THE GULF OF ALASKA SPRING BLOOM AND A STABILITY RATIO

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1. INTRODUCTION

What controls the timing and magnitude of the spring bloom in the coastal Gulf of Alaska? At this northerly latitude, light limitation of phytoplankton growth in winter and early spring is highly likely. Establishing a stable, stratified water column in spring will therefore be essential for a bloom to start. Stratification in this region will rely on a balance between processes which mix the water column, and those that stabilize it. Mixing arises primarily from wind stress, whilst surface heating and freshwater input encourage stratification. We define a 'stability ratio' which parameterises the competition between buoyancy and mixing and compare it to the timing of the spring bloom.

2. DATA

We use weekly satellite derived chlorophyll concentration data from SeaWiFS for 1998-2005. The data were spatially averaged over a series of boxes (**Figure 1**), excluding fjords and inland waters. The start date of the bloom was estimated following Siegel et al. (2002) and Henson et al. (2006). Wind friction mixing (u_*^3) was derived from QuikSCAT scatterometer data. Net heat flux and freshwater runoff are NCEP reanalysis products. Salinity data were obtained from the ECCO-GODAE model.

3. THE SPRING BLOOM

To illustrate the characteristics of the CGOA spring bloom, two years have been selected which typify 'early' and 'late' blooms (2002 and 2004 respectively). The time series of SeaWiFS chlorophyll data for each year and each region is shown in **Figure 2a**. In 2002 the bloom starts ~ day 90 in all three regions. In 2004 the bloom starts between 7 and 20 days later (the difference is greatest in Region A). Note also that the early bloom in 2002 is of greater magnitude than the late bloom of 2004 (at least in Regions A and C).

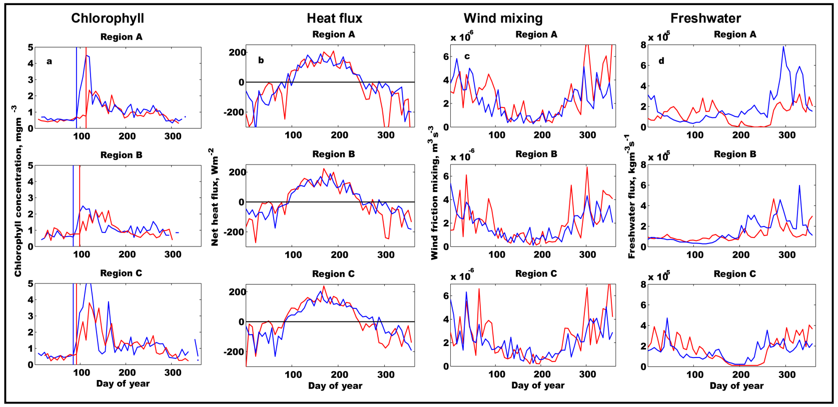

Figure 2: Weekly data in three regions for 2002 (blue) and 2004 (red) of a) chlorophyll concentration, b) net heat flux, c) wind friction mixing and d) freshwater runoff. Vertical lines in 2a mark the bloom start dates.

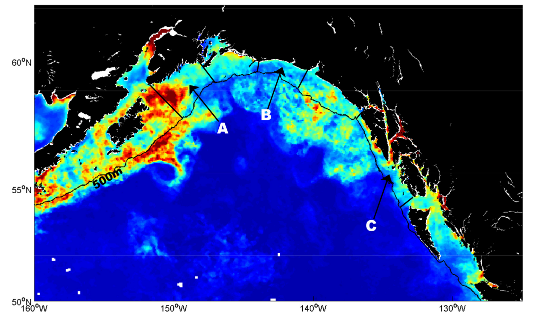

Figure 1: Mean SeaWiFS chlorophyll (mg m^{-3}) May-June 2000. Location of the three boxes used in this study, and 500m depth contour, are marked.

