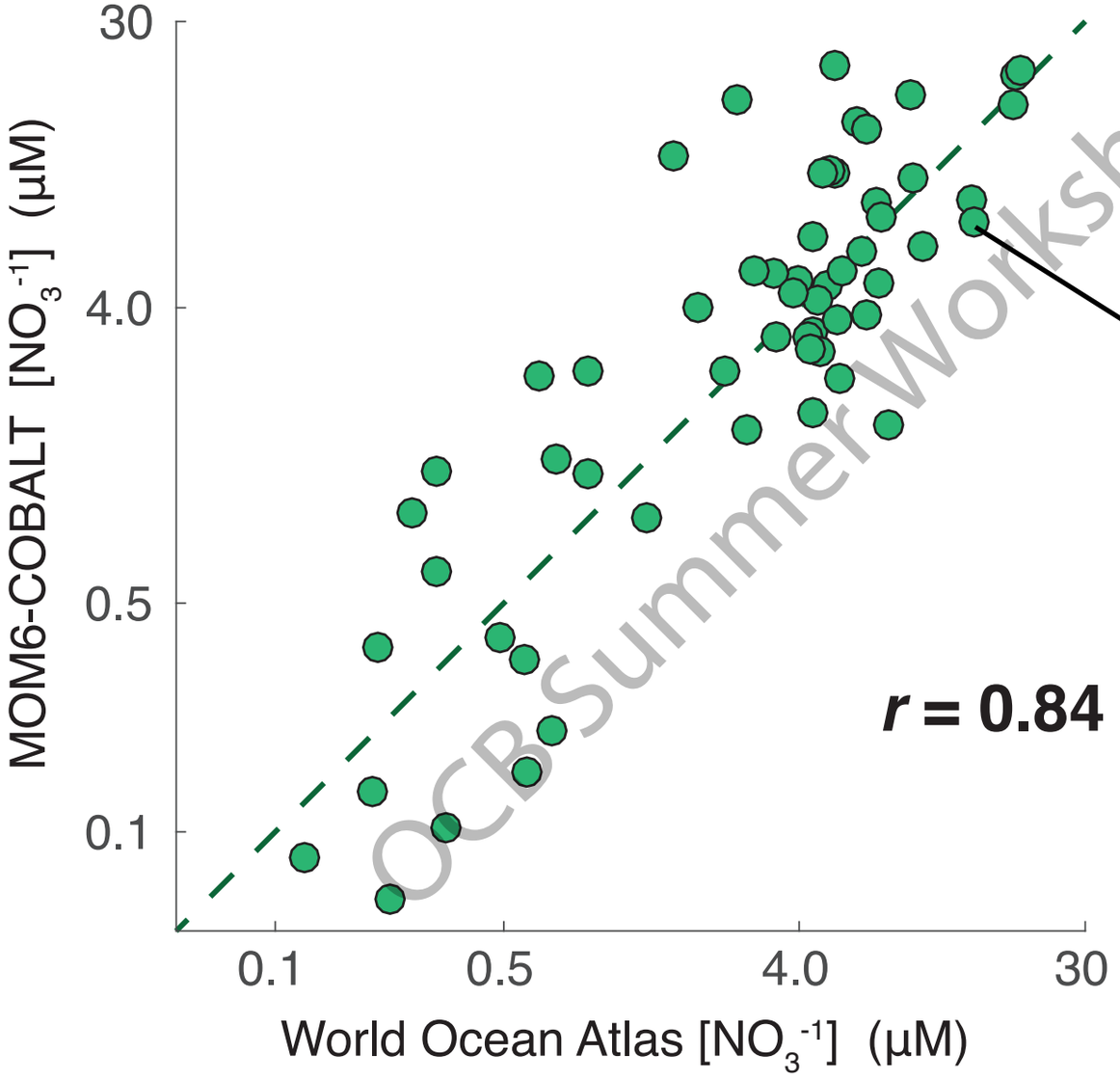
[#]A sub-domain of the LME is selected to compare with observations as the sampling sites only represent a small fraction of the relatively large LME. *Residence time is estimated based on either a) direct measurements on currents and water mass properties or b) mass balances of geochemical tracers (e.g. Ra isotopes). [^]Coastal grid cells (shallower than 200 m) are not present in the model for the region.

Coastal domains (<200m) of the 66 Large Marine Ecosystems (cLME)

Liu et al. in revision

Coupled Model Resolving Coastal N Dynamics

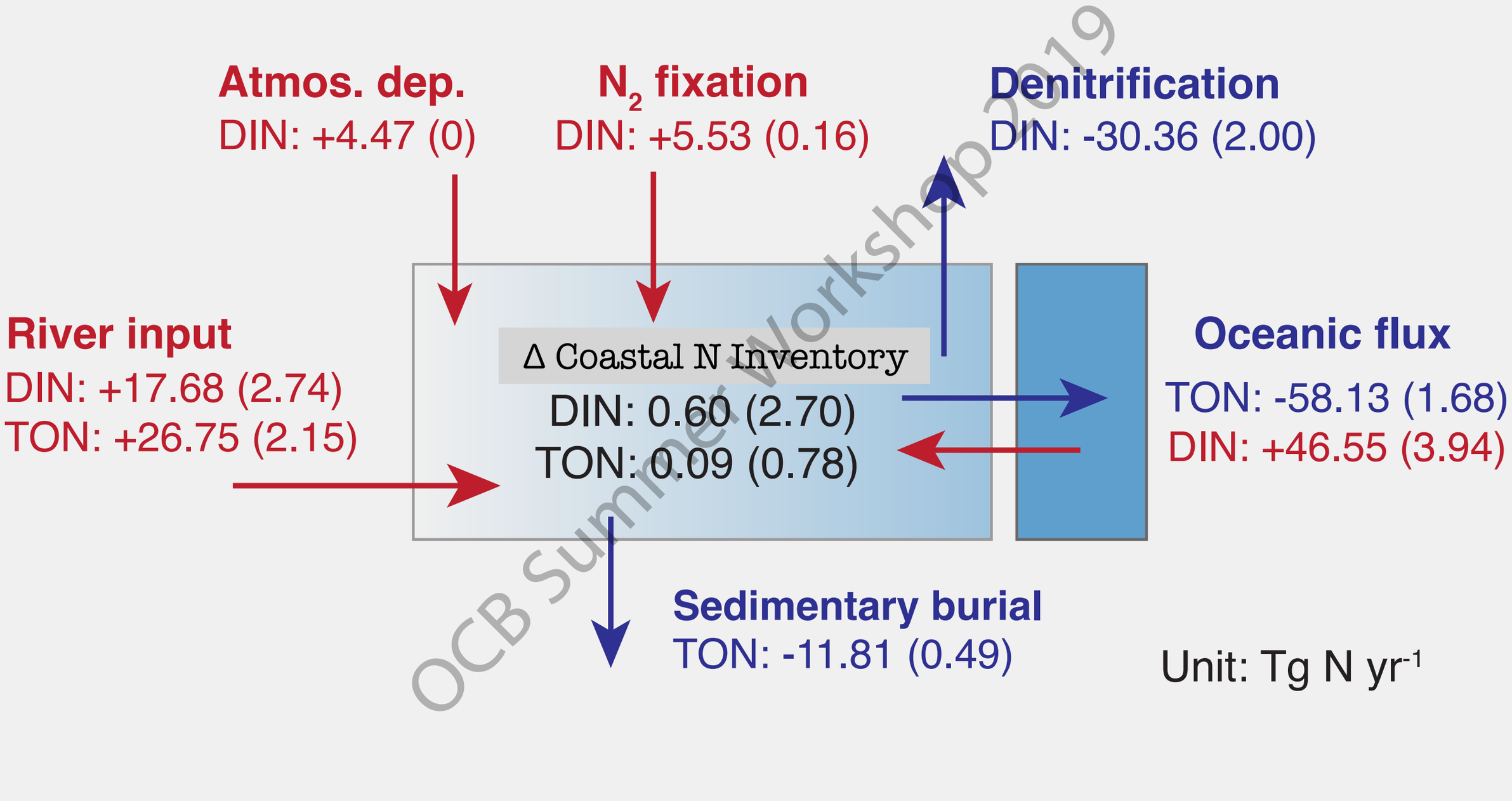
1/4° MOM6-COBALT forced by JRA-55, monthly varying river N loading, constant atmospheric input (1990); 184-year spin-up; 1961-2010 for analysis.



