Climate-driven changes in removal of DOC in a small boreal lake: a 30-year time series.

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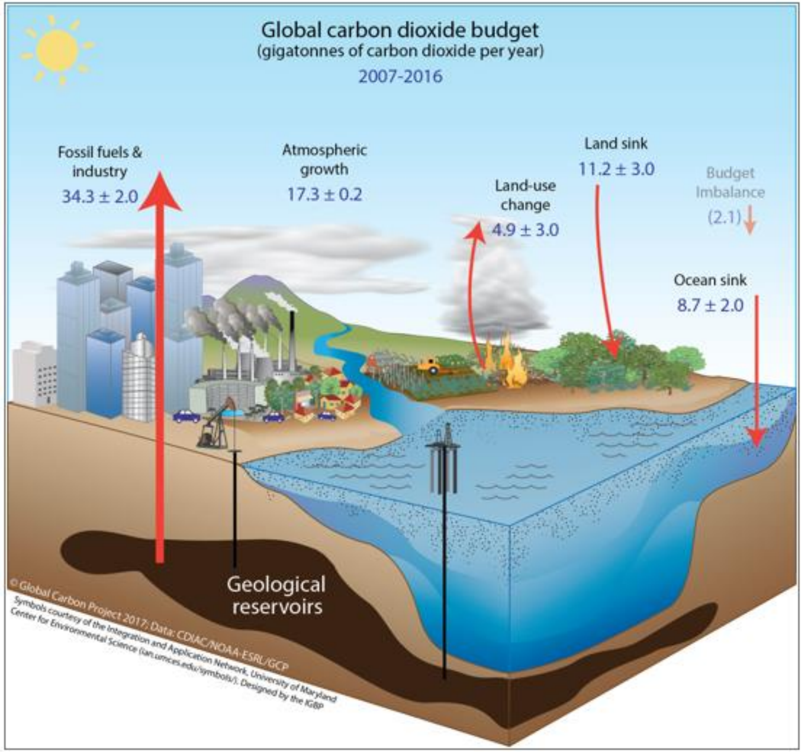
Anthropogenic perturbation of the global carbon cycle

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2007–2016 ($GtCO_2$/yr)



The budget imbalance is the difference between the estimated emissions and sinks.

Source: CDIAC; NOAA-ESRL; Le Quéré et al 2017; Global Carbon Budget 2017

Global carbon project
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Fate of anthropogenic CO_2 emissions (2007–2016)

Sources = Sinks

34.4 $GtCO_2$/yr
88%

12%
4.8 $GtCO_2$/yr

17.2 $GtCO_2$/yr
46%

30%
11.0 $GtCO_2$/yr

24%
8.8 $GtCO_2$/yr

Budget Imbalance:
(the difference between estimated sources & sinks)

6%
2.2 $GtCO_2$/yr

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2017; Global Carbon Budget 2017

