VGC Short Course ‘4D change analysis of near-continuous LiDAR time series for applications in geomorphic monitoring’

Getting started with 4D change analysis in py4dgeo

See the full workflow in https://github.com/tum-rsa/vgc2023-shortcourse-4d/blob/main/course/practical/vgc2023_time_series_change_analysis.html

Katharina Anders
k.anders@tum.de

Technical University of Munich
TUM School of Engineering and Design
Professorship for Remote Sensing Applications

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The case for py4dgeo

4D → massive multitemporal point cloud data
- Automating change analysis
- Bundling state-of-the-art methods

Open-source Python library for change analysis in 4D point cloud data: https://github.com/3dgeo-heidelberg/py4dgeo

… providing 3D/4D methods:
- M3C2 (Lague et al., 2013)
- 4D objects-by-change (Anders et al., 2021)
- Correspondence-Driven Plane-Based M3C2 (Zahs et al., 2022)
- M3C2-EP (Winiwarter et al., 2021)
- …

… and a flexible interface for analysis workflows

See the basic usage tutorials: https://py4dgeo.readthedocs.io and [materials in the E-TRAINEE online course](#)

4D HEIDELBERG

py4dgeo
Open source Python library for geographic change analysis in 4D point cloud data

Creating epochs from point cloud arrays:

```
print('[%s] Creating epoch 1...' % (datetime.now().strftime('%Y-%m-%d %H:%
epoch1 = py4dgeo.Epoch(coords1)

print('[%s] Creating epoch 2...' % (datetime.now().strftime('%Y-%m-%d %H:%
epoch2 = py4dgeo.Epoch(coords2)

print('[%s] Epochs successfully created, kd-trees built' % (datetime.now()
```

```
[2021-12-23 10:41:54] Creating epoch 1...
[2021-12-23 10:41:55] Creating epoch 2...
[2021-12-23 10:41:56] Epochs successfully created, kd-trees built
```

M3C2 distance calculation

Configuring and running M3C2:

```
print('[%s] Configuring M3C2...' % (datetime.now().strftime('%Y-%m-%d %H:%
m3c2 = py4dgeo.M3C2(epochs=(epoch1, epoch2), corepoints=corepoints, radii=
m3c2_multiscale = py4dgeo.M3C2(epochs=(epoch1, epoch2), corepoints=corepoi

print('[%s] Running M3C2...' % (datetime.now().strftime('%Y-%m-%d %H:%M:%S
distances, uncertainties = m3c2.run()
distances_multiscale, uncertainties_multiscale = m3c2_multiscale.run()
print('[%s] Calculation successful' % (datetime.now().strftime('%Y-%m-%d %
```

```
[2021-12-23 10:41:56] Configuring M3C2...
[2021-12-23 10:41:56] Running M3C2...
[2021-12-23 10:41:58] Calculation successful
```

Accessing all result information, i.e. `lodetection`, `num_samples`, and `stddev` in `uncert`

```
lodetection = uncertainties['lodetection']
stddev1 = uncertainties['stddev1']
numsamples1 = uncertainties['num_samples1']
stddev2 = uncertainties['stddev2']
numsamples2 = uncertainties['num_samples2']
normals = m3c2.directions()
```

Change Analysis in py4dgeo

class **Epoch**

- Data: coordinates (nx3 array)
- Property: metadata (dictionary), transformation
- Methods:
  - calculate_normals()
  - transform()
  - save/load()
- Created using py4dgeo.read_from_las() / py4dgeo.read_from_xyz()

```
# import the library for M3C2 distance calculation
import py4dgeo

# load point clouds as epoch objects
epoch_2009, epoch_2017 = py4dgeo.read_from_las(
    las_data2009_aligned, las_data2017
)
```

https://py4dgeo.readthedocs.io/en/latest/pythonapi.html#py4dgeo.Epoch

Bitemporal Change Analysis

… using the M3C2 algorithm (Lague et al., 2013)

Parameters:
- Normal radius (can be multiscale)
- Cylinder radius (‚projection scale‘ d/2)
- Max. search depth
- Registration error (for consideration of distance uncertainty)

