The Matariki Project

www.otago.ac.nz/surveying/potree/pub/nfc/matariki

3D-Change detection
The Photogrammetry strikes back!

Pascal Sirguey
National School of Surveying, University of Otago

Mountain Research Centre
Aotearoa – New Zealand

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

XERRA

GNS SCIENCE TE PŪ AO

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

School of Surveying
Te Kura Kairūri

What do these processes have in common?

11 Nov 2017, Brewster Glacier winter accumulation

Silberhorn
30 Dec 2020
c.160,000m³

Plateau Hut

Slide: Simon Cox/GNS

Christchurch urban (re)development (2010-2018)   cccbeforeafter.digitalnewzealand.info

26 Mar 2019, Waiho River flood

14 Nov, 2016 Mw 7.8 Kaikōura earthquake   Franz Josef Glacier/Kā Roimata o Hine Hukatere in 2007 and 2021

Photo: Nicolas Cullen

Photo: Wayne Costello/Doc

Photo: Dr Katherine Pedley   Photo: Christoph Kraus   Ruapehu eruption and lahar, 1995

Stay home. Save lives.
New Zealand Government   Find out more   Unite against COVID-19

Surface elevation changes

Photo: stuff.co.nz

Photo: Thorvaldur Thordarson, GNS

Journée du bicentenaire Aimé Laussedat (1819-1907)

première annonce

À l'occasion du bicentenaire du colonel Aimé Laussedat, la Société Française de Photogrammétrie et de Télédétection et l'Association Française de Topographie organisent une journée en hommage à l'inventeur de la photogrammétrie.
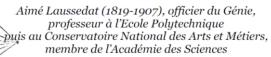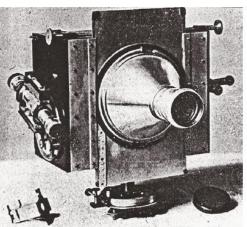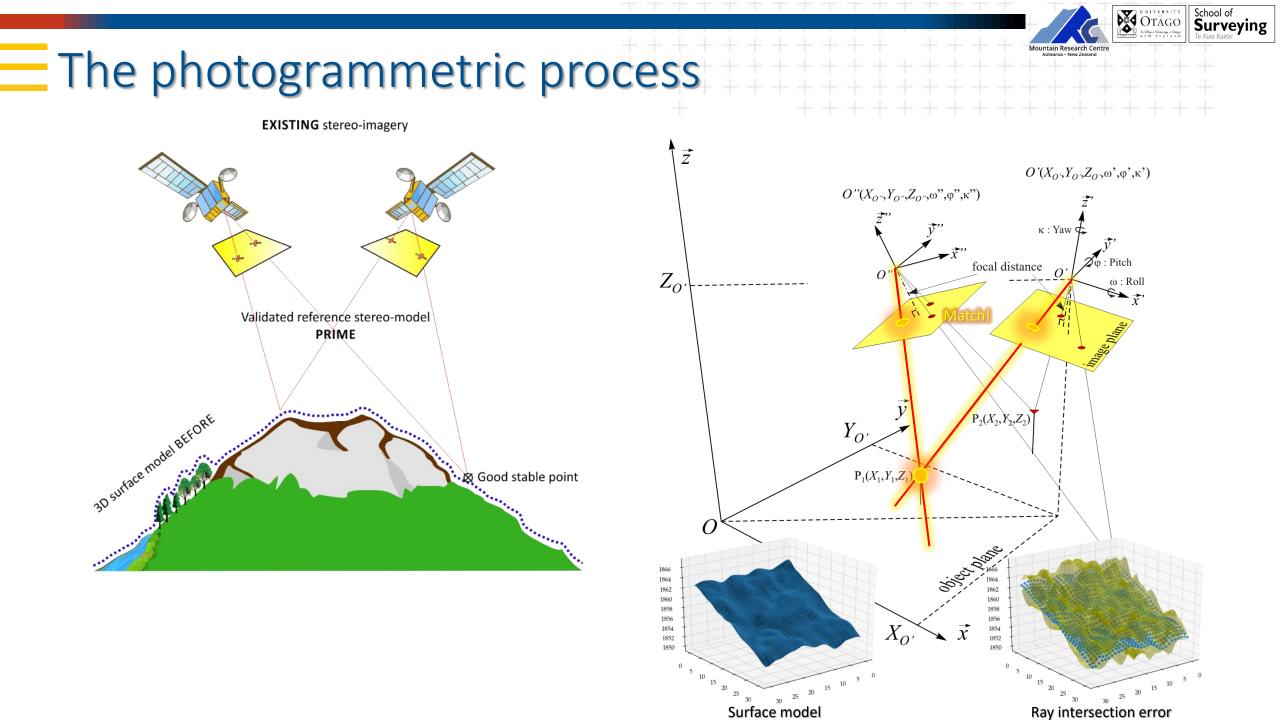
Vue prise de la station n° 1 du plan ci-dessous.

Plan du Village de Bu, près Versailles

Levé en 1861 à l'aide d'une photographie à l'échelle de 1/40 — Réduit à l'échelle de 1/120

Plan d'un village levé en 1861 à l'aide de la Photographie.

Aimé Laussedat (1819-1907), officier du Génie, professeur à l'Ecole Polytechnique puis au Conservatoire National des Arts et Métiers, membre de l'Académie des Sciences

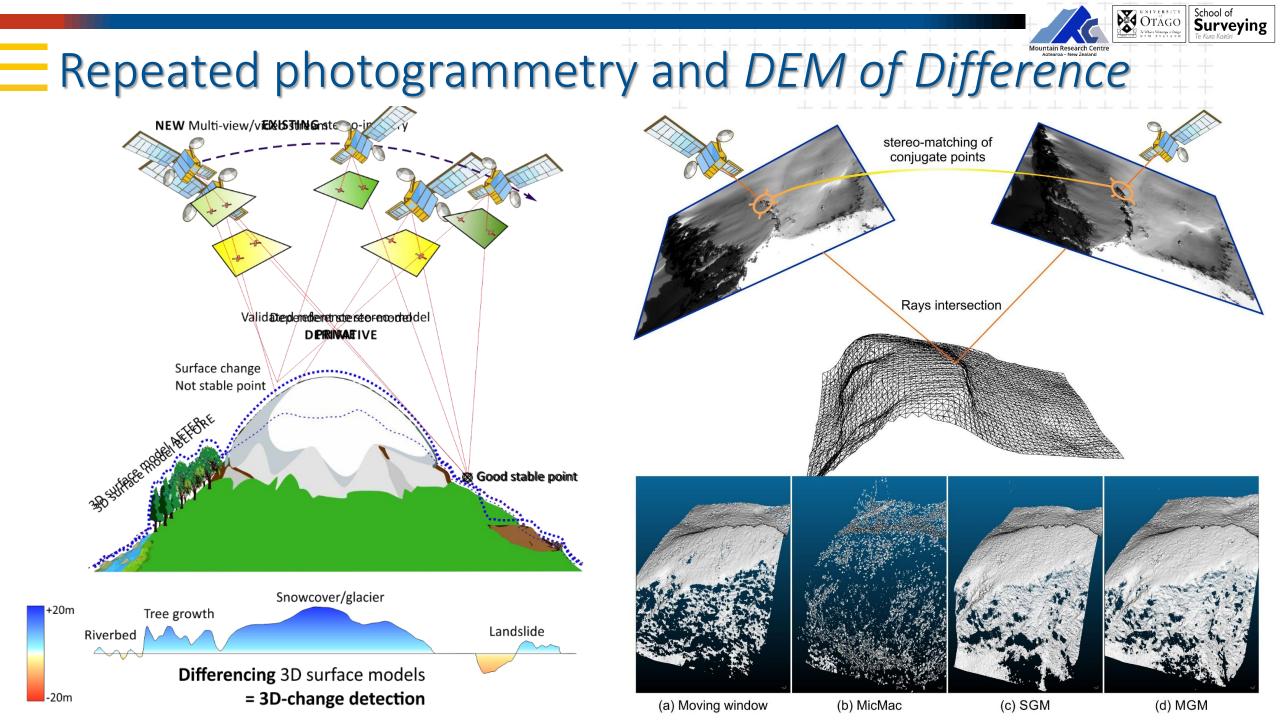Le Conservatoire National des Arts et Métiers, que Laussedat dirigea de 1881 à 1900, accueillera cette journée du bicentenaire

Informations et manifestations d'intérêt : isabelle.grujard@sfpt.fr, tel (33) 1 64 15 32 86
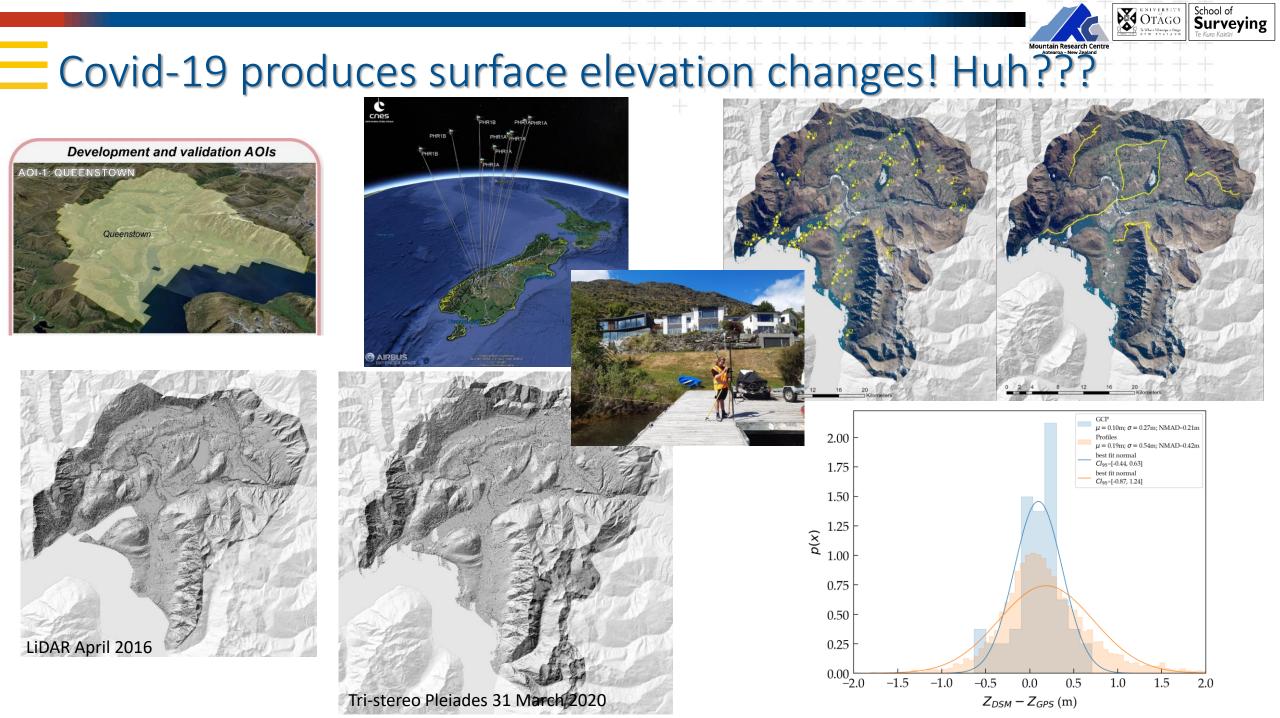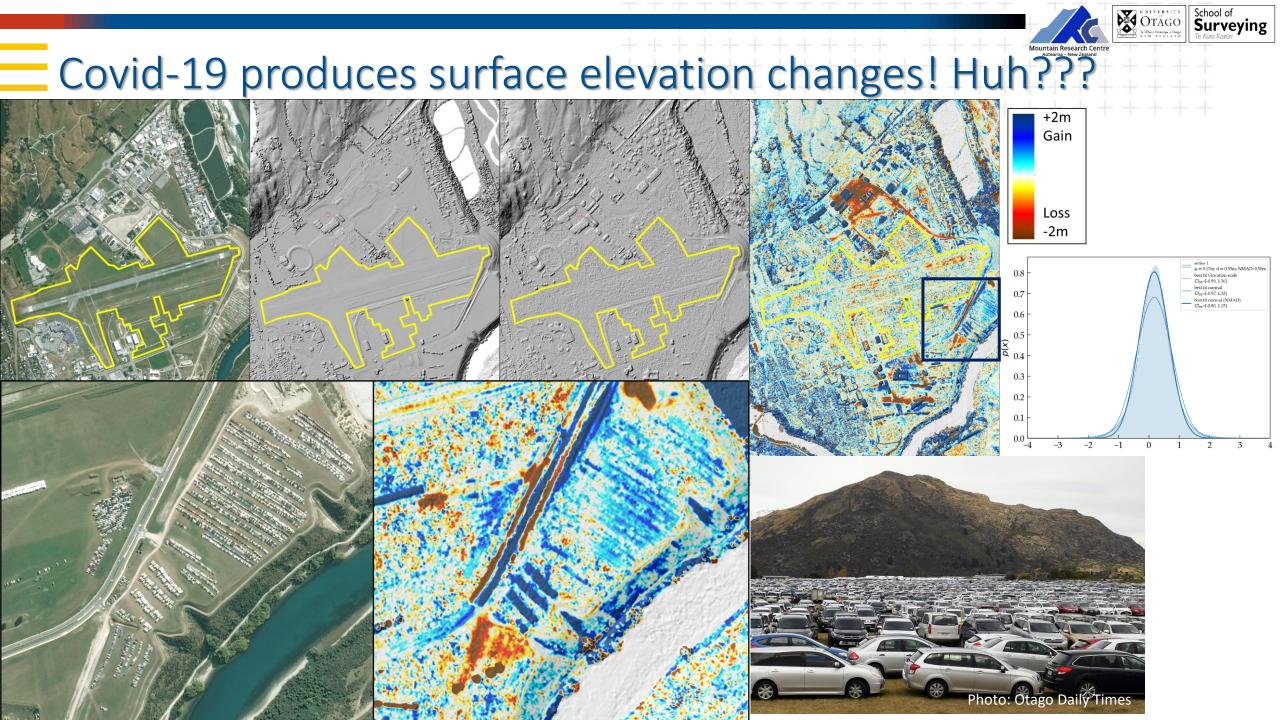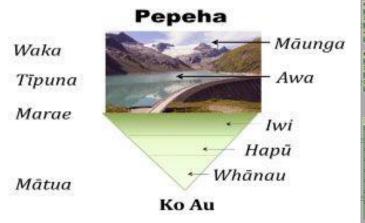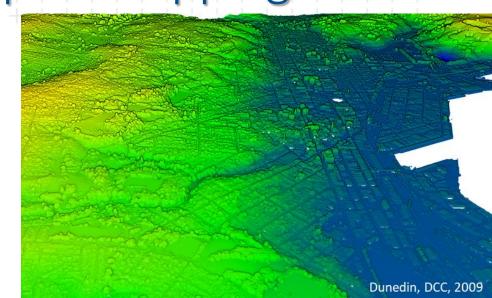Plus d'information prochainement sur www.sfpt.fr