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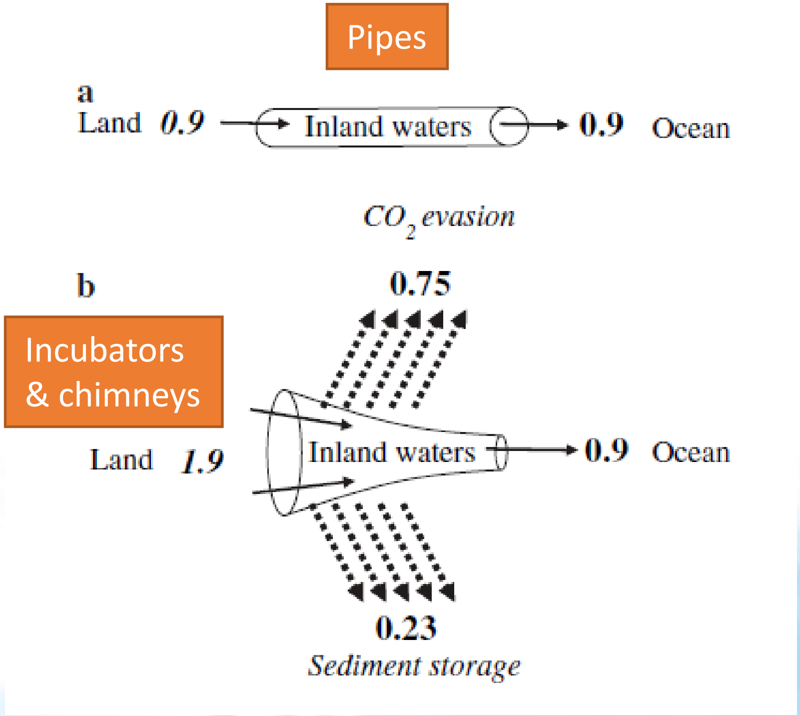
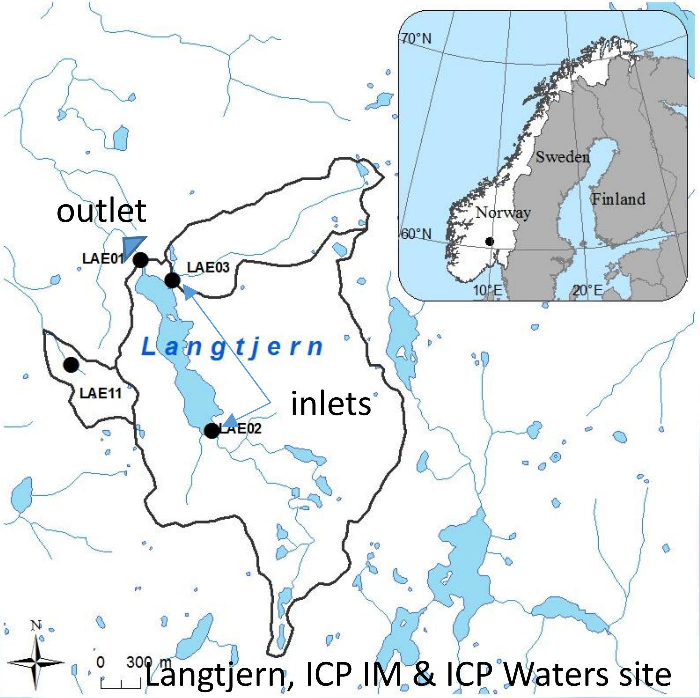
Are boreal lakes pipes or chimneys?

- Are boreal lakes passive pipes for terrestrial OC (DOM), or do they contribute significantly to conversion of DOM to atmospheric CO2?
- Impact of climate change?



Cole et al. 2007 Ecosystems

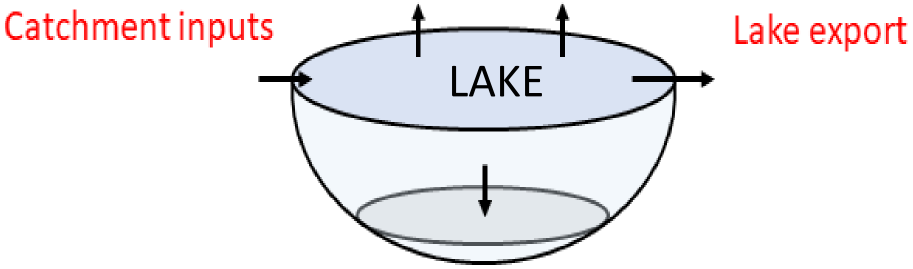
30 year timeseries of catchment inputs and lake export of DOC in forested, boreal catchment



