DAVID EDGAR CARTWRIGHT
21 October 1926 — 2 December 2015
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David Cartwright was one of the world’s leading authorities on the tides. However, when reflecting on his life, Cartwright made the point that his early scientific career was not a success. Indeed in 1953, at the age of 27, he had virtually despaired of any creative scientific future. At the time he was being pressurized to stop his work on the statistics of ship motions but his prospects rapidly changed when he was invited to apply for a post at the new National Institute of Oceanography (NIO) being set up by George Deacon.

At NIO he soon made important contributions to the study of ocean waves, especially the calculation of directional spectrum and wave climate. His earlier involvement with ship motions also culminated in a successful joint study with Louis Rydill on the response of ships to the spectrum of waves. Following this, his use of computer methods for time-series analysis led to an invitation to the Scripps Institution of Oceanography where, with Walter Munk, he developed the response method of analysing tides making use of the very long tidal records collected from Hawaii and Newlyn. He was also made aware of the significant lack of good tidal data from the deep ocean.

Returning to the UK, he continued these interests, studying the deep-ocean tides of the Atlantic and leading an international collaboration that measured deep-ocean tides. He also investigated the effect of tides on storm surges around the UK. He became assistant director in charge of the Institute of Oceanographic Sciences (IOS) Bidston laboratory, where he continued these activities and started research on estimating the tides using data from the Seasat radar altimeter.

After retirement he successfully extended this work with Richard Ray at the Goddard Space Flight Center. Using Geosat altimeter data they generated accurate global maps of the tides in a set of papers that Cartwright considered to be his best work. He wrote a successful book

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titled ‘Tides: a scientific history’, and later published further work with Ray on the internal tides of the ocean.

**EARLY LIFE**

David Cartwright was born on 21 October 1926 in the London suburb of Stoke Newington. His father Edgar Cartwright ran a detective agency in the City of London. His mother, Lucienne Tartansson, was a French teacher who had also helped found a Montessori kindergarten. David had a full sister, Marguerite, born in 1920 and a step-sister Julie, born in 1905, whose mother had died.

When Cartwright was two, the family moved from London to Worthing on the south coast of England where his parents owned and ran the Channel View Hotel. This contained about 25 bedrooms and was situated on the front facing the sea. Thus at an early age the sea, in particular the beach, the waves and the regular ebb and flow of the tides, became an everyday part of Cartwright’s life. There, in 1929, he also experienced his first storm surge, when the hotel basement was flooded and the hotel had to be evacuated. Later in life he was to carry out a study of storm surges, which included this event.

Cartwright went to school first in Worthing and then as a boarder at a Roman Catholic Jesuit school in Brighton run by the Xaverian Order. Here an enthusiastic teacher stimulated an interest in chemistry, which led to some interesting experiments at home, first in his father’s office and later, because of the smells, in an outside bicycle shed.

While he was young the family had few chances to travel, but Cartwright remembered picnics with his mother on the hills behind Worthing. The ancient earthworks there led to a later interest in megalithic monuments and their layout relative to the rising and the setting of the Sun and Moon. They also took trips on a paddle steamer to the Isle of Wight and travelled by boat and train to visit his mother’s family in Paris. His mother’s interest in music also led to Cartwright taking piano lessons from an early age. This resulted in another lifelong interest.

The school in Brighton eventually stopped taking boarders and Cartwright went to Mayfield, a second Xaverian school. There the quality of scientific teaching was not very great, and there was no chemistry, but Cartwright enjoyed the mathematics and otherwise excelled, obtaining eight distinctions in his School Certificate exams. Financial pressures, the hotel being closed during the war, meant that Cartwright had to return home and attend the Worthing High School for Boys. Here he chose to study sciences but disliked the large amount of memorizing needed for the chemistry exams and much preferred the mathematical content of the physics and dynamics courses. In his final Higher School Certificate exams he obtained As in pure and applied mathematics but only Bs in physics and chemistry.

**CAMBRIDGE**

Cartwright wanted to go to university and applied for a conditional entrance to St John’s College, Cambridge, in the hope that his grades were good enough for a State Scholarship. Unfortunately this was not the case. Instead he was offered a State Bursary. This was a two-year university course in natural sciences and electronics, extensible to three for
exceptional students. However, it also involved a commitment to provide technical expertise for the military or an appropriate industry following the degree.

