The Carbon Cycle in Hudson Bay: Overview and Gaps

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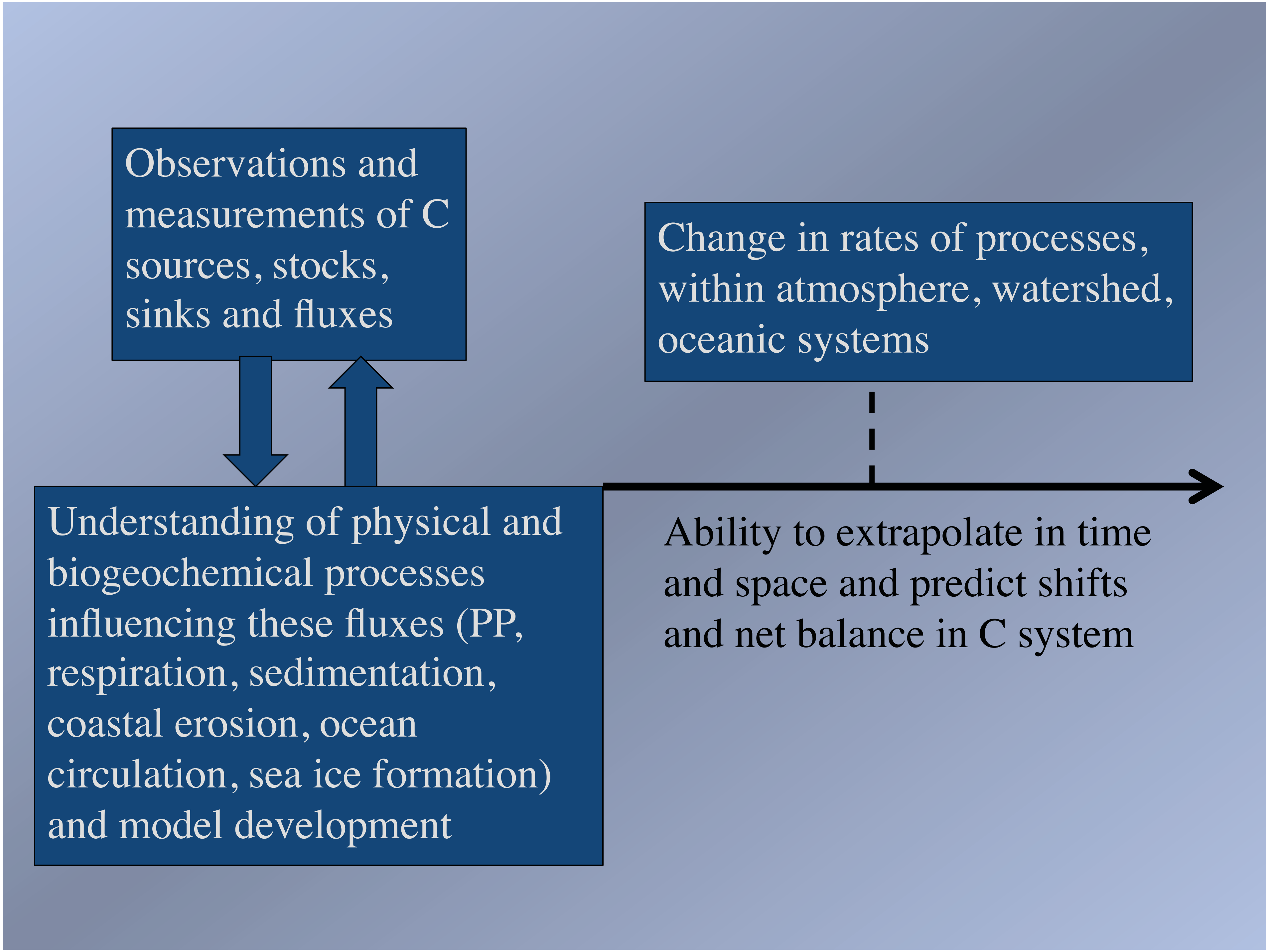
Motivation

- Continental shelf systems are very important in global C cycle
    - Intermediary between terrestrial, atmospheric, oceanic C reservoirs
    - Biologically and biogeochemically active and physically dynamic, so large transfers/fluxes
  - Can be sink or source for atmospheric CO_2
  - Sensitive to climate changes
    - Arctic margins generally sinks but rise in terrestrial C delivery, decrease in primary production, increase in oxidation, etc. may weaken CO_2 uptake potential

CEOS

Motivation (continued)

- Hudson Bay System
  - Large continental shelf area (~1.2×10^6 km^2 or 4.5% of total shelf area)
  - Massive drainage basin with discharge representing ~23% of the Arctic Ocean's total riverine input
  - Located at southern margin of the Arctic, where climate changes may be faster and more dramatic
    - Indicator of future changes in Arctic Ocean shelves?
  - Greater development in basin compared to more remote Arctic areas
    - Offer insights into impact of local human activities?


Observations and measurements of C sources, stocks, sinks and fluxes
Change in rates of processes, within atmosphere, watershed, oceanic systems
Understanding of physical and biogeochemical processes influencing these fluxes (PP, respiration, sedimentation, coastal erosion, ocean circulation, sea ice formation) and model development
Ability to extrapolate in time and space and predict shifts and net balance in C system

Terrestrial Organic Carbon

Frozen soils in Arctic and sub-arctic regions hold ~50% of global terrestrial OC.

Warming, increased river discharge, and other changes/activities in watersheds may mobilize more of this OC and transport it to the ocean.

Terrestrial Dissolved Organic Carbon (DOC)

