OCEANIC NEW PRODUCTION: A COMPARISON OF SATELLITE AND MODELING APPROACHES

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NEW PRODUCTION: WHAT IS IT AND WHY DO WE CARE?

Carbon fixed by photosynthesis, or primary production (PP), is a major term of the global carbon budget through its influence on atmospheric CO_2. Oceanic and terrestrial PP are approximately equal.

New production is the oceanic PP fueled by nutrients originating outside the illuminated upper layer, in contrast to regenerated production which results from nutrients within the layer (Dugdale and Goering 1967).

Steady state requires that the uptake of new nutrients be balanced by the export of carbon from the upper layer (Eppley and Peterson 1979).

The impact of increased atmospheric CO_2 due to anthropogenic input cannot be understood without proper quantification of total and new production.

The ratio of new to total production, the f-ratio, ranges from less than 0.1 to 0.6.

HEAT STORAGE FROM ALTIMETER

Oceanic heat storage anomaly (HS) is derived from the sea surface height anomaly (η) measured by the TOPEX/Poseidon altimeter (T/P) (Polito *et al.* 1999).

η is separated into additive components associated with the seasonal cycle, Rossby and Kelvin waves, and mesoscale eddies using a two-dimensional finite impulse response filter.

The heat storage obtained from the sum of the components is in close agreement with *in situ* measurements of heat storage:

r= 0.67 to 0.89; rms $\sim$ 30% of the mean.

We use the annual peak-to-peak range in HS measured by T/P for 1993-1998 from the amplitude of the sine fit to the 6-year time series.

NUTRIENT UPTAKE FROM HEAT STORAGE

Changes in HS are inversely related to changes in the storage of total inorganic nitrogen (TIN = nitrate plus nitrite), or nitrogen storage, NS.

$$
\begin{aligned}
NS &= \int_{-h}^{0} TIN(z)dz, & (1)\\
NS &= a + b * HS, & (2)\\
NS' &= b * HS', & (3)
\end{aligned}
$$

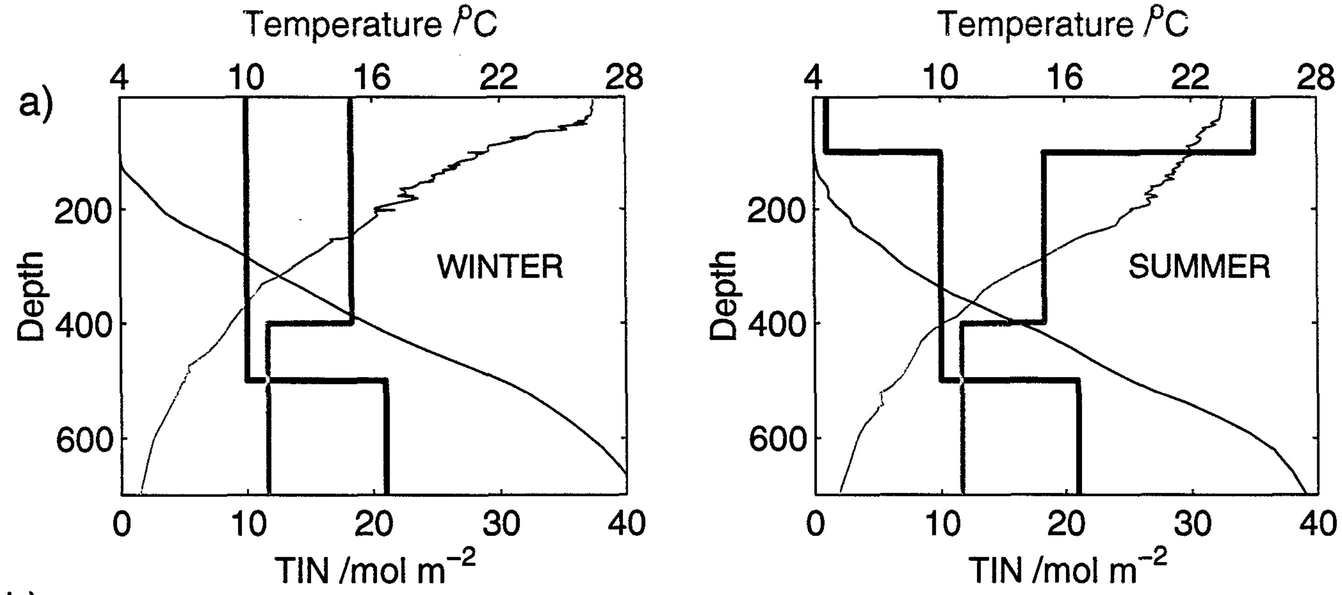
where primed quantities denote the time rate of change, and the slope, b, is a negative number, as high heat content corresponds to low TIN.

