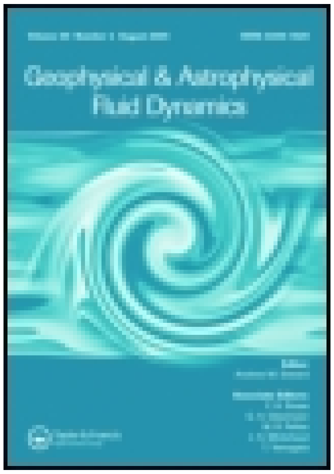

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Physical oceanography of the European shelf-seas: A report on the geophysical fluid mechanics symposium of the E.G.S. (1980)

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Physical Oceanography of the European Shelf-Seas: a report on the Geophysical Fluid Mechanics Symposium of the E.G.S. (1980)

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As part of the seventh annual meeting of the European Geophysical Society, a symposium was convened by the authors on the physical oceanography of the European shelf seas. The meeting was held in Budapest from 26–27 August 1980, and twenty three papers were presented by participants from nine countries.

1. INTRODUCTION

The sea adjacent to our shores is an important part of our environment. The waves and currents batter our coastlines and scour the sea bed, rivers empty into it and we pour many of our waste products into it. We fish it and, in the warmer parts at least, we swim in it and sail on it. We are also being increasingly obliged to exploit the energy and mineral resources which lie beneath it.

It is no accident, therefore, that considerable effort is devoted to studying the oceanography of coastal waters. The European shelf seas (see figure 1) are no exception and the Baltic, the Norwegian Sea, the North Sea, the Irish Sea and the Mediterranean are being actively investigated. As much of this work has similar goals we felt that it would be appropriate to bring together oceanographers and fluid dynamicists working in this area.

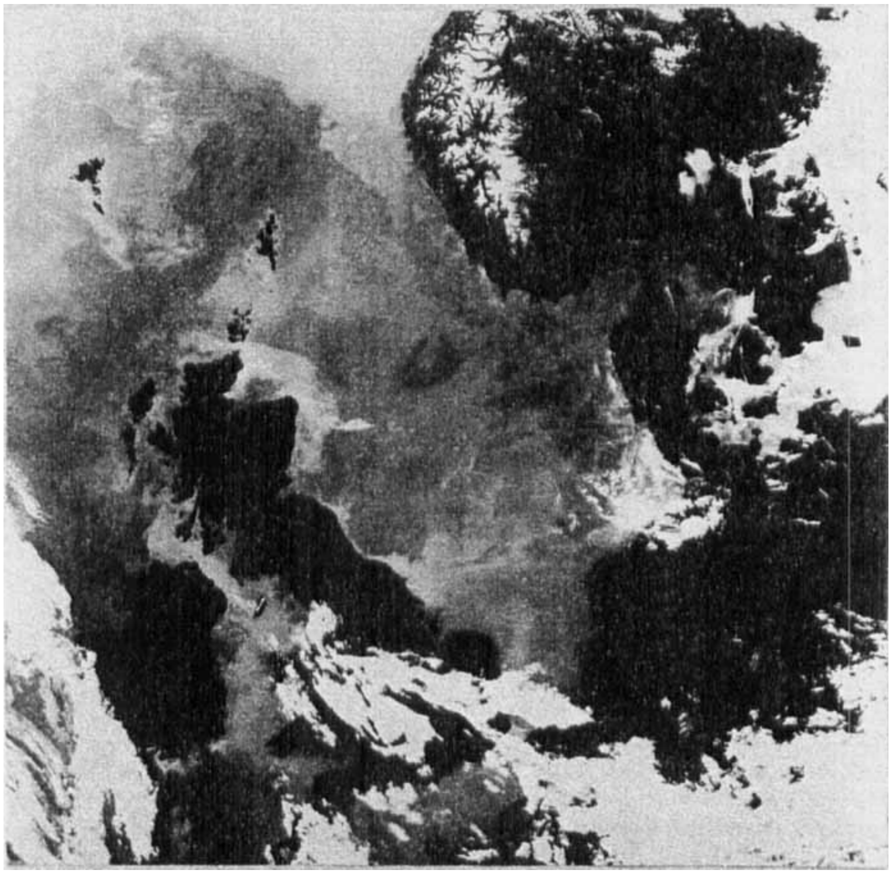

FIGURE 1 The shelf seas of north-western Europe as seen in the thermal infra-red (10.5–11.5 μ) by NOAA6 on 18 May 1980 at 0827 GMT. The image has been enhanced for optimum contrast in the sea surface temperature range. Image darkness increases with surface temperature.

