A comparison of absolute and relative vertical rates at the New Zealand cGPS@TG sites

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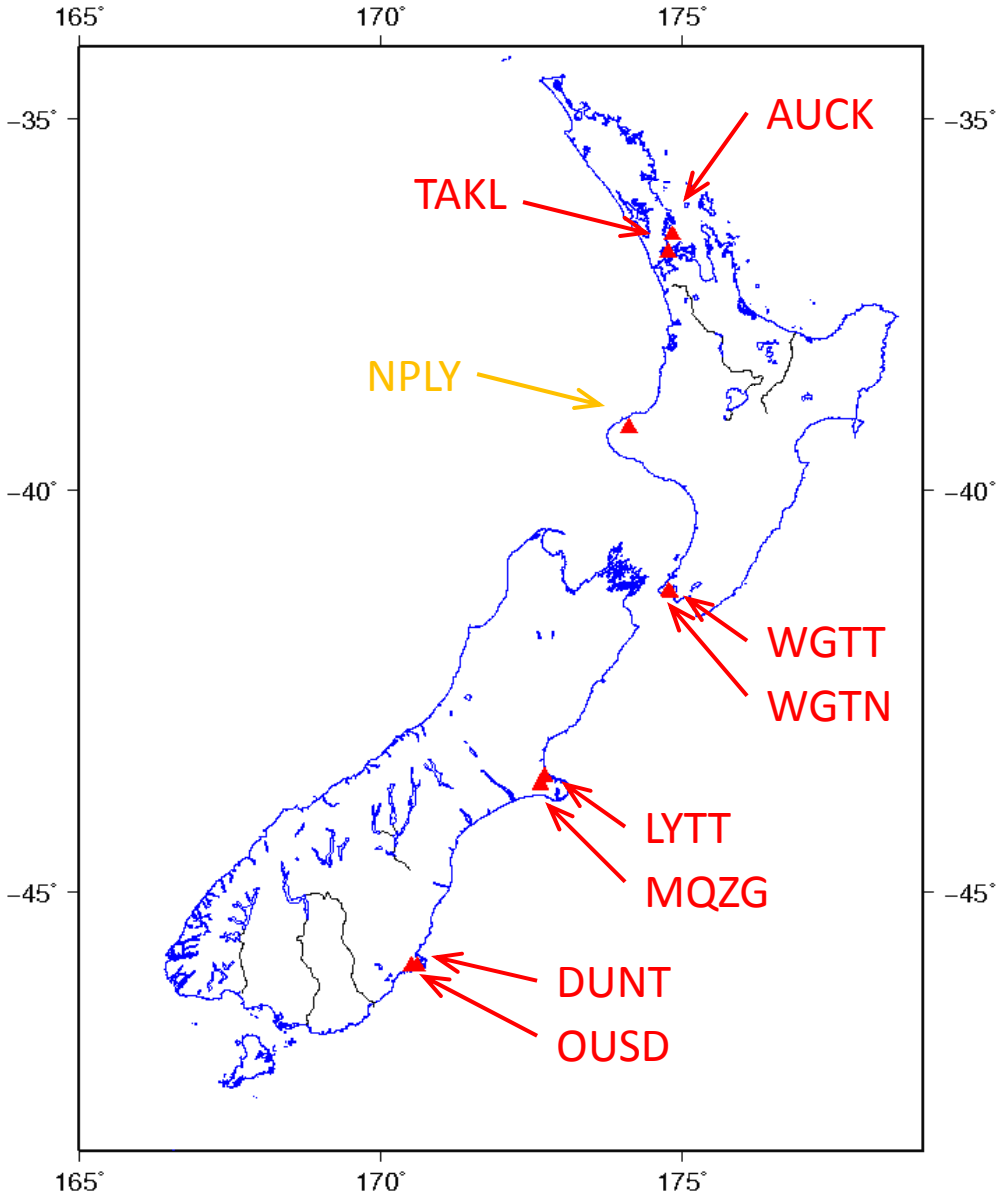
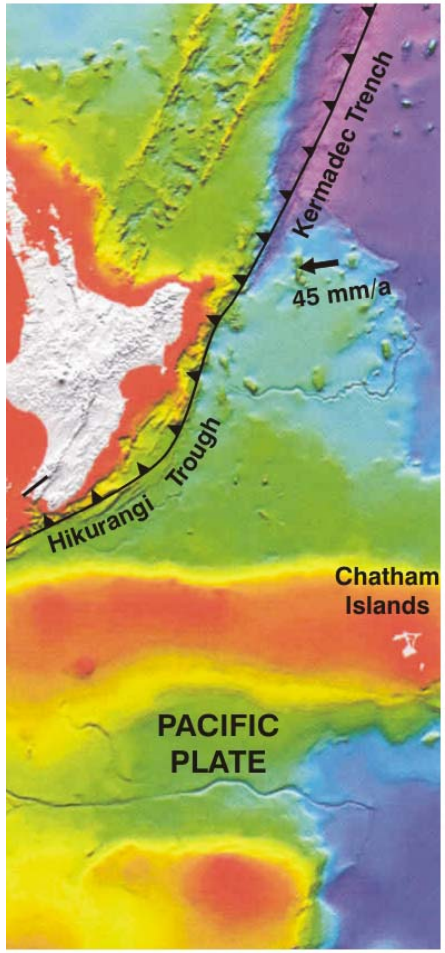
Outline

