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Supplement of

Iron budgets for three distinct biogeochemical sites around the Kerguelen archipelago (Southern Ocean) during the natural fertilisation experiment KEOPS-2

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Supplementary material

This section includes the detailed description of the method used for determination of the vertical of iron supply term due to entrainment by transient (intra-seasonal) mixed layer deepening. The mixed layer is subject to transient deepening due to a variety of processes. Our goal here is to estimate the order of magnitude of iron entrainment into the mixed layer that could be explained by these events. We assume a well-homogenized mixed layer with an increase of dFe below the mixed layer (Supplementary Figure 1). When the mixed layer deepens, dFe from deeper waters is introduced to the surface. The mixed layer base eventually comes back to its original depth, 'detraining' some of the entrained dFe. The difference between the original profile and the final profile is what we refer to as entrained iron. Iron entrainment by a given transient event depends therefore on three parameters, namely: the shape of the dFe profile (the gradient below the mixed layer); the depth of the mixed layer (H); and the depth of the deepening event (H'):

$$dFe_{entrained} = \frac{H}{H+H'}\int_0^{H+H'} dFe \cdot dz - \int_0^{H} dFe \cdot dz \, ,$$

where dFe is dissolved iron concentration, and $dFe_{entrained}$ is the amount of entrained dFe for each H' deepening event (Supplementary Figure 2).

To estimate the depth integrated iron amounts, we used observed dFe profiles from both KEOPS cruises and associated observed mixed layer depths (Supplementary Figures 3b-3c). For the plateau dFe profile, station A3 was used for both KEOPS-1 and KEOPS-2 (Figure 4b); for the plume dFe profile, station A11 for used for KEOPS-1 (Blain et al., 2008b) and E stations used for KEOPS-2 (Figures 3d-3f). As an estimate of the order of magnitude of typical H' events in the area of the KEOPS experiment, we used the standard deviation of all mixed layer estimates available in the area, computed for each month of the year from the climatology of all mixed layer depth estimates. To estimate a flux, one also needs to know the time frequency of the deepening events. No time series exists to document this frequency in the Southern Ocean. However, we know that the mixed layer deviation H' is related to frequency of events by:

$$[H'/std(H)]^2 = 1/2\, F^{-1}$$ (Supplementary Figure 2).

For the purpose of quantifying an order of magnitude of entrainment, we consider here one deepening event per week to a depth:

$$H' = \sqrt{7/2} \cdot std(H) \approx 1.9 \cdot std(H).$$

Although non-linear, deeper deepening is compensated by a smaller frequency, while shallower deepening by larger frequencies. If regular instantaneous events are concerned we have:

$$Std(H)^2 = \frac{t_0 \cdot H'^2 + \ t_0 \cdot H'^2 + 0 \cdot (T - 2t_0)}{T}$$

and thus:

$$[H'/std(H)]^2 = \frac{1}{2}\frac{T}{t_0} \ = \ \frac{1}{2}F^{-1}$$

If we consider all kinds of deepening events, with a Gaussian distribution, we have:

$$f(H_0) = \frac{A}{std(H)\sqrt{2\pi}} \ e^{\frac{-[H_0 - mean(H)]^2}{2\ std(H)^2}}, \text{ with: } B = \frac{A}{std(H)\sqrt{2\pi}}\,.$$

