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Settlement monitoring using space-borne radar interferometry in the context of large infrastructure projects

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Norwegian Geotechnical Institute

2. Symposium zur angewandten Satellitenerdbeobachtung, 12.-13.11.2019, Köln

InSAR applications in large infrastructure projects

Pre-construction → Construction → Post-construction

Time

Planning

Developing baselines and locating areas of greatest stability/instability

Asset Management

Pinpointing the amount and location of displacement to prioritize inspection and maintenance

Risk Mitigation

Identifying hazards to pro-actively prevent failures

Historic Assessment

Measuring what moved, when, and by how much

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Source: own modification, based on Murray Down, 3v Geomatics

Planning / InSAR in the pre-construction phase

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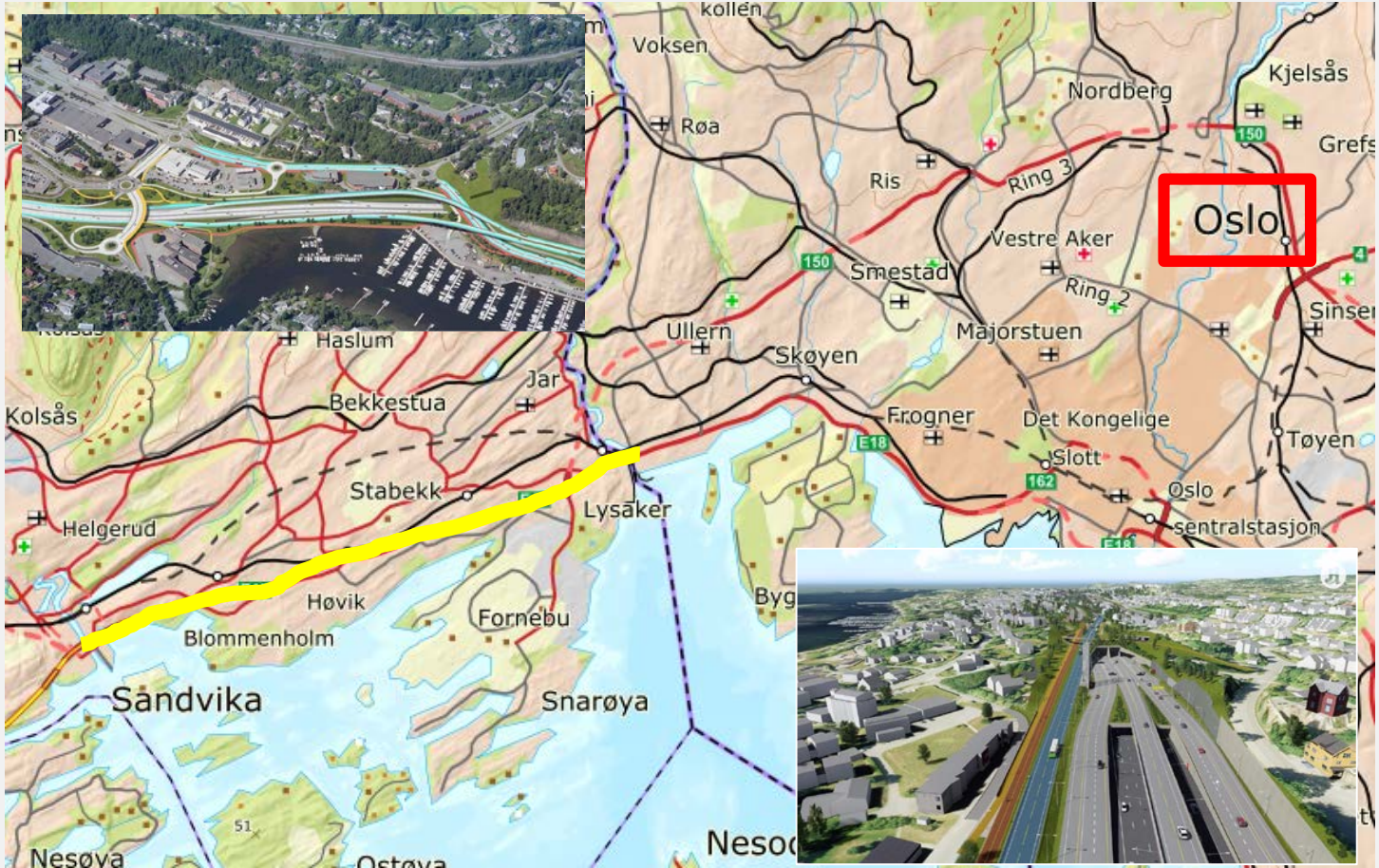
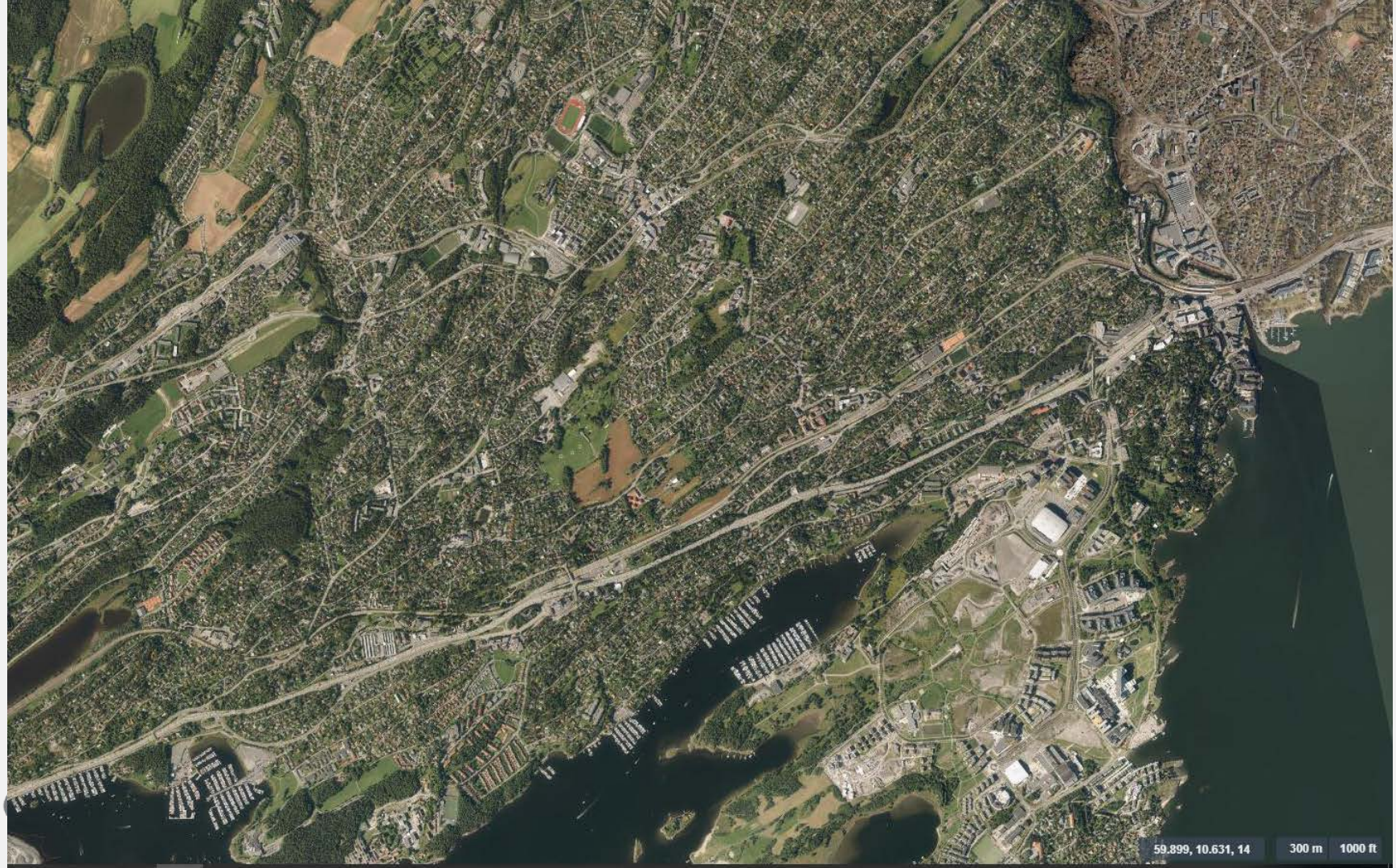
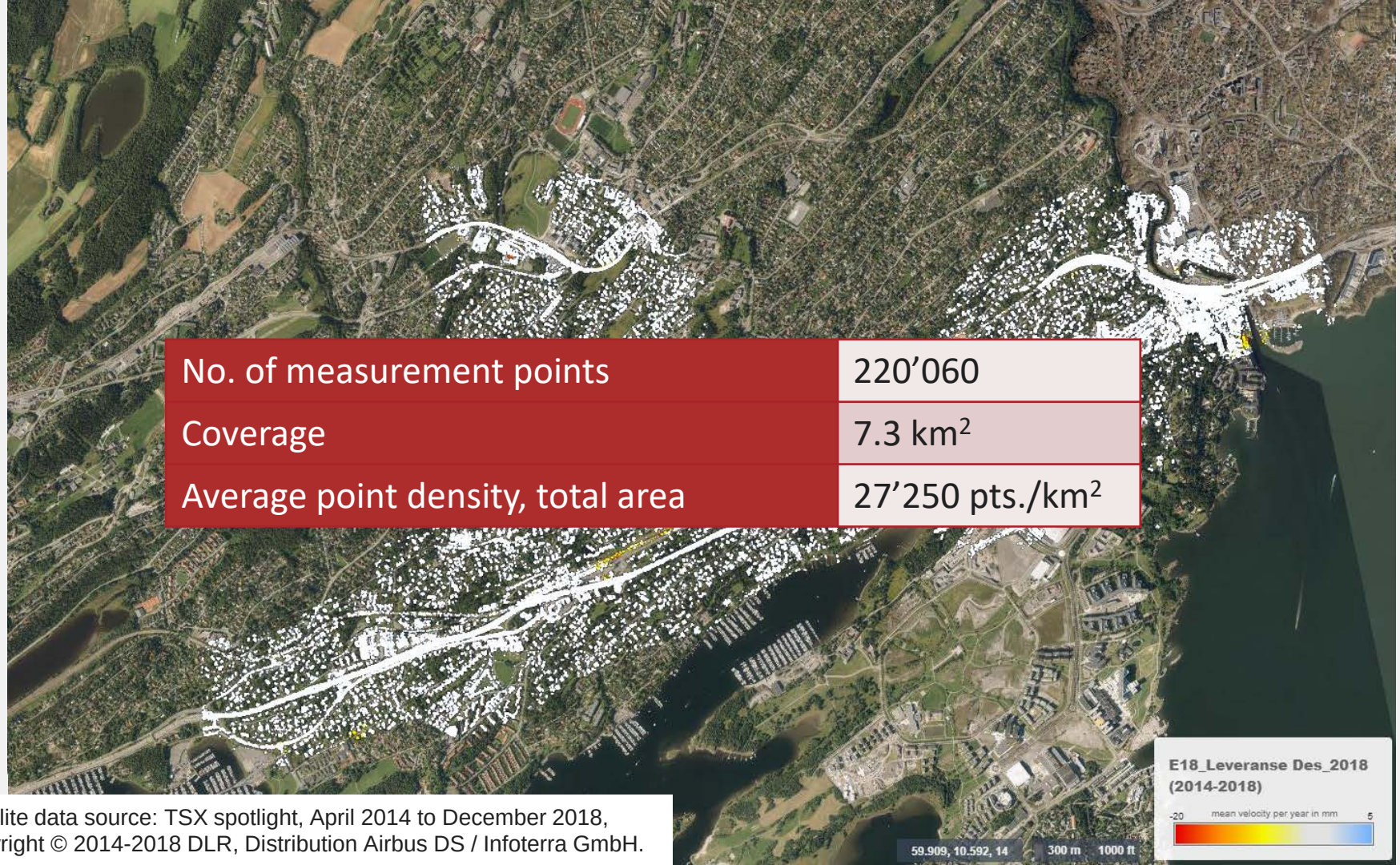
New/upgraded highway E18



