PICES 2009 Annual Meeting

Understanding Ecosystem Dynamics and
Pursuing Ecosystem Approaches to Management

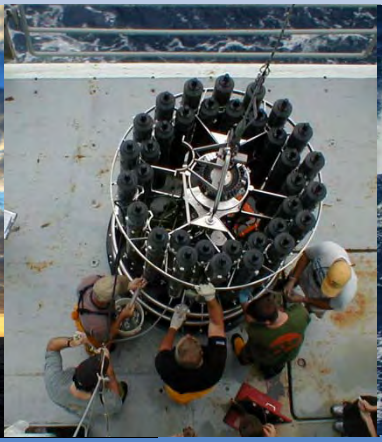
October 23 - November 1, 2009, Jeju, Korea

Past and Present Trends in Ocean Carbon Uptake and Storage in the North Pacific

by

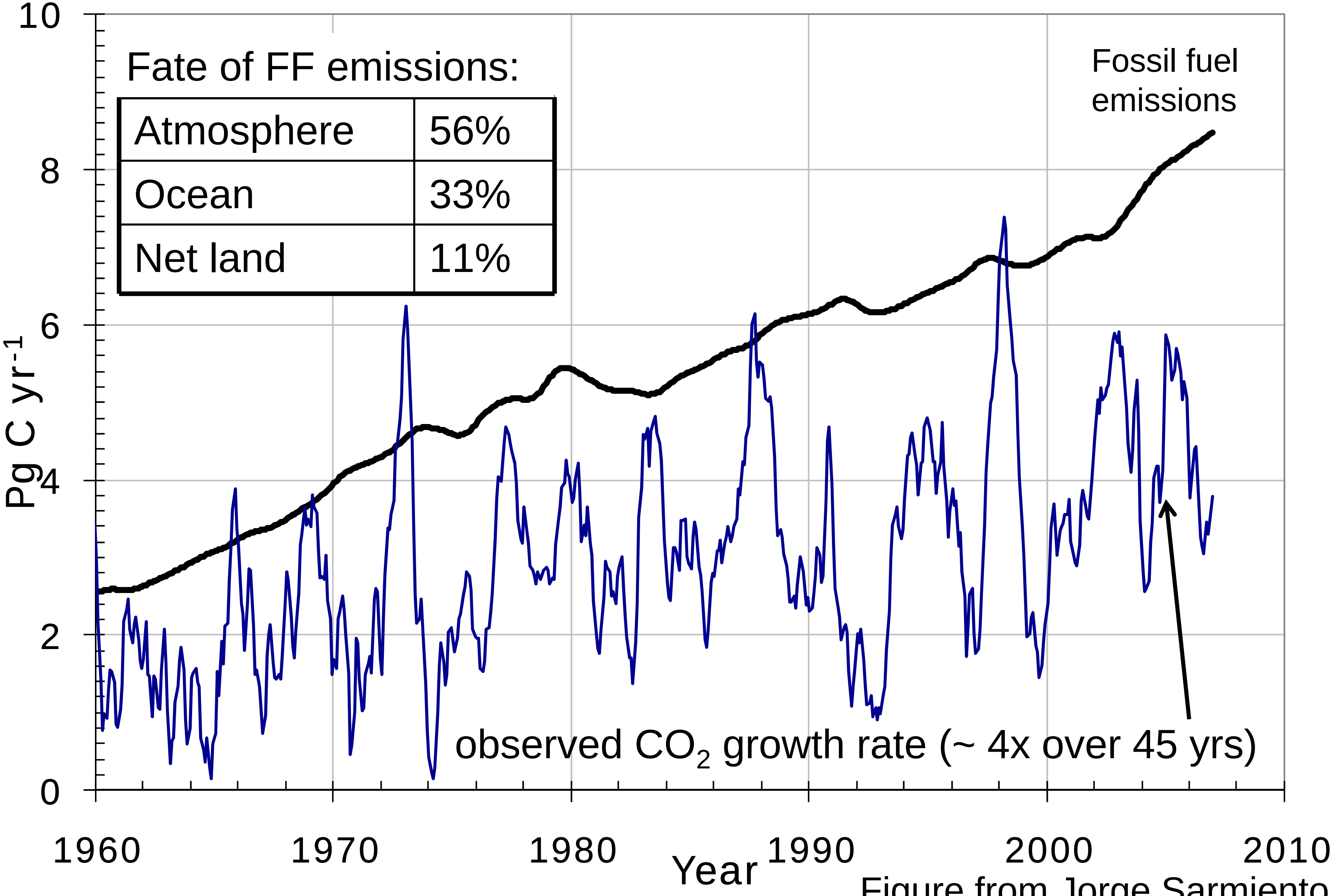
Christopher L. Sabine, Richard A. Feely, François M. M. Morel, Eric S. Egleston and Dana Greeley






This work would not be possible without the efforts of many scientists involved in the hydrographic survey cruises

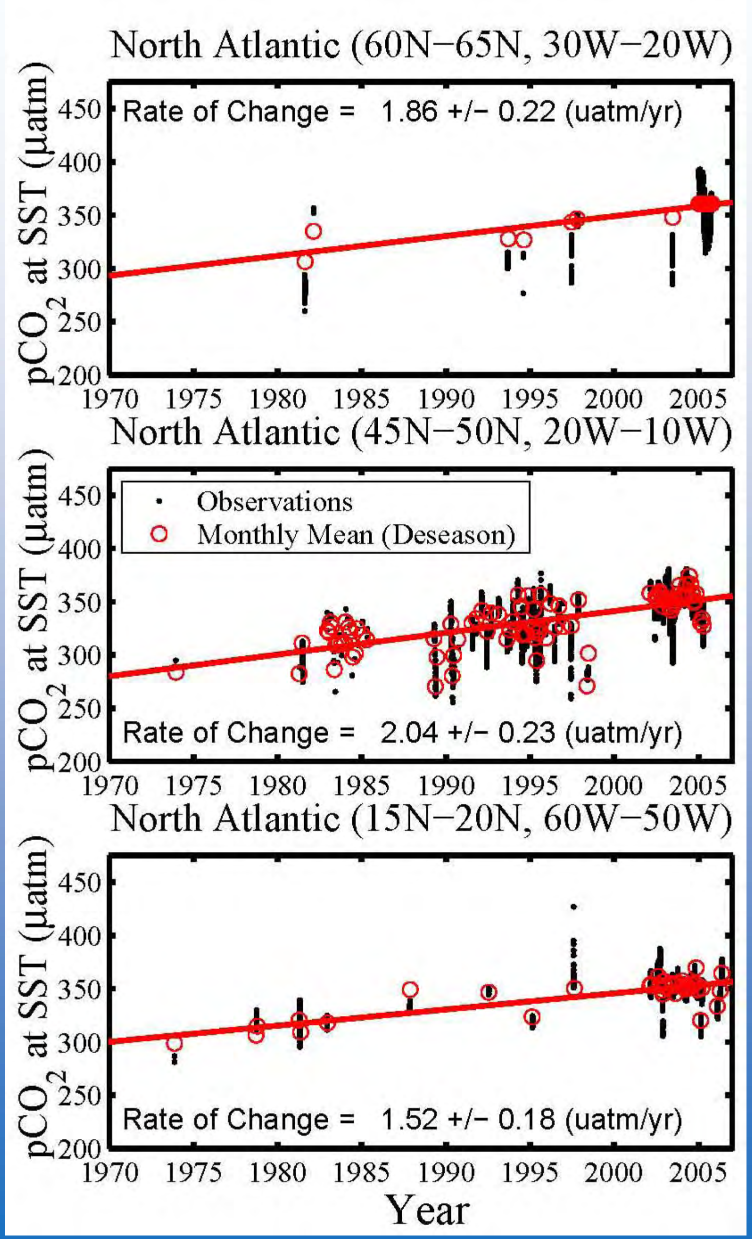
The atmospheric CO_2 growth rate is highly variable and increases with time

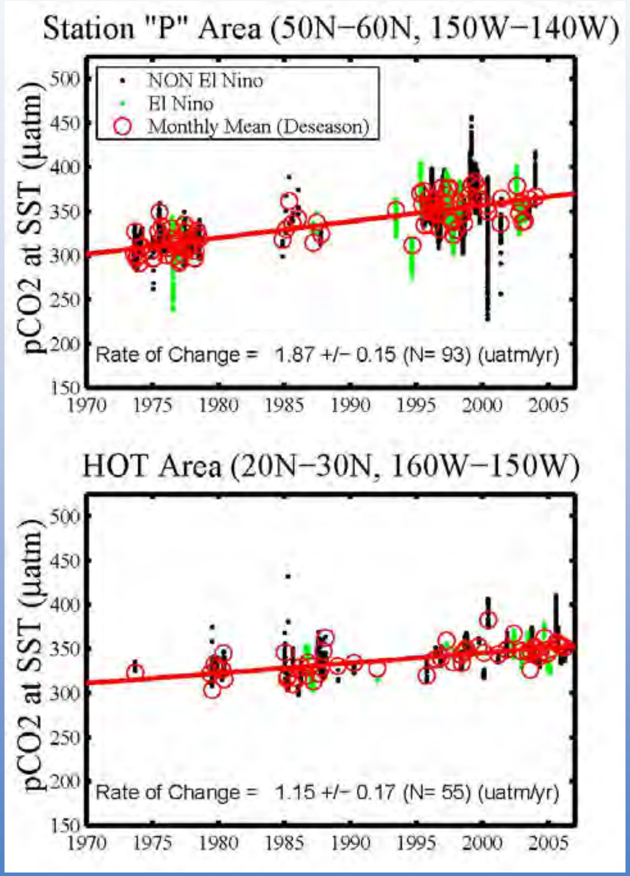


Atmosphere	56%
Ocean	33%
Net land	11%

Figure from Jorge Sarmiento

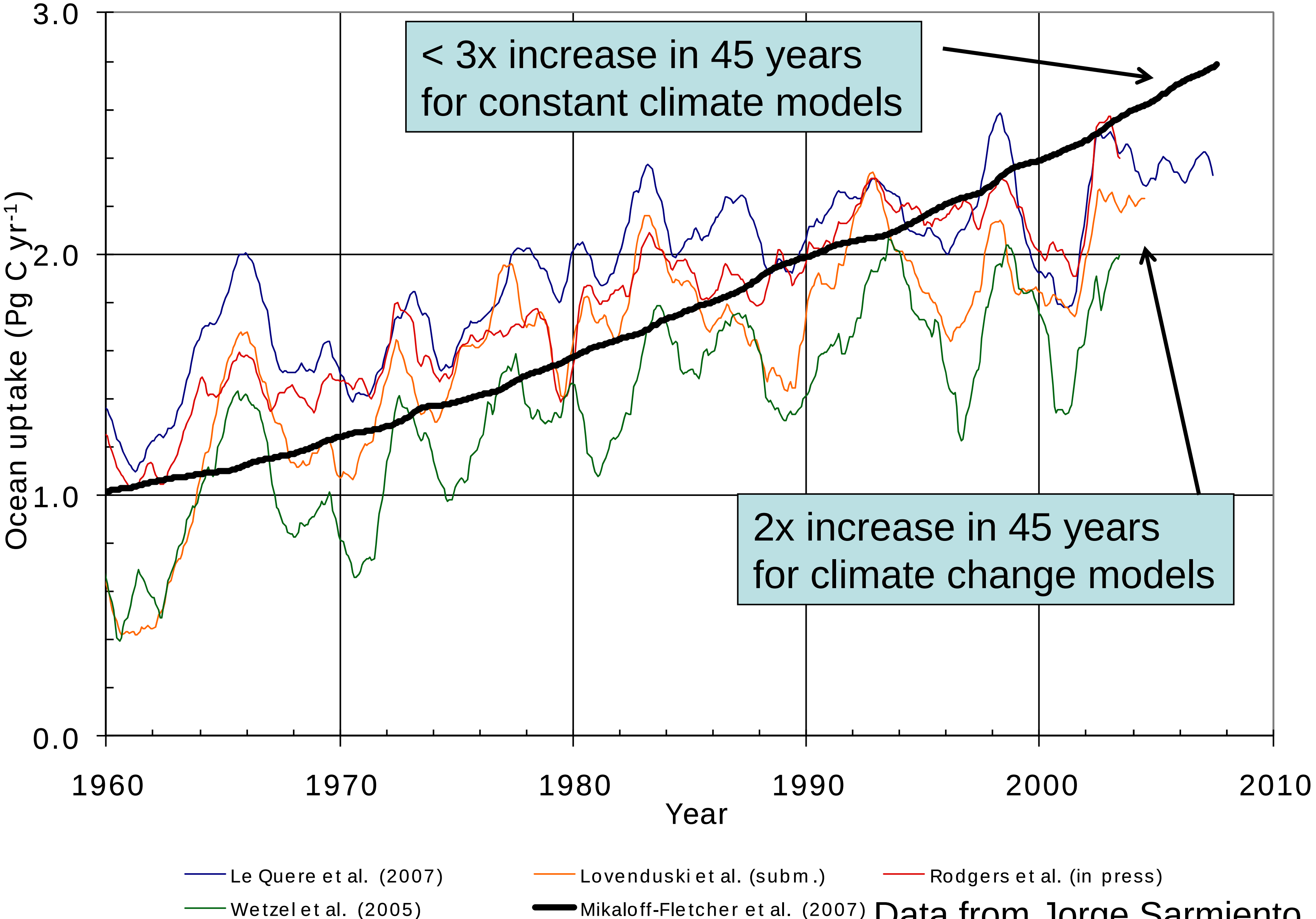
Generally surface ocean CO_2 values track the atmospheric increase