~18 rivers in HBS (HB, HS, FB) sampled to date

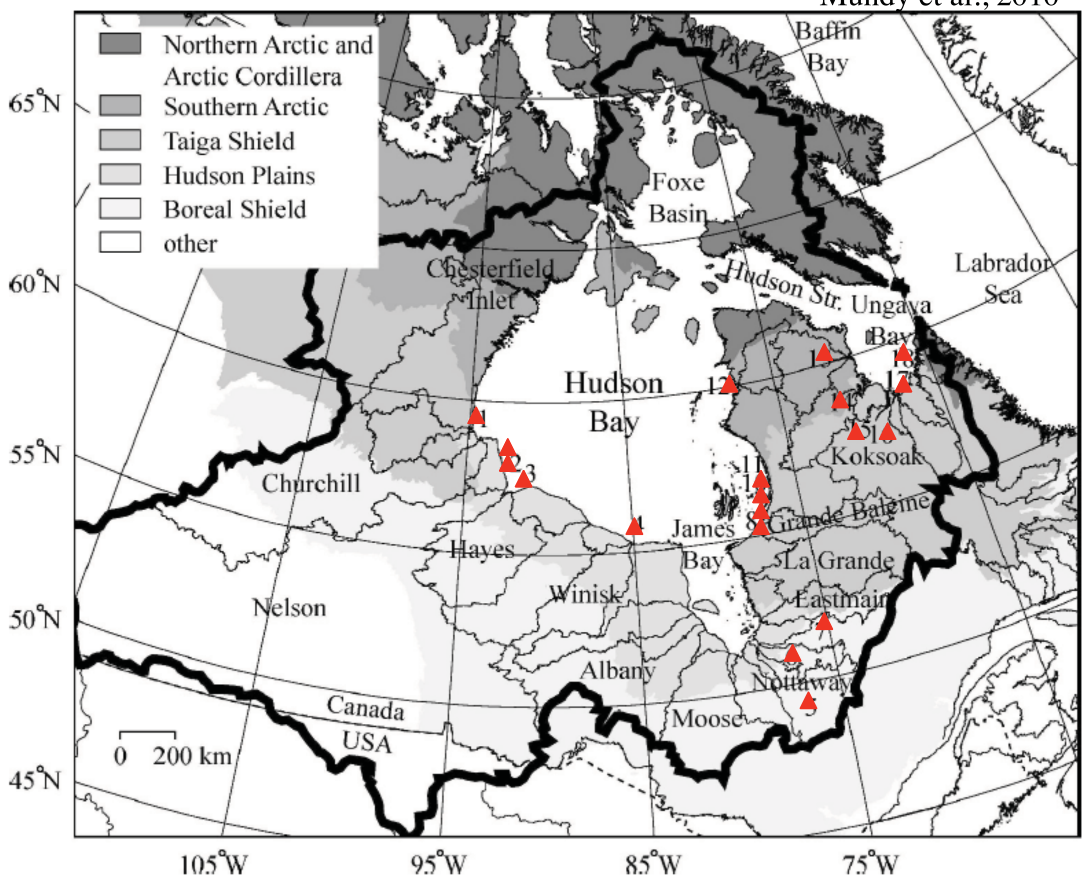
-DOC concentrations varied 100-1200 uM

-Total riverine input of DOC estimated at ~5.5 -5.9 Tg C/yr (Mundy et al., 2010)

=14%-22% of DOC input from rivers to Arctic Ocean (vs. receiving volume of HBS only ~1%)

So DOC inputs from rivers to HB very significant!

Mundy et al., 2010



Characterizing sources and composition of DOC (CDOM)

Statistically significant differences in CDOM fluorescence and absorbance characteristics among various river/estuary systems (Granskog et al., 2007; Guéguen et al., 2011)

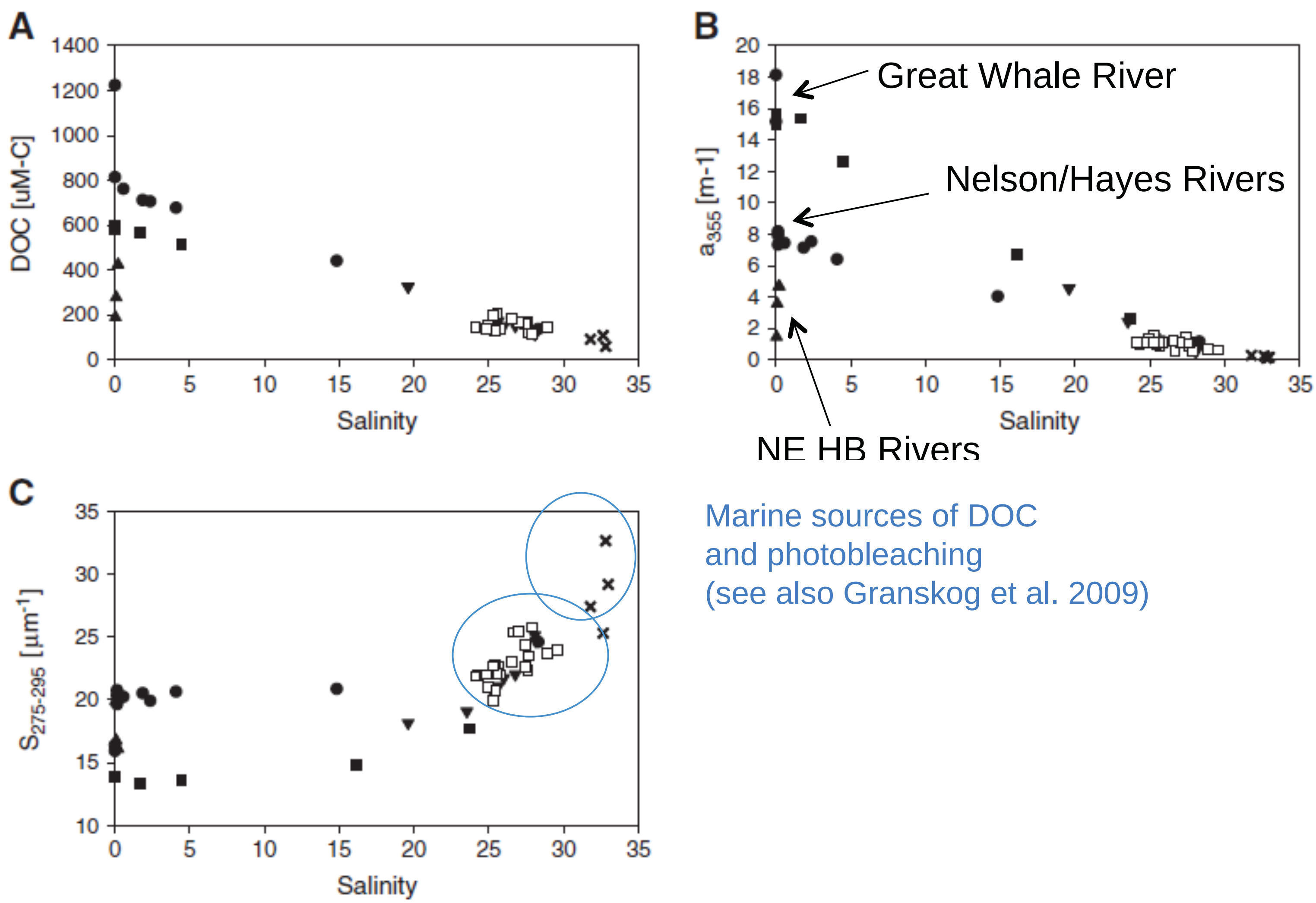
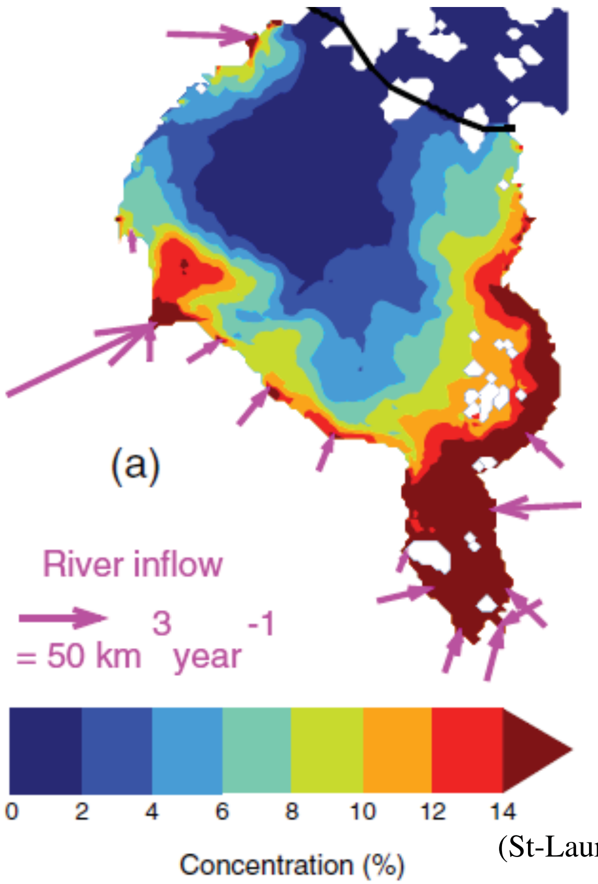


Fig. 2. Dissolved organic carbon (DOC) concentration, absorption coefficient at 355 nm (a_{355}), spectral slope ($S_{275-295}$) and spectral slope ratio (S_r) as a function of salinity in Hayes/Nelson River estuary (•), Great Whale River estuary (■), Winisk River estuary (▼), NE Hudson Bay Rivers (▲), Hudson Bay (□) and Hudson Strait (x).

