Re-setting science and innovation for the next 20 years

Environmental prediction and innovation

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Using weather-related hazards research as a starting point, this paper shows how a research effort focused on natural hazards prediction has developed a capability (EcoConnect) that is now demonstrating benefits far beyond its primary focus. In this regard EcoConnect meets one of the generally accepted definitions of innovation: 'the successful exploitation of creative ideas within an organisation'. EcoConnect is built on the creative capabilities of a multi-disciplinary team of scientists and ICT specialists and has adopted a partnership-based approach to working with potential end-users. In this way scientists and end-users are exposed to each other's ideas – leading to both more informed research directions, and, among end-users, a better understanding of the strategic (as well as tactical) potential of new science results. It is also noted that while an 'innovation system' is only as good as the quality and quantity of research and technology that underpins it, funding that alone is not sufficient. Investors must be willing to sustain the effort (from basic research to end-user engagement – including iterative innovations arising therefrom) over a long period – especially if the innovation is likely to be disruptive to existing technologies/capabilities.

Introduction

Ongoing innovation is considered important for both economic and social prosperity. Coming to grips with what the term means, and therefore how trends in innovation may be measured is less clear. From the macro-economic point of view policy makers often infer that innovation is related to the size of R&D investment, and/or the rate at which patents are granted, and/or measures of commercialisation success (e.g. MoRST 2008; Little 2010; Hendy & Sissons 2010). An underlying assumption in such approaches is that innovation is a linear process of investment in R&D leading to commercialisation (and innovation?) by farsighted management in industry (DIUS 2008). However, this scenario is at best only a special case. For innovation to occur, a much wider set of actors will generally be involved (e.g. scientists, engineers, end-users, ICT professionals, marketers, etc.) (e.g. Hughs 2007; Hauser 2010).

The following definitions of 'science' and 'innovation' will be used. Science (or research) is what we do to generate new knowledge – both fundamental and applied, while innovation is the successful exploitation of creative ideas within an organisation (Amabile *et al*. 1996) (as distinct from 'innovative-science' which is just an aspect of 'science'). In this definition, an 'organisation' is a quite general concept – it generally refers to an external end-user, but it could also include another scientific research activity. Innovation is not the same as invention.

The hypothesis this paper presents is that innovation 'happens' when all of the following are present:

- Creative individuals and multi-disciplinary teams are set free to work together on problems of shared interest.
- New capabilities result that span multiple (end-user) sectors leading to new opportunities and spill over benefits.
- The important role of relationships between the scientists involved and end-users is recognised.
- Investing institutions understand that technical and commercial risk must be accommodated (i.e. funded) – perhaps for long periods.
- There is an acceptance that, while failure is unwelcome, it is a possible outcome.

The last two points are important since, while the risk of failure is present in part because of technical risk (not all good ideas will succeed), other important impediments to success include resistance from incumbents, or, if the innovation brings an unexpected new capability to some sector in a market that is normally price-dominated, that market may be too slow to embrace the advantages of the innovation in its widest (i.e. strategic) context. This paper outlines an example of innovation in the environmental sciences.

Weather-related hazards research

High-impact weather is the primary driver for many of the extreme hazards that confront New Zealand's infrastructure, communities, and the natural and built environments. These include river-flood, coastal inundation, marine waves, rain-induced landslide, snow avalanche, tornados, hail, and wildfire

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as well as more direct effects – high winds, heavy rain, snow, fog, and low or high temperatures. The potential to mitigate the impacts of many of these hazards lies in an ability to both establish climatologies of the hazards, and accurately forecast their occurrence at lead times that permit adaptive mitigation strategies to be employed. The first of these is a necessary input to the design of infrastructure, etc., while the second is focused on what individuals, organisations, and communities can do in advance of anticipated events that may breach engineered containment solutions, or affect operations (e.g. stopbank exceedence, rail buckling, wildfire, etc.).

Weather-related hazards research is an aspect of environmental science, and is one of the 'grand challenge' problems facing mankind – made even more pressing by the prospect of climate change. It employs probably the most sophisticated and complex scientific numerical (i.e. computer) simulation codes existing today, and requires the use of the most powerful supercomputers available. Through observations of the ocean, land, and atmosphere this research effort is leading to an improving understanding of the physical processes that shape the environment, which in turn is being used to inform the development of simulation models and ultimately to forecasting systems that can predict its future state. In more detail, the laws of physics provide the framework in which the observations and underlying physical processes can be understood and formulated into mathematical equations that, when solved on supercomputers, simulate the temporal and spatial evolution of the system. By combining (real-time) data from observational networks with these numerical models it is possible to forecast the future state of the environment with a high level of confidence.