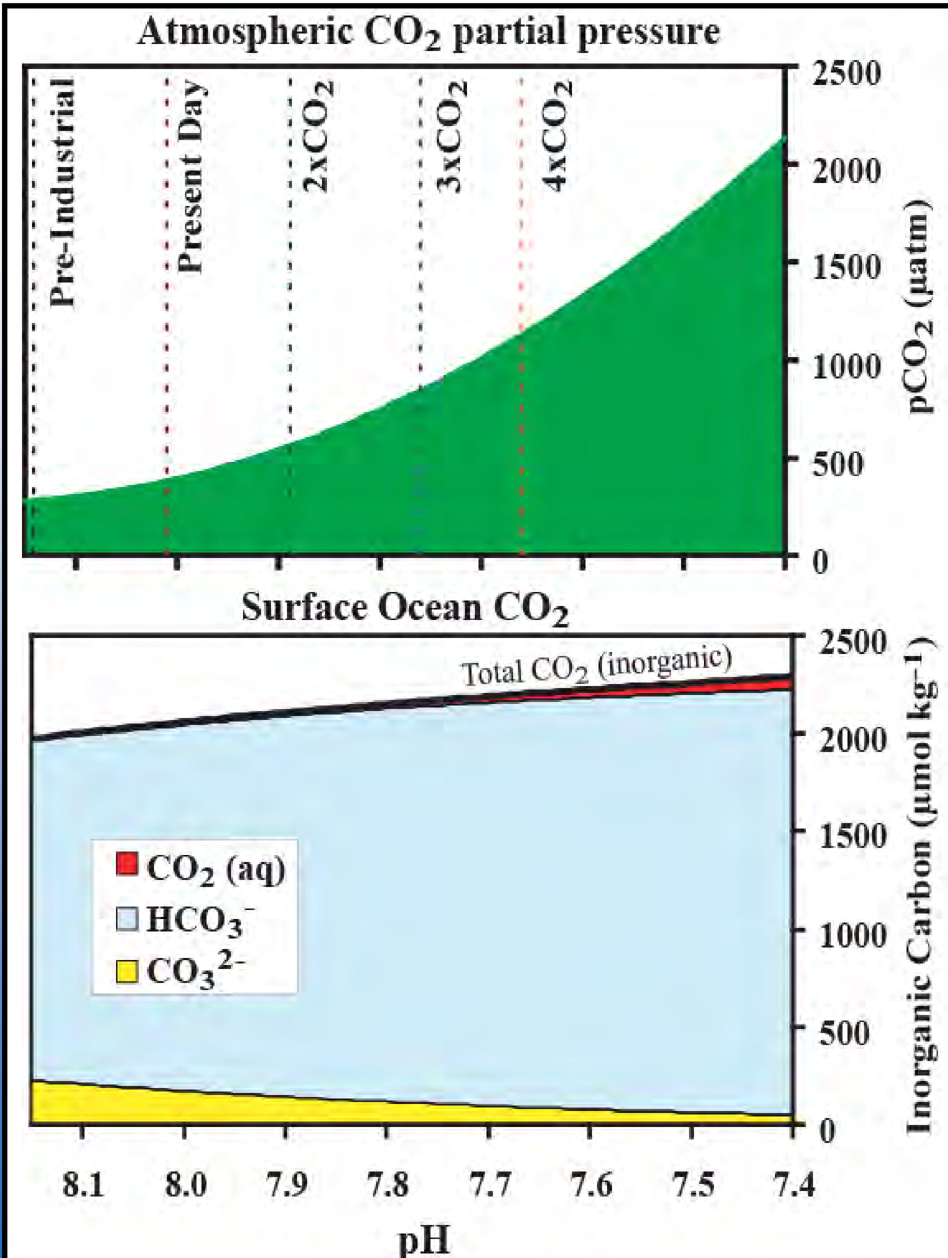
From Takahashi et al 2009

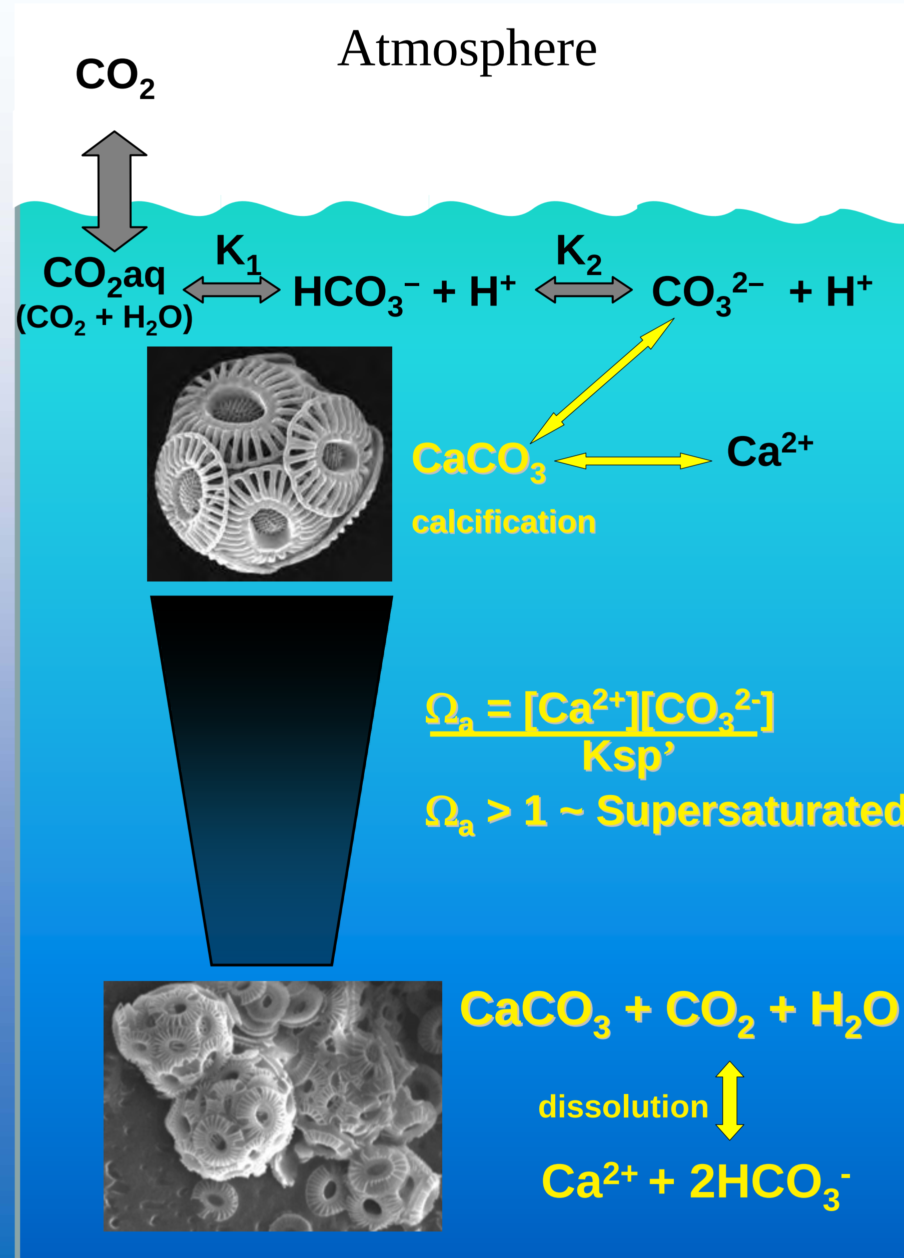
Models suggest that uptake efficiency will decrease in future



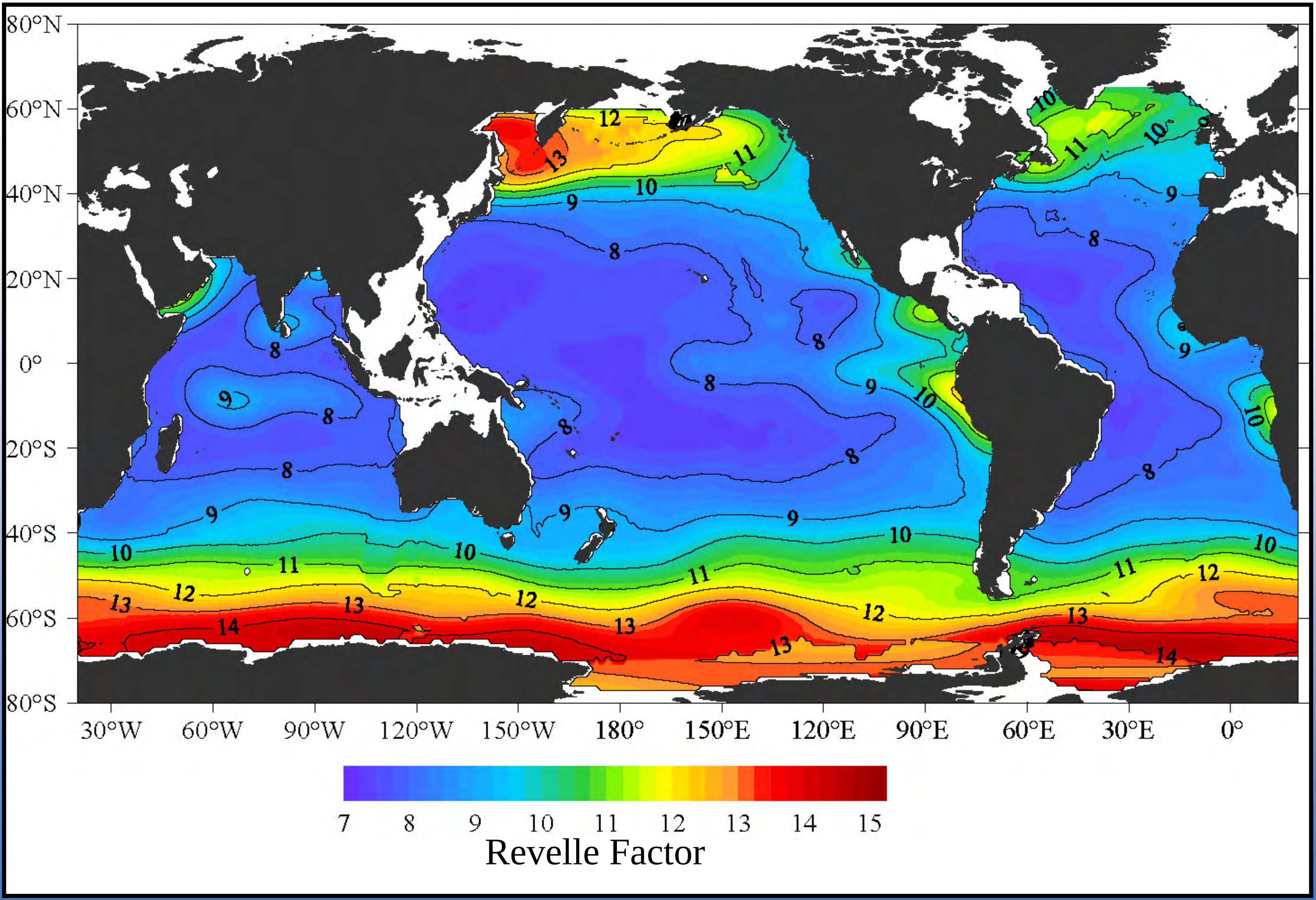
Data from Jorge Sarmiento

Chemical Reactions of Carbonate Species in Seawater





Global Distribution of Surface Revelle Factor



R. Revelle, H.,E. Suess, Tellus 9, 18 (1957)

$$\frac{(\Delta fCO_2 / \Delta DIC)}{(fCO_2 / DIC)}$$

Here we define six new buffer factors, each of which can be explicitly calculated:

$$\gamma_{\mathrm{DIC}} = \left(\frac{\partial \ln[\mathrm{CO_2}]}{\partial \mathrm{DIC}}\right)^{-1} = \mathrm{DIC} - \frac{\mathrm{Alk_C^2}}{S}$$

equivalent to traditional Revelle Factor that can be used to determine the efficiency of the ocean sink as CO_2 rises

$$\gamma_{\mathrm{Alk}} = \left(\frac{\partial \ln[\mathrm{CO_2}]}{\partial \mathrm{Alk}}\right)^{-1} = \frac{\mathrm{Alk_C^2} - \mathrm{DIC} \times S}{\mathrm{Alk_C}}$$

similar to Revelle Factor but looks at the impact of changing alkalinity on CO_2

$$\beta_{\mathrm{Alk}} = \left(\frac{\partial \ln[\mathrm{H^+}]}{\partial \mathrm{Alk}}\right)^{-1} = \frac{\mathrm{Alk_C^2}}{\mathrm{DIC}} - S$$

general buffer capacity – resistance of pH to addition of acid/base

Revelle Factor = DIC/γ_{DIC}

$$\beta_{\mathrm{DIC}} = \left(\frac{\partial \ln[\mathrm{H^+}]}{\partial \mathrm{DIC}}\right)^{-1} = \frac{\mathrm{DIC} \times S - \mathrm{Alk_C^2}}{\mathrm{Alk_C}}$$

in practice this is equivalent to - γ_{Alk}

$$\omega_{\mathrm{DIC}} = \left(\frac{\partial \ln \Omega}{\partial \mathrm{DIC}}\right)^{-1} = \mathrm{DIC} - \frac{\mathrm{Alk_C} \times P}{[\mathrm{HCO_3^-}]}$$

a measure of the impact of DIC changes on saturation state

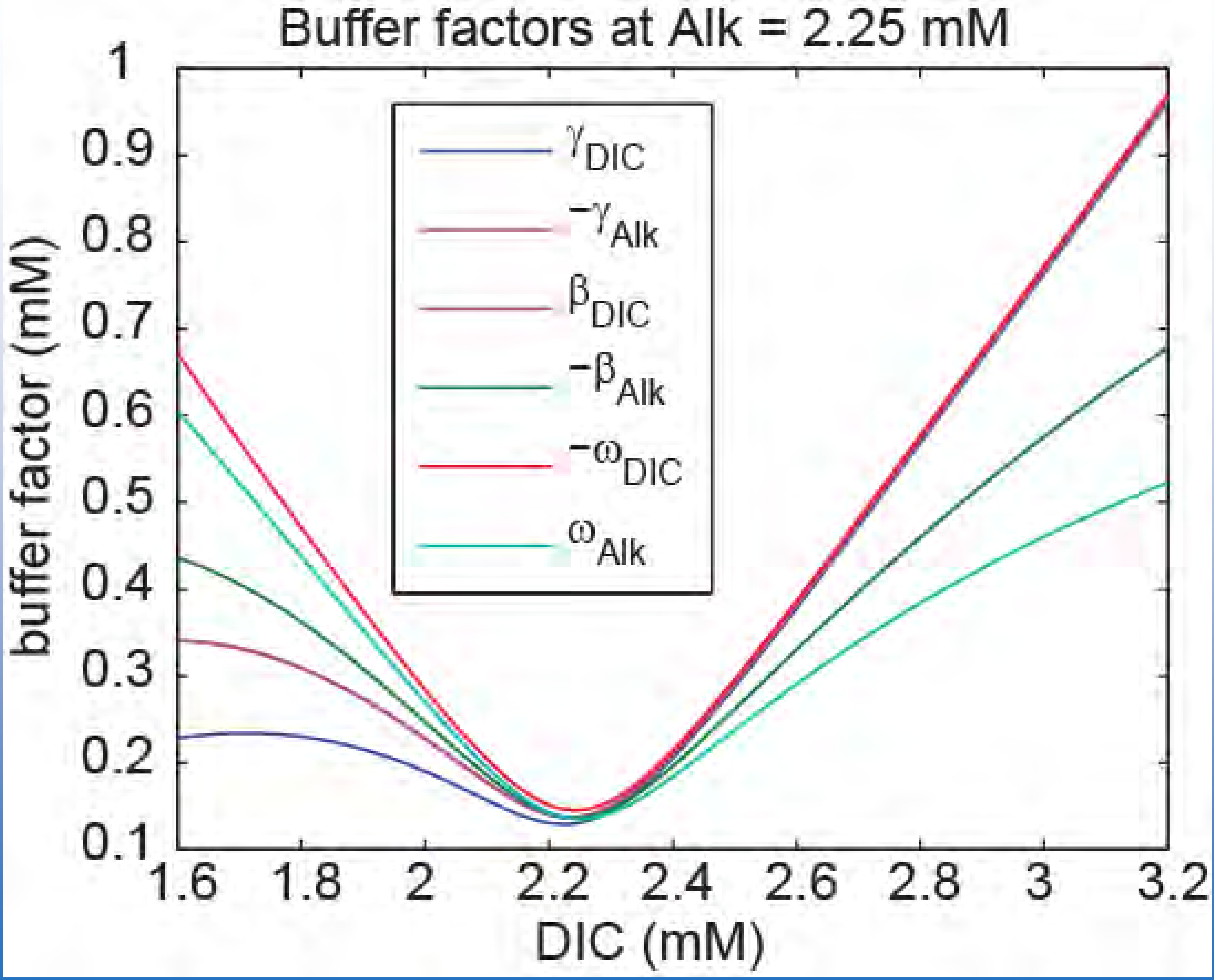
$$\omega_{\mathrm{Alk}} = \left(\frac{\partial \ln \Omega}{\partial \mathrm{Alk}}\right)^{-1} = \mathrm{Alk_C} - \frac{\mathrm{DIC}[\mathrm{HCO_3^-}]}{P}$$