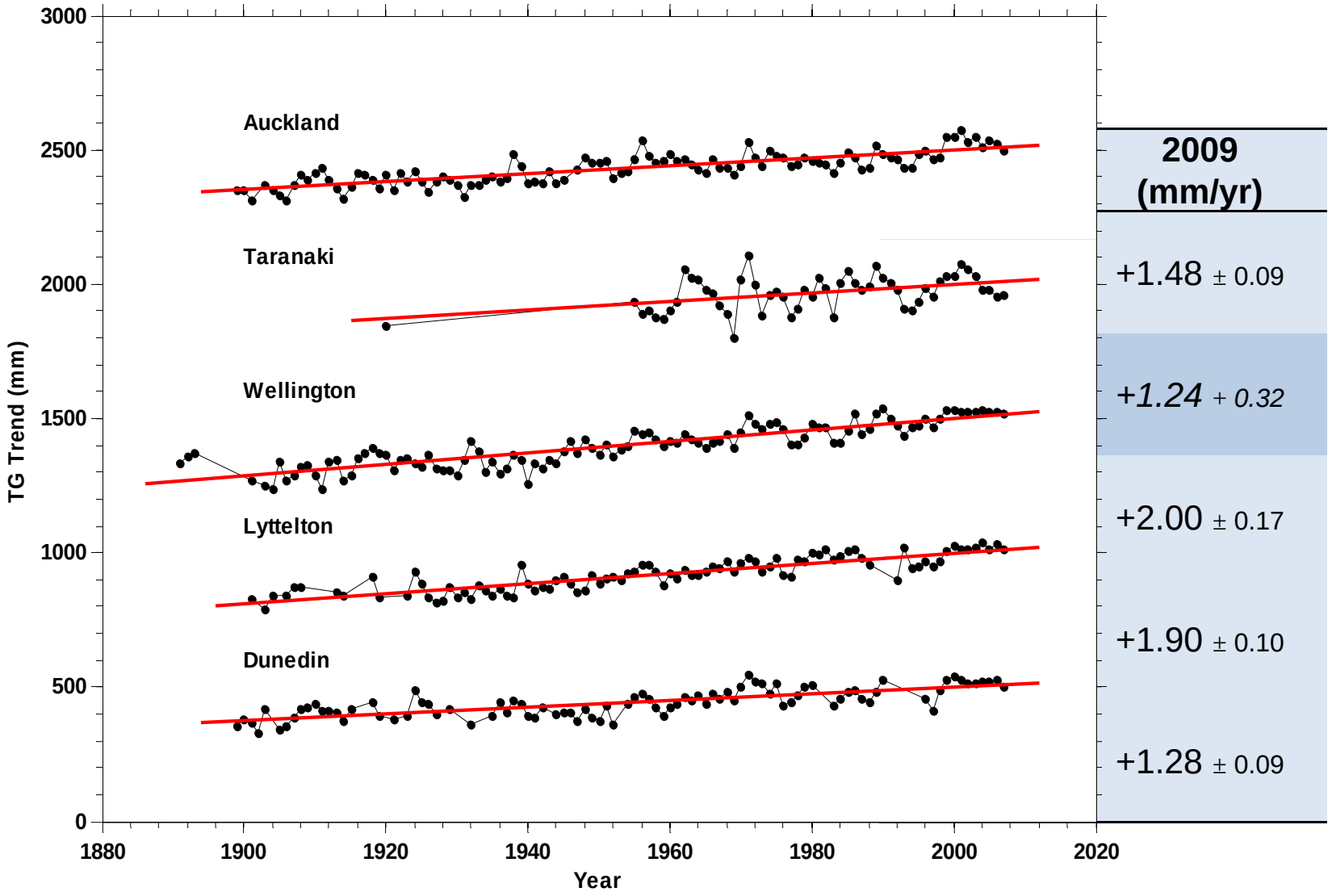
- Tide gauge records
- Tide gauge site stability
- Vertical velocity rates

cGPS@TG sites in NZ





RSL Trends – 2009 Analysis



RSL Rates

Analysis	1990 (mm/yr)	2004 (mm/y	
TG Site			
Auckland	1.3	1.3	1.5
Taranaki			1.2
Wellington	1.7	1.8	2.0
Lyttelton	2.3	2.1	1.9
Dunedin	1.4	0.9	1.3
Mean		**1.**	
		Hannah	

< 1944, based on annual means rather than hourly data

In 2004, wharf pile assumed to subsiding at -0.3mm/yr

Higher rate assumed to be due to lack of data < 1924

New negative correction of 0.012m since 1956

1 sigma: ± 0.1 – 0.3 mm/yr

Factors Affecting Trends

- GPS Environment
  - Harbour location
  - Reclaimed land — Auckland, Wellington, Lyttelton, Dunedin
  - Proximity to CBD — Auckland, Wellington
  - Proximity to hills — Lyttelton, Dunedin

