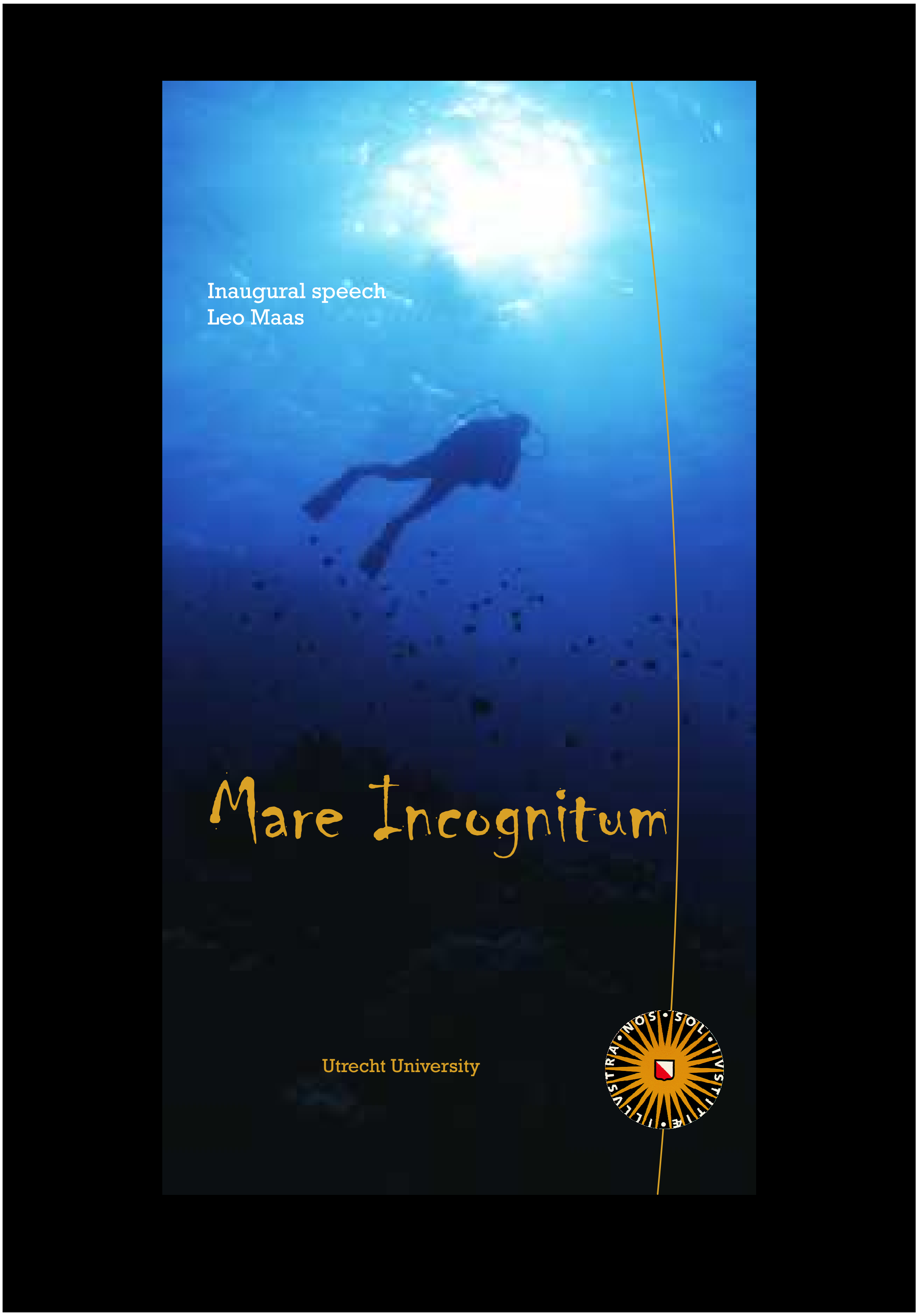
Inaugural speech
Leo Maas
Mare Incognitum
Utrecht University

Mare incognitum

Inaugural speech delivered upon accepting

the position of extraordinary professor[1] occupying

the chair of *Wave dynamics of the Ocean*

at the department of Physics and Astronomy,

part of the Bèta faculty of Utrecht University,

on Monday May 11 2009

by

Leonardus Richardus Marie Maas

[1]This is a translation of the (obligatory) Dutch original. While an ordinary professor is appointed by the University, those appointed by other companies, as in this case the Royal Netherlands Institute for Sea Research, are called ”extraordinary”.

Mr. rector, members of the board of the NIOZ Royal Dutch Institute for Sea Research, colleagues, family, friends and other esteemed guests:

"*Mare incognita, Mare incognitum..*": there was some confusion about the correct spelling of the title of this inaugural speech, at least on my part. This perhaps illustrates the issue that I want to address here, namely: "do we know the sea?" 'But, when there is confusion even about the title's *spelling*', you may worry, 'shouldn't you doubt each subsequent statement as well?' Hmm, I think this is indeed fitting. To the layman, doubt may be synonymous to stupidity or ignorance, for the scientist it is instead a noble quality, one that is not lightly renounced. Only that knowledge that resists repeated attacks of doubt and counter arguments , thus purified, turns out to be of permanent value.

