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SCIENCE AND ENGINEERING CHALLENGES IN THE OCEANS AND THEIR RELATION TO MARINE POLICY DEVELOPMENTS

Dr C P Summerhayes
PhD DSc CMarSci
President, Society for Underwater Technology and Fellow,
Institute of Marine Engineering, Science and Technology

INTRODUCTION

The oceans cover 72% of the planet's surface. In 2008, ocean activities excluding coastal leisure contributed some 3.9% of UK GDP, most (46%) from the oil and gas sector. Other sectors contribute less: ports (12%), shipping (8%), equipment (7.8%), defence (6.7%), cables (6.4%), and business services (5%). Renewables contributed 0.02%. Leadership in ocean science and engineering in academia and industry comes about through the application of novel leading edge technologies. Developments in technology depend on a combination of current trends and unexpected imports from other technology fields, influenced by policy and regulation.

Forecasting future developments requires an appreciation of context. By 2100, 2 billion more people will have been added to the planet. As populations become affluent they use more energy. By 2020, demand will be 70% above 1997 levels. We are approaching peak oil, and approaching peak gas. The easy oil has been found and exploration has moved into deep water. Operations are more costly, so oil prices are rising. The climate is warming, ice is melting, and the seas are rising. Nations are moving towards low carbon economies, and investing in renewable energy sources. Copenhagen achieved no binding agreements, but industrialised nations are proposing to lessen their use of oil, gas and coal with time. We will still be using oil and gas by 2100, not least to meet the demands of transport. Meanwhile developing countries will be increasing their use of coal, oil and gas. Melting sea ice is opening up the Arctic, where nations are claiming exclusive economic zones. Nations will squabble over the extension of resource-rich continental shelves into deeper Arctic waters.

Technological developments are driven largely by the need to ensure reliability and reduce cost, which often leads to de-manning. In all fields we see trends to growth towards: automation and robotics; lighter weight and stronger materials; improved connectors and cabling; miniaturisation; computerisation; increased use of fibre-optics in communication; numerical modelling of operations and environment; visualisation of processes and operations ahead of deployment; underwater in situ power generation (eg from currents); and high voltage subsea energy supply. In all fields there is more use of satellites for remote sensing, positioning, and communicating with instruments and between instruments and the shore.

The field is subject to both opportunities and threats. Growth in ocean policy leads to growth in regulation, some governed by international agreements. Developing new technologies and markets demands financial incentives. Deployment of those technologies may be stymied by NIMBYism. Ageing North Sea infrastructure must be decommissioned. Small independent operators are entering the North Sea; they lack financial stability in comparison with the majors. The largest threat may come from China, which is massively investing in cheap, green technologies – competition will be fierce. Waste needs to be stopped – especially gas flaring at offshore production platforms worldwide. Difficulties in mitigating the effects of climate change will require geoengineering solutions including Carbon Capture and Storage (CCS), demands for which can be met by subsea storage of CO_2 in empty petroleum reservoirs. Ships may be deployed to spray water droplets above the sea to form clouds over the ocean to reflect sunlight.

OIL AND GAS

The average recovery from North Sea oil reservoirs is 40-50%, and from gas reservoirs 50-60%. The challenge is to raise recovery to 80%+. That requires better techniques for imaging, visualising and monitoring reservoir behaviour. The challenge in deep water is to extend production from water depths of 2500m from surface facilities and 3000m from subsea facilities to recovery from water depths of 4000-4500m, combined with recovery from up to 12,000m below seabed. Drilling costs go up with water depth, so new techniques like seabed drilling and riserless and dual-gradient drilling are required, along with novel methods for casing the drill hole, like continuous reeled casing.

Subsea production requires automated subsea systems for pumping, processing (eg oil-water separation), monitoring, controls, and high-power electrical supply. Future seabed production systems will be connected to processing and export systems and managed from the beach. Advanced remotely-operated underwater vehicles (ROVs) will be used for intervention (doing things) and inspection, with ROVs eventually being replaced by autonomous underwater vehicles (AUVs).

