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COLLEGE OF ENGINEERING | School of Civil and Construction Engineering

Challenges with managing Linear Distortion in remotely sensed data Two Case Studies

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OREGON GNSS USERS GROUP

SERVING SURVEY & GIS PROFESSIONALS

DISCLAIMER

I have financial interests in the company EzDataMD LLC, and commercialization of technology involving point cloud data processing (e.g., EZProj). The conduct, outcomes, or reporting of this research could benefit EzDataMD LLC and could potentially benefit me.

Challenges

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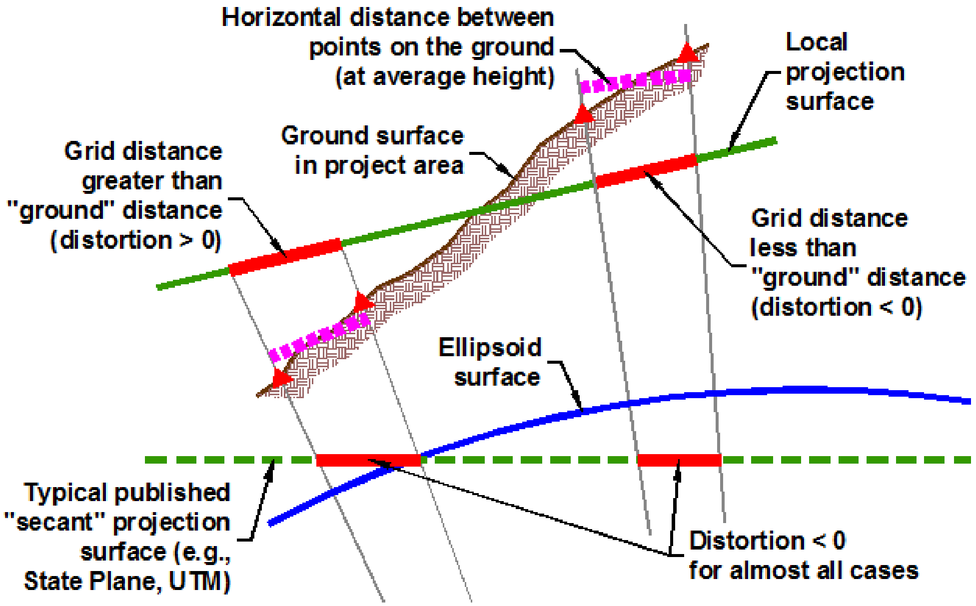
- Varying support of coordinate systems in 3D laser scan software (Earth is flat?)
- Many people are not aware\do not consider map projection distortion between grid and ground measurements
- Difficult and confusing to implement scale factors
- Distortion can be cm-level across small sites (<100m), leading to unreliable deformation analysis.
- Precision of software/las files can lead to truncation
- Issues scale with data size



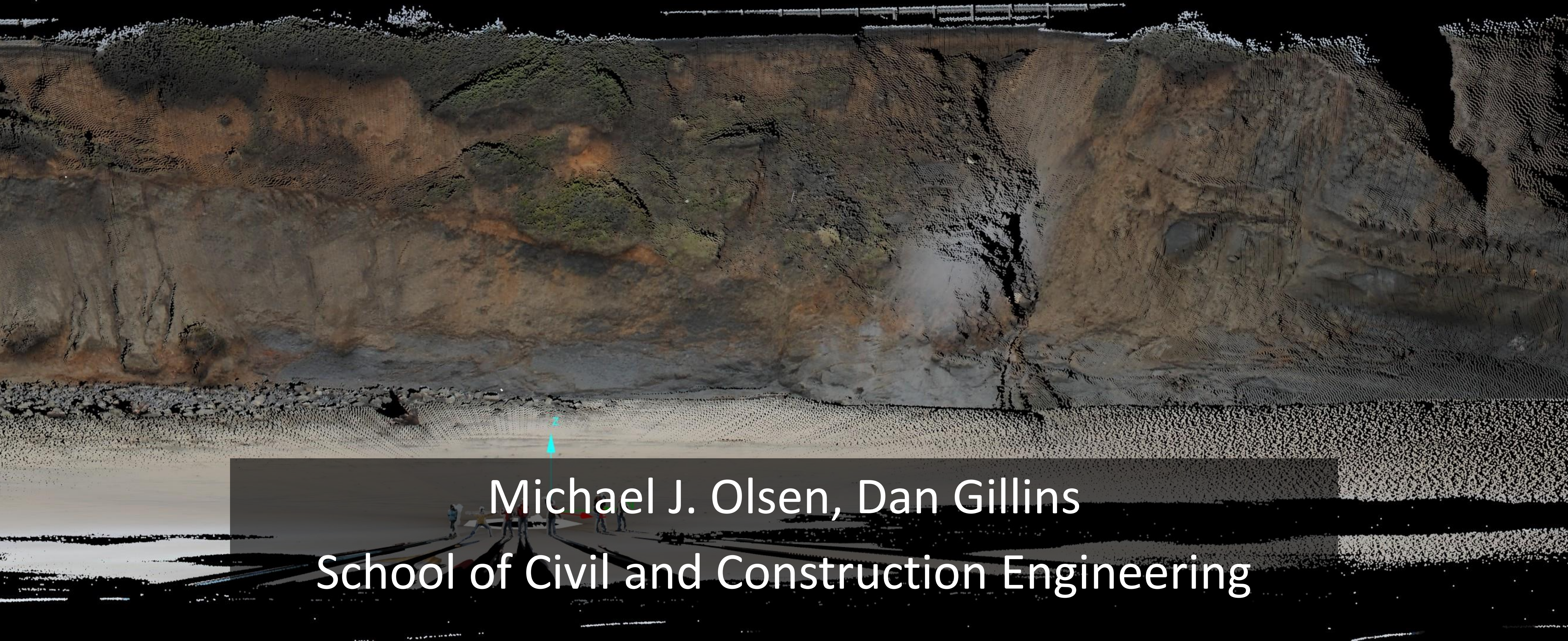
Schematic illustrating linear distortion, courtesy of Michael Dennis and Mark Armstrong, NGS

Pixy dust (noun)

- Data collected through "SfM" or "phodar" techniques by someone with limited experience or minimal training either due to ignorance or just plain laziness. The operator/ provider are generally solely interested in how cheap and fast the data collection is. Use with EXTREME CAUTION!

Case Study 1: Dotting the Coast

Strategies and considerations when using lidar data for coastal studies



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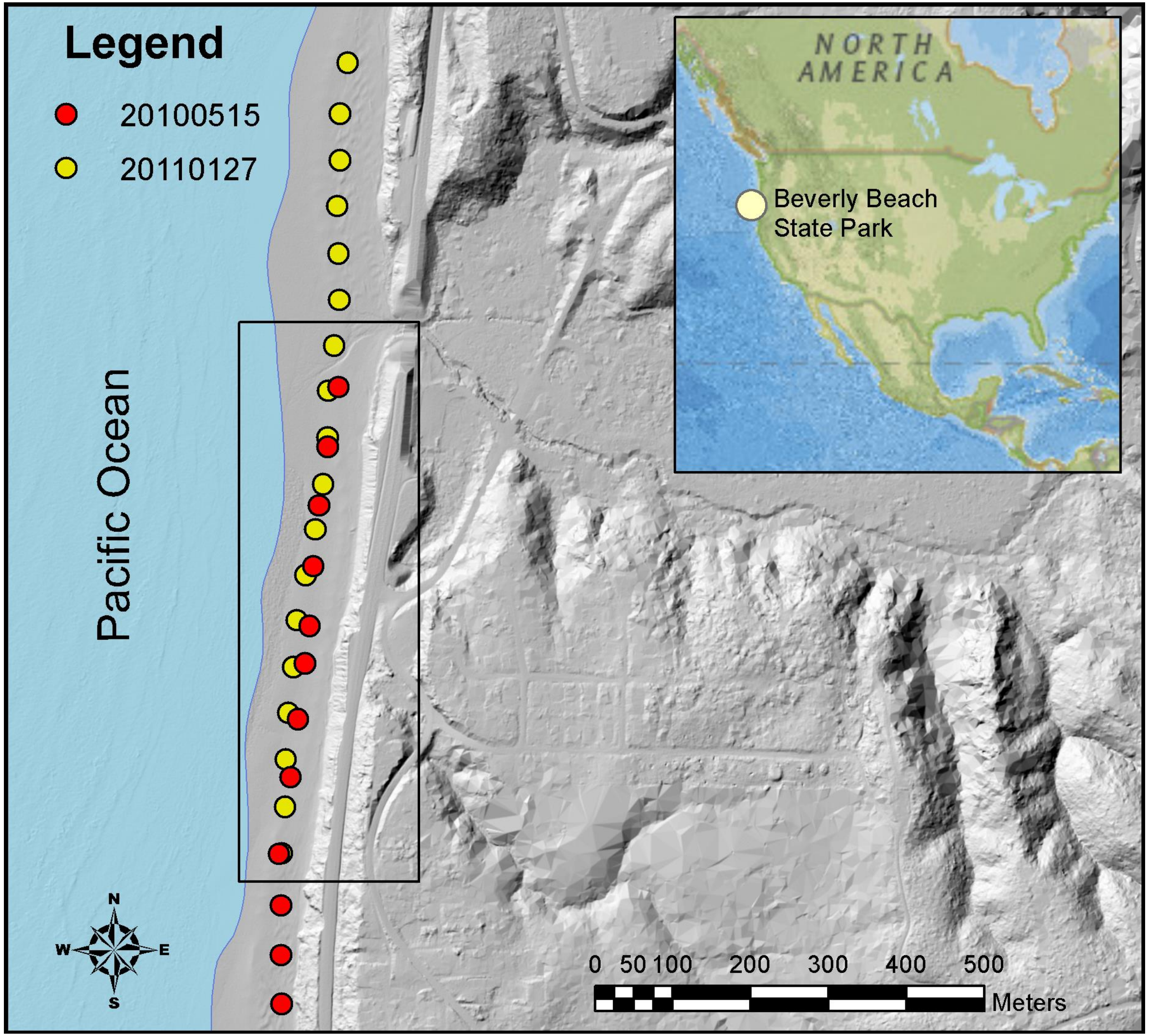