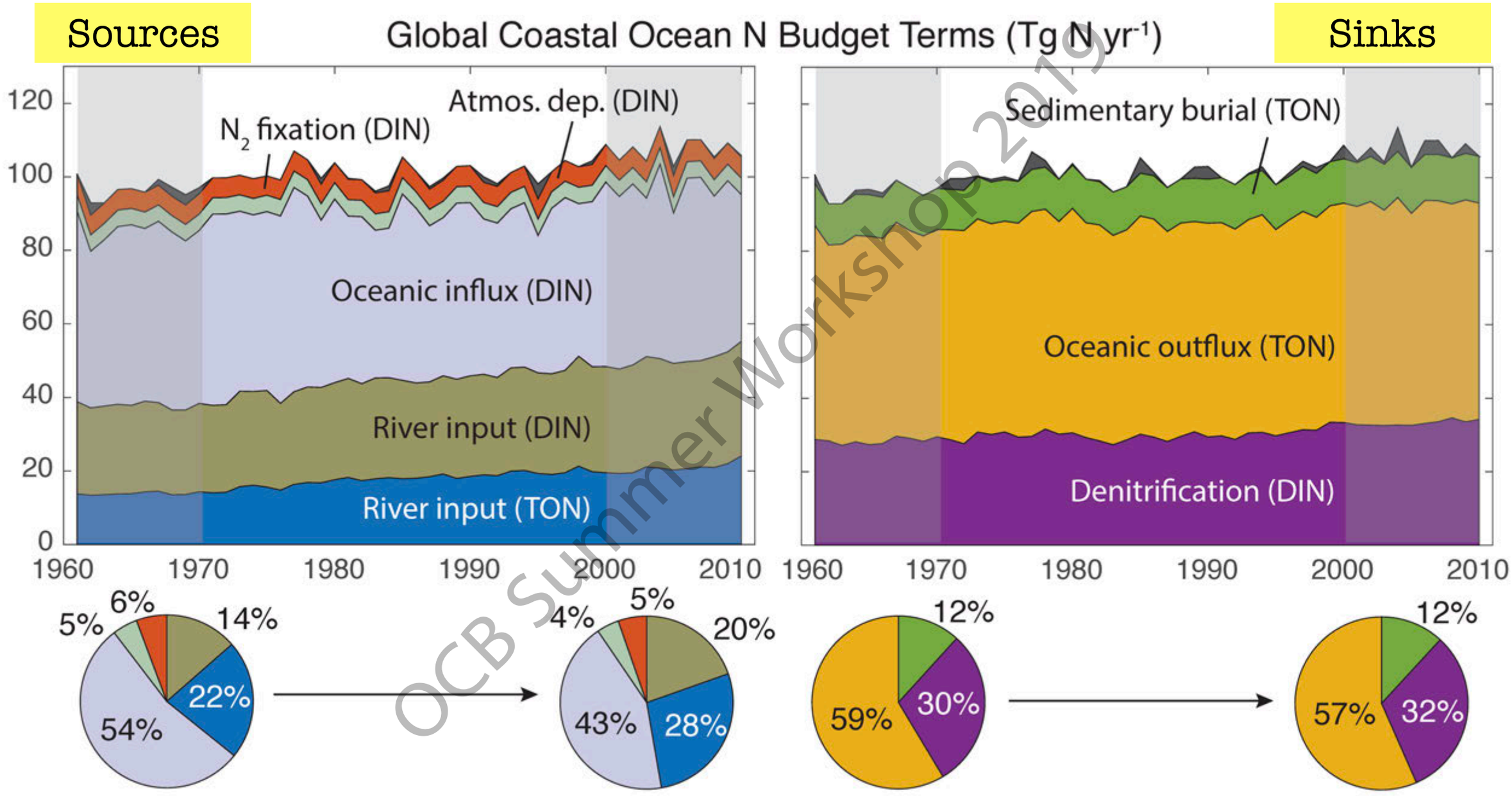
[NO_3^{-1}], 0-100 m

each of the 66 cLMEs

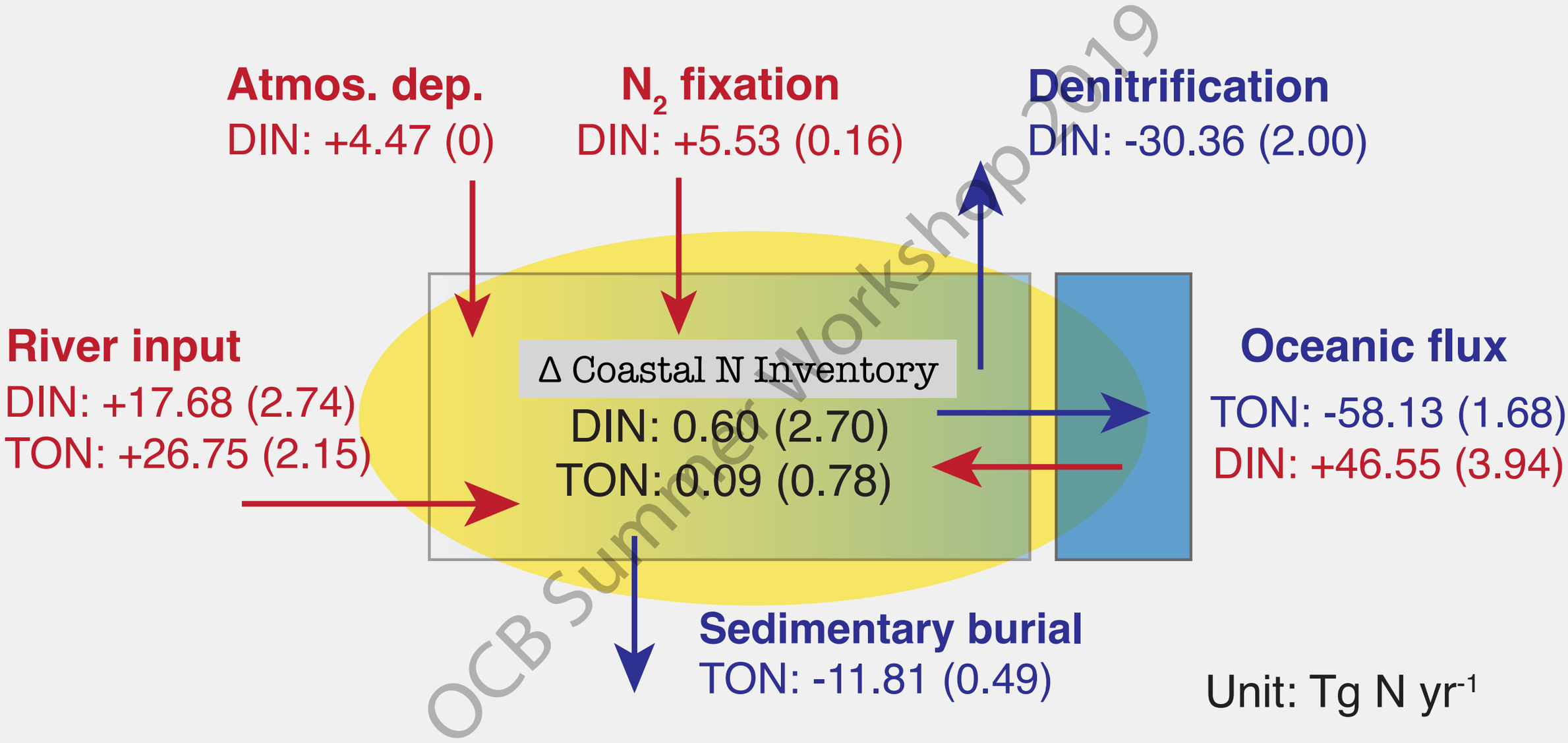
Simulated Global Coastal N Budgets (1961-2010)



Increasing River N Loading and Contribution



Increasing Coastal N Inventory -> Eutrophication



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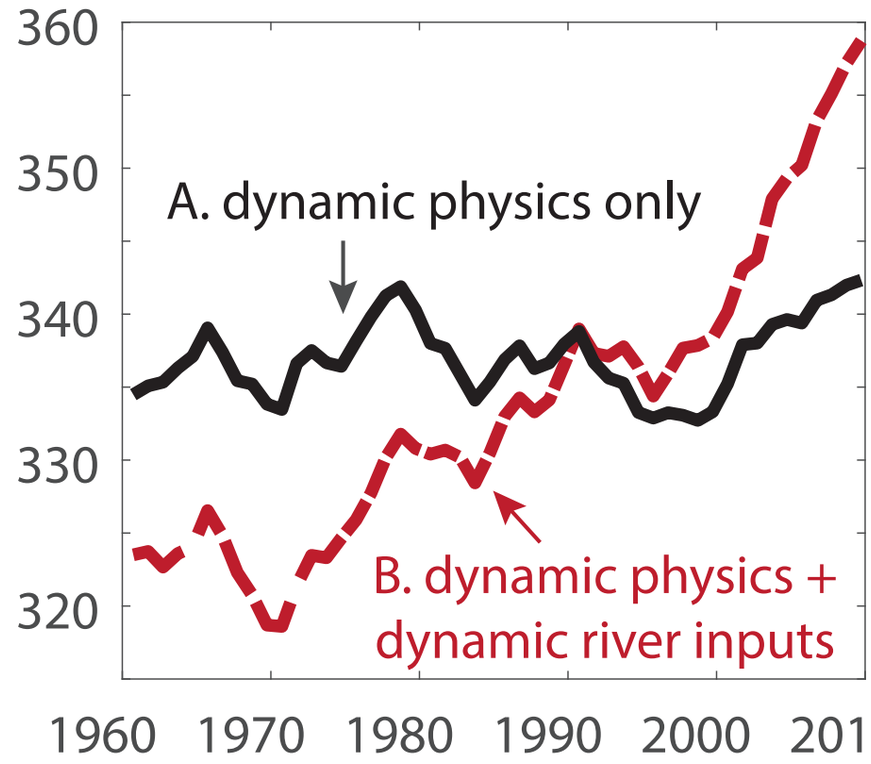
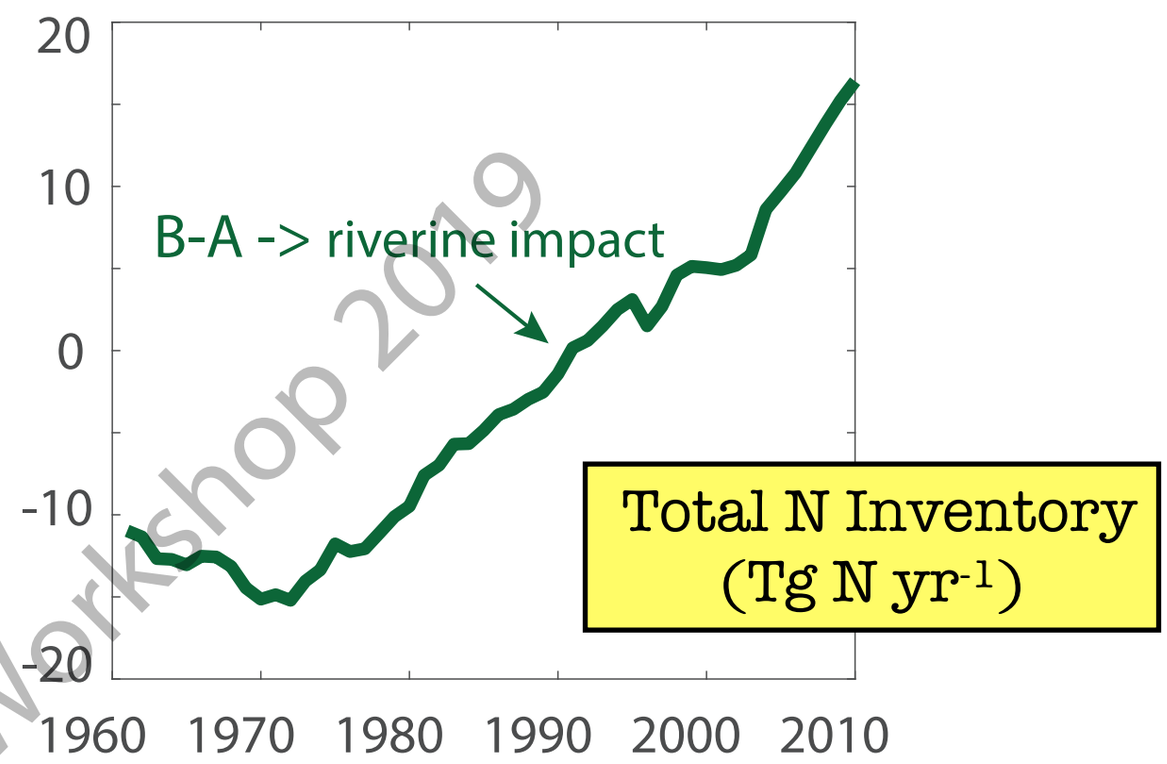
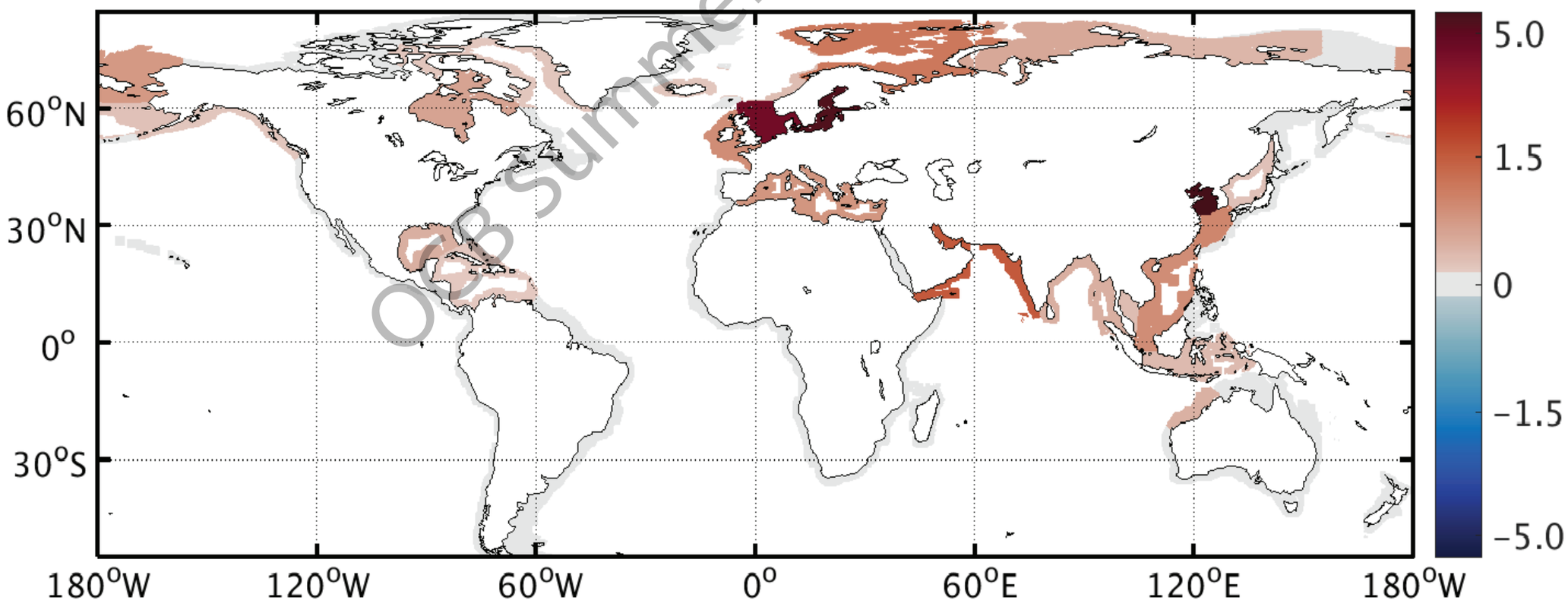
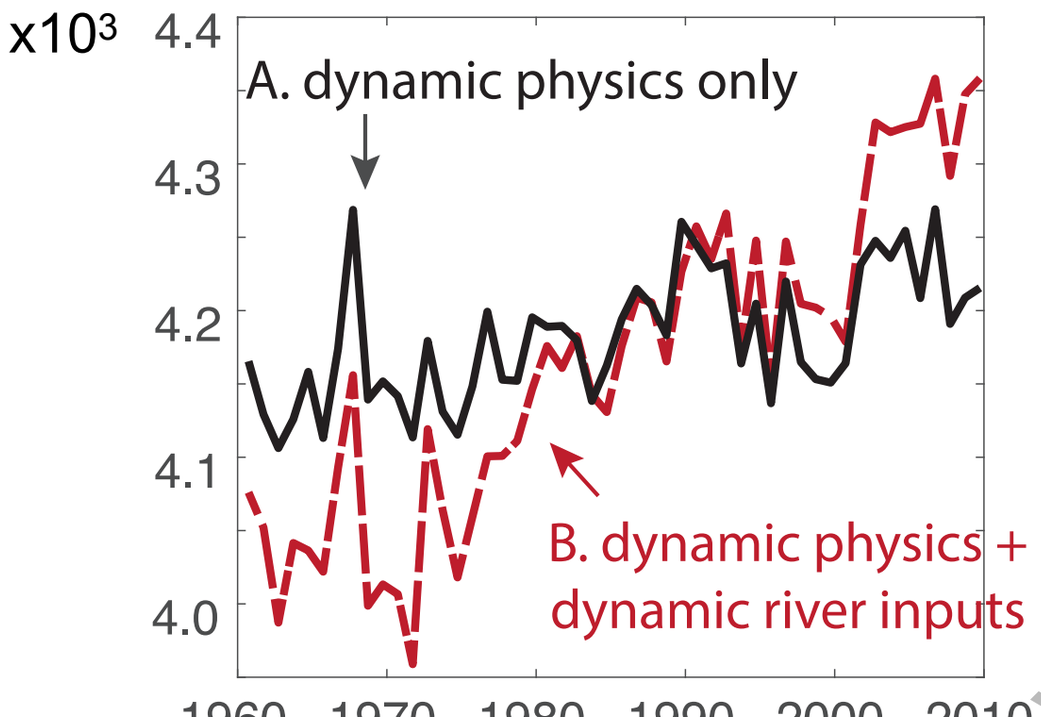