The fundamental research effort underpinning weather-related hazards research is multi-disciplinary, covering a wide range of research fields including, for example, atmospheric radiative transfer modelling, mathematics, the physics of fluid motion, heat and phase transitions, hydrology, soil science, geography, complex systems, satellite sensors, observing networks, data analysis, and numerical algorithms, as well as scientific software development, optimisation and supercomputing. To place this multi-disciplinary aspect in the context of a societal outcome, for example, flood forecasting for a location adjacent to the coast (many communities in New Zealand lie adjacent to river mouths – e.g. Lower Hutt), the key research milestones to this goal include:

1. A weather prediction model that can both simulate all of the key physical processes that govern the temporal evolution of weather systems over New Zealand's complex terrain. This model must resolve significant catchments, and be able to provide accurate forecasts of the physical drivers of a hydrological model, including the onset, duration, spatial distribution and intensity of precipitation (including snow), along with simultaneous predictions of surface temperature, relative humidity and winds.
2. A sea-level model that can forecast the sea-level boundary at the river mouth. Changes to sea level can aid or restrict river flows, and hence have an impact on the flood forecast. The sea-level model includes: a tide model (which is solely dependent on date, location, and time) and storm-surge model (which is dependent on wind and surface pressure forecasts, from 1) and a wave forecast model that also depends on wind forecasts from 1.
3. A hydrological model that, given the weather and discharge forecast forcing data indicated in 1 and 2 and real-time measures of river flow, can physically simulate the flow of water (including sub-surface flows) in each sub-catchment within a basin, route run-off into the streams within the catchment, and forecast river flows both within the basin and at its outlet.
4. An inundation model that, given the forecast flood hydrograph (from 3), together with the detailed features of the flood plain (from elevation to obstructions thereon) and of the evolving river channel, is able to forecast water depths and velocities when the river is outside its channel.
5. Support end-user decision (warning) processes by providing them access to the numerical forecast guidance (and associated observations) resulting from the forecasts at each of the steps above.

In most international settings, achieving such a diverse set of research milestones would require coordination across a number of independent organisations with attendant high overhead costs. For example, the development and operation of a storm surge forecasting system (just one of the models noted above) in the UK includes contributions from six separate entities. However, following the establishment of sector-oriented Crown Research Institutes in New Zealand (i.e. vertically integrated with respect to capabilities), the range of skills required to achieve sector-outcomes that are critically dependent on multi-disciplinary science and technical skills are more likely to lie within one CRI – NIWA, in this instance. In the case study reported here, minimising the impediments to collaboration through a single point of scientific leadership and the ability to assemble the best (national) team available, without regard to institutional boundaries, were critical to the success of both research and innovation components.

While deriving from research focused on weather-related hazards, environmental forecasts can provide benefits across a wide range of sectors – where knowledge of what will happen in the future has value – even when the forecast includes no hazardous events. Such forecasts have the potential to improve: the management of our renewable energy systems (wind, hydro, and marine), improve the efficiency of infrastructure operators (e.g. transport, mining, electricity grid), the management of water resources (especially those used for irrigation), agricultural and horticultural outcomes, and even the health outcomes of sufferers of chronic obstructive pulmonary disease (COPD), as well as helping managers to prepare 'today' for hazards such as flooding that will occur 'tomorrow'. This is a case where the 'whole' is potentially much larger than the sum of the parts (hazards research) – and where there are many spill-over benefits across a wide range of sectors that would not generally be associated with weather-related hazards research.

The setting in which this weather-related hazards research was (and is) carried out includes a number of the hypothesised pre-conditions needed for innovation. It is an integrated, creative, multi-disciplinary research team that is well connected internationally, ensuring that it can leverage international developments, and it has access to the necessary infrastructure (supercomputer, data networks, ICT services). This has allowed it to efficiently develop new capabilities – that are yet to be repeated elsewhere globally.