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Coordinate System Options

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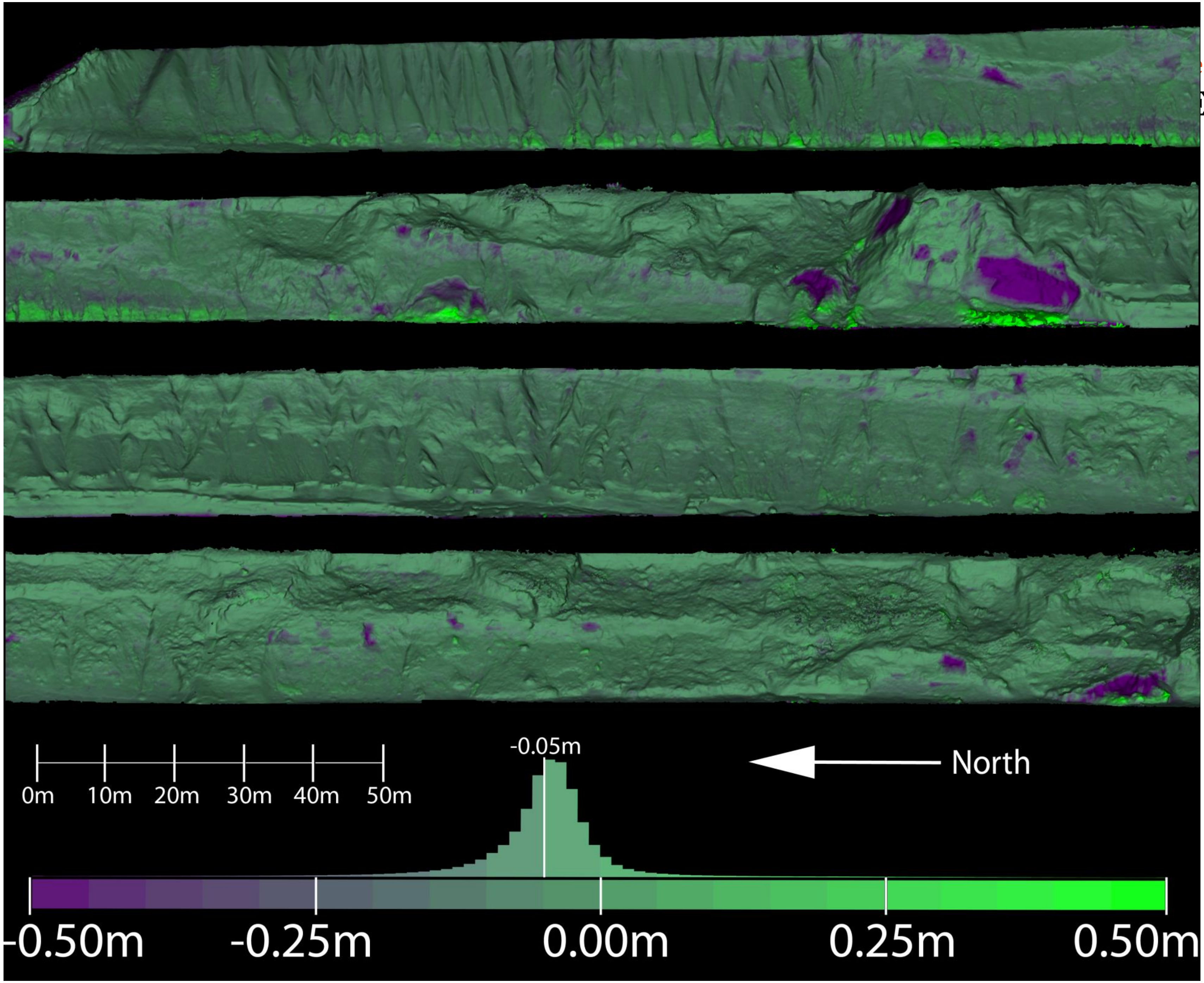
Coord-inate System	Attributes		
	Design distortion	Advantages	Disadvantages
UTM	1:1,000	- Commonly used for scientific studies - Much available data have been processed in UTM - Covers relatively large areas	- Large distortion - A regional scale study may straddle multiple zones (e.g., Zones 10 & 11 for the US West Coast).
State Plane	1:10,000	Commonly used for engineering and land surveying	- 2 distinct zones in state of Oregon, others for other states.
OCRS	1:100,000	- Low distortion	- Multiple small zones
ECEF	No distortion	- Same coordinate system worldwide - true 3D coordinates	-Requires advanced geodetic computations to compute distances along the ground surface of the Earth -Large coordinates - Elevation, Z-up?



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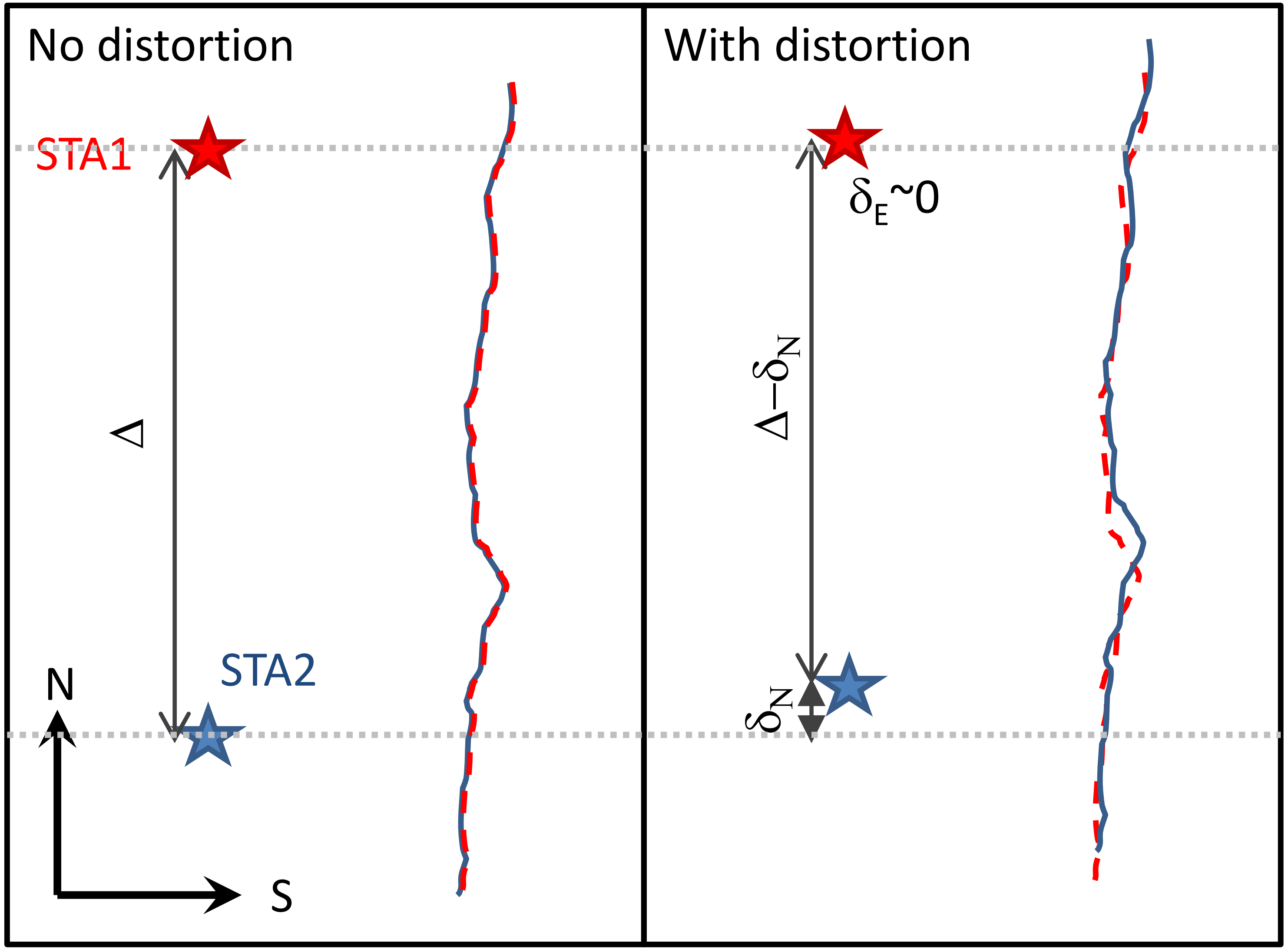
Theory