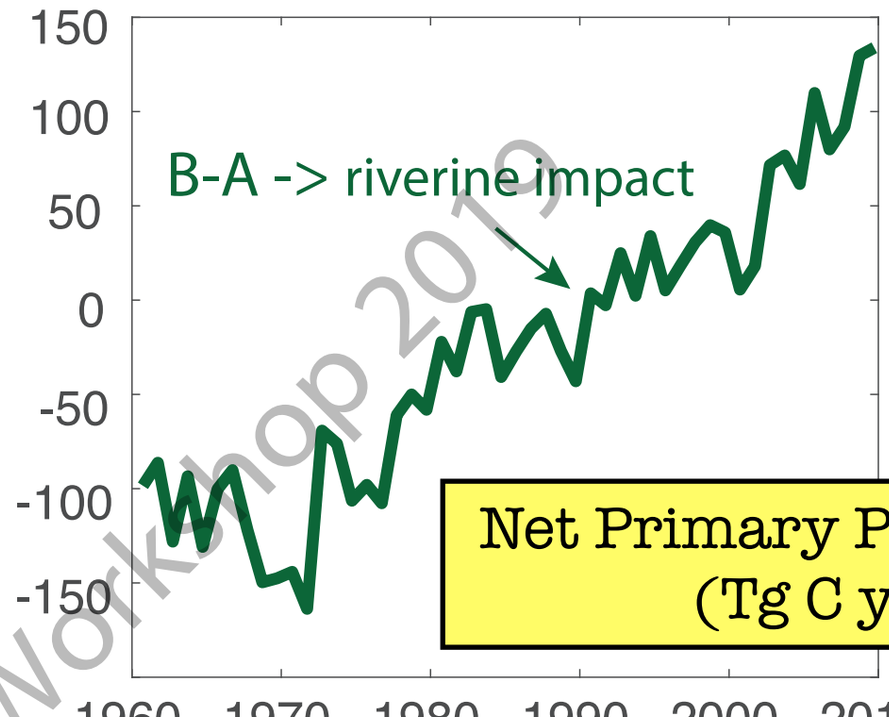


Total N Inventory
(Tg N yr^{-1})

