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DEVELOPMENT OF NEW ZEALAND'S NETWORK OF OPEN-COAST, SEA-LEVEL RECORDERS

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Abstract: The New Zealand network of open-coast sea-level stations has expanded from one prior to 1992 to twenty (including one in Antarctica) in 2003. All the stations have high quality instrumentation, comprising a sea-level recorder, barometer, and air and sea temperature sensors. All stations are telemetered, most by cell phone. They are automatically interrogated daily and the retrieved data are analysed, checked for storm-surge activity and posted on an Intranet. A wide variety of science and now-casting products have resulted and several more are planned.

Keywords: sea-level recorder, sea levels, tides, storm surge, tsunami, long waves, New Zealand.

INTRODUCTION

Prior to 1992, New Zealand's coastline was monitored by only one open-coast sea-level recorder, at Moturiki Island (Figure 1). There were tide gauges at the main ports of course, but their data were of highly varying quality, and the sea levels they measured were modified by shallow-water effects and port dredging or reclamation works. In a watershed paper, Goring & Bell (1996) described the previous situation: "to grace the motley collection of tide recorders around the NZ coast with the term "network" is an exaggeration, for it wrongly implies that there is some overall plan for the collection of tidal and sea-level data". This parlous state of sea level monitoring inspired the team at NIWA to develop and co-ordinate the establishment of a network of open-coast gauges that produces data to a scientifically-defensible accuracy, rather than simply meeting the immediate needs of maritime operations. The network now (mid-2003) numbers 19 stations around New Zealand (Figure 1), and another on Ross Island, Antarctica.

In this paper we describe the criteria we have used for siting and instrumentation, how we built up the network, how we have garnered support from other organizations, our quality assurance procedures, and how we are using the data.

CRITERIA

Our initial sponsors were Environment Canterbury, University of Canterbury, and NIWA. Together they provided capital for us to build an initial network of 8 stations based on purely scientific criteria for siting and instrumentation. This meant we were free from the need to compromise to accommodate maritime operations, and allowed us to choose the best sites and the best instruments for science. The criteria we decided upon were:

- Open coast—well away from harbours and the effects of siltation and dredging. Coastal islands or headlands are the best candidates;
- Strategic sites—even north/south/east/west coverage around the country, and some were placed under TOPEX/Poseidon satellite tracks;
- High-quality instrumentation—expensive, but necessary for scientific quality and reliability;