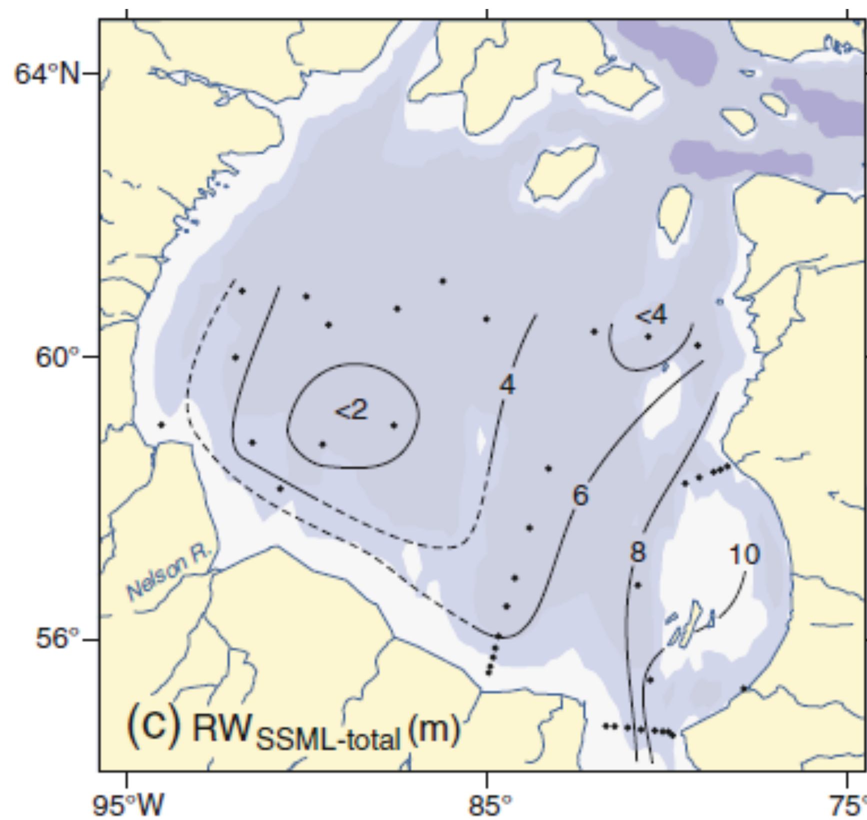
Guéguen et al., 2011

Distribution, impact and fate of terrestrial DOC in Hudson Bay → **Distribution of river water**

River tracer experiment conducted using 3-D numerical model (left) and also conservative tracers ($\delta^{18}O$ and S) were applied to differentiate RW vs SIM (right).
-Most of the RW remains in coastal region in summer, with limited exchange into the interior of the Bay (at most 25% diverted into interior by winds).



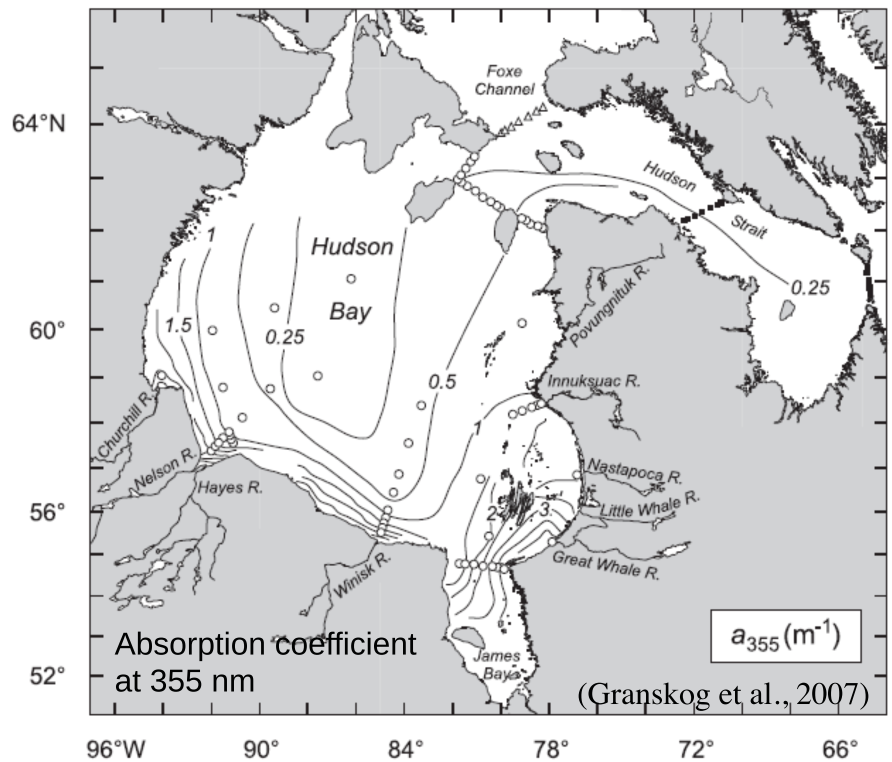
(St-Laurent et al., 2011)



(Granskog et al., 2011)

Distribution, impact and fate of terrestrial DOC in Hudson Bay

- CDOM distributed mostly along coast
  - influences light absorption and thus primary production, thermodynamics and stratification of the coastal waters

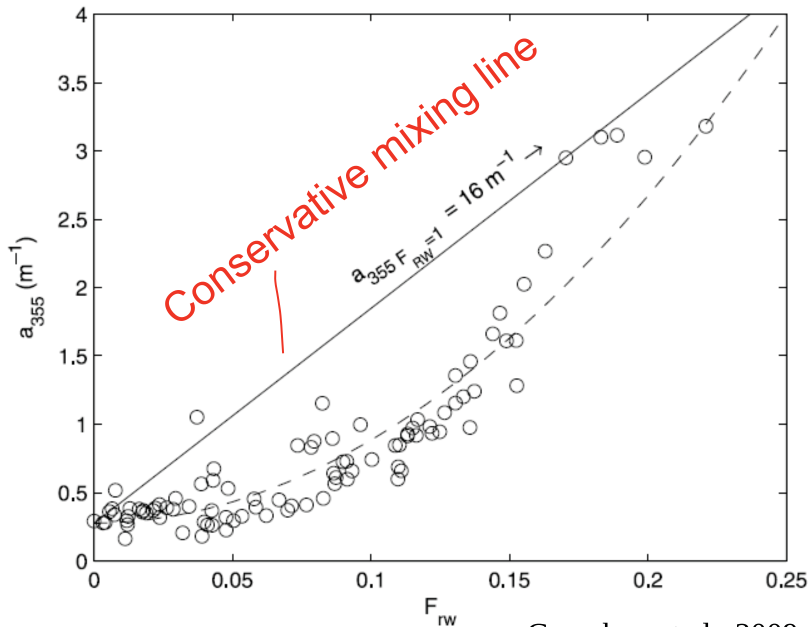


- CDOM effects on light penetration through water column incorporated into 3D biophysical model (via RW tracer) (Sibert et al., 2011).