This picture is reproduced by kind permission of P. Baylis and J. Brush, University of Dundee.

There were four sessions under the headings

1) Estuarine processes
2) Vertical mixing in shelf seas
3) Coastal flow and sediment transport
4) Shallow sea circulation

The same grouping will be adopted in this report, although with some changes in the order to facilitate discussion of related papers.

2. ESTUARINE PROCESSES

This session was introduced by Chatwin (Liverpool, England) who presented an invited review of longitudinal dispersion processes in estuaries. He began by pointing out that the conventional wisdom is to describe the dispersion by means of an effective dispersion coefficient. The numerical value of this dispersion coefficient depends on both the horizontal and vertical shear and the tidal oscillations. If the contaminant is not passive then the influence of buoyancy must also be included, usually in an ad hoc manner. In addition to these effects, there are also other complicating features such as non-uniform cross-section which may lead to trapping of pollutant in bays and stagnant pools, interactions between temperature and salinity stratification (Smith, 1978) and the effects of Coriolis forces and channel curvature. Taylor (1954) showed that, for a passive contaminant in steady flow with a uniform cross section, it is valid to use a constant dispersion coefficient provided the time $t \gg h/u_*$, where h is the depth and u_* the friction velocity. This is equivalent to having a Gaussian distribution of mean concentration. However, nearly all observations are non-Gaussian and Dewey and Sullivan (1977) found skewed distributions even with $tu_*/h > 10^3$. Chatwin then discussed some ways of attempting to account for the observed non-Gaussianity, but concluded that probably the most satisfactory procedure was to measure the deviations from Gaussianity and to try and understand these with the help of analytical studies and numerical simulations.

The next two papers provided examples of numerical simulations. Hunter (Menai Bridge, Wales) showed that in estuaries and shallow seas the dominant scale of horizontal turbulent motions are typically no more than an order of magnitude larger than the water depth. Horizontal motions on scales larger than this tend to be deterministic (e.g. headland eddies). Under these conditions patches of contaminant larger than the scale of the turbulent motions (i.e. several hundreds of meters) can be modelled by a constant eddy diffusion coefficient, provided that the tidal deformations are modelled correctly.

Hunter then described how Fickian diffusion may be modelled by the use of a random walk method, a technique also applied by Allen (Liverpool, England) to examine turbulent dispersion in estuaries. Fluid particles are tracked as they move about in the velocity field which is composed of the observed mean flow together with a random element which simulates the uncorrelated turbulent motions. Allen showed that at short times after release, contaminant tends to be trapped near the bottom. At longer times the concentration distribution becomes more symmetric. Even though the variance of the distribution is proportional to time, the distribution is not Gaussian. She estimates that for an estuary such as the Mersey, Gaussianity would not be achieved for at least 20 hours.

Le Hir (Brest, France) pointed out that, although it is difficult and computationally expensive to carry out full three-dimensional numerical models of estuaries, a knowledge of the vertical structure of the velocity, temperature and salinity fields is often important. He described some numerical solutions which where obtained by examining the deviations from a depth-averaged model for currents off the Seine Estuary. Coriolis forces were included and the vertical structure showed evidence of an Ekman spiral.

A fjord is an atypical estuary in many respects, and in particular there is a very strong halocline between the deep water and the surface layer fed by run-off. McClimans (Trondheim, Norway) described the results of a field study carried out in a Norwegian fjord, where Rhodamine dye was added to the river discharge throughout a tidal period. The river water mixed near the mouth with the more saline water in the fjord and flowed as a brackish layer above the halocline. The effects of the Earth's rotation caused the river outflow to veer to the right until it reached the side of the fjord. The brackish water then flowed along the edge of the fjord as a boundary current similar to those produced in the laboratory by Griffiths and Linden (1981). Measurements of dye concentrations showed that the nature of this flow field has a significant effect on the longitudinal distribution of the Rhodamine, which was poorly predicted by laterally averaged models.