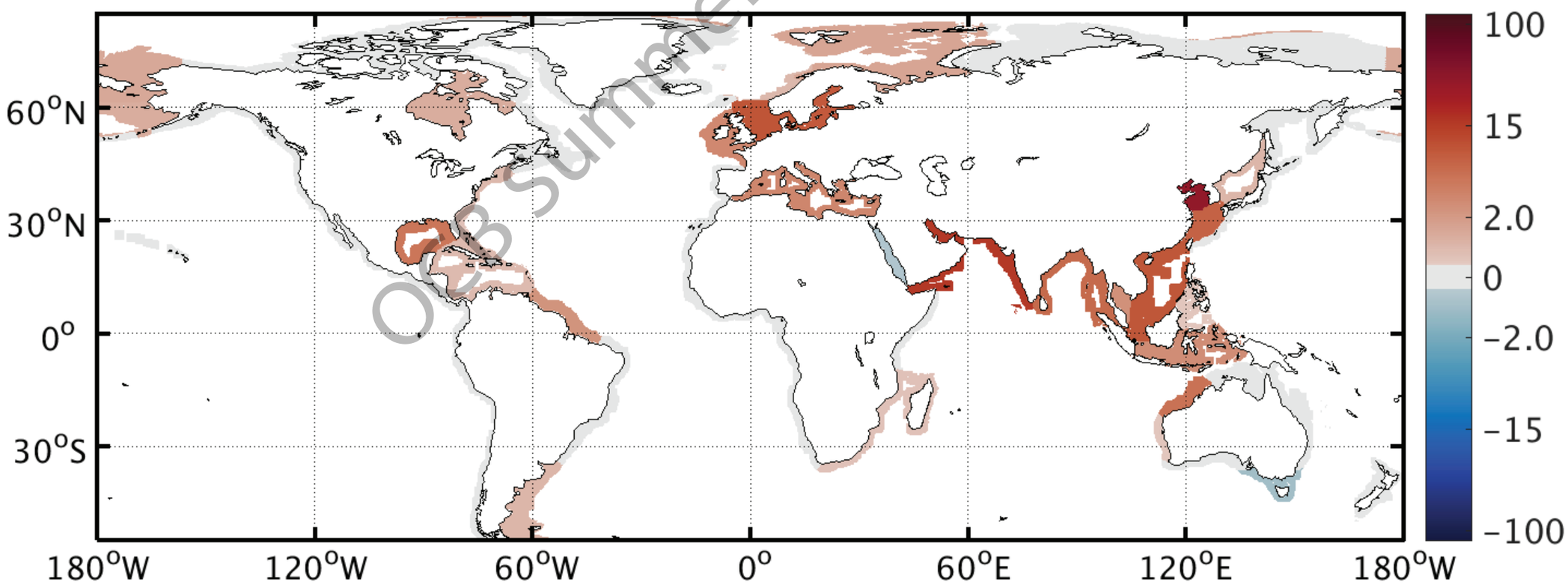


Biogeochem. Response —> Primary Productivity

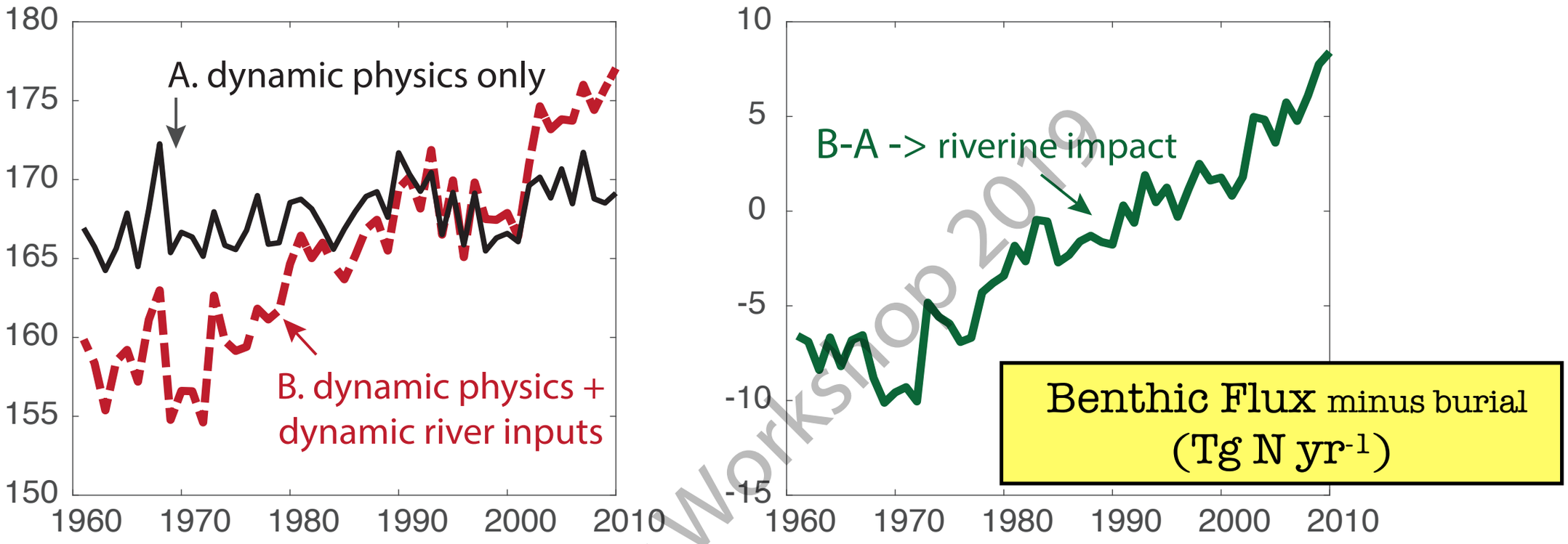


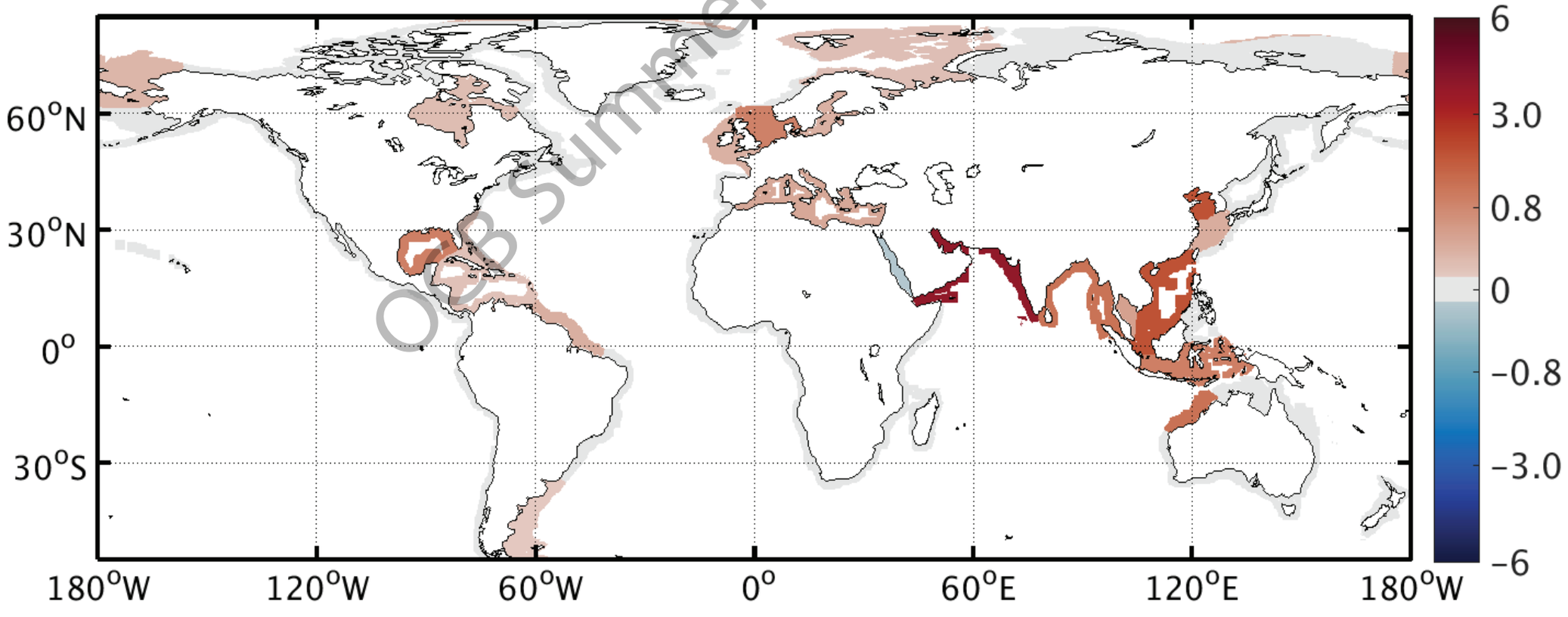


Net Primary Productivity
(Tg C yr^{-1})



Biogeochem. Response —> Benthic Flux minus burial

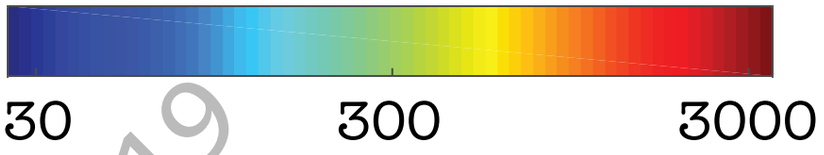


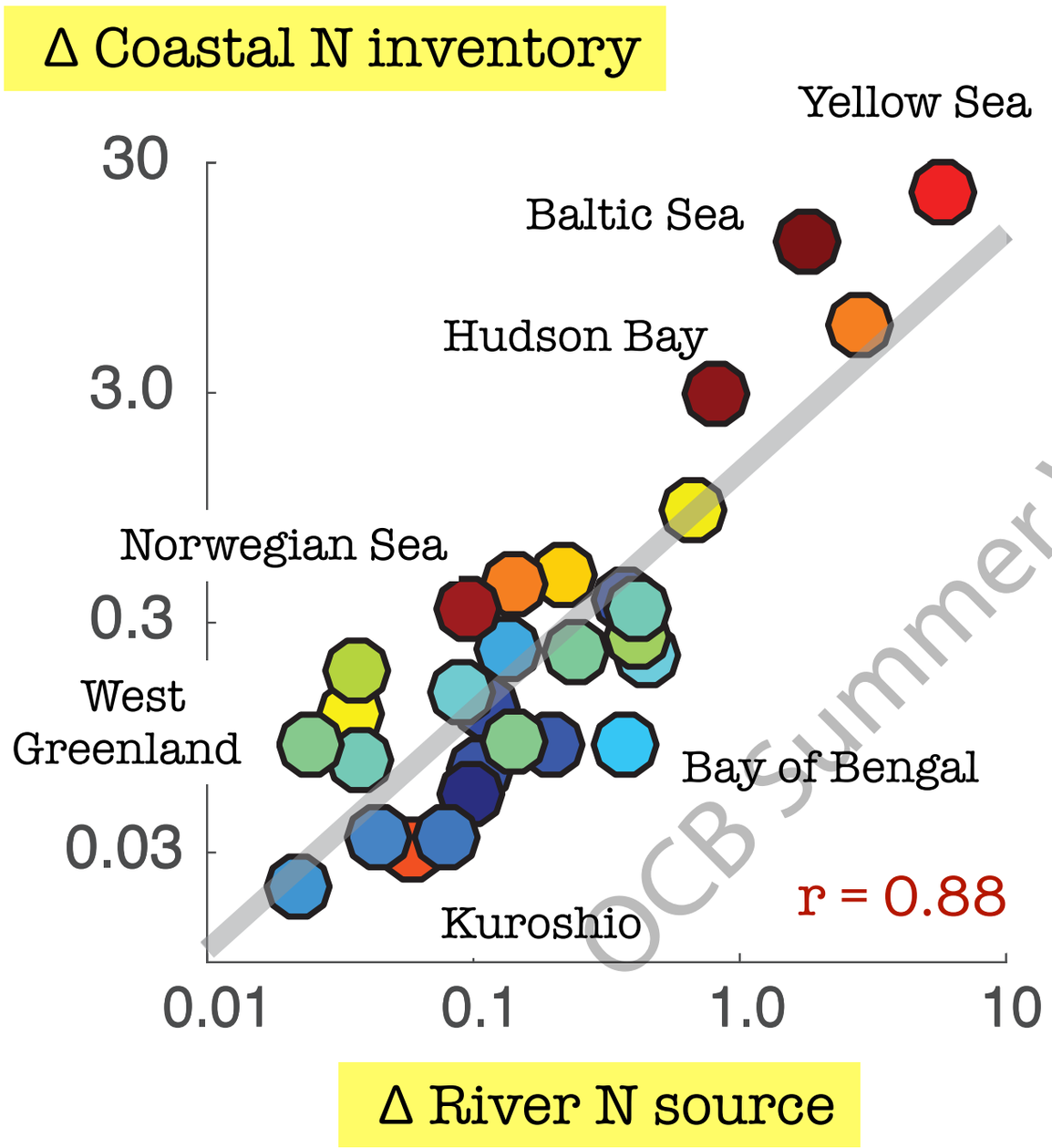


Linking River N Loading to Ecosystem Change

Area-normalized : (flux) g N or C m^{-2} yr^{-1}
(inventory) g N m^{-2}

Coastal Residence Time (days)