Distribution, impact and fate of terrestrial DOC in Hudson Bay

- Quantification of fraction RW (vs SIM) allowed assessment of CDOM fate
    - CDOM almost conservative within estuaries but degraded >50% during regional mixing (as RW diminished to 5-10%, 1-3 month residence time)

CDOM in southwest sector of the Bay



Granskog et al., 2009

- Photobleaching and/or micobial degradation represents important sink for DOC entering from rivers

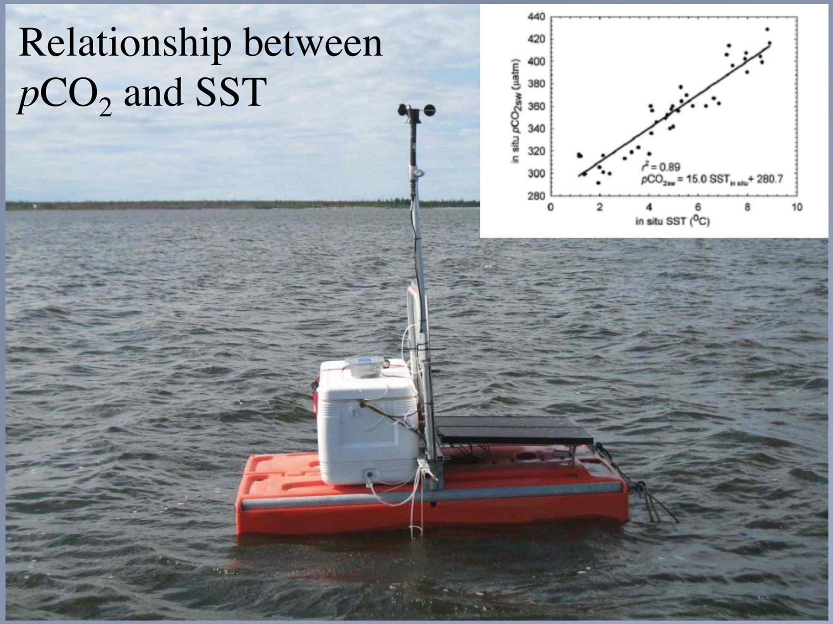
CO_2 System

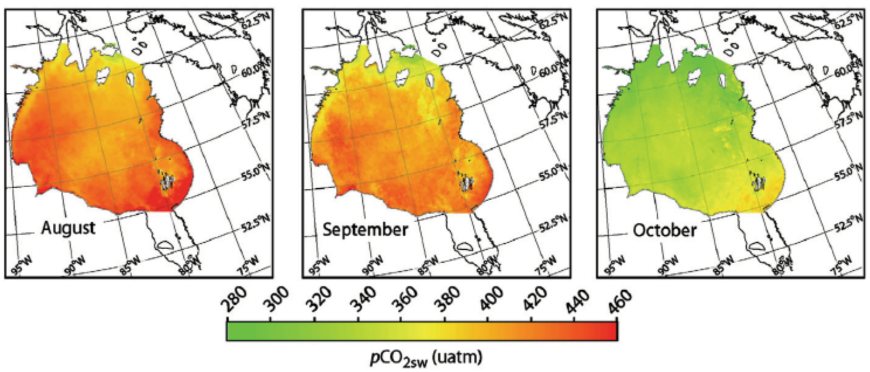
Observations (raft-, boat- and ship-based) of river/marine dissolved gases and key variables have provided insight into local and regional air-sea CO_2 exchange budgets, metabolic function and CO_2 dynamics of rivers/estuaries.

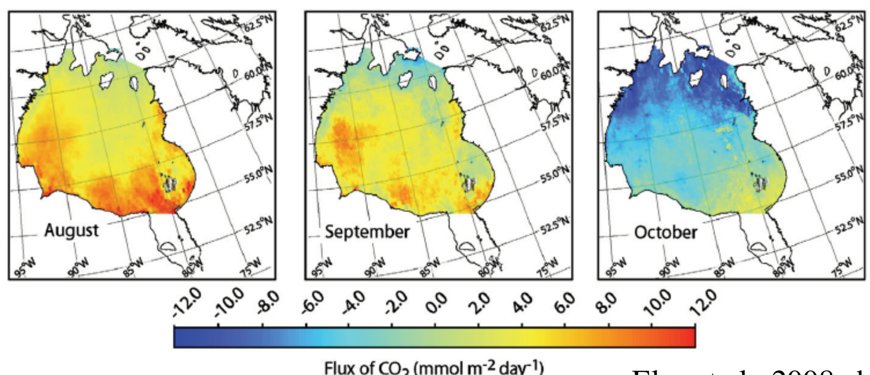
Strong relationships between pCO_2 and RW distribution (as indicated by S and CDOM). Coastal waters are supersaturated in CO_2 with respect to atmosphere, while interior waters undersaturated.

Estimated fluxes imply weaker net C sink in HBS compared to other Arctic shelf environments…..*but large seasonal and probably inter-annual variability*