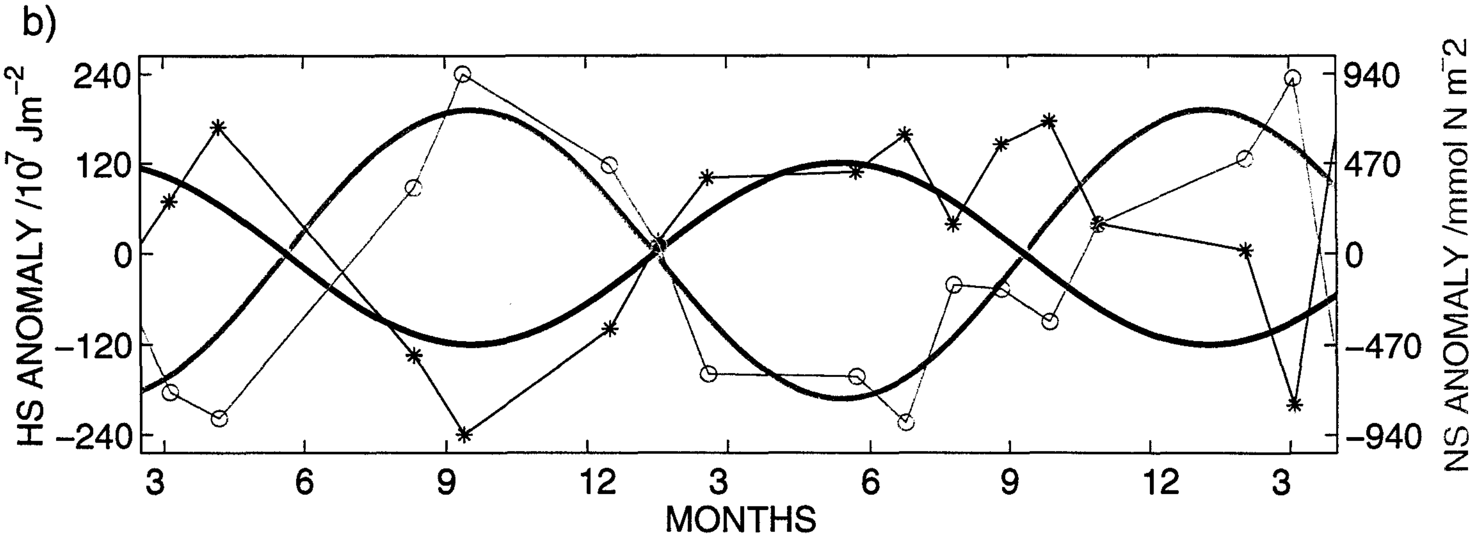
An increase in HS corresponds to the drawdown (biological uptake) of nutrients, thus a decrease in NS.

When the annual peak-to-peak range in HS is used, the derived NS' is the annual new production.

This method is similar to estimating new production as the product of surface winter nitrate concentration and the depth of the nitrate-depleted upper layer at the end of summer (Strass and Woods 1991).

Idealized profiles (bold) and at the HOT station (thin) of temperature and TIN for winter (April 1993) and summer (September 1993).





Time series of the seasonal anomaly of HS and NS for two years, idealized (bold) and at HOT (thin) from March 1993 to March 1995.

DETERMINATION OF THE SLOPE BETWEEN HS AND NS

We used climatological fields to estimate the relationship between the seasonal change in HS and NS. The climatological nutrient concentrations were prepared by Louanchi and Najjar (2000). This climatology uses data from Ocean Atlas 1998 and consists of monthly average fields at 2° resolution of the concentration of phosphate, nitrate, and silicate and 11 standard depths. The temperature fields of Levitus (1998) were used to estimate the HS.

A linear regression was made between the 12-month anomalies of HS and NS estimated between the surface and each available depth level.

