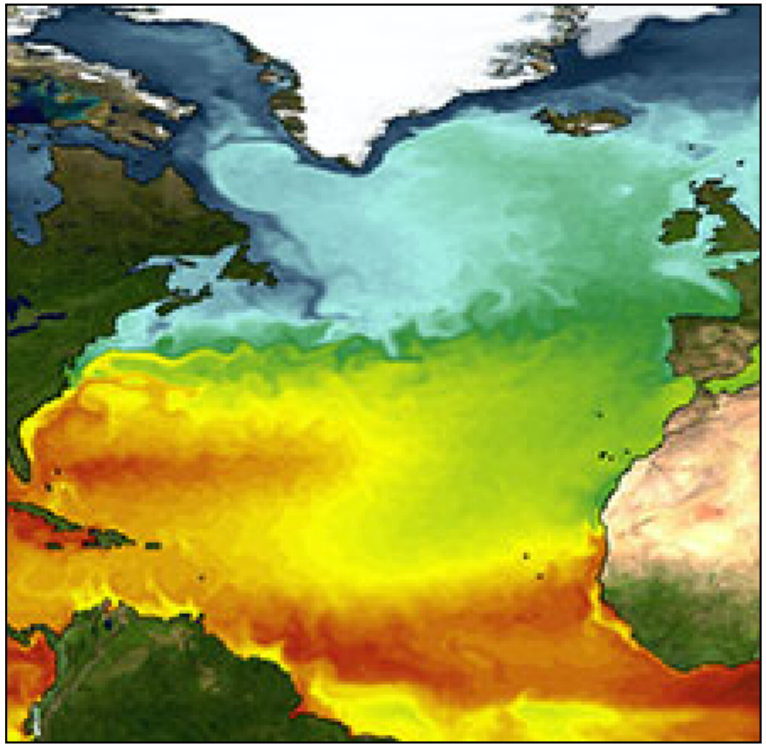
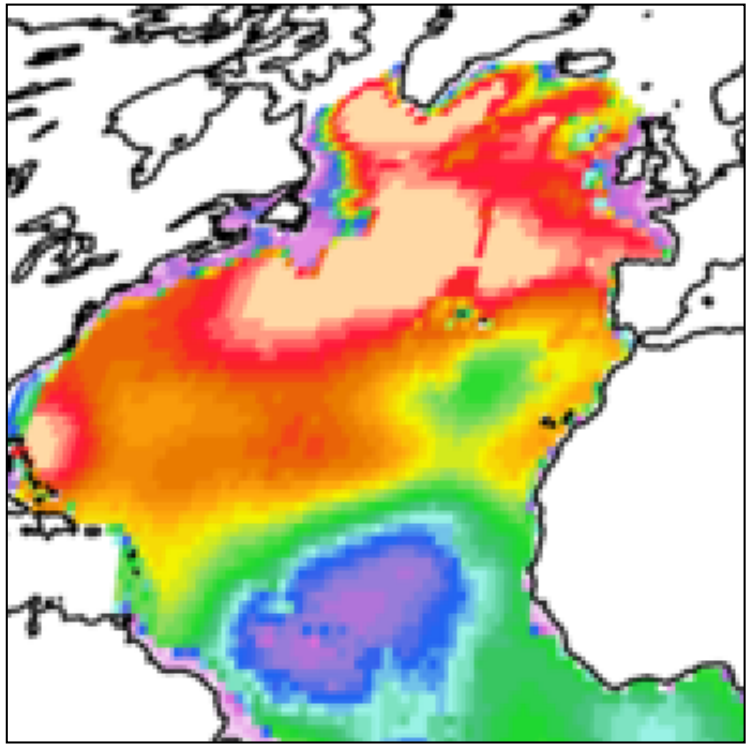
Does the $^{231}Pa/^{230}Th$ ratio record information about rates of ocean circulation?





Gideon Henderson

UNIVERSITY OF OXFORD

Biogeosciences, 15, 1–15, 2018
https://doi.org/10.5194/bg-15-1-2018

Biogeosciences Open Access EGU

Evolution of ^{231}Pa and ^{230}Th in overflow waters of the North Atlantic

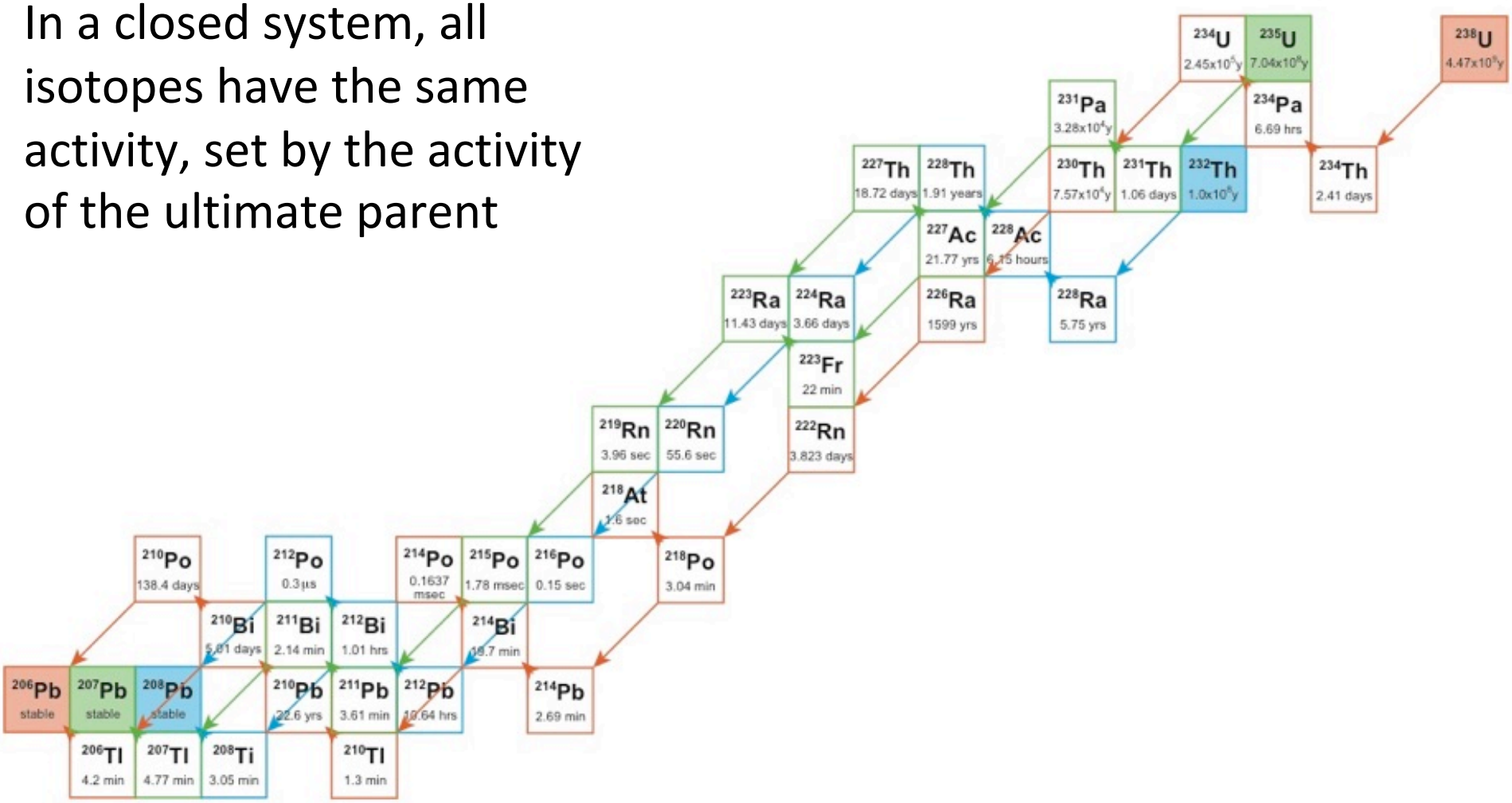
Feifei Deng[1], Gideon M. Henderson[1], Maxi Castrillejo[2,3], Fiz F. Perez[4], and Reiner Steinfeldt[5]

[1]Department of Earth Sciences, University of Oxford, South Parks Road, Oxford, OX13AN, UK
[2]Laboratory of Ion Beam Physics, ETH-Zurich, Otto Stern Weg 5, Zurich, 8093, Switzerland
[3]Institut de Ciència i Tecnologia Ambientals & Departament de Física,

Results from the GEOVIDE cruise

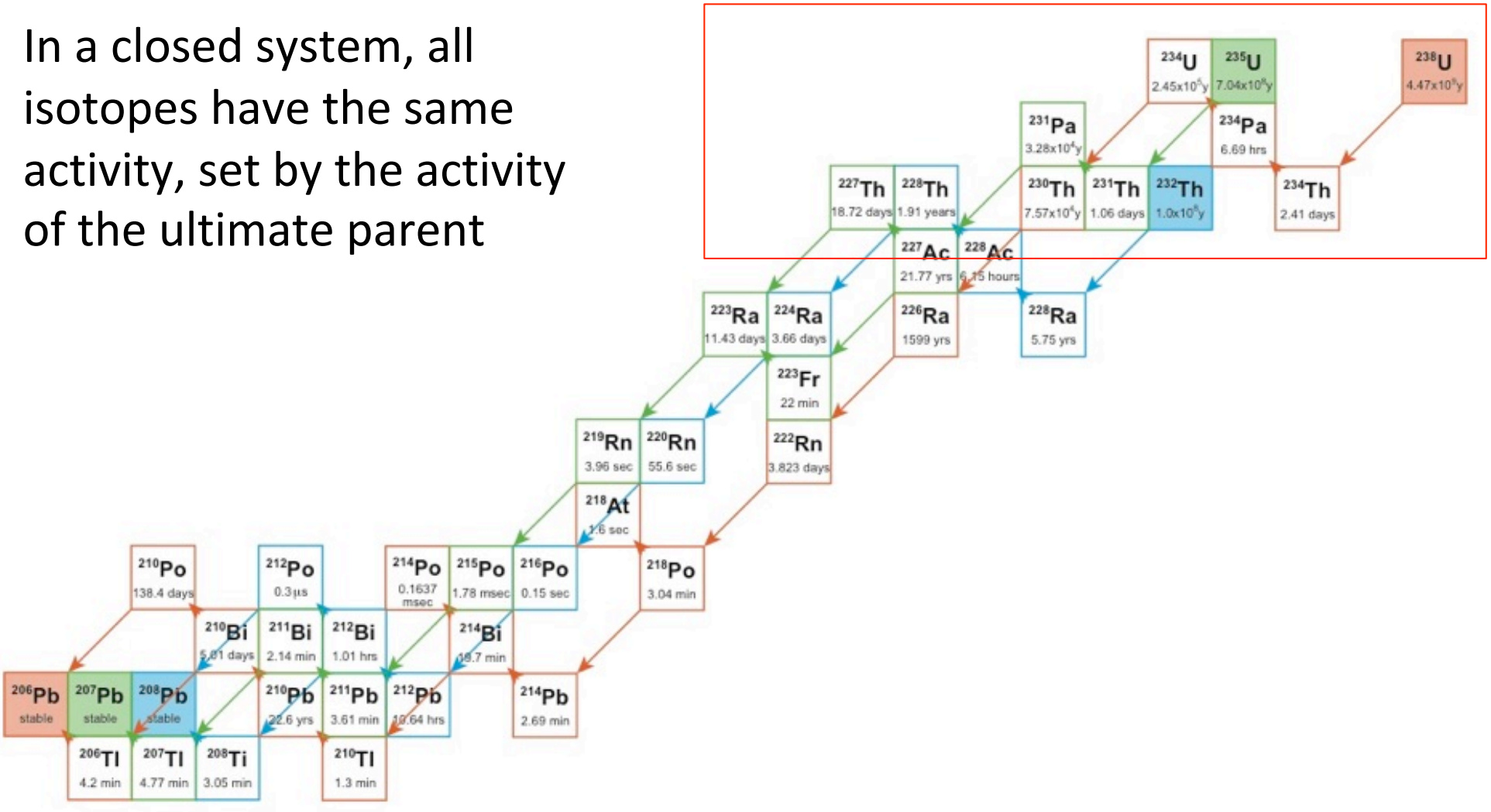
U-series isotopes

In a closed system, all isotopes have the same activity, set by the activity of the ultimate parent

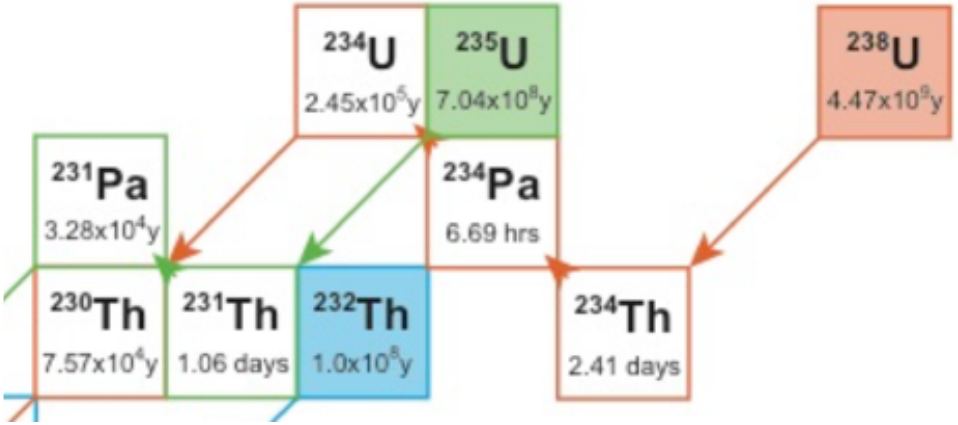


U-series isotopes

In a closed system, all isotopes have the same activity, set by the activity of the ultimate parent