Obtained variables:
- Distance
- Normal vector (direction)
- Num. samples n
- Spread σ
- Level of detection

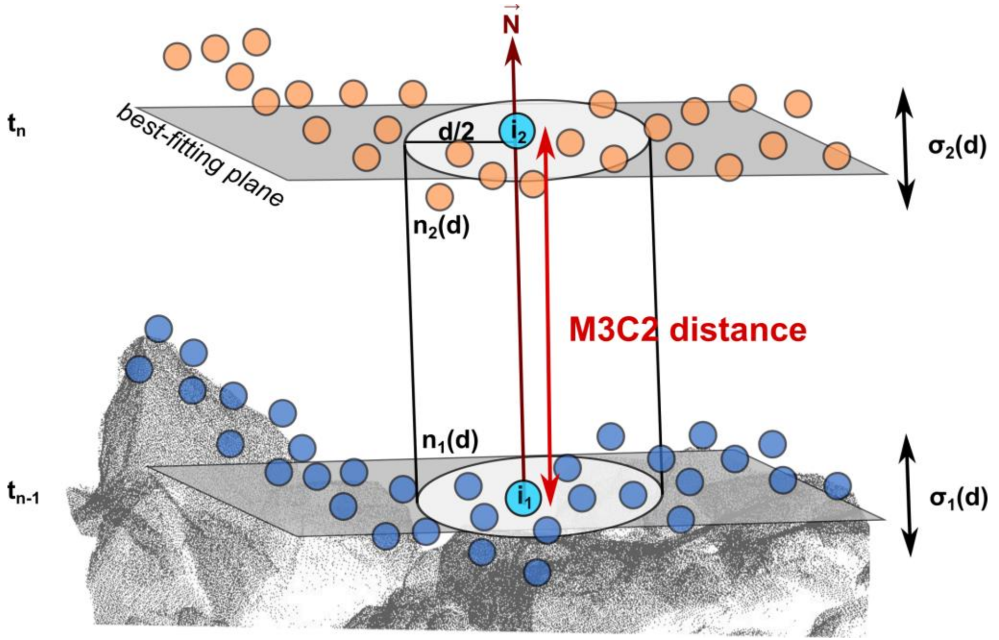


Figure by V. Zahs modified from Zahs et al. (2022)

Bitemporal Change Analysis

… using the M3C2 algorithm (Lague et al., 2013)

- Executed on **core points**
- Parameters are passed on instantiation of the algorithm
- Running the algorithm returns
  - **Distances**
  - **Uncertainty** data → structured array with
    - lodetection
    - num_samples[1/2]
    - spread [1/2]