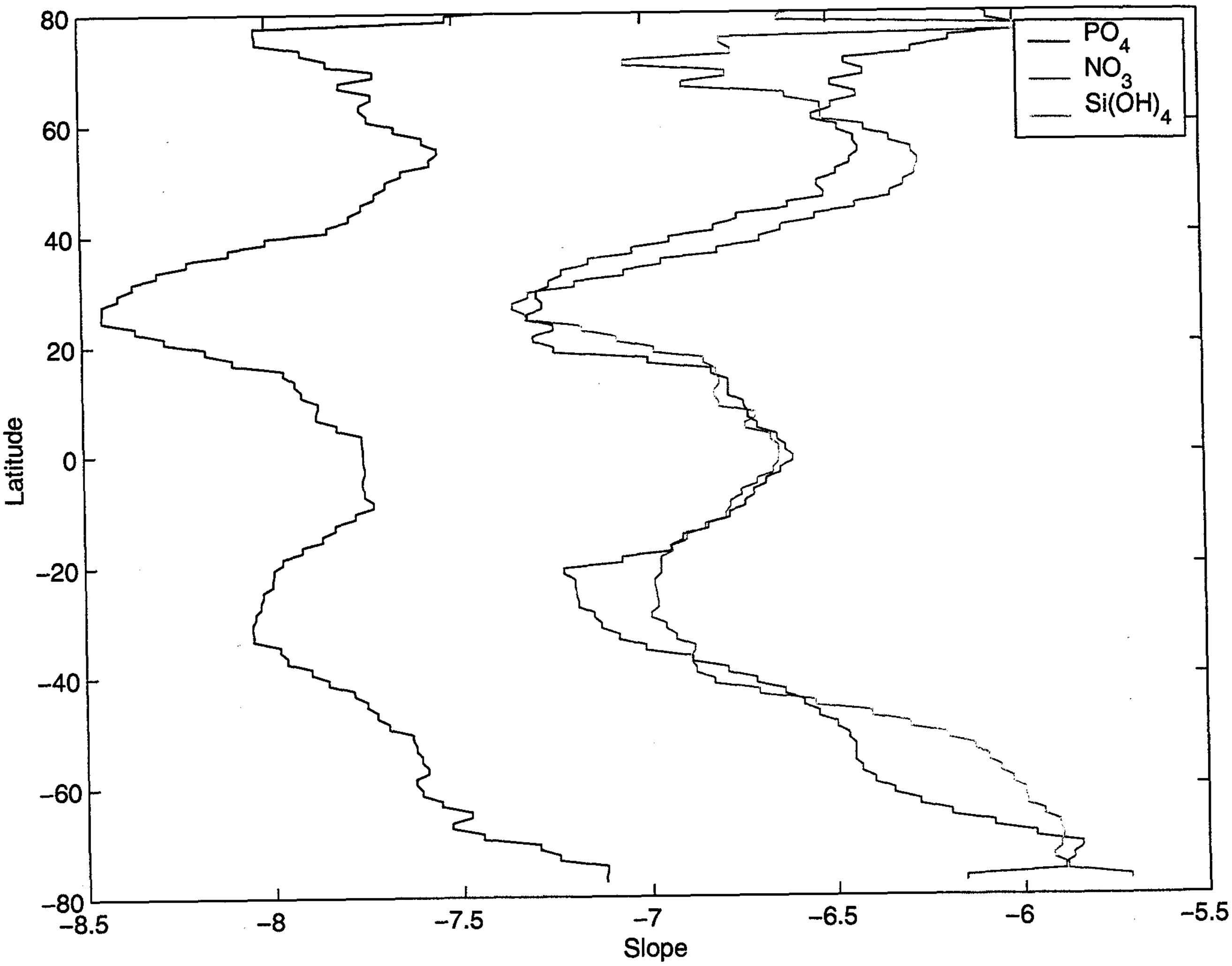
The integration level presenting the highest correlation coefficient between the regressed and observed time series of NS was chosen as the 'best' estimate of the relationship (or slope) between HS and NS.

The slope ranged between -10^{-6} and -10^{-9} mmoles m^{-3} (W m^{-2})$^{-1}$.

The integration level was shallower than 100m for approximately 70% of the world ocean for the three nutrients. It was generally deeper in the equatorial regions and subtropics than at high latitudes.

A small area of the ocean (2-4%) presented positive slopes indicating that increased heat storage led to increased nutrient uptake. These regions occurred in the subtropical gyres, where the seasonal signal is weak and often coinciding with low data density.