- Ongoing work – 2005 vs 2010







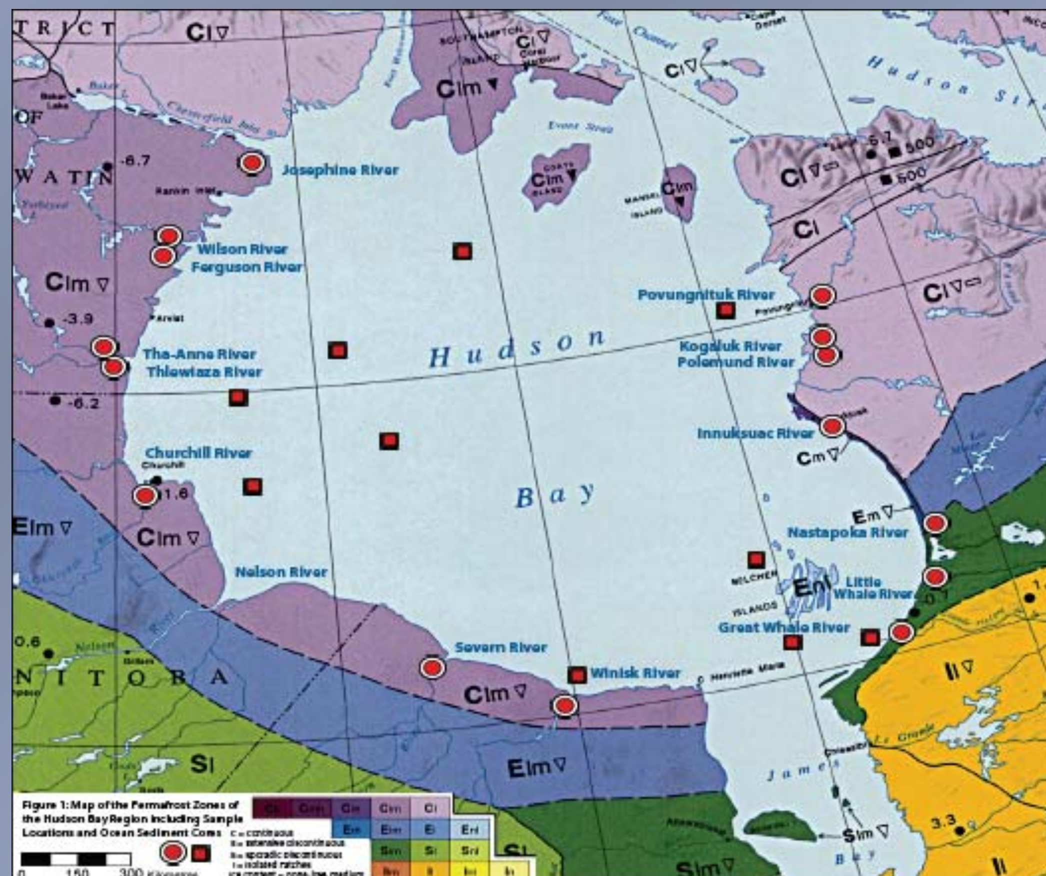
Else et al., 2008a,b

Terrestrial POC

Riverbank erosion often significant source of sediment and POC; supply enhanced by thermal degradation of permafrost, high river flows, ice jams, ice scouring, onshore winds, high tides, etc.

Terrestrial POC generally efficiently buried in Arctic shelf sediments, representing important C sink.

Sources and composition of river particulate, soils, and permafrost studied using OC/N, $\delta^{13}C$, $\delta^{15}N$, lignin, $\Delta^{14}C$



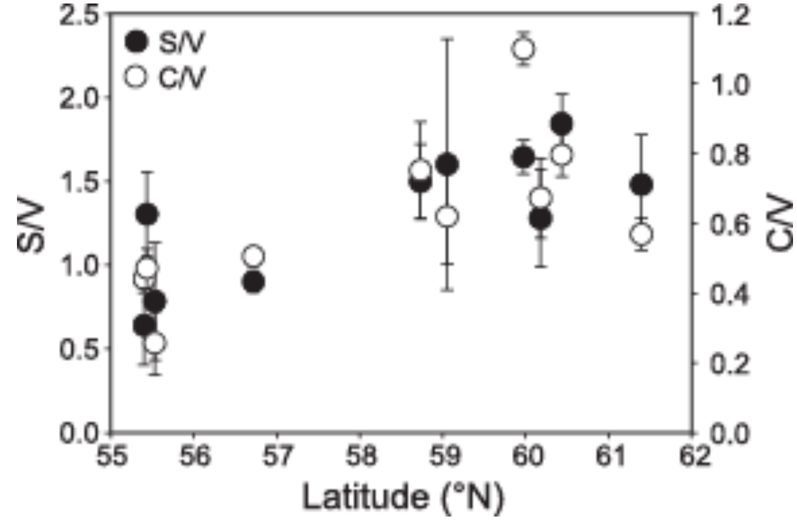
Kuzyk et al., 2008, 2009; Godin et al. in preparation

Terrestrial POC

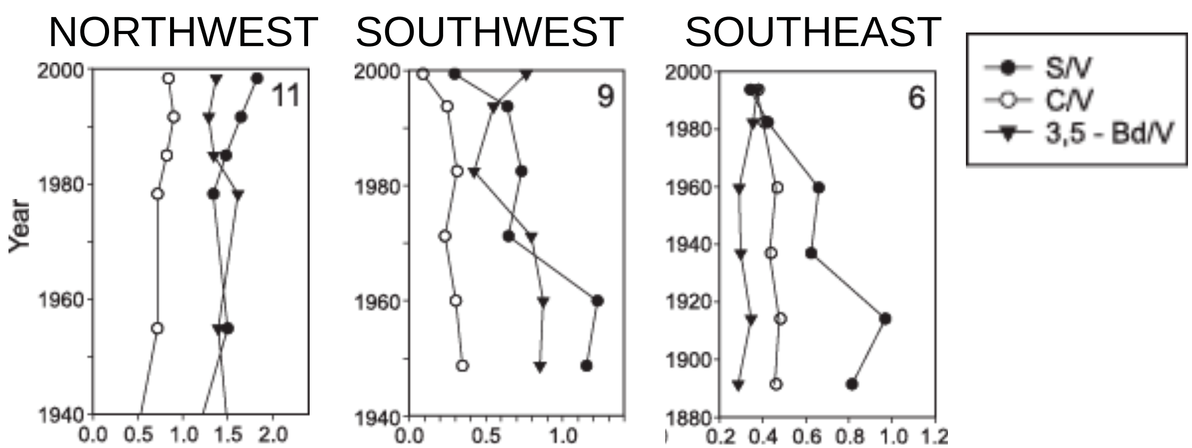
Terrestrial POC varies from river to river, reflecting differences in vegetation in watersheds. Currents redistribute POC throughout HB, preserving some regional differences (e.g., latitudinal trend).

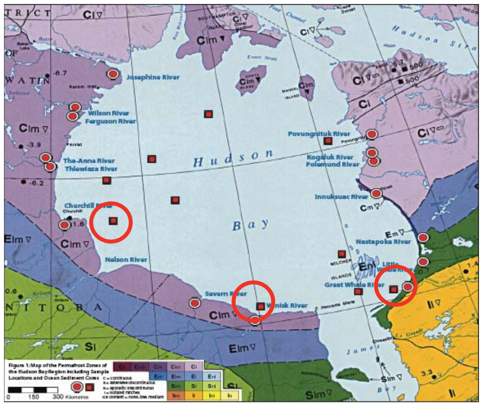
Modifications in POC composition imply some degradation (perhaps more than in other Arctic systems).

Lignin compositional ratios



Sediment core records show changes in POC over last ~100 yrs.