Th and Pa chemistry in the ocean



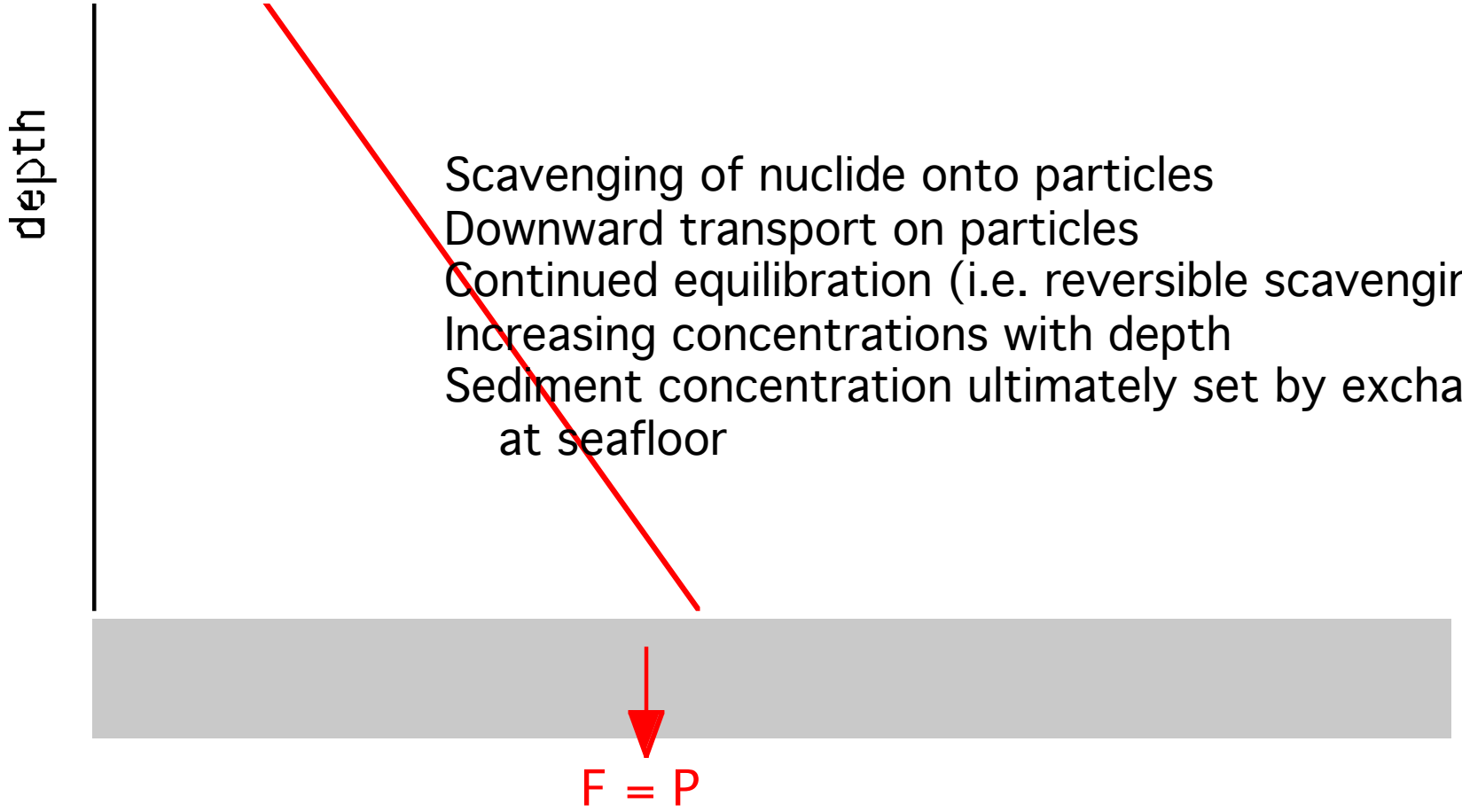
Uranium: conservative

Protactinium and thorium:
Rapidly removed
$\approx 10^{-4}$ secular equilibrium value

T_{res} $^{230}Th \approx 20$ years
T_{res} $^{231}Pa \approx 150$ years

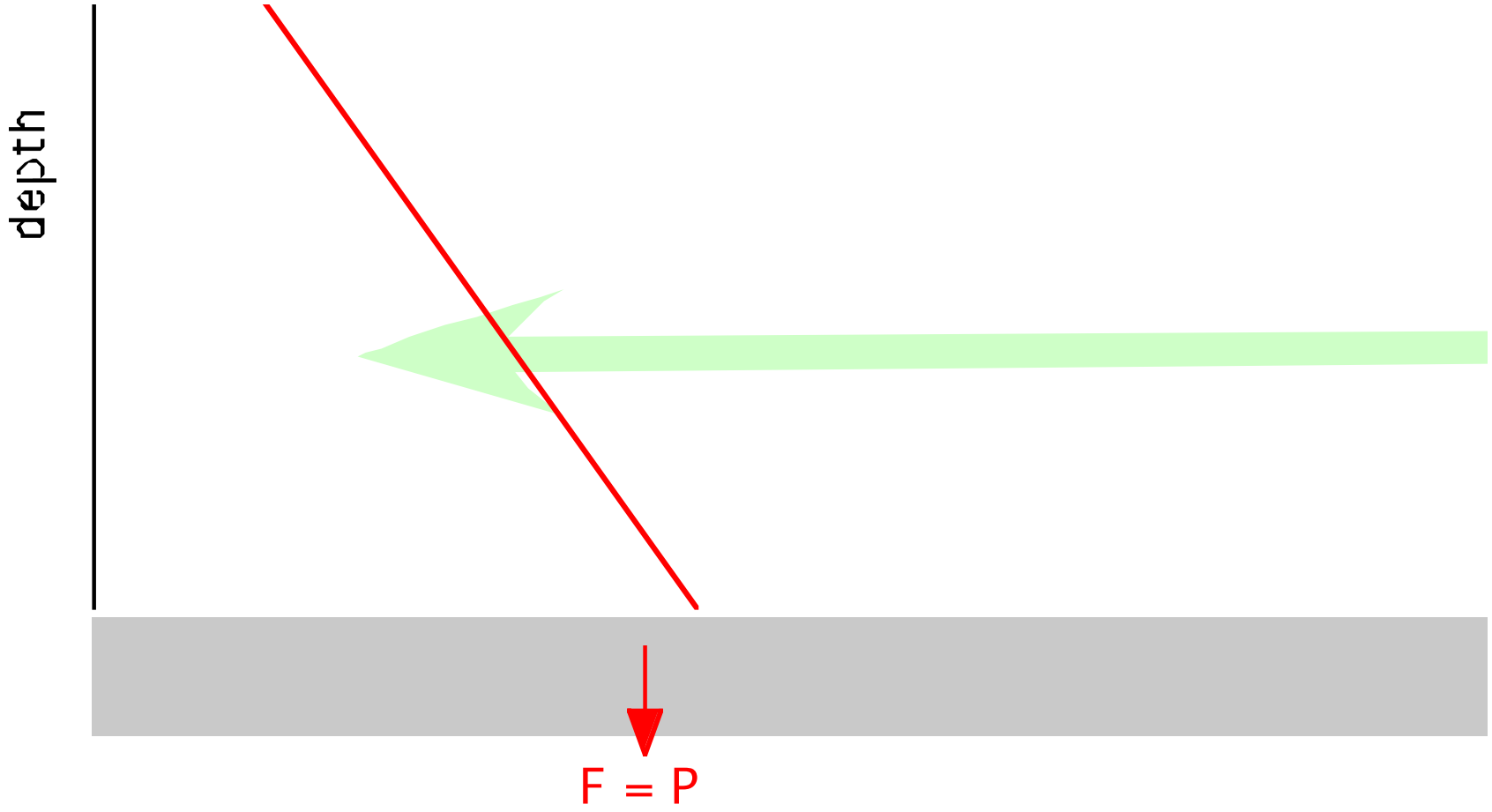
^{230}Th scavenged 5 – 10 times faster than ^{231}Pa
This difference referred to as F ($= Kd_{(230Th)}/Kd_{(231Pa)}$)

