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TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

Effects of former coalmining in south-Limburg, the Netherlands: decreasing the InSAR search space of sinkhole formation with geological constraints

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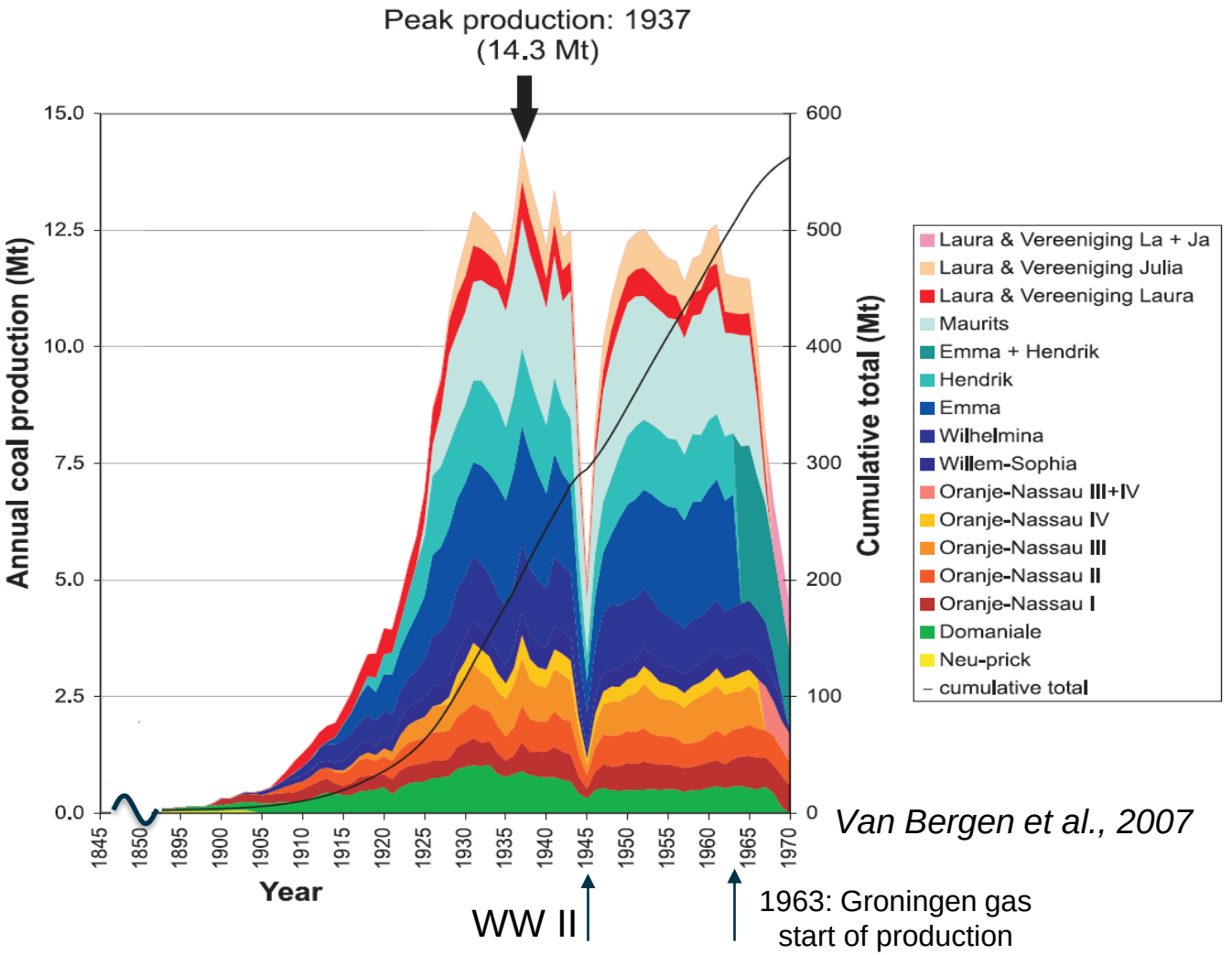
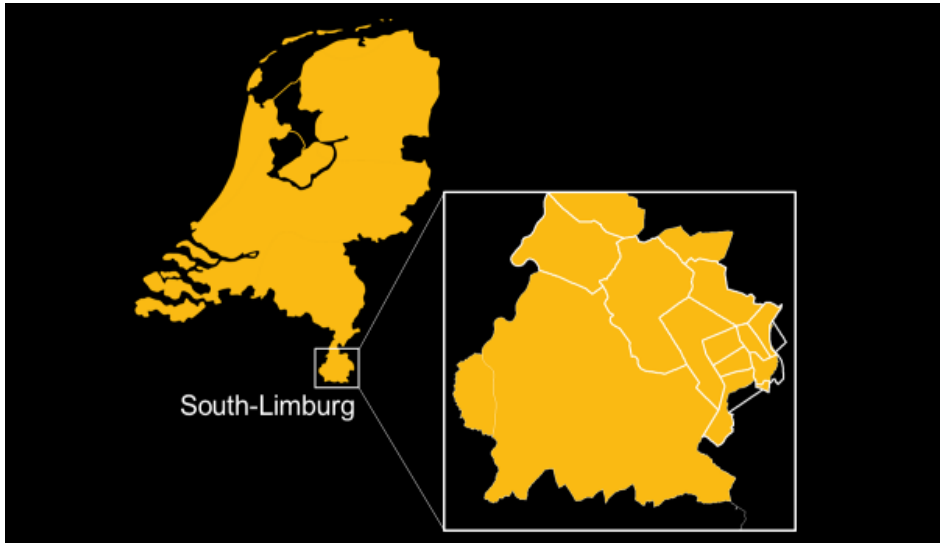
TNO (Netherlands Organisation for Applied Scientific Research)

26/05/2022

Coal mining South Limburg: co-mining period



Van Bergen et al., 2007

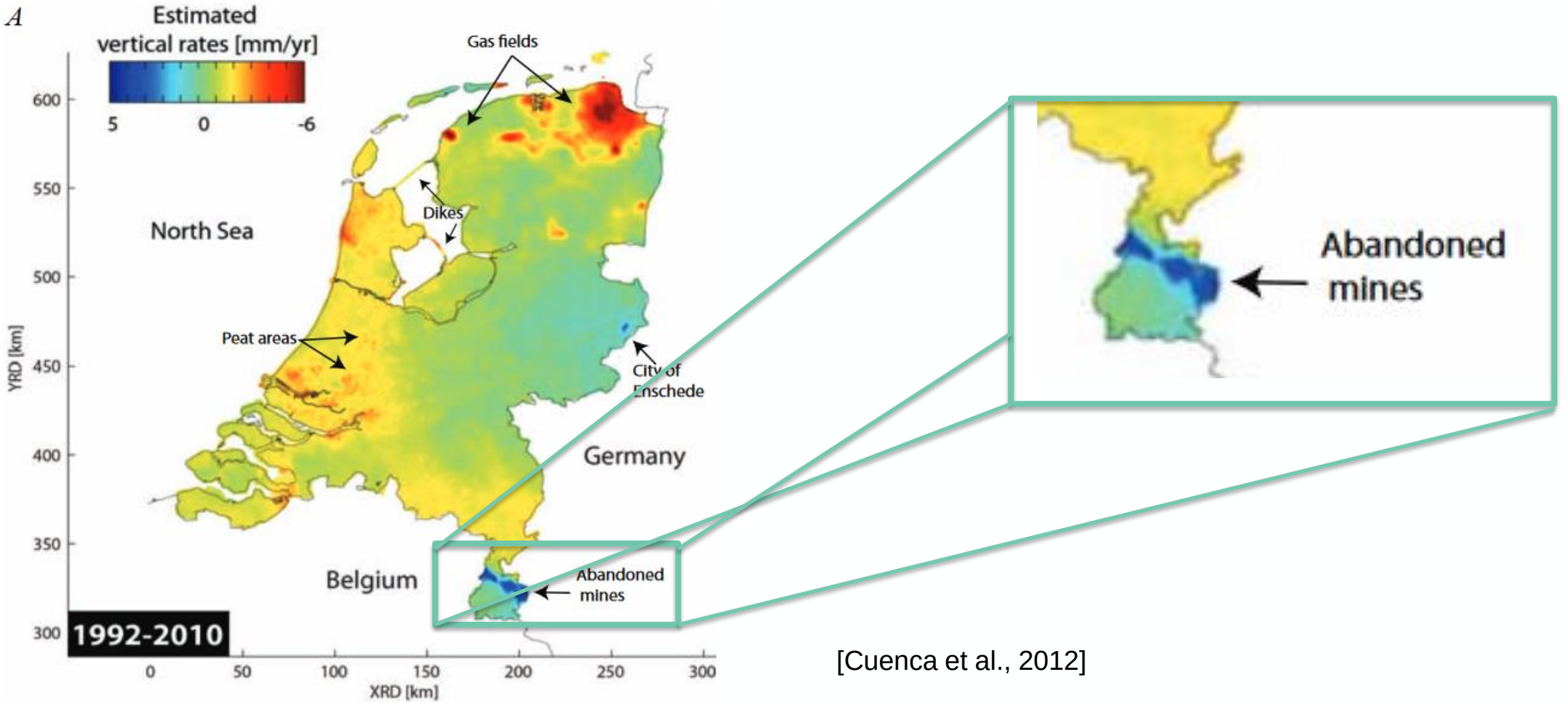


Surface displacements during the Coal-mining period:

- ✓ Surface subsidence as result of coal extraction (order of meters)
- ✓ Collapse of mining cavities and formation of hundreds of sinkholes
- ✓ Surface subsidence due to pumping of mines (probably order of cm)
- ✓ Tectonic movement along reactivated faults; karstic features.

