

IMAGIN'LABS CORPORATION

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November 17, 2011

Dr. Hannah Brackley
GNS Science - Te Pu Ao,
1 Fairway Drive,
PO Box 30368, Lower Hutt,
New Zealand

CC: Dr. John Beavan

Dear Dr. Brackley,


This letter is to confirm the completion of the work specified in the contract between GNS Science and Imagin'Labs Corporation dated from November 2nd, 2011. The work specified and accomplished consisted in analyzing seven LiDAR data set, for which displacement maps, strain maps, vector arrow fields, and visualization output have been delivered electronically in previous correspondence. If you have not received some of the agreed upon results, please inform us within 10 days of receiving this letter. Without further notice within this time, Imagin'Labs Corporation will consider that GNS Science has effectively received, and is satisfied with, the results of the aforementioned contract.

In accordance with GNS Science, the seven LiDAR data set processed consisted of:

- 2003-2011c
- 2005-2011c
- 2010-2011c – central extent
- 2010-2011c – northern extent
- 2010-2011c – western extent
- 2011a-2011c
- 2011b-2011c

The following pages summarize the processing and work accomplished by Imagin'Labs Corporation, along with directions for basic assessment of quality of the results. We hope you are satisfied with the products delivered, and be assured that satisfaction of our clients is very important to us.

Sincerely,



Dr. Sébastien Leprince

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Summary of work for the data sets:

- **2003-2011c**
- **2005-2011c**
- **2010-2011c - central extent**
- **2010-2011c - northern extent**
- **2010-2011c - western extent**
- **2011a-2011c**
- **2011b-2011c**

All methods were optimized to deliver best overall compromises between accuracy of results, high spatial density of measurements, low measurement uncertainty, and adequate rejection of spurious measurements. After investigating sub-pixel correlation at several scales (i.e., using correlation windows of 128x128, 64x64, 32x32, and 16x16 pixels), and after testing different filtering and correction methods, we have settled on the following procedures to extract relevant horizontal information from the gridded LiDAR data provided:

- Sub-pixel correlation using 64x64 pixel windows. Since windows are weighted by a Hanning window, this processing produces independent measurements at about every ~40 pixels. The measurements at smaller scales were too noisy to produce adequate strain measurements. Since measurements are only independent every about 40 pixels (40m) the displacement maps are delivered with a spatial sampling of 4m, which was found sufficient to visually show all the information present in the data.
- The Lidar data contains jitter artifacts due to inaccurate aircraft attitude variations. These artifacts were mostly removed by destripping, i.e., by subtracting the mean value along the direction of artifacts, considering their amplitude constant in the other directions. This assumption has proven to hold reasonably well. To avoid introducing additional artifacts from outliers in the destripping, the destripping model was estimated from heavily filtered measurements. The jitter correction was then applied to the raw measurements. Destripping was done in several directions, from up to four iterations with different azimuthal directions.
- Poor correlation values (low confidence as estimated by the correlation signal-to-noise ratio), and correlation values presenting large unphysical displacements (outliers) were discarded and replaced with 'Nan' values (missing data). In addition to removing unphysical values, measurements extracted from areas of low data coherence (such as water areas) were classified and removed to produce cleaner output.
- Resulting displacement fields were filtered using a modified version of the Non-Local mean filter. This filter preserves edges without introducing artifacts or excessive blurring. Only patterns with similar characteristics are averaged. In practice, results are much better than standard anisotropic diffusion filters. The NL-Means filter was modified to accept data with missing values, and a linear implementation was used. The 'linear implementation' takes into account the linear trend of the data in an effort to avoid biasing the gradient information from the underlying data (as opposed to simply denoising the data itself). Several parameters were tested to achieve best compromise between noise reduction and loss of spatial resolution.

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- Isolated missing values were extrapolated using a 3x3 pixel median filter. The size of the filter was kept small to maximize spatial information. Filling small gaps avoids propagating them when computing the strain and produces strain maps with fewer missing data.
- Additional filtering using the Non-Local Means filter was added in a last round using very small noise estimates (6-10cm) and large windows to allow for best rendering of the strain.
- Large zones of decorrelation were manually removed using visual inspection of the correlation quality. Doing so allows the production of better maps with large erroneous zones removed, enhancing the visibility of correct measurements.
- Strain was derived using 3x3 (12x12m) pixel windows.
- Arrow-plots were generated by averaging and sampling the displacement field measured at every 14 pixels, i.e., $14 \times 4 = 56\text{m}$. It was found to be a good compromise between readability of the results and density of the information delivered.

Some considerations about the results:

- The 2011c data showed reasonable quality regarding jitter, with accuracy comparable to the 2011b data. Both 2011b and 2011c data showed superior quality in terms of jitter compared to the other data processed.
- Conclusions reported in previous reports are reinforced with the processing of the 2011c data: the 2003, 2005, and 2011a data show large jitter residual, which could not be entirely corrected. Displacements measured from previous surveys are also measured from the study of the 2011c data, confirming the robustness of previous findings.
- Although some artifacts remain, the study of the 2011b-2011c data brings new information on the June 2011 event. The northern part, around 43.414S, 172.710E show ground displacement of up to 60-80cm. Some displacement also seemed to have been recorded around 43.529S, 172.724E, also on the order of 60-80cm. It is not clear whether lateral spreading occurred along the river as well, as potential displacements compete with jitter residual, on the order of 5-10cm.

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