- 4-lane highway
- additional bicycle lanes
- connections to future public transport
- 2 new tunnels

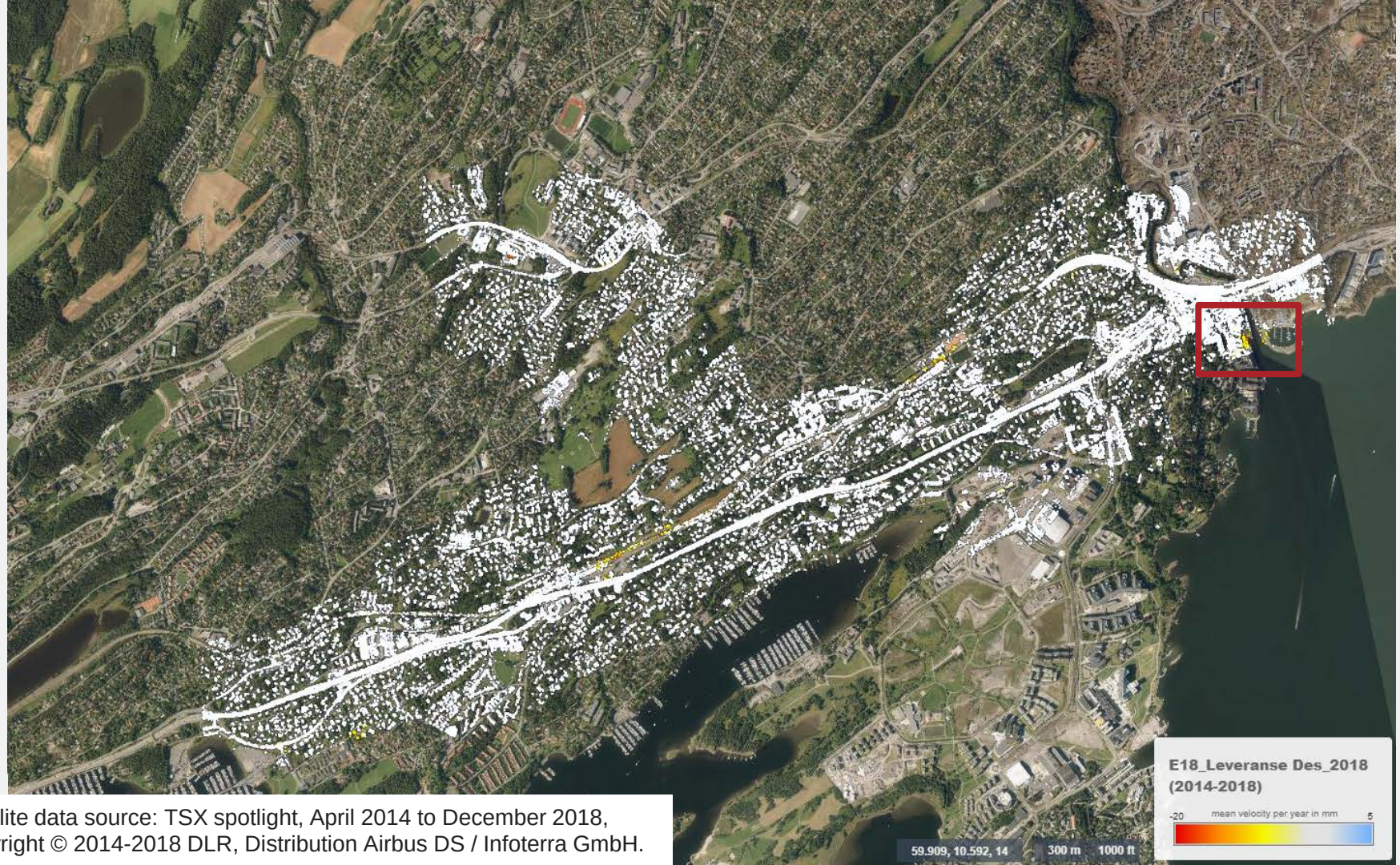
- Wealthy area, potentially many claims
- Purpose of InSAR in this phase → Baseline!


