Phosphate and iron concentrations in an ocean carbon cycle model

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Objects

- To represent realistic global phosphate and iron distribution in comparison with observational database in an general circulation model
- To understand the reasonable parameters in a model for the current distribution of phosphate and iron

Physical model

- CCSM3 POP (Keihl and Gent, 2004)
- Horizontal; about 3 degree, Vertical; 25 layers
- 3rd order upwind advection scheme
- KPP scheme (Large et al., 1994)
- Momentum; anisotropic GM scheme (Smith and McWilliams, 2003)
- Tracer; GM scheme (Gent and McWilliams, 1990)
- Normal Year Forcing (Large and Yeager, 2005)
- Lax and Wendroff advection scheme for tracer
- Near-boundary eddy flux parameterization (Danabasoglu, et al., 2006)

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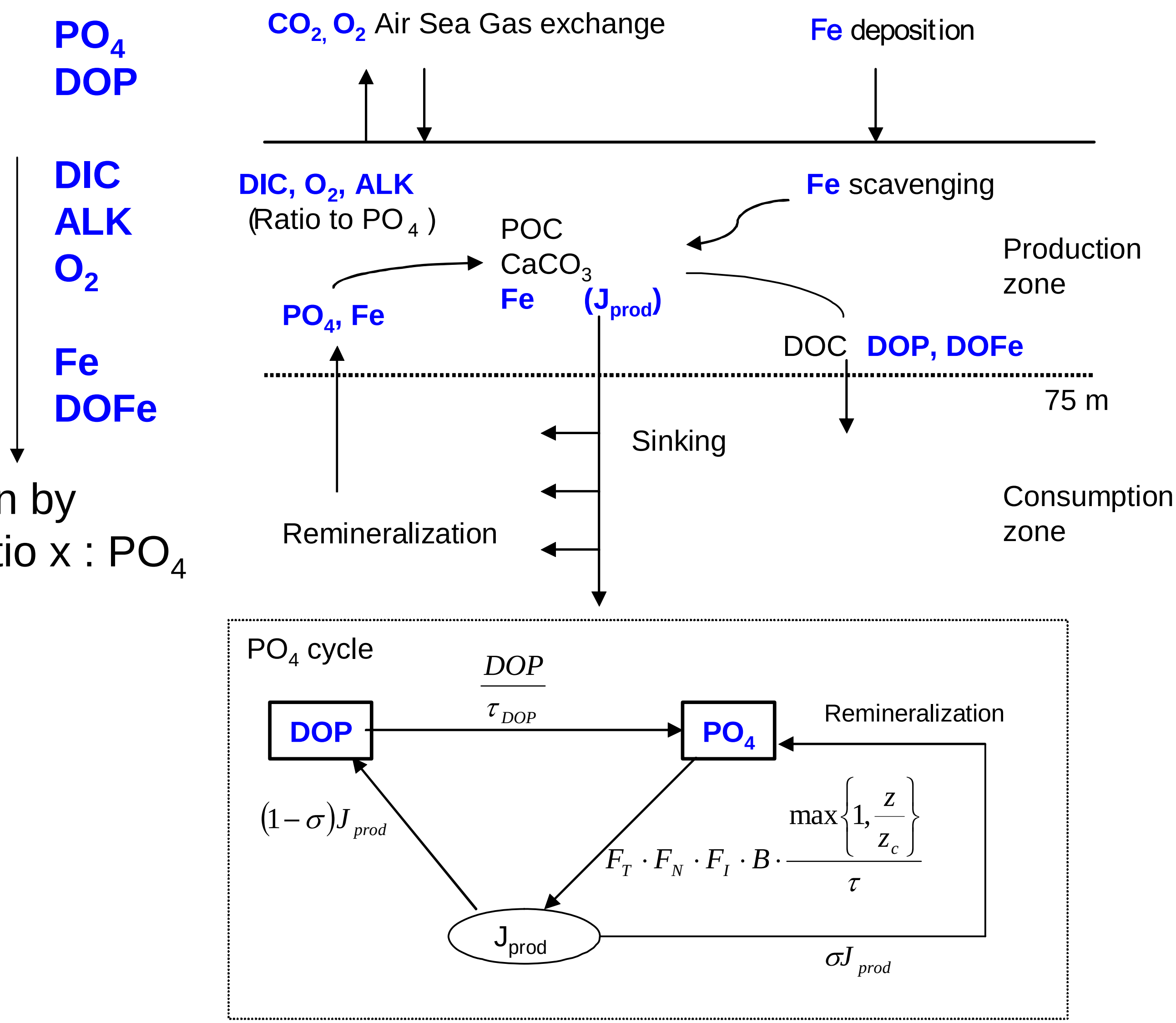
Schematic of ocean carbon cycle model (OCMIP')



Calculation by
Uptake ratio x : PO_4

Prognostic PO_4 cycle

Parameter for PO_4

- Equation for PO_4 cycle

$$\frac{d}{dt}PO_4 - \nabla\mathbf{D}\nabla PO_4 = -J_{prod} + \frac{DOP}{\tau_{DOP}} + \frac{\partial}{\partial z}F_{POP}$$

$$F_{POP} = \left(\frac{z}{z_c}\right)^{\beta} \sigma \int_{-z_c}^{0} J_{prod}(x,y,z,t)\,dz$$

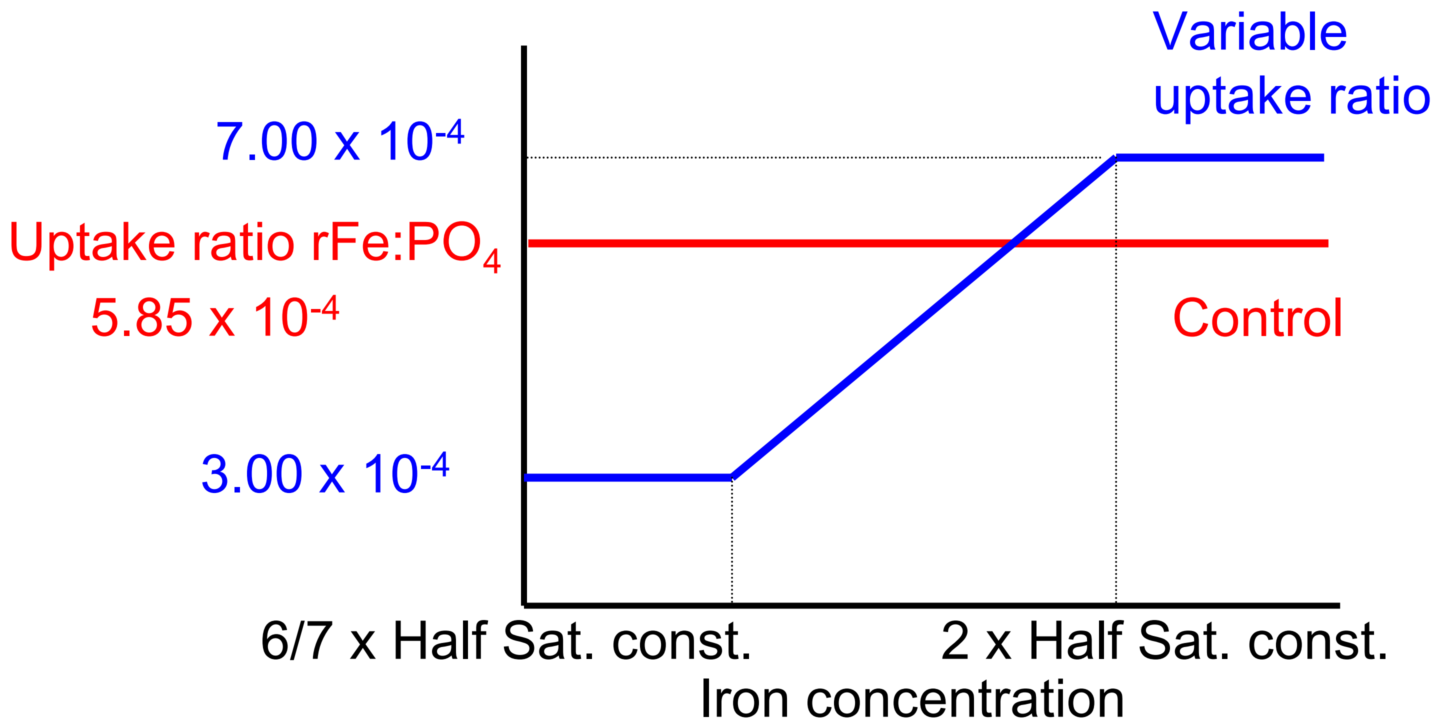
$$J_{prod} = F_T \cdot F_N \cdot F_I \cdot B \cdot \frac{\max\left\{1, \frac{z_{ml}}{z_c}\right\}}{\tau}$$

Production time scale
τ= 15, 5,1

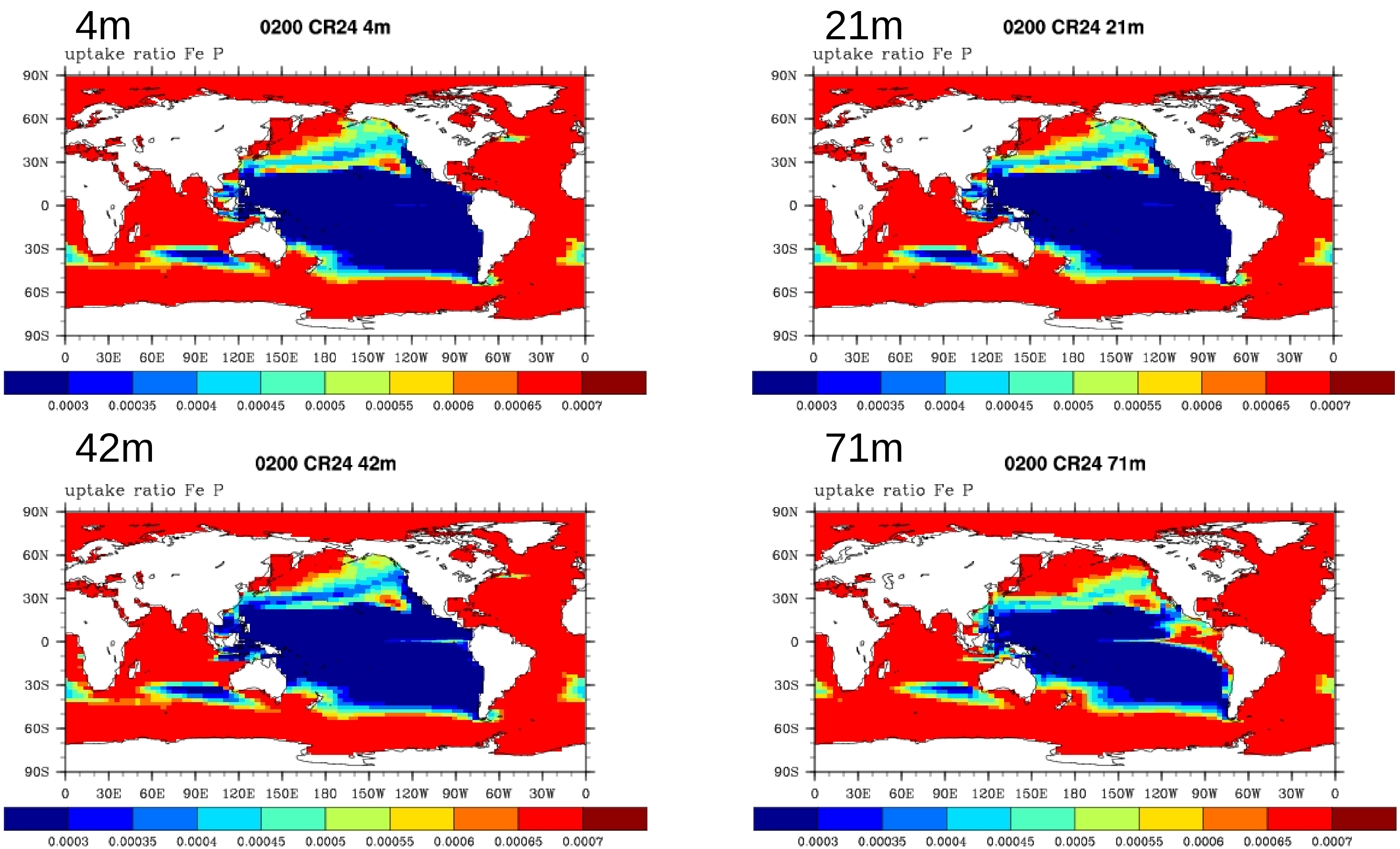
F_T ; Temperature limitation function
F_N ; Nutrient limitation function, Michaelis-Menten limiting term, PO_4 or Fe
F_I ; Light (Irradiance) limitation function
B ; Proxy for biomass , PO_4 or Fe
Z_{ml} ; Mixed layer depth
Z_c ; Compensation depth, 75m