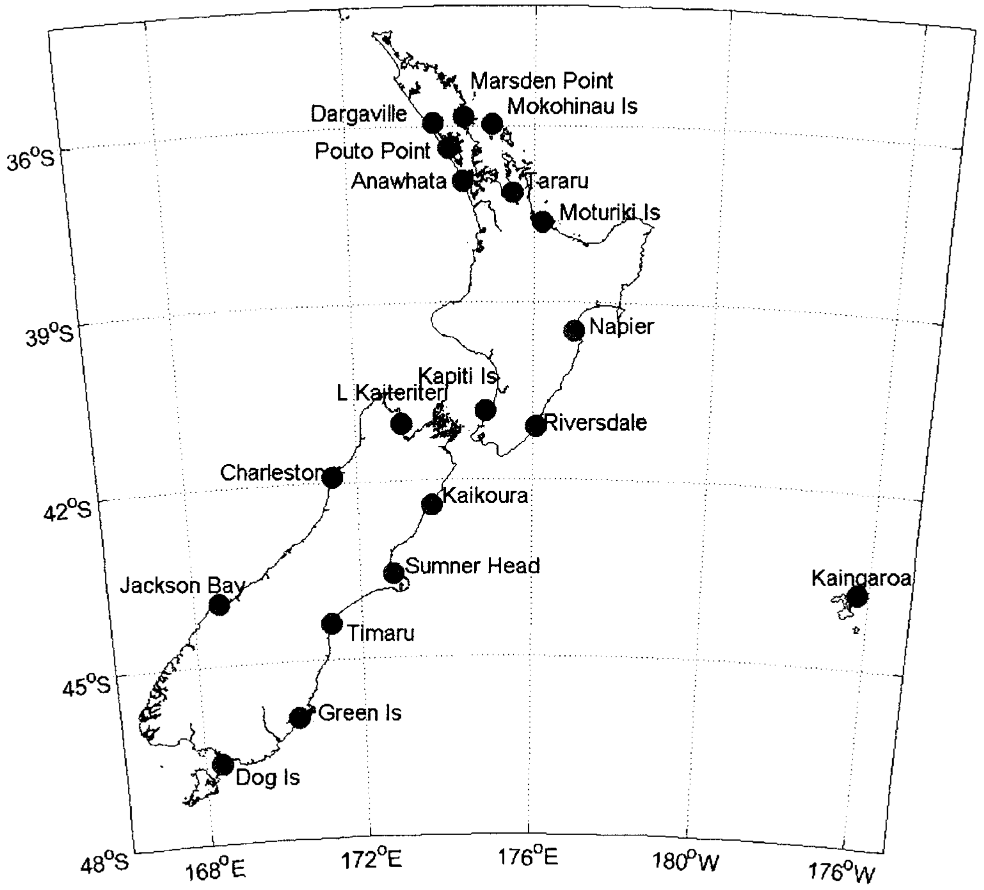

Figure 1. The New Zealand open-coast sea-level recorder network as at June 2003.

Table 1. List of stations in the sea-level network. Agency abbreviations are: EW = Environment Waikato; ECan = Environment Canterbury; UCG = University of Canterbury (Geography); NTF = National Tidal Facility (Adelaide); NRC = Northland Regional Council; ARC = Auckland Regional Council; TDC = Tasman District Council; PPT = PrimePort Timaru; ORC = Otago Regional Council; HBRC = Hawke's Bay Regional Council.

Station	Latitude °S	Longitude °E	Date On	Agency
Moturiki Island	37.633	176.193	27-May-1971	NIWA
Tararu	37.133	175.542	1-Nov-1992	EW
Sumner Head	43.574	172.767	6-Jun-1994	NIWA, ECan
Kaikoura	42.415	173.703	10-Aug-1994	NIWA, UCG
Jackson Bay	43.957	168.616	13-Dec-1996	NIWA, NTF
Dog Island	46.652	168.412	5-Apr-1997	NIWA
Riversdale	41.095	176.074	9-Jul-1997	NIWA
Kapiti Island	40.842	174.938	24-Jul-1997	NIWA
Charleston	41.908	171.433	25-Apr-1998	NIWA
Marsden Point	35.842	174.5	1-Aug-1998	NRC
Mokohinau Is.	35.965	175.103	17-Aug-1998	NIWA, ARC
Anawhata	36.921	174.461	19-Nov-1998	NIWA, ARC
Little Kaiteriteri	41.048	173.027	17-Jun-2000	NIWA, TDC
Kaingaroa	43.732	183.733	24-Sep-2000	NIWA
Timaru	44.392	171.254	30-Nov-2001	NIWA, ECan, PPT
Poutu Point	36.362	174.182	21-Apr-2002	NRC
Dargaville	35.94	173.87	21-Apr-2002	NRC
Green Island	45.956	170.383	6-Dec-2002	NIWA, ORC
Napier	39.477	176.898	17-Feb-2003	HBRC

- Other parameters—in addition to sea level, we took the opportunity to measure atmospheric pressure, and sea and air temperatures at each site to provide supporting diagnostic information.
- Telemetry—to ensure automatic quality assurance procedures could be implemented. Cell phones are preferred, but landlines are used if necessary.
- High sampling rate—decided maximum sampling interval would be 5 minutes, in order to capture seiche and tsunami. Subsequently, after missing a tsunami event through aliasing, tsunami ring-buffers have been installed in most sites with 1-minute sampling.

Following advice from the USA and the UK, the instrumentation we decided upon for the sea-level recorders was nitrogen bubblers with high-quality Paroscientific gauge (vented) pressure transducers that are accurate to ± 1 mm. These have proved to be extremely reliable and accurate, apart from one or two that malfunction in heavy seas.

THE SEA-LEVEL NETWORK

The network locations are shown in Figure 1 and the contributing agencies and partners are listed in Table 1. The first of the new-generation gauges installed was at Sumner Head near Christchurch in June 1994. It was here that we first experimented with nitrogen bubbler technology and determined its viability for open-coast deployments from cliffs. This was followed a few months later by Kaikoura, which was initially a student project, supported by NIWA. This was followed by Jackson Bay, a joint project between NIWA and NTF Adelaide, using a NOAA acoustic tide gauge with satellite telemetry. The major advance occurred from 1997 to 1998, when NIWA provided capital funds to cover the installation of six recorders at Dog Island, Riversdale, Mokohinau Island, Anawhata, Kapiti Island, and Charleston, followed by upgrades to bubbler systems for Moturiki Island and Kaikoura.

