Long-term variability of surface nutrient concentration in the North Pacific

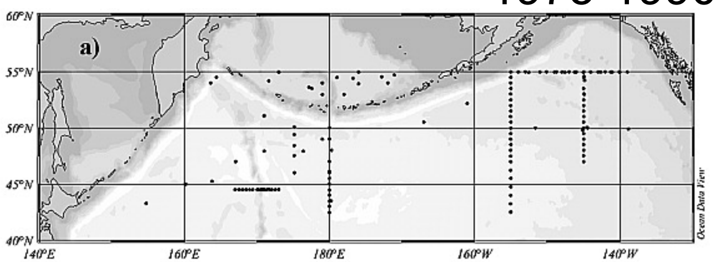
Sayaka Yasunaka (JAMSTEC, Japan)
with T. Ono, Y. Nojiri, F. A. Whitney, C. Wada, A. Murata, S. Nakaoka, and S. Hosoda

- Trends toward lower nutrient concentrations in the subarctic North Pacific (Freeland et al. 1997; Ono et al. 2002; 2008)
  ← Shallowing mixed layer depths ← Global warming
- N decrease < P and Si decrease (Watanabe et sl. 2008)
  ← Increasing atmospheric nitrogen deposition (Duce et al. 2008; Kim et al. 2011)
- Decadal variations in upper ocean nutrient concentrations have also been reported in the North Pacific
  (Pena and Varela 2007; Di Lorenzo et al. 2009; Yasunaka et al. 2014).

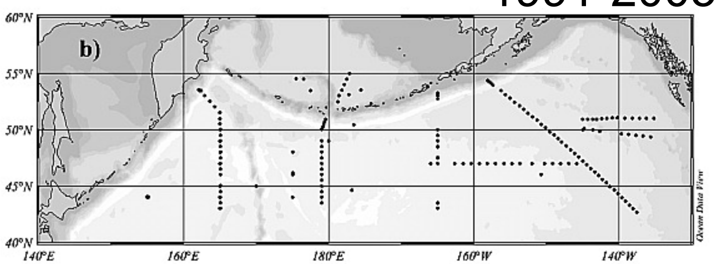
Observational data

Ono et al. (2008)

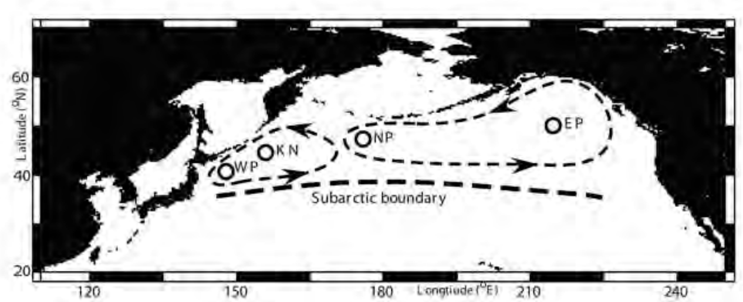
1975-1990



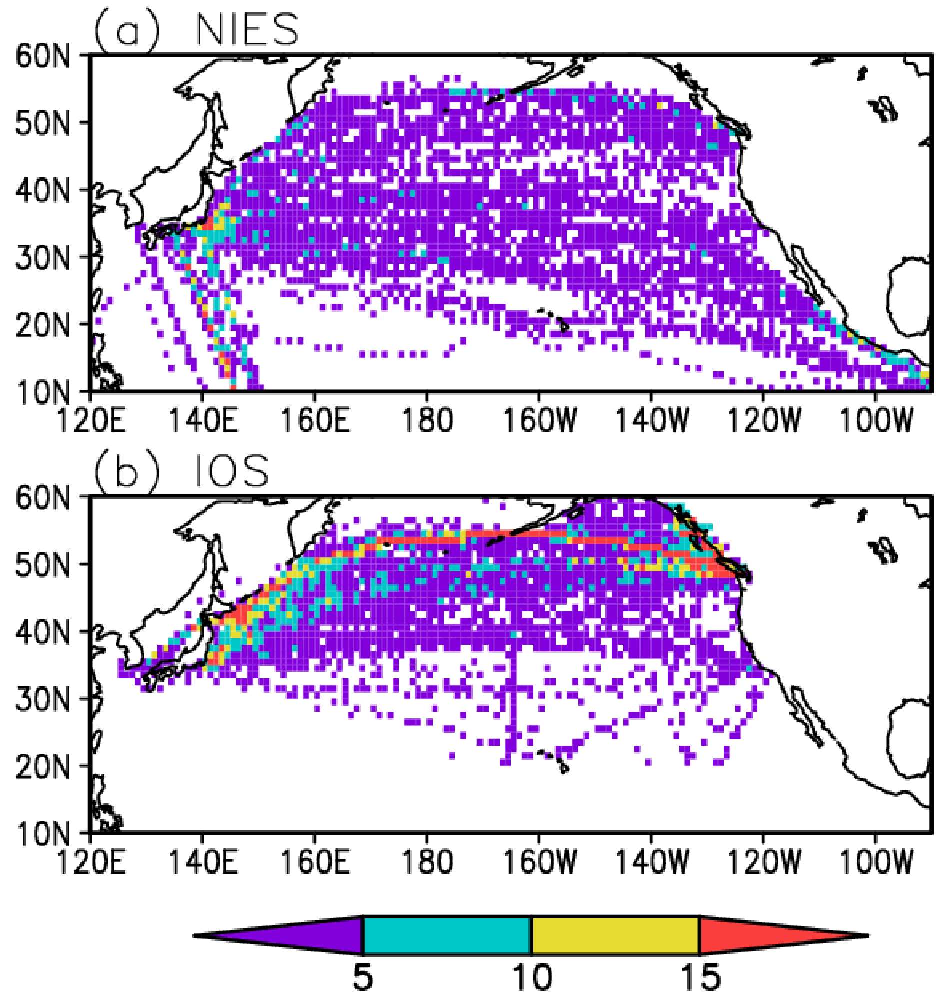
1991-2005



Watanabe et al. (2008)

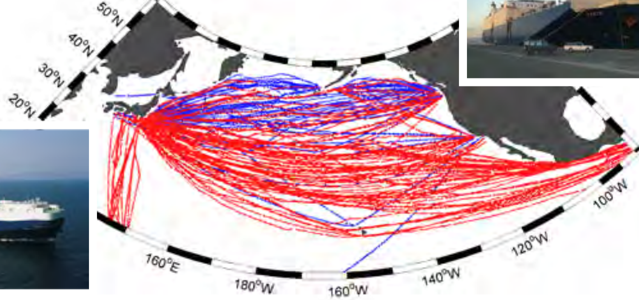


Nutrient Sampling (2001-2010)



