Modelling the impact of climate change on the carbon cycle: Redfield and non-Redfield models

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Multi-elemental models: why bother?

- flexible ratios permit decoupling of photosynthesis and cell growth under high-light, low nutrient conditions

- carbon cycle is primary interest, and fixed-ratio models perform poorly under these environmental conditions

- relative availability of different nutrient elements (e.g., N, P, Fe) may change over time

CRM = Constant Ratio Model

Redfield stoichiometry for phytoplankton, grazers, and production of DOM; diagnostic chlorophyll

VRM = Variable Ratio Model

cellular-regulation photosynthesis model (Geider et al., 1998) with Redfield upper limits for N and P cell quotas; prognostic chlorophyll

Both have:

- **simultaneous N, P, light limitation of phytoplankton growth**
- **dynamic pools of DOC, DON, and DOP**
- **carbon chemistry; air-sea exchange of CO_2 and O_2**
- **parameterized N_2 fixation**

Model domain:

- **Station ALOHA (22°45'N, 158°W)**
- **1D (depth-time) mixed layer model (Price et al., 1986) model; 500 m domain with 1 m vertical resolution**

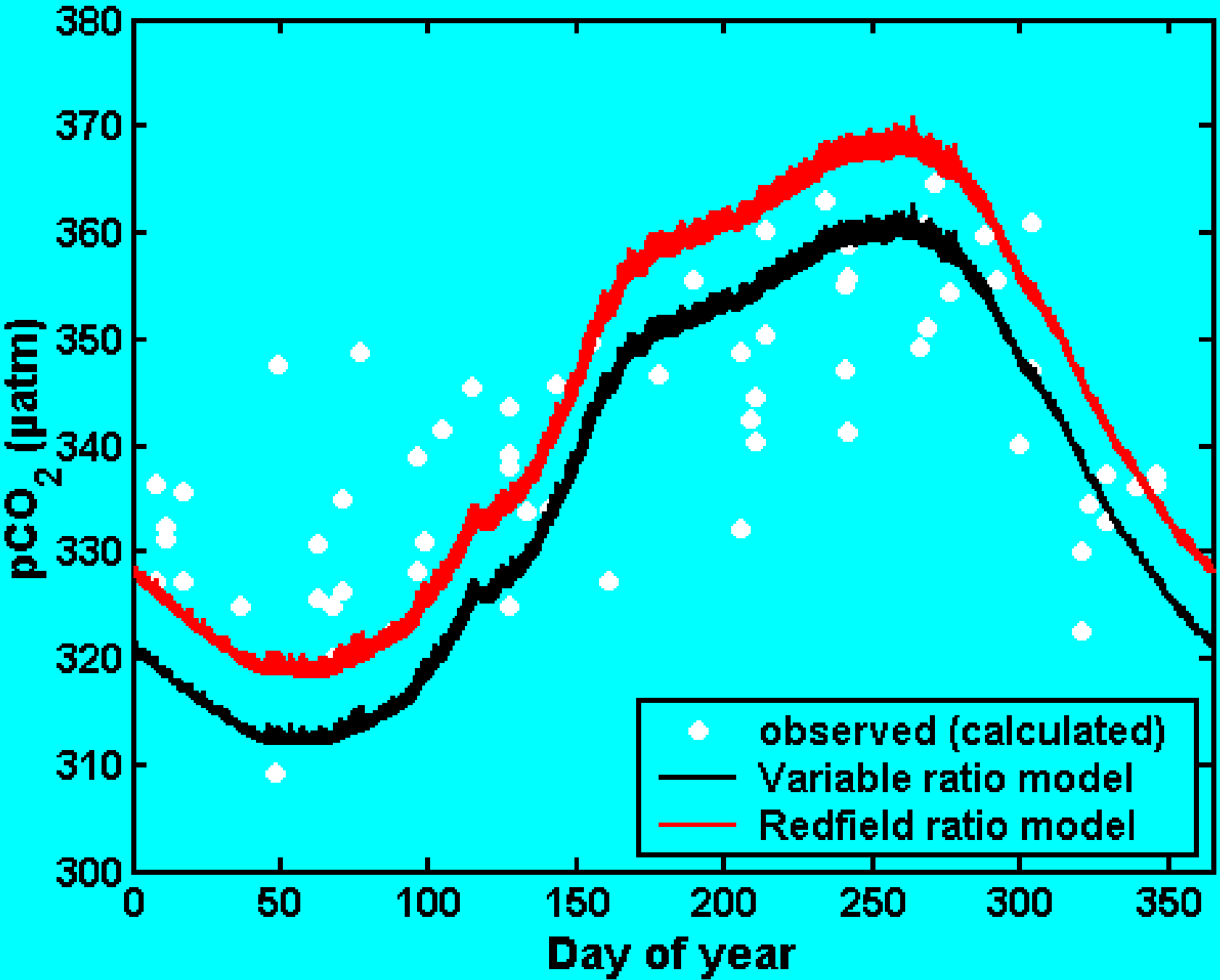
Carbon fluxes in CRM and VRM

Model	Forcing	PP	NCP	Export (sinking)	Export (mixing)	Air-sea flux
CRM	Climatology	11.0	1.4	1.0	0.76	-0.32
	Interannual	11.1	1.5	1.0	0.77	0.12
	Interannual + 1988 aCO_2					-0.24
VRM	Climatology	36.1	2.7	1.2	0.82	0.44
	Interannual	40.4	2.9	1.3	0.91	1.05
	Interannual + 1988 aCO_2					0.68
Observed		38.6	7.0	2.4	2.4	2.1
Source		Karl	Quay	Karl	Emerson	Quay

Sources: Karl et al., 1996, DSRII 43: 539;

Emerson et al., 1997, Nature 389: 951;

Quay and Stutsman, 2003, DSR I 50: 1045


380
370
360
350
340
330
320
310
300
0
50
100
150
200
250
300
350
pCO2 (µatm)
Day of year
observed (calculated)
Variable ratio model
Redfield ratio model

What have we learned?

- export is generally lower than observationally-based estimates, but higher in VRM than CRM

- ocean CO_2 uptake consistently higher in VRM

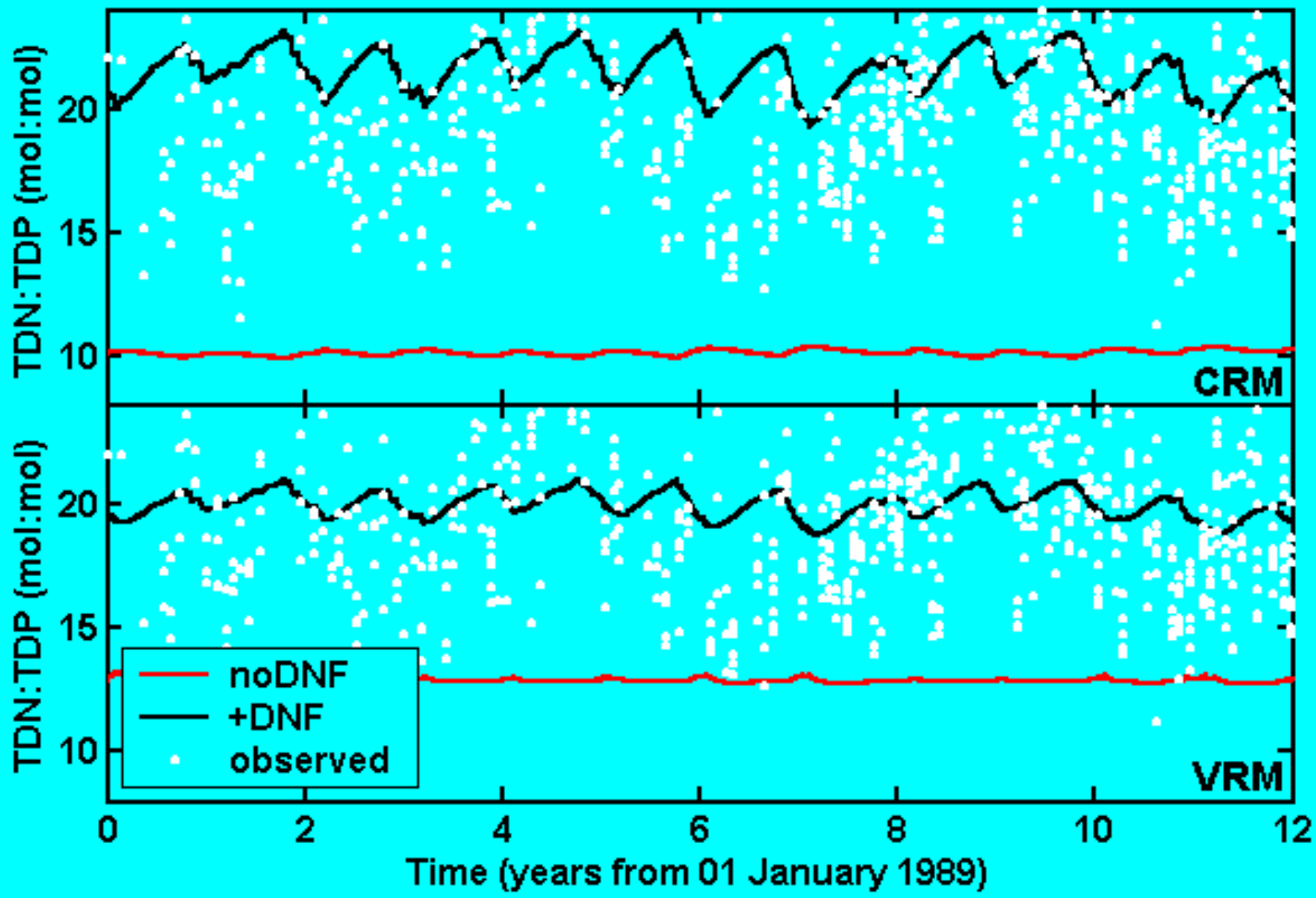
- there is an upper limit to stimulation of export by new N ("P-sparing" effect saturable)