A temporary recorder at Kaingaroa on Chatham Island recorded the Peru tsunami of 23 June 2001, some 2.5 hours before it reached the New Zealand mainland, so the installation was made permanent to provide a degree of warning for remote tsunami from the eastern Pacific. Subsequently in the past two years, Northland Regional Council has incorporated their three sea-level recorders at Marsden Point, Poutu Point (Kaipara Harbour) and Dargaville into the network, Environment Waikato has incorporated their Tararu recorder and Hawke's Bay Regional Council has incorporated the Napier gauge. NIWA has jointly funded gauges at Little Kaiteriteri (with Tasman District Council), Green Island (with Otago Regional Council) and Timaru (with PrimePort Timaru and Environment Canterbury). This co-operation has enabled a "national" facility to be established around the New Zealand coast, as well as Antarctica (Ross Sea), that can be monitored daily (or hourly if needed) for storm-tide events from a single office location in Christchurch.

SUPPORT & PARTNERSHIPS

A lesson we learnt early on in the establishment of the network is that it is very difficult and expensive for a science organization to secure the resource consents needed for installation of field equipment like sea-level recorders. In most cases, the instrumentation is housed in a weather-tight compartment that occupies a land space of less than 1 m^2, connected to a hose (similar to garden hose diameter) that runs down into the sea to below the low water mark. Central government agencies responsible for administering public land tend to treat organizations like NIWA the same as any other company in terms of cost recovery, even though we are trying to provide a public service. However, because regional councils (RCs) are familiar with resourceconsent procedures and the required consultation, partnering with RCs means their staff can assist in securing the consents more efficiently. Generally, they also have better relationships with central government agencies. These factors, along with the need for RCs to acquire sea-level data as part of their charter to monitor natural hazards and undertake state of the environment reporting, makes them natural partners in developing a sea-level network. Thus, any future sea-level recorders that are added to the network will usually be done in partnership with a RC or a territorial authority.

Ongoing maintenance and operational costs are a problem with the network, given the reduction of research funds in real terms. Where possible, we have endeavoured to negotiate with a RC or central-government agency for them to cover the maintenance costs in exchange for scientific analysis and provision of the data. However, there are strategic network sites like Dog Island, Charleston, Kapiti Island and Riversdale that are only funded from research monies, and therefore their long-term tenure is uncertain. Indeed, Riversdale on the Wairarapa coast will be decommissioned in 2003 as a result of both research cut-backs and the recent installation of a near-by gauge further up the coast at Napier by the Hawke's Bay Regional Council.

QUALITY ASSURANCE

Experience dealing with historical tide gauges records (Goring & Bell, 1996) has taught us that a quality-assurance programme is vital if the data are to be useful scientifically. Otherwise, an inordinate amount of the time is spent in correcting and cleaning up the record. Quality assurance also enables us to detect early that we have a problem with a recorder and then we can deal with it immediately, rather than have to cope with long gaps in the record.

Figure 2 shows a typical plot that is produced automatically every day for each station in the network by a server in our Christchurch office. In the upper panel we compare the raw (actual) sea level with the forecast tide, the latter extending for a few days into the future. The human eye is a very precise instrument in comparing two signals like these—it can be accomplished with 100% reliability in less than 1 second.

The lower panel (Figure 2) compares the total storm surge SS (the smoothed residual of the difference between the actual sea level and predicted tides in the upper plot) with the inverted-barometer component IB (derived from the atmospheric pressure record). IB sea-level rises under low-pressure systems or depressions where a 1 cm rise in sea level occurs for every 1 hPa fall in atmospheric pressure below the mean-annual pressure, and vice versa for anticyclone systems. We expect the SS and IB curves to track together, but they may be offset. When they differ or diverge widely, it usually means that the storm surge is not simply related to the inverted-barometer effect, but instead is governed by a complex interaction of other "drivers" such as regional winds or coastally-trapped long waves propagating from outside the region.

When the magnitude of SS reaches above 0.2 m or so, we have a storm-surge event (either positive or negative). Storm-induced inundation or sea flooding of low-lying areas is determined by the combination of both the tide and the SS, or "storm-tide", which can be read from the magnitude of the actual (raw) sea level, as plotted in top panel (Figure 2).