Partnership in innovation: Science and end-users

As proposed above, innovation requires that new (science) knowledge and capability be successfully exploited within an organisation (or organisations). For this to be possible – a bridge between the scientific effort (and outputs) and end-users is necessary. Where potentially disruptive innovation is anticipated, it is our suggestion that the 'distance' between end-users and the scientists involved should be minimised – so that the scientists involved can clearly hear the expressed needs of end-users, and that end-users can be encouraged to consider new opportunities (both tactical and strategic) that arise from the new scientific knowledge. This enhanced end-user understanding has the potential to further drive innovation within the end-user's value chain. The key point here is that disruptive innovations are likely to encounter resistance from multiple incumbents (e.g. it can be perceived as a threat, or may lead to a loss of control), and end-users need to be encouraged to think beyond tactical (only) cost-replacement issues. This requirement suggests that a partnership model (between science and end-users) is most likely to succeed, and militates against a linear commercialisation approach. Assuming a common vocabulary can be agreed, a trust-based partnership (or perhaps network) approach ensures that expert knowledge – both that held by scientist and that held by end-users – can be shared, which in turn can inform planning. End-user engagement is critical to innovation as proposed here. However, for this to be achievable, end-users must be able to engage with the new scientific knowledge – to allow them to put it into their context, and so begin to explore its possibilities.

Innovation in action: EcoConnect

NIWA developed EcoConnect as a platform that would allow end-users to directly engage with its leading-edge science outputs, including environmental forecasts, climate analyses (and outlooks), and real-time data. It provides a platform on which to build partnerships between end-users and science, enabling the exploitation of new science knowledge. To underpin the importance of this connection, the EcoConnect user interface was developed (from the very beginning) in collaboration with end-users through a formal design process, ensuring that key end-user requirements were captured (even if they could not be fully implemented). However, EcoConnect is more than a window (or bridge) into scientific outputs. Fundamentally, it can be thought of as three integrated components:

1. An operational forecasting and information system generating environmental information that provides numerical guidance pertaining to the past (through climate analyses), the present (real-time observations), and the future (environmental forecasts and climate outlooks). This component embodies the science advances (the new knowledge) derived from past and ongoing research effort/investment.
2. A '3-tier', ICT, product delivery system that (a) manages and stores all data products generated by the science component, (b) enables secure access to these products, and (c) a presentation layer or user interface (a web application) that allows users to display and interact with data products, including forecast-event based alerting. This '3-tier' software provides end-users with direct access to the science products generated in the first component (more than 40 000 presently) – either visually (via the presentation layer user interface), or via computer-to-computer workflow interactions, or if an alert is triggered, then via SMS or email. As a result of this structure, end-users gain immediate access to science advances as they are introduced into the operational system (i.e. component 1)
3. A 'Business Model' that supports the end-user–science partnership, by providing a structure in which scientists and end-users work together to understand opportunities and constraints, leading to the development of new derived products and services that can demonstrably meet their requirements, and their value chains – all based on the most advanced science available.

The major sub-components of the EcoConnect Forecasting and Information (science) system and its relationship to the web delivery tool are indicated in Figure 1. Here, the 'Web Application' is the '3-tier' component noted above that provides user access to the environmental products generated by the science systems. Figure 2 shows an example display of EcoConnect products – as a user would view them on their PC. More advanced user applications can ingest data products via web services in some workflow as and when they are needed.

To give a sense of the scale of collaboration involved, the scientific and technical effort involved in establishing EcoConnect so that it could be demonstrated to end-users included the efforts of: 20 multi-disciplinary science staff spread over 6 locations and 12 time zones, 5 software developers, 2 ICT staff working at the science/computer systems interface, 6 ICT support staff (to maintain 24 × 7 operations), 1 Legal Counsel,

