MCCIP Marine Climate Change Impacts Partnership

Topic

Shelf Sea Stratification and the Spring Bloom

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Executive summary

Freshwater Stratification: As stratification of the regions of freshwater influence in Liverpool Bay and the southern North Sea depends on the balance between the rate of supply of the estuarine water and the strength of the mixing processes, changes in winds and rainfall will modify this balance.

Onset of Thermal Stratification and the Spring Bloom: Away from sources of freshwater, large areas of the UK shelf seas stratify in response to sunlight in spring and summer (e.g. the Celtic Sea, the North Sea north of Dogger Bank, the Malin Sea). The onset of thermal stratification in spring locks **phytoplankton** in the surface layer, where they receive lots of sunlight and grow rapidly. Following limited growth through the winter this "spring bloom" is the year's first appearance of significant concentrations of organic fuel to feed the rest of the ecosystem. There is evidence of a recent trend to earlier stratification and blooms largely in response to warming air temperatures. Our understanding of how shallow seas respond to meteorology suggest that stratification and the associated spring bloom will, on average, occur earlier in a warmer climate.

Sub-surface Production The interface between the warm surface layer and the deeper cold water (the **thermocline**) becomes a layer of significant growth for phytoplankton once the spring bloom has decayed. Growth here is a response to the supply of sunlight from the surface and weak flow of nutrients mixing up from deeper water. These controlling factors are likely to be influenced by changing climate but exactly how remains an area of limited understanding.

Full review

A region of the sea is "stratified" when a layer of less dense water sits above denser water. The surface layer could be less dense because it is less salty than the deeper water (e.g. because of an input of fresher water from an estuary), or because it is warmer than the deeper water (i.e. because the surface has been warmed by sunlight). Whether or not a region becomes stratified depends on the balance between the inputs of fresher water and/or heat, and the effects of turbulence that act to erode the stratification (e.g. turbulence caused by tidal currents, wind, and waves).

Stratification is a key control on shelf sea marine ecosystems. The interface between the surface and deeper layers acts as an efficient barrier to the vertical exchange of water. Any dissolved substance (e.g. nutrients, oxygen) or passive particle (e.g. phytoplankton, sediments) in the water will be affected by this reduced capacity for transfer between the surface and deeper waters. Stronger stratification has a correspondingly greater impact of vertical exchange.

Outside of the estuaries the strength of the tidal currents around much of the UK coast generates sufficient turbulence and mixing to prevent stratification that would otherwise form due to the inputs of estuarine (low salt) water. Instead coastal waters tend to be vertically well-mixed, but with salt content gradually increasing offshore away from the estuaries. Two notable exceptions to this are the eastern Irish Sea (Liverpool Bay, influenced by the estuaries of the Dee, Mersey, Ribble, Wyre and Lune (Sharples & Simpson, 1995) and the southern North Sea (influenced by the Rhine, Souza & Simpson, 1996), where a fresher surface layer can form during weaker tidal flows (neap tides) but is then eroded when the tidal currents increase (spring tides). The development of stratification in these coastal areas can be associated with an increase in the transport rates of estuarine water and its constituents (sediments, nutrients, anthropogenic contaminants) away from the coast at the sea surface, but at the same time increased onshore transports of material in the bottom waters. Coastal stratification is also implicated in many harmful algal blooms (Tett *et al.,* 2003), and the development of reduced oxygen in the bottom waters (Karlson *et al.,* 2002). As stratification by fresher water at the coast is dependent on the balance between the rate of supply of the estuarine water and the strength of the mixing processes, changes in the climate (i.e. changes in winds and rainfall) will modify this balance. There are suggestions that warmer, drier summers may lead to more harmful or nuisance blooms (Huisman *et al.,* 2004). However, there are still uncertainties in the regional variations of likely meteorological changes (Buonomo *et al.,* 2007) and the problem of how changes in sunlight, rainfall and winds may impact coastal seas has not yet been addressed with confidence.

Away from sources of freshwater, large areas of the UK shelf seas stratify in response to sunlight in spring and summer (e.g. the Celtic Sea, the North Sea north of Dogger Bank, the Malin Sea). Again, whether or not the sea stratifies depends on the balance between the rate at which sunlight warms the sea surface and the rate at which the mixing processes can re-distribute that heat vertically. The geographical pattern of which regions will develop a warm surface layer, and which will remain vertically mixed, is well-understood and predictable (Simpson & Hunter, 1974; Pingree & Griffiths, 1978).

Mixing by the strong tides around the UK is the key factor in determining the pattern of mixed and stratified regions, and it is broadly robust to the changes in heat supply and sea level predicted under a changing climate over the next century. However, the timing of when thermal stratification begins appears sensitive to changes in meteorology and it is an event of pivotal significance for the marine ecosystem. The onset of stratification in spring locks phytoplankton (single-celled marine plants that form the base of the marine food chain) in the surface layer, where they receive lots of sunlight and grow rapidly. Following the limited phytoplankton growth through the winter this “spring bloom” is the year’s first appearance of significant concentrations of organic fuel to feed the rest of the ecosystem. The timing of the bloom is thought to be an important factor in, for instance, the survival of fish larvae (Platt *et al.,* 2003). There is evidence of a recent trend to earlier stratification and blooms (Young & Holt, 2007) largely in response to warming air temperatures (Sharples *et al.,* 2006). How the spring bloom timing will change in the next decades is only now being investigated, though there is moderate evidence (based on our understanding of how shallow seas respond to meteorology) that stratification will on average occur earlier in a warmer climate.

In thermally-stratified regions during summer, following the decay of the spring bloom, the interface between the warm surface layer and the deeper cold water (the “thermocline”) is an important site of primary production, with a layer of phytoplankton growing in response to sunlight and to a weak supply of nutrients mixing upwards from the deeper water. These thermocline phytoplankton probably contribute about 50% of the total annual primary production (i.e. about the same as the spring bloom) (Richardson et al., 2000). Recent evidence (moderate confidence) suggests that this population of phytoplankton is very sensitive to changes in sunlight (sunnier weather might increase growth) but is ultimately limited by the supply of nutrients (sensitive to winds). However, our understanding of the physics of thermocline mixing and the ecosystem response is not yet advanced enough to allow a prediction of how this growth might change as the climate changes.

Confidence assessments

‘What is already happening’ – **Medium** overall based upon a high level of agreement between the observation and modelling studies and good understanding of the basic controls of stratification, but only a moderate amount of evidence being available (there are no long-term time-series of direct observations of stratification).

‘What could happen in the future’ – **Low** The amount of understanding is probably moderate given that we have a fairly good knowledge of how the process of stratification is driven but a low level of certainty in how the drivers will change and how they will interact.

Knowledge gaps

The limited work that has taken place modelling the impact of potential future changes in the climate on stratification is currently being improved, and will be a part of the next **UKCIP report in 2008**.
Our understanding of the climatic influence in the physics of thermocline mixing and the response of associated subsurface productivity is an area of active study but is not yet able to assess the potential for future change.

Commercial impacts

The most direct effect is that changes in stratification may change the occurrence of harmful phytoplankton that can cause the closure of shell-fisheries. Other commercial effects would be seen mainly through modification of ecosystem function leading eventually to fisheries impacts. One could also speculate that the influence of stratification on sediment transport may impact commercial interests.

References

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