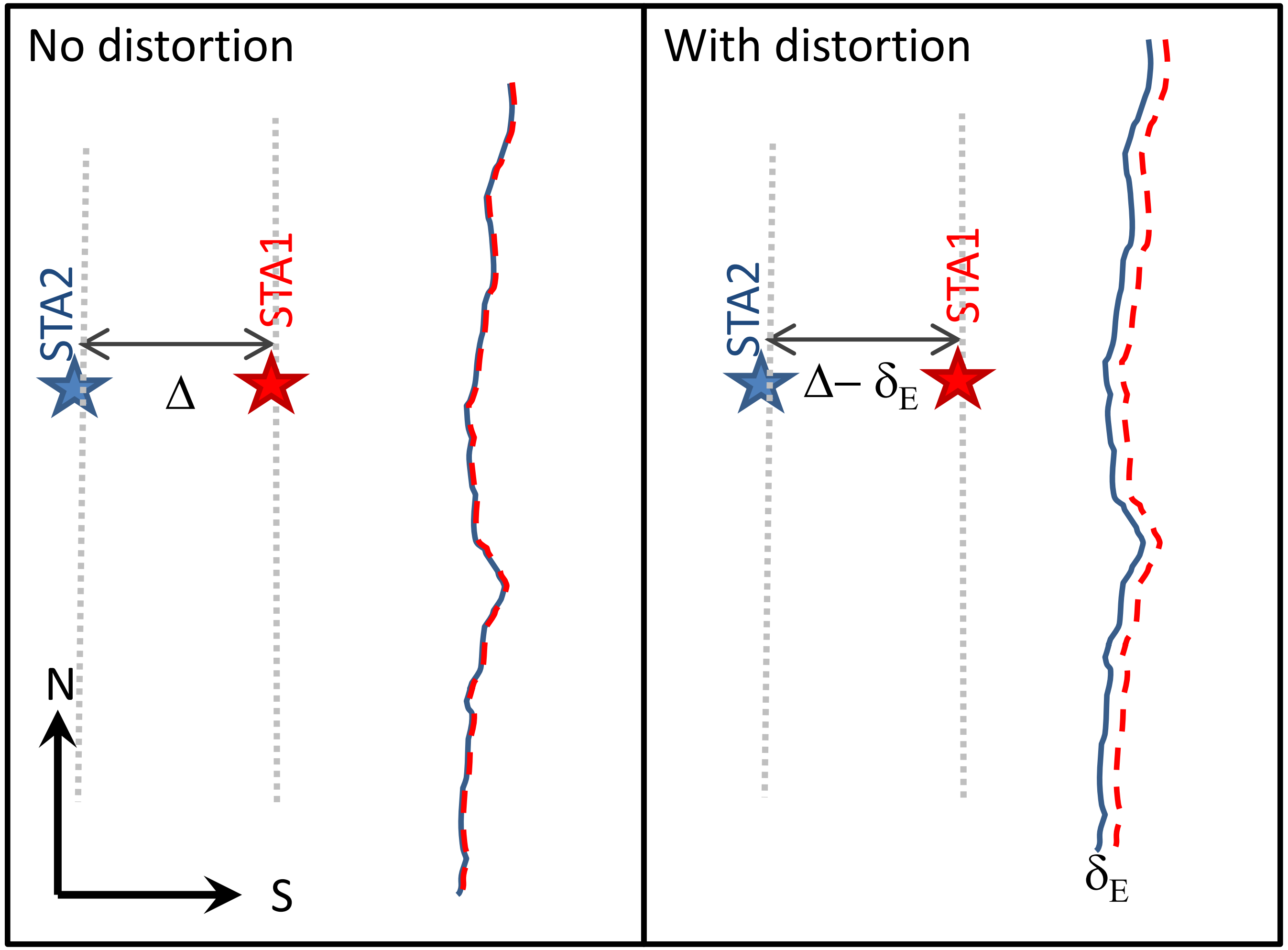
- Linear distortion effects are minimized when a systematic process is utilized and the topography is not very complex.



Note that the actual location (in the East direction) of the cliff on the grid will be equally incorrect in both of the scans. Typically scans will be spaced at a similar distance to their distance from the cliff, so this offset would be approximately δ.

Theory

- Linear distortion can be a significant problem if scans are done at varying distances from the cliff



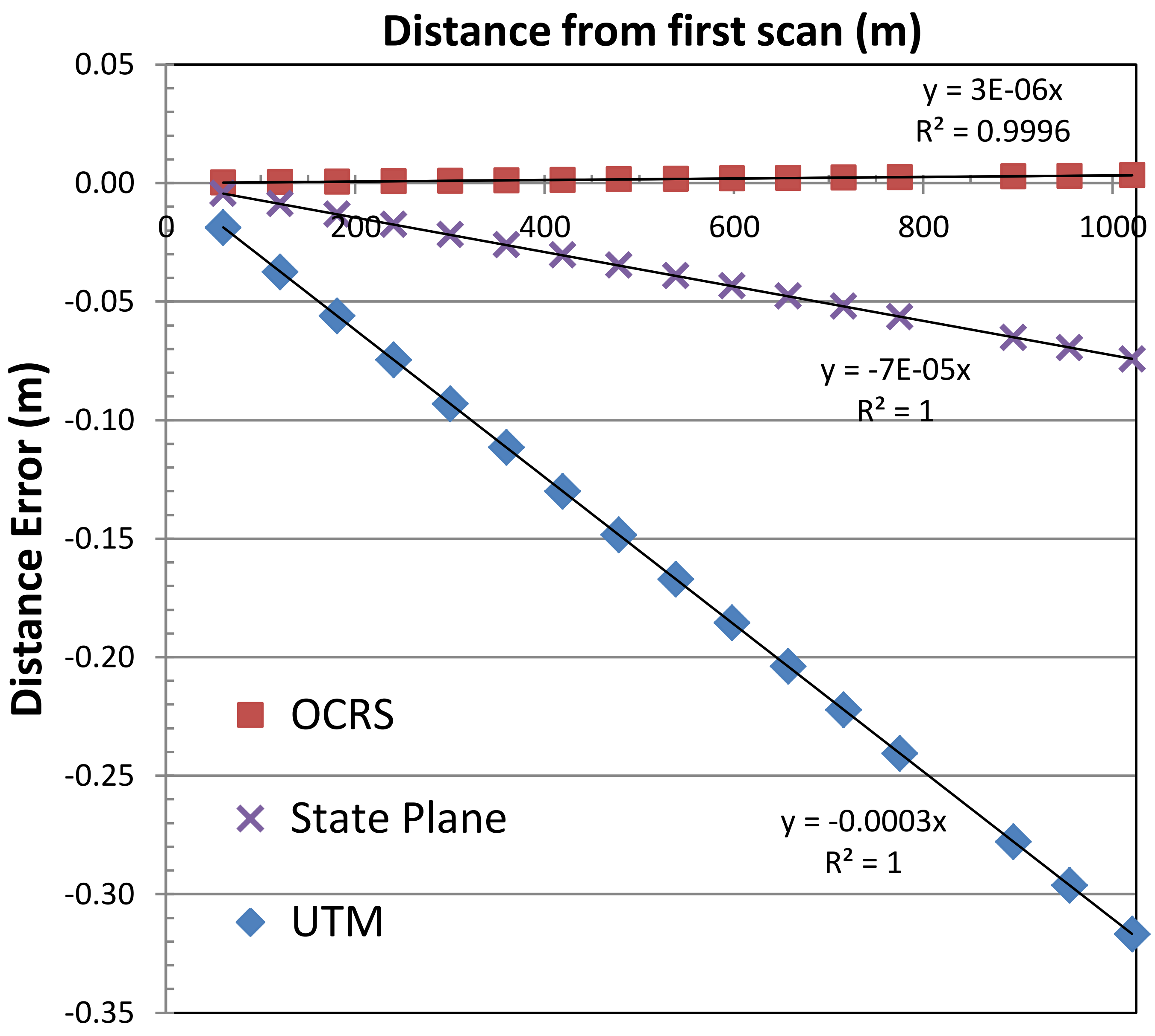
In this case, the actual location (in the East direction) of the cliff on the grid will not be equally incorrect in both of the scans. The offset of the cliff position that would appear as change would be approximately equal to δ, because of the larger distance to the cliff in STA2 compared to STA 1.

RSTA2 = RSTA1+D

RSTA2 = RSTA1+D +dE

Distance Distortion

- Compare OCRS, State Plane, and UTM to ECEF 3D coordinates (between scans at end)
- UTM shows significant distortion, OCRS shows minimal distortion
- Distortion error is linear and systematic
- Scale factor (grid to ground)
  = 1- line slope