Despite significant zonal and interbasin differences in storage fields, the slope was fairly homogeneous with latitude. Thus to reduce noise, the global slope estimate was zonally averaged.


PO4
NO3
Si(OH)4
Latitude
80
60
40
20
0
-20
-40
-60
-80
-8.5
-8
-7.5
-7
-6.5
-6
-5.5
Slope

GLOBAL NEW PRODUCTION

The global new production estimates are given below in Gt C per year.

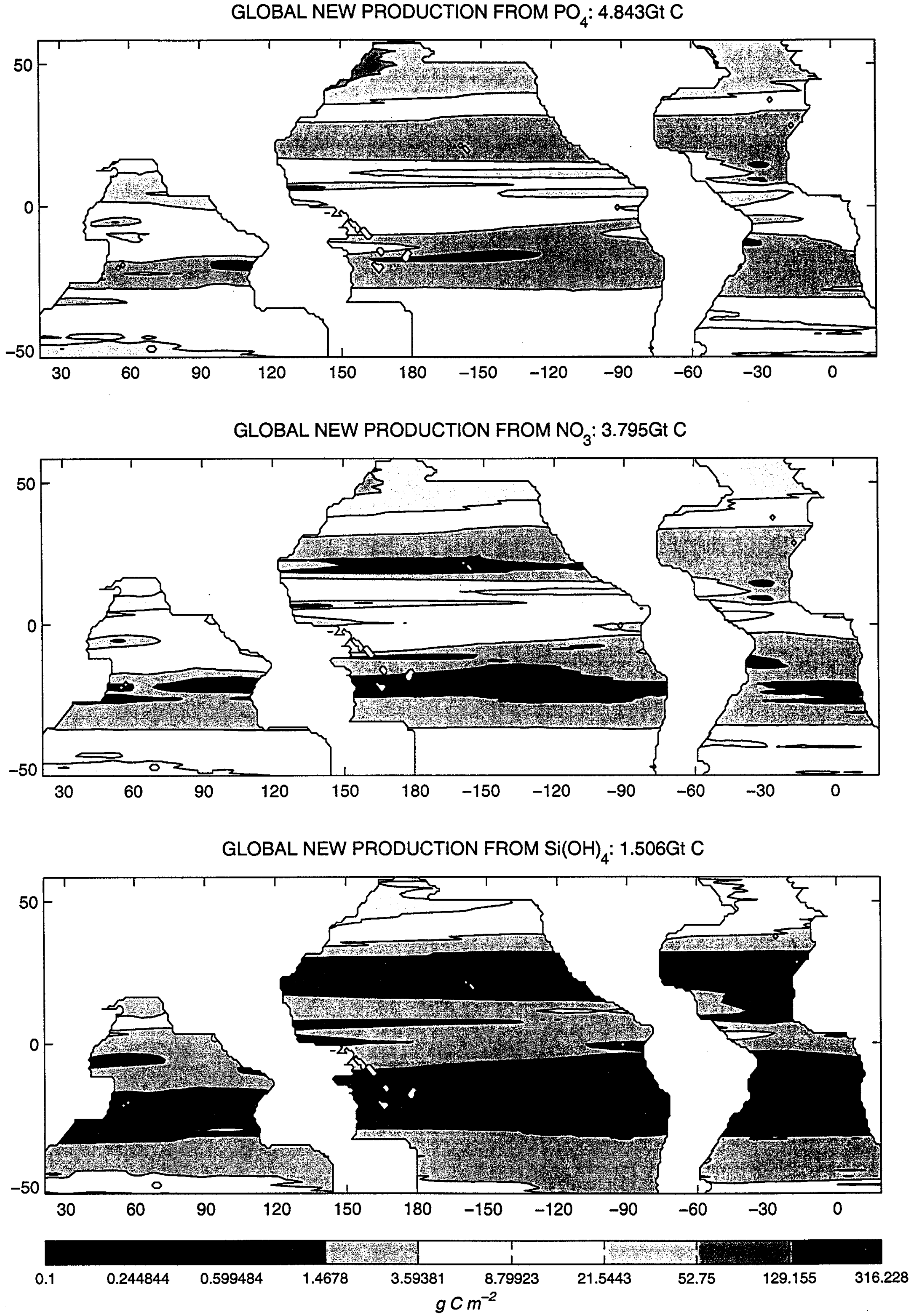
Nutrient	**PO_4**	**NO_3**	**$Si(OH)_4$**
	4.8	3.8	1.5

The maximum estimate was derived from phosphate, which is consistent with its role as major limiting nutrient.