a measure of the impact of alkalinity changes on saturation state

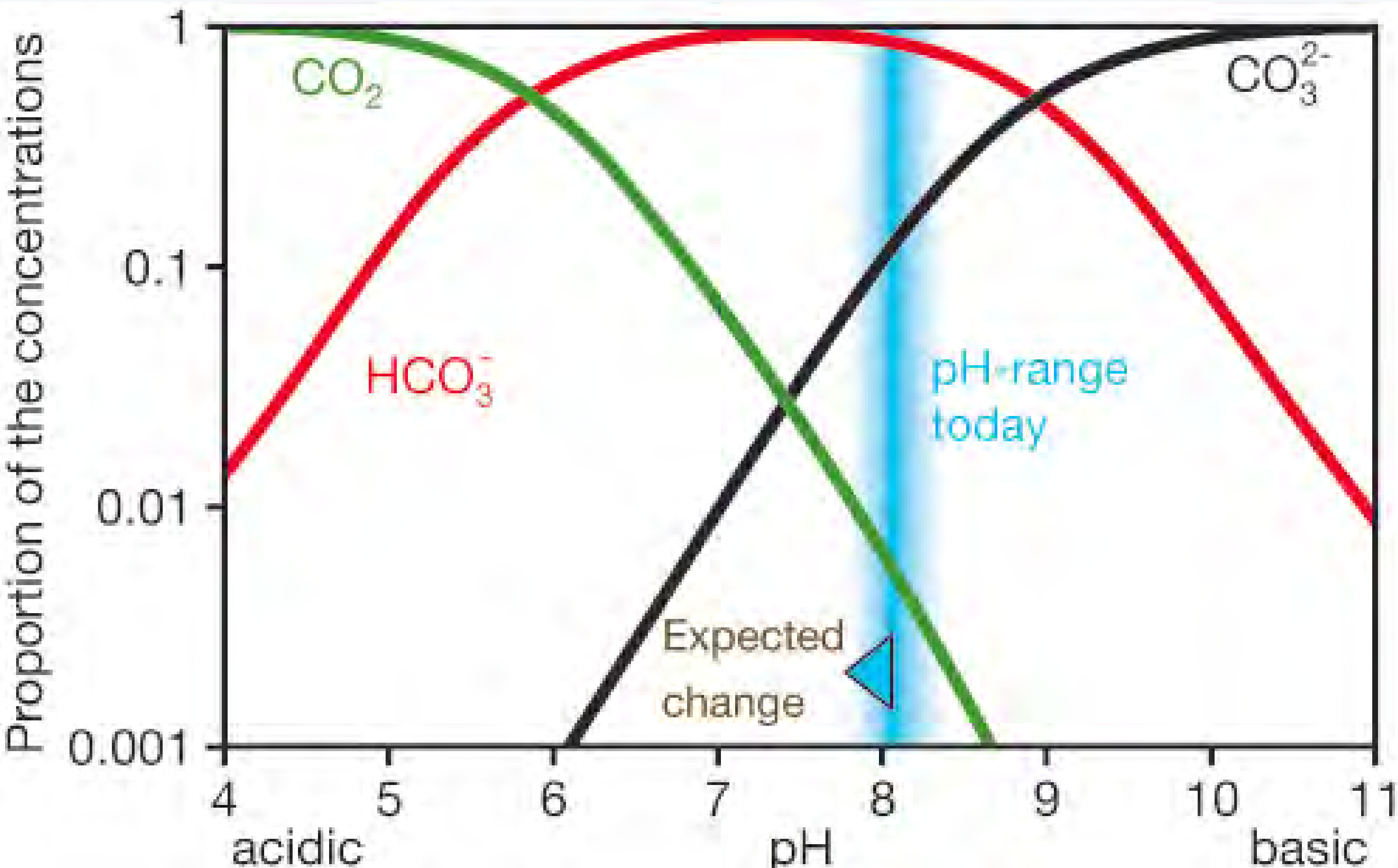
$$S = [\mathrm{HCO_3^-}] + 4[\mathrm{CO_3^{2-}}] + \frac{[\mathrm{H^+}][\mathrm{B(OH)_4^-}]}{K_{hb} + [\mathrm{H^+}]} + [\mathrm{H^+}] - [\mathrm{OH^-}]$$

$$P = 2[\mathrm{CO_2}] + [\mathrm{HCO_3^-}]$$

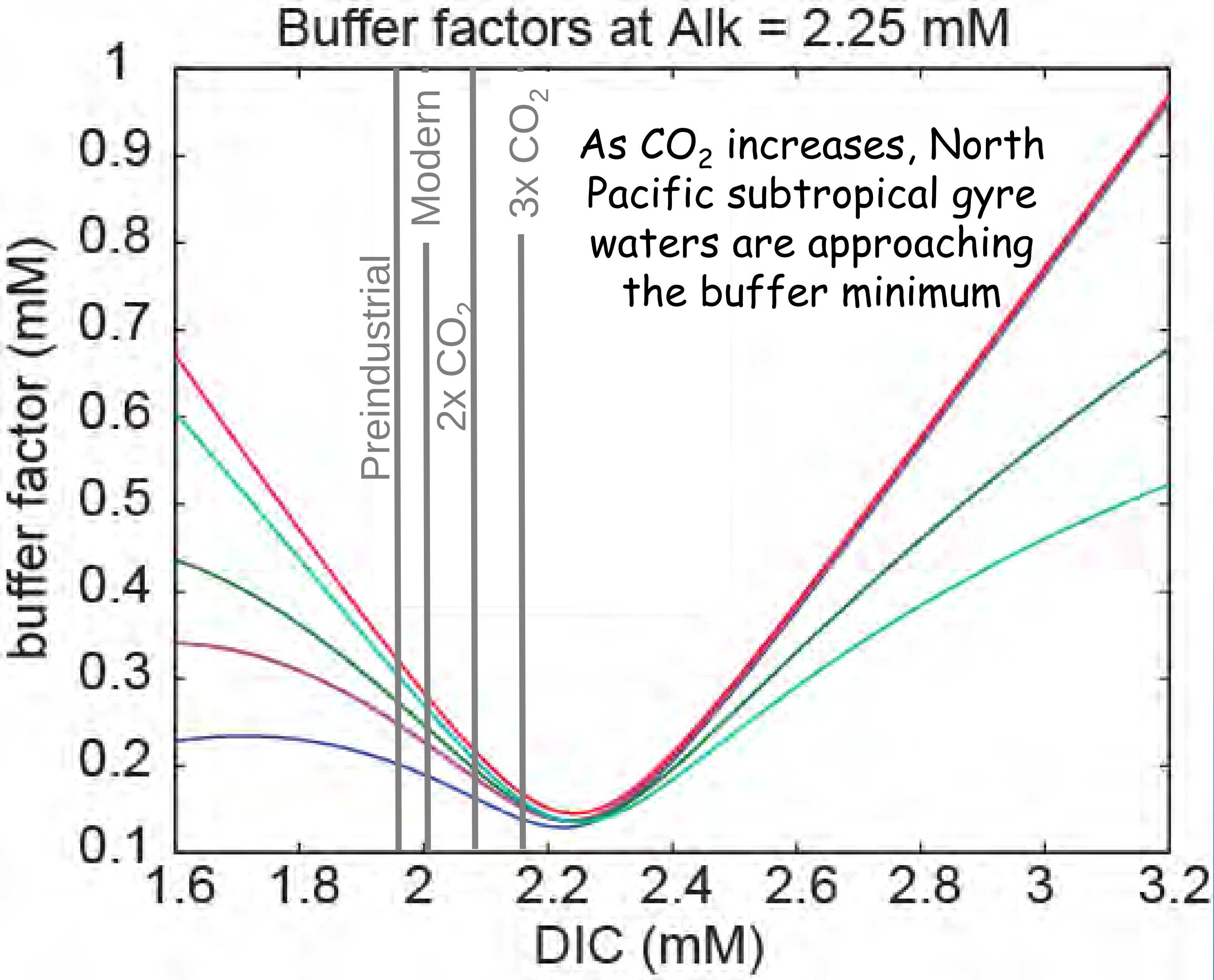
All Buffer Factors show a minimum where DIC=Alk



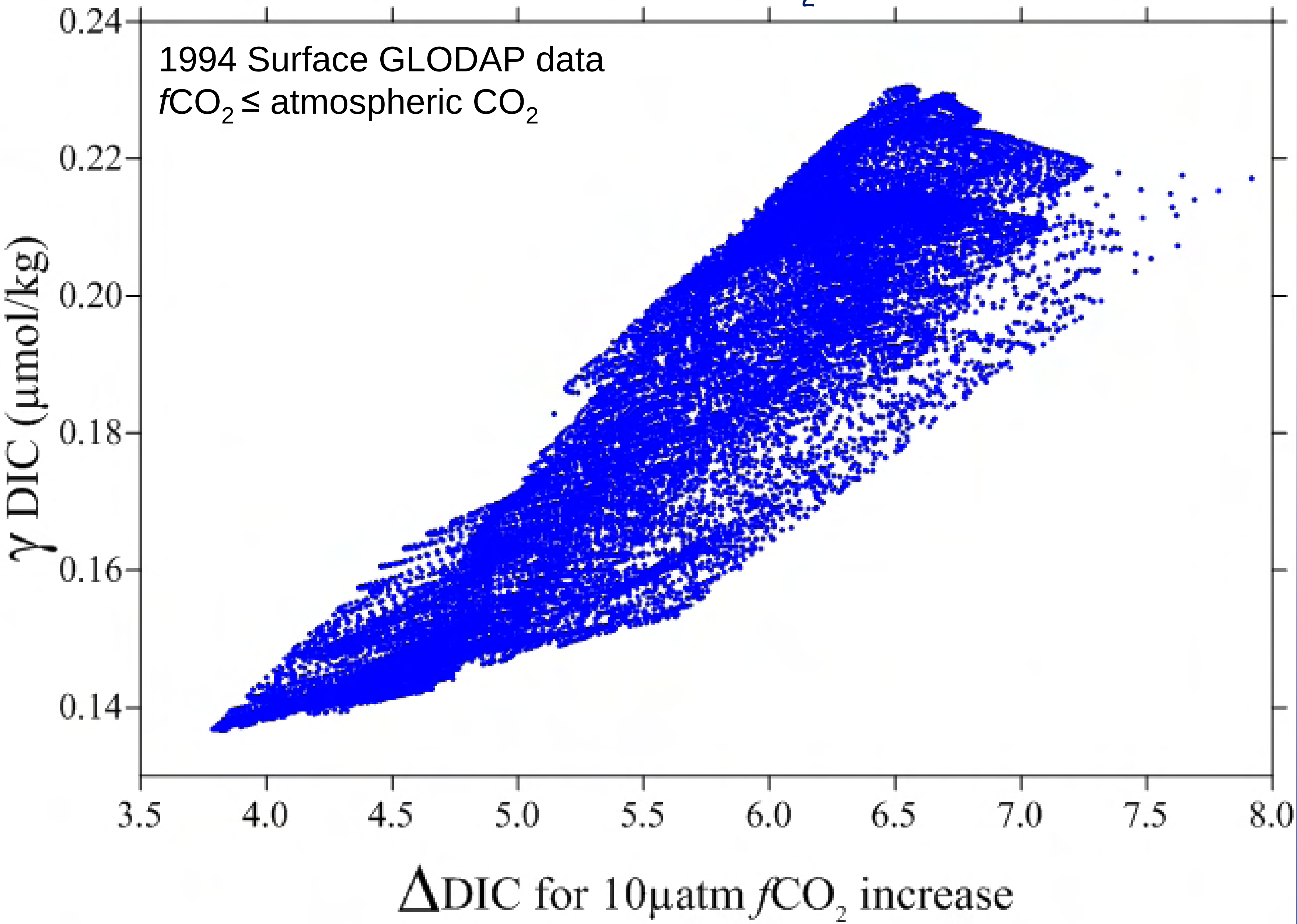
$$CO_{2(aq)} + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + H^+$$



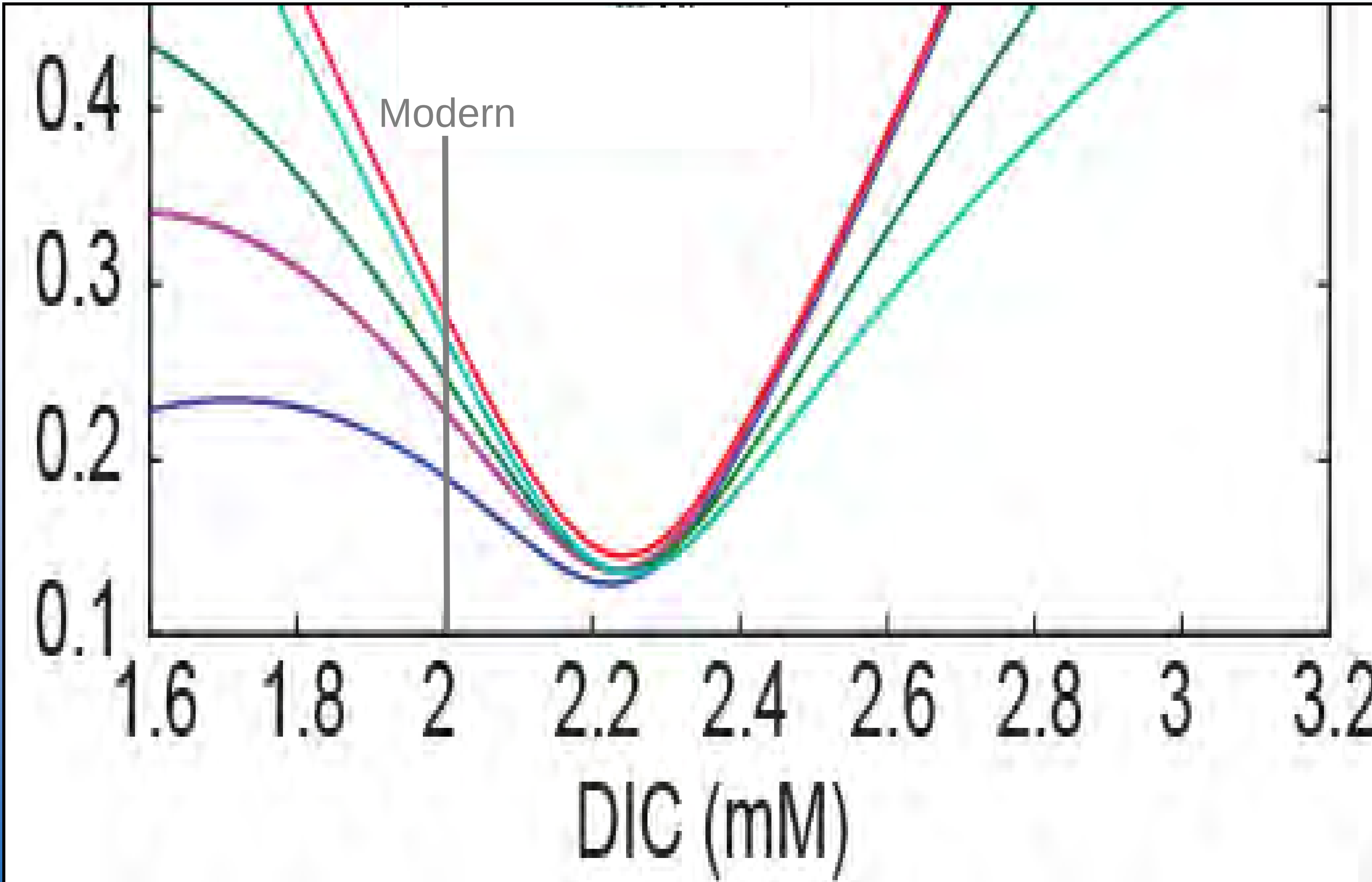
All Buffer Factors show a minimum where DIC=Alk