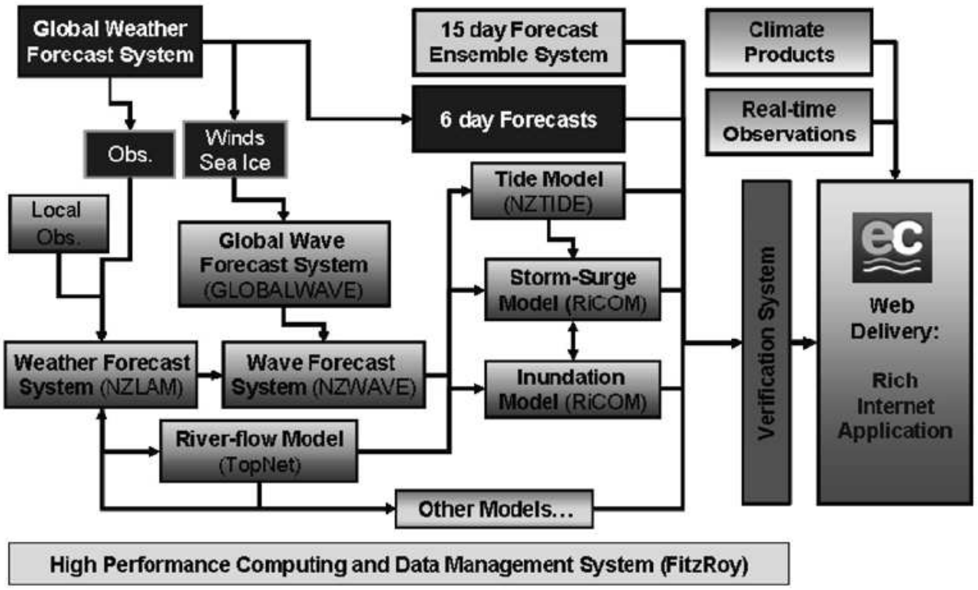

Figure 1. The EcoConnect Forecast System, showing the interactions between the major science components of the operational system – all of which are built on ICT systems that range from simple servers to a supercomputer.

and 1 business development specialist (or marketer). Other important elements were: international science collaborations which enabled access to leading edge numerical models (e.g. the Unified Model (Davies *et al.* 2005) that underpins the weather prediction system embodies thousands of man-years of scientific and technical development), eScience tools (video conferencing, issue tracking software and collaboration wiki), NIWA satellite- and ground-based observing networks, the MetService observing network, and the NIWA supercomputer and its large-data management capabilities.

While this system was initially designed to forecast and deliver information on weather-related hazards to end-users, it was also designed, from the ground up, for flexibility, with the result that, with little additional effort, National Climate Centre climate analyses, climate outlooks, and real-time observational data were later added, providing seamless access to information over a range of temporal and spatial scales, from the past, to the present, to the future. As a result of end-user interactions, EcoConnect has been further enhanced (i.e. iterative innovation) to incorporate end-user's own observational data – leading to improved forecast and data products.

Cross-sector national benefits

Weather-related hazards are ever-present; whether it is fog disrupting flights into and out of Wellington, high rainfall causing flooding that threatens a city or town, intense rainfall that leads to slope instability, or damaging waves that threaten a coastal community. However, such hazards will have benefits too. For example, high rainfall may provide fuel for a hydro dam, or end a drought, and high (but not too high) winds provide fuel for a wind farm. In addition there are quiescent intervals, too – which may lead to other hazards (e.g. drought, rail buckling, or wildfire) or provide opportunities – especially for agriculture.

The EcoConnect environmental forecasting system therefore provides valuable information to end-users both during and between high-impact weather events (and their downstream effects). Moreover, there are further possibilities, since an environmental forecasting system that is capable of making accurate forecasts of future events must be able to simulate the key physical processes that will shape those events (i.e. the right answers for the right reasons – not from compensating errors). In addition, the observations that specify the initial conditions critical to forecast accuracy and reliability must be assimilated into the forecasting models, with the result that, even if imperfect, it is likely that the gridded output from these dynamical (as opposed to statistical) models will provide the best estimate of the physical parameters that shape our environment, and hence of our surface, atmospheric and marine resources. For example:

Soil moisture: The weather prediction model (New Zealand Limited Area Model (NZLAM)) that underpins EcoConnect (weather-related hazards) forecasts (Webster *et al.* 2008) includes: a coupled land surface model (Yang *et al.* 2010) that includes processes that simulate photosynthesis, plant respiration, vegetation and soil carbon, soil thermodynamics and hydrology, canopy aerodynamic resistance, conductance and heat capacity, and surface evaporation. Given the coupled forecast winds, temperature, precipitation and radiative fluxes, the 'weather-hazards' forecast model is able to predict soil moisture and temperature at four sub-surface levels. As the accuracy of this land surface model improves, such forecasts will provide a strong basis for enabling the development of many 'downstream' products (or value propositions) that have national benefits, e.g. fire weather indices, pasture growth forecasts, irrigation schedules, optimised fertilizer applications.

Improving the efficiency of coolstore operations: The thermal inertia of coolstores mean that forecasts of temperature, relative humidity and wind speed can be used by coolstore operators to minimise their energy costs by proactively managing the energy demands required to keep temperatures within the optimal range.

Horticulture: EcoConnect environmental forecasts also have the potential to improve the efficiency of some of our significant export industries and their value chains. For example, better estimates of the dates of fruit maturation will enable more efficient planning of associated services – be they labour resources, transport operations, coolstore management, shipping or marketing.