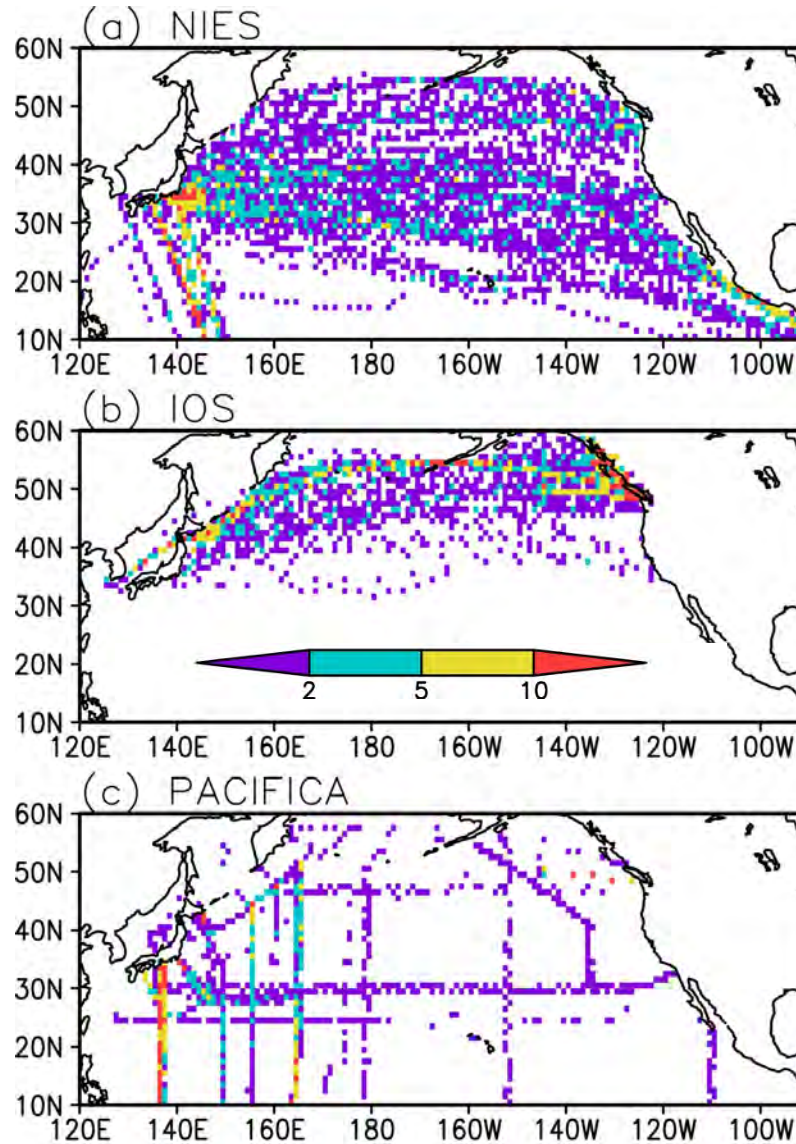
Ship-of-opportunity sampling for nutrients

- NIES and IOS have carried out ship-of-opportunity nutrient sampling.



- Surface water samples were manually collected from the seawater lines, routinely at 2 or 3 samples per day.
- Sampled nutrient tubes were stored frozen, then analyzed by colorimetric techniques in the onshore laboratories.
- Ship-of-opportunity nutrient sampling improved data coverage of bottle samplings by the research vessels.

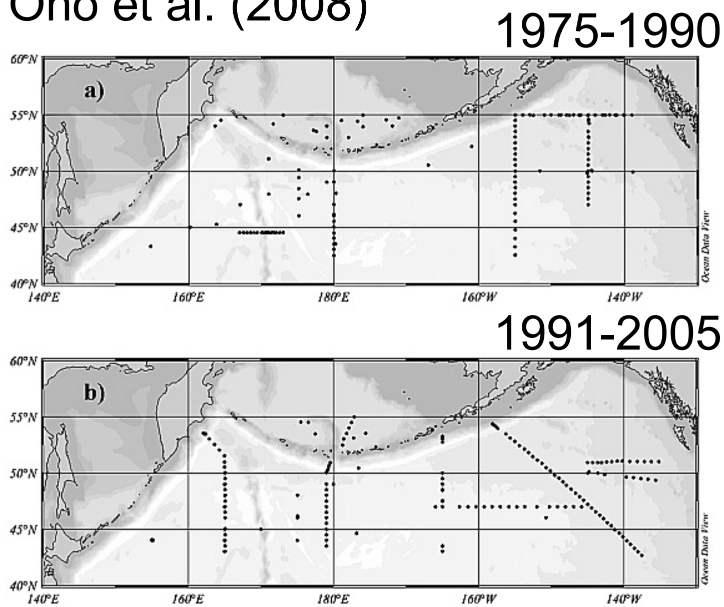
Nutrient Sampling (2001-2010)



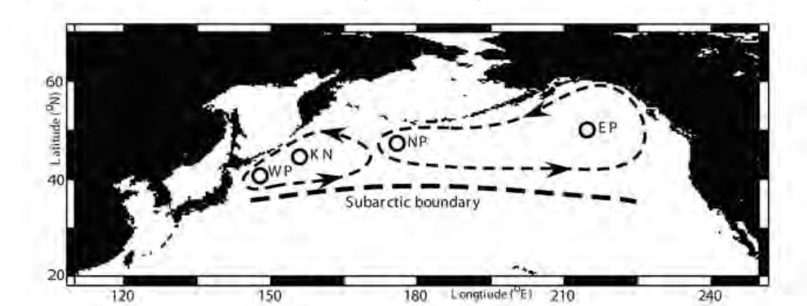
Whitney (2011); Yasunaka et al. (2014)

Observational data

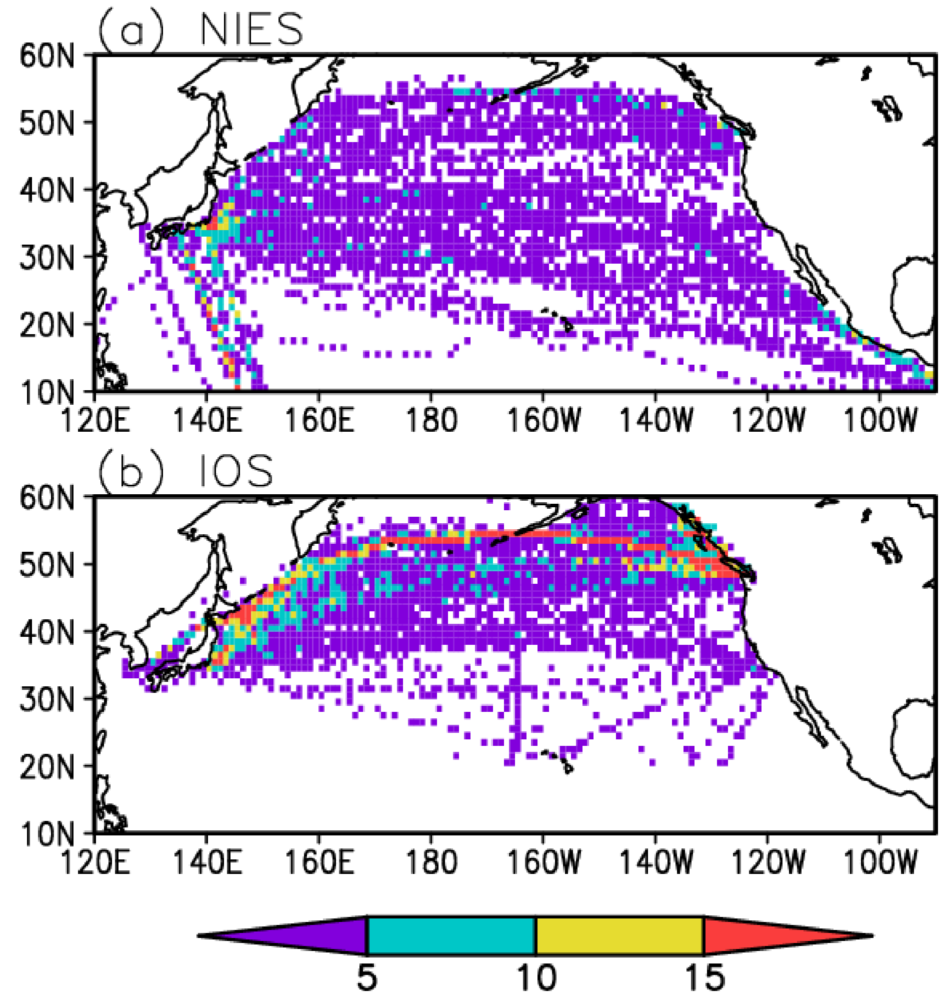
Ono et al. (2008)



