An N-, P- and Si- based Model of Primary Production and Export Applied to Station ALOHA: Can we get the model to agree with the data for primary production, DOM concentrations and POM flux?

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FRSGC Frontier Research System for Global Change
TOWARD THE PREDICTION OF GLOBAL CHANGE

N:P:Si Ecosystem Model

Developed by
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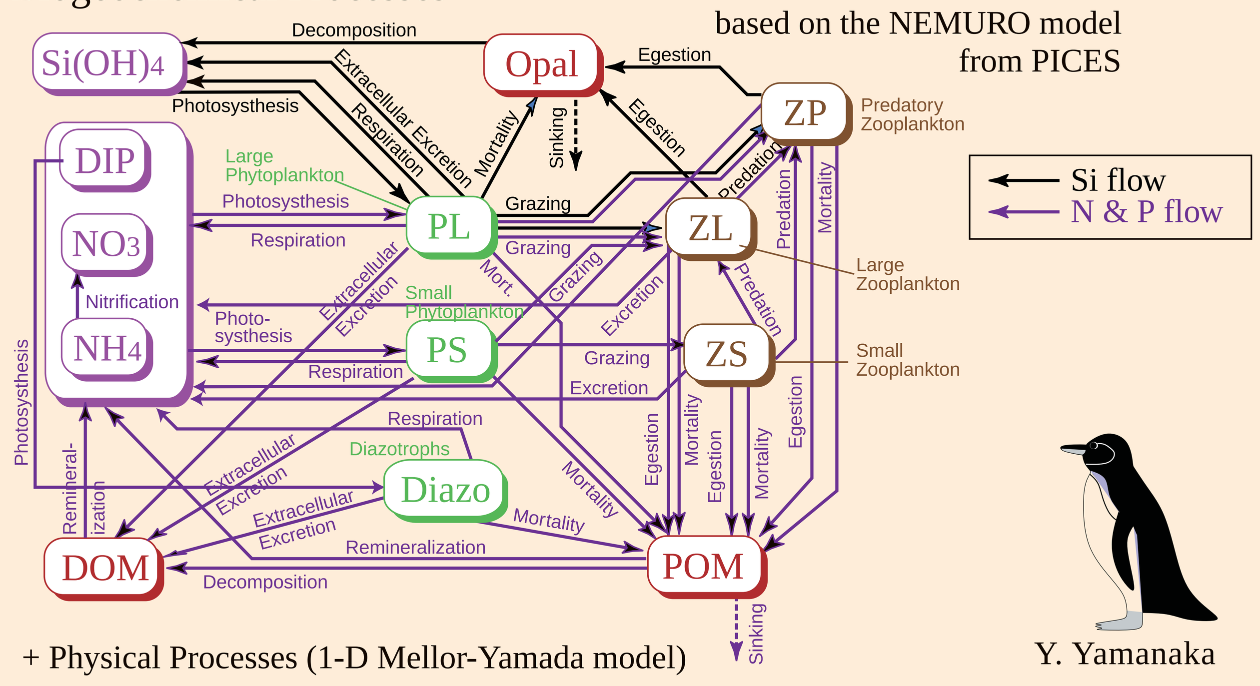
Biogeochemical Processes

based on the NEMURO model from PICES



+ Physical Processes (1-D Mellor-Yamada model)

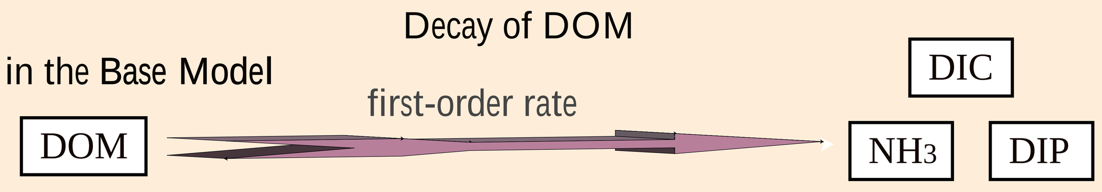
Y. Yamanaka

Our modifications to the NEMURO formulation

Diazotrophs (N_2 fixers) based on the model by Fennel et al [2002].
Phosphorous cycles and components for DIP, DOP & POP.
Carbon cycles & components for DIC, DOC & POC

This is what we call our Base Model for this presentation.