Parameter for PO_4

- Uptake ratio $Fe:PO_4$



Variable uptake ratio Fe : P

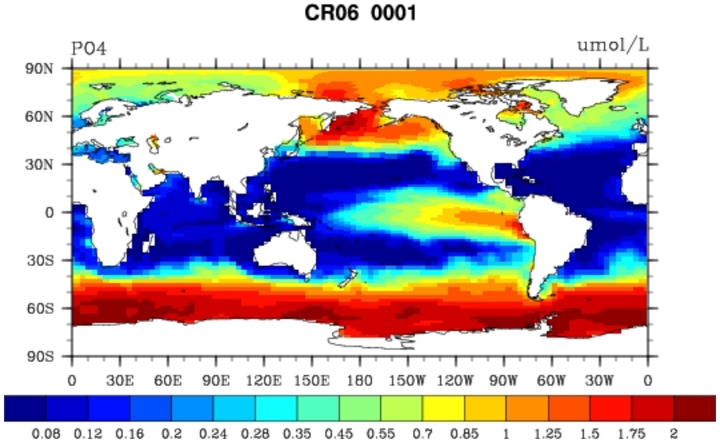


Uptake ratio change with iron concentrations

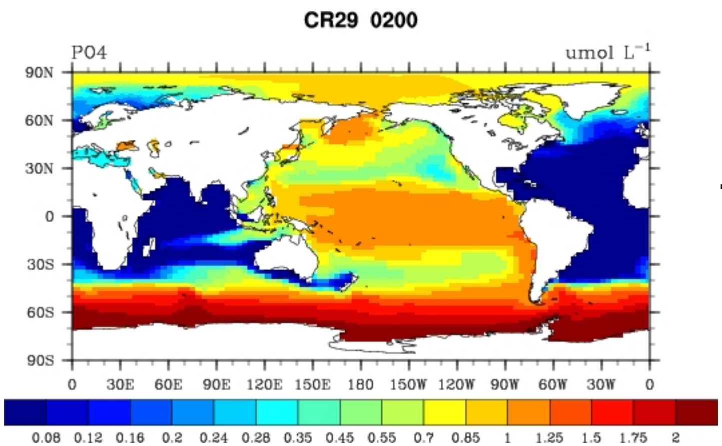
Constant uptake ratio is about 6.0e-4

PO_4 surface concentrations

Observation

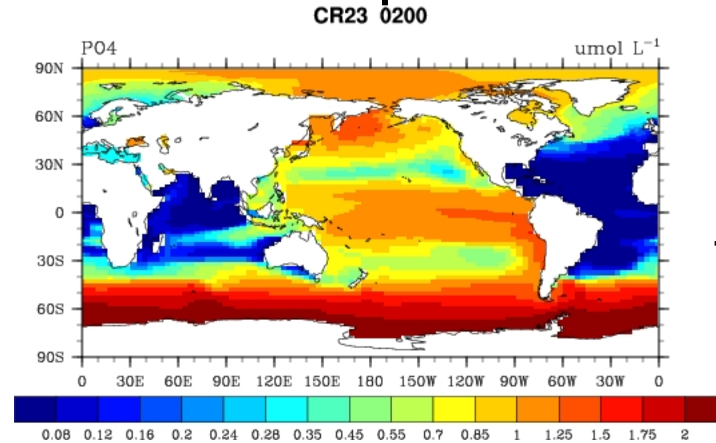


Constant Uptake ratio

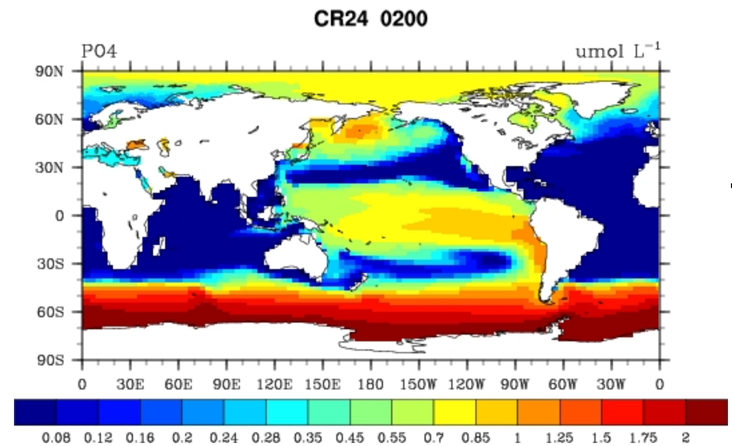


τ=5

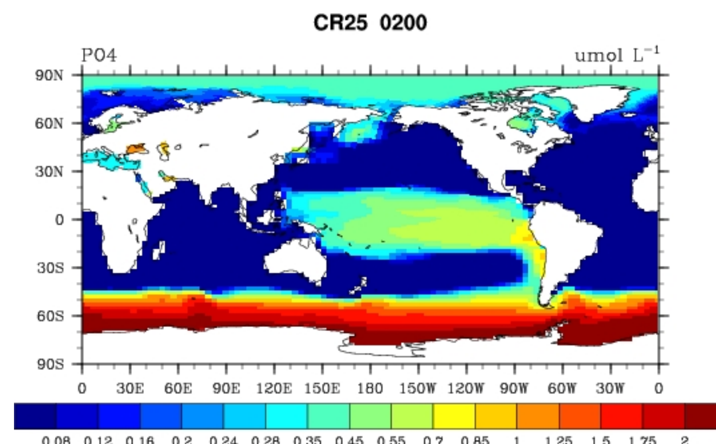
Variable Uptake ratio



τ=15



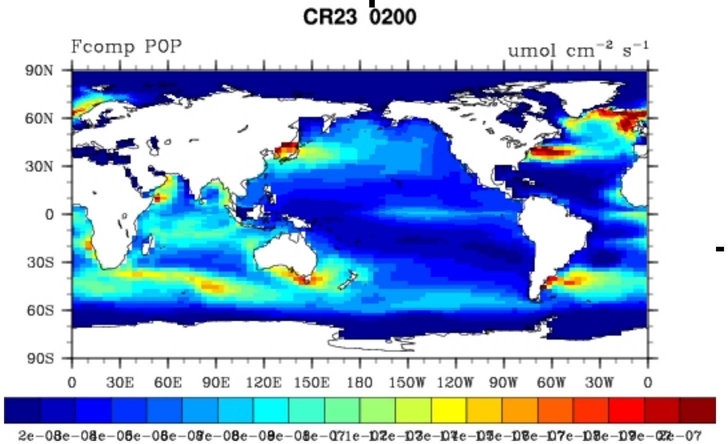
τ=5



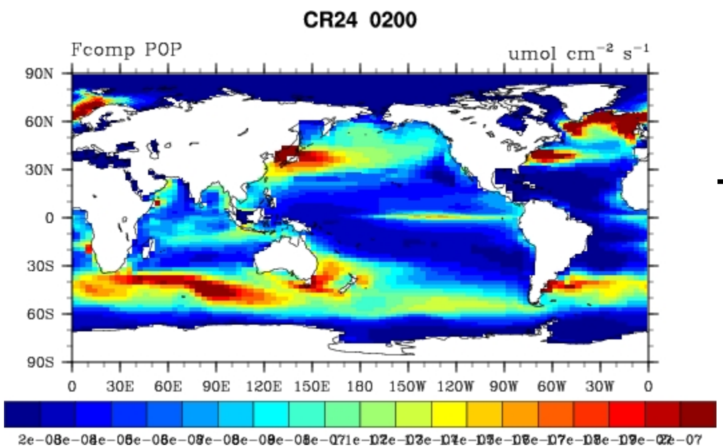
τ=1

POP export flux at 100m depth

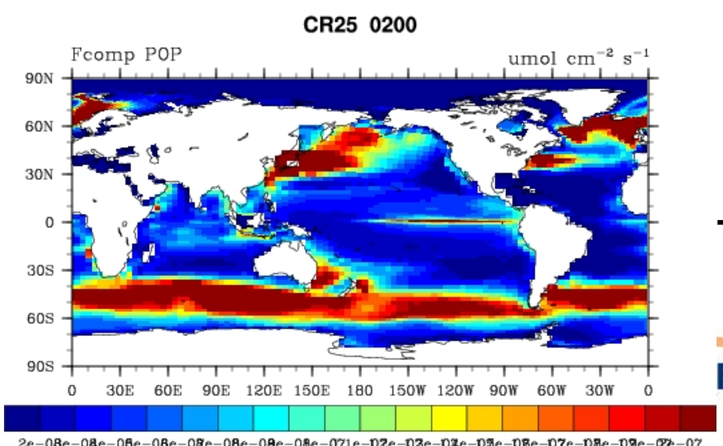
Variable Uptake ratio



-=15

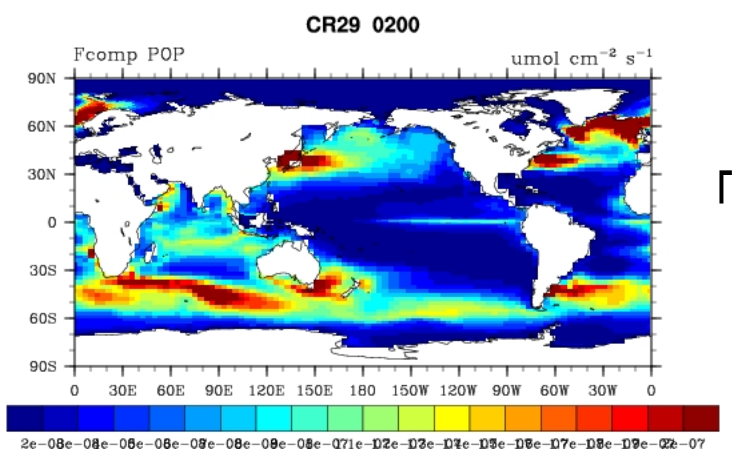


τ=5



τ=1

Constant Uptake ratio

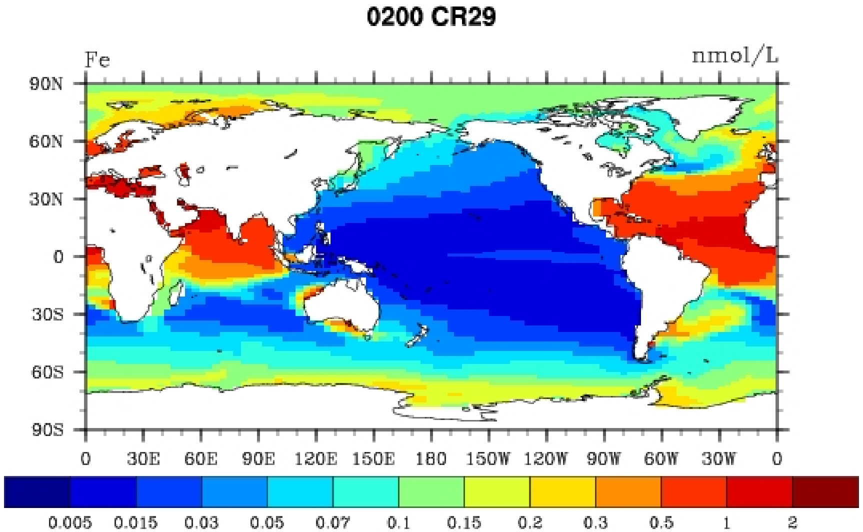


r=5

Iron surface concentrations

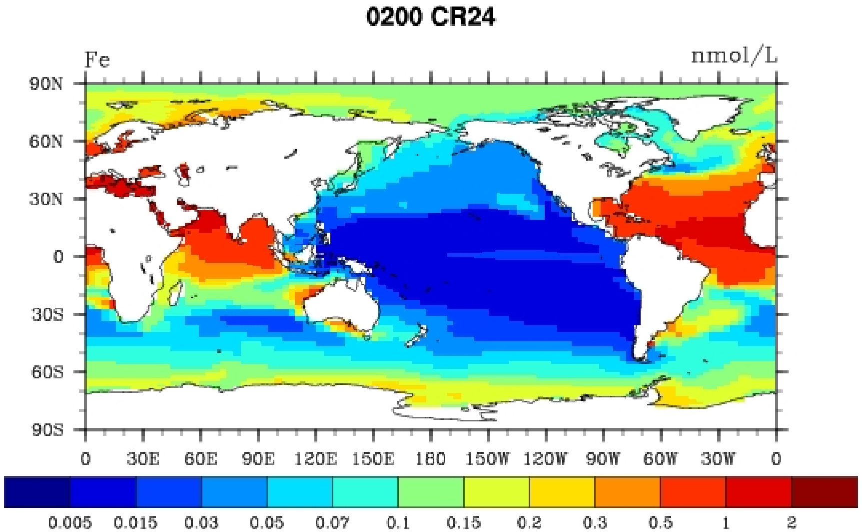
Constant Uptake ratio

$\tau=5$

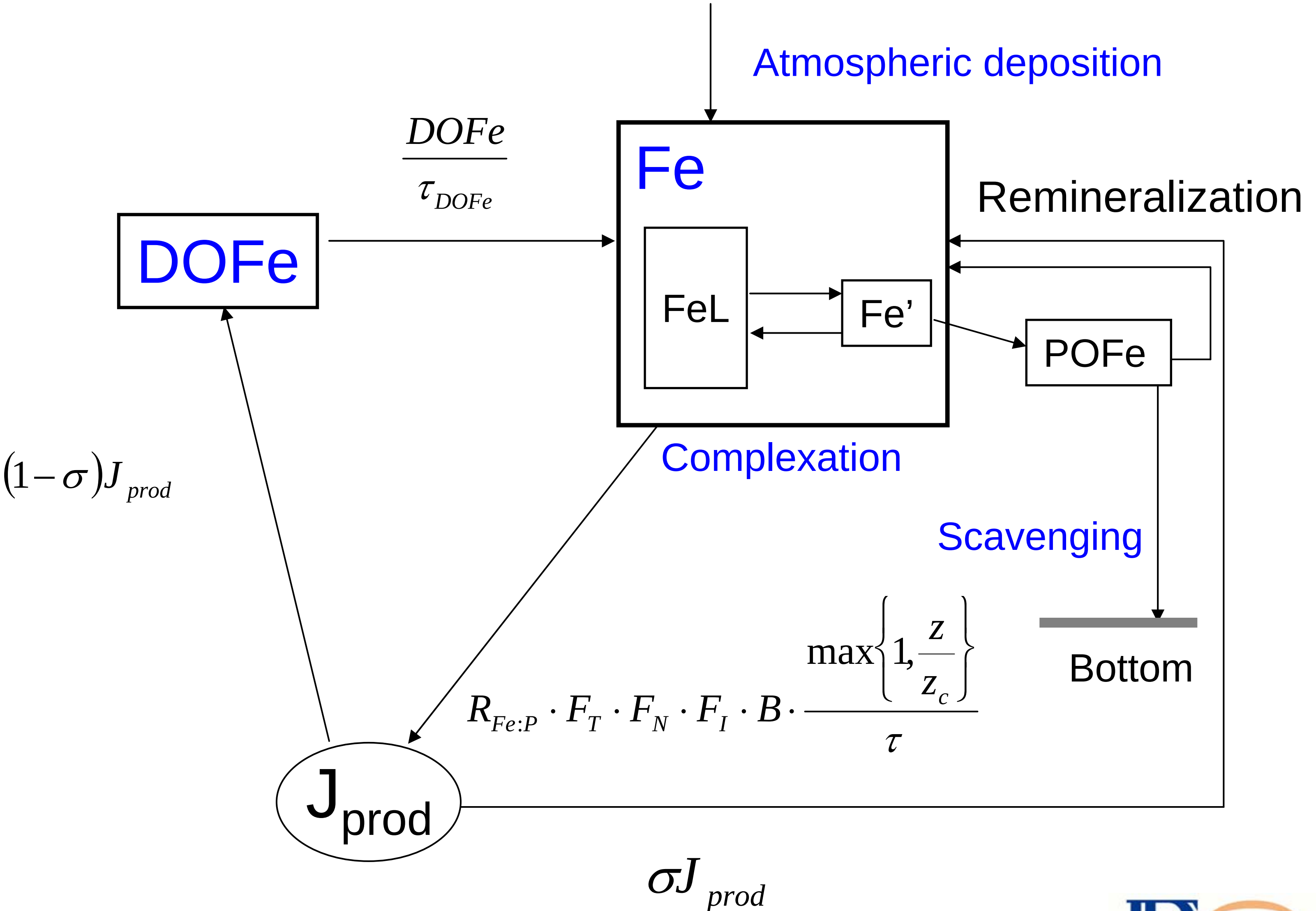


Variable Uptake ratio

$\tau=5$



Iron cycle (Doney et al., 2006)