What have we ignored?

- variability, regulation of N_2 fixation and calcification

- N_2 fixation, alkalinity estimated from observations collected since 1988

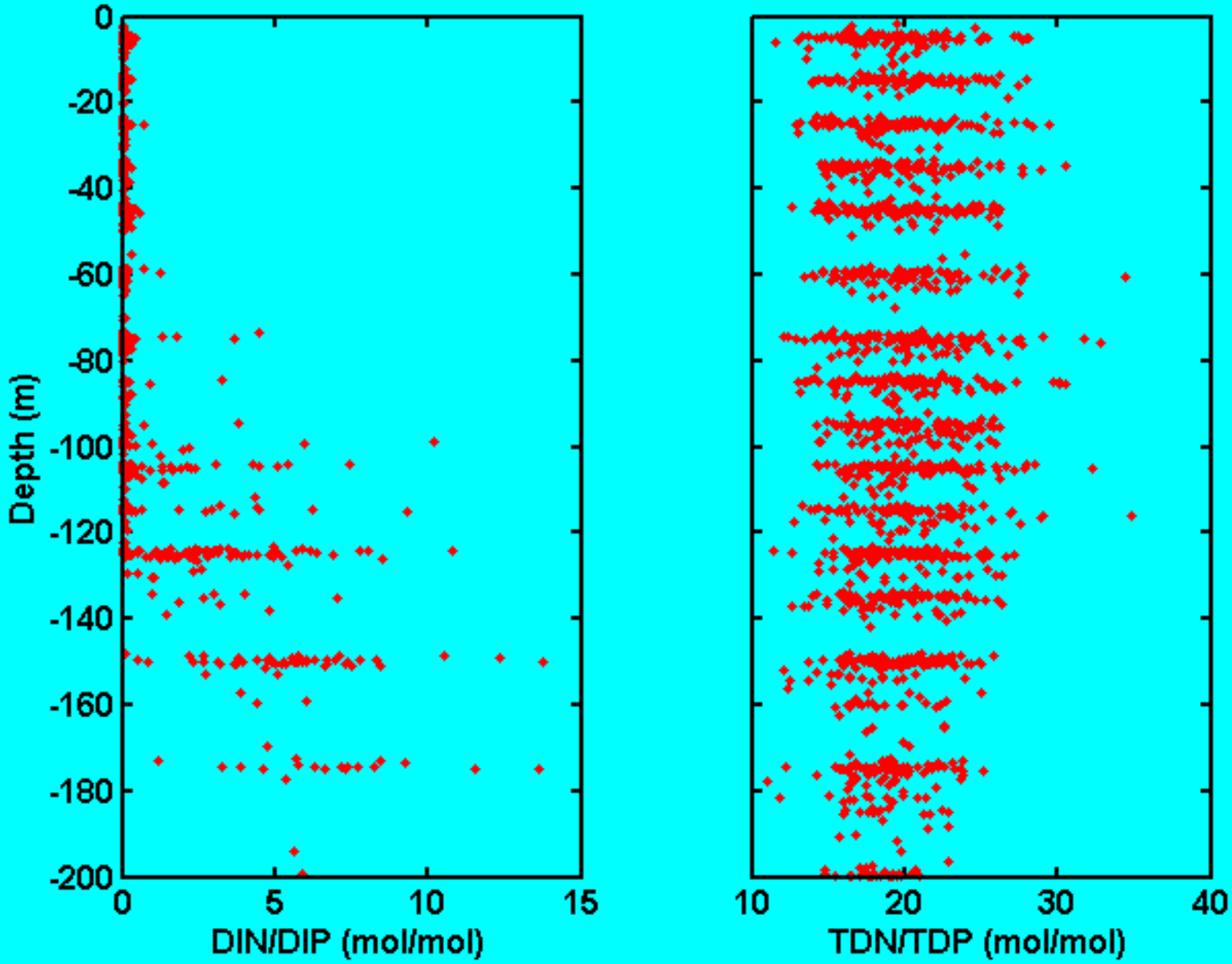
- model forced with means but real ocean not stationary over time