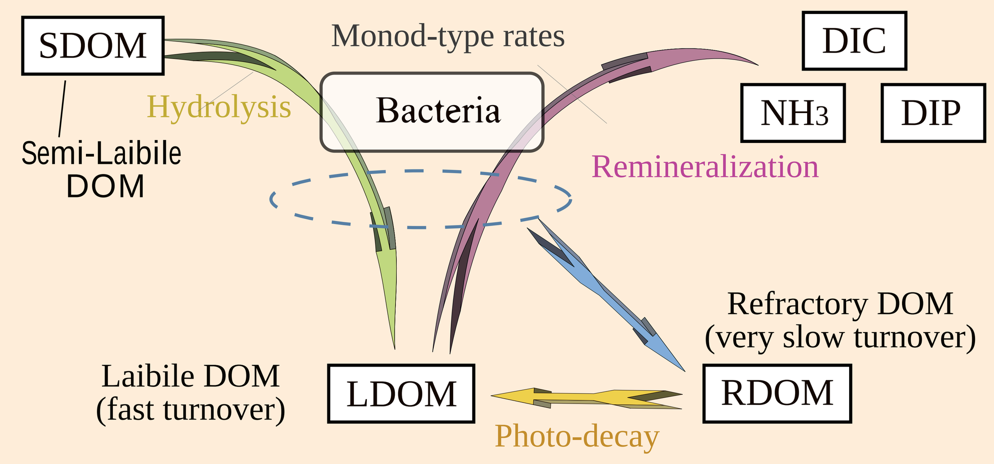
Decay of DOM



R-DOM is assumed constant.
We substituted the MFW formulation to get our MFW model.

MFW (Microbial Food Web) model for Cycling of DOM

Anderson and Williams' [1999]
(rates are based on Carbon)
Developed to simulate the vertical distribution of DOM



Data for Forcing & Comparsion

- HALE-ALOHA Buoy (Pierre Flament, Univ. of Hawaii at Manoa)
  Wind Velocities & Solar Radiation @ ~ 10 minute intervals
- Cruise Data (approx. monthly) (JGOFS/ HOT-DOGS website http://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html)
  (NO_3 + NO_2), DIP, Si
  DOC, DON, DOP, PN (Particulate Nitrogen), PP (Particulate Phosphorous)
  Fluxes of POC, PON & POP from Sediment traps

To Drive the Model for 1997 & 1998

30 min. Averages of Solar Radiation, Wind Stress (calc'd from data)
Monthly T & S from cruises, used to damp from 0 to 150 m depth
(no data for Jan., 1997; interpolated betw. Dec., 1997 & Feb., 1997)
Minimum diffusive mixing coeff. of 0.5 cm^2 / s ; Downwelling of 5 m /yr (est., Y. Sasai)

Spin-up 1 year, then run: 1997 forcing Once, then 1997 & 1998 simulation

Stoichiometries (C:N:P ratios) are fixed for all living organisms & R-DOM.

component	C:N	N:P	sources
PS, PL	6.625	14*	assumed Redfield; *N:P from Fennel et al
Diazo	6.625	45	Fennel et al [2002]
ZS	5.5	14*	Anderson [1992], value for protozoa
ZL, ZP	4.9	14*	Anderson [1992], value for copepods
Bacteria	5.1	9*	Goldman [1987]
RDOM	20.2	54.1	Averages for all Stn. ALOHA Data from 1997-98 for depths >= 750 m