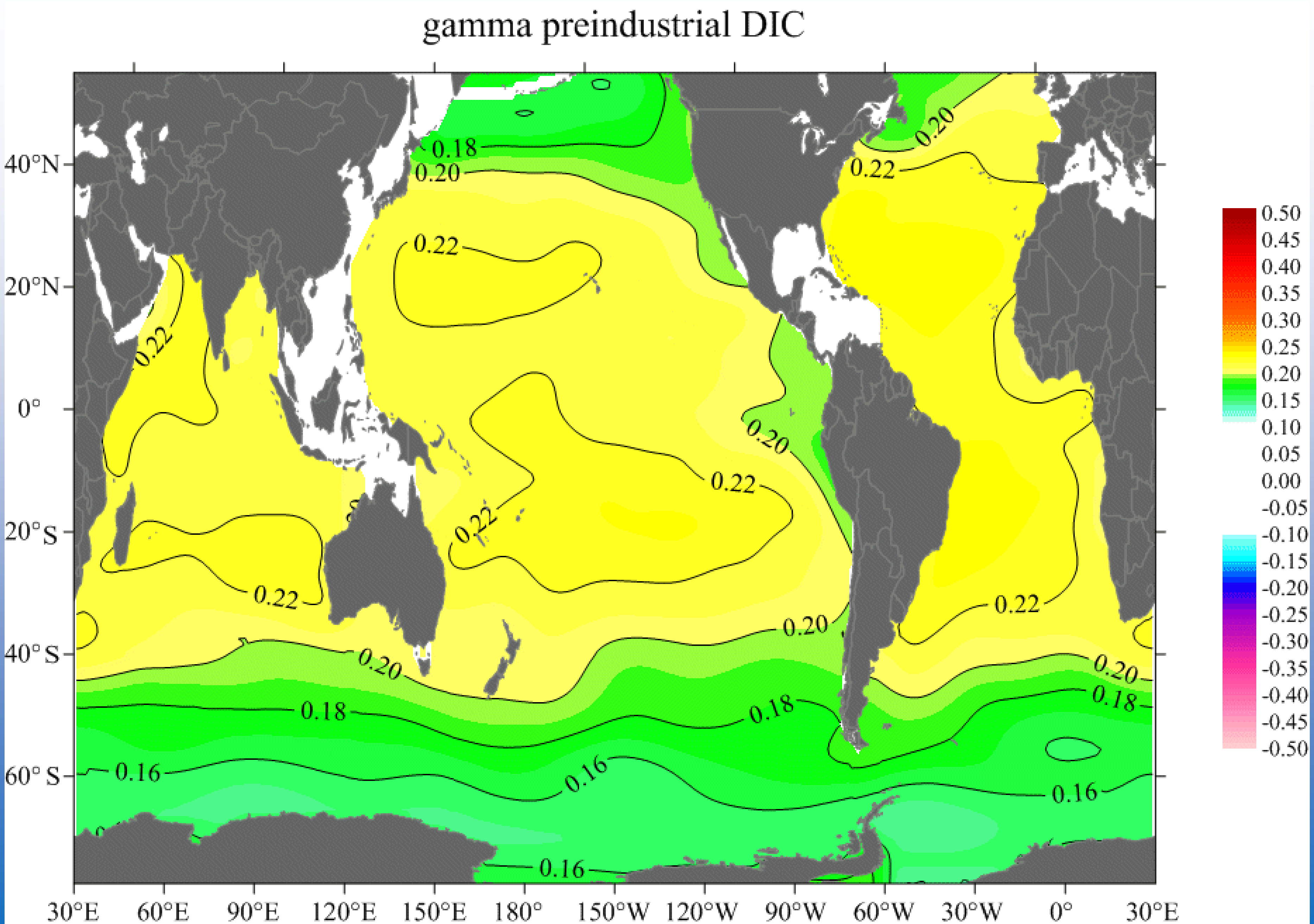
Higher buffer factor means larger DIC increase for the same amount of CO_2 rise



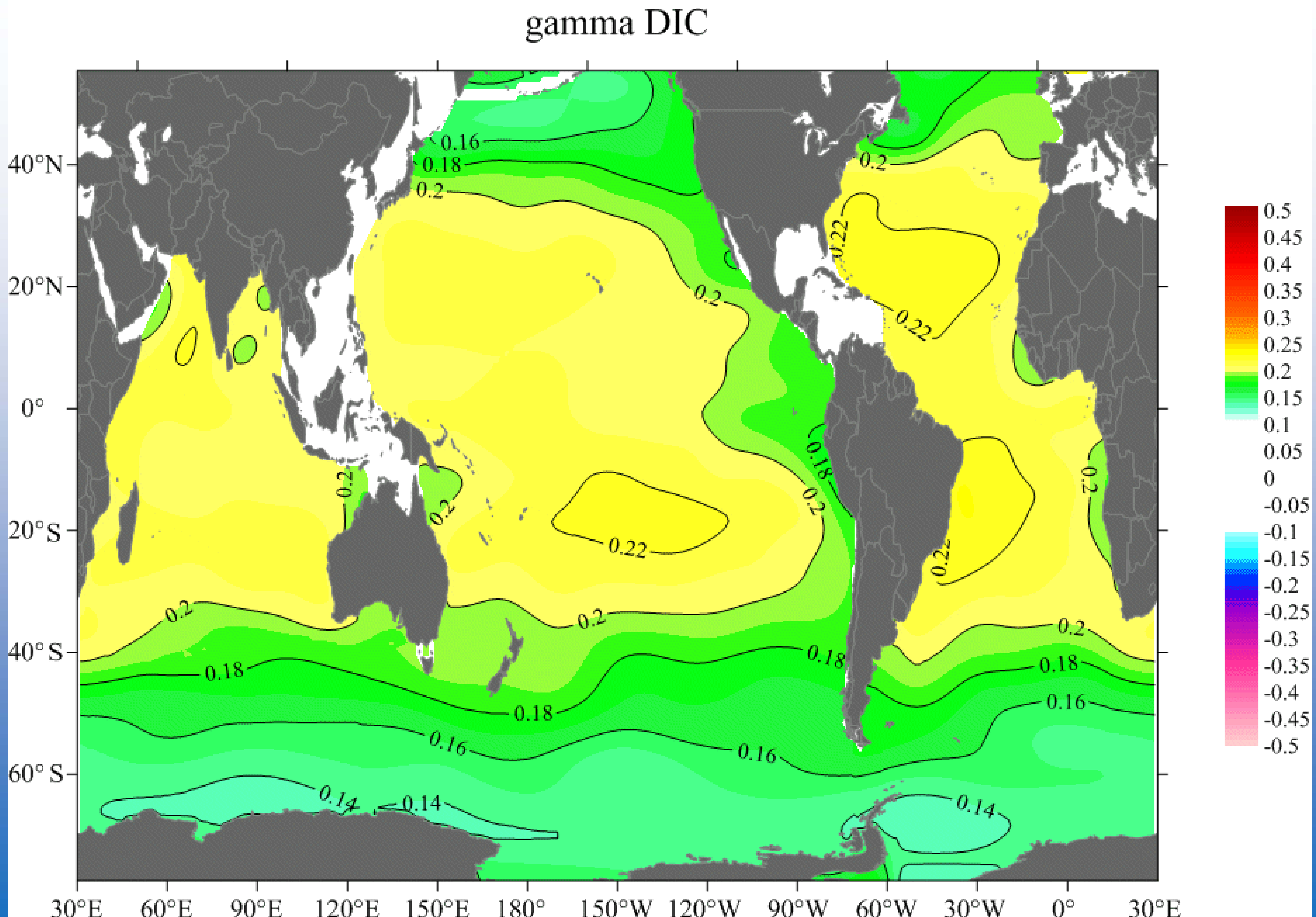
Range is from the shallow slope, but as DIC increases the slope increases



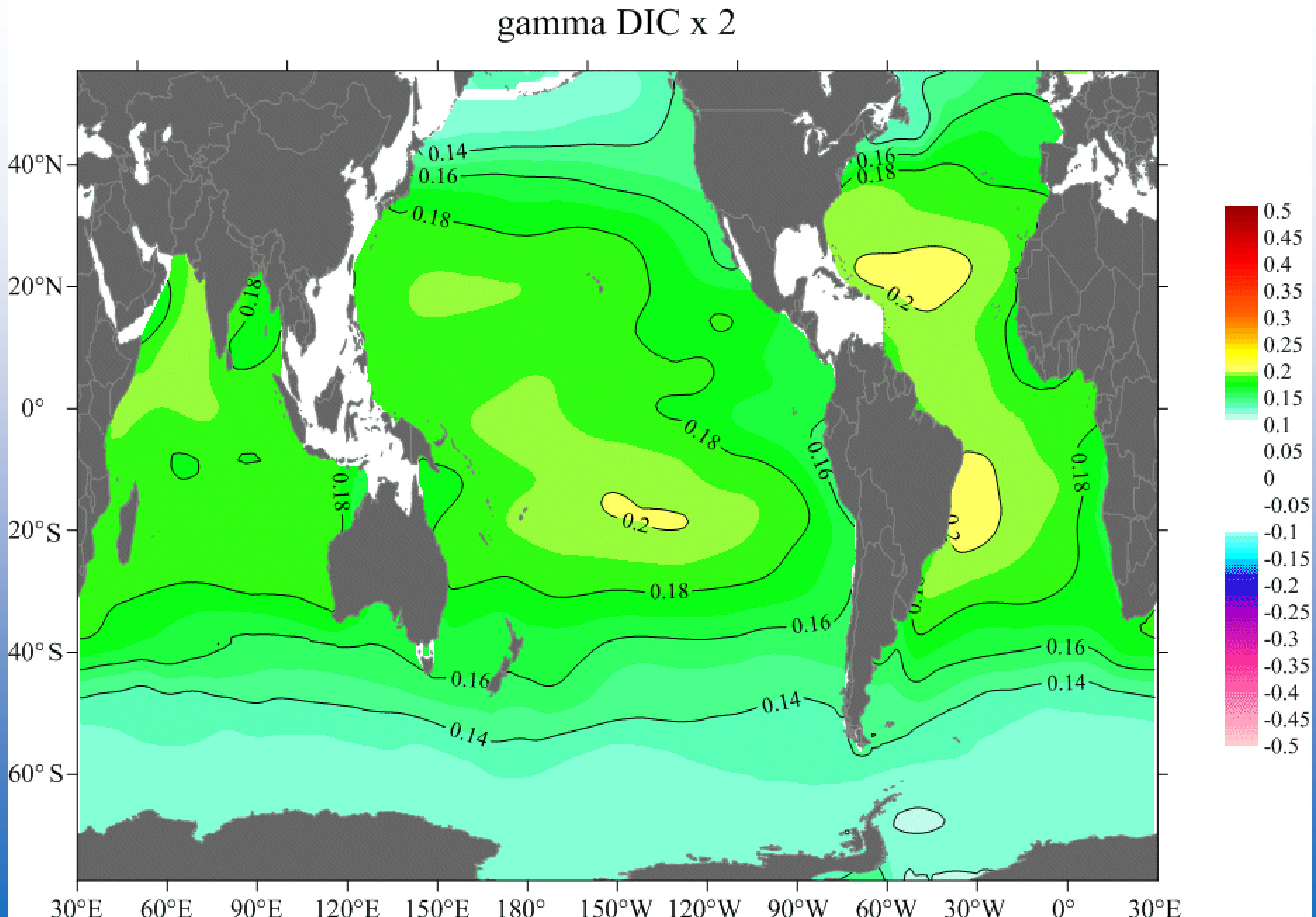
Preindustrial North Pacific ranges from 0.17-0.23 (Δ=.06)



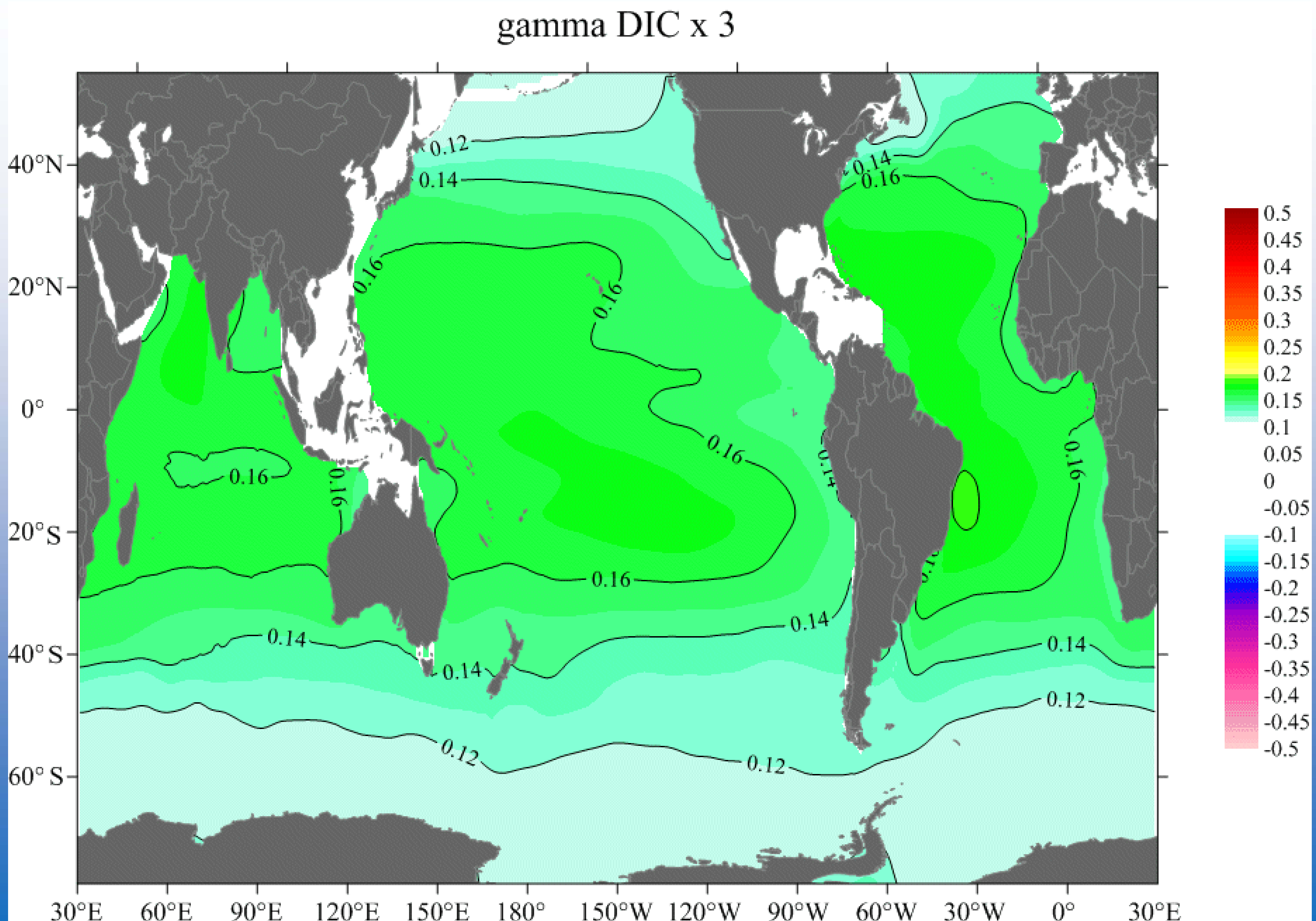
Modern North Pacific ranges from 0.15-0.21 (Δ=.06)



