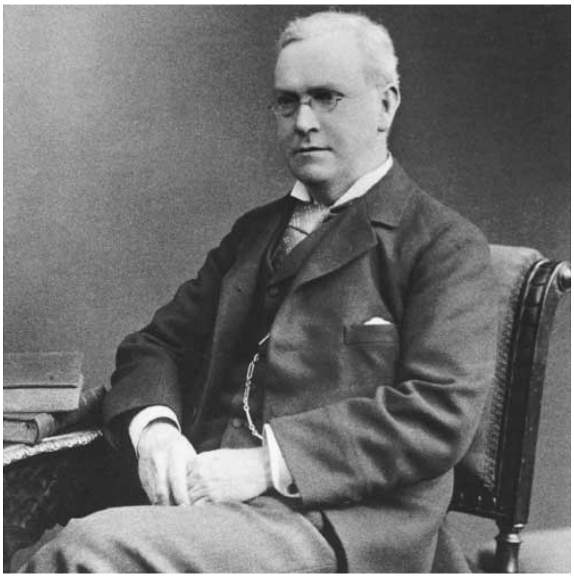
Between the Devil and the Deep Blue Sea… Lie the Details

Craig Stevens

"I am an old man now, and when I die and go to Heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics and the other is the turbulent motion of fluids. And about the former I am rather more optimistic." So said Sir Horace Lamb, the writer of one of the foundation texts[1] on fluid mechanics - the behaviour, dynamics and transport of air, water, magma and other fluids. Of course I didn't think about this too much in the mid-1980's sitting in the sweltering Horace Lamb lecture theatre at the University of Adelaide in nylon football shorts and black tee-shirt with some band's name on it, wondering where the girls were at. I've thought about it since though. If enlightenment can be said to include measuring turbulence in the real world, then I've come to think about it a great deal.



*Horace Lamb 1911 (*http://www.lms.ac.uk/newsletter/320/320_12.html*)*

Such thoughts are not confined to the heavens alone. The Berkeley Professor Hugo Fisher stated in his text on aquatic turbulent mixing[2] that "turbulence was a lot like pornography, difficult to define but you know it when you see it". Fisher elsewhere equated estuaries to pornography so I don't quite know what was going on there. But the heart of the matter is clear - one person's noise is another's signal. It's not so much about perception as active filtering. One deliberately seeks a viewpoint so as to gain ground in understanding, the cost being that which was lost in the interaction with the filtered material. There is much to be gained from understanding the different perspectives and approaches in order to make sense of the entire picture.

We inhabit a fluid world – atmosphere, oceans, magma. But this fluid world is no simple treacle. Instead it is a world filled with overturns, bursts, whorls, eddies and vortices. This complexity leads transport of things we require – oxygen in our blood, nutrients in our oceans, climate-controlling gases in our atmosphere and so forth. If it were left to the vibration of molecules to drive all this we'd have a very different world. Spatial scales would shrink and timescales would stretch out just so things could happen. But it doesn't, instead turbulence is King. At sea for example, the world beneath is roiling in a silent, internal and incompressible way. Giant underwater waves as high as Niagara Falls march across oceans, breaking, mixing and transforming as they go. Slow motion submarine rivers plunge in waterfalls down seabed ridges. Continents made entirely of ice come and go with the seasons. A slow rain of carbon from the upper ocean to depth plays a leading hand in the outcome of our species' present climate experiment. All these processes drive and are driven by turbulence.

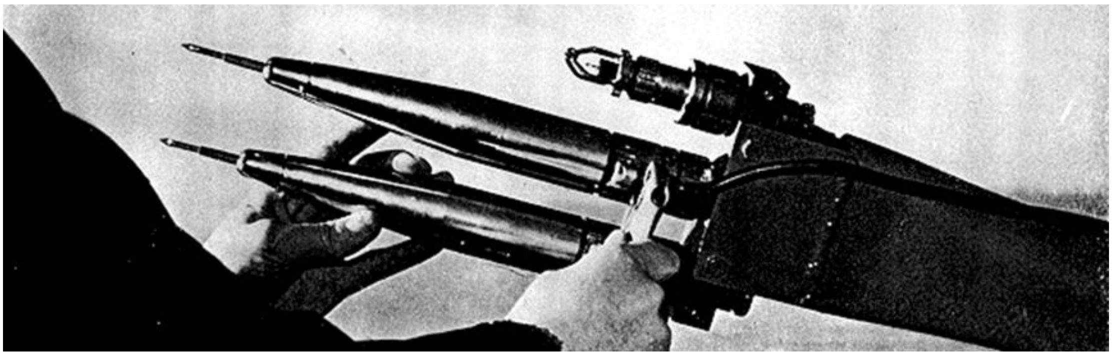
Turbulent eddies on Jupiter (NASA)

