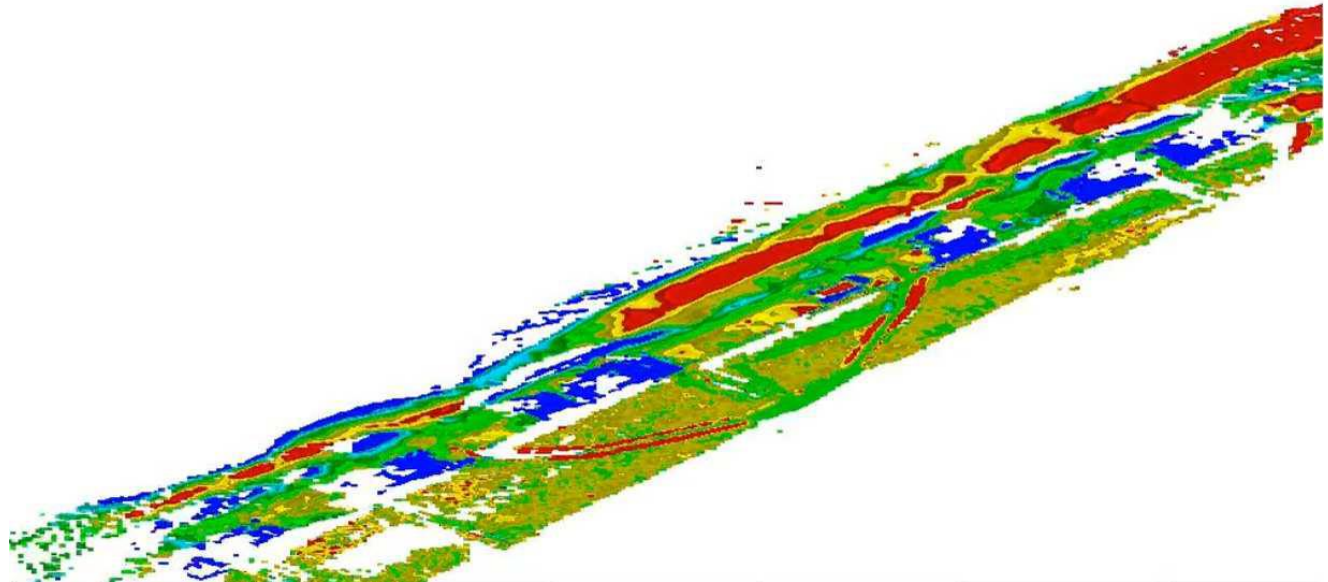


Kijkduin beach difference (2017-04-02)  
Compared to 2016-11-11. Color: Red=+0.5 m - Blue=-0.5m

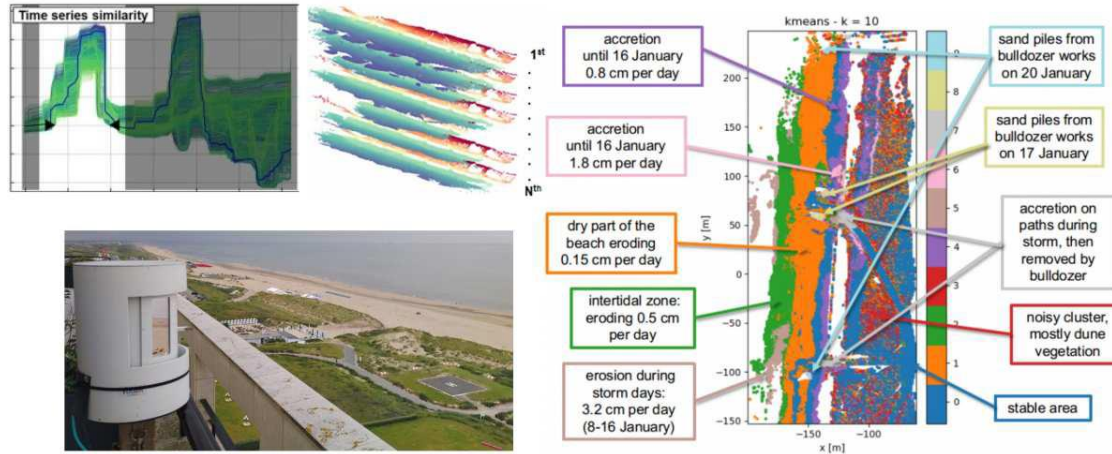
- 1) Katharina Anders
- 2) Mieke Kuschnerus
- 3) Roderik Lindenbergh