EXISTING stereo-imagery

Validated reference stereo-model
PRIME

3D surface model BEFORE

⊗ Good stable point

$\vec{z}$

$O''(X_{O''},Y_{O''},Z_{O''},\omega'',\varphi'',\kappa'')$

$O'(X_{O'},Y_{O'},Z_{O'},\omega',\varphi',\kappa')$

$Z_{O'}$

κ : Yaw

$\vec{z}''$ $\vec{y}''$

$\vec{x}''$

$\vec{z}'$

$\vec{y}'$

φ : Pitch

ω : Roll

O'' focal distance O' $\vec{x}'$

Match!

image plane

$\vec{y}$

$P_2(X_2,Y_2,Z_2)$

$Y_{O'}$

$P_1(X_1,Y_1,Z_1)$

O

object plane

$X_{O'}$ $\vec{x}$

Surface model

Ray intersection error

Repeated photogrammetry and *DEM of Difference*

NEW Multi-view/video stereo-imagery EXISTING

Validate reference stereo-model
Dependent stereo-model
PRIMARY
DERIVATIVE

Surface change
Not stable point

3D surface model AFTER
3D surface model BEFORE

⊗ Good stable point

+20m

Riverbed
Tree growth
Snowcover/glacier
Landslide

-20m

Differencing 3D surface models
= **3D-change detection**

stereo-matching of
conjugate points

Rays intersection

(a) Moving window   (b) MicMac   (c) SGM   (d) MGM

Development and validation AOIs

AOI-1: QUEENSTOWN

Queenstown

LiDAR April 2016

Tri-stereo Pleiades 31 March 2020

Photo: Otago Daily Times

Elevation information and topographic mapping

Dunedin, DCC, 2009

- A foundation of modern societies supporting:
  - **Economic development and growth**
    - o **Inform** land suitability for use and development
    - o **Enables** the **design** of infrastructures for communication, commercial exchanges
    - o **Provide** a **base for** intelligence, strategic, tactical **decisions**
  - **Sustainability and social resilience**
    - o **Characterization** of **changes** and mass movements
    - o **Assessment** of geo-hazards and **risks**
  - **Natural character and culture**
    - o Land (*Whenua*) underpins the corpus of **Māori mythology** with a central place in people's genealogy (*Whakapapa*).
    - o NZ topographic character is an attractive asset for **tourism**

credit: wiki

credit: Pascal Sirguey

Elevation information and topographic mapping

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  - **Economic development and growth**
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      central place in people's genealogy (*Whakapapa*).
    - NZ topographic character is an attractive asset for **tourism**

- Increasing need for high quality information:
  - Navigation, recreation planning
  - Environmental modelling
    - Climatology, meteorology, hydrology, land & soils
    - Impact of sea-level rise, tsunamis
  - Spatially-aided decision making process
  - Computer Graphics Imagery (CGI)
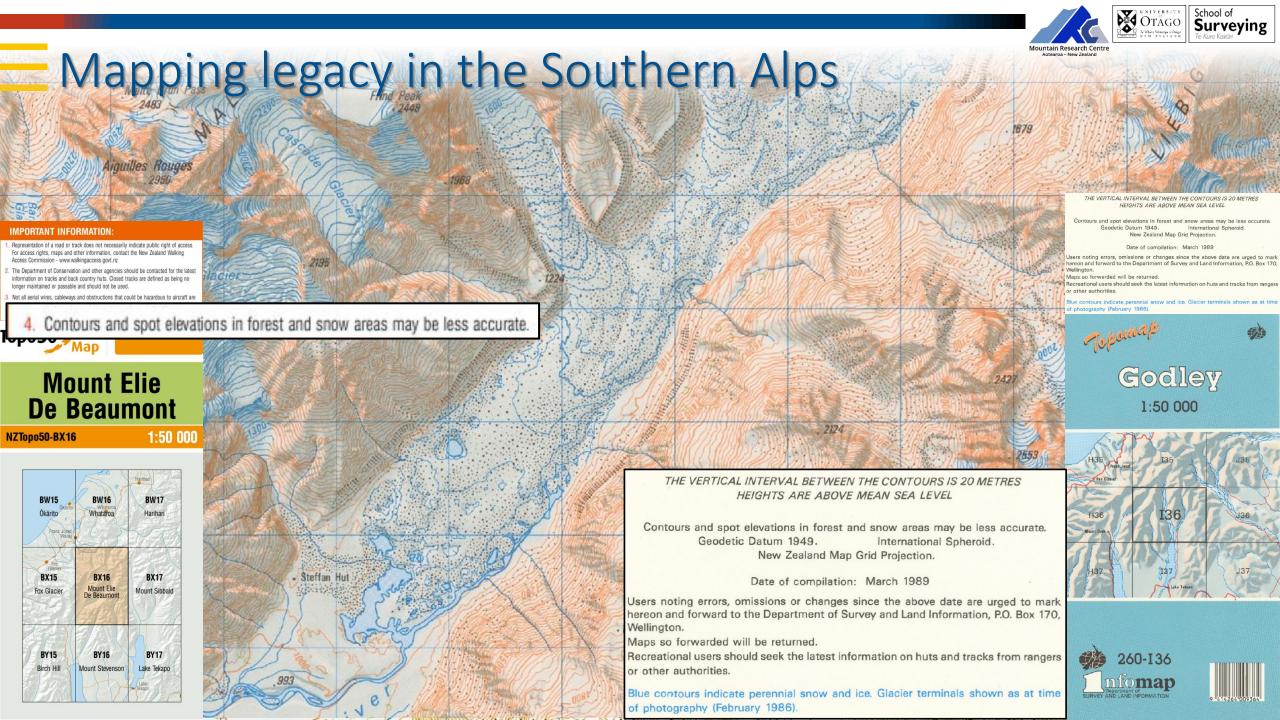
Mapping legacy in the Southern Alps
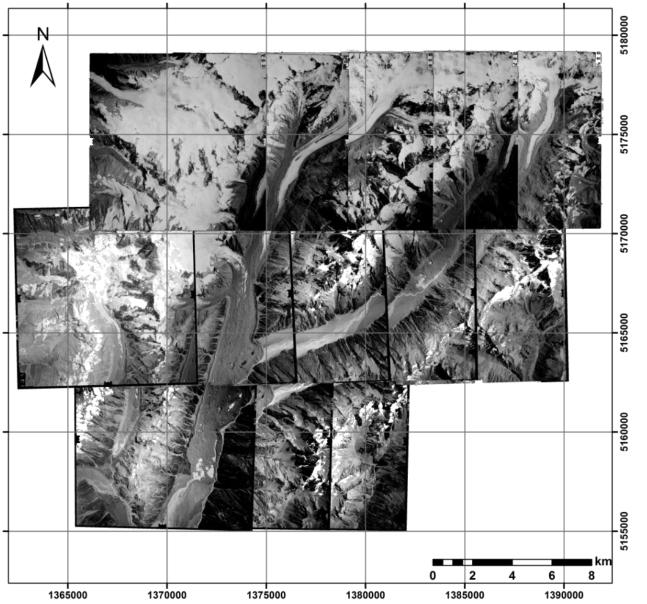
Stereo imagery and airborne photogrammetry
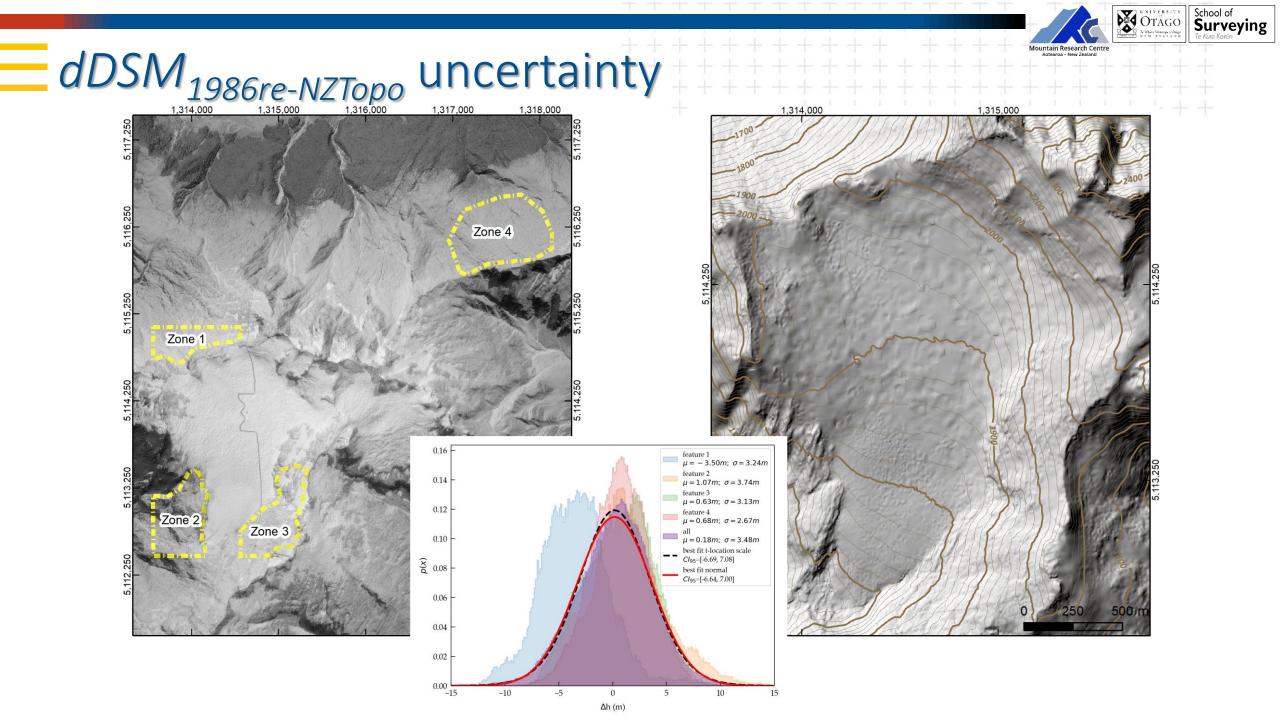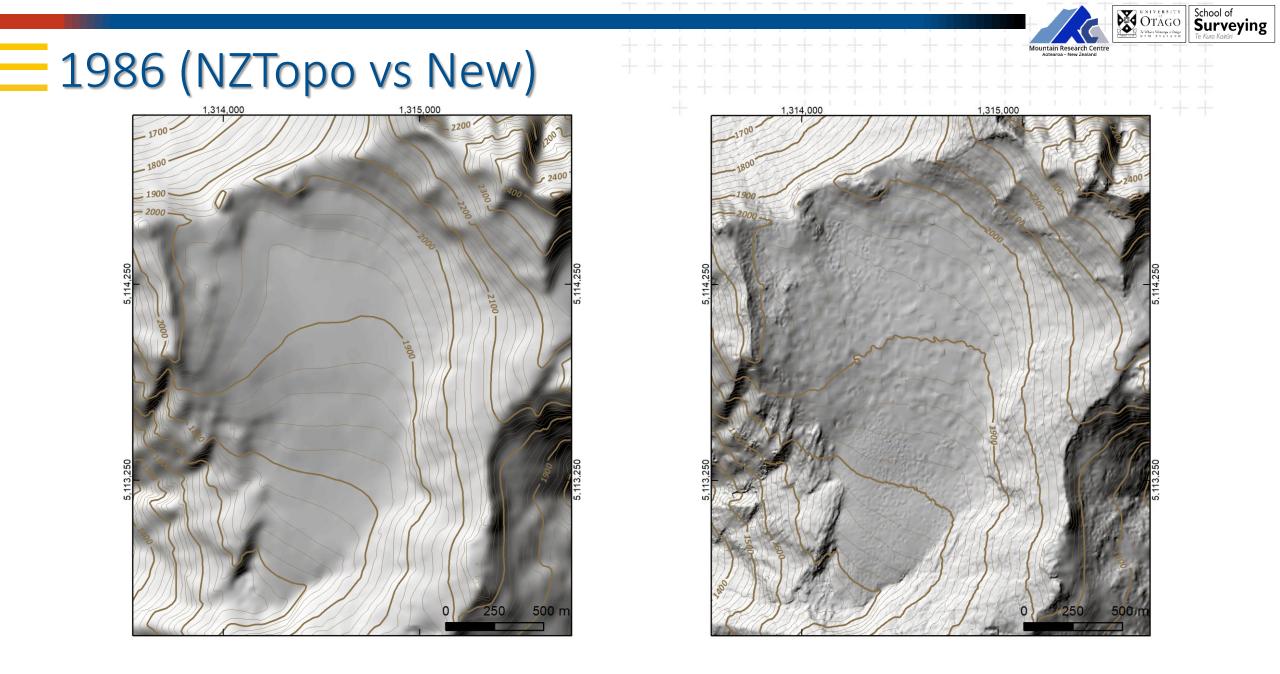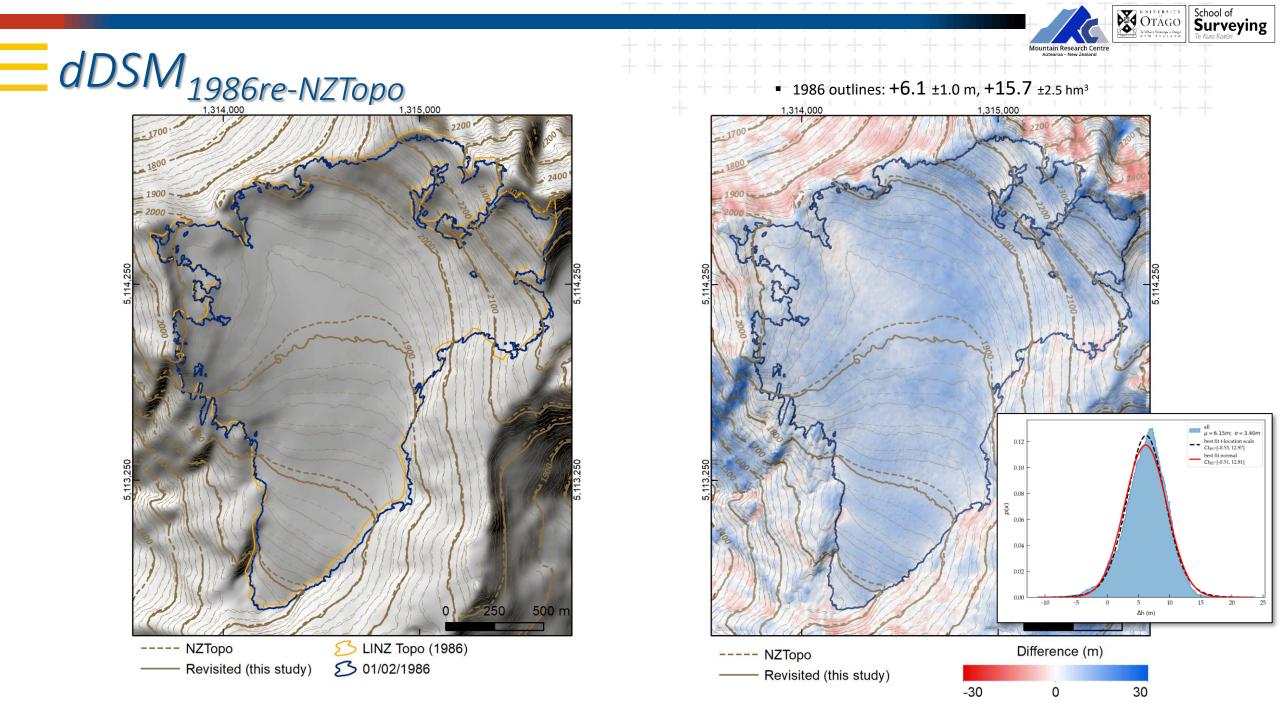

