

## Text S1

### Methods

The high-resolution (2km) coastal model extends 192 km in the alongshore direction, 384 km in the offshore direction, and in depth ranges from 40m at the coast to 1800m offshore. With 32 vertical levels in a sigma-coordinate grid, the vertical resolution changes from less than 2 m on the shelf to approximately 56 m offshore. However, in order to maintain a uniform resolution for the bottom and surface boundary layers, vertical resolution is set as 8 m and 5 m at the bottom and top grid boxes, respectively. The north and south boundaries are periodic. The shore, offshore, and bottom boundaries are closed. The model is set on an f plane at 42° N.

In order to eliminate upwelling from occurring at the offshore wall, the mean alongshore density is restored to the initial density profile within 40 km of the offshore boundary according to (Lathuliere et al., 2010)

$$\frac{D\rho}{Dt} = \frac{-(\rho_{mean} - \rho_0(z))}{\lambda_{restore}} \quad (\text{Eq. S1})$$

where  $\rho$  is the local potential density,  $\rho_{mean}$  is the alongshore averaged density,  $\rho_0$  is the initial density profile, and  $\lambda_{restore}$  is the restoring timescale of one day.

The model is initialized with a density profile measured on the RV Wecoma during a CTD cast in over 1500 meters of water off the coast of Newport, Oregon in August, 2009 shown in Figure S1. The model is run with constant upwelling-favorable winds of  $-0.15 \text{ N/m}^2$  for 23 days prior to altering the wind forcing as described in the numerical experiment section. An alongshore barotropic pressure gradient is applied to the slope region of the model in order to generate the poleward undercurrent (Pringle et al, 2009). The barotropic pressure gradient is

subtracted from baroclinic pressure gradient in the alongshore direction applied uniformly everywhere with a value of  $0.00004 \text{ N m}^{-3}$ .

Several assumptions are made in the design of the iron-like tracer. First, the flux of iron from the sediments is taken to be constant, although it is known to change with water column oxygen concentrations, which are variable on the west coast of the US (Severmann et al, 2010). While oxygen is not explicitly considered in the tracer design, experiments are carried out to assess the sensitivity of the iron export ratio to a varying flux of iron from the sediments. Second, the consumption of the iron-like tracer by phytoplankton is not limited by the presence of other nutrients like nitrate (Chase et al, 2002). The coastal waters off of Oregon are not limited by nitrate, so this assumption seems valid.

Another assumption lies in the first order uptake design of the iron tracer. The model formulation, while inconsistent with previous modeling studies, is a conservative approach to estimating iron export efficiency. In a productive region like the shelf, the first order uptake in our model consumes more iron than a model that would saturate like a Michaelis-Menton formulation. Further, we are not attempting to model the concentration of iron in the water column, but instead we are asking how efficiently iron can be moved from point A to point B by modeling an anomaly in iron concentration, due to the source from the sea floor. Saturation of biological uptake depends on the total iron pool, not just the sedimentary derived iron.

To verify that the inability to achieve steady state does not impact the fraction of sediment-derived iron that is exported to the slope, an experiment was designed to force a steady state by increasing the scavenging rate. The scavenging rate in Equation 1 ( $\lambda_{\text{scav}}$ ) was increased

by four orders of magnitude to  $0.1 \text{ d}^{-1}$ . The fraction of exported sediment-derived iron from the shelf remained the same (16%) when the model forcing is kept the same.

### **Supplemental Discussion**

#### **Comparison of Modeled vs Measured Circulation**

The modeled mean circulation is shown in Figure 1. The model captures the varying direction of the alongshore shelf circulation and the two alongshore jets on the slope – the equatorward surface jet and the poleward undercurrent. However, overall, the currents on the shelf, as well as on the slope, are stronger than the observational averages.

The shelf circulation during upwelling events has a mean equatorward flow that averages  $-0.3 \text{ m/s}$  and extends past the shelf onto the slope where the shelf jet merges with the equatorward slope jet. While this is stronger than the observed averages reported in the literature, observations of equatorward flows of that magnitude have been found to exist and these results compare well with previous modeling studies (Federiuk & Allen, 1995). The lack of a separation between the flow on the shelf and slope is consistent with observations (Huyer et al., 2002).

The slope circulation is stronger than observed and the poleward undercurrent has a core that is deeper in the water column than observations (Huyer et al, 2002; Pierce et al, 2000). Although observations below 500 meters are rare, the few that exist confirm the existence of poleward flow as deep as 1000 meters. The flow at around 1000 meters is observed on average to be only  $0.01 \text{ m/s}$  to  $0.15 \text{ m/s}$  (Ramp et al, 1997; Noble and Ramp, 2000), which is consistent with model predicted values. The deepest observations of the transition between the

surface equatorward flow and the undercurrent occur around 100-200 meters below the surface, which is consistent with the model results.

When forced with realistic winds, the magnitudes of the alongshore velocities agree more with observations than in the oscillating wind scenario. In addition, the transition between equatorward and poleward flow on the slope is shallower than the oscillating wind case. However, the structure of the poleward undercurrent remains the same in the sense that the core of the undercurrent resides around 1000 meters, which is much deeper than observations.

Due to the periodic boundaries and the idealized bathymetry, the model neglects several key variables (e.g. alongshore variations in bathymetry or density, internal tides, etc), which are thought to play a role in the formation and variation of the poleward undercurrent. The poleward undercurrent may result from more than one factor, which may be variable, but only a constant alongshore pressure gradient is employed here.