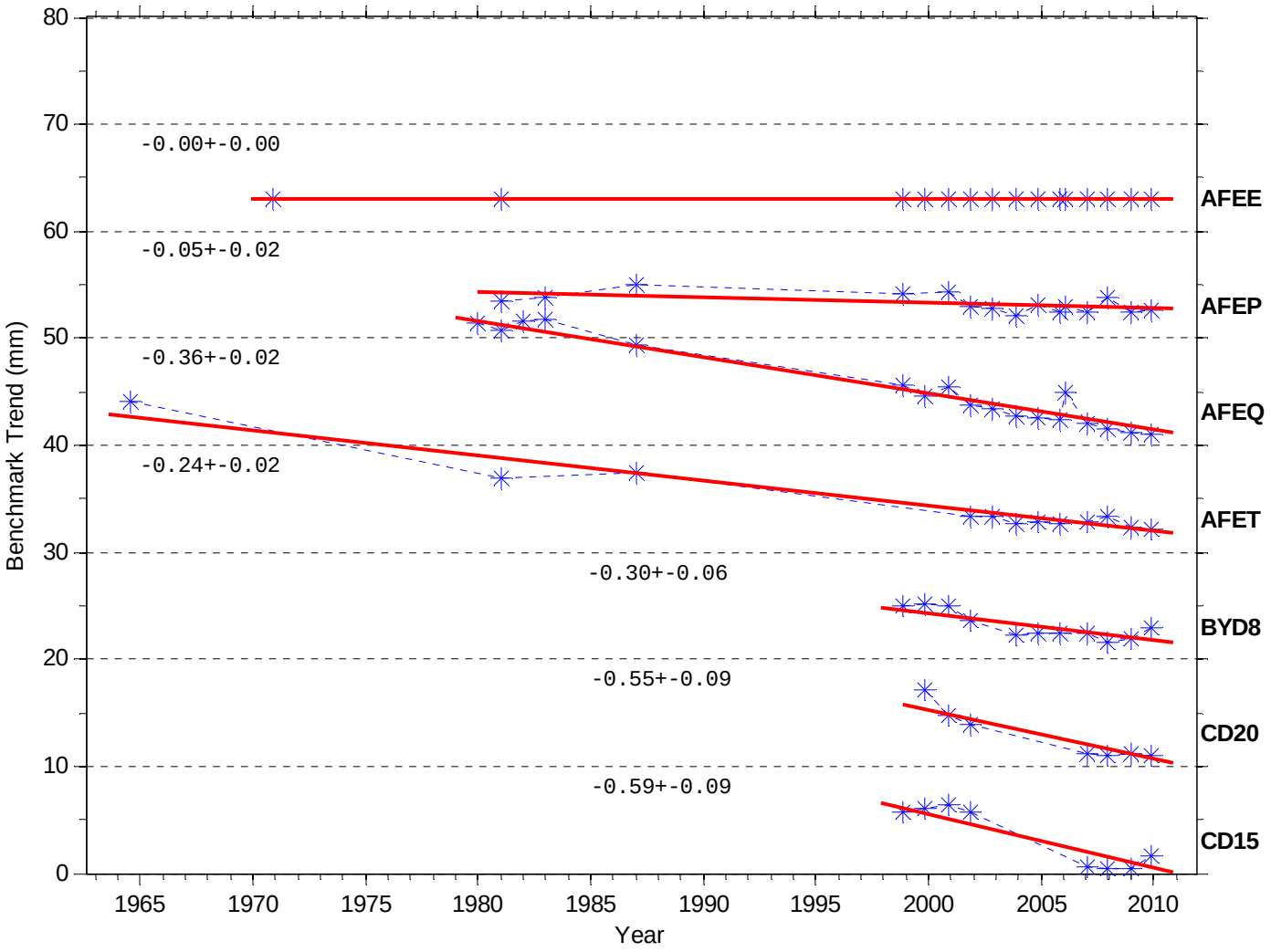
- Vertical deformation
  - Sedimentation
  - Compaction *
  - Water, gas, oil extraction
  - Tectonic effects at plate boundaries *
  - Glacial Isostatic Adjustment (GIA) *

TG / cGPS Site Stability Monitoring

- Local stability:
  - TG pole/recorder connected to local benchmark network
- Regional stability:
  - dual cGPS@TG sites

	TG to cGPS@TG (km)	Connection	cGPS to cGPS@TG (km)
Auckland	Collocated	Precise levelling	27.3
Wellington	0.55	Precise levelling + GPS	4.2
Lyttelton	Collocated	Precise levelling	12.0
Dunedin	0.4	Precise levelling	11.0