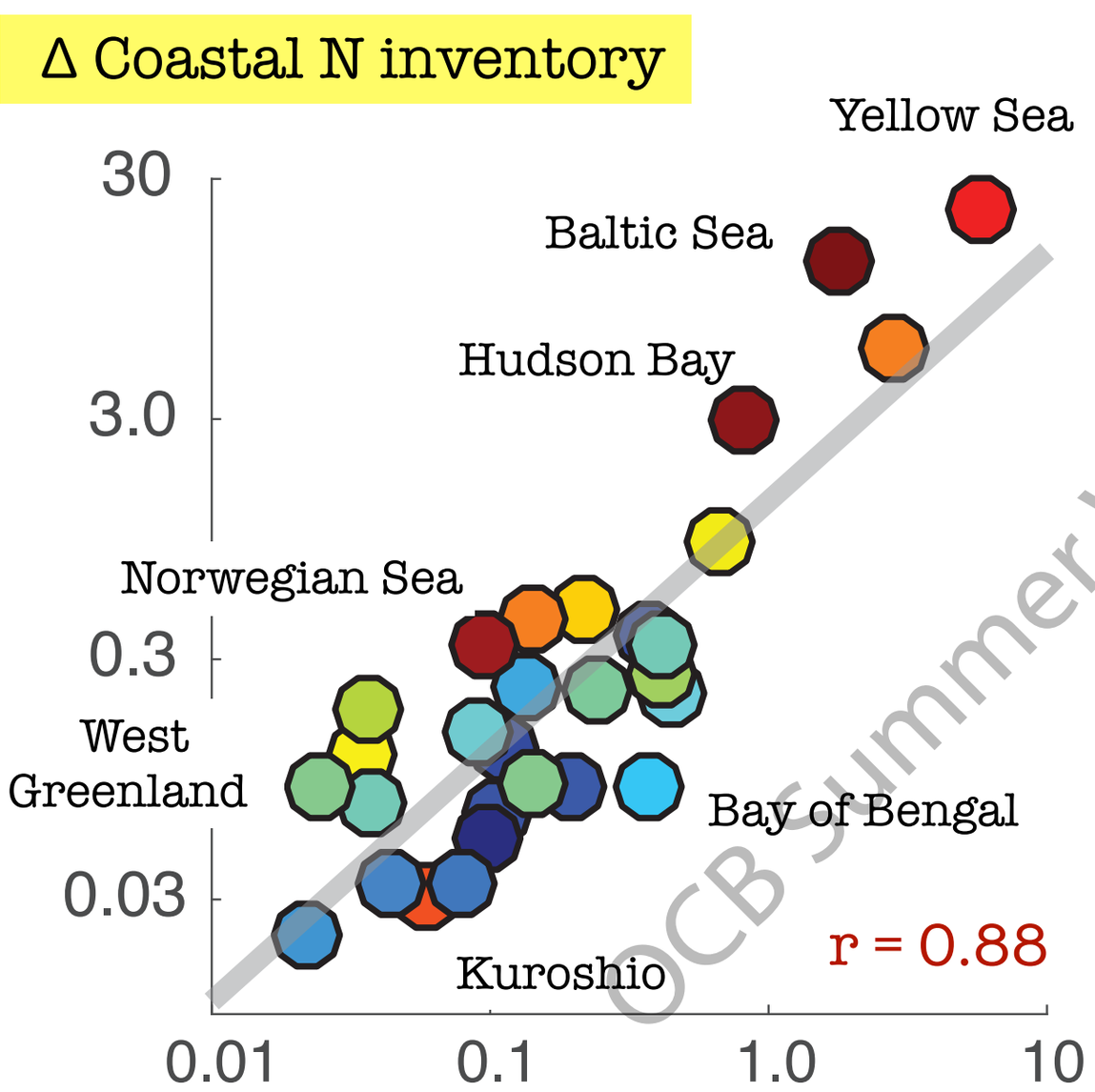


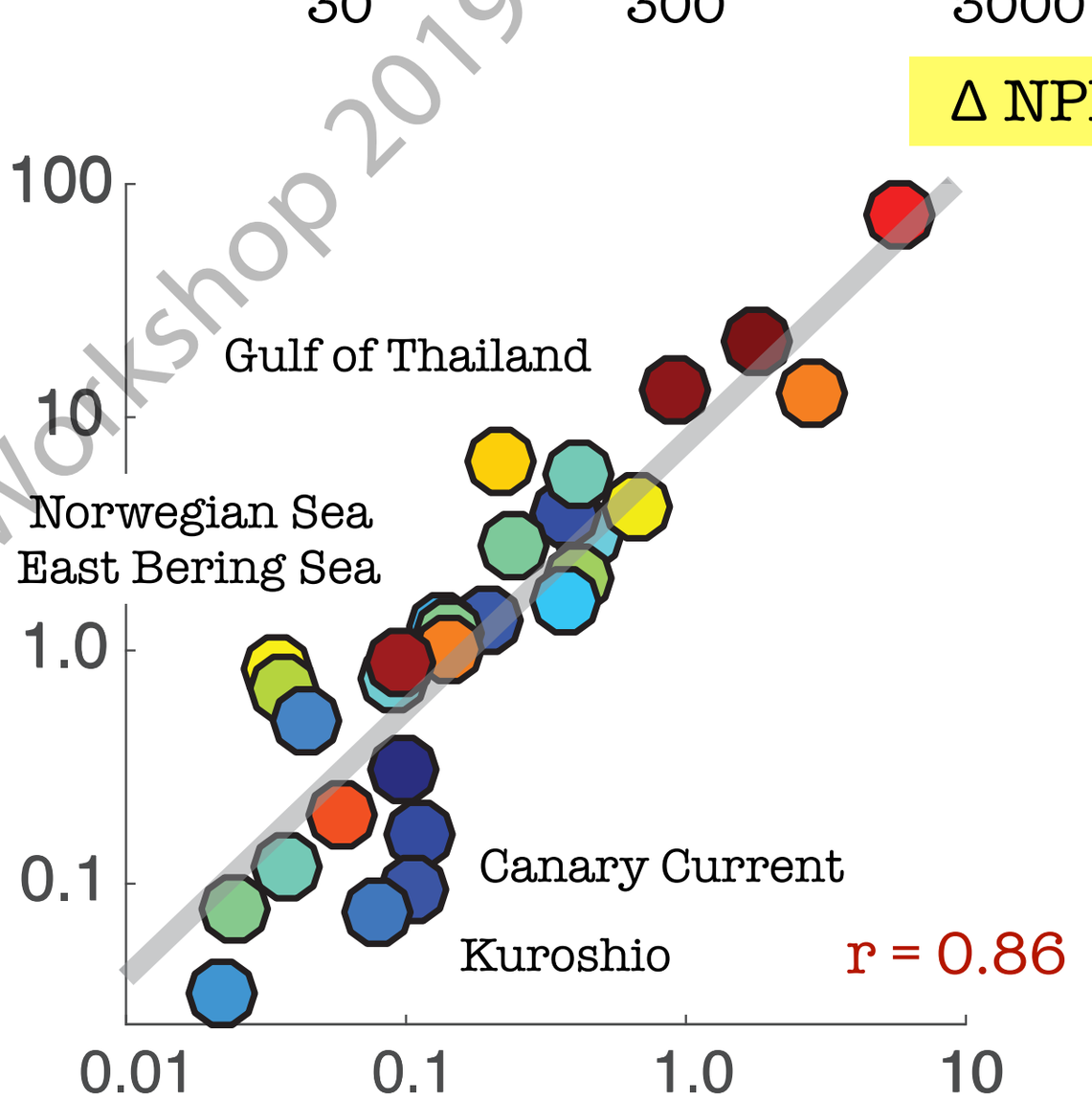
Linking River N Loading to Ecosystem Change

Area-normalized : (flux) g N or C m^{-2} yr^{-1}
(inventory) g N m^{-2}

Coastal Residence Time (days)

30 300 3000





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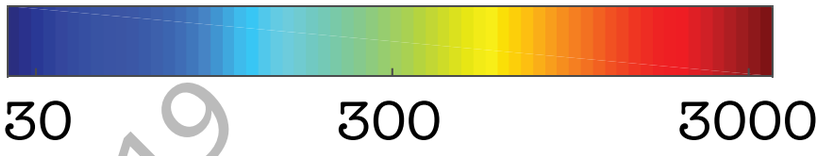
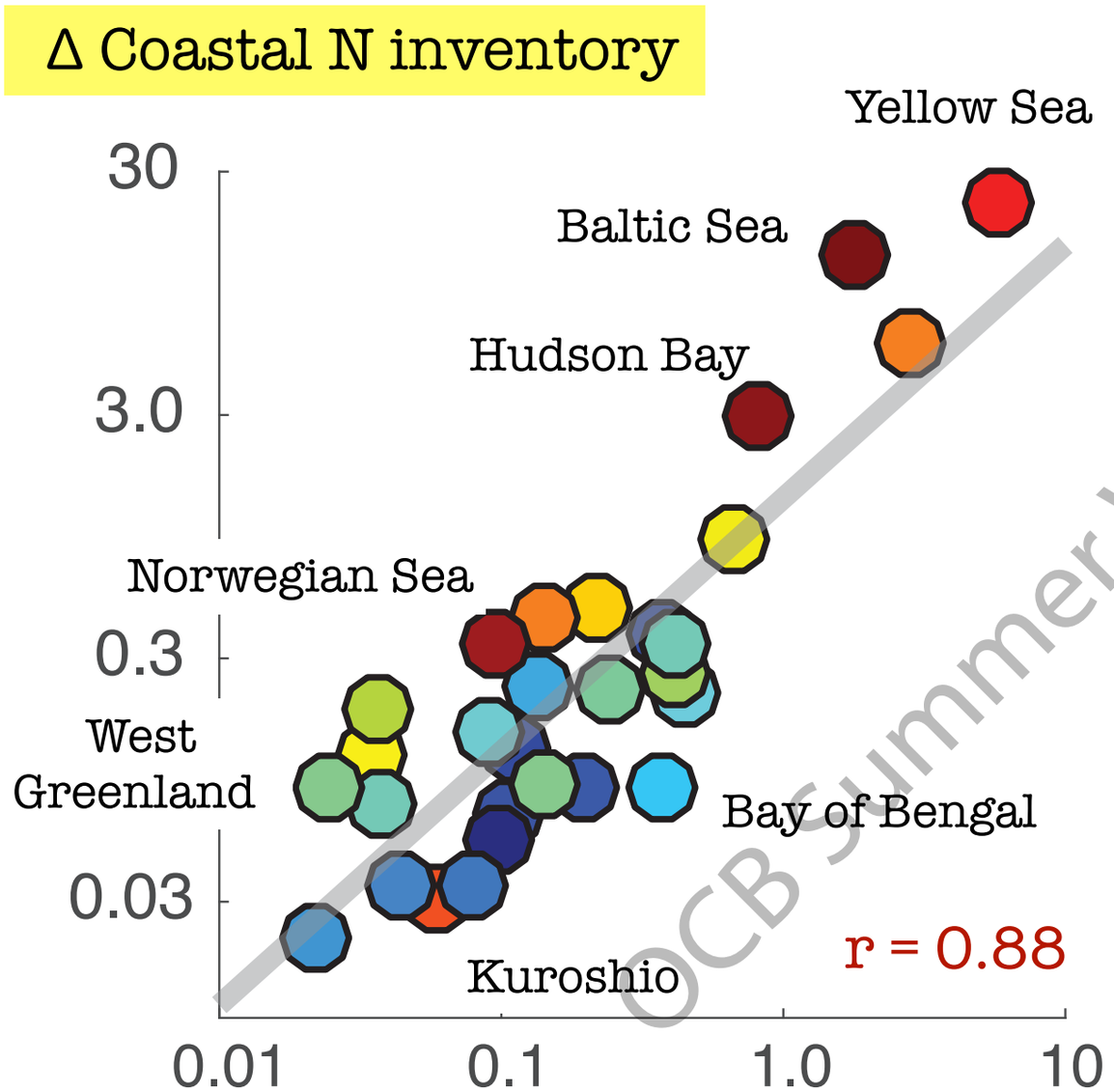
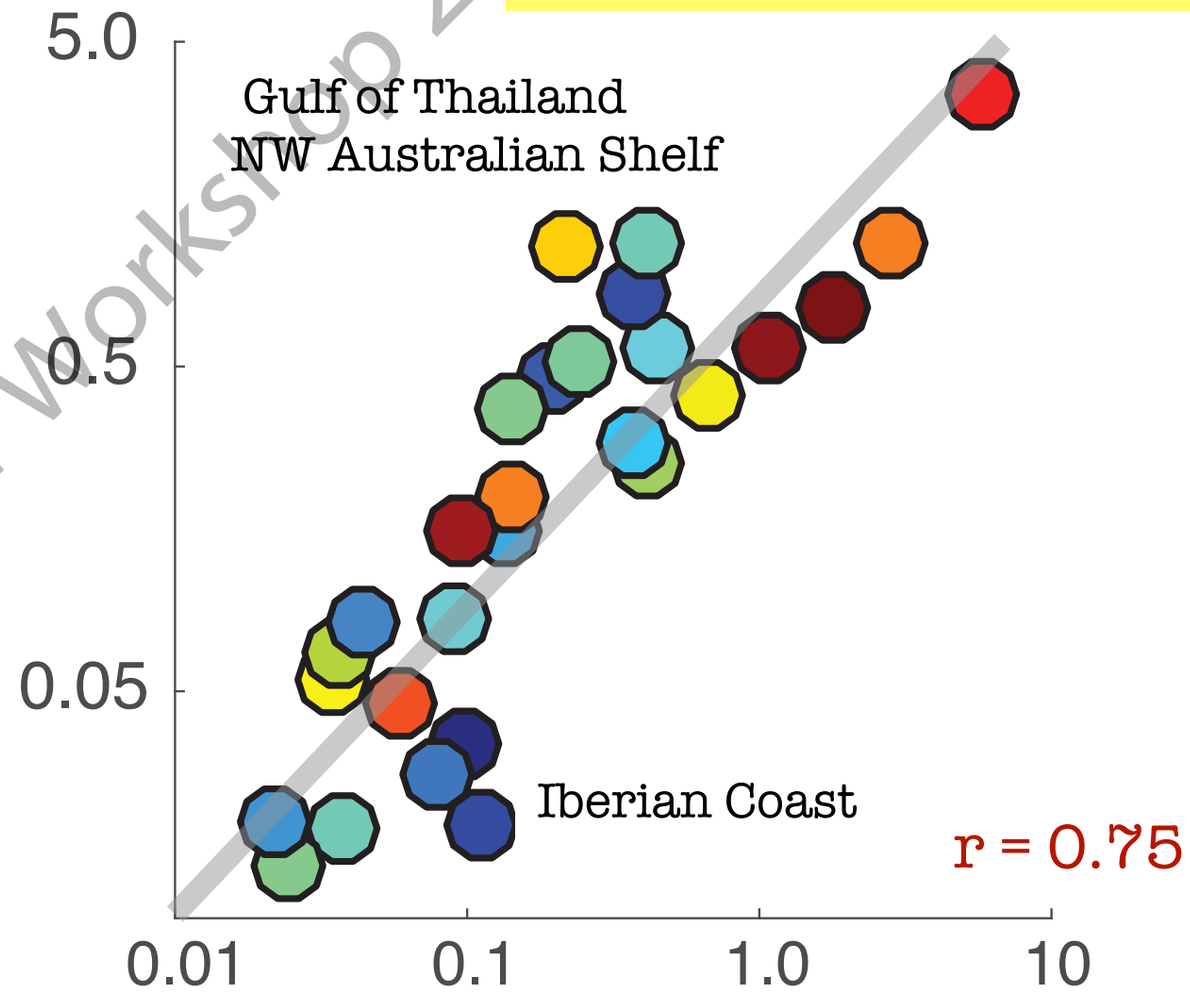






