IMAGIN'LABS CORPORATION

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September 2, 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 August 18th, 2011. The work specified and accomplished consisted in analyzing five 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 five LiDAR data set processed consisted of:

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

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:

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

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 typically 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).

- 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 not bias 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.

- 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.

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- 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 15 pixels, i.e., 15x4 = 60m. It was found to be a good compromise between readability of the results and density of the information delivered.

Some considerations about the results:

- It seems that the quality of the 2011a data (processed during our last contract) was limiting the measurement accuracy of the last data sets. In particular, too many artifacts were corrupting the measurements and some long wavelength artifacts were present. The 2010-2011b results are, overall, of better quality than the 2010-2011a results. More accurate horizontal information further west along the meanders of the river (2010-2011 central part) can be noticed from the 2010-2011b results, which we could not access from previous data. In the 2010-2011b Central data you will notice some long-wavelength deformation in the north-east part (172'42E,43'30S). These are likely to indicate real signal are they are confirmed on both results from 2010-2011a and 2010-2011b.

- The Northern part of the 2010-2011b results show clear deformation, which were occluded by heavy jitter on the 2010-2011a results.

- The 2010-2011b_west and 2011a-2011b do not seem to show any deformation. You will notice that the noise level is low (~10-15 cm) in many areas, so at least within that range, it is likely that no major deformation occurred. It is certainly an interesting record.

- The 2011a-2011b is not as nice as one could expect, in particular due to the high and inconsistent jitter present in the 2011a data, as mentioned earlier. The corrections were difficult to apply and some jitter residuals still exist, but the displacement uncertainty remains low anyway. Stdev is about 13-15cm on each EW and NS bands.

- Overall, these results give nice confirmation of the previous processing and add a lot of small and interesting details to the story. The 2003-2011b confirms the results measured from other data sets and overall quality seems better than previous 2003-2010a results.