NZIMAges
ISSUE EIGHT

N Z I M A • I M A G E S • M A Y • 2 0 1 0

Predicting hydrothermal eruptions

NZIMA scholar and Massey University PhD student Luke Fullard is developing new mathematical models to explore how hydrothermal eruptions can be better predicted. By Jenny Rankine.

Rotorua residents may be familiar with hydrothermal eruptions, as they happen reasonably regularly in the Taupo volcanic zone. These eruptions have occurred in Kuirau Park for more than 100 years, and caused many of its craters. The eruption in 2001 was big enough to shower mud and hot water over the roof of nearby Rotorua Hospital.

Unlike geysers, hydrothermal eruptions occur with little or no warning. They can throw large amounts of water, steam and mud high into the atmosphere, suddenly and fast. They are believed to be triggered by a catastrophic drop in the pressure of geothermal water close to the earth's surface, causing it to boil, lift the ground and form an eruption jet.

Luke Fullard's honours year project developed existing partial differential equations of underground fluid flow for these eruptions from a single vertical dimension to two dimensions.

For his PhD he is focussing on how these eruptions are initiated, and uniting previously separate eruption models for geothermal fluid underground and ejected material above.

"I am using a 'shock-tube' model to see what happens when the high-pressure water is exposed to the lower pressure atmosphere."

"Numerical schemes used to solve these equations used finite difference methods, but they don't work when you have discontinuous data. Usually you have a smooth pressure curve, but we had a big jump in pressure. So we used finite volume methods, which can deal with discontinuities."

Fullard developed a finite volume method for three-phase flows to take account of the actions of water, steam and air in a fractured porous medium.

Each step using the finite volume solver had to tack gravity on at the end. In the steady state case, the two almost exactly cancelled each other but with a slight error, "which is a problem if you're simulating over a long time".

He modified the three middle wave speeds out of the nine speeds in these equations to exactly cancel gravity out to zero. Now he is able to code his data into the maths computer program Matlab.

He will also explore the effect of water in surrounding fields on the eruption, by playing with a "toy problem of pumping water out of a well". He hopes to figure out what initial conditions make these eruptions more likely.

"For example, is there an increased risk if the porosity of the rocks is higher than x, or when a body of water is a certain distance from the surface?"

Fullard's supervisor Tammy Lynch built the first laboratory model of a hydrothermal eruption and used nuclear magnetic resonance techniques to visualise the progression of a boiling front in a porous medium.

Main image: The result of a hydrothermal eruption in Rotorua. Photo courtesy GeoNet, www.geonet.org.nz/

Welcome

Welcome to our eighth issue of NZIMAges, which contains articles on randomness and coincidence, statistics, hydrothermal eruptions, genetic trees, Maori and Pasifika education as well as a project that is crocheting a coral reef using principles of hyperbolic geometry. We hope you enjoy reading it.

Marston Conder and Vaughan Jones
Co-Directors

INSIDE

New Zealand Institute of Mathematics & its Applications

Keepers of the flame

"If you're bored in statistics it's your fault," says NZIMA Maclaurin Fellow Professor David Brillinger; "there are so many wonderful problems out there to work on." He talked with Jenny Rankine.

He uses 250-year-old Newtonian mechanics to analyse trajectories, curves of object movement that are a common type of data. He calls his field random process data analysis: "random means probability is attached; process means evolving in space and time. I enjoy taking that maths and applying it to a soccer ball on the field, whale sharks across the ocean, elk in Oregon. I have a lot of fun interacting with scientists in the field."

Brillinger, who is Canadian, has maintained New Zealand connections from his first visit in 1976 to work on earthquake risk, a field where "New Zealand has some very good statisticians". His son lived here for a time and he visited his grandchildren regularly. One of his Berkeley students, Ross Ihaka, returned to New Zealand and developed the statistical analysis package R*, and Brillinger says he tends "to look after Kiwi students I encounter visiting Berkeley".