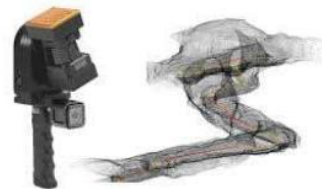
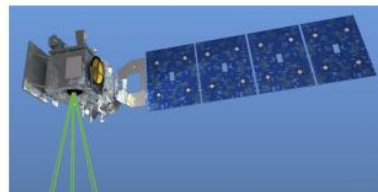
# Schedule

- 1) **Introduction to 4D point clouds** (RL, 15 min)
- 2) **Getting started with 4D point cloud analysis** (KA/py4dgeo, 20 min)
- 3) **Method I: Clustering** (MK)
  - a) Theory (10 min)
  - b) Practical (25 min)
- 4) **Q&A and Outlook** (10 min)
- 5) Break (15 min)
- 6) **Method II: PCA** (RL)
  - a) Theory (10 min)
  - b) Practical (25 min)
- 7) **Method III: 4D objects-by-change** (KA)
  - a) Theory (10 min)
  - b) Practical (25 min)
- 8) **Q&A and Wrap-Up** (15 min)

# Introduction to 4D point clouds

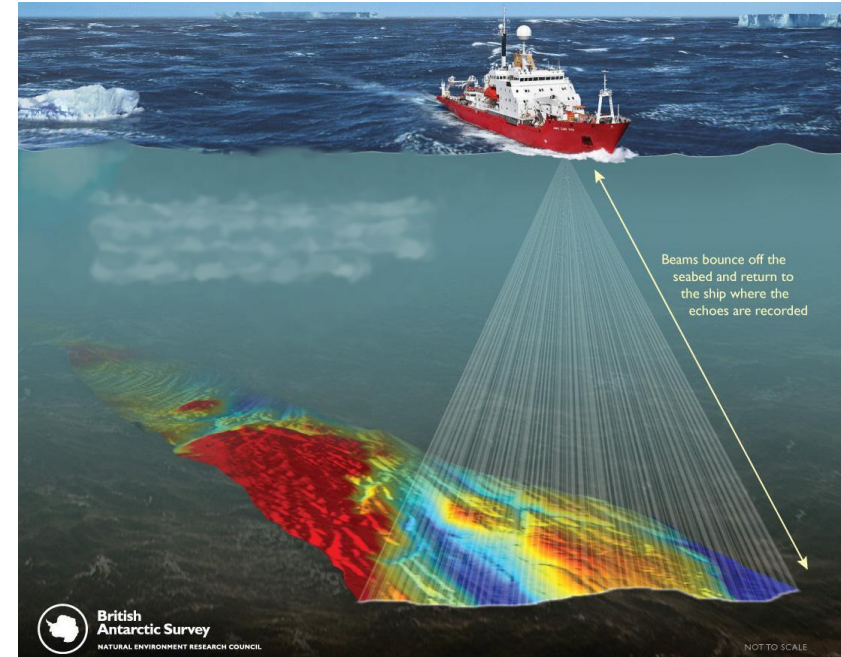
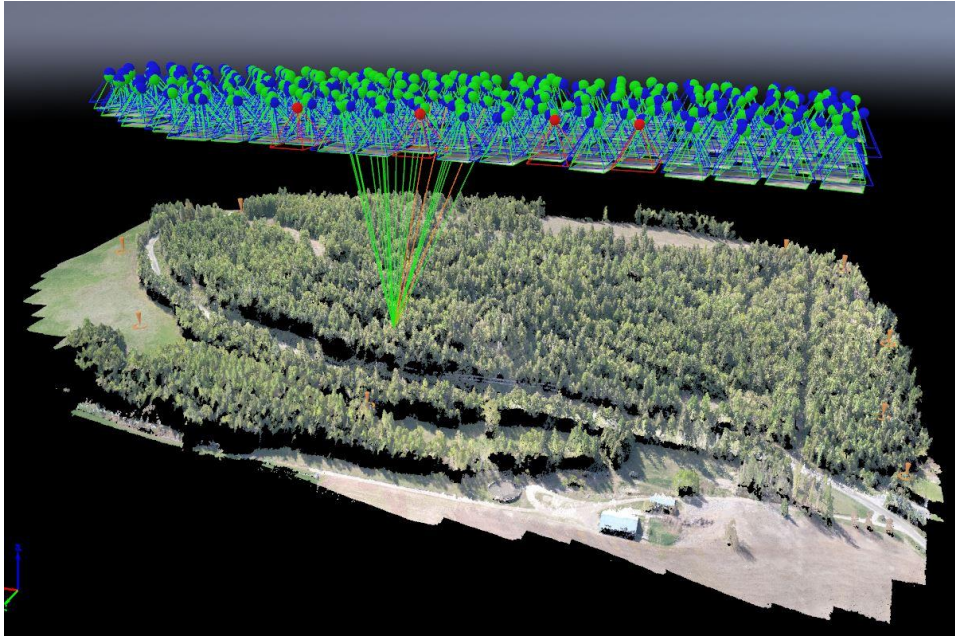