Around the time of Horace Lamb's plea, a Soviet, Andrei Kolmogorov, laid the foundation stone for a peaceful internment. He published a paper[3] that described the smallest scales of turbulence and predicted their behaviour using a model that related the difference in velocities at two points to the separation scale between the points. And furthermore, that the smallest scales of turbulent motion - what we now call the Kolmogorov microscales – can be related to the rate at which energy is dissipated by a turbulent fluid as all the swirling eddies rub against one another. The inherent stickiness in the fluid turns the smallest eddies into heat. This is the theoretician's view of how energy first injected into the earth from celestial drivers - mostly by solar heating and the moon's gravitational attraction - ends up being absorbed in fluid variations perhaps a millimetre across.

At Cambridge University, on the other side of what was to become an iron curtain and roughly contemporary to Kolmogorov, G.I. Taylor was developing ideas on turbulent mixing and its role in dispersing material in oceans and atmospheres[4]. To read what people like Kolmogorov and Taylor were developing, in their spare time when they weren't working on turbulence, is beyond belief. It turns out to be just one area of their individual contributions to our collective knowledge of all things. As examples Kolmogorov developed ideas fundamental to describing any random process whilst Taylor invented an anchor that's in common use today.

As someone bound by the stricture of direct observation, the forward thinking and power of something that has emanated purely from the mind astounds me. Maybe in hindsight Taylor and Kolmogorov had it easy, in that now we dogmatically try and squeeze results into the framework described in an almost total absence of direct evidence. Of course they didn't have it easy – this is the whole point of genius – they make those astounding leaps upon which we can build but which seem reasonably plainly given afterwards.

But someone has to turn imagination into reality. In the early 1950s a pair of Canadians, R.W. Stewart and H.L. Grant, recently returned from Taylor's group in Cambridge, were seeking to capture the signatures of cold war submarines - effectively underwater vapour trails[3]. Instead, as is the way with science, they created a foundation for the tools to capture turbulent energy transformation in the ocean. Essentially they were trying to prove Kolmogorov's theories through design of underwater record needles mounted onto old torpedo bodies and then towing them through highly turbulent water flows[5]. With this you could measure the variance in a number of properties and relate these back to the driving forces. This was the birth of our ability to measure environmental turbulence in the ocean.

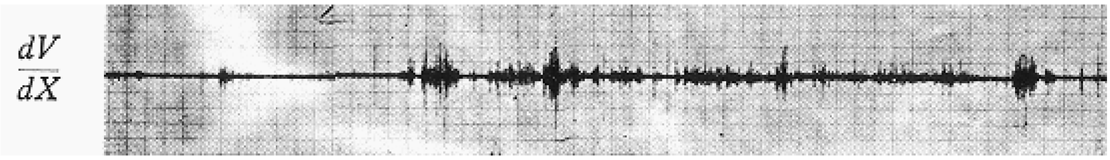


JFM 1962

There's a striking photograph in one of Stewart and Grant's key papers[5] showing their instrument sensor probe being prepared for deployment. Thinking past the phallic imagery, it's inspiring in so many ways. The instrument makes a perfect diagonal in steely black and white, the ruthless beauty of technology, but aimed against an enemy of totally unknown strength and resilience. An operator's arm provides scale, but the jacket cuff is all frayed – there's no unnecessary expenditure here. Best of all, he's holding an adjustable spanner, an Englander. Amongst all this precision, time and effort is the greatest hack-tool of all.

If you take the modern microstructure profiler, the equivalent to Stewart and Grant's torpedo sensor and drop it through the ocean, say in the highly turbulent waters of the tiny oceanic fissure between the Tasman Sea and the Pacific Ocean we call Cook Strait[6], you can measure instantaneous versions of the properties proposed by Kolmogorov. But if you repeat the procedure, just 20 minutes later you can get significantly different results. And again and again. It's only by averaging the results that meaning emerges from individual viewpoints. The events being captured are true ephemera. It is only when the ephemera are compiled and summarized that some meaning emerges. It's like producing an encyclopaedia from millions of trivial, forgettable events. This is the observationalist's view.