Coal mining South Limburg: post-mining period

ERS + ENVISAT

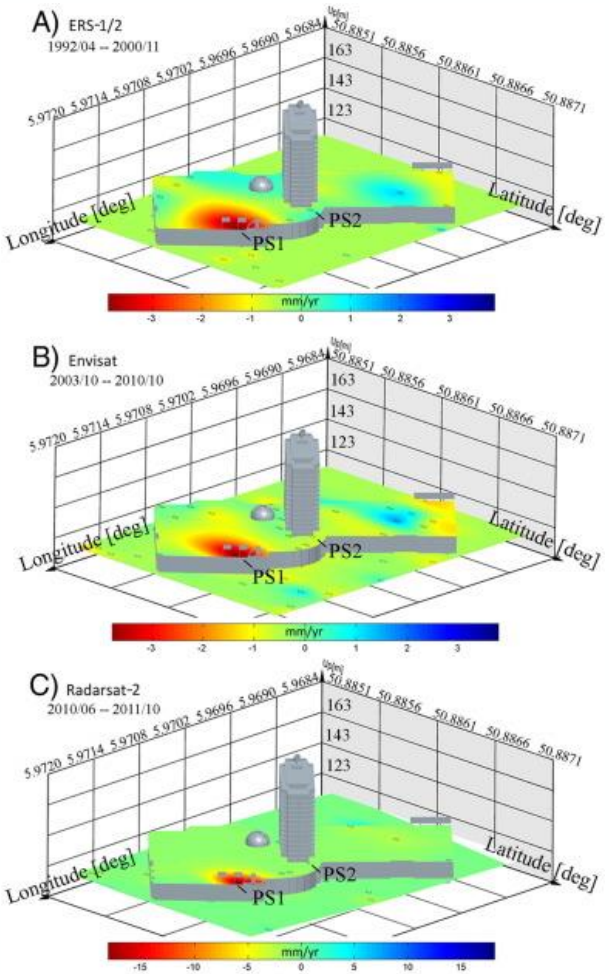


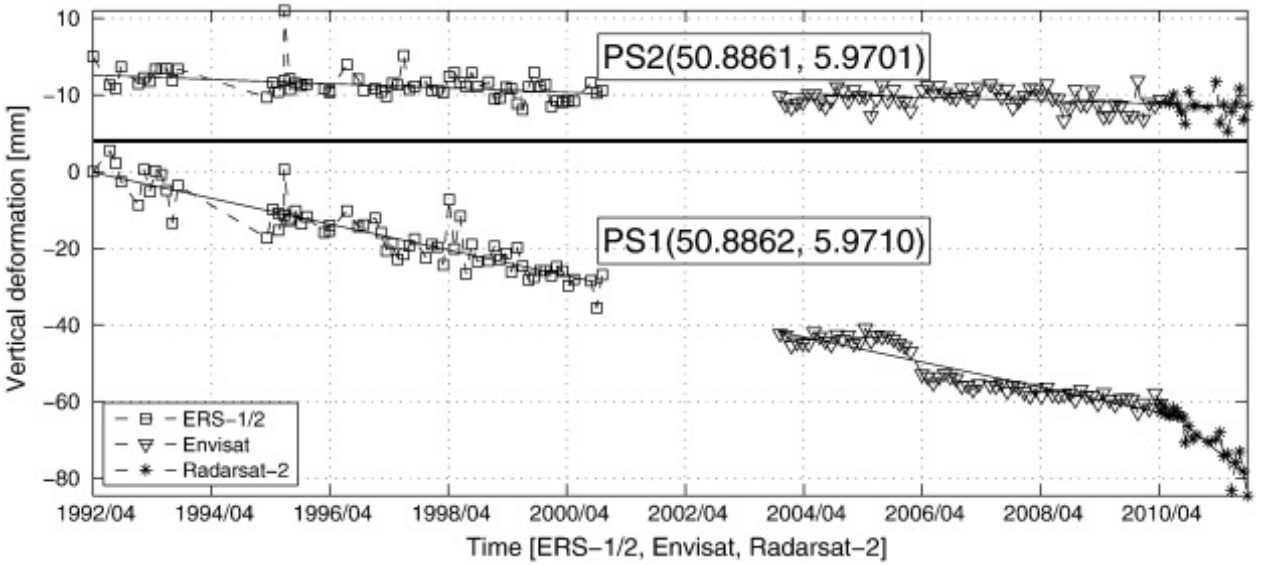
[Cuenca et al., 2012]

‘T Loon sinkhole, 2011

Coal mining South Limburg: post-mining period

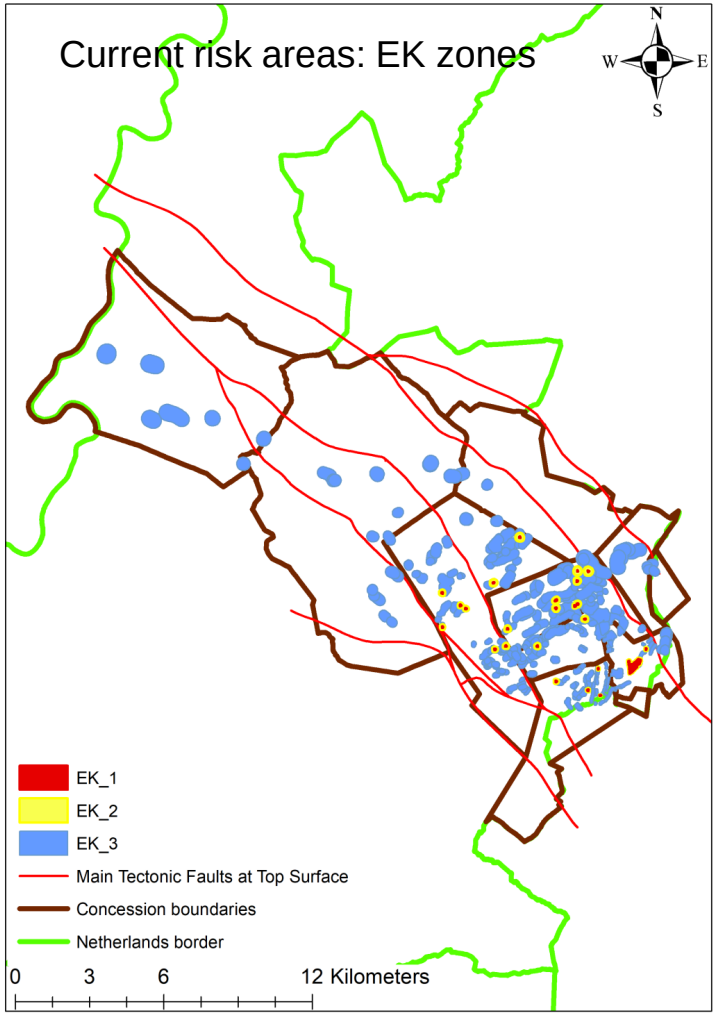
ERS + ENVISAT + Radarsat





[Chang and Hanssen, 2014]