Nuclide concentration with depth

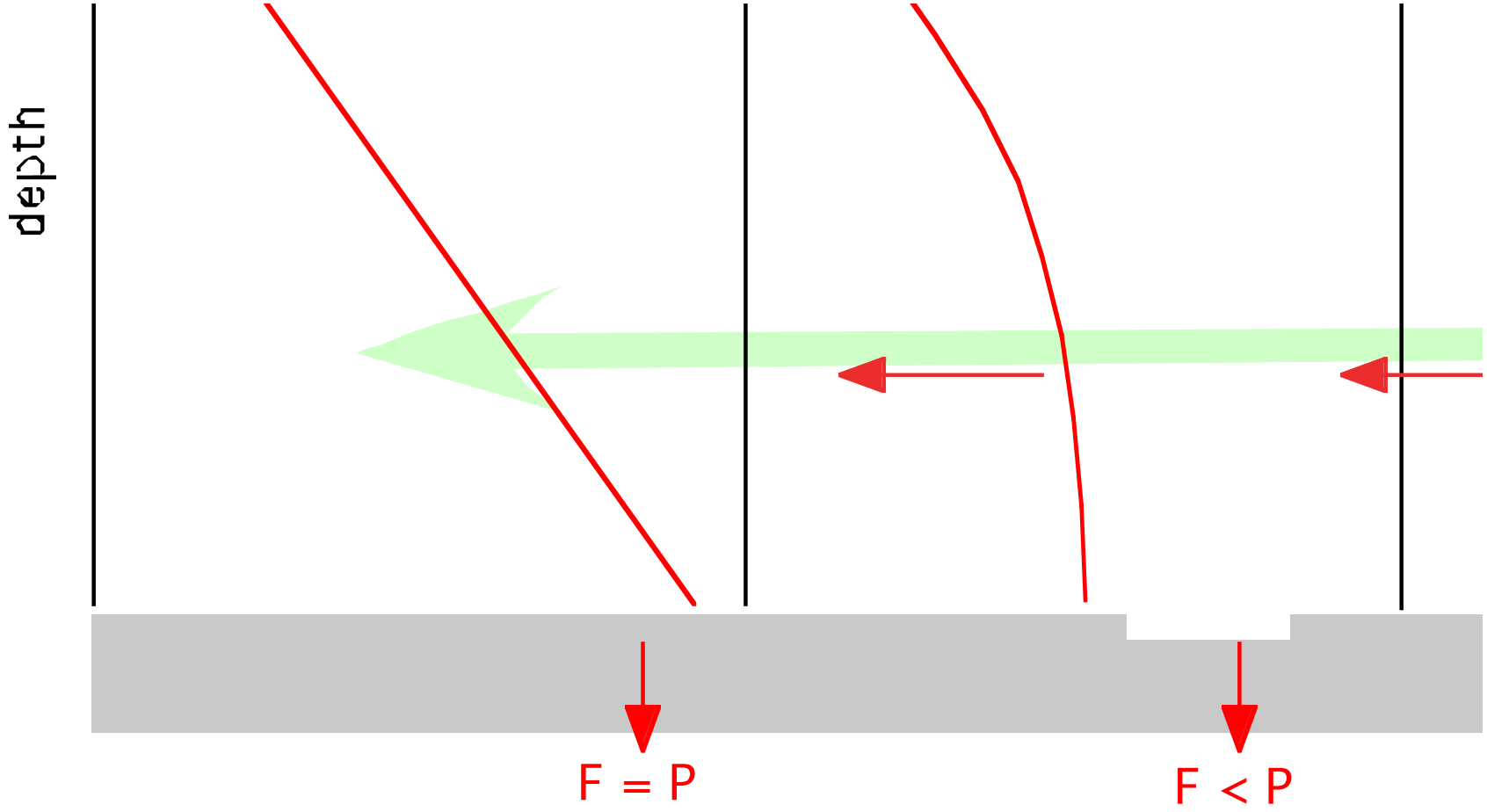


Bacon and Anderson 1982, Anderson and Bacon 1983

Nuclide concentration with age

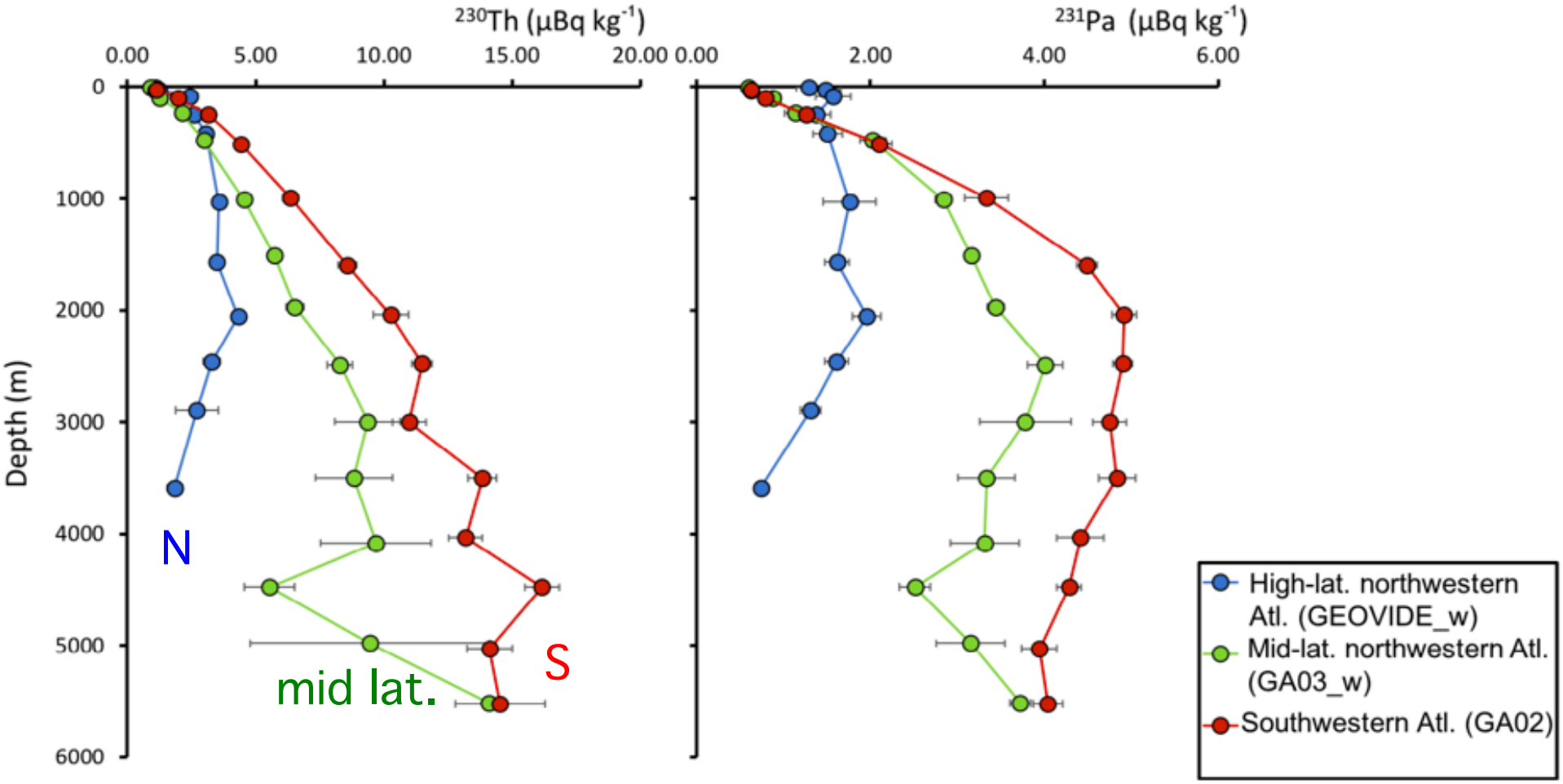


Nuclide concentration with age



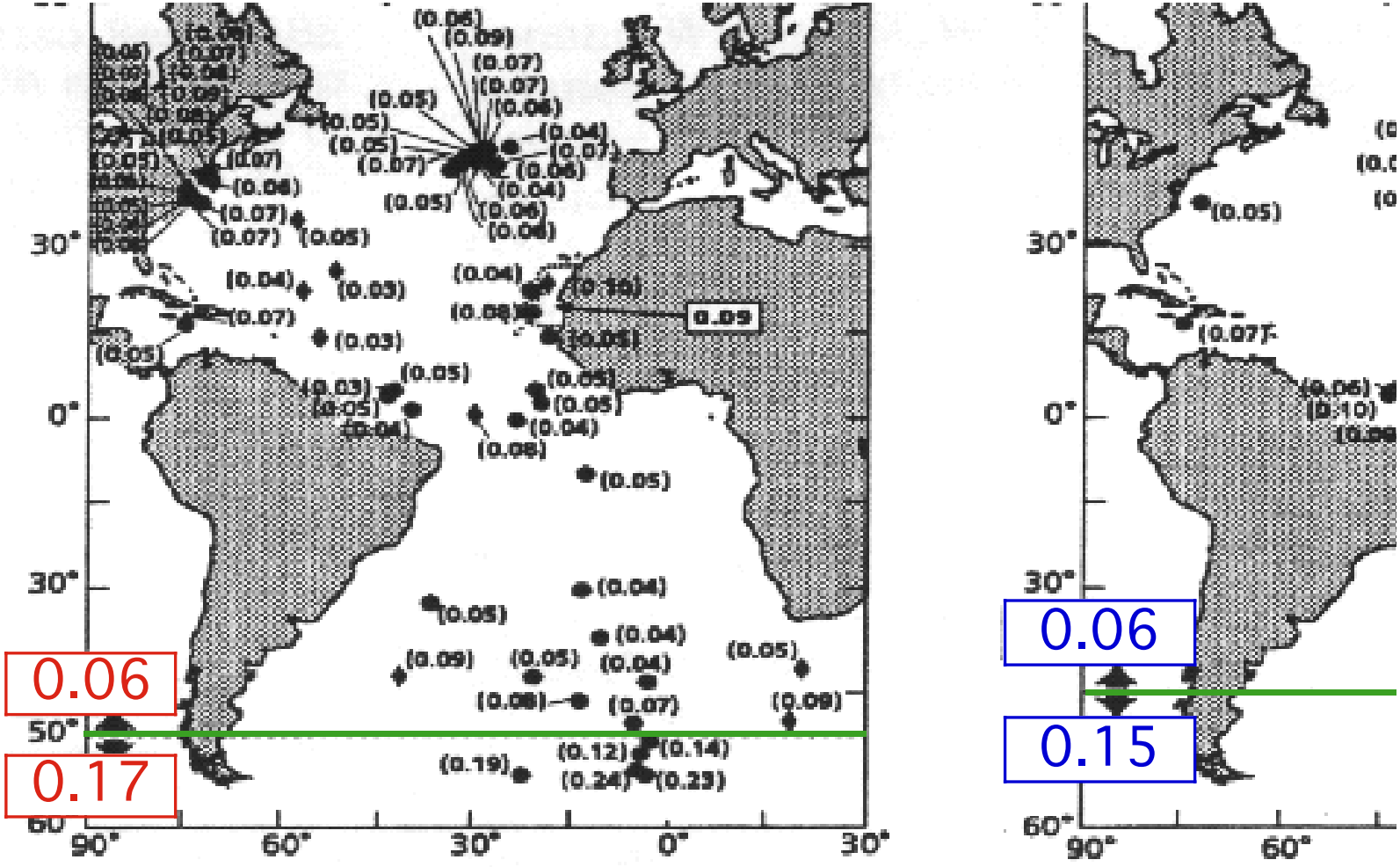
Low concentrations → lower flux to sediment → water column increase
Until an equilibrium profile is reached