He started his work on animal movement, using data from marine biologists about how much time elephant seals spent diving, how deep, and where they swam. From this he developed models of seal movements, and helped deduce how they might be navigating.

Then he moved up to whale sharks, also tagged with GPS units. Like whales, these sharks eat phytoplankton, tiny algae. Brillinger compared shark movements with data on winds, currents, and chlorophyll density to associate their travel with algal blooms and strong currents.

His next project was a space analysis for NASA, which wanted a review of their estimates about the risk of debris damaging the international space station and the space shuttle. Astronomers had used radar to scan the sky and provide data on the size distributions of debris orbiting the earth. Brillinger's results were used to design the space station shields to withstand most predicted impacts.

"We have to make approximations because we don't get exact results very often; I'm concerned about how good these approximations are in practice. For example, a whale shark will be swimming continuously but we will only have data every three hours."

"The sort of statistics I do means I can look at something in one field, abstract it and apply it to other fields. Those space station results can be used with trajectories of other objects. Statisticians are often the ones who transfer information from one field to another," he says; "something learnt from biology might be passed onto engineering."

"Statisticians are the keepers of the scientific method," Brillinger asserts. "We say whether the scientists can reasonably draw that conclusion from the data they have. We do both exploratory and confirmatory data analysis, so we lose very few arguments. Scientists have to make assumptions, but we ask why should we believe that assumption? We also have to teach our students how to respond to that criticism of their work!"

* See IMAges 3.

Top: Elephant seals such as this male, female and pup have been tagged and their migration tracked across the Pacific. Brillinger's analyses have helped pinpoint how they and other animals navigate and behave at sea. Photo: Mila Zinkova, Wikimedia Commons.

MATHEMATICAL EVENTS

29 June - 1 July, Massey University, Palmerston North
NZSA 2010 Conference and International Conference on Statistical Methodologies and Related Topics
http://nzsa_cdl_2010.massey.ac.nz/

29-30 November, Auckland
Annual Conference of the Operations Research Society of NZ
www.orsnz.org.nz/#conference

6-9 December, University of Otago, Dunedin
Annual NZ Mathematics Colloquium
Details in next issue.

9-14 January 2011, Raglan
Annual NZMRI/NZIMA Summer Meeting; theme: Dynamical Systems
www.math.canterbury.ac.nz/NZMRI2011/

ISSN: 1177-4819

Design:
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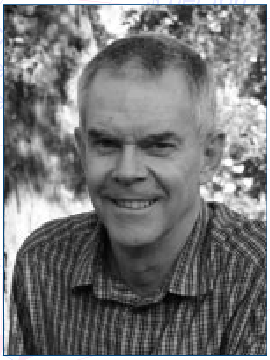
Counting on power



Unitec Civil Engineering Associate Professor Jonathan Leaver is predicting that New Zealand's future vehicle fleet will be a mix of battery electric and hydrogen fuel cell vehicles. Jenny Rankine reports.

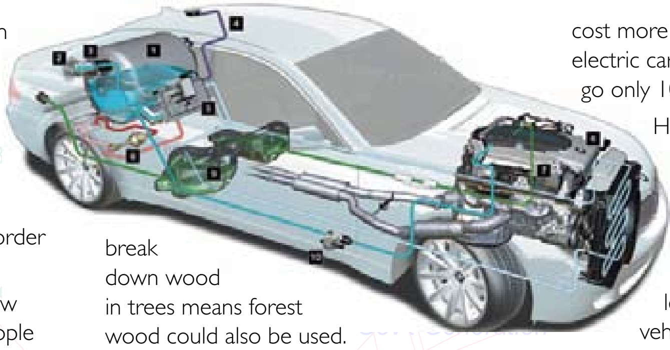
With Andrew Baglino, and Kenneth Gillingham of Stanford University in the USA, Leaver has developed an original integrated computer model of New Zealand's energy economy. It includes 1,200 variables and 7,500 lines of computer code, using algebra, statistics and first order differential equations.