The large density differences which occur, for example, in fjords can drive gravity currents and intrusive flows. Faust and Plate (Karlsruhe, Germany) described a laboratory study of the intrusion of a fluid along the interface separating two uniform layers. They found, as have Britter and Simpson (1981), that the thickness of the interface affects the shape of the front of the intrusive flow—the head. Since the head acts as a hydraulic control for these flows, the speed of advance of an intrusion depends on the interface thickness.

3. VERTICAL MIXING IN SHELF SEAS

In the open ocean the wind and convective cooling provide the main energy supplies for mixing the top 50 m or so. In shelf seas, however, tidal flow can generate turbulence at the bottom which can be sufficiently energetic to mix the whole water column. The intensity of this bottom generated turbulence depends on both the depth of the water H and the mean tidal velocity U. For a given surface buoyancy flux B_0, the strength if the turbulence can be characterised by the non-dimensional parameter B_0H/U^3, which is the ratio of the water depth to the Monon-Obukhov length. When this parameter is small the water column will be completely mixed by the turbulence, whilst at large values of B_0H/U^3, the buoyancy flux will be large enough to stratify the sea. If the buoyancy flux is constant over a given area, then fronts between well mixed and stratified regions should lie along contours of H/U^3.

Simpson and Argote-Espinosa (Menai Bridge, Wales) have discussed tidal mixing around an island in these terms. The intensification of the tidal streams, caused by the presence of the island, together with the shallow depth promotes enhanced vertical mixing. A prediction of the H/U^3 parameter for the Scilly Isles region based on a hydrodynamic model was compared with observations of the temperature—salinity structure. The data show, as predicted, a marked asymmetry in the distribution of stratification around the island with high values along the major tidal axis and two minima on the flanks of the island. These mixing regions have low surface temperature and may also act as sources of nutrient rich water fuelling the greatly enhanced biomass production around the island where levels of chlorophyll *a* are a factor of 10 greater than in the surrounding area.

These global energy arguments described above implicitly assume that the turbulence does not decay significantly from the bottom, where it is generated, to the surface where it acts on the buoyancy flux. This assumption may be perfectly adequate under some circumstances, but it is of interest to examine its limitations. Hopfinger and Linden (Cambridge, England) described some laboratory experiments in which the decay with distance from the point of generation of the turbulent kinetic energy was known. They found that the depth D of the well-mixed layer scaled on the *local* energy balance which explicitly included the decay of the turbulence. Therefore, the global scalings should only be applied with caution to situations where the turbulence is approximately uniform over the depth. They also found that the onset of surface stratification is characterised by a critical value of $DB_0/U^3 \approx 1.5$ where U is the local velocity. At large values of this parameter, all the heat goes into a thin surface layer and a runaway stratification occurs. In tidal regions, changes from a well mixed zone to a zone with surface stratification follow approximately contours of $D/|U|^3$ (Simpson and Hunter, 1974), where $|U|$ is the r.m.s. velocity over a tidal cycle.

The role of air bubbles introduced into the surface waters by breaking waves was discussed by Thorpe (Wormley, England) who presented the results of measurements in Loch Ness in which bubbles are detected acoustically. He found that the bubbles penetrated to the bottom of the mixing layer, although the majority remained near the surface (the *e*-folding depth was 70 cm) as a result of their buoyancy. The total bubble surface area increased exponentially with wind speed and became equal to the surface area at wind speeds of $20\,ms^{-1}$. At large wind speeds the bubbles make an important contribution to the air-water gas flux, particularly as they are compressed at depth.

Piacsek, Warn-Varnas, Peffley and Niiler (St. Louis, U.S.A.) examined the effect of internal waves on the mixing across the thermocline. Using a finite difference technique they computed the deepening of the mixed layer in the presence of internal waves and tides. Their results showed that the r.m.s. shear across the thermocline was increased by the presence of the waves and that this led to an increase in the mixing there.