Iron scavenging (Archer and Johnson, 2000)

$$Fe^{2}{}_{free} + \left(L + \frac{1}{K_L} - Fe \right) Fe_{free} - \frac{Fe}{K_L} = 0$$

- Fe_{free} ; Fe that is not bound to ligands
- L ; concentration of ligand
- K_L ; Strength of the binding reaction
- L = 1.0 nmol/L, K_L = 300 L/nmol

$$Fw_{scav} = Fe_{Free} \cdot C_0 \cdot \left(1 + \alpha \exp\left(-\frac{z}{z_{scav}} \right) \right)$$

- C_0=0.2 y-1, α=200, z_{scav} = 250m
- Scavenging Fe is attached to the sinking particles to form POFe
- A fraction (40%) of the scavenged Fe is assumed to be insoluble and is directly lost to the sediments.
- The remaining 60% can be remineralized back to dissolved form below z_c

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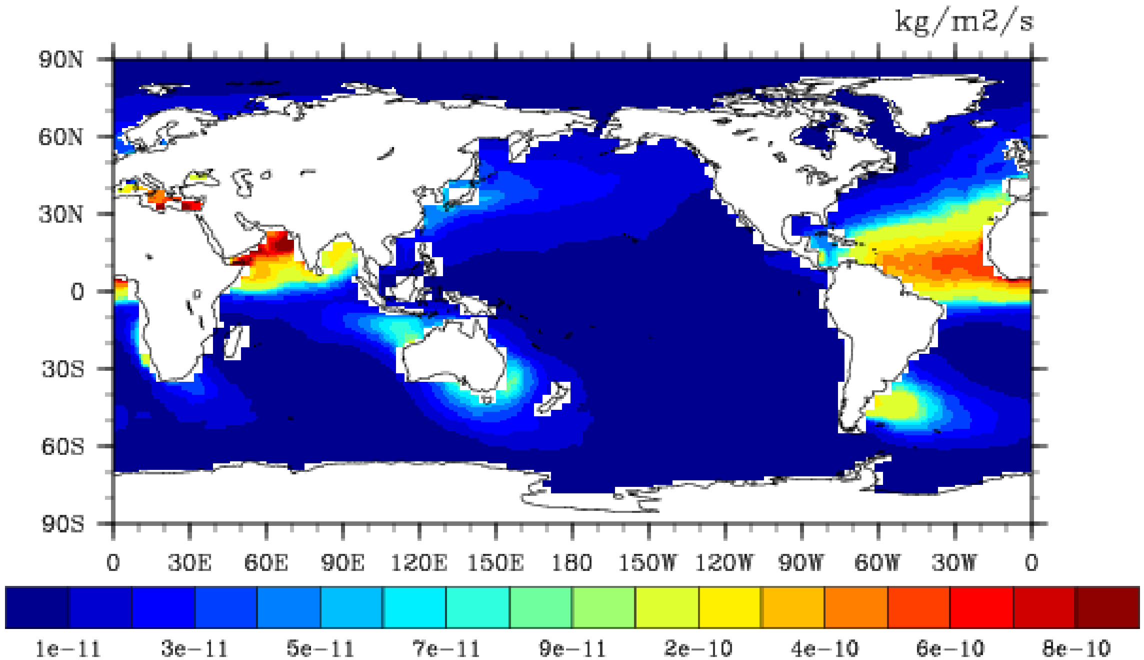
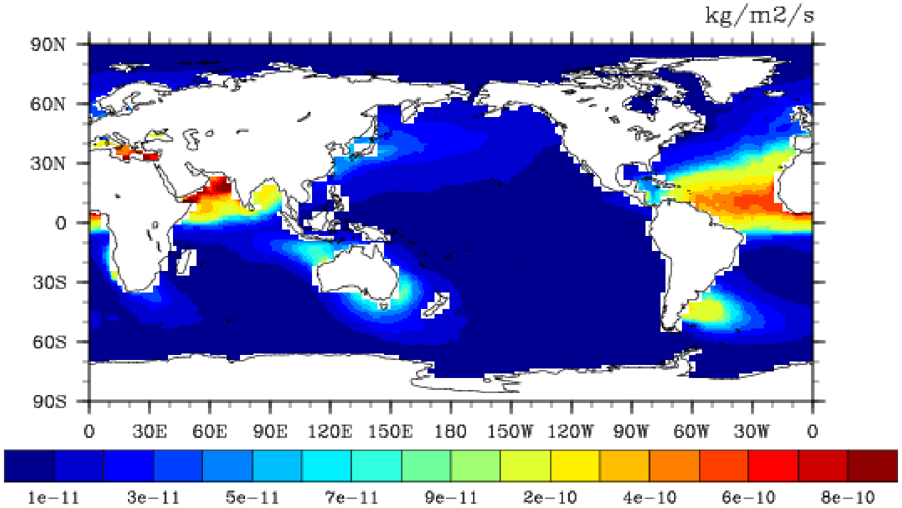
Iron supply from atmospheric dust

- Monthly data (Mahowald et al., 2003)
- 3.5% Fe by weight with 2% of the Fe bioavailable (Fung et al., 2000)。

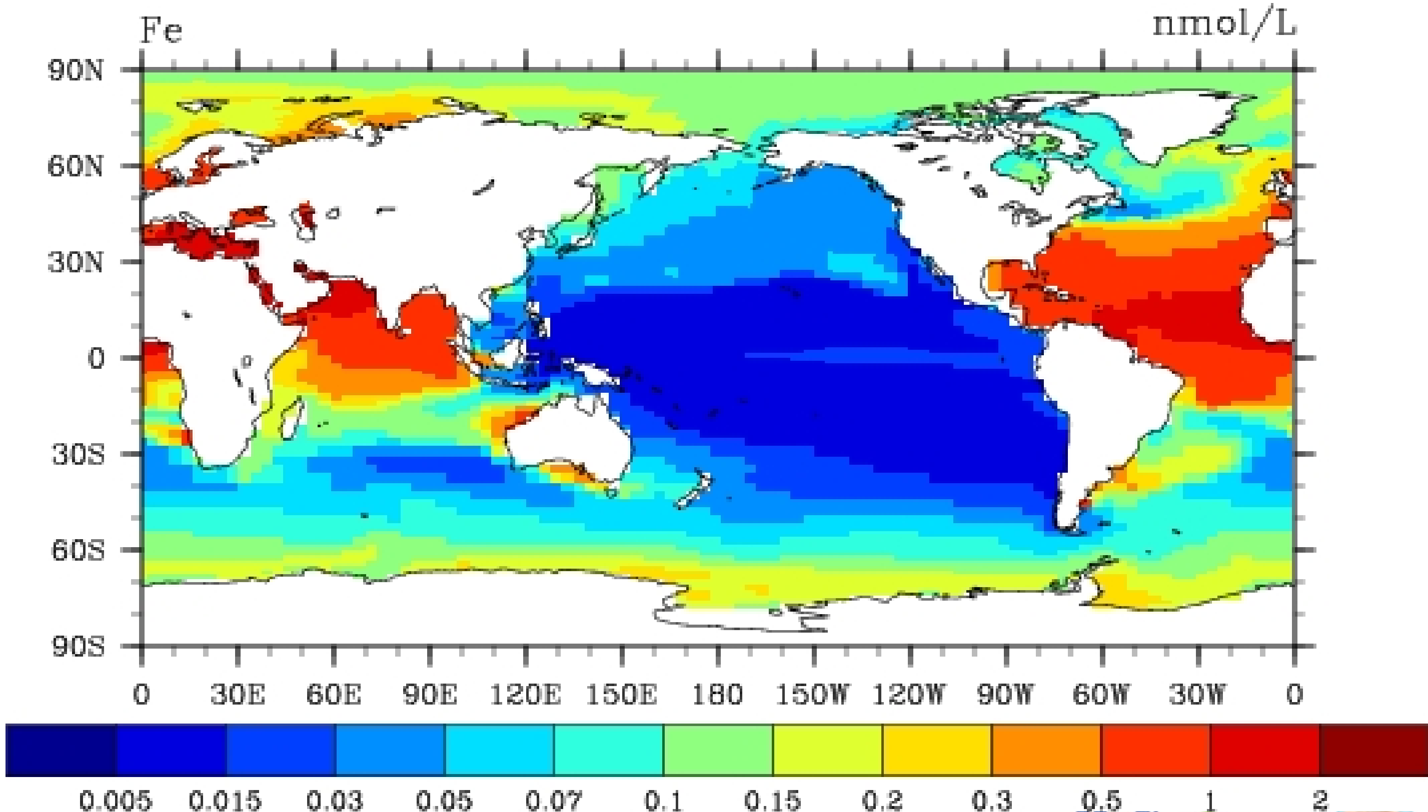


Annual mean dust flux (kg/m²/s)

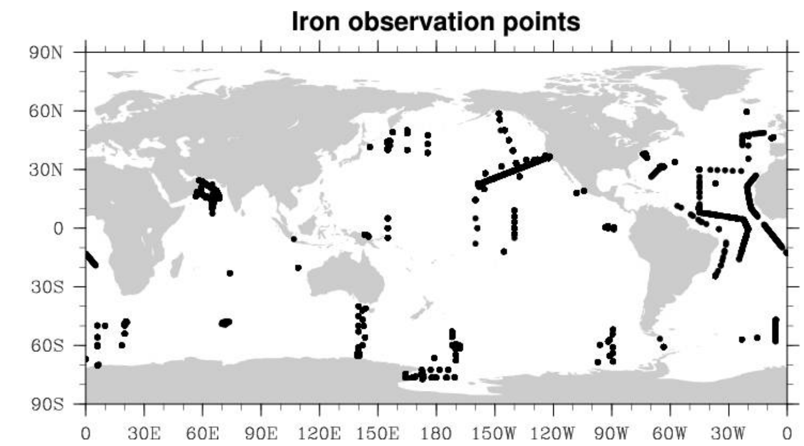
Surface distribution of iron



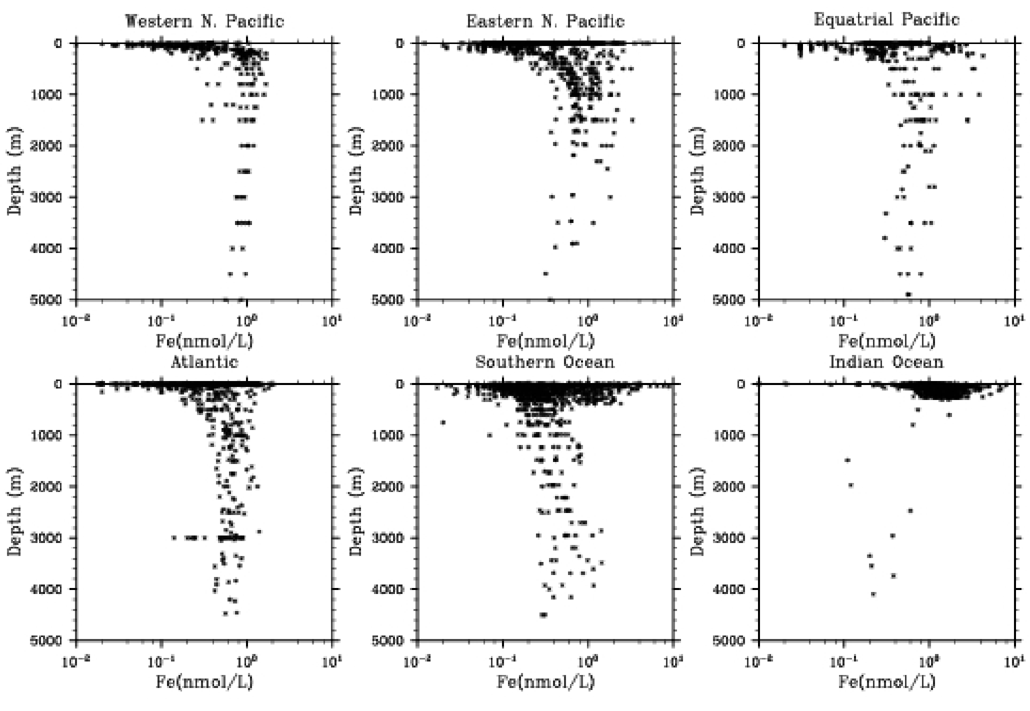
0200 CR24

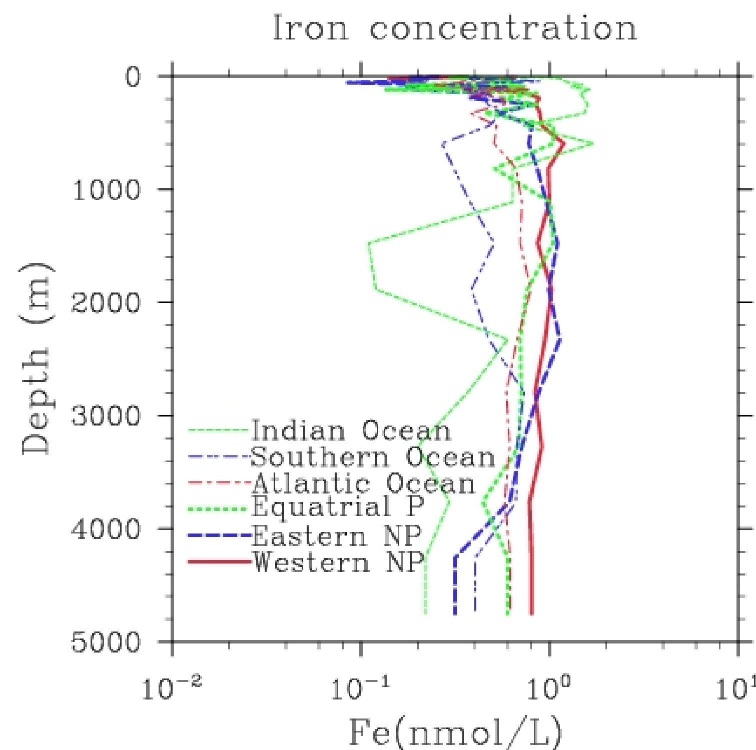


Iron observation

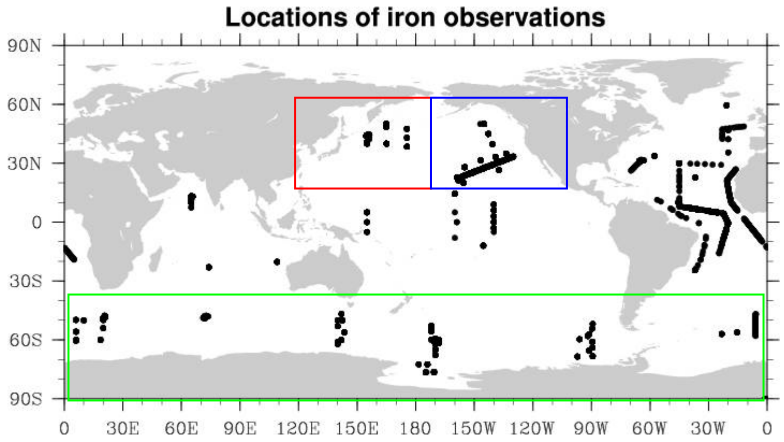


5500 samples
Based on Parekh et al., 2005 (Moore et al., in preparation)