Take-home Messages

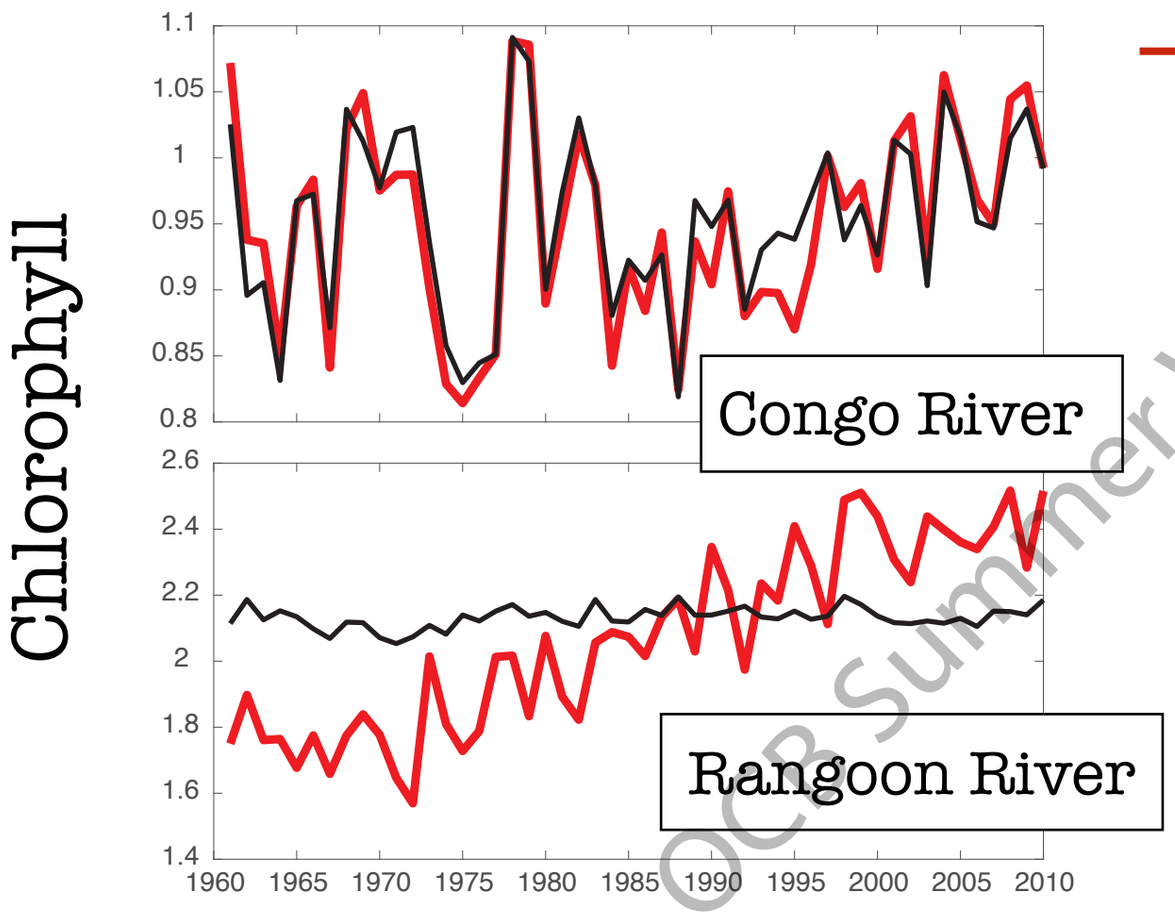
* River N loading to coastal oceans has increased substantially over the past half century (36 -> 47 Tg N yr^{-1}; ~30%); 35 Tg N has accumulated in coastal waters.

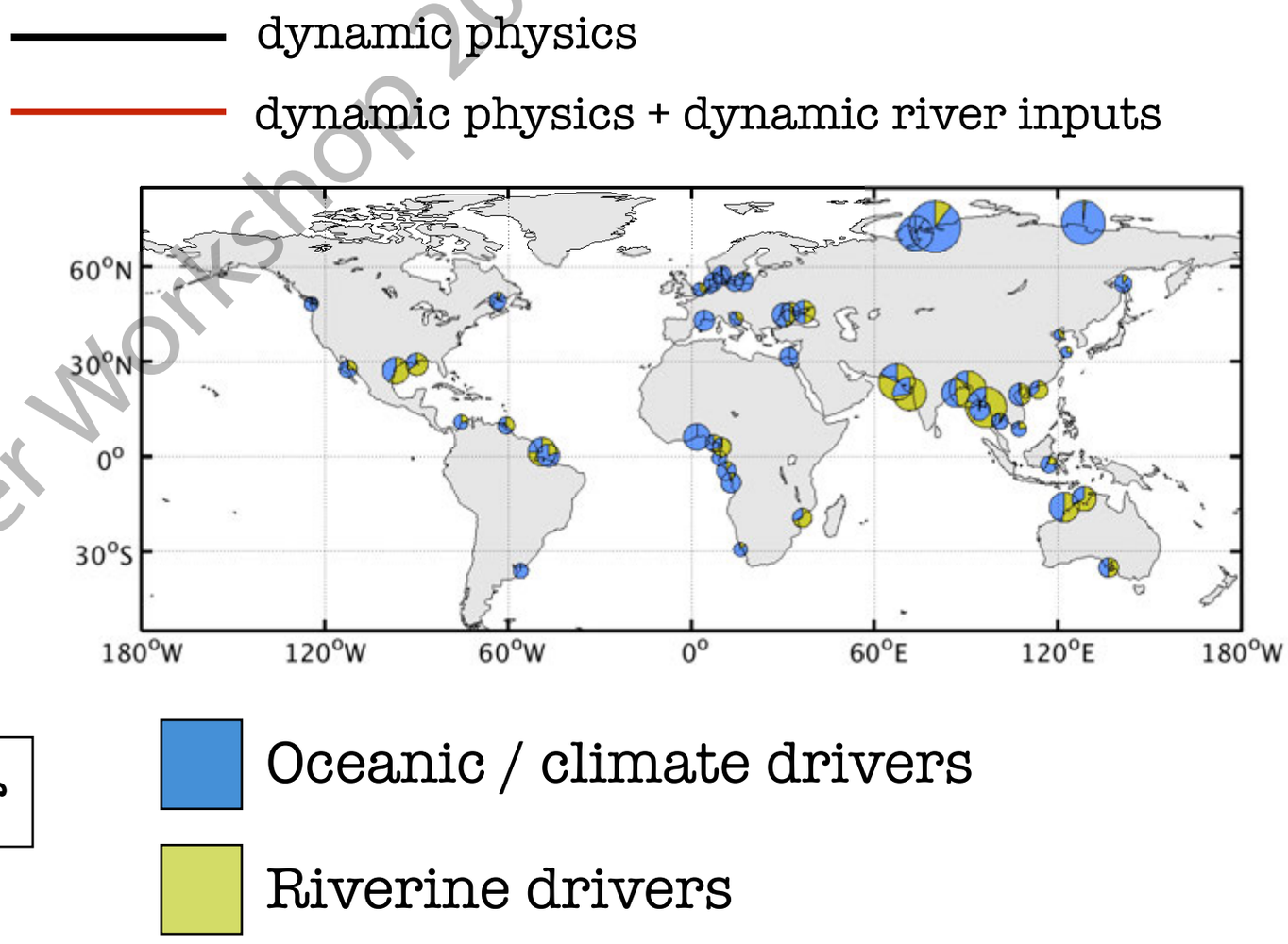
* Eutrophication has led to elevated NPP and benthic O_2 demand in 29 out of the 66 coastal systems globally.

* Eutrophication and ecosystem sensitivity to increasing river N loading varies substantially across systems.