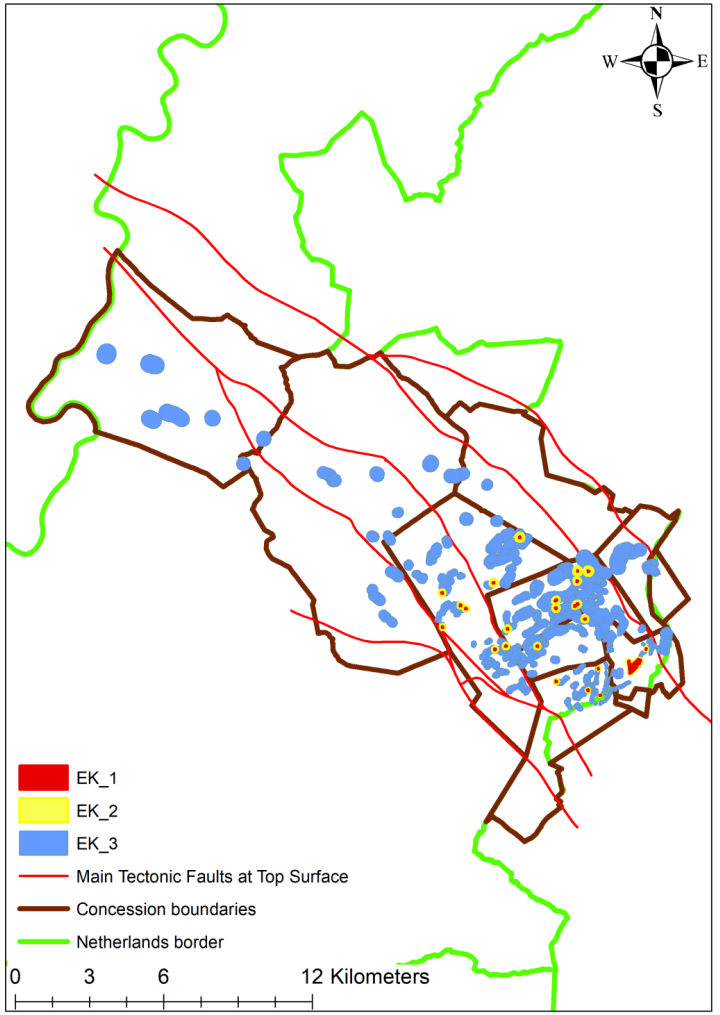
Motivation



['Na-ijlende gevolgen steenkolenwinning Zuid-Limburg', 2015]

- There are millions of PS/DS InSAR points
- Sinkhole mechanisms are not well known
- Superimposition of different surface deformation mechanisms

Research questions



['Na-ijlende gevolgen steenkolenwinning Zuid-Limburg', 2015]

How to reduce the InSAR search space while pointing out possible areas for sinkholes?

Which other information is relevant?

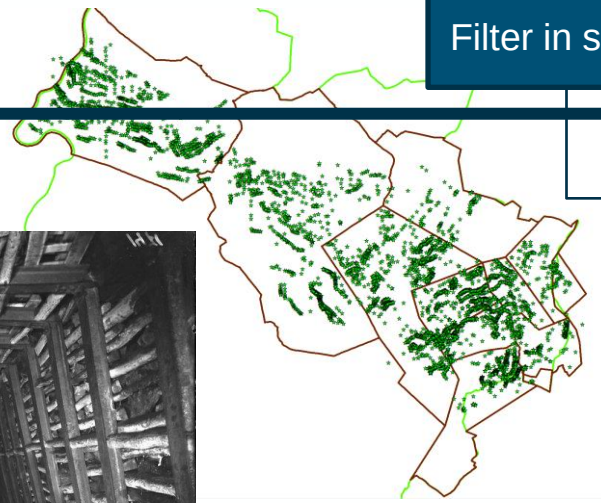
How to combine it with InSAR in an optimal way?

Should these risk areas as previously defined in 2015 be re-evaluated?

Approach to decrease InSAR search space

Spatial constraints

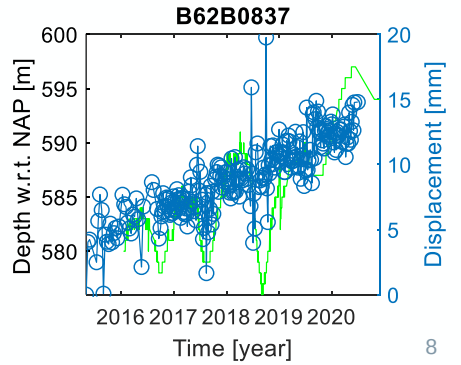
- ✓ Mining maps
- ✓ core descriptions
- ✓ upward drilling logs
- ✓ Location of high-rise and public building



Spatio-temporal constraints

- ✓ InSAR derived surface deformation
- ✓ Time-series classification (ML clustering)
- ✓ Groundwater pressures from piezometers

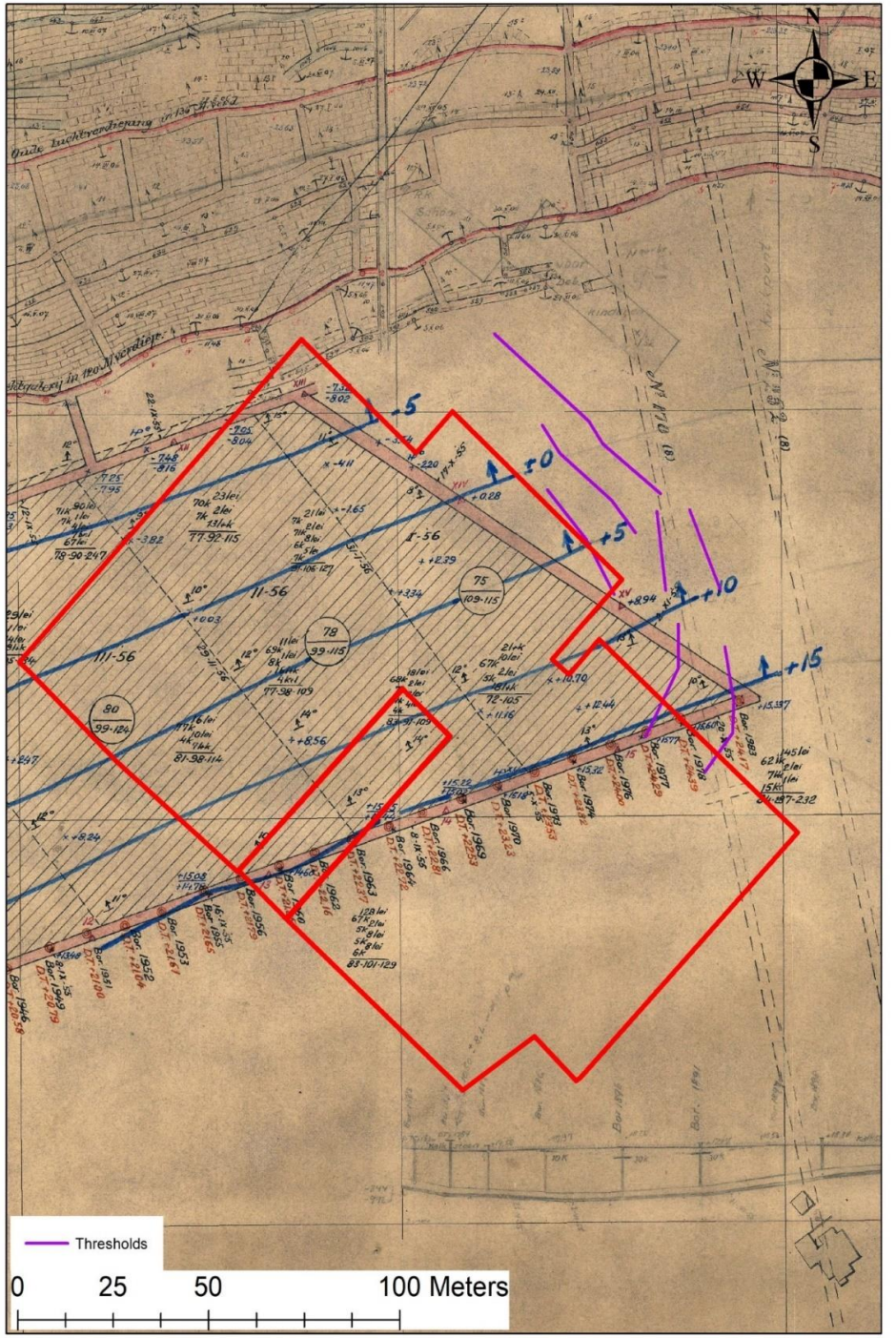
satellite	Processed period
ERS-1/2	**1992-2000**
ENVISAT	**2003-2010**
RADARSAT-2 (I)	**2010-2014**
TERRASAR-X	**2013-2017**
SENTINEL	**2015-2020**
RADARSAT-2 (II)	**2017-2020**
TOTAL > **500 acquisitions**	Datasets procssed by TUDelft and SkyGeo



Learning from ‘T Loon sinkhole

Sinkhole formation criteria

- 1. The presence of a mining gallery vertex below the building.
- 2. The presence of a mining panel directly below the building.
- 3. The building is located directly above the highest point of the mining panel.
- 4. The thickness of the consolidated rock above the mining panel is less than 20 meters (safety roof thickness).
- 5. The presence of upward drillings under the building.
- 6. The presence of ‘steps’ (‘thresholds’) within tens of meters of the building.