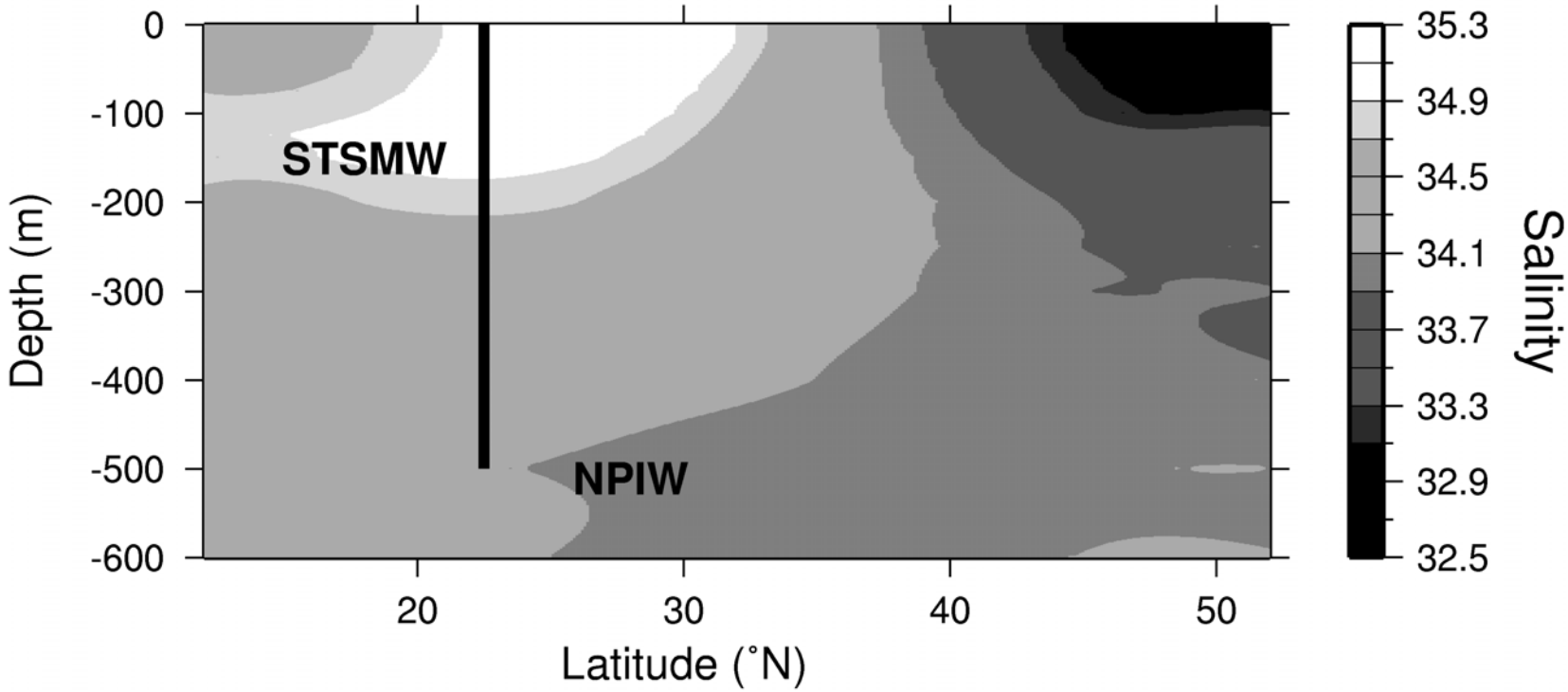

TDN:TDP (mol:mol)
20
15
10
CRM
TDN:TDP (mol:mol)
20
15
10
noDNF
+DNF
observed
VRM
0
2
4
6
8
10
12
Time (years from 01 January 1989)