Deep Conc. of RDOM: RDOC = 46, RDON = 2.3, RDOP = 0.038 mmoles / liter

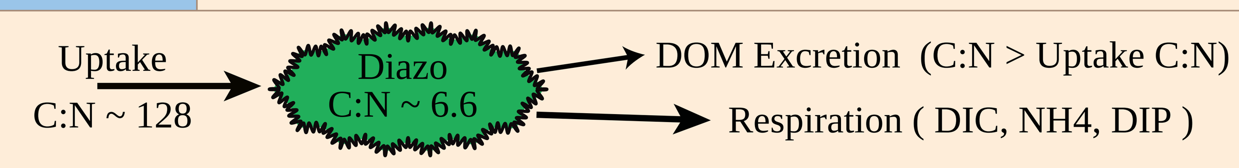
Compositions of all other DOM & POM are variable.

High Uptake Ratios of C:N

Could allow higher Primary Production (C) per mole of N, P

Orcutt et al's [2001] Study of Trichodesmium spp. at BATS
measured daytime C : N Uptake mean of 128 (range: 14 - 425)
but Biomass remaining near 6.625
They claim this could explain high drawdown of DIC, yet cite studies that found low Excretion (7% of prod., as DOC)

Initial conditions for nutrients and DOM were fixed by interpolation from a spline fit vs. depth for all data from 1997-1998.



If nearly all of this C Uptake is respired to DIC, it can't explain High P. Prod'n
But, Gilbert and Bronk [1994] found avg. 50% of N_2 fixation excreted (as DON)
Higher-than-avg. C : N uptake in light (Geider [1992]) for many phytoplankton
Pennock [1987]: means of 35 for light-sat'd, 13 for daylight, 8.5 over 24 hrs.
This would also give higher C : N for DOM near the surface (as observed)
Therefore, we tried C : N uptake ratios of 128 for Diazo and 13 for PS & PL

Parameters

based loosely on the NEMURO default values for the N. Pacific, but
Mortality & Grazing rates were increased to reduce suspended PN, PP concs.
Almost all rates are temperature-dependent, with Q_{10} = 2
Excretion as a fraction of Gross Production for phytoplankton
Diazo & PS 0.3 (Hood et al, 2002), PL 0.14 (NEMURO std.)
for MFW, from Anderson and Williams [1999]
rates were assumed to apply at 20 deg. C, and a Q_{10} of 2 was applied for each
Degradation of POM is based on measured rates by Fujii et al [2002]
1st order rate: k = 0.15 / day (@ 20 deg. C); Q_{10} = 2, assuming sinking rate = 6.4 m / day

Parameters Tuned for Each Pair of Simulations

to simulate Nutrients, DOM & POM data

Base Model:	Decay rate of DOM
MFW Model:	Mortality rate of Bacteria

Conclusions

Differential Remineralization (DR) allows the (simulated) ecosystem to retain nutrients near the surface and increase total production by ~100 % for the Base model and by ~200 % for the MFW model (over the Standard Simulations).
DR also improves significantly the simulated profiles of DOC and DOP.

N_2 fixation in the Standard Simulations is limited severely by low DIP concentrations, but is consistent with data-based estimates and other models in all simulations using DR.

The total primary production simulated using the High Uptake C : N ratios is higher by a factor of 2 to 3 than that in the DR simulations with Redfield stoichiometry for uptake (C : N = 6.6). This corresponds to production of large amounts of C-rich DOM which is then degraded relatively slowly (& might not decay during Prim. Prod. incubations).
Even so, the simulated primary production values are only ~ 1/3 of the measured primary production.
The simulated DOC is also much better (at least for the MFW model).

The simulations with DR do however seem to overestimate DOC export significantly.

More (better) tuning will almost certainly give better agreement with the data.
(The very high DOC concentrations for the base model in the High Uptake Sims. could be remedied by tuing DR parameters.)

But what can we say from just fitting our model ?
We can test whether ideas like DR and High C : N Uptake can account for the high primary production at places like Stn. ALOHA & BATS, and maybe improve our ability to simulate carbon & nutrient cycles.