# LIDAR sensors



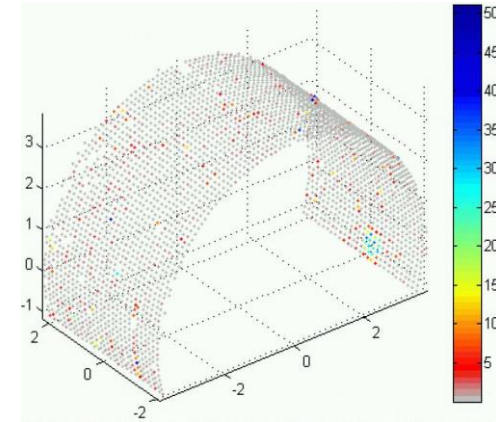


# Photogrammetry & Echo Sounding

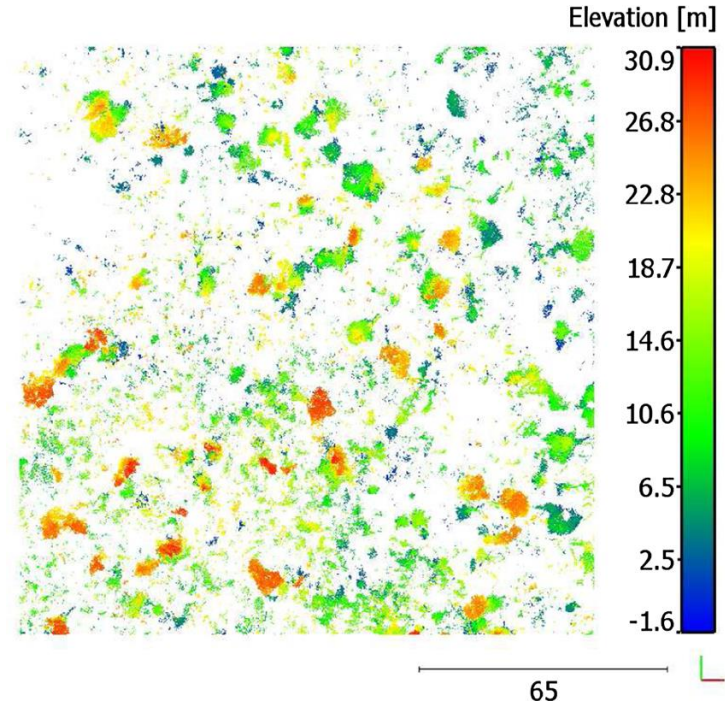
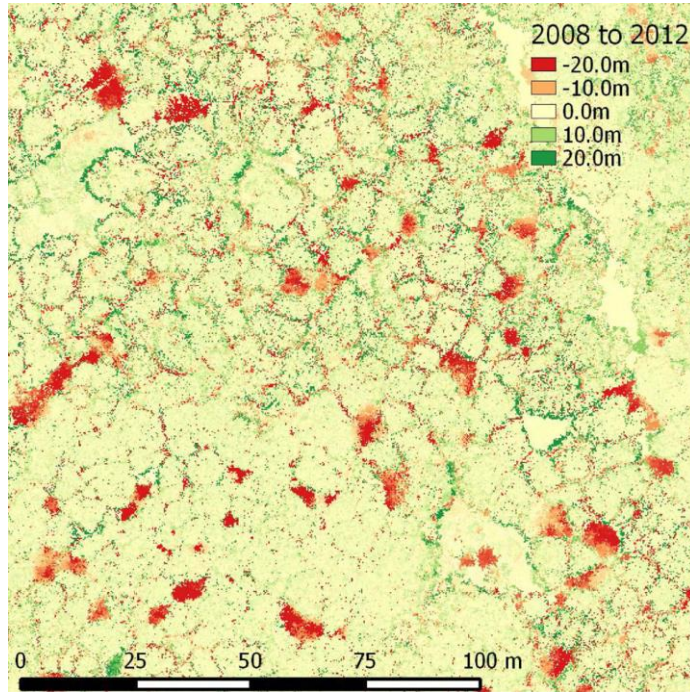