Example of auxiliary information

Available auxiliary information e.g.:

- High-rise and public buildings (higher risk)
- Upward drilling lines (mining configuration)

Upward drillings indicate;

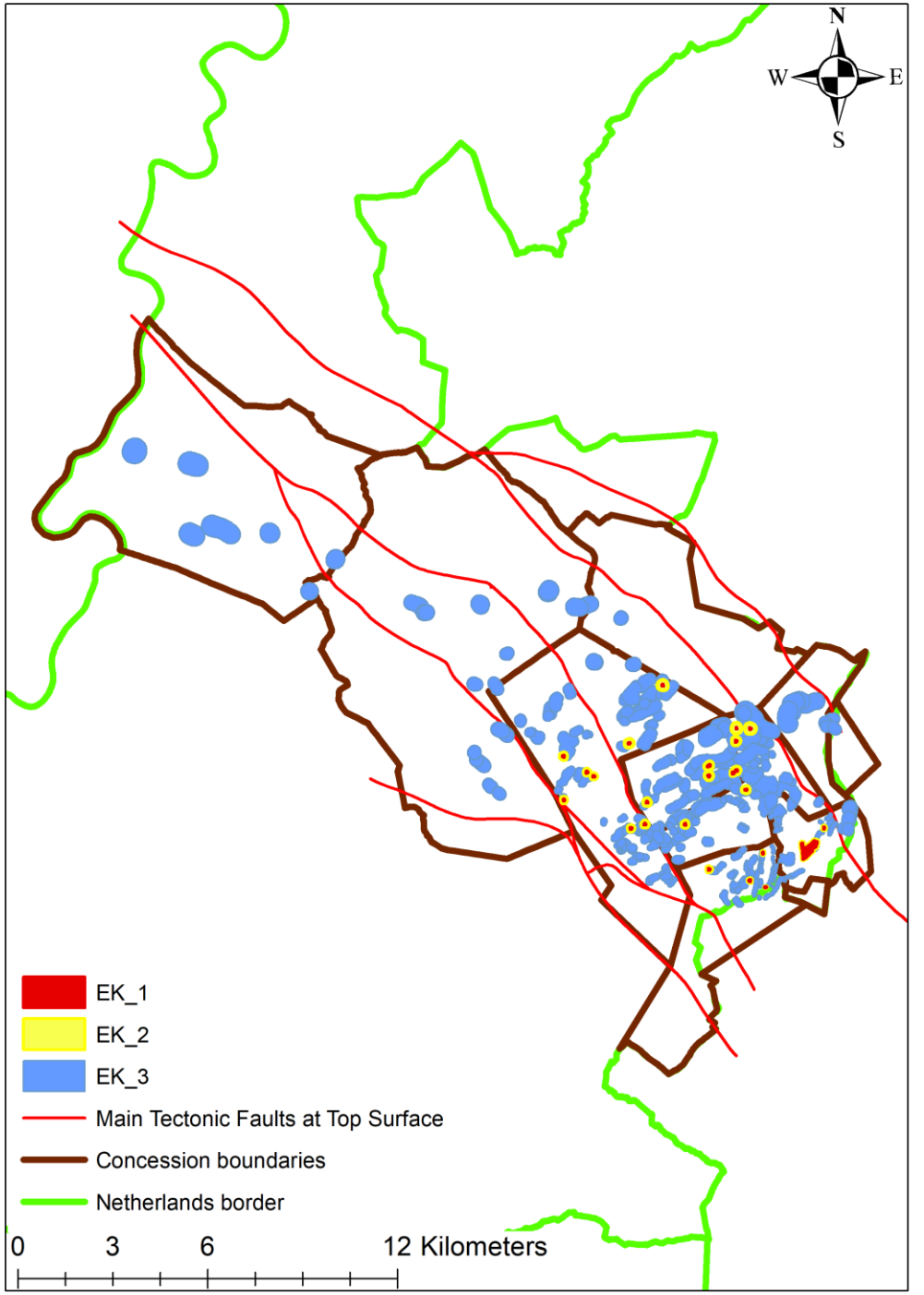
Mining panel is present

Thin carboniferous roof

End of a series of upward drillings might be an acute angle of galleries

Concept: decreasing in space

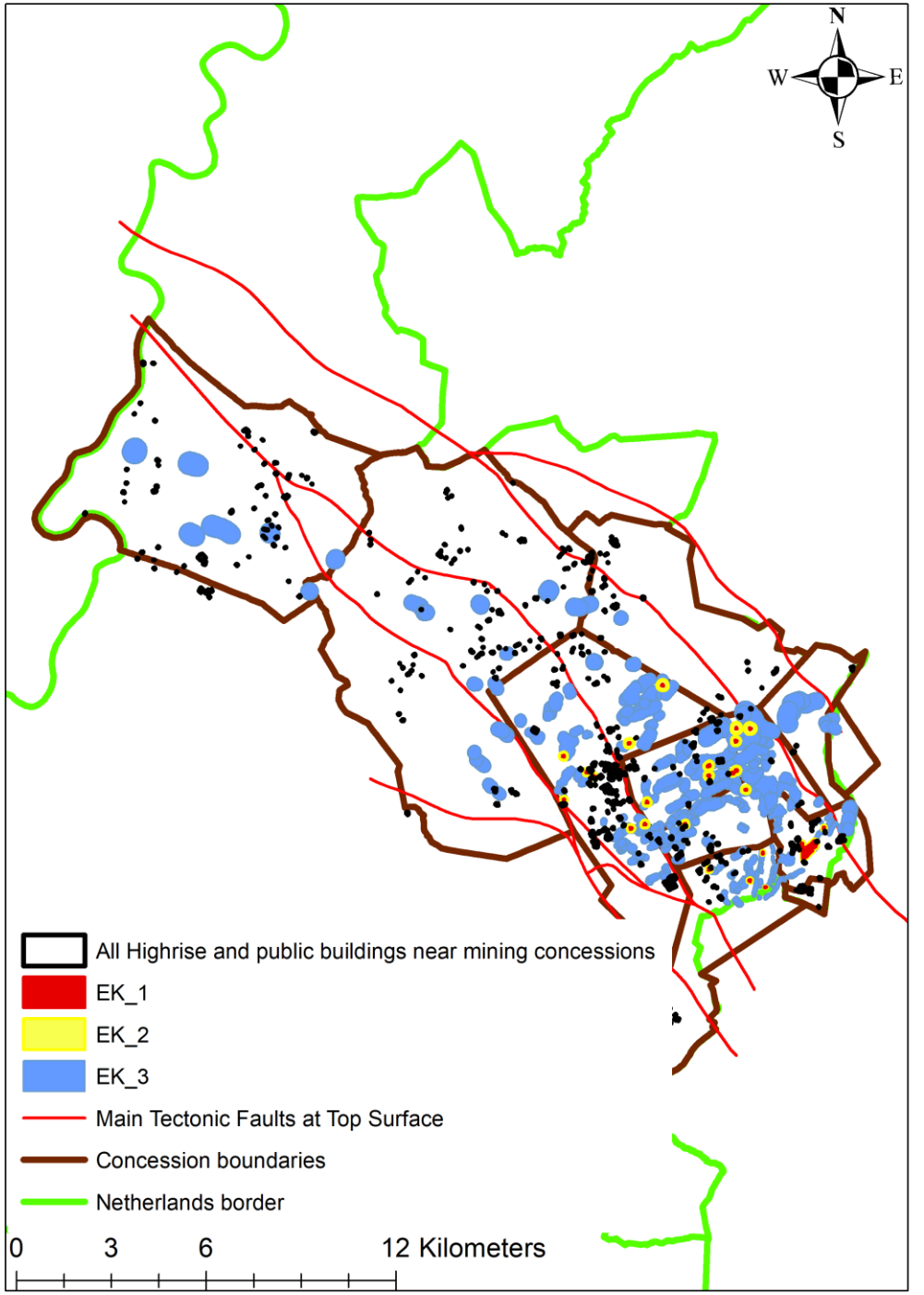
- ✓ Previously defined risk areas



EK1, EK2 and EK3 from ‘Na-ijlende gevolgen steenkolenwinning Zuid-Limburg’, 2015

Concept: decreasing in space

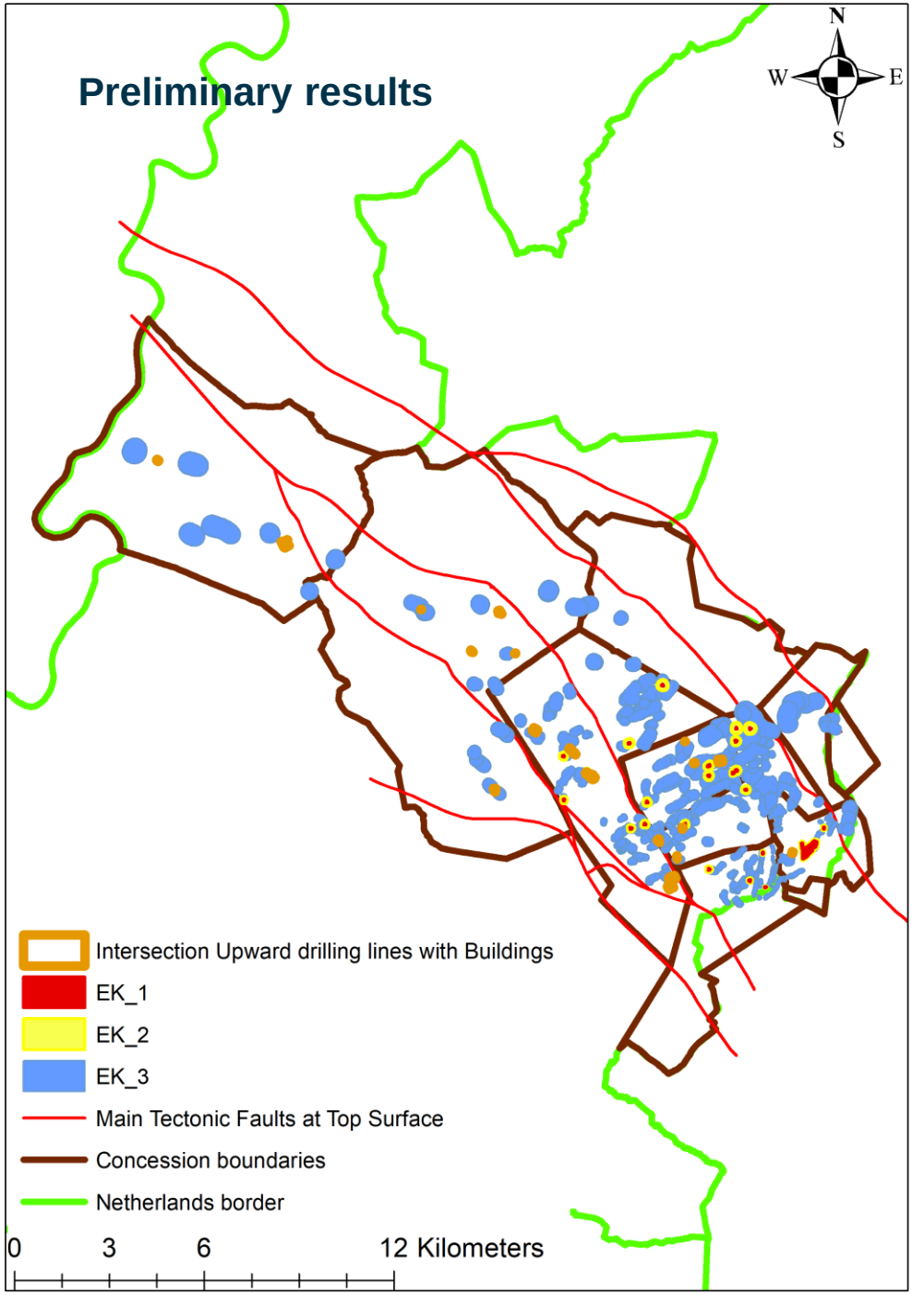
- ✓ Previously defined risk areas