MARINE RENEWABLE ENERGY SOURCES

The Government plans significant growth in offshore renewable energy, mostly from wind near-shore (<25m deep); near-shore winds have higher energy than winds on land. Offshore wind farms have hidden costs; they demand a considerable shipping resource for deployment and maintenance, use vast amounts of steel and concrete, and require lots of maintenance due to corrosion by salt water and salt spray. The potential area of near-shore wind is about the size of Wales. Deep offshore wind (in water 25-50m deep) would double the possible area of wind farms. Shallow water wind farms cost 2x land wind farms; they are affordable because they are subsidized. Deep-water wind farms are not yet economically feasible.

Extracting power from tides and currents is technologically feasible. Although tidal power units can be environmentally contentious, tide pools generating hydro-power used to be widespread on small rivers on the UK coast. Discrete tidal energy units can generate the same power as large wind power units. The down side is that, as in the case of wind, this means that vast areas (or farms) are needed to generate significant power. Happily, the North Sea is a natural tide pool of the right size. It could be fitted with underwater "wind mills" in current streams, like the SeaGen device in Strangford Lough in Northern Ireland. Tidal power can also come from barrages across major estuaries, like the Rance in France. The Severn and the Wash both have possibilities. Tidal power could be cheaper than wind power, as the units would be smaller and exposed to less extreme variability, thus reducing costs for safety and maintenance. Does UK tidal power have a fair shake in comparison with wind?

Waves require wind speeds of >0.5m/sec. The west coast, especially off Scotland, Ireland, and Cornwall, has the greatest potential. Three UK-built Pelamis wave energy collectors have operated off Portugal. Each could deliver an average of 300kW. But they are costly – the steel requirement is 3x that for wind power.

To be successful (and cheap) renewable power plants need reliability and maintainability in harsh environments. They demand appropriate marine construction skills and technologies, and the skills and resources for regular maintenance. One can envisage sharing vessels and maintenance and inspection skills and technologies with the offshore oil and gas industry.

SHIPPING

There is a growing demand for vessels for deep offshore oil and gas (tankers and platforms) and for offshore wind, as well as for increased trade by sea. There are demands for greener, cleaner, more efficient and safer operations, which will become stronger with regulated limitations on gas emissions. This will require improved engine, ship and ship system design, and use of lower carbon fuels and high temperature fuel cells. Increasing vessel traffic will require improved navigation, vessel traffic management, information services, digital charting, and hydrographic surveying. Ports will need to think how to respond to the effects of sea level rise.

DETECTING AND MONITORING CLIMATE CHANGE

The oceans store vast amounts of heat and freshwater, and move them around to control climate. Oceans can be monitored via ocean observing systems comprising national components co-ordinated by UN agencies. These systems comprise satellites, aircraft, ships, underwater gliders, AUVS, in situ techniques (moorings), and coastal systems (tide gauges and radars) feeding data into forecast models. Advances require novel sensors and missions. Novel satellite missions include Gravity from Altimetry, and Swath Altimetry (from the Surface Water and Ocean Topography mission). We also need fast deep AUVs. Continuity is essential in coverage of the ocean's surface by satellites and of the ocean's interior by Argo floats. The Global Ocean Observing System (GOOS) is around 60% complete; the aim is for 100% by 2020. Beneficiary sectors include those on land (eg agriculture; water supply; energy supply), as well as those at sea (fishing; navy; shipping; coastal engineering; ports; search and rescue).

COASTAL OBSERVATIONS

Coastal seas are grossly under-sampled. The present UK coastal seas observing network grew like Topsy; it needs restructuring to meet the complex information needs of today. Numerical models will show agencies how the environment works, and detect where and what observations are needed. There is a pressing need for long-term, full-water-depth, multi-disciplinary observations, supplemented by surface data from instrumented ferries. Developing new ocean observing technologies will capitalise on advances in the fields of medicine; microelectronics; microprocessors; and materials. Smaller, lighter, more advanced sensor packages free of biofouling will underpin application of the new science of operational oceanography.