NZAM Rockwell Commander and ZEISS 15/23 camera
Wild BC1 Analytical stereoplotter   (Stephens et al., 1991)

dDSM *1986re-NZTopo*

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▪ 1986 outlines: +6.1 ±1.0 m, +15.7 ±2.5 hm³

- - - - NZTopo
——— Revisited (this study)
〜 LINZ Topo (1986)
〜 01/02/1986

- - - - NZTopo
——— Revisited (this study)

Difference (m)

-30   0   30

Mapping legacy in the Southern Alps

- **Current knowledge of the Southern Alps topography boils down to…**
  - … Analytical photogrammetric processing of **late 1980s** B&W aerial imagery
    - More recent imagery exist but not processed for topography
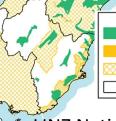
- **LINZ committed to National DEM**
  - Aerial Laser Scanner (ALS/LiDAR) co-Funded by Provincial Growth Fund
  - Uncertain repeat

- Rapid response 3D mapping capacity will:
  - Characterize regular + disruptive changes
  that constantly reshape the Alps
  - Assess environmental resources
  - Assess geohazards
  - Help understand processes
  - Refine modelling frameworks

- Contribute to improve resilience

Historic aerial photo surveys
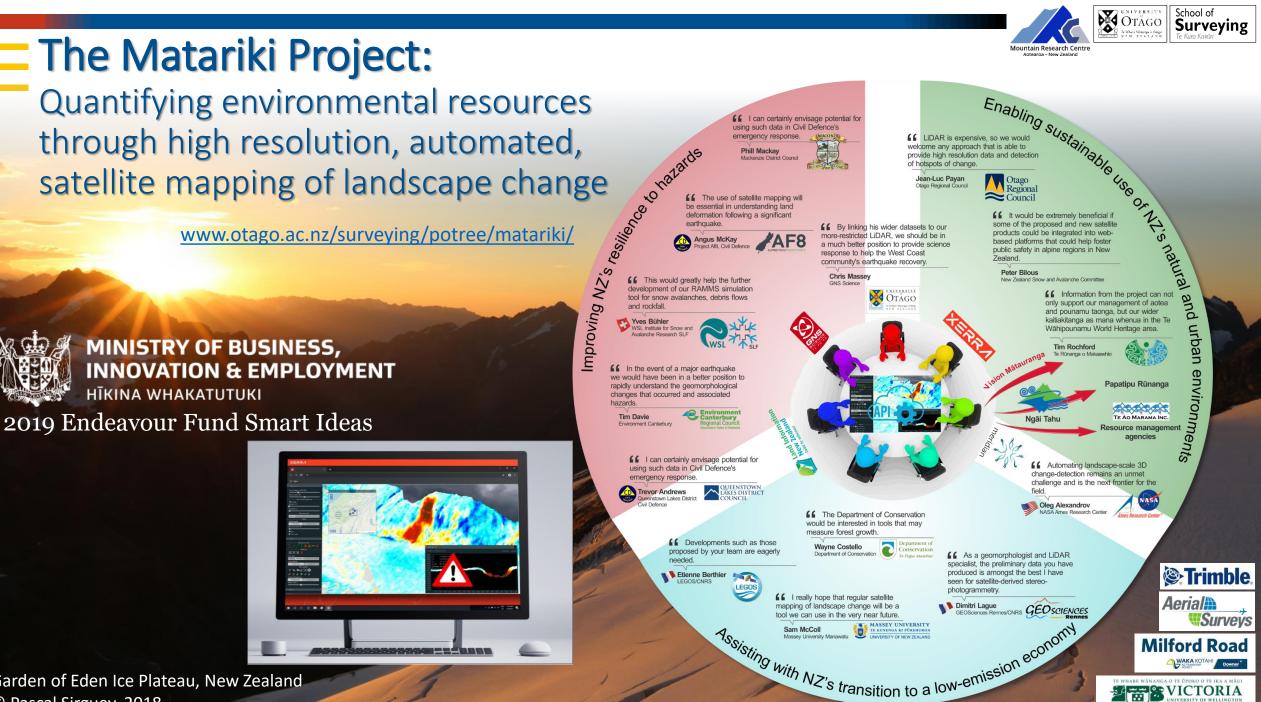
Available now
Coming soon - see below
Surveys planned or in progress
No national data available or planned
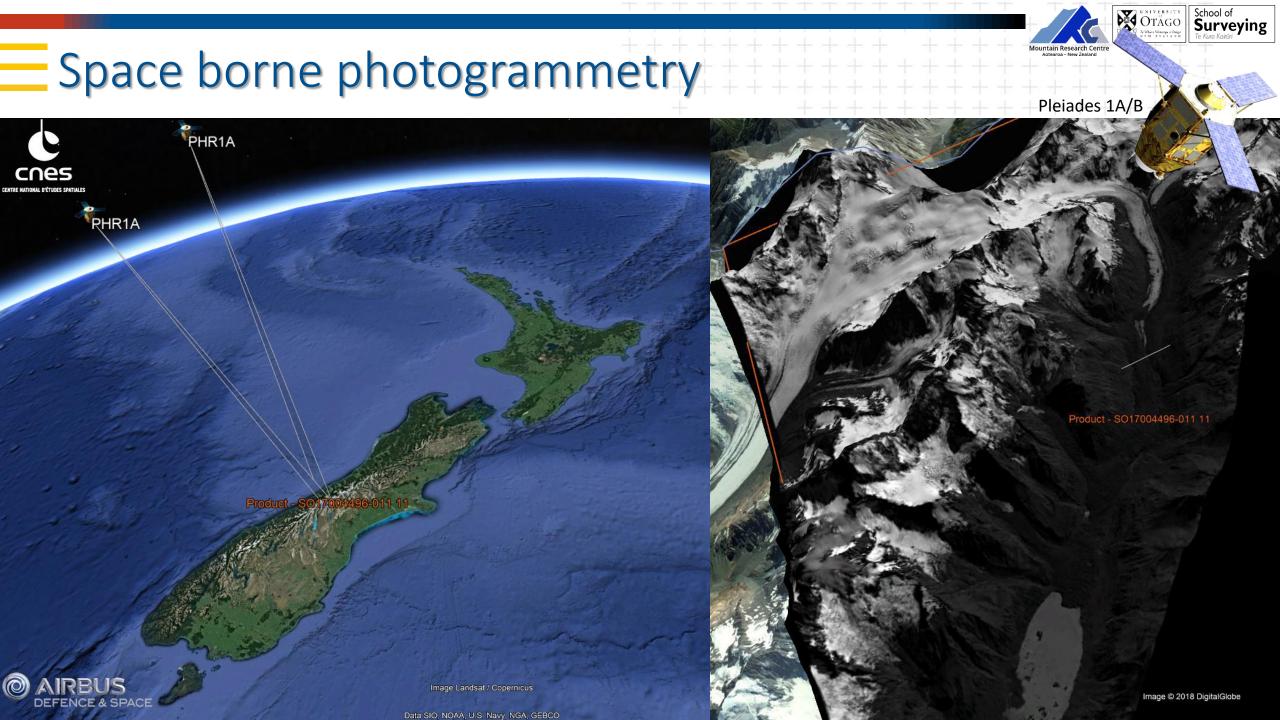
LINZ National LiDAR coordination (available + planned)

LINZ orthophoto mosaic (last visited Aug 2021)

The Matariki Project:
Quantifying environmental resources through high resolution, automated, satellite mapping of landscape change

www.otago.ac.nz/surveying/potree/matariki/

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2019 Endeavour Fund Smart Ideas

Garden of Eden Ice Plateau, New Zealand
© Pascal Sirguey, 2018

Improving NZ's resilience to hazards

"I can certainly envisage potential for using such data in Civil Defence's emergency response."
Phill Mackay
Mackenzie District Council

"The use of satellite mapping will be essential in understanding land deformation following a significant earthquake."
Angus McKay
Project Af8, Civil Defence — AF8

"This would greatly help the further development of our RAMMS simulation tool for snow avalanches, debris flows and rockfall."
Yves Bühler
WSL Institute for Snow and Avalanche Research SLF — WSL SLF

"In the event of a major earthquake we would have been in a better position to rapidly understand the geomorphological changes that occurred and associated hazards."
Tim Davie
Environment Canterbury — Environment Canterbury Regional Council

"I can certainly envisage potential for using such data in Civil Defence's emergency response."
Trevor Andrews
Queenstown Lakes District Civil Defence — Queenstown Lakes District Council

Enabling sustainable use of NZ's natural and urban environments

"LiDAR is expensive, so we would welcome any approach that is able to provide high resolution data and detection of hotspots of change."
Jean-Luc Payan
Otago Regional Council

"By linking his wider datasets to our more-restricted LiDAR, we should be in a much better position to provide science response to help the West Coast community's earthquake recovery."
Chris Massey
GNS Science

"It would be extremely beneficial if some of the proposed and new satellite products could be integrated into web-based platforms that could help foster public safety in alpine regions in New Zealand."
Peter Bilous
New Zealand Snow and Avalanche Committee

"Information from the project can not only support our management of aotea and pounamu taonga, but our wider kaitiakitanga as mana whenua in the Te Wāhipounamu World Heritage area."
Tim Rochford
Te Rūnanga o Makaawhio

Papatipu Rūnanga

Resource management agencies

Vision Mātauranga

Ngāi Tahu

meridian

"Automating landscape-scale 3D change-detection remains an unmet challenge and is the next frontier for the field."
Oleg Alexandrov
NASA Ames Research Center

"The Department of Conservation would be interested in tools that may measure forest growth."
Wayne Costello
Department of Conservation

"Developments such as those proposed by your team are eagerly needed."
Etienne Berthier
LEGOS/CNRS

"I really hope that regular satellite mapping of landscape change will be a tool we can use in the very near future."
Sam McColl
Massey University Manawatu

"As a geomorphologist and LiDAR specialist, the preliminary data you have produced is amongst the best I have seen for satellite-derived stereo-photogrammetry."
Dimitri Lague
GEOSciences Rennes/CNRS

Assisting with NZ's transition to a low-emission economy

Land Information New Zealand

API

Mountain Research Centre
Aotearoa – New Zealand

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School of Surveying
Te Kura Kairūri

Trimble
Aerial Surveys
Milford Road — WAKA KOTAHI / Downer
VICTORIA UNIVERSITY OF WELLINGTON — TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI

Pleiades 1A/B

Effective 3D-CD needs dense and accurately co-registered DSMs

- Hillary Ridge landslide 14 July 2014 (Cox et al., 2015)

Hillary Ridge landslide 14 July 2014

C2C absolute distances[<150] (Z)

48.231201
43.673401
39.115601
34.557800
30.000000
22.500000
15.000000
7.500000
0.000000
-7.500000
-15.000000
-22.500000

University of Otago
PGO/PLEIADES © CNES, 2017, distribution Airbus DS, all rights rese

The Matariki Project

The Matariki Project, Areas of Interest

New Zealand

Davos (snow)

Kilimanjaro (glaciers)

Avalanche modelling (Aubrey Miller, PhD topic)

Credit: Milford Road Alliance

© University of Otago/NZAM (2007)/PGO/© CNES
distribution Airbus DS

Te Koroka/Slip Stream tōpuni in Dart Valley
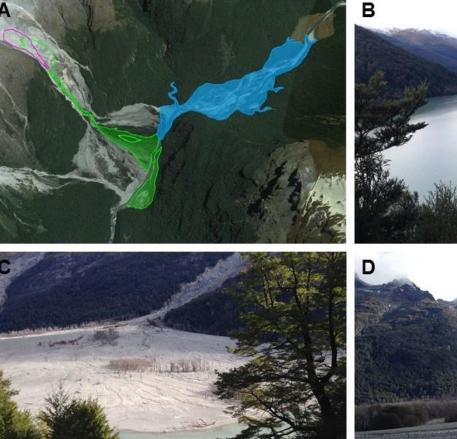
Dart River landslide