Watanabe et al. (2008)



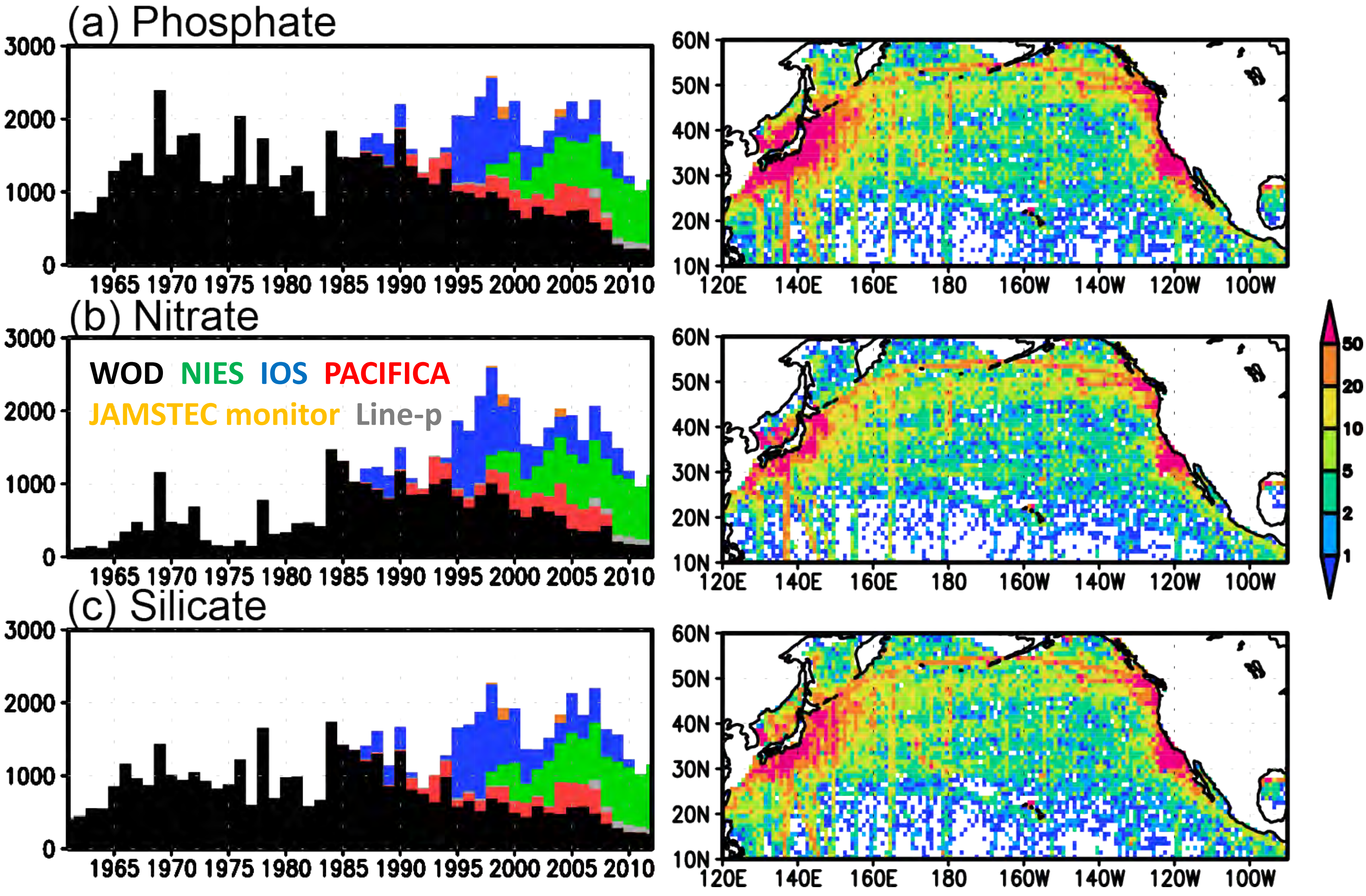
Nutrient Sampling (2001-2010)



Present study elucidate spatial patterns and temporal changes in the long-term variability of surface nutrient concentrations, using ship-of-opportunity observations with bottle samples collected by research vessels.

Nutrient sampling at ocean surface

Nutrient Sampling (1961-2012)



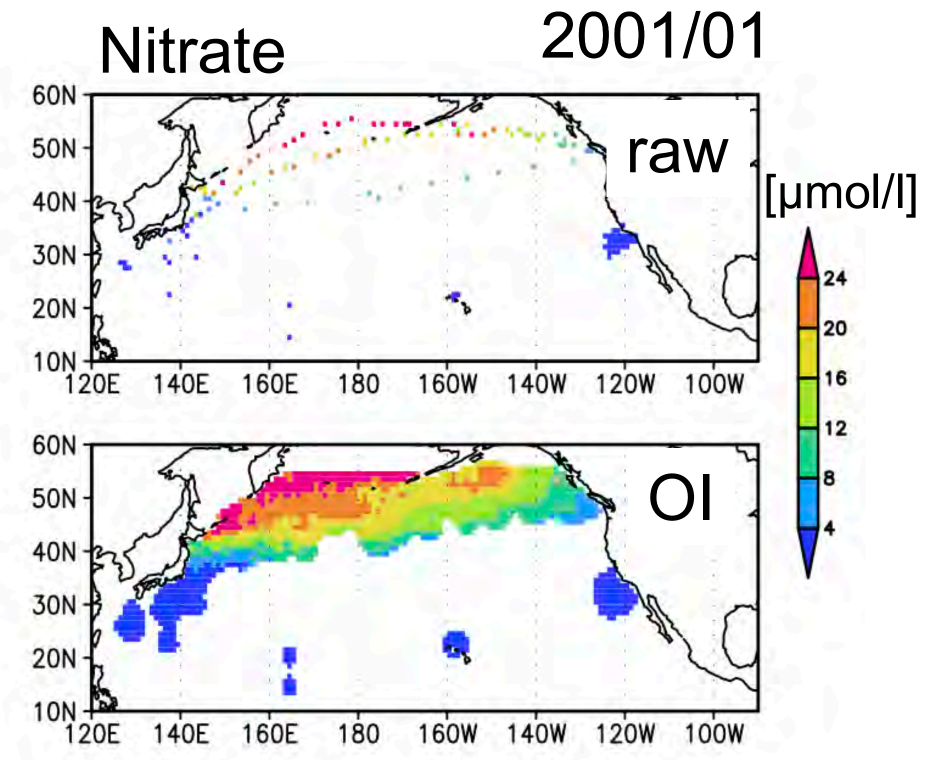
Optimal interpolation (1961/01−2012/12)