# Change detection

- 1) Consider two 3D data sets of a given scene:
  - Before
  - After
- 2) Did the scene change?
- 3) How **confident** are we that the scene changed, given the quality of the data?
- 4) How **much** did the scene change?
- 5) In which **direction** did the scene changed?



# 2D vs. 3D change

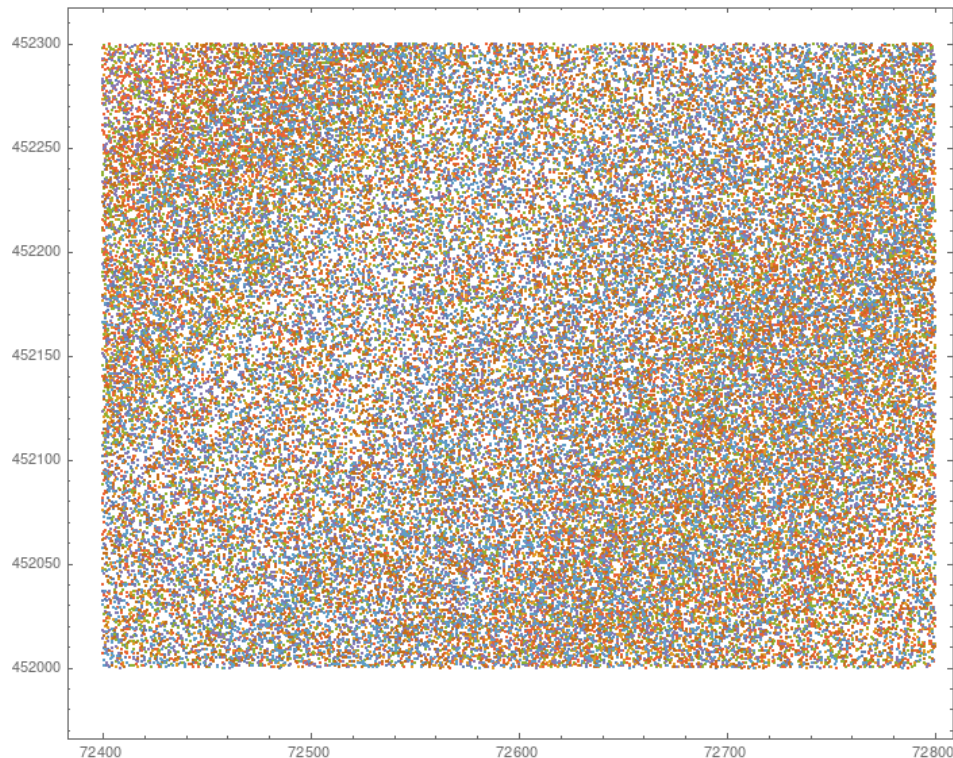
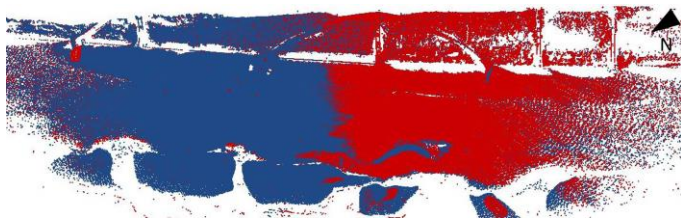