Mount Ferguson
2480 m

New Zealand reshaping topography

- Dart River, January 2013

Cox et al. (2014)
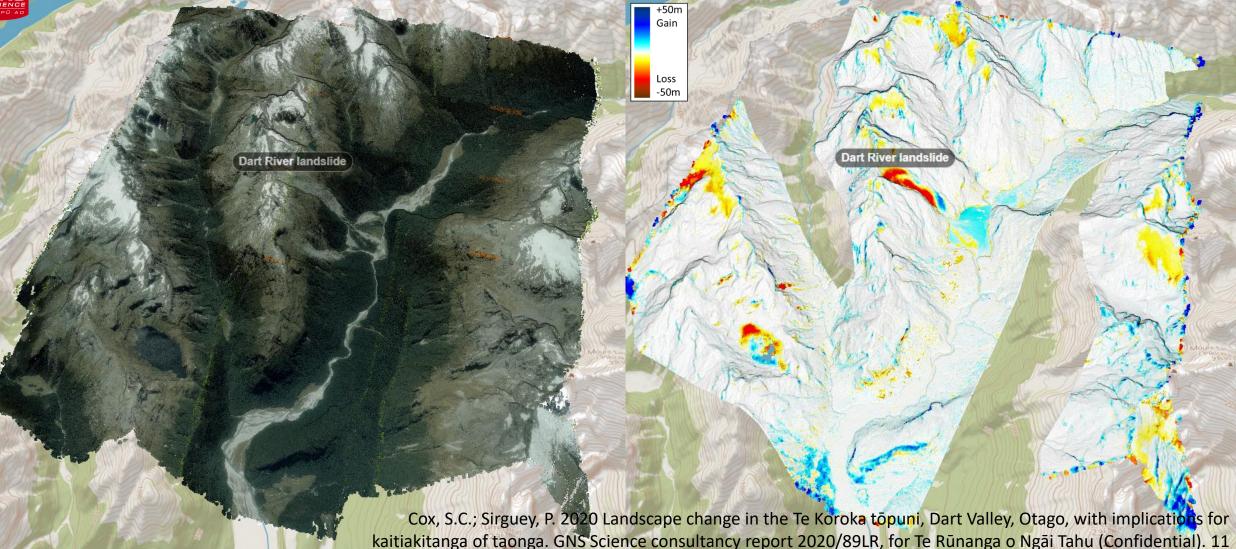
http://www.travelinggeologist.com/2015/02/life-in-the-slip-stream-new-zealand-with-simon-cook/

Te Koroka/ Slip Stream tōpuni in Dart Valley

Cox, S.C.; Sirguey, P. 2020 Landscape change in the Te Koroka tōpuni, Dart Valley, Otago, with implications for kaitiakitanga of taonga. GNS Science consultancy report 2020/89LR, for Te Rūnanga o Ngāi Tahu (Confidential). 11

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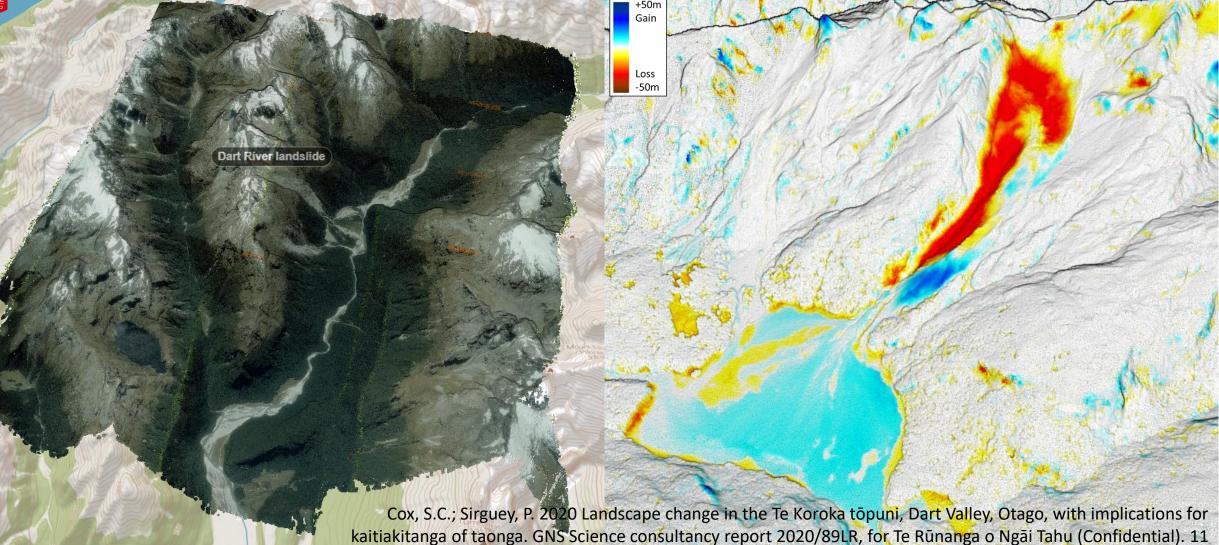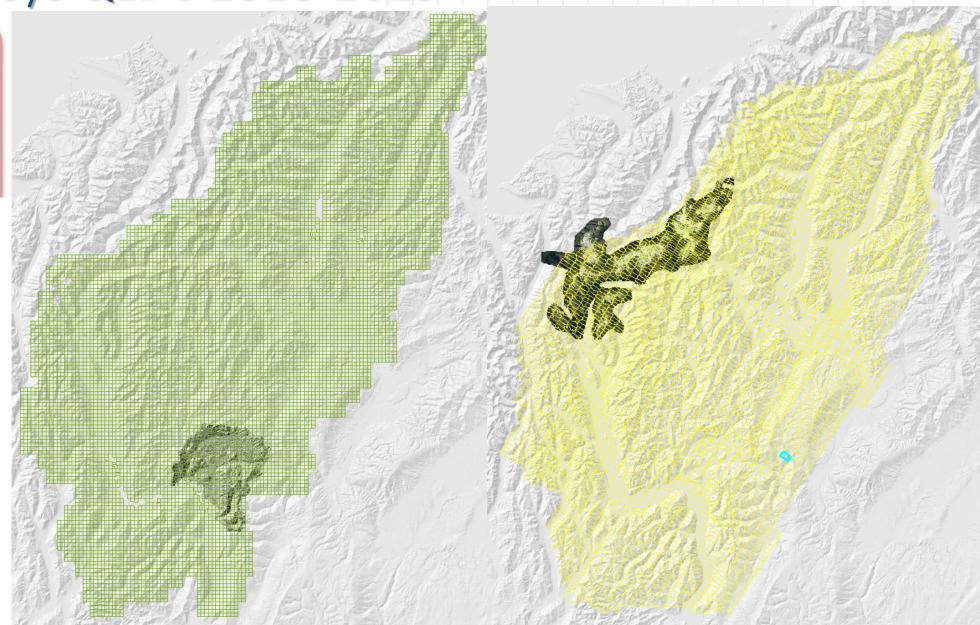
Aerial Surveys QLDC 2018-2019
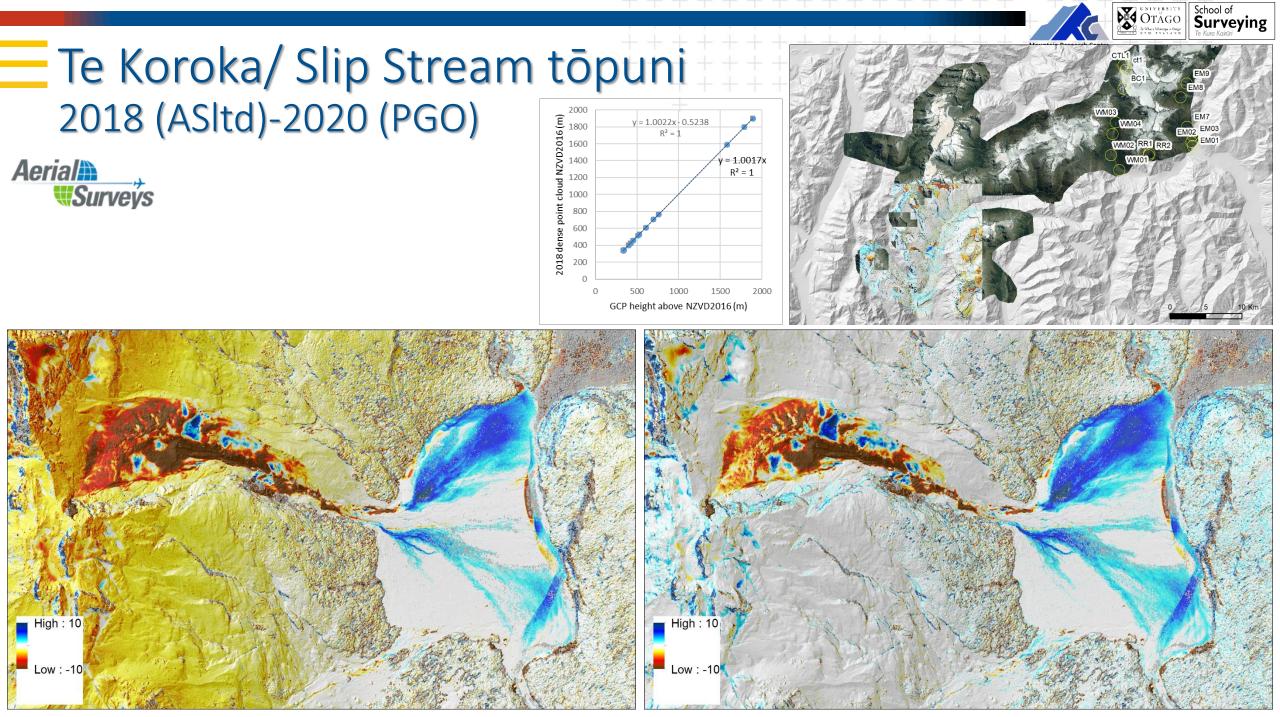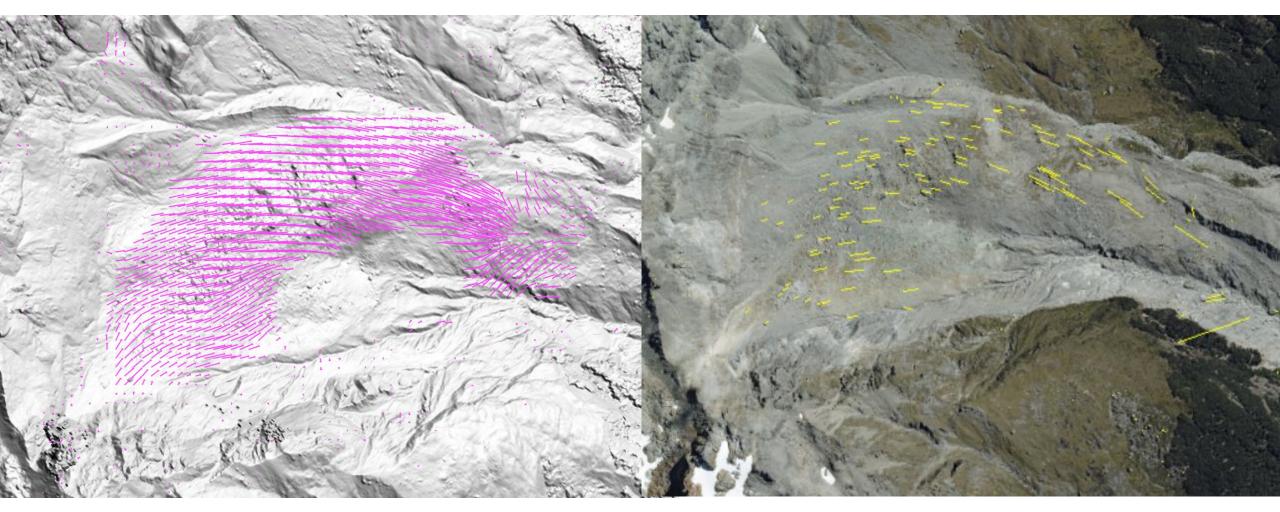
Te Koroka/ Slip Stream tōpuni
2018 (ASltd)-2020 (PGO)

Te Koroka/ Slip Stream tōpuni 2018 (ASltd)-2020 (PGO)

- Carle, E. 2021, **Tracking Features** on a DTM using **Optical Flow** Technique. SURV509 project report, 19pp.

Cox, S.C.; Sirguey, P. 2020 Landscape change in the Te Koroka tōpuni, Dart Valley, Otago, with implications for kaitiakitanga of taonga. GNS Science consultancy report 2020/89LR, for Te Rūnanga o Ngāi Tahu (Confidential). 11

Fox Glacier/Te Moeka o Tūawe Valley

Stuff.co.nz

Torrential rain causes chaos on the West Coast

Flood water surges down the Fox River on the West Coast after extreme weather, in March 2019. A New Zealand Transport Agency (NZTA) statement ...
26/03/2019

AOI-2: WEST COAST

Franz Josef

Fox Glacier/Te Moeka o Tūawe Valley

- 26 March 2019: 1 in 100-year flood (600mm rain) gouged out legacy Landfill

Credit: DOC, CC BY 4.0

Westland District Council/Stuff

Westland District Council/Stuff

Fox Glacier/Te Moeka o Tūawe Valley

"We used a 90 tonne digger to build the rock wall - some of the rocks are 100 tonnes each, so that's stopped more rubbish coming away." Rosco Moore, RNZ, 16 January 2021

"We will remove the 14,000 cubic metres of rubbish" Rosco Moore, RNZ, 16 January 2021

100 m

Data credit: Matariki Project, University of Otago/PLEIADES © CNES (2020,2021), distribution Airbus DS

Fox Glacier/Te Moeka o Tūawe Valley

"We will remove the 14,000 cubic metres of rubbish" Rosco Moore, RNZ, 16 January 2021

100 m

Fox Glacier/Te Moeka o Tūawe Valley

15,506 m³

"We will remove the 14,000 cubic metres of rubbish" Rosco Moore, RNZ, 16 January 2021