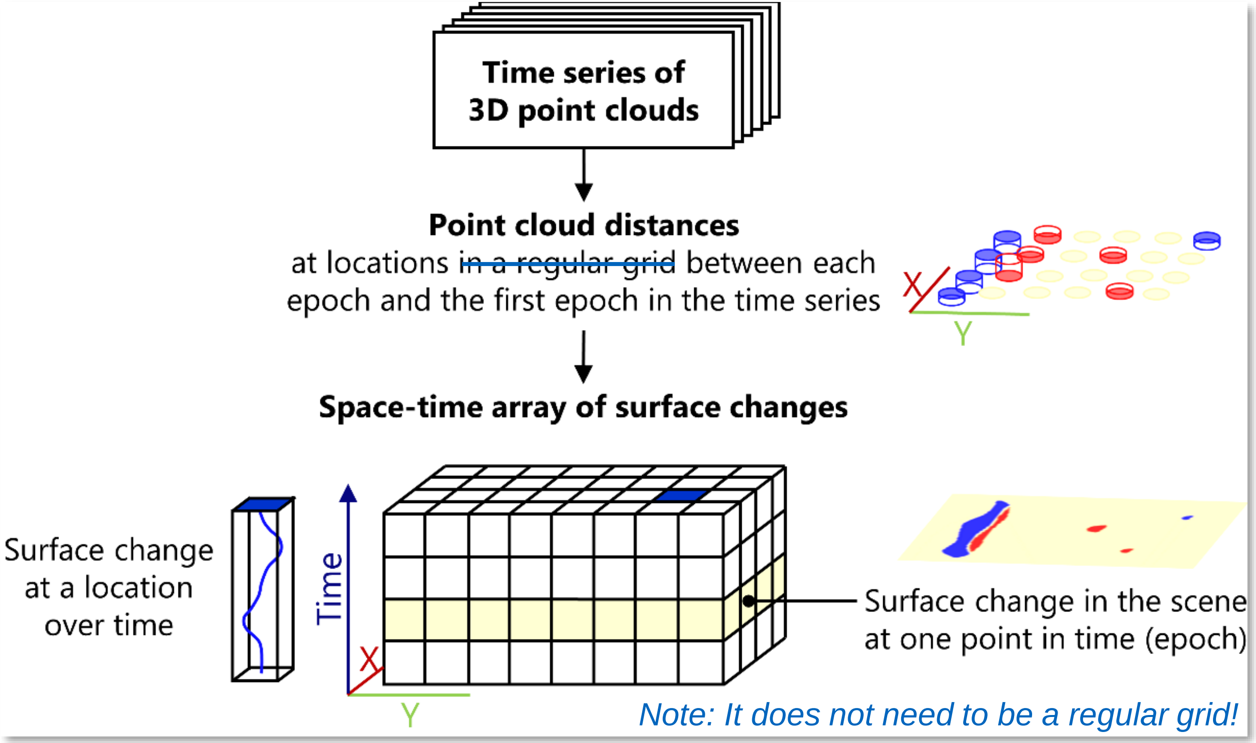
```
# define a set of corepoints
corepoints = epoch_2009.cloud[::]
```

```
m3c2 = py4dgeo.M3C2(
    epochs=(epoch_2009, epoch_2017),
    corepoints=corepoints,
    normal_radii=(2.0, 1.0, 8.0),
    cyl_radii=(2.0,),
    max_distance=(50.0),
    registration_error=(1.31)
)

m3c2_distances, uncertainties = m3c2.run()
```

Time Series Change Analysis in py4dgeo

class **SpatiotemporalAnalysis**

- **Data** (properties):
    - corepoints
    - reference_epoch
    - timedeltas
    - m3c2 → algorithm settings
    - **distances** (M2C2 result)
    - uncertainties (M2C2 result)
- Data is added via **add_epochs(*epochs)**



Note: It does not need to be a regular grid!

Anders et al. (2021)

https://py4dgeo.readthedocs.io/en/latest/pythonapi.html#py4dgeo.SpatiotemporalAnalysis

Creating a SpatiotemporalAnalysis (1/2)

```
analysis = py4dgeo.SpatiotemporalAnalysis(f'{data_path}/kijkduin.zip', force=True)
```

```
# specify the reference epoch
reference_epoch_file = os.path.join(pc_dir, pc_list[0])

# read the reference epoch and set the timestamp
reference_epoch = py4dgeo.read_from_las(reference_epoch_file)
reference_epoch.timestamp = timestamps[0]

# set the reference epoch in the spatiotemporal analysis object
analysis.reference_epoch = reference_epoch
```

```
# Inherit from the M3C2 algorithm class to define a custom direction algorithm
class M3C2_Vertical(py4dgeo.M3C2):
    def directions(self):
        return np.array([0, 0, 1]) # vertical vector orientation

# specify corepoints, here all points of the reference epoch
analysis.corepoints = reference_epoch.cloud[::]

# specify M3C2 parameters for our custom algorithm class
analysis.m3c2 = M3C2_Vertical(cyl_radii=(1.0,), max_distance=10.0, registration_error = 0.019)
```

Creating a SpatiotemporalAnalysis (1/2)

```
an                                            s(f'{data_path}/kijkduin.zip', force=True)
```

```
#
r                                             dir,

#                                             time
r                                             (ref
r                                             0]

# set the reference epoch in the spatiotemp
analysis.reference_epoch = reference_epoch
```

```
# Inherit from the M3C2 algorithm class to
class M3C2_Vertical(py4dgeo.M3C2):
    def directions(self):
        return np.array([0, 0, 1]) # vertic

# specify corepoints, here all points of th
analysis.corepoints = reference_epoch.cloud

# specify M3C2 parameters for our custom al
analysis.m3c2 = M3C2_Vertical(cyl_radii=(1.
```

