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Observations of rotational motions around vertical and horizontal axes: comparison with translations

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1 Introduction

With the developing potential of using optical (or other) sensor technology to observe the complete components of rotational ground motions, it is worth re-addressing the well known problems with rotational motions affecting classical inertial measurements or translations using tiltmeters or seismometers.

First, we report observations from ring laser systems measuring the rotational motions around a vertical and a horizontal axis installed in **Christchurch, New Zealand.** While it is now well established that the rotational motions around a vertical axis are compatible with collocated broadband observations under the assumption of plane wave propagation, the **rotations around a horizontal axis using this optical recording technology had so far not been studied in detail**. At the Earth's surface this component of rotation is equal to tilt. However, as tiltmeters are sensitive to horizontal acceleration, a pure tilt signal is difficult to obtain in a broadband spectrum. Here, we investigate whether the tilt observations are as compatible with the broadband translations as the rotations around a vertical axis. Second, we compare tilt derived from seismic array measurements with tilt estimated from translations using vertical and radial components and a plane-wave assumption. **How does the observed horizontal component of rotation rate compare with the vertical component (S/N ratio, absolute amplitude). What do we expect theoretically (synthetic seismograms). How do these observations compare with translation-derived tilt?** We are just at the beginning of analyzing the Christchurch data systematically.

2 Ring laser specifications

From the four ring lasers situated in the Cashmere Cavern in Christchurch, NZ, three were used for this study. These can measure rotational motions around a vertical and a horizontal axis with high resolution. All three ring lasers UG, GO and CII are located in the Cashmere Cavern in Christchurch, New Zealand. They all differ in size and therefore in sensitivity. While UG and CII are mounted in a horizontal position on the cavern floor, GO is attached to the wall.

	A = Area	P = Perimeter	Sagnac frequency
CII	1m	4m	~ 79Hz
GO	12.25m	14m	~ 287Hz
UG	366.86m	76.93m	~1512Hz

Table 1: Details of the three relevant ring lasers in Christchurch, NZ. G0 is mounted on a wall and is thus measuring the tilt rate.

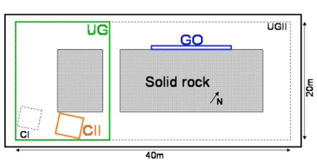

Figure 1: Sketch of the Cashmere Cavern, Christchurch, NZ

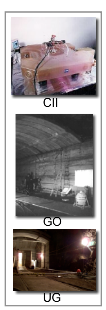

Figure 2: Ring lasers systems in Christchurch, NZ

3 CII vs. UG

A comparison of the two horizontally mounted ring lasers UG and CII emphasizes the quality of the rotational measurements. **Do they see the same signal?** In Figure 3 one can see that the two rotational signals are almost identical in waveform and spectrum. For the two shown events we used a lowpass filter with a cutoff period of 10s.

The lower S/N ratio of the large UG ring is visible in both the time series and the spectra. Such locations will be important for testing lower-resolution sensors.

	distance	magnitude
Papua New Guinea	4724km	6.8
Kermadec Islands	1645km	6.7
NZ West Coast Region	132km	5.1
NZ Canterbury Region	138km	4.8

Table 2: Earthquakes used in this study.

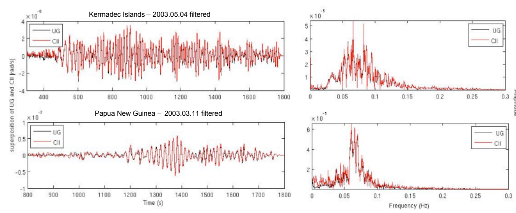

Figure 3: Superposition of rotation rate and the corresponding amplitude spectra

4 GO: Tilt rate vs. vertical acceleration

From plane wave analysis we expect similarity between horizontal components of rotation rate and vertical (or radial) components of acceleration. We are particularly interested in the tilt (rate) signal, as this may allow correction of translational observations for pollution through tilt (particularly in a strong-motion environment).

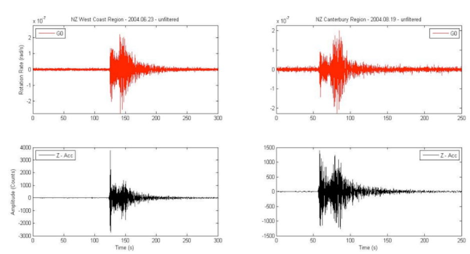

Figure 4: Comparison of rotation rate and Z-Acceleration for two local events observed with G0. Qualitatively the envelopes are similar. Unfortunately, there are still uncertainties about the absolute amplitudes of the translations, thus we have not yet investigated the magnitude of tilt estimates using translations.

5 Translation vs. Rotation

We need a correct tilt observation in order to estimate tilt-to-ring laser coupling. Here, we compare array-derived tilt (see poster S23B-0156 for array geometry) with translation-derived tilt (see S23B-0157), assuming plane P-wave propagation and known (or observation-derived) incidence angle (observations from Wettzell, Germany).

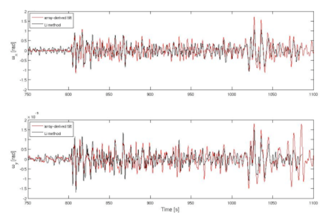

Figure 5 : Red: Tilt derived from seismic array data. Black: Tilt derived from the vertical and two horizontal components of translations. Top: x-component of tilt. Bottom: y-component of tilt. Data from a teleseismic event (Papua). Time window contains direct P-wave, P coda and P multiples. M6.3 Gibraltar event 24 February 2004.

These results suggest that – at least for teleseismic events – tilt derived from single-station translations are fairly accurate in waveform and amplitude compared to tiltmeter observations (that show amplitudes two orders of magnitudes stronger because they are sensitive to transverse accelerations) and can be compared with the direct measurement of the G0 ring laser in Christchurch (at least for P-arrivals and coda).

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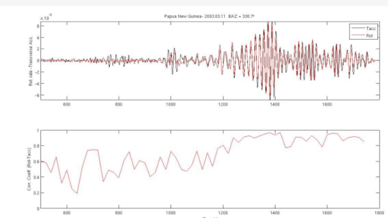

Figure 6: Top: Comparison of transverse acceleration and rotation rate in a broadband frequency range for an event in the Papua region. The waveform fit is similar to the ones reported for the Wettzell ring laser (Igel et al., 2005, 2006) but further systematic studies are necessary. Bottom: Correlation coefficient in a sliding window between rotation rate and transverse acceleration (almost one on the window containing Love waves).

Conclusions

- **G0** offers a unique opportunity to investigate "true" tilt signals in the seismic broadband range
- Detailed analysis and comparison with translation-derived tilt is only at the beginning, tilt in the P-coda may be estimated from z component analysis
- Optical rotation (tilt) sensors may play an important role in the development of six-component sensors that allow recovering the complete displacement history.