Distance Differences

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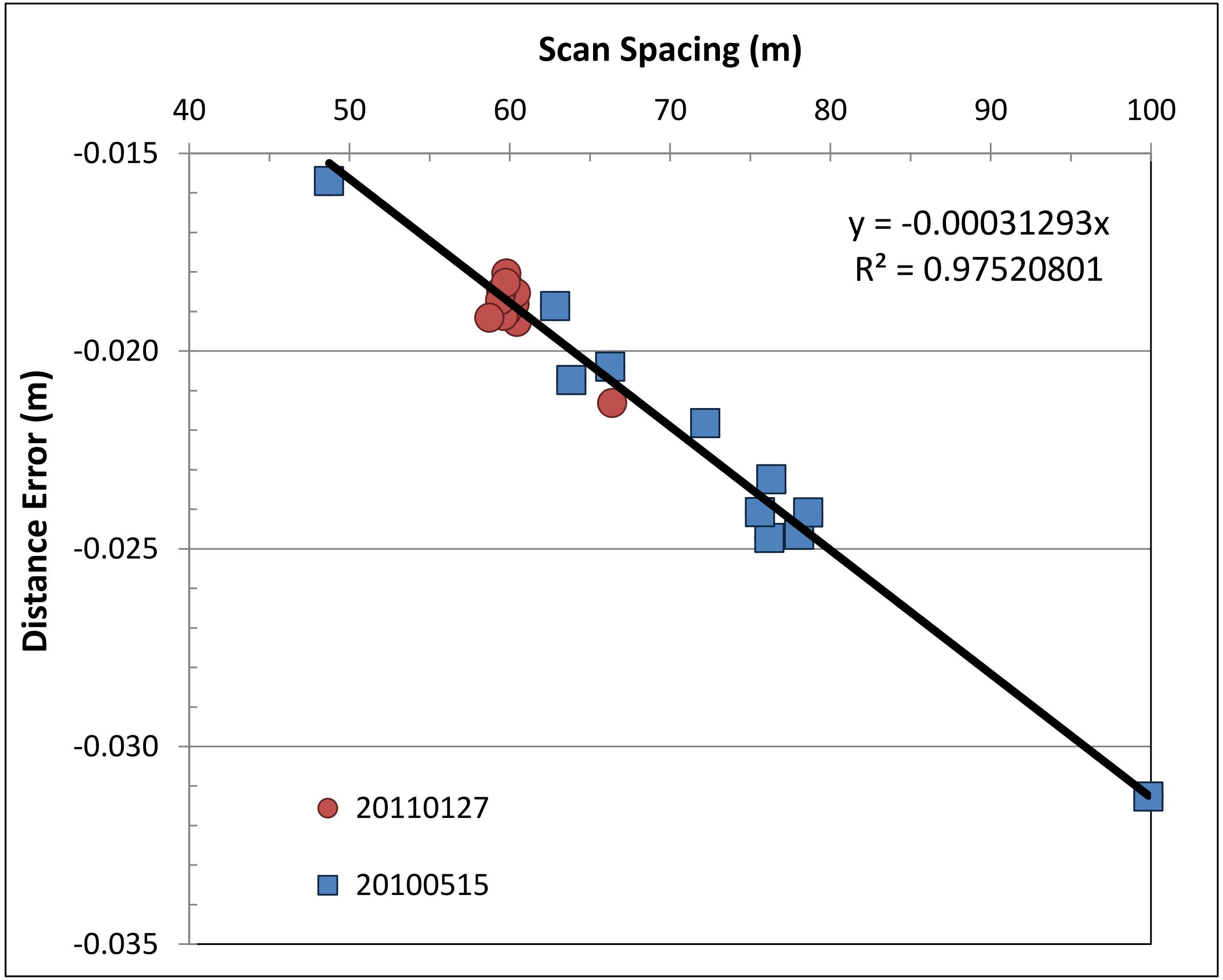
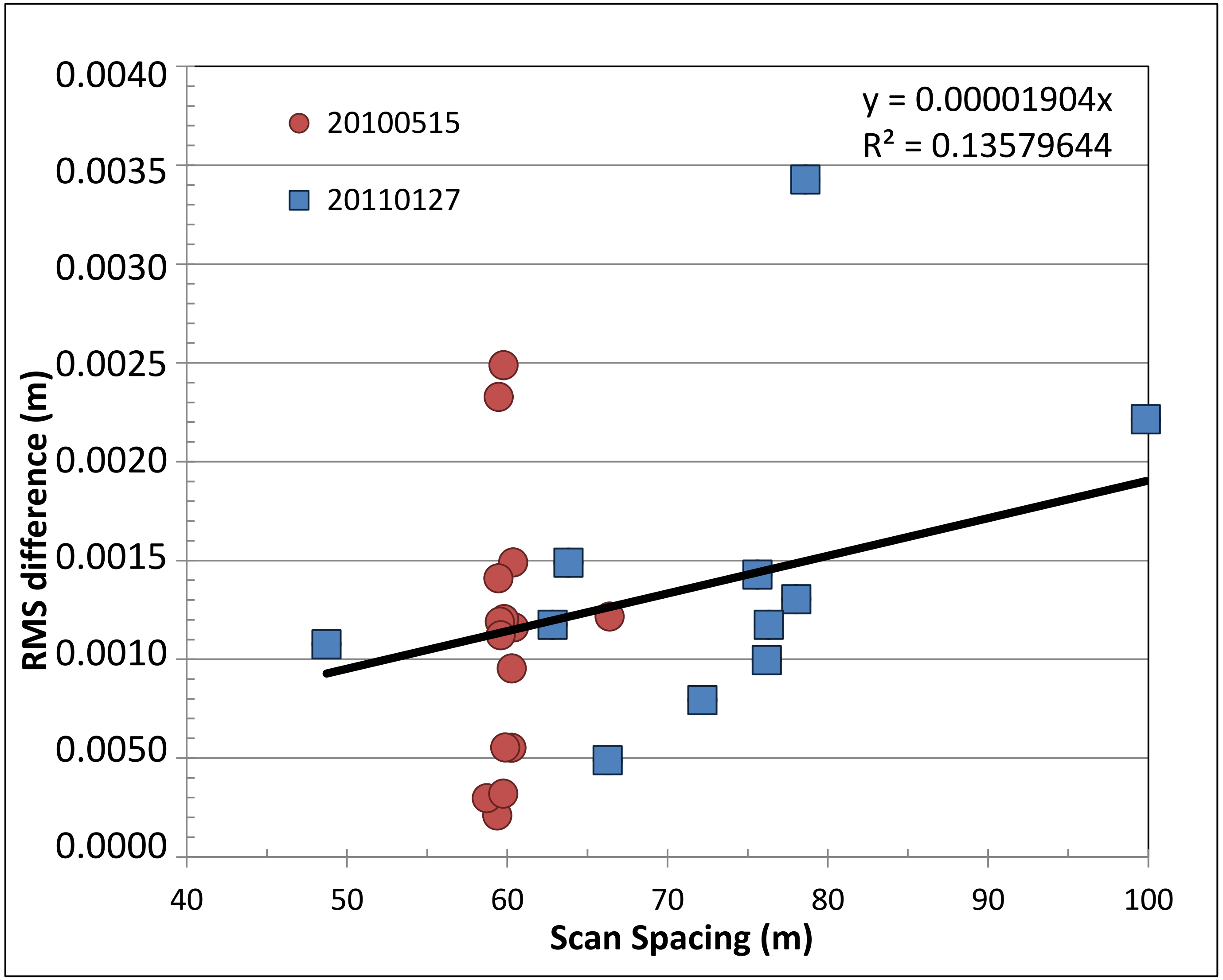
- UTM vs OCRS
- Automatic bias in data.
- Some gets “absorbed” in other registration parameters (e.g., rotation), mixed up in ICP.



Impact on adjacent scan matching

- Compare RMS residual results using UTM and OCRS horizontal coordinates for scan positions
- Slightly higher RMS for UTM
- No clear relationship- likely due to RMS calculation method in scan data, estimating matching points (iterative closest point\plane)



What to do?

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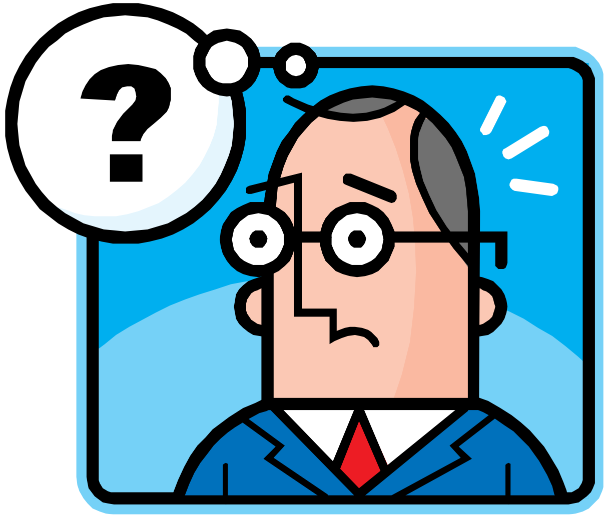

- Limited support in lidar software for coordinate systems, projections directly
- Work in ECEF (Not intuitive)
- Use a LDP (e.g., OCRS)
- Scale measurements directly – as done with total station (need your own code). Apply SF to data before volume calcs. (Hard to be systematic/document what was done)
- Apply SF correction to volume and other calculations at very end!

#1 Summary

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- The low distortion projection (OCRS) minimizes error and shows consistent results to the fully 3D ITRF coordinates
- Effects on retreat rates\landslide advance can be substantial when scans are performed at different distances from the cliff
- Effects on volume calculations are small when a similar distance from cliff is maintained.
- Effects on scan alignment residuals are slight
- A systematic collection, processing and analysis process reduces the impact of distortion
- Several methods to account for distortion are presented

#2. Eagle Creek-Debris Flow Mapping Data Fusion Confusion

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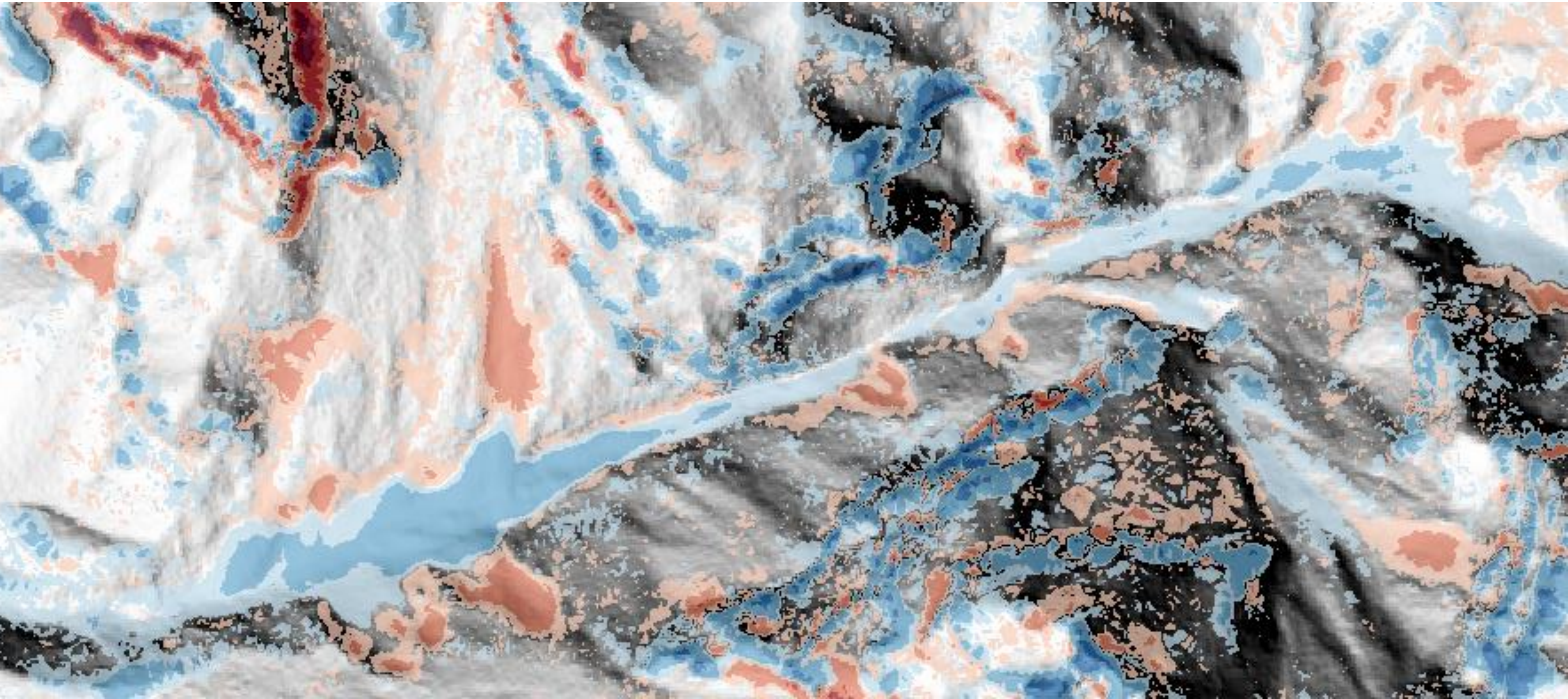