COASTS

Coastal populations are growing faster than elsewhere, along with a growth in marine leisure. Sea level is rising slowly (3.4mm/yr). The maximum forecast for 2100 is around 2m, which represents 2cm/yr. This is not a tidal wave. It can be dealt with by deployment of barriers and dykes (eg Thames Barrier) and by managed coastal retreat in selected areas. Offshore sand and gravel will continue to be required for coastal construction (housing, defences, beach replenishment). There is an increasing demand for environmental forecasts of pollution, eutrophication (too many nutrients = algae using up oxygen), changing ecosystems and fish stocks, endocrine dysfunction, and harmful algal blooms. Such forecasts require developing technologies in environmental chemistry, ecotoxicology, and biomarkers to identify potential hazards.

SKILLS

Investment in advanced education and training is essential to supply the skills base to support growing offshore activities. A supply of highly skilled offshore engineers, marine scientists and technicians is imperative for the UK to remain competitive in the rapidly advancing offshore technology arena. A long-term strategy is needed to meet the technological demands of rapid growth in offshore renewables, eg to rapidly ramp up tidal and current energy plants. We can also retrain established engineers, physical scientists and technicians (eg with funding for mature students, plus conversion courses). Incentives are needed to get the right growth in skills supply. Robust co-operation between industry and academia is essential to ensure world-class skills development in the right areas at the right rates. The message about the excitement of offshore applications should be transmitted to schools to interest the coming generation.

A MARINE TECHNOLOGY STRATEGY

Meeting these various challenges calls for a strategic approach: the UK needs centres of excellence in developing marine technologies and in building skills through advanced education and training in offshore engineering and associated marine science and technology. These demands are not covered by the new UK marine science strategy.

INNOVATIVE MARINE ENGINEERING AND SCIENCE – ARE WE SWIMMING OR SINKING?

THE OCEAN SINK FOR MAN-MADE CO_2

Professor Peter S Liss FRS
School of Environmental Sciences,
University of East Anglia

THE GLOBAL CARBON CYCLE

The oceans are a substantial sink for man-made carbon dioxide, and are currently taking up about a quarter of the amount of the gas emitted to the atmosphere by human activities. This mainly comes from fossil fuel burning and cement manufacture (about 85% of the total), with the other approximately 15% coming from man-induced land-use changes (mainly conversion of virgin land to agricultural and other uses). The oceans thus provide a substantial service to us since if they were not taking up the CO_2 much of it would likely stay in the atmosphere and so add to the global warming already occurring. However, the ocean sink at 25% is only one place where the extra CO_2 we are injecting into the atmosphere ends up, with almost 30% of the rest being taken up by land plants and the remainder (about 45%) remaining in the atmosphere leading to the observed CO_2 increase and consequent additional greenhouse heating.

All the percentages given above are best estimates and have various degrees of uncertainty, with the ocean sink one of the better known terms. If we now compare the present values of the various sources and sinks of man-made CO_2 with estimates of what they were (say) a decade ago it is clear that, although emissions have increased, the sinks have risen roughly in proportion. The open question is will this continue into the future? On the emissions side it is up to we humans to decide how much we wish the emissions from fossil fuel consumption and land-use change to increase. But we have essentially no control over the amount the oceans and land biosphere take up into the future; that will be determined by whatever natural and man-induced changes occur. In the case of the oceans such changes could be due to increased stratification due to warming of the surface waters or altered biological uptake of CO_2 by microscopic plankton in the sunlit upper layers.

CARBON DIOXIDE UPTAKE BY THE OCEANS

So do we have any evidence concerning change in the ocean uptake of CO_2 over recent years? Some of my colleagues at University of East Anglia have been working on this problem in two of the main regions where CO_2 uptake occurs – the Southern Ocean around Antarctica and the North Atlantic.