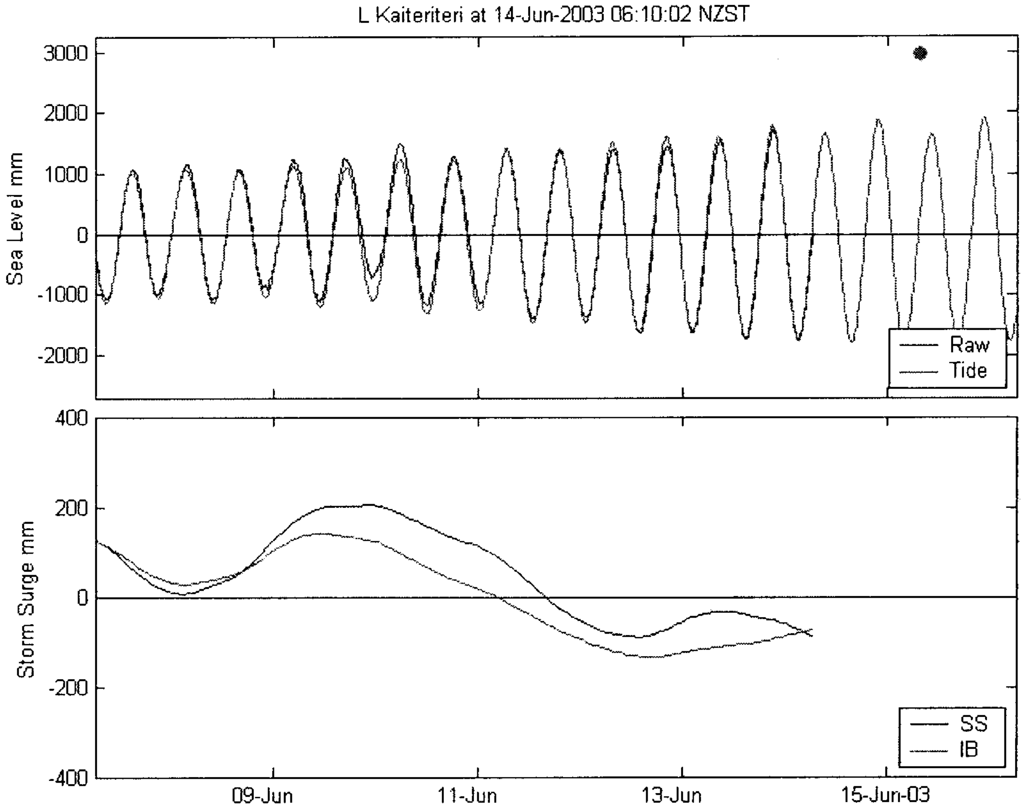

Figure 2. Typical daily plot comparing raw sea-level data with forecast tide (top); and storm surge SS, with inverted barometer IB (bottom). Yellow diamond marks the lunar perigee (when the Moon is closest to the Earth each month) and magenta circle is Full Moon.

To further illustrate the value of these plots, consider Figure 3, which shows an instrument that has malfunctioned and within two days has been fixed. Without daily monitoring like this, the malfunction could have gone unnoticed for days or even weeks, resulting in a large gap in the data.

The daily plots (like Figure 2 and 3) for each of the sites in the network are posted to a web page on an Intranet so that anyone within the institute can view them. For field staff, it is quite embarrassing to have one's "dirty laundry" (e.g., Figure 3) displayed across the organisation, so there is a strong incentive to address problems without delay. NIWA is just putting the finishing touches to an Internet-based system to allow the network partners access to these daily plots.