Health services: There is good evidence that temperature forecasts can, in many cases, predict the onset of Chronic Obstructive Pulmonary Disease (COPD), which in turn can be used to manage patients at risk in advance of the onset, leading to lower rates of hospitalisation, better health outcomes for the patients, and lower costs to the health system.

These are but a few of the examples of real and potential spill-over benefits that arise from weather-related hazards research. Through its partnership-based approach with end-users, EcoConnect is enabling conversations with many sectors of the New Zealand economy, and in the process building new, and wider collaborations.

Closing thoughts

EcoConnect is enabling NIWA to both showcase its science advances in the area of environmental analysis and prediction, and to allow multi-disciplinary scientific research advances to be shared with end-users outside the hazards sector. Science products developed by this research are now being adopted by a number of sectors – so in this sense it meets the specified definition for an 'innovation' (i.e. Amabile *et al.* 1996). The development of EcoConnect has certainly involved creative individuals who have worked together to achieve something that is much larger than the sum of the parts. It is spawning new opportunities outside the natural physical hazards sector, and end-users have played, and continue to play, an important part in its development. There have been large technical risks – both scientific and ICT (e.g. the 3-tier delivery system was a significant software development, and the need for a supercomputer). NIWA has been willing to carry the commercial risk over the long term, because it understands the significant (potential) national benefits of this research. In this regard it also satisfies the wider hypothesis of what is needed for 'innovation' to occur.

EcoConnect would not have been possible without continuing significant co-investment by NIWA. The Foundation for Research Science & Technology contract that funds the basic research covers of the order of 50% of the cost of this entire effort. While an 'innovative system' is only as good as the quality and quantity of the education, research and technology that underpins it, that alone is not sufficient. Investors must be willing to carry the developmental risk while a potentially broad range of end-users come to appreciate the benefits of particular