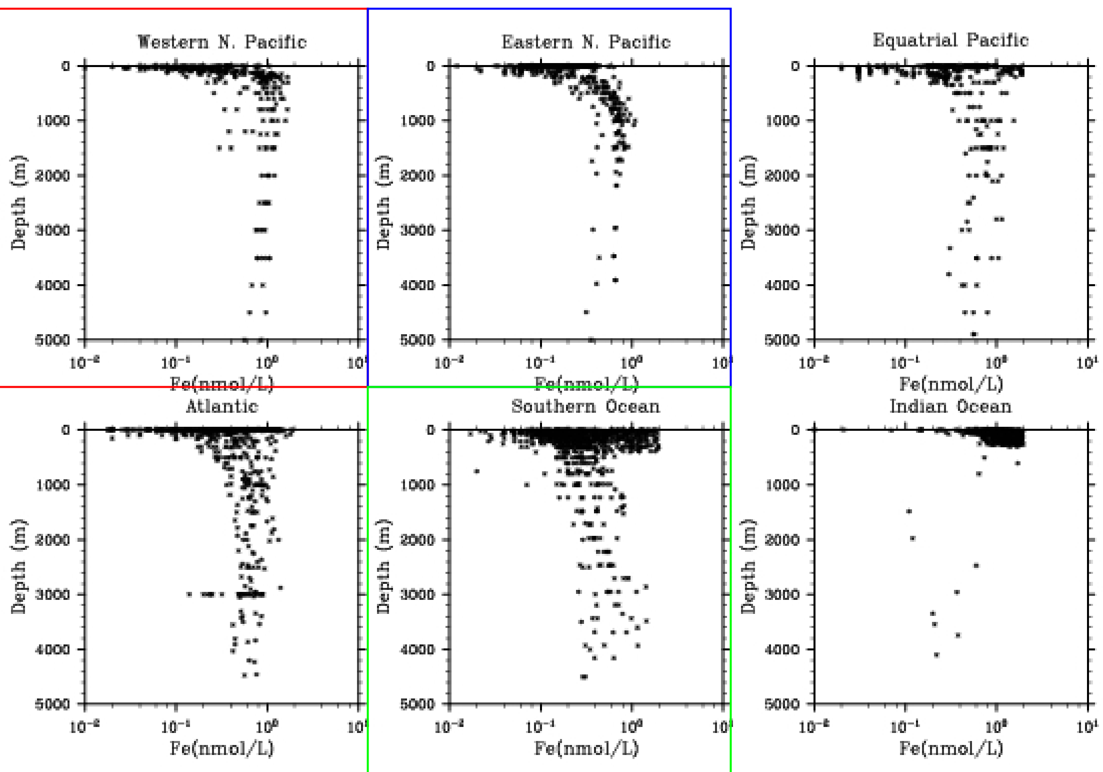


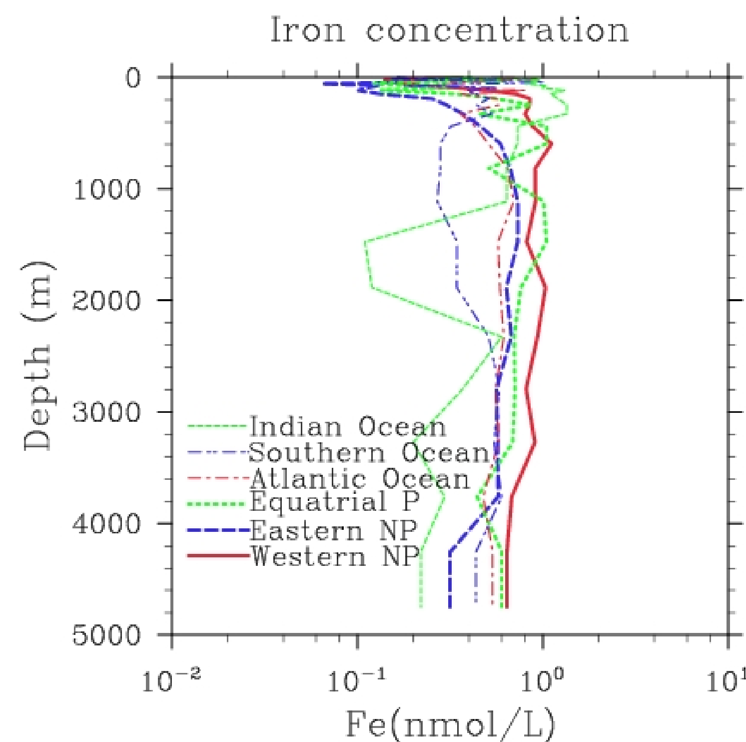
Iron observation



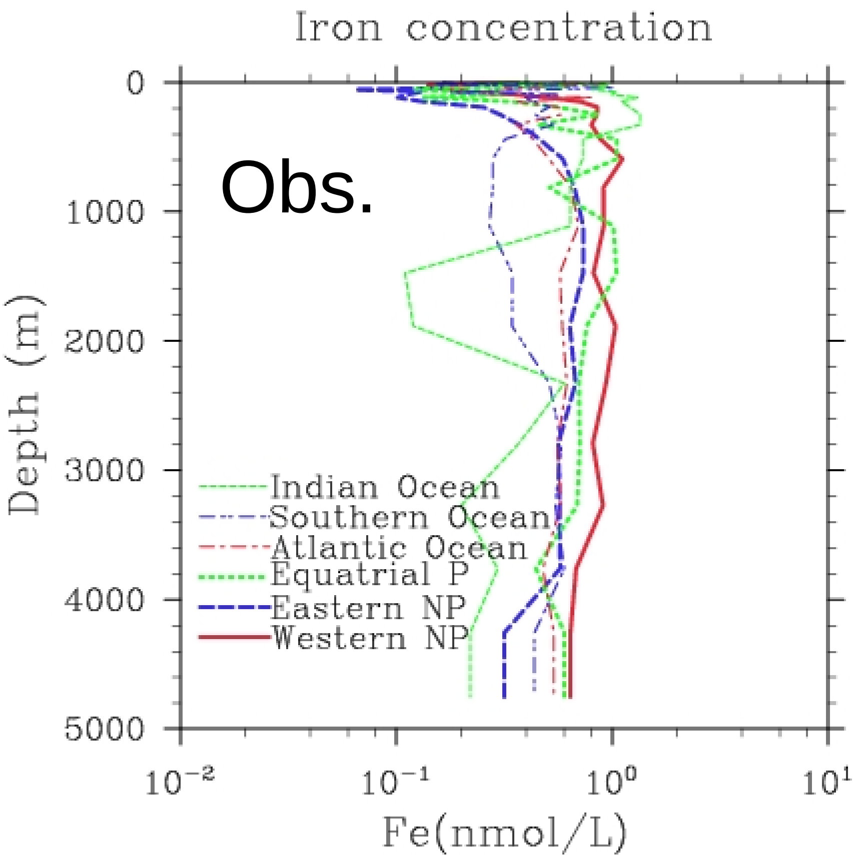
Remove coastal zone

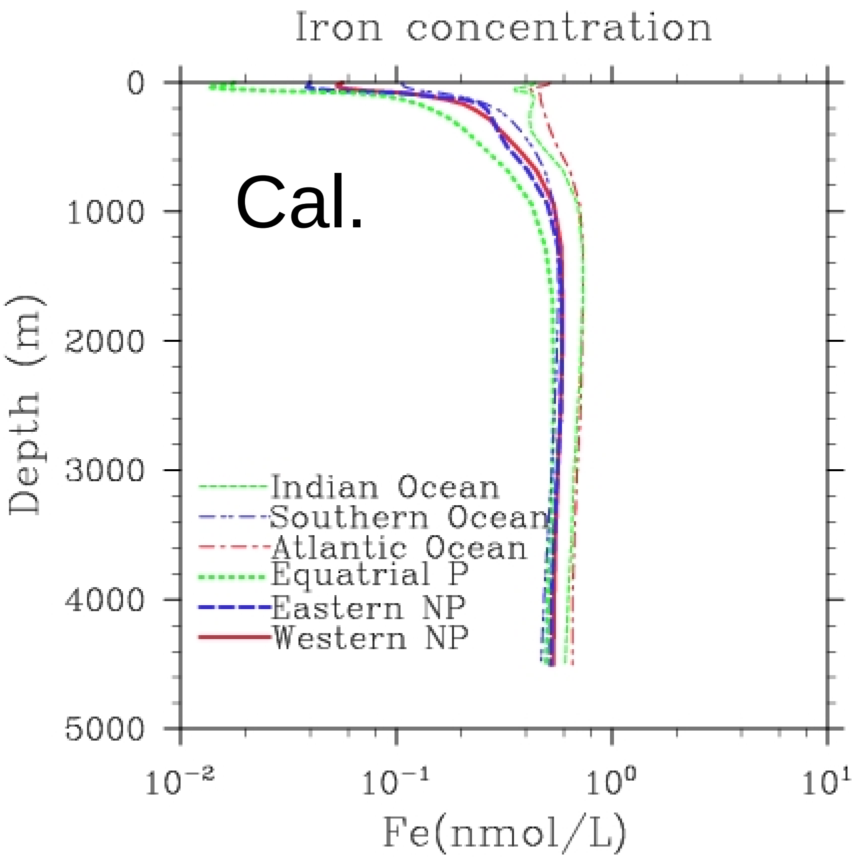
- Western NP is higher than eastern NP
- SO is lower
- Indian Ocean is higher
- Atlantic Ocean is not so higher





Vertical distribution of iron

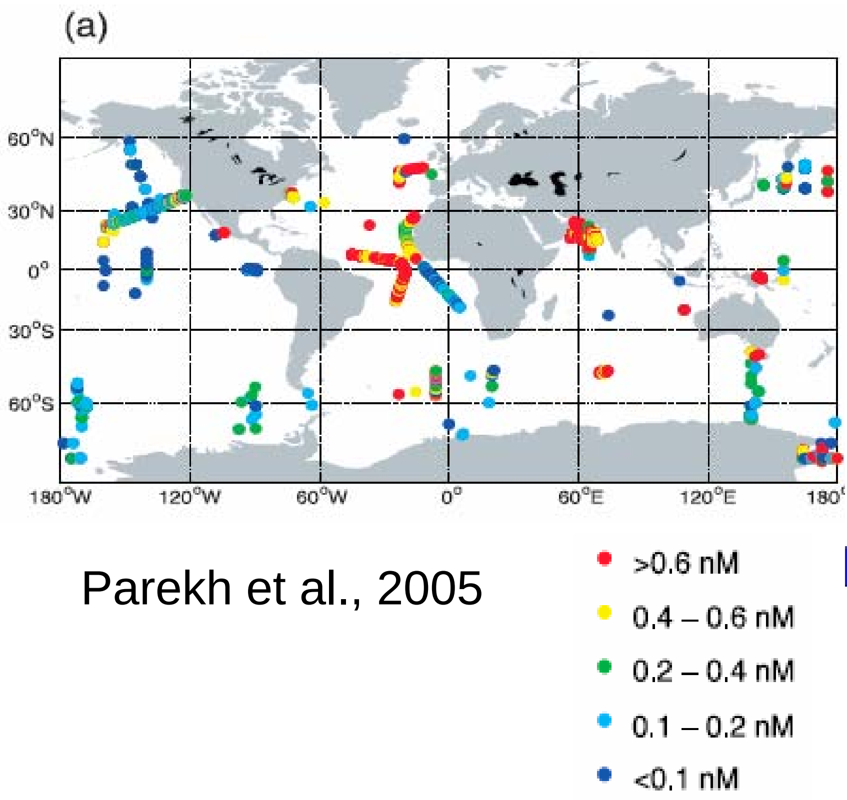




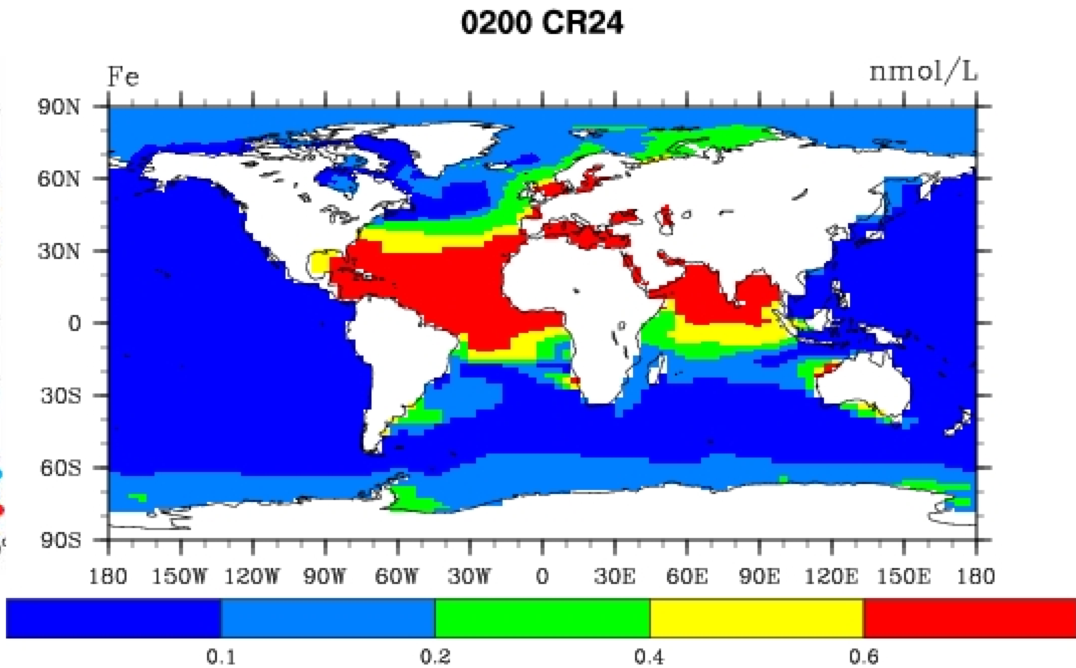
Western NP is higher than eastern NP
SO is lower
Indian Ocean is higher
Atlantic Ocean is not so higher

Modeling of scavenging with complexation is important for reasonable vartical profile.
Not different between basins.