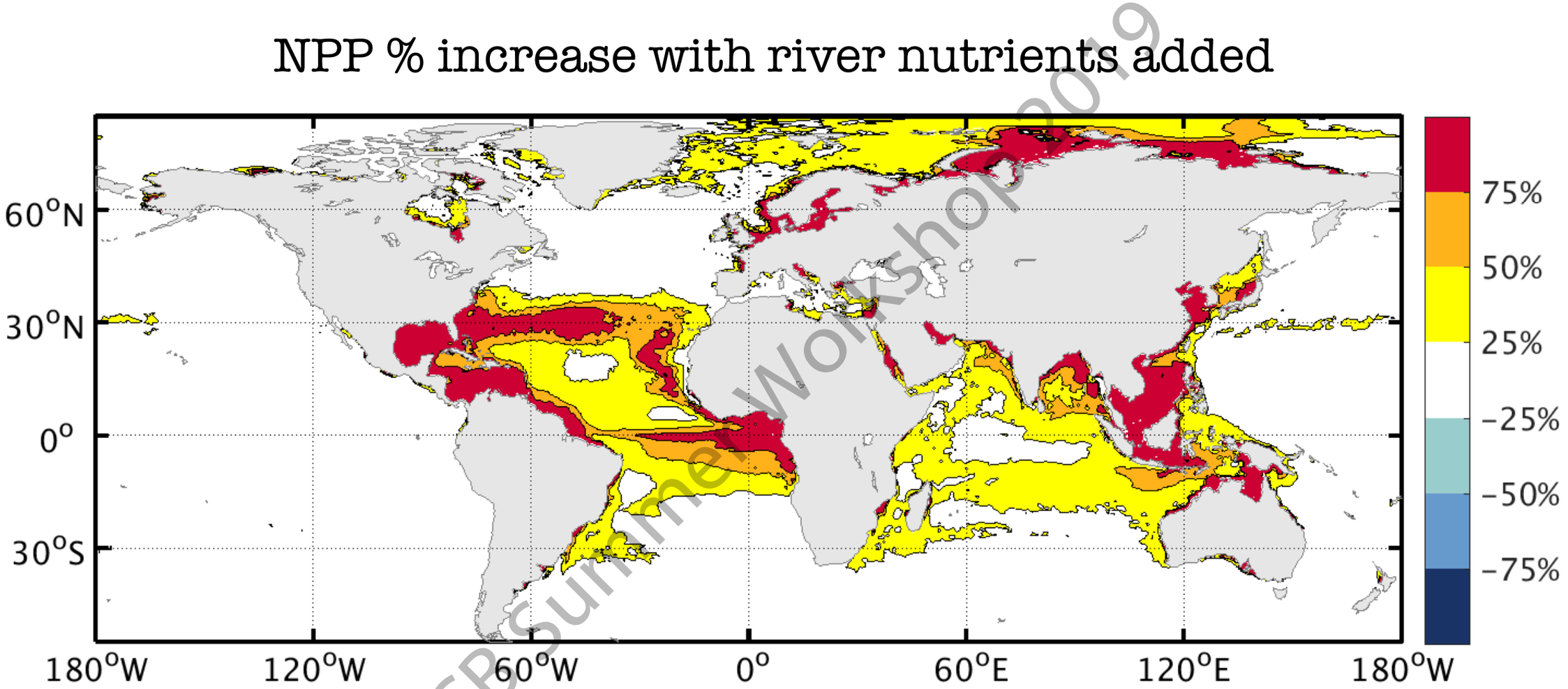
* Coastal residence time plays a critical role in driving the sensitivity of eutrophication to river N loading but more factors contribute to ecosystem responses.

What is the dominant driver for interannual variability in coastal phytoplankton blooms, oceanic or riverine?





Where across the ocean do we find biogeochemical imprints of rivers?



How is the pattern associated with coast-ocean exchange?

Challenges of Scaling Up from Local to Global

- Estuarine processes
- Groundwater and submarine discharge
- Tidal mixing and storm water flushing
- Benthic fluxes
- Unique features of different coastal systems
- Many others

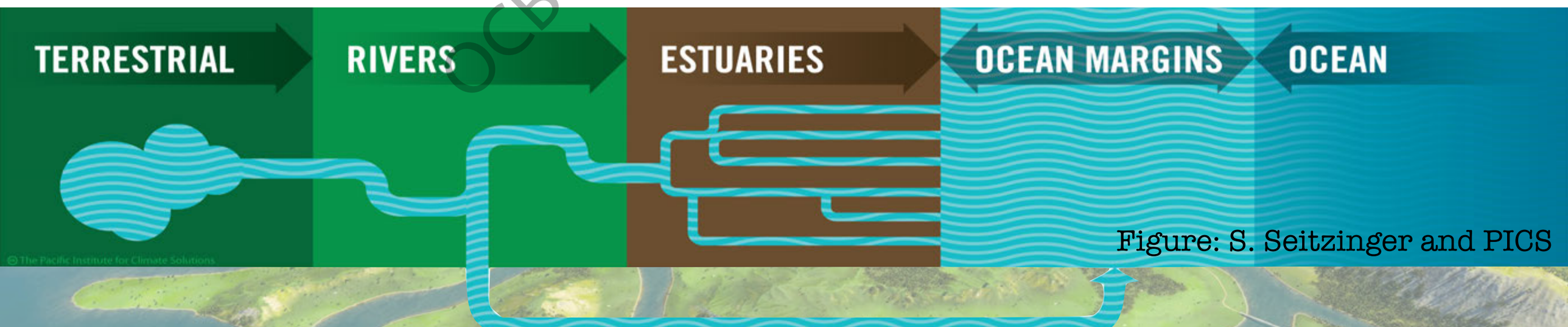


Figure: S. Seitzinger and PICS

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Thank you!

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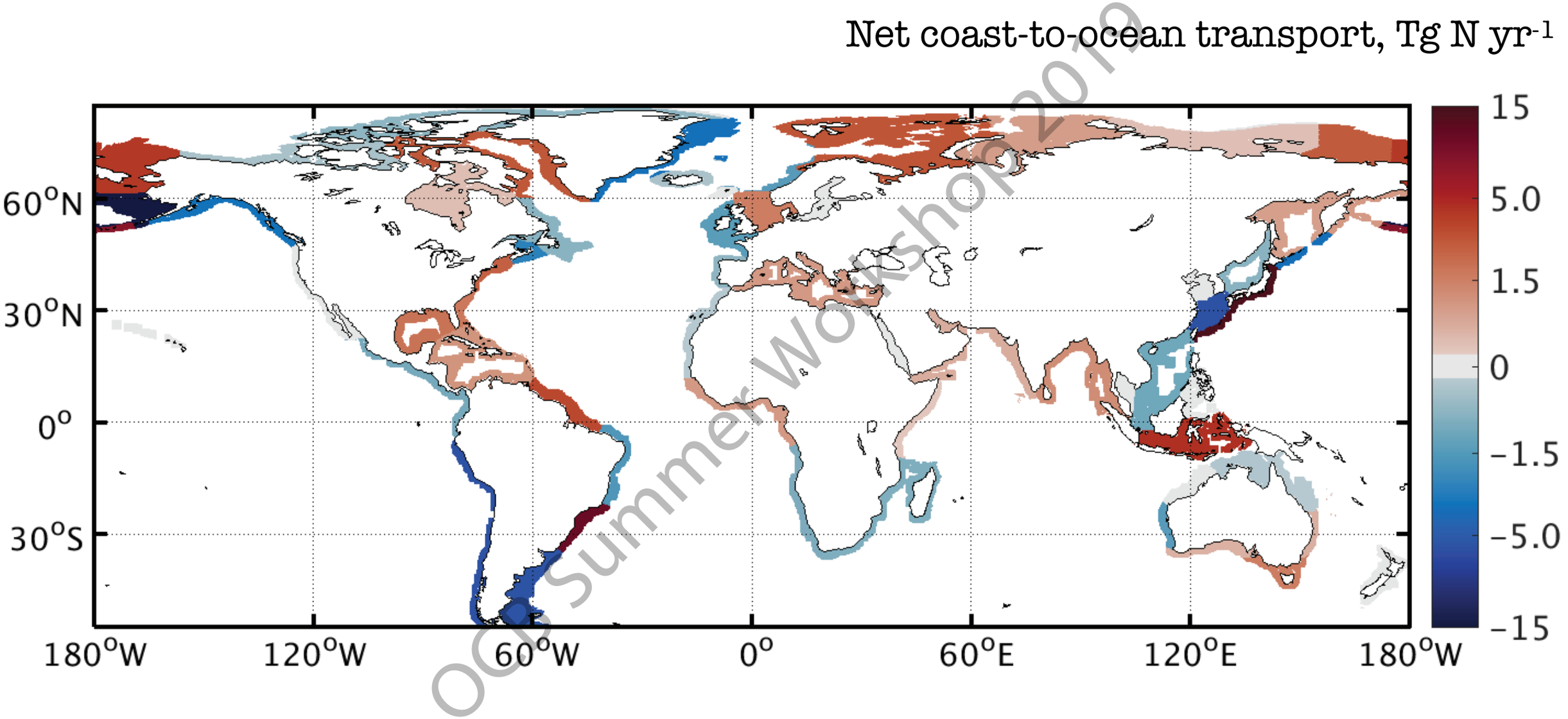
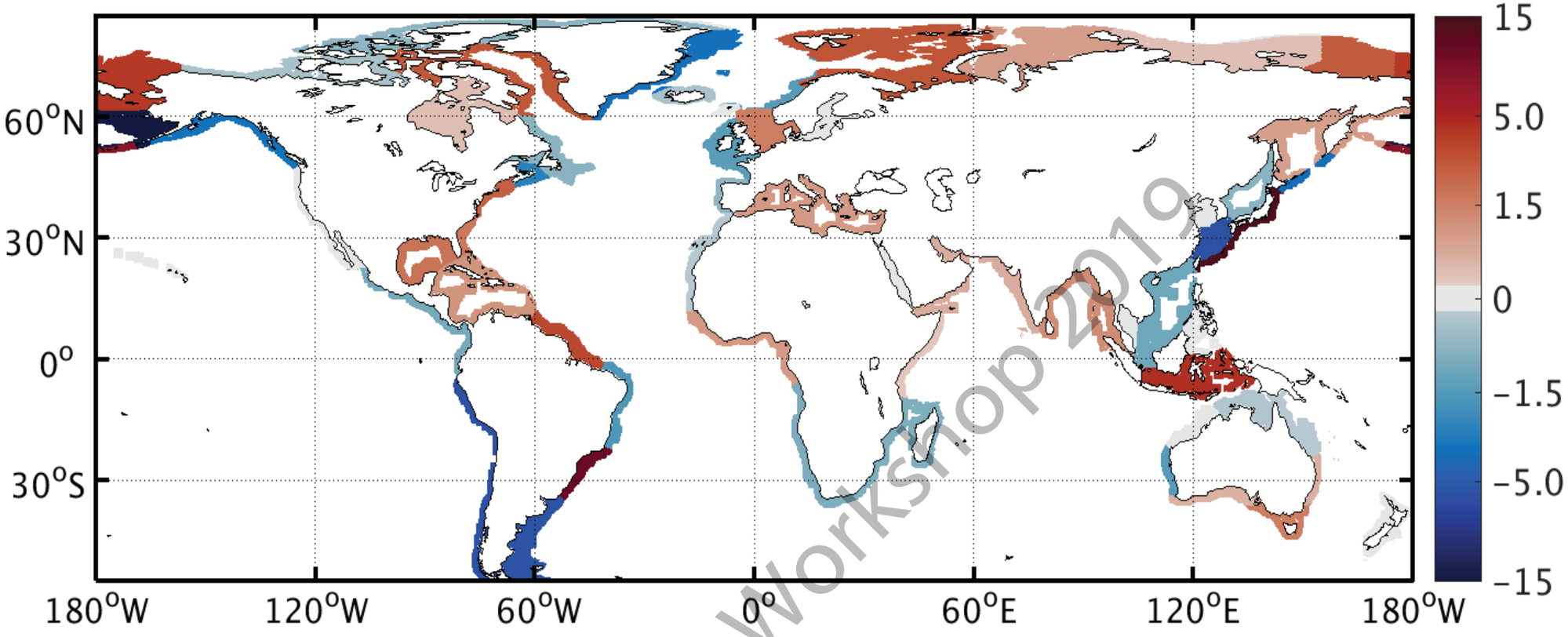
Figure: S. Seitzinger and PICS