Some real data: Western Atlantic



Deng et al. 2018

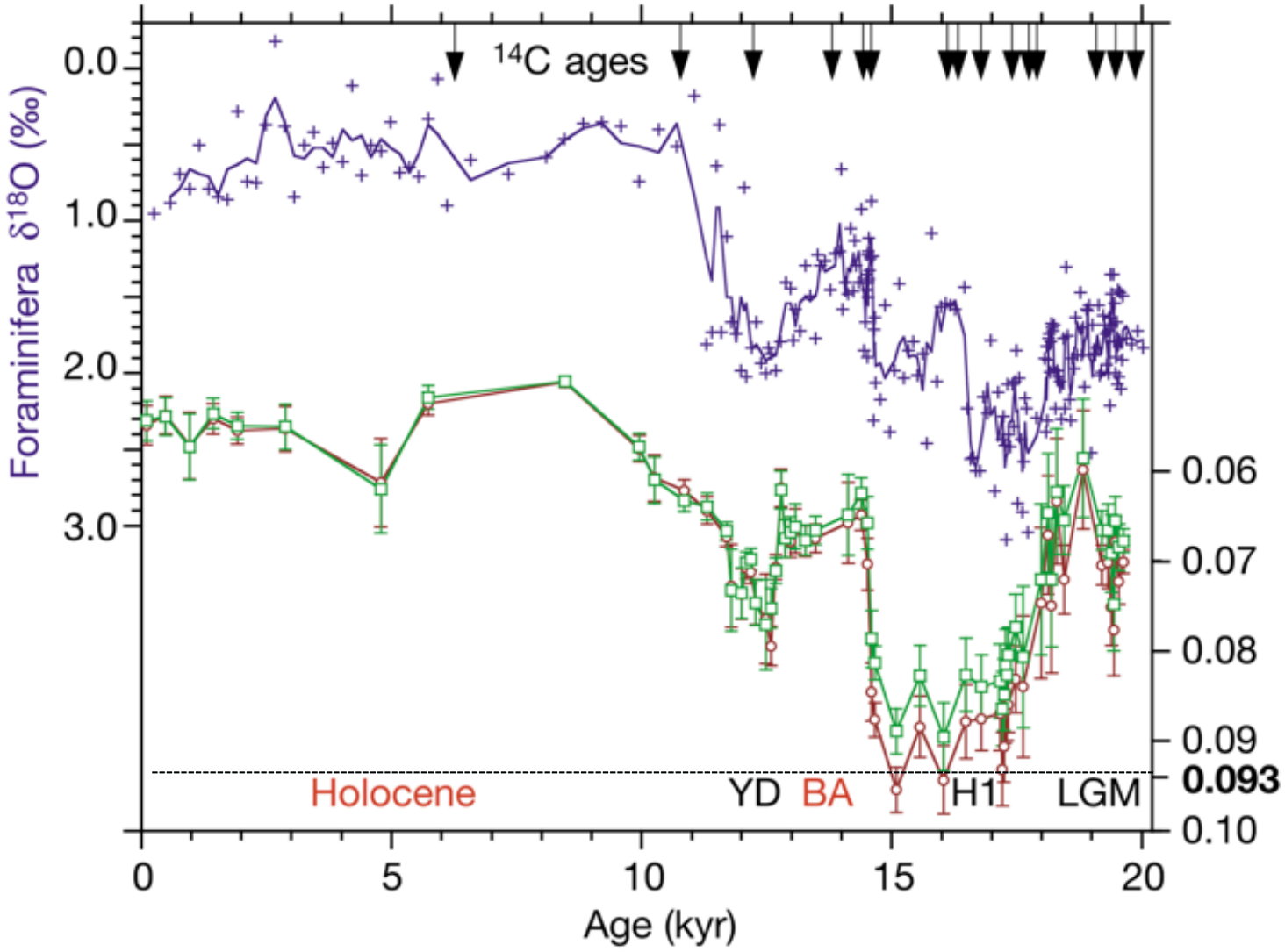
Time slice maps of $^{231}Pa/^{230}Th$



Compared $^{231}Pa/^{230}Th$ ratios with production ratio = 0.093

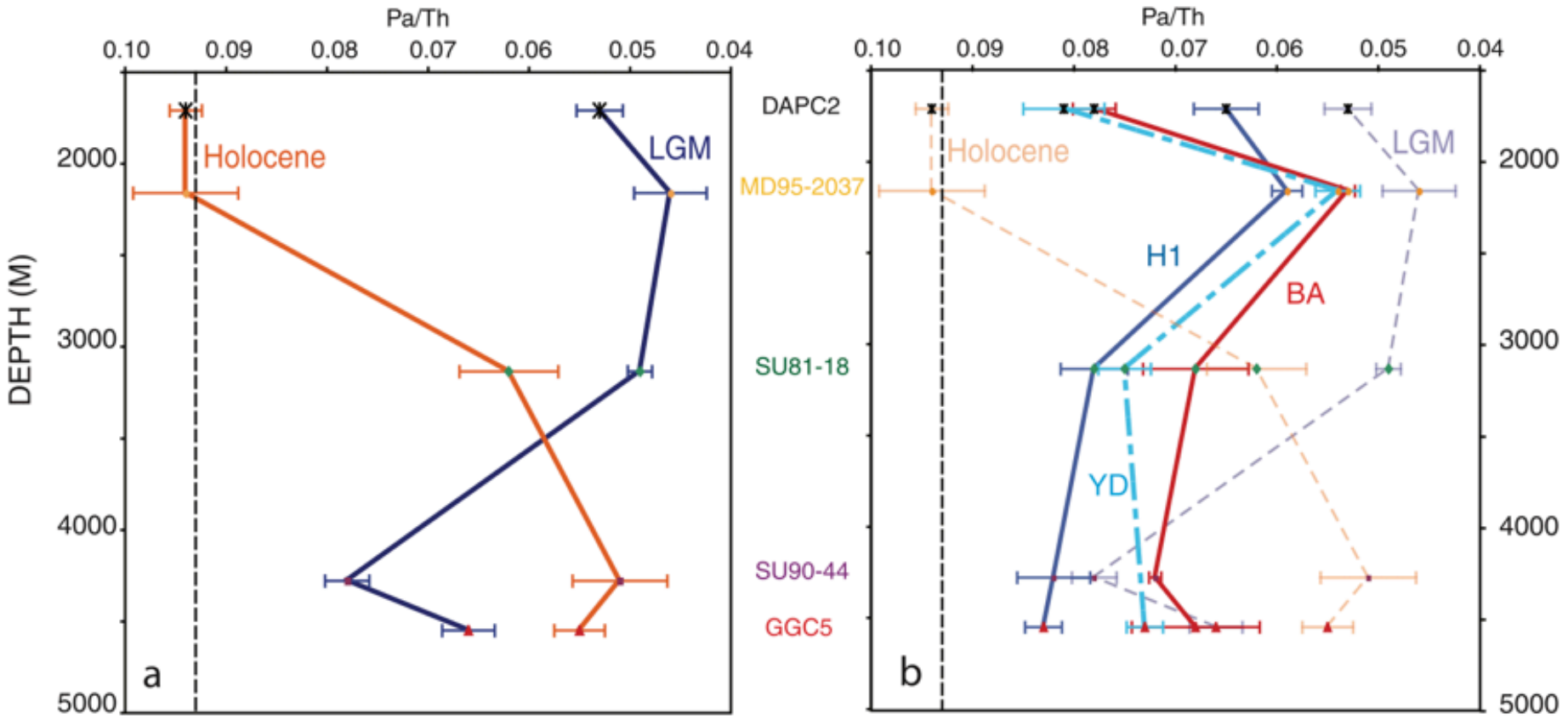
Yu et al. 1996

Time series of $^{231}Pa/^{230}Th$



McManus et al. 2004

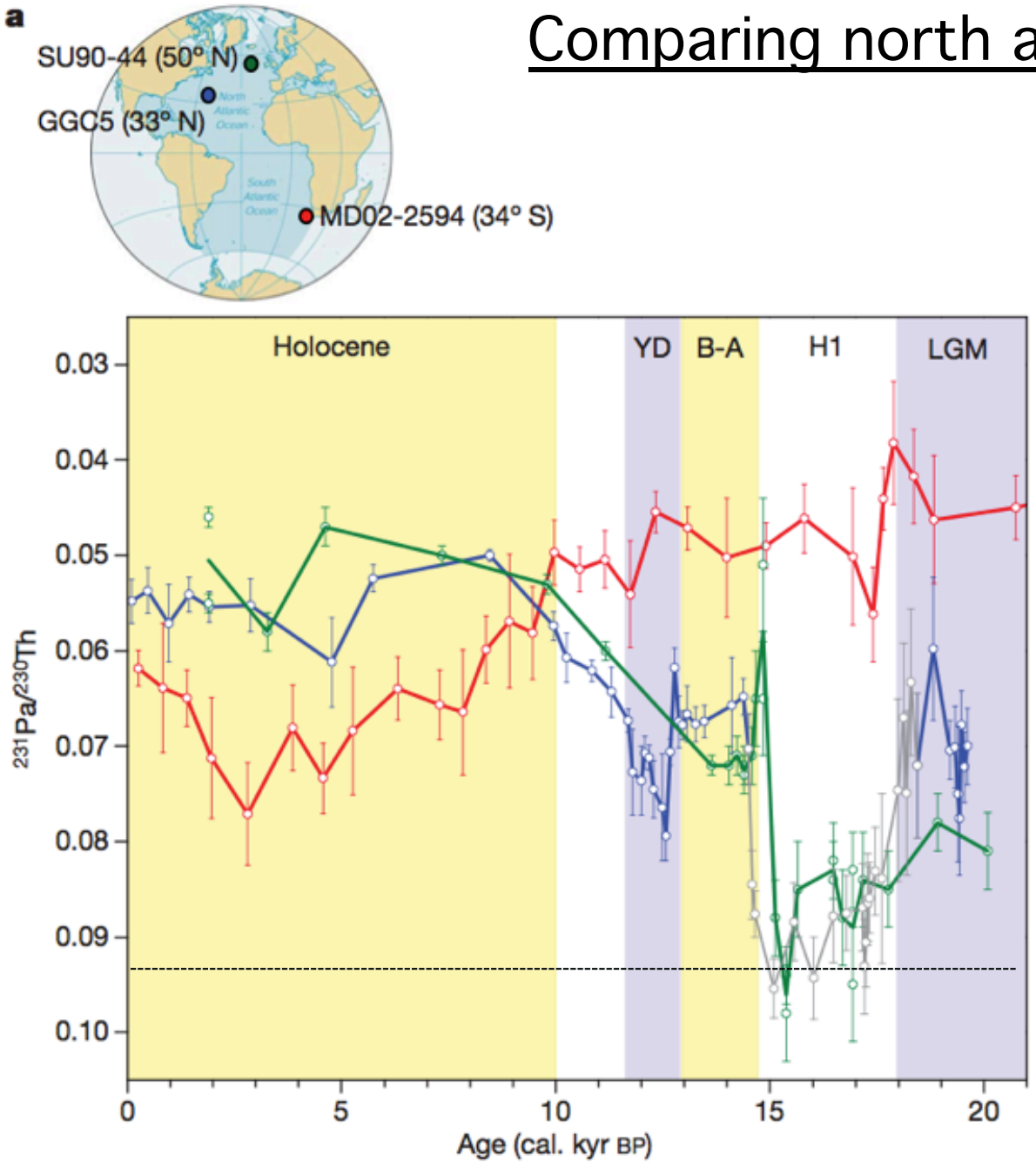
Depth resolved records



Relies on different behaviour in different waters

Gherardi et al. 2009

Comparing north and south Atlantic



Negre et al. 2010

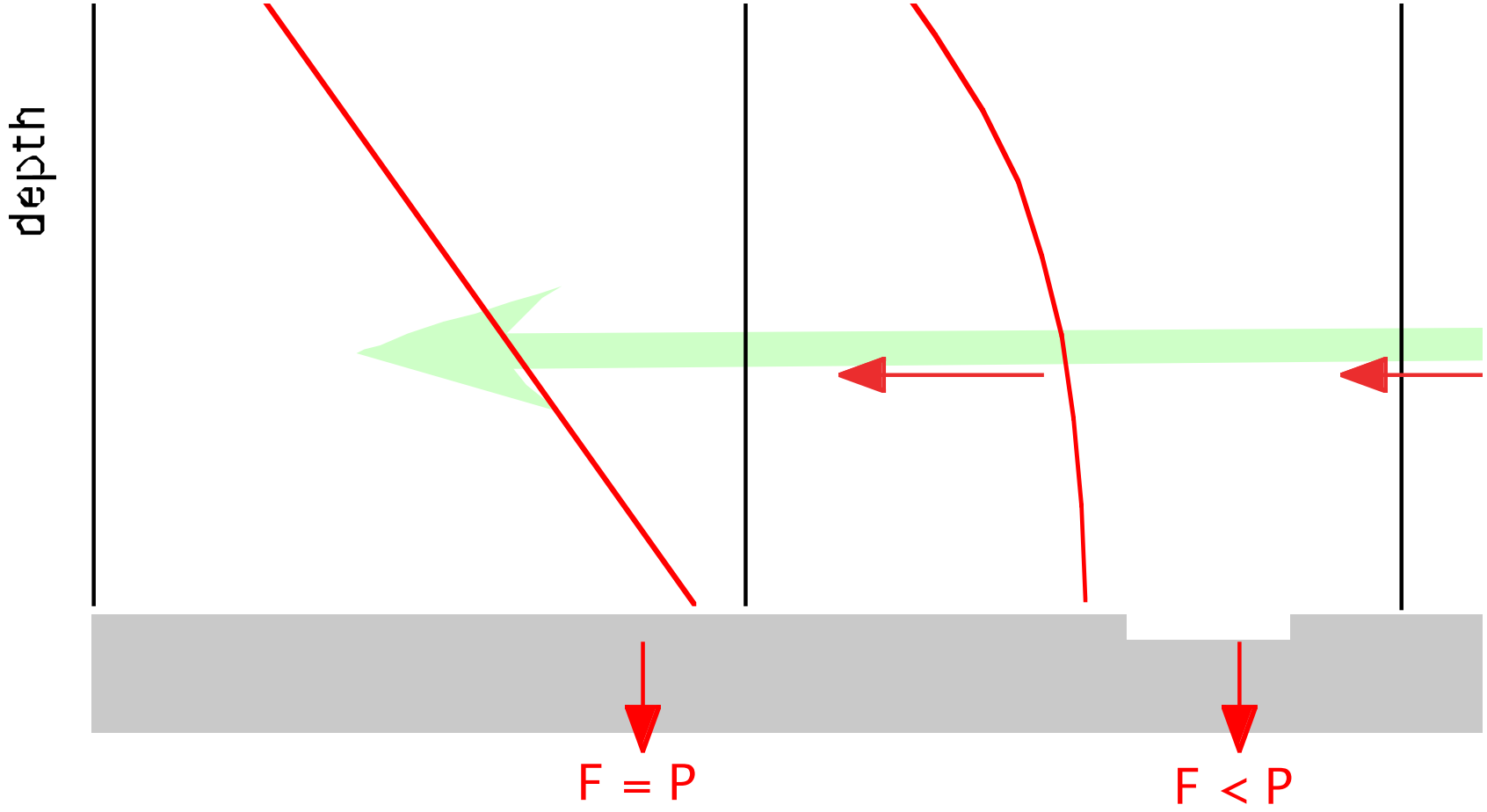
Two ways to connect sedimentary $^{231}Pa/^{230}Th$ to rate of circulation:

Model 1:

Basin Advection

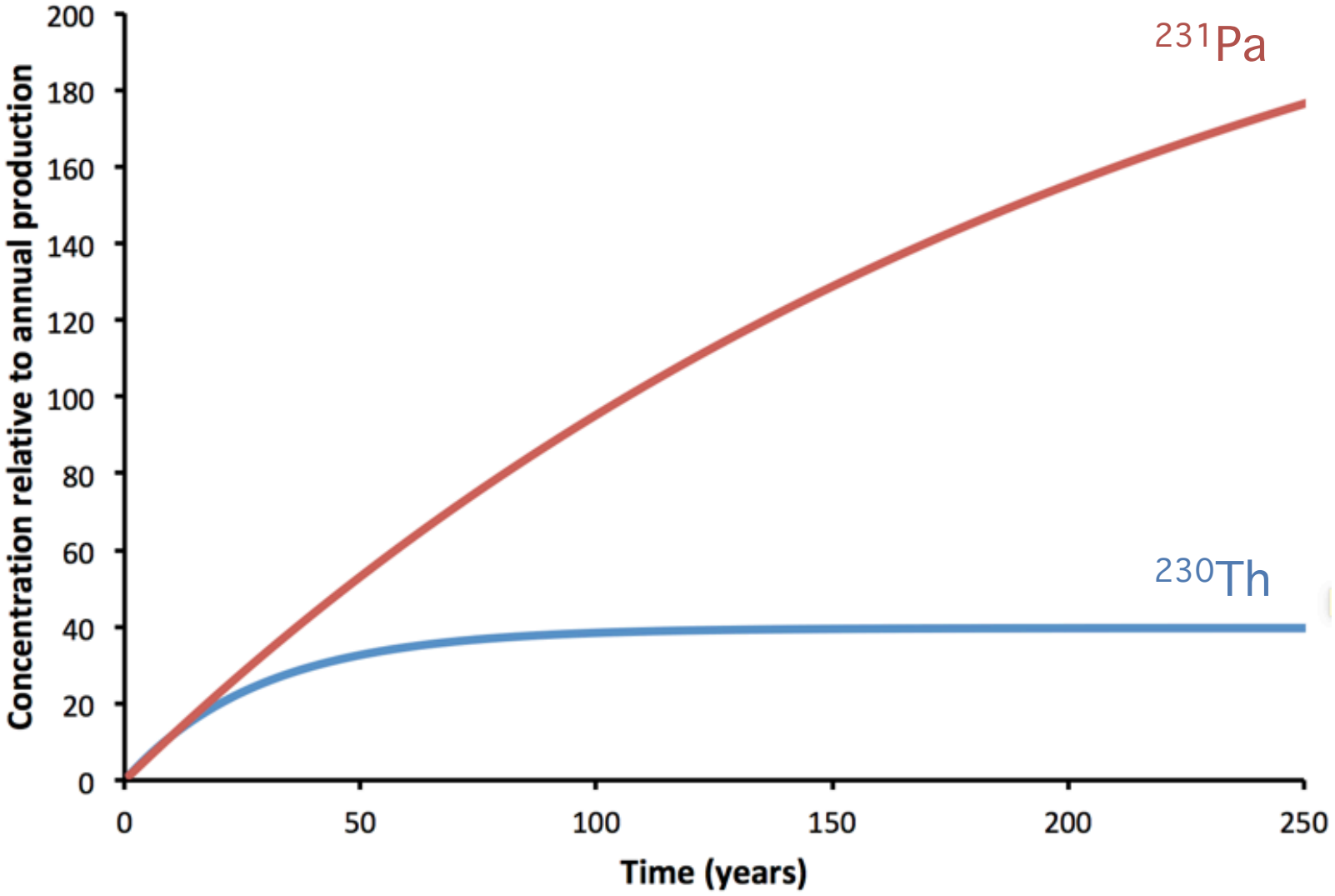
(e.g. Yu et al. 1996, Bradtmiller 2014)