Correlation scale:

- Zonal: 23°
- Meridional: 20°
- Temporal: 3-month

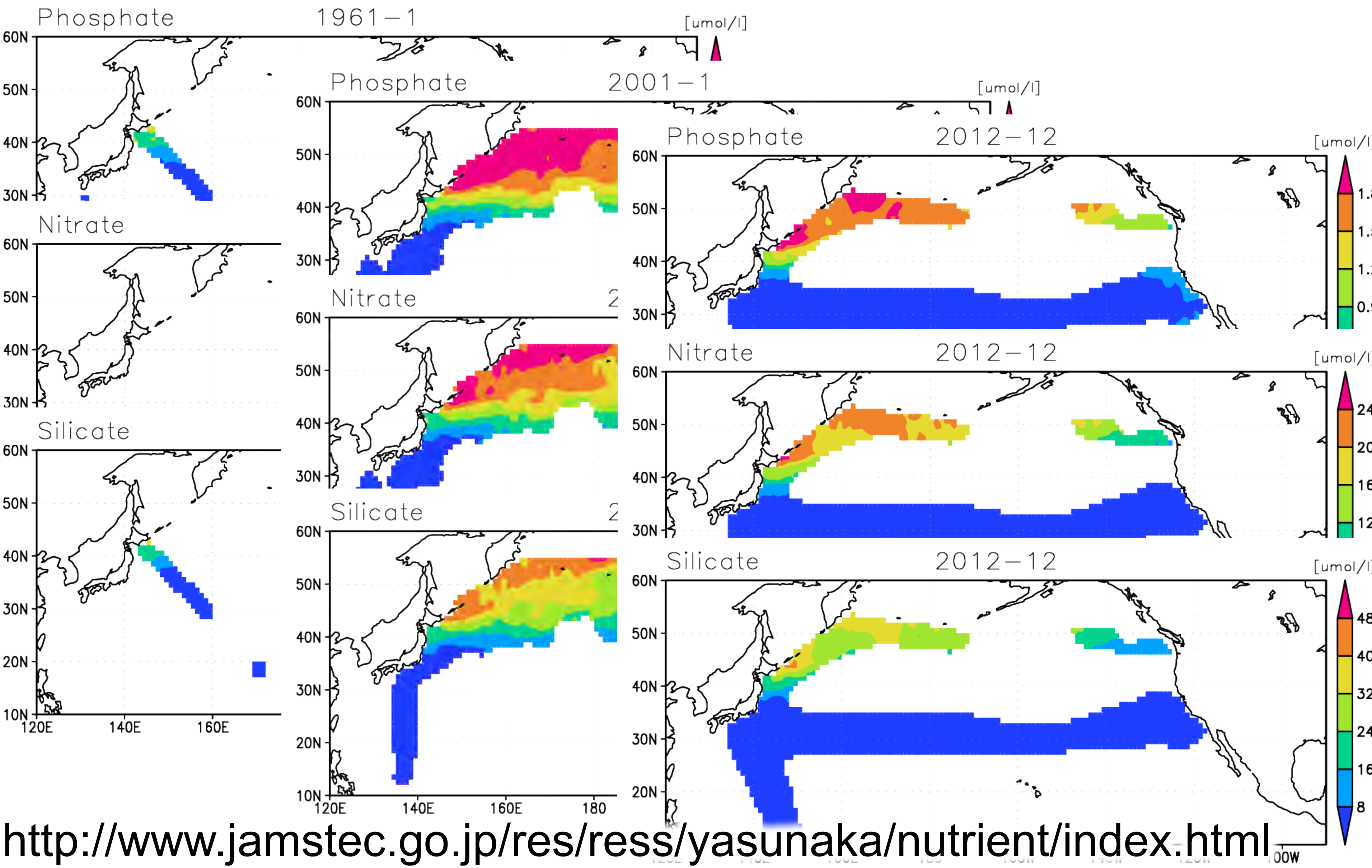
SN ratio: 1.5

Interpolation error ^{2} < 0.7



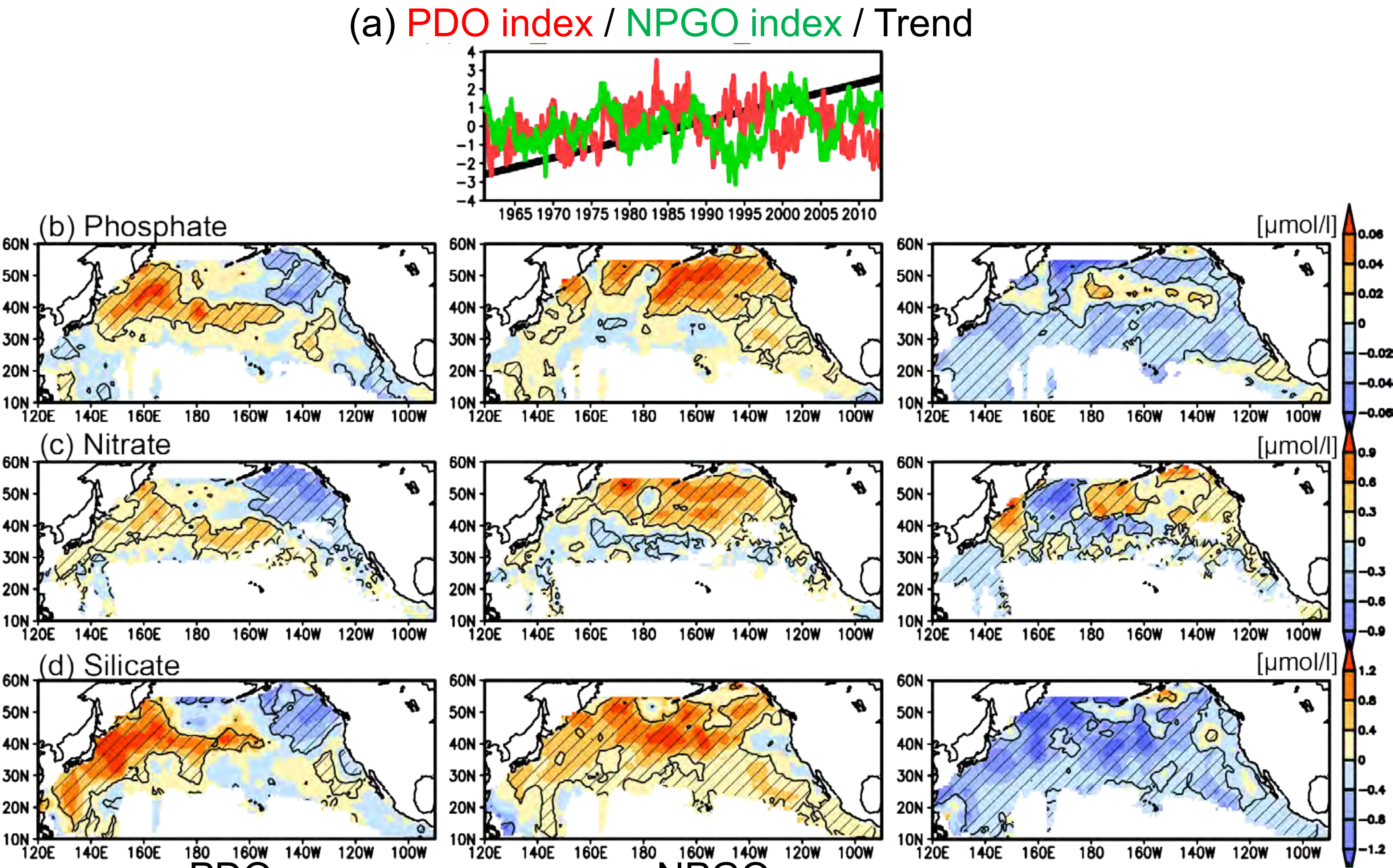
Optimal interpolation (1961/01−2012/12)