- ✓ High-rise and public buildings



EK1, EK2 and EK3 from ‘Na-ijlende gevolgen steenkolenwinning Zuid-Limburg’, 2015

Concept: decreasing in space

- ✓ Previously defined risk areas
- ✓ High-rise and public buildings
- ✓ Decreased search space: Intersection of upward drillings with special buildings (reduced to 22 buildings)



EK1, EK2 and EK3 from ‘Na-ijlende gevolgen steenkolenwinning Zuid-Limburg’, 2015

Approach to decrease InSAR search space

Spatial constraints

- ✓ Mining maps
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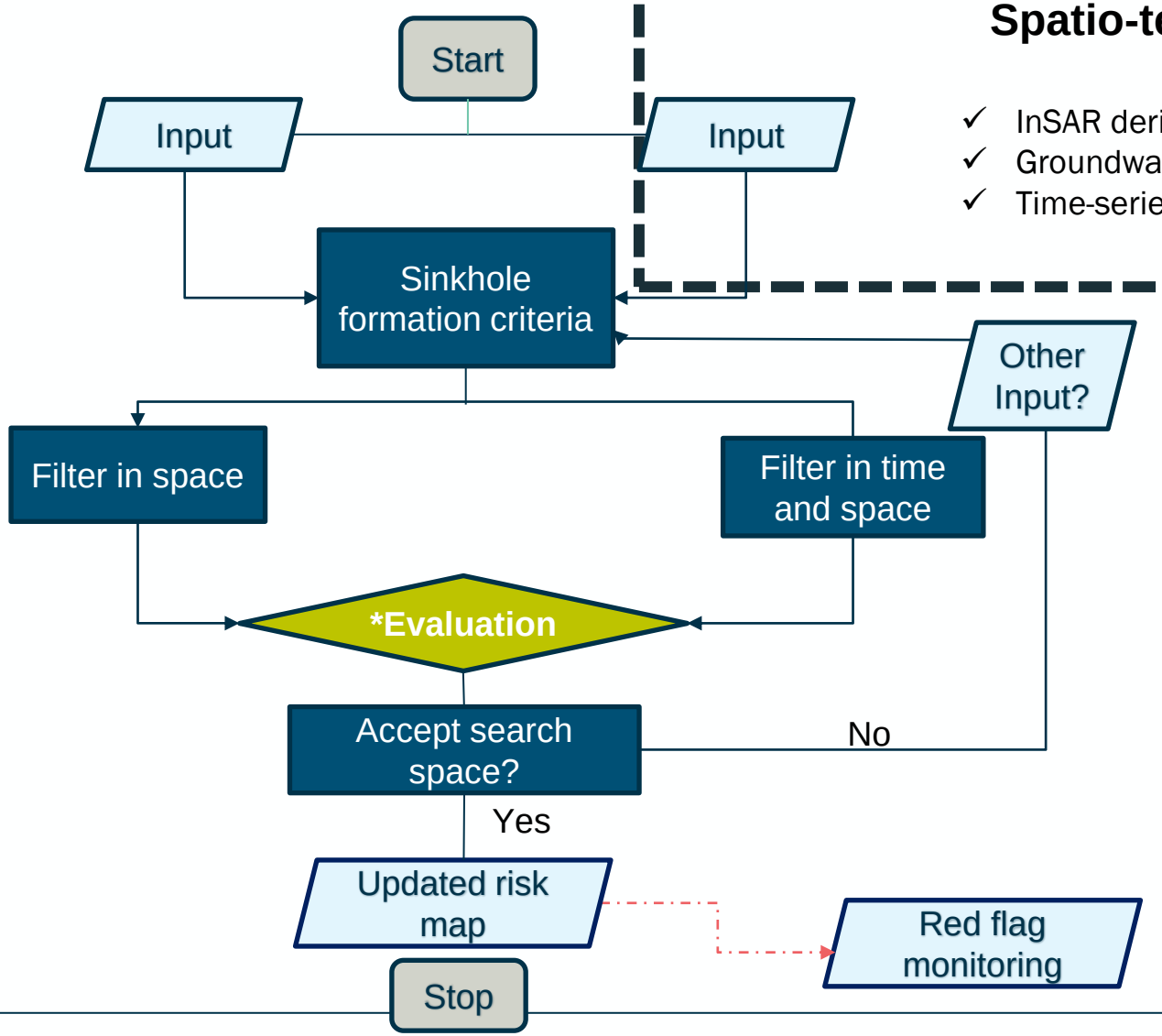
- ✓ Location of high-rise and public building