But, let me return to the question that occupies my mind: "Do we know the sea?" And what does this "know" actually mean? Indeed, how *do* we *know*? Well, in the first place we know through perception, by means of our senses - or with the aid of 'sensitive' instruments that extend these. Using light and sound waves, seeing and hearing enable us to sense at a distance; smell, taste and touch do so mainly via contact, by conduction and exchange of material. In addition, according to some, we also know from inside: we supposedly have a sixth sense, consisting of 'intuition', 'insight', or a nondescript instinct.

In science we basically have a similar division. 'Measuring is understanding' according to an old saying. Imaging by gathering an object's external signals is known as 'observation'. Opposite to this we have knowledge about an object's inside by speculation about its internal structure and by modelling thereof. This leads to prediction, the pendant of the 'instinct'. This form of knowledge is known as 'theory'.

Let me illustrate the difference with my first experience with an oceanographical slant. It consisted of trips to the beach with my parents, brothers and sisters. There we saw the waves continuously rolling towards us, waves that were breaking just in front of the shoreline. When you swam in the breaker zone you could avoid the punch of such a breaker by diving below it. The deeper you swam, the more the breaker was damped.

Apart from seeing, hearing and feeling, however, insight played a role as well. My father pointed out to us that waves also transport water towards the coast, water that subsequently had to return seaward. He warned us that when you were trapped in such a rip current, you should at first not oppose it, but swim along with it, even when you were sucked down, and only then, when you had not drowned by then, swim away sideways.

An understanding why waves got weaker below the surface, and why each seventh wave was bound to be a big wave, came much later. I could not know then that this other intriguing wave asymmetry would keep me fascinated for years to come, namely that waves always seem to just *approach* the coast and not leave it. It is as if the coast attracts waves, a phenomenon which, for this reason, I have come to call a *wave attractor*. Well, there is of course no magnet stored in the coast, but waves that approach it from some oblique angle move slower in the shallower parts, thus refracting towards the coast. They become higher and steeper, and by consequence ultimately often break. This wave breaking forms an irreversible process, so that in the end the waves are not able to reverse either. In a manner to be discussed later, wave attractors also seem able to shape the deep sea. There they can produce *subsurface wave breaking*, a phenomenon once crudely brought to the attention of a submarine's crew when their submarine, while at great depth, was pushed into the bottom.

Perception of the surroundings versus experiment

Thus, observation as well as theory may both lead to an increase in knowledge. Observation can itself still be distinguished into two parts. First, in the unfocused perception of the surroundings, by simply opening one's senses; and, second, in the focused observation, by performing experiments under controlled circumstances. While, perception of the surroundings does indeed provide us with knowledge of the *all*, a *holistic* perception, it does not give us a clue about cause and effect, because all kind of processes are intermingled. It is not clear which process causes what. Questions posed to science by politics or society, for instance those related to sea level rise or climate change, usually pertain to this 'all'. But the conscientious scientist is often unable to answer these holistic questions unambiguously because the problems are often too complex. For if one is unable to answer even the underlying simpler questions, how can he or she say anything reliable about those issues where different processes occur together and interact? History has shown that an understanding of cause and effect can be obtained only when the complexity of reality is reduced to such extent that only a single process is decisive, a *reductionist* approach.

Dead-water

Let me give an example illustrating the way observation, theorizing and experimental verification have together led to oceanographic insight.

At the end of the nineteenth century the Norwegian Fridtjof Nansen used his ship the *Fram* in an attempt to be the first person to reach the North Pole. Nansen found that, while the wind was strong enough, the *Fram* yet occasionally came to a sudden stop in the Norwegian fjords, as if the ship

Figure 1: Polar explorer Fridtjof Nansen and his ship the *Fram*.

had hit the bottom. The sounding rod, however, indicated that there was still enough water below the hull. Upon questioning the crew he learned that this was a well known phenomenon. The suggestion that a ship had hit the bottom was at times so strong that several ships had been sent to the dockyard for repair, only to discover that there was nothing wrong with the ship at all. The motionless state that had caught the ship could last for hours. The seafarers addressed this phenomenon as 'dead-water', which reflected the motionless impression that the water offered, caused by the fact that ship and water moved exactly at the same speed. The absence of any velocity difference had the nasty consequence that there was no pressure on the rudder, rendering the ship steer less. Nansen heard that captains had therefore tried everything to break free from the dead-water. Some had instructed there crew to run back and forth across the deck. Others had poured oil on the water. Still others had, in that typical manner in which mankind responds to the unknown, shot at the water! And then the water was really dead... But nothing worked. Returning from his attempt to reach the North Pole, that he had to abandon at 86^o North, Nansen described his dead-water experiences to Vilhelm Bjerknes, a prominent meteorologist in those days, who promptly came with the following hypothetical explanation:

The fjords are filled with a thin layer of melt water of a couple of meters thickness. This water is less dense than the salty ocean water over which it spreads. It is 'lighter'. The fjords are thus filled with two layers of water that hardly mix with each other. Bjerknes suspected that the enormous resistance that brought the ship to a stand still was caused by the ship

Figure 2: Sea battle at Actium, 31 before Christ, in which dead-water may have played a decisive role. Painting by Lorenzo A. Castro (1672).

generating internal waves, at the interface between both layers; waves that apparently were hardly noticeable at the surface. Bjerknes had the issue investigated by his student Vagn Walfrid Ekman, who was to become a very famous oceanographer himself. Ekman started with a thorough literature search. He found that Roman historians Pliny and Tacitus had given descriptions that were reminiscent of dead-water. Ekman suspected that the historical sea battle in 31 before Christ at Actium, in front of the coast of Greece, was settled by the same phenomenon. In that event the fleet of Mark Antony and Cleopatra had lost the battle against Octavian, the future Roman emperor August, who used smaller but much more manoeuvrable ships. In Roman times this was attributed to sucking fish, *Remora*, that were supposed to have attached to the hull of the tall ships and that allegedly would have impeded their manoeuvrability...