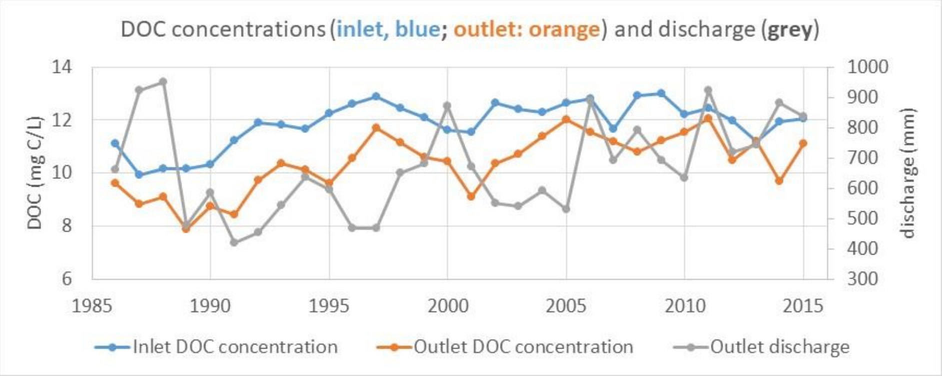
- 4.8 km^2 catchment, 0.23 km^2 lake
- Water residence time lake 2 months
- Acidified, humic, oligotrophic
- Ca 6 months of ice cover

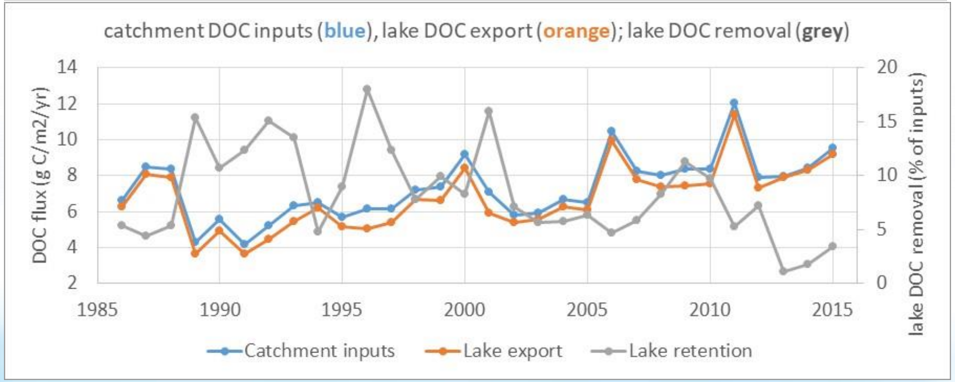
Methods: calculations of lateral fluxes

- Monitoring programme (1986-2015):
  - Two inlet streams: weekly to monthly DOC (TOC = 95% DOC)
  - Outlet stream: weekly DOC
  - Daily discharge
- Catchment DOC inputs to lake calculated by:
  - interpolation to daily DOC concentration, multiplied with discharge;
  - area-scaled (inlet sub-catchments cover ca 70% of catchment)
- Lake DOC export calculated by:
  - interpolation to daily DOC concentration, multiplied with discharge
- Annual lake DOC removal: difference between annual catchments inputs to lake and lake export