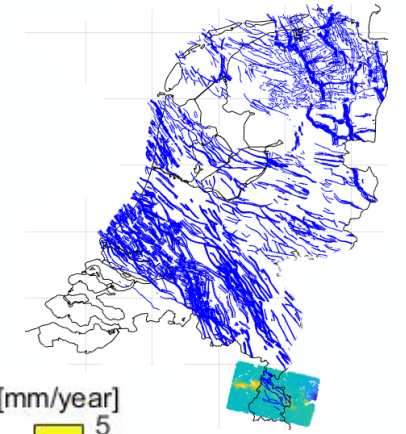
Spatio-temporal constraints

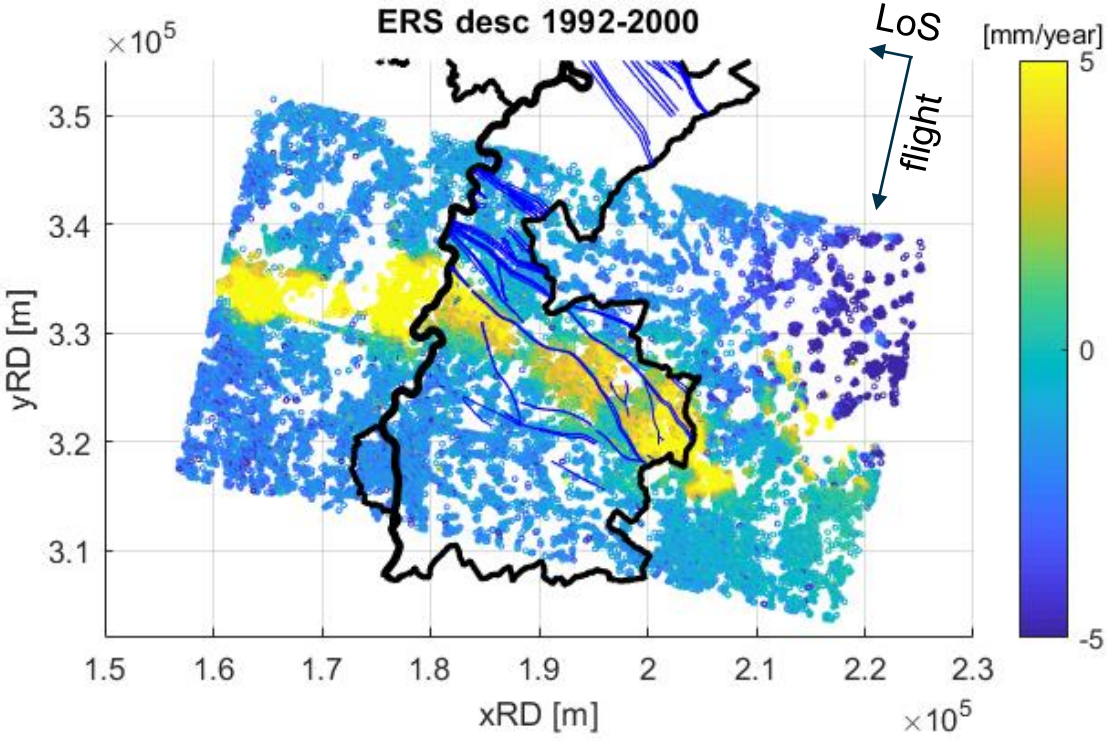
- ✓ InSAR derived surface deformation
- ✓ Groundwater pressures from piezometers
- ✓ Time-series classification (ML clustering)

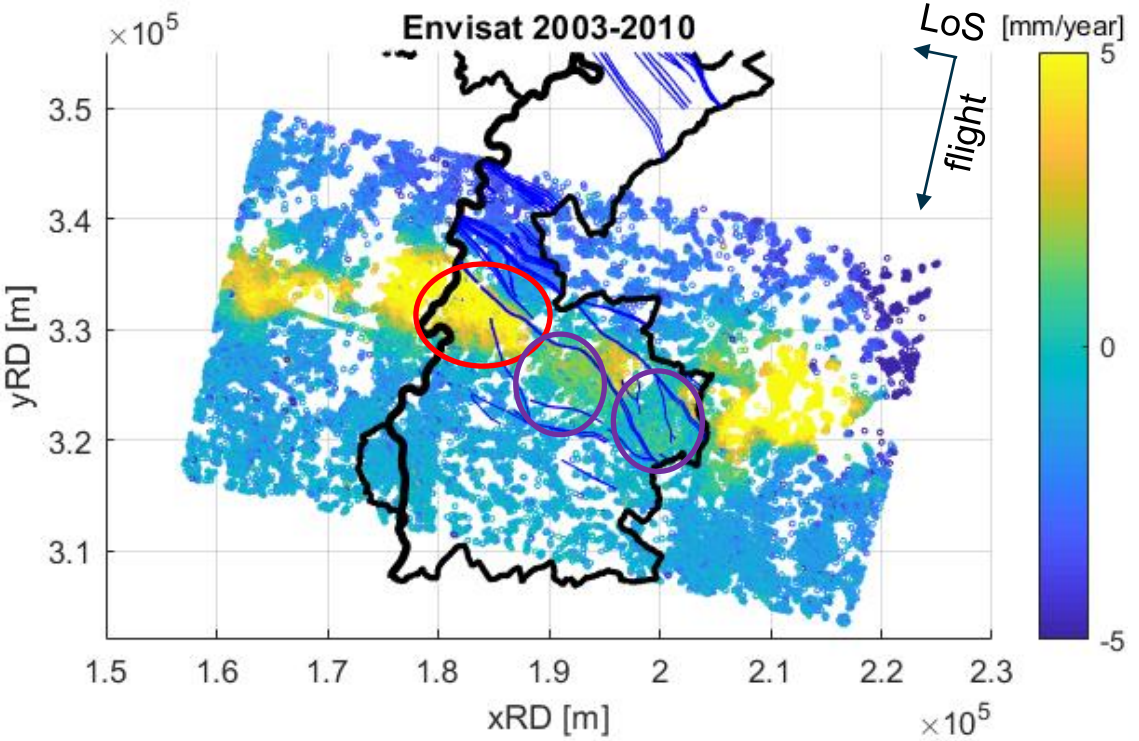
Historical InSAR regional surface deformation

1992-2000 vs 2003-2010

- Increase of uplift over some areas (red ellipse)
- Decrease on others (purple ellipse)