Cartwright said that his years at Cambridge (1944–1946) were an educational disaster. His tutor, an economist who never remembered Cartwright’s name, advised him to study as many sciences as possible. Cartwright chose not to do chemistry, but selected mathematics, which was only for one year, physics, geology and mineralogy as well as the mandatory electronics.

The course was very intense. Lectures were to 200 or more noisy students, with little time to make notes or review progress. Tutorials were essentially non-existent. Cartwright did however make friends, continued his interest in cross-country running, which had been his main sport at school, and obtained a university Half Blue.

He also continued improving his skill with the piano, hiring one for practice in his room and playing Beethoven and Schubert sonatas at musical evenings. At one stage he had a dream of being a recitalist, but although never good enough it did not stop him playing throughout his life for his own enjoyment and the enjoyment of others.

At Cambridge he graduated after two years with a 2.2. Under the terms of the bursary he was then given a list of firms requiring physics graduates and chose the Dublier Condenser Company, in Acton, West London, where he was involved in the design and testing of capacitors. This did not go well and he was sacked after six months for incompetence. He moved a short distance to the GEC Illumination Engineering Laboratory in Wembley where he was involved in the design and testing of lenses and the glasses used in street lighting. This was more successful and he enjoyed working there.

However in 1949 his commitment to the bursary came to an end and having decided that the choice of natural sciences at Cambridge had been a mistake, he resolved to return to university and study a single subject to Honours Degree level.

**King’s College, London**

In the autumn of 1949, Cartwright started a three-year mathematics degree at King’s College, London. Initially his parents funded him but after the first term he obtained a state grant, which covered all three years of the course. Lectures included dynamics, hydrodynamics, electromagnetics, mathematical analysis, analysis of complex variables and statistics. When offered a choice Cartwright tended towards the ‘applied’ subjects partly because they would be more useful in the outside world.

In contrast to Cambridge, classes were small and left the afternoons free for revision, and both mathematical and physical exercises. He was captain of a successful college cross-country team in winter and took part in track events in summer. This is also the time when he made himself into a proficient classical pianist with respectable performances and occasional prizes at competitions in suburban London music festivals.

At the end of this period he was disappointed to get a 2(ii) BSc Honours degree, but at least felt well equipped to face the world.

**Admiralty Career**

A recruiting team from the Royal Navy Scientific Service attracted Cartwright and he was offered a post as a Scientific Officer attached to the Department of Naval Construction in
Biographical Memoirs

Bath. He was also offered a higher paid job with the Bristol Aircraft Company, but chose Bath because of its connections with the sea.

After the initial novelty had worn off Cartwright realized that Bath was dominated by construction engineers. The few scientific officers were really juniors, employed in principal to work on special technical problems to do with vibrations, noise and the wave induced motions of ships. Most engineers had little idea of how to make good use of the scientists but Cartwright made contact with Alan Williams who worked on the statistics of ship motions and had a large number of ‘wiggly-line’ records. These were made by pens on a moving strip of paper and recorded the pitch and roll of a ship. Cartwright became interested in these random, near Gaussian processes, and devised a number of original analysis techniques, which were used by Williams in a paper published by the Royal Institution of Naval Architects.

It was about this time that Cartwright met Anne-Marie Guerin, from St Prix near Paris, where his uncle lived. This happened when Anne Marie was an au pair for six months at his parents’ hotel. They started going for long walks together on the hills behind Worthing and subsequently kept in touch through letters and visits. They were married in St Prix on 12 July 1952 and moved into Cartwright’s small flat at Freshford, southeast of Bath.

Unfortunately Mr Williams, Cartwright’s collaborator at Bath, was then promoted. At the same time his group’s targets became more focussed on noise reduction in ships and submarines, to which Cartwright found little to contribute. He remained interested in understanding how the pitch and roll of a ship depended on the ocean wave field, and became convinced that the way to proceed was to measure surface waves and ship motions at the same time. This is the time that Cartwright felt his scientific career was really at an end. However, it was soon after this that he was able to visit the wave group at the Admiralty Research Laboratories, Teddington, which had developed a shipborne wave recorder. The visit was a success and he was subsequently invited to see the equipment working on the Royal Research Ship *Discovery II* during a short cruise out from Plymouth.

The Plymouth trip gave Cartwright a chance to talk to the people involved and especially with Malcolm Tucker, a physicist and senior member of the group that had developed the wave recorder. It was during one of these talks that Tucker suggested that Cartwright write to his director, George Deacon FRS (later Sir George Deacon), asking to be transferred. At the time Deacon was setting up the new National Institute of Oceanography (NIO) based at Wormley, near Godalming in Surrey, and it was expected that new posts would become available.