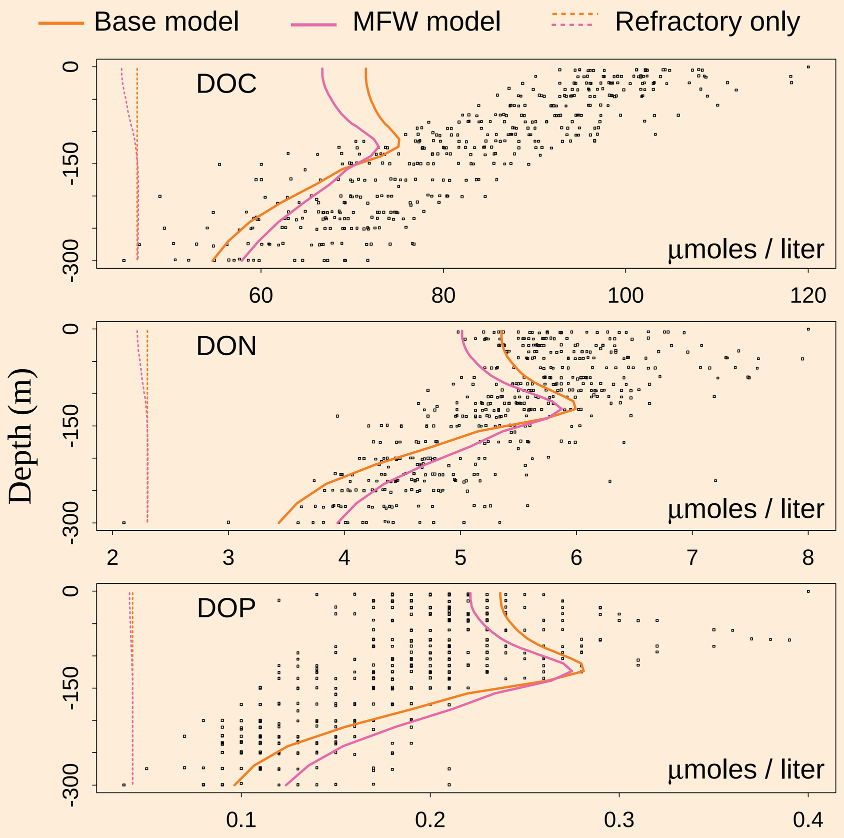
Table 1: Simulations and Data

Quantity (mean for 1997-98)	Data	Standard		Diff. Remin.		High Uptake	
		Base	MFW	Base	MFW	Base	MFW
Fluxes (mg m^{-2} day^{-1}), mean of meas. & sim. for all cruises @ 150 m							
POC Flux	30	18	20	28	37	29	35
PON Flux	4.2	3.3	3.7	3.9	5.3	4.1	5.2
PON Flux	0.36	0.51	0.58	0.33	0.44	0.35	0.44
Molar Ratios, , mean of meas. & sim. for all cruises @ 150 m							
C:N ratio of POM	8.4	6.5	6.2	8.4	8.2	8.4	7.8
P:N ratio of POM	26.9	14	14	26	27	26	26
Export of C at 150 m (mg C m^{-2} day^{-1}), mean for 2 yrs. simulated							
as DOC	13*	15	17	20	21	40	31
as POC	30	18	20	28	37	30	35
Primary Production (mg C m^{-2} day^{-1}), mean of meas. & sim. for all cruises							
Total Primary Production	478	34	28	69	80	206	162
N_2 Fixation (mmoles N m^{-2} yr^{-1}), mean for 2 yrs. simulated							
N_2 Fixation	below	3	3	38	38	36	38

Data-based estimates of N_2 Fixation range from 31 +/- 18 to 51 +/- 26 mmoles N m^{-2} yr^{-1} (*Fennel et al* [2002])
* estimate of DOC export based on a spline fit to all data (97-98) and the min. diffusive mixing coefficient

Standard Simulations

Vertial Profiles of Total Simulated DOM & Data
means of simulations (lines) & all data for 1997-1998



In the Standard Simulation, both models simulate DON better than DOC & DOP. Both underestimate DOC and overestimate DOP. Simulated primary production is also only about ~10% of observed.