And yet, despite the importance of the synthesized encyclopaedia, with each profile an individual story is held. That's the way it was at that time and place. It was never actually like the averaged description. So you can't help but scroll through the profiles to look inside the ocean's internal workings when the sensor slices through these overturns, bursts and eddies. With a practised eye, and no one around to tell you you're wrong, you can speculate that *this wiggle was from that*, and *those steps came from there* – and *boy that was a big burst* - and so on. These are the microscales at play.



A segment of microstructure data

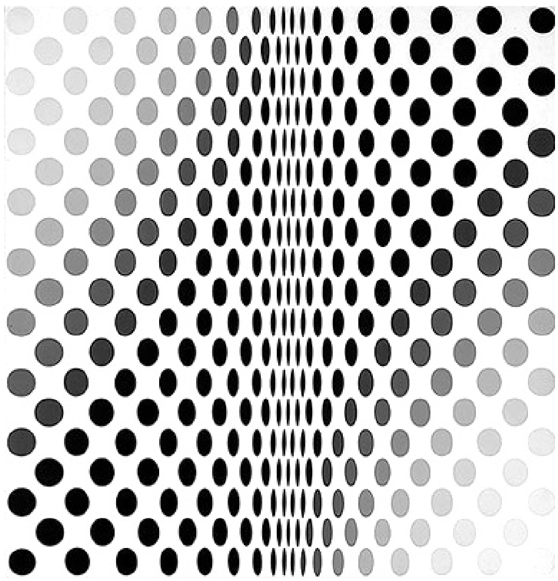
One of the great challenges of our scientific age is to build the physical implications of Kolmogorov microscales – maybe as small as a millimetre – into global climate models. Simulators that can for example predict what the future global climate might be like in five hundred years. The Japanese Earth Simulator is one such tool[7]. Filling a warehouse with computational nodes, it separates the earth and all its fluid media up into computational boxes. The boxes are typically squashed to give better detail in the vertical, so more like pizza boxes spread in layers. Each box is assigned internal processes that give life, whilst exchange coefficients control the movement of things into and out of neighbouring pizza-boxes. The exchange processes are guarded by conservation laws – rules that make sure no more energy or material is added or removed from the system than is proper. Then, the earth's future worlds are tested. With ever-larger computers, the modeller has a hitherto unheralded viewpoint where they can play god.

The smallest swirls of motion

The catch is that necessarily this has to be a god who doesn't think too much about the detail. From the perspective of a ship at sea, where your horizon is closer than the edges of the computer model pizza box, the suite of equations describing all these internal processes suddenly seems flimsy against the weight of variability. And while the Kolmogorov microscales might be small – in fact they actually get smaller with higher energy flows – the bursts of variability that generate them can be much larger, perhaps tens of metres in scale. However, while dwarfing the microscales, something ten metres in size in the ocean becomes the tiniest pin-point at a global scale built from 10 km-wide pizza boxes.

To use a contextually unfortunate analogy, there are many coal-faces for this science. The coal-face of the mind must somehow intersect with the coal-face of capturing such processes in the real world. Einstein said "no amount of experimentation can ever prove me right; a single experiment can prove me wrong." This is all very well in the rarefied world of controlled laboratory experimentation, but when sampling the environment with its myriad interactions and non-linearities, a huge number of experiments are required before any systematic picture can emerge. Many argue that we've not even sampled enough of the ocean to fully understand its range of possibilities let alone its systematic process behaviour.

It is relatively easy to fix yourself in one of these frames of understanding: observation, analytic structure and model synthesist. But tangible advance requires that all three come together. Finding a way to see the same thing with these three minds' eyes has some parallels with visual art. The discreet nature of Bridget Riley's op-art[8], contemporary with the efforts of Stewart and Grant and their Englanders and frayed jackets, holds structure and variability by using only a few different scales. A series of dots could be complemented with a slow gradation in greyness or colour. Whilst simple in elemental structure, the optical clashes are such that it can actually hurt to look at the images as shapes and distortions emerge from the simple structure. This is the world of the earth system modeller where they seek to reduce processes to their raw elements and then regain complexity through interaction between events.