1961/01 ··· 2012/12



http://www.jamstec.go.jp/res/ress/yasunaka/nutrient/index.html

Decadal & long-term variability

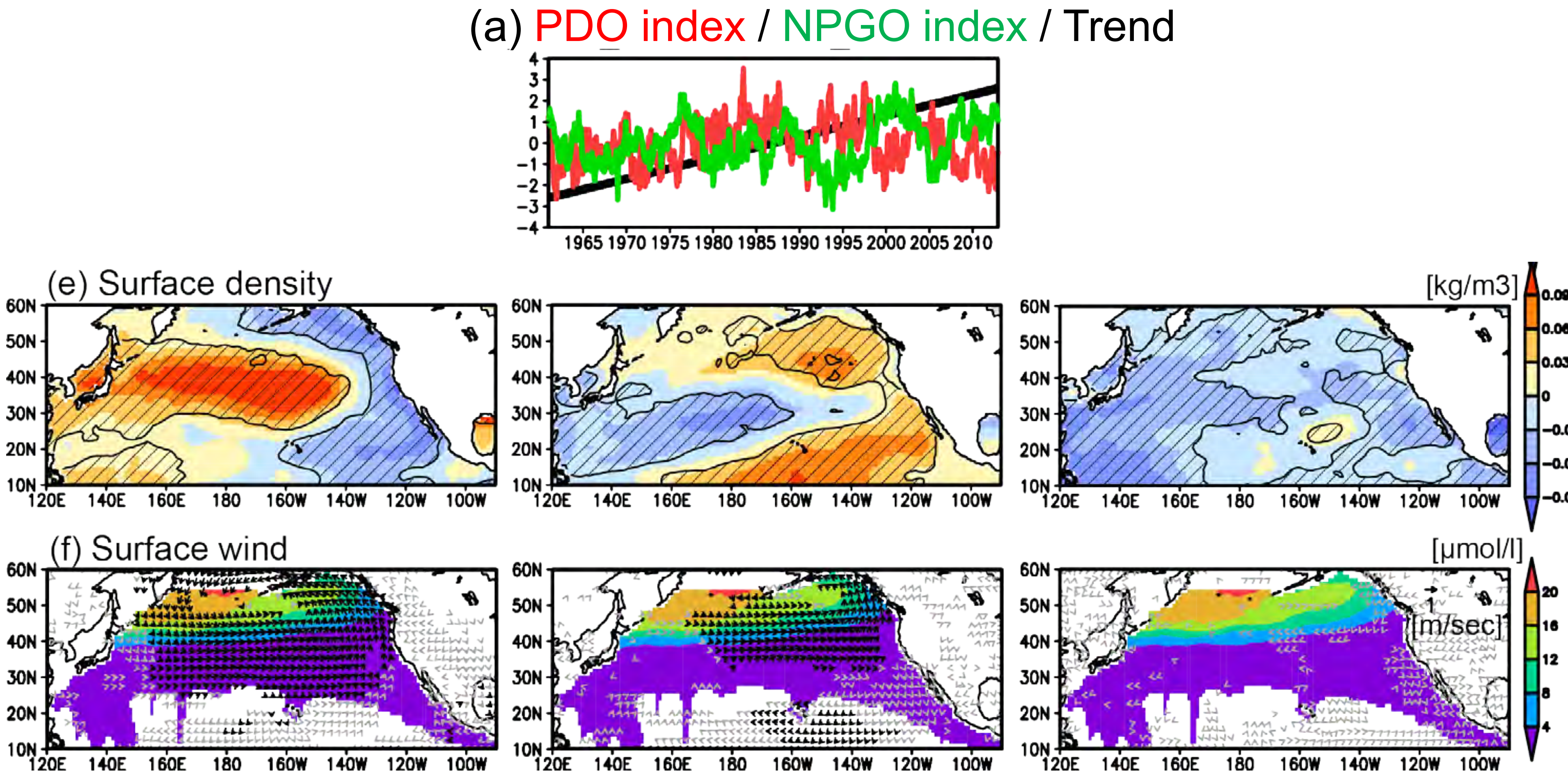


PDO
Pacific Decadal Oscillation

NPGO