**WAVE RESEARCH AT WORMLEY (1954–1963)**

Cartwright’s application was successful and he transferred to the NIO in June 1954. The new national institute brought together oceanographic experts in physics, biology, chemistry, geology and geophysics, but Deacon also ensured that the scientific programme was supported by the engineers, electronic and instrument specialists needed to both advance the technology and operate in the extreme conditions experienced at sea.

Initially Cartwright shared an office with Tucker and Michael Longuet-Higgins (FRS 1963). With their help he first started on a project to estimate the direction spectrum of sea waves using measurements made by the shipborne wave recorder. A series of measurements had been obtained on the *Discovery II* as the ship sailed along the 12 sides of a regular dodecahedron. Records were in the form of lines on a chart and although there was no way to
digitize the records and computers were not available, spectra could be obtained by mounting the record on a rotating drum and using the drum speed and a tuned circuit to sample different frequencies.

Cartwright (1)* used these results to show that it was possible to follow the main peaks in the spectrum as the ship’s heading changed. In most cases he found only a single peak due to the locally generated wind waves but in one case there were two peaks, the second corresponding to the swell from a distant storm.

Cartwright then, in collaboration with Professor Louis Rydill from the Royal Naval College Greenwich, wrote a major paper on the pitch and roll of a ship at sea (3). Using similar methods to those in the previous paper they showed that the pitching of *Discovery II* depended on the apparent frequency of the waves relative to the moving ship but that its rolling motion was dominated by the natural roll period of the ship. They also studied the probability distribution of pitch and roll and the extreme values measured. The results generally supported theory but emphasized the importance of rolling, a factor often ignored in tank experiments on hull forms.

One consequence of the collaboration with Professor Rydill was an invitation to join a working group being set up by the Ship Division of the National Physical Laboratory (NPL). This had the aim of setting up trials, similar to those on *Discovery II*, but on a range of ships and with the full backing of professional ship engineers. As well as the NPL, the working group also contained representatives from the British Ship Research Association and the Admiralty. The resulting set of studies, similar to those first envisaged by Cartwright in Bath, continued until 1963 and resulted in a series of important papers.

Cartwright also became involved in a separate study of the statistics of wave heights. Previously, both Cartwright and Longuet-Higgins had worked on related problems and they combined to develop a method to relate the highest wave in a record to the RMS wave height (2). A variant of this analysis was used in the Cartwright and Rydill study (3).

The method could also be used in the opposite sense, to estimate the r.m.s amplitude from a measurement of the highest wave. However for a typical 900 s wave record, the limited number of waves means that the errors could be large. In further work Cartwright (4) showed that a better estimate could be obtained by also using the heights of the second and third highest waves. Tucker adapted this scheme, using the two highest and two lowest waves, to analyse the analogue wave records being collected from lightships around the coast. The resulting wave climate dataset became crucial in the following decades during the development of the off-shore oil and gas fields around the UK.

*The pitch–roll and clover-leaf buoys*

An alternative instrument for measuring directional spectrum was the pitch–roll buoy that had been developed by Norman Smith. This was a circular buoy that lay low in the water, with gyro stabilized vertical accelerometer, tilt meters and compass. In principle it could be used to determine directional wave spectra from a single 15 min record.

Unfortunately the data were still in the form of chart records and the tilt data needed compass corrections before being correlated with the vertical acceleration data. However about this time two English Electric Deuce computers were installed nearby in Farnborough and made available to the NIO researchers. Cartwright made good use of the new resource,

* Numbers in this form refer to the bibliography at the end of the text.
first digitizing the chart data at half second intervals and then processing the card data on the new computers, using one of the newly developed efficient Fourier transform methods (Watt 1959). The results were very successful (6) and the method became one of the standard ways of estimating directional wave spectra. The buoy was also used in the ship trials referred to earlier.

A related development was the clover-leaf buoy designed to give higher angular resolution. The story goes that the basic design was sketched out on the back of a discarded cigarette packet by Smith and Cartwright during a long rail journey from Edinburgh to London. The design, in which three connected buoys could pivot and measure the curvature of the sea surface, was a success.