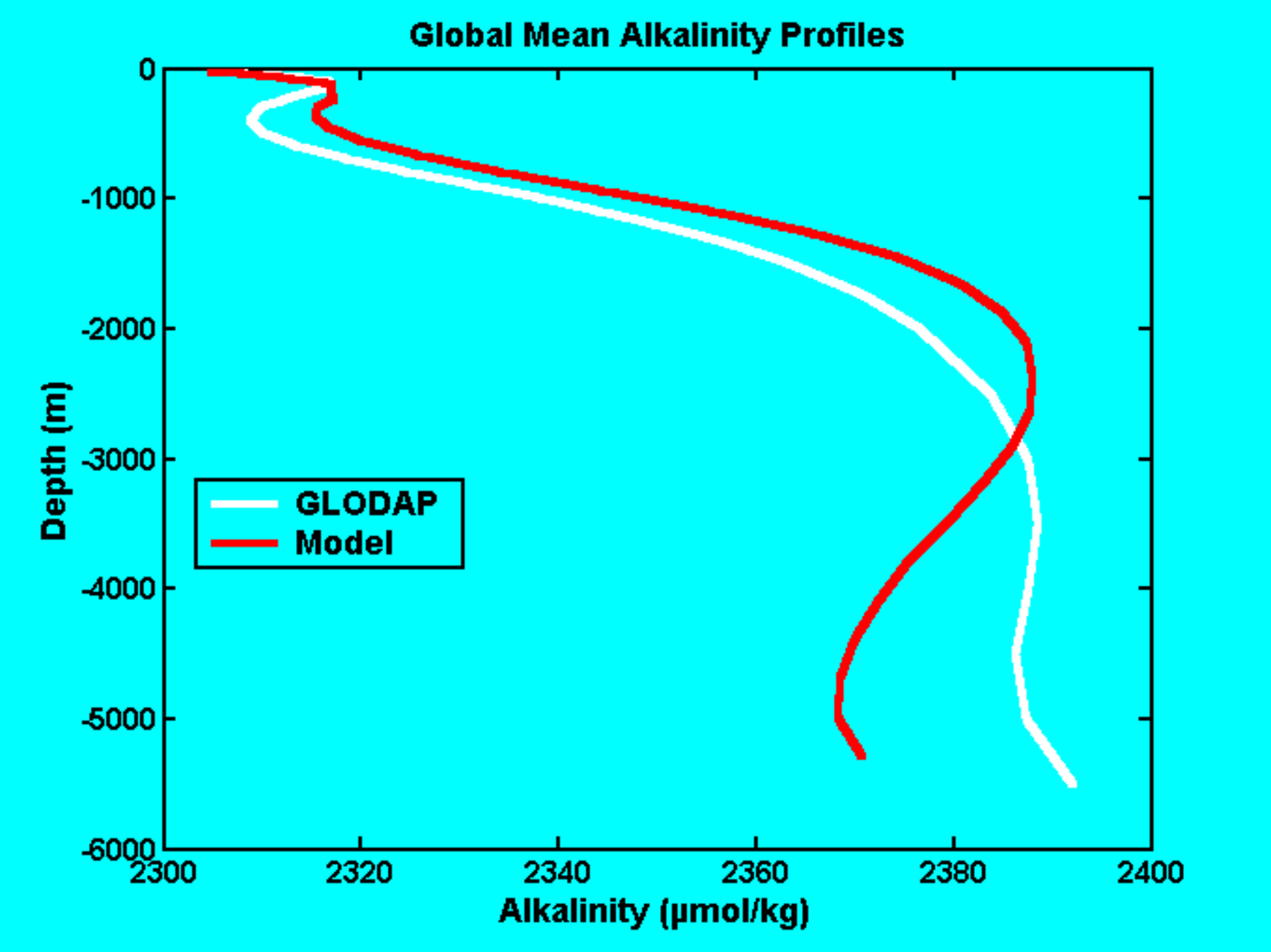
Is enhanced carbon flux in VRM sustainable?

DIN/DIP < RR in upper thermocline. Why?

- nonlocal source
- differential remineralization
- ‘fossil’ pools from previous system states


0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Depth (m)
0
5
10
15
DIN/DIP (mol/mol)
10
20
30
40
TDN/TDP (mol/mol)


0
-100
-200
-300
-400
-500
-600
Depth (m)
STSMW
NPIW
20
30
40
50
Latitude (˚N)
35.3
34.9
34.5
34.1
33.7
33.3
32.9
32.5
Salinity


Global Mean Alkalinity Profiles
0
-1000
-2000
-3000
-4000
-5000
-6000
Depth (m)
GLODAP
Model
2300
2320
2340
2360
2380
2400
Alkalinity (µmol/kg)

Conclusions

- biological export of C from surface ocean enhanced in VRM

- there is an upper limit to stimulation of export by new N

- effect of past and future climate variability unclear, but steady-state unlikely

- need to include more realistic representation of calcification and N_2 fixation