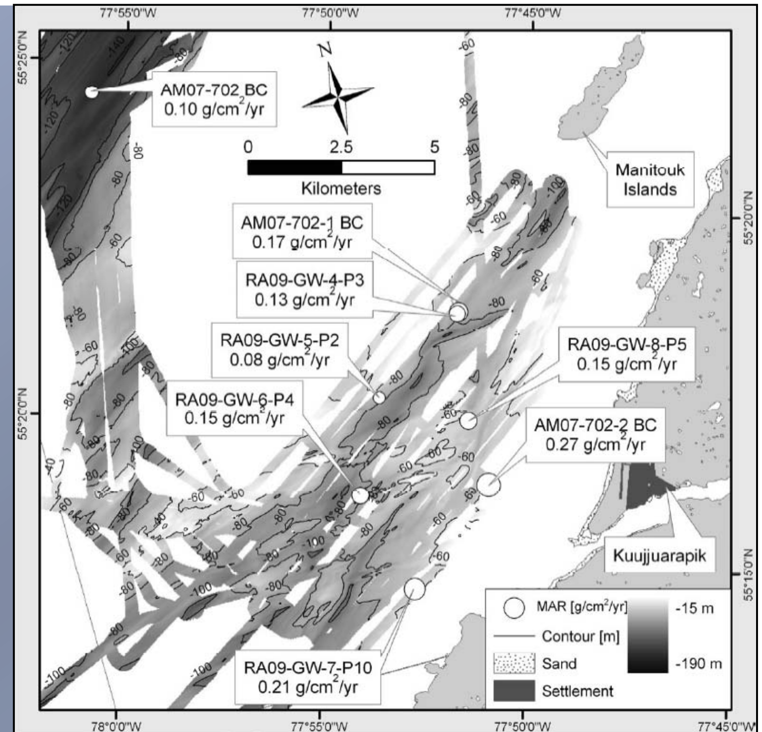


Kuzyk et al., 2008

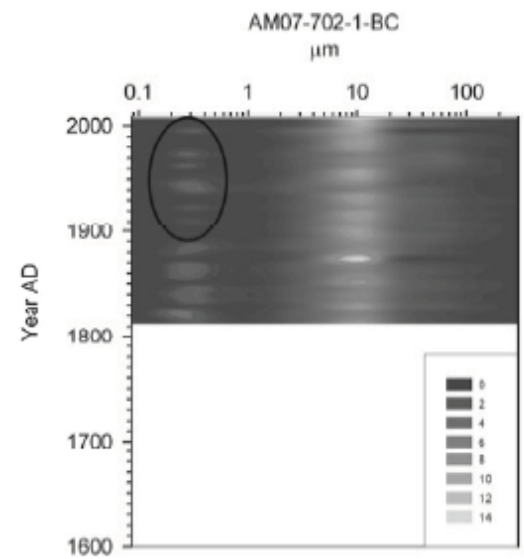
Regional sediment core studies

E.g., 8 sediment cores from small sedimentary basins at mouth of Great Whale River (Hulse et al., 2012).

- Sediment accumulation rates calculated from ^{210}Pb and ^{137}Cs profiles suggest an offshore shift in the locus of fine sediment deposition in recent decades, which may be a sign of increased wave resuspension due to a more energetic environment (related to less sea-ice cover during fall?)
- Periodic variation in sediment particle size over last ~100 yrs, which correlated across cores, imply variations in sediment discharge from river, changing sediment source, and/or winnowing (related to wave climate and/or sea-ice cover?)
- Effects on POC still to come!

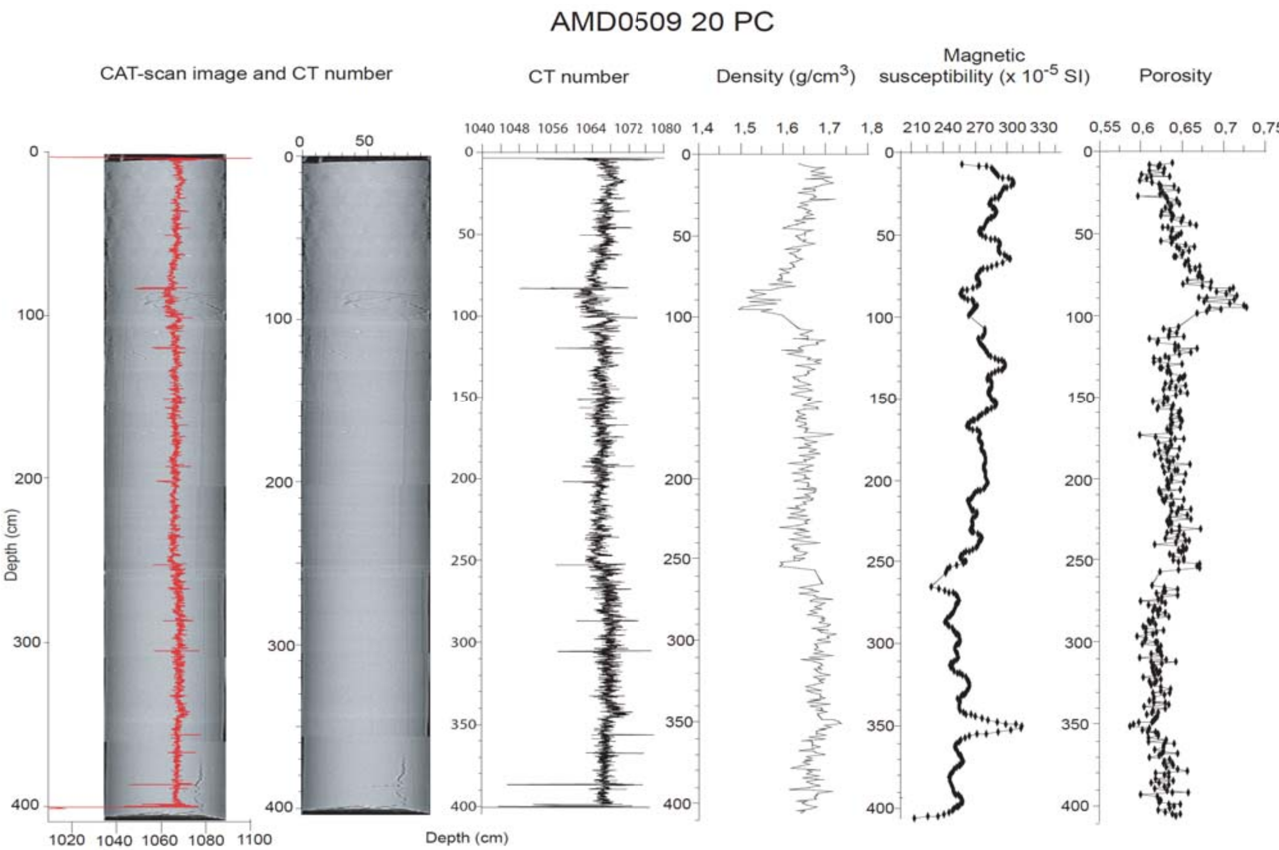


Downcore grain diameter frequencies



Ongoing work with archived sediment boxcore and piston core samples, soil and permafrost samples

- Pollen (Heikkila et al., in prep.)
- Geochemical indicators of fire history and vegetation (Goni et al., in prep., Godin et al., in prep)



Marine POC

Studies of biological processes ⟷ Geochemical studies –
- primary production, microbial effect of labile C metabolism
recycling, particle export on sediment geochemistry

HB is fundamentally oligotrophic

-3-D biophysical coupled model (Sibert et al., 2011)

-measures of primary productivity (Ferland et al., 2011)

-measures of export fluxes (Lapoussière et al., 2009; Lalande & Fortier, 2011)

-labile C flux to sediments inferred from sediment redox geochemistry (Kuzyk et al., 2011)