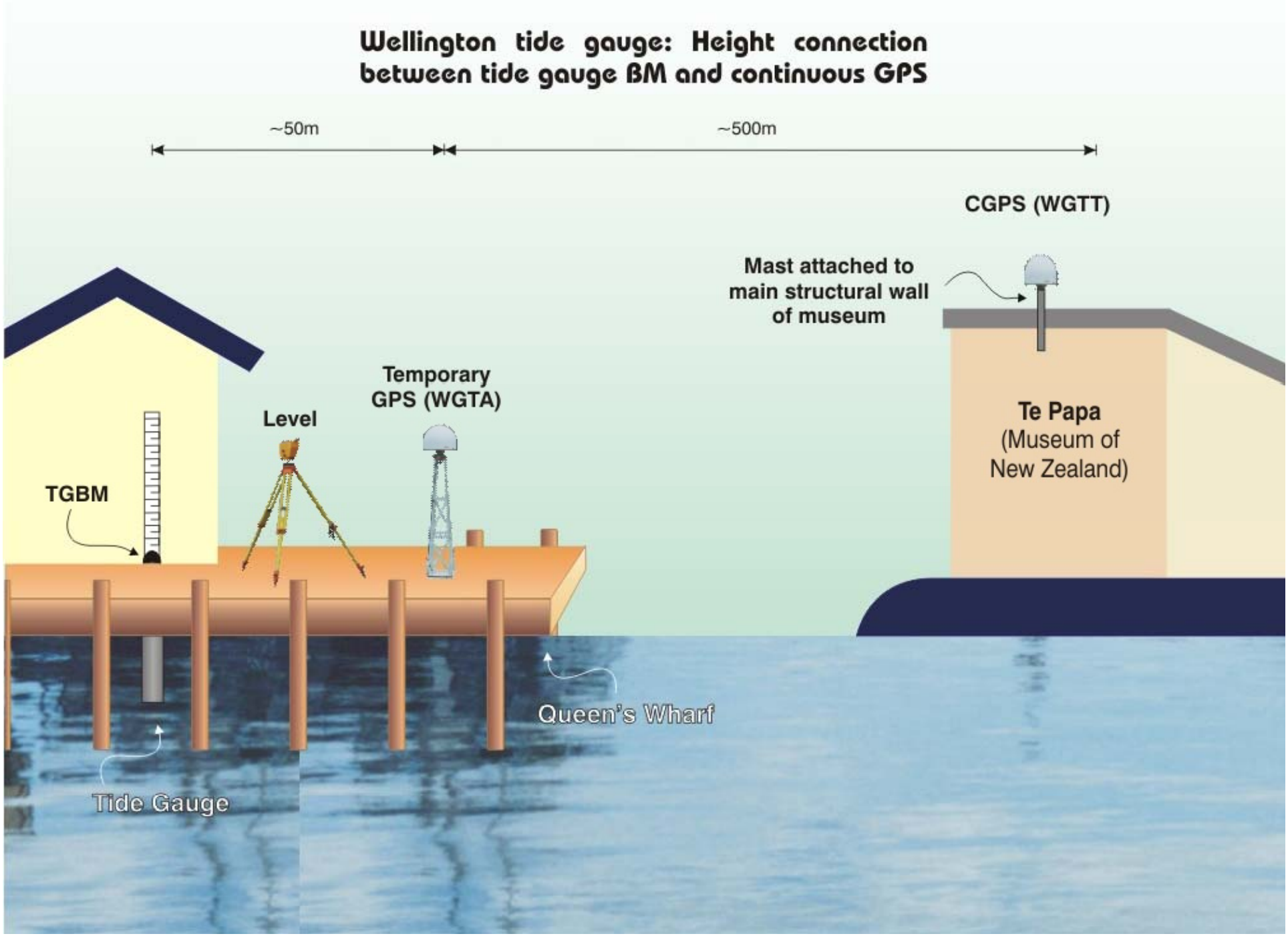
Dunedin TG Benchmarks



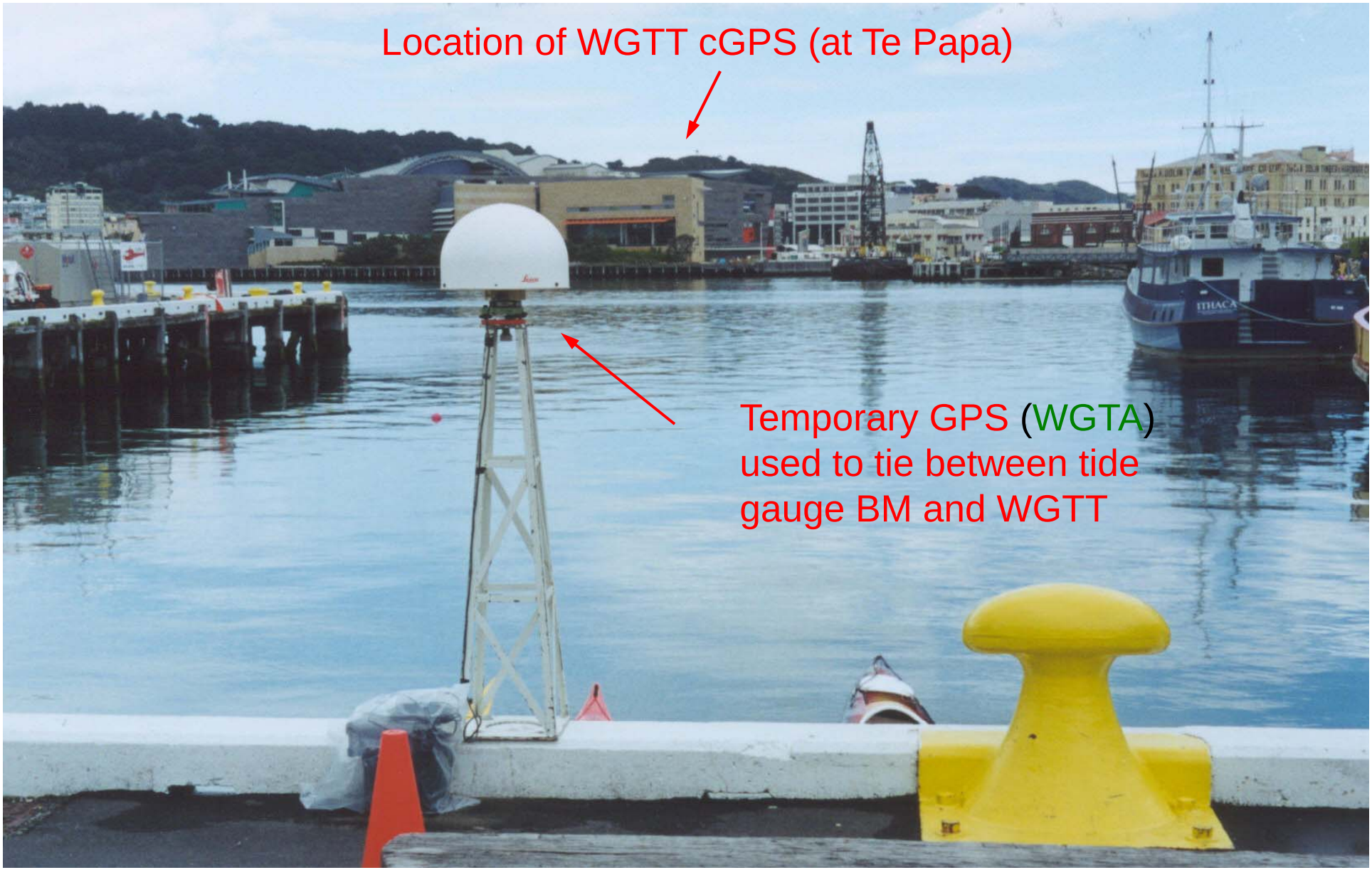
Fixed BM

TG Pole BM

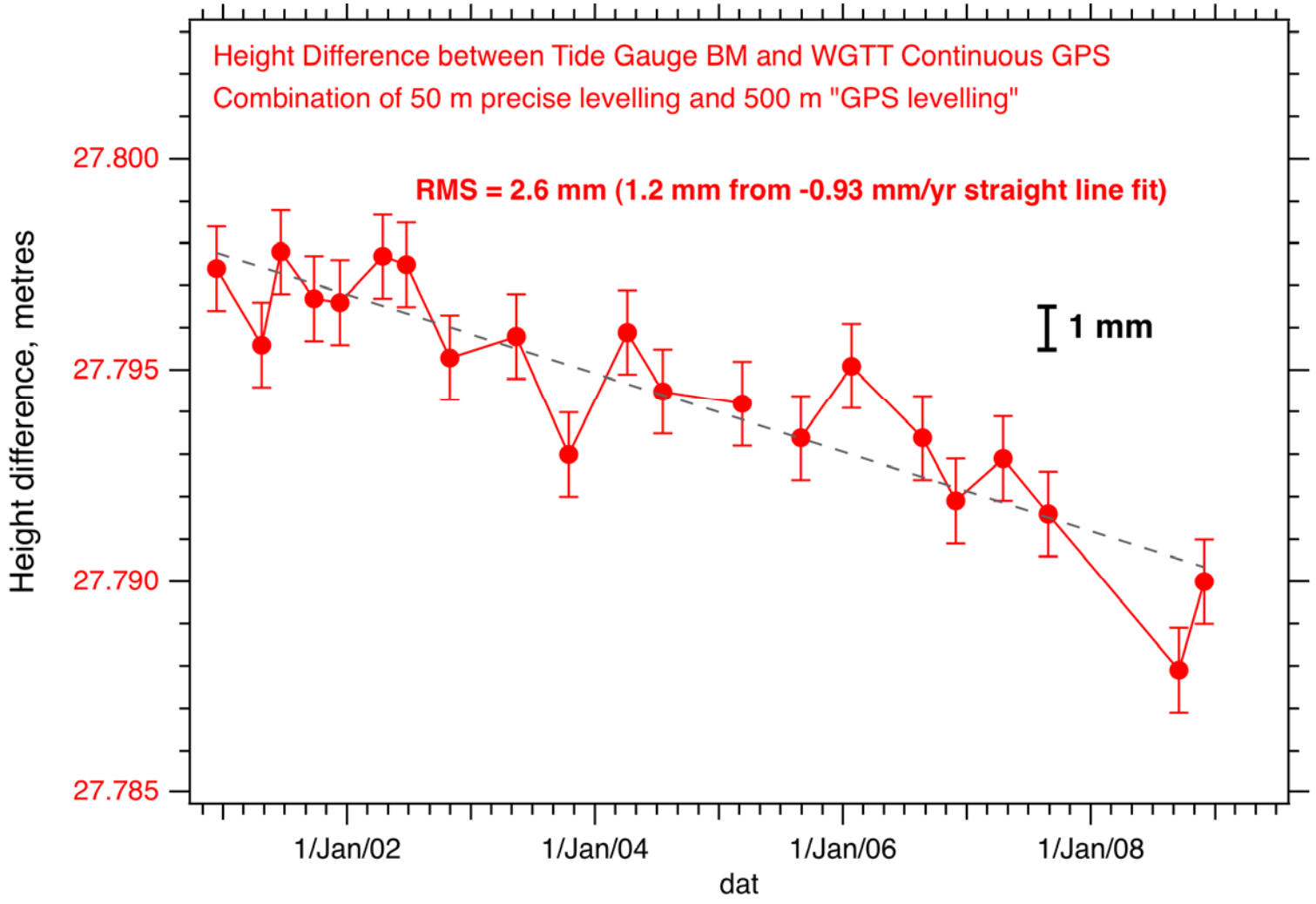
TG Ref BM


Wellington tide gauge: Height connection between tide gauge BM and continuous GPS
~50m
~500m
CGPS (WGTT)
Mast attached to main structural wall of museum
Temporary GPS (WGTA)
Level
TGBM
Te Papa (Museum of New Zealand)
Queen's Wharf
Tide Gauge