5m

-5m

100 m

Virtual GCP with computer vision
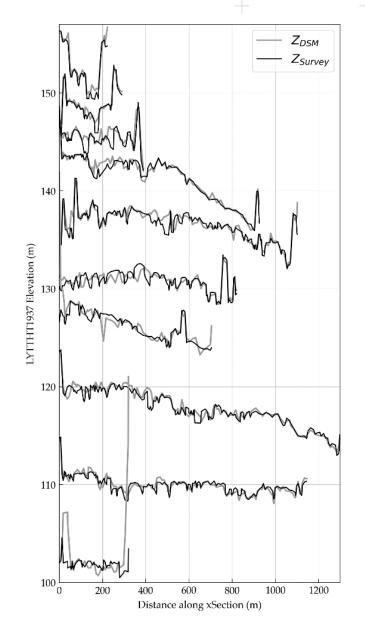
- Zareei et al. (2021) Virtual ground control for survey-grade terrain modelling from satellite imagery, submitted to ICCV2021.
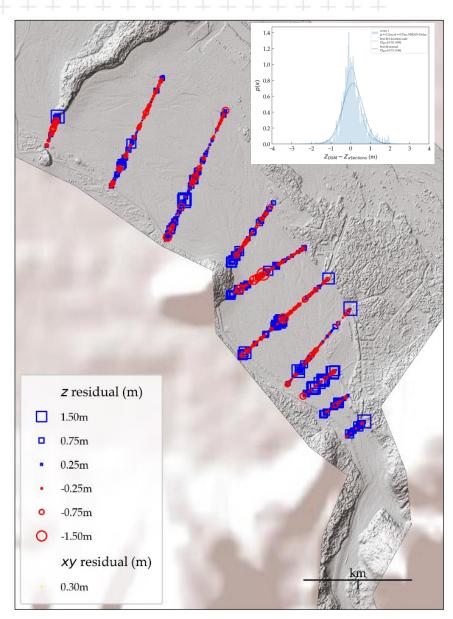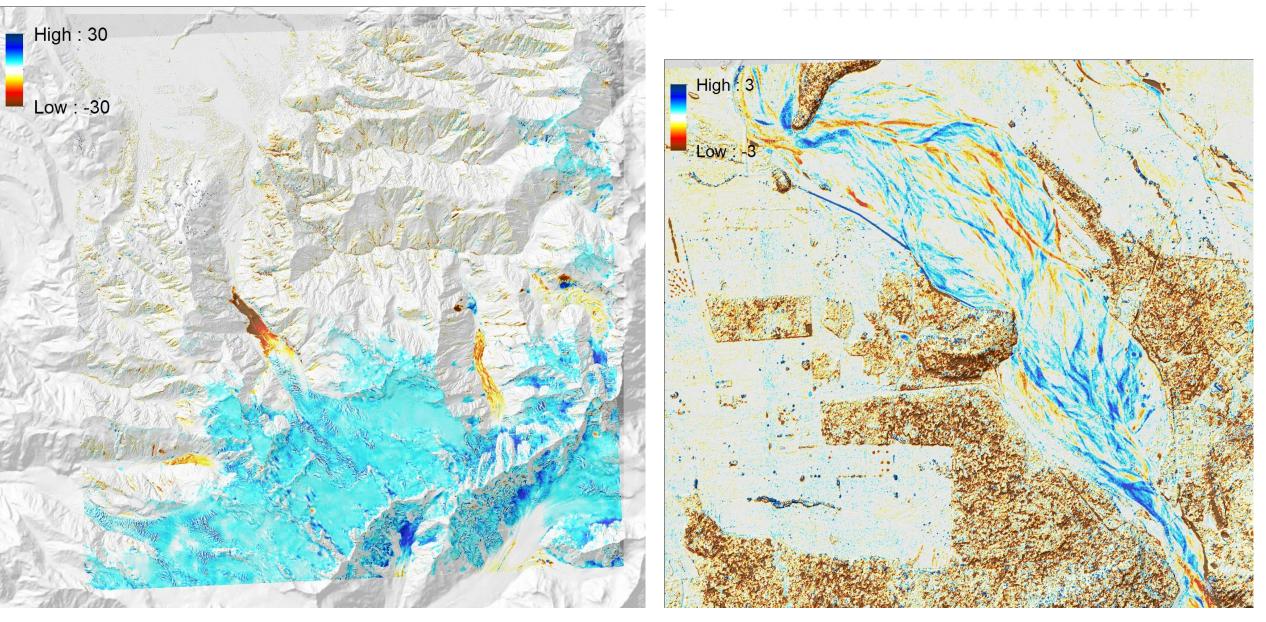
1/04/2020

18/03/2021

5 Km

Table 1: Number of point matched by ASP *(number of cross-matches)*

	Right Ref	Left Source	Right Source
Left Ref	4519	563 *(124)*	328 *(165)*
Right Ref		486 *(124)*	516 *(165)*
Left Source			2220

Method	No. of Points			mean (m)			rms (m)			DSMtest-DSMexpert	
	VGCP	CP	TP	Easting	Northing	Height	Easting	Northing	Height	mean (m)	std (m)
Direct geo-referencing	NA	12	0	-1.61	-0.94	-0.32	1.61	0.95	0.34		
							planimetric 1.87			-0.25	1.73
VGCP-BBA (proposed method)	124 (left src) 165 (right src)	12	2220	-0.10	-0.47	-0.11	0.15	0.51	0.39		
							planimetric 0.53			-0.05	0.55

3m

-3m

5 Km

2012-2014 Franz Josef

Fox Glacier/Te Moeka o Tūawe Valley

28/03/2019

AOI-2: WEST COAST

Franz Josef

Alpine Garden (Fox Glacier Valley)
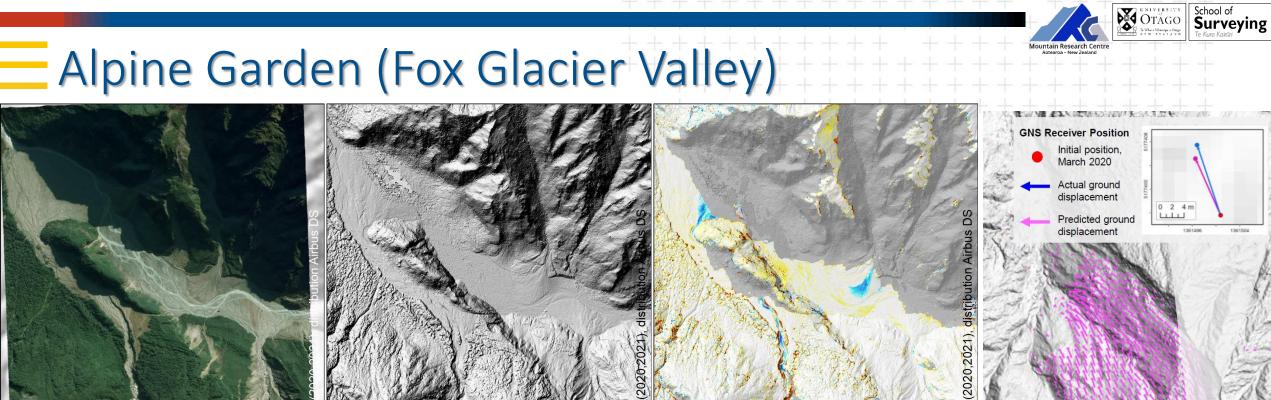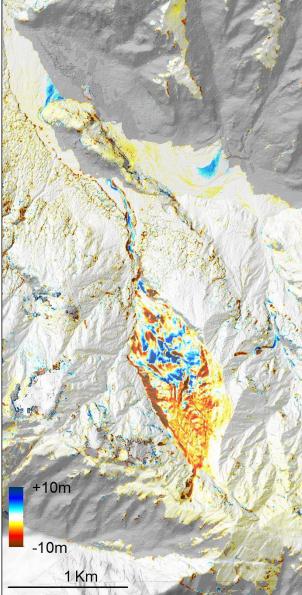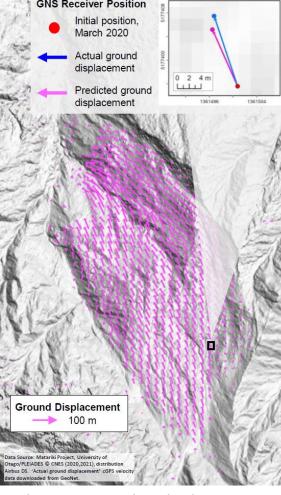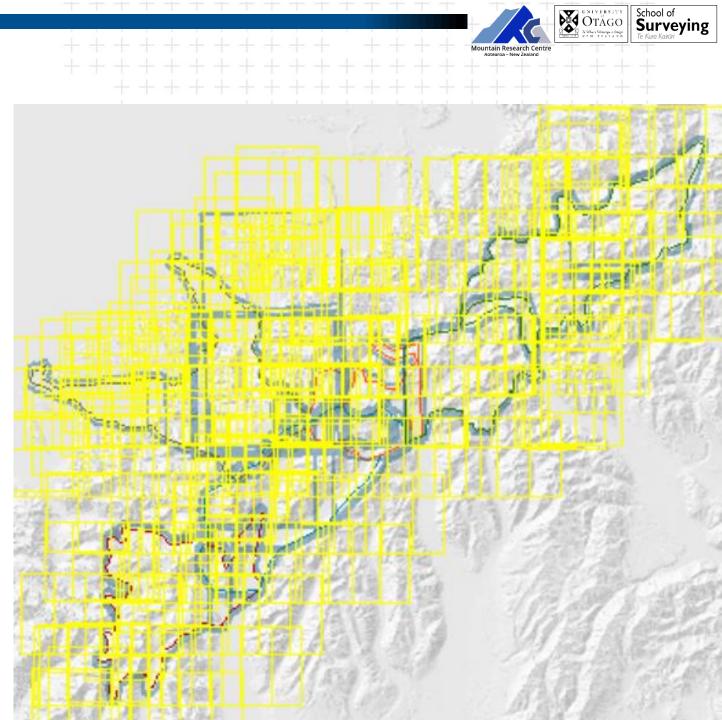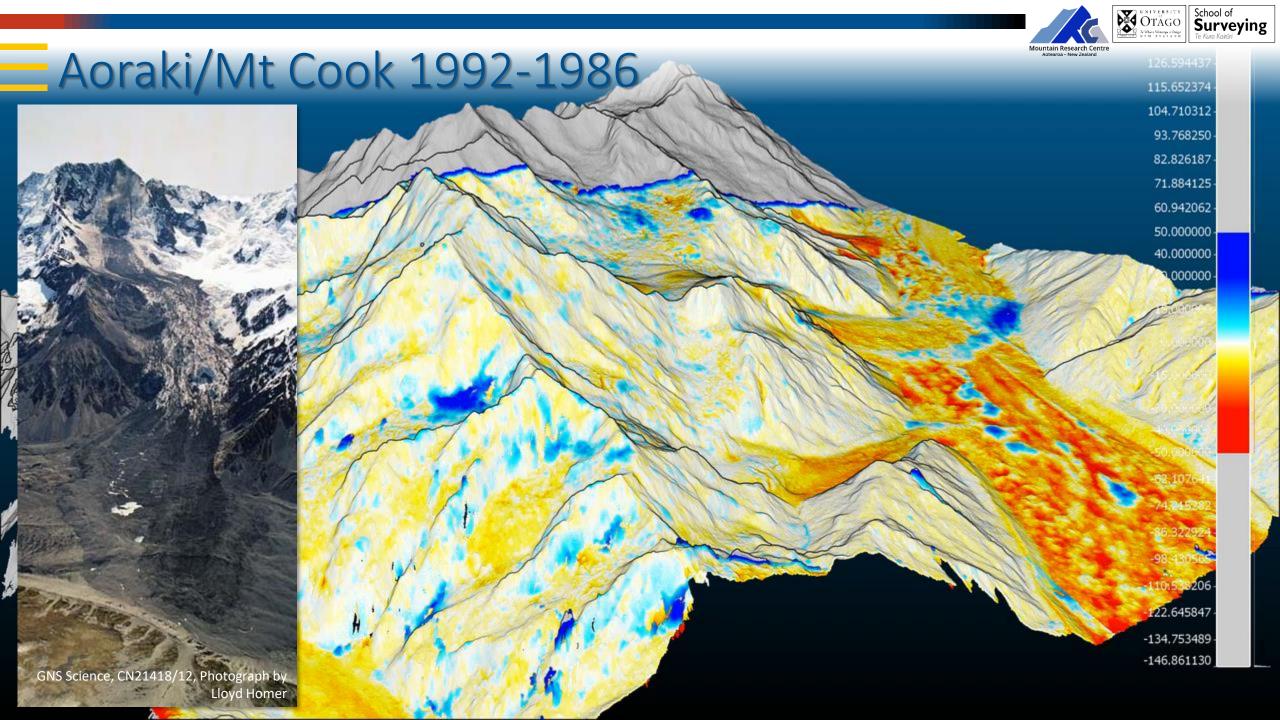
Carle, E. 2021, Resolving landscape dynamics in the Fo Glacier/ Te Moeka o Tūawe catchment with remote sensing and 3D change detection. Poster @ Geography Postgraduate Symposium
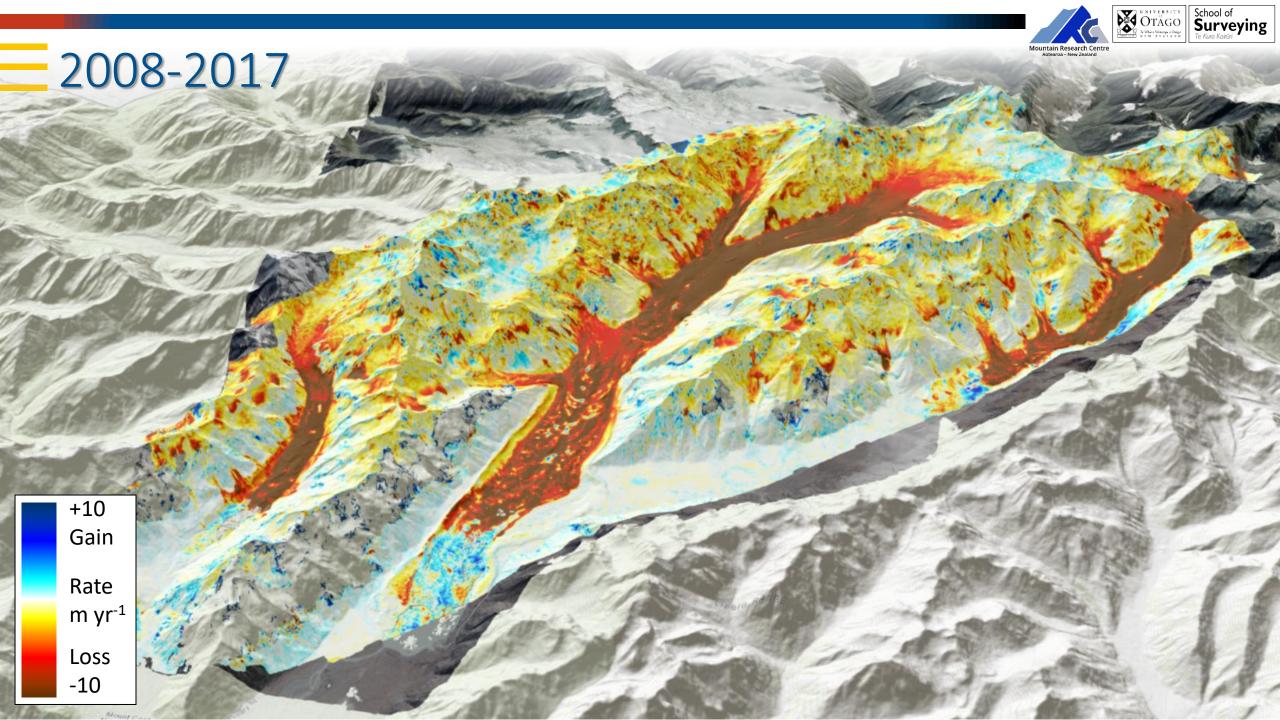
Central Southern Alps