Surface distribution of iron



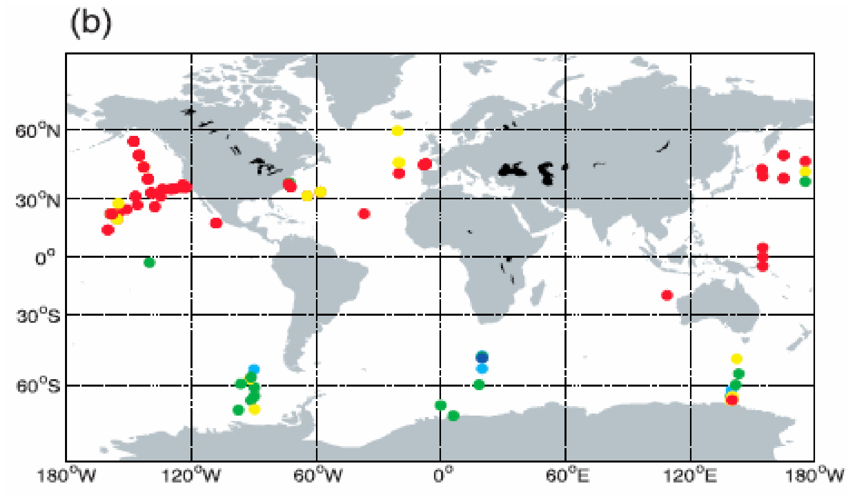
Parekh et al., 2005



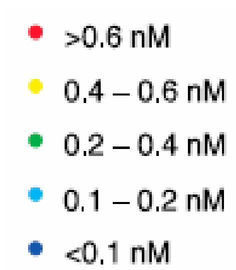
Observation

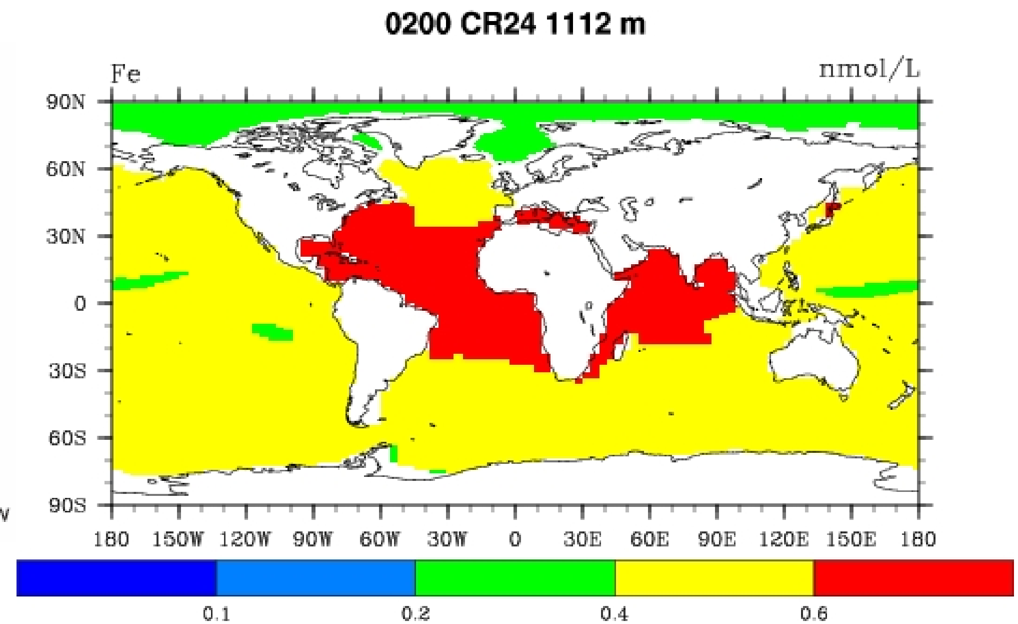
Calculation

Iron distribution at the depth of 1000m



Parekh et al., 2005



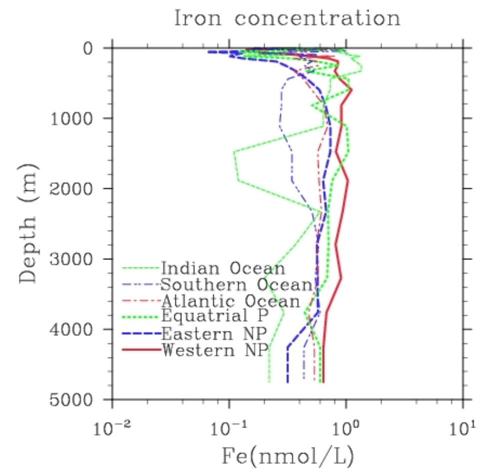


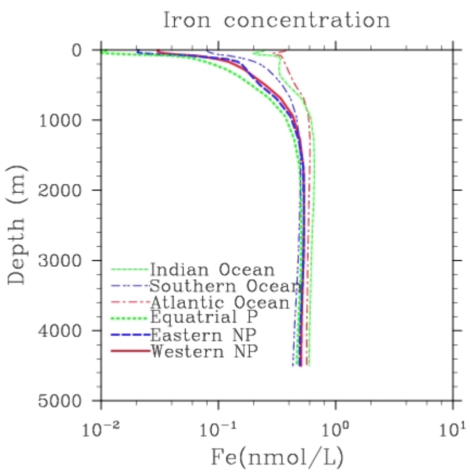
Observation

Calculation

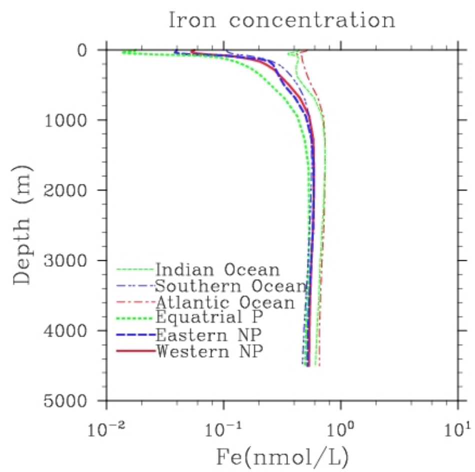
Parameter of iron dust deposition

- 3.5% Fe by weight with 2% of the Fe bioavailable (Fung et al., 2000)。

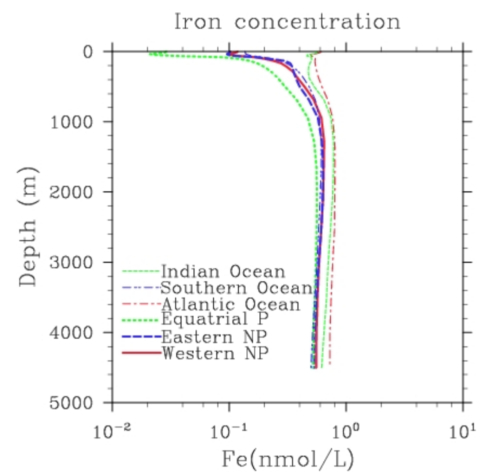




1%

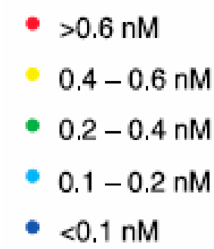


2%



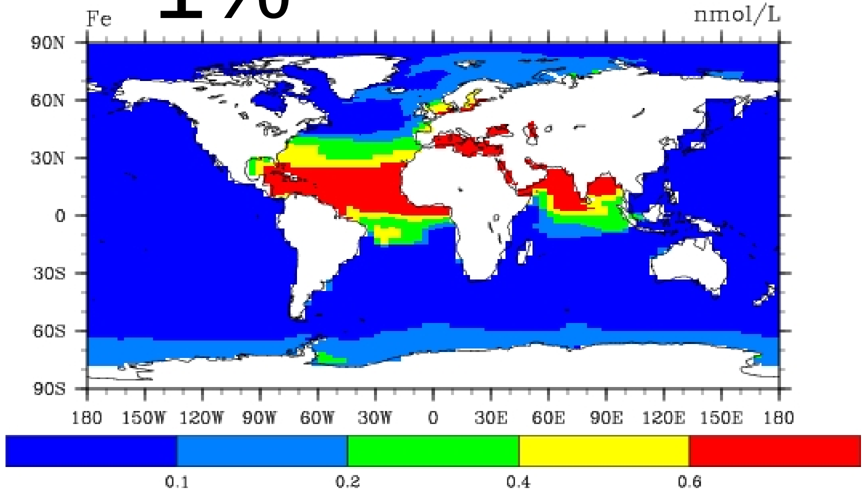
3%

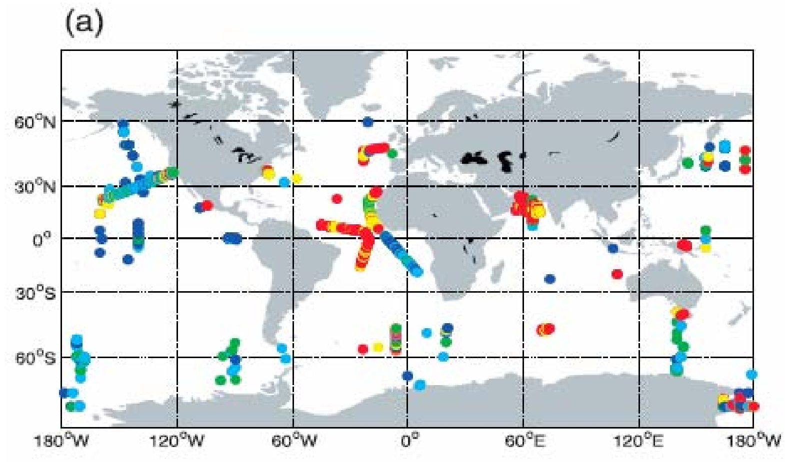
Iron concentration dust deposition



1%

0200 CR30

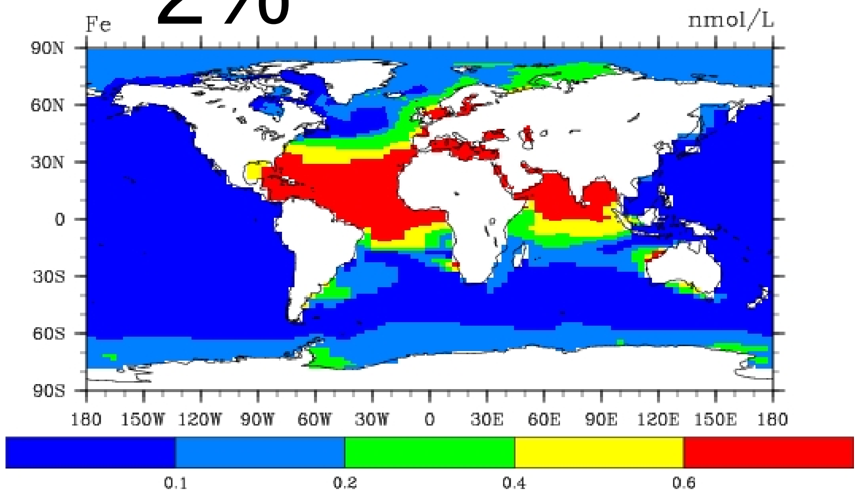




Parekh et al., 2005

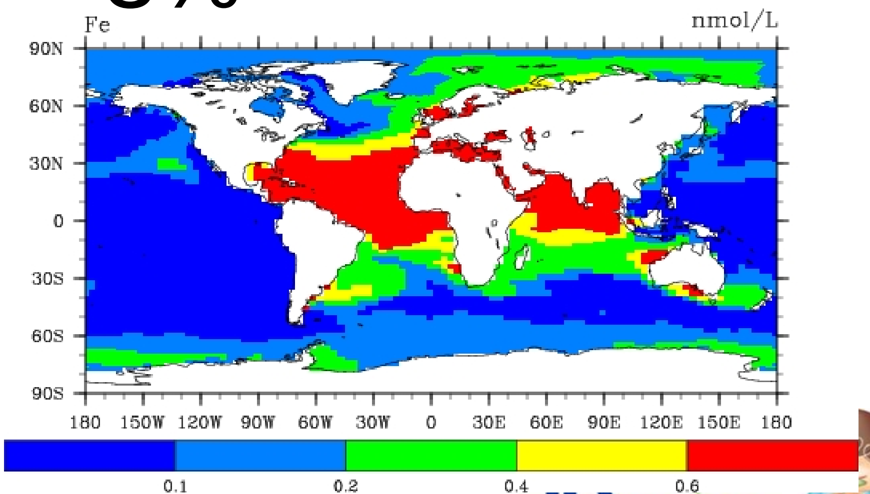
2%

0200 CR24