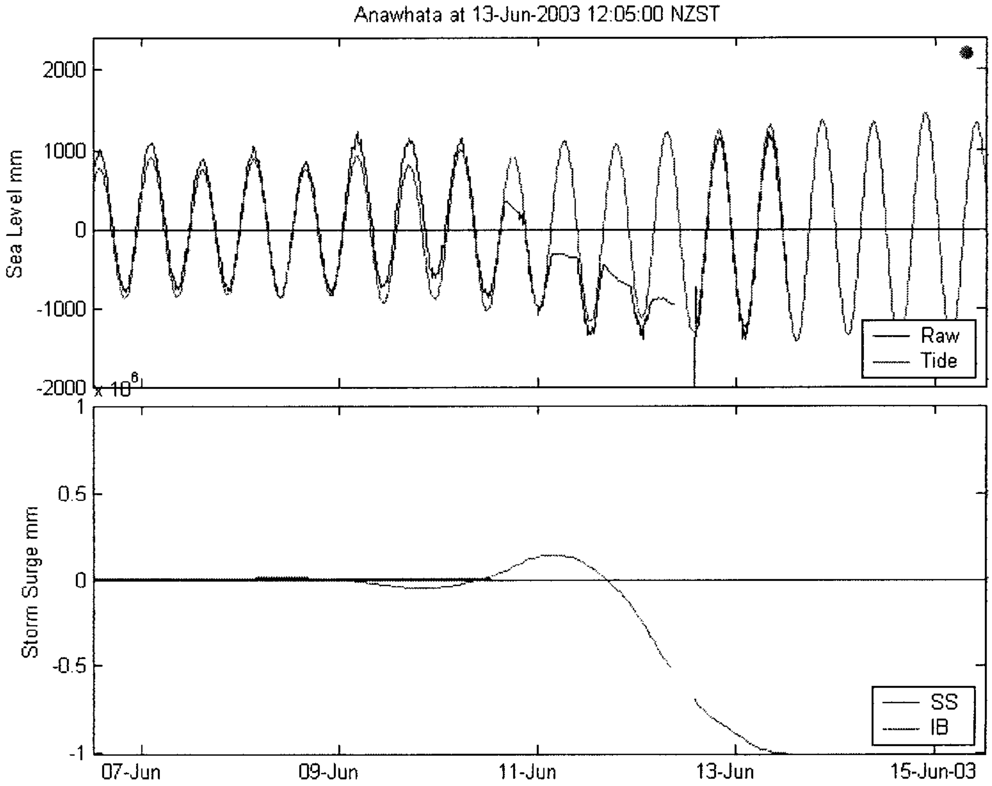

Figure 3. Daily plot showing an instrument malfunction that was fixed within two days and normal service resumed.

DATA USES

The data from the network are being used for a wide variety of scientific and operational purposes, some of which include:

- Calibration of local-area tide models (Walters et al. 2001; Goring 2001; Foreman et al. submitted);
- Storm surge monitoring and forecasting, including red-alert days for very high tides (http://www.niwa.co.nz/rc/prog/chaz/news/coastal#red);
- Analysis of seiche (Goring & Henry 1998);
- Analysis of tsunami (Goring 2002);
- Maritime hazards e.g., detection of long-wave events (Goring 2003) and ship groundings;
- Support for hydrographic surveys e.g., tidal and meteorological corrections on the fly;
- Support of estuary and coastal monitoring e.g., mosquito sampling programme in Kaipara Harbour;
- Analysis and prediction of long-period sea-level effects (Bell et al 1999; Bell & Goring 1999; Bell et al. 2000; Goring & Bell 2001);
- Assessment of temperature effects (Bell & Goring 1998);
- Assessment of coastal inundation hazards e.g., for hazard zones and engineering design;
- Antarctica sea and ice level fluctuations (Goring & Pyne 2003, Padman et al. 2003)

Work on the data from the network that is underway or planned for the future includes:

- Analysis of the temporal and spatial variability of the annual cycle in sea-level;

- Validation of a storm surge model for the New Zealand region;
- Development of automatic, real-time forecasting routines for storm tide (tides plus storm surge), tsunami, and long-waves.

CONCLUSIONS

The New Zealand network of open-coast sea-level stations has expanded from one installation prior to 1992 to twenty (including one in Antarctica) in 2003. All the stations have high quality instrumentation, comprising a sea-level recorder, barometer, and air and sea temperature sensors. All stations are telemetered. They are automatically interrogated daily and the retrieved data are analysed and posted as summary plots on an Intranet, and soon to be available to partners on the Internet. A wide variety of science products have resulted and several more are planned.

In the future, the existing cell phone technology at the stations will be replaced by the new general packet radio service (GPRS) that will make the data available continuously in a web environment. This will obviate the need to interrogate the stations and will facilitate real-time now-casting and forecasting that is impractical today. No doubt, this new technology will enable us to provide other products we have not even contemplated yet.

ACKNOWLEDGEMENTS

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