The C:N & N:P ratios of POM in the simulations are both significantly lower than observed, meaning that the models are exporting too much N and P for each mole of C.

Preferential Remineralization of both POM and DOM is a means by which the ecosystem can retain nutrients in the shallower waters and maintain higher production.

We have introduced parameters $g_{CN,POM}$ and $g_{NP,POM}$ to fix the ratios of the rates of remineralization of C:N and N:P, respectively, for POM. Analogous parameters were applied for degradation of non-refractory DOM (for hydrolysis of SDOM in the MFW model). Setting these parameters to unity results in the standard formulation in which rates follow the stoichiometry of OM.

These are our Differential Remineralization (DR) Simulations. The values of the g's are:

$g_{CN,POM}$ = 0.70, $g_{NP,POM}$ = 0.50
$g_{CN,DOM}$ = 0.60, $g_{NP,POM}$ = 0.60

Thus C is remineralized more slowly than N, which is remineralized more slowly than P.

The fits to DOP & DOC are better, but the concentration and C : N ratio of DOM near the surface are too low.

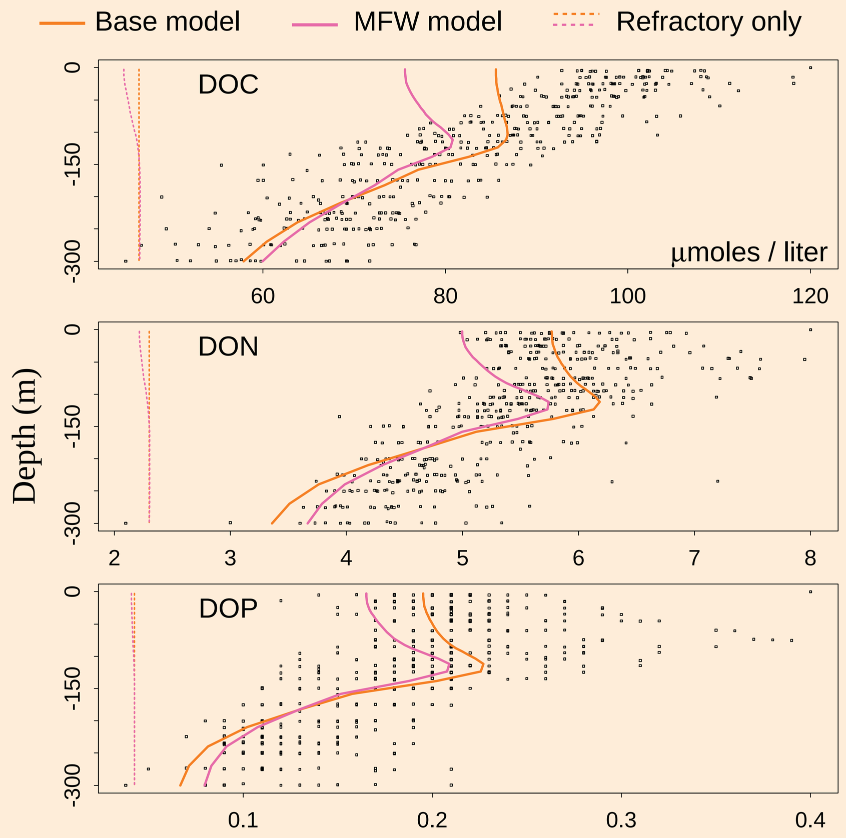
For the High Uptake Simulations, the g's are:

$g_{CN,POM}$ = 0.70, $g_{NP,POM}$ = 0.50
$g_{CN,DOM}$ = 1.15, $g_{NP,POM}$ = 0.60

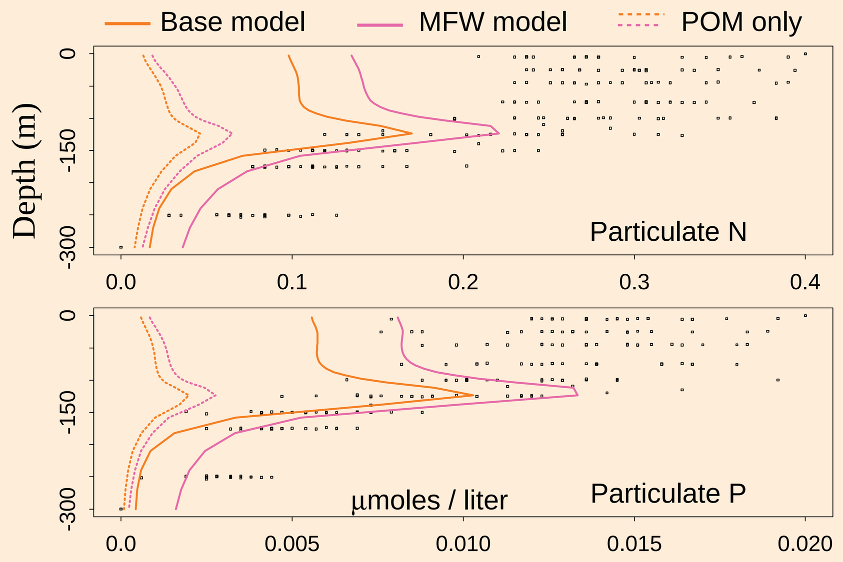
Thus DOC is remineralized faster than DON, which is remineralized more slowly than DOP.

Simulations with Differential Remineralization

Vertial Profiles of Total Simulated DOM & Data
means of simulations (lines) & all data for 1997-1998