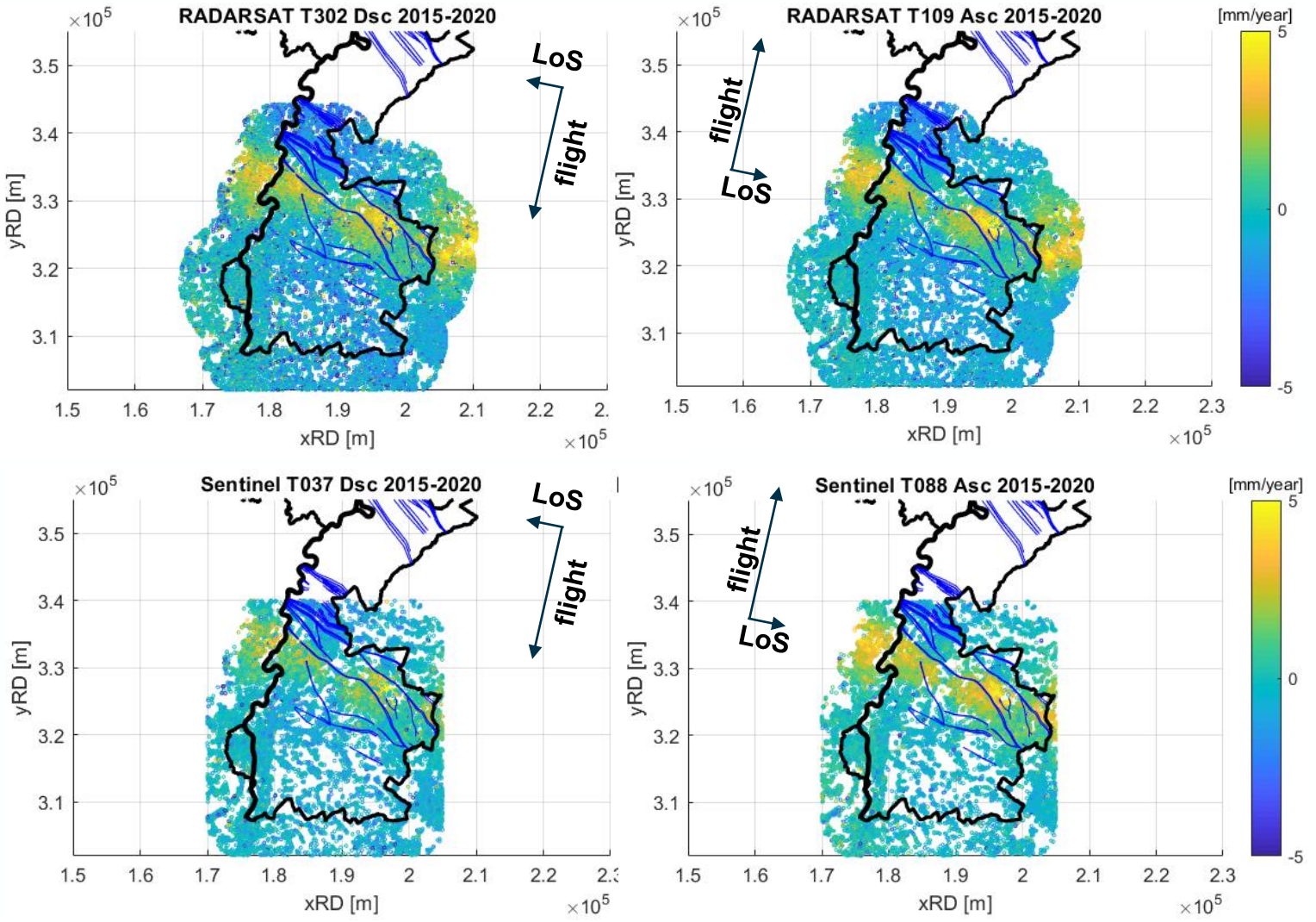


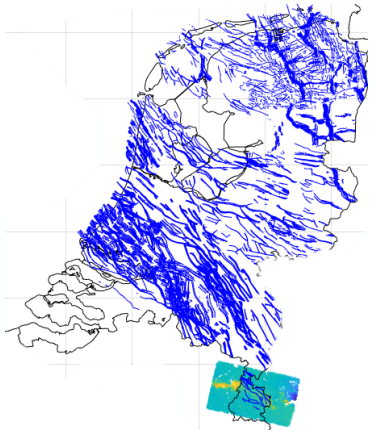


Recent InSAR regional surface deformation

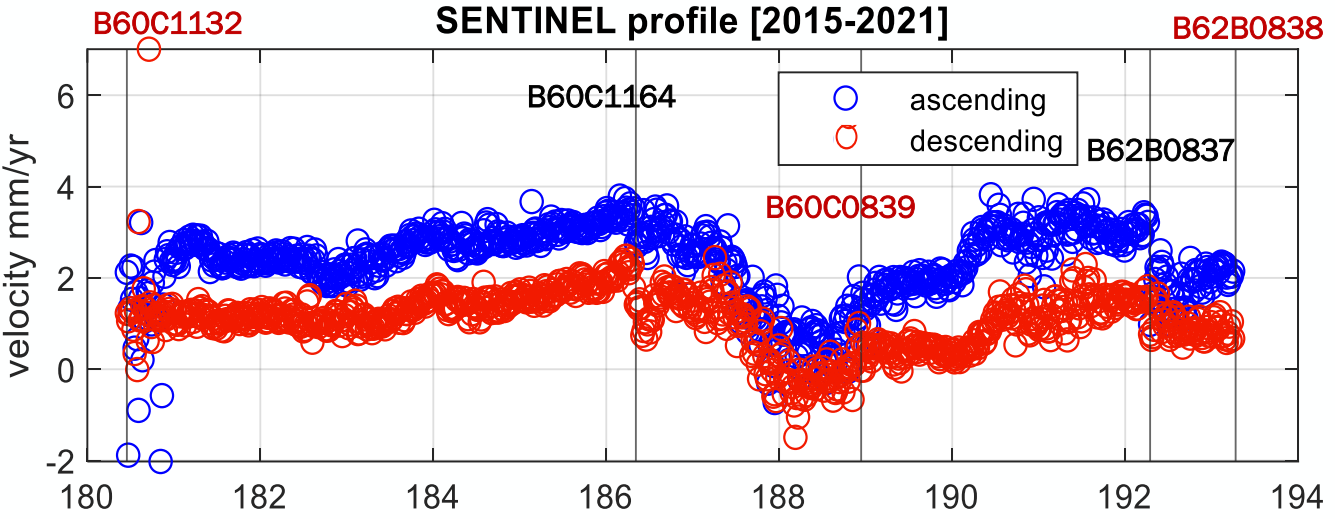
2015 - 2020

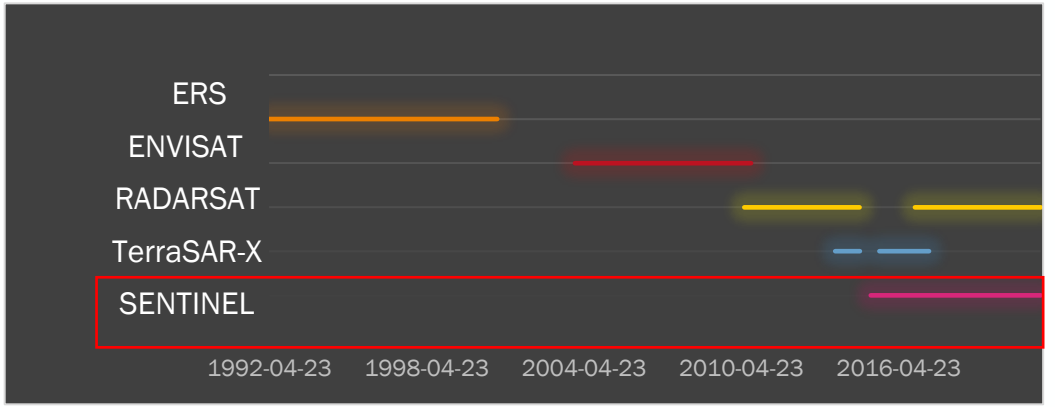
- Regional uplift still up to 5 mm/year
- Ascending orbit geometry seems to detect higher uplift rates

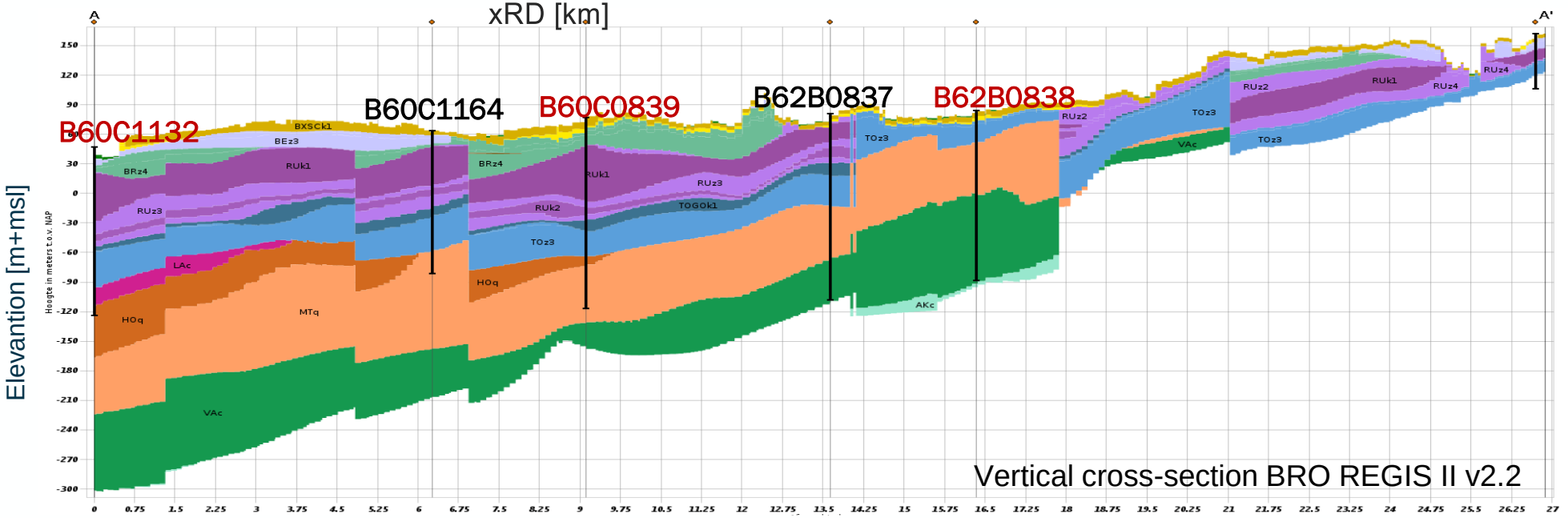




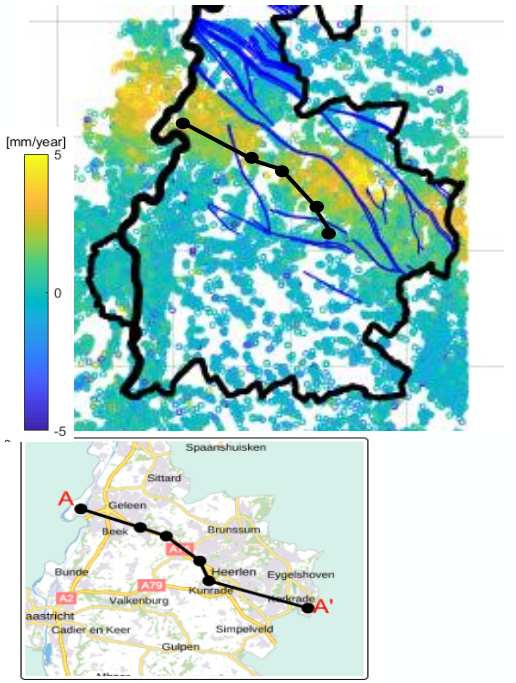
Hydrogeology cover layers & Rate of displacement