While this explanation for the mysterious dead-water phenomenon sufficed in ancient times, it did not satisfy Ekman. He therefore decided to test the hypothesis of his teacher in a laboratory experiment, an experiment that I have repeated for you with the aid of a few high-school students. Using a thin thread and a weight of less than a gramme, a 'ship' (log of wood) is being dragged through a two meter long tank. To study the impact of stratification the experiment was performed twice. Once in a tank with tap water and a second time in a tank with a salty and therefore 'heavy'

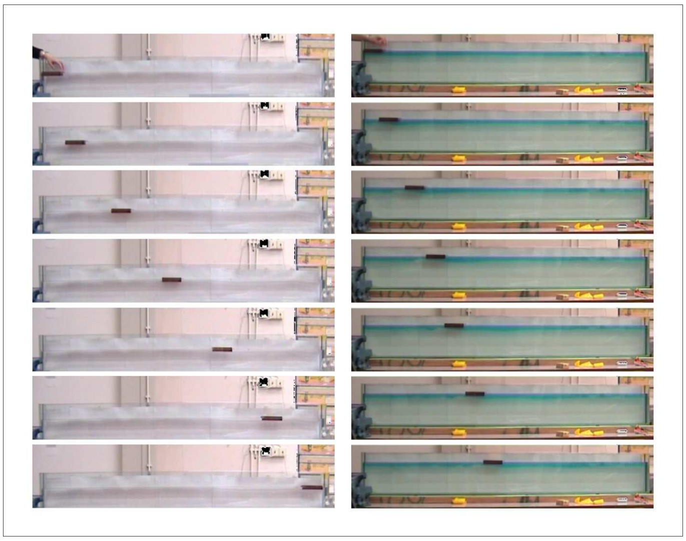

Figure 3: Two identical experiments in which a log of wood is dragged through a tank containing water without (left) or with salt stratification (right).

lower layer, having a layer of unsalted water on top of it. To visualize the underwater waves the upper layer was dyed blue. Like Ekman we find that in stratified circumstances a ship is indeed retarded due to interfacial wave generation. This turns out to be especially the case when the ship speed is about the same as that of the interfacial waves that have a wavelength similar the length of the ship. Remarkably, the free surface is apparently undisturbed, precisely what made the dead-water phenomenon so mysterious in the first place.

Laws of nature

To return to the question "how do we know?" we find that in healthy science observation and theorizing are continuously 'in discussion'. A new observation can completely change our concept about the way a hitherto success full theory operates. on the other hand, new theoretical insight, while agreeing with all available observations of a particular phenomenon, might still make a new, unexpected prediction. Observation and theory sharpen each other.

But, new theory is not simply invented. In physics it has to obey stringent laws, based on the principle that no thing comes from nothing, more or less like in your wallet! The laws of nature are therefore called 'conservation laws'. The discovery of the laws of nature culminated in the formulation of laws for the motion of solid objects and liquids, for electromagnetic radiation and for the smallest and largest structures in the universe. Theoretical physicists aim to find these laws. The unification of all known forces in a

Figure 4: Oceanographic eddy of about 100 km diameter in the Sea of Ochotsk, west of the Siberian peninsula Kamtsjatka, visualized by ice floes and photographed from an airplane by Wakatsuchi and Ohshima.

single unifying theory is seen as the holy grail of physics. Achieving this goal is hampered, however, because more and more extravagant theories have difficulties making predictions that can be verified or falsified experimentally.

Rich physics

Another approach is therefore taken by applied physicists who view these laws of nature as given and who search for their consequences. Oceanography, describing the physics of the ocean, is such an applied physics field. It employs classical mechanics that Newton developed for point particles, but extended to a many particles system that governs the motion of fluids and gasses. For oceanography and the related field of meteorology this is called geophysical fluid dynamics.

The laws of fluid dynamics may be known, but their consequences can still be very surprising. The many interactions that particles can have with each other can lead to feedbacks that are responsible for 'rich physics'. 'Rich' in the sense of 'many-sided' or 'exquisite'; more or less the sensation one gets when visiting Venice of Florence. It turns out that by using certain assumptions, from the exact, but complex laws one can extract some strongly simplified models as good approximation. In different circumstances these give precise descriptions of oceanographic phenomena as diverse as eddies, waves, currents, sound and turbulence. The richness of phenomena in oceanography and meteorology is evident from the fact that these are also the fields where 'solitons' and 'strange attractors' were first discovered, concepts that turned out to be relevant in many other branches of physics and beyond. Very briefly, a soliton is a kind of wave that does not go back-and-forth, but that, as the stem *solo* suggests, consists of a single wave crest. And as an image of a strange attractor you might think of a city that during the weekend clearly exerts an irresistable attraction to youngsters from the neighbouring country side around the city, but where one cannot predict where these youngsters actually will go within the city: to church, shopping centre or pub.

Multiple equilibria

Geophysical fluid dynamics does not only describe many different phenomena, but it appears that even one and the same phenomenon can, under identical circumstances, express itself in different ways. I will illustrate this with an anecdote.