Results – concentrations and fluxes

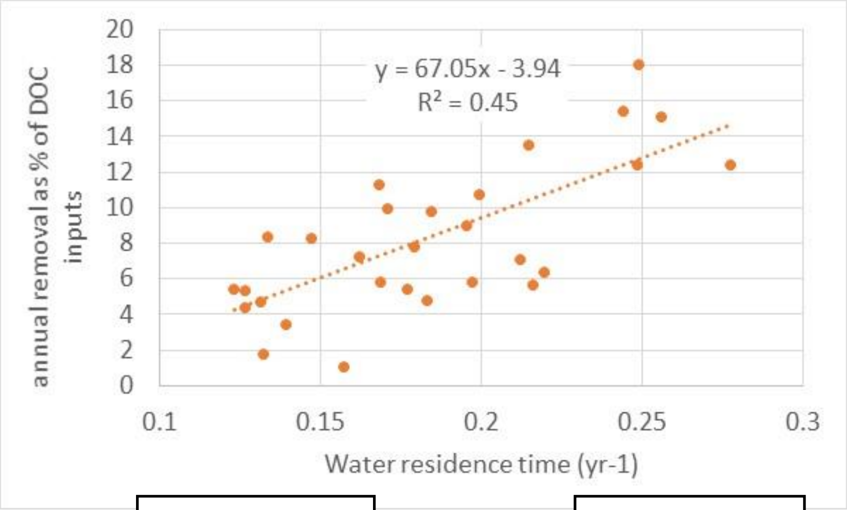




- The lake is browning ($p<0.01$)
  - Related to reduced SO4 deposition (increased OM solubility)
- Increases in lateral DOC fluxes ($p<0.001$)
  - Related to 1) increased discharge (thus, rainfall); 2) browning (thus, SO4 deposition)
- Removal of DOC (% of inputs) is declining ($p<0.01$)

%DOC removal in lake related to WRT (water residence time)

DOC removal in lake as % of inputs vs WRT

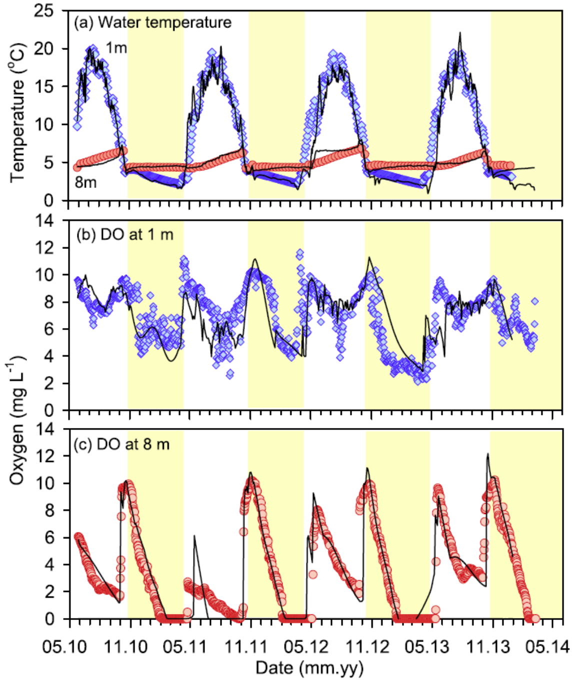


High rainfall/ discharge ↔ Low rainfall/ discharge

- A higher % of annual DOC inputs to lake (upto ca 18%) is removed by in-lake processing at high water residence time
- Relatively more lake DOC processing in dry years
- Mean removal: 8% of inputs

Methods: attributing in-lake DOC removal to processes, using process-based model

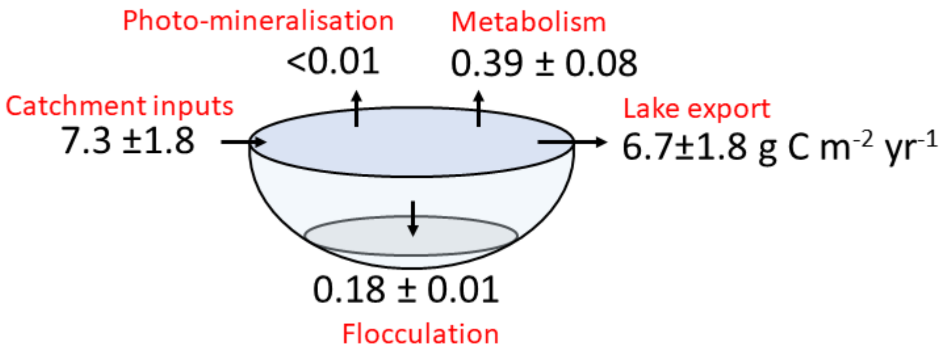
- MyLake model
  - Heat balance of lake (ice cover, thermal stratification)
  - Microbial metabolism (3 pools of DOM (labile, semi-labile, recalcitrant); processing rates dependent on T and O_2), flocculation, photo-degradation of DOM
- Calibrated using high-frequency monitoring of T and O_2 with lake buoy, and dated sediment core
  - Sedimentation at deepest point 'anchored' with dated sediment core



Couture et al. 2015
J of Geophys Res

Which processes remove DOC in the lake?