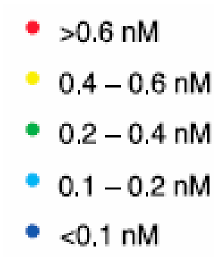
3%

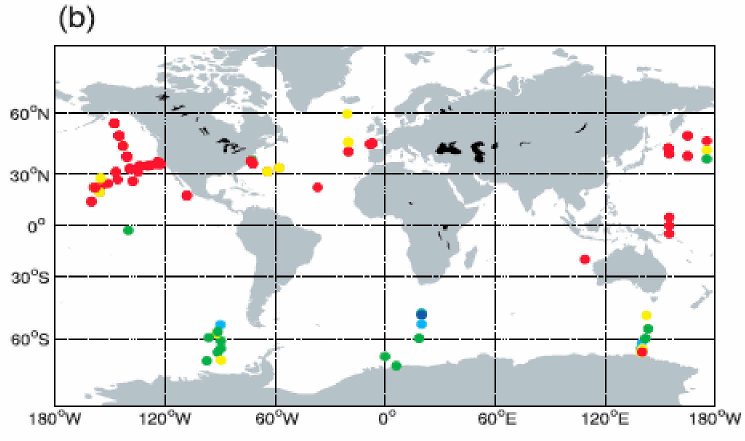
0200 CR31



Iron concentration dust deposition

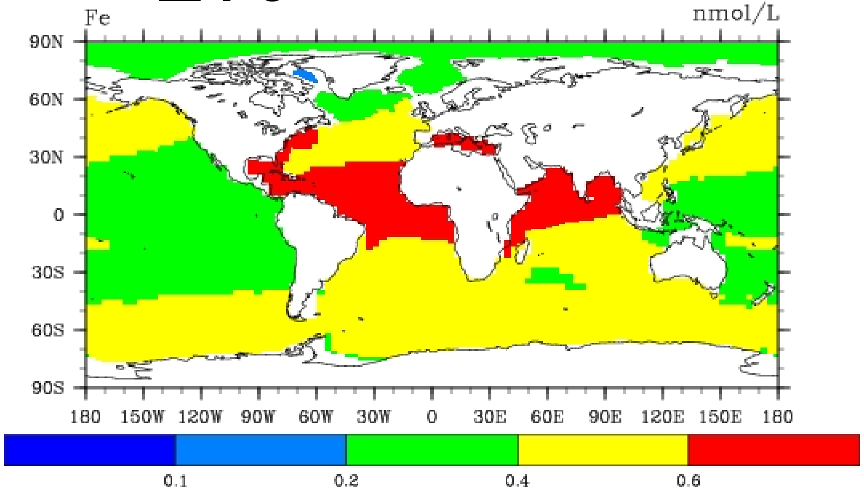
Fe concentration at 1000m



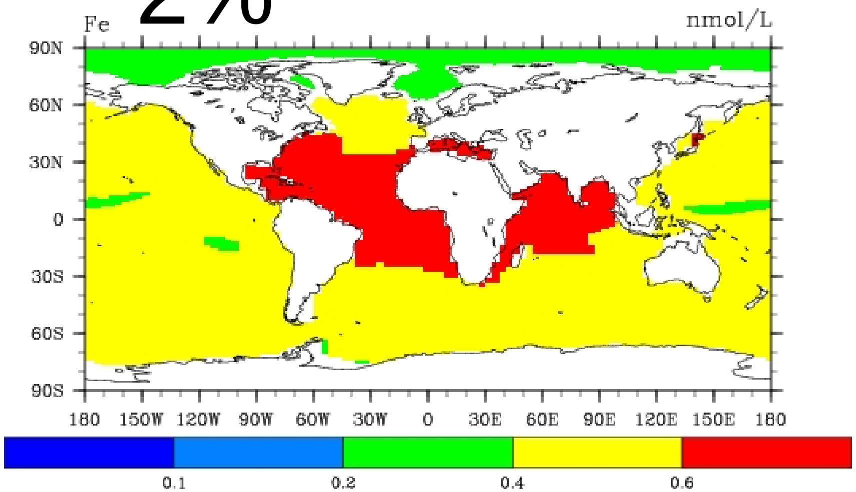


Parekh et al., 2005

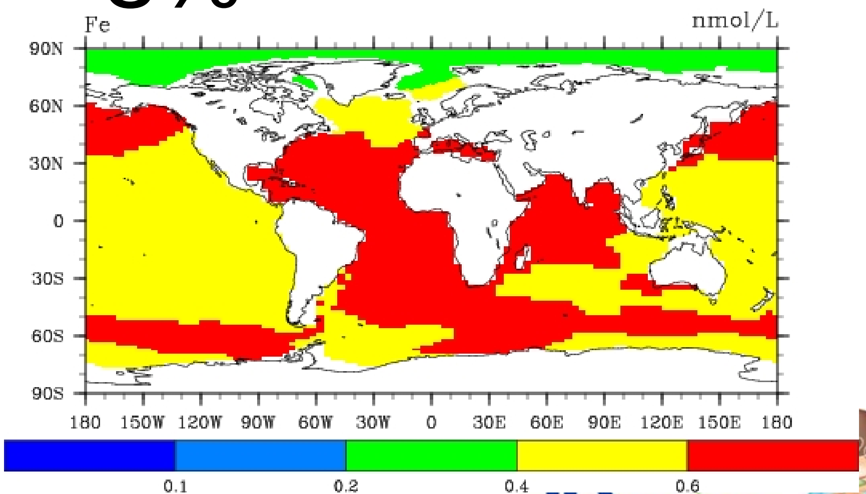
1% **0200 CR30 1112 m**



2% **0200 CR24 1112 m**

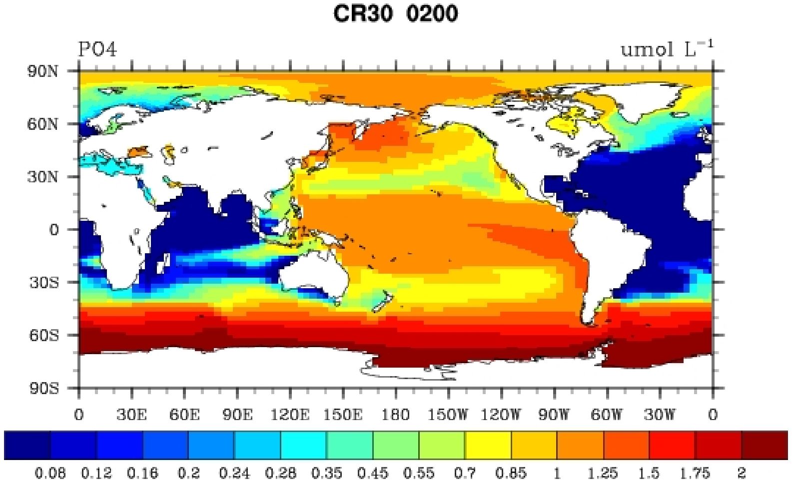


3% **0200 CR31 1112 m**

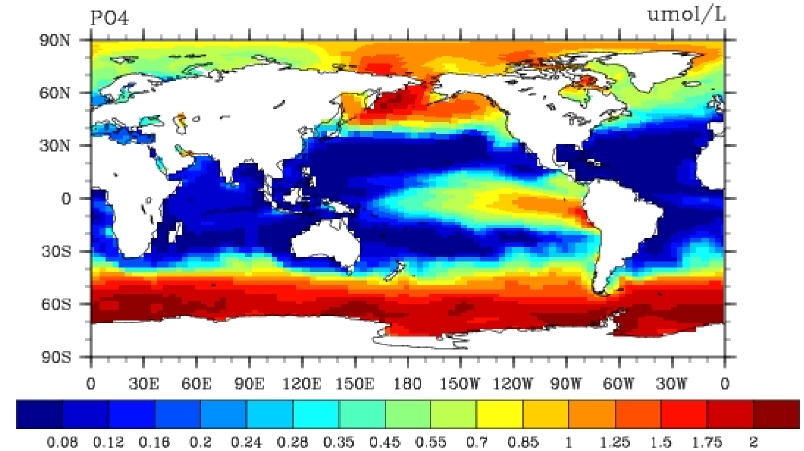


PO_4 concentration dust deposition

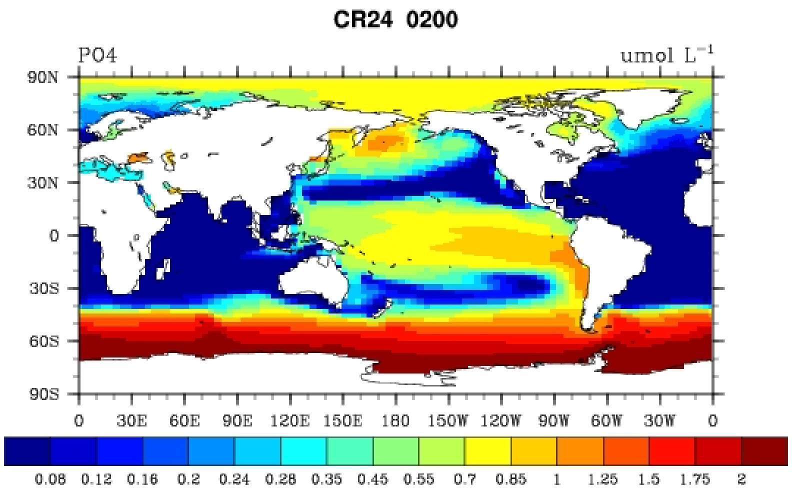
1%



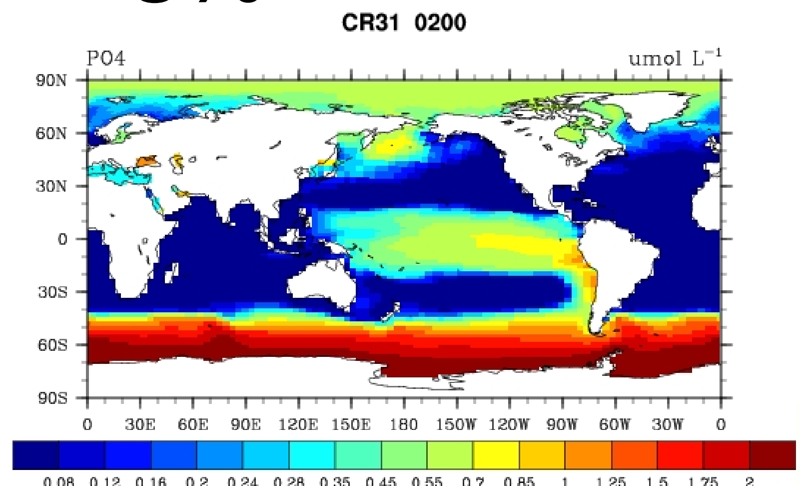
Obs.



2%

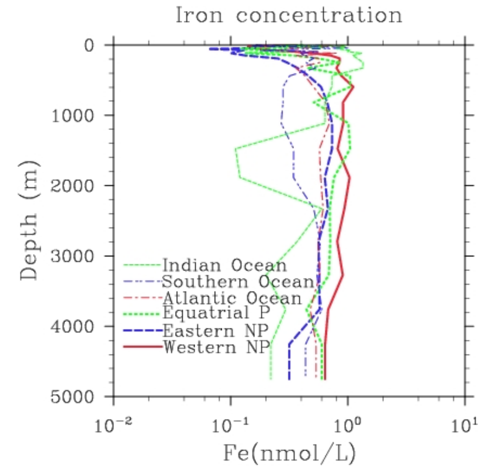


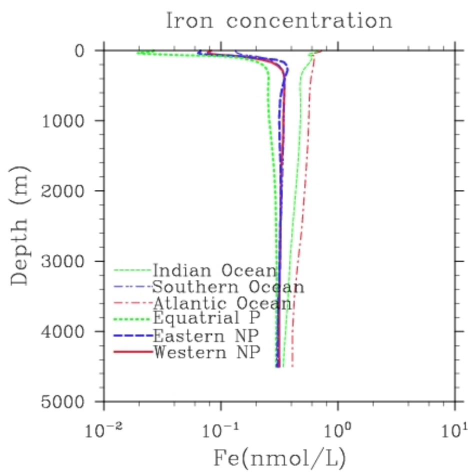
3%

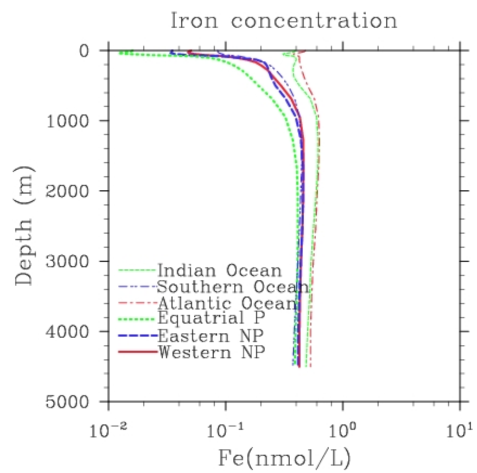


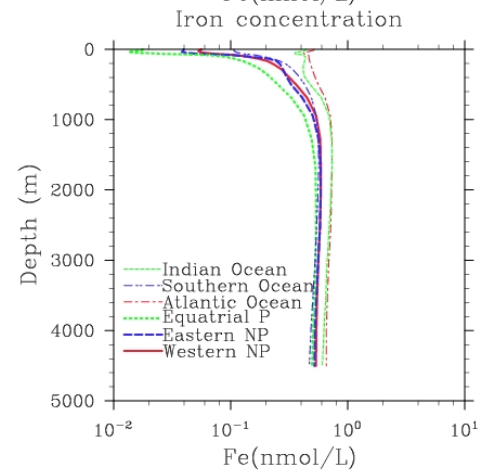
Scavenging parameters

$$Fw_{scav} = Fe_{Free} \cdot C_0 \cdot \left(1 + \alpha \exp\left(-\frac{z}{z_{scav}}\right)\right)$$