North Pacific Gyre Oscillation

Trend

Decadal & long-term variability

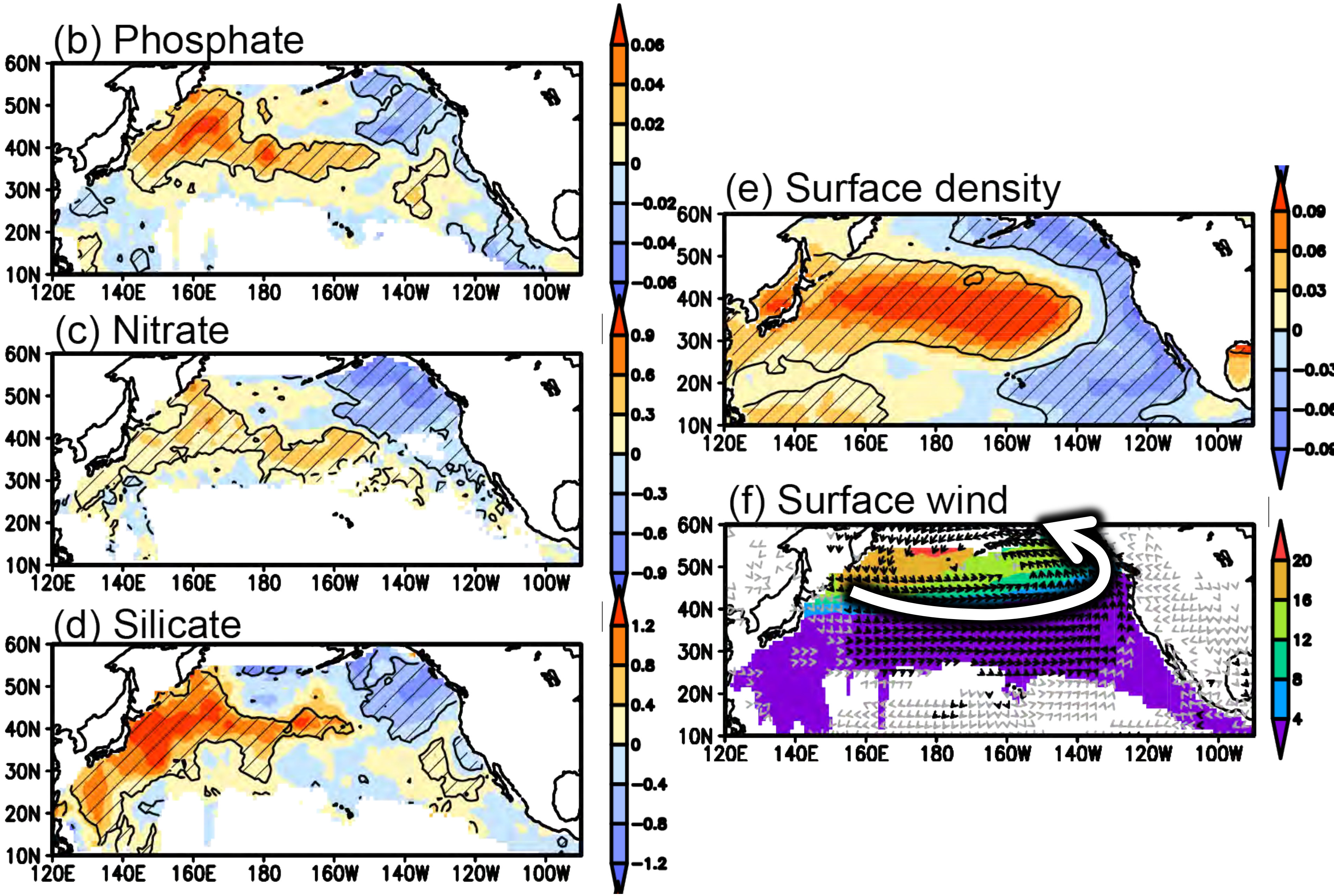


PDO
Pacific Decadal Oscillation

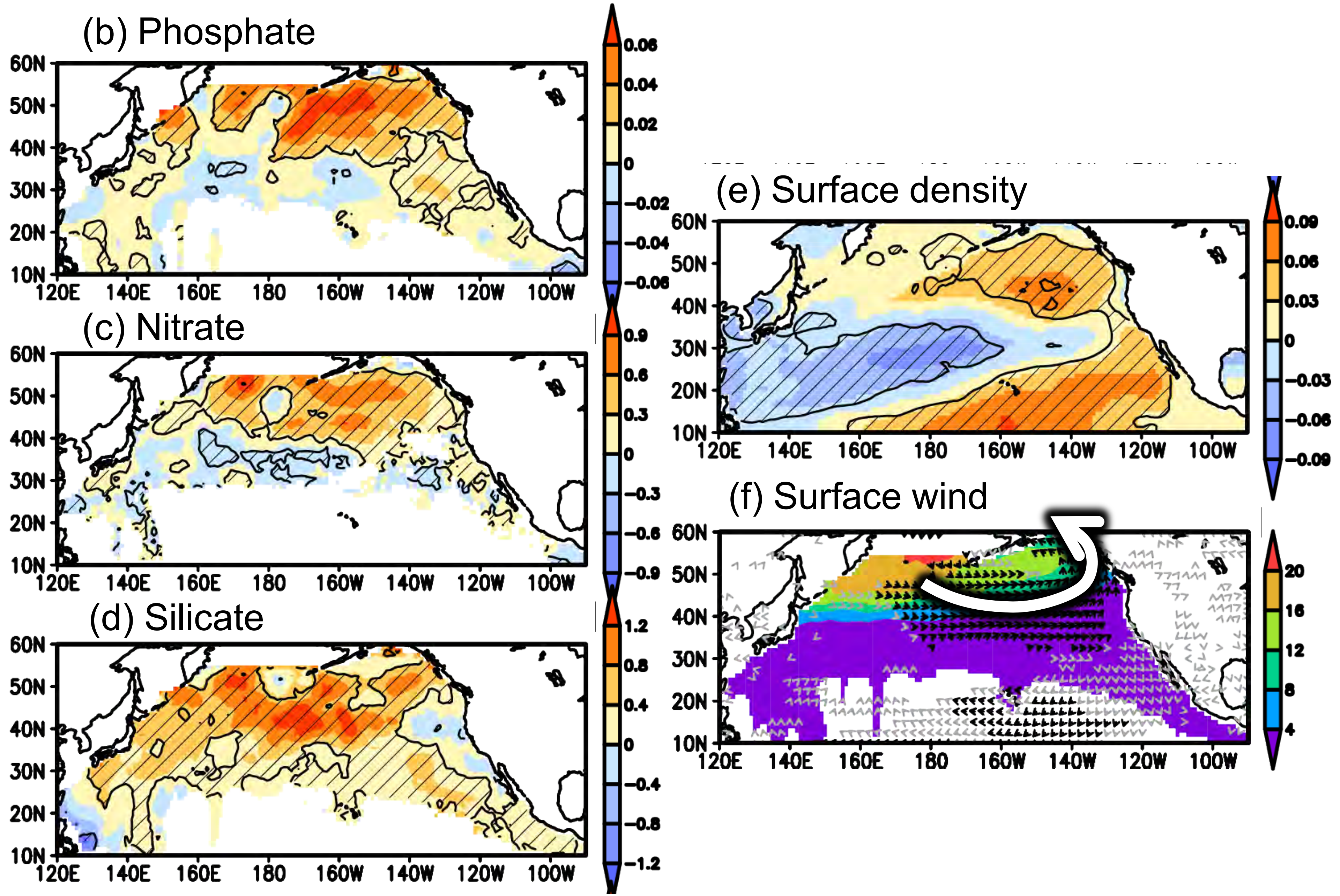
NPGO