The subject of the final paper in this section was the upwelling in the Gulf of Lions. Millot and Wald (La Seyne, France) presented observations of upwelling as observed by the Tiros *N* satellite. These showed that the upwelling is very patchy and seems to be related to the local topography. In particular, the presence of capes and bays seems to inhibit the upwelling which occurs preferentially along straight sections of the coastline. In situ current and temperature measurements confirm the features observed by remote sensing. The response to the wind fields is found to be predominantly barotropic, and the temperature is observed to decrease by 5°C in a day in some places.

4. COASTAL FLOW AND SEDIMENT TRANSPORT

This subject was introduced by an invited review by Zimmerman (Texel, The Netherlands) who discussed the dynamics of tidal residual eddies. When tidal motions are removed residual circulations are found to have a typical scale of about 20 km and a residual vorticity of 10^{-7} to $10^{-5}\,s^{-1}$. These motions are closed streamlines related to the local topography (see e.g. Pingree, 1978), and the tidal residual circulation is generated by a non-zero vorticity flux averaged over a tidal period. For example, for the basin eddy the velocity is greatest near the middle of the mouth and decreases towards both the sides and the end of the basin. Consequently, net cyclonic vorticity is advected in, on the flood, and anticyclonic vorticity out on the ebb. Eddies can also be produced by bottom topography as vortex lines are stretched as the tidal current flows over a bump. Zimmerman described how friction also contributes some residual circulation, and showed that the effects are additive when a ridge is inclined anticlockwise with respect to the major axis of the tidal ellipse. When the ridge inclination is clockwise the effects of friction and the Coriolis force tend to cancel. This asymmetry is consistent with the observation that, in the northern hemisphere, sand ridges tend to be inclinded anticlockwise to the major axis of the tidal ellipse, suggesting that the residual eddy produces enhanced sediment deposition. Off (1963) reports that sand ridges have an average length of 29 + 18 km which is consistent with the typical size of residual circulations. This suggests that residual circulations are important for sediment transport and, that a thorough investigation of them should include a three-dimensional study.

Robinson and Wolton (Southampton, England) discussed how residual circulation is produced by tidal flow past a headland. Using a two-dimensional numerical model they demonstrated that in order to generate a residual eddy, the vorticity generation must vary during a tidal cycle. They showed that a pair of vortices are produced, one each side of a headland, during a tidal cycle, and that the pair propagate away under the mutual interaction of their vorticity.

A numerical model of the Southern Bight of the North Sea was presented by Komen and Riepma (de Bilt, The Netherlands). They evaluated the residual circulations generated by the wind stress interacting with variable bottom topography. For reasonable values of the eddy viscosity, they found that these wind driven currents can also produce significant residual vorticity. At wind speeds greater than $5\,\mathrm{ms}^{-1}$ the wind generated residual becomes comparable with the tidally produced circulations, and they concluded that it was necessary to include these wind driven currents in models of sediment transport.

Robinson and Srisaenthong (Southampton, England) described the use of satellite imagery for measuring sediment transport. LANDSAT gives, on average, 2–5 clear weather pictures each year and has a spatial resolution of 80 m. Satellite imagery gives excellent synoptic views of an estuary and Robinson discussed how the images were being calibrated by carrying out simultaneous standard measurements. It is possible to see down to depths of around 10 m and attempts are being made to determine the depth dependence by looking in different wavelength bands. The images showed a considerable amount of spatial structure in the sediment concentration and were beginning to reveal how the sediment motion is related to the tidal flow.

Sediment transport in the Bristol Channel was discussed by Ferentinos (Patras, Greece) and Collins (Swansea, Wales). They observed that sediment transport was towards the west in the main channel, but in the opposite direction near the coastal zone. The transport is consistent with the tidally induced residual circulation.

Wave measuring facilities on the platform Nordsee were described by Beier (Karlsruhe, Germany). An array of 7 elevation transducers provides directional information on the wave field while a 5 m test cylinder is being used to make direct measurements of the forces exerted by the waves. The results will permit evaluation of semi-empirical formulae like Morrison's equation which predict forces from basic wave characteristics.