- Satellite Image block from
  - 2012, 2014 (WC)
  - 2017 (Mt Cook, GoEA)
  - 2018 (Sierra Naumann, Two Thumb)
  - 2020, 2021 (WC)
- Aerial image block from
  - 2 Nov 2008 (NZAM, RC30)
- Aerial data 1984-1988
  - (NAZM for NZMS260, Zeiss RMK)

Aoraki/Mt Cook, 14 December 1991

Sirguey *et al.* (2014)

(credit: Ian Owens)

3724 m
3723.99 m ±0.51 (95%)

GNS Science, CN21418/12, Photograph by Lloyd Homer

Aoraki/Mt Cook 1992-1986

GNS Science, CN21418/12, Photograph by Lloyd Homer

Murchison Hut 2017-2008
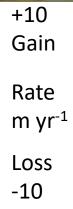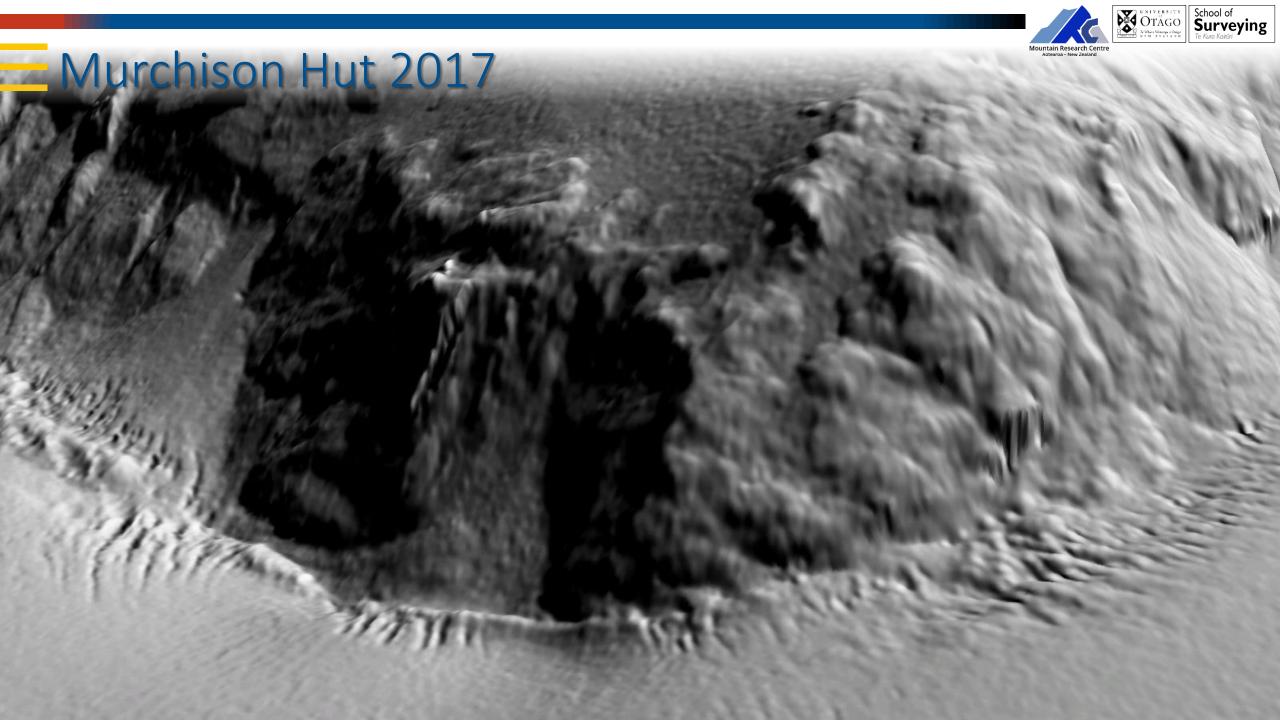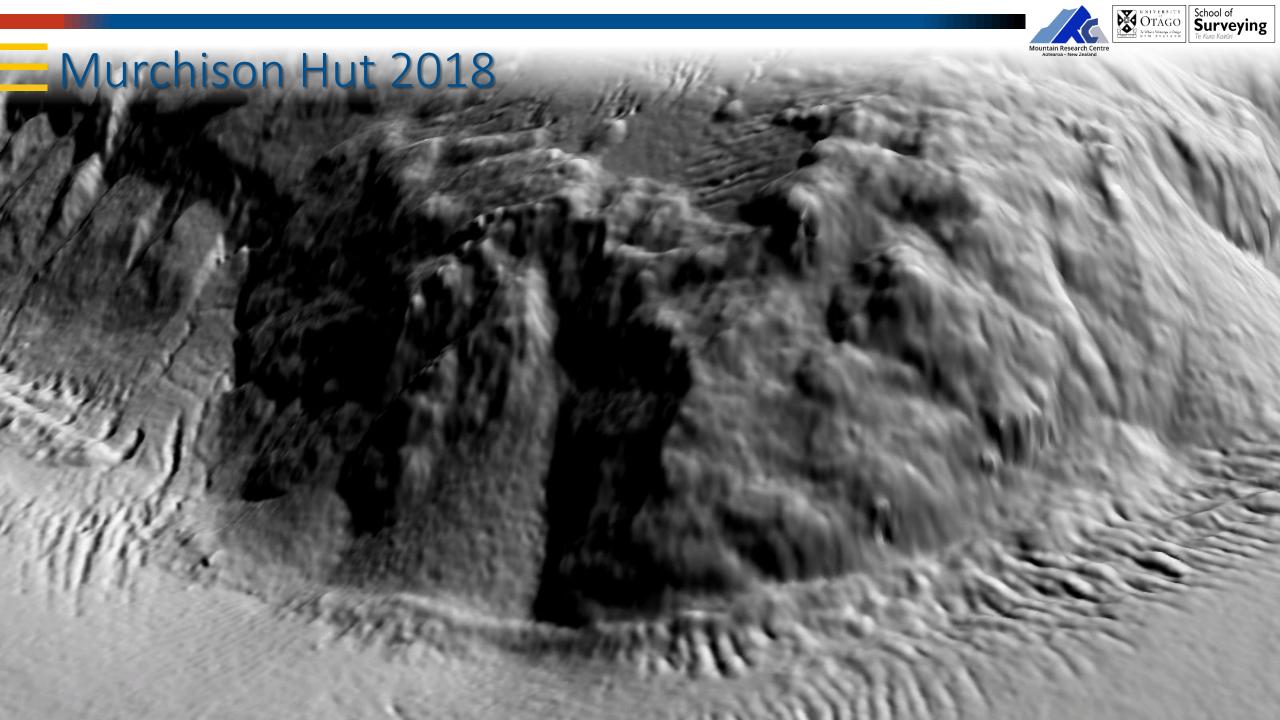
Murchison Hut 2018-2017
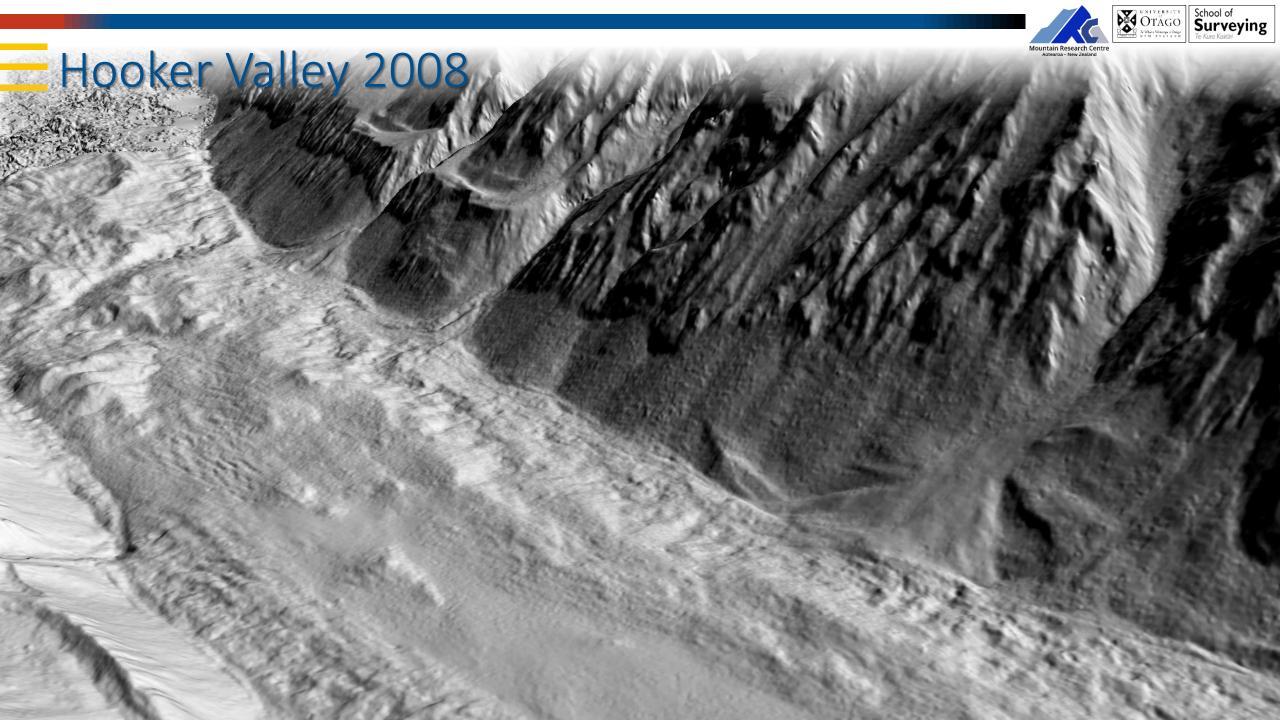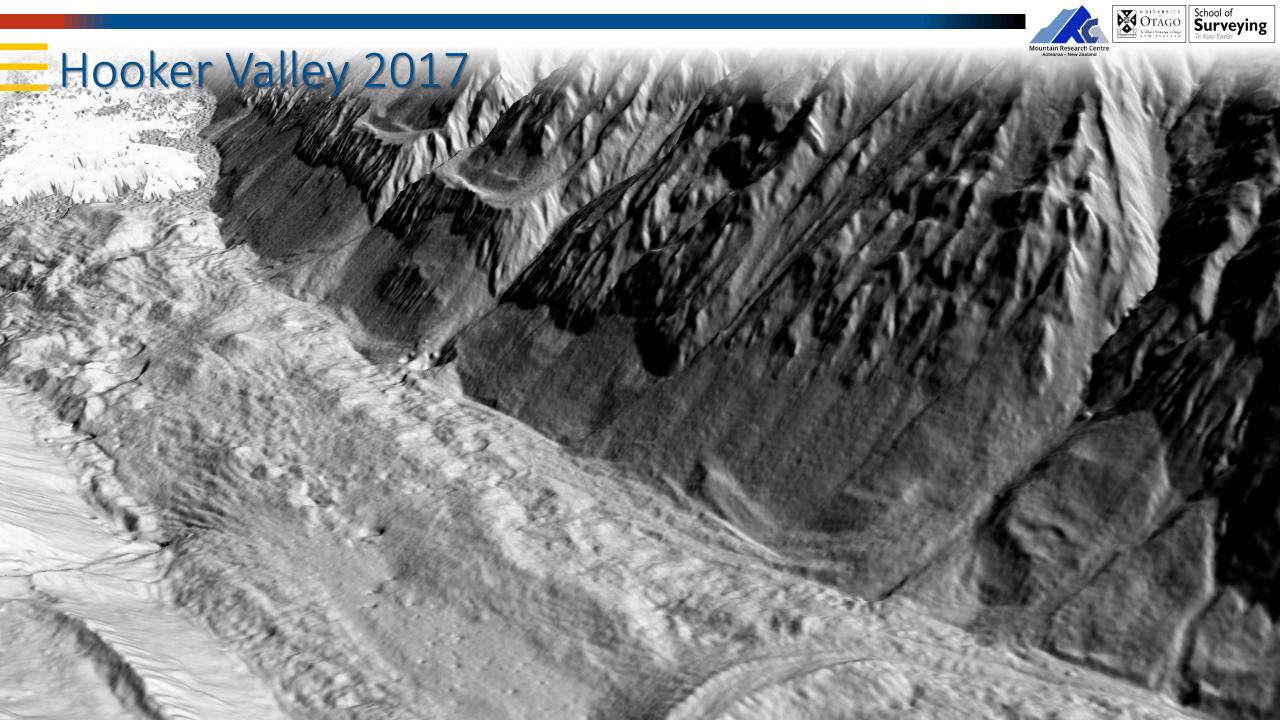
Murchison Hut 2018

Hooker Valley spreading

Hooker Valley spreading

Hooker Valley 2008

Hooker Valley 2017

Murchison Valley spreading

Murchison Valley spreading

Murchison Valley 2017
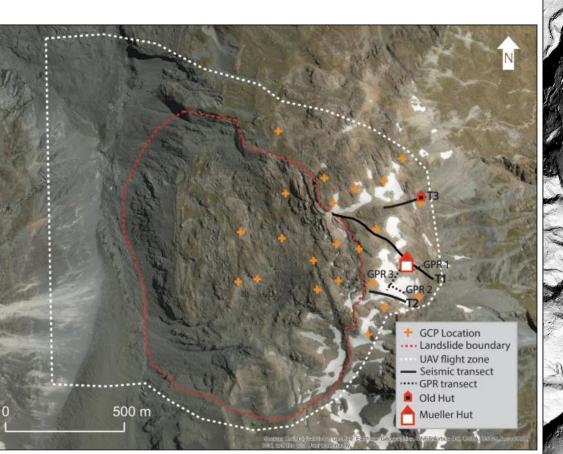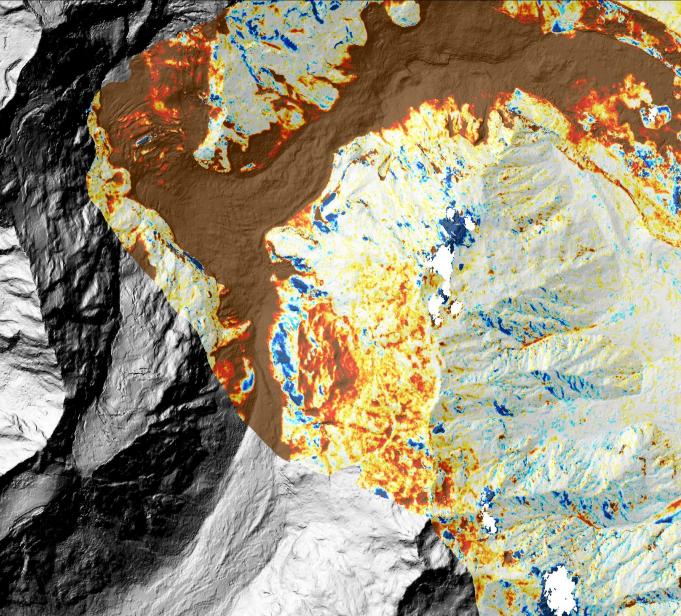
2008-2018 Mueller hut