59.899, 10.631, 14
300 m
1000 ft



No. of measurement points	220’060
Coverage	7.3 km^2
Average point density, total area	27’250 pts./km^2

Satellite data source: TSX spotlight, April 2014 to December 2018,



Satellite data source: TSX spotlight, April 2014 to December 2018,
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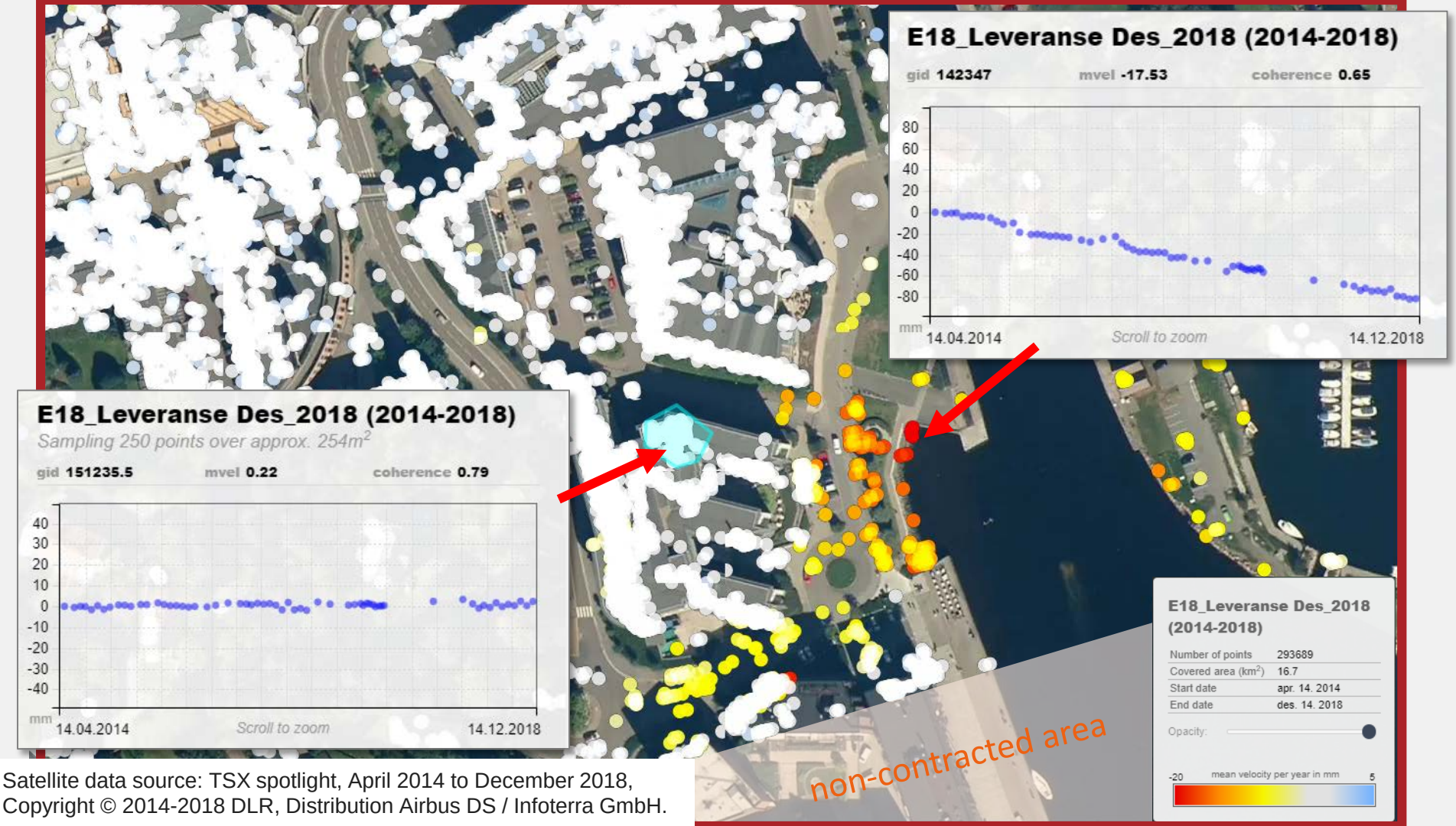