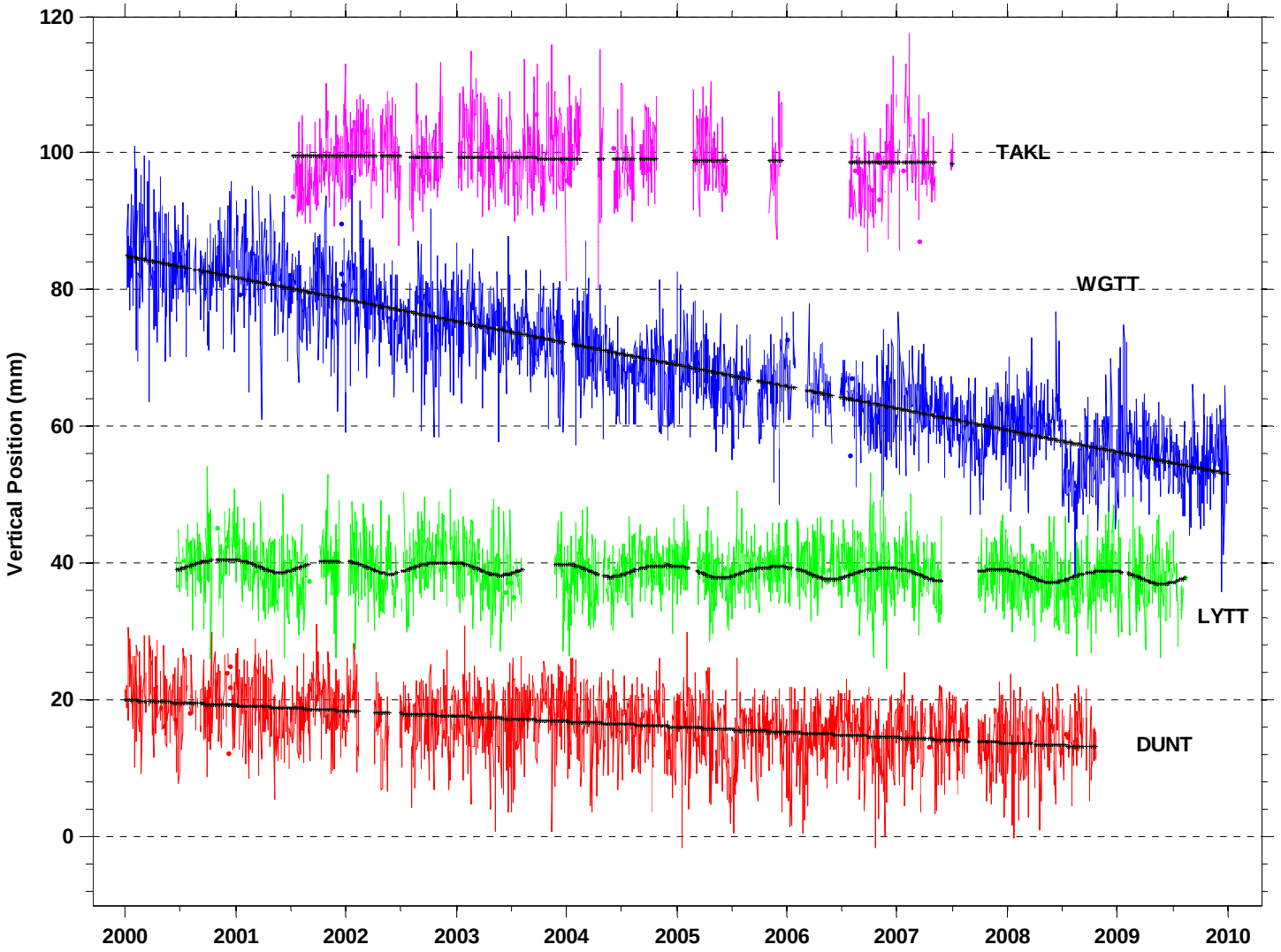
GPS levelling: WGTA to WGTT CGPS



Precise and GPS levelling results: Wellington tide gauge



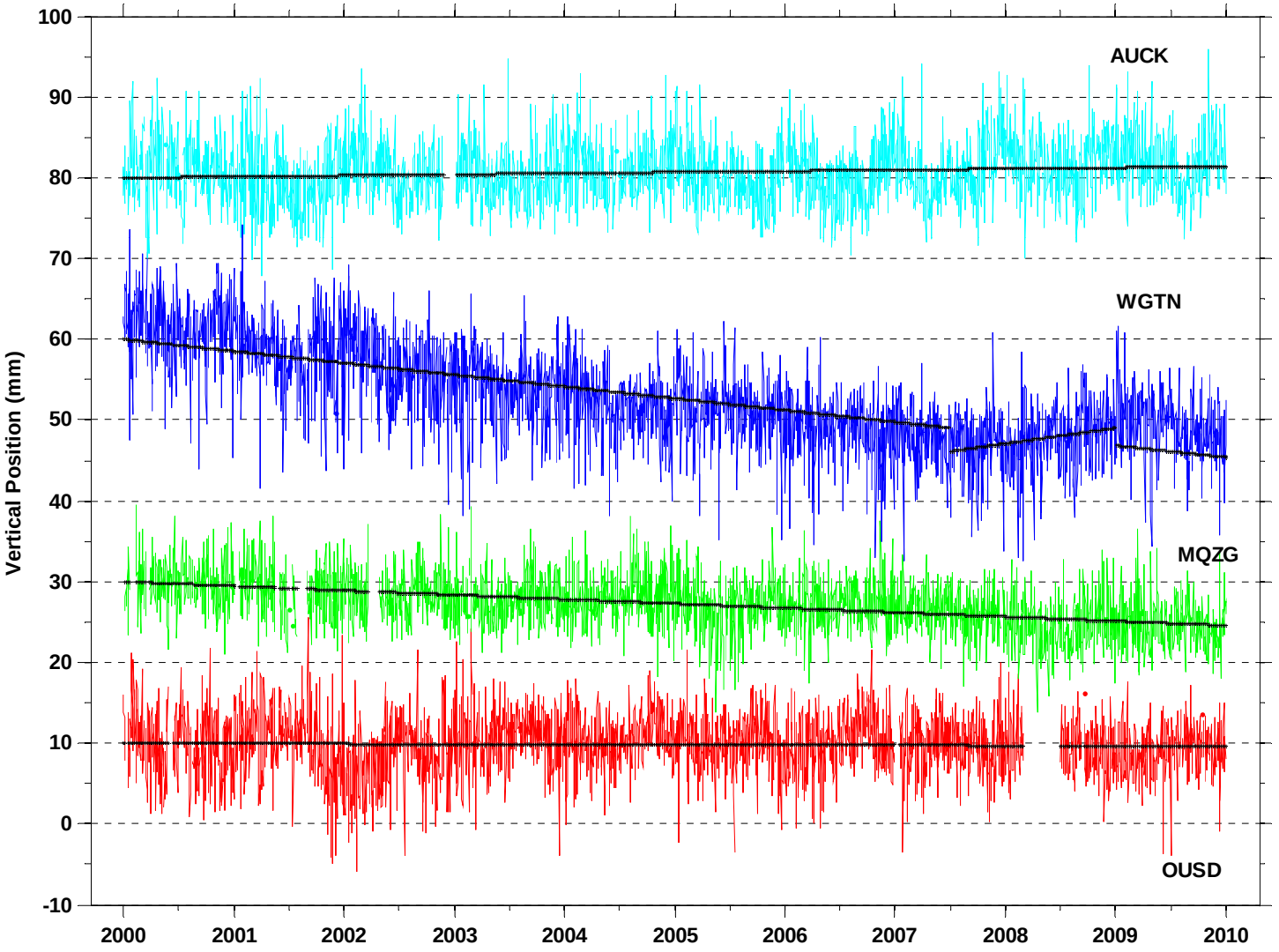
Dual cGPS baselines



cGSP Data Processing

Model		OU Relative Solution	NCL Global Solution
Frame	*	IGS2005 (JPL Reproc 1)	ITRF2005 (NCL Reproc 1)
Observables		Double Differenced Phase	PPP
Sessions		24hr, epoch Interval 300s	24hrs, epoch Interval 300s
Elevation Cut-off	*	7°	10°
Antenna PCV	*	Absolute, I05.ATX	Absolute, I05.ATX
Ocean Loading Model		GOT00.2	FES2004
Ionospheric Refraction		Ionosphere Free LC 1st Order effect	Ionosphere Free LC 1st + 2nd Order
Tropospheric Refraction	*	Hourly ZD, daily gradient GMF	Hourly ZD, daily gradient VMF1
Ambiguities		QIF Strategy, fixed	Unfixed