At the start of the nineteenth century across the whole of Europe goods were transported by means of tow boats. These were towed by horses that trudged along the tow path. One day, one such a horse panicked and rushed off in a gallop, dragging the tow boat behind it. The merchant had great difficulties getting his horse under control again. After some time he succeeded in taking the horse back into a trot, but not into step, apparently, however, without causing the horse extra fatigue. For this reason the tow boat arrived at the port of call much earlier than expected. The merchant instantly saw the commercial value of this and made it into a recipe. From then on, at the beginning of a trip the horse was first brought into a gallop, after which the journey was continued in a trot. The English shipping authorities whom he informed about this curious phenomenon concluded that the galloping horse send the towing boat planing. In other words, while the boat, when the horse went stepwise, ploughed *against* the bow wave in front of the boat it was surfing its stern wave when the horse went into a trot. The presence of two states, characterized by either a slow or a fast transit, apparently at the same expense, forms an illustration of a phenomenon called 'multiple equilibria'. The speed that a boat needs to surpass in order to start planing is called the 'hull speed'. The resistance hill that needs to be overcome is analogous to that which Nansen and his crew came across in their attempts to free themselves of dead-water. It is also analogous to the sound barrier. Times they are a-changing, for I feel compelled to explain the latter concept to the younger persons in the audience. In former times, one could regularly hear a loud bang, indicating that a low-flying airplane had broken the sound barrier. In present times this barrier is broken far above ground level, so that such bangs are rare. But, it should be clear that at this passage a lot of sound waves are generated. That this involves lots of additional energy losses can still be heard in such terms as 'barrier' and 'breaking'.

Knowledge of the sea?

But, given that at sea phenomena can appear in 'rich' forms and thus be multi-facetted, what do we actually *know* about the sea and ocean? In terms of geographical location and current patterns, a lot of knowledge has historically been obtained by navigation. Later remote observations were added, obtained from satellites, for instance of water level and temperature. Both, however, reveal something of the ocean surface in particular. The deep sea is much less accessible. Our sight is limited there; even in clear water light can penetrate only a few hundred meters. For this reason, oceanographers have searched for other means to get an image of that which occurs in the abyss. For instance, by using sound, that can penetrate further. A modern current meter, for example, uses reflection of sound off moving material to estimate the speed with which that material moves. The travel time is used to determine the distance to this reflector, while the velocity of the reflector can be inferred from the change in pitch between emitted and back-reflected sound. This method uses the Doppler effect, well known from the drop in pitch that a passing ambulance brings about. Assuming that most of the reflecting material does not swim actively, but moves passively with the water, we can thus infer the velocity of the water in this manner; *i.e.* the velocity in the direction of 'sight'. By using three or four 'eyes', looking into different directions, and by combining the velocities in these directions, we can compute the three-dimensional velocity of the water along their center line. This is, however, still not offering a comprehensive image, I am afraid.

Using sound, we can also, as in a medical echo, get an image of the 'patient', the sea, by listening from many different positions. However, this observation has its problems too, because sound, as light in a mirage, is refracted due to density differences: an acoustical *fata morgana*.... For this reason, part of the sea is what I shall call, 'in*trans*audible'. In short, in the deep sea remote observations are problematic. What remains are contact measurements, from a ship, of from free drifting or moored buoys. In this manner, subsurface observations of temperature, salinity and currents are presently routinely being measured and stored electronically. While this measuring principle has assumed vast proportions, these contact measurements still say relatively little about how these quantities may vary at some distance from the measuring equipment. Here we face the fact that the ocean is so vast. By its intransaudibility and intransparency we hear, see and feel less of the sea than we do of the universe!

But, can theoretical insight in the working of sea and ocean perhaps help us supplement the missing knowledge? After all this comes directly from the carefully verified laws of fluid mechanics. These not only contain long

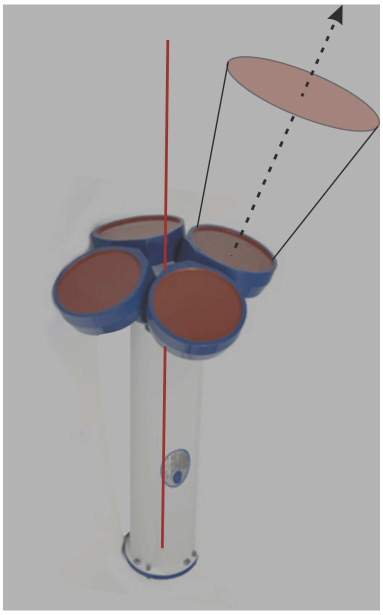

Figure 5: Current meter (ADCP) that uses Doppler's principle. The area that is seen by one of the four 'eyes' (orange circles) covers the indicated cone; the viewing direction is indicated by an arrow. By combining currents in the four viewing directions, the velocity of the water along the red center line is measured.

distance forces as gravity, or Coriolis force, produced by the rotation of the earth, but also short-range electromagnetic interactions, that manifest themselves in the form of friction, leading to mixing of adjacent water masses. As mentioned before, the sheer number of phenomena that can be explained in an approximative manner by these laws is bewildering. But, when these occur simultaneously and are entangled, as in the sea, it is in general impossible to disentangle them. So, when we observe at sea, *what* do we observe? And when we model the sea, what exactly does our theoretical model describe?