# Challenges

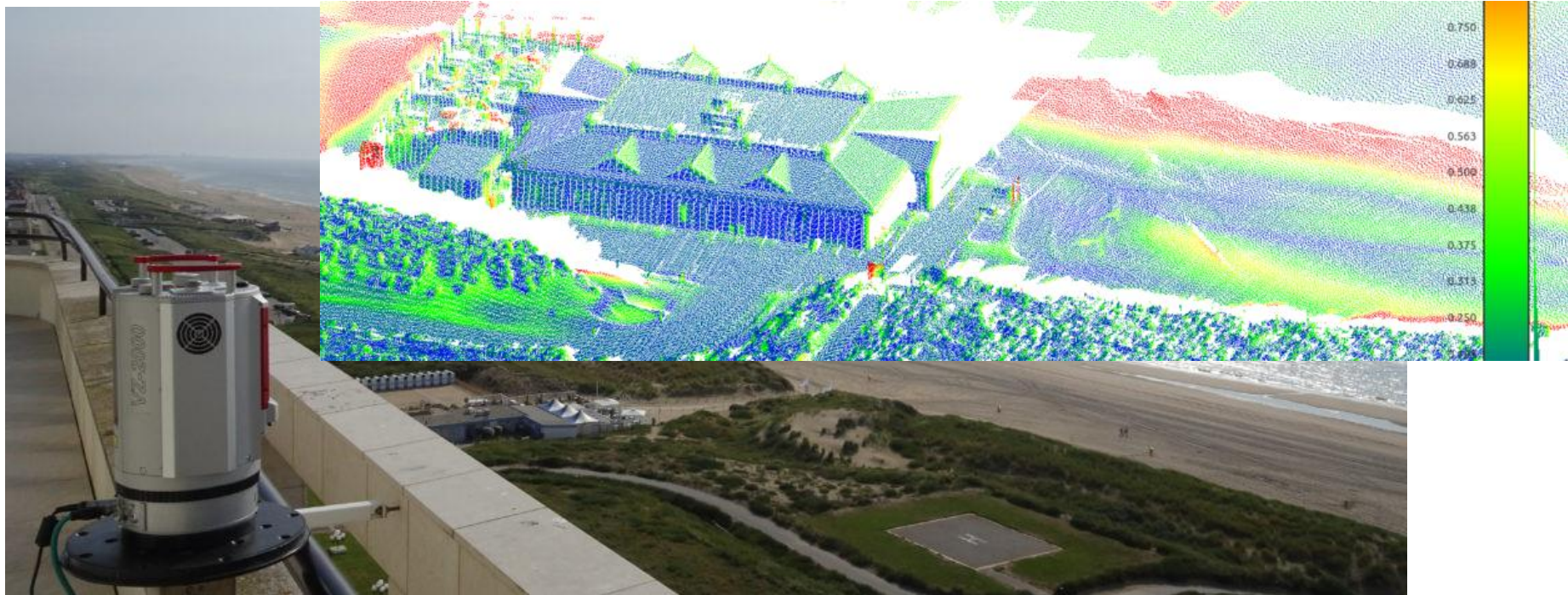
## Data issues:

- Point clouds are not aligned
- Different epochs or even different points in point cloud have different (unknown) quality
- Point clouds are too big
- Points from different epochs are at different locations
- ...