Coordinate System Chaos

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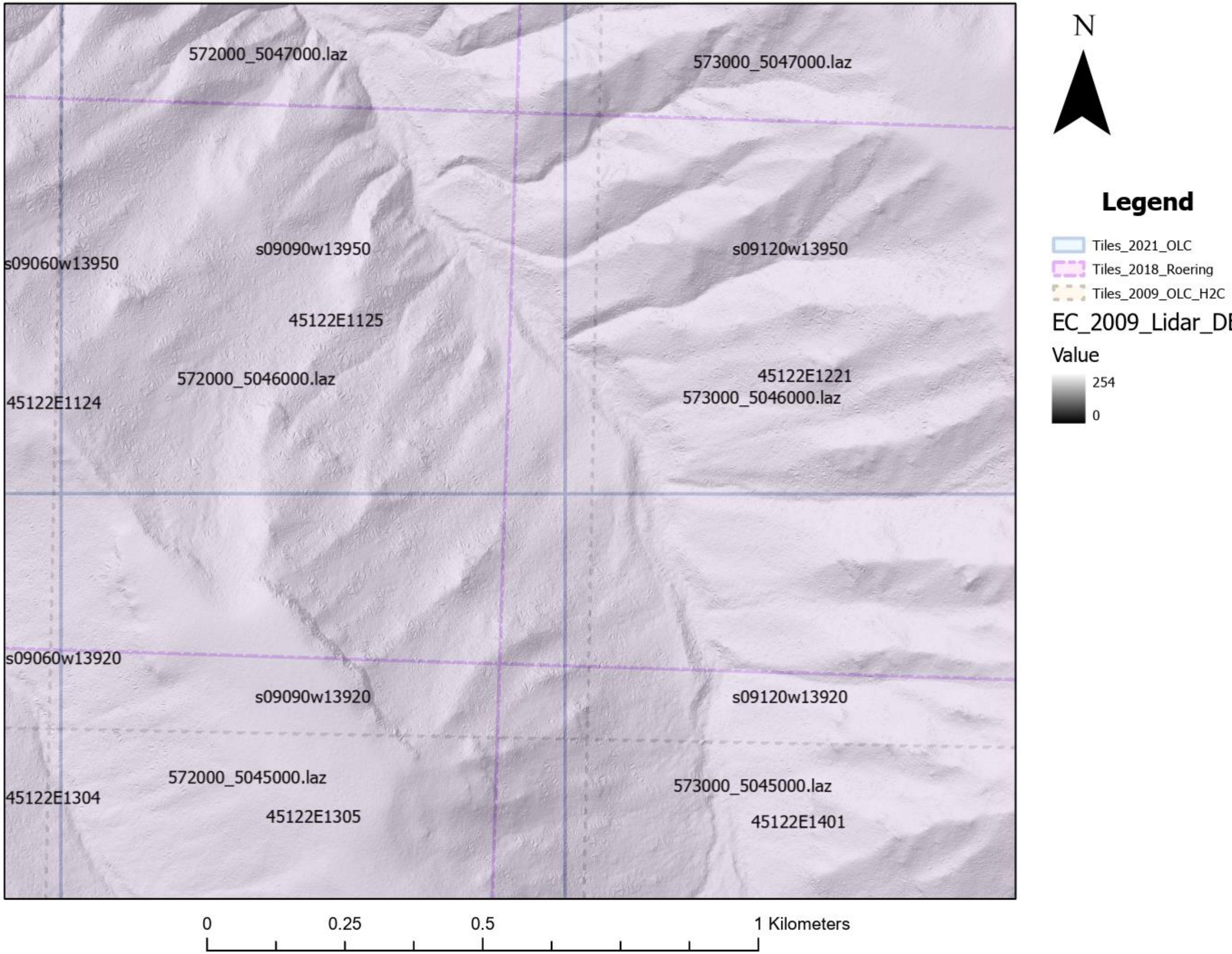
Dataset	Horz. CSYS	Horz. Ref. Frame	Horz. Units	NAVD88 Geoid	Vert. Units	Original Cell Size	Notes
2009 Hood to Coast	SPCS Oregon North 3601 [EPSG 6885]	NAD83(CORS96), EPOCH 2002.	Int. Feet	Geoid 03	US. Survey Feet	0.91 m (3 ft)	Data originally labeled as NAD83(HARN) [EPSG 2913] [EPGS 6884 for m]
2018 Eagle Creek	UTM Zone 10N [EPSG 6339]	NAD83 (2011) (EPOCH:2010)	Meters	NAVD88 (GEOID 12B) [EPSG: 5703]	Meters	1.0 m	Erroneously labeled as [EPSG: 26910-NAD83] in laz files
2021	Oregon Statewide Lambert [EPSG 6557]	NAD83 (2011) (EPOCH:2010)	Int. Feet	Geoid 18	Int. Feet	0.91 m (3 ft)	[EPSG 6556 for m]
2022	Oregon Statewide Lambert [EPSG 6557]	NAD83 (2011) (EPOCH:2010)	Int. Feet	Geoid 18	Int. Feet	0.91 m (3 ft)	[EPSG 6556 for m]

North?

- Each coordinate system has a different north
- Tiling schemes vary



Why process at the point cloud vs raster level?

- Closer to the source.
- Less accumulated error for transforms.
- Can control grid structure- no awkward intervals/spacing from unit conversions/transforms.
- Better representation of values for the cell as it is recomputed specifically for the grid structure. Reduces alignment/offset issues or interpolation.
- Can evaluate offsets\issues easier with the point cloud.

What tools are available to transform?

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- ArcGIS (ESRI)
- LP360 (GeoCue, uses ArcGIS)
- LasTools (RapidLasso)
- Vdatum (NGS)
- EZProj
- TLS software
  - Riegl Riscan Pro
  - Maptek Point Studio
  - Cyclone Reg360 (a few options)
- SfM software
  - Context Capture
  - Agisoft Metashape

- Variable options
- Slow
- Datum realizations?
- Coordinates varied by a few cm to dm.
- Let’s not start talking about epochs!!!
- Batch processing???

NGS - VDatum

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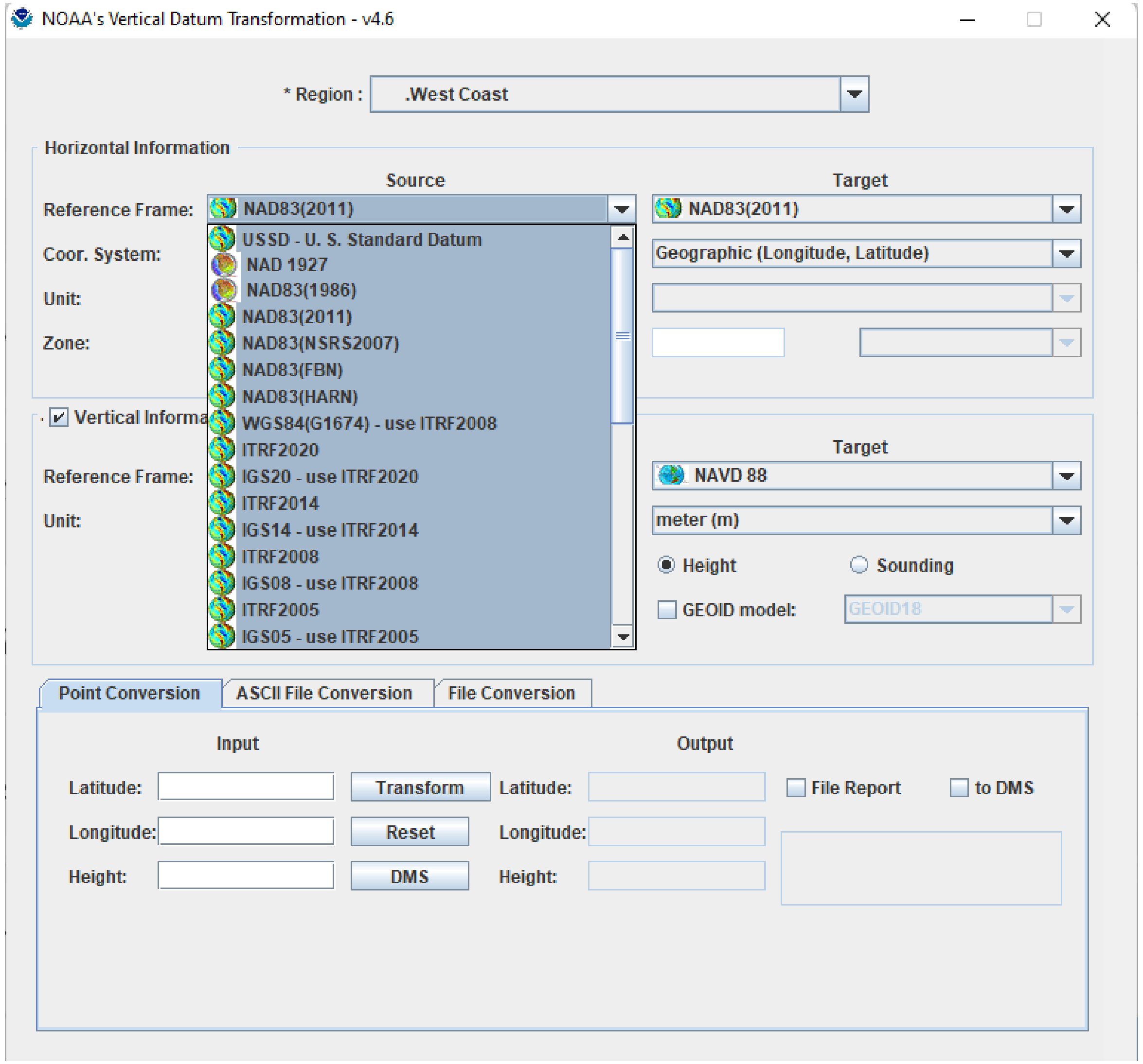

Where available and uncertainties are established, VDatum supports the conversions among following:

- **Coordinate Systems:** Geographic, UTM, State Plane Coordinates (SPC), and geocentric (ECEF)
- **Horizontal Datums:** NAD27, NAD83_2011, NAD83_1986, NAD83_FBN, and NAD83_HARN; and ellipsoidal datums such as of ITRF, WGS84, and NAD83 serializations
- **Vertical Datums:**
  - **Ellipsoidal Datums:** NAD83_2011, WGS84, ITRF88, ITRF89, ITRF90, NEOS 90, PNEOS 90, ITRF91, ITRF92, SIO/MIT 92, ITRF93, ITRF94, ITRF96, ITRF97, IGS97, ITRF2000, IGS00, IGb00, ITRF2005, IGS05, ITRF2008, IGS08, ITRF2014, IGS14, WGS84(transit), WGS84(G730), WGS84(G873), WGS84(G1150), WGS84(G1674), NAD83(PACP00), NAD83(MARP00)
  - **Orthometric Datums:** NAVD88, NGVD29, PRVD02, VIVD09, ASVD02, GUVD04, NMVD03, HAWAII EGM2008, EGM1996, and EGM1984
  - **Tidal Datums:** MLLW, MLW, LMSL, DTL, MTL, MHW, LWD, MHHW and Local Tidal(LT)
  - IGLD85, LWD IGLD 1985, OHWM IGLD 1985
- **GEOID models:** GEOID18, GEOID12B, GEOID12A, GEOID09, GEOID06 (Alaska only), GEOID03, GEOID99, and GEOID96
- **EGM models:** EGM2008, EGM1996, and EGM1984
- **xGEOID models:** xGEOID16b (BETA), xGEOID17b (BETA), xGEOID18b (BETA), xGEOID19b(BETA), and xGEOID20b(BETA)
- **Supported file format:** text(ASCII), LiDAR(.LAS, *.LAZ) version 1.0, 1.1, 1.2 and 1.4 with Classification, ESRI ASCII Raster(.ASC), ESRI 3D shapefile

NGS- NCAT

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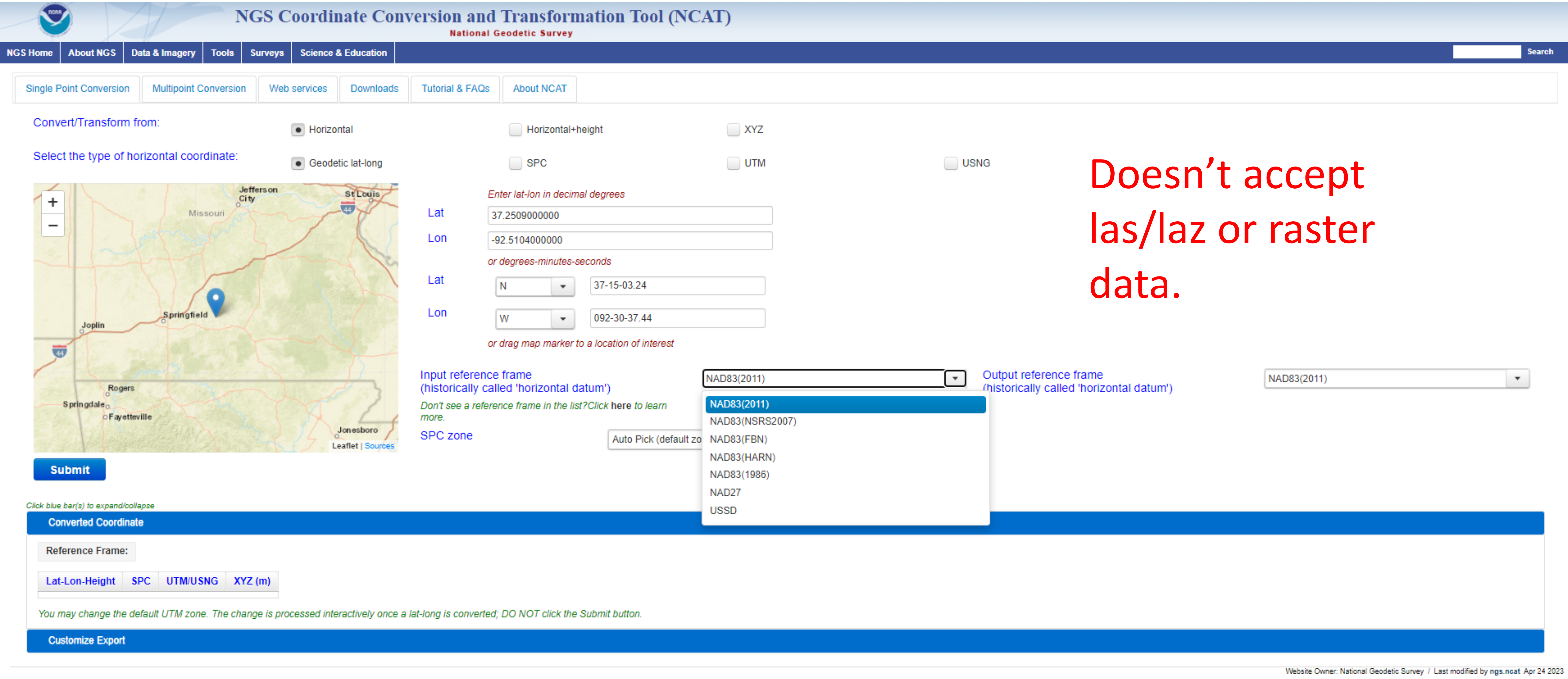

Doesn't accept las/laz or raster data.

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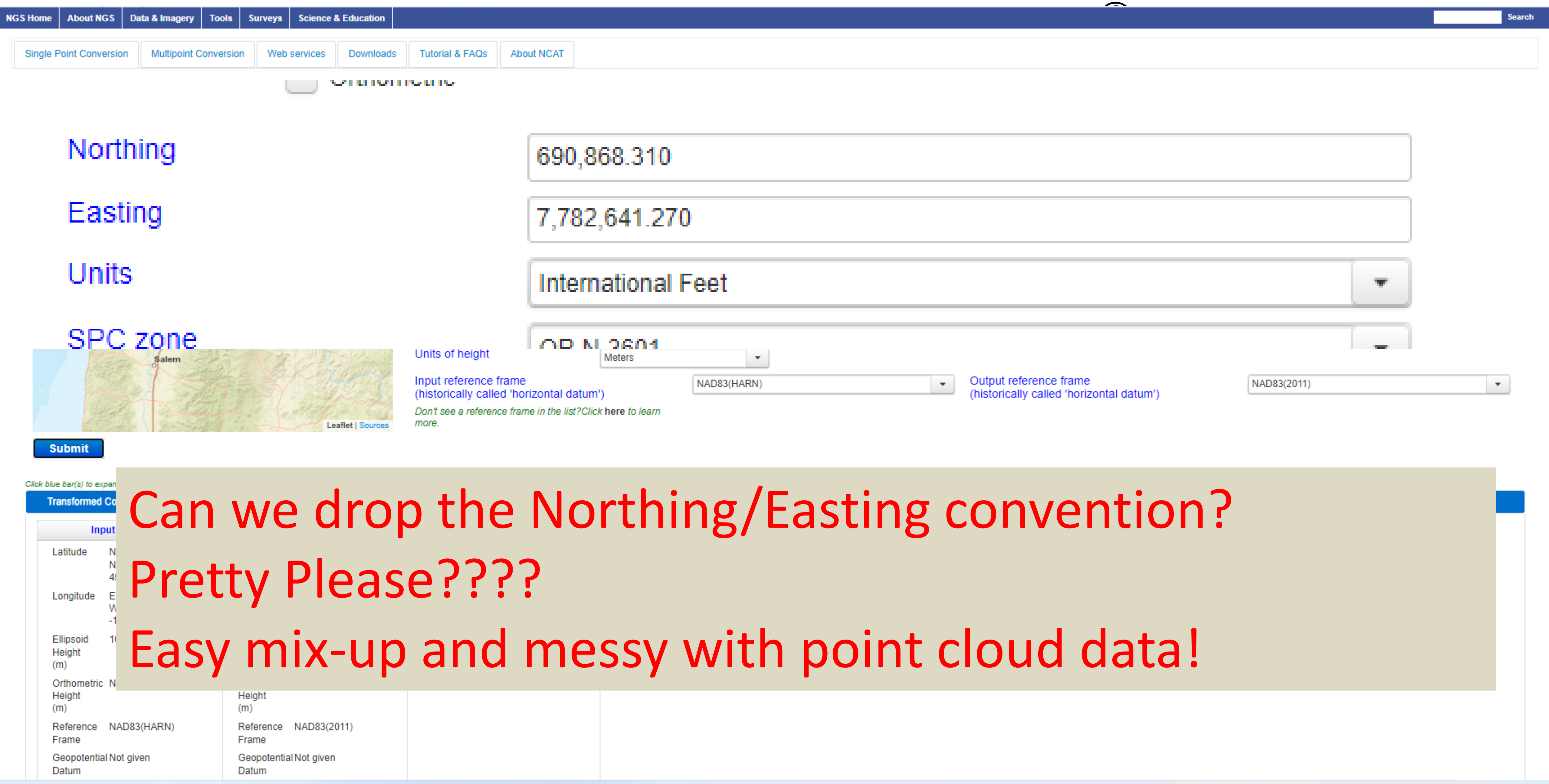
The NAD 83(CORS 96) and N... 83(NSRS2007) realizations... North American Datum of 198...

- NGS has adopted a realization of NAD 83 called NAD 83(N... ...on of coordinates at ~70,000 passive geodetic control monuments. This realization *approximates* (but is not, an... ...o) the more rigorously defined NAD 83(CORS 96) realization in which Continuously Operating Referenc... ...ates are distributed. NAD 83(NSRS2007) was created by adjusting GPS data collected during various camp... performed between the mid-1980's and 2005. For this adjustment, NAD 83(CORS 96) positional co... ...ere held fixed (predominantly at the 2002.0 epoch for the stable north American plate, but 2007.0 in Alaska... ...tain consistent positional coordinates for the ~70,000 passive marks, as described by Vorhauer [2007]. **Derived ... ...ional coordinates should be consistent with corresponding NAD 83 (CORS 96) positional coordinates t... ...ne GPS data** used in the adjustment and the accuracy of the corrections applied to these data for systemat... ... In particular, there were no corrections made to the observations for vertical crustal motion when converti... ...S survey into the epoch of the adjustment, while the NAD 83 (CORS 96) coordinates do reflect moti... CORS sites. **For this reason alone, there can never be total equivalency between NAD 83(NSRS2007) a...**
- Note: NGS has not... ...007) velocities for any of the ~70,000 passive marks involved in this adjustment. Also, the positional coord... ...l make reference to an epoch date. Epoch dates are the date for which the positional coordinates were adjuste... ...ered valid (within the tolerance of not applying vertical crustal motion). Because a mark's positional coordinates w... ...ynamic nature of the earth's crust, the coordinate of a mark on epochs different than the listed epoch date can only be accu... ...a 3-dimensional velocity has been computed and applied to that mark.

http...//www.ngs.noaa.gov/NationalReadjustment/difference.html

NAD83 (HARN) & NAD83 (CORS96) =
Awkward Teenage years?