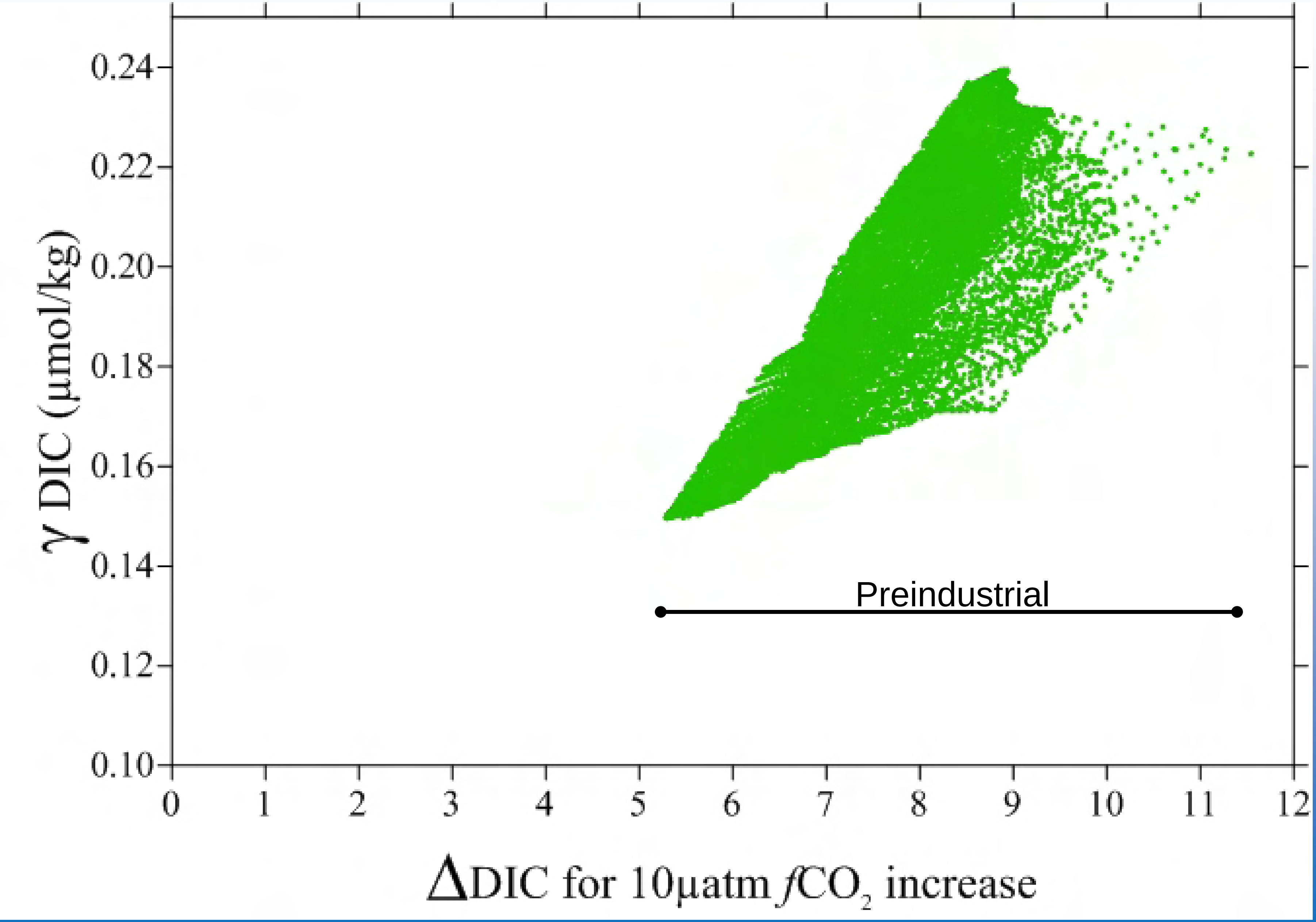
Modern North Pacific ranges from 0.13-0.19 (Δ=.06)



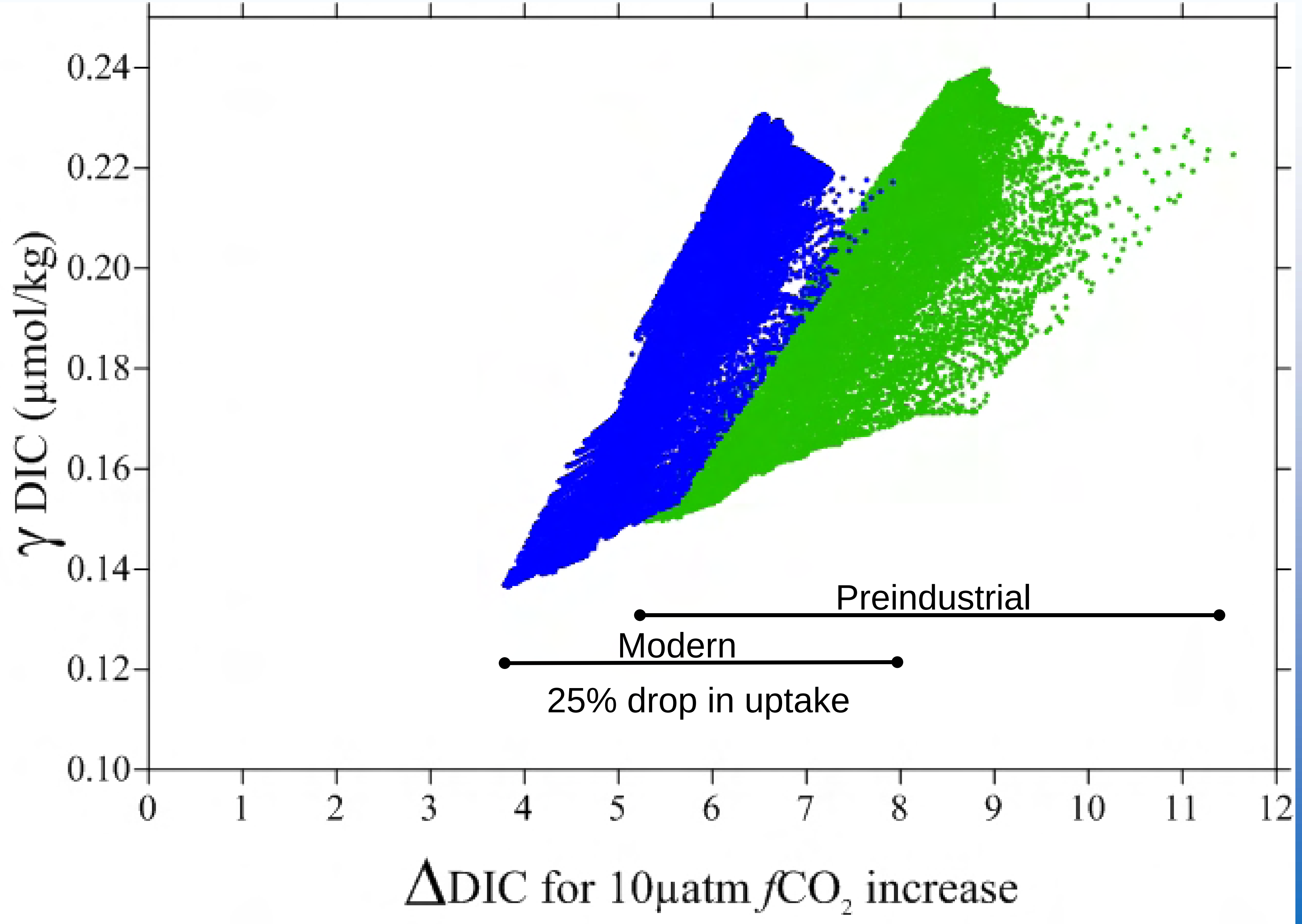
Modern North Pacific ranges from 0.11-0.17 (Δ=.06)



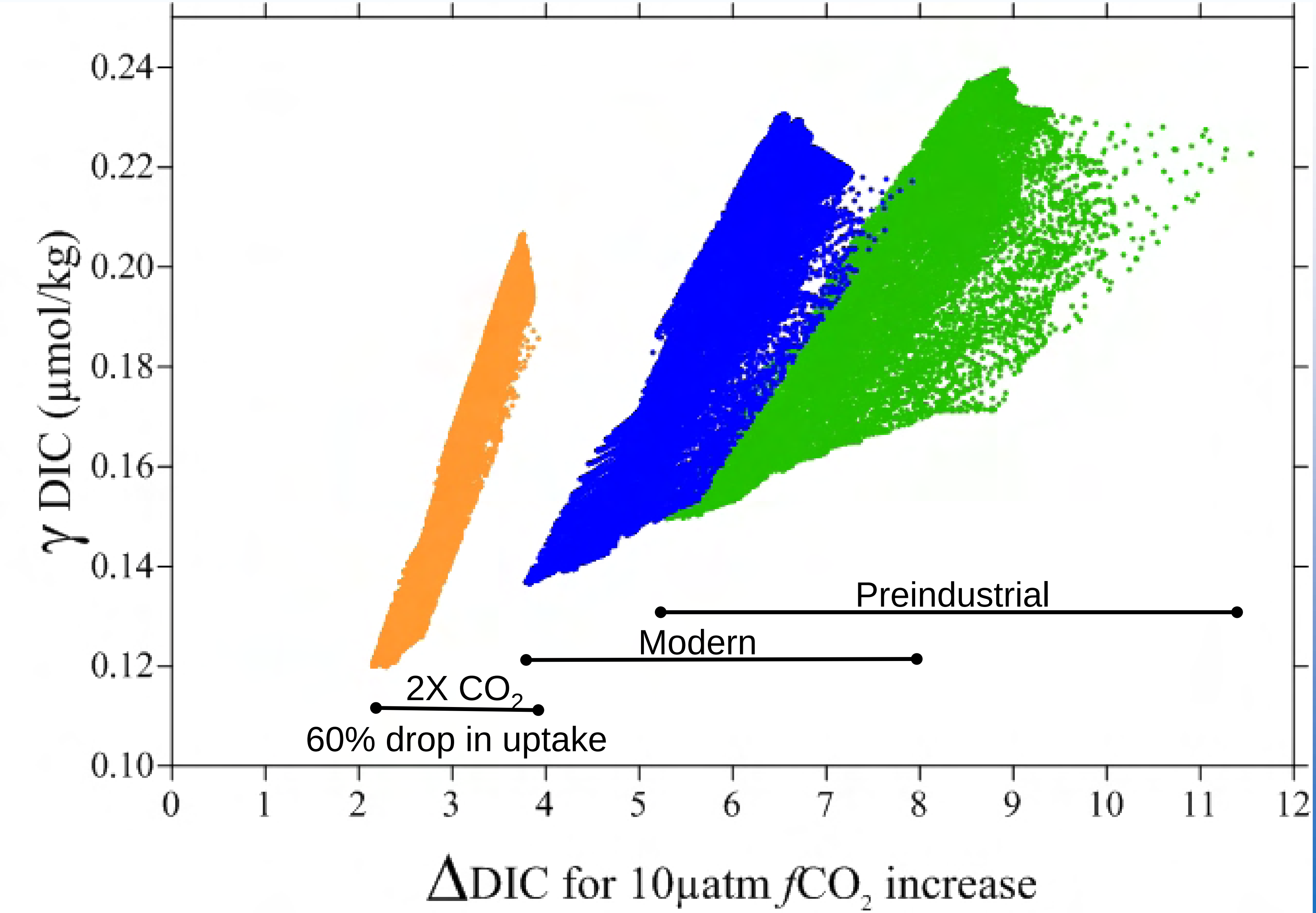
Higher buffer factor means larger DIC increase for the same amount of CO_2 rise