Codi et al. (2020), Landslides, https://doi.org/10.1007/s10346-019-01316-2
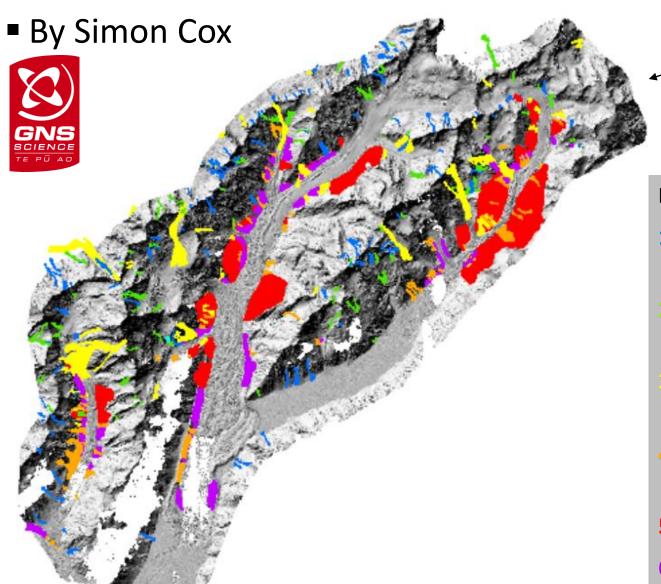
Landslide Inventory: by type

- By Simon Cox

393 km^2 AOI
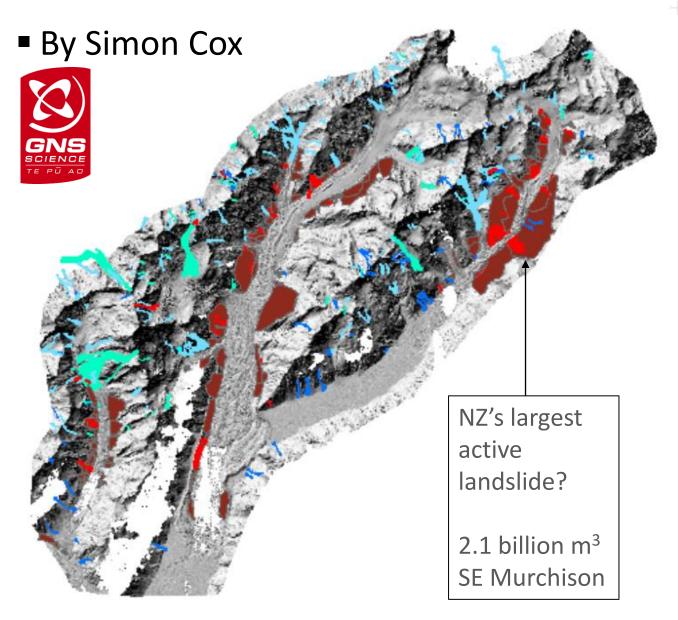
10.5% active landslide
4.6% 'hazardous' (Type 1-4) landslides
in < 1 decade (3010 days)
Daily Pr area affected by hazard ~ 10^{-5}

LANDSLIDES (n=574) BY TYPE

1. **slopewash/debris flow n=161**
   (water-course driven, or saturated colluvium collapse)

2. **toppling/rockfall or blockfall   n=117**
   (smaller, may be multiple rockfalls)

3. **spontaneous collapse (wedge, chockstone) n=109**
   retrogressive, larger, single deposit – rock avalanche

4. **headward/gulley erosion   n=94**
   (debris flows & rockfall)

5. **creeping landslide (bedrock)/rockfall n=38**

6. **collapse moraine wall, moraine n=55**
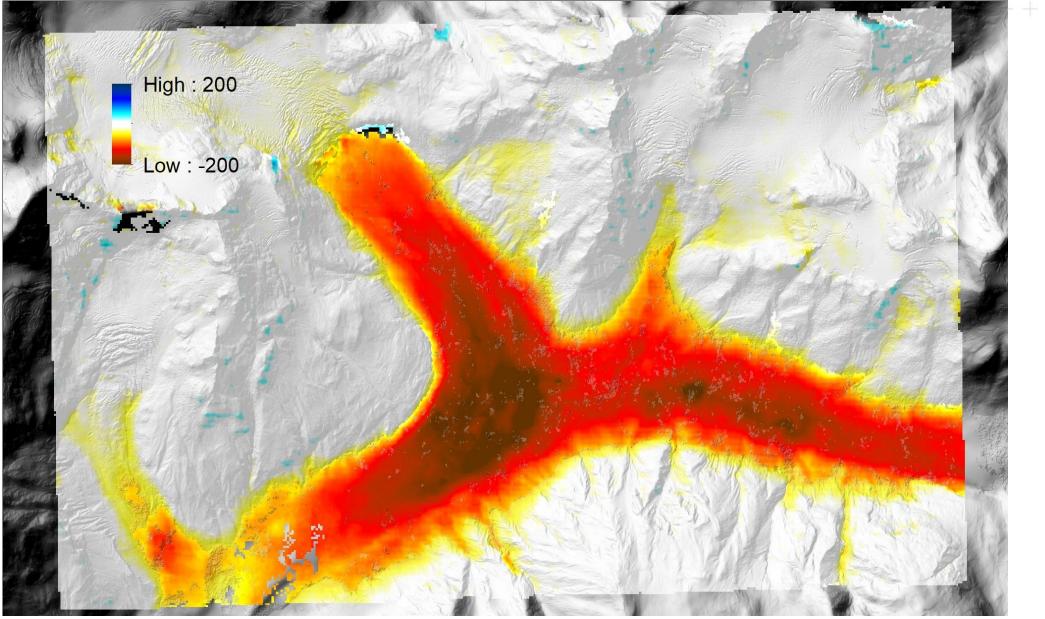
Landslide Inventory: mechanistic factors

- By Simon Cox

NZ's largest active landslide?

2.1 billion m³ SE Murchison

LANDSLIDES (n=574) BY TYPE
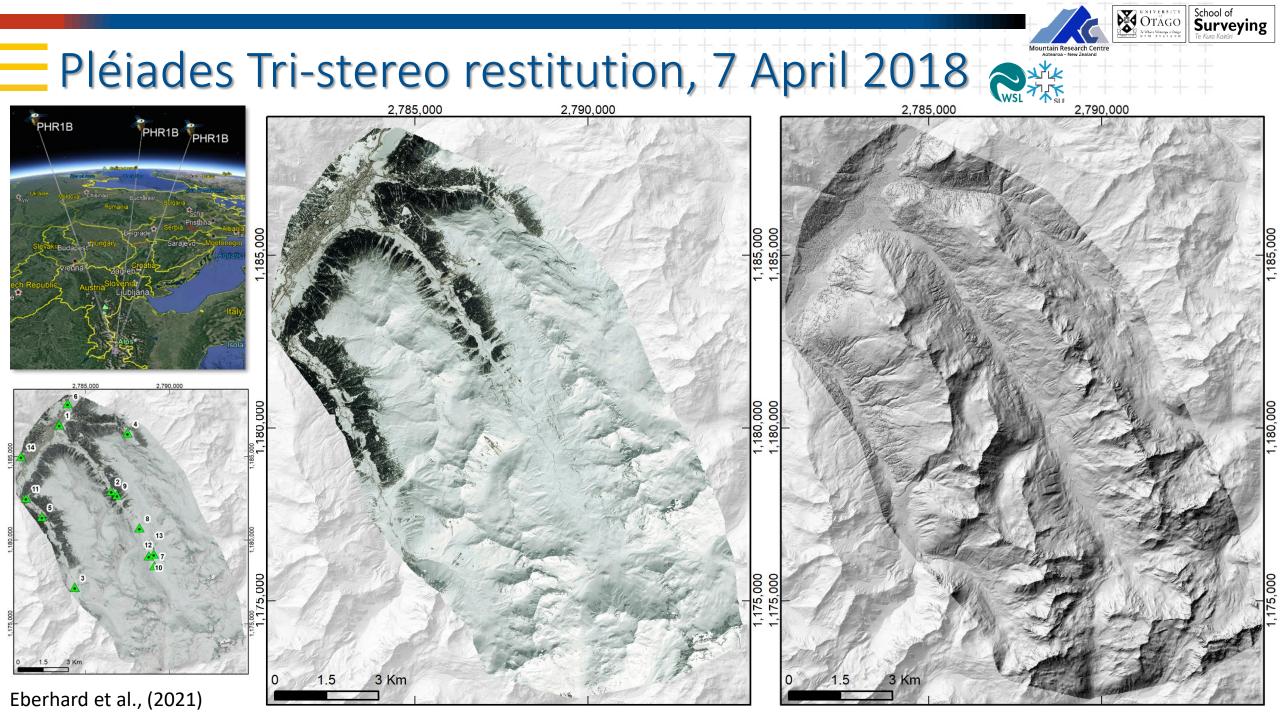
1. **trunk glacier downwasting (n=150)**

2. Snowfield/ice thinning or melting (n=221) (removal of snow as a support or snowmelt destabilizing the rock mass)

3. **involving water/river movement – slopewash, debris flows (n=78)**

4. unknown/unclear/spontaneous (n=45) (?permafrost degradation, freeze/thaw)

5. **previous landslide/ongoing landslide interaction/reactivation (n=80)**
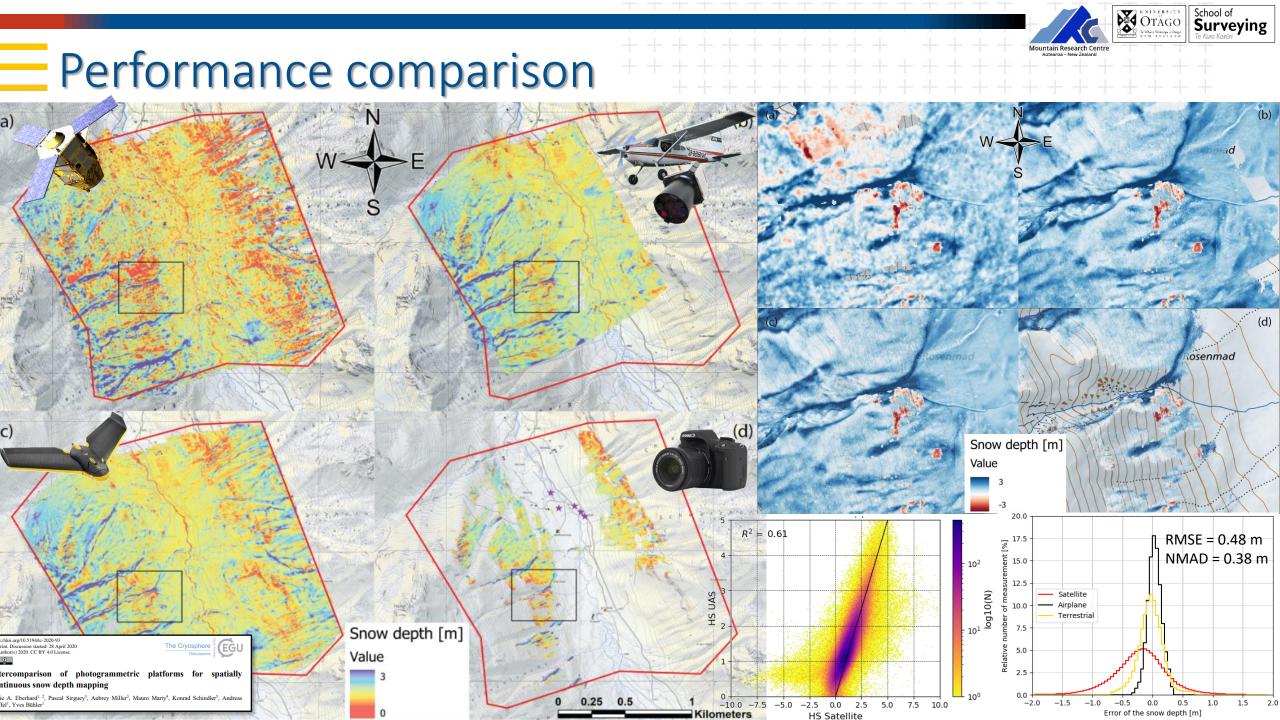
1986-2018 Godley Glacier

Eberhard et al., (2021)

RMSE = 0.48 m
NMAD = 0.38 m

$R^2 = 0.61$

Snow depth [m]