Can we drop the Northing/Easting convention?

Pretty Please????

Easy mix-up and messy with point cloud data!

NGS Home | About NGS | Data & Imagery | Tools | Surveys | Science & Education | Search

Single Point Conversion | Multipoint Conversion | Web services | Downloads | Tutorial & FAQs | About NCAT

Convert/Transform from: Horizontal | Horizontal+height | XYZ

Select the ... USNG

Select a he...

Total Change + Uncertainty

Latitude	0.00527" ±0.000202" (0.163 m ±0.0062 m)*
Longitude	0.00222" ±0.000230" (0.048 m ±0.0050 m)*
Ellipsoid Height	-0.277 m ±0.023 m
Orthometric Height	Not given

Submi...

Click blue bar(s) ...

Transfor...

Latitude

Longitu...

Ellipsoi... Height (m)

Orthom... Height (m)

Reference Frame	NAD83(HARN)	Reference Frame	NAD83(2011)
Geopotential Datum	Not given	Geopotential Datum	Not given

Changing the "horizontal" datum NAD83(HARN) to NAD83(2011) results in changes to the ellipsoid height

Processing Times

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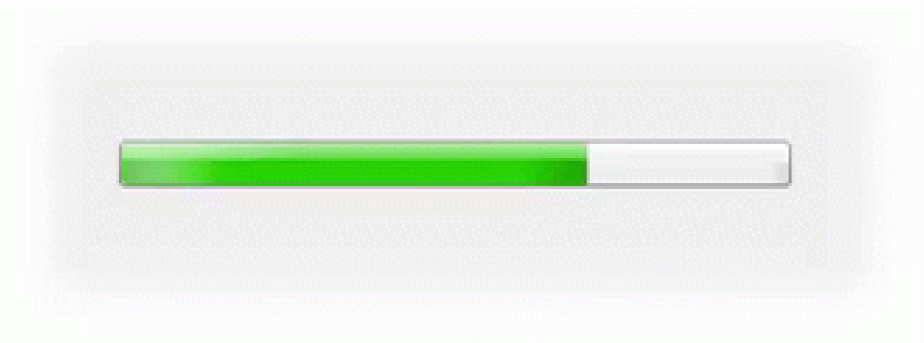
- Total: 1,149 files.
  [2009 (356), 2018 (373), 2021 (325), 2022 (95)]

- Vdatum ~15 minutes per scan (12 days)
- EzProj ~0.2 minutes per scan (~4 hours)



Georeferencing Error

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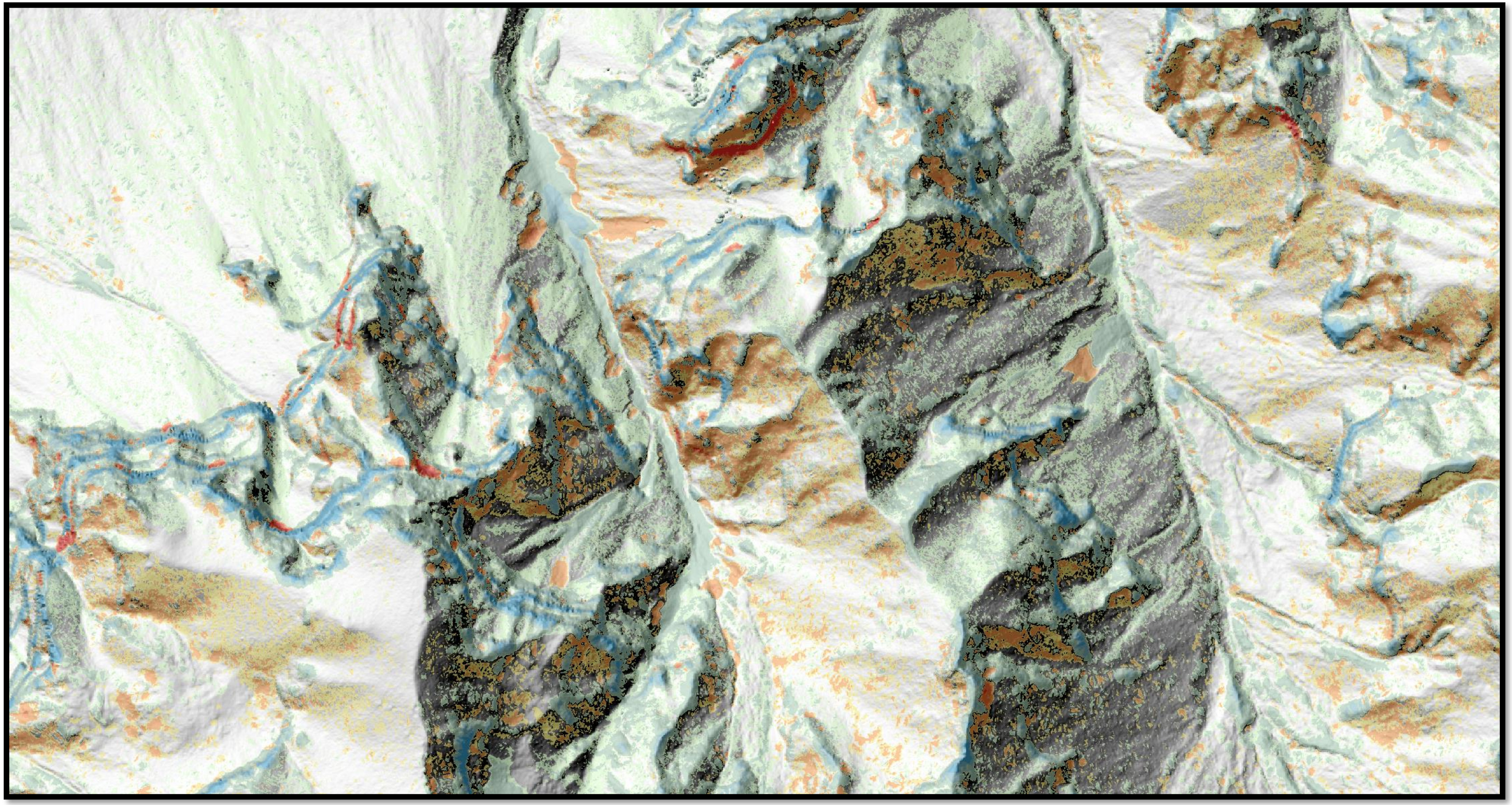

Georeferencing Error Corrected

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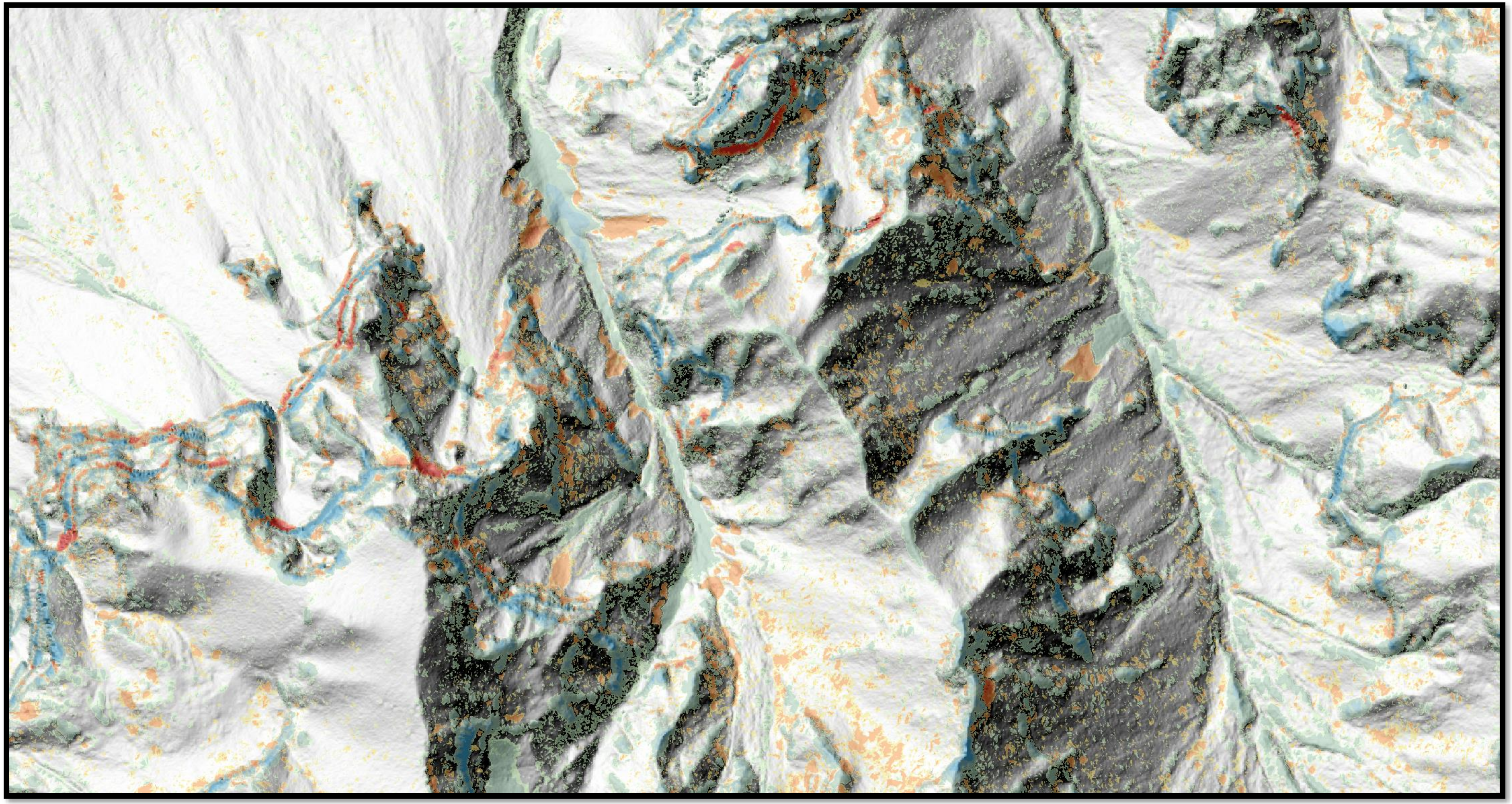

Discussion

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- Ideal to handle transformation at the point cloud level not raster level.
- Repeat data helps identify errors but also creates challenges.
- Many tools are limited in terms of what they can do. Difficult to keep up to date (e.g., Proj library).
- What is the uncertainty posed by the transformation?
- Issues compound with large data volumes.