Hint: Explore the possibilities of py4dgeo with in-notebook help

```
?py4dgeo.SpatiotemporalAnalysis
```

```
Init signature:
py4dgeo.SpatiotemporalAnalysis(
    filename,
    compress=True,
    allow_pickle=True,
    force=False,
)
Docstring:      <no docstring>
Init docstring:
Construct a spatiotemporal segmentation object

This is the basic data structure for the 4D objects by change algorithm
and its derived variants. It manages storage of M3C2 distances and other
intermediate results for a time series of epochs. The original point clouds
themselves are not needed after initial distance calculation and additional
epochs can be added to an existing analysis. The class uses a disk backend
to store information and allows lazy loading of additional data like e.g.
M3C2 uncertainty values for postprocessing.

:param filename:
    The filename used for this analysis. If it does not exist on the file
    system, a new analysis is created. Otherwise, the data is loaded from the existent file.
```

Creating a SpatiotemporalAnalysis (2/2)

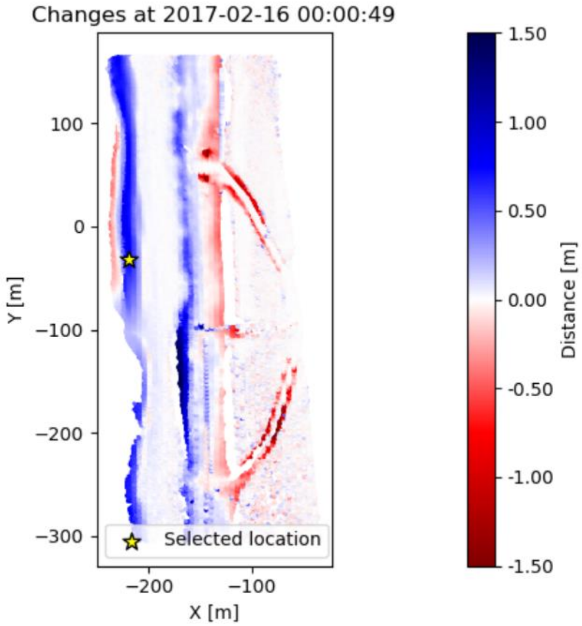
```
# create a list to collect epoch objects
epochs = []
for e, pc_file in enumerate(pc_list[1:]):
    epoch_file = os.path.join(pc_dir, pc_file)
    epoch = py4dgeo.read_from_las(epoch_file)
    epoch.timestamp = timestamps[e]
    epochs.append(epoch)

# add epoch objects to the spatiotemporal analysis object
analysis.add_epochs(*epochs)

# print the spatiotemporal analysis data for 3 corepoints and 5 epochs, respectively
print(f"Space-time distance array:\n{analysis.distances[:3,:5]}")
print(f"Uncertainties of M3C2 distance calculation:\n{analysis.uncertainties['lodetection'][:3, :5]}")
print(f"Timestamp deltas of analysis:\n{analysis.timedeltas[:5]}")
```