Daily Solutions		Minimally constrained NNT	7 Parameter Helmert

cGPS @ TG baselines



Vertical Velocity Estimates Stochastic Model

- General linear model
  - diagonal covariance matrix of observations

$$\mathbf{Y} = \mathbf{A}x + \boldsymbol{\varepsilon}$$

$$\mathbf{C}y = \begin{bmatrix} \sigma_1^2 & & \\ & \ddots & \\ & & \sigma_n^2 \end{bmatrix}$$

- White Noise Process:
  - assumes uncorrelated observations

- e.g. – time series

$$y_i = y_0 + (t - t_0)v + \sum_{j=1}^{m} H_j o_j + \sum_{k=1}^{n} a_k \cos w_k t + b_k \sin w_k t + \boldsymbol{\varepsilon}_i$$

velocity — Offset terms — Periodic terms

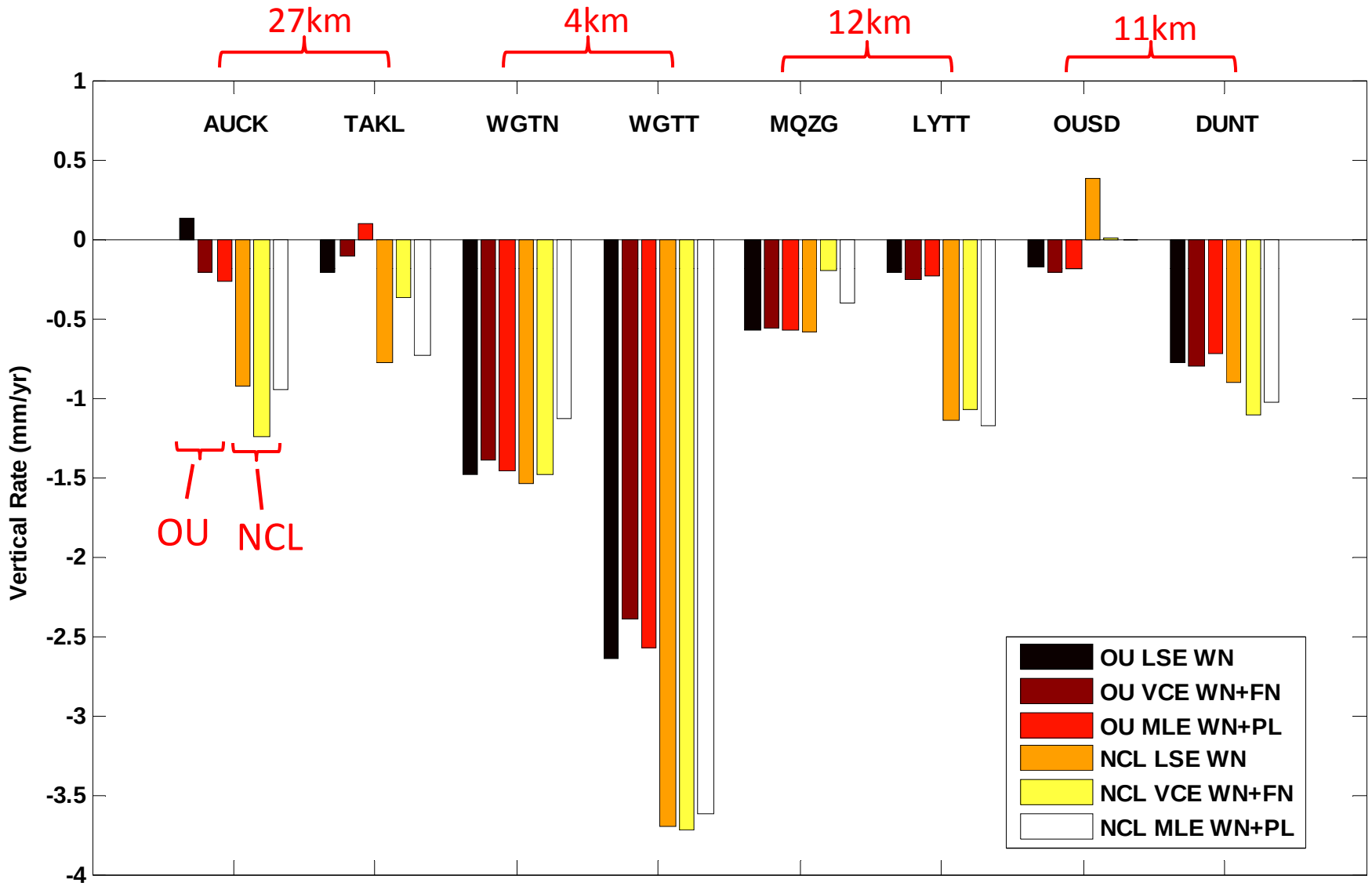
Time Series Estimation

- Techniques
  - Maximum Likelihood Estimation
  - VC Estimation e.g. MINQUE
  - Allan Variance
  - Auto Regression