Theory in numerical models

Computer models seem best suited to take all these interacting processes into account. I will therefore call such a model a *overall model*. But even computers have their limitations. When we resolve processes acting on an ocean scale we pay for this in having to neglect small-scale processes, of scales less than 10 km say. It seems therefore that even such kind of models are not that 'overall'. Incorporating the impact of unresolved processes is called parametrisation. Significantly, all *resolved* large-scale processes can change considerably when this parametrisation is chosen differently. We assume, for example, that the large-scale circulation looses energy by me-

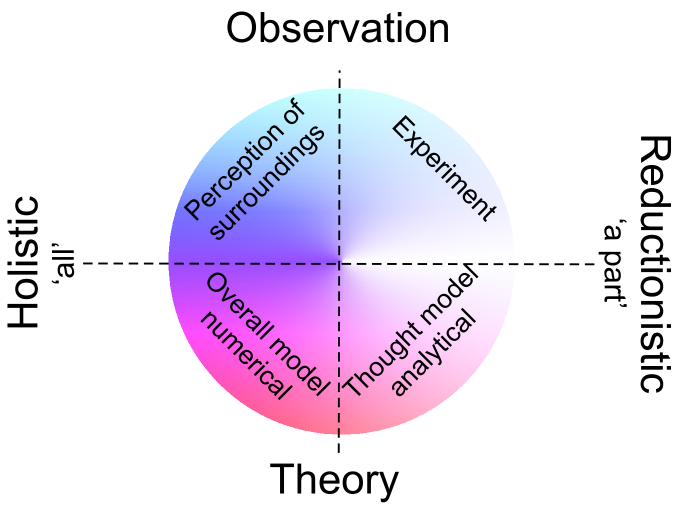

Figure 6: Four ways to obtain knowledge.

andering, by eddy shedding or by wave generation. Understandably, even though we do not explicitly resolve eddies and waves, because they are too small to be taken into account, we still want to capture their *effect* on our current, namely as a mixing process that leads to damping. There are, however, circumstances in which eddies and waves do not retard the current at all, but, instead accelerate it. As if, in your car, you think you put on the brake, but to your dismay, find yourself stepping the gas in doing so. Comprehension about when and why this mixing is braking or, instead, is accelerating the flow can only be obtained by isolating the process and by subsequently building this as a module into a more complex model.

Theory in analytical models

The strength of computer models, their ability to take many interactions into account, even in complicated surroundings, can thus be misleading. The ocean currents that they predict, may look as complex as those that we observe at sea. But is this the same complexity? And, do we understand why this occurs? Our brains are not really suited to distinguish one complex field from another. Real understanding of complicated feedbacks arises in *thought models* in which, from all conceivable interactions, only the *essential* ones are isolated. I consider myself lucky to have learned oceanography to an appreciable extent from Sjef Zimmerman, who is very skillful in making up these kind of thought models. His ability to combine model simplicity with physical insight is unprecedented and this has been a great stimulus for me.

Knowledge quadrants

In answer to the question "how do we know?" we can say that knowledge may come both from outside, by observation, as well as from inside, by theorizing. Both can acquire a holistic or a reductionistic character, when they pertain to 'all' or to 'a part'. By combination we get four complementary ways in which knowledge can be acquired. The answer to the question "do we know the sea?" thus depends on the knowledge quadrant from which we address this question; on the way we look at it.

The sea: a perturbed state of rest

I like to see motions of sea and ocean in a reductionist manner, namely as perturbations of a stable state of rest. In this picture the sea is seen as a thin shell containing stratified fluid, that, while rotating with the earth, is for the rest at first instance quiescent: immovable. Admittedly this is a somewhat abstract point of view, not entirely in line with our feelings once we traverse the roaring seas... But remember that in this imaginary state of rest, the sea is still revolving through space; at the equator even with a speed of about 440 m/s! Because both land and sea revolve together, we do not notice anything of this. The term 'stable state of rest' implies that this state can exist without spontaneously generating disturbances. Any perturbation of this equilibrium state will evoke a force that tries to restore the state of rest. By inertia, as the tongue of a bell, it will pass through its equilibrium, will then reverse, and this oscillation will repeat itself. In other words, perturbations of the state of rest manifest themselves in the form of waves. In the ocean we find these perturbations taking the shape of sound waves, surface gravity waves (as wind waves, tides and tsunami's) and of internal waves, as the interfacial waves that we encountered before. In contrast to the dead-water story, the deep sea's density does often not increase with depth in a shock like manner, but rather *gradually*, and internal waves can occur at all depths. The importance of all these waves lies in their ability to transport energy and perform work elsewhere. For surface waves we know that this work is often performed near the coast, in the surf zone, when these waves break. But, for internal waves we usually only have a vague idea where this 'elsewhere' is situated. It will turn out, however, that internal waves can likewise become concentrated and break, and can then cause mixing in the deep sea.

Inertial waves

A beautiful example of the ability of relatively weak internal waves to perform work in a concentrated manner elsewhere was experimentally discovered at the end of the nineteenth century by lord Kelvin, well known from the Kelvin temperature scale.