Nuclide concentration with age

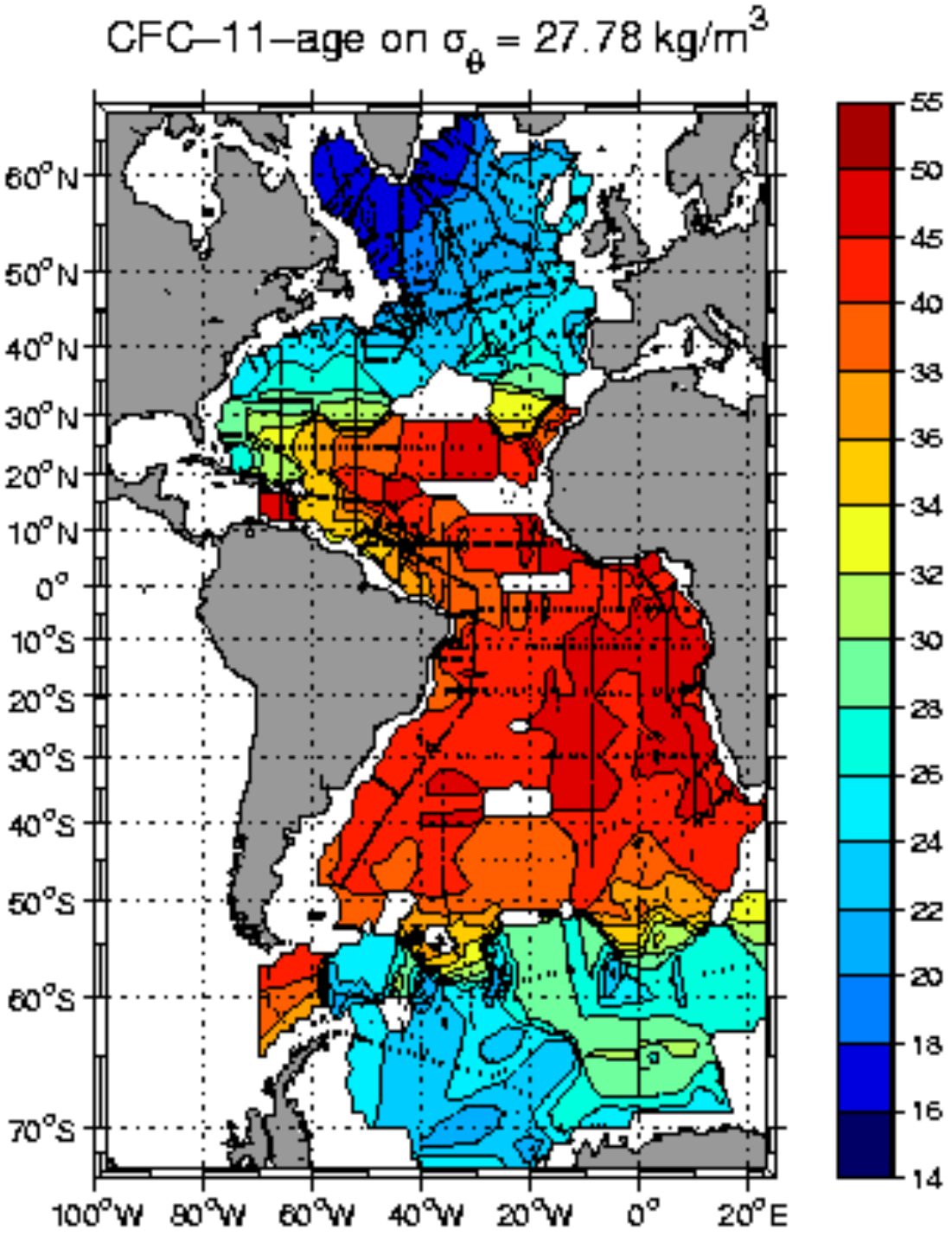


Low concentrations → lower flux to sediment → water column increase

Concentrations of nuclides in ageing waters



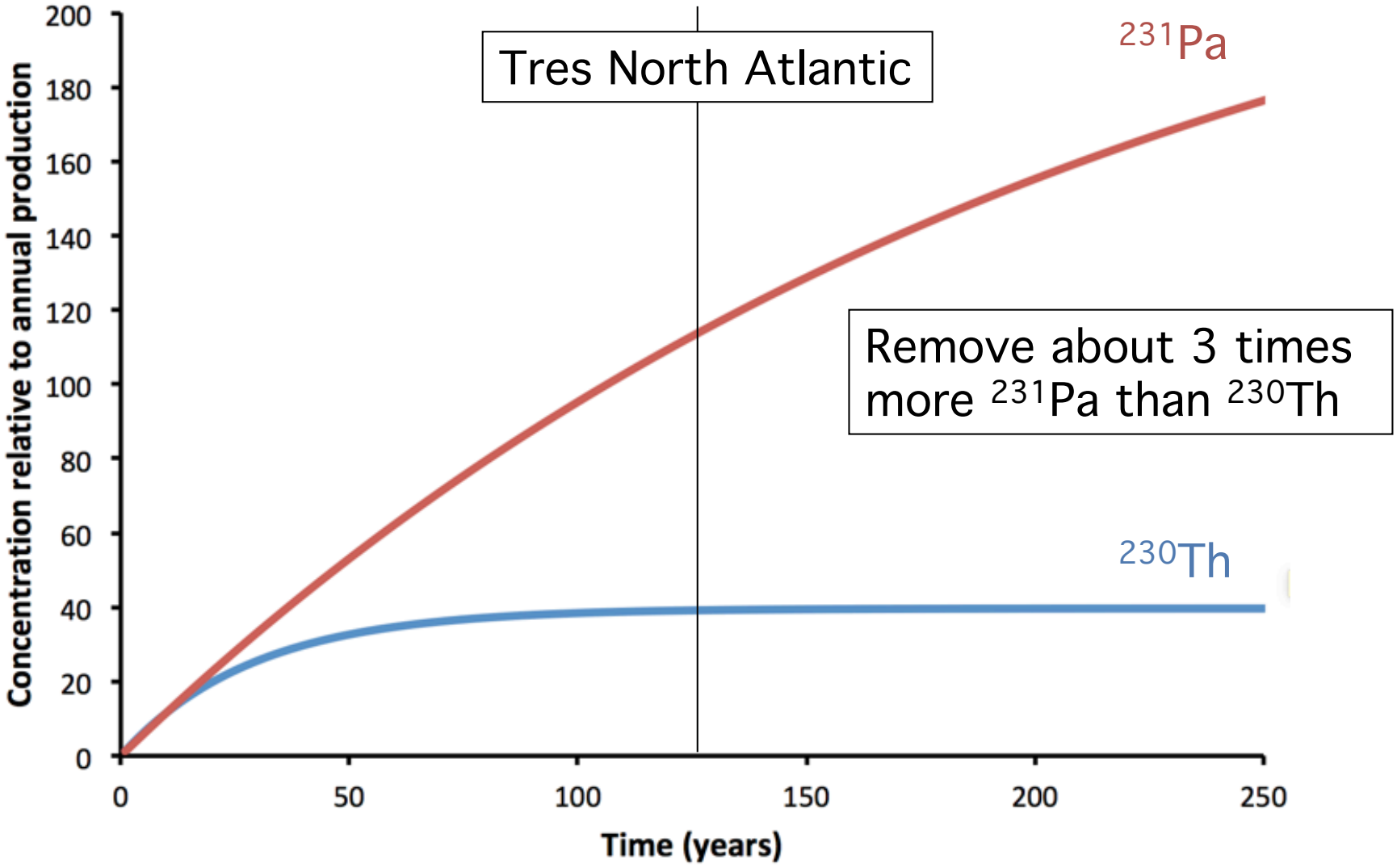
Waters leaving a basin remove more ^{231}Pa than ^{230}Th



Residence time of waters in Atlantic

Average Tres from water budgets ≈125 years

Concentrations of nuclides in ageing waters



Waters leaving a basin remove more ^{231}Pa than ^{230}Th

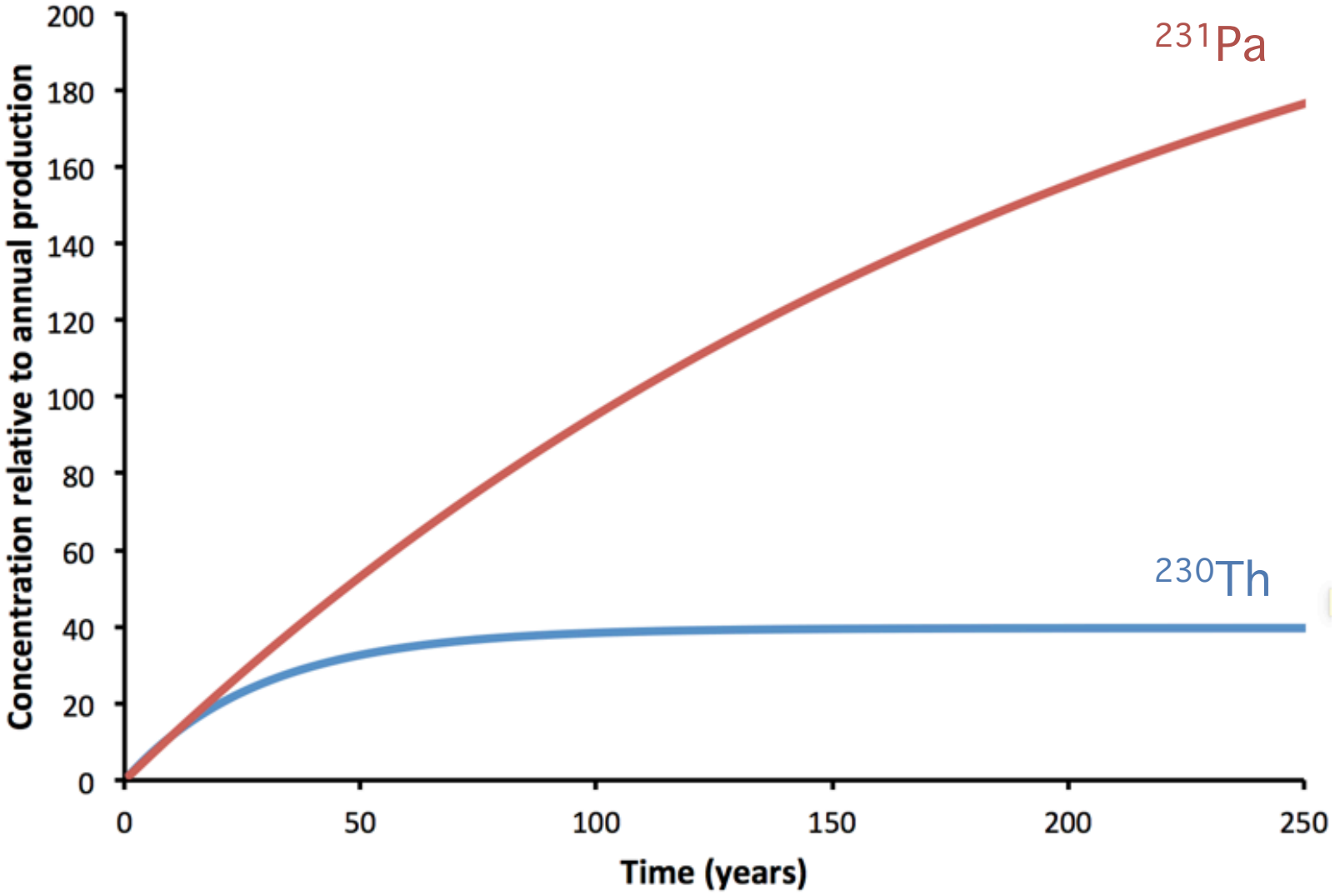
Two ways to connect sedimentary $^{231}Pa/^{230}Th$ to rate of circulation:

Model 2:

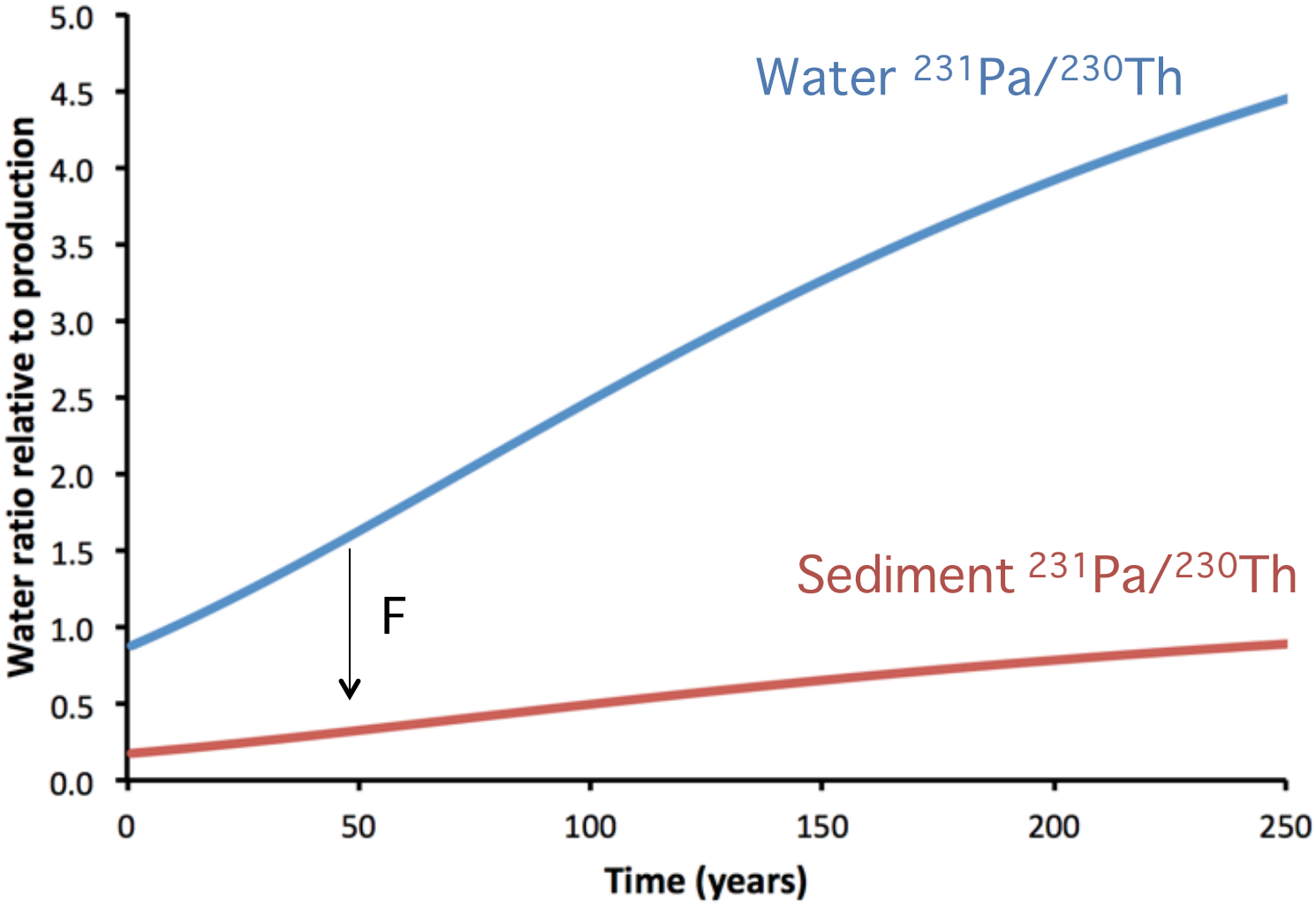
Chemical evolution

(e.g. Negre et al. 2010, Gherardi et al 2009)

Concentrations of nuclides in ageing waters



$^{231}Pa/^{230}Th$ ratio in aging waters

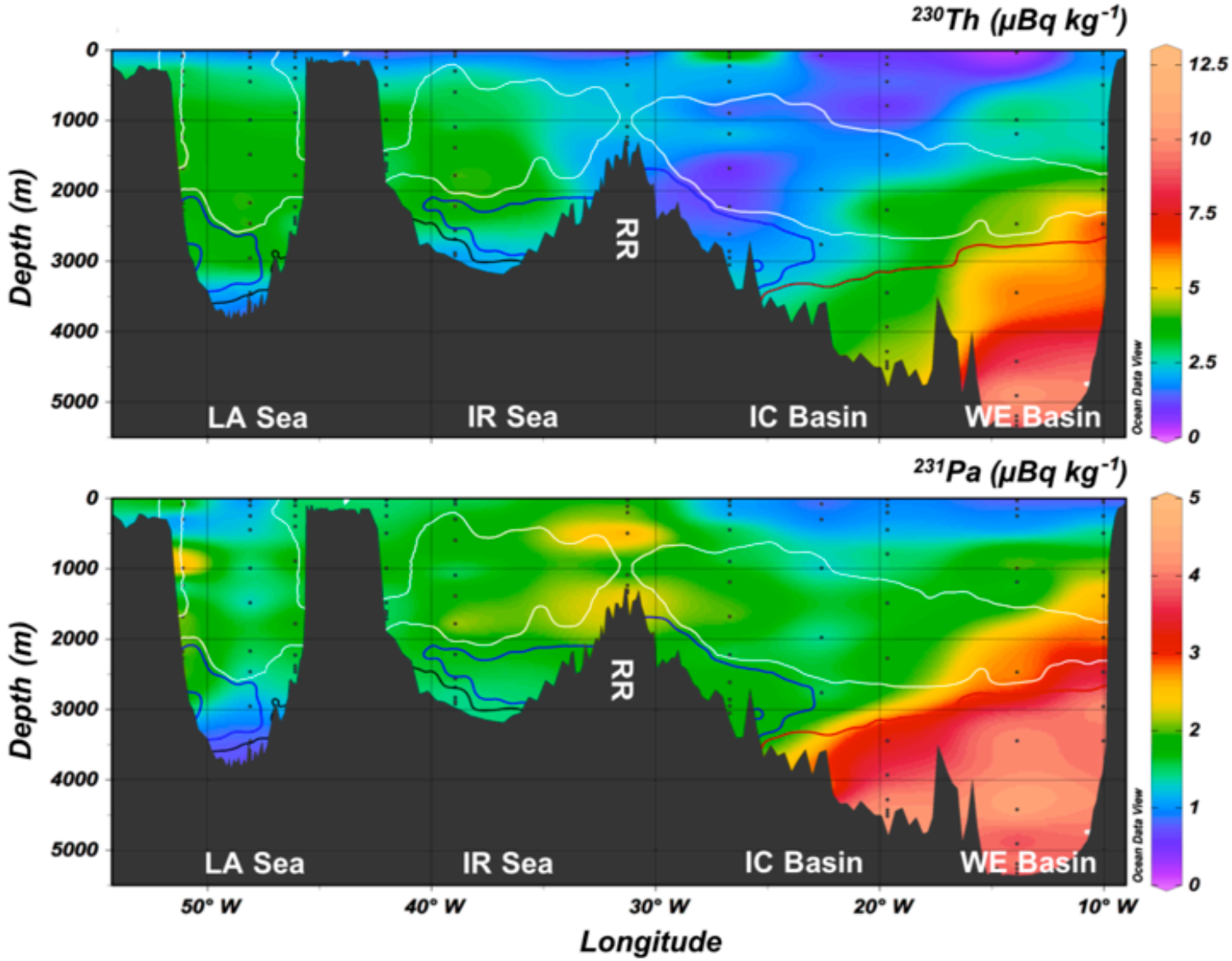


Sediments capture higher ratio as waters age
So strong ventilation leads to lower ratios

The basin advection model: Does it work in the modern?