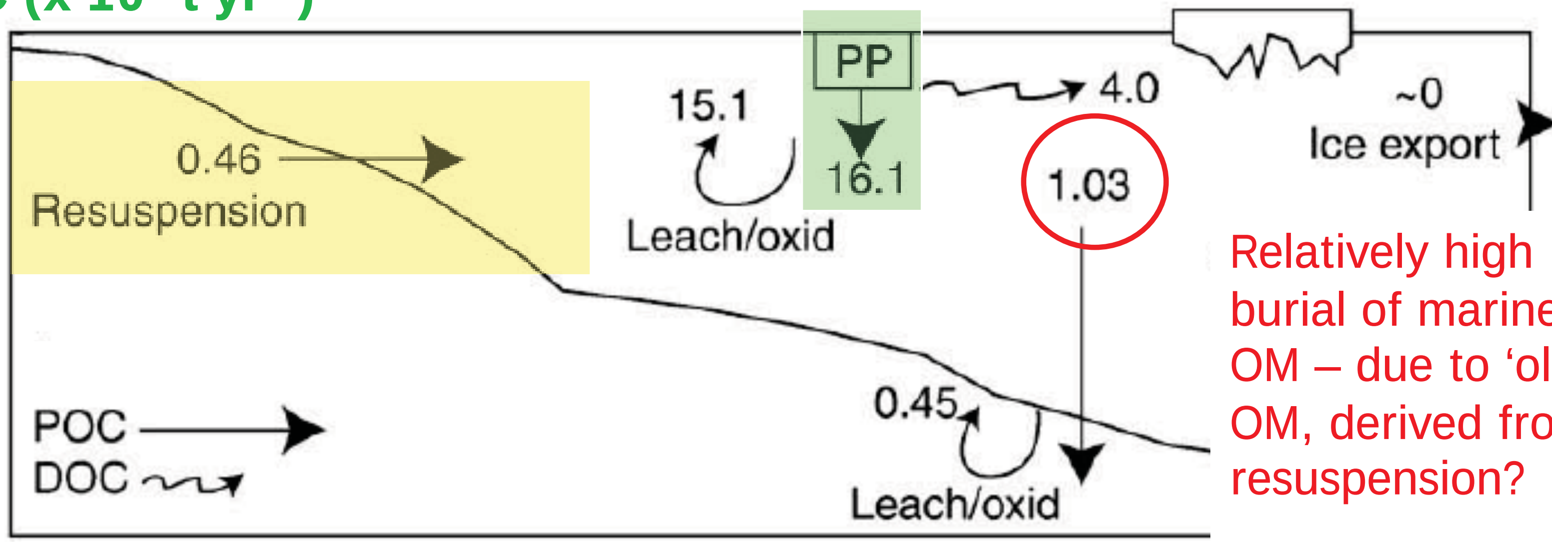
Improved understanding of relationships with environmental conditions.

Appreciation of inter-annual, regional and sub-regional variability.

Coupled with short time-series, this means that temporal trends difficult to address.

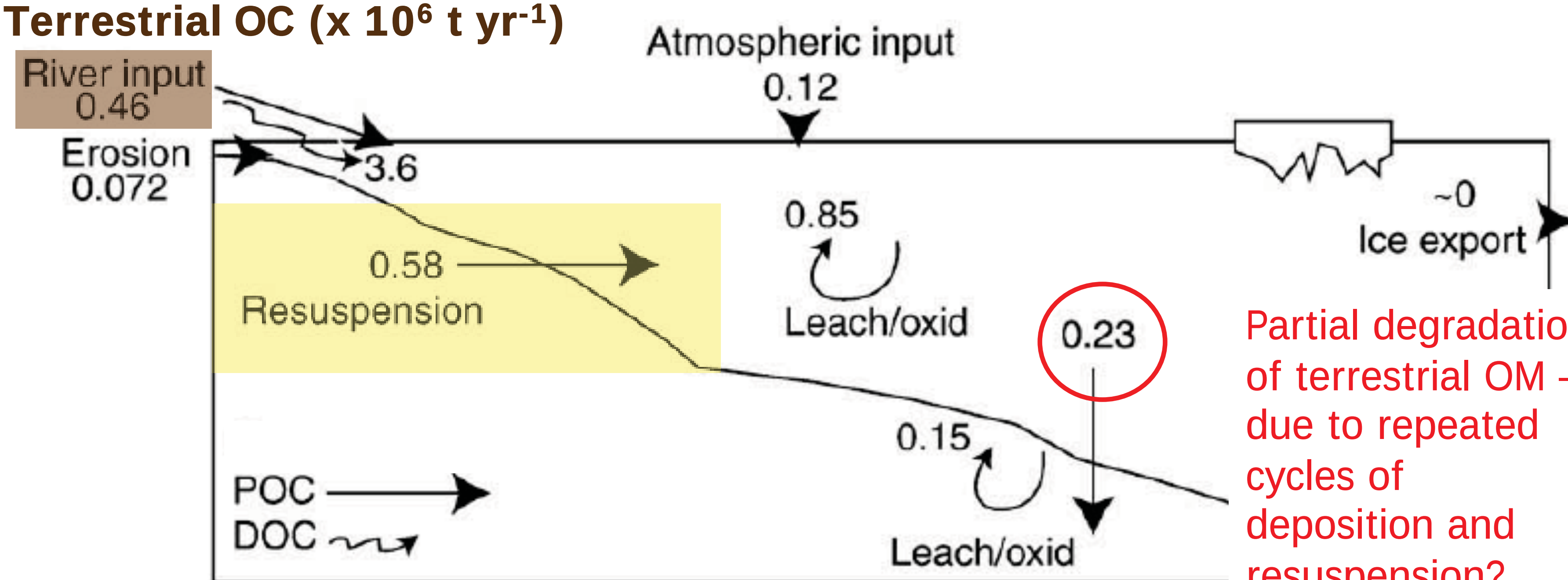
Preliminary OCterr and OCmar Budgets

Marine OC (x 10^6 t yr^{-1})



Relatively high burial of marine OM – due to ‘old’ OM, derived from resuspension?

Terrestrial OC (x 10^6 t yr^{-1})



Partial degradation of terrestrial OM – due to repeated cycles of deposition and resuspension?

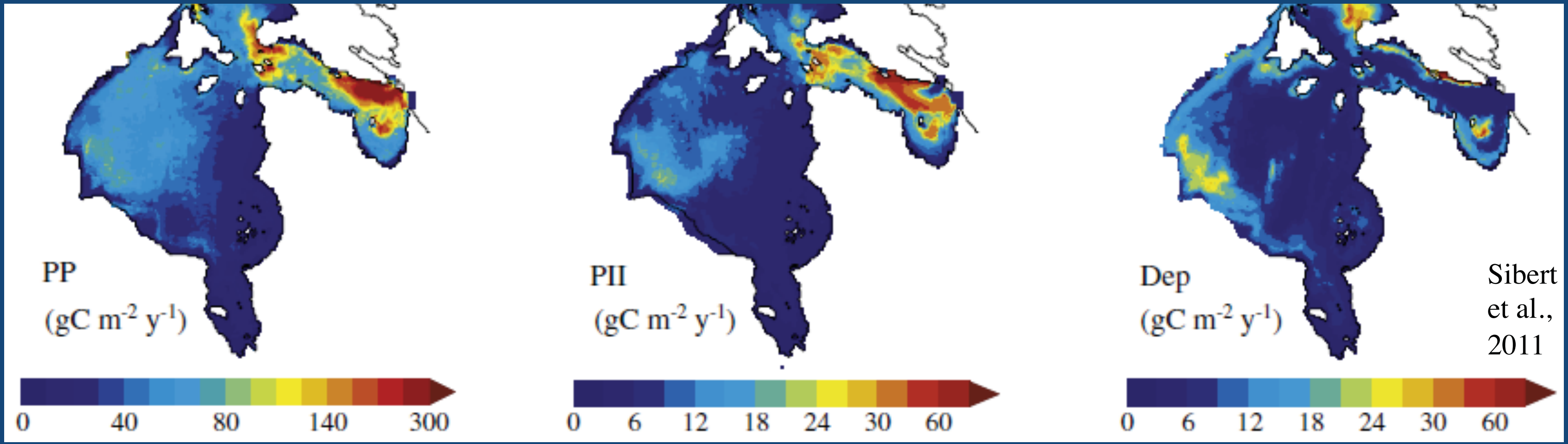
Kuzyk et al., 2009

Gaps & Priorities

- Limited observational record hinders assessment of C cycle, including development of budgets, and forecasts of sensitivity to environmental change (anthropogenic and natural)
  - Propose strategic deployment of monitoring facilities/moorings
    - Buoys suited for time-series observations of CO_2 and associated air-sea exchange parameters
    - Improved temporal and spatial coverage