PROJ

Current Release

- 2023-06-01 proj-9.2.1.tar.gz (md5)
- 2023-06-01 proj-data-1.14.tar.gz

Past Releases

- 2023-03-01 proj-9.2.0.tar.gz
- 2022-12-01 proj-9.1.1.tar.gz
- 2022-09-01 proj-9.1.0.tar.gz
- 2022-06-15 proj-9.0.1.tar.gz
- 2022-03-01 proj-9.0.0.tar.gz
- 2022-01-01 proj-8.2.1.tar.gz
- 2021-11-01 proj-8.2.0.tar.gz
- 2021-09-01 proj-8.1.1.tar.gz
- 2021-07-01 proj-8.1.0.tar.gz
- 2021-05-05 proj-8.0.1.tar.gz
- 2021-03-01 proj-8.0.0.tar.gz
- 2021-01-01 proj-7.2.1.tar.gz
- 2020-11-01 proj-7.2.0.tar.gz

GEO-ESCON Member Institutions

California State University, Fresno	University of Arkansas Fayetteville	Michigan Technological Institute
Florida International University	University of Colorado Boulder	Mississippi State University
Oregon State University	University of Florida	Missouri State University
Purdue University	*University of California San Diego	The Ohio State University
Saint Louis University	Missouri University S&T	*Southern Illinois University
	University of Missouri St. Louis	University of Texas at Austin

*Pending contract execution

Geoescon Research Project @ OSU

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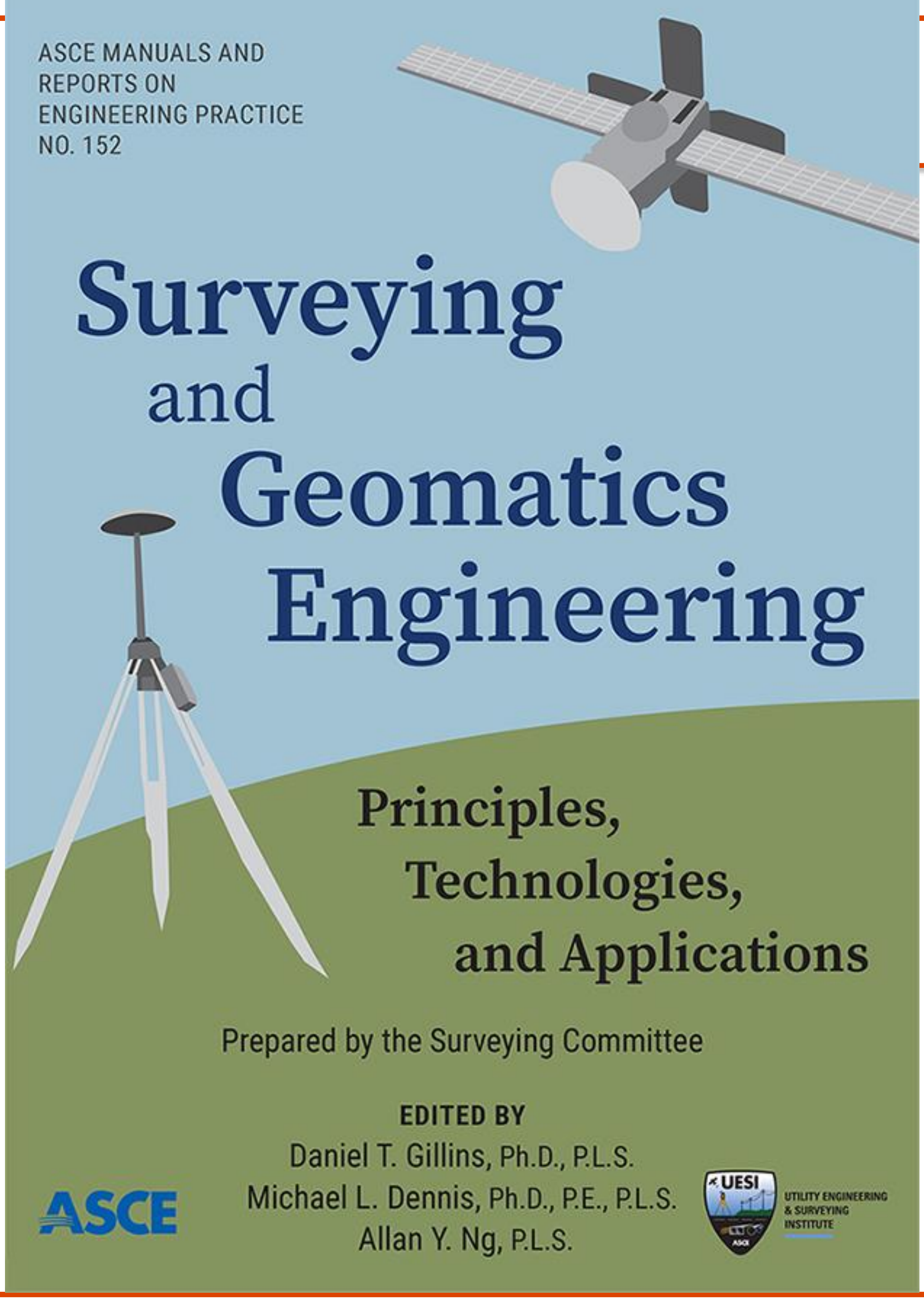
GEO-ESCON
Advancing Geomatics

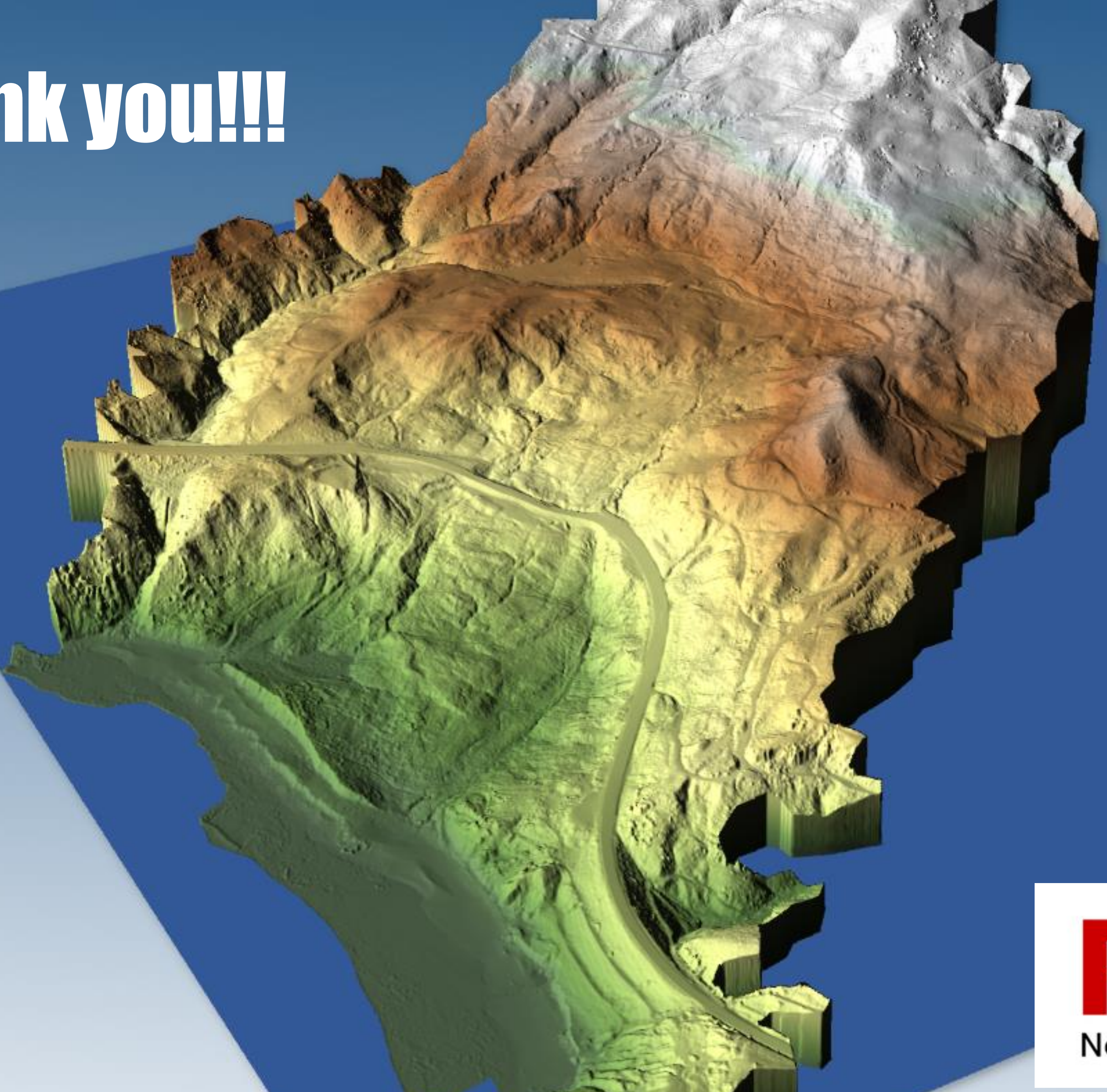
- Explores the reliability of point cloud coordinate and reference frame transformations
- Develops robust techniques to perform and evaluate these transformations.
- Focuses on change detection applications where “minor” coordinate system and datum issues (e.g., improper datum realization) can lead to substantial error in change detection
- Produce a “Point Cloud Transformation Toolkit (PoCToK)” capable of geodetic grade transformations.



- Geodesy,
- Coordinate systems and transformations,
- Least squares adjustments and error propagation,
- Modern surveying and remote sensing technology,
- Analysis and establishment of control,
- Geographic and building information systems,
- Construction surveying, and
- Best practices.

MOP 152 can be used as a summary and a reference for practicing engineers, surveying and otherwise, to help provide a solid understanding of the state of the surveying and geomatics engineering field.

Thank you!!!



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