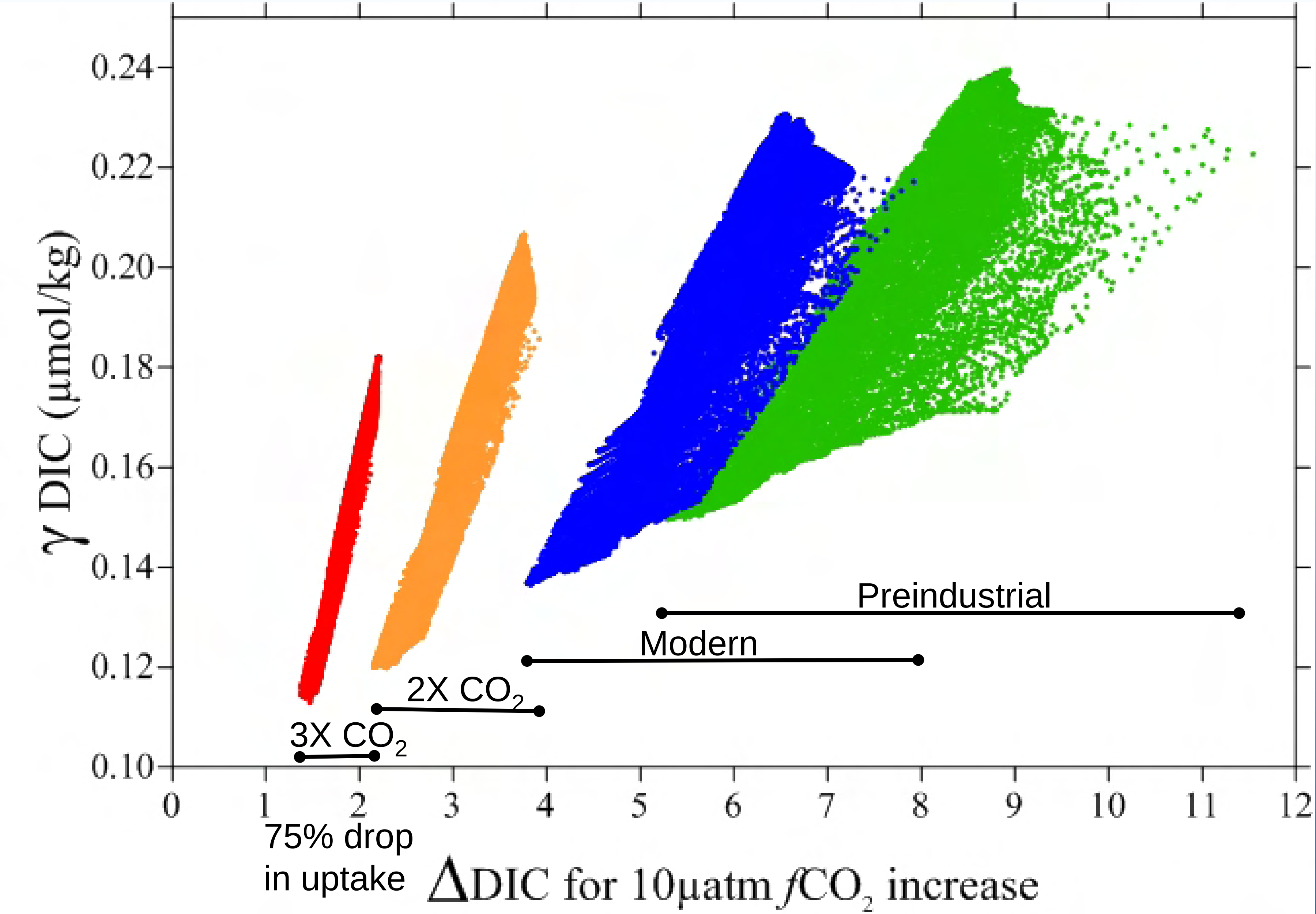
Higher buffer factor means larger DIC increase for the same amount of CO_2 rise



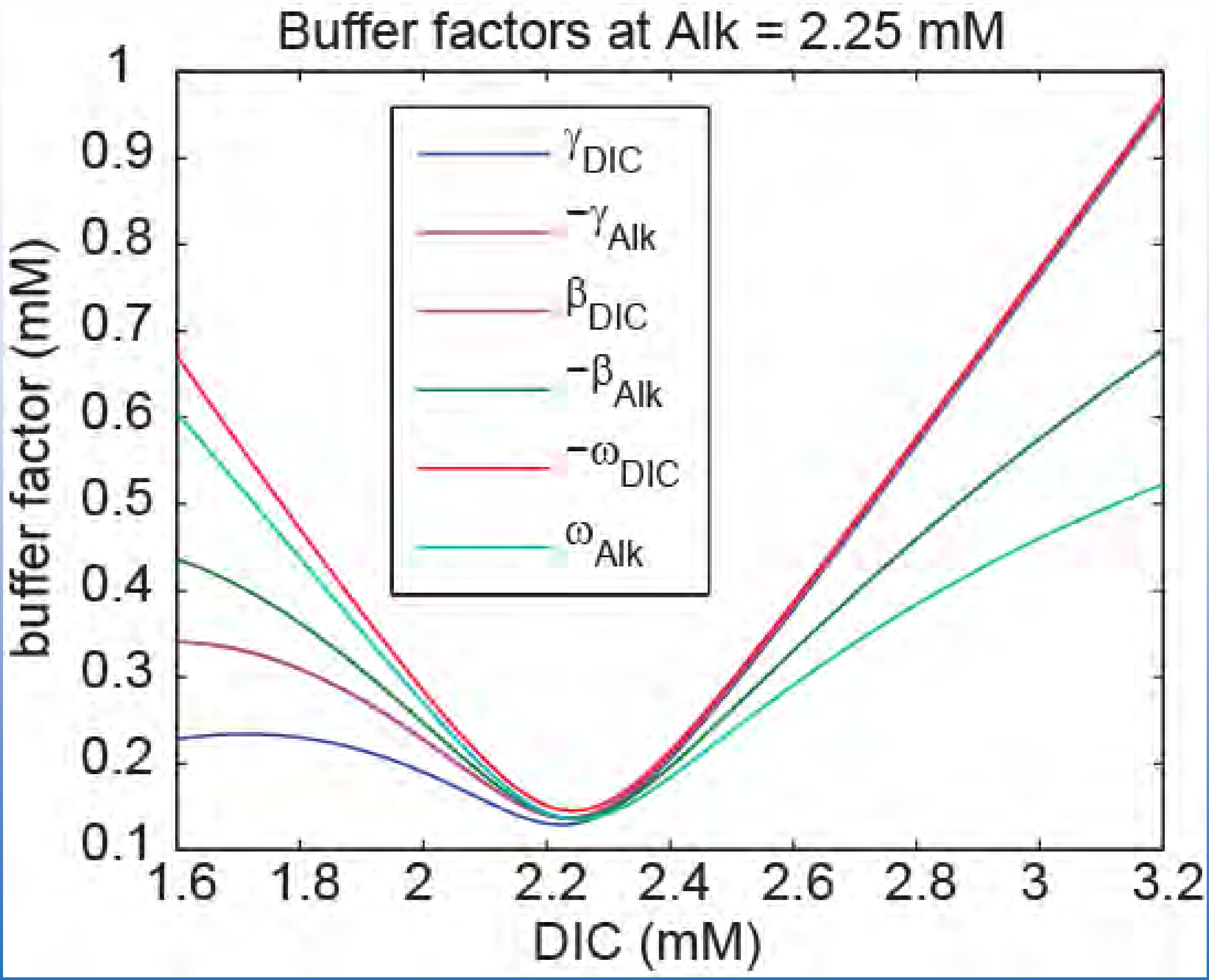
Higher buffer factor means larger DIC increase for the same amount of CO_2 rise



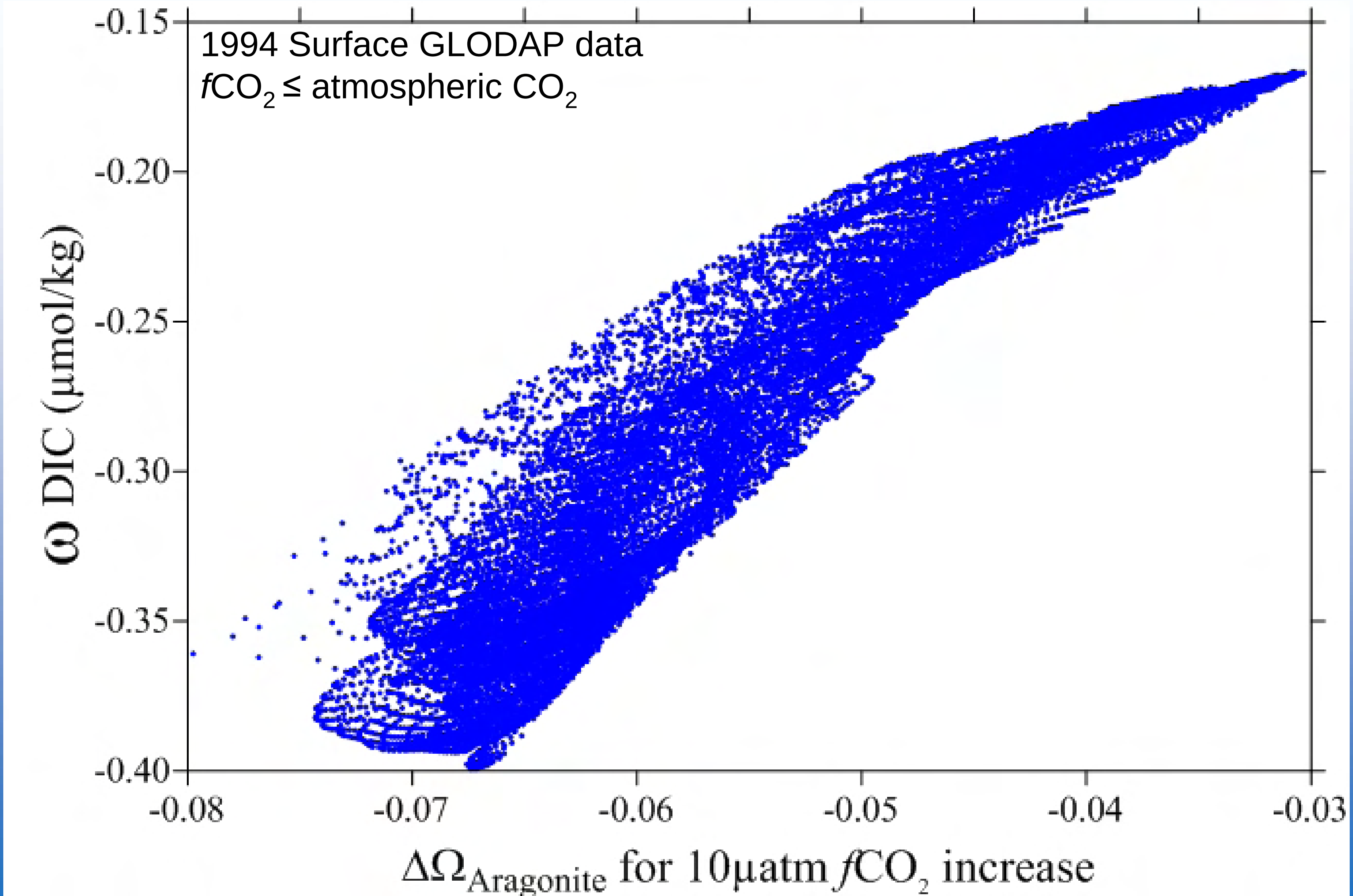
Higher buffer factor means larger DIC increase for the same amount of CO_2 rise



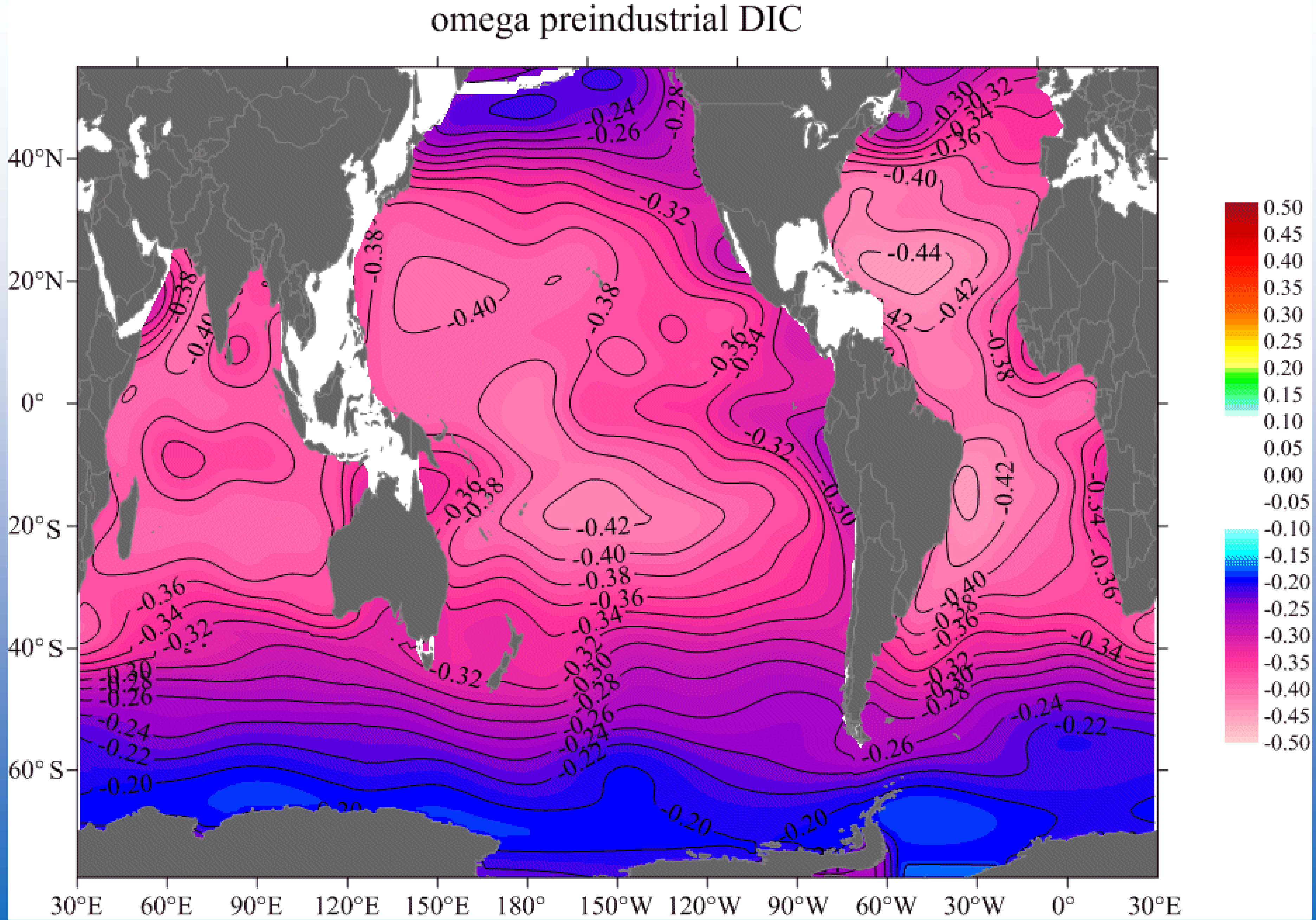
Omega-DIC has much steeper slope than gamma-DIC