The wave research also prompted other developments. During an instrument testing cruise in 1955, Deacon pointed out some striking waves seen in the echo-sounder records close to the continental shelf edge. This led to a paper on the submarine sand waves generated by the internal tide and a related paper on sand waves in the North Sea (5). Cartwright also took over responsibility for a storm surge study of the North Sea from his colleague James Crease, while the latter was in the USA. Storm surges also involved the tides, so Cartwright used his expertise with time-series analysis to develop what was probably the first set of computer programs for analysing a year’s tidal data including its storm surge components.

On moving to the NIO, Cartwright and his wife had first lived in one of the post-war prefab houses in Haslemere. But in 1957 they were able to buy their own cottage where they started a family, Marie being born in 1958, Bruno in 1959 and Timothy in 1962. Their second daughter, Natalie, was born in 1965, after a remarkable sabbatical year in California.

IGPP AND A NEW METHOD FOR ANALYSING TIDES

Cartwright met Walter Munk (ForMemRS 1976) at a meeting on waves in Finland. Like Deacon, Munk had been involved in wave prediction studies during World War II and, in 1963, was director of the new Institute of Geophysics and Planetary Physics (IGPP) based at La Jolla, California. The IGPP is now a central part of the Scripps Institution of Oceanography.

Major strengths of the institute included a powerful computer and specialist software useful for the processing of long time-series. The IGPP also held collections of wave and tide records on magnetic tape and data from seismometers that were being used to study the deep structure of the Earth. At the time Munk’s own research was still focussed on ocean waves but he was becoming excited about new ways of analysing tidal records. As a result he invited Cartwright to take a sabbatical at the IGPP so that they could work together on the problem.

Cartwright and his family moved to La Jolla in the autumn of 1963 and stayed until early 1965 (figure 1). The plan during the visit was to move away from the traditional harmonic approach to tidal analysis and instead treat the tides as the oceanic response to the forcing by the Moon and Sun, similar to Cartwright’s previous investigation of a ship’s response to forcing by sea waves.

In practice the project involved processing 20 years of hourly data from Honolulu (Hawaii, USA) and Newlyn (Cornwall, UK) together with the time-series of the forcing functions for the same period. For forcing functions Cartwright used a spherical harmonic expansion of the tidal potential, its advantage being that one of the terms in the expansion captures almost all
of the global forcing of the semi-diurnal tide and a second almost all of the forcing of the diurnal tide.

Cartwright also made an estimate of the radiational forcing term due to the Sun. Both of the tide stations had good quality records covering many years, but whereas Honolulu was an island station where non-linear effects should be small, Newlyn was more typical of a coastal region where non-linear effects could be significant.

The project was important both in itself and in the way it helped change the focus of Cartwright’s career. The key result of the work was to show that the ocean’s tidal response function was smooth across each of the tidal bands (7). The curvature at Newlyn was greater than that at Honolulu, but the results showed that once the forcing time-series was calculated, the tide at any port could be predicted using only a few parameters. In contrast the traditional harmonic method needed a large number of constituents for the same accuracy.

Cartwright’s careful statistical analysis of the residuals also provided information on the background noise in the ocean at a resolution of one cycle per year. This showed that there was an increase in the background noise around each of the main tidal constituents possibly due to storm surges or irregularities in the generation of internal tides.

**Offshore tides**

On his return to NIO in March 1965, Cartwright continued his interest in waves, his last major involvement being with JONSWAP (12), an international experiment which was crucial in our understanding of how a sea wave spectrum develops. However Cartwright’s main research interest was now tides, initially on applications of the response function method, the analysis method he had developed with Munk, and later on observations of deep-sea tides.
During this period his response function research was focussed on the tides around the UK and their interaction with storm surges. He investigated the non-linearities affecting the tides at Newlyn and Southend, and showed that after taking non-linearities into account the response method was more accurate than harmonic analysis (8). He also included the effect of atmospheric pressure and showed that it was possible to forecast storm surge levels a few hours in advance. However he was the first to admit that the method was soon superseded by storm surge forecasts coming from the new computer models. Although he never liked committees, the work on storm surges also led to Cartwright participating in a Port of London committee planning the Thames Barrier.

At IGPP, Cartwright had become interested in the deep-sea tide problem through the work of Frank Snodgrass who was developing a deep-sea tide gauge. At the time, tidal charts of the ocean were constructed either qualitatively, based on measurements at coastal and island stations, or on the basis of the early computer models of the tides. The problem arose because in both methods the data only weakly constrained the tides in the deep ocean and estimates of tidal energy dissipation based on the resulting tidal charts were inconsistent with astronomical estimates.