The difference in new production from phosphate and from nitrate corresponds to the new production due to nitrogen fixation. It appears to approximately 1.3 Gt C. The spatial differences bewteen the two are consistent with the distribution of nitrogen fixers.

The lowest estimate is from silicate, which corresponds to the carbon export due to diatoms. It is confined to high latitudes and the equatorial regions, which present of high silicate concentrations.

According to this estimate diatoms account for 30% of global new production while nitrogen fixation accounts for 20%.


GLOBAL NEW PRODUCTION FROM PO4: 4.843Gt C
50
0
−50
30 60 90 120 150 180 −150 −120 −90 −60 −30 0
GLOBAL NEW PRODUCTION FROM NO3: 3.795Gt C
50
0
−50
30 60 90 120 150 180 −150 −120 −90 −60 −30 0
GLOBAL NEW PRODUCTION FROM Si(OH)4: 1.506Gt C
50
0
−50
30 60 90 120 150 180 −150 −120 −90 −60 −30 0
0.1 0.244844 0.599484 1.4678 3.59381 8.79923 21.5443 52.75 129.155 316.228
g C m−2

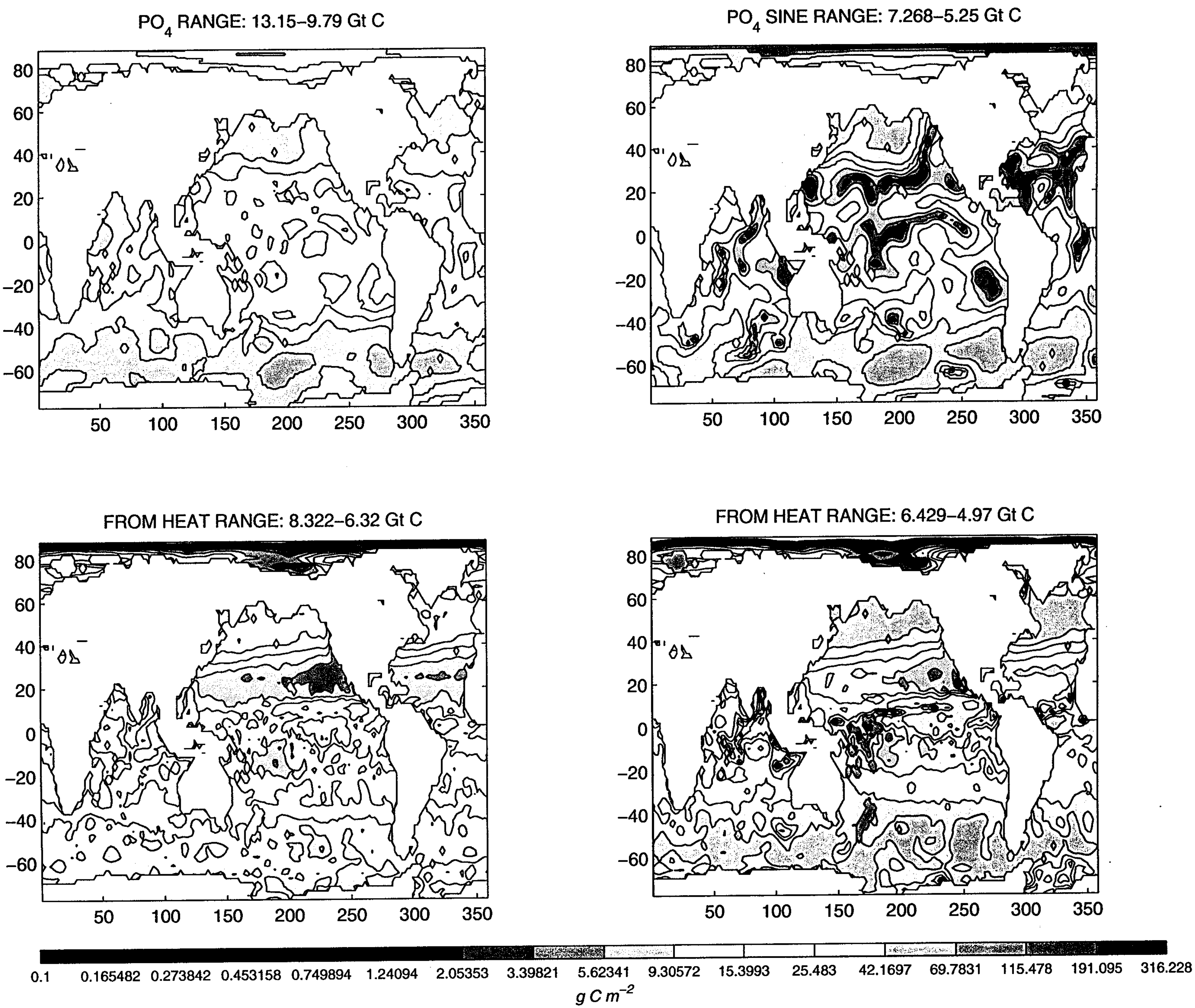
GLOBAL NEW PRODUCTION FROM CLIMATOLOGY

We estimated the drawdown of nutrients from the climatological data to test the method and calculated the new production in Gt C per year.