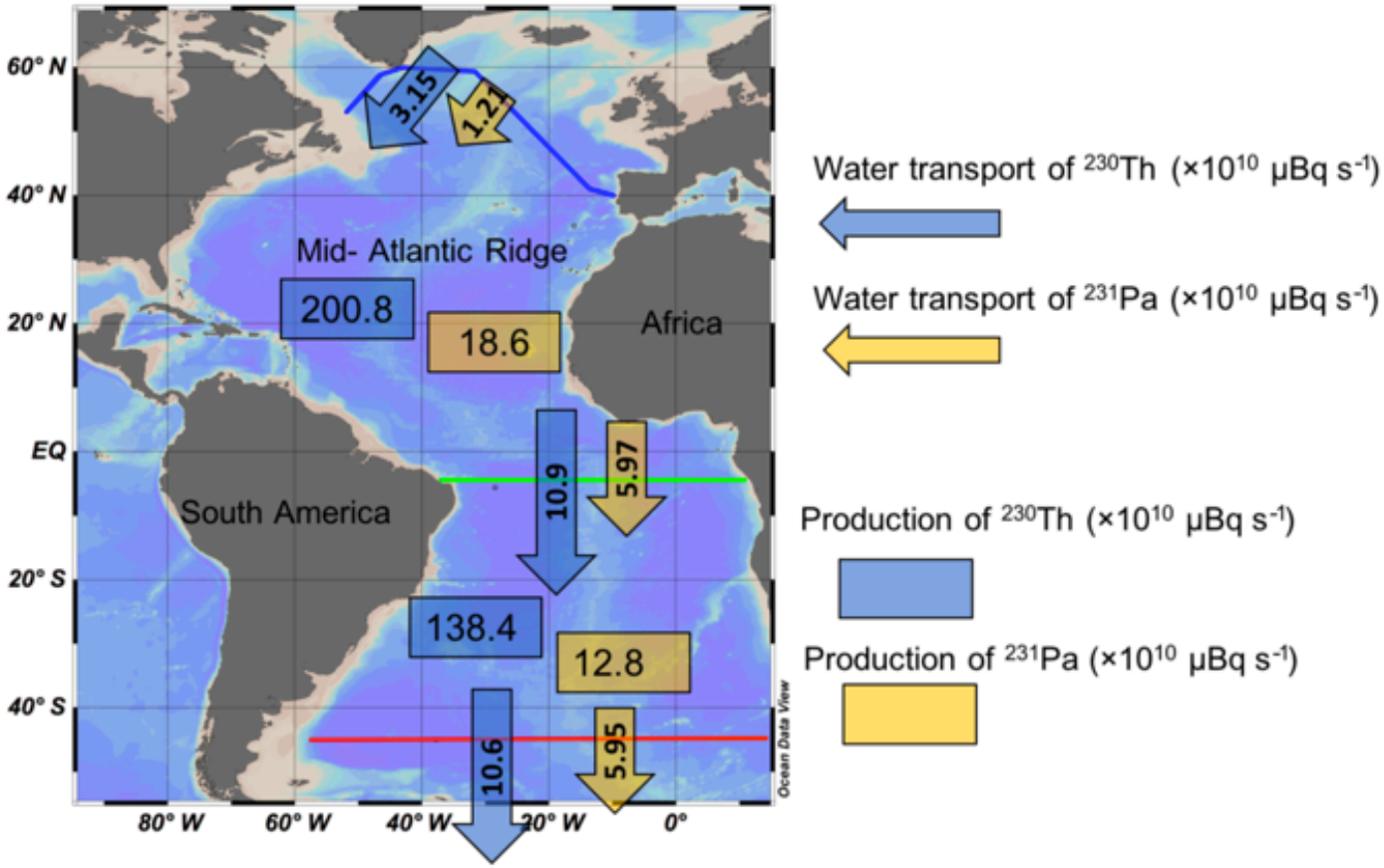
Budget for ^{230}Th and ^{231}Pa using GEOTRACES measurements and known water fluxes

GEOVIDE data completes the budget



Deng et al 2018

Complete budget for Atlantic basins



4% of ^{230}Th and 26% of ^{231}Pa are advected out of North Atlantic
Suggest average N. Atlantic sediment ^{231}Pa/^{230}Th ≈ 0.07
I.e. < 0.093 due to deep-water advection

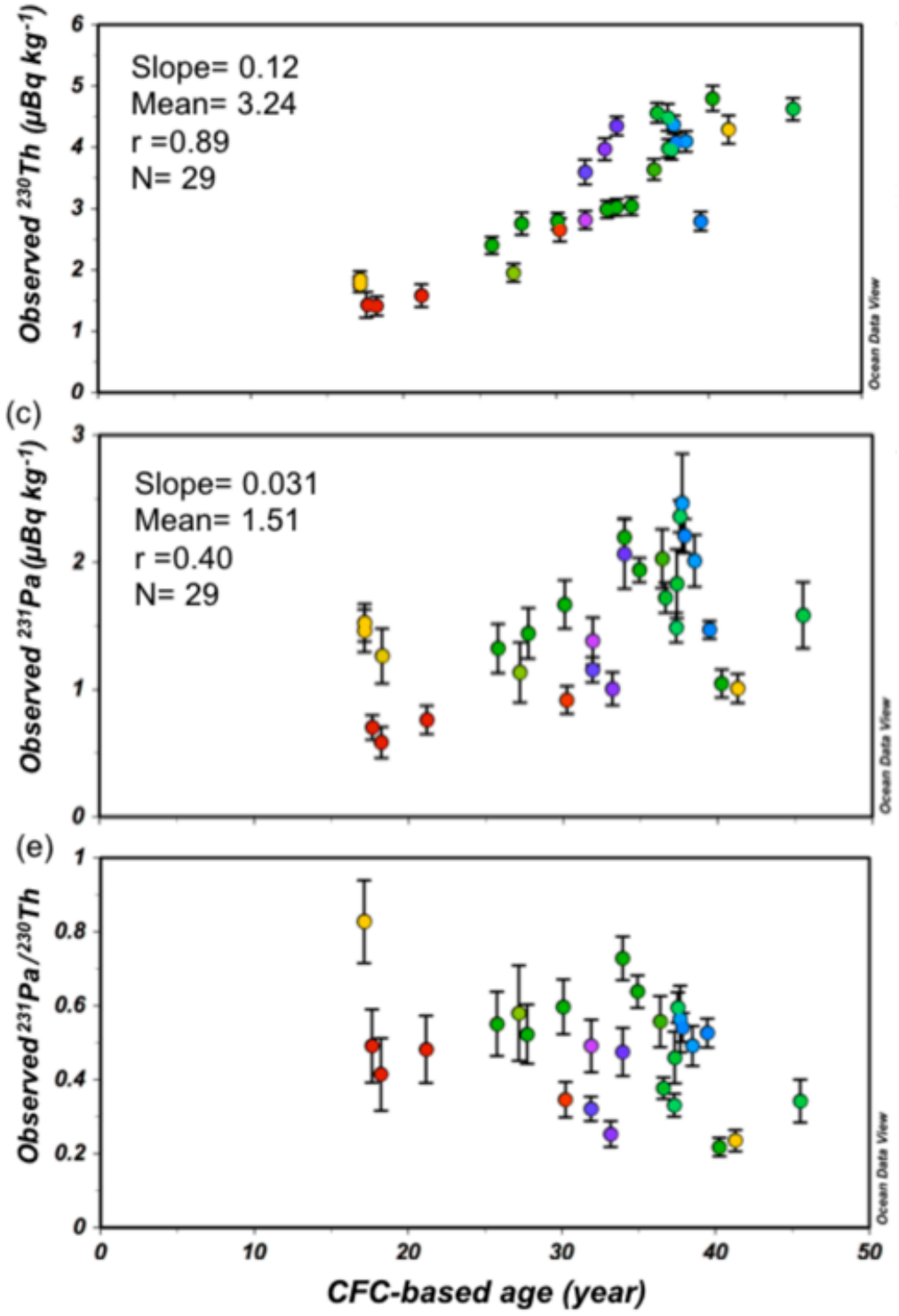
South Atlantic is very close to balance. Average sediment ^{231}Pa/^{230}Th expected to be ≈0.093

Deng et al 2018

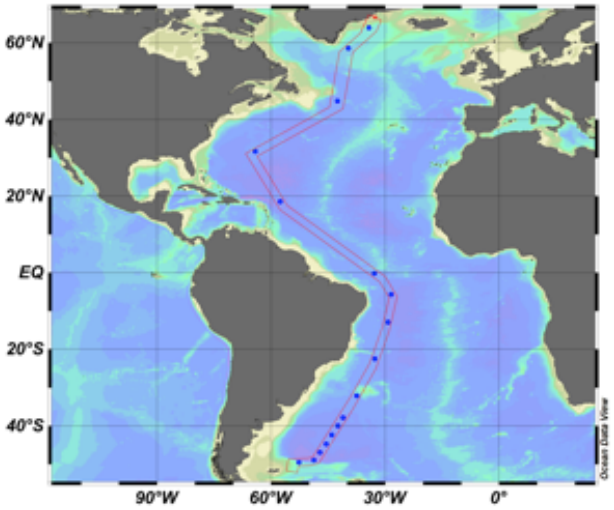
The chemical evolution model: Does it work in the modern?

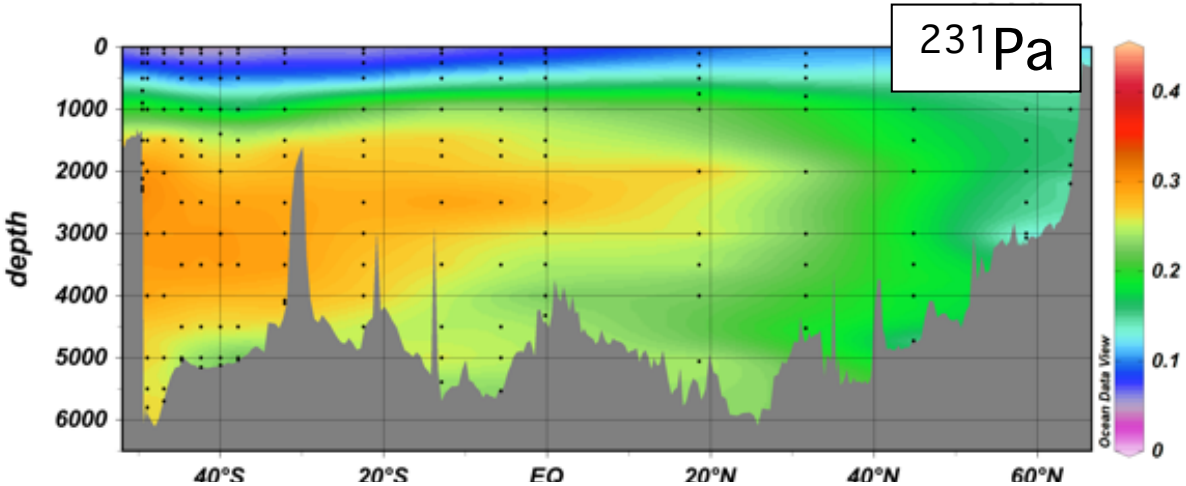
GEOVIDE data compared to CFC-derived ages:

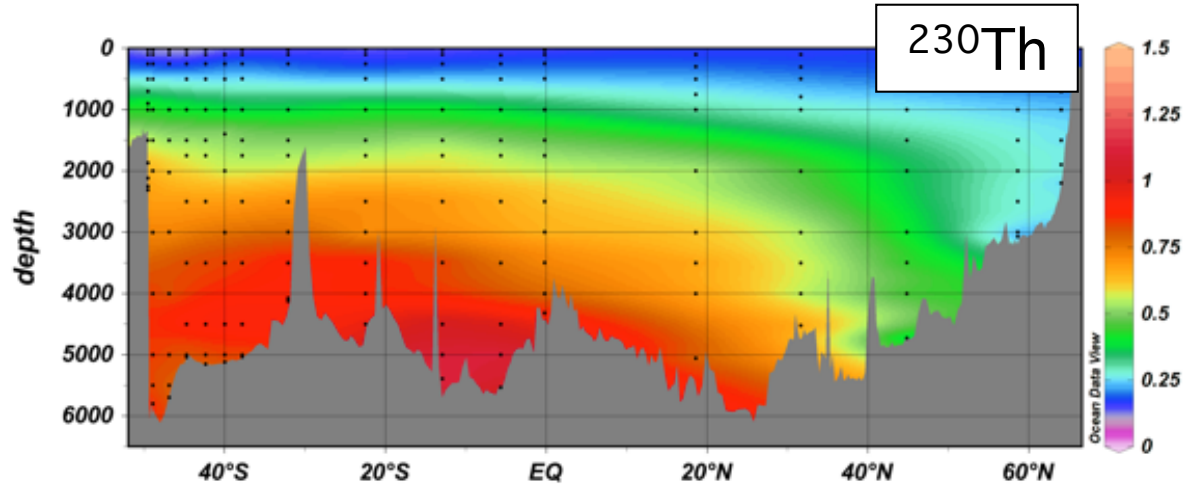
$^{231}Pa/^{230}Th$ does not increase with age