Cartwright was keen that NIO develop its own deep-sea tide gauge and, with the encouragement of Deacon, a prototype design was developed by Tucker and Malcolm Harris. Peter Collar developed the low power CMOS transistor electronics, a very new technology at the time, and together with Robert Spencer developed the instrument for operational use. Measurement of the small pressure differences at depth, due to the tides, was hampered by the slow drift of the early sensors.

The first successful deployment of the instrument occurred in 1969 and by 1971 it was being used to record pressure time-series at the edge of the continental shelf. The results were then used as boundary conditions for storm surge and other continental shelf models (11). A related series of sea level and current measurements on the outer continental shelf showed unusually strong diurnal currents off the Outer Hebrides, identified as due to a continental shelf wave resonance (9). The existence of trapped waves along the east coast of Shetland was also inferred with the use of sea level measurements at Lerwick and Baltasound (13).

Internationally the measurement of deep-sea tides was being encouraged by the Scientific Committee for Oceanographic Research (SCOR) through Working Group 27 on ‘Tides of the Open Sea’. Cartwright became chairman of the group in 1974, but just before this, in 1973, he organized an intercomparison of instruments developed by member groups from the USA, Canada and France. The intercomparison was carried out at two sites near Brest, one at a depth of 200 m and a second at 2000 m. Despite all the measurement problems, there was excellent agreement between the different instruments (14) (figure 2).

Cartwright noticed that one area with very limited tidal data was the South Atlantic, so in 1969 he arranged to visit St Helena with John Driver and make 39 days of continuous seabed pressure measurements using the NIO deep-sea tide gauge. These were then combined with other data sets from Ascension Island, Isla de Trindade and Tristan de Cunha, to generate new tidal maps of the South Atlantic (10). A comparison with observations at St Helena made in 1761, by the astronomers Charles Mason and Nevil Maskelyne FRS, showed that over two centuries the semi-diurnal tides were virtually unchanged but there appeared to be a significant change in the diurnal tides.
In 1974, Cartwright was made Assistant Director in charge of the Bidston laboratory of the new Institute of Oceanographic Sciences (IOS). The laboratory, which had originally been the Liverpool Tidal Institute and just previously the Institute of Coastal Oceanography and Tides, was located on Bidston Hill directly opposite the port of Liverpool. As a result of the changes, Cartwright and his family moved to Heswall where their house overlooked the Dee Estuary.

The responsibilities of the laboratory included the analysis and prediction of tides for ports in the UK and overseas. It also included strong emerging groups measuring tides at coastal locations and offshore, measuring and understanding Earth tides (the flexing of the solid Earth in response to the same tidal forcing), and developing new computer models of tides, currents and storm surges.

In contrast to Wormley, Cartwright was now surrounded by many more researchers with similar interests. With the exception of Norman Heaps, a leading ocean modeller, most were very young. Cartwright’s mentoring style with these young scientists was in the Wormley tradition of ‘hands off’, giving staff the space to develop their own ideas. However, when a paper was approaching publication, and when invited to read it, he would return the manuscript
Figure 3. Deep-sea tide gauge recovered from mid-Atlantic, during RRS Discovery Cruise No. 115, December 1980, with, from left to right: D. Cartwright, K. Parry, I. Vassie, B. Hughes and R. Spencer. Image used with permission from the National Oceanography Centre. (Online version in colour.)

next day, replete with valuable suggestions for improvement and positive encouragement. Cartwright both set and raised the laboratory’s standard of scientific excellence. As a result when he returned to Wormley some 12 years later many of the young scientists had established their own international reputations.

Administratively however there were problems, though Cartwright was protected from the direct influence of the overall funding body, the UK Natural Environment Research Council (NERC), by the IOS Director based at Wormley. Initially this was Henry Charnock (FRS 1976) and he was succeeded in 1978 by Anthony Laughton (FRS 1980; later Sir Anthony Laughton).

Before Cartwright’s time the Bidston laboratory had been independent with its own director. The amalgamation with Wormley led to tensions, especially with the entrenched attitudes of some senior staff, but these were soon resolved. Although administration was not one of Cartwright’s strengths, during his time there the laboratory thrived. This was helped by the support Cartwright received from his staff, especially Norman Heaps, Trevor Baker, John Huthnance, David Pugh and Tom Dugdale.