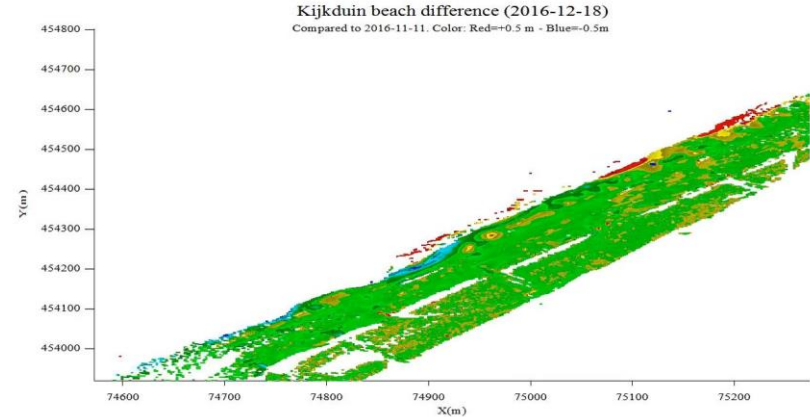
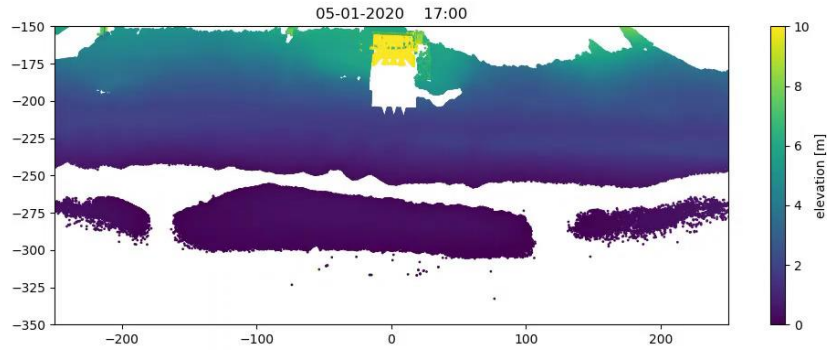


# Automatized, repeated acquisition



Vos, S., Anders, K., Kuschnerus, M., Lindenbergh, R., Höfle, B., Aarninkhof, S., & de Vries, S. (2022). A high-resolution 4D terrestrial laser scan dataset of the Kijkduin beach-dune system, The Netherlands. *Scientific Data*, 9(1), 191.

# 4D Data



Videos: <https://coastscan.citg.tudelft.nl/index.php/data-publication/>

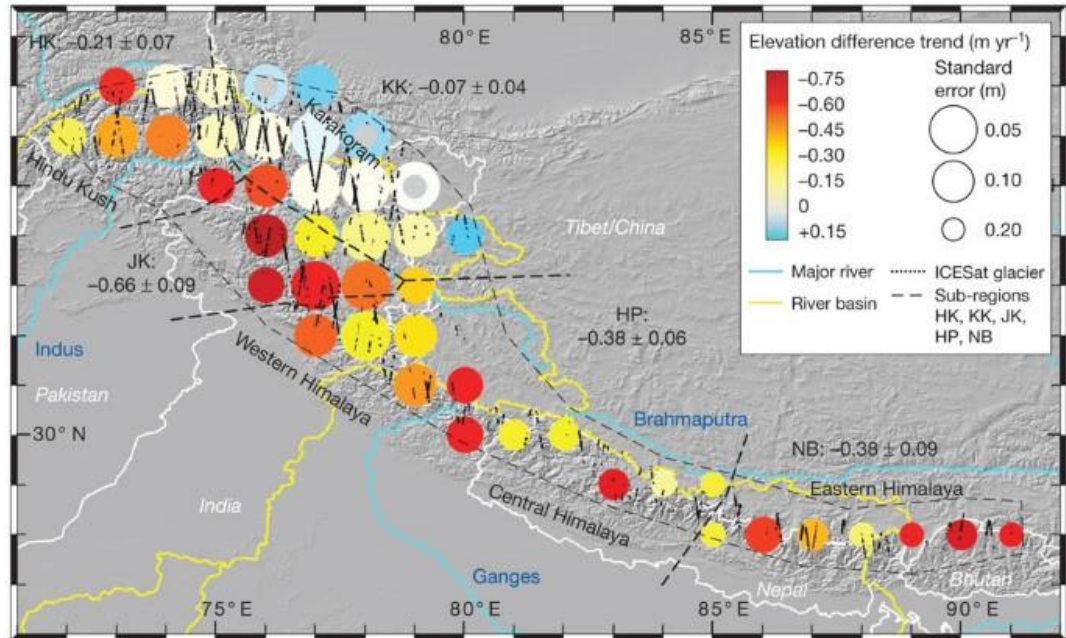
4D Data: repeatedly available 3D point cloud data with a significant temporal dimension