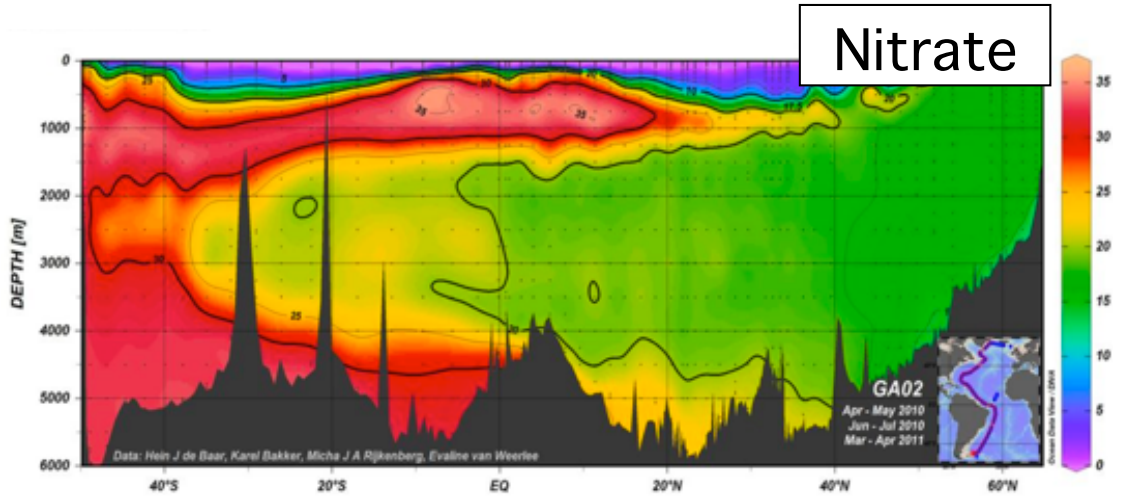


^{231}Pa and ^{230}Th with age of waters



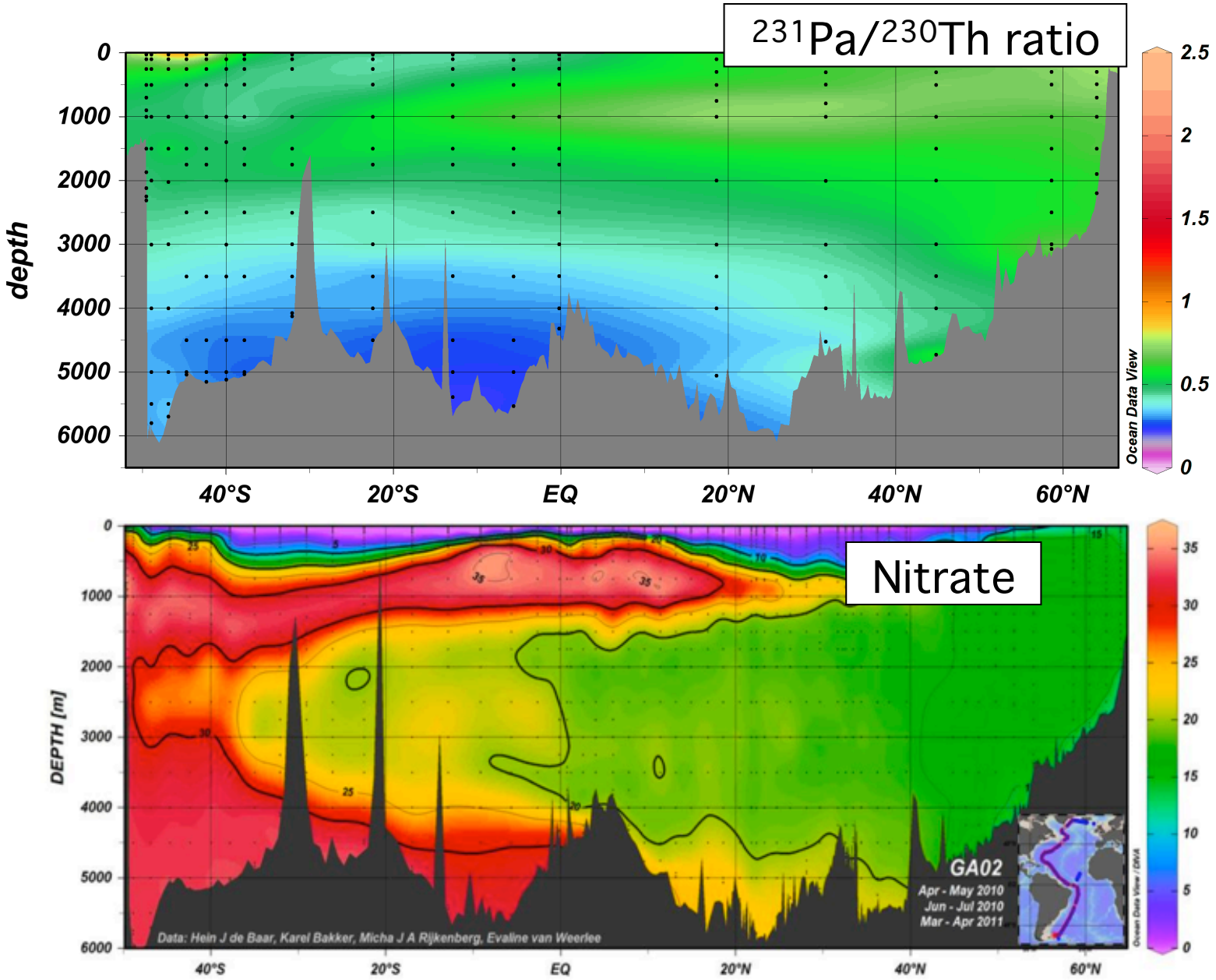






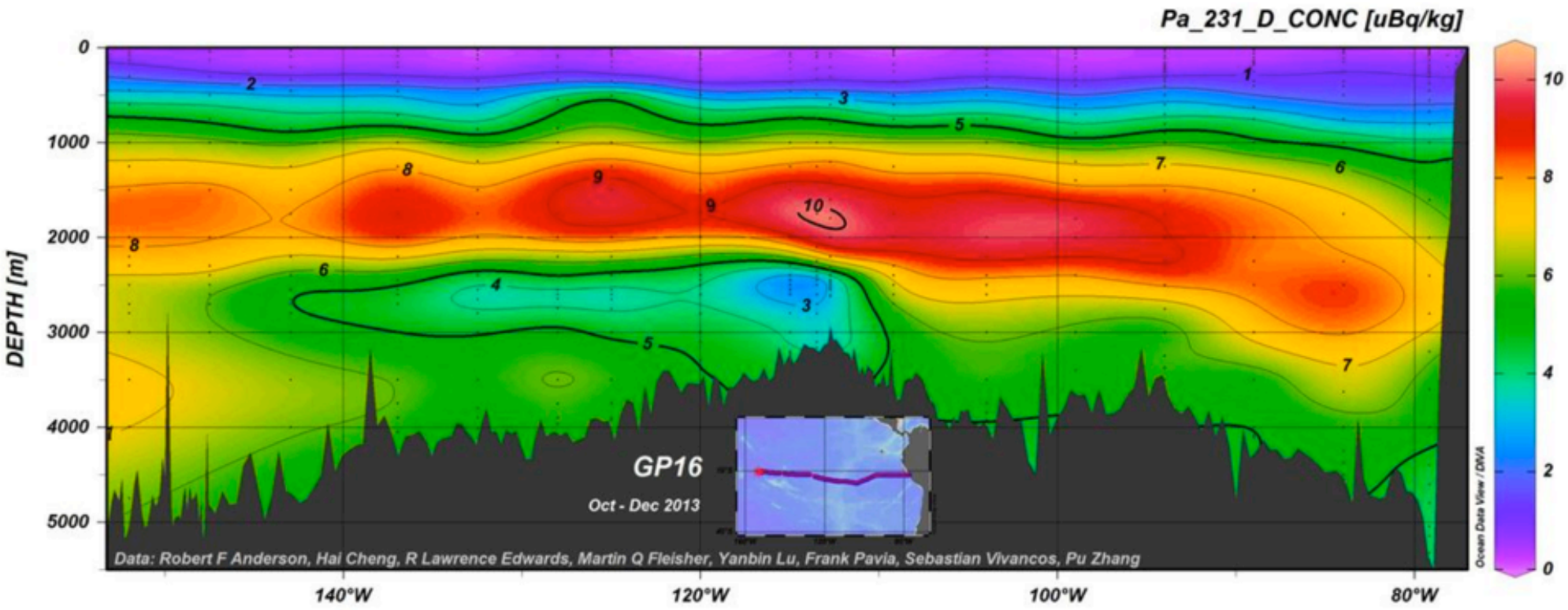
Deng et al. 2014
Kretschmer unpublished

No systematic relationship between Pa/Th and age



Mid water column maximum

A common feature, unrelated to age



In the modern ocean:

Model 1: Basin advection – passes

There is net advection of ^{231}Pa from the North Atlantic

Model 2: Chemical evolution – fails

Water masses do not have distinct Pa/Th ratios, and do not show clear evolution of the ratio with age

Limitations applying the basin advection model to the past

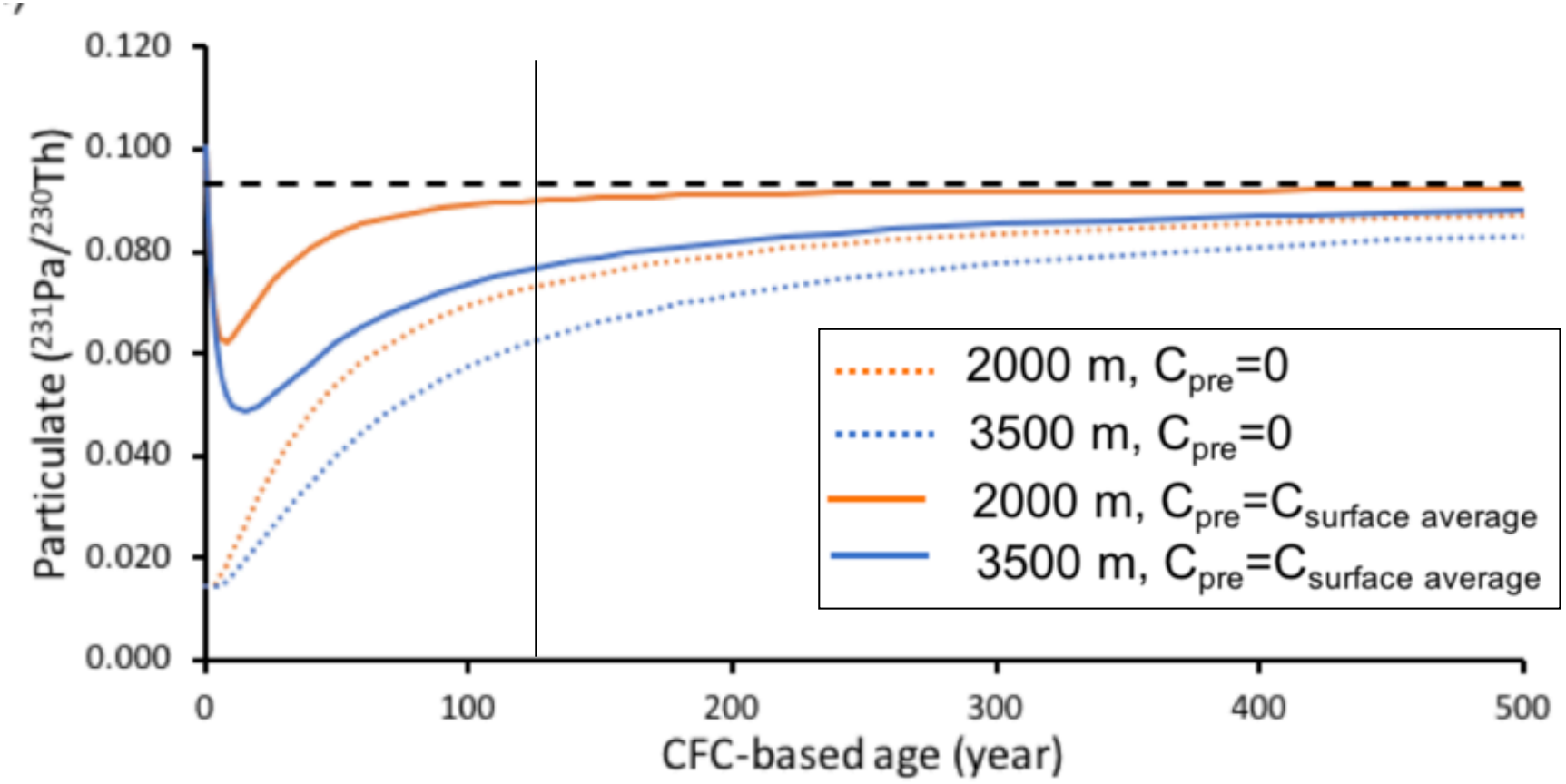
1. Core does not reflect whole basin
   (boundary scavenging; changes in productivity)

2. Change average F in basin
   (decrease F – sediment Pa/Th increases with no change in flow
   Suggested for H1 due to opal productivity)

3. Preformed values

4. Layered flow

Influence of preformed nuclides



Surface values have long-term impact on sedimentary Pa/Th

Deng et al 2018

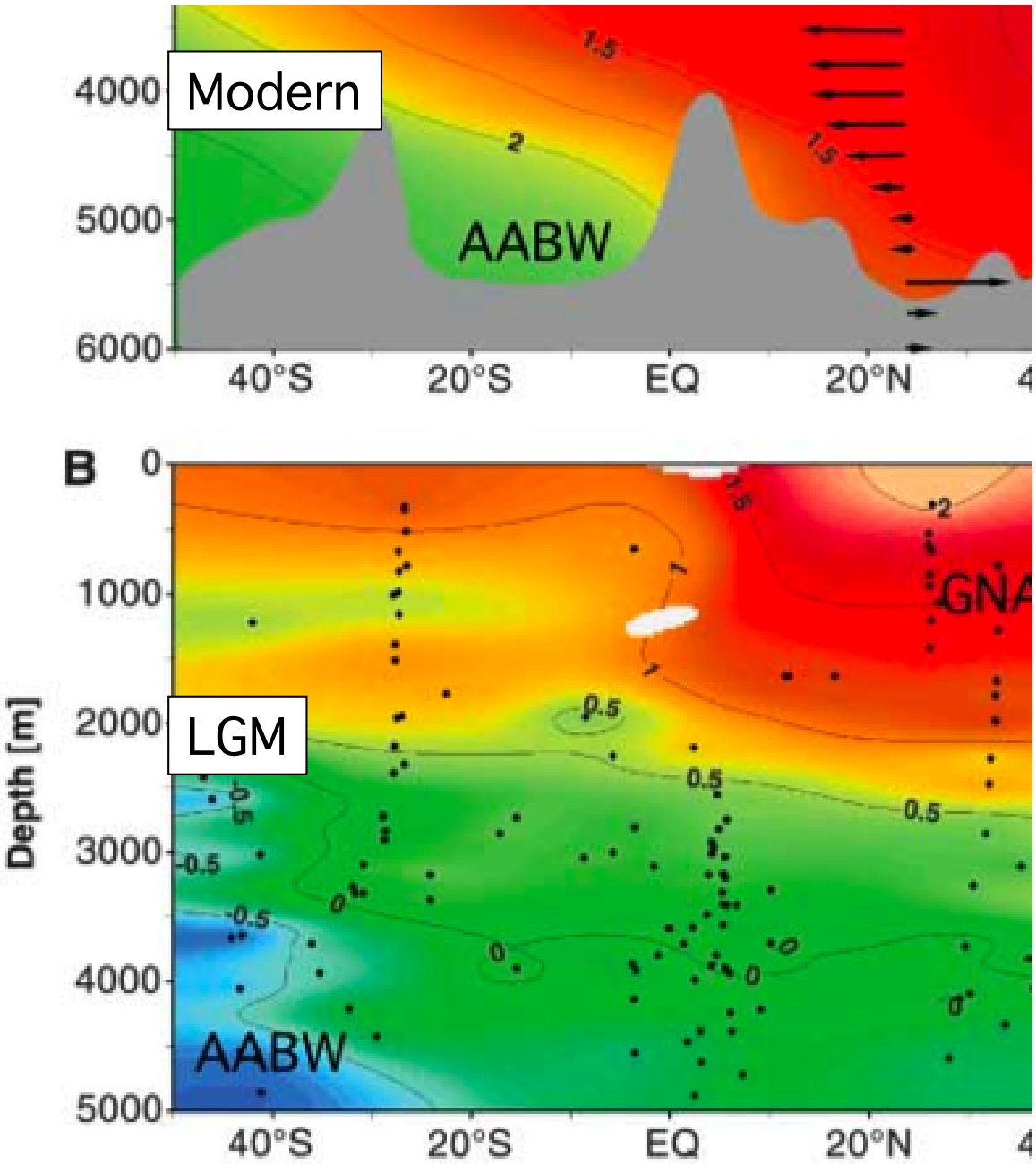
Limitations applying the basin advection model to the past