Intercomparison of photogrammetric platforms for spatially continuous snow depth mapping
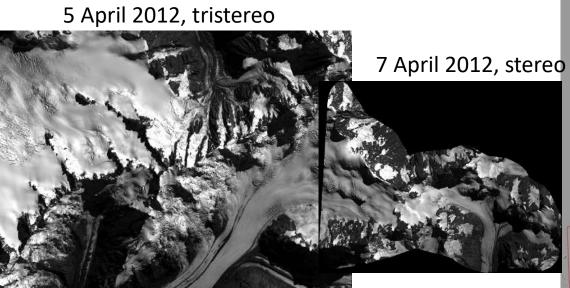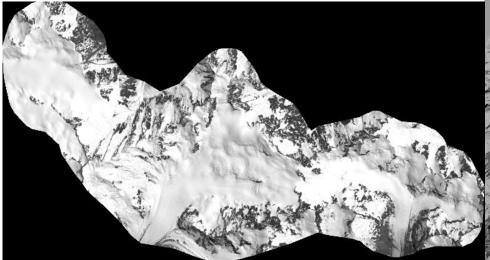
Davos 7 April 2018 (with WSL-SLF)
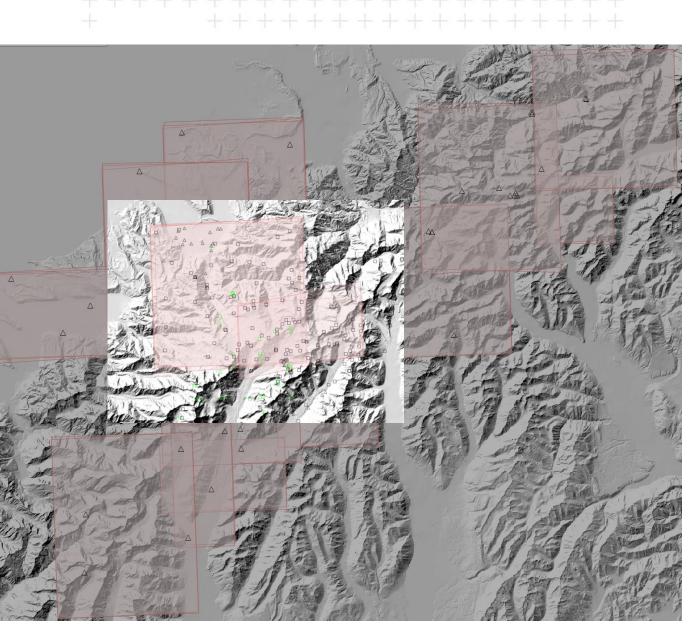
University of Otago/WSL-SLF
PLEIADES © CNES (2018), distribution Airbus DS

Central Southern Alps

5 April 2012, tristereo

7 April 2012, stereo

23 Dec 2012, stereo
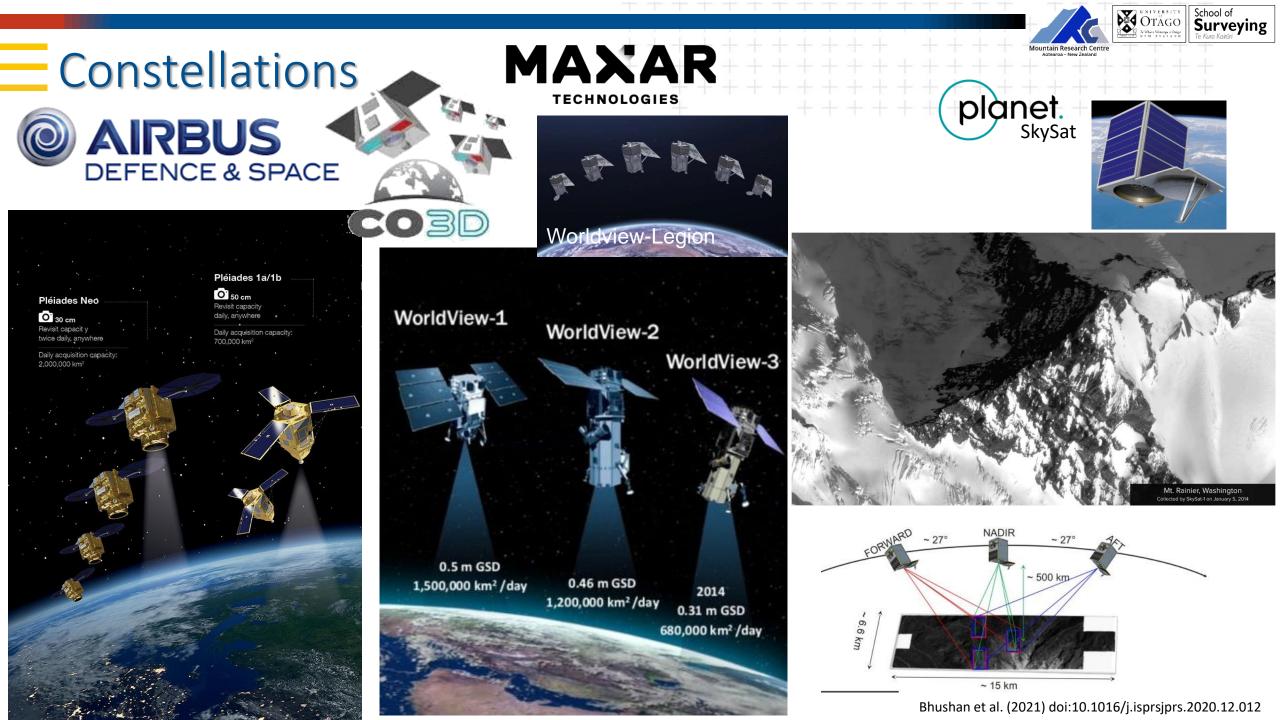
Main Divide April-December 2012

Constellations

Worldview-Legion

Pléiades Neo — 30 cm — Revisit capacity twice daily, anywhere — Daily acquisition capacity: 2,000,000 km²

Pléiades 1a/1b — 50 cm — Revisit capacity daily, anywhere — Daily acquisition capacity: 700,000 km²

WorldView-1 — 0.5 m GSD — 1,500,000 km²/day

WorldView-2 — 0.46 m GSD — 1,200,000 km²/day

WorldView-3 — 2014 — 0.31 m GSD — 680,000 km²/day

Mt. Rainier, Washington
Collected by SkySat-1 on January 5, 2014

FORWARD ~ 27° NADIR ~ 27° AFT
~ 500 km
~ 6.6 km
~ 15 km

Bhushan et al. (2021) doi:10.1016/j.isprsjprs.2020.12.012

Thank you! Questions?

Whakaari / White Island 2008-2011 (lidar)

dDSM (1986-0.43)-NZTopo

- 1986 outlines: **+6.1** ±1.0 m, **+15.7** ±2.5 hm³

1986

NZAM, 01/02/1986

2006

NZAM, 13/03/2006

2018

AS/ORC, 31/01/2018

Brewster Geodetic Mass Balance 2006-1986

Brewster Geodetic Mass Balance 2018-2006

+1.5
Gain

Rate
m yr⁻¹

Loss
-1.5

Photogrammetry strikes back

Photogrammetry strikes back

Photogrammetry strikes back

Photogrammetry strikes back

Photogrammetry strikes back

Photogrammetry strikes back

+1.5
Gain

Rate
m yr^{-1}

Loss
-1.5

Photogrammetry strikes back

Photogrammetry strikes back

01/02/1986

13/03/2006

Photogrammetry strikes back

24/12/2015 GE1

Photogrammetry strikes back

-43.4 m

+9.2 m

$\overline{A}$	42,502 m^2
ΔV	-639,000 ±43,000 m^3
	-304,000 ±35,000 m^3 (10m trees)
	-188,000 ±40,000 m^3 (15m trees)
Δz	-14.7 ±0.9 m
	-9.0 ±1.0 m (10m trees)
	-4.3 ±0.9 m (15m trees)

$\overline{A}$	152,940 m^2
ΔV	430,000 ±44,000 m^3
Δz	2.8 ±0.3 m

+30m
Gain

Loss
-30m

Photogrammetry strikes back

Photogrammetry strikes back

5, Tree Height Growth and Stand Top Height
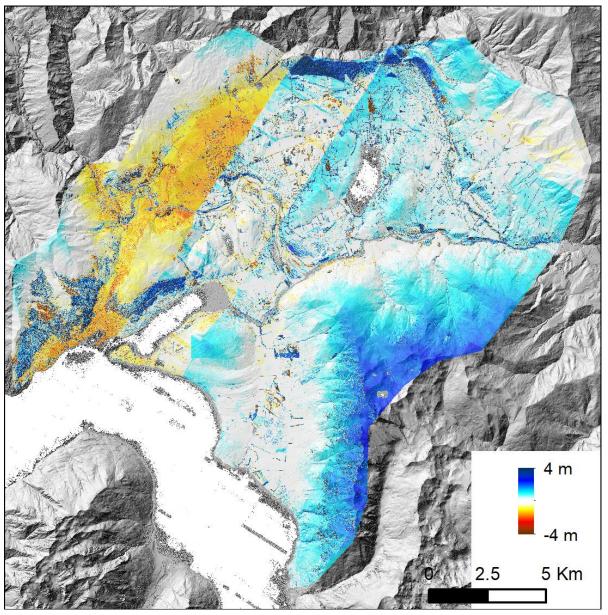
Hocking and Kenderine (1945) found at Rangataua Forest that between the 30th and 40th years, stand trees had an average annual height increase of 24.4 cm per year. The rate of height increase declined steadily as age increased, and between the 110th and 120th years was 6.1 cn per year. This further declined to 3.0 cm per year between the 170th and 180th years.

Manson (1974)

+10m
Gain

Loss
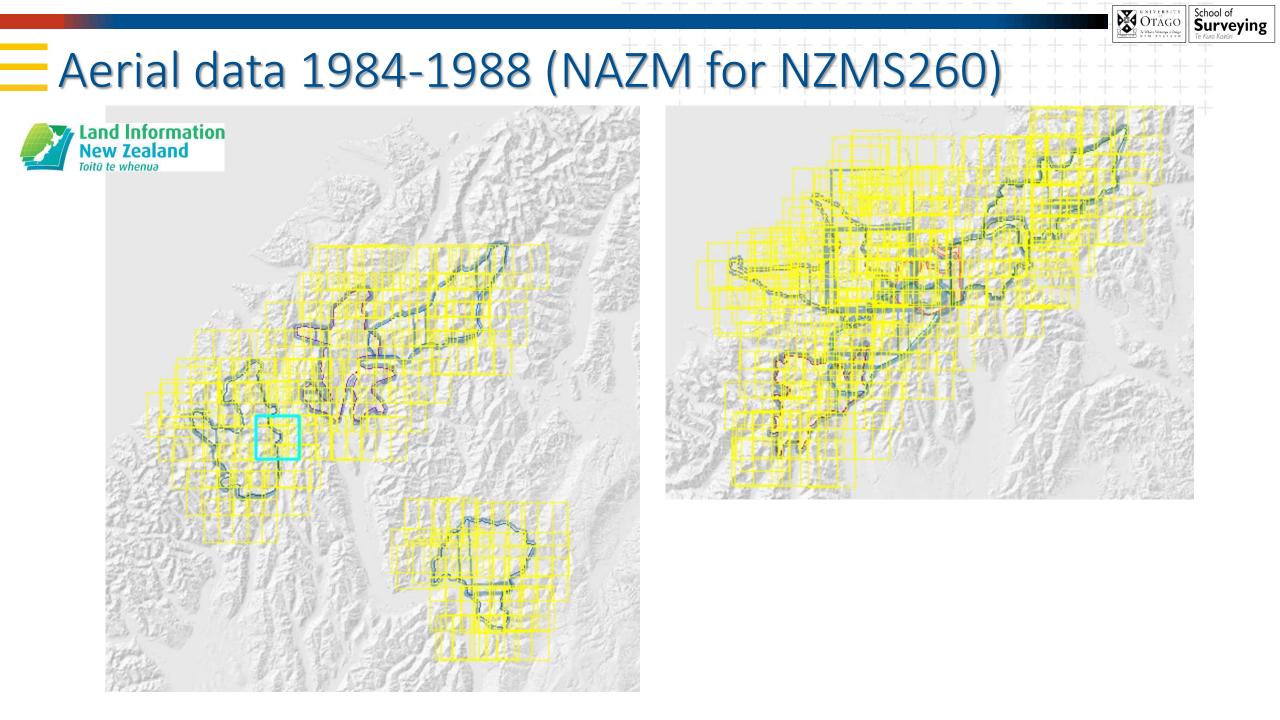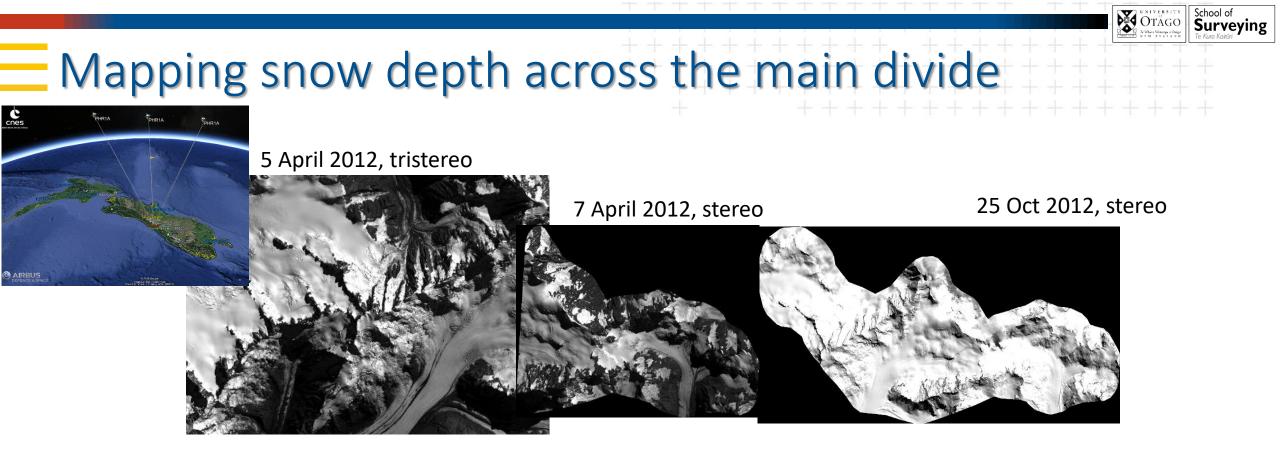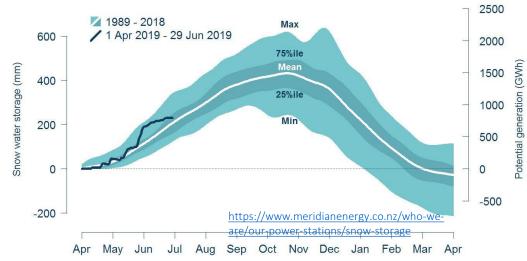-10m

Mapping snow depth across the main divide

5 April 2012, tristereo

7 April 2012, stereo

25 Oct 2012, stereo

23 Dec 2012, stereo

https://www.meridianenergy.co.nz/who-we-are/our-power-stations/snow-storage

+2m
Gain

Loss
-2m

+10
Gain

Rate
m yr^{-1}

Loss
-10

+50m
Gain

Loss
-50m