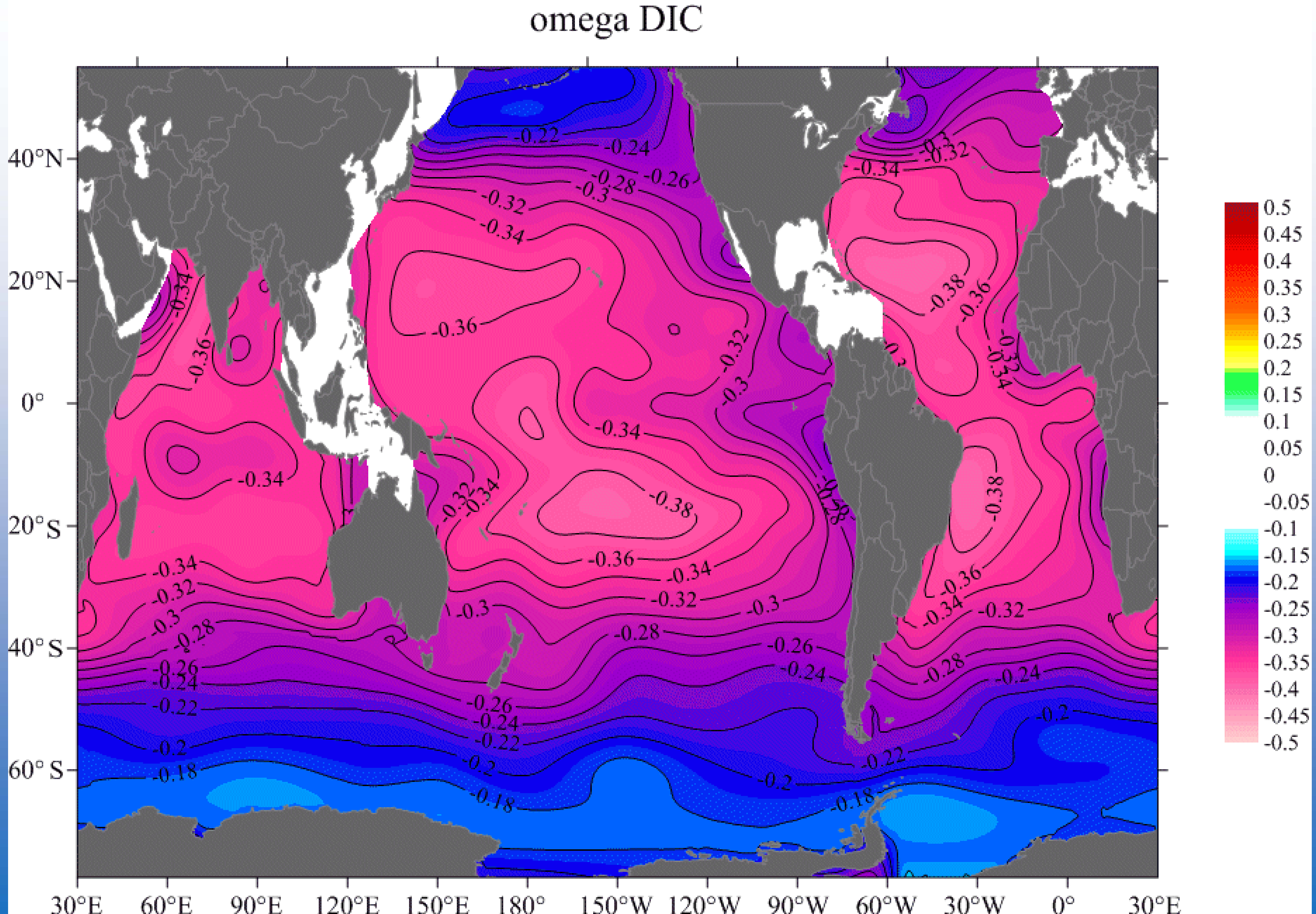
The more negative omega-DIC gets, the larger the drop in saturation state



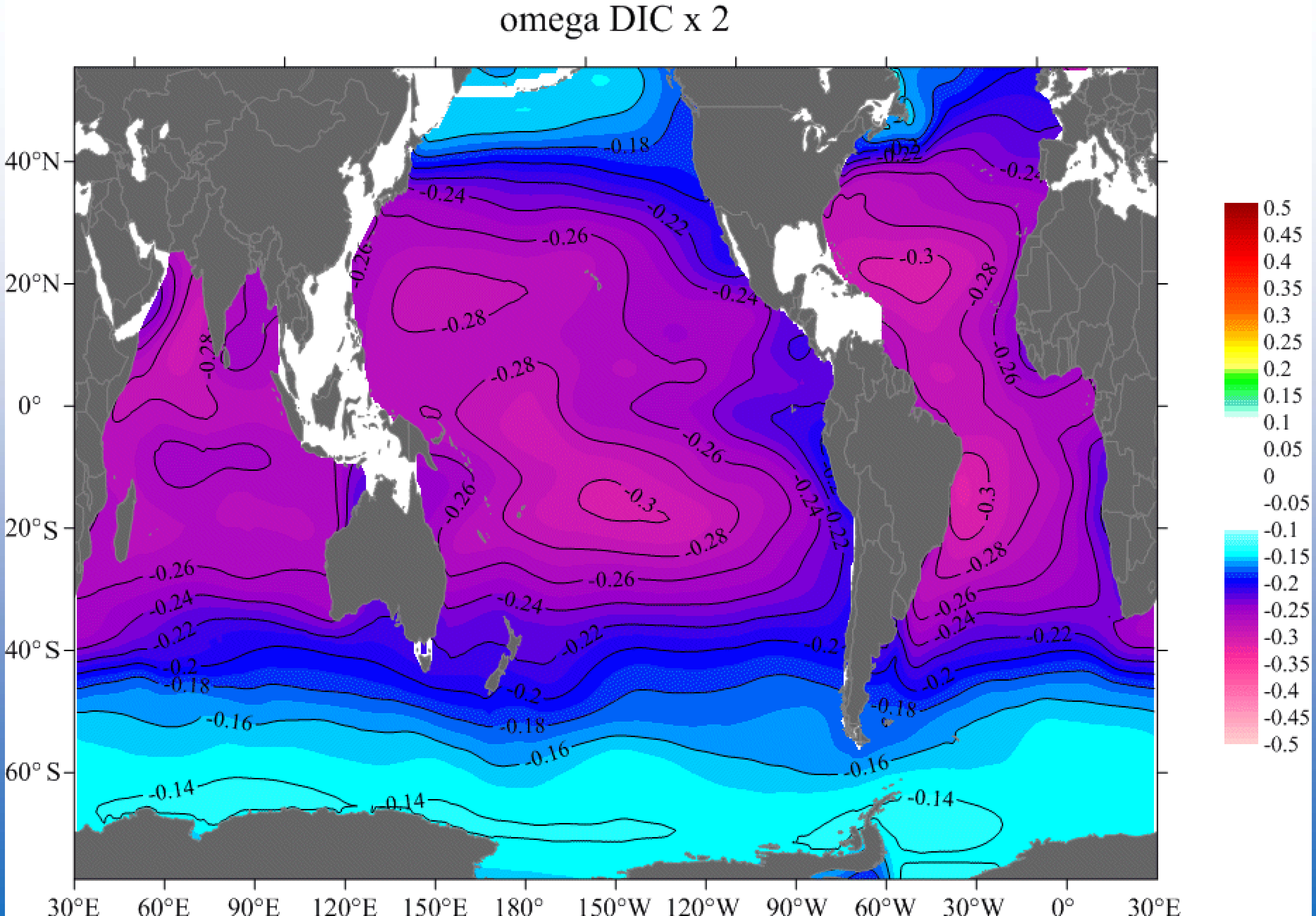
Preindustrial North Pacific ranges from -0.22-0.41 (Δ=.19)



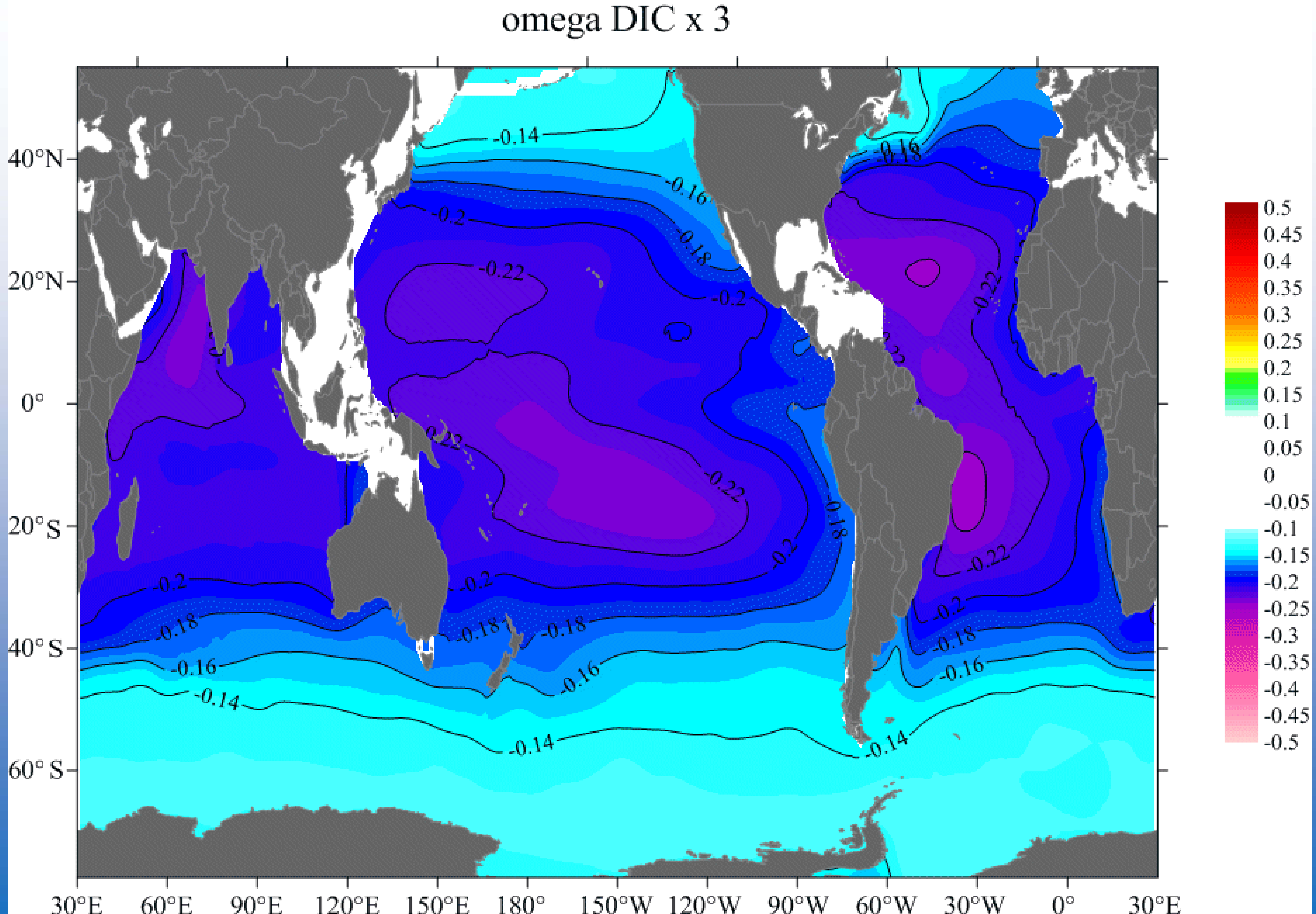
Modern North Pacific ranges from -0.20-0.37 (Δ=.17)



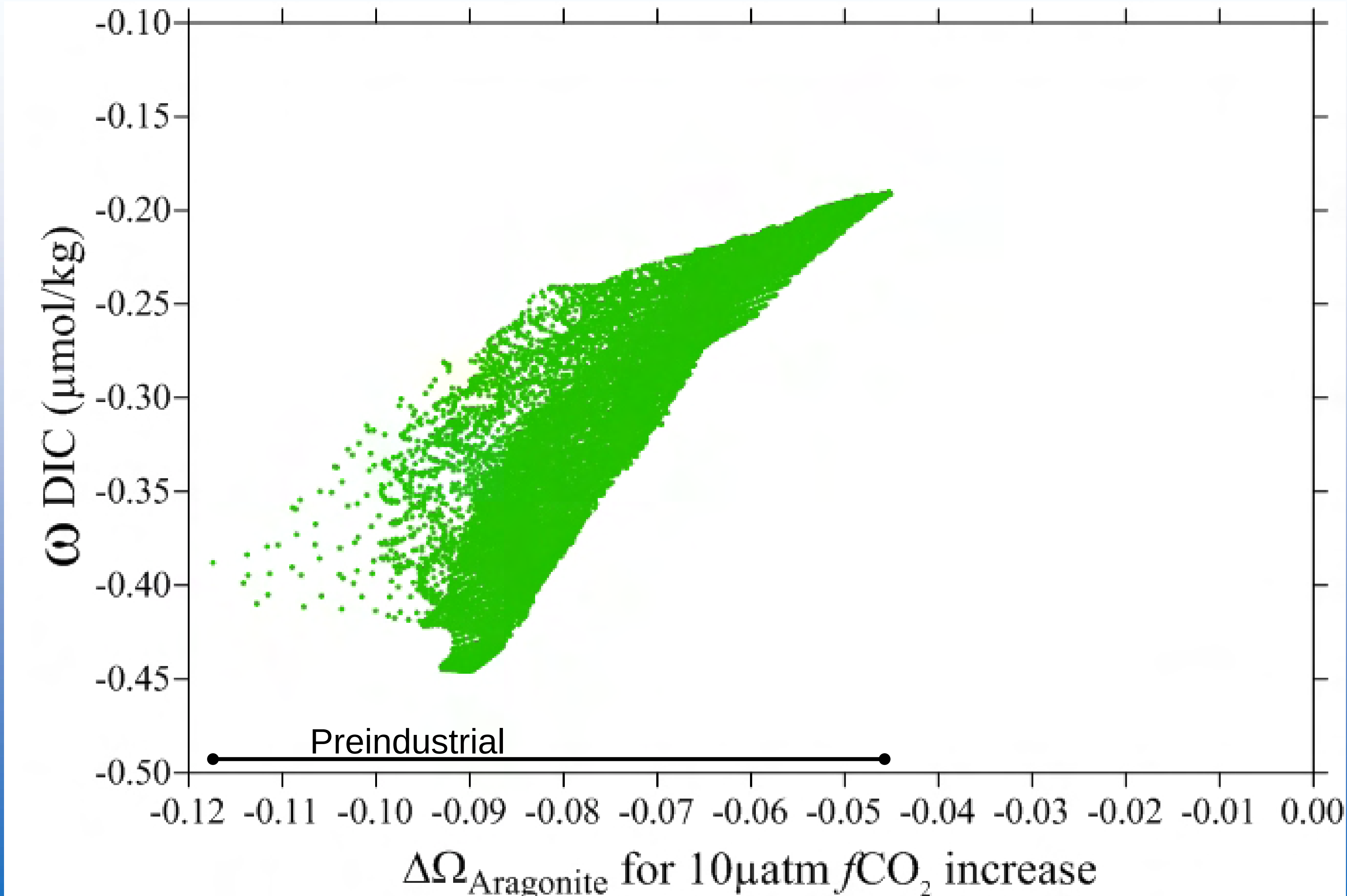
2X CO_2 North Pacific ranges from -0.15-0.28 (Δ=.13)