Satellite data source: TSX spotlight, April 2014 to December 2018,
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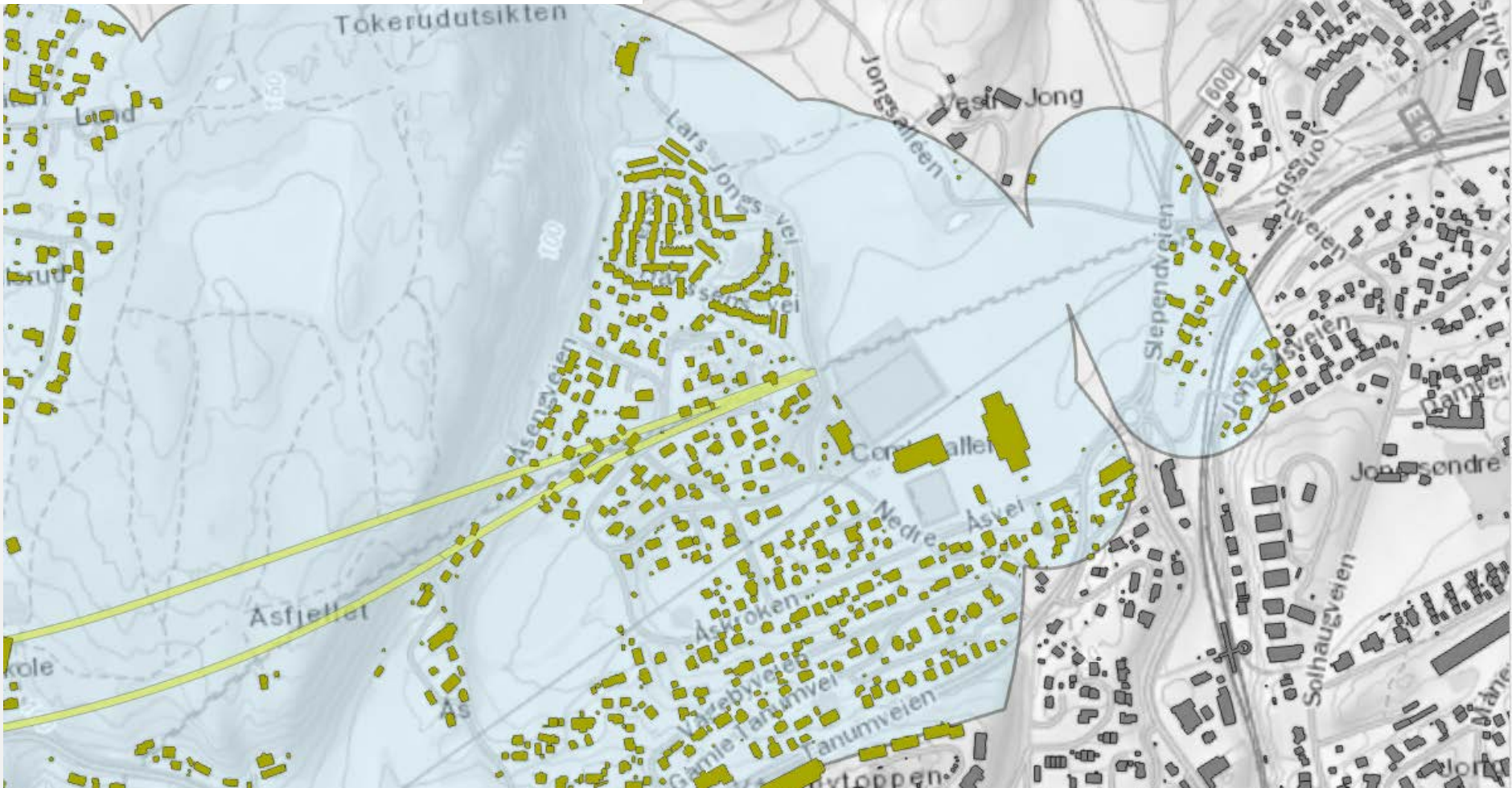
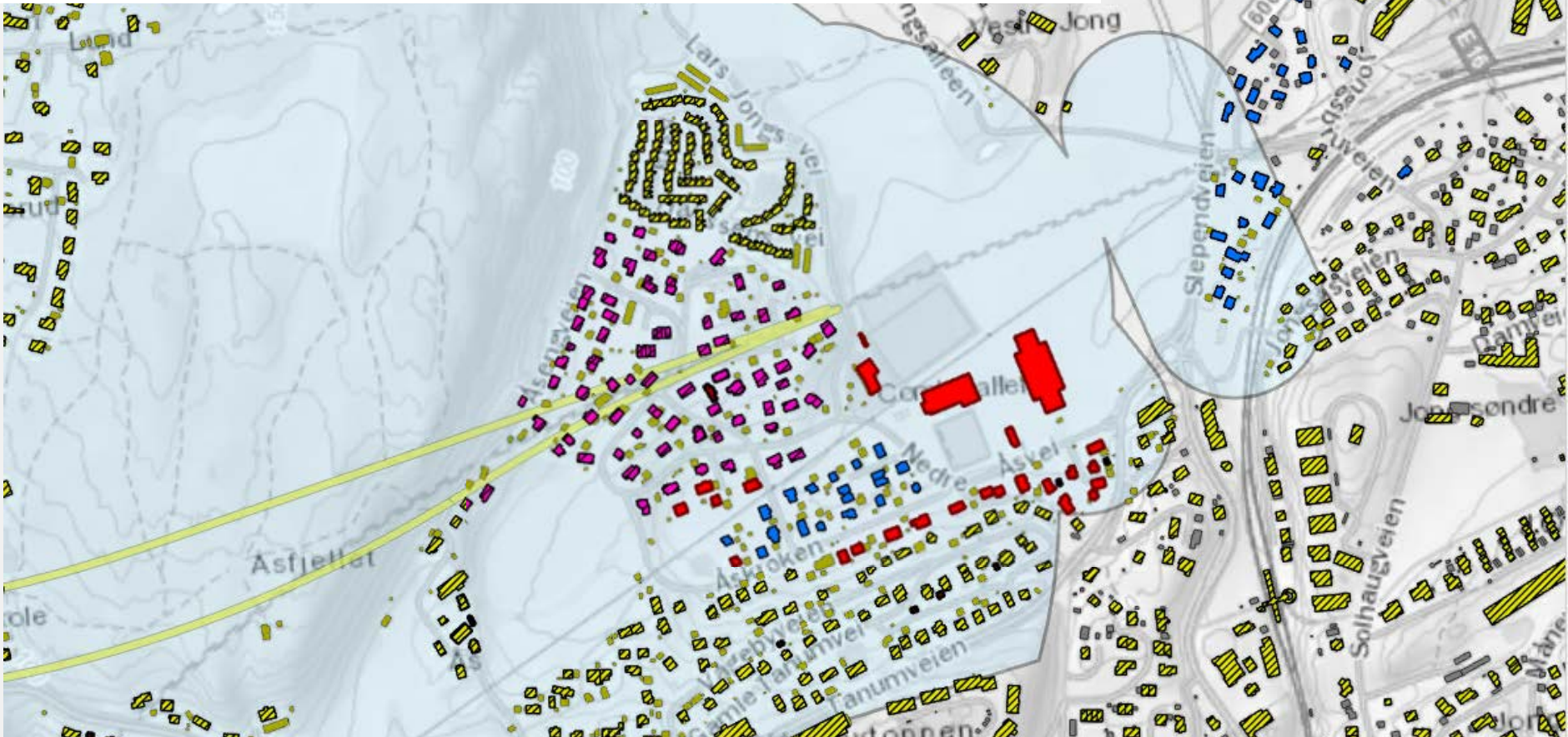
Buildings in the «influence zone»



Buildings monitored with survey markers and by InSAR

Buildings that need additional in-situ monitoring



Asset Management/
Risk Mitigation
InSAR during construction

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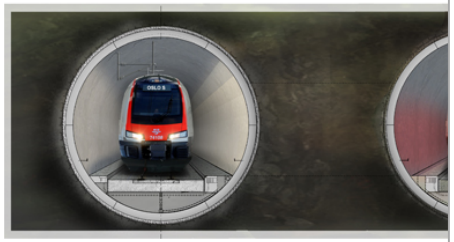
BANE NOR

Bane NOR > Projects > The Follo Line Project

- Modernization of the Vestfold line
- Construction Arna-Bergen

The Follo Line Project

The project is currently the largest transp
Norway and includes the country's long
(20 km). Combined with the existing Øst
tracks to the capital Oslo will represent n
faster trains on schedule.



The Follo Line will form the core part of the InterCity devel
from Oslo. The project will comprise a 20 km long tunnel w
first long twin tube rail tunnel.

BANE NOR

Hva ser du

Nyheter Om oss Karriere Jernbanen Sikkerhet Prosjekter Kundeportal Marked Kund

Forside > Prosjektoversikt > Follobanen > Om Follobaneprosjektet > Innhold > 2018 > Satellitt-overvåking for tunnel-naboer

Satellite monitoring for tunnel neighbours

NGI og Bane NOR/Follobanen har inngått en avtale om bruk av målinger fra satellitt for å følge opp terreng og eiendommer mens jernbanen bygges ut. På sikt kan satellittmålinger redusere behovet for målebolter i grunnmurer langs jernbanetraseer.