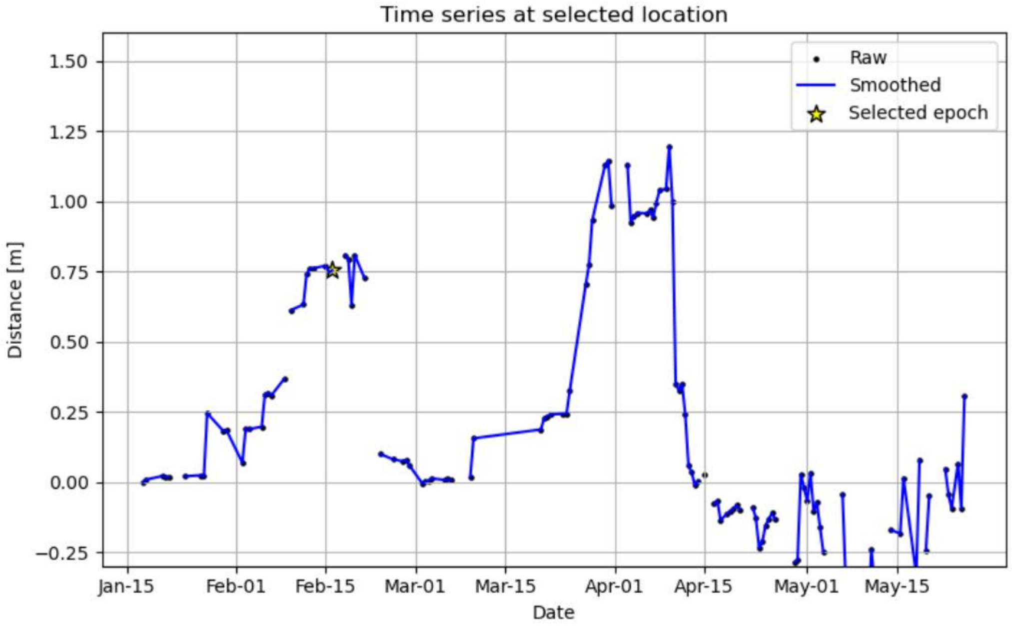
```
# get the corepoints
corepoints = analysis.corepoints.cloud
```

```
# get the list of timestamps from the reference epoch timestamp and timedeltas
timestamps = [t + analysis.reference_epoch.timestamp for t in analysis.timedeltas]
```

Making use of the SpatiotemporalAnalysis Object

```
cp_idx_sel = 15162 # selected core point index
epoch_idx_sel = 28 # selected epoch index
```

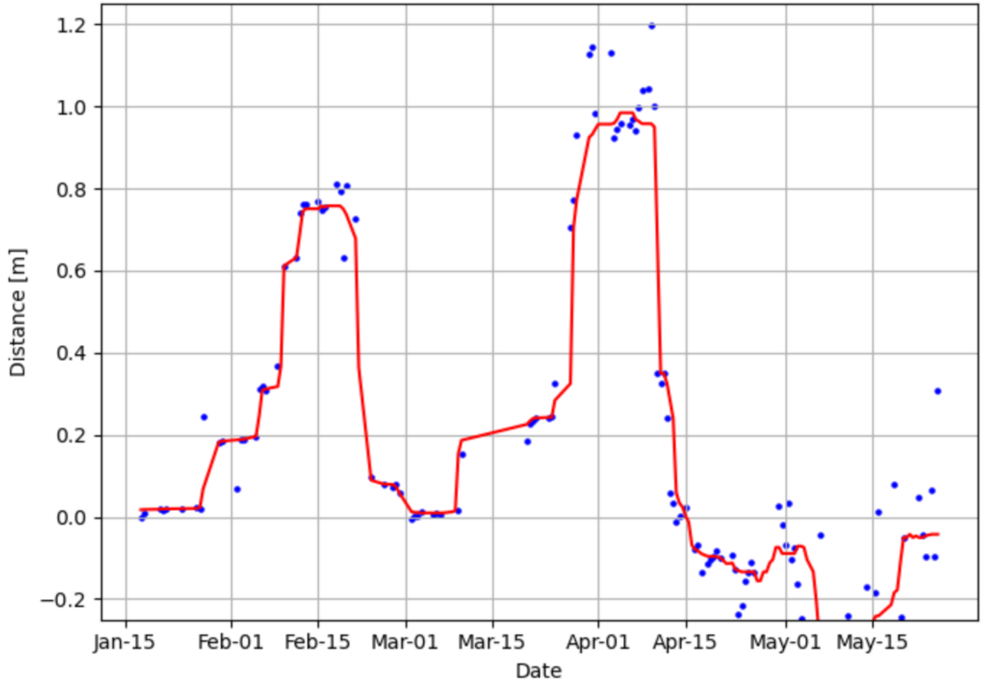




Temporal Smoothing

… following 4D filtering by Kromer et al. (2015)

```
analysis.smoothed_distances = py4dgeo.temporal_averaging(analysis.distances, smoothing_window=14)
```



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