In a paper published by Corinne leQuere and co-workers (Science (2007) 316:1735-1738) atmospheric measurements of CO_2 made in the Southern Ocean from 1981 to 2004 are incorporated into an 'inverse' mathematical model to derive change in the strength of the ocean sink of CO_2 over this period. The results indicate that the sink has indeed changed significantly. The authors attribute this to increase in wind strength (itself a result of human activities) bringing deeper CO_2-rich water to the surface thus reducing the air-sea concentration gradient that drives the oceanic uptake. They also predict that this reduction in the efficiency of the Southern Ocean sink will continue in the future.

The second ocean region that has been studied in this context is the North Atlantic where Andrew Watson and colleagues have been using a more direct (observational) approach to try to ascertain if the ocean CO_2 sink varies from year to year and whether any temporal trend in uptake can be observed. To do this they have co-operated with oceanographers from several European countries to measure concentrations of CO_2 in both air and surface seawater from commercial vessels. From the measurements over the period 2002-2007 the amount of CO_2 uptake can be derived with a much improved spatial and temporal coverage compared to that achieved previously. This has required a huge co-ordinated effort and the development of automated instruments to measure CO_2 without scientists being aboard the commercial ships. The results (Science (2009) 326: 1391-1393) indicate considerable variation between years in the CO_2 sink for this ocean basin. Because of this and the relative shortness of the record, it is difficult to be sure whether the sink for CO_2 is changing in any systematic way. However, if the more limited data for earlier years back to 1995 are used along with the much more complete record since 2002 then it appears that the sink has decreased by maybe 20% over this period.

Both this result and that from the modelling study of the Southern Ocean sink should be treated with caution since such studies are quite recent and the observational records on which they both rely only cover rather short periods of years during which time only small changes seem likely to have occurred. As we move forward, and assuming continued increases in atmospheric CO_2 as well as concomitant changes in atmospheric and oceanic circulation, larger changes in the marine CO_2 sink seem possible. It is clearly vital that such studies need to be continued and extended to other oceanic areas in order to quantify properly how the oceanic sink for CO_2 may be changing.

GEO-ENGINEERING THE OCEANS

Driven largely by the difficulty the global community is having in agreeing reductions in CO_2 and other greenhouse gases, there is increasing interest in the possibility of large-scale manipulation of the planet (often called geo-engineering) in order to ameliorate the effects of increasing CO_2 on climate. One proposed approach is purposely to increase ocean biological productivity, and hence increase CO_2 uptake, by enriching ocean areas with iron, since for about 25% of the ocean this element appears to be the limiting factor for ocean productivity. To date about a dozen small-scale oceanic experiments have been carried out and they certainly show that by adding minute amounts of iron to the seawater large increases in productivity can be produced. However, what is very uncertain is how much of the extra CO_2 taken up by the plankton actually sinks out of the surface ocean and so gets removed from the air-sea system for a substantial time. Modelling studies indicate that if global scale ocean fertilization with iron was carried out for 100 years then a drawdown of about 30 ppm (less than 10% of current atmospheric concentration) might occur. For the huge effort that would be involved, to say nothing of possible unexpected or undesirable secondary effects, this seems like a very poor return.

OCEAN ACIDIFICATION

One consequence of the uptake of additional CO_2 by the oceans, as a result of rising levels of the gas in the atmosphere due to human activities, is that the oceans, particularly surface waters, are becoming more acidic. This is because when CO_2 dissolves in water it becomes more acidic (soda water) as measured by a drop in its pH. So far surface seawater pHs have dropped by about 0.1 units which indicates a 30% increase in acidity since pre-industrial times. If we continue to put CO_2 into the atmosphere at anything like the present rate then seawater pH could increase by 300% (corresponding to a drop of 0.5 in pH) by the end of the century. An important question then is what effect will these changes have on ocean biology? One thing that seems pretty certain is that any effect will be greatest for those organisms that form their structures of calcium carbonate since this mineral is known to be subject to acidic dissolution. Organisms that use calcium carbonate range from corals to some microscopic plankton. We know little of the detail of how such changes will occur, in part because of the difficulty of conducting what are necessarily short-term experiments in the context of changes that will occur on the decadal to century timescale. The topic of ocean acidification is currently the subject of several research programmes both in the UK and abroad.