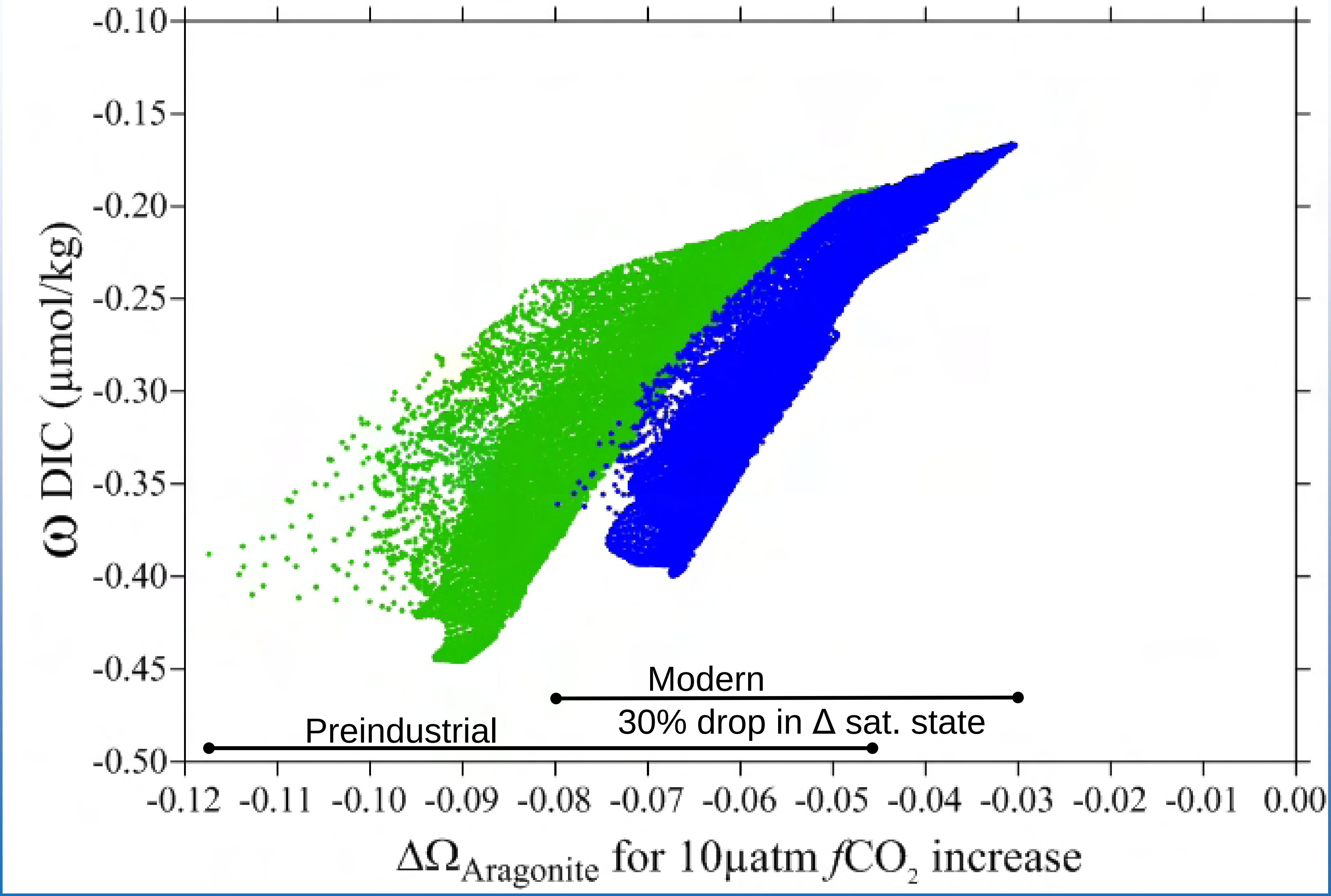
3X CO_2 North Pacific ranges from -0.14-0.22 (Δ=.08)



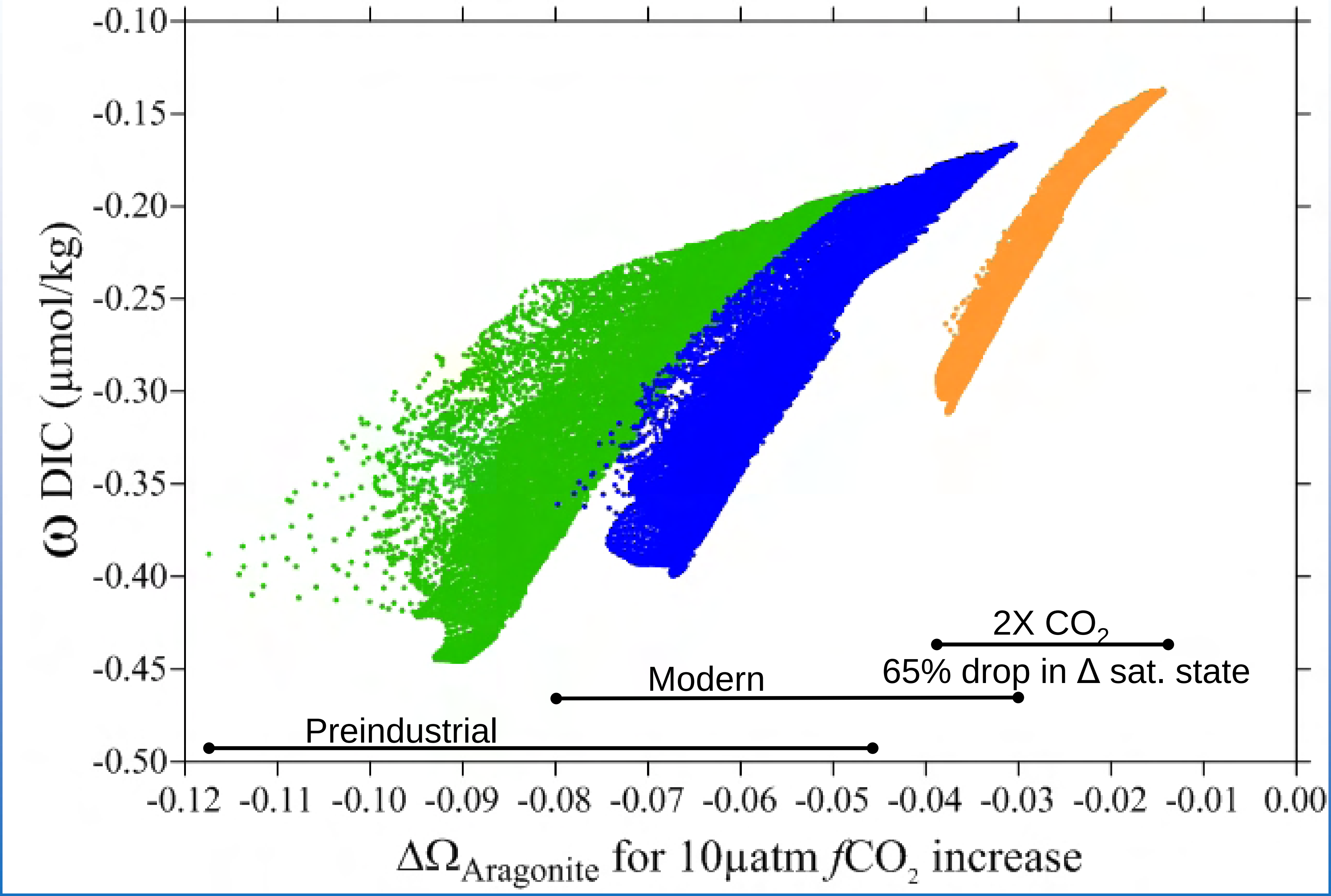
The more negative omega-DIC gets, the larger the drop in saturation state



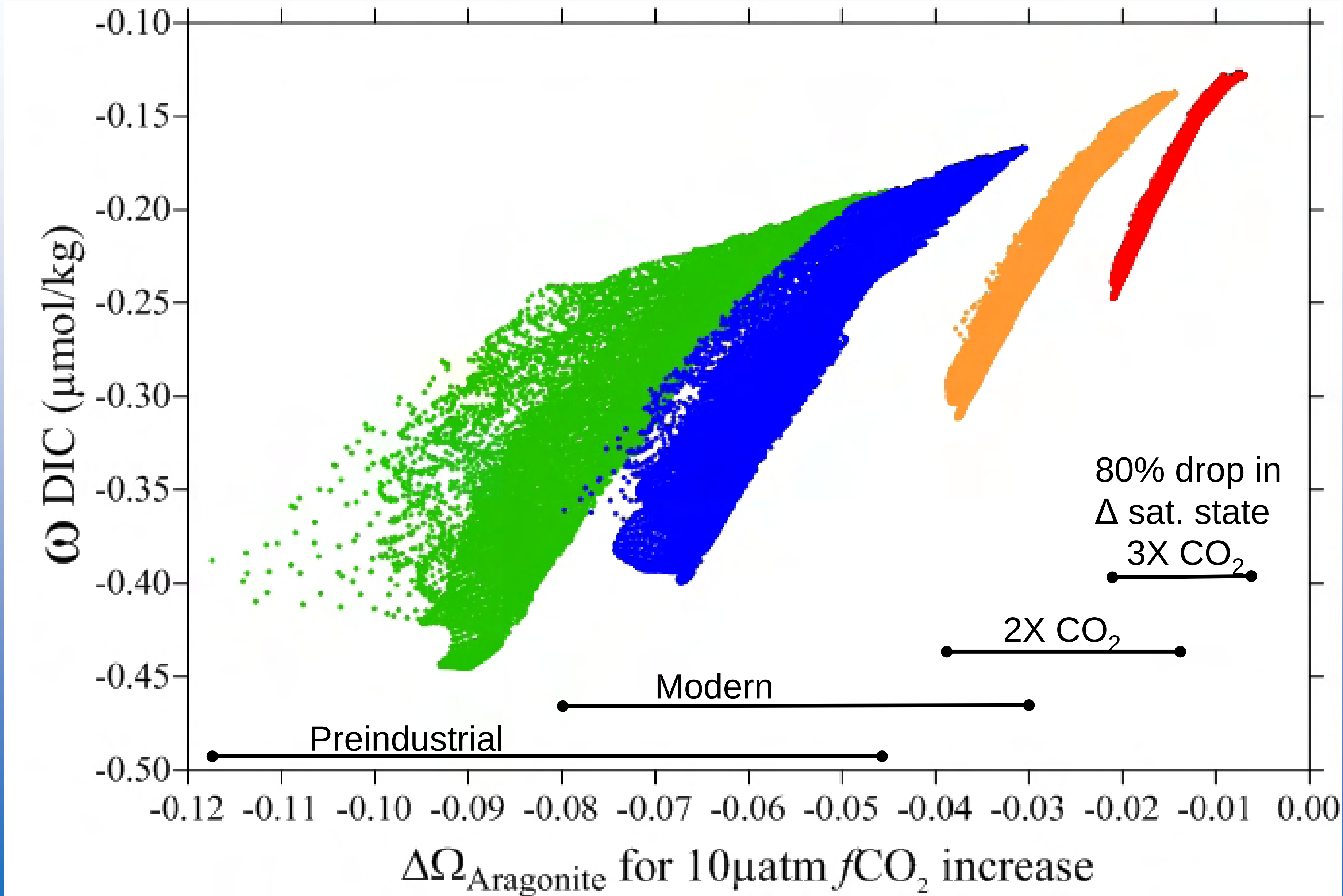
The more negative omega-DIC gets, the larger the drop in saturation state



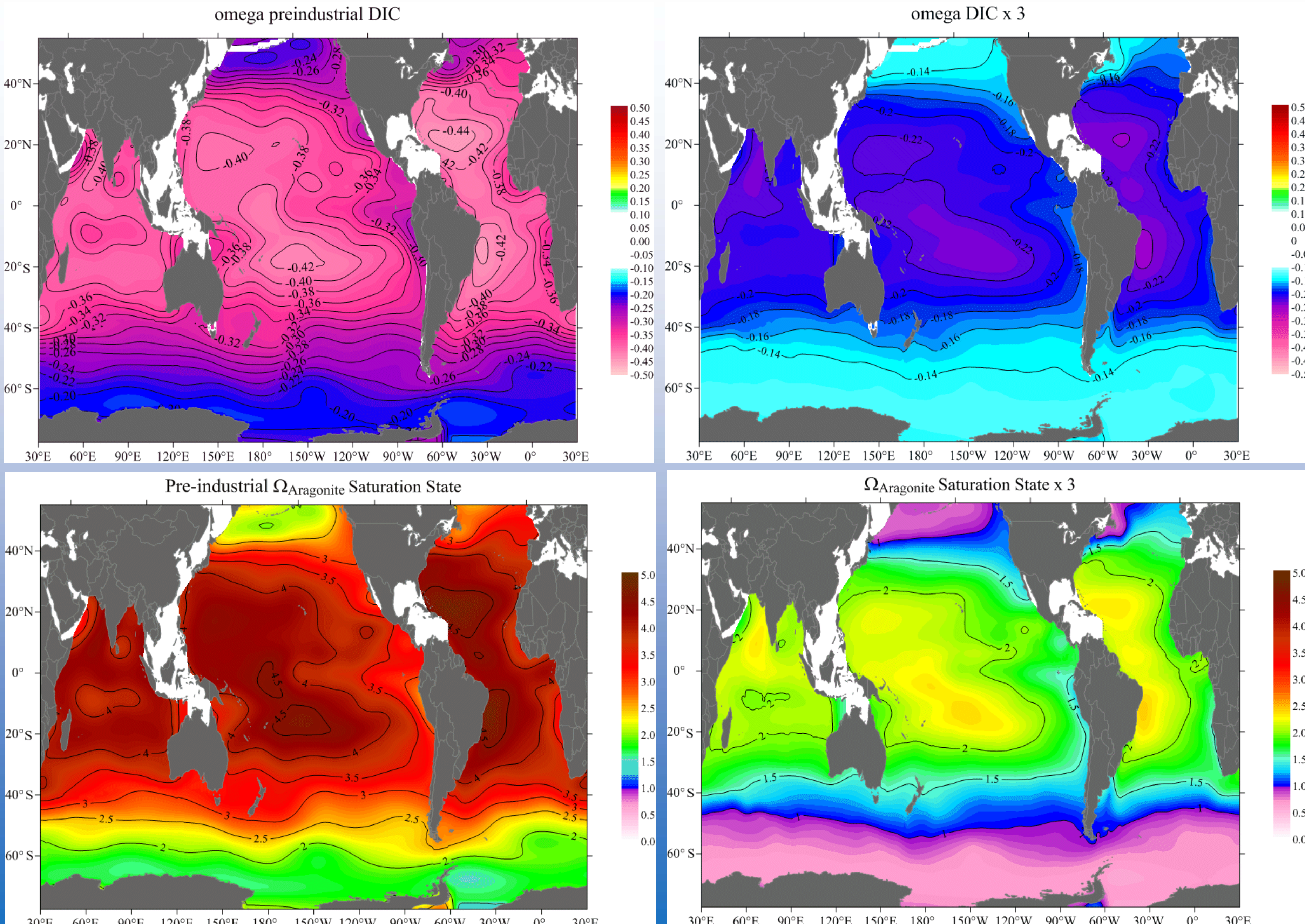
The more negative omega-DIC gets, the larger the drop in saturation state



The more negative omega-DIC gets, the larger the drop in saturation state



As we move to higher CO_2 levels, the spatial gradients get smaller



Conclusions

1) Buffer factors are a useful way to examine how ocean carbon chemistry will change as a result of rising CO_2.
2) The buffer capacity of the surface ocean will decrease until DIC=ALK, then will increase again sharply as CO_2 continues to rise.
3) The average uptake efficiency of the ocean will drop by 75% from preindustrial conditions to 3x CO_2.
4) The saturation state of the waters is more sensitive to change than either pH or DIC.
5) The decrease in uptake efficiency, however, will result in an 80% decrease in the SS change for a given increase in CO_2 between the preindustrial and the 3x CO_2 world.