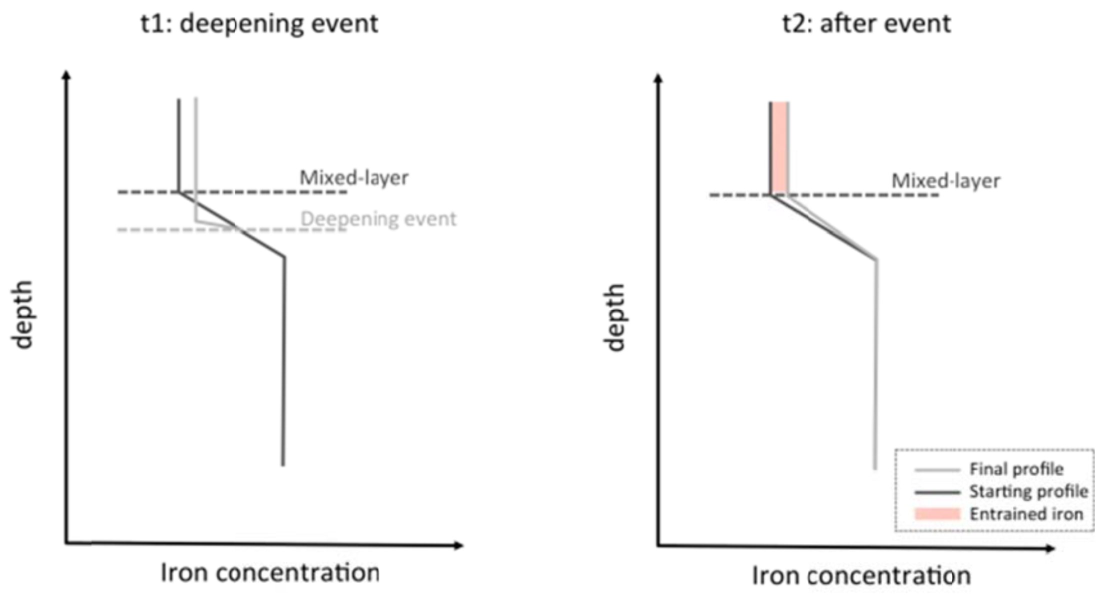
The frequency F(H’) of one event:

$$H' = H_0 - mean(H) \text{ is} = \frac{f(H')}{\int_{-\infty}^{+\infty} f(x)dx} = \frac{1}{std(H)\sqrt{2\pi}} \ e^{\frac{-H'^2}{2\ std(H)^2}}.$$

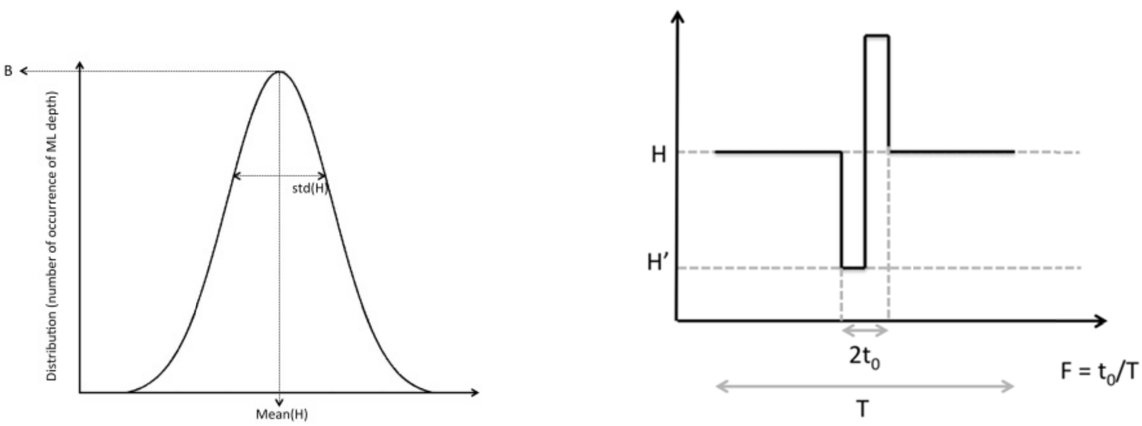
Thus net entrainment can be obtained by summing entrainment due to a suite of events of varying H’ with: $0 < H' < 100 \cdot std(H)$, and at the associated frequency F(H’). We used this second approach to estimate entrainment.

Supplementary figures

Supplementary Figure 1. Schematic representation of entrainment and its impact on dissolved iron concentration in the mixed layer.



Supplementary Figure 2. Plots describing the different notations used in the calculation of iron supply by entrainment. (a) Distribution of magnitudes of the mixed layer deepening events. (b) Relationships between deepening and restoration durations (t0) and their frequency of occurrence (F).



Supplementary Figure 3. Locations and origins of the vertical profiles of density used for the determination of the climatologies of the mixed layer depth above the plateau and in the plume: (a) the two regions examined; (b, c) the mixed layer depth seasonal variations (mean and standard deviations) in the plume and over the plateau from shipboard, Argo autonomous profiling float observations, and CTD sensors attached to elephant seals; (d, e) details of the available data sources for each region.