North Pacific Gyre Oscillation

Trend

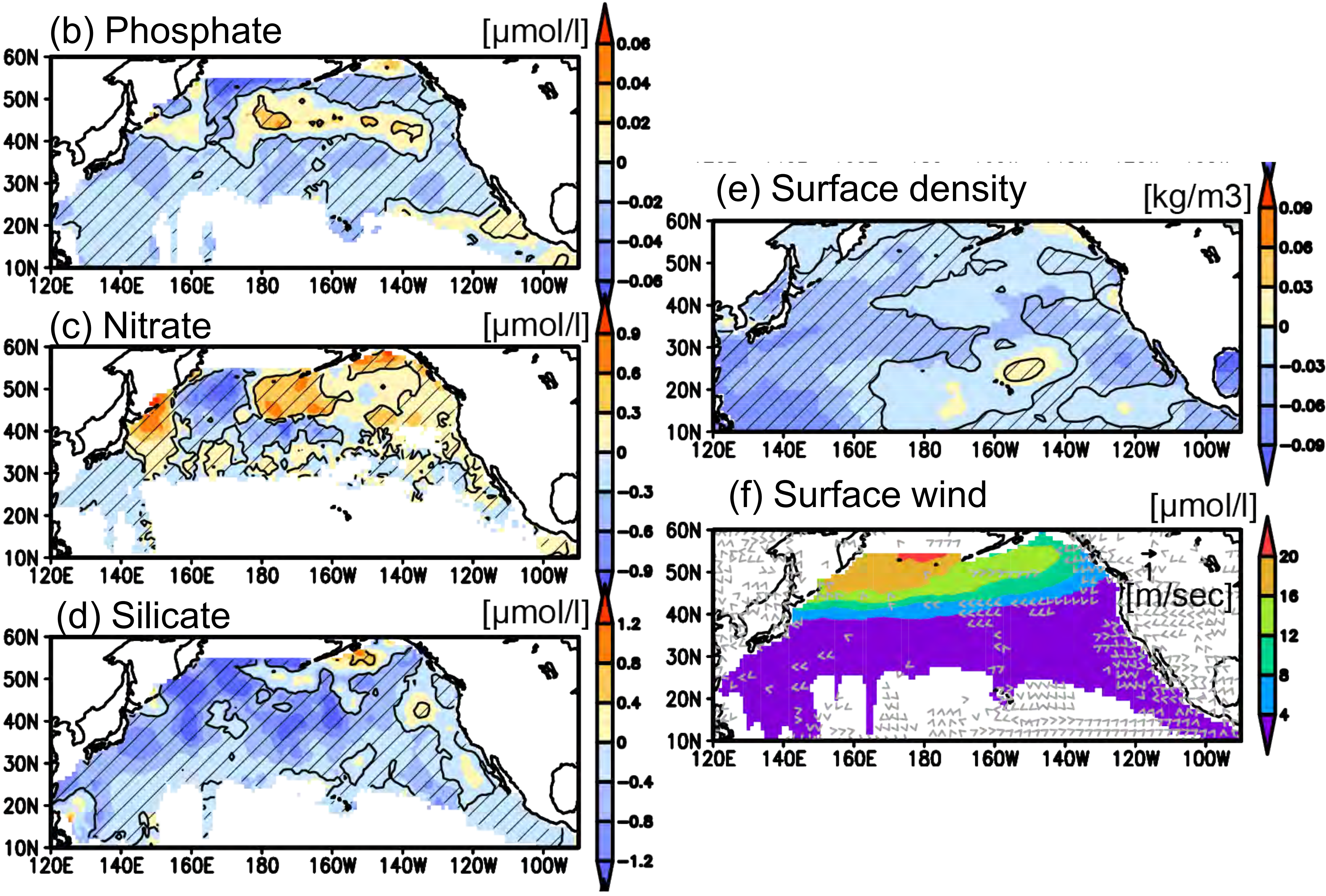
PDO: entrainment + advection → nutrient



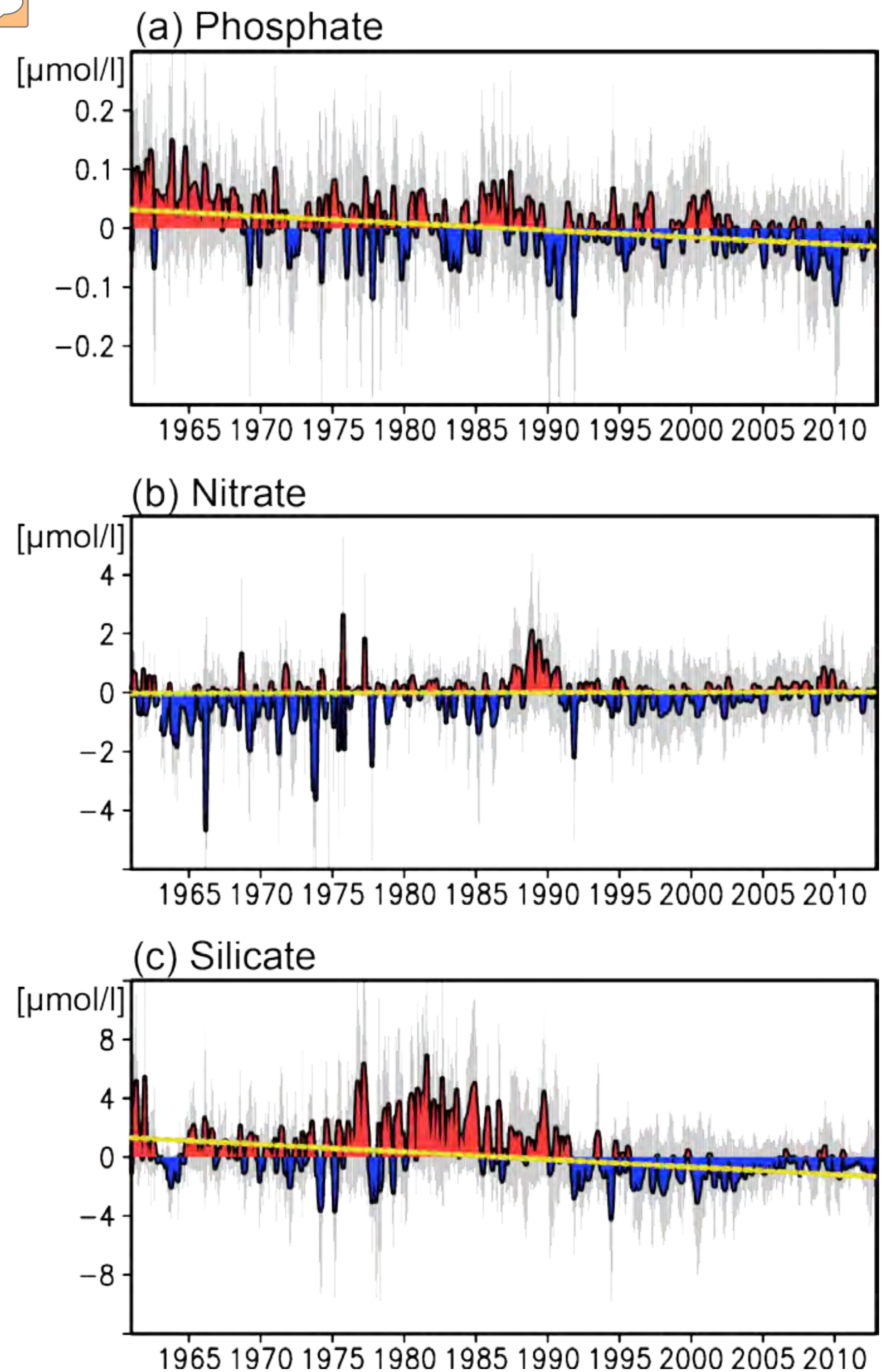
NPGO: entrainment + advection → nutrient