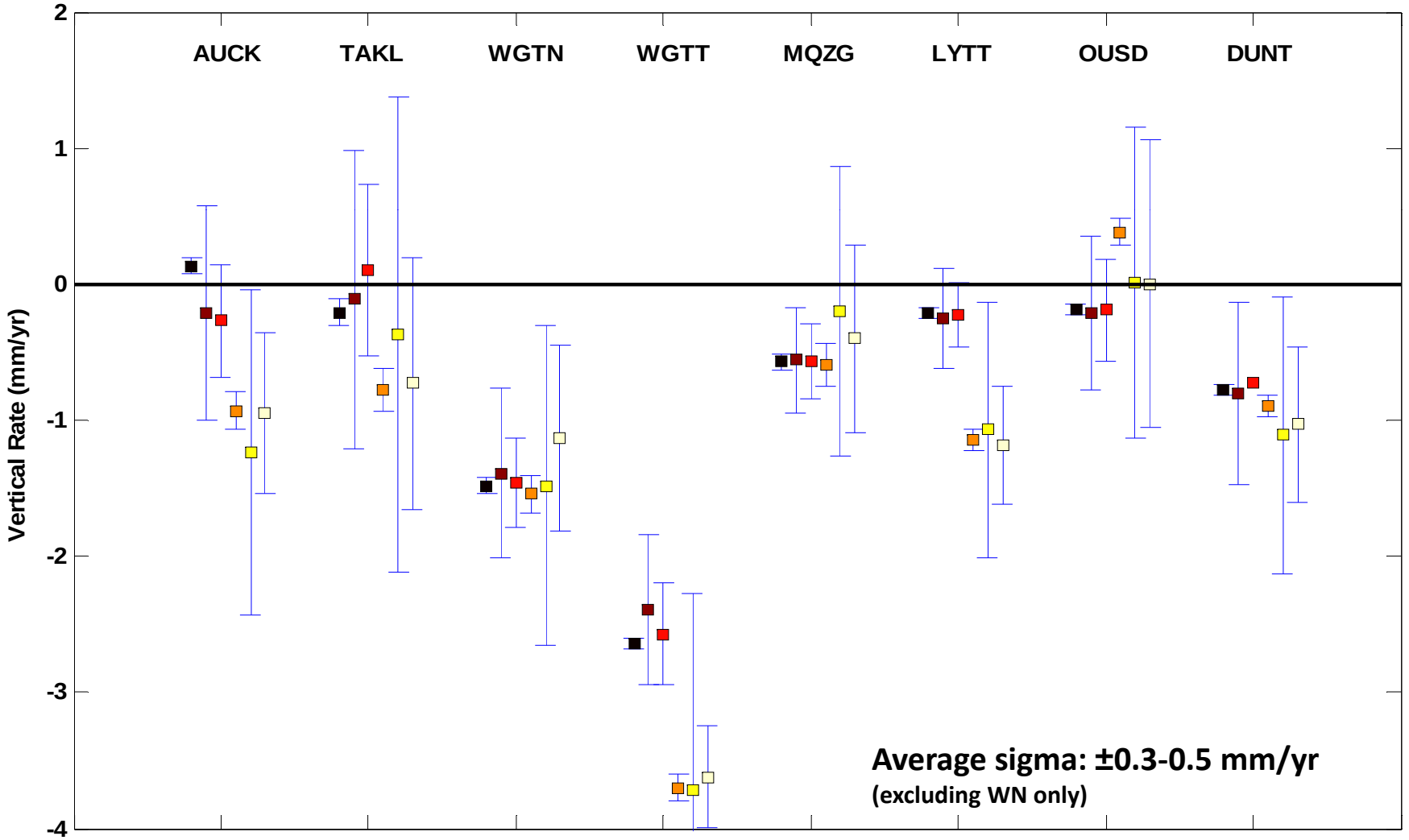
- Three solutions
  -
  - LSE : white noise
  - VCE : white noise + flicker noise
  - MLE : white noise + power law

	Approx. Time
	< 1s
	1-10m
CATS	2-4hrs
Cheetah	1-10m

Vertical Rates



Vertical rates and precisions (95% CI)



Preliminary Rates

	RSL Rate (mm/yr)		OU GPS rate (mm/yr)	SL Rate (mm/yr)		NCL GPS rate (mm/yr)	SL Rate (mm/yr)
TG Site							
Auckland	+1.5		-0.1	**+1.4**		-0.4	**+1.1**
Wellington	+2.0		-1.4	**+0.6**		-1.5	**+0.5**
Lyttelton	+1.9		-0.2	**+1.7**		-1.1	**+0.8**
Dunedin	+1.3		-0.2	**+1.1**		0.0	**+1.3**
	Mean			+1.2			+0.9
	Stdev			±0.4			±0.3

Summary

- Site stability is critical – TG and cGPS@TG sites
  - Most located on/close to reclaimed land
  - Monitoring is essential
  - Monitored using a variety of methods
    - Precise levelling to close BMs
    - GPS “levelling” to regional cGPS and TG BM
    - Dual cGPS baselines
- cGPS velocity estimates
  - Consistency
    - <0.3 mm/yr within the relative (OU) and global (NCL) velocities
  - Estimated precision ~±0.3-0.5 mm/yr (1 sigma)
  - Mixture of agreement
    - 0.3 – 1 mm/yr between relative (OU) and global (NCL) velocities