5. SHALLOW SEA CIRCULATION

The final session concentrated on the residual non-tidal currents induced by either buoyancy effects or surface stress. In practice these two types of forcing are not always easily separable and may interact strongly. This point was illustrated by Wittstock (Kiel, Germany) who described observations of the exchange flow between the Skagerrak and the Baltic. A long time series of near bottom current data from the Vajnas channel showed inflow velocities of more than $100\,cm\,s^{-1}$ with strong fluctuations which were found to be closely correlated with the wind. Both barotropic and baroclinic motions induced in the Baltic by windstress are thought to play a part in controlling water exchange. Major high salinity inflow events occur approximately once per hundred days in response to the atmospheric pressure field.

Another study of water movement in the Skagerrak by Shaffer and Djurfeldt (Goteberg, Sweden) was concerned with the coastal currents in the vicinity of the Gullmar fjord. The results of a three month survey of currents and *T-S* structure have been analysed in terms of empirical orthogonal functions with a view to determining the principal modes of motion near the coast. A significant peak in the kinetic energy spectra of the currents at a period of ~ 2 days is associated with a similar feature in the wind spectra, though it is not yet clear whether this represents the response to local wind forcing or is the result of wind driven motions of larger scale.

Johnson (Norwich, England) continued the discussion of wind driven currents with the presentation of an analytical model of the response of a weakly stratified shelf region to wing forcing, using different forms of windstress. Stratification, fixed at the shelf edge, is modified over the shelf by upwelling motions driven by the wind which will cause the pycnocline to outcrop. Where this happens, the model shows a weakening of horizontal gradients so that no pronounced front is observed. Johnson also presented numerical solutions for unsteady winds showing shelf wave behaviour.

In some regions of the shelf seas, the buoyancy driven current component may predominate as, for example, in the Norwegian Coastal Current where freshwater input drives a clearly defined flow northwards. The instability of such currents was discussed by Griffiths and Linden (Cambridge, England) on the basis of laboratory experiments on a rotating table. The current was produced by releasing fresh water at the surface of a layer of brine from a circular source adjacent to a vertical cylinder. As the source fluid spreads radially on the surface it conserves angular momentum and an anticyclonic current is produced. This anticyclonic flow produces, in turn, a radial Coriolis force which balances the buoyancy force. With the continuous addition of source fluid this quasi-geostrophic current grows in width and depth and finally becomes unstable to azimuthally travelling waves. These waves appear to break backwards (see Griffiths and Linden, 1981). The wavelength of the waves is typically 1–3 times the width of the current, which is in agreement with the results of a simple baroclinic model and observations of the Norwegian Coastal Current.

The effects of friction on internal Kelvin waves were described by Martinsen and Weber (Oslo, Norway). Analytical solutions were given for the two cases of (a) continuous stratification with friction represented by an eddy viscosity and (b) a two layer model with a linear bottom stress law. Both systems exhibit a strong bending of the internal cotidal lines away from the coast relative to the barotropic model of the same wavelength.

Storm surge prediction is now generally based on elaborate numerical computations requiring inputs of meteorological and sea surface elevation data. An interesting alternative approach, which dispenses with these requirements, was discussed by Kumpel (Kiel, Germany). Observations of crustal tilt in North Germany show that it correlates closely with sea level. Maxima in tidally filtered tilt occur up to 12 hours ahead of storm surges in the German Bight and so could be used as a forecasting tool. Both direct gravitational attraction and crustal loading apparently contribute to the tilt signal which was simulated using a hydrodynamic storm surge model of the North Sea and the Baltic. This paper was followed by a lively discussion of the relative merits of different methods of surge prediction.

6. CONCLUSION

The special emphasis of this Geophysical Fluid Dynamics session on the shelf seas succeeded in bringing together, from different European countries, many scientists who are involved in similar innovative developments on various aspects of coastal oceanography. This was particularly apparent in the sessions on "Estuarine Processes" and "Coastal flow and sediment transport", which seemed to us to identify areas of active progress which merit special encouragement and where exchange was particularly valuable. A number of useful links were undoubtedly established in these and the other areas of our discussions, and we look forward to building on these in future meetings.

It is a matter of some disappointment to us, however, that few of the new links established involve East European marine scientists. Many of these scientists have interests in coastal problems, but they were mostly unable to attend this symposium in spite of early publicity.

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