Kelvin had put a copper sphere that was filled with tap water into rotation. This appeared to act as a gyroscope, for when he hit the side of the rotating sphere it did not respond to it. But, when Kelvin hammered the sphere into the shape of a rugby ball, and subsequently hit the rotating ball, something

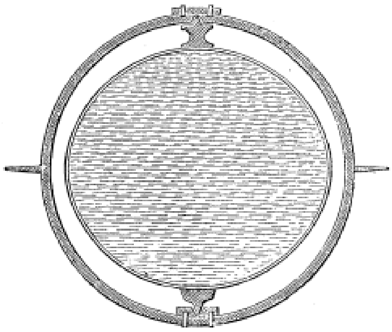

Figure 7: Kelvin's rotating, water-filled copper 'rugby ball' with handles.

strange happened. The rugby ball 'spontaneously' broke free from its gimbals, missing the head of the assistant by an inch only. Curiously, nothing happened when there was no water in the rugby ball, or when the sphere was hammered into disc shape. Apparently, some kind of internal waves were excited, restored by the Coriolis force, called inertial waves, that organized themselves in such a manner as to create a destructive couple on the casing. This phenomenon is still considered a curiosity. Why the rotating rugby ball was ejected, but the sphere and disc shaped rotating ball were not, is to my understanding still unexplained!

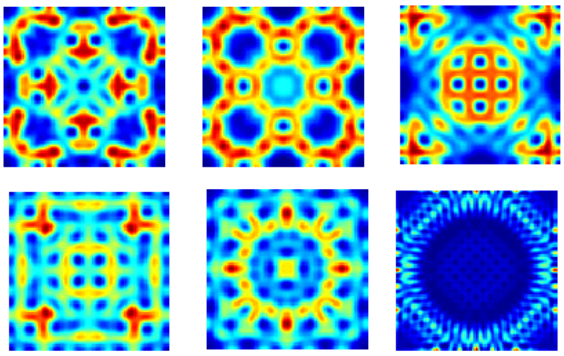

Figure 8: Inertial wave patterns in a rotating cube filled with a homogeneous fluid.

This lack of interest in inertial waves in rotating fluids is, given the fact that the universe rotates from its smallest to largest scales, somewhat disconcerting. To lift a tip of the veil I have computed some inertial wave patterns in a rotating cube that was put in its flat position onto a turntable. The computation shows some fairly complex wave patterns, purely as a consequence of rotation. My NIOZ colleague, Hans van Haren, has however recently observed that these kind of waves also occur in the deep sea, where they

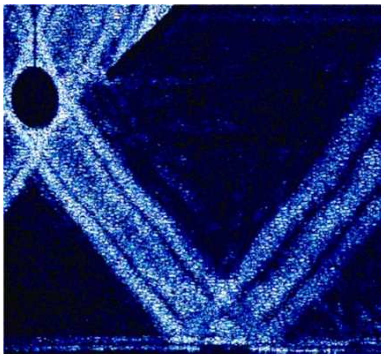

Figure 9: Internal wave beams propagating obliquely upwards and downwards. Experiment performed by Stuart Dalziel.

facilitate energy transport through thick layers of homogenized water.

Subsurface waves

It is remarkable that precisely those two aspects that characterize geophysical fluid dynamics, namely their continuous stratification and their rotation owing to the rotation of the earth, both lead to waves that differ strikingly from well known sound, light and surface gravity waves. They propagate namely *obliquely* through the fluid, under a fixed angle with the vertical, that is set by their frequency. It is equally remarkable that the consequences of this property can be most easily analyzed by geometrical methods, by means of pencil and geometrical triangle say. These are methods that have been superseded when Newton and Leibniz discovered how to formulate problems analytically, in terms of mathematical equations. This despite the fact that Newton still wrote his classical master piece, the *Principia*, using the geometrical method. But he did so only because his contemporaries were not yet familiar with the analytical method.

When modelling internal waves in a uniformly stratified ocean, the opposite occurs. With the analytical method, finding the solution of the relevant mathematical equation, the wave equation, in an arbitrarily shaped domain is very complicated, if not impossible. But it is child's play using the geometrical method...! I have once taken this literally and have asked my two eldest children, then seven and five years old, to help me find the internal wave patterns in a basin that contained a uniformly stratified fluid. The only principle that they had to use was to start drawing a line from an arbitrary point at the 'surface' under an inclination of 45 degrees downwards. Then, whenever this line crossed the bottom, they had to switch to the line perpendicular to the previous line, to the part that stayed within the fluid domain, the 'sea', etcetera. With children's hands this turned out to be still

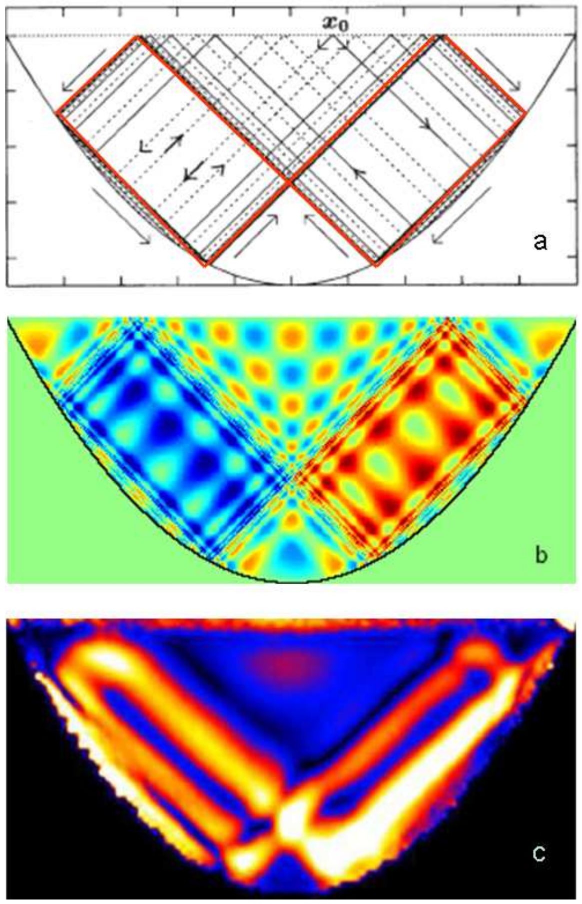

Figure 10: Internal wave attractor in a parabolic ocean basin (a) Wave rays and attractor (red); (b) theoretical wave field; (c) observed current field, intensifying around the attractor - measurement: Jeroen Hazewinkel.