IN DISCUSSION THE FOLLOWING POINTS WERE MADE:

Solar energy as a source of electric power is primarily sourced from deserts but not yet from the oceans. The Royal Society assessed geo-engineering in a recent report but it is not known whether it will work, especially as there is always potential for unintended consequences.

Education is important, effort is going into retraining people for work in the marine environment and strategies are required to ensure that the appropriate technologies are developed and the right type of people employed.

Are wind farms economic? How will they be hooked up to the National Grid? Wind farms are not expected to be able produce more than 25% of the UK's total power requirements. More research is required to make wind turbines more efficient.

Ocean acidity results from absorption of CO_2 and if the oceans eventually become sufficiently acidic this may badly affect organisms such as corals and plankton with carbonate skeletons. On the Precautionary Principle it is clear that Ministerial Targets for 2020 will not be met for CO_2 reduction. It will therefore be necessary to advance on three fronts, Mitigation, Adaptation and Geo-engineering. Adaptation to sea level rise must be accepted as an unintended consequence arising from ocean warming and expansion and melting ice sheets. It is estimated that by the end of this century, sea level will have risen between 1 and 2 metres. Redesign of the Thames Barrier will take into account the need to defend London from up to a 2 metre rise in sea level. How will those who live outwith the Thames Estuary be protected?

The division in the continental shelf between UK and Norway follows the geographical median line. The national claims to Exclusive Economic Zones in the Arctic are nominally 200 nautical miles, but may extend further if geological structures prolong the continental shelf beyond the 200 mile boundary. It was pointed out 35 years ago in this room that a government department for Marine Affairs was needed. Are government departments up to the task of managing Marine Affairs today, and if not what should be done? The Antarctic Treaty works very well, economic development is not permitted and nobody lives there, so any problems arising are manageable. The Arctic Ocean is surrounded by people with legal rights to claim within and without their EEZs. The Arctic International Common Space in the centre is in very deep water and unlikely therefore to contain significant oil and gas resources, but is nevertheless likely to remain a contentious area.

A Marine Agency was proposed but not accepted; however, a Marine Science Strategy was launched last week. We need a companion Marine Technology Strategy. There is nothing equivalent to a UN for the Oceans. UN Agencies dealing with the Oceans and Climate include UNESCO's IOC and the WMO. In addition, the FAO looks after Fisheries, UNEP plays a role in coastal seas, and the International Seabed Authority, in Kingston, Jamaica, assesses claims for EEZs. There is no major UN Session dedicated to ocean matters. The net result is the open ocean remains a global commons (hence overfished).

Long-term atmospheric observations are now well established as the remit of national meteorological agencies. Many countries have no oceanic equivalent, so the bulk of ocean observations (including most satellite missions) are normally funded by specific short term R&D budgets. Long-term commitments to ocean observations are needed (the oceans cover 72% of the planet's surface), and should be institutionalised in some way to avoid the short-term approaches of ocean business ventures and university funding. There is no Met Office equivalent for the Oceans, but the Met Office has taken on an operational role for ocean observations, which could be developed further, to provide the continuity required for ocean and climate forecasting. A multiplicity of research experiments has been undertaken globally, with huge disparities in the measurements made. A new regime is now required globally and locally, where everyone measures the same thing, using the same standards, over the same time frame and at the same parts of the tidal cycle, thus enabling us to see how the seas and oceans work. Can we ask DEFRA to do that for UK waters?