4. PHYSICAL CONDITIONS

Time series of the net heat flux, wind friction mixing and freshwater runoff data for the three regions in 2002 and 2004 are plotted in **Figure 2b-d**. In Region A the net heat flux becomes positive (i.e. into the ocean) a little earlier in 2002 than in 2004, but in Regions B and C it occurs at about the same time. Wind friction mixing is stronger in early spring in 2004 than in 2002 in all three regions. Freshwater runoff is also greater in springtime in 2004 than 2002 in all three regions. This leaves us with a somewhat confused picture….in 2004 (the late bloom year) it makes sense that springtime wind mixing is stronger (destratifying effect), but what about the high freshwater runoff and the not-unusual heat flux (stratifying effects)? No single parameter by itself can explain the timing of the spring bloom, rather the interaction between the factors needs to be examined.

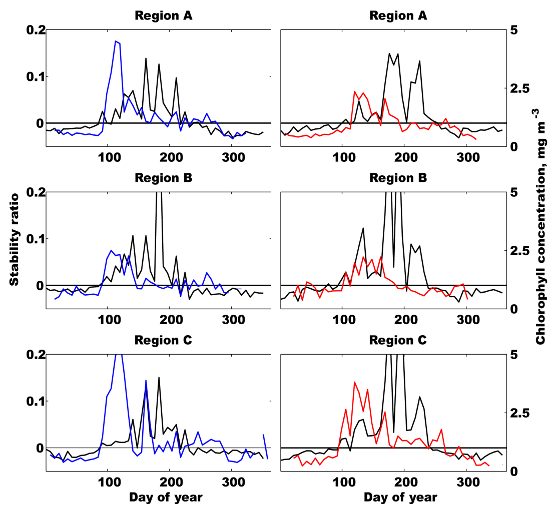

Figure 3: Chlorophyll concentration (blue, 2002 and red, 2004) and stability ratio *R* (black) for three regions. When *R* > 0 buoyancy effects dominate mixing, and vice versa. Note the strong correspondence between timing of spring chlorophyll increase and *R* exceeding zero.

5. STABILITY RATIO

The onset of the bloom is likely light limited, and therefore requires that positive buoyancy effects (i.e. those which encourage water column stability) must be greater than mixing effects….

$$\frac{\text{Buoyancy}}{\text{Mixing}} > 0$$

We assume that the only mixing arises from wind friction (u_*^3) and that the buoyancy term has two components: a heating (B_q) and a freshwater (B_m) term….

$B_q = \frac{g\,\alpha\,Q}{\rho\,C_p}$,where Q is net heat flux, g is gravitational acceleration, α is the thermal expansion coefficient, ρ is density and C_p is specific heat capacity

$B_m = \frac{g\,\beta\,S}{\rho} \cdot (E - P - F)$,where E is evaporation, P is precipitation, F is freshwater flux, S is salinity, g is gravitational acceleration, β is saline contraction coefficient and ρ is density

Plugging in the relevant NCEP and ECCO model data, we obtain our 'stability ratio', *R*. In **Figure 3** the stability ratio is plotted along with the chlorophyll data for 2002 and 2004 in the three regions. The start of the spring bloom consistently occurs within a couple of days of the stability ratio exceeding zero – i.e. when buoyancy effects outweigh mixing.

6. CONCLUSIONS

In the coastal Gulf of Alaska phytoplankton growth is likely to be light limited in winter and early spring. The onset of stratification will therefore be key to the timing of the bloom. We have a defined a 'stability ratio' as the ratio of buoyancy effects, due to heating and freshwater input, to mixing effects, due to wind stress. A ratio > 0 indicates that buoyancy effects dominate mixing, and therefore stratification is possible. We identify two years with contrasting chlorophyll characteristics (2002 – early, strong bloom; 2004 – late, weak bloom), but find that the physical conditions, considered separately, do not show consistent differences between the two years. However, when parameterised as the stability ratio, we find a close correspondence between the ratio becoming > 0 and the timing of the spring bloom. This simple ratio between buoyancy and mixing defines, to the first order, periods when stratification can potentially occur. It clearly also has significance for the timing of the phytoplankton spring bloom.