# Methods for 4D analysis

## Consecutive difference with first epoch/reference DEM

Kääb, A., Berthier, E., Nuth, C. *et al.*  
Contrasting patterns of early  
twenty-first-century  
glacier mass change in the Himalayas.  
*Nature* **488**, 495–498 (2012).  
<https://doi.org/10.1038/nature11324>

Applied on non-repeated  
ICESat profiles





# Methods for 4D analysis

## Trend Analysis

- <http://doris.tudelft.nl/~rlindenbergh/publications/igarssposter.pdf>
- Kalman filtering, <https://doi.org/10.5194/esurf-11-593-2023>
- Advanced version, presentation MK @ VGC

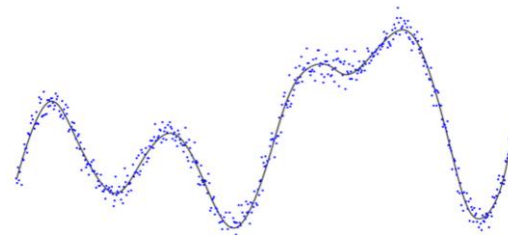
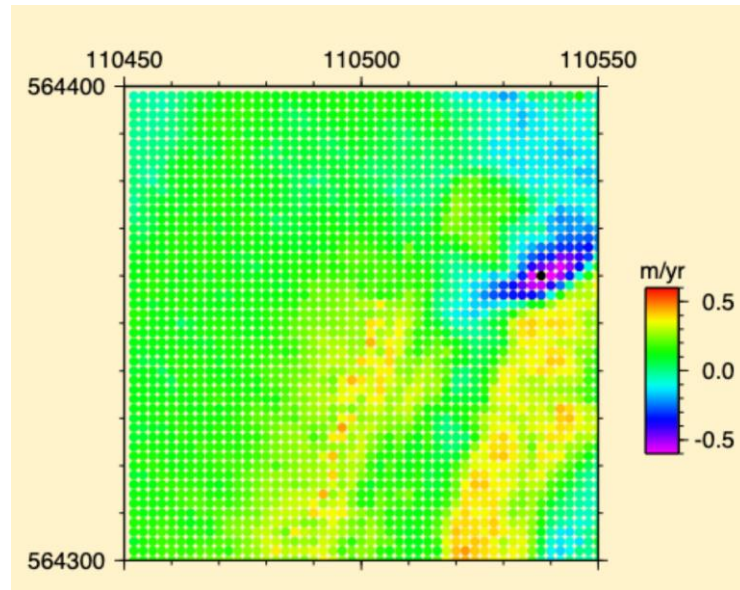
## Coefficients of fitted functions

- Reduces data volume
- Allows to interpolate missing epochs

## Clustering: MK

## PCA: RL

## 4D objects-by-change: KA



# Conclusions on 4D analysis

## 4D data is more and more coming available

- Different repositories of Permanent Laser Scan data
- Repeated 'institutional' airborne laser scan and photogrammetric elevation data, and MBES data
- Repeated UAV and TLS campaigns

Institutional example: <http://doris.tudelft.nl/~rlindenbergh/vgc/>

## Several methods were developed for 4D change analysis:

- Properties/feasability of different methods in practice not yet fully known
- Methods were often developed for one particular data set
- Interactive & combined use of these methods has often hardly been done

We are looking forward to you experiences.