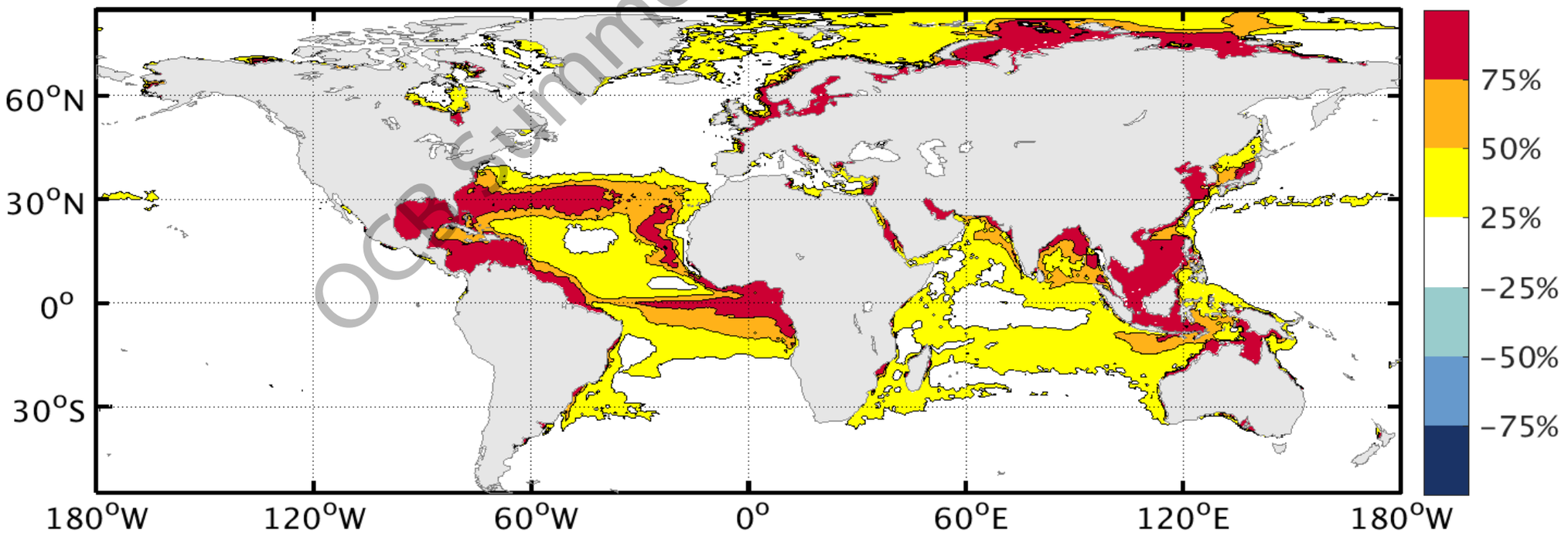
Are continental shelves N sources or sinks?



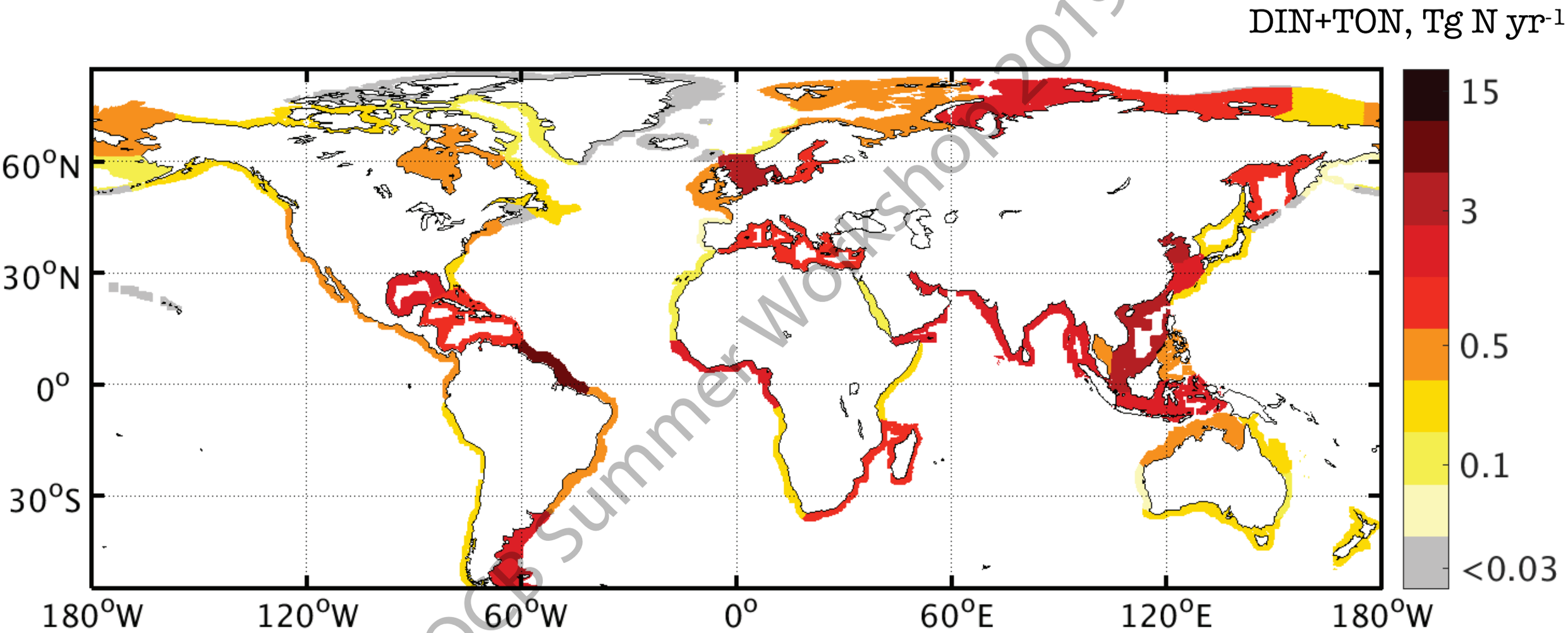
Net coast-to-ocean N transport, Tg N yr^{-1}



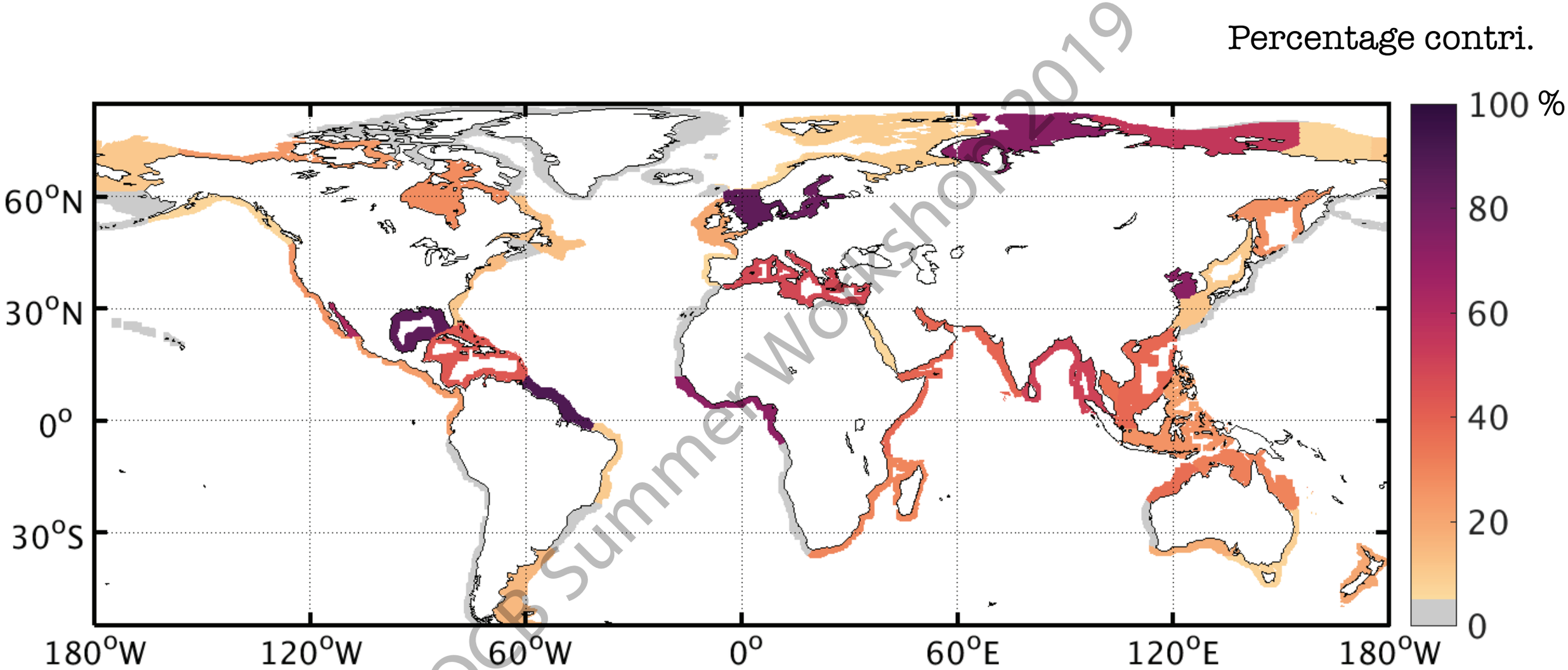
Imprints of river nutrients



How does riverine N loading vary from shelf to shelf?



How important is river N relative to total regional source?



Representing Coast-Ocean Exchanges

freshwater plumes