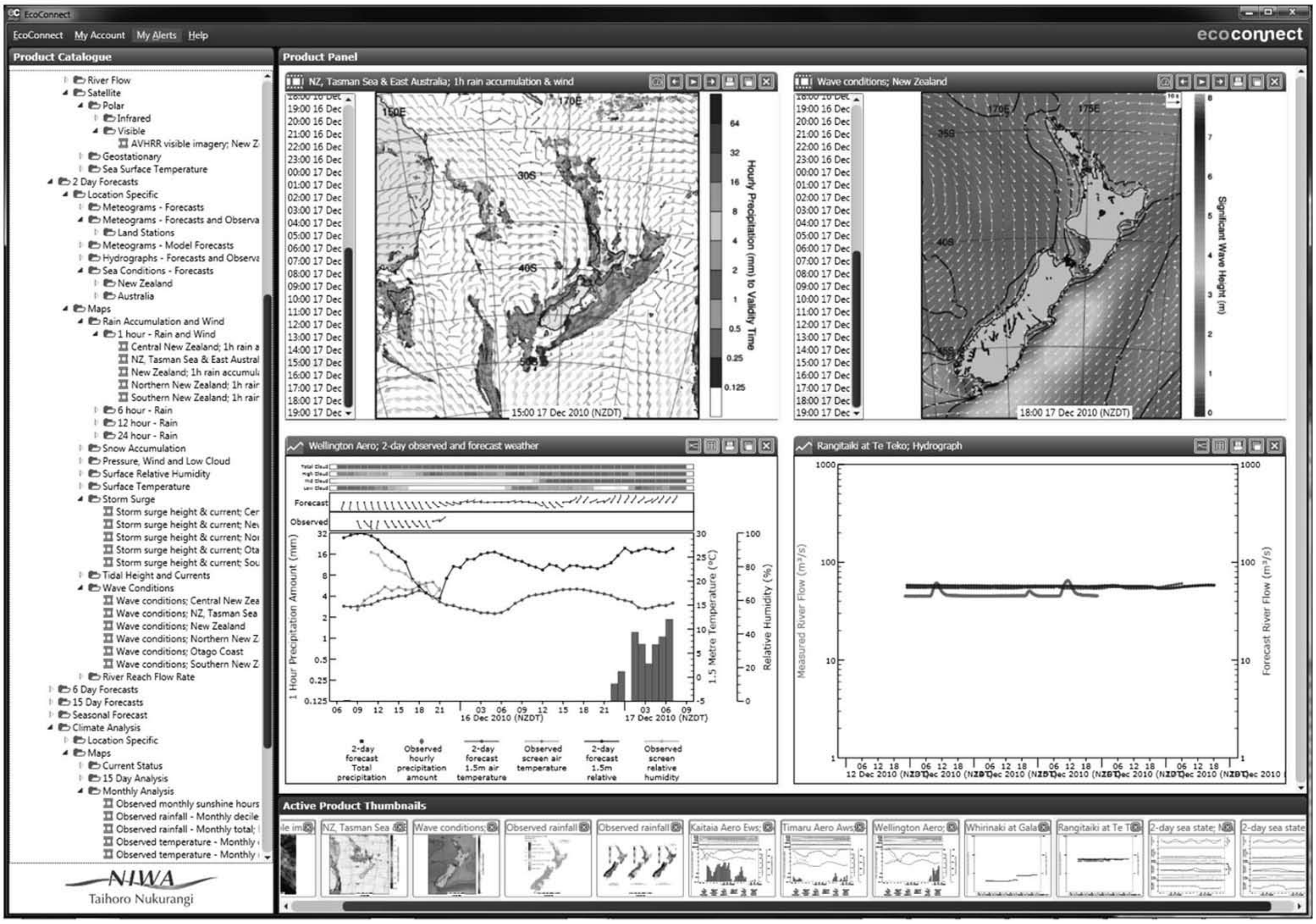

Figure 2. EcoConnect User Interface (or Presentation Layer), showing a selection of forecast products. Top left: hourly rainfall and 10 m winds. Top right: significant wave height, wave direction and period. Bottom left: Cloud, wind, relative humidity, temperature and precipitation forecasts for Wellington – together with verifying real time observations. Bottom right: Rangitaiki forecast river flow (at Te Teko) and verifying real-time observations. The bottom thumbnail panel shows other products that are ready to be viewed – including satellite imagery, monthly analyses of precipitation, and sea conditions forecast for tide, storm surge, wave height, wave direction, and spread. The left-hand side panel shows a catalogue of other data products available for viewing.

innovations – after which time they might be expected to pay a larger proportion of the costs of the underpinning infrastructure and services that deliver the innovations that are of value to their organisations.

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References

Amabile, T.M.; Conti, R.; Coon, H.; Lazenby, J.; Herron, M. 1996: Assessing the work environment for creativity. *Academy of Management Journal 39*: 1154–1184.

Davies, T.; Cullen, M.J.P.; Malcolm, A.J.; Mawson, M.H.; Staniforth, A.; White, A.A.; Wood, N. 2005. A new dynamical core for the Met Office’s global and regional modelling of the atmosphere. *Quarterly Journal of the Royal Meteorological Society 131*: 1759–1782.

DIUS 2008. *Innovation Nation*. Department for Innovation, Universities & Skills (now Department for Business, Innovation and Skills), 97 p. http://www.bis.gov.uk/assets/biscore/corporate/migratedD/ec_group/18-08-C_b.pdf

Hauser, H. 2010. *The current and future role of technology and innovation centres in the UK.* Department for Business, Innovation and Skills, 28 p. http://www.bis.gov.uk/assets/biscore/innovation/docs/10-843-role-of-technology-innovation-centres-hauser-review.pdf

Hendy, S.; Sissons, C. 2010. Innovators, innovation and increasing returns to scale: Solving New Zealand’s productivity paradox. *New Zealand Science Review 68*: 22–26.

Hughs, A. 2007. Innovation policy as cargo cult: Myth and reality in knowledge-led productivity growth. *Centre for Business Research, University of Cambridge, Working Paper 348*. http://www.econ.cam.ac.uk/cgi-bin/cbr_wpfull3.pl?series=cbrwps&filename=cbr2007&paperid=WP348

Little, S. 2010: Role of innovation in economic growth in a New Zealand context. *New Zealand Science Review 68*: 5–8.

MoRST 2008. Government’s agenda for New Zealand Research, Science and Technology. 67 p. http://www.morst.govt.nz/Documents/publications/policy/Governments-Agenda-for-RST.pdf

Webster, S.; Uddstrom, M.; Oliver, H.; Vosper, S. 2008. A High Resolution modeling case study of a severe weather event over New Zealand. *Atmospheric Science Letters 9*: 119 – 128. http://www3.interscience.wiley.com/cgi-bin/fulltext/118677446/PDFSTART

Yang, Y.; Uddstrom, M.; Revell, M.; Andrews, P.; Oliver, H.; Turner, R.; Carey-Smith, T. 2010. Numerical simulations of effects of soil moisture and modification by mountains over New Zealand in Summer. *Monthly Weather Review*. doi: 10.1175/2010MWR3324.1