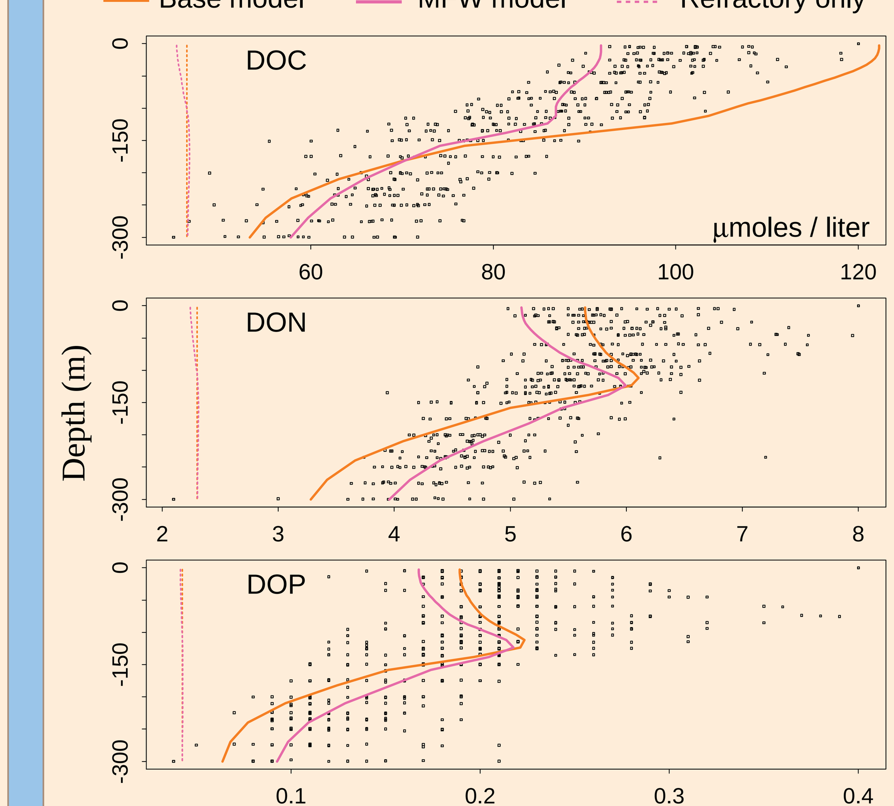


Vertical Profiles of Total Simulated PM & Data

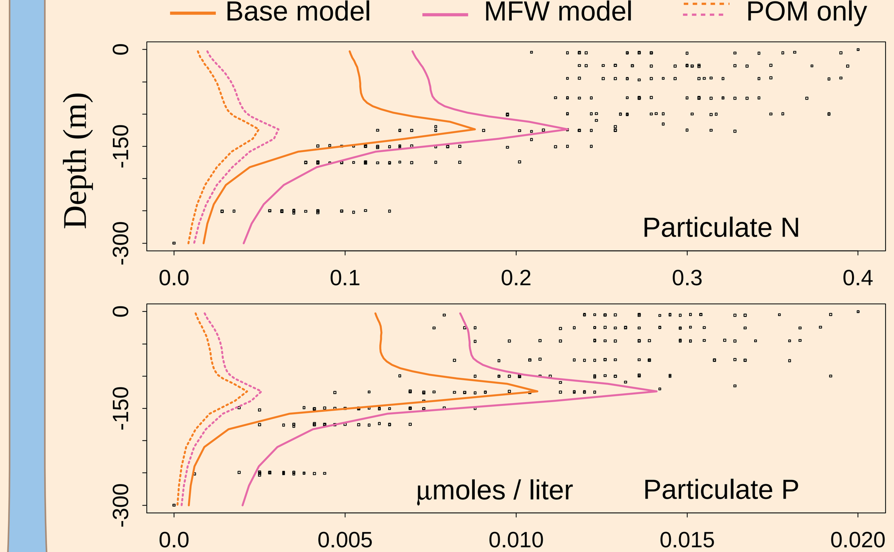


Simulations with High Uptake Ratios

Vertial Profiles of Total Simulated DOM & Data
means of simulations (lines) & all data for 1997-1998



Vertical Profiles of Total Simulated PM & Data



References

Anderson, Thomas R., 1992. *J. Plankton Res.* 14(12), p. 1645-1671
Anderson, Thomas R. and P. J. le B.Williams, 1998. *Estuarine Coastal Shelf Sci.* **46**, p. 93-109
Anderson, Thomas R. and P. J. le B.Williams, 1999. *Global Biogeochemical Cycles*, vol. 13, no. 2, p. 337-349
Fennel, K., Y. H. Spitz, R. M. Letelier, M. R. Abbott and D. M. Karl, 2002. *Deep-sea Research II* **49**, p. 149-174
Fujii, M, S. Murashige, Y. Ohnishi, A. Yuzawa, H. Miyasaka, Y. Suzuki and H. Komiyama, 2002. *J. of Oceanography*, **58**, p. 433-438
Geider, R. J., 1992. In Falkowski, P. G., Woodhead, A. D. (eds.), *Primary Productivity and Biogeochemical Cycles in the Sea*, Plenum Press, New York, p. 333-360
Goldman, Joel C., D. A. Caron and M. R. Dennett, 1987. Limnol. Oceanogr., **32**(6), p.1239-1252,
Hood, Raleigh R., N. R. Bates, D. G. Capone and D. B. Olson. 2001 *Deep-sea Research II* **48**, 1609-1648
Orcutt, Karen M., F. Lipschultz, K. Gundersen, R. Arimoto, A. F. Michaels, A. H. Knap and J. R. Gallon, 2001. *Deep-sea Research II* **48**, p. 1583-1608
Pennock, J. R., 1987. *Estuarine Coastal Shelf Sci.*, 24, p. 841-857
Redfield, A. C., B. H. Ketchum and F. A. Richards, 1963. In The Sea, vol. 2 (ed., M. N. Hill), Interscience, New York, p. 26-77