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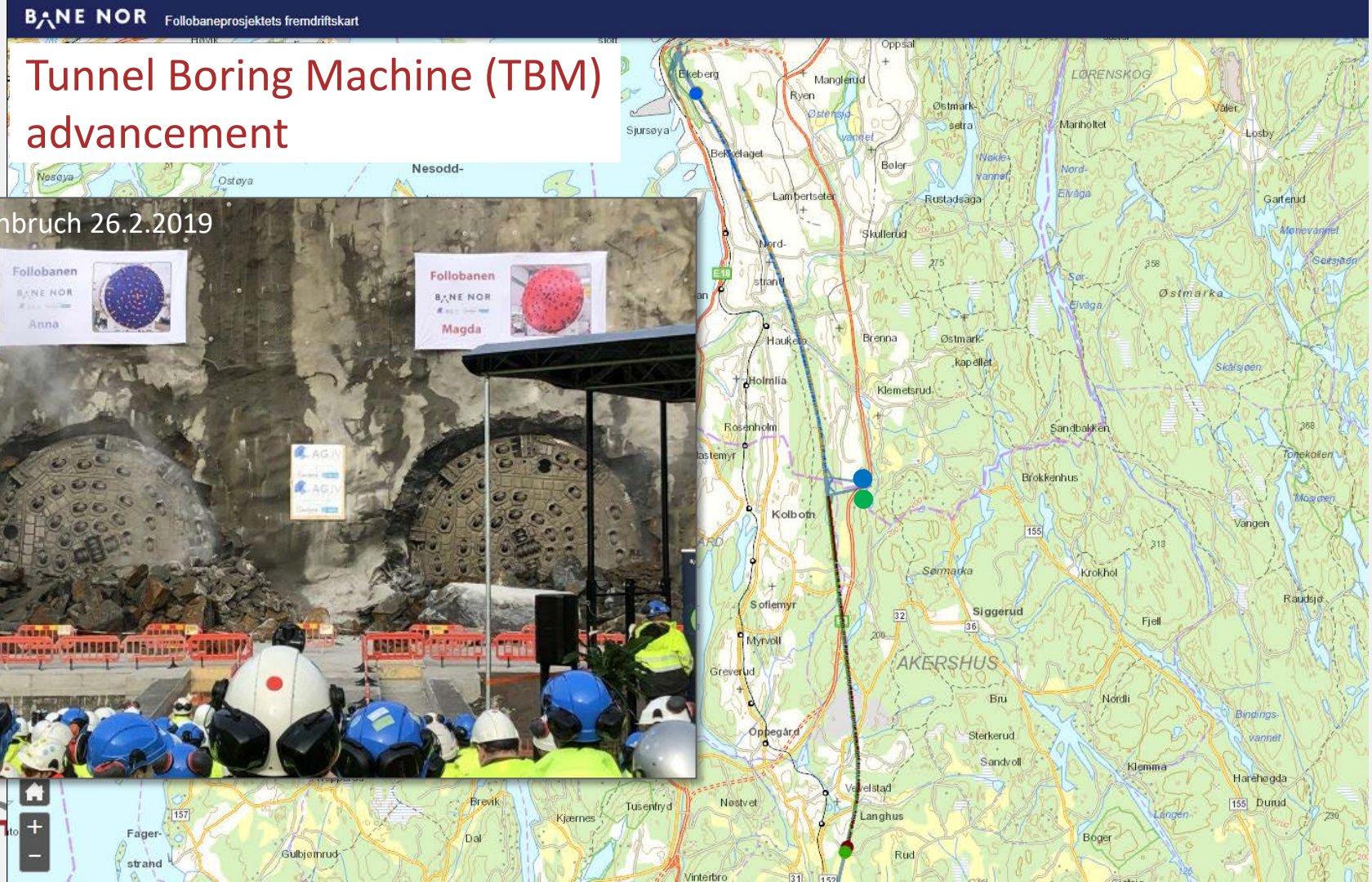
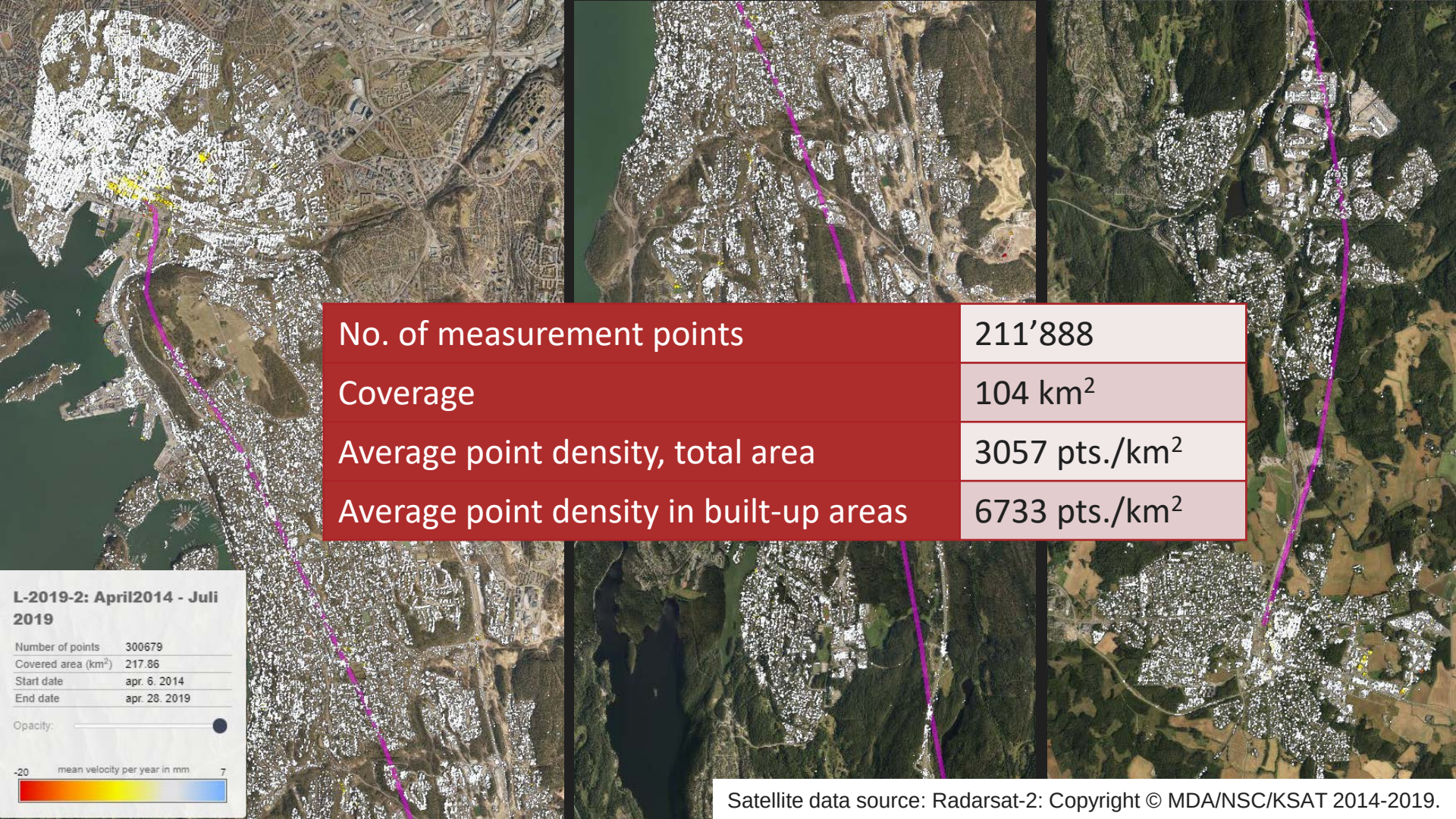