It even includes an algorithm about how these vehicles will be perceived by people walking into the sales yard, who take into account price, servicing, running costs and other factors. The model can assess which of the energy technologies available in the next 40 years are the most likely to be adopted given a range of oil prices and carbon taxes.

He presented the model at a 2009 workshop in the NZIMA Energy Wind and Water programme.

The battle between alternative energy technologies is hotting up. Hydrogen, when used in a special battery called a fuel cell, produces electricity and releases only water and heat. Cars running on hydrogen fuel cells will eventually be only 10 percent more expensive than current models, with cheaper fuel costs. However, they would need a whole new distribution system.

Ethanol is harder to make, but can be produced from anything organic; sweetcorn is most common. Research into enzymes to break down wood in trees means forest wood could also be used.



Ethanol uses a lot of heat and raw materials to produce and is more polluting than hydrogen produced using electricity from wind turbines. For example, we would need 2.5 times our current forest harvest to run our vehicle fleet only on biofuel from our forests; up to two-thirds of this new land would come from existing pasture.

Electric cars powered by batteries will require an extensive upgrade to the electricity distribution system to homes to cope with everyone plugging their cars in overnight. Also, battery electric cars that match the range of current cars would cost more than twice as much. Short range electric cars would cost about the same but go only 100 kilometres between charges.

Hybrid vehicles that combine small petrol engines with batteries or fuel cells are a compromise between cost and range. Whatever the technology, Leaver predicts that petrol will power less than half of all New Zealand vehicles in 30 years.

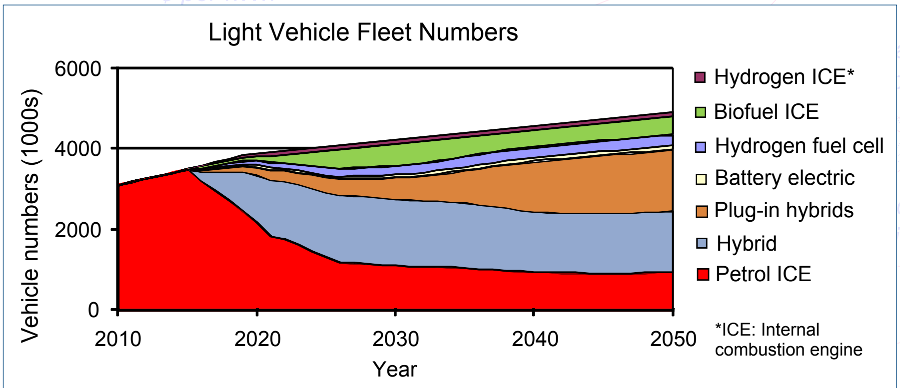
"It's a big call for the government; we need billions of dollars of infrastructure to support one of those technologies," says Leaver. Vehicle manufacturers are going with full or hybrid battery electric vehicles, but Leaver believes consumers will resist full battery electric vehicles, especially the 50 percent living in rural areas, because of their range limitations, capital cost and time they take to charge.

Leaver has also profiled likely electricity generation, air and water pollution costs and greenhouse gas emissions to 2050. "They're looking pretty good; we have massive potential for wind generation, more than three times the total electricity we generate at the moment."

Leaver will also examine a new way of burning coal in a special way to generate hydrogen; the resulting carbon dioxide could fill old gas fields and not add to global warming.

See also: www2.esc.auckland.ac.nz/EnergyWindWater/Presentations/Presentation%2008%20Jonathan%20Leaver.pdf

http://en.wikipedia.org/wiki/BMW_Hydrogen_7



Above: The limited production BMW Hydrogen 7 is powered by a 6-litre internal combustion engine that burns hydrogen and petrol. BMW claims the vehicle will reach 230 kilometres per hour.

Left: The graph shows one potential scenario from the model for our light vehicle fleet.

Background: A diagram of carbon emission variables from Leaver's UNISYD model.