Method	PO_4	NO_3	$Si(OH)_4$
Drawdown	7.3 (5.3)	6.9 (4.6)	2.9 (1.8)
Heat	6.4 (5)	5.5 (3.8)	2.4 (1.5)

We obtained excellent agreement between the measured new production and the estimated new production using the heat storage and the zonal slope estimate for each nutrient. Using HS and the slope tends to underestimate the measured drawdown by 14-20%.

The number in parenthesis corresponds to the value estimated for the global ocean measured by the T/P altimeter (no information poleward of 52°S and 58°N).


PO4 RANGE: 13.15–9.79 Gt C
PO4 SINE RANGE: 7.268–5.25 Gt C
FROM HEAT RANGE: 8.322–6.32 Gt C
FROM HEAT RANGE: 6.429–4.97 Gt C
80
60
40
20
0
−20
−40
−60
50
100
150
200
250
300
350
0.1
0.165482
0.273842
0.453158
0.749894
1.24094
2.05353
3.39821
5.62341
9.30572
15.3993
25.483
42.1697
69.7831
115.478
191.095
316.228
g C m^-2

Nitrogen fixation appears to represent 0.4 Gt C globally and 1.3 Gt removing the high latitudes. This is consistent with the spatial distribution of nitrogen fixers (tropical and subtropical).

The new production due to diatoms suffers the greatest relative loss (40%) by removing high latitudes.