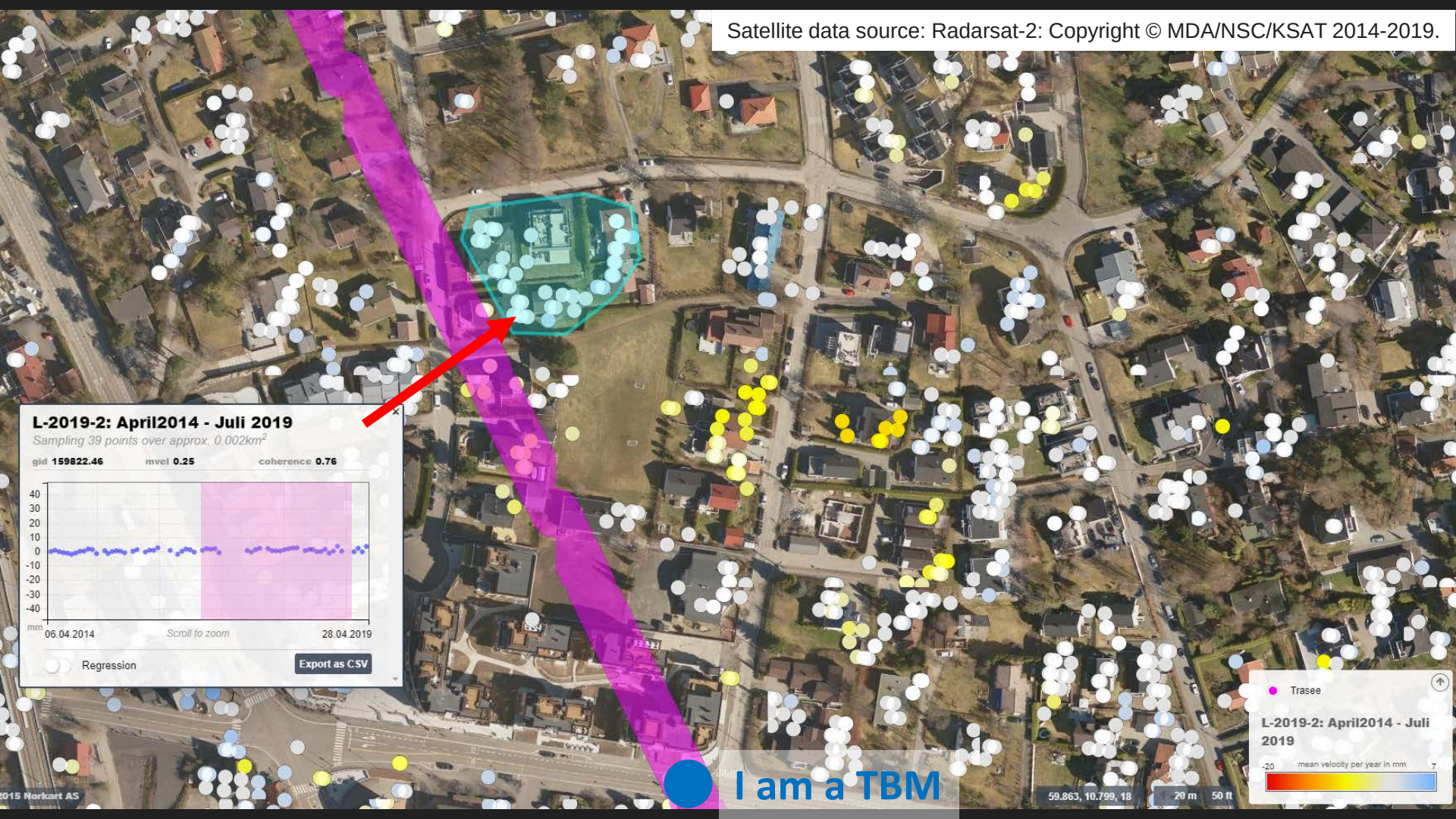
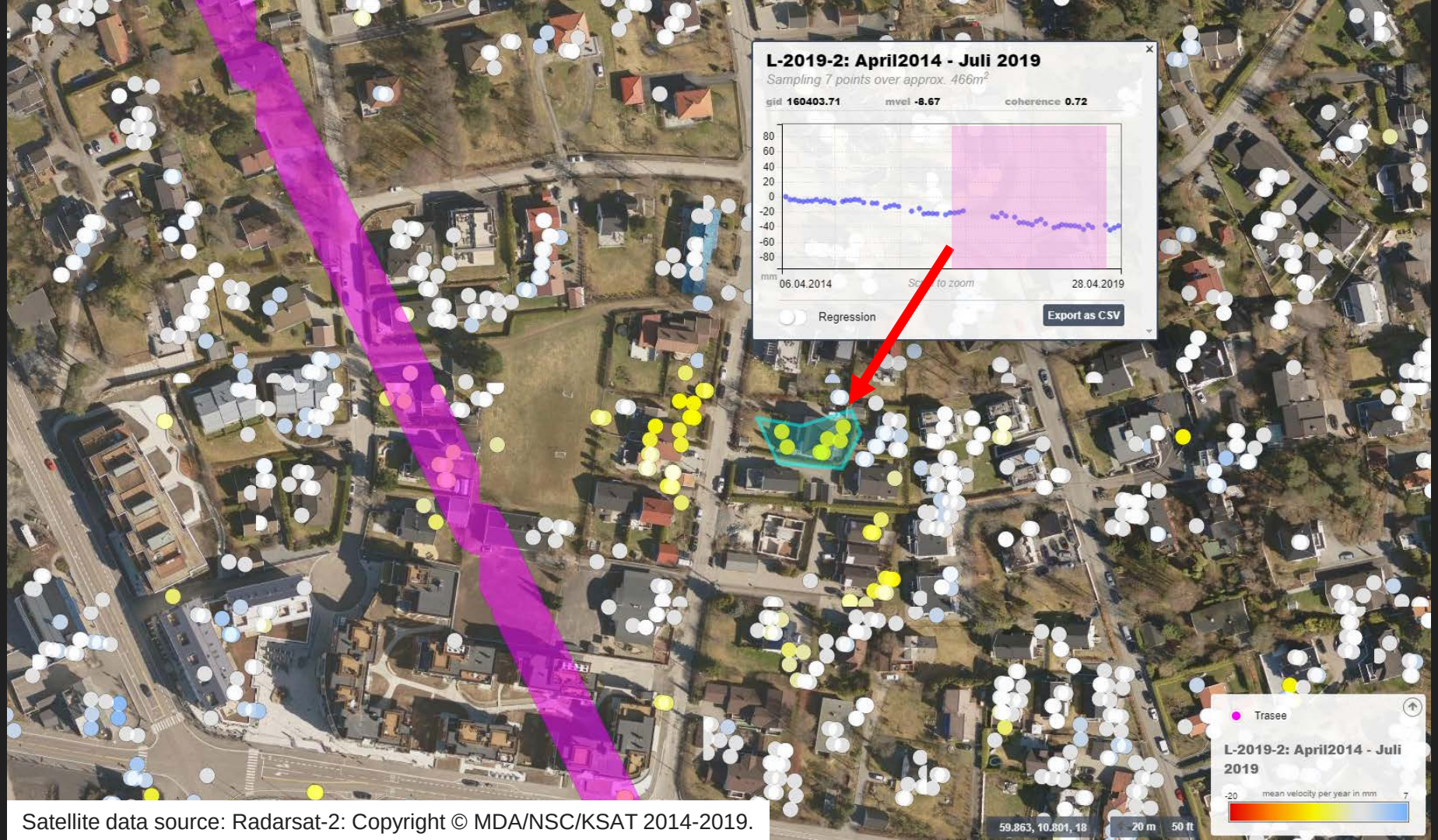
Tunnel Boring Machine (TBM) advancement