quite complicated, but a computer programme that I developed, together with former PhD student Frans-Peter Lam, made clear that the line segments along which the waves propagate are almost always attracted towards a closed orbit, an *internal wave attractor*. These line segments function a bit as the nerves of the sea. They are the lines along which the pressure is passed through. They illustrate the proverb: "when I press here, it hurts there..." . The wave attractor is also exactly the place where experiments show that the wave energy is concentrated. In the same way as the beach attracts surface waves, this closed orbit appears to attract internal waves from all over the sea, waves that subsequently mix there.

From theoretical and experimental perspective accumulation of wave energy around wave attractors may seem inevitable, however, the big question is of course "do these wave attractors also exist in the sea?" And if so, "where exactly?" Presently this is not obvious at all. In analogy to *Terra incognita*, the unknown territory that appealed to the imagination of explorers like Fridtjof Nansen, there is now, Ladies and Gentlemen students, a *Mare incognitum* for you to discover! However, it seems that for this exploration a ship, or should I say, 'one ship', may not suffice, as you may need to employ all observational and theoretical means available to discover the deep sea, both from the outside as well as the inside!

Future plans

Let me therefore mention a few topics that I would like to investigate with you. In the first place, to elucidate the impact of the sea's stratification on particle and heat transport. The oceanographic community repeats as a mantra the importance of internal waves for vertical transport of heat, nutrients and dissolved gasses, without, however, acknowledging that transport in a stratified sea meets with a principal problem.

Let me illustrate this by means of the communication between mountain villages, situated at the flank of a deep valley. It is remarkable that the inhabitants have more contact with villages a few kilometers away that lie on the *same* altitude than with villages closer by, but differing in altitude by a few hundred meters. It seems that nobody likes the idea of having to climb and descend, and thus having to perform work against gravity, repeatedly. We find the same thing in the ocean: particles preferably stay at the same height, where their density matches that of the stratified fluid. Recent experiments by PhD student Jeroen Hazewinkel show that vertical transport is usually indeed suppressed, except in intense internal wave beams, as in the wave attractor. The wave attractor seems to attract not only waves, but also particles. These first move horizontally, towards the beams, but are subsequently also pushed obliquely, along the beams. Perhaps this is the long sought mechanism which forms the quest of our colleagues who

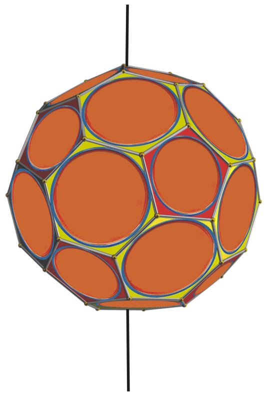

Figure 11: Sketch of a potentially developable spherical Doppler current meter in a 'bucky ball configuration', having 32 'eyes' (orange circles). Using sound, this current meter would be able to measure currents, not as usual along 1, but along 60 lines, and would therefore be able to measure currents in a spherical domain.

study cold water corals. Cold water corals are anemones, polyps that live at great depth in cold, dark water at the bottom. These catch food from their environment and eventually turn it into calcite. Their dependence on fresh plankton from the surface suggests the existence of a kind of 'food highway' between surface and bottom, a highway which the internal wave beam might be a candidate for.

This brings me to the second point: to detect these wave beams and this transport in the sea our instruments are insufficient. We need new measurement equipment, able to resolve phenomena with relatively small scales of 1 - 1000 m, not only along a line. Therefore we want to develop a spherical version of the previously introduced Doppler current meter; one with 'eyes' that look into *all* directions, so that the three-dimensional velocity can be determined in a *volume*, rather than along a line segment. Advantage of such a spherical current meter is that the accuracy of these current measurements can be improved because they need to satisfy a number of constraints. For instance, because there can be no net flow of water through any particular spherical shell.

Another point of research, closer to home, is the question whether internal waves might play a role in the exchange of sediments between North Sea and Wadden Sea? The accompanying photo, taken by my wife Cathy from the TESO-ferry between Den Helder and Texel, shows a stripe pattern in Marsdiep inlet that is remarkably similar to that which is characteristic for a particular kind of internal waves, solitons, the solitary waves that we encountered before. This photo is taken in windless conditions during slack tide. Whether these stripes are really due to solitons is presently investigated by a student using dedicated measurements in Marsdiep inlet.

As mentioned, the abyss is unknown territory partly because it is hard to obtain an image by use of light or sound. Actually, for this imaging it is more logical to employ those waves that the stratified ocean *does* sup-

Figure 12: Surface stripes visualize subsurface waves.

port: the internal waves themselves. In other words: can we perhaps use these strange, obliquely propagating internal waves to build an image of ocean shape and stratification? Can we 'see' with internal waves? This is a fascinating but difficult problem. For light waves, for instance, different frequencies correspond to different colors. But when internal waves differ in frequency they propagate under a different inclination with the vertical. So, what kind of image does this supply? This is one of the theoretical questions that may in the future perhaps throw a different light on the ocean!