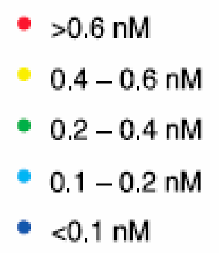
C_0=1.0 y^{-1}
α=9
z_{scav} = 500m

C_0=0.5 y^{-1}
α=100
z_{scav} = 250m

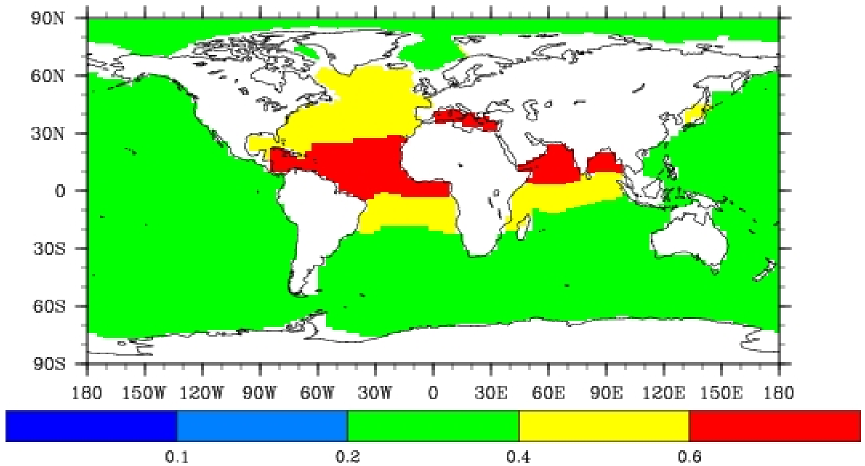
C_0=0.2 y^{-1}
α=200
z_{scav} = 250m

Scavenging parameters

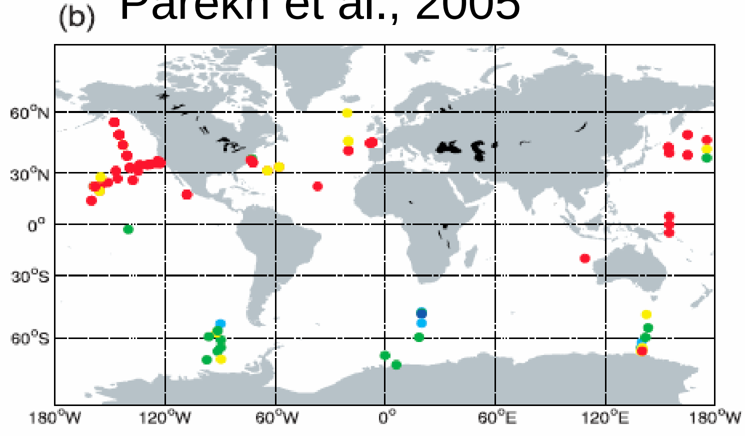
Fe concentration at 1000m



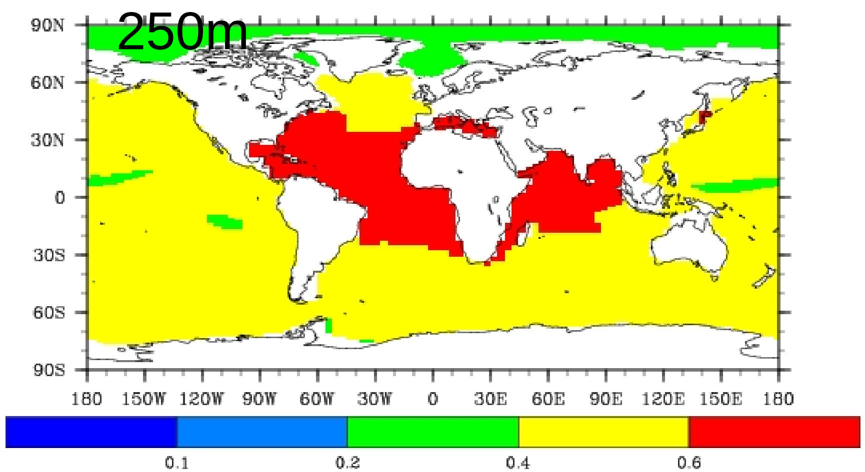
C_0=1.0 y^{-1} α=9 z_{scav} = 500m



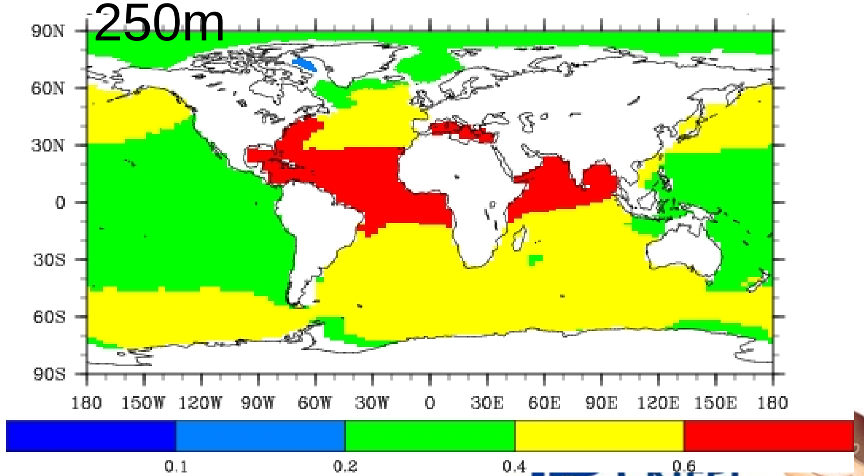
(b) Parekh et al., 2005



C_0=0.5 y^{-1} α=100 z_{scav} = 250m



C_0=0.2 y^{-1} α=200 z_{scav} = 250m



Conclusions

- Variable uptake ratio provides the reasonable distribution of phosphate and dose not affect the iron distribution.
- Iron scavenging model with complexation provides the reasonable vertical distribution of iron.
- When only iron input from atmosphere is considered, the difference of iron concentration between basins can not be represented in this model.
- Iron dust deposition rate affect the iron distribution but it is difficult to understand which is better rate due to still sparse observational database of iron concentrations.
- We acquired the reasonable phosphate and iron distribution for future numerical experiments to understand the effect of input from Amour river via Okhotck ocean to iron concentration in the western North Pacific ,and artificial iron fertilization experiments.

end

Sinking flux to the sea bottom Z_b

Archer and Johnson (2000)

$$POFe(z_b) = POFe(z_t) + (z_b - z_t)(0.6Fe_{scav} - POFe_{remin})$$

$$POFe_{remin} = \frac{POFe(z_t) - POFe(z_b)}{z_b - z_t}$$

$$= POFe(z_t)\frac{1-(z_b/z_t)^{-\beta}}{z_b - z_t}$$

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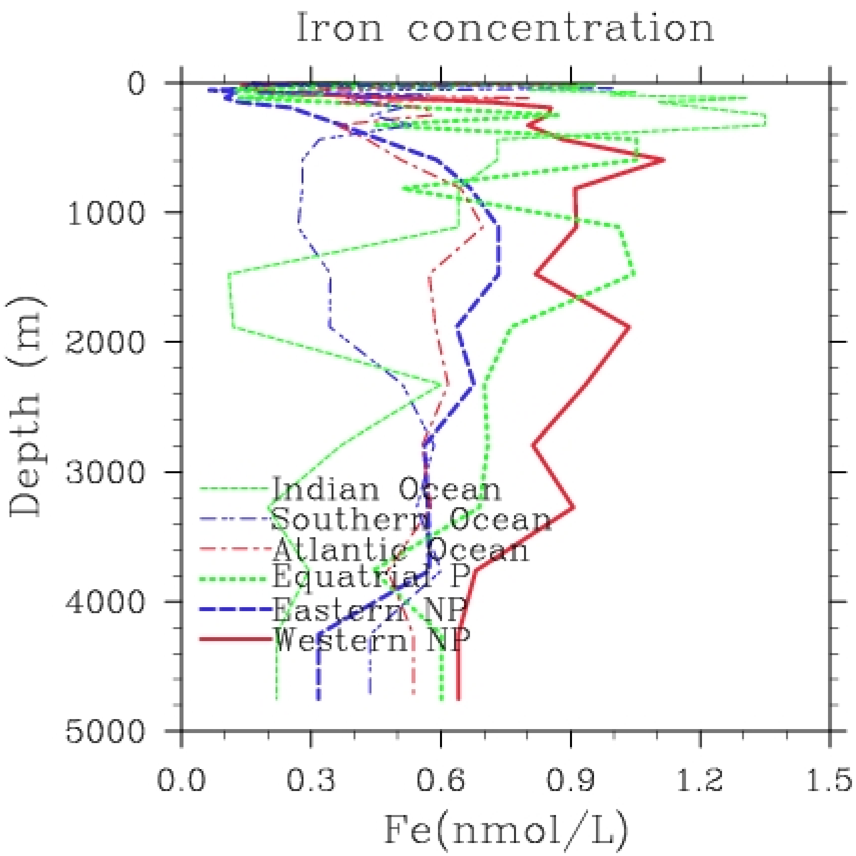
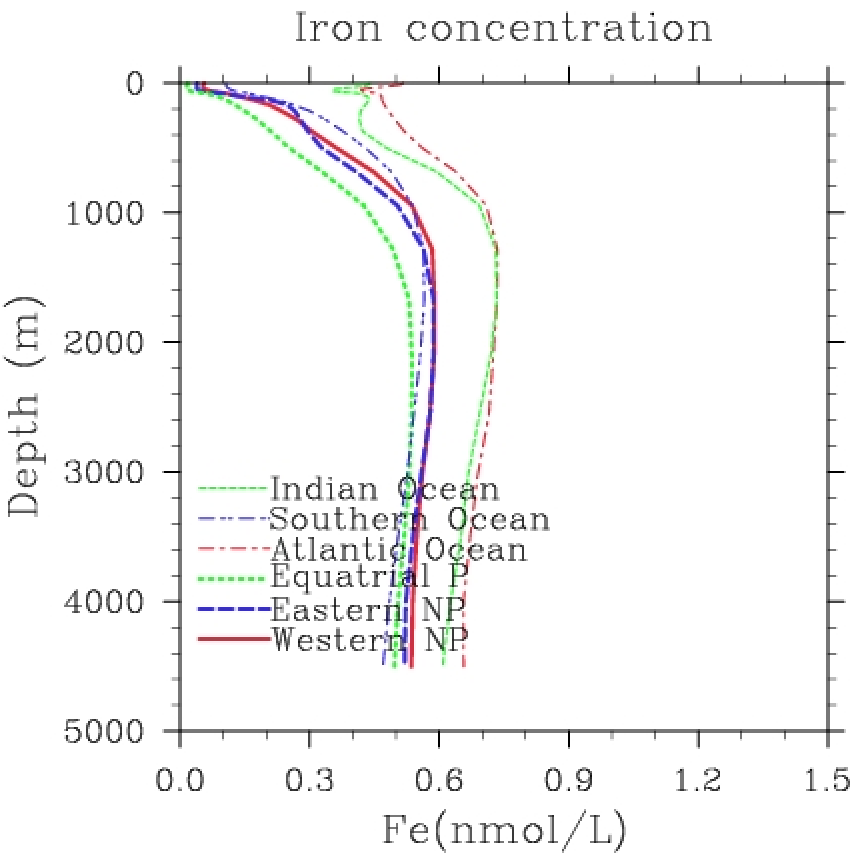
Vertical distribution of iron