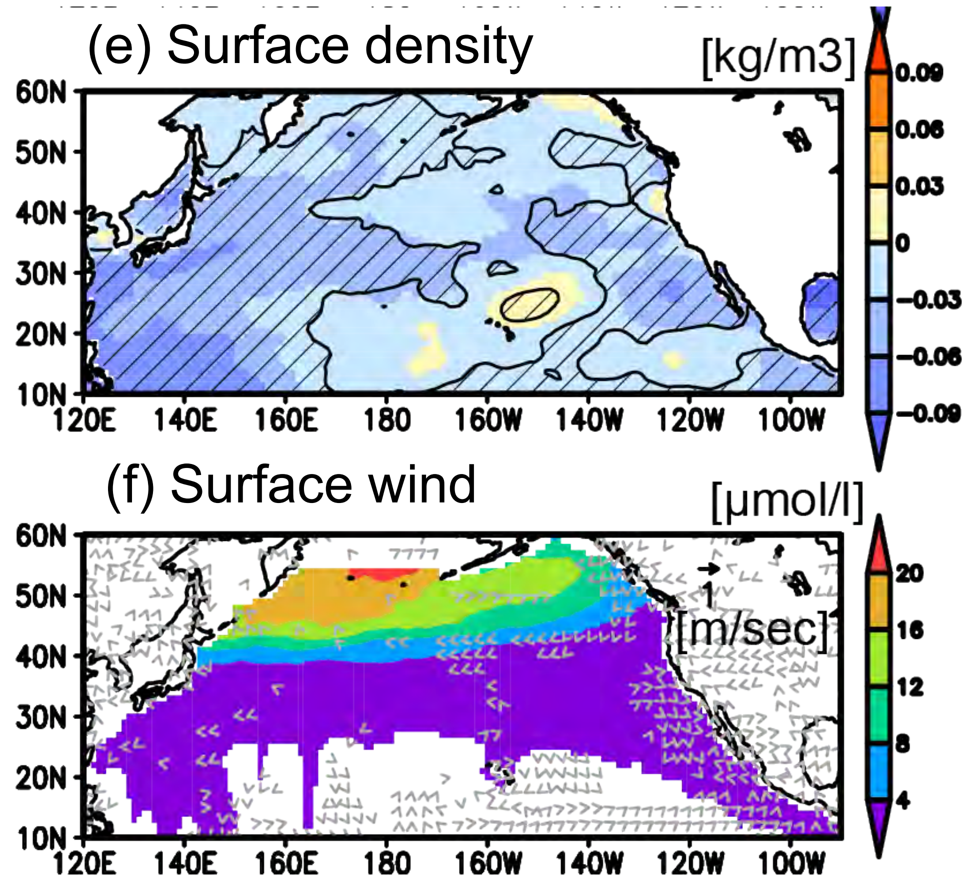
Long-term trend



Long-term trend



P: −0.012 ±0.005 μmol/l/dec
N: −0.001 ±0.013 μmol/l/dec
Si: −0.38 ±0.13 μmol/l/dec
N*: 0.020 ±0.021 /dec



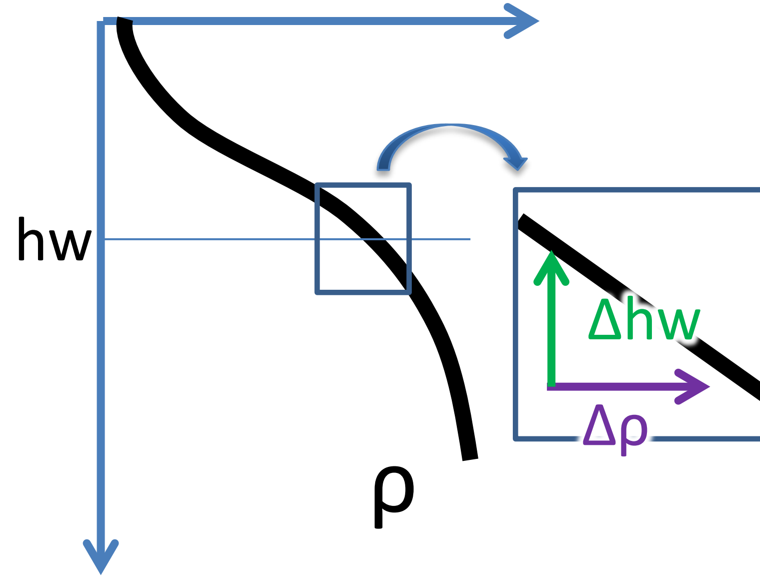
Estimate of entrainment reduction

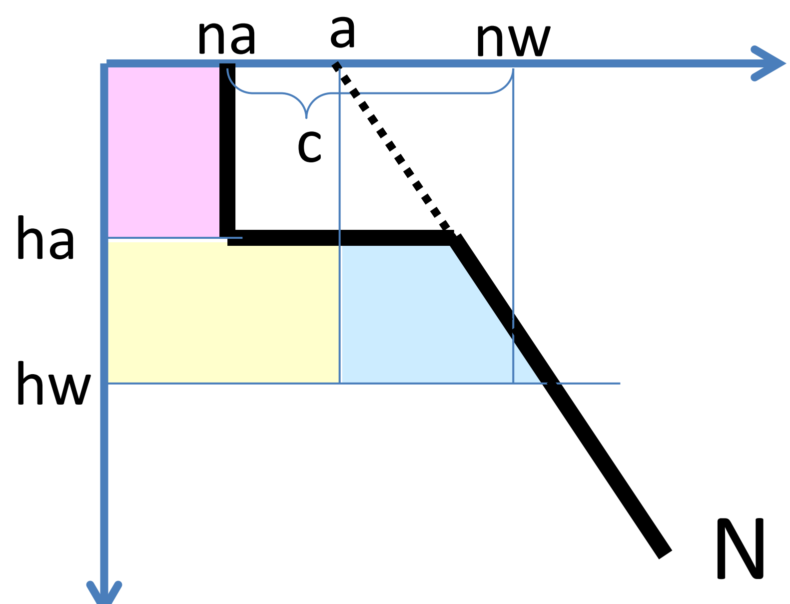
1. Obtain ρ data from T and S data from Ishii and Kimoto (2009).
2. Convert the surface ρ-trend into a long-term trend of MLD by using the climatological ρ-profiles during summer at the climatological MLD in winter. → 2.3 ± 0.9 m decade^{-1}
3. Assuming that annual new production is constant (c), determine the winter nutrient concentration at year i+1 (n^{i+1}_w) from the winter nutrient concentration at year i (n^i_w), the winter mixed layer depth (h^{i+1}_w), and summer euphotic zone depth (h_s):

$$n^{i+1}_w = \{(n^i_w - c)\, h_a + [a + b\,(h_a + h^{i+1}_w)/2](h^{i+1}_w - h_a)\}/h^{i+1}_w$$

by Freeland et al. (1997).

4. Integrate this equation over 52 years.





Long-term trend

Observed trend
P: −0.012 ±0.005 μmol/l/dec
N: −0.001 ±0.013 μmol/l/dec
Si: −0.38 ±0.13 μmol/l/dec

Entrainment effect
P: −0.014 ±0.006 μmol/l/dec
N: −0.19 ±0.09 μmol/l/dec
Si: −0. 45 ±0. 21 μmol/l/dec

P and Si trend ← deepening MLD

- Global anthropogenic N depositions：
  54 TgN/yr (Duce et al. 2008 and references therein)

→ If it is uniformly distributed in the upper 500 m of the ocean,
it increases the N concentration by 0.2 μmol/l/dec.

N trend ← deepening MLD + anthropogenic N depositions

Summary

- By using extensive ocean surface nutrient concentration data, we elucidated the spatial patterns of the nutrient concentration variabilities, which can be explained by changes in horizontal advection and vertical mixing related to the PDO and the NPGO.
- We also determined surface trends of phosphate and silicate averaged over the North Pacific that corresponded well with the effect of shoaling of the mixed layer.

Yasunaka et al. (2016), Geophysical Research Letters, 43(7), 3389-3397