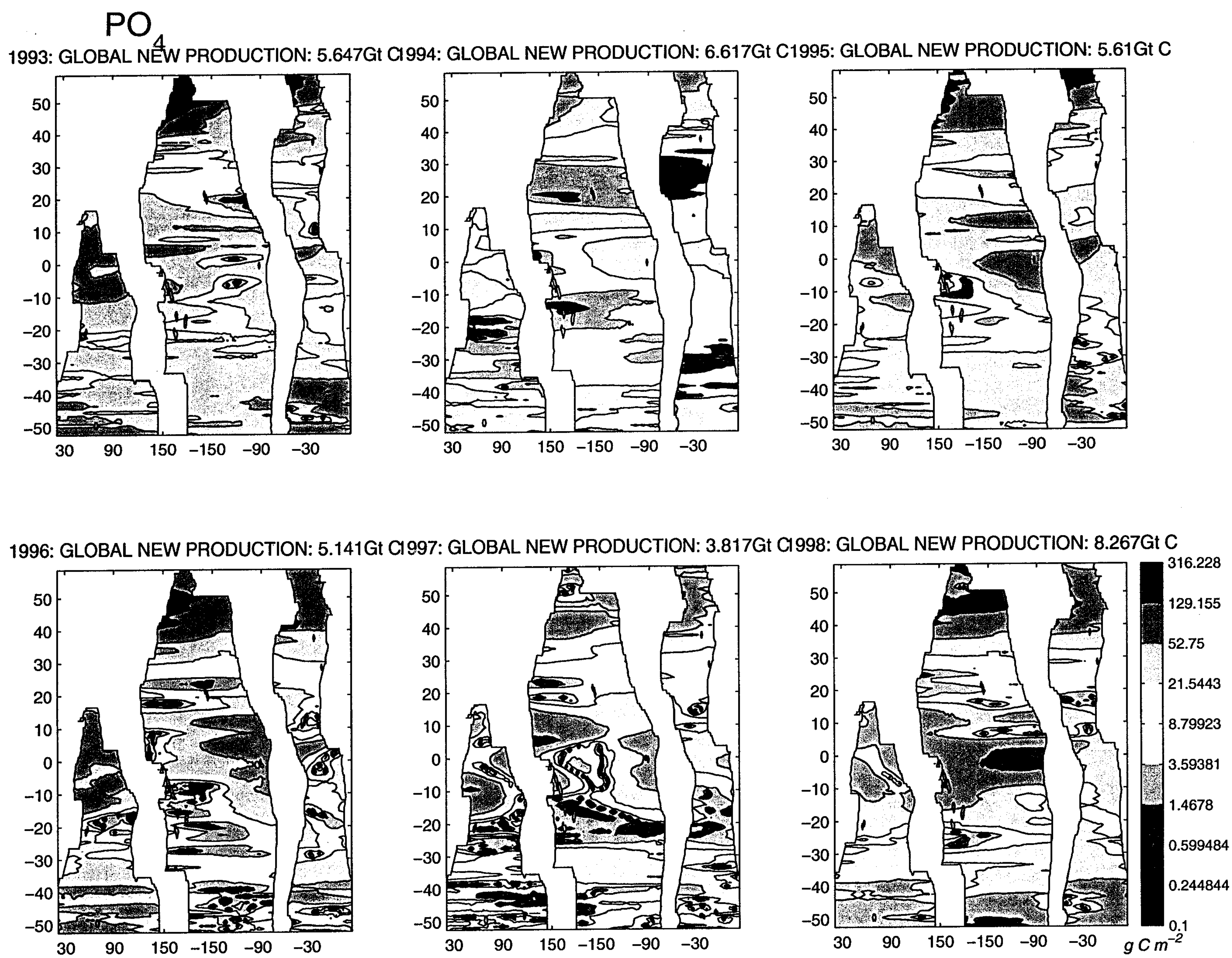
The T/P estimate is 83% (nitrate and silicate) to 90% (phosphate) of the observed nutrient drawdown from climatology and 96% to 100% of the value estimated from the climatological HS for the same latitude range. It is 55% (nitrate) to 75% of the global drawdown estimate.

INTERANNUAL VARIABILITY IN GLOBAL NEW PRODUCTION

We estimated the change in new production for each year between 1993 and 1998 by fitting a sine to the annual period and estimating the range minus the annual mean. The annual mean allows us to distingush between anomalous years as it does not approach 0 at shorter time scales.

Nutrient	PO_4	NO_3	$Si(OH)_4$
1993	5.6	4.4	1.7
1994	6.6	5.2	2.0
1995	5.6	4.4	1.7
1996	5.1	4.0	1.6
1997	3.8	2.9	1.0
1998	8.3	6.5	2.5

The lowest year on record was 1997, in which the effects of the El Niño were very strong and widespread. The highest year is 1998, which is due in part to the quick response to La Niña conditions in the equatorial Pacific.



PO4
1993: GLOBAL NEW PRODUCTION: 5.647Gt C
1994: GLOBAL NEW PRODUCTION: 6.617Gt C
1995: GLOBAL NEW PRODUCTION: 5.61Gt C
1996: GLOBAL NEW PRODUCTION: 5.141Gt C
1997: GLOBAL NEW PRODUCTION: 3.817Gt C
1998: GLOBAL NEW PRODUCTION: 8.267Gt C
50
40
30
20
10
0
−10
−20
−30
−40
−50
30
90
150
−150
−90
−30
316.228
129.155
52.75
21.5443
8.79923
3.59381
1.4678
0.599484
0.244844
0.1
g C m−2

CONCLUSIONS

The global new production estimates from T/P altimeter fall within the range of other global values (3.4-22 Gt C per year).

The method inherently underestimates by about 20%. Likewise the spatial coverage leads to a total decrease of about 35%. This raises the annual global estimate to around 5 Gt C.

Interannual variability is very large, O(50%) of the long-term average. Much of this variability occurs at high latitudes and in the tropics because they contribute most to the global signal, although the subtropical regions vary significantly as well.

The T/P nutrient storage method, unlike most new production methods, is completely independent of chlorophyll concentration, primary production, or f-ratio measurements, for which we have relatively little data.

An additional advantage over most satellite-based approaches is that it relies on radar altimetry, which is not limited by cloud coverage and already has a relatively long continuous time series (7 years).

FINAL

ACKNOWLEDGEMENTS

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