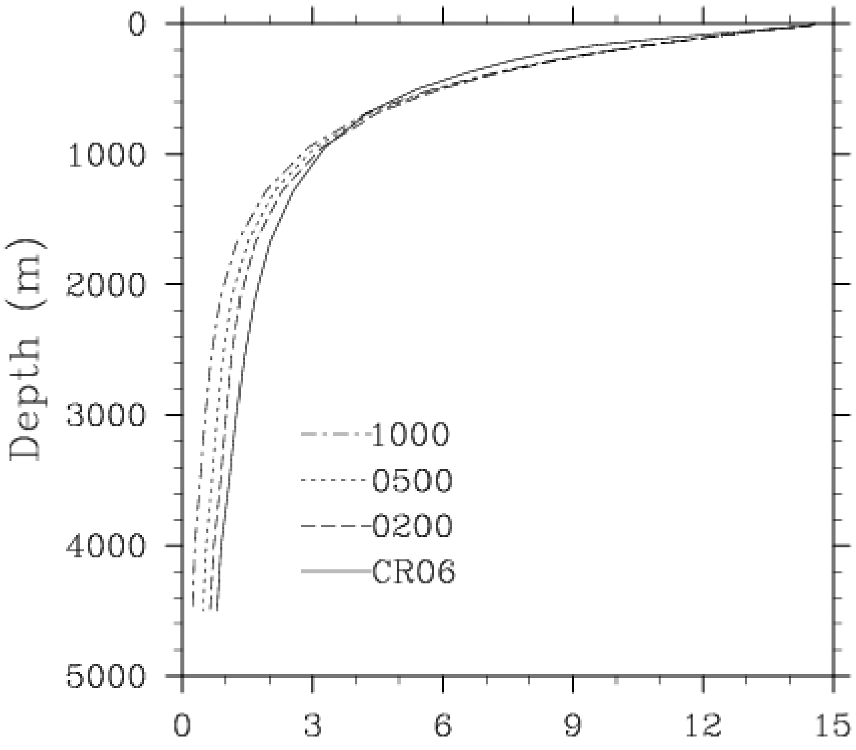


Observation

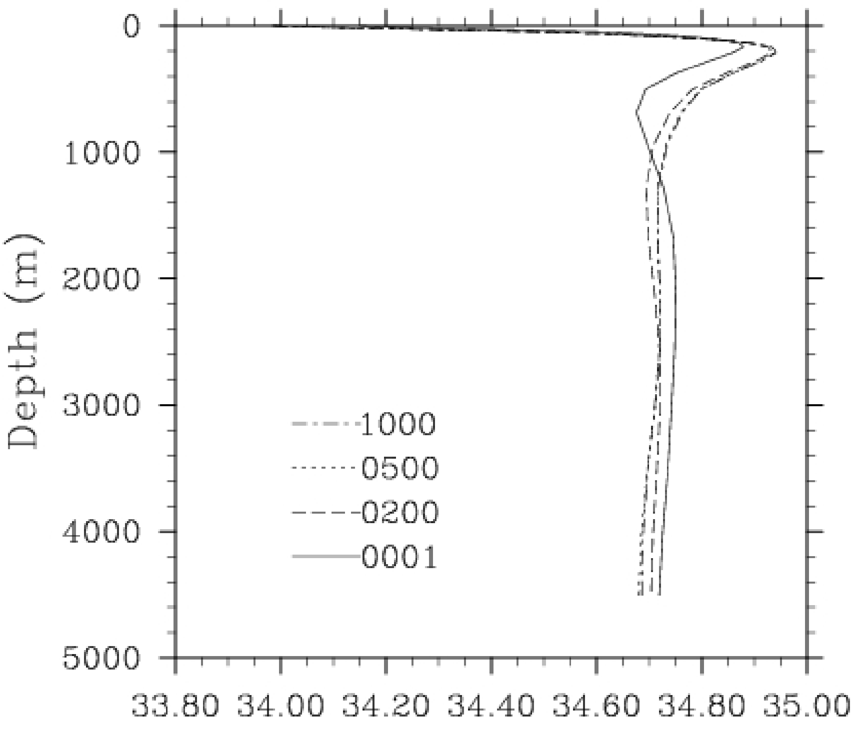


Calculation

Long term trend



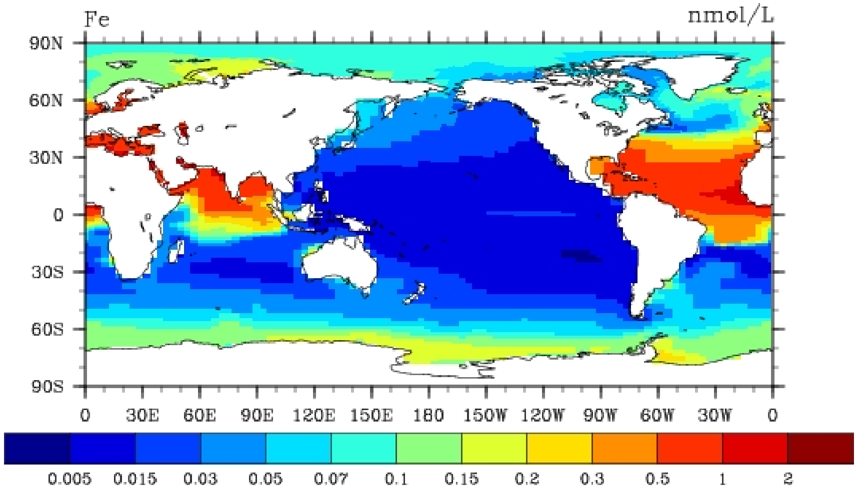
Temperature



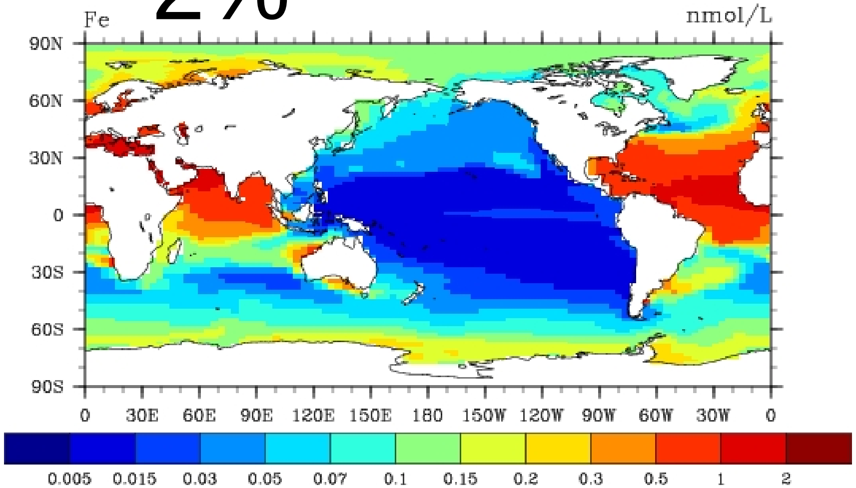
Salinity

Iron concentration dust deposition

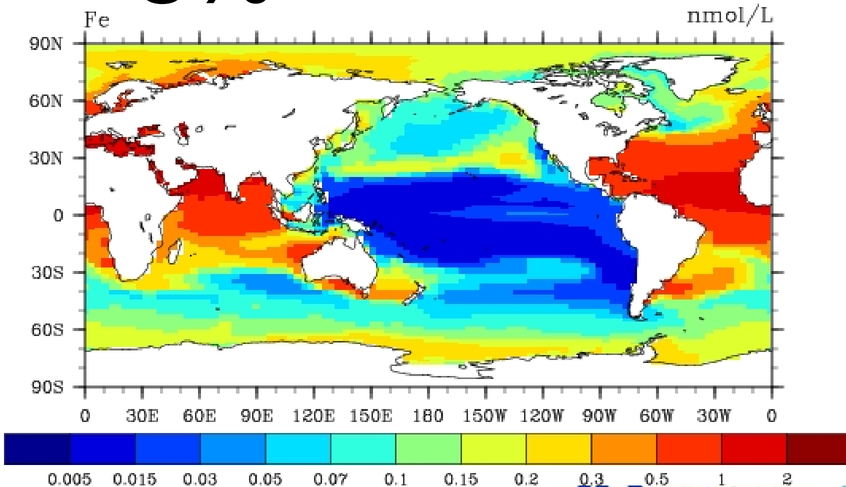
1% 0200 CR30



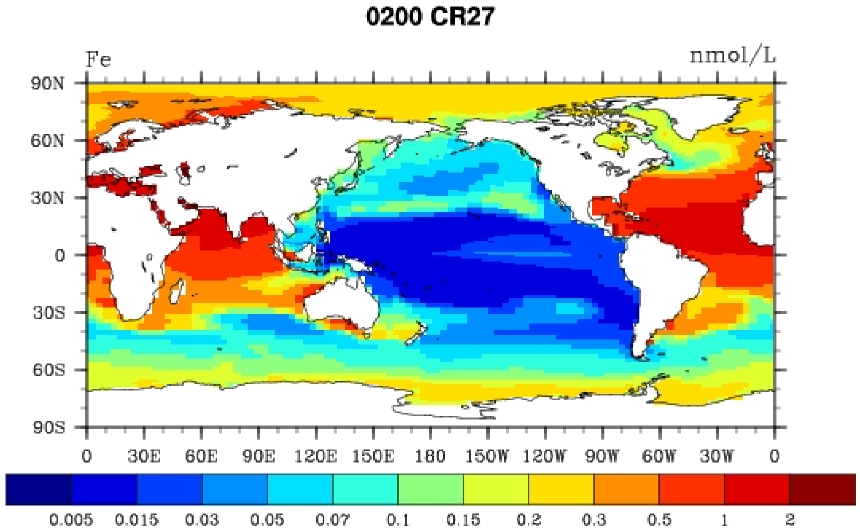
2% 0200 CR24



3% 0200 CR31



Scavenging parameters

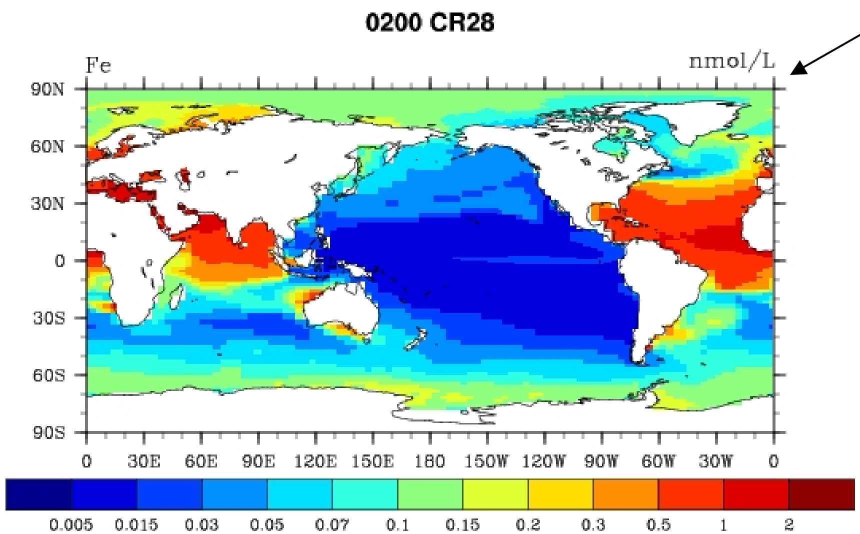


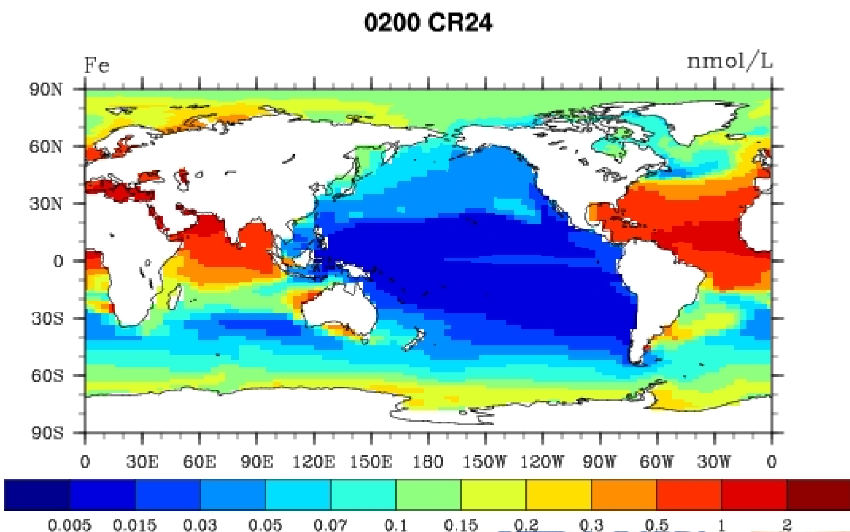
C_0=1.0 y^{-1}
α=9
z_{scav} = 500m

$$Fw_{scav} = Fe_{Free} \cdot C_0 \cdot \left(1 + \alpha \exp\left(-\frac{z}{z_{scav}}\right)\right)$$

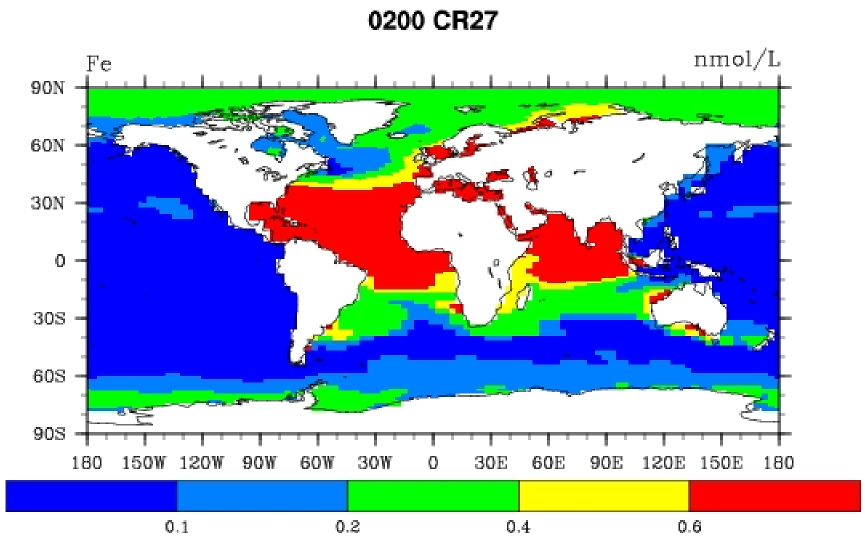
C_0=0.5 y^{-1}
α=100
z_{scav} = 250m

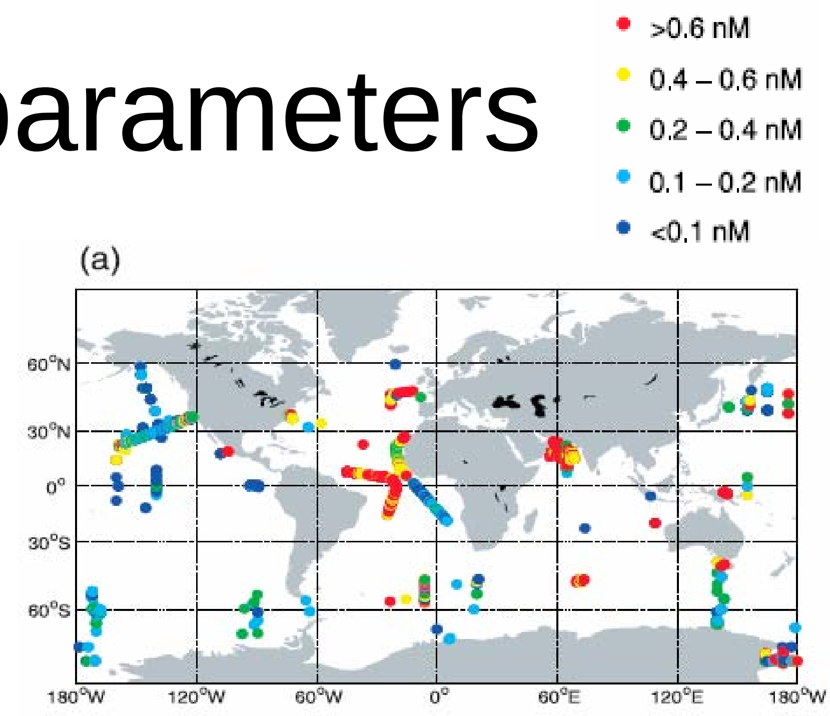
C_0=0.2 y^{-1}
α=200
z_{scav} = 250m



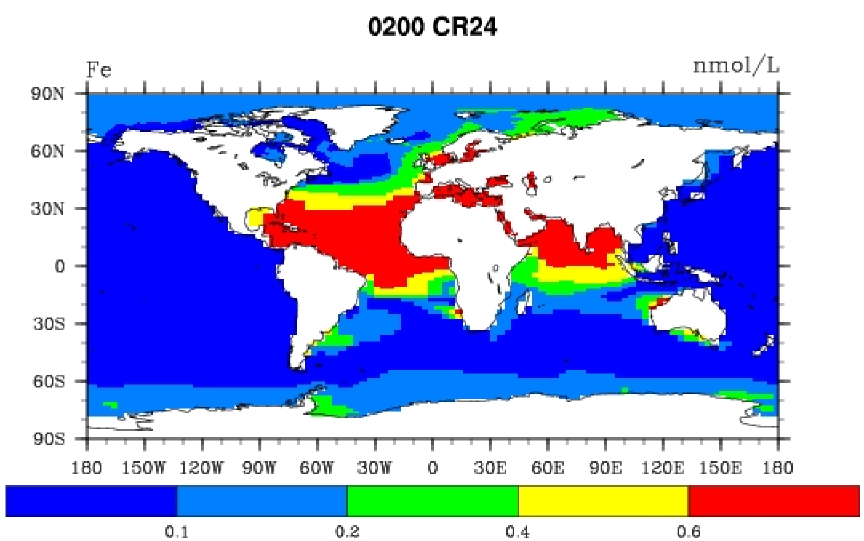


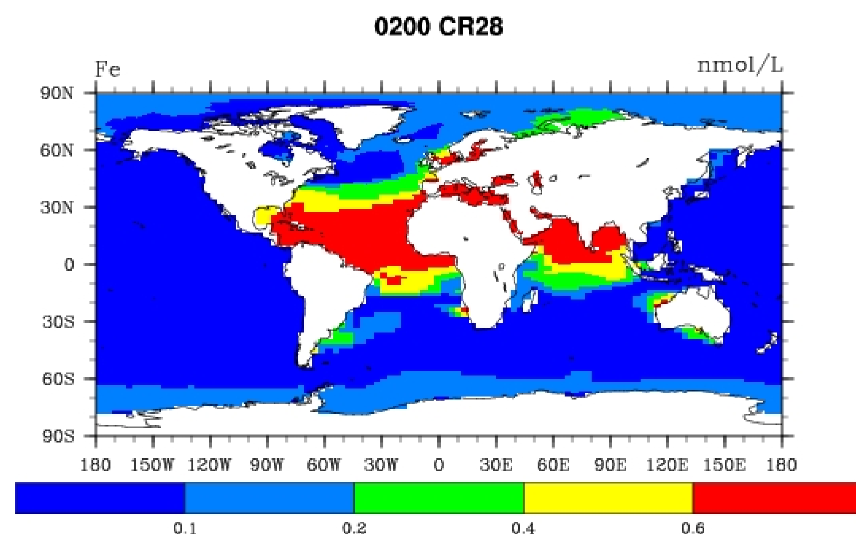
Scavenging parameters





Parekh et al., 2005





PO_4 concentration scavenging paremeter

Obs.