Word of thanks
I would now like to say a word of thanks to a number of institutions and persons. First, I thank the board of the NIOZ Royal Netherlands Institute for Sea Research, for installing this chair. Also, I thank the board of the department of Physics and Astronomy of the Bèta faculty of Utrecht University for supporting this initiative. I thank IMAU, the Institute for Marine and Atmospheric sciences Utrecht where the chair has received hospitality, and especially my oceanography colleagues: Will de Ruijter, Henk Dijkstra en Huib de Swart.

For my scientific training I am much obliged to my former PhD supervisor and present colleague, Sjef Zimmerman. He taught me how to reduce problems to their essence, without however throwing out the baby with the bath-water. GertJan van Heijst, of the Technical University Eindhoven, with whom I briefly shared an office during my graduate studies at IMAU, inspired me not to live just in a Platonic world, a world that I have for myself sometimes called *Phantasia*, but to test model results against reality, no matter how simple reality may look like in an experiment. I thank Arjen Doelman, of the Centre for Mathematics and Informatics and of the University of Amsterdam for the pleasant collaboration in supervising two PhD students. His straightforward attitude in addressing not only mathematical problems but also those of society, is catching. I am grateful to my NIOZ

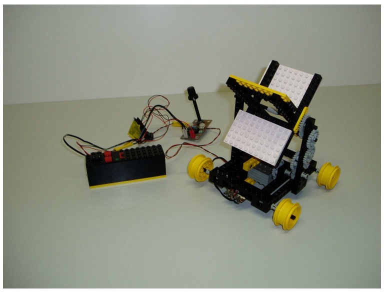

Figure 13: LEGO carriage with paddle wheel.

oceanography colleagues, Hans van Haren, Theo Gerkema and Hendrik van Aken and many MSc, PhD students and post-docs for their unrestrained efforts in our collaboration to clarify the importance of internal waves. I am grateful to my other NIOZ colleagues for their enthusiasm to search for lateral connections between our disciplines. Also I am grateful to all assistants and support departments at NIOZ for their excellent support to experimental and observational research. Working with you has always been very stimulating.

It should be clear to you now that Oceanography is sometimes a bit of a family enterprise, in my case at least. It is therefore with special pleasure that I want to express my gratitude:

- to my parents, for their loving care. It is a pity that my father is no longer here. I am sure that he, as an ex-mariner, would have loved to hear about subsurface waves;

- to Cathy, with whom I celebrate life, and whose cheerfulness and matter-of-fact-ness kept me from getting lost in *Phantasia*;

- and to our children, Suzanne, Ruben and David, who always patiently helped me building yet another *LEGO* model, even if this was no longer quite suitable with regards to age. That is, ... their age!

Finally

In closing, can I give you perhaps some practical advice about the topic of my chair: 'wave dynamics of the ocean'? Well, I told you that the sea can be stratified. Several of you will have swam in open water and can confirm based on their own experience that surface and deeper water can sometimes differ in temperature considerably. In view of the retarding effect that this stratification may have on ships, it is obvious to ask whether swimmers may suffer from dead-water too? Experiments, carried out with Huub Toussaint of the Free University of Amsterdam, and two of his students, have shown that there are indeed indications for this. However, swimming with 'tentacles', as hands and feet is of course quite different from propulsion

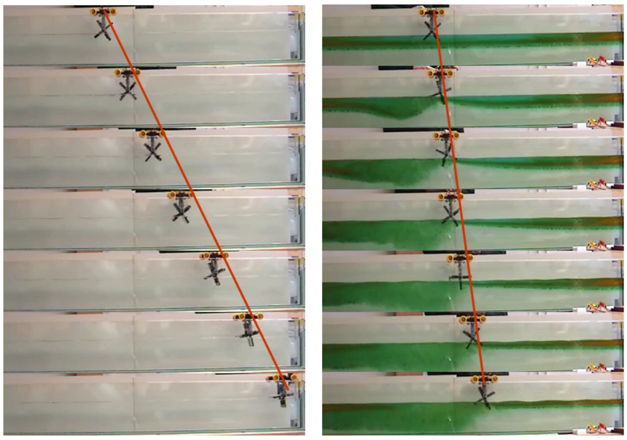

Figure 14: Six successive photos of two identical experiments without (left) and with salt stratification (right) through which a carriage pulls itself forward. The paddle wheel turns at the same angular speed.

by sail or engine. For this reason, together with some students I made a carriage that can roll along the edge of a tank which simulates hand motion by dragging itself forward, employing a paddle wheel. The experiment shows a remarkable difference between paddling in homogeneous and stratified water. Therefore, next time when you swim at sea and you sense such a temperature difference and notice that you go slower, perhaps this aspect of the sea at least may appear less obscure to you...

I thank you all for your presence and attention.

I have said.

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Colofon
Photo on front and back page by Maggy Nugues,
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Leo Maas was born on January 11, 1956 in Dordrecht, the Netherlands. Following a Master study in physics at Utrecht university, focused on physical oceanography, he graduated there in 1987 on a thesis entitled *tide-topography interactions in stratified shelf seas*. For two years he was appointed as a postdoc at NIOZ, where he subsequently obtained a tenured position. In 1992-1993 he has served a one year term as visiting professor at the University of Victoria, Canada. Apart from an interest in surface and internal waves his attention centers on the development of simple conceptual models of oceanographic processes and the testing thereof in laboratory and seagoing experiments.