- Best model fit indicates that on average
  - 67% of DOC is removed by microbial activity
  - 33% is removed by sedimentation
  - Photo-oxidation negligible
    - Humic lake, 6 months ice cover, little UV penetration, 2 months residence time



All fluxes expressed in g C / m^2 catchment /yr
Standard deviation shows interannual variation

Role of residence time for aquatic DOC processing

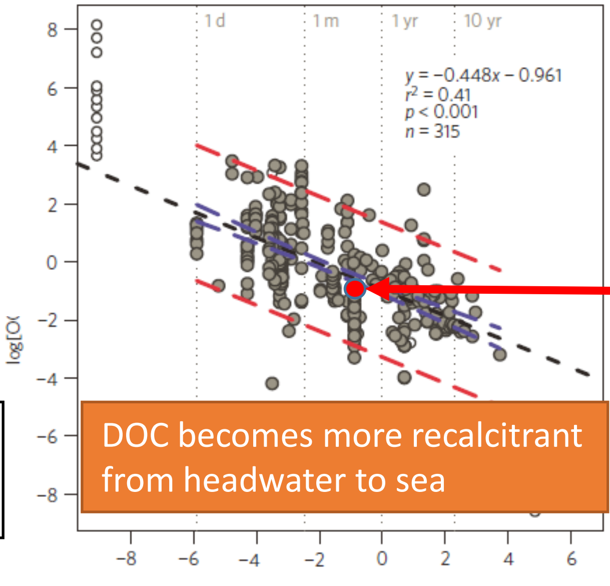
Log OC decay rate ≈ lake DOC removal rate

$$k = -\frac{\ln\left(\frac{DOCout}{DOCin}\right)}{WRT}.$$

Unit: yr^{-1}

Spatial (headwater to ocean) gradient

Log (DOC decay rate) (yr^{-1})



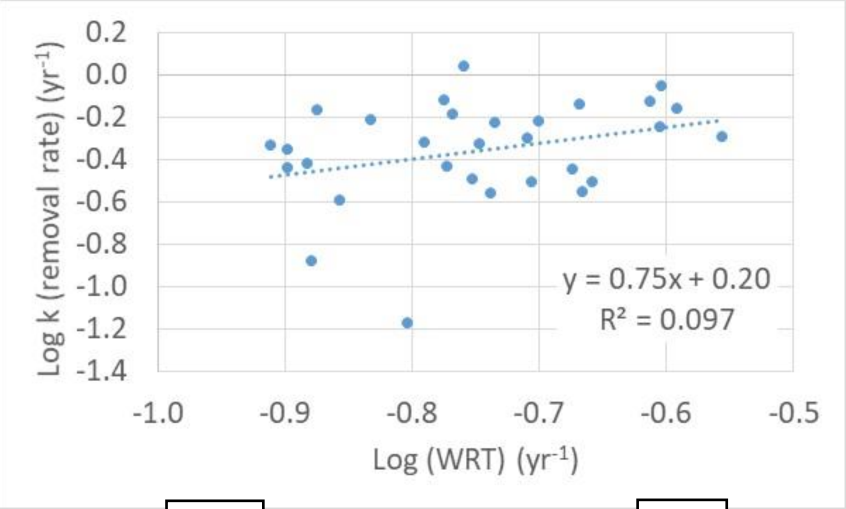
DOC becomes more recalcitrant from headwater to sea

Log (water residence time((yr^{-1})