While at Bidston Cartwright continued his research on deep-ocean tides, supported by a strong technical and analytical team (figure 3). By this time the IOS deep-sea tide gauges could be deployed at full ocean depths. They were first used to measure the tides along the mid-ocean ridge to provide better tidal maps for the whole North Atlantic (15). Further deployments were made along the Equator to measure the tides, in collaboration with the US and French SEQUAL and FOCAL programmes, which were concerned with investigating the equatorial current system in the Atlantic.

The tidal observations, together with the observations from the South Atlantic, resulted in new co-tidal charts for the whole of the Atlantic (19). The observations on the Equator also showed that, except for the tides, the deep-ocean pressure signal there was very quiet, so much so that the seasonal changes were later interpreted as a result of the changing mass of the whole ocean, due to exchanges with the land and atmosphere.

By this time Cartwright had developed an appreciation of satellite altimeter observations of the ocean sea surface. The first ocean altimeter had been flown in Seasat in 1976 and
usually the results from computer models were used to estimate and remove the tidal signal. However, Cartwright developed a method to determine tidal constants from the altimeter signal itself. He used this method to extract the M2 tide in the northeast Atlantic from the Seasat data. (The M2 tide is the dominant tidal constituent due to the Moon.) Unfortunately the satellite had only survived for 105 days but despite this he was able to show that the analysed tidal constants were in good agreement with those derived from the deep-sea pressure measurements (16).

On the basis of this work he then extended the method to map the M2 tide over the whole of the ocean surveyed by Seasat (17). Again, despite the shortness of the record, the results were in good agreement with independent observations. The results also showed significant differences with model results based primarily on coastal data.

Cartwright’s interest in deep-ocean tides also resulted, in the early 1980s, in his involvement in the planning of future satellite altimeter missions. He had been involved in a study of potential satellite orbits (18) and as a result advised against the use of sun-synchronous orbits in both the European ERS 1 and French/U.S.A. Topex/Poseidon missions, as sun-synchronicity would alias part of the tide. Nevertheless, ERS 1 was eventually limited to a sun-synchronous orbit but Topex/Poseidon used an asynchronous one.

Cartwright’s programmes of research also led to a gradual expansion of the areas of ocean studied by other IOS Bidston researchers. Thus the deep-sea tide gauge group became heavily involved in the ACCLAIM programme (Spencer et al. 1993) where they deployed instruments in the South Atlantic and Indian oceans, and, in collaboration with the British Antarctic Survey (BAS), on either side of the Drake Passage. These later deployments also became part of the UK contribution to WOCE, the World Ocean Circulation Experiment, and were used to study variations in the strength of the Antarctic Circumpolar Current.

The Topex/Poseidon satellite and its radar altimeter measurements of sea surface height were a central component of the WOCE programme. IOS Bidston researchers used the deep-sea tide gauges to calibrate the altimeter measurements far from land. Later they also analysed the data coming from the altimeter and, together with computer model data from the UK Fine Resolution Antarctic Model and in collaborations with BAS, carried out further research on the currents and changes in sea level of the Southern Ocean.

**PETERSFIELD, GODDARD AND RETIREMENT**

Cartwright was due to retire in October 1986, but as retirement neared, it was obvious to Laughton, the IOS Director, that Cartwright was finding the increased NERC administration duties onerous. So, with a new NERC marine laboratory structure in prospect, in early 1986 Cartwright was moved back to Wormley and subsequently Bidston and Wormley became independent again, Bidston becoming the Proudman Oceanographic Laboratory.

Cartwright also kept up his contacts with the satellite altimeter community and applied for a grant to work at the NASA Goddard Space Flight Center in Greenbelt, Maryland after he retired. This was successful and he was awarded a Senior Research Associateship by the US National Research Council. As a result, in March 1987 Cartwright and Anne-Marie moved to Greenbelt, staying there for two years. This was some 20 years after his first successful sojourn in the United States.

Cartwright joined a group headed by James Marsh, which was developing the software and skills needed for the planned Topex satellite mission. Following on Cartwright’s work with
the Seasat data, one of their aims was to use the accurate Topex altimeter to generate a better set of global tidal fields. This could then be used to generate improved tidal corrections to the altimeter data, making it easier, for example, to investigate other contributions to changes in sea level.