1. Core does not reflect whole basin
   (boundary scavenging; changes in productivity)

2. Change average F in basin
   (decrease F – sediment Pa/Th increases with no change in flow
   Suggested for H1 due to opal productivity)

3. Preformed values

4. Layered flow



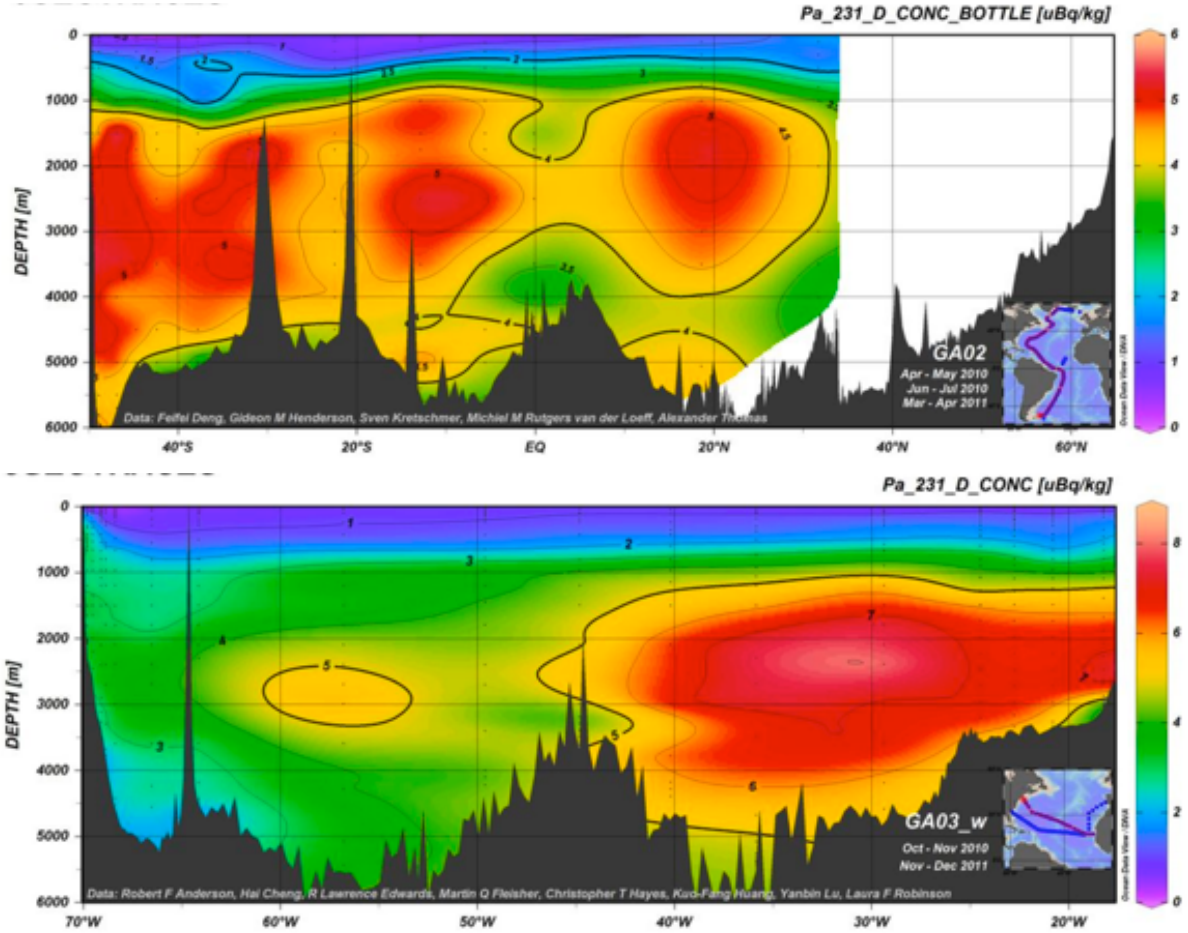
Past North Atlantic not always flushed by single water mass

e.g. LGM – layered flow

Deep water flowing into basin, intermediate water flowing out
Divide at ≈2.5 km

Lynch-Stieglitz et al. 2007

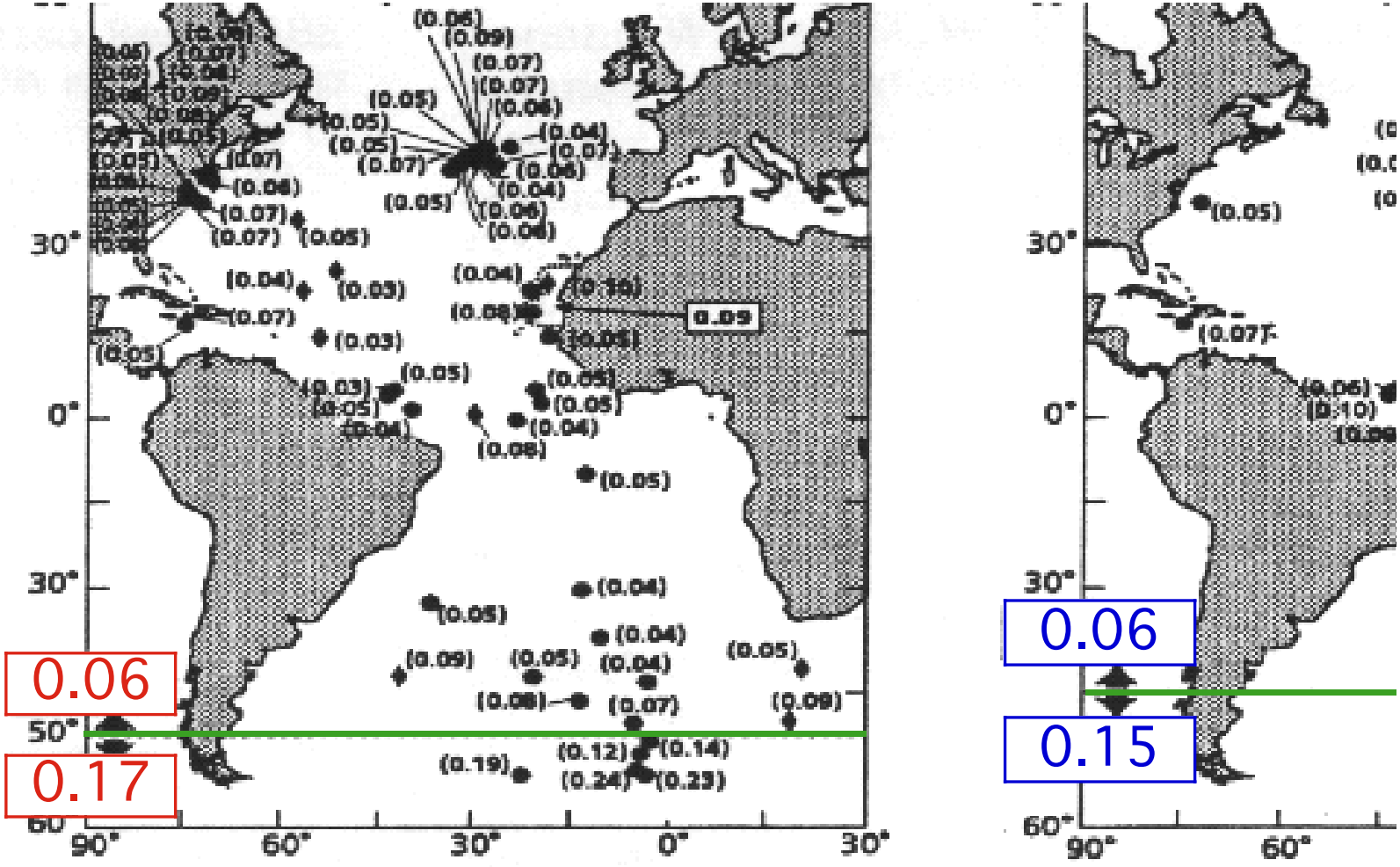
Basin advection balance for LGM



Today, ^{231}Pa concentrations similar above and below 2.5km

To maintain same North Atlantic Pa/Th at LGM as today requires same southward flux of water
Plus additional southward flux for any northward deep flux.

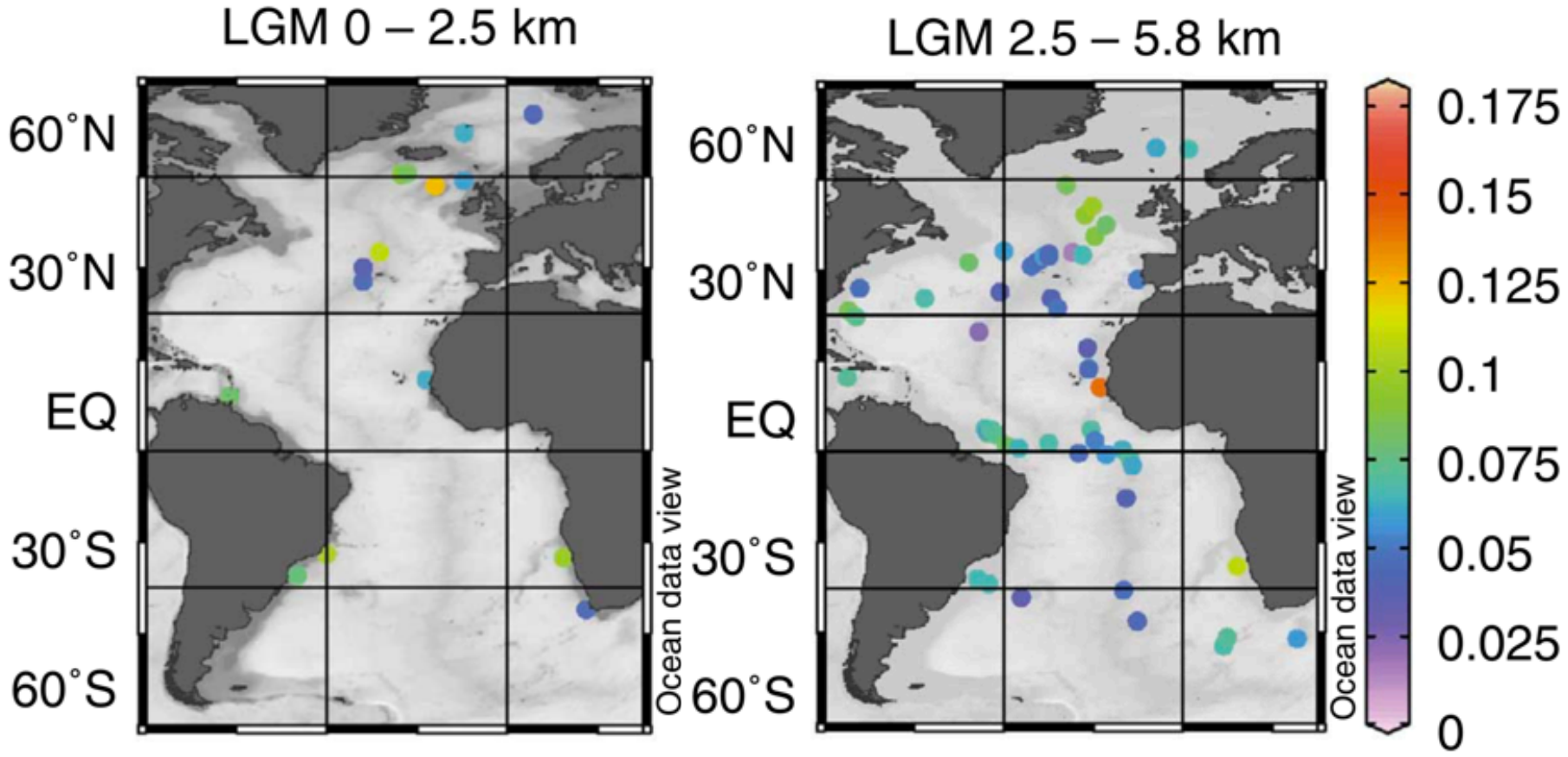
Time slice maps of $^{231}Pa/^{230}Th$



Compared $^{231}Pa/^{230}Th$ ratios with production ratio = 0.093

Yu et al. 1996

Atlantic LGM Pa/Th ratios



Latest compilation continues to support Yu et al.
Average LGM similar to Holocene

Bradtmiller et al. 2014

Summary

Modern net advection of ^{231}Pa from Atlantic indicates potential for Pa/Th as a proxy for deep-water flow at basin scale

Lack of any clear relationship of Pa/Th with water mass or age in GEOTRACES data indicates that chemical evolution of waters cannot be used to constrain rate

Depth resolved Pa/Th records, and comparison of Pa/Th from different basins are challenging, unless they can be interpreted in terms of basin advection

Challenges

Do we believe that intermediate water flux out of North Atlantic was greater than total NADW flux today?

If not, where is the missing ^{231}Pa in the North Atlantic?

What is the impact of surface water Pa and Th on North Atlantic balance (both for advection, and as preformed concentrations)?

Can we constrain average North Atlantic F values for past times?

Where is the missing ^{231}Pa in South Atlantic?

What processes control ^{231}Pa in the water column (e.g. the mid-water maximum)?