Riley's Metamorphosis (http://art-documents.tumblr.com/post/342148540/bridget-riley-metamorphosis-1964)

But of course the real world has a continuous spectrum of colours, shapes and sizes. Seeking to extend beyond Riley's limited-scales imagery, it's straightforward to appeal to Jackson Pollock's abstracts[9] with their continuum of swirls, drips, splashes and slashes that seem to hint at a tangible reality full of detailed content but no global framework. The birth of Pollock's style emerged around the same time as Kolmogorov's keynote paper - and from the other side of a huge geopolitical wall. Separate from the underlying form of the world, this is microstructure laid bare in liquid resin paint. This world is that of basic science that seeks to understand the mechanics driving events in all its complexity. But in order to make any headway the structure is often quit idealized, symbolic and separate from its global support.

The Starry Night

Moving further back in real time but strangely closer to "reality" we require the Dutch artist Vincent van Gogh's eyes to see the swirls, iridescent boundary-layers and multiple moons of *The Starry Night*[10]. Dominated by a deep blue with swirling patterns, it has it all. The driving celestial bodies are there, albeit in the form of multiple moons. The boundary-layers where fluid rubs up against solid ground are plain to see. Organisms exist, trees and bushes cross these boundary-layers while a small village of humans is cradled within this fluid world. Best of all though are the swirling vortices of fluid motion. It might seem a little surreal but this merges basic mechanics with the key elements of our earth system – just a little more so. The swirls have been compared to all sorts of esoterica but plainly they are nothing more or less than Kelvin-Helmholtz instabilities. These instabilities may appear a mouthful, but they are a fundamental process in the speed-up of transport in fluids beyond molecular transport timescales. One layer of fluid flows past another until a certain balance is reached, at which point the layers roll up, intertwine and then explode in a myriad of mixing events. The result being conditions for life as we know it.

Van Gogh's *The Starry Night* was painted between Horace Lamb's tenure in Adelaide and the publication of his monumental text *Hydrodynamics*[1]. This is astounding in opposing ways. First, van Gogh is old-school art yet it's contemporary with the birth of proper fluid mechanics. Second, how can something so fantastical as *The Starry Night* be so old? If we've only been going for a few scientific generations on turbulence maybe there is hope after all. The plea for a restful confinement fully cognisant of the intricacies of turbulent motion has been attributed to Heisenberg, Einstein and a couple of others along the way - as well as Horace Lamb. While van Gogh's innate understanding of turbulence didn't appear to bring him happiness during his life, it's nice to think that perhaps it did so in some afterlife.

Bibliography

[1] Lamb, H. 1994. *Hydrodynamics*, 6th Edition, Cambridge University Press, Cambridge, U.K. pp. 768.

[2] Fisher, H.B., E.J. List, R.C.Y. Koh, J. Imberger and N.H. Brooks, 1979. *Mixing in Inland* and Coastal Waters, Academic Press, New York.

[3] Stewart, R.W. and C. Garrett. 2004. Kolmogorov, turbulence and British Columbia. *π in the Sky*, 8, 32-34.

[4] Taylor, G.I., 1958-1971. *Scientific papers*. Edited by G.K. Batchelor,Cambridge University Press.

[5] Grant, H.L., R.W. Stewart, and A. Molliet, 1962. Turbulence spectra from a tidal channel. Journal of Fluid Mechanics,.12, 241-268.

[6] Stevens, C; and M. Smith, 2009. Cook Strait: The Nexus in New Zealand's Coastal Oceanography, Proceedings of the Australasian Coasts and Ports Conference, Wellington, New Zealand.

[7] Jamstec, 2008. Annual Report of the Earth Simulator Centre. www.jamstec.go.jp/esc/publication/annual/annual2008/index.html

[8] Moorhouse, P. 2003. *Bridget Riley*, Tate Publishing, U.K. pp. 244.

[9] Pollock, J. 1952. *Blue Poles (number 11, 1952)*, National Gallery of Australia, www.nga.gov.au/International/Catalogue/Detail.cfm?IRN=36334&MnuID=2&GalID=1.

[10] Van Gogh, V. 1889. *The Starry Night*, Museum of Modern Art, New York. www.moma.org/collection/object.php?object_id=79802

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