Catalan et al. 2016 NatGeoSci

Headwaters ↔ Oceans

Time series of 30 years in headwater



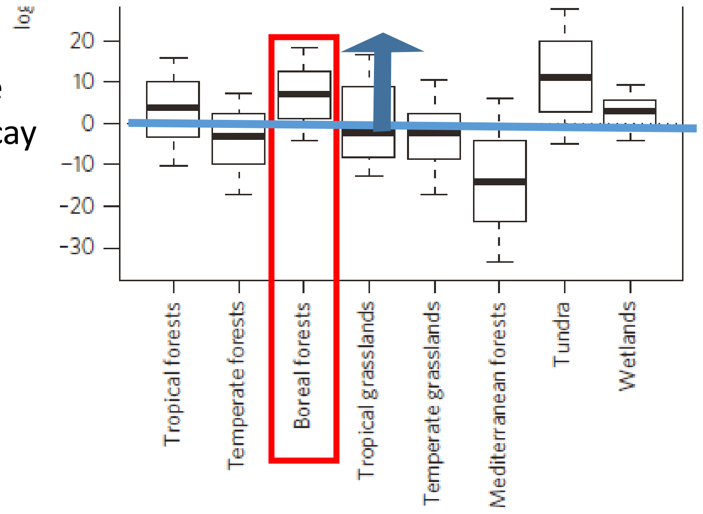
wet ↔ dry

Climate wetting impact on DOC decay: space-for-time substitution ≠ time series

Projection for lakes in boreal forests:

Climate warming -> wetting -> shorter WRT ->increase in decay rate

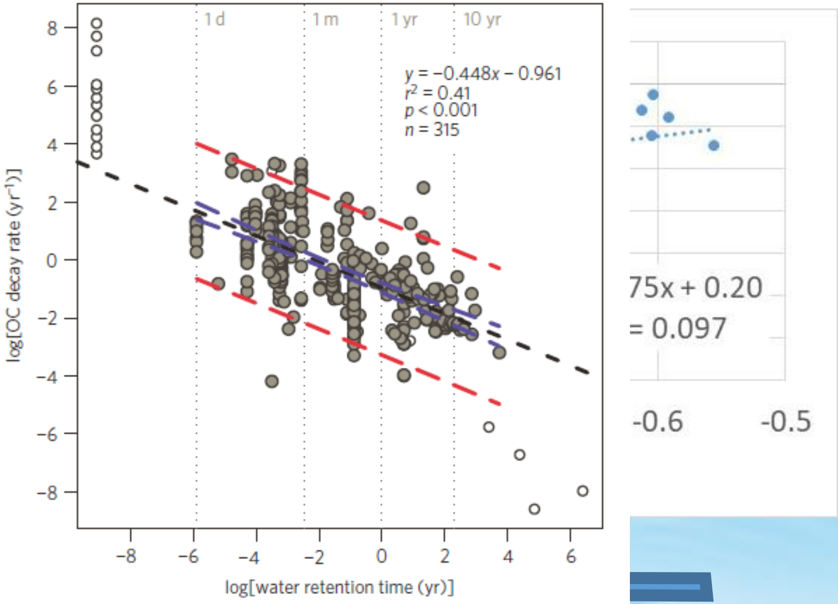
% change in OC decay



Catalan et al. 2016 NatGeoSci

Empirical evidence of climate impact in lakes in boreal forest:

Climate warming -> wetting -> shorter WRT



Conclusions

Time series

- In small boreal lakes (and large catchment to lake ratio), %DOC removal is low.
- A wetter climate results in large increase in lateral DOC fluxes, and in lower % lake removal of DOC
  - Most DOC is removed by microbes
- Lakes act more like pipes than chimneys/incubators under a wetter climate

Space-for-time substitution

- Wetter climate results in faster DOC removal because of a change in DOM character (less time to process, less recalcitrant)
  - Support for 'lakes as incubators'
- Space for time substitutions assume that spatial variation is equivalent to temporal change (Pickett 1989).

Reference & acknowledgements

De Wit H.A., R.M. Couture, L.A. Jackson-Blake L.A., M.N. Futter, S. Valinia, K. Austnes, J.L. Guerrero and Y. Lin. **2018**. Limnology and Oceanography Letters. *Pipes or chimneys? For carbon cycling in small boreal lakes, precipitation matters most.*

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