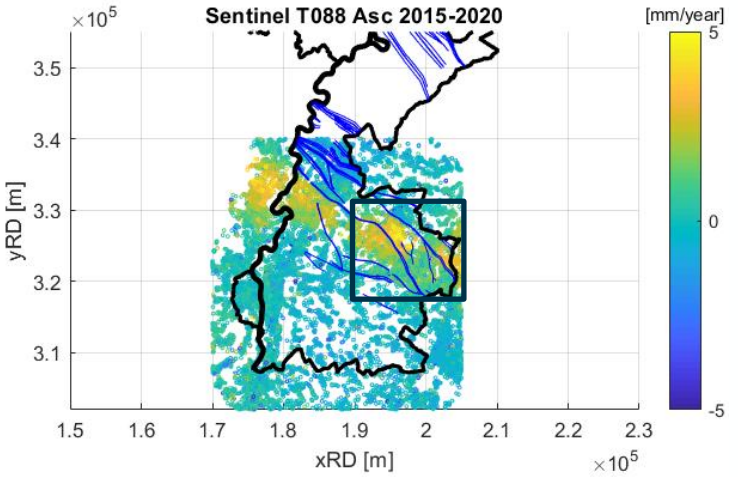


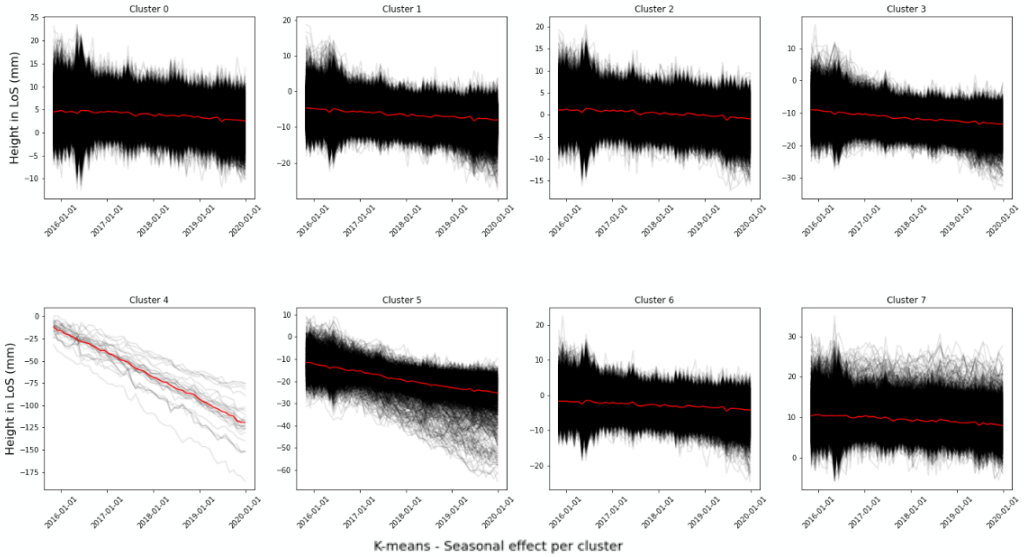
Vertical cross-section BRO REGIS II v2.2

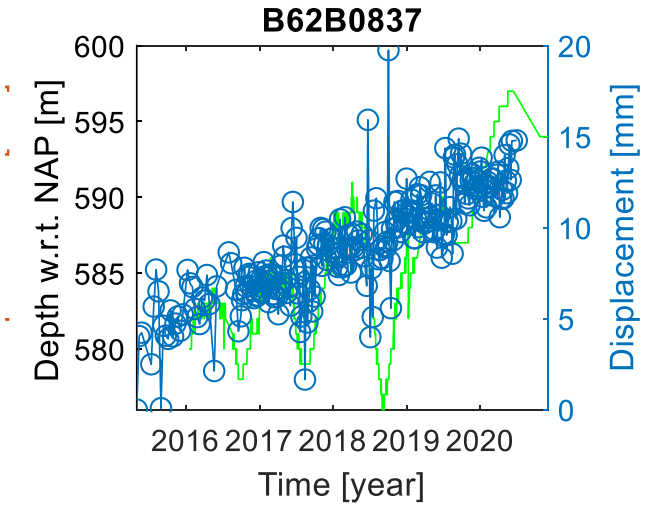


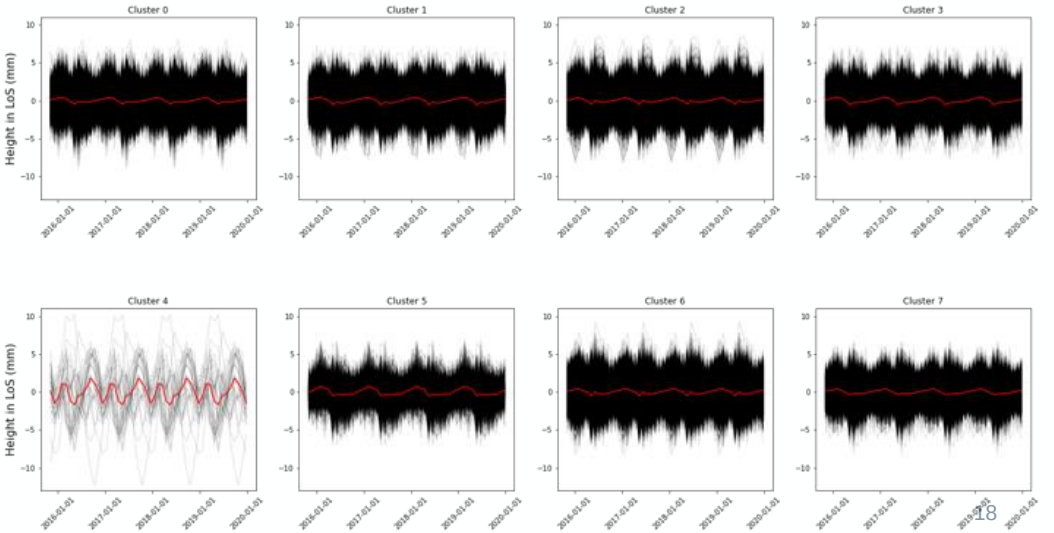
Time series clustering: seasonal + trend

- Classification, regression and *clustering* using statistical models to include seasonality effects detection and reduction.
- Does the seasonality estimated from InSAR fit the seasonality of the piezometers?









Summary:

- ✓ Combining measurements and historical mining information is crucial
- ✓ Multiple characteristics in the subsurface are identified which play an important role in sinkhole formation.
- ✓ Previous risk areas should be updated

- ✓ InSAR → **to get early warning of surface deformation preceding sinkhole;**
  - → **understand underlying mechanisms concerning the uplift**
  - → **Validate geomechanical models**
- ✓ Mining maps:
  - → Acute corner of mining galleries → **indication of where to start looking**
  - → Thin or unstable mining gallery roof: Upward drillings nearby → **indication of where to start looking**
  - → Mining induced fractures reach top of the consolidated rock → **can be calculated from mining maps**
  - → Piezometers → **detect (anomalies in) surface response to increasing groundwater pressures**
  - → Surface information (buildings, water/gas pipes) → **risk estimation**

Thank you!

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Picture: https://vantilt.nl/
“Het Nederlandse mijnverleden in word en beeld”
(The Dutch mining history in words and images)