### **The Importance of Eddies**

In Figure S2, results of two simulations with a different alongshore domain dimension are plotted. The domain in Figure S2a is smaller than the Rossby radius of deformation and thus does not generate eddies. In Figure S2b, the domain is larger than the Rossby radius of deformation and consequently produces eddies. The effect of eddies on the exported iron can be ascertained by comparing the two time-averaged sections of sediment-derived iron concentrations.

Without eddies the efficiency of exported iron is 0.24; the export of sediment-derived iron occurs along isopycnals which intersect the upper slope with the maximum in the iron concentration focused in a narrow depth range between 100 and 450 meters. Eddies spread out

the iron throughout the water column and reduce the efficiency of export to 0.19. They act to reduce the velocity of the poleward undercurrent, which reduces the shear on the upper slope, effectively reducing the efficiency of lateral export from the shelf. However, the structure of the iron in the water column on the slope is different, and more iron ends up further offshore when the eddies are present. While eddies do not determine how much iron ends up offshore, they do aid in transporting iron offshore.

### **Influence of Alongshore Pressure Gradient**

The alongshore pressure gradient influences the source water depth for the upwelled water in an upwelling regime (Pringle et al, 2009). The direction of the alongshore flow on the slope controls the direction of the flow in the bottom boundary layer. The poleward undercurrent causes water to move downslope in the bottom boundary layer. One way to show the influence of the poleward undercurrent on the source water depth is to compare the iron export efficiency in the model forced with different alongshore pressure gradients.

Without an alongshore pressure gradient, a weak poleward flow develops on the deep slope. The reversal in the alongshore flow occurs around 1000 meters. Iron is still exported offshore, but less efficiently ( $E_{\chi} = 0.14$ ). With a weak alongshore pressure gradient, a weak poleward undercurrent develops in the model. As the alongshore pressure gradient is increased, the strength of the poleward undercurrent, the vertical shear, and the efficiency of exported iron increases (see Table S1). As the poleward undercurrent increases in magnitude, it resides closer to the surface. Eventually, when the highest pressure gradients are applied, the poleward undercurrent surfaces, reaches unrealistic magnitudes ( $\sim 3$  m/s) and the equatorward surface flow

disappears. As the magnitude of the undercurrent increases, so does the shear on the upper slope, which increases the lateral pumping of iron offshore.

The cross-shelf transport in the bottom boundary layer increases with the strength of the alongshore poleward flow on the slope. A strengthening of the poleward flow on the slope results in more of the iron being exported in the BBL.

### **Influence of the Turbulence Closure Scheme**

The efficiency of iron exported from the coastal ocean to the open ocean in the west coast simulation is about the same whether choosing the Mellor-Yamada or k-eps turbulence closure schemes. However, the constant vertical mixing case results in nearly a factor of 2 less exported iron than the shear based turbulence closure schemes. Despite this difference, the response of exported iron to the winds is the same over time – iron is exported most efficiently during downwelling events. The wind-driven circulation controls the timing of the export more than the turbulence closure scheme.

Spatially, the dispersal of the exported iron in the water column on the slope also differs between the turbulence closure schemes and the constant vertical mixing. With a turbulence closure scheme, the concentration of exported iron peaks in the water column near the region of low velocity where the alongshore velocity switches direction, around 100-200m. The exported iron builds on the upper slope and is transported offshore along the isopycnals between the equatorward surface and poleward undercurrents. This is also the location of highest vertical mixing in the bottom boundary layer because of the high vertical shear associated with the intersection with the boundary there. The mixing in the bottom boundary effectively pumps iron

offshore along the isopycnals that intersect the slope in this region of high vertical mixing and shear.

Iron is also entrained into the core of the poleward undercurrent on the deep slope, but the majority is exported just below the surface. In response to constant vertical mixing, the exported iron does not build on the upper slope, but rather is transported in the bottom boundary layer on the slope to the depths of the domain. In contrast to the turbulent closure scheme runs, the iron is exported offshore equally along the subsurface isopycnals and downslope into the core of the poleward undercurrent on the deep slope.

### **The Importance of the Uptake Rate ( $\lambda_{\text{prod}}$ )**

Sensitivity analysis was performed on ( $\lambda_{\text{prod}}$  and is shown in Table S1. The uptake rate was varied between  $(1 \text{ day})^{-1}$  and  $(12 \text{ days})^{-1}$  consistent with the range observed in Sunda and Hunstman (1995). The export efficiency increased with decreasing uptake rate and ranged between 11% and 34% for the uptake rates chosen, though always resulting in export. The smaller the uptake rate, the more iron ends up offshore.

### **The Importance of the Source Term ( $\text{Fe}_{\text{sed}}$ )**

The observed flux of iron from the sediments varies from  $2 \text{ umol m}^{-2} \text{ yr}^{-1}$  to over  $100 \text{ umol m}^{-2} \text{ yr}^{-1}$  (Severmann et al, 2010). When the source of iron from the sediments was varied over that range in the model, the efficiency of export of iron did not change much (see Table S1). In other words, the fraction of exported iron remained the same over a wide range of iron fluxes.

### **The Importance of Scavenging Rates ( $\lambda_{\text{scav}}$ )**

The observed rates range from  $10^{-4}$  to  $10^{-5}$  day<sup>-1</sup> in Moore and Braucher, 2008. Over this range, scavenging is negligible compared to the other sources and sinks for Fe. Hence, the scavenging rate does not affect the fraction of exported iron as shown in Table S1.

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