No. of measurement points	211’888
Coverage	104 km^2
Average point density, total area	3057 pts./km^2
Average point density in built-up areas	6733 pts./km^2


Satellite data source: Radarsat-2: Copyright © MDA/NSC/KSAT 2014-2019.
L-2019-2: April2014 - Juli 2019
Sampling 39 points over approx. 0.002km²
gid 159822.46
mvel 0.25
coherence 0.76
40
30
20
10
0
-10
-20
-30
-40
mm
06.04.2014
Scroll to zoom
28.04.2019
Regression
Export as CSV
Trasee
L-2019-2: April2014 - Juli 2019
-20
mean velocity per year in mm
7
I am a TBM
59.863, 10.799, 18
20 m
50 ft
2015 Norkart AS



Satellite data source: Radarsat-2: Copyright © MDA/NSC/KSAT 2014-2019.

Extend in-situ series with InSAR

Nivellement series 1

Nivellement series 2

InSAR

Address	No. of measurement points	Baseline (month-year)	Last measurement	Settlement (mm)	Comment	
N 13B Bygn. 1.135	3	04-2005	05-2009	0 til -2	Stable	House 1
N 13B Bygn. 1.135	2	04-2005	05-2011	0 til -1	Stable	
N 13B		04-2014	06-2017		Stable	
N 13D Bygn. 1.137	3	04-2005	05-2013	-89 til -131	Unstable	House 2
N 13D		04-2014	06-2017		Unstable	
N 15A	7	1990	06-1994	0 til -5	Stable	House 3
N 15A	1	1990	06-2007	-1	Stable	
N 15A Bygn. 1.131	7	04-2005	05-2011	+2 til -1	Stable	
N 15A		04-2014	06-2017		Stable	
N 15B	4	1990	05-2005	-59 til -71	Unstable	House 4
N 15B	2	1990	04-2008	-74 til -91	Unstable	
N 15B Bygn. 1.133	6	04-2005	09-2011	-34 til -71	Unstable	
N 15B Bygn. 1.133	4	04-2005	05-2013	-57 til -96	Unstable	
N 15B		04-2014	06-2017		Unstable	

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Historic assessment / InSAR in the post-construction phase

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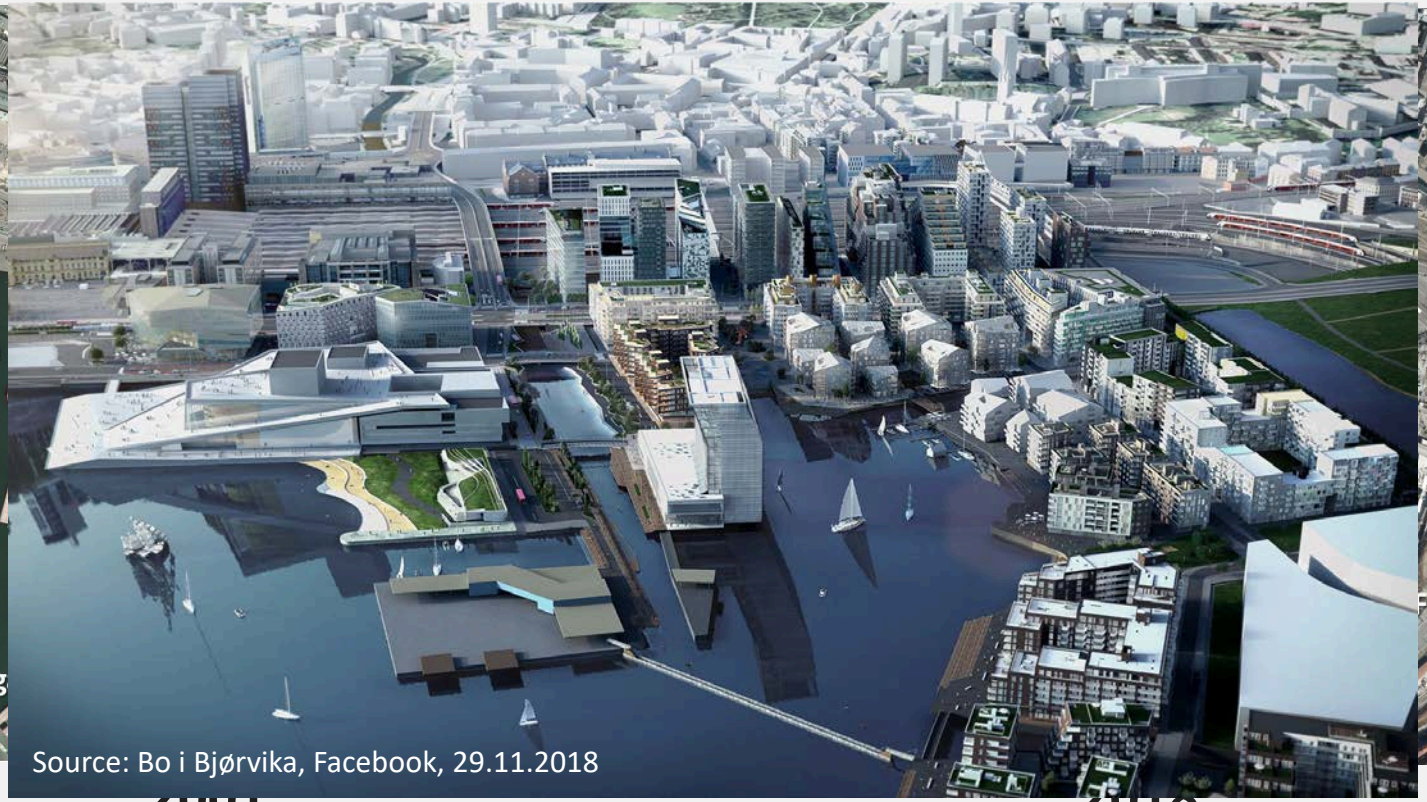
Development of the area 2001 vs. 2018 vs. 2026++



Source: Bo i Bjørvika, Facebook, 29.11.2018

2001

2018

Oslo Fjord City, 2026

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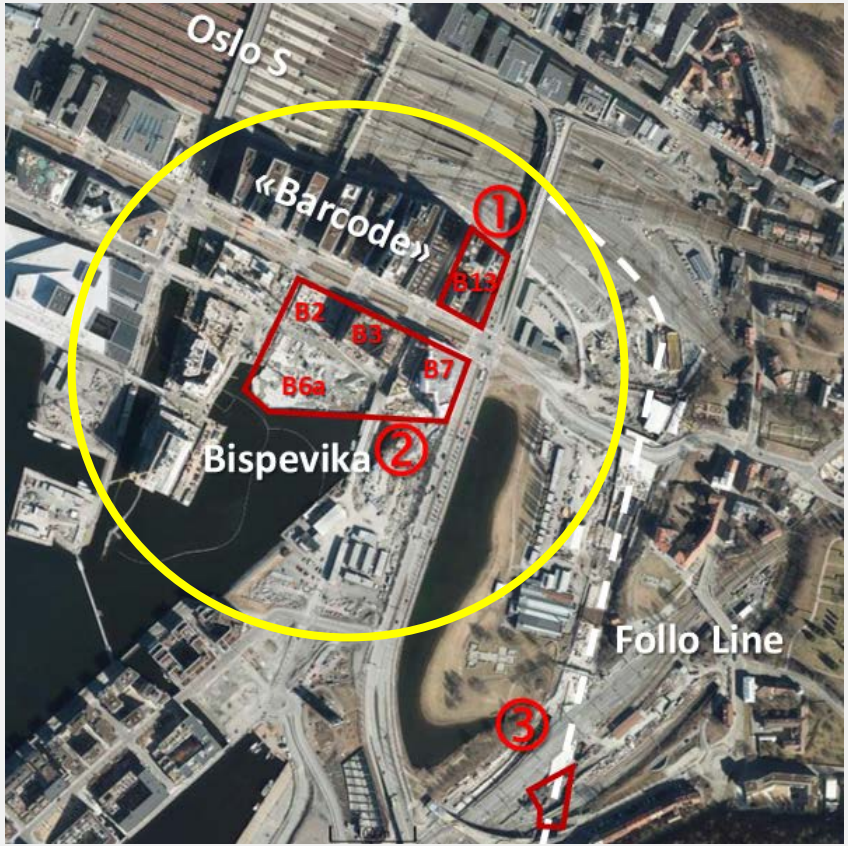
Settlements due to deep excavations

- Deep excavations have the potential to lower pore pressure and cause settlements over huge areas
- Extensive construction activities for 15 years
- Leakages due to drilling activities
  (piles and anchors)
- Normally consolidated clay



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Settlements in protected old masonry buildings

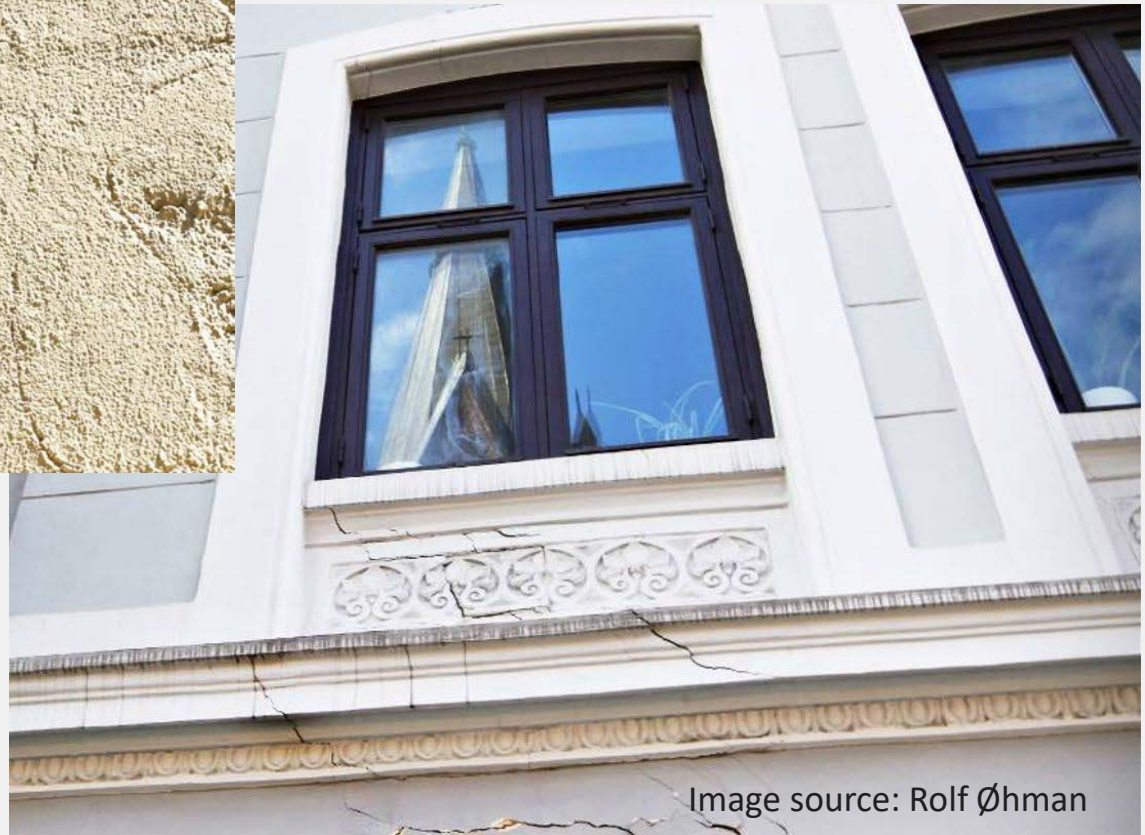

Image source: Rolf Øhman

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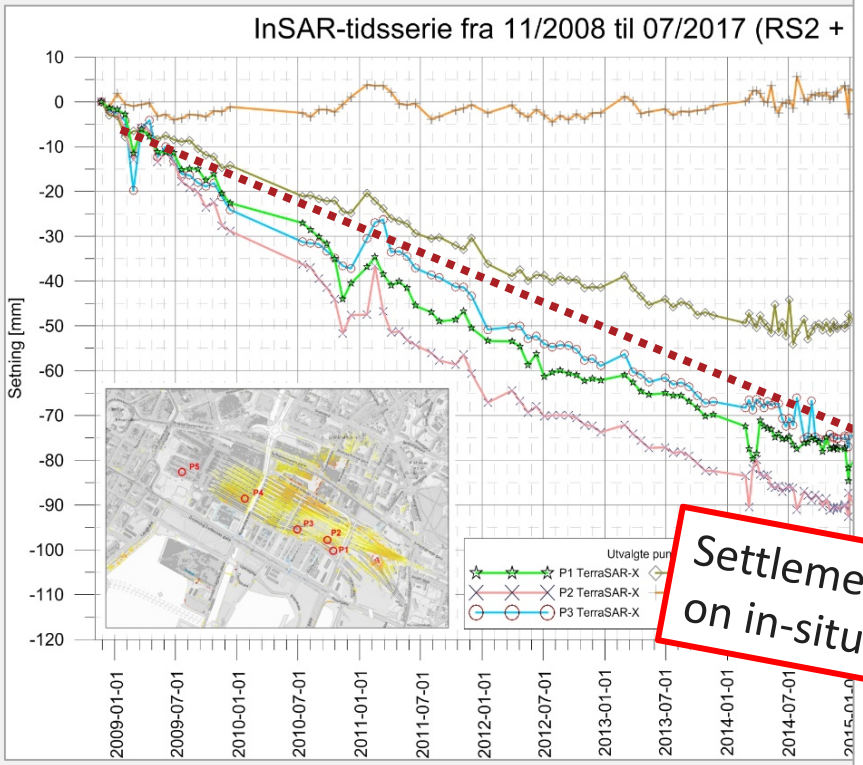
Norkart AS

Satellite data source: TSX staring spotlight, January 2014 to June 2018, Copyright © 2014-2018 DLR, Distribution Airbus DS / Infoterra GmbH.

InSAR helped to conf



Setningene under Oslo S avtar

www.jernbaneverket.no/Nyheter/Nyhetsarkiv/2015/setningene-under-oslo-s-avtar/

Grunnen under deler av Oslo S beveger seg mindre enn tidligere. De setninger utbyggingen av Barcode-rekken førte med seg, er nå i ferd med å stabilisere seg og gå tilbake mot mer normalt nivå.

De setninger utbyggingen av
mer normalt nivå.
Nye utbygging

Det viser den siste rapporten fra Norges Geo
seg på data fra både måleutstyr rundt Oslo S, og data fra sa
oppdrag av Jernbaneverket følge opp setninger og poretrykk fram til 2024. Ut
og betaler for overvåkingen.

Settlements below Oslo S decreasing. Observation based on in-situ measurements and satellite monitoring.

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Summary I

- Radar interferometry offers substantial added-value to geotechnical and civil engineering work and is today successfully applied in big infrastructure projects, alongside targeted traditional levelling of selected “hot-spot” objects.
- Depending on the spatial resolution of the satellite data, the InSAR results can be used to gain an overview over settlement/subsidence hotspots, or they can be directly tied to pre-existing in-situ measurement records.

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Summary II

- The method can be applied for **historical assessments**, in order to measure what has moved when and by how much (Oslo central railway station example). This, provided that necessary satellite data is available.
- Preferably, however, the method is applied for planning and asset management **prior to construction** (E18 example).
- And/or for risk mitigation **during construction** (Follo Line tunnelling example).

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Acknowledgements

- The main funding for these projects came from Bane NOR and the Norwegian Public Roads Administration.
- In addition, some activities were funded by the Norwegian Space Centre and the Norwegian Research Council.
- We are grateful to Bane NOR and the Norwegian Public Roads Administration for their permission to present these results.

- **Data Sources:**
  - TerraSAR-X: Copyright © 2014-2018 DLR, Distribution Airbus DS/Infoterra GmbH
  - Radarsat-2: Copyright © MDA/NSC/KSAT 2014-2019

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#onsafeground

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