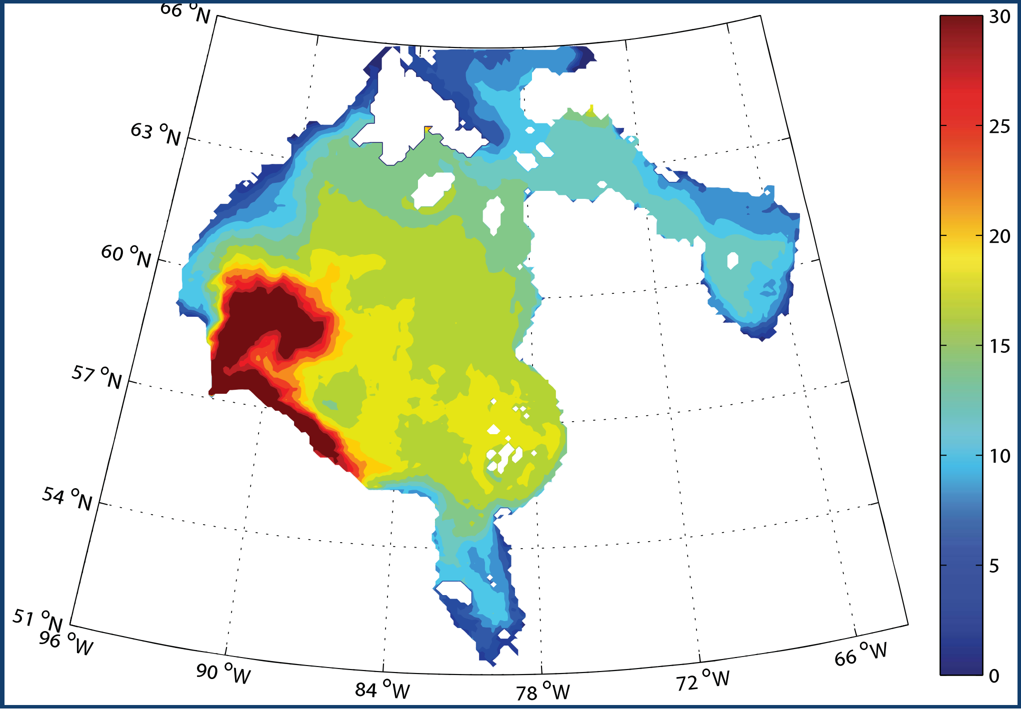
Gaps & Priorities

- $\delta^{18}O$ data imply ~20% of RW exported into deep layer
  - winter densification in polynyas (also supported by DOC data)
- Model results suggest spatial uncoupling PP/C deposition
  - higher POC fluxes to seafloor on shallow W shelf of HB
  - sediment records do not show particular accumulation
  - points to resuspension and transport, perhaps with dense water?
- Propose sampling/moorings to examine dense water formation on W shelves and transports to interior



Gaps & Priorities

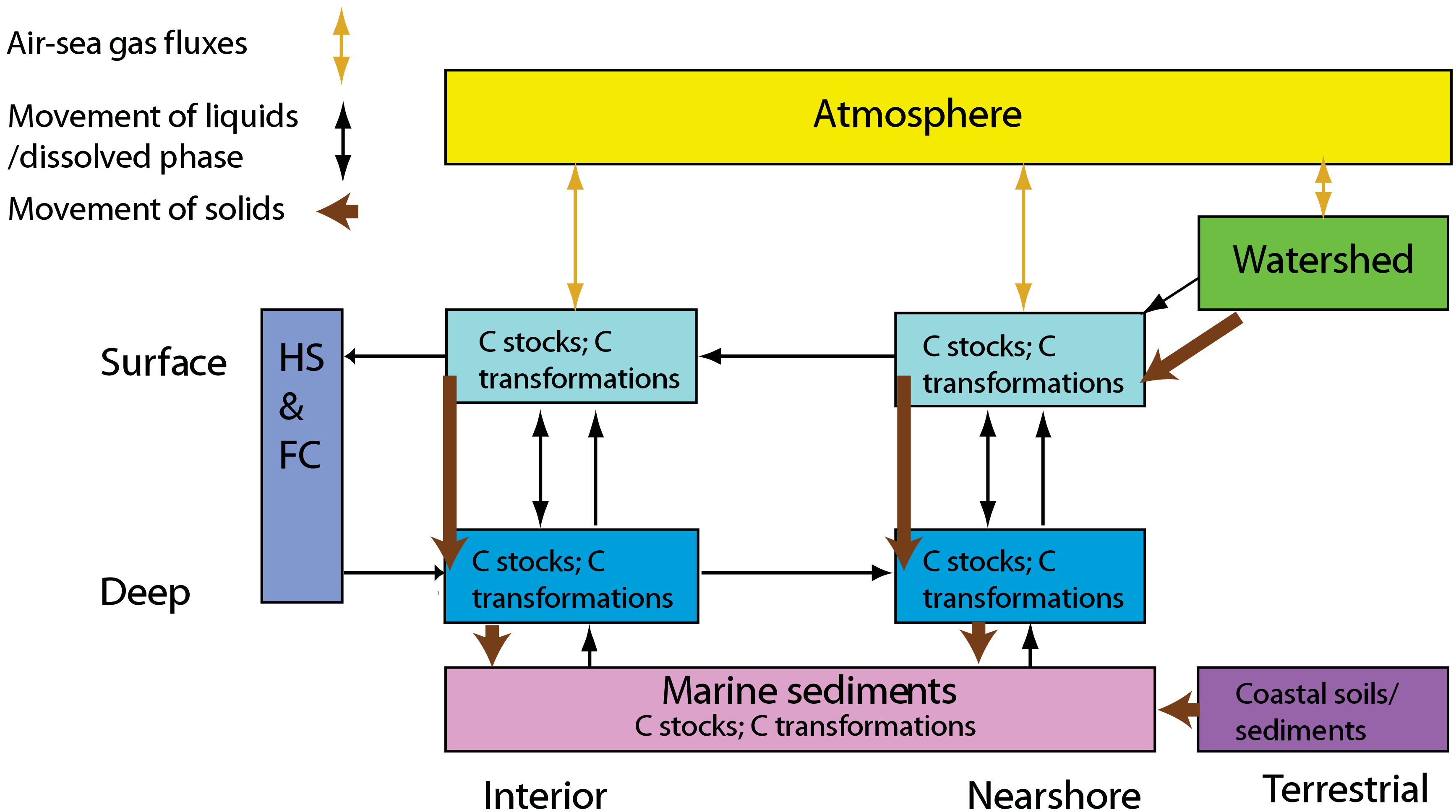
- Characterizing and tracing fate of C components from watersheds/rivers of origin, through estuaries and into HB marine system
  - Apply fingerprinting tools in coordination with watershed researchers, collect observations to compare to model



Portion of RW from Nelson River (%) during 2005 field campaign

(Wang et al., in prep.)

Conceptual model of C cycle, viewing HB as integrated system of land-atmosphere-ocean



Acknowledgements

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