By a stroke of good fortune, the US Navy had just then launched the Geosat mission. This also included an altimeter although the accuracy was less than that planned for Topex. Cartwright teamed up with Richard Ray and together they developed and ran the software needed to derive the tides from the Geosat data. The Geosat satellite was kept in a repeat orbit for three years, so, together with an improved altimeter and improved tracking, it should be possible to generate global charts of the tide to a much greater accuracy than had been possible with Seasat. As before they had to overcome problems such as the poorly known underlying geoid and differences in the satellite track from one orbit to the next. However the final results were very successful (20, 21).

Comparison with island stations and bottom pressure measurements showed that the satellite derived tide was usually in close agreement with the other observations. Also the altimeter based estimate of total tidal energy dissipation was in better agreement with astronomical estimates than those derived from tidal models.

Cartwright found Goddard to be very stimulating. He enjoyed the experience of working with leading authors on the Earth’s gravity field, the high precision determination of satellite orbits and the use of altimeters to study the ocean. He also contrasted the lively and positive approach to science he found there with, in his opinion, ‘the low-morale, economically squeezed atmosphere which had pervaded the British Earth-science community during the 1980’s and before’.

On returning to the UK, Cartwright continued working with Ray, producing more papers on the global tide. Possibly because they provided some closure to his attempts to map the global ocean tides Cartwright later considered two of the papers (20, 21), to be his ‘best work’.

Following retirement Cartwright had time to expand his interest in music and also go on long hikes with the South Downs Society. He continued playing the piano, sometimes with friends who sang or played an instrument, and was one of the patrons of the Florestan Trio. Later, when age affected his playing, he was still very involved with music, travelling with Anne-Marie to many concerts and music festivals. However, well before this, in 1996, Cartwright turned 70 and the event was celebrated by colleagues who organized a two-day symposium at the Royal Society in his honour. The meeting attracted senior scientists from around the world, with the papers published in a special volume of Progress in Oceanography.

The year previously, 1995, Cartwright had turned his energies to his final major work, a book on the history of tidal science. Here he made use of his interest, knowledge and understanding of both the history and the science of his subject. The result, ‘Tides: a scientific history’ (22), was published by Cambridge University Press in 1999 and is now a standard reference on the history of tides.

He continued his interest and research on tides, attending Royal Society meetings and, in his final publication with Ray (23), using satellite altimeter data to map the internal tides of the ocean. Although there was a later note on the history of tides, this paper remains a fitting closure to his significant series of contributions to the science of tides: which had started with those observation of sand waves, generated by the internal tide, during his first ever oceanographic cruise in 1955.

To close, in the words of a colleague from Bidston: ‘Overall, I remember a kind person who was indeed approachable but a bit shy and insular. And very bright of course’.
HONOURS AND AWARDS

Degrees
1946 BA (University of Cambridge)
1951 BSc (University of London)
1968 DSc (University of London)

Fellowships
1975 Royal Astronomical Society
1984 Royal Society
1991 American Geophysical Union

Honorary degrees
1992 Docteur Honoris Causa, University of Toulouse

Other distinctions
2000 Oceanography Award, The Society for Underwater Technology

Appointments
1951–54 Department of Naval Construction, Admiralty, Bath
1954–74 National Institute of Oceanography, Wormley, Surrey
1964–65 Research Associate, University of California, La Jolla, California
1974–86 Assistant Director, Institute of Oceanographic Sciences, Bidston, Birkenhead
1987–89 Senior Research Associate, NASA-Goddard Space Flight Center, Greenbelt, Maryland

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AUTHOR PROFILE

Dr David Webb trained as a physicist at Manchester where he obtained a PhD in Theoretical Physics. In 1969 he joined the CSIRO Division of Fisheries and Oceanography in Australia, where he worked on tides, biological diversity and took part in research at sea. He returned to the UK in 1973 and joined IOS where he initially shared an office with David Cartwright. He continued to work on tides, but also carried out theoretical, experimental and model studies of ocean surface waves and the large-scale ocean circulation. Among other roles he was chairman of a WMO committee concerned with developing ocean models for climate change research, was President of the EGU Division of Ocean Sciences and was a founding editor of Ocean Science.
Biographical Memoirs

REFERENCES TO OTHER AUTHORS


BIBLIOGRAPHY

The following publications are those referred to directly in the text. A full bibliography is available as electronic supplementary material via http://dx.doi.org/10.1098/rsbm.2017.0001 